Polar ozone anomalies, radiative effects, and their connection to mesospheric tidal dynamics during extreme events

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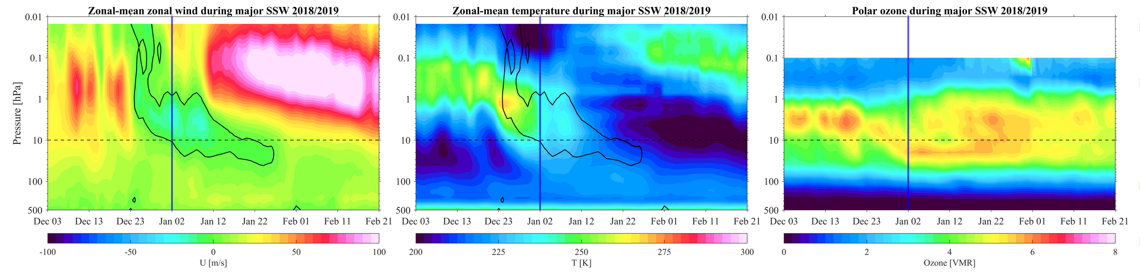
Motivations & Objectives

In the context of extreme events, such as sudden stratospheric warmings (SSWs), these events can disrupt atmospheric circulation, leading to substantial changes in polar ozone as well as affecting the dynamics of the mesosphere and lower thermosphere (MLT) [1,2]. Ozone is a major contributor to short-wave heating and long-wave cooling in the middle atmosphere, thereby influencing the radiation balance. By combining tidal amplitude anomalies with ozone variations, induced by large-scale dynamical changes caused by the breaking of planetary waves, this research provides new observational insights into ozone anomalies, transport, and tides at polar latitudes, enhancing our understanding of the complex interactions between atmospheric constituents and dynamic processes. Key questions are as follows:

- How do diurnal tide (DT), semidiurnal tide (SDT) amplitudes in the polar MLT vary during and after major SSWs?
- How do changes in ozone during major SSW events contribute to shortwave heating and longwave cooling rates?
- What role does ozone play in radiative processes that influence mesospheric tidal enhancements?

