Understanding Hydrological Dynamics in the Tropical Andes of Peru and Ecuador and Their Responses to Climate Change

Carlos A. Fernandez Palomino[1,4], **Waldo Lavado**[2], Ronald Gutiérrez[3], Fiorella Vega-Jácome[4], Fred Hattermann[1], Valentina Krysanova[1], William Santini[5], Axel Bronstert[4]

[1]Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany
[2]The National Service of Meteorology and Hydrology of Peru (SENAMHI), Lima, Peru
[3]Departamento de Ingeniería (GERDIS, GEOSED), Pontificia Universidad Católica del Perú, Lima, Peru
[4]Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany
[5]Institut de Recherche pour le Développement, Laboratoire GET (IRD, CNRS, UPS, CNES), Toulouse, France

Contact: palomino@pik-potsdam.de

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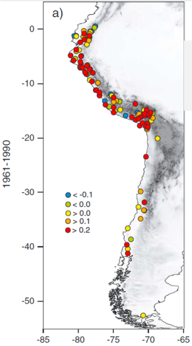
Content

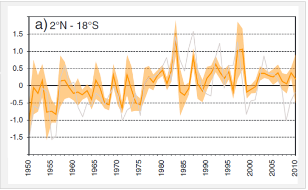
Impacts of climate change and extreme variability

Changes in temperature

Total temperature trend [°C/dec.]

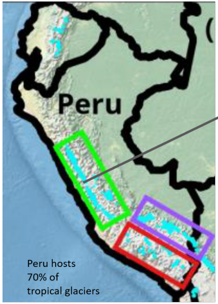


Annual mean temperature anomaly relative to 1961-1990 average



Changes in glacier surface

Tropical glaciers



Pastoruri glacier retreat (60%)

In the tropical Andes (2°N–18°S), a significant warming trend of 0.13°C per decade has been observed between 1950 and 2010 (Vuille et al., 2015).

The surface area of Peruvian glaciers has decreased by more than 50% since the 1960s (INAIGEM, 2018).

Impacts of climate change and extreme variability

Floods

Iquitos, during the historic rise of the Amazon River, 2012

Lima, during the "Coastal El Niño", 2017

Droughts

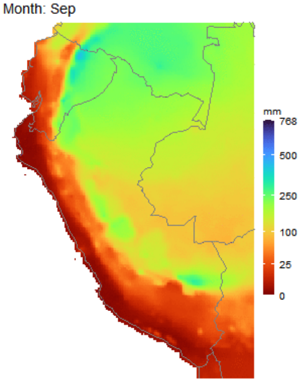
Given the evidence of climate change impacts, it is crucial to analyze hydrological projections in Peru and Ecuador to develop effective adaptation strategies

Objectives

- To develop a new gridded precipitation dataset for Peru and Ecuador.
- To regionalize simulations from CMIP6 climate models for Peru and Ecuador.
- To set up, calibrate, and validate the Soil and Water Assessment Tool (SWAT) hydrological model.
- To assess projected changes in water balance components and hydrological extremes under different climate change scenarios.

Rain for Peru and Ecuador (RAIN4PE)

- **Method:**
  1. The **RAIN4PE** precipitation data were generated by merging precipitation data from multiple sources (*satellite*, *reanalysis*, and *804 rain gauges*) and elevation using the **Random Forest** method.
  2. In some Andes-Amazon transition watersheds, precipitation estimates were further adjusted using streamflow data via **inverse hydrology** with SWAT to achieve water balance closure.
- **Resolution:** Daily, 10 km
- **Period:** 1981-2015
- **Open Access Data:** `https://doi.org/10.5880/pik.2020.010` and awesome-gee-community-datasets.
- Soon the new version!



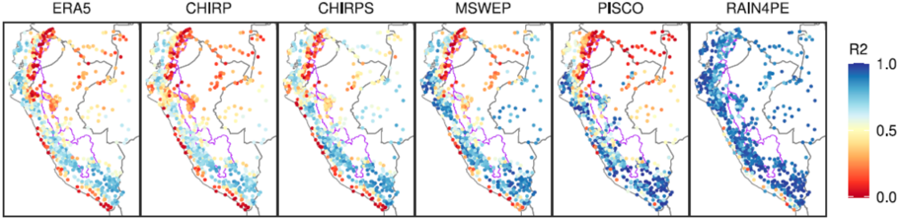
Precipitation climatology

Reference: Fernandez-Palomino et al. (2022). A Novel High-Resolution Gridded Precipitation Dataset for Peruvian and Ecuadorian Watersheds: Development and Hydrological Evaluation. *Journal of Hydrometeorology*. `https://doi.org/10.1175/JHM-D-20-0285.1`

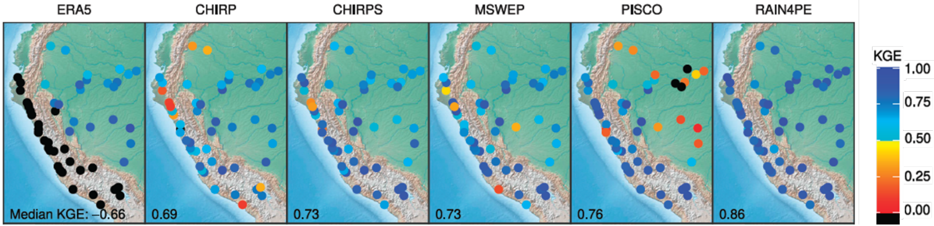
Rain for Peru and Ecuador (RAIN4PE)

Comparison of different precipitation datasets:

- With observed precipitation data at monthly scale for 1981-2015.



