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Editorial

Current status of Andean glaciers

1. Introduction

Glaciers are sensitive indicators of climate variability and in turn they can also affect climate by means of complex feedback mechanisms. After the Little Ice Age (LIA), a cold climate period reported mainly for the Northern Hemisphere that culminated in mid-late 19th century, glaciers started retreating on a global scale. Although some glaciers have advanced over the last century in some regions of the world, overall the glaciers show a clear retreat, primarily as a response to global warming. In this current warming scenario, glacier recession has been recognized as a key variable for climate change in terms of public awareness (IPCC, 2001).

Worldwide, glaciers and ice sheets store 68.8 m of global sea level (IPCC, 2001) and ~70% of the surface freshwater on Earth, the major part being concentrated in Antarctica and Greenland. Although the total sea level equivalent of South American glaciers to sea level is small (~3 cm), their contribution to sea level rise in terms of unit area is significant, being even larger than the contribution of Alaskan glaciers (Rignot et al., 2003).

Except for a few cases in Patagonia and Tierra del Fuego, glaciers in South America have shown a generalized retreat and wasting, in agreement with the global trend. In recent decades an enhanced retreat trend is evident. Small glaciers are particularly vulnerable to wasting, several of them having disappeared since the LIA and many others being in the final stages of complete wasting, for, e.g., glacier Chacaltaya in Bolivia is predicted to vanish completely within 15 years (Ramirez et al., 2001).

Glaciers in South America are critically important for water resources, including domestic, agricultural and industrial uses, particularly in equatorial, tropical and subtropical latitudes. Enhanced melt should cause runoff increase in the short term but decreased availability in the long term. Andean glaciers also cause geological hazards throughout the Andes, such as lahars related to volcanic eruptions, rock/ice avalanches, debris flows and glacier floods (e.g., Ames, 1998; Carey, 2005; Corripio and Purves, 2005) related to gravity, climatic processes and ice dynamics, a phenomenon which is also occurring on other high mountain areas (e.g., Ageta et al., 2000; Salzmann et al., 2004).

The 1st Symposium on Mass Balance of Andean Glaciers was held in Valdivia, Chile, in March 12–14, 2003, under the sponsorship of the International Commission on Snow and Ice (ICSI), the International Glaciological Society (IGS), Institut de Recherche pour le Développement (IRD) and Centro de Estudios Científicos (CECS), in order to present advances and current understanding related to mass balance and glacier changes of Andean glaciers of South America. The symposium ensued from the ICSI-sponsored symposium on “Glaciers of the Southern Hemisphere”, held in Melbourne, Australia, in July 1997 (Global and Planetary Change, Vol. 22).

The following topics related to mass balance of Andean glaciers were addressed in the symposium, with a total of 59 contributions covering glaciers of all of South America, except for Venezuela:

- mass balance measurement techniques;
- mass balance monitoring programs;
- recent glacier variations and their relation with climate; and
- glacio-hydrological studies and the relation with glacier mass balance.

The 1st Mass Balance Workshop on Andean Glaciers was also held concurrent to the symposium, including an attendance of 62 people, with the goal of planning a future mass balance network for Andean glaciers at a continental scale.

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A review of the main advances in Andean glaciology is presented, based on the collection of 20 papers published in this volume.

2. Systematic long-term mass balance observations in the Andes as a high-priority need in worldwide climate-related glacier observation programs

Fluctuations of mountain glaciers and ice caps are key variables for early-detection strategies in global climate-related observations (IPCC, 2001). Corresponding observations have been systematically carried out for more than a century in various parts of the world and are now coordinated by the World Glacier Monitoring Service (WGMS) of ICSI/IAHS (International Commission on Snow and Ice/International Association of Hydrological Sciences) as a service of FAGS/ICSU (Federation of Astronomical and Geophysical Data Analysis Services/International Council for Science). Since the beginning of observations, however, various aspects involved have changed in a most remarkable way. It is becoming increasingly clear that the worldwide and fast glacier shrinkage at the century time scale is of non-cyclic nature. There is definitely no more question of the originally envisaged "variations périodiques des glaciers" (Forel, 1895). Under the influence of human impacts on the climate system (enhanced greenhouse effect), dramatic scenarios of future developments – including complete deglaciation of entire mountain ranges – must be taken into consideration. Such scenarios may lead far beyond the range of historical/Holocene variability and most likely introduce processes (extent and rate of glacier vanishing, distance to equilibrium conditions) without precedence in the recent history of the earth.

