Climate Variability and Change in the Andean Highlands

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ABSTRACT
The Altiplano region of Bolivia and Peru is vulnerable to both climate variability and climate change. Its proximity to El Niño and the Southern the Southern Oscillation (ENSO) yields changes in the rainy season from year-to-year. In addition, the region depends on snowpack and glacial meltwater for water resources during the long dry season, which are diminishing due to greenhouse warming. As part of a larger study to understand how market forces and climate change are affecting highland agriculture, this research explores recent and future climate variability and change in the region. The observed 20th century climate and recent trends are evaluated using global gridded datasets, and station data. In addition, several global climate models employed in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) are evaluated for the recent period. Preliminary analysis of the 21st century scenarios for the highland region are also presented.

Figure 1. *Satellite map of Bolivian region. The central Andean highland region, Altiplano, is visible on the western and southern boundary of Bolivia and extending into Peru and Chile. Also shown are locations of station data and several agricultural sites in which this study participates.*

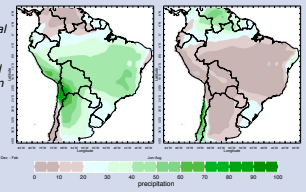
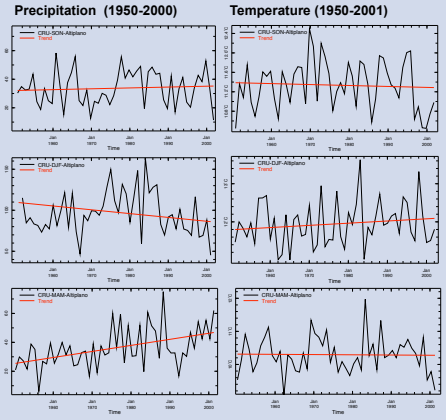


Figure 2. *Fraction of annual precipitation, given in percent, for DJF (left) and JJA (right). From the CRU observational estimates.*



RECENT CHANGES: Observed Estimates

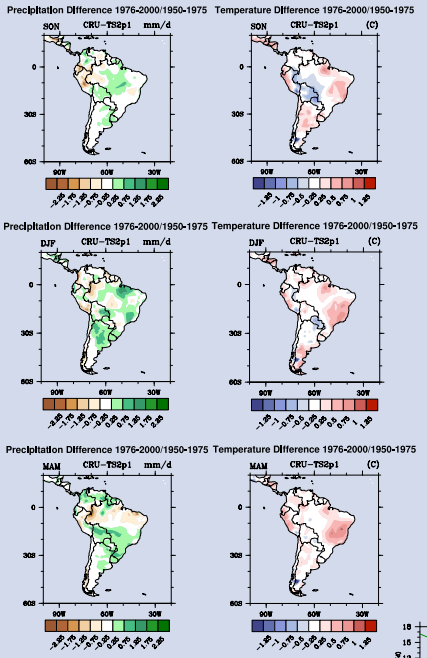


Figure 3. *(above) Recent changes (1976-2000) - (1950 -1975) in precipitation (left) and temperature (right) from CRU observed estimates for the early rainy season, SON (top), the peak rainy season, DJF (middle), and the late rainy season MAM (bottom).*

Figures 3 and 4 describe recent changes in precipitation and temperature from the CRU gridded observed estimates. Precipitation in the western north Altiplano appears to have decreased slightly during the peak rainy season, while increasing during the late season. This is visible in the maps (above) and regional time series (left). Also seen in the maps is the increase in precipitation in southeast South America, which has been documented by Liebmann et al. (2004). The changes in temperature have been more subtle, with slight increase during the warm season. Analysis of station data has shown little coherence in recent trends in this regiona of the Altiplano (Vuille et al. 2003).

