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

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News headlines about 2016/17 winter in Arctic: Christmas heat wave

WEATHER

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

By Jonathan Belles · December 22 2016 12:00 AM EDT · weather.com

Capital Weather Gang

Pre-Christmas melt? North Pole forecast to warm 50 degrees above normal Thursday

By Jason Samenow Dece

AdChoices

CLIMATE

Temperatures spike almost 50 degrees in North Pole

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

Capital Weather Gang

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

By Jason Samenow February 10

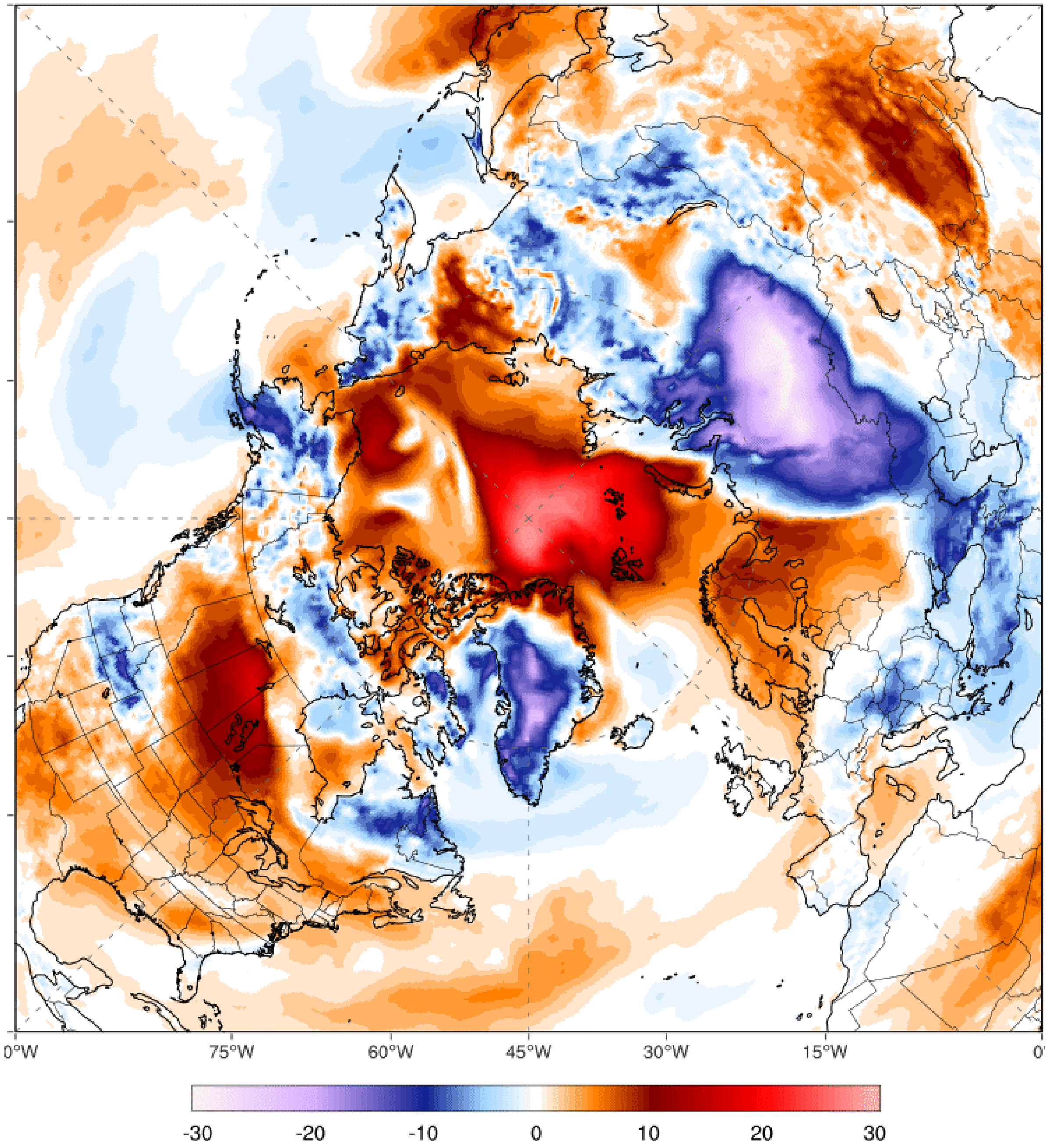
AdChoices

Energy and Environment

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

By Chris Mooney and Jason Samenow

Other headlines

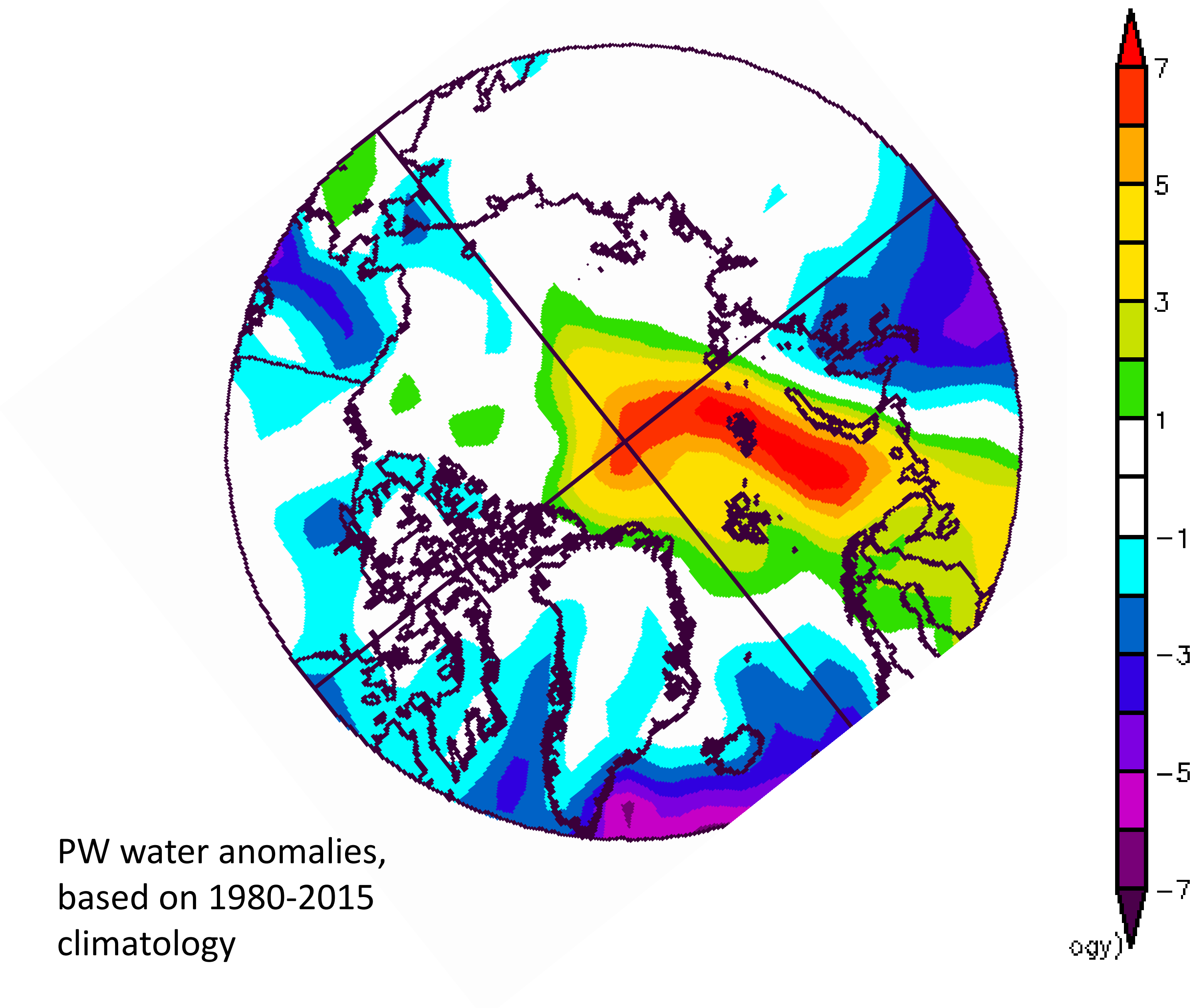


December 22, 2016

Surface temperature anomalies of greater than 20-30 degrees Celsius above average over the pole

