Impacts of Climate Change: Atmospheric Rivers and Arctic-Mid-latitude Connection

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Who are we?

I’m a project scientist in the “Magnusdottir’s Group” of the Earth System Science department at UCI. I got my PhD degree at the French National Center of Meteorological Research, Toulouse, in 2010.

Collaborators

Gudrun Magnusdottir
Zack Labe
Ashley Payne
2 sections in this talk

Atmospheric rivers and their potential changes during the 21st century

Arctic changes: what impacts in the mid-latitudes?
Evolution of the global mean temperature from 1850 to present

Paris agreement: “Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels; ... “
Climate change over the last century

Video by NASA Goddard
Atmospheric rivers and their potential changes during the 21st century

Arctic changes: what impacts in the mid-latitudes?
What are atmospheric rivers?

Atmospheric River

A narrow band of moisture that transport huge amounts of water vapor towards the West Coast.

MERRA reanalysis, figure by Ashley Payne
What are atmospheric rivers?

23 Dec 1996 – 00 h
Associated with heavy precipitation

Southern California
March 01 – 03 1938

Flooding along the Santa Ana, Los Angeles and San Gabriel Rivers

$40 million in damage
Associated with heavy precipitation

Washington and Oregon
November 06 – 07 2006

8 – 20 inches rainfall over coastal mountains

$50 million in damage
A drought buster!

U.S. Drought Monitor
California

March 28, 2017
(Released Thursday, Mar. 30, 2017)
Valid 8 a.m. EDT

Drought Conditions (Percent Area)

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<th>None</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
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<tr>
<td>Current</td>
<td>78.54</td>
<td>23.46</td>
<td>8.24</td>
<td>1.06</td>
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<td>Last Week</td>
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<td>23.46</td>
<td>8.24</td>
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<td>3 Months Ago</td>
<td>17.47</td>
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<td>62.27</td>
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<td>03-26-2016</td>
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<td>90.58</td>
<td>72.82</td>
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Intensity:
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Severe Drought
- D4 Extreme Drought
- D5 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Eric Luebchen
U.S. Department of Agriculture

http://droughtmonitor.unl.edu/
AR shows some predictability

Wick et al. (2013):
TPW (top)
Location (bottom)

San Francisco or LA?
Atmospheric rivers and climate change

How are ARs represented in GCMs? > Evaluation of CMIP5 simulations

28 different models participating in CMIP5

Frequency of AR occurrence in historical simulations compared to two reanalysis datasets (MERRA and ERA-Interim)

How will ARs respond to warming? > 7 high performing models selected
Atmospheric rivers and climate change

Projected response at the end of the century (2080 - 2100 compared to 1980 – 2000)

Absolute increase in moisture flux but little change in anomalies relative to future climate

Increase in years with extreme numbers of AR dates

Their relative intensity does not increase, but their frequency does
Atmospheric rivers and their potential changes during the 21st century

Arctic changes: what impacts in the mid-latitudes?
A strong indicator of climate change: Arctic sea ice decline

~ 30% of decline in 40 years

Source: NSIDC
Dramatic decline in Arctic sea ice volume in recent years

DATA: PIOMAS v2.1 (Zhang and Rothrock, 2003)
CSV: http://psc.apl.washington.edu/zhang/IDAO/
GRAPHIC: Zachary Labe (@ZLabe)

Courtesy to Zack Labe, UCI
Effect of decreased sea ice cover

![Diagram showing the albedo change with and without ice]

- Snow and ice covered water: 90% reflectivity (10% absorption)
- Water without snow and ice: 6% reflectivity (94% absorption)

Albedo change, by Sam Carana for Arctic-news.blogspot.com
Arctic Amplification

Temperature trend in recent decades

At the surface: Slight increase in temperature
Along the atmospheric column: Significant increase in temperature

- Snow and ice covered water: 10% increase, 90% decrease
- Water without snow and ice: 94% decrease, 6% increase

~ 5km variation in temperature
What impacts on the large-scale atmospheric circulation and the mid-latitude climate?
Global circulation and jet streams

Schematic view of the global atmospheric circulation
Illustrating video of mid-latitude jet stream

Source: NASA's Goddard Space Flight Center
Impact of jet streams on weather

“Polar vortex” of 2014, Lake Michigan.

Heat wave 2003, Paris
Effect of Arctic Amplification on the large-scale atmospheric structure
The thermal wind balance

- Geostrophic wind (coming out of the page)
- PGF - pressure gradient force
- Co - Coriolis Force

Source: University of Eastern Illinois

\[
\frac{\partial u}{\partial z} = \frac{g}{\rho f} \frac{\partial \rho}{\partial y}
\]
Effect of Arctic Amplification on the large-scale atmospheric structure

Air flows “downhill” from the south to the north and is deflected by Coriolis force.

Mid-latitude jet stream
Effect of Arctic Amplification on the large-scale atmospheric structure

With Arctic warming faster than low-latitudes, the slope becomes less steep.

Reduced and shifted south jet stream.
Suggested chain of mechanisms with the mid-latitudes

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 hypothesis
Warm Arctic, a wavier jet stream?
Warm Arctic – Cold Continents?

Source: Cohen et al. (2014) Recent Arctic amplification and extreme mid-latitude weather. Nature Geosciences, doi:10.1038/ngeo2234
A major debate among climate scientists

Some believe evidences of an Arctic influence on the mid-latitude climate has emerged (e.g., Francis And Vavrus 2012, 2015, Cohen et al. 2014) but if the signal exists, it is (still) hardly distinguishable from internal variability of the atmosphere (e.g., Barnes and Screen 2015, Cattiaux et al. 2016, Overland et al. 2016).