An international network of glacier observations such as the WGMS of ICSI/IAHS and the FAGS/ICSU, together with its Terrestrial Network for Glaciers (GTN-G; Haeberli et al., 2000) within the Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS), is designed to provide quantitative and understandable information concerning questions on processes, the detection of change, model validation and environmental impacts in a transdisciplinary knowledge transfer to the scientific community, policy makers, the media and the public. This difficult but increasingly important task makes adequate perception of glacier changes a challenge of historical dimensions. Observational strategies established by expert groups within international monitoring programs build on advanced process understanding and include extreme perspectives. These strategies make use of the fast development of new technologies and relate them to traditional approaches in order to apply integrated, multilevel concepts (in situ measurements to remote sensing, local process oriented to regional and global coverage), within which individual observational components (length, area, volume change) fit together, enabling a comprehensive view (Haeberli et al., 1998, 2000, 2002).

The Terrestrial Observation Panel for Climate (TOPC) has created a Global Terrestrial Network for Glaciers (GTN-G) managed by WGMS in order to meet the needs of the GTOS and the GCOS of WMO (World Meteorological Organisation), ICSU, IOC (International Oceanographic Commission), FAO (Food and Agriculture Organisation), UNEP (United Nations Environment Programme) and UNESCO (United Nations Educational, Scientific and Cultural Organisation). This network was developed by matching the WGMS sites against the concept of a Global Hierarchical Observing Strategy (GHOST). According to a corresponding system of tiers, the regional to global representativeness in space and time of the records relating to glacier mass and area should be assessed by more numerous observations of glacier length changes as well as by compilations of regional glacier inventories repeated at time intervals of a few decades—the typical dynamic response time of mountain glaciers. The following is a list of the individual tier levels, which are further described in Haeberli et al. (2002):

Tier 1. Multi-component system observation across environmental gradients.
Tier 2. Extensive glacier mass balance and flow studies within major climatic zones for improved process understanding and calibration of numerical models.
Tier 3. Determination of regional glacier volume change within major mountain systems using cost-saving methodologies.
Tier 4. Long-term observations of glacier length change data within major mountain ranges for assessing the representativeness of mass balance and volume change measurements.
Tier 5. Glacier inventories repeated at time intervals of a few decades by using satellite remote sensing.

The Andes are identified as one of the most critical parts in the existing mass balance network as they not only cover a broad range of climatic conditions for potential two-tier programs but also form the one and only meridional transect in the southern hemisphere within the glacier network of GTOS and WGMS. The continuation of ongoing and the build-up of new long-term glacier mass balance observations are therefore strongly encouraged.

3. New advances in Andean glaciology

A brief review of the main advances in the glaciological knowledge of Andean glaciers is made based on the 20 papers published in this issue. More than half of the papers refer to Patagonia. No papers deal with glaciers in Venezuela, Colombia or Ecuador. The geographical distribution of papers is as follows (see Fig. 1):

Global and hemispheric: 2 papers
South America: 1 paper
Peru: 3 papers
Bolivia: 1 paper
Central Argentina: 1 paper
Southern Chile: 1 paper
Patagonia and Tierra del Fuego: 11 papers.

Although some papers were clearly multidisciplinary, they could be classified according to their different thematic topics as follows: glaciological mass balance methods (2 papers); hydrological methods (2 papers); glacial geology (2 papers); remote sensing, Geographical Information Systems (GIS) and geodesy (7 papers); climatology and meteorology (4 papers); ice flow modelling (1 paper); and biological methods (2 papers).

