# Five-tiered integrated climate-related biodiversity vulnerability assessment in the Tropical Andes

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**The Tropical Andes are one of the top biodiversity hotspots on Earth. Long-term climate change and rapid land-use change are both threatening the integrity and functioning of Andean ecosystems and thereby the environmental goods and services they provide to humans (Herzog et al., 2011). Whereas numerous global and regional climate models exist, climate change and vulnerability analyses at a local scale – the scale most relevant to decision makers and land-use planners – are virtually non-existent in the Andes.**

With regard to biodiversity, large-scale patterns and gradients of species richness are fairly well established in the region for a handful of selected taxonomic groups, but vast knowledge gaps exist at smaller spatial scales and for the great majority of taxonomic groups. Local biological inventory data, where available, have not been integrated into multidisciplinary analyses. Furthermore, although recent advances in the mapping and classification of Andean ecosystems represent immense progress, the vulnerability of these ecosystems to climate change can only be crudely guessed in the most general terms. Thus, an integration of all this available information and approaches into local-scale analyses represents a novel approach in the Andes.

In this five-tiered project we are studying near-term climate change trends, land-use patterns, biodiversity patterns and gradients, the vulnerability of species and ecosystems to changes in historical climatic conditions, as well as local perceptions of climate variability and change in two binational transboundary study areas: on the Pacific slope of the northern Andes in the border region between Colombia (Nariño department) and Ecuador (Carchi province), and on the Amazonian slope of the central Andes in the border region between Bolivia and Peru, in the Madidi – Apolobamba – Bahuaja-Sonene – Tambopata protected area complex. These regions are renowned for their exceptional biodiversity and endemism and have been considered key Andean biodiversity hotspots. Results will then be integrated to pinpoint high-risk areas and ecosystems that are particularly vulnerable to the synergistic effects of long-term climatic changes and land-use change. Our interest is to assist the four Tropical Andean countries (Bolivia, Colombia, Ecuador, and Peru) in the implementation of a standard methodology for estimating climate change risks for biodiversity at a local scale that could subsequently be expanded to other strategic areas. The overall goal is to support and guide adaptation measures and sustained conservation programs for key tropical environments. Here we briefly describe some recent advances of the climate analyses and summarize the objectives of the main components (climate, biodiversity, social, land use/cover, and outreach and capacity building) of our ongoing research project[1] .

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## The climate component

The main objective of the climate component[2] is to develop knowledge on

1 The multidisciplinary project "Impacts of climate change on biodiversity in the Tropical Andes: climate-related vulnerability assessments and improved decision making processes for conservation and land use planning in two Andean biodiversity hotspots" is funded by the John D. and Catherine T. MacArthur Foundation through a grant to the Inter-American Institute for Global Change Research. D. Ruiz is also partially supported (as in-kind contribution) by the Department of Earth and Environmental Sciences at Columbia University in the City of New York (USA), the International Research Institute for Climate and Society at Lamont-Doherty Earth Observatory (USA), and the Antioquia School of Engineering (Colombia).

2 The following scientists participate as co-PIs: Dr. Mark Cane (Department of Earth and Environmental Sciences at Columbia University in the City of New York, USA), Dr. Jorge Ignacio del Valle (Universidad Nacional de Colombia Sede Medellín), Dr. Laia Andreu Hayles (The Tree Ring Laboratory, Lamont-Doherty Earth Observatory-Columbia University in the City of New York, USA), Ángel G. Muñoz (PhD student at Department of Earth and Environmental Sciences at Columbia University in the City of New York, USA), David Suarez Duque, MSc. (Corporación Grupo Randi Randi-Ecuador), and Remi Cousin (Staff Associate at International Research Institute for Climate and Society, Columbia University in the City of

