



## Understanding precipitation could be lifesaving for Andean communities

Precipitation on the Andes mountain range has a monumental effect on livelihoods across South America. Glacial water is used for agriculture, hydropower, ecosystem balance and freshwater storage, and if lost could threaten the livelihoods of millions. **Dr Baker Perry** from Appalachian State University is drawing on several atmospheric and glaciological disciplines to further advance the understanding of Andean precipitation processes, in an effort to draw attention to its importance, and the challenging future of highland water availability.

**W**ater has always been an essential part of life for the people living in the tropical Andes. During the Incan Empire (1438–1533),

Andean societies constructed mountain-top civilisations to be closer to the Gods and lived off precious water springs which they believed to be the blood of mountains, from *Pachamama* (Mother Earth). Today, water is just as important, in fact now there are many more human lives relying on freshwater that comes from the Andes. With climate change already causing substantial impacts to the region, it is urgent that scientists better understand the atmospheric processes to enhance projections of future climate change.

Dr Baker Perry and his team from Appalachian State University, which includes his close colleague Dr Anton Seimon and students:



Far left: Citizen science precipitation observer Clemente Mamani in the community of Pinaya at the base of Nevado Illimani, Bolivia. Above: The town of Sorata and neighboring communities at the base of Ancohuma massif, Bolivia. Left: Appalachian State University research and education field experience in the Cordillera Vilcanota, Peru, with Nevado Ausangate in the background.

equipment, global satellite imagery and the analysis of ice cores has provided scientists with many answers, and yet more questions. Dr Perry wants to discover as much as possible about the variation in Andean weather patterns to improve our understanding of past climate changes and inform projections of future climate change.

Firstly, Dr Perry and his team will examine the origins of precipitation at his sites. Where has the moisture come from? This mainly uses a programme based on atmospheric reanalysis data called *HYSPLIT*. It traces the movement of air masses so their 'backward trajectory' can be observed, and ultimately their location of origin. Records to date have shown Dr Perry that the majority of air masses responsible for the precipitation originates in the Amazon Basin to the north and northwest of the study regions, whereas previous studies assumed that moisture arrived from the east.

It's also important to look at the change over time, which Perry will be examining on a variety of timescales. Over the last 25 years, ►

Jason Endries, Evan Montpellier, Eric Burton, Courtney Cooper, and Heather Guy, are working with collaborators and partners worldwide to gather more information about the atmospheric processes occurring in and around the tropical Andes mountains. These locations are difficult to access, and highly isolated, so data are scarce. Dr Perry's team has established two high altitude (>4000m) field sites in Peru (Cordillera Vilcanota) and Bolivia (Cordillera Real) which are providing a variety of measurements about the surrounding atmosphere and environment. The team has also introduced a new citizen-science initiative in local communities to

collect scientific measurements that would otherwise be impossible to gather. Along with his Appalachian State teammate Dr Anton Seimon and collaborator Dr Paul Mayewski at the University of Maine, Dr Perry is also investigating the relationships between atmospheric circulation and the isotopic and chemical composition of tropical Andean snow and ice.

### A DETAILED FORECAST

Gathering data on changes in atmosphere within this part of the world has only recently become achievable on a detailed scientific level. Recent advances in data collection





Team members representing the Universidad Nacional de San Antonio de Abád del Cusco, Servicio Nacional de Meteorología e Hidrología, Appalachian State University, and the Crispin Family on the Quelccaya Icecap, Peru.

rainfall has been measured at Cusco (Peru) and La Paz (Bolivia), and compared against variations in the ocean and atmosphere (e.g., El Niño and La Niña). El Niño events drastically affect the South American climate and investigations are ongoing to understand this complex relationship. As part of this project, citizen scientist observers are collecting daily measurements about the type of precipitation (snow, hail, rain), and quantity of precipitation, allowing Dr Perry and his team to compare these across monthly and yearly timescales to investigate when weather variation has the most impact.

