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Editorial: Stratosphere-Troposphere Coupling and its Role in Surface Weather Predictability

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Editorial on the Research Topic

Stratosphere-Troposphere Coupling and its Role in Surface Weather Predictability

The stratosphere can affect the troposphere and surface through various chemical, radiative, and dynamical processes. This coupling between the troposphere and stratosphere, often referred to as the "downward impact" of stratospheric variability, provides long lead information for leading modes of tropospheric variability such as the Arctic Oscillation, and their associated extreme weather. Incorporating stratospheric variability realistically in models can help improve both weather forecasts and climate predictions.

This Research Topic brings together a total of 8 papers studying the underlying dynamic/thermodynamic processes of stratosphere-troposphere couplings, their impacts on surface weather, their contribution to climate change, and their influences on temporo-spatial variations of trace gases important for environmental health. An improved understanding of these processes is essential to maximizing the value of the upper-boundary in the operational sub-seasonal forecasts, (complimentary to the low-frequency low-boundary forcing from ocean and land), and in future climate change projections. The findings of the studies published in this Research Topic provide ample evidence supporting the importance of stratosphere.

The stratospheric "downward impact" is found not to be the same or even present in all cases. The quasi-simultaneous relationship between stratospheric anomalies and weather regimes is one of the focuses of this Research Topic. The best-known phenomenon, Sudden stratospheric warmings (SSWs), and its weather impact have been revisited by Choi et al. Building on the traditional two-type classification (i.e., displacement and split types), they put forward a new three-type classification that yields a clearer picture of the relationship between weak vortex states and tropospheric cold events. Specifically, they classified the conventional split type into displacement–split (DS) and split–split (SS) types based on the temporal evolution of the stratospheric polar vortex structure and wavenumber-1 and -2 wave activities. The conventional displacement type is classified as a displacement–displacement (DD) type. It is found that the surface air temperature drops notably over central to eastern North America within 20 days following a DS-type SSW. Hence, distinguishing among the three types of SSW can help improve forecasts of cold weather over North America, although the mechanism for the development of the North Pacific ridge remains to be investigated. In addition to the cold temperatures associated with a weakened stratospheric polar vortex, abnormally warm temperatures can be partly explained by the stratosphere as well. Zhang et al. reported that the abnormal warm weather in 2019/2020 winter and spring was highly related to the continuously positive Arctic Oscillation. One of the critical dynamical processes responsible for the continuously positive phase of Arctic Oscillation is the strong upward propagation of planetary

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waves that causes the subsequent downward propagation of the zonal circulation anomalies from the stratosphere to the troposphere.

On interannual timescales, the stratospheric polar vortex also exhibits a close linkage to the winter climate in the extratropics. The anomalous weakening of the stratospheric polar vortex in winter can be closely related to the joint effect of a La Niña event, the west phase of the Quasi-Biennial Oscillation (QBO) and warm sea surface temperature anomalies in the North Pacific, based on findings of Han et al. In turn, the stratospheric pathway is a major driver of El Niño– Southern Oscillation impacts on the mid-latitude tropospheric circulation and winter weather. The weakened stratospheric polar vortex induced by El Niño conditions tends to increase the risk of cold spells, especially over Eurasia. However, for North American, Zhou et al. reported the decrease of extreme cold events during extreme El Niño events, which is attributed to the advection of warmer air masses guided by an enhanced ridge over Canada and a trough over the Aleutian Peninsula. Moreover, Zhang et al. find that the combination of the El Niño and a rare SSW event in the Southern Hemisphere that occurred in austral spring 2019 caused the reduced precipitation in eastern Australia. This reduced precipitation led to the 2019–20 Australian Bushfire, which then further impacted the atmospheric environment.

Another topic in this Research Topic is the transport and chemistry of trace gases in the stratosphere, with a particular focus on ozone, Hydrogen chloride (HCl), and carbon monoxide (CO) as they play a critical role in air pollution and global climate change. The "ozone valley" over the Tibetan Plateau in summer has attracted scientists' attention due to its important role in changing the amount of Ultraviolet radiation received at the surface. It is widely accepted that dynamical transport processes associated with the atmospheric circulation are important in the distribution of ozone. Applying the Lorenz circulation decomposition method on data with a high spatial and temporal resolution, Xu et al. investigated the respective effects of stationary and transient transport of ozone on the ozone valley over the Tibetan Plateau in summer. Their key findings show that the stationary zonal (meridional) transport of ozone strengthens (weakens) the ozone valley. The transient zonal (meridional) transport of ozone, in contrast, weakens (strengthens) the ozone valley, although the effect of transient transport is weaker than that of stationary transport. Chang et al. put forward several key factors affecting the variations of circulation anomalies and thus the resultant dominant patterns of the ozone valley. The east-west dipole mode of ozone in low latitudes is mainly attributed to air-sea interactions. The east-west tripole mode in mid-latitude region is related to the rise of tropopause height. The south-north mode is more sensitive to the location of the west Pacific subtropical high. The temporal variation of HCl, which can effectively change the gas phase chemistry of ozone depletion, is also of great interest for monitoring the recovery of the ozone hole. Han et al. found that the increasing trend of HCl in recent decades might be elusive. The trend no longer exists after removing the period of 2010–2011 when there was a significant increase of Northern Hemisphere stratospheric HCl due to a strong polar vortex and a weakened residual circulation. He et al. found that the CO mixing ratio within the Asian Summer Monsoon Anticyclone (ASMA) region tends to be higher in the east phase of the QBO and the investigated potential dynamical mechanisms behind it.

An emerging research question coming out of the papers included in the Research Topic is if and how the downward impacts from the stratosphere are related to the upward impacts from the troposphere either temporally (i.e., lead/lag) and/or spatially (i.e., spatially alternating upward/downward impacts). A better understanding of the spatiotemporal evolution of upward/ downward impacts would shed new light on how anomalous thermal forcings in the tropics (e.g., MJO and ENSO) and at the surface (e.g., sea ice and snow cover) influence weather and climate via tropical-extratropical and stratosphere-troposphere couplings. Another important research area is what are the sources of the relatively longer predictability in the stratosphere than the troposphere, and whether operational forecasts of weather/climate extremes at the surface are actualizing the benefits to be gained by considering the stratospheric state.

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YY wrote the main text with editing and additional contributions from MC and CG.

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