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Towards implementing climate services in Peru – The project CLIMANDES

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ABSTRACT

CLIMANDES is a pilot twinning project between the National Weather Services of Peru and Switzerland (SENAMHI and MeteoSwiss), developed within the Global Framework for Climate Services of the World Meteorological Organization (WMO). Split in two modules, CLIMANDES aims at improving education in meteorology and climatology in support of the WMO Regional Training Center in Peru, and introducing user-tailored climate services in two pilot regions in the Peruvian Andes.

Four areas were prioritized in the first phase of CLIMANDES lasting from 2012 to 2015 to introduce climate services in Peru. A demand study identified the user needs of climate services and showed that climate information must be reliable, of high-quality, and precise. The information should be accessible and timely, understandable and applicable for the users' specific needs. Second, the quality of climate data was enhanced through the establishment of quality control and homogenization procedures at SENAMHI. Specific training and application of the implemented methods at stations in the pilot regions was promoted to ensure the sustainability of the work. Third, the specific work on climate data enabled the creation of a webpage to disseminate climate indicators among users. The forth priority of the project enhanced the broad communication strategy of SENAMHI through creation of a specialized network of journalists, diverse climate forums, and the establishment of a user database.

The efforts accomplished within CLIMANDES improved the quality of the climate services provided by SENAMHI. The project hence contributed successfully to higher awareness and higher confidence in the climate information by SENAMHI.

Practical Implications

Climate variability and change strongly influence the socio-economic development of all countries (IPCC, 2007). Further, a changing climate may have adverse effects. It can, for example, decrease water availability, and at the same time increase the potential for natural hazards. Such changes and hazards strongly distress vulnerable communities, such as rural communities in developing countries (Smit and Pilifosova, 2001; Adger et al., 2003; Bradley et al., 2006; Salzmann et al., 2009). To address the threats due to climate variability and change in a specific region, it is imperative that users and policy makers have access to adequate and high-quality climate information.

The Global Framework for Climate Services (GFCS) program, initiated at the World Climate Conference-3 in 2009 (WMO, 2009), aims at strengthening the provision and use of climate products and information worldwide. Climate services translate

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climate data into information and products that are tailored towards the specific needs of the diverse end users. GFCS recommends the establishment of Climate Services on a regional and national scale. It was, for example, implemented on a regional scale by the Copernicus Climate Change Service (managed by the ECMWF) and on a national scale by the Swiss National Centre for Climate Services NCCS (managed by MeteoSwiss). GFCS is based on five pillars (Fig. 1), namely: Observations and Monitoring; Research, Modeling and Prediction; Climate Services Information System; User Interface Platform; and Capacity Building.

The project CLIMANDES, introduced in this study, is a pilot project of GFCS between the Peruvian National Service for Meteorology and Hydrology (SENAMHI) and the Swiss weather service MeteoSwiss. Aiming at implementing climate services in the Peruvian Andes, CLIMANDES integrated much of GFCS through a twinning approach between the two weather services. Therein, the concept of capacity building was a keystone and one of the all-encompassing activities. Capacity building was achieved through the close collaboration between the technical personnel of the two weather services (peer-to-peer collaborations) and was supported by classroom courses and the development of e-learning material. These peer-to-peer collaborations have shown to be very fruitful, and have overcome language and other cultural differences. Through the building of technical capacities within the institution, it is ensured that the benefits of such a twinning project remain for the long term.

In its first phase presented here, the project CLIMANDES focused mainly on the first of the five above mentioned GFCS pillars, namely on ''Observations and Monitoring''. Some of the efforts made within CLIMANDES to guarantee high-quality observations and monitoring at SENAMHI are highlighted in more detail in the following paragraphs. Diverse enabling technologies are required to ensure the continuous monitoring of the climate, for example an operating data management system. However, data management systems often do not exist yet in developing countries (WMO, 2011). The ''Observations and Monitoring''-Pillar hence highlights the need of having basic infrastructure to manage climate data. First of all, an institution (e.g., a national weather service) has to be functioning at the country level and be responsible for the compilation of climate information. Before providing climate information to a user, the institution needs to ensure adequate quality of the data for diverse applications, such as analyses of past climate, monitoring of the current climate, data assimilation in climate models, or model validation, among others. Regarding these applications, the need for a reliable data storage system in an appropriate database, as well as the operational implementation of quality control and homogenization methods, becomes apparent. At the institutional level, it is necessary that the decision makers (for example, managers of the weather service) are aware of the importance of operative data management systems. If they are, they might grant the necessary human and monetary efforts needed to fulfill these requirements.

On a more technical level, the implementation of climate services relies on well-structured data stored in high-performance databases. These databases need to be built according to adequate data models fulfilling specific requirements. Such requirements are given by the data type and the users, and should allow different (internal and external) users and procedures to access the data. For example, climate analyses require high-quality and homogenized data; it should hence be possible to store different data versions in a database (e.g., raw, quality controlled, homogenized data). Further, data treatment procedures (such as quality control and homogenization procedures) performed directly on the database ensure the sustainability of the work and avoid redundancies in data storage. On earlier occasions at SENAMHI for instance, the results of data quality control efforts realized in individual project were not integrated into the institutional database, generating duplication of the work efforts.

At SENAMHI, these issues are being improved through the systematic documentation and organization of systems and processes. It is worth emphasizing here that the development of the necessary infrastructure is complex and requires sufficient resources. In order to promote sustainability of such systems, well-trained permanent staff is of fundamental importance for operation, maintenance, and further developments. For example, quality control is a continuous process, which cannot be permanently accomplished within a project such as CLIMANDES – in contrast to the construction of quality control software. To improve the capabilities of the staff at SENAMHI in data management and quality, all work done during CLIMANDES was executed in close collaboration between SENAMHI and MeteoSwiss. This peer-to-peer collaboration resulted in an effective way to increase knowledge and train the technical staff at SENAMHI with respect to the mentioned issues.

During the setup of the GFCS it was very clearly seen that there is a great lack in what is called *user-provider dialogue*. This means that there are a large number of potential beneficiaries of climate services, the users, which do not actually know that such services are available. Activities within user dialogue encompass, for instance, the compilation of the users' needs and the utilization of appropriate communication means to disseminate climate information. Within CLIMANDES, several approaches have been implemented, for example the creation of a webpage providing information through climate change indicators, or the completion of workshops with policy makers. However, while the newly developed internet platform may be useful for decision makers, farmers in the Peruvian Andes might be unable to apply this information. Detailed explanations should accompany the information to be understood appropriately, and these explanations need to be tailored towards the current knowledge and educational standard of the user. Further, farmers usually do not have access to data provided through a web platform. To reach countryside communities, climate information is communicated through the use of community radios which is a common communication medium used in the rural Andes. Through these radio networks, relevant climate information can be broadcast using a user-tailored language. In addition, dealing with the uncertainty inherent to climate information in a proper way is another huge challenge, as users must learn to understand how to extract the right content of uncertain information.

