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

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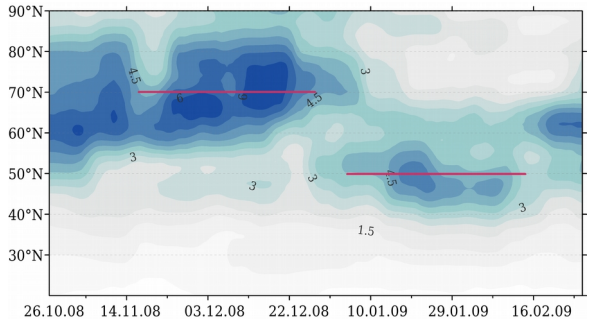
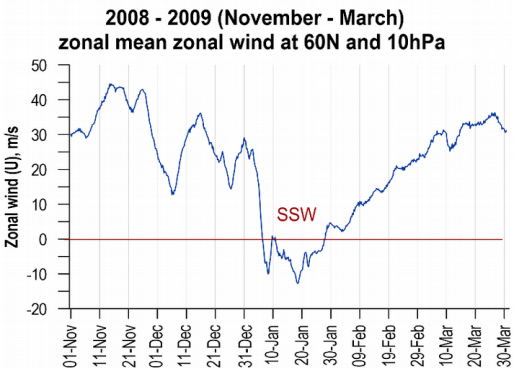
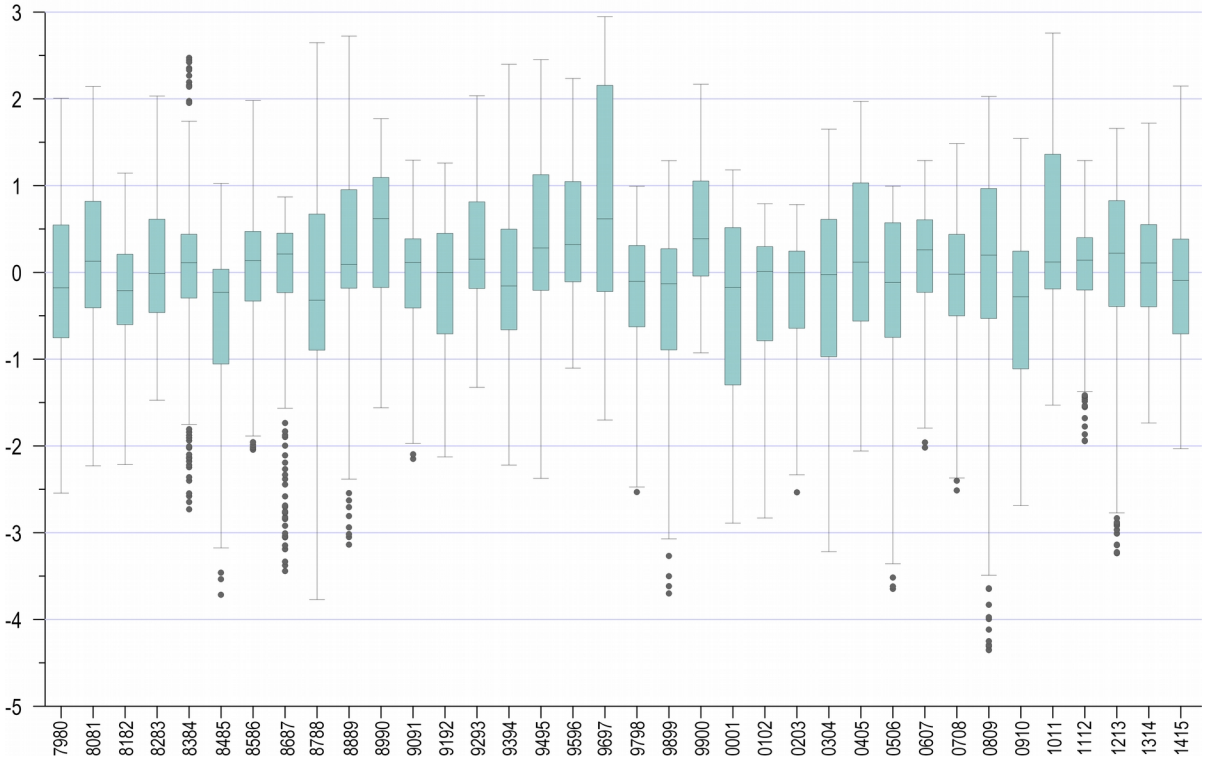
Motivation

Intra seasonal variability



Meridional time cross section of the HGT 1000 hPa, band-passed with period 2 – 6 days along 40 W





Kidston, J., Scaife, A. A., Hardiman, S. C., Mitchell, D. M., Butchart, N., Baldwin, M. P., & Gray, L. J. (2015). Stratospheric influence on tropospheric jet streams, storm tracks and surface weather. *Nature Geoscience*, *8*(6), 433.

Baldwin, M. P., & Dunkerton, T. J. (2001). Stratospheric harbingers of anomalous weather regimes. *Science*, *294*(5542), 581-584.

Question

- How the stratosphere affect the troposphere dynamics on long-term scales?

Points

- What is the role of the extremely strong polar vortex events?
- Is there a long term changes in the position and the strength of the Polar Vortex?

Clustering of the states of the Polar Vortex

Data **JRA 55**: 10hPa Geopotential Heights, Potential Vorticity at 850K north from 40°N

Dimension of the fields is 288 (lons) x 40 (lats) = **11520**

Time steps 59 winter periods (1958/59 – 2016/17) x 360 (6-hourly data) = **21240**

The curse of dimensionality (The expression was coined by Richard E. Bellman)

As the number of Features or Dimensions grows, the amount of data we need to generalize accurately grows exponentially.

