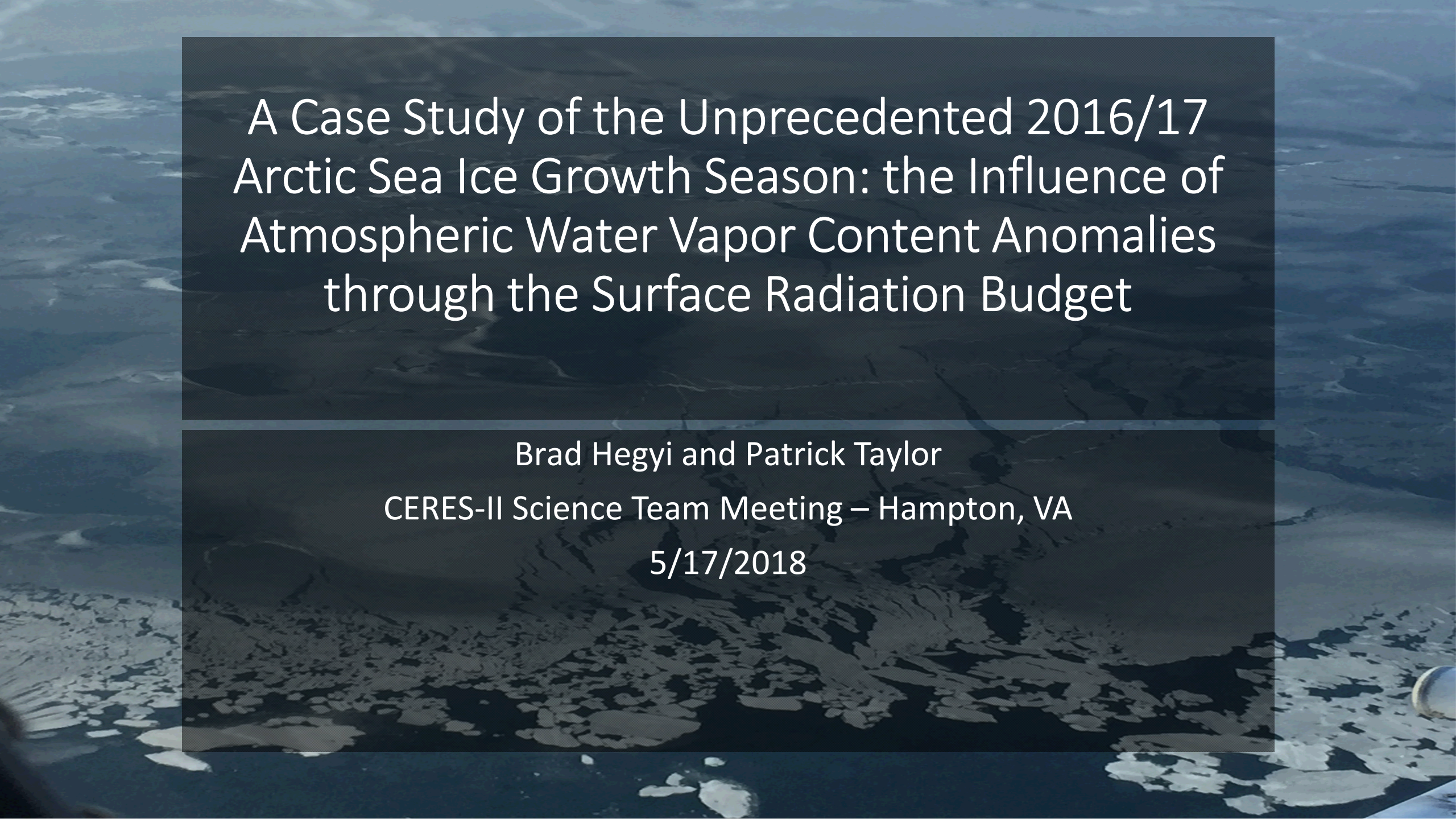


A satellite image of the Arctic region showing a vast expanse of sea ice. The ice is composed of numerous small, irregular floes of varying sizes, creating a textured, mosaic-like appearance. The colors range from dark blue in the open water to white and light blue on the ice floes. The overall scene is a high-altitude, wide-angle view of the polar region.

A Case Study of the Unprecedented 2016/17 Arctic Sea Ice Growth Season: the Influence of Atmospheric Water Vapor Content Anomalies through the Surface Radiation Budget

Brad Hegyi and Patrick Taylor
CERES-II Science Team Meeting – Hampton, VA
5/17/2018

The North Pole is an insane 36 degrees warmer than normal as winter descends

WEATHER

News headlines about 2016/17 winter in Arctic

By Chris
Capita
North Pole Flirts With the Freezing Point, Nearly 50 Degrees Above Average

P1 By Jonathan Belles · December 22 2016 12:00 AM EDT · weather.com
50 degrees above normal Thursday warm

By Jason Samenow December 20, 2016

Capital Weather Gang

It's about 50 degrees warmer than normal near the North Pole, yet again

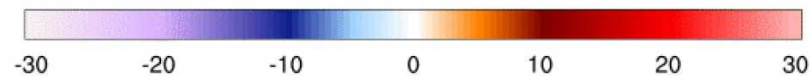
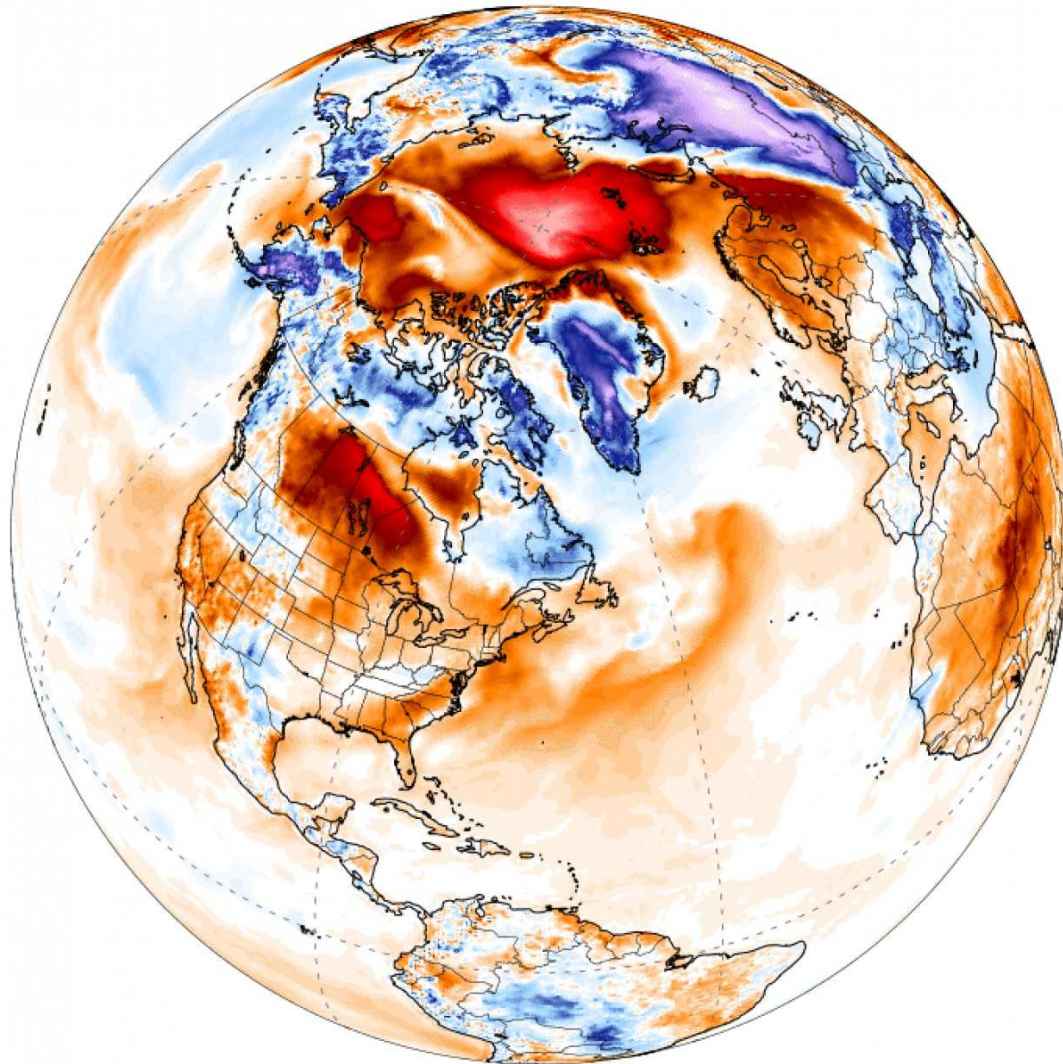
CLIMATE

