



Can/should we use ERA5-Land forcing data to represent the mountain snowpack in the Andes Cordillera?

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Mountain Hydrology Group UDEC

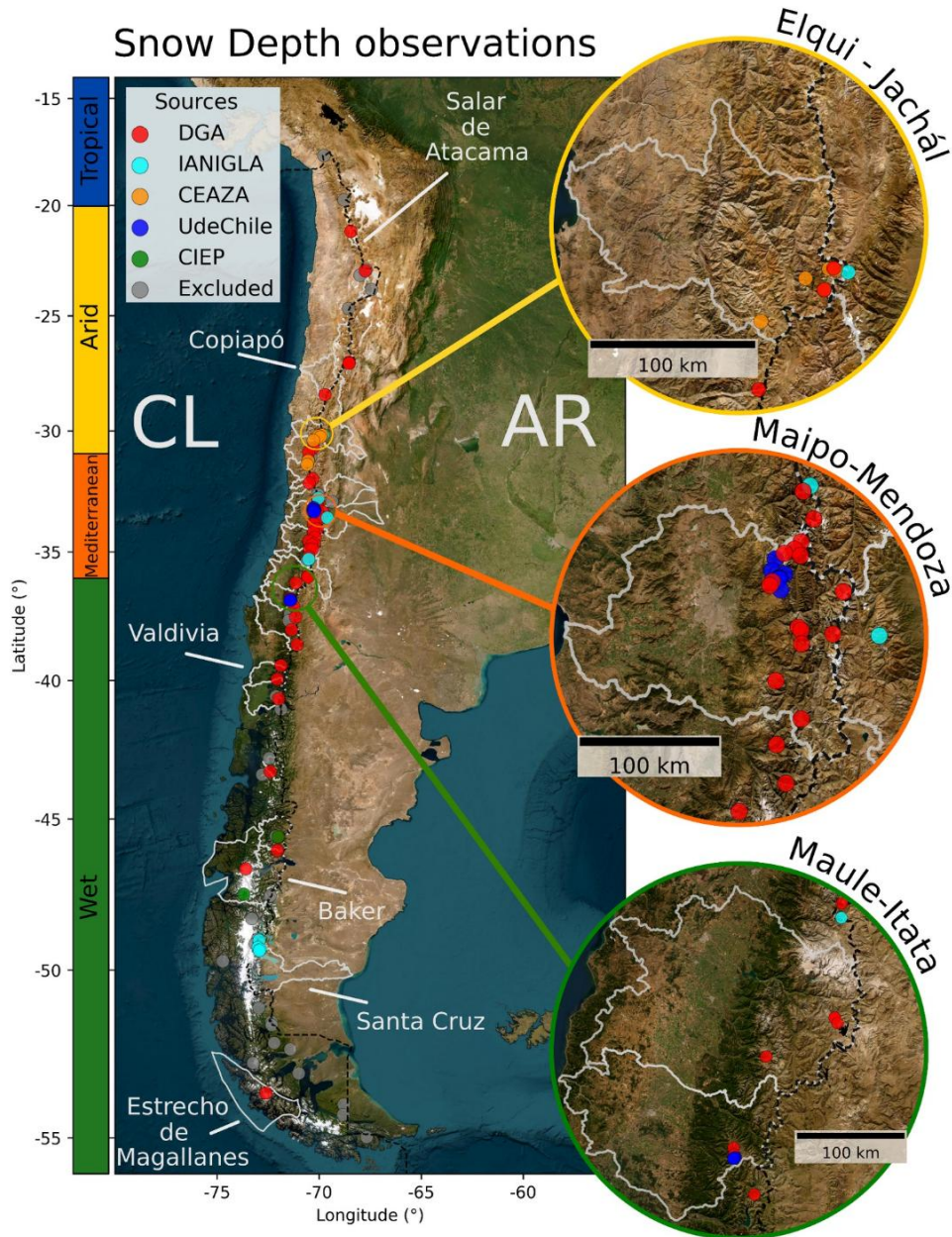


Funding: ANID-Fondecyt N°1261545 (SK)
INARCH Workshop, Kananaskis, Canada, Sept 8-10, 2026



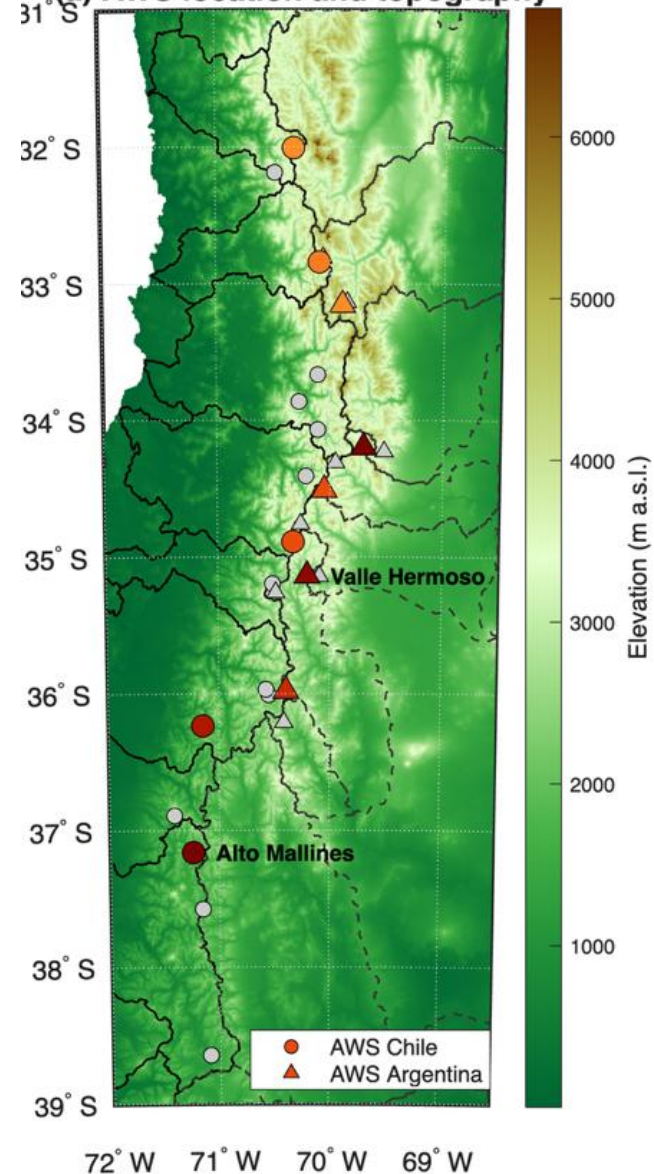
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Snow Depth observations



Caro et al. under review, HESS

(a) AWS location and topography

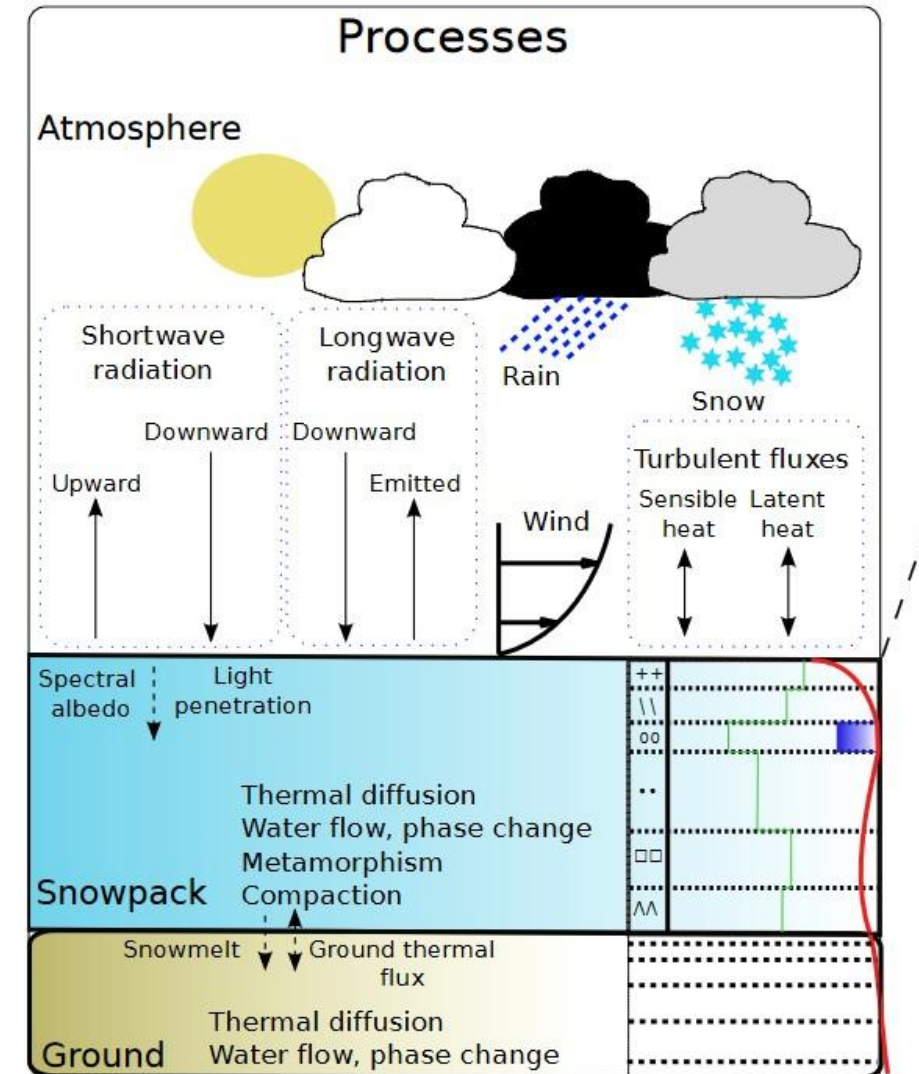


Krogh et al., in prep.

Limited number of mountain AWS **challenge modeling and snowmelt water diagnosis and prediction** in the Andes and other mountain systems.

- 81 snow depth stations in Chile
- Long-term and reliable SWE: 5 in Chile + 5 in Argentina

- Energy-balance snowpack models require reliable and **physically-consistent subdaily forcing data** to represent snow accumulation and melt processes.
- Examples: CROCUS, SNOWPACK, SNOBAL, FSM
- Due to limited data availability in mountain environments, such **data is scarce and often not available**.
- Bias-corrected reanalysis or atmospheric models are typically used to complement limited observations, **bringing the gap in a physically consistent way**
- Bias-correction often rely on **in-situ daily data** (if any)
- However, processes such as sub daily thermal inversions, mountain-valley winds, and diurnal changes are **challenging to represent and difficult to validate**.

