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INSTITUTE FOR SPACE STUDIES OF CATALONIA*

The Institute for Space Studies of Catalonia (catalan acronym: IEEC) is a private, non-profit foundation whose purpose is to cooperate and participate in the development, promotion and implementation of activities, studies and projects related to spatial technology and scientific research of and from the space in aid of every person, entity or institution interested in their knowledge.

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Earth sciences

The IEEC Earth Sciences Department (ESD) is involved in many projects, doing basic research and developing applications using the Global Positioning System and Very Long Base Interferometry. The group is also actively working with the industry in the area of applications of Global Navigation Satellite Systems. In the research arena the group's efforts are dedicated to Earth Studies Using Space Techniques: Remote Sensing, Very Long Baseline Interferometry (VLBI), Water Vapor Radiometry (WVR) and the Global Positioning System (GPS), using either ground networks or orbiting instrumentation. Some of the work areas are:

– Studies of horizontal and vertical Earth crust motion, using VLBI and GPS.
– Studies of variations in the mean sea level, with climatological applications.
– Determination of atmospheric water vapor content, with applications to climatology and weather forecasting.
– GPS data assimilation into Numerical Weather Prediction systems.
– Characterization of the Ionosphere using GPS. Space weather.
– Global Atmospheric Parameters using Low Earth Orbiters and Global Navigation Satellite Systems.

As for applications, we should mention:

– Instrumental calibration of tropospheric and ionospheric effects, with applications to Radar Altimeter calibration and SAR
– GPS Navigation and Tracking, including sea buoy tracking, volcano monitoring, aircraft and spacecraft tracking
– GPS Radio Occultation analysis, with applications to ionospheric and tropospheric science.
– Real-time GPS Water Vapor estimation system development, with astronomical and meteorological applications.
– GPS Tropospheric Tomography.
– Early warning of GNSS Integrity Failure.
– Differential GPS applications. EGNOS, WAAS.
– Software development of GPS positioning, interfaces and GPS ionospheric and trospheric tomographers: XT-NORIT (NOvaltel Receiver Interface), dGPS (differential GPS software), XT-GIST (Global Ionospheric Stochastic Tomographer), LOTTOS (LOcal Tropospheric Tomographic SOftware).

The ESD is carrying out research in the following areas:

GNSS Reflections for Remote Sensing

GPSR research areas of work of the IEEC-ESD group:

– Electromagnetic modeling for scattering.
– Geometric modeling of signal characteristics at receiver, including geoid effects.
– Constellation analysis.
– Waveform Synthesis.
– Instrumental issues.
– Data flow from constellations issues.
– Development of Geophysical model functions. From waveforms to wind.
– Assimilation of GPSR data into NWP models, Ionospheric models.

GNSS Meteorology

The ESD is researching different meteorological aspects, but specially the GPS data for meteorological purposes. The water vapor distribution and content are critical parameters for the description of the state and evolution of many physical processes in the Earth's atmosphere . However, the distribution of water vapor is a highly variable function of

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both time and space, and correlates poorly with surface humidity measurements. Lack of precise and continuous water vapor data is one of the major error sources in short term forecasts of precipitation . Although ground based techniques such as Radiosondes (RS) or Water Vapor Radiometers (WVR), are sensitive to the water vapor content present in the atmosphere, they can be expensive to operate and they provide either poor temporal resolution, poor spatial coverage, or both (RS are launched typically only once every twelve hours and they are sparse over wide areas in the globe; in contrast to space based WVR, ground based WVR provides good temporal resolution but poor spatial coverage). New observational techniques that are sensitive to the spatial and temporal distribution of the water vapor content in the atmosphere have made now possible the retrieval of precise and continuous estimates of water vapor with high spatial density. This is the case of the Global Positioning System (GPS) technique.

