Regional climate modelization of precipitation diurnal cycle and associated valley wind circulations over an Andean glacier region (Antizana, Ecuador)

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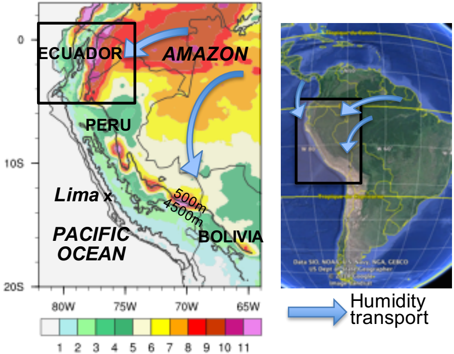
Summary

Introduction

The tropical Andes climate

- Tropical Andes = natural barrier for the tropical circulation
- Humidity transport from the Amazon + equatorial Pacific
- Strong zonal precipitation gradient

Precipitation in the Andes



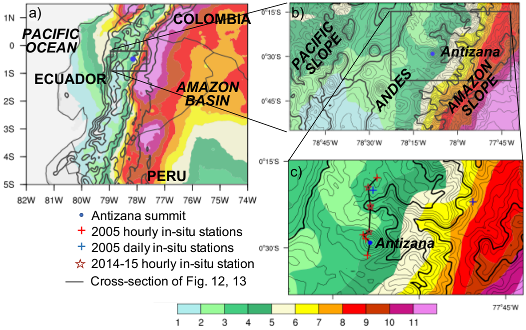
Climatology 1980-2018
CHIRPS mm/day

Introduction

The Antizana region (Ecuadorian Andes)

- The Antizana glacier (5700m) is situated in the eastern side of the Ecuadorian Andes (South East of Quito city), close to the Amazon region.
- 3 main climate zones :
  - The humid Pacific slope,
  - The dry Andes mountains,
  - The very humid Amazon slope

2005 precipitation mean (mm/day) from CHIRPS



Objectives

Main objective

- Analyze the influence of the complex local orography on the diurnal cycle distribution of the precipitation in the Antizana region and the associated valley wind circulations in regional climate modelizations.

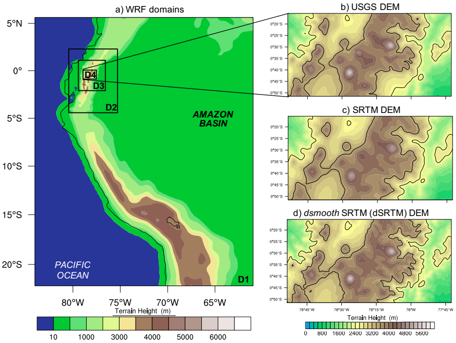
Sub-objectives

- Simulate the precipitation at high spatio-temporal resolution (1km; 1h) in the region with a regional climate model.
- Identify how different orographic forcing data and model parameterizations (including convection-permitting configurations) can influence the diurnal cycle of precipitation at local scale.
- Understand the atmospheric processes associated with the different model configurations, including the local valley wind circulations.

Dynamical downscaling in the Antizana region

WRF regional climate model

- WRF 3.7.1 = Weather Research and Forecasting (NCAR)
- 4 Nesting domains (D1-D4), one simulated year 2005 (available in-situ data)
- 3 DEM (Digital elevation domain) : **USGS** (United States Geological Survey ; default data in WRF3.7.1; original resolution of 1km, and **SRTM** (Shuttle Radar Topography Mission; Farr et al., 2007; original resolution : 90m (3 arc-seconds), with a possibility of *dsmooth* option; hereafter called **dSRTM**



Experiments of the dynamical downscaling

Characteristics and parametrizations of the WRF modelisation (1/2)

Table 1: Characteristics of the WRF simulations at the four different spatial scales.

	WRF-27km	WRF-9km	WRF-3km	WRF-1km
Horizontal resolution (km)	27	9	3	1
Domain	Tropical Andes	Ecuador	Northern Ecuador	Antizana region
Domain center coordinates	8°30'S, 72°W	15°32'24''S, 70°33'34''W	13°25'37''S, 72°34'3''W	0°33'26''S, 78°18'3''W
Configuration	Regional simulation	One-way nesting	One-way nesting	One-way nesting
Forcing	NCEP_FNL	WRF-27km	WRF-9km	WRF-3km
Vertical resolution	30 sigma levels	30 sigma levels	30 sigma levels	30 sigma levels
Run time-step (s)	150	50	16.667	5.556
Outputs time resolution (h)	6	3	3	1

Table 2: List of the WRF physical parameterizations tested in the simulations.