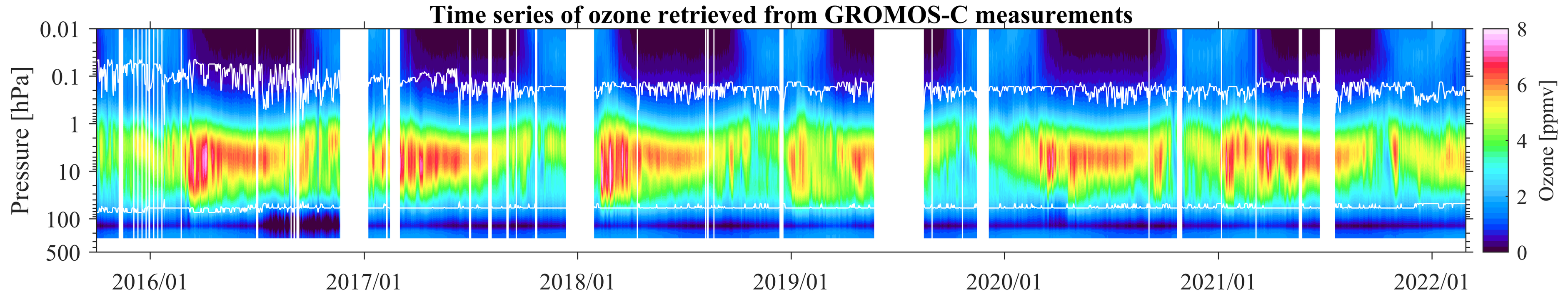


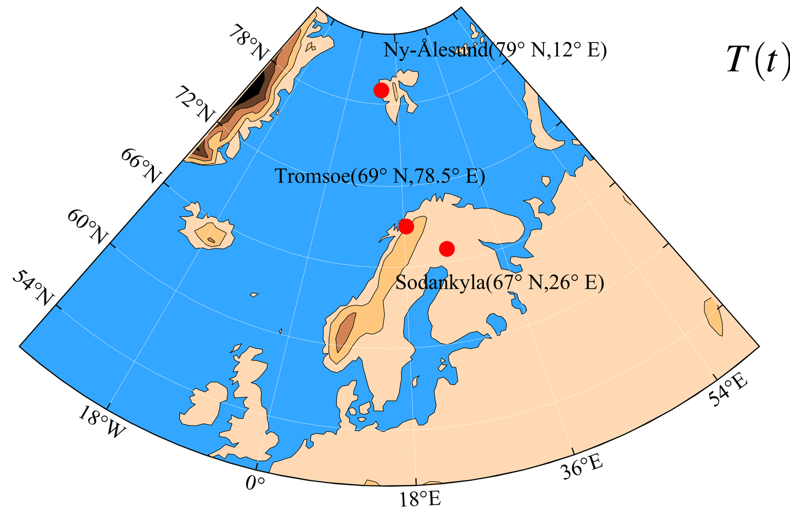
- Definition of SSW event.
- Zonal wind reverses from westerly to easterly.
- Zonal temperature increases rapidly.
- Ozone is greatly enhanced from the onset.

Instruments and datasets

GROMOS-C, Meteor Radars, Aura/MLS satellite, MERRA-2 reanalysis, and WACCM-X(SD) model datasets

- Ground-based microwave radiometer
- Built by the University of Bern
- Located in Ny-Ålesund, Svalbard (79° N, 12° E)
- Measures the 110 GHz ozone emission line at 22° elevation
- Observations in four cardinal directions (N, E, S, W)
- Altitude range: 20 - 70 km
- Vertical resolution: 10-12 km
- Time resolution: 2 hours
- Observation period: September 2015 to present

