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Comparing peasants' perceptions of precipitation change with precipitation records in the tropical Callejón de Huaylas, Peru

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Abstract

Pronounced hygric seasonality determines the regional climate and, thus, the characteristics of rain-fed agriculture in the Peruvian Callejón de Huaylas (Cordillera Blanca). Peasants in the Cuenca Auqui on the eastern slopes above the city of Huaraz attribute recently experienced challenges in agricultural production mainly to perceived changes in precipitation patterns. Statistical analyses of daily precipitation records at nearby Recuay (1964 to 2013) and Huaraz (1996 to 2013) stations do not corroborate the perceived changes. Either insufficient temporal resolution of available precipitation records or other environmental and sociopolitical factors impacting traditional farming methods may be the reason for the lack of concordance between the two information sources investigated in this study.

1 Introduction – considering different perspectives on a complex problem

Scientific evidence of climate warming and of projected resulting impacts can provide the basis for a responsible and efficient adaptation strategy if implemented in a timely and careful fashion, but can also be misused to legitimize particular interests (Arnall et al., 2014; Dietz, 2011; Neuburger, 2008). While the physical aspects of climate change are, though complex, of relatively straightforward nature, societal processes in reaction to them are contingent upon and characterized by the different interests, positions and vulnerabilities of affected groups.

A region of specific interest is the Callejón de Huaylas (the valley drained by the Río Santa) in Peru, where water availability is determined by particular climate and topographical settings (e.g. Kaser et al., 2003). While the tropical atmosphere is thermally homogeneous, the region is characterized by single-peaked hygric seasonality. Precipitation increases from August towards the October to April core wet season and is close to nil during June and July (e.g. Bury et al., 2010; Kaser and Osmaston, 2002; Mark et al., 2010; Schauwecker et al., 2014). Dry season runoff, and thus water sup-

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ply, is comprised of up to two thirds glacial melt water from the Cordillera Blanca (e.g. Baraer et al., 2012; Kaser et al., 2010; Mark and Seltzer, 2005, 2003). They smooth the seasonal runoff to a degree that varies with the proportion of sub-catchments that are covered by glaciers (e.g. Kaser et al., 2003; Mark and Seltzer, 2003). While the highest glacier cover of up to 41 % is found in the northern Cordillera Blanca valleys, rivers draining the western Cordillera Negra are lacking in glacier contribution (e.g. Kaser et al., 2003).

Glacier contribution definitely has a considerable effect on the runoff of the Río Santa during the dry season (Bury et al., 2013; Carey et al., 2014) and even more so on the tributaries draining the Cordillera Blanca. Both ancient and modern channel systems have witnessed the sophisticated use of river water for agriculture and other needs (Bury et al., 2013; Gelles, 2001). Many studies were dedicated to the impact of glaciers on runoff and water availability in the region (Baraer et al., 2012; Carey et al., 2014; Mark et al., 2010). The increasing knowledge of human-caused climate warming and resulting impacts has attracted much attention in the region up to now (Baraer et al., 2012; Bury et al., 2013; Carey, 2010; Carey et al., 2014; Chevallier et al., 2011; Juen et al., 2007; Mark et al., 2010; Vuille et al., 2008) and, among other interests, our interdisciplinary research team also focuses on this issue.

Yet, by gradually deciphering natural components of water availability, societal practices of water use, and emerging trends of water conflicts, we have identified important non-glacial aspects of the question of water supply in our study region. Even on the slopes of the heavily glaciated Cordillera Blanca many small scale farmers have no access to nearby glacier-fed river runoff due to unequal land and water distribution systems.

Accounts from local peasants suggest that changes in precipitation patterns e.g. during the onset of the wetter season (August–September), the traditional period for ground preparation and first seeding, have caused detrimental effects on the crops' growth and, thus, on overall agricultural production. However, human perception can often fail to accurately determine the drivers of concern (e.g. precipitation, solar ra-

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diation, temperature, deforestation, changes in seed types etc.) for the experienced impacts (changing soil moisture, problems with seedlings and harvests). A full range analysis of crop yield and precipitation data, of forest degradation, soil erosion, changing seeds, cultivating methods, development/liberalization of agricultural markets, political programs and dominant discourses etc. would lead to a most comprehensive answer to whether and why crop yields may have changed and how counter measures could be applied. Yet sustainability farming is rarely accompanied by systematic data collection and change monitoring, hindering a comprehensive analysis of drivers of alterations in crop growing. General statistics on agricultural production changes for the entire Department of Ancash do not allow for the derivation of local information and understanding the complexities of changes (Bury et al., 2013).

Also, precipitation data in the Callejón de Huaylas have been recorded more from the perspective of hydropower use than of agriculture, and thus long term measurements with high temporal resolution (at least daily values) as required for analyzing potential impacts on crop yields are rare. Nevertheless, for this study we were able to assemble time series of daily precipitation totals for two sites in the Southern Cordillera Blanca, for the periods 1964 to 2013 and 1996 to 2013 respectively. These data allow us to examine one potentially powerful (and the most blamed) driver of the experienced changes in rain-fed agriculture.

In this study we examine the issue by (i) characterizing agricultural practices of Andean peasant families along the Río Auqui (crop types used, seasonal cycle of sowing, growing and harvesting) and presenting and evaluating the peasants accounts of changes, (ii) analyzing available information on local precipitation, and (iii) touching on potential effects on small scale farming as far as possible from available data. Aspects of climate change impacts not investigated in this study and potential other disturbances of agricultural performance will be briefly referred to in the discussion section.

The outcome of this study may shed light on other peasant communities in the region whose economy is based on rain-fed agriculture and, more generally, on mountain regions with similarly vulnerable communities and with similarly poor availability of information. It also takes account of potential complications caused by the different approaches of scientific groups in an interdisciplinary setting.

2 Study site

Our study site (here called Cuenca Auqui) stretches from the city of Huaraz along the slopes south of the Río Auqui up to the highest settlements close to Río Shallap and includes five main villages with about 1500 inhabitants in total: Los Pinos, Ichoca, Collyur, Paquishka and Jancu (Fig. 1). The narrow bottom of the valley is well-defined by steep slopes reaching altitudes up to 4500 m a.s.l. that become gentler towards the crests. Aside from some houses at the valley flanks, all settlements are located close to the road at an altitude of 3200 m a.s.l. (Los Pinos) to 3800 m a.s.l. (Jancu). The cultivation area in the Cuenca Auqui is naturally concentrated towards the valley bottom but also extends to the adjacent slopes. Irrigation is currently only available for relatively small areas close to the river (Fig. 1). The Cuenca Auqui stretches from the Río Santa into the heavily glaciated Cordillera Blanca, which together with the ice-free Cordillera Negra in the West, defines the Callejón de Huaylas.