	Parameterizations	References
Clouds microphysics	New Thompson Scheme **(NT)** Purdue Lin scheme **(L)**	Thompson et al. (2008) Chen and Sun (2002)
Radiation	Longwave: Rapid Radiative Transfer Model (RRTM)	Mlawer et al. (1997)
	Shortwave : Dudhia Scheme	Dudhia (1989)
Cumulus parametrization	Grell-Devenyi ensemble scheme **(GD)** Grell-Freitas scheme **(GF)**	Grell and Devenyi (2002) Grell and freitas (2014)
Planetary boundary layer	Yonsei University Scheme Wind topographic correction (option 1)	Hong et al. (2006) Jimenez and Dudhia (2012)
Land surface	Noah-MP (Multi-Physics) with partitioning precipitation option 2	Niu et al. (2011); Yang et al. (2011)
Surface layer	MM5 similarity	Paulson (1970)

Experiments of the dynamical downscaling

Characteristics and parametrizations of the WRF modelisation (2/2)
–> 10 experiments, 3 groups of analysis for different purposes

Experiment name	USGS DEM	SRTM DEM	dsmth	Cu (D1,D2)	Cu (D3,D4)	MI	Analysis Group(s)
USGS_NT	X			GD	GD	NT	1
USGS_L	X			GD	GD	Lin	1
USGS_GF	X			GF	GF	NT	2
USGS_GFNoCu	X			GF	0	NT	2
dSRTM_NT		X	X	GD	GD	NT	1
SRTM_L		*X*		*GD*	*GD*	*Lin*	*1, 3*
SRTM_LRad		X		GD	GD	Lin	3
dSRTM_L		*X*	*X*	*GD*	*GD*	*Lin*	*2, 3*
dSRTM_LNoCu		X	X	GD	0	Lin	2
dSRTM_LRad		X	X	GD	GD	Lin	3

Table 3 : List of the experiments and their characteristics.

Group 1 (USGS/SRTM/dSRTM)

Analysis of different DEM data forcings with two microphysical schemes (NT, L)

Group 2 ('NoCu' exp.)

Analysis of parameterization with or without convection-permitting

Group 3 ('Rad' exp.)

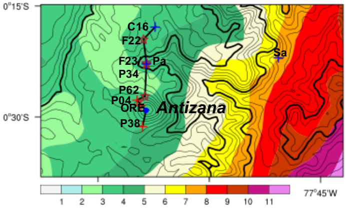
Analysis of options of mountain slope and shading effects (slope rad=1, topo shad=1)

In-situ observations data and satellite products

In-situ observations data :

- 10 in-situ meteorological stations from EPMAPS, FONAG, INAMHI and SNO GLACIOCLIM.

2005 precipitation mean (mm/day) from CHIRPS



- • Antizana summit
- + 2005 hourly in-situ stations
- + 2005 daily in-situ stations
- ☆ 2014-15 hourly in-situ stations
- —— Cross-section of Fig. 12, 13

Station Name	Lat	Lon	Alt (m.)	Avail. period	Time-scale
Papallacta (Pa)	-0.381	-78.141	3140	2005	Daily
Sardinas (Sa)	-0.367	-77.845	1615	2005	Daily
C16	-0.297	-78.122	3747	2005	Hourly
F22	-0.325	-78.148	3648	2014-2015	Hourly
F23	-0.378	-78.141	3103	2014-2015	Hourly
P34	-0.381	-78.141	3140	2014-2015	Hourly
P62	-0.453	-78.144	4346	2014-2015	Hourly
P04	-0.462	-78.162	4455	2005	Hourly
ORE	-0.474	-78.154	4850	2005	Hourly
P38	-0.521	-78.150	4320	2005	Hourly

Satellite products:

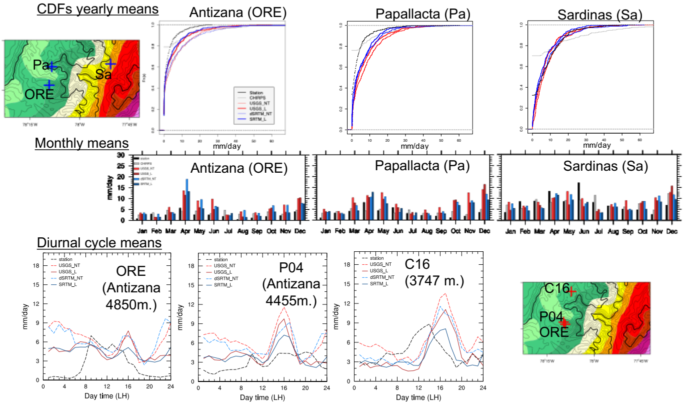
- CHIRPS (5kmx5km, daily) Climate Hazards Group InfraRed Precipitation with Station data (chg.geog.ucsb.edu/data/chirps/)

Group 1 : Statistical precipitation analysis

Results of experiments (WRF-1km) when compared with in-situ stations

Influence of DEM forcings with 2 microphysics

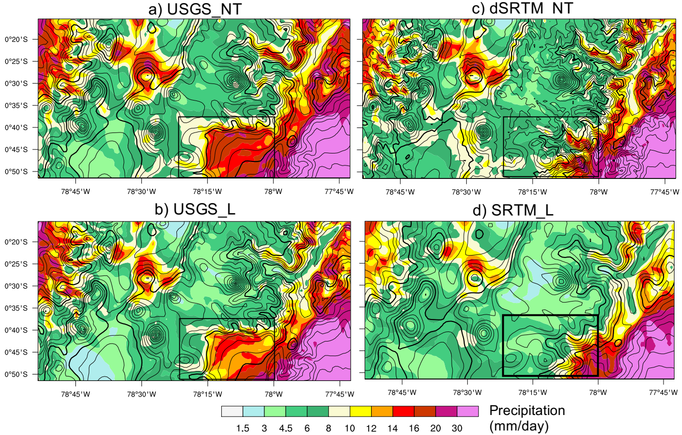
- Cumulative density functions (CDFs) : The SRTM DEM reduces positive precipitation biases at altitude stations (ORE and Pa). In the Amazon valley (Sa) the model reproduces better CDFs than CHIRPS.
- Every simulation shows a relatively good seasonal cycle, but with overestimation of the peak in altitudes (ORE and Pa) and subestimation in the Amazon valley (Sa).
- Overestimation of the precip during night (ORE and Pa) –> bias decreased with **Lin microphysics**. In every station, **SRTM L** reduces the afternoon peak overestimation.



Group 1 : Analysis of precip spatial variability
and associated physical processes (WRF-1km)

Influence of different DEM forcings : **regional scale**

- Orography : A mountain is missing in USGS DEM (black box)
- The dSRTM DEM shows a better representation of the topography than SRTM (without desmooth)



Group 1 : Analysis of precip spatial variability
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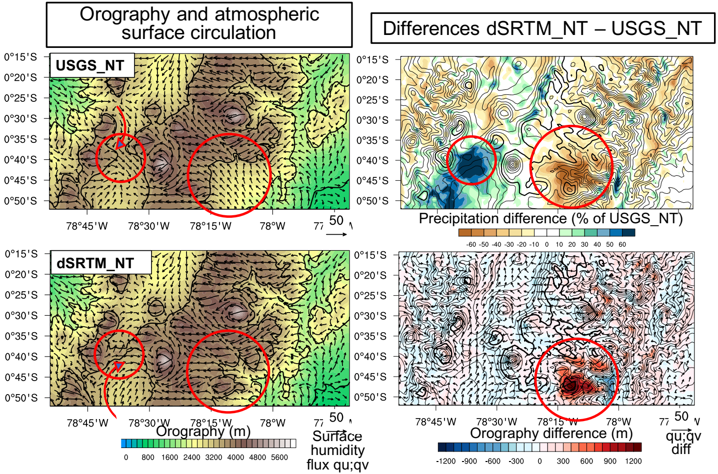


- Orography changes –> surface humidity flux changes –> precip changes
- Change in the orientation of the surface humidity flux –> precip changes

Conclusions of Group 1 : Influence of different DEM forcings with 2 microphysic schemes

