Understanding the role of the Stratospheric Polar Vortex for Cold Extremes

Using Machine Learning Algorithms

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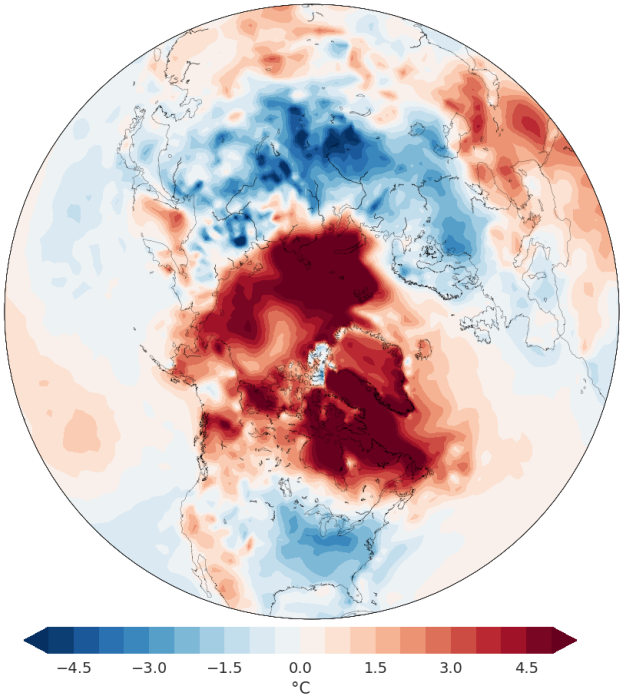
Several Cold Extremes in Recent Decades



Winter (JF) temperature trend since 1990

Motivation

What is the role of the stratospheric polar vortex for (the recent) cold extremes?

Outlook

Different stratosphere-troposphere coupling mechanisms are relevant for cold-spells over North America and Eurasia

Case Study: Winter 2017/18

Different Definitions of weak Polar Vortex states

- Sudden Stratospheric Warming (SSWs)
  - Major/minor warming
  - Split/displacement
  - wave1/wave 2-driven
  - Downward/non-downward propagating
  - Absorbing/reflecting
- Northern Annular Mode (NAM)
- Polar night jet oscillation (PJO)
- …

see. e.g. Thompson& Wallace (1998), Hitchock et al. (2014), Kidston et al. (2015), Butler et al. (2014), Karpechko et al. (2017)…

Clustering of Daily Polar Vortex Patterns

Data

Daily geopotential height anomalies at 100 hPa
January-February from 1979-2017 (Era Interim)

Method

Hierarchical Clustering
"Ward criteria"

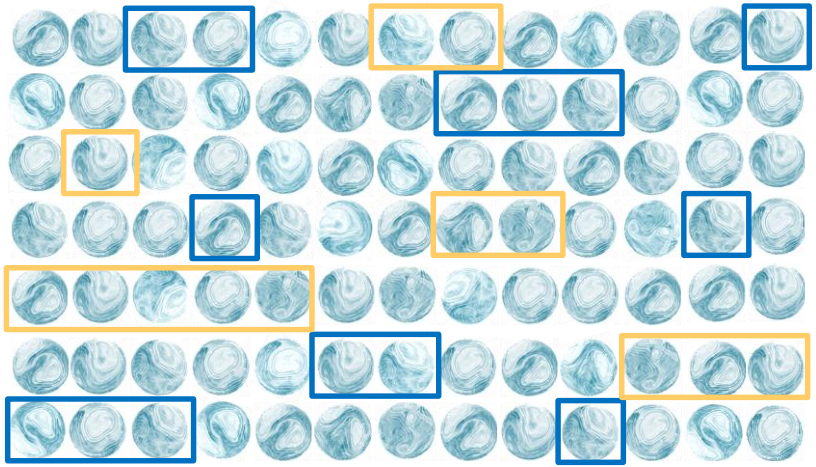
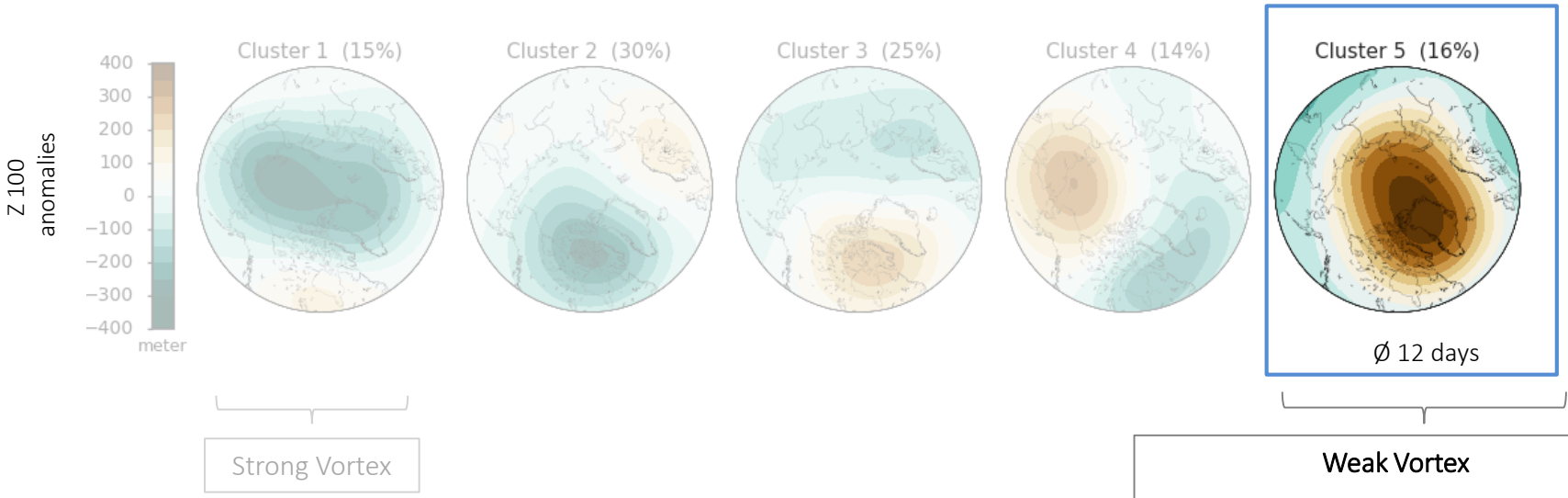


Image source: https://ozonewatch.gsfc.nasa.gov/facts/vortex_NH.html

CLUSTERS REPRESENTING DIFFERENT POLAR VORTEX STATES



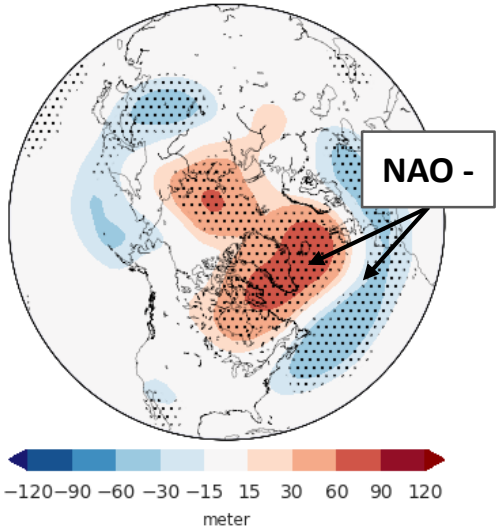
Kretschmer et al., *npj* (2018)