3.1. Glaciological mass balance methods

The fact that only two papers addressing glacier mass balance series were presented points to the serious gap in the observation of South American glaciers. As was widely established throughout the symposium and is clearly pointed out in the two reviewed papers, the glaciers are retreating overall, giving a clear signal of changing climate. Their impact on runoff and water availability is crucial in many cases and shows large changes and retreating glaciers give occasionally cause to hazardous situations. Still, the climate drivers and glacier mass balance remains subject to reconstruction and deductive estimates in most cases. The mass balance papers by Leiva et al. (2007-this issue) and by Strelin and Iturraspe (2007-this issue) illustrate two of the very few exceptions of glacier mass balance measurements in the Andes. Both are carried out on small glaciers and show, thus, a high variability in annual net mass balance. Beyond showing the troublesome filling of gaps between the measured values, Leiva et al. point out the importance of glacier contribution to runoff as well as the ability of mass balance series for the assessment and projection of regional water availability. Strelin and Iturraspe explore the possibility of glacier mass balance measurements for understanding the climate role in reconstructed glacier variations in a barely explored area in Tierra del Fuego, even though measurements exist so far for a very short period of a few years. Both examples show the possibilities provided by measured mass balance series but they also indicate the problems in carrying out such measurements under the challenging logistical difficulties and under unreliable financial support.

3.2. Hydrological methods

Simultaneous accumulation and ablation during the wet season make tropical glaciers particularly sensitive to climate change. Glacier melt has a strong impact on the seasonal as well as the inter-annual variation of runoff in the high altitude catchments of the Andes. Two papers involve the runoff of glacierized tropical catchments and link melting of a glacier with mass balance estimates. Sicart et al. (2007-this issue) present the measurements undertaken since 1991 on a small glacier, Zongo Glacier, in Bolivia. The authors compare the hydrological and glaciological methods in order to estimate the mass balance of the glacier. Juen et al. (2007-this issue) show the possibilities provided by a runoff model based on an extended vertical balance profile model developed for low latitude circumstances, at Llanganuco basin in the Peruvian Cordillera Blanca, where monthly runoff data are used exemplarily for the model applications.

For the Zongo Glacier, Sicart et al. (2007-this issue) report that the hydrological budget is less than the glaciological balance, but both methods reproduce similar inter-annual variations. Sicart et al. conclude that hydrological budgets are too low due to the catch deficiency of rain gauges and the absence of precipitation measurements at high altitudes. Juen et al. (2007-this issue) simulate future runoff based on different IPCC climate change scenarios. Mean annual total runoff remains almost unchanged but the seasonality is amplified: dry season runoff is reduced due to a decreasing amount of glacier melt, although direct runoff increases on larger glacier free areas. Both papers point out the interest of undertaking simultaneously hydrological and glaciological programs in order to validate methods for present mass balance estimates and for prediction of climate change impacts in high mountains.

3.3. Glacial geology

The scarcity of data concerning the timing and nature of climatic shifts from the Southern Hemisphere is a major