The end goal of climate information is its usage, and through it, improving the welfare of the user. While it is necessary that information reaches the user in an appropriate language and through the proper means, the user will remain in a vulnerable condition if she/he does not have a response action. In this context, CLIMANDES facilitated the participation of SENAMHI in strategic alliances, such as for example in the agricultural and educational sector. These alliances seek to create public policies that generate response actions such that the benefits of climate information can be made tangible for the user.

While all these issues might sound trivial, the implications for an institution providing climate services are large. For instance, capacity building is needed on two fronts. On one hand, the provider must increase its abilities to socialize useful information. On the other, users require familiarity with climate information terminology. Further, the direct and continuous contact with the user is a key aspect to establish trust and understanding.

In conclusion, this manuscript presents a project which aims at implementing climate services according to the guidelines provided through GFCS. It is an example of a very successful twinning project between Peru and Switzerland, and can be seen as an example that may be up-scaled to other countries and regions.

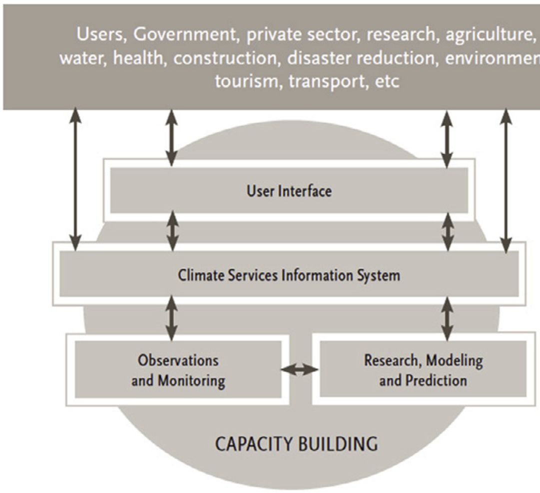


Fig. 1. Schematic illustration of the five pillars of the GFCS and their links to various user communities (GFCS, 2014).

1. Introduction

Climate variability and change exerts an increasing influence on the economic and social development of all countries (IPCC, 2007; INEI, 2013a). Decreasing water availability along with increasing natural hazard potential strongly affect vulnerable rural communities in developing countries (Smit and Pilifosova, 2001; Adger et al., 2003), and may have multiple adverse effects at the local scale (Bradley et al., 2006; Salzmann et al., 2009). High-quality information on past climate variability is therefore a vital prerequisite to assess trends and elaborate adaptation and mitigation strategies.

Climate services translate climate data into tailored information suited to meet the specific needs of various end user groups. They encompass a range of activities that deal with generating and providing information based on past, present, and future climate as well as on its impacts on natural and human systems. Climate services may contribute to the reduction of risks and maximize opportunities associated with a variable and changing climate, and provide substantial social and economic benefits for, among others, the sectors of agriculture, health, energy, tourism, and transport. At the global scale, currently around 70 countries do not have the basic capabilities needed to provide sustainable access to climate services (WMO, 2011). In developing and emerging countries, climate data are often of insufficient quality and do not meet the prerequisites for the provision of climate services for political decision makers.

To combat these challenges, the World Meteorological Organization (WMO) launched the program Global Framework for Climate Services (GFCS) which was introduced at the World Climate Conference-3 in 2009 (WMO, 2009). The main objective of the initiative is to build and develop the capacities of National Meteorological and Hydrological Services (NMHSs) in generating climate products and services, and to link climate service providers and users in a way that allows better use of climate information. The necessity of reliable climate data is seen worldwide through a variety of projects, such as DECADE in Bolivia (provision of climate information in the Central Andes, http://www.geography.unibe.ch/research/climatology_group/research_projects/decade/index_eng.html), CLARIS (provision of regional climate change impacts on La Plata basin, http://cordis.europa.eu/project/rcn/89402_en.html), the WASCAL and SASSCAL projects (aimed at improving the data availability in western and southern Africa, respectively, for climate change adaptation measures, http://www.sasscal.org/ and http://www.wascal.org/), and PRASDES (improvement and standardization of databases across the boarders for the countries of the tropical Andes (Bolivia, Peru, Ecuador, and Colombia), http://www.prasdes-ciifen.org/).

In addition, the project PRAA (Regional Project for Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes) of the Andean Community and the World Bank sought to strengthen the resilience of local ecosystems and economies in relation to the impact caused by rapid glacier retreat in the tropical Andes (CARE, 2011; SENAMHI, 2007a,b). Integrated, participatory management of water resources were promoted in the Shullcas River basin inside the Mantaro River basin and the Santa Teresa, Sacsasara and Acobamba districts in the Urubamba River basin (Avalos et al., 2011a,b). Additionally, the project PACC (Proyecto de Adaptación al Cambio Climático) has recently contributed to the improvement of the adaptive capacities of the local population, through provision of a number of adaptation measures and stimulation of awareness at different social and political levels (Salzmann et al., 2009). Further, 19 selected time series of the Peruvian meteorological network were quality controlled and homogenized using the R-code “rsnht.r” (Aguilar, 2011) within a series of workshops of South American NMHSs. This homogenized dataset has contributed to the analysis of changes in temperature (T) and precipitation (P) extremes over South America (Skansi et al., 2013). The experiences from these initiatives highlight the potential benefit as well as underpin the importance of operationalizing data quality control and homogenization methodologies at SENAMHI. The transfer of specific know-how of data quality control and homogenization to the personnel of SENAMHI is a key element that ensures the sustainability of the implemented procedures and guarantees high-quality observations and monitoring. Also, to enhance the socio-economic benefits of climate information, the specific needs of diverse user groups must be collected, and appropriate communication channels must be provided.

Switzerland and Peru have maintained a longstanding collaboration for over 50 years to fight poverty and promote sustainable development. The countries share high mountainous topography and face impacts of climate change such as glacier retreat (e.g., Rabatel et al., 2013). The Global Program for Climate Change of the Swiss Agency for Development and Cooperation (SDC) therefore supports innovative projects which contribute to finding solutions to the climate change challenge in Peru and the Andean region. The GFCS twinning project CLIMANDES (Servicios CLIMáticos con énfasis en los ANdes en apoyo a las DEcisioneS) is a bilateral project between SENAMHI and the Swiss Federal Office of Meteorology and Climatology MeteoSwiss. Running from 2012 to 2015, the project sought to improve education in meteorology and climatology in support of the newly established WMO Regional Training Center in Lima, hosted by the National Agrarian University La Molina (UNALM) (Module 1). It was also designed to build and implement sustainable climate services in two Peruvian regions (Module 2). The overall coordination of CLIMANDES is carried out by WMO, while the project is implemented by SENAMHI and MeteoSwiss in collaboration with the UNALM, the University of Bern (Switzerland), and Meteodat GmbH (Switzerland). More specifically, Module 2 of CLIMANDES (presented in this manuscript) focuses on the two river basins of Urubamba and Mantaro (Fig. 2), which are mainly situated in the Cuzco and the Junín region, respectively. The Mantaro basin has an area of 34,550 km^2 and the Urubamba basin has an area of 76,200 km^2. Both river basins are partly glacierized and their water resources are important for agriculture, hydro-electricity, and the mining industry.

