# ON THE USE OF HYDROLOGICAL MODELING FOR TESTING THE SPATIO-TEMPORAL COHERENCE OF HIGH-RESOLUTION GRIDDED PRECIPITATION AND TEMPERATURE DATASETS IN THE ALPINE REGION

***Stefano Mallucci [1*], Lavinia Laiti [1], Sebastiano Piccolroaz [2,1], Alberto Bellin [1], Dino Zardi [1], Aldo Fiori [3], Grigory Nikulin [4] & Bruno Majone [1]***

*(1) Department of Civil, Environmental and Mechanical Engineering, University of Trento (Trento, Italy).*
*(2) Institute for Marine and Atmospheric research Utrecht, Department of Physics and Astronomy, Utrecht University (Utrecht, The Netherlands).*
*(3) Department of Engineering, University Roma Tre (Rome, Italy).*
*(4) Swedish Meteorological and Hydrological Institute, Rossby Centre (Norrköping, Sweden).*

**email: stefano.mallucci@unitn.it*

***KEY POINTS***

- *Hydrological modeling as a tool to assess the coherence of precipitation and temperature datasets*
- *Gridded climatic datasets show different spatial and temporal behaviors in the Southern Alps*
- *Spatial resolution is crucial for the accuracy of gridded datasets at both large and local scales*

## 1 INTRODUCTION

Assessing the accuracy of gridded datasets of precipitation and temperature obtained from the interpolation of in-situ measurements, satellite remote sensing or atmospheric reanalysis (e.g., *Michaelides et al., 2009* for precipitation and *Harris et al., 2014* for temperature) is highly relevant to climate change impact studies, since evaluation, bias correction and statistical downscaling of climate models commonly use these products as a reference. Among all impact studies those addressing hydrological fluxes are the most affected by errors and biases in these data. The error associated to gridded data is often unknown or, at least, difficult to quantify (*Isotta et al., 2015*). Measurement errors depend on local conditions and increase with the elevation. The interpolation method is an additional source of error, even when sophisticated geostatistical spatial analysis techniques are adopted. Moreover, the accuracy of gridded climate data derived by remote sensing techniques is closely linked to their spatio-temporal resolution (*Prein & Gobiet, 2017*). Applying hydrological modeling to different gridded meteorological datasets has received attention recently, particularly over relatively short time periods in the context of flood forecasting applications. Furthermore, the aim of these studies is to evaluate the sensitivity of streamflow to changes in the forcing, rather than ranking the datasets according to their hydrological coherence. This work introduces an efficient methodology to rank gridded meteorological datasets according to their hydrological coherence with observed data and possibly reject them when their coherence is judged too low. We called this framework as HyCoT (Hydrological Coherence Test; *Laiti et al., 2018*). Coherence is evaluated by benchmarking streamflow, computed with a hydrological model fed by the selected datasets and applied in an inverse modeling framework against available measurements. The test allows, along a goal-oriented approach, to evaluate and rank the gridded datasets according to their hydrological coherence and provides a framework for excluding those not complying with hydrological observations, as function of the particular goal at hand.

## 2 DATA AND METHODS

HyCoT is applied to the Adige River Basin (northeast of Italy) for streamflow analysis, using a distributed hydrological model coupled with the HYPERstream routing scheme (*Piccolroaz et al., 2016*). HYPERstream routing scheme was designed in order to be coupled with gridded climate datasets and climate models, since it inherits the computational grid from the overlaying meteorological forcing, still preserving geomorphological dispersion caused by the river network irrespectively of the grid resolution.

The parameters space was explored for optimality, as defined by the Nash-Sutcliffe (NSE) (*Nash & Sutcliffe, 1970*) and the Kling-Gupta (KGE) (*Gupta et al., 2009*) efficiency indexes, by using the Particle Swarming Optimization algorithm (*Kennedy and Eberhart, 1995*). In doing this, two of the eight gauging stations considered were used in a multi-site calibration framework, whereas the remaining six stations were used only for validation purposes. In order to verify whether a simple rainfall correction procedure can improve the performance of biased datasets a Linear Scaling (LS) (*Lenderink et al., 2007*) transformation of the gridded precipitations was also employed. LS is a simple multiplicative correction method generally applied to correct biases in meteorological forcing as derived from Regional Climate Models (RCMs) simulations.