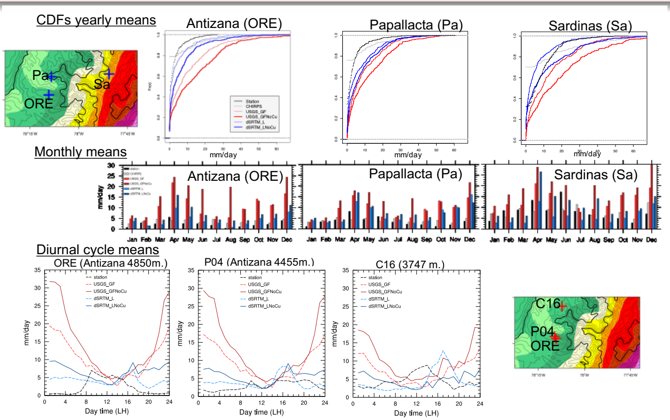
- Good desmooth orography (dSRTM) = more realistic high resolution climate simulation in mountain regions.
- Locally around the Antizana mountain the microphysic change has more impact to reduce precipitation biases than the DEM forcing change.
- For WRF 3.7.1 these results suggest to use a combination of the dSRTM DEM and the Lin microphysic scheme.
- The versions of WRF 3.8 and above use a similar DEM than dSRTM (by using default WPS configuration) so there is no need to change the default DEM configuration anymore (not shown here).

Group 2 : Statistical precipitation analysis

Results of experiments (WRF-1km) when compared with in-situ stations

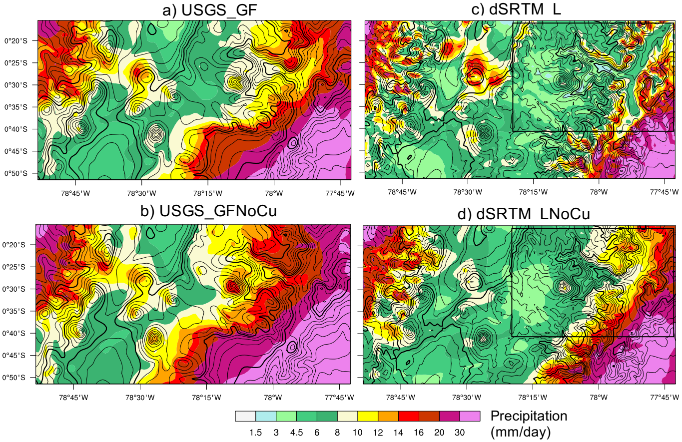
Influence of convection-permitting with 2 Cu schemes

- **CDFs** : For the 2 tested Cu schemes, using convection-permitting at high resolution (NoCu) increases the positive bias for altitude stations (ORE and Pa). Using GF instead of GD increases the bias in every exp and each station.
- **Seasonal variability** : Using NoCu increases the positive bias for almost every month, (particularly during the dry season fo GF) for each station.
- **Diurnal cycle** : The precip overestimation of NoCu and GF are mainly due to **nighttime hours** –> need to better understand the nighttime processes in order to reduce this bias.



Influence of convection-permitting with 2 Cu schemes

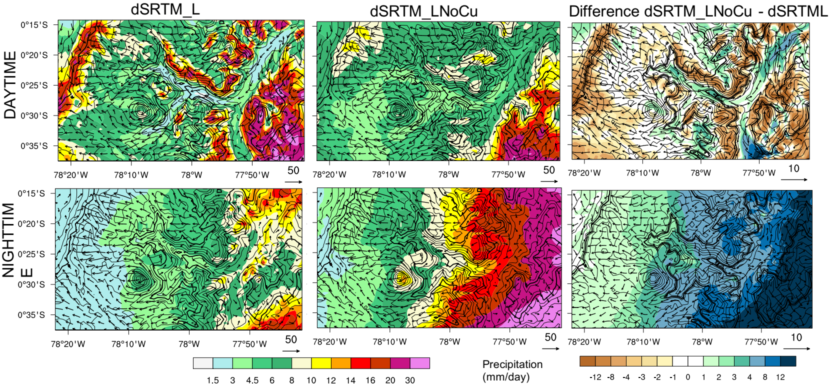
- Using NoCu produces westward and upward shifts of the convection for both tested Cu and both DEM (USGS and dSRTM), and a decrease of mid-slope precipitation for dSRTM.
- –> need to differenciate daytime/nighttime and local/regional processes.