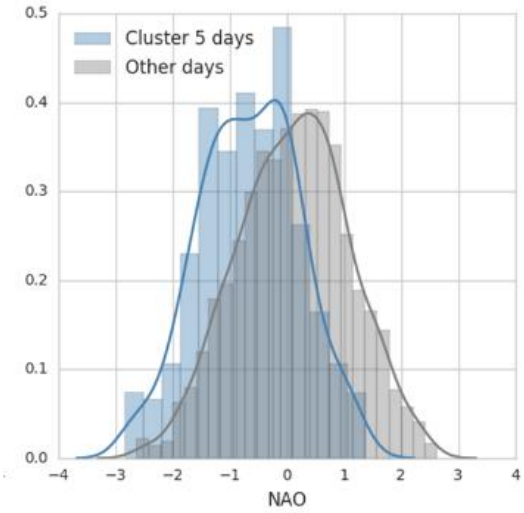
CLUSTER 5

Stratospheric variability can explain most of the Eurasian winter cooling trend

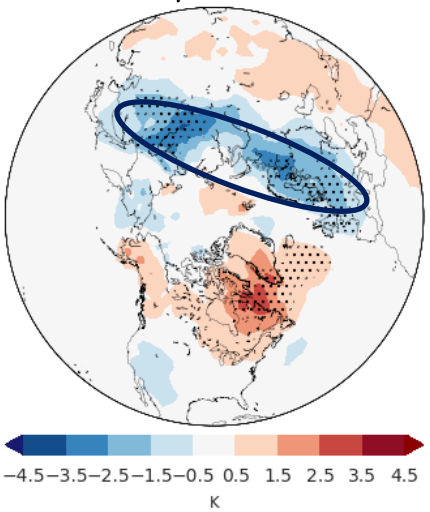
Tropospheric "Response"

Z500



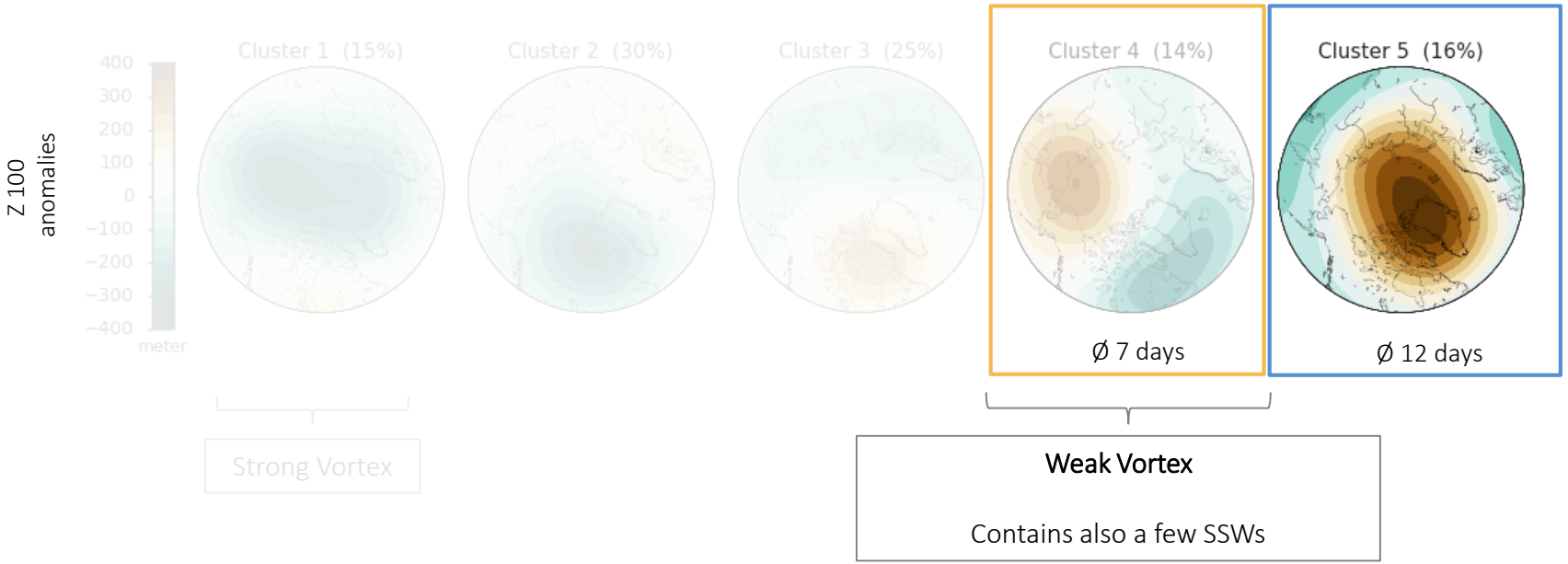


Temperature



Kretschmer et al. *npj* (2018), Kretschmer et al. *BAMS* (2017)

Clusters Representing different Polar Vortex States

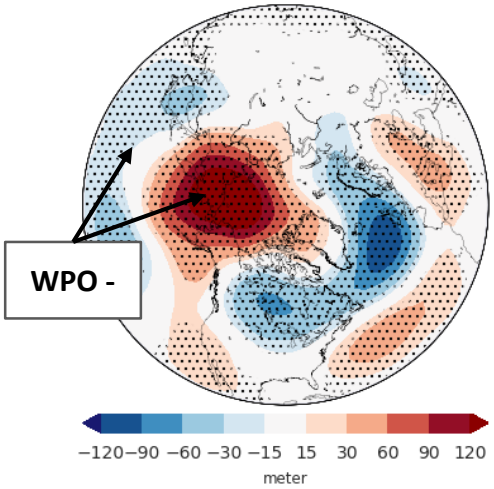


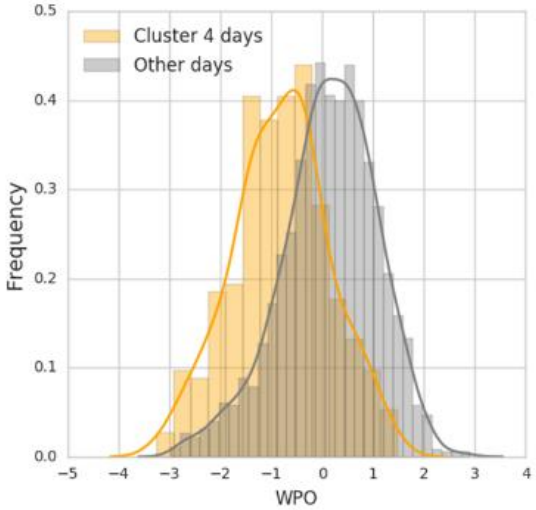
Kretschmer et al. *npj* (2018)

