UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE CIENCIAS FÍSICAS

TESIS DOCTORAL

Contribuciones a la maximización de la vida útil de los telescopios de gran tamaño del proyecto Cherenkov Telescope Array

Contributions to the maximization of the useful life of the large size telescopes of the project Cherenkov Telescope Array

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Patricia Márquez Paniagua

Director

José Miguel Miranda Pantoja

Madrid

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A mis padres.

Sin los que hubiera sido imposible llegar hasta aquí.

A David.

Quien me ha apoyado y aguantado durante todo el trabajo aquí presentado.

AGRADECIMIENTOS

En primer lugar quiero darle las gracias a mi director de tesis, José Miguel Miranda Pantoja, quien confió en mí desde el principio para llevar a cabo este trabajo de investigación, el cual no ha sido sencillo desde la distancia. Sin su apoyo y paciencia esta tesis no hubiera sido posible.

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Finalmente, quiero expresar mi agradecimiento a los Telescopios MAGIC, al Gran Telescopio de Canarias (GTC), al Telescopio Mercator, al Telescopio Nazionale Galileo (TNG) y al Instituto de Astrofísica de Canarias (IAC), los cuales han compartido información conmigo para utilizarla en esta tesis. Gracias a ellos he podido conocer el funcionamiento y el trabajo de otros proyectos científicos, logrando ampliar mis conocimientos.

Note

During the finalisation of this thesis, an exceptional event took place which is closely related to the topics addressed here: the eruption of volcano in Cumbre Vieja. The data and information provided in this documented has been updated until 21st October 2021. The volcanic eruption continues during the date of submission of this thesis.

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CONTRIBUCIONES A LA MAXIMIZACIÓN DE LA VIDA ÚTIL DE LOS TELESCOPIOS DE GRAN TAMAÑO DEL PROYECTO CHERENKOV TELESCOPE ARRAY

Radiotelescopios, telescopios de infrarrojos, telescopios ópticos y de rayos gamma…

Todos ellos, entre otros, son instrumentos que permiten obtener información distinta y complementaria de la radiación emitida por la materia que existe en el universo. La parte de la radiación que se produce a las más altas energías de fotón que se conocen hoy en día genera una cascada de partículas subatómicas al incidir en la atmósfera terrestre. Esta cascada es la que da origen a la luz detectada por los telescopios que se han estudiado en esta tesis: los telescopios de gran tamaño (LST) de los futuros observatorios Cherenkov Telescope Array (CTA).

Habrá dos grupos de telescopis CTA, CTA-Norte en La Palma, España, y CTA-Sur en Atacama, Chile. Actualmente solo un telescopio de CTA-Norte está construido, el LST1, el cual está en fase de puesta en marcha.

La vida útil estimada de los LST es de 30 años. Tratar de investigar qué podemos hacer para prolongar esta vida útil de los LST en CTA-Norte es el principal objetivo de esta tesis. Al mismo tiempo, se pretende exponer y defender una serie de recomendaciones prácticas, así como proporcionar información relevante, que puedan ayudar a incrementar la disponibilidad de estos telescopios durante su funcionamiento, reduciendo los esfuerzos de mantenimiento y mejorando la fiabilidad de los subsistemas.

Durante este estudio se han identificado distintos factores de especial relevancia para la vida útil de los LST. La climatología es uno de ellos.

CTA-Norte está localizado en el Observatorio Roque de Los Muchachos (ORM), a más de 2000 metros sobre el nivel del mar.

Las actividades en el ORM dependen de la meteorología, tanto operaciones como actividades de mantenimiento u otro tipo de actividades como visitas. Por esta razón, los telescopios tienen estaciones meteorológicas, porque monitorizar el clima es esencial para trabajar de forma efectiva en el ORM.

Los principales parámetros meteorológicos que se monitorizan regularmente son: temperatura, viento, concentración de polvo, tormentas y rayos y radiación solar. La radiación solar no se puede evitar pero los telescopios se pueden proteger de los demás parámetros. Las especificaciones de los telescopios han sido definidas en base a los valores extremos de los parámetros meteorológicos.

La Palma puede verse afectada por riesgos naturales, antrópicos y tecnológicos. Si un evento causa un daño de severidad y magnitud significativa, se considera catastrófico. En los últimos años los eventos catastróficos más comunes han sido fuertes tormentas y rayos seguidos de incendios forestales. Los eventos catastróficos pueden tener también efectos indirectos sobre el observatorio. En cualquier caso, el ORM no tiene un gran riesgo de sufrir eventos catastróficos.

Para tener una visión general del ORM, se ha hecho una revisión a otros telescopios del observatorio. El primer telescopio empezó a operar antes de 1985 y ahora hay operando más de veinte instrumentos.

El LST está compuesto por 5 subsistemas: mecánico, óptico, cámara, auxiliar y común.

El sistema mecánico es el soporte del telescopio. Tiene una estructura inferior de acero, sobre la que se sustenta una estructura de plato de acero, aluminio y fibra de carbono. Asimismo, este sistema incluye la estructura de soporte de la cámara, el riel de sistema azimutal, el sistema de soporte central azimutal, el sistema de empuje azimutal, el sistema de anclaje azimutal, el soporte de elevación, el sistema de empuje en elevación, los contrapesos, la torre de acceso a la cámara, el sistema de fijación en la cámara y las plataformas de trabajo y acceso.

El sistema óptico está compuesto por 198 espejos, los platos de soporte de ellos y los actuadores y las cajas AMC para controlar los espejos.

La cámara recibe la Luz Cherenkov reflejada en los espejos del sistema óptico.

El sistema auxiliar incluye el almacenamiento de energía, la protección contra rayos, los dispositivos de calibración y control, el sistema de control de movimiento y el cableado.

Finalmente, hay otros subsistemas (o subsistema común). Son el sistema de baja tensión y generador diésel, el contenedor de telecomunicaciones, el contenedor de puesta en marcha y las infraestructuras.

Además de la parte física del LST, la gestión del telescopio es fundamental para tener una buena operación del mismo. La contribución a la mejora de la vida útil del LST se ha hecho en esta parte del proyecto.

El plan de análisis de riesgos del LST ha sido aplicado a los riesgos que pueden afectar al LST. Se han analizado y sugerido medidas de mitigación.

Un análisis de fiabilidad fue hecho en el LST con una simulación de Monte Carlo. Los puntos de fiabilidad más críticos están relacionados con las condiciones atmosféricas adversas. El software Reliasoft se usa para análisis de fiabilidad y mantenimiento el cual se ha aplicado en esta tesis.

El plan de calidad es esencial para cumplir con los requerimientos de vida útil. LST1 es un prototipo y algunas especificaciones no estaban listas durante la fase de diseño del telescopio. El control de calidad necesita seguirse durante la fase de operación también. Problemas detectados en el LST1 serán resueltos en los nuevos LST y el plan de calidad incluirá cada punto crítico.

La seguridad es fundamental para el LST1. Hay procedimientos de seguridad que tienen que ser seguidos por cada usuario del telescopio. Algunos procedimientos de seguridad del LST1 han sido hechos y actualizados durante el desarrollo de esta tesis.

Las operaciones no están dentro de esta tesis pero también forman parte de la gestión.

El procedimiento de logística ayuda con la trazabilidad de los repuestos y materiales en el proyecto.

El mantenimiento del LST es asimismo fundamental para que el telescopio alcance la longevidad requerida. Está directamente relacionado con el plan de calidad, la logística y la seguridad. Hay mantenimiento preventivo y correctivo, el segundo no es predecible pero el mantenimiento preventivo puede ser controlado. Durante el periodo de esta tesis, la gestión del mantenimiento se ha mejorado con el análisis de actividades y la creación del documento “regulaciones de actividades de mantenimiento”.

Disponer de una cantidad óptima de repuestos ayuda a la reducción de costes. Actualmente no hay métodos para controlar los repuestos en el LST1. Durante esta tesis, se ha hecho un análisis de los métodos de control de materiales y se propone aplicar el análisis ABC con el método de aprovisionamiento periódico. Durante el análisis, vimos que estos métodos están centrados en sectores industriales, por esa razón se ha desarrollado una metodología propia, obteniendo una ecuación para conocer cuáles son los repuestos más importantes que necesitamos tener en el almacén. El aprovisionamiento periódico ha sido aplicado en varios repuestos del LST pero la conclusión es que no se puede aplicar al LST, pero si podemos aplicar el concepto teórico: pedir los repuestos una vez al año y ajustar la cantidad a número de repuestos en el almacén. Tener un inventario es imprescindible para realizar un control óptimo de los repuestos. Durante el desarrollo de esta tesis no se ha completado el inventario de repuestos, pero se ha elaborado un método para producirlo.

Durante la operación del LST1, se ha hecho una lista de incidencias y de fallos las cuales se han solucionado. La mayoría de ellas están relacionadas con condiciones meteorológicas adversas.

En conclusión, hay riesgos que no se pueden evitar pero se pueden aplicar medidas de mitigación para hacerlos tolerables. Una gestión adecuada es fundamental para llegar al final de la vida útil del telescopio y este mismo razonamiento es igualmente aplicable a cada instalación científica.

Durante la elaboración de esta tesis se han presentado cinco[1] publicaciones científicas y tres más están en proceso de publicación. Además se ha participado en 17 workshops y conferencias internacionales, siendo la autora de esta tesis la ponente en trece de ellas. También se han elaborado seis documentos internos del proyecto LST1 en colaboración con otros miembros del proyecto o con autoría única.

[1] Tres de estas publicaciones son las presentadas en la tesis de Oibar Martínez.

ENGLISH ABSTRACT

CONTRIBUTIONS TO THE MAXIMIZATION OF THE USEFUL LIFE OF THE LARGE SIZE TELESCOPES OF THE PROJECT CHERENKOV TELESCOPE ARRAY

Radiotelescopes, infrared telescopes, optical telescopes, gamma ray telescopes…

All of them, among others, are instruments that allow us to obtain different and complementary information on the radiation emitted by the matter that exists in the universe. The part of the radiation that is produced at the highest photon energies known today generates a cascade of subatomic particles by impacting the Earth's atmosphere. This cascade is what gives rise to the light detected by the telescopes studied in this thesis: the Large Size Telescopes (LST) of the future Cherenkov Telescope Array (CTA) observatory.

There will be two CTA observation stations, Northern Array in La Palma, Spain, and CTA-South in Atacama, Chile. Currently only one telescope from CTA-North has been built, the LST1, and it is in commissioning phase.

The expected lifespan of LST is 30 years. To try to investigate what can be done to enlarge this lifespan in CTA-North is the main objective of this thesis. At the same time, it is intended to present and defend a series of practical recommendations, as well as to provide relevant information, that can help to increase the availability of these telescopes during their operation, reducing maintenance efforts and improving the reliability of the subsystems.

During this study, several factors have been identified that are especially relevant for the lifespan of LST. The climatology is one of them.

CTA-North is located in the Observatorio Roque de Los Muchachos (ORM), at more than 2000 m.a.s.l..

Activities in ORM depend on weather, such as operations as maintenance activities or other type of activities as visits. For this reason, the telescopes have weather stations: monitoring the weather is essential to achieve an effective work in the ORM.

The main weather parameters that are regularly monitored are: temperature, wind, dust concentration, storms, lightning strikes and solar radiation. The solar radiation cannot be avoided but telescopes can be protected from other adverse parameters. Requirements of telescopes are defined according to extreme values of weather parameters.

La Palma can be affected by natural, anthropic and technological risks. If an event causes damage to property of significant severity and magnitude it is a catastrophic event. In the last years the most common catastrophic events have been the strong storms and lightning strikes followed by wildfires. Catastrophic events can have indirect effects on the observatory. In any case, the ORM doesn’t have a high risk of catastrophic events.

In order to provide a general insight of the current status of ORM, a review of other telescopes from observatory has been done. The first telescope started to operate before 1985 and now there are more than twelve instruments in operation.

LST is composed of five subsystems: mechanical, optical, camera, auxiliary and common.

Mechanical system is the support of telescope. It has a lower structure of steel, which provides mechanical support to a dish structure of steel, aluminium and carbon fibre. In addition, this system includes the camera support structure, the azimuth system rail, the azimuth system central support, the azimuth drive, the azimuth locking system, elevation bearing, elevation

drive, counterweights, camera access tower, camera locking device and working platforms and catwalks.

Optic system has 198 mirrors, interface plates and actuators in charge of fixing the mirrors, as well as a set of AMC boxes to control mirror positioning.

Camera system receives the Cherenkov Light reflected on mirrors from optic system.

The auxiliary subsystem includes the energy storage, lightning protection, calibration and control system, structure condition monitoring and cabling structure.

Finally, there are other subsystems, called common components. They are the low voltage installation and diesel generator, IT container, commissioning container and infrastructure.

In addition to the hardware layer of LST, the management of telescope is essential to ensure a good operation of the telescope. The contribution to the improvement of the useful life of LST has been made mostly in this part of the project.

The risk management plan (LST-RAMS/20181203) from LST has been applied to risks than can affect to LST. Mitigation actions has been analysed and suggested.

A Reliability analysis was done in LST with a Monte Carlo simulation. The most critical reliability issues are related to adverse environmental conditions. The software Reliasoft is used to run the Reliability and Maintenance Analysis which has been applied in this thesis.

The quality plan is essential to meet the shelf life requirements. LST1 is a prototype and some specifications were not ready during the design of telescope. The quality control needs to be followed during the operation phase of telescope too. Detected problems in LST1 will be resolved in the new LST and the quality plan will include every critical topic.

Safety is essential. There are safety procedures that must be followed for every user of telescope. Several safety procedures of LST1 have been approved, delivered ~~done~~ and updated during the development of this thesis.

Operations are not included in this thesis, but it is a part of management.

Logistic procedure helps with the trace of spares and materials on site.

Maintenance of the LST is also essential for the telescope to achieve the required longevity.

Maintenance of LST is essential for arriving to final of lifespan. It is directly related with quality plan, operations, logistic and safety. There are preventive and corrective maintenance, the second is not predictable, however the preventive maintenance can be controlled. During the period of this thesis, the management of maintenance has been improved with the analysis of activities and the creation of document “regulations of maintenance activities”.

An optimal spare stock plays a major role in maintenance cost reduction. Currently there is no formally approved protocol to manage the spare stock in LST1. During this thesis, an analysis of stock control methods has been done and the proposal is to apply the ABC´s analysis with the periodic provisioning method. During the analysis, we saw that these methods are focused to industrial sectors, for this reason, a custom made protocol has been developed. It includes an equation to control the most important spares that we need to have in the warehouse. The periodic provisioning method has been applied in several LST´s spares but the conclusion was that it cannot be applied in LST, but we can apply the theoretical concept: to order spares once per year and to adjust the spare quantity to lower the number of spares in the warehouse. There is currently no official inventory in LST, but a method for developing it is proposed in this thesis too.

During the operation of LST1, an incident and system failure list is created. After an incident, a solution and improvement is applied. Most of the incidents are related to environmental conditions and adverse weather.

In conclusion, there are risks that cannot be avoided but we can apply mitigation actions to make them tolerable. A proper management is essential to achieve the desired lifespan of the telescope, and this argument is equally applicable to every single scientific facility.

During the preparation of this thesis, five[2] scientific publications have been presented and three more are in the process of being published. The author of this thesis has also participated in 17 international oral presentations in workshops and conferences, being the speaker on thirteen of them. She has also produced six internal LST1 project documents either in collaboration with other project members or alone.

[2] Three of these publications were presented in the Oibar Martinez´s thesis.

1. INTRODUCTION

1.1. What is the gamma ray and why do we want to investigate this?

To understand the gamma rays, it is important to understand the electromagnetic spectrum before.

Light is a group of electric and magnetic waves which frequency (number of waves that pass through a point in one second) or wavelength (the distance from one peak of a wave to the next one) can be measured. The longer the frequency, the smaller the wavelength. *The electromagnetic spectrum is the range of all types of electromagnetic radiation* [1] (Fig. 1-2).

The frequency range of gamma rays does not have an upper limit. With the electromagnetic spectrum, scientists can see the Universe from different points of view, one of them being gamma rays. The gamma rays detected with CTA may provide direct information on dark matter, as well as evidences for the validity of special relativity theory.

Understanding the Origin and Role of Relativistic Cosmic Particles is another major motivation for the study of gamma rays. Gamma rays do not have an electric charge to deviate their path as they pass through Earth magnetic fields, and therefore they provide unaltered pictures of their sources and the energetic particles that created them.

Furthermore, the gamma rays to be detected by CTA will have energies well beyond those of X-rays or even gamma rays detected by space instruments. As a result, they will provide information on the most energetic environments in the Universe.

Probing Extreme Environments is another major aim. For instance, gamma rays have been observed coming from jets of many black holes. This kind of processes cannot be easily seen or reproduced in laboratories. Finally, it is expected to find major discoveries in fundamental physics.

The gamma rays that the CTA will detect are about 10 trillion times more energetic than visible light [2].

The next picture is an example of several ways to see the CRAB NEBULA:

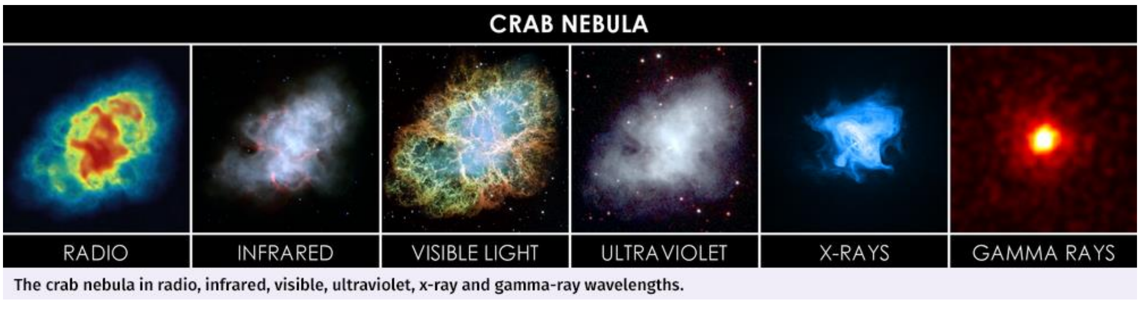


Fig. 1-1: Multiwavelength Crab Nebula [2]

The CTA will explore in-depth the Universe's very high energy gamma rays and investigate cosmic processes leading to relativistic particles, in cooperation with other observatories working with other wavelength ranges of the electromagnetic spectrum [3].

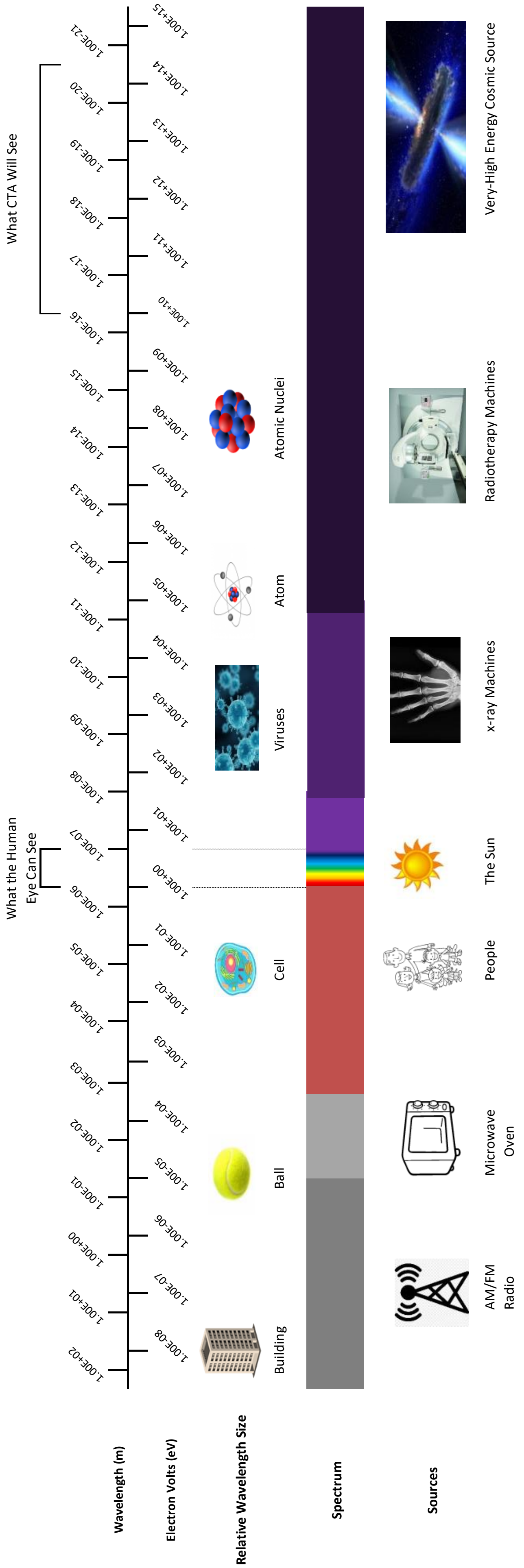


Fig. 1-2: The Electromagnetic Spectrum.

Currently, there are already hundreds of known objects which emit gamma rays, but with the CTA observatory, we expect to detect 1000s only in the Milky Way. Furthermore, new gamma ray extragalactic sources are expected to be found [4].

The cosmic gamma rays cannot arrive at the earth´s surface, but CTA can see them from the ground using the subatomic particle cascades (Fig. 1-3) that the gamma rays produce in contact with the earth's atmosphere. These particles have an average speed faster than light in atmosphere and emit visible light known as Cherenkov radiation. The LST can collect and record the nanosecond flash of light so that the incoming gamma ray can be traced back to its source. To get more information on the incoming gamma ray, the CTA Observatory needs to collect as much data as possible. For this reason, there will be two arrays with several telescopes each one. The properties of these arrays are:

- Telescopes do stereoscopic observations (for this reason we need to have several telescopes close by).
- Collection area, for this reason we need to have many telescopes.
- The visibility of sources (for this there is a site in the north and a site in the south).

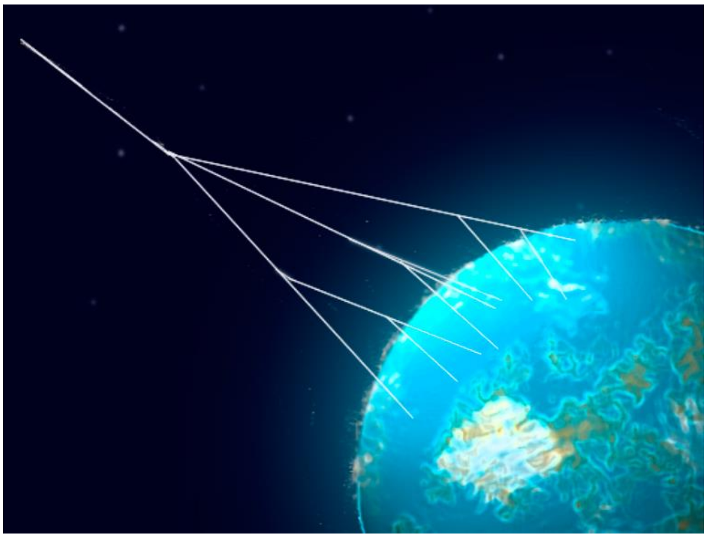


Fig. 1-3: Gamma rays cascade

CTA North is in the northern hemisphere and it is in The Observatorio Roque de Los Muchachos, in La Palma (Spain). The second Observatory is in the southern hemisphere and it is the CTA South. It is located in Paranal (Chile).

Fig. 1-4 is an old sketch with the location of every telescope in the CTA North Observatory and the CTA South Observatory. It shows 19 telescopes in CTA North and 99 Telescopes in CTA South. However, in 2021, after more detailed Monte Carlo simulations of the facility, the telescopes distribution changed to "Alpha Configuration". The Alpha Configuration currently approved will have 13 Telescopes in CTA North (4 LST and 9 MST) and 51 Telescopes in CTA South (14 MST and 37 SST) [2]. However it is foreseen that the number of telescopes might increase if financial aid is improved.

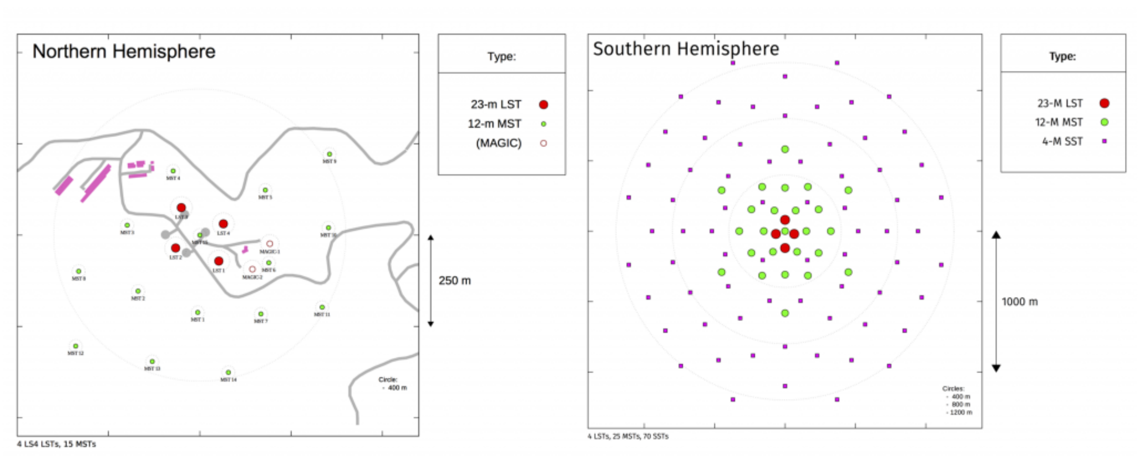


Fig. 1-4: Old sketch of CTA North Observatory Location and CTA South Observatory Location [2].

1.2. History of gamma ray detectors

There are four different projects using gamma ray detectors working currently (H.E.S.S., VERITAS, FACT and, MAGIC) around the world (see Fig. 1-6 and Fig. 1-7). However, the project Cherenkov Telescope Array (CTA) is the last generation of gamma ray detectors and it will be ten times as sensitive and will have unprecedented accuracy in its detection of high-energy gamma rays. In Fig. 1-5 we can see the lifespan of most important installations. Red colour indicated operation up to current date, whereas orange colour shows the future operation life according to current expectations.

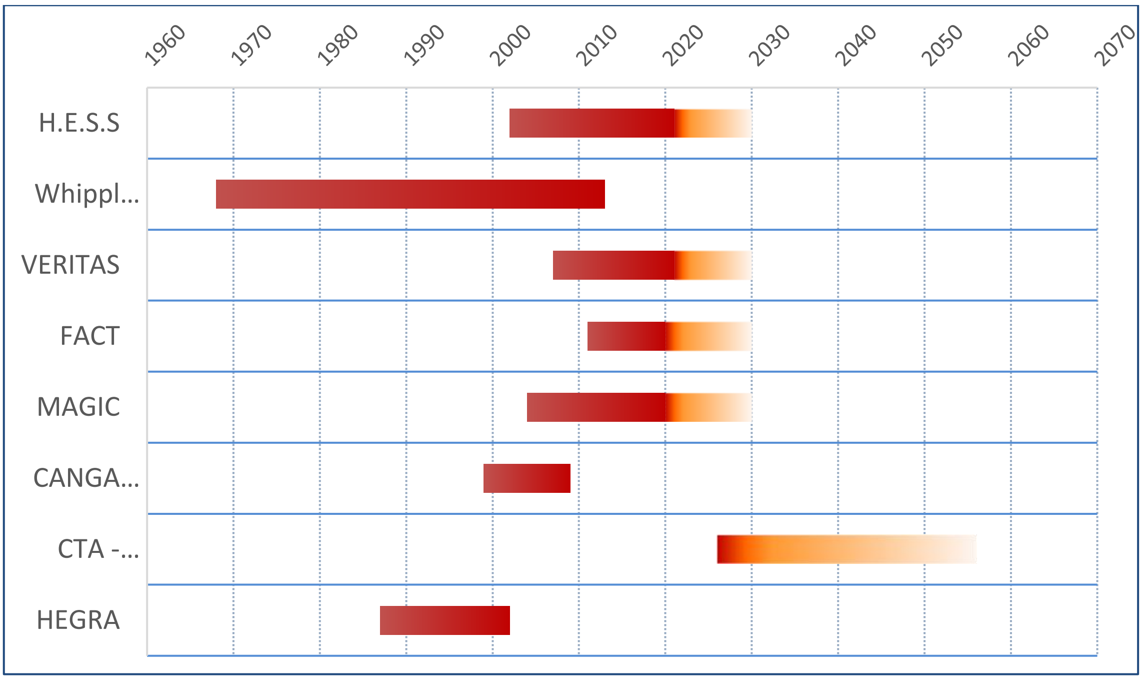


Fig. 1-5: Lifespan of gamma ray telescopes

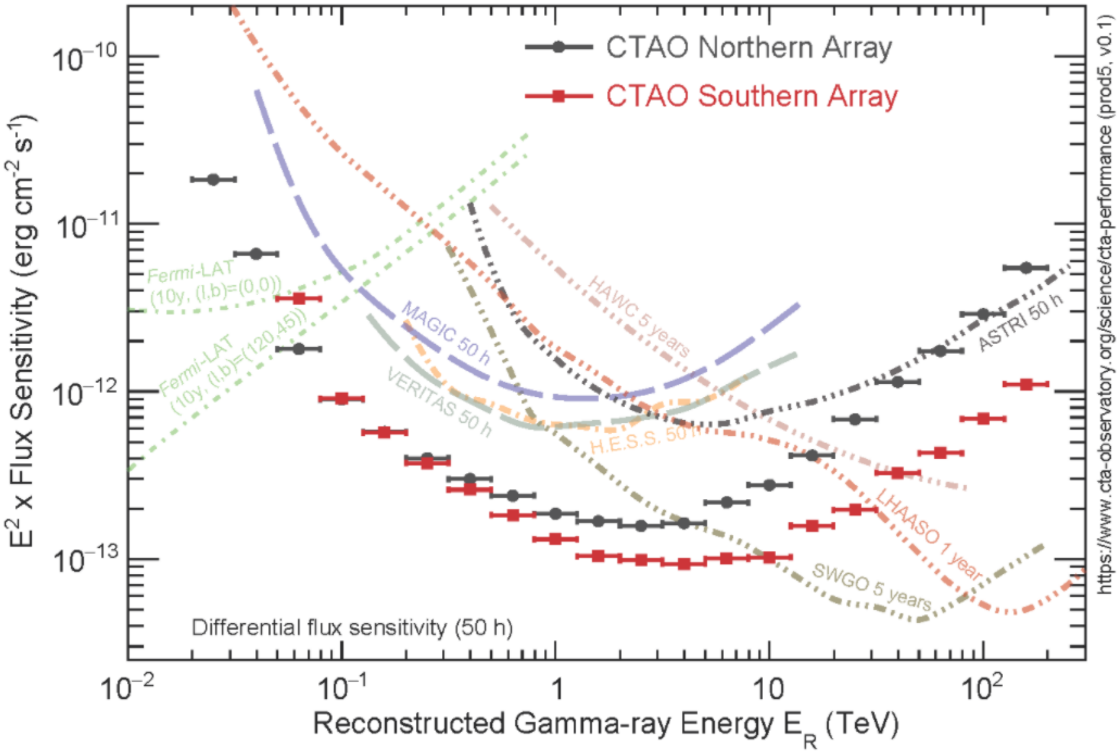


Fig. 1-6: Sensitivities of some present and future HE gamma detectors, measured as the minimum intensity source detectable at 5. The performance for EAS and satellite detector is based on one year of data taking; for Cherenkov telescopes, it is based on 50 hours of data [5]. *Credits: https://www.cta-observatory.org/science/ctao-performance/#1472563157332-1ef9e83d-426c*

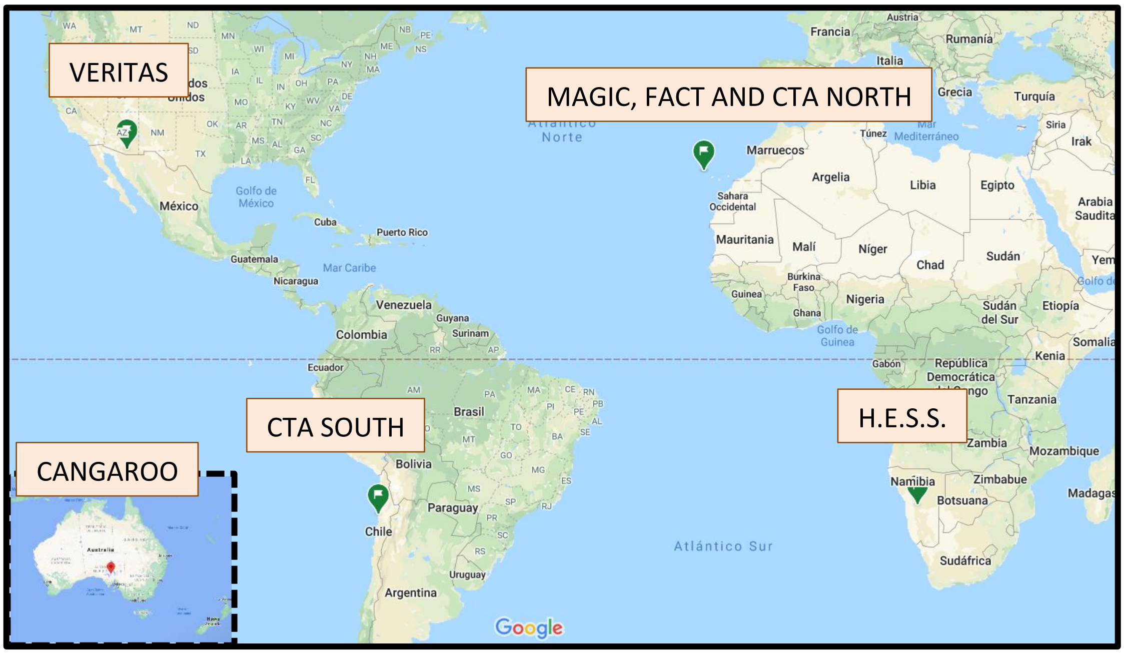


Fig. 1-7: Location of gamma ray detectors

H.E.S.S (High Energy Stereoscopic System)

H.E.S.S. is a system of five telescopes of Imaging Atmospheric Cherenkov Telescopes that investigates cosmic gamma rays in the energy range from 10s of GeV to 10s of TeV. The name of this telescope is intended to pay homage to Victor Hess, who received the Nobel Prize in Physics in 1936, for his discovery of cosmic radiation. Scientists can investigate the gamma-ray sources with intensities at a level of a few thousandths of the flux of the Crab nebula[3]. H.E.S.S. is located in Namibia. Its first telescope (H.E.S.S.I) started the operation in 2002, all four were operating in December 2003 and they were officially inaugurated in 2004 (September). The fifth telescope (H.E.S.S.II) was inaugurated in 2012. In 2016 the cameras of H.E.S.S.I were fully refurbished using the new technology of CTA [7]. This project is at 1815 m.a.s.l. The 4 H.E.S.S.I telescopes are identical (12 m diameter) while H.E.S.S.II is a much larger one (32.6 m diameter) [7].

Fig. 1-8: H.E.S.S Telescopes [7].

Whipple 10m Telescope and Blazar Lightcurves

The Whipple Telescope was located at the Fred Lawrence Whipple Observatory, in Arizona. It collected data from 1968 until 2013. VERITAS was installed in the same place [8]. This project was at 1275 m.a.s.l.

HEGRA (High Energy Gamma Ray Astronomy)

It was an atmospheric Cherenkov telescope for Gamma-ray astronomy that took data 1987 and 2002 when it was removed for installing the project MAGIC (see 2.4.2.14).

The detectors CRT (Cosmic Ray Tracking) were in operation at the site of the HEGRA between 1993 and 1996. There were six telescopes in this project

VERITAS (Very Energetic Radiation Imaging Telescope Array System)

VERITAS (Very Energetic Radiation Imaging Telescope Array System) is a ground-based gamma-ray instrument operating at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona, USA. It is an array of four 12m optical reflectors for gamma-ray astronomy in the GeV - TeV energy range. These imaging Cherenkov telescopes are deployed to get the highest sensitivity in the VHE energy band (50 GeV - 50 TeV), with maximum sensitivity between 100 GeV and 10 TeV. The first light of the prototype took place in 2004. 3 years later was the first light Celebration of another 4 telescopes. In 2012, the camera PMTs was upgraded to high-quantum-efficiency PMTs [9]. This project is at 1268 m.a.s.l.

[3] The Crab Nebula is the brightest steady source of gamma rays in the sky.

Fig. 1-9: View of the FLWO basecamp and the VERITAS array [9].

FACT (First G-APD Cherenkov Telescope)

The First G-APD Cherenkov Telescope (FACT) is the first imagining atmospheric Cherenkov Telescope using Geiger-mode avalanche photodiodes (G-APDs) as photosensors [10]. It uses the mount of the former HEGRA telescope in La Palma, in ORM.

MAGIC (Major Atmospheric Gamma Imaging Cherenkov)

The MAGIC system consists of two 17m diameter telescopes. They observe the gamma rays from galactic and extragalactic sources in a very high energy range (VHE, 30 GeV to 100 TeV). The MAGIC telescopes are in the Observatorio Roque de Los Muchachos, in La Palma (Spain). The distance between telescopes is 85 meters and they operate in coincidence, in the stereoscopic mode [11].

Fig. 1-10: MAGIC TELESCOPES.

CANGAROO (Collaboration between Australia and Nippon for a Gamma Ray Observatory in the Outback)

The Cangaroo project is a collaboration between Australia and Nippon for Gamma Ray Observatory. There is a telescope at 165 m.a.s.l. in a desert town 500km from Adelaide. A large 10m telescope, that was constructed on-site. The operation started in March 1999. There is another telescope “Cangaroo II” (December 2002) and two else: “Cangaroo III” and “Cangaroo IV” (2003) telescopes [12] [13]. Cangaroo stopped the observations in 2009 [14].

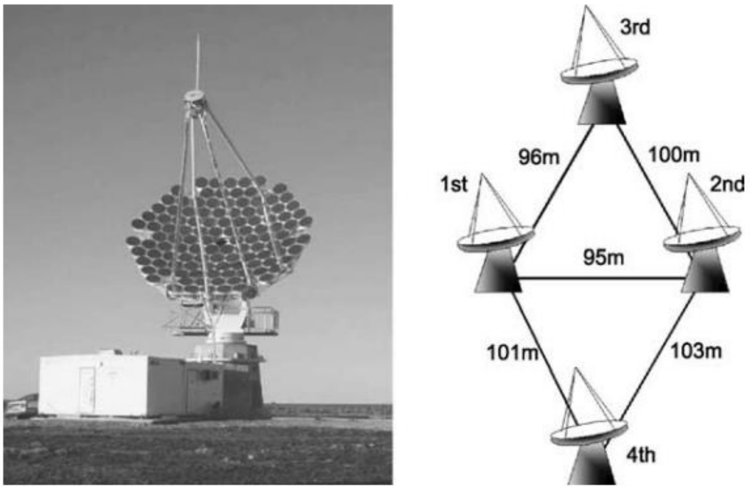


Fig. 1-11: Cangaroo Project Gamma-Ray Telescope [13]

1.3. Aims and scope of this thesis

This thesis aims to investigate what can be done to enlarge the lifespan of the large size telescopes in the Cherenkov Telescope Array northern observatory (CTA-N). At the same time, it is intended to unveil practical hints and relevant information that might help to increase the availability of these telescopes during their operation, by reducing the maintenance efforts and improving the reliability of the subsystems. Many arguments support the interest of facing these goals.

CTA collaboration includes 1,500 members from more than 150 institutes in 25 countries. The LST project team comprises more than 200 scientists from 10 countries. In addition, the CTA-N will be the first ground-based gamma-ray observatory open to the scientific community. This is expected to significantly strengthen the scientific knowledge in the fields of Astrophysics and Astroparticle Physics. But the CTA not only means top-quality scientific return.

The multidisciplinary expertise required to build CTA has attracted strong interest from numerous companies and institutions. A wealth of high-tech sectors with promising industrial potential may benefit from CTA technology. Furthermore, hosting CTA-N in La Palma is already bringing an undeniable prestige to Spain, and significantly contributing to the economical development of the island.

All the previous arguments help to understand how relevant it is to enlarge the lifespan of the CTA's telescopes. And although this thesis is focused on the LSTs, we believe that the results presented here will facilitate the cooperation among telescope developers that aim to improve the lifespan and availability of all instruments to be deployed at ORM.

Maintenance and operation of gamma-ray telescopes, particularly the telescopes that will configure the CTA-N observatory, pose challenging difficulties that are not to find in other, more conventional instruments. An optical telescope is typically designed to be covered by a dome. Telescope domes efficiently protect the telescope against wind stress, rain, snow and dust, and at the same time ensure that sensitive components are not exposed to extreme temperatures.

On the other hand, the CTA-N site was chosen for its suitability to astronomical observations, being free from terrain obstacles and with a large number of clear sky nights. Located at around 2400 m above sea level, it offers a top-quality sky. However, the site also features challenging conditions for the observatory's longevity. Environmental conditions that might limit the telescope’s lifespan are UV radiation, rain, snow and calima, among others.

The terrain is volcanic and has a high electrical resistivity, which is typically in the kOhm·m range. This directly leads to difficulties in the achievability of the maximum earth resistances of the grounding systems that are typically required by the standards, and, as a result, to difficulties in the protection of the electronics against lightning strikes and surges. El Roque de Los Muchachos observatory also has a large number of days with very low humidities, and this favours electrostatic discharges.

In addition, the astrophysics observatories are usually in isolated places. For this reason, having storage or a workshop close is difficult if there is a problem. It is needed to find a balance between a correct number of spares and preventive and corrective maintenance.

I am currently working in the LST collaboration group and my position is the LST Telescope Manager and INFRA responsible. This has made a strong influence on the organization of this thesis and the definition of the major subjects of my contributions, which are all in close harmony with the main duties that were approved by the LST management for these positions.

The next chapter is devoted to the host observatory and environmental matters. It includes an exhaustive study of weather conditions as well as risks and catastrophic events in ORM. In addition, a description of other installations and scientific facilities located at ORM is also provided.

Chapter 3 describes the LST hardware covering all major subsystems: mechanics, optics, camera, auxiliary and other components.

Chapter 4 describes the main aspects of the management that are relevant to the LST longevity. It covers the risk management plan implementation, reliability, quality plan, safety, operations, logistic, maintenance, the optimal quantity of spare stocks, incidents and proposals for improvements to LST1 management.

Finally, Chapter 5 includes the conclusions.

2. OBSERVATORIO ROQUE DE LOS MUCHACHOS (ORM)

The Observatorio Roque de Los Muchachos is in La Palma Island (Spain). To understand the characteristics of the observatory, we need to know La Palma before. Environmental conditions and natural hazards are key factors for assessing the RAM performance and lifetime of a product.

2.1. Global description of La Palma

La Palma is a volcanic island, around 3 million years old and it is younger than other Canary Islands (like Lanzarote or Fuerteventura). La Palma is a medium island from the Canary Islands (Spain) and it is located in the Atlantic Ocean. The surface is 708,32 km^2 and the population is 82.671 people (2019) [15] [16] [17].

The capital city is Santa Cruz de La Palma. However, the town with the highest population is Los Llanos de Aridane (INE 2018). There are 14 municipalities in La Palma and only one of them does not have a coast. The ORM is in Garafia and Puntagorda.

Since 2002, La Palma has been classified as a “Natural Reserve” from UNESCO along with Lanzarote and El Hierro. In the centre of the Island is the Natural Park: La Caldera de Taburiente. This National Park was inaugurated in 1954. Around the crater, there are high points between 1,700 m.a.s.l and 2,426 m.a,s.l. The highest point in La Palma is “El Roque de Los Muchachos”; close to this place is the Astrophysics Observatory.

The deepest access to La Caldera de Taburiente is the “Barranco de Las Angustias”, which is closed during the rain alerts because of the high volume of water that can run across this ravine. Some other natural parks are “Las Nieves” and “Cumbre Vieja”.

The landscapes of La Palma are very diverse, deforested coast, laurel forest, pine forest and High Mountain. There are endemic plants: Drago, Canary Pine and Canary Palm Tree. According to the altitude, we can find different plants, between 2000 and 2400 m.a.s.l. there is “matorral de cumbre”.

There are 4 protected landscapes: El Tablado, Barranco de las Angustias, Tamanca and El Remo.

There are also 5 main roads in La Palma, LP-1 to 5, the road to Roque de Los Muchachos is the LP-4. The quality of the roads is good. However, due to the landform of the island, there are a lot of curves and slopes. Access to La Palma is possible by air (there is an airport) or by sea (the main port being Santa Cruz de La Palma which offers several ferries per day).

There are 2 distinctive climatic areas in La Palma, west and east, and the limit is a line of volcanos (Cumbre Vieja) [17]. In the south area, there are active volcanos as Teneguia Volcano (its last eruption was in 1971), it is in Fuencaliente and it is an interesting scientific point. As an interesting fact, there is a Thermal Water Spring: Fuente Santa. The north area is older and in this area is located the “La Caldera de Taburiente”, where is a big crater of 9 km diameter [18]. The weather in La Palma is influenced by several factors [19]:

2.1.1. Factors affecting the weather

Factor 1: The geometry of the island, is very abrupt, narrow and high and it is very close to Africa (big surface of earth). The latitude is 28°40'north. The maximum altitude is 2,426 m.a.s.l. (Roque de Los Muchachos) and it is the second-highest on the Canary Islands after Tenerife’s (3,718 m.a.s.l.).

Fig. 2-1: Geometry of La Palma. Credits: GRAFCAN

Factor 2: The trade winds. In the Northern Hemisphere, warm air around the equator rises and flows north toward the pole (see Fig. 2-2). As the air moves away from the equator, the Coriolis Effect deflects it toward the right. It cools and descends near 30 degrees North latitude. The descending air blows from the northeast to the southwest, back to the equator (Ross, 1995). A similar wind pattern occurs in the Southern Hemisphere; these winds blow from the southeast toward the northwest and descend near 30 degrees South latitude. These are the trade winds. The origin of this name is historical because of the ships that used to utilised these winds between Europe and America to optimise their sea routes [20]. La Palma is 28.6ºN. However, there is an important influence of "Trade Winds". For this reason, the weather is mild. The Canary Islands are influenced by **lower trade winds** (cold and wet) which are located between the sea level and the 1500 m.a.s.l and **upper trade winds** (hot and dry) which are above the 1500 m.a.s.l. (see Fig. 2-3)

Factor 3: The seven Canary Islands are an obstacle in the direction and speed of these winds. The result of the mix of these trade winds is the "**thermal inversion**" [21]. The **inversion limit** is around 1500 m.a.s.l. Due to the thermal inversion, the temperature is higher and the air drier in the area above the inversion limit, than in the area beneath it, where the atmosphere is colder and wetter.

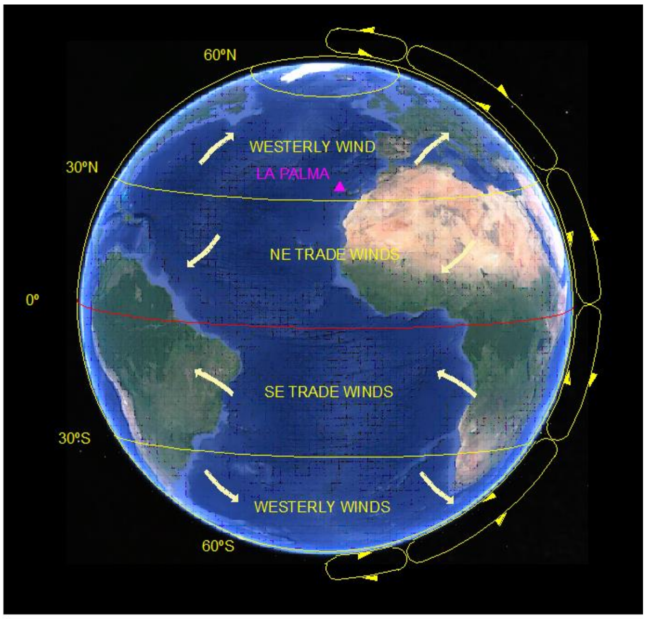


Fig. 2-2: Global Circulation and Trade Winds.

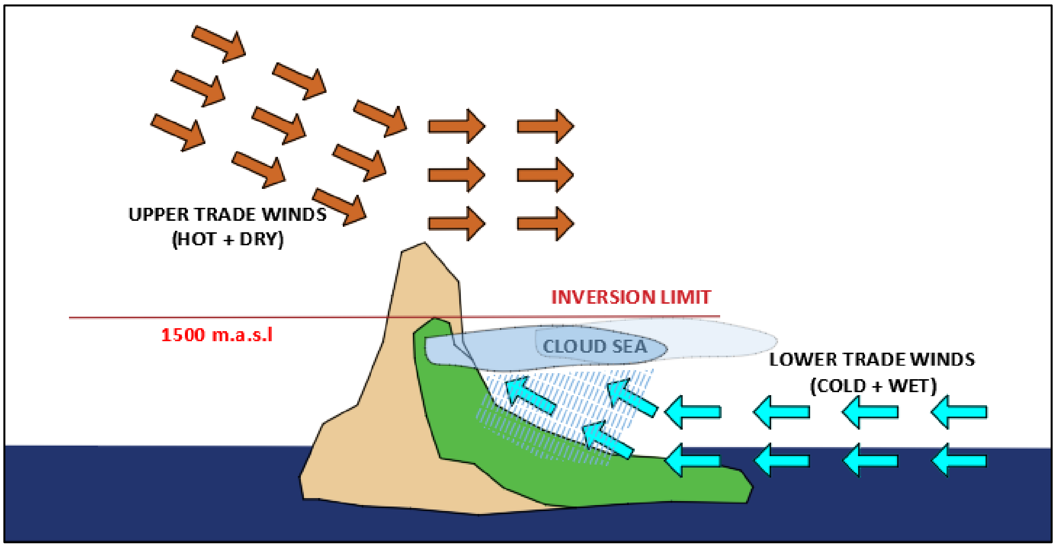


Fig. 2-3: Sea clouds

Factor 4: The lower trade winds are capturing water when they are travelling to the south and the temperature is increasing. When they arrive at the Canary Islands, they hit the highest mountains in the north face of the islands and they start to rise next to the ground. In this movement, the humidity increases and the air starts to condensate. The upper trade winds are a barrier for the lower trade winds around 1,500 m.a.s.l and at this altitude, the "**cloud sea**" is produced (Fig. 2-4). The cloud sea controls the temperature and the humidity under it [20].

Fig. 2-4: Gran Telescopio de Canarias (GTC) with the cloud sea back. Picture took at 2,200 m.a.s.l.

Factor 5: The Atlantic Meridional Overturning Circulation (AMOC) and the **upwelling** [22] [23]. The oceanic current is descending parallel to Portugal and Morocco and it should be hot. However, the trade winds move the hot superficial water to the west area and finally the water in this area is colder.

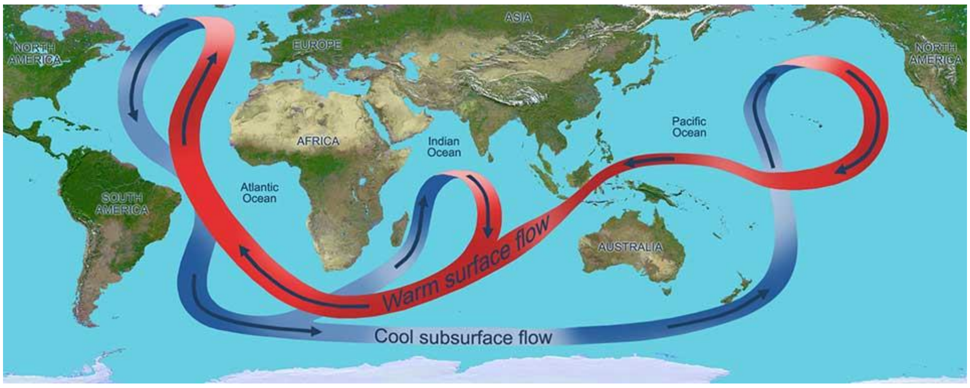


Fig. 2-5: Ocean surface flows. Credits: NOAA

Factor 6: Calima. The Canary Islands are very close to Africa and sometimes there is a wind coming from Africa to Canary Island. This wind is hot and dry and it is coming from the Sahara desert, as result, a red dust cloud moves towards the Canary Islands.

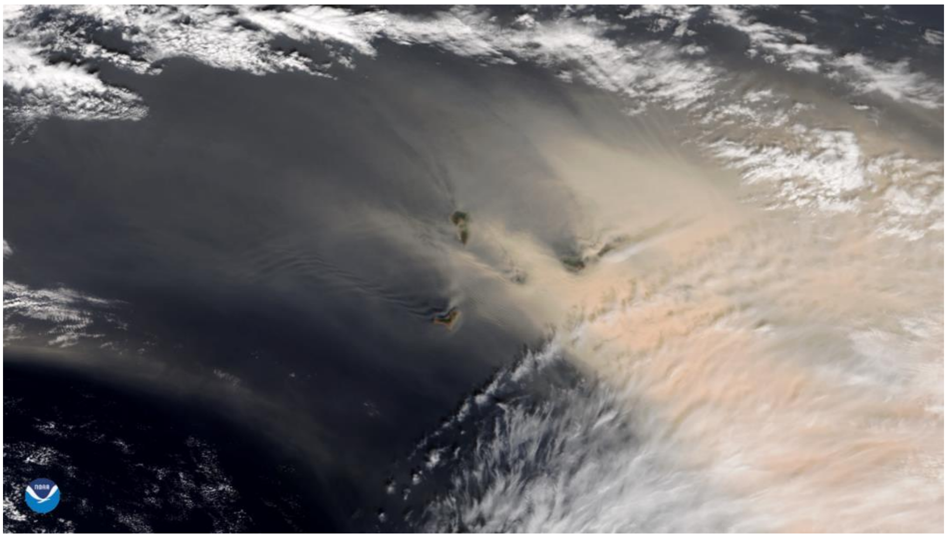


Fig. 2-6: Radar image of CALIMA (23rd Feb 2020). Credit: NOAA

2.2. Weather conditions

The ORM is more than 2,200 m.a.s.l. It is affected by the upper trade winds and the weather is hot and dry (if we compare with the temperature around 1,500 m.a.s.l). The cloud sea is below the ORM and sometimes there is Calima, but in general, the quality of the sky is exceptional. The temperature at sea level is between 18ºC and 28ºC but it can be under 0ºC at the top of the mountains, e.g. Roque de Los Muchachos.

Knowledge about the ORM's climatological data is essential for the proper functioning of the telescopes since their operation depends on environmental factors. For this reason, the climatology of ORM is measured with weather stations from several telescopes installed in the observatory. The older time series dating back to 1984. The oldest weather station in the LST telescopes area is the MAGIC weather station. The data from this WS is essential for the LST telescopes. Therefore, the LST1 WS was installed during the summer of 2020. The Magic WS has been taking data since 2003, however, there is only data from the last 8 years. The data from MAGIC´S weather station is in a restricted online database. Several weather parameters (atmospheric temperature, humidity, wind speed, wind gust, dust concentration…) can be selected and they can be represented in graphics or tables.

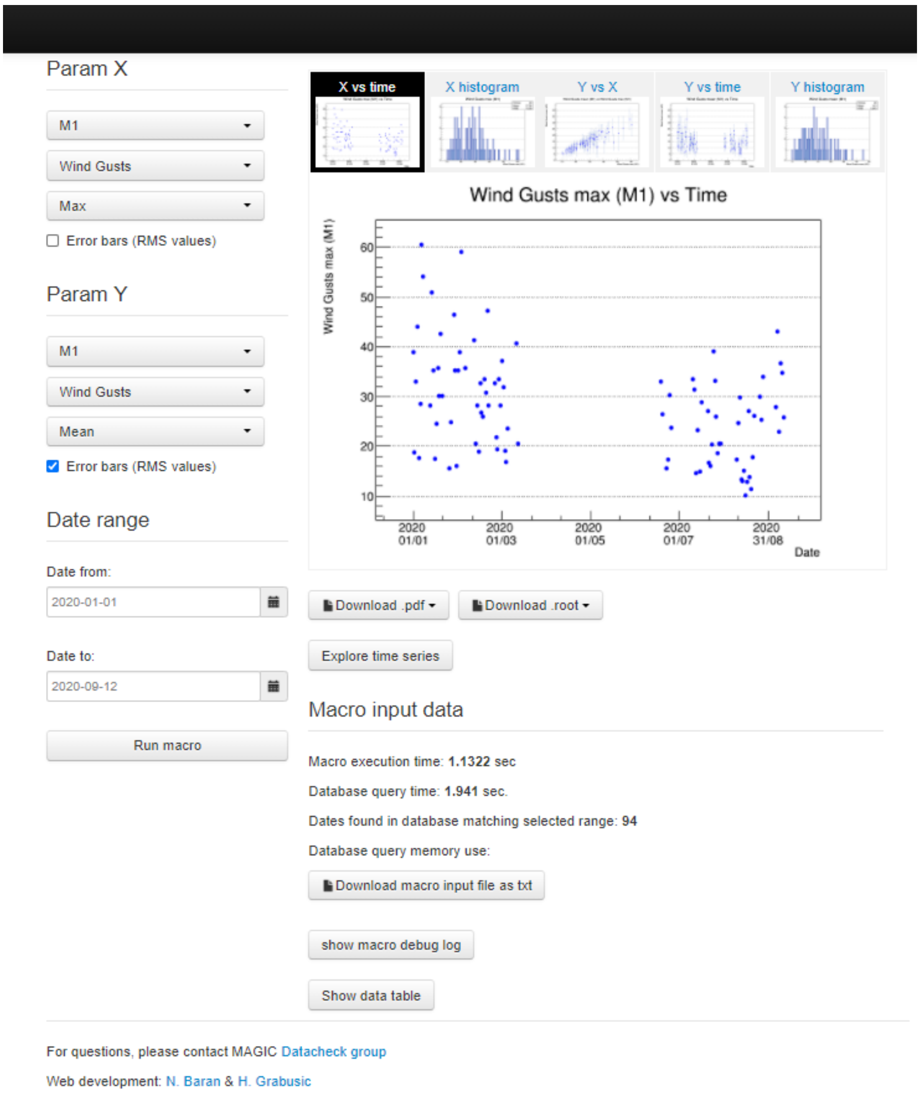


Fig. 2-7: Interface of MAGIC weather station database [24]

The ANNEX 1: Database of humidity, temperature, wind speed and dust concentration since Nov.2012 to Aug.2021 from Magic WS [24] is the database of Magic WS of last 8 years.

2.2.1.Temperature

The average temperature in the ORM is around 8ºC, with a difference of about 2ºC between day and night, the average annual minimum and maximum being around -8ºC and 28ºC [25][26].

According to the Magic WS, 2021 is being the hottest year since 2012. If we don't consider the year 2021 in this comparison (2021 has not finished yet), the hottest year is 2020 and the coldest one 2018 (database of 2012 is not complete) (Fig. 2-8 and Table 1). The average maximum temperature was 23.38ºC on the 16th of Aug of 2021. The average temperatures around 23ºC were not very common in the period of these 8 years (Fig. 2-9). The coldest winter was winter 2014-2015 (Fig. 2-8) but this temperature last only for few days (Fig. 2-9). The difference in temperature during the year 2015 was the biggest in this period of the last 8 years. The average temperature in Magic WS is 10.7 ºC, which is higher than the average temperature in ORM [25] but it has sense due to the location of Magic WS.

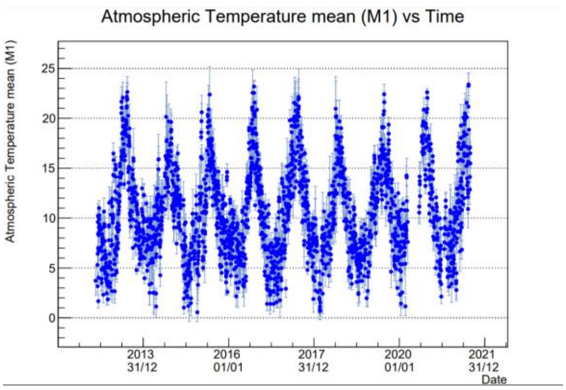


Fig. 2-8: Average atmospheric temperature (2012-2020). Credits: Magic WS

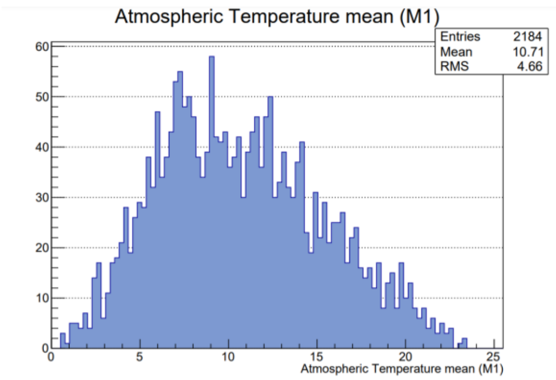


Fig. 2-9: Atmospheric temperature histogram (2012-2020). Credits: Magic WS

Table 1. Average temperature per year from Nov.2012 to Aug.2021

	T (ºC)
2012	7.45
2013	10.99
2014	10.49
2015	10.34
2016	10.46
2017	11.16
2018	10.13
2019	10.76
2020	11.25
2021	11.49

The environmental temperature affects the thermal expansion of the telescope and the activities on-site because working with very low or very high temperatures can negatively affect the health of the workers. Knowing the coldest and hottest month is very useful to coordinate the activities on-site.

Table 2 is the average temperature per month from Nov. 2012 to Aug. 2021. The hottest month is August and the coldest one, February. Fig. 2-10 is a graphic of the average temperature per month in the same period.

Table 2: Average temperature per month from Nov.2012 to Aug.2021

	T (ºC)
Jan	6.36
Feb	**6.26**
Mar	7.19
Apr	8.03
May	9.88
Jun	12.67
Jul	16.95
Aug	**17.03**
Sep	13.40
Oct	11.45
Nov	8.41
Dec	7.26

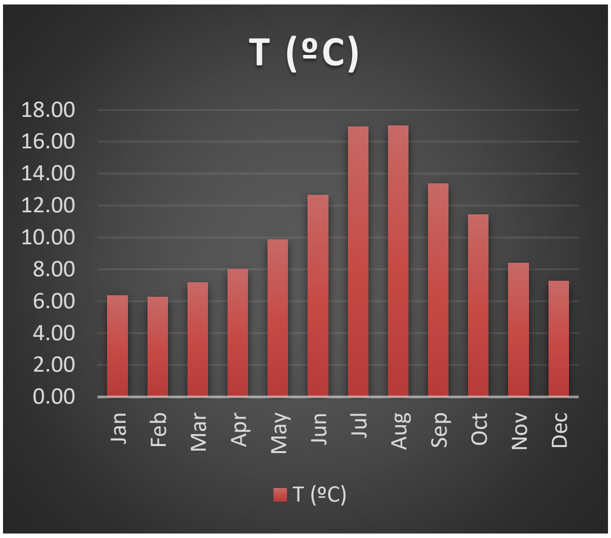


Fig. 2-10. Graphic of average temperature per month from Nov.2012 to Aug.2021

The Gobierno de Canarias activates "alarm status" if very high or very low temperatures are forecasted.