Dr Perry and his collaborators want to understand and investigate the physical structure of the atmosphere when precipitation is falling. A vertically pointing Micro Rain Radar (MRR) measures the reflectance and speed of falling precipitation. Lower fall speeds indicate snow, whereas higher fall speeds identify rain. The MRR therefore provides Dr Perry and his team with direct measurements of the melting layer height, where descending snowflakes melt into raindrops.

Finally, one ground-breaking aspect of the team's work is analysing snow and ice samples from mountain peaks in the region. By looking at the ratio of oxygen isotopes in the ice ( $\delta^{18}\text{O}$ ) as well as the trace chemical elements in the ice, the team is working to develop a

model linking local meteorology to the snow precipitation. The team's work is designed to inform how scientists can improve climate reconstruction from tropical ice cores, thereby providing a key reference on climate variability and change.

#### THE START OF A PERFECT STORM

Understanding the aforementioned factors will shed a light on the fate of glaciers in the tropical Andes. These glaciers store a huge amount of fresh water for populations stretching beyond the Andean region. Sunlight, precipitation, and humidity directly influence the behaviour of these glaciers; recent changes in these atmospheric processes have led to widespread glacier retreat and the disappearance of many smaller glaciers. One new finding is that the majority of heavy precipitation occurs overnight, and further investigations into the consequences of this are ongoing.

The melting layer heights also have important implications on the health of Andean glaciers, as rainfall on frozen surfaces greatly intensifies glacial ablation (loss of ice). Dr Perry has found that the melting layer at the Cusco and La Paz sites normally lies just below for the lower margins of the studied glaciers. However, Dr Perry's team predicts that a rise of just 1.2°C (the estimated rise in global temperature by 2050 projected by the IPCC) will result in a 200 m rise in the melting layer height causing half

## Q&A

### Why does it help you to run backwards air trajectories? Why is it useful to know where the air masses originate from?

Backwards air trajectories help us to better understand the atmospheric circulation associated with precipitation events in the region. In particular, we run the trajectories with ending points at the altitude of the lower cloud layer, which therefore provides an approximation of the low-level moisture source regions. Knowing the origin of the air masses is important for identifying which moisture source regions and trajectories are associated with heavy vs. light precipitation. Our team is also investigating the relationships between moisture source region and oxygen stable isotopes and trace elements preserved in the snow/ice with the goal of improving reconstruction of past climates from ice cores in the region.

### What precipitation change might we expect to see during an El Niño event? What is strange about what has been observed so far?

Previous work suggested that El Niño events were dry and La Niña events wet across the central Andes but our results show that it is a more complex spatiotemporal pattern, with locations in the vicinity of the Cordillera Vilcanota of Peru exhibiting positive anomalies with many El Niño events. Preliminary results from the Lake Titicaca basin and Cordillera Real in Bolivia show more of a mixed pattern, although the major El Niño events of 1982-83 and 1997-98 are associated

with negative anomalies. What appears to be somewhat strange about these results is the high degree of precipitation variability among El Niño events, suggesting that the atmospheric response to the tropical Pacific sea-surface temperature (SST) anomalies is highly variable and may depend strongly on the spatial patterns of the SST anomalies.

### You have found so far that many heavy precipitation events happen at night, and are stratiform (layered) – how can this information be used?

Our results indicate that the heavier, longer duration stratiform nighttime events are more regionally coherent and exhibit greater spatial coverage than the afternoon convective events. This information suggests that observations of precipitation timing, vertical structure, and melting layer heights are also regionally coherent and that the patterns of atmospheric circulation associated with the nighttime precipitation are somewhat similar across the region. In particular, it increases our confidence that vertically-pointing radar observations from Cusco and La Paz are also representative of precipitating storms in the nearby glacierised cordilleras. Likewise, the confirmation of stratiform nighttime precipitation is important in understanding the meteorological controls on the oxygen stable isotopes preserved in tropical Andean snow/ice and ultimately improving reconstruction of past climates.