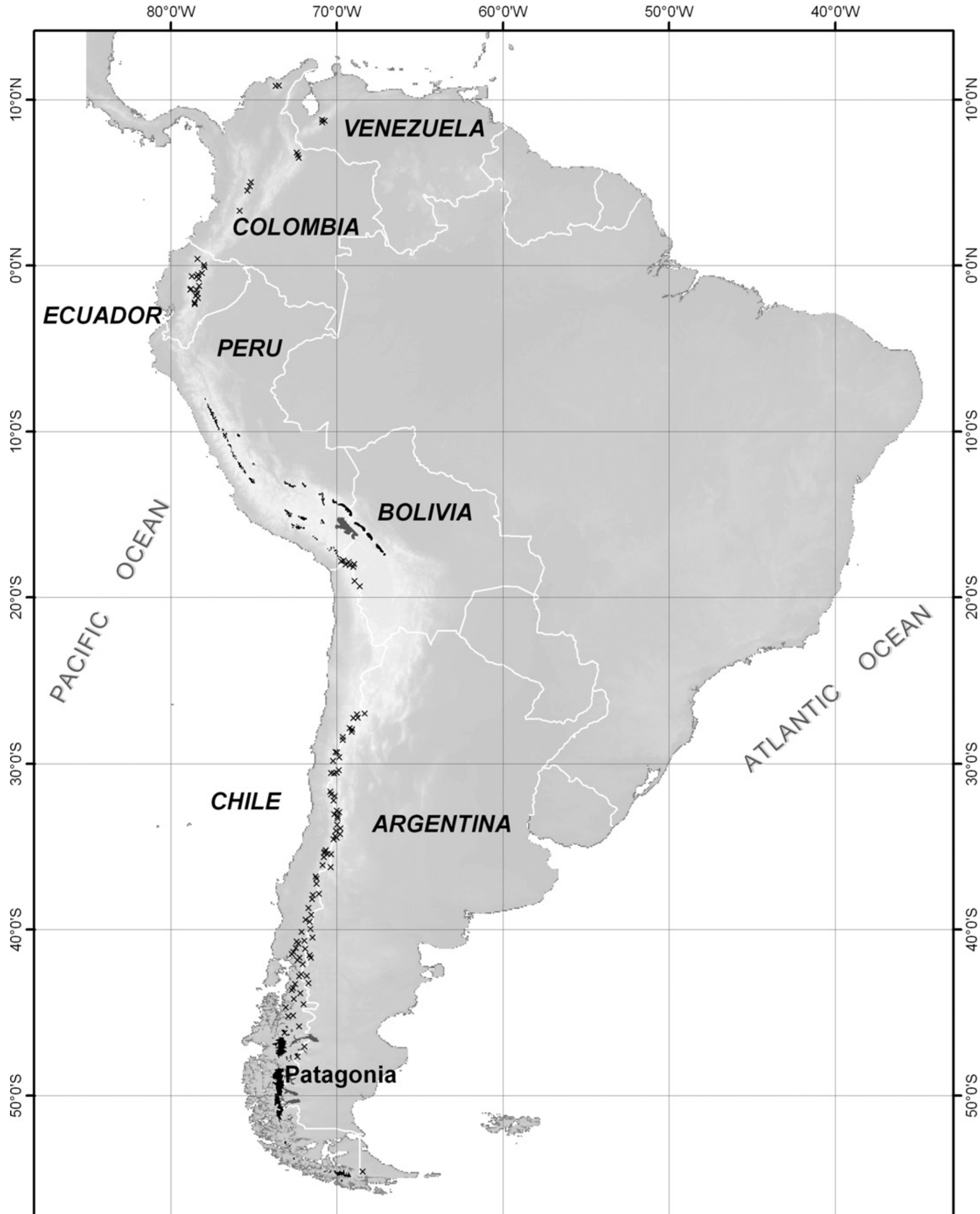

Fig. 1. Map of the glacier distribution in South America. Elevated areas are represented in white, while low areas are shown in light grey, as adapted from an anaglyph representation of SRTM elevation data (http://www2.jpl.nasa.gov/srtm/southAmerica.htm#PIA03389image). Single glaciers are shown as crosses, while glacier bodies are shown in black. Major lakes are shown in dark grey. North of 46°S the location of glaciers was adapted from USGS (1999), except for the region between 20°S and 26°S where no glaciers are assumed to exist since previously described glaciers are most probably only snow patches. In the area south of 46°S the location of glaciers was compiled directly from Rivera et al. (2007-this issue), Schneider et al. (2007a-this issue), Strelin and Iturraspe (2007-this issue) and available visible satellite imagery. Approximate glacier areas for tropical South America are 1.8 km^2 for Venezuela, 87 km^2 for Colombia, 90 km^2 for Ecuador, 1780 km^2 for Peru and 534 km^2 for Bolivia, with a subtotal area of 2492.8 km^2 (Kaser, 1999; Kaser and Osmaston, 2002). For Chile and Argentina the approximate glacier area is 23,300 km^2, with more than 85% located in Patagonia and Tierra del Fuego (Naruse, 2006).