In this paper, we present the results of Module 2 of CLIMANDES, i.e., the approach followed to generate reliable climate data and disseminate information of the past climate. The chosen approach is as follows:

a) Determination of the user needs and requirements on climate information through the realization of a demand study;
b) Implementation of data quality control (DQC) and homogenization techniques for operational use at SENAMHI;
c) Calculation of climate change indicators for the two pilot regions based on enhanced data (i.e., quality controlled and homogenized measurements); and
d) Dissemination of the climate information to regional governments and decision makers through a web-platform and user workshops.

Sustainability is a primary goal of CLIMANDES, and hence the outlined approach is designed to be up-scaled to other regions and different climatological variables.

2. Study site

Peru is located at the central and occidental coast of South America, directly below the equatorial line between 0°01′48″S and 18°21′03″S, and 68°39′27″W and 81°19′34.5″W (Fig. 2). The Peruvian climate is influenced by many factors such as a broad latitudinal range and a complex orography, which is strongly shaped by the Andean cordillera, the cold coastal Humboldt stream, the anticyclone of the southern Pacific, and even by the southern Atlantic. Peru encompasses up to 27 different climate types (Thornthwaite, 1948); however, three climatological regimes can be distinguished: the coastal region, the Andean region, and the Amazon basin. The coast and the Amazon basin are characterized by high temperatures (highest observed value is 42 °C), while in the high Andes minimal temperatures (lowest observed value is −28.2 °C) are recorded, specifically in the Altiplano. With regard to precipitation, only few annual amounts (1–50 mm) can be measured in the central and southern coast of Peru. Precipitation is moderate in the Andes (50–1000 mm) and abundant in the Amazon basin (1000–3000 mm).

The inter-annual climate variability in Peru is mainly determined by the presence of the El Niño-Southern Oscillation (ENSO). This ocean-atmosphere coupled climate mode exhibits warm (cold) anomalies in the central-eastern equatorial Pacific during its El Niño (La Niña) phase, which induces climate signals worldwide with an irregular frequency (2–7 years) (Díaz and Markgraf, 1992; Garreaud, 2009). The anomalous sea surface temperature and the accompanying atmospheric circulation during El Niño years, especially at its peak during the December to February period (e.g. 1982/83 and 1997/98), tend to cause a dramatic temperature rise throughout the country and torrential rains along the coast, while dryer conditions are observed on the equatorial Andes (Vuille et al., 2000; Garreaud, 2009). Almost opposite signatures are expected during La Niña events. Evidence has shown that climate variability of similar characteristics might take place at the decadal timescale (Jacques-Coper and Garreaud, 2014; Vuille et al., 2015), a phenomenon that has been associated by some authors with the Pacific Decadal Oscillation (PDO, Mantua and

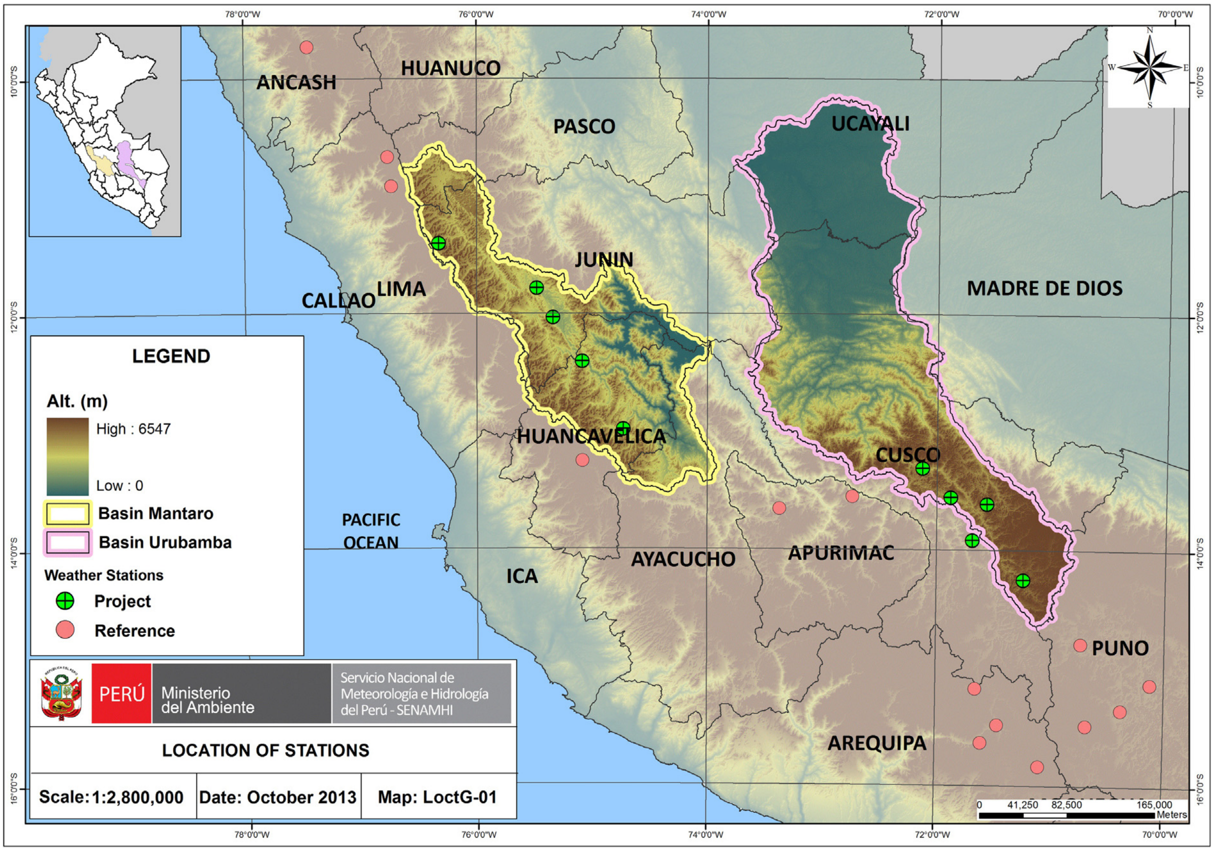


Fig. 2. The two basins Mantaro (yellow) and Urubamba (purple) of the CLIMANDES project. The green crosses indicate the long-term climatological series that are of principal concern in the project. The stations outside the basins (red dots) are used as references for homogenization. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Hare, 2002). Extreme weather events, climate variability and climate change affect the land surface and the water cycle in different ways.

