Abrupt Change in the Lower Thermospheric Mean Meridional Circulation during Sudden Stratospheric Warmings and its Impact on Trace Species

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Introduction

The climatological lower thermospheric (LT) mean meridional circulation (MMC) is a narrow gyre that is characterized by upwelling in the middle winter latitudes, equatorward flow near 120 km, and downwelling in the high summer latitudes. Previous studies revealed that the climatological direction reverses following the onset of the sudden stratospheric warming (SSW) (Miyoshi et al., 2015; Oberheide et al., 2020). However, the robustness of such changes and the dominant wave forcings involved remain unclear. Based on the hourly output from an ultra-high top model, we examine the roles of planetary waves (PWs), gravity waves (GWs) and atmospheric tides in driving the LT MMC and its response to the SSW with an elevated stratopause (ES-SSW).

Data and Method

We analyze the 15-year (2000-2014) hourly output from the NCAR CESM2 Extended Version of the Whole Atmosphere Community Climate Model with specified dynamics **(SD-WACCM-X)**.

Following Zhang et al. (2021), 9 ES-SSW events were identified in SD-WACCM-X based on the criteria of Limpasuvan et al. (2016). To develop a robust response to SSW characteristics, we perform a composite analysis. A quiet winter climatology, characterized by the circulation without ES-SSW events, is constructed using the remaining 6 winters from the 2000–2014 period.

The semidiurnal tide comprises periods between 11.8 and 12.2 hours and the diurnal tide periods between 23.8 and 24.2 hours. PWs includes travelling waves with zonal wavenumbers 1 to 5 and periods between 2 and 20 days.

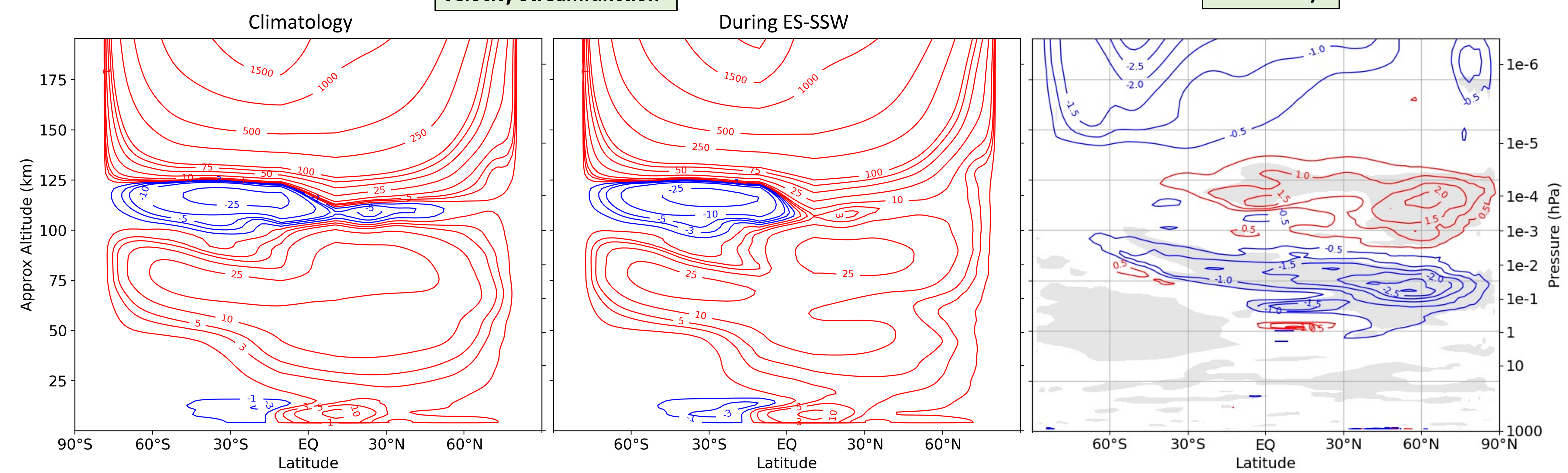
Wave-mean flow interactions are examined with the Transformed Eulerian Mean formalism, accounting for scale height variation with altitude (through dry air gas constant and gravity acceleration).