2.2.2. Wind

The average wind speed at the ORM is around 4 m/s, and the percentage of nights with a constant wind speed higher than 15 m/s is below 4.2% [27]. Fig. 2-11 shows the distribution of 10-minutes wind speed averages and wind gusts, obtained with the MAGIC weather station spanning a time period from 2003 to 2021. The median wind average measured by the Magic Weather Station is 3.2 m/s, lower than the Observatory average. This may be due to the fact that other telescopes such as the TNG are located at the mountain rim, which suffers from higher wind speeds. They can be considered "catastrophic events" as we will see in Section 2.3**¡Error! No se encuentra el origen de la referencia.**. Most of the winds blow from the East and South-Eastern directions. The maximum wind gust detected was in Feb. 2020, where the anemometer reached its sensitivity maximum of 157 km/h. It is possible that even higher winds occurred during that time, undetectable for the MAGIC weather station. For instance, the NOT weather station displayed wind speeds up to 163 km/h, consistent with the maximum wind speed measured by the AEMET station.

The Government of the Canary Islands activates an "alarm status" when high speed winds are forecasted. The design specifications of the first LST (LST1) consider wind speeds higher than 200 km/h. However, more restrictive safety procedures can force to stop the operation of the telescope [28] since even winds below this limit can compromise the safety of people.

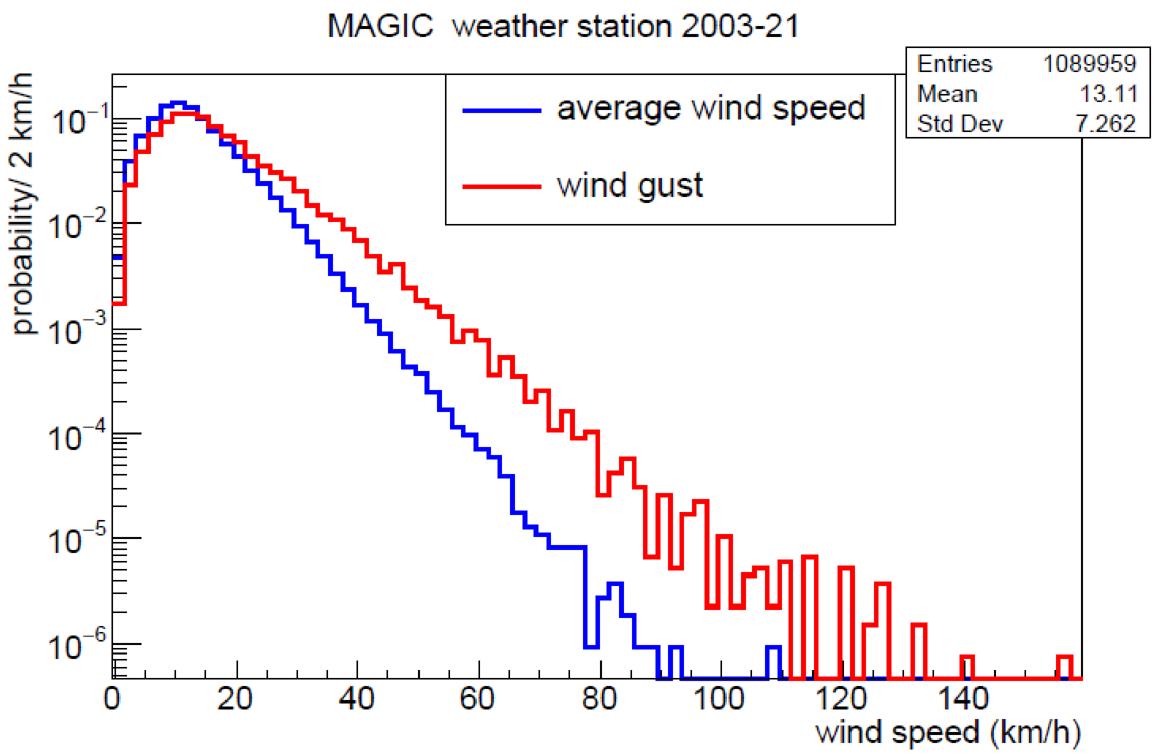


Fig. 2-11: Distribution of wind speeds from 2003 to 2021.

The year with the highest wind speed was 2017 and the year with the lower wind speed was 2013 (we cannot consider 2021 and 2012 because the database is not complete) (Table 3).

Table 3. Average wind speed per year from Nov.2012 to Aug.2021

	WS (km/h)
2012	11.25
2013	11.07
2014	11.69
2015	12.06
2016	11.75
2017	12.42
2018	11.46
2019	11.44
2020	11.18
2021	10.16

The specifications of the design of the telescope LST1 are meant for wind gust of more than 200 km/h. In addition, there are more restrictive safety procedures in which the operations need to be stopped [28] because the wind risks excessively the safety of the people. Knowing the most and the least windy months is very useful to coordinate the activities on-site.

Table 4 is the average wind speed per month from Nov. 2012 to Aug. 2021. The windiest month is December and the least windy month are August and September. Fig. 2-12 is the graphic of wind speed per month in the same period.

Table 4. Average wind speed per month from Nov.2012 to Aug.2021

	WS (km/h)
Jan	12.79
Feb	12.86
Mar	13.06
Apr	10.85
May	10.91
Jun	10.54
Jul	10.48
Aug	**10.27**
Sep	**10.27**
Oct	11.27
Nov	12.50
Dec	**13.65**

Fig. 2-12. Average wind speed per month from Nov.2012 to Aug.2021

The Gobierno de Canarias activates an "alarm status" if high-speed wind is forecasted.

2.2.3. Dust concentration

Monthly averages of PM10 percentile 75% are below 10 µg/m3 (extremely clean environments) throughout the year, except during the calima events. 50% of the time, the atmosphere is even cleaner than the ultra-clean Antarctic environment. A detailed study, covering 20 years, from the ORM, obtained a median coefficient KV = 0.13 mag/airmass. Ninety per cent of the time during the winter months resulted dust-free. For the summer months, the percentage is around 75% [29].

The Magic WS cannot register the dust concentration, however, the TNG WS can read it. Fig. 2-13 and Fig. 2-14 illustrate the dust concentration since 2012. The biggest average dust concentration was in 2020 (Fig. 2-14 and Table 5).

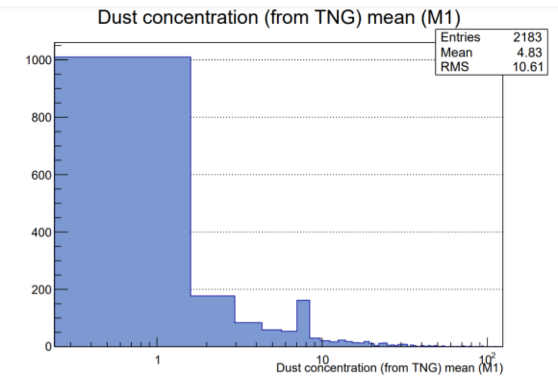


Fig. 2-13: Dust Concentration histogram (2012-2020). Credits: TNG WS

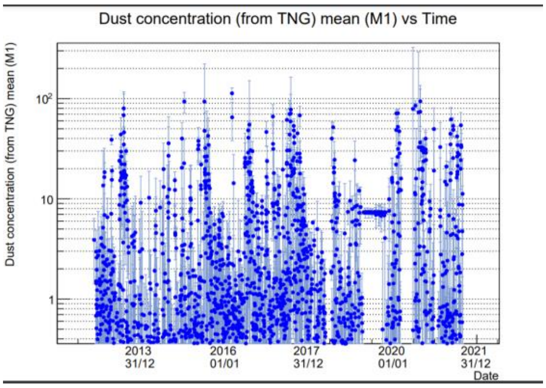


Fig. 2-14: Average dust concentration (2012-2020). Credits: TNG WS

Table 5. Average dust concentration per year from Nov.2012 to Aug.2021

	DC (µg/m3)
2012	1.29
2013	4.05
2014	**1.67**
2015	4.49
2016	4.54
2017	7.36
2018	1.96
2019	4.84
2020	**10.95**
2021	6.10

The dust concentration affects the operation of the telescopes [30]. Knowing the month with maximal dust concentration and the month with minimal one is very useful to coordinate the activities on-site.

Table 6 is the average temperature per month from Nov. 2012 to Aug. 2021. The month with maximal dust concentration is August and the month with minimal one is November. Fig. 2-14 is a graphic of the average temperature per month in the same period.

Table 6. Average dust concentration per month from Nov.2012 to Aug.2021

	DC (µg/m3)
Jan	2.34
Feb	5.44
Mar	3.31
Apr	2.22
May	3.47
Jun	4.53
Jul	9.98
Aug	**11.64**
Sep	4.62
Oct	3.79
Nov	**1.82**
Dec	2.58

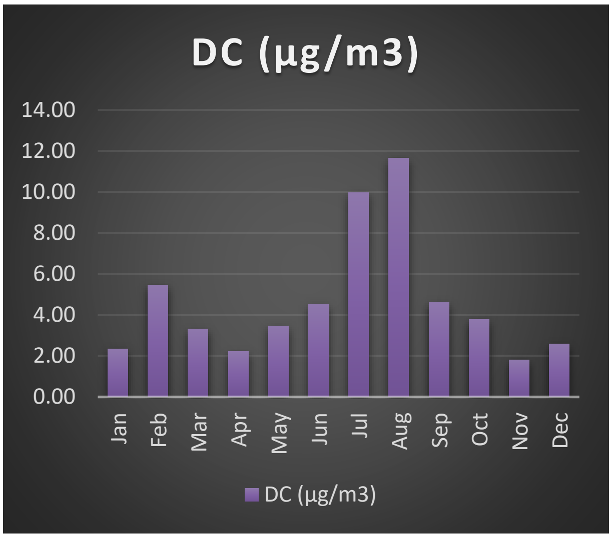


Fig. 2-15. Average dust concentration per month from Nov.2012 to Aug.2021

2.2.4. Storms and lightning strikes

The Magic WS does not have any sensor of storms. The parameter that can be measured is the humidity which is directly related to storms. The most humid year since 2012 was 2015 (Fig. 2-16 and Table 7). The average humidity during the period Nov.2012 to Aug.2021 is 31.36%. Higher humidities are not very typical however sometimes it reaches 100% (Fig. 2-17).

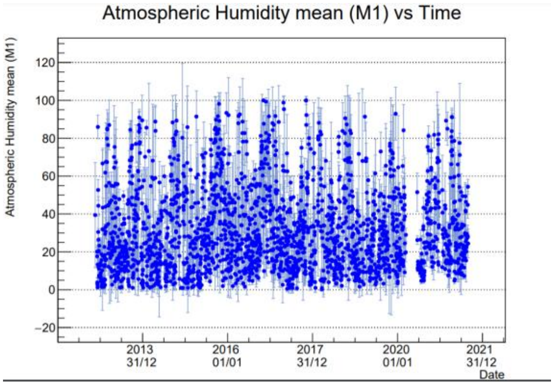


Fig. 2-16: Average atmospheric humidity (2012-2020). Credits: Magic WS

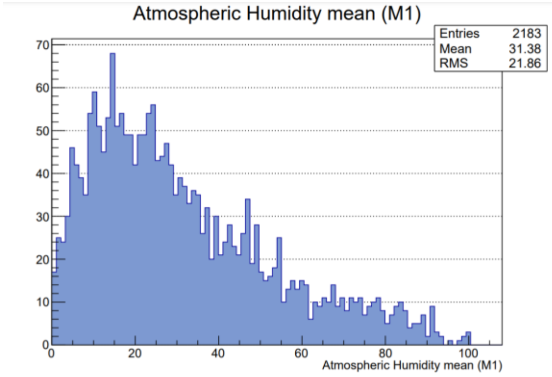


Fig. 2-17: Atmospheric humidity histogram (2012-2020). Credits: Magic WS

Table 7: Average humidity per year from Nov.2012 to Aug.2021

	HR (%)
2012	22.15
2013	29.20
2014	28.74
2015	35.51
2016	34.60
2017	30.05
2018	32.94
2019	27.89
2020	32.86
2021	31.32

There are restrictive safety procedures in which the operations need to be stopped [28]. The humidity affects the activities on-site because working with very low or very high humidity can negatively affect the health of the people. Knowing the most and the least humid months is very useful to coordinate the activities on-site. Table 8 is the average humidity per month from Nov. 2012 to Aug. 2021. The most humid month is November and the least humid one is July. Fig. 2-18 is a graphic of the average temperature per month in the same period.

Table 8. Average humidity per month from Nov.2012 to Aug.2021

	HR (%)
Jan	26.33
Feb	31.70
Mar	28.16
Apr	34.27
May	26.33
Jun	28.22
Jul	**19.66**
Aug	27.33
Sep	37.28
Oct	40.20
Nov	**46.52**
Dec	34.31

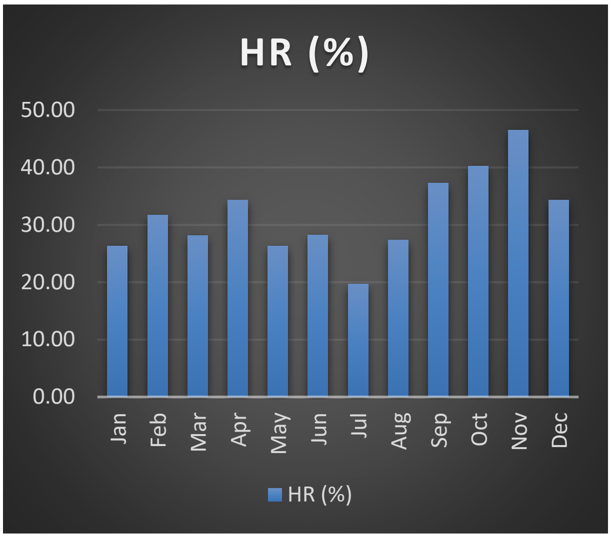


Fig. 2-18. Average humidity per month from Nov.2012 to Aug.2021

Lightning strike risks have been studied in detail Fig. 2-19 shows the strikes recorded by GLD360 Network around the area of LST1, between 2013 and 2020, and located within the square defined by coordinates 28°47'42.0"N 17°55'48.0"W and 28°45'36.0"N 17°51'00.0"W.

GLD360 is a Global Scale Lightning Located System launched by Vaisala Inc. in 2009, which uses a combination of direction finding and arrival time measurements [31], [32]. GLD360 integrates an array of broadband sensors operating at the VLF band (3 kHz -30 kHz). The arrival time is taken from either the ground wave or one of the subsequent sky waves generated by the strike. With the aid of a propagation model, the system can estimate both the polarity and peak current of each discharge [33].

A total of 20 strikes were detected. Remarkably, only two storms were the source of 13 of them. The storm on the 11th December 2013 produced six strikes, the other occurred on the 15th November 2016 and produced seven strikes, including the strongest one (with a current of -693 kA). The image is not centred at LST1 because no strikes were detected at the southern area of the telescope. This might be due to the presence of Caldera del Taburiente, an inactive volcanic crater which is about 1 km across, with abrupt walls that reach 2000 m over the Caldera's floor. El Roque de Los Muchachos is located right on the top of the northern wall.

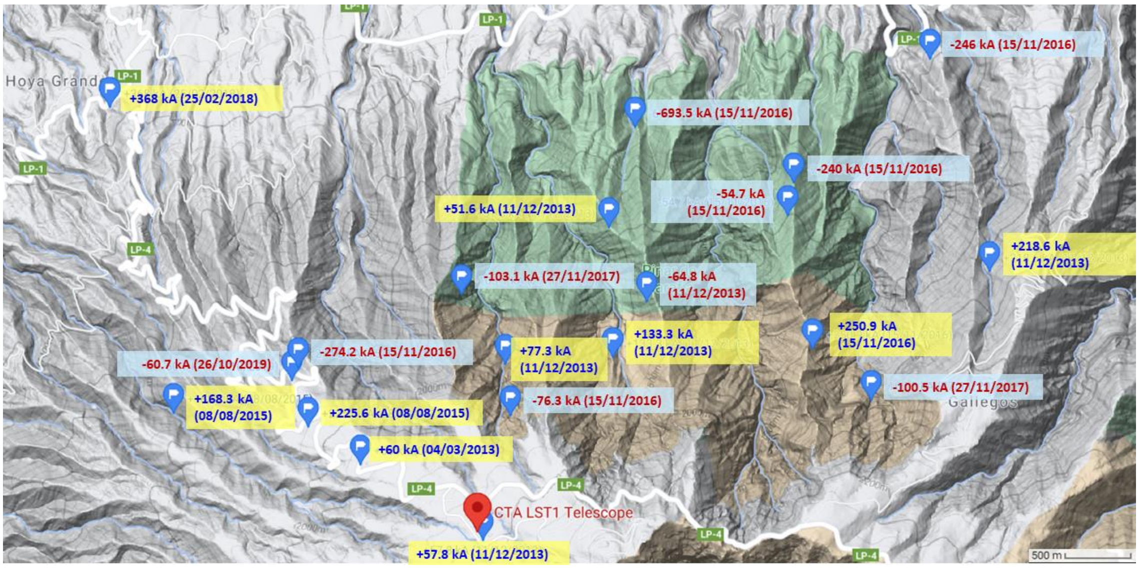


Fig. 2-19. Lightning strikes recorded by Vaisala GLD360 Network around LST1. Data correspond to events registered between 2013 and 2020. The image shows all the strikes registered within the square defined by corners 28°47'42.0"N 17°55'48.0"W and 28°45'36.0"N 17°51'00.0"W. Credits: Vaisala

2.2.5.Solar radiation

Solar radiation is not an environmental condition; however, it has a high influence on the ORM.

Solar radiation has 4 types of rays [34][35]:

- 49% are infrared (IR) rays that provide heat.
- 43% are visible rays (VI) that provide light.
- 7% are ultraviolet (UV) rays.
    - Ultraviolet A or UVA: They easily pass through the atmosphere, reaching the entire earth's surface.
    - Ultraviolet B or UVB: Short-wavelength. Has greater difficulty passing through the atmosphere. They reach the equatorial zone more easily than at high latitudes.
    - Ultraviolet C or UVC: Short-wavelength. They do not pass through the atmosphere. They are absorbed by the ozone layer.
- 1% are other types of rays.

The UV rays are only 7%; however, they have a high influence on the health, weather, biologic process, ecologic and photochemical processes. In addition, if the ozone cape is thin, the consequences can be worse. For this reason, the World Health Organization (WHO) started to measure the UVB.

The European Union started in 1996 the program COST[36], under the COST Action 713, to set a standard measure of UVB in Europe. There is a standard of the dangerousness of UV radiation, which is the UVI (Ultraviolet Index). The UVI is the multiplication of “erythematic irradiance” in W/m2 by 40. The ranges of dangerousness are:

Table 9: UV index

LOW	MODERATE	HIGH	VERY HIGH	EXTREME
0, 1, 2	3, 4, 5	6, 7	8, 9, 10	>10

The ranges of program COST from the EU are the same as the ranges of the U.S. National Weather Services [37].

The program COST did a study of data available in Europe. They did a compilation of a catalogue with a survey of the available UV and related the ozone and aerosol. In the document [36] there are tables with this information. The guide of UV on the Canary Islands [38] based in this program, indicate that the estimation of UVI in June is around 11 and the estimation in January is 3-5.

The AEMET (Agencia Española de Meteorologia) has the maximum UVI prediction. In La Palma, the average UVI at 9th May 2021 is between 10 and 11 (Extreme) (Fig. 2-20). To collect real in the ORM, the weather station of some telescopes can measure the UV Index and the Global Radiation. The weather station of the TNG Telescope has this tool.

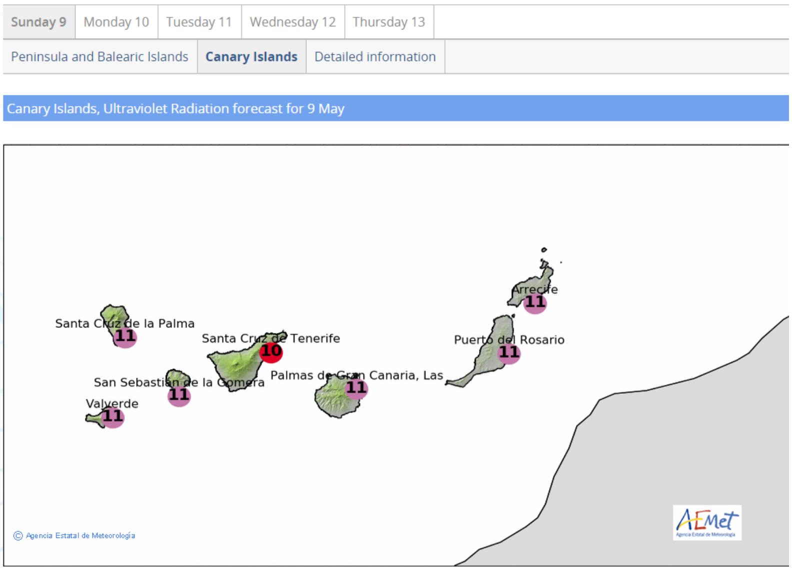


Fig. 2-20: Ultraviolet Radiation Forecast on 9th May 2021. Credits: AEMET

The UV Index in the TNG Telescope (Fig. 2-21) is 9 and it is according to Aemet prediction.

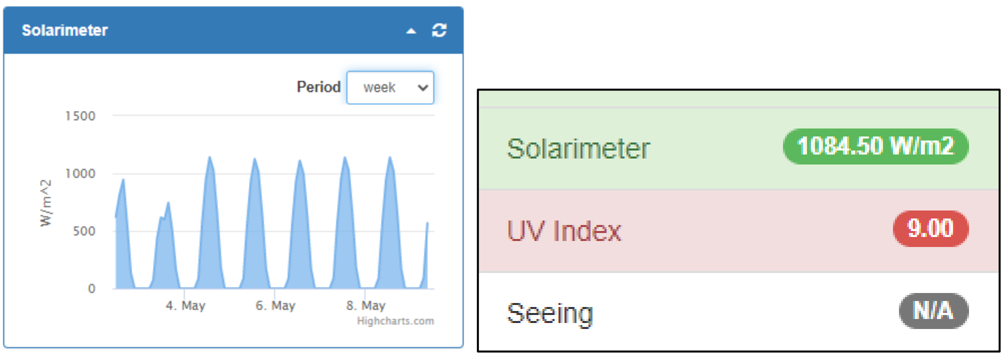


Fig. 2-21: Solarimeter and UV Index at 9th May 2021 (12:28 p.m). Credits: TNG Telescope

In the ORM we need to live together with solar radiation and UVI. The solar UV accelerates the degradation of plastics, rubber and wood material [39]. Wood is not used in the Telescope LST1, but many plastic materials are. Carbon fibre materials are at risk of degradation due to UV exposure [40]. On the opposite site, we can find the metals, which can be considered impervious to UV degradation [41].

The first negative effect of the UVI in plastic materials of Telescope LST1 affected the plastic ties. Metallic ties have replaced the plastic ties that had been supporting the pipes on the telescope because they broke due to degradation by the sun. This damage happened in 3 years. We need to remark that these plastic ties, which were damaged by the UVI, were not UV resistant. Other rubber/plastic elements have been degraded in these first 3 years of the commissioning phase (Fig. 2-22). The paint has been damaged in several places too due to solar radiation (Fig. 2-23).

Fig. 2-22: Damages in plastic/rubber materials of Telescope LST1

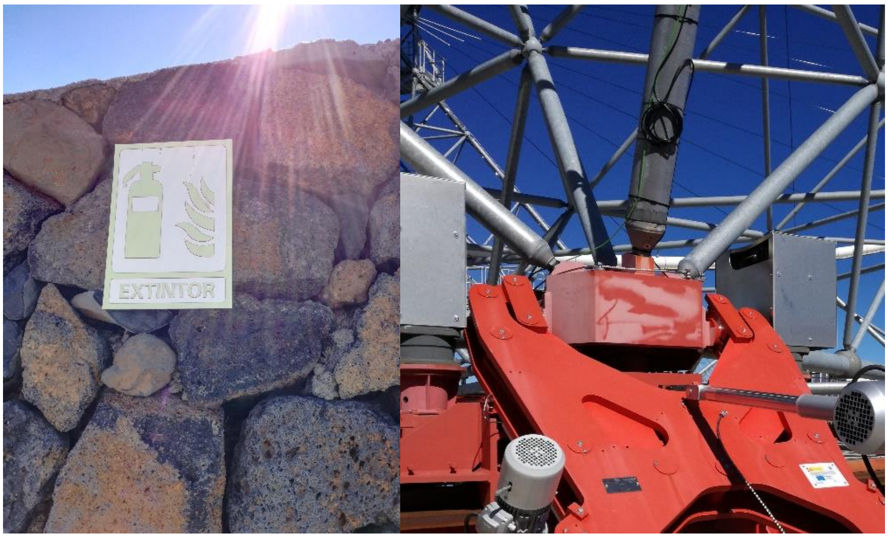


Fig. 2-23: Damaged paint in the telescope LST1

2.3. Risks and catastrophic events in the ORM

In this Section we will use the term risk according to the definition approved by PLATECA.

Knowing the natural risks or threats that can affect the infrastructures, structures and people is very important because, with this information, it is possible to design the infrastructures and structures according to the risks and prevent people from being in risk areas. Risk maps are a useful tool for knowing, preventing and resolving these issues and can be used in spatial planning and emergency management [42]. The project RIESGOMAP is doing it in the Canary Islands and the information is available online by the Gobierno de Canarias[43]. The risk maps done by RIESGOPMAP are explained in the reference [42].

To minimize the risks, predictive, preventive and corrective measures should be carried out. If the risks are not minimized, a catastrophic event can be produced [42].

According to PLATECA, the Canary Islands are exposed to the risks listed in Table 10:

Table 10: Risks according to PLATECA [44]

NATURAL RISKS	Floods
	Seismic movement
	Volcanic eruptions
	Associated with phenomena of adverse weather (snow, storms, cold wave, heatwave, calima, winds)
	Gravitational Movements
	Locust plague
	Wild fire
ANTHROPIC RISKS	Structures collapse
	Fires
	Risks in activities specialized sports
	Anomalies in the supply of basic services
	Health risks
	Risks due to human concentrations
	Intentional
TECHNOLOGICAL RISKS	Industrial origin
	Transports (accident or dangerous products)

Sometimes, one risk can be mixed with another.

A catastrophic event is a disaster of natural or no-natural origin that causes damage of significant severity and magnitude. Usually, the no-natural events have a human action origin. The Natural Risks affecting the Canary Islands are more frequently catastrophic rather than Technological. The main reason is that there are high safety measures to minimised the technological risks [45]. The natural phenomenas have caused the greatest catastrophes in the Canary Islands: floods, landslides, heat waves, locust plague, high wind storms and forest fires. In addition, human action can modify the topography and can affect the natural landscape [45], which can increase the negative consequences of natural hazards.

The pandemics are events with impact on people and workers; however, it has indirect consequences on the structures and the telescope.

In 2020 started an international pandemic: Covid-19. Due to the Covid-19, the borders of a lot of countries were closed and people were not allowed to travel. There were set new laws and rules in the affected countries. Only essential works could be done in Spain for almost 2 months. The effect in the Telescope LST1 was that preventive maintenance activities and operations were not done during this time.

Since 1949 some of the more catastrophic events in La Palma are in Table 11.

Table 11: Catastrophic events in La Palma since 1949

			1949	1971	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL (EVENTS)
NATURAL RISKS	Flood + rains								1			1					1		1											4
	Volcano´s eruption		1	1																									1	3
	Adverse weather	Snow											1						1							1			2	5
		Storms			1		1					1	Delta Storm			1	1	1			1		1	1		1		1		12
		Heat wave										1			1															2
		Calima								1													1					1		3
		Lightning Strikes																			7		2	7	2	1	1			20
	Wild Fire							1					1				1			2				1				1		7
ANTHROPIC RISKS	Pandemic																											1	1	2

The natural risks that can affect the ORM are the next:

2.3.1.Flood and rains

The strong rains can provoke floods and some of them had severe consequences in La Palma. The ORM's location on top of the Island favours not being affected by them usually. According to the risk map from the "Gobierno de Canarias", there is a low or very low risk around the telescope LST in the ORM. (Fig. 2-24)

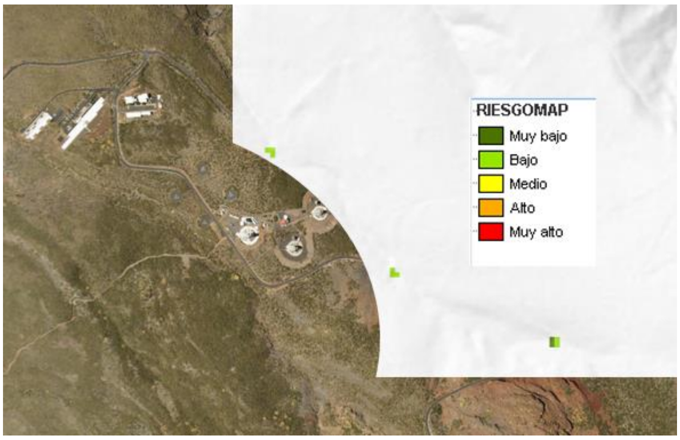


Fig. 2-24: Flood risks [16].

The last floods in La Palma are the next listed ones. They did not have direct consequences in the ORM, however, they were occasioned during storms.

- 20th November 2001: "Riada de Las Angustias". Intensive rain and flood in La Palma. Winds of more than 60km/h. Death toll 3 in La Caldera de Taburiente.
- 1st May 2004: Flood in Barranco de Las Angustias.
- Dec. 2009: Strong storm in La Palma and flood.
- Oct. 2011: Flood.

2.3.2.Seismic movement

Seismic movements are those generated by tectonic movements. The Canary Islands are on The African tectonic plate and its plate is passive; it is the reason why the risk of seismic movements is not too high.

Fig. 2-25 is the risk seismic map in the CTA North area. The risk in this area is low, only the area with buildings (ORM´s Residence) has medium risk regarding the consequences if there is a seismic movement [43].

Fig. 2-25: Seismic risk map (yellow=medium, green=low) [16]

2.3.3. Volcano eruption

La Palma is a volcanic island (see 2.1) and during the last 100 years, there has taken place the eruption of 3 volcanos in La Palma (there were more eruptions in some other Canary Islands).

- 1949: Eruption of Volcano San Juan
- 1971: Eruption of Volcano Teneguia
- 2021: Eruption of Volcano in Cumbre Vieja

The construction of the ORM started in 1973, then, there is no information about the eruptions of 1949 and 1971.

On 19th Sep 2021, started the last eruption in La Palma, in Cumbre Vieja. Days before eruption, there were seismic movements in the south of La Palma but they didn't affect to ORM. Currently the eruption is active (Fig. 2-26) and the consequences in ORM are ashes and dust (lava doesn't affect to ORM) [46] [47]. Ashes are abrasive and they can made damages in people, structures, vehicles and building and contaminate water supplies. Ashes must be cleaned as soon as possible. Telescope LST1 stopped the operations and it will be protected from ashes until the situation will be safe [48] [49].

Fig. 2-26. Cumbre Vieja volcano on 13rd October 2021

According to the risk map from the "Gobierno de Canarias", there is a low or very low risk around the telescope LST in the ORM (Fig. 2-27). The area of the ORM residence has a risk which is slightly higher than its surroundings since the analysis considers that the building is permanently occupied by people.

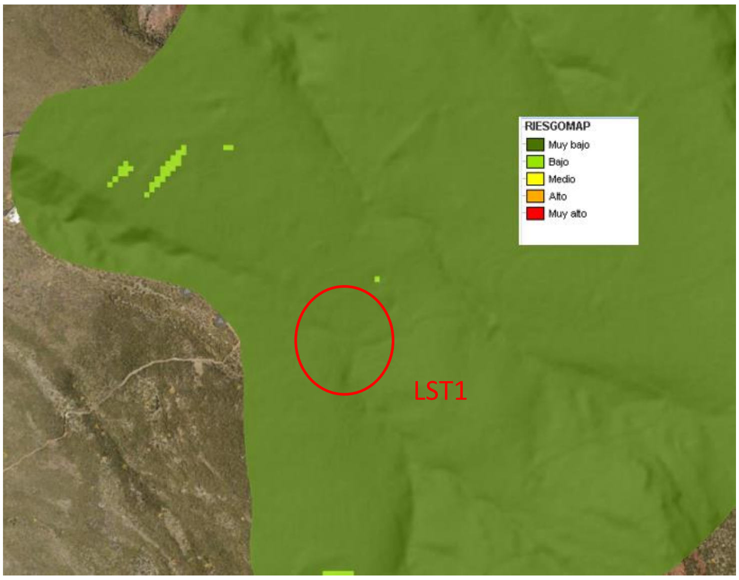


Fig. 2-27: Areas of risk volcanic eruptions [16] *(dark green: very low; green: low; yellow: medium; orange: high; red: very high)*

2.3.4. Associated with phenomena of adverse weather (Snow, storms, cold wave, heatwave, calima, winds)

2.3.4.1. Snow

The snow on top of La Palma is very common due to the altitude of this island. It has a direct impact on the ORM and it can affect the Telescopes and the workers.

Five important snow storms took place in Feb. 2005, Jan. 2011, Feb 2018, Jan 2021 (Fig. 2-28) and Feb 2021. Due to the last two snow storms, the telescope LST was stopped (for one week the first time and for 4 days the second one). The ice had to be melted before operating the telescope again because the cables, motors and other devices were trapped in it. In addition, inspections [28] were needed when the telescope was run again and several small reparations were needed too.

Fig. 2-28: CTA North area after snowstorm (2021)

2.3.4.2. Storms

The storms of strong winds and strong rain are the most common ones in La Palma. Since 1997, 11 important events have taken place, however, only a few of them affected directly the ORM.

The dates and consequences of those events were the following:

- 14-18 January 1997: winds > 75km/h. 2 deaths in Tijarafe. Airports were closed.
- 1st – 8th January 1999: strong winds and rains. Wind> 100km/h.
- 19th Feb 2004: Strong storm significant wind and rain of 183 l/m2 (historical maximum in 24 hours).
- 28th November 2005 (Delta): worst storm since 1996. It was a Tropical Storm. The airport from La Palma was closed and several roads too. It was the only Tropical Storm during the XX century. The maximum velocity of the wind in La Palma was 152km/h. Wind gust in Izaña (Tenerife) was more than 256 km/h [50].
- 10th Feb. 2008: Strong storm in the ORM.
- Dec. 2009: Strong storm in La Palma and flood.
- Feb 2010: Cyclogenesis Xynthia. Gust winds of more than 150 km/h.
- 3rd Mar. 2013: Strong storm. A wind gust of more than 156km/h in La Palma Airport.
- Oct. 2015: Strong storm.
- Jan. 2016: Storm Alex.

- Feb 2018: Storm that affected the LST1 during the construction [51].
- Feb. 2020: Strong Storm. It affected the ORM [52].

2.3.4.3. Heat waves

The heat waves have a direct impact on people, mainly. The most important heat waves in La Palma were in 2004 and 2007 [45].

2.3.4.4. Calima

Although calima events are common in the Canary Islands only three were reported as catastrophic since 1997 (see section 2.1). These events have a direct impact on the ORM due to the damage in the electronic, the optical surface [53] and the bad quality of the sky during these days. Under exceptionally strong calima events the operation must be halted. However under regular calima, Cherenkov data can be corrected if the LIDAR is available.

In addition, there are indirect impacts, e.g. the airports can close and the workers cannot arrive at the observatory. In 2009, a study about the Calima in the Canary Islands determined that the impact in the ORM is lower than the impact in the OT [54].

The last calima events occur in:

- January 2002.
- December 2015 [55].
- Feb. 2020: the calima was very intense in the ORM and the Canary Islands. The Carnival was cancelled in several cities and the airports were closed. Fig. 2-29 [56].

Fig. 2-29: Telescope LST1 on 25th Feb 2020 during the Calima Storm and on 3rd Sep 2020 (a normal day) [57]

2.3.5. Gravitational movements

There is a low risk of gravitational movements in the area of the LST1. However, it is very common in the access road and it can be considered an indirect impact because the workers and the transports cannot arrive at the ORM. In Fig. 2-30 we can see gravitational movement risk areas around the access road to ORM from Santa Cruz de La Palma.

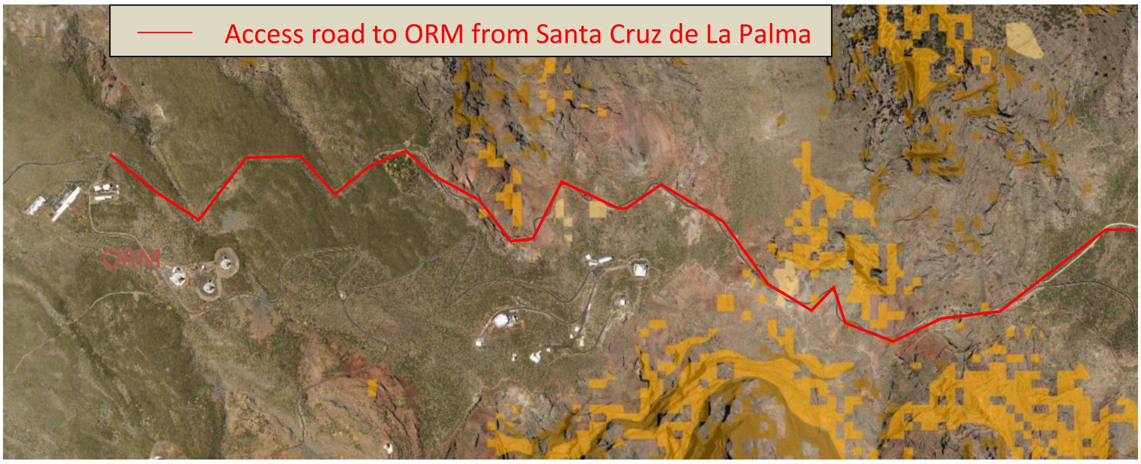


Fig. 2-30: Gravitational movement risks areas(yellow) in the access road to the ORM [16].

2.3.6. Wildfires

Wildfires are the second most common catastrophic event in La Palma. In the last years, 7 serious wildfires took place.

The "Gobierno de Canarias" has a map of "areas of high risk of wild fires" since 2011 and the ORM is located in the risk area (Fig. 2-31). Usually, the wildfires do not have direct incidence in the ORM because there are preventive measures but they can have indirect incidences: smoke and evacuation of people.

Fig. 2-31: Areas of high risk of wildfires [16]

The dates and consequences of these events were the following:

- Oct. 1997: Fire on ORM. It destroyed part of the HEGRA telescopes. It was not considered a wild fire.
- 20th Jul. – 4th Aug. 2000: Wildfire. 5500 Ha were burned (Garafia, Tijarafe and Puntagorda). This fire affected the ORM and it was evacuated [58]. A 3% of observation time was lost due to this fire [59].
- Sep 2005: Wildfire. 2500 Ha were burned (Garafia). The ORM was evacuated but it did not affect the functioning [60].
- Jul. 2009: Villa de Mazo. The Fire lasted for 49 days.

- July 2012: El Paso. The fire lasted for 52 days.
- Aug 2012: Villa de Mazo.
- Aug 2016: wildfire. It was a very aggressive wildfire in La Palma burn the flames (Fig. 2-32) did not reach the ORM. However, the dust concentration during this period was significant (Fig. 2-33).

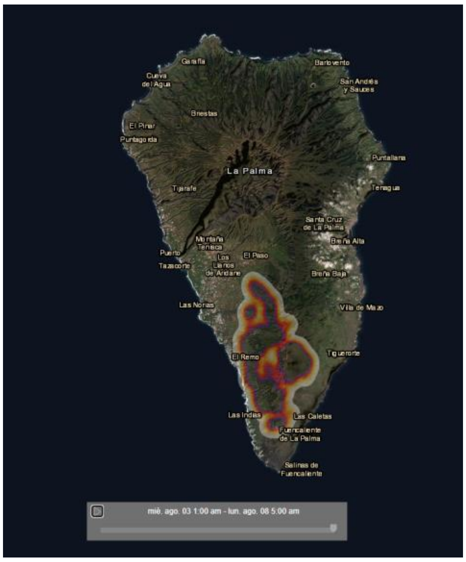


Fig. 2-32: Wildfire location on 3rd Aug. 2016. Credits: [61]

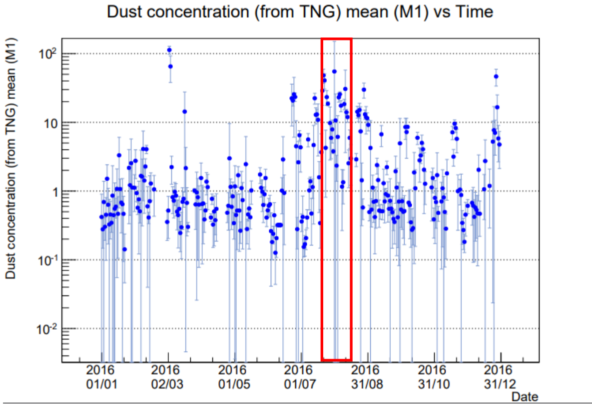


Fig. 2-33: Dust concentration at Magic Weather Station. Credits: Magic

- Aug. 2020: Wildfire. 800 Ha were burned (Garafia). The ORM was evacuated and the activities were cancelled during the evacuation time.

2.4. The observatory ORM

The Spanish Royal Family inaugurated the Observatorio Roque de Los Muchachos in 1985. The property belongs to the "Instituto de Astrofísica de Canarias" (IAC) [62].

The location of this observatory was selected considering several factors: it is in the highest point of La Palma, La Palma is in the Atlantic Ocean and the luminance pollution is minimum, the weather conditions are very special (see point 2.2). The sea cloud is a natural barrier of artificial lights and in addition, there is a special law, "Law for the Protection of the Astronomical Quality of the IAC Observatories".

2.4.1. History of Canary Observatories

The IAC was created in 1975 but the first astronomic observation happened earlier. The first official astronomic observation in the Canary Islands was in 1856. The British astronomer Piazzi Smyth *showed for the first time that high altitude sites provide clear advantages for astronomical observing*[4] *.*

In 1910, Jean Mascart observed Halley´s comet from Tenerife, on Guajara Mountain. Many astronomers visited Izaña (Tenerife) for observing the Solar Eclipse of 1959, this year the idea of building a permanent observatory was born and the same year, the Teide Observatory (Tenerife)

[4] Credits: IAC

was officially created, it was under the responsibility of the Rectorate of the University of La Laguna.

In 1961 Francisco Sanchez (founded-director of IAC) arrived at the Canaries to study the astronomical quality of the mountain tops of Tenerife. In 1964, the first professional telescope is installed at the Teide Observatory (OT), a photopolarimetric telescope for night-time observations, from the University of Bordeaux (France). The first research group in the country "Upper Atmosphere and Interplanetary Medium" was created. After this telescope, other telescopes were added until the current status. In 1969 the first solar telescope was installed. *The installation of each telescope has always been preceded by the corresponding agreement, following the model established with the Bordeaux Telescope: sky in exchange for a telescope. In this way, the prejudices of the European Astronomers about the conditions for astronomy in the Canaries were overcome, and the Spanish authorities (both local and national) began to understand that this "natural resource", the Canary sky, could be exploited, and in addition used to initiate and develop astrophysics in Spain*[5]*.*

In the decade of the ´70s, European astronomers tested the sites of the mountains of Tenerife and La Palma and the excellent quality of the skies in the Canaries Islands was recognized. The OT was inaugurated in 1970. In 1972, the biggest infrared telescope in the world (at this moment) came into service in this observatory (property of the Imperial College London).

In 1973, the "University Institute of Astrophysics" was created at the University of La Laguna and it later took charge of the OT. In 1975, the IAC was founded (agreement between the University of La Laguna, the Higher Council for Scientific Research (CSIC) and the Joint Council of the Cabildos of the Province of Santa Cruz de Tenerife). The same year, the first National Assembly of Astronomy and Astrophysics was celebrated in Tenerife and the IAC initiated the first National Programme for the Training of Researchers in Astrophysics.

The exploitation of the sky on the Canary Islands was regulated after the negotiations with various Europan scientific institutions interested in installing telescopes in the islands. After that, the Agreements for Cooperation in Astrophysics were signed.

In 1979 in Santa Cruz de La Palma, the "Agreement and Protocol of Cooperation in Astrophysics" between Spain, Denmark, Sweden and the United Kingdom, by which the Teide Observatory (Tenerife) and the Roque de Los Muchachos Observatory (La Palma) were internationalised.

New institutions and countries decided to install their telescopes on the IAC´s Observatories and agreements were negotiated: Germany (1983), Finland and Norway (1986) and France (1988).

In 1985, the official inauguration of the IAC, OT and ORM took place, with monarchs and members of the Royal Families of five countries (Spain, Denmark, the United Kingdom, The Netherlands, and Sweden) and two other heads of state (Germany and Ireland).

In 1988, the "Law for the Protection of the Astronomical Quality of the IAC Observatories" (Law 31/1988 of October 31st) was approved, whereby the mountain tops of the islands of Tenerife and La Palma were recognised as world astronomical reserve.

[5] Credits: IAC

2.4.2. Telescopes, experiments and other installations in the ORM

The ORM is an observatory in continuous growth. Fig. 2-34 is a graphic with the life of the current and future (EST and TMT) telescopes. The new projects that are going to be or could be installed in the ORM are:

- European Solar Telescope: on May 2021 was approved the installation of the EST telescope in the ORM. It is a Telescope with a 4.2-metre primary mirror and it will study the magnetic coupling of the solar atmosphere. The construction will start in 2023/2024 and it will continue for 5 years. The Operation phase is expected to last for 30 years [63].
- Thirty-meter telescope (TMT): the TMT *will be the most advanced and powerful ground-based telescope in history and the largest* ***optical/near-infrared*** *telescope in the Northern hemisphere* [64]. The ORM is a candidate location for the construction of this telescope. The Lifespan of TMT would be 50 years [65].

Fig. 2-34 is a graphic with a lifespan of current and future installation in ORM. The lifespan of foundations can be longer than lifespan of the whole telescope. According to Spanish Concrete Regulation EHE-08 [66], foundations might have typical lifespans of 50 years.

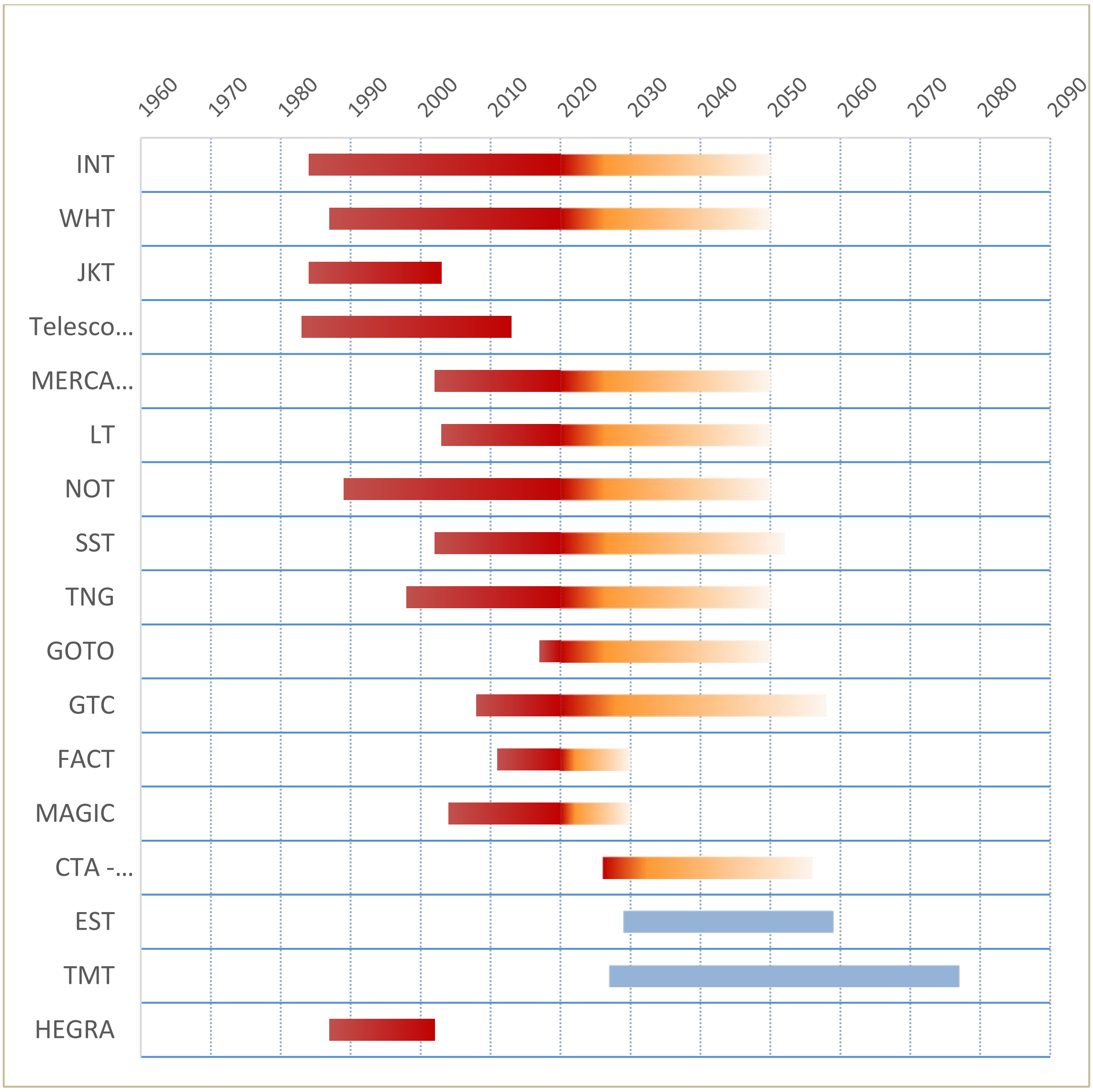


Fig. 2-34: Life of ORM´s Telescopes (red=past; orange=future of current installations; blue=future installations)

2.4.2.1. Isaac Newton Telescope (INT) [67]

The Her Majesty the Queen inaugurated the INT in 1967 in Herstmonceux (Sussex, UK). This telescope would be used by all UK astronomers, however, the atmospheric conditions of this location were not the best to use the telescope, the performance of the INT would have been better with better weather. The weather conditions from La Palma are better than the weather conditions from Herstmonceux, then, during the '70s the movement of the telescope from Herstmonceux to La Palma was planned. The INT started the operation in La Palma in 1984, but it was re-inaugurated on 29th June 1985 when the inauguration of the Canary Islands Observatories was done.

The INT is a telescope from the group ING with the WHT. The ING is owned and operated jointly by the Particle Physics and Astronomy Research Council (PPARC) of the United Kingdom, the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) of the Netherlands and the Instituto de Astrofísica de Canarias (IAC) of Spain.

It is an optical telescope with a system of type "Cassegrain[6]". The primary mirror is 2.54m in diameter and the focal length is 7.5m. The weight is about 4.4tonnes. The material of the primary mirror is a low expansion glass-ceramic Zerodur. The total weight of the telescope is about 90 tonnes.

The INT is an optic telescope and it is inside the building (Fig. 2-36). When the dome lower shutter is down the lower observation limit is at an elevation of 33 degrees. When the dome lower shutter is raised the observation limits are between Elevation=20 to 34 degrees.

Fig. 2-35: Entrance to the INT

Fig. 2-36: INT´s shutter (closed and opened)

Fig. 2-37: Control room

Instruments:

[6] Cassegrian: paraboloid primary mirror and a hyperboloid secondary

- **IDS:** The Intermediate Dispersion Spectrograph (IDS) is a long-slit spectrograph. It is in the Cassegrain Focal station of the 2.5m Isaac Newton Telescope.
- **WFC:** The Wide Field Camera (WFC) is an optical mosaic camera for use at the prime focus of the 2.5m telescope.

Maintenance notes:

In the Isaac Newton Group of Telescopes (INT, JKT and WHT) the Stand-downs are periods of major maintenance or instrumental commissioning [68] [69] [70] [71] [72] [73] [74]. Table 12 is the Percentage of weather and technical downtime by semester. See Fig. 2-38.

In 1997, a detector workshop to provide an area for tests and maintenance work on detectors is under construction in the WHT building. The workshop room in the INT was reorganized to improve the work environment.

Downtime due to: (%)	WHT	WHT	INT	INT	JKT	JKT
	Bad weather	Technical	Bad weather	Technical	Bad Weather	Technical
89 B	42.5	10.5				
90 (A+B)	40.25	7.3	13	5		
91 (A+B)	23.6	8.8	24.95	5.05		
92 (A+B)	27.6	11.3	29.2	5.2		
93 (A+B)	25.4	4.6	24.3	3.75		
94 (A+B)	16.5	3.3	17.7	2.9	20.4	3.9
95 (A+B)	30.9	3.1	25.9	3.2	24.2	2
96 (A+B)	33.2	2.4	27.2	2.1	36.4	2.9
97 (A+B)	17	2.3	21.4	3.8	23.8	3.1
98 (A+B)	18.3	2.7	18.5	5.2*	20.2	2.3
99 (A+B)	28.3	4.1	24	4.5	26.6	3.5
00 (A+B)	22.8	2.1	22.8	3	22.8	2.7
01 (A+B)	24.6	3.3	24.6	1.1	24.6	1.2
02 (A+B)	26	2.6	26	1.1	26	1.7
03 (A+B)	23	2.3	23	1	23	2.7
04 (A+B)	35	3.4	35	1.5		
05 (A+B)	34	1.5	34	1.4		
06 (A+B)	20.5	1.5	25.9	2.3		
07 (A+B)	20.2	2.8	20.1	3.5		

Table 12. Percentage of weather and technical downtime by semester (A: first semester and B: second semester). Credit: INT Group

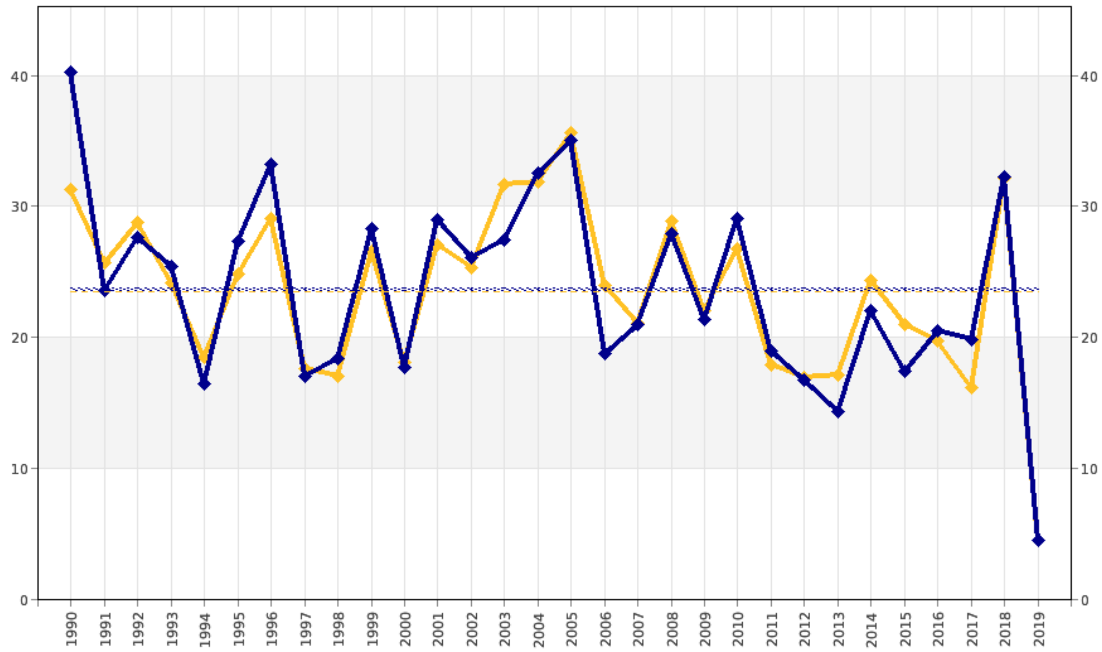


Fig. 2-38: Relative-to-night-length percentage weather downtime per year (semesters A+B) excluding from the calculation S/D/commissioning nights as well as nights when visiting instruments were used. Blue: WHT. yellow: INT. The dotted lines show the average values (WHT average: 23.7%. INT average: 23.5%). Credit: ING

With the entrance of the year 2000, several computing problems could have happened but the ING computers were checked before 31st December and no major problems occurred during the last night of the year 1999. The primary mirror's reflectivity on the three telescopes continues to be maintained by regular CO2 snow cleaning and regular measures are made to monitor reflectivity and scattering. This year **the first in situ mirror washing** was done and the result was very promising because cleaning in snowy conditions could have a degradation of the mirror with time. **During the winter 99-00 weather conditions were particularly adverse.**

The telescope operation activities are carried out by a single Operation Team covering the three telescopes. In 2000-2001, **the cleaning of the primary mirror from WHT was done with CO2 snow-clean**. During the summer of 2000, **the domes of WHT and INT were painted externally.**

In 2003, the normal control of the JKT was changed to IAC. Between 2002 and 2003, the air conditioning units from the control room, computer room and terminal area of the WHT were changed. In the INT, **the installation of a cold air circulation system** to take away warm air that builds up during the day immediately below the INT observing floor was completed. It is expected that this system will reduce heat transfer into the dome area, thus improving the local seeing conditions. The computers of the ING were uploaded, **faster machines were installed.**

During 2004 and 2005, there were not too many problems with the ING telescopes. The 1-m JKT does not host science observations anymore but is now regularly being used to measure the atmospheric turbulence profile above the observatory by the IAC. The year 2005 was the end of an important reorganisation that was the result of a phased reduction of the operating cost of the observatory. **The mirrors of INT and WHT were re-aluminised** (**The past two years both the mirror of the Nordic Optical Telescope and the Liverpool Telescope were aluminized by ING**).

In the period 2006-2007, the most important maintenance activity was the **aluminising of the WHT primary mirror**. In between aluminising runs, the mirrors are regularly inspected and cleaned using CO2 snow and, in this way, the efficiency of the largest optical component is kept at the highest levels

The obsolete technology sometimes must be replaced and modernised. This year, a phased replacement of some older control systems was initiated. The prime-focus platform controls were upgraded with programmable logic controllers, providing better reliability and maintainability.

2.4.2.2. William Herschel Telescope (WHT)

The WHT is an optic telescope and it has a primary mirror of 4.2m in diameter. The WHT is a very versatile telescope and it is one of the most scientifically productive telescopes in the world. The WHT is a classic Cassegrain telescope. The primary mirror has parabolic shape and the thermal expansion coefficient is nearly zero. The mirror is coated with a thin layer of aluminium. The secondary mirror is 1m in diameter and is made of Zerodur. There is a third mirror. It is flat and it can be tuned up to 45 degrees. The total weight of the telescope is 200 tonnes.

The WHT project started in the ‘60s years when astronomers were wondering what kind of powerful telescope they should build in the northern hemisphere. The Science and Engineering Research Council (SERC) of the United Kingdom started to plan the WHT in 1974. The precise diameter of 4.2 metres was determined by the availability of the mirror blank. made by Owens-Illinois (USA). The mirror was figured at Grubb Parsons (United Kingdom).

The construction of the telescope started in 1983 and the first light took place on 1 June 1987.

It is an optic telescope and it is into a building with a dome (Fig. 2-39). The weight of the dome is 320 tonnes and it was completed by the Canadian firm Brittain Steel in 1984. The skin of the dome was built on-site from a 6.3 mm steel plate and the wind shield and shutters were constructed from aluminium. There is a 35-tonne crane, supported by the top part of the dome. This was used during the telescope construction, and now it is used for the mirror’s aluminizing and telescope maintenance. The telescope is supported by a reinforced concrete which puts the centre of rotation of the telescope. The dome is supported by a rail set onto a cylindrical concrete building structure. Into the dome there is very little thermal disturbance of the air near the telescope this is further facilitated by large extractor fans set into the cylindrical structure.

Fig. 2-39: WHT telescope.

Fig. 2-40: WHT telescope during the construction. Credit: WHT

Instruments:

The common user instruments[7] in the WHT are:

- **ISIS:** The Intermediate-dispersion Spectrograph and Imaging System (ISIS) is mounted at the Cassegrain focus of the 4.2m William Herschel Telescope. It is a high-efficiency double-arm medium-dispersion (8-121 Å/mm) spectrograph. *The use of dichroic filters permits simultaneous observing in the blue and red arms. with a ~200Å wavelength range of reduced throughput at the dichroic cross over from reflection to transmission. The arms are optimised for their respective wavelength ranges. and specific wavelength ranges are set by rotating the grating cells. Linear and circular spectropolarimetry. and imaging polarimetry. Modes are also available*[8].
- **LIRIS:** Long-slit Intermediate Resolution Infrared Spectrograph is a near-IR imager/spectrograph for use at the Cassegrain focus of the WHT.
- **ACAM:** ACAM is a spectrograph instrument. Its operation started in 2009 and it belongs to the Isaac Newton Group of Telescopes, in the William Herschel Telescope. It can be used for high-throughput broad-band imaging, narrow-band imaging and low-resolution spectroscopy.
- **WEAVE:** WHT Enhanced Area Velocity Explore. It is a new multi-object survey spectrograph. It will start operating in 2020[9].

There are more instruments[10] in the WHT and some of them are:

- **ULTRACAM:** The ULTRACAM is an ultra-fast triple-beam CCD camera. High-speed, three-colour CCD camera designed to provide imaging photometry at high temporal resolutions. The operation started in 2002.
- **INTEGRAL:** The operations of INTEGRAL started in 1997.

[7] April 2020 information
[8] Credits: ING
[9] April 2020 information
[10] April 2020 information

Maintenance notes:

The aluminizing plant was installed in the WHT. During the aluminizing process, a total of 63 g of aluminium is evaporated. 3.5 g being deposited on the $13m^2$-surface of the primary mirror to create a reflective surface 100 nm thick. The power consumption of the plant rises to 85 KVA for the 90 seconds duration of the evaporating stage. Mirrors are aluminized once a year or a year and a half.

In January 2013, the lower dome shutter was out of action and it was in service again in August the same year. In March 2017, the lower dome shutter was repaired.

Fig. 2-41: aluminizing plant. Credit: ING

See the Isaac Newton Telescope (INT) maintenance notes (Point 2.4.2.1).

2.4.2.3. Jacoubus Kapteyn Telescope (JKT)

The Jacoubus Kapteyn Telescope (JKT) is a 1-meter telescope. The Commissioning was done by the United Kingdom, Ireland and the Netherlands more than 30 years ago but with the Isaac Newton Telescope, the common observations finished in 2003. The Telescope was transferred to the IAC in 2012. The JKT is an optical and robotic telescope.

Fig. 2-42: JKT Telescope. Credits: IAC

Maintenance notes:

See the Isaac Newton Telescope (INT) maintenance notes (Section 2.4.2.1).

2.4.2.4. Telescope Carlsberg Meridian

The Telescope Carlsberg Meridian is a meridian circle that is dedicated to performing high precision optical astrometry. It was working between 1983 and 2013. This telescope was used by La Armada Española with the IAC.

2.4.2.5. Mercator [75]

The MERCATOR telescope is semi-robotic. The primary mirror´s diameter is 1.2m (mass of 385 kg) and the secondary mirror´s diameter is 0.3m. There is a third mirror which can be in several positions. The high quality of the mirrors ensures that the sharpness of the images is only set by atmospheric turbulence. The primary mirror is supported by 15 dorsal and four radial pressurized air pads plus 6 fixed points. The last aluminization was in May 2003.

Fig. 2-43: Mercator Telescope.

It is operated by the University of Leuven (Belgium). The operation started in 2001. This telescope has a flexible operation scheme because it is possible to monitor its campaigns on very different timescales.

This telescope is into a building and it is covered by a metallic dome. The motor to open the dome is in the top part of the dome. The dome can rotate and it is supported in a wood beam.