Source:
ClimateReanalyzer.org,
CFSR data

December 22, 2016



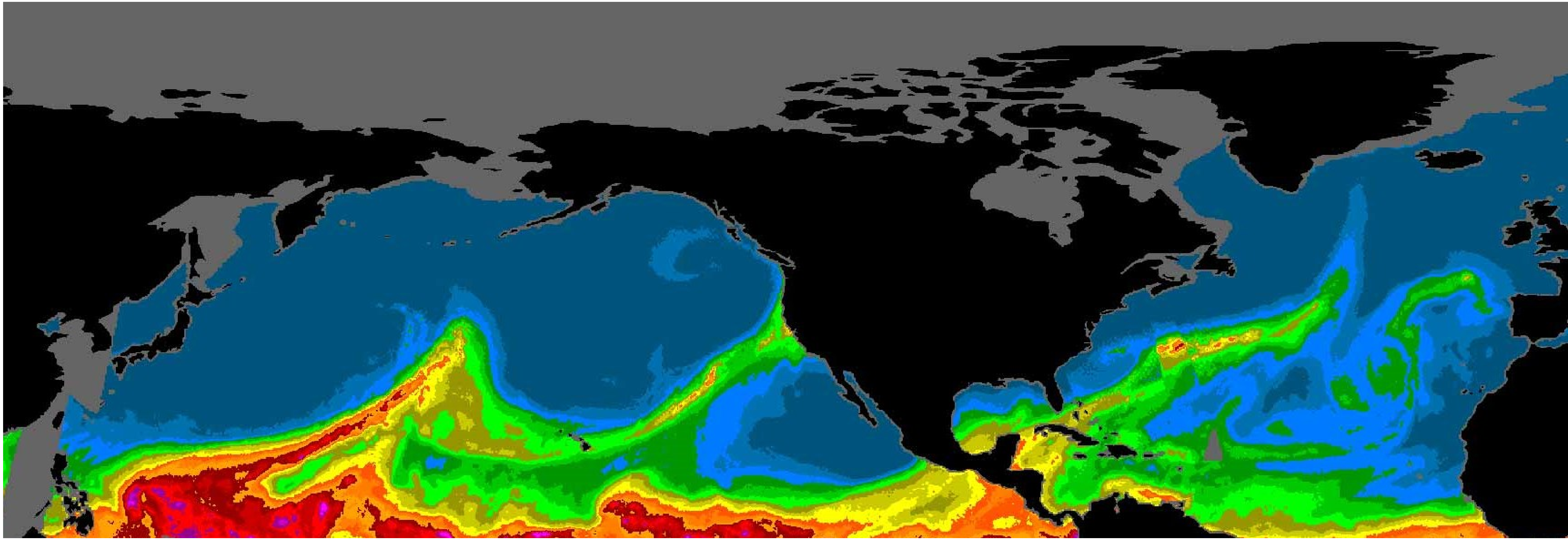
PW water anomalies, based on 1980-2015 climatology

Moisture intrusions: transport of high atmospheric water vapor (precipitable water, PW) values from lower latitudes In this case, an increase of 50-150% of climatological values) (e.g. Woods et al. 2013; Woods and Caballero 2016)

-or-

Arctic atmospheric rivers (AARs): Relatively narrow "river-like" transport of . (e.g. Baggett et al. 2016)

Source: NCEP/NCAR reanalysis data



Integrated column water vapor over Northern Hemisphere

Arctic atmospheric rivers have a similar structure to atmospheric rivers over the subtropics

Roadmap for today's talk

- ✓**I Introduction**
  - ✓**Definition of moisture intrusions/AARs**
- **II Characteristics of the 2016-17 sea ice growth season (October 1-March 1) and connection to moisture intrusions/AARs**
  - How do moisture intrusions/AARs contribute to the low sea ice growth in 2016-17?
- **III Importance/Context**
  - How the results here fit in the larger discussion of Arctic amplification?

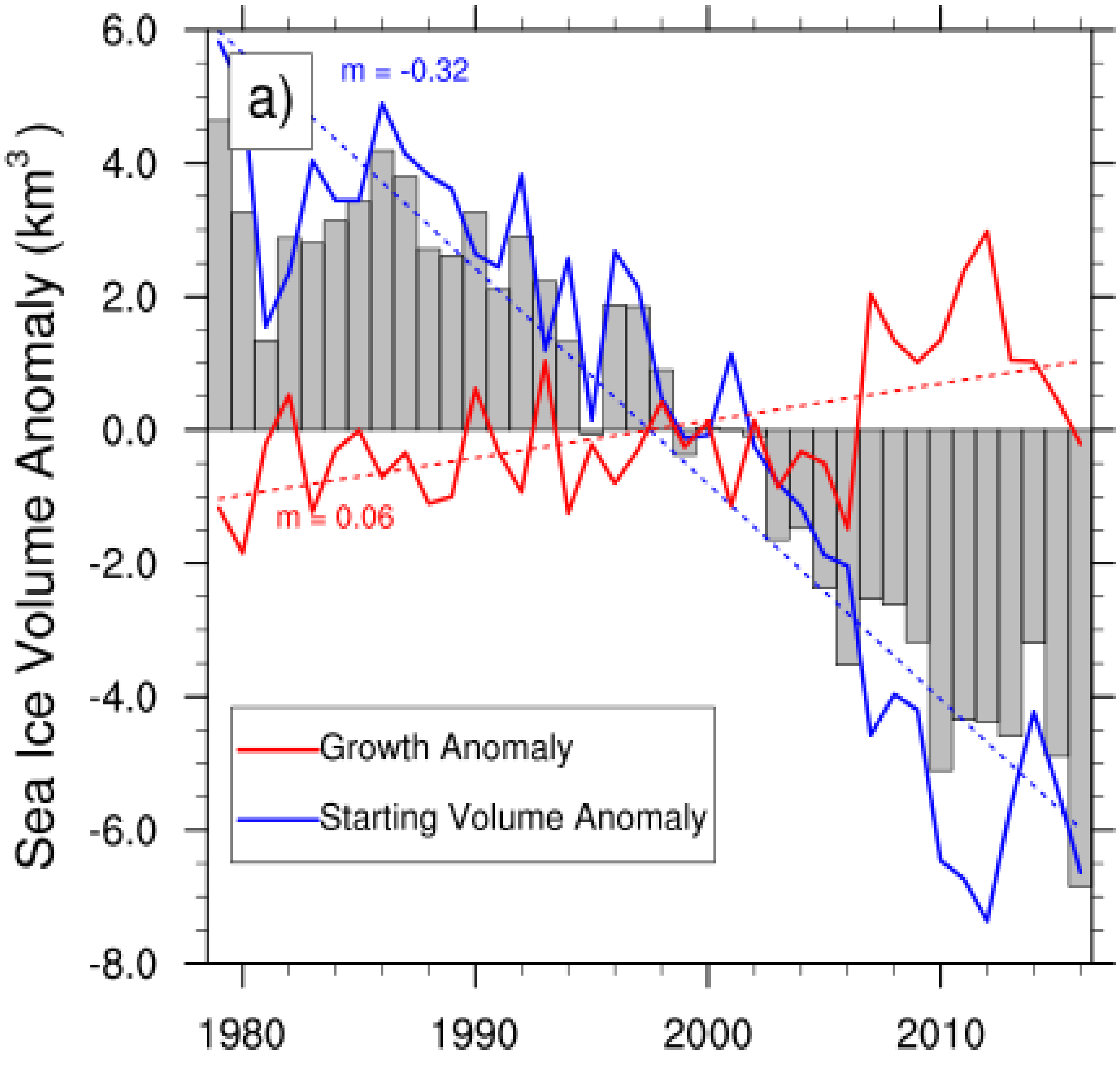
Focus: Surface radiative fluxes

Characteristics of the 2016-17 season

- Low growth led to lowest-end of season sea ice volume and extent
- Arctic-average near surface temperature and column water vapor amount was highest in MERRA-2 reanalysis record
  - Most days during season where PW >1.5 standard deviations above mean
  - Record cumulative downwelling LW fluxes into surface

Low growth led to lowest-end of season sea ice volume and extent

Sea Ice Volume



Hegyi and Taylor 2018
accepted

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).