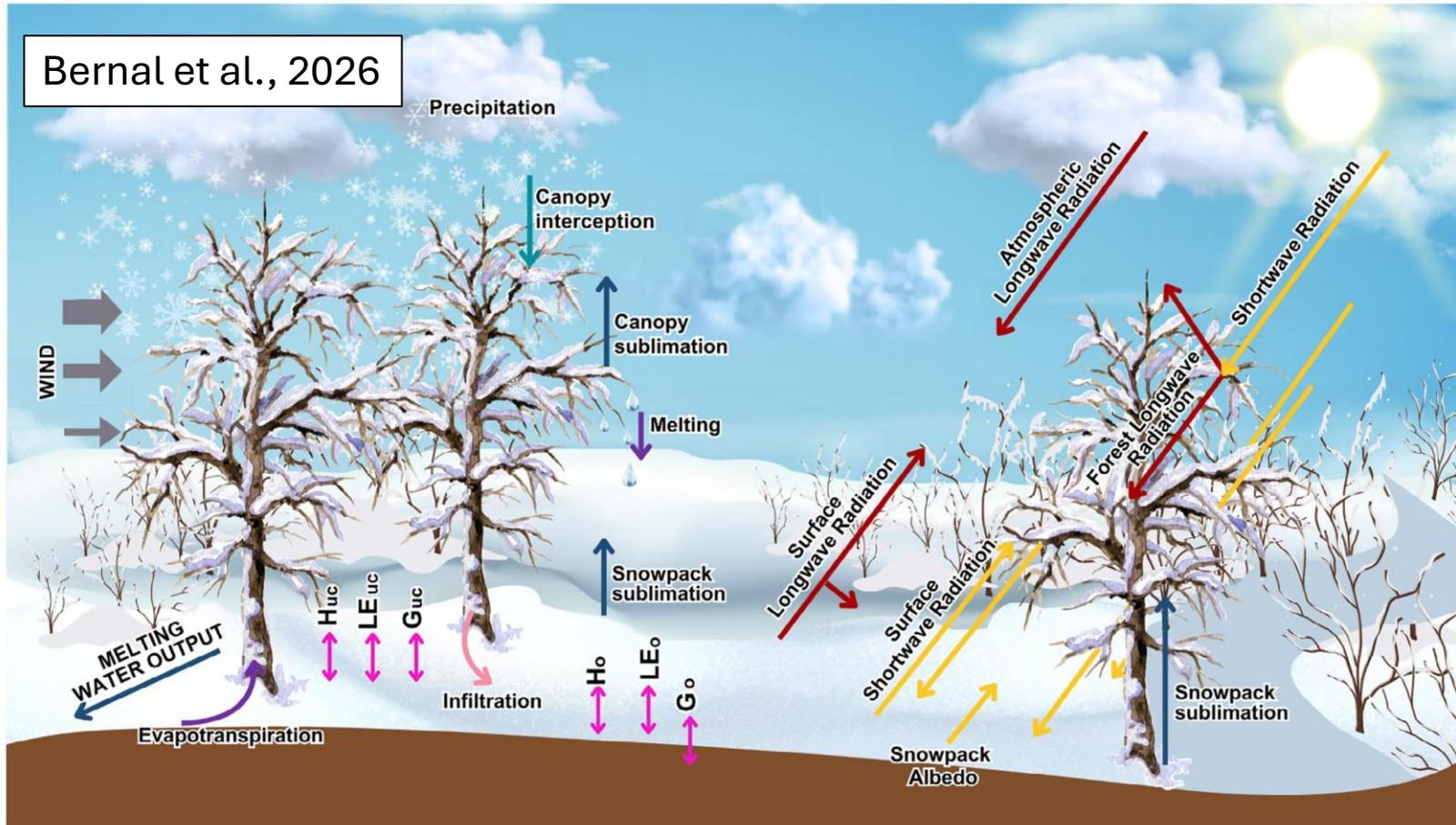




Research question:

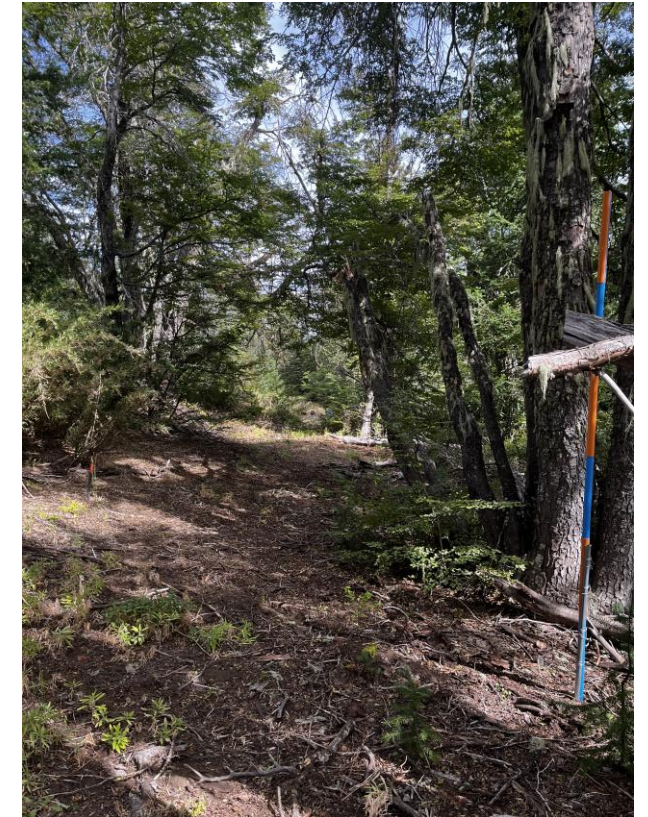
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Snow Model Configuration - CRHM



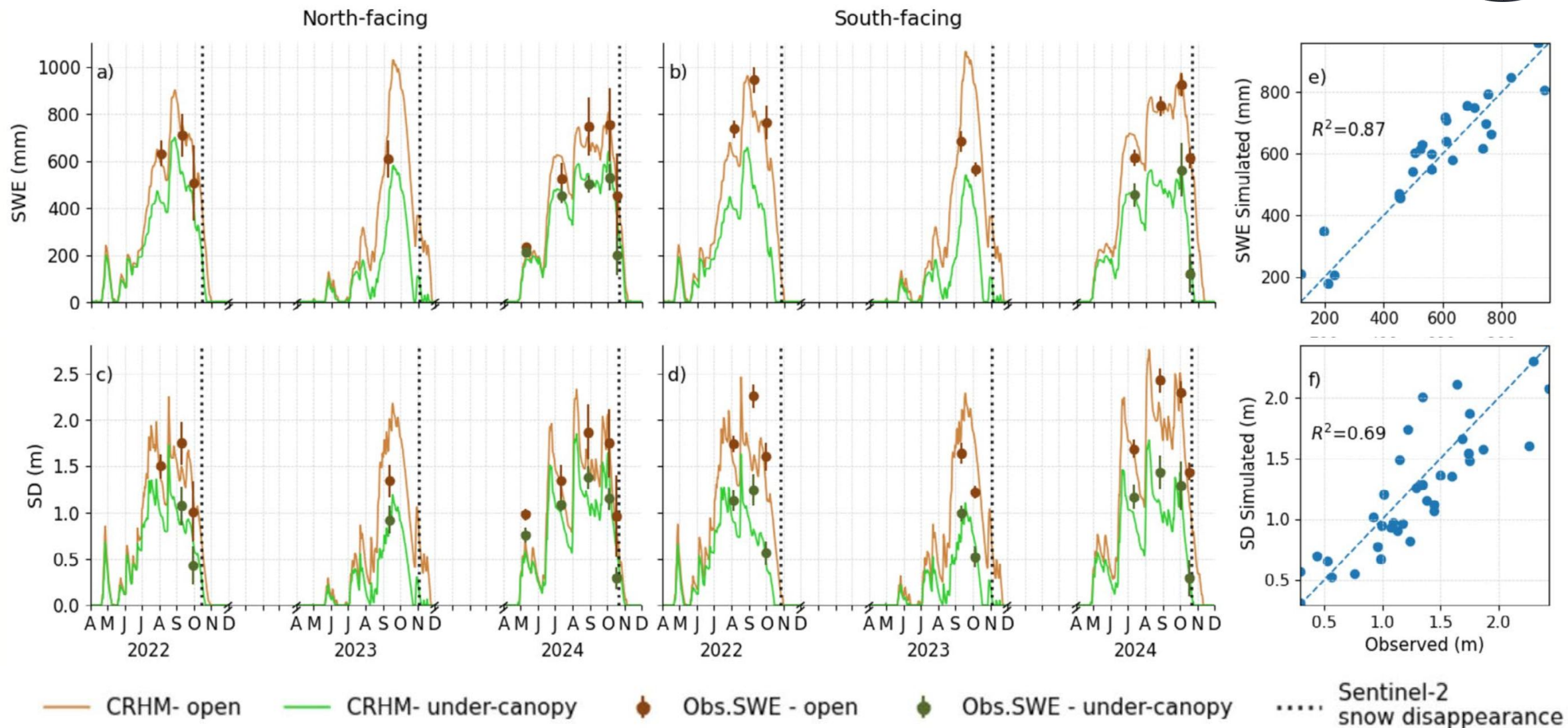
- Two-layer energy balance model – Snobal
- Canopy interception and sublimation (Hedstrom and Pomeroy, 1998)
- Albedo decay, precipitation partitioning (Harder and Pomeroy, 2013)
- North- and south-facing vs open and under canopy configurations

Under canopy snow course (NF)

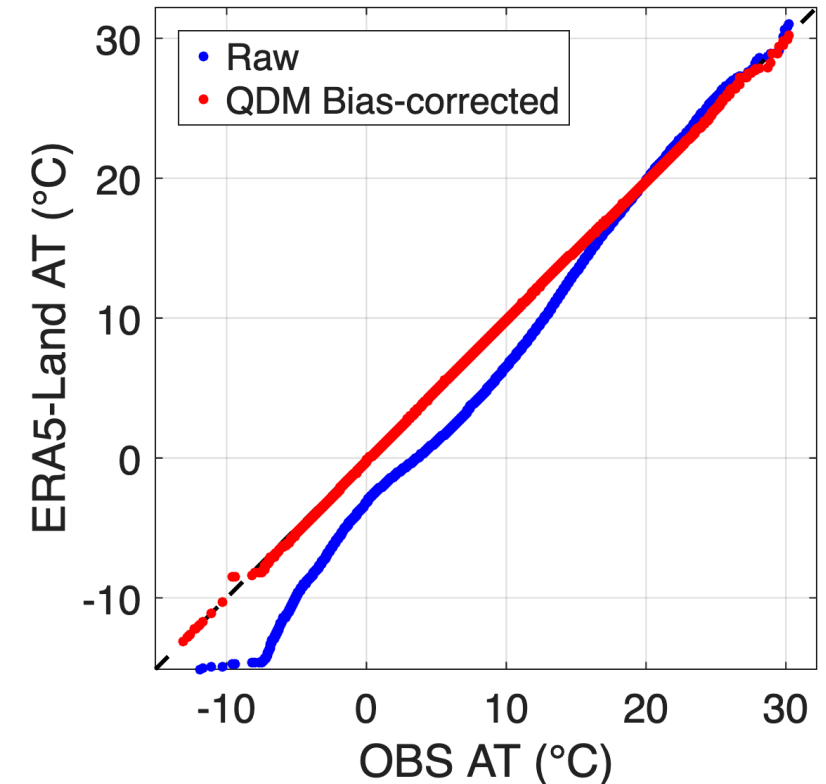
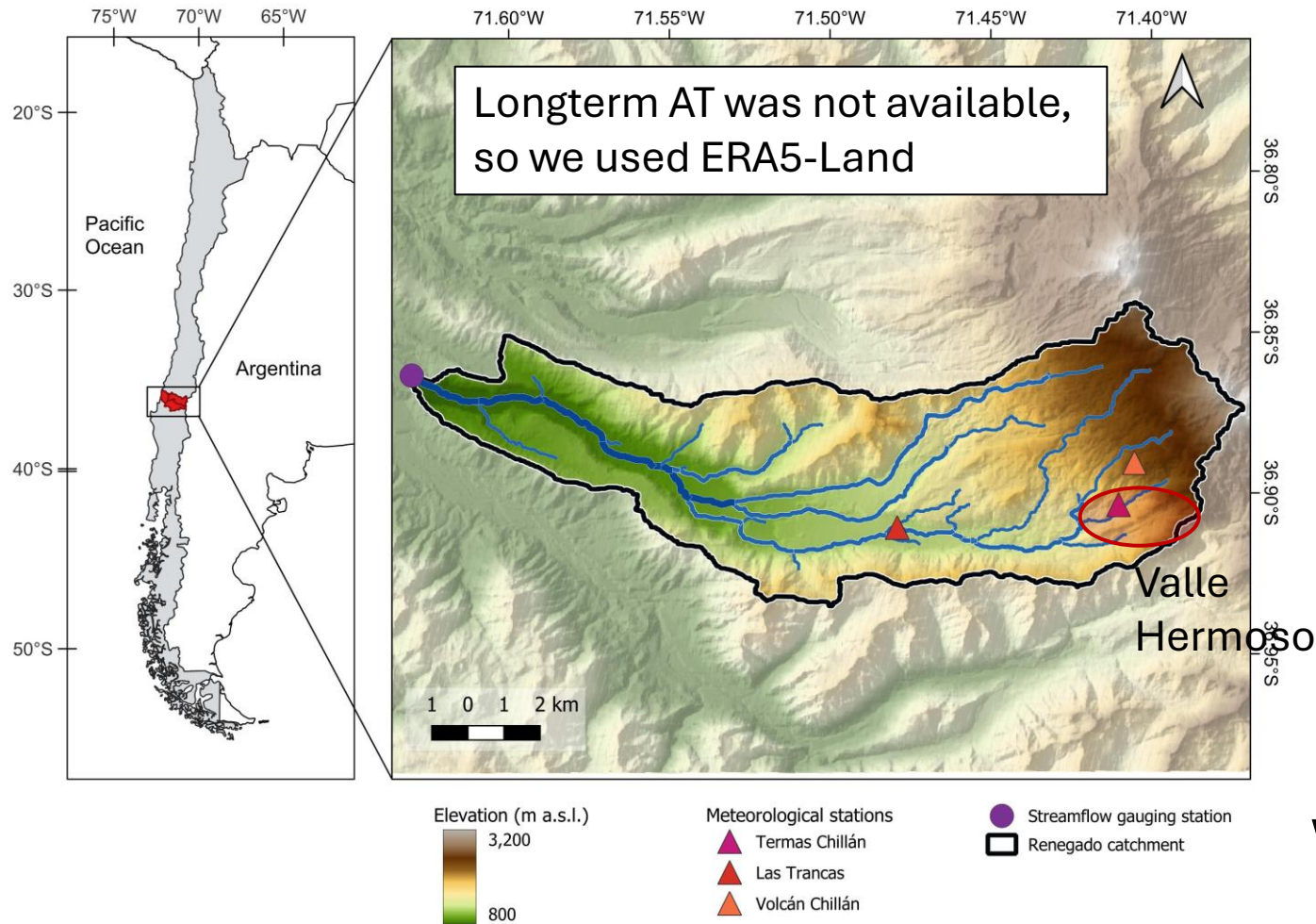