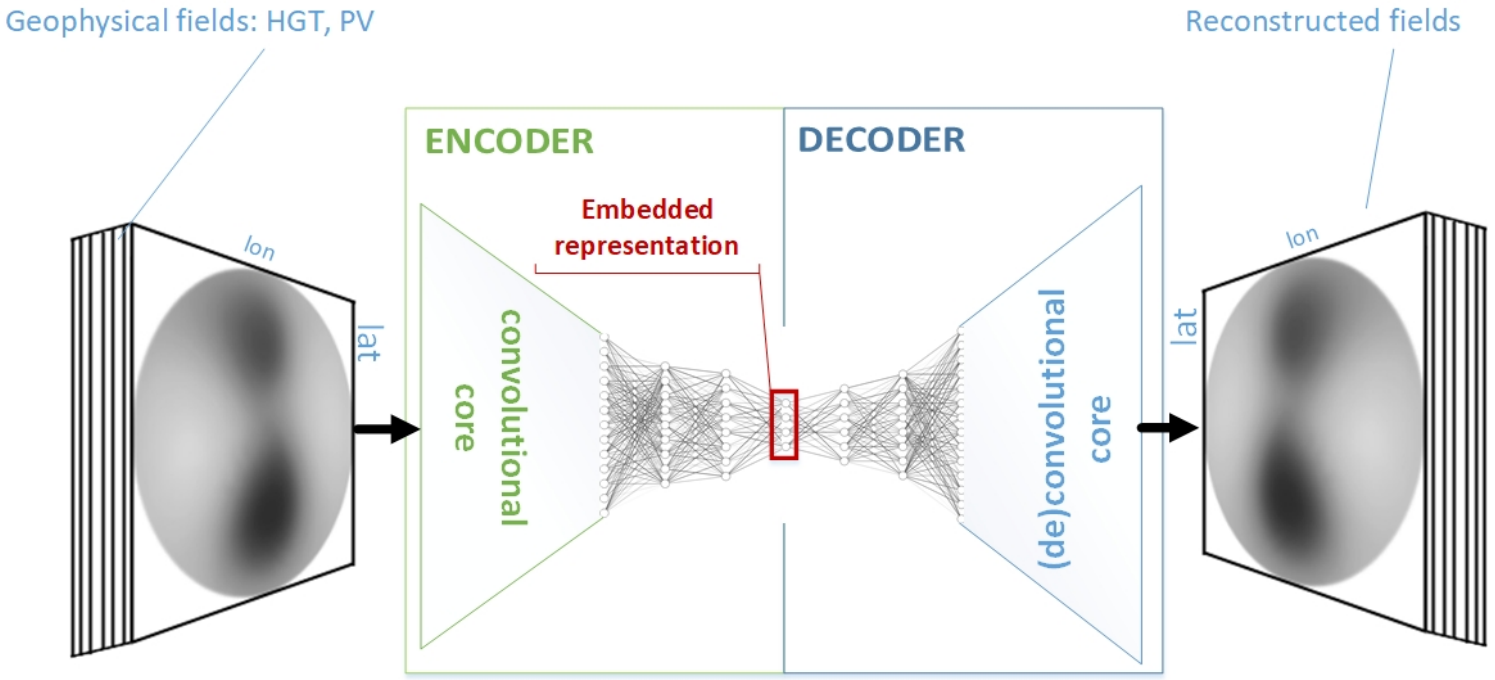
This phenomenon can have a considerable impact on various techniques for classification (including the k-NN classifier), semi-supervised learning, and clustering.

The first task is the **Reduction of Dimensionality**

Fujiwara, Masatomo, et al. "Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. " *Atmospheric Chemistry and Physics* 17.2 (2017): 1417-1452.

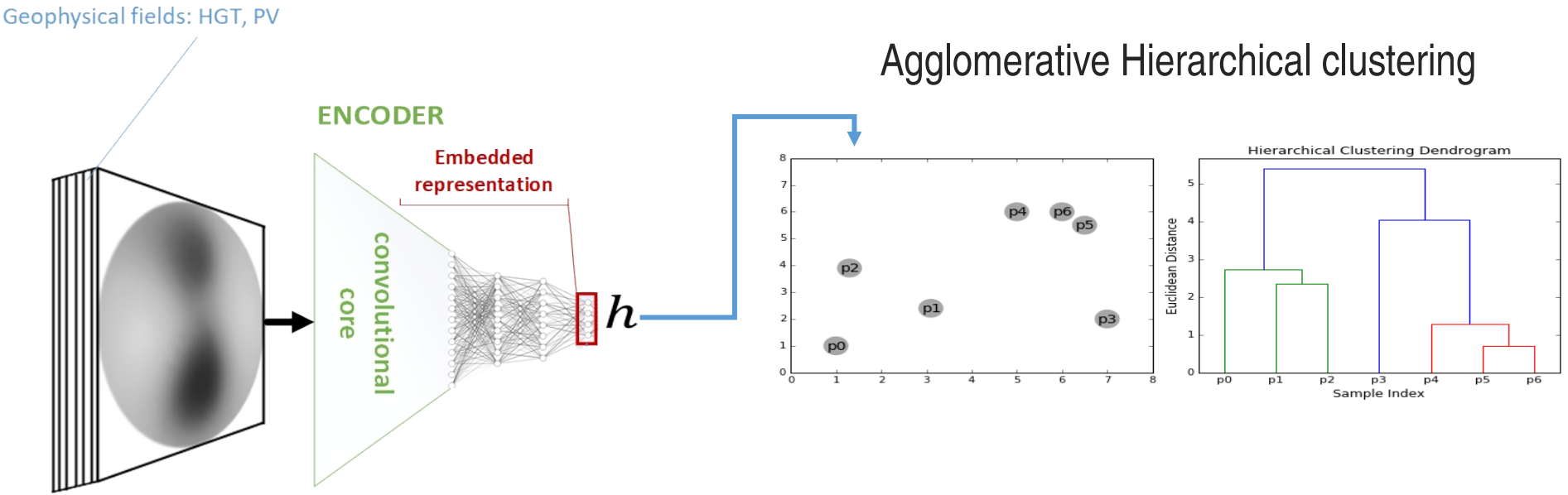
Reduction of dimensionality

Sparse Convolutional Variational Autoencoder (SpCVAE)



Key feature – convolutional neural networks (CNNs)
for nonlinear dimensionality reduction taken spatial features of examples into account

Clustering of the states of the Polar Vortex



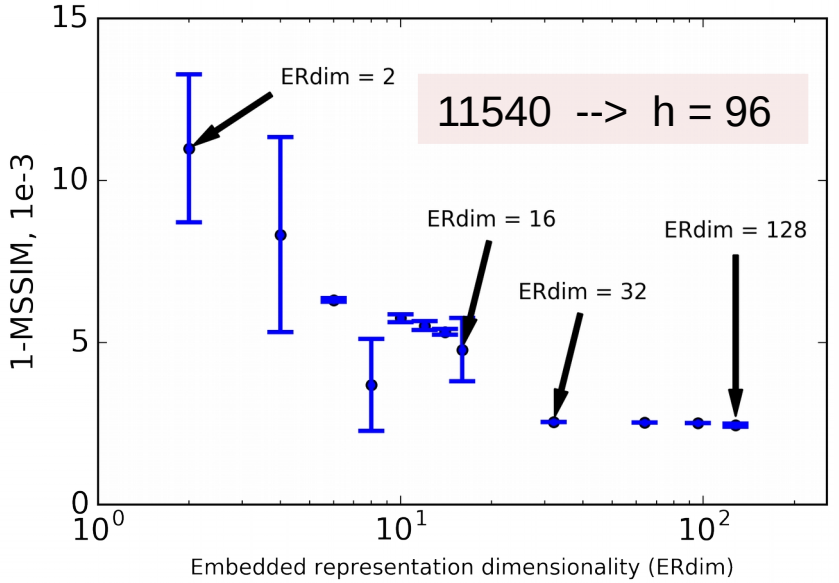
This is a "bottom-up" approach: each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy.