With the implementation of the agrarian reform in 1969, four former haciendas (colonial large scale farms) at the southern side of the Río Auqui were divided into small plots and distributed among the local farmers of the Cuenca Auqui. Since then, agricultural activities are characterized by subsistence production of potatoes, grain and corn, with surpluses being sold at the markets in Huaraz. Fast-growing eucalyptus has been planted for construction, heating and cooking purposes. An irrigation channel fed by the Río Auqui could supply most farm land in the watershed, but it is out of service and the water is contaminated by heavy metals and thus not applicable for irrigation agriculture (Mark et al., 2005).

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3 Agricultural practices and peasants' accounts of changing precipitation

3.1 Collecting information on agricultural practices and perceived changes

Based on the idea that local people are closely linked to their environment through continued practice of resource-based livelihoods, as a first step we collected information on the local ecological knowledge of peasants in the Cuenca Auqui. Emphasis was on local climate and environmental changes, with particular interest in agriculture and related community activities (e.g. Agrawal, 1995; Alexander et al., 2011; Klein et al., 2014). We understand this type of knowledge as a continuous iteration between individual and collective perceptions, practices and beliefs, modified by specific political and discursive dynamics (Boillat and Berkes, 2013). The derived information represents a snapshot of the broad local knowledge about environment, society and history.

We conducted semi-structured and narrative interviews in all five communities of the Cuenca with peasant individuals and families (Table 1). A greater proportion of men were interviewed because the traditional gender-specific division of labor defines water management and crop production as a male responsibility. Nevertheless, women are involved in animal husbandry, with ecological knowledge about pastures at higher elevations. The interviewees were selected by "snowball sampling" (Goodman, 2010; Heckathorn, 2011) starting with the community authority, who then indicated other families in their community. A sequence of interviews was conducted in each community until reaching saturation to ensure that no new themes emerged. We conducted the interviews in Spanish and were supported by a local translator when interviewees – mostly in the community of Jancu – only spoke Quechua. All interviews included questions about household, agricultural practices (products, technology and intermediate goods, man power, agricultural calendar), community life, and questions of integrating environmental character. Main focus was on their experienced changes for each issue as well as the mutual dynamics over the last decades. Despite the frequently used

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vague time references like “in former times” or “before the earthquake”[1] the analysis of the interviews gave several hints for enhanced challenges in agricultural production during the “last decade”. Overall, these interviews represent experiences of each individual or family which – in a communicative process – forms the collective memory of the whole community. However, information is diverse due to the fact that ecological conditions vary strongly within the Cuenca Auqui along the strong climatic gradients up-valley from west to east.

In a second step we applied additional methods of qualitative analysis. We conducted expert interviews with the community authorities, the elected political representatives of each community. They represent the community externally and internally, coordinate community activities such as maintenance of communitarian infrastructure like roads, irrigation channels, water reservoirs, and community centers, and settle disputes within the community. Additionally, we questioned officials of the Juntas Administradoras de Servicios de Saneamiento (JASS, local administrative boards of sanitation) and Juntas de Riego (committees of irrigation) that are responsible for water supply and irrigation in the communities. To capture most recent discussions on potential climate related changes we organized a participative mapping meeting in December 2013 with 16 representatives of all communities in the Cuenca. The representatives designed maps of their communities showing relevant issues and changes related to agriculture, water resources and community life. A participants’ comparative discussion revealed similarities as well as differences between communities in the Cuenca Auqui.

In a final step we extended our interviews to individuals and institutional experts outside the Cuenca Auqui in order to relate our knowledge to the wider upper Callejón de Huaylas. We therefore conducted “go-along interviews” (e.g. Anderson, 2004; Bergeron et al., 2014; Evans and Jones, 2011) with two informants from neighboring communities. One of them is a local guide from Llupa, who regularly accompanies international scientific expeditions in the Cordillera Blanca, and the other is a local historian

[1] In 1970 an earthquake caused huge damages in the region (Lipton, 2014).

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of the community Chontayoc, located in the Cordillera Negra. These interviews yielded details about ecological conditions and agricultural practices in the Cuenca Auqui and the nearby Río Santa valley. Furthermore, we interviewed 26 representatives of public institutions and NGOs in Huaraz which deal with agricultural and environmental issues. From these “expert interviews” we gathered technical, agronomic and political information about structures and dynamics in agriculture, water policies, population, and migration at regional level. With these interviews we cross-checked the Cuenca Auqui peasants’ reports and added details.

All interviews and meetings were recorded, transcribed and analyzed with the software MaxQDA. In the digital documents we marked all comments on agricultural practices (including experienced changes), on environmental and climate issues linked with agriculture, and on all connections established between changes in climatologic phenomenon and agriculture.

To enhance the reliability of our results, we only include individual statements which were confirmed in focus group discussions or by institutional or NGO representatives in our analysis. Since individual perceptions and collective memory in the Cuenca Auqui and beyond are mutually linked, only very few statements differ from the general view.

3.2 Agricultural practices

The peasant families of the Río Auqui watershed cultivate an average area of around three hectares per family which are distributed in small plots over different altitudes of the valley (Fig. 1) in order to guarantee diversified production for each family (Vos, 2010). If possible, families combine irrigation and rain-fed agriculture, but overall only few are privileged in having access to irrigation for year round cultivation. The large majority of the families depend entirely on rain-fed agriculture and, consequently, on precipitation. The cultivation calendar in Fig. 2 results from our interviews and fieldwork.

Rain-fed agriculture is strongly dominated by the pronounced seasonal cycle in precipitation and crops are vulnerable to changes during different phases of the cultivating cycle. Different crops and the different altitudes and climates in which they are cul-

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tivated increase the resilience of a community, yet irregularities or extremes during specific times of the agricultural year are still viewed with concern.

The first rain events after the core dry season in August and September are of particular importance as they mark the start of the rainy season. According to the reports, these first rainfall events are of gentle character, providing favorable conditions for preparing the fields. They are of great importance to agricultural life and were celebrated with festivals following ancient traditions. The enduring importance of these gentle rains is evident by the persistent use of the ancient *quechua* term "*puspa*". Potential temporal shifts of the *puspa* are therefore viewed with great concern by the farmers despite the sometimes broad time range suitable for agricultural practices – such as the sowing period for potatoes (Fig. 2) – due to different types of crops as well as the wide altitude range in which fields are cultivated in the Cuenca Auqui.