Open site snow course (NF)

Snow model evaluation (Bernal et al., 2026, INARCH special issue HP)



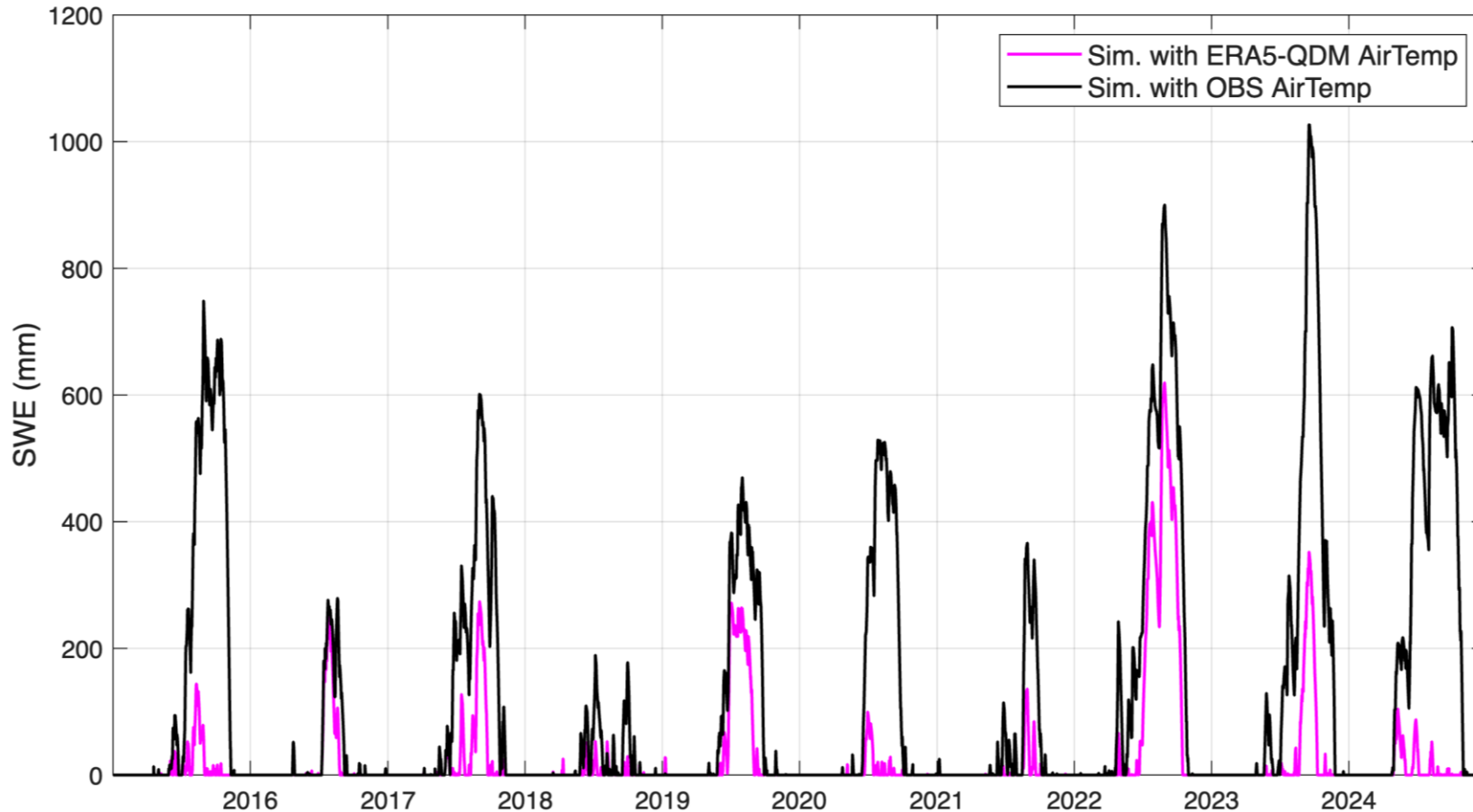
Upscaling the model to the Renegado Creek Basin (~ 100 km²) – 1990-2024



We did Quantile Delta Mapping to bias correct ERA5-Land AirTemp **using hourly observations** and run the model for a longer period



Simulated SWE comparison using observed vs bias-corrected (QDM) ERA5-Land AirTemp

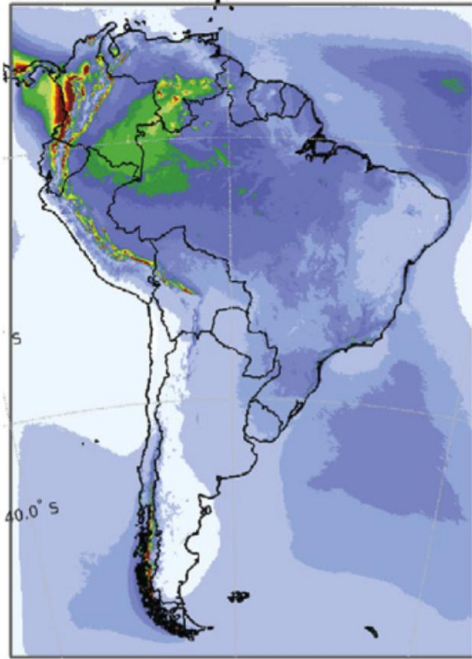


(2015-2024)	Peak SWE (mm)	Snow Persistence (days)	Melt Rate (mm/d)
Sim. With OBS AirTemp	582	144	14.2
Sim. With ERA5-QDM AirTemp	231	78	12.6
Absolute Δ	351	67	2
Relative Δ	60%	46%	11%

Despite using **bias-corrected AirTemp** (Quantile Delta Mapping) simulations are significantly biased – **much less snow is simulated**

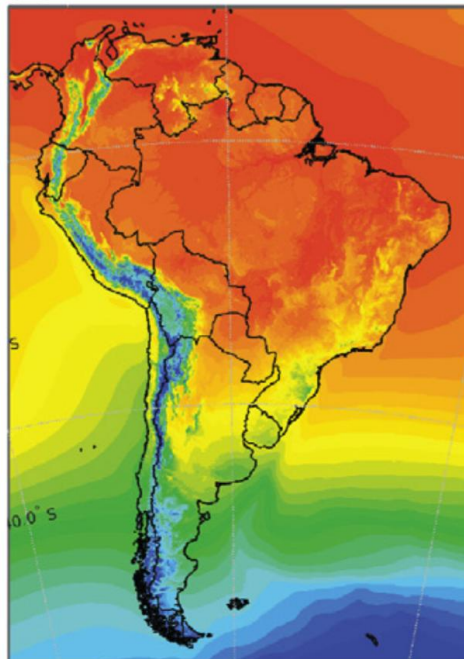
WRF-SAAG (South America Affinity Group)

(a) WRF



Annual mean daily precipitation

(d) WRF



Annual mean 2-m air temperature

4-km simulation: 2000-2021 + Pseudo Global Warming (LENS-2)

Formulario de consulta
Configura periodo, área y variables

TIPO DE SIMULACIÓN ?

Histórico Futuro (PGW)

DIMENSIÓN

2D 3D

1 Periodo de tiempo

Años Meses Días Horas

Seleccionar todo Limpiar

2000 2001 2002 2003 2004 2005
2006 2007 2008 2009 2010 2011
2012 2013 2014 2015 2016 2017
2018 2019 2020 2021

0 años 0 meses todos días 0 horas/día

2 Área geográfica

También puedes seleccionar el área directamente en el mapa →

Ingresar coordenadas manualmente

NORTE (LAT MÁX) SUR (LAT MÍN)
ej: -17.5 ej: -56.0
OESTE (LON MÍN) ESTE (LON MÁX)
ej: -76.0 ej: -66.0

Aplicar Limpiar

3 Variables Ver más variables

Q Buscar variable

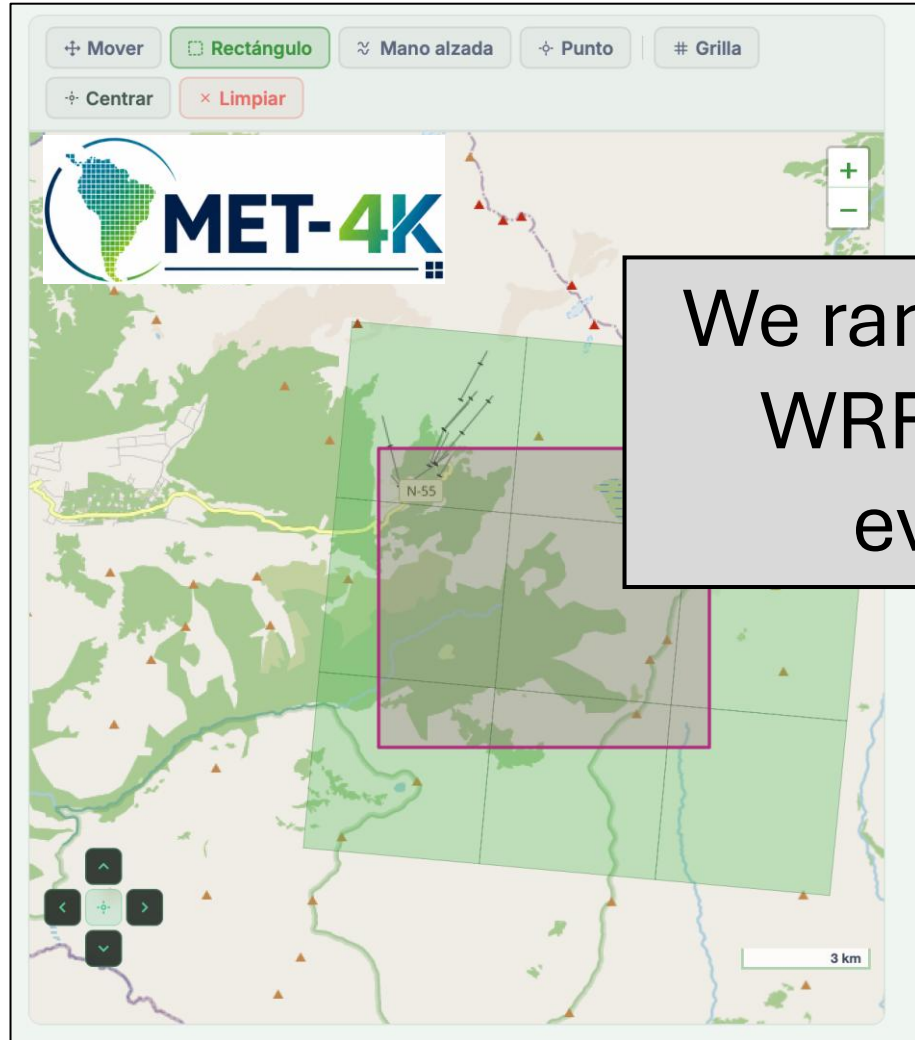
Limpiar todo **Consultar datos**

Resumen de la consulta

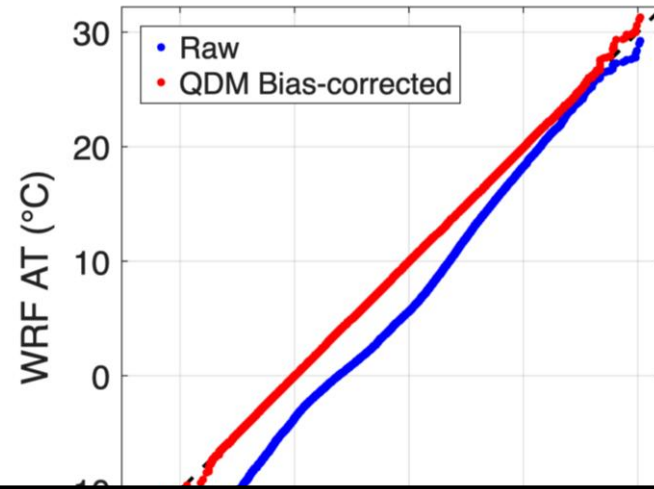
ÁREA **Sin seleccionar** VARIABLES **—** TAMAÑO **Calcular**

Mapa de América del Sur con una zona de simulación delimitada por una línea punteada azul. Países etiquetados: México, Colombia, Perú, Bolivia, Brasil, Paraguay / Paraguai, Chile, Argentina, Mauritania. Escala: 1000 km.