Minimization of the increase in variance for the cluster being merged (Ward's criterion)

Stop when we reach defined number of clusters

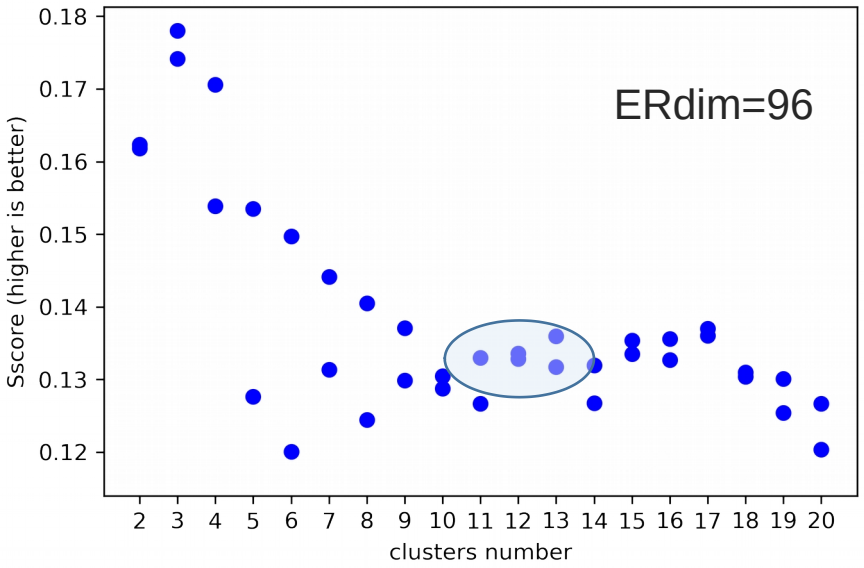
Hyperparameters choice

Dimensionality of the Embedded Representation



Multi-scale structural similarity index (**1-MSSIM** lower is better)

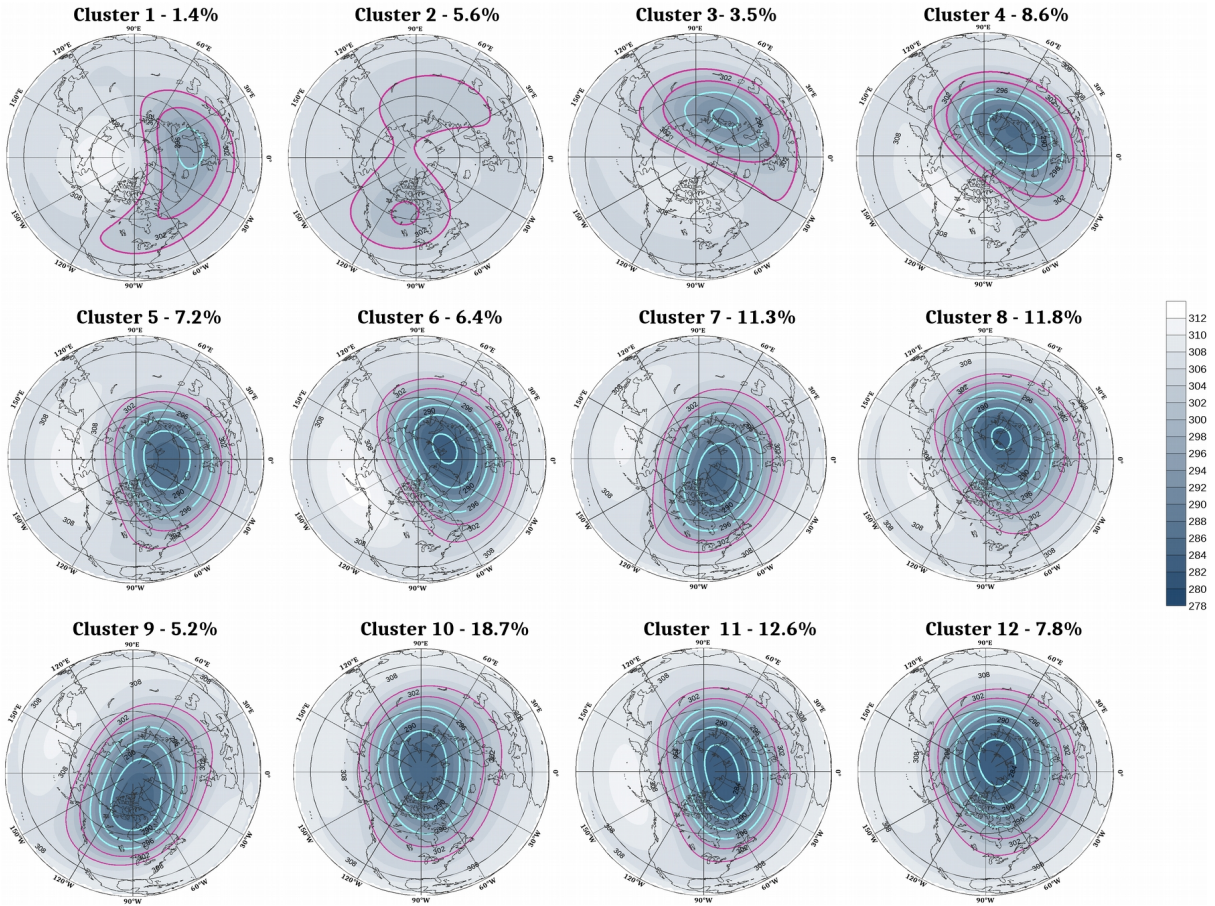
Number of Clusters

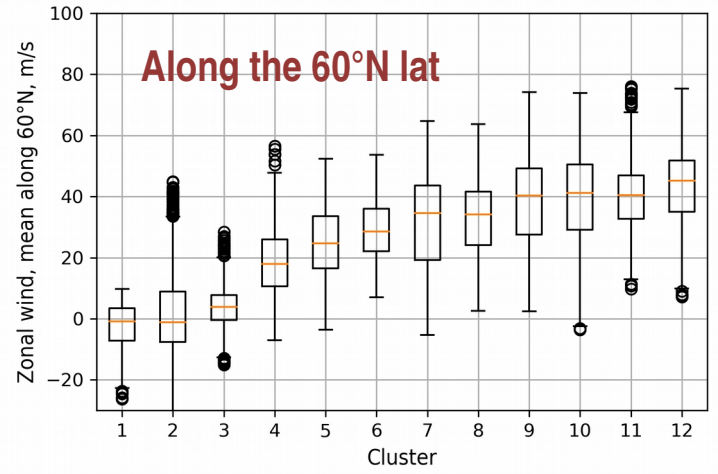


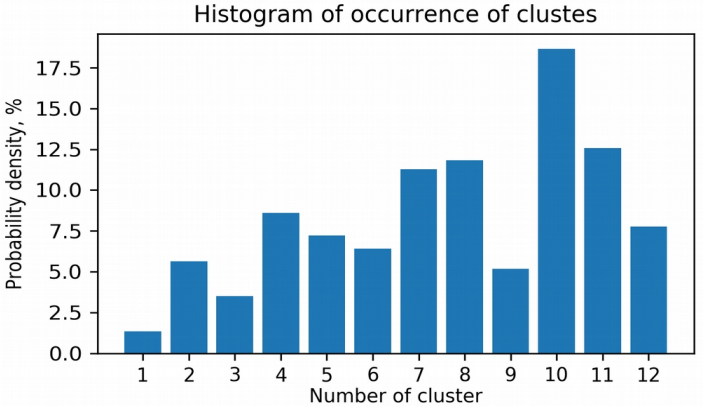
Silhouette score is a method of interpretation and validation of consistency within clusters of data (higher is better)

