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

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

Temperatures spike almost 50 degrees in North Pole

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

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

Source: ClimateReanalyzer.org, CFSR data
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

PW water anomalies, based on 1980-2015 climatology
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
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).

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

Sea Ice Volume

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

Periods of a few days where sea ice extent growth was reduced or negative.

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

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

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Data: MERRA2 reanalysis data

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
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: MERRA-2 reanalysis data
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.
What is the source of this water vapor?

Mechanism linking atmospheric water vapor content with sea ice growth over established ice

**Key:** Sets a higher equilibrium temperature over ice

Does this mechanism operate on shorter time scales?
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.

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

Peaks associated with mainly with increases in clear sky fluxes...

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

**SLP, PW_anom, 925 hPa Winds: 12/22/2016**

**Computed Surface Longwave Flux Down, All-sky conditions, Daily Means**

**Sea Ice Extent change (5-day centered mean)**

**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.
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)

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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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