Fig. 2-44: Door and dome of Mercator Telescope

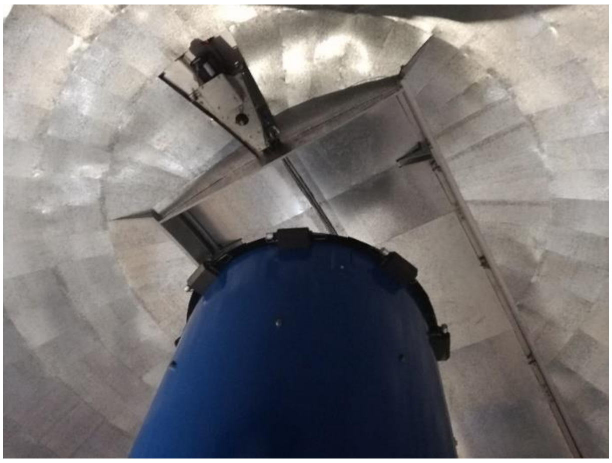


Fig. 2-45: Door and motor for opening the dome of Mercator Telescope

Fig. 2-46: Wood beam and motor for moving the dome

During the day, the cooling system controls the temperature to "temperature of the beginning of the observation" because the temperature of the main mirror needs to be constant (the reference temperature is the ambient temperature when the dome is opened).

Instruments:

- **MAIA**: The Mercator Advanced Imager for Asteroseismology (MAIA) is a new fast 3 channel photometric instrument. MAIA has 3 cameras to simultaneously observe the same image in three different colour bands. The commissioning of this instrument finished in 2013 and the installation was done in 2012.

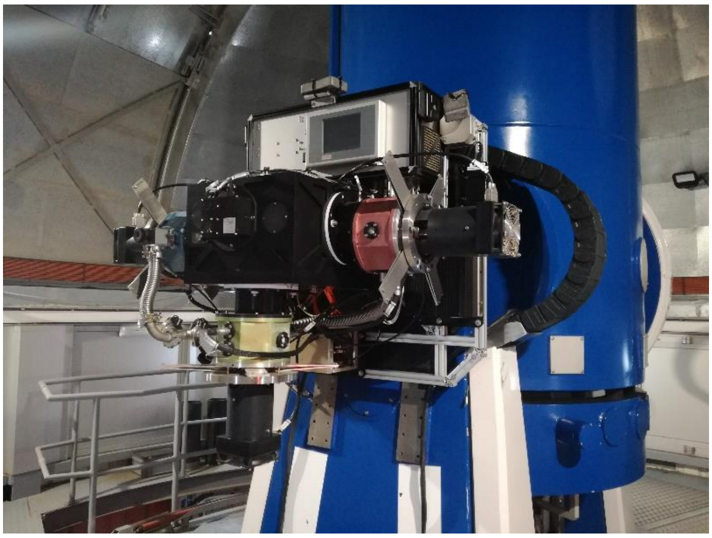


Fig. 2-47: MAIA

- **HERMES** (High Efficiency and Resolution Mercator Echelle Spectrograph): It is a fibre-fed prism cross dispersed echelle spectrograph. It is mounted in a temperature-controlled room and fibre-fed from the Nasmyth A focal station through an atmospheric dispersion corrector (ADC).

Maintenance notes[11]:

The Mercator telescope does one preventive maintenance per year; the cleaning of the mirrors is included in these activities.

When the Mercator Telescope was built, several pieces were handmade and they were unique, it was a problem when any piece went broken and buying a new piece was not possible (e.g. the manufacture had closed, the material was obsolete). The current tendency is to use commercial off the shelf components (COTS) because it is easier to find spares.

The Mercator Telescope is installing PLC (Programmable Logic Controller) items when they need to change any piece of the telescope. The PLC receives information from connected sensors or input devices, processes the data, and triggers outputs based on pre-programmed parameters.

The Mercator Telescope waits for the failure to do the maintenance of several pieces. Because, for doing a good maintenance of everything, they need to remove other pieces and they can be damaged during the disassembly.

The main external risks in the Mercator Telescope are adverse environmental phenomena, power cut supply, lightning and wildfire. During the “Delta” storm in 2005, there were several incidents in the telescope

2.4.2.6. Liverpool Telescope (LT)

The Liverpool Telescope is a project of Liverpool John Moores University and the Royal Greenwich Observatory, the project started in 1996. The company Telescope Technologies Limited was created close to Liverpool for building the telescope and to look for contracts

[11] Information from a meeting with Mercator Staff.

for doing more telescopes. This company has built 5 telescopes in total, the LV and others in India, Hawaii, China and Australia.

The LV saw the first light in July 2003 and it started the operation in January 2004. The Robotic Control was installed in April 2004 and since December 2004 it has been running with no observers at night.

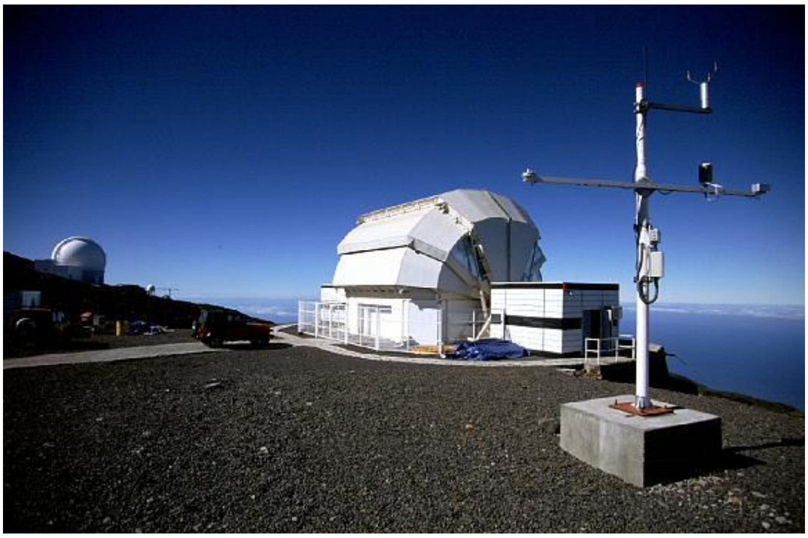


Fig. 2-48: The LT. Credits: LT

The Liverpool Telescope is an optical astronomical telescope of 2-metre diameter. The use is mainly robotic. This telescope is used for the study of variable astronomical phenomena sources which vary on timescales between seconds and years (variable stars, black holes, neutron stars, white dwarf stars, quasars and active moving targets like asteroids and comets. The telescope is operated by Liverpool John Moores University. It is available to European astronomers.

Instruments:

- **IO:O** (Optical Wide Field Camera): it is the optical imaging component of the IO (Infrared-Optical) suite of instruments. It provides a wider field of view and greater sensitivity than RATCam. The operation started in 2014.
- **IO:I:** it is the Near-Infrared Camera of the IO suite of instruments.
- **RISE**: it is the Fast-readout Wide Field Camera. It is developed in collaboration with Queens University Belfast for the precision measurement of transiting exoplanet timing.
- **SPRAT:** Spectrograph for the Rapid Acquisition of Transients (SPRAT) is a low resolution, high throughput spectrograph. It started operating in 2013, in replace of RATCam.
- **FRODOSpec** (Fibre-fed RObotic Dual-beam Optical Spectrograph): it is a dual-beam design with the beam split before the entrance to the individually optimized collimators. *Two resolution options are available on each arm. With low resolution selected on each arm, the entire spectrum from the blue cutoff of the optical fibres (around 3800 Angstroms) to the red limit of the detectors at around 1 micron can be*

obtained in a single shot. The low resolution is implemented using conventional transmission gratings[12]*.*

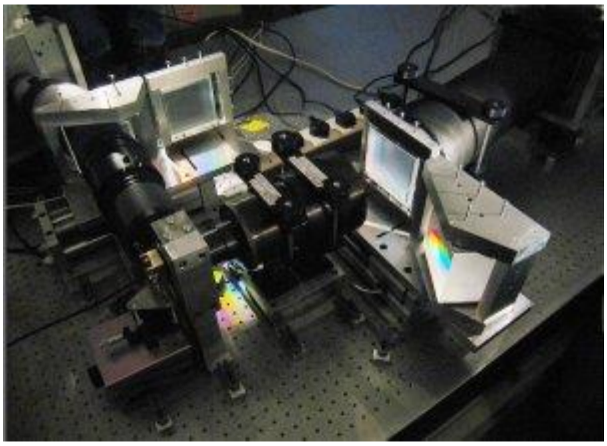


Fig. 2-49: Part of FRODOSpec on optical bench before shipping to site [76] *.*

- **SkyCam:** The SkyCam is a project aimed at providing simultaneous wide-field observations in parallel with normal LT data taking. Three cameras, each offering a different field of view (FOV), are being used: SkyCam-A is giving a fish-eye view of almost the entire sky above the telescope. SkyCam-T currently offers a roughly 20-degree field-of-view. SkyCam-Z is housed within an Orion AG8 telescope to give a finer resolution, though a smaller 1° field of view. At any given time, SkyCams T and Z image whatever field is being observed by the primary science instruments on the telescope.
- **MOPTOP (M**ulticolour **OPT**imised **O**ptical **P**olarimeter): It is under development [76]. It is a dual-beam polarimeter. Incoming collimated light will first pass through a continuously rotating half-wave plate which will modulate the beam's polarisation angle. The polarised light will then pass through a wire-grid polarizing beamsplitter. This will split the light into the p and s polarised states and send them through filter wheels to a pair of low-noise fast-readout imaging cameras. Image acquisition will be electronically synchronised to the rotation angle of the half-wave plate. This combination of half-wave plate and beamsplitter will provide about twice as much throughput as a conventional polarimeter using a polaroid filter as the analyser.

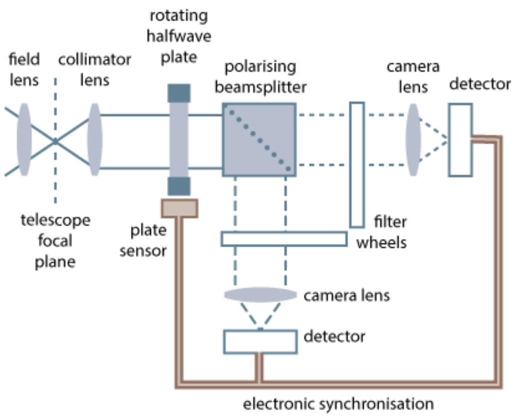


Fig. 2-50: Optical schematic of MOPTOP [76].

[12] Credits: http://telescope.livjm.ac.uk/TelInst/Inst/FRODOspec/

Maintenance notes:

In September 2019, the LT had the “re-aluminise” maintenance of the primary mirror and other essential maintenance. The throughput of the telescope improved by over 40%.

The re-aluminise is necessary because the telescope mirrors are different from normal domestic mirrors. The telescope mirrors have a reflective layer deposited on the front surface of glass instead of having it encapsulated behind a layer of glass. The surface of this type of mirror is better for precision scientific optics and provide optimum reflection quality, but it degraded faster than a domestic mirror because it is exposed to the atmosphere. The periodic re-coating is therefore an expected maintenance task for any telescope mirror [76].

The telescope needs to be dismantled for removing the mirror, but it is not necessary to transport it to sea level. The LT uses the vacuum mirror coating chamber from the WHT.

The LT primary mirror is 2 meters in diameter and weighs 1.3 tonnes. The transport of this mirror to the WHT is a delicate activity. The primary mirror in its mirror cell was slid out from underneath the telescope and immediately covered for protection and to prevent dangerously focused solar reflections. It is removed with a crane towards a truck (Fig. 2-51). The truck goes down until the WHT slowly.

Fig. 2-51: The primary mirror suspended from the crane [76]

At the WHT, the aluminium layer from the mirror is removed with acids. The glass "blank" is washed and placed in the WHT's huge re-aluminizing chamber.

A few days later, the primary mirror is put back in the same way it came out. After that, the cell is connected to the telescope, and refitting to the instruments is the next activity. In two days the telescope and all instruments are reassembled.

The telescope had its major optical components dismantled and reassembled, and all instruments had been removed and remounted. From 30th September to 2nd October, a full end-to-end test of the telescope's electrical, hydraulic, pneumatic and optical systems was made, along with similar tests for each instrument. This lengthy sequence of tests proved the telescope was operating nominally and that all of its instruments were in focus and working properly.

Some robotic observations were allowed to be made during recommissioning partly for testing purposes, but proper robotic observing essentially recommenced on 2nd October.

During this activity, more maintenance activities were done (normally there is no access to every part of the telescope):

- **Cassegrain rotator mechanism**: this piece normally is not accessible. During the maintenance of the mirror, access is possible. Both of the Cassegrain rotator's gearboxes were replaced, the drive motors realigned and the optical encoder tape cleaned.
- **SkycamZ:** SkycamZ. itself an 8-inch Newtonian reflecting telescope mounted piggyback on the LT's top-end ring, was removed and dismantled. The SkycamZ primary was cleaned. This was done and the telescope was reassembled.
- **Primary mirror support**: These supports were serviced and the accompanying pipework and fittings were all replaced.
- **SkycamT:** SkycamT was removed from the LT's top-end ring and cleaned, realigned, refocussed and refitted.
- **Other optical cleanings:** Other optical components cleaned were the LT's tertiary (science fold) mirror, the auto-guider pickoff mirror and all the filters. The telescope's secondary mirror was not recoated this time.

The previous re-aluminise maintenance was in August 2015.

2.4.2.7. **Nordic Optical Telescope (NOT)** [77]

The Nordic Optical Telescope is a 2.6m diameter telescope. It is located at the highest site of the ORM. NOT started the operation in 1989 and it is operated by Research Councils from Denmark, Finland, Norway, and Sweden and the University of Iceland.

The first proposal for building the NOT was done in 1980 by Profs. Bengt Strömgren and Anders Reiz. A NOT project study was presented at the end of 1982. The Optical Telescope Committee was formed in September 1982 and revised. In 1985, was decided to install the telescope in the ORM and, after hard work, the NOT was inaugurated in 1989. The operation started in 1990. The Universities of Turku (Finland) and Aarhus (Denmark) are the new proprietary owners of NOT since October 2019. The inauguration was a party, where workers from the other telescopes were invited.

Gradual instrumentation upgrades continued, and financial reserves also made it possible to overhaul and completely renew the telescope control and cooling systems to continue operating safely for another couple of decades.

The primary mirror of NOT is 2.6 m in diameter. The telescope moves on vertical and horizontal axes, under full computer control. The lightweight building rotates together with the telescope itself. The building is designed to avoid all disturbing heat sources, and the dome is cooled during the daytime. Through wide shutters, the dome is flushed with ambient air at the beginning of the night.

The dome was delivered by Ash Dome, Illinois, USA. The material is galvanized steel, its diameter is 11.1m and the total weight is around 4 tonnes. It is covered by two hatches. The upper hatch moves along the dome structure. The lower hatch opens in a drop-out fashion. Both hatches are remotely operated. The dome is insulated with 5 centimetres of polyurethane foam sheeting. The minimum free distance between telescope top end and dome insulation is around 25 centimetres.

A crane is used, directly on the observing floor, to move heavy or large instrumentation. This crane handles up to 500 kg.

It is important to verify that the dome-air temperature stabilization system works correctly during the daytime to avoid the heating of the dome's air and the telescope structure. In the evening, the entrance door of the telescope building should have stabilized temperature. This is managed automatically. As soon as the upper dome hatch is opened, cooling of the entrance door is engaged at the same time as cooling of the air around the telescope is disengaged. Optimum air flushing of the telescope ambience requires, to open the wall gates and opening of dome hatches. Both hatches should be opened in the evening, as soon as possible. For optimum functioning of the thermal control system, entrances need to be closed as much as possible.

Sometimes there are problems with the upper hatch when there is bad weather. The operating system for the upper dome hatch will be upgraded, including an additional system for emergency closing. The building of NOT was designed for supporting winds of 225 km/h. The ice in the dome can be a problem and it may imply serious risks. If the ice and snow are falling down on the stairs and catwalks, it can damage them. **Over the stair, a mesh was installed to avoid huge blocks of ice and snow that can damage the stair**. The doors are fire-resistant.

Instruments:

- **NOTCam:** The Nordic Optical Telescope near-infrared Camera and spectrograph is a multi-mode instrument for use in the short-wave infrared (SWIR) region of the electromagnetic spectrum (0.8 - 2.5µm).
- **ALFOSC:** The Alhambra Faint Object Spectrograph and Camera (ALFOSC) was built at the Astronomical Observatory (AO) by the Niels Bohr Institute for Astronomy Physics and Geophysics (NBIfAFG). It is the property of the Instituto de Astrofisica de Andalucia (IAA), Granada, Spain. ALFOSC has a field of view of 6.4x6.4 arcminutes in imaging mode. and can also be used for low/medium resolution spectroscopy and polarimetry.
- **FIES:** The high-resolution FIbre-fed Echelle Spectrograph is a cross-dispersed high-resolution spectrograph.
- **MOSCA:** The MOSaic Camera is an optical element to apply a desired filter in the light path.
- **StanCam:** the stand-by CCD camera is used as an optical imaging instrument when ALFOSC or MOSCA is not mounted and also as a FIES fibre viewer. StanCam is less sensitive and has a smaller field of view than ALFOSC.

2.4.2.8. First G-APD Cherenkov Telescope (FACT)

The First G-APD Cherenkov Telescope (FACT) was installed in 2011. FACT camera was installed in the focus of one of the former HEGRA telescopes [62].

After the assembly of the camera, there were some problems with several pixels, but it meant a loss of 2 $^{0}/_{00}$, which is acceptable. During the first 1.5 years of operation, 5 hardware problems were occasioned [78]. This telescope is operated by remote. This project is in the ORM at 2200 m.a.s.l. in the areas of Magic Telescopes and CTA North.

2.4.2.9. Swedish Solar Telescope (SST) [79]

The Swedish solar telescope is the largest solar telescope in Europe. The lens is made of fused silica and is 1m in diameter. The resolution of this telescope is 0.1 arc seconds in blue light; this corresponds to 70 km on the solar surface.

The SST is owned and operated by the Institute for Solar Physics of the Royal Swedish Academy of Sciences. The operation of SST started in 2002.

The main obstacle of solar observations is the Earth's atmosphere, whose inhomogeneity and motions cause astronomical seeing and thus blurry images. In addition, the solar telescopes have another problem, they suffer from heating by the sunlight of the optics and the air within the telescope tube. This causes the image to shiver and become blurred. The SST is a vacuum telescope, which reduces the heating of the air in the telescope.

Fig. 2-52: SST telescope.

2.4.2.10. Telescopio Nazionale Galileo (TNG)

The Telescopio Nazionale Galileo (TNG) is a 3.6m alt-azimuth telescope with a Ritchey-Chretien optical configuration and a flat tertiary mirror feeding two opposite Nasmyth foci and represents the largest Italian optical/infrared telescope[80] [81].

The project of TNG started in 1982 and was inaugurated in 1996.

The TNG is into a building of 24m in height. The building consists of a rotating octagonal dome, a lower rounded building enclosing the central pillar and an annexe one-story service building.

Fig. 2-53. Telescopio Nazionale Galileo

2.4.2.11. Gravitational-wave Optical Transient Observatory (GOTO)

The Gravitational-wave Optical Transient Observatory (GOTO) is a telescope for detecting signatures of gravitational waves. GOTO is an autonomous intelligent telescope, which will search for unusual activity in the sky following alerts from gravitational wave detectors - such as the Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) [82].

The operation started in 2017.

2.4.2.12. Gran Telescopio de Canarias (GTC)

The idea of this telescope started in 1987 by IAC. The construction was done by the public company "GRANTECAN" created with the goal of gaining efficiency in the paperwork and production of the project and other preparatory plans and investments for its operation. The Comunidad Autonoma de Canarias and the Spanish General State Administration are partners in this enterprise. In addition, the Instituto de Astronomía de la Universidad Nacional Autónoma de Mexico (IA-UNAM) and the Instituto Nacional De Astrofísica Óptica y Electrónica (INAOE) cofinanced by the Consejo Nacional de Ciencia y Tecnología de México. (CONACYT) are contributing 5% of the project's total cost as well as the University of Florida (United States of America) with another 5%. These counties receive the 5% of the observating time of GTC [83] [84]. The lifespan of GTC is 50 years [85].

The first light ceremony was celebrated in 2007 but the scientific production of the telescope started in 2009.

The Gran Telescopio de Canarias (GTC) is an optic telescope. The primary mirror is made of "Zerodur" and it is 10.4 metres in diameter. It is one of the most advanced telescopes in the world and the largest of the optical infrared ones. It has a secondary mirror and a tertiary mirror too. With the primary mirror, it is produced the telescope focal plane on the focal station of choice. The telescope is mounted in a steel structure, which allows the rotational movements of the telescope. The telescope is constructed inside a building and it is closed with a dome that protects it from outside elements. The dome was designed to minimize the turbulence of the air close to the telescope. When an observing night commences, the dome is opened allowing the light from the stars to strike the telescope. The dome is moved from the control room. The total weight of GTC (moving part) is 400 tonnes and the weight of the primary mirror is 17 tonnes. The GTC is fitted with bearings that effectively float the whole superstructure on a thin film of pressurised oil. The job of these bearings is to make it easy for the telescope to rotate and to lessen vibration. The 2.700 litres of oil needed to make this possible are constantly pumped through a circuit, cooled and returned to the bearings. Thanks to this "pool of oil" the whole telescope structure can be moved with just a push of the hand.

The GTC also makes use of an advanced control system and has high reliability of operation through a **preventive maintenance program** designed to identify potential malfunctions before they occur, ensuring that downtime caused by these failures in the system are kept to the minimum. Part of the preventive maintenance is to ensure that the mirrors remain clean so that they optimally reflect the light. They are regularly cleaned by spraying CO2 snow over their surface. But, about **every two years, each mirror segment comes out of the telescope to put a new reflective aluminium coating on its surface**[86] [84]**.**

Instruments:

- **MIRADAS:** The instrument MIRADAS is in the ORM. The operation started in 2019. It is a spectrograph polarimeter of intermediate resolution. Miradas will operate in the 1 to 2.5-micron infrared band with a resolution of 20000. It is an instrument for the GTC. Miradas is a multi-object spectrograph able to observe until 20 objects simultaneously.

- **HORUS:** The instrument HORUS is in the ORM. It is a high-resolution (R=25000) spectrograph for GTC. It collects light at the Nasmyth focal plane, shared with OSIRIS, with microlenses, into optical fibres that form a pseudo-slit at the spectrograph entrance. The light is dispersed with a 79 gr/mm echelle grating and cross-dispersed with three prisms, providing almost continuous coverage between 380 and 690 nm. The operation started in 2019

- **FRIDA:** This instrument was installed in 2018 and the operation started in 2019 in GTC. Imaging and integral-field spectroscopy Spectral resolution 1500 to 30000.
- **GTCAO:** GTCAO is an instrument of GTC it started its operation in 2018. The main components of GTACAO are the wavefront corrector, the wavefront sensor, the calibration system, the test camera, the mechanical structure and the control system.
- **MEGARA:** Megara is an instrument of GTAC it started its operation in 2017. The construction was done by the Universidad Complutense de Madrid with other universities from Mexico. Megara will study stars outside the Milky Way.
- **EMIR:** Emir is an instrument of GTC and it started its operation in 2016. It is a camera and spectrograph multi-object of intermediate resolution in close infrared.
- **CIRCE:** Circe is an instrument from the University of Florida. The operation started in 2005. Imaging and polarimetry. Upgradable to spectroscopy.
- **OSIRIS:** The Optical System for Imaging and low intermediate-Resolution Integrated Spectroscopy (OSIRIS) is an imager and spectrograph for the optical wavelength range located in the Nasmyth-B focus of GTC. It will be moved to Cassegrain Station when it is available.

2.4.2.13. High Energy Gamma Ray Astronomy (HEGRA)

See point 1.2.

2.4.2.14. Major Atmospheric Gamma Imaging Cherenkov (MAGIC)

The project of MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescopes started in 1996. They are 2 telescopes of 17m in diameter and the operation of the first one (Magic I) started in 2004. The operation of MAGIC II started in 2009. Since 2009 MAGIC I and MAGIC II operate in the stereoscopic mode.

These telescopes are Cherenkov type and they detect gamma rays of very high energy.

MAGIC is not into a building, so it is exposed to environmental agents. MAGIC operates during the night and the operators control the telescopes from the Magic Counting House, which is a small building next to the telescopes.

The MAGIC telescope has 234 segmented spherical mirrors arranged in a parabolic shape (236 square meters) and the focal length and diameter are around 17 meters. A mount supports the mirrors. The mount is moving in azimuth and elevation and it is connected to the ground with six bogies over a circular rail. The material of the back mount of the mirrors is carbon fibre reinforced plastic tubes based on a rod-and-knot system without welds by the German construction design company MERO. The camera is supported by an aluminium tubular arc secured against transverse movements by pre-stressed steel cables. The total weight of one MAGIC telescope is 64 tons. Each mirror is supported by 3 points or actuators that can move the mirror in any direction. The adjustment of mirrors is done by the Active Mirror Control (AMC) system, it focuses the mirrors during the telescope's operation. The camera has 1039 photomultiplier tubes (PMTs) that are in a circle of 1meter in diameter.

Fig. 2-54: MAGIC telescope.

The operation of MAGIC telescopes is done by a group of "shifters" that goes to La Palma to operate the telescope for 3 weeks approximately. There is a free week during the full moon, it is the moon break. When this group finish the operation, they send a "monthly report" with the comments during the shift.

In 2011/2012, a new 1039-pixel camera and a larger area digital trigger system were installed in MAGIC I. After this actuation the camera of Magic I ended being similar to the camera of Magic II [87] [88].

Given the fact that the MAGIC telescopes are very similar to the LST, LST designers could extract lessons learned from the maintenance activities and spare management carried out of the MAGIC telescopes. This reflected how much the design was improved in the last 15 years.

2.4.2.15. Residence and technical building on ORM

The IAC has common installation in the ORM. They are diurnal bedrooms, night bedrooms, a restaurant, living room, workshops and other facilities. The residence has two buildings and there is a third building with offices and technical installations as workshops, diesel stations and storages.

The maintenance of these installations is managed by the IAC continually.

In 2008, the IAC coordinated an inspection of conservation and maintenance of the common installations. It was conducted by an external company (Bureau Veritas). The conclusion was that several installations needed to be updated and renovated. The IAC made the improvements as soon as possible [89][90].

Fig. 2-55. ORM Residence

2.4.2.16. Cherenkov Telescope Array (CTA) Northern Array – Large Size Telescope (LST1)

The Alpha Configuration of the CTA Northern Array consists of 13 telescopes and more facilities (weather stations, operation building …). The LST´s are the biggest telescopes from the CTA project.

The construction of the first LST (LST1) finished in Oct. 2018 and after that, the commissioning phase started. The LST1 was built by the LST collaboration and its team include more than 100 scientists from 10 countries. After the construction of all telescopes. CTAO will be operating for 30 years.

The LST1 has a parabolic plate of mirrors (198 mirrors), the diameter of the mirror's plate is 23 metres. Each mirror is supported on 3 different points, one of them is fixed and the other can be moved. Those are the actuators and the function is to focus or defocus the mirrors. The adjustment of mirrors is controlled by the Active Mirror Control (AMC) system. The mirrors are mounted in a structure of tubes, whose design belongs to the German company, "MERO". The tubes are made of three materials: steel, aluminium and carbon fibre. The total weight of LST is around 100 Tons but the telescope can turn in 20 seconds (~80 km/h).

The mount has two movements, azimuth and elevation. To allow rotation, the mount is supported by six bogies that are on a rail. They are braking with two Azimuth Locking Systems (ALS).

The camera is divided into 265 modules, each equipped with 7 photomultiplier tubes (total of 1855 PMTs). The total weight of the camera is around two Tons and it is supported by a carbon fibre arc. The arc is supported by 26 carbon fibre cables. During the parking position, the arc is fixed to the camera access tower where the maintenance of the camera can be done.

The telescope is operated during the night. The telescope is moved during the day only for maintenance works, and the mirrors must be covered. The mirrors need this precaution to prevent the direct reflection of the sun because the sensitive equipment can be damaged.

The next points of this thesis are about the Telescope LST1.

Fig. 2-56: LST1

3. TELESCOPE LST1 SUBSYSTEMS

The telescope LST is a complex system with five subsystems. The five subsystems are divided according to the Product Breakdown Structure (PBS) of LST.

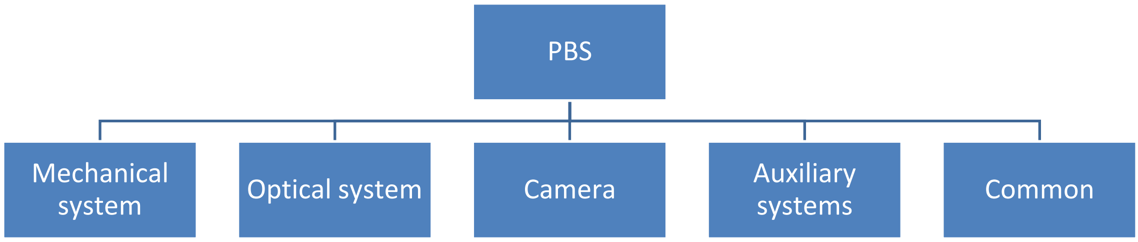


Fig. 3-1: Product Breakdown Structure

The description of each subsystem will be given in the next points.

3.1. LST1 Mechanical subsystem

The design [91] and production of the mechanical subsystem [92] of the LST Telescope is done by several institutes. Each institute is responsible for a different part, the parts of the mechanical subsystem are: the Camera mount, the camera support structure, the elevation structure, the mirrors, the elevation axis, the elevation drive, the ground structure and the azimuth drive interface [93]. See the Fig. 3-2

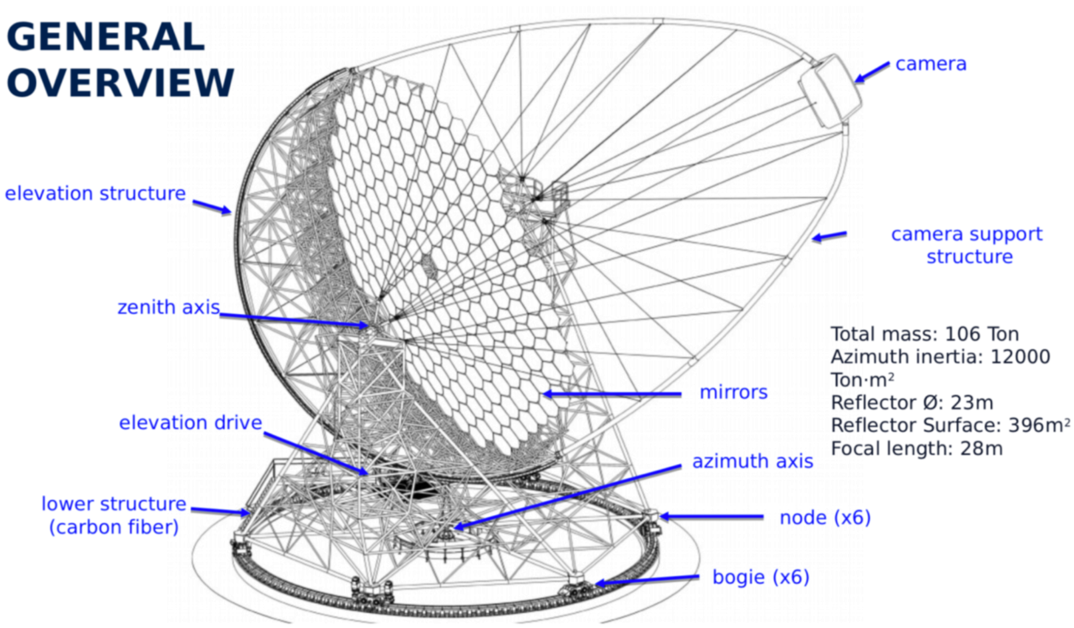


Fig. 3-2: Mechanical subsystem

Some key numbers are:

- Total mass: 103 tons
- Diameter of reflector: 23 m
- Focal length: 28 m

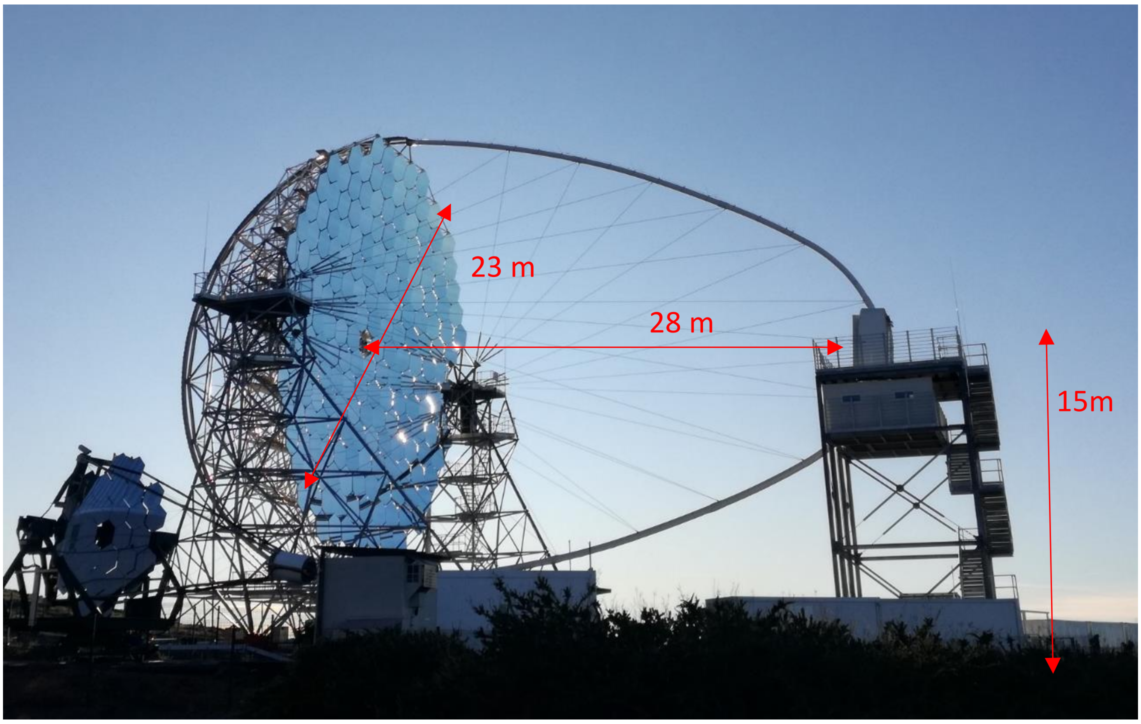


Fig. 3-3: Key numbers

3.1.1.Lower structure

The lower structure is the connection between the azimuth drive and the elevation assembly. It consists of bars of galvanized steel connected to each other by knots of aluminium and provides a bifurcated shape with two pillars or towers. On the top of the towers, an interface to elevation structures is installed. The lower structure has interfaces with the bogies and the central pin. The location of the central pin is defined in the centre of that cycle described by the bogie's knots. The lower structure has 390 bars and 122 knots. The design of this structure was done by the company MERO.

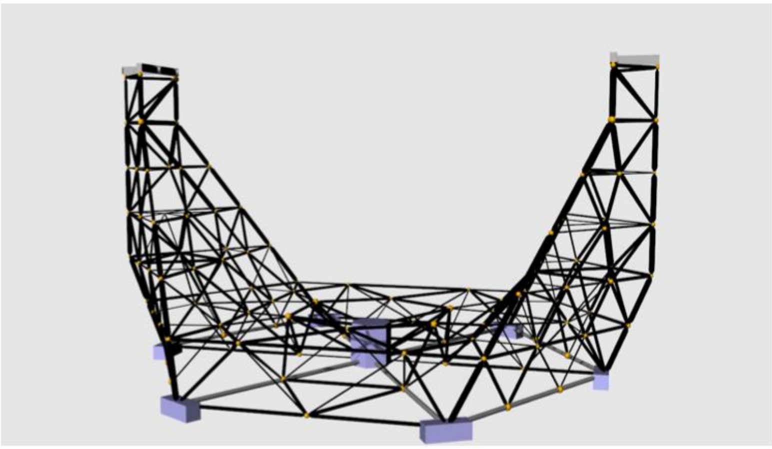


Fig. 3-4: Lower structure

3.1.2.Dish structure

The dish structure serves as the main support for the optical support structure. This structure was made by MERO too, and the system is similar to the lower structure. The bars of the dish structure are of carbon fibre and aluminium material. These materials are lighter than steel. The bars are connected by aluminium knots. The dish structure is connected to the lower structure by the bearing system. The dish structure is equipped with a semi-circular elevation drive arch (curved beam) located at the opposite side of the parabolic reflector (backside of the dish structure). The centre of the elevation arch coincides with an imaginary axis going through the centre of the elevation bearings (elevation axis).

The diameter of the dish structure is 23m. The number of mirrors that are connected is 198.

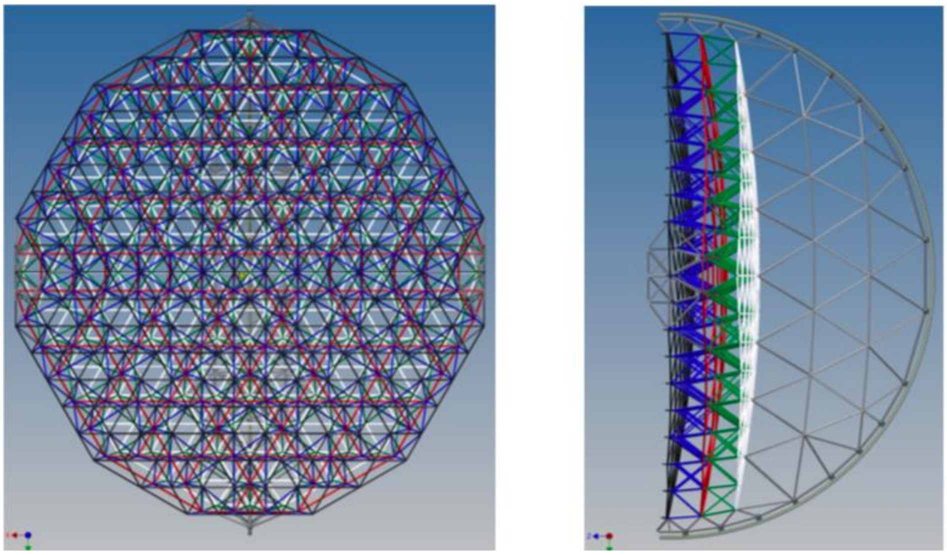


Fig. 3-5: Dish structure

3.1.3.Camera support structure

The camera support structure is a carbon fibre arch with a camera frame. It is connected to the dish structure in two points and it is supported by 26 cables of carbon fibre. The connection of the cables to the arch is done with special stain steel pieces.

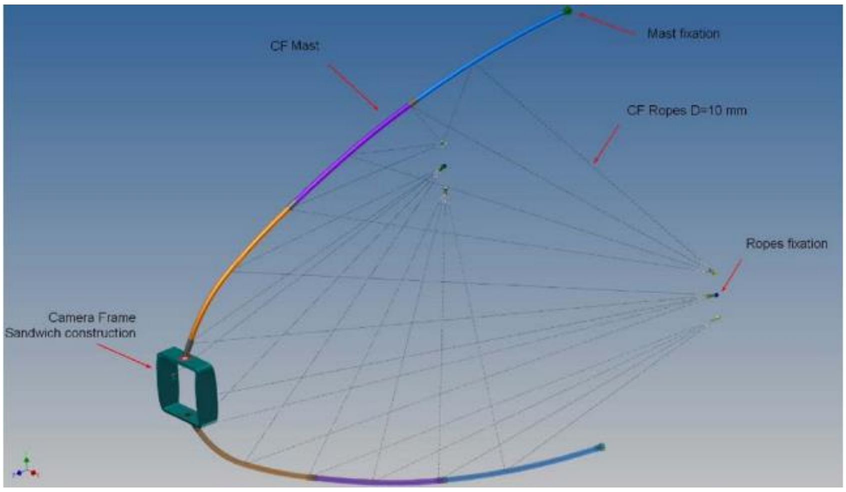


Fig. 3-6: Camera support structure

3.1.4.Azimuth system rail

The azimuth drive consists of six bogies, which are running on a circular rail system. The rail system is fixed to the foundation by anchors bolts. It is made through sub-sectors, which material is steel and it has coating protection.

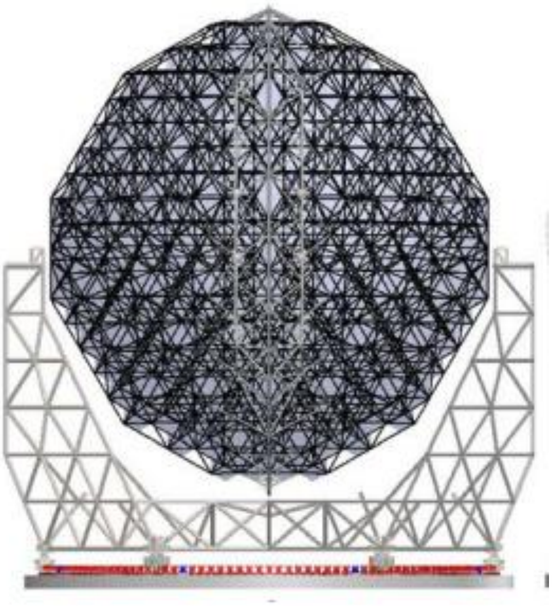


Fig. 3-7: Rail

3.1.5. Azimuth system central support

The central support constitutes the rotation axis of the azimuth drive system. The central support consists of a socket integrated into the foundation. The lower structure is connected to the socket via a spherical roller bearing. The socket is made of steel tubes and plates connected by welding.

3.1.6. Azimuth drive

The azimuth drive system has six bogies. Two of them are equipped with motors and brakes, those are the “heave bogies”. The other four bogies are the passive or light bogies, they don’t have motors or breaks. The six bogies are very similar, the only difference between them is their motor. The bogies are equipped with four wheels and four rollers to guide the bogie radially along the rail system. Four additional rollers are provided which are accommodated underneath the rail system, preventing the uplift of the bogies. The pinion of the gearbox engages with the crown wheel accommodated along the azimuth system rail.

3.1.7. Azimuth locking system

The azimuth locking system blocks the azimuth drive in a tangential direction and prevents the uplift of the telescope under stormy conditions. The azimuth locking system is automatic but can be moved manually. This system has 2 pieces, one on the east side and the other on the west side. It is connected to the foundation with anchor bolts. It is mainly made of steel and it has coating protection. There are three motors in each piece.

Fig. 3-8: West azimuth locking system.

3.1.8. Elevation bearing

The elevation assembly carrying the reflector and the camera is fixed to the azimuth assembly through two elevation bearings and the elevation drive. The elevation axles are fixed to the lower structure by means of two sockets each clamping the axle in its position. The connection to the corresponding dish knots is realized by means of a spherical roller bearing.

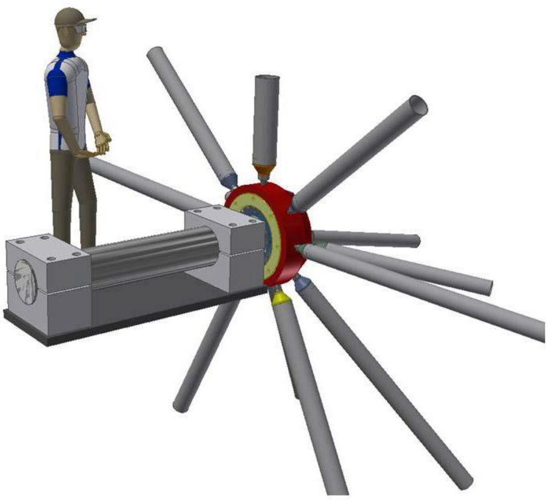


Fig. 3-9: Elevation bearing.

3.1.9. Elevation drive

The elevation drive is a structure with 2 motors with gearboxes each one. It is connected to the elevation drive arch through guiding rollers. The transfer of the driving forces is led by two chain wheels joining a double row roller chain, which is fixed to the arch. Furthermore, the drive is equipped with an external brake designed to keep the elevation in the right position when the motors are not powered and the telescope is not parked. In the parking position, the elevation is locked by an automatic bolt connecting the drive support through the arch (there is a manual safety bolt). The bolt is movable in a longitudinal direction using an electric actuator. Both the locking system and the external brake are included in the elevation drive support. To transmit the forces of the drive, a strut connects the drive support to the central part of the lower structure (central axis). The elevation drive components are made of steel.

3.1.10. Counterweights

Counterweights are needed to balance the optical support structure in elevation. The permanent part of the counterweight has a mass of 2.5 tons. It is connected to the drive arch.

3.1.11. Camera access tower

The camera access tower is the structure utilised to do the maintenance of the camera. In addition, during the parking position of the telescope, the camera access tower supports the camera.

The camera access tower is a metallic structure with two platforms (galvanized steel). The upper platform has two moveable sections, which are opened to unpark the telescope.

Under the platforms, there are two containers, the drive container and the energy storage container.

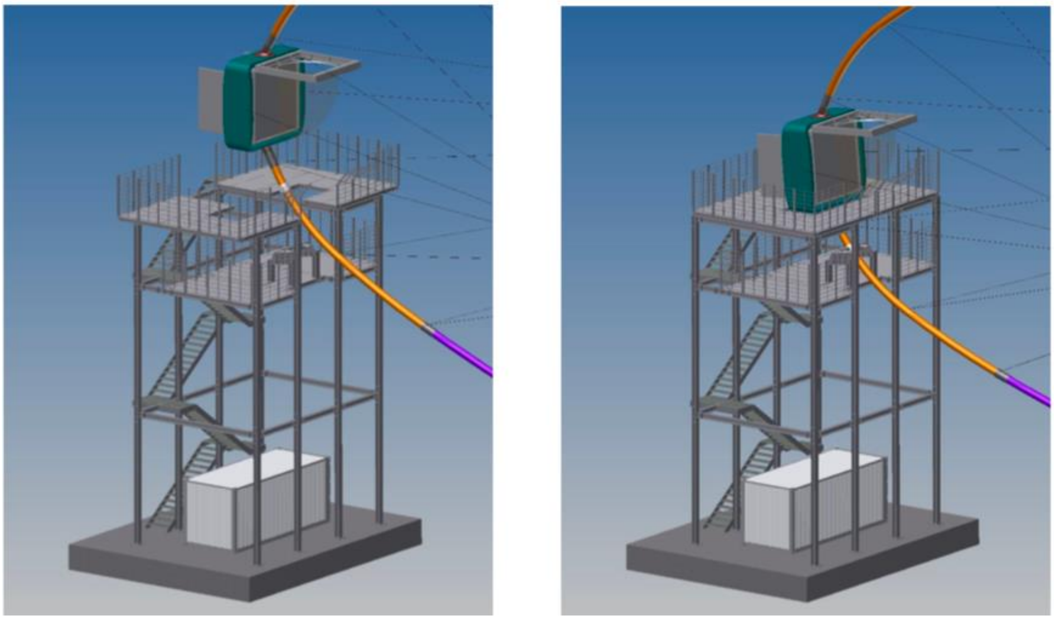


Fig. 3-10: Camera access tower

3.1.12. Camera locking device

The camera locking device is installed on the first platform of the camera access tower. It secures the camera while it stays in the parking position. The locking device consists of a set of wire rope isolators. These isolators are very robust and possess a high damping capability.

3.1.13. Working platforms and catwalks

To ensure the safe maintenance of the telescope, there are working platforms, catwalks and ladders. Some of them have handrails. The main material is aluminium. Nine horizontal lifelines are installed with the catwalks in the back part of the telescope.

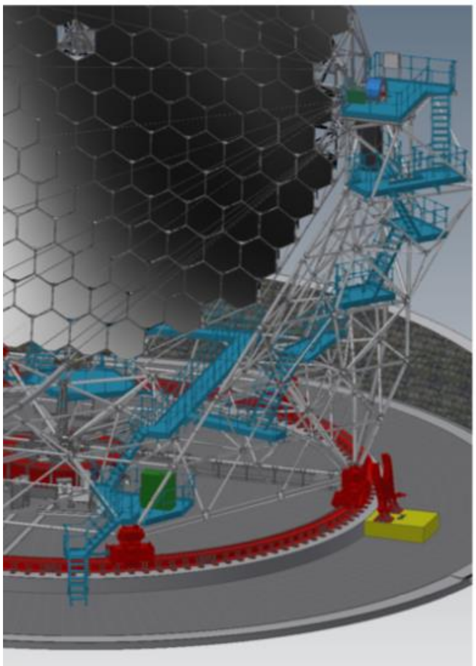


Fig. 3-11: Ladders and platforms

3.1.14. Limitations of mechanical subsystem

The mechanical subsystem is designed to the following environmental conditions:

Operational air temperature range	-15ºC to 25ºC
Survival air temperature range	-20ºC to 40ºC
Max. constant wind speed during observation	36 km/h
Max. constant wind speed in safe state condition (parking position)	120 km/h
Max. short term gust in safe state condition (parking position)	200 km/h
Max. layer of snow in safe state condition	500 mm
Max. layer of ice in safe state condition	20 mm

3.2. LST1 Optic subsystem

3.2.1. Mirror facet

198 mirrors compose the primary reflector. There is not secondary reflector in the telescope LST [94].

The final shape is a hexagonal mirror. There is a cut-out part to accommodate a camera for AMC. The thickness of the mirror is 73 +/- 2 mm.

Its structure is a composite of glass + aluminium honeycomb + glass. The structure is IP67 but if there is water inside the mirror, there is a pipe to let the liquid out. The weight of the mirror is around 45 +/- 5kg. The frame of the mirror is made of stainless steel. There are 3 pads of stainless steel on the backside of the structure. They are the connection to the actuators. Its backside surface is painted with white paint that has a durability of longer than 10 years. It is resistant to a temperature change from -10 degC to 40 degC and with a change rate lower than 10 degC per hour.

3.2.2.Interface plates and actuators

The mirror interface plate is fixed to the dish structure by hose clamps. There are two types of mirror interfaces.

The interface plate connects three mirrors facets to the dish structure through 3 actuators. There are 225 interface plates in the telescope for connection 198 mirrors. There are normal and “special” interface plates. These special interface plates (49) are located in the corners where less than three mirrors are installed.

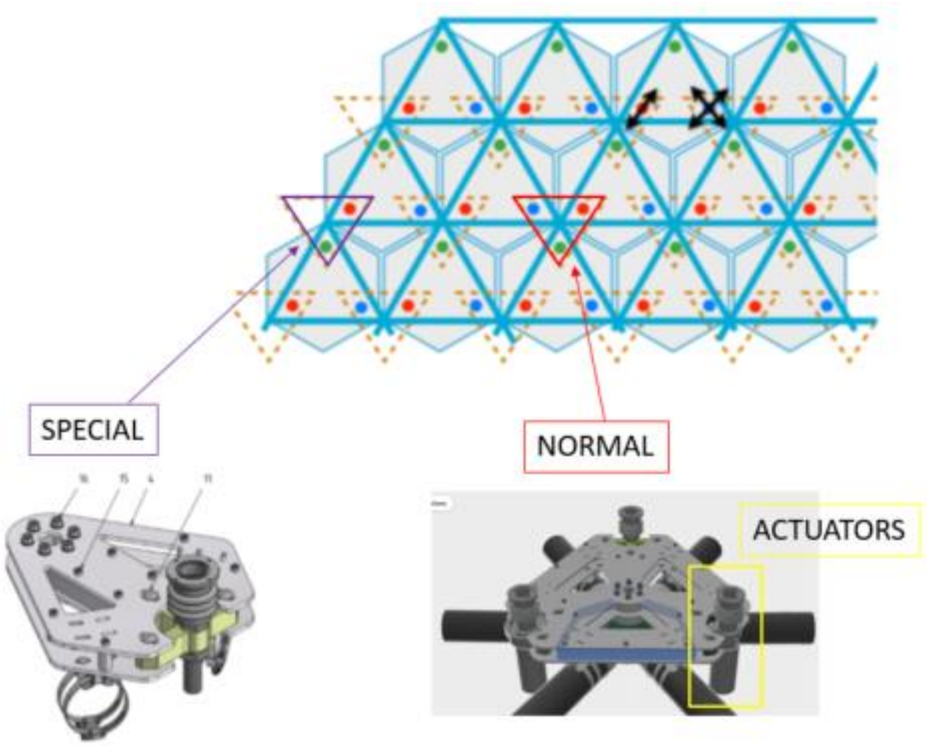


Fig. 3-12: interface plates

3.2.3.AMC boxes

The devices needed for the AMC functions are installed inside a small cabinet, called the AMC box. There will be 16 boxes in total per telescope to be installed inside the dish structure along the catwalk.

3.3. LST1 Camera subsystem

The LST design is optimized to detect the lowest gamma-ray energies. This leads to some particular requirements that are detailed in the document LST/120920. One of the strategies to lower the energy threshold as much as possible is to trigger single telescopes deeply into the NSB (Night Sky Background) regime and wait for a trigger in another LST before reading out the event. The LST camera (LST-CAM) must sustain an acquisition rate of 10 kHz and should assure a memory depth of at least 3500 ns to operate in this mode. For the same reason, the requested minimum photo-detection efficiency is established to 15%. From Monte Carlo simulations, the LST-CAM is required to have at least 4.5° of field of view and pixels not larger than 0.11° [95]. Other requirement is the weight, it must be lower than 2 Tn and the dimensions are 2854 x 2884x 1105 mm.

The camera design follows a modular principle for its focal plane instrumentation (FPI) and trigger electronics, which are installed in a compartment with a tightly integrated water and air based environmental control system, which also host all camera auxiliary elements. This compartment has a controlled air exchange with the environment, isolating all the electronics from the ambient conditions. It also holds an optical window, that allows light to reach the photodetectors at the focal plane, and a shutter that protects the window and photodetectors from sunlight during day. Additionally, a few external elements are considered part of the camera and provide services to it: an external cooling unit provides water to the environmental control system; a camera server collects data from the camera via optical fibers; and a calibration box provides an external optical pulse used to calibrate the focal plane photodetector response.

Each FPI module contains a set of seven light guides coupled to photomultipliers with the auxiliary electronics, and a trigger and readout system. The modules are installed in a rack-like structure that has been designed to allow an easy replacement in case of failure or degradation. This structure is integrated within the camera body.

The camera body is the main structural element of the camera, which holds all its elements with the necessary stiffness to guarantee the physics goals. It is covered by a light and rigid aluminium honycomb skin. The skin is painted with white paint that reduces the absorption of solar radiation. The frontal part of the camera has a plexiglass optical windows (Fig-3-13). The photomultipliers of the FPI modules are located behind the optical window. The back part of the camera has the auxiliary mechanics and electronic devices (see Fig 3-14). The camera is waterproof and the difference of pressure between the internal part of camera and the environment are compensated using differential pressure valves.

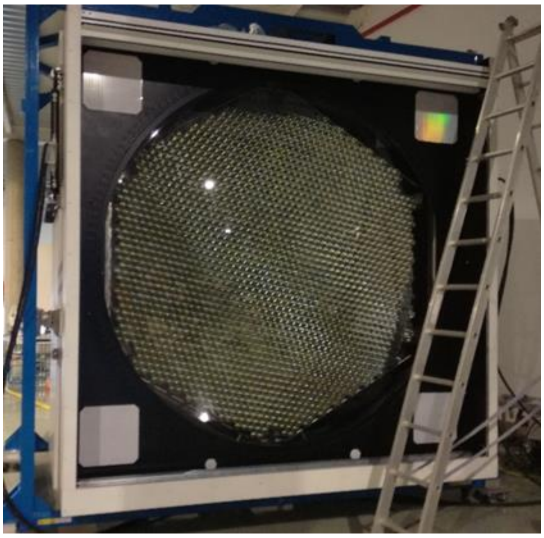


Fig-3-13. Frontal view of camera (shutter is opened)

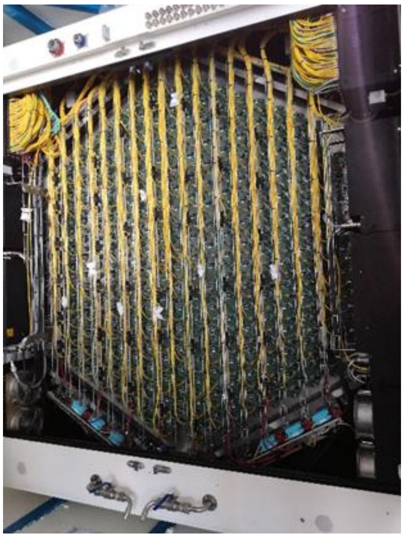


Fig 3-14. Back internal part of camera

The camera is attached to a carbon fibre frame, which is part of the telescope mechanical structure. The interface between the camera and this frame consists of a set of four rails where the camera is attached in eight points. (Fig. 3-15). These rails allow to load and unload the camera from the frame for maintenance activities or to adjust its position with respect the telescope mirror.

During day time, the camera is closed with a shutter that prevents the incidence of the sun light on the front of the camera. The shutter is opened and closed automatically every day for regular operations but it can be moved manually too.

The environmental conditions inside the camera are controlled with an Environmental Control System (ECS). It can stabilize the temperature inside the camera in less than 1 hour. When the ECS is not in operation, the camera internal temperature can be between 0ºC and 30º C when the telescope is not operating, and the humidity is below 65%. The ECS is based on both liquid and air cooling systems.

The light sensors in the focal plane of the camera detect the Cherenkov photons generated by air showers in the atmosphere (Fig. 3-16). The selected light sensor for the first LST is the bialkali PMT R11920-100 from Hamamatsu Photonics, which has a spectral sensitivity optimized for the Cherenkov light spectrum.

A camera event builder software application collects by Ethernet the event fragment data from the front-end modules of the assigned telescope and runs in the camera server with a multi-core Intel CPU. It assures the reconstruction and buffering of camera events downloaded into the computer from an individual telescope.

The slow control hardware logic is placed inside the camera. It ensures the reliable functioning and the safety of the camera. The main tasks are:

- Provide remote communication with the OES through Ethernet and the generic and standard OPC-UA tool.
- Ensure safe conditions for the camera components and prepare the camera for observations. It checks that everything is working properly when the camera is switched on.
- Take emergency decisions to protect the camera in case of anomalous situations as very high temperature or water inside the camera.

The slow control system is connected to an UPS, if there is a power cut it can be activated to close the shutter.

The maximum power needed for the camera is 8 kW. The camera has two power lines, one phase AC 230 V UPS and three phases AC 400 V. The first power line feed the systems that need power in case of a power failure for safety.

Fig. 3-15. Connection of camera to frame by rails

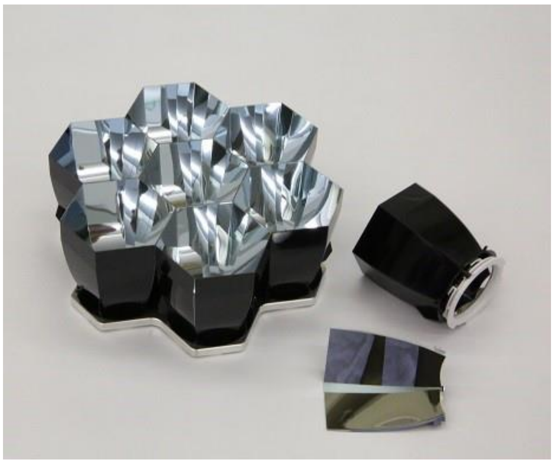


Fig. 3-16. Light guides [95]

3.4. LST1 Aux subsystem

The auxiliary systems in the telescope LST are: energy storage, lightning Protection, calibration and control point, drive control system, drive container, structure condition monitoring and cabling structure.

3.4.1.Energy storage container

The energy storage is a container with a group of elements that control the energy that is received by the telescope for moving. This container is located under the camera access tower and before the drive container.

The container is a standard 20-feet transport container but it has been modified for working inside.

Into the Energy Storage Container, there are: a UPS, 2 Fly Wheels, 3 Air conditioning units, Fire alarm system and other electronic controls and equipment.

The UPS is connected to the FlyWheels and they are the safety power control of the telescope. If there is a power cut in the power line of the observatory, this UPS will keep administrating power to the telescope while the generator re-starts.

The flywheel, using technology, stores kinetic energy in the form of a rotating mass and is designed for hi-power, short time discharge applications. The technology includes a high-speed motor generator and active magnetic bearings that are used to levitate and sustain the rotor during operation. The flywheel assembly includes a superior control system that provides information on system performance. This innovative technology allows the flywheel to charge and discharge at high rates for countless cycles, providing much superior operation over conventional battery use [96].

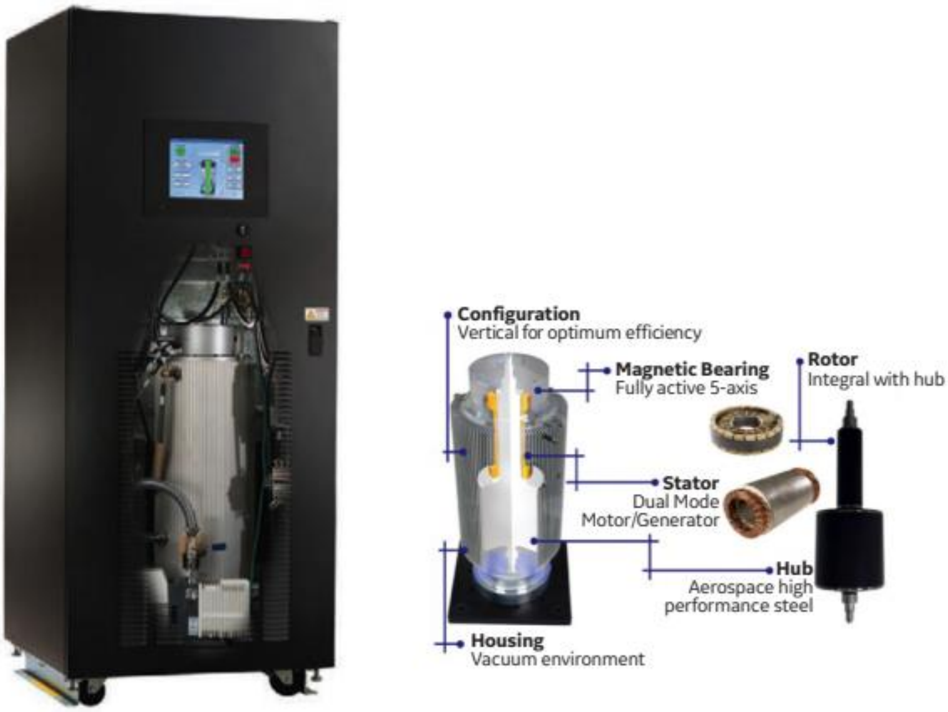


Fig. 3-17: Flywheels

The UPS and the flywheels need to have a controlled atmosphere (temperate and humidity). For this reason, three air conditioning systems are installed into the container.

Two of the safety equipment most important pieces are the fire extinguisher detectors and alarms and the leak rope detector

The monitoring control is into the Commissioning Container, then, the operators of the telescope control the parameters of this equipment when they are operating the telescope.

3.4.2. Lightning protection

The requirement of LPS must be protected with a Class 1 lightning protection system following the international lightning protection standard IEC 62305-1-4:2010.12 [97].

The first studies of lightning protection systems were done by Vektor Plan [98] and Fichtner [99]. However, the final design was done by a local engineer following the basis of previous studies. According to the Spanish regulations, the local engineer did the design of the lighting protection system, which is: "Instalación de protección contra sobretensiones y descargas atmosféricas para el telescopio LST-1 de la red Cherenkov Telescope Array (CTA) (visado Nº 2073/2019) [100].

