Global and Planetary Change 119 (2014) 85–97

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Climate trends and glacier retreat in the Cordillera Blanca, Peru, revisited

S. Schauwecker [a,d,*], M. Rohrer [a], D. Acuña [b], A. Cochachin [c], L. Dávila [c], H. Frey [d], C. Giráldez [d], J. Gómez [e], C. Huggel [d], M. Jacques-Coper [f], E. Loarte [g], N. Salzmann [d,h], M. Vuille [i]

[a] Meteodat GmbH, Technoparkstr. 1, 8005 Zurich, Switzerland
[b] SENAMHI, av. Las Palmas s/n, Lima, Peru
[c] ANA, UGRH, Huaraz, Peru
[d] Department of Geography, University of Zurich, Winterthurerstr. 190, 8057 Zurich, Switzerland
[e] SERNANP, ANP Huascarán, Huaraz, Peru
[f] Institute of Geography, University of Berne, Hallerstr. 12, 3012 Berne, Switzerland
[g] Facultad de Ciencias del Ambiente, Universidad Santiago Antúnez de Mayolo, Huaraz, Peru
[h] Department of Geosciences, University of Fribourg, Chemin du Musée 4, 1700 Fribourg, Switzerland
[i] Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York, 1400 Washington Ave., Albany, NY 12222, USA

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 11 April 2014
Accepted 27 May 2014
Available online 2 June 2014

Keywords:
Cordillera Blanca
Glacier change
Climate change
Equilibrium-line altitude (ELA)
Precipitation
Air temperature

ABSTRACT

The total glacial area of the Cordillera Blanca, Peru, has shrunk by more than 30% in the period of 1930 to the present with a marked glacier retreat also in the recent decades. The aim of this paper is to assess local air temperature and precipitation changes in the Cordillera Blanca and to discuss how these variables could have affected the observed glacier retreat between the 1980s and present. A unique data set from a large number of stations in the region of the Cordillera Blanca shows that after a strong air temperature rise of about 0.31 °C per decade between 1969 and 1998, a slowdown in the warming to about 0.13 °C per decade occurred for the 30 years from 1983 to 2012. Additionally, based on data from a long-term meteorological station, it was found that the freezing line altitude during precipitation days has probably not increased significantly in the last 30 years. We documented a cooling trend for maximum daily air temperatures and an increase in precipitation of about 60 mm/decade since the early 1980s. The strong increase in precipitation in the last 30 years probably did not balance the increase of temperature before the 1980s. It is suggested that recent changes in temperature and precipitation alone may not explain the glacial recession within the thirty years from the early 1980s to 2012. Glaciers in the Cordillera Blanca may be still reacting to the positive air temperature rise before 1980. Especially small and low-lying glaciers are characterised by a serious imbalance and may disappear in the near future.

1. Introduction

The tropical Andes – and especially the Cordillera Blanca (CB) – have been recognized as a region highly vulnerable to climate change and the related glacier recession (e.g. Bury et al., 2010; Mark et al., 2010; Deutsch, 2012). Glaciers in this region act as a temporal water storage for precipitation falling as snow at high elevations in the wet season from about October to April. The stored water is partly released during the dry season, compensating for the lack of water due to scarce precipitation events between May and September (Kaser et al., 2003). The discharge from the glaciated catchments is used in the downstream settlements particularly for mining, agriculture, domestic consumption and hydropower (Vuille et al., 2008a). The disappearance of these natural reservoirs has a dominant impact on the water availability in the Rio Santa valley particularly during the dry season (Juen et al., 2007; Baraer et al., 2012). As outlined by Deutsch (2012), rural communities and poor urban neighbourhoods in the Santa watershed, which drains the western part of the CB, face a threat of losing access to clean water, adequate to meet their basic domestic and livelihood needs. It is therefore indispensable to understand the response of glaciers to a changing climate in order to develop and implement related adaptation measures.

