Crazy Weather and Climate Change: Are They Connected?

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In collaboration with Steve Vavrus, U. of Wisconsin
Boston
One of the many snowstorms during winter 2015

"Long term I’m worried about global warming—short term, about freezing my ass off."

The New Yorker
Extreme weather events are on the rise...

from Munich RE
Is human-caused climate change playing a role?

YES!
We’ve put ourselves in a real pickle...

Present CO₂ levels are WAY out of whack with temperature.

The last time CO₂ levels were this high, the globe was several degrees warmer, sea levels were tens of feet higher.

CO₂ now highest in at least the past 800,000 years. NAS, Oct. 2012.
But warming is not even around the globe. Jan. 2015 was 359th consecutive month warmer than 20th century average.

CO₂ levels are highest in at least 800,000 years, and Earth’s temperature is responding...

...the warmest 19 years occurred in the past 20 years.
How do we know that humans are responsible?
Evidence implicating humans

One of our best tools: computer programs - climate models - that simulate the complex physics of the atmosphere, ocean, snow, ice, and land and all the forces acting on them.

- **Solar + volcanic**
  - **Observed**
  - **Modeled**

- **All forcings**
  - **(natural + human)**
And the atmosphere is gaining moisture...

...providing more fuel to energize storms, a stronger greenhouse effect...

...and an increased frequency of heavy precipitation events.

from ClimateWatch.noaa.gov
Sea ice is now a mere shadow of former self...

About \textit{half} of summer ice cover has been lost...

...in only 30 years

What's left is "rotten" and "slushy"...
How unusual is the recent loss of Arctic sea ice?
The Arctic is warming 2-3 times faster than the rest of the globe.
“Arctic Amplification”

Near-surface air temperature (Fall)
Arctic Amplification

Not confined to surface!

Temperature changes 1995 to 2013

Height changes 1995 to 2013
Consider a layer of atmosphere stretching from here (warm) to the Arctic (cold).

Because warm air expands, the layer will get thicker here than it is in the Arctic.

Air flows down this “hill”, turns to the right as the Earth spins, and creates the Jet Stream.

As the Arctic warms faster, the hill flattens, and the jet stream weakens.
West Winds are Weakening...

"Weaker Westerly Wind is Wavier"
When the waves are small, they move eastward quickly.

When the waves are large, they shift eastward more slowly.

Graphics by John Garrett for SkepticalScience.com
Why do we care about these waves? The Jet Stream makes our weather

[Diagram showing the Jet Stream, with arrows indicating cold and warm air, and labels for wet and stormy, dry and settled weather conditions.]

NASA Jet Stream
Chain of Events Linking Arctic Amplification (AA) with Increased Extreme Weather in Mid-Latitudes: a hypothesis

Arctic Amplification

Poleward temperature gradient weakening

Upper-level westerly winds decreasing

Upper-level flow becoming more meridional

Amplified patterns more frequent

Larger waves progress eastward more slowly

More persistent weather patterns, extremes more likely

The mechanisms are emerging...

Francis and Vavrus, 2012
Is the jet stream becoming wavier?
A “topographic map” of a layer in the atmosphere
High-Amplitude Patterns (HAPs)

500 hPa contour range > 35° latitude

Amplified patterns more frequent

Unprecedented Spain flooding

Jan 6 2014 “Polar Vortex”
Are very wavy jet-stream patterns really happening more often?

- Fall (Oct-Dec) Northern Hemisphere
- Upper-level westerly winds
### Change (%) in frequency of high-amplitude patterns 1995-2013 versus 1979-1994

<table>
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<td>Northern Hemisphere</td>
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Francis and Vavrus, 2015

* > 1 SD, ** > 2 SD
Do recent extreme weather events patterns fit this story?

Boston - early February 2015
March 2012

Surface Temp. differences from normal

Feb. 1-14 2015

Accuweather
“Ridiculously Resistant Ridge/Trough:” Dec.’13-Feb.’14
“Ridiculously Resistant Ridge/Trough”
19 Feb. 2015

Déjà vu?
Ridiculously Resilient Ridge/Trough Pattern Evident in 2014 Average Temperature Departures
Did Climate Change Contribute to Sandy?
YES! - In At Least 5 Ways

The Arctic was MUCH warmer than normal

Was block strengthened, extended northward, or prolonged by warm Arctic? We think so.

J.A. Francis
Summary

Arctic warming

West winds weakening

? 

Europe this March

COLD & WET STORMY
EVIDENCE IS THAT INCREASED EXTREME WEATHER IS DUE TO CLIMATE CHANGE

THANK-YOU !!

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Extras
THANK-YOU!!

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January 2015 is warmest January on record.

Jan. 2015 zonal temperature anomalies