The reinforcement of the foundation is connected to metal plates, which are extended outside the reinforced concrete in the four cardinal directions. The metal plates are also connected to the metal structure of the telescope. 6 lighting rods, 2 in the camera access tower and 2 in each access tower are integrated into the LST1 structure and the upper level of the camera access tower (Fig. 3-18). There are small lighting rods on the arch and around the mount. They are connected to the earthing system by stainless steel cables, which merge in an earth pit (point 5, Fig. 3-19) with a lightning counter. From this pit, an extension of the earth system was made with a copper plate ended in three additional plates arranged as a goose radial leg (point 6, Fig. 3-19) and located on the eastern side of the telescope [101]. Fig. 3-20 and Fig. 3-21 are pictures of the current lighting rods.

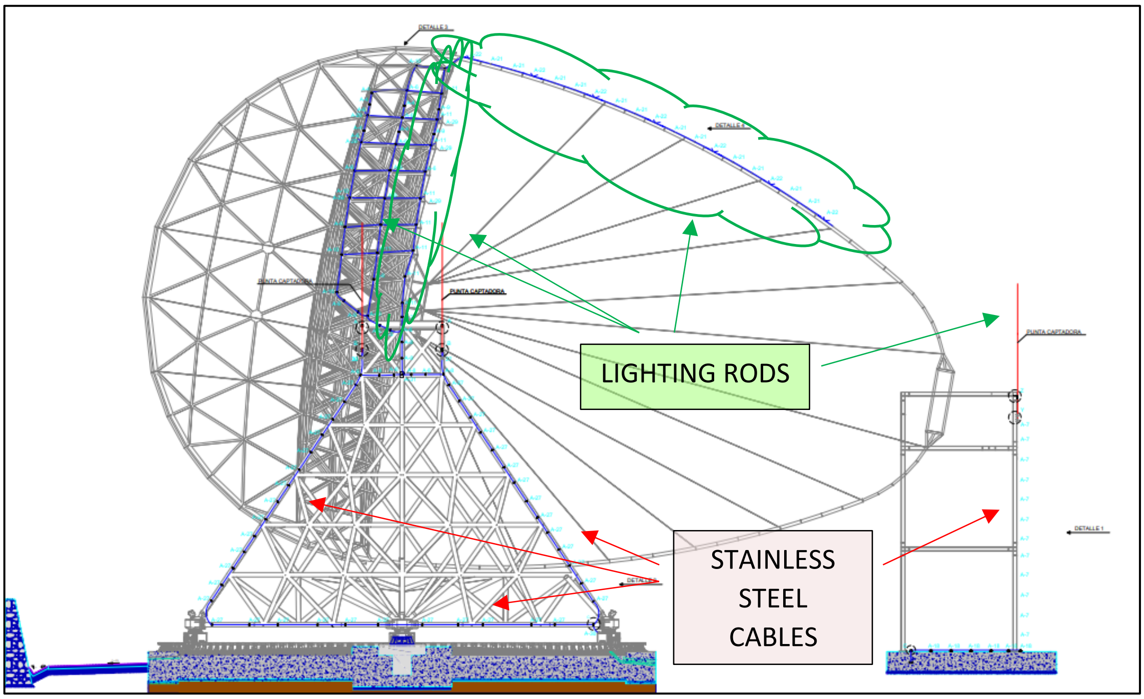


Fig. 3-18: Vertical section of LPS [100]

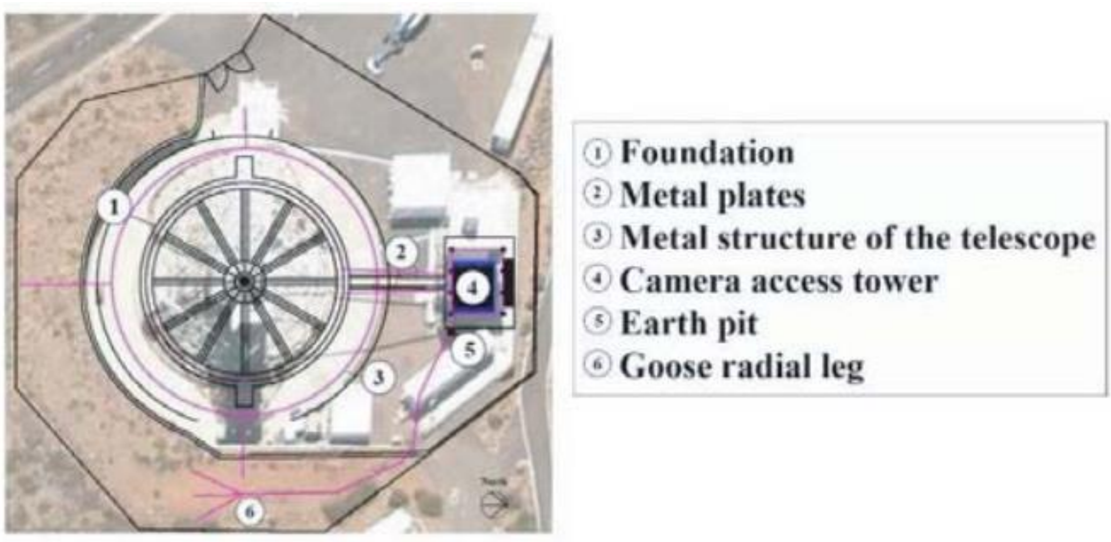


Fig. 3-19: Schematic of the real earthing system designed for LST telescopes [102]

Fig. 3-20: lighting rods on the arch

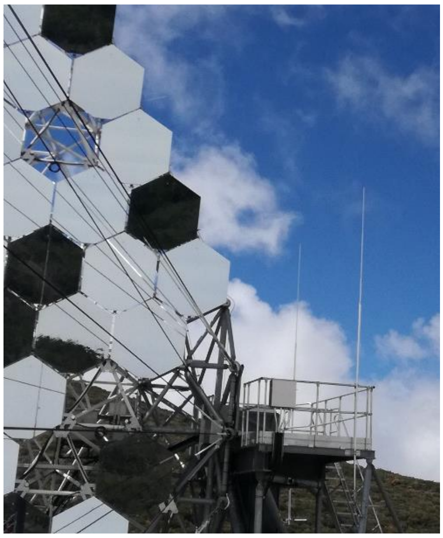


Fig. 3-21: lighting rods on the tower access

3.4.3. Calibration and control point

In the centre of the mirror dish, are places calibration and control points.

Starguider: to determine the actual pointing of the telescope and use the deviation from the intended pointing in the offline data analysis [103].

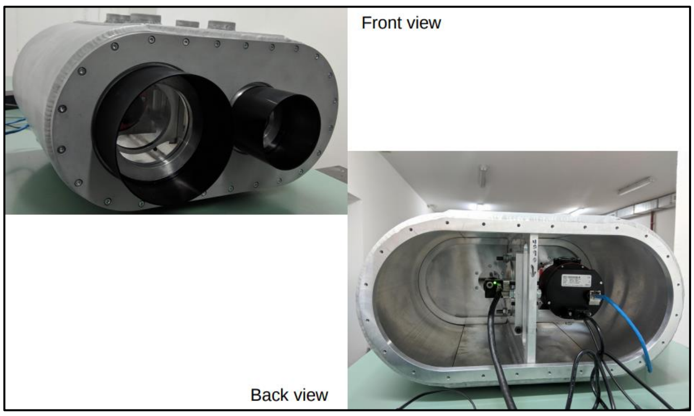


Fig. 3-22: Starguider

Optical axis reference laser inclinometer and distance meters: Provide reference laser along an optical axis, monitoring tilt of dish, monitoring distance between camera and dish and stiff connection between all devices and dish structure [104].

3.4.4. Drive control system and drive container [105]

The drive system is composed of one container with all the electronics and the control/monitoring system, the motors (4 in azimuth and 2 in elevation) plus various devices inside the telescope.

Once received on-site, the container was installed under the camera access tower. Already prepared cables from the telescope elements (motors, sensors, power lines to all elements in the telescope…) were connected inside the container.

Inside the drive container, is controlled the status of the telescope. There are three possible statuses: manual, service and automatic. Manual is only used by experts during maintenance activities, service is to go into the camera access tower and at this mode, it is not possible to move the telescope and automatic is for the normal operation activities.

3.4.5. Structure condition monitoring

Condition monitoring is often defined as the process of monitoring a parameter of condition in machinery such that a significant change is indicative of developing failure [106]. The structure condition monitoring is a group of devices that monitor the status of different parts of the telescope during the lifespan and help with the maintenance [107] because it reads the status of the pieces continuously. The system monitors the condition through sensors that read their data over a network to be subsequently analysed, displayed to the operators and produce in real-time alarms and warnings on the possible wearing of the different components [108].

There are different types of condition monitoring in the LST, depending on the parameter that they to control:

- **Thermographic measure:** the measure the temperature of pieces for checking if there is an extreme temperature that can produce a failure or lead them to collapse. E.g: a thermal camera can measure the temperature of a group of cables into an electronic cabinet. If there is an extreme temperature at one point, can happen a short circuit in this point. It is a regular preventive inspection of the drive control system [109].
- **Vibrations**: accelerometers check the vibrations that can give information of the system's health with frequency and/or time analysis. Linear sensors can monitor the system vibrations too. E.g: the bogies of LST are equipped with accelerometers for monitoring the data from them [110].
- **Tension monitoring:** load pins (strain gauges embedded in the pin body) for monitoring the tension of cables. E.g: the load pins (Fig. 3-23) are installed in the fibre cables that support the arch for monitoring the tension of cables [111].

Fig. 3-23: Load pins

3.4.6.Cabling structure

The cabling structure is a complex system of cables in the telescope. In some places, the quantity of cables is so high that they need to be installed in cable chains to be ordered. It is the case of cables in the central pin or cables that go up to the elevation bearing.

The cabling of LST1 was fabricated following the next steps [112]:

1. Installation of the cabinets on the ground and exit of the azimuth cable chain and connections of the cable chain inside the cabinets
2. Installation of the cabinets at the entry and exit of the elevation cable chain and in the dish centre and connections od the cable chain inside cabinets
3. Cabling of various ducts (Fig. 3-24) in the concrete and the ground
4. Connections of ducts bundles inside the cabinets
5. Cabling the camera bundle inside the dish and connection inside the cabinet
6. Cabling the cabinet for the CSS assembly.

Most of the cabinets and cables are outdoor so they must support the environmental conditions.

Fig. 3-24: Cable ducts

3.5. LST1 common subsystems

3.5.1. Low voltage installation and diesel generator

The design of the low voltage installation was done by a local engineer according to the Spanish regulations. The project is: INSTALACIÓN ELÉCTRICA EN BAJA TENSIÓN PARA SUMINISTRO AL TELESCOPIO LST-1 DE LA RED CHERENKOV TELESCOPE ARRAY (CTA) (visado Nº 3495/2017).

The low voltage is connected to the low voltage line of the Observatory in the “Centro de Transformacion”. The power line of the Telescope goes across the Diesel Generator of 650 KVAS before entering the Telescope Area.

During the Commissioning phase, into the telescope area there are 4 power lines:

- Line 1: Commissioning Container
- Line 2: Telescope (drive)
- Line 3: IT container
- Line 4: Energy storage container of the new telescopes.

When the commissioning phase finish, only line 2 will be kept, the other three lines will be used for the new telescopes (LST2, LST3 and LST4).

3.5.2. IT container

The IT container hosts the Data Center of CTA North until the CTA N Operation building is ready.

The IT (Information Technology) container is a prefabricated container. It contains electronic devices (servers, GPS, switches), an UPS, a humidifier and an air cleaning system.

This container is isolated and its sensors control the temperature and humidity, according to the specifications of electronic devices. There are three cooling units and an automatic fire extinguisher system.

This container has sensors in several devices and the working parameters are controlled by Schneider. The parameters and alarms can be checked in a mobile application. Schneider is the company that manufactured the container. There is an annual maintenance contract with them.

3.5.3. Commissioning container

During the commissioning phase, the operation of the telescope is controlled from the commissioning container. It is a prefabricated container of 12meters with an operation room and a workshop room. The operation room has 12 monitors to control the telescope (Fig. 3-25).

This container is the coordination point if there is an emergency. In the operation room, there is a radio connected to the ORM radio, walkie talkies and safety information. The personal protection equipment is in the container too.

In the workshop room, there are servers and the temperature must be controlled.

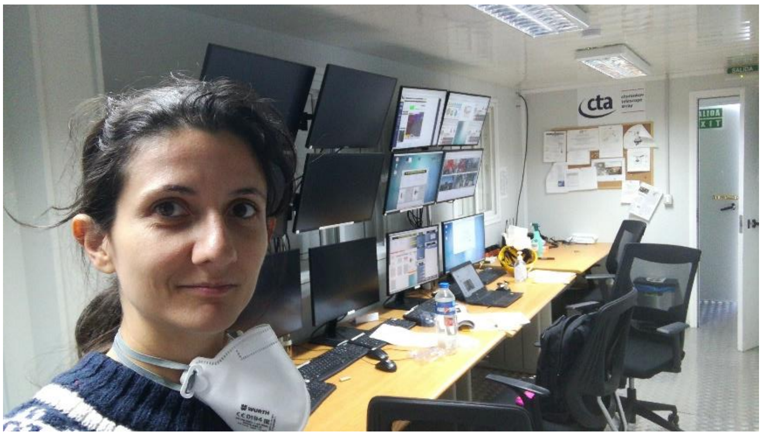


Fig. 3-25. Operation room

3.5.4. Infrastructure

The infrastructure of the telescope LST is the interface between the other subsystems. The most important points of infrastructure are [95]:

- Shipping containers
- Machinery for the installation, assembly and maintenance of the telescope
- Power line
- Buildings and civil works
- Storages

It is the last point but without INFRA is not possible to build telescopes. Power lines, building, civil works and storages are essential during the lifespan of the telescope.

4. TELESCOPE LST1 MANAGEMENT

The high-level organization of LST1 also plays a major role in the optimization of the risk management as well as in the Reliability, Availability, Maintenance and Safety (RAMS) activities.

4.1. Risk management

The LST Risk Management Plan [113] defines all elements needed for the proper implementation of Risks Analysis in the LST project. This document is based on the thesis [114]. The Risks Management procedure followed in the LST project is composed of four steps.

1. Define Risks Management implementation requirements
2. Identify and assess the Risks

Table 13: Definition of Risks severity levels for the different types of Risks

LEVEL	SEVERITY	COST RISKS	TECHNICAL RISKS	SCHEDULE RISKS	OTHER RISKS
5	Catastrophic	Project cannot be funded	Project is not feasible	Project termination	Project termination
4	Critical	Project cost increases up to 30%	Complete re-design of the project	Project length enlarged up to 2 years	Project could continue in 25% of the cases
3	Major	Project cost increases up to 20%	Re-design of up to 50% of the project	Project length enlarged up to 1 year	Project could continue in 50% of the cases
2	Significant	Project cost increases up to 10%	Re-design of up to 25% of the project	Project length enlarged up to 6 months	Project could continue in 75% of the cases
1	Negligible	Minimal or no impact	Minimal or no impact	Minimal or no impact	Minimal or no impact

Table 14: Definition of Risks Probability of occurrence levels

LEVEL	PROBABILITY OF OCCURRENCE	LIKELIHOOD CONVENTION
E	Maximum	High probability to occur
D	Medium	Likelihood up to 0.1
C	Low	Likelihood up to 0.01
B	Very Low	Likelihood up to 0.001
A	Minimum	Likelihood up to 0.0001 or less

3. Decide and act according to Table 15: Risk Magnitudes table: Definition of Acceptable and Not Acceptable Risks based on their Risk index

Table 15: Risk Magnitudes table: Definition of Acceptable and Not Acceptable Risks based on their Risk index

		RISK MAGNITUDE CONVENTION BASED ON THE RISK INDEX				
PROBABILITY OF OCCURRENCE	E	TBC	Not acceptable	Not acceptable	Not acceptable	Not acceptable
	D	Acceptable	TBC	Not acceptable	Not acceptable	Not acceptable
	C	Acceptable	Acceptable	TBC	Not acceptable	Not acceptable
	B	Acceptable	Acceptable	Acceptable	TBC	Not acceptable
	A	Acceptable	Acceptable	Acceptable	Acceptable	TBC
		1	2	3	4	5
		RISK SEVERITY				

- For Acceptable Risks: No additional tasks to be done → proceed to STEP 4.
- For Not Acceptable Risks: Reduce the Risk index or define a Mitigation action.
- The Risks ranked in this table with a magnitude labelled as TBC – To Be Confirmed– shall be analysed on a case by case basis to determine whether they are considered Acceptable or Not Acceptable. Regardless the final choice taken, the Risk Delegate shall provide the appropriate justification to the final Risk magnitude set in all of the TBC cases identified. The category TBC is considered valid in all cycles except the last one.

4. Monitor, report and accept Risks

If we apply the four previous steps from the LST Risk Management Plan to the identified risks that affect an area of CTA in the ORM (point2.3) we have Table 16.

Table 16: Risks that affect Telescope LST1

ID	Description of the Risk	Risk Type	Severity	Probability	Magnitude	Suggested Mitigation Action	Comments
1	Flood and rains	Cost	4 - Critical	A - Minimum	Acceptable		
		Schedule	2 - Significant	A - Minimum	Acceptable		
2	Seismic movement	Cost	4 - Critical	B - Very low	TBC	Insurance	The probability of a seismic movement is very low. The seismic movement can be of high or low magnitude. If there is an intensive seismic movement, the consequences can be catastrophic, but the risk needs to be assumed. There are not seismic movements registered in the ORM.
		Schedule	4 - Critical	B - Very low	TBC	Insurance	
3.1	Volcanic eruption (ashes + toxic gases)	Cost	1- Negligible	B - Very low	Acceptable	To cover susceptible parts of telescope Insurance	Mitigation action proposed because RIESGOMAP considered only most probable wind directions and may under estimate the true ash risk probability for ORM.
		Schedule	2 - Significant	B - Very low	Acceptable		
3.2	Volcanic eruption	Cost	5- Catastrophic	A - Minimum	TBC	Insurance	

ID	Description of the Risk	Risk Type	Severity	Probability	Magnitude	Suggested Mitigation Action	Comments
	(lava + pyroclastic flows)	Schedule	5- Catastrophic	A - Minimum	TBC	Insurance	
4	Snow	Cost	2 - Significant	D - Medium	TBC	Protection equipment Insurance	If there is a snowstorm, the mitigation action is to use protection equipment. The solution consists of removing the snow as soon as possible and to prevent high damage through protection equipment.
		Schedule	1 - Negligible	D - Medium	Acceptable		
5	Storms	Cost	1 - Negligible	E - Maximum	TBC	Protection equipment Insurance	If there is a rain/wind storm, the mitigation action consists of using adequate protection equipment. The solution is to prevent major damage through protection equipment and to repair damage as soon as possible.
		Schedule	1 - Negligible	E - Maximum	TBC		
6	Heat waves	Cost	1 - Negligible	B - Very low	Acceptable		
		Schedule	1 - Negligible	B - Very low	Acceptable		
7	Calima	Cost	1 - Negligible	D - Medium	Acceptable		Calima may affect the operation of the telescope. During strong calima, observation is not possible. Cleanup after a calima event may be necessary.
		Schedule	1 - Negligible	D - Medium	Acceptable		
8	Gravitational movements	Cost	3 - Major	B - Very low	Acceptable		
		Schedule	2 - Significant	B - Very low	Acceptable		
9	Wild Fire	Cost	5 - Catastrophic	C - Low	Not acceptable	Firewalls Fire prevention systems Emergency equipment Insurance	A fire can be catastrophic in the observatory. Currently there are fire prevention systems (alarms, smoke sensors) and emergency equipment available. A firewall around the observatory might be considered.
		Schedule	5 - Catastrophic	C - Low	Not acceptable		
10	Lightning Strikes	Cost	2 - Significant	C - Low	Acceptable		
		Schedule	1 - Negligible	C - Low	Acceptable		
11	Pandemic	Cost	2 - Significant	B - Very low	Acceptable		

ID	Description of the Risk	Risk Type	Severity	Probability	Magnitude	Suggested Mitigation Action	Comments
		Schedule	2 - Significant	B - Very low	Acceptable		

The conclusion of Table 16 is that there are risks that cannot be avoided. If the magnitude of the risks/severity/probability is acceptable, we can live with them.

If the magnitude is not acceptable, we have to find solutions and tools to defend ourselves from them (mitigation actions). However, sometimes the preventive mitigation actions are not enough, in this case, the priority will be the social risk (the safety of the people) and having insurance that covers the cost of repairs.

In the worst case, the risk will not come alone, in which case we will have to face them as efficiently as possible so that the consequences are as mild as possible.

In Table 16 we analysed the risks that can happen in La Palma but there can be events in far apart places that affect us. On 11 April of 2021 [115], there was a volcano eruption in America and the SO_2 from this event arrived in La Palma. The suspended particles from the said eruption were detected by the meteorological stations of the observatory's telescopes (see Fig. 4-1). In far events like this, the main consequence is a poor quality of the sky and therefore the observation with the telescope is not 100% optimal.

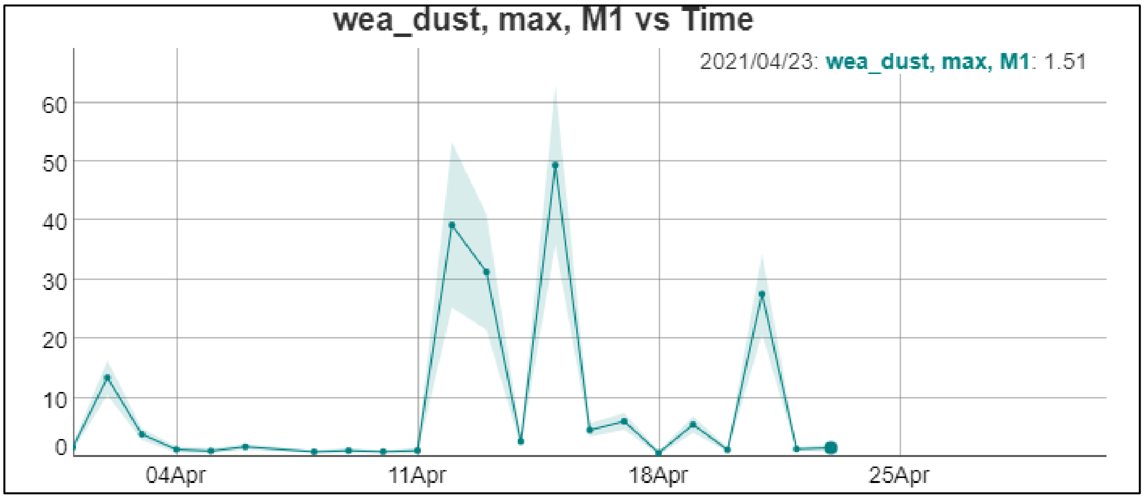


Fig. 4-1: Dust max in April 2021. Credits: Magic and TNG weather stations

4.2. Reliability

Reliability engineering is an engineering discipline for applying scientific know-how to a component, product, plant, or process in order to ensure that it performs its intended function, without failure, for the required time duration in a specified environment [116]. This concept is applied in the project CTA because with a reliability analysis we can estimate the corrective maintenance parameters and define the safety integrity level of the safety hardware. It has an essential role in the availability calculation or simulation [117].

The reliability analysis of LST was done and documented in the document [95].

Reliability requirements were approved during the initial phase of the project in several documents and the requirements per subsystem are in sections where we can see the estimated lifespan.

The Aux, camera, optic and mechanical teams have the responsibility of choosing the materials for their subsystems with the maximum lifespan of their products. The quantity of components of the LST telescope is so big for this reason; a Monte Carlo simulation was done to identify the most critical parts of the telescope.

The most critical reliability issues are related to adverse environmental conditions:

- Altitude: on high altitudes, the air is less dense than at sea level reducing its convective capability, overall heat capacity, therefore, all electronics that rely on natural or forced convection to dissipate heat will experience greater air, and the component temperature rises for the same amount of power at high altitudes. It is compensated with a thermal system. Altitude can also affect the performance of lubricants. The difference in pressure affects fluids into the instrumentation, e.g. the air into the honeycomb of the mirrors.
- Temperature: the isolated subsystems have their own thermal system, e.g. the camera of the telescope. Other subsystems have considered thermal expansion in their design.
- Humidity: low humidity can accumulate static electricity in electronic devices. High humidity can reduce the resistance of insulation materials. A cooling system can control the humidity.
- Wind and rain: during a storm, the water from the rain can enter every place if there is wind. The closed facilities (camera or containers) consider it during the design. The mirrors are more exposed, for this reason, the lifespan of mirrors is shorter than other component's. The wind produces deformation in the structure too and can move the telescope, affecting the torque of the structure. The effects of the wind were considered during the design of the telescope
- UV Radiation: exposure to UV radiation accelerates the ageing of the telescope, especially the mirror facets
- Dust: it can be an abrasive agent. The mirrors are especially exposed as well as the mechanical elements such as gears and bearings. The camera and the control container are protected against dust penetration.

The lifespan of subsystems of telescopes are [97]:

- Structure: 30 years
- Drive: 15 years
- Mirrors: 15 years. Recoating may be expected on a frequency of less than once every 6 years.
- Camera: 15 years
- The lifespan of the on-site Data Centre computing hardware must be at least 5 years.
- The lifespan of the network cabling hardware must be at least 15 years.

The Monte Carlo analysis of the LST reliability performed during the preparatory phase play a major role in the optimization of some critical subsystems but it didn't cover the entire telescope. The CTA project office proposed a revision of the requirements for reliability that requested a specific commercial software tool: Reliasoft.

The software Reliasoft is used to run the Reliability and Maintenance Analysis.

The Reliasoft software has six applications: Weibull++, BlockSim, XFEA, RCM++, Lambda Predict and MPC (Fig. 4-2). Lambda Predict and BlockSim will also be used in this thesis.

- Lambda Predict: *ReliaSoft Lambda Predict facilitates reliability prediction analysis based on the major published standards, including MIL-HDBK-217F (MIL-217),* *Bellcore/Telcordia, FIDES, NSWC Mechanical and Siemens SN 29500. It offers a full set of supporting tools, including easy-to-use component library functionality, a reliability allocation utility, derating analysis and the ability to transfer and manage your data via flexible import/export or copy/paste with a complete array of calculated results, graphical charts and customizable reports* [118].

  - Some of the advantages of MIL-217 are: that it can be used in many types of industries, it has 14 environments, and it has a free handbook. However, it gives pessimistic results and it is not updated (recent technologies are not included).
  - Telcordia analyses are quick and easy but there is no free handbook available.
  - Fides takes into account the maturity of the component and the process but hundreds of audit questions need to be answered and the analysis is not easy nor fast.
  - Siemens has the most advanced calculation models for electromechanical components, it has components that are not included in other standards. However, the handbook is not free and there is only one environmental type.
  - NSWC is a mechanical standard that uses a series of models for various categories of mechanical components but the assumption of constant failure rate is not the best for the mechanical components.

The results with each standard will be different because they use different formulas/parameters [119].

Into Lambda Predict is possible to create a Bill of Materials (BOM) and it can be imported to an excel file.

- BlockSim: *ReliaSoft BlockSim provides a comprehensive platform for system reliability, availability, maintainability and related analyses that allows you to model the most complex systems and processes using reliability block diagrams (RBDs), fault tree analysis (FTA), or Markov diagrams. Using exact computations or discrete event simulation, BlockSim facilitates a wide variety of analyses for both repairable and non-repairable systems* [118].

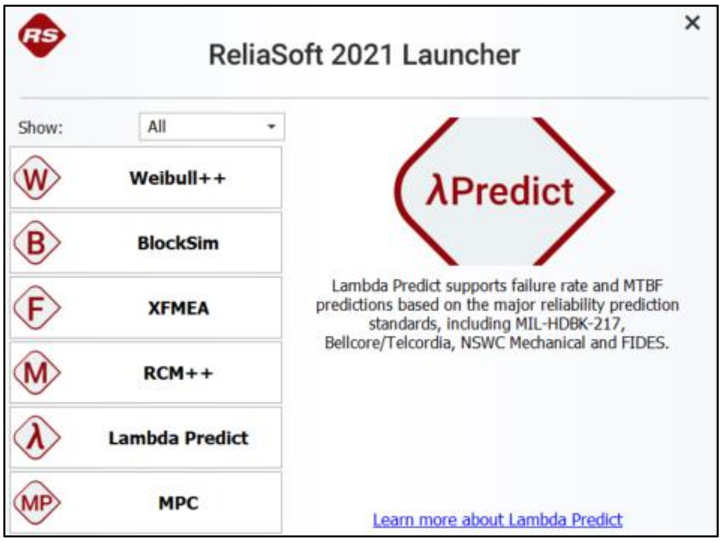


Fig. 4-2: Reliasoft applications

The first application in Reliasoft is the creation of the PBS of LST as a BOM in Lambda Predict. The current template that is foreseen for the corresponding documentation is described in ANNEX 2: PBS as BOM in Lambda predict template (Reliasoft)

4.3. Quality Management

The QUALITY is the degree to which a set of inherent characteristics of an object fulfils requirements [120].

The QUALITY PLAN is the specification of the procedures and associated resources to be applied when and by whom to a specific object [120].

It is clear that the elements of the telescope must be according to the specifications; however, there is a problem with the telescope LST1. The telescope LST1 is a prototype and some of the specifications were created during its design. It will be different from the newer telescopes LST2, LST3 and LST4 because they will be built after the good experience of LST1. The LST1 will lead the specifications of LST2, LST 3 and LST4.

With this statement, we can confirm that there was not a complete or standard quality management during the design of the LST1 because the technical specifications were not complete. The existing specifications considered the environment, the atmospherics events, the experiences with similar observatories (see point 2.4.2) and the own load of telescope. The design of the LST1 was, therefore, the first phase of the project.

The second phase of the project is the construction of the telescope. In this case, the quality control of the construction followed the design of the physical part of the project.

The third phase of the project is the commission phase. It includes the integration of the software with the hardware. During this phase, the faults that appear must be corrected until the telescope is usable by its end-user.

The first version of the LST Quality Plan [121] is from 2011. This plan collects the quality responsible and their roles and the regulations of quality in hardware and software.

Quality assurance guarantees that the processes comply with the requirements and specifications. In this case, we can confirm that the project meets its technical characteristics during its useful life. As we said before, the LST 2-4 have the specifications of LST1 but the LST1 is very recent (2018) and it is very early to confirm if the design of the new telescopes will be useful for 100% of their useful life.

If we compare a scientist project (Telescope LST1) with a commercial factory (e.g. factory of cars) the main difference is the repeatability. If the same product is made 100 times per day, the quality control is mechanic and known. However, on a scientific project where the product is made just once, having complete quality control is difficult, because there are no traceability or experience with the product and we are going to find the problems during the operation of the Telescope.

Quality control is not only a punctual activity, it needs to be done during the total life of the project. If the quality control is done, we can be sure that the telescope is in good condition to work and to prevent the problems as soon as possible.

Detected problems in LST1 will be resolved in next telescopes and they will be included in the new version of quality plan.

4.4. Safety

For working correctly in the Telescope LST1, local safety standards must be followed. The emergency procedure plan from ORM must be followed by users of Telescope LST1 too. This plan is coordinated by the IAC.

The coordination of business activities into the Telescope LST is done by an external company: Quiron Prevencion. This company has an OHS website platform where every company and every worker that is going to work into the Telescope LST1 must be correctly registered. Quiron Prevencion asks for documents from every company and worker according to the activity, according to the Local Regulations and Laws. If these documents are not approved by Quiron Prevencion, the company and the workers cannot enter into the LST.

The people from scientific institutions who are going to work in the LST project must follow the "Basic Safety Document" [28]. A checklist must be received by the person before starting the work into the telescope across the Quiron website. It is a document with basic safety rules and recommendations. The safety limits when there are adverse meteorological events are included here.

The people going to work in special places into the telescope as "experts" need to follow specific procedures:

- Procedure for work at the Mechanical Structure and Camera Access Tower [122].
- Procedure for work at the IT Container [123].
- Procedure for work at the Drive Container [124].
- Procedure for work at the Energy Container [125].
- Procedure for work with the Calibration Lasers (OARL and CalibBox) [126].
- Procedure for work with the Cherry Picker [127].

All documents are available at the safety point on the LST website. Sometimes, the workers need special training. e.g. work at height course.

The internal Emergency Protocols are included in the basic safety document and they are made according to the ORM emergency protocols. If there is an external emergency, it is coordinated by the IAC. e.g. the evacuation of the ORM during a wildfire.

Due to external companies need to work into the LST too, additional safety documents are available for them. These safety documents are related to the basic safety document and they are adapted to the external companies.

The risk evaluation of the LST site is done by an external and expert company, it is Quiron Prevención. They did an initial inspection of the site and after that, they do an annual inspection to check the safety on-site.

The security at the CTA North LST facilities is the document [128].

4.5. Operations

The operations of the LST telescope are not in the scope of this thesis. However, there is a relation between the operations, the safety and the weather which is very important for the useful life of the telescope. When there are adverse weather conditions, the operation of the telescope is limited for safety reasons.

The operational safety limits are [129]:

– **Wind** gusts must be below 60 km/h to unpark the telescope or open the camera shutter.

- **Mean wind speed must be below 50 km/h** to open the camera shutter.
- **Outside humidity must be below 90% and no rain** to open the camera shutter and to operate the calibration box.

4.6. Logistic procedure

Logistics has a wide scope, including procurement, supply, inventory, and everything that is related to the movement of people and/or goods. A significant part of this work remains pending to be defined. Here we focus on the shipment procedure, which has already been approved by LST Management.

The procedure to send a package to La Palma is defined in the CTA-LST – Guidelines for shipping packages to La Palma [130].

When a package is going to be sent to La Palma. The first step is to inform the lst-logistic group about the following data:

1. Shipment sender name
2. Sender Institution
3. Manufacturing Company or supplier
4. Reference official document: Please attach design/description documents of the shipment contents or a link to the bidding (if available) and datasheet (if applicable)
5. Description of the contents
6. Shipment Origin
7. Shipment Destination: ORM | CALP | Tenerife
8. Number of boxes/containers/pallets
9. Transport company
10. Economic value of the shipment
11. Dimensions and weight of the packages
12. Estimated shipping and arrival dates
13. Storage needs

The Telescope Manager includes this information in the logistic database. This database is very important to track the pieces and spares.

When the package arrives at La Palma and the material reception has been done by the LST Team, the Telescope Manager sends an email to the lst-logistic team with the material reception report of this shipment and the information. Documents and pictures are included in the database.

4.7. Maintenance

The first step for understanding the maintenance is to know the different types of maintenances:

- Preventive maintenance: activities in pre-determined intervals or according to prescribed criteria (e.g. manufacture recommendations) and intended to reduce the probability of failure or the performance degradation of the item. The preventive activities are scheduled [131].
- Corrective maintenance: activities carried out after a failure. The corrective maintenance intended to restore the item to a state in which it can perform its required function. [131] Corrective maintenance is the activity or repair necessary to correct the wear or malfunction of something during its normal operation. A necessary repair due to a failure caused by a third party or due to causes other than the operation for which

the equipment has been intended is not considered corrective maintenance, but rather a major repair.

Preventive maintenance is very clear for everybody, however, corrective maintenance has different interpretations and sometimes the difference between corrective maintenance and repair is subjective. According to different authors, the corrective maintenance activities are identified during the routine inspection or the preventive maintenance. Corrective maintenance is the activity or repair necessary to correct the wear or malfunction of something during its normal operation. A necessary repair due to a failure caused by a third party or due to causes other than the operation for which the equipment has been intended is not considered corrective maintenance, it is a major repair [132].

Once we have clear the definitions and the types of maintenance, the next step is to plan the maintenance. For planning the maintenance activities, we need to ask ourselves the following question:

Which is better, invest in exhaustive preventive maintenance or wait for something to fail (corrective maintenance) and spend less on preventive?

The current CTA maintenance requirements are [97]:

Table 17: Maintenance requirements

B-LST-0320 Telescope Preventive Maintenance (Mech + Opt +Aux)	The preventive maintenance of a single LST Telescope Structure on-site must require on average < 2 person hours / week
B-LST-0330 Telescope Corrective Maintenance (Mech + Opt + Aux)	The corrective maintenance of a single LST Telescope Structure on-site must require on average < 4 person hours / week
B-LST-1560 Camera Preventive Maintenance	The preventive maintenance of a single LST Camera on-site must require on average < 1 person hours / week.
B-LST-1565 Camera Corrective Maintenance	The corrective maintenance of a single LST Camera on-site must require on average < 2 person hours / week.

During the construction phase, a maintenance estimation was done and it was compared with the requirements (Table 17). The maintenance estimation is a detailed table with every preventive and corrective maintenance activity per subsystem. The final analysis gave that the preventive maintenance didn´t comply with the requirements (Table 18). The last update was in 2019 during the commissioning phase.

Table 18: Maintenance analysis estimation

Maintenance type	ACTIVITY TYPE		REQUIREMENT	
	Preventive	Corrective	Preventive	Corrective
PBS based Activities	5.6	1.9		
Documentation	0.3	0.0		
Mechanical System	1.3	0.2		
Optical System	1.8	1.2		
Camera	**1.2**	**0.4**	1	2
Auxiliary Systems	1.1	0.1		
Total Telescope Structure	**4.1**	**1.5**	2	4

Since 2019 the maintenance analysis has been done with the real numbers. In 2018 the analysis was not done because of the construction phase in October.

To realised the analyses in 2019 and 2020 the next information was needed:

- Activities schedule per year to know what activity was done in each moment
- Safety information to know the number of people that were working in each activity
- Emails from experts or working group coordinators to get the details of the activities before doing them and after that
- Maintenance reports for further more information

Compiling all information, a table was done with the information of the preventive and corrective maintenance activities, the subsystem, the number of days and the manpower.

The ANNEX 3: Analysis of maintenance activities in 2019 is the maintenance analysis of 2019. The summary of preventive and corrective maintenance activities per subsystem is in Table 19. If we compare these numbers with the maintenance requirements (Table 17), we can see that they do not comply with the requirements. 2019 was the first year of the commissioning phase; however, there were several corrective maintenance activities after starting the operations, maybe due to previous problems but they were identified when the commissioning started. About the preventive maintenance, we can see that the number of structures is far away from the requirements.

Table 19: Maintenance analysis in 2019

Pers/Hours total per subsystem						
2019	Mech	Optics	Camera	Aux	Common	Structure (Mech+Opt+Aux)
Preventive	7.85	2.15	2.08	3.08	3.77	13.08
Corrective	3.08	0.00	2.77	7.08	1.40	10.15

The ANNEX 4: Analysis of maintenance activities in 2020 is the maintenance analysis of 2020. 2020 was affected by the Covid-19 pandemic and during almost 2 months there were not activities on-site, only activities by remote with local staff and safety inspections twice per week also by local staff. However, the maintenance activities that were not done between March and May were done after the finalisation of the Spanish frontier lockdown. The summary of preventive and corrective maintenance activities per subsystem is in Table 20. We can see that the maintenance activities related to the camera comply with the CTA requirements. The corrective structure maintenance is close to the requirement (4.68 Vs 4) but the preventive structure maintenance is far away from the requirement again and the optic preventive maintenance was not done due to frontiers lockdown and problems for travelling.

Table 20: Maintenance analysis in 2020

Pers/Hours per week per subsystem						
2020	Mech	Optics	Camera	Aux	Common	Structure (Mech+Opt+Aux)
Preventive	4.30	0.00	0.31	1.99	6.27	6.29
Corrective	0.00	4.60	0.46	0.08	2.09	4.68

At this point, we can see that the requirements do not accord with the real number and we need to look for the problem. We can think that the requirements are very strict but it will be the last point to review so we are going to evaluate our procedure again.

The activities schedule is an excel table with the information per day, not per hour. It means that the real working time is not the number of days per 8 hours and sometimes we did not have the real working time in the rest of the information (emails or maintenance reports) to do a better analysis. The real working time can change to 8 hours because the expert teams when travel to La Palma try to do as many activities as possible and maybe they travel to do the preventive maintenance of the camera and finally they need to do the commissioning of another facility too. Another typical problem is adverse weather conditions, especially in winter. If the experts' team is in La Palma and there is a snowstorm, they cannot work outside and it affects the schedule but again, the activities schedule is not changed.

Our procedure had mistakes and we needed to improve the management of the maintenance. The improvement proposals were:

- Improve the activity schedule with more information. Separate the preventive maintenance and the corrective maintenance.
- Update the maintenance plan for LST to REGULATION OF MAINTENANCE ACTIVITIES FOR LST.

The development of a document with the “**regulations of maintenance activities**” is very useful to have orderly maintenance that can comply with the requirements. This document has been created as a chapter of this thesis [133]. It is valid during the commissioning and operating phases of the telescope LST1 and it can be applied to the next telescopes LST2, LST3 and LST4.

According to this document, there are 7 needed deliverables:

- Subsystem maintenance plans
- Global schedule of preventive maintenance activities
- List of subsystem spares and the global list of spares
- Daily record of the maintenance activities
- Maintenance activity report
- Maintenance biannual report

The **subsystem maintenance plans** (one per subsystem: mechanical system, the optical system, the camera, the auxiliary systems and the common systems) are a description of the regular inspections for preventive maintenance activities and the most common corrective maintenance activities. The tools and the de list of spares and materials needed will be included. The coordinator of each working group is the person responsible for this document.

The **global schedule of preventive maintenance activities** (ANNEX 5: Global schedule of preventive maintenance activities (at September 2021)) is a live document that needs to be uploaded periodically. With this schedule, we can have a global vision of the activities and plan the travels of the experts, the tools and the spares. The global schedule of preventive maintenance activities is done according to the designers’ requirements and the local standards (e.g. revision of fire extinguishers).

To do this schedule we need to consider the limitations of the maintenance activities:

- Maintenance activities cannot be done outside during the night.
- An expert cannot do several maintenance activities at the same time.

- If a special tool is needed for two activities, they cannot be done at the same time.
- Some activities need a safe area where other activities cannot be done. E.g: two teams cannot work in the same vertical plane at the same time.
- If there is adverse weather (see point 4.4)

The **list of subsystem spares** is a part of the subsystem maintenance plan. The QA/RAMS Manager is responsible for doing the global list of spares.

The **record of the maintenance activities** will be sent during or after the maintenance activities. Follow the schedule, plan and having feedback and a record of these activities is necessary. To prepare reports is long, for this reason in the Telescope LST1 we are using the tool: ELOG

The **maintenance biannual** report will be done twice a year with a summary of the maintenance activities during this period.

The improvement proposals started to be used in 2021. At the moment of the presentation of this thesis, some deliverables are not finished but every document is ongoing and the people involved in the maintenance are working for improvement.

The subsystem maintenance plans are ongoing, some of them are approved. As a complementary document to subsystem maintenance plans, CTA created tables (templates) to fill with the description of the maintenance type of every piece. These tables are completed in mechanical, optical, camera and auxiliary subsystems by experts of every subsystem.

Table 21 is a part of the maintenance table of the camera subsystem. Each line is the description of one piece of the camera. The category can be:

- LRU: A modular unit designed to be easily exchanged for a replacement part in a relatively short time by only opening and closing fasteners and connectors
- LLRU: The smallest faulty unit the maintenance personnel can identify and isolate at the first two levels of maintenance (FLCM, SLCM) within a given Mean Time to Repair (the smallest part of an item that can be replaced to provide an effective repair). Repairs of LLRU's will be undertaken in the specialized workshop.
- Replaceable but not LRU/LLRU

The class can be repairable or not repairable

Table 21: Maintenance table of the camera subsystem

PBS	SYSTEM	SUBSYSTEM	ASSEMBLY	DESCRIPTION	CATEGORY	CLASS	Manufacturer
8.3.1.1.2	CAM	Mechanics Structure	Camera Body	Module Holder: Backplane Spacer M4	LLRU	Non-Repairable	CIEMAT (Designer LST1), RAMEM/IAC (LST2-4)
8.3.1.1.2	CAM	Mechanics Structure	Camera Body	Module Holder: Backplane Spacer M6	LLRU	Non-Repairable	CIEMAT (Designer LST1), RAMEM/IAC (LST2-4)
8.3.1.1.2	CAM	Mechanics Structure	Camera Body	Module Holder: Screw M6 with Hole	LLRU	Non-Repairable	CIEMAT (Designer LST1), RAMEM/IAC (LST2-4)
8.3.1.1.2	CAM	Mechanics Structure	Camera Body	Module Holder: Plastic Rail	LLRU	Non-Repairable	Kitagawa
8.3.1.3.1	CAM	Mechanics Structure	Camera Enclosure	Camera skin: Lateral wall seal	LLRU	Non-Repairable	ESSENTRA
8.3.1.3.2	CAM	Mechanics Structure	Camera Enclosure	Back door: Seal	LLRU	Non-Repairable	TECAI
8.3.1.3.2	CAM	Mechanics Structure	Camera Enclosure	Back door: Hinge	LLRU	Non-Repairable	TECAI

PBS	SYSTEM	SUBSYSTEM	ASSEMBLY	DESCRIPTION	CATEGORY	CLASS	Manufacturer
8.3.1.3.2	CAM	Mechanics Structure	Camera Enclosure	Back door: Lock	LLRU	Non-Repairable	TECAI
8.3.1.3.3	CAM	Mechanics Structure	Camera Enclosure	External Patch Panel: Power Connector 32 amp	LLRU	Non-Repairable	AMIDATA
8.3.1.3.3	CAM	Mechanics Structure	Camera Enclosure	External Patch Panel: Power Connector 16 amp	LLRU	Non-Repairable	AMIDATA
8.3.1.3.3	CAM	Mechanics Structure	Camera Enclosure	External Patch Panel: Fiber Optic Single Mode connector	LLRU	Non-Repairable	CONEC
8.3.1.3.3	CAM	Mechanics Structure	Camera Enclosure	External Patch Panel: Fiber Optic Duplex Mode connector	LLRU	Non-Repairable	CONEC
8.3.1.3.3	CAM	Mechanics Structure	Camera Enclosure	External Patch Panel: Fiber Optic CAP	LLRU	Non-Repairable	CONEC

The list of subsystem maintenance spares is almost finished. Experts finished the first version of the tables [134][135][136][137], and the global list is still ongoing. The subsystem "others" does not have a spare´s list.

The first maintenance biannual report was done in June 2021 and it is an useful summary of maintenance activities during the period Jan- Jun 2021 [138].

ANNEX 6: Analysis of maintenance activities in 2021 (until 15th Aug) is the maintenance analysis of 2021 (until 15th Aug). The summary of preventive and corrective maintenance activities per subsystem is in Table 22. Again, the numbers do not comply with the requirements but they are very close and the year has not finished yet. Their numbers are by 32 weeks. The deliverable **record of the maintenance activities** (Fig. 4-5) is helping a lot for a more accurate analysis.

Table 22: Maintenance analysis in 2021

Pers/Hours per week per subsystem						
2021	Mech	Optics	Camera	Aux	Common	Structure (Mech+Opt+Aux)
Preventive	0.63	0.00	1.13	0.47	1.11	1.09
Corrective	0.13	3.13	2.50	0.81	2.98	4.06

Fig. 4-3 and Fig. 4-4 show the comparison of structural maintenance (P-h) and camera maintenance in 2019, 2020 and 2021 with the CTA maintenance requirements.

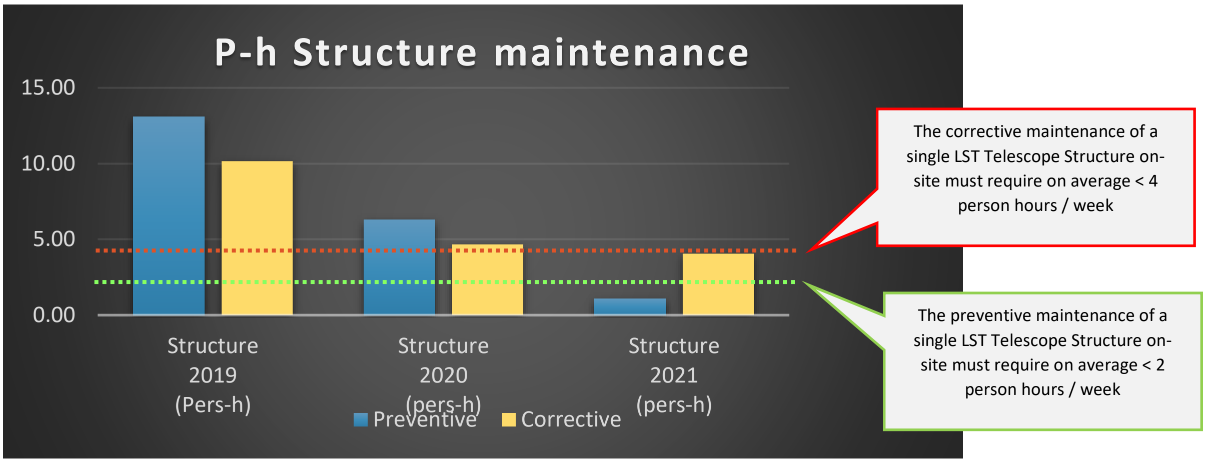


Fig. 4-3: Comparison of P-h by Structural maintenance in 2019, 2020 and 2021

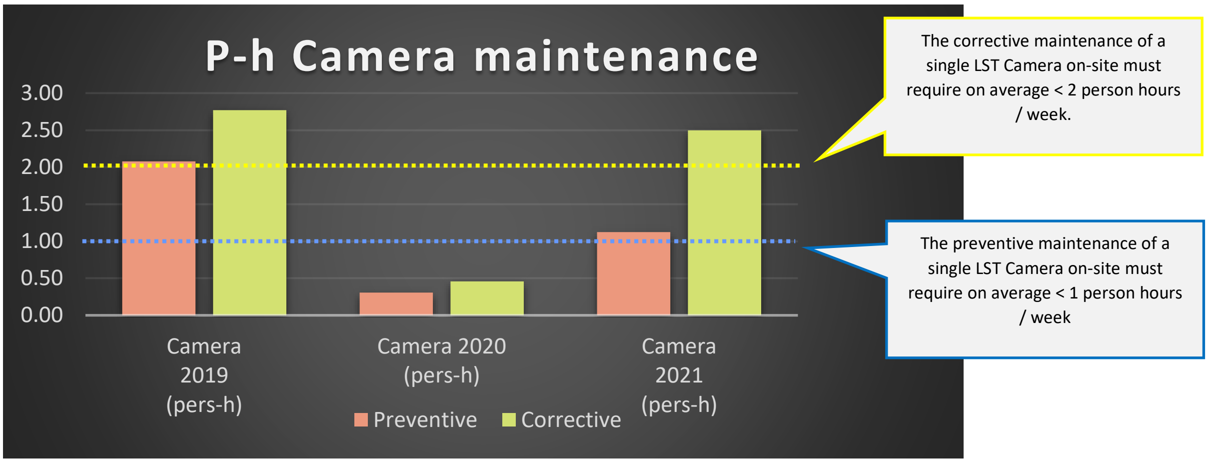


Fig. 4-4: Comparison of P-h by Camera maintenance in 2019, 2020 and 2021

When the maintenance activity is about to be done, the spares and tools are sent to the LST1 according to the “Logistic Procedure”, (see the section 4.6).

After finishing the maintenance activity, the waste must be managed according to the “Waste Management Plan” [6]. This procedure is done according to the Spanish law 22/2011 of 28th July of waste and contaminated grounds [139]. This law aims to regulate waste management by promoting measures that prevent its generation and mitigate the adverse impacts on human health and the environment, associated with its generation and management, improving efficiency in the use of resources. It also aims to regulate the legal regime of contaminated soils. They must be managed by an authorized waste manager.

Main Logbooks page | LST commissioning | Shift checklists | Safe state checklists | Maintenance activities | Old logbooks |
Maintenance activities

Maintenance activities, Page 1 of 2

New | Find | Select | Import | Config | Logout | Last day | Help

Full | Summary | Threaded

Goto page 1, 2 Next All

ID	Date	Author	Start date	End date	Working hours	Company/Institute	Person in charge	Manpower	Subsystem	Type of Maintenance	Spares	Reference documents	Status	
1	Fri Mar 19 12:37:44 2021	Patricia Marquez	17/03/2021	17/03/2021	5	Pedro Brito	Koji Noda	2 people	Auxiliary	Preventive		https://edms.cern.ch/document/2510524/1	Fixed	Description of activities: Pedro Brito did the preventive
2	Fri Mar 19 12:48:39 2021	Patricia Marquez	24/02/2021	24/02/2021	5	ABB	Koji Noda	1 PERSON (Antonio Molina)	Auxiliary	Corrective	1 MBC (FW)		Under Process	Description of activities: ABB
3	Fri Mar 19 12:56:13 2021	Patricia Marquez	23/02/2021	23/02/2021	4.5	ABB	Koji Noda	1 PERSON (Antonio Molina)	Auxiliary	Corrective	1 fan		Fixed	Description of activities: One fan of the UPS of the UC2 was
4	Fri Mar 19 13:02:16 2021	Patricia Marquez	29/09/2020	30/09/2020	37	ERGA	Koji Noda	3 people	Auxiliary	Preventive	2 filters and oil	https://edms.cern.ch/document/2424749/1	Fixed	Description of activities: Genset annual inspection
5	Tue Mar 23 16:34:44 2021	Patricia Marquez	23/03/2021	23/03/2021	2	Extinpalma	Koji Noda	1 person	Auxiliary	Preventive		https://edms.cern.ch/document/2512125/1	Fixed	Description of activities: Preventive maintenance of fire
6	Wed Mar 24 13:33:51 2021	Patricia Marquez	02/02/2021	02/02/2021	4	Pedro Brito	Koji Noda	1 person	Auxiliary	Corrective		https://edms.cern.ch/document/2493728/1	Fixed	Description of activities: Reparation
7	Wed Mar 24 13:35:32 2021	Patricia Marquez	22/01/2021	22/01/2021	2	Extinpalma	Koji Noda	1 person	Auxiliary	Preventive		https://edms.cern.ch/document/2471274/1	Fixed	Description of activities: Fire
8	Wed Mar 24 13:40:02 2021	Patricia Marquez	22/01/2021	22/01/2021	1	Tyco - Schneider	Daniela Hadasch	1 person	Common	Preventive		https://edms.cern.ch/document/2471277/1	Fixed	Description of activities: Preventive maintenance of fire
9	Wed Mar 24 13:42:26 2021	Patricia Marquez	12/01/2021	15/01/2021	32	Solclima - Schneider	Daniela Hadasch	2 people	Common	Corrective		https://edms.cern.ch/document/2512866/1	Fixed	Description of activities: inrow2 was repaired
10	Wed Mar 24 13:57:50 2021	Patricia Marquez	23/02/2021	23/02/2021	3	Extinpalma	Koji Noda	2 people	Auxiliary	Corrective	2 sirens		Fixed	Description of activities: 2 sirens in UC2 and UC3 were changed
11	Wed Mar 24 13:59:48 2021	Patricia Marquez	03/03/2021	03/03/2021	3	Opein	Paolo Calise	1 person	Common	Preventive		https://edms.cern.ch/document/2512899/1	Fixed	Description of activities: Cherry Picker preventive maintenance
12	Wed Mar 24 14:05:57 2021	Patricia Marquez	04/03/2021	04/03/2021	8	Solclima - Schneider	Daniela Hadasch	2 people	Common	Corrective	Compresor of inrow1		Fixed	Description of activities: To change the compresor of inrow1
13	Wed Mar 24 14:07:14 2021	Patricia Marquez	05/03/2021	05/03/2021	8	Solclima - Schneider	Daniela Hadasch	2 people	Common	Preventive			Fixed	Description of activities: Preventive maintenance of cooling
14	Wed Mar 24 14:10:03 2021	Patricia Marquez	04/03/2021	04/03/2021	1	APINSA	Patricia Marquez	1 person	Common	Preventive		https://edms.cern.ch/document/2499441/1	Fixed	Description of activities: Preventive maintenance of pest
16	Tue Apr 6 16:46:58 2021	Patricia Marquez	06/04/2021	06/04/2021	5.5	Solclima - Schneider	Daniela Hadasch	2 people	Common	Corrective		https://edms.cern.ch/document/2520101/1	Fixed	Description of activities: problem
17	Tue Apr 20 12:11:19 2021	Patricia Marquez	20/04/2021	20/04/2021	1.5	Tyco - Schneider	Daniela Hadasch	1	Common	Preventive		https://edms.cern.ch/document/2564366/1	Fixed	Description of activities: Fire
18	Sat Apr 24 12:11:52 2021	Luis Angel Tejedor	15/12/2020	02/02/2021	40	UCM	Luis Angel Tejedor	Luis Ángel Tejedor and Alejandro Pérez	Camera	Corrective			Fixed	Description of activities: Firmware update and tests.
19	Sat Apr 24 12:20:05 2021	Luis Angel Tejedor	25/06/2020	25/06/2020	3	UCM and IAC	Luis Angel Tejedor	Thomas Schweizer, Patricia Márquez and Luis Angel Tejedor	Camera	Corrective			Fixed	Description of activities: Firmware update of UCTS. New firmware

Fig. 4-5: ELOG: record of maintenance activities

4.8. Optimal quantity of spare stock

The LST management has approved the regulation of maintenance activities proposed by the author of this thesis [133]. This document describes the main actors of the spare logistics, which led to the first list of spares for every LST subsystem. However, the detail procedures of the spare management are still pending to be defined. This section describes a proposal to organize the spare stock.

According to the Colling Dictionary, *you use **spare** to describe something that is the same as things that you are already using, but that you do not need yet and are keeping ready in case another one is needed.*

According to the RAE (Real Academia Española), the **stock** is the quantity of a commodity that we have in storage.

The spares are some of the commodities that there are in the storage, then, we will talk about the stock of spares.

The need of having a stock of spares is because if we need to replace a piece and this activity is not planned before (incident or not planned corrective maintenance), we need to reduce as much as possible the time lost during this activity. If the spare is in the storage, the lost time will be the needed time for changing the piece; however, if the spare is not in the storage, we will need to ask for it and wait to receive the piece before planning the installation. Some spares are not critical and we can operate without this piece but that is not always possible. For this reason, having an optimal quantity of spares is very important.

Having a stock of commodities in the storage is not for free, there are costs that we need to consider [140]:

- Maintenance costs
  - Cost of warehouse
  - Cost of maintenance and personnel
  - Cost of expiration
  - Vandalism cost
  - Cost of insurances and security
- Cost of out-of-stock
  - Cost if we need to stop the operation

There are several procedures to guarantee an optimal quantity of stock.

4.8.1. Methods to have an optimal quantity of stock

1. **ABC´s analysis** [140][141]
   The ABC analysis increases the efficiency because concentrate resources in the areas where they are requested the most, makes them available faster. This analysis follows the Pareto rule.
   - Articles A: The most important products (more used and more urgent products). Few products. Most expensive products. Careful control is required
   - Articles B: Regular important products. Moderate control is required.
   - Articles C: Less important products. A minimum control is required.

   When each product of our stock is classified as A, B or C we can know how to manage the products; however, classify the products is not trivial.

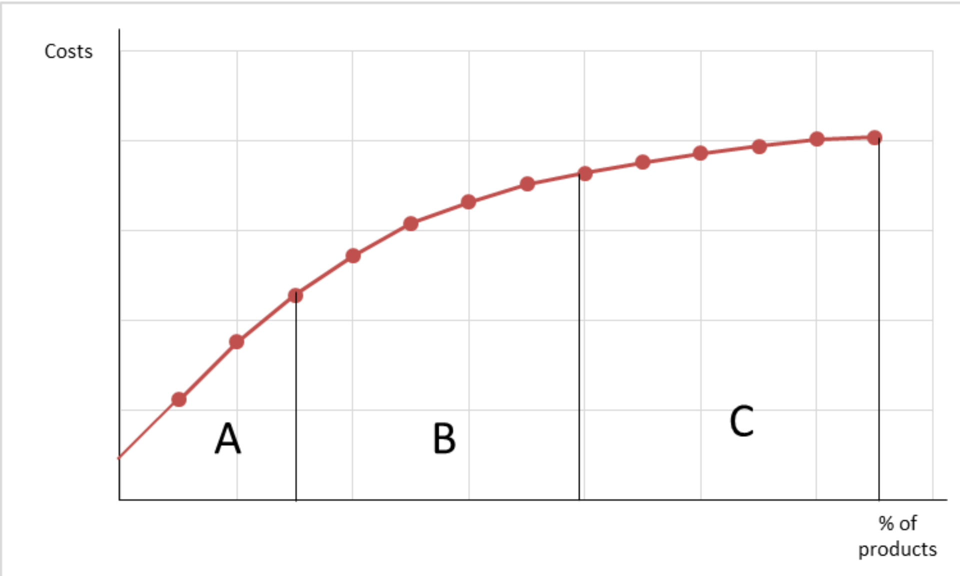


Fig. 4-6: ABC´s analysis

2. **Order point method (continuous review)** [140] [141] [142]

   In this method, we need to fix the minimum stock of the commodities that we need to have. When they arrive at this point (order point), we need to order the products (lot). These parameters (order point, lot) are fixed to minimize costs. In this case, there could be a stock out (point 6 of Fig. 4-7) because the demand for products is bigger than the ordered lot (Q). The Order point must be according to the number of items that we have in the warehouse at the moment of the order point.

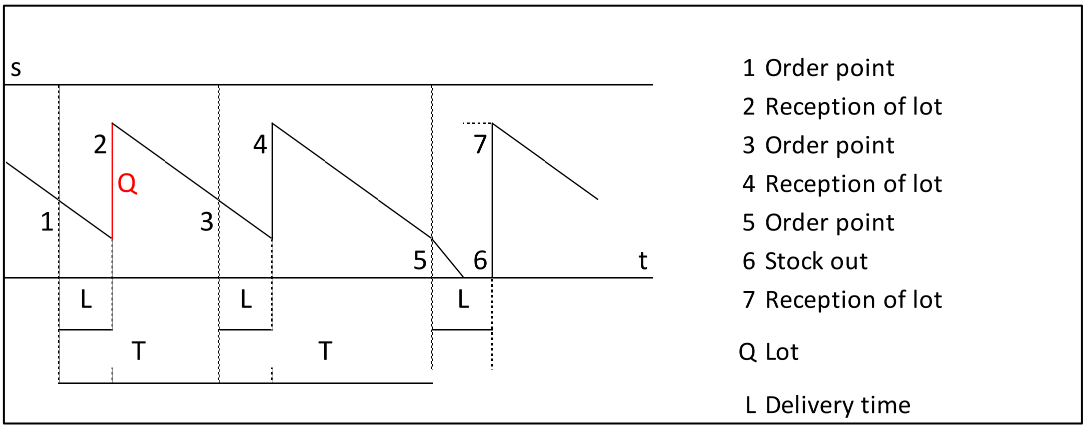


Fig. 4-7: Order point method

3. **Periodic provisioning method (periodic review)** [140] [141] [142]
   In periodic points, the stocks are checked and a lot is asked. The lot is different depending on the setpoint quantity, coverage, and available stocks. In this case, there could be a stock out (point 6 of Fig. 4-8) because the demand for products is bigger than the ordered lot (Q).