WRF-SAAG Air Temperature (2015-2021)

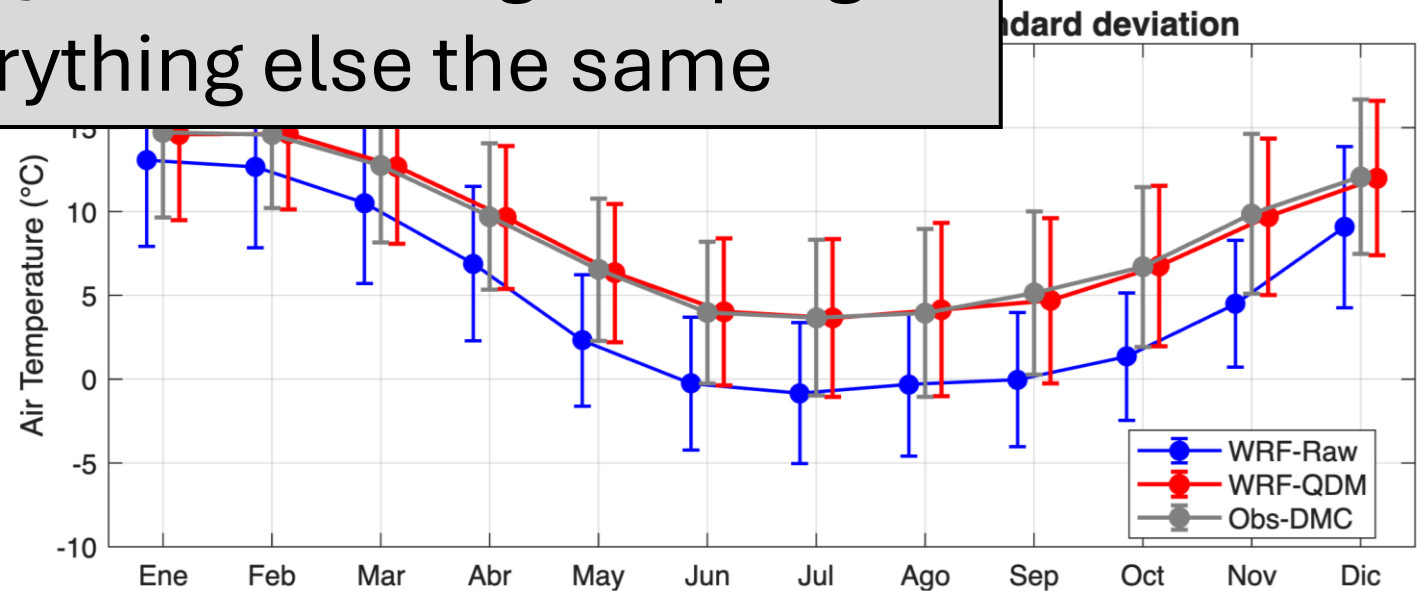


We ran the snow model again with WRF-QDM AT forcing, keeping everything else the same



- Systematic cold-bias -3.9°C corrected with QDM (each month treated separately)

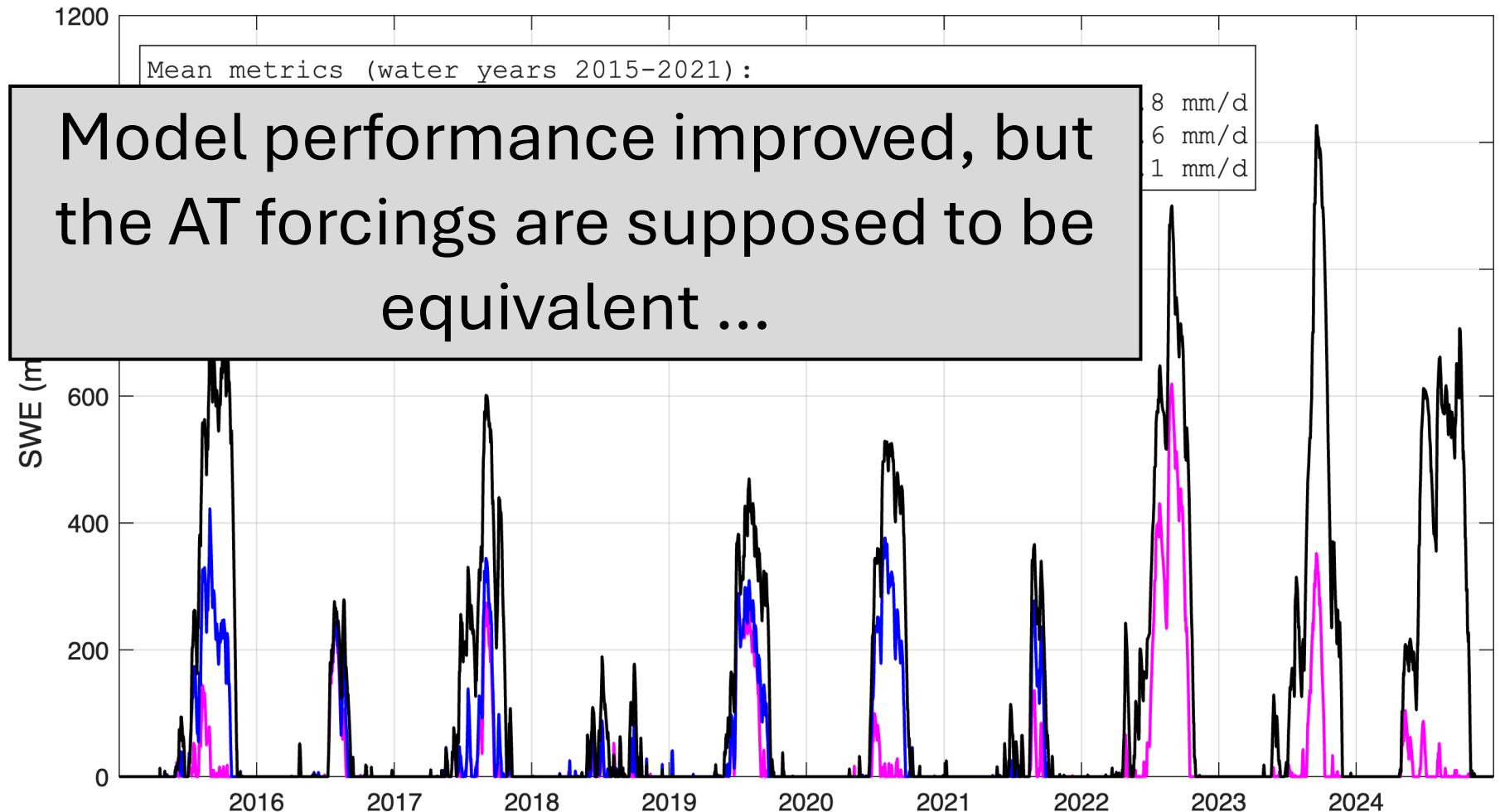
- Seasonality well presented





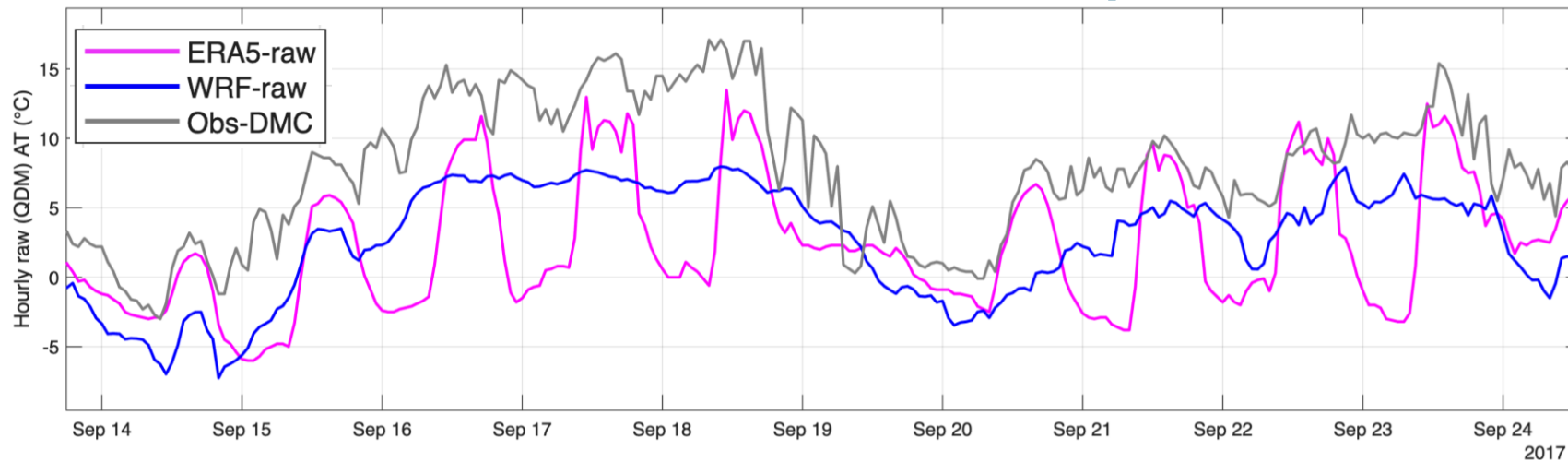
(2015-2021)	Absolute Δ ERA5	Absolute Δ WRF	Relative Δ ERA5	Relative Δ WRF
Peak SWE (mm)	-278	-160	-61%	-35%
Snow Persistence (days)	-56	-24	-78%	-19%
Melt Rate (mm/d)	-1.5	-0.7	-11%	-5%

Including bias-corrected WRF AirTemp
significantly improves snow metrics

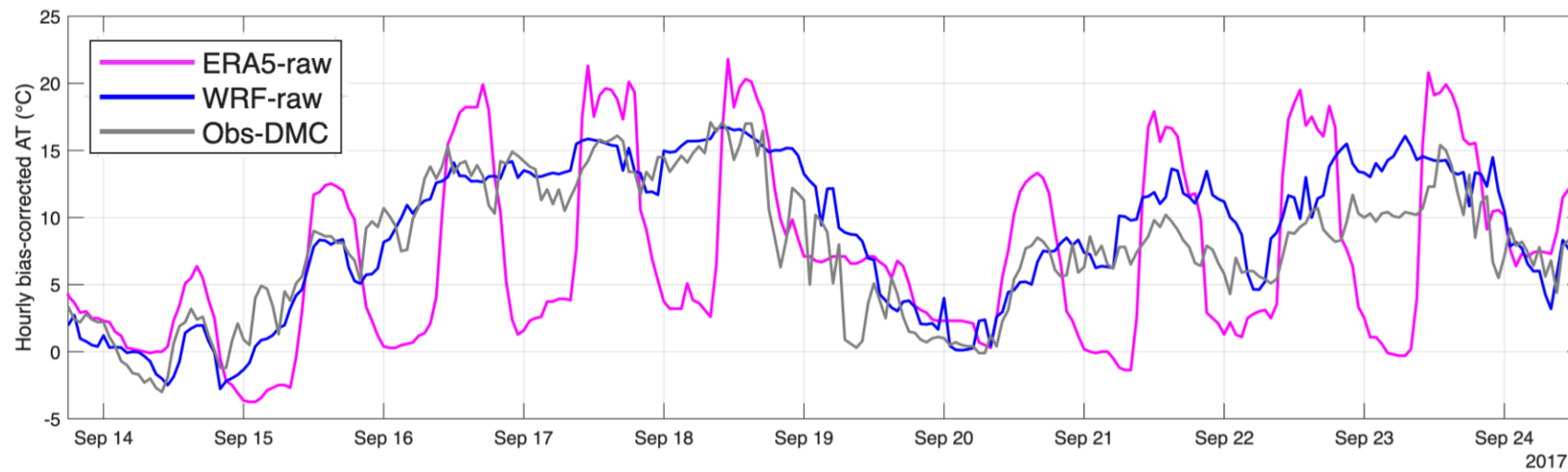


Both hourly time series AirTemp (ERA5 and WRF) have the same quantile distribution, so what's causing this difference?