Temperatures spike almost 50 degrees in North Pole

By Michael Casey · Published January 01, 2016 · Fox News

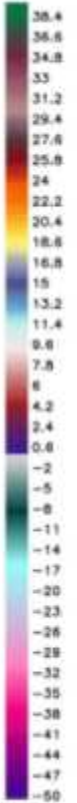
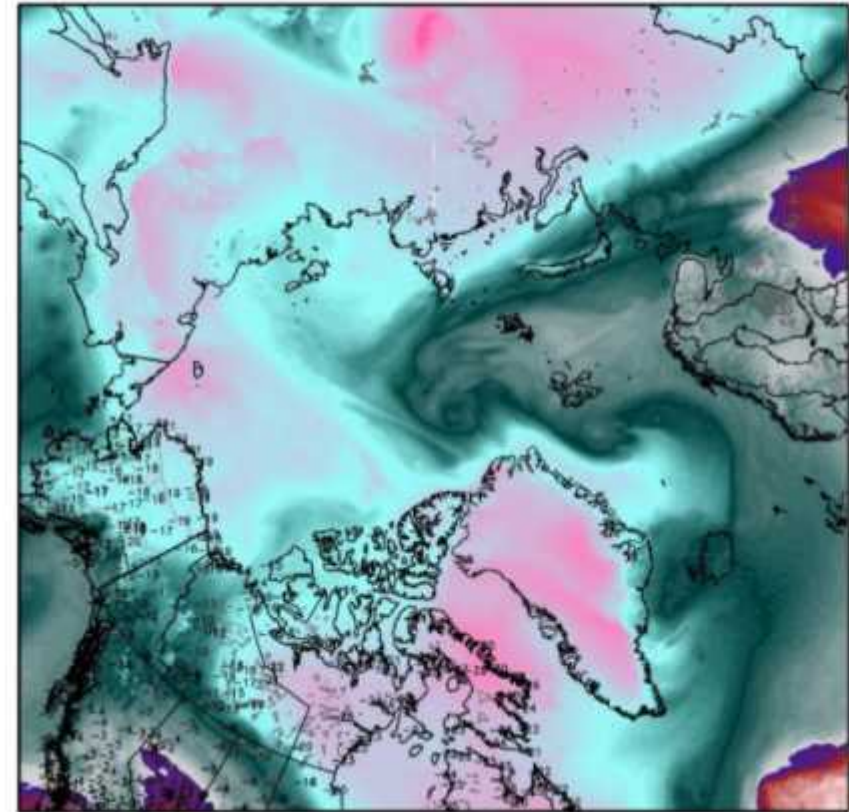
[f](#) [t](#) [g](#) [e](#) [p](#)

2-meter temperature anomaly: December 22, 2016



Washington Post: Capital Weather Gang

World
+ 0.4 °C
NH
+ 0.6 °C
SH
+ 0.1 °C
Arctic
+ 3.0 °C
Antarctic
+ 0.8 °C
Tropics
+ 0.4 °C



850 hPa temperature: December 22, 2016

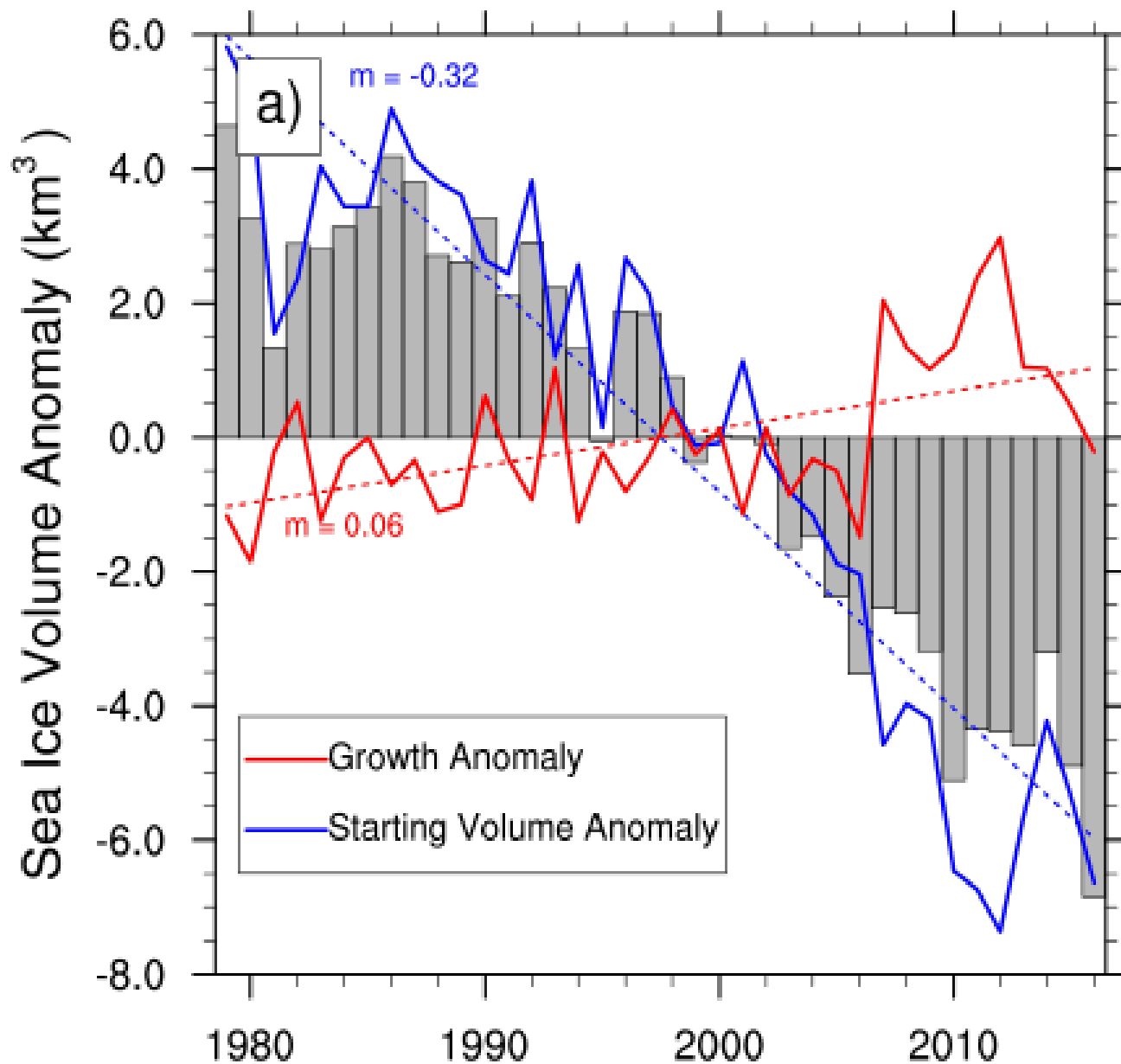
December 22, 2016

Roadmap for today's talk

✓ I Introduction

- II 2016-17 sea ice growth season
 - Why was this season unprecedented? So what?
- III Importance/Context
 - How the results here fit in the larger discussion of Arctic amplification?