Cluster validation

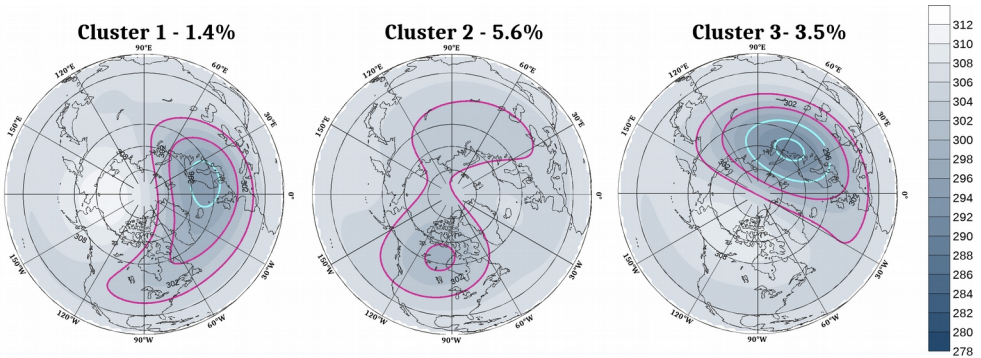
Geopotential heights 10 hPa composites [*10² m]



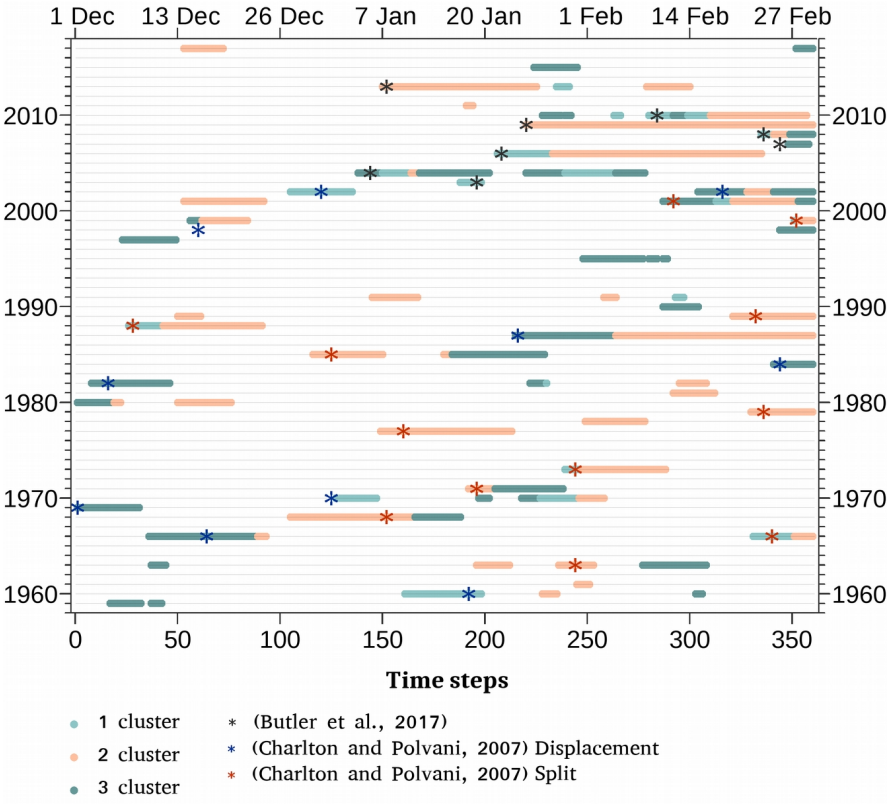




Cluster validation



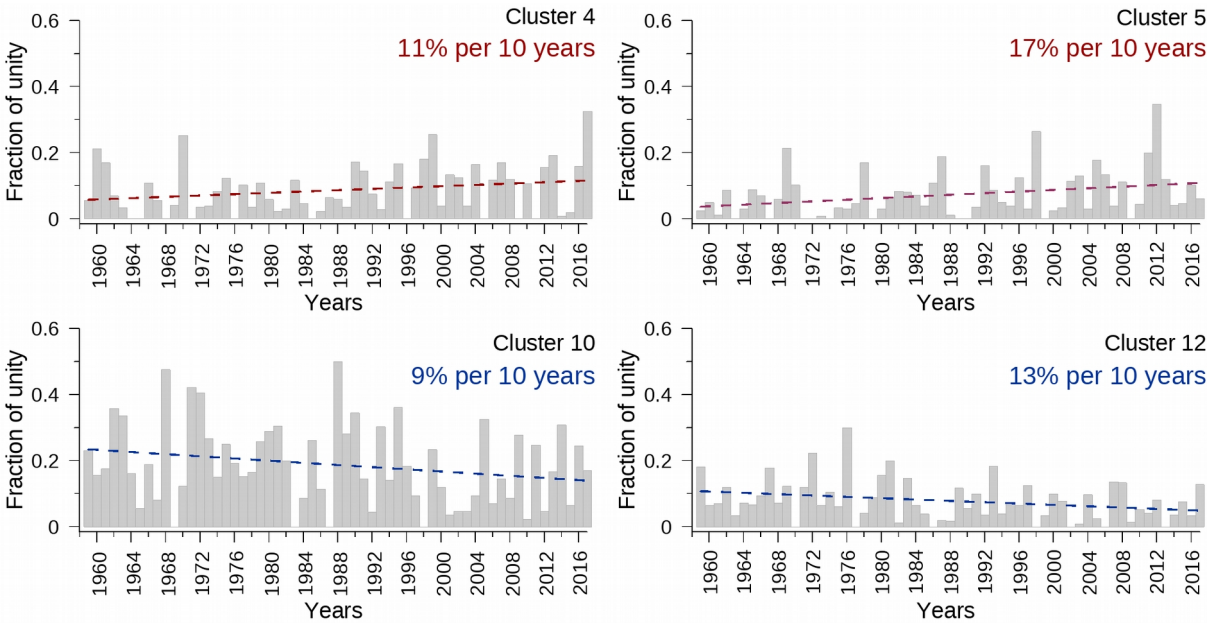
"… between 5 days before the central date and 10 days after the central date … "
(Charlton and Polvani, 2007)

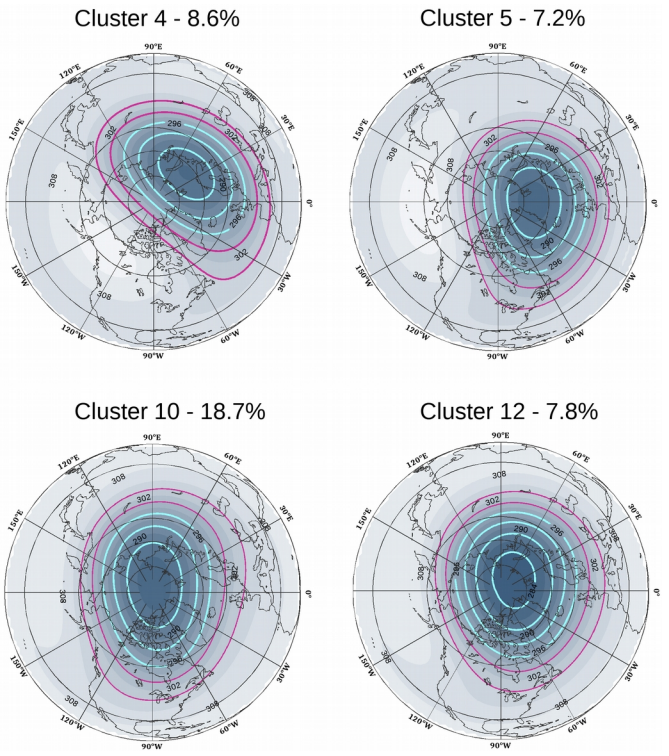


Charlton, A. J., & Polvani, L. M. (2007). A new look at stratospheric sudden warmings. Part I: Climatology and modeling benchmarks. Journal of Climate, 20(3), 449-469.
Butler, A. H., Sjoberg, J. P., Seidel, D. J., & Rosenlof, K. H. (2017). A sudden stratospheric warming compendium. Earth System Science Data, 9(1).

