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Optimal surface temperature and salinity perturbations of the Atlantic meridional overturning circulation in a realistic ocean model

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In this study we compute optimal initial perturbations in surface temperature and salinity for the Atlantic Meridional Overturning Circulation (AMOC) in a realistic ocean general circulation model. The optimal perturbations are obtained for two different measures of the AMOC (the meridional volume and heat transports) and for different surface boundary conditions (the flux and mixed boundary conditions). Our calculations involve a maximization procedure based on Lagrangian multipliers in a non-autonomous context. The structure of the optimal perturbations is characterized by anomalies in temperature or salinity localized in the northern Atlantic off the east coasts of Greenland and Canada centered south of the Denmark Strait. The maximum impact of the perturbations on the AMOC is reached after 7 to 9 yr. These are robust results independent on the type of perturbations, the measures used, the boundary conditions, or other additional constraints. The AMOC transient growth involves the following mechanism: a positive initial perturbation in density generates a cyclonic geostrophic flow that extracts a temperature anomaly (with a zonal gradient) from the mean temperature field (with a strong meridional gradient). In turn, the anomalous zonal temperature gradient induces, by thermal wind balance, a northward flow in the upper ocean and a southward flow in the deep ocean, thus strengthening the AMOC. The optimal perturbations not only generate the transient growth of the AMOC, but also excite a damped oscillatory eigenmode in the system with a period of about 24 yr. An idealized model, formulated to investigate this mechanism, highlights the nonnormality of the dynamics leading to the transient change including the role of deep ocean and convection. Simple estimates show that realistic changes in salinity or temperature in the upper ocean (such as changes due to the Great Salinity Anomaly) can induce AMOC variations *via* this mechanism on the order of several Sverdrups, or 10-20% of the mean meridional overturning.