Focus: Surface radiative fluxes



Hegyí and Taylor 2018
accepted

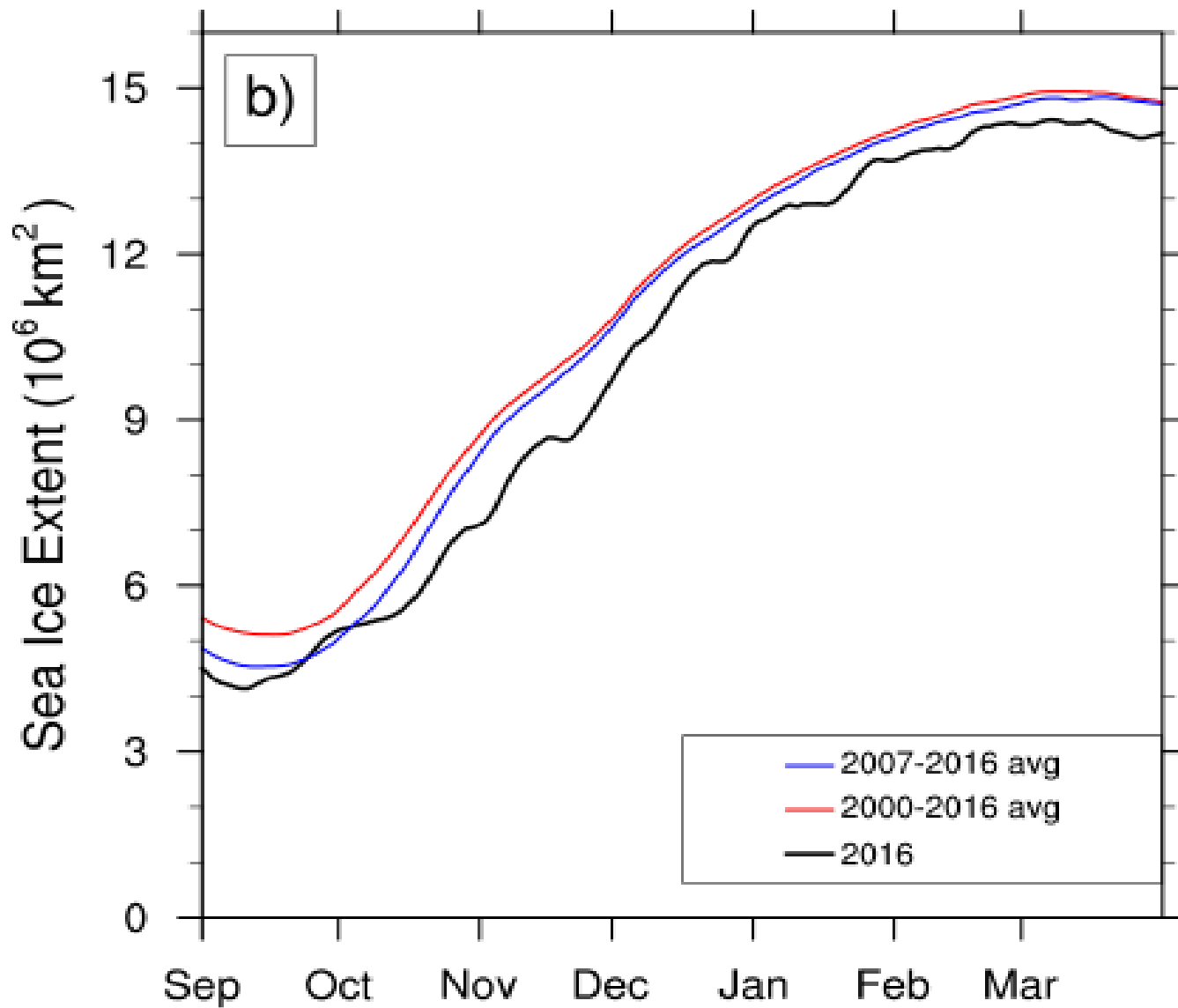
Sea Ice Volume

2016-17 exhibited the lowest end-of-season sea ice volume of any year since 1979, driven by starting at a lower volume in September (**blue line**), and less growth in previous year (**red line**).

blue line + **red line** = gray bar

Sea ice volume and extent

Total end of season (October-March) sea ice volume anomaly (bar), with growth and starting column contributions (lines)
Data: PIOMAS daily sea ice thickness data



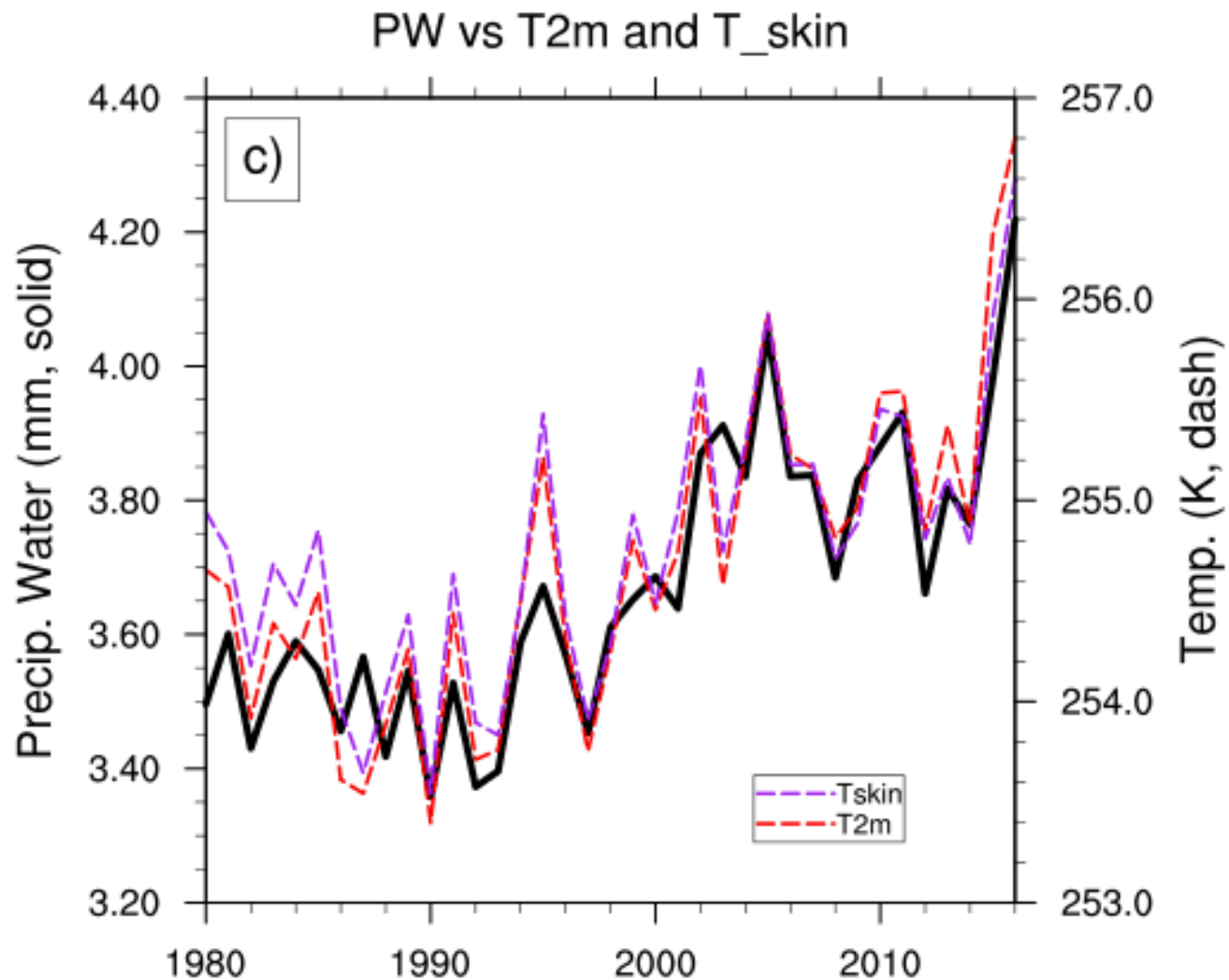
Sea Ice Extent

2016-17 also exhibited the lowest winter sea ice extent from October-March.

Sea ice volume and extent

Arctic sea ice extent in 2016/17 and recent climatology
Data: SSM/I passive microwave sea ice concentration data

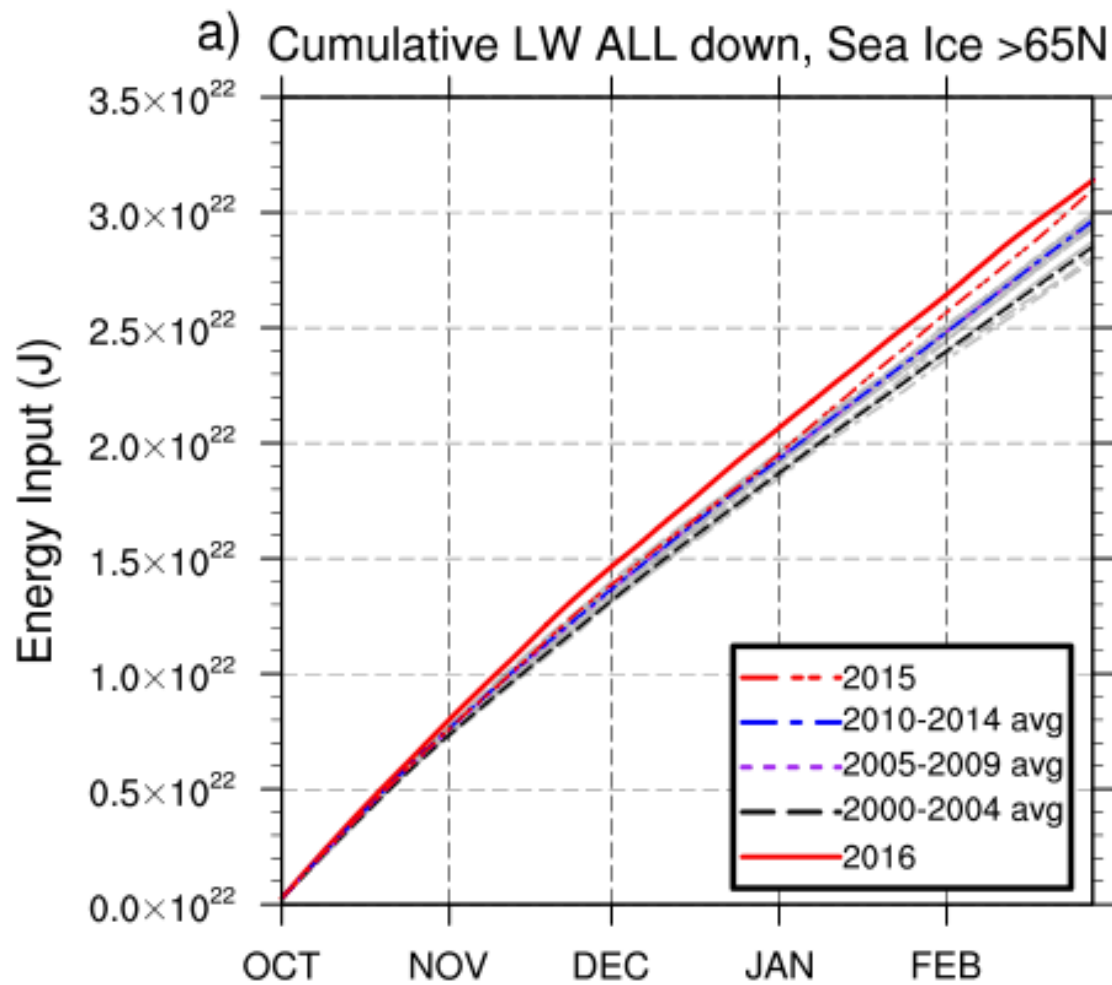
Surface temperatures and precipitable water