The comparison covers the period 1989-2008 and includes five daily meteorological gridded datasets (Figure 1): E-OBS, MSWEP, MESAN, APGD and ADIGE. They are characterized by relatively high nominal spatial resolutions (grid spacing < 25 km) and a daily temporal aggregation. For more details see *Laiti et al. (2018)*. The 1989-2008 period was identified as common time frame for the analysis.

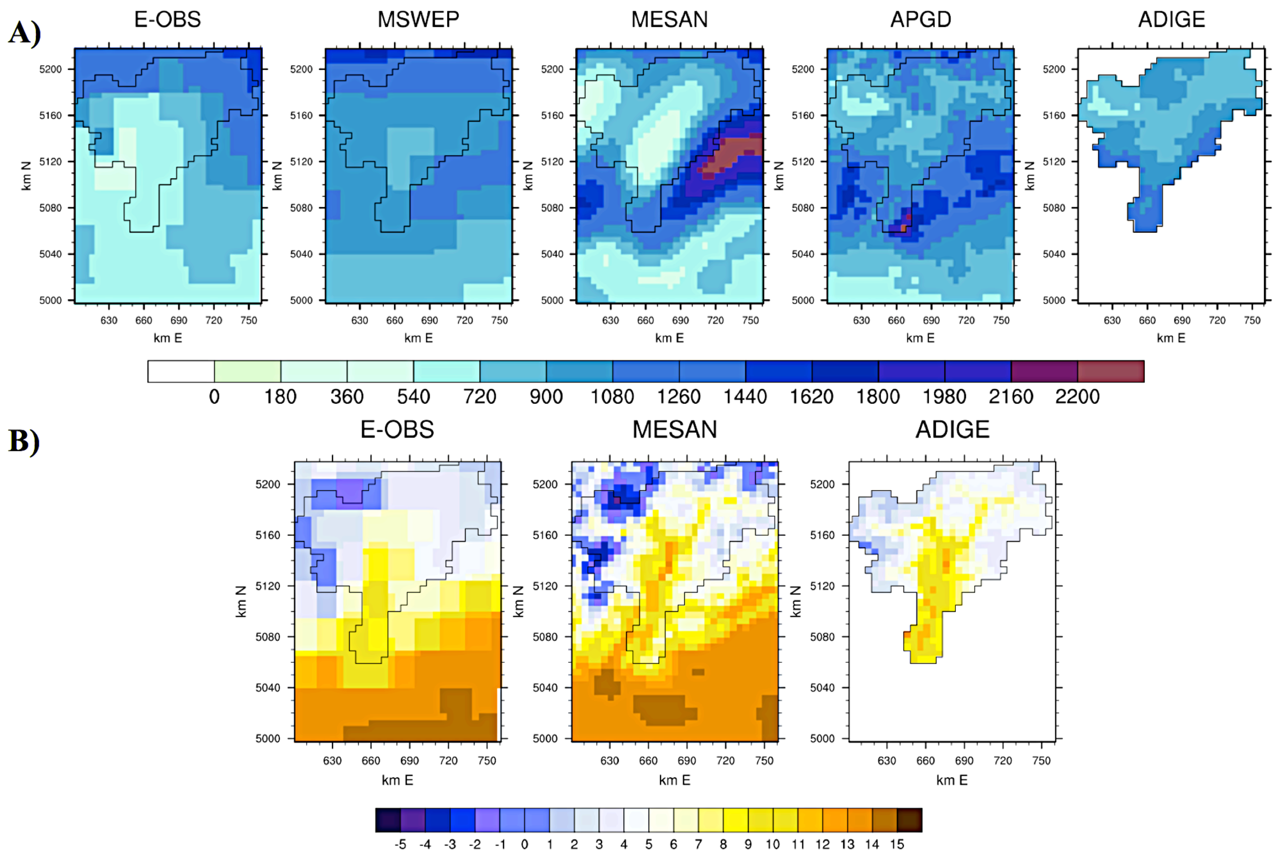


**Figure 1.** Maps of (A) mean annual precipitation totals [mm] and (B) mean annual temperatures [°C] averaged in the period 1989-2008 according to the five different climatic datasets. Notice that temperature data are not available for MSWEP and APGD datasets. Reproduced from *Laiti et al. (2018)*.