CLUSTER 4

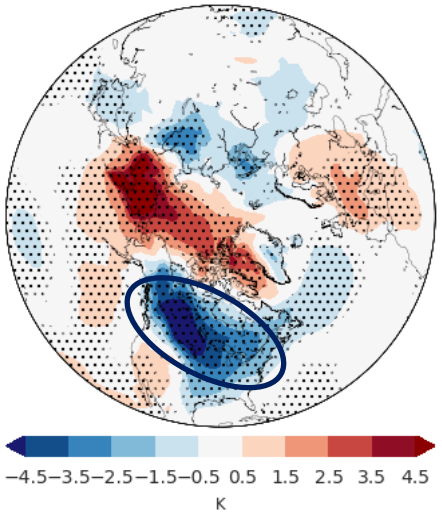
Tropospheric “Response”

Z500



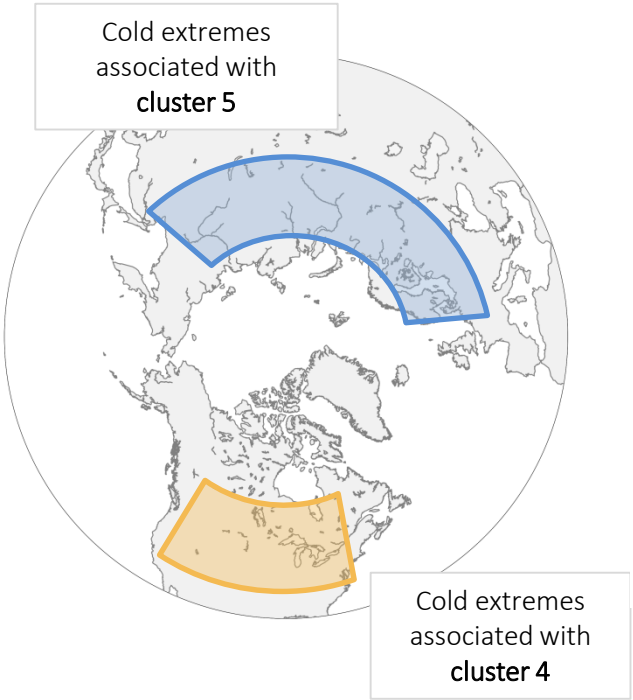


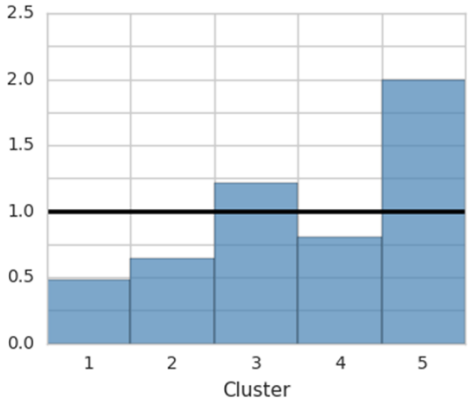
Temperature

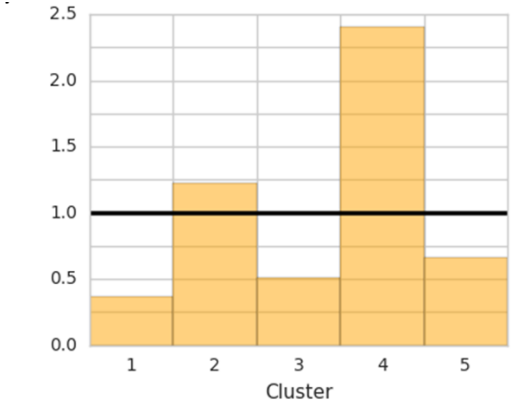


Kretschmer et al., *npj* (2018)

Occurrence Frequency of Clusters During Cold Extremes



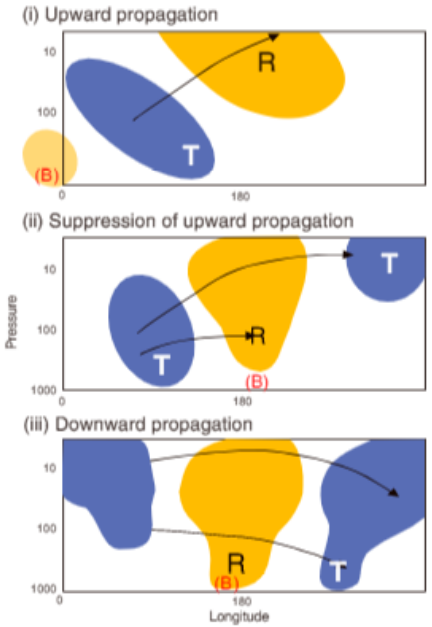




Kretschmer et al., *npj* (2018)

DIFFERENT MECHANISMS?

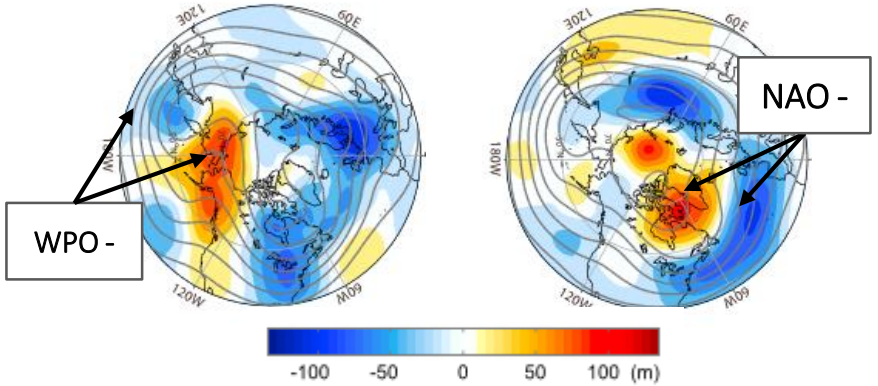
Kodera et al. (2013)



Z500 composites
(0-5 days after)

Reflecting SSWs

Absorbing SSWs

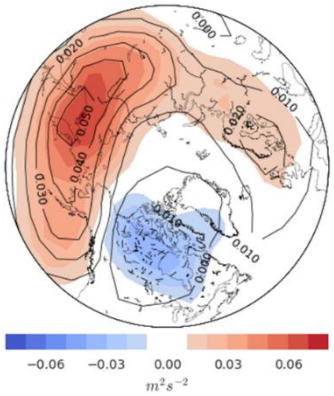


See also: Kodera et al. (2008, 2013, 2016), Perlwitz & Harnik (2003, 2004), Shaw et al. (2010)

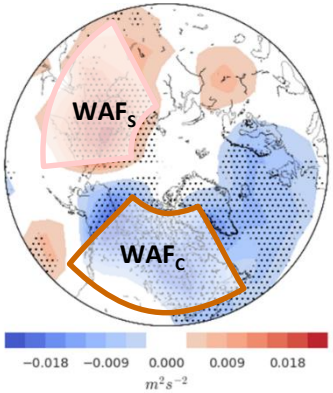
Wave Reflection as a Mechanism for cluster 4 Events?