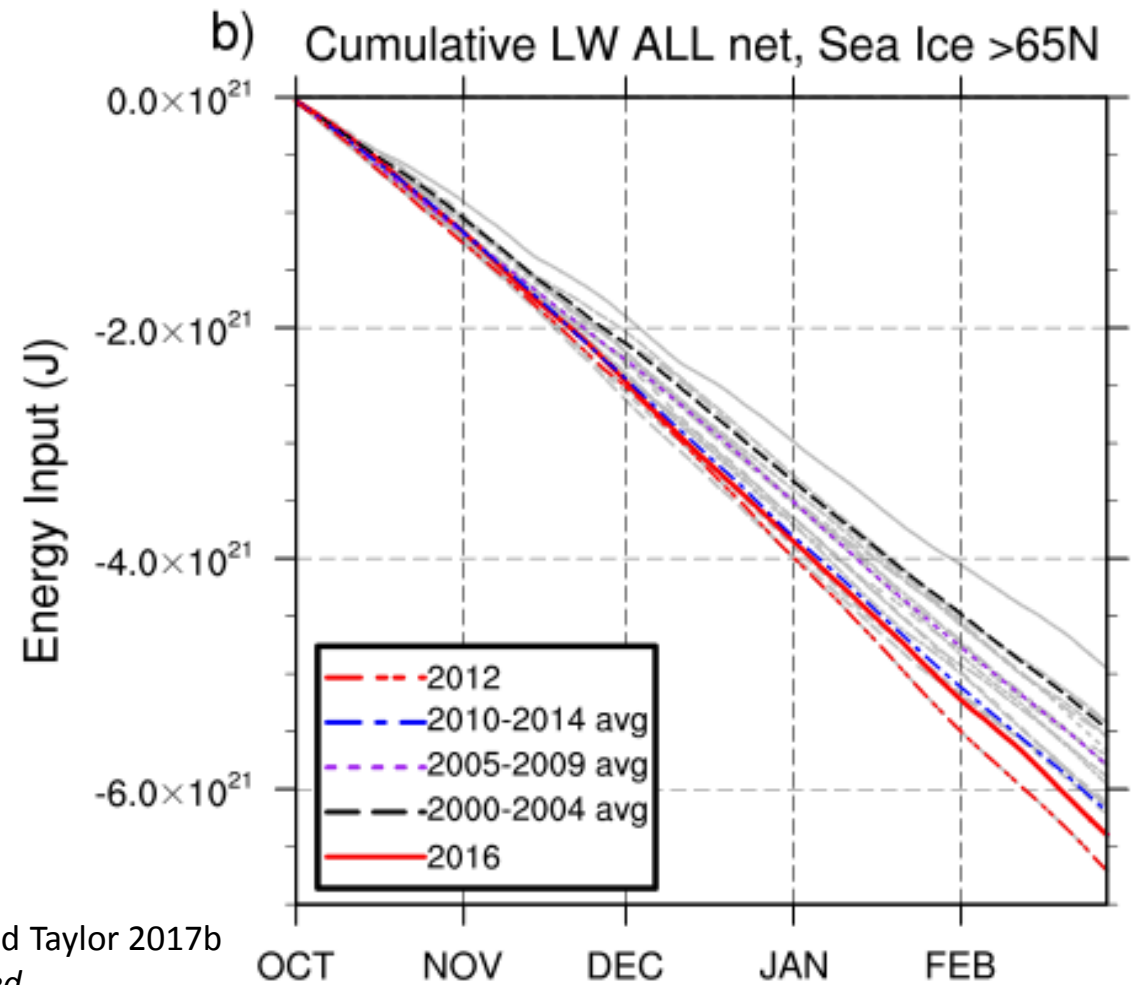
Surface temperatures and atmospheric water content in the 2016-17 fall and winter season were also the highest since 1980, 1 degree and 0.4 mm above previous peak (2005).

Hegy and Taylor 2018
accepted

Atmospheric temperature and precipitable water values
ONDJF mean precipitable water (PW) and surface temperature values over the Arctic cap
Data: MERRA2 reanalysis data



Hegyí and Taylor 2017b
submitted



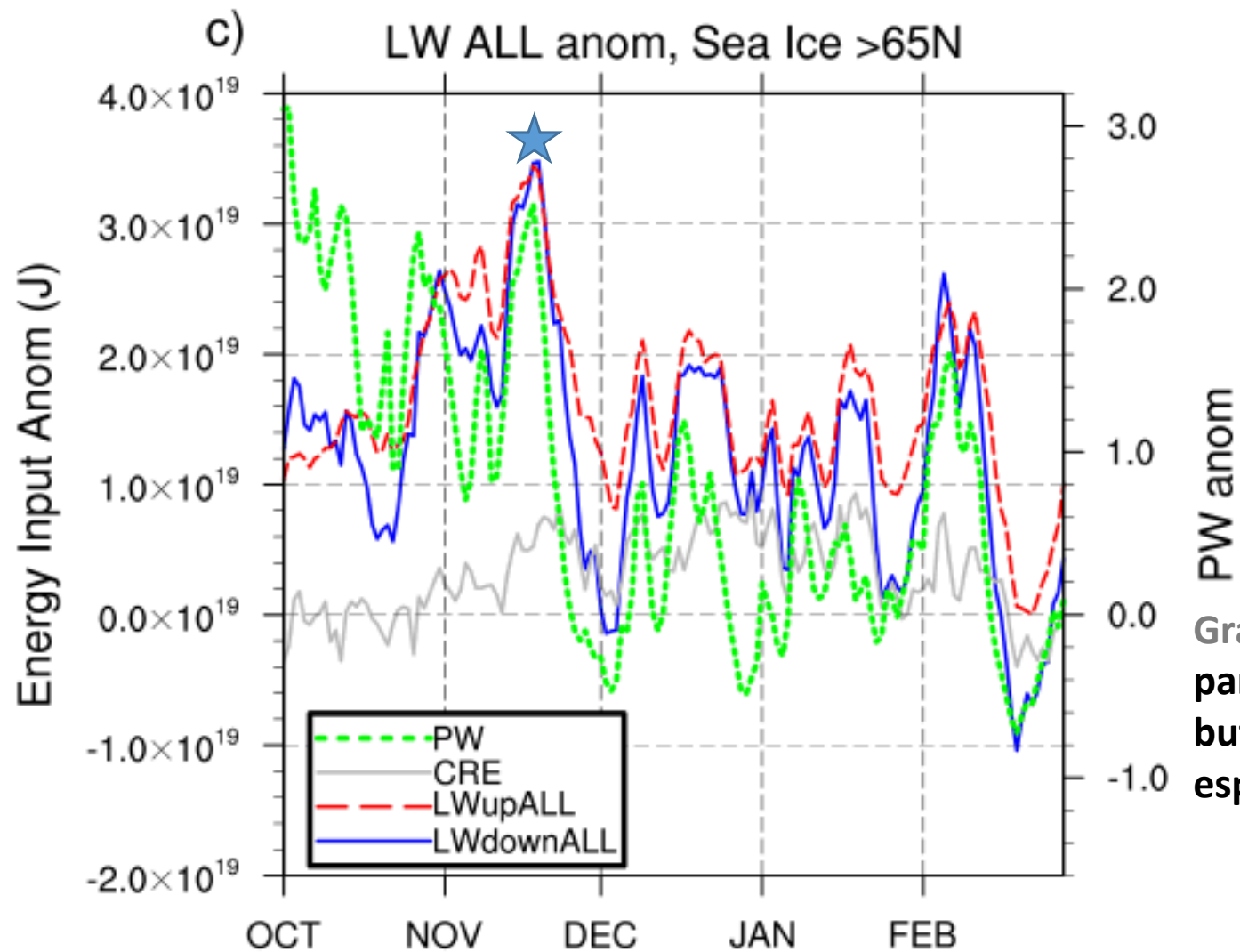
As a result of the warm and moist atmosphere, input by cumulative downwelling LW fluxes was highest since 2000. **Increase in downwelling LW fluxes was counteracted by increased upwelling LW fluxes.**

Cumulative energy input by LW surface fluxes

Left: Cumulative energy input by downwelling surface LW fluxes in 2016 (red) and other years since 2000

Right: Cumulative energy input by net surface LW fluxes in 2016 (red) and other years since 2000

