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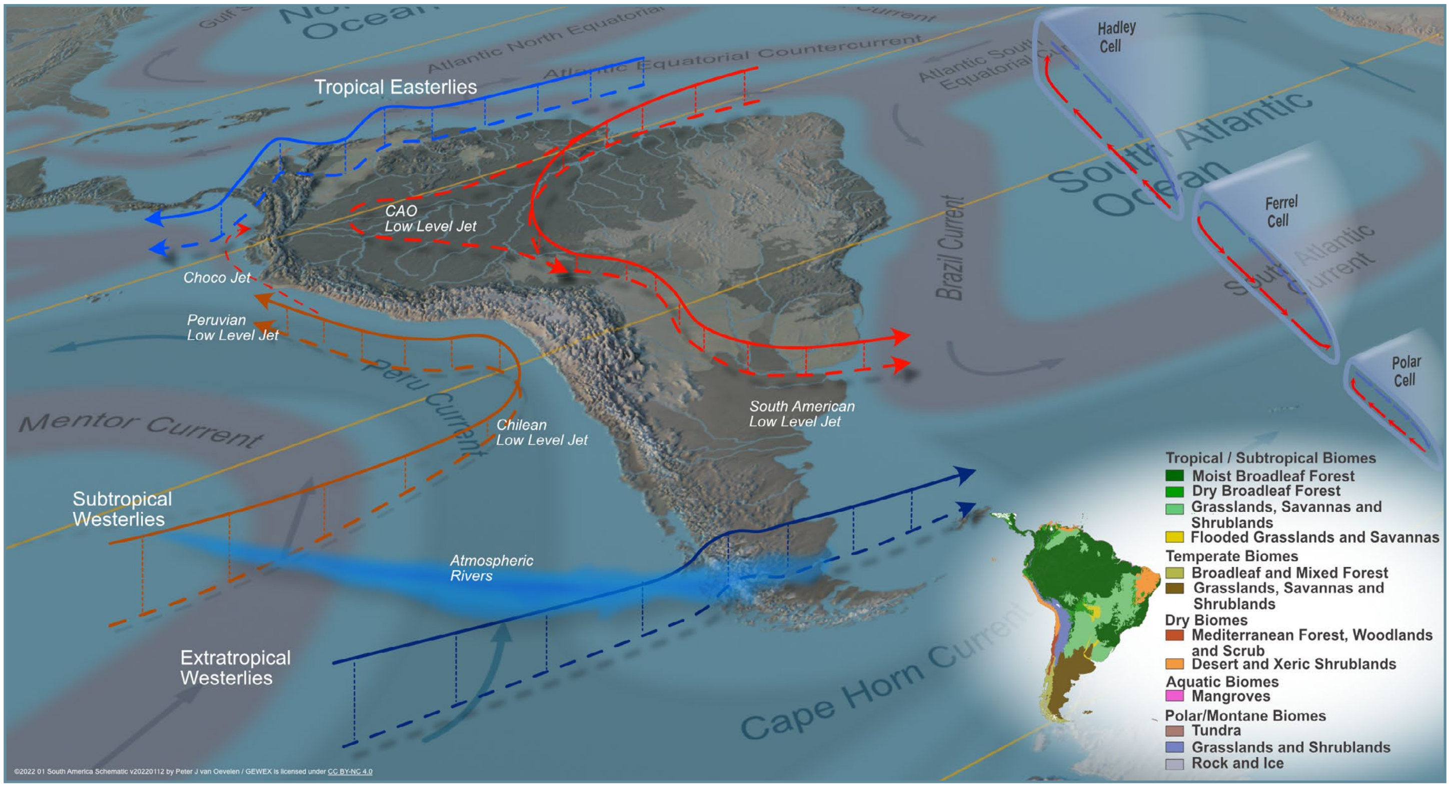
SPECIAL ISSUE

A Focus on South America



This schematic depicts the main features of the hydroclimate of South America, including atmospheric circulation features, low-level jets, biomes, and oceanic currents (©2022 01 South America Schematic v20220112 by Peter J. van Oevelen/GEWEX is licensed under CC BY-NC 4.0); see South American Affinity Group on page 28.

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GEWEX Quarterly Newsletter Special Edition on South America

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South America is often called the continent of rivers, with half of the world's largest rivers by discharge located there. With the Andes, it also has one of the most remarkable orographic structures. These geographic features ensure that South America is one of the most interesting continents for hydroclimatic studies. The towering mountains to the west are the dominant source of water for the large rivers flowing to the east, feeding a network of floodplains, which ensure a constant interaction between the continental and atmospheric water cycles. Because the continent straddles the equator, a large part of its water cycle is driven by the tropical inter-annual variability. Moreover, South America hosts some of the most bio-diverse regions in the world, and is home to more than 400 million people. It is an honor for GEWEX to support the efforts of the South American scientific community to coordinate its activities with the aim of elaborating on and providing the countries of the region with the knowledge needed for their adaptation to a changing climate and fluctuating water resources, given the high social and biophysical vulnerability of the region to hydroclimate variability and change.

This special edition of the *GEWEX Quarterly* newsletter highlights seven of the multiple research projects and programs currently led by South American scientists that are focused on the different aspects of hydroclimate systems and climate change and variability within the continent. In particular, this issue concentrates on scientific initiatives at national, regional, and continental scales, such as: (i) the AdaptaBrasil platform, an initiative to consolidate, integrate, and disseminate climate change information in Brazil; (ii) SOS-Cuenca, a research program aimed at investigating the sustainability of ecological and social systems in Colombia under climate change and deforestation scenarios; (iii) CLIMAX, a Euro-South American initiative for strengthening societal adaptation response to extreme events, led by Argentinian scientists; (iv) the AMANECER-MOPGA project, helmed by a Peruvian scientist at the Research Institute for Development (IRD) of France and focused on the role of Amazon rainforest in the Andes-Amazon hydroclimate connections; (v) the GreatICE Laboratory and the ANDES-C2H International Research Network, projects addressing hydrology and glaciers in the Andes, led by the IRD in France and South American scientists; (vi) Convección Permitida para América del Sur (cpAmSur), an ongoing proposal aimed at providing convection-permitting climate simulations of high resolution at continental scale, directed by South American scientists; and (vii) the South America Affinity Group (SAAG), an initiative led by the National Center for Atmospheric Research (NCAR) Water System program in the United States that now includes multiple scientists in South America to provide convection-permitting climate modeling over the region. These research projects and programs are only some of the many examples of the ongoing momentum of the South American research community on understanding the coupled dynamics between biosphere-atmosphere and hydroclimate variability and change, including not only their biophysical features, but also the social implications and connections. Moreover, this community is leading continental initiatives like ANDEX, an initiating Regional Hydroclimate Project (RHP) in GEWEX, with the goal of improving the current understanding and prediction of climate and hydrology along the Andes cordillera.

South America is an excellent test case for GEWEX to ensure progress in its goals of predicting and observing the reservoirs and fluxes of the water, energy, and carbon cycles as well as advancing our understanding of the processes coupling these cycles. The expertise that the South American research community is building is relevant to all GEWEX Panels. Strengthening Earth system sciences in the Global South is absolutely necessary for the reduction of social vulnerability and inequity, and it will also help accelerate GEWEX's quest to advance our understanding of the global energy and water cycles.

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Becoming an Active Bystander: Why and How to Make Work Environments Work for Everyone

Written by Zoe Kanavas[1], edited by Dan Myers[2] and Danyka Byrnes[3]

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On November 18, 2021, the Hydrology Section Student Subcommittee (H3S) of the American Geophysical Union (AGU) hosted a workshop with the ADVANCEGeo partnership to train active bystanders to confront sexual harassment and other harmful practices in research environments. ADVANCEGeo (*bit.ly/ADVANCEGeo*) is a partnership between the Earth Science Women's Network, the Association of Women Geoscientists, and AGU to transform the workplace climate of the earth, space, and environmental sciences. This partnership developed bystander intervention education training that addresses changes needed at the institutional level, structurally, and individually to combat the problem of sexual harassment and other exclusionary behaviors. AGU-H3S reached out to ADVANCEGeo to solicit their workshop *Improving workplace climate: empowering individuals to become active bystanders* (*bit.ly/Workplace_Climate*). The topics covered in this 3-hour workshop included the different forms in which harassment can manifest in research environments, strategies for bystander intervention, and resources for institutional and structural change.

The workshop hosted nearly 50 participants from the AGU Hydrology Section and featured traditional lectures broken up by breakout sessions, each with a facilitator from ADVANCEGeo. In the lectures, we learned about different forms of harassment and strategies for safe intervention. In each breakout room, the facilitator(s) would talk the small group through different example scenarios. The group would first identify the harassment, provide example responses and interventions, and conclude with a further discussion about the example scenario with questions, comments, or personal anecdotes. Participants felt that the breakout rooms were "a safe space to discuss concerns relevant to early career researchers disrupting institutions and systems we are just starting to break into." Throughout the workshop, the attendees were informed about workshops for early-career scientists [see *Preparing for an Academic Career* (*bit.ly/AcademicCareer*) and W*orkshop for Early Career Geoscience Faculty* (*https://bit.ly/ECGFaculty*) for examples of past events] and were provided with resources (*https://bit.ly/AG_Resources*) that address transforming workplace climate.

The success of this workshop was encouraging. AGU-H3S hopes to work with ADVANCEGeo again in the future to participate in another one of their workshops, such as *Tackling implicit bias and microaggressions in the workplace* (*bit.ly/WorkplaceImplicitBias*) and *Improving work climate: developing effective codes of conduct* (*bit.ly/CreateCodesofConduct*). Future workshops will be posted on the H3S webpage and *agu-h3s.org/events*, advertised on our Twitter account (@AGU_H3S). You can also contact AGU-H3S at *h3s.agu@gmail.com* for more information.

YESS Past Activities at a Glance

Faten Attig Bahar[1], Muhammad Adnan Abid[2], and the YESS Executive Committee

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The Young Earth System Scientists (YESS) community has successfully organized a Learning Group activity focused on Machine Learning methods (*https://www.yess-community.org/2021/06/16/yess-learning-groups-and-webinar-series*). These learning groups were intended to provide early career researchers (ECRs) with the opportunity to engage in a guided and collaborative process via participation in small learning groups on the different Machine Learning (ML) methods as applied to Earth system sciences.

The activity started with two webinars that took place in July, first with Dr. Marlene Kretschmer from the University of Reading, U.K., who introduced the use of Machine Learning in climate science, followed by Dr. Jing Gao from the University of Delaware, U.S., who spoke about data-driven spatiotemporal modeling for long-term human-environment interactions. Forty-five participants took part in those ML training activities and worked on different case studies between August and December 2021. Additionally, the teams collaborated across different time zones using virtual platforms, organized their approach to acquiring skills, and applied them in a scientific project in Earth science.

In addition to the Learning Groups, YESS has recently partnered with the Global Weather Enterprise Forum (GWE) to produce a series of episodes for The Weather Pod podcast, developed by GWE and co-presented by Alan Thorpe and David Rogers (*https://www.gweforum.org/series/podcasts/*).

In the 14th episode, YESS members Yuhan (Douglas) Rao and Chen Chen presented an overview of Machine Learning applications in weather and climate research and presented a glimpse of the innovative research in this field. In the 15th episode, YESS members Nina Reader and Faith Taylor discussed the challenges and the huge impact of extreme weather and climate events–especially compound events, such as heat waves followed by heavy rainfall–on urban areas and human settlements and discussed the importance of building urban resilience for thee types of compound extreme weather events.

Safe Landing Climates

Gabriele Hegerl[1], Steven Sherwood[2], Pascale Braconnot[3], Pierre Friedlingstein[3,4], Heiko Goelzer[5], Neil Harris[6], Beth Holland[7], Hyungyun Kim[8,9], Paulo Nobre[10], Bette Otto-Bliesner[11], Kevin Reed[12], and Jim Renwick[13]

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The World Climate Research Programme (WCRP) Safe Landing Climates Lighthouse Activity (LHA) is an exploration of the routes to "safe landing" spaces for human and natural systems. It will explore future pathways that avoid dangerous climate change while at the same time contributing to the United Nations Sustainable Development Goals (SDGs), including those of climate action, zero hunger, clean water and sanitation, good health and well-being, affordable and clean energy, and healthy ecosystems above and below water. The relevant time scale is multi-decadal to millennial. Many of the themes considered relate to GEWEX interests and interact with core theme activities through GEWEX members who are involved in the leadership team and reporting to core projects, but they also connect to many other projects including the Past Global Changes (PAGES) program and related international activities (see development plan). Useful links are highlighted in the theme descriptions below.

Our aim is to focus on what changes need to have been implemented to remain on a habitable planet that supports healthy populations and ecosystems. A novel aspect will be to more thoroughly illustrate alternative futures and highlight what dangerous changes need to be avoided, focusing not only on climate measures, but also on the SDGs. While this draws on projection work completed to date, it is a refocus away from best estimates with uncertainty ranges to a risk-based assessment of future climates (see Sutton, 2019). It has been informed by discussions during the centennial American Geophysical Union Fall Meeting, concerns about recent high-impact extreme events, and the increased focus on risk by the recently-released Intergovernmental Panel on Climate Change (IPCC) Working Group 1 (WG1) report (IPCC, 2021), connecting to discussions of risk considered in WGs 2 and 3. By identifying and highlighting research needs to address the safe-landing aims, this LHA will contribute to fundamental understanding of the climate system, particularly the interactive Earth system–cryosphere, ocean, land surface, and atmosphere–by focusing on how to avoid impacts beyond the capability to adapt, and better understand how feedbacks between carbon and water cycles, sea-level rise and high risk events, large scale extremes and vegetation, for example, will affect future habitability of the Earth. This Lighthouse also draws on process understanding, including GEWEX's work.

The new scientific components of the Safe Landing Climates LHA are explored in the subsequent sections of this plan. Much of the required research draws on work that is ongoing, but that will take a more risk-based approach and aim to more fully incorporate the possibility of nonlinearities, "tipping points", and other global-scale risks. This includes those that can arise from linkages and feedbacks between Earth system components that transcend traditional disciplines, and that are not at present fully integrated in much of current projection work.

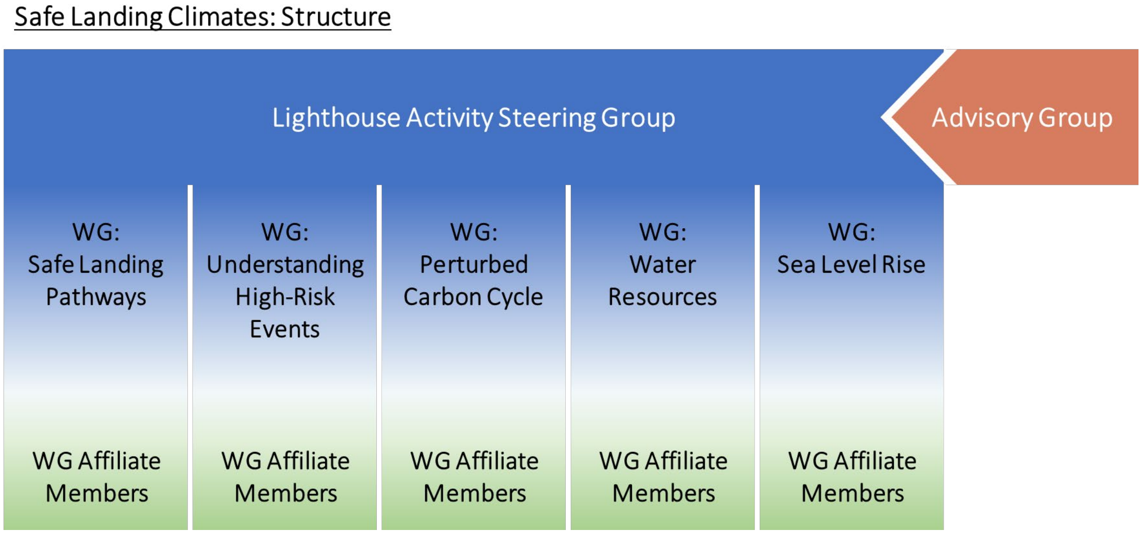
We have identified five research themes that we developed over 2021. We have now entrained further team members with more diversity in geographic base and career-stage. Below we list these research themes, which are organized by subgroups (see figure) and brought together in the overarching Lighthouse Activity. Presently, we participate in online discussion groups and plan cross-cutting workshops for the future to further develop these themes. We hope that the community engages with us and helps us develop these themes further. We welcome affiliate members and will have occasional calls for working group membership.