Temperatures have increased by up to 0.2 °C per decade between 1968 and 2010 in most of the Peruvian territory (SENAMHI, 2010). Average rainfall has increased on the coast and in the northern Andes (around 30–40%), and has significantly decreased (around 20–30%) in the northern Amazon from 1965 to 2006 (Obregón et al., 2009). During the last three decades, the tropical Andean glaciers have rapidly decreased (Rabatel et al., 2013), which has also particularly been seen in the Southern part of Cuzco (Salzmann et al., 2012). This trend is of serious concern as a large proportion of the Peruvian population lives in arid regions and relies on water supply for agriculture, domestic consumption, and hydropower (Vergara et al., 2007).

The two regions Cuzco and Junín, located in the Andean zone of Peru, were selected as pilot regions for this project due to their high topographic and climatic variability, and more importantly due to the vulnerability of the population (around 1.3 million inhabitants in each region (INEI, 2013a)) to climate change hazards (e.g. heavy precipitation events, cold waves, landslides (INDECI, 2012)). Agriculture in the region Junín is the main provider of agricultural products for Lima, the capital of Peru with around 10 million inhabitants. The regions of Cuzco and Junín are responsible for a considerable percentage of Peru's main productive activities, namely 9% of the gross agricultural product, about 9% of the electric power production, 47% of the coffee production, and 19% of the mining product (INEI, 2013b). Cuzco, internationally known for its archaeological heritage site and touristic attraction of Machu Picchu, has also a great potential for hydroelectricity due to diverse glaciers and lakes. Both regions are highly vulnerable to hazards such as landslides or mudflows due to their steep topographies (Huggel et al., 2012). The presence of large cities that have a continuous socio-economic growth in these regions, such as Cuzco and Huancayo, respectively, underscores the importance of producing and disseminating climate information in the region.

3. Approach

With respect to the goals of Module 2, the following four major steps were adopted in this project: a) realization of a *demand study* to identify user needs and requirements on climate services in Peru, b) implementation of adequate *data quality control and homogenization procedures* at SENAMHI, c) application of quality control and homogenization methods to provide *reliable climate information through climate change indices* (*CCIs*) for the pilot regions, and d) development of a web-platform and communication networks that allow *dissemination of the climate information* to the local decision makers. These four steps are based upon three general principles: use of existing infrastructure at SENAMHI whenever possible, application of international guidelines, and the possibility to expand the methods to further measurements, e.g., through up-scaling to the national level and adaptation to other climatological variables.

3.1. Demand study

A demand study was conducted in the pilot regions Junín and Cuzco to identify the various types of climate information needed by the users, and also to determine the different types of users requesting such information. The results of this study provide guidance to SENAMHI for the development of climate products and services. Specifically, the main goal of the institution is to support the improvement in the climate-related risk management within multiple economic sectors in the pilot regions. In particular, the concrete purposes of the study are: 1) to describe the demographics of current and potential users that require climate services, according to age, educational level, and socio-economic activity, 2) to distinguish specific requirements on climate products and services, 3) to characterize possible improvements in the current climate products and services, so that they effectively address the users' needs, 4) to explore the users' satisfaction levels concerning climate products and services, and 5) to assess the effectivity of the communication channels currently used by SENAMHI and to formulate ways to improve them. The survey focused on decision makers, on representatives of selected climate-dependent economic sectors, and on farmers themselves, given that agriculture is the most vulnerable sector to climate variability and change. The methodology consisted of in-depth interviews with decision makers (30 in each region) and in a survey conducted among farmers (150 in Junín and 160 in Cuzco).

3.2. Data quality control and homogenization procedures

Climate data constitute the principle component for the development of climate services. At SENAMHI, the main climatological variables (temperature, precipitation, humidity, wind speed and direction) have been measured systematically since 1964. The manual measurements are stored on handwritten papers, which are digitized and entered on a monthly basis into the central database at the head quarter. However, the data is usually not systematically quality controlled or homogenized. Quality control and homogenization is mostly only done within individual projects (e.g., Skansi et al., 2013). To provide reliable climate information, it is imperative to operationalize quality control and homogenization at SENAMHI.

CLIMANDES aims at implementing suitable quality control and homogenization procedures at SENAMHI. The procedures are selected according to international standards (e.g., Klein Tank et al., 2009; Venema et al., 2012) and methods successfully implemented in MeteoSwiss (van Geijtenbeek et al., 2009; Scherrer et al., 2011) and other meteorological offices (e.g., DWD, 2015; ZAMG, 2015). The selected procedures are adapted and implemented according to the specific needs of SENAMHI as in the treatment of daily manual measurements. In addition, institutional policies supporting the regular quality control and homogenization are improved. To consolidate institutional capacities, several workshops providing guidance from external as well as internal experts were held at SENAMHI.

3.3. Reliable climate information in the pilot regions

With respect to the pillar "Observations and Monitoring" of the GFCS, the data quality control and homogenization methods were applied to the pilot stations in parallel to the development of the systems introduced in Section 3.2. In a first step, suitable stations from the pilot regions were selected based on completeness and visual quality checks (e.g., Hunziker et al. (submitted)). Stations with severe data problems (e.g., missing data intervals, reduction/augmentation of the variability, drifting coupled with changes in the variability, etc.) were marked as not suitable. CLIMANDES focused on stations measuring both temperature and precipitation (hereafter referred to as *conventional stations*).

The data was quality controlled using rule-based quality checks implemented in the R-program RClimDex (Zhang and Yang, 2004), and homogenized using HOMER (Mestre et al., 2013). HOMER was selected for homogenization since it is state-of-the-art (Venema et al., 2012), it is freely available, and runs on the open source software R (R Development Core Team, 2014). The *enhanced data* was used to calculate the 27 CCIs (Table 1) using the R-package "climdex_pcic" (Klein Tank et al., 2009). The 27 CCIs were

Table 1
Definition of climate change indicators implemented during CLIMANDES, defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) http://etccdi.pacificclimate.org/list_27_indices.shtm (Karl et al., 1999; Peterson et al., 2001).

ID	Indicator name	Definitions	Units
FD0	Frost days	Annual count when TN(daily minimum) < 0 °C	Days
SU25	Summer days	Annual count when TX(daily maximum) > 25 °C	Days
ID0	Ice days	Annual count when TX(daily maximum) < 0 °C	Days
TR20	Tropical nights	Annual count when TN(daily minimum) > 20 °C	Days
GSL	Growing season length	Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with TG > 5 °C and first span after July 1 (January 1 in SH) of 6 days with TG < 5 °C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
RX1 day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
Rx5 day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP ⩾ 1.0 mm) in the year	Mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP ⩾ 10 mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP ⩾ 20 mm	Days
Rnn	Number of days above nn mm	Annual count of days when PRCP ⩾ nn mm, nn is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ⩾ 1 mm	Days
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR ⩾ 1 mm)	mm

developed to support NHMSs, to identify and describe changes in extreme values under climate change conditions, and to provide a software package that implements a basic set of indices for climate extremes. These indices and corresponding trends are depicted on a web platform for dissemination (Section 3.4).

