Poleka Kasué Mountain Observatory

Los Nevados Natural Park, El Ruiz-Tolima volcanic massif, Central Cordillera, Colombia

Multi-tiered integrated approach to assess the impacts of changes in climatic conditions on the integrity of páramo environments

For further information, please proceed to the virtual catalog of high-altitude flora in Los Nevados (available in Spanish):

https://catalogofloraaltamontana.eia.edu.co/

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1. General description

A faster tropical upper-tropospheric warming is having a negative impact on the overall integrity of páramo environments. The goal of our long-term, multi-tiered research project is to deepen our understanding of the function and importance of these environments and assess the best suite of adaptation strategies for their conservation. Activities are focused on the Los Nevados Natural Park, on the El Ruiz-Tolima volcanic massif, a key protected area in the Colombian Central Andean region. The proposed socio-ecological, mountain monitoring system integrates seven components of analysis: (i) long-term changes in key circulation dynamics (e.g. convective processes); (ii) diagnostics of water balance and potential changes in hydrological regimes; (iii) assessments of biodiversity levels and vulnerabilities; (iv) role of anthropic disturbances; (v) carbon capture and storage in soils, peatlands and aquatic microhabitats; (vi) socio-economic factors (e.g. ecosystem services valuation, communities perceptions, land-use practices, and prevalent concerns of stakeholders); and (vii) long-term changes in climatic conditions (past climate reconstructions, analysis of instrumental periods, hindcasts, and climate model projections). Research activities are supported on the analysis of primary data collected by weather and gauging stations, georreferenced photographs, biological parameters from vegetation experimental plots, and sets of U23-001 HOBO® temperature and relative humidity data loggers. The latter were installed along ~4,000 m altitudinal gradients and are now providing insights into the dynamics of the unusual upper-tropospheric warming. Our group is mainly supported by the Escuela de Ingeniería de Antioquia and has received academic, logistic and financial contributions from the International Research Institute for Climate and Society, the World Bank, the MacArthur Foundation, and the Colombian Natural Parks Unit. Analyses of ongoing changes in climatic conditions suggest that páramos are experiencing region-wide, cumulative and irreversible increases in climatic stress. Ambitious sustainable management strategies are urgently required to protect these unique and highly endangered high altitude environments.

Our history of quarterly field trips to monitor on-the-ground climatic and environmental variables in the Los Nevados Natural Park spans back almost seven years. In such a short time period, our group of scientists and supporting field personnel have learned to overcome the challenge of coping with extreme weather conditions that characterize the upper altitudinal range of Los Nevados: near-surface air temperatures below freezing point at night and average 15°C and above midday temperatures. Our research team frequently sets up campsites within walking distance from local community-owned farm houses that are located on the buffer zone of the protected area, and carries all the weight to base camps. The range of equipment includes high-tech outdoor camping tents and high-pressure oxygen cylinders, but most of the weight in our backpacks comes from a short list of devices. They include portable video-cameras, digital cameras, tripods, personal laptops, new-generation GPSs, precision compasses, digital thermometers and hygrometers, altimeters, two-way radios, solar power packs and inverters, and optical USB stations. The latter, in particular, are required to read out hourly temperature, relative humidity and dew point records gathered at a set of HOBO data loggers that were deployed along the mainstream of the Claro River and Quindío River high-altitude basins in Los Nevados. Such a set of digital sensors was installed with the purpose of improving our understanding of the potential changes in atmospheric instability on the integrity of páramo environments under the ongoing warming conditions. They also fill in the gaps of historical

climatic information in Colombian high-altitude environments. Our resource intensive, but funding-limited, research activities are worth conducting in the selected logistically challenging setting if we want to assess the impacts on key regional and local circulation dynamics of the faster tropical upper-tropospheric warming.

