AgroClim - Huaraz

Water availability and water demand of small-scale farmers in the Peruvian Andes

2019 – 2023

Final project report

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https://agroclim-huaraz.info

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Summary

In the semi-arid Peruvian Andes, the unique landscape and climatic conditions greatly influence local agriculture. Recent climate change, coupled with the growing demands for food and water in expanding cities, has presented significant challenges for small-scale subsistence farming. To develop effective adaptation strategies, it is crucial to accurately quantify the recent variability and changes in climate variables that are relevant to rain-fed agriculture. This will enable us to inform local stakeholders and farmers about current and near-future climate conditions and expected rainfall behavior.

Our interdisciplinary project employed a combination of atmospheric modeling, in-situ and remote sensing observations, and close collaboration with local farmers and scientists. We focused on a study area spanning from the Cordillera Negra to the Cordillera Blanca near Huaraz. The project financed three scientists from the University of Innsbruck (two postdocs and a PhD candidate) and fostered collaborations with institutions in Peru, the UK, France, and Switzerland. Despite facing significant challenges due to travel restrictions during the pandemic, the project achieved remarkable success.

One of our key accomplishments was the generation of new gridded climate data at an unprecedented resolution of 4 km for the period 1980–2018, in collaboration with the UK-based projects PeruGROWS and PEGASUS. These data allowed us to study past climate change, complementing intermittent past observations. By analyzing the complex interactions between atmospheric dynamics and precipitation variability in our study region and the wider subtropical Andes, we discovered that the onset of the rainy season, characterized by light precipitation, exhibits high variability between years. This poses a threat to local farmers when the rainfall arrives too late or is too intense. Our findings were further corroborated by remote sensing products, which confirmed the significant variability in the start of the growing season and revealed a notable greening during the dry season over the past two decades. In addition, using statistical methods, we downscaled global climate models to project future climate change. Projections suggest a substantial increase in temperature and precipitation by the late 21st century. Crucially, significant increases in precipitation extremes occur together with an intensification of meteorological droughts caused by increased evapotranspiration.

During the entire project, a strong emphasis was placed on capacity building and the dissemination of our results beyond traditional academic circles. We regularly organized workshops and training sessions with local partners, including the Universidad Nacional Santiago Antúnez de Mayolo (UNASAM) and the Autoridad Nacional del Agua (ANA). Some of our project members also participated in summer schools for Peruvian researchers and stakeholders, as well as the COP27 in Egypt, to raise awareness about the challenges faced by local agriculture in the context of climate change. Two of our collaborators and key members of the ANA in Huaraz were participating in the International Mountain Conference 2022 and the associated summer school. Our project results, publications, and datasets are all openly accessible and disseminated through our project website: http://agroclim-huaraz.info.

Zusammenfassung

In den semi-ariden Peruanischen Anden haben die einzigartigen Landschafts- und Klimabedingungen die lokale Landwirtschaft stark beeinflusst. Der Klimawandel und der wachsende Bedarf an Nahrungsmitteln und Wasser in den expandierenden Städten stellen die kleinbäuerliche Subsistenzwirtschaft vor große Herausforderungen. Um wirksame Anpassungsstrategien zu entwickeln, müssen die jüngsten Schwankungen und Veränderungen der Klimavariablen, die für die regenabhängige Landwirtschaft von Bedeutung sind, genau quantifiziert werden. Dadurch können Landwirte vor Ort über die aktuellen und zukünftigen Klimabedingungen und erwartete Niederschlagsveränderungen informiert werden.

Unser interdisziplinäres Projekt setzte auf eine Kombination aus atmosphärischer Modellierung, In-situ- und Fernerkundungsbeobachtungen sowie eine enge Zusammenarbeit mit Landwirten und Wissenschaftlern vor Ort. Wir konzentrierten uns auf ein Untersuchungsgebiet, das sich von der Cordillera Negra bis zur Cordillera Blanca bei Huaraz erstreckt. Das Projekt finanzierte drei Wissenschaftler der Universität Innsbruck (zwei Postdocs und einen Doktoranden) und förderte die Zusammenarbeit mit Institutionen in Peru, Großbritannien, Frankreich und der Schweiz. Trotz erheblicher Herausforderungen und Planänderungen aufgrund von Reisebeschränkungen während der Pandemie erzielte das Projekt bemerkenswerte Erfolge.

Eine unserer wichtigsten Errungenschaften war die Generierung neuer Klimadaten mit einer noch nie dagewesenen Auflösung von 4 km für den Zeitraum 1980-2018 in Zusammenarbeit mit den im Vereinigten Königreich angesiedelten Projekten PeruGROWS und PEGASUS. Diese Daten ermöglichten es uns, den vergangenen Klimawandel zu untersuchen und die sporadischen Beobachtungen der Vergangenheit zu ergänzen. Wir haben komplexe Wechselwirkungen zwischen der atmosphärischen Dynamik und der Niederschlagsvariabilität in unserer Untersuchungsregion und in den weiteren subtropischen Anden analysiert. Dabei haben wir festgestellt, dass der Beginn der Regenzeit, der durch leichte Niederschläge gekennzeichnet ist, von Jahr zu Jahr eine hohe Variabilität aufweist. Diese Variabilität stellt in Jahren, in denen die Niederschläge sehr spät oder intensiv eintreffen, eine große Herausforderung für die örtlichen Landwirte dar.. Fernerkundungsdaten bestätigten unsere Ergebnisse und zeigten einen bemerkenswerten und überraschenden Trend zu grüneren Oberflächen (mehr aktive Pflanzen) während der Trockenzeit in den letzten zwei Jahrzehnten. Zusätzlich haben wir mithilfe statistischer Methoden globale Klimamodelle auf eine höhere räumliche Auflösung skaliert, um zu erwartende klimatische Veränderungen in der Region zu prognostizieren. Die Projektionen deuten auf einen erheblichen Anstieg von Temperatur und Niederschlag bis zum Ende des 21. Jahrhunderts hin. Eine signifikante Zunahme der Niederschlagsextreme geht mit einer Intensivierung der meteorologischen Dürren einher, die durch eine erhöhte Evapotranspiration in niederschlagsarmen Perioden verursacht werden.

Während der gesamten Projektlaufzeit haben wir großen Wert auf den Aufbau von Kapazitäten und die umfassende Verbreitung unserer Ergebnisse über die traditionellen akademischen Kreise hinaus gelegt. Regelmäßig haben wir Workshops und Schulungen in Zusammenarbeit mit lokalen Partnern wie der Universidad Nacional Santiago Antúnez de Mayolo (UNASAM) und der Autoridad Nacional del Agua (ANA) organisiert. Darüber hinaus

haben einige unserer Projektmitglieder an Sommerschulen für peruanische Forscher und Interessenvertreter sowie an der COP27 in Ägypten teilgenommen, um das Bewusstsein für die Herausforderungen zu schärfen, denen sich die lokale Landwirtschaft angesichts des Klimawandels gegenübersieht. Zwei Projektpartner und wichtige Akteure der ANA in Huaraz waren zudem in die International Mountain Conference 2022 und die begleitende Sommerschule involviert. Unsere Projektergebnisse, Veröffentlichungen und Datensätze sind frei zugänglich und werden über unsere Projektwebsite http://agroclim-huaraz.info verbreitet.

Resumen

En los semiáridos Andes peruanos, el paisaje y las condiciones climáticas únicas ejercen una influencia significativa en la agricultura local. El cambio climático reciente, combinado con la creciente demanda de alimentos y agua en las ciudades en expansión, ha planteado desafíos importantes para la agricultura de subsistencia a pequeña escala. Para desarrollar estrategias de adaptación efectivas, es fundamental cuantificar con precisión la variabilidad y los cambios recientes de las variables climáticas relevantes para la agricultura de secano. Esto nos permitirá informar de manera adecuada a las partes interesadas locales y a los agricultores sobre las condiciones climáticas actuales y futuras, así como sobre el comportamiento proyectado de las precipitaciones.

Nuestro proyecto interdisciplinario empleó una combinación de modelización atmosférica, observaciones in situ y por teledetección, y una estrecha colaboración con agricultores y científicos locales. Nos enfocamos en un área de estudio que abarcó desde la Cordillera Negra hasta la Cordillera Blanca, cerca de Huaraz. El proyecto financió a tres científicos de la Universidad de Innsbruck (dos posdoctorandos y un doctorando) y promovió la colaboración con instituciones de Perú, Reino Unido, Francia y Suiza. A pesar de enfrentar desafíos significativos debido a las restricciones de viaje durante la pandemia, el proyecto logró un éxito notable.

Uno de nuestros logros más destacados fue la generación de nuevos datos climáticos a nivel de cuadrícula con una resolución sin precedentes de 4 km para el período de 1980 a 2018, en colaboración con los proyectos PeruGROWS y PEGASUS con sede en el Reino Unido. Estos datos nos permitieron examinar el cambio climático en el pasado y complementar las observaciones intermitentes previas. Al analizar las complejas interacciones entre la dinámica atmosférica y la variabilidad de las precipitaciones en nuestra región de estudio y en los Andes subtropicales más amplios, descubrimos una gran variabilidad en el inicio de la temporada de lluvias, que se caracteriza por precipitaciones ligeras. Esta variabilidad representa una amenaza para los agricultores locales cuando las lluvias llegan tarde o son demasiado intensas. Además, nuestros hallazgos fueron respaldados por productos de teledetección que confirmaron la significativa variabilidad en el inicio de la estación de crecimiento y revelaron un notable reverdecimiento durante la estación seca en las últimas dos décadas. También utilizamos métodos estadísticos para escalar los modelos climáticos globales y proyectar el cambio climático futuro, lo que nos permitió identificar un aumento sustancial en la temperatura y las precipitaciones para finales del siglo XXI. Es importante destacar que se prevé un incremento significativo en las precipitaciones extremas, así como una intensificación de las sequías meteorológicas causadas por el aumento de la evapotranspiración.