3.4. Dissemination of climate information

Dissemination of climate information is an essential component of successful climate services. Within CLIMANDES, two levels of dissemination are distinguished: 1) the direct communication channel established with the trained end users of the climate information (from both the public and the private sectors) and 2) the mass communication channel, which aims at providing general climate information to the population of Peru.

Direct communication with trained users is done on a technical basis through an appropriate web platform (http://www.senamhi.gob.pe/climandes/?p=indicadores). The platform may be accessed by decision makers and a broader public, and contains both climate information itself, in the form of CCIs, and graphical outreach material, such as news, photo galleries, and videos related to the development of climate information. Besides, publications prepared during the project, such as studies on the socio-economic benefits of pilot climate services (e.g., MeteoSwiss/SENAMHI, 2015), are available on the platform. Concerning mass communication, climate information is presented at diverse workshops in the pilot regions, as well as through networks of journalists that were trained in general meteorology and climatology.

4. Results

4.1. Demand study

The demand study shed light on the users' landscape and their needs with respect to the climate services currently provided by SENAMHI, as well as to those that may be potentially developed in the future. In the following sections, the main results of the demand study are presented. The current users of climate information are members of public and private institutions which maintain a formal link to SENAMHI. Although they have a technical background and are aware of the incidence of climate in their activities, they report not to use the tools that would allow them to incorporate climatic variables into their decision-making process in an official way. In fact, results show that although only about 25% of the interviewed institutions show dissatisfaction regarding the information provided by SENAMHI, 42% does not extensively utilize this information.

The study detected that the most climate-sensitive economic sectors are agriculture, tourism, and health in Cuzco, and agriculture and transport in Junín. In this article, we focus on the findings raised for the agricultural sector. The presented results are structured according to the purposes of the demand study outlined in Section 3.1.

4.1.1. Users

Most farmers in the Junín region (67%) are between the ages of 30 and 59 years. These farmers grow a variety of crops, in most of the cases (93.3%) in own plots, from which the majority are smaller than 5 ha. In the zones of Pucará and the Mantaro Valley, the major climatic menaces are due to extreme events, such as intense precipitation, floods, and droughts, as well as frosts and hail storms. In the Cuzco region, 68% of the farmers belong to the same age group mentioned above. In this case, however, individual land plots are mostly (93.1%) smaller than 2 ha. Besides the extreme climate events identified above for Junín, this region is also susceptible to strong winds. The survey identified the existence of a common practice among the farmers, named here "Ancestral Visual Indicator". It consists of a hereditary climate-related knowledge, based on the observation of the sky. This usage is mainly spread among old farmers (older than 70 years), for whom it has higher credibility than the information provided by SENAMHI. In contrast, young farmers tend not to adopt this ancestral knowledge, refusing non-modern and for them unreliable habits. Hence, without criticizing the ancestral knowledge, this results in a further opportunity for SENAMHI concerning the development of modern climate services.

4.1.2. Users' requirements

Concerning their specific needs, the users stated that climate-related information might be useful to determine the beginning of the agricultural season, as well as for planning measures to enhance the yield, e.g. the protection of crops against adverse climate events. Specifically, the climate services requested by the users were the monthly and seasonal forecasts of precipitation, droughts, and high floods, as well as of frosts and extreme temperatures, since the said events are among the most dangerous crop threats. Plagues and diseases affecting crops (such as coffee rust), are also often climate related (MeteoSwiss/SENAMHI, 2015). A very practical user-tailored climate service would be one that effectively warns about forecasted conditions that trigger the outbreak of such plagues and diseases.

While it was found that some users demand only information on the mean future climate conditions (i.e. below, above or close to the climate mean), it was recognized that other users express a wish to get forecasts that are precise concerning both the frequency and the duration of the events. Whereas in Junín farmers manifest their wish to obtain this information 1–3 weeks prior to the respective events, in order to prevent monetary losses due to e.g., delayed sales, in Cuzco this time span declared by users grows up to 1–2 months. Within the public sector, processes undertaken by specialized institutions (e.g., the Insituto Nacional de Defensa Civil (INDECI), the Centro Nacional de Estimación, Prevención y Reducción de Riesgo de Desastres (CENEPRED), Regional Governments, and other state organisms), aiming at increasing the awareness among the population and at planning prevention measures, need to be activated enough in advance. This is, for example, the case of water management strategies implemented by Irrigation Committees.

In summary, the attributes that climate information should bear are mainly the following three: 1) reliability, i.e. that it explicitly shows the source of the information, such as the station's location and name, and that it has passed a quality control check, 2) quality, i.e. that it has been tailored to the user's needs, that it is accessible at the appropriate time, and easy to understand and to apply, and 3) precision, i.e. that it is spatially adjusted to the very location of the final user, and not just issued for a broad region.

4.1.3. Improvements of climate services

Climate information should be reliable, accessible, and precise. Therefore, the coverage of SENAMHI's instrumental network should be improved, especially in high Andean zones. Further, the quality of the measurements should be enhanced in order to ensure the quality of the climate services. Then, the information should be regularly updated and timely.

4.1.4. User satisfaction

In contrast to the public and private institutions (only about 25% of dissatisfaction), 64% of the farmers indicate that their confidence in climate services provided by SENAMHI is low. As mentioned above, improved (spatial and temporal) precision of the climate and weather information could increase the confidence of the farmers in SENAMHI's products. An improved communication strategy to reach the local communities would also point to this goal.

4.1.5. Communication strategy

The study revealed that SENAMHI needs to improve its corporate image and its positioning as provider of climate services, facing both the public and the private sectors. This issue requires a strong communication strategy. The information should be delivered on time and guidance should be offered to the users, so that they can know how to interpret and manage it. Further, the content of climate information (e.g., Climate Bulletins) transmitted to the users should be easy to understand, clear and direct. The users expressed that they prefer specific information at regional to local level rather than information covering the whole country. The survey indicated also that rural radio stations, community assemblies, and communitarian loudspeakers, as well as cell phones could be used by SENAMHI as effective communication means. Here, it is noteworthy to mention that while farmers do not really trust the information issued in a centralized way by SENAMHI in Lima via e.g. TV, they are more likely to trust it when it is transmitted by more local channels, such the said rural radio stations.

4.2. Quality control and homogenization procedures

To enhance the operational quality control at SENAMHI and ensure the sustainability of the elaborated work, quality control rules were defined, documented (SENAMHI, 2013), and implemented in the database at SENAMHI. They were defined according to WMO (2011), suggestions from the literature (e.g., Boulanger et al. 2010; Brunet et al., 2008; Rusticucci et al., 2001) and from experience gained at MeteoSwiss, and adapted according to the current needs of SENAMHI to correct data from conventional climate stations. Along with the automatic detection of errors an interactive interface is being developed at SENAMHI that allows for correction of the errors. This system will include digitized versions of the original datasheets and the thermo-hydrographs to simplify the correction procedure. For homogenization, the program HOMER was introduced and applied at SENAMHI (see Section 4.3). Diverse workshops held internally fostered the institutional knowledge on homogenization. Further, a study on the use of HOMER in low density networks showed that the root mean squared error of estimated trends is reduced by around 50% after homogenization in low-density networks (Gubler et al. (under review)).