2. Research interests

Long-term changes in convective processes. A faster warming of the tropical upper troposphere worsens the already rapid shrinkage of tropical mountain glaciers and disrupts key local circulation dynamics. Our research is focused on understanding the potential impacts of changes in convective processes on the integrity of páramo environments in 4,000 to 4,500 m altitudinal gradients of the tropical Andes. These include the Los Nevados Natural Park, in the Colombian Andean region; the El Angel-El Golondrinas ecological reserve, in the Colombia-Ecuador transboundary region; and the Madidi-Apolobamba protected complex area, in the border region between Bolivia and Peru. Several U23-001 HOBO® data loggers measuring near-surface air temperature, relative humidity and dew point at hourly intervals were deployed along the altitudinal transects at elevational intervals of 300-500 meters. Data are read out during quarterly field campaigns and processed to characterize ground-based environmental lapse rates, time of occurrence of vertical motions, and moist and dry Brunt-Väisälä frequencies. Historical records in Los Nevados span back to December 2008. In Colombia-Ecuador and Bolivia-Peru, records are available for the historical periods August 2011 to present, and September 2011 to present, respectively. Hourly data are shared with the main institutions involved in research activities in text files and MS Excel spreadsheets. They are also posted to data library sites to provide free access to historical records and visual representation. Analyses of static unstable, conditionally unstable, and absolutely stable atmospheric conditions are providing us with numerous insights into the role of convection in the integrity of high-altitude environments.

Diagnostics of water balance and potential changes in hydrological regimes. Upper tropospheric warming and its concomitant changes in the snowline, Equilibrium Line of Altitude and Level of Free Convection are having numerous impacts on the altitudinal distribution of solid and liquid precipitation in high-altitude Andean watersheds. Our research team is studying the eco-hydrologic response of mountain basins to such long-term changes in climatic conditions. Two key watersheds in Colombia have been selected for the study: the Claro and Otún rivers, both located on the western flank of the El Ruiz-Tolima volcanic massif, in the Central Cordillera. Homogeneity analysis of hydrometeorological and hydrological data is performed to detect anomalous records, long-term trends, and abrupt changes in the mean and the variance in historical time series, using records from several weather stations. Data from digital thermometers and hygrometers, installed by our research team at different altitudes, are being processed to fill in the gaps of climatic information. Spatially-distributed hydrological modeling is implemented to assess changes in water balance and hydrological regimes. High-resolution digital elevation models from ASTER and SRTM1 data were used to obtain fine-resolution drainage networks and flow direction maps. Traditional deterministic approaches and advanced Kriging interpolation techniques are used to assess rainfall and actual evapotranspiration fields. Geostatistical analysis is performed to assess the robustness of the obtained spatial distributions. On-the-ground activities aimed at measuring changes in snowpack melting, peatland and lagoon water storage, instant streamflow, horizontal precipitation, and water retention

in páramo vegetation are being conducted to support the study. Errors between simulated and observed mean annual discharges and surface water supply have reached values as low as 0.4%. We anticipate that our research activities will bring several insights into the potential impacts of climate change on the mountain water cycle.

Assessments of biodiversity levels and vulnerabilities. An in-depth understanding of the potential impacts of changing climatic conditions on the integrity of tropical high-altitude páramo environments implies considering multiple approaches. Our research activities in Colombia integrate different ecological scales (from general ecosystem approach to specific species level) and multiple methodological approaches (from geographical modelling to in-situ observations and long-term monitoring). Our group has worked on geographical modelling of possible changes in (i) Holdridge life zones based on limiting conditions, (ii) distributions of plant growth forms based on environmental gradients, and (iii) plant species using niche modelling. We have also assessed the vulnerability to climate change of several plant species using the Nature Serve Vulnerability Index, which combines climatic exposure and species sensitivity. All of these activities, on different ecological scales, provide similar evidence of expected upward shifts and distinct responses for each ecosystem, growth form or species. Results provide immediate information regarding potential responses to climate change. However, actual vegetation (or ecosystem) response might differ from modelling projections, as in the latter ecological processes such as adaptive plasticity, species interactions, or species evolution are not considered. Should species have different vulnerabilities to climate change, and therefore varied responses (either surviving, dying or migrating), changes in the composition of ecosystems and plant communities could be expected to have predicted results. In-situ monitoring should thus complement modelling exercises. Our research group has installed experimental plots along altitudinal gradients to describe plant species presence and abundance periodically, gathering baseline data for composition and distribution of plant communities, and potential changes over time. A detailed photographic record of experimental plots and plant species is being stored for comparison throughout the years. Vegetation data are tied to climatic records of temperature and relative humidity from data loggers installed at the same elevation, and topographical information on slope and aspect.

