



Departamento de
Recursos Hídricos
Universidad de Concepción



“Exploring the capacity of high-resolution, snow-drift permitting modeling across the Andes Cordillera”

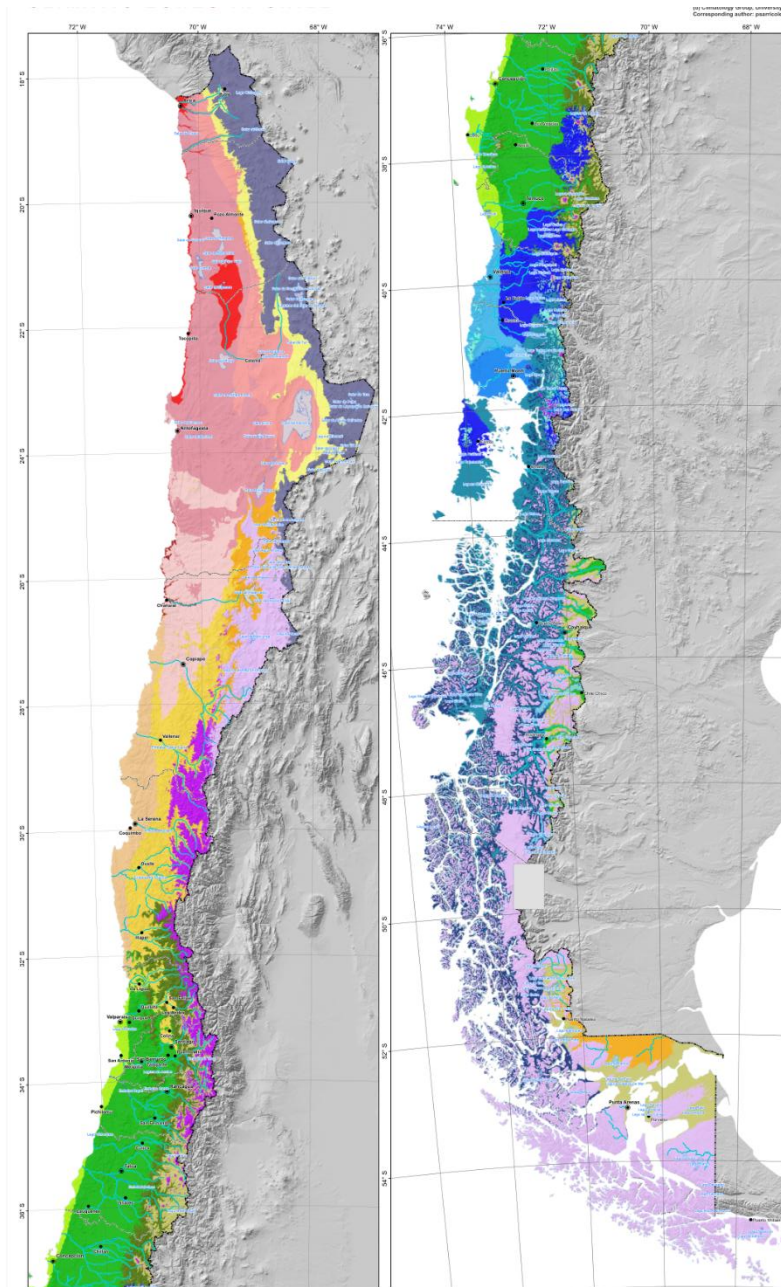
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Introduction

- The Chilean Andes Cordillera act as water tower maintaining industry, human consumption and ecosystems.
- The snowpack in the Andes accumulate water resources in winter and release it during the spring-summer season.
- The strong latitudinal climate gradient in Chile produces significant snowpack spatial heterogeneity, which is yet to be fully understood and quantified.
- Arid conditions dominate to the north and wetter and more temperate dominate to the south



Climatic zones

(based on modified Köppen-Geiger system)

Arid

- BWh Hot Desert climate
- BWh(s) Hot Desert climate with dry summer
- BWk Cold Desert climate
- BWk(s) Cold Desert climate with dry summer
- BWk(w) Cold Desert climate with dry winter
- BSk(s) Cold Semi-arid climate with dry summer and oceanic influence
- BSk(s) Cold Semi-arid climate with dry summer
- BSk Cold Semi-arid climate
- BSk(w) Cold Semi-arid climate with dry winter

Temperate

- Csb' Mediterranean climate (warm summer) with oceanic influence
- Csb Mediterranean climate (warm summer)
- Csb(h) Mediterranean climate (warm summer) with mountain influence
- Csc Mediterranean climate (mild summer)
- Cfb'(s) Marine West Coast climate (warm and dry summer) with oceanic influence
- Cfb(s) Marine West Coast climate (warm and dry summer)
- Cfb' Marine West Coast climate (warm summer) with oceanic influence
- Cfb Marine West Coast climate (warm summer)
- Cfc(s) Marine West Coast climate (mild and dry summer)
- Cfc Marine West Coast climate (mild summer)

Polar

- ET(s) Tundra climate with dry summer
- ET Tundra climate
- ET(w) Tundra climate with dry winter
- EF(s) Ice Cap climate with dry summer
- EF Ice Cap climate
- EF(w) Ice Cap climate with dry winter

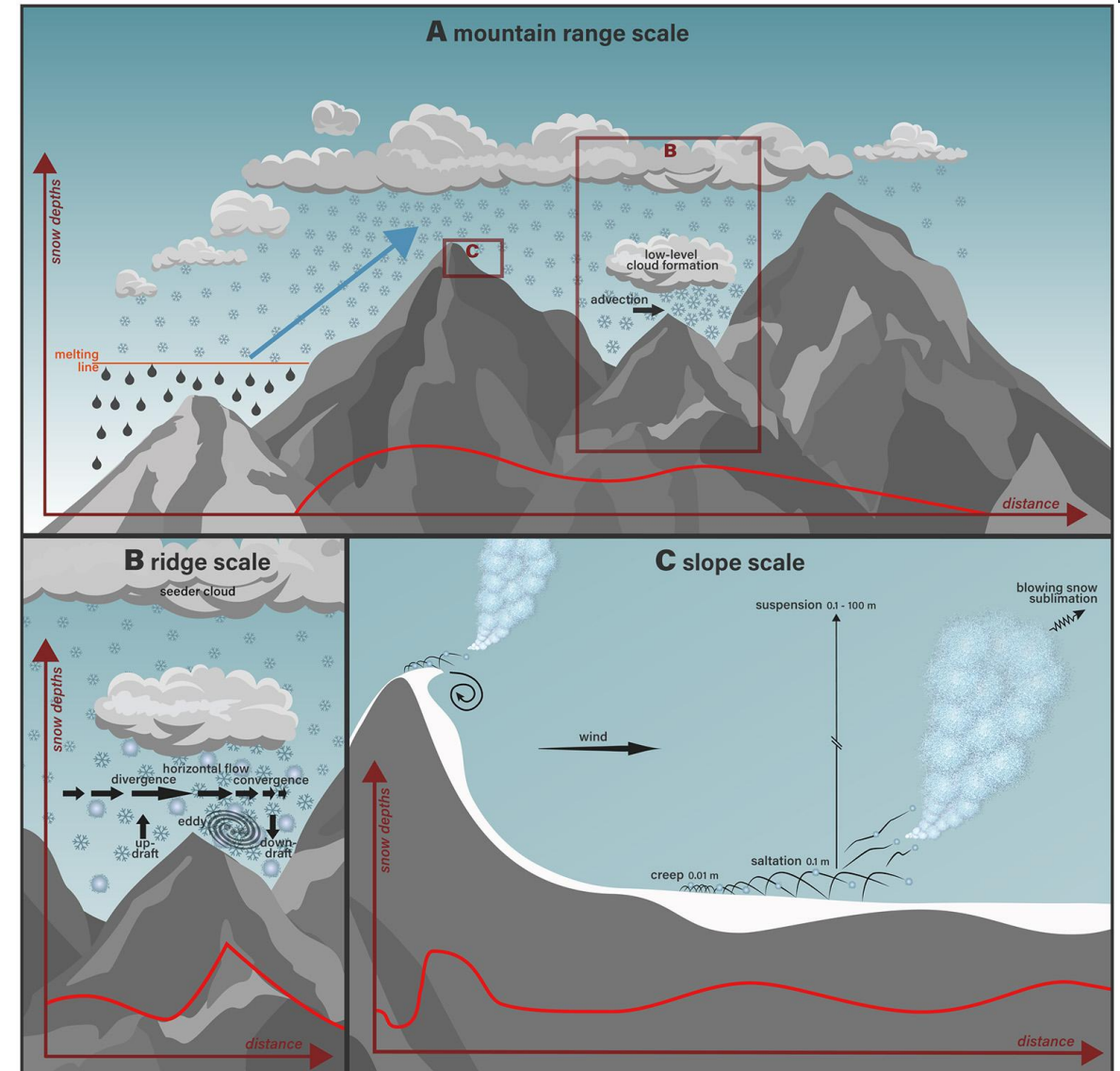


Sarricolea et al. (2017).