Group 2 : Analysis of precip spatial variability
and associated physical processes (WRF-1km)

Influence of convection-permitting : **local scale**

- **Daytime** : Activating Cu at high resolutions increases local convection in the slopes of the valleys through activating local valley/mountain wind circulations.
- **Nighttime** : The convection-permitting exp. (NoCu) increases nighttime precipitation everywhere, particularly in the Amazon slope.



Group 2 : Analysis of precip spatial variability

and associated physical processes (WRF-1km)

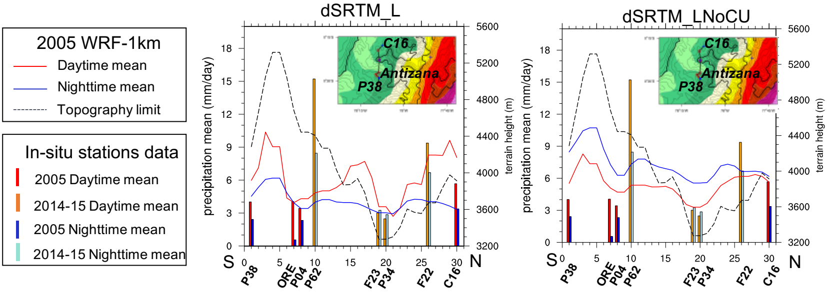
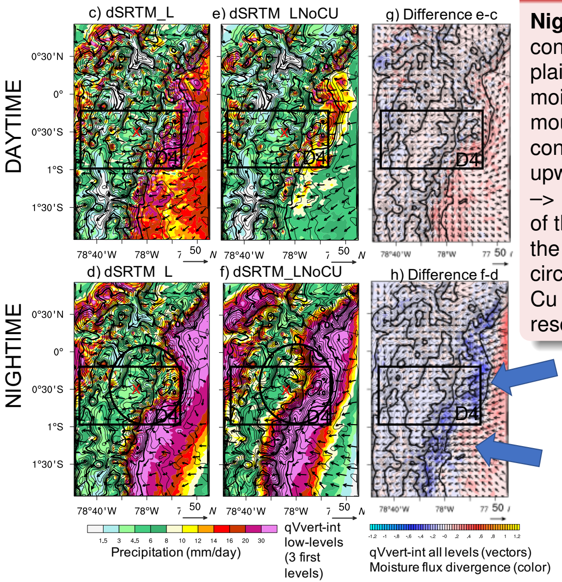


Fig.12 : **Precipitation cross-section** (mm/day) from P38 to C16 grid-points (see map of Fig. 1c) for two WRF experiments outputs (color lines) and available in-situ stations (histograms) during nighttime (blue) and daytime (red). The black dashed line is the topography (m.)

local scale : validation with available in-situ data

- **Nighttime** : The nighttime precipitation bias is largely reduced when activating Cu schemes at high resolution.
- **Daytime** : During 2014-2015, some precipitation peaks have been observed locally. It is not the case in 2005, perhaps because of a dry period during the first months of the year. Using convection-permitting seems to reduce these localized peaks and reduce some positive biases.
- **The ORE station case** : The higher in-situ station of our study shows very dry nights, uncorrectly represented by the model in both experiments (also see the EGU work of Ruiz et al).

Group2 : Analysis of precip spatial variability
and associated physical processes ((WRF-3km; D3)



Regionale scale

Nighttime : In NoCu : less convection in the Amazon plains –> stronger westward moisture flux reaching the mountains –> orographic convection is pushed upwards in high altitudes –> Indirectly, the influence of the low pre-relief East of the Antizana region over the circulation is stronger when Cu is activated at high resolution