Example winter 2017



Both raw time series have a **significant cold bias** ($>3^{\circ}\text{C}$). ERA5-Land **thermal amplitude is significantly biased**.

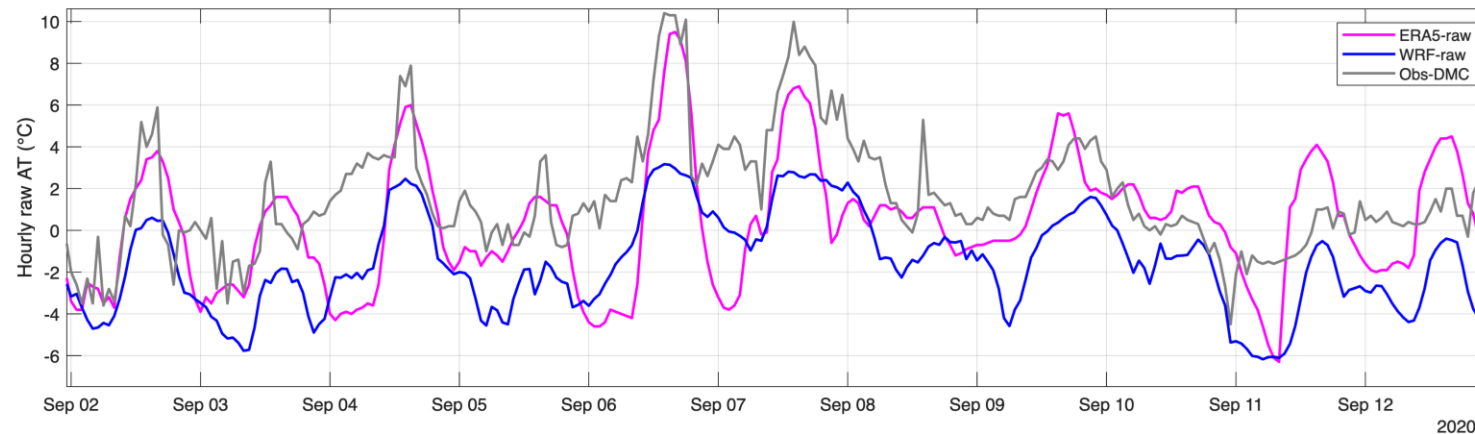


QDM removes the systematic cold-bias; however, **differences in ERA5-Land thermal amplitude persists**.

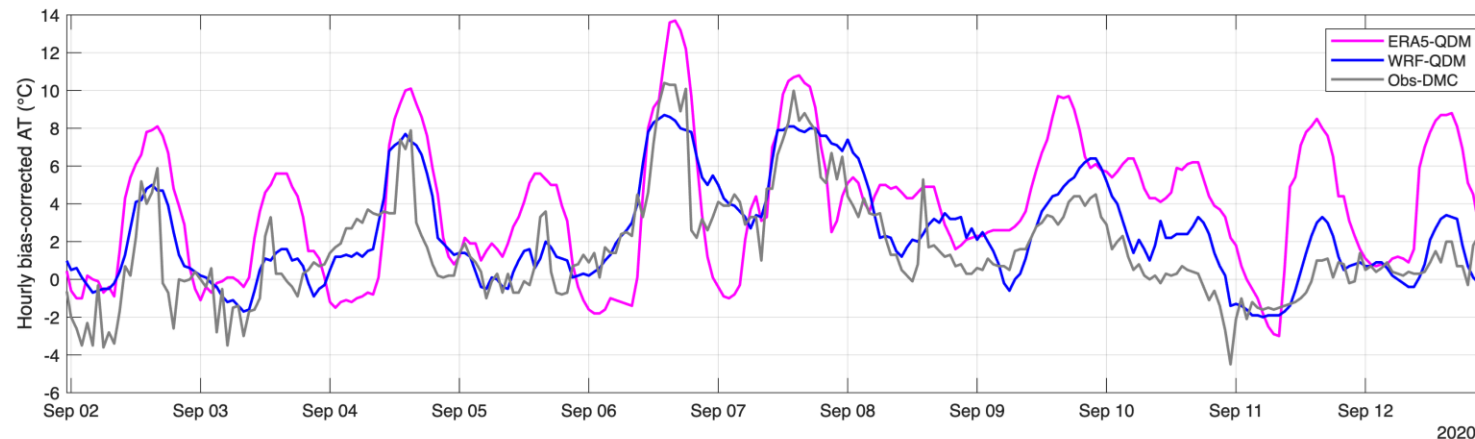
Both time series AirTemp (ERA5 and WRF) have the same quantile distribution, so what's causing this difference?



Example winter 2020



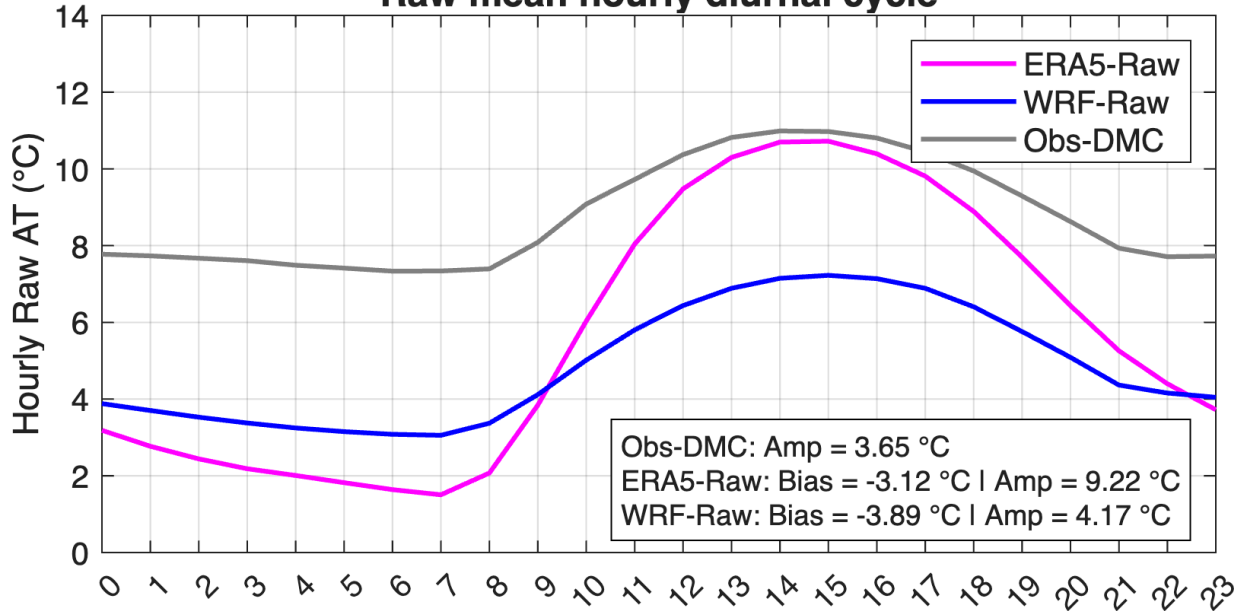
Both raw time series have a **cold bias**. ERA5-Land thermal amplitude is **significantly biased**.



QDM removes the systematic cold-bias; however, **differences in ERA5-Land thermal amplitude persists**.

Do we see this pattern throughout the 2015-2021 period?

Raw mean hourly diurnal cycle

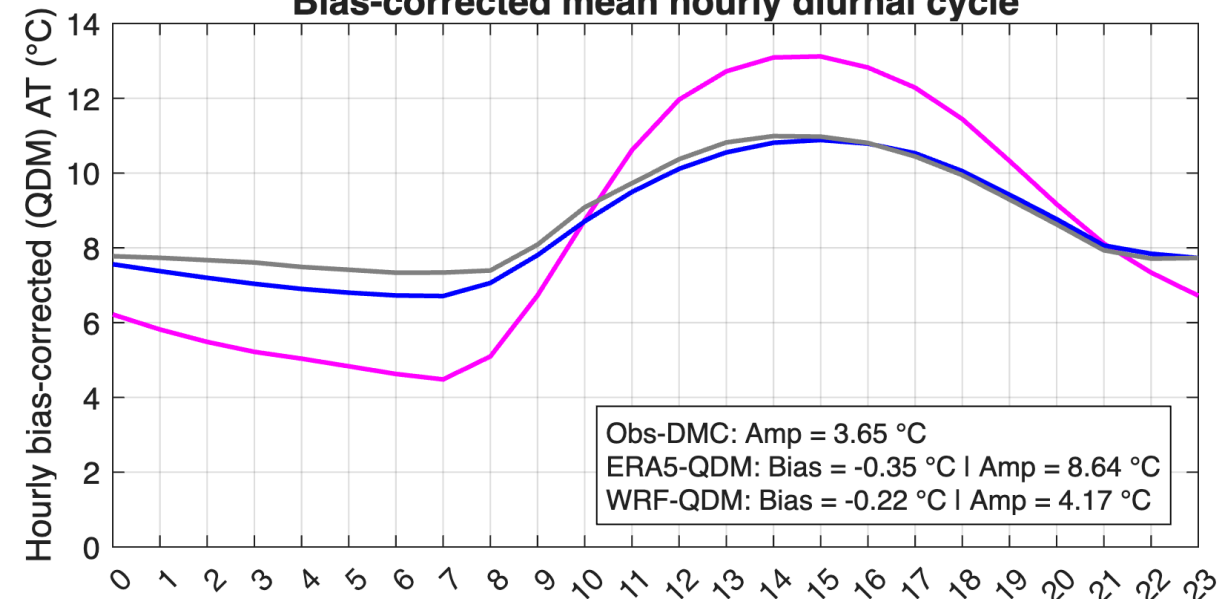


Significant **cold-bias** from both datasets (2015-2021) – **diurnal differences** dominate with ERA5-Land