Wave Activity Flux (100 hPa)

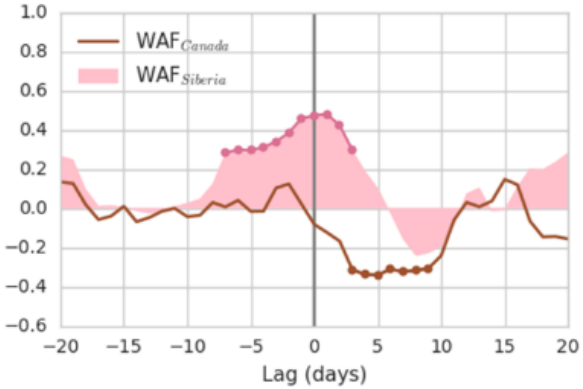
Absolute values



Anomalies

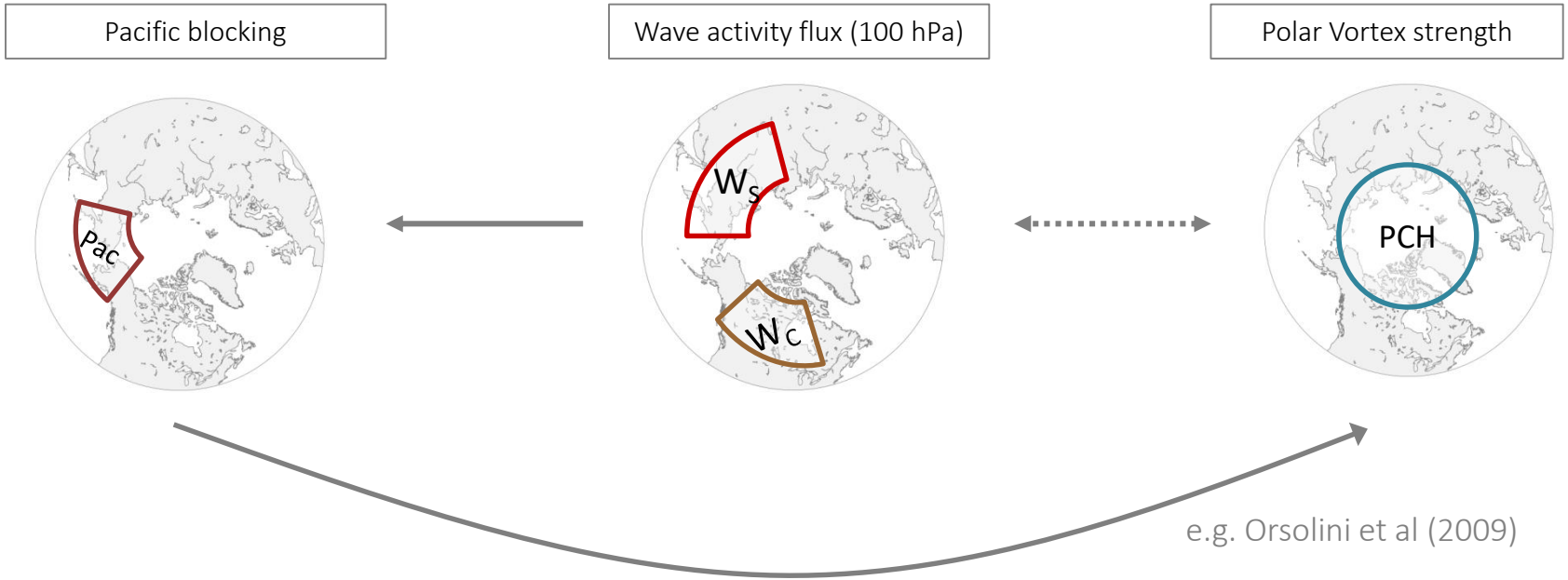


Temporal Evolution



Kretschmer et al., *npj* (2018)

What is the Direction of Causality?



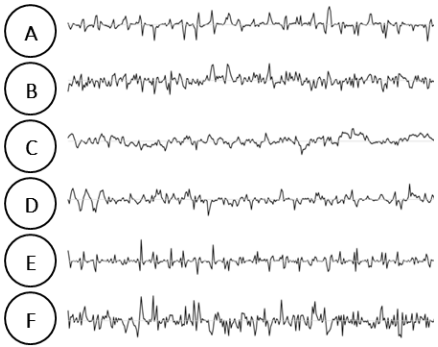
e.g. Orsolini et al (2009)

Detecting Cause-Effect Relationships in Data

Problem

What is the influence of
A on B at lag τ ?

Time-series



Approach

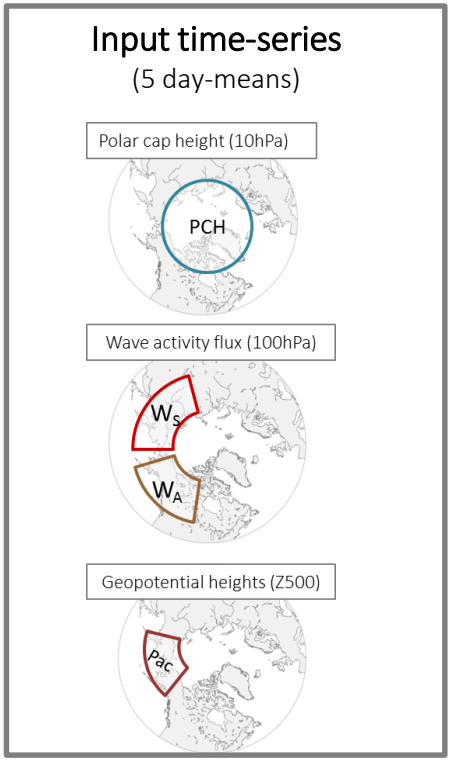
$r(A_{t-\tau}, B_t)$ — Correlation

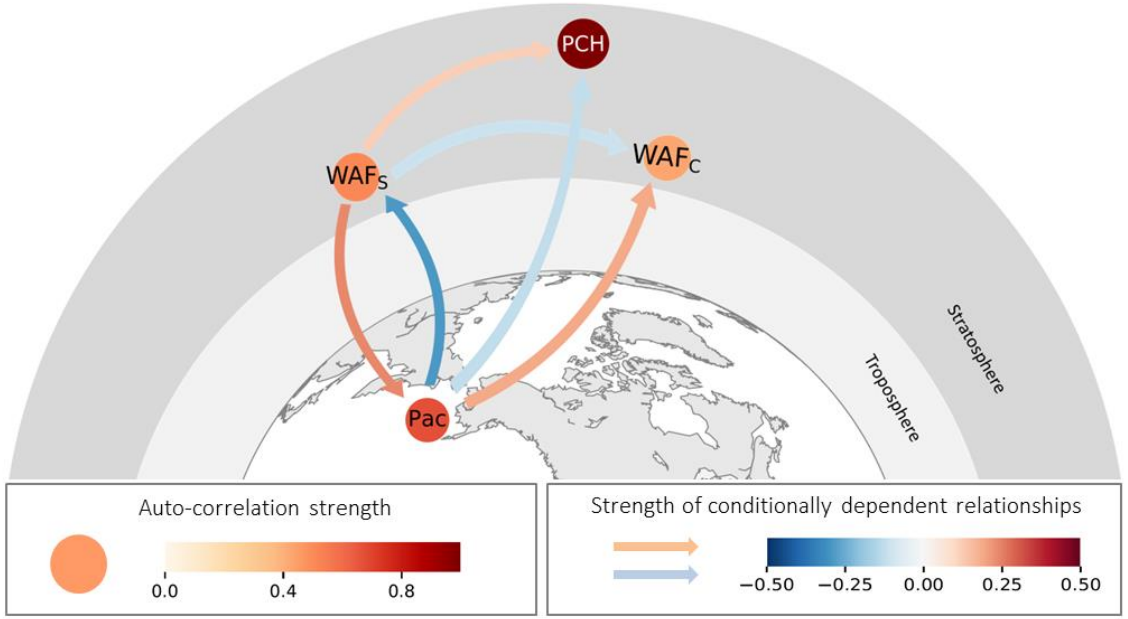
$r(A_{t-\tau}, B_t \mid z)$ — Partial Correlation