Theme: Safe Landing Pathways

This activity determines what climate trajectories and destinations are relatively safer than others, and for whom and/or where, and asks the question which ones are unsafe and why. We will bring together interdisciplinary communities to determine pathways and "landings" that preserve habitability and food security, respect planetary boundaries (Rockstroem et al., 2009), and identify societal adaptation limits and changes that must be avoided. This may involve finding a common footing for measuring and comparing impacts as seen from the SDG point of view. Addressing this goal requires a framework for defining and measuring safety, giving attention to how various communities are individually affected, and should consider interactions between SDGs, adaptation, and mitigation measures, including geoengineering. We plan to better understand and constrain individual risks, and assign overall levels of risk to different potential future pathways, as well as to consider adaptation and resilience strategies across communities and ecosystems and their impact on SDGs, both regionally and globally. Overall, we need to apply a whole-of-system approach to account for climate risk along the entire climate trajectory, with the goal of staying within multiple "planetary boundaries" (Mangan et al., 2021), drawing on quantification of climate risks (e.g., Zommers et al., 2020). This theme draws on results of the following themes.

Theme: Understanding High-Risk Events

We aim to identify risks from low-probability, high-impact possibilities with global-scale ramifications. What is known about their occurrence probabilities and consequences, and what significant scientific gaps exist? This theme will seek to identify unexpected risks, and to better incorporate known risks into projection ensembles. Risks that we will consider will include large natural carbon release, ice shelf/sheet collapse, regime shift of ocean/atmosphere circulation, extreme



Organization of the Lighthouse Activity. The steering group consists of overall leads and theme leads, while each theme is led by a team of scientists and a wide group of affiliate scientific members, which should include WCRP core project members. We also aim to entrain an advisory group of stakeholders who may be outside the scientific domain.

cloud feedbacks and climate sensitivity, multiplicative effect of compound hazards, biome (e.g., Amazon) collapse, “Fireball Earth”, and large-scale extremes that challenge adaptation such as large-scale desertification, land and marine heat waves, or storm sequences that exceed physiological limits or otherwise render large regions effectively uninhabitable.

We will identify adaptation limits for human, land, and ocean ecosystems and resources, worst case (extreme/existential) scenarios, and global-scale tipping elements and points. We aim to encourage and improve sufficient understanding of the physical processes underlying tipping points and high-impact events to reliably quantify risks, and will draw on and interact with process understanding developed by GEWEX core themes, such as the energy and water cycle and climate sensitivity. We encourage improving Earth system models so that they can credibly incorporate and predict tail risks, compound extremes, uncertain shocks, and tipping elements, including those arising from feedbacks between multiple components of the Earth system. We aim to develop strategies to accurately and transparently incorporate low probability/high impact possibilities into projections, risk analysis, and adaptation planning.

Theme: Perturbed Carbon Cycle

We will explore the acceptability and climate implications of carbon dioxide removal (CDR) systems [including bioenergy with carbon capture and storage (BECCS)] while maintaining food and water supply, preserving biodiversity, and limiting ocean acidification. A further goal is to assess the risk of surprises or a rapid change in Greenhouse Gases (GHGs), including large or rapid carbon release (e.g., from permafrost melt, large scale fires, or the Southern Ocean), the reversibility of the anthropogenic perturbation, and climate and carbon cycle feedbacks in the context of negative emissions. We will also explore metrics for controlling short- vs. long-lived forcing in the context of negative emissions, and implications for allowable GHG emissions in the context of the Paris Agreement. We will build an understanding of the coupled carbon-energy-water cycle, drawing on process understanding developed in GEWEX. We will explore its impact on food, water supply, and biodiversity. We hope to foster improved observation and modeling of terrestrial biogeochemistry (in particular permafrost) and possible future sources of GHGs, as well as the ocean carbon cycle, especially in the Southern Oceans, and improved integration of ocean and land biogeochemistry models within Earth system models. This would help to better constrain the future evolution of natural greenhouse gas sources and sinks in a world with negative emissions. Furthermore, we aim to improve understanding of the risk of land/ocean CO_2 release when atmospheric CO_2 decreases, and assess potential carbon dioxide removal CDR strategies (e.g., efficacy, side effects).

Theme: Water Resources

We will address uncertainties in the long-term redistribution of water in land-based natural systems or man-made reservoirs, their resilience and vulnerabilities, and impacts of changes to these systems. Key systems include glaciers (crucial for water supply in mountain regions) and tropical rainforests (which play an important role in the local water cycle and deliver other important ecosystem services). We consider impacts on these systems from climate change and also directly from human activities (e.g., deforestation, groundwater exploitation, aerosol darkening of glaciers), seek to determine thresholds of tolerance beyond which substantial change or collapse occurs, and better characterize the possible consequences for society and ecosystems if this were to occur. We aim to integrate research across physical/climate and social sciences and local and Indigenous knowledge to assess and communicate the value of these systems and evaluate the implications of different mitigation and adaptation scenarios. This will also be used to prioritize science needs, among which are water recycling and transport, atmospheric chemistry in the canopy area, and feedback mechanisms between these water systems and regional and global climate. This theme will directly touch on many GEWEX activities in both observations and modeling, and we aim to stay in close contact with this work. This Lighthouse Activity specifically aims to address gaps in understanding and modeling of coupling between the land biosphere, cryosphere, and atmosphere, including via chemical processes and aerosols, and address gaps in knowledge of forest and glacier dynamics and resilience. It also needs to connect physical sciences with human systems (e.g., water management, adaptation) in order to ensure water resource changes and responses are reflected in safe landing pathways.

Theme: Sea Level Rise

This theme aims to quantify an "acceptable" rate of sea level rise and its irreversibility from multiple decades to millennia. We will estimate the impact of storm surges and cyclones on coastal communities and assess the potential for adaptation. The aim will be to improve projections by facilitating better coordination between global climate, cryosphere, and coastal modeling. This requires a regional/local perspective and interaction with coastal planners, because anthropogenically-induced sea-level hazards are already affecting coastal habitats and threatening livelihoods in some regions. Depending on the local setting, safe landing in terms of sea level means that the rate of sea-level rise must be limited, slowed, or reversed to allow adaptation measures to keep pace and be effective. The goal is a more accurate understanding and prediction of poorly-understood processes including ice sheet melting and future dynamic ice loss in Antarctica and Greenland, storm surges, and other global and regional sea-level drivers (including land subsidence). This will be supported by a fuller range of ice sheet models of different levels of complexity and resolution with evaluation to better constrain uncertainties, and will also be aided by GEWEX work on water transport from continents to oceans with melting. New research is needed on frameworks of coastal planning, adaptation, coastal protection, and the limits of adaptation as well as on the interaction of modeling efforts across spatial scales from global to coastal.

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Understanding the Diurnal Cycle of Precipitation in Weather and Climate Models Using Long-Term SCM Simulations

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The diurnal cycle of precipitation (DCP) is one of the most important temporal variabilities dominated by diurnal variation of solar insolation and regulated by large-scale circulation and mesoscale propagating systems. General Circulation Models (GCM) have for decades exhibited difficulties in modeling DCP. An international multi-model intercomparison project is being organized by the GEWEX Global Atmospheric System Studies (GASS) Panel to investigate the interactions between convection and environmental conditions, processes that control nocturnal convections, and the transition from shallow to deep convection on a diurnal timescale (*https://portal.nersc.gov/project/capt/diurnal/*). Results from the GASS DCP project's single-column model (SCM) intercomparison have been published (Tang et al., 2021). Eleven SCM versions of GCMs from eight modeling centers and groups around the world participated in the study.

Different from earlier SCM intercomparison studies, which mainly focused on specific cases, Tang et al. (2021) utilized the multi-year continuous forcing data (Xie et al., 2004) from the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) program to provide long-term statistical insights on which physical processes are essential in climate models to simulate DCP. This is because short-term simulation of a few days or a few weeks may not be long enough to build robust statistics for phenomena such as DCP since *a simulated diurnal peak may be determined by a few strong precipitation events and is largely controlled by the specified large-scale forcing for the SCM framework*.

The simulations are performed at two continental sites: the ARM Southern Great Plains (SGP) in the USA for 12 summer months from 2004 to 2015 and the ARM Manacapuru site in the central Amazon (MAO) in Brazil for two full years from 2014 to 2015, with distinguished and representative characteristics of the large-scale environment, clouds, and precipitation. Precipitation over these two sites is contributed by a few distinct types of convective systems that occur at different times of the day. Two regimes of DCP are examined here. One is surface-driven afternoon convection, and the other is nocturnal precipitation caused by elevated convection or propagating convective systems. The mean precipitation diurnal cycle at SGP (summer only) peaks at nighttime, while that at MAO peaks in the early afternoon.

As shown in Fig. 1, in the afternoon precipitation regime, most of the eleven SCMs initiate precipitation 1 to 4 hours earlier than observation. At SGP, the early onset of afternoon precipitation may be due to the missing transition of shallow-

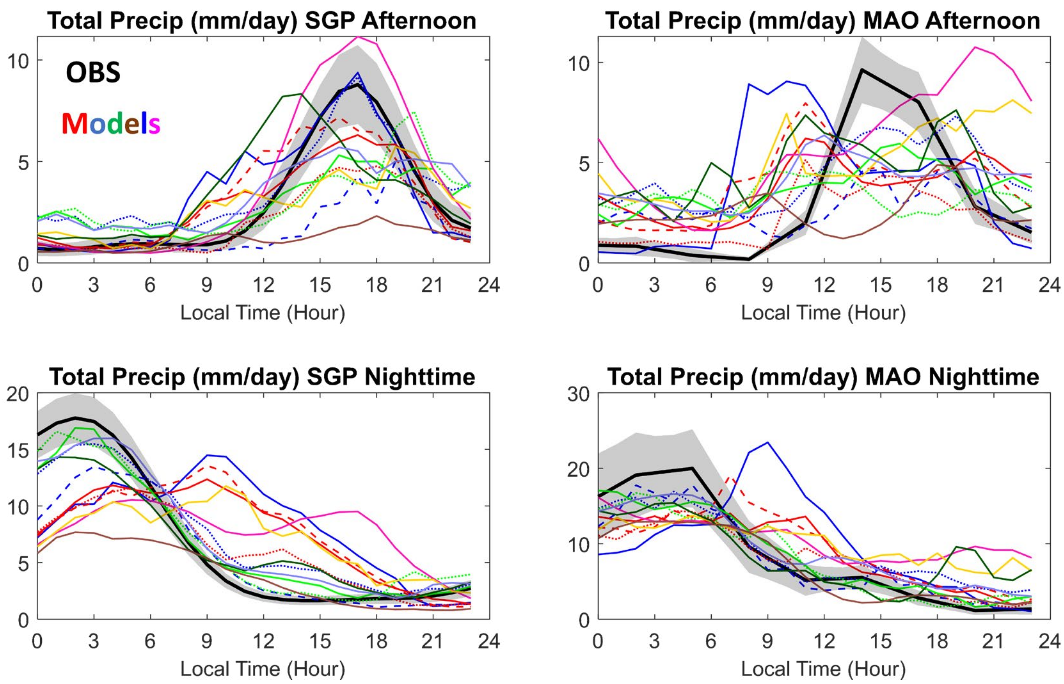

Figure 1. *The composite diurnal cycle time series of total precipitation averaged for the selected (top) afternoon and (bottom) nighttime precipitation days during the long-term simulation periods at (left) SGP and (right) MAO.*

to-deep convection in climate models. More sophisticated parameterizations that unify shallow and deep convection better simulate the onset time of precipitation. At MAO, the early onset of precipitation is more severe than at SGP. Models also generate convective heating in a much lower level than derived from observation, and produce rainfall too evenly spread across times of the day. In other words, models fail to develop strong deep convection but precipitate too easily from convection in the lower troposphere for the MAO afternoon cases.

For nocturnal precipitation, although all SCMs produce considerable precipitation at night, the partitioning of convective precipitation and large-scale precipitation differ dramatically among models. SCMs with most of the nocturnal precipitation generated from large-scale are likely driven by the prescribed large-scale forcing. Although models still struggle to propagate convection from one grid to another, those that produce most of nocturnal precipitation from convection all allow convection to be triggered above the boundary layer. This indicates the importance of model capability to detect elevated convection for simulating nocturnal precipitation.

The GASS DCP project is a multi-year research project. Our current effort emphasizes the GCM part of the project. It includes both climate simulations and hindcast runs with global weather and climate models. The project is still open for participation. The deadline for submission of your GCM model simulation data is April 30, 2022. A breakout session on discussing initial results from the GCM intercomparison is being planned at the upcoming 3rd Pan-GASS Meeting in July 2022 in Monterey, CA, U.S.A. Please visit *http://portal.nersc.gov/project/capt/diurnal/* or contact Dr. Shaocheng Xie at *xie2@llnl.gov* for more details on the DCP project.

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Recent News

GEWEX SoilWat Initiative Member Elected to National Academy of Engineering

Prof. Dani Or of the Desert Research Institute and ETH Zürich is one of this year's inductees to the National Academy of Engineering. He is being honored for his "contributions coupling soil physics, hydromechanics, and microbiology through novel measurements, theory, and models of key near-surface hydrologic processes." His involvement in the GEWEX SoilWat Initiative has been key in supporting the group's goal of improving representation of soil and subsurface processes in climate models.

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AdaptaBrasil MCTI: Innovative Platform for Analyzing Climate Change Impacts in Brazil

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Climate change is already affecting every region on Earth in multiple ways, including more frequent wildfires, more extended periods of drought, as well as an increased number, duration, and intensity of heavy rainfall events. Moreover, the changes we experience will increase with additional warming, according to the latest and most comprehensive assessment of climate change science, the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2021).

Studies led by the National Institute for Space Research (INPE) show that different regions of Brazil have experienced more intense and frequent climate extremes over the past decade, which have an impact several important sectors, such as water, energy, and agriculture (Santos et al., 2020). For example, some regions have been affected by droughts, as in Amazonia and Northeastern (Marengo et al., 2018; Jimenez et al., 2019) and Southeastern Brazil (Nobre et al., 2016), but also by heavy rainfall (Dalagnol et al., 2021).

In these circumstances, climate change could push Brazil farther from sustainable development and create more difficulty addressing the inequality that already represents major challenges for the country. It presents enormous socioeconomic and biophysical heterogeneities. Achieving better societal outcomes is inherent in mainstreaming the climate change agenda into public policies and decision-making (Coutinho et al., 2020).

The complexity of climate change requires making choices, establishing priorities, and negotiating solutions among different stakeholders. Adopting a risk management approach is one way forward to pursue these tasks. It allows combining the climate's future evolution with potential socioeconomic and ecosystem effects, together with vulnerability and exposure aspects of the analyzed system. This combination permits the assessment of climate-related risks, including its conditioning factors (or influencing factors). It thus contributes to proposing different climate adaptation initiatives for the more systemic causes of vulnerability (OECD, 2015).

To advance these initiatives, one of the main challenges is enabling access to practical information on a climate risk assessment that could support adaptation public policy planning and implementation across multiple levels, particularly at the national, subnational, and sector levels. Efforts have been made to bring scientific climate research closer to the stakeholders who define and implement these policies (Gutiérrez et al., 2014; Nicolletti et al., 2020). For example, working on Brazil's National Adaptation Plan, stakeholders identified a vital need for accessible information on climate adaptation that stressed the lack of an online platform on adaptation knowledge.

In this context, the AdaptaBrasil MCTI platform (*https://adaptabrasil.mcti.gov.br/*) is being developed to consolidate, integrate, and disseminate robust information in a centralized and easily-accessible manner. This platform analyzes observed and projected impacts over the 5,570 Brazilian municipalities (and other territorial aggregations) on strategic sectors such as food, energy, and water security. In addition, it provides greater awareness and understanding of how climatic and non-climatic aspects are interrelated in generating risks to society.