The velocity streamfunction of the residual mean circulation can be estimated from a latitudinal integration of the vertical component of the residual mean flow with a boundary condition.

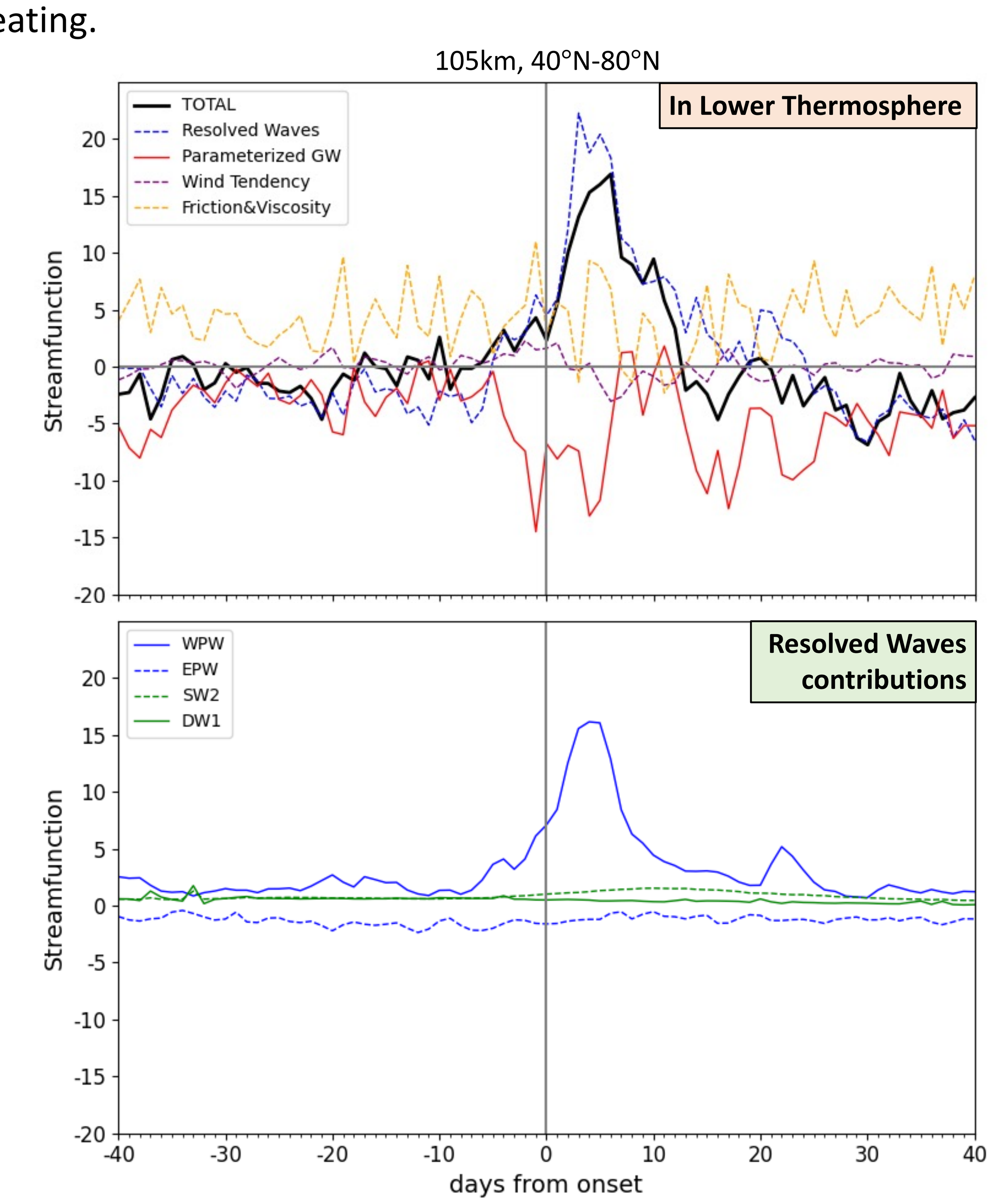
The contributions of the different wave forcings to the velocity streamfunction are estimated using the method of Sato and Hirano (2019).