$r(A_{t-\tau}, B_t \mid$ *Iterate through combinations of conditions*$)$ — Causal Effect Network

Kretschmer et a. (2016), Runge et al. (2014, 2019)

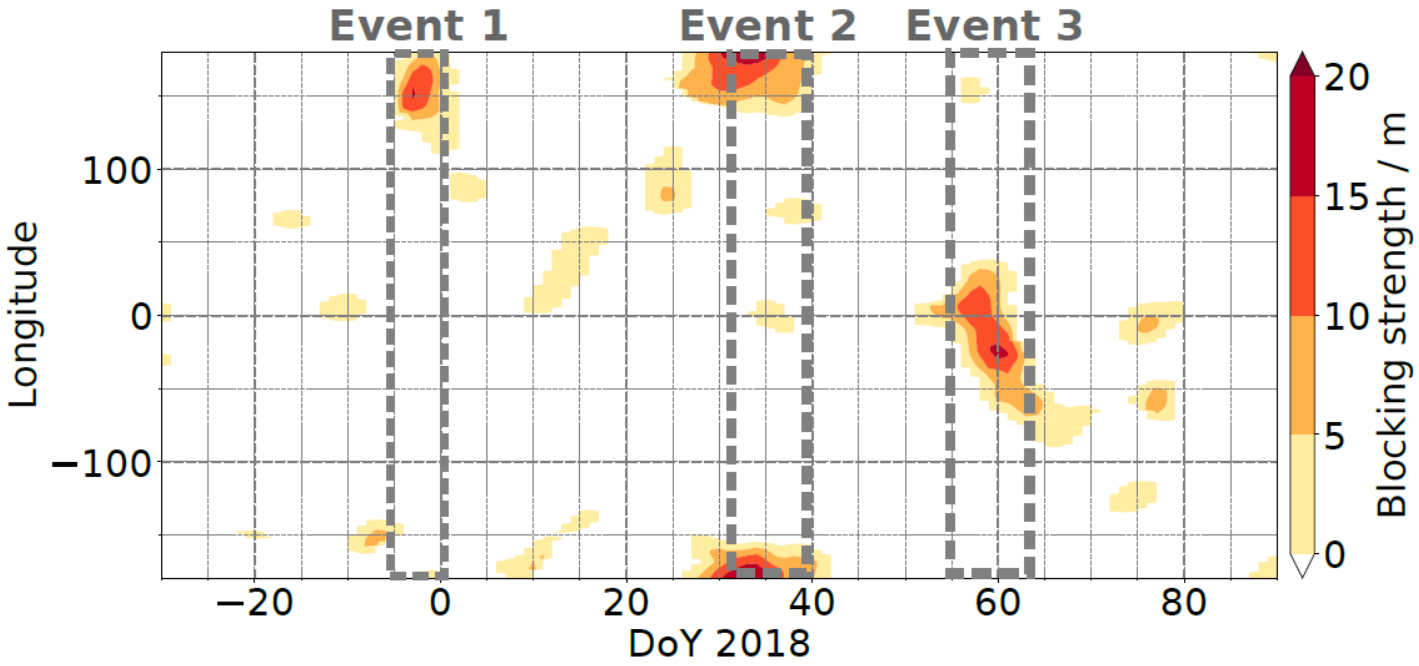
Reflection Mechanism Confirmed by causal Effect Network



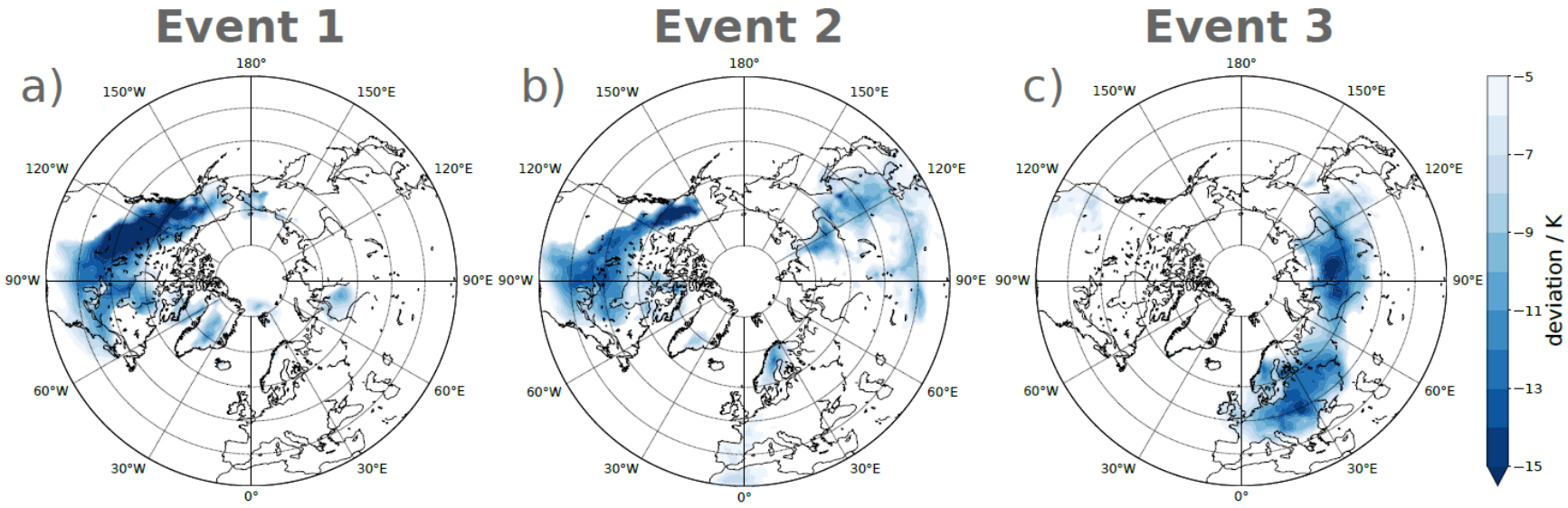


Kretschmer et al., *npj* (2018)