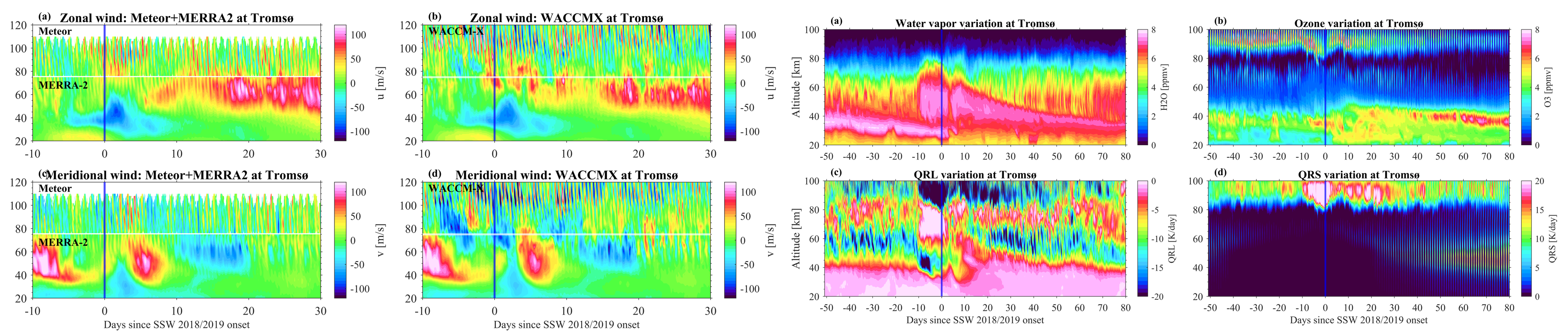




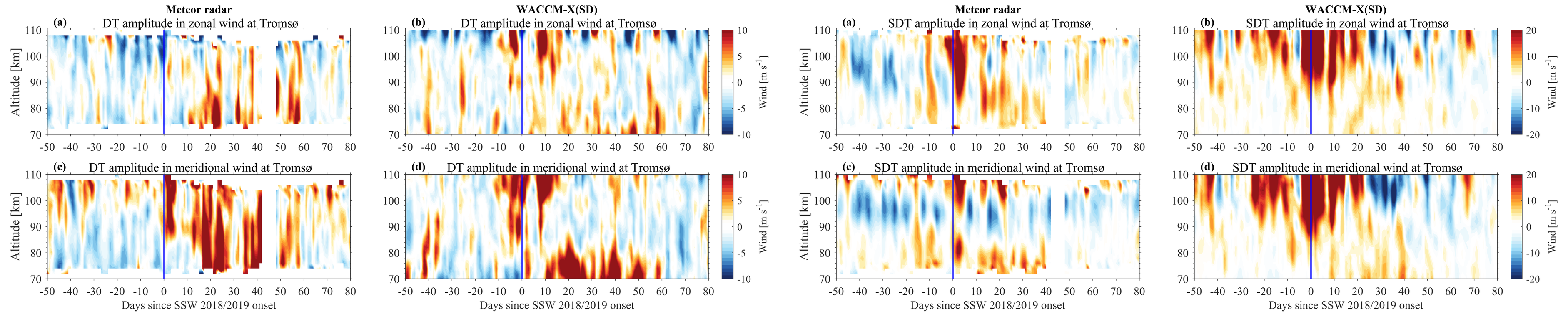
$$T(t),u(t),v(t) = T_0,u_0,v_0 + \sum_{n=1}^{3}\left[A_n \sin\left(\frac{2\pi}{P_n}t\right) + B_n\cos\left(\frac{2\pi}{P_n}t\right)\right] \quad (1)$$

- T, u, and v are temperature,zonal and meridional winds
- P_n is 8, 12 and 24 h, corresponding to terdiurnal tides (TDT), semidiurnal tides (SDT) and diurnal tides (DT)
- A_n and B_n denote the Fourier coefficients for the tidal amplitudes.
- The zonal mean zonal and meridional wind and the zonal mean temperature are given by T_0, u_0, and v_0.

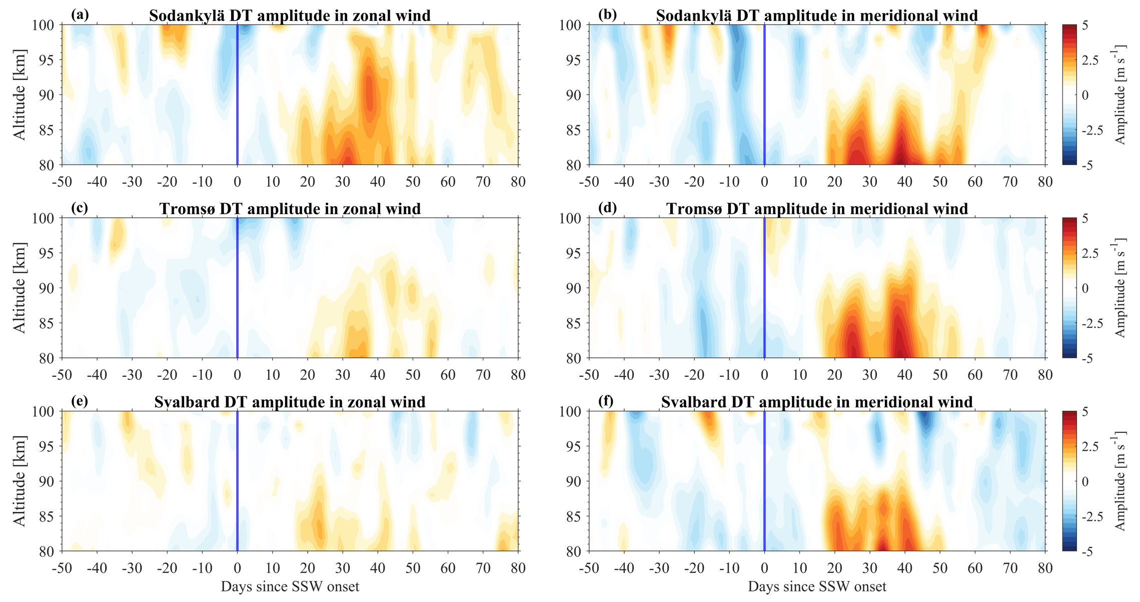
Case study: trace gases, heating/cooling rates, and tides during SSW 2018/2019