Data: CERES Longwave surface fluxes



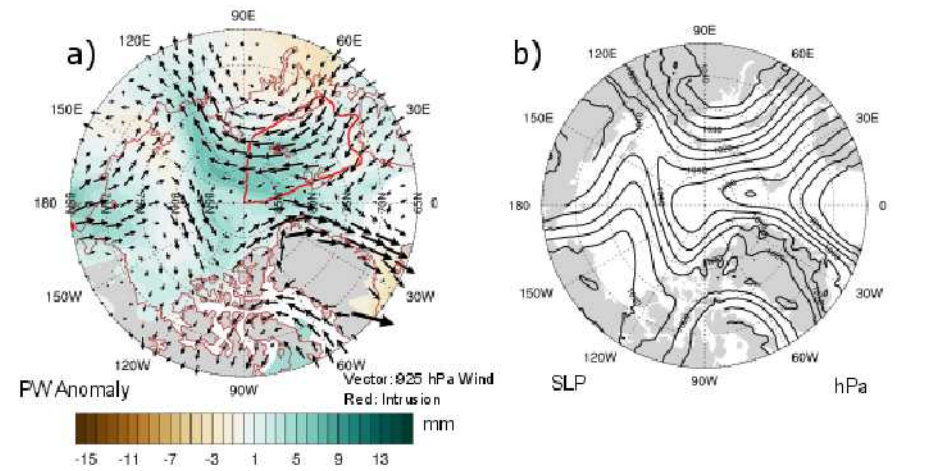
What are the associated meteorological conditions with these peak PW events?

Gray line: Cloud radiative effect changes part of increase in total LW surface flux, but clear-sky effects dominate, especially in October and November.

Several periods of elevated downwelling flux and associated increase in column water vapor content (i.e. precipitable water). These correspond to periods of reduced sea ice growth.

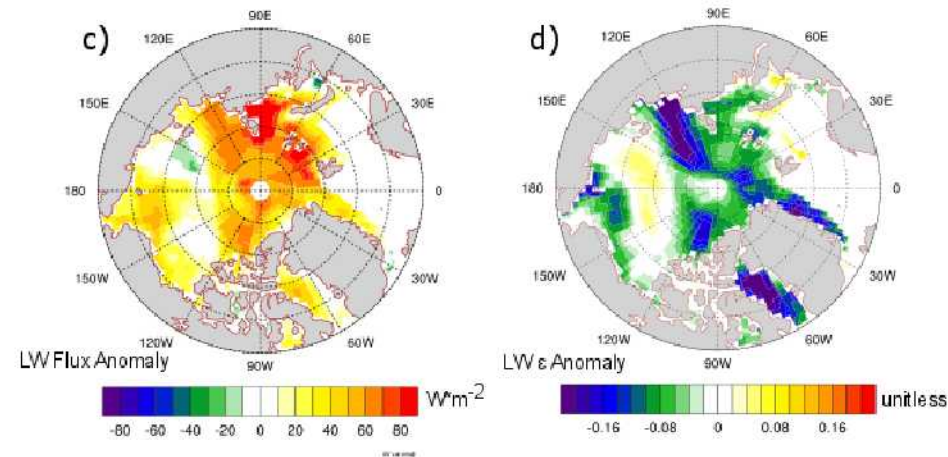
Daily evolution of precipitable water and energy input by surface LW fluxes over all sea ice areas north of 65°N
 Blue (red) line: All-sky downwelling (upwelling) LW fluxes
 Green line: Precipitable water
 Gray line: LW cloud radiative effect
 Data: MERRA2 reanalysis data and CERES surface flux data

Presence of a
moisture intrusion

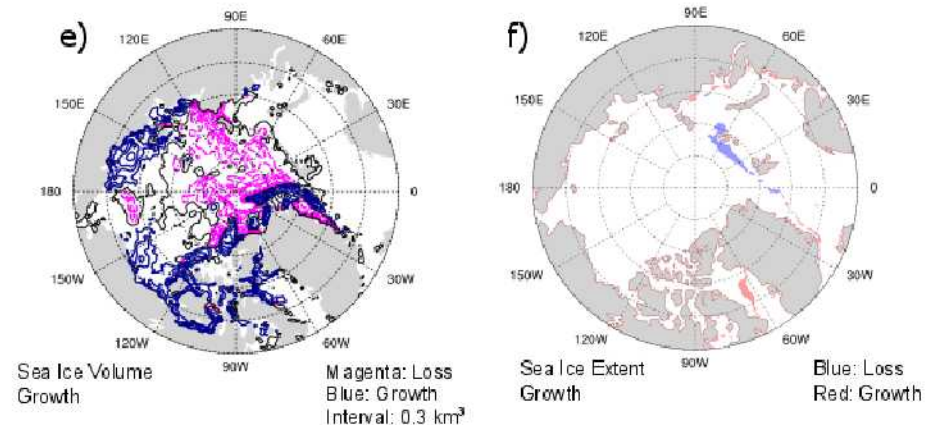


SLP pattern supported
the advection of
water vapor from
lower latitudes

Increased
downwelling LW
fluxes



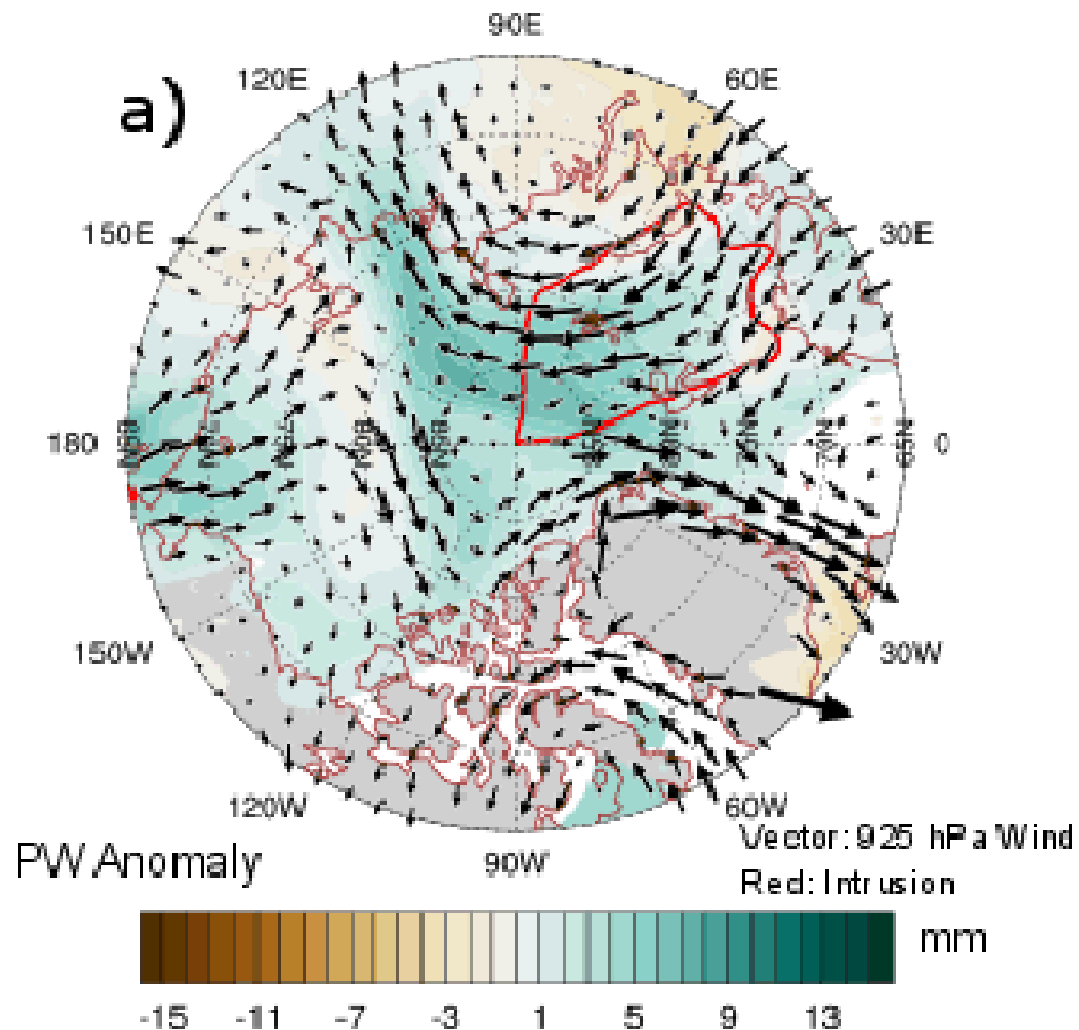
Sea ice volume loss



Sea ice extent retreat

November 17, 2016

- a) Anomalous PW (shading), 925 hPa winds (vectors), and area of moisture intrusion (red contour)
- b) Total sea level pressure (SLP) field
- c) Anomalous downwelling LW flux anomaly
- d) LW cooling efficiency anomaly
- e) Sea ice volume growth
- f) Sea ice extent retreat



