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Polar Vortex: long-term variability of main characteristics, and links to the dynamics of the troposphere

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Profound understanding of the stratospheric wintertime dynamics or stratospheric polar vortex (PV hereafter) and its climate changes are essential for improving seasonal forecast skill.
We tried to answer the following questions. Is there a persistent shift of PV from the pole? Is the "shifted" PV weaker than "centered" on the pole or not? What anomalies of the planetary waves activity leads to PV displacement? Is there a response in the tropospheric dynamics to the displacement of PV from the pole and is the direction of this displacement important in this scope? Whether there is a long-period variability of the vortex strength?
To answer these questions firstly it is essential to define PV states and their clustering. Manual classification is a highly time-consuming task suffering of researcher subjectivity. Instead of manual classification, we applied deep learning methods that let us clustering PV states based on their spatial structure. We used a particular kind of neural networks named sparse variational convolutional autoencoder (SpCVAE), in conjunction with the state-of-the-art clustering algorithm. PV states were described by geopotential fields at the 10 hPa level from JRA55 (Japanese 55-year Reanalysis). This method for the first time is capable of discriminating weak PV states of types "displacement" and "split" which is crucial for the stratosphere-troposphere interactions analysis. It is also able to classify weak PV states corresponding to its transitional periods or PV recovery.
For the first time also, the proposed method is capable of classifying stable states of strong PV with different directions of its center shift. This classification was found to be physically valid.
We have constructed the calendar of the PV states based on the clustering result. Clustered events of weak PVs were examined and demonstrated good correspondence with the calendar of sudden stratospheric warmings that have been built manually.
We showed that the frequency of the cluster describing a vortex centered at the pole has a significant negative trend, while a cluster describing a vortex with its center being shifted towards Eurasia has a positive trend. For other clusters, no significant trends were found. All of the above proves the significance of PV shifting.
For each time step, we calculated the velocity of the jet stream along the edge of the vortex. The edge of the vortex was determined by calculating the equivalent latitude and searching for the maximum gradient of potential vorticity. Thus it might be concluded that the "shifted" vortex is not weaker than the vortex centered at the pole.
By analyzing the matrix of transitions from one state to another, we demonstrated which anomalies of the Eliassen-Palm flux cause the shift of the vortex in one direction or another.
The presented clustering method for the first time provides an opportunity to analyze the influence of the strong PV with various shifts on circulation characteristics of the troposphere.
These results are now the basis for our stratosphere-troposphere interactions research for present and future climate scenarios.
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