One of the perhaps most suitable atmospheric applications of GPS is the assimilation of water vapor content estimates into numerical weather prediction (NWP) and climate modeling systems. The lack of humidity measurements that could potentially be assimilated into NWP forecast models is the main reason of its (sometimes) low reability. The fact that GPS can supply these data in near-real-time and at low cost, is changing, at the algorithmic level, the way these models are being used to assimilate the GPS estimates. GPS slant delay measurements, the delay along the lines-of-sight from the receiver to the satellites (as opposed to zenith delays, the delay in the zenith direction) provide information that can be used to extract vertical profiles of the index of refraction of the atmosphere. These data will possibly be assimilated into NWP models in the future in a variational assimilation context. In preparation for these efforts, it is necessary to determine how NWP models will fare in simulating GPS slant delay measurements. In this project, we have concentrated on estimates of PW and Zenith Total Delays (ZTD) derived from GPS measurements acquired at several ground based GPS sites over the Western Mediterranean. At IEEC, we are using two NWP systems: the hydrostatic HIRLAM (HIgh Resolution Limited Area Modeling) model, which is run at the Spanish Weather Service (INM), and the non-hydrostatic MM5 (Mesoscale Modeling) system developed at the National Center for Atmospheric Research (NCAR), Boulder, Colorado, USA.

GNSS Radio Occultation Analysis

Atmospheric Sounding with Radio Occultation has gained interest since the advent of the GPS/MET mission on board the Microlab-1 satellite. The IEEC Earth Sciences Department (ESD) has conducted research work on the topic, providing scientific advice to different European and US projects. Issues such as Precise Orbit Determination, Clock Calibration and the retrieving algorithm and its timeliness have been analyzed with emphasis placed on Near Real Time Systems.

Radio Occultation technique has been used for some 20 years to infer properties of the atmosphere of other planets in the Solar System. The availability of GPS signals constantly illuminating the Earth allows for a thorough sounding of the atmosphere when receiving GPS signals in an receiver onboard a Low Earth Orbiter (LEO) satellite: viewed from the LEO, when the transmitting GPS satellite approaches the Earth limb, the received signal traverses the atmosphere and bends according to the refractivity profile that the ray encounters. Using inverting techniques (Abel transform, for instances) allows to extract the profiles from the measured delay on the signal. The proof-of –concept mission was GPS/MET, which was added as a secondary load to the Microlab-1 satellite.

The processing of radio occultation data involves a precise determination of the orbits of both transmitter and receiver, a strategy for clock calibration and an inverting technique. Precise Orbit Determination has been analyzed at IEEC for MetOp-1 and for GPSOS. Clock Calibration requires a differencing geometry, as presented below: the ground station is used as a reference to calibrate the clock instabilities both from the receiver and from the GPS satellite (SA in particular).

Radio Occultations provide information on the vertical structure of the atmosphere. This information can be used to improve tomographic images of the ionosphere, and then make these maps useful for instrumental calibration

The IEEC GOT has participated in different projects related to Radio Occultations, which are here summarized:

- CLIMAP: GOT role in the project is to provide the ground data processing to be combined with Oersted RO data. A European Network of Ground Receivers is being processed on a Near Real Time basis for this purpose.
- GRASMA: GOT acted as subcontractors of GMV and analyzed the timeliness of the algorithms for RO data processing and the ground network needed for clock calibration.
- GPSOS-PDR: Saab-Ericsson Space project in which support for POD was provided for GNSS and LEO satellites.
- DOPA: Analysis of Feasibility of including a GNSS receiver in the Minisat-02 mission.
- Ionospheric Tomography including GPS/MET occultation: improved maps can be used for Radar Altimeter Calibration. A software package (XT-GIST) was developed for end-to-end data processing.

Instrumental Calibration

The ESD is investigating GPS-based approaches for instrumental calibration. The electron content in the ionosphere produces delays in the phase and group propagation of radio waves. Thus, the operation of satellite radar altimeters, for instance, is affected by the electronic distribution in the ionosphere. For this reason, some satellite altimeters such as the NASA altimeter (NRA) aboard TOPEX/POSEIDON (T/P) operate at two frequencies and make use of the dispersive nature of ionospheric refractivity to correct for this effect.

