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Physical processes in present and future large-scale models

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Summary

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Systematic errors need to be evaluated both in terms of the mean error (bias) and the variability. The variability aspect is evaluated both the terms of the variances and spatial (and temporal) covariance. Examples of metrics of covariance are teleconnection patterns and extra-tropical flow-regimes such as NAO and blocking. An accurate model variability is crucial for correctly capturing the uncertainties in ensemble forecasting. While a mean error is relatively straight-forward to correct a posteriori the covariance aspects are much more difficult, and the way forward is model improvement.

Systematic errors can be diagnosed on different time-scales ranging from a few hours into the forecast to up seasonal time-scales (and longer). For the shortest time-scale (first 12-hours) the mean increments of the data assimilation system are used to analyse initial model drift (Klinker and Sardeshmukh, 1992; Rodwell and Palmer, 2007; Klocke and Rodwell, 2014). The increments are the adjustments by the observations to the short forecast used as a first guess in the data assimilation. By saving the model tendencies from each physical parameterisation package, the mean increment can be compared to the mean tendency from each package and give more insights about the initial model drift. The advantages with diagnostics on this time-scale are that the drift has little time to influence other parts of the atmosphere, and the possibility to compare with observation feedbacks in the data assimilation. The disadvantage is that it does not diagnose the variability aspects and that it usually only focuses on a relatively short period within the same year (different years can have different type of systematic errors due to differences in dominating weather patterns).

Systematic errors are evaluated for medium-range and extended-range forecasts as well. To investigate errors on the seasonal time-scale we are using seasonal forecast hindcasts, typically run with several ensemble members for initial dates ranging over 30 years. The model climate is evaluated both in coupled and uncoupled mode to inspect the difference between solely atmospheric biases and errors arising from the coupled atmosphere-ocean system. The forecasts are compared with ERA-Interim reanalysis and various observational data sets. However, one needs to pay attention to the errors in the verification data sets as well to fully understand the errors of the model.

From this evaluation setup mean errors as well as various variability patterns can be evaluated. Comparing the seasonal forecasting System 3 (from 2006) and System 4 (from 2010) several variability measures were clearly improved such as Madden-Julian Oscillation and Euro-Atlantic regimes. This was mainly due to the improvement in the convection scheme (Bechtold et al., 2008; Jung et al. 2010).

Since the introduction of the seasonal System 4 in 2010, ECWMF has introduced 6 new model versions for medium-range and monthly forecasts. Testing these cycles for seasonal forecasts, we find an improved mean temperature climate by a reduction of the cold bias in the atmosphere. This improvement is due to a series of model changes in physical parameterisation in the atmosphere as well as in the ocean model. One example is cold SST bias that was reduced in the tropical Pacific due to improvements in the ocean model and the coupling between the surface waves and the sub-surface, but a cold bias remains along the equator.

The SST cold bias in the tropics is linked with biases in surface winds and precipitation. The current model version (41r1), both in coupled and uncoupled mode, has a positive precipitation bias over the maritime continent and too strong easterly surface winds in the western tropical Pacific. The wind bias is present from the first days of the forecast. In coupled mode the biases increase and are also accompanied by a cold SST bias along the equator. This is a common bias among climate models (e.g Wang et al., 2014).

These biases are linked in a positive feedback loop (Bjeknes feedback). The positive precipitation bias increases the influx of air to the maritime continent and increases the easterly winds. Too strong easterly winds leads to increased upwelling of cold water along the equator and supresses the convection in the central part of the basin and increases the precipitation over the maritime continent.

In order to investigate the impact of the biases in the tropical Pacific on the ENSO variability and teleconnection patterns, Magnusson et al. (2013a, b) applied flux corrections in the coupling from the atmosphere to the ocean model in decadal simulations. The details about the experiment setup can be found in the cited papers. The flux correction was applied to the momentum flux alone or in combination with a correction of the heat flux. The rationale behind the experiments was to see the impact on the variability from a better mean state of the ocean. Already the momentum flux-correction alone was able to reduce the SST bias, indicating the impact of the wind bias on the ocean circulation. By applying both momentum and heat-flux correction the SST is, by construction of the flux correction, very small. By applying the flux correction (both configurations) the annual cycle of ENSO variability (with its maximum around December) was much improved as it was missing in the uncorrected simulations. The strength and position of the precipitation anomaly response to El Nino events was improved as well.

The latent heat release in the precipitation is creating a Rossby wave source that leads to a modification of the extra-tropical flow (e.g Hoskins and Karoly, 1981). By adding the flux correction, the position and strength of this heat source during El Nino events were better modelled and the teleconnection pattern for the northern extra-tropical winter was improved. The conclusion from these experiments was that the mean climate in the tropical Pacific is critical to simulate the ENSO variability and the teleconnection patterns to the extra-tropics. These properties are necessary (but not sufficient) for good seasonal forecasts outside the tropics.

To summarize, it is important to evaluate systemic error for coming model upgrades and to find areas for further improvements. A good model climate is necessary to simulate the variability, which is needed to correctly simulate the forecast uncertainties (with an ensemble) and to capture the teleconnections in the atmosphere.

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