Introduction

- The snow accumulation and ablation dynamics is influenced by physical processes that happens in different scales.
- From a large to the finest scales, we have **orographic precipitation, preferential deposition and snow redistribution.**

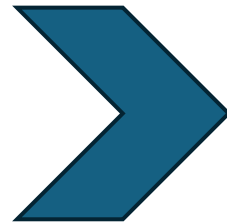
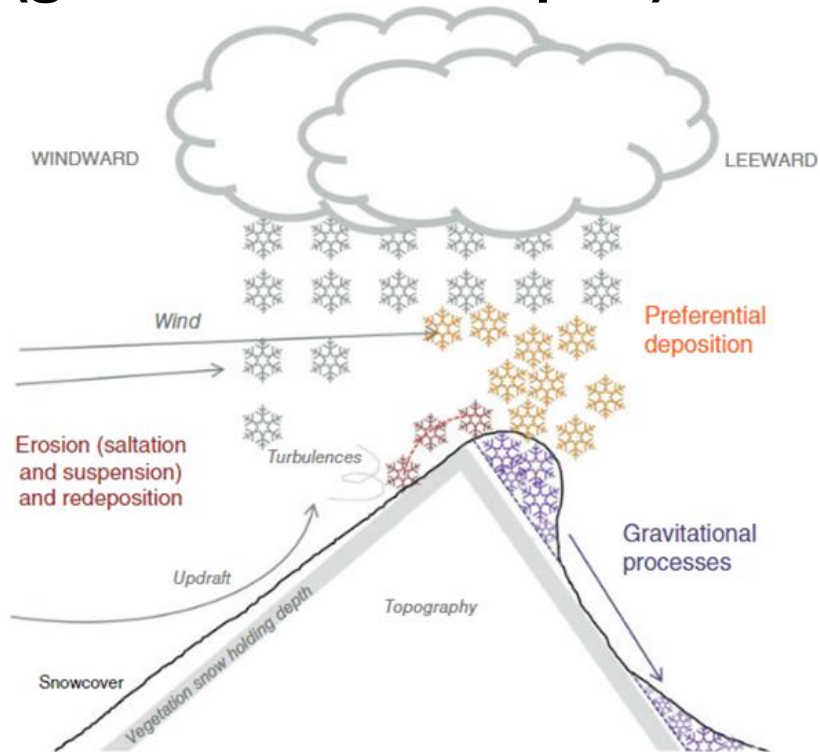


Mott et al. (2017).

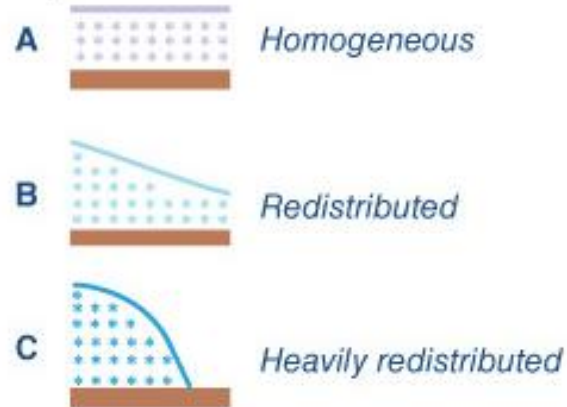


Introduction

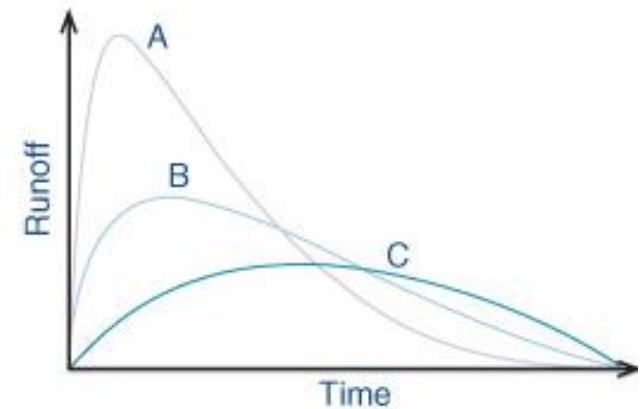
- The mainly slope scale process are **blowing snow redistribution and avalanches** (gravitational transport)



Spatial distribution of snow cover



Snow melt runoff



Freudiger et al. (2017).

- The snow redistribution can generate drifts changing the runoff generation.
- This processes can be represented in snow models, but the are sensitive to spatial grid resolution.
- Choose the spatial resolution is a tradeoff between snow heterogeneity and computer resources.



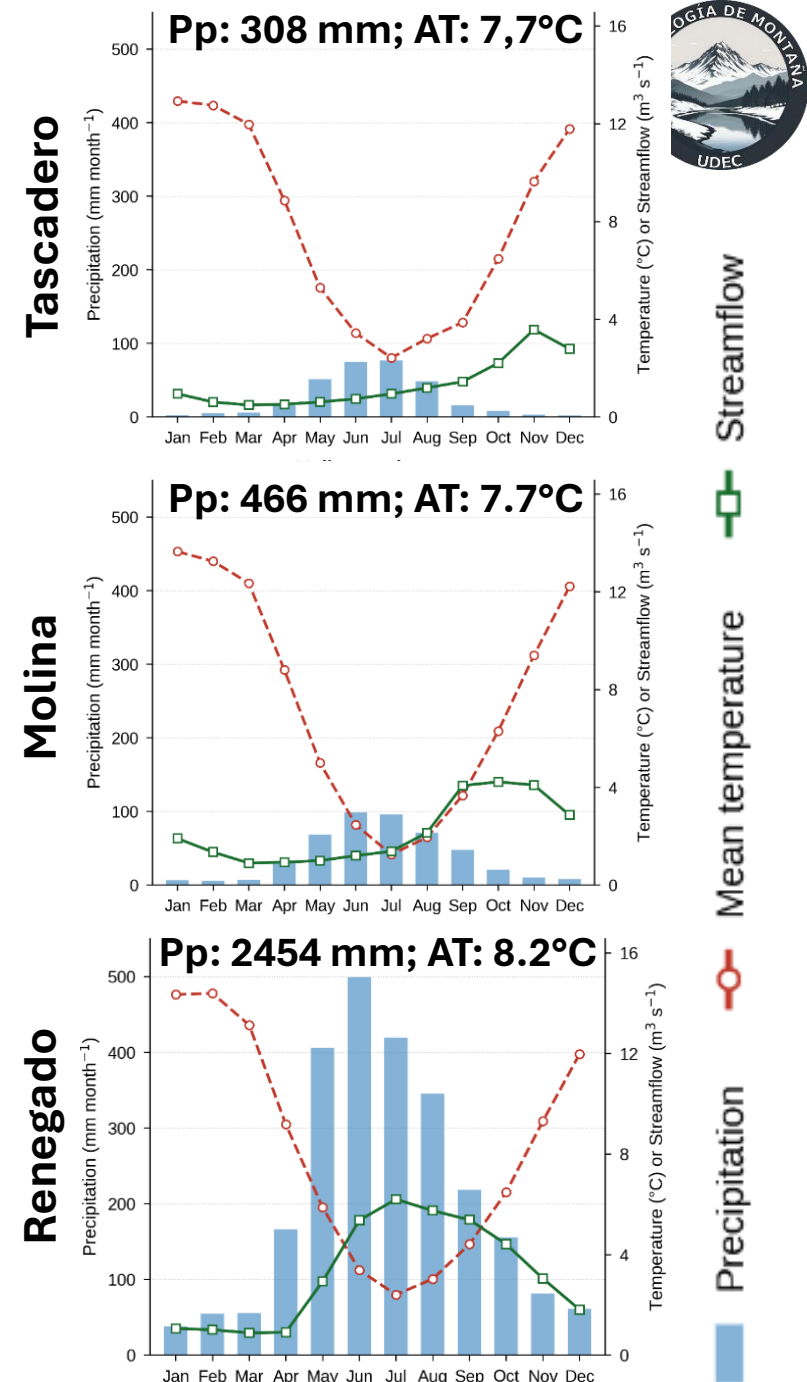
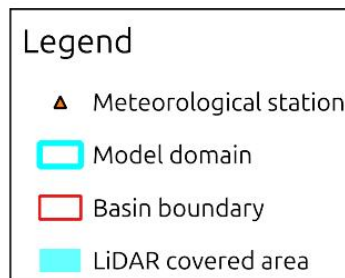
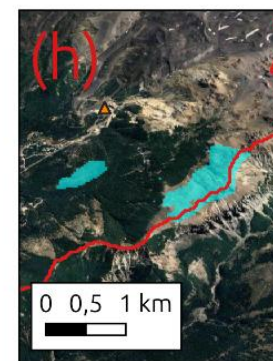
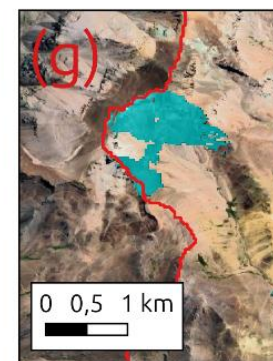
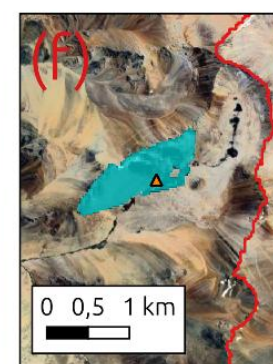
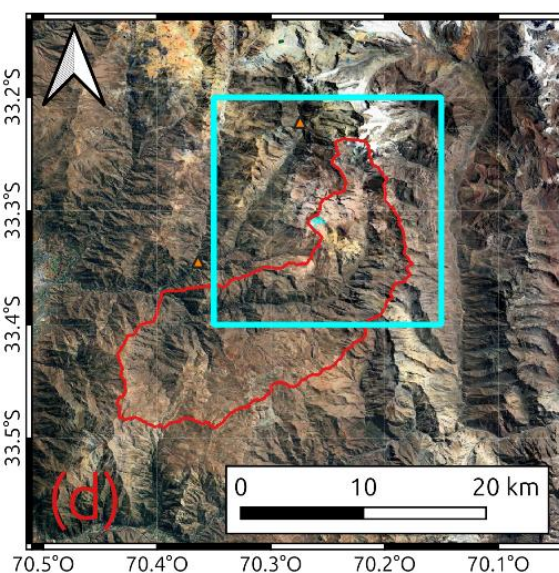
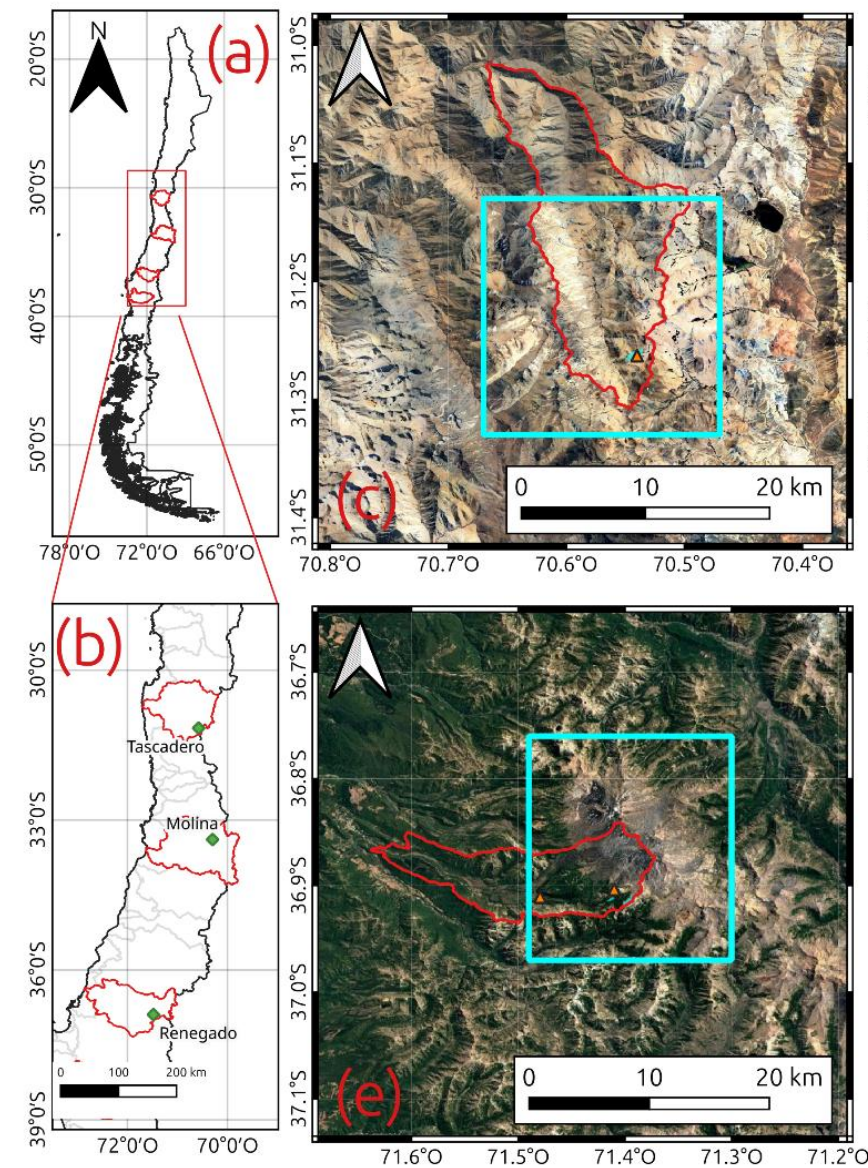
Research Questions