Unfortunately, because of its electronic nature, this correction needs to be calibrated. It is assumed that the uncorrected ionospheric delay and the true delay differ by a time-independent bias, at least for periods of the order of a day. In our group we investigate the ionospheric calibration of single and dual frequency radar altimeters using TEC fields estimated with IGS and GPS/MET data and using tomographic techniques. GPS data has been used extensively for ionospheric studies. Tomography should in principle be superior to estimating TEC using thin-shell mapping function techniques, since it allows greater freedom in the vertical distribution estimation.

Tracking, Timing and Navigation

The ESD is involved in the application of GNSS technologies to the navigation and tracking of vehicles equipped with GNSS receivers. Areas in which we have applied our expertise are :

- Orbits and clock determination of Low Earth Orbiters for atmospheric and ionospheric sounding. We have analyzed GPS/MET data to retrieve profiles of the electron density of the ionosphere as well as the tropospheric refractivity. Part of the analysis requires the determination of the orbits of the GPS and LEO satellites as well as a stochastic description of the satellite oscillators.
- Motion determination of wave rider buoys as a tool for oceanographic studies. Our purpose here is to provide tools for calibrating radar altimeters and our activities include the development of strategies for precise data processing as well as to cooperate with the Institut Cartografic de Catalunya and the Universitat Politècnica de Catalunya in the design of instrumented buoys.
- Monitoring of tectonic movements in volcanic areas. In cooperation with the Hawaii University and the USGS we have been analyzing the movements of GPS receivers as part of our attempt of developing techniques for GPS meteorology.
- Carrying out feasibility studies of the possible use GPS receivers on board future spanish MINISAT satellites for navigation and for atmospheric and ionospheric research. These activities have been performed in cooperation with the Instituto Nacional de Tecnica Aeroespacial and the Spanish companies GMV and INDRA.

In addition we have contributed as consultants as well as developers of differential GNSS in industry studies dealing with the European Global Navigation Overlay System (EGNOS) project. Part of this project is the development of dGPS, a software package for the analysis of GPS in differential mode. Resources for the performance of these activities have been obtained through different projects.

GNSS Real-time WV Retrieval

The ESD is also researching real-time issues, related to WV retrieval from GPS measurements and tracking. We are currently involved in the development of real-time WV retrieval integrated products, with meteorological and navigation applications.Real-time WV retrieval and analysis systems, for instance can and will have a tremendous impact on the way meteorological forecasting is done, and will provide another source of data that may be very useful for risk management, alerting of upcoming flooding events.

GNSS Tropospheric Tomography

The ESD is researching the application of GPS WV retrieval technologies to tropospheric tomography. We are leaders in this field in the area of Ionospheric Tomography using GPS data, and we are now applying these techniques to imaging the WV content in the troposphere using GPS WV slant delay data. Stay tuned for further developments in this page. This work is part of the IEEC contribution to the WAVEFRONT project.

Geodesy

The ESD is involved in a European wide effort to determine horizontal as well as vertical crustal motion using geodetic VLBI and GPS observations. The European network momentarily consists of 10 stations (see figure) and will be extended in the near future by an additional telescope in Westerbork, The Netherlands. As the bulk of the stations is along a north-south axis (Ny Alesund to Noto), the Madrid stations (DSS65 and Yebes) as well as the station in Crimea, Ukraine, play an important role in stabilizing the net in a east-west direction.