We conclude that additional efforts are required to improve climate analyses in countries of low station densities: quality enhancement of existing measurements and integration of stations from partner networks to increase the number of available measurements, and the collection of meta-information from the past for quality control. However, it is further worth mentioning here that ex-post data quality control and homogenization cannot compensate for all errors made during the measurement process. Therefore, the establishment of measures that allow immediate intervention in case of measurement errors is crucial to avoid data loss that may severely affect or even ruin long-term time-series of measured data (e.g., Hunziker et al. (submitted)). At SENAMHI for example, a system was developed that allows transmitting manually measured data directly by cellphones. Of course, entering invalid or impossible data – as e.g. negative precipitation values – is prevented. But, within this system, other simple quality control measures – such as extreme value or internal consistency checks – could be integrated, allowing intervention directly in the case of implausible data. Intervention could be done either through an alarm directly to the observer or through intervention (telephone, visit) by an expert of the NMHS at the station. At many Peruvian stations, redundant measurements are obtained through thermo-hygrographs and pluviographs. These could be enhanced by targeted observer training to cross-compare the values of the hand-written measurements of thermometers, pluviometers or hygrometers/psychrometers with the thermo-hygrographs or pluviographs. Large

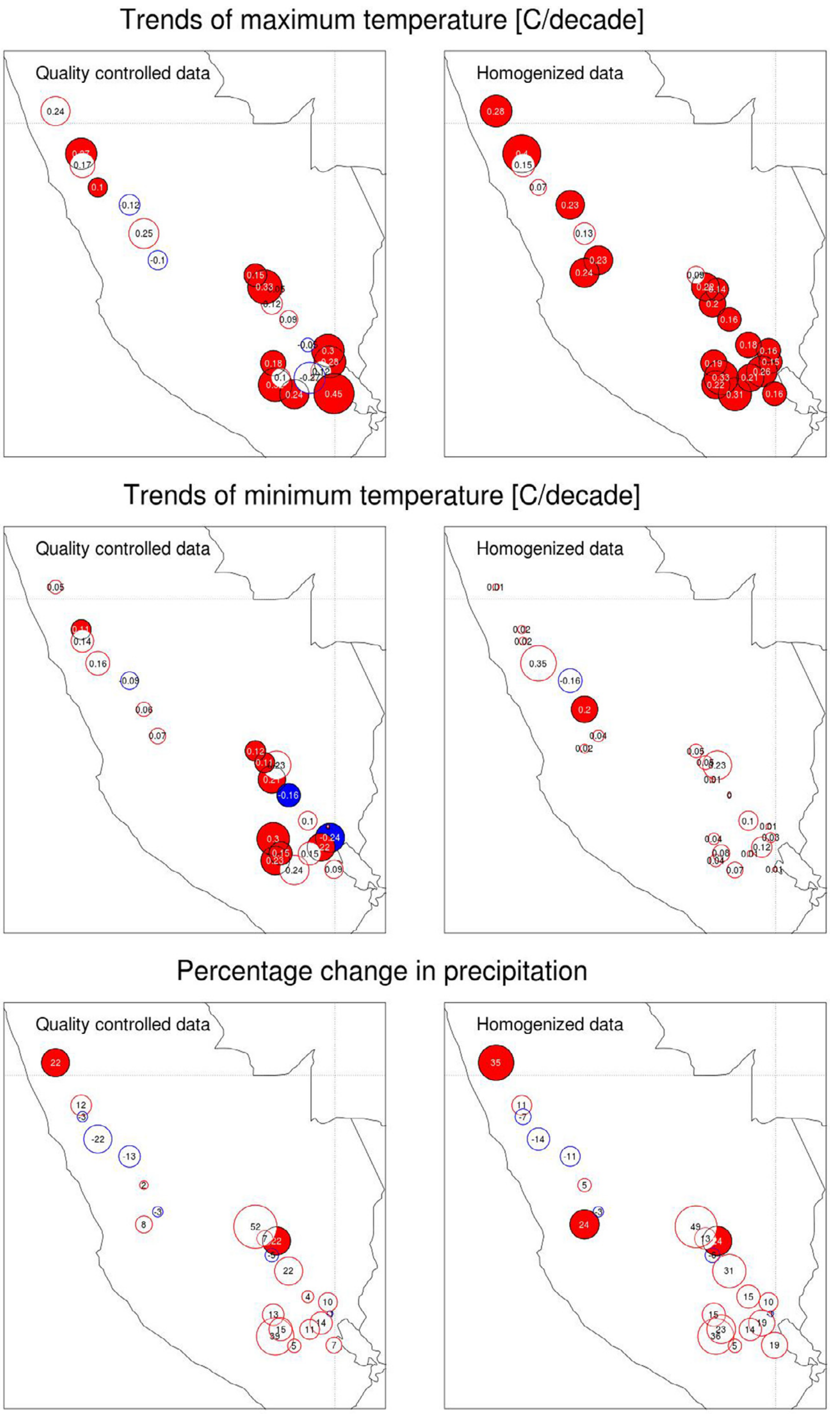


Fig. 3. Trends of maximum and minimum temperature [°C/decade], and percentage change of precipitation from 1964 to 2013. On the left, trends of the quality controlled data are shown, while the right hand figures show trends after homogenization. The size of the circle shows the size of the trends. Red circles indicate positive trends while blue circles show negative trends. The filled circles indicate that the trends are significantly different from zero. Maximum temperatures show a significant trend of 0.21 °C/decade on average. The trends of minimum temperature range around 0.06 °C/decade and are mostly not statistically significant. Similarly, changes in precipitation (on average 13%) are mainly not significant. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

disagreements could be due to a single misreading – or even an indication for systematic measurement errors – that could thereby be detected and corrected. Introduction of such measures however is a task that could be accomplished in the future.

