Supplement of Atmos. Chem. Phys., 22, 9499–9511, 2022
https://doi.org/10.5194/acp-22-9499-2022-supplement

Atmospheric Chemistry and Physics Open Access

Supplement of

The semi-annual oscillation (SAO) in the upper troposphere and lower stratosphere (UTLS)

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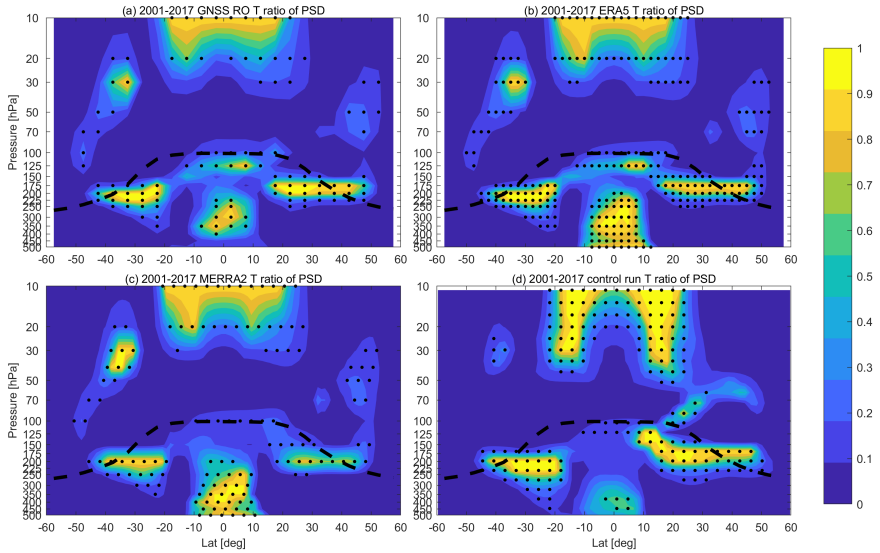

Figure S1: The ratio between SAO and annual cycle PSD based on COSMIC-1 (2007-2017) (a), ERA5 (2007-2017) (b), MERRA2 (2007-2017) (c) and model simulation (2007-2017) (d). The dots mark the significant area at 95% level.The dashed black lines mark the tropopause height calculated with GNSS RO data.

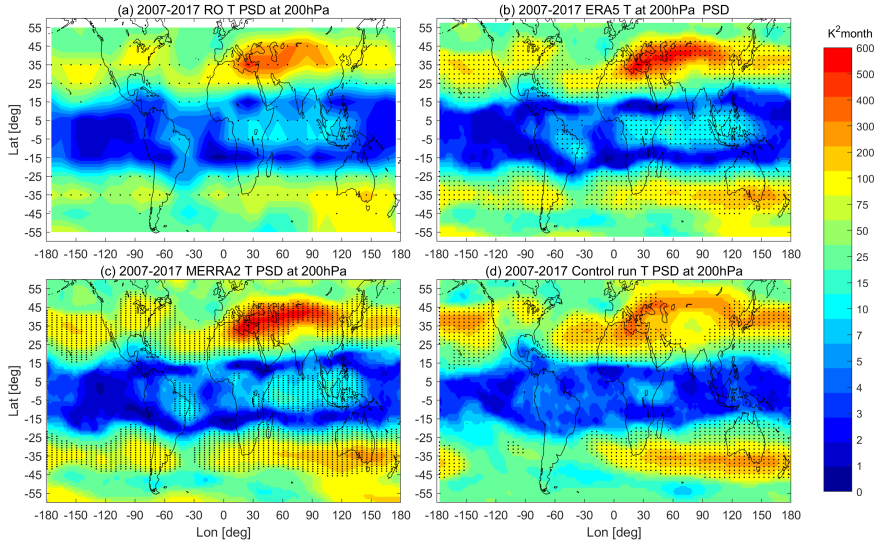

Figure S2: The PSD of SAO based on COSMIC-1 (2007-2017) (a), ERA5 (2007-2017) (b), MERRA2 (2007-2017) (c) and model simulation (2007-2017) (d) at 200hPa. The dots mark the significant area at 95% level.