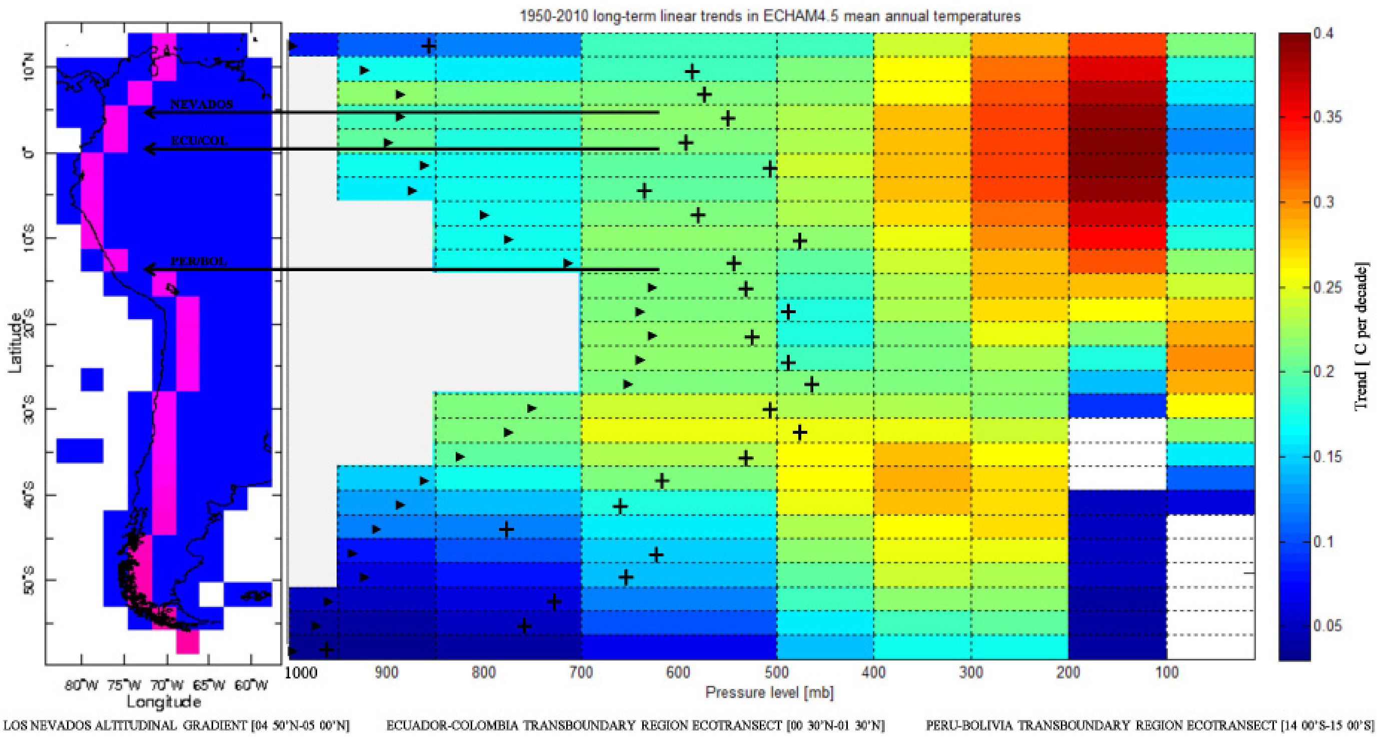


Figure 1. 1950-2010 long-term linear trends in ECHAM4.5 mean annual air temperatures (Roeckner et al., 1996) along the longitudinal axis of the Andes Cordillera (see pink 2.8125° grid cells in map panel on the left; location of the ecotransects under study indicated with horizontal arrows), for the latitudinal range of 15°N to 60°S, and for 9 pressure levels (1000, 950, 850, 700, 500, 400, 300, 200, and 100 mb; see x-axis of right panel). Air temperatures are obtained through ECHAM4.5 ensemble simulation runs. Trends are expressed in °C per decade; see color scale on the right. Only statistically significant (at $\alpha<0.05$) long-term linear trends are displayed; i.e. nonsignificant trends are depicted by white boxes. Black triangles and crosses depict, respectively, the average and maximum altitudes (expressed in atmospheric pressures) of the NOAA NGDC GLOBE gridded 1-km, quality controlled global digital elevation model (Hastings and Dunbar, 1999) in each ECHAM4.5 model grid cell. Areas blocked in grey depict grid boxes below the ground surface. Analyses of ECHAM4.5 simulation runs indicate, in particular, that air temperatures have increased at all latitudes and pressure levels at a rate ranging from +0.03 to +0.40 °C per decade. Between 15°N and 15°S and at higher elevations [100-400 mb], air temperatures have increased at a maximum rate ranging from +0.27 to +0.40 °C per decade. This rate of warming in the upper troposphere in the 15°N to 15°S latitudinal range is 1.8 times greater than that simulated for the lower troposphere over the available 61-year historical period. Note also the differences above and below the tropopause, which is defined as 100 mb at the equator with a linear increase with latitude to 300 mb at the poles.