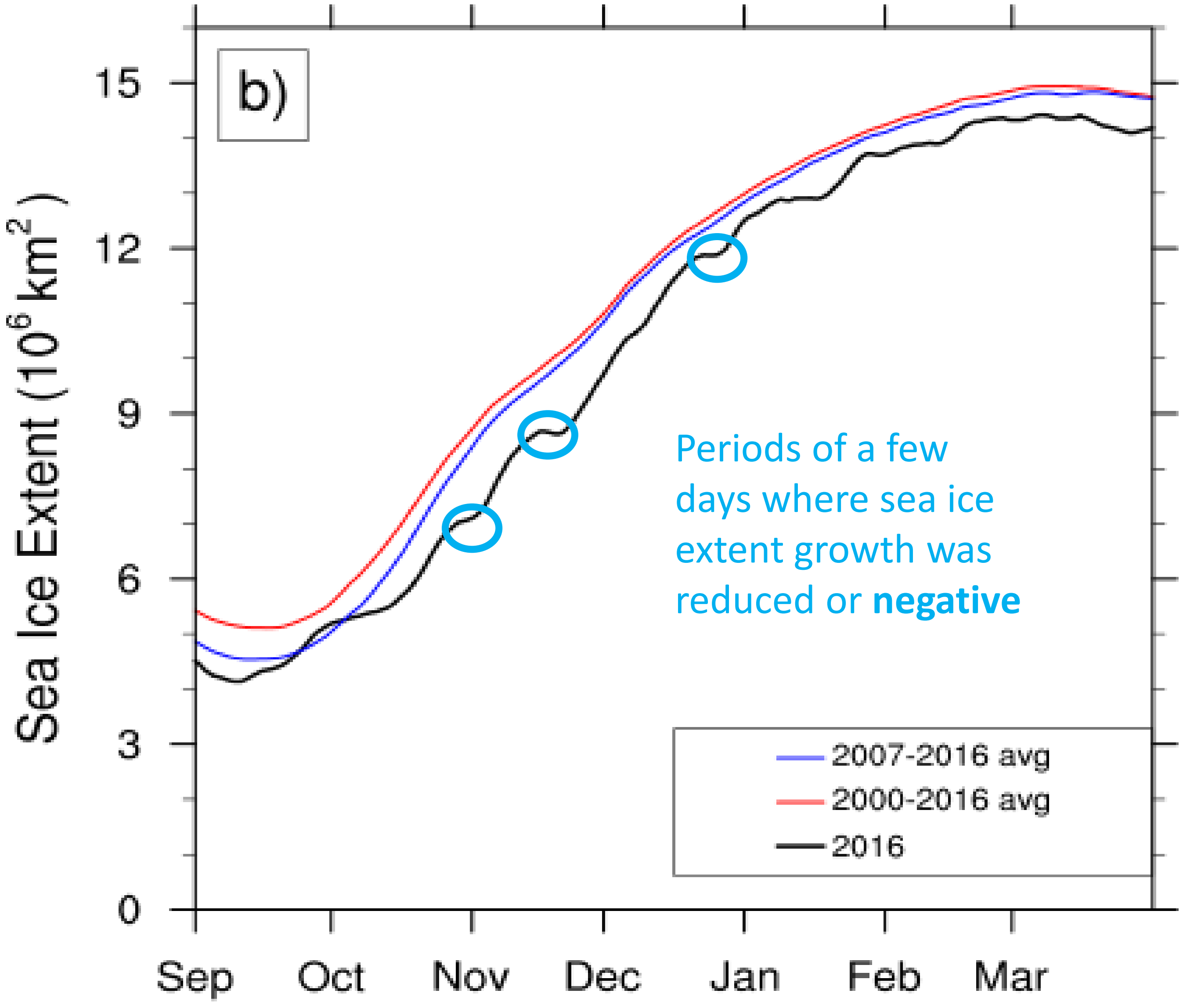
blue line + red line = gray bar

Robust: Minimum also found in CryoSat2 data

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

Low growth led to lowest-end of season sea ice volume and extent

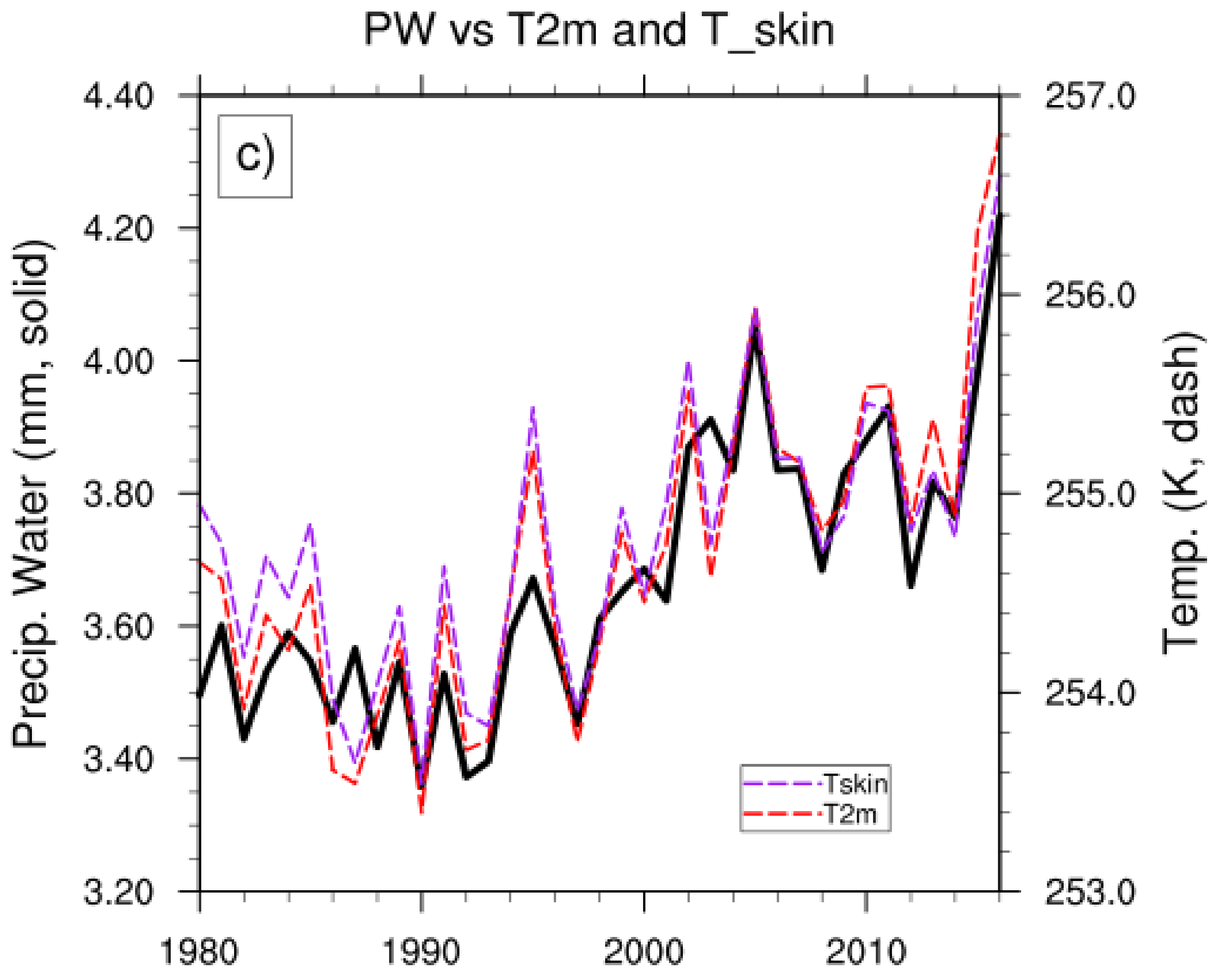
Sea Ice Extent



Hegyi and Taylor 2018 *accepted*

2016-17 also exhibited low sea ice extent from October-March, well below recent averages.

Sea ice volume and extent
Arctic sea ice extent in 2016/17 and recent climatology
Data: SSMI passive microwave sea ice concentration data



Hegyi and Taylor 2018
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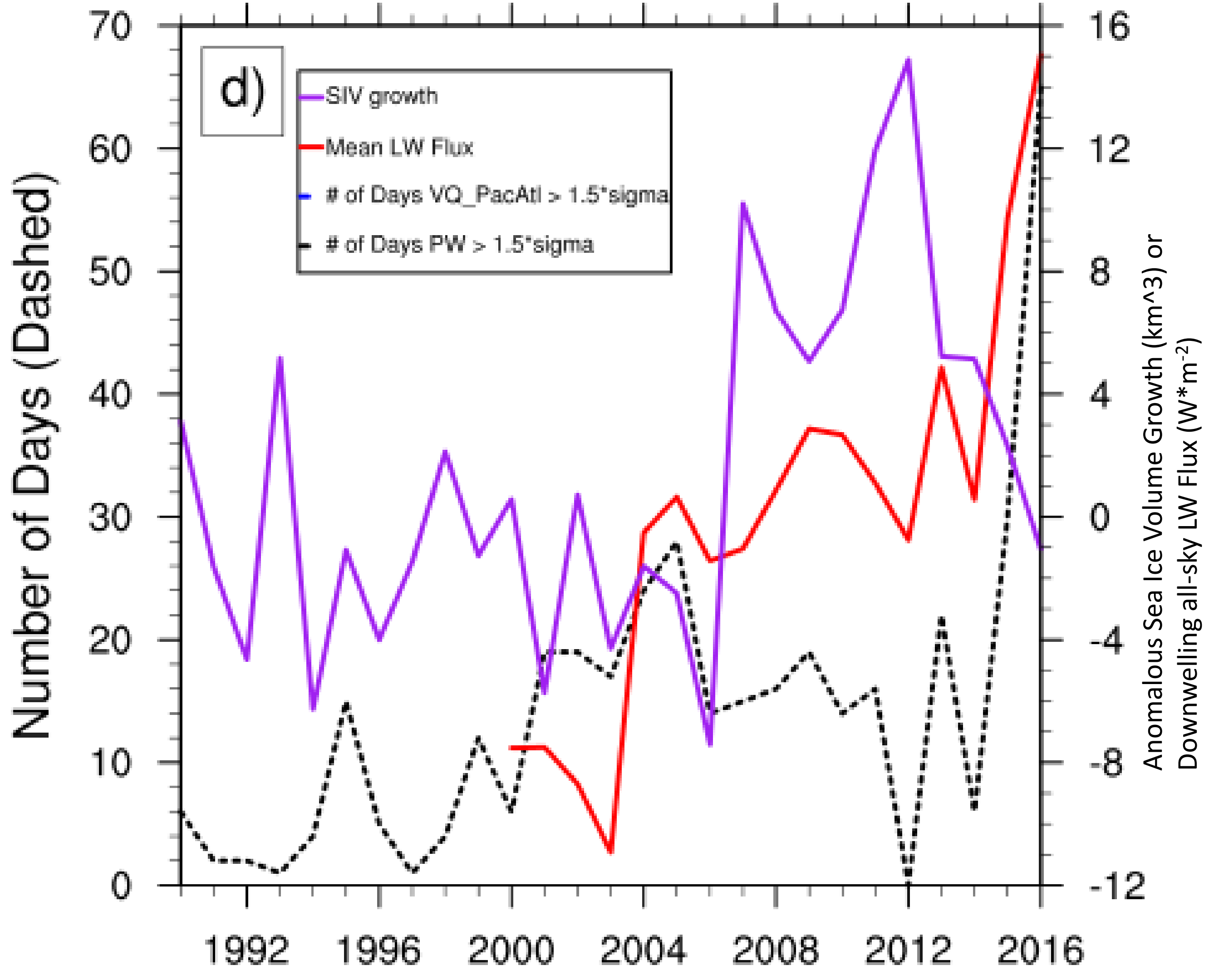
Surface temperatures and precipitable water