The main crops for subsistence in the Cuenca Auqui are potato, wheat, corn, and the traditional *oca* and *olluco* (Fig. 2). Potato (Solanum tuberosum) is typically sowed from mid-September to the end of October and harvesting starts in February and extends until June. At the altitudes above 3800 m a.s.l. farmers cultivate six varieties of native potatoes due to the fact that these are especially resilient to extreme climate conditions Tapia and Fries, 2007). In the lower areas the commercially used ameliorated potato variety "Yungay" dominates. Compared to native varieties the vegetation period of the "Yungay" is reduced to four months while productivity is approximately doubled (Tapia and Fries, 2007). The farmers reported that the "Yungay" potato requires the use of chemical fertilizer and insecticides and is much more sensitive to dry spells in the growing period.

Besides some high altitude adapted species of wheat, corn and wheat are mainly cultivated in lower areas (below 3500 m a.s.l.) because they are vulnerable to frost. While corn is sowed in August or September and has a relatively long vegetation period of approximately seven months, wheat is sowed in December and harvested between June and July. Both crops consume a lot of water and are vulnerable to dry spells in their growing period, as well as to frost and hail toward the later stages of growth.

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Furthermore, they are sensitive to wet conditions and heavy rain events in the ripening period.

For *Oca* (*Oxalis tuberosa* Mol.) and *Olluca* (*Ullucus tuberosus* Loz.), two traditional products of Andean agriculture adapted to high altitude climate (Tapia and Fries, 2007), sowing time in the Cuenca Auqui starts in March when the soils are saturated with water, and the growth period extends into the dry season. Harvesting of *oca* and *olluca* starts in September. Besides light rainfalls and morning dew, the hilling practiced is a traditional water harvesting technique that keeps the soils humid for these crops throughout the dry season. They are often planted in rotation with potato. In rare cases, they substitute potato following the same cultivation cycles. *Oca* and *ollcua* (as well as the variety *mashua*) are quite resistant to plagues, diseases and low temperatures (Tapia and Fries, 2007).

3.3 Peasants' reports about changing precipitation patterns

Over a period referred to as the "last decade(s)", as compared to undated "past times", farmers report the following changes:

- The *puspa* starts only in September and sometimes comes as a single rain event only, which is insufficient for increasing the soil moisture. The farmers are confronted with a difficult problem: if they plant potato and sow corn (as the first products of the new cultivation period) before the *puspa*, the seeds or young plants might be damaged by water scarcity or by frost during the following dry nights. If they wait for the delayed *puspa*, the growing period becomes short and crop yields are reduced.

- The beginning, duration, and end of the wet and dry seasons have become more variable and, in general, rainfall has become more irregular, which complicates successful farming overall.

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- The occurrences of hail and heavy rain events have become more frequent during September and October, when corn and potato are in their sensitive phase of germination and initial growth, but also throughout the entire wet season, causing high surface runoff and increased soil erosion. Damages to crops during both flowering and the harvest season are more frequent.
- Ground frost has become more frequent during September and October, damaging the crops in the early vegetation period.

These reports are in line with the results presented in an earlier study in the region (e.g. Mark et al., 2010a) where the farmers perceived similar changes in the precipitation patterns. In addition to consistent reports on experienced changes in weather conditions, farmers report different impacts on agricultural activities depending on the location and altitude of their plots as well as on the type of crops with different water demands in different time periods. Families in Jancu and Paquishka, for instance, mainly cultivate traditional crops and identify less weather-related challenges than communities at lower elevations (Los Pinos, Ichoca and Collyur), where modern crop types and steep fields are more vulnerable to heavy rain.

4 Measured precipitation

4.1 Available records

Most questions related to changes in rain-fed agriculture require at least daily temporal resolution. Only two stations in the surroundings of our study area (Fig. 1) provide daily precipitation values (7 a.m. to 7 a.m.) over time periods of an appropriate length. Huaraz at the bottom of our study area (3052 m a.s.l.) has a record of daily precipitation from 1996 to 2013 (with several gaps) when merging the station records of "Huaraz" and "Santiago Antunez de Mayolo". Recuay at 3445 m a.s.l. is about 25 km up-valley along the Rio Santa from Huaraz and covers a much larger period from 1964 to 2013,

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with gaps of 156 days in total that could be closed with data from Recuay Sut and Laguna Ututo, 1 and 10 km from the Recuay station respectively. The data were made available by SENAMHI, National Meteorological and Hydrological Service of Peru.

In order to test the representativeness of these two stations for the study area we were able to use unpublished time series of weekly precipitation sums measured at Llupa (3435 m a.s.l.; from 2003–2013) relating to research projects conducted by our group in the Cordillera Blanca. Over approximately 10 years of overlapping time series, mean weekly precipitation deviated by only 2 mm week^{-1} (Recuay-Llupa) and 0.1 mm week^{-1} (Huaraz-Llupa) with correlation coefficients of 0.66 and 0.78 respectively. Thus, the magnitude and the variability of measured precipitation in Recuay and Huaraz seem to be comparable with those that can be expected in the area of the Cuenca Auqui. Lack of information about the measuring systems in Recuay and Huaraz inhibits assessing their uncertainties. Information from atmospheric model output (ERA interim with 0.75° horizontal resolution) with the grid points surrounding the study area does not catch the daily variability of precipitation well enough ($r < 0.6$). In consequence, the records from Recuay and Huaraz are taken for further analysis in this paper. For practical reasons values for 29 February were removed from the series.

4.2 Defining agro-relevant criteria for precipitation statistics

The farmers' reports and concerns reflect the strong influence of several features in the annual precipitation cycle on farmers' lives and the agricultural year in the Cuenca Auqui. The steadiness of these characteristics determines the success or failure of sowing, growing and harvesting (Ambrosino et al., 2014; Kniveton et al., 2009; Raes et al., 2004). To extract the agriculturally relevant information from the seasonal cycles of daily precipitation to be compared with the farmers' experiences, we defined 8 criteria, mainly empirically and inspired by methods presented, for example, by Laux et al., 2008. In the following, P is the daily precipitation sum, d is the Julian day of the respective year and N is the number of days that fulfill a certain criterion.

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1. *Puspa:* cannot be quantified in most cases due to the coarse temporal resolution and measurement accuracy of the available precipitation records.