4.3. Reliable climate information for the pilot regions

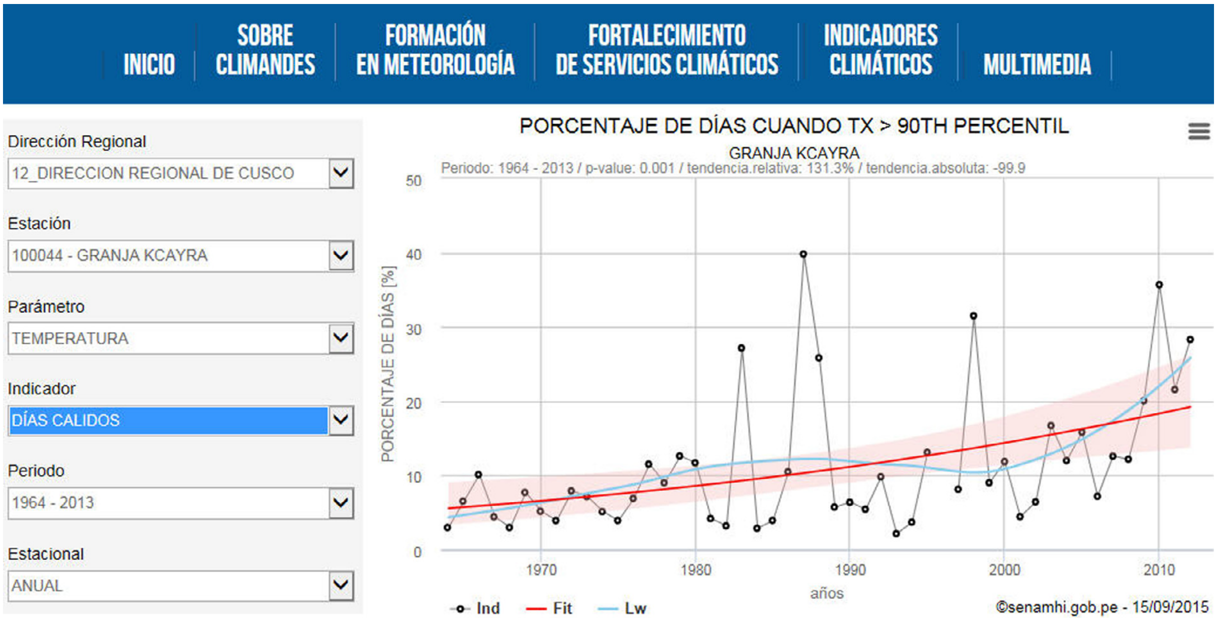
While SENAMHI runs many stations in the two pilot regions, a conclusion of this work is that only a few of them are useful for climate studies. A pre-selection of the data was necessary to avoid erroneous climate analyses in the region. It was based on criteria such as data length, completeness, and quality (Section 3.3). Finally, ten conventional stations for the Urubamba and the Mantaro basin were selected, corresponding to a station density of roughly one per 10,000 km^2. For homogenization, the station network was complemented with stations from neighboring regions in the Andes, resulting in a number of 24 climatological stations (Fig. 2). All stations were quality controlled, corrected, and homogenized during CLIMANDES. Suspicious data detected by RClimDex was controlled and corrected "by hand" using the original data sheets. The quality controlled data was homogenized using HOMER within a workshop given by an external expert. Due to the lack of metadata (e.g., station histories), homogenization was based on statistical evidence alone. During the homogenization, special care was given to the acceptance/rejection of break points in years of strong El Niño events.

The homogenized data is stored in the database at SENAMHI. The centralized storage of the enhanced data ensures the sustainability of the work done in CLIMANDES, e.g., it guarantees that the same data is used for different climate analyses (ensuring the consistency of different climate analyses) and it prevents reduplication of the data treatment effort by providing access to the enhanced data to different users. To illustrate the climate change indicators on a webpage, an R-script was developed that reads the homogenized data from the database, calculates the ETCCDI climate change indicators (Table 1) and respective trends, and stores the results in the database. From there, they are automatically read and illustrated on a webpage (Section 4.4).

After homogenization, significant (non-significant) warming trends of around 0.21 °C/decade for TX (around 0.06 °C/decade for TN) were estimated (Fig. 3). The trends are in accordance with trends published by other studies in the region (López-Moreno et al., 2015). The variance of the estimated trends is reduced by more than 50% after homogenization. The precipitation sums increase by 13% on average over the last 50 years, however the changes in precipitation are mostly not significant (Fig. 3).

4.4. Dissemination of climate information

Decision makers in the pilot regions may access information of the CCIs on the web platform (http://www.senamhi.gob.pe/climandes/?p=indicadores, see Fig. 4). The platform, which constitutes the main direct communication means between SENAMHI and trained end users (e.g. decision makers, broad public, economy actors), allows a map-, region- and name-based selection of individual stations. Relevant CCIs for each station appear in a drop-down system that can be explored by the user. On the interactive graphic, the measured values, the trend, as well as a smoothed curve may be obtained. The apparent advantages of such a web-based solution are the quasi real-time and fully automatic update of the analyses. However, experience in Switzerland has shown that solely providing graphical analyses is only one aspect end users are interested in. This information aspect is improved via the elaboration and distribution of documents and brochures explaining the meaning of the CCIs, as well as information on the trends and possible implications for the communities. The documents serve as tools to support decisions in planning, to foster socio-economic development, as well as to treat risks and manage adaptation to climate change. Another improvement of the web platform considers the inclusion of a podcast section. This allows sharing multimedia files, such as testimonies and comments on the utilization and application of climate services. Further, users are able to subscribe to the webpage updates and send their feedback to SENAMHI. A survey of the webpage over the last months has shown that on average 300 persons visit the webpage per month.



Dirección Regional: 12_DIRECCION REGIONAL DE CUSCO
Estación: 100044 - GRANJA KCAYRA
Parámetro: TEMPERATURA
Indicador: DÍAS CALIDOS
Periodo: 1964 - 2013
Estacional: ANUAL

PORCENTAJE DE DÍAS CUANDO TX > 90TH PERCENTIL
GRANJA KCAYRA
Periodo: 1964 - 2013 / p-value: 0.001 / tendencia.relativa: 131.3% / tendencia.absoluta: -99.9

Fig. 4. Screenshot of the interactive web-platform that was built to disseminate information on climate extremes through climate change indices. The interactive web platform allows a region- and station-based selection to display the 27 ETCCDI climate change indicators (Table 1). This figure for example shows that the percentage of warm days in Granja Kcayra (Cuzco) has increased since 1964.

Even in developed countries, users often lack knowledge on the current climate and its influence on their activities and applications. To give an example, a study by Zubler et al. (2015) in Switzerland examined the relation between the amount of salt needed to prevent the streets from freezing in winter. The study indicates a strong dependence between the number of fresh snow and the amount of salt, a very useful relation to plan the required salt amount under climatic change.

In the Peruvian highlands, planning of infrastructure to prevent damage during extreme events, or infrastructure for irrigation in agriculture require information on average and extreme precipitation as well as on droughts. Other sectors, such as the health sector, benefit from monitoring and predicting extreme cold events and solar radiation to plan protective actions for the population.

The information on CCIs displayed on the webpage may help increase the awareness of the interactions between the climate and particular applications in some sectors, and improve planning under present climatic conditions. In addition, the information on trends displayed on the webpage may indicate that actions taken in the past may not be sufficient for the future, and that ancestral knowledge on the climate is not sufficient to face climatic change.

Mass communication channels between SENAMHI and a broader public were built in the two study regions Cuzco and Junín via telephone, social networks, and climate reports. Today, SENAMHI counts on a communication database covering more than 3000 users at the national level, including decision makers, stakeholders, journalists, among others. These communication channels are maintained by staying in continuous contact with the end users, an aim that requires keeping institutional directories and e-mail addresses up-to-date and holding regular work meetings.