Role of anthropic disturbances. Fires are considered one of the most serious threats to the integrity of Andean high-altitude ecosystems, and one of the most critical challenges for the conservation of high-mountain protected areas. At higher altitudes, fires cause numerous and almost-irreversible damage to páramo soils, wetlands, fauna, and flora. Fire-induced changes in the structure and composition of páramo ecosystems affect their ability to provide several ecosystem services. In the surroundings of Los Nevados, in particular, lower areas and buffer zones are inhabited by smallholder farmers whose main productive activities include grazing dairy cattle and the cultivation of potato crops. Fires are usually set to regenerate grass for livestock, prepare land after harvesting crops and expand utilized and cultivated land areas. These burns are set without using appropriate techniques for controlling fires, which can lead to their rapid spread into non-targeted natural vegetation inhabiting páramo zones. Fires are even more hazardous during dry seasons, given the high to extreme vulnerability of páramo habitats during these periods. Over the past decades, the annual number of fires, the total annual affected areas, and the average duration of fires in the area of Los Nevados have all shown strong increasing trends. This is in response to several factors such as a weaker institutional capacity to react to fires, more combustible material in the area, and climatic conditions more favorable to the spread of fires. Most incidents have been induced by (or are related to) human activities, including grass and crop renovations, tourism, arsonists, illegal armed groups,

and hunters, but it is likely that changing climatic conditions have favored their rapid spread. Increases in the number of events and affected areas seem to encompass the increasing and decreasing trends observed in temperature and relative humidity records, respectively. Our group is currently working on understanding the slow recovery time of páramo ecosystems, by observing several places that were affected by small-scale high-altitude fires.

Carbon capture and storage in soils, peatlands and aquatic microhabitats. Carbon budget in high mountain soils results from the accumulation of organic matter, as a product of chemical and biological processes. Soils and peatlands in high-altitude ecosystems serve as carbon sinks because of the slow mineralization and decomposition rates caused by specific environmental conditions such as reduced oxygen availability, low pressure and low temperatures. The location on a volcanic environment creates particular conditions in the soils of the region. Over time, volcanic eruptions develop layers of ashes that bury the organic material, on which vegetation later grows. This dynamic creates alternate soil horizons with particular characteristics. The role of high-mountain soils and peatland as carbon sinks is not fully understood and very few studies have tried to quantify the amount of stored carbon. Our aim is to properly estimate the amount of carbon stored in these sinks, taking into account the local ecosystems and atmospheric conditions. Until now, soil samples from different horizons have been collected in several locations along the altitudinal transect. These samples were processed to determine the total amount of organic material in soils and its fraction of non-labile carbon. This information will be useful to determine the carbon accumulation rates in the soils and the possible release of carbon under different scenarios of environmental pressure.

Socio-economic factors. In order to assess the integrity of high mountain ecosystems in the Andes, our multidisciplinary team has developed a monitoring system integrating multiple thematic fields, including socio-economic assessment. The economic valuation of these ecosystems is our next step: an additional and transversal topic within our system aimed at identifying the most prevalent concerns of multiple stakeholders. Several techniques from the economic valuation literature can be used to estimate the value of high mountain ecosystems, some of which involve asking people about their preferences through questionnaires. We propose the use of a series of these surveys as an assessment tool based on climatic, hydrologic and ecosystem descriptions for the páramo environments, in the context of climate change and its possible impacts. The tool should be implemented with local communities, visiting tourists and other potential users of the environmental services of the Colombian Los Nevados National Park and its surrounding areas. The tool will serve a double purpose: to inform the community about our scientific finds and to obtain monetary values for the attributes and functions of Colombian páramos. The results of the valuation process will let us evaluate and rank how the community values high mountain ecosystem environmental services, and provide information to be shared with planning and conservation institutions and policy makers in charge of designing and implementing adaptation strategies. In this way, we will successfully link our role as researchers to the interests and concerns of the communities and inform policy makers, and we will contribute to the social construction and appropriation of knowledge.