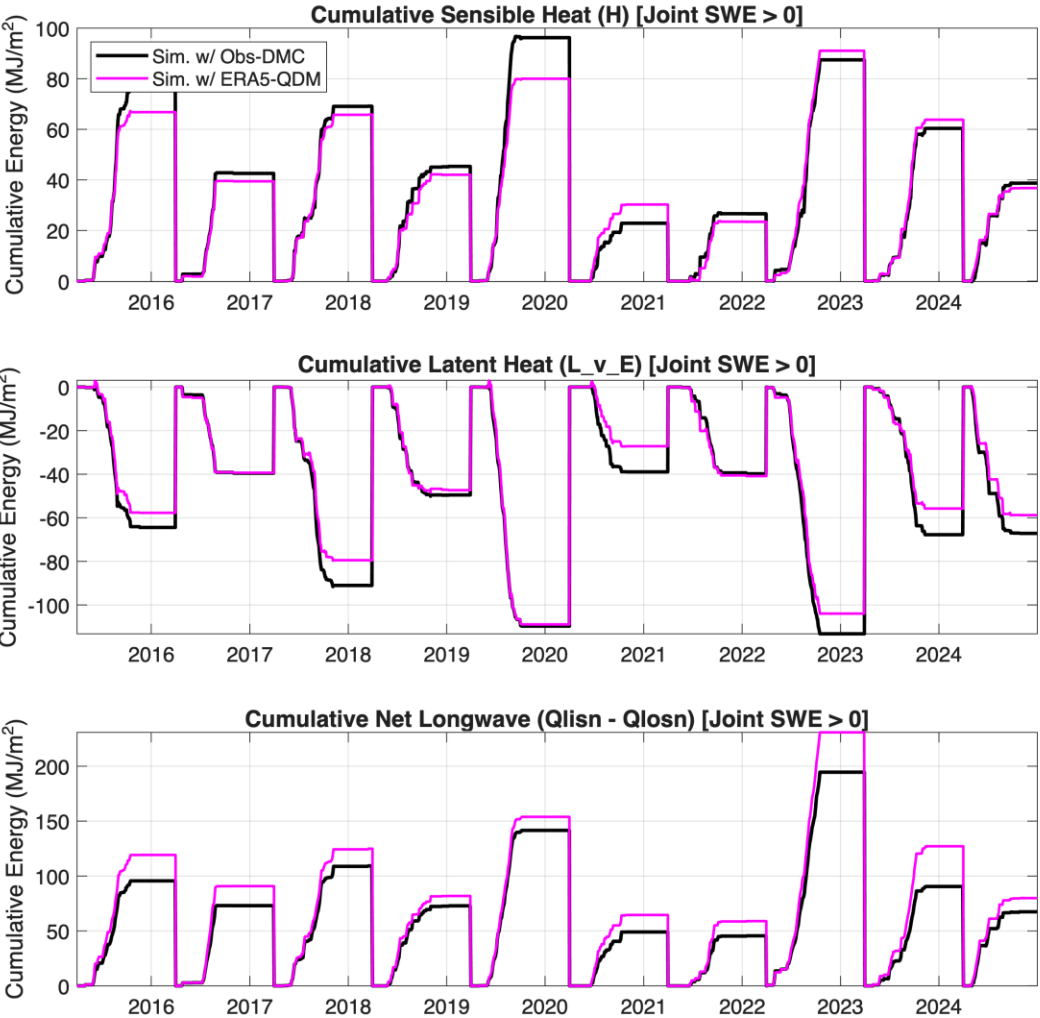
Cold-bias is removed; however, significant **diurnal differences** in ERA5-Land remain.

- Obs. Amplitude = 3.65°C
- ERA5-QDM amplitude = 8.64°C
- WRF-QDM amplitude = 4.17 °C

Bias-corrected mean hourly diurnal cycle



Cumulative energy fluxes: Sim. with Obs vs ERA5-QDM

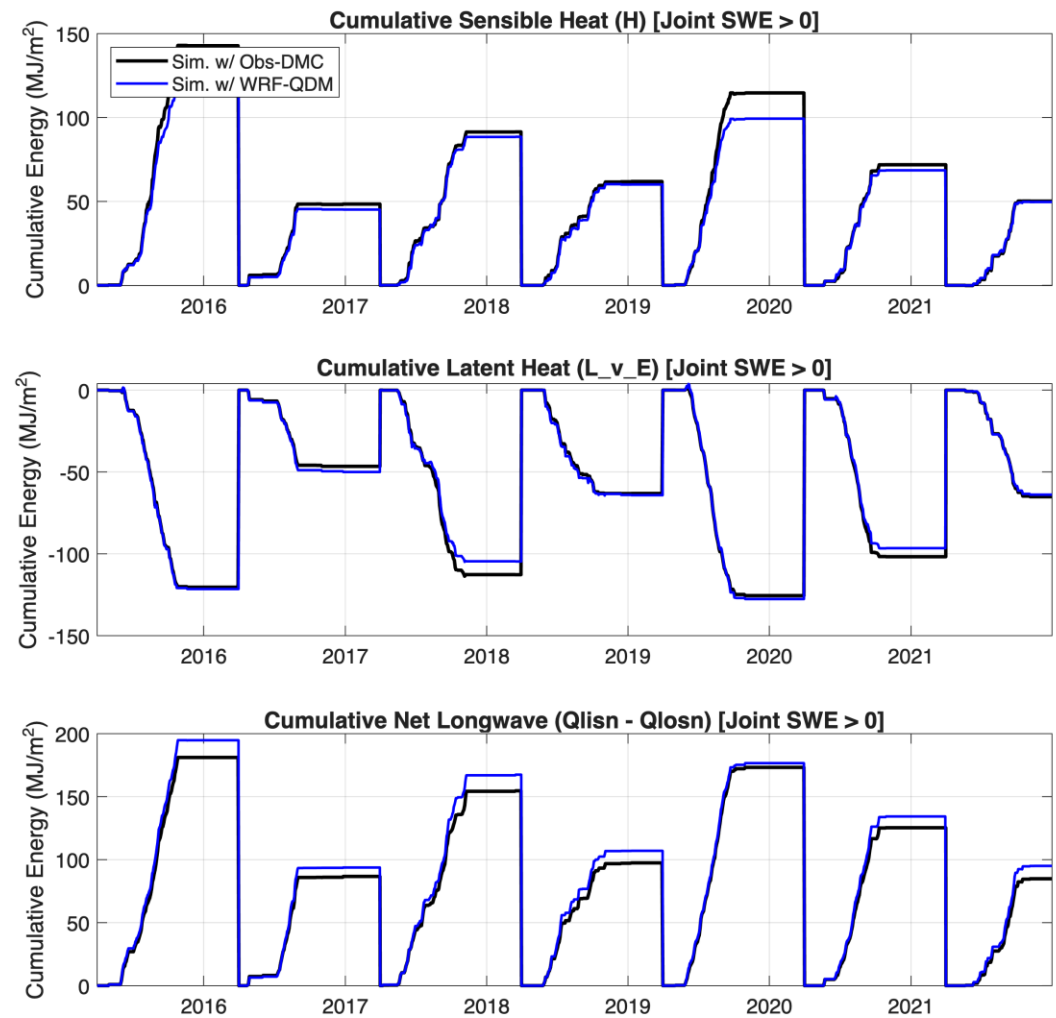


Only looking at hours where simulation forced by **Obs and ERA5-QDM AT have SWE>0**

Mean anual cumulative values (SWE_{obs} & $SWE_{WRF}>0$)

2015-2021	Sin. with Obs	Sim. with ERA5-QDM	Δ Absolute (MJ/m ²)	Δ Relative (%)
Sensible Heat (MJ)	54	50	-4	-4%
Latent Heat (MJ)	-62	-57	5	8%
Net Longwave (MJ)	84	99	15	21%

Cumulative energy fluxes: Sim. with Obs vs ERA5-QDM

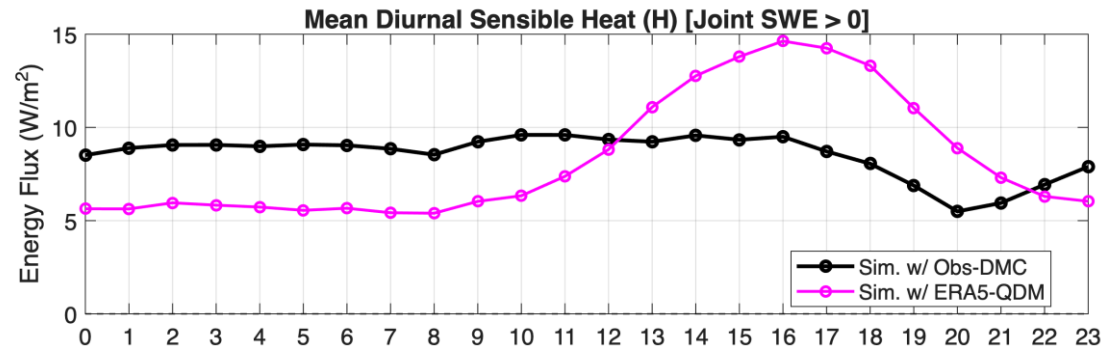


Only looking at hours where simulation forced by **Obs and WRF-QDM AT have SWE>0**

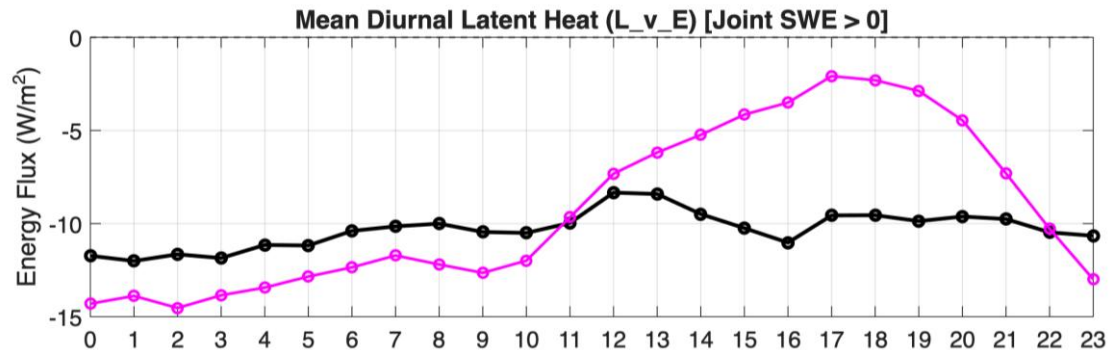
Mean anual cumulative values (SWE_{obs} & SWE_{WRF}>0)

2015-2021	Sin. with Obs	Sim. with WRF-SAAG	Δ Absolute (MJ/m ²)	Δ Relative (%)
Sensible Heat (MJ)	83	76	-7	-6.6%
Latent Heat (MJ)	-91	-90	1	0.4%
Net Longwave (MJ)	129	138	9	7.8%

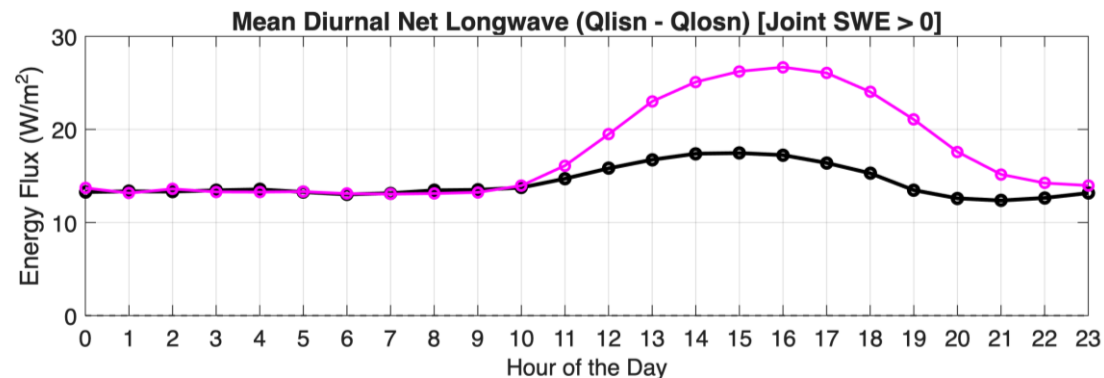
Mean diurnal energy fluxes (SWE_{obs} & $SWE_{ERA5-QDM} > 0$)



- Lower overall H
- Lower H overnight due to colder AT
- Higher daytime H due to higher AT

