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Unravelling the sources of uncertainty in glacier runoff projections in the Patagonian Andes (40–56° S)

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Table S1. Regional surface mass balance models applied in the Patagonian Andes (40–56º S). In parenthesis the initial spatial resolution of the gridded climate. AWS: Automatic weather station. PP: Precipitation. T2M: Air temperature at 2m. GMB: Geodetic mass balance. NPI: Northern Patagonia Icefield. SPI. Southern Patagonia Icefield. GCN: Gran Campo Nevado. CDI: Cordillera Darwin Icefield.

Study area	Period	Reference climate	Downscaling	Target resolution	Timestep	SMB model	Calibration/validation of mass balance	Reference
NPI	1975–2099	Output from WRF run (5 km) based on NCEP-NCAR (2.5º)	T2M: Constant lapse rate of 6.5 ºC km^{1}. PP: Gradient of 0.05% m^{-1}. AWSs were used for validation.	450 m	Daily	Simplified energy balance	GMB: Willis et al. (2012) and Rignot et al. (2003)	Schaefer et al. (2013)
GCN	2000–2005	PP: NCEP-NCAR (2.5º). T2M: AWSs	T2M: Constant lapse rate of 5.8 ºC km^{1}. PP: Gradient of 0.15% m^{-1}. Orographic precipitation model as an alternative.	90 m	Daily	Degree-day model	Ablation stakes for validation	Weidemann et al. (2013)
NPI + SPI	1979–2012	Output from RACMO run based on ERA-Interim (~80 km)	No downscaling. AWSs were used for model evaluation	5.5 km	6 hours	Energy balance (RACMO2.3)	Ice cores for validation	Lenaerts et al. (2014)
SPI	1975–2011	Follows Schaefer et al. (2013)	Follows Schaefer et al. (2013)	180 m	Daily	Simplified energy balance	Parameters from Schaefer et al. (2013). Ablation stakes and ice cores for validation	Schaefer et al. (2015)
Andes	1979–2014	NASA MERRA (~0.5º)	Downscaling based on MicroMet (Liston and Elder, 2006)	1 km	3 hours	Energy balance (SnowModel)	SMB observations of seven glaciers (only one in the Patagonian Andes)	Mernild et al. (2017)
NPI + SPI	1976–2050	RegCM4.6 output (10 km) based on MPI-ESM-MR model	No downscaling. AWSs were used for model evaluation	10 km	Daily	Energy balance	Validation based on multiple GMBs (NPI and SPI)	Bravo et al. (2021)
NPI + SPI	1980–2015	RegCM4.6 output (10 km) based on ERA-Interim model	Follows Schaefer et al. (2013). CR2MET was used for validation	450 m	3 hours	Simplified energy balance	Calibration based on SMB estimates from Minowa et al. (2021)	Carrasco-Escaff et al. (2023)
CDI	2000–2022	ERA5 (0.25º) and AWSs	Several methods depending on the variable	200 m	3 hours	Four different models	Multiple strategies using ablation stakes, geodetic mass balance and mass budgeting	Temme et al. (2023)
Andes	2000–2019	Bias-corrected version of TerraClimate (4 km)	Lapse rates depend on the glaciological zones	f (glacier area)	Monthly	Degree-day model (OGGM)	GMB from Hugonnet et al. (2021) and volume from Farinotti et al. (2019)	Caro et al. (2024)

Table S2: Selected General Circulation Models (GCMs) of the CMIP6 projects. All GCMs only consider one output (r1i1p1f1). The equilibrium climate sensitivity (ECS) and the transient climate response (TCR) were obtained from Hausfather et al. (2022). Values of Past Performance Index (PPI) for precipitation (PPI_{PP}) and temperature (PPI_{T2M}) were obtained from Gateño et al. (2024). The selected PPI accounts for seasonal cycles, monthly probabilistic distribution, spatial patterns of climatological means, and the capability of the GCMs to reproduce teleconnection responses (optimal value of 1). The asterisk indicates the GCMs obtained from model screening approach (more details in Cateño et al.).