Long-term changes in climatic conditions. As part of a larger investigation of the role of the Tropics in the global climate, our group teamed up with researchers from the University of Maine (USA) to study the geologic record of glaciation from the northern Andes in order to assess tropical climate variability over the last ~20,000 to 30,000 years. We are studying unconsolidated glacial debris and other geological formations that may keep a record of the timing and magnitude of past glacial advances. Field work activities involve detailed mapping of glacial landforms and collection

of samples from several moraines for surface-exposure dating. Our investigation will provide a northern hemisphere counterpart to existing datasets from the Peruvian Andes, and will support ongoing research projects in Colombia investigating the rapid melting of mountain glaciers. Our chronologies will also provide valuable context for the analysis of the changing distribution of páramo environments in a future warmer world. Ground truth records/meteorological data (sunshine, rainfall, temperature, diurnal temperature range, relative humidity, actual and potential evapotranspiration, and dew point), cloud characteristics and sea surface temperatures are processed to determine changes in climatic patterns over recorded, instrumental periods on three spatial scales: nationwide, regional, and local climatic conditions. Exploratory/Confirmatory analyses, Empirical Orthogonal Function modes and Fourier analyses are conducted to detect potential long-term trends, and abrupt changes in the mean and the variance in historical annual records, as well as to assess main modes of spatio-temporal variability, and determine the underlying structures and compositions of climatic datasets. Statistically significant trends are presented graphically for various spatial domains and plotted versus altitude to explore potential mechanisms. Lastly, retrospective and prospective simulation outputs of several Atmospheric General Circulation Models (CCM3v6 and NCAR:CCSM3; COLA T63 and NCAR:CCSM3 COLA T63; ECHAM4.5 and MPIM:ECHAM5; GFDL and GFDL_CM2; NSIPP and NASA:GISS-AOM) are processed to assess historical and projected changes in prevalent climatic conditions. Analyses also include NOAA NCEP-DOE Reanalysis-2 data available through the Atmospheric Model Intercomparison Project. Individual, multi-member simulation outputs and reanalysis data are periodically processed to assess non-homogeneities in historical time series of mean annual near-surface and free air temperatures, specific humidity and more. Equally-weighted, multi-model ensemble prospective simulation runs and differential model weighting schemes are proposed to assess climate change scenarios (e.g., mean annual near-surface temperature anomaly maps) at regional and local scales, respectively. Climate-exposure severity intervals are then quantified to implement the Nature Serve Climate Change Vulnerability Index for the risk assessment of several plant, insect and bird species.

3. Research projects

2017-present. A tropical multi-proxy approach to testing the role of CO2 in the last glacial termination. Research project led by University of Ireland at Galway.

2017-2019. Dinámica eco-hidrológica de la vegetación de páramo asociada a sus rasgos funcionales, bajo condiciones climáticas actuales y proyectadas. Funded by Universidad EIA-Universidad Nacional de Colombia Sede Medellín.

2017-2019. Reconstrucción geomorfológica de eventos glaciares Holocenos en la vertiente occidental del Nevado Santa Isabel. Funded by Universidad EIA.

2017. Definición de línea base de cambio y variabilidad climática, recurso hídrico y biodiversidad en el Parque Nacional Natural Los Nevados y sus áreas circundantes. Funded by WWF.

2015-2016. Caracterización hidroclimática de la cuenca del Río Claro, Parque Nacional Natural Los Nevados, enfocada a la generación de energía geotérmica. Funded by Isagen.