A lo largo de todo el proyecto, hicimos especial hincapié en el desarrollo de capacidades y en la difusión de nuestros resultados más allá de los círculos académicos tradicionales. Organizamos regularmente talleres y sesiones de formación en colaboración con socios locales como la Universidad Nacional Santiago Antúnez de Mayolo (UNASAM) y la Autoridad Nacional del Agua (ANA). Además, algunos miembros clave de nuestro equipo participaron en escuelas de verano dirigidas a investigadores y partes interesadas peruanas, así como en la COP27 en Egipto, con el objetivo de aumentar la conciencia sobre los desafíos que enfrenta la agricultura local en el contexto del cambio climático. Dos de

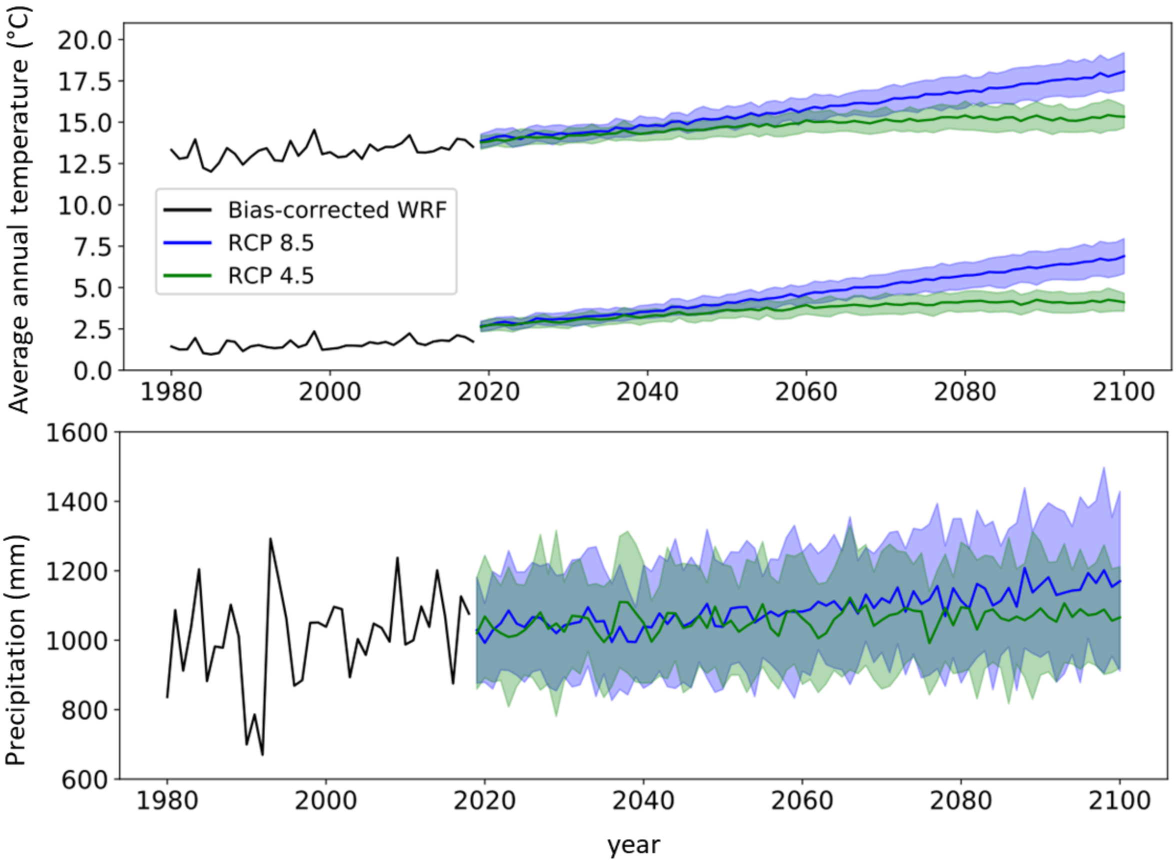
nuestros colaboradores y miembros clave de la ANA en Huaraz participaron en la Conferencia Internacional de Montaña 2022 y en la escuela de verano asociada. Todos nuestros resultados, publicaciones y conjuntos de datos son de acceso libre y se difunden a través de nuestro sitio web del proyecto: http://agroclim-huaraz.info.

Selected highlights

Publication highlight:
A future of extreme precipitation and drought in the Peruvian Andes

Potter et al., accepted for publication in npj Climate and Atmospheric Science

By running a high-resolution climate model over the Rio Santa region we unravel past climatic trends in precipitation and temperature. Future changes are determined from an ensemble of statistically downscaled global climate models. Projections under the high emissions scenario suggest a substantial increase in temperature of 3.6 °C, and a 12% precipitation increase by the late 21st century. Crucially, significant increases in precipitation extremes (accounting for around 75% of total precipitation on very wet days) occur together with an intensification of meteorological droughts caused by increased evapotranspiration.

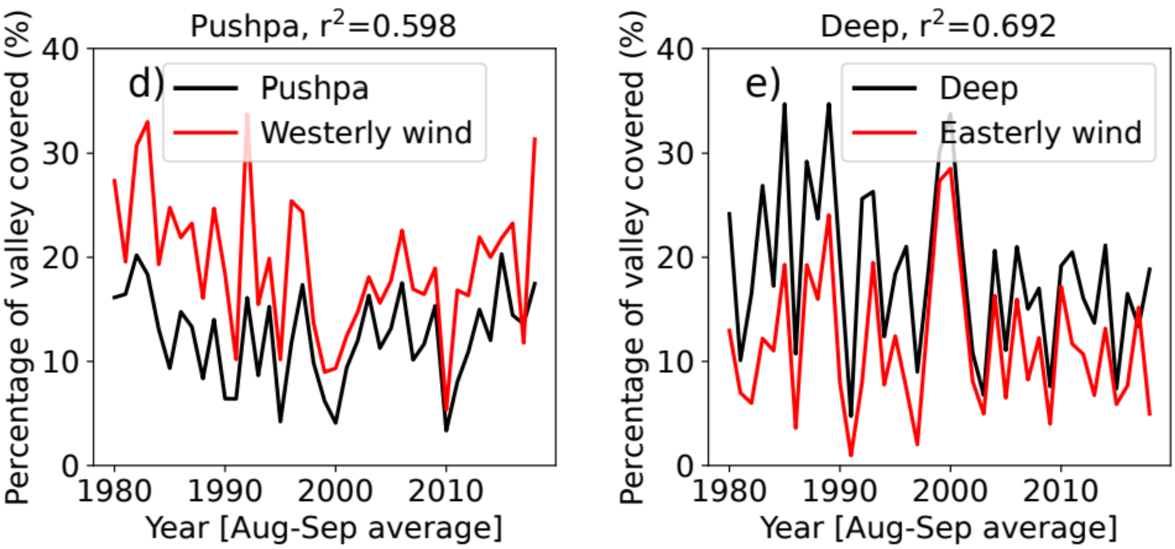


Paper summary figure: Timeseries of the basin-averaged recent past (1980-2018) and future (2019-2100) annual-averaged minimum and maximum daily temperature (top; °C) and precipitation (bottom; mm). Black lines show the basin-averaged values from the bias-corrected WRF hindcast. Blue lines show the mean of all statistically downscaled CMIP5 models for the RCP8.5 scenario, and green lines show the RCP4.5 scenario. Shading indicates one standard deviation from the mean (across the 30 statistically downscaled CMIP5 models).

Publication highlight: Farmers' first rain: investigating pushpa characteristics in the Peruvian Andes

Klein et al., in review for Environmental Research Communications

This study for the first time explored the characteristics and atmospheric drivers of August-September dry season rainfall in the Rio Santa valley, also known locally by farmers as "pushpa". Softening soils and improving sowing conditions, pushpa rains are crucial for planting dates and agricultural planning. Combining observations and convection-permitting model simulations, we found that pushpa rains coincide with dry, upper-level westerly winds that cause the small-scale, low rainfall intensities that are reportedly typical for pushpa. Larger, more intense rainfall events increase in frequency under more humid easterly winds in September. We identified high inter-annual and -decadal variability in the contribution to total area covered by rainfall from pushpa versus heavy rainfall types during the August-September key sowing period. The study highlights that the sowing and germination season is crucially affected by the balance of pushpa versus heavy rain, resulting in a higher probability for late first rains to be more intense. Based on our findings, we argue that improving the predictability of periods with prolonged westerly versus easterly wind could be a first step to better constrain the occurrence of rainfall types and the timing of the onset of the peak rainy season that brings heavy rains.

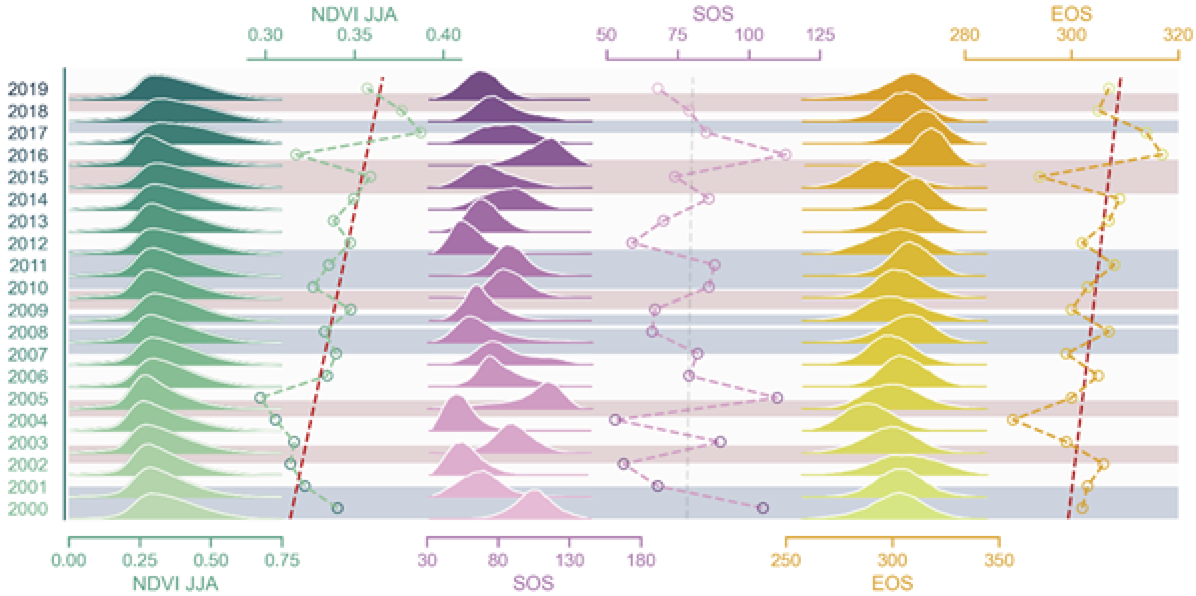


Paper summary figure: Based on 35 years of high-resolution Weather Research and Forecasting (WRF) model data (Potter et al. 2023, accepted), we identified the spatial rainfall cover extent of pushpa (left panel, black line) versus deep, heavy rainfall (right panel, black line). The spatial rainfall extent within the Rio Santa valley is highly variable from year to year, ranging from 5-23%. This behaviour is strongly correlated with the spatial coverage of 200 hPa westerly (left panel, red line) or easterly (right panel, red line) wind for pushpa and heavy rainfall, respectively. The strong link between rainfall type and upper-level wind direction may be an avenue for better prediction of rainfall types from large-scale dynamic drivers - which have higher predictability than rainfall itself.

