Preliminary Results: Using GPM to Quantify Moisture Transport in Arctic Cyclones

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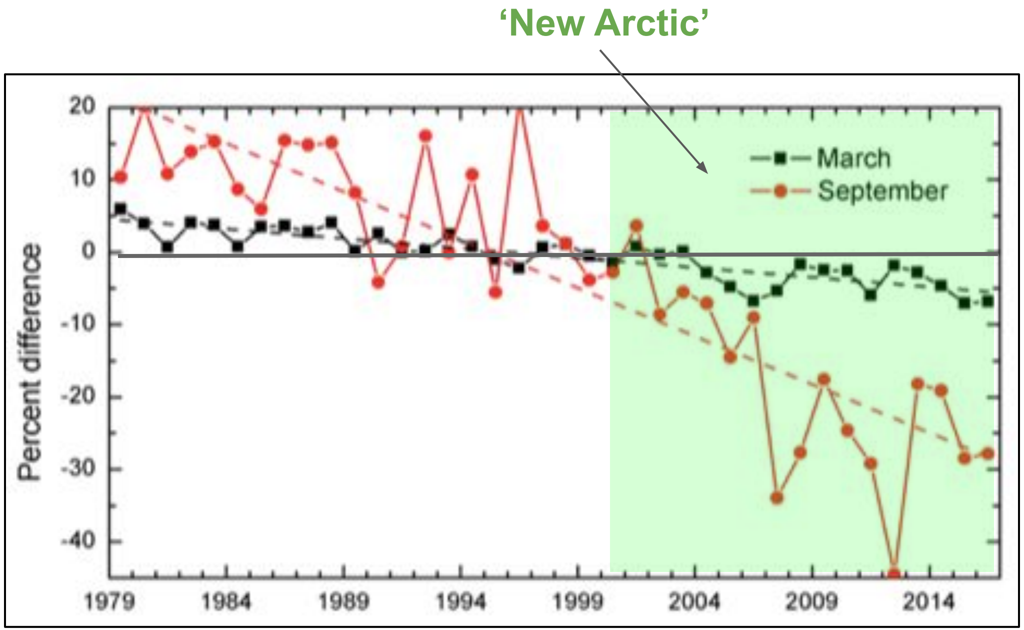
The ‘New Arctic’

- Drastic change witnessed with the decline in Arctic sea ice extent since the late 1970s [Parkinson and DiGirolamo, 2016].

- Worth mentioning, since the early 2000’s:
  - The sea ice has experienced an increased rate of decline in extent & thickness
  - Arctic has become warmer and wetter [Boisvert and Stroeve, 2015]
  - Evaporation from the ice-free ocean has been increasing [Boisvert et al., 2015]
- These large changes observed in the Arctic climate system since the 2000’s has been coined the **‘New Arctic’**, where sea ice:
  - Is more responsive to atmospheric forcing (e.g. increases in ice dynamics) [Kwok et al., 2013]) and the role of cyclones in anomalous sea ice melt events (Simmonds and Rudeva, 2012)