CASE STUDY: THE WINTER 2017/2018



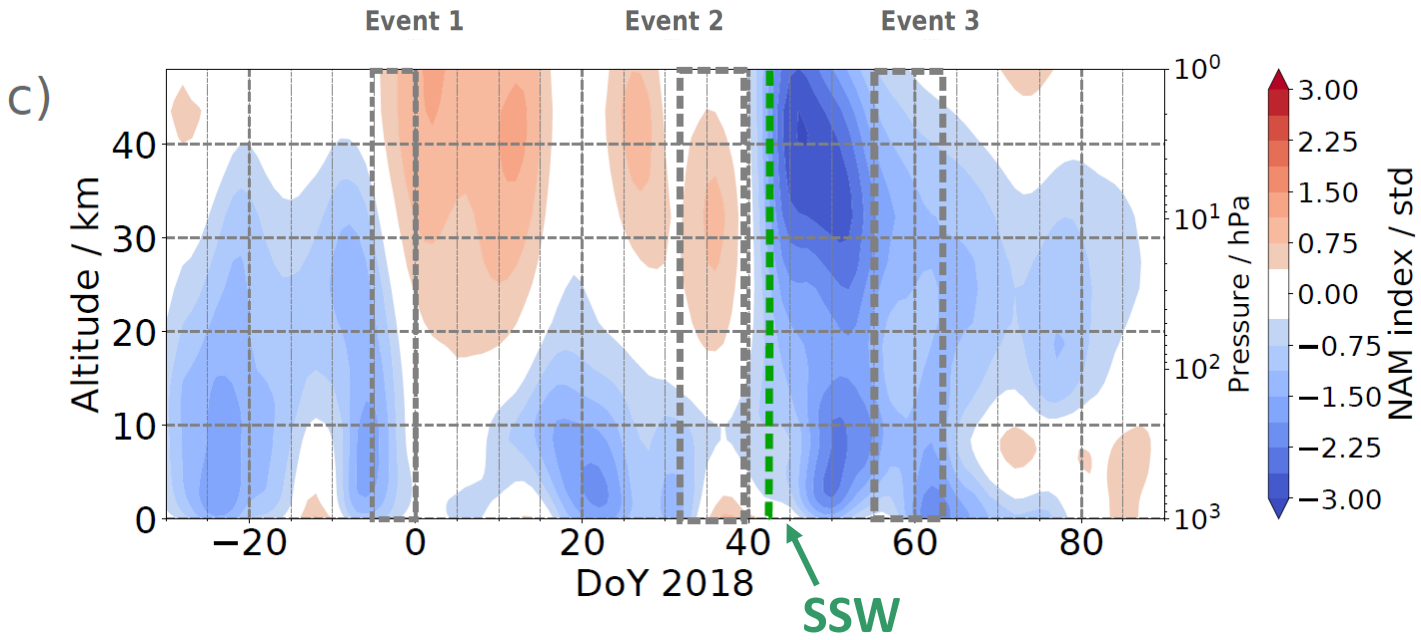
Case Study: The winter 2017/2018



Wave reflection?

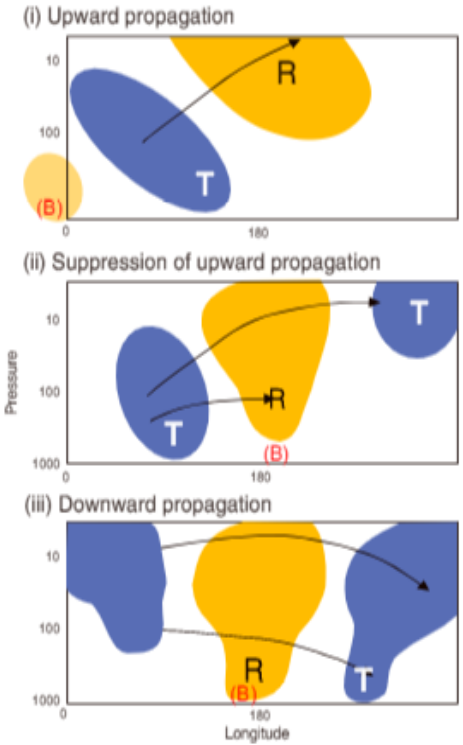
SSW?

NAM INDEX DURING THE WINTER 2017/18

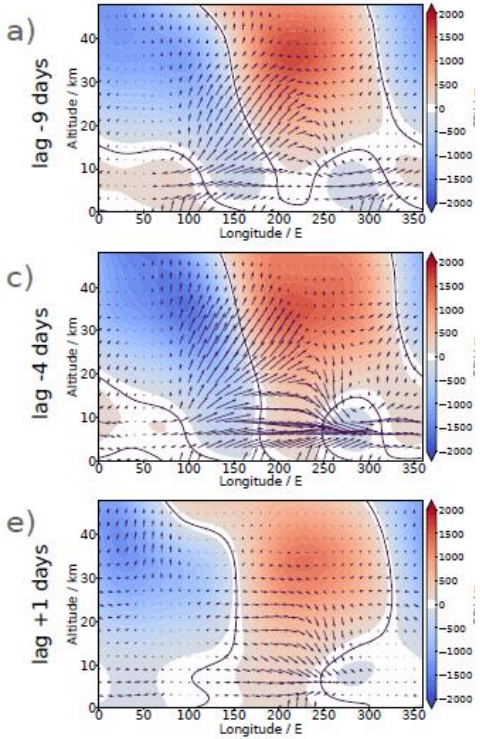


WAVE REFLECTION?

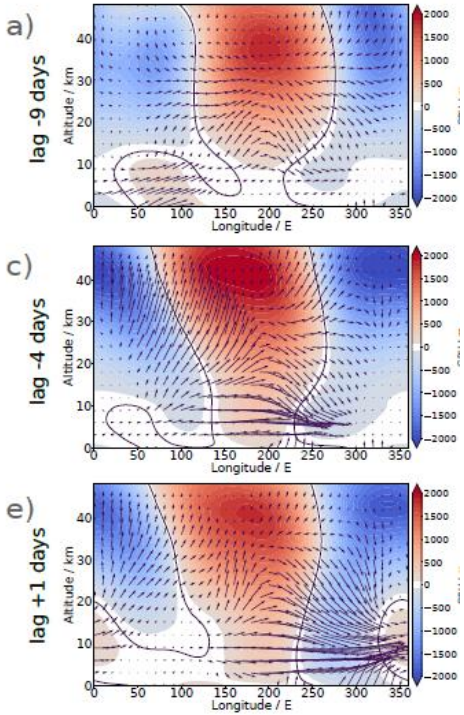
Kodera et al. (2013)