Conclusions of Group 2 : Influence of convection-permitting configuration

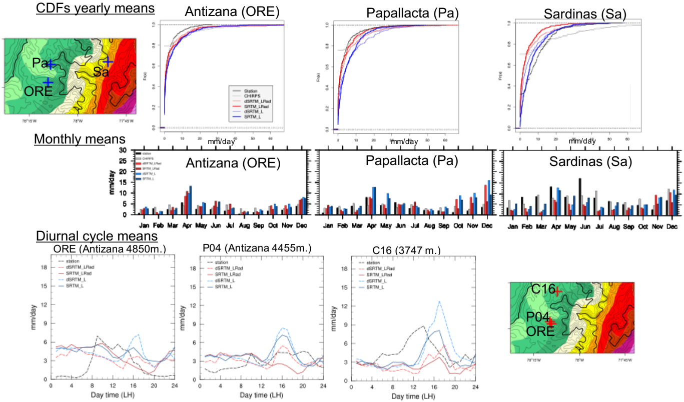
- Using convection-permitting in the Antizana region induces a positive precipitation bias in high altitudes during the night.
- When activating Cu schemes at high spatial resolutions, while not physically recommended, it indirectly reduces this bias by increasing the Amazon convection and reducing the easterlies moisture flux.
- However, during daytime, the Cu activation increases valley/mountain winds circulation and precipitation increases strongly locally in slopes and in some localized relative orographic peaks. While observations show such spatial features for a few years, our one year of simulation alone is not sufficient to be completely conclusive on this point. This process should be studied with more years of simulation and more in situ stations, particularly located on the slopes where they are mainly missing today.
- Finally, while Cu schemes are not physically implemented for high resolutions, it appears that locally and indirectly they can reduce precipitation biases in high mountain regions. This configuration should be used with caution, but could be considered for ex. to simulate atmospheric forcings for further be used in hydrological/glaciological models.

Group 3 : Statistical precipitation analysis

Results of experiments (WRF-1km) when compared with in-situ stations

Influence of slope and shading option effects (hereafter 'Rad' options)

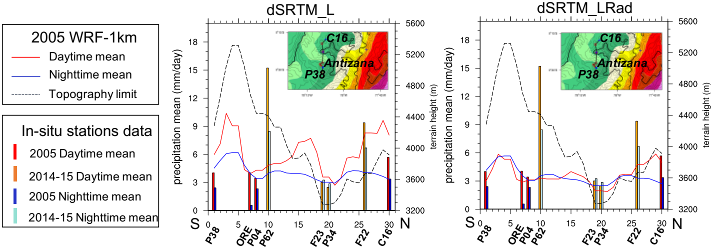
- **CDFs** : Using the Rad otions decrease precipitation during the day. Therefore, it decreases (increases) precipitation biases in high stations (in the Amazon valley).
- **Seasonal variability** : The seasonal peak and the dry season is more close to observations when using the Rad options in high altitudes. In addition, using a desmooth option (dSRTM) with these options seems to increase the positive bias of precip. On the contrary, in the Amazon valley (Sa), Rad options and desmooth induce a negatve bias, except for the last months of the year.
- **Diurnal cycle** : as expected, main changes are during daytime, decreasing the afternoon peak.



Group 3 : Analysis of precip spatial variability
and associated physical processes (WRF-1km)

Influence of slope and shading option effects (‘Rad’ options)

- **Daytime** : Logically mainly daytime changes are found. These options seems to strongly reduce the localized precipitation peaks shown by the model when Cu activated.
- **Nighttime** : as seen before, the Rad options weakly reduce the nighttime precipitation bias.
- –> The dSRTM LRad experiment shows the best results in terms of daytime and nighttime precipitation, when compared with in-situ stations.



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Conclusions of group 3 : Influence of slope and shading options

- Using slope and shading options mainly produce a reduction of precipitation during daytime in mountains, through radiative processes and a reduction of the daily surface heating associated with the local afternoon convection, mainly in localized orographic peaks.
- In the Amazon valley (Sa), these options induce a negative precipitation bias for the same reasons.
- Using both options and a desmooth topography induce a strong decrease of local precipitation during the afternoon, producing for some stations a negative bias (ex. Sa). Using both configuration needs to be used with caution only where the model strongly overestimates in-situ data.

Final Conclusions

Summary and conclusions

- The WRF model is able to simulate precipitation at high spatio-temporal resolution (1km; 1h) in the Antizana region, and associated atmospheric processes (in terms of surface humidity fluxes) .
- We found that the dSRTM DEM is the more appropriate DEM to use at high spatial resolution in this region as the topographic forcing
- By using the dSRTM DEM, changing the microphysic parameterization, activating Cumulus parameterization and adding slope and shading options we were able to reduce substantially a strong positive precipitation bias.
- However, this configuration induces a sub-estimation of the precipitation in the Amazon region.
- This study was performed with the objective of using the WRF outputs of meteorological variables as forcing for hydro-glaciological models. The results of this study show that the Cumulus activation at high resolutions can indirectly reduce precipitation bias in an Andean altitude region, due to an increase in the hotspot Amazon nighttime convection and a decrease in the regional westward humidity flow. However, this configuration should be used with caution.

Thank you !