Linear trends in frequency of occurrence

Number of days of cluster per winter period (DJF)

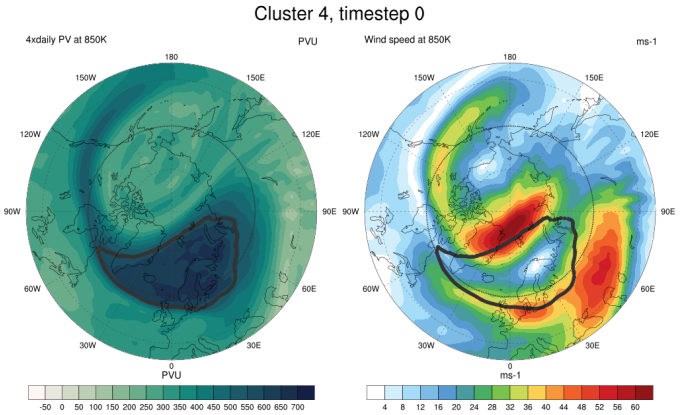


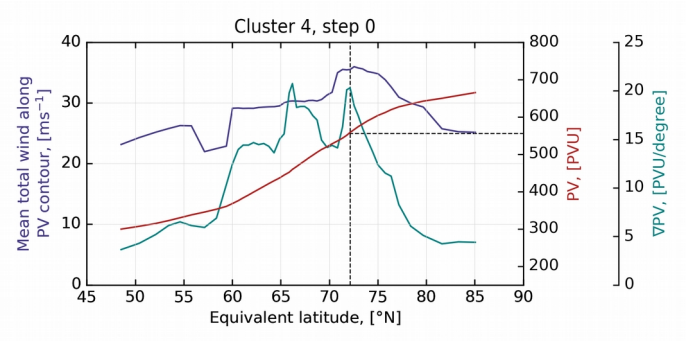


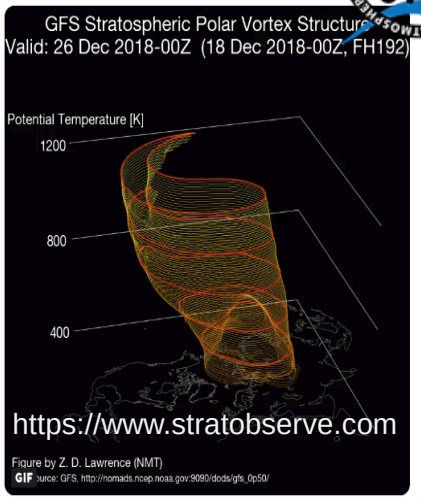
There is increasing probability of the “shifted” PV state (Zhang et al., 2016)

Zhang, J., Tian, W., Chipperfield, M. P., Xie, F., & Huang, J. (2016). Persistent shift of the Arctic polar vortex towards the Eurasian continent in recent decades. Nature Climate Change, 6(12), 1094.

Strength of the Polar Vortex (Edge finding)







Nash, E. R., Newman, P. A., Rosenfield, J. E., & Schoeberl, M. R. (1996). An objective determination of the polar vortex using Ertel's potential vorticity. Journal of Geophysical Research: Atmospheres, 101(D5), 9471-9478.

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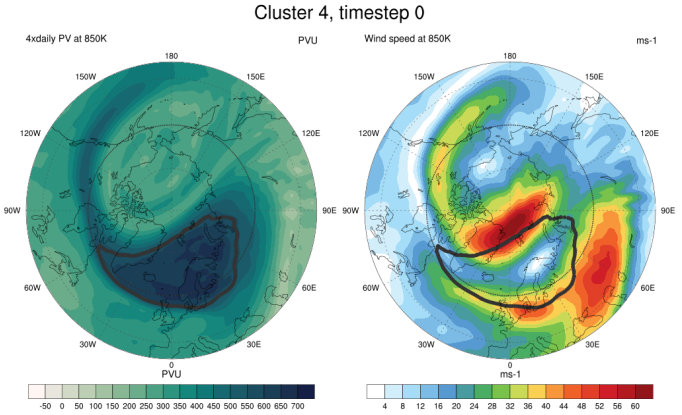
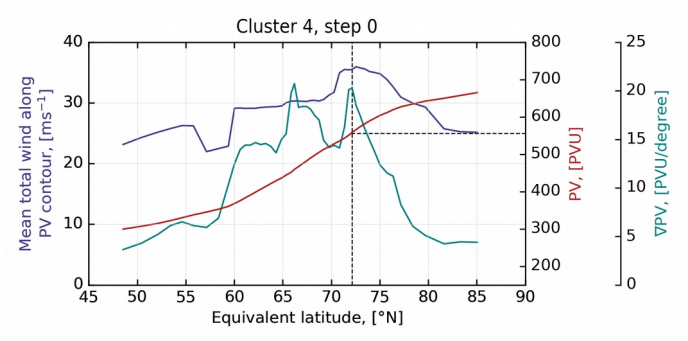
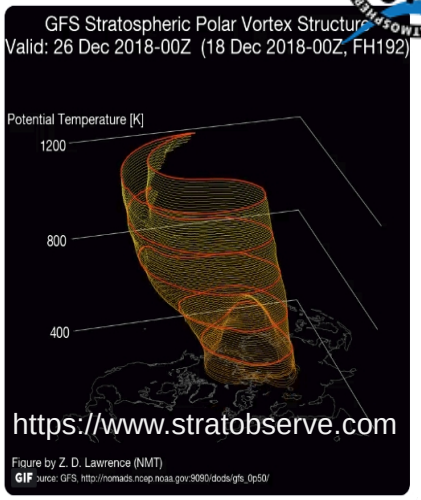
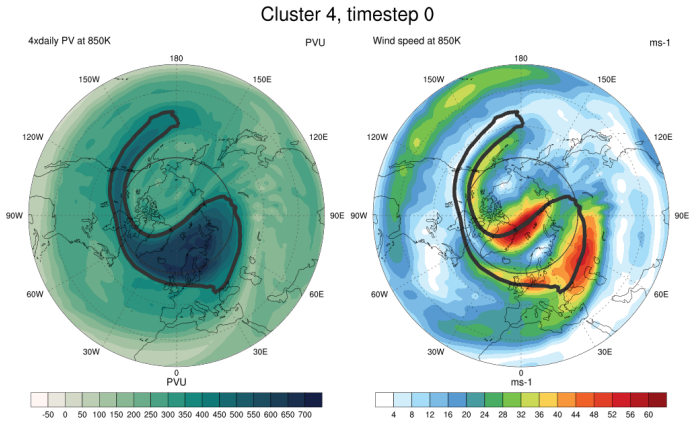
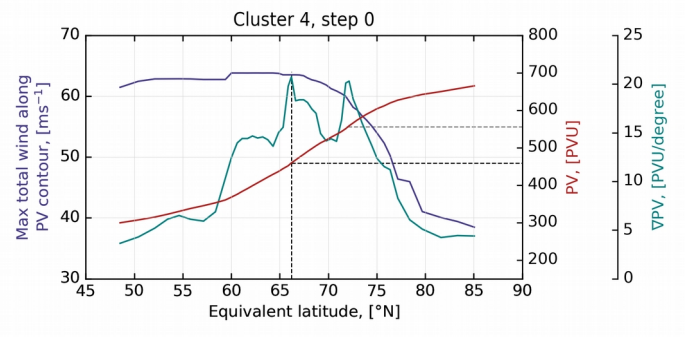
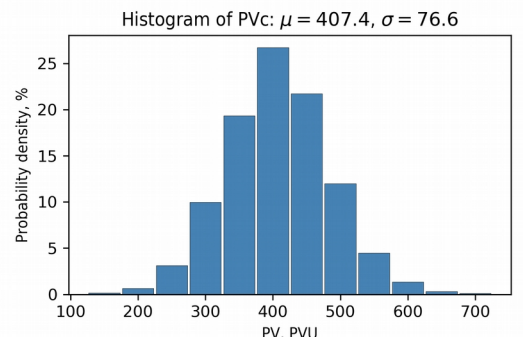






