Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 245-247.

CONCORD AND CIRMOUNT: ANTICIPATING THE EFFECTS OF GLOBAL CLIMATE CHANGE IN THE AMERICAN CORDILLERA

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1. INTRODUCTION

Two conceptual programs, CONCORD (Climate Change—Organizing the Science for the American Cordillera) and CIRMOUNT (Consortium for Integrated Climate Research in Western Mountains) are being developed to help focus climate and global change issues on the regions of the American Cordillera (see the respective website address below). The projects are collaborative and interdisciplinary in nature and share the common goals to improve knowledge of high-elevation climate systems and to integrate knowledge of the possible impacts of climate variability and change on water, land, and ecosystem resources into natural-resource management and policy, as well as into social planning activities.

Mountain environments may be particularly sensitive to changes in climate because of its sharp vertical gradients Beniston et al. 1997, Diaz et al. 2003). The stacking of natural ecotones with elevation in mountainous regions may lead to rapid and irreversible changes in a number of areas, ranging from major changes in the seasonal hydrographs of meltwater-driven streams affecting communities that depend on the melting of frozen precipitation for their water supplies, to major changes in growing seasons and species extinction.

Some of the key scientific findings that support the above statements and provide a basic rationale for establishing a focused program of climate research in our mountains are examined, taking as a point of departure the analyses of different types of climate observations and environmental responses documented in the past several years. Results from relevant climate model simulations will be also be examined to provide additional context and impetus to the goals of the two initiatives.

http://www.ires.ubc.ca/projects/concord/
http://www.fs.fed.us/psw/cirmount/

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2. CLIMATE VARIABILITY AND CHANGE IN THE AMERICAN CORDILLERA

It has been known for some time (Houghton et al. 1990 and earlier references therein) that global warming will change the climate of higher latitudes to a greater extent than elsewhere due to changes in the cryosphere and the large positive feedback effect of changes in the albedo of snow- and ice-covered surfaces.

What is perhaps not appreciated as much is the fact that a similar positive feedback effect operates in the world's high mountain regions. This "altitude effect" influences the landscape in a manner analogous to that associated with changes in latitude. However, such changes occur over much shorter distances.

There are two outcomes of climate change that are important factors in amplifying the global climate change signal in mountains. One is this altitudinal "foreshortening" that can translate relatively modest climatic changes into much larger changes with elevation and result in much larger landscape responses compared to latitudinal changes. A second factor deals with the expected amplification of the warming signal in the atmosphere with height (Figure 1).

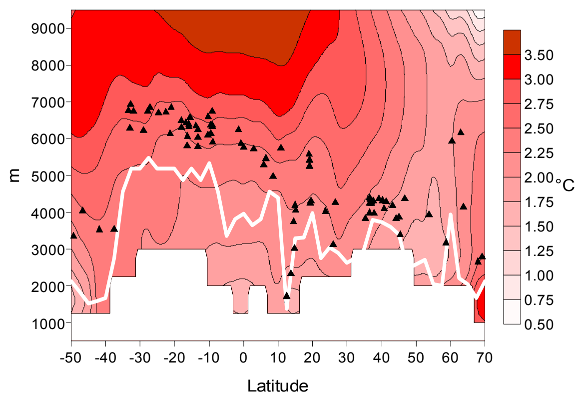

Figure 1. Mean change in temperature (2x CO_2 minus control runs) for December–February for 7 global climate models used in the IPCC 3rd Assessment Report (Houghton et al. 2001). Data are displayed only for those latitudes and levels where data are available from all seven models. The small black triangles represent the highest elevation mountains in countries along a transect

of the North and South American Cordillera. The solid white line shows the maximum elevation over a 5'x5' area in each grid box. This line crosses the missing data region in a few places due to some rounding in interpolation by the imaging software and to the topography files used by the models, which use sigma (or hybrid sigma) levels. From Bradley et al. (2004).

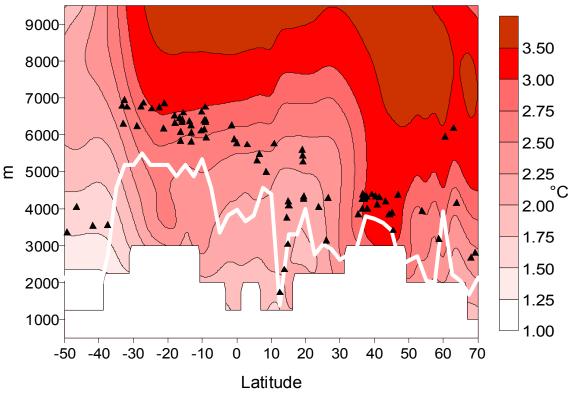

Figure 2. As in Fig. 1, but for June–August.

A number of recent studies have shown that temperatures in the American Cordillera have risen substantially over the past several decades [see Huber et al. 2005, and special issues of the journal *Climatic Change*: 1997, **36**(3–4); 2003, **59**(1–2)].

Evidence from high elevation glaciers and ice caps indicate that they are losing mass at a rapid rate (Francou et al. 2004; Huber et al. 2005). Indeed glacier retreat is under way in all Andean countries from Columbia to Chile. A convergence of factors may contribute to these changes. Rising freezing levels (Diaz and Graham 1996, Diaz et al. 2003) lead to increased melt and increased exposure of the glacier margins to rain as opposed to snow. Higher near-surface humidity leads to more of the available energy going into melting snow and ice, rather than the more energy-demanding process of sublimation, thereby increasing the ablation rate. In some areas, changes in the amount of cloud cover and the timing of precipitation may have contributed further to glacier mass losses, via their impact on albedo and the net radiation balance. As these processes continue, more ice is exposed and absorption of the intense high elevation radiation increases, thus accelerating the changes underway through positive feedbacks.

