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# Uncovering the forced climate response from observations or a single model run using statistical learning

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Internal atmospheric variability fundamentally limits short- and medium-term climate predictability and obscures evidence of anthropogenic climate change on regional scales. Dynamical adjustment techniques characterize and subsequently remove the influence of internal atmospheric variability on target variables such as temperature or precipitation. The residual component maintains the signal of the external forced response but reduces circulation-induced noise. Existing techniques have led to important insights into recent trends in regional (hydro-)climate and their drivers but the variance explained by these methods is often low.

Here, we introduce a novel dynamical adjustment technique using statistical learning principles with the goal of increasing the variance explained by atmospheric circulation. We demonstrate in a 21-member Community Earth System Model (CESM) ensemble that statistical learning methods such as regularized linear models establish a consistent relationship between internal circulation variability and atmospheric target variables, relying only on short time periods for training (around$\sim$10-30 years). The method accounts for an average of 83% and 78% explained variance in European monthly winter temperature and precipitation; and around 80% variance is explained in global annual mean temperature and zonal mean precipitation.

An accurate estimate of the total forced climate response is maintained in the residuals of the prediction. Hence, the number of ensemble members to extract the regional or global total forced climate response can be reduced by a factor of about 3-5.

Lastly, we illustrate and apply the new technique to regional winter temperatures in Switzerland using a long-term homogenized observational record. The analysis reveals that about 88% of winter temperature variability can be explained by internal atmospheric variability. The adjusted series reveals a smooth upward winter trend since the late 1960s, indicating that an abrupt change in the original winter time series around 1988 might be due to a combination of atmospheric circulation variability superimposed upon a relatively smooth externally forced trend.

Overall, statistical learning techniques for dynamical adjustment enable uncovering the forced climate response at regional and global scales, thus contributing to reducing uncertainties around internal variability and facilitating the interpretation of regional-scale climate records.