Event 1

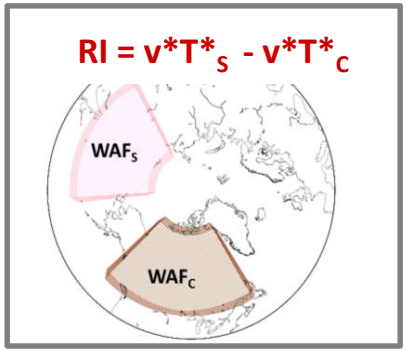


Event 2

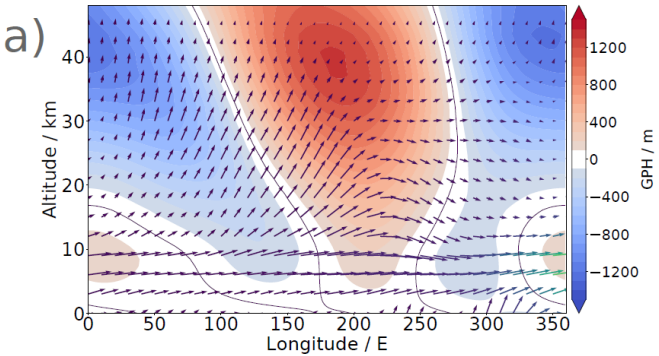


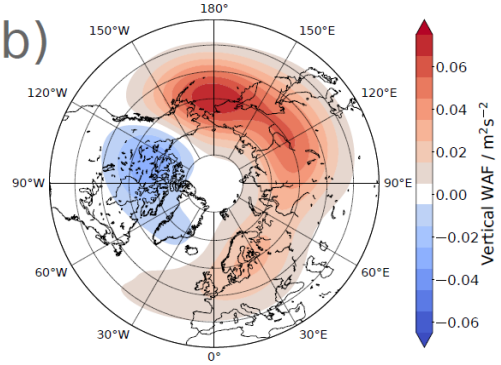
Matthias & Kretschmer (under review)

A simple Reflection Index



Composites of WAF over all detected events



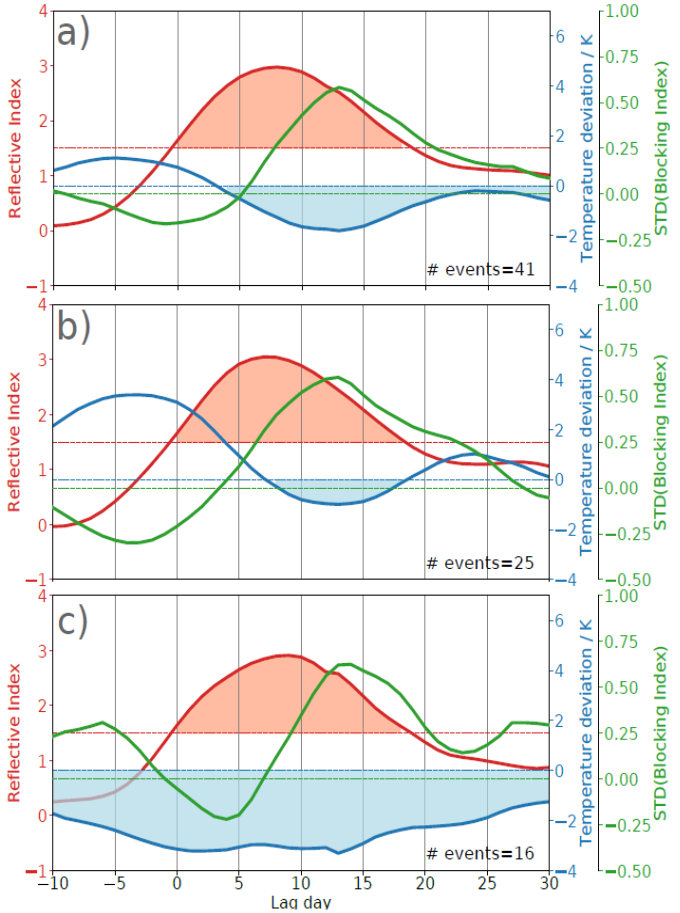


Matthias & Kretschmer (under review)

A simple Reflection Index

$$RI = v^*T^*_S - v^*T^*_C$$

Temperatures over North America



SUMMARY

- Additional evidence that wave reflection is a relevant mechanism for cold-spells over North America (in reanalysis data)

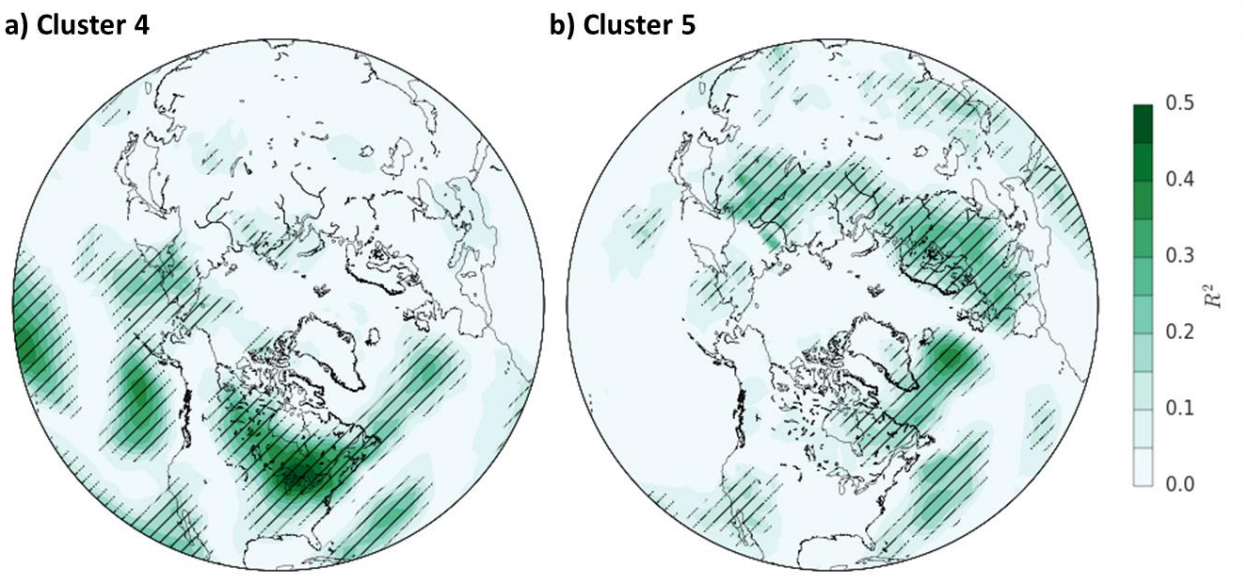
- The “canonical” SSW-NAO relationship is not the full story

- Identifying stratospheric impacts depends on the considered metrics, seasons, regions, time-scales…

- Example of how machine learning can be useful

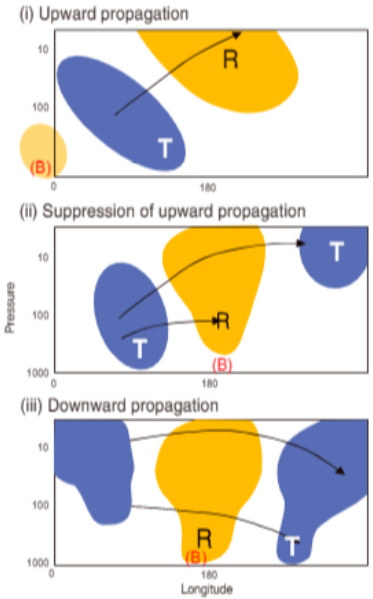
Thank You!