This study focuses on climatic trends and related glacier changes in the CB in the Peruvian Andes. Glaciers in the tropical Andes have witnessed a strong retreat during the last decades

Abbreviations: AAR, accumulation area ratio; ANA, National Water Authority; ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer; CB, Cordillera Blanca; DJF, MAM, JJA, SON, abbreviations for seasons; DTR, daily temperature range; ECMWF, European Centre for Medium-Range Weather Forecasts; ELA, equilibrium line altitude; ERA, reanalysis at ECMWF; GDEM, Global Digital Elevation Map; GLIMS, Global Land and Ice Measurements from Space; NCAR, National Center for Atmospheric Research; NCEP, National Centers for Environmental Prediction; NOAA, National Oceanic and Atmospheric Administration; PACC, Programa de Adaptación al Cambio Climático en el Perú; PDO, Pacific Decadal Oscillation; SENAMHI, National Meteorological and Hydrological Service of Peru; SEPA, Southeastern Pacific Anticyclone; SPOT, Satellite Pour l'Observation de la Terre; UGRH, Glaciology and Water Recources Unit; WGMS, World Glacier Monitoring Service.

* Corresponding author at: Meteodat GmbH, Technoparkstr. 1, 8005 Zurich, Switzerland. Tel.: +41 44 445 34 20.
E-mail address: schauwecker@meteodat.ch (S. Schauwecker).

http://dx.doi.org/10.1016/j.gloplacha.2014.05.005
0921-8181/

(e.g. Kaser et al., 1990; Hastenrath and Ames, 1995; Kaser and Georges, 1997; Georges, 2004; Mark and Seltzer, 2005; Silverio and Jaquet, 2005; Raup et al., 2007; Vuille et al., 2008a; Rabatel et al., 2013; Salzmann et al., 2013). Small glaciers in the tropical Andes at low altitudes show a more pronounced retreat, as the current equilibrium line altitude (ELA) climbed up towards the upper reaches causing a reduction or even loss of the accumulation area (Rabatel et al., 2013).

Several studies focusing on climate trends in the tropical Andes and the CB have been published. Based on a large number of stations along the tropical Andes between 1°N and 23°S, Vuille and Bradley (2000) and later Vuille et al. (2008a) observed a significant warming of approximately 0.1 °C per decade between 1939 and 2006. They included station data from the network maintained by SENAMHI, however, they did not analyse temperature and precipitation trends for the region of the CB specifically. For the area of the CB, Mark and Seltzer (2005) reported a temperature increase of 0.39 °C per decade between 1951 and 1999 and 0.26 °C per decade between 1962 and 1999. They used data from the SENAMHI network from 29 and 45 stations for temperature and precipitation respectively, until 1998. They used temperature data to compute a trend for two time periods (1951–1999 and 1962–1999) and did not consider 30-year running trends as in the present work.

Precipitation changes are more difficult to document than temperature trends because of missing station records (Rabatel et al., 2013). In southern Peru and the Bolivian Altiplano, precipitation has decreased in the period 1950 to 1994, while station data indicate a slight increase for northern Peru for the same period (Vuille et al., 2003). Since precipitation is characterised by a large spatial variability, no clear pattern of increasing or decreasing precipitation can be found on a regional scale for the tropical Andes (Vuille et al., 2003). The understanding of local trends in meteorological variables is crucial to examine the glacier retreat in the CB. Therefore, trends of precipitation and air temperature in the CB are identified based on an extensive and unique in-situ data base. It is assessed how these local trends differ from general trends along the tropical Andes as published in e.g. Vuille et al. (2003) or Rabatel et al. (2013). The results are related to existing studies about linear temperature change in the CB such as from e.g. Mark and Seltzer (2005) and it is assessed how running 30-year trends varied in time.

The main objectives of this study can be summarized as follows: (i) Assessing recent trends in precipitation and near-surface as well as 500 hPa air temperature in the CB based on extensive in-situ measurements and reanalysis data with a focus on differences to the general trends in the tropical Andes. Additionally, it is examined how the running 30-year linear trends have changed in time since the 1960s and meteorological variables are compared to the upper-air zonal wind component during the austral summer and the Pacific Decadal Oscillation (PDO). (ii) Applying a novel approach to assess the increase in the freezing line altitude during precipitation days and to estimate the amount of precipitation needed to balance such an increase. (iii) Analysing the relation of precipitation and air temperature trends to observed glacier change using available mass balance measurements.