- **(i) How does grid resolution influence the spatiotemporal distribution of the snowpack?**
- **(ii) Can redistribution processes be neglected in the Andes and represent the observed spatial distribution?**
- **(iii) Is the spatial resolution or the inclusion of snow redistribution more critical for capturing the heterogeneity of snowpack?**



Study Site



Source: CAMELS-CL

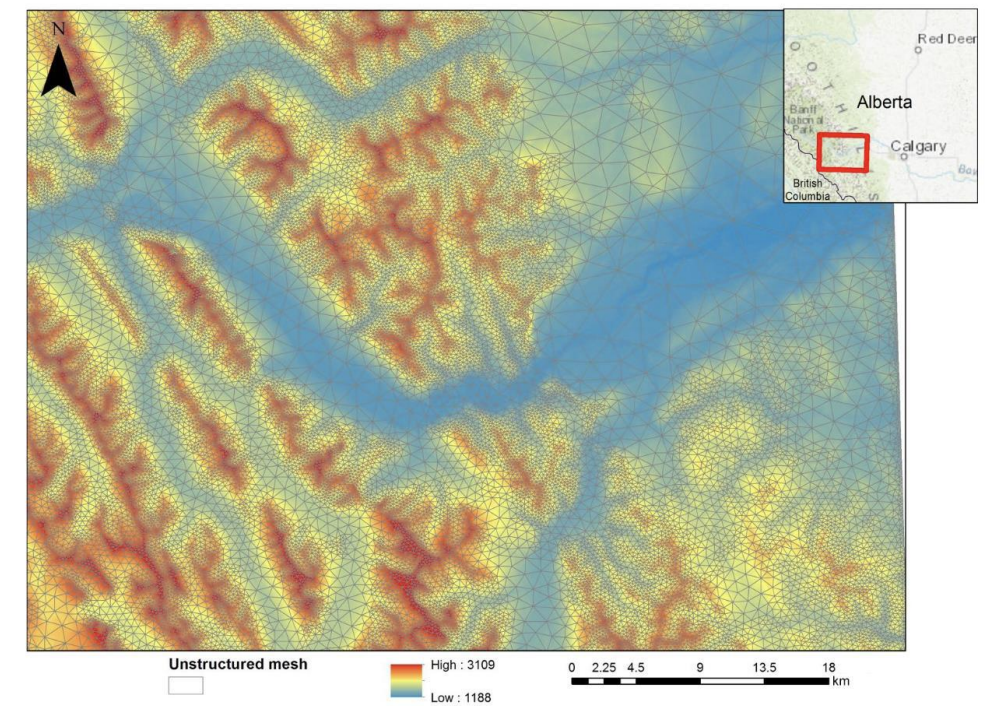


Canadian Hydrological Model (CHM)

- Physically based and fully spatially distributed.
- CHM uses an unstructured triangular mesh (TIN).
- It's modular and has multiple process representation.
- Can be used with Windmapper to downscaling wind fields (speed and direction) .



Physical processes	Modules
Snowpack balance energy	Snobal (Mark et al., 1999), SNOWPACK (Bartelt & Lehning, 2002) and FSM (Essery, 2015; Mazzotti et al., 2020).
Forest interception	Ellis et al. (2010) y Pomeroy et al. (1998).
Snow redistribution	Blowing snow (PBSM 3D; Marsh, Pomeroy, Spiteri, et al., 2020) y avalanches (SnowSlide; Bernhardt & Schulz, 2010) .



Marsh et al. (2020).



CHM configuration



- Windmapper was set up with 12 wind direction and a 50 m resolution.
- The selected modules to represent each process are:

Physical processes	Modules
Precipitation phase	Harder_precip_phase (Harder and Pomeroy, 2015).
Snowpack balance energy	FSM (Essery, 2015).
Forest interception	Ellis et al. (2010) and Pomeroy et al. (1998).
Blowing snow events	PBSM 3D (Marsh, Pomeroy, Spiteri, et al., 2020)
Avalanches	SnowSlide (Bernhardt & Schulz, 2010) .

- Forest interception was included only in Renegado Catchment.
- To generate the meshes FABDEM 30-m resolution and Glad Canopy Height Model 30-m were used.
- The maximum and minimum mesh resolution used is 30 and 1500 m and three mesh error configuration were generated: RMSE15, RMSE30 and RMSE 60.
- The redistribution process were activated and deactivated producing 6 model scenario per each study site.



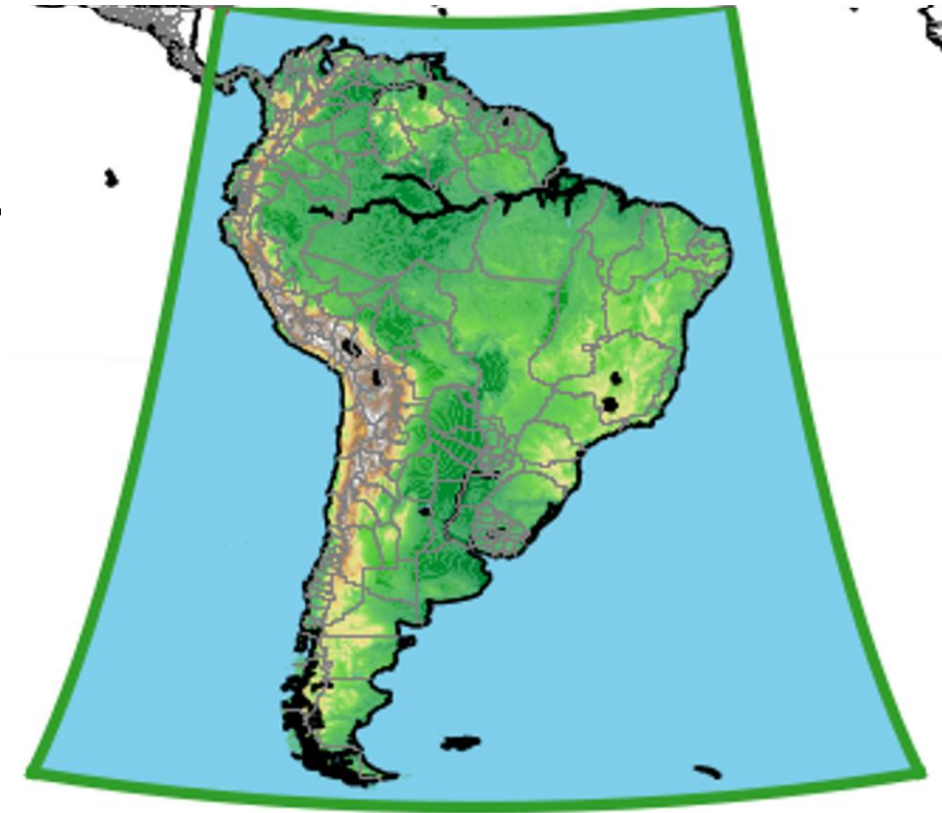
Meteorological forcing data



- CHM was forced with the Weather Research and Forecasting Model at 4km spatial resolution generated by the South America Affinity Group (SAAG).
- WRF-SAAG is an hourly meteorological product available between 2000-2021.
- Three water years (Apr- Mar) were simulated for 2000-2021:

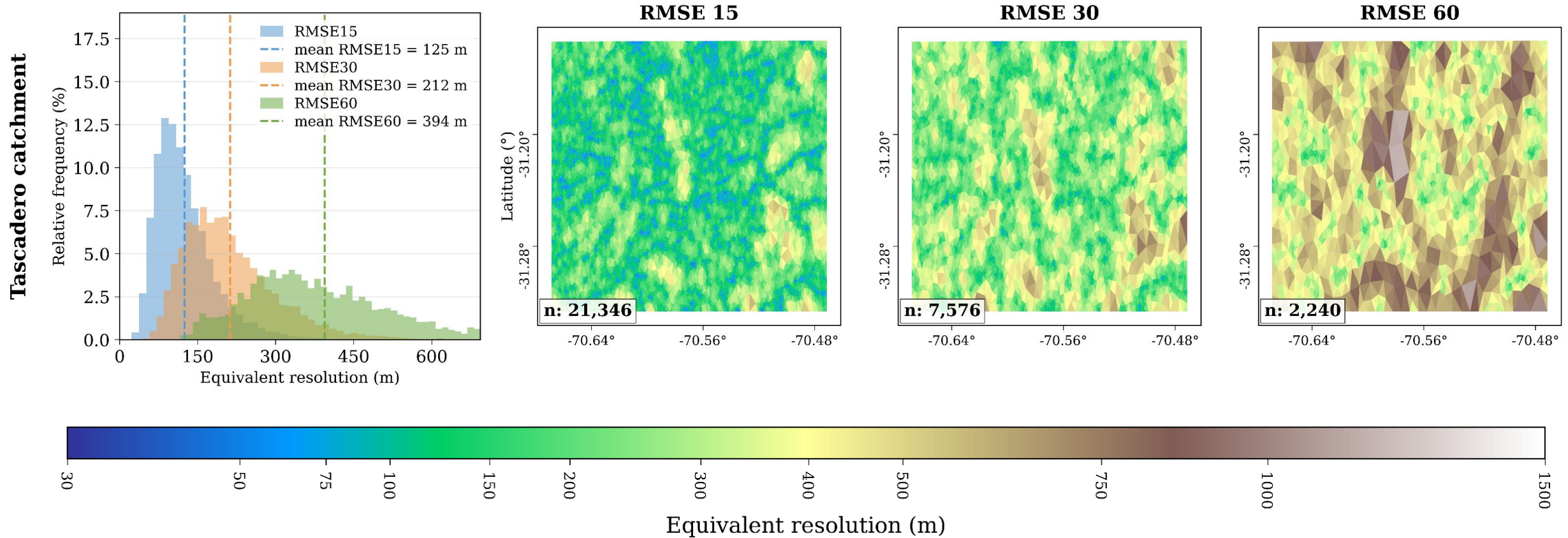
Study Site	Driest	Wettest	With LiDAR
Tascadero	2019/2020	2002/2003	2018/2019
Molina	2019/2020	2005/2006	2018/2019
Renegado	2016/2017	2002/2003	2018/2019

- Daily precipitation and temperature, hourly wind speed were bias corrected using AWS and Quantile Delta Mapping (Connan et al. 2015).



<https://met4k.cr2.cl/>

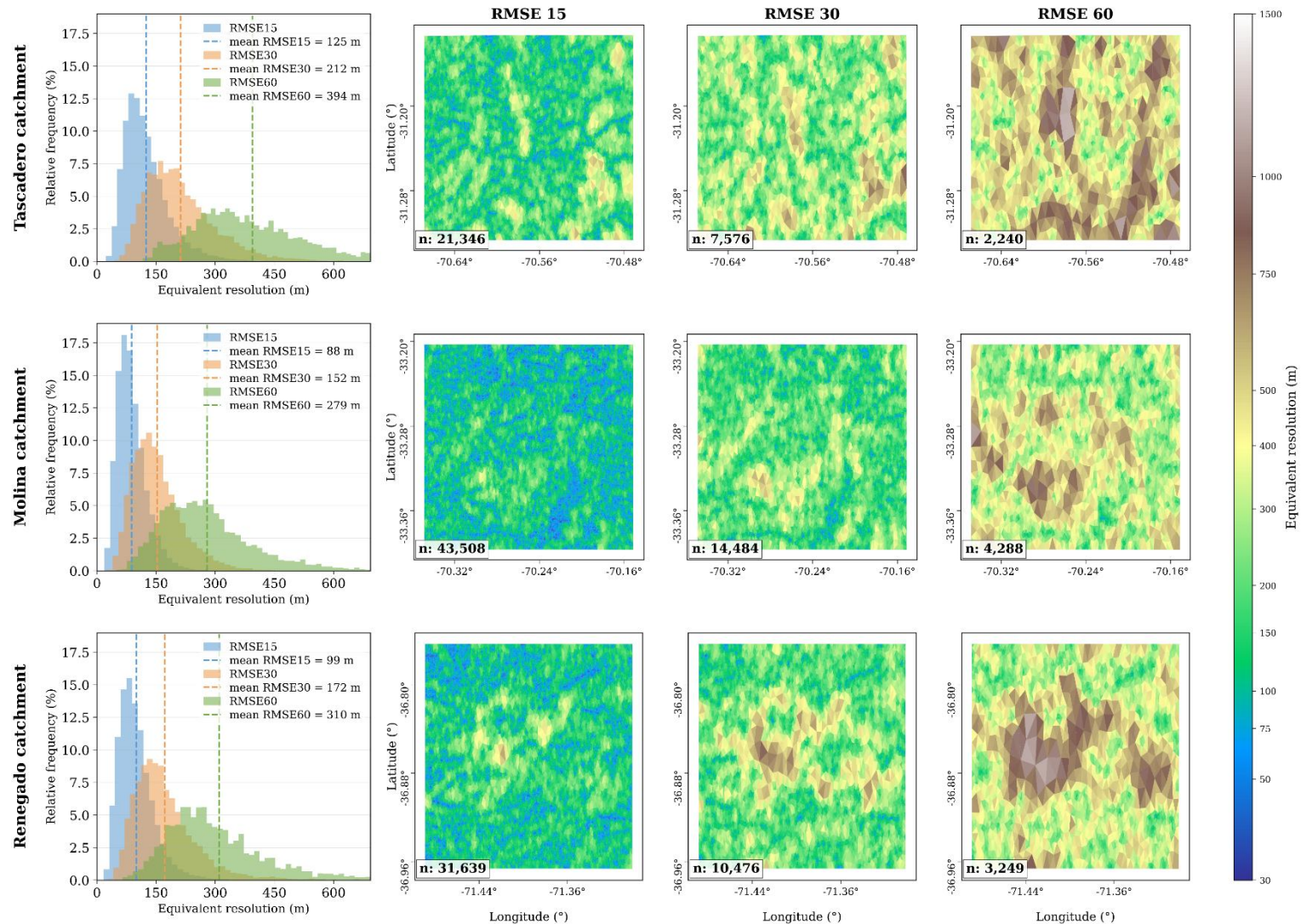
Mesh scenarios: RMSE 15, 30 vs 60



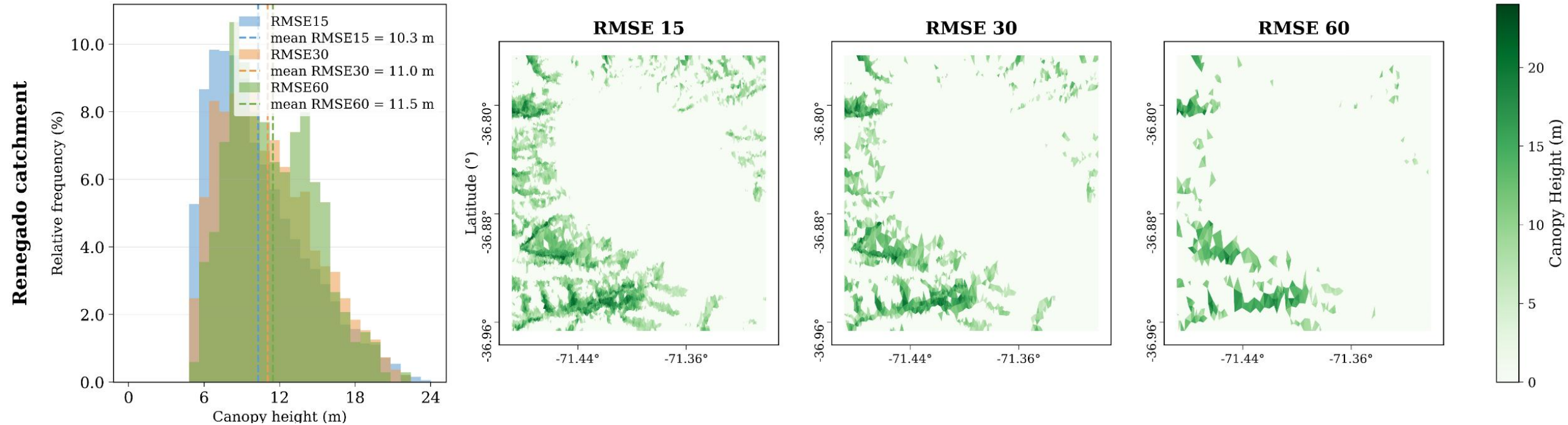
- The equivalent resolution is root square of the triangle area, and it can be interpreted like the resolution of each triangle. If the TIN were a regular grid
- Less tolerance constrain the mesh triangles producing higher resolution, but it increases the number of elements up to **one magnitude order**.