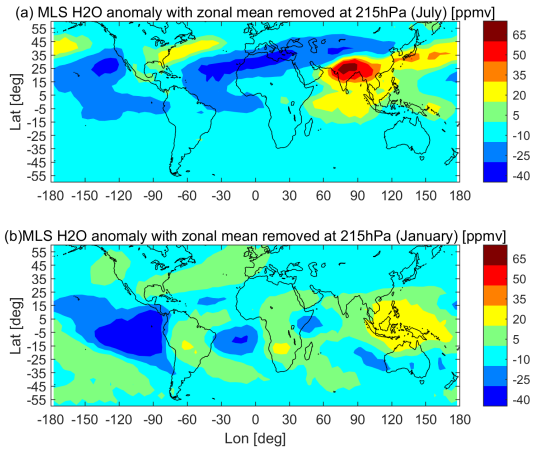

Figure S3: The July (a) and January (b) water vapor anomaly with zonal mean removed in ppmv of 2005-2017 microwave limb sounder (MLS) at 215hPa.

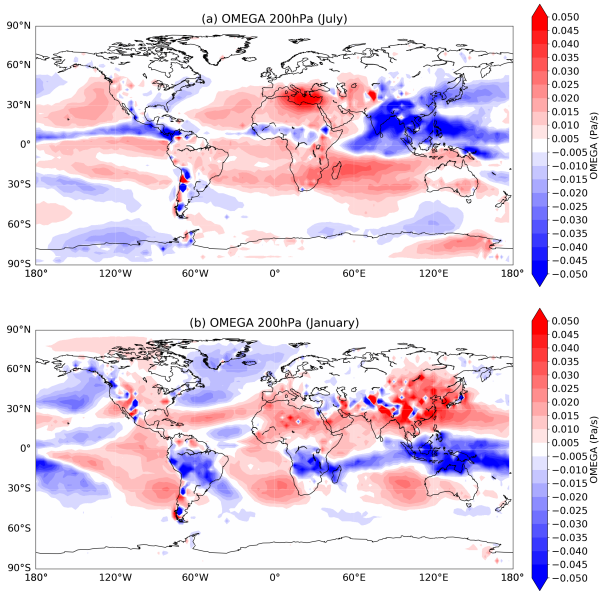

Figure S4: The July (a) and January (b) averaged vertical velocity in Pa/s of 2001-2017 ERA5 at 200hPa.

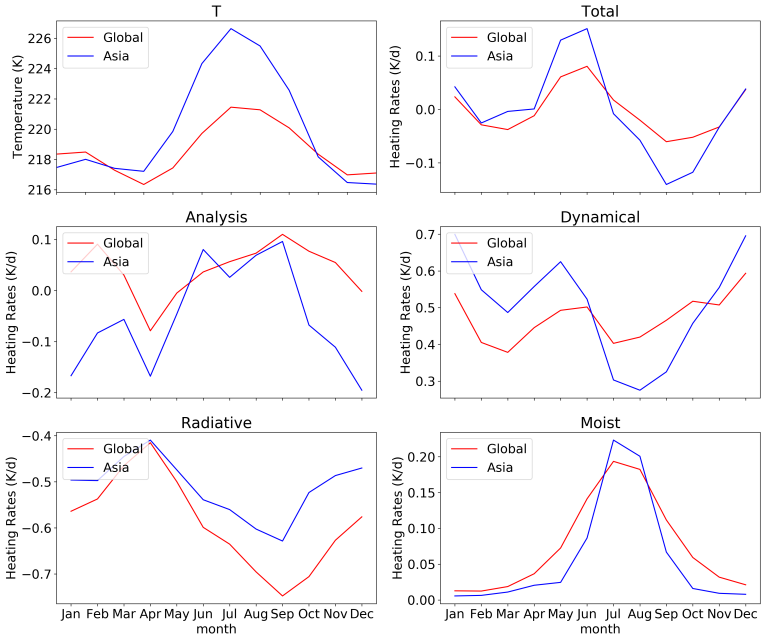

Figure S5: Annual cycle of the zonal mean temperature (T), total heating rates (Total), analyzed heating rates (ANA), dynamical heating rates (Dynamical), radiative heating rates (Radiative), and moist heating rates (Moist) at 200hPa averaged around the Asia region with blue lines (25°N-45°N, 20°E-100°E) and global region with red lines (25°N-45°N) using MERRA2 data. The total heating rates equal the sum of analyzed, dynamical, radiative, and moist heating rates.