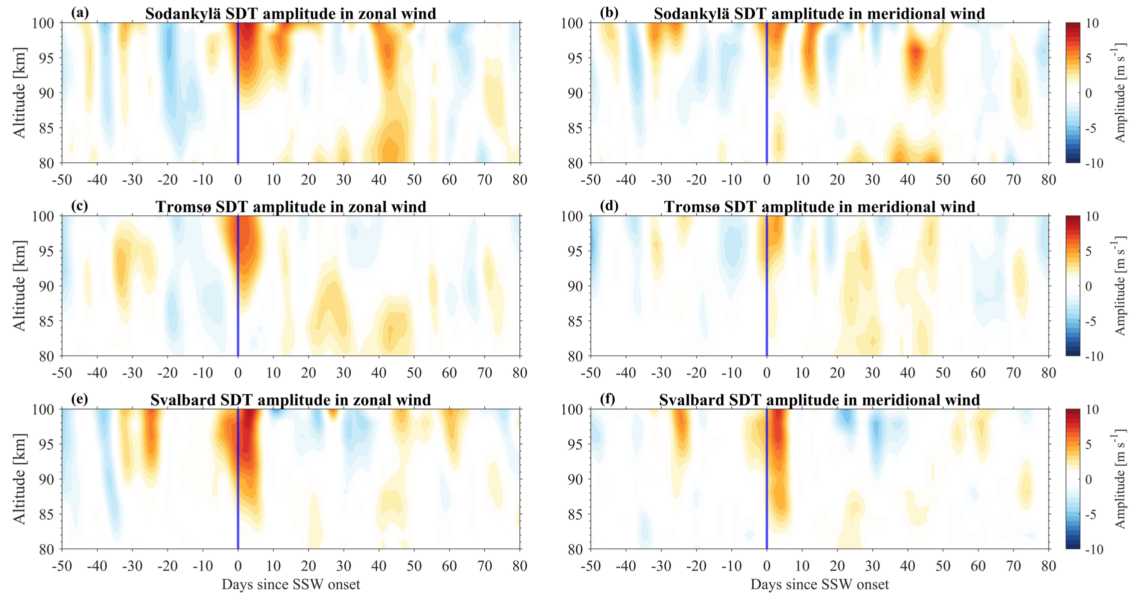
- Initial comparison of WACCM-X(SD) and combined Meteor Radar and MERRA-2 fields for SSW 2018/2019
- The 3-hourly ozone and water vapor VMR, long-wave cooling rates (QRL), and short-wave heating rates (QRS) variations for the location of Tromsø during SSW are observed.
- Variations in QRL are more closely aligned with temperature (warming in the stratosphere, cooling in the mesosphere, and warming above) rather than changes in water vapor. Variations in QRS are primarily associated with ozone in the middle atmosphere.