Publication highlight: Widespread greening suggests increased dry-season plant water availability in the Rio Santa valley, Peruvian Andes

Hänchen, et al., Earth Syst. Dynam., doi:[10.5194/esd-13-595-2022](https://doi.org/10.5194/esd-13-595-2022)

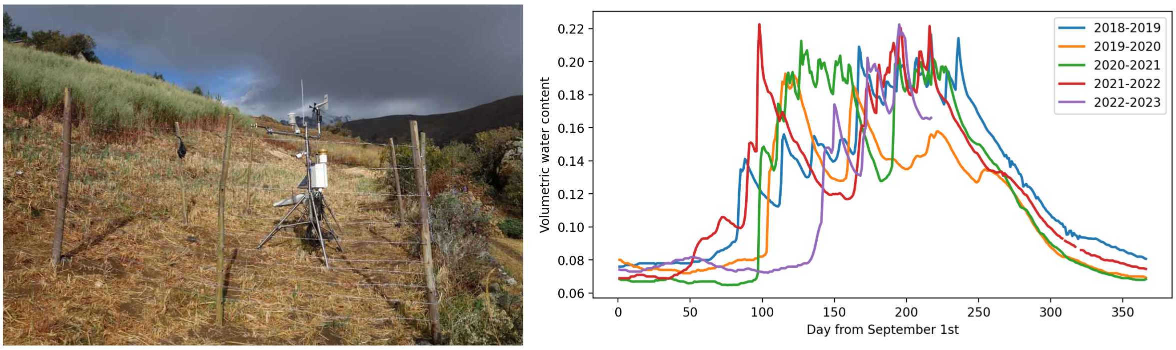
The main result of this study is a significant increase of plant greenness in the Rio Santa basin, particularly pronounced during the dry season, indicating an overall increase of plant available water over the past two decades. Regarding the seasonality of vegetation greening, we find a significant delay of the end of the growing season which matches the pattern of dry season greening and either implies a later retreat of the seasonal rainfalls or larger amounts of rainfall during the wet season feeding storages of the hydrological system. The start of the growing season, however, fluctuates highly from year to year with variation of up to two months, governing the overall growing season length. This variability is likely linked to the perception of local farmers, as it hampers the planning of sowing dates and overall complicates successful farming.



Paper summary figure: Pairwise figures for the average NDVI value of dry season (JJA, June, July, August). NDVI (Normalized Difference Vegetation Index) is an indicator for plant greenness and dimensionless. SOS and EOS are the start and end of the growing season in days from September 1st of the corresponding year. The ridgelines are showing the distribution over the study region of the corresponding values for each growing season. For SOS and EOS, a smaller width of the distribution can be interpreted as plant growth in the Rio Santa basin being temporally more uniformly, while a larger width shows larger deviations of the timing within the domain. The line plots show the median values of the ridgelines on a narrower axis limit to visualize the trends. By this, we can see the greening trend in the dry season, a trend towards later EOS and no significant trend for the SOS. Additionally, the plots display the large variability of SOS over the observation period while the EOS shows comparably less variability. In the background the phases of ENSO are displayed. Red (blue) colour corresponds to El Niño (La Niña) periods and no colour to neutral conditions.

Dataset highlight: 5 years of measurement in the community of Llupa

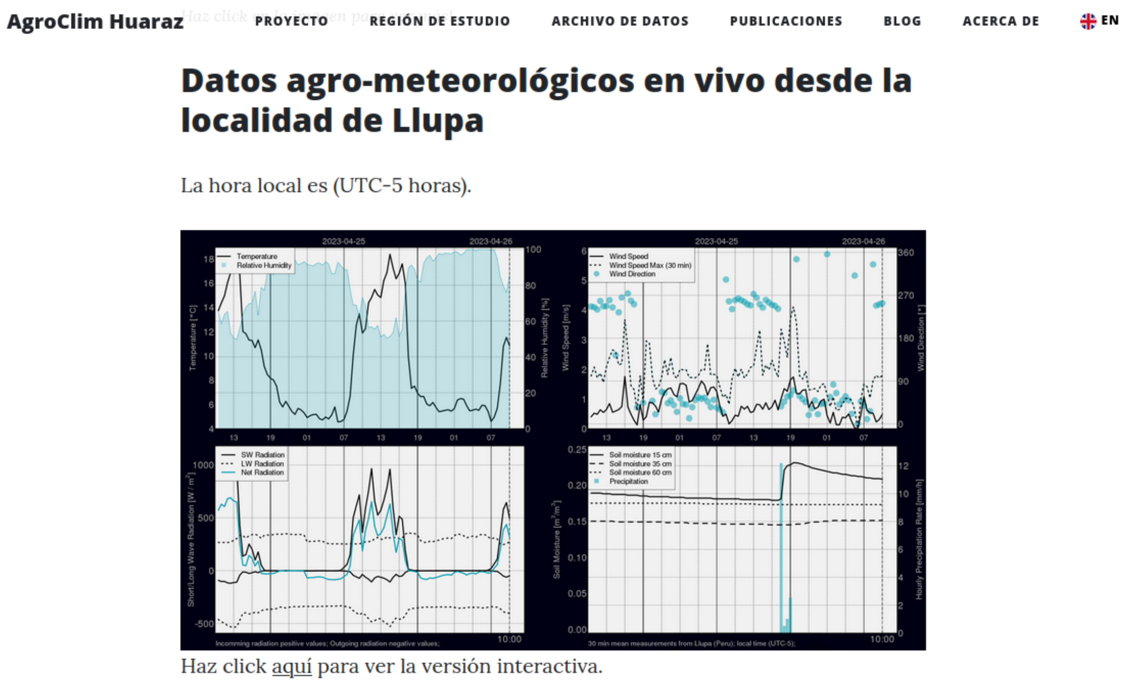
The automatic weather station installed in 2018 and maintained during the project continues to operate today. It measures important agro meteorological variables such as radiation, temperature, precipitation, as well as soil moisture content and temperature (very rarely available in this data scarce region). The station is installed on Hector Horopeza’s field at 3747 m a.s.l. Thanks to a long standing collaboration with Hector, the communication with the local community at Llupa has been very successful and the presence of the station has been accepted by the community.



Left: picture of the weather station in 2018. Right: 5 years of measurements of soil volumetric water content at 60 cm depth in the soil below the weather station. It illustrates very well the variability of the start of the rainy season between years.

Dataset highlight: Open data practices in AgroClim-Huaraz

All project outputs are openly accessible. Major project publications (Hänchen et al., 2022; Klein et al., 2023a,b; Potter et al., 2023) are published in gold open access (or soon will be). All data gathered during the project are available for download without restriction at agroclim-huaraz.info/live and will remain accessible on https://acinn-data.uibk.ac.at on the long term.



Screenshot of the spanish version of the project webpage http://agroclim-huaraz.info/es/live showing live data from the Llupa agrometeorological station.

Outreach highlight: AgroClim-Huaraz symposium at UNASAM

In April 2023, during the final month of our project, we organized a symposium together with our partners at the local university in Huaraz, UNASAM. The event attracted a lot of attention from local students, stakeholders from local institutions, and the interested public. During the presentation, we used a hybrid of Spanish and English, and both our team and our Peruvian partners gave talks that sparked a productive discussion.

Climate Variability and Changes in the Peruvian Andes: Consequences and risks for local communities
Variabilidad y Cambio Climático en los Andes Peruanos: Consecuencias y riesgos para las comunidades locales

FECHA: Miércoles 05 de abril
HORA: 15:30 - 19:00 (GTM-5)
LUGAR: Auditorio de la FCAM (J-104) - Shancayán, Huaraz, Perú

Inscripciones		
15:00 - 15:30		En el auditorio de la FCAM.
Detalle del Simposio		
15:30 - 15:40		Palabras de bienvenida y apertura al simposio
		Pedro Liberato Valladares Jara Decano de la Facultad de Ciencias del Ambiente - FCAM
15:40 - 16:00	Tema 1:	Lessons learned from the AgroClim-Huaraz research project (2019-2023)
	Ponente:	Fabien Maussion Investigador University of Innsbruck, Austria / University of Bristol, UK
16:00 - 16:20	Tema 2:	Proyectos en glaciares desarrollados por la UNASAM: IAT-Glaciar, GlaEs-FotoVideo y MicroDebris-Glacier
	Ponente:	Edwin Loarte Cadenas Investigador de la UNASAM - CCSH - AIRSEN
16:20 - 16:40	Tema 3:	Farmers' first rain: investigating pushpa characteristics in the Peruvian Andes
	Ponente:	Cornelia Klein Investigadora University of Innsbruck, Austria / UK Centre for Ecology & Hydrology, UK
16:40 - 17:00		Preguntas del público (1ra ronda)
17:00 - 17:20	Tema 4:	Variación del albedo y su relación con el derretimiento de glaciares en el Perú
	Ponente:	Rolando Cruz Encarnación Investigador de la ANA, Perú
17:20 - 17:40	Tema 5:	A future of extreme precipitation and drought in the Peruvian Andes
	Ponente:	Emily Potter Investigadora University of Innsbruck, Austria
17:40 - 18:00	Tema 6:	Widespread greening suggests increased dry-season plant water availability in the Rio Santa valley, Peruvian Andes
	Ponente:	Lorenz Hänchen Investigador University of Innsbruck, Austria
18:00 - 18:20		Preguntas del público (2da ronda)
18:20 - 18:40	Tema 7:	Hydrological impact monitoring in 2 Andean micro-watersheds
	Ponente:	Danny Robles Sanchez Investigador del CIAD - UNASAM, Perú
18:40 - 18:50		Palabras de cierre del simposio
		Fabien Maussion Investigador principal del proyecto "AgroClim Huaraz"