AdaptaBrasil MCTI is a bottom-up institutional effort to bring research institutes and academia together to meaningfully help the public and private sectors act on climate risk and adaptation. It connects organizations working on climate-related issues across Brazil, spanning regional and thematic differences. Its development involves dozens of organizations through a participatory process. This type of process is crucial for the platform and could be helpful for a large range of stakeholders.

A major challenge for the platform is to design an approach that integrates different data sources such as measurements, climate models, surveys, and expert-based appraisals. AdaptaBrasil MCTI uses composite and hierarchical indicators following the risk framework proposed by the IPCC and the hierarchical construction of indicators based on methodological steps in Nardo et al. (2008), where the climate risk is defined through the characterization of the social and natural systems and the vulnerability and exposure of these systems to a given hazard (AR5, 2014).

The collaborative development of AdaptaBrasil takes place in the scientific and technological groups. In the scientific group, several workshops took place to select and weigh the most critical indicators in each strategic sector. In the technological group, a Design Sprint workshop and several user experience (UX) cycles took place, together with scientists and stakeholders, to bring together the end-users to define the main concepts and functionalities of the platform. This interface between science and technology and the development of AdaptaBrasil MCTI helped to properly communicate all the scientific knowledge produced by the platform to end-users.

In the AdaptaBrasil MCTI platform (Figure 1a), the climate change impact risk is analyzed for the present and two time frames, the 2030s and 2050s, based on two climate change scenarios from the IPCC Fifth Assessment, representative concentration pathways (RCPs) 4.5 (optimistic) and 8.5 (pessimistic). For instance, to analyze the risk of the impact of climate change in the strategic sectors related to the climate threat of drought, 23, 34, and 13 indicators are assessed for the strategic sectors of water, food, and energy security, respectively (Figure 1b). The AdaptaBrasil MCTI framework allows a user to visualize and download the Risk of Impact on Drought for each scenario of the three different strategy sectors (Figure 1c). All the steps of conception, design, exploratory

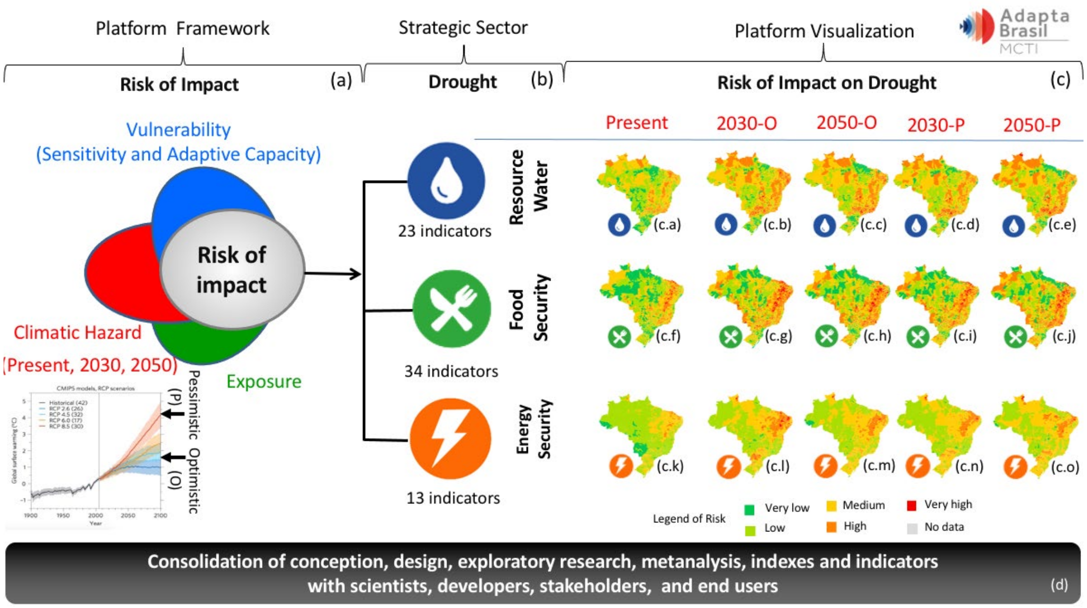

***Figure 1**. AdaptaBrasil MCTI Platform: (a) platform framework; (b) strategic sectors; (c) platform visualization*

research, metanalysis, indexes, and indicators are consolidated with scientists, developers, stakeholders, and end-users (Figure 1d). The analysis is performed at the municipality level for the entire country, transparently navigating the hierarchy of indicators used to estimate the impact risk in each municipality.

For water resources, preliminary results show a predominance of municipalities with low to medium risk at present. However, Southeast Brazil has the highest percentage of municipalities in a high-risk class, both for the optimistic (49.34%) and pessimistic (51.20%) scenario in the 2050s. Like food security, most municipalities have low to medium risk classes at present, but, in the future, the risk of impact increases in many cases to medium to high, particularly in Southeast Brazil (around 50% municipalities). Finally, despite the different national and regional characteristics, it is observed that vulnerability is the most critical dimension that contributes to the composition of the impact risk index in both strategic sectors. For instance, 86% of the municipalities have high vulnerability for water security and 96% for food security.

AdaptaBrasil MCTI was developed by INPE, in collaboration with the Brazilian National Research and Educational Network (RNP) and Brazilian Research Network on Global Climate Change (Rede CLIMA), and it is being coordinated by Brazil's Ministry of Science, Technology and Innovation (MCTI). It is a long-term project whose analysis and indicators will be refined and extended to other strategic sectors in the future.

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The SOS-Cuenca Project: Sustainability Of ecological and Social systems in the magdalena-Cauca basin Under climatE chaNge and deforestation sCenArios

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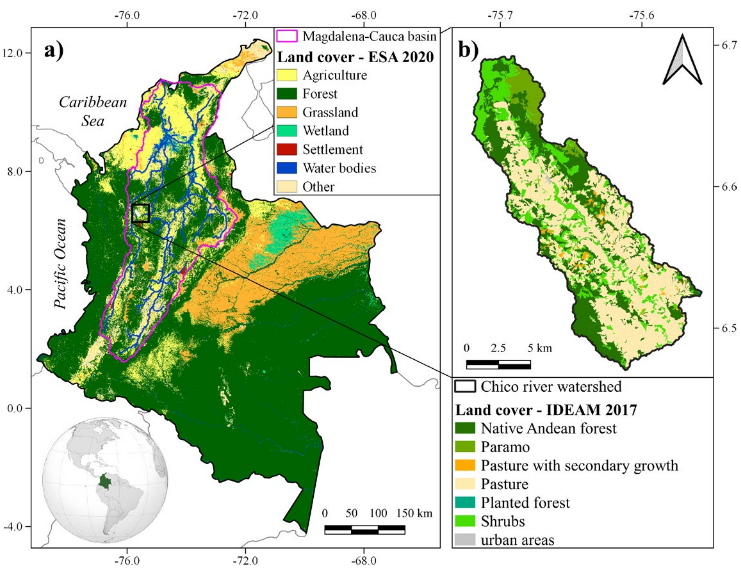

***Figure 1**. The Magdalena-Cauca basin and the Chico River watershed in Colombia*

The Magdalena and Cauca rivers form the largest basin within Colombia, draining an area of about 276,000 km^2 in northwestern South America (Fig. 1). This basin is home to most of the Colombian population and the primary water source for the country, including hydropower generation that supplies around 70% of the country's energy (MINENERGÍA, 2019). In addition, the Magdalena-Cauca (MC) river basin hosts a variety of ecosystems that provide essential ecosystem services, including paramos, wetlands, and tropical forests that play critical roles in regulating the carbon and water cycles on land, among other functions. Furthermore, the MC basin contains several biodiversity hotspots, and is in a region identified as highly vulnerable to climate change.

The sustainability of Colombian society is, and will continue to be, strongly dependent on the sustainability of the MC basin, as the country's water, energy, food security, and many of its ecosystem services rely on it. Since September 2020, a scientific team from the University of Antioquia, the National University of Colombia, and CES University, all three in Medellín, Colombia, has been developing the SOS-Cuenca research project to investigate the sustainability of ecological and social systems in the MC basin under climate change and deforestation scenarios. The Colombian Ministry of Science, Technology, and Innovation (MINCIENCIAS) is providing the core funding.

The acronym SOS-Cuenca has three different meanings based on the Spanish words for sustainability (*SOStenibilidad*) and basin (*Cuenca*). (i) "Sos Cuenca" literally means "you are basin," which we interpret as saying that everyone is part of a basin and, particularly, that most Colombians depend on and affect the MC basin. (ii) "Sos Cuenca" is also an emergency call: "S.O.S. basin," highlighting the urgent need to enhance environmental protection while supporting social systems in the basin. And (iii) "*SOStenibilidad [en la] CUENCA*" means "Sustainability [in the] basin", the project's core research topic.

SOS-Cuenca focuses on four research questions related to different aspects of MC basin sustainability:

Question #1: How does climate change affect the basin's hydrology and climate?

Question #2: How does Amazon deforestation affect the basin's hydrology and climate?

Question #3: How will Andean ecosystems in the basin respond to global warming?

Question #4: How do local socio-ecological systems in the basin evolve in a changing environment?

Two core premises of the SOS-Cuenca Project are, first, that the systems under study are socio-ecological, i.e., systems that depend strongly on social dynamics; and, second, that these systems' sustainability depends critically on changes occurring both inside and outside the basin, i.e., endogenous and exogenous factors, at multiple scales. The project focuses on two large-scale exogenous influences, climate change and deforestation in the Amazon, and two endogenous factors, ecosystem response to global warming and socio-ecological interactions at the local scale (e.g., a small watershed within the MC basin; see Fig. 1).

Climate Change

The most recent climate report from the Intergovernmental Panel on Climate Change (IPCC) indicates that climate change is already affecting every inhabited region in the world in different ways (IPCC, 2021). In particular, northwestern South America (NWS), the region where the MC basin is located, has been experiencing more frequent and severe hot weather extremes since 1950 due to human activity, as well as increases in relative sea level, ocean acidification, and marine heatwaves. Projections suggest that these changes will continue through the 21st century, in addition to increases in mean precipitation, coastal flooding, and coastal erosion (Arias et al., 2021; Table TS.5). Moreover, the IPCC climate report indicates that there is limited evidence of changes in intensity and frequency of heavy precipitation in this region, due to limited data/literature that there is low agreement in the type of change regarding agricultural and ecological droughts

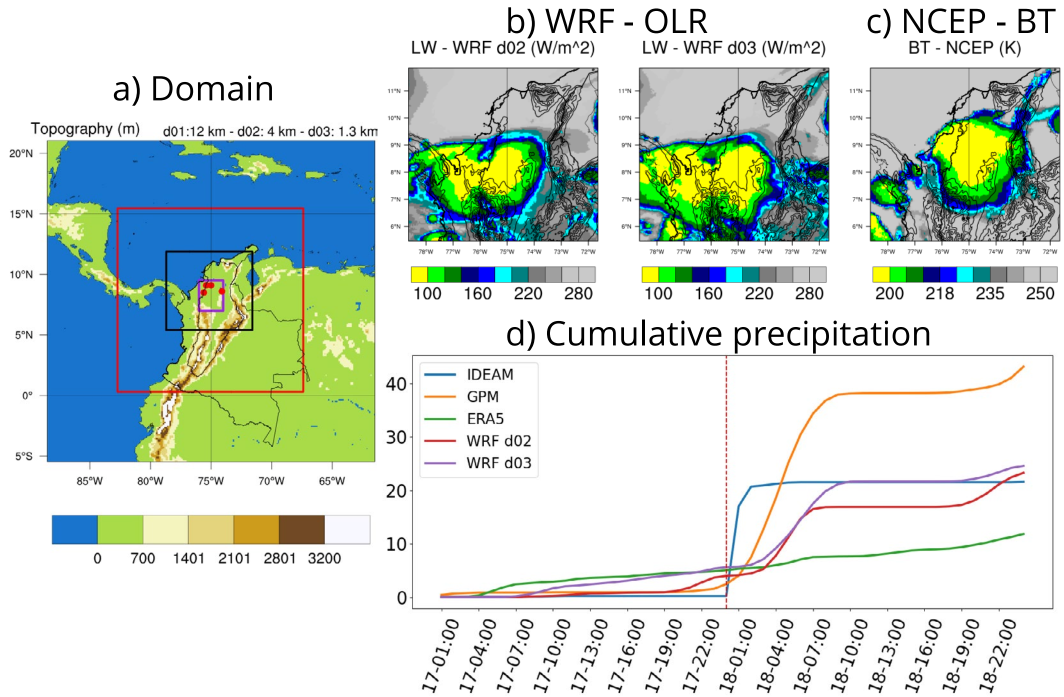

Figure 2. *a) Domains considered when performing convection-permitting simulations in the MC basin using the Weather Research and Forecasting (WRF) model. b) Simulations of outgoing longwave radiation (OLR) for a specific MCS in the lower MC basin, for two domains (d02: 4 km; d03: 1.33 km). c) National Centers for Environmental Prediction (NCEP) brightness temperature (BT) from the NCEP-MERGIR database for the MCS taken into account here. d) Cumulative precipitation during the MCS event from different databases [Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) rain gauges, Global Precipitation Measurement (GPM) data, European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) data] and the WRF simulation for the d02 and d03 domains.*

(IPCC, 2021; Figure SPM3). In order to understand the impacts of climate change, we need to better understand the critical systems that play a role in the hydroclimate of the MC basin, including the Orinoco low-level jet (OLLJ; Torrealba and Amador, 2010) and precipitating systems linked to heavy precipitation events, like Mesoscale Convective Systems (MCSs). The SOS-Cuenca Project studies the OLLJ using historical and future simulations from general circulation models under different socioeconomic (and hence emission) scenarios, as well as regional atmospheric simulations and observations-based data, aiming to understand the OLLJ's role in precipitation over the upper MC basin in the Andes-Amazon transition region (e.g., Jiménez-Sánchez et al., 2019, 2020; Martínez et al., 2022). MCSs over the lower part of the MC basin will be studied with observational data sets and convection-permitting simulations (Fig. 2).

Amazon Deforestation

The Amazon forest covers more than 6 million square kilometers in tropical South America; it is the largest tropical forest in the world and is being destroyed rapidly (Junior et al., 2021). An essential question for South America is how the continent's sustainability at different scales and places may change due to the Amazon deforestation. A critical aspect of sustainability is water security; water insecurity has destabilized societies in the past and will very likely destabilize societies in the future (Diamond, 2011). In the MC basin, a large fraction of precipitation comes from evapotranspiration in the Amazon through atmospheric pathways leading to continental moisture recycling (e.g., Poveda et al., 2014; Hoyos et al., 2018; Agudelo et al., 2019; Molina et al., 2019). This implies that forest change in the Amazon likely has a strong potential to alter hydrology and water availability in the MC basin through impacts on precipitation, such as through changes in atmospheric moisture transport and regional circulation (Ruiz-Vasquez et al., 2020; Sierra et al., 2021). Some previous studies have investigated these links between the Amazon and Andean basins (see, e.g., Espinoza et al., 2020); however, the understanding of how forest change in the Amazon may affect the MC basin's hydrology, climate, and sustainability remain incomplete. The SOS-Cuenca Project seeks to advance this understanding. Research activities include climate model simulations of Amazon deforestation scenarios, hydrological model simulations of the response of the MC basin and some of its sub-basins to climate change and Amazon deforestation, and conceptual advances in understanding basins' regulation capacity and response to external forcings (Salazar et al., 2018; Salazar et al., 2021; Posada-Marín and Salazar, 2022).