- For monthly streamflow simulations for 1985-2015.

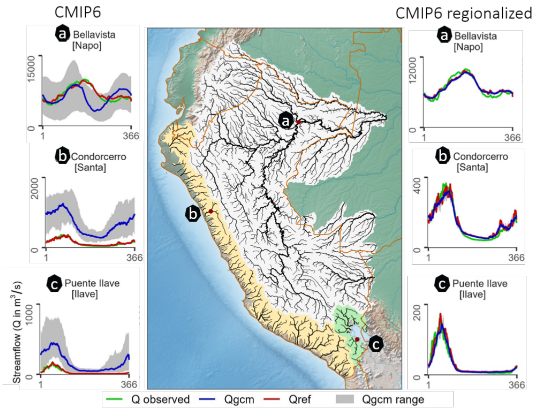


RAIN4PE currently stands as the most reliable precipitation dataset for hydro-meteorological applications throughout Peru and Ecuador

Regionalized CMIP6-GCM simulations for Peru and Ecuador (BASD-CMIP6-PE)

- **Method:** the ISIMIP3b bias Adjustment and Statistical Downscaling.
- **Reference data:** RAIN4PE precipitation and PISCO temperature.
- **Scenarios (3):** SSP1-2.6, SSP3-7.0, SSP5-8.5
- **GCMs (10):** CanESM5, IPSL-CM6A-LR, UKESM1-0-LL, CNRM-CM6-1, CNRM-ESM2-1, MIROC6, GFDL-ESM4, MRI-ESM2-0, MPI-ESM1-2-HR, EC-Earth3.
- **Variables (4):** Precipitation, Min/Max/Mean temperature.
- **Period:** Historical (1850-2014) and projections (2015-2100).
- **Open access data:** `https://doi.org/10.5880/pik.2023.001`

Impact of raw versus regionalized CMIP6 climate data on streamflow simulation

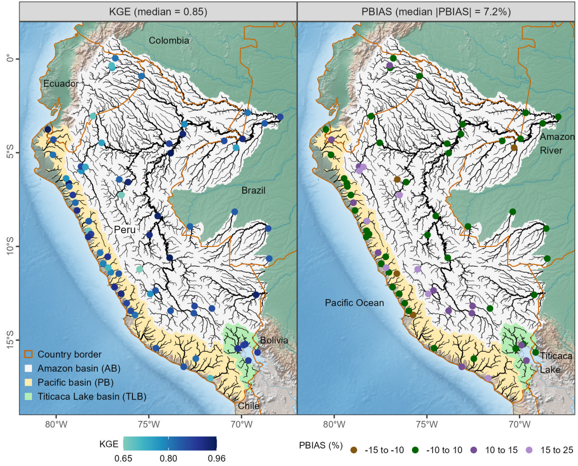


Reference: Fernandez-Palomino et al. (2024). High-resolution climate projection dataset based on CMIP6 for Peru and Ecuador: BASD-CMIP6-PE. *Scientific Data*. `https://doi.org/10.1038/s41597-023-02863-z`

Performance of Soil and Water Assessment Tool (SWAT)

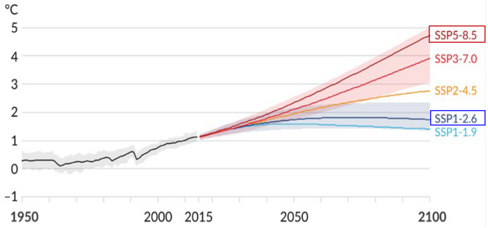
Kling-Gupta efficiency

Percentage of bias



Hydrological projections under two Shared Socioeconomic Pathways (SSP)

- Sustainable (SSP1-2.6)
- Fossil fuel based development (SSP5-8.5)



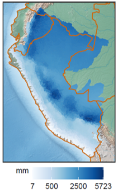
Global surface temperature changes relative to 1850-1900 (IPCC 2021)

Reference: Fernandez-Palomino et al. (2024). Pan-Peruvian Simulation of Present and Projected Future Hydrological Conditions Using Novel Data Products and CMIP6 Climate Projections. *preprint at SSRN*. `https://doi.org/10.2139/SSRN.4602668`