Promotional flyer and timetable of the event. (Source: Edwin Loarte, UNASAM)

Crowded room during Cornelia Klein's talk. (Photo: Lorenz Hänchen)

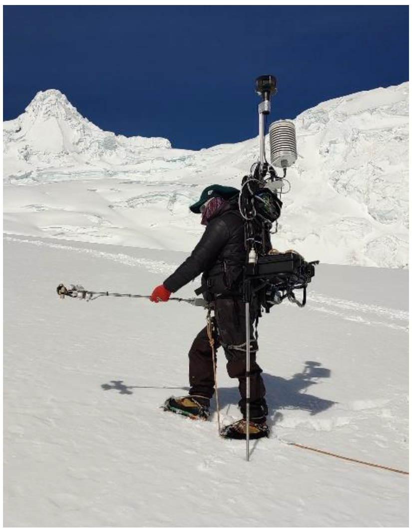
Outreach highlight: COP27

Project PI Fabien Maussion joined the Conference of Parties (COP27) in Sharm-El-Sheik, Egypt, in November 2022. There he was a presenter and panelist at the side event "*State of the Cryosphere in Peru: Progress and Challenges for Adaptation to Climate Change*" organized by the Ministry of the Environment of Peru and INAIGEM (*Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña*).

Left: Fabien Maussion presenting at the COP27 cryosphere pavilion. Right: panelists at the side event and members of the Peruvian delegation at COP27 (Photos: Mira Khadka).

Capacity building highlight: Rolando Cruz Encarnación

Rolando Cruz Encarnacion (research and field scientist at the ANA) was a key partner for the project. During the duration of the project and while working at ANA, he decided to study in his free time for a master degree in environmental engineering (obtained in 2022 at UNASAM). In 2023, he registered for PhD studies at the Universidad Nacional Agraria La Molina in Lima, with project leader Fabien Maussion as co-supervisor. The AgroClim Huaraz project supported him in these endeavors by inviting him to Innsbruck twice (once for the project kickoff and a second time for the International Mountain Conference 2022 and the associated summer school) as well as by training him in new monitoring techniques and meteorological station maintenance.



Left: As our fieldwork did not go as planned in light of the pandemic, Rolando could profit from the training with the EcoBot he received. For his original research within ANA on surface energy balance of glacier surfaces he could take measurements with our mobile device. Right: temporarily lending sensors to the ANA led to improved data for their studies. (Photos: Rolando Cruz Encarnacion)

Project output

Peer-reviewed publications

Project publications
Rainfall and vegetation in the Peruvian Andes

In preparation

- Potter et al: Mechanisms of precipitation in the Peruvian Andes: ENSO and extremes
- Hänchen et al.: Elevation-dependent surface temperature change and its drivers on global scale
- Hänchen et al.: Determining and validating rainy season metrics in the Peruvian Andes

In review / accepted

- Potter, E.R., Fyffe, C.L., Orr, A., Quincey, D.J., Ross, A.N., Rangecroft, S., Medina, K., Burns, H., Llacza, A., Jacome, G., Hellström, R.Å., Castro, J., Cochachin, A., Loarte, E. and Pellicciotti, F.: A future of extreme precipitation and drought in the Peruvian Andes, NPJ Climate and Atmospheric Science, accepted
- Klein C, Potter ER, Zauner C, Gurgiser W, Encarnación RC, Rapre AC, Maussion F: Farmers' first rain: investigating pushpa characteristics in the Peruvian Andes, Environmental Research Comms., in review

Published

- Klein, C., Hänchen, L., Potter, E. R., Junquas, C., Harris, B. L. and Maussion, F.: Untangling the importance of dynamic and thermodynamic drivers for wet and dry spells across the Tropical Andes, Environ. Res. Lett., 18(3), 034002, doi:10.1088/1748-9326/acb72b, 2023.
- Hänchen, L., Klein, C., Maussion, F., Gurgiser, W., Calanca, P., and Wohlfahrt, G.: Widespread greening suggests increased dry-season plant water availability in the Rio Santa valley, Peruvian Andes, Earth Syst. Dynam., 13, 595–611, doi:10.5194/esd-13-595-2022, 2022.
- Fyffe, C. L., Potter, E., Fugger, S., Orr, A., Fatichi, S., Loarte, E., et al. (2021). The energy and mass balance of Peruvian glaciers. Journal of Geophysical Research: Atmospheres, 126, e2021JD034911. https://doi.org/10.1029/2021JD034911

Broad-scope collaborative publications
Rainfall variability in the subtropics and tropics

- Semeena, V. S., Klein, C., Taylor, C. M., & Webster, S. (2023). Impact of land surface processes on convection over West Africa in convection-permitting ensemble forecasts: A case study using the MOGREPS ensemble. Atmospheric Science Letters, e1167. https://doi.org/10.1002/asl.1167

- Crook, J., Klein, C., Folwell, S., Taylor, C. M., Parker, D. J., Bamba, A., and Kouadio, K. (2023): Effects on Early Monsoon Rainfall in West Africa due to Recent Deforestation in a Convection-permitting Ensemble, Weather Clim. Dynam., https://doi.org/10.5194/wcd-2022-49
- Fletcher, J. K., [...], Klein, C. M., et al.: Tropical Africa's first testbed for high-impact weather forecasting and nowcasting, Bull. Am. Meteorol. Soc., https://doi.org/10.1175/BAMS-D-21-0156.1, 2022.
- Talib, J., Taylor, C. M., Klein, C., Harris, B. L., Anderson, S. R. and Semeena, V. S. (2022): The sensitivity of the West African monsoon circulation to intraseasonal soil moisture feedbacks, Q. J. R. Meteorol. Soc., 148(745), 1709–1730, https://doi.org/10.1002/qj.4274
- Taylor, C. M., Klein, C., Dione C., Parker DJ., Marsham J, Diop CA., Fletcher J., Chaibou AAS., Dignon BN., Shamsudheen SV. (2022): Nowcasting tracks of severe convective storms in West Africa from observations of land surface state, Environ. Res. Lett. 17 034016, https://doi.org/10.1088/1748-9326/ac536d
- Taylor, C. M., Klein, C., Parker, D. J., Gerard, F., Semeena, V. S., Barton, E. J. and Harris, B. L. (2022): "Late-stage" deforestation enhances storm trends in coastal West Africa, PNAS, 119(2), https://doi.org/10.1073/pnas.2109285119
- Klein, C., Jackson, L. S., Parker, D. J., Marsham, J. H., Taylor, C. M., Rowell, D. P., Guichard, F., Vischel, T., Famien, A. M. and Diedhiou, A. (2021): Combining CMIP data with a regional convection-permitting model and observations to project extreme rainfall under climate change, Environ. Res. Lett., 16(10), https://doi.org/10.1088/1748-9326/ac26f1
- Klein, C., Nkrumah, F., Taylor, C. M., & Adefisan, E. A. (2021). Seasonality and Trends of Drivers of Mesoscale Convective Systems in Southern West Africa, Journal of Climate, 34(1), 71-87, https://doi.org/10.1175/JCLI-D-20-0194.1
- Barton EJ, Taylor CM, Klein C, Harris PP, Meng X (2021): Observed Soil Moisture Impact on Strong Convection over Mountaineous Tibetan Plateau, J. Hydrometeorol., 22(3), 561–572, https://doi.org/10.1175/JHM-D-20-0129.1
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Master theses

During the project

- Albrecht, P. (2022): Past climate change in the Rio Santa Basin, Peruvian Andes, https://diglib.uibk.ac.at/ulbtirolhs/content/titleinfo/7149410

- Stockhard, M. (2022): Elevation-dependent surface temperature changes in the Andes. MSc thesis Universität Bayreuth, https://agroclim-huaraz.info/img/MA_Stoeckhardt.pdf
- Wöckinger, S. (2022): High Resolution Climate Simulations in the Rio Santa Basin, Peru, with COSMO-CLM-GPU, https://diglib.uibk.ac.at/ulbtirolhs/content/titleinfo/7301691
- Schirmeister, Z. (2021): Future climate change in the Peruvian Andes as described by CORDEX data, https://diglib.uibk.ac.at/ulbtirolhs/content/titleinfo/5884055
- Zauner, C. (2021): Meteorological analysis of a Puspa rain event in the Callejón de Huaylas, Peruvian Andes, with the help of atmospheric simulations and observations, https://diglib.uibk.ac.at/ulbtirolhs/content/titleinfo/5548678

In preparation for the project

- Schlumpberger, M. (2017): Wet and dry spells in the Rio Santa Basin, Peruvian Andes, and connections to the large scale circulation, http://diglib.uibk.ac.at/urn:nbn:at:at-ubi:1-6985
- Siller, M. (2017): WRF simulation of wet and dry spells in the Rio Santa Basin, Peruvian Andes - A WRF Modeling Case Study, http://diglib.uibk.ac.at/urn:nbn:at:at-ubi:1-7816

Conferences contributions (selection)

International Mountain Conference 2022:

- Potter, E., Fyffe, C., Orr, A., Quincey, Q., Ross, A., Rangecroft, S., Medina, K., Burns, H., Llacza, A., Jacome, G., Hellström, R., Castro, Cochachin, A., Klein, C., Loarte, L., Pellicciotti, F.: Projected increases in climate extremes and temperature-induced drought over the Peruvian Andes, 1980-2100. European Geosciences Union (EGU) General Assembly 2022, Wien 24.05.2022
- Stöckhardt, M. Co-AutorInnen: Hänchen, L.; Thomas, C.; Maussion, F.; Wohlfahrt, G.: Elevation-Dependent Surface Temperature Changes In The Andes. International Mountain Conference (IMC2022), Innsbruck, 14.09.2022.