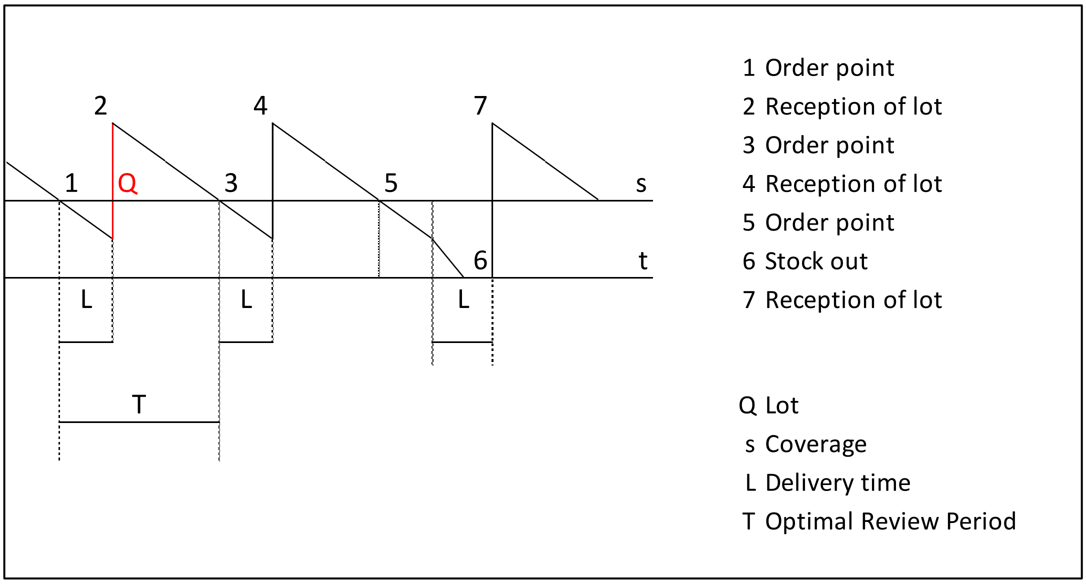


Fig. 4-8: Periodic provisioning method

The calculation of Optimal Review Period (T) is [140] [143]:

$$T^* = \sqrt{\frac{2 \cdot CL \cdot H}{h \cdot d}}$$

Equation 1: Optimal Review Period

- CL: Launch Cost. Cost for doing an order
- H: Planning horizon
- h: Cost of storing a unit of a product during the planning horizon.
- d: Demand during a Forecasted Period

4. Material requirements planning (MRPI) [142] [144]

This method is based on the previous methods but here the manufacture time is considered too.

It is a production, planning, inventory and scheduling control system used to manage manufacturing processes. To use this method is needed a software because the calculation has many variables (what, how many, when).

The system MRP has 3 parallel objectives:

- Product forecast: Ensure the raw materials for production
- Stocks: Maintain the lowest possible material and product levels instore
- Production plan: Plan manufacturing activities, delivery schedules and purchasing activities

To use the MRP method, mainly three inputs are needed: the master production schedule (MPS), the product structure records or bill of material records (BOM) and the inventory status records.

With the MPS and the BOM, the MRP will determine the gross component requirements. It will be reduced by the available inventory. See Fig. 4-9.

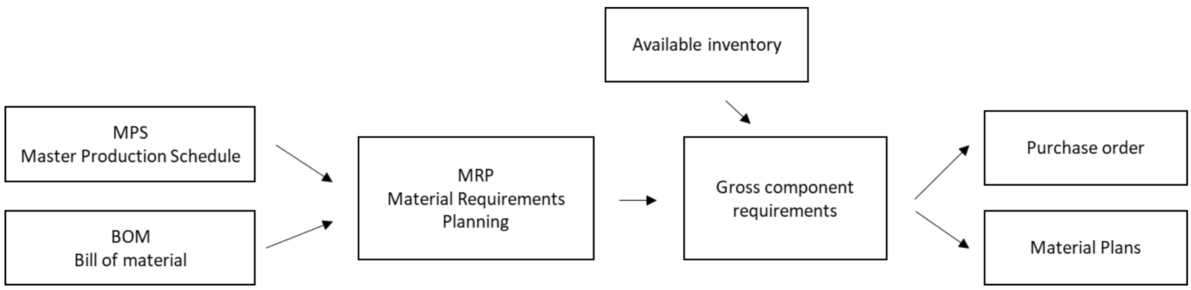


Fig. 4-9: MRP method sketch

5. Manufacturing resource planning (MRPII) [142] [144]

The MRPII is an extended version of MRPI with additional variables as an integrated manufacturing system, marketing and finance.

The benefits of the MRPII in comparison to MRPI are better control of inventories, improved scheduling, reduced capital for inventory.

To use this method, a computer is needed and a lot of information is needed too (Fig. 4-10).

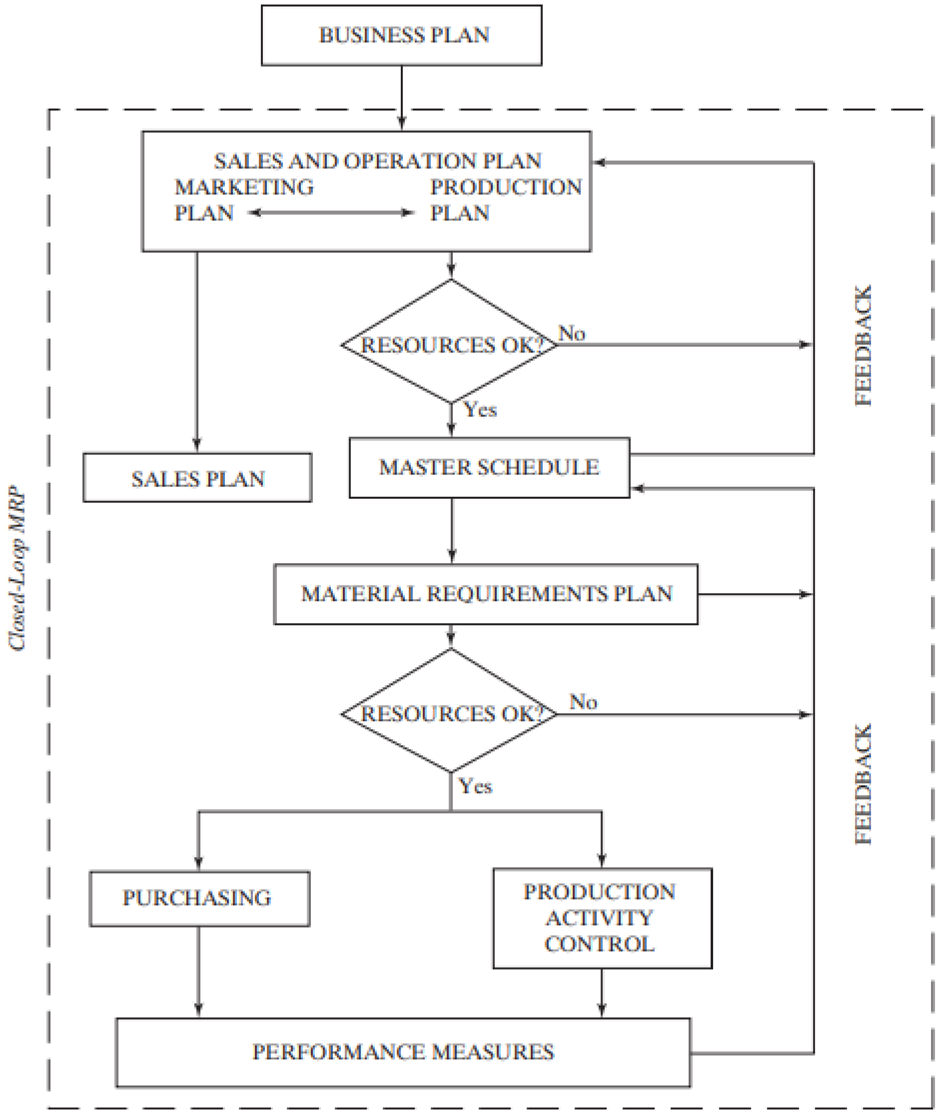


Fig. 4-10: MRP II [145]

6. **Just in Time (JIT)** [142]

The JIT method created by Toyota is a control procedure for materials, stocks and activities that tries to minimize the loss of money due to waste and maximize the production of the workers. According to Toyota, the waste can be produced by:

- Overproduction
- Loss of time
- Transports
- Bad procedures
- Stocks. According to Toyota, it is the main waste
- Unproductive movements
- Defective products

The objective of this method is to make only the needed products, in the quantity needed, at the needed moment and with the best quality. This is the ideal goal but it is never achieved, although it must be pursued continuously.

This method is mainly used in factories.

4.8.2. Analysis of the optimal method for the Telescope LST

In the previous point, we did a review of several methods to have an optimal quantity of stocks, but we must ask ourselves the following question:

Which is the best method for the Telescope LST?

We know the real problems of the telescope; for this reason, we are going to analyse the previous methods for the telescope's case.

The **ABC´s analysis** could be good for a good warehouse. The first trouble is to classify the elements of the telescope in A, B or C. The Telescope LST is a complex system for this reason we are going to use a general concept with some examples, a total classification will not be included in this thesis

- Articles A Items without which the own telescope may be at risk or may be a risk for humans and the environment. E.g if there is a power cut during the operation of the telescope, the diesel tank of the generator is empty and the telescope cannot arrive at the parking position. The diesel of the diesel generator is an article type A.
- Articles B: Items without which the telescope cannot operate at 100%. E.g if the shutter of the camera is damaged and it cannot be opened. The shutter is an article type B because some operations of the telescope can be done, however, it cannot be used to 100%
- Articles C: Items without which the telescope can operate. E.g The ladder of the camera access tower is broken. The telescope can be used during the reparation of the ladder.

According to this analysis, we must have spares of articles A always, articles B are recommended and articles C are not needed. Of course, if articles B and C are not an extra cost we can have them, however in the case of the LST it does not apply. The warehouse is limited and to have not-important products is an extra cost.

For using the **Order point method**, we need to have the next information of the telescope.

- TS: Quantity of commodities or bill of materials that we have in the warehouse. The installed products are not included in this list.
- SS: Minimum stock of commodities that we need to have in the warehouse. It can be zero or another number.
- Q: Lot. Quantity of products that we are going to ask for in each order point.
- DT: Delivery time (days).
- O: Order point: it is made according to the number of items that we have in the warehouse at the moment of the order point.

$$O = SS + d * DT$$

Equation 2

  - d = Medium demand per day = D/365 (uds/day)
  - D = Annual demand
  - DT = delivery time

Having these numbers is a long work but once you have them, they will be very helpful.

The TS can be given by an inventory of the current warehouse.

The SS is a % and it is related to the demand. The problem with the telescope is that we can know the demand for products that are used during the planned corrective maintenance activities. However, we cannot know the demand for the products that will be needed after a not planned activity. The warehouse in the LST is limited, for this reason, we cannot have the same SS for everything.

The Telescope LST is a prototype and it is the first one in the world. With time, we will have the D of the spares but knowing it is difficult because the telescope started the commissioning in 2018. We can calculate the D of products from the first light until now, but the demand will need to be updated every year.

After my experience with the logistic, I can consider that the DT has 2 main variables, the shipment time of the product from the origin to La Palma and the manufacture time of the product before starting the travel to La Palma. In Table 23, we can see an average estimation of delivery time according to the experience during the construction and commissioning phase of Telescope LST1.

- Shipment time. The estimation is per week according to the experience in La Palma
- Time of fabrication. The time of fabrication is the time since we ask for the product until it is sent. If the product is in stock, the delivery time will be 0 weeks. It depends on the manufacture. If the product is sold in lots, the time of fabrication is per lot (not per unit).

Table 23: Delivery Time (DT)

Delivery time (DT)			Manufacture Time (weeks)					
			0	1	2	4	8	>8
Shipment time (Weeks)	La Palma	0	0	1	2	4	8	>8
	Canary Islands	1	1	2	3	5	9	>9
	Spain (mainland)	2	2	3	4	6	10	>10
	EU	4	4	5	6	8	12	>12
	No EU	8	8	9	10	12	16	>16
	Special cases	>8	>8	>9	>10	>12	>16	>>16

Zero
Acceptable
Mediun
Too much time

In conclusion, this method has few variables and that we could use. The main problem is that the telescope is a prototype and we do not have enough historical information for some parameters as the “demand” but it is a part of the prototype, to know and to get more information about the telescope with the time. Another problem with this method is that it does not consider the costs of managing the products.

The **periodic provisioning method** is similar to the previous system but the order point is periodic. At the moment of the order point, we will need to check the stock of the warehouse and the lot that we are going to ask for. Getting the information for this method is easier than for the other one.

The **MRPI** can be considered as the next level of order point method and periodic provisioning method. The MRPI considers the manufacture time. The Telescope LST is a scientist installation and when we need to order a new product, the manufacture time can be considered into the delivery time (see Table 23). The subsystems of the telescope, e.g. the camera, have a lot of components and, usually, a completely new camera will not be ordered, a piece of the camera will be. For this reason, we do not need to consider the “manufacture time of the camera”.

For using the MRPI we need to do a Master Production Schedule [146] and it can make sense in a factory but not in an installation because the Telescope does not produce pieces, the telescope is the last user of them. With this in mind, we can think that the MRPI requires too much development to be used in the Telescope LST or other scientist installation.

The **MRPII** is more extended than the MRPI and it considers the costs and has better control of the inventories but, again, it does not make much sense since we are the last link of the chain, the client during the commissioning phase.

In the **Just in Time (JIT)** method we have the same problem as with the MRPI and MRPII. Of course, it is the ideal procedure to control the products but the Telescope LST and in general, the scientist installations are not factories; for this reason, the JIT is not an option, especially because to use the JIT method an extra effort is needed and, in this case, it does not make sense.

In conclusion, in the Telescope LST and, in general, in a Scientist installation, warehouses are needed and managing them properly during the operation and maintenance activities is enough. For this reason, we could apply the first three methods.

4.8.3.Application of the optimal methods for the Telescope LST

After the discussion of the methods that we can apply to the Telescope LST, we are going to explain the conclusions. However, we saw before that the installation of the Telescope LST is very special and to apply to 100% a method is not the solution. For this reason, we are going to ask ourselves the following questions about each product to know if we need to have spares of a product in the warehouse or not. We are going to create a quantitative method of points (see Table 24).

Table 24: Questions of quantitative method

QUESTION	SCORE
Q1. How critical is this product?	Q1
Articles A or most critical: Items without which the own telescope may be at risk or may be a risk for humans or the environment. If we cannot have these articles in the warehouse, we need to be sure that they are available always with a delivery time of zero.	90
Articles B or medium criticality: Items without which the telescope cannot operate at 100%.	50
Articles C or less critical: Items without which the telescope can operate.	0
Q2. What is the delivery time? *See Table 23*	Q2
Zero	0
Acceptable	5
Mediun	10
Too much time	15
Q3. Has the spare an expiration time?	Q3
Yes	0
Not	5
Q4. Which is the storage requirement?	Q4
Much space (>1 container)	0
Medium space (1 container)	5
Little space (<1 container)	10
Q5. Is it a dangerous material? (chemical product, inflammable)	Q5
Yes	0
No	5
Q6. What is the cost of the product?	Q6
High purchase cost (>1000€)	5
Low purchase cost (≤1000€)	0

$$TQ = Q1 + Q2 + Q3 + Q4 + Q5 + Q6$$

Equation 3: Summation of quantitative method

Table 25: Range of TQ

TQ > 100	Spare
100 ≥ TQ > 50	Check if the spare is needed
TQ ≤ 50	No Spare

To use this method, we need to ask ourselves the six questions by each product.

If TQ is more than 100 score, spares of this product will be needed. It is clear that the first question, about how critical the product is, is the most decisive one because is if there is a product type A and it is not available in La Palma, we will need to have a spare of it.

If TQ is between 50 and 100, we will need to study if the spares are needed or not. If the manufacturing cost is high and the delivery time is high but does not require too much space in the warehouse, having spares can be useful. The manufacturing cost is another important point, if the fabrication of an item is more expensive than the fabrication of 10, will be better to have spares in the store because to buy only one item will have a similar cost as the 10 items.

If TQ is less or equal to 50, have spares is not needed.

With this method, we will adjust the number of spares from the spare list. If the TQ is more than 100 score, it will be needed to add one unit more.

Examples:

Table 26: Examples of quantitative method

		Diesel (diesel generator)	Steel tube (Mero)	Temporal camera cover	Fibre cable (arc)	Step of ladder	Mirror
Q1. How critical is this product?	**SCORE**						
Articles A	90	90		90	90		
Articles B	50		50				50
Articles C	0					0	
Q2. What is the delivery time?							
Zero	0	0		0		0	
Acceptable	5						
Mediun	10		10		10		
Too much time	15						15
Q3. Is there an expiration time?							
Yes	0	0	0				
Not	5			5	5	5	5
Q4. Which is the storage requirement?							
Much space (>1 container)	0						
Medium space (1 container)	5						
Few space (<1 container)	10	10	10	10	10	10	10
Q5. Is it a dangerous material? (chemical product, inflammable)							
Yes	0	0					
No	5		5	5	5	5	5
Q6. What is the cost of the product?							
High purchase cost (>1000€)	5				5		5
Low purchase cost (≤1000€)	0	0	0	0		0	
SCORE	**TOTAL**	**100**	**75**	**110**	**125**	**20**	**90**
Quantity of spares		n.a.	0	0	No info	No info	16
Adjusted quantity of spares		**n.a.**	**0**	**1**	**≥1**	**-**	**16**

Table 26 shows six examples of pieces or materials of LST1 applying the quantitative method.

Two products should have spares on site (temporal camera cover and fibre cable). The temporal cover could be bought in La Palma but if there is an incident during a holiday day or weekend, it is not possible; as a consequence, we will need to have at least one spare. If a fibre cable (tension cables & anchoring devices for CSS) breaks, it should be changed as soon as possible and during this time, the telescope cannot be moved. The temporal camera cover is not on the list of spares because it is not a piece of the telescope. The quantity of spares of fibre cable is not defined in the spares list but at least, we would need one spare.

The diesel of diesel generator has 100 points. Storage diesel could be very useful but a special tank is needed and the LST1 does not have big tanks for diesel. If there is a power cut during the operation of LST1, there are protocols for using the minimum of electricity in the telescope and for moving the telescope to a parking position. The diesel generator has a diesel tank of 1000L and when it is to 40% of its capacity, a diesel truck refills the diesel tank (the problem is if we need to refill the diesel tank during a holiday day or weekend).

If a mirror is damaged, it can be removed and the telescope can still operate. Having spares is recommended because the mirrors come from Japan and they are delicate. There are spares of mirrors in La Palma. Damaging a steel tube is very difficult and the operation would not be affected.

There are a lot of ladders and a step in the LST1 that could be damaged (e.g. ice). However it does not affect the operation of the telescope; then, have spares is not needed.

To organise the warehouse, we are going to use **ABC´s analysis.** Articles A will be in a place of easy and fast access, articles B will be in a medium access site, and articles C (if any) in the least comfortable and visible places. There are, currently, two warehouses for LST1, the first one is a container on-site and the second one is a big storage building at sea level. The storage building is not too far (1 hour by car) however the transport of high pieces has limitations because if a truck or crane are needed, it cannot be available during a weekend or on a holiday day.

Once we know the products which we need to have spares of, the **periodic provisioning method** would be the most convenient to replenish the products in the warehouse because we would need to check the inventory and order the spares with less frequency than in other methods.

We are going to apply Equation 1 to previous spares (Table 26) to calculate T* in Table 27, Table 28, Table 29, Table 30, Table 31 and Table 32. It must be pointed out that in the case of steel tubes (Table 28) is a rough example since LST´s have a number of tubes of many different types. Therefore, it should be necessary to consider that having a single spare for every tube is not feasible because the cost is high and most of the tubes would remain unused after the lifetime of the telescope. Like the example of the tubes LST has a number of other critical but unique parts that would not need spares.

Table 27: Application of Equation 1 to Diesel

Diesel (600L)					
CL	900.00 €	H	1	T*	
h	?	d	?		
Remarks					
The diesel is used in the emergency diesel generator. The diesel tank of the diesel generator has a capacity of 1000L and when it is at 40% (400L) the diesel is refilled. 900€ is the cost of refill 600L of diesel at ORM H can be 1 year. h: There is no storage of diesel on-site, then, this value does not apply. d: There is no demand during a forecast period, if the diesel generator is used, the diesel tank is refilled when it is at 40% but there is not a fixed demand, it depends on the number of hours in which the diesel generator is used. T*: we cannot calculate T*					

Table 28: Application of Equation 1 to Steel tube

Steel tube (Raw tube from epsilon 80 mm diameter)					
CL	25.00 €	H	1	T*	
h	42	d	0		
Remarks					

The steel tube (Raw tube from epsilon 80 mm diameter) is included in the spare list of MECH subsystems. According to the spare list, the cost of this tube is less than 25€ (CL), the delivery time is less than 4 weeks and the lifespan is more than 30 years.
CL: 25€ [134]
H: can be 1 year.
h: If we use the building storage building, the storage cost is (3500€*12)/1000 (12 months and 1000 pieces). It is an estimation because we do not know the storage cost of every piece in the building, we only know the total cost of the building.
d: If the lifespan of a steel tube is longer than the lifespan of the telescope (30 years) the demand will be 0
T*: we cannot calculate T*

Table 29: Application of Equation 1 to temporal cover

Temporal Cover (camera)					
CL	1,039.00 €	H	1	T*	
h	?	d	1		
Remarks					

The temporal cover is used to cover the camera if the shutter is damaged.
CL: 1,039.00 €. It was the cost of the last cover.
H: can be 1 year.
h: It is on-site and we do not know the storage cost.
d: 1 per year if the shutter is damaged.
T*: We cannot calculate T*

Table 30: Application of Equation 1 to fibre cable

Fibre cable					
CL	1,600.00 €	H	1	T*	
h	42	d	?		
Remarks					

The fibre cables (Tension Cables & Anchoring Devices for CSS) are included in the Mech subsystem spare list but there is no information about this item.
CL: 1,600€. It was the purchase cost.
H: can be 1 year.
h: The same as a steel tube
d: No info
T*: We cannot calculate T*

Table 31: Application of Equation 1 to Step of ladder

Step of ladder					
CL	200.00 €	H	1	T*	
h	0	d	1		
Remarks					
The score is very low, this spare is not needed. CL: 200€. It is the average cost of a step of ladder H: can be 1 year. h: We do not store this item d: 1 per year (experience in the last years) T*: We cannot calculate T*					

Table 32: Application of Equation 1 to Mirror

Mirror					
CL	5,000.00 €	H	1	T*	15.43
h	42	d	1		
Remarks					
The score is very low, this spare is not needed. CL: 5000€. It is the cost according to the Optic spare list [136]. H: can be 1 year. h: The same as a steel tube d: 1 per year (experience in the last years) T*: The optimal period to order spares is 15.43 years. According to Jama [97], the lifespan of mirrors is 15 years however according to the Optic spare list, the lifespan of mirrors is 10 years [136]. If there are 16 spares, at the moment of the order, there will be one mirror in the storage.					

The concept of periodic provisioning method is easy. Nevertheless, apply the equations is not possible in our case because:

- The demand is not fixed always, it can depend on incidents
- There is no storage for everything
- The cost of the storage building is known but it is the total cost. If we want to know the "h" we would need to have an inventory of storage buildings and to know the space of every item in the storage.
- The cost of storage on-site is not known but it is not free
- The spare lists are not complete and we do not know the demand for several spares.

4.9. Incidents

The incidents with the telescope are registered in a "wiki". The incidents per subsystem will be included in the next points. The analysis of these incidents is mandatory to do a good optimization of the life of the telescope.

The "ANNEX 7: Incidents and system failures table of LST1" is the list of incidents in LST1 since 2018. The second column describes the decisions taken by the LST Management. The last column of the table was added in order to clarify the influence of the environmental conditions on the risk magnitude. The LST1 has a Wiki where the incidents are recorded. In total, 34 incidents were recorded.

During the construction phase, there was one incident (#1). A machine was damaged and a new machine was needed to continue with the reparation. The old machine needed a new piece from the USA and the reparation took very long.

Per subsystem, the number of incidents is in Table 33

Table 33: Quantity of incidents per subsystem

	Incidents per subsystem:
Mech	9
Opt	4
Cam	4
Aux	4
Other	12

In most of the incidents, the operation of LST1 was not affected. The incidents that affected to operation (7 incidents) were related to the movement of the telescope or the safety. E.g: In incident #11, the water was detected during an inspection in the UC1 and everything worked properly, but the container was switched off for safety reasons until the water was removed. Incidents in mechanical subsystem and optical subsystem are the most important to the operation.

The LST1 has been stopped by incidents for 26 days. Only 8 days were because of bad weather but in several cases, the reason of the incident was not clear. The longest stops were incidents #11 and #13, in both cases, the technicians were not in La Palma and they needed to coordinate the travel from other places, which slows down the inspection/repair time.

Most of the incidents (19 of 34) are related to environmental conditions and adverse weather.

Fig. 4-11 is a graphic of incidents per subsystem. In red are the incidents produced by environmental conditions or bad weather. In green the incidents that are not caused by them and in purple are the incidents which origin is not identify.

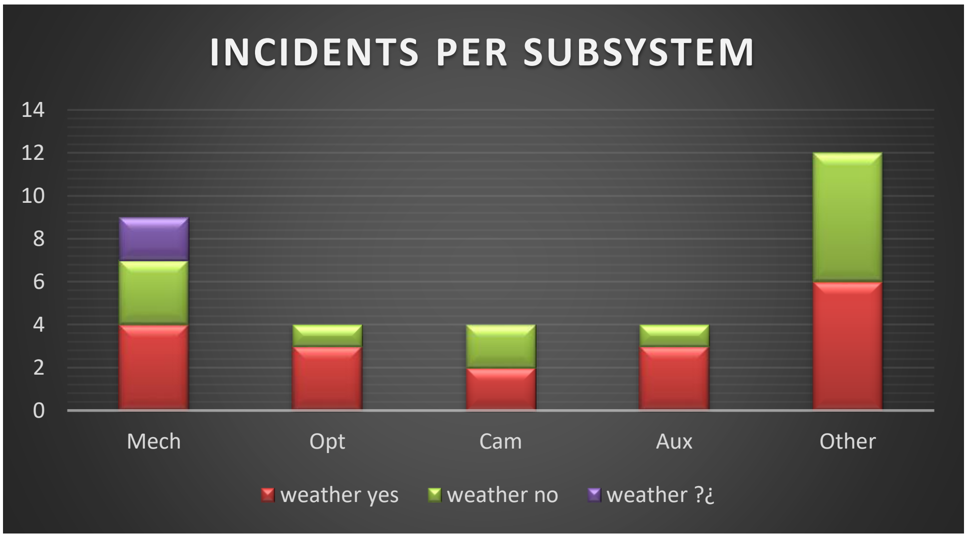


Fig. 4-11: Graphic of incidents per subsystem

4.10. Proposal for improvements to LST1 management

During the risk analyses (point 4.1) there is looked for risks of high severity that can affect the LST. Table 16 has suggested mitigation actions by risk according to severity and probability but if we want to optimize the mitigation actions, the proposal is **to use common mitigation measures for various risks**, such as "all-risk" insurance.

With the reliability analysis of LST, the most critical issues were identified, they align with the risk of ORM.

The lifespan of LST is 30 years and the lifespan of subsystems is shorter, however, the lifespan of concrete structure is longer, 50 years (according to local regulations) [66]. The subsystems with lifespans shorter than the one of the telescope are replaced after their lifespans for new, upgraded ones. In addition, if we want to have a real-life of 30 years, we will need to consider that it can be affected by the next:

- Obsolescence: four types of obsolescence [143] can affect the lifespan of the scientific facility:
    - Logistical: the pieces (materials, software or manufacturing) cannot be procured
    - Functional: the system or subsystem is still working but the requirements have changed; then, the system or subsystem is obsolete because the function, performance and reliability are different.
    - Technological: there are advances in components every day. If there is storage with spares it does not affect too much but if the spare needs to be bought to the manufacture, it cannot be available because the manufacture is making advanced components.
    - Functionality Improvement Dominated Obsolescence (FIDO): the manufactures must change the products to maintain the market competence with other similar manufacturers.

  The four types of obsolescence can affect only one part of the facility of several. If the obsolescence of a part of the facility conditions its lifespan, a valuation to change this part, need to be done.
- Catastrophic events: the scientist facilities are designed according to environmental specifications. These specifications are established according to the historical information of the place where the facility will be built. When there is an extraordinary environmental event, which is stronger than the specifications, the facility can suffer terrible consequences. The damage valuation after the event versus the cost of the reparation is what decides if the operation of the facility continues or not. A catastrophic event can happen at any moment.
- Lack of financial support for the maintenance: usually the scientific facilities are public projects and the financial support is linked to public budgets. The public budgets are approved yearly. When a scientific facility is going to be built, there is a compromise from the public authorities to operate and maintain the facility X years. However, if there are setbacks in the economy (e.g. economic crisis), the public budgets can be affected and that will affect the scientific projects. In the USA, Spain and other countries, founds for scientific progress have been cut in the last years [147] [148] but it is difficult to find references about that.
- Misuse of the instrument: during the operation phase, the operators of the scientific facilities must follow the manual operation of the facility. If the manual is not followed correctly, the facility can be damaged by the missuse of the instrument. In addition to the manual operation, the operators must have enough formation according to their activities.

Safety and security are primordial in the LST. There are safety and security procedures done by LST safety responsible and inspections and other documents from external and expert companies. Their safety documents are filled by everybody and if there is an incident, there is an investigation about the origin of the problem to prevent new similar incidents. Not everybody follows the safety and security rules, sometimes, people do not know what documents need to be read/follow. A general safety plan where all safety procedures and protocols are related should be done because it would be faster and easier to use.

The importance of good quality control is known. The Quality Control Plan has the minimum information needed for doing the quality control but it could improve with forms.

In point 4.7 we asked ourselves a question: **Which is better, invest in exhaustive preventive maintenance or wait for something to fail (corrective maintenance) and spend less on preventive?** Clearly, the maintenance estimation (Table 18) tends to be preventive, if it is done according to the specifications, designer's and manufacture's recommendations, the lifespan of the telescope will be longer. In addition, it is better to reduce the break of operation time as much as possible. For this reason, it is better to have programmed preventive maintenance than a longer brake during corrective maintenance. The break of preventive can be planned almost always, however, if a spare is needed during corrective maintenance and it is not in La Palma, the break can be longer than we planned and it will affect the operation and other activities. In conclusion, exhaustive preventive maintenance is better than waiting for something to fail and it is spent less on preventive maintenance.

Between 2020 and 2021, the coordination of maintenance activities improved but they need to improve more. The deliverables need to be finished (subsystem maintenance plans, spare list) and the preventive maintenance activities must be planned according to maintenance requirements (Table 17) which is far from reality. The LST1 is very new and LST2-4 are in the production phase. Non-compliance with maintenance requirements can be solved in two different ways:

- Preventive maintenance revision and reduction of manpower load.
- Confirmation of requirement unfeasibility and requirement revision.

Optimize the operation time is the goal and, as we saw before, having a short break for corrective maintenance or reparations is very important. Since 2019, the LST has been stopped by incidents 26 days and sometimes it was because the spare was not available. Other minor reparations were also delayed because the spare was not available, but they were not considered incidents and they are not in ANNEX 7: Incidents and system failures table of LST1.

At this point is clear that having a correct stock of spared is mandatory. In point 4.8.3 we created a method to know if a spare is needed or not and with the ABC´s analysis we can order the storage. If the needed spares are available in La Palma (LST´s storage or local shops) and a repair is needed, it can be fast; however, if the incident is during a holiday or weekend and the work needs to be coordinated with an external company, it is not possible. The only solution would be to have an LST team that could cover every activity of external companies, e.g. to have trucks, cranes and a diesel tank on site. The storage building (Fig. 4-12) at sea level is very useful, especially because there are limitations in the ORM, but again, transporting spares from sea level to ORM can be tricky during holidays, weekends or adverse weather because the road can be closed. Fig. 4-12 and Fig. 4-13 shows the distance from the storage building at sea level to ORM.

Fig. 4-12: Storage building at sea level

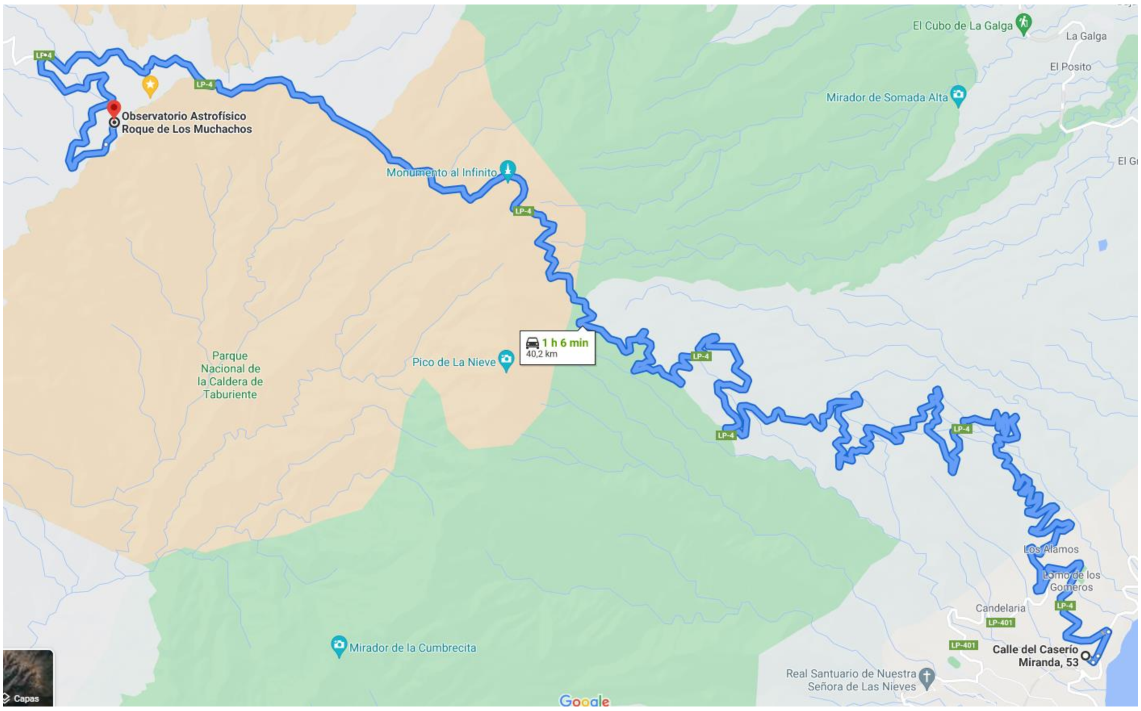


Fig. 4-13: Distance from Storage Building at sea level to ORM

Periodically, the spared will be replenished, but applying a standard method is difficult because we do not have a fixed demand, we do not know the storage costs and the data of spares from experts are not complete.

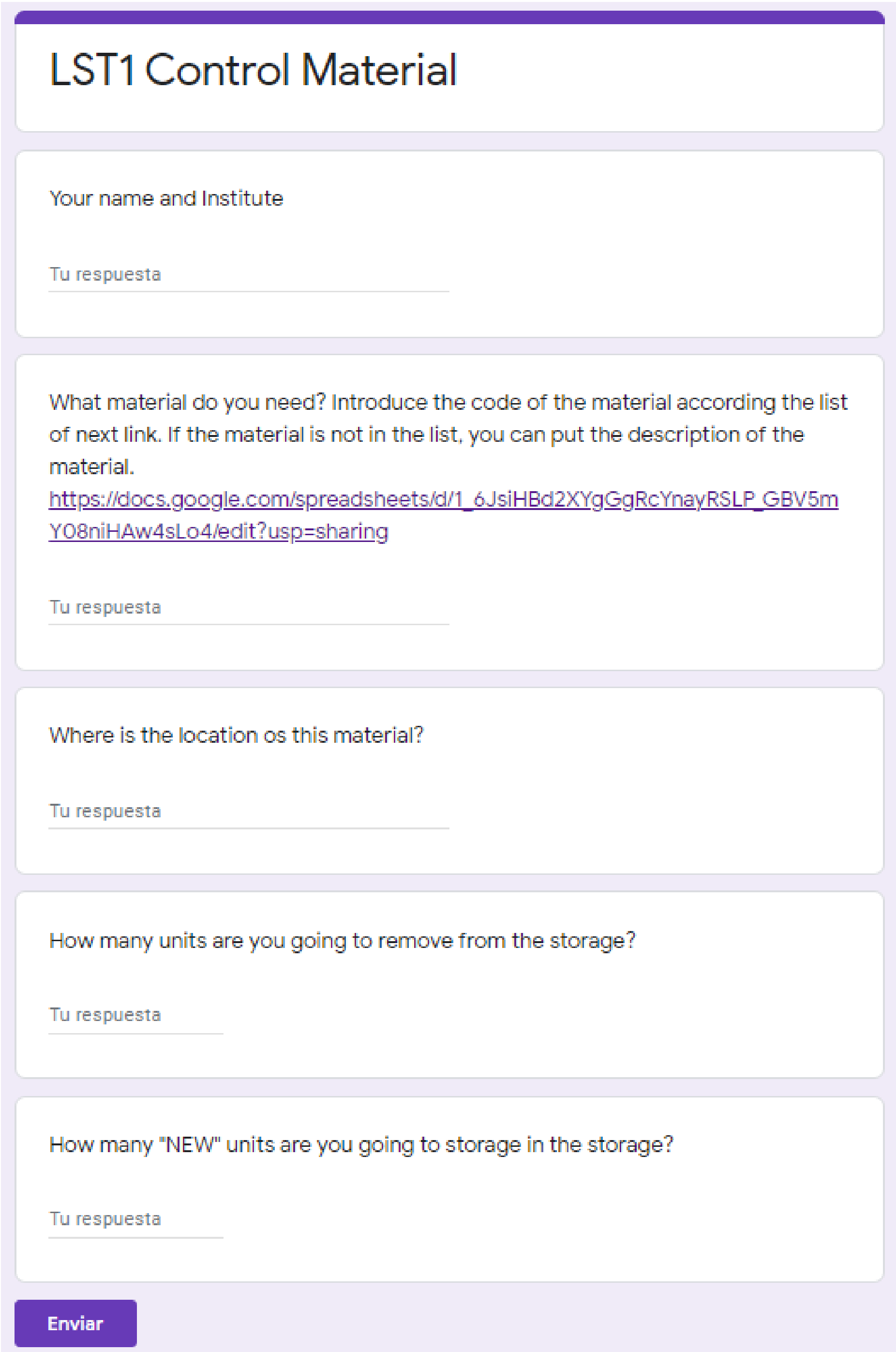
In conclusion, this periodic provisioning method can help the LST a lot but now we could apply only the theoretical concept. The proposal is:

1. When can we do the order? → Once a year
2. How many are we going to ask? → The adjusted quantity of spares lower the number of spares in the warehouse

Another proposal is that the LST must have an updated **inventory** of everything on-site/storage, including the spares to have control of its materials. Without an inventory, it is impossible to apply the previous proposals. An initial inventory has been done during the development of this thesis to help with ordering the storage but it is not being updated.

Another tool to help with the inventory is a google form (Fig. 4-14) to ask everybody who is going to use the spares about them. Forms will send the information to a google excel file and it will increase or decrease the quantities of spares. The ANNEX 8: Example of inventory form use is an example of how to use the google form if I would take one mouse from the storage.

The link to the google form is: https://forms.gle/xkMQa8FAEiYkWGSr9



LST1 Control Material

Your name and Institute

Tu respuesta

What material do you need? Introduce the code of the material according the list of next link. If the material is not in the list, you can put the description of the material.
https://docs.google.com/spreadsheets/d/1_6JsiHBd2XYgGgRcYnayRSLP_GBV5mY08niHAw4sLo4/edit?usp=sharing

Tu respuesta

Where is the location os this material?

Tu respuesta

How many units are you going to remove from the storage?

Tu respuesta

How many "NEW" units are you going to storage in the storage?

Tu respuesta

Enviar

Fig. 4-14: Inventory´s form

5. Conclusions

The aim and scope of this thesis were to contribute to the maximization of the useful life of LST of the CTA North project, and the main motivations have been explained in the first chapter. To address this objective, I checked first the environmental conditions affecting ORM and then I compiled all the available information on useful lifetime and reliability issues of other infrastructures built in the same observatory. This was followed by the study of the telescope hardware with special emphasis on the most critical parts, and finally management issues were analysed.

The agents that have a direct influence on the useful life of the telescopes are described below.

A. <u>Weather conditions</u>

They have a direct influence on the LST, especially because the LST is not protected inside of a building, although it has been found that the telescopes built inside buildings as WHT, INT or JKT also have downtime issues due to adverse weather conditions.

- Temperature: affects the thermal expansion of the installation and the laboral conditions of workers. A statistical analysis revealed that the hottest month is August and the coldest month is February.
- Wind: affects the deformation and torque of the structure and the safety of the workers. The windiest month is December and the least windy months are August and September.
- Dust concentration: An abrasive agent can damage the mirrors and other elements of LST and affect the working conditions. The month with the maximal dust concentration is August and the month with the minimal dust concentration is November.
- Storms and lightning strikes: wind, rain, and lightning strikes are a bad combination because water can enter everywhere if there is wind and lightning strikes can affect electronic devices. They affect the safety and working conditions of workers. The most humid month is November and the least humid month is July.
- Solar radiation: causes the fast degradation of some materials.

Besides the direct impact, these factors have in principle indirect effects too, which were analysed. CTA North is in La Palma and there are two ways to get there, by airplane or by ship. Both accesses are sensitive to adverse weather conditions and indeed the port or the airport suffered from closed and workers from outside of La Palma and material shipments will not arrive. Nevertheless, it is not a common problem because the weather conditions are usually optimal.

The weather conditions were considered during the initial reliability analysis of LST and some recommendations were included in the requirements for the design of the project. However, after the incidents on-site since 2018, the selection of materials need to be improved with:

- UV resistant material.
- IP 67: electrical and electronic devices that are installed outside must be IP 67

B. <u>Risks and catastrophic events</u>

The risks and catastrophic events that can affect the area of CTA North are:

- Flood and rains (very low risk).
- Seismic movements (low risk).
- Volcano eruption (very low risk).
- Associated with phenomena of adverse weather.

    - Snow (high risk).
    - Storms (very high risk)
    - Heat waves (low risk)
    - Calima (high risk)
- Gravitational movements (low risk)
- Wildfires (medium risk)
- Pandemic (low risk)

Calima events are very typical due to the geographic location close to the Sahara desert. Storms are also frequent during winter; however, the benefits of ORM location are more than the disadvantages as far as "catastrophic events" concerns. In addition, the requirements of LST considered storms and strong winds of 200km/h and having a stronger storm is very unlikely.

The worst consequences of snowstorms are the pieces of ice that may fall from the highest parts of the telescope. Ice pieces can damage the structures, mirrors, cars … and of course, they are a high risk for workers, who cannot enter the site until the area is secured. Ice pieces are a risk for all installations in ORM as NOT or MAGIC.

The pandemics have indirect consequences on the telescope because it affects to workers. During the Covid-19 pandemic, the restrictions affected the availability of workers on-site due to closed borders and the commissioning was affected in a large extent. Only essential works were done in LST for almost 2 months.

These events can not be avoided. However, we can take actions before the event occurs to minimise its consequences. The suggested mitigation actions to catastrophic events are:

- Having complete insurance that can cover different events. There is one on-site but it needs to be maintained every year
- Using specific protection equipment's (low temperatures, fire blankets). There is currently specific protection for local staff but not for non-local staff.
- Building a firewall around the ORM
- Improving the fire prevention systems. There are fire prevention and fire extinguisher systems on-site but they can be improved
    - Using automatic fire detectors in every container
    - Receiving the fire alarm when nobody is on-site
    - Training the staff for using fire extinguishers
    - Installing automatic fire extinguishers in the container with electrical and electronic devices
- Collaborating with emergency equipment. This point is addressed in coordination with IAC.

From an internal point of view of the telescope, the lifespan of 30 years can be affected too. For arriving at the age of 30 years (or more if it is possible) is mandatory to manage correctly the telescope. Currently, there is a good and correct management of LST but it can be improved too. The proposals are:

- Create only one safety document with all information
- Add forms to Quality Control Plan
- Continue with the new maintenance measures and complete the requirement feasibility analysis.
- Create and use an inventory.
- Apply the control of stock to help with corrective maintenance and repairs.

- Increase the use of commercial pieces to facilitate the provision of spares.

Ideally, it would be convenient to develop a similar maintenance concept for the whole CTAO at the northern site, and from this derive the equivalent maintenance concept for a single telescope. This could be a joint effort with the CTAO personnel.

In summary, to have a long real lifespan of the facilities, a constant balance between the cost of the installation and the benefits of the operation is needed. A proper spare and maintenance program, as well as formed operators, are needed to keep the facilities in good conditions.

The final proposal is to unify the technology of several telescopes so that spare parts can be shared and thus reduce waiting times.

As future research line, a proposal is to use the software Realiasoft for doing a Bill of Material of spares.

6. Scientific publications

The scientific publications which I have authored during this thesis and their status is listed below.

Risk assessment of environmental conditions affecting the useful lifespan of scientific installations at the Roque de los Muchachos observatory [149]

- **Authors:** Patricia Marquez, Oibar Martinez and Jose Miguel Miranda
- **Abstract:** The Roque de Los Muchachos Observatory (ORM) hosts a number of large scale instruments for astrophysics research, which will significantly increase during this decade. We analyse in this paper the environmental conditions affecting the useful lifespan of scientific instruments installed at ORM. After a detailed risk analysis, we conclude that the most feared events are connected to wild fires and storms.
- **Status:** under internal revision

Useful life of astrophysical scientific facilities [150]

- **Authors:** Patricia Marquez, Oibar Martinez and Jose Miguel Miranda
- **Abstract:** The scientific facilities are expensive facilities that cannot be used infinitely. In this paper we will be analysing the lifespan of past and current observatories and telescopes and the parameters that affect the lifespan will be identified. The useful life of these facilities will also be defined.
- **Status:** Accepted for publication in the World Journal of Engineering and Technology

Verification Protocols for the Lightning Protection of a Large Scale Scientific Instrument in Harsh Environments: A Case Study [151]

- **Authors:** Oibar Martinez, Silvia Ronda, Clara Oliver, Patricia Marquez, Jose Miguel Miranda.
- **Abstract:** This paper is devoted to the study of the most suitable protocols needed to verify the lightning protection and ground resistance quality in a large-scale scientific facility located on a site with high risk of lightning strikes. We illustrate this work by reviewing a case study: the largest telescopes of the Northern Hemisphere Cherenkov Telescope Array, CTA-N. This array hosts sensitive and high-speed optoelectronics instrumentation and sits on a clear, free from obstacle terrain at around 2400 m above sea level. The site offers a top-quality sky but also features challenging conditions for a lightning protection system: the terrain is volcanic and has electrical resistivities well above 1 kOhm·m. In addition, the environment often exhibits humidities well below 5%, and strong winds pose challenging conditions. On the other hand, the high complexity of a Cherenkov telescope structure does not allow a straightforward application of lightning protection standards. We describe here how the risk assessment of direct strike impacts was made and how contact voltages and ground system were both tested. Finite Element Simulation (COMSOL Multiphysics) has been used to estimate the current flowing through the parts of the earthing system designed for the telescopes in the case of a direct strike impact. This work is intended to provide assistance to scientists and managers involved in the construction of scientific installations, particularly those in charge of defining verifiable reliability and safety requirements for lightning protection.
- **Status:** Published in Journal of Power and Energy Engineering on June 2021. *This paper is part of Dr Oibar Martinez Thesis, which was published in publication list format.*

Applying Electromagnetic Field Analysis to Minimize the Earth Resistance on High Resistivity Soils [102]

- **Authors:** Silvia Ronda Peñacoba, Clara Oliver García, OIbar Martínez Vilchez, Patricia Márquez Paniagua, and Jose Miguel Miranda Pantoja
- **Abstract:** Different optimization strategies to reduce the earth resistance in a high resistivity soil are discussed in this work and illustrated with a practical example. Finite Element simulations reproducing real-world conditions in terms of structure design and soil profiles have been made to evaluate the improvements that should be adopted to minimize earth resistance. We analyze an example of an earthing system of an array of four identical telescopes installed on high resistivity (k¢m order) soils with two different behaviors. In the first one, current dissipation occurs in an uniform soil. In the second one, a terrain with four layers of different resistivities is considered. This situation corresponds to a real world case of an observatory constructed in a volcanic terrain. It was found that the best strategy in each case differs: extend horizontal electrodes as far as possible from the foundation in the first case and combine these electrodes with buried vertical electrodes that connect with deep high conductive layers in the second. The results are discussed in terms of the achieved improvements depending on the modifications introduced in the main structure.
- **Status:** Published in Progress In Electromagnetics Research M in September 2020. *This paper is part of Dr Oibar Martinez Thesis, which was published in publication list format.*

Finite Element Analysis and Experimental Characterization of Soil Electrical Resistivity at El Roque de los Muchachos Observatory [152]

- **Authors:** Ronda Silvia, Martinez Oibar, Oliver Clara, Marquez Patricia, Miranda Jose Miguel
- **Abstract:** This paper presents a study of the soil electrical resistivity of El Roque de los Muchachos Observatory, located in La Palma Island (Spain). This work is mainly motivated by the current plans of building an array of Cherenkov Telescopes (CTA) as well as other scientific installations, which demand low earth resistances for the operation of sensitive instruments, prevention of damage due to electrostatic discharges and protection against lightning strikes. Despite the top quality of the sky, the terrain is mostly filled of hard rocks and materials with high resistivity and hardness. No reliable data of resistivities could be found in available literature, therefore a dedicated resistivity survey onsite like the one presented here is essential to optimize the earth resistance of future installations. In this work, we present measurements done in six different locations of an area covering around 250 m × 275 m and centered on coordinates 28˚45'42.9"N, 17˚53'28.5"W. Low resistivity (<2 kΩm) layers have been found at specific places and depths. The resistivity at the sites has been simulated with COMSOL Multiphysics software using two different models: a simple single layer model and a three-layer model. Agreement with measurements within 10% discrepancies was obtained in all cases. The main contributions of this work are the presentation of reliable values of soil resistivity at ORM, together with the accurate simulation of the soil profiles.
- **Status:** Published in Journal of Electromagnetic Analysis and Applications in July 2020. *This paper is part of Dr Oibar Martinez Thesis, which was published in publication list format.*

Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre [153]

- **Authors:** A. Acharyya et al. including Patricia Marquez
- **Abstract:** We provide an updated assessment of the power of the Cherenkov Telescope Array (CTA) to search for thermally produced dark matter at the TeV scale, via the associated gamma-ray signal from pair-annihilating dark matter particles in the region around the Galactic centre. We find that CTA will open a new window of discovery potential, significantly extending the range of robustly testable models given a standard cuspy profile of the dark matter density distribution. Importantly, even for a cored profile, the projected sensitivity of CTA will be sufficient to probe various well-motivated models of thermally produced dark matter at the TeV scale. This is due to CTA's unprecedented sensitivity, angular and energy resolutions, and the planned observational strategy. The survey of the inner Galaxy will cover a much larger region than corresponding previous observational campaigns with imaging atmospheric Cherenkov telescopes. CTA will map with unprecedented precision the large-scale diffuse emission in high-energy gamma rays, constituting a background for dark matter searches for which we adopt state-of-the-art models based on current data. Throughout our analysis, we use up-to-date event reconstruction Monte Carlo tools developed by the CTA consortium, and pay special attention to quantifying the level of instrumental systematic uncertainties, as well as background template systematic errors, required to probe thermally produced dark matter at these energies.
- **Status:** Published in *Journal of Cosmology and Astroparticle Physics*, vol. 2021, Jan. 2021, doi: 10.1088/1475-7516/2021/01/057.

Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation [154]

- **Authors:** H. Abdalla et al. including Patricia Marquez
- **Abstract:** The Cherenkov Telescope Array (CTA), the new-generation ground-based observatory for γ-ray astronomy, provides unique capabilities to address significant open questions in astrophysics, cosmology, and fundamental physics. We study some of the salient areas of γ-ray cosmology that can be explored as part of the Key Science Projects of CTA, through simulated observations of active galactic nuclei (AGN) and of their relativistic jets. Observations of AGN with CTA will enable a measurement of γ-ray absorption on the extragalactic background light with a statistical uncertainty below 15% up to a redshift z=2 and to constrain or detect γ-ray halos up to intergalactic-magnetic-field strengths of at least 0.3pG. Extragalactic observations with CTA also show promising potential to probe physics beyond the Standard Model. The best limits on Lorentz invariance violation from γ-ray astronomy will be improved by a factor of at least two to three. CTA will also probe the parameter space in which axion-like particles could constitute a significant fraction, if not all, of dark matter. We conclude on the synergies between CTA and other upcoming facilities that will foster the growth of γ-ray cosmology.
- **Status:** *Journal of Cosmology and Astroparticle Physics*, vol. 2021, Feb. 2021, doi: 10.1088/1475-7516/2021/02/048.

Measuring the Earth Resistance in Large Scale Facilities: Practical Improvements to the Slope Method proposed in IEEE Std 81-2012

- **Authors:** Oibar Martínez, Silvia Ronda, Clara Oliver, Patricia Márquez y José Miguel Miranda.
- **Status:** in preparation

7. Oral presentations

Scientific presentations in workshops and international meetings/conferences.

- A Demonstration Experiment of Charge Accumulation in Human Body. Congress IEEE-URSI: "International Conference on Electromagnetics in Advanced Applications", Honolulu, USA. (Remote). 09/08/2021
- Applying the European Electromagnetic Compatibility Directive to Large Scientific Plants: A Case Study. Congress IEEE-URSI: "International Conference on Electromagnetics in Advanced Applications", Honolulu, USA. (Remote). 09/08/2021
- Finite Element Studies of Large Scale Earth Resistance Measurements. Congress IEEE-URSI: "International Conference on Electromagnetics in Advanced Applications", Honolulu, USA. (Remote). 09/08/2021
- Status and results of the prototype LST of CTA. 37th International Cosmic Ray Conference (ICRC2021). (Remote). 06/07/2021 [155]
- El Proyecto CTA y los LST. Workshop: Compatibilidad Electromagnética para Grandes Instalaciones Científicas (remote, Facultad de Ciencias Físicas -Universidad Complutense de Madrid (UCM). 12/07/21
- Telescope Manager Report. LST General Meeting (remote). 30/04/2021
- Maintenance. LST General Meeting (remote). 27/04/2021
- Regulations of Maintenance activities at LST. Maintenance coordination meeting NectarCam-LST (remote). 25/01/2021
- LST: Tecnología para cubrir las energías más bajas de rayos gamma. Workshop: Explorando el universo as extremo desde Canarias con CTA (remote). 10/12/2020
- Telescope Manager Report. LST General Meeting (remote). 04/11/2020
- Maintenance. LST General Meeting (remote). 02/11/2020
- Tracking current Maintenance needs. LST Meeting on maintenance (remote). 23/07/2020
- Telescope Manager Report. LST General Meeting (remote). 08/06/2020
- Maintenance. LST General Meeting (Marseille, France). 02/12/2019
- Onsite status and INFRA. LST General Meeting (Marseille, France). 02/12/2019
- Maintenance. LST General Meeting (Rijeka, Croatia). 09/07/2019
- Status Infrastructure and Institute Coordination. LST General Meeting (Rijeka, Croatia). 09/07/2019

In addition to previous workshops and international meetings/conferences, I have regularly attended the internal and weekly meetings of: LST1 Commissioning (since 2019), LST1 Executive Board (since 2018), LST1 System Engineering (since 2019) and CTA Project Team in charge of design and construction of LST2-4 (since 2019).

