

Supplementary Information

Climate Dynamics (CLDY)

Coupling between maximum temperature and ozone levels in the lower stratosphere and extreme cooling events in Northeast China

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1. Seasonal change in monthly mean profile of tropopause pressure/altitude in the Northern Hemisphere

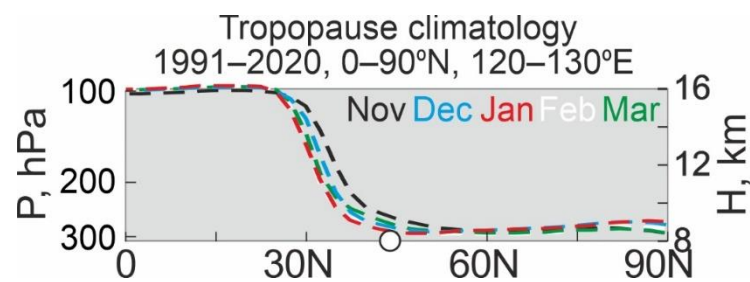


Fig. S1. Seasonal change in monthly mean profile of tropopause pressure/altitude in the Northern Hemisphere meridional plane averaged in the Changchun longitude segment 120–130°E. The NCEP-NCAR reanalysis (NRR) data are used.

2. Climatology of the monthly mean air temperature in the Northern Hemisphere

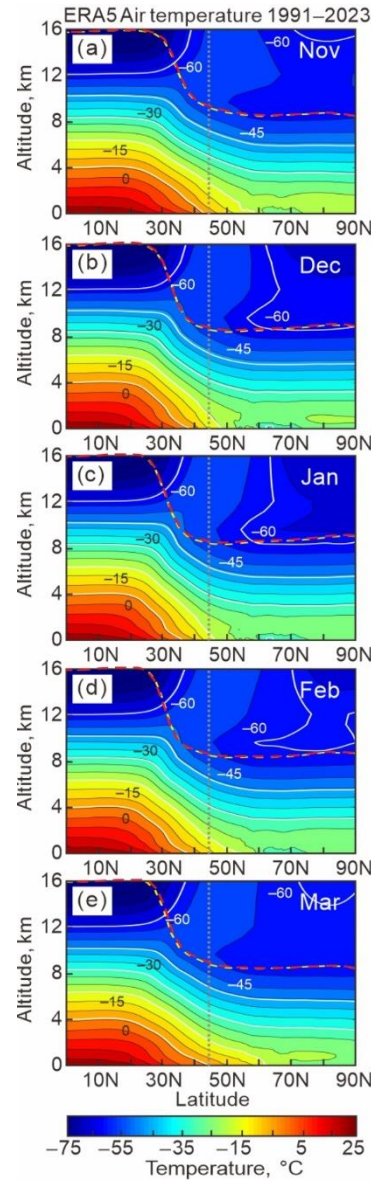


Fig. S2. Climatology of the monthly mean air temperature in the Northern Hemisphere in the latitude–pressure cross-section (0–90°N; 1000–100 hPa, or 0–16 km) for the Changchun segment 120–130°E in (a) November, (b) December, (c) January, (d) February and (e) March. The ERA5 reanalysis data of 1991–2023 are used. Compare to Fig. 2 of the main text based on the NNR data. Yellow and red dashed curves show tropopause pressure profiles from the ERA5 and NNR reanalyses, respectively.

3. Stratospheric temperature at the 100-hPa pressure level

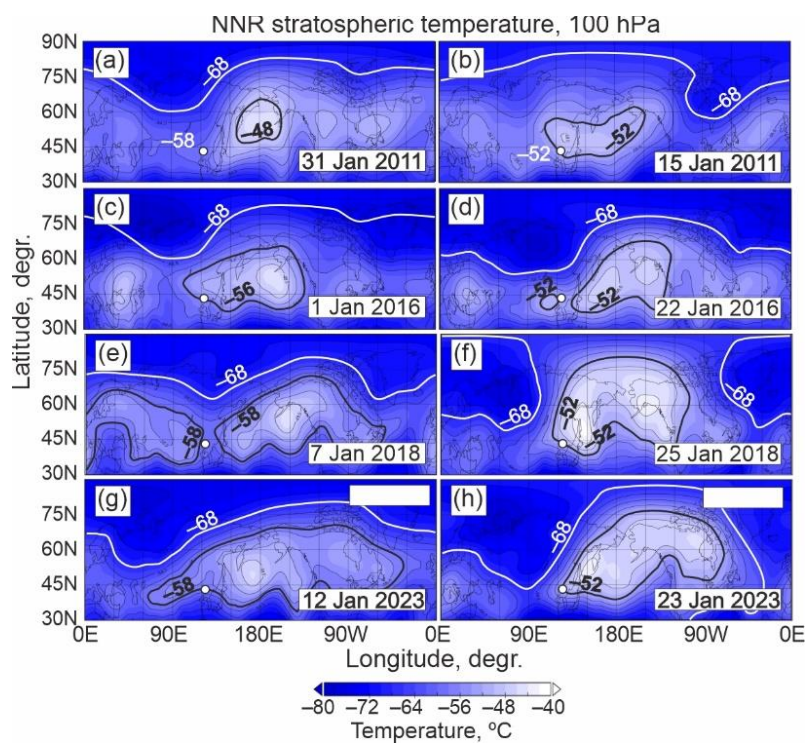


Fig. S3. Stratospheric temperature at the 100-hPa pressure level in the days of (left) highest and (right) lowest surface temperatures in Changchun in January (a, b) 2011, (c, d) 2016, (e, f) 2018 and (g, h) 2023. The white contour of -68°C marks the conditional boundary of the coldest air, and the black contour characterizes the temperature change in the region adjacent to the city. The NNR data are used.

