The performance of convection permitting climate models in capturing land-atmosphere interactions across the Andes-Amazon transition region

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Background and rational

- The Andes-Amazon transition region refers to the area located between the western amazon lowlands and eastern tropical Andes.
- It is the wettest region of the Amazon basin receiving **7000 mm** of precipitation per year [1].
- >30% of this precipitation originates from **recycled moisture** that is returned to the atmosphere via evapotranspiration [2].
- Moisture is transferred westward via the South American Low-Level Jet (SALLJ) and drives high orographic precipitation over the eastern Andes [3].
- Moisture recycling is important for sustaining regional water resources [3].

Evaluation of model performance

- Analysis conducted on existing simulations from Weather Research and Forecasting model (**WRF**) (4km) and Met Office Unified Model (**Met UM**) (4.5km)
- Model performance evaluated through comparisons to observation-based data (e.g. station data, reanalysis, satellite datasets)

RQ1. How well do CPCMs represent the spatial distribution of precipitation?

RQ2. How well do CPCMs represent the diurnal cycle of precipitation?

Results: Spatial distribution of precipitation

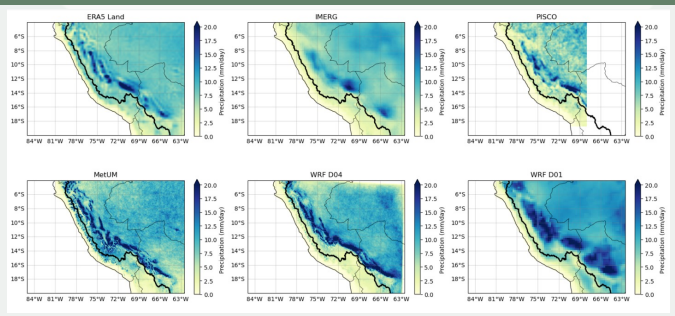


Figure 2. Average daily precipitation during the DJF wet season across the period 2000 – 2005 for the ERA5 Land, IMERG and PISCO reanalysis (A - C), Met UM and WRF D04 convection permitting simulations (D - E), and WRF D01 outer domain simulation (F) for the WRF D04 modelling domain. The thick black line represents the western boundary of the Amazon basin.

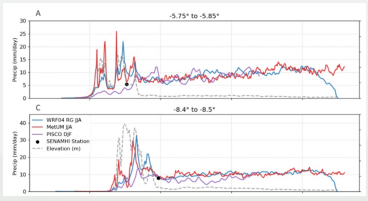


Figure 3. West-east transects of average daily precipitation for DJF 2000 – 2005 across 0.1 degree latitude bands from Met UM, WRF D04 and the PISCO reanalysis dataset. The dashed line represents the WRF D04 elevation and the black point shows the precipitation data from the SENAMHI in-situ weather stations and it's position along the transect. Transect location shown in Figure 1.

Performance of CPCMs in capturing the spatial distribution of precipitation:

- Overall MetUM and WRF D04 perform well in capturing the locations of precipitation hotspots across the eastern Andes (Fig. 2).
- Models overestimate the magnitude of precipitation when compared to satellite and reanalysis data (Fig. 2).
- WRF D01 overestimates precipitation across the transition region.
- Clear added value of running at convection permitting scales vs. regional climate model scales (36 km).
- CPCMs successfully simulate peak in precipitation located on the eastern side of the Andes, as would be expected from orographic influence of mountains on westward moving air (Fig. 3)
- Some difference between locations and elevation of peak precipitation in CPCM simulations (Fig. 3) due to differences in model elevations.
- Models perform well in capturing magnitude of precipitation at weather station locations (Fig. 3)

Conclusions

Spatial Distribution of Precipitation: Both CPCMs (4 km) successfully capture the location of Andean precipitation hotspots and show improved performance from coarse regional climate models (36 km) despite an overall wet bias when compared to observation-based data.

Diurnal Cycle of Precipitation: WRF performs better that Met UM, accurately capturing the observed early-morning precipitation over the foothills driven by convergence of katabatic (downslope) and Amazonian air.

Convection permitting climate models (CPCMs)

High **uncertainty** in simulations from **coarse resolution** global and regional climate models

Poor representations of complex topography

Rely on parameterizations of convection

CPCMs are very high resolution (several kms) - can directly simulate convection

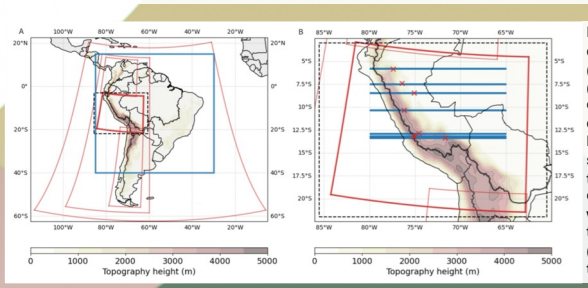


Figure. 1 Modelling domains for MetUM (blue box) and WRF (red boxes) with the convection permitting domains shown in bold (a). The blue lines show the positions of the east-west transects with the locations of the SENAMHI stations (Table 1) marked by the red crosses (b).