8. LST internal documents

Basic safety guidelines [28]

- **Authors:** Martin Will, Juan Cortina and Patricia Marquez

Work with the Cherry Picker

- **Authors:** Patricia Marquez, Martin Will, Paolo Calisse

LST1 Waste management procedure [6]

- **Authors:** Patricia Marquez

LST1 Environmental management plan

- **Authors:** Patricia Marquez

Regulation of maintenance activities for LST [133]

- **Authors:** Patricia Marquez and Jose Miguel Miranda

CTA-LST guideline for shipping packets to La Palma

- **Authors:** Otger Ballester and Patricia Marquez

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10. List of abbreviations

A

AC: Alternating current

ADC: Atmospheric dispersion corrector

AEMET: Agencia Española de Meteorología

ALFOSC: Alhambra Faint Object Spectrograph and Camera

ALS: Azimut Locking System

AMC: Active Mirror Control

AMOC: Atlantic Meridional Overturning Circulation

Aux: Auxiliary

B

BOM: Bill of material

C

CANGAROO: Collaboration between Australia and Nippon for a Gamma Ray Observatory in the Outback

CONACYT: Consejo Nacional de Ciencia y Tecnología de México

COST: European Cooperation in Science and Technology

CRT: Cosmic Ray Tracking

CTA: Cherenkov Telescope Array

D

degC: Degrees Celsius

E

ECS: Environmental Control System

EHE: Instrucción de hormigón Estructural

EST: European Solar Telescope

EU: European Union

F

FACT: First G-APD Cherenkov Telescope

FIES: FIbre-fed Echelle Spectrograph

FLWO: Fred Lawrence Whipple Observatory

FOV: field of view

FPI: Focal plane instrumentation

FRODOSpec: Fibre-fed RObotic Dual-beam Optical Spectrograph

G

GeV: Giga-Electron-Volt

GOTO: Optical Transient Observatory

GPS: Global Positioning System

GTC: Gran Telescopio de Canarias

H

H.E.S.S: High Energy Stereoscopic System

HEGRA: High Energy Gamma Ray Astronomy

HERMES: High Efficiency and Resolution Mercator Echelle Spectrograph

I

IAC: Instituto de Astrofísica de Canarias

IA-UNAM: Instituto de Astronomía de la Universidad Nacional Autónoma de México

IDS: Intermediate Dispersion Spectrograph

INAOE: Instituto Nacional De Astrofísica. Óptica y Electrónica

INE: Instituto Nacional de Estadística

INT: Isaac Newton Telescope

IO: O; Optical Wide Field Camera

IR: infrared

ISIS: Intermediate-dispersion Spectrograph and Imaging System

J

JIT: Just in Time

JKT: Jacoubus Kapteyn Telescope

K

kg: Kilograms

KV: extinction coefficient

KVA: kilovolt ampere

L

LIRIS: Long-slit Intermediate Resolution Infrared Spectrograph

LST: Large Size Telescope

LT: LIVERPOOL TELESCOPE

M

m.a.s.l: Meters Above Sea Level

MAGIC: Major Atmospheric Gamma Imaging Cherenkov

MAIA: Mercator Advanced Imager for Asteroseismology

mm: millimeters

MOPTOP: Multicolour OPTimised Optical Polarimeter

MOSCA: MOSaic Camera

MRPI: Material requirements planning

MRPII: Manufacturing resource planning

N

N: North

nm: Nanometre

NOT: Nordic Optical Telescope

NOTCam: Nordic Optical Telescope near-infrared Camera

NWO: Nederlandse Organisatie voor Wetenschappelijk Onderzoek

O

OPC-UA: Open Platform Communications Unified Architecture

ORM: Observatorio Roque de los Muchachos

OT: Observatorio del Teide

P

PLATECA: Plan Territorial de Protección Civil de la Comunidad Autónoma de Canarias

S

SERC: Science and Engineering Research Council

SPRAT: Spectrograph for the Rapid Acquisition of Transients

SST: Swedish Solar Telescope

T

TeV: Teraelectronvolt

TMT: Thirty meter telescope

TNG: Telescopio Nazionale Galileo

Tn: Tonnes

U

U.S.: United States

UCM: Universidad Complutense de Madrid

UNESCO: United Nations Educational Scientific and Cultural Organization

UPS: uninterruptible power supply

USA: United States America

UV: Ultraviolet

UVC: Untraviolet C

UVI: Ultraviolet Index

V

V: Volts

VERITAS: Very Energetic Radiation Imaging Telescope Array System

VI: visible rays

W

W: West

WEAVE: WHT Enhanced Area Velocity Explore

WFC: Wide Field Camera

WHO: World Health Organization

WHT: William Herschel Telescope; William Herschel Telescope

WS: Weather Station

ANNEX 1: Database of humidity, temperature, wind speed and dust concentration since Nov.2012 to Aug.2021 from Magic WS [24]

Table 34. Database from Magic WS

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
19/11/2012	39.404326	3.725085	6.212593	3.892468
05/12/2012	20.117107	5.305407	13.511232	0.681164
06/12/2012	17.654331	3.175525	6.929277	1.505171
07/12/2012	3.842684	6.425428	5.411992	2.971572
08/12/2012	2.780897	9.609021	6.143405	1.433318
09/12/2012	1.248405	10.21727	7.874255	0.878807
10/12/2012	3.377666	8.413851	9.99576	0.509993
11/12/2012	13.294688	6.972507	20.177891	2.58797
12/12/2012	85.956657	1.677617	6.027328	1.957062
14/12/2012	52.677573	4.034572	9.762017	0.808301
15/12/2012	30.494593	6.703547	5.415654	1.227377
16/12/2012	44.341247	8.292493	10.551493	0.988289
17/12/2012	26.412499	9.075838	10.878059	0.691607
18/12/2012	12.028018	11.0026	18.940055	0.716119
19/12/2012	20.549204	10.28303	17.47076	0.397615
20/12/2012	20.324556	9.916537	9.063773	0.44433
21/12/2012	11.008569	9.376999	12.160448	0.298906
22/12/2012	7.513097	8.708708	12.909	0.728225
23/12/2012	6.752783	9.194761	17.061537	0.276059
24/12/2012	23.24192	6.814479	18.507688	2.71943
03/01/2013	14.017538	7.084916	10.011683	3.023498
04/01/2013	7.29191	8.846756	10.456446	1.509738
05/01/2013	6.693008	7.108082	14.544657	0.852422
06/01/2013	8.861006	3.893602	8.98128	1.584796
08/01/2013	4.537817	4.833304	9.850084	1.375586
09/01/2013	5.649887	3.919697	8.425894	0.445617
10/01/2013	12.940471	3.489987	10.311617	1.396456
11/01/2013	15.635558	5.861656	8.220206	0.6895
12/01/2013	18.749236	7.900284	8.37892	0.493828
13/01/2013	1.967947	8.395208	17.153016	0.284854
14/01/2013	4.40484	6.676421	11.482074	0.229213
15/01/2013	1.524707	7.545815	9.60138	0.485574
16/01/2013	1.426683	9.007776	13.821437	1.176862
17/01/2013	1.956227	7.616309	13.647098	0.556181
18/01/2013	2.821662	8.036885	6.998975	0.3258
19/01/2013	10.236229	7.661805	10.789055	0.742888
20/01/2013	31.931547	7.369914	17.258565	4.064311
21/01/2013	66.67197	5.03386	9.652599	0.810191
23/01/2013	43.358231	2.321951	22.995822	1.479724
24/01/2013	17.866183	4.80631	20.368489	3.49645
25/01/2013	31.758888	6.064752	14.220565	1.001067

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
29/01/2013	3.960844	10.64944	12.07148	0.563224
31/01/2013	3.392856	9.138343	13.63379	1.69366
01/02/2013	3.034282	9.402657	16.491791	3.385339
02/02/2013	4.586527	9.376412	21.309099	2.673865
03/02/2013	1.516176	7.72047	14.227035	0.840384
04/02/2013	5.628677	9.149046	12.316821	0.877274
05/02/2013	17.8216	7.694928	19.122848	5.154007
06/02/2013	22.60952	6.193498	9.049881	13.58894
07/02/2013	12.253051	6.717922	11.101014	2.319845
08/02/2013	16.834013	4.949985	12.191312	0.74482
09/02/2013	18.251997	4.559277	17.24355	1.096847
10/02/2013	13.147295	4.401611	17.820187	0.657371
11/02/2013	2.50998	5.943065	13.820374	0.220767
12/02/2013	5.316152	6.350595	13.152508	1.951591
13/02/2013	29.470329	6.018685	11.346056	0.182
14/02/2013	61.844752	3.893091	21.148937	1.941552
15/02/2013	15.489397	6.103933	21.12223	3.298564
16/02/2013	33.035321	5.5146	22.295958	16.46946
17/02/2013	30.701829	5.225842	26.477603	6.896091
18/02/2013	43.901692	3.970281	16.564583	18.43312
20/02/2013	67.583819	3.60601	9.755622	2.330225
21/02/2013	16.069368	5.231381	6.251702	1.210176
22/02/2013	54.790336	2.454877	8.571522	1.530844
23/02/2013	33.751122	3.632554	11.712658	2.23323
28/02/2013	79.817397	3.414323	5.05863	0.606943
01/03/2013	67.383918	4.304335	9.529789	1.139095
02/03/2013	85.090692	3.229087	17.284168	0.489255
03/03/2013	84.630222	1.851637	16.159705	0.790504
09/03/2013	76.395143	3.628638	17.296435	0.847664
10/03/2013	19.152548	5.033546	11.343197	2.141815
11/03/2013	34.722397	5.210515	3.237753	2.487563
12/03/2013	44.435468	7.778627	3.269059	0.383758
13/03/2013	44.843712	9.164851	6.635336	0.403815
14/03/2013	12.107801	9.288966	7.313355	1.488584
15/03/2013	21.829294	11.53446	18.598435	6.548724
18/03/2013	56.469891	6.399998	13.114462	0.059216
19/03/2013	86.995591	3.084256	20.460559	0.15625
20/03/2013	25.020885	5.604243	4.965357	1.272373
21/03/2013	23.488011	5.074382	12.076003	0.584444
23/03/2013	19.064251	3.083131	12.087432	0.459786
24/03/2013	46.249513	3.49169	12.057965	0.672684
25/03/2013	45.866814	5.516084	9.215277	0.204527
29/03/2013	16.764258	10.33466	6.815948	3.056424
30/03/2013	18.453933	11.53031	5.811235	2.233706
31/03/2013	23.568886	11.71674	12.732813	0.570551
01/04/2013	29.676485	7.775074	13.286665	0.718733

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
02/04/2013	10.980552	7.21894	10.825385	0.980115
06/04/2013	6.75406	7.306517	12.044296	0.523841
07/04/2013	23.209011	4.846133	6.877568	0.494769
08/04/2013	47.196784	2.678731	13.155291	1.528233
09/04/2013	54.922764	4.292087	14.422009	0.614537
10/04/2013	40.411653	11.16564	9.224002	0.174482
11/04/2013	20.69973	11.95218	8.246194	0.177652
12/04/2013	9.612345	10.20883	5.890189	0.932872
13/04/2013	18.300586	7.336236	11.58023	0.780129
14/04/2013	2.629572	9.523245	6.181916	1.749511
15/04/2013	27.528309	9.861362	10.122687	0.835776
16/04/2013	22.876542	10.0189	10.124743	1.390018
17/04/2013	27.289202	10.35161	12.559612	7.089336
18/04/2013	37.720378	10.13047	19.718642	1.805604
19/04/2013	24.172767	14.33742	17.297594	3.007787
20/04/2013	20.176413	16.47765	18.377115	38.88292
22/04/2013	30.480585	15.81255	13.92405	15.49054
23/04/2013	25.811369	14.26512	10.450263	19.03892
28/04/2013	54.734849	5.85019	6.653499	2.345911
29/04/2013	49.150539	5.369205	11.049782	1.998482
30/04/2013	70.135258	4.312832	13.1177	1.149654
01/05/2013	64.525436	2.667745	12.150433	1.985093
02/05/2013	22.237948	5.383114	6.223868	0.603774
03/05/2013	7.666127	6.736571	9.305065	1.884643
04/05/2013	10.222428	6.881664	8.005382	0.401168
05/05/2013	75.393038	6.508651	10.863835	0.255978
06/05/2013	20.378472	12.67531	12.39875	0.242227
07/05/2013	13.828812	14.86382	11.705573	0.34227
08/05/2013	4.372259	15.34154	13.193231	0.292299
09/05/2013	29.900196	14.94779	8.56161	0.364546
10/05/2013	38.091323	14.98901	9.797958	0.086569
11/05/2013	33.419363	14.13713	9.092591	0.212748
12/05/2013	45.963542	12.58349	16.531355	0.977077
13/05/2013	48.581659	11.83724	20.463941	2.666567
14/05/2013	56.038173	8.150153	5.813373	0.123855
15/05/2013	67.283418	4.72561	16.754616	1.055498
16/05/2013	6.217583	6.257578	4.841168	1.05959
17/05/2013	55.617153	4.543549	6.763948	0.246028
18/05/2013	15.523286	7.14797	12.827944	0.280189
19/05/2013	22.286717	9.10553	7.95937	0.291845
20/05/2013	14.19712	7.919741	7.116935	0.15845
21/05/2013	6.604422	8.893881	6.392235	0.270841
22/05/2013	42.624841	7.400647	8.503749	1.148407
23/05/2013	14.817318	7.432451	9.91058	0.305822
27/05/2013	8.797204	9.482132	10.315219	0.181441
28/05/2013	16.694178	6.952205	2.751365	0.301037

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
29/05/2013	43.057732	8.633376	8.367813	0.152591
30/05/2013	55.746184	7.510681	7.566362	0.139661
31/05/2013	28.049322	10.40107	17.932569	0.658715
01/06/2013	6.07982	13.19332	14.301284	0.319581
02/06/2013	5.638658	11.68306	10.438455	0.570318
03/06/2013	9.390559	12.41983	7.065328	0.489189
04/06/2013	6.159333	11.51078	9.560277	0.237146
05/06/2013	8.149049	10.77307	6.719762	0.258527
06/06/2013	15.049162	9.269985	12.737474	0.267544
07/06/2013	11.818616	8.829606	7.302548	0.146841
08/06/2013	9.053158	11.14139	10.114254	0.729812
09/06/2013	25.325774	11.69564	4.00274	0.191224
10/06/2013	16.637474	12.17269	8.085339	0.255569
11/06/2013	24.855895	11.64605	12.788407	0.282877
12/06/2013	18.001035	12.2734	10.471418	0.19018
13/06/2013	22.587977	13.36537	12.503596	0.580286
14/06/2013	47.853271	14.09699	15.350798	0.147516
15/06/2013	39.858235	15.18085	10.941862	0.145552
16/06/2013	31.823453	15.46245	9.552998	0.078184
17/06/2013	13.961696	14.08959	11.65715	0.232751
18/06/2013	25.633155	14.50895	6.578487	0.197219
19/06/2013	1.188502	13.42898	12.504851	0.536206
20/06/2013	23.246541	14.55364	17.690997	1.376051
21/06/2013	19.197897	14.06818	20.5779	1.409367
26/06/2013	17.179733	16.14496	6.819477	0.993807
27/06/2013	10.99009	20.5094	10.89628	8.695277
28/06/2013	14.240167	21.65538	8.203798	24.03823
29/06/2013	10.154945	21.06666	15.061442	23.84436
30/06/2013	4.424791	16.73878	18.95456	6.225677
01/07/2013	1.231913	15.85304	13.651015	0.456986
02/07/2013	10.70725	14.42216	14.658824	1.383494
03/07/2013	13.29286	18.4746	10.519789	10.87051
04/07/2013	10.953603	16.54859	11.424405	15.25696
05/07/2013	1.464353	16.29161	7.845354	0.203614
06/07/2013	29.537025	16.1741	4.076693	-0.00701
07/07/2013	20.441088	16.60444	6.033759	0.379066
08/07/2013	14.356322	17.95601	10.614189	1.315787
09/07/2013	5.033133	22.05675	13.393175	0.607541
10/07/2013	34.469633	19.80252	10.933008	43.89849
11/07/2013	22.689684	19.98956	11.055419	18.26901
12/07/2013	21.345636	19.13814	11.123079	29.56939
13/07/2013	29.474666	18.60766	9.438262	16.19865
14/07/2013	19.562539	19.24708	9.616958	26.40236
15/07/2013	22.234008	18.41745	9.114008	16.0702
16/07/2013	22.840463	16.84947	8.873802	22.22427
17/07/2013	20.849329	16.51185	7.523531	12.92616

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
18/07/2013	17.711206	17.41873	6.31519	17.33784
19/07/2013	5.908494	16.28038	6.862756	0.536027
20/07/2013	49.487316	13.39664	9.97634	0.267039
26/07/2013	37.47349	16.22545	6.653201	0.43387
27/07/2013	35.223149	15.78483	9.217407	0.165523
28/07/2013	34.733125	16.23038	14.162307	0.113356
29/07/2013	9.658076	19.10677	7.828422	1.232136
30/07/2013	16.416741	19.18796	13.465203	3.663119
31/07/2013	11.519933	18.89022	12.850483	8.437484
01/08/2013	12.405916	18.81302	8.740343	0.371448
02/08/2013	15.005318	18.50302	6.558029	0.613878
03/08/2013	22.500898	18.42289	9.741723	68.31076
04/08/2013	25.741279	18.84889	9.014074	79.92612
05/08/2013	21.147849	19.38288	7.612381	34.84019
06/08/2013	23.053001	19.83309	8.953863	46.06009
07/08/2013	20.869521	19.8233	9.773749	19.11252
08/08/2013	22.110279	19.27934	9.502908	16.63476
09/08/2013	17.084695	18.22499	3.956508	11.0549
10/08/2013	11.556311	19.58223	8.425088	18.23702
11/08/2013	19.55872	21.05693	7.015239	12.7262
12/08/2013	16.985222	21.1995	11.360076	22.11138
13/08/2013	17.576117	22.18581	7.44474	17.4341
14/08/2013	20.904661	21.83031	6.814282	14.35456
15/08/2013	24.359218	21.86439	5.538691	7.262898
16/08/2013	19.616385	21.96628	10.682564	9.150402
17/08/2013	18.621324	22.63524	17.356054	16.12832
24/08/2013	30.414521	20.25458	7.807882	29.95967
25/08/2013	45.242328	17.29315	6.487502	17.12999
26/08/2013	17.444679	14.61704	4.67806	0.586262
27/08/2013	14.525196	12.78622	3.295609	0.751807
28/08/2013	13.08961	13.55064	8.59009	0.966323
29/08/2013	9.924215	14.90304	6.555304	0.503461
30/08/2013	5.455724	15.1474	10.424324	0.420962
31/08/2013	4.10137	18.22898	10.43094	0.467487
01/09/2013	47.461239	18.06375	7.395522	9.662754
02/09/2013	46.838042	17.75067	13.110427	13.235
03/09/2013	30.506909	17.46529	19.527193	6.095947
04/09/2013	38.042488	18.98497	7.086861	4.946824
05/09/2013	2.473691	17.21429	7.292869	0.541609
06/09/2013	1.847819	15.04444	6.861604	0.275151
07/09/2013	28.394724	10.46121	5.134681	0.194293
08/09/2013	62.527991	9.796561	9.898709	0.372983
09/09/2013	46.091712	11.95657	7.378151	0.390958
10/09/2013	28.859393	13.02361	8.221432	0.336941
12/09/2013	68.323879	12.89259	10.759833	6.002581
13/09/2013	56.641804	10.19934	7.926856	3.314742

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
14/09/2013	21.662926	10.72812	6.668832	0.39759
15/09/2013	64.995716	10.74749	10.39984	2.899364
16/09/2013	21.550242	10.69291	10.638679	0.468317
17/09/2013	84.448518	9.149095	7.855635	0.388157
24/09/2013	11.872149	13.02062	6.839156	0.092094
25/09/2013	68.37473	11.58189	14.983701	0.14455
27/09/2013	74.639381	10.66422	14.656256	0.401572
28/09/2013	69.827044	12.42113	13.080002	0.168863
29/09/2013	56.047042	14.03731	9.923414	0.132919
30/09/2013	44.802866	14.86047	7.734384	0.100219
01/10/2013	48.689458	14.37062	9.511817	0.066491
02/10/2013	76.204049	12.72984	13.075865	1.471503
04/10/2013	60.045326	7.012537	4.915245	0.172537
05/10/2013	24.929367	9.876312	7.933582	0.349027
06/10/2013	18.539468	13.92741	13.419444	0.334288
07/10/2013	6.477336	13.85916	7.761355	0.152098
08/10/2013	1.020975	15.98663	7.477301	0.389614
09/10/2013	12.459244	15.7314	8.687942	0.197605
10/10/2013	15.905263	12.78107	9.671064	0.044569
11/10/2013	6.29971	11.91093	9.433845	0.040354
12/10/2013	7.814728	12.0621	8.662979	0.027156
13/10/2013	20.974473	11.65545	4.980807	0.058444
14/10/2013	8.901845	11.83818	6.565628	0.0323
15/10/2013	31.626382	12.08217	4.439107	4.233209
16/10/2013	13.192105	12.58129	13.344869	0.895675
17/10/2013	37.542403	11.91974	8.621853	3.586027
22/10/2013	28.512896	12.59707	9.994683	0.157781
23/10/2013	42.063747	13.11849	9.129845	0.057213
24/10/2013	39.905514	13.1095	15.942561	0.073766
27/10/2013	27.701607	7.879146	18.066928	0.894335
28/10/2013	33.221532	7.275562	16.381898	0.858036
30/10/2013	44.624118	9.122303	10.921696	4.366521
31/10/2013	15.337439	9.699159	17.926128	0.522383
01/11/2013	36.331973	8.549991	17.769828	0.322209
02/11/2013	40.489094	11.17772	16.829794	3.302178
03/11/2013	36.852661	11.58929	13.187256	3.789939
04/11/2013	77.029047	4.790412	11.318278	0.88404
05/11/2013	48.2362	8.45634	15.896331	1.511083
06/11/2013	24.407279	10.82695	5.699897	0.43203
07/11/2013	52.592144	11.34002	3.580084	0.592022
08/11/2013	48.926386	8.662737	13.660606	0.27647
10/11/2013	22.513275	12.38655	15.963827	0.094678
11/11/2013	30.610124	10.63051	7.964823	1.069105
12/11/2013	39.549827	8.99857	3.502739	4.607969
13/11/2013	10.478487	8.951018	9.694336	0.118029
14/11/2013	38.921944	10.38609	11.825738	0.228057

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
15/11/2013	50.585096	7.860702	9.327957	0.105896
21/11/2013	13.854947	7.79017	12.159642	0.350493
22/11/2013	62.768698	7.760776	12.339135	0.17243
23/11/2013	48.047068	9.119679	6.103403	0.148444
24/11/2013	62.41865	9.468777	9.346815	0.108291
25/11/2013	37.544895	8.951708	12.800652	0.10296
26/11/2013	5.631649	7.182652	9.797982	0.200213
27/11/2013	14.576294	6.999073	17.888512	0.265312
29/11/2013	57.706471	5.379988	10.430989	0.358022
30/11/2013	83.687239	6.892613	8.247497	0.116826
01/12/2013	86.954922	8.619436	12.111531	0.129956
02/12/2013	83.324058	8.098532	14.584891	0.128982
03/12/2013	90.926091	8.18682	15.636067	0.229638
04/12/2013	77.076557	5.88447	17.418023	0.572491
05/12/2013	53.445175	6.441514	11.060812	0.546233
07/12/2013	85.247193	6.043904	9.78488	0.438887
08/12/2013	77.9214	6.543684	8.218516	0.575144
09/12/2013	72.245718	6.88388	14.500767	0.519259
20/12/2013	22.409349	10.90567	22.735116	2.971923
21/12/2013	3.479285	12.97943	16.59285	0.998771
22/12/2013	19.154545	10.60491	20.025673	0.301714
23/12/2013	17.669137	7.367215	15.370332	1.094627
24/12/2013	17.60275	5.967977	13.234344	0.238602
25/12/2013	15.758759	8.048964	7.849927	0.123958
26/12/2013	45.592166	10.24908	11.385244	0.255015
27/12/2013	54.371228	8.850379	5.507592	0.276463
28/12/2013	89.435938	6.159982	8.638896	0.275845
30/12/2013	8.043968	8.634379	23.580747	9.142532
31/12/2013	4.926886	9.602526	11.996193	0.415397
01/01/2014	2.284859	7.638109	12.21368	0.275239
02/01/2014	10.571379	8.032946	10.734262	0.310958
03/01/2014	10.117126	8.45748	8.83987	0.890397
04/01/2014	4.053276	9.648151	10.516514	0.547756
05/01/2014	3.907368	12.26627	12.253415	0.275629
06/01/2014	1.07462	12.3279	10.496624	0.155253
07/01/2014	32.279357	9.988883	14.014947	0.255793
08/01/2014	35.531854	8.021035	23.780349	1.646319
11/01/2014	57.681552	3.966448	15.428028	3.145785
12/01/2014	34.594685	5.978057	8.621057	0.702472
13/01/2014	24.352149	7.953507	6.148291	0.265633
14/01/2014	17.588623	7.730335	7.11392	0.382286
22/01/2014	70.200777	6.630332	14.367247	0.134593
27/01/2014	32.039734	11.4554	26.120316	0.688742
28/01/2014	24.447967	9.676157	11.937526	0.175404
29/01/2014	43.748311	6.798745	11.408863	0.240526
01/02/2014	42.421873	7.761674	8.784869	0.053635

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
02/02/2014	25.040716	6.771011	9.678698	0.125117
03/02/2014	85.555913	4.734282	10.090076	0.058909
04/02/2014	7.171618	7.80121	11.038295	0.212002
05/02/2014	32.457691	7.259525	8.676466	0.039096
06/02/2014	21.069206	7.895312	19.566024	0.232691
07/02/2014	3.315599	5.261887	5.392833	0.14709
08/02/2014	14.956718	8.312719	12.228862	0.173005
09/02/2014	12.489231	7.88713	5.800521	0.131275
10/02/2014	41.490597	6.98239	13.972437	0.503962
11/02/2014	18.921768	9.119613	13.834792	0.541425
12/02/2014	2.220696	9.927294	11.032553	0.08509
22/02/2014	28.691284	7.017723	9.871614	0.118135
23/02/2014	38.374627	3.352358	8.420242	0.025454
24/02/2014	73.183394	2.513302	13.13548	0.422701
25/02/2014	26.417382	5.475797	12.122535	0.334682
26/02/2014	22.191995	6.888365	21.147767	0.527445
27/02/2014	22.949525	7.939239	16.892394	0.245643
01/03/2014	16.359859	9.494525	19.060649	0.284212
02/03/2014	20.727461	9.242967	14.71057	0.072646
03/03/2014	17.785063	8.145898	20.67232	0.142699
04/03/2014	1.17108	9.894964	15.896519	0.081805
05/03/2014	21.825501	9.081452	16.423434	0.124132
06/03/2014	29.245596	9.692543	13.651001	0.155123
07/03/2014	26.727103	8.06	14.350399	0.381051
08/03/2014	5.227031	6.963836	22.025016	0.112396
09/03/2014	20.447899	5.824863	10.452524	0.293266
12/03/2014	54.756748	3.452498	18.090419	10.24972
13/03/2014	7.306272	6.842265	13.940417	0.074888
14/03/2014	7.971183	5.77295	11.185081	0.171806
19/03/2014	8.846906	7.12722	10.714176	0.719903
20/03/2014	18.570919	5.95231	5.126617	1.434147
21/03/2014	1.470936	7.511985	13.531934	0.236551
22/03/2014	12.185007	8.139803	18.289702	0.420201
23/03/2014	59.323686	5.642431	19.123424	0.276017
24/03/2014	22.592103	5.52251	18.719286	0.212613
25/03/2014	19.303334	9.944402	15.754658	0.296283
26/03/2014	13.321736	8.904098	23.393193	0.369191
27/03/2014	5.352244	9.093598	19.950899	1.258223
28/03/2014	68.166258	2.506382	15.275841	0.422665
03/04/2014	58.431002	2.538516	7.824725	0.221926
05/04/2014	30.038357	11.15946	11.454584	0.337964
06/04/2014	33.37415	7.951617	7.563211	0.142846
07/04/2014	33.58101	8.343169	8.836457	0.352023
08/04/2014	24.059754	9.954033	12.458797	0.216091
09/04/2014	9.44141	7.398986	17.372278	0.140623
10/04/2014	2.262924	10.35622	21.504664	0.225511

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
11/04/2014	18.168498	10.08663	14.516279	0.169764
17/04/2014	14.428432	8.127306	8.653907	0.244237
18/04/2014	25.950248	7.722068	8.370819	0.27639
19/04/2014	58.981916	6.062435	22.984655	0.369476
20/04/2014	88.810131	2.451155	20.367741	0.083105
21/04/2014	83.910242	1.144332	7.871271	0.352386
22/04/2014	3.269415	6.382075	3.941763	0.560046
23/04/2014	27.830409	8.741602	7.35454	0.212624
24/04/2014	22.246167	7.461593	7.502278	0.13233
25/04/2014	12.634129	11.30423	11.014604	0.410416
26/04/2014	14.275969	11.3612	11.274548	0.228725
27/04/2014	10.605399	11.75035	12.026571	0.486414
28/04/2014	14.517836	12.04185	9.522233	0.257092
29/04/2014	12.532497	12.95495	11.124574	0.20802
30/04/2014	25.829326	11.92735	7.343886	1.9139
01/05/2014	26.496193	9.972951	7.037078	3.074137
02/05/2014	10.488733	11.04327	10.892877	0.701991
03/05/2014	19.135136	12.18822	9.091239	0.204831
04/05/2014	5.038652	10.5156	7.278403	0.176788
05/05/2014	10.143647	9.7819	4.117222	0.223946
06/05/2014	6.23741	8.971805	8.184629	0.169643
07/05/2014	29.168595	8.371741	12.680089	0.179471
08/05/2014	8.909663	10.76456	19.974916	1.094669
09/05/2014	35.11378	12.36462	19.568021	5.38874
10/05/2014	16.571276	15.8552	13.73749	7.608468
11/05/2014	7.431489	14.89042	11.484535	0.610858
12/05/2014	9.466728	15.90608	10.720749	4.569534
17/05/2014	2.687334	12.15807	7.885686	0.193311
18/05/2014	37.229222	8.337693	16.744613	1.389167
19/05/2014	6.773922	9.271689	6.232897	0.221483
20/05/2014	10.135359	9.771463	5.624738	0.286966
21/05/2014	4.320216	7.232777	8.703822	0.377645
22/05/2014	18.657131	7.435231	7.642351	0.248165
23/05/2014	13.573827	7.124124	5.746165	0.406722
24/05/2014	25.5518	7.550861	13.103819	0.243869
25/05/2014	29.501688	6.08911	15.047593	0.123609
26/05/2014	56.629928	4.271854	17.873376	0.232371
27/05/2014	19.226796	7.766947	15.268518	0.407095
28/05/2014	37.054315	9.330317	16.486679	0.407788
29/05/2014	30.532473	9.768089	24.469807	0.503464
30/05/2014	21.481549	10.85791	19.547686	0.168054
31/05/2014	17.245928	10.87443	17.896231	0.380022
01/06/2014	14.980651	11.18407	10.896219	0.25014
02/06/2014	17.989015	11.51609	12.502267	0.310791
03/06/2014	13.832512	11.68774	6.284123	0.45456
04/06/2014	1.341689	12.08182	6.487843	0.166432

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
05/06/2014	13.663509	9.301038	3.955827	0.123103
06/06/2014	36.597491	9.228701	6.002656	0.119677
07/06/2014	13.360728	8.83501	10.82006	0.169357
08/06/2014	23.7816	9.705054	13.806331	0.18743
09/06/2014	41.709268	10.071	6.017699	0.053547
10/06/2014	40.14538	10.62117	11.430208	0.091399
16/06/2014	38.480476	12.10549	5.734249	8.184335
17/06/2014	22.748577	11.58111	9.311292	0.323786
18/06/2014	46.247248	11.00741	5.357533	0.140893
05/07/2014	14.132062	14.18925	6.748692	0.26836
06/07/2014	59.956888	14.49428	5.827689	4.416066
07/07/2014	13.586173	13.05147	8.392284	3.589638
08/07/2014	46.871122	10.86895	20.771516	0.780662
09/07/2014	41.857843	12.24094	23.943877	0.415707
10/07/2014	20.560414	16.22885	16.541702	2.840531
15/07/2014	5.695147	20.14523	10.284643	0.176461
16/07/2014	14.048101	16.06894	21.492791	19.78806
17/07/2014	15.080262	15.87444	13.187218	13.13959
18/07/2014	1.82795	14.98488	5.019262	0.688329
19/07/2014	7.036661	17.6981	7.310207	0.448011
20/07/2014	8.057382	16.032	6.494148	0.244766
21/07/2014	4.241614	15.89949	3.519679	0.12691
22/07/2014	7.498257	17.82901	8.848476	0.434601
23/07/2014	48.911166	14.01181	10.822804	0.136413
24/07/2014	41.252822	13.92372	12.058917	0.110559
25/07/2014	27.434775	13.79738	11.329289	0.331599
26/07/2014	13.380508	15.05989	6.656956	1.48773
27/07/2014	11.359509	13.07154	3.266787	1.017843
28/07/2014	6.616935	13.47124	12.759694	1.796871
29/07/2014	12.18563	16.72124	13.730505	1.793524
30/07/2014	28.122705	15.66251	10.046375	0.476849
31/07/2014	10.187301	16.13178	6.392193	0.318699
01/08/2014	4.308554	16.34475	7.345889	0.298962
02/08/2014	29.494775	15.45728	11.462569	0.326785
03/08/2014	40.326648	12.60401	17.804381	0.296213
04/08/2014	32.636639	13.14753	9.572203	0.289097
05/08/2014	40.267333	15.22961	8.782109	0.335672
06/08/2014	18.441191	19.70217	8.997232	0.22389
17/08/2014	13.271678	17.32225	7.87836	0.446258
18/08/2014	8.990564	15.72637	15.440529	1.466612
19/08/2014	17.432794	16.772	13.744704	10.48734
23/08/2014	70.071015	17.50743	10.466747	0.935133
24/08/2014	40.249835	16.66593	9.9444	7.418056
25/08/2014	12.140373	16.18332	10.922957	0.26717
26/08/2014	17.973539	18.66479	5.955807	1.516968
27/08/2014	25.036696	19.62735	9.050032	6.471595

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
28/08/2014	39.03801	18.86319	5.869624	26.90377
29/08/2014	39.045627	17.9853	7.152255	35.83675
30/08/2014	14.088346	17.42893	9.379515	9.096817
31/08/2014	4.404171	14.65239	11.744022	2.427395
01/09/2014	57.49619	12.32062	8.81728	1.237298
02/09/2014	59.981892	11.24832	7.995515	0.439204
03/09/2014	45.184715	12.39975	6.791346	12.44257
04/09/2014	60.825787	10.9268	5.660883	0.296014
05/09/2014	47.474831	12.35871	7.815169	0.248357
06/09/2014	36.739231	13.76488	9.259085	0.376106
07/09/2014	66.347723	11.14407	9.296709	0.086898
12/09/2014	23.032565	15.45591	15.796975	0.387235
13/09/2014	16.647163	15.37134	18.440649	0.544486
14/09/2014	25.956469	13.47954	14.231479	0.163517
15/09/2014	25.915706	14.29309	18.298362	0.169091
16/09/2014	88.355396	10.91789	25.197623	0.497845
17/09/2014	12.240123	11.54722	14.161732	0.253659
18/09/2014	44.942183	9.732696	6.8178	0.495262
19/09/2014	37.76812	10.20284	6.075156	0.104553
20/09/2014	57.623067	10.61619	6.07063	0.179786
21/09/2014	79.872123	9.056055	9.664986	0.323199
22/09/2014	7.960969	11.90707	4.870141	0.169944
23/09/2014	2.814464	12.34383	10.368225	0.275069
24/09/2014	6.026009	11.69914	4.920128	0.188878
25/09/2014	47.507398	13.15733	7.333551	0.309822
27/09/2014	78.099754	12.11118	10.264722	0.234227
28/09/2014	69.275748	12.50352	6.381733	0.204723
29/09/2014	77.757678	12.06002	4.244339	0.380828
30/09/2014	76.124594	10.81217	11.833681	0.151227
01/10/2014	48.685727	11.45533	16.093249	0.19135
02/10/2014	11.824519	14.74362	13.089648	0.142169
03/10/2014	10.444039	15.44886	13.910534	0.33603
04/10/2014	26.73118	15.5212	11.31228	0.046815
05/10/2014	13.068505	14.81031	5.771421	0.137574
06/10/2014	3.502565	13.11715	13.329287	0.108527
08/10/2014	12.165387	11.25049	6.52645	0.05477
09/10/2014	22.364493	11.44511	5.273426	0.119947
10/10/2014	9.391702	12.76356	7.110164	0.167582
11/10/2014	81.935733	11.32967	10.135936	0.217081
12/10/2014	45.661375	9.065704	2.566378	0.125269
13/10/2014	49.128377	7.443061	5.611262	0.402492
14/10/2014	30.928259	11.57375	11.341376	0.106488
15/10/2014	46.191866	12.52186	8.012315	0.440286
16/10/2014	30.368191	15.14255	8.215286	0.276583
17/10/2014	49.401249	12.35586	9.444635	0.066285
18/10/2014	83.523652	13.11425	13.424464	0.187828

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
19/10/2014	89.317655	11.8947	19.92906	0.253217
22/10/2014	55.032272	14.2212	17.289464	6.865878
23/10/2014	35.390203	16.48059	10.538047	15.28468
24/10/2014	38.582435	14.92	7.793346	12.24568
25/10/2014	58.025615	12.85841	11.535387	6.842226
26/10/2014	41.61266	13.84005	17.942109	4.557699
27/10/2014	53.103808	12.19129	20.92888	4.346426
28/10/2014	50.164813	11.69358	9.935055	1.046507
30/10/2014	48.900568	10.09316	8.547434	0.377938
31/10/2014	22.440824	10.42424	5.768536	0.396503
01/11/2014	68.619406	9.542111	15.324054	0.332531
04/11/2014	70.811254	9.266087	8.192254	3.215964
09/11/2014	24.843579	11.20194	14.154938	0.784857
10/11/2014	56.905449	8.907504	14.83661	0.234032
11/11/2014	43.36383	11.4516	7.648768	0.302115
12/11/2014	27.827098	12.30149	9.111176	0.248966
13/11/2014	17.872654	11.81878	6.643616	0.201122
14/11/2014	5.70229	12.17791	7.783181	0.037056
15/11/2014	33.971834	10.99431	5.386541	0.281708
16/11/2014	50.072917	8.736396	13.991603	0.717334
26/11/2014	0.974706	7.25917	8.17185	0.458537
03/12/2014	0.979421	6.997675	11.160945	0.214874
04/12/2014	0.970765	5.214577	11.585014	0.246364
09/12/2014	80.247796	6.128993	18.709077	0.966619
10/12/2014	0.981308	11.28073	12.344628	1.07541
11/12/2014	0.977809	11.8274	11.187389	1.028942
12/12/2014	0.98	8.415516	4.851196	0.487689
13/12/2014	4.99073	6.847271	9.201868	1.735468
14/12/2014	36.003248	1.031087	10.248065	0.860212
15/12/2014	61.29067	1.943458	15.946247	0.848778
16/12/2014	51.087249	4.322051	22.169942	1.78494
17/12/2014	43.676379	6.913228	25.099419	0.748222
18/12/2014	44.186789	7.75137	21.385881	1.229827
19/12/2014	14.294688	9.370561	19.141491	0.153648
20/12/2014	42.128971	5.261047	10.464369	0.420941
21/12/2014	49.49369	6.262848	12.242036	0.257387
22/12/2014	65.43693	3.937637	15.280513	1.094038
23/12/2014	59.890053	2.566562	15.323674	20.44985
24/12/2014	34.403113	4.201132	19.080021	39.95981
25/12/2014	13.466499	7.304259	19.597147	3.410641
26/12/2014	28.094223	6.67793	7.903526	6.373064
27/12/2014	5.698959	8.101967	11.893202	2.743254
28/12/2014	4.179597	7.085295	8.722274	0.688329
29/12/2014	4.157257	9.57316	10.600478	0.246476
01/01/2015	54.426173	3.394933	20.568274	4.827564
02/01/2015	46.508103	5.401992	13.140658	3.054703

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
06/01/2015	5.547807	2.737678	11.305648	0.477149
07/01/2015	3.507355	4.656628	12.299416	0.172038
11/01/2015	53.522474	2.213142	10.334814	22.62507
13/01/2015	52.557811	2.062542	12.508471	93.77059
15/01/2015	47.495821	3.14368	19.051382	3.492067
16/01/2015	14.418796	4.839326	10.767705	0.705888
17/01/2015	16.562547	4.31405	12.837433	1.308647
18/01/2015	51.251036	4.594663	18.067904	0.996857
19/01/2015	66.97608	3.337988	18.136824	1.288219
21/01/2015	85.835471	1.191782	22.40381	1.057068
22/01/2015	6.593069	5.272231	14.718085	0.549865
23/01/2015	3.500597	5.432517	16.314338	0.426238
24/01/2015	8.243653	5.012455	15.603193	0.131343
25/01/2015	0.974691	4.438594	16.484797	0.46311
26/01/2015	3.950744	6.248162	19.443361	0.408579
27/01/2015	6.008062	5.711655	16.431555	0.456756
28/01/2015	28.244531	3.605272	5.691579	0.211757
29/01/2015	10.544078	5.373594	14.500787	0.507601
04/02/2015	9.073709	5.793549	12.75531	0.063096
05/02/2015	8.272972	6.428545	9.971751	0.144879
06/02/2015	10.410754	4.206627	6.461756	0.184627
07/02/2015	12.319772	4.552683	7.512451	0.094483
12/02/2015	35.870511	1.478672	5.84257	2.565434
13/02/2015	27.695903	1.95182	12.595508	1.82321
14/02/2015	22.457739	3.910023	19.096129	1.068085
15/02/2015	18.834946	7.060306	17.858014	0.800475
16/02/2015	24.204115	7.460062	16.452921	0.453586
17/02/2015	63.324701	5.94544	20.117072	0.463
23/02/2015	43.49564	7.242341	22.551474	0.832084
24/02/2015	4.936412	9.514221	18.891014	1.112228
27/02/2015	9.206858	10.44329	23.485561	1.648104
01/03/2015	33.712376	9.309367	21.162015	0.418911
02/03/2015	1.275197	9.650418	13.469173	0.477907
03/03/2015	4.444903	9.547301	10.833226	0.492005
04/03/2015	24.702845	8.009917	18.031283	7.482598
05/03/2015	51.797748	5.941455	9.798648	13.21213
06/03/2015	43.671573	6.625762	14.386465	3.35552
07/03/2015	25.779014	8.116157	14.652589	10.10147
11/03/2015	17.416061	6.47893	11.860824	9.758697
12/03/2015	21.427309	6.09032	10.673455	7.95468
13/03/2015	9.252409	5.908665	10.958665	5.650332
14/03/2015	10.775341	6.724125	12.780802	3.55662
15/03/2015	2.124073	8.106476	22.060822	1.154214
16/03/2015	1.913496	7.707437	12.906075	0.619897
17/03/2015	5.497798	6.47196	7.632058	0.422837
18/03/2015	12.688773	5.402461	15.292913	0.432282

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
27/03/2015	24.328255	8.564329	13.700248	0.170867
28/03/2015	45.680994	9.992665	12.188987	0.162697
29/03/2015	30.60105	12.23258	16.718362	0.147095
30/03/2015	27.132002	10.42301	24.596431	1.931647
31/03/2015	21.97285	11.3422	10.270185	1.693729
01/04/2015	17.217232	8.803411	10.011386	0.267664
07/04/2015	59.14873	4.879572	13.081512	0.505704
08/04/2015	91.44303	0.557958	12.998823	0.362342
09/04/2015	27.283539	4.640373	5.716169	0.573665
10/04/2015	26.377211	4.452885	7.183795	0.83341
11/04/2015	17.642619	5.458867	14.878651	0.549025
12/04/2015	17.591541	4.47852	6.266795	0.465595
13/04/2015	37.752307	3.315134	6.769758	0.48792
15/04/2015	29.834164	5.805249	10.034719	0.186702
16/04/2015	17.65607	6.17772	9.014172	0.971391
17/04/2015	9.20663	6.543467	7.635389	0.601683
18/04/2015	2.608727	7.618219	6.938736	1.126164
19/04/2015	7.304596	7.29993	13.237854	1.694774
20/04/2015	18.452528	6.648354	14.122623	0.460634
21/04/2015	60.806874	4.242848	14.765788	0.349947
22/04/2015	6.245232	7.168588	6.622195	0.65072
23/04/2015	3.184611	9.771503	9.816737	0.325563
24/04/2015	45.969152	8.179282	5.3488	0.431421
25/04/2015	32.119973	10.05503	9.911715	0.184985
26/04/2015	27.461012	10.08701	5.456881	0.264673
27/04/2015	5.385529	9.842541	9.740931	0.545605
28/04/2015	3.538931	12.44339	12.666316	0.553396
29/04/2015	9.738462	13.123	10.297541	0.735032
30/04/2015	6.445328	11.40935	9.262428	0.454693
01/05/2015	1.681571	11.91644	4.41753	0.044102
07/05/2015	34.598842	11.61886	15.374996	0.363294
08/05/2015	3.839797	12.09431	11.271169	1.072029
09/05/2015	6.261151	13.12359	9.243948	0.415088
10/05/2015	1.057442	16.12702	9.711058	0.879754
11/05/2015	5.625344	18.11326	15.16755	6.07352
12/05/2015	13.432095	18.59184	10.829455	31.14419
14/05/2015	14.273751	19.71684	17.826157	31.39604
16/05/2015	16.171796	20.60539	10.231851	37.77044
17/05/2015	17.363402	15.94593	4.13818	34.2904
18/05/2015	28.007702	12.43531	6.442002	0.574192
19/05/2015	21.432848	10.53785	13.259635	0.677575
22/05/2015	8.352192	8.726035	22.496415	2.235382
23/05/2015	2.367277	7.647871	13.537459	1.585808
24/05/2015	31.995091	5.769027	15.350284	1.047082
25/05/2015	36.621782	6.115264	7.618325	1.337014
26/05/2015	24.004846	8.540092	10.689717	0.436448

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
27/05/2015	25.273617	6.034437	11.688771	0.439503
28/05/2015	71.133124	5.010936	8.634589	1.267719
29/05/2015	47.990987	7.59945	14.867975	1.535392
30/05/2015	53.903846	5.807872	5.985361	1.638046
05/06/2015	26.42147	13.88232	13.349391	2.670124
06/06/2015	57.56854	10.67778	19.021033	13.59113
07/06/2015	69.72441	9.352988	13.241171	12.49938
08/06/2015	56.82009	11.22364	4.664788	22.00007
09/06/2015	25.028221	11.16528	6.102967	0.411901
10/06/2015	25.927381	10.53566	12.388529	0.132318
11/06/2015	65.427959	7.107392	10.432225	0.529923
12/06/2015	37.382913	8.65965	7.689198	0.403156
13/06/2015	43.67744	8.433343	7.75951	0.421731
15/06/2015	61.546968	6.635384	9.157806	0.33881
16/06/2015	23.145335	11.09292	15.667094	1.520236
17/06/2015	28.688485	11.75322	9.264806	0.454865
18/06/2015	31.205114	13.46443	8.22939	0.581119
19/06/2015	32.120036	10.47313	4.211329	0.332188
20/06/2015	26.518814	12.23491	8.205095	0.373075
21/06/2015	12.131626	12.90069	9.275276	0.322676
22/06/2015	8.502914	12.79743	14.93293	0.423008
23/06/2015	15.698884	10.60637	11.146853	0.148799
24/06/2015	17.762247	11.426	12.482004	0.281731
25/06/2015	72.196786	11.09768	5.504104	0.136408
26/06/2015	52.108205	11.42754	14.548306	0.129197
27/06/2015	22.979626	14.23665	18.116161	0.33958
28/06/2015	17.119398	14.79128	8.111617	4.033064
29/06/2015	6.569681	16.76205	8.894633	0.682302
05/07/2015	27.713563	15.24004	9.803336	0.265
06/07/2015	10.54793	19.10795	15.378725	1.492879
07/07/2015	20.620595	20.34873	7.458767	93.44303
08/07/2015	34.945883	20.2117	14.668231	47.71735
09/07/2015	21.084111	19.63014	10.119613	14.98506
10/07/2015	24.231194	18.56758	14.471248	26.33244
11/07/2015	33.81831	17.85113	16.018306	18.42526
12/07/2015	16.95212	16.37627	16.974963	19.85038
13/07/2015	17.306528	17.78239	13.736265	17.45519
14/07/2015	28.186621	20.88617	9.300058	32.10909
15/07/2015	31.313354	19.72453	14.015887	12.71417
16/07/2015	34.245667	17.48246	10.815828	14.14148
17/07/2015	31.556599	17.20138	7.135846	13.47891
18/07/2015	37.313075	15.35355	11.494054	13.85508
19/07/2015	28.26294	12.99921	11.084065	2.864913
20/07/2015	35.692508	12.94828	16.926307	5.730905
21/07/2015	38.197552	15.75598	17.445391	11.50813
22/07/2015	9.537457	19.79152	14.551536	4.266475

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
23/07/2015	16.641216	22.38098	8.836748	23.91638
24/07/2015	13.180462	19.23605	4.533764	14.95638
25/07/2015	23.641292	15.92601	17.362562	10.05622
26/07/2015	19.166497	15.12583	10.984957	0.393064
27/07/2015	27.198616	15.61597	10.670053	0.538353
28/07/2015	48.011747	14.73994	12.021753	0.491423
29/07/2015	34.295543	17.54915	10.981183	26.56263
03/08/2015	4.382446	15.01265	8.871823	1.127038
04/08/2015	10.571716	16.87912	9.652925	6.768777
05/08/2015	25.333284	17.98372	9.876304	4.779805
06/08/2015	40.538518	17.75571	13.691976	2.570277
07/08/2015	8.803805	17.73876	13.001026	1.043764
08/08/2015	57.110669	17.24675	14.247571	42.51293
10/08/2015	73.933188	15.4514	13.301144	17.72019
12/08/2015	79.298918	16.06127	12.196818	-1
13/08/2015	59.121065	17.93775	13.290222	34.46594
14/08/2015	70.962748	16.62037	7.535791	15.28374
15/08/2015	61.355937	15.67998	11.243316	13.42442
16/08/2015	60.455017	14.20069	5.132518	8.057055
17/08/2015	29.720087	12.1028	13.88329	2.560929
18/08/2015	34.868816	12.11082	17.890635	3.561415
19/08/2015	50.059645	11.26328	8.805803	0.977778
20/08/2015	16.583858	15.38018	10.751576	0.337298
21/08/2015	53.141107	16.31332	10.044223	5.199739
22/08/2015	25.20768	16.45834	11.771806	12.73482
23/08/2015	15.076741	15.03556	13.030212	0.569343
24/08/2015	15.982953	13.88214	6.523417	0.363836
25/08/2015	36.129177	15.68865	9.013639	4.271473
26/08/2015	40.274829	13.53945	7.906701	2.578132
27/08/2015	21.787962	12.89403	7.843796	3.252848
28/08/2015	22.859163	14.22025	13.633824	7.259716
01/09/2015	37.776911	14.59082	8.997175	1.529938
02/09/2015	14.275846	13.65445	4.473004	2.727819
03/09/2015	45.917154	14.38248	16.824028	3.761769
04/09/2015	52.830813	14.84062	10.400986	2.845068
05/09/2015	38.786045	13.16635	7.657733	1.154566
06/09/2015	77.555306	12.28892	8.4476	0.641589
07/09/2015	59.735046	12.17935	7.693696	0.634764
08/09/2015	45.673294	13.77115	5.682293	0.755554
09/09/2015	46.571358	13.47245	10.771486	1.404702
10/09/2015	60.658412	12.99233	14.494815	3.000722
12/09/2015	54.587424	11.97036	4.559261	2.230532
13/09/2015	84.594246	11.82034	7.994682	0.530709
14/09/2015	40.980357	12.21514	6.544557	0.385568
15/09/2015	49.833649	13.63209	8.683061	0.593876
16/09/2015	11.113111	13.24967	4.816235	2.355632

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
17/09/2015	24.405853	11.35552	3.566462	-0.99864
18/09/2015	79.42219	11.69091	7.386487	-0.99781
19/09/2015	85.573757	9.299415	6.286451	-0.99857
20/09/2015	78.255999	8.303287	10.731142	-0.99847
21/09/2015	55.022761	12.34968	14.185158	-0.99933
22/09/2015	48.387747	13.21578	16.465474	-0.99804
23/09/2015	89.774083	11.82172	16.770669	-0.99893
24/09/2015	55.063148	13.26667	14.912169	-0.99923
25/09/2015	64.808463	12.61645	14.181659	-0.99852
26/09/2015	61.243091	9.509829	8.652668	0.064545
27/09/2015	82.223647	8.990663	11.041099	1.13905
28/09/2015	44.939098	10.00915	12.848242	0.919934
30/09/2015	17.718032	10.91478	10.445087	0.780247
01/10/2015	24.279616	12.42546	13.238033	0.195472
02/10/2015	82.658308	12.53414	17.882744	5.549932
03/10/2015	83.664375	13.69386	15.562975	4.144656
05/10/2015	71.853402	14.65193	24.293166	3.971395
06/10/2015	66.563351	13.33592	14.03126	1.623395
07/10/2015	18.199564	13.01319	9.194631	0.995611
08/10/2015	12.347747	11.73188	5.557529	0.738689
09/10/2015	26.985332	12.54848	5.074222	0.920986
10/10/2015	91.630158	12.42116	11.697057	0.447324
11/10/2015	82.635326	10.10794	10.620554	1.334511
12/10/2015	70.533122	10.49805	4.315446	0.336507
13/10/2015	49.20671	10.42395	7.406283	0.271101
14/10/2015	50.212833	6.986234	6.470284	0.86051
15/10/2015	75.067277	9.034347	15.802459	2.052843
19/10/2015	84.690634	6.313514	13.904967	2.343467
20/10/2015	98.149459	5.329253	11.972522	1.299797
22/10/2015	89.147838	5.089985	19.4832	2.88076
26/10/2015	60.351921	6.629838	9.572564	1.506244
27/10/2015	34.76409	8.510621	4.318879	1.266854
28/10/2015	41.270723	6.700572	8.509986	0.577812
29/10/2015	15.181514	9.824032	5.568272	0.443328
30/10/2015	35.995238	9.426039	7.408057	0.805178
31/10/2015	79.402108	7.804433	6.916786	0.874336
02/11/2015	68.963025	4.509487	5.505509	0.233446
03/11/2015	63.67358	5.165946	5.537037	0.232687
04/11/2015	71.933851	9.607972	3.43058	1.580172
05/11/2015	62.015169	10.0134	6.945087	0.314011
06/11/2015	47.988474	12.23075	13.775506	0.321394
07/11/2015	26.302653	10.09596	9.304243	0.282096
08/11/2015	28.682232	10.96169	8.321499	0.380438
09/11/2015	47.046634	11.31932	12.205151	3.392358
10/11/2015	53.66302	11.87945	16.870593	4.374155
11/11/2015	67.330073	8.501002	19.501288	3.598796

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
12/11/2015	65.64013	7.474412	11.690347	4.087058
13/11/2015	64.122306	8.896158	10.502068	5.098681
14/11/2015	54.160033	9.667514	14.777254	6.148103
15/11/2015	53.088528	9.538216	15.215673	3.427079
16/11/2015	72.47897	7.697258	6.659815	5.931321
17/11/2015	65.638274	6.394866	6.681432	4.863639
18/11/2015	9.342243	9.846086	15.04816	1.957908
19/11/2015	19.211365	9.380504	21.165259	2.434207
20/11/2015	20.831681	11.20522	10.722162	0.822373
21/11/2015	1.919738	12.20875	15.010661	2.174837
22/11/2015	4.813308	11.4351	18.224675	0.718127
24/11/2015	15.828647	8.782222	22.045364	1.423919
28/11/2015	34.619016	9.157076	19.919759	0.121305
29/11/2015	31.679242	8.671694	15.605077	0.324756
30/11/2015	42.213914	7.48292	14.611687	0.963509
01/12/2015	71.433477	7.009444	21.581989	3.495207
02/12/2015	74.387345	7.249295	14.617297	2.144134
03/12/2015	46.64692	5.976246	11.4747	0.888573
04/12/2015	46.023998	6.354199	8.804151	0.845058
05/12/2015	52.646213	8.560927	16.844427	3.205805
06/12/2015	51.034671	11.38065	17.462734	0.824071
07/12/2015	6.207371	9.141669	19.189156	1.401119
09/12/2015	48.127819	4.712296	15.522936	7.131498
10/12/2015	36.240306	4.134495	10.189795	2.479121
11/12/2015	52.730666	3.559518	13.642739	2.160907
12/12/2015	29.095939	4.385056	10.283806	1.055357
13/12/2015	26.783285	5.423159	8.809693	0.447361
14/12/2015	31.232082	7.789411	14.422253	0.385231
15/12/2015	27.15313	9.628673	15.576542	1.254371
16/12/2015	24.142448	9.766028	33.04187	6.682029
17/12/2015	16.072609	13.80522	11.886726	0.507329
18/12/2015	6.047222	14.15171	10.995332	0.374544
19/12/2015	10.32492	14.60715	16.528986	0.275656
20/12/2015	34.361898	7.945527	10.590038	0.720352
21/12/2015	44.811559	4.611974	12.227951	0.477044
22/12/2015	93.372789	2.601044	25.9022	2.234437
29/12/2015	56.494409	7.075732	11.696118	0.407557
30/12/2015	42.376519	7.157201	10.231136	0.651173
31/12/2015	16.594962	8.318653	12.089002	0.938239
01/01/2016	20.805068	8.758643	11.247864	0.419443
02/01/2016	16.812722	7.596727	13.603447	0.277676
03/01/2016	17.968534	7.787753	7.007154	0.692212
04/01/2016	24.531823	7.692285	10.549796	0.302315
05/01/2016	66.614342	6.043045	5.337047	0.45106
06/01/2016	11.047309	6.490116	20.549372	1.509445
07/01/2016	23.847565	7.507803	13.662518	0.632563

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
08/01/2016	41.183421	8.675835	7.927099	0.326935
09/01/2016	92.204677	5.958602	12.553708	0.455365
10/01/2016	9.693857	6.290779	9.019755	0.34559
11/01/2016	32.995144	6.269666	8.055334	0.857146
12/01/2016	13.864629	10.43177	11.398109	0.446283
13/01/2016	11.021775	9.132923	11.491007	0.553516
14/01/2016	50.378998	11.86313	8.681146	0.594545
15/01/2016	45.940147	11.53192	6.769002	1.076085
16/01/2016	39.888491	10.53745	5.641162	0.466469
17/01/2016	39.910025	8.186956	8.4055	3.313752
18/01/2016	71.444126	6.950354	11.736019	1.071081
19/01/2016	35.448454	4.213469	11.024107	0.681481
20/01/2016	30.33252	5.412348	13.849767	0.642708
21/01/2016	48.68707	7.76701	13.864453	0.466159
22/01/2016	45.891245	7.981561	13.073694	0.141841
26/01/2016	29.587939	6.165667	10.730249	2.174978
27/01/2016	6.645848	9.063813	12.732668	1.218596
28/01/2016	10.407031	7.325676	9.289454	2.543467
29/01/2016	19.445979	5.917545	8.370428	1.124573
31/01/2016	15.09631	9.387582	12.851474	1.116798
01/02/2016	6.587829	10.81812	22.653065	2.752442
02/02/2016	12.07643	8.420034	8.888936	0.933543
03/02/2016	16.630272	7.936291	11.81423	0.571674
04/02/2016	18.675019	7.530562	14.274423	0.756855
05/02/2016	27.207001	6.134128	10.559216	0.507004
06/02/2016	29.061476	5.968741	10.03298	1.662713
07/02/2016	29.688718	6.736864	7.494262	1.619571
08/02/2016	23.574927	9.017248	9.94299	4.092958
09/02/2016	34.107147	9.540719	4.260601	1.42279
10/02/2016	46.057278	9.985377	5.831698	2.274058
11/02/2016	39.385232	9.038747	7.841696	4.064013
12/02/2016	47.455406	8.577326	17.081719	0.600028
13/02/2016	20.521347	10.73229	13.5529	0.412855
14/02/2016	26.475361	10.37218	11.563991	0.711463
15/02/2016	1.914932	9.02554	20.399617	1.28886
18/02/2016	40.73625	4.8568	9.966768	1.059153
01/03/2016	33.166163	7.917197	19.687466	0.355335
02/03/2016	17.682048	8.783678	19.923165	0.520007
03/03/2016	41.215616	6.087216	19.019665	112.9845
04/03/2016	45.997916	5.087153	7.668064	65.11036
05/03/2016	8.395458	5.594763	4.624157	2.233219
06/03/2016	42.802244	3.503892	8.344279	0.814175
07/03/2016	50.223779	2.149138	17.309069	0.724359
08/03/2016	29.981562	4.179459	21.540739	0.974271
09/03/2016	30.334607	6.025453	21.997973	0.857078
10/03/2016	15.116677	7.840856	18.020051	0.502597

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
11/03/2016	29.014361	9.017655	15.424337	0.446478
12/03/2016	3.378054	9.044316	12.04702	0.550689
13/03/2016	7.845544	7.053707	15.574423	0.24548
14/03/2016	13.534353	7.031111	12.984909	0.297453
15/03/2016	20.754383	7.268276	7.874766	0.697329
16/03/2016	15.261337	9.301539	13.064508	0.773304
17/03/2016	20.312806	9.478517	13.325066	14.32901
18/03/2016	30.306332	6.729965	8.107825	2.157563
19/03/2016	26.097977	6.03934	5.171552	0.673133
20/03/2016	57.977613	2.970223	8.224954	0.301373
26/03/2016	13.101861	7.593318	7.613187	1.016609
27/03/2016	5.068229	5.886832	10.130918	0.638839
28/03/2016	22.224782	7.558886	10.828898	0.954751
29/03/2016	5.399115	8.397154	8.937184	0.811514
30/03/2016	24.006175	5.324325	9.91337	0.635069
01/04/2016	16.471247	7.496091	15.268639	1.5484
02/04/2016	21.34523	6.421791	7.143376	0.648967
03/04/2016	87.940485	3.581545	11.975295	0.659249
04/04/2016	48.418337	6.269508	12.566537	0.386606
05/04/2016	91.773108	6.453926	16.339211	0.522606
06/04/2016	72.632409	7.350994	23.15788	1.370312
07/04/2016	56.24074	6.17123	21.007101	1.141234
10/04/2016	28.544602	5.647961	9.565912	0.412863
11/04/2016	16.231953	5.57013	7.168164	0.771402
12/04/2016	23.334364	6.525857	11.747905	0.325434
13/04/2016	9.438176	5.77178	10.436342	0.504064
14/04/2016	38.866494	5.254757	13.418295	0.376944
15/04/2016	92.612081	5.324611	20.32085	0.550468
25/04/2016	21.279134	8.388826	10.600162	0.483071
26/04/2016	6.21494	9.664736	11.542516	0.609807
27/04/2016	6.654327	10.76875	8.484505	2.992713
28/04/2016	34.048358	10.59496	6.030377	1.149603
29/04/2016	24.296936	8.013132	5.186001	0.589053
30/04/2016	61.37444	8.119246	10.774255	0.836645
01/05/2016	16.660597	7.998141	9.362021	0.341631
02/05/2016	33.949595	6.491493	20.092494	1.169084
03/05/2016	58.589107	3.252123	6.746312	0.448427
04/05/2016	26.565361	3.826794	9.512367	0.519919
05/05/2016	43.703665	6.98739	8.997235	1.697962
06/05/2016	24.451708	7.666584	9.410069	0.519825
07/05/2016	43.981678	6.103948	5.697838	0.264814
08/05/2016	82.683676	5.167023	18.424875	1.104439
09/05/2016	88.785308	3.451454	17.828142	0.738119
12/05/2016	78.225909	3.134091	7.835982	2.460168
13/05/2016	53.776814	5.384788	9.387547	0.28015
14/05/2016	14.759694	8.052544	15.142089	0.457288

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (μg/m3)
15/05/2016	9.863112	9.410339	16.922841	0.557658
16/05/2016	3.321029	11.09763	14.43001	0.416403
17/05/2016	39.614849	6.334835	18.61044	1.022063
25/05/2016	8.495145	10.33271	8.69671	1.741003
26/05/2016	38.891838	5.935633	11.27392	1.113955
27/05/2016	82.712196	3.719183	14.730798	0.979146
28/05/2016	59.69116	4.139731	11.381456	0.627408
29/05/2016	1.58702	9.264134	5.347995	0.898052
30/05/2016	10.175979	9.102777	6.584947	1.549694
31/05/2016	18.854549	9.780081	9.639802	0.411343
01/06/2016	11.225335	12.45203	6.425582	0.524118
02/06/2016	10.395155	11.82309	8.071915	0.612037
03/06/2016	26.497303	12.59702	6.64927	0.643434
04/06/2016	39.6015	11.94517	7.994155	0.261556
05/06/2016	17.129067	13.61702	5.062955	0.181503
06/06/2016	26.746975	10.99467	8.640651	0.238482
07/06/2016	51.206334	12.47285	9.243113	0.444355
08/06/2016	26.097415	11.61648	8.673841	0.12648
09/06/2016	9.118572	13.9367	5.937503	0.206577
10/06/2016	22.804658	12.7469	10.632091	0.32
11/06/2016	78.280248	9.794215	15.291729	0.32
12/06/2016	49.45514	13.03158	27.87717	0.32
13/06/2016	47.327082	11.45869	14.189787	0.32
14/06/2016	19.288314	14.16938	17.025129	1.01622
15/06/2016	51.384939	11.61575	14.262177	2.882635
16/06/2016	71.643226	9.051373	8.424126	0.93916
23/06/2016	17.387589	17.52861	13.258749	22.40217
24/06/2016	28.978734	18.78237	12.276425	20.71852
25/06/2016	28.345989	19.03736	11.997551	25.59918
26/06/2016	32.15971	16.91705	8.867157	23.39391
27/06/2016	20.106076	13.40431	9.095798	4.494193
28/06/2016	26.697412	12.39246	10.78314	0.279084
29/06/2016	20.949668	14.07487	12.224372	2.62185
30/06/2016	54.199472	12.75759	14.462233	6.495647
01/07/2016	38.07036	12.02515	9.815698	4.327736
02/07/2016	23.093807	13.79778	15.516609	0.360859
03/07/2016	16.68677	13.43564	12.460292	0.419819
04/07/2016	11.963072	13.98187	10.427891	0.153789
05/07/2016	10.627828	14.32959	7.329686	0.169087
06/07/2016	5.034131	14.12535	4.848792	0.206921
07/07/2016	6.807177	13.18225	12.738935	0.412093
08/07/2016	27.394353	13.58973	26.423869	5.632656
09/07/2016	17.340508	16.03782	19.788637	1.022464
10/07/2016	36.576271	14.94901	20.181154	1.383083
11/07/2016	34.482252	14.57479	19.255119	0.471791
12/07/2016	27.094701	15.18199	27.633053	1.143624

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
13/07/2016	8.731556	17.68411	15.313064	4.667933
14/07/2016	15.644635	17.12438	6.978363	22.41128
15/07/2016	10.074701	18.93174	5.088816	12.8785
16/07/2016	10.847142	19.46935	9.014883	13.04665
17/07/2016	10.776975	16.00291	5.92512	10.87805
18/07/2016	13.260171	15.54516	5.551105	1.587357
19/07/2016	16.22776	15.46138	9.590546	0.342175
20/07/2016	9.675115	21.08768	13.320037	3.672772
21/07/2016	55.428157	19.85236	9.749843	28.89244
22/07/2016	52.51944	20.83307	14.475216	48.19669
23/07/2016	42.721238	18.45067	9.023634	40.6923
24/07/2016	9.625884	18.82423	9.666	4.252027
25/07/2016	20.330751	22.5557	12.985247	23.27825
26/07/2016	24.535152	21.09813	12.033802	18.64213
28/07/2016	13.056915	18.57258	17.1466	9.765164
29/07/2016	14.576856	17.16002	8.367545	5.932686
30/07/2016	37.320647	17.68491	6.605473	7.883489
31/07/2016	43.018493	17.36695	6.10719	3.782391
01/08/2016	25.527813	17.28551	3.911899	54.9416
02/08/2016	4.638878	17.00411	7.877598	10.66208
03/08/2016	8.513395	15.12913	8.61827	2.344477
04/08/2016	17.751874	20.45342	10.396417	6.146475
05/08/2016	19.811895	23.18658	11.76593	23.0916
06/08/2016	23.292784	22.53154	9.357898	25.6163
07/08/2016	14.749268	20.33135	10.100698	17.47606
08/08/2016	55.198178	14.88973	14.686218	1.159116
09/08/2016	30.147628	17.26843	13.390666	1.342117
10/08/2016	24.99811	21.56439	10.814663	18.41469
11/08/2016	24.924484	20.61901	11.884848	30.59984
12/08/2016	24.501031	20.18794	11.632968	14.03198
13/08/2016	24.754614	18.99268	13.525575	11.93876
14/08/2016	11.51265	15.04412	13.222571	2.537557
15/08/2016	58.569933	11.27516	27.405153	5.945161
16/08/2016	23.550259	14.46449	13.59142	2.975971
21/08/2016	30.662627	15.34898	20.792624	2.895162
22/08/2016	45.412019	17.01027	18.744582	14.27902
23/08/2016	39.06286	18.4971	7.335654	12.68563
24/08/2016	34.955044	18.38428	6.440197	15.14144
25/08/2016	14.316824	13.83062	8.073687	7.394381
26/08/2016	23.263996	13.5657	13.38832	1.436236
27/08/2016	15.4739	17.43907	11.135426	0.57623
28/08/2016	63.136958	16.63794	9.537242	29.89419
29/08/2016	46.596949	17.11952	8.205995	13.06659
30/08/2016	27.364126	20.86162	10.570795	11.85139
31/08/2016	54.335466	15.62028	17.282888	11.47364
01/09/2016	28.607669	14.12363	14.002983	9.187269