Hydrological projections in water balance components

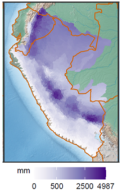
Climate 1985-2015

Precipitation

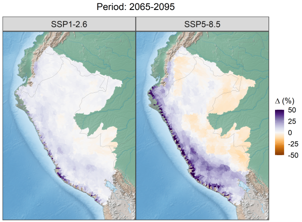


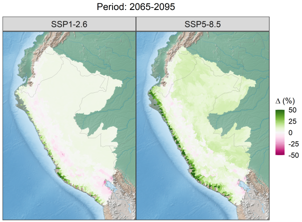
Evapotranspiration

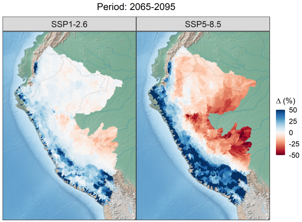
Water **Y**ield (P-E)



Projected changes







↑ P along the Andes

↓ P over the Amazon lowlands (esp. in the S.)

No changes in ET over Andean basins

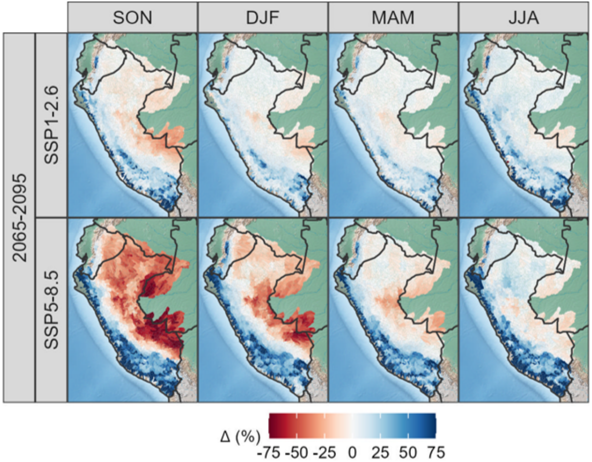
↑ ET in the Amazon lowlands and arid coastal areas

↑ WY over Andean basins

↓ WY over the Amazon lowlands (esp. in the S.)

Hydrological projections in water balance components

Projected changes in seasonal water yield



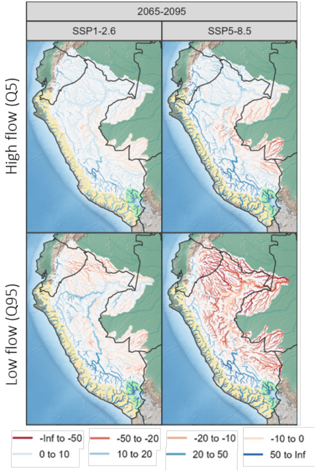
Water yield projections indicate:

- ↑ in the Andean regions year-round.
- ↑ in the northern Amazon during the rainy season (JJA).
- ↓ in the Peruvian Amazon lowland year-round, with the greatest decline from September to February.

Reference: Fernandez-Palomino et al. (2024). Pan-Peruvian Simulation of Present and Projected Future Hydrological Conditions Using Novel Data Products and CMIP6 Climate Projections. *preprint at SSRN*. `https://doi.org/10.2139/SSRN.4602668`

Hydrological projections in extreme flows

Projected changes in high and low flows



Projections indicate:

- ↑ Q5 in the Andean rivers and in the northern Amazon.
- ↓ Q5 in the Amazon lowland tributaries.

- ↑ Q95 in the Andean rivers.
- ↓ Q95 in the Amazon lowland tributaries.

Reference: Fernandez-Palomino et al. (2024). Pan-Peruvian Simulation of Present and Projected Future Hydrological Conditions Using Novel Data Products and CMIP6 Climate Projections. *preprint at SSRN*. https://doi.org/10.2139/SSRN.4602668

Summary and conclusions

- The RAIN4PE dataset is currently the most reliable precipitation data for Peru and Ecuador.
- The regionalized climate projection database (BASD-CMIP6-PE) is the most appropriate source for assessing regional climate change impacts.
- Hydrological projections indicate:
  - Increased water availability and a greater risk of floods in the Andean basins.
  - Anticipated water stress in the Amazon lowland, potentially affecting ecosystems, river transportation, and food supply.
  - Severe changes under a high-warming scenario (SSP5-8.5), emphasizing the urgent need for implementing adaptation measures to mitigate climate change impacts on water resources in Peru.

References:

- Fernandez-Palomino et al. (2022). A Novel High-Resolution Gridded Precipitation Dataset for Peruvian and Ecuadorian Watersheds: Development and Hydrological Evaluation. *Journal of Hydrometeorology*. `https://doi.org/10.1175/JHM-D-20-0285.1`
- Fernandez-Palomino et al. (2024). High-resolution climate projection dataset based on CMIP6 for Peru and Ecuador: BASD-CMIP6-PE. *Scientific Data*. `https://doi.org/10.1038/s41597-023-02863-z`
- Fernandez-Palomino et al. (2024). Pan-Peruvian Simulation of Present and Projected Future Hydrological Conditions Using Novel Data Products and CMIP6 Climate Projections. *preprint at SSRN*. `https://doi.org/10.2139/SSRN.4602668`
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Thanks