Dates of negative sea ice growth

November 17-19, 2016

December 23, 2016

January 9, 2017

January 13, 2017

January 15, 2017

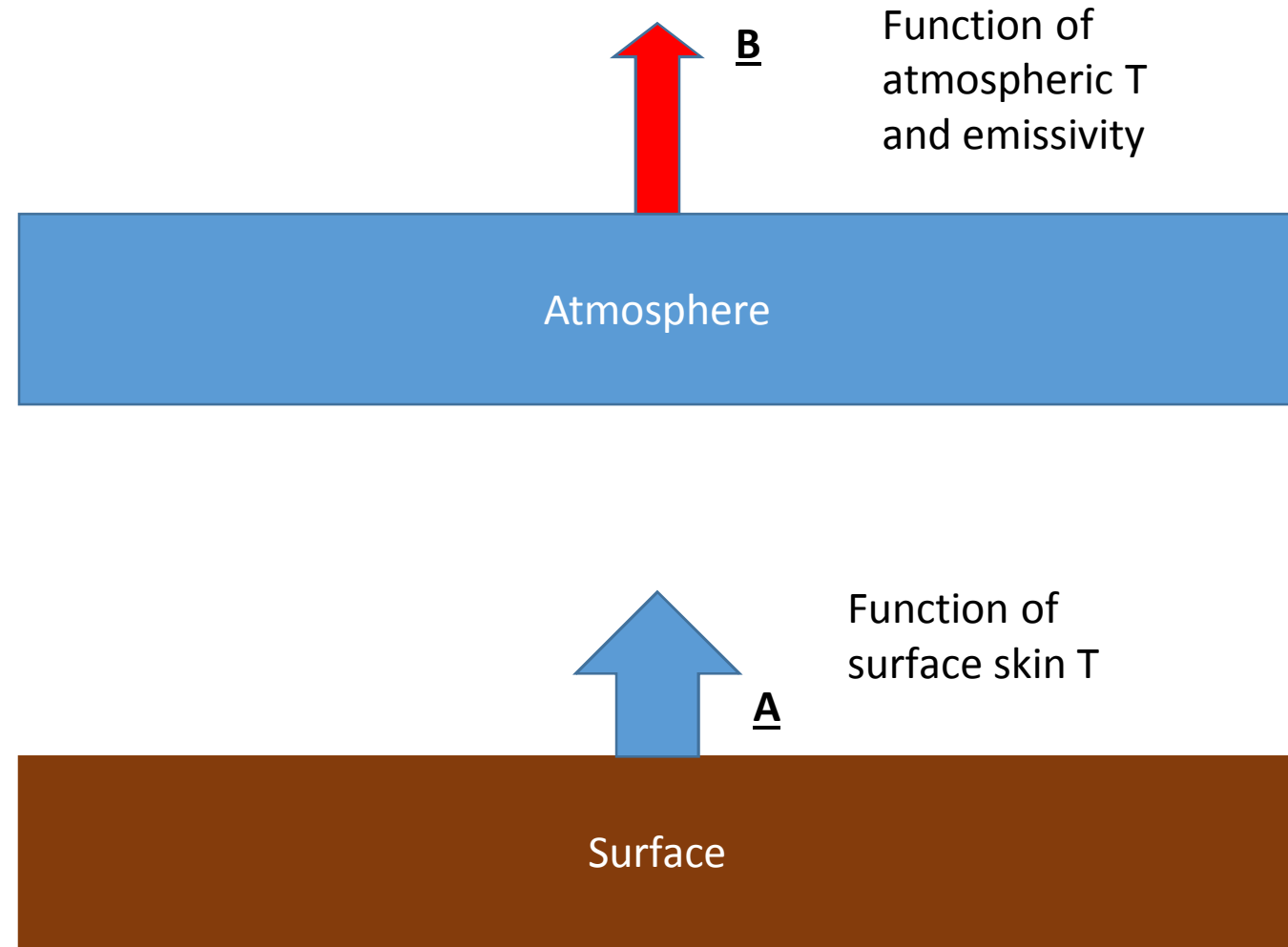
January 28-30, 2017

February 10-11, 2017

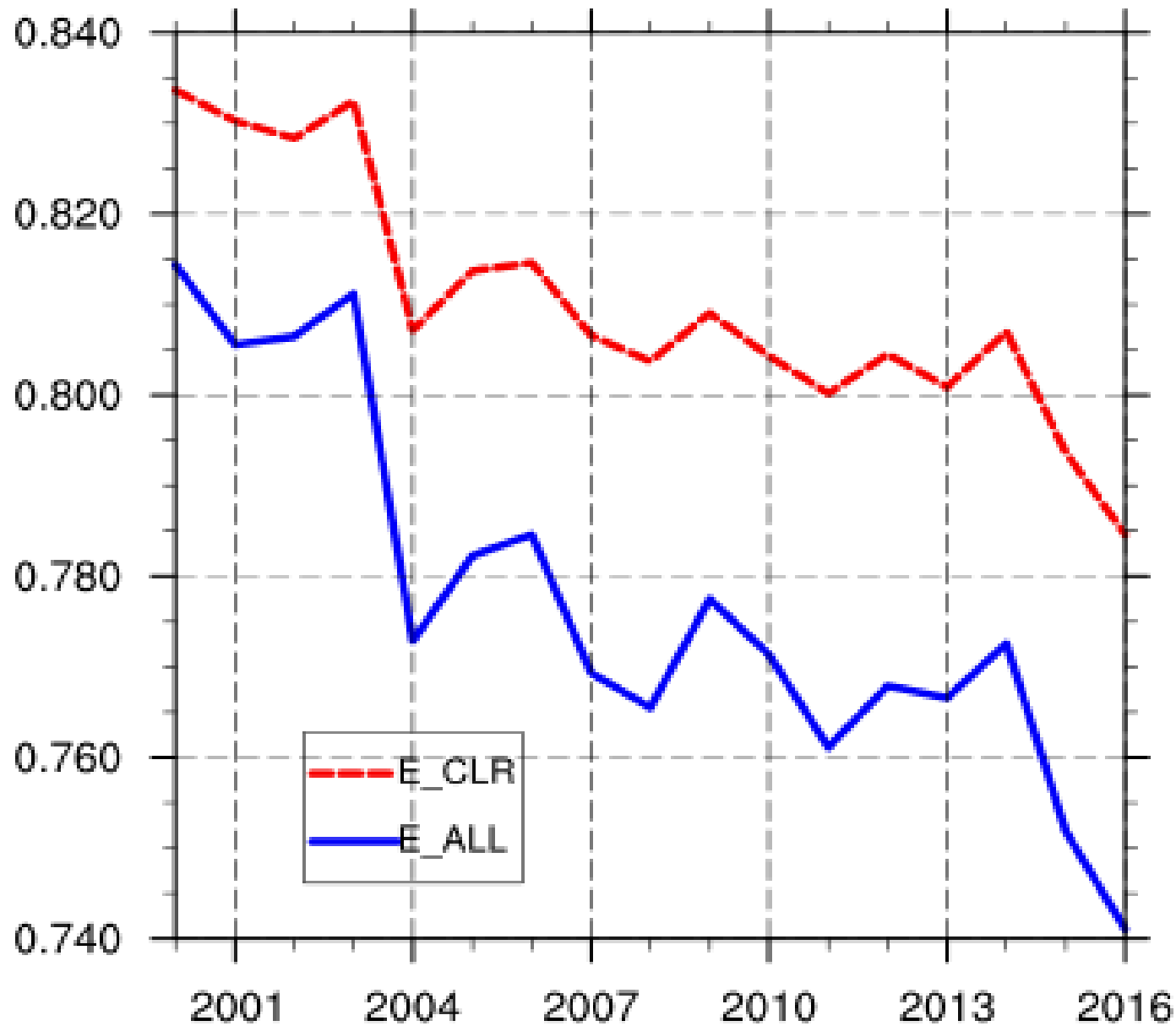
February 26-28, 2017

Longwave Cooling efficiency

$$\varepsilon = \left(\frac{LW_{TOA,up}}{LW_{SFC,up}} \right) = \frac{B}{A}$$



Efficiency (unitless)



What does this mean cooling efficiency of the atmosphere?

Decreasing trend in cooling efficiency of the atmosphere in recent years.