Andean Ecosystems

Andean forests are some of the most diverse ecosystems that are tied to not only the conservation of biodiversity on the planet (Enquist et al., 2019), but also the provision of ecosystem services that benefit over one hundred million people in South America, with around twenty-five million in Colombia (Anderson et al., 2011; Llambí et al., 2020; Duque et al., 2021). However, these strategic ecosystems are threatened by global change-related events such as droughts (Poveda et al., 2020; Arias et al., 2021), which could alter ecosystem function, structure, and composition via the specific vulnerability of species to these extreme events. Recent research has shown that drought events are the main cause of tree mortality for tropical moist forests (Bittencourt et al., 2020) and tropical dry forests (Powers et al., 2020). Nevertheless, this type of information is unknown for Andean forests. In addition, there is no information about Andean tree species' vulnerability. Therefore, the SOS-Cuenca Project seeks to understand tree responses to water limitation at early life stages throughout experimental settings (Fig. 3), which allows us to establish a plethora of possible mechanisms that make Andean tree species vulnerable to changes in precipitation patterns.

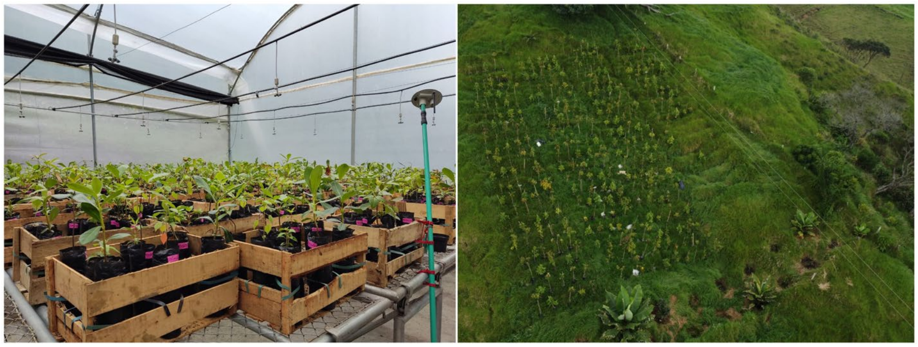

Figure 3*. Experimental settings for seedlings in the greenhouse and for saplings in the field*

Local Socio-Ecological Systems

A socio-ecological system (SES), such as the MC Basin, is a bio-geophysical unit in which ecosystems and social systems interact (Örjan Bodin and Tengö, 2012; Martín-López et al., 2017). In an SES, there is a dynamic and double-way relationship between the functioning of the ecosystem and the well-being of society. The dynamics of such a relationship are determined by the changes in the ecological integrity due to direct drivers of change, such as climate change and land use/land cover changes (Berrio-Giraldo et al., 2021). In these complex and dynamic scenarios, the health of the SES can be assessed by studying properties such as vulnerability, resilience, and sustainability through time (Berrouet et al., 2018; Fang et al., 2021; Vázquez-González et al., 2021). The sustainability of an SES can be understood as a condition of the system in which the satisfaction of the aspirations and needs of the social system is achieved, taking into account the limits imposed by the biophysical system over a period (Ekins et al., 2003; Ostrom, 2009; Pérez-Maqueo et al., 2013; Pelenc and Ballet, 2015; Fang et al., 2021). Assessing changes in sustainability due to direct and indirect drivers contributes to the design of policies and strategies of territorial planning and ecosystem management. In recent years, different approaches have emerged to analyze sustainability (Bastian et al., 2013; Zang et al., 2017; Perchinunno et al., 2020; Fang et al., 2021). However, there are elements associated with the SES dynamics and complexity, especially in the case of hydrographic basins, which have yet to be conceptually and operationally incorporated into the sustainability analysis. The SOS-Cuenca Project contributes to the literature by designing and implementing a methodology to evaluate the sustainability of an SES in the context of hydrographic basins that considers SES dynamics and complexity.

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CLIMAX

Climate Services Through Knowledge Co-Production: A Euro-South American Initiative for Strengthening Societal Adaptation Response to Extreme Events

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Climate variability patterns linking the South American Monsoon region, including Amazonia, with southeastern South America influence climate extremes and impact several societal sectors. More than 200 million people live in this area, which is also one of the largest agricultural production regions of the world and where the world's second largest hydroelectric power plant is situated. In addition to recent progress, further efforts are needed to better understand and predict regional climate variability. Therefore, an inter- and trans-disciplinary framework based on a European-South American research cooperation has been implemented since 2016 to underpin climate services in South America. CLIMAX Project objectives are:

1. to better understand the combined role of remote and local drivers on South American climate variability from sub-seasonal to decadal timescales, and its impact on the occurrence and intensity of extreme events. Special focus is given to an improved understanding of the effects of land use changes from the Amazon to the subtropics and their impact on extreme precipitation events
2. to assess the predictability levels associated with regional climate patterns from sub-seasonal to decadal time scales; to develop innovative regional prediction tools, not only of climate variability, but also of climate impact on both agriculture and hydrology in southern South America (SSA) on sub-seasonal and seasonal time scales
3. to engage in a climate knowledge co-production process to revise how climate data are used by various stakeholders in their socio-cultural contexts, and to analyze communication conditions of the interdisciplinary and trans-disciplinary process of knowledge co-production that determines the usefulness of climate information in the process. Innovative technologies are co-developed to produce products and tools by the project for regional climate services focusing on agriculture and hydropower sectors.

CLIMAX underpins the operational activities of the Southern South America Regional Climate Centre (SSA-RCC, http://www.crc-sas.org/es/), headed by the National Meteorological Services of Argentina and Brazil and sponsored by the World Meteorological Organization. The project not only includes actors from the national meteorological services, but also from agriculture and energy sectors and other key organizations.

The project consortium includes the following institutions: Centre National de la Recherche Scientifique CNRS/Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos (UMI-IFAECI) (Argentina-France); Potsdam-Institut für Klimafolgenforschung (PIK) (Germany); Technical University of Munich (TUM) (Germany); Centro de Previsão de Tempo e Estudos Climáticos (CPTEC)/Instituto Nacional de Pesquisas Espaciais (INPE) (Brazil); Wageningen University and Research (WUR) (The Netherlands); Institut de Recherche pour le Développement (IRD)/ Unité Mixte de Recherche (UMR 245) (France); and the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) (France). The project is sponsored by the Collaborative Research Action (CRA) on "Climate Predictability and Inter-Regional Linkages" of the Belmont Forum, launched in 2015.

Highlights

Some relevant results of two main project themes are described below. Further information is available at http://www.climax-sa.org/.

Dynamic Vegetation Modeling and Land-Surface Processes

Four state-of-the-art dynamic global vegetation models [DGVMs: the Integrated model of LAND surface processes (INLAND), the Lund-Potsdam-Jena managed Land model version 4 (LPJmL4), the Lund-Potsdam-Jena General Ecosystem Simulator (LPJ-GUESS), and Organising Carbon and Hydrology In Dynamic Ecosystems model (ORCHIDEE v2.0)] have been developed and/or used in the context of the project to improve the simulation of the interaction between tropical vegetation and climate variability in South America. For example, Sakschewski et al. (2021) developed an approach of implementing variable rooting

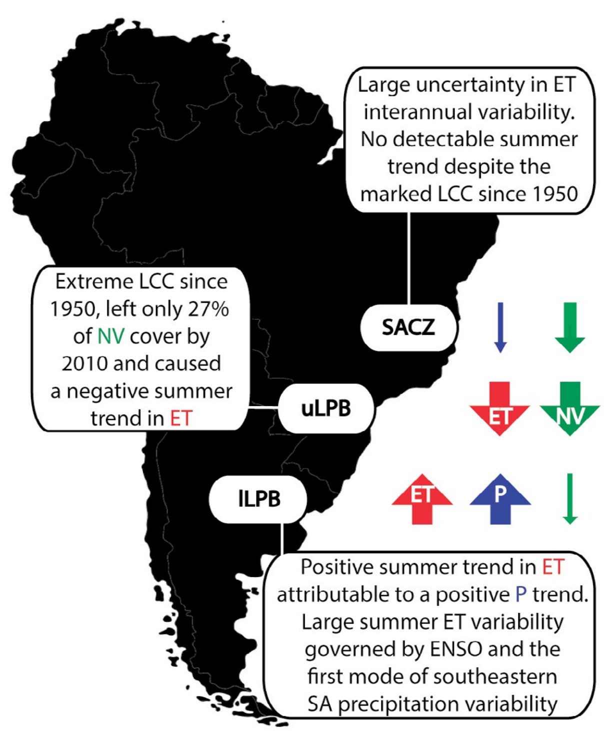

***Figure 1**. Role of land-cover change and precipitation variability in explaining evapotranspiration trends and variability in the lower La Plata Basin (lLPB), upper la Plata Basin (uLPB) and the South Atlantic Convergence zone (SACZ) regions. (Figure 9 from Ruscica et al., 2021)*

***Figure 2**. Bermejo community rainfall monitoring network (Figure 3 from Hernández et al., 2021)*

strategies and dynamic root growth into the LPJmL4.0 DGVM and applied it to tropical and sub-tropical South America under contemporary climate conditions. They show how competing rooting strategies, which underlie the trade-off between above- and below-ground carbon investment, lead to more realistic simulation of intra-annual productivity and evapotranspiration and consequently of forest cover and spatial biomass distribution.

The four DGVMs were used to perform 24 simulations forced by three different atmospheric data sets, each using two different land-cover conditions, observed land-cover changes (LCCs) and natural vegetation (NV). Among other ongoing studies, the ensemble of model simulations was used by Ruscica et al. (2021) to assess the influence of local LCC and precipitation as drivers of regional evapotranspiration (ET) long-term trends and variability in southeastern South America. This region that encompasses the La Plata Basin is subject to considerable precipitation variability on seasonal to decadal timescales and has undergone very heavy LCCs since the middle of the past century. It was found (Fig. 1) that in the lower La Plata Basin, ET was driven by precipitation variability and showed a positive summer trend. On the contrary, in the upper La Plata Basin, LCCs forced the negative summer ET trend. In the South Atlantic Convergence Zone region, the high ET uncertainty across ensemble members impeded finding robust results, which highlights the importance of using multiple DGVMs and atmospheric forcings instead of relying on single model/forcing results.

Climate Knowledge Co-Production

Co-production has been implemented in the project as a particular knowledge creation device. It facilitates the development of socially-meaningful and appropriable products and has provided a continuous learning space for all the actors involved. One of the main achievements of the project is the co-production of climate services (weekly forecasts, meteorological and hydrological information) for family farming in Argentina's Chaco region (Bermejo case study), allowing the development of adaptation strategies according to local agroclimatic conditions (Hernández et al., 2021). First, we codesigned a community rainfall monitoring network (Fig. 2), and second, we codeveloped an online application for open science and open-source sharing of co-produced climate information between academics and non-academics (*https://bermejo.cima.fcen.uba.ar/*). Jointly with the local rural schools, we codeveloped educational tools on climate issues including content on climate change and its impacts on agricultural activities for their academic curriculums. In cooperation with local institutions, we also developed an informative bulletin addressing the current climate conditions and outlooks as well as the relationship between climate and agriculture, which is broadcast by radio throughout the area. The success of this climate services coproduction process prompted the Chaco Province Government to propose scaling up this experience to the whole province and to participate in the development of the online application by providing climate information produced by the province's network of automatic weather stations.

The analysis of the interaction between social conditions (social structure, socio-technical trajectories, productive activity, use of commons, the role of transition policies towards sustainable systems, etc.) and climatic-environmental conditions (predictability, wetland regime, El Niño-Southern Oscillation influence, etc.) allowed us to understand the development of adaptation strategies for family farming. We also found that the generic climate products available for the agriculture sector are not easily adopted by family farming productive profiles. These products are generally oriented to exportation crops (soy, corn, wheat, and sorghum) produced on large scales using unsustainable technological packages (transgenic seeds, agrochemicals). Instead, CLIMAX climate services addressed the needs of family farming by focusing on the crops they grow for local markets while promoting agroecological systems. In addition, the codesigned climate products gave rise to new ways of conceptualizing and visualizing climate monitoring and forecasting information, proposing forecast formats and communication media (free open application and radio program).

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The AMANECER Project

AMazon-ANdEs ConnEctivity: Impacts of Climate-Vegetation Changes on the Water Cycle of the Amazon-Andes Transition Region

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Introduction

The Amazon is the world's largest river basin and comprises about 40% of the planet's tropical forests. It plays a key role in the water, energy, and carbon cycles that interact with the global climate system. The Amazon hydrological system now faces great risks due to climate change and increased anthropogenic pressure such as deforestation. These environmental alterations require a better understanding of their potential impacts on the components of the basin's water cycle at different scales. Recently, significant changes in the Amazon hydrological cycle have been documented, including more frequent and intense extreme floods and droughts (Espinoza et al., 2022; Marengo et al., 2022). Recent extreme droughts caused intense forest fires and tree mortality in the southern Amazon (Arias et al., 2020; Espinoza et al., 2021) and an increase in biomass mortality, resulting in a long-term reduction of the Amazon carbon sink (Gatti et al., 2021). Due to the global relevance of the Amazon rainforest, detected extreme droughts and rainfall-biomass changes could intensify the global and regional climate system (Nobre et al., 2016).

In this context, South American scientists and their partners in French laboratories proposed in 2018 the AMANECER project (*https://sites.google.com/view/amanecer-project/*), funded by the French National Research Agency (ANR) and the French National Research Institute for Sustainable Development (IRD) in the context of the French government's "Make our planet great again" initiative (*https://makeourplanetgreatagain-cnrs.com*). The main goal of AMANECER is to better understand how climate change and regional modification of land cover could affect the water cycle in tropical South America, particularly in the Andes-Amazon transition region. At the heart of AMANACER is the co-construction of projects between South American and French scientists, and the training of students from the Amazon-Andean countries. This project also aims at consolidating a unique Franco-South American research network, which includes scientists from Peru, Bolivia, Ecuador, Argentina, Colombia, and Brazil. In this article, we provide a brief summary of a selection of key scientific results obtained during the first three years of the project.

Impacts of Large-Scale Climate Variability on the Amazon Water Cycle and Vegetation

The dry season in southern tropical South America has lengthened in recent decades, mainly associated with a delayed onset of the South American monsoon system (SAMS) (e.g., Agudelo et al., 2019). In Espinoza et al. (2021), we analyze the characteristics of atmospheric variations over tropical South America using the pattern recognition framework of weather typing or atmospheric circulation patterns (CPs). This analysis revealed significant changes in the CPs during the dry-to-wet transition season in South tropical South America (STSA) during the 1979–2020 period. Nine CPs are defined using a k-means algorithm based on daily unfiltered 850-hPa winds over 10˚N–30˚S, 90˚–30˚W. One of the wintertime patterns increases from 20% in the 1980s to 35% in the last decade while a transitional CP, related to the triggering of rainfall over STSA, decreases from 13% to 7% during the same periods. In addition, the interannual frequency of one particular CP is well associated with the date of the SAMS onset and with the intensity of the fire season in this region. This CP explains around 35%–44% of the interannual variations of fire counts over STSA during the period of 1999–2020.

These results provide further insights into the identification of atmospheric states particularly relevant for understanding the SAMS onset. In addition, these CPs, which are based only on low-level wind circulation, provide new perspectives for seasonal forecasting systems of the dry-season length and related impacts on the intensity of the fire season over this region.