2011-2015. Impacts of climate change on biodiversity in the Tropical Andes: climate-related vulnerability and risk assessments and improved decision-making processes for conservation and land use planning in two Andean biodiversity hotspots. (Parallel study site). Funded by The MacArthur Foundation.

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4. Scientific literature

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5. Dissertations and theses

PhD dissertations

Gutiérrez, ME. Tesis de Doctorado en Ecología (ongoing) 'Dinámica ecohidrológica de tipos funcionales de vegetación en los páramos bajo condiciones climáticas actuales y proyectadas'. Departamento de Ciencias Forestales, Posgrado en Bosques y Conservación, Universidad Nacional de Colombia, sede Medellín.

Cárdenas Agudelo, María Fernanda (2016). Ecohydrology of páramos in Colombia: vulnerability to climate and land use change. PhD en Ecología, Departamento de Ciencias Forestales, Posgrado en Bosques y Conservación, Universidad Nacional de Colombia Sede Medellín.

Ruiz, D. PhD dissertation 'Adaptation strategies to climate change in the tropics: analysis of two multi-factorial systems (high-altitude Andean ecosystems and *Plasmodium falciparum* malaria infections)'. Department of Earth and Environmental Sciences, Columbia University in the City of New York (USA), 2013. http://academiccommons.columbia.edu/catalog/ac%3A161418

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Gutiérrez, ME. 'Vegetation-environment relationships under current and future climate in the páramos, tropical high mountain ecosystems of Colombia'. State University of New York, College of Environmental Science and Forestry (SUNY-ESF, Syracuse), 2012.

Undergraduate theses

2017: Andrés José Escobar (Ing. Civil). Dirección: Daniel Ruiz. Huella del ENSO en la densidad estomática de hojas del fuste de ejemplares centenarios de *Espeletia* del Parque Nacional Natural Los Nevados, Colombia.

2016: María Juliana Ramírez y Verónica Díez (Ing. Ambiental). Dirección: Adriana Quinchía. Fraccionamiento de la materia orgánica del suelo en la cuenca alta del río Claro, Caldas.

2016: Juan Pablo Cárdenas (Ing. Ambiental). Dirección: Martha Isabel Posada. Aplicabilidad del software InVEST para el mapeo de servicios ecosistémicos: caso cuenca alta del río Claro.

2016: Andrés Felipe Echandía (Ing. Ambiental). Dirección: Martha Isabel Posada. Presión antrópica en la cuenca alta del Río Claro: cambios en usos y coberturas del suelo.

2015: Maria Camila Arango y Margarita Atehortúa (Ing. Ambiental). Dirección: Adriana Quinchía. Cuantificación del carbono almacenado en los suelos del Parque Nacional Natural Los Nevados.

2015: Juanita Cuevas (Ing. Ambiental). Mención de honor. Dirección: Daniel Ruiz. Inferencia del comportamiento del nivel de condensación por elevación en un sitio estratégico de los Andes tropicales. Fase 1: componente física.

2015: Tomás Vanegas y Juan Andrés Estrada (Ing. Ambiental). Dirección: Catalina Londoño. Valoración económica de los páramos: Parque Nacional Natural Los Nevados.

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2013: Natalia Arcila y Carolina Gutiérrez (Ing. Ambiental). Mención pública. Dirección: Maria Elena Gutiérrez. Vulnerabilidad al cambio climático de tres especies de flora del páramo. Estudio de caso: Parque Nacional Natural Los Nevados.

2007: Maria Elena Gutiérrez y Paula Andrea Zapata. Mención de honor. Dirección: Daniel Ruiz. Hacia el entendimiento de las señales de cambio climático o variabilidad climática en la oferta hídrica superficial de cuencas hidrográficas en zonas de alta montaña. Estudio de caso: Río Claro, Parque Nacional Natural Los Nevados.

6. In-situ instrumentation

Climate data: hourly near-surface air temperature, relative humidity and dew point records gathered at twenty-eight (28) U23-001 HOBO® dataloggers installed along the mainstreams of the Claro River, Las Nereidas Creek, Molinos River, and Las Juntas Creek high-altitude watersheds.