Model	Resolution (Lon – Lat)	ECS	TCR	PPI_{PP}	PPI_{T2M}
ACCESS-CM2	1.2 – 1.8	4.66	1.96	-0.15	0.42
BCC-CSM2-MR	1.1 – 1.1	3.02	1.55	-0.17	0.63
CMCC-ESM2	1.4 – 1.4	3.58	1.92	0.02	0.59
CMCC-CM2-SR5	0.9 – 0.9	3.56	2.14	-0.15	0.62
FGOALS-f3-L*	2.3 – 2.3	3.00	1.94	0.78	0.68
GFDL-ESM4*	1.0 – 1.3	2.65	1.63	0.78	0.78
KACE-1-0-G	2.2 – 2.2	4.75	2.04	-	-
MIROC6*	1.4 – 1.4	2.60	1.55	0.40	0.57
MPI-ESM1-2-HR	0.9 – 0.9	2.98	1.64	0.24	0.44
MRI-ESM2-0*	1.1 – 1.1	3.13	1.67	0.79	0.72

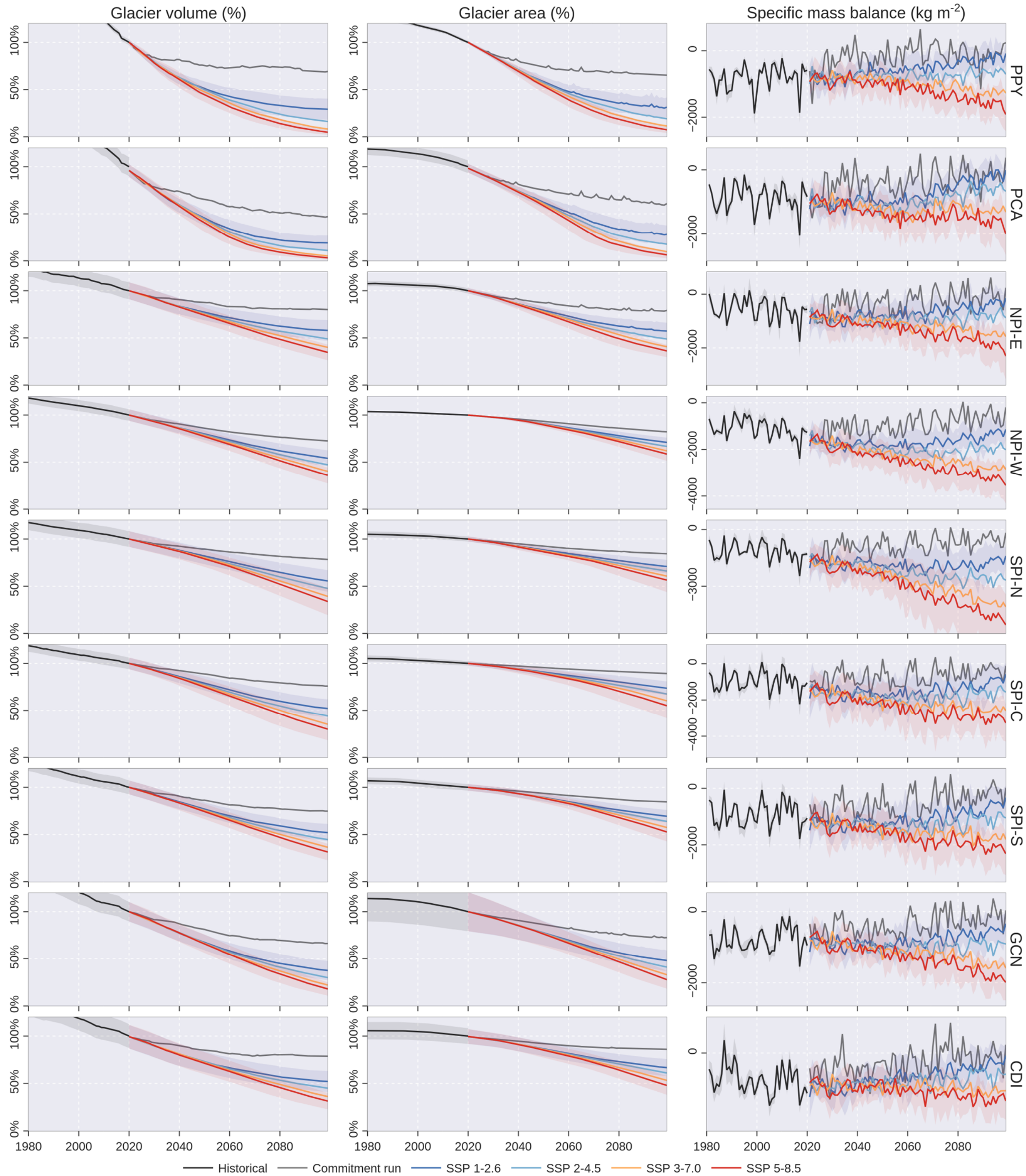


Figure S1. Glacier volume, area, and specific mass balance for each hydrological zone. The solid line represents the mean for each scenario, while the uncertainty bands represent ± one standard deviation (shown only for historical, SSP 1-2.6 and SSP 5-8.5 for visualization purposes). Note that each panel of specific mass balance has a different scale.