FIRE Remote Sensing and modeling (in collaboration with the Astrophysics group)

Our main areas of research are:

- Remote sensing
- Fire propagation modeling
- Meteorology for fire modeling
- Data issues: validation and operational requirements for monitoring and propagation forecasting.
- Space and ground data assimilation approches into models

Space weather

The ESD is researching different meteorological aspects, specially the best use of GPS data for meteorological purposes. The water vapor distribution and content are critical parameters for the description of the state and evolution of many physical processes in the Earth's atmosphere. However, the distribution of water vapor is a highly variable function of both time and space, and correlates poorly with surface humidity measurements. Lack of precise and continuous water vapor data is one of the major error sources in short term forecasts of precipitation. Although ground based techniques such as Radiosondes (RS) or Water Vapor Radiometers (WVR), are sensitive to the water vapor content present in the atmosphere, they can be expensive to operate and they provide either poor temporal resolution, poor spatial coverage, or both (RS are launched typically only once every twelve hours and they are sparse over wide areas in the globe; in contrast to space based WVR, ground based WVR provides good temporal resolution but poor spatial coverage). New observational techniques that are sensitive to the spatial and temporal distribution of the water vapor content in the atmosphere have made now possible the retrieval of precise and continuous estimates of water vapor with high spatial density. This is the case of the Global Positioning System (GPS) technique.

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Cosmo sciences

Cosmology and space mathematics

We are trying to promote a working group in the area of Cosmology, devoted to fundamental and observational space research. We try to contribute to the understanding of the origin of large scale structure and its relation with primordial universe physics. To this end, we deal with observed fluctuations at the local universe level (eg galaxies), at high redshifts (eg quasar) as well as with fluctuations in microwave background data. Have these fluctuations been generated at an inflationary epoch? or rather they require more exotic initial conditions? Are primordial fluctuations seeds for galaxy formation? If so, how and when did galaxies (and stars) form? These question have not been answered yet, in spite of the big leaps forward during the last twenty years, both in the theory and in the observations.

We investigate essential subjects in cosmology and gravitation, ranging from black holes to phenomenological, observational and theoretical analysis of properties such as the luminosity function, peculiar velocity field distribution, dark matter studies by means of gravitational lensing, X rays and dynamical estimations, biasing, distortions in the redshift space, reconstruction of the dynamics and initial conditions, studies of galaxy clusters, etc. An important priority of the group is also the investigation in depth of a number of essential physico-mathematical tools that are fundamental for the development of future space research. Statistical and numerical techniques, special functions and neural nets, applied to the subjects already described and further to projects with exterior projection.

Specific subjects under development presently:

- Lossless compression of a noisy signal.
- Analysis of possible quantum instabilities of primordial black holes.
- The determinant anomaly and its consequences.
- Quantum vacuum structure analysis in different configurations.
- Scalar-Tensor Theories of Gravity.
- The 3-point function in Galaxy Catalogues.
- Clustering in the QSO Lyman-alpha Forest.
- Likehood analysis of large data sets: covariance of error estimators.
- The Local Galaxy Luminosity function.
- Galaxy velocity fields.
- Cosmology and Gravitational waves.

High energy astrophysics

High-energy astrophysics is one of the newest and most promising branches of space astrophysics. Its development has only been possible over the last 25-30 years, since the launch of X-ray detectors on board rockets in the 1960's enabled cosmic sources of X-radiation to be discovered. The discipline is of particular interest in that it allows science and technology to be closely interrelated; all the information on which it is based is closely linked to technological advances in the field of space instrumentation for X and gamma energy ranges. The group works in the area of nuclear astrophysics and its implications for high-energy astrophysics. In particular, it studies the structure and evolution of stars, focusing mainly on the final stages of stellar evolution. The properties of stellar explosions in the form of novas and supernovas are also considered. The study of these explosions is carried out by means of one– and multidimensional numerical simulations. These violent phenomena are important for the dynamics of the galaxy (formation of new stars) and for its enrichment in elements heavier than hydrogen and helium (chemical evolution of the galaxy). The cooling of white dwarfs –stellar fossils which enable the history of our galaxy to be studied– is also considered. The group is involved with the research objectives of ESA's future INTEGRAL satellite, among which novas and supernovas are of particular importance. Another area of work involves the design of instrumentation for X astronomy.