Relationship between Changes in Land Surface Conditions and Water Cycle

Wongchuig et al. (2021) analyzed the relationships between changes in the observed components of the water cycle with changes in forest cover during the last 40 years. In the southern Bolivian Amazon, the tendency of decrease in precipitation is systematic, mainly in places where there is a high ratio (>40–50%) of non-forested areas (Fig. 1). The increases in potential evapotranspiration are systematic, mainly in the Andes and over deforested regions, due to large-scale processes (e.g., global warming) and changes in the surface energy partitioning, respectively. In southern Peru and Brazil, a decrease in actual evapotranspiration is observed in highly deforested areas due to a reduced access to soil moisture from the deepest root zone. Implications on the water and energy balance were also evaluated, looking at changes in the components of Budyko's theoretical framework. Among these components, the dryness index, i.e., the ratio between potential evapotranspiration and precipitation, indirectly indicates aridity conditions, and a transition from energy to water limited in evapotranspiration. Results suggest that in places with a high ratio of deforestation located in the southern Amazon in Bolivia, the tendency to become a region with savannah-like conditions is significant. In addition, Arias et al. (2020) show that the ongoing warming in tropical North Atlantic, which has intensified since the 1970s, generates changes in surface winds and atmospheric moisture transport in the region. These changes lead to de-

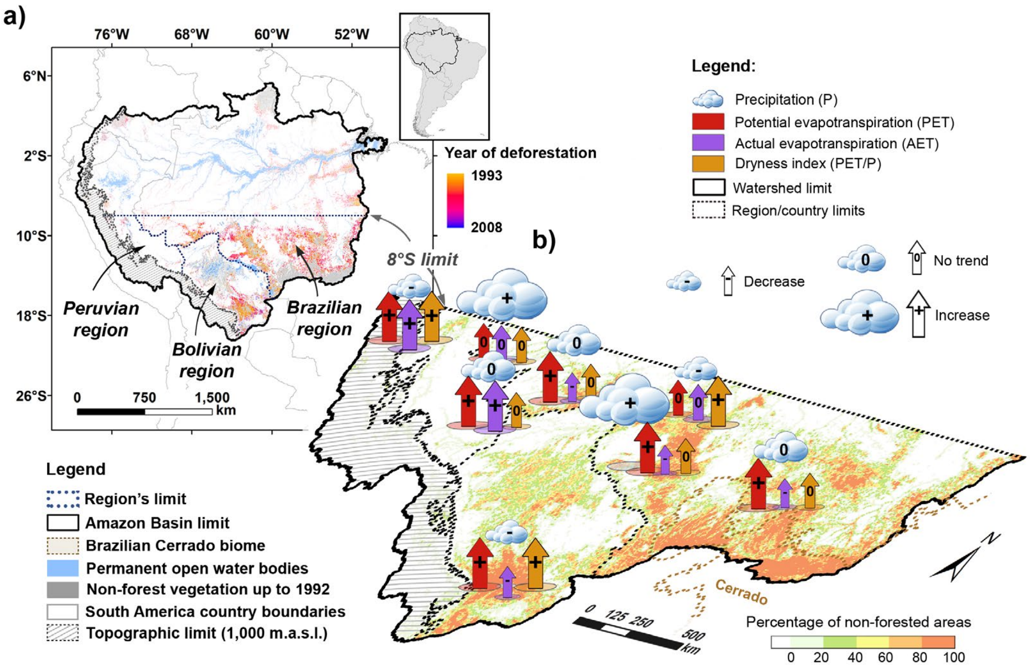

Figure 1. (a) Map of non-forest vegetation up to 1992 (grey) and deforested areas (yellow-red-blue bar colors) for the 1992–2018 period in the Amazon Basin. (b) Schematic distribution of increased (large icon with "+"), decreased (small icon with "-") and non-trend (medium icon with "0") for precipitation (cloud), potential evapotranspiration (red arrow), actual evapotranspiration (purple arrow), and dryness index (gold arrow) for areas displaying the most significant variations from 1981–2018. The percentage of non-forest vegetation areas as of 2018 is represented by the green-red color bar. Adapted from Wongchuig et al. (2021).

creasing precipitation in southern Amazonia, inducing a decrease of soil moisture, moisture recycling, and impacting vegetation and the water cycle over this region (Gutierrez-Cori et al., 2021). These findings provide a new perspective on the spatial variability of atmosphere and land surface interactions, which indicates a complex dependence not only on large-scale processes, but also on local-regional processes.

Recent Changes in the Amazon-Andes Hydroclimatic Connectivity

Austral summer precipitation in the tropical Andes is the most important water resource for the population and ecosystems of the tropical Andes. In Segura et al. (2020), we focus on analyzing the interannual and long-term variability of the Altiplano precipitation during the austral summer in relation to changes in Amazon atmospheric circulation, involving the recent intensification of the Hadley and Walker cells (Espinoza et al., 2019). Related to the SAMS, an anticyclonic system called the Bolivian High (BH) is located over the Bolivian Andes at 200–300 hPa (Lenters and Cook, 1997). Our study demonstrates that December–February precipitation over the Altiplano shows a positive trend in the 1982–2018 period. However, this trend was not explained by an intensification of the BH, as expected considering scientific literature (Espinoza et al., 2020). In contrast, this rainfall trend is explained by ascending motion over the western Amazon, which has intensified in the 1980–2018 period. Furthermore, this has also changed the interannual relationship between the BH and precipitation over the Altiplano. Until 2002, the interannual variations of the BH clearly explained dry and wet summer seasons on the Altiplano. This is no longer valid, since precipitation in the Andean region significantly synchronizes with interannual variations in the upward motion over the western Amazon in recent decades (Segura et al., 2020).

Our results point out that changes in the BH could be offset by the strengthened convection over the Amazon; however, convection in western Amazonia is strongly related to land surface processes that can be modified under deforested scenarios of the Amazon rainforest.

Deforestation Impacts on the Amazon-Andes Hydroclimatic Connectivity

The continued deforestation caused by rural development during the last half-century in the Amazon basin threatens the existence of the biggest rainforest in the world (Nobre et al., 2016). One of the main aims of the AMANECER project is to analyze the effects of Amazonian forest loss on the hydroclimatic connection between the Amazon and the eastern tropical Andes region, which is considered a hotspot of biodiversity and rainfall (Hoorn et al., 2010; Espinoza et al., 2015). New insights on this topic have been documented in the recent study from Sierra et al. (2021). Through the use of high-resolution simulations with the regional climate Weather Research and Forecasting (WRF) model and a deforestation scenario of 45% of cleared Amazon area, this study identified strong alterations in the surface energy balance. Enhanced energy losses are caused by the combined effect of increases in the albedo/shortwave radiation reflection and reductions in the incoming longwave radiation due to a drier atmosphere. Our results show a decrease in the moisture transport entering the continent from the Atlantic Ocean, a reduction in moisture convergence and ascending air velocities, and rainfall depletion of about 20% in the Amazon basin as a consequence of the alterations in the regional surface energy balance (see Fig. 2 a–b). Over the western part of the basin, daytime precipitation is reduced between 10–20% in the deforested area of the Amazon lowlands. However, during the night, a 20–30% rainfall reduction is concentrated over the eastern flank of the Andes and the Bolivian piedmont as the result of weaker moisture transport from the Amazon to the tropical Andes. This nocturnal convection is very important because it corresponds

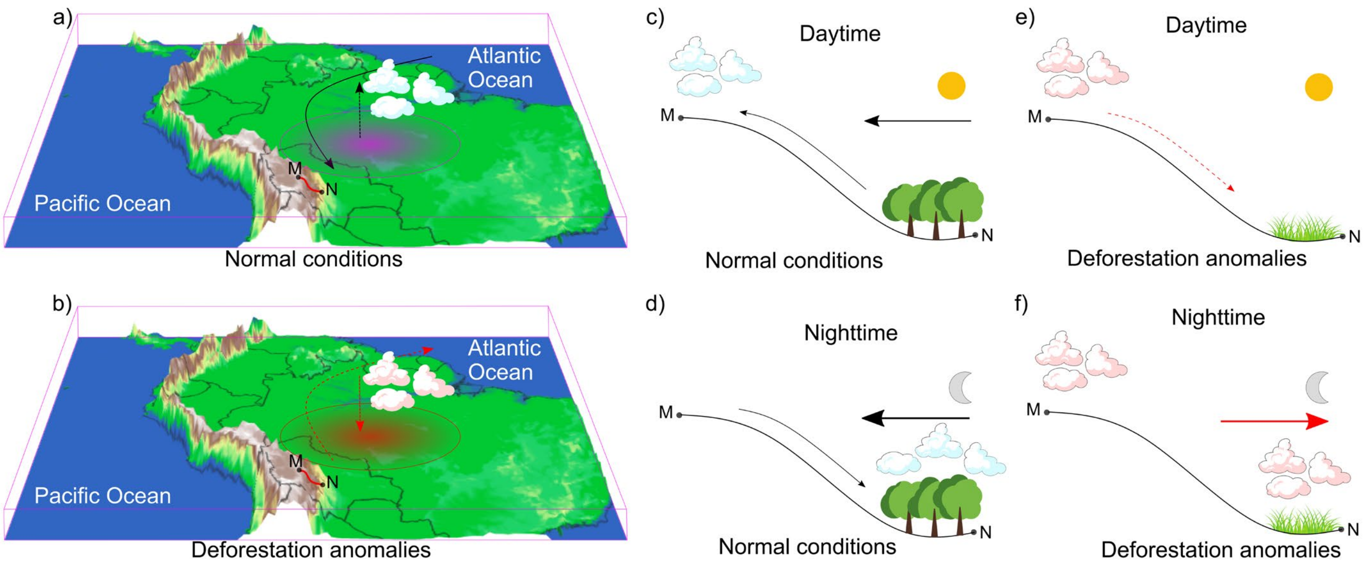

***Figure 2**. Simplified representation of the regional circulation and moisture transport over tropical South America during December–February in normal land cover conditions (a) and anomalies induced by deforestation (b). Line M-N shows the approximate location of the Bolivian Andean valleys. Local characteristics of moisture transport along the valleys during daytime (c) and nighttime (d) under normal land cover conditions. Local deforestation impacts on atmospheric circulation during daytime (e) and nighttime (f). Black (red) thin arrows represent moisture flux in normal (deforested) conditions. Vertical black (red) arrows show ascending (descending) motion under normal (deforested) conditions. Magenta (red) shaded area shows moisture convergence (divergence). Blue (red) clouds indicate rainfall maxima (rainfall decrease) under normal (deforested) conditions. Figure adapted from Sierra et al. (2021).*

to nearly 70–80% of the daily summer precipitation in the Amazonian tropical Andes (Junquas et al., 2018). Finally, at a local scale and using rainfall in situ records, this study demonstrates how deforestation's regional effects decrease the nocturnal precipitation in two Andean Bolivian valleys through a reduction in the entry of South American low level jet moist winds. Results show that the local deforestation inside the valleys themselves weakens the anabatic winds during the daytime and causes a shallower planetary boundary layer (see Fig. 2 c–f).

Ongoing Works and Perspectives

Currently, efforts are oriented towards providing future scenarios of climate-related changes in Amazonian vegetation and their implications for precipitation in the Andes. For this, we will identify future changes from general circulation model (GCM) [World Climate Research Programme (WCRP)/Coupled Model Intercomparison phase 6 (CMIP6)] simulations in the main climatic forcing modulating vegetation activity and forest fire (e.g., changes in the atmospheric circulation patterns). Thus, projections of precipitation change in the Andean region, based on GCM bias corrections and high-resolution climate simulations, will be produced for the long-term (last decades of the 21st century). With this methodology, we expect to identify future local-scale precipitation changes in the Andes-Amazon region associated with changes in i) atmospheric circulation and ii) land-cover as a function of changes in atmospheric circulation. Finally, the impact of these changes in the hydrological cycle of Andean mountains, high plateaus, and valleys will be quantified.

The Amazon-Andes hydroclimatic connectivity is an excellent case study for improving our understanding of the coupled dynamics between the water and energy cycles. Reduced uncertainties in future projections of water availability and extreme events is a key topic under the ongoing context of climate change and land use changes in South America. Therefore, results from the AMANECER project will be particularly relevant for starting scientific initiatives at continental scale, such as ANDEX, Convección Permitida para América del Sur (cpAmSur), the South America Affinity Group (SAAG), etc.

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The GREAT ICE and ANDES-C2H Programs: A Focus on the ANDES as a Nexus of the Atmosphere, Cryosphere, and Hydrosphere

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Two international initiatives, the Glacier and Water Resources in the Tropical Andes: **Indicators of Changes in the Environment (GREAT ICE) International Joint Laboratory** (2011–2021; Sicart et al., 2015) and the **Andes, Climate, Cryosphere and Hydrosphere International Research Network (ANDES-C2H IRN)** (2021–2026) have been successively led by a French–South American researcher community under the umbrella of the Institut de Recherche pour le Développement (IRD) to strengthen glaciological, climatological, and hydrological studies in the Andes, promote collaborative projects, and develop educational programs with local universities. The ongoing ANDES-C2H IRN structures our community through a partnership beyond that of its predecessor GREAT ICE (Bolivia, Peru, and Ecuador), with the aim of broadening the research topics to include groundwater resources and climatology on the one hand, and establishing new collaborations in Colombia, Chile, and Argentina to study climatological, glaciological and hydrological processes throughout all the Andes on the other hand.

General Objective

The general topic of the ANDES-C2H International Research Network (*https://sites.google.com/view/andes-c2h/*) is the study of the water cycle in interaction with climate processes and environmental changes along the Andean mountain range. The Andes, which extend from 10°N in Colombia to 55°S in Patagonia, encompass a variety of climate types ranging from very wet conditions near the equator, on the eastern flank of the tropical Andes and in western Patagonia, to very dry conditions in the central Andes. In addition to the diversity of climates observed from north to south, there are strong east/west climate gradients caused by the orography of the Andes. Our research aims at better understanding the water cycle through the monitoring, analysis, and modeling of water pathways in the different compartments of the cycle (atmosphere, soil and aquifers, surface, vegetation, rivers, lakes, glaciers, etc.). We study these processes at several spatio-temporal scales, from global [climate change, El Niño-Southern Oscillation (ENSO), etc.] to local (glaciers and valleys) and from hourly to interdecadal time scales. A particular focus is on the cryosphere (snow/ice), which can play an important role in the water cycle. Mountain basins, glacierized or not, provide sources of drinking water (Kinouchi et al., 2019), subsistence (Tito et al., 2018), and energy for several million inhabitants of the Andes. Being able to better predict the evolution of water resources is timely in the context of accelerated global changes and rapid economic and demographic growth. Changes in rainfall and hydrological regimes, as well as the recession of glacierized areas, have an impact on downstream water resources and ecosystems. Innovative modeling tools have enabled us to quantify the current contribution of glaciers to regional water resources under extreme drought conditions. During such events observed over the last decade, glaciers contributed ~15%, 85%, and 90% of consumable water for the cities of Quito, La Paz, and Huaraz, respectively (Buytaert et al., 2017; Soruco et al., 2015). Such types of information allow better planning of actions to mitigate the effect of the progressive reduction of these inputs under climate change. In this context, the evolution of groundwater resources and their recharges in these glacierized basins is still poorly studied, even though these resources are increasingly under pressure in the arid and semi-arid regions of the Andes (Vuille et al., 2018). Finally, there is an urgent need to better understand and model the entire hydrological cycle in the Andean mountains using a multidisciplinary approach (climatology/glaciology/hydrology/hydrogeology) at the continental scale.

What Are the Scientific Challenges along the Andes?

The Andes are the longest continuous mountain range in the world. Due to its configuration, they are responsible for a "barrier" effect of the air circulations in the lower and mid-layers of the atmosphere. The orographic effect on atmospheric circulation is not only regional, but also global, and manifests notably through large-scale circulation patterns (Walker and Hadley cells, South American monsoon, ENSO, Rossby waves, tropical-extratropical disturbances, etc.). The Andean region is characterized by strong precipitation gradients, from hyper-arid conditions (western side of the tropical Andes, a few mm/year) to very humid conditions (6000 to 12000 mm/year) in the eastern tropical Andes and in the extreme northwestern part of the continent, as well as in some regions of Patagonia (Espinoza et al., 2020). The temporal variability of the Andean rainfall regimes is therefore influenced by the variability of local processes (e.g., valley/mountain winds, E/W slope exposure, orographic convection, etc.) and their interactions with regional processes (e.g., monsoon flows, upwelling of cold fronts from the South, moisture inputs from the Amazonian forest, etc.) as well as global processes (Arias et al., 2021). With regard to glacier processes, mass balance measurements conducted on several Andean glaciers have allowed us to link climate variability with glacier response. At the same time, local processes are increasingly becoming better-quantified in term of turbulent fluxes, role of albedo on melting, etc. Two recent remote sensing studies have allowed a regional quantification of mass balance variations along the Andes since 2000, and they showed that all Andean glaciers are losing mass, with spatial differences among glaciers according to their geographic location, and temporal variability according to decade (2000/2010 or 2010/2018) (Dussaillant et al., 2019; Hugonnet et al., 2021). However, the role of the different atmospheric and local morpho-topographic variables in controlling the behavior of various types of glaciers remains poorly understood (Masiokas et al., 2020). Given these challenges, the main aims of the ANDES-C2H International Research Network are the following:

1. a better understanding of spatial and temporal variability of the hydrological cycle in the Andes; atmospheric circulation, moisture sources, precipitation, cryosphere (seasonal snow, glaciers, permafrost), surface water (lakes, rivers), sub-surface and groundwater (soils and aquifers); availability of resources for water uses. A large part of the South American population (more than 80 million inhabitants) depends on water resources in the Andean areas (drinking water, industry, hydroelectricity, agriculture).
2. a better evaluation of the risks associated with extreme events (droughts and floods, low and high temperatures, frosts) and polluting human activities in countries undergoing very rapid environmental, economic, and social changes.
3. a better characterization of changes in the precipitation regime of the Andes linked to global climate change and linked to land use changes (in the Andes and in the Amazon). These changes may modify the water cycle at local and regional scales (Sierra et al., 2021). A particular focus of the project is the massive deforestation activities and forest fires that can impact glacier melting (Magalhães et al., 2019) as well as precipitation patterns.