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
02/09/2016	23.557	14.12238	13.662087	0.494557
03/09/2016	11.031843	13.65981	8.863791	4.247908
04/09/2016	15.037082	14.201	7.543452	0.537469
05/09/2016	11.348595	12.65778	4.863434	1.122976
06/09/2016	7.254272	15.02378	7.068505	0.697394
07/09/2016	10.114287	15.10229	8.007639	0.418545
08/09/2016	44.50046	16.36824	4.051777	0.716052
09/09/2016	55.937884	15.87221	4.136238	2.385795
10/09/2016	25.796376	15.20046	4.646947	1.446662
11/09/2016	19.698677	13.32341	6.263905	0.519575
12/09/2016	19.518976	14.69153	8.4612	0.513368
13/09/2016	46.550739	13.30802	15.314349	6.701063
14/09/2016	24.990222	12.63063	4.918541	0.508389
15/09/2016	31.56191	12.3004	14.209616	1.298966
16/09/2016	27.787823	13.89468	15.258095	0.706623
17/09/2016	16.486007	13.08019	13.241098	0.903286
18/09/2016	15.595452	13.01772	5.603739	2.224808
19/09/2016	27.383724	12.75682	13.256209	0.859766
20/09/2016	13.046257	10.69536	6.086495	0.551678
21/09/2016	15.25423	9.967978	5.36804	0.721831
22/09/2016	6.23103	11.68484	9.828041	0.555731
23/09/2016	27.669849	11.4392	10.960875	0.490971
24/09/2016	21.426825	13.2632	14.117139	0.393876
25/09/2016	28.989021	11.51532	18.429287	0.3553
26/09/2016	48.661031	12.82535	26.534609	1.940385
27/09/2016	15.248093	14.91749	9.588494	1.124722
28/09/2016	26.072843	14.30841	5.58762	0.41493
29/09/2016	25.245475	15.04091	12.53456	0.70467
30/09/2016	27.291535	12.54201	9.863708	4.946753
01/10/2016	12.573796	10.60553	10.913184	0.539158
02/10/2016	15.265137	10.2073	10.112529	0.711173
03/10/2016	22.591222	10.56498	7.113148	0.498468
04/10/2016	54.891737	8.36628	16.108301	0.512082
05/10/2016	63.970621	9.344945	24.049029	8.535738
06/10/2016	55.927474	11.14	26.915754	7.226497
07/10/2016	40.393092	10.17473	17.02911	8.569881
08/10/2016	19.243213	10.48725	11.331206	0.677301
09/10/2016	21.232487	12.72853	6.790188	0.624263
10/10/2016	18.317391	13.16498	4.727774	0.350756
11/10/2016	24.097111	12.45039	8.619715	0.272568
12/10/2016	21.899115	11.25727	7.598348	0.288887
13/10/2016	81.275578	8.391729	9.926987	1.8666
14/10/2016	39.258617	8.546787	7.649854	1.097336
16/10/2016	72.658405	9.56448	17.646726	5.958367
18/10/2016	66.110978	11.51837	17.519386	2.798947
19/10/2016	67.50379	10.50892	10.549549	3.294323

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
20/10/2016	75.377462	10.04351	8.368479	5.021592
21/10/2016	78.348668	7.935899	10.483198	4.059871
22/10/2016	76.239103	7.891831	10.297878	2.040434
23/10/2016	74.072713	7.142059	11.581295	1.27683
29/10/2016	60.306901	7.224607	11.983662	1.130013
30/10/2016	38.2901	9.06701	21.585515	1.546681
31/10/2016	47.794314	9.929924	19.36532	0.387235
01/11/2016	33.567745	8.294194	7.829111	0.795936
02/11/2016	42.87599	9.435496	13.645052	0.691992
03/11/2016	64.234139	7.253275	6.516266	1.702278
04/11/2016	99.98955	4.64613	16.764476	0.480584
07/11/2016	87.662211	4.258954	9.158944	0.706578
08/11/2016	47.740271	7.00218	15.328374	1.096132
09/11/2016	47.008588	6.81928	9.907488	0.808051
10/11/2016	9.875684	10.99191	14.469893	0.496152
11/11/2016	20.01512	11.17548	16.579038	0.283375
12/11/2016	66.649968	8.202931	30.780844	1.807016
17/11/2016	38.364022	7.113578	15.676492	7.154721
18/11/2016	47.318848	10.10985	9.901564	3.167602
19/11/2016	54.814332	9.157694	10.667444	9.555663
20/11/2016	68.731232	7.002156	6.880445	8.270465
21/11/2016	69.122585	6.956563	6.289768	5.751819
22/11/2016	78.502789	5.2167	11.590507	0.996515
24/11/2016	38.366462	2.942128	9.449416	1.051076
25/11/2016	74.457866	1.405729	9.101383	0.876485
26/11/2016	99.327347	3.293803	14.568808	0.343945
27/11/2016	82.811317	2.806494	8.079542	0.270808
28/11/2016	41.482295	3.754475	6.694889	0.182329
29/11/2016	36.106124	4.066808	3.924434	0.453094
01/12/2016	17.014911	6.046066	12.008323	0.609826
05/12/2016	75.361841	6.841249	4.03341	0.674121
06/12/2016	53.255129	10.43768	14.692679	0.611431
07/12/2016	49.43069	9.079969	9.621189	0.420942
08/12/2016	23.322768	11.30161	15.41914	0.574327
09/12/2016	20.071657	10.41296	18.029052	0.532993
10/12/2016	26.494715	6.945806	7.957768	0.474235
11/12/2016	66.365311	4.193746	5.598488	2.037501
12/12/2016	72.409146	2.727981	10.478353	0.467355
16/12/2016	14.411305	7.232265	9.438612	1.062987
17/12/2016	79.722638	2.751641	21.798384	2.735815
21/12/2016	91.568919	2.299439	8.950868	1.189663
24/12/2016	81.60774	1.405866	11.222401	5.240878
25/12/2016	77.952312	2.503495	23.174388	7.692569
26/12/2016	53.971225	3.936791	11.157396	7.035061
27/12/2016	52.277795	3.9263	14.142662	46.46232
28/12/2016	64.226473	6.066834	15.622578	16.56308

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
29/12/2016	49.575146	6.562435	12.044929	5.835915
30/12/2016	36.57308	7.243136	17.061726	4.755085
31/12/2016	40.656022	7.468032	17.079452	3.006219
01/01/2017	39.818933	5.618433	23.378448	2.774345
02/01/2017	46.869807	4.538257	20.558832	23.79408
03/01/2017	54.390033	4.575619	19.396045	1.6178
04/01/2017	20.808112	6.513452	16.046949	3.100881
05/01/2017	41.817956	4.984361	30.528438	14.06939
09/01/2017	27.271405	5.490999	20.659979	14.14718
10/01/2017	44.847731	6.652437	5.014897	7.348122
15/01/2017	30.906622	7.058038	15.540426	1.83506
16/01/2017	9.43504	7.055815	18.779254	0.706375
17/01/2017	16.419703	4.924166	14.267683	0.504426
18/01/2017	15.293645	2.711936	8.616447	1.602261
19/01/2017	31.928353	4.902884	8.886338	1.685813
20/01/2017	41.901445	2.651609	13.807486	0.780835
21/01/2017	87.978788	1.398328	10.366248	1.34495
23/01/2017	84.31362	2.596421	14.730983	0.084906
24/01/2017	31.709786	5.21511	15.768547	0.292192
25/01/2017	20.74599	4.507456	8.542496	0.518981
26/01/2017	43.023859	3.88612	9.626091	0.395466
27/01/2017	21.45335	5.044629	9.397158	0.861511
28/01/2017	43.303407	6.662379	6.491472	0.234345
29/01/2017	9.359379	5.65541	7.852461	0.250256
30/01/2017	27.447525	5.18149	12.742503	0.367683
31/01/2017	75.90904	5.162256	12.031343	0.95395
01/02/2017	29.467357	3.291075	14.790061	0.717154
02/02/2017	87.079973	3.966598	10.801061	0.481399
03/02/2017	28.508155	6.37348	10.269207	0.634615
04/02/2017	12.085997	6.538881	7.027928	0.723968
05/02/2017	12.997122	7.168531	9.96966	0.471602
06/02/2017	32.58055	7.944207	10.248679	0.350271
07/02/2017	11.048291	8.808042	12.513591	0.687523
08/02/2017	15.341709	7.327283	9.733219	0.274362
09/02/2017	24.736757	5.154925	8.479941	0.189285
14/02/2017	71.078058	1.58048	7.93036	0.427305
15/02/2017	91.708385	4.03845	11.915152	0.540231
16/02/2017	78.229773	4.019489	7.876358	0.241134
17/02/2017	51.648503	6.199713	15.840506	0.543766
18/02/2017	52.692997	7.286451	16.264983	8.996694
19/02/2017	15.053968	7.687828	16.856644	0.759042
20/02/2017	65.495077	3.598217	15.707706	0.983132
22/02/2017	73.553727	2.376837	11.00388	66.23167
23/02/2017	57.208942	4.030592	10.118226	35.37974
24/02/2017	50.820991	3.116404	13.136797	8.439529
25/02/2017	37.22145	2.791753	12.837771	31.43688

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
26/02/2017	27.880945	5.533424	20.315565	1.29551
27/02/2017	15.308788	6.659432	12.703614	0.661717
28/02/2017	17.228429	6.512659	8.978042	0.448029
01/03/2017	17.868546	7.430104	12.864534	0.302438
02/03/2017	22.00921	10.00424	17.814105	18.06539
03/03/2017	41.73948	4.952108	13.695201	7.360212
04/03/2017	22.197409	4.373917	13.717356	0.836804
05/03/2017	52.416707	7.882333	19.632647	1.589639
06/03/2017	37.810726	11.67447	24.591405	1.459082
07/03/2017	32.284095	10.61706	11.983552	6.325058
08/03/2017	28.270994	12.08029	13.250181	12.66971
09/03/2017	25.3349	11.99818	11.673899	12.30441
10/03/2017	32.072331	11.69605	12.50518	8.988465
15/03/2017	8.069141	6.91033	5.588552	0.81618
16/03/2017	88.587263	1.771938	11.429676	2.681076
21/03/2017	21.312135	5.736069	11.20005	4.116905
22/03/2017	6.799858	6.919454	12.995233	1.530553
23/03/2017	11.347311	6.30926	19.03849	1.60325
24/03/2017	18.680356	4.009249	20.542185	1.607726
25/03/2017	43.274192	6.723592	9.81609	1.1003
26/03/2017	25.696114	2.842275	5.042175	0.612826
27/03/2017	39.031517	3.745072	7.137482	0.561344
28/03/2017	26.304245	4.984422	5.997261	0.329215
29/03/2017	35.968922	5.903121	9.04137	0.58759
30/03/2017	37.33992	7.173075	9.577069	1.002381
31/03/2017	11.686712	10.6562	11.225281	1.103575
01/04/2017	24.422589	13.93663	14.448858	8.772982
02/04/2017	13.081379	13.95913	12.312286	9.328983
03/04/2017	10.174601	13.459	10.567361	7.191235
04/04/2017	22.112757	13.58202	15.554707	5.236226
05/04/2017	24.594326	10.84409	14.652238	0.837351
06/04/2017	20.433477	7.387531	8.046487	0.933199
07/04/2017	18.303076	6.496409	10.2491	0.622099
08/04/2017	14.678225	7.340987	11.201971	0.376422
14/04/2017	35.185552	9.257252	18.17338	6.916993
15/04/2017	47.816334	9.725244	13.476768	7.944779
16/04/2017	32.922403	11.90272	14.980202	10.97175
17/04/2017	27.209015	12.65219	11.62092	13.20403
18/04/2017	24.548826	13.12997	17.017893	13.5255
19/04/2017	2.60623	12.20015	13.535927	2.971404
20/04/2017	19.347301	10.40523	6.956896	4.47038
21/04/2017	9.90082	7.836189	8.585603	0.849179
22/04/2017	65.358208	7.219858	9.522216	0.918521
23/04/2017	62.909178	6.512018	11.747724	0.354073
24/04/2017	47.108648	5.958245	7.339689	0.886108
25/04/2017	42.297468	9.08884	8.21964	1.284243

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
26/04/2017	98.810526	6.838933	22.385463	1.451943
30/04/2017	95.344761	7.234382	8.403461	1.559251
01/05/2017	37.337896	8.602455	11.622696	1.039969
02/05/2017	43.81043	8.704206	6.097891	1.033211
03/05/2017	18.140426	11.48322	9.671237	1.002604
04/05/2017	30.281254	11.31471	14.729409	0.550036
05/05/2017	62.669044	2.918568	13.891855	1.361245
06/05/2017	22.700281	8.83354	8.511688	0.796243
07/05/2017	10.846348	9.593044	9.840289	0.701333
14/05/2017	33.165281	11.05968	16.078991	0.904989
15/05/2017	29.28139	15.17962	9.950228	1.030046
16/05/2017	23.38204	14.20712	10.451595	0.62301
17/05/2017	18.810304	14.09755	8.995911	0.848397
18/05/2017	27.078027	13.07896	18.364439	1.082805
19/05/2017	27.346908	12.24929	7.746072	19.58855
20/05/2017	25.586615	13.91368	6.902557	5.157343
21/05/2017	13.516388	12.17514	11.306712	0.973182
22/05/2017	14.885499	10.3878	8.951061	0.626215
23/05/2017	15.701403	9.803871	9.413808	0.567414
24/05/2017	4.708499	10.61733	7.895762	1.119459
25/05/2017	19.305263	10.15901	7.170692	1.871538
26/05/2017	71.982856	8.830197	7.139203	1.396402
27/05/2017	0.455021	10.80212	12.175991	0.956864
28/05/2017	41.023528	11.39876	4.969292	0.72
29/05/2017	62.514056	11.17471	4.419851	1.061994
30/05/2017	10.276086	14.02396	11.65084	0.653187
31/05/2017	28.031743	11.25427	13.384263	4.189099
01/06/2017	23.707278	12.72874	11.78934	0.488472
02/06/2017	14.797096	15.28414	12.933874	0.631775
03/06/2017	31.290425	12.4267	16.712636	0.402793
04/06/2017	27.166018	11.21701	11.627632	0.541785
05/06/2017	2.738861	13.65868	15.323194	0.681234
06/06/2017	12.319472	14.49408	18.197854	0.90348
07/06/2017	25.509231	19.79365	13.380918	0.429833
12/06/2017	17.004187	11.16263	9.407004	6.851992
13/06/2017	4.481826	12.26401	3.415169	1.264962
14/06/2017	0.940758	12.43536	5.179625	0.552211
15/06/2017	42.247794	11.97297	15.941834	1.790629
16/06/2017	28.413965	13.25838	18.711804	2.32013
17/06/2017	5.246952	14.01807	8.954087	1.161116
18/06/2017	2.194019	16.37504	9.534567	0.588853
19/06/2017	9.070006	14.62885	6.306621	0.574468
20/06/2017	14.545536	15.48273	7.03607	1.552455
21/06/2017	5.665451	15.36603	13.286745	0.511312
22/06/2017	42.677759	17.28992	18.158556	22.25851
23/06/2017	28.166142	19.2376	15.041779	22.95952

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
24/06/2017	41.040696	18.59659	10.677773	61.43209
25/06/2017	30.634112	19.86167	8.891537	22.84839
26/06/2017	56.574889	17.18389	10.89271	30.41501
27/06/2017	48.534618	17.64185	9.616063	16.99592
28/06/2017	47.646555	16.86312	3.584797	8.1462
29/06/2017	11.064201	15.42655	6.278604	1.803641
30/06/2017	2.545583	14.78416	19.303805	4.585804
01/07/2017	1.960776	14.10142	20.00904	1.879823
02/07/2017	2.032526	15.81121	13.84775	0.685848
03/07/2017	17.176263	16.06761	6.151373	0.984528
04/07/2017	8.97675	15.95804	5.890449	2.001211
05/07/2017	23.786411	12.42529	11.965833	4.00878
06/07/2017	22.967843	12.12678	13.354628	4.055608
12/07/2017	0.871042	14.32265	11.181756	1.630775
13/07/2017	8.790308	16.60082	10.863876	0.639035
14/07/2017	2.717818	19.94102	11.401523	0.623844
15/07/2017	5.932736	21.55343	10.256731	13.57447
16/07/2017	12.585925	20.16413	7.421301	30.4602
17/07/2017	27.248486	19.77937	6.985111	70.20468
18/07/2017	16.594541	19.14058	5.827663	43.76162
19/07/2017	9.827439	19.66923	10.507467	14.15977
20/07/2017	11.356014	19.27387	8.769201	3.660318
21/07/2017	48.880278	15.13464	12.204508	1.500831
22/07/2017	12.523786	13.06158	14.421692	1.829302
23/07/2017	10.477288	15.01671	12.510693	0.965282
24/07/2017	7.217831	16.44892	10.817198	0.760821
25/07/2017	28.75299	21.49865	10.407757	21.77143
26/07/2017	35.396277	20.76882	7.395407	59.23433
27/07/2017	34.590771	19.80374	8.874296	71.02276
28/07/2017	25.495363	19.1273	4.841984	77.90185
29/07/2017	22.715481	21.4032	7.140294	20.43755
30/07/2017	16.418064	19.91277	6.062277	16.86896
31/07/2017	14.70053	15.76019	4.900801	1.400096
01/08/2017	34.223093	13.68762	10.103693	2.575236
11/08/2017	14.108181	20.33589	13.918226	18.75685
12/08/2017	8.783104	19.75548	13.273145	5.492725
13/08/2017	14.236408	18.10269	9.749902	24.11198
14/08/2017	28.857903	16.63056	11.688295	17.66732
15/08/2017	7.052798	17.17349	13.145012	1.166195
16/08/2017	12.50548	19.27176	11.905699	0.774004
17/08/2017	8.760674	20.5486	8.040295	2.945319
18/08/2017	30.52207	20.19658	7.595146	11.43243
19/08/2017	8.785805	21.86938	19.357056	10.91082
20/08/2017	0.731582	20.9216	12.689554	1.614531
21/08/2017	11.487588	22.14149	7.402735	18.91282
22/08/2017	24.312077	20.99048	5.371372	53.4167

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
23/08/2017	19.335412	21.2011	15.996613	48.24822
24/08/2017	20.150449	22.01655	8.06238	25.77796
25/08/2017	15.414782	20.17207	10.848271	18.08042
26/08/2017	45.265507	17.78002	6.097396	41.59419
27/08/2017	35.664223	17.25605	5.052917	36.04513
28/08/2017	32.250141	15.4067	5.60019	19.8609
29/08/2017	9.947448	14.87496	4.593848	1.947459
30/08/2017	22.746693	12.60353	14.146529	1.706242
31/08/2017	32.879626	13.30531	23.693743	6.096671
01/09/2017	30.686137	13.53387	13.665587	0.8543
02/09/2017	11.136841	15.64271	9.671195	0.794566
03/09/2017	15.289942	16.08622	10.303156	0.58836
04/09/2017	19.557095	18.44526	9.969076	1.550599
09/09/2017	24.432798	18.7525	4.637428	10.39484
10/09/2017	15.918465	16.26565	3.773292	2.28888
11/09/2017	37.721622	13.3599	10.634788	1.47259
12/09/2017	23.818092	13.10042	11.367899	0.491325
14/09/2017	31.42209	13.68535	16.141453	0.314554
15/09/2017	25.643573	14.96708	12.3284	4.84889
16/09/2017	34.032172	16.88465	10.304008	4.872538
17/09/2017	40.942958	15.05842	16.170781	7.796308
18/09/2017	38.959862	16.28163	10.842003	12.57884
19/09/2017	24.890318	18.10013	6.317444	28.28455
20/09/2017	24.722586	17.24474	8.00899	23.7622
21/09/2017	21.807543	12.92871	9.978694	0.735644
22/09/2017	47.12074	9.573765	18.330987	2.017512
23/09/2017	16.145481	13.7991	15.859963	0.934049
24/09/2017	36.983059	15.00414	21.684218	45.07688
25/09/2017	54.302792	14.46753	18.768474	11.91353
26/09/2017	59.34172	13.21635	13.642253	4.952622
27/09/2017	65.119578	12.05562	14.995021	8.707213
28/09/2017	74.957789	11.24137	12.45107	6.052434
29/09/2017	56.874459	9.774592	5.083207	8.136771
30/09/2017	36.175934	11.41133	14.30788	1.127284
01/10/2017	33.575756	13.21652	18.420553	2.777985
02/10/2017	23.204358	13.17256	12.747663	0.932421
03/10/2017	24.732248	14.40467	13.184612	0.788274
04/10/2017	12.770227	13.99644	11.358835	1.882455
08/10/2017	55.012805	7.309496	6.740613	2.632247
09/10/2017	36.610528	7.710742	5.101188	2.488444
11/10/2017	19.625116	11.51992	9.250636	8.5508
12/10/2017	32.259738	14.60862	23.628791	10.31801
13/10/2017	27.087214	16.51642	15.004295	28.35166
14/10/2017	27.777478	16.45646	15.246508	68.07919
15/10/2017	34.716819	15.20997	15.52605	25.72086
16/10/2017	29.977812	13.66473	24.357484	17.87298

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
17/10/2017	31.345376	11.82066	16.529103	23.37523
18/10/2017	30.401103	9.749255	7.252522	4.403892
19/10/2017	41.155002	9.713219	7.583961	2.117547
20/10/2017	19.714965	10.31026	10.588723	1.527365
21/10/2017	8.806235	11.31581	14.475693	2.416238
22/10/2017	41.578321	11.09774	19.251182	3.509901
23/10/2017	21.81345	12.06493	11.576781	2.447037
24/10/2017	33.599828	12.04934	22.955017	5.482581
25/10/2017	32.908265	13.12794	15.371173	8.28887
26/10/2017	39.63981	13.74579	18.148965	5.487879
27/10/2017	35.7465	12.48159	20.447492	4.878516
28/10/2017	13.476519	14.58784	11.673833	5.985154
29/10/2017	11.932778	13.24783	11.179432	8.55322
30/10/2017	11.983521	12.60697	13.207012	1.204159
31/10/2017	15.190126	11.59046	10.292257	0.384601
01/11/2017	9.845625	10.93619	11.073318	1.287661
02/11/2017	8.176979	11.49178	6.451608	0.71616
06/11/2017	99.920687	4.800575	27.380364	1.223899
07/11/2017	100	5.502188	18.870138	0.993087
08/11/2017	87.029225	7.025589	17.597388	3.04026
09/11/2017	92.237042	7.530934	25.725969	6.402668
10/11/2017	33.327935	9.86736	18.02969	2.091876
11/11/2017	53.679804	11.26909	19.266346	3.564603
12/11/2017	32.896947	13.7592	11.689716	12.61418
13/11/2017	44.837635	10.56657	6.574191	7.583968
14/11/2017	61.889059	9.127781	12.608063	5.225948
15/11/2017	59.158017	9.391434	16.357986	8.917058
16/11/2017	52.63416	8.788567	7.030252	6.301795
17/11/2017	54.006299	9.323461	11.034484	5.522722
18/11/2017	58.950557	8.264544	13.080771	3.904184
19/11/2017	51.973825	6.509876	10.269475	2.87168
20/11/2017	50.901631	6.488839	14.494954	2.783793
21/11/2017	30.308765	7.232619	18.804098	11.06161
22/11/2017	30.307619	7.113019	24.64785	5.969064
23/11/2017	60.73453	7.880345	20.147192	3.123921
24/11/2017	31.589155	9.444027	13.746759	2.505398
29/11/2017	76.860122	7.390618	20.157216	1.910547
02/12/2017	80.083361	6.768136	4.46786	0.728291
06/12/2017	11.516075	6.291152	12.475195	5.383578
07/12/2017	4.101617	7.855854	18.084215	3.071999
08/12/2017	2.501906	8.797233	15.170699	4.39996
09/12/2017	8.415538	9.34117	20.752889	3.190734
10/12/2017	14.376153	7.157557	9.601936	0.529526
11/12/2017	23.650196	7.42433	7.195627	0.941186
15/12/2017	33.101047	6.192881	19.923064	2.578226
16/12/2017	74.365522	5.116241	13.66754	1.609899

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
18/12/2017	3.976807	9.421397	24.951715	2.646495
19/12/2017	7.174927	7.403367	14.799167	1.710606
20/12/2017	2.892661	8.064558	13.470978	1.14174
21/12/2017	8.689873	7.837386	22.423277	2.056718
22/12/2017	4.623002	9.003653	19.141657	2.947767
23/12/2017	17.657694	6.103245	15.028781	0.615875
24/12/2017	7.240858	5.449108	17.548408	0.528449
25/12/2017	6.330386	4.104102	12.130242	0.435676
26/12/2017	18.368342	1.892169	10.368308	0.399906
27/12/2017	5.313513	3.842874	11.706499	0.479928
28/12/2017	25.591559	7.504624	17.606713	1.167644
29/12/2017	18.378425	8.435511	11.863229	0.304219
30/12/2017	10.396332	9.995391	12.662452	0.256694
05/01/2018	33.780111	6.747961	15.139099	0.431059
06/01/2018	57.953205	3.703723	14.527642	3.367437
10/01/2018	64.381947	7.790927	5.450125	0.601039
11/01/2018	20.758594	9.281025	9.763797	1.152318
12/01/2018	33.281476	9.311132	7.74381	0.737594
13/01/2018	13.596895	9.928914	7.217617	0.824416
14/01/2018	72.148824	4.66709	14.09374	1.160722
15/01/2018	43.331323	2.735278	14.876925	0.819498
19/01/2018	28.796093	4.572922	19.861036	3.105787
20/01/2018	30.540203	7.221396	21.912657	1.231286
21/01/2018	19.599527	7.632829	17.427463	1.1193
22/01/2018	4.027506	8.076064	13.149374	2.788894
23/01/2018	14.473488	7.584501	16.753634	1.27463
24/01/2018	20.703519	7.735362	21.503274	0.954057
26/01/2018	0.984828	6.631956	19.251513	1.577809
27/01/2018	13.490837	7.329687	21.974655	1.405779
04/02/2018	36.178977	2.577886	22.262269	5.79
15/02/2018	34.087257	4.651664	14.23601	3.426438
16/02/2018	46.899139	1.998162	10.811786	3.856019
17/02/2018	44.536497	1.82677	10.088535	1.865667
18/02/2018	35.767868	3.448307	12.544355	0.404232
19/02/2018	81.033188	0.84031	11.929256	0.138784
20/02/2018	79.32204	0.670962	15.080658	0.290491
21/02/2018	79.988205	1.140114	14.276193	1.249369
22/02/2018	40.918111	2.767638	5.134012	0.153481
23/02/2018	50.397782	1.533099	10.752687	0.525779
24/02/2018	88.141465	0.719245	4.212851	0.240338
25/02/2018	61.361338	3.34586	25.424868	0.313525
08/03/2018	76.537333	5.743501	13.80831	0.244047
09/03/2018	83.42879	8.018458	20.786889	0.405688
11/03/2018	5.075983	7.171821	8.164927	0.435851
12/03/2018	58.487883	6.764293	8.463821	0.269649
13/03/2018	30.991221	8.285404	3.582723	1.379017

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
14/03/2018	33.370231	8.888621	10.03781	0.254568
15/03/2018	55.166226	9.084521	14.498067	4.985962
16/03/2018	81.997197	2.432536	13.555351	0.377583
17/03/2018	4.837849	4.380111	9.266257	0.663153
18/03/2018	64.043856	6.204057	11.650273	0.609031
20/03/2018	42.159693	5.447902	17.416172	1.194217
21/03/2018	5.662416	6.973511	25.516724	2.63675
22/03/2018	0.124964	7.915555	15.835186	0.549695
23/03/2018	0.86478	6.582608	10.328696	0.415448
24/03/2018	30.737527	7.108053	13.415417	0.119642
26/03/2018	46.961501	7.779508	26.539172	0.573801
27/03/2018	27.27987	10.66303	9.621867	0.307067
03/04/2018	23.395251	8.432409	7.479131	0.836695
04/04/2018	10.059903	7.181942	10.539208	0.788577
05/04/2018	4.381083	8.031076	10.215635	0.951742
06/04/2018	34.010865	6.63555	5.660383	0.726536
08/04/2018	22.939625	4.949908	19.84898	1.244689
11/04/2018	33.827938	7.224049	13.945684	1.455779
12/04/2018	54.492148	5.328168	10.04312	1.251122
16/04/2018	5.706062	9.227336	10.960789	1.430149
18/04/2018	17.098672	9.722962	10.6719	2.306245
19/04/2018	20.055367	9.144871	12.433589	2.024155
25/04/2018	68.122841	6.443055	18.49844	2.92777
26/04/2018	22.225808	7.563488	11.236308	2.424816
03/05/2018	38.896096	5.450794	6.835111	0.34791
04/05/2018	20.418317	7.258151	13.307532	0.508699
05/05/2018	14.958136	8.169622	11.717911	0.805681
07/05/2018	26.65238	4.23296	4.416248	0.621471
08/05/2018	17.739297	8.606388	10.402419	0.836871
09/05/2018	29.636096	9.435521	12.835145	1.553846
10/05/2018	26.366841	10.18323	13.704956	0.559046
11/05/2018	11.913676	12.36585	12.077843	0.74709
14/05/2018	9.288903	10.33532	10.257983	0.361989
15/05/2018	18.240099	12.45923	9.294165	1.079723
16/05/2018	39.858258	6.389301	12.832883	0.717317
17/05/2018	15.657588	8.303965	16.54875	0.568285
19/05/2018	19.793852	8.718058	9.839425	0.20091
20/05/2018	3.991715	8.111675	7.835417	1.793043
21/05/2018	21.076217	6.963791	11.592531	0.729567
23/05/2018	36.912736	6.347831	6.676822	0.423253
24/05/2018	43.46443	6.351899	8.184959	0.463231
25/05/2018	49.799268	5.809742	13.090293	0.198207
01/06/2018	19.301957	10.53459	7.640307	0.17
02/06/2018	12.983265	10.42226	8.971262	0.17
03/06/2018	20.186131	11.49885	13.530385	0.17
05/06/2018	38.19315	11.49766	6.273843	0.17

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
06/06/2018	30.222509	13.24614	9.22505	0.17
07/06/2018	27.29994	12.51287	10.806569	0.17
08/06/2018	48.414291	11.5797	8.555523	-1
09/06/2018	57.848338	9.093572	8.187079	-1
10/06/2018	33.969987	8.851956	7.20275	-1
11/06/2018	38.985605	9.242218	14.191952	-1
12/06/2018	42.856996	10.33736	15.417576	-1
13/06/2018	56.511045	9.959702	19.300024	-1
14/06/2018	11.524014	9.452297	14.898526	-1
15/06/2018	15.868697	9.537009	18.475221	-1
16/06/2018	14.999444	13.22323	19.902955	-1
17/06/2018	46.58509	10.96122	22.257256	-1
18/06/2018	43.293863	10.55885	10.149953	-1
19/06/2018	30.832706	13.66514	9.284218	-1
20/06/2018	31.843848	12.4478	4.615847	-1
21/06/2018	36.982713	14.93358	9.148054	-1
22/06/2018	35.296898	12.16038	8.083387	-1
23/06/2018	37.914954	10.54739	4.27667	-1
24/06/2018	39.612629	9.838924	6.318742	-1
25/06/2018	26.412118	11.36999	7.342766	-1
01/07/2018	40.327554	9.414525	12.129141	-1
02/07/2018	25.769764	12.81216	10.800527	-1
03/07/2018	20.6189	14.12101	7.776272	-1
04/07/2018	24.986208	18.25123	9.147703	-1
05/07/2018	5.272472	20.95404	6.939566	-1
06/07/2018	7.095455	20.17297	7.788063	-1
07/07/2018	8.29825	15.44544	11.573664	-1
08/07/2018	10.078393	16.8633	8.621354	-1
09/07/2018	18.874502	20.11643	11.82788	-1
10/07/2018	20.902803	20.09913	8.759649	-1
11/07/2018	22.343958	20.21971	4.165764	-1
12/07/2018	27.333022	17.92253	6.572727	-1
13/07/2018	7.283366	14.22737	3.653858	1.87
14/07/2018	24.398112	12.4362	6.223849	1.87
15/07/2018	14.924626	12.51617	4.746976	1.86548
16/07/2018	8.358669	15.45244	6.115945	1.838262
17/07/2018	10.744005	14.27269	13.28573	0.308204
18/07/2018	15.305083	15.39326	15.297531	0.207875
19/07/2018	11.563592	19.04728	11.047354	5.975785
20/07/2018	42.99639	18.19023	8.280248	39.94018
22/07/2018	3.309763	15.65229	5.282004	0.740215
23/07/2018	13.492041	16.02841	8.534367	0.386288
24/07/2018	13.99501	16.82693	9.264948	0.175458
25/07/2018	3.333367	17.96439	8.008271	0.627441
31/07/2018	27.972867	17.31457	4.646975	51.84525
01/08/2018	6.121478	15.81741	12.081929	5.03755

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
02/08/2018	25.81745	13.33992	8.332249	14.32556
03/08/2018	13.5167	15.49305	6.809863	0.371091
04/08/2018	17.314468	16.58564	9.817589	2.117041
06/08/2018	32.817586	19.70485	21.513412	18.3219
08/08/2018	28.209709	17.68471	10.776118	20.50714
09/08/2018	10.979031	15.55903	7.833343	18.32435
10/08/2018	33.940284	14.14315	10.945317	0.363597
11/08/2018	13.420253	14.53041	9.708165	0.374777
12/08/2018	47.349445	15.4884	16.325726	11.27349
13/08/2018	72.74079	17.10002	8.378154	24.52529
14/08/2018	80.799714	16.45804	6.661156	10.59452
15/08/2018	76.864136	16.95781	5.886011	9.298657
16/08/2018	58.057093	14.62249	12.499254	11.38468
17/08/2018	22.90134	14.1132	11.179168	0.333858
18/08/2018	23.282064	14.08811	16.155149	0.381871
19/08/2018	12.540245	15.19023	11.602538	0.537379
20/08/2018	13.477018	15.66643	7.125593	0.975033
21/08/2018	16.106844	19.00218	9.607879	2.737805
22/08/2018	37.738381	18.11616	9.989274	8.364232
23/08/2018	46.400003	16.9648	10.391199	9.90034
24/08/2018	59.685101	16.0111	3.745066	5.789332
29/08/2018	8.941185	17.066	7.003954	1.007343
30/08/2018	10.714984	16.5731	10.344536	0.915965
31/08/2018	33.122938	13.28726	20.550126	4.711798
01/09/2018	5.155685	14.50557	11.973983	8.570387
02/09/2018	5.255861	15.14309	5.270297	3.143652
03/09/2018	5.015079	14.4015	4.236496	6.416409
04/09/2018	23.79425	14.04091	4.638851	0.245106
05/09/2018	24.222941	12.52924	5.268619	0.431199
07/09/2018	11.720877	11.49507	7.606914	0.469931
09/09/2018	2.072588	12.21322	8.844075	0.357873
10/09/2018	7.090083	14.04947	13.935985	0.446373
11/09/2018	7.573974	12.89581	12.296731	0.292483
12/09/2018	12.085264	14.7609	12.464362	0.335204
16/09/2018	83.82352	9.715953	19.71594	9.494062
17/09/2018	11.193721	12.87247	10.686286	1.25303
18/09/2018	19.521539	12.28812	8.606537	0.331456
19/09/2018	17.088799	13.41671	9.142698	0.418956
20/09/2018	34.923112	12.97076	10.578097	2.332922
21/09/2018	30.744239	11.50843	7.442008	0.650801
22/09/2018	15.302998	14.93784	11.281848	0.597216
23/09/2018	53.552713	13.88239	11.343074	10.95988
29/09/2018	48.232121	12.1082	11.207602	1.900579
30/09/2018	53.520659	9.914394	6.730107	1.486077
01/10/2018	53.583929	8.847424	2.548733	1.299579
02/10/2018	54.669036	9.63713	8.093731	1.668976

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
03/10/2018	35.325904	12.03103	5.004046	0.900038
04/10/2018	45.823085	12.13808	5.102518	0.787367
06/10/2018	68.489215	9.024481	4.980789	0.580203
07/10/2018	82.620025	9.764989	18.892077	1.631598
09/10/2018	90.549667	9.245825	21.39408	1.992284
11/10/2018	77.362395	9.1408	6.774355	0.37918
12/10/2018	21.915322	11.10812	7.551708	0.287945
14/10/2018	47.026204	12.42031	7.79971	0.081623
15/10/2018	36.164435	12.27817	7.749601	0.254858
16/10/2018	38.180772	12.43936	5.419405	0.059205
17/10/2018	7.420329	12.54246	11.25293	0.371691
18/10/2018	26.742949	12.4982	20.481554	0.388036
19/10/2018	53.573241	6.585255	18.653444	0.928017
21/10/2018	87.269679	4.674926	5.562755	0.362643
29/10/2018	76.171863	4.953833	14.576688	1.110552
30/10/2018	61.004677	4.180451	8.91174	0.623797
31/10/2018	69.374255	5.084164	10.35688	0.651326
01/11/2018	67.500454	7.071838	12.989326	0.204639
02/11/2018	43.230292	10.59733	16.635592	0.127148
03/11/2018	23.863619	12.47313	24.967316	0.6342
04/11/2018	22.630932	11.87446	17.159462	0.234408
05/11/2018	21.070739	9.592489	13.152223	0.221905
06/11/2018	67.796468	6.960491	10.603522	0.147577
07/11/2018	32.732752	7.918645	9.586688	0.218631
08/11/2018	5.218539	8.544976	10.482601	0.152556
09/11/2018	43.754989	6.932739	6.834446	4.514468
10/11/2018	11.129552	9.133582	11.990677	0.575358
11/11/2018	40.926663	9.016089	15.549239	0.161075
12/11/2018	76.506051	6.703902	8.881248	0.358999
14/11/2018	57.830334	4.26395	16.510386	0.534177
15/11/2018	69.577127	4.295535	7.268243	0.37126
16/11/2018	17.904636	4.051407	7.063123	1.012167
17/11/2018	49.970031	6.639774	15.481644	0.955471
20/11/2018	84.064734	3.409341	13.031015	0.359778
26/11/2018	67.284926	7.266019	3.887764	0.18836
27/11/2018	82.605065	6.033082	5.655616	0.190076
28/11/2018	60.497794	6.505721	15.19509	0.158011
29/11/2018	41.309952	8.050935	9.717816	0.097632
30/11/2018	32.637693	8.327822	6.558035	0.10765
02/12/2018	20.728703	9.886111	11.312958	0.276176
03/12/2018	14.647745	11.10095	20.651134	0.178435
04/12/2018	14.082762	9.803616	23.552803	0.2129
05/12/2018	51.997474	6.960784	21.636845	0.724054
06/12/2018	43.958467	7.854587	19.493623	0.627783
07/12/2018	27.823062	8.580756	15.413498	7.422049
08/12/2018	16.850165	10.86199	18.530783	1.081125

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
09/12/2018	8.354508	11.06059	10.203828	0.398349
10/12/2018	28.670856	10.23923	9.217496	1.660467
12/12/2018	42.432947	7.157083	13.644262	2.056962
13/12/2018	49.212576	6.679927	17.353429	1.392247
14/12/2018	42.630827	7.650591	14.241264	0.348604
15/12/2018	29.708706	9.272852	14.219654	0.189229
16/12/2018	18.908078	10.31442	13.174155	0.184105
17/12/2018	29.269342	8.158366	13.315569	0.524035
18/12/2018	33.863579	7.289753	9.21287	1.446341
19/12/2018	17.062969	8.476317	11.473057	1.075693
20/12/2018	16.176905	8.33785	12.602682	0.33752
26/12/2018	22.891639	7.403055	13.906928	9.576604
27/12/2018	19.50308	5.654296	12.872375	3.488857
28/12/2018	8.755826	7.02279	14.086633	1.165143
29/12/2018	16.332084	6.118946	13.659307	0.438455
30/12/2018	4.730504	5.825792	6.703509	0.278251
31/12/2018	14.10596	3.601466	6.051889	0.154334
01/01/2019	11.667652	5.337392	15.945261	0.144265
02/01/2019	8.071102	5.737554	9.742571	0.699504
03/01/2019	14.949366	6.905966	8.684604	0.651758
04/01/2019	18.710457	6.873412	9.734831	0.078276
05/01/2019	19.556171	6.434539	10.517274	0.075618
06/01/2019	8.455875	5.601583	16.254129	0.15172
07/01/2019	12.283202	5.538921	15.085515	0.589234
08/01/2019	6.430286	5.632911	13.856099	0.398104
09/01/2019	4.800163	5.833376	15.824804	0.207299
10/01/2019	11.193596	3.623757	8.463251	0.313137
11/01/2019	5.025322	6.116341	6.644449	0.156054
12/01/2019	32.143216	5.143842	14.679221	0.489991
13/01/2019	23.967891	4.767694	14.790083	0.872692
14/01/2019	20.652775	4.139187	10.984964	7.909932
15/01/2019	35.667376	2.387537	4.481085	5.890021
16/01/2019	19.563001	2.485595	10.183237	0.576049
19/01/2019	41.692657	4.840209	19.331924	0.542309
23/01/2019	6.58331	5.988068	16.564953	0.29181
24/01/2019	12.981866	5.686349	14.913993	0.34804
25/01/2019	31.143928	5.480317	11.934998	0.265775
26/01/2019	39.83256	3.676102	9.760365	0.215081
28/01/2019	16.296888	7.027285	13.102524	0.162135
29/01/2019	10.179666	7.553551	10.288564	0.147701
30/01/2019	8.152219	7.874129	9.137598	0.207135
31/01/2019	30.143382	6.099381	9.906959	0.271823
01/02/2019	8.266529	6.441859	6.734474	0.114465
02/02/2019	71.739301	4.437378	14.659626	0.718377
03/02/2019	24.74136	7.750187	16.730334	0.199275
05/02/2019	38.936371	5.036269	23.743463	24.26917

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
06/02/2019	5.723817	6.334188	17.336388	8.326719
07/02/2019	10.443853	6.193908	13.45026	1.456023
08/02/2019	4.467786	5.771212	6.071754	0.814751
09/02/2019	1.589493	5.250639	8.226129	0.488108
10/02/2019	9.132429	6.245464	13.079173	0.655209
11/02/2019	13.985394	7.769444	17.471512	5.458758
12/02/2019	26.866344	7.13693	8.190027	6.103302
13/02/2019	26.727365	9.06101	10.628906	3.585819
17/02/2019	33.673051	3.698326	9.787933	3.476404
23/02/2019	21.33604	7.462508	27.8226	8.588312
25/02/2019	14.30618	7.704985	8.840404	6.077396
02/03/2019	4.360549	8.250703	13.045778	1.829935
04/03/2019	26.774948	6.003517	11.132818	0.090064
05/03/2019	14.059244	7.35098	8.660211	0.157389
06/03/2019	68.033692	4.179236	13.457787	0.540388
07/03/2019	27.048835	5.744961	13.555832	0.764508
09/03/2019	9.663544	9.38675	26.251782	1.213786
13/03/2019	16.121551	7.490128	9.16765	1.693025
14/03/2019	9.248844	7.860572	13.716024	0.658721
15/03/2019	35.157005	6.307802	18.352223	12.07667
16/03/2019	34.655493	6.498904	15.083355	7.256176
17/03/2019	26.790611	4.951828	8.247391	5.557217
18/03/2019	2.884093	6.858036	10.140552	0.888857
23/03/2019	12.099378	8.855715	9.609413	1.00956
27/03/2019	91.381993	1.972358	10.780074	8.288886
05/04/2019	67.864712	2.697415	8.548883	0.895321
07/04/2019	69.378097	4.121342	6.078781	0.277732
08/04/2019	20.58826	6.391667	5.817304	1.032624
09/04/2019	9.307045	7.502661	5.899556	0.575788
10/04/2019	28.328752	4.528429	8.895964	0.708416
12/04/2019	36.985464	4.604062	14.795698	0.472821
13/04/2019	51.317044	5.569571	17.459165	0.338811
14/04/2019	18.898499	10.49046	11.915383	0.050066
15/04/2019	31.240014	8.155682	7.028065	0
22/04/2019	34.202056	8.464859	17.482414	7.34
23/04/2019	45.907688	6.552886	16.044594	7.34
24/04/2019	57.84148	5.253933	10.914448	7.34
26/04/2019	22.876484	8.735506	10.5885	7.34
01/05/2019	37.261094	11.4447	9.371038	7.34
03/05/2019	21.030353	7.089731	7.184244	7.34
04/05/2019	16.406789	8.31855	5.319702	7.34
05/05/2019	10.477408	8.056558	4.554758	7.34
06/05/2019	11.70654	9.851205	7.146304	7.34
07/05/2019	22.120971	10.29145	4.161179	7.34
08/05/2019	10.687871	12.0655	7.442614	7.34
09/05/2019	4.71566	11.98246	5.099274	7.254842

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
10/05/2019	8.722413	10.41206	8.793812	7.337227
11/05/2019	6.430426	11.38648	9.80822	7.34
12/05/2019	12.113722	13.41617	12.301898	7.34
13/05/2019	19.384725	13.55779	14.643755	7.34
14/05/2019	20.234704	12.46412	8.813245	7.34
15/05/2019	20.798366	13.53986	7.303367	7.34
21/05/2019	11.91085	12.31344	13.245744	7.34
22/05/2019	26.363546	10.31746	11.139554	7.34
23/05/2019	35.527654	10.01049	17.760479	7.34
24/05/2019	14.976725	13.4302	15.515621	7.34
25/05/2019	18.332667	13.35436	9.626692	7.34
26/05/2019	29.432504	12.90075	15.25824	7.34
27/05/2019	28.339599	13.30299	9.536789	7.34
28/05/2019	32.322014	12.00391	9.200496	7.34
29/05/2019	18.664492	12.87792	10.70206	7.34
30/05/2019	10.160778	14.03462	9.663165	7.34
31/05/2019	17.916062	13.95802	8.811696	7.34
01/06/2019	23.080025	16.24952	12.014198	7.34
02/06/2019	35.095922	15.56853	18.970581	7.34
03/06/2019	28.939498	15.94605	19.846483	7.34
04/06/2019	26.922239	14.48397	9.009263	7.34
05/06/2019	39.455507	10.9579	8.3282	7.254664
06/06/2019	5.909753	10.31589	8.383759	7.34
07/06/2019	32.281654	9.534821	14.391897	7.34
08/06/2019	46.397726	9.430991	6.880436	7.34
09/06/2019	23.163715	11.27282	10.800241	7.34
10/06/2019	26.293309	11.1215	11.640992	7.336221
11/06/2019	50.43925	11.72847	15.826935	7.34
12/06/2019	46.627024	11.99841	15.611193	7.34
13/06/2019	40.062929	8.481094	7.154181	7.34
14/06/2019	31.202295	8.497615	3.817172	7.34
20/06/2019	13.392103	11.91872	5.582555	7.34
21/06/2019	30.764462	11.08616	7.374738	7.34
22/06/2019	37.677718	11.99976	7.648069	7.34
23/06/2019	44.844769	11.56282	3.324119	7.34
24/06/2019	61.420661	11.85285	5.011971	7.34
25/06/2019	52.394352	12.5419	10.60705	7.34
26/06/2019	9.871708	13.72491	7.073534	7.34
27/06/2019	2.791631	13.48943	6.43081	7.34
28/06/2019	6.275309	11.63211	5.408436	7.34
30/06/2019	6.09039	11.89805	4.263177	7.34
01/07/2019	8.588731	14.40297	7.794344	7.315105
02/07/2019	4.034067	15.03897	7.387833	7.34
03/07/2019	11.626248	14.00037	10.066376	7.264152
13/07/2019	0	16.12999	0	7.34
20/07/2019	41.745748	13.93446	20.19063	7.34

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
21/07/2019	14.897565	15.79409	11.72394	7.34
22/07/2019	9.191145	15.45535	8.371618	7.34
23/07/2019	7.316516	15.46042	12.03038	7.34
24/07/2019	12.683664	16.21916	17.838552	7.34
25/07/2019	18.620601	15.97862	10.586154	7.34
26/07/2019	31.426118	16.85169	7.502527	7.34
27/07/2019	23.447899	17.87213	4.311794	7.34
28/07/2019	17.17312	16.86757	8.549007	7.34
29/07/2019	49.376172	14.11807	12.617155	7.34
30/07/2019	36.474829	12.78935	20.011101	7.34
31/07/2019	21.318871	14.26599	14.234435	7.34
01/08/2019	11.54598	14.08669	10.58126	7.34
02/08/2019	12.027766	13.43199	8.067622	7.34
03/08/2019	26.826502	12.75198	9.391409	7.34
04/08/2019	16.307725	13.35625	12.016151	7.229358
05/08/2019	26.411387	12.3452	15.202874	7.231969
06/08/2019	33.334639	11.84401	13.448259	7.34
07/08/2019	12.04262	16.94417	13.09111	6.932327
08/08/2019	5.523572	19.1428	11.301307	7.34
09/08/2019	11.6858	19.05046	10.668275	7.34
10/08/2019	73.008176	16.70583	6.110757	7.300155
11/08/2019	11.515411	17.32316	5.552559	7.34
12/08/2019	50.669837	16.44369	18.213939	7.34
13/08/2019	50.10148	14.8888	14.098336	7.34
19/08/2019	23.550493	20.38191	8.753414	7.34
20/08/2019	19.728916	19.10562	13.425768	7.34
21/08/2019	32.248038	15.95497	12.83831	7.34
22/08/2019	29.494257	16.07484	17.837696	7.34
23/08/2019	23.998902	20.72922	6.235718	7.34
24/08/2019	24.022873	22.40089	8.37718	7.34
25/08/2019	28.781011	21.62712	15.895085	7.34
27/08/2019	35.940067	16.89579	8.789234	7.34
28/08/2019	35.385375	16.22624	6.649545	7.34
29/08/2019	33.970654	16.17904	5.892196	7.34
30/08/2019	30.048436	16.36599	9.485639	7.34
31/08/2019	28.389736	16.35577	9.384835	7.34
01/09/2019	24.374037	15.90112	4.760152	7.34
02/09/2019	16.77613	13.6517	7.536376	7.009568
03/09/2019	3.219902	14.24018	7.91598	7.34
04/09/2019	12.911544	13.5136	9.687103	7.117678
05/09/2019	15.161755	14.51695	7.632165	6.998683
06/09/2019	35.903017	12.22904	16.351027	7.34
07/09/2019	49.140814	11.06878	7.219661	7.34
08/09/2019	26.139594	12.31359	9.654841	7.34
09/09/2019	45.42587	12.30713	21.82294	7.34
10/09/2019	42.475709	13.90627	9.556429	7.34

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (μg/m3)
11/09/2019	31.163726	15.35087	8.763197	7.34
12/09/2019	38.645648	13.76029	13.963621	7.34
17/09/2019	10.58443	16.40849	11.287141	7.34
18/09/2019	9.45255	15.20374	7.28812	7.34
19/09/2019	33.532216	14.75832	3.793229	7.34
20/09/2019	13.658024	13.3789	5.186174	7.34
21/09/2019	20.440399	13.60082	8.067158	7.34
22/09/2019	61.104791	13.15407	6.27867	6.771888
23/09/2019	65.488123	11.51357	5.95544	7.34
24/09/2019	16.712329	14.32192	11.430139	7.34
25/09/2019	28.24236	15.79407	13.756811	7.34
26/09/2019	29.599377	15.19782	14.217264	7.34
27/09/2019	16.716173	15.83852	11.372303	7.182509
28/09/2019	10.820991	16.4352	16.167417	7.246051
30/09/2019	27.430639	17.42828	16.283353	7.34
01/10/2019	21.600805	19.36896	10.265731	7.34
02/10/2019	23.600784	18.45406	6.483597	7.34
03/10/2019	25.10894	17.81465	7.036898	7.34
04/10/2019	26.76395	16.79367	10.905936	0.496649
05/10/2019	30.454199	15.09548	9.795475	-1
06/10/2019	41.845908	13.88905	19.244486	-1
07/10/2019	23.991888	14.73442	11.611903	-1
08/10/2019	16.096174	15.5422	9.359383	-1
09/10/2019	21.200625	13.03425	5.813579	-1
10/10/2019	15.648047	10.22744	9.472175	-1
11/10/2019	26.856512	9.760249	8.045504	7.34
18/10/2019	23.188689	10.44443	5.35644	7.34
19/10/2019	13.002501	11.00495	6.214168	7.34
20/10/2019	48.965571	9.638727	7.758443	6.832394
22/10/2019	44.177877	4.62889	17.261642	7.34
23/10/2019	11.294259	7.641249	13.219157	7.34
24/10/2019	6.639947	11.92774	16.582517	7.34
25/10/2019	9.40438	13.51748	18.898941	4.057807
28/10/2019	75.799377	12.91576	18.616893	7.34
29/10/2019	77.200257	12.61423	13.464637	7.34
30/10/2019	67.651215	12.76604	4.959689	7.34
31/10/2019	63.610787	13.86984	18.329674	-1
03/11/2019	73.49755	11.68371	18.556665	-1
04/11/2019	59.931232	10.04901	15.674954	-1
05/11/2019	73.676088	8.34669	17.740629	-0.49298
06/11/2019	66.577006	6.764597	14.848631	0.390723
07/11/2019	48.884184	8.165272	19.542169	-0.02138
09/11/2019	17.787911	11.36858	20.263756	0.554798
18/11/2019	40.082895	5.963668	14.991817	0.121184
19/11/2019	34.575769	5.71112	12.900981	0.090309
20/11/2019	72.402473	5.309689	5.937218	0.558334

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
21/11/2019	71.866007	5.160972	7.143672	0.740368
22/11/2019	69.445629	6.179699	7.011883	0.831972
23/11/2019	60.16454	7.920476	8.606657	0.126357
24/11/2019	38.073513	8.184165	16.37788	0.130949
25/11/2019	10.357747	11.25361	12.407384	0.04834
26/11/2019	15.064171	12.16253	14.455253	0.009288
27/11/2019	36.028031	8.958294	12.112929	0.157
28/11/2019	31.444611	8.969671	11.791437	0.679946
29/11/2019	49.098034	8.56044	19.751045	1.41
30/11/2019	47.769225	10.05194	16.238102	9.916476
01/12/2019	51.719383	7.675748	9.268987	7.576521
02/12/2019	32.786592	7.1803	6.965487	0.115911
03/12/2019	63.124115	4.928445	14.308192	0.322852
04/12/2019	23.928974	7.304165	14.607412	-1
10/12/2019	14.897052	10.60812	15.981207	0.361347
15/12/2019	9.516709	5.795893	4.709924	0.044733
16/12/2019	92.939443	2.992266	14.266856	1.011702
18/12/2019	53.732232	5.779093	6.175625	0.142176
19/12/2019	48.858011	6.108055	11.785504	-0.00906
20/12/2019	39.890487	7.557462	8.278968	0.114305
21/12/2019	17.965197	8.225851	5.076758	0.060043
22/12/2019	8.002876	12.49349	13.103725	0.145209
23/12/2019	22.761212	10.42254	16.409514	0.168815
24/12/2019	19.198512	9.443993	29.079862	0.519127
25/12/2019	22.022856	9.685885	19.357768	15.41341
26/12/2019	37.042611	7.173087	11.444963	16.20344
27/12/2019	25.319649	10.17197	18.277874	5.838906
28/12/2019	30.645839	9.407137	21.1862	14.66576
29/12/2019	33.725674	10.02665	14.535494	2.235504
30/12/2019	16.41521	9.278081	11.469818	1.718618
31/12/2019	8.14328	10.68381	14.487985	0.578475
01/01/2020	6.734289	9.609697	17.687243	0.518866
02/01/2020	16.870723	6.031296	10.07963	0.767657
03/01/2020	3.382217	6.658248	15.916749	0.550941
04/01/2020	4.374718	7.228513	19.208602	0.846029
05/01/2020	33.501697	4.797042	9.184677	0.586493
06/01/2020	12.191065	5.412589	9.353272	0.125677
07/01/2020	64.583942	2.320111	21.116117	1.429548
08/01/2020	53.135214	2.367542	19.623674	4.719521
13/01/2020	19.041245	6.842916	12.932378	0.046661
14/01/2020	39.688432	3.781345	18.287764	6.892786
15/01/2020	50.601941	1.431574	8.436099	2.901913
16/01/2020	22.243794	4.639801	6.658662	2.064823
17/01/2020	17.48643	7.630839	13.577186	0.229747
18/01/2020	10.302924	8.920631	14.320935	0.646187
19/01/2020	11.282072	10.84278	14.421935	0.252316

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
20/01/2020	27.080781	9.045872	16.474616	0.395307
21/01/2020	14.720337	5.356425	8.241898	0.76022
26/01/2020	20.565861	2.550017	5.337796	2.263013
27/01/2020	13.450104	6.200441	11.151542	0.131208
29/01/2020	14.806687	9.109252	20.459121	0.626349
30/01/2020	48.811473	8.369064	14.878111	22.00904
31/01/2020	46.461078	7.053538	6.229565	48.59106
01/02/2020	35.034295	8.270287	15.098946	71.32178
02/02/2020	16.248235	11.44239	19.057223	2.442702
03/02/2020	18.62252	9.234054	26.55116	3.400018
06/02/2020	14.314996	8.927869	8.079214	0.734621
12/02/2020	31.597522	7.679439	14.623078	14.42738
13/02/2020	32.210657	6.246592	8.618042	26.27896
14/02/2020	42.977496	7.450518	9.645128	52.34633
15/02/2020	65.324356	6.496341	6.798268	71.5337
16/02/2020	32.61024	5.416755	13.189097	31.54475
17/02/2020	33.205738	7.053644	10.292438	11.70592
18/02/2020	33.207432	8.293696	10.084812	4.43009
19/02/2020	14.248345	10.77931	13.066287	1.036038
20/02/2020	15.584011	9.378778	14.812881	0.559008
21/02/2020	12.48238	5.420773	11.343846	0.978491
22/02/2020	84.185318	1.157779	11.304069	5.77744
26/02/2020	54.133756	8.859356	10.617675	47.23911
27/02/2020	37.019048	9.142799	10.723337	12.39751
28/02/2020	42.219545	8.366597	8.129982	1.964147
29/02/2020	48.577022	8.727186	13.096596	35.84596
01/03/2020	50.019177	8.028123	6.879423	28.38992
02/03/2020	44.717747	8.797786	15.63735	4.243185
03/03/2020	9.19208	14.26687	14.697828	0.655742
04/03/2020	24.456997	14.07938	11.867497	0.620446
05/03/2020	38.722377	11.71086	5.697819	0.751675
06/03/2020	19.346258	10.77709	11.201049	0.337194
12/03/2020	19.764586	9.61098	11.331922	12.19786
13/03/2020	28.969831	7.608986	7.817738	15.94816
19/06/2020	51.508419	10.55072	13.148549	0.205586
20/06/2020	26.218005	11.15269	9.021499	0.273373
23/06/2020	11.47913	14.16588	8.443131	0.129033
24/06/2020	10.634959	13.72201	9.519397	0.256386
25/06/2020	14.779649	13.37408	13.200159	78.98218
26/06/2020	13.123876	12.20057	11.391611	0.488482
11/07/2020	10.659606	18.18899	11.833625	4.990204
12/07/2020	10.410146	17.66477	14.67522	11.46651
13/07/2020	13.221709	18.16645	6.13357	2.256246
14/07/2020	8.783193	16.64095	9.86516	0.959748
16/07/2020	10.101607	17.88967	6.732837	11.05144
17/07/2020	26.477737	19.25533	13.79226	85.11431

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
21/07/2020	11.711148	17.5184	12.060325	1.037086
22/07/2020	14.460397	16.37199	8.17072	15.94011
23/07/2020	10.400123	19.53419	7.148846	1.539412
24/07/2020	4.733612	19.67466	8.873694	
25/07/2020	13.832182	16.95934	16.646119	0.597233
26/07/2020	19.008642	16.91484	14.398644	0.588819
27/07/2020	11.129799	18.28958	11.054629	0.314684
28/07/2020	7.034218	20.86415	7.654064	2.785661
29/07/2020	15.459645	18.32895	6.128399	1.119453
30/07/2020	8.145823	16.52437	11.00632	0.493296
10/08/2020	31.834281	14.3233	9.377052	5.696392
11/08/2020	33.482533	13.22858	10.561854	0.498705
12/08/2020	43.306449	13.84411	10.221254	0.418483
13/08/2020	6.058506	14.83401	4.950443	73.129
14/08/2020	15.14312	17.08577	6.191789	0.470845
15/08/2020	4.852152	19.48254	7.488051	0.961788
16/08/2020	24.855599	19.11675	4.516851	32.7028
17/08/2020	14.293768	19.12709	5.637381	19.67646
18/08/2020	7.4846	19.02336	10.469103	0.505083
19/08/2020	9.225893	17.94763	7.747033	2.800024
20/08/2020	9.963049	17.85804	3.8245	0.351901
21/08/2020	22.188881	17.73492	5.956418	3.331814
22/08/2020	22.121863	20.58766	13.344911	3.363748
26/08/2020	22.335369	22.60801	12.053668	36.50235
27/08/2020	42.810393	20.95191	12.021481	73.99804
28/08/2020	22.460638	22.03826	14.669559	93.99886
06/09/2020	25.116599	14.04411	11.58097	1.76379
07/09/2020	19.213472	17.21898	16.464338	8.899067
08/09/2020	50.277011	18.24672	9.996475	32.74518
09/09/2020	45.017535	17.95962	16.339747	30.51929
10/09/2020	40.810525	17.3951	13.897371	20.02318
11/09/2020	47.014859	15.34869	10.371812	12.70322
12/09/2020	37.707752	13.92369	10.732754	9.577479
13/09/2020	57.428552	10.4512	15.765892	10.57041
14/09/2020	46.716651	11.27964	11.653228	0.362867
15/09/2020	29.351932	16.77343	8.061899	14.64172
16/09/2020	75.389238	12.47384	12.326503	19.93502
17/09/2020	62.73882	13.91202	12.121213	19.27115
18/09/2020	22.700951	14.81979	10.321227	1.998395
19/09/2020	29.120453	14.15921	3.417515	0.180553
20/09/2020	29.252916	16.94711	5.707764	7.278231
21/09/2020	37.373724	16.75823	5.430463	30.98136
22/09/2020	35.025629	16.83914	3.392508	32.2006
23/09/2020	46.542631	14.82789	7.268561	31.94524
24/09/2020	81.171547	9.701368	9.486837	6.095791
25/09/2020	73.512364	11.97198	17.305343	11.05514

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
26/09/2020	48.678212	17.43803	6.757863	23.73103
27/09/2020	51.40317	14.11913	10.555494	28.95679
28/09/2020	24.588414	13.31006	13.459617	3.323082
29/09/2020	23.761487	12.39215	10.517441	1.861335
05/10/2020	56.160117	12.98006	18.26692	0.742661
06/10/2020	23.8747	13.94322	9.392257	0.339803
08/10/2020	41.795475	13.93482	9.854268	2.179947
09/10/2020	29.009352	11.87092	4.766571	1.50665
10/10/2020	21.483023	11.02593	5.983045	0.340501
11/10/2020	21.920358	12.62072	10.391422	0.764298
12/10/2020	36.380136	15.66605	12.366432	29.12265
13/10/2020	34.992491	16.20723	6.939979	39.85426
14/10/2020	42.682789	14.71846	7.967972	31.10112
15/10/2020	43.01926	13.92551	11.368628	28.8476
16/10/2020	73.414094	10.84453	7.979974	24.34899
17/10/2020	64.399751	8.145834	2.371292	1.491088
18/10/2020	63.303356	9.534642	9.910748	0.692841
24/10/2020	17.155921	7.823654	13.767464	0.553919
25/10/2020	14.658657	9.173979	7.134525	0.718732
26/10/2020	57.799966	10.07992	5.760357	1.167893
27/10/2020	12.141103	9.852987	5.308736	0.287883
28/10/2020	25.642077	9.061467	7.09684	2.966508
07/11/2020	21.763722	4.993929	9.874046	0.28646
09/11/2020	25.629293	7.980374	8.124369	0.353705
10/11/2020	14.218903	10.18275	7.402464	0.315942
11/11/2020	22.902399	12.07412	12.086766	0.193386
12/11/2020	81.811219	11.43292	8.821369	0.737262
16/11/2020	35.338532	10.68738	23.10862	4.694006
17/11/2020	43.110179	11.09929	17.069172	9.471619
18/11/2020	47.476531	10.03178	12.226523	4.977291
19/11/2020	55.117174	8.023521	6.747152	6.777096
20/11/2020	59.124908	7.243646	16.443555	-1
21/11/2020	53.729902	8.444385	11.537907	-1
22/11/2020	43.023904	7.827614	15.943213	-1
23/11/2020	22.406872	9.764955	15.339471	0.768219
24/11/2020	27.9372	8.061379	11.267111	0.870404
25/11/2020	45.922579	5.660817	6.814566	7.964968
07/12/2020	45.323197	4.322248	16.526656	0.501629
08/12/2020	26.652085	6.519285	13.017155	0.255511
09/12/2020	67.207598	4.161713	18.792548	0.622727
10/12/2020	69.606302	5.48322	20.097814	0.218674
11/12/2020	20.419397	9.972936	22.372551	1.010214
13/12/2020	57.46899	6.965956	6.8031	-1
14/12/2020	79.189075	4.967094	5.843083	-1
15/12/2020	68.733348	3.635276	6.618648	0.507629
16/12/2020	14.61643	5.420599	8.226741	0.372279