Arctic-average near surface temperature and column water vapor amount was highest in MERRA-2 reanalysis record

Surface temperatures and atmospheric water content in the 2016-17 fall and winter season were also the highest since 1980, 1 degree Celsius and 0.17 mm above previous peak (2005).

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

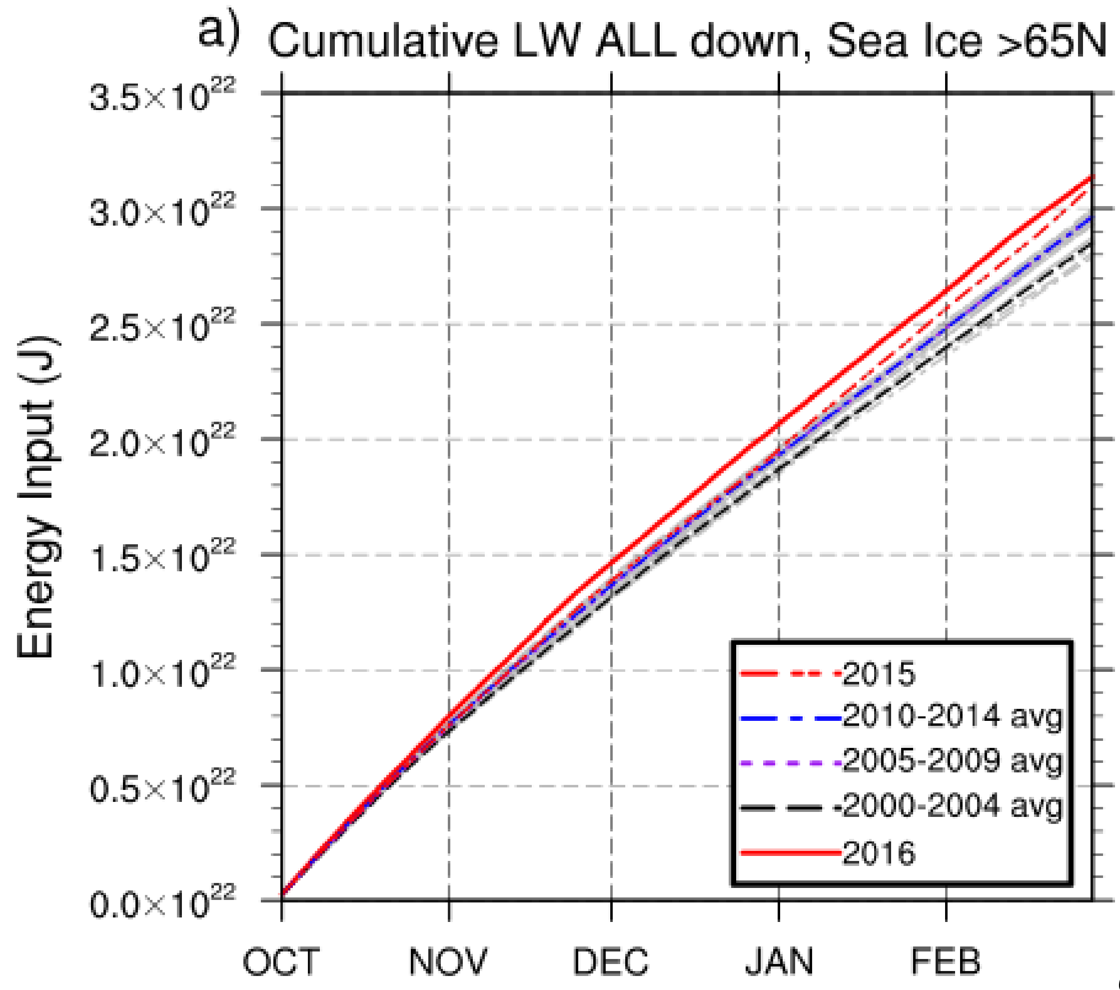


Surface temperatures and precipitable water

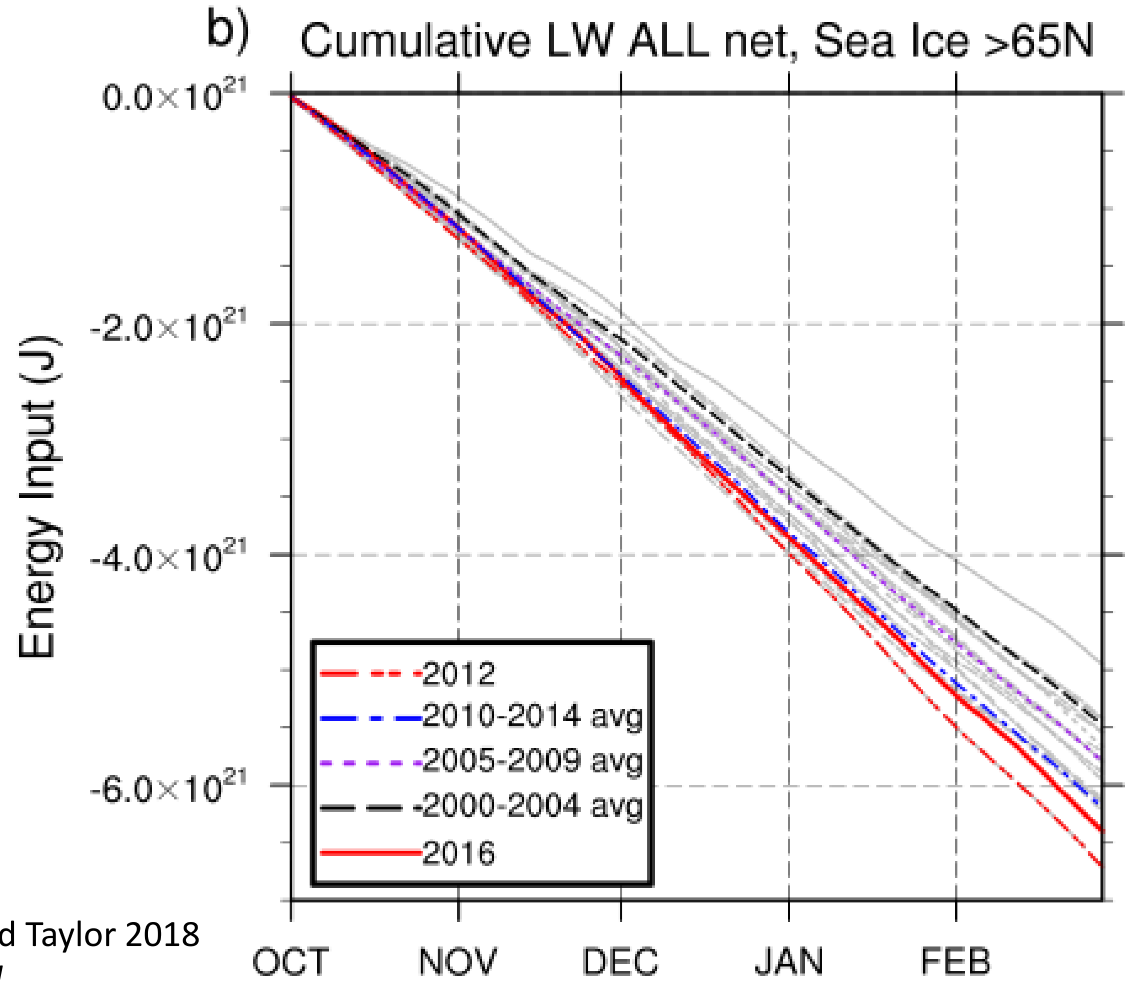
Arctic-average near surface temperature and column water vapor amount was highest in MERRA-2 reanalysis record

67 days in ONDJF period where PW was >1.5 standard deviations above mean over Arctic polar cap, greater than double the next highest year (2005 – 27).