2. *Onset day wet season:*
   $P(d) > 0$ and $\text{sum}(P(d:d+6)) > 10\,\text{mm}$ and $N(P(d:d+30) > 0) > 10$
   For the onset day of the wet season, the three requirements to be met are (i) that there is precipitation measured on that day, (ii) that the sum of measured precipitation in the next 7 days is $> 10\,\text{mm}$ and (iii) that the number of days with precipitation within the following 31 days (1 month) is > 10. Criterion 2 was empirically defined by optically analyzing the onset days for each year with respect to the annual cycles of precipitation. Of course the transition from dry to wet season is not spontaneous, so that the selected day can just be an approximation for this transition time. In some years there would be more than one reasonable date. The additional criteria presented in the following allow detection of potential ambiguities by adding further information.

3. *First sowing conditions after 1 August:*

   a. $\text{sum}(P(d:d+2)) > 10\,\text{mm}$ and $N(P(d:d+2) > 0) = 3$

   b. $\text{sum}(P(d:d+6)) > 25\,\text{mm}$

   Different to the other criteria, criteria 3a and 3b, yielding start dates for the sowing season, are based on information from literature as these criteria are more objectively assessable than, for example, the human-perceived onset of the wet season. Criterion 3a follows data presented in Table 1 in (Sanabria et al. (2014) which is the only study we know that presents typical precipitation values required for planting of different crop types in the region. Three days of consecutive precipitation with total precipitation $> 10\,\text{mm}$ should give a rough estimate when sowing conditions for typical crops in the Cuenca Auqui (see Sect. 3.2) might be favorable for the first time after 1 August of each year (when farmers are expecting the onset of the wet season). To avoid reliance on only one criterion, we also calculated

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the MET criterion used in Zimbabwe (Raes et al., 2004) that advises planting if the rainfall sum exceeds 25 mm in 7 days (3b).

4. *Dry spell during wet season:*
   $\text{sum}(P(d:d+6)) < 10\,\text{mm}$
   Criterion 4 marks dry periods (1 week with precipitation < 10 mm). The limit of 10 mm of weekly precipitation to define dry spells is mostly arbitrary as there is no universal amount of weekly precipitation that is required to keep different soil types with different slopes and aspects wet for optimal plant growth, and different crops have different water demands. However, we consider this amount to be a rough indication of when soils get drier and plants might suffer from water scarcity, especially when several dry spells follow each other. It is worth mentioning explicitly that a single dry/wet spell stands at least for one week (whereas the date used in Fig. 3 is defined as the 3rd day of the respective week). Each consecutive dry spell enlarges the period by 1 day. The overall duration of a dry spell period (which might be a series of dry spells) can easily be estimated from Fig. 3 with respect to the time-axis.

5. *Heavy precipitation day:*
   $P(d) > P$ (95 % Quantile)
   In our definition of criterion 5, a heavy precipitation day has a precipitation total that is above the 95 % quantile of all measured precipitation amounts larger than 0. Even though the length of the time series available for Recuay and Huaraz is differs between the stations, the value of the 95 % quantile for daily precipitation for each is close to 17 mm day^{-1}.

6. *Onset day of the dry season:*
   $P(d) = 0$ and $\text{sum}(P(d:d+45)) < 10\,\text{mm}$
   For the onset day of the dry season, the two requirements to be met are (i) that there is no precipitation measured at that day, and (ii) that the sum of measured precipitation in the next 45 days is < 10 mm. As for criterion 2, this criterion was

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optimized by analyzing the calculated onset day of the dry season with respect to the annual precipitation cycles.

7. *Wet spell during dry season:*
   $\text{sum}(P(d : d + 6)) \geq 10\,\text{mm}$
   Criterion 7 marks wetter periods during the defined dry season with weekly precipitation sums of at least 10 mm.

For a small number of years with unusual precipitation patterns e.g. our criteria 2 and 6 did not yield reasonable results (dry season onset Recuay in 1985, wet season onset Recuay 1972) or even failed (wet season onset Recuay in 1992). We accept these minor problems as we tried to keep all 8 criteria as simple as possible to facilitate comprehensibility. More sophisticated criteria could tend to over-interpret our limited information. Some other missing values in individual years (e.g. 1974–1978 in Recuay; 2012 in Huaraz) are the result of data gaps in the precipitation records.

For analyzing potential trends in the calculated features of the precipitation time series we applied the Mann–Kendall trend test (significance threshold set to the 90 % confidence level) to all features presented in Figs. 3 and 4 for the 1981 to 2010 time span[2] (agricultural years) available for Recuay.

4.3 Precipitation analysis

In order to facilitate a comparison between human perceptions and memories and measured records, we classified the precipitation data along the 8 criteria presented in Sect. 4.2. The results are presented in Fig. 3 by starting with the agricultural year on 1 August. In the following sections a value given for a certain year (e.g. 2003) refers to the agricultural year (1 August 2003 to 31 July 2004). Data statistics are discussed along the issues raised by the farmers and listed in Sect. 3.3.

[2] As for the year 1991 no onset date for the wet season could be calculated for Recuay we skipped this year for analyzing potential trends in the wet season onset dates.

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We first comment on the *puspa*. As mentioned in Sect. 3.2, they are of gentle character with moistening the ground for the first time after the dry season and of high cultural importance in the community life. Yet, the distance of the rain gauges from the affected fields, the temporal resolution of the measurements, and the measuring accuracy make it impossible to detect any potential changes in the occurrence of the *puspa*.

As a first objective indicator of the start of agricultural year we present the *onset of the wet season* which should, by definition (Sect. 4.2), approximate the time when the weather conditions change from continuously dry to frequently humid. For Recuay (1965–2012), the date is typically in September or early October with the earliest onset calculated for 13 August (1988) and the latest for 20 November (1972), the arithmetic mean value being 23 September. For 1991, no onset of the wet season could be calculated as there was an unusual dry period from autumn 1991 to spring 1992 (also described by Schauwecker et al., 2014). For Huaraz (1996–2012) the onset day occurred typically 5 days later than in Recuay with a mean value centered on 28 September, the earliest day being 4 September (2001), the latest 25 October (2011). The mean variability of the onset was ±14.6 days in Recuay (44 years available) and ±11.1 days in Huaraz (17 years available). The results for Recuay do not show a significant trend in the onset date of the wet season. The average year-to-year variability was 22.75 days between 2003 and 2012, 13.7 days between 1993 and 2002 and 22.0 days between 1983 and 1992 for Recuay.