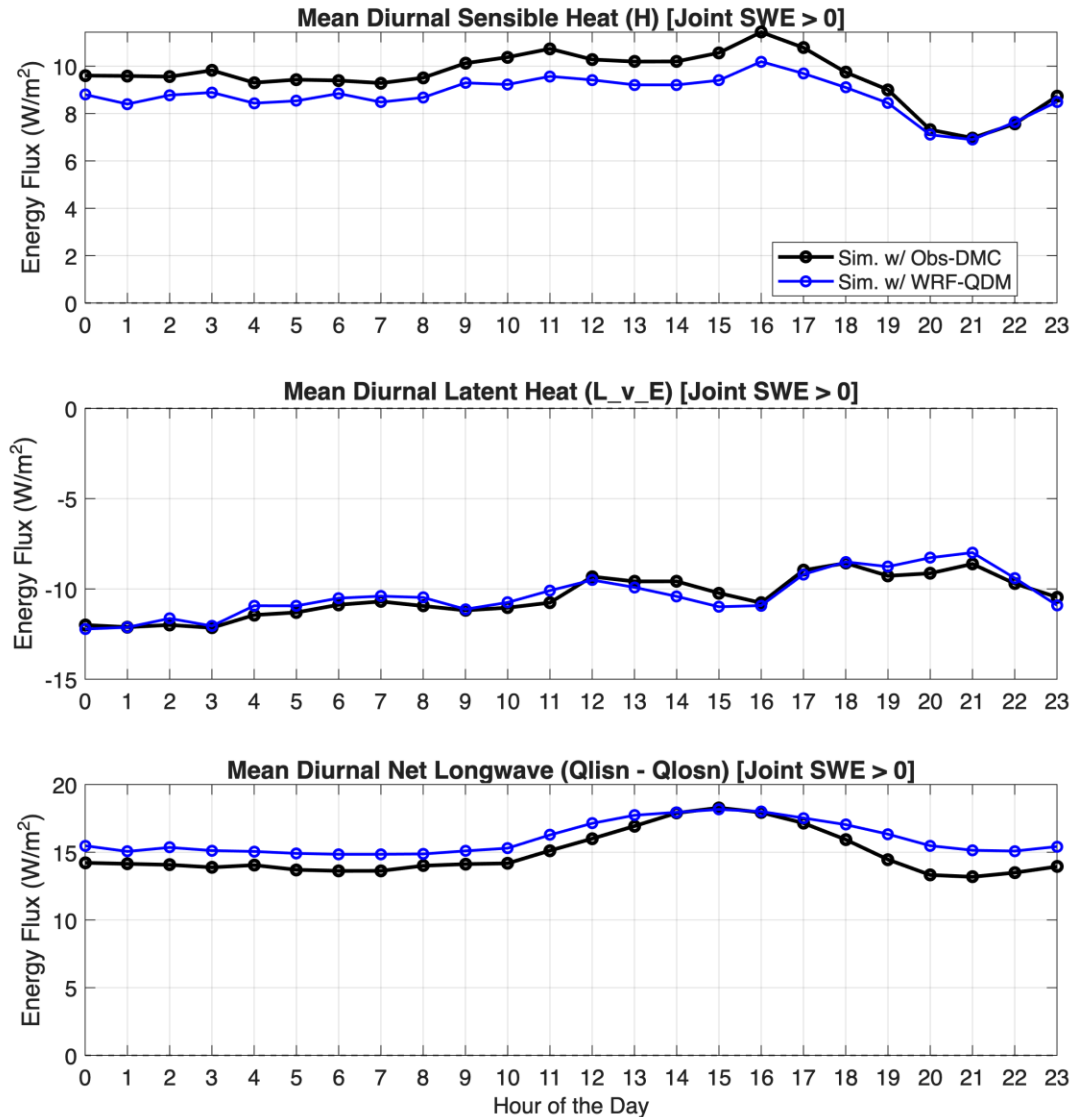


- Less overall turbulent latent heat exchange – less sublimation



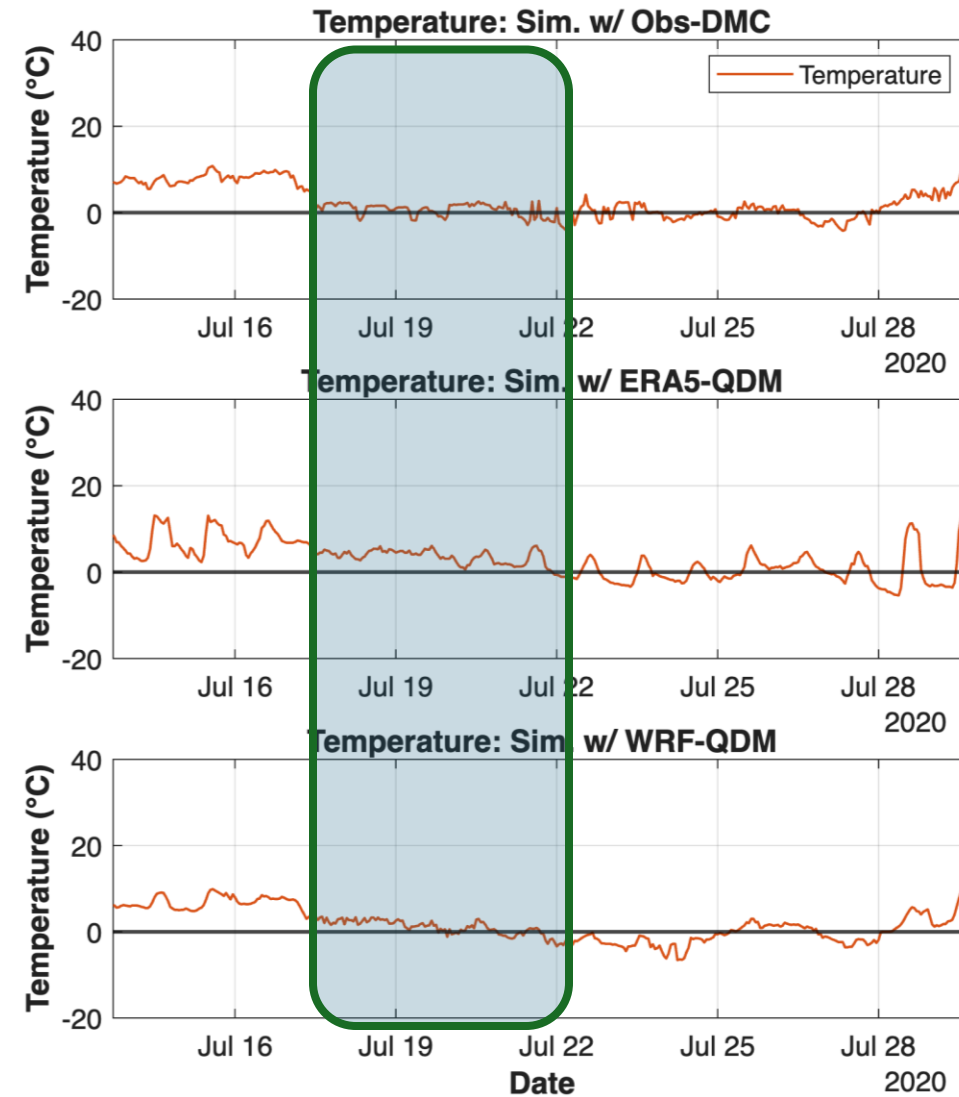
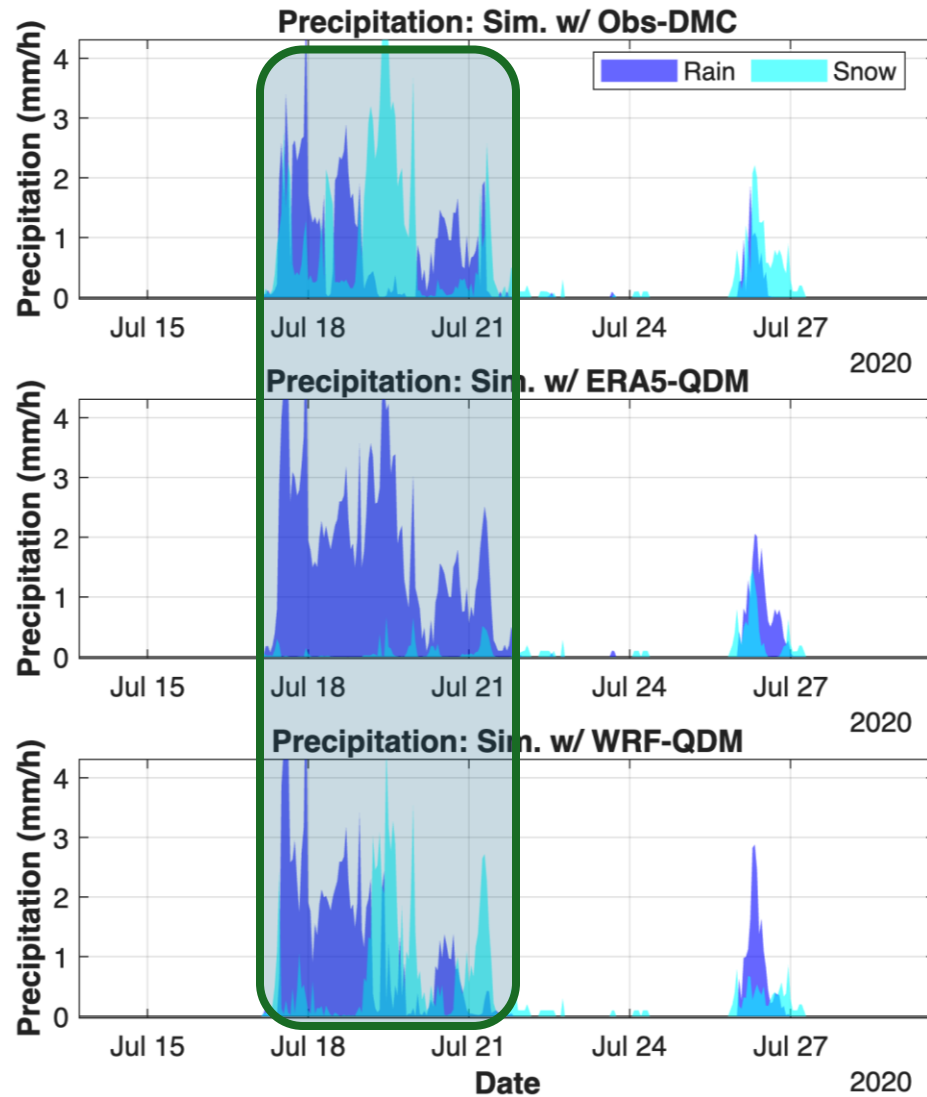
- More overall net Longwave during the day

Mean diurnal energy fluxes (SWE_{obs} & $SWE_{WRF} > 0$)



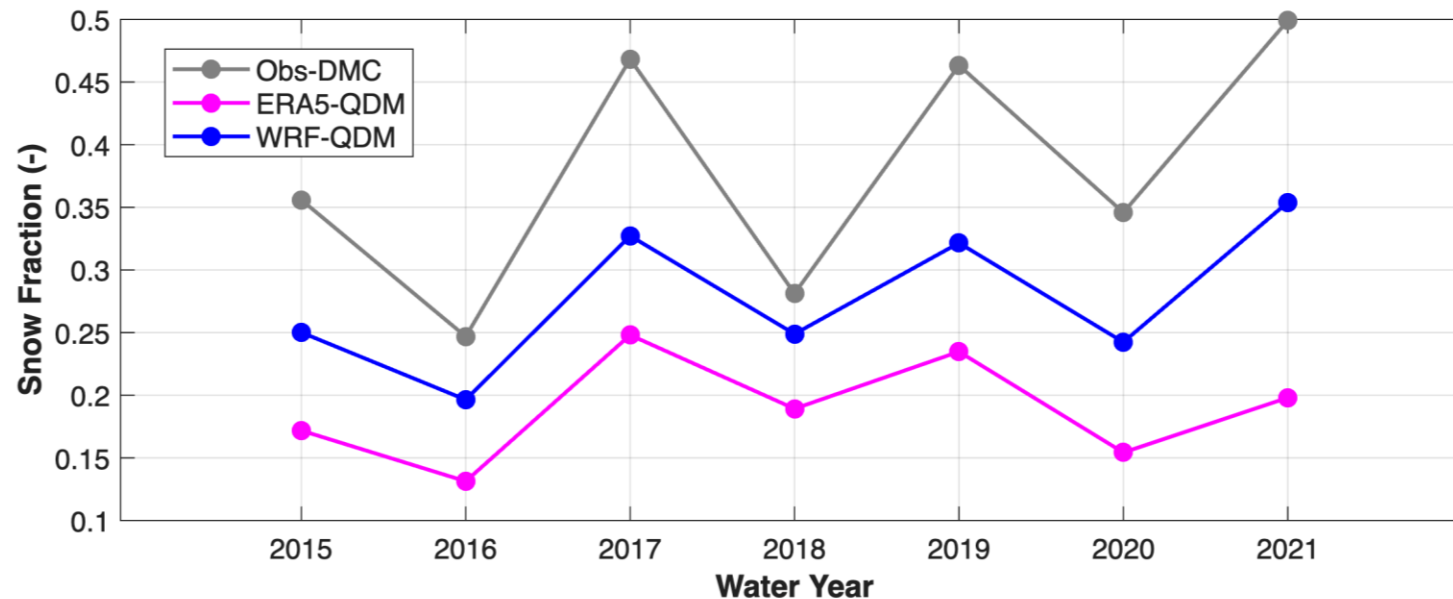
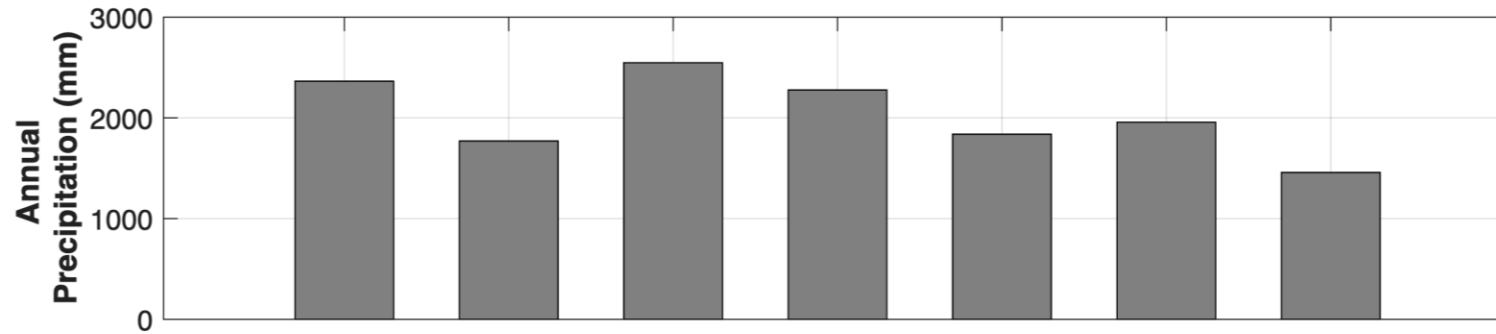
- Lower overall H
- Virtually the same latent heat – snowpack sublimation
- Slightly higher Net Longwave

