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Stratosphere - Troposphere Coupling in a Linear Framework

Daniela Domeisen and Alan Plumb

Massachusetts Institute of Technology, Department of Earth, Atmospheric, and Planetary Sciences, Cambridge, United States (ddaniela@mit.edu)

The influence of stratospheric flow anomalies on the troposphere has recently attracted an increasing interest. It is suggested that large anomalies in the stratospheric wind and temperature pattern, such as stratospheric sudden warmings, may be followed by tropospheric flow anomalies, e.g. changes in weather patterns.

While the mechanism of stratospheric influence on the troposphere has not been clearly identified to date, it is widely observed in modeling studies and suggested in observational studies. It has in addition been observed in modeling studies that the state of the troposphere at the time of the stratospheric anomaly considerably influences the tropospheric response to stratospheric anomalies.

The tropospheric signal of the coupling manifests itself in the form of the “Annular Modes”, which are dominantly driven by synoptic wave activity in the troposphere. Some previous studies have presented these modes as deep structures during active stratospheric seasons (winter/spring in the northern/southern hemispheres). We have applied Principal Oscillation Pattern (POP) analysis to reveal separate tropospheric and stratospheric modes, though they tend to co-vary during seasons of strong vertical coupling.

Considering the effect of the troposphere on the stratosphere, theory as well as observations suggest that the state of the stratosphere (in terms of wind strength and structure) can strongly limit the effect which tropospherically induced planetary waves exert on the stratosphere. This is theoretically stated using the Charney-Drazin criterion, which limits wave propagation to regions where zonal background winds are westerly and do not exceed a critical velocity which is dependent on wave number. This constrains strong coupling by planetary wave propagation between the stratosphere and the troposphere to the active stratospheric seasons, which is confirmed in observations.

Although wave propagation and interactions between forcings and the mean flow exhibit a highly nonlinear structure, the promising success of e.g. the Charney-Drazin condition at explaining wave propagation suggests that linear theory gives strong insights into the complex coupling mechanism between the troposphere and the stratosphere.

In this paper, we seek to understand the mutual coupling between the troposphere and the stratosphere by applying a linear framework. We argue that the main part of the coupling mechanism occurs through the planetary scale waves, and that the coupling may be usefully described by considering the linear response of an external forcing onto the evolving atmospheric flow.
For this purpose we employ the atmospheric spectral core GFDL model as well as ERA40 reanalysis data for zonal mean zonal wind distributions and the study of wave propagation.