European Geosciences Union 2022:

- Potter, E., Fyffe, C., Orr, A., Quincey, Q., Ross, A., Rangecroft, S., Medina, K., Burns, H., Llacza, A., Jacome, G., Hellström, R., Castro, J., Hosking, J.S., Cochachin, A., Klein, C., Loarte, L., Pellicciotti, F.: Projected increases in climate extremes and temperature-induced drought over the Peruvian Andes, 1980-2100. European Geosciences Union (EGU) General Assembly 2022, Wien 24.05.2022
- Stöckhardt, M. Co-AutorInnen: Hänchen, L.; Thomas, C.; Maussion, F.; Wohlfahrt, G.: Elevation-dependent surface temperature changes in the Andes. European Geosciences Union (EGU) General Assembly 2022, Wien, hybrid, 24.05.2022.

American Geosciences Union 2021:

- Hänchen, Lorenz Co-AutorInnen: Klein, Cornelia; Maussion, Fabien; Gurgiser, Wolfgang; Calanca, Pierluigi; Wohlfahrt, Georg: Vegetation Indices as Proxies for spatio-temporal Variations in Water Availability in the Rio Santa Valley (Peruvian

Andes). American Geophysical Union (AGU) Fall Meeting 2021, New Orleans, hybrid, 14.12.2021.

European Geosciences Union 2021:

- Hänchen, L., Klein, C., Gurgiser, W., Maussion, F., Wohlfahrt, G.: Vegetation indices as a proxy for spatio-temporal variations in water availability in the semi-arid Rio Santa valley. European Geosciences Union (EGU) General Assembly 2021, Wien

Conectate A+ 2020:

- Maussion, F., Klein, C., Hänchen, L., Wohlfahrt, G., Gurgiser, W., Calanca, P., Cochachín Rapre, A., Cruz Encarnación, R., and Quiñonez Collas, F.: AgroClim Huaraz: water availability and water demand of small-scale farmers in the Rio Santa basin. Online conference Conectate A+,, 2020

European Geosciences Union 2020:

- Hänchen, L., Wohlfahrt, G., Gurgiser, W., Maussion, F., Calanca, P., Cochachín Rapre, A., Cruz Encarnación, R., and Quiñonez Collas, F.: Agro-climatic observations in Huaraz, Peru – first insights from water, energy and carbon dioxide flux measurements. European Geosciences Union (EGU) General Assembly 2020, Wien
- Klein, C., Gurgiser, W., and Maussion, F.: Observed local drivers of rainfall variability and changes in the Rio Santa Basin, Tropical Andes of Peru. European Geosciences Union (EGU) General Assembly 2020, Wien

Capacity building and impact beyond academia

- Potter, E., Fyffe, C., Orr, A., Quincey, Q., Ross, A., Rangecroft, S., Medina, K., Burns, H., Llacza, A., Jacome, G., Hellström, R., Castro, J., Hosking, J.S., Cochachin, A., Klein, C., Loarte, L., Pellicciotti, F.: “Projected increases in climate extremes and temperature-induced drought over the Peruvian Andes, 1980-2100”. Guest Lecturer in the summer school “Ecosistemas Andinos y Cambio Climático”, 2022 (Ecosystems and climate change in the Andes) to Peruvian and researchers and stakeholders.
- Fabien Maussion (2022): participation in the COP27 conference in Egypt. Interventions on the topics of glacier change, including a side event with the Peruvian delegation with the title *“State of the Cryosphere in Peru: Progress and Challenges for Adaptation to Climate Change”* (see “highlights”)
- Fabien Maussion (2019-present): several contributions to training and workshops at the UNASAM university in Huaraz, including capacity building on meteorology and glaciology.
- Lorenz Hänchen (2019): training for local scientists to maintain and run automatic weather stations and conduct biomass and albedo measurements on selected crops.
- Emily Potter (2023): Emily presented results on behalf of the whole project at the Geophysical Institute of Peru, in Lima. Two students working with the IGP also presented their thesis work. There was considerable discussion after the seminar, and ongoing talks about possible future collaborations.

Detailed report and work-packages

For each work-package (WP), we will start by summarizing the WP **objectives**, the WP **changes** to the original plans. This summary is followed by a description of the **outputs** (published papers, student theses, non-published outputs, etc.).

The accepted project proposal can be downloaded here.

Staff

Faculty at University of Innsbruck (in-kind contribution):
- Assoc. Prof. Fabien Maussion
- Assoc. Prof. Georg Wohlfahrt
- Dr. Wolfgang Gurgiser

Hired on project funds:
- Dr. Cornelia Klein (Postdoc, 70% from December 2019 to August 2021, and 20% from September 2021 to April 2023)
- Dr. Emily Potter (Postdoc, 100% from March 2022 to February 2023, and 75% from March 2023 to April 2023)
- Lorenz Hänchen (PhD candidate, 75% from May 2019 to April 2023)

Local partners (in-kind contribution, partly funded):
- Alejo Cochachín Rapre (Autoridad Nacional de Agua, Unidad de Glaciología y Recursos Hídricos)
- Rolando Cruz Encarnación (Autoridad Nacional de Agua, Unidad de Glaciología y Recursos Hídricos)
- Fiorella Quiñonez Collas (student from UNASAM)
- Hector Oropeza Chinchay (farmer in Llupa)

Project partners (in-kind contribution):
- Pierluigi Calanca (Agroscope, Zürich, Switzerland)
- Thomas Condom (Institute of Research for Development, Grenoble, France)
- Clémentine Junquas (Institute of Research for Development, Grenoble, France)
- Christian Huggel (University of Zürich, Switzerland)
- Martina Neuburger (Universität Hamburg, Germany)

Master students (in-kind contribution): Peter Albrecht, Marie Stöckhardt, Simon Wöckinger, Cornelia Zauner, Zora Schirmeister, Miriam Schlumpberger, Maria Siller.

WPA Atmospheric modelling

Objectives

The purpose of WPA was to: *"provide reliable climate information at a spatio-temporal resolution suitable for addressing rain-fed farming related questions in our study region. These data will be obtained from a variety of sources, but the central product of the project will originate from a high-resolution, physically consistent downscaling experiment for the period 1980 to present, using a modelling strategy specifically designed for this project".*

The specific subpackages were:
WPA.1 Downscaling setup, implementation, production, and post-processing
WPA.2 Validation and uncertainty assessment
WPA.3 Precipitation: processes and drivers

Changes

There were no significant changes to the proposed plan except that the atmospheric simulations were run in collaboration. All objectives have been reached beyond expectations. Unlike originally planned, the simulations were not run at the University of Innsbruck but in collaboration with a NERC funded project in the UK (Peru GROWS), with participation of Dr. Emily Potter, who was subsequently hired on the project to finalize the dataset. This excellent collaboration led to a number of joint publications and avoided useless work duplication.

Outputs

- Climate model data at 4 km resolution over the Rio Santa basin for 1980 to 2018. This dataset is unprecedented in resolution and accuracy. It will be made available soon, together with the scientific publication Potter et al. (accepted)
- This data, and other high-resolution climate data is used in an accepted paper (Potter et al., 2023), and one under review (Klein et al., 2023)
- 4 master theses that dealt with atmospheric modeling in particular
- Precipitation processes have been investigated, including the drivers behind wet and dry spells across the Tropical Andes as well as local dry-season rain, the effects of the El Niño–Southern Oscillation (ENSO) on precipitation, and the causes of extreme wet season precipitation.

Detailed summary

We ran the WRF model at 2 km resolution to investigate a specific precipitation event observed and captured by the network of observational stations. We also used output from a high-resolution climate model (the Weather Research and Forecasting (WRF) model V3.8), which was run at 12 km resolution over Peru and 4 km resolution over the Rio Santa Basin (and the Vilcanota-Urubamba basin to the south) from 1980-2018. These data were validated and bias-corrected against a network of precipitation and temperature sensors in and around the Rio Santa.

These data have been used as the basis for one accepted paper (Potter et al., 2023), one in review (Klein et al., 2023) and one in preparation (Potter et al., 2023). Between these papers we investigate the processes of drivers of wet events in August and September (the end of the dry season), the effects of ENSO on precipitation, and the drivers of extreme precipitation. Details are given below.

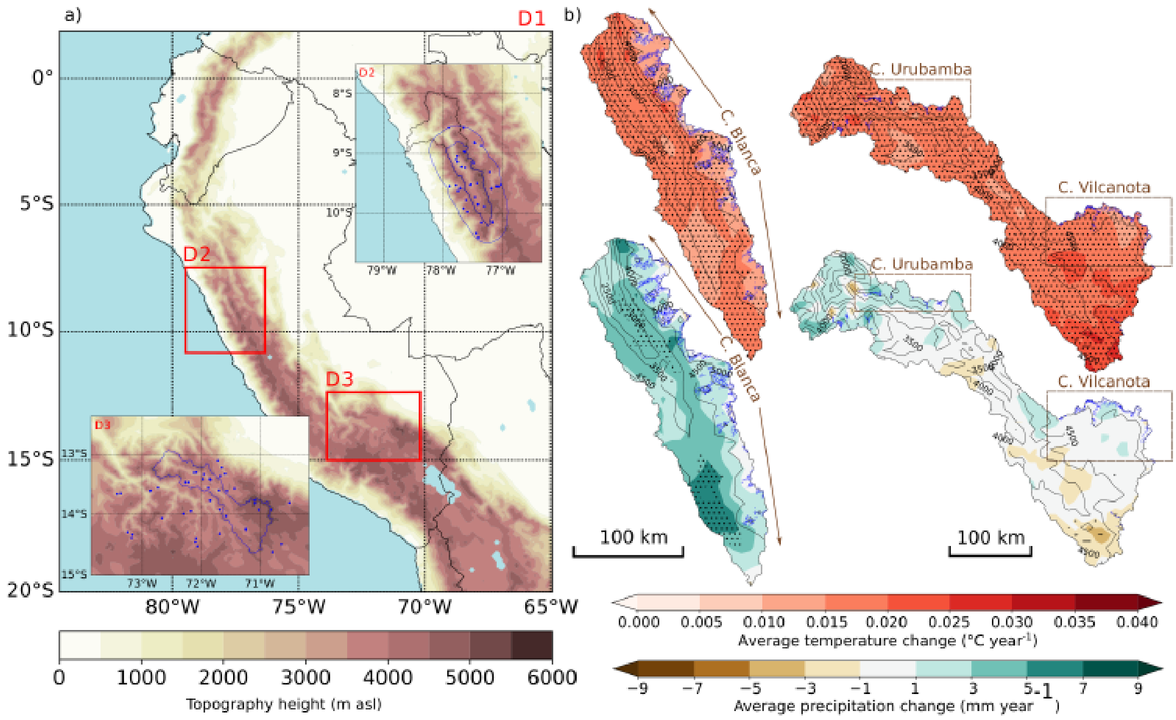

Figure: (a) The three WRF model domains (D1-D3) used for the 1980 to 2018 hindcast. The outer domain, D1, covers all of Peru at 12 km resolution. D2 and D3 show the inner domains at 4 km resolution, covering the Rio Santa basin and the Vilcanota-Urubamba basin, respectively. The two river basins are outlined in black, with the upper Rio Santa and 30km boundary from which station data were used are outlined in blue. The terrain height is shown as lled contours, the ocean and other water bodies are shown in blue, and all stations used in the bias-correction are shown as blue dots. (b) The 1980-2018 annual trends in temperature (top; °C/year) and precipitation (bottom; mm/year) from the bias-corrected WRF hindcast, shown spatially for the upper Rio Santa (left) and Vilcanota-Urubamba (right), with stippling indicating areas of significant trend and black contours showing elevation in 500m intervals. The location of the Cordillera Blanca is shown with brown arrows, and the Cordilleras Urubamba and Vilcanota are shown as brown boxes. The outlines of the glaciers are shown in blue.