Consequence: **More energy is being retained in the atmosphere, both because of the increased upwelling flux from a warmer surface and an increased emissivity of the atmosphere.**

Atmospheric cooling efficiency in clear-sky and all-sky conditions

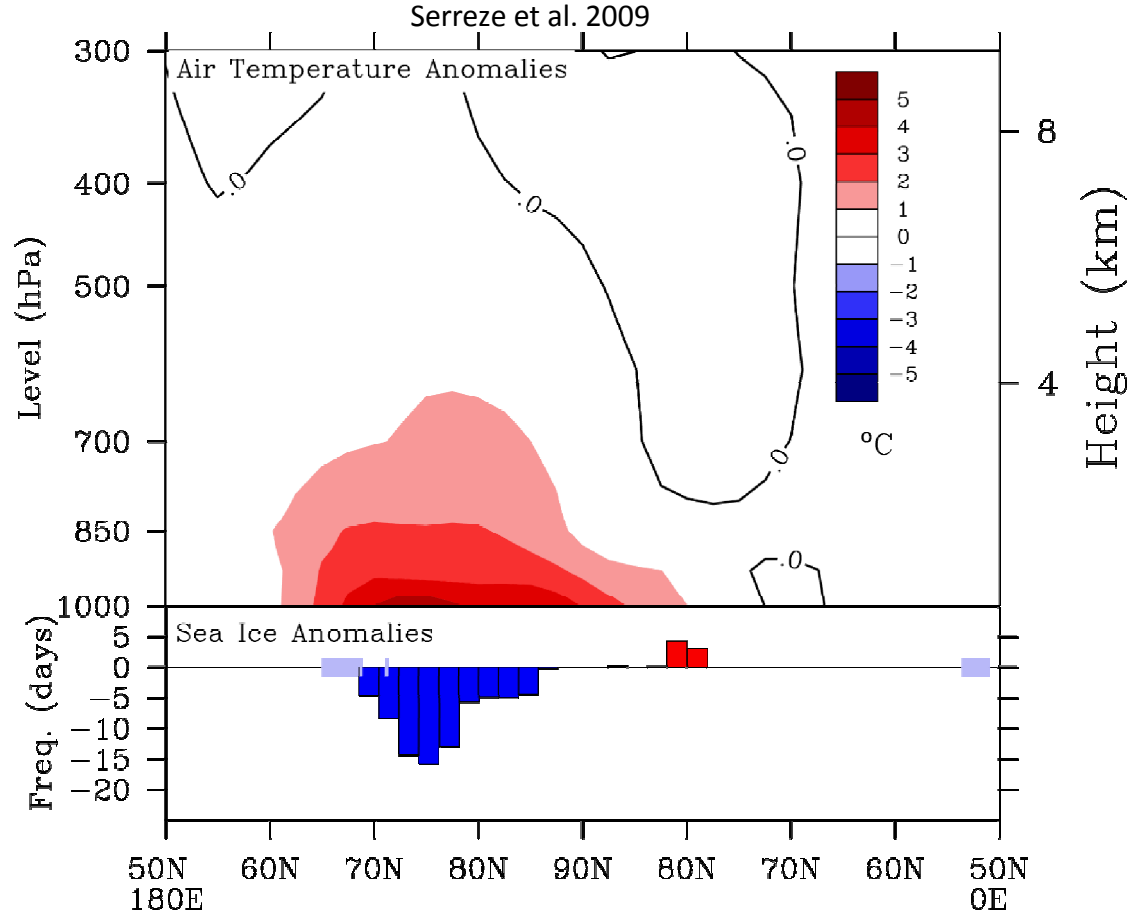
Lines: clear-sky efficiency (red)

All-sky efficiency (blue)

Characteristics of the 2016-17 sea ice growth season

- **Lowest end-of-season sea ice volume and extent on record**
 - Based on PIOMAS data
- **Warmest atmosphere and highest atmospheric water vapor content since 1979**
 - Result: Increased downwelling LW fluxes -> higher surface temperatures->less sea ice growth
- **Reduced longwave cooling efficiency**
 - Consequence: More energy radiated from surface is retained in the atmosphere rather than being radiated out to space
 - Decreased cooling efficiency associated with similar conditions as sea ice decline (high PW, high downwelling LW)

Local Forcing, Sea ice driven?

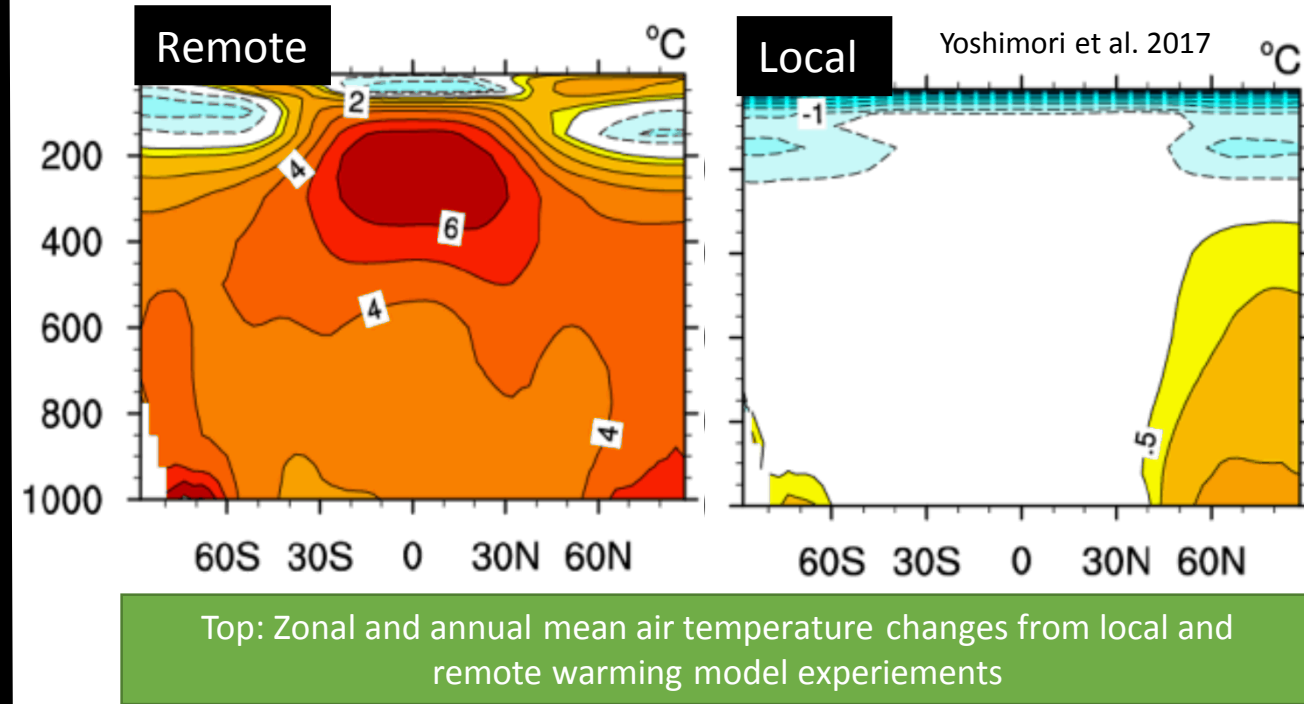


Top: 2003-2007 autumn temperature anomalies relative to climo in NCEP-NCAR reanalysis Bottom: Sea ice anomalies

Ice-albedo feedback: less ice results in more stored energy from ocean mixed layer released in fall and winter (e.g. Screen and Simmonds 2010)

versus

Remote forcing, dynamics/transport driven?



Increased downwelling LW fluxes warming the surface, facilitated by transport from lower latitudes (e.g. Alexeev et al. 2005, Yoshimori et al. 2017). Organized by tropical convection and Rossby wave response? (TEAM hypothesis, Lee et al. 2011, Gong et al. 2017)

What's next?

- What are the key surface energy fluxes that define the total impact of Arctic atmospheric rivers (AARs) on the surface and Arctic sea ice growth?
- What are the processes that “resolve” the AAR-induced surface energy perturbations and determine the total lifetime impact of AARs?
 - Radiative or turbulent fluxes, transport?
- Is there a trend in the strength/frequency of AARs associated with the trends in Arctic surface temperatures?

The answers to these questions have the potential to improve our understanding of Arctic amplification and the future evolution of the Arctic surface temperatures and sea ice growth in fall and winter.