Mesh scenarios



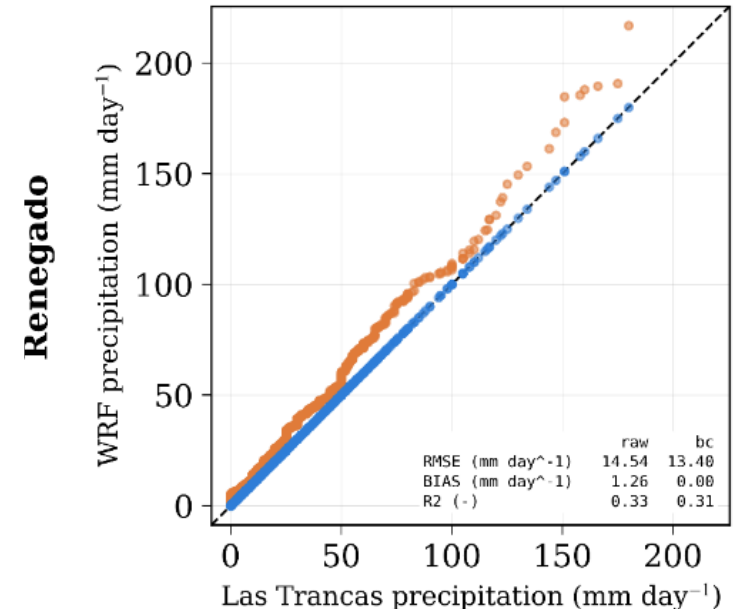
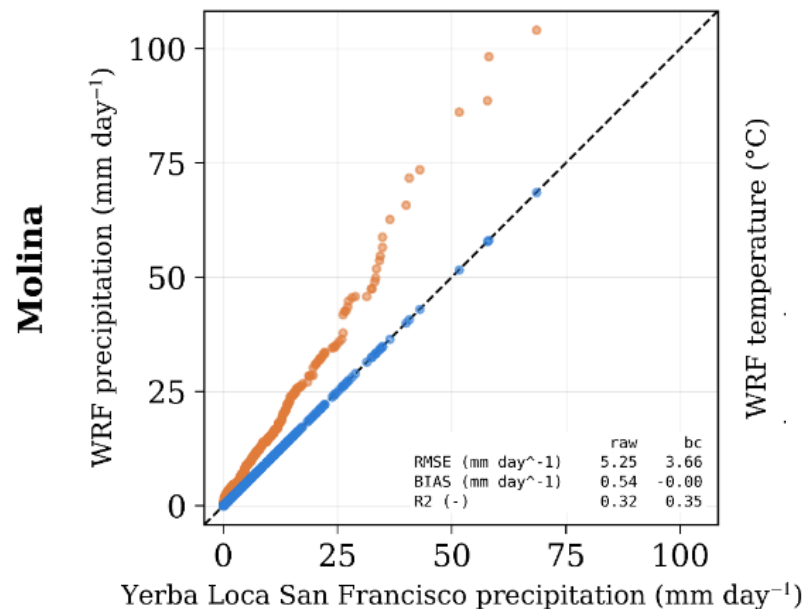
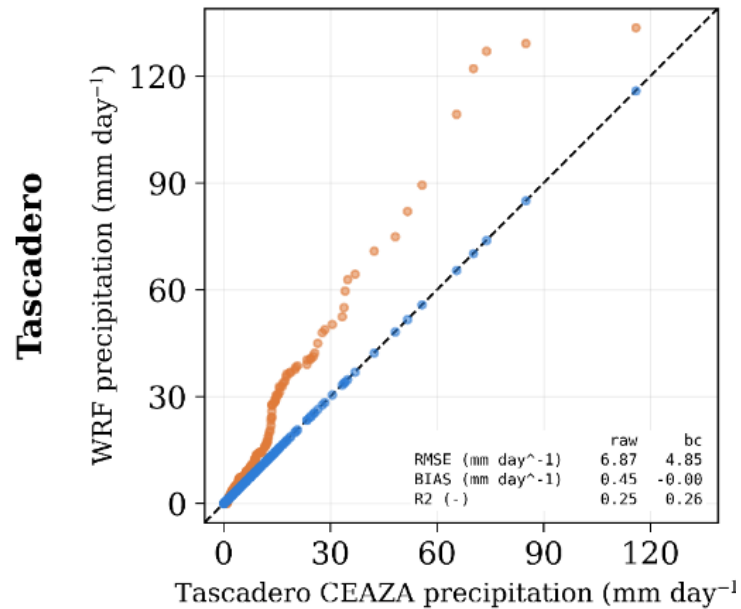
Property	Study Site	RMSE15	RMSE30	RMSE60
Number of elements	Tascadero	21,364	7,576	2,240
	Molina	43,508	14,484	4,228
	Renegado	31,639	10,476	3,294
Mean resolution (m)	Tascadero	125	212	394
	Molina	88	152	279
	Renegado	99	172	310



- The representation detail of the forested areas also depends on the mesh resolution, in coarse resolutions it could lose triangles with forest
- Also greater tolerance increase de mean Canopy Height.



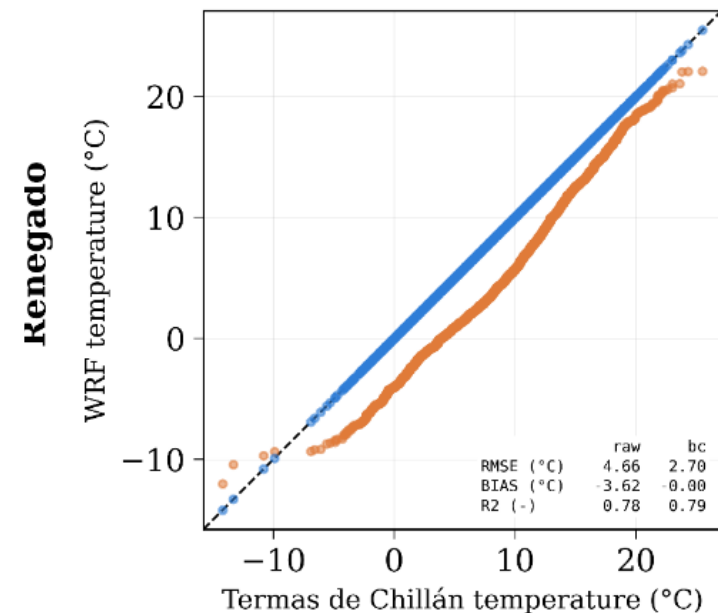
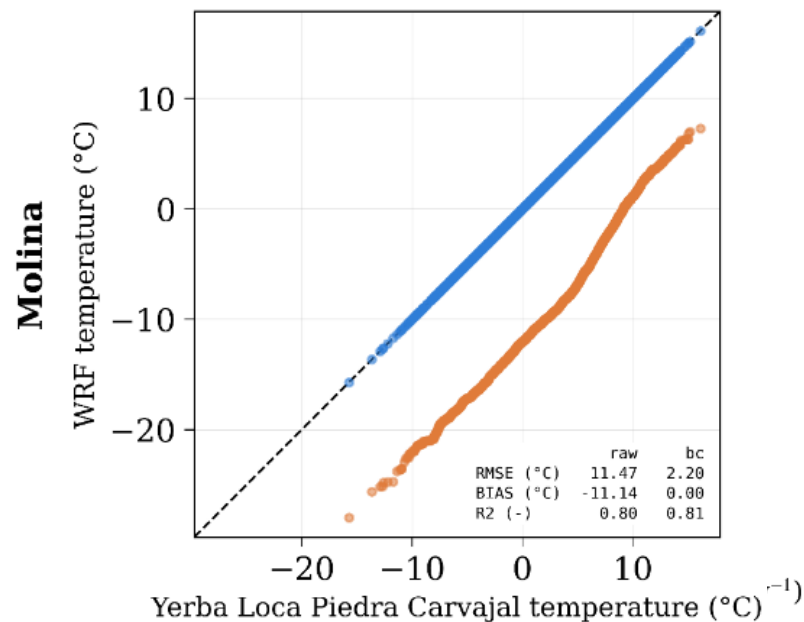
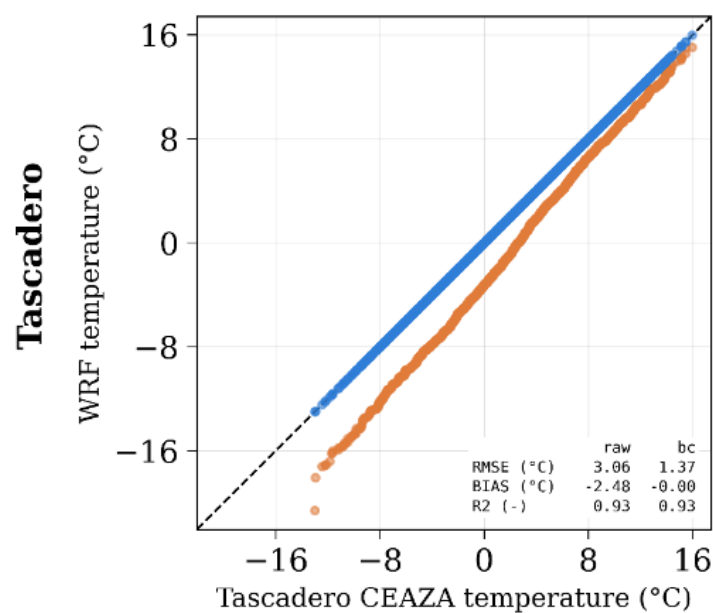
WRF bias correction: precipitation



PP (mm/d)	Study Site	RMSE	BIAS	R ²
Raw	Tascadero	6.87	0.45	0.25
	Molina	5.25	0.54	0.32
	Renegado	14.54	1.26	0.33
Bias corrected	Tascadero	4.85	0.0	0.26
	Molina	3.66	0.0	0.35
	Renegado	13.4	0.0	0.31