Botanical/vegetation data: five (5) experimental parcels in the altitudinal range 2300-2400 masl of the Andean forest, and fifty-nine (59) parcels in the altitudinal range 3800-4500 masl of the páramo.

Taxonomy: floristic records for multiple species in the altitudinal range 2000-4500 masl (Andean forest and páramo): in the range 2000-3800 masl, the total number of species reaches 398 grouped into 100 families; in the paramo, 160 species have been identified and grouped into 60 families. Further information in our portal (in Spanish): https://catalogofloraaltamontana.eia.edu.co/

High-resolution photography: +1,200 pictures of high-altitude flora.

Land-use and cover: almost up-to-date high-resolution maps.

7. Awards

Honorary mention, Fundación Alejandro Ángel Escobar. Área de Medio Ambiente y Desarrollo Sostenible. Proyecto 'Signals of climate variability/change in surface water supply of high-mountain watersheds - Case study: Claro River high-mountain basin, Los Nevados Natural Park, Andean Central Mountain Range'. 2011.

8. Outreach

Intervention during the installation of the High-Altitude Ecosystems Commission at the Colombian House of Representatives, an event that took place virtually on August 31, 2020. The goal of the commission is to protect the high-altitude environments (high Andean forests, paramo and mountain glaciers) inhabiting the upper ranges of the Andes Mountains in Colombia. Full installation available at: https://www.youtube.com/watch?v=QIVIgFifimo&feature=youtu.be

Our water depends on these places – and we still don't understand well, exactly how. Danish Development Research Network, November 15, 2019: https://ddrn.dk/our-water-depends-on-these-places-and-we-still-dont-understand-well-exactly-how/.

The spectacled bear just doesn't sell as well as the polar bear. Danish Development Research Network, October 25, 2019: https://ddrn.dk/the-spectacled-bear-just-doesnt-sell-as-well-as-the-polar-bear/.

New book highlights threatened plants of the Tropical Andes. State of the Planet blog, The Earth Institute – Columbia University in the City of New York, July 19, 2019: https://blogs.ei.columbia.edu/2019/07/19/bosque-andino-plants-tropical-andes/.

"Los Andes es uno de los 'hotspots' críticos del mundo". Centro de los Objetivos de Desarrollo Sostenible para América Latina. Junio 2019: https://cods.uniandes.edu.co/los-andes-es-uno-de-los-hotspots-criticos-del-mundo/.

Voices in the wind. Page 52 in Mountain Views, Volume 13, Number 1, Chronicles of the Consortium for Integrated Climate Research in Western Mountains – CIRMOUNT, May 2019: https://www.fs.fed.us/psw/cirmount/publications/pdf/Mtn_Views_may_19.pdf.

This unique Andean ecosystem is warming almost as fast as the Arctic. State of the Planet blog, The Earth Institute – Columbia University in the City of New York, 15 November 2018: https://blogs.ei.columbia.edu/2018/11/15/paramos-ecosystem-climate-change/ .

End of Colombia conflict may bring new threats to ecosystems. State of the Planet blog, The Earth Institute – Columbia University in the City of New York, 12 September 2018: https://blogs.ei.columbia.edu/2018/09/12/colombia-conflict-ecology-biodiversity/ .

FARC and the forest: peace is destroying Colombia's jungle — and opening it to science. Nature News, 12 June 2018: https://www.nature.com/articles/d41586-018-05397-2 .

La diversidad biológica de los Andes tropicales y el cambio climático (IAI video): https://www.youtube.com/watch?v=avD3onIH2Uc

Calentamiento global amenaza a los Páramos en los Andes (EarthSky video): http://www.youtube.com/watch?v=17ibHzxspes&list=UUf-JPl019c-wzBG_PvUlgYA&index=3&feature=plcp

Climate change threatens a fragile ecosystem in the Andes (Spanish and English versions). (Vimeo) http://vimeo.com/23937998 ; (YouTube) https://www.youtube.com/watch?v=RL7zKzQlNRI