problem in palaeoclimatology. This is important to understand the timing and effects of climatic changes, and also to evaluate the synchronicity between the hemispheres. There are few detailed studies from the Southern and Northern Patagonian ice fields but the available evidence suggests that the outlet glaciers of this region are extremely sensitive to climatic changes. Two papers study palaeoecological constraints in order to improve the knowledge on regional and global control on glacier recession. Kilian et al. (2007-this issue) investigate Late Glacial to Holocene changes along a 120-km-long fjord system in the southernmost Andes (53°S). They make a special emphasis on latitudinal shifting of the westerlies and its impact on ice retreat. Harrison et al. (2007-this issue) focus on glacier fluctuations during and after the Little Ice Age in the Northern Patagonian Ice Field. One conclusion of Kilian et al. is that the small present-day ice cap of Gran Campo Nevado has reacted more sensitively and partly distinctly to climate change, compared to the Patagonian ice fields. Harrison et al. find largely synchronous glacier recession on the western and the eastern Northern Patagonian Ice Field. They argue that present ice-field-wide glacier recession represents a response to post-Little Ice Age warming. In this part of the South American continent, the climate forcing overrides second-order controls on glacier behavior such as the nature of the terminus environment.

3.4. Remote sensing, GIS and geodesy

The majority of the papers submitted to this special issue dealt with remote sensing and Geographical Information Systems methods for obtaining mass balances, areal and frontal changes, volumetric changes, updating glacier inventories and classifying the surface of the glaciers. Traditional techniques such as photogrammetry are still in use in both approaches, analogue (Bown and Rivera, 2007-this issue) and digital (Schneider et al., 2007a-this issue). New techniques such as laser altimetry (Keller et al., 2007-this issue) and new data sets such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) derived DEMs (Racoviteanu et al., 2007-this issue; Rivera et al., 2007-this issue) and Interferometric Synthetic Aperture Radar (InSar) data (Bamber and Rivera, 2007-this issue) are becoming more relevant, especially for areas commonly affected by bad weather conditions precluding cloud free images, and where logistic constrains restrict the accessibility for direct measurements.

In spite of all these recent technological and scientific advances regarding Andean glaciology, there are still many areas poorly studied, where even glacier inventories have not been completed or updated. Addressing this problem, a couple of papers deal with glacier inventories and areal changes in Patagonia. In the Northern Patagonia Ice Field, Rivera et al. (2007-this issue) completed and updated the glacier inventory, detecting since 1979 an area shrinkage of 140 km^2 or 3.4% of the total initial surface. In Gran Campo Nevado and the southern portion of Peninsula Muñoz Gamero, Schneider et al. (2007a-this issue) inventoried 252.5 km^2 of ice which has suffered an estimated areal loss of 2.4% since 1942. This new inventory is 26% greater than the previous estimation made by Lliboutry (1956), representing a clear improvement of our knowledge from this remote region. In Perú, Racoviteanu et al. (2007-this issue) updated the glacier inventory of Nevados de Coropuna, obtaining a total area of 60.8 km^2 in year 2000, yielding a total reduction of 27% of the existing ice area in 1962.