WRF bias correction: air temperature

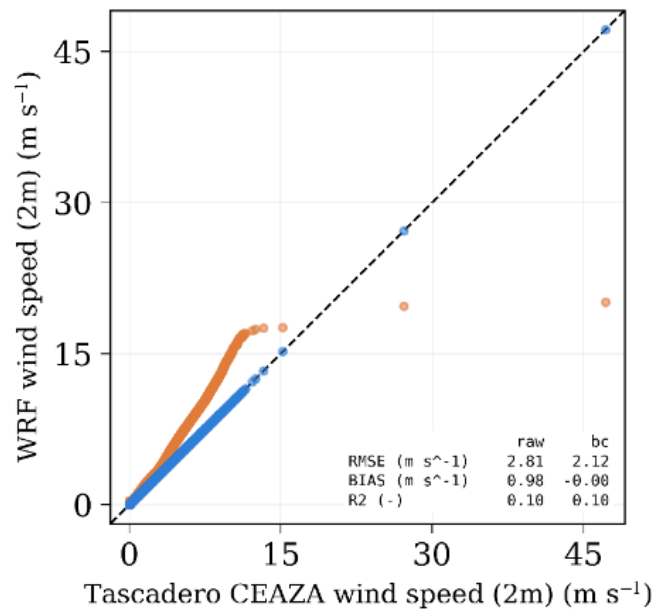


T (°C)	Study Site	RMSE	BIAS	R ²
Raw	Tascadero	3.06	-2.48	0.93
	Molina	11.47	-11.14	0.8
	Renegado	4.66	-3.62	0.78
Bias corrected	Tascadero	1.37	0.0	0.93
	Molina	2.2	0.0	0.81
	Renegado	2.70	0.0	0.79

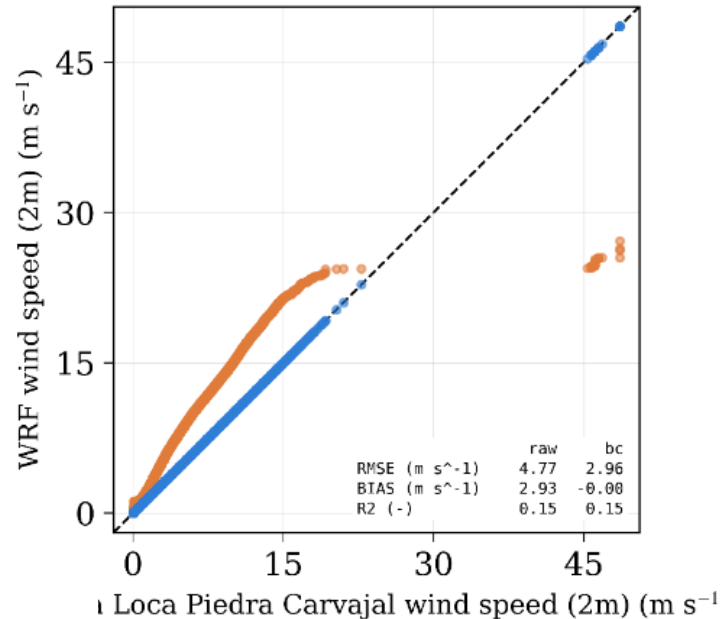


WRF bias correction: wind speed

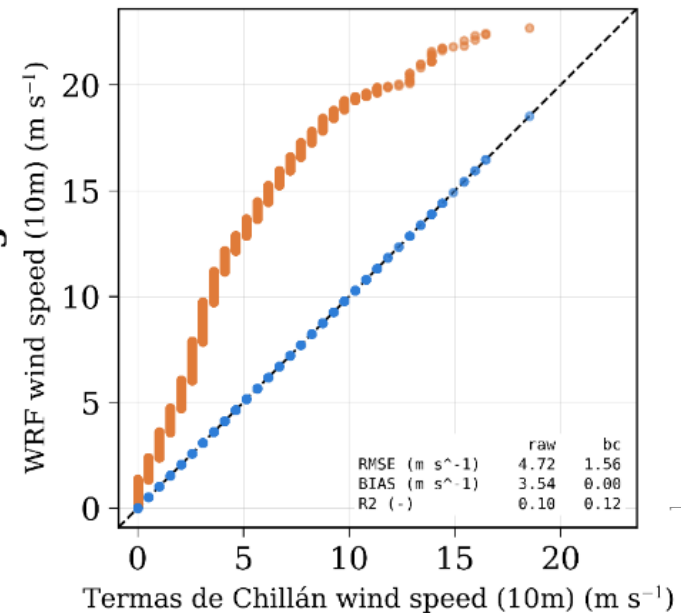
Tascadero



Molina



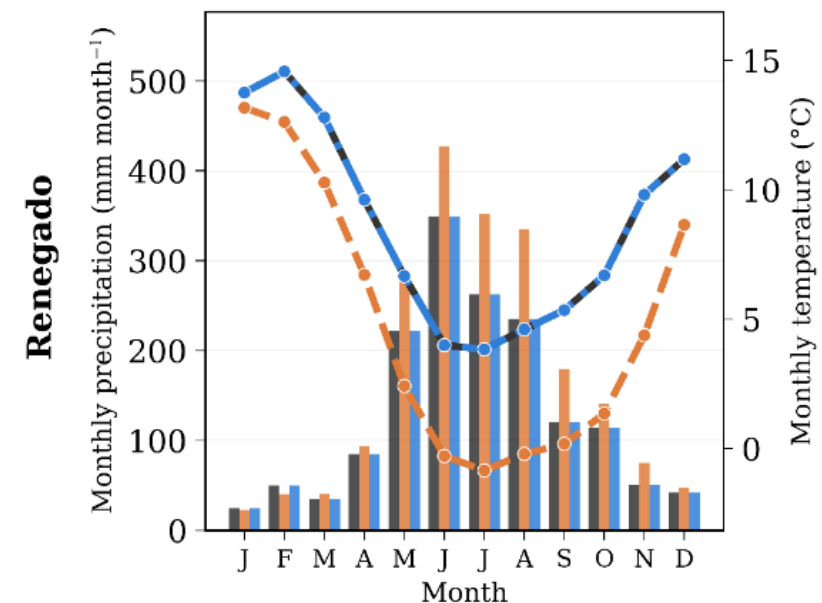
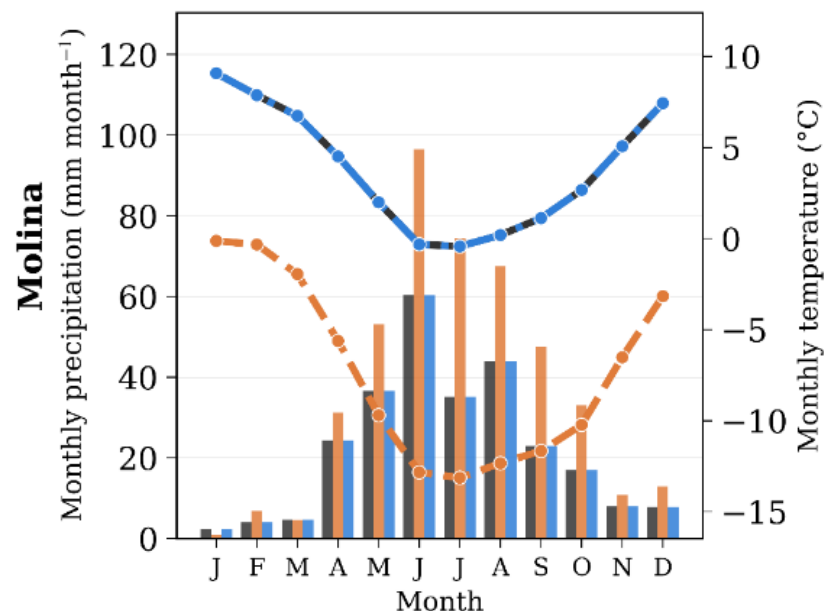
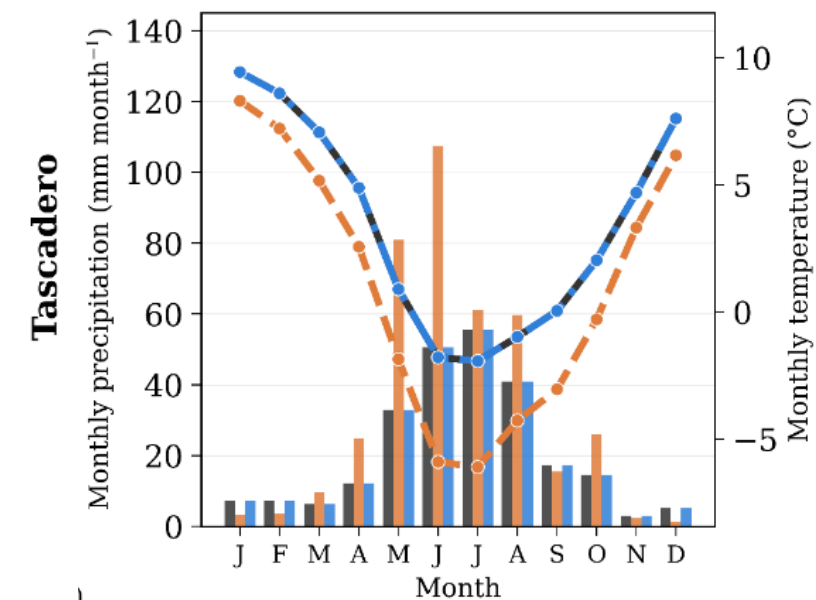
Renegado



WS (m/s)	Study Site	RMSE	BIAS	R ²
Raw	Tascadero	2.81	0.98	0.10
	Molina	4.77	2.94	0.15
	Renegado	4.72	3.54	0.10
Bias corrected	Tascadero	2.12	0.0	0.10
	Molina	2.96	0.0	0.15
	Renegado	1.56	0.0	0.12