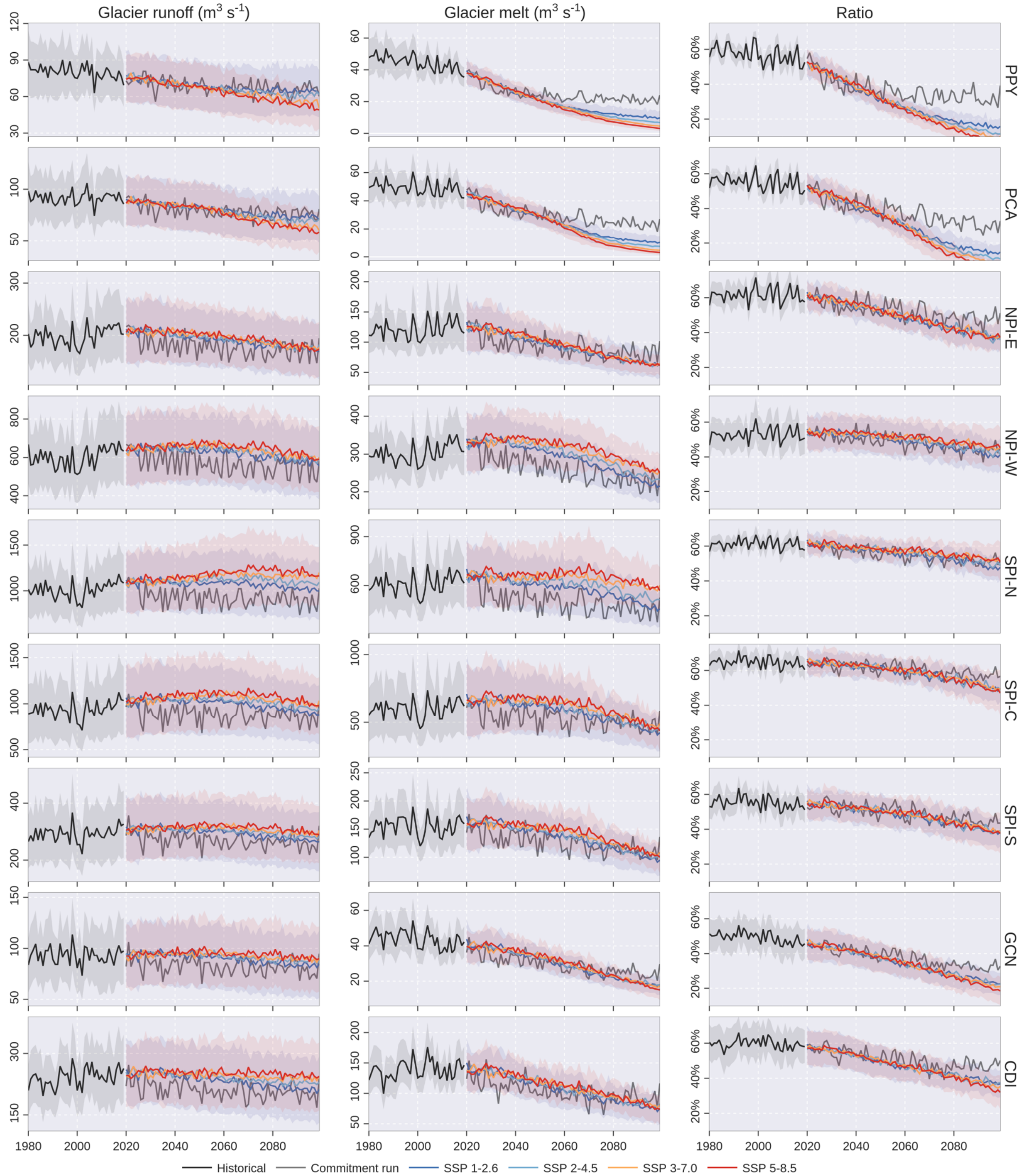


Figure S2. Total runoff, melt on glacier, and the ratio of both variables. The solid line represents the mean for each scenario, while the uncertainty bands represent ± one standard deviation (shown only for historical, SSP 1-2.6 and SSP 5-8.5 for visualization purposes). Note that each panel has a different scale.