Areas of work:

- Gamma astronomy: explosions of novas and supernovas.

  Detailed models of type Ia nova and supernova explosions are developed, with special emphasis on their nucleosynthesis and emissions in the X and gamma bands of the spectrum (only detectable by current satellites, such as SAX, ASCA, CGRO, or the future XMM and INTEGRAL ones).
- X astronomy: instrumentation design SIXE: feasibility study of an X-ray instrument for the MINISAT 02 (website available shortly).

- Other areas:
  - Physics and evolution of white dwarfs. The physics and evolution of isolated white dwarfs are studied, providing important information about the history and age of the galaxy.
  - Hydrodynamic simulation of stellar collisions.

Projects:
- Gamma emission during stellar eruptions and its study via the INTEGRAL satellite.
- Physics and evolution of white dwarfs. General development of knowledge, DGICYT.
- Nucleosynthesis and final stages of star evolution. General development of knowledge, DGICYT.
- Feasibility study of the SIXE project (Spanish-Italian X-Ray Experiment). National Space Research Plan.
- Numerical simulation of stellar collisions. Joint Spanish-French venture.
- Nova and supernova explosions and their diagnosis by means of their gamma emissions. Joint Spanish-Italian venture.
- Current problems in numerical astrophysics. INTAS project.
- Cosmic sciences, consolidated research group of the CIRIT.

Galactic and stellar astronomy

The working group was consolidated on the basis of its involvement in ESA's Hipparcos mission. It was involved in developing the input catalogue (obtaining three Main Participants in the mission) and the main scientific applications of the data. As preparation for this work it developed robust algorithms for determining stellar parameters (temperature, gravity, age, luminosity) and for the study of the structure and evolution of the galaxy (young stars, associations). The Hipparcos data as a whole, along with the methods developed for applying it, are now enabling the group to develop its research further and address crucially important areas such as determining the distances of the RR-Lyrae and the Cefeides (a key to understanding the size of the universe), violent star formation, or testing stellar evolution models for stars of very low metallicity.

In addition, the team continues to be involved in research from space, both in terms of collecting data (ISO, HST) and via its active role in the scientific and technological design of future projects, some of which are already up and running (the OMC of INTEGRAL), while others are still being defined (spectroscopic survey, GAIA).

Areas of work:
- Galactic structure and evolution.
- Associations and open clusters.
- Calibration of luminosities and statistical treatment of Hipparcos errors.
- Physical parameters of stars.
- Optical Monitoring Camera (INTEGRAL).
- Minisatellites.

Planetary engineering sciences

Areas of work:
- Geochemistry of planetary material.
- Origin of the organic material of comets and meteorites.
- Evaluation of natural resources and new materials for the development of lunar bases.

Sun-Earth system physics

The group's basic aim is to study the influence of the Sun (photonic radiation) and its activity (ejection of coronal material, flashes, etc.) on the Earth and its immediate surroundings. This influence varies according to whether it is studied in the short or long term, and both need to be understood in order to assess the risks which this activity poses for our way of life. Due to its industrial, social and scientific implications, the United States has given maximum priority to the Space Weather Forecast program.

Areas of work:
- Analysis of data obtained from satellite-based instruments and interplanetary probes about particles, solar wind plasma and interplanetary magnetic fields.
- Developing models of particle transport in magnetic fields in order to explain these observations (solar energetic particle events (DAM-UB)).
- Development of an operational model for predicting the flux of solar particles produced by the Sun in interplanetary space (space meteorology).
- Research into variations in solar irradiance (DAM-UB) produced by solar activity.

The IEEC has been an ISU Affiliate Campus since February 1995. Since then an exchange of students, teachers and research information has been established. The International space university (ISU) is an international institution of higher education devoted to the study of extraatmospheric space, with peaceful purposes, for the realization of investigation and international cross-disciplinary teaching programs. Scientists of all the world visit IEEC.