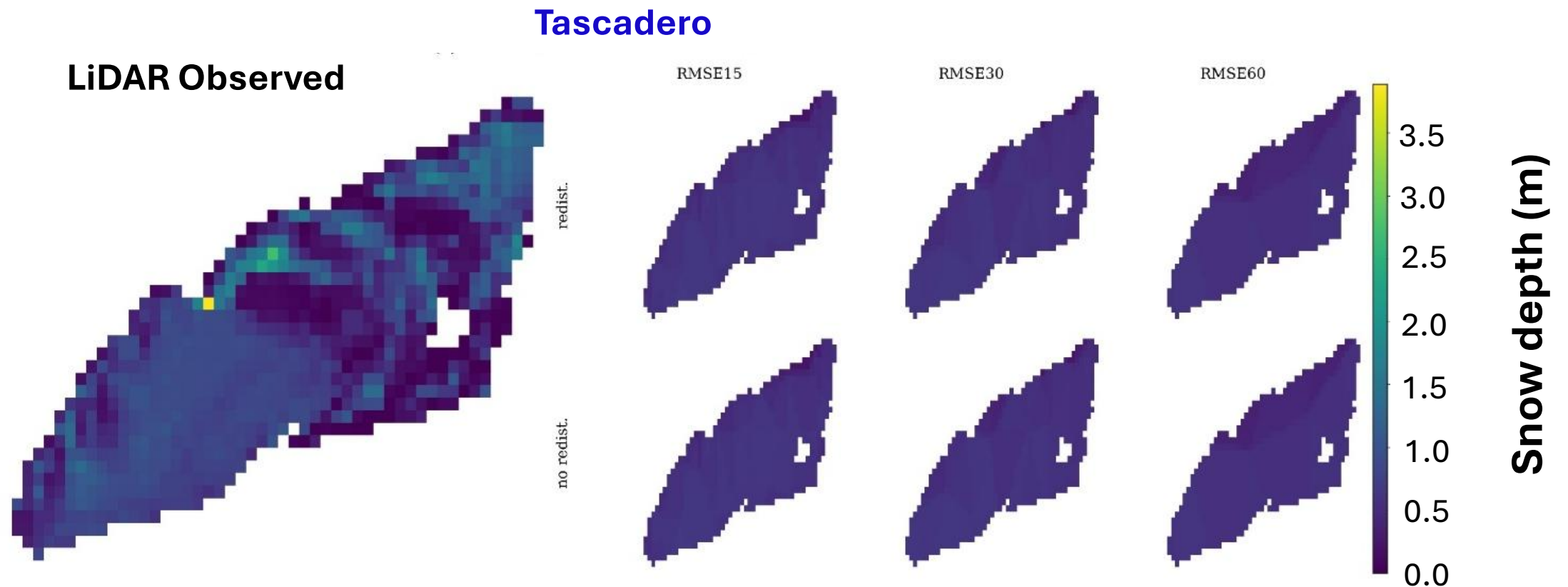


WRF bias correction



- **WRF SAAG-4km overestimate precipitation and wind speed but has cold bias for temperature.**
- **The values of the mean bias and RMSE are lower after QDM, but the R^2 is almost equal.**
- **Seasonality the greater bias for temperature and precipitation are on May, June and July.**

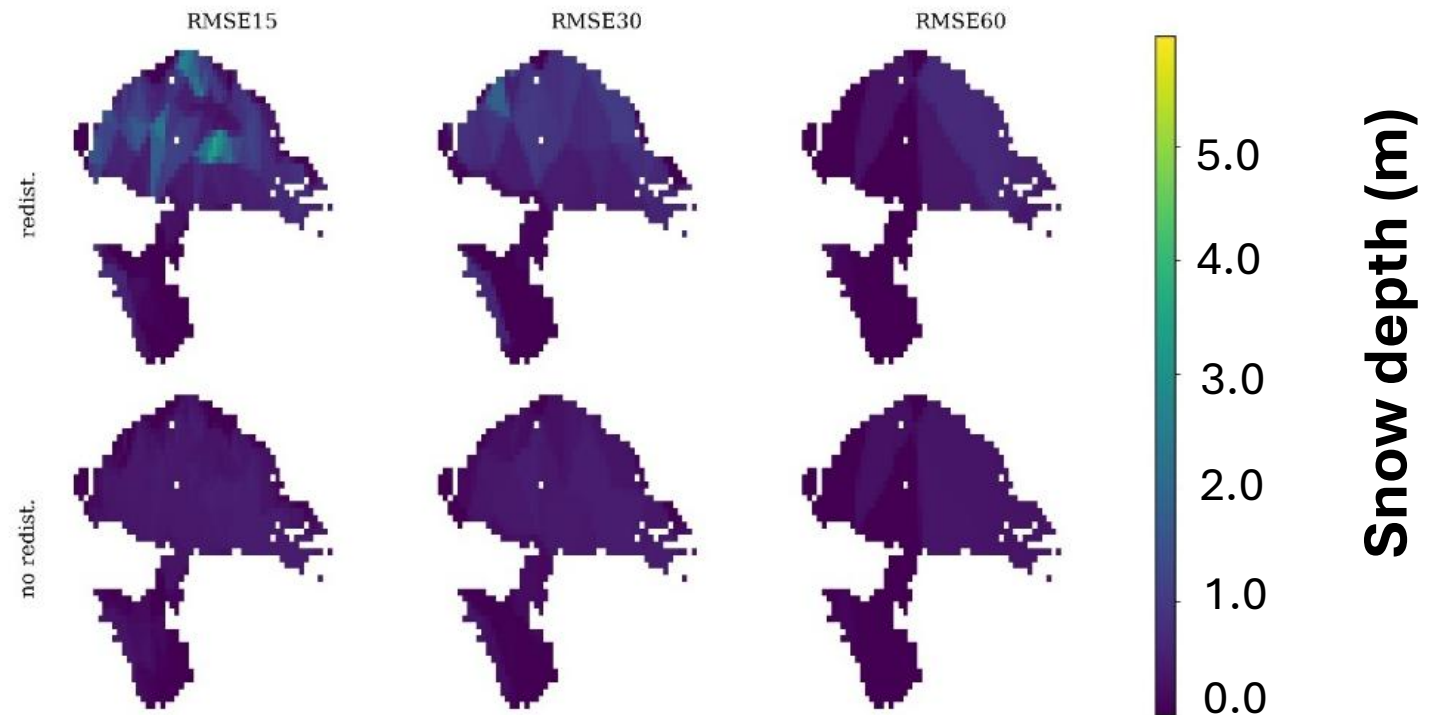
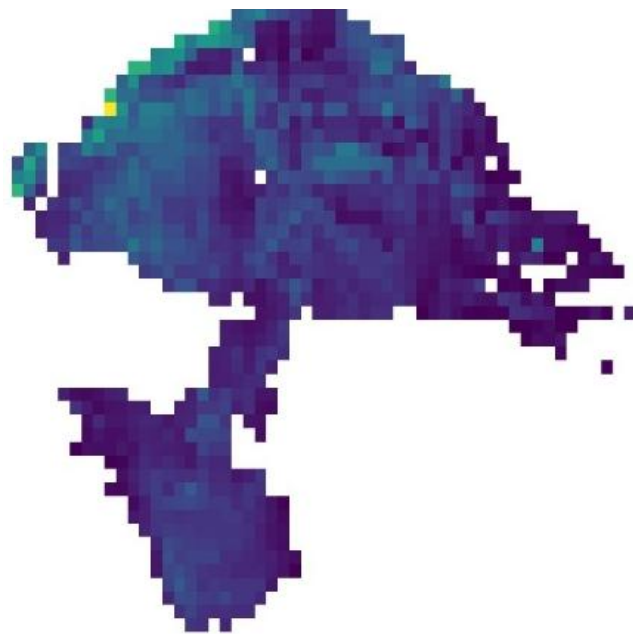
- In Tascadero and Molina the snow depth is underestimated but in Renegado is overestimated.
- Qualitatively the configuration RMSE15 with redistribution has similar behavior in Molina and Renegado however in Tascadero there is no difference between scenarios.



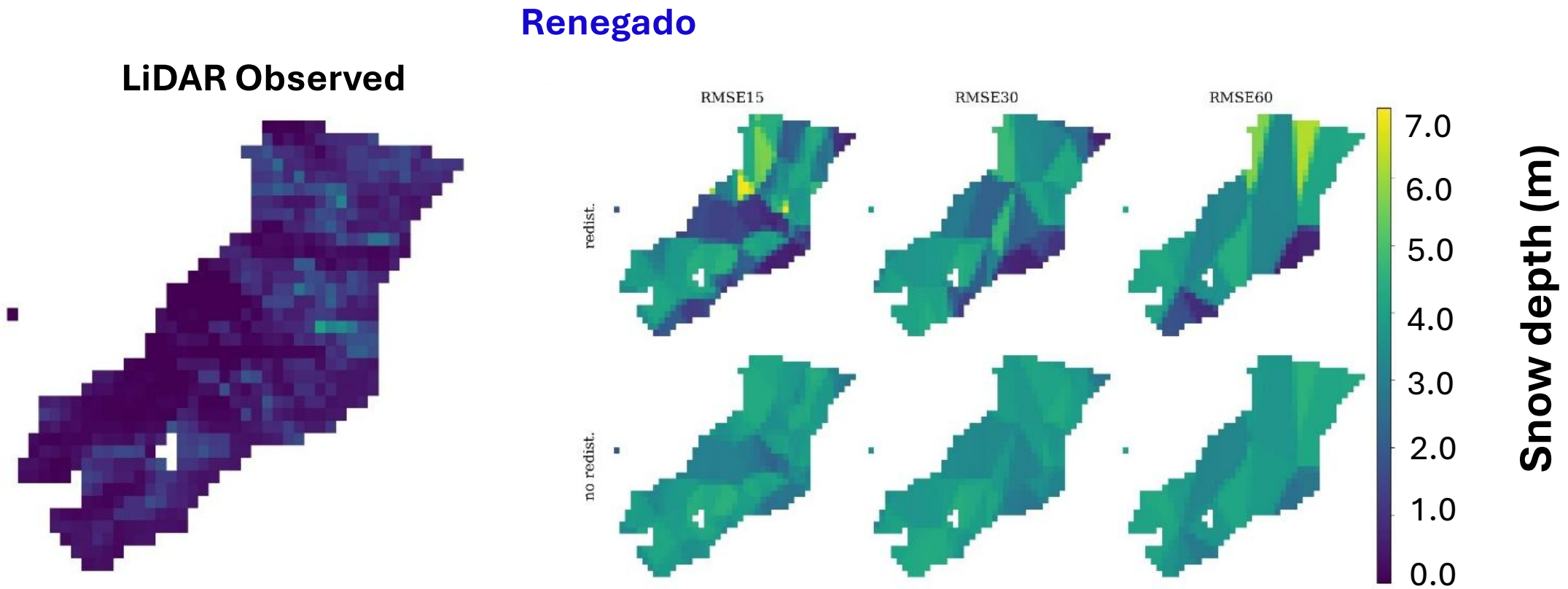
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Molina