Results

Velocity Streamfunction **V* Anomaly**



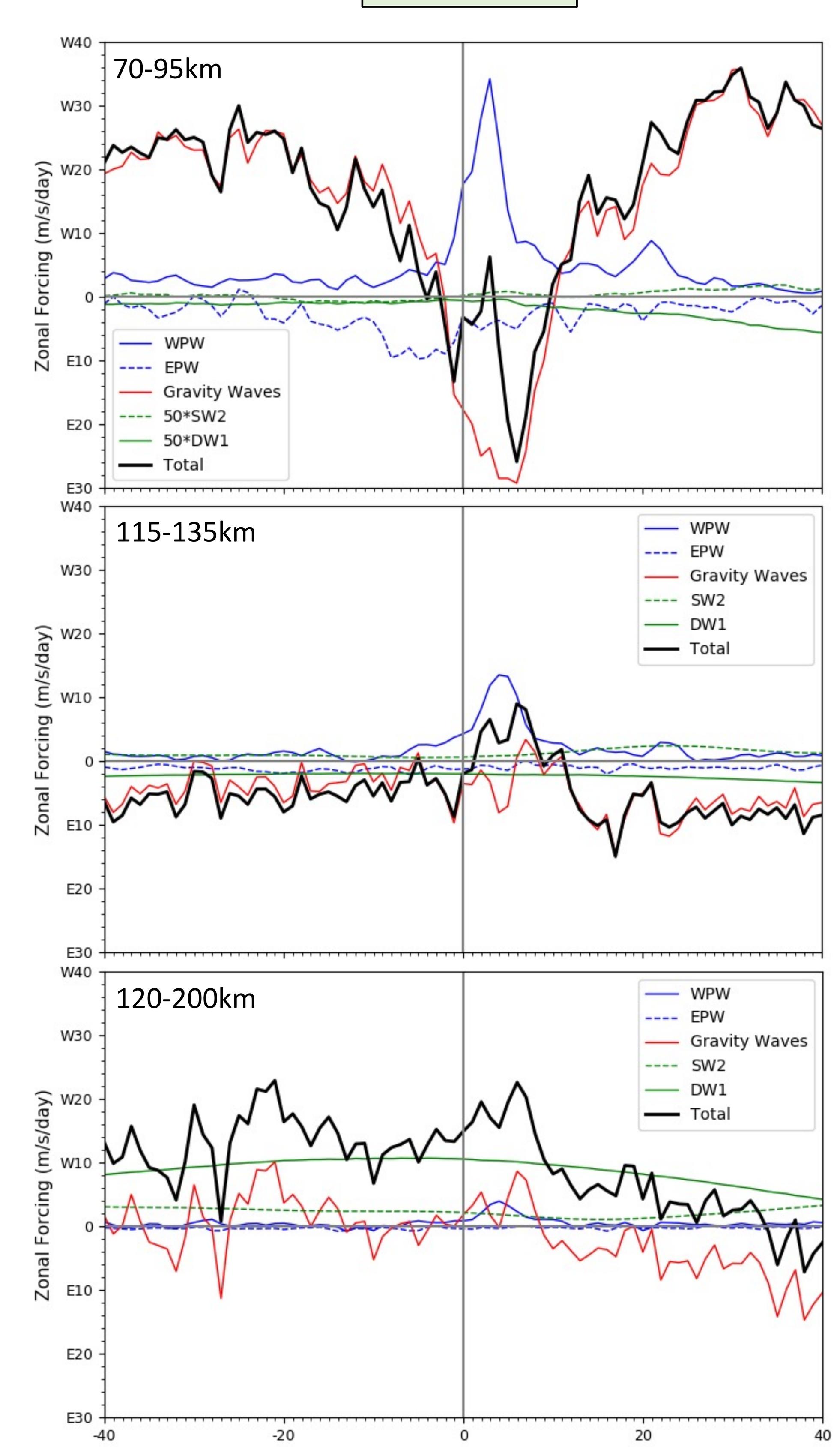
- Mesospheric MMC is clockwise.
- The LT MMC is a narrow counterclockwise circulation and spans the layer 100–125 km.
- Higher in the thermosphere, the LT circulation transitions toward the deep summer-to-winter thermospheric MMC driven by solar heating.