## 3 RESULTS

The parameters of the hydrological model were inferred for each dataset by maximizing separately the average NSE and KGE of Trento and Bronzolo gauging stations (Figure 2). At these two gauging stations the highest NSE are obtained with the ADIGE and APGD datasets, with NSE values higher than 0.83. E-OBS and MESAN provide the lowest NSE at both gauging stations, whereas MSWEP shows an intermediate behavior. The ranking holds by considering KGE instead of NSE, as can be seen by comparing Figures 2A and 2B, though differences between the datasets and locations is tighter. In general, KGE values are higher than NSE counterparts. This suggests that with KGE a reduction of bias is achieved with a small deterioration in the correlation. Notice that APGD and ADIGE are the datasets with the highest effective resolution (i.e. station density).

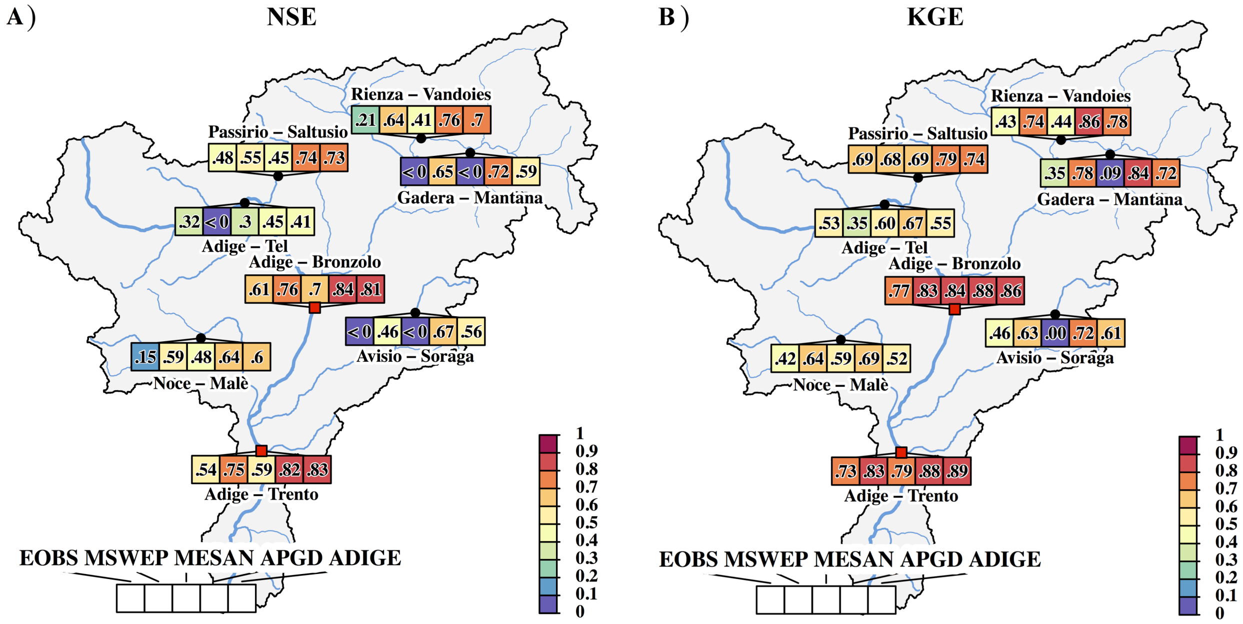


**Figure 2.** Maps of the (A) NSE values and (B) KGE values calculated at the gauging stations of the Adige River Basin. Simulated streamflow were obtained by calibrating HYPERstream such as to maximize the average NSE and KGE at the gauging stations of Trento and Bronzolo. The model has been calibrated separately for each dataset. Reproduced from *Laiti et al. (2018)*.