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

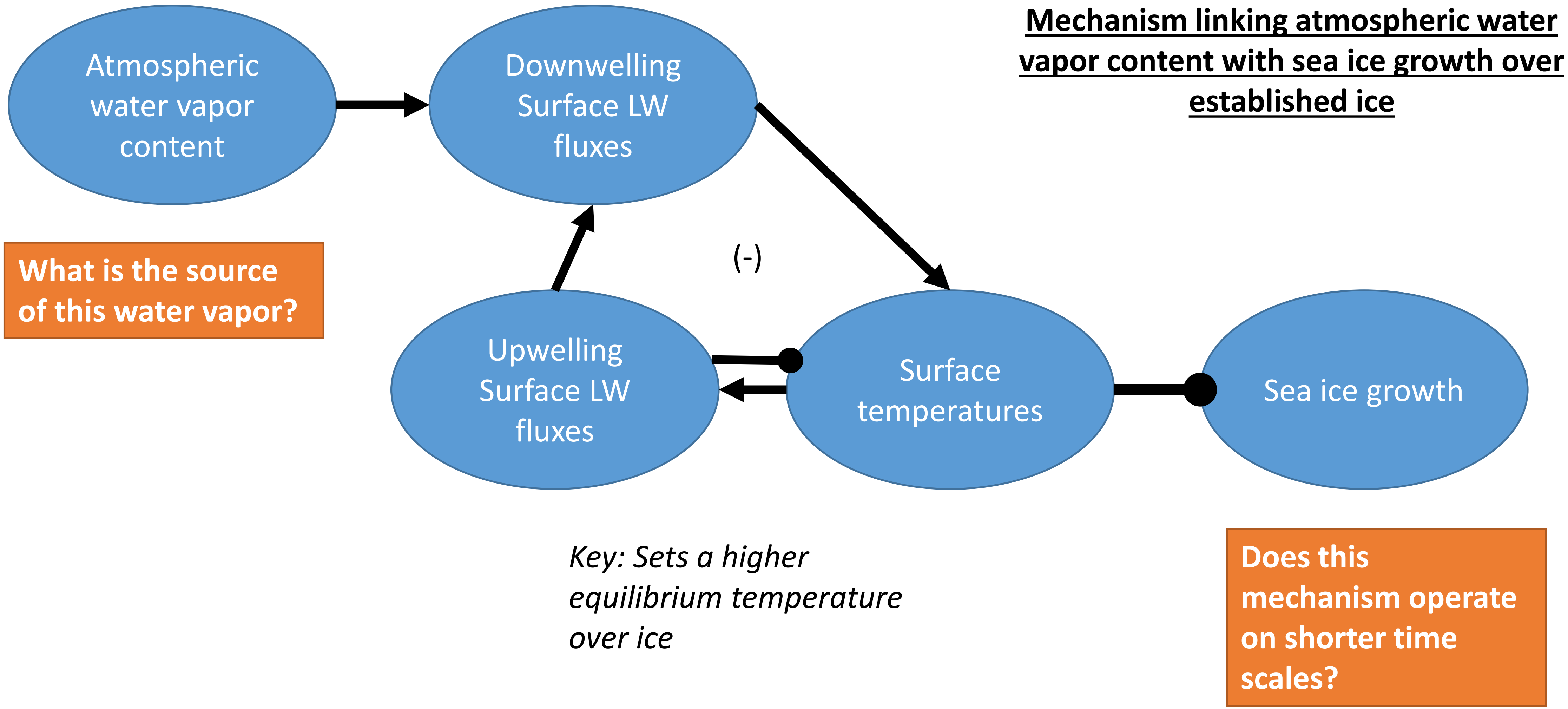


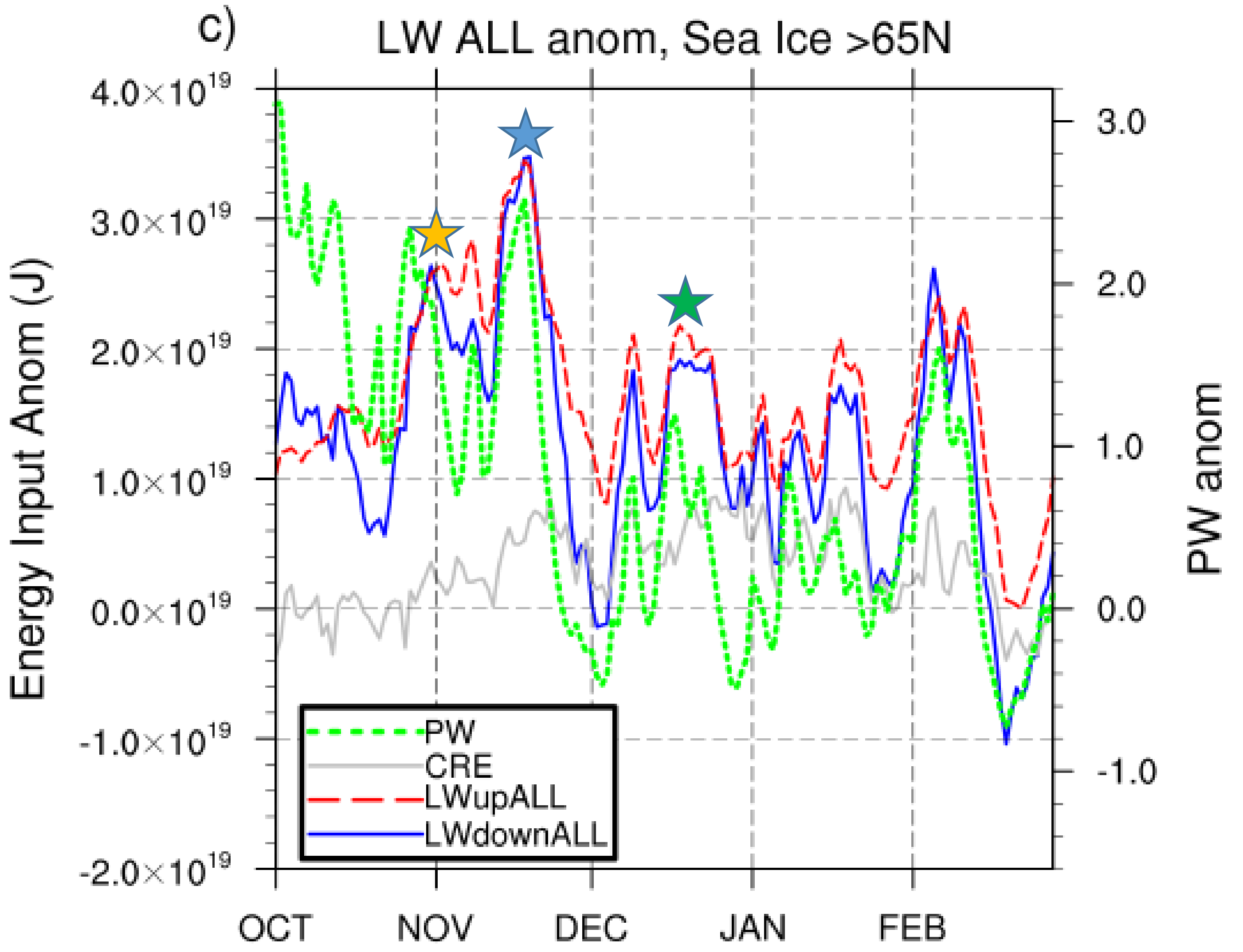
Hegyi and Taylor 2018
accepted

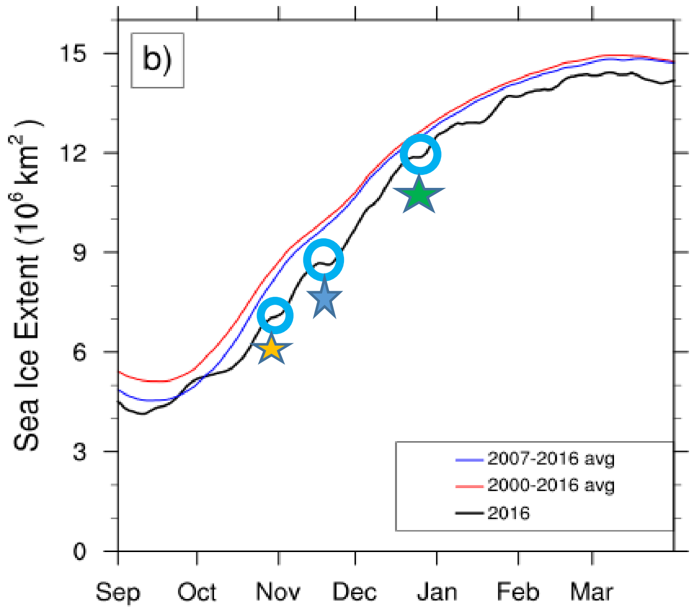


As a result of the warm and moist atmosphere, input by cumulative downwelling LW fluxes was highest since 2000. **Increase in downwelling LW fluxes was counteracted by increased upwelling LW fluxes, but this means higher surface temperature.**

Cumulative energy input by LW surface fluxes over sea ice areas
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


Mechanism linking atmospheric water vapor content with sea ice growth over established ice
Atmospheric water vapor content
Downwelling Surface LW fluxes
What is the source of this water vapor?
(-)
Upwelling Surface LW fluxes
Surface temperatures
Sea ice growth
Key: Sets a higher equilibrium temperature over ice
Does this mechanism operate on shorter time scales?