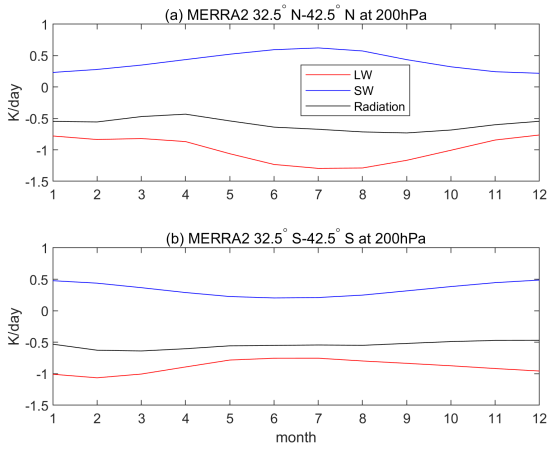

Figure S6: MERRA2 annual cycle of radiation heating rates at 200 averaged around the Northern Hemisphere Mid-latitudes (NHM) 32.5°N-42.5°N (a) and the Southern Hemisphere Mid-latitudes (SHM) 32.5°S-42.5°S (b). The red, blue and black lines indicate the heating rates related to long-wave, short-wave and radiation terms.

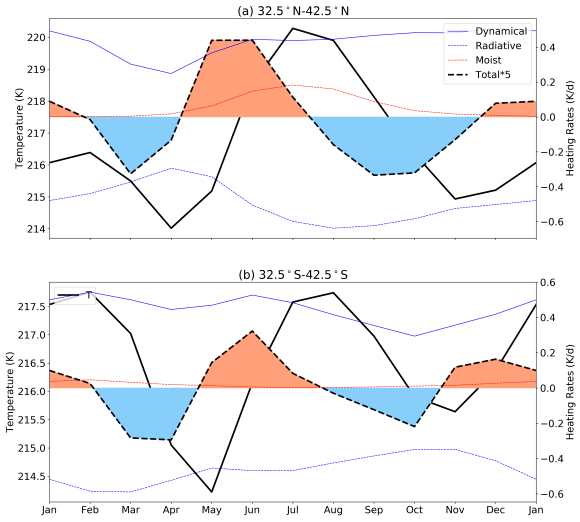

Figure S7: Annual cycle of the zonal mean temperature (T) and heating rates at 200 hPa averaged around the NHM 32.5°N-42.5°N (a) and the SHM 32.5°S-42.5°S (b) based on Control simulation. The blue, dashed blue and dashed red lines indicate the heating rates related to dynamics, radiation and condensation processes, respectively. The positive total heating rates are filled with light red color and the negative total heating rates are filled with light blue color. The total heating rates, which are the sum of dynamical, radiative and moist heating rates, have been 5 times enlarged to be more visible in the figures.

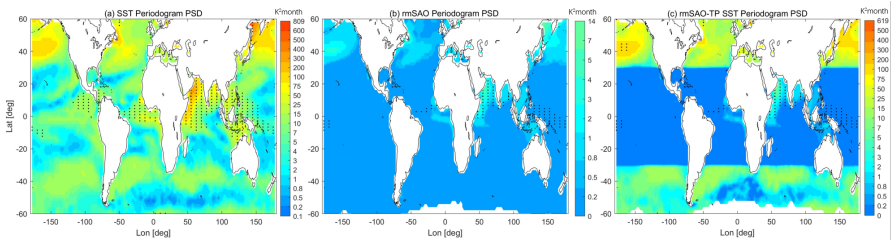

Figure S8: SAO power spectrum of SSTs in the Control (a), rmSAO (b) and rmSAO-TP (c) simulations. The dots indicate where the SAO power spectrum is significant.

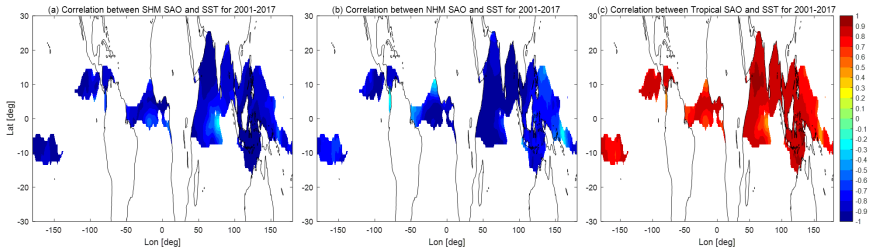

Figure S9: Correlation between ERA5 temperature SAO signal at 200 hPa averaged around the SM (32.5°S-45°S, 20°E-100°E) (a), NM (32.5°N-45°N, 20°E-100°E) (b), Tropical SAO (5°S-5°N, 20°E-100°E) (c)),and SST-SAO.