Receding Andean Glaciers Submitted to Contrasted Climates

Like most mountain glaciers worldwide, glaciers in the Andes have been rapidly receding since the late 1970s. Although sporadic positive annual mass balances have been observed in some glaciers, the average mass balance has been mostly negative over the past 50 years. In 2010, tropical glaciers in the central Andes covered about 1,920 square kilometers in Bolivia (20%), Peru (71%), Ecuador (4%), and Colombia-Venezuela (4%). They play a significant role in freshwater availability in highly populated regions and are key indicators of recent climate changes in poorly-documented mountainous regions (Rabatel et al., 2013).

At the scale of the entire Andes, a recent review article identified the remaining challenges preventing a complete understanding of the variability of the cryosphere (snow and ice) (Masiokas et al., 2020). A recent study by Millan et al. (2022) provided new estimates of mountain glacier ice thickness distribution and glacier volume at the global scale. At the scale of the Andes, they found a total amount of ice of 6 x10^3 km^3, 99% of which is stored in the Southern Andes. However, even if the ice volume of the tropical Andes is low, estimates from Millan et al. (2022) found an estimate that is 27% lower than previous studies. This would further increase the conflicts around future water management strategies in the tropical cordilleras all the more.

For the glaciers subjected to various climate types, the explanatory variables, inducing the spatial variability of glacier mass fluctuations and of the general retreat of the Andean glaciers, are still a subject of debate. A recent study from Caro et al. (2021) proposes 12 new clusters for the glaciers along the Andes based on the relationships between area and mass balance changes with morphometric and climatic variables (Fig. 1). Specifically, the spatial and seasonal variability of precipitation dominates the spatial variability of glacier changes from the Outer Tropics to the Dry Andes (8–37°S), explaining between 49 and 93% of variances, whereas across the Wet Andes (40–55°S), the spatial variability of temperature is the most important climatic variable and explains between 29 and 73% of glacier changes' spatial variance. This work allowed the identification of a new spatial framework for hydro-glaciological analysis composed of 12 glaciological zones, derived from a clustering analysis, which includes 274 watersheds containing 32,000 glaciers. These new zones consider different seasonal climate and morphometric characteristics of glacier diversity in a better way. This study shows that the exploration of variables that control glacier changes, as well as the new glaciological zones established on the basis of these variables, would be very useful for analyzing hydro-glaciological modeling results across the Andes (8–55°S).

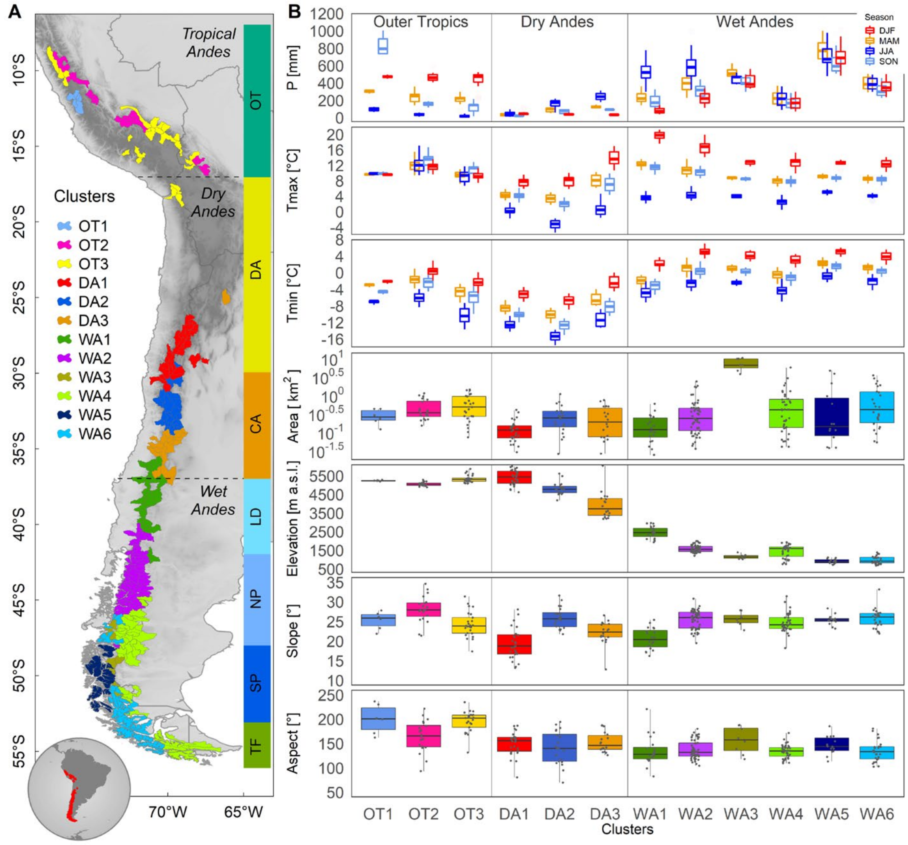

Figure 1. The 12 clusters of the glacierized watersheds across the Andes (8–55°S) and the behavior of climatic and morphometric variables. The average values of variables (for 274 watersheds and using 31,963 glaciers) are presented for the 12 clusters identified (Partitioning Around Medoids, or PAM, algorithm) using the glacier area variation (GAV) and glacier mass balance (GMB) explanatory variables (Least Absolute Shrinkage and Selection Operator, or LASSO, algorithm). These clusters are found in three regions: Outer Tropics (OT; 8–17°S), Dry Andes (DA; 17–37°S), and Wet Andes (WA; 37–55°S). (A) shows the cluster distribution across the Andes and the classic zones, from north to south, are: Outer Tropics (OT; 8–17°S), Desert Andes (DA; 17–30°S), Central Andes (CA; 30–37°S), Lakes District (LD; 37–42°S), North Patagonia (NP; 42–48°S), South Patagonia (SP; 48–53°S), and Tierra del Fuego (TF; 53–55°S). (B) presents the climatic variables (1980–2019) which are grouped into the summer (DJF), autumn (MAM), winter (JJA), and spring (SON) seasons for the Southern Hemisphere. The sum of the precipitation and the extreme temperatures averages are shown here. Additionally, morphometric variables associated with the glacierized area (i.e., surface area, elevation, slope, and aspect) are shown. From Caro et al., 2021

A Prerequisite: A Good Understanding of the Spatio-Temporal Variability of Precipitation

In both the GREAT-ICE and ANDES-C2H initiatives, an important focus is to achieve a better understanding of the spatio-temporal variability of precipitation in terms of frequency, intensity, and phase. Indeed, glaciers and more generally water fluxes in the mountainous catchments are highly dependent on precipitation, especially in the tropics and arid temperate regions. Several recent studies are based on a multiscale approach from global, regional, and local scales, taking into account climate variability and change, and land use changes (e.g., Saavedra et al., 2020; Sierra et al., 2021). For instance, in the outer tropics of Bolivia and Peru, characterized by a marked seasonality in cloud cover and precipitation, process-based energy balance studies have investigated the local and large-scale atmospheric forcings that control seasonal and interannual variations in the glacier mass balance (e.g., Sicart et al., 2011; Sicart et al., 2016). During the melt season, light snowfalls are frequent, and the glacier surface continuously alternates between ice and thin layers of snow that rapidly melt, so that the melt rate strongly depends on the frequent changes in surface albedo. Therefore, continuous spatially extended in situ measurements is crucial for monitored glaciers (Condom et al., 2018).

Process-based balance studies have also shown that tropical glaciers are characterized by large vertical mass balance gradients due to the frequent changes in snow cover throughout the long ablation season. Ablation and accumulation processes are closely related, and the mass balance strongly depends on the timing and length of the wet season, which arrives during the summer months, interrupting the period of highest melt rates caused by solar radiation (Sicart et al., 2011).

In order to improve our knowledge of precipitation spatio-temporal variabilities in mountain regions, analyses of the different precipitation products and associated atmospheric processes are conducted. First, with a dense network of hourly in situ measurements, it is possible to decipher the characteristics and the influence of humidity, as done, for example, in the Antizana region by Ruiz- Hernández et al. (2021) in Ecuador. In this region, situated near the Antizana ice cap, the discrimination of the precipitation phase can be reached thanks to optical disdrometers (Campozano et al., 2021). A way to better understand the dynamical conditions in the atmosphere that generate precipitation is to use Regional Climate Models. For instance, the Weather Research and Forecasting (WRF) model allows the characterization of the spatio-temporal variability of the precipitation from hourly to seasonal time scales. However, a careful analysis of the parametrization schemes and the digital elevation model forcing (Junquas et al., 2022) as well as a bias correction have to be conducted before using these simulations in hydrological models (Heredia et al., 2018). Fig. 2 issued from a recent study shows that in the case of the glacierized Santa Basin, the Amazonian region is not the unique source of moisture, as the Pacific Ocean provides a significant amount of water (Rosales et al., 2022).

Water Resources in the Andes

In hydrology, the precise quantification of the different sources of water flow in the rivers (surface, underground, ice and snow melt) remains challenging in mountainous regions due to the scarcity of in situ measurements and high spatial gradients of atmospheric variables across small distances. The supply of water from glacierized mountain chains is critical for estimating agricultural and domestic water consumption as well as for hydropower generation. Considering the retreat of the glaciers, the impact on downstream rivers will first produce an increase until a peak water level is reached and subsequently a decrease in the runoff originating from the glacier melt. In order to have more accurate estimates of the water fluxes in the glacierized catchment, the reduction of the uncertainty on the mass balance calculation can be obtained with the geodetic mass balance method (Basantes-Serrano et al., 2018).

In the ANDES-C2H International Research Network, we will aim for a better representation of water balances, in particular the evolution of snow cover where albedo feedback phenomena are important, as well as a better consideration of glacier/surface water/groundwater relationships, considering historical observations and future climate projections. As an example, a first multidisciplinary study carried out on the Katari/Titicaca Lago Menor basin on the Bolivian Altiplano made it possible to characterize the physical and chemical properties of the aquifer between the Cordillera Real and Lake Titicaca located in sediments resulting from Pleistocene glaciations (Aviles et al., 2022). The importance of glaciers in the recharge of these fluvio-glacial aquifers and, more generally, the modifications of the hydrological cycle in the face of climate change are still poorly understood and will be studied through the collaboration of climatologists, hydro-glaciologists, and hydrogeologists.

The future period (end of the 21st century) will also be explored through high-resolution climate modeling and the study of general circulation model outputs [collaboration underway between the Institute for Geosciences and Environmental Research (IGE), Laboratoire de Météorologie Dynamique (LMD)/Institut Pierre Simon Laplace (IPSL), Centro de Investigación del Mar y la Atmósfera (CIMA)/Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos (UMI-IFAECI)]. Studies will be conducted on the impacts of future land cover changes on the regional water cycle. The spatial scales considered will therefore range from a global and continental view to a local view (ice-covered catchment area). The temporal scales considered will range from hourly (diurnal cycle) to multi-decadal (instrumental period of ~50 years). The space-time scales described above for climate will be identical for the other processes of the hydrological cycle, with catchment areas ranging from a few to several hundred thousand square kilometers.

Ongoing Works and Perspectives

Firstly, the acquisition of in situ meteorological, glaciological, and hydrological data through existing networks [Service National d'Observation-Les Glaciers, un Observatoire du Climat (SNO-GLACIOCLIM), national meteorological services, Ministry of Water, etc.] must be perpetuated and consolidated. We will then test different hydro-glaciological models of varying complexity on several basins spread from Colombia to Patagonia to improve the robustness of the simulations of the last few decades; this is an indispensable prerequisite for all future simulations linked to climate change. Research conducted in the framework of the ANDES-C2H International Research Network will be based on a multi-source data approach (with in situ, reanalysis, satellite, and model data) considering the scarcity of in situ meteorological, glaciological, and hydrological measurements in mountainous environments (Condom et al., 2020).

From an organizational point of view, there is a strong demand from partners from countries in the South to train new researchers. The diversity of expertise within our international research group provides a unique framework for research in a global and regional context, and at the scale of high-altitude watersheds that sometimes have a glacial component. We actively participate in the facilitation of the GEWEX-World Climate Research Programme (WCRP) Regional Hydroclimate Project (RHP) named ANDEX, "A regional Hydrology Program for the Andes" (*https://www.gewex.org/project/andex/home/*). This group is already well established and the participants of the ANDES-C2H International Research Network are very well integrated into it. Our general philosophy in this group will be a strong emphasis on training students through research with the supervision of "licenciatura" or "maestria" level internships (equivalent to Bachelor's and Master's degrees) in local Andean universities and the follow-up of Master's and Doctorate degrees in French and Andean universities. This will strengthen an already solid network of South American researchers. Generally speaking, we will actively promote exchanges with researchers from the Andean countries. In addition to these academic trainings, we have, over the last 6 years, carried out trainings on climate modeling, photogrammetry, hydrological modeling, and on geophysical methods and modeling in hydrogeology.

List of Partner Institutions and Acknowledgments

The 20 partner institutions are: IGE, France; University of Antioquia, Medellin, Colombia; Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Bogota, Colombia; Universidad Nacional de Colombia (UNC), Medellin, Colombia; Escuela Politécnica Nacional (EPN), Quito, Ecuador; Instituto Nacional de Meteorología e Hidrología (INAMHI), Quito, Ecuador; Universidad Regional Amazónica (IKIAM), Tena, Ecuador; SENAMHI, Lima, Péru; Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (INAIGEM), Huaraz, Péru; Instituto Geofísico del Perú (IGP), Lima, Péru; Universidad Nacional Agraria La Molina (UNALM), Lima, Péru; Universidad Mayor de San Andrés (UMSA), La Paz, Bolivia; Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Mendoza, Argentina; CIMA, UMI-IFAECI, Buenos Aires, Argentina; Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile; Centro de Ciencia del Clima y la Resiliencia (CR2), Santiago, Chile; Laboratorio de Investigación de la Criósfera y Aguas (LICA), Copiapó, Chile; Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Toulouse, France; Centre d'Etudes Spatiales de la Biosphère (CESBIO), Toulouse, France; LMD, Paris, France.