### Why did your team install a comprehensive monitoring station at

### 5,650 m on the Quelccaya Icecap and what are some of the challenges in operating the station?

Although ice cores from the Quelccaya Icecap are some of the most important paleoclimatic archives in the tropics, detailed measurements of precipitation characteristics have been lacking. Our team installed a comprehensive meteorological station near the summit of the Quelccaya Icecap in 2014, that in addition to standard meteorological sensors, included a weighing precipitation gauge to accurately measure the liquid equivalent of snow, a double alter shield to minimise wind influences on precipitation totals, a present weather sensor, and a snow-depth sensor. Since this is located in the accumulation zone on the icecap, our team must raise the station approximately 2 meters each year to ensure the station does not get buried.

### Why are the tropical Andes particularly good for ice core analyses?

The majority of the world's population lives in the tropics but there are few good paleoclimatic archives in this part of the world. The tropical Andes comprise 99% of all tropical glaciers and several mountain summits have the necessary elevation and morphology to provide hundreds and sometimes thousands of annual layers of well-preserved ice that allow scientists to reconstruct past regional and global climates by drilling ice cores on their summits.

the precipitation to fall as rain on the tropical Andean glaciers. During the exceptional warmth accompanying the strong El Niño event of 2015-16, his team's measurements showed a similar rise occurred temporarily with 47% of the precipitation falling on glacier surfaces at 5000 m near La Paz falling as rain.

#### ANSWERS IN THE ICE

Thanks to the efforts of Dr Perry and his team, as well as technological aids, we are on our way to understanding atmospheric changes in this region like never before. A new analytical tool developed by collaborator Dr Anton

Seimon named QUIPU (Quelccaya Isotopic Profile Utility) is advancing the understanding and comparison between modern day  $\delta^{18}\text{O}$  profiles and the surrounding meteorology. This tool is essentially a shortcut to reconstructing ancient climates at a much greater efficiency from the data stored in ice. When observing the annual layer profiles (layers in the ice) and the  $\delta^{18}\text{O}$  readings, more detailed reconstructions of past climates are possible.

As this project progresses, Dr Perry and his team's new data are continuously processed

to refine meteorological models such as QUIPU, while at the same time, ominous projections can often be used to influence large organisations and policy makers who wish to adapt to and mitigate future climate changes. In the process, Dr Perry is collaborating with universities and inhabitants across and beyond the study area. This vital communication will be pivotal to raising awareness, gathering more information from this data-limited region, and inspiring a new generation of climate scientists at such an important time.

## Detail

#### RESEARCH OBJECTIVES

Dr Perry and his team are working with collaborators and partners worldwide on this five-year project that promotes collaborative interdisciplinary research, education, and outreach activities designed to advance scientific understanding of the multiscale atmospheric processes responsible for precipitation delivery in the tropical Andes Mountains.

#### FUNDING

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#### COLLABORATORS

Dr Anton Seimon, Dr Marcos Andrade, Dr Maxwell Rado, Nilton Montoya, Sandro Arias, Nelson Quispe, Dr Sandra Yuter, Dr Paul Mayewski, and Dr Doug Hardy

#### Institutes:

North Carolina State University, University of Maine, University of Massachusetts, Universidad Mayor de San Andrés (Bolivia), Universidad Nacional de San Antonio Abád del Cusco (Peru), Servicio Nacional de Meteorología e Hidrología (SENAMHI Peru), Grandfather Mountain Stewardship Foundation, and Watauga County Schools

#### BIO

Dr Perry is Graduate Program Director and an Associate Professor in the Department of Geography and Planning at Appalachian State University in Boone. He holds a PhD in Geography (Climatology) from the University of North Carolina and his research interests include precipitation formation in mountains, snow and ice, and precipitation-glacier-climate interactions.

#### CONTACT

L Baker Perry, PhD  
Graduate Program Director & Associate Professor of Geography  
375 Rankin Science West, 572 Rivers Street,  
Appalachian State University  
Boone, NC 28608  
USA

**E:** [perrylb@appstate.edu](mailto:perrylb@appstate.edu)

**T:** + 1 828-262-7597

**W:** <https://geo.appstate.edu/faculty-staff/faculty/baker-perry>

**Understanding how and when past climate changes occurred will greatly enhance our ability to predict, and adapt to similar events today**