4. Time series of MERRA2 zonal mean temperature for the four winters

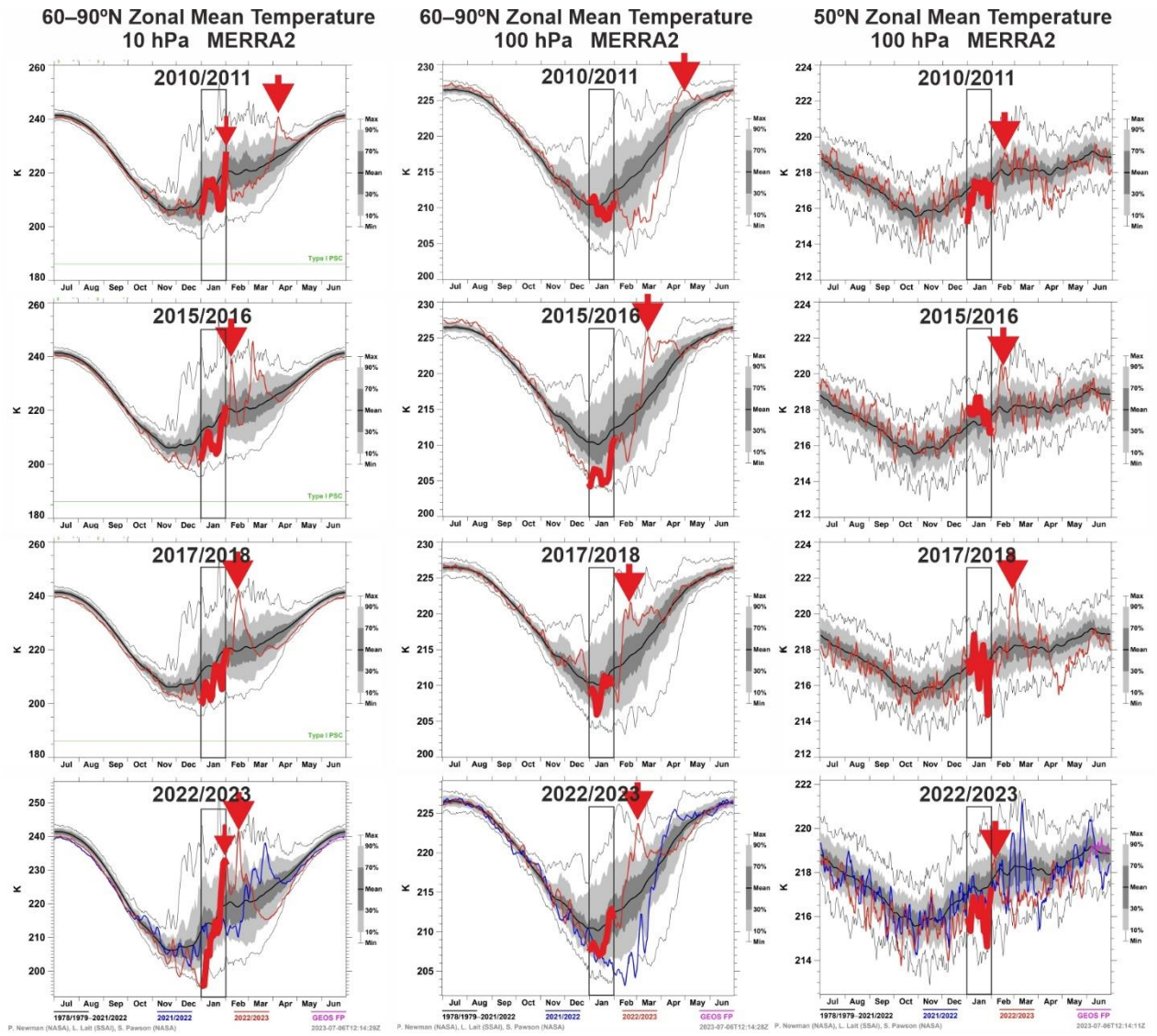


Fig. S4. Time series of MERRA2 zonal mean temperature for the four considered winters. The left and middle columns show pressure levels of 10 hPa (middle stratosphere) and 100 hPa (lower stratosphere) in the polar region 60–90°N. The right column is for a pressure level of 100 hPa at a circle of midlatitudes of 50°N. Red arrows indicate dates of minor, major and final warmings. The red thickened parts of the curves show January temperature fluctuations relative to long-term mean values (thick black curve). Data are available at the National Aeronautics and Space Administration, Goddard Space Flight Center, Atmospheric Chemistry and Dynamics Laboratory website from https://acd-ext.gsfc.nasa.gov/Data_services/met/ann_data.html.