Finally, we applied a simple Linear Scaling (LS) to the MESAN dataset, since it is representative of underperforming datasets, whereas APGD is selected as observational benchmark due to its higher accuracy in reproducing the observed streamflow. In this case, the LS method consists in rescaling MESAN precipitations by a constant multiplicative factor, given by the ratio between the precipitations of APDG and MESAN. In total, 4 different rescaling scenarios were applied, in which the multiplicative factors were computed as follows: (i) on the annual catchment-averaged precipitations; (ii) on the monthly catchment-averaged precipitations; (iii) on the annual precipitations of each cell; (iv) on the monthly precipitations of each cell. The most striking result is that none of the LS scenarios is able to provide similar performance as APGD. This is valid for all the investigated locations. This demonstrates that the correct reproduction of the spatio-temporal distribution of the precipitation field is fundamental for an accurate reproduction of hydrological processes in climate change impact studies, particularly when assessments are performed at small spatial scales and in areas characterized by complex topography.

## 4 CONCLUSIONS

In this work we proposed a methodology, called as Hydrological Coherence Test (HyCoT), that consists in the use of a physically-based hydrological model as a tool to test the hydrological "coherence" of precipitation and temperature datasets. In the Adige River Basin, APGD and ADIGE are the best candidates for hydrological applications. On the contrary, despite acceptable results at the larger basin scale, E-OBS, MESAN and MSWEP were found unable to correctly reproduce the observed streamflow at the smaller sub-catchments. Results of our analyses are relevant for climate change impact assessments in the Alpine region where available gridded products are in general characterized by low observational density (i.e., low effective spatial resolution and accuracy). HyCoT reveals deficiencies in the representation of spatio-temporal patterns, which cannot be corrected by simple rescaling of the meteorological forcing, as often done in bias correction of climate model output. We recommend this framework in the context of large-scale hydro-climatic studies for evaluating and selecting gridded climate datasets.

## REFERENCES

Gupta, H. V., Kling, H., Yilmaz, K. K., and Martinez-Barquero, G. F (2009), Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modeling, J. Hydrol., 377, 80-91.

Harris, I., P.D. Jones, T.J. Osborn, and D.H. Lister (2014), Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 dataset, Int. J. Climatol., 34, 623-642.

Isotta, F.A., R. Vogel, and C. Frei (2015), Evaluation of European regional reanalyses and downscalings for precipitation in the Alpine region, Meteorol. Z., 24(1), 15–37.

Kennedy, J., and R. Eberhart (1995), Particle swarm optimization, in Proceedings of IEEE International Conference on Neural Networks, Institute of Electrical & Electronics Engineering, University of Western Australia, Perth, Western Australia, 1942–1948.

Laiti,L., S. Mallucci, S. Piccolroaz, A. Bellin, D. Zardi, A. Fiori, G. Nikulin & B. Majone (2018), Testing the hydrological coherence of high-resolution gridded precipitation and temperature datasets, under review in Water Resources Research.

Lenderink, G., A. Buishand, and W. van Deursen (2007), Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach, Hydrol. Earth Syst. Sci., 11, 1145–1159.

Michaelides, S., V. Levizzani, E. Anagnostou, P. Bauer, T. Kasparis, and J.E. Lane (2009), Precipitation: measurement, remote sensing, climatology and modeling, Atmos. Res., 94, 512–533.

Nash, J.E. and J.V. Sutcliffe (1970), River flow forecasting through conceptual models part I. A discussion of principles, J. Hydrol., 10, 282–290.

Piccolroaz, S., M. Di Lazzaro, A. Zarlenga, B. Majone, A. Bellin, and A. Fiori (2016), HYPERstream: a multi-scale framework for streamflow routing in large-scale hydrological model, Hydrol. Earth Syst. Sci., 20, 2047–2061.

Prein, A.F. and A. Gobiet (2017), Impacts of uncertainties in European gridded precipitation observations on regional climate analysis, Int. J. Climatol., 37, 305–327.