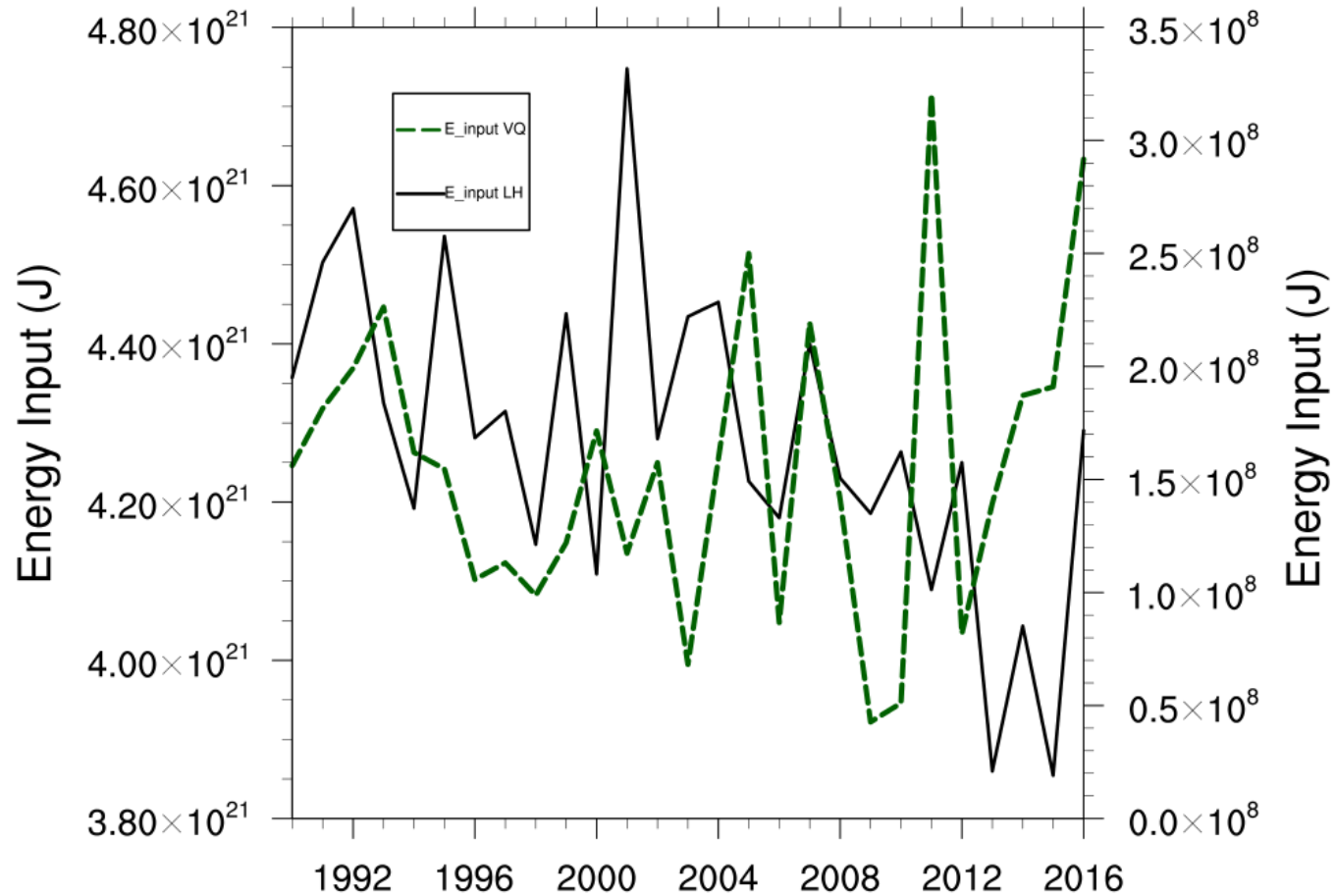
Presentation summary

- I: Cold, dry Arctic atmosphere with little solar radiation -> LW fluxes dominate surface radiative fluxes and water vapor anomalies have significant effect on surface LW fluxes. Sea ice growth a function of surface temperature.
- II: Sea ice volume and extent growth in 2016/17 was reduced, with contributions from multiple AARs increasing downwelling surface LW fluxes and reducing the cooling efficiency of the atmosphere by LW fluxes
- Context: Arctic amplification, locally or remotely forced?

Contact: bradley.m.hegyi@nasa.gov

Extra Slides

Cap energy input by evaporation and transport across 65N

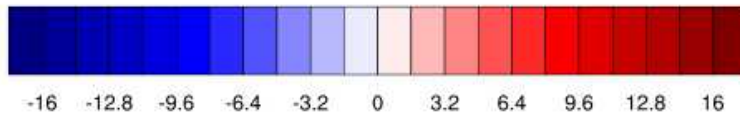
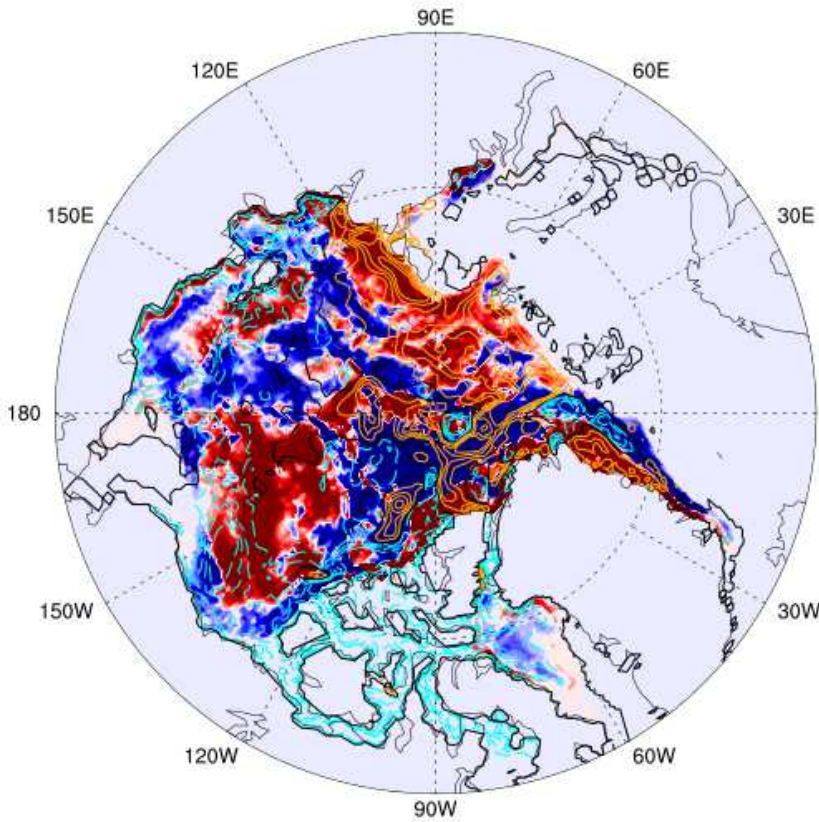


2016-17: Second highest energy input by VQ in period. Evaporation was increased, but not peak in the period.

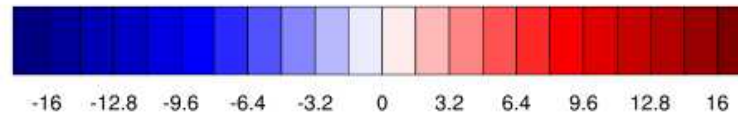
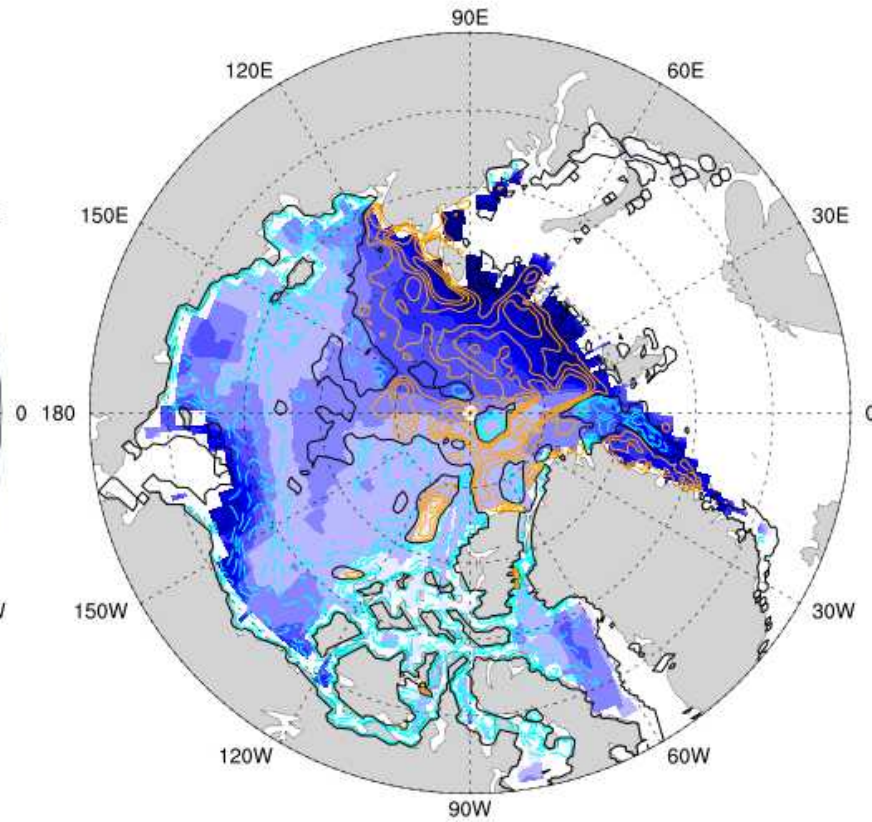
Cumulative energy input by evaporation and meridional water vapor transport
ONDJF sum for all quantities
Data: MERRA2

What about sea ice drift?

Drift Comp.



LW Anom Comp.



Over the 10-day period around November 17, 2016, downwelling LW anomalies primarily contributed to loss of sea ice volume in the Atlantic sector.

Contributions of sea ice drift and LW flux anomalies to sea ice volume growth from November 11-20, 2016

Red: Contribution to sea ice growth

Blue: Contribution to sea ice loss

Data: NSIDC Polar Pathfinder Sea Ice Drift; CERES