- The streamfunction is negative (counterclockwise) at long leads prior to the ES-SSW event, with GWD is the leading contributor.
- Among the resolved waves, WPWs are the main contributor to the positive (clockwise) velocity streamfunction after the ES-SSW onset.

- Following the ES-SSW onset, between 95 and 125 km, there is anomalous poleward motions associated with anomalous descent from the mid-latitudes to the North Pole.

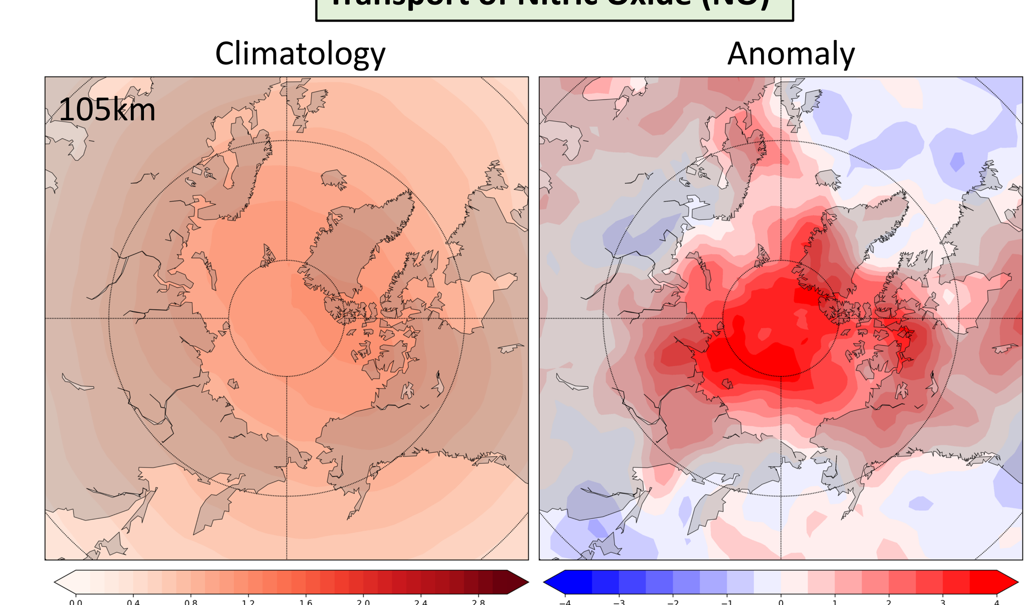
Wave Forcing



Summary

- The northern hemisphere climatological LT MMC is driven by (fast eastward-propagating) GWs and extents vertically from approximately 100 km to 125 km.
- The LT MMC reverses briefly following ES-SSW onset, resulting in a "chimney-like" feature of un-interrupted polar descent from the altitude of 150 km down to the upper mesosphere.
- The LT MMC reversal is driven by the WPW forcing, which exerts a brief but significant westward forcing, surpassing the parametrized GWD and providing the main contribution to the velocity streamfunction reversal at 105 km. The tidal forcings become important above 120 km.
- The attendant descent leads to a short-lived enhancement of NO into the polar LT and upper mesosphere.

Transport of Nitric Oxide (NO)



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