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

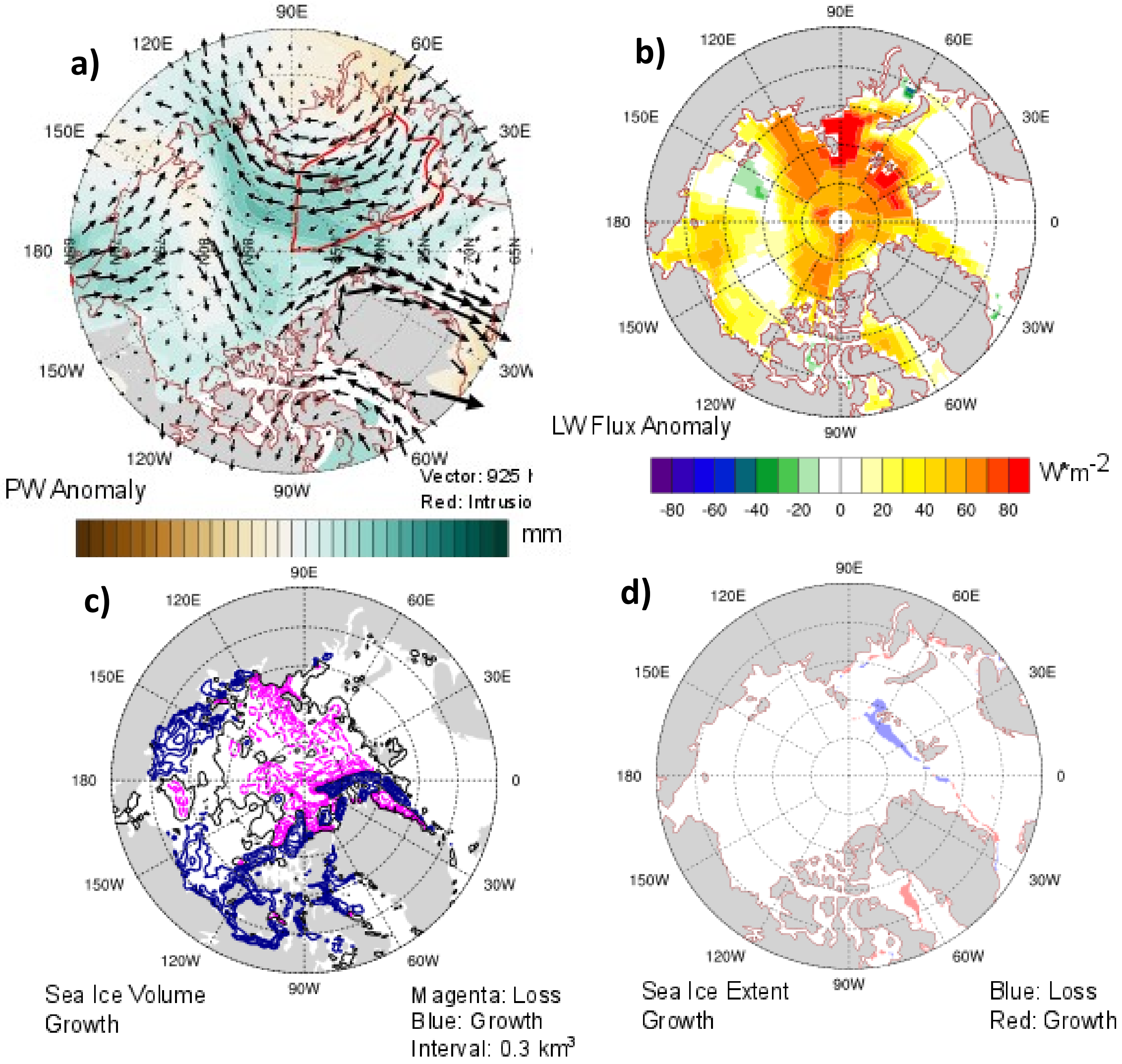
Peaks associated with mainly with increases in clear sky fluxes…

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 SYN surface flux data

Presence of a moisture intrusion

Increased downwelling LW fluxes



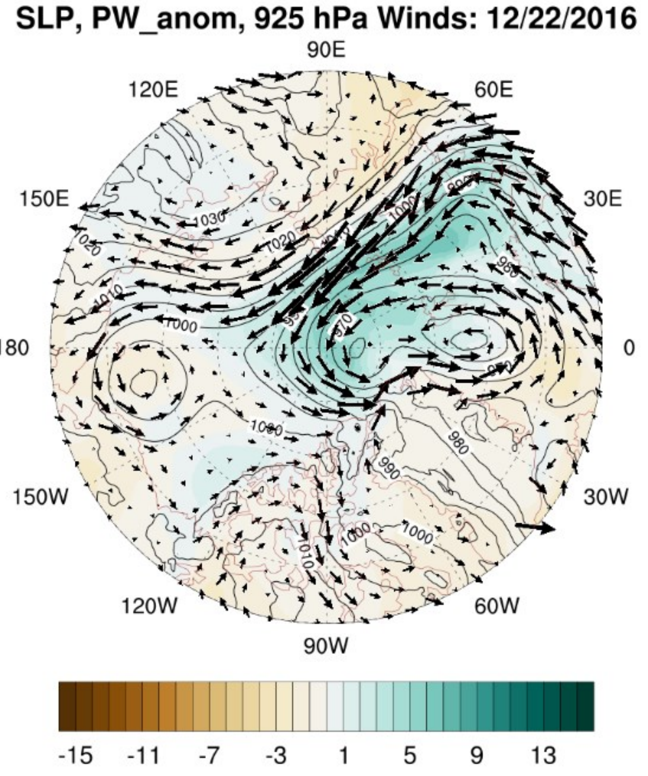
November 17, 2016

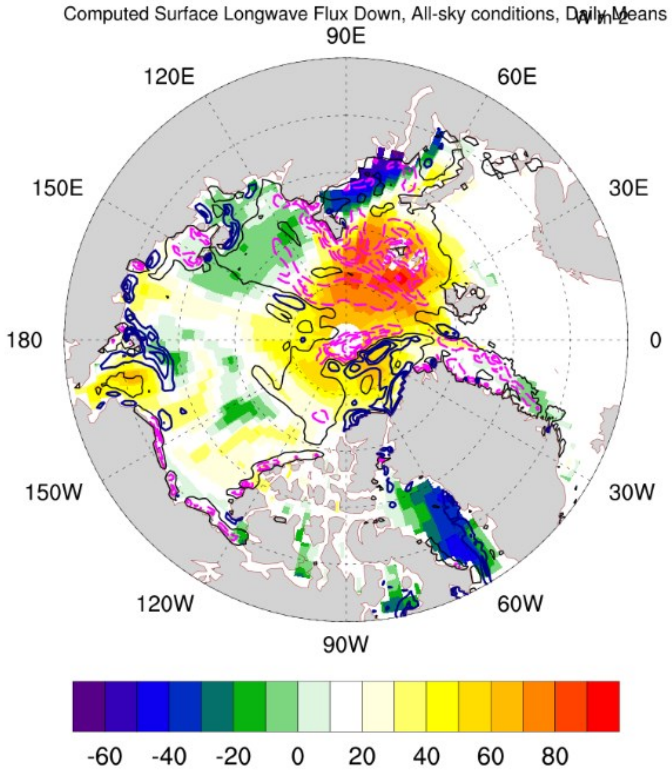
a) **Anomalous PW (shading), 925 hPa winds (vectors), and area of moisture intrusion (red contour)**
b) **Anomalous downwelling LW flux anomaly**
c) **Sea ice volume growth**
d) **Sea ice extent retreat**