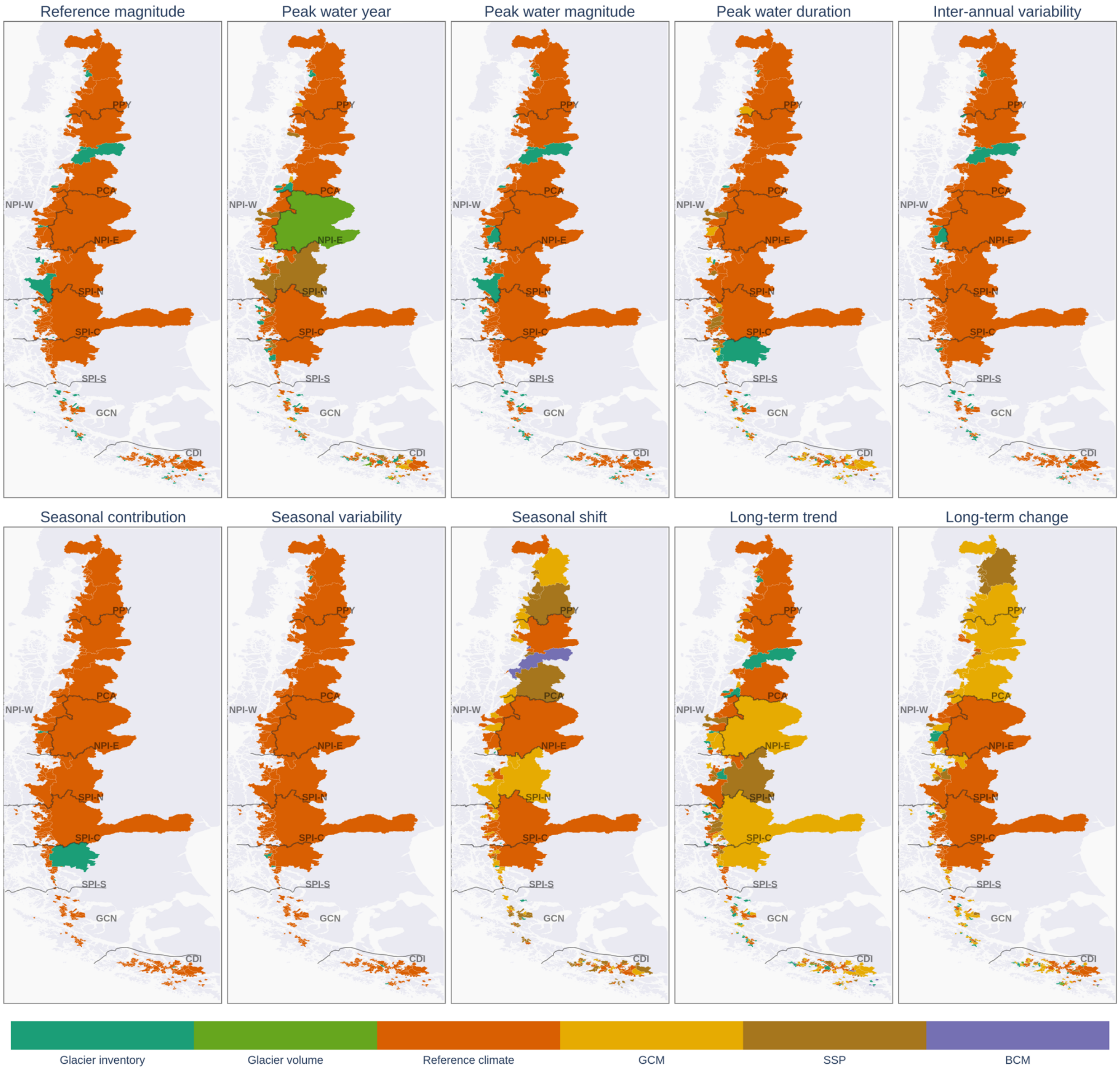
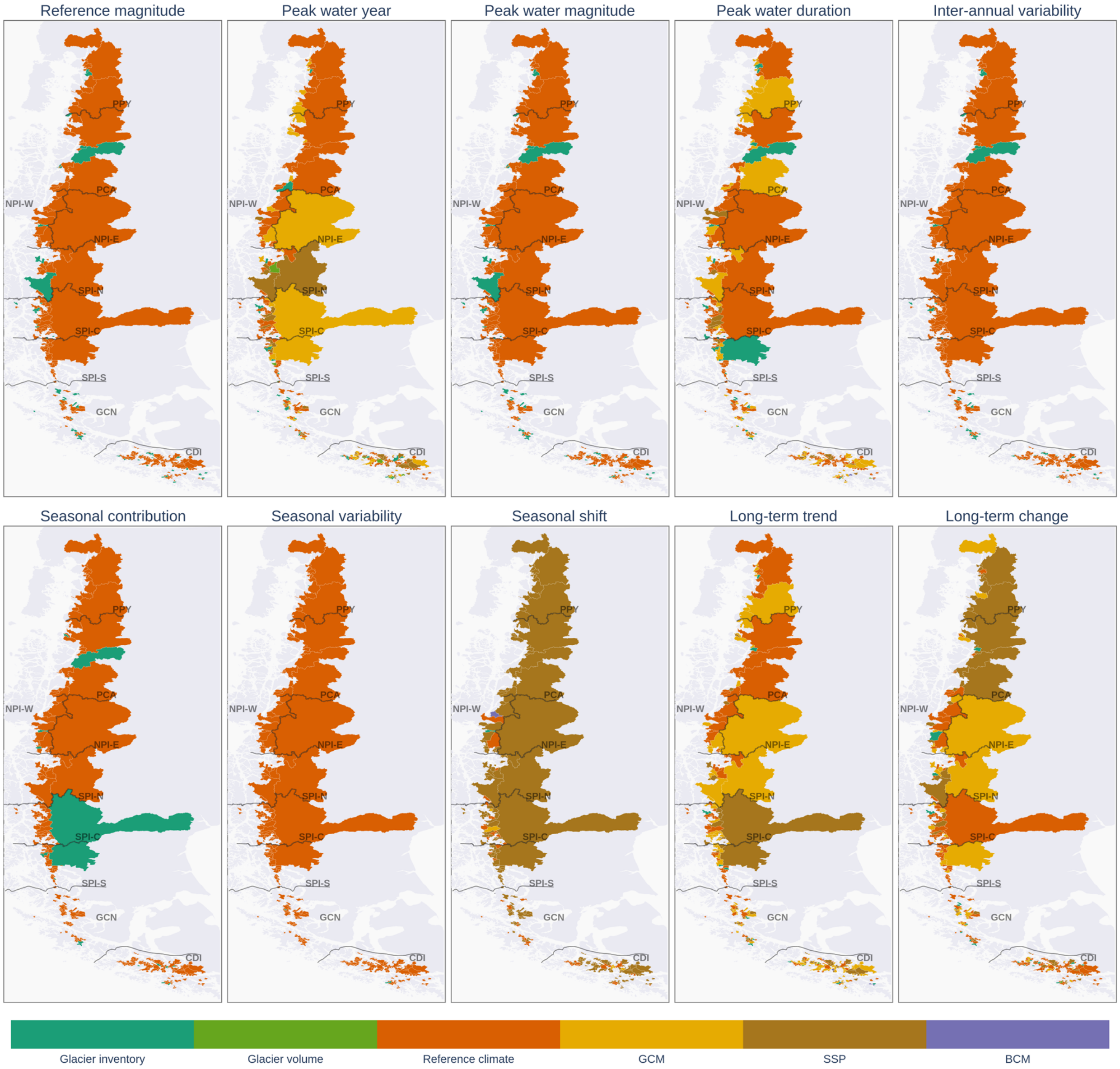


Figure S3. Largest source of uncertainty for each catchment and hydrological signature based on glacier melt (Table 2). The importance of each source was calculated as the percentage of the average change in the Root Mean Square Error (RMSE).