Apart from frontal and areal changes, very little is known about ice volumetric changes in the Andes. The main problem for accounting elevation changes in this region is the lack of accurate glacier surface topography. Most of the Andean glaciers have been mapped using aerial photogrammetric procedures without enough control points, most of them without contrast on snow covered surfaces. As a result, the surface topographies exhibit vertical errors that are often higher than glacier elevation change signals (for a discussion on this topic, see the paper by Bamber and Rivera, 2007-this issue). However, the use in recent decades of new technologies, such as GPS, laser altimeters (airborne and satellite) and DEM generation from satellite images (ASTER, SPOT, InSar), has improved the accuracy and coverage of surface topography maps, being possible to measure ice elevation changes, by comparing these more accurate and recent data sets to old and mostly inaccurate maps. This type of analysis was done in several areas: in Nevado Coropuna of Peru by Racoviteanu et al. (2007-this issue) who compared Shuttle Radar Topography Mission (SRTM) data to ASTER derived DEMs; in the Chilean Lake District, where Bown and Rivera (2007-this issue) compared the surface topography of Glaciar Casa Pangue between 1961 and 1998; in the Northern Patagonia Ice Field (NPI) where Rivera et al. (2007-this issue) generated a DEM based upon ASTER images and compared these data to photogrammetrically derived DEMs based upon aerial photographs of 1975; in the Southern Patagonia Ice Field (SPI) where Bamber and Rivera (2007-this issue) accounted for elevation changes on Glaciar Chico based upon DEMs and GPS data from different dates and with different accuracies; and on Glaciar Tyndall of the SPI where Keller et al. (2007-this issue) used laser altimetry data compared to previous DEMs obtaining a mean thinning rate of −3.1 ± 1.0 m/

year for the ablation area of the glacier, with a maximum of −7.7 ± 1.0 m/year near the freshwater calving front.

Ice elevation changes measurements illustrated above are an important step toward a remote sensing approach for measuring the mass balance of the glaciers. Due to the economical, logistical and personnel restrictions of direct measurements of mass balance, indirect approaches are highly welcome in the Andes, specially if remote sensing techniques are validated with ground truth data and error assessments are completed for each data set.

Several methodological approaches for measuring glacier mass balance have been shown in this special issue. A detailed description of these methods was compiled by Bamber and Rivera (2007-this issue), including the use of the geodetic method based upon comparison of surface topographies from different dates and the use of the component approach which analyses ice fluxes at a gate of a glacier compared to the accumulation and ablation taking place above this gate. This second approach has been widely used in Antarctica where a grounding line can be detected in many glaciers and can serve as an ideal gate, which is not the case for the Andes. Apart from this problem, little is known about the accumulation or ablation processes taking place in the Andes because most of the direct measurements have been undertaken at the lower ends of the glaciers and very few campaigns are conducted to the accumulation areas, particularly in Patagonia. For these more inaccessible reaches of the Andean glaciers, remote sensing techniques, such as the analysis of Landsat images presented by De Angelis and Skvarca (2007-this issue), could improve our understanding of snow characteristics, snow accumulation and spatial distribution of grain sizes.

The use of remote sensing, GIS and geodesy techniques is widely spread among glaciologists working in the Andes, with satellite image data available free of charge for many areas thanks to global programs such as GLIMS (Global Land Ice Measurements from Space) and GLCF (Global Land Cover Facility). However, most approaches are traditional, and very little has been done with radar satellite images and InSar techniques, being imperative to work with new data sets such as IceSat, ERS, ENVISAT and RADARSAT. These techniques are not the panacea for solving the Andean glaciological problems but are increasingly necessary for a better understanding of our glaciers.

3.5. Climatology and meteorology

The contributions from the viewpoint of meteorology and climatology cover a wide range of topics from a hemispheric perspective (Fitzharris et al., 2007-this issue) to the application of point energy balance calculations on an individual glacier in Patagonia (Schneider et al., 2007b-this issue).

Fitzharris et al. (2007-this issue) analyze glacier response to Southern Hemispheric (SH) climate forcing by comparing glacier changes of the Southern Alps of New Zealand and in the Andes at a time scale of decades. They find strong indications that retreat phases of glaciers of the Patagonian ice fields and the Southern Alps and advance phases of tropical glaciers in South America are linked to weaker westerlies, blocking events in the southeast Pacific and a higher frequency of La Niña events. However, other studies show that weaker westerlies and enhanced blocking in the southeast Pacific are linked to El Niño conditions (e.g., Renwick, 1998; Turner, 2004). Also, the effect of ENSO on glaciers in southernmost Patagonia and on Tierra del Fuego may well be different from the effect on glaciers in central Chile and Argentina and the Patagonian ice fields due to the complex pattern of precipitation associated with shifts of SH westerlies (Schneider and Gies, 2004).

