An Arctic Connections to Extreme Weather in Mid-Latitudes? New Evidence, Mechanisms, Metrics, and Emerging Questions

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In collaboration with
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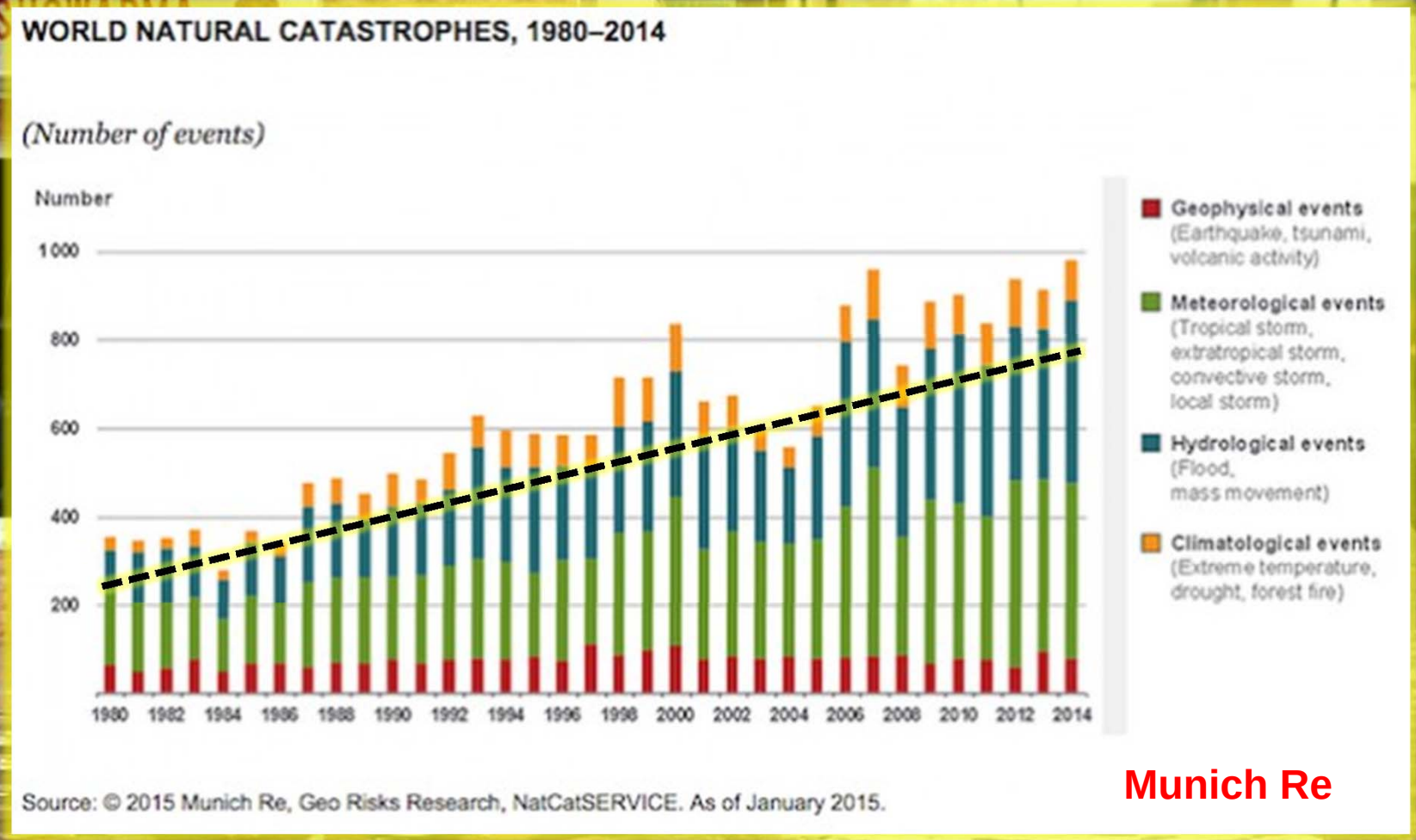
Natasa Skific – Rutgers


U.S. Western drought 2014-2015

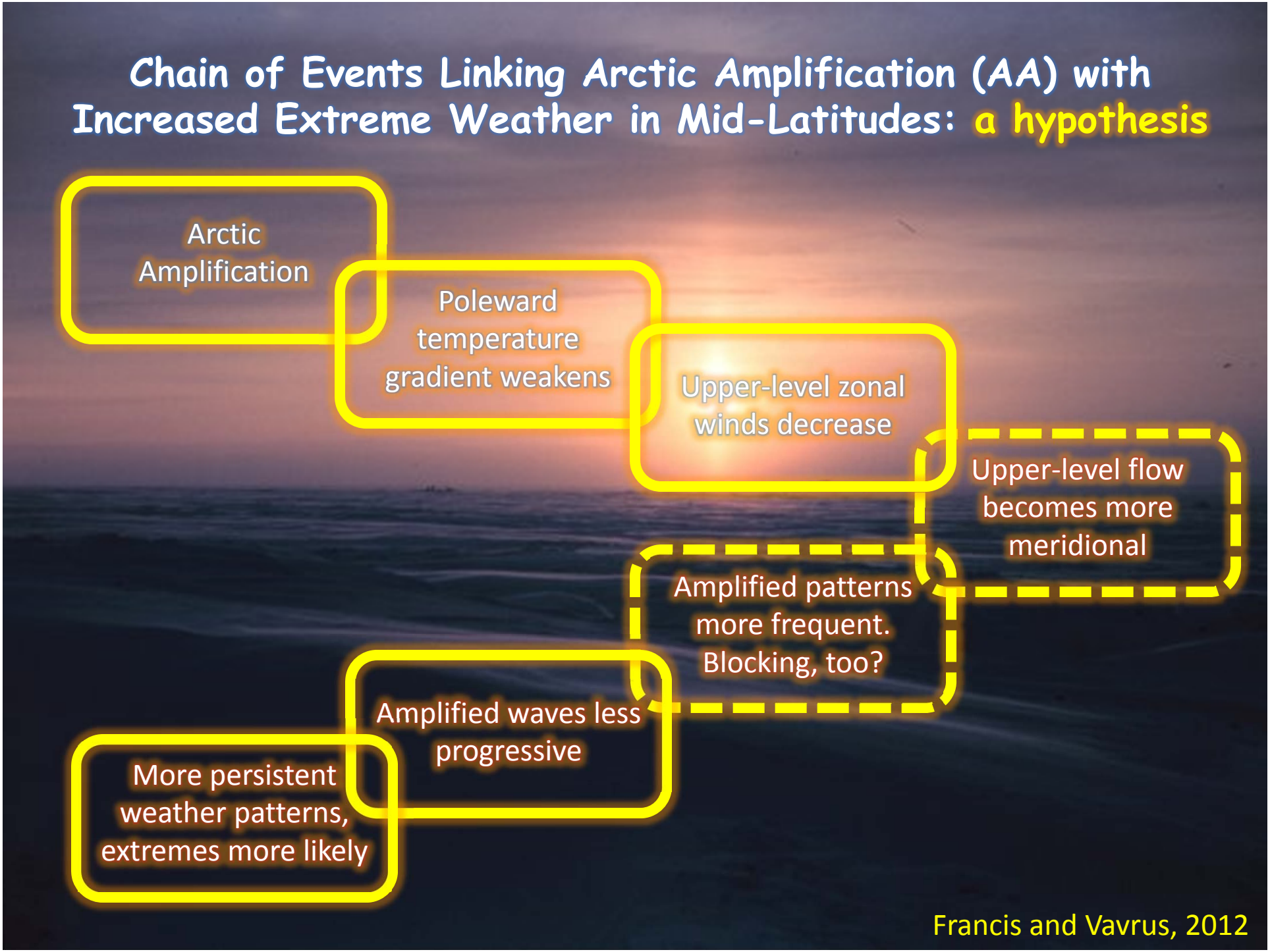

U.S. Eastern freeze 2014-2015

Extreme weather events are on the rise…

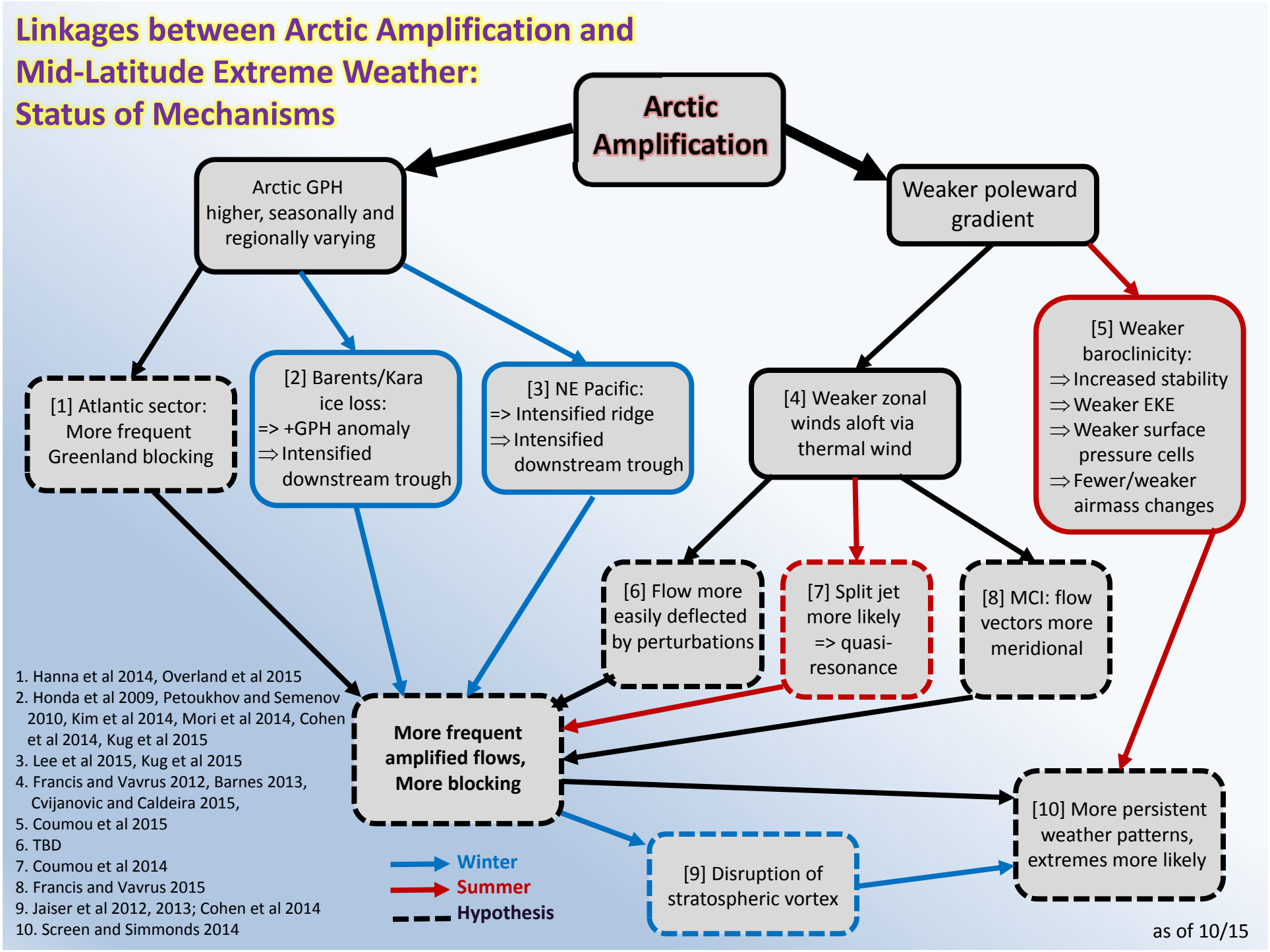


Spring 2012

What do these extreme events have in common?
They're caused by "stuck" weather patterns.


Chain of Events Linking Arctic Amplification (AA) with Increased Extreme Weather in Mid-Latitudes: a hypothesis
Arctic Amplification
Poleward temperature gradient weakens
Upper-level zonal winds decrease
Upper-level flow becomes more meridional
Amplified patterns more frequent. Blocking, too?
Amplified waves less progressive
More persistent weather patterns, extremes more likely
Francis and Vavrus, 2012

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



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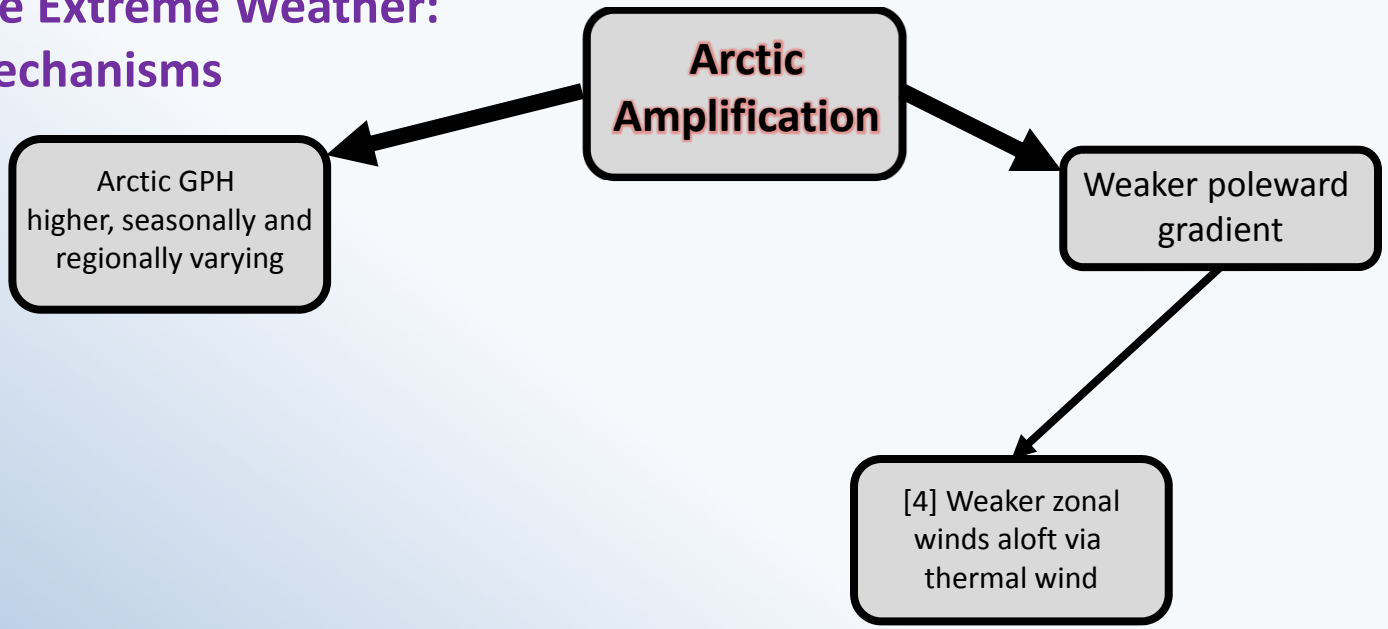
as of 10/15

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



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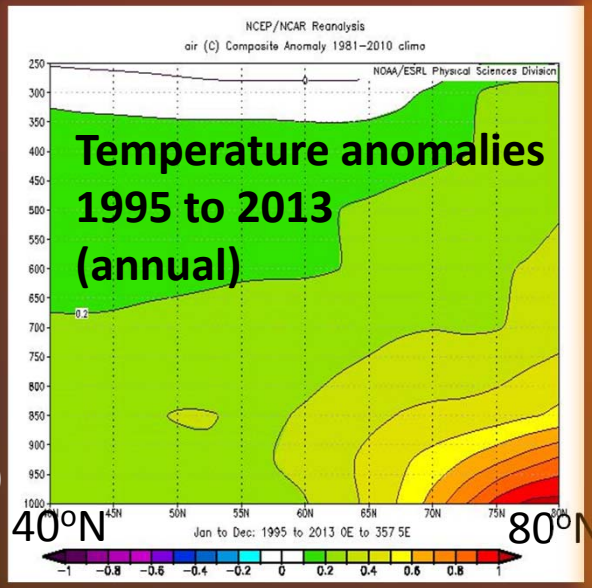
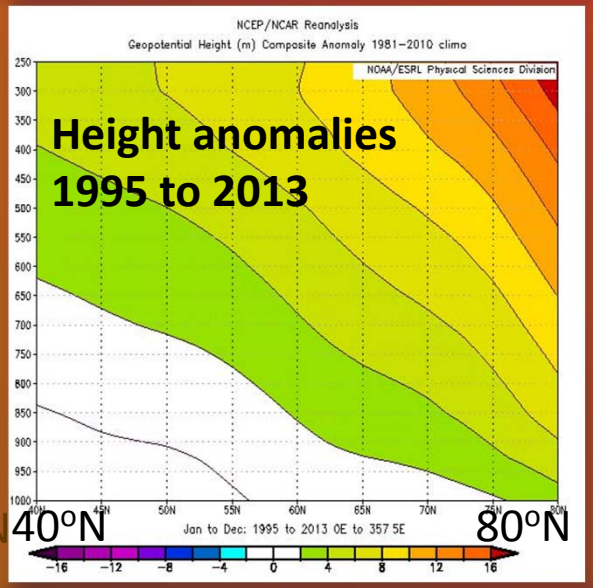
Arctic Amplification (observed)

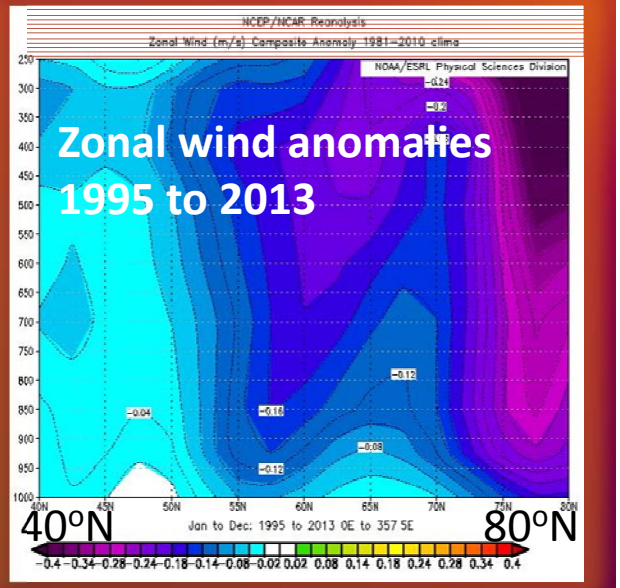
Not confined to surface!