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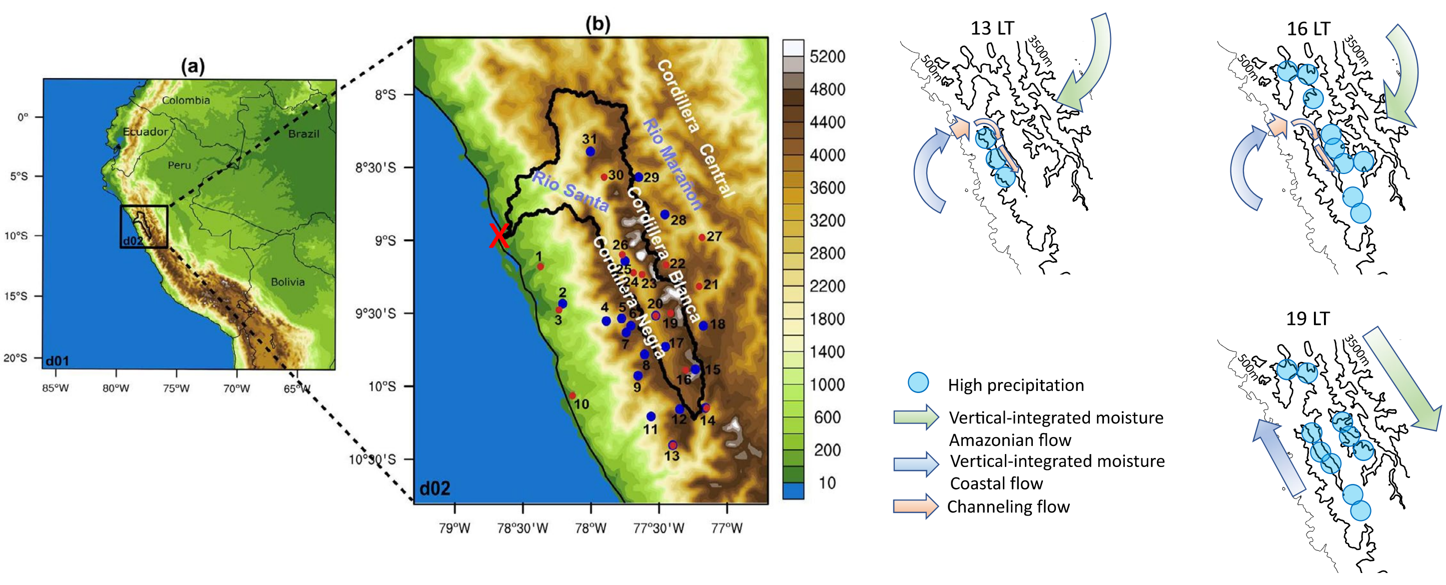

Figure 2*. a) Location of the Santa River basin in the central Peruvian Andes and WRF domains for WRF-6km (d01) and WRF-2km (d02) with corresponding WRF topography (shaded; meters above sea level). (b) Geographical details of d02. In both panels, the upper Santa River basin location is indicated by the bold black line. In (b), color dots indicate the meteorological station positions with their respective reference number. Blue and orange dots correspond to Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI) and Universidad Nacional Santiago Antúnez de Mayolo (UNASAM) stations, respectively. The red cross indicates the outlet of the basin. At the right, schematic diagrams of the main atmospheric circulations in the region of the Santa River basin associated with the maximum precipitation according to model simulations for 13 LT, 16 LT, and 19 LT DJFM mean. The thin and bold black contours are topography limits at 500 m and 3500 m respectively. From Rosales et al., 2022*

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cpAmSur: Climate Simulations at Very High Resolution and High Complexity in South America

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Introduction

The Convección Permitida para América del Sur (*cpAmSur*, *http://ifaeci.cima.fcen.uba.ar/cpAmSur.php*) is the proposal of a scientific project elaborated by an international team of researchers from South America and France. The project aims to realize regional climate simulations over the whole South American continent at a spatial resolution of 4 km using the Institut Pierre Simon Laplace (IPSL, *https://www.ipsl.fr/*)'s Regional Earth System Model (RESM), RegIPSL.

The climate of South America includes processes and structures of many different scales, from continental (thousands of kilometers) to local (e.g., scale of ecosystems; see, e.g., Espinoza et al., 2020). There is a sizeable body of literature on some of the largest climate systems and patterns, for which past and current data sets with relatively coarse resolutions have been valuable. However, for many other features and processes, their development across multiple scales and/or the interaction of larger and smaller scales (e.g., from synoptic to mesoscale to local) is instrumental in describing and understanding them. Some of these important systems and processes include: the South American Monsoon System; impacts of El Niño-Southern Oscillation and sea surface temperature variability at meso- and local-scales; transport of atmospheric moisture via structures with mesoscale features like the South American low level jet; and the mountain hydroclimate of the Andes, including mesoscale wind systems, local circulations, orographic precipitation, and mountain planetary boundary layer complexity, among others. South American societies and economies strongly rely on the above-described climate variability. This project presents a necessary initiative for the region. These systems and processes are connected in different ways across the continent (see more on the AMANECER project in this isssue on page 16). In particular, the distribution of the Andes along most of the latitudes of the continent helps with the latitudinal transport of atmospheric moisture (e.g., Insel et al., 2010), thus connecting regions. Cross-equatorial moisture transport between the Orinoco and Amazon basins is an important source of moisture, both from the Atlantic and the Orinoco basin, such as during the monsoon onset (Li and Fu, 2004). Atmospheric moisture from the Atlantic crossing northern South America is also important for precipitation hotspots along the Andes-Amazon transition region (Espinoza et al., 2020). In turn, the evapotranspiration of the Amazon forest is an important source of atmospheric moisture for different parts of the continent. During most of the year, the southern Amazon is an important source of atmospheric moisture for the La Plata basin, which in turn receives most of its atmospheric moisture from land evaporation from different parts of South America (Martinez and Dominguez, 2014). Part of this transport supplies the formation of mesoscale convective systems over southern South America, contributing to some of the most powerful storms on Earth.

Current data sets used to project changes in climate and their impact do not have enough resolution to fully represent the details of climate across the region. Thus, climate projections in the continent might provide an underrepresented overview of the changes to come. The cpAmSur data set aims to solve this issue and has enormous potential to provide new insights about the changes and future impacts to come.

Convection-permitting simulations are currently a worldwide extended practice in small domains (Coppola et al., 2020) and crucial for better representation of regional climate (Prein et al., 2015; Doblas-Reyes et al., 2021; Lucas-Picher et al., 2021). These simulations will allow us to study the dynamics of the climate at the continental scale and evaluate the impacts of climate change at a level of detail without precedent; for example, we will be able to incorporate fine-scale features of the landscape, including high altitude mountain zones where Andean ecosystems are located as well as heterogeneous mosaics of different land surfaces. Additionally, this project will provide free access to a climate data set of high quality, with the aim of helping to improve decision making for adaptation to the potential negative impacts of climate change on environmental, social, and economic systems.

At the same time, cpAmSur has great international relevance, since currently there are only simulations of this kind in very few continents.

Proposal

We will use the state-of-the-art RegIPSL model to perform climate simulations [project submitted at the Partnership for Advanced Computing in Europe (PRACE) program, *https://prace-ri.eu/*] covering various temporal intervals (Table 1).

Table 1: Simulations of cpAmSur

Experiment	Period	Forcing
Control	2000–2020	ERA5*
Present climate	2000–2020	GCM CMIP6**
Near future	2040–2060	GCM CMIP6

**European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalyasis version 5 (ERA5)*

***Global Climate Model–Coupled Model Intercomparison phase 6*

The RegIPSL dynamically couples three state-of-the-art models [Weather Research and Forecasting (WRF), Organising Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE), and Nucleus for European Modelling of the Ocean (NEMO)], one per component of the climate system (atmosphere, land surface, and ocean, respectively). Such a modeling framework (regional versions of an Earth System Model, or ESM) provides a more complete description of the dynamics and interactions that occur when compared to the use of a single model. In cpAmSur, though we only use the version where WRF and ORCHIDEE models are activated, the degree of complexity and amount of processes included in ORCHIDEE ensures a complete representation of land processes, and potentially a more-detailed simulation of land-atmosphere interactions. Moreover, ORCHIDEE's routing and floodplains scheme will provide surface water dynamics and additional information about river discharge. These simulations allow the analysis of the changes in the simulated climate when comparing present and future climate runs.

1.0 Three Axes: Simulations, a Data Portal, and Community Building

The proposed project is articulated around three main axes: (1) simulations, (2) data access, and (3) a training and networking program (Fig. 1). These three axes might interact with various GEWEX activities: (1) Regional Information for Society (RIfS, *https://www.wcrp-climate.org/rifs-overview*), in terms of establishing a robust and effective relationship between climate, impact, and stakeholder communities in South America; (2) the My Climate Risk Lighthouse Activity (*https://www.wcrp-climate.org/my-climate-risk*), with the assessment of climate impacts at high resolution over the entire continent; (3) the Digital Earths Lighthouse Activity (*https://www.wcrp-climate.org/digital-earths*), since RegIPSL is an example of a high-resolution ESM and a provider of a large amount of climate data; (4) the World Climate Research Programme (WCRP) Academy Lighthouse Activity (*https://www.wcrp-climate.org/academy*), with cpAmSur's planned 6-year itinerant modular training program; and (5) the ANDEX Regional Hydroclimate Project (*https://www.gewex.org/project/andex/*), which may benefit from cpAmSur involvement.

The project will produce a high-resolution, model-driven climate data set for the entire South American continent. This data set will complement the currently-existing coarser-resolution data sets used in the region. This will contribute to:

- Analysis of multiple phenomena and processes of the South American climate, which are still poorly understood and require high-resolution data sets for improved comprehension
- Detailed descriptions of regional climate change projections, which are useful for understanding their physics and can contribute to better-informed adaptation policy planning
- Reinforcing the continent's existing research community by providing a data server and portal supplying access to cpAmSur data in addition to a 6-year training program for the South American climate, impact, and stakeholder communities on how to use project outcomes.

cpAmSur is a holistic, multidisciplinary approach that covers all aspects of interest in the field of climate change. This ranges from cutting-edge regional climate simulations to the benefits of using those simulations as information sources for the environmental, social, and economic fields affected by the changes projected in South America's climate. Therefore, cpAmSur is an empowering, cutting-edge project managed mostly by local scientists for South America.

Main Scientific Objective

The cpAmSur project is guided by the following main science question:

> *Do convection-permitting climate runs of an RESM at a continental scale in South America uncover new insights in projected changes in the climate and provide more reliable data for climate impact studies?*

In order to address this question, the main objectives of the proposal are to:

- Understand climate processes and dynamics at several spatio-temporal scales that are poorly understood due to the current low resolution of available climate simulations
- Facilitate the study of new climate processes depicted by the high resolution, continental scale, and complex characteristics of the simulations
- Understand new climate change signals that arise from the newly-represented processes that were previously underrepresented
- Provide continuous training on the use of convection-permitting climate simulations
- Encourage multidisciplinary engagement among climate, impact, and stakeholder communities all over the continent

2.1 Simulations

The simulations will have three main characteristics: (1) high complexity, due to the use of the RegIPSL; (2) high resolution, where convection is explicitly solved by the dynamics of the atmosphere and smaller-scale effects of the topography (e.g., the Andes) on the low-level flow are better represented; and (3) a continental domain, ensuring that air flows and interactions among various regions of the continent can be simulated.

2.2 Data Portal

The project intends to provide autonomy and access to high-resolution, continental-scale climate data for South American researchers. With that purpose in mind, all data produced will be hosted in South America. It will be necessary to secure high-capacity data storage, and at the same time ensure all-purpose, open access to the data through the configuration of a portal that will allow users to perform calculations directly on the data, independent of their technical skills. We also hope to host ongoing similar projects from the MetOffice (UK) and the National Center for Atmospheric Research (NCAR) South American affinity group (US, https://ral.ucar.edu/projects/south-america; see "Historical and Future Hydroclimate of South America: What We Can Learn from Convection-Permitting Simulations" on page 28), establishing an unmatched ensemble of continental convection-permitting climate simulations.

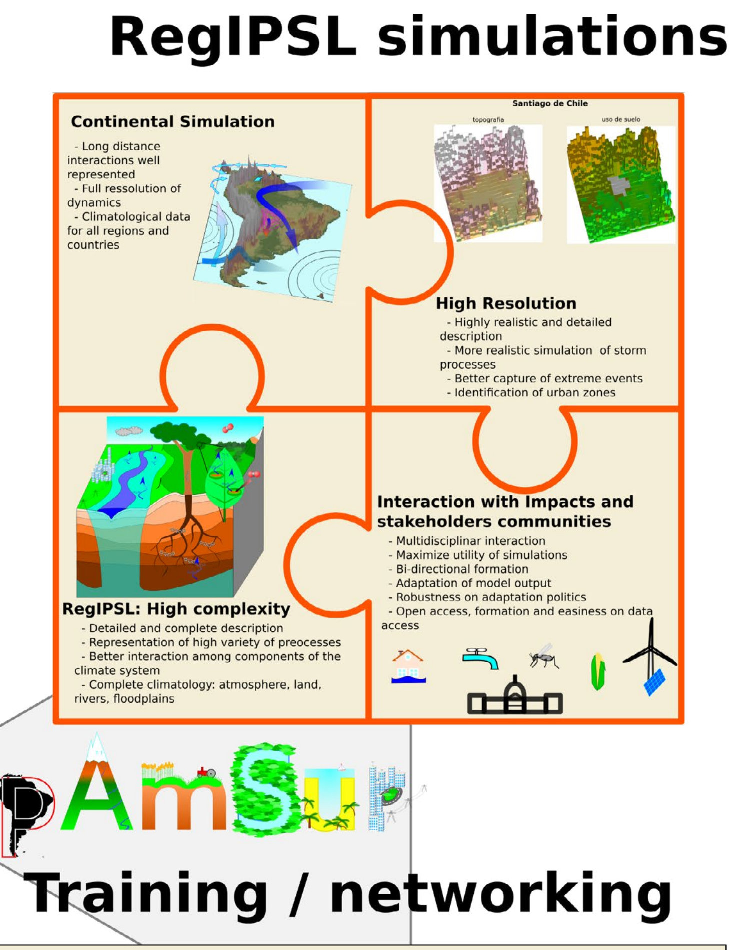
2.3 Community Building

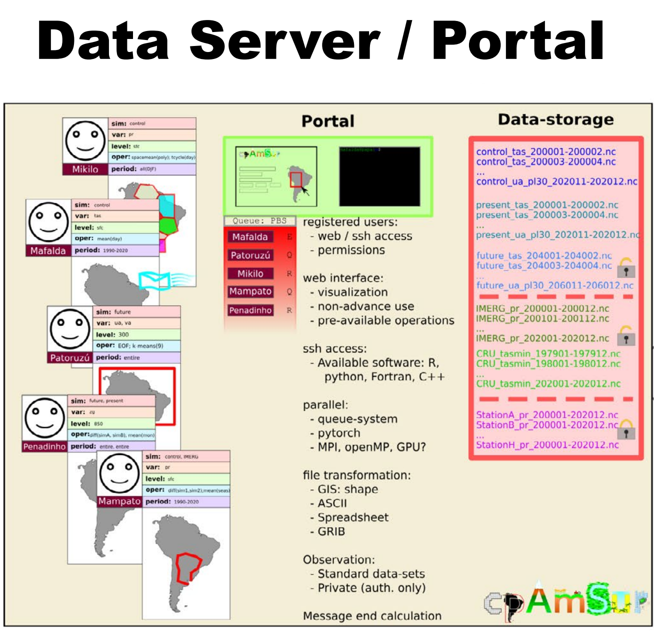
In order to maximize and extend the use of the data set, the project aims to establish:

- A 6-year itinerant modular training program on using the data aimed at students, researchers, and stakeholders, which can be adapted to their needs and demands
- Various editions of a biennial scientific meeting on South American climate simulations at convection-permitting resolutions
- A program of scientific visits for students and researchers within South America
- Direct and open communication between local experts and the media, multiple institutions, stakeholders, and local South American communities

The project will also be integrated with similar ongoing efforts from the MetOffice and NCAR in order to establish an unrivaled ensemble of simulations for the South American continent.

The project encompasses the development of three 20-year simulations, and requires an award of 120 million computational hours and funding for 3.0 PTB of data storage, a portal for in situ calculations, and the implementation of additional community-building activities.





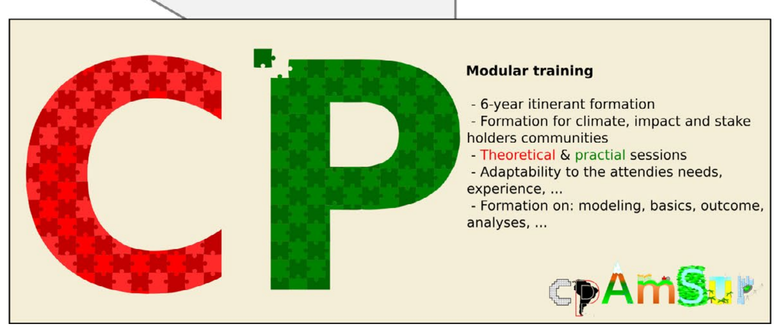


***Figure 1**. The three axes of the cpAmSur project*

Within the sprit of the project, members of the team are currently working on the organization of the 6th Convection-Permitting Climate Modelling Workshop (vi CPCMW, *http://www.cima.fcen.uba.ar/cpcmw2022/*) to be held in Buenos Aires from the 7th to 9th of September 2022, and the first edition of the Convection-Permitting Climate Modeling school (*http://www.cima.fcen.uba.ar/cpCMSchool2022/index.php*) will be held also in Buenos Aires on the 10th of September.