Bown and Rivera (2007-this issue) also give an important example of distinct local circumstances of glacier climate interactions, showing that variations of the glacier mass balance within the Chilean Lake District is not directly linked to measured surface temperature trends because surface cooling reported in this region is accompanied by upper air warming during recent decades. They relate the decrease in measured precipitation to enhanced frequency and strength of El Niño events. However, this would be in contradiction to the reasoning that enhanced El Niño events foster an increase of precipitation over coastal areas of south-central Chile north of approximately 45°S (e.g., Aceituno, 1988; Grimm, 2000). In this respect, both contributions (Fitzharris et al., 2007-this issue; Bown and Rivera, 2007-this issue) open new and important perspectives to debate the impact of SH circulation patterns on glaciers in various parts of South America.

A straightforward scheme for the computation of the space and time evolution of equilibrium-line altitudes along the Andes from 10°N to 50°S latitude is presented by Condom et al. (2007-this issue). Although the formulation is based on observations from tropical and subtropical glaciers only, it returns meaningful results for the whole range of locations and climates along the Andes and will probably open the door to a series of important studies dealing with palaeoclimatic and future glacier scenarios along the Andes.

Rasmussen et al. (2007-this issue) use reanalysis data to examine the relative influence of upper air conditions on the Patagonian ice fields by applying a moisture flux model to the westerly air flow over the Cordillera. The results reveal that the positive trend in temperature over the last 4 decades resulted in a shift from snow to rain of approximately 5% of the precipitation while annual melt increased in the ablation areas by approximately 0.5 m water equivalent per year. This is in excellent agreement with other studies showing strongly negative mass balances of the Patagonian ice fields during this period (e.g., Rignot et al., 2003).

An evaluation of the energy balance in the ablation zone during the summer season at the Gran Campo Nevado Ice Cap in the Southernmost Andes is provided by Schneider et al. (2007b-this issue). They demonstrate that the sensible heat flux is of great importance in this extremely humid environment where on average it is larger than the radiation balance. According to this study, ablation during summer can be estimated very well using air temperature and wind velocity as proxies.

3.6. Ice flow modelling

Studies on ice flow modelling are critically important for understanding the present controls on glacier behavior, modelling past fluctuations and projecting future changes. In spite of this, only 1 paper (Thomas, 2007-this issue) presented at the symposium dealt with ice flow modelling. The work of Thomas tackles the relevant problem of up-glacier transmission of longitudinal stresses over large distances in calving glaciers and its effect on glacier stability. This has major implications for the modelling of glacier mass balance, determining the time and dynamic response of glaciers to changes such as the collapse of ice shelves, as is already happening in Antarctica and has resulted in substantial acceleration of inland glaciers (e.g., Rignot et al., 2004). Calving glaciers in Patagonia therefore provide an adequate model for studying the effect of frontal perturbations in upglacier flow in larger ice shelf-glacier or ice shelf-ice sheet systems. A force-perturbation model is used by Thomas for calculating the effect of tides on glacier strain rates. The model is applied to the fast-moving Glaciar San Rafael, Northern Patagonia Ice Field, showing that the existing tidal amplitudes of ±0.8 m could cause a variation in frontal velocities of ±2 cm h^{-1} about its average value of 75 cm h^{-1}, with a dynamic effect that could reach up to 20 km inland.