Precipitation increased over the Rio Santa by an average of 3.1 mm/year between 1980 and 2018 according to the bias-corrected WRF data, but the increases are only statistically significant over the south-west of the region (Fig. 1. b.). In the Vilcanota-Urubamba, precipitation has increased in the north of the basin, around the Cordillera Urubamba, and decreased in the south, but with no statistically significant trends when considered annually (Fig. 1. b.). In September-October-November (SON) there is statistically significant drying over some glacierized regions of both the Rio Santa and the Cordillera Urubamba, as well as in the south of the Vilcanota-Urubamba Basin (not shown here). The combination of a particularly large increase in temperature and a reduction in precipitation in September-October-November (which is the end of the dry season), is likely to have been particularly damaging to the glaciers, which have the lowest snow cover and therefore lower albedos at this time. A drying trend during the start of the wet season may also lead to agricultural changes, as September rainfall is important for crop sowing.

Considering rainfall mechanisms, we investigated atmospheric drivers of rainy or dry periods of 3-7 day length (i.e. 3-7 day wet and dry spells) based on combining cloud cover and rainfall estimates from satellite data with an atmospheric reanalysis.

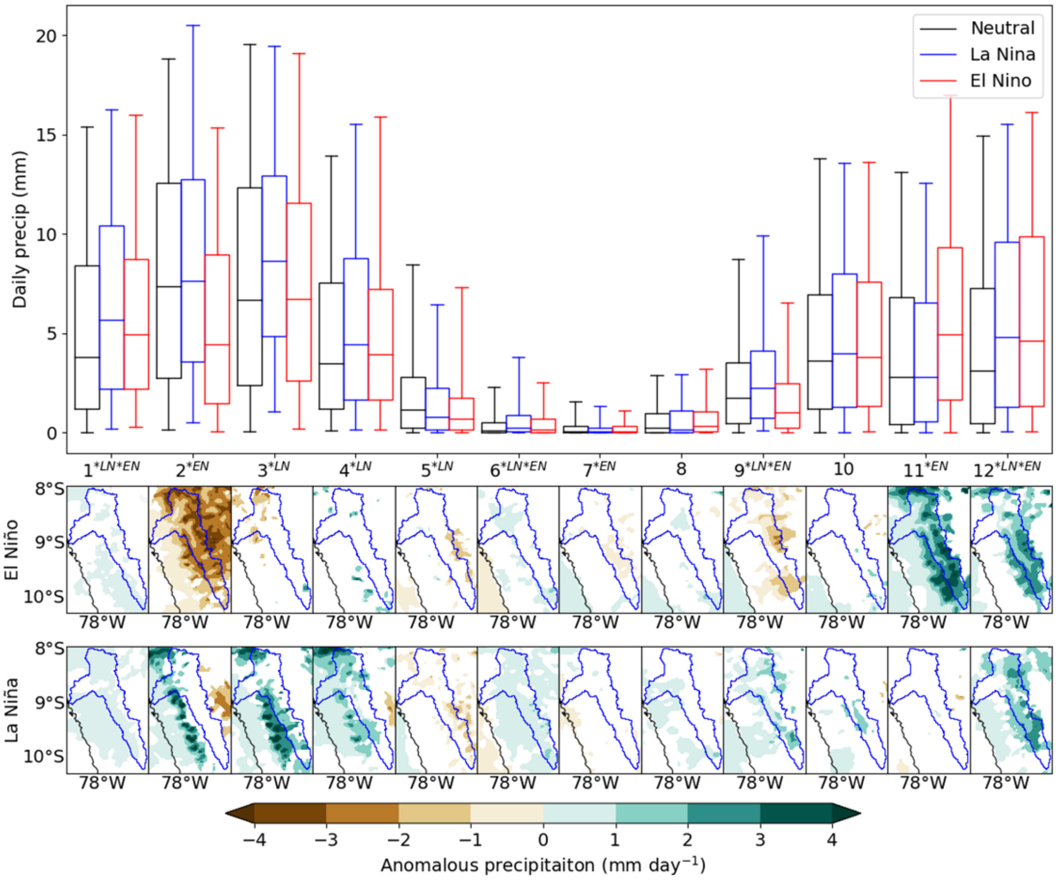

Figure: The effects of ENSO on precipitation patterns in the Rio Santa. The bar plot shows the valley-averaged precipitation for each month in neutral (black) El Niño (red) and La Niña (blue) years from 1980-2018, with the middle bar showing showing the median year (for that month), box edges showing the 25th and 75th quantiles, and the whiskers showing the maximum and minimum year. Starred months show statistical significant differences between El Niño (EN) or La Niña (LN) years, compared to neutral years. The contour plots show the spatial distribution of anomalous daily precipitation in El Niño (top) or La Niña (bottom) months, with only statistically significant pixels shown.

Data from the 4 km resolution dataset were used to determine the effects of the El Niño Southern Oscillation (ENSO) on precipitation in the Rio Santa between 1980 and 2018. We find a drying signal from El Niño in February, but that November and December are generally wetter in El Niño years. These results are relatively spatially consistent over the valley, with larger anomalies at higher elevations (which are wetter in general) (Fig ?). La Niña years are generally slightly wetter in the wet season (December to April), but this wetting signal is strongest on the western side of the Cordillera Negra, mostly out of the Rio Santa basin boundary (Fig ?). Overall, this suggests that the wet season may start earlier during El Niño years, but the peak precipitation months may be less strong.

WPB Crop modelling

Objectives

The objectives of WPB were to "*Assess crop water demand for a range of crops and agricultural management practices using a comprehensive crop model. Soil samples collected during targeted field campaigns, along with a blend of stationary and mobile field observations, remote sensing and agricultural census data will be used to calibrate and verify the model. Crop choices and agricultural methods will be investigated to reflect the most common practices in smallholder agriculture in the study region*."

The specific subpackages were:
WPB.1 In-situ data acquisition
WPB.2 Adding NDVI capability to AquaCrop
WPB.3 Plot-scale calibration and validation of AquaCrop for present day conditions

Changes

This WP was severely affected by the COVID pandemic. Initially, all activities went as planned – the equipment to be deployed in Peru was assembled and tested at the University of Innsbruck and then in September 2019 a group of three flew to Peru to set up the eddy covariance flux system to continuously measure the seasonal variation of evapotranspiration at a field site provided by a local farmer. In order to quantify the spatial variability in evapotranspiration between different crops, the EcoBot (Wohlfahrt & Tasser, 2015) was also brought to Peru. During the following 3 months, PhD student Lorenz Hänchen remained in Huaraz for selecting the EcoBot study sites and teaching local collaborators from ANA and UNASAM how to maintain the eddy covariance measurements and conduct the EcoBot measurements. During this period and the following 3 months all activities went as planned. As an example, we show the eddy covariance CO2 flux time series in the figure below, which nicely illustrates the phenological development of the sown crop which manifests in a steady increase in the daytime net uptake of CO2. First campaigns with the EcoBot were conducted as well and showed promising results as demonstrated in Fig. x, which compares the energy balance components as measured with the EcoBot and the eddy covariance method. Due to the severe lockdown in Huaraz and the travel restrictions, those activities came to a halt in spring 2020 and thus the critical period of the final phase of crop development and harvesting towards the end of the rainy season could not be captured and thus the goals of WPB.1 could not be reached. Lacking the data for calibration and validation of the AquaCrop model, the goals of WPB.3 could not be reached as well. Given the failure of WPB.3, there was no point in adding NDVI capability to the AquaCrop model and thus also WPB.2 failed to achieve its goals.

In order to make the best out of the situation and still achieve the goals of WPB, the project team decided to build up on the idea underlying WPB.2 and work with remotely sensed NDVI as an integrated proxy for water demand and supply. The results of this work were published in Hänchen et al. (2022). The main result of this study is a significant greening trend, which mainly results from greening during the dry season, suggesting higher water availability, which is not or only poorly captured in existing precipitation records. The study also demonstrated the start of the growing season to be highly variable, which reflects the farmers perception of increasing difficulties in determining the correct timing for sowing crops. This in turn suggests that local farmers could greatly profit from reliable mid-term precipitation forecasts during the months of October to November in order to plan crop sowing.

Outputs

- Incomplete eddy covariance, EcoBot and biomass datasets. These data are available on demand
- Capacity building and strong collaboration with local partners despite of the pandemic
- Publication: Hänchen et al. (2022) see “Highlights”
- Publications in preparation: Hänchen et al.