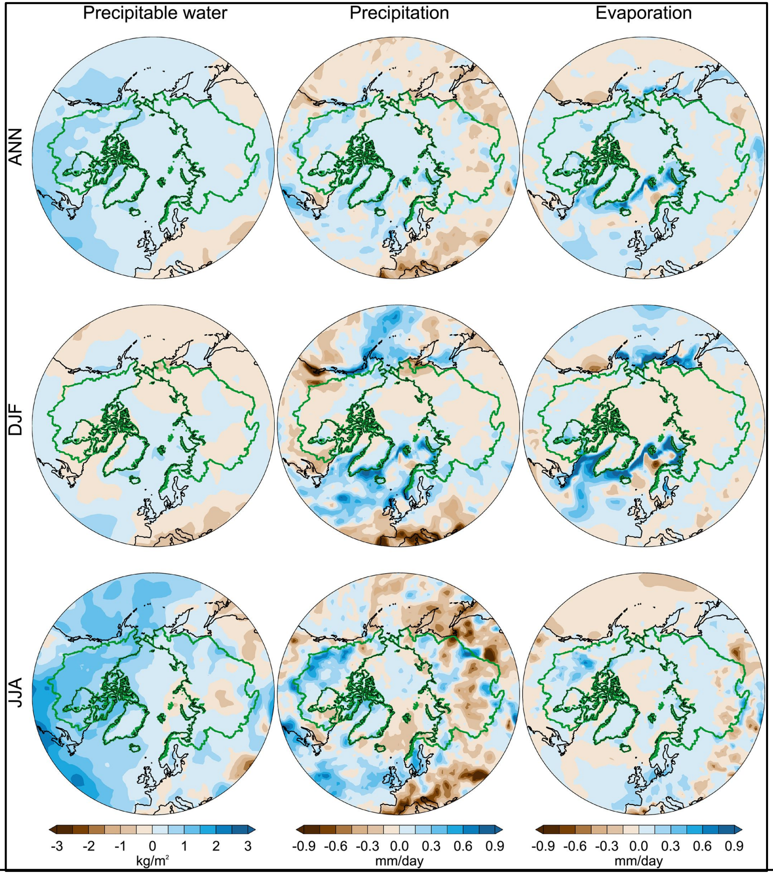


Time series of Arctic sea ice extent anomalies in March & September. The anomaly value for each year is the difference (in %) in ice extent relative to the mean for 1981-2010.

‘New Arctic’ Climate System

- Currently: all aspects of the hydrologic cycle are likely affected by & also feedback on these large & rapid changes in the ‘New Arctic’ [Vihma et al., 2016].
  - Cyclones bring a large majority of moisture to the Arctic from lower latitudes [Jakobson and Vihma, 2010]
  - Changes in their frequency & intensity will also impact the hydrologic cycle significantly.
- A better understanding of Arctic E-P is requisite for closing the local and global freshwater [Lique et al., 2016] & energy budgets where large uncertainties remain currently and in the future.

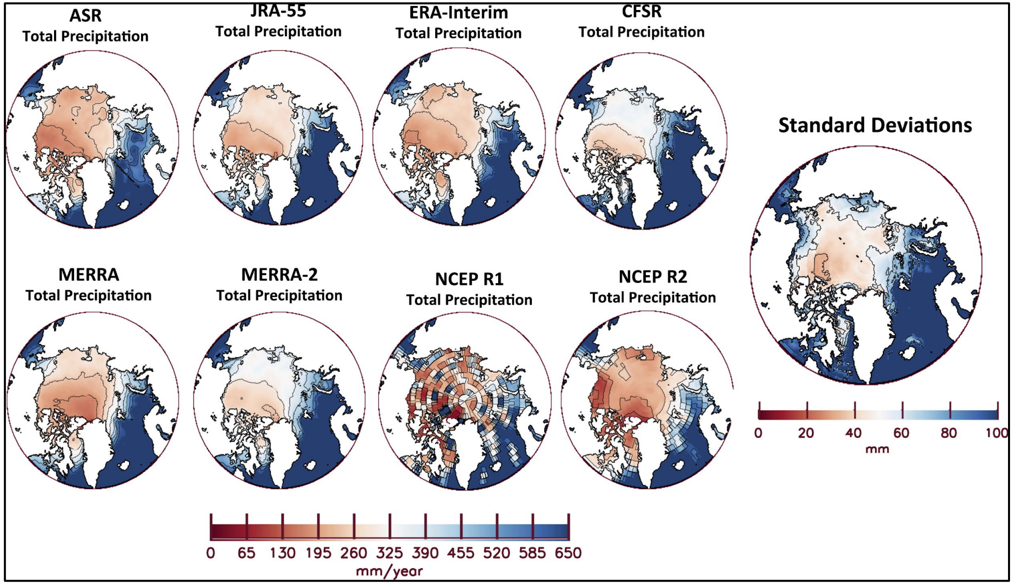
Figure shows increases in precipitable water, precipitation and evaporation are all increasing on an annual basis (also in JJA) in a more recent Arctic compared to years past, likely due to warming conditions and loss of sea ice.