Two workshops were held in November 2014 in Cuzco and in Junín. The aim of these workshops was to present a selection of results of CLIMANDES to diverse stakeholders such as the regional governments as well as the sectors of agriculture, risk management, health, and education. These workshops train professionals to improve their understanding of climate information and its applications. Further, they allow direct interaction with the end users and provide information on the users' visions and expectations, a basis needed for the continuous improvement of the climate services provided by SENAMHI. During these first climate workshops, SENAMHI obtained a lot of feedback: for example, there is a need to present climate information in a more "friendly" way, e.g., climate bulletins need to be improved using simple language, terminologies, and self-explaining figures. In addition, the information provided needs to be tailored towards specific interests of the individual sectors or users. For example, decision makers are often short on time and need quick condensed information that can simply be integrated in their daily business and decision making.

The improvement of the climate services provided and the integration of the recommendations of different users is a continuous process. The first areas of improvement will be acted on in the second phase of the CLIMANDES. In addition, the use and the applications of the provided climate information in the diverse sectors will be monitored.

Due to the role journalism plays in connecting institutions with the public, a network of specialized journalists was built. Two workshops in the pilot regions, taking place in 2014 in Junín and 2015 in Cuzco, were held with a total of 150 journalists. These journalists were trained with respect to climate information and the diverse products generated by SENAMHI, and they were familiarized with the meteorological and climatological terminology. For example, misinterpretations of information such as "the temperature is decreasing by 5 °C" emitted by SENAMHI, which in the past have also been translated to "the temperature is 5 °C", may thereby be avoided. Another focus was on how such information should be communicated to the public, emphasizing simple and understandable language. In conclusion, this network of journalists is better prepared to communicate climate information to diverse audiences (from local governments to the broad public) using the appropriate language.

Radio spots have been part of the recent communication strategy of SENAMHI, in particular concerning the emission of warnings on frosts and extreme cold conditions (locally known as "friajes"). Currently, these spots reach a broad audience within fifteen regions prioritized by SENAMHI, thanks to agreements signed between this institution and the National Broadcasting Coordination Agency (*Coordinadora Nacional de Radio,* CNR), as well as with the National Radio. Thereby, SENAMHI established the first communication channels reaching rural communities directly. The transmission of warnings (which might be seen as a weather service rather than a climate service) serves as a strategy of approximation to the users (the rural community), a community which previously did not have any direct contact with such information. Once established, this communication channel will also serve to disseminate climate information and may improve the economic activities in rural communities. Future steps towards an enhanced communication strategy of SENAMHI require that alliances with commercial, educational, and community radio stations are strengthened.

5. Conclusions

National adaptation and mitigation strategies and climate-related policy decisions need to be based on high-quality climate information. The WMO-led Global Framework for Climate Services is designed to bridge the gap between scientific knowledge and end users' requirements. In this context, CLIMANDES is an innovative twinning project between the National Meteorological Services of Switzerland and Peru. CLIMANDES provides climate services to inform decision makers in Peru and the Andean region. The key element is the web-based platform, which serves as a user interface to disseminate user-tailored climate information to specific groups, in particular to political decision makers. Experience gained from this work should be used as a basis for upscaling the technical results to the national and regional level through institutions such as WMO and the *Centro Internacional para la Investigación del Fenómeno de El Niño* (CIIFEN) through workshops with NMHs from neighboring countries.

Within CLIMANDES, a demand study was conducted among current users of the climate information delivered by SENAMHI, as well as among potential new users. Although this survey was done in a late stage of the project, and thus no crucial adaptations could be implemented, its results provide a framework for a second phase of CLIMANDES that started in January 2016. Based on the outcomes of the demand study, the efforts will focus on the development of reliable and precise monthly-to-seasonal forecasts of precipitation, temperature, and related climate events. The study showed that a fundamental drawback to tackle in Peru is the availability of good quality climate observations of high spatial coverage. Further, climate services should be tailored to the specific users' needs concerning their geographical reality. Also, the background knowledge of the end users concerning climate information should be considered within SENAMHI's communication strategy, so that right guidance is provided. This is a crucial aspect for the proper interpretation and application of the information. The demand study as a first approach to determine the needs of the users of weather and climate information was an interesting exercise performed by SENAMHI to change its focus of perception, to determine the needs of users in dependence of diverse factors, such as region, economic interest (subsistence or selling producers), responsibility in society (family livelihood or regional authority).

To improve the basis for climate services, a great effort has been undertaken to improve the quality of climatological data at SENAMHI. The approach of the project was threefold: a) application of selected methods to stations in pilot regions to obtain exemplary results that can be up-scaled to the larger region and that may be used for training purposes, b) development of tools to facilitate quality control procedures and ensure sustainability, and c) training of dedicated staff at SENAMHI. The joint efforts of SENAMHI and MeteoSwiss have shown to be very constructive in order to adapt and develop tailored procedures to improve the data chain at SENAMHI. Further, the diverse technical exchanges of professional staff of both institutions allowed to ensure a profound training and exchange of experiences between the two meteorological offices.

Challenges in the data chain remain due to the pronounced need for a general revision of the data management concept and the set-up of the data base at SENAMHI. These and other issues that clearly emerged as a current need at SENAMHI are addressed in the second phase of the project. Further, the operationalization of the quality chain at SENAMHI requiring dedicated human resources will be continuously monitored during the second phase, ensuring the sustainability of the obtained results.

The results of the technical part of the project are provided through climate change indicators (CCIs) on the web to decision makers. The web platform is the main direct communication channel between SENAMHI and trained end-users developed within CLIMANDES. Additionally, mass communication with a broader audience is reached through other channels, such as mobiles, social networks, and reports. This resulted in effective communication means in the project that allowed to raise the awareness of climate information in public and private institutions. Individuals of the public and private sectors were trained during diverse events in order to improve their understanding of the climate information and its applications such that the information is used appropriately and understood correctly. These events further allowed to obtain direct feedback from the users on how to improve the services provided by SENAMHI, which, in a continuous process, will be implemented in the future. Further, a network of specialized journalists has been established to reach and inform the public properly through an adequate use of language. Targeting more urban users, specifically the tourism sector in Cuzco, SENAMHI envisions the development of a mobile app, inspired by the MeteoSwiss App, so that tourists are able to better plan their leisure activities. Further, alliances with local communication channels, such as communitarian radio stations, were strengthened. In the future and concerning the agricultural sector in particular, radio spots that deliver climatic information will raise sensitivity awareness related to climate services among farmers. For that, their traditional knowledge should be incorporated and combined with the climate services developed by SENAMHI. Moreover, climate information will be translated into Quechua and Aymara, the native languages of a considerable part of the farmers within the pilot regions. Through all these efforts, the quality of the climate services as well as the communication means were improved through CLIMANDES, resulting in higher awareness and higher confidence of the users of climate information.

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