Analyzing the precipitation records in view of *favorable sowing conditions* shows that criteria 3a and 3b (see Sect. 4.2) are typically met between Mid-September and Mid-October at both measuring sites, with individual dates ranging from 30 September ±13.6 days/10 October ±12.1 days for criteria 3a/3b respectively at Huaraz, and 27 September ±15.4 days/7 October ± 17.6 days for criteria 3a/3b at Recuay. As for the onset of the wet season, there is no statistically detectable trend in the Recuay record (1981–2010) regarding the occurrence of sowing conditions. Comparing the results for the two criteria shows that in most cases the dates occur only a few days apart. Only in few cases (1971, 1989, 2000, 2005 and 2012 for Recuay, 2010 for Huaraz) is crite-

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rion 3b met more than a month later than criterion 3a. As visible in Fig. 3, these latter cases were always accompanied by pronounced *dry spells* between the first sowing dates according to criteria 3a and 3b. Criterion 3b therefore seems to be particularly conservative regarding the possible start of sowing in years with low rainfall amounts in the early wet season.

However, there are also cases where both criteria generated the same dates for good sowing conditions (e.g. 1999 and 2003) which were then followed by pronounced dry spells. Such patterns indicate particularly challenging conditions for farmers if, motivated by the first rainfalls, they sowed before the likely harmful dry spells. A rough estimate suggests that such potentially problematic conditions occurred in 7 out of 17 years between 1996 and 2012, both in Huaraz and Recuay. As a side note it is worth mentioning that in two occasions (1971 and 1989) first sowing conditions (criterion 3a) occurred during a (rare) wet spell in August (earliest date in record: 14 August 1989) which could also have provoked farmers to sow, only to face a pronounced dry period soon after.

Dry spells also occur from December to April, reflecting pronounced variability of precipitation even during the core wet season. However, dry spells during the middle of the wet season were less frequent than during the transition periods (expect for few years like 2000 at both sites and the exceptional year 1991 in Recuay). They also have lower potential to harm the plants, being in advanced stages of growth by then. Overall, as visible in Fig. 4c, we have no evidence for increased frequency of dry spells in each agricultural year (no significant trend in Recuay data).

Heavy precipitation days (here defined as $> 17\,\text{mm}\,\text{day}^{-1}$) potentially damage crops. They were most frequent between January and March (Fig. 3). The highest numbers of days with intense precipitation occurred in Recuay in 1997 (18) and in Huaraz in 1997 (13) and 2011 (14). Days with intense precipitation were generally rare, particularly during the first years of observations in Recuay (5 per year on average) and have increased to 9 or 10 events per year since 1978 (Fig. 4d). In several years, heavy precipitation days occurred during the sowing seasons in September and October with

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the potential for particularly negative consequences by washing out the seeds or by reducing the quality of the harvest, but the average number is less than one heavy precipitation day per 2 month interval (September, October) in Huaraz and Recuay. Again, the available data records do not confirm the perceived increases (Sect. 3.3) in heavy precipitation days during that period of the agricultural year. However, the available daily precipitation sums do not allow assessments on short term convective events with locally high rainfall intensities.

The transition from wet to dry conditions marked by the *onset day of the dry season* (criterion 2) towards the end of the agricultural year is centered around 17 May (earliest on 23 April in 1981; latest on 14 July in 1984, possibly an outlier caused by our algorithm as a consequence of unusually high precipitation values of around 10 mm within 3 days at the beginning of July). For Huaraz the dry season onset is found to be around 16 May, earliest on 23 April in 2005 and latest on 26 June in 1999, the latter again as a consequence of unusually high precipitation during the preceding three days (> 15 mm in total). For 1996–2012, the onset of the dry season is on average 10 days later in Recuay than in Huaraz, reflecting the slightly wetter climate there.

As with the onset of the wet season, there is quite a high year-to-year variability in the calculated onset dates of the dry season at both sites (±11.2 days for Recuay and ±12.8 days for Huaraz) but no significant trends towards earlier or later onsets or increases in year-to-year variability are detected. The high frequency of dry spells towards the end of the wet season only shows the typical transitional characteristics for approximately one month. These dry spells late in the agricultural year are considered to be a problem only if they appear unusually early, like in 1996.

The overall *length of the wet season* is plotted in Fig. 4a and shows a year-to-year variability between 180/204 days and 289/281 days (average 239/231 ±20.5/16.4 days) in Recuay (1965–2012)/Huaraz (1996–2012) respectively, but no detectable increase in year-to-year variability or significant trend toward longer/shorter wet seasons.

Mean total precipitation during the wet season was 810 mm for both sites with a markedly variability between 370/571 mm and 1200/1064 mm for Recuay/Huaraz

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(Fig. 4b) respectively. The total precipitation amount during the wet season shows no significant trend in the Recuay record.

Finally, we also tested the time series of monthly precipitation (Fig. A2) with the Mann–Kendall analysis at 90 % confidence level for possible trends in Recuay between 1981 and 2010. As shown in Fig. A2 (dashed red line) March precipitation increased significantly by approximately +36 mm decade^{-1} but did not contribute to a significant trend in total annual precipitation (Fig. A1). Enhanced precipitation in March may detrimentally affect corn wheat and native potato plants in their flowering and ripening phase, and harvesting "Yungay" potatoes gets more difficult under wet conditions.

5 Discussion

Multiple environmental changes are perceived by peasants living on the eastern slopes above the city of Huaraz in the upper Callejón de Huyalas. The most prominent changes – as expressed in interviews collected for this and for a former study (Mark et al., 2010) – were felt in the context of climate, such as the shrinkage of glaciers, decreasing dry season river discharge, or changes in weather patterns. These reports stimulate hypotheses to be tested against measured records. Whereas Mark et al. (2010) intensively investigated changes in (glacier-fed) river runoff, we here focused on temporal precipitation patterns in view of their impact on rain-fed agriculture.

Daily time series of precipitation yield interesting insights in rainfall characteristics of the last decades and allow the comparison with peasants' statements: starting in search of the light *puspa* – which is considered to moisturize the soil as a minimum precondition for sowing after the dry season – we found no evidence that precipitation values got lower in the month of August or September over the last decades (Fig. A2), neither in Recuay nor in Huaraz. However, as stated before, the temporal resolution and the accuracy of the measurement systems do not allow to derive robust statements from our data whether there were changes in the *puspa* over time or not. Another source of uncertainty is that closer to the Andean crest precipitation events during

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the dry season are generally more frequent than in the main valley where the Huaraz precipitation was measured (Niedertscheider, 1990).