Epoch differences between 1986–2013 and 1958–1985 for precipitable water, precipitation, and evaporation on the basis of JRA-55 reanalysis for annual (ANN) means, winter (DJF), and summer (JJA). The green lines indicate the boundaries of the Arctic river catchment. Taken from Vihma et al., 2016 JGR

Problems with Arctic Precipitation

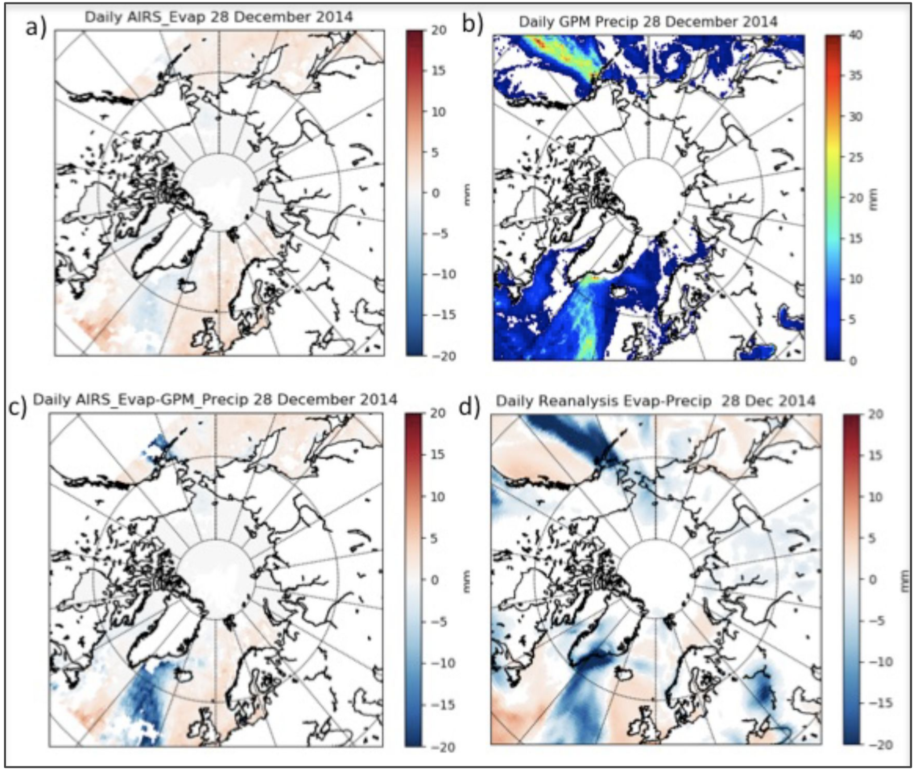
- (E-P) associated with Arctic cyclones is one of the most important yet uncertain climate variables, whether it be modeled or observed [Vihma et al., 2016].
- <u>Observations</u>:
  - Lack & difficulty of collecting long term, large-scale observations in the vast, harsh environment
  - Issues associated with measuring snowfall.
  - Direct measurements of evaporation (E) do not exist.
- <u>Modeling</u>:
  - Large uncertainty & spread across precipitation (P) products from reanalyses [Boisvert et al., 2018]
  - Lack of knowledge on clouds & the microphysical processes that are unique to the Arctic climate.



Averaged 2000–10 yearly total precipitation accumulations (mm yr^{-1}) from each of the eight reanalyses. The image on the right shows the standard deviations (mm) between the eight reanalyses. Contour lines are on the color bars. Taken from Boisvert et al., 2018, J. Climate.

Motivation