3.7. Biological methods

Biological methods can be a powerful complement to glaciological studies, adding new information that would otherwise not be possible to obtain. In this regard, lichenometry is a well-proven method for establishing moraine ages extending up to several thousand years. Solomina et al. (2007-this issue) present a successful combination of lichenometric and geomorphic studies at Cordillera Blanca, Peru, for dating ages of Little Ice Age moraines. The chronologies were established by recalibration of the growth rate of *Rhizocarpon* subgenus *Rhizocarpon* growth curve. Deposition ages of the main terminal and lateral moraines on the western Cordillera Blanca were dated between AD 1590 and AD 1720, showing good correlation with cold and wet periods in the tropical Andes derived from ice core data. Lichenometric data also showed less prominent advances between AD 1780 and AD 1880.

A recent method for dating firn and ice cores is the measurement of algal biomass contained within the glacier, which is assumed to attain minimum values in winter and increase during the summer. Kohshima et al. (2007-this issue) apply this novel method for dating annual layers in a 45.97-m-long ice core from Glaciar Tyndall, Southern Patagonia Ice Field. Algal cells found near the surface belonged to *Chloromonas sp.* and an unknown green algal species with concentrations that deceased rapidly below the upper 3 m, probably due to melt water elution and/or biological decomposition. In spite of dampening of seasonal cycles at depth, meaningful values of algal biomass could be detected throughout the core, with an estimated net annual accumulation rate of 12.9 m a^{-1} w eq. from winter 1998 to winter 1999, and 5.1 m w. eq. from the beginning of winter to December 1999. Although these large accumulation rates are far larger than previous rates obtained from other firn cores in Patagonia, they agree with $\delta^{18}O$ and D-excess values interpreted from the same core (Shiraiwa et al., 2002) and are similar to estimates from meteorological and hydrological models (e.g., Escobar et al., 1992).

4. Conclusions and recommendations

The current knowledge and new advances in Andean glaciology presented at the 1st Symposium on Mass Balance of Andean Glaciers shows that glaciers in South America have experienced a strong generalized retreat and thinning, especially in recent years, in agreement with the regional and global warming trend. Small glaciers are wasting rapidly. Enhanced melt is likely to result in short-term increase of runoff, but in the long-term changes in runoff may occur which could severely affect the availability of water resources, particularly during dry periods. Glacier hazards such as outbursts of ice- and moraine-dammed lakes will certainly change and possibly increase. In spite of the relevance of glaciers in a changing climate, the symposium has established that mass balance studies are critically missing in many areas of the Andes. More and detailed glacier inventories are needed, together with data on glacier fluctuations and mass balance. As a result of the Valdivia symposium and accompanying workshop a Snow and Ice Group for Latin America and the Caribbean (SIG-LAC) was created under the auspices of the International Hydrological Programme (IHP) of UNESCO. One of the main tasks of the Group is the creation of an Andean glacier monitoring network (A-GMN), established in close collaboration with ICSI, IRD (Institut de Recherche pour le Développement)—France, the University of Innsbruck, Austria and organizations from all participating Andean countries (except Venezuela so far), and including Mexico as well. The A-GMN is based on current monitoring programs, the need for critical new data covering existing gaps and logistic considerations. The Valdivia symposium and workshop were followed by the Second Symposium on Mass Balance of Andean Glaciers, organised by INRENA (Instituto Nacional de Recursos Naturales, Peru) and IRD (Institut de Recherche pour le Développement, France), and co-sponsored by ICSI and its mother organization, the International Association of Hydrological Sciences (IAHS), held in Huaráz (Peru) from 6 to 9 July 2004, with the proceedings having been published in a special section of Hydrological Sciences Journal (Coudrain et al., 2005). A year later, during the VIIth IAHS Scientific Assembly held in Foz do Iguaçu (Brazil) from 3 to 9 April 2005, one symposium was held on snow-glacier hydrology and one workshop on glaciology, the proceedings of which will be published as a IAHS Red Book. In both venues (Huaráz and Foz do Iguaçu) the SIG-LAC had the opportunity of meeting and further advancing its work on the A-GMN, which will provide systematic data and contribute to the global knowledge on the evolution of glaciers and the study of climate change.

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