2. Study area

The CB is located between approximately 8°S and 10°S in the Ancash Region of Peru (Fig. 1), spanning roughly 180 km in length and 20 km in width. The highest peak in this mountain range is the southern summit of the glaciated Nevado Huascarán with an elevation of 6768 masl. Although the distance to the Pacific Ocean is only about 100 km and more than 4000 km to the Atlantic, this range marks the continental divide. The Río Santa drains the western part of the CB, flows to the northwest into the Pacific and separates the CB from the Cordillera Negra in the west, which reaches altitudes of about 5200 masl. The western foothills of the Cordillera Negra descend to the Pacific coast.

The study site lies in the outer tropical zone and exhibits a typical climate for this region with a pronounced seasonality mainly in precipitation, cloud cover and specific humidity. The pronounced dry season spans from May to September, while the wet season is dominant in austral summer (Kaser and Georges, 1997). About 70 to 80% of the total annual precipitation falls within the pronounced wet season (Kaser et al., 1990). The seasonal distribution of precipitation is caused by the onset and demise of the South American monsoon system (Garreaud et al., 2009). During the wet season, precipitation mainly results from easterly winds transporting moisture from the Amazon Basin (Garreaud et al., 2003). During the dry months, precipitation in the valley bottom is almost zero, as plotted in Fig. 2a. Precipitation at high elevations in the CB is more abundant. In contrast to the strong differences in seasonal precipitation, the area is characterised by small seasonal temperature variability (Fig. 2b). Air temperature shows stronger diurnal than seasonal variability. The diurnal variability is higher in the dry season due to the lower humidity and cloud cover.

The mountain range of the CB is the largest glacierized area in the tropics, containing about one quarter of all tropical glaciers (Kaser and Osmaston, 2002). Several studies about glacier retreat in the CB have been published and they show consistently that total glacier area diminished heavily since 1930, as compiled in Fig. 3. For 2003, Racoviteanu et al. (2008) document an area of 596.6 $km^2 \pm 21\ km^2$, whereas in 1930 the glacierized area was still around 800 to 850 km^2 (Georges, 2004).

3. Data

3.1. Meteorological station data

Station data were provided by the National Meteorological and Hydrological Service of Peru (SENAMHI), which maintains a national network of climate stations. The network consists of over 100 stations in the Ancash and the surrounding regions of which several are located in the CB. Additional daily time series are available from a network of six stations maintained by the Glaciology and Water Resources Unit (UGRH) of the National Water Authority (ANA) in Huaraz. The latter time series are available only since early 2000, which is too short of a period to compute climatically meaningful trends. However, this set provides important and unique information about air temperature in the last decade at high altitudes of more than 4000 masl. Mean monthly precipitation data are used from the network of Electroperú S.A. to calculate vertical precipitation gradients.

The available variables are daily mean, minimum and maximum temperature and total daily precipitation. Some stations also provide other variables like dew point, relative humidity, air pressure, wind speed and direction. Due to the large uncertainty associated with the data, these variables have not been considered in the present study. The data are available through a data portal, originally developed in the framework of the Swiss–Peruvian initiative for Climate Change Adaptation in Cusco and Apurimac (Programa de Adaptación al Cambio Climático en el Perú, PACC) from the Swiss Agency for Development and Cooperation (SDC), as described in Schwarb et al. (2011). For the present study, the data portal has been modified and contains also data of the CB now.

Fig. 1 shows the locations of the available stations and Table 1 provides the details. The three highlighted stations Recuay, Artesoncocha and Buena Vista in Fig. 1 were used to reconstruct reference stations. For the trend analyses in this work, the area is separated into two zones: Coast and Cordillera. The coastal region is defined for elevations up to 400 masl. For the Cordillera Region, only stations with a high correlation to the final reference station are considered. The lowest station with temperature data is Huari (3025 masl) and the lowest with precipitation data is Pampa Libre (1960 masl).