3. IMPACTS OF CLIMATIC CHANGE IN THE AMERICAN CORDILLERA

Despite the complexity of processes involved in mass balance changes at any one location, temperature is a good 'proxy' for these processes and most of the observed changes are linked to the rise in temperature over recent decades. Many Cordilleran glaciers may completely disappear within the next few decades, with significant consequences for people living in the region. Changes in streamflow, due to the lack of a glacial buffer during the dry season, will significantly affect the availability of drinking water, and water for agriculture and hydropower production (Coudrain et al. 2005). Many large cities in the Andes, are located above 2,500 m and thus depend almost entirely on high altitude water stocks to complement rainfall during the dry season. For example, Ecuador's capital Quito currently receives part of its drinking water from a rapidly retreating glacier on Volcano Antizana (Francou et al. 2004, Bradley et al. 2006).

Agriculture in many dry inter-andean valleys is dependent on glacier runoffs—for instance, 30-45% of streamflow in glacierized catchments in the Peruvian Cordillera Blanca results from glacier melt and 10-20% of the Rio Santa, which drains the Cordillera Blanca in Peru, comes from melting ice that is not replenished by annual precipitation (Bradley et al. 2006). With continued glacier retreat these water resource buffers will shrink further and, in some watersheds, disappear completely within a short time span.

In most Andean countries, hydropower constitutes the major source of energy for electricity generation. As these resources are impacted by future reductions in runoffs and unreliable water regulation caused by the disappearance of water stocks in the mountains, these nations will have to shift to other energy sources, including fossil fuels, causing large capital outlays, higher operation and maintenance costs and higher fossil-fuel emissions.

Mountain ecosystems are complex, and include cold desert biomes, subpolar biomes found in the upper treeline zone, and tundra ecosystems, occurring above timberline. Many studies (Huber et al. 2005) suggest that high elevation environments, comprising glaciers, snow, permafrost, water, and the uppermost limits of vegetation and other complex life forms are among the most sensitive to climatic changes occurring on a global scale. The stratified, elevationally-controlled vegetation belts found on mountain slopes represent an analogue for the different latitudinally-controlled climatic zones, but these condensed vertical gradients are capable of producing unique hotspots of biodiversity, such as those that serve as habitat for a variety of species ranging from butterflies, frogs and toads, to species of birds, trout and salmon. High relief and high gradients make mountain ecosystems very vulnerable to slight changes of temperatures and to extreme precipitation events. Impacts of climate change on some of these mountain ecosystems are already in evidence (Pounds *et al.* 2006).

4. SUMMARY

The mountain regions of the western American Cordillera may be especially vulnerable to changes in climate, to the ensuing changes in snowpack, streamflow, ecosystem functioning, and to a host of impacts on human and natural systems. In these mountain regions relatively small perturbations in global processes can cascade to produce large changes in both highlands and lowlands, ultimately affecting the health, safety and prosperity of people throughout the country. Accelerating research in these regions and on these topics will benefit communities and nations across the Western Hemisphere

5. ACKNOWLEDGEMENTS

Efforts to bring attention to the special needs of mountain regions in the western hemisphere in the face of climate change are broad-based. I would point the reader to the CIRMOUNT and CONCORD websites for the names and links of some of the institutions and individuals involved in climate research in mountains. Some are involved in evaluating the impacts of such changes on the societies of the region and developing plans to mitigate and adapt to the coming changes.

6. REFERENCES

Beniston, M., H.F. Diaz, and R.S. Bradley, 1997: Climatic Change at High Elevation Sites: An Overview. *Climatic Change*, **36**, 233–251.

Bradley, R.S., F.T. Keimig, and H.F. Diaz, 2004: Projected temperature changes along the American Cordillera and the planned GCOS Network. *Geophys. Res. Lett.* 31(16), doi:10.1029/2004GL020229.

Bradley, R.S., M. Vuille, H.F. Diaz, and W. Vergara, 2006: Glaciers, water and temperature change in the Tropical Andes. *Science* (in press).

Coudrain, A., B. Francoou, and Z. W. Dundzeweicz, 2005: Glacier shrinkage in the Andes and consequences for water resources—Editorial. *Hydrological Sciences*, **50**(6), 925–932.

Diaz, H. F. and N. E. Graham, 1996: Recent changes in tropical freezing heights and the role of sea surface temperature. *Nature*, **383**, 152-155.

Diaz, H.F., M. Grosjean, and L. Graumlich, 2003: Climate variability and change in high elevation regions: Past, present and future. *Climatic Change*, **59**, 1–4.

Diaz, H. F., J. K. Eischeid, C. Duncan, and R. S. Bradley, 2003: Variability of freezing levels, melting season indicators, and snow cover for selected high-elevation and continental regions in the last 50 years. *Climatic Change*, **59**, 33–52.

Francou, B., M. Vuille, M. Favier, and B. Cáceres, 2004: New evidences of ENSO impacts on glaciers at low latitude: Antizana 15, Andes of Ecuador, 0˚28'. *J. Geophys., Res.*, **109**, DOI 10.1029/2003JD004484.

Houghton, J. T., G. J. Jenkins, and J. J. Ephraums (eds.), 1990: *Climate Change, The IPCC Scientific Assessment*. Cambridge University Press, 364 pp.

Houghton, J. T. *et al.* (eds.), 2001: *Climate Change 2001, The Scientific Basis.* Cambridge University Press, 881 pp.

Huber, U.M., M.A. Reasoner, and H.K.M. Bugmann (eds.), *Global Change and Mountain Regions, An Overview of Current Knowledge*. Springer, 650 pp.

Pounds, J.A. *et al.*, 2006: Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, **439**, 161–167.