local climate gradients and to determine short- to medium-term climate scenarios (10-20 years ahead) by combining observed and projected climate trends derived from computer modeling, climatological field stations (ground-truth data), climate change indices, local temperature and humidity records from digital sensors, and reconstructions of pre-instrumental periods through classical dendrochronological techniques (tree-ring records). Statistical analyses of observed and simulated data include Empirical Orthogonal Functions/Principal Component Analyses, observatory and confirmatory (hypothesis tests) analyses for the detection of statistically significant long-term trends as well as changes in the mean and the variance, and assessments of spatial and altitudinal patterns. Spatial scales of analysis include local and regional conditions. Analyses of the former include case studies in the two binational transboundary areas specifically examining historical minimum temperatures, maximum temperatures, and daily rainfall. With these binational regions, and with a similar ongoing initiative in Los Nevados Natural Park in the Colombian Central Andean region (Ruiz et al., 2012), climate-related risk assessments of highly strategic Andean environments at local scale are now covering three study sites in the northern and central Andes. Analyses of regional conditions are based on evidence from near-term historical climate models' simulation runs (reanalysis data) and comprise the full length of the Andes Cordillera and all pressure levels (Figure 1). The group is specifically studying long-term trends and changes in 1950-to present mean annual near-surface and free air temperatures, environmental lapse rates, dew points, specific humidity, squared moist and dry Brunt-Väisälä frequencies, lifting condensation levels, and convective available potential energies, all of them suggested by ensemble simulation outputs. Analyses of regional conditions are complemented with the study of cloud

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New York, USA). The following students participate as Graduate Research Assistants: David Andrés Herrera (MSc candidate at Universidad Nacional de Colombia Sede Medellín), Fabian Suntaxi (MSc candidate at Escuela Politécnica del Litoral-ESPOL-Ecuador), and Segundo Chimbolema (Corporación Grupo Randi Randi-Ecuador).

Colombian-Ecuadorian Altitudinal Ecotransect © Daniel Ruiz Carrascal

characteristics suggested by satellite records and monthly sea surface temperature anomalies observed in the spatial domains [30°S-30°N, 30°E-90°W] of the tropical Indo-Pacific region and [30°S-30°N, 60°W-15°E] of the tropical Atlantic Ocean over the period 1942-to present.

At least 12 data loggers/digital sensors measuring temperature and relative humidity at hourly intervals have been installed in each of the study areas to complement the available hydrometeorological networks, which include 75 and 17 weather stations in the Colombian-Ecuadorian and Bolivian-Peruvian transboundary regions, respectively. Data loggers have been deployed at elevational intervals of 500 meters across two ca. 4,500 m altitudinal gradients (Figure 2) and in as many ecosystems as possible. Gathered data are improving our understanding of the physical processes taking place along the altitudinal transects such as conditions of atmospheric instability, and local seasonal temperature and precipitation anomalies. A better understanding of local mechanisms and their relationships with inter-annual (El Niño-Southern Oscillation events) to multi-decadal phenomena will provide elements for the analysis of long-term changes and for better simulation and validation efforts. Digital sensor data are currently being combined with weather station records, whose historical periods span over 50 years, to build a set of climate change indices and to assess near-term historical conditions of atmospheric instability and moist convection in the two study areas. The dendrochronological work, in turn, aims to reconstruct the past ca. 100-200 years along the upper portion of the elevational gradients. A long list of Andean tree species has been analyzed to identify key species with sufficiently wide elevational ranges, distinctive annual rings, and long life spans. The result, a short list of tree species with dendrochronological potential currently includes 5 species for the analysis of páramo environments and high-Andean forests (such as *Polylepis incana* and *Weinmannia cochensis)* and 5 species in upper cloud forests (such as *Symplocos carmencitae, Ocotea sp*. and *Cedrela montana*). The oldest individuals of the selected tree species have been georeferenced, initially in the Colombia-Ecuador border area, in relatively well