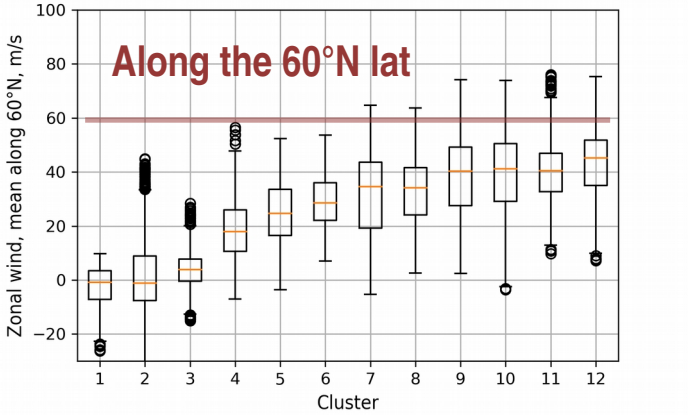


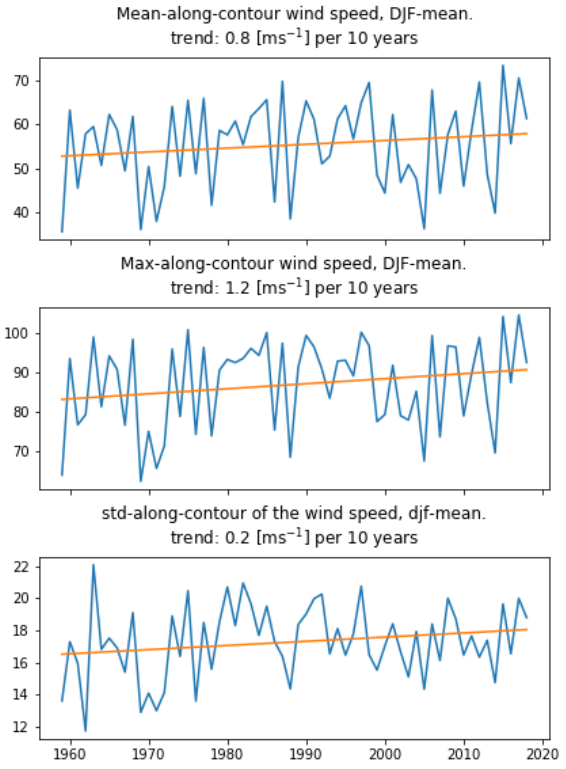


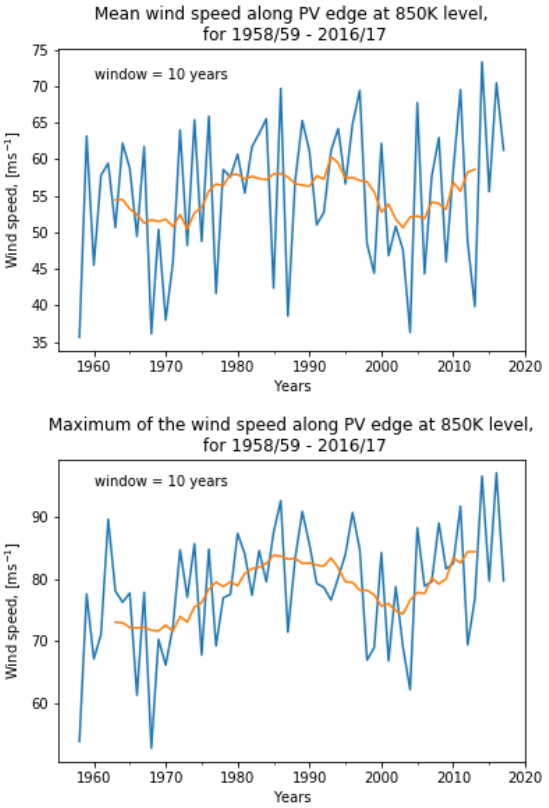


Nash, E. R., Newman, P. A., Rosenfield, J. E., & Schoeberl, M. R. (1996). An objective determination of the polar vortex using Ertel's potential vorticity. Journal of Geophysical Research: Atmospheres, 101(D5), 9471-9478.