Figure 4. *(left) 1950-2000 time series of precipitation (left) and temperature (right) from CRU observed estimates for the early rainy season, SON (top), the peak rainy season, DJF (middle), and the late rainy season MAM (bottom). The least squares fit trend for the period is given for each in red.*

RECENT CHANGES: Simulated

21st CENTURY CHANGES: Simulated

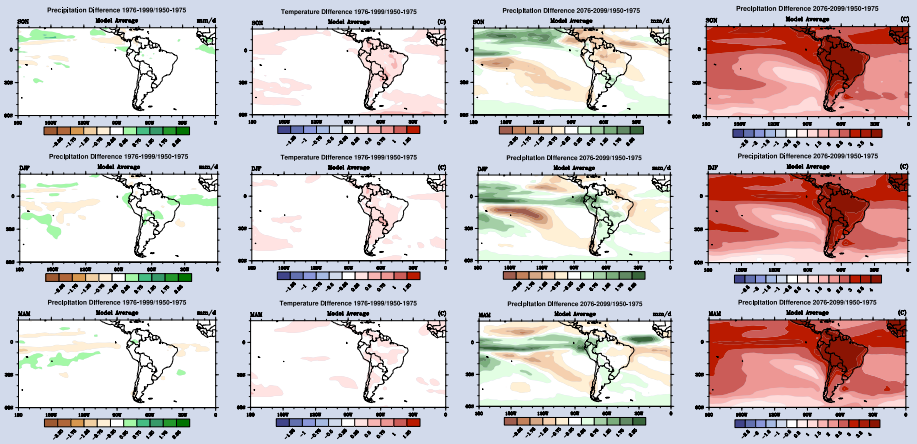


Figure 6. *(above) IPCC AR4 multi-model average (CCSM3, GFDL, ECHAM5, HadCM3) precipitation (left) and temperature (right) changes in the recent period (1976-2000) minus (1950-1975) (left 2 columns) and for the 21st century (2076 -2100) minus (1950-1975) (right 2 columns). Difference maps are shown for early season, SON (top), peak rainy season, DJF (middle), and late rainy season MAM (bottom).*

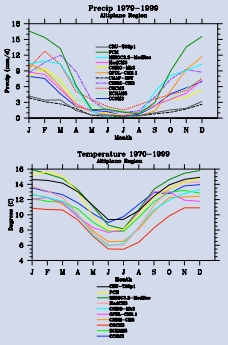


Figure 5. *(above) Precipitation (top) and temperature (bottom) climatology for the Altiplano region from observed estimates (black) and the IPCC AR4 coupled models (color).*

DISCUSSION
The AR4 models are generally wetter than the observed estimates during the rainy season. While the annual cycle of temperature is well simulated in amplitude, a number of models are colder than observed. The models used in the 21st century analysis generally demonstrate smaller biases in the Altiplano region.

The models' simulation of the recent period show little change in precipitation over South America, while describing mild warming through much of the continent. The models are not describing the observed changes during the recent period.

The SRES A2 scenarios from the models depict more coherent changes by the end of the 21st century. These results suggest a drying tendency during the early rainy season in much of the Amazon extending south to the Altiplano, and wetter conditions during the peak rainy season, and perhaps late season in the Altiplano. Also of note are the drier conditions in Northeast Brazil during MAM, which is the main rainy season there. Temperature increases are greater than 3.5 degrees C through the Altiplano in all seasons by the end of the century.

The combined effects of drier early season and substantially warmer temperatures are likely to stress water resources, which will also be affected by changes in glacial melt.

METHODS/DATA
This analysis employs global coupled model data from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) archive at Lawrence Livermore National Laboratory (LLNL). Employed are 10 models with simulations for the 20th century and SRES A2 scenario (stabilization of CO2 at ~ 750 ppm) for the 21st century.

The Climate Research Unit (CRU) at the University of East Anglia .5 degree gridded observations of temperature and precipitation (Mitchell and Jones, 2005) are used to evaluate recent climate and for comparison with the model data. Evaluation of the CRU data against individual station precipitation in the region showed reasonable agreement.

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