30 **Figure S4. Largest source of uncertainty for each catchment and hydrological signature based on total glacier runoff (Table 2). The importance of each source was calculated as the percentage of the average change in the Root Mean Square Error (RMSE).**

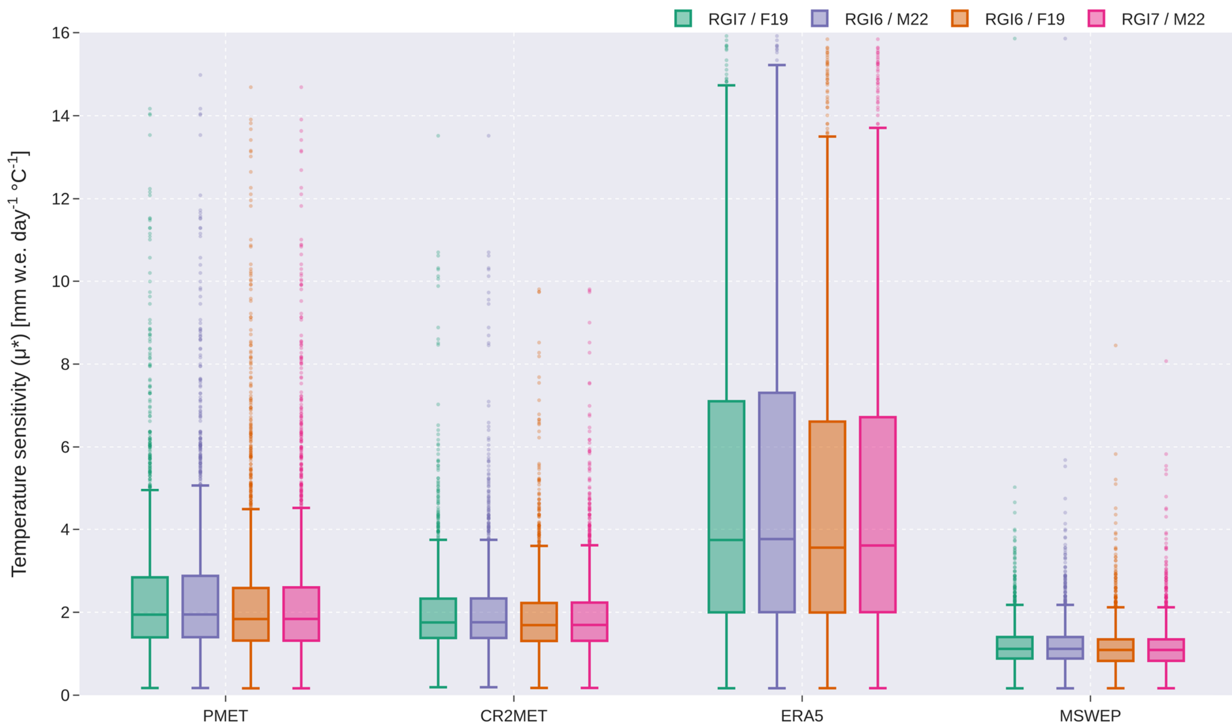
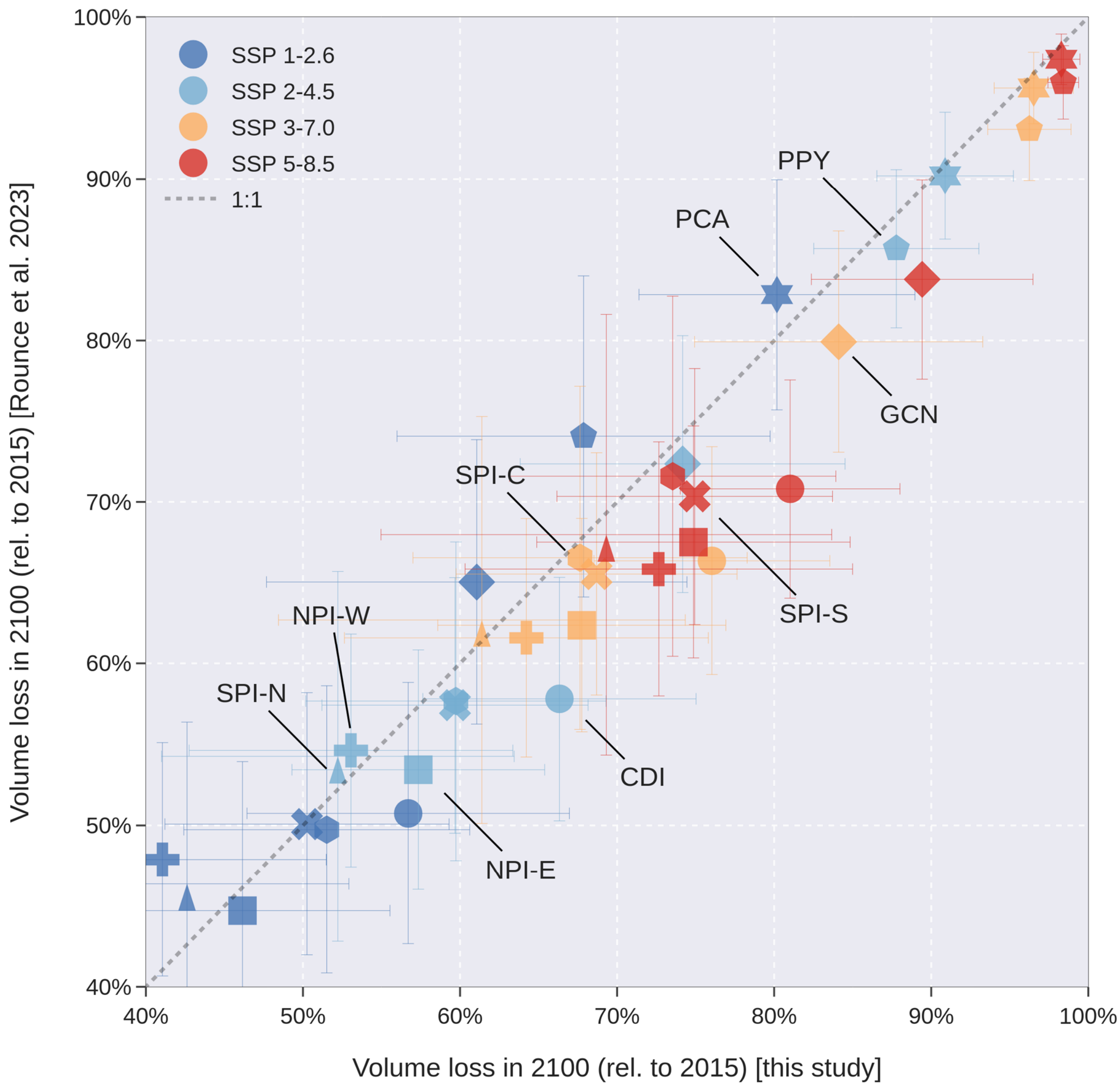


Figure S5. Temperature sensitivity for each historical scenario (n = 16). The historical conditions involved in the calibration process considered the geometry obtained from the glacier inventories (RGI6 and 7), the volume obtained from ice thickness datasets (F19 and M22), and the reference climate dataset (PMET, CR2MET, MSWEP and ERA5). More details on the historical conditions can be found in Section 3.2.1. Each boxplot aggregates all simulated glaciers (glacier area > 1 km2), corresponding to 2,034 and 1,837 glaciers for RGI6 and RGI7, respectively.



40 **Figure S6. Projected mean mass loss in 2100 (rel. to 2015) compared to Rounce et al. (2023). Each symbol represents a different hydrological zone, and each colour indicates a different emission scenario. The errors bars are calculated using one standard deviation (n = 480 per SSP). Note that Rounce et al. (2023) used PyGEM, and ERA5 as the reference climate.**