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
17/12/2020	76.810794	5.313735	14.8459	1.449247
18/12/2020	46.474923	6.879242	10.747573	0.155327
19/12/2020	13.150354	5.847365	8.72871	0.093632
20/12/2020	82.170293	5.812062	12.892099	0.663404
21/12/2020	32.84261	8.96443	12.914288	0.167816
22/12/2020	34.206184	7.247269	9.743054	0.084684
23/12/2020	43.453536	4.750303	15.947359	1.727495
24/12/2020	51.324195	3.381021	15.397171	19.13305
25/12/2020	67.947405	2.132625	14.784468	49.71226
20/01/2021	11.873018	6.897819	7.694111	-0.07065
21/01/2021	52.630418	7.566007	7.994416	0.199401
23/01/2021	40.676377	8.374233	8.567183	-1
24/01/2021	31.62774	9.021823	4.966942	-1
25/01/2021	29.267529	9.104763	2.989385	-1
26/01/2021	19.941974	9.986829	9.030292	-1
01/02/2021	27.433658	11.75659	15.543265	0.538908
02/02/2021	18.225389	11.12492	12.203676	0.103352
03/02/2021	32.303058	8.888268	6.815439	0.608671
13/02/2021	44.513059	6.089817	13.183944	0.098243
14/02/2021	10.91357	8.881476	14.319513	0.062935
15/02/2021	31.213468	7.411994	17.265466	0.81824
16/02/2021	42.791762	4.896347	10.536972	6.641235
17/02/2021	24.173275	4.779224	17.546514	32.85867
18/02/2021	14.356219	4.058637	11.686358	7.733582
19/02/2021	23.822541	6.112719	7.639861	5.335934
20/02/2021	29.66167	5.95225	14.307329	0.664262
22/02/2021	89.276007	4.175098	7.728267	2.778363
23/02/2021	15.413536	8.288723	10.112678	0.060802
24/02/2021	13.937288	8.40843	8.637468	0.062625
02/03/2021	28.218718	3.126104	10.783523	0.406804
03/03/2021	22.122342	4.998593	7.94636	0.735477
04/03/2021	15.550137	6.058506	7.67178	0.322988
05/03/2021	85.029684	4.667148	13.053116	0.35334
10/03/2021	21.862382	7.159614	18.641963	1.732227
11/03/2021	28.546408	9.158248	17.468148	0.83629
12/03/2021	21.138882	10.78773	12.554217	0.591072
13/03/2021	7.523881	8.886642	11.826365	2.314793
14/03/2021	7.709844	9.593544	16.368425	1.318536
15/03/2021	18.690945	7.619399	7.943587	0.846454
16/03/2021	20.508925	10.51321	10.739808	0.292841
17/03/2021	18.444873	7.500847	9.753917	0.097994
18/03/2021	14.751268	6.745522	9.050021	0.375536
19/03/2021	23.705366	4.221249	13.406761	0.560615
20/03/2021	9.967814	5.488994	11.34948	0.194652
21/03/2021	25.745595	6.155984	9.5378	0.196136
22/03/2021	13.784811	5.530377	11.099156	0.211958

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
23/03/2021	32.877008	3.416026	6.447407	0.262965
24/03/2021	34.18888	7.005739	18.778161	2.129263
31/03/2021	24.157583	5.438712	21.817112	14.84044
01/04/2021	59.094961	4.18568	11.696376	0.429405
02/04/2021	17.345586	10.48834	5.760695	1.806359
03/04/2021	15.53882	8.490711	3.450981	0.851289
04/04/2021	13.869118	8.523328	5.232015	0.339907
05/04/2021	16.050033	7.826847	9.63412	0.597626
06/04/2021	73.000363	4.689696	4.277088	0.538736
08/04/2021	66.264477	5.973004	5.795856	0.474394
09/04/2021	80.689874	6.229299	6.046261	0.255808
10/04/2021	73.524188	5.458639	2.984911	0.52945
11/04/2021	83.739301	5.840676	3.085171	0.127083
12/04/2021	91.234512	7.23676	7.712051	21.0136
13/04/2021	78.262948	8.857924	7.577007	13.87227
14/04/2021	91.107219	4.99032	4.597608	1.91474
15/04/2021	73.807151	4.483211	5.179178	4.599845
16/04/2021	70.855822	4.922335	11.417383	0.622432
17/04/2021	37.557984	8.205701	15.210036	0.6529
18/04/2021	15.487026	9.542079	12.453316	0.360314
19/04/2021	35.091411	11.06224	13.462159	0.883046
20/04/2021	36.757957	9.792376	10.558601	0.780244
21/04/2021	38.132043	10.6088	9.327106	2.414687
22/04/2021	35.415824	10.20014	6.561345	0.694611
23/04/2021	54.847186	11.04293	7.703252	0.739922
01/05/2021	46.115518	3.455358	12.481152	0.250864
02/05/2021	59.429625	3.688928	11.548195	0.259823
03/05/2021	78.617354	2.787379	7.689825	6.835582
04/05/2021	59.625114	4.471898	12.91996	0.656077
05/05/2021	4.762093	7.541896	12.353091	0.242762
06/05/2021	9.656636	10.6922	8.833842	0.174842
07/05/2021	14.95835	12.96397	8.755571	0.572826
08/05/2021	5.41745	9.923978	8.828604	-0.13865
09/05/2021	46.520621	7.962963	9.545082	0.693397
10/05/2021	41.745212	8.641153	5.789505	0.236814
11/05/2021	14.516299	10.25827	10.638003	0.534562
12/05/2021	31.70342	12.36669	12.380557	0.4101
13/05/2021	37.001902	11.53713	9.866572	0.331332
14/05/2021	32.778263	11.65322	17.958436	0.721727
16/05/2021	24.658935	12.4031	20.202632	15.28036
17/05/2021	22.92742	16.44396	11.523255	44.53991
18/05/2021	20.834972	15.69108	13.301032	34.91996
19/05/2021	8.743493	12.94978	14.621688	4.335296
21/05/2021	23.861399	17.16904	19.05925	18.01581
22/05/2021	33.282773	17.52949	12.484115	62.03249
23/05/2021	23.348851	11.79119	11.546159	-1

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
29/05/2021	22.444925	10.4956	9.304294	0.67557
30/05/2021	34.776536	9.345341	7.011913	0.125064
31/05/2021	14.385831	10.57655	9.122533	0.431392
01/06/2021	15.137551	11.07112	8.045257	0.406198
02/06/2021	39.255968	8.582403	6.581218	0.365814
03/06/2021	66.13245	6.667914	10.430566	0.595057
05/06/2021	13.975385	8.750537	12.447098	0.480104
06/06/2021	8.611308	11.611	10.093694	0.434772
07/06/2021	16.148877	13.23782	8.368724	0.634905
08/06/2021	31.812636	15.84583	13.746507	4.465562
09/06/2021	60.349694	13.67657	15.480987	25.53366
10/06/2021	39.658254	18.01849	9.659116	53.40711
11/06/2021	23.730323	19.2788	9.765062	48.79038
12/06/2021	10.25627	16.91227	6.146902	6.301292
13/06/2021	16.329774	13.99042	7.262459	0.445223
14/06/2021	22.498867	13.67446	3.601519	2.487378
15/06/2021	32.090853	11.67526	4.92351	0.926938
16/06/2021	54.224613	9.486616	7.966791	2.622231
18/06/2021	77.518806	9.08666	12.678889	0.44548
19/06/2021	71.147351	6.837674	17.40663	1.235117
20/06/2021	8.592146	10.80212	20.798429	0.712115
21/06/2021	47.23327	12.21775	11.58498	0.954841
22/06/2021	27.544234	13.00888	5.495407	0.011089
27/06/2021	11.257612	17.16135	4.92918	0.035066
28/06/2021	11.65415	15.70724	5.490258	0.324968
29/06/2021	24.126431	14.51191	17.564747	0.436264
30/06/2021	51.587208	12.93683	9.993582	0.286248
01/07/2021	18.590895	11.3937	8.852468	0.248951
02/07/2021	8.180354	17.46449	8.809835	0.11613
03/07/2021	8.043713	20.07519	8.008433	5.256728
04/07/2021	8.886469	18.20499	8.575079	0.103605
05/07/2021	32.661658	17.55667	9.529556	0.142225
06/07/2021	27.932636	17.2333	6.650891	0.7564
07/07/2021	12.941748	18.61057	3.86277	4.298688
08/07/2021	33.193641	16.47181	9.158014	1.800058
09/07/2021	34.565472	11.98859	16.252494	0.397475
10/07/2021	12.237661	16.21158	15.005241	0.707603
11/07/2021	19.52296	19.3949	12.555691	16.26849
14/07/2021	49.434815	19.79542	8.744484	41.97182
15/07/2021	17.992404	20.48815	14.057051	26.46851
16/07/2021	15.587325	20.4687	14.307173	17.5159
17/07/2021	18.540177	20.00378	9.948454	18.65202
18/07/2021	23.483361	20.11367	6.604641	34.37498
19/07/2021	21.79777	20.01362	4.423237	28.90676
20/07/2021	19.653989	18.37032	6.886236	21.2864
21/07/2021	7.552925	16.34218	5.971442	4.0245

Date	Humidity (%)	Temperature (ºC)	Wind Speed (Km/h)	Dust Concentration (µg/m3)
27/07/2021	34.020783	15.20134	11.433103	2.105894
28/07/2021	11.672874	17.16534	14.949723	4.735183
29/07/2021	7.228256	18.38478	12.454675	2.025568
30/07/2021	16.740083	21.54969	12.886171	8.781745
31/07/2021	18.946747	20.12542	5.657871	27.64159
02/08/2021	21.424324	13.99506	12.984946	1.355893
03/08/2021	29.838105	13.26257	12.243241	0.287807
04/08/2021	16.869423	16.35126	11.169383	0.44277
05/08/2021	29.787773	16.24958	19.067355	1.190914
06/08/2021	28.942557	16.37459	10.198759	0.682865
07/08/2021	49.300224	15.38619	7.402908	0.588642
08/08/2021	41.795362	13.59023	5.665892	0.18716
09/08/2021	41.25426	12.092	5.008213	0.420476
10/08/2021	25.504804	12.81418	10.748257	1.841365
11/08/2021	46.419488	10.911	3.601498	0.170154
12/08/2021	29.124967	12.49699	11.094753	0.428532
13/08/2021	15.442051	15.63969	10.774812	0.698091
14/08/2021	22.235465	21.16707	14.900527	19.95399
15/08/2021	20.159069	23.25453	7.354054	24.32827
16/08/2021	23.083057	23.38813	11.744602	54.18162
19/08/2021	26.992721	18.84737	13.590503	34.20289
20/08/2021	29.450692	16.97103	7.87947	32.85089
26/08/2021	28.39116	12.84932	4.320893	0.586515
27/08/2021	44.819977	14.11295	5.433862	2.809313
28/08/2021	27.838038	17.08309	8.014931	4.740029
29/08/2021	54.379386	16.49845	7.942036	8.696907
30/08/2021	24.406226	15.47587	4.635336	11.21432

ANNEX 2: PBS as BOM in Lambda predict template (Reliasoft)

Name: MIL-HDBK-217F

Failure Rate(t=INF) (FPMH): -

Category: MIL-HDBK-217F

User Name: Patricia Marquez

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8 LST1		Block			-	-	-	1
8 Documentation		Block			-	-	-	1
8.0.1 Technical Design Report		Block			-	-	-	1
8.0.2 Management		Block			-	-	-	1
8.0.2.1 Organizational policy		External			-	-	-	1
8.0.2.2 Product Breakdown Structure		External			-	-	-	1
8.0.2.3 Work Breakdown Structure		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.0.2.4 Cost estimates		External			-	-	-	1
8.0.2.5 Schedule		External			-	-	-	1
8.0.2.6 Risk Registry		External			-	-	-	1
8.0.2.7 Budget		External			-	-	-	1
8.0.2.8 Harmonized Documentation		External			-	-	-	1
8.0.3 Plans		Block			-	-	-	1
8.0.3.1 Management Plan		External			-	-	-	1
8.0.3.2 Risk Assessment Plan		External			-	-	-	1
8.0.3.3 Construction Plan		External			-	-	-	1
8.0.3.5 Maintenance Plan		External			-	-	-	1
8.0.3.6 Safety Plan		External			-	-	-	1
8.0.3.7 Quality Plan		External			-	-	-	1
8.0.4 Failure mode, effects, and criticality analysis		Block			-	-	-	1
8.0.4.1 Design FMECA		External			-	-	-	1
8.0.4.2 Safety FMECA		External			-	-	-	1
8.0.5 Design Verification Document		Block			-	-	-	1
8.0.6 Interface Control Documents		Block			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.0.6.1 Internal Interfaces		External			-	-	-	1
8.0.6.2 External Interfaces		External			-	-	-	1
8.0.7 Technical Documentation		Block			-	-	-	1
8.0.7.1 Manuals		External			-	-	-	1
8.0.7.2 Drawings & Schematics		External			-	-	-	1
8.0.7.3 Software & Firmware		External			-	-	-	1
8.0.7.4 Simulations		External			-	-	-	1
8.0.7.5 Site Documentation		External			-	-	-	1
8.0.7.6 Spare List		External			-	-	-	1
8.0.8 Specifications		Block			-	-	-	1
8.0.8.1 Camera Specifications		External			-	-	-	1
8.0.8.2 Structure Specifications		External			-	-	-	1
8.1 Mechanical System		Block			-	-	-	1
8.1.0 Common		Block			-	-	-	1
8.1.0.1 Licenses		External			-	-	-	1
8.1.0.2 Tests reports		External			-	-	-	1
8.1.1 Mount		Block			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.1.1.0 Documentation and Review reports		External			-	-	-	1
8.1.1.1 Lower Structure		External			-	-	-	1
8.1.1.2 Elevation Drive		External			-	-	-	1
8.1.1.3 Elevation Bearing		External			-	-	-	1
8.1.1.4 Platform at Elevation Bearing		External			-	-	-	1
8.1.1.5 Stair case up to Elevation Bearing		External			-	-	-	1
8.1.1.6 Platform at Elevation Drive		External			-	-	-	1
8.1.1.7 Bogie Nodes		External			-	-	-	1
8.1.1.8 Bogies		External			-	-	-	1
8.1.1.9 Rail		External			-	-	-	1
8.1.1.10 Central Pin		External			-	-	-	1
8.1.1.11 Azimuth Locking		External			-	-	-	1
8.1.1.12 Azimuth Cable Chain		External			-	-	-	1
8.1.1.13 Elevation Cable Chain		External			-	-	-	1
8.1.1.14 Cable Ducts		External			-	-	-	1
8.1.2 Optical Support Structure		Block			-	-	-	1
8.1.2.1 Dish Structure		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.1.2.2 Elevation Drive Arch and Cables		External			-	-	-	1
8.1.2.3 Camera Support Structure (CSS)		External			-	-	-	1
8.1.2.4 Tension Cables & Anchoring Devices for CSS		External			-	-	-	1
8.1.2.5 Dish Access (stairs, catwalks, safety elements)		External			-	-	-	1
8.1.2.6 Counterweight		External			-	-	-	1
8.1.2.7 Cable Ducts		External			-	-	-	1
8.1.3 Camera Access Tower		Block			-	-	-	1
8.1.3.1 Access Tower Structure		External			-	-	-	1
8.1.3.2 Arch Locking System		External			-	-	-	1
8.2 Optical System		Block			-	-	-	1
8.2.1 Primary Mirror		Block			-	-	-	1
8.2.1.1 Mirror Facets		External			-	-	-	1
8.2.1.2 Mirror Supporting Pads		External			-	-	-	1
8.2.2 Optics Alignment		Block			-	-	-	1
8.2.2.1 Actuators		External			-	-	-	1
8.2.2.2 Interface Plates		External			-	-	-	1
8.2.2.3 AMC Control & Power Boxes		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.2.2.4 AMC Cameras		External			-	-	-	1
8.2.2.5 AMC Cabling		External			-	-	-	1
8.2.2.6 AMC Main Cabinet		External			-	-	-	1
8.3 Camera		Block			-	-	-	1
8.3.1 Mechanics Structure		Block			-	-	-	1
8.3.1.0 Assembly and Testing		External			-	-	-	1
8.3.1.1 Camera Body		Block			-	-	-	1
8.3.1.1.1 Main Structure		External			-	-	-	1
8.3.1.1.2 PMT Modules Holder		External			-	-	-	1
8.3.1.1.3 Modules Mechanical Structure		External			-	-	-	1
8.3.1.1.4 Auxiliary electronics mechanic support		External			-	-	-	1
8.3.1.1.5 Camera Cabling System		External			-	-	-	1
8.3.1.1.6 Internal Walls		External			-	-	-	1
8.3.1.2 Camera Fixation		Block			-	-	-	1
8.3.1.3 Camera Enclosure		Block			-	-	-	1
8.3.1.3.1 Camera Skin		External			-	-	-	1
8.3.1.3.2 Back Door		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.3.1.3.3 External Patch Panel		External			-	-	-	1
8.3.1.4 Camera Front Door		Block			-	-	-	1
8.3.1.4.1 Camera Shutter		External			-	-	-	1
8.3.1.4.2 Entrance Window		External			-	-	-	1
8.3.1.4.3 Targets for Displacement Monitor		External			-	-	-	1
8.3.1.4.4 Support for LEDs and DM targets		External			-	-	-	1
8.3.1.4.5 Mechanics for the Camera Front Door		External			-	-	-	1
8.3.1.4.6 Hydraulic System		External			-	-	-	1
8.3.1.5 Star Imaging Screen		Block			-	-	-	1
8.3.2 Focal Plane Instrumentation		Block			-	-	-	1
8.3.2.1 Light Guides		Block			-	-	-	1
8.3.2.2 Photosensors		Block			-	-	-	1
8.3.2.2.1 PMT + HV board		External			-	-	-	1
8.3.2.2.2 Shield		External			-	-	-	1
8.3.2.3 Preamplifier Board		Block			-	-	-	1
8.3.2.3.1 PACTA		External			-	-	-	1
8.3.2.3.2 Preamplifier PCB		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.3.2.4 FPI Slow Control Board		Block			-	-	-	1
8.3.3 Signal Processing		Block			-	-	-	1
8.3.3.1 Readout Board		Block			-	-	-	1
8.3.3.2 L0L1 Trigger		Block			-	-	-	1
8.3.3.2.1 L0 ASIC		External			-	-	-	1
8.3.3.2.2 L1 ASIC		External			-	-	-	1
8.3.3.2.3 L0L1 mezzanine		External			-	-	-	1
8.3.3.3 Backplane		Block			-	-	-	1
8.3.3.4 Trigger Interface Board		Block			-	-	-	1
8.3.4 Camera Auxiliary Systems		Block			-	-	-	1
8.3.4.1 Ethernet Switches		Block			-	-	-	1
8.3.4.2 Power Distribution System		Block			-	-	-	1
8.3.4.2.1 Power Supply Box		External			-	-	-	1
8.3.4.2.2 Power Distribution Box		External			-	-	-	1
8.3.4.2.3 Bus Bars		External			-	-	-	1
8.3.4.3 Environmental Control		Block			-	-	-	1
8.3.4.3.1 Cooling System		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.3.4.3.2 Dehumidification		External			-	-	-	1
8.3.4.3.3 Pressure Control		External			-	-	-	1
8.3.4.4 Embedded Camera Controller		Block			-	-	-	1
8.3.4.4.1 Compact RiO		External			-	-	-	1
8.3.4.4.2 Reference LEDs		External			-	-	-	1
8.3.4.5 UCTS Auxiliary		External			-	-	-	1
8.3.4.6 Camera Cabling		Block			-	-	-	1
8.3.4.6.1 Camera Internal Cabling		External			-	-	-	1
8.3.4.6.2 Camera External Cabling		External			-	-	-	1
8.3.4.7 External Cooling Unit		External			-	-	-	1
8.3.4.8 Camera Server		External			-	-	-	1
8.3.4.9 Central CCD Camera Pixel		External			-	-	-	1
8.3.4.10 Hydraulic Pump		External			-	-	-	1
8.3.4.11 Transportation and Installation Tool		External			-	-	-	1
8.4 Auxiliary Systems		Block			-	-	-	1
8.4.1 Energy Storage		External			-	-	-	1
8.4.2 Lightning Protection		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.4.3 Calibration and Pointing Control		Block			-	-	-	1
8.4.3.1 Camera Displacement Monitoring and Star Guider Hood		External			-	-	-	1
8.4.3.2 Camera Displacement Monitoring		External			-	-	-	1
8.4.3.3 Starguider		External			-	-	-	1
8.4.3.4 Optical Axis Reference Laser		External			-	-	-	1
8.4.3.5 Calibration Light Source		External			-	-	-	1
8.4.3.6 Distance Meter		External			-	-	-	1
8.4.3.7 PSF Camera		External			-	-	-	1
8.4.4 Drive Control System		Block			-	-	-	1
8.4.4.1 Main Drive Control System		External			-	-	-	1
8.4.4.2 Encoders		External			-	-	-	1
8.4.4.3 Azimuth		Block			-	-	-	1
8.4.4.3.1 Az Gearbox		External			-	-	-	1
8.4.4.4 Elevation		Block			-	-	-	1
8.4.4.4.1 Elevation Gearbox		External			-	-	-	1
8.4.4.4.2 Elevation Brake		External			-	-	-	1
8.4.4.4.3 Elevation Bolt		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.4.4.5 Precision Inclinometer		External			-	-	-	1
8.4.4.6 Drive Cables		External			-	-	-	1
8.4.4.7 End		External			-	-	-	1
8.4.5 Drive Container		Block			-	-	-	1
8.4.5.1 Container		External			-	-	-	1
8.4.5.2 Racks		External			-	-	-	1
8.4.5.3 UPS		External			-	-	-	1
8.4.6 Structure Condition Monitoring		Block			-	-	-	1
8.4.6.1 Accelerometers		External			-	-	-	1
8.4.6.2 Strain Gauges		External			-	-	-	1
8.4.6.3 Readout of Structure Condition		External			-	-	-	1
8.4.6.4 Structure Condition Cabling		External			-	-	-	1
8.4.6.5 CSS Load Pins		Block			-	-	-	1
8.4.6.5.1 Load Pins		External			-	-	-	1
8.4.6.5.2 Readout of Load Pins		External			-	-	-	1
8.4.6.5.3 Load Pin Cabling		External			-	-	-	1
8.4.7 Cabling Structures		Block			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.4.7.1 Main Electrical Cabinet		External			-	-	-	1
8.4.7.2 Structure Cabinets		External			-	-	-	1
8.4.7.3 Structure Cables		External			-	-	-	1
8.4.7.4 Access Tower Platform Cabinet		External			-	-	-	1
8.5 Common and AIV		Block			-	-	-	1
8.5.1 Management		Block			-	-	-	1
8.5.1.1 Project manager		External			-	-	-	1
8.5.1.2 Systems Engineer		External			-	-	-	1
8.5.1.3 Coordinators		External			-	-	-	1
8.5.1.4 Telescope Site Manager		External			-	-	-	1
8.5.2 Telescope Foundation		External			-	-	-	1
8.5.3 Telescope Control Software		External			-	-	-	1
8.5.4 Host Contracts		External			-	-	-	1
8.5.5 Telescope Commissioning		External			-	-	-	1
8.5.6 Infrastructure		Block			-	-	-	1
8.5.6.1 Logistics		External			-	-	-	1
8.5.6.2 Telescope safety		External			-	-	-	1

Name	Part Number	Category	Reference Designator	Supplier	Failure Rate(t=INF)	MTBF (hrs)	Contribution	Quantity
8.5.6.3 Commissioning Building / Container		External			-	-	-	1

ANNEX 3: Analysis of maintenance activities in 2019

Table 35: Annex 3

2019						
Intervencion	**Preventive/Corrective**	**Subsystem**	**Days**	**People**	**Hour**	**Person-h**
Mirror and AMC	Preventive	Optics	6	1	48	48
Bogie ALS	Preventive	Mech	6	1	48	48
Mirror and actuators	Preventive	Optics	6	1	48	48
IT CONTAINER	Corrective	Aux	8	2	64	128
Shutter repair	Corrective	Camera	5	2	40	80
ALS	Preventive	Mech	5	4	40	160
Energy system maintenance	Corrective	Energy	2	1	16	16
Shutter repair	Corrective	Camera	4	2	32	64
Bogie ALS	Preventive	Mech	5	4	40	160
Camera works	Preventive	Camera	4.5	3	36	108
New floor	Corrective	Other	2.5	2	20	40
Plant control	Preventive	Other	5	4	40	160
Cleaning	Preventive	Other	52	1	10	10
Temp. Measurement	Preventive	Other	1	1	8	8
Tubes repair	Corrective	Mech	2	2	16	32
IT CONTAINER	Corrective	IT	1	1	8	8
IT CONTAINER	Corrective	IT	1	1	8	8
Cherry Picker	Corrective	Other	3	1.67	10	16.66
Pest control	Preventive	Other	0.875	1	7	7
Energy system maintenance	Corrective	Energy	4	5	32	160
Genset	Preventive	Energy	2	3	16	48
Tower platform repair	Corrective	Mech	2.5	4	20	80
Actuator checks	Preventive	Optics	1	2	8	16
Energy system maintenance	Preventive	Energy	2	4	16	64
Energy system maintenance	Corrective	Energy	2	4	16	64
Fiber inspction	Preventive	Aux	1	2	8	16
Tubes repair	Corrective	Mech	1	2	8	16
Life Line inspection	Preventive	Mech	1	2	8	16
Tubes repair	Corrective	Mech	1	2	8	16
Cable protection	Preventive	Mech	1	2	8	16
Tubes repair	Corrective	MECH	1	2	8	16
Genset	Preventive	Energy	1	4	8	32
Fire ext	Preventive	Other	0.139	1	1.11	1.11
Fire ext	Preventive	Mirca	0.125	2	1	2
Camera tower inspection	Preventive	MECH	1	1	8	8
Epis revision	Preventive	Other	1	1	8	8

ANNEX 4: Analysis of maintenance activities in 2020

Table 36: Annex 4

2020						
Intervencion	**Preventive/Corrective**	**Subsystem**	**Days**	**People**	**Hour**	**Person-h**
cherry picker	Corrective	Other	0.5	2	4	8
Fire ext	Preventive	Other	0.25	1	2	2
cherry picker	Preventive	Other	0.875	1	7	7
IT	Corrective	IT	0.5	1	4	4
Bogies, rail and ALS	Preventive	Mech	4	4	32	128
IT	Corrective	IT	0.5	1	4	4
IT	Corrective	IT	0.5	1	4	4
cherry picker	Corrective	Other	0.375	1	3	3
Pest control	Preventive	Other	0.125	1	1	1
Life Line	Preventive	Mech	1	2	8	16
Pest control	Preventive	Other	0.125	1	1	1
Fence repair	Corrective	Other	0.5	2	4	8
calibox	Corrective	Camera	3	1	24	24
IT	Preventive	IT	2	3	16	48
IT	Corrective	IT	2	2	16	32
AMC PS Repair and current limiters	Corrective	Optics	15	2	120	240
Energy Storage container	Preventive	Energy	5	2	40	80
Pest control	Preventive	Other	0.125	1	1	1
Fire ext	Preventive	IT	0.5	1	4	4
Bogies, rail and ALS	Preventive	Mech	5	2	40	80
UPS MAINTENANCE IT	Preventive	IT	1	1	8	8
GENSET MAINTENANCE	Preventive	Energy	1	3	8	24
cherry picker	Preventive	Other	1	1	8	8
cherry picker	Preventive	Other	2	2	16	32
Fujitsu corrective	Corrective	IT	0.25	1	2	2
IT cooling maintence	Corrective	it	1	2	8	16
Fire alarm buttons	Corrective	aux	0.5	1	4	4
Plant control	Preventive	Other	6	3	48	144
Quiron inspection	Preventive	Other	0.13	1	1.04	1.04
cherry picker	Preventive	Other	0.5	2	4	8
Fujitsu maintenance	Corrective	it	0.5	1	4	4
A/C	Corrective	Other	1	1	8	8
Cleanning	Preventive	Other	6.5	1	52	52
EPIS revision	Preventive	Other	1	1	8	8
Cooling system IT	Corrective	IT	1	2	8	16
Pest control	Preventive	Other	0.125	1	1	1
Pest control	Preventive	Other	0.125	1	1	1
Camera preventive maintenance	Preventive	Camera	1	2	8	16

ANNEX 5: Global schedule of preventive maintenance activities (at September 2021)

Table 37: Maintenance calendar

Preventive Maintenance activity	Institute /Company	2021																											
			JAN					FEB				MAR					APR				MAY					JUN			
		53	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
MECHANICAL SUBSYSTEM																													
LIFE LINE	Vertical 7																									1			
ALS								5																					
CAMERA ACCESS TOWER	----																												
Global	Local enginneer																												
Pillars, beams and diagonal tensioners	Local enginneer																												
Platforms	Local enginneer																												
Access doors	Local enginneer																												
Container	Local enginneer																												
Staircases	Local enginneer																												
Moving platform drive	Local enginneer																												
CSS Locking system	Local enginneer																												
Front scaffolding	Local enginneer																												
MOUNT (TELESCOPE STRUCTURE)	----																												
Interface rail to foundation	Local engineer?																												
Central pin	Local engineer																												
Telescope structure - lower structure	Local engineer																												
Telescope structure - dish structure	Local engineer																												
Telescope structure - elevation drive arch	Local engineer																												
Access elements - mount access	Hired company																												
Access elements - dish access	Local enginner																												
Elevation drive	Local engineer																												
BOGIES - RAIL	IFAE							1																					

Preventive Maintenance activity	Institute /Company	2021																											
			JAN					FEB				MAR					APR				MAY					JUN			
		53	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
MECHANICAL SUBSYSTEM																													
OPTICS SUBSYSTEM (LST/20190715)																													
Mirror facets: Eye inspections for the whole part, mirror pads (	Opt. Expert									1																			
Actuators, CMOS, facet cables: Eye inspections for the actuato	Opt. Expert									1																			
AMC boxes	Opt. Expert									1																			
PSF camera	Opt. Expert									1																			
CAMERA																													
Camera body	CIEMAT																			1									
Camera Fixation	CIEMAT																			1									
Camera Enclosure (Camera Skin, Backdoor y External Batch Panel)	CIEMAT																			1									
Camera front door - shutter	CIEMAT																			1									
Camera front door - entrance window	CIEMAT																			1									
Camera front door - Targets for Displacement Monitoring	CIEMAT																			1									
Star Imaging Screen	CIEMAT																			1									
Light Guides	CIEMAT																												
Trigger Interface Board	CIEMAT																												
Power Distribution Box	CIEMAT																			1									
Bus Bars	CIEMAT																			1									
Environmental Control (Cooling System, Dehumidification, Pressure)	CIEMAT																			1									
Embedded Camera Controller (Compact Rio and Reference LEDs)	CIEMAT																			1									
Unified Clock & Trigger Stamping Auxiliary	CIEMAT																			1									
Camera Cabling	CIEMAT																			1									
External Cooling Unit	CIEMAT																			1									
Camera Server	CIEMAT																												
AUXILIARY																													
ENERGY STORAGE CONTAINER																													
UC-FIRE EXTINGUISHER SYSTEM (4/year by Extinpalma)	EXTINPALMA				1									1													1		
FE-LST-UC1/UC2/UC3/UC4 (1/year)	EXTINPALMA				1																								
UC-PAC (2/year since April by Pedro Brito)	PEDRO BRITO												1																
UC-ELECTRONIC (1/year by ABB)	ABB																												
DISH CENTER ELEMENTS																													
OARL + INCLINOMETERS (2/year)	??																1												
Distance Meter (2/year)	??																1												
SG+CDM HOOD (2/year)	??																1												
Calibration Box (2/year)	??																1												
Cable chain (freq??)	??																												
Cabling - 6 months inspection	Local worker																1												
Cabling - 2 year months inspection	Local worker																1												
Lightning Protection	Hired company																												
Drive control system																													
Structure contitioning monitoring																													

Preventive Maintenance activity	Institute /Company	2021																											
			JAN					FEB				MAR				APR					MAY					JUN			
		53	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
MECHANICAL SUBSYSTEM																													
OPTICS SUBSYSTEM (LST/20190715)																													
Mirror facets: Eye inspections for the whole part, mirror pads (	Opt. Expert									1																			
Actuators, CMOS, facet cables: Eye inspections for the actuato	Opt. Expert									1																			
AMC boxes	Opt. Expert									1																			
PSF camera	Opt. Expert									1																			
CAMERA																													
AUXILIARY																													
COMMON																													
Telescope Foundation and Commissioning Container	Local engineer																												
GENSET (1/year by ERGA)	ERGA																												
CHERRY PICKER (CTA) (4/year by Opein)	OPEIN											1													1				
CENTRO DE TRANSFORMACION (IAC)	Hired company																												
IT CONTAINER																													
FUJITSU (no preventive maintenance)	Fujitsu																												
IT-Visual, electronic, power and ambient inspection (1/year)	Schneider																												
IT UPS (1/year)	Schneider																					1				1			
IT Cooling system (2/year)	Schneider			5							1					5													
IT-Fire extinguisher system (4/year)	Schneider				1													1								1			
PPE - Yellow helmets	Local engineer																									1			
PPE - Climbing material	Arquitectura Vertical																												
PPE- White helmets	Local engineer																												
FE-LST-CC/DRIVE/TOWER/EXT	EXTINPALMA																												
A/C C.C.	Local engineer				1				1					1				1					1						
PEST CONTROL	Apinsa										1																		1
PLANT CONTROL	Hired company																	1											
INSURANCE - ORM																													
QUIRON-EVALUATION RISK ORM																													
FE-MIRCA	EXTINPALMA																												
INSURANCE - MIRCA																													
QUIRON-EVALUATION RISK Mirca																													

Preventive Maintenance activity	Institute /Company			JUL				AUG				SEP					OCT					NOV				DEC		
			28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1
MECHANICAL SUBSYSTEM																												
LIFE LINE	Vertical 7																											
ALS																												
CAMERA ACCESS TOWER	----																											
Global	Local enginneer																2											
Pillars, beams and diagonal tensioners	Local enginneer																2											
Platforms	Local enginneer																2											
Access doors	Local enginneer																2								2			
Container	Local enginneer																2											
Staircases	Local enginneer																2											
Moving platform drive	Local enginneer																2											
CSS Locking system	Local enginneer																2											
Front scaffolding	Local enginneer																2											
MOUNT (TELESCOPE STRUCTURE)	----																											
Interface rail to foundation	Local engineer?																2											
Central pin	Local engineer																2											
Telescope structure - lower structure	Local engineer																2											
Telescope structure - dish structure	Local engineer																2											
Telescope structure - elevation drive arch	Local engineer																2											
Access elements - mount access	Hired company																2											
Access elements - dish access	Local enginner																2											
Elevation drive	Local engineer																2											
BOGIES - RAIL	IFAE															2												

Preventive Maintenance activity	Institute /Company	JUL				AUG				SEP				OCT					NOV				DEC				
		28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1
MECHANICAL SUBSYSTEM																											
OPTICS SUBSYSTEM (LST/20190715)																											
Mirror facets: Eye inspections for the whole part, mirror pads (	Opt. Expert																										
Actuators, CMOS, facet cables: Eye inspections for the actuato	Opt. Expert																										
AMC boxes	Opt. Expert																										
PSF camera	Opt. Expert																										
CAMERA																											
Camera body	CIEMAT																										
Camera Fixation	CIEMAT																										
Camera Enclosure (Camera Skin, Backdoor y External Batch Panel)	CIEMAT																										
Camera front door - shutter	CIEMAT																										
Camera front door - entrance window	CIEMAT															2											
Camera front door - Targets for Displacement Monitoring	CIEMAT															2											
Star Imaging Screen	CIEMAT															2											
Light Guides	CIEMAT																										
Trigger Interface Board	CIEMAT																										
Power Distribution Box	CIEMAT																										
Bus Bars	CIEMAT																										
Environmental Control (Cooling System, Dehumidification, Pressure)	CIEMAT																										
Embedded Camera Controller (Compact Rio and Reference LEDs)	CIEMAT																										
Unified Clock & Trigger Stamping Auxiliary	CIEMAT																										
Camera Cabling	CIEMAT																										
External Cooling Unit	CIEMAT																										
Camera Server	CIEMAT																										
AUXILIARY																											
ENERGY STORAGE CONTAINER																											
UC-FIRE EXTINGUISHER SYSTEM (4/year by Extinpalma)	EXTINPALMA																2							2			
FE-LST-UC1/UC2/UC3/UC4 (1/year)	EXTINPALMA																										
UC-PAC (2/year since April by Pedro Brito)	PEDRO BRITO																2										
UC-ELECTRONIC (1/year by ABB)	ABB																2										
DISH CENTER ELEMENTS																											
OARL + INCLINOMETERS (2/year)	??																2										
Distance Meter (2/year)	??																2										
SG+CDM HOOD (2/year)	??																2										
Calibration Box (2/year)	??																2										
Cable chain (freq??)	??																										
Cabling - 6 months inspection	Local worker																2										
Cabling - 2 year months inspection	Local worker																										
Lightning Protection	Hired company											1															
Drive control system																											
Structure contitioning monitoring																											

Preventive Maintenance activity	Institute /Company	JUL				AUG				SEP					OCT				NOV				DEC				
		28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1
MECHANICAL SUBSYSTEM																											
OPTICS SUBSYSTEM (LST/20190715)																											
CAMERA																											
AUXILIARY																											
COMMON																											
Telescope Foundation and Commissioning Container	Local engineer															2											
GENSET (1/year by ERGA)	ERGA															2											
CHERRY PICKER (CTA) (4/year by Opein)	OPEIN																						2				
CENTRO DE TRANSFORMACION (IAC)	Hired company																										
IT CONTAINER																											
FUJITSU (no preventive maintenance)	Fujitsu																										
IT-Visual, electronic, power and ambient inspection (1/year)	Schneider																2										
IT UPS (1/year)	Schneider																										
IT Cooling system (2/year)	Schneider															2											
IT-Fire extinguisher system (4/year)	Schneider															2											
PPE - Yellow helmets	Local engineer																										
PPE - Climbing material	Arquitectura Vertical													2													
PPE- White helmets	Local engineer										3																
FE-LST-CC/DRIVE/TOWER/EXT	EXTINPALMA										1																
A/C C.C.	Local engineer																										
PEST CONTROL	Apinsa									1																	
PLANT CONTROL	Hired company																2										
INSURANCE - ORM															2												
QUIRON-EVALUATION RISK ORM															2												
FE-MIRCA	EXTINPALMA										1																
INSURANCE - MIRCA		1																									
QUIRON-EVALUATION RISK Mirca															2												

OK	1
NEXT INSPECTION	2
PENDING	3
ON GOING	4
REPAIR	5

ANNEX 6: Analysis of maintenance activities in 2021 (until 15th Aug)

Table 38: Annex 5

2021						
Intervencion	**Preventive/Corrective**	**Subsystem**	**Days**	**People**	**Hour**	**Person-h**
Cooling system IT (Solclima)	Corrective	IT	4	2	32	64
Fire extinguisher UC maint	Preventive	Energy	0.25	1	2	2
Fire system IT	Preventive	IT	0.125	1	1	1
					0	0
Firmawae update o UCT. New firmware	Corrective	Camera	5	2	40	80
					0	0
ALS corrective	Corrective	Mech	0.5	1	4	4
Bogies maintenance	Preventive	Mech	1.5	1	12	12
Reparation of PAC into the UC1	Corrective	Energy	0.5	1	4	4
Mirrors activities	Corrective	Optics	3.125	4	25	100
Fire extinguiser UC sirens	Corrective	Energy	0.375	2	3	6
MBC UC4, FAN UC2	Corrective	Energy	2	1	16	16
Cherry Picker preventive maintenance	Preventive	Other	0.375	1	3	3
Inrow 1	Corrective	IT	1	2	8	16
Pest control	Preventive	Other	0.125	1	1	1
Cooling system IT (Solclima)	Preventive	IT	1	2	8	16
UC cooling system	Preventive	Energy	0.625	2	5	10
Fire extinguisher UC maint	Preventive	Energy	0.25	1	2	2
Cooling system IT (Solclima)	Corrective	IT	0.688	2	5.5	11
FE IT	Preventive	IT	0.188	1	1.5	1.5
Camera maintenance	Preventive	Camera	2.25	2	18	36
IT-FE	Preventive	IT	0.25	1	2	2
Annual inspection of lifeline	Preventive	Mech	0.5	2	4	8
Annual preventive maintenance of UPS	Preventive	IT	0.375	1	3	3
PPE preventive maintenance	Preventive	Other	0.25	1	2	2
Cherry Picker preventive maintenance	Preventive	Other	0.625	1	5	5
FE UC	Preventive	Energy	0.125	1	1	1
Pest control	Preventive	Other	0.125	1	1	1
Cherry Picker preventive maintenance	Corrective	Other	0.525	1	4.2	4.2

ANNEX 7: Incidents and system failures table of LST1

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
1	Cherry picker from CTA had an incident. Basket fell out and it hit the ground	Other	Hired company: Opein	Other cherry picker was rented during the reparation of original cherry picker.	17/04/2018	01/11/2018	198	The construction phase was affected until the rented cherry picker arrived to the site.	No
2	Mirror ID plates found on the ground	Opt	Hired company: Casana	All ID plates were removed.	08/11/2018	10/11/2018	2	No, but the access to telescope area was limited.	Yes, solar radiation. The ID plates on the back were not covered by UV resistant paint
3	There are electrical discharges in the commissioning container	Other	Hired companies: Casana and Kaplan	Some elements of Commissioning Container are not connected to grounding. It was changed and improved.	09/01/2019	01/07/2019	173	No	Low humidity affects to electrical discharges. The design of the floor was not the correct.
4	Water into the electrical boxes of the temporal Azimuth Locking System. The boxes were replaced. Plastic boxes of IP66 were installed.	Mech	Hired company: Ayumar	Plastic boxes were installed	22/01/2019	21/02/2019	30	no	Yes, rain. The original boxes were not appropriate.
5	One of the four Elevation breaks is stuck during drive tests. C-Lock Washer of the shaft fell into the disks.	Mech	Hired company: Casana MPI	The break had to be removed and C-Lock Washer put back 2 days later.	23/01/2019	25/01/2019	2	Yes	No

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
6	The glue of one mirror (position: -8, -6; fixed point) got loose	Opt	ICRR CIEMAT Hired company: Casana	Mirror was changed by a new one	05/02/2019	06/02/2019	1	Yes	Apparently no
7	Power cut into Commissioning Container after bad weather. The problem was in line X1.6	Other	Hired company: Kaplan and Opein	New power connection into the Commissioning Container was done. The CC was sealed again	16/02/2019	18/02/2019	2	Yes	Yes, snow storm. The problem came when the snow melted and the water entered into the CC.
8	Perimeter fence was broken by wind	Other	Hired company: Bediesta	The fence was repaired and the foundations were reinforced.	18/02/2019	06/03/2019	16	No	Yes, there was a storm with strong winds.
9	UPS from IT container stopped	Other	Hired company: Schneider	One Intelligent Module needed to be changed by Schneider	20/02/2019	27/02/2019	7	No	No
10	After a drive test, the upper platform of the camera access tower blocked.	Mech	MPI	It was repaired few days later.	12/03/2019	14/03/2019	2	No	No
11	There was water inside the UC1 (roof, floor, wall and door)	Aux	Hired company: Hitachi	Local crew switched off the UC1 on 03.04.2019. Technicial from Hitachi checked the UC1. Aparently everything was fine but the equipments were not swichted on because there was a lot of water inside the container. Metal plates were sealed with new silicone. Several holes around the door were detected on 04.04.2019. Technicial from Hitachi swiched on the UC1 on	03/04/2019	09/04/2019	6	Yes	Yes, snow storm. The problem came when the snow melted and the water entered into the container

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
				06.06.2019. Technicial from Hitachi Malasia checked the UC1. There was not water. Container was checked with Cerrapalma too on 09.04.2019. Sensor of water was tested by technicial from Hitachi and it was working fine. 12.04.2019 Hitachi repaired the container on 18.07.19					
12	The fire alarm of UC1 rang. There was snow	Aux	Hired company: Hitachi	Technician from Hitachi checked the fire alarm and he detected that the external button was damaged. Button was changed by Hitachi on 10.04.2019	03/04/2019	10/04/2019	7	No	Yes, snow storm. The problem came when the snow melted and the water entered into the button
13	The shutter of camera was damaged when it was moved while the telescope was pointing to about 20 degrees zenith angle	Cam	CIEMAT	The shutter was repaired by Ciemat	08/04/2019	23/04/2019	15	Yes	No
14	Fire Alarm from IT Container was pre-activated. Power was switched off	Other	Hired company: Schneider	Technician from Schneider needs to check the Inrow 2 and Inrow 3. Inrow 3 was repaired by Schneider on july.2019. Inrow 2 and 3 were repaired by Schneider on October 2019. The Fire Alarm Panel was repaired by Schneider on Oct.2019	07/06/2019	01/10/2019	116	No	No
15	Fly Wheel 2 from UC 1 was stopped	Aux	Hired company: Hitachi	There are vibration and rotation Alerts in the MBC parameters. Hitachi repaired the FW on 18.07.19	09/06/2019	18/07/2019	39	No	No
16	Coating protection of concrete beam is damaged in several points.	Other	No repaired yet		11/06/2019		-43627	No	No

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
17	IT container door(s) not/very hard to open	Other	Hired company: Schneider	Schneider repaired the door	18/07/2019	01/07/2020	349	No	No
18	Rubber seal in the frontal part of the camera is damaged.	Cam	CIEMAT and LST Team	Rubber was damaged on 08-04-2019. The rubber was cut by LST team on 02.09.2019. The rubber was removed by Ciemat on Nov. 2019	02/09/2019	01/11/2019	60	No	No
19	The screws of two aluminium tubes in the dish structure were broken. The screws were replacement as soon as possible.	Mech	Hired company: Casana	According the designer, the structure should be safe, but there is a danger of the tube detaching completely after more movement. The way the tube is positioned there is almost no chance it will detach in park position. Still, any movement by people in the rear part of the telescope must be limited to the minimum possible amount, meaning only the people who will repair the tube are allowed back there.	27/11/2019	16/01/2020	50	No	
20	There are drops of water from the humidifier in the wall of the IT container	Other	Hired company: Schneider	Schneider and LST Team checked the humidifier and there was a loop in the drainage pipe. The loop was removed. The bottle was removed and it was broken. A new bottle was installed but the new holes are looking to the ceiling and they produce condensation on the ceiling. The humidifier cannot be connected in this situation because the water can wet the leak rope. The humidifier was repaied by Schneider on week 30 (2020)	28/01/2020	15/03/2020	47	No	No

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
21	The camera access tower was opened after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00. No damages	Mech	Hired company: Casana	It was repaired few days later.	23/02/2020	25/02/2020	2	No	Yes. A strong storm affected to Canary Islands in Feb. 2020
22	The camera shutter was broken after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Cam	CIEMAT	It was repaired as soon as possible. Temporal camera cover was needed	23/02/2020	01/10/2020	221	No	Yes. A strong storm affected to Canary Islands in Feb. 2021
23	The camera maintenance room was moved after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Mech	Hired company: Casana	It was repaired few days later.	23/02/2020	25/02/2020	2	No	Yes. A strong storm affected to Canary Islands in Feb. 2022
24	Several signs were removed and broken after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Other	LST Team	It was repaired as soon as new signs were bought.	23/02/2020	20/03/2020	26	No	Yes. A strong storm affected to Canary Islands in Feb. 2023

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
25	2 piles from the fence were moved (the fence is not opened) after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Other	Hired company: Bediesta	They were repaired as soon as possible	23/02/2020	01/06/2020	99	No	Yes. A strong storm affected to Canary Islands in Feb. 2024
26	A cover from the camera chiller was damaged after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Cam	Hired company: Casana	It was repaired few days later.	23/02/2020	25/02/2020	2	No	Yes. A strong storm affected to Canary Islands in Feb. 2025
27	The roof of the chiller was damaged after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Other	Hired company: Casana	It was repaired few days later.	23/02/2020	25/02/2020	2	No	Yes. A strong storm affected to Canary Islands in Feb. 2026
28	Several cable trays were damaged after a wind storm, the maximum wind gust speed reported by the MAGIC weather station during the storm was 157 km/h at ~8:00.	Aux	Hired company: Bediesta	They were repaired as soon as possible	23/02/2020	01/06/2020	99	No	Yes. A strong storm affected to Canary Islands in Feb. 2027

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
29	Elevation drive got stuck at ~60° zd after the night. Four persons at hand wheels and remote expert intervention were needed to bring telescope and camera in safe state around 9:30 (local) in the morning	Mech	Hired company: Casana LST Team	On the inspection two days after, large amount of debris was found on the arch where the guiding wheels of the elevation drive move within the arch. Debris could be sanded down and smoothed. Another test was made in the evening, when the arc was again sanded and thoroughly cleaned from debris again between 50deg and 95deg Zd. Afterwards another cycle of park-out, Zd 30, park-in confirmed that there was no more scraping sounds at any point. It was concluded that the problem is fixed, although the cause still not perfectly clear. As for the cause, no larger debris or piece could be found that looks like it could have fallen into the drive. It is possible that it was a slow process over several days or weeks where small metallic debris was embedded and compacted on the guiding wheels and at one point finally started to scrape so much on the surface of the arc that the motors overheated and overtorqued. Loose zinc coating was found on the steel tubes directly above the back arc which may have flaked off and fallen into the elevation drive. A single flake should not be hard enough to cause a problem, but possibly an accumulation over several weeks	19/08/2020	21/08/2020	2	Yes	No

#	WHAT HAPENNED	Affected subsystem	Who did repair the incident?	Comments	Initial date	Final date	Total days	Did the telescope stop?	Was related with a risk or weather conditions?
				might cause a problem.					
30	A camera front scaffolding was moved by the wind.	Mech	LST Team	It was fixed as soon as possible. There were not damages	19/10/2020	20/10/2020	1	No	Yes, wind and a human mistake
31	Consequences of snow storm in the ORM (January 2021): 1. Cover of motors of ALSs are damaged; 2. Handrail of camera access tower is damaged; 3. A network cabinet is damaged; 4. A cable of ALS-West was removed; 5. Cover of cable trays were removed	Mech	LST Team IFAE Hired company: Casana Hired company: Bediesta	Everything was repaired as soon as possible. The telescope was stoped until the ice was removed.	19/01/2021	08/02/2021	20	No	Yes. A snow storm
32	A part of a mirror was found in the ground after a snow storm.	Opt	Hired company: Casana	The mirror was repaired (tape) as soon as possible.	18/02/2021	24/02/2021	6	No	It was detected after a snow storm.
33	Since 2020 the automatic bolt is not working	Mech			12/07/1905			No	
34	The pad of a mirror peeled off	Opt	ICRR Hired company: Casana	The problem was investigated by experts. The damaged mirror was removed as soon as possible. Other mirrors were removed too by prevention. The mirrors were repaired (glue and paint) and they were installed again.	25/03/2021	13/07/2021	110	Yes, but only few days	The initial problem was detected during stong winds.

ANNEX 8: Example of inventory form use

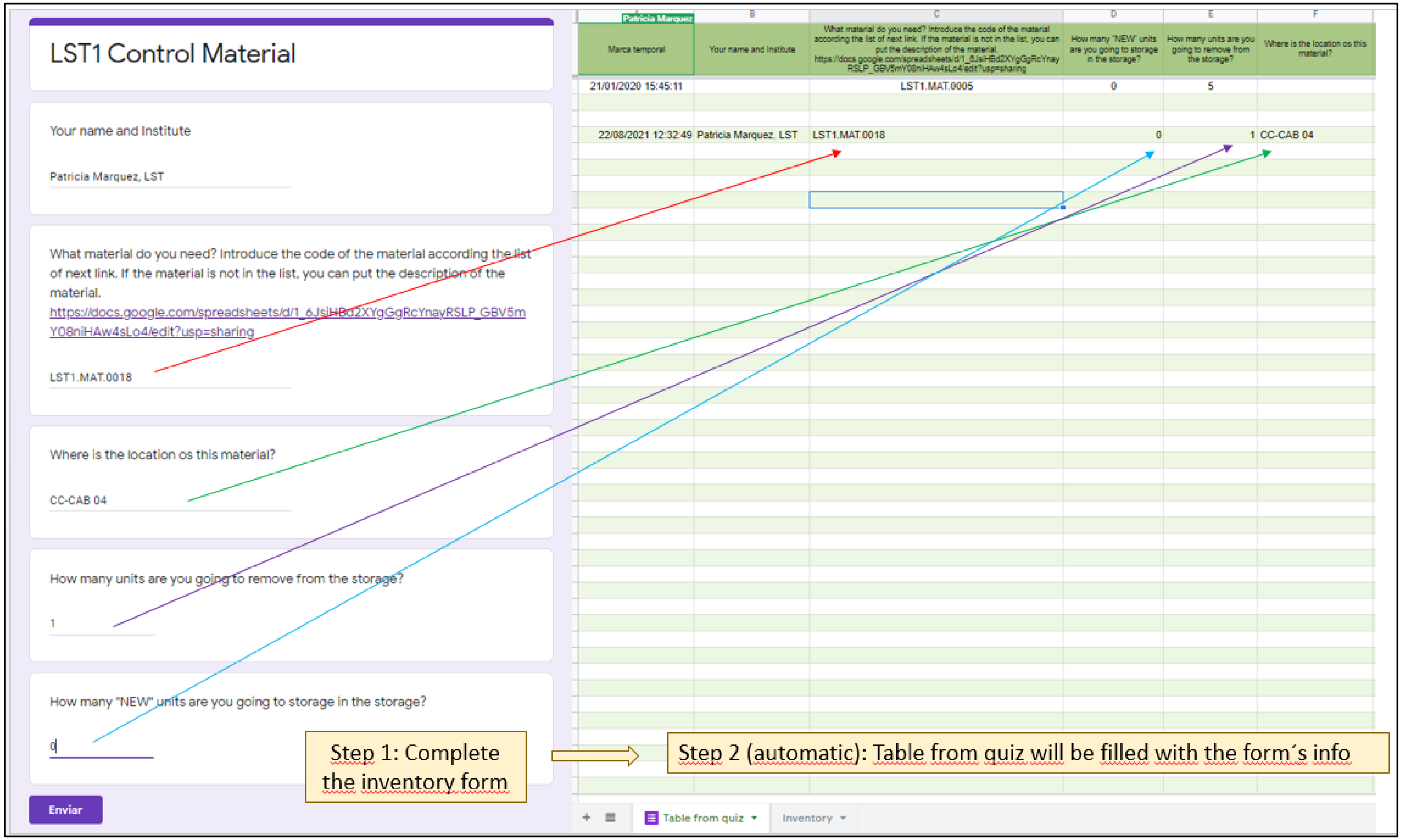
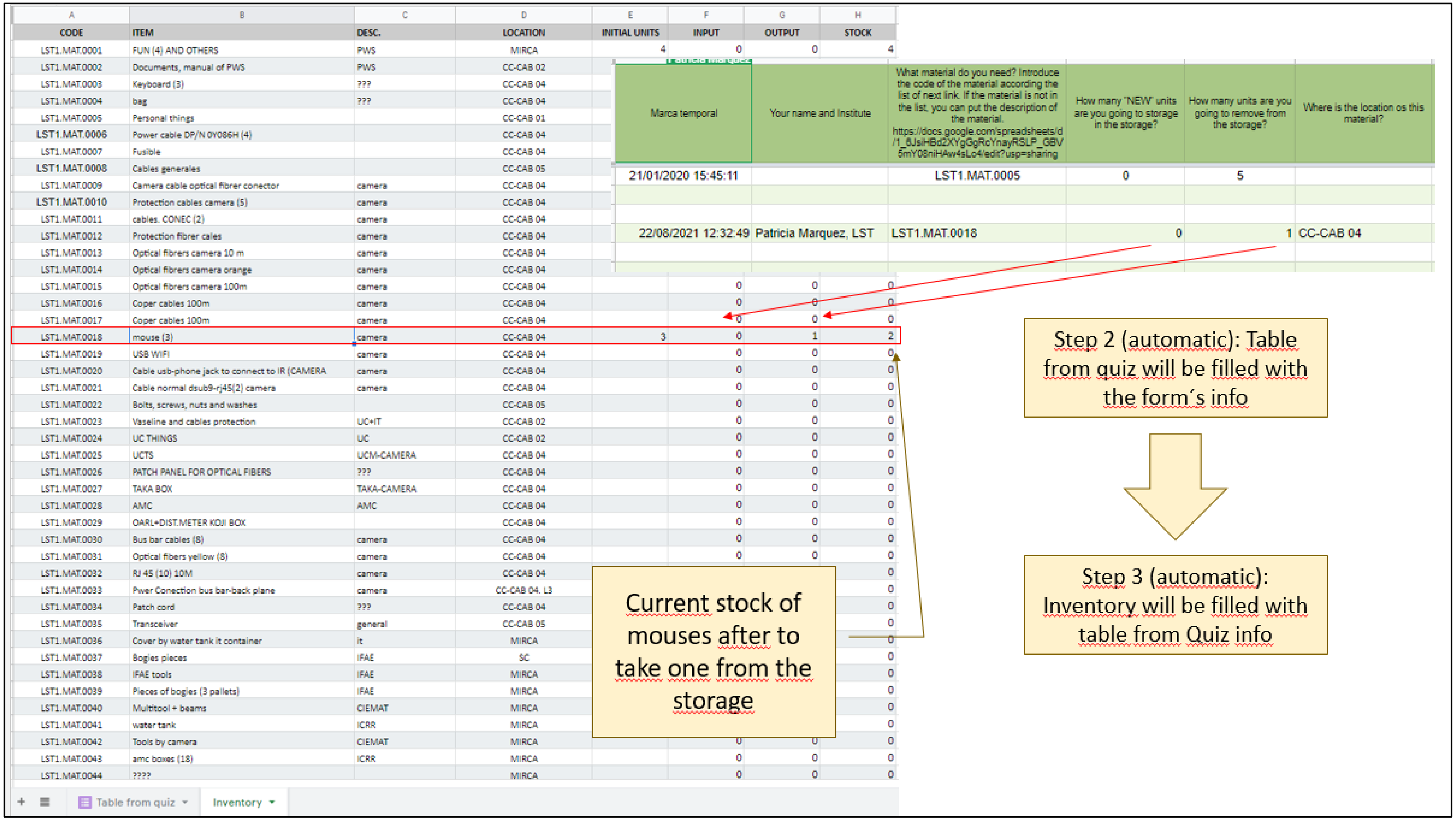


Fig. 0-1: Steps 1 and 2 of inventory´s from use



CODE	ITEM	DESC.	LOCATION	INITIAL UNITS	INPUT	OUTPUT	STOCK
LST1.MAT.0001	FUN (4) AND OTHERS	PWS	MIRCA	4	0	0	4
LST1.MAT.0002	Documents, manual of PWS	PWS	CC-CAB 02				
LST1.MAT.0003	Keyboard (3)	???	CC-CAB 04				
LST1.MAT.0004	bag	???	CC-CAB 04				
LST1.MAT.0005	Personal things		CC-CAB 01				
LST1.MAT.0006	Power cable DP/N 0Y086H (4)		CC-CAB 04				
LST1.MAT.0007	Fusible		CC-CAB 04				
LST1.MAT.0008	Cables generales		CC-CAB 05				
LST1.MAT.0009	Camera cable optical fibrer conector	camera	CC-CAB 04				
LST1.MAT.0010	Protection cables camera (5)	camera	CC-CAB 04				
LST1.MAT.0011	cables. CONEC (2)	camera	CC-CAB 04				
LST1.MAT.0012	Protection fibrer cales	camera	CC-CAB 04				
LST1.MAT.0013	Optical fibrers camera 10 m	camera	CC-CAB 04				
LST1.MAT.0014	Optical fibrers camera orange	camera	CC-CAB 04				
LST1.MAT.0015	Optical fibrers camera 100m	camera	CC-CAB 04		0	0	0
LST1.MAT.0016	Coper cables 100m	camera	CC-CAB 04		0	0	0
LST1.MAT.0017	Coper cables 100m	camera	CC-CAB 04		0	0	0
LST1.MAT.0018	mouse (3)	camera	CC-CAB 04	3	0	1	2
LST1.MAT.0019	USB WIFI	camera	CC-CAB 04		0	0	0
LST1.MAT.0020	Cable usb-phone jack to connect to IR (CAMERA	camera	CC-CAB 04		0	0	0
LST1.MAT.0021	Cable normal dsub9-rj45(2) camera	camera	CC-CAB 04		0	0	0
LST1.MAT.0022	Bolts, screws, nuts and washes		CC-CAB 05		0	0	0
LST1.MAT.0023	Vaseline and cables protection	UC+IT	CC-CAB 02		0	0	0
LST1.MAT.0024	UC THINGS	UC	CC-CAB 02		0	0	0
LST1.MAT.0025	UCTS	UCM-CAMERA	CC-CAB 04		0	0	0
LST1.MAT.0026	PATCH PANEL FOR OPTICAL FIBERS	???	CC-CAB 04		0	0	0
LST1.MAT.0027	TAKA BOX	TAKA-CAMERA	CC-CAB 04		0	0	0
LST1.MAT.0028	AMC	AMC	CC-CAB 04		0	0	0
LST1.MAT.0029	OARL+DIST.METER KOJI BOX		CC-CAB 04		0	0	0
LST1.MAT.0030	Bus bar cables (8)	camera	CC-CAB 04		0	0	0
LST1.MAT.0031	Optical fibers yellow (8)	camera	CC-CAB 04		0	0	0
LST1.MAT.0032	RJ 45 (10) 10M	camera	CC-CAB 04				0
LST1.MAT.0033	Pwer Conection bus bar-back plane	camera	CC-CAB 04. L3				0
LST1.MAT.0034	Patch cord	???	CC-CAB 04				0
LST1.MAT.0035	Transceiver	general	CC-CAB 05				0
LST1.MAT.0036	Cover by water tank it container	it	MIRCA				0
LST1.MAT.0037	Bogies pieces	IFAE	SC				0
LST1.MAT.0038	IFAE tools	IFAE	MIRCA				0
LST1.MAT.0039	Pieces of bogies (3 pallets)	IFAE	MIRCA				0
LST1.MAT.0040	Multitool + beams	CIEMAT	MIRCA				0
LST1.MAT.0041	water tank	ICRR	MIRCA				0
LST1.MAT.0042	Tools by camera	CIEMAT	MIRCA				0
LST1.MAT.0043	amc boxes (18)	ICRR	MIRCA		0	0	0
LST1.MAT.0044	????		MIRCA		0	0	0

Marca temporal	Your name and Institute	What material do you need? Introduce the code of the material according the list of next link. If the material is not in the list, you can put the description of the material. https://docs.google.com/spreadsheets/d/1_6JsiHBd2XYgGgRcYnayRSLP_GBV5mY08niHAw4sLo4/edit?usp=sharing	How many "NEW" units are you going to storage in the storage?	How many units are you going to remove from the storage?	Where is the location os this material?
21/01/2020 15:45:11		LST1.MAT.0005	0	5	
22/08/2021 12:32:49	Patricia Marquez, LST	LST1.MAT.0018	0	1	CC-CAB 04

Fig. 0-2: Steps2 and 3 of inventory´s from use