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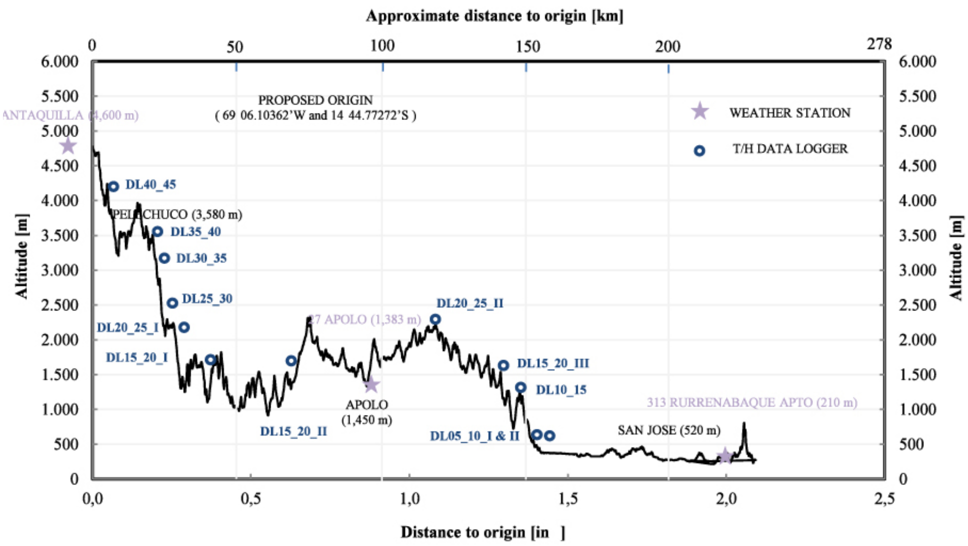


Figure 2. Vertical profile of the 4,500 m altitudinal ecotransect and location of the temperature/relative humidity data loggers on the Amazonian slope of the Central Andes, in the border region between Bolivia and Peru.

preserved environments. To date the group has sampled 64 increment cores of *W. cochensis*, 139 of *P. incana*, 76 of *S. carmencitae*, 65 of *Ocotea*, and 64 of *C. montana*. Tree-ring width chronologies are currently under construction and radiocarbon analyses will be used to assess periodicity (i.e. annual) of tree rings in different species.

### The biodiversity component

The main objectives of the biodiversity component include: (i) to develop knowledge on current biodiversity patterns (by ecosystem) and gradients (by elevation) using several higher taxonomic groups of plants (e.g., ferns, bromeliads, palms) and two animal groups (birds, dung beetles) as proxies for overall diversity, based on existing species-locality data and on field inventories where knowledge gaps exist; and (ii) to evaluate the vulnerability of species and ecosystems (based on the pooled vulnerability of their component species) to climate change using the NatureServe Climate Change Vulnerability Index (http://www.natureserve.org/prodServices/climatechange/ccvi.jsp).

### The social component

The main objective of the social component is to consult local communities on ecosystem goods and services of particular value to them, on their perception of any changes in the provisioning of such goods and services due to climate change, and on whether local land-use practices and patterns have been already adapted or changed in response to climate change. Within this component, the Corporación Grupo Randi Randi, based in Quito, Ecuador, conducted a survey of 545 persons (50% women) during 2011 to learn more about local perceptions of climate change and how people are making adaptations to changes perceived in their local climates. The survey sites comprise a series of transects across sections of the western flanks of the Andes in the north (southern Colombia and northern Ecuador), and sections of the eastern flanks in the south (southern Peru and northern Bolivia) within the two transboundary Andean areas defined for the larger study. The surveys were complemented with key informant in-depth interviews in each community surveyed, together with participatory mapping exercises on vulnerability with focus groups composed of local men and women. The initial results of this study will be available in late 2012.

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### The land-use component

The land-use component aims to determine land-use types and patterns based on satellite imagery and local information, and to relate biodiversity and vulnerability patterns/gradients to existing climate gradients, climate change trends and forecasts, land-use patterns, and predicted changes in land-use due to climate change using Geographic Information Systems.

### The outreach/capacity building component

Finally, the main objectives of the outreach and capacity building component include: (a) to determine potential adaptive management measures and actions to increase the resilience of high-risk biodiversity areas to climate change; (b) to provide capacity building on the developed tools and analysis to institutions in Andean countries including Ministries of Environment, National Climate Change Adaptation Programs, meteorological services, universities, and non-governmental organizations to ensure that the approach can be replicated elsewhere; and (c) to disseminate the results and conclusions in order to facilitate their incorporation into action plans of national and international institutions.

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