Superposed epoch analysis of the mean response of tides during SSW events

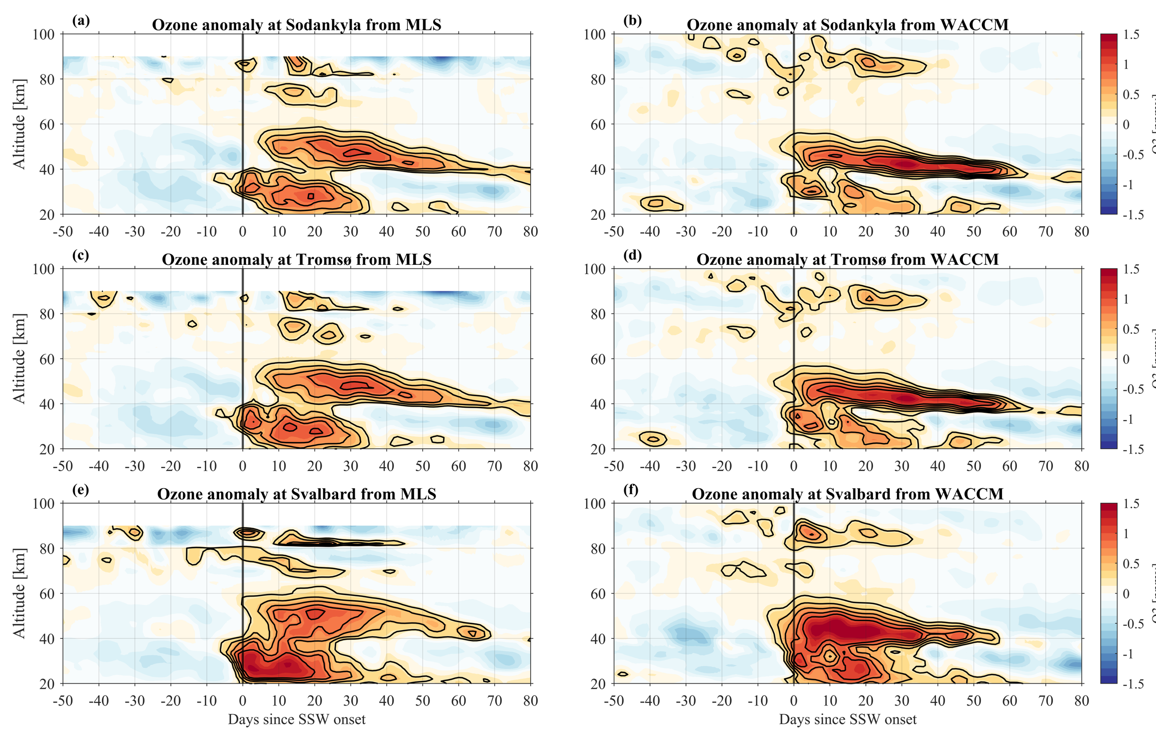


- DT amplitude starts to enhance around 20 days after the SSW onset, reaching a peak nearly 40 days post-SSW.
- This enhancement in DT amplitude persists for about a month, indicating a delayed response to the SSW.
- The stronger positive amplitude anomalies are more evident in the meridional wind component than in the zonal wind component.

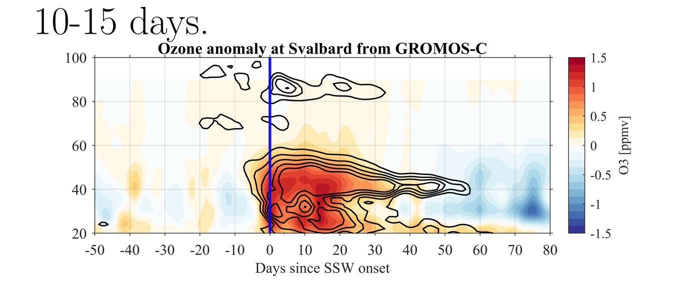


- SDT amplitude anomalies at the three stations, in both wind components, can reach up to 10 m/s close to the SSW onset.
- Indicate an enhancement of SDT amplitude during SSW.
- The SDT amplitude anomalies are found to be approximately twice as large as those of DT, highlighting the sensitivity of SDT to SSW-induced disturbances.