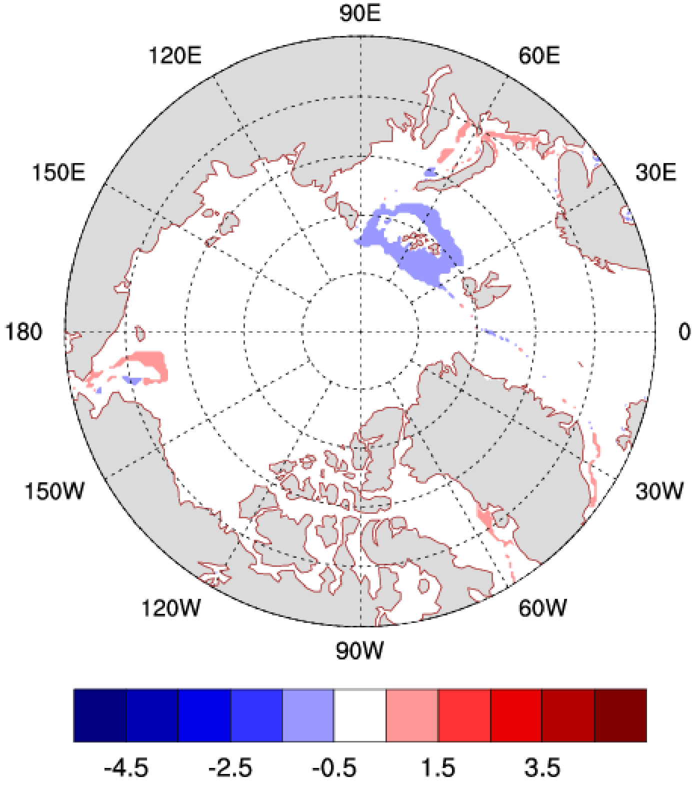
Sea ice volume loss

Sea ice extent retreat

December 22, 2016







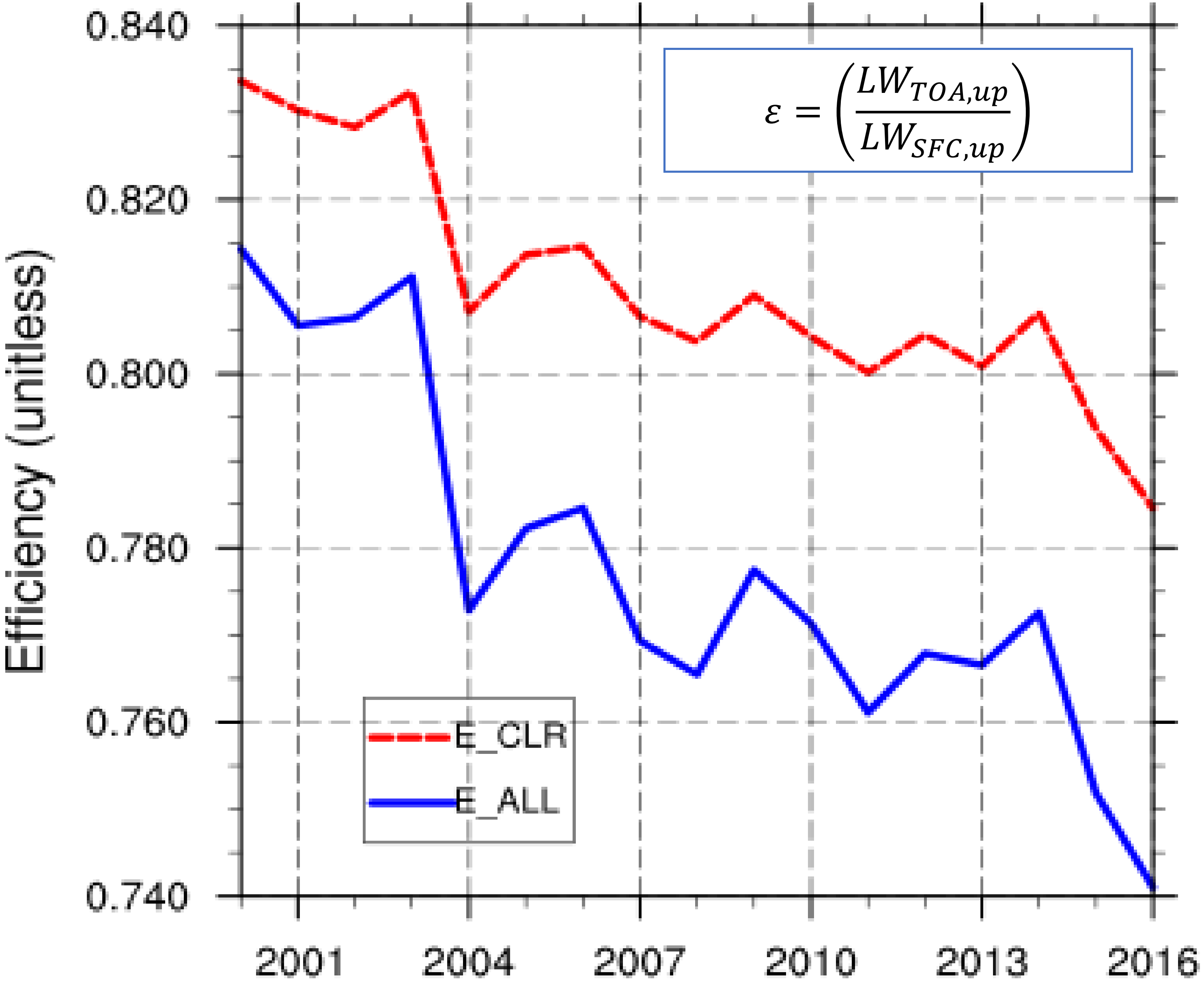
PW (shading) **and 925 mb winds** (vectors)

Downwelling surface LW flux anomalies (shading) and **sea ice thickness growth** (negative: magenta contours)

Sea Ice Extent change (5-day centered mean)

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
  - Marked with episodes of increased water vapor and decreased sea ice growth that define the seasonal average



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.**

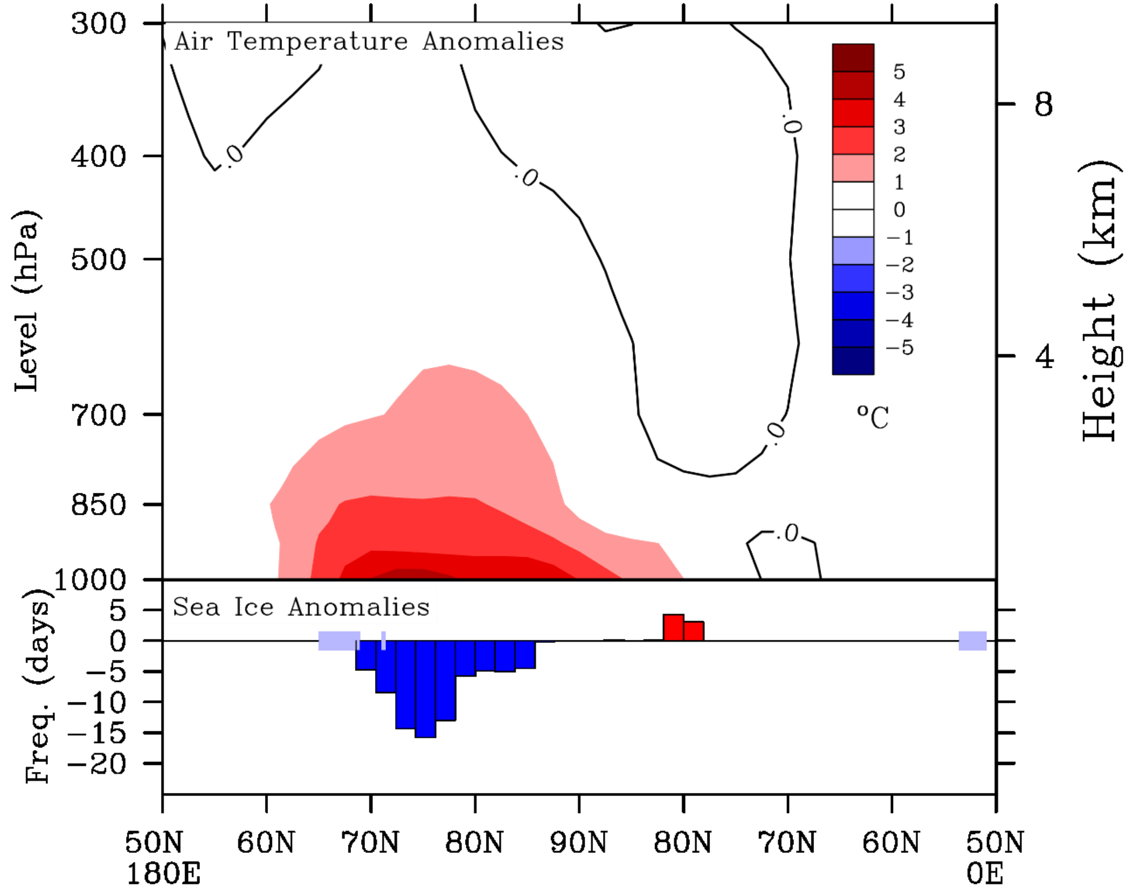
Atmospheric cooling efficiency in clear-sky and all-sky conditions over Arctic polar cap
Lines: clear-sky efficiency (red)
All-sky efficiency (blue)
Data: CERES EBAF data

Local Forcing, Sea ice driven?