Linear trends in intensity of the Polar Vortex

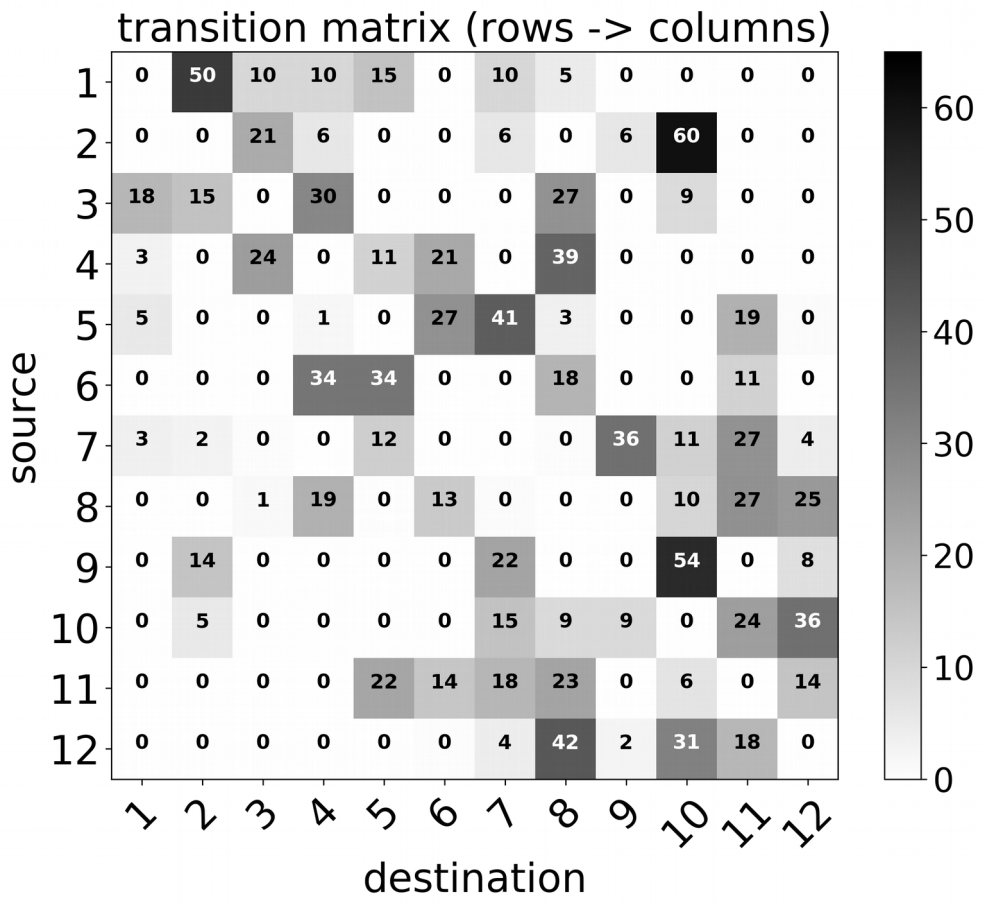




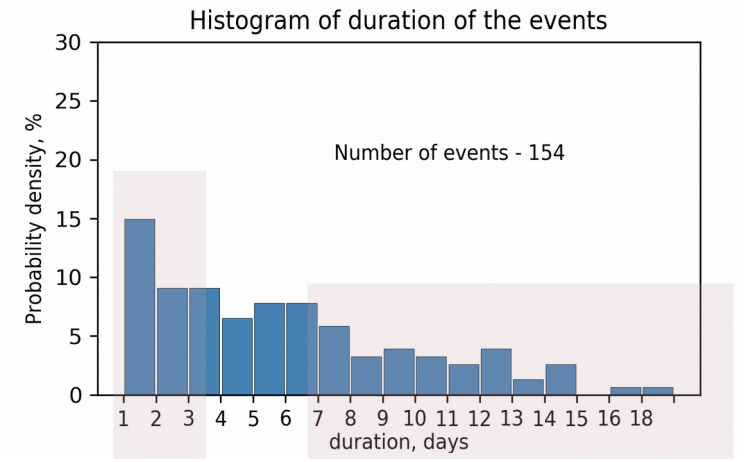


Zhang, J., Tian, W., Chipperfield, M. P., Xie, F., & Huang, J. (2016). Persistent shift of the Arctic polar vortex towards the Eurasian continent in recent decades. Nature Climate Change, 6(12), 1094.

Transition matrix and perspectives



Cluster 10



Transition states

Steady states

Cascade transition

10+12 ---> 8 ----------> 4

|---> 6 ---> 4

Plumb Flux (daily z-component)

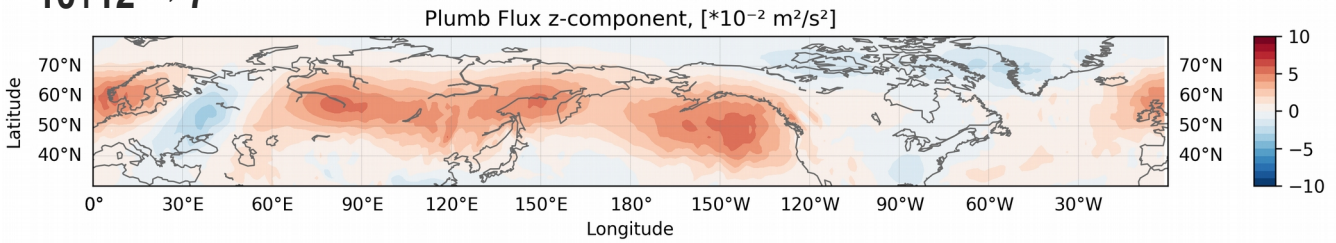
Composites of the daily values of the Plumb flux during transition

Used filtered fields with periods more than 20 days

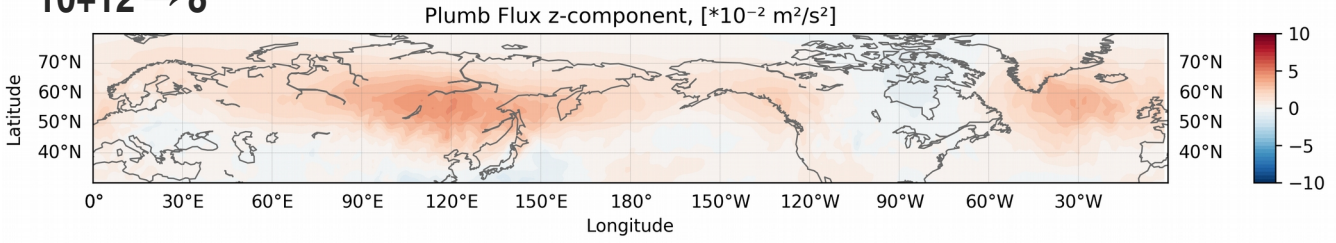
Transition from one steady (more than 7 days) cluster to another

To eliminate the blinking situation

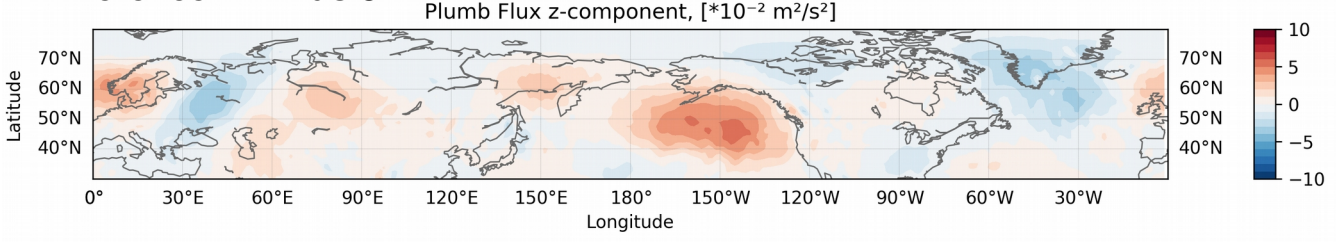
10+12 → 7



10+12 → 8



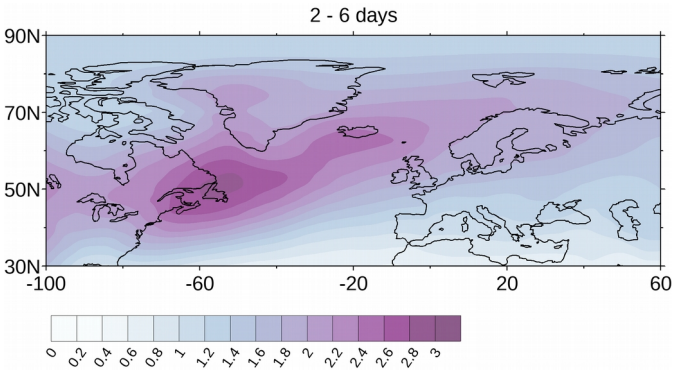
Difference 7 minus 8



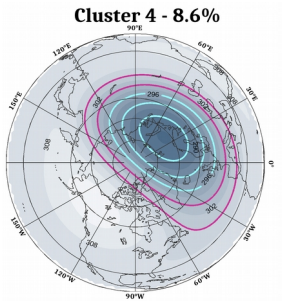
Response of the storm track to the strong steady “shifted” events