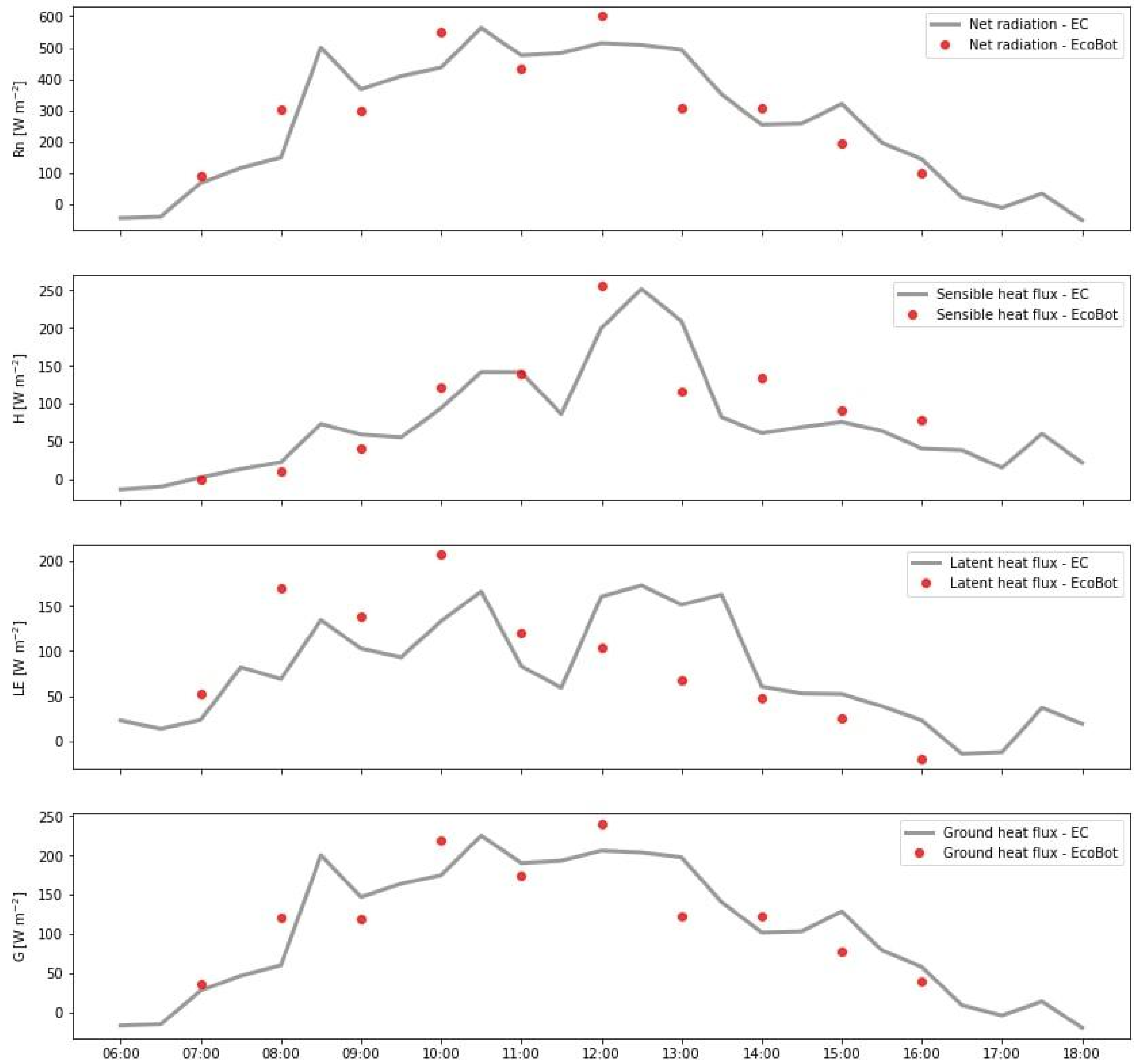

Figure: Example of energy balance components measured or modelled from EC and EcoBot on the 19-Nov-2019. This data exemplifies the promising approach of representing spatial variability through EcoBot measurements. From top to bottom: Net radiation (Rn) Sensible heat flux (H), Latent heat flux (LE) and Ground heat flux (G)

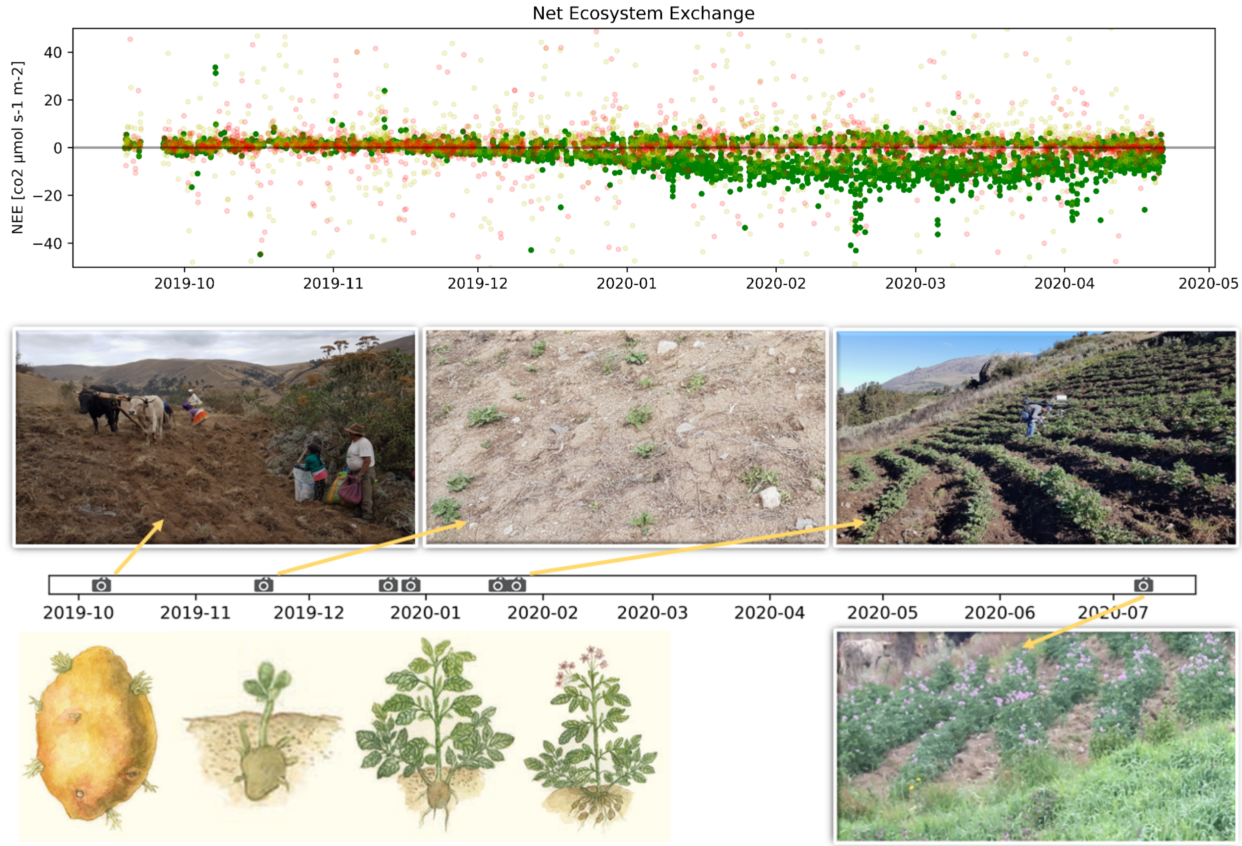

Figure: Top: Net ecosystem exchange (NEE) as measured by the EC station, green points represent high and transparent yellow and red point medium to low quality 30-min averages. Bottom: Sowing and phenological development of the potato plants.

Detailed summary

Changing water availability is making climate change tangible and is often a great concern for affected societies. In rural settings of the global south where the livelihood of many people relies on subsistence-based agriculture, changes in seasonality of climate variables or increasing weather extremes can have far-reaching consequences including rural exodus and increase of poverty and vulnerability. The slopes of the Rio Santa basin, located in the Peruvian Andes, are home to many farmers whose livelihoods have already been increasingly challenged by economical and societal developments in the past decades. The local agriculture is mostly rain-fed and plant-growth is determined by the appearance of seasonal rainfalls which are occurring during an annual cycle of a distinct wet and dry season. Recently, farmers reported that they are facing changed timing and intensities of seasonal rainfalls with detrimental effects on crop yields. These reports were not supported by analysis of historical meteorological records in previous research, but there remains considerable uncertainty regarding the quality of the data.

Since the seasonality of vegetation greenness in the region is (mostly) governed by the seasonality of rainfalls, we used satellite-derived vegetation greenness data as an integrated proxy in a high spatial and temporal resolution to gain new insights into recent trends and changes in the variability of water availability. Additionally, we analyzed several rainfall and one soil moisture product to quantify the relation between vegetation greenness and components of the hydrological cycle and to illustrate the benefits of using this proxy over meteorological data.

The analysis of the rainfall datasets yielded inconsistent results, but we find a significant increase of plant greenness in the Rio Santa basin, particularly pronounced during the dry season, indicating an overall increase of plant available water over the past two decades. Regarding the seasonality of vegetation greening, we find a significant delay of the end of the growing season which matches the pattern of dry season greening and either implies a later retreat of the seasonal rainfalls or larger amounts of rainfall during the wet season feeding storages of the hydrological system. The start of the growing season, however, fluctuates highly from year to year with variation of up to two months, governing the overall growing season length. This variability is likely linked to the perception of local farmers, as it hampers the planning of sowing dates and overall complicates successful farming.

Finally, we wanted to explore if and how atmospheric drivers at larger scales drive the greening trend and/or the variability of the start of the growing season locally. We explored the control of El Niño Southern Oscillation (ENSO), as it is known to be the most influential driver of rainfall anomalies on the South-American continent with various, often contrary effects at different geographical locations. Our results show that alternations of El Niño and La Niña phases are not controlling the greening trend in the Rio Santa basin, but we find hints towards increased early season rainfall and earlier dates of the growing season start during phases of El Niño (and vice versa for phases of La Niña).

WPC Model integration and synthesis

Objectives

The objectives of WPB were to "*Merge these data and methods to identify the main vulnerabilities of today's farming practices and develop a model framework aiming at (i) a better understanding of the drivers of changes in water availability and demand and (ii) delivering a set of recommendations for the most resilient crops and agricultural methods for present and expected near-future (+10 years) climate conditions refined on the basis of the detailed and improved baseline generated in A and B.*"

The specific subpackages were:
WPC.1 Crop water demand and potential agro-climatic vulnerabilities in rain-fed farming
WPC.2 Development and documentation of a model chain for sustainable reuse
WPC.3 Practical and scientific recommendations

Changes

This work-package was affected by the changes in WPB, notably the inability to calibrate and validate the AquaCrop model, which would have been used to study how climatic changes affect crop performance in the study area. We were however able to make significant advances using different methods and collaborations. Furthermore, thanks to a collaboration with other running projects in the region (UK NERC funded PeruGROWS and

PEGASUS), we also expanded the range of our projections to the 21st century using downscaling methods.