The observational record is relatively short (satellite data starting in the 70’s)

Climate scientists rely on climate models to complement the incomplete view that observations provide us.
A numerical laboratory to explore the Arctic mid-latitude linkage

**Atmospheric Model** : Community Atmospheric Model version 5 (CAM5) from the National Center for Atmospheric Research (NCAR)

Land-Atmosphere-only model with prescribed sea surface temperature (SST) and sea ice concentration (SIC): allows us to force the model with certain SIC/SST anomalies, then analyze the atmospheric response to the forcing.
Climate vs weather: problem of boundary rather than initial conditions

- The atmosphere is a **chaotic system**, i.e. its exact trajectory (weather) is unpredictable beyond 15 days (Lorenz 1956)

- On the other hand, **slow-evolving components** of the climate system force the long-term evolution of the atmosphere (solar, sea surface temperature, stratosphere, volcanoes, land surface, ...)

The seasonal cycle is a good example: we can’t predict the weather we’ll get on say, August 15, but it is very likely to be hotter than January 15. In this case, the external forcing involved is the amount of received solar radiation.
Role of recent sea ice decline: modified Arctic sea ice concentration

"CTL", control run
Prescribed 1979-2000 SIC/SST, repeated for 50 years

"2010C", effect of present-day sea-ice decline
Modified Arctic SIC to their 2007-2012 values, 50 members starting from CTL initial conditions
2 experiments with modified Arctic sea ice concentration

Annual cycle of Arctic SIC in each experiment

MONTH

SIC (%)
2 experiments with modified Arctic sea ice concentration

Less sea ice results in:

• **Warming** located over the areas of sea ice loss and adjacent continents

• The loss of sea ice results in **more heat being absorbed in the ocean in summer/fall, that is then released in the atmosphere** in winter through heat flux exchanges

• Generally speaking, we did not find a strong impact on the atmospheric circulation, **except in late winter** ...

2-meter temperature in CTL, and anomalies due to sea ice loss (winter, DJF)

Changes in heat flux exchanges between the atmosphere and the ocean (winter, DJF)
A link with the stratosphere
A link with the stratosphere in late winter

Change in stratospheric zonal wind (polar vortex) in February

Change in near-surface upward planetary waves in February

According to our simulations, recent sea ice anomalies:

• enhance the propagation of planetary waves that are naturally forced by orography and land-sea thermal contrast.

• the anomalous propagation of the waves transport momentum in the stratosphere, where it decelerates the polar vortex.

• the stratospheric perturbation then propagates downward and reaches the surface a couple of weeks later.
Projected changes at the end of the 21st century

CESM large ensemble (CESM-LENS) from NCAR

- 40 members of coupled ocean-atmosphere simulations
- From 1920-2100
- RCP8.5 anthropogenic emissions

Evolution of annual Arctic SIC in CESM-LENS

Changes in surface temperature in function of time and latitude

An opportunity to investigate with robustness how the mid-latitude climate responds to a strong Arctic sea ice decline
The sinuosity metric

A straightforward metric to measure the waviness of the atmospheric circulation, i.e. meanders in the mid-latitude jet stream, and how it responds to climate change.

Example of the atmospheric sinuosity in mid-latitudes for a given day

Analog to river sinuosity used in geomorphology
The sinuosity metric

Changes in sinuosity at 50°N in CESM-LENS

Does not support to the so-called “Francis and Vavrus hypothesis”!
Changes in the mid-latitude jet stream

2071-2100 vs 1981-2010

Changes in zonal mean temperature, shown in a pressure vs latitude cross-section

“Tug-of-war” between the Arctic warming and the tropical warming in the upper-troposphere, with opposite effects on both sides of the jet

Changes in westerly wind in the lower troposphere in function of month and latitude

Arctic sea ice loss explains the asymmetry between the Northern Hemisphere and the Southern Hemisphere where no sea ice loss is induced in the Antarctic
Conclusions on the Arctic influence on mid-latitudes

The problem can be posed in three distinct questions (Barnes and Screen 2015):

• Can it? **Yes**, as suggested by the theory and idealized numerical studies

• Has it? **Unclear**, if the signal exists it has **not clearly emerged yet**

• Will it and how? **Unclear**, large sea ice loss will undoubtedly have consequences on the large-scale atmospheric circulation, but it competes with other aspects of global warming (tropics).

Prospects for new developments on this topic

• CLIVAR working group on the matter: International collaboration that aims to coordinate efforts, especially dedicated numerical experiments.
Thank you for your attention, and to Gary for inviting me!
Additional figures
A perspective from paleoclimate indicators
Earth’s energy balance

Projected changes at the end of the 21st century

2071-2100 vs 1981-2010 changes in CESM-LENS

- (a) SIC (%)

- (b) T2M (°C)
  (global mean removed)
Changes in the mid-latitude jet stream

We find a narrowing of the mid-latitude jet stream under climate change at the end of the 21st century in CESM-LENS.

Consistent with decreased waviness in the mid-latitudes, since the atmospheric waves and the jet meanders are confined in a narrower latitudinal band.
What are atmospheric rivers?

MERRA reanalysis, figure by Ashley Payne
Not only in California ...
A drought buster ...

Important source of precipitation globally (up to 50% in CA; Dettinger et al. 2011)

“Drought Busters”
(break 33 – 74% of droughts depending on region; Dettinger 2011)
Associated with heavy precipitation

Sacramento and the Central Valley
*December 1861 – January 1862*

Series of winter storms – rainfall for a 4 week period over California, Nevada and Oregon

Largest recorded flooding in western North America