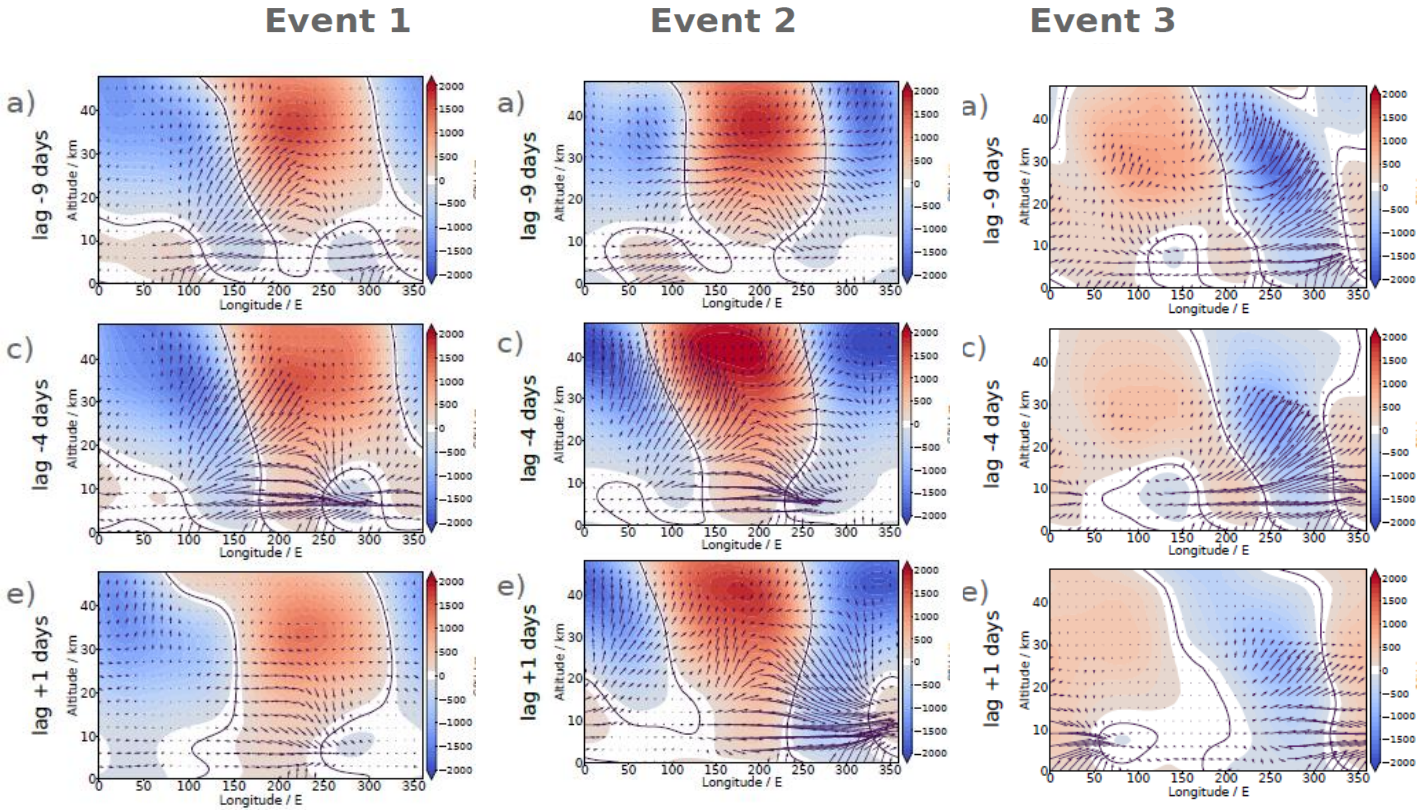
Explained Variance of Winter-Mean Temperature By

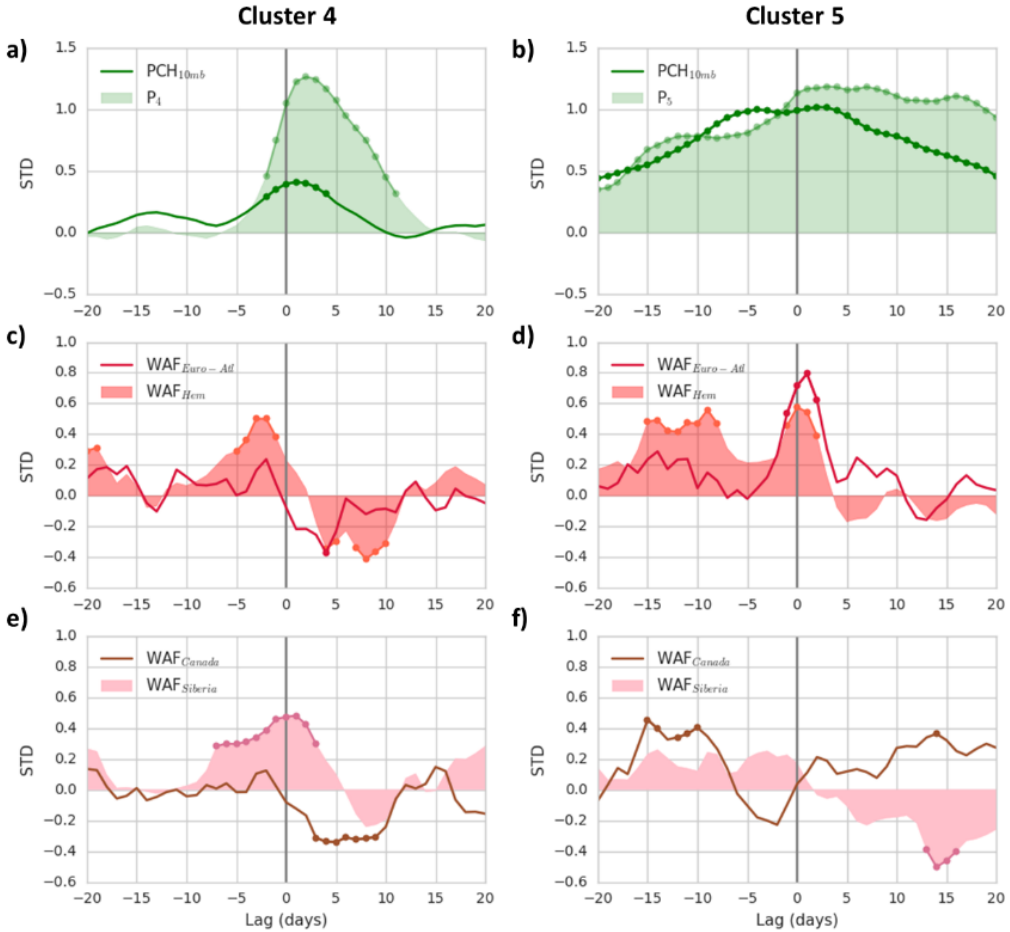


Kretschmer et al., *npj* (2018)

Kodera et al. (2013)






Cluster 4
Cluster 5
a)
b)
c)
d)
e)
f)
PCH10mb
P4
P5
WAFEuro−Atl
WAFHem
WAFCanada
WAFSiberia
STD
Lag (days)