Results: Diurnal cycle of precipitation

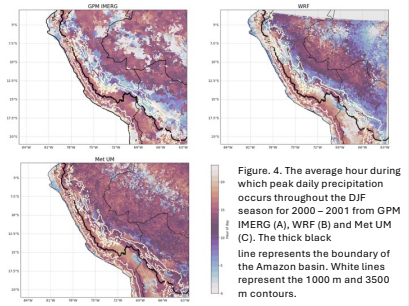


Figure. 4. The average hour during which peak daily precipitation occurs throughout the DJF season for 2000 – 2001 from GPM IMERG (A), WRF (B) and Met UM (C). The thick black line represents the boundary of the Amazon basin. White lines represent the 1000 m and 3500 m contours.

Timing of peak precipitation:

- WRF captures the observed early morning peak (12-5 am) in precipitation over the eastern foothills, as in GPM IMERG (Fig. 4)
- Met UM simulates an afternoon peak at lower elevations (Fig. 4)
- Both models capture late afternoon solar radiation driven peak at higher elevations (Fig. 4)

Surface wind dynamics (WRF):

- 10 m wind vectors and cross slope component show nocturnal downslope (katabatic) winds and convergence at lower elevations (~ 1000 m) (Fig. 5).
- Transition to upslope westward moving winds during the late afternoon driving precipitation at higher elevations (Fig. 5).

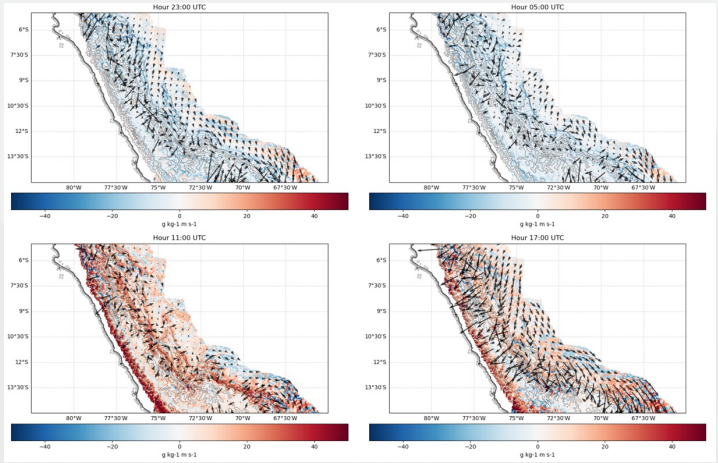


Figure. 5. Diurnal cycle of the Cross Slope Component ([qu*(dz/dlon) + qv*(dz/dlat)]/sqrt((dz/dlon)^2 + (dz/dlat)^2) (Junquas et al., 2018) and surface 10 m winds from WRF for the DJF season from 2000 – 2001. Blue represents the downslope winds and red the upslope winds.

Precipitation mechanisms:

- **Overnight peak (WRF):** Driven by convergence of downslope katabatic winds with westward moving Amazonian air [4]
- **Afternoon peak (Met UM):** Traditional afternoon convection from surface heating and anabatic (upslope) winds [5]

1. GUTIERREZ-VILLARREAL, R. A., JUNQUAS, C., ESPINOZA, J.-C., BABY, P. & ARMIJOS, E. 2025. Influence of local topographic structures on the atmospheric mechanisms related to the Andean-Amazon rainiest zone. *Atmospheric Research*, 320, 108068.
2. STAAL, A., TUINENBURG, O. A., BOSMANS, J. H. C., HOLMGREN, M., VAN NES, E. H., SCHEFFER, M., ZEMP, D. C. & DEKKER, S. C. 2018. Forest-rainfall cascades buffer against drought across the Amazon. *Nature Climate Change*, 8, 539–543.
3. ESPINOZA, J. C., GARREAUD, R., POVEDA, G., ARIAS, P. A., MOLINA-CARPIO, J., MASIOKAS, M., VIALE, M. & SCAFF, L. 2020. Hydroclimate of the Andes Part I: Main Climatic Features. *Frontiers in Earth Science*, 8.
4. CHAVEZ, S. P. & TAKAHASHI, K. 2017. Orographic rainfall hot spots in the Andes-Amazon transition according to the TRMM precipitation radar and in situ data. *Journal of Geophysical Research: Atmospheres*, 122, 5870–5882.
5. JUNQUAS, C., TAKAHASHI, K., CONDOM, T., ESPINOZA, J. C., CHAVEZ, S., SICART, J. E. & LEBEL, T. 2017. Understanding the influence of orography on the precipitation diurnal cycle and the associated atmospheric processes in the central Andes. *Climate Dynamics*, 50, 3995–4017.

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