Acknowledgements

This project would not exist without the support of IPSL, particularly J. Polcher and R. Pennel from the Laboratoire de Météorologie Dynamique (LMD-Palaiseau), IPSL, Centre National de la Recherche Scientifique (CNRS), Institut de Recherche pour le Développement (IRD), France. We thank the PRACE program for the RegIPSL performance tests carried out on the simulation domain with allocation 2010PA5940. J. Fernández, A. Cofiño (Instituto de Física de Cantabria-Consejo Superior de Investigaciones Científicas or IFCA-CSIC, Spain) and D. San Martín (Predictia, Spain) are acknowledged for their guidance on planning the data storage and portal.

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Historical and Future Hydroclimate of South America: What We Can Learn from Convection-Permitting Simulations

South America Affinity Group (SAAG)

South America is an ideal testbed for understanding how climate and land use change interact to alter hydroclimate processes, particularly related to convective precipitation. The continent is home to some of the most diverse ecosystems on the planet (see Fig. 1). Over the recent decades, a growing population with large urban areas and an advancement of agricultural frontiers with increasing agricultural and cattle production have resulted in large changes in land surface and a loss of biodiversity. This is particularly concerning, as a large fraction of precipitation over the continent originates from terrestrial evapotranspiration (or recycled precipitation). In fact, the percentage of recycled precipitation reaches 35–50% in the lowlands of the Amazon river basin, and up to 60–90% over the Andes (Zemp et al., 2014). Further downwind, more than 60% of the precipitation in the La Plata basin is of terrestrial origin as the South American low level jet (SALLJ) redistributes water throughout the continent (Martinez and Dominguez, 2014). The importance of the natural ecosystems of South America in maintaining the hydroclimate of the continent or the effects of land use change cannot be overstated (Builes-Jaramillo and Poveda, 2018). In addition to land use change, climate change will impact water and food security for millions of people on the continent, and threaten ecosystem health and the fragile equilibrium between communities and their environment (Magrin et al., 2014). In recent decades, the continent has experienced warming and an increasing drying trend in the southern Amazon (Espinoza et al., 2019) while rainfall in southeastern South America is increasing (Carvalho, 2020). Most of the high Andes show a clear decline in snowfall, glacier extent, and snow persistence (Masiokas et al., 2020). Projections of future climate indicate continued warming of the continent, with reductions of precipitation in northeast Brazil, an increase in dry spells in tropical South America, and an increase in precipitation in southeastern South America (Magrin et al., 2014). As such, collaborative research efforts are required to understand the historical and future hydroclimate of these complex continental systems that rely on convective precipitation for sustainable living and regional growth.

State-of-the-art global climate models (GCMs) routinely used to make future climate projections are unable to capture details of the continental hydroclimate and have significant uncertainties. Part of the problem is the coarse GCM resolution, with typical grid spacing of 100–200 km. Critically, the complex topography of the Andes mountains and other topographical features are not captured at coarse resolutions. The poor representation of topography in coarse resolution models causes large biases in orographic precipitation/snowfall and mountain snowpack/glaciers (Rasmussen et al., 2011). Most tropical glaciers are in the tropical Andes, and their meltwater provides a significant supply of freshwater during the dry season for a large population living around the Andes, as does the seasonal

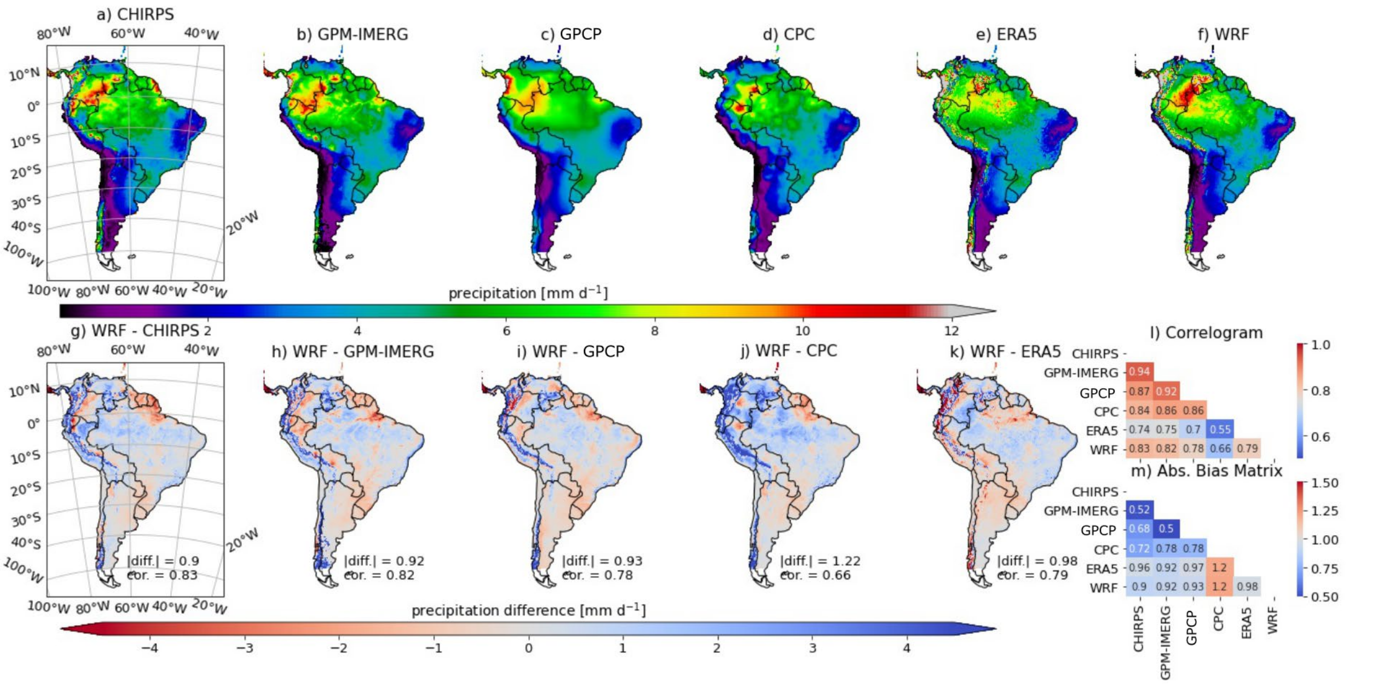

Figure 2. Annual average precipitation during the period 2000 to 2008 from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS), Global Precipitation Measurement-Integrated Multi-satellite Retrievals (GPM-IMERG), Global Precipitation Climatology Project (GPCP), Climate Prediction Center (CPC), 5th Generation European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis (ERA5), and SAAG WRF simulations (from left to right in the top row). Differences between the WRF simulation and the observational data sets are shown in the bottom row in addition to a pattern correlation correlogram (l) and absolute biases (m).

snowpack in the Andes of the outer tropics (Masiokas et al., 2020). In addition, convection and organized mesoscale convective systems contribute a significant portion of the annual precipitation over both the tropical and the subtropical continent. However, organized convection is poorly represented in coarse-resolution models with parameterized convection. The SALLJ, Corriente de los Andes Orientales (CAO), and Choco low level jet traverse the continent transporting mass, energy, and moisture (Fig. 1). These systems are tied to topographical features such as the Andes mountains and are affected by land-sea contrasts and land-atmosphere interactions, which are also poorly represented in coarse-resolution models.

Convection-permitting simulations can alleviate many of the formerly-discussed problems in GCM simulations. The National Center for Atmospheric Research (NCAR) Water System group has extensive experience performing and analyzing convection permitting (4 km horizontal grid spacing) climate simulations (Liu et al. 2017 provides a nice summary of current work). The South America Affinity Group (SAAG, *https://ral.ucar.edu/projects/south-america*) was initiated in early 2019 by the NCAR Water System program in an effort to overcome some of these deficiencies in climate projections over South America by performing convection-permitting climate modeling (CPCM) over that continent. The goal of SAAG is to run 20-year CPCM simulations over South America for the historical and future climate to support climate change research efforts such as the ANDEX Regional Hydroclimate Program. The effort builds on and has learned from prior CPCM activities over North America (Rasmussen et al., 2011; Liu et al., 2017; Prein et al., 2016). SAAG was established as a grassroots activity that started with a dozen members, but quickly grew into a hub for South American research with close to 100 participants from more than ten countries. The group has devoted significant time and effort in preparation for the large simulations, including running the benchmark simulations, acquisition of computational resources, collection of observational data sets, the definition of model output variables that serve a wide range of research interests, the coordination of research activities, and the sharing of large model-output data volumes. This effort has paid off as initial model comparisons with observations show very promising results (see Fig. 2).

The SAAG is performing two 20-year Weather Research and Forecasting (WRF) model simulations: one for current and one for future climate using 4 km horizontal grid spacing covering the entire South American continent. The long-term convection-permitting downscaling of the present and future climates will provide a highly-detailed representation of the Andes cordillera, atmospheric convection, mesoscale circulations, snowpack, and many other land surface and atmospheric processes. The main scientific foci/questions we address in this work are: how well can we represent and understand the spatiotemporal features of the continental-scale water cycle over South America, including deep convection, mesoscale convective systems, orographic processes, diurnal cycle of convection, LLJs, and gravity waves, among others? Additionally, can the 4 km simulations capture extreme hydrometeorological events including droughts and floods?

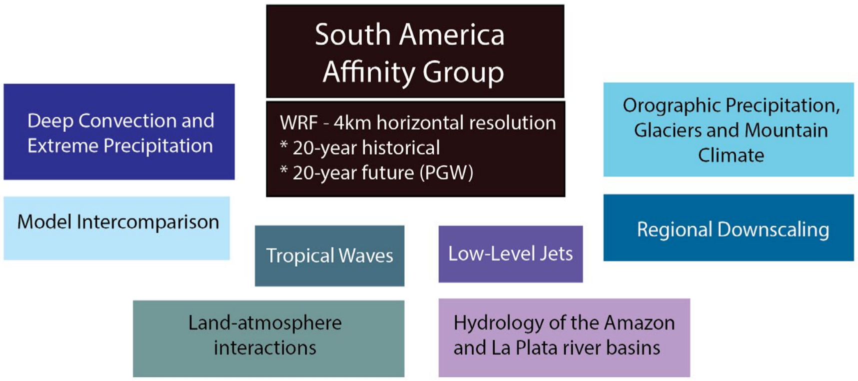

***Figure 3**. Conceptual diagram of the SAAG simulations and the different research areas that have stemmed from the simulations*

How does climate change affect the spatiotemporal features of the continental-scale water cycle over South America and how will the intensity/duration/frequency of extreme events change in a changing climate?

We aim to provide a community data set for further research with the goal of facilitating detailed process studies. These include subsequent very-high-resolution (~1 km) WRF simulations over the complex terrain of the northern Andes using the WRF ndown technique from the 4 km simulations. Very high resolutions allow a more detailed representation of glacier/snow modeling and hydrological modeling for terrestrial water cycle studies. Subsequent simulations will also tackle the critical problem of land-atmosphere interactions and the effects of land use and land cover change (Zemp et al., 2017). The community has self-organized into different research areas based on the SAAG simulations (Fig. 3).

The first SAAG simulation phase focuses on a retrospective/control simulation intended to reproduce the climate of the past 20-year period (June 2000–May 2020). Three-hourly, TL639, N320 resolution ERA5 reanalysis data provide boundary and initial conditions. The simulation starts in June, when the Intertropical Convergence Zone is north of the domain and most of the continent experiences a dry season. The simulation runs continuously for 20 years. Phase 2 is a perturbation or climate sensitivity experiment over the same 20-year period (2000–2020). It will closely follow the Pseudo Global Warming (PGW) approach used in prior Colorado Headwaters and Continental United States simulation work (Rasmussen et al., 2014; Liu et al., 2017), where the reanalysis-derived initial and boundary conditions are perturbed with climate change signals from an ensemble of Couple Model Intercomparison Phase 6 (CMIP6) models under the Shared Socioeconomic Pathways 5 to 8.5 (SSP5-8.5) emission scenario.

In summary, the overarching goals of this large SAAG community effort led by NCAR's Water System program are two-fold: 1) to reach a better understanding and representation of critical hydroclimate processes in the region, and 2) to provide communities in the region with relevant information for improved decision-making in a changing climate. Initial results are promising, and we hope to finalize this effort by 2023. SAAG is an open community and can be joined by reaching out to Andreas Prein (prein@ucar.edu) or Roy Rasmussen (ramsus@ucar.edu). An opportunity to learn more about SAAG activities and convection-permitting modeling in South America will be the 6th Convection-Permitting Climate Modeling workshop that will be held in Buenos Aires, Argentina from 7–9 September 2022 (http://www.cima.fcen.uba.ar/cpcmw2022/).

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GEWEX/WCRP Calendar

For the complete Calendar, see http://www.gewex.org/events/

3–5 May 2022—34th Session of the GEWEX Scientific Steering Group, Part A (SSG-34A) (*by invitation only*)—Paris, France
9–12 May 2022—Workshop on Model Uncertainty—Reading, UK
16–18 May 2022—Global Water Futures (GWF) Open Science Meeting 2022—Online
18–20 May 2022—Conference on Groundwater, Key to the Sustainable Development Goals—Paris, France
22–27 May 2022—Japan Geoscience Union (JpGU) 2022—Chiba, Japan, and Online
23–27 May 2022—European Space Agency's 2022 Living Planet Symposium (LPS2022)—Bonn, Germany
23–27 May 2022—European Geosciences Union (EGU) General Assembly 2022—Vienna, Austria
29 May–3 June 2022—XIth Scientific Assembly of the International Association of Hydrological Sciences (IAHS 2022)—Montpellier, France
30 May–3 June 2022—4th Baltic Earth Conference—Jastarnia, Hel Peninsula, Poland
31 May–1 June 2022—3rd International Symposium on Climate Change and Water—Tours, France
19–24 June 2022—Frontiers in Hydrology—San Juan, Puerto Rico, USA
20–22 June 2022—6th Pannonian Basin Experiment (PannEx) Workshop—Cluj-Napoca, Romania
25–29 July 2022—3rd Pan-GASS Meeting: Understanding and Modeling Atmospheric Processes (UMAP 2022)—Monterey, California, USA
26 July 2022—34th Session of the GEWEX Scientific Steering Group, Part B (SSG-34B) (*by invitation only*)—Monterey, California, USA
27–30 July 2022—Pan-GEWEX Meeting (*by invitation only*)—Monterey, California, USA

3rd Pan-GASS Meeting

Understanding and Modeling Atmospheric Processes (UMAP 2022)

In-Person Event

25–29 July 2022 | Hyatt Regency Monterey, CA, USA

About

The GEWEX Global Atmospheric System Studies Panel (GASS) will hold its 3rd Pan-GASS Meeting, Understanding and Modeling Atmospheric Processes (UMAP 2022), at the Hyatt Regency Hotel in Monterey, CA, USA, from 25–29 July 2022.

UMAP 2022 aims to bring together weather and climate scientists, including both observationalists and modelers, to discuss the key issues of atmospheric science. The program will include all aspects and methods of model development, from deterministic numerics to stochastic forcing, process modeling to parametrization, observational constraints to diagnostic techniques, and idealized modeling to operational forecasting and climate predictions. The purpose of the conference is to discuss progress in understanding atmospheric processes and representing them in models, to coordinate current initiatives and make plans for the future.

Information and Registration

For detailed information and to register, please visit the UMAP 2022 website at *https://bit.ly/3DOBgTe*.

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