Outputs

- Collaborative publications: Klein et al., 2023, Klein et al., in review, Potter et al., accepted.
- Collaborative publications Potter et al, Hänchen et al (in preparation)
- Dataset: agrometeorological measurements at Llupa (5 years)

Paper highlight

Klein, C., Hänchen, L., Potter, E. R., Junquas, C., Harris, B. L. and Maussion, F.: Untangling the importance of dynamic and thermodynamic drivers for wet and dry spells across the Tropical Andes, Environ. Res. Lett., 18(3), 034002, doi:10.1088/1748-9326/acb72b, 2023.

Andean vegetation and agriculture depend on the patterns of rainfall during the South American monsoon. However, our understanding on the importance of dynamic (upper-level wind circulation) as compared to thermodynamic (Amazon basin moisture) drivers for Andes rainfall remains limited. This study examines the effect of these drivers on 3–7 day wet and dry spells across the Tropical Andes and assesses resulting impacts on vegetation. Using reanalysis and remote sensing data from 1985–2018, we find that both dynamic and thermodynamic drivers play a role in determining the rainfall patterns. Notably, we show that the upper-level wind is an important driver of rainfall across the entire Tropical Andes mountain range, but not in the Amazon lowlands, suggesting a crucial role of topography in this relationship. From thermodynamic perspective, we find wet spell conditions to be associated with increased moisture along the Andes' eastern foothills accompanied by a strengthened South American low-level jet, with moisture lifted into the Andes via topography and convection for all considered regions. Our results suggest that while changes in Amazon basin moisture dominate rainfall changes on daily time scales associated with three day spells, upper-level dynamics play a more important role on the synoptic time scale of 5–7 day spells. Considering impacts on the ground, we find that only 5–7 day spells in the semi-arid Andes have a prolonged effect on vegetation. Our study emphasizes the need to consider both dynamic and thermodynamic drivers when estimating rainfall changes in the Tropical Andes, including in the context of future climate projections.

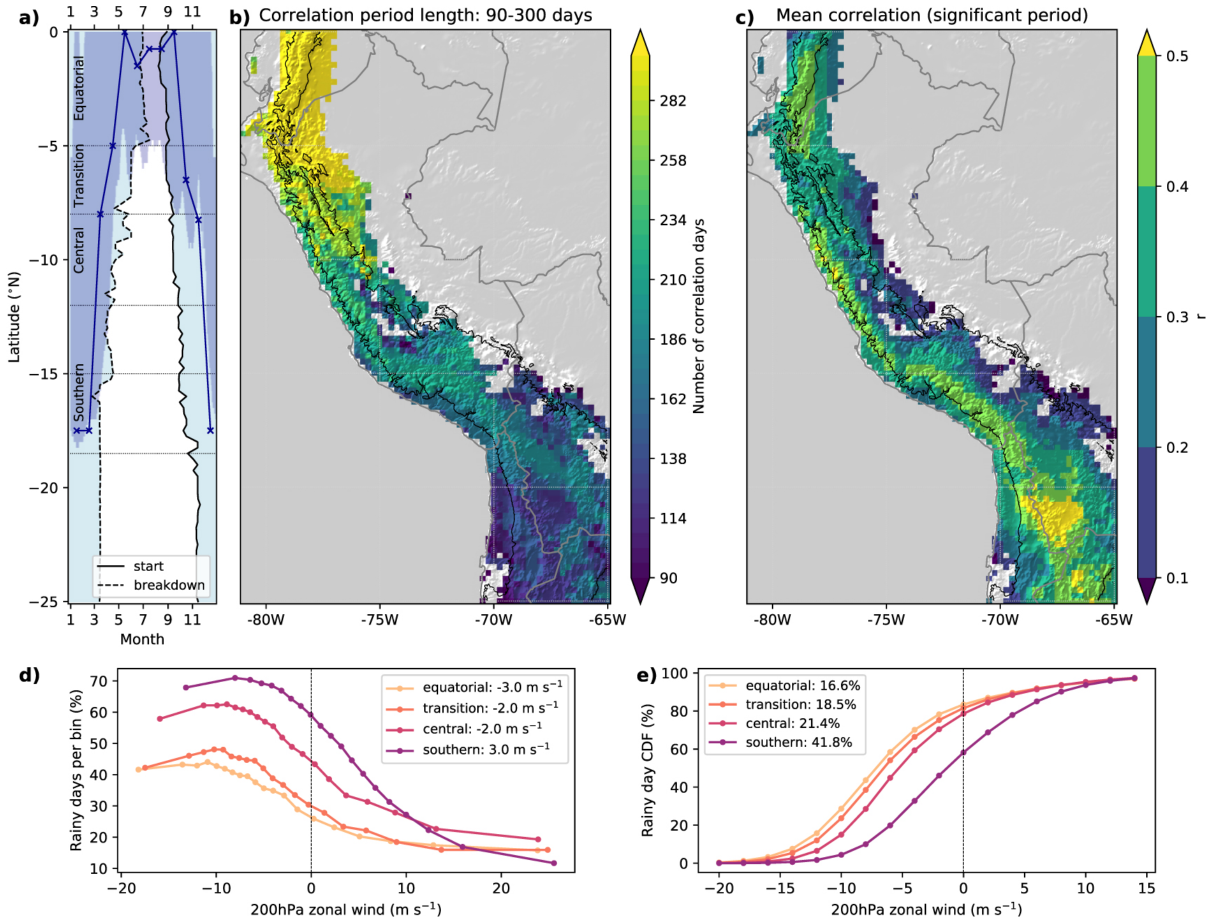

Figure: dynamical rainy seasons (DRS) for 1985–2018. (a) Shows the zonal-median calendar day for the start (solid black line) and breakdown (dashed black line) of the correlation between 200 hPa zonal wind and CTTs, defining the DRS (light blue area). Overplotted are latitudes of zonal-mean three day rolling easterly wind (dark blue shading), and maximum relative rainfall (blue line, % = [mm month−1/mm year−1]), with indicated Tropical Andes sub-regions. (b) Shows the DRS length and (d) the mean DRS correlation coefficient for significant periods. (d) Shows the frequency (%) and (e) the cumulative distribution function (%, CDF) of rainy days (>1 mm day−1) as a function of pixel-wise co-located 200 hPa zonal wind per sub-region. Legends show (d) climatological mean zonal wind and (e) fraction of rainy days under westerly wind. DRS correlations are calculated for the full domain, with insignificant regions shown grey in (b) and (c). For (a), (d) and (e), only significant DRS pixels >2000 m altitude (black contour in (b) and (c)) are considered. From Klein et al., 2023

WPD Training and Dissemination

Objectives

The objectives of WPD were formulated as such: “*Within the possibilities of a project of this size, we aim to continue our strategy of capacity building in the local communities by providing training to local stakeholders who themselves can share their gained knowledge. In particular, we want to extend our collaboration with Roland Cruz E. who is specialized in glacier-climate relationships and could become an expert for agro-climatic topics as well. We also aim to continue our long-lasting collaboration with Hector Oropeza C. and provide him detailed information on the agro-climatic processes happening on his plots. If possible, we would like to learn from, involve and provide training to 2-3 more local (early-career) scientists and farmers. To communicate our findings and potential recommendations at the end of the project, we will organize “delivery-workshops”. Our local partners (e.g. Rolando* *and Hector) will be in the focus of these events to increase their visibility as local experts and contact persons*"

Changes

Despite the challenges of the pandemic, this work package could be conducted very well. We could run most of the planned capacity building activities, and kept in contact with Rolando Cruz, Fiorella Quiñonez Collas and Hector Oropeza via WhatsApp during lockdowns. We could organize a workshop at the end of the project as planned. One main change however was not due to COVID but to communication problems with the community in Chincay and the problem of superstition in rural communities.

One main objective of the project was to install a weather station similar to the one in Llupa in the Cordillera Negra, in the village of Chincay. This weather station would mirror the one in Llupa and allow us to assess the changes in climate variables between the two mountain chains (Cordillera Negra and Blanca). We had excellent contact with the teacher of the local elementary school who was very keen on installing the station on the school grounds, allowing the pupils to learn about the weather and climate. To avoid unwanted animosity and fear of foreign influence, all communication with the local community and the village mayor was handled by our local partners at the ANA (see photos).

The station was installed in early 2020 but, unfortunately, had to be dismantled only a few weeks thereafter. According to the local population the rain "changed" after the installation of the station, and the local community accused the station of being responsible for this change. Our local partners at ANA had to dismantle the station within 24 hours or we would have risked losing it. Similar problems have been reported elsewhere in the region, and it emphasizes the importance of communication and involvement of the local communities in all aspects of a measurement campaign. Despite all the efforts of our colleagues at ANA (who are from the region and speak Quechua), we could not convince the community of the benefits of the station.


Left: weather station at Chincay after construction. Right: meeting with the local community at the school led by Alejo Cochachin Rapre (head of ANA) to explain the objectives of the measurements to the farmers. Unfortunately, this was not enough and the station was dismantled a few weeks later. Photos: Rolando Cruz Encarnacion.

Outputs

- Fabien Maussion (2022): participation in the COP27 conference in Egypt. Interventions on the topics of glacier change, including a side event with the Peruvian delegation with the title “State of the Cryosphere in Peru: Progress and Challenges for Adaptation to Climate Change” (see “highlights”)
- Fabien Maussion (2019-present): several contributions to training and workshops at the UNASAM university in Huaraz, including capacity building on meteorology and glaciology.
- Lorenz Hänchen (2019): training for local scientists to maintain and run automatic weather stations and conduct biomass and albedo measurements on selected crops.
- Emily Potter (2023): Emily presented results on behalf of the whole project at the Geophysical Institute of Peru, in Lima. Two students working with the IGP also presented their thesis work. There was considerable discussion after the seminar, and ongoing talks about possible future collaborations.
- Participation of Rolando Cruz Encarnacion to the IMC2022 and associated summer school.