Nevertheless, data presented in Fig. 2 show that the agriculturally relevant sowing period for potatoes typically starts in September and continues until mid of October. For most years the calculated onset date of the wet season and the dates for the first sowing conditions after the dry season fell into that period (Fig. 3). Yet, the pronounced year-to-year variability of these dates challenges agricultural success, especially in the absence of reliable precipitation forecasts. Furthermore, it is hardly possible to predict devastating dry spells following a couple of days or weeks with good sowing conditions. Our "hind-cast" detected several such potentially harming sequences (Fig. 3) even though we could not find long term changes in the dry spell frequency (Fig. 4c).

Overall, and despite no detectable trends in the total amount of precipitation during the wet seasons (Fig. 4b) nor any other trend, the high inter-annual variability of (1) the timing of the onset of the agricultural year (as determined by the first pronounced precipitation event) and (2) dry spells during the wet season, especially during the very sensible early phase of plant growing, kept rain-fed farming constantly challenging.

In the absence of adequate temporal data resolution, this study cannot give conclusive answers on the potential impacts of intense precipitation events, possibly accompanied by destructive hail and flooding. For daily rainfall sums we found neither a trend in the frequency of heavy precipitation days during the wet season, nor during September and October, the period recognized as most sensitive by the peasants.

We have not investigated thermal conditions but the perceived increase in the frequency of ground frosts in the early growing season (as stated by some farmers) contradicts increasing minimum temperatures as reported by Schauwecker et al., 2014. These increases are reported to be most pronounced in the dry and early wet season. Also the freezing level rose by 160 m from the 1960s to the 1980s, remaining constant afterwards.

To extend information about climate impacts on rain-fed agriculture beyond the results presented in this study, it would be desirable to analyze local extremes in tem-

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perature and also precipitation intensities based on data collected by onsite automatic weather stations with high temporal resolution in upcoming studies.

Potential impacts of future climate conditions are currently highly uncertain due to missing or unreliable data of high spatial and temporal resolution as required for investigating impacts on rain-fed agriculture in the complex Andean terrain (Sanabria et al., 2014). Further uncertainty is due to the questionable future evolution of the El Niño Southern Oscillation (e.g. Vecchi and Wittenberg, 2010) which effects the year-to-year climate variability in the Cordillera Blanca (e.g. Garreaud et al., 2009; Vuille et al., 2008).

Beyond climate there are several factors not investigated within this study that could have impacts on the small scale rain-fed farming in the study region. Neoliberal agrarian policies since the 1990s and the loss of manpower due to emigration, particularly of young community members (Crabtree, 2002; Lynch, 2012; Trivelli et al., 2009) are among the potential causes for the decrease in the traditional adaptive capacity of peasants in the Cuenca Auqui. Deforestation, the cultivation of water-demanding eucalyptus trees, land use change followed by soil erosion, and the change from traditional to industrial seed types are some of the manifestations of the manifold changes.

6 Summary

We investigated agricultural practices and peasants' perceptions about climate impacts on rain-fed farming in small settlements of the Cuenca Auqui in the Cordillera Blanca, Peru, and compared these with agro-relevant precipitation features derived from daily data recorded at neighboring stations. The most important agricultural crops are potatoes (native and industrial varieties), *Oca* and *Olluca*, as well as corn and wheat. Sowing and cultivation periods vary strongly along the elevation bands of the Cuenca Auqui.

Farmers and local experts concur in their statements that changes in the climatic conditions have detrimental effects on agriculture. This also corresponds generally to findings made by Mark et al. (2010). Overall they view rain-fed agriculture as having be-

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come more challenging in recent years/decades and believe the reasons are changed precipitation patterns with less rain in August and the early wet season, more variable onset dates and durations of wet and dry seasons, and more intense rainfall events. Increased frequency of temperature related ground frost was also reported.

Our precipitation analysis cannot confirm any precipitation changes but show high year-to-year variability in the onset dates of the wet season, the dates for the first sowing conditions after the dry season, and the number of heavy precipitation events per agricultural year. We also found that in several years pronounced dry spells occurred shortly after several wet days in the early cultivation season, encouraging the famers to sow too early.

In conclusion, the year-to-year variability in seasonal and total precipitation during the agricultural year generally poses challenges for successful rain-fed farming in the region but no trends at all can be seen in the available precipitation data. Potential effects of heavy precipitation events and trends in their frequency could only partially be addressed in this study due to the lack of adequate data.

The study also shows that there is often no easy way to perform interdisciplinary research on complex climate change impact issues and that, in turn, there is a strong need for further developing interdisciplinary approaches that analyze all factors of concern: environmental as well as sociopolitical. Identifying the driving factors of detrimental changes experienced and their interactions is definitely of high concern.

Author contributions. W. Gurgiser performed the precipitation analysis, and coordinated and merged the contributions. I. Juen prepared the precipitation data and assisted in preparing the manuscript. K. Singer carried out the interviews and the related analysis. S. Schauwecker assisted in preparing the precipitation data. M. Hofer advised precipitation downscaling attempts. W. Gurgiser, M. Neuburger and G. Kaser wrote the paper. All authors continuously discussed the methods and results, and developed the study further.

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Table 1. List of interviews of farmers in the communities of Cuenca Auqui.

Community	Estimated Population*	Altitude range of the cultivated area	Number of interviews	Gender	
				female	male
Los Pinos	95	3150–3450	7	3	4
Ichoca	464	3200–3750	13	6	7
Collyur	668	3250–4000	4	–	4
Paquiska	218	3400–4000	5	2	3
Jancu	135	3600–4000	8	1	7
Total	1580	3150–4000	37	12	25

* Source: Ministério de Salud (2013), Informe del Estado situacional de los sistemas de auga de consumo humano del ambito rural – Distrito de Huaraz, Lima, pp. 2–3.

