Assessment of Snow Water Equivalent Estimates from Reanalysis and Rainfall-Runoff Modeling in Northern Italy

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1. STUDY AIM

- To evaluate the accuracy of three large-scale land surface reanalysis products in estimating Snow Water Equivalent (SWE) at grid and catchment scales by comparing them with a snow reanalysis reference dataset, IT-SNOW (Avanzi et al., 2023).
- To assess the performance of the CemaNeige-GR6J rainfall-runoff model in simulating SWE at catchment scales in Northern Italy's mountainous regions.

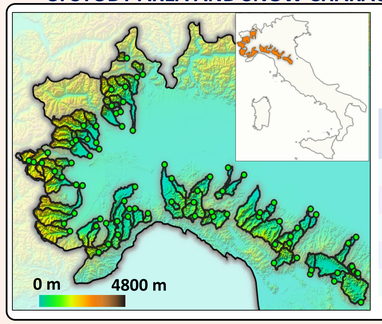
2. IT-SNOW REFERENCE DATASET AND EVALUATED LARGE-SCALE REANALYSIS PRODUCTS

IT-SNOW, developed by **CIMA Research Foundation**, serves as the **high-resolution reference dataset** (**0.5km, daily**) for this study. This validated dataset combines the S3M snowpack model with ground measurements, radar data, and satellite observations (**2011-present**) to provide robust SWE estimates **across Italy**. We evaluated three reanalysis products (table below) against this reference to assess their accuracy in representing SWE dynamics.

Dataset	Coverage	Resolution	Atmospheric model	Land surface model	Produced by
ERA5-Land (Muñoz-Sabater et al., 2021)	Global, 1950-present	9 km, Hourly	IFS (ERA5 atmospheric forcing)	CHTESSEL	ECMWF
CERRA-Land (Verrelle et al., 2022)	Europe, 1984-05.2021	5 km, Hourly	HARMONIE-AROME (CERRA atmospheric forcing)	SURFEX	Copernicus Climate Change Service (C3S)
VHR-REA_IT (Raffa et al., 2021)	Italy, 1981-2023	2.2 km, Hourly	COSMO-CLM	TERRA-ML	CMCC

* All results are shown for the period 09.2010 – 09.2020 to match the overlapping periods of the reanalyses products.
* Results are shown only for grid cells with SWE > 1 mm and |BIAS| > 0.5 mm to highlight significant differences..

3. STUDY AREA AND SNOW CHARACTERISTICS



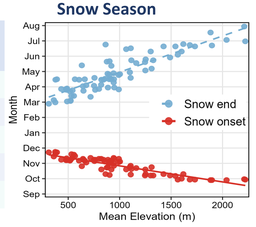
The study examines 83 catchments across Northern Italy's Alpine and Apennine regions, capturing diverse snow regimes and topographical conditions.

Mean Annual SWE > 1 mm for all catchments

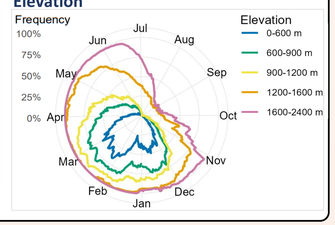
Catchment Elevation

Elevation Layers	No of Catch	Mean area (km²)
0 - 600m	17	316
600 - 900m	21	272
900 - 1200m	17	218
1200 - 1600m	14	393
1600 - 2400m	14	333

Snow Season



Snow Presence by Catchment Average Elevation



4. CEMANEIGE-GR6J RAINFALL-RUNOFF MODEL: CALIBRATION PROCESS AND MODEL PERFORMANCE

GR6J conceptual rainfall-runoff model, while primarily designed for streamflow prediction, is coupled with the **CemaNeige** snow accounting module to simulate **SWE** as an internal state variable. This study evaluates the model's capacity to represent snow dynamics when calibrated solely against discharge measurements.

2 CemaNeige + 6 GR6J = **8 parameters**

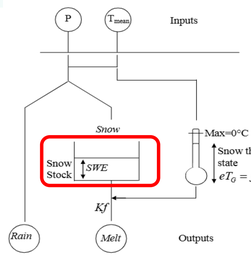
Objective Function: KGE (Gupta et al. 2009)
Input Data: Pr, Tmean, Pot. Evap. | SCIA Dataset (Desiato et al., 2011)

Calibration Period: 09.2010 / 09.2016
Validation Period: 09.2016 / 09.2023

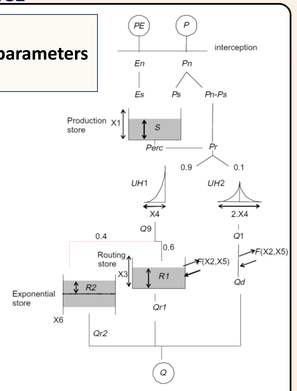
Model Performances in simulating streamflow

Stage	1st Quartile	Median	Mean	3rd Quartile
Calibration	0.875	0.903	0.892	0.929
Validation	0.681	0.903	0.837	0.928

The model performs very well in simulating streamflow in the studied catchments.