Impact on rain vs snow partitioning (example)





Impact on rain vs snow partitioning



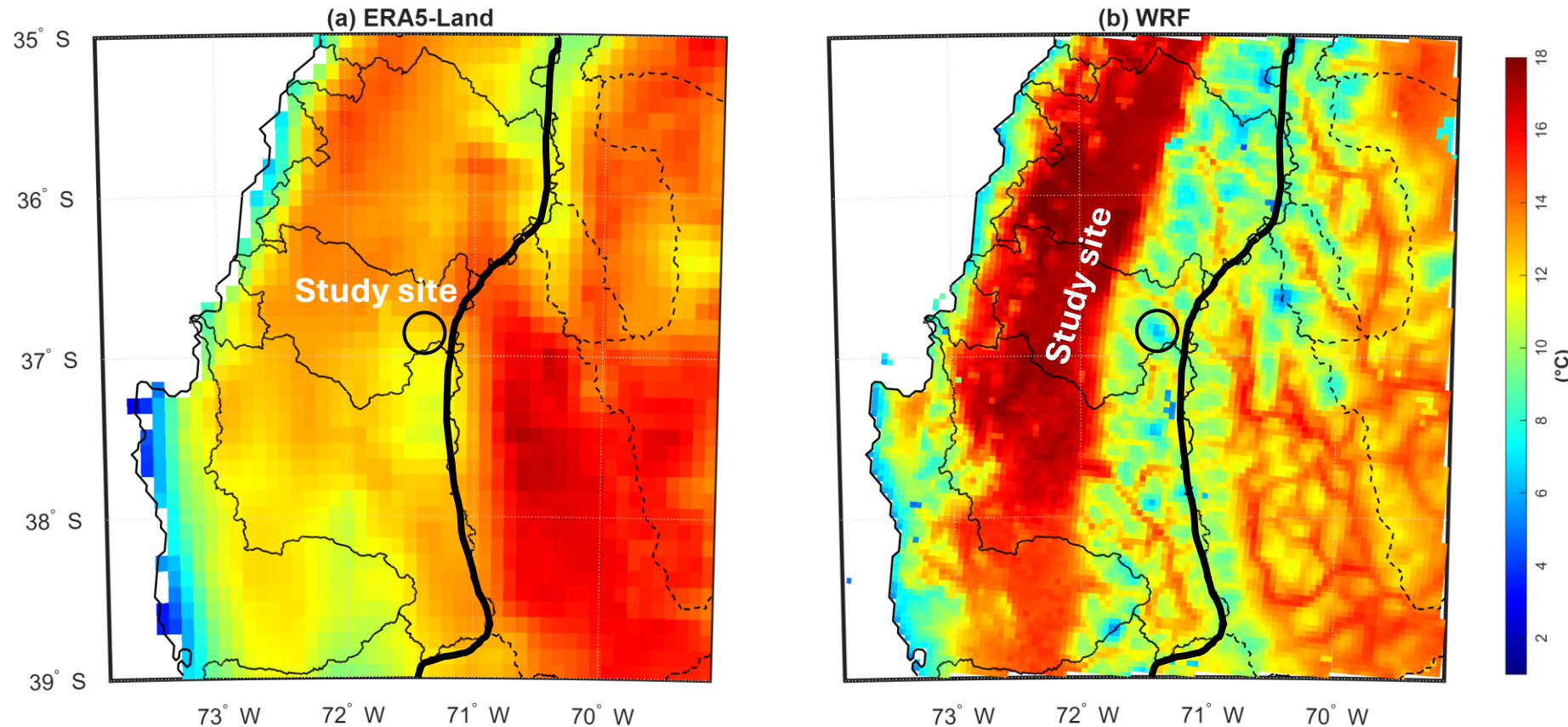
	Rain (mm)	Snow (mm)	Snow fraction (.)
Sim. with OBS	1263	768	0.38
Sim. with ERA5-QDM	1641	389	0.19
Sim. with WRF	1470	560	0.28

Significant **underestimation of Snow Fraction** → Higher with ERA5-QDM but also significant with WRF-QDM

Is this an isolated case or **is there a systematic bias:** Regional ERA5-Land vs WRF-SAAG



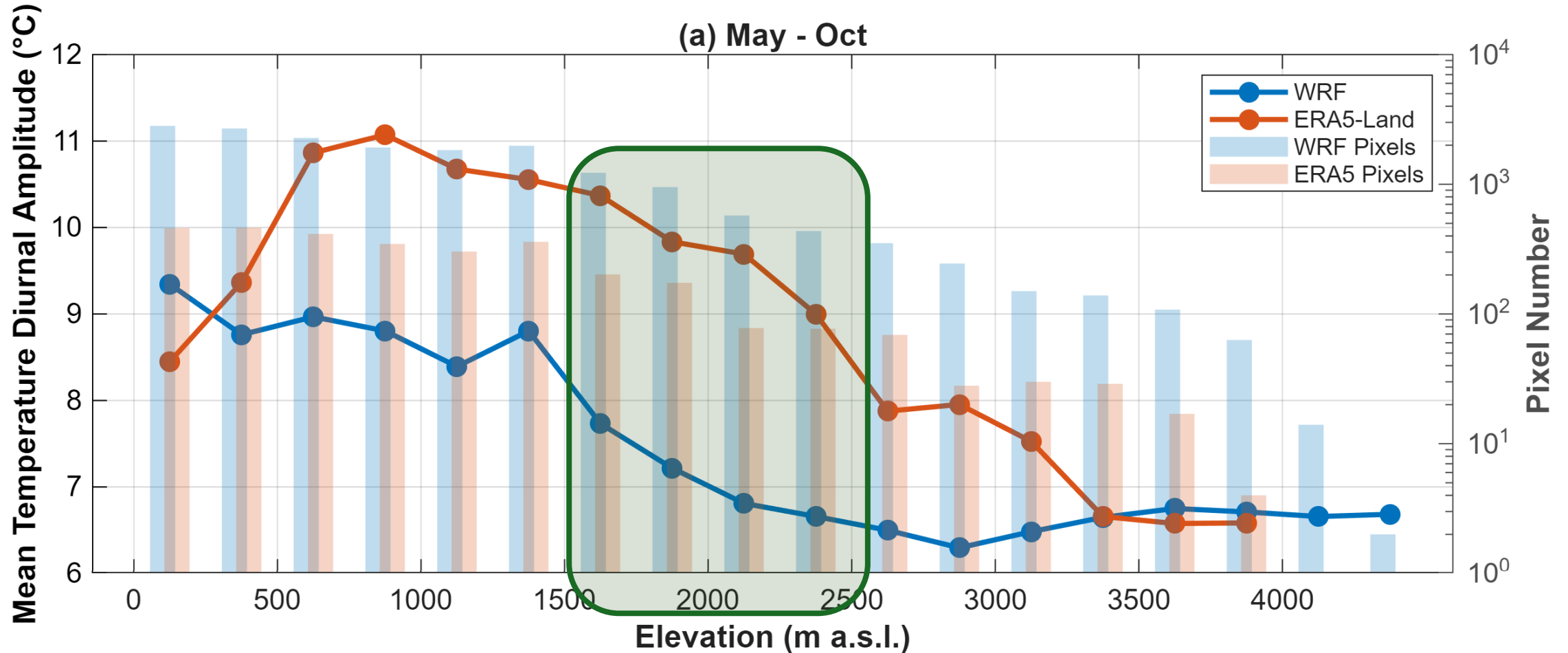
Mean Temperature Diurnal Amplitude (Nov-Apr)



Pacific Ocean ← Continental water divide → Atlantic Ocean

- Systematic differences
- Chile Central valley AT amplitude:
WRF > ERA5 land
- Mountain AT amplitude:
WRF < ERA5-Land

Difference in AT Diurnal cycle across elevations: ERA5-Land vs WRF-SAAG





Final Remarks

- Can we use ERA5-Land AT? Daily simulations probably OK, but a **careful assessment is advised for hourly energy balance models**
- Using **high resolution, convection permitting atmospheric models** (e.g., WRF-SAAG) provide more reliable forcing data in mountain environments – better representation of the AT diurnal cycle (and windspeed; not shown)
- **Precipitation partitioning is the main issue** → Will this still be the case at higher elevations with higher snow fractions? – need to assess
- Issues in the energy balance with ERA5-QDM AT: **less sensible and latent Heat and more Net Longwave**. Using WRF-SAAG AT improved simulations.
- Can we incorporate the **diurnal cycle as another restriction to the standard bias correction methods** to remediate this issue?
- Need to **incorporate more observations to assess this issue in other mountain sites** in the Andes and other INARCH sites (?)



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Thanks!

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The major June 2023 flood event in Central Chile: Hydrometeorological characterization and rain-on-snow contribution

Sebastian A. Krogh, Rene Garreaud, Lucia Scaff, Deniz Bozkurt, and Raul Valenzuela

Online Publication: **18 Aug 2026**

DOI: <https://doi.org/10.1175/JHM-D-25-0149.1>

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Abstract/Excerpt

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Abstract

In June 2023, an extreme hydrometeorological event caused widespread flooding across Central Chile (34–39°S), abruptly interrupting a 13-year dry period. This study provides a comprehensive analysis of the event, characterizing its atmospheric drivers, hydrological impacts, and the role of rain-on-snow (ROS) in a representative catchment. A Category 4 Zonal Atmospheric River persisted for 4 days in a warm environment, resulting in a steep orographic precipitation gradient over the foothills of the Andes with rainfall accumulations of up to 600 mm, and the freezing level above 3,000 m ASL. Many rivers reached their highest flows on record, with peak discharges associated with return periods ranging from 9 to 199 years, resulting in significant damage to critical infrastructure and the general population. We also present a quantitative diagnosis of a ROS event in the Andes Cordillera using a physically-based and semi-distributed hydrological model in a representative catchment. Simulations reveal that snowmelt plus rainfall from snow-covered areas contributed ~15% to the total flood volume, of which snowmelt was the secondary source driven by net longwave radiation and heat from the warm rainfall. This event serves as an example of a compound hydrometeorological extreme event, where intense and prolonged precipitation, combined with high temperatures, converged to produce a major flood in Central Chile. Our findings highlight the region's vulnerability to extreme events and underscore the need for future studies to assess the potential of an integrated hydrological forecasting system to mitigate the impacts of extreme events.

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