250

1000



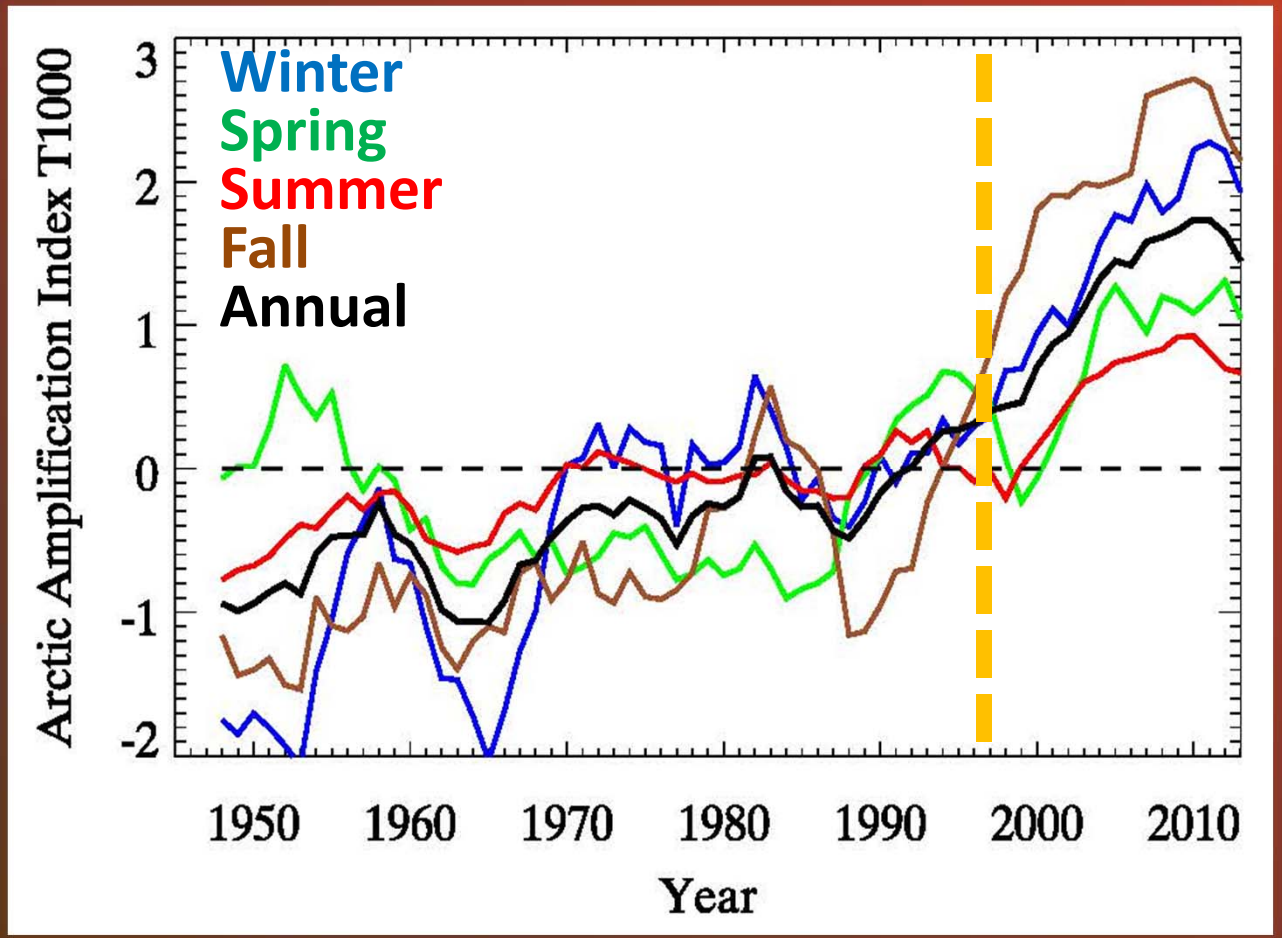




...but with large regional and seasonal variability

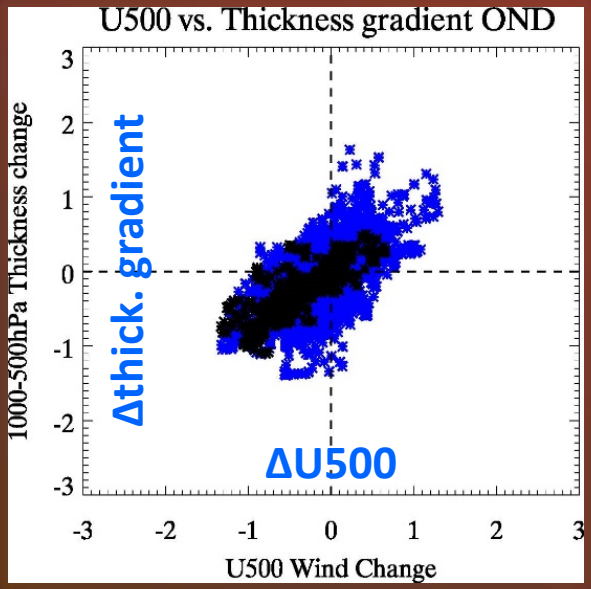
Arctic Amplification

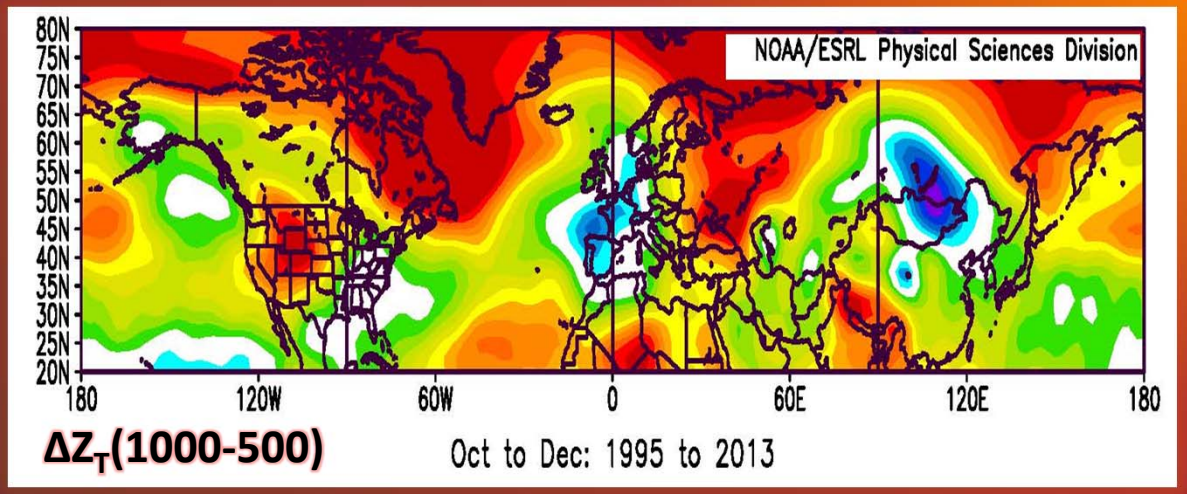
Difference in near-surface air temperature anomalies
Arctic (70°N-90°N) – Mid-latitude (30°N-60°N)

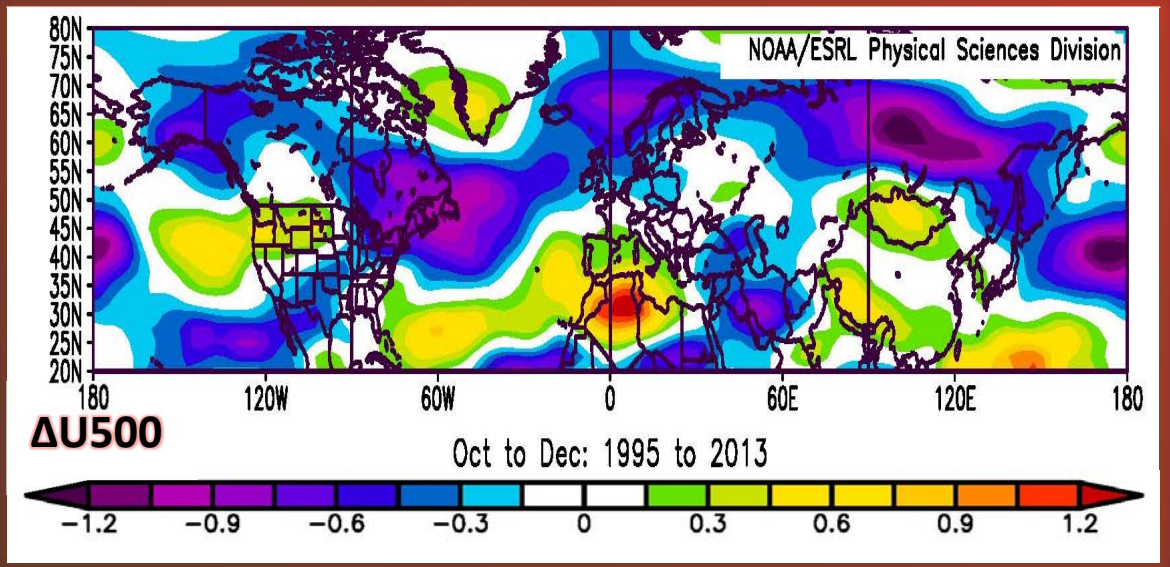


Oct.- Dec.

Thickness anomalies 1995-2013 from NCEP Reanalysis

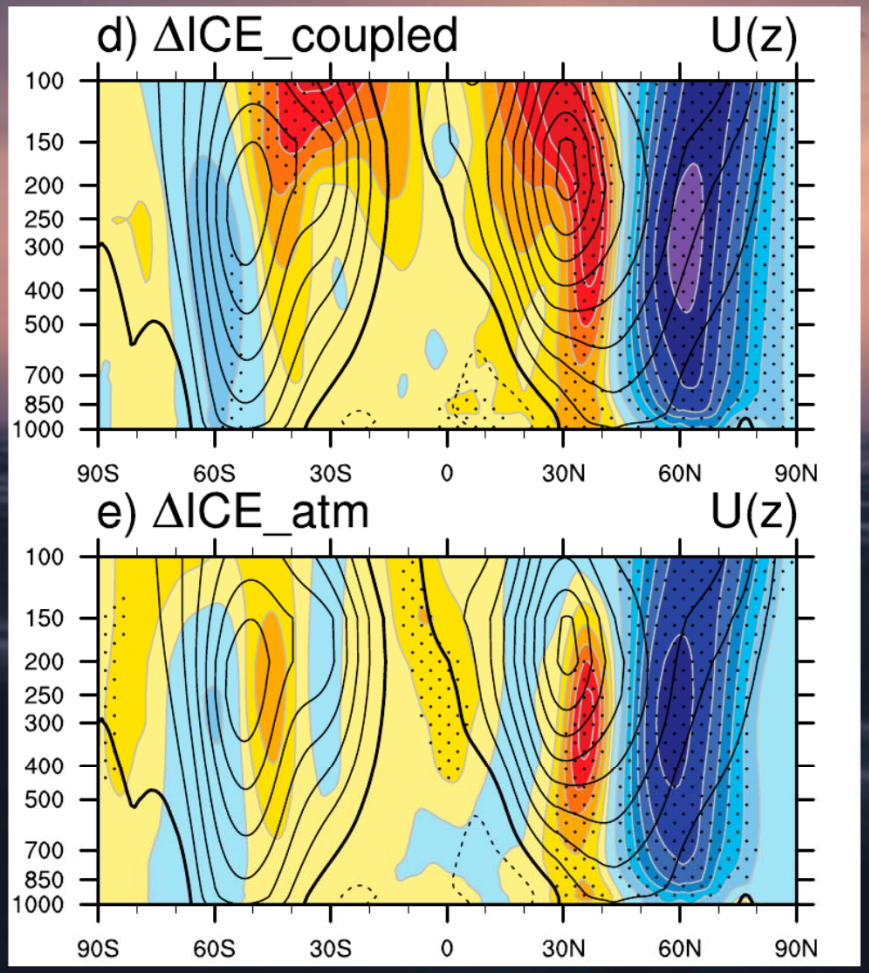






Francis and Vavrus, ERL, 2015

Models Consistent with Obs

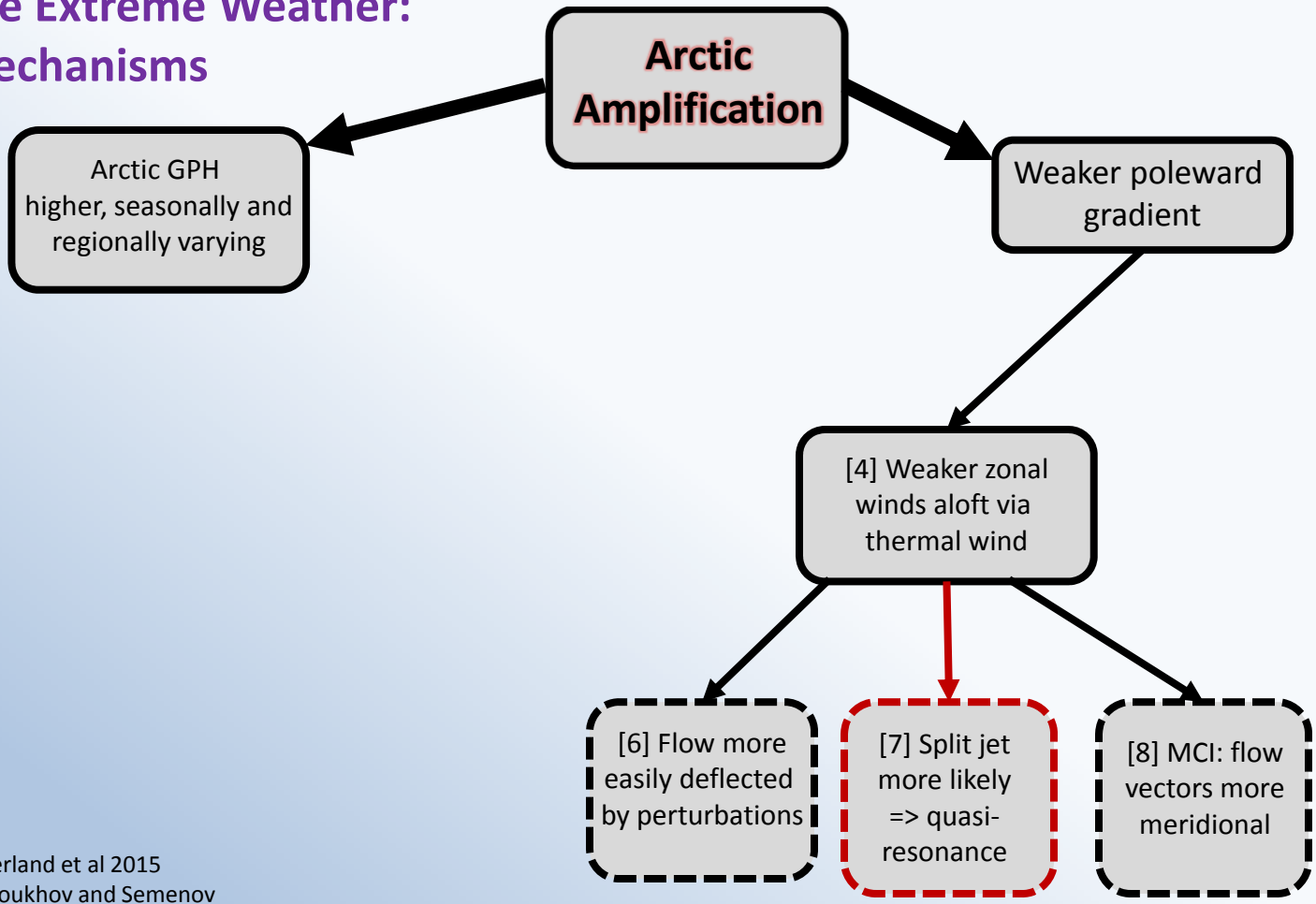


Deser et al 2015

Atmospheric response with fully coupled ocean

Atmosphere only

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



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Winter
Summer
Hypothesis

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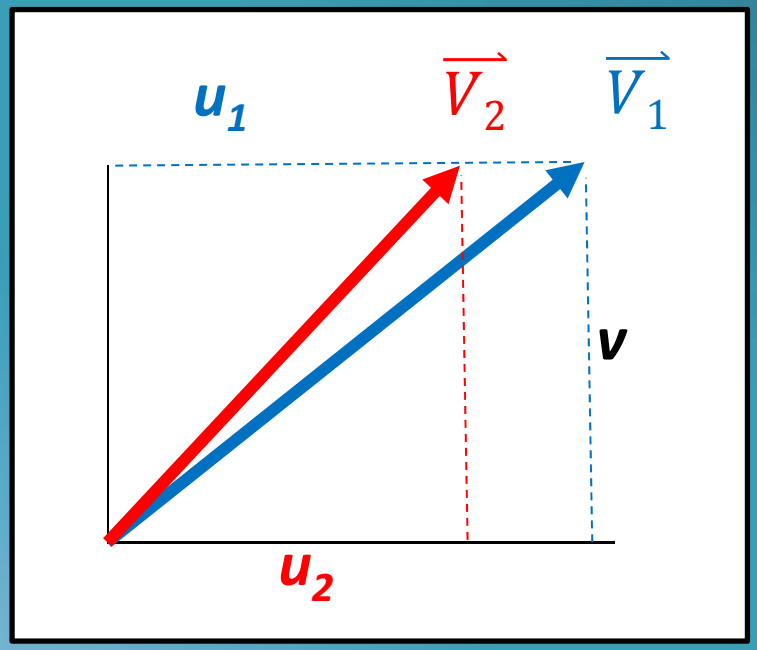
Meridional Circulation Index (MCI)

$$MCI = \frac{v * |v|}{u^2 + v^2}$$

v = meridional wind

u = zonal wind



Francis and Vavrus, 2015

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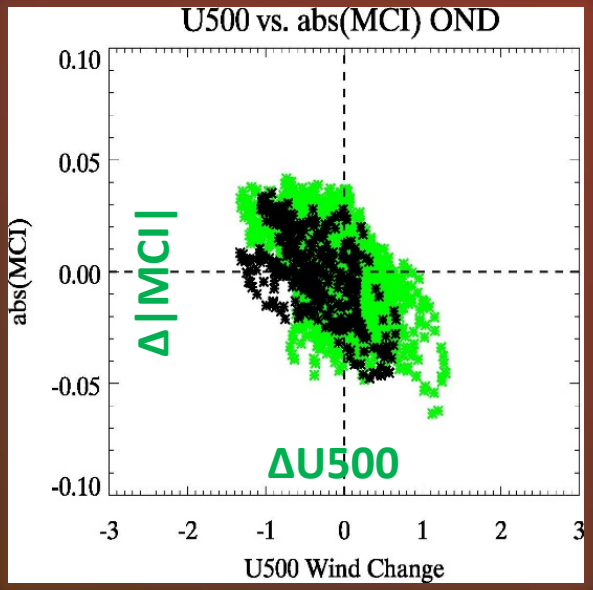

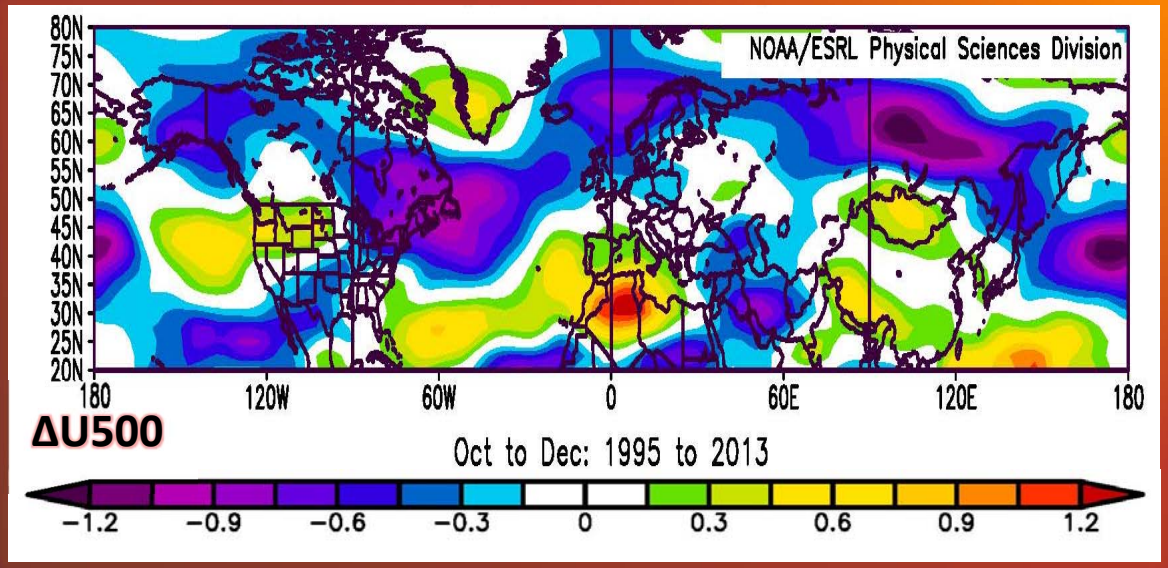

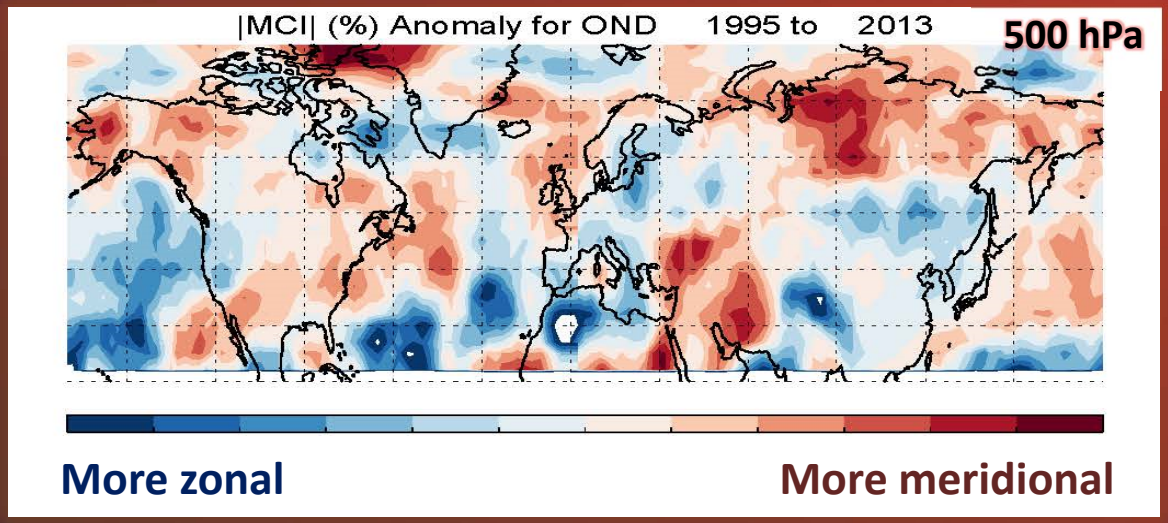

Francis and Vavrus, 2015

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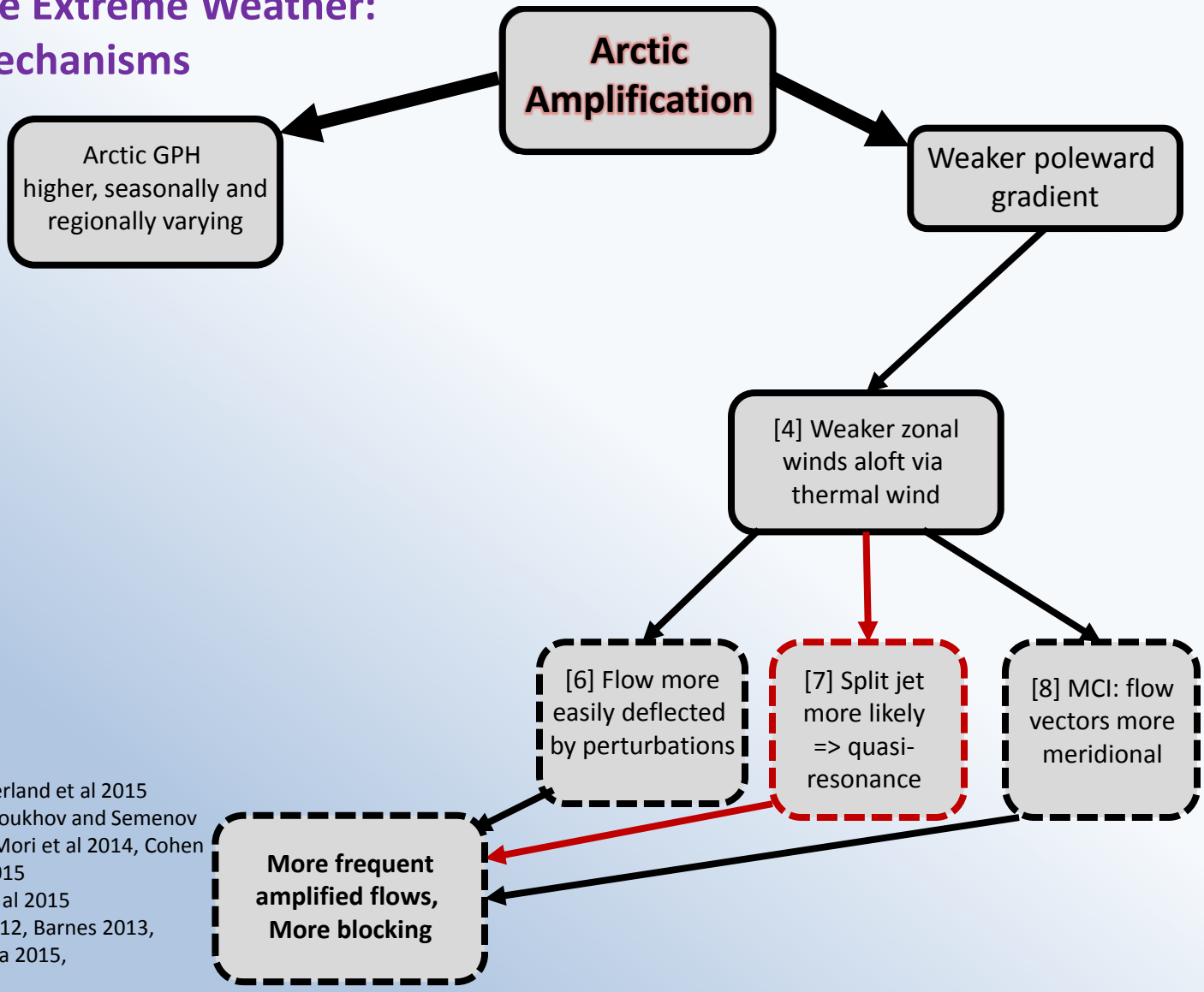

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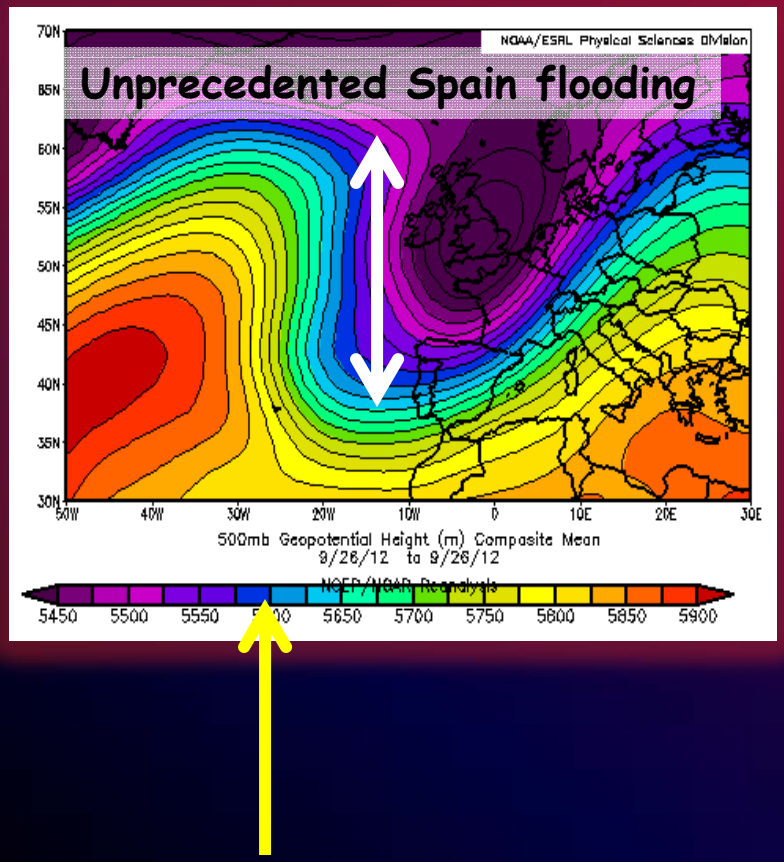
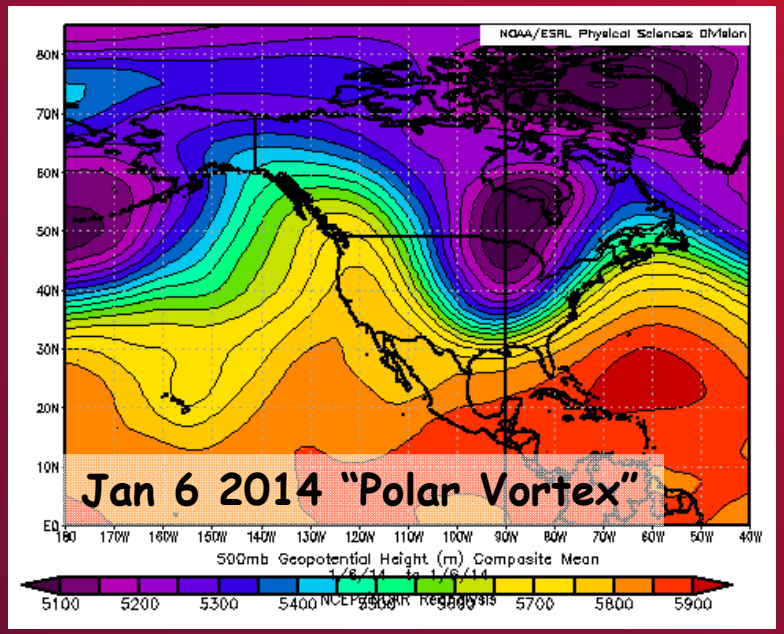
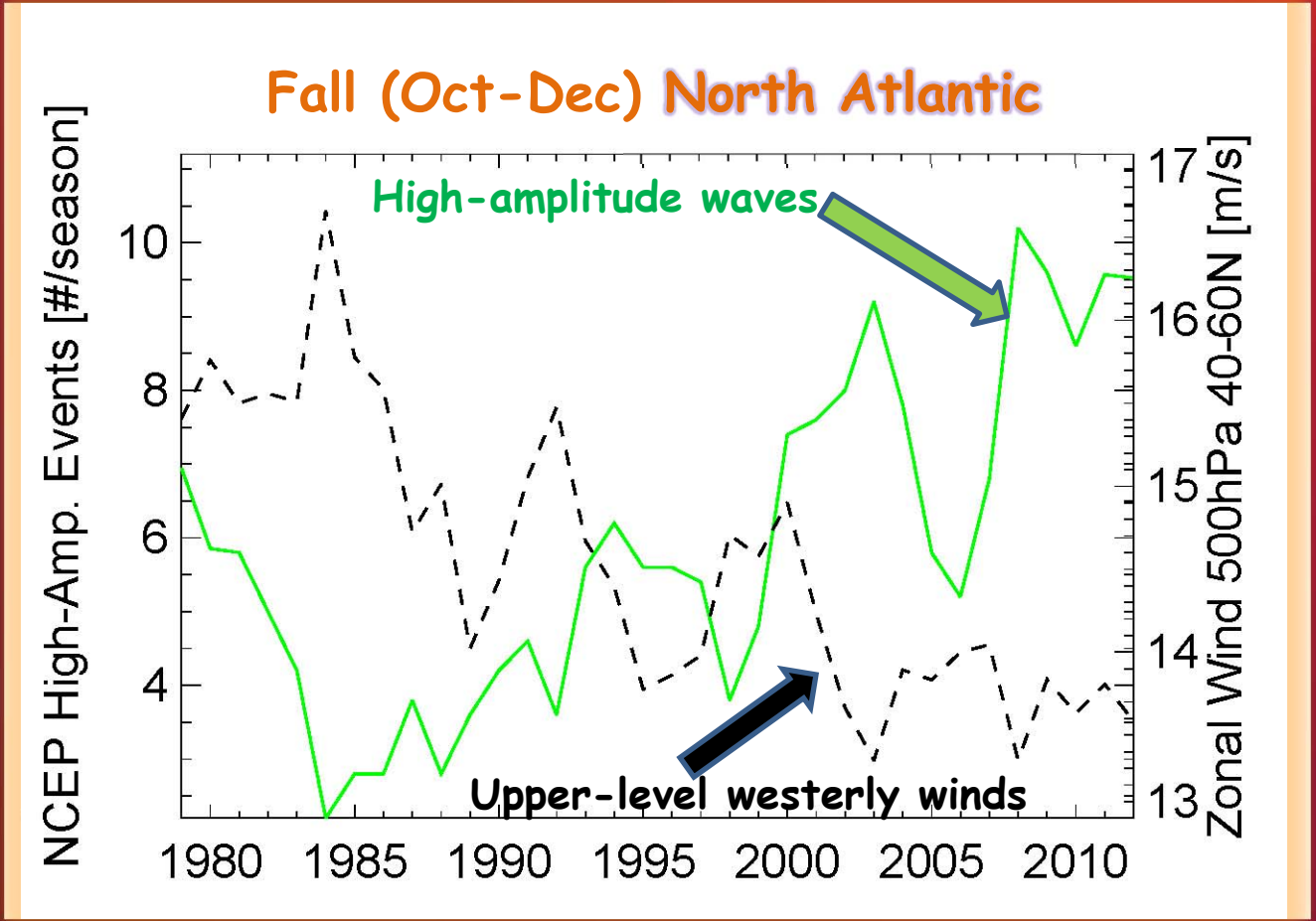
Measuring High-Amplitude Patterns (HAPs)

500 hPa contour range > 35° latitude





Are HAPs happening more often?



Francis and Vavrus 2015

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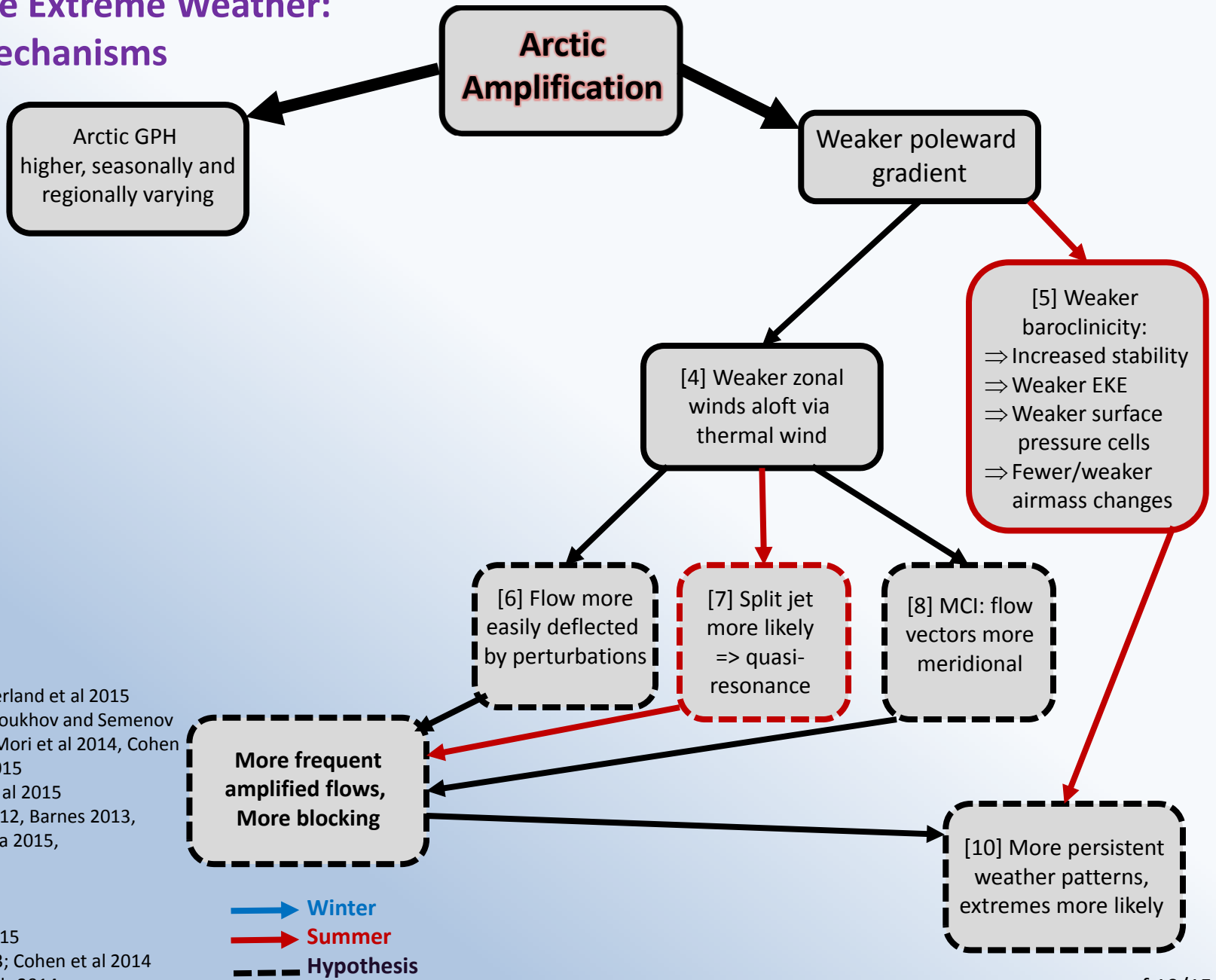

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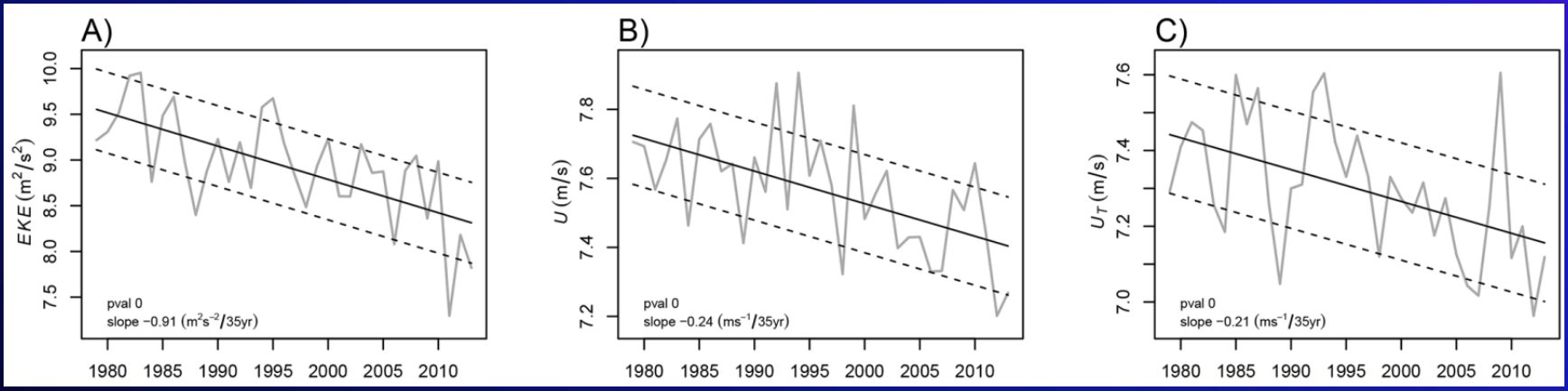
Weakening summer circulation in the mid-latitudes

June-July-August 500 hPa 35-70°N

EKE Zonal wind Thermal wind



Wavenumbers > 6

Coumou et al, *Science* 2015

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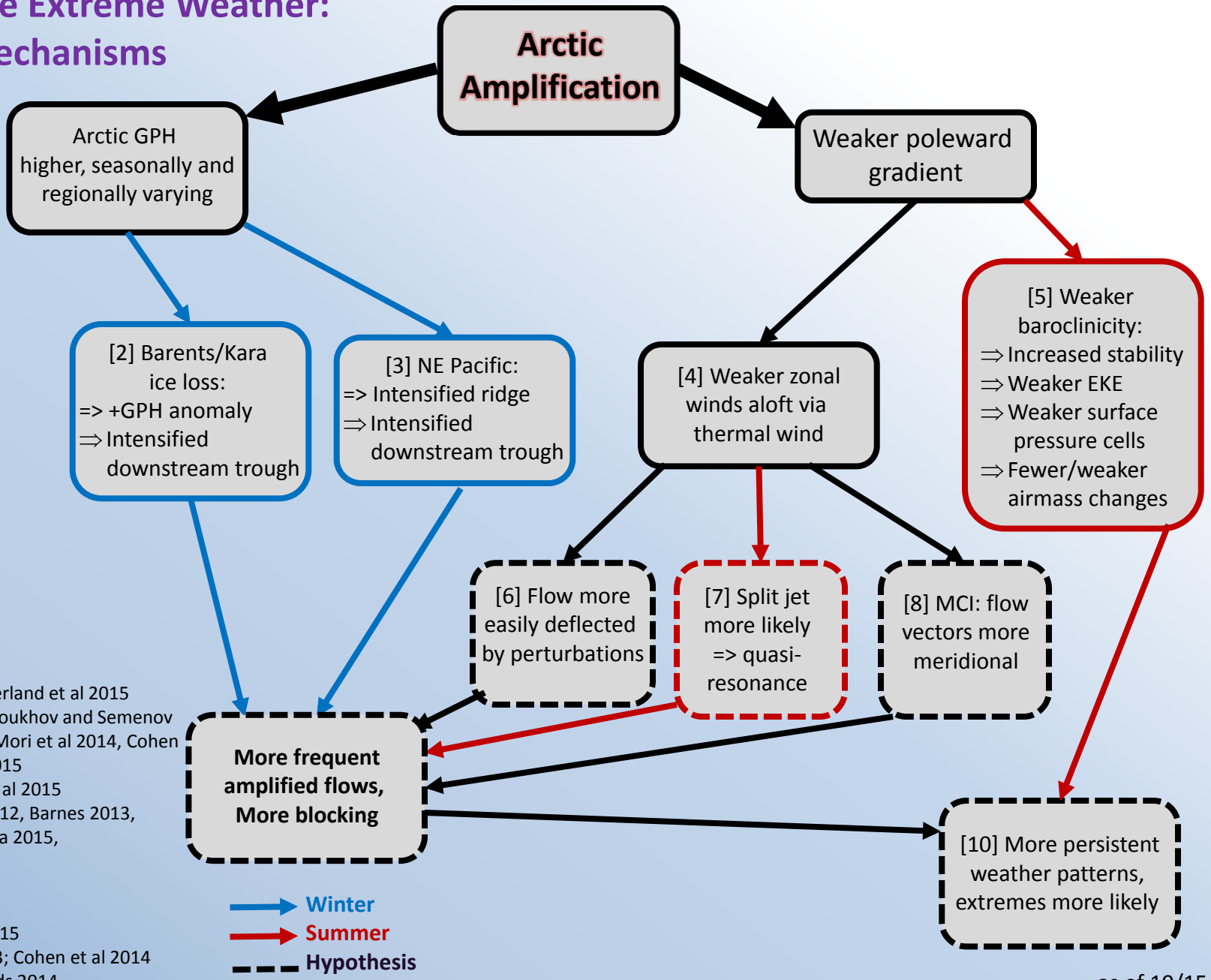

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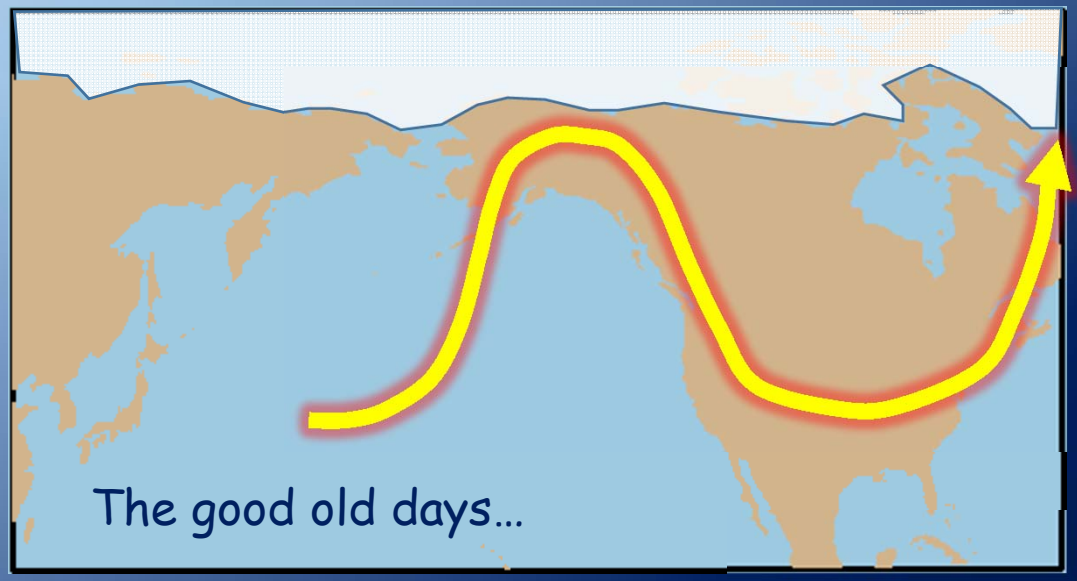
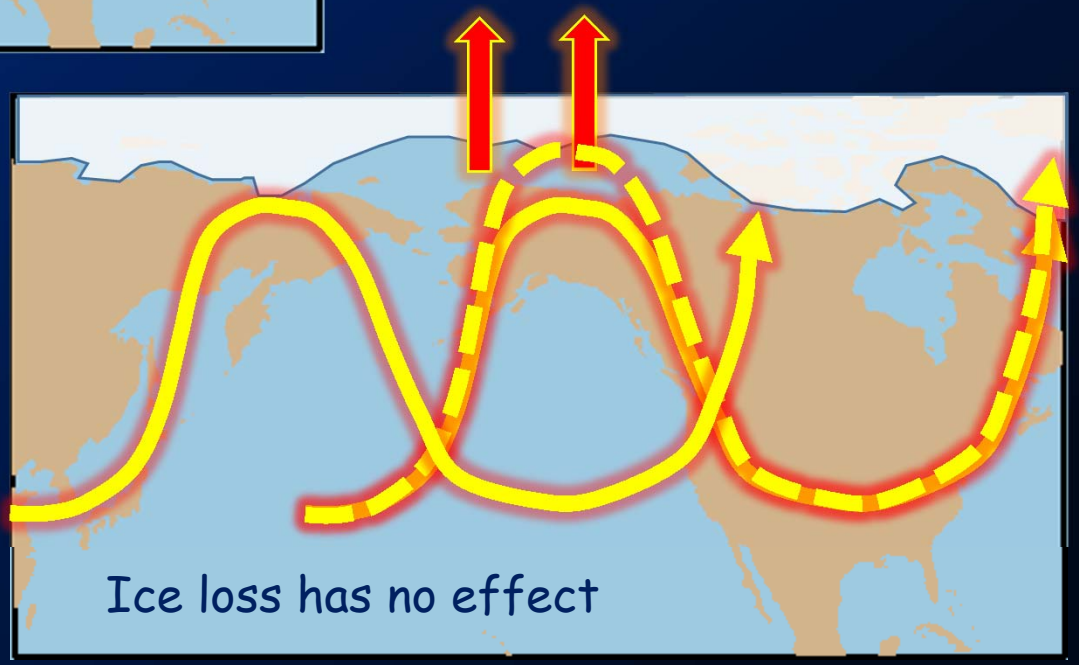
The "It Takes Two to Tango" hypothesis



Extra heating intensifies ridge, making it more persistent.

Two necessary factors, neither sufficient alone!!



Barents/K
Ice los

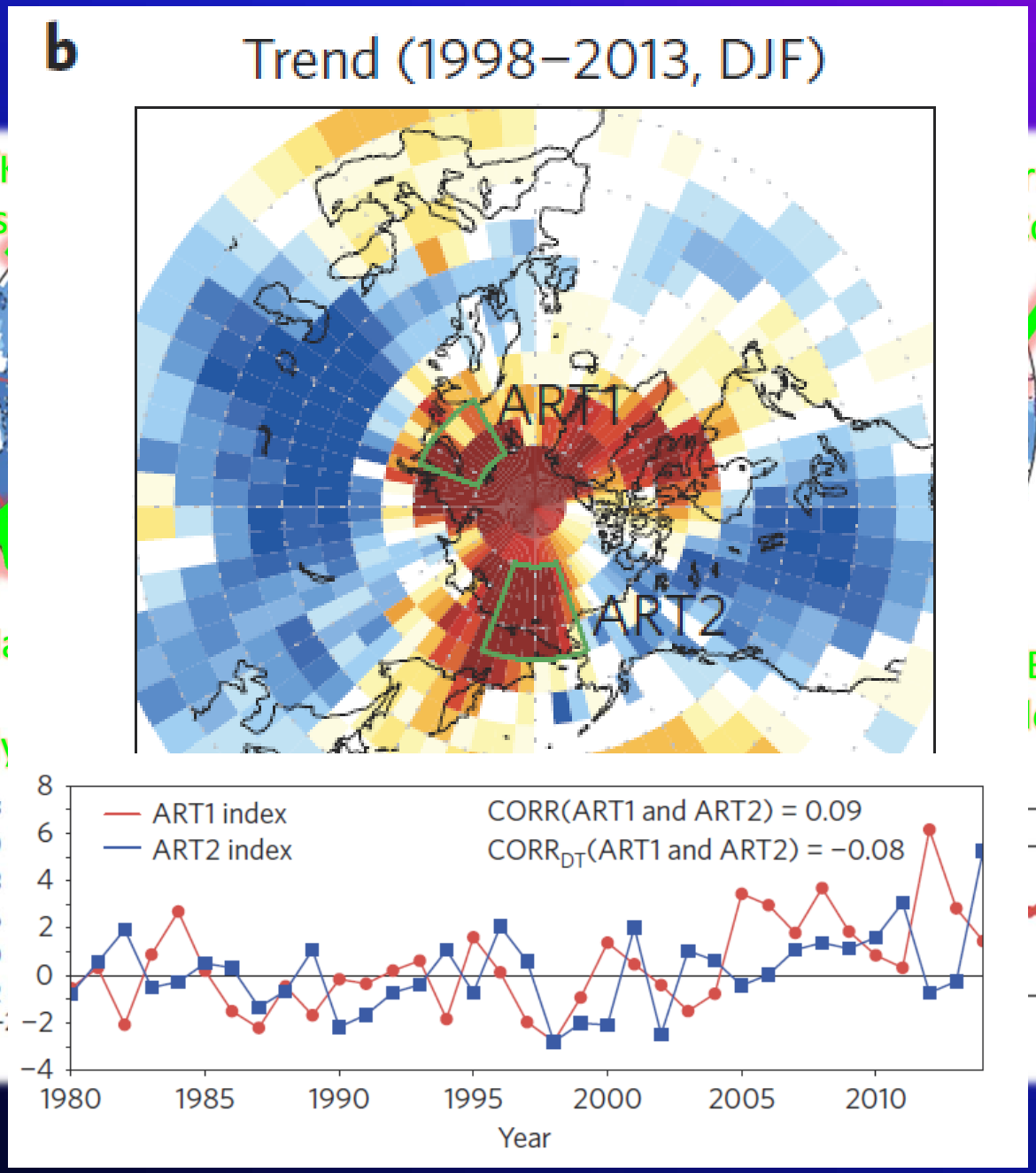
East Asia
cold
anomaly

rn North America
old anomaly

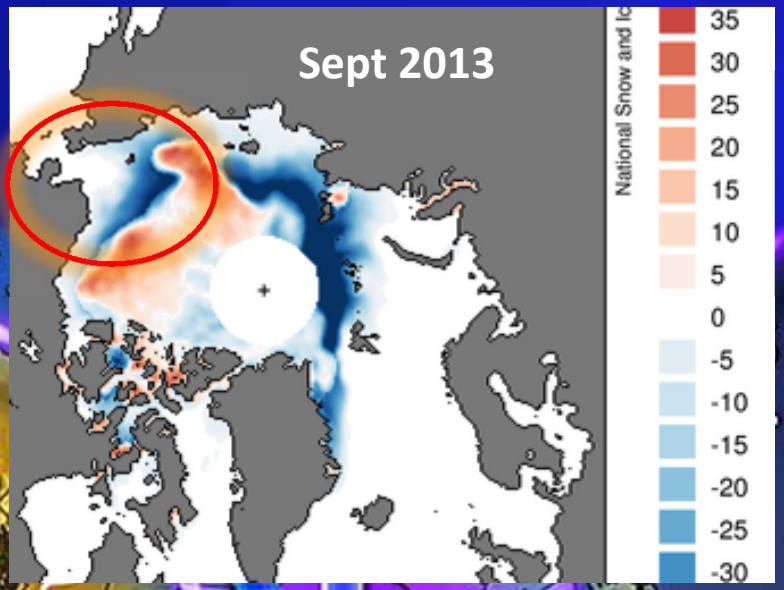
face
erature
nds

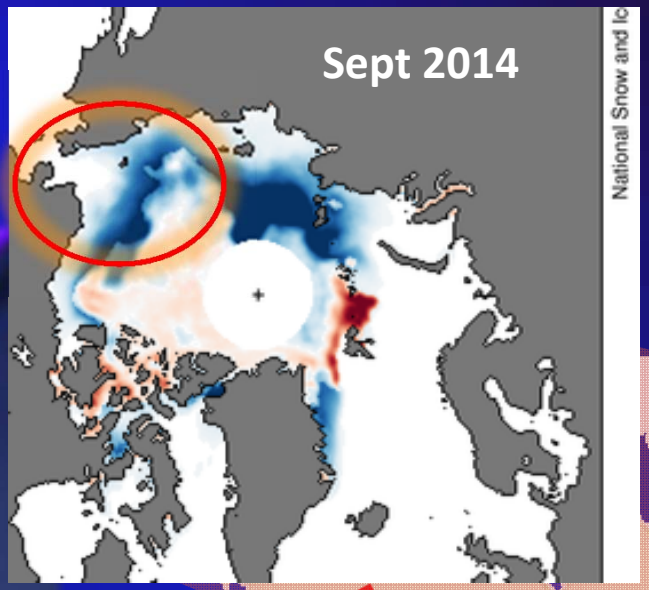
Beaufort
loss

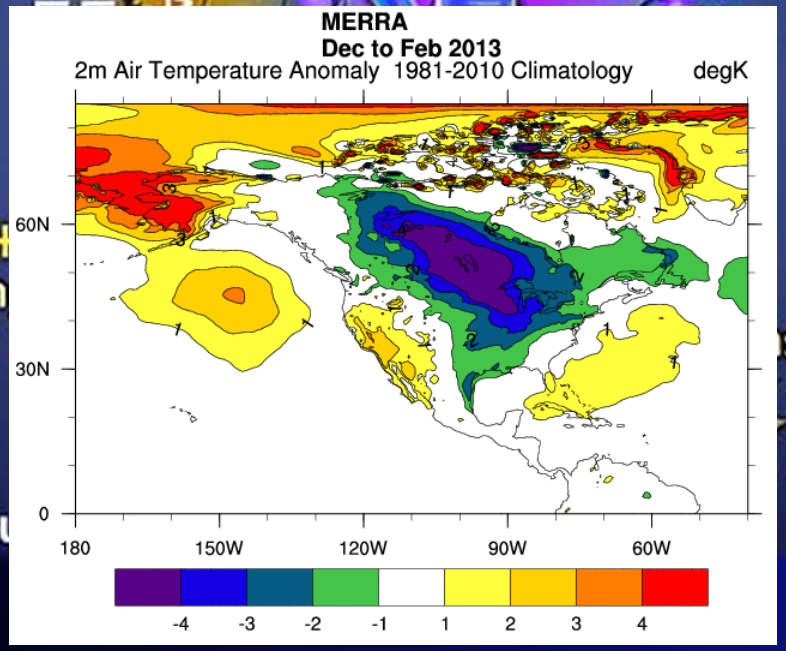
30 (Day)

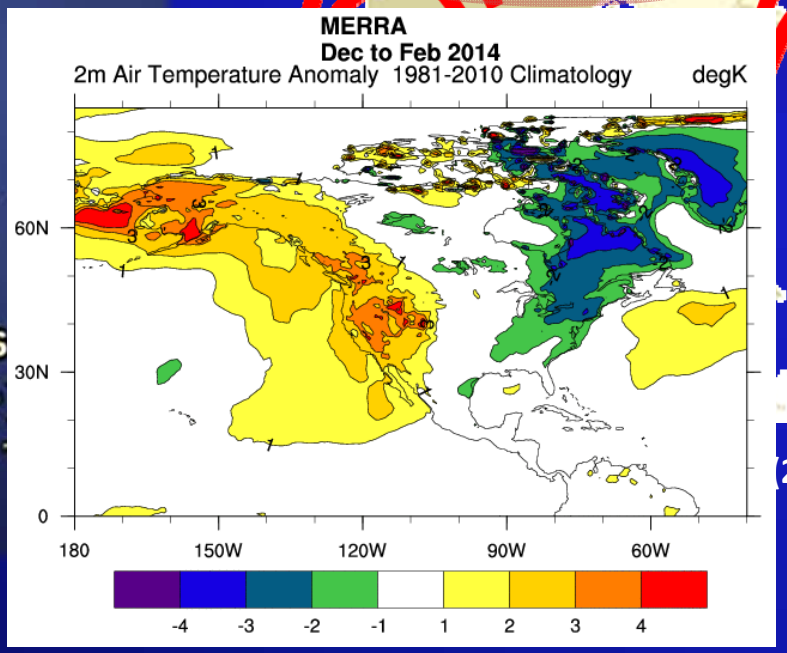


Kug et al, Nature Geosci. 2015









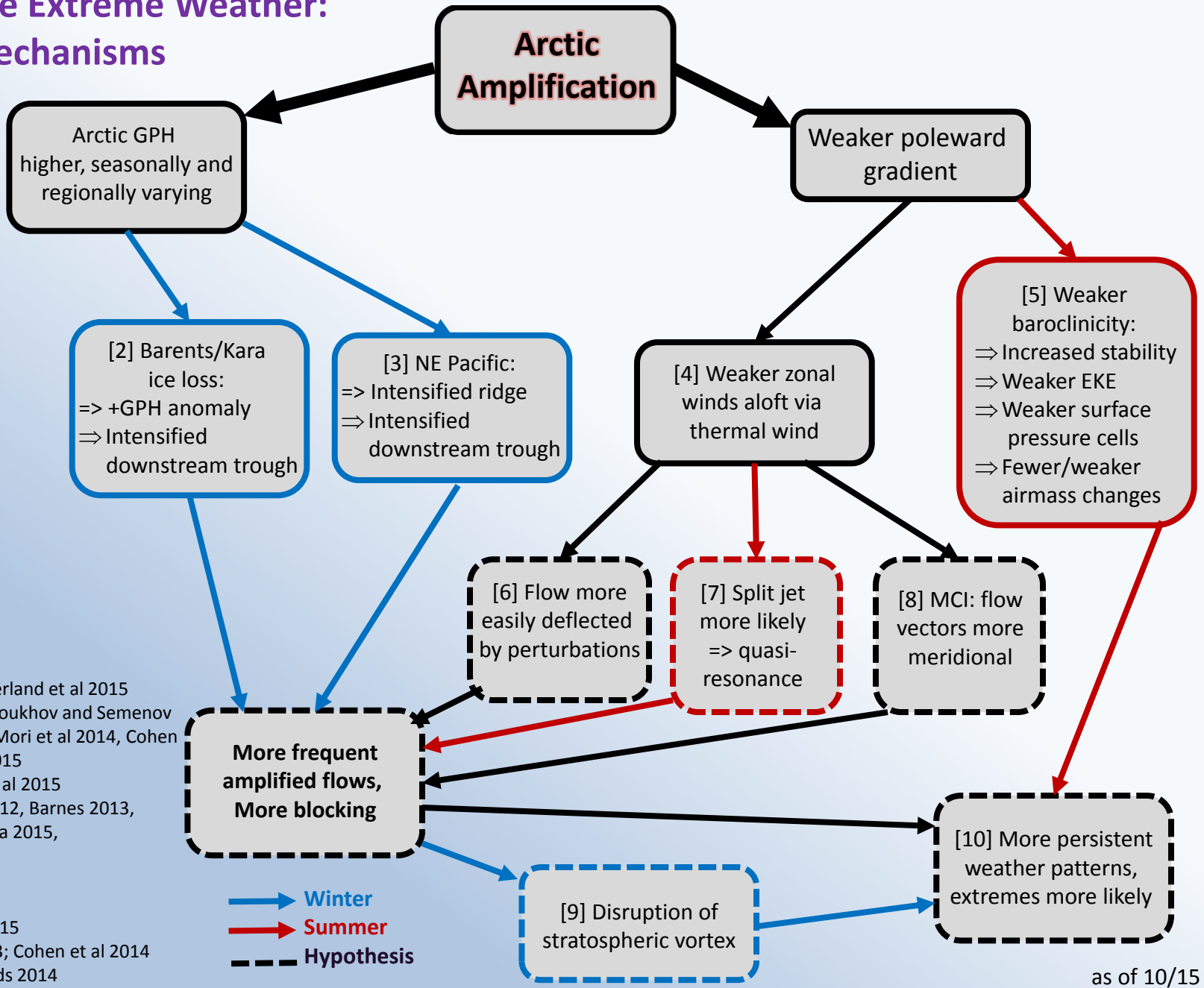
+11.4°
Anchorage

Los An

Accu

(2012)

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



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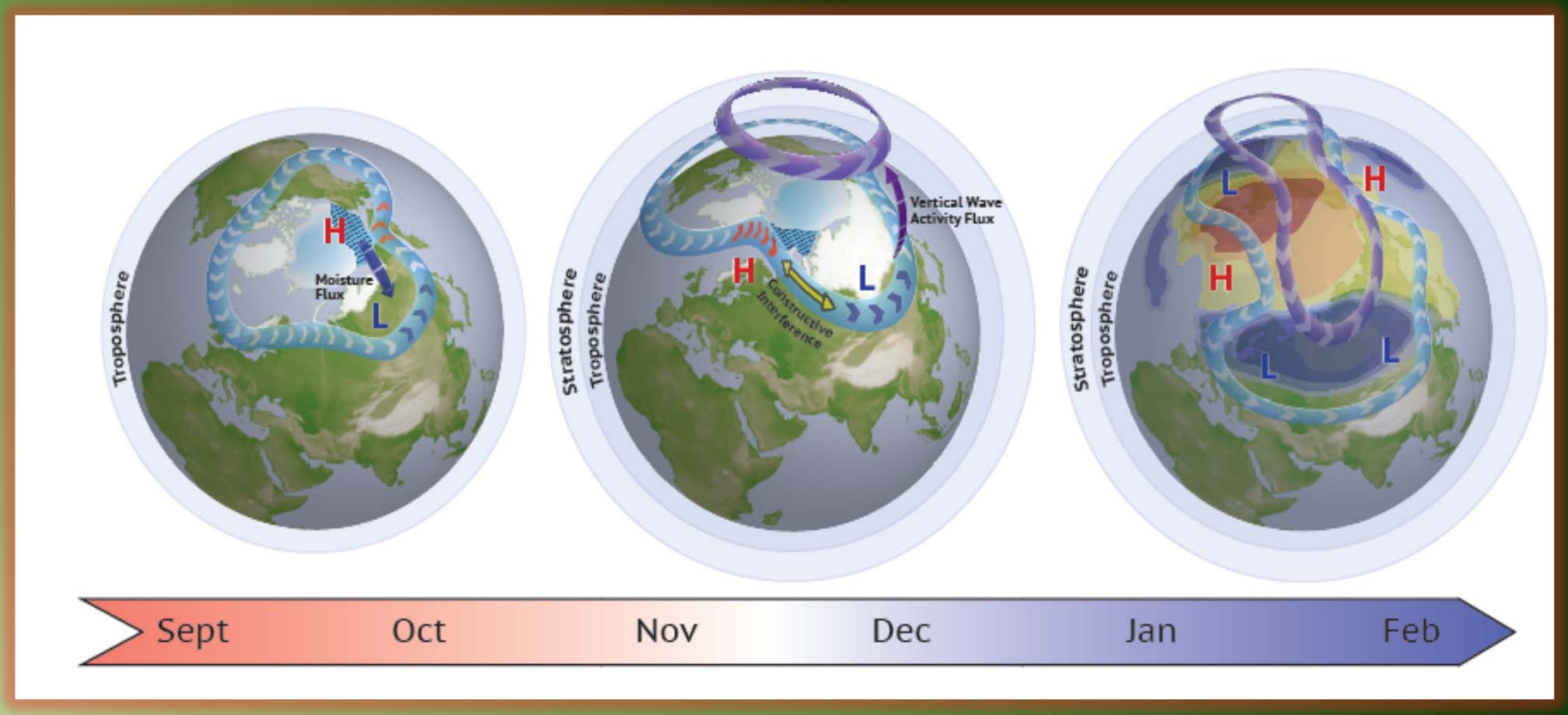
A stratospheric connection?



Cohen et al, Nature Geosciences, 2014

also Jaiser et al 2012, 2013; Kim et al 2014

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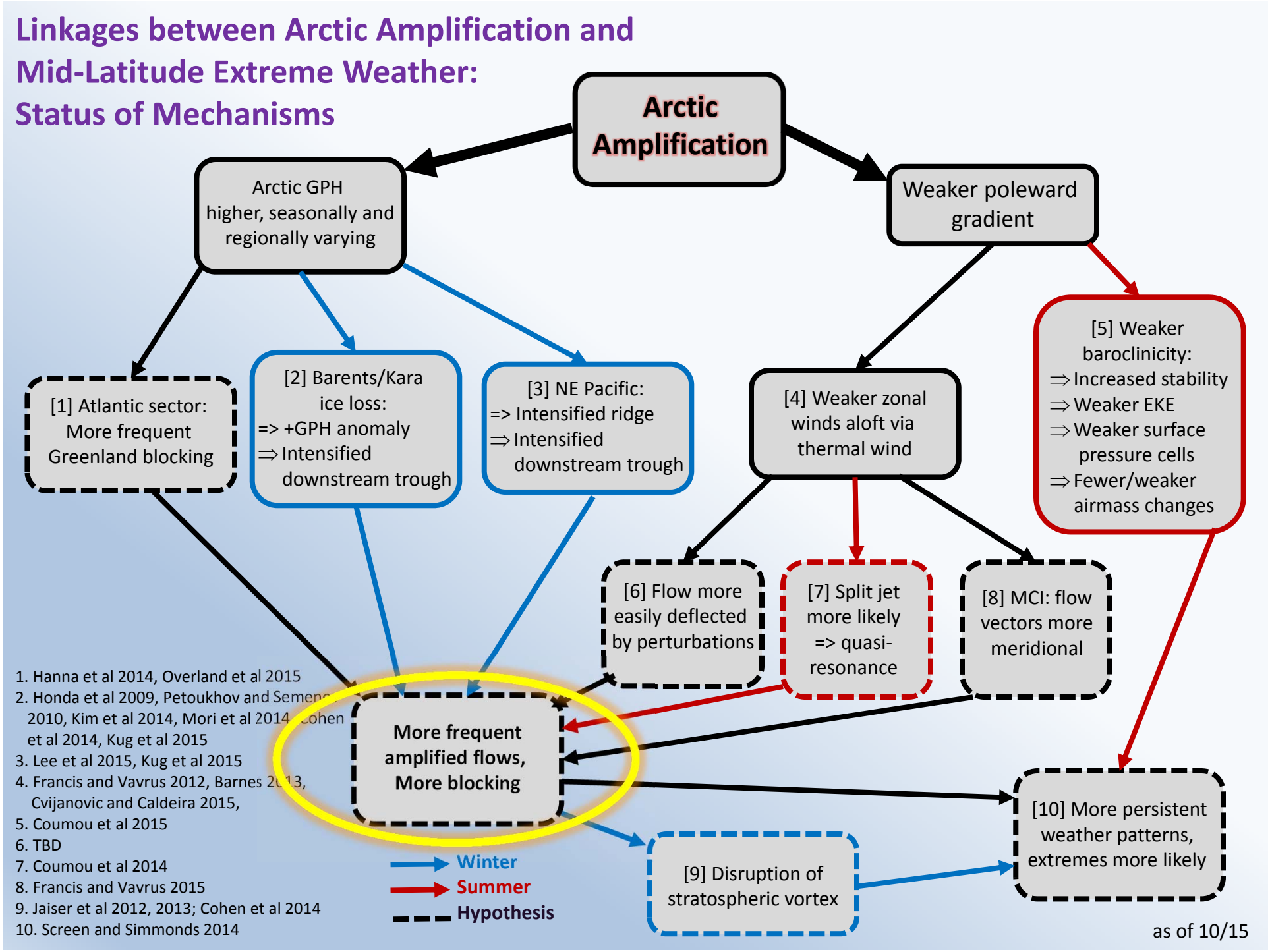

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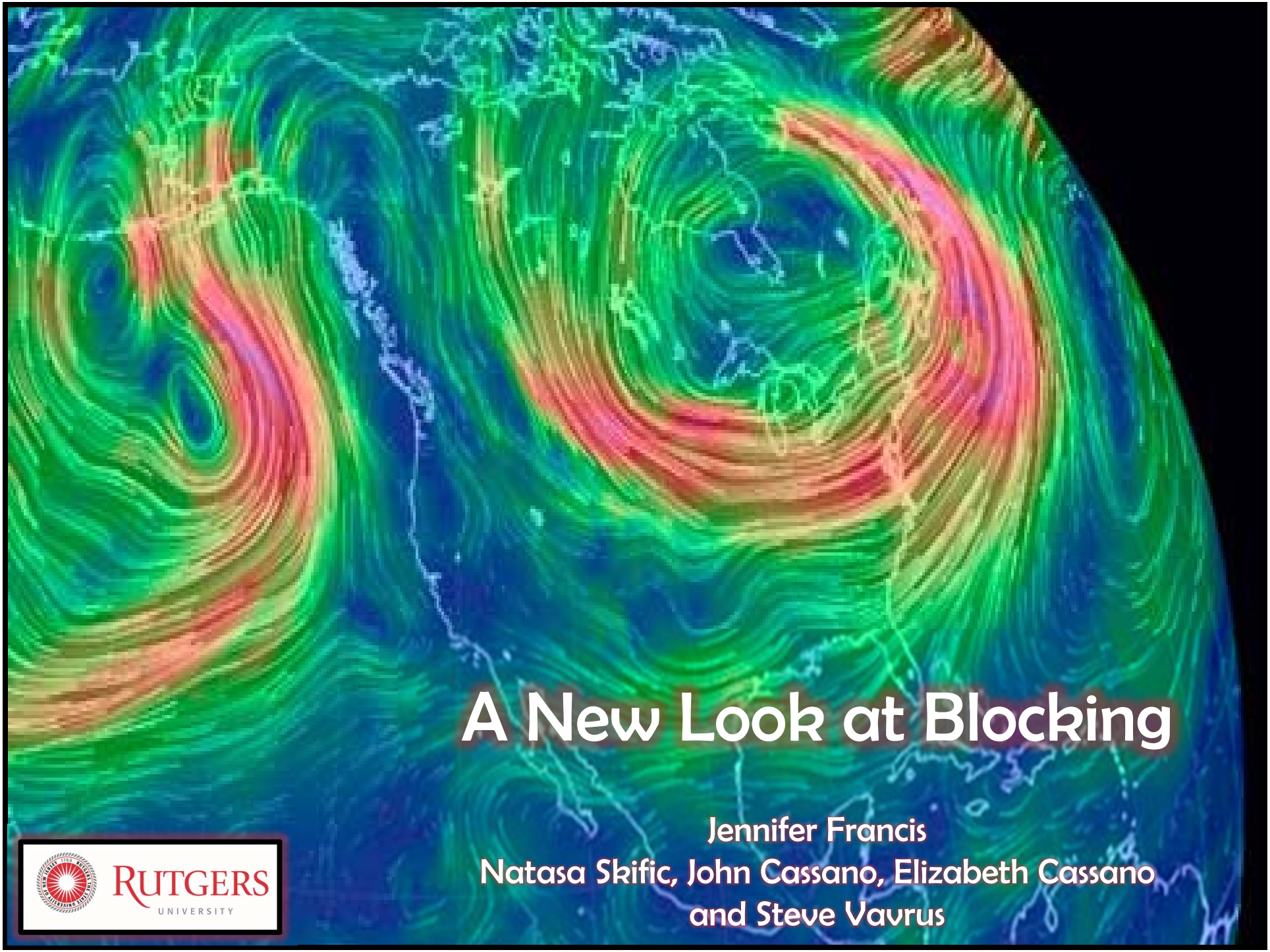


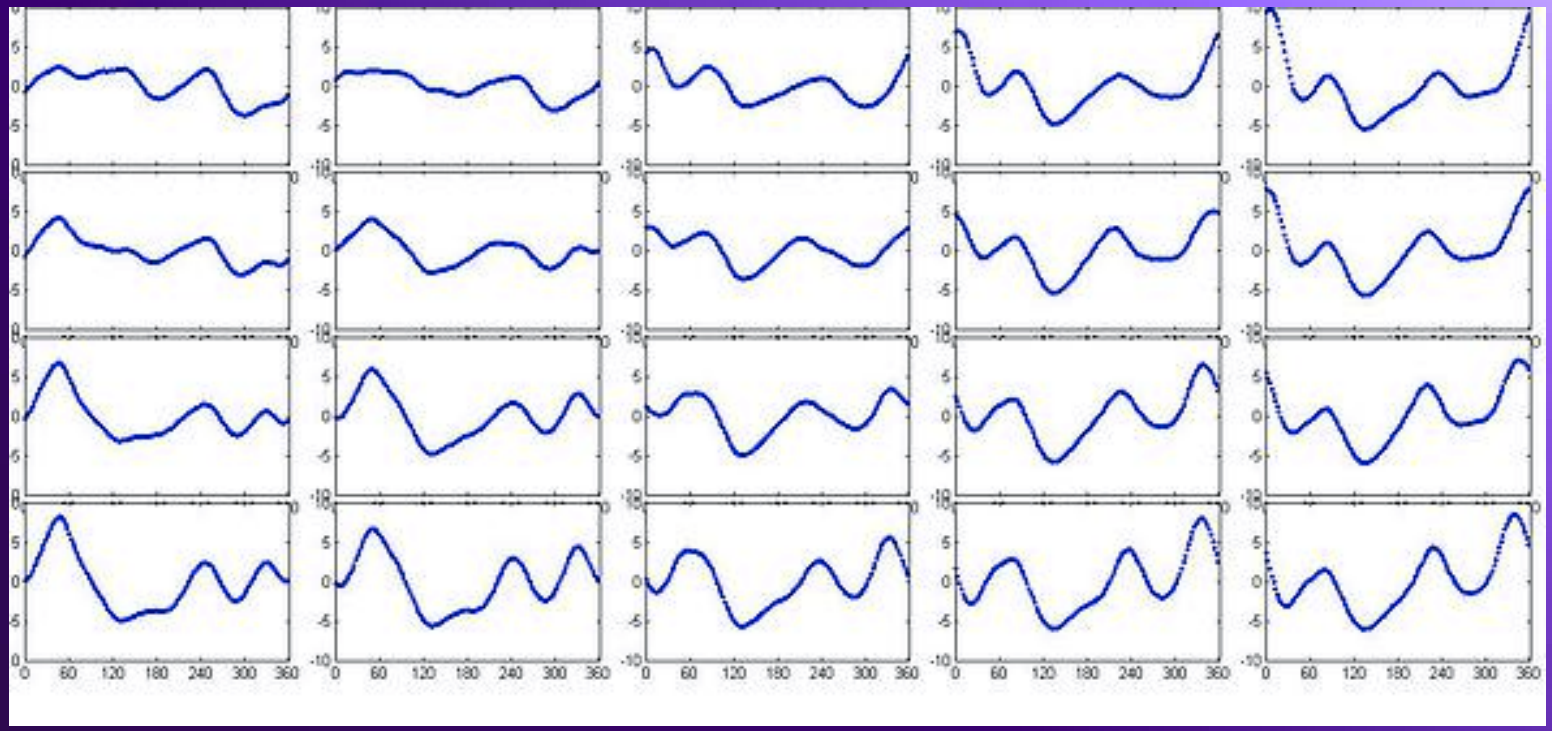
A New Look at Blocking

Jennifer Francis
Natasa Skific, John Cassano, Elizabeth Cassano
and Steve Vavrus

RUTGERS
UNIVERSITY

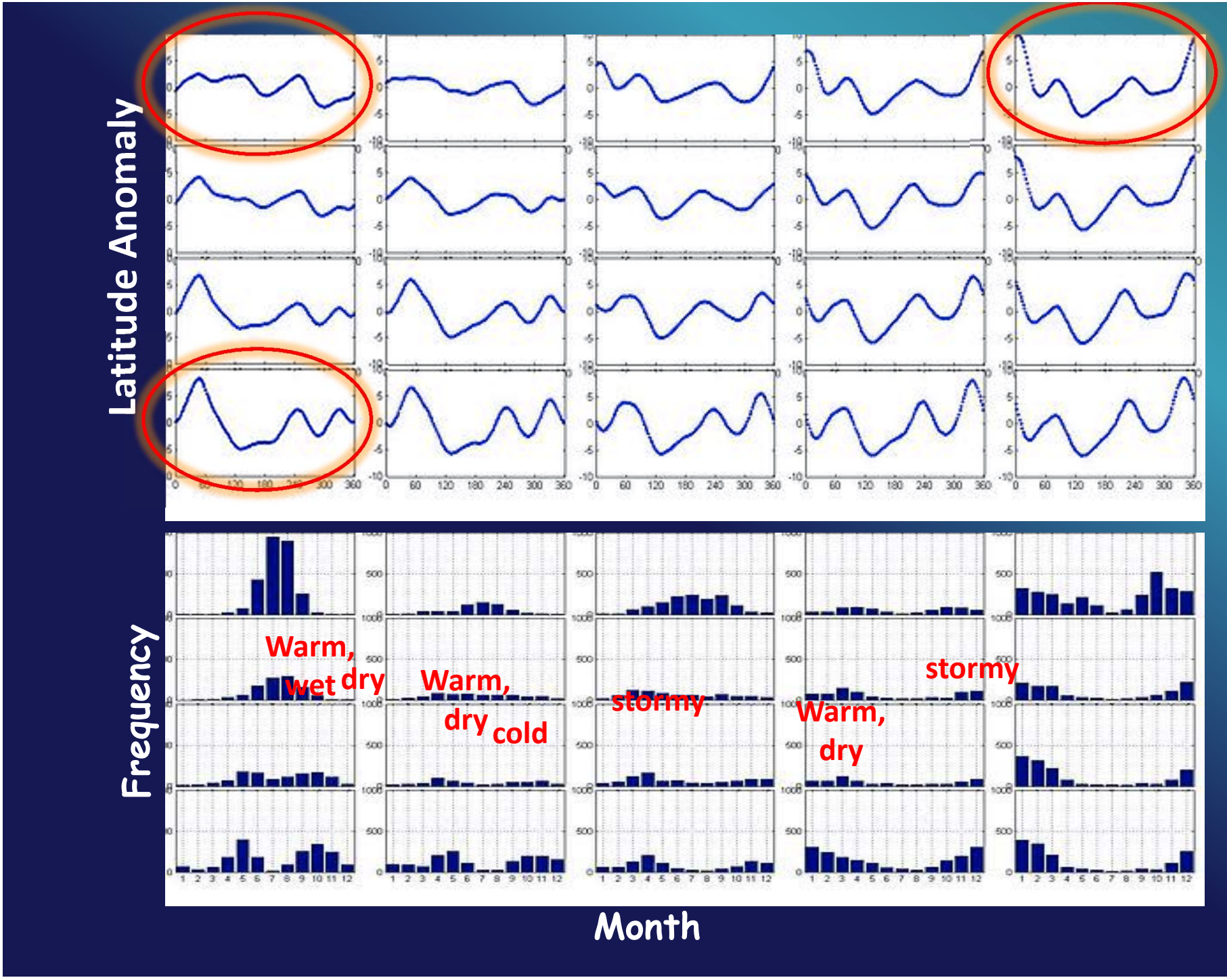
Self-Organizing Maps (SOMs)

A neural-network approach to identify characteristic patterns in large data sets

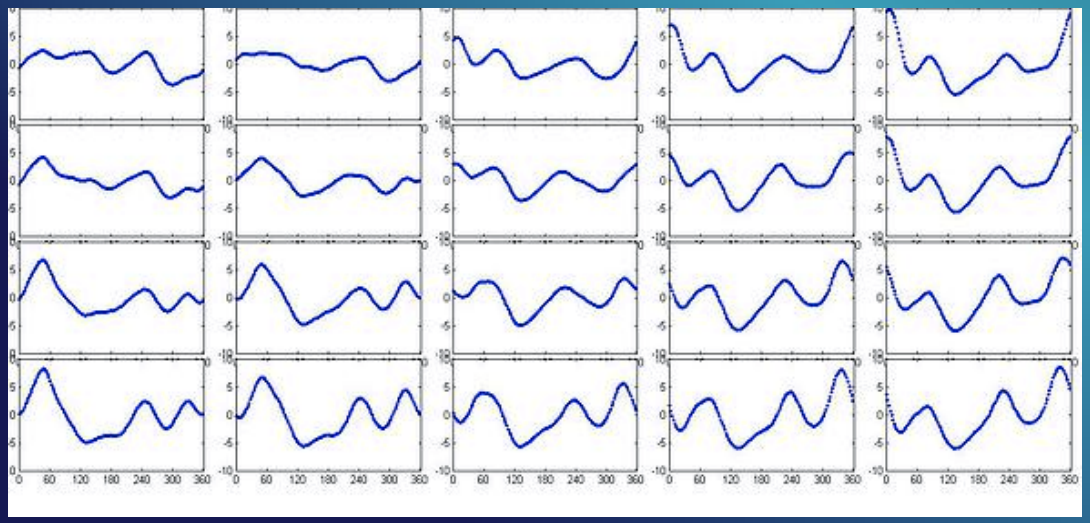


66 years of daily height contours (500 hPa, 5600m) from NCEP/ERA-I reanalysis (~36,000 fields) are used to create the matrix of clusters

Francis, Skific, Vavrus, Cassano, and Cassano, in prep

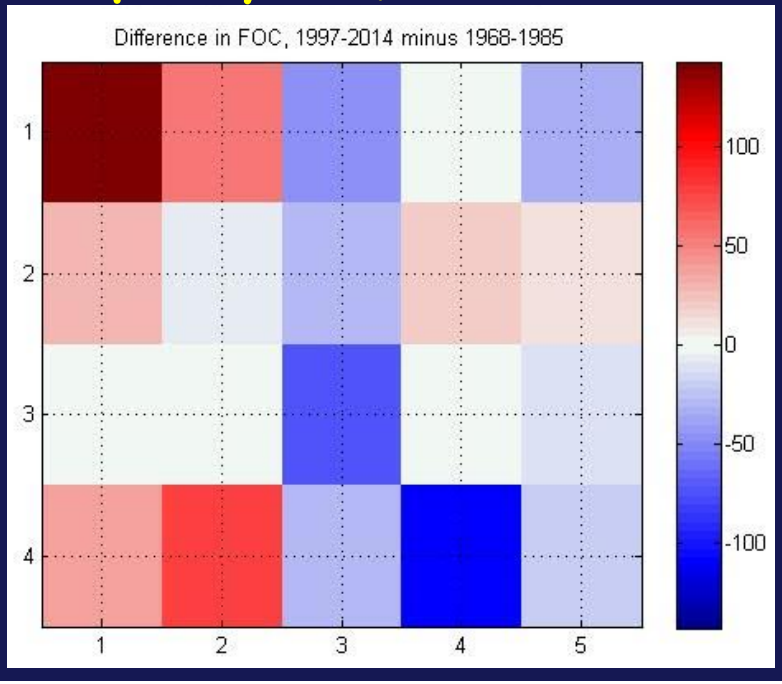

Latitude Anomaly
Frequency
Warm, wet
dry
Warm, dry
cold
stormy
Warm, dry
stormy
Month

Frequency and Amplitude

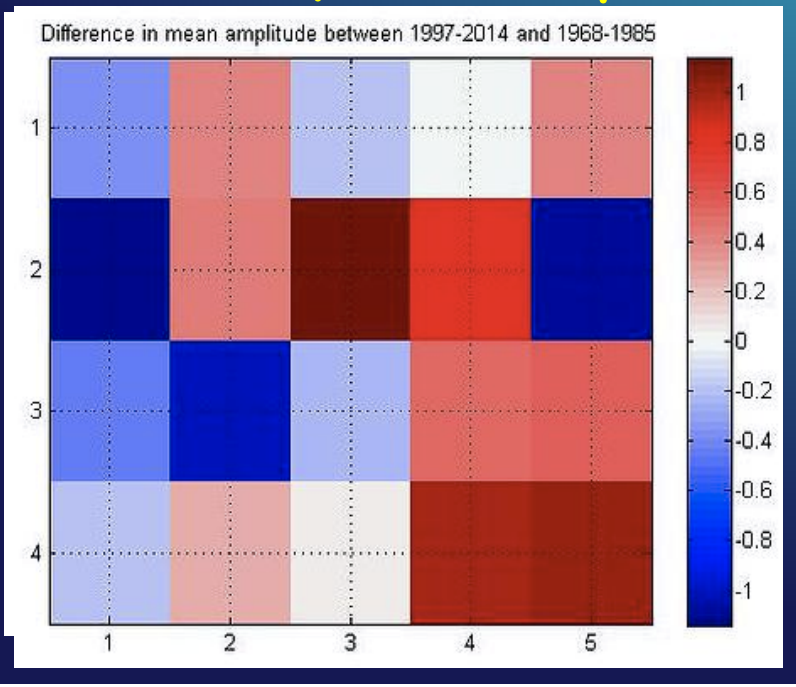


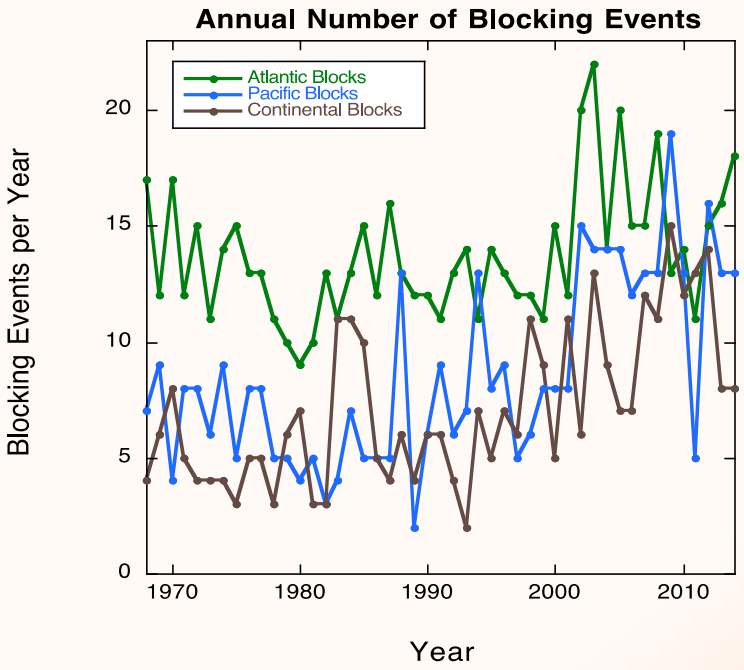
(1997-2014)
minus
(1968-1985)

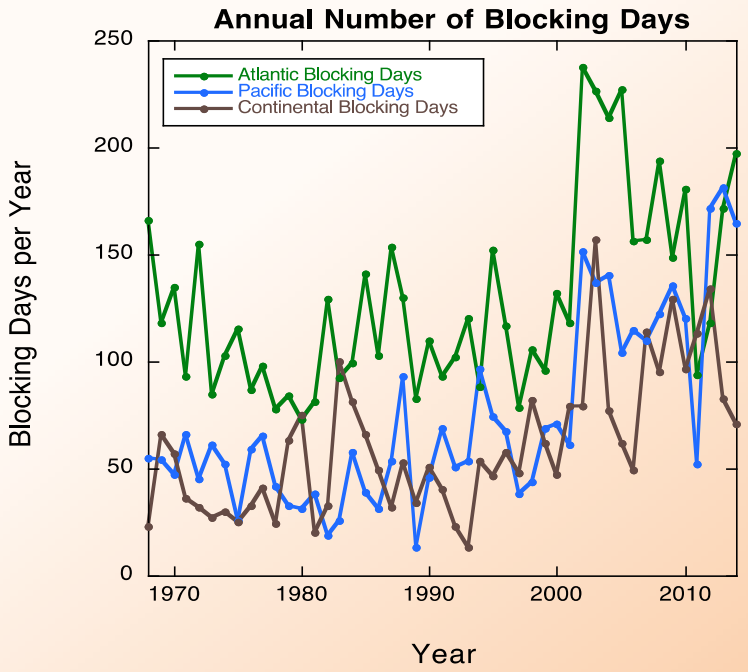
Frequency (difference)

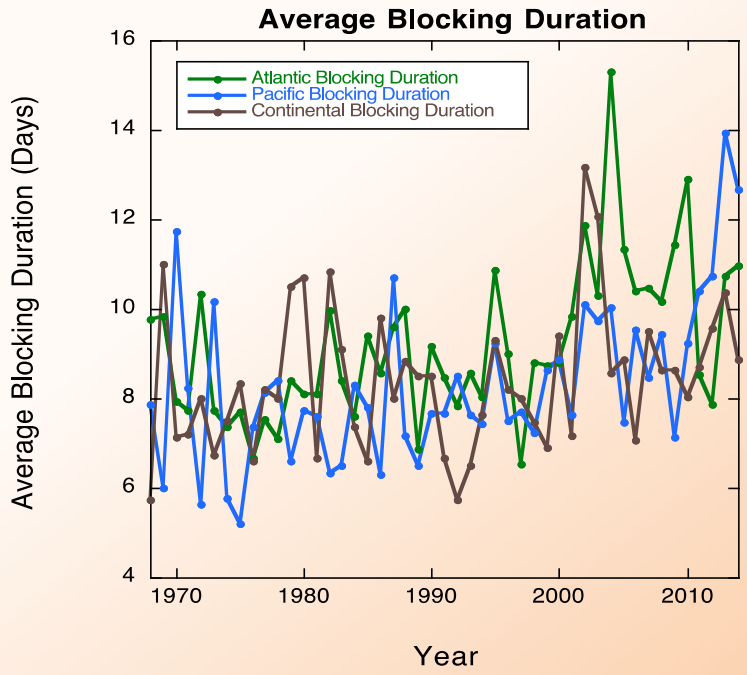


Amplitude (difference)



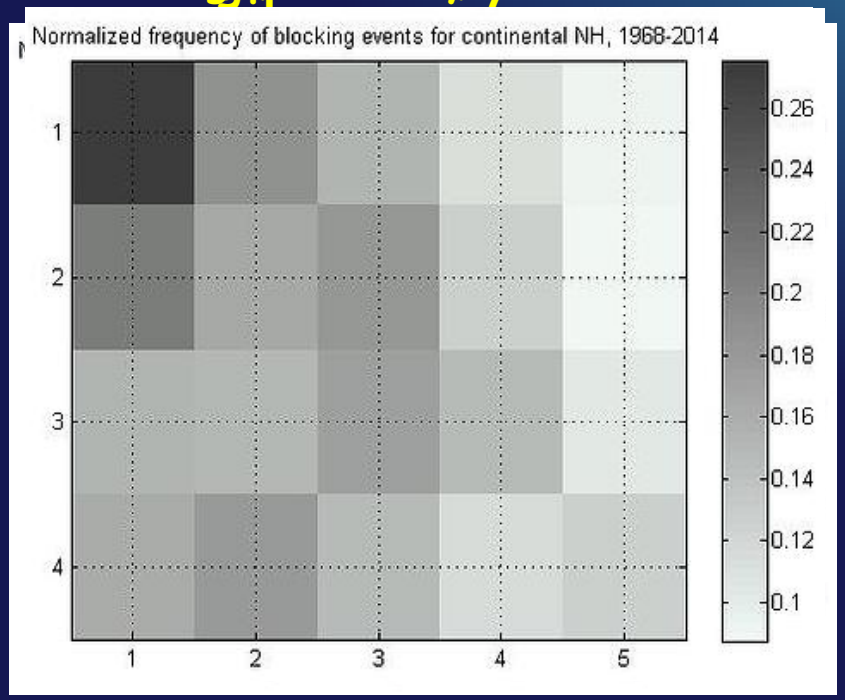


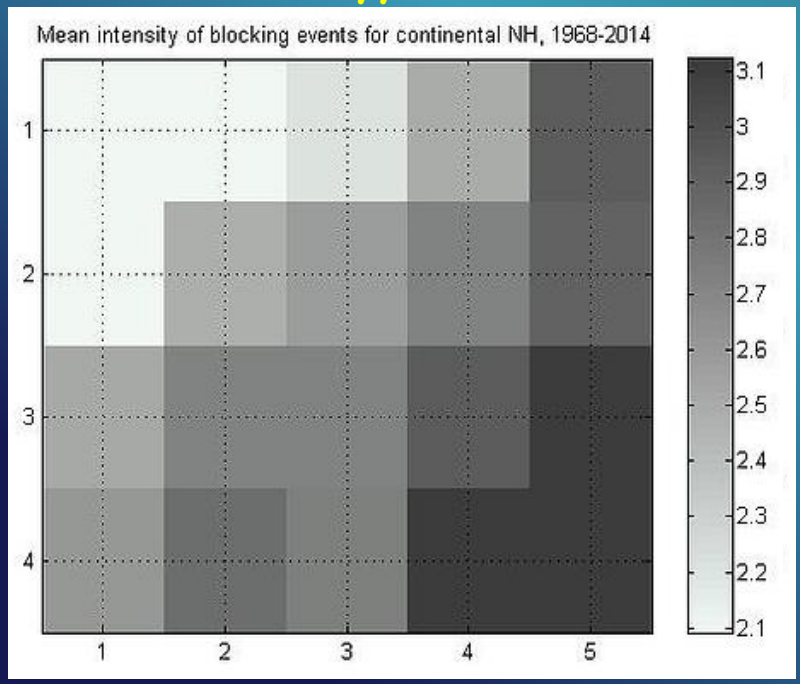


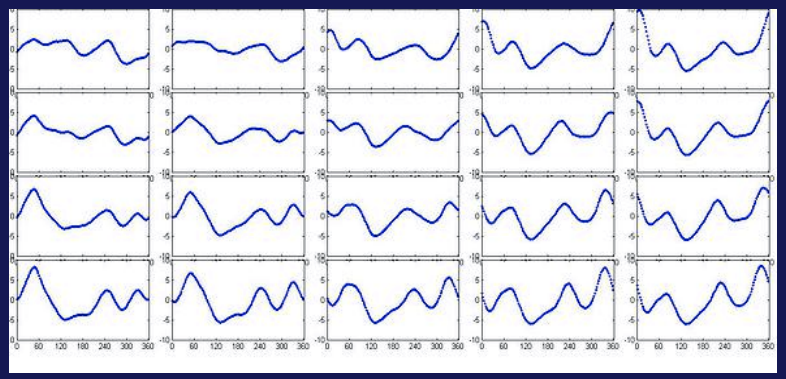


Blocking data from A. Lupo
http://solberg.snr.missouri.edu/gcc/
based on Wiedenmann et al (2002)

Blocking Frequency and Intensity

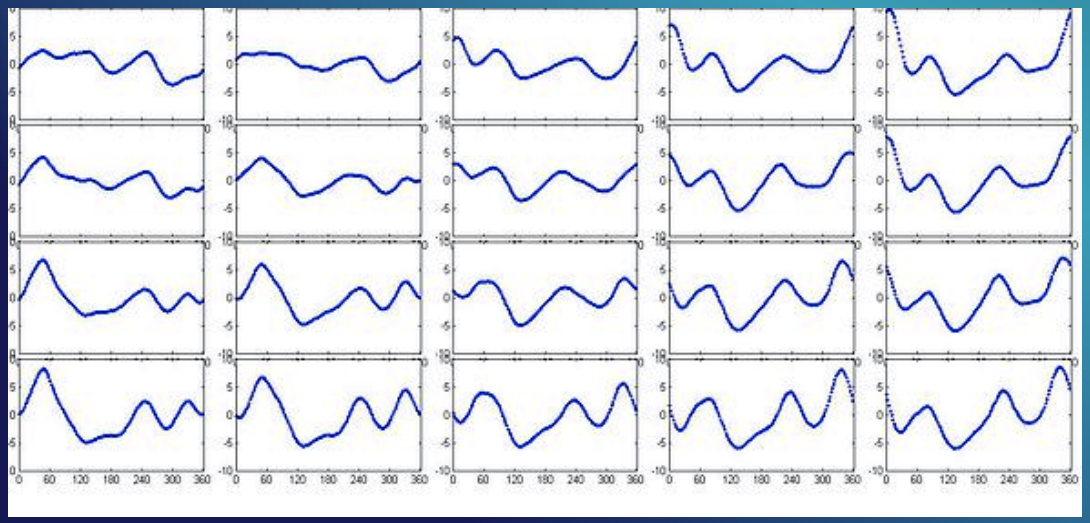






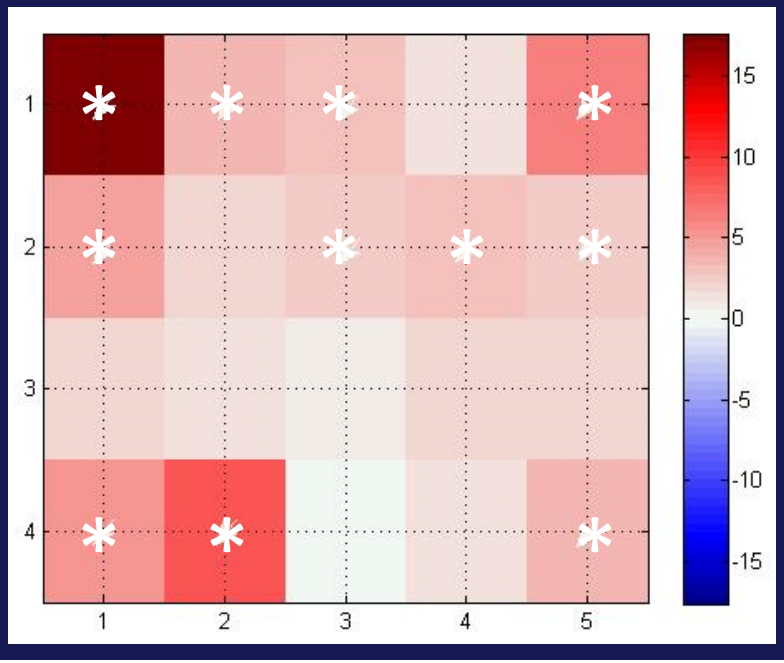
Blocking data from A. Lupo
http://solberg.snr.missouri.edu/gcc/

Changes in Blocking Frequency and Intensity

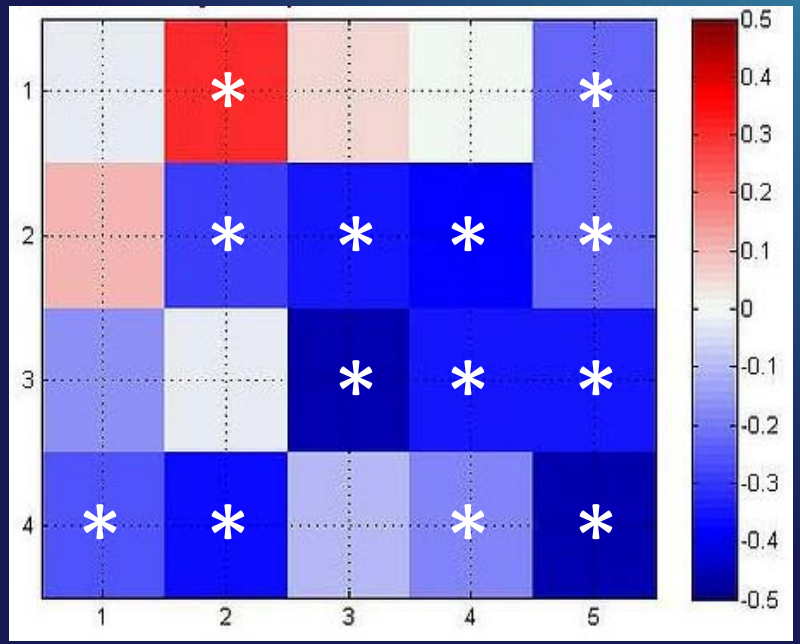


(1997-2014)
minus
(1968-1985)
* p < 0.05

Frequency difference (days/year)

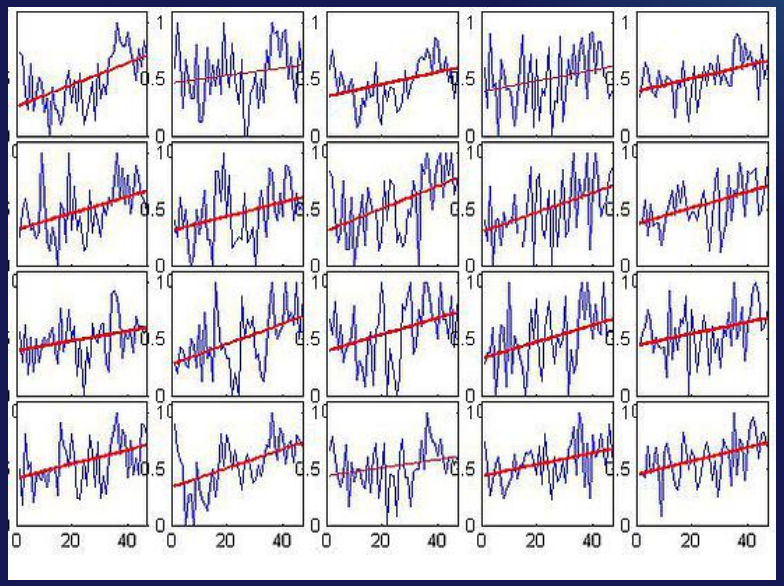


Intensity difference

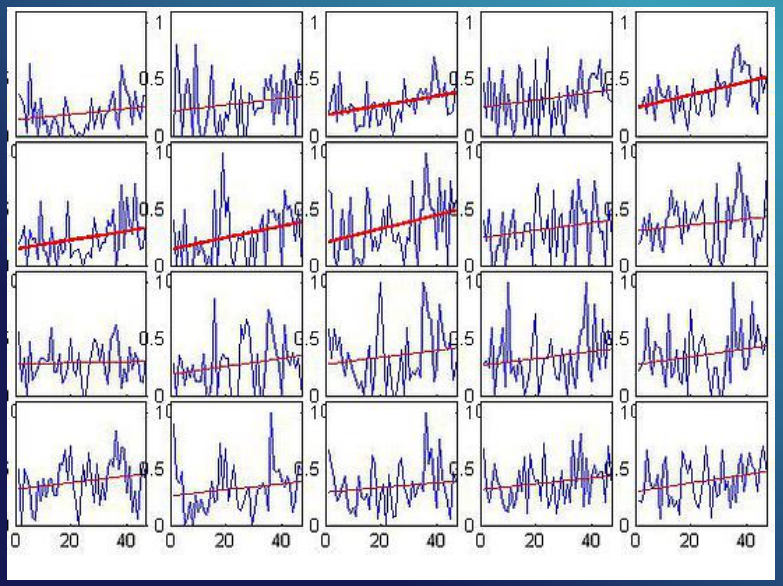


Trends in Blocking Probability

Northern Hemisphere



Atlantic sector

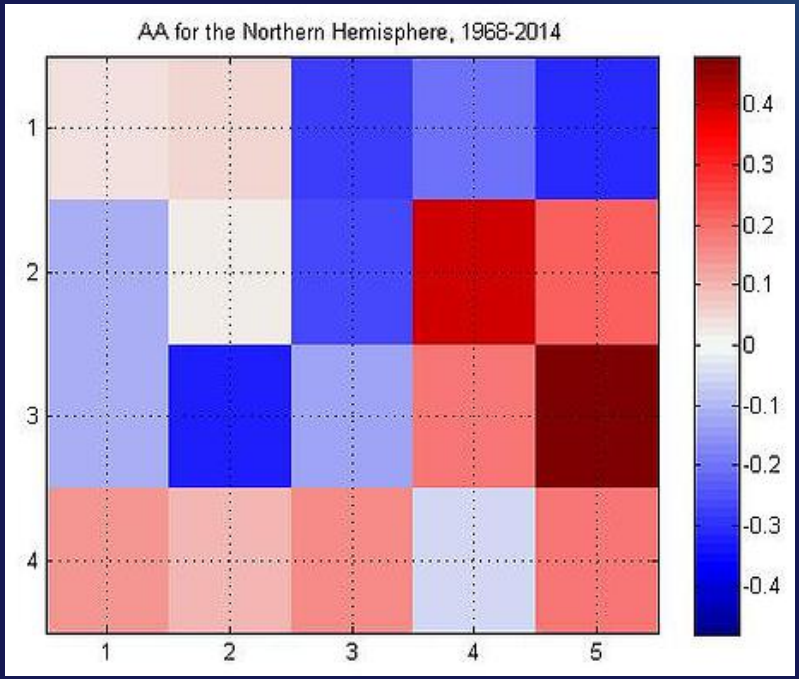


Blocking data from A. Lupo
http://solberg.snr.missouri.edu/gcc/

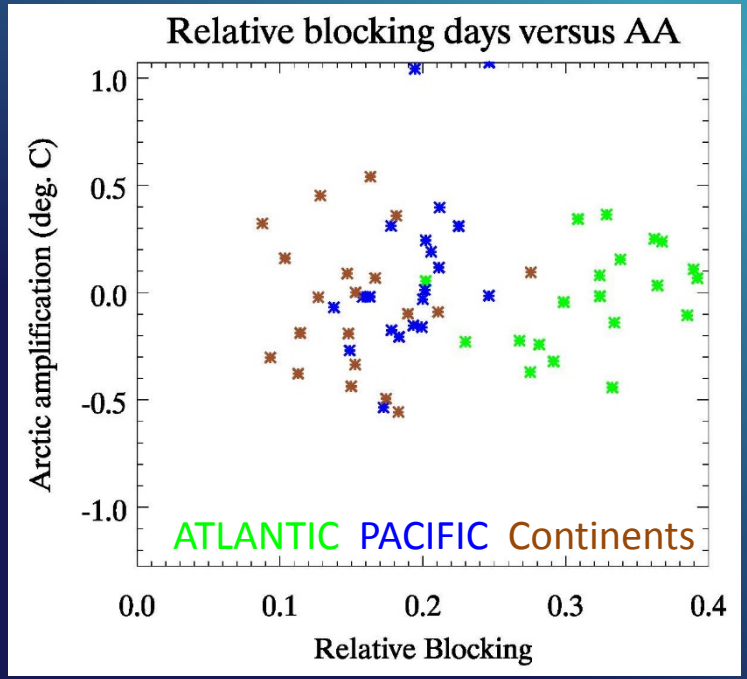
Blocking versus Arctic amplification

T_{2m} (70°N-90°N) – (30°N-60°N)

AA: Northern Hemisphere

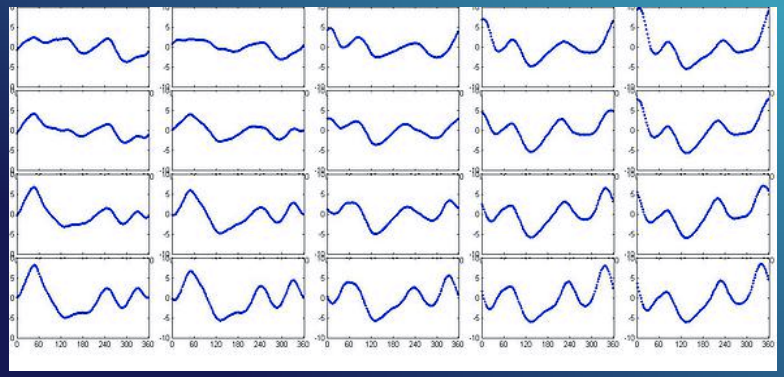


Blocking versus probability

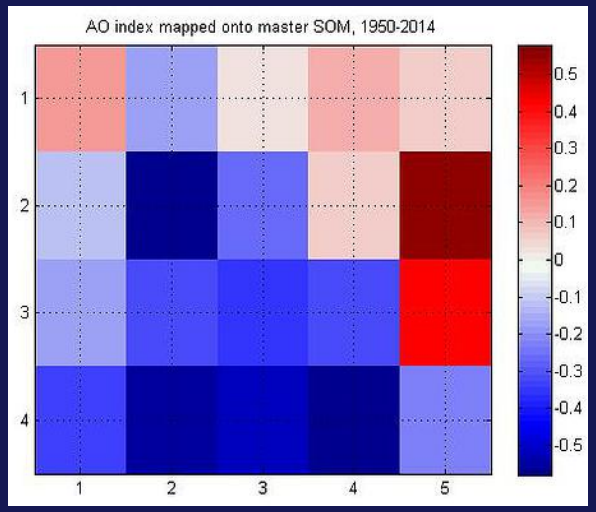


Capitals: $p < 0.1$

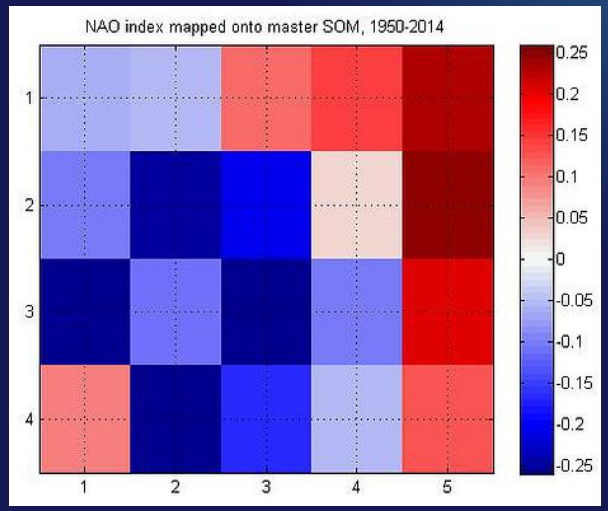
Blocking versus AO, NAO, and PNA



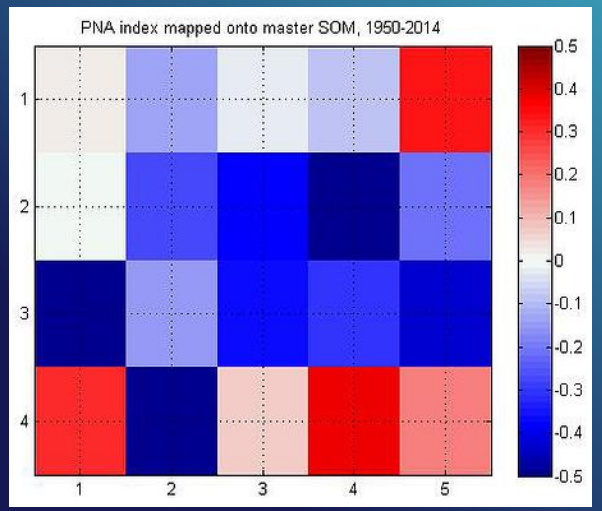
Arctic oscillation



NAO

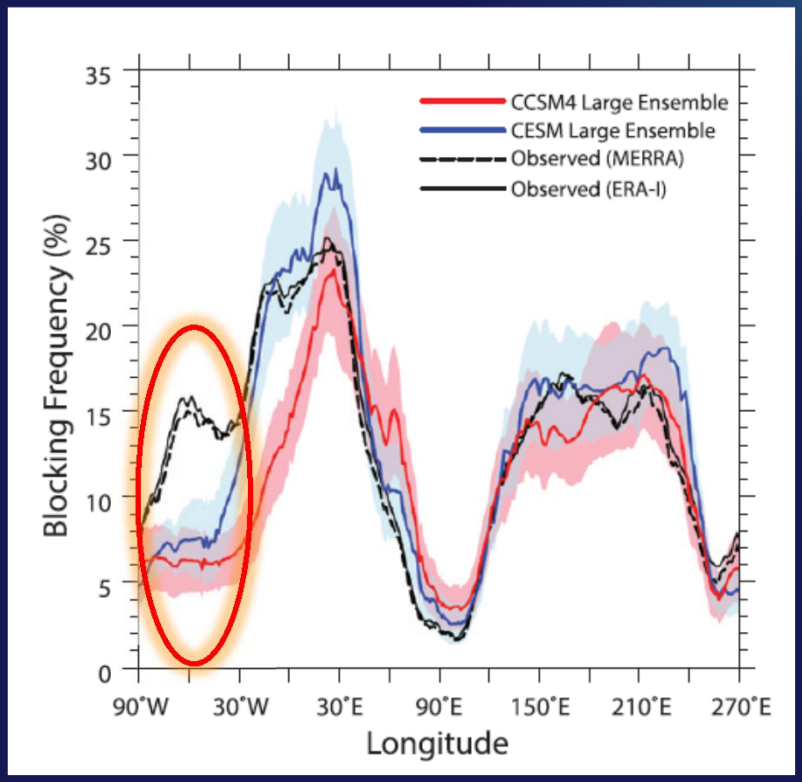


PNA

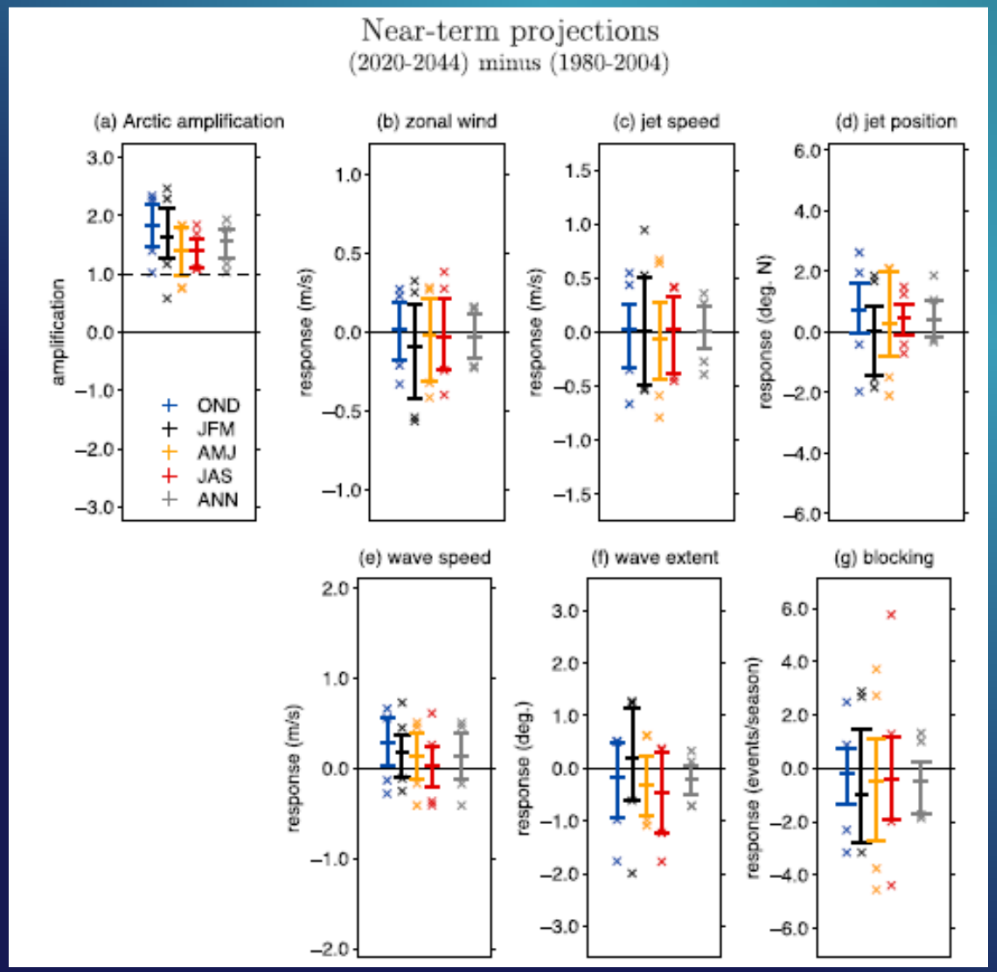


- Block prob in Pac
  $p < 0.1$

The blocking story is complicated…



Kay et al, BAMS 2015

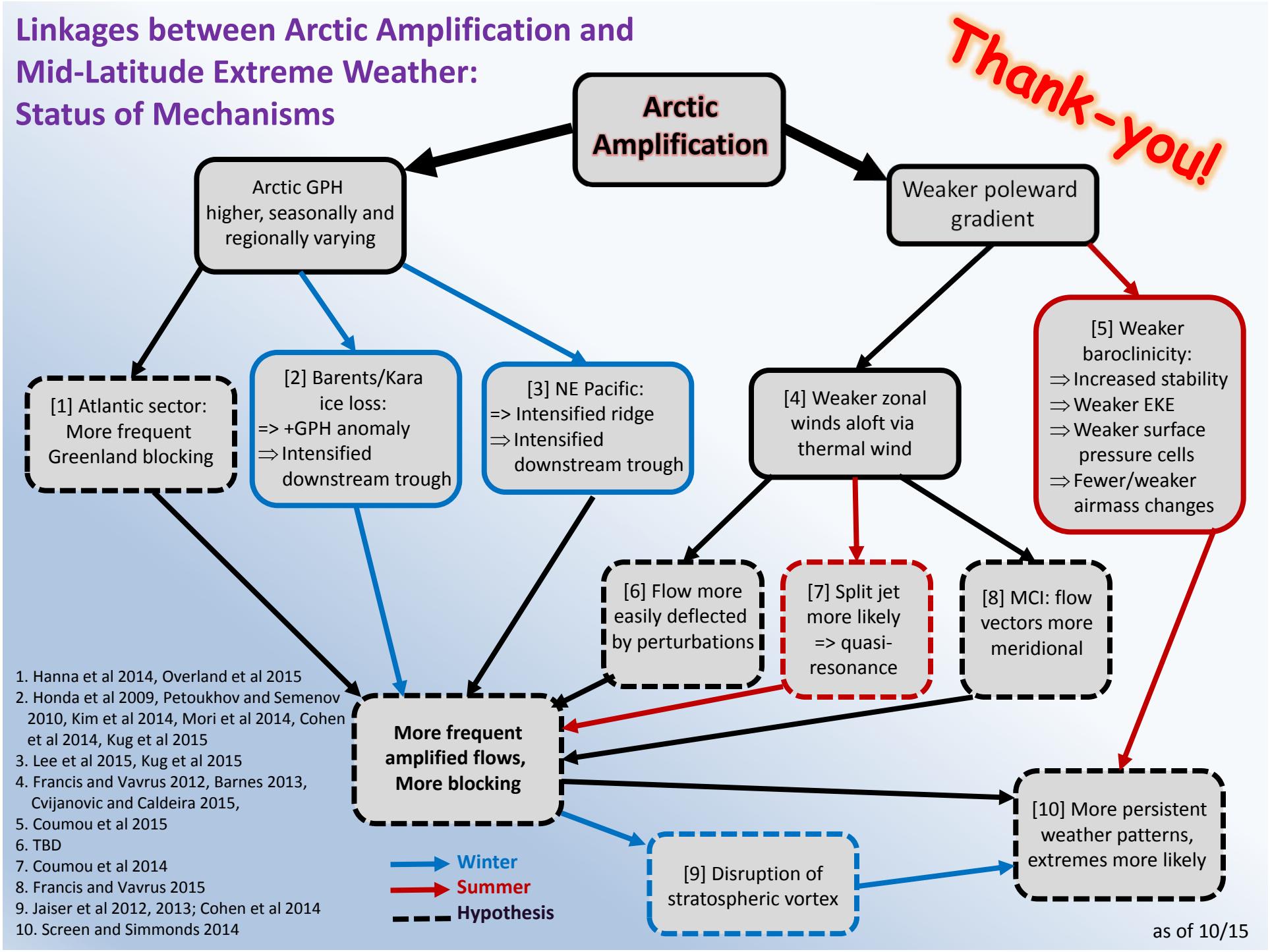


Barnes and Polvani, J. Clim. 2015

Food for thought…

- A flurry of new studies suggest a rapidly warming Arctic will favor more persistent weather patterns via various mechanisms
- More persistent patterns ⇒ longer dry, hot, wet, & cold spells
- Day-to-day variability will decrease while "Weather whiplash" increases
- AA augments some natural patterns to foster extreme events
- "Same old" metrics (averaging over time, space, and ensembles) not well suited to this problem
- Pattern-based analysis (SOMs) may help separate signal from chaos of natural variability:
  - Probability of blocking in given pattern is increasing; block intensity is decreasing
  - AA appears to be associated with increased blocking probability
  - Can models capture these types of amplified relationships?

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



1. Hanna et al 2014, Overland et al 2015
2. Honda et al 2009, Petoukhov and Semenov 2010, Kim et al 2014, Mori et al 2014, Cohen et al 2014, Kug et al 2015
3. Lee et al 2015, Kug et al 2015
4. Francis and Vavrus 2012, Barnes 2013, Cvijanovic and Caldeira 2015,
5. Coumou et al 2015
6. TBD
7. Coumou et al 2014
8. Francis and Vavrus 2015
9. Jaiser et al 2012, 2013; Cohen et al 2014
10. Screen and Simmonds 2014

as of 10/15

Extras

HAPs versus Blocking

This raises some interesting questions about the effects of a weakened poleward gradient and zonal winds on the behavior of the jet stream:

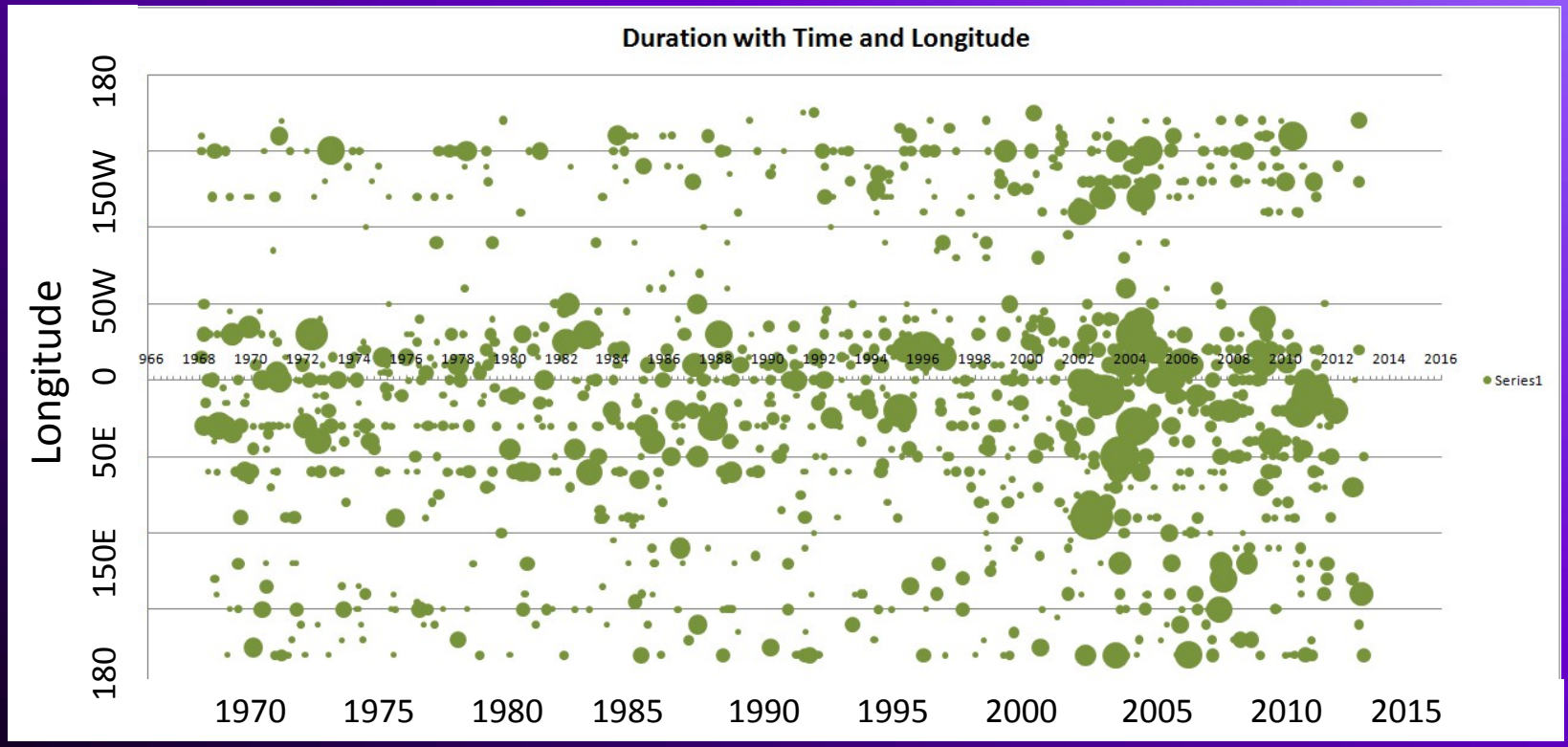
- Blocking is caused by wave breaking, which increases in strong gradients (winter) => should become less frequent and less intense in future as AA increases. CMIP5 models show this, observations do not!
- HAPs more frequent when gradients weak (summer) => should increase in future. Observations agree.
- Cut-off lows also more common in summer when gradient is weak. => increase in future?

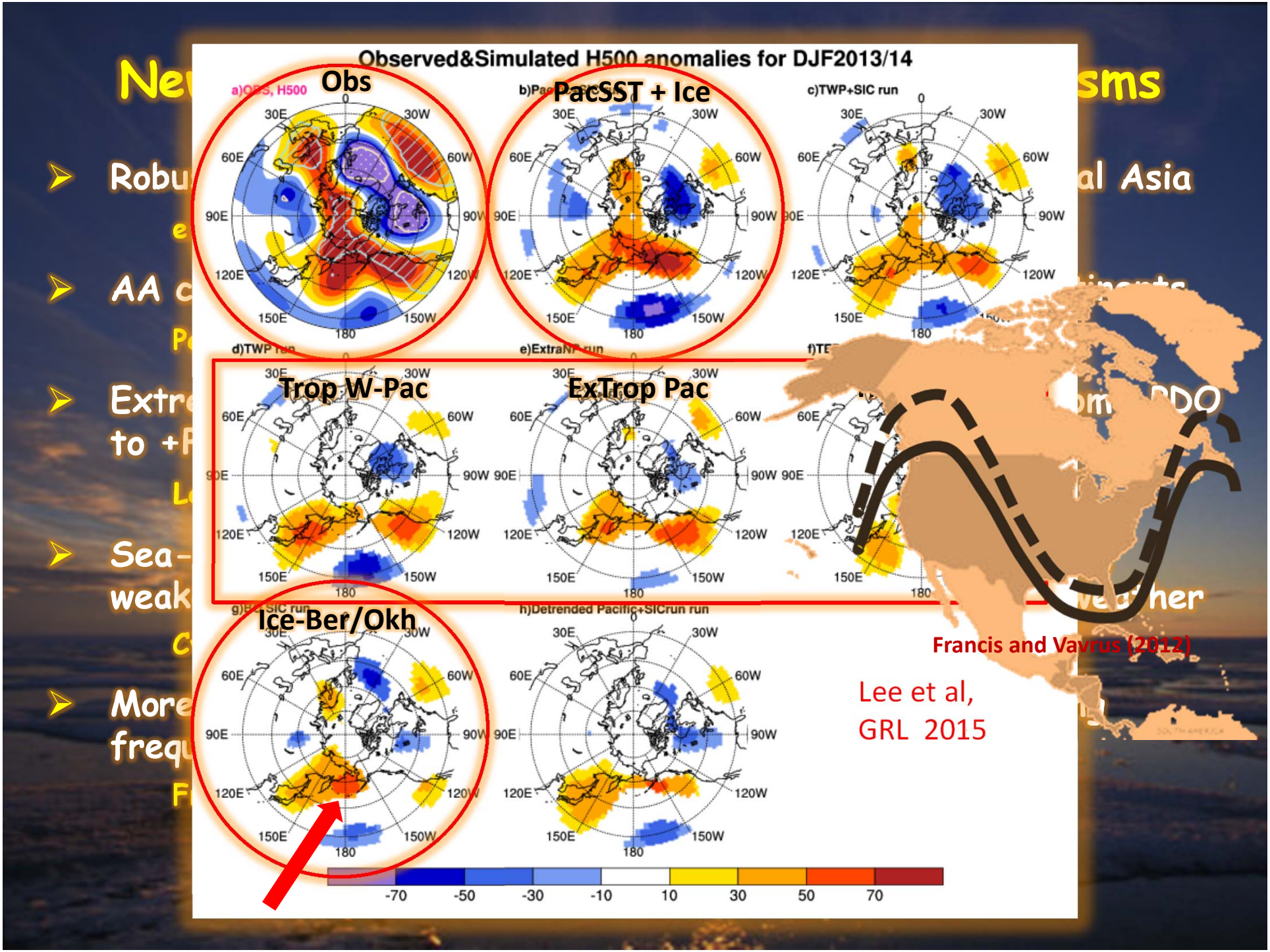
Blocking Persistence

Blocking data from A. Lupo, http://Solberg.snr.Missouri.edu/gcc/

Analyzed and plotted by C. Reynolds

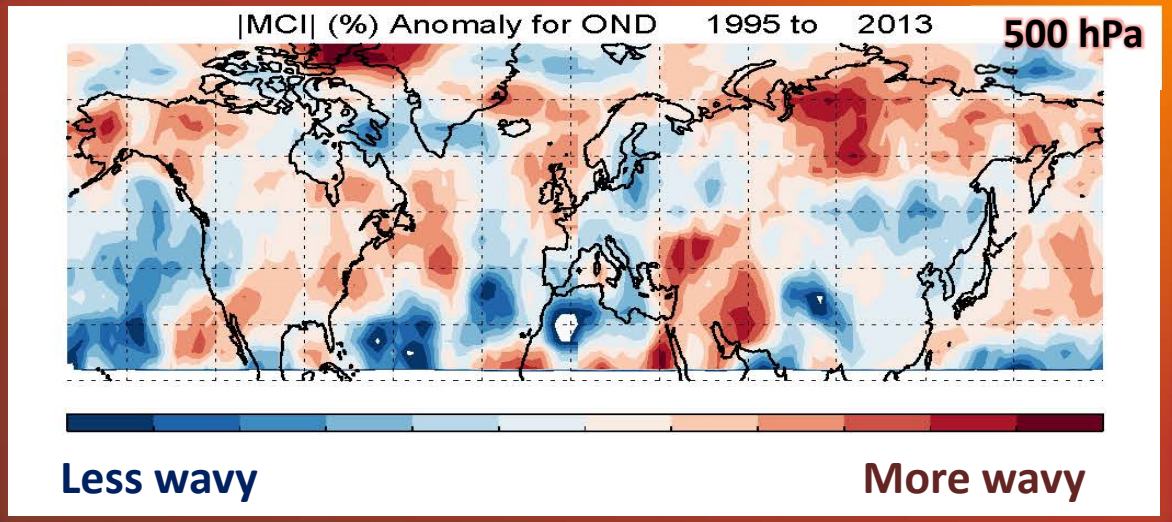
http://dosbat.blogspot.com/2013/01/northern-hemisphere-blocking.html

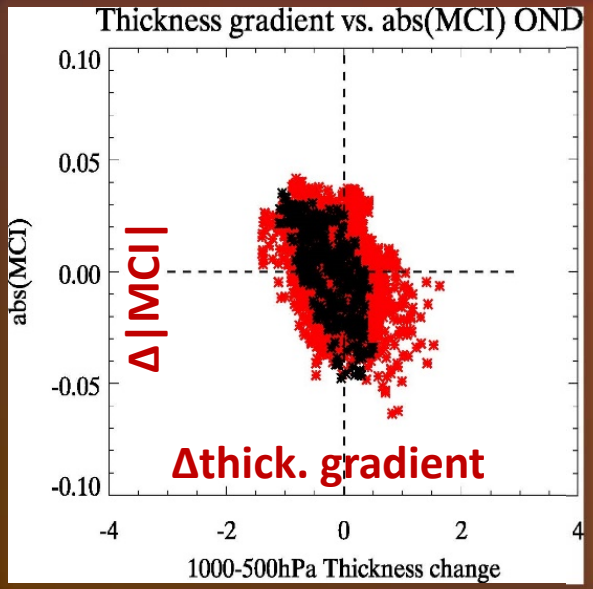


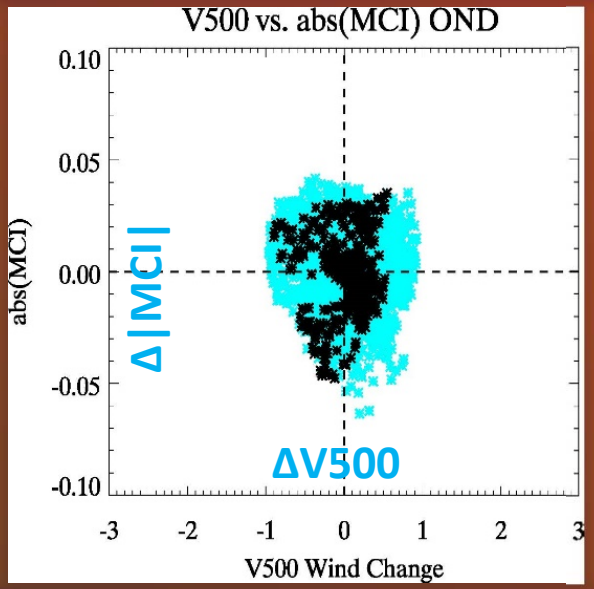

Observed&Simulated H500 anomalies for DJF2013/14
Obs
PacSST + Ice
Trop W-Pac
ExTrop Pac
Ice-Ber/Okh
c)TWP+SIC run
h)Detrended Pacific+SICrun run
-70 -50 -30 -10 10 30 50 70
Francis and Vavrus (2012)
Lee et al,
GRL 2015

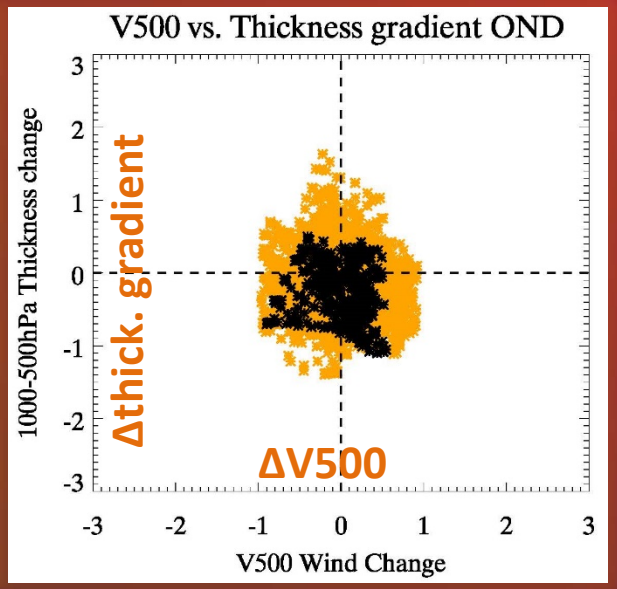
OND

4 Upper-level flow becoming more meridional







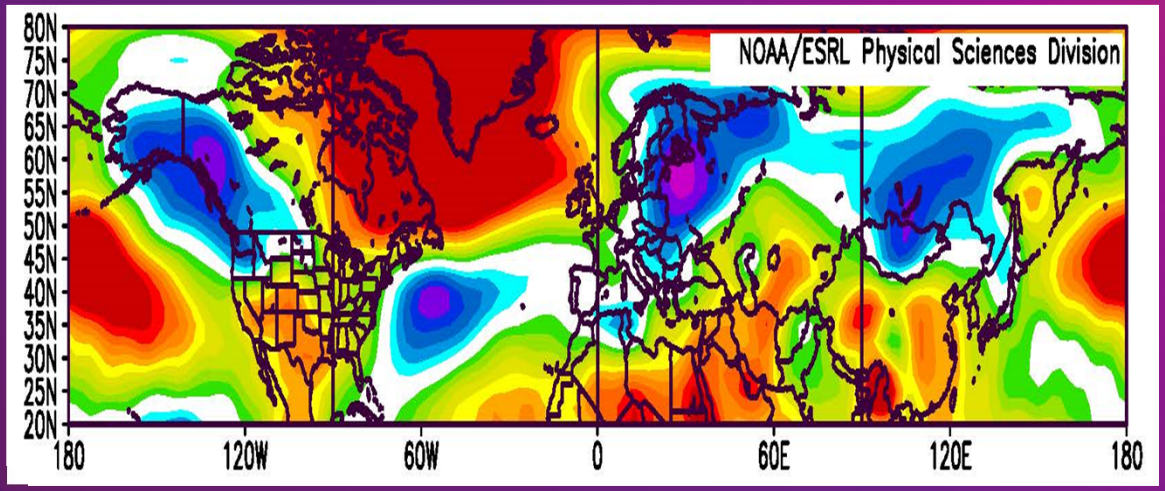


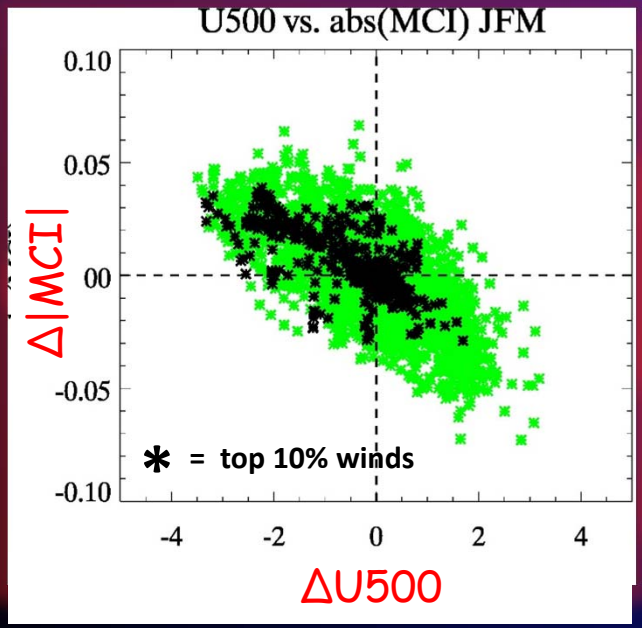
Francis and Vavrus, 2015

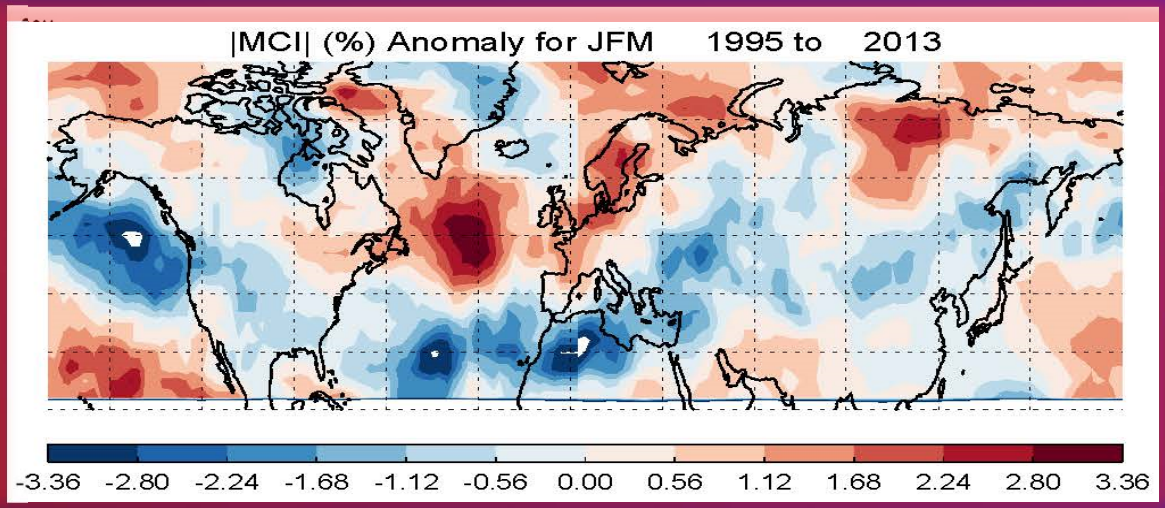
JFM

2 Poleward temperature gradient weakening

1000-500 hPa Thickness Anomaly
1995 to 2013



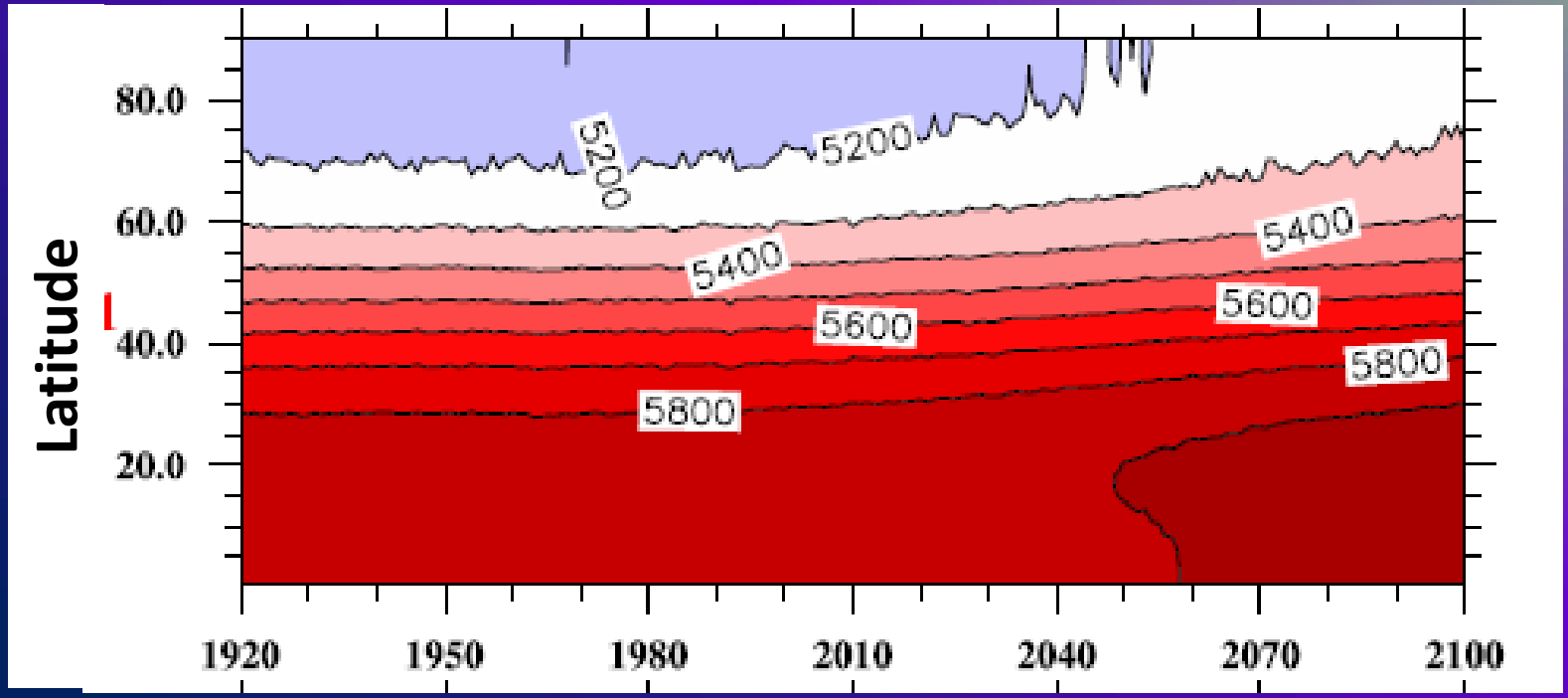




Change in contour height with time

From 30-member CESM-CAM5 Large Ensemble

November



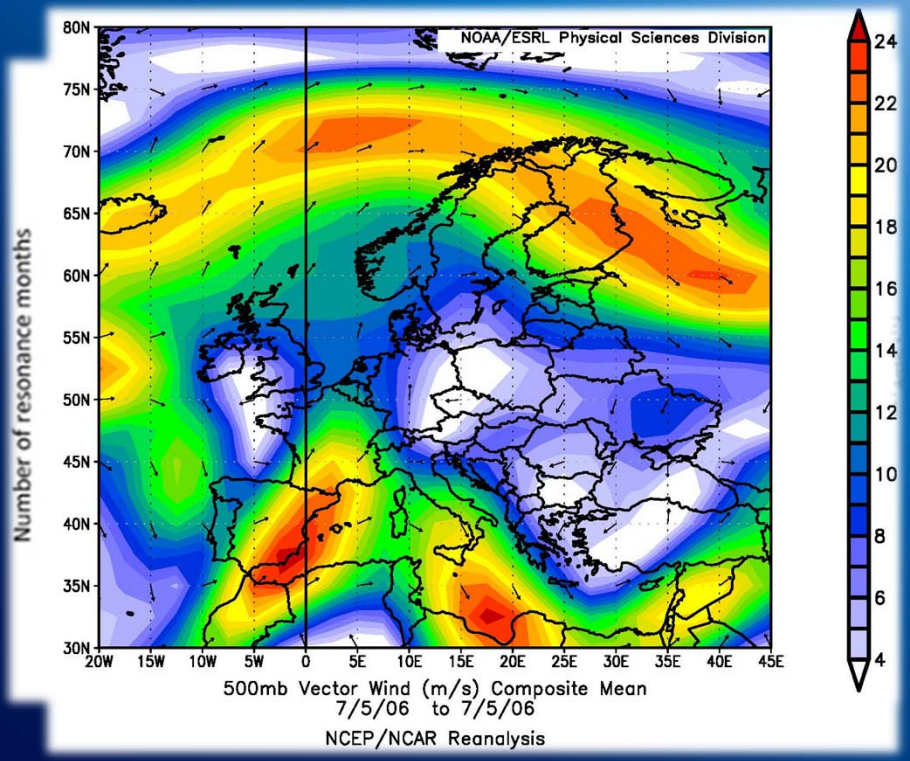
from F. Wang, pers. comm.

Emerging mechanisms

Quasi-resonance (summer only)

Coumou et al (2014), Petoukhov et al (2013)

- Many summer extreme events (heat waves, floods, drought) caused by persistent, high-amplitude jet-stream waves
- Waves trapped in “wave guides” created by split jet; become stagnant
- Split jets more likely when west/east jet winds are weak
- Arctic amplification causes weaker west/east winds



Split jet stream during extreme European heat wave in July 2006