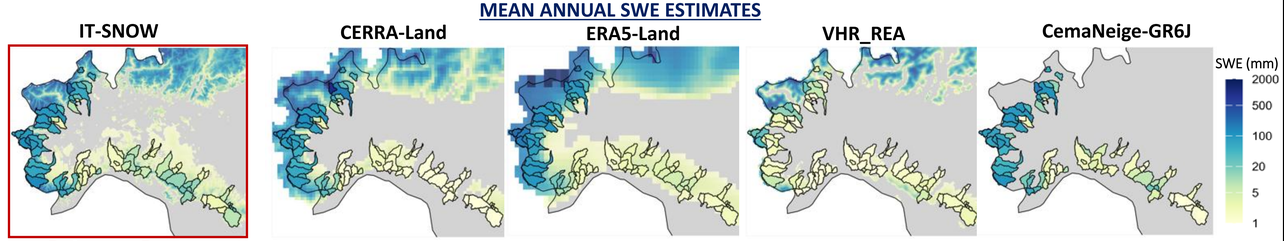
CemaNeige snow model (Valéry et al., 2014)



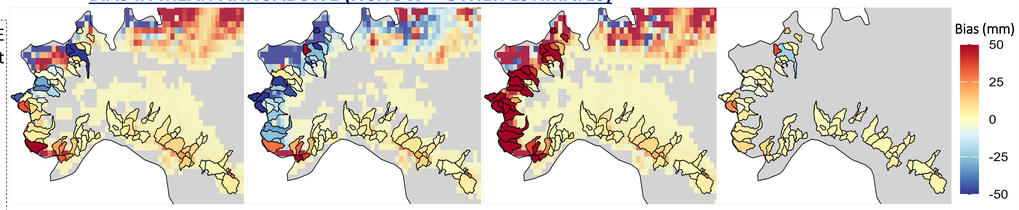
GR6J model scheme (Pushpalatha et al., 2011)

5. ASSESSMENT OF THE SWE ESTIMATES IN GRID AND CATCHMENT SCALE (09.2010 – 09.2020)

MEAN ANNUAL SWE ESTIMATES



BIAS IN MEAN ANNUAL SWE (ITSNOW – OTHER ESTIMATES)



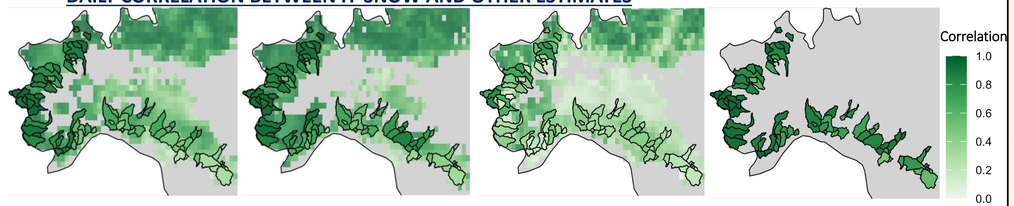
CERRA-Land: Underestimates SWE across lower elevations; significant overestimation in the highest catchments.

ERA5-Land: Significantly overestimates in high mountains, especially above 1200m. Best correlation among reanalyses.

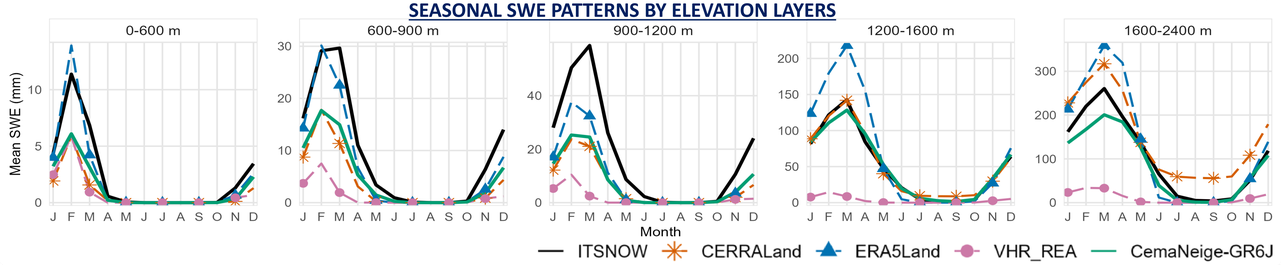
VHR-REA: Consistently underestimates at all elevations; weakest temporal patterns.

CemaNeige-GR6J: Best overall match to reference data; captures seasonal dynamics well at higher elevations. Underestimation in lower catchments

DAILY CORRELATION BETWEEN IT-SNOW AND OTHER ESTIMATES



SEASONAL SWE PATTERNS BY ELEVATION LAYERS



6. CONCLUSION

Comparison of Reanalysis Performance: Reanalysis products exhibit elevation- and seasonal-dependent variability in SWE estimation performance:
- ERA5-Land shows better performance at lower elevations.
- CERRA-Land better estimates SWE patterns in catchments above 1200m, with summer overestimations.
- The Italian product VHR-REA exhibited the poorest performance in estimating SWE.

Hydrological Model Performance: CemaNeige-GR6J outperforms the reanalyses in simulating SWE, but has potential for further refinement.

Future Direction: Ongoing research focuses on multi-objective calibration with discharge and IT-SNOW data to improve rainfall-runoff model parameterization and develop more robust hydrological models with a better representation of snow dynamics.

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