versus

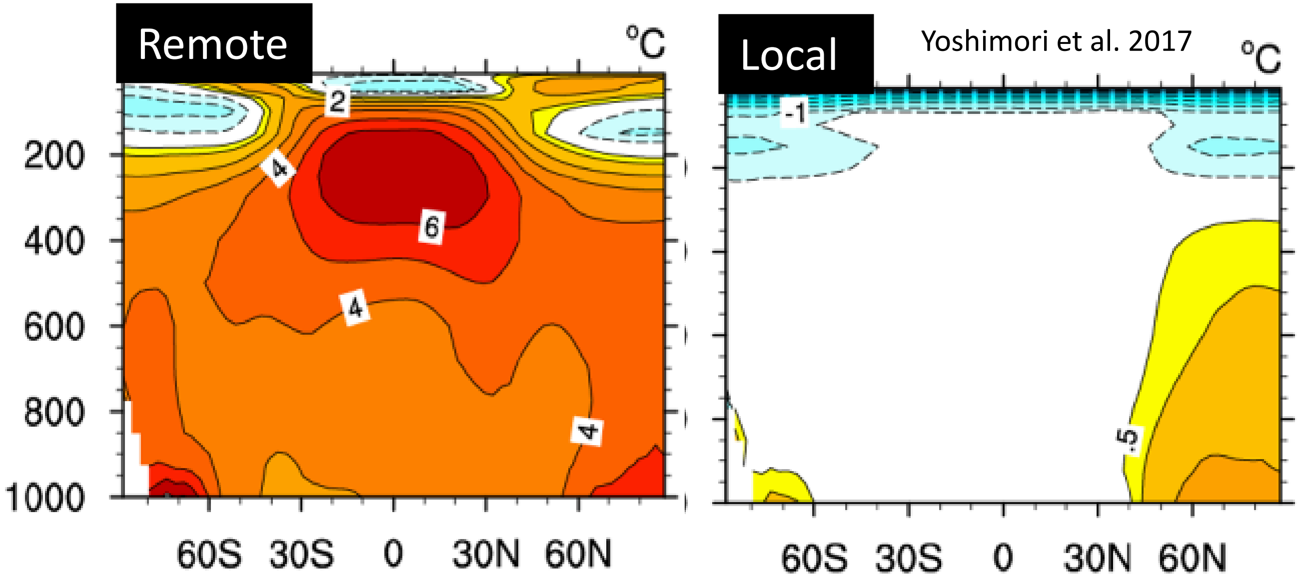
Remote forcing, dynamics/transport driven?

Serreze et al. 2009



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)



Top: Zonal and annual mean air temperature changes from local and remote warming model experiments (*from Yoshimori et al. 2017*)

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)

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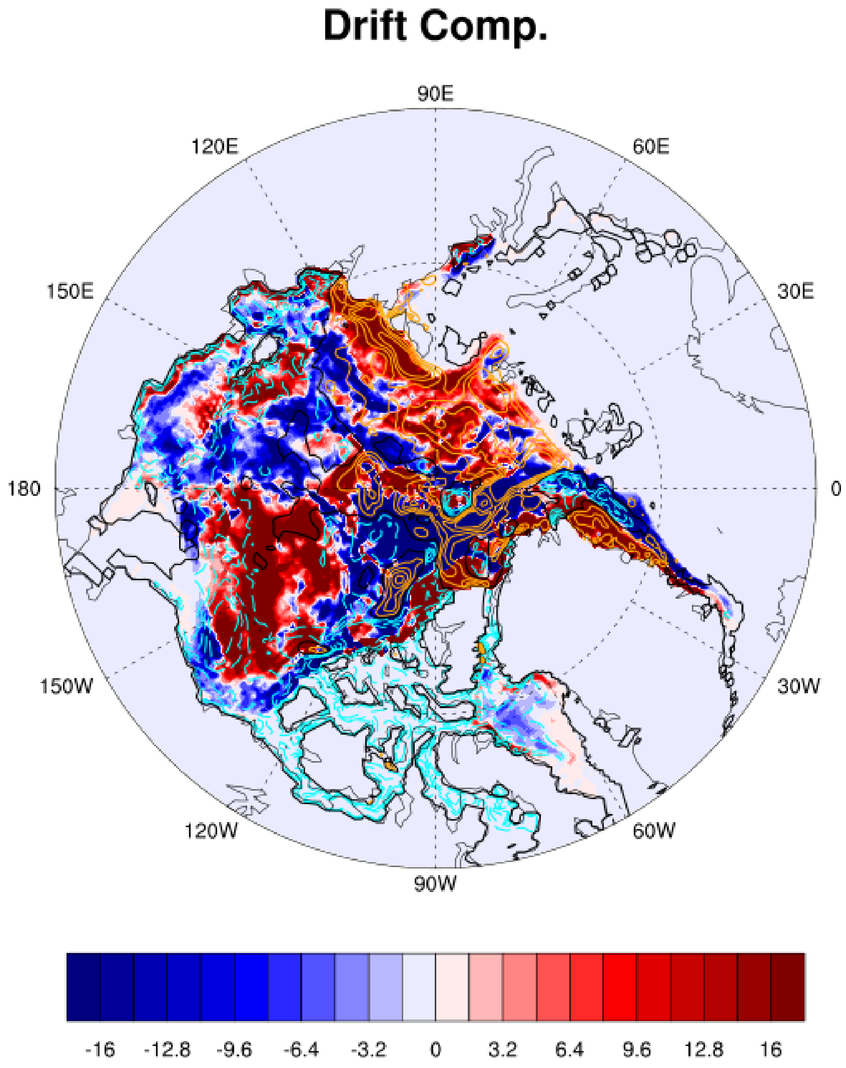
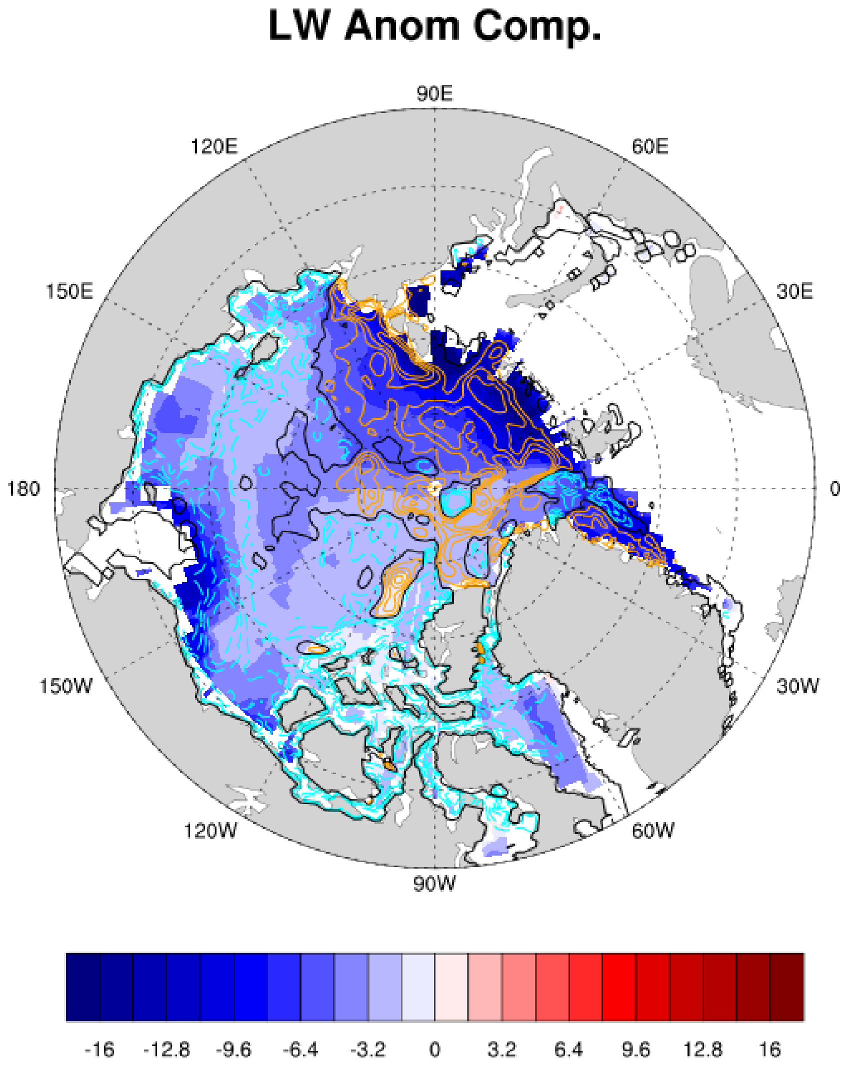
Contact: bradley.m.hegyi@nasa.gov
Results published in: Hegyi, B.M., and Taylor, P.C. (2018), **The unprecedented 2016-17 Arctic sea ice growth season: the crucial role of atmospheric rivers and longwave fluxes, GRL.**

Extra Slides





What about sea ice drift?

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