# The role of catchment properties on the importance of initial hydrologic conditions for seasonal hydrological forecasting in alpine areas

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**Abstract**

A well-known approach to seasonal hydrological forecasting involves the use of ensembles as forcing to a hydrological model, based either on historical meteorological data (Ensemble Streamflow Prediction, ESP) or on forecasts produced by one or more dynamic climate models (multi-model approach). This work aims at investigating the role of initial hydrologic conditions (ICs) and seasonal climate forecast skill on the accuracy of seasonal hydrologic predictions in alpine regions, as a function of catchment properties. The Integrated Catchment-scale HYdrological Model (ICHYMOD) is employed, forcing it with historical meteorological data and multi-model ensemble climate predictions produced by the climate forecast systems NCEP CFSv2 and ECMWF SEAS5 (the latter analysis is not included in the present work). The hydro-climatic prediction system is tested on two catchments in the Eastern Italian Alps, that are different in terms of orography and soil/groundwater storage capacity. The diverse catchment properties result in differential parameterization of the subsurface processes in the hydrological model, hence in a different impact of the initial hydrologic conditions on the seasonal runoff predictions.

**Keywords:** seasonal hydrological forecasting, alpine area

## 1. Introduction

Skillful seasonal hydrological forecasts are necessary for anticipated preparedness against natural disasters, management of hydropower plants, water supply and irrigation of agricultural crops (Yossef at el., 2013). The main aim of seasonal hydrological forecasting is the prediction of the land surface hydrologic variables at monthly to seasonal time scales based on their dependence on initial states (Yuan at el., 2015). The skill of these forecasts depends on the accurate representation of initial land surface conditions (ICs) from upstream river flow (Yossef et al., 2013) snow water equivalent or soil moisture (Koster et al., 2010), and on the quality of the meteorological forcing (Yuan et al., 2013). For catchments with different soil properties (e.g. water storage capacity, permeability), the effect of ICs on the seasonal runoff predictions can be diverse. This study aims at elucidating the role of ICs and seasonal climate forecast skill on the accuracy of seasonal hydrologic predictions in alpine regions, as a function of catchment properties.

## 2. Methodology

### 2.1. Methods and case studies

The modelling chain involves the Integrated Catchment-scale HYdrological Model (ICHYMOD) and multi-model ensemble climate predictions produced by (a) resampling from historical meteorology (Ensemble Streamflow Prediction, ESP) and (b) the climate forecast systems NCEP CFSv2 and ECMWF SEAS5. For this work only the results of the ESP are presented. The hydro-climatic prediction system is tested in hindcasting mode for the ablation season (May-October) of 2013 in two snow-dominated catchments in the upper Adige river basin (Eastern Italian Alps): the Gadera catchment at Mantana (area: 390 $km^2$, elevation range: 810–3050 m a.s.l.) and the Passirio catchment at Merano (area: 402 $km^2$, elevation range: 360–3500 m a.s.l.). The catchments are diverse in terms of orography and soil/groundwater storage capacity. The Gadera catchment is characterized by prevailing carbonate rocks and significant karst processes, implying high permeability, whereas the Passirio basin is characterized by more metamorphic formations, implying less permeable conditions. The historical meteorological record utilized spans the period 2000-2018.

### 2.2. ESP

Within the ESP workflow (Day, 1985), a hydrological model is forced by observed meteorological data up to the start time of the forecast to estimate the ICs and is afterwards employed in forecast/hindcast mode using ensemble meteorological data resampled from historical

meteorology. Thus, the ESP represents the forecast uncertainty due to uncertainty in the meteorological forcing and derives its skill from the ICs. The ESP hindcasts are evaluated against a retrospective control simulation driven by observations to exclude model error.
The predictability of the ESP hindcasts is quantified using a ratio of variances framework that compares the skill of the ESP with the skill resulting when climatology is used as an ensemble prediction (Wood and Lettenmaier, 2008). To this end, the mean square error (MSE) of the ESP and the climatology are calculated for each month of the ablation season of the year 2013 (starting in May, with a lead time of 6 months), according to the following equations:

$$MSE[ESP] = \frac{1}{M}\sum_{m=1}^{M}\left(Q_{m,ESP}(t) - Q_{ctrl}(t)\right)^2$$

$$MSE[Clim] = \frac{1}{M}\sum_{m=1}^{M}\left(Q_{m,Clim}(t) - Q_{ctrl}(t)\right)^2$$

where M: number of ensemble members during 2000–2018, excluding 2013 (i.e., 18), $Q_m(t)$: streamflow at lead time t obtained from the ESP/climatology experiment of year m, $Q_{ctrl}(t)$: streamflow generated by the control simulation at lead time t.
When the ratio of MSE of the ESP forecast to the MSE of the climatology is equal to 1, the forecast skill is equal to that of a climatological forecast. When the ratio is smaller than 1, the ESP forecast is more skillful than climatology, whereas when the ratio is greater than 1, the ESP forecast is less skilled than climatology. For a perfect forecast, the ratio approaches zero.

## 3. Results

For the Passirio catchment, the ESP (knowledge of ICs) is more skillful compared to climatology when the soil moisture states are high (at the beginning of the ablation season) (Figure 1). After May, due to snow melting and the subsequent depletion of the snow water equivalent (SWE) and soil moisture, the ESP gradually loses its skill (the ratio of MSE approaches 1).
In the Gadera catchment, where the soil is more permeable and with higher water storage capacity, the soil moisture is high throughout the ablation season, hence the ESP is generally skilful for the entire simulation period (ratio of MSE lower than 1) (Figure 1). Towards the end of summer the catchment reaches its driest conditions, slightly diminishing the importance of knowledge of the ICs in that period (increase in the ratio of MSE).

## 4. Conclusions and Outlook

The contribution of ICs (ESP) to hydrologic prediction skill is important when moisture is accumulated in the soil and the snowpack, implying that the ESP can be a powerful tool for seasonal hydrologic predictions in highly-permeable catchments. In less permeable catchments, depleted moisture states result in decreased ESP skill, implying that most probably meteorological forcings control the hydrologic response in the end of the ablation season.
The ESP procedure will be applied for the period 2000–2018 to assess the overall capability of the ESP to predict streamflow for different seasons. Further steps include (a) the application of the reverse ESP to assess the uncertainty from ICs and (b) the assessment of the potential forecast skill of the climate forecast systems NCEP CFSv2 and the ECMWF SEAS5 for seasonal streamflow forecasting in alpine regions.

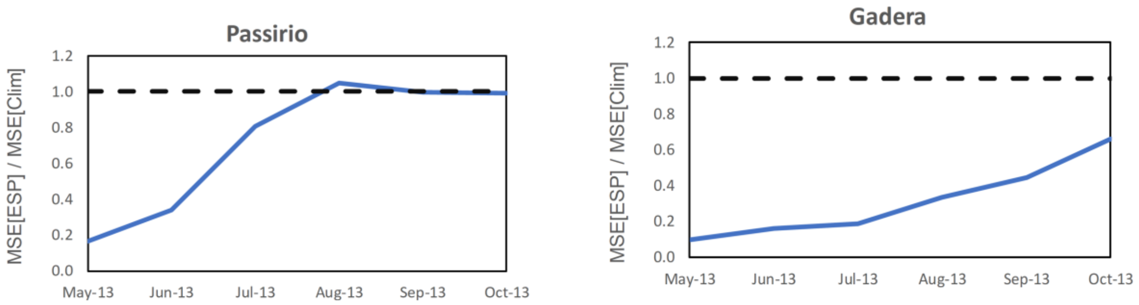


**Figure 1.** Ratio of MSE of ESP to MSE of climatology for the ablation season 2013 in the two study areas


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