UNDERSTANDING THE ROLE OF THE STRATOSPHERIC POLAR VORTEX FOR COLD EXTREMES USING MACHINE LEARNING ALGORITHMS

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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)

...
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

Strong Vortex

Cluster 1 (15%)
Cluster 2 (30%)
Cluster 3 (25%)
Cluster 4 (14%)

Cluster 5 (16%)

Weak Vortex

Contains most of the major, absorbing, downward propagating SSWs

Kretschmer et al., npj (2018)
Stratospheric variability can explain most of the Eurasian winter cooling trend

Tropospheric “Response”

Clusters representing different polar vortex states

Strong Vortex
- Cluster 1 (15%)
- Cluster 2 (30%)
- Cluster 3 (25%)
- Cluster 4 (14%)

Weak Vortex
- Contains also a few SSWs

Cluster 5 (16%)
- Ø 7 days
- Ø 12 days

Kretschmer et al. npj (2018)
CLUSTER 4

Tropospheric “Response”

Kretschmer et al., npj (2018)
Occurrence frequency of clusters during cold extremes

Cold extremes associated with cluster 5

Cold extremes associated with cluster 4

Kretschmer et al., *npj* (2018)
DIFFERENT MECHANISMS?

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?

- Pacific blocking
- Wave activity flux (100 hPa)
- Polar Vortex strength

e.g. Orsolini et al (2009)
**DETECTING CAUSE-EFFECT RELATIONSHIPS IN DATA**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Approach</th>
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<tbody>
<tr>
<td>What is the influence of $A$ on $B$ at lag $\tau$?</td>
<td>$r(A_{t-\tau}, B_t)$ Correlation</td>
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<tr>
<td>Time-series</td>
<td>$r(A_{t-\tau}, B_t \mid z)$ Partial Correlation</td>
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<tr>
<td>$A$</td>
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<td>$B$</td>
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<td>$F$</td>
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Iterate through combinations of conditions

Causal Effect Network

Kretschmer et al. (2016), Runge et al. (2014, 2019)
**Reflection Mechanism Confirmed by Causal Effect Network**

**Input time-series** (5 day-means)
- Polar cap height [10hPa]
- Wave activity flux [100hPa]
- Geopotential heights [2500]

Kretschmer et al., *npj* (2018)
CASE STUDY: THE WINTER 2017/2018

Event 1  Event 2  Event 3

Longitude

Blocking strength / m

DoY 2018
CASE STUDY: THE WINTER 2017/2018

Event 1
Wave reflection?

Event 2

Event 3
SSW?
NAM INDEX DURING THE WINTER 2017/18

Matthias & Kretschmer (under review)
WAVE REFLECTION?

Kodera et al. (2013)  
(i) Upward propagation  
(ii) Suppression of upward propagation  
(iii) Downward propagation

Event 1

Event 2

Matthias & Kretschmer (under review)
A SIMPLE REFLECTION INDEX

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

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

Matthias & Kretschmer (under review)
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

a) Cluster 4  
b) Cluster 5

Kretschmer et al., npj (2018)