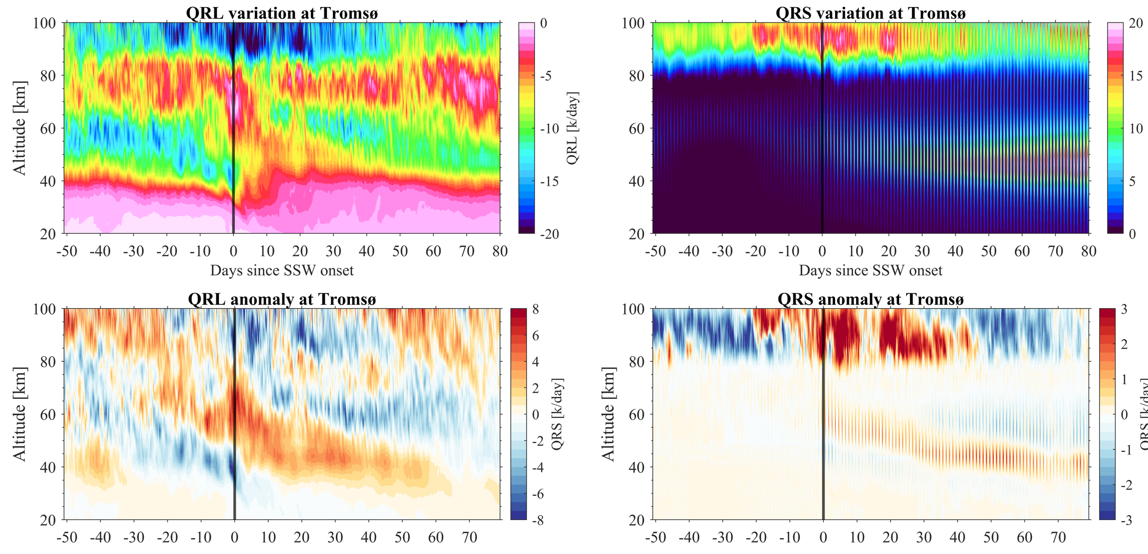
Superposed epoch analysis of ozone anomalies during SSW events

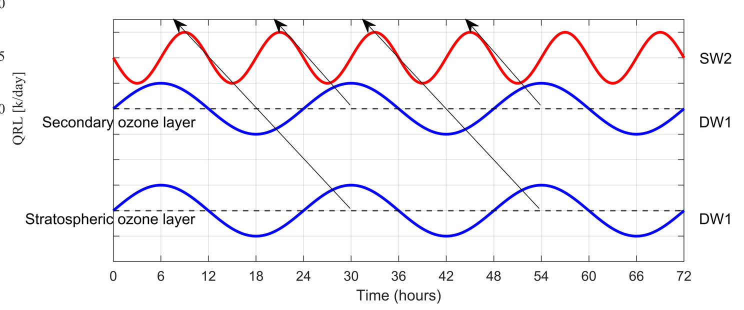


- Positive ozone anomalies are up to 1.5 ppmv and persist for approximately two months after the onset in the stratosphere.
- The persistence of positive ozone anomalies reflects prolonged changes in middle atmospheric circulation following the SSW.
- The secondary ozone layer responds to the SSW with anomalies reaching a maximum 10-15 days.



Superposed epoch analysis of radiative processes during SSW events





Mixing of two diurnal tidal forcings at the mesosphere and stratosphere due to ozone and other chemical species forces two diurnal tidal waves.

- The wave mixing approach, which involves two diurnal tidal waves influenced by the absorption of solar radiation at different altitudes and their vertical propagation, enables the mechanism for enhancing the SW2 during SSWs.

Conclusions

- The strongest positive ozone anomalies of up to 1.5 ppmv for more than 30 consecutive days after the SSW onset in the middle and upper stratospheric layers are evident.
- Leveraging the meteor radars at high-latitude stations, enhancements of SDT and DT amplitudes are observed in the mesosphere and lower thermosphere during and after SSWs.
- The immediate responses of SDT are most likely driven by dynamical effects accompanied by the radiative effects.
- Radiative forcing change during SSW likely plays a secondary role in DT tidal changes, but appears to be important 20 days after the event towards the spring transition.

References

1. Shi, G., Krochin, W., Sauvageat, E., and Stober, G.: Ozone anomalies over the polar regions during stratospheric warming events, Atmospheric Chemistry and Physics, 24, 10 187–10 207, 2024.
2. Stober, G., Baumgarten, K., McCormack, J. P., Brown, P., and Czarnecki, J.: Comparative study between ground-based observations and NAVGEM-HA analysis data in the mesosphere and lower thermosphere region, Atmospheric Chemistry and Physics, 20, 11 979–12 010, 2020.

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