Model uncertainty in global ocean models: Stochastic parametrizations of ocean mixing

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Model resolution of current state-of-the-art ocean models, especially on timescales of seasons to decades, is of the order of 100km. Mesoscale eddies in the ocean are, however, about an order of magnitude smaller. Therefore most ocean models used for seasonal or decadal predictions utilize resolutions where mesoscale eddies are not or only partially resolved. As a consequence, the effects of unresolved eddies on the resolved, large scale circulation need to be parametrized.
Eddies are just one of many sub-grid scale ocean processes that are not explicitly resolved in ocean models. Most of the commonly implemented parametrizations deal with unresolved horizontal and vertical sub-grid scale mixing processes that can vary strongly with time and location. Oftentimes these parametrizations and their parameters are imperfectly constraint, due to missing process understanding or unavailable observations. In this context, stochastic parametrizations can help to introduce a measure of uncertainty estimation in the model that deals specifically with the uncertainty originating from parametrized processes. Furthermore, stochastic perturbations can be used to represent not only the mean impact of the sub-grid scales on the resolved flow but also reintroduce some of the sub-grid scale variability that is not captured by classical deterministic parametrization schemes.
One approach to reintroduce sub-grid scale variability as well as implement uncertainty estimates in current state-of-the-art climate models is to identify crucial, imperfectly constrained parameters or parametrization tendencies and perturb those in a symmetric, multiplicative way. We identified three different parametrizations in the NEMO global ocean model with a 1 degree horizontal resolution for which certain parameters meet these criteria:

- The Gent-McWilliams parametrization parametrizes unresolved eddy advection of temperature and salinity, especially in the Southern Ocean. It generally leads to a flattening of overly steep isopycnal slopes, but the exact amplitude of this process is quite uncertain.
- The strength of vertical mixing in the NEMO ocean model is based on a parametrization using a prognostic turbulent kinetic energy formulation, which defines the intensity of vertical mixing especially in the upper ocean.
- In the case of unstable stratification, an enhanced vertical mixing parametrization is used to stabilize the water column.

The amplitudes and timescales of these three mixing parametrizations were perturbed by stochastically perturbing important parameters used in their formulation. The applied random perturbations were tuned in their amplitude and exhibited temporal and spatial correlations.
The results show that in uncoupled forced ocean-only simulations the perturbations to sub-grid scale mixing parametrizations lead to an increase in low frequency variability in eddy-active regions for a variety of variables, even though the perturbations themselves exhibit high frequency variability. Interannual variability for sea surface temperature, sea surface height, integrated heat content and zonally averaged streamfunction was increased predominantly in the Southern Ocean and along western boundary currents such as the Kuroshio region. This is in accordance with missing low frequency variability in these regions when compared to observations and reanalysis products. Therefore, including high frequency perturbations in parametrizations of horizontal and vertical mixing improves the representation of low frequency variability in the ocean model, an effect that can also be achieved by increased resolution but at increased computational costs. However, the effect of the stochastic perturbations is not sufficient to fully compensate for the effects of the missing eddy variability in the 1 degree ocean model.
In coupled ECMWF seasonal forecasts with the same ocean model and horizontal ocean resolution, the stochastic perturbations increase the ensemble spread again especially in the eddy-active regions of the Southern Ocean and the western boundary currents, for variables such as sea surface temperature and upper ocean heat content (see figure). This is the case for months 3 to 10 of the 10-

month forecasts. The increase in spread leads to an increase in forecast reliability in the Southern Ocean, where ensemble spread strongly underestimates the forecast error. The forecast error itself is affected by the stochastic perturbations as well, but while the error is reduced in some regions, in other regions the stochastic perturbations lead to an increase in forecast error. However, it should be noted that the seasonal forecasts are not retuned after implementation of the stochastic schemes. Also, the effect of the increased spread is generally larger than the effect of the schemes on forecast error. Future studies will analyse the seasonal forecasts in more detail and will also introduce new stochastic perturbation schemes.

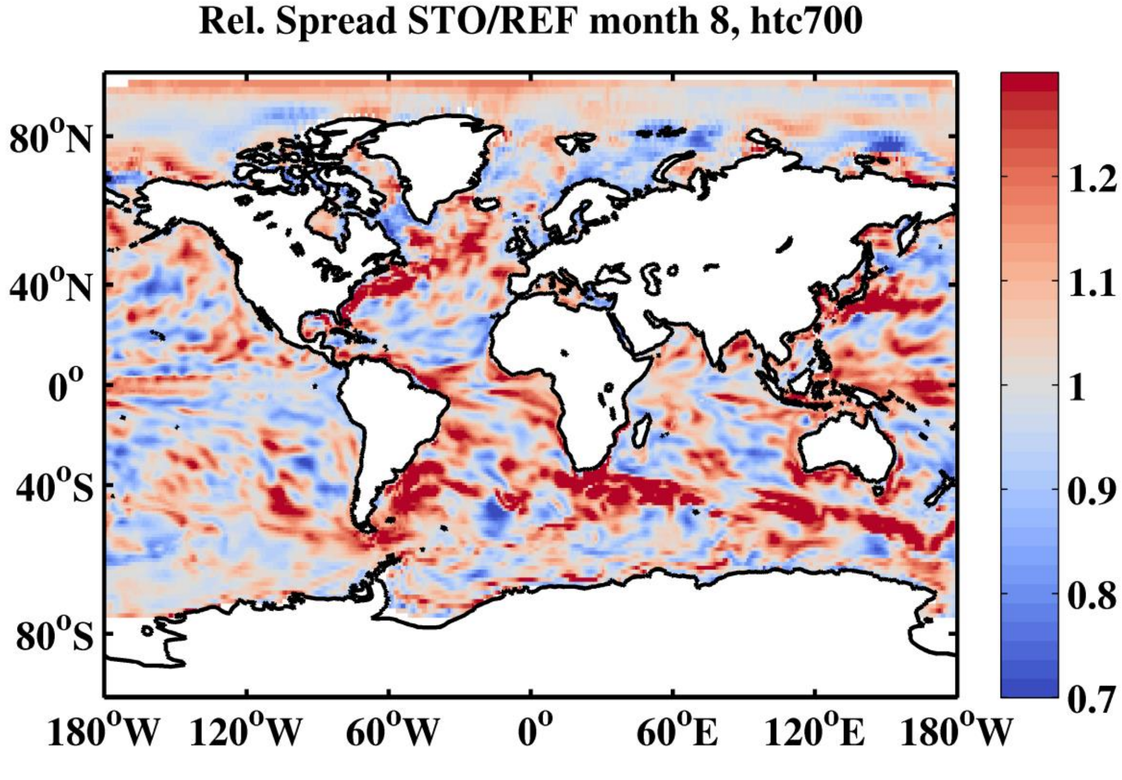

Figure 1 Relative changes in spread between the stochastically perturbed forecasts (STO) and the reference forecasts (REF) for 20-member ensembles, averaged over the years 1981 to 2005, initialised in May and integrated for 10 months. Shown are the results for 700 meter heat content and month 8, i.e. December. The spread in the eddy-active regions is increased by more than 30 %.