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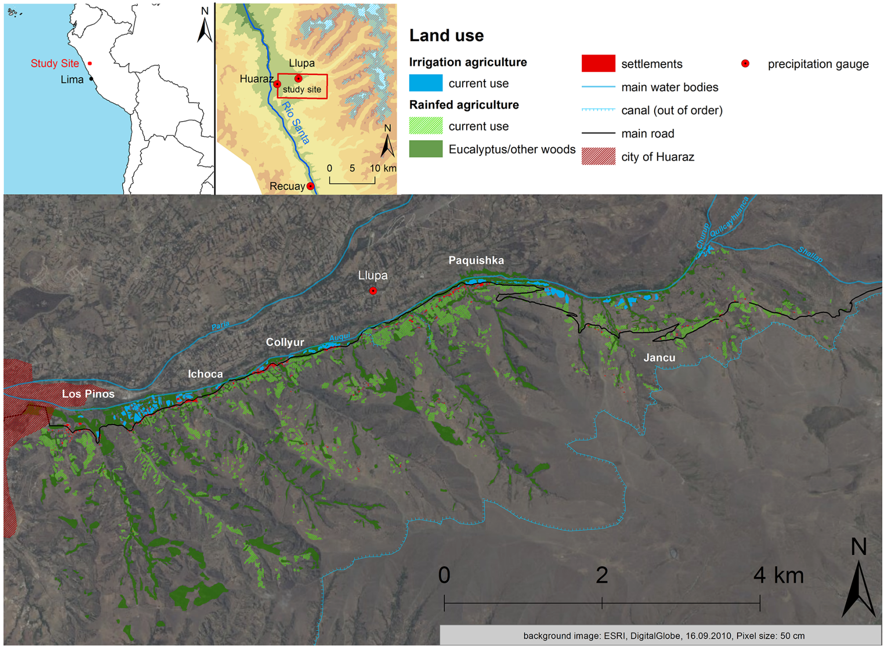

Figure 1. Map of study region located South of Rio Auqui.

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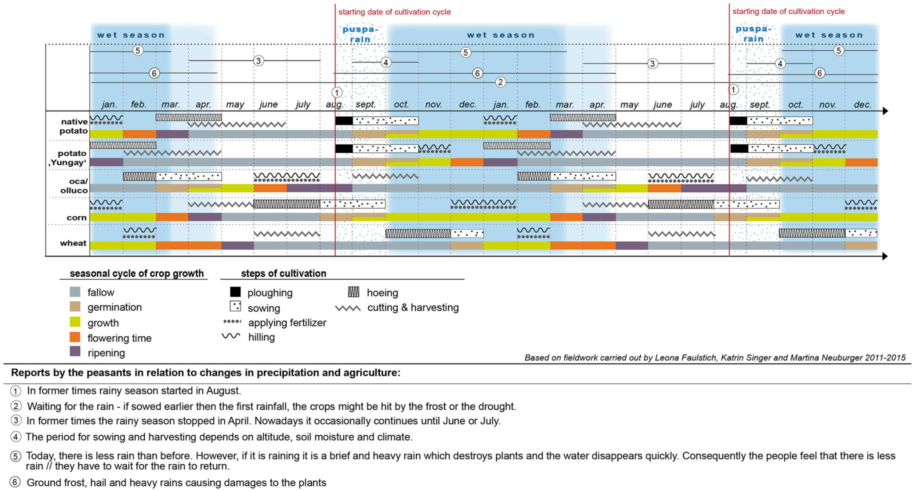

Figure 2. Agricultural calendar of the main crops used in the Cuenca Auqui.

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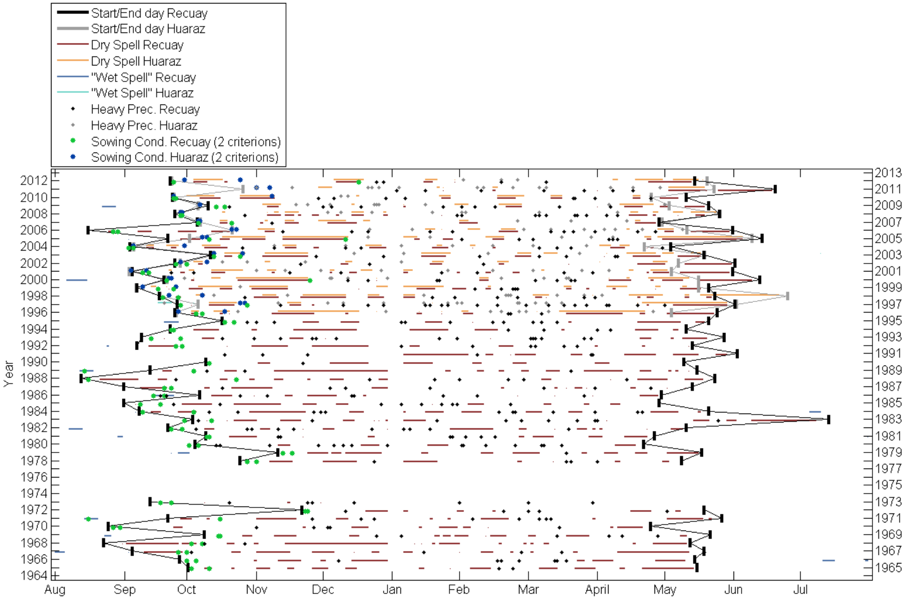

Figure 3. Precipitation features derived from daily precipitation sums based on measurements in Recuay (1964 to 2013 with gaps) and Huaraz (1996 to 2013), with the criteria described in Sect. 3.3. The y-axes show the calendar year in which each agricultural year (1 August to 31 July) starts.

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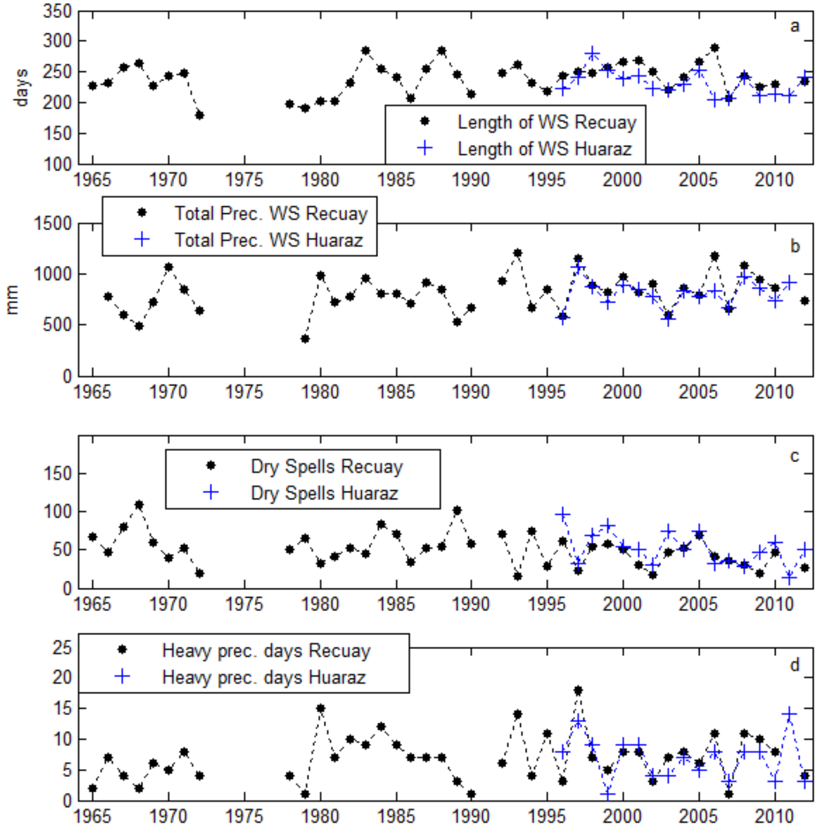