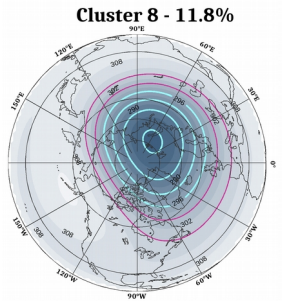
(mean wind >80 m/s, lasts more than 7 days)

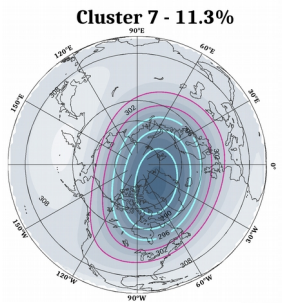
Eulerian view of the storm track
Climate mean (1958/59 – 2016/17)



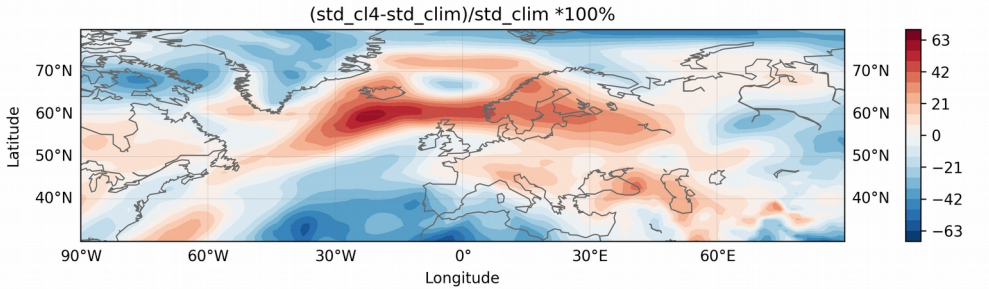
Band-passed HGT 1000 hPa
Period 2 – 6 days

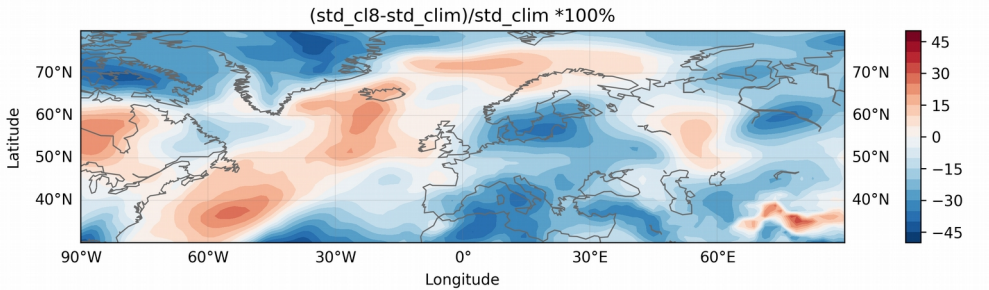


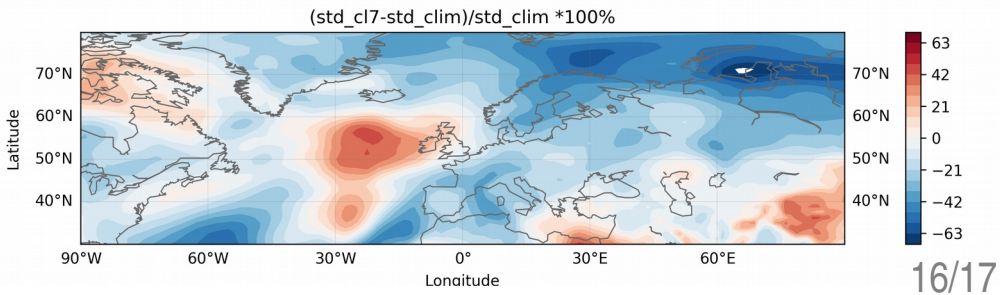




Percentage of the anomaly of the synoptic activity relative to the mean values







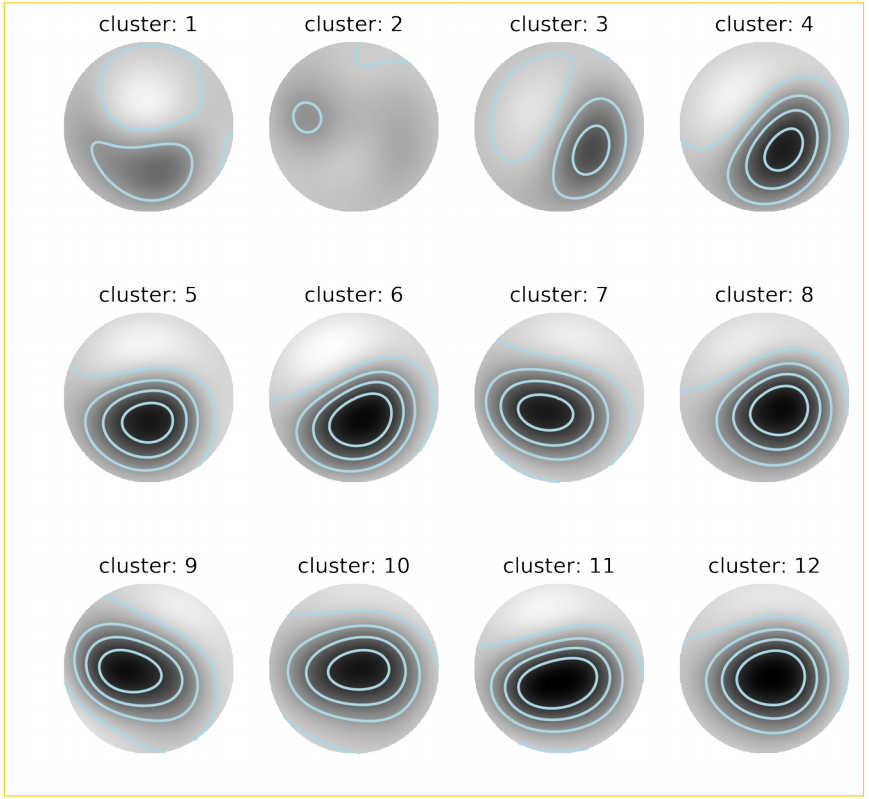
Summary

- Applied method (SpCVAE) allowed to classify stable states of Polar Vortex with different directions of its center shift
- There is a persistent shift of the center of the vortex towards Eurasia and Greenland
- During the last 15 years we find a strengthening of the vortex
- The stratosphere can contribute to the poleward deflection
- It is important to consider mean total wind speed along the vortex edge and position of the center of PV when evaluate strong “event” effect

Annex

Preliminary results…

Composites (HGT field)



Sanity checks:

- Known SSW events of “split” and “displacement” types were clustered
- For strong vortex: variance of center coordinates within a cluster is low