LiDAR Observed

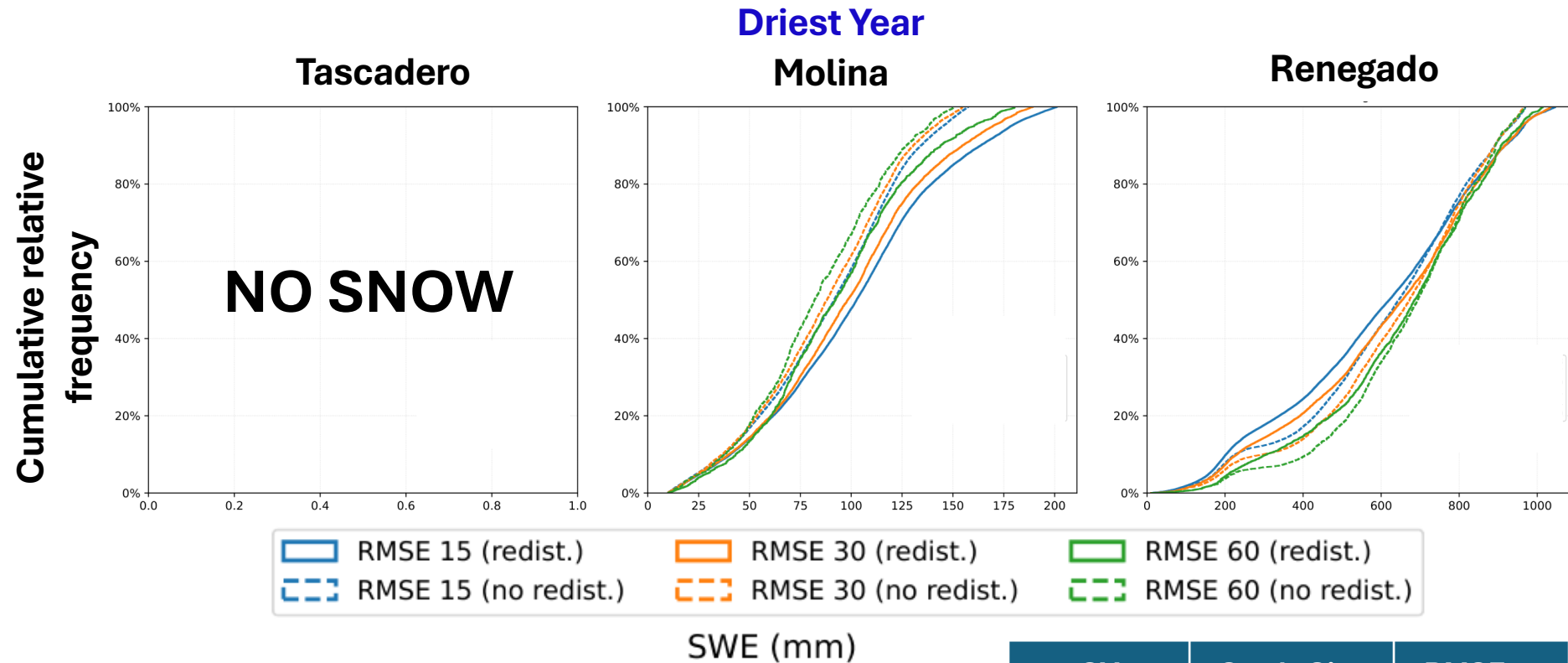


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Peak SWE cumulative frequency histogram (September 1st)

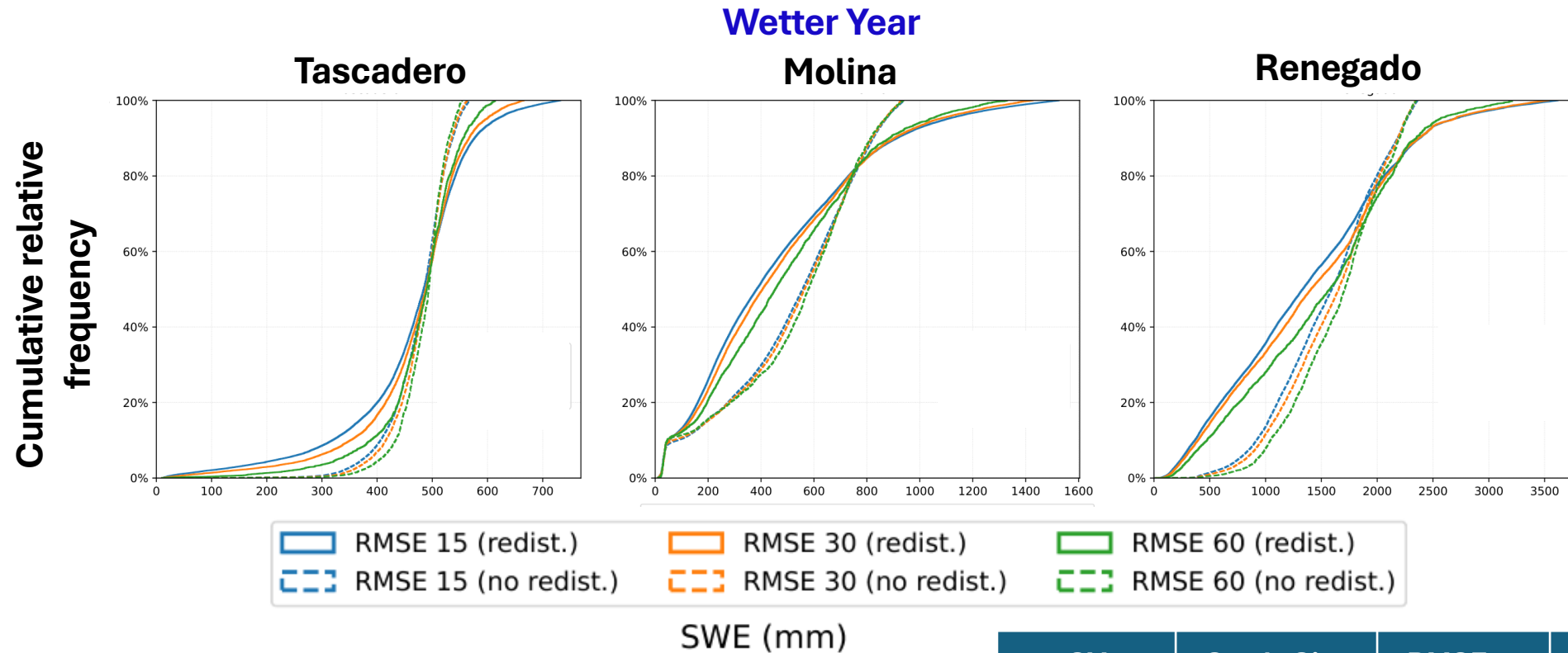


- The snowpack is more variable when we use the redistribution in Renegado catchment but in Molina the CV values are almost equal.

CV	Study Site	RMSE15	RMSE30	RMSE60
Redist.	Tascadero	ND	ND	ND
	Molina	0.44	0.43	0.41
	Renegado	0.43	0.39	0.34
No Redist.	Tascadero	ND	ND	ND
	Molina	0.40	0.40	0.40
	Renegado	0.37	0.34	0.30



Peak SWE cumulative frequency histogram (September 1st)



- In the wetter year the inclusion of redistribution is more important than a higher resolution mesh to obtain greater CV values.

CV	Study Site	RMSE15	RMSE30	RMSE60
Redist.	Tascadero	0.25	0.22	0.16
	Molina	0.73	0.69	0.63
	Renegado	0.56	0.54	0.47
No Redist.	Tascadero	0.11	0.10	0.09
	Molina	0.49	0.49	0.48
	Renegado	0.30	0.28	0.26



Conclusion



- The error metric choice (RMSE) in the mesh generation can increase the number of element up to one order (from 10^3 - 10^4).
- Snow redistribution and spatial resolution don't have a significant impact on peak SWE heterogeneity for the dry year.
- But in the wet year the snow redistribution have a greater impact in peak SWE heterogeneity than the resolution of the mesh.
- The model in the drier areas underestimate the LiDAR SD but in the wetter overestimate

Next steps

- Quantify the error of the model against LiDAR, snow cover from satellite and AWS.
- Include a fourth site further south
- Simulate the study over a larger temporal extension (2010-2021) to extent the validation perios.



Thanks for your attention!

Acknowledgment:

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