Figure 4. Time series of **(a)** the length of the wet season (for the agricultural years starting in the year shown on the *y* axis), **(b)** the total precipitation during the wet season. (For the exceptional year 1991 no wet season start could be calculated. Thus, we used the date for the first sowing conditions derived from criterion 3b as the start date of the wet season for this and the following subplots.) **(c)** The frequency of dry spells during the wet season until 1 May, and **(d)** the frequency of heavy precipitation days during the wet season.

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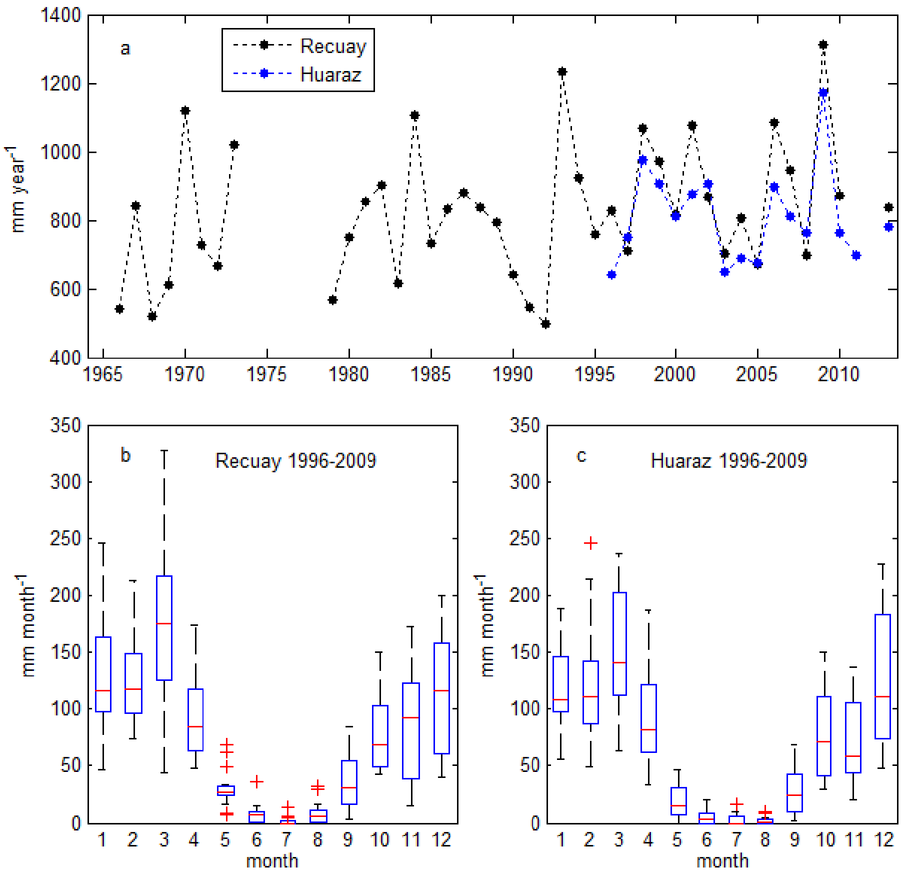

Figure A1. Annual precipitation sums in **(a)**, boxplots for monthly precipitation sums for the overlapping period 1996–2009 for Recuay **(b)** and Huaraz **(c)** respectively.

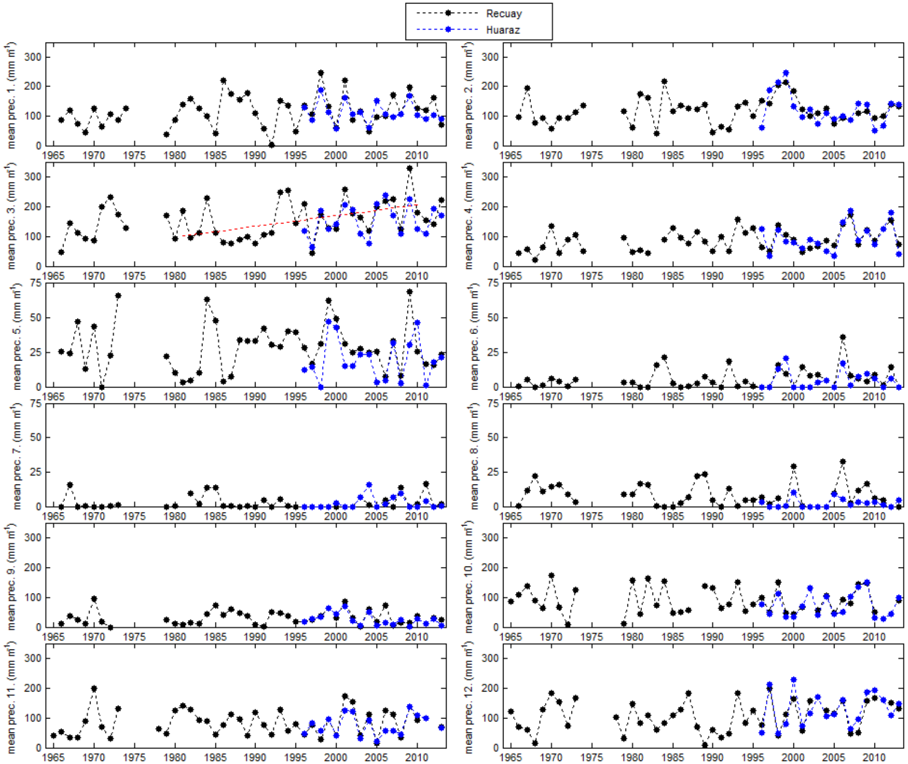

Figure A2. Monthly precipitation totals from Recuay and Huaraz time series. The number in the *y* label corresponds to the month. Be aware of the different *y* axis for month 5–8 (May to August). The red dotted line shows a significant trend.