Evidence Linking Arctic Amplification with Changing Weather Patterns in Mid-Latitudes

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Chain of Events Linking Arctic Amplification (AA) with Increased Extreme Weather in Mid-Latitudes

Arctic Amplification

Poleward temperature gradient weakening

Upper-level westerly winds decreasing

Upper-level flow becoming more wavy

Amplitude of waves increasing, blocking more likely

Larger waves more likely to progress eastward more slowly

More persistent weather patterns, extremes more likely
Arctic Amplification

JAS 2000 to 2012

1000-500hPa Thickness Anomalies (m)

1000-500mb Thickness

Arctic Amplification Index T1000

1000mb

90-70°N – 70-30°N

Arctic Amplification Index ZT_1000-500

Year

Poleward temperature gradient weakening

OND
Trends in poleward thickness gradient (1000-500 hPa) from 1979 to 2012

Zonal winds decreasing where gradient weakens

% Change in U−wind 500hPa by Season
CCSM4 4xCO2

% change in 500 mb zonal winds in 4 x CO₂ run of CCSM4

Winter
Fall
Spring
Summer
Upper-level flow becoming more meridional

CCSM4 4 x CO₂
Change in Meridional Wind Fraction @45°N
Trends in meridional component of the 500 hPa wind (1979 to 2011)

- Winter: +33%
- Spring: +21%
- Summer: +21%
- Fall: +19%

Less wavy
More wavy
Amplitude of waves increasing, blocking more likely

Francis and Vavrus, GRL 2012
Amplitude of waves increasing, blocking more likely

OND
Northern Hemisphere

Ridge peaks

Trends in Amplitude

from Barnes (2013)

500mb heights
2000-2012
Amplitude of Rossby waves increasing, blocking more likely

Blocking => “Extreme Waviness”
A typical blocking high

March 2012 Heatwave

Unprecedented Spain flooding
Record snowfall in Japan

Jan 6 2014 “Polar Vortex”
Types of “Extreme Waviness”

Count “extreme waves” exceeding 40° latitude
Increasing frequency of large waves

Thickness Anomalies

High-amplitude waves

OND Northern Hemisphere

Folding contours

$r = -0.68$
Increasing frequency of large waves

Do GCMs capture this behavior?

=> 4 members of CMIP5:

Models seem to capture about the right number, some have increasing trends, some not.
Attack of the Polar Vortex - Early January 2014

ECMWF 500 hPa Geopotential Height [x10 gpm] & Anomaly [gpm]
INIT: 12Z02JAN2014 fx: [102] hr --> Mon 18Z06JAN2014

Warm
Cold
Warm
Mild
Frigid
Summary

- Some links in the chain are solid:
  - AA is emerging in all seasons, strongest in fall and winter
  - Poleward gradients weakening, but seasonally and spatially variable
  - Where gradients weaken, upper-level zonal winds decrease, flow becomes more meridional (wavy)

- Others not so much:
  - Changing amplitude and propagation speed of large-scale waves, mechanism linking to AA unconfirmed
  - Changing frequency of persistent weather patterns?
  - Interactions among AA and other large-scale influences (ENSO, PDO, NAM, PNA, stratosphere, etc.)?

Thank-you!
Extras
More persistent weather patterns, extremes more likely

Summer heat waves

Summer loss of sea-ice and snow cover associated with heat, sea-ice influence stronger

Tang, Zhang, and Francis, Nature Cl. Ch. (2013)
Upper-level flow becoming more meridional

CCSM4 4 x CO₂
Trends in meridional component of the 500 hPa wind (1979 to 2011)

- **Winter**: +39%
- **Spring**: +21%
- **Summer**: +21%
- **Fall**: +19%

Less wavy
More wavy
Large-scale waves progress more slowly eastward.

From Barnes (2013) “We find a robust decrease in wave phase speeds in OND, which is consistent with the $u500$ reductions.”
An Artifact of the Methodology?

Wave amplitude (deg. latitude) from Barnes (2013)

500 mb height with maximum waviness

1980-1995
1996-2011

500 mb height contour used in FV12
An Artifact of the Methodology?

Wave amplitude (deg. latitude) from Barnes (2013)

Contour with max waviness has different shape from FV12's contour in max gradient
An Artifact of the Methodology?

Contour with max waviness had 15° northward shift away from FV12's wind zone, not representative of jet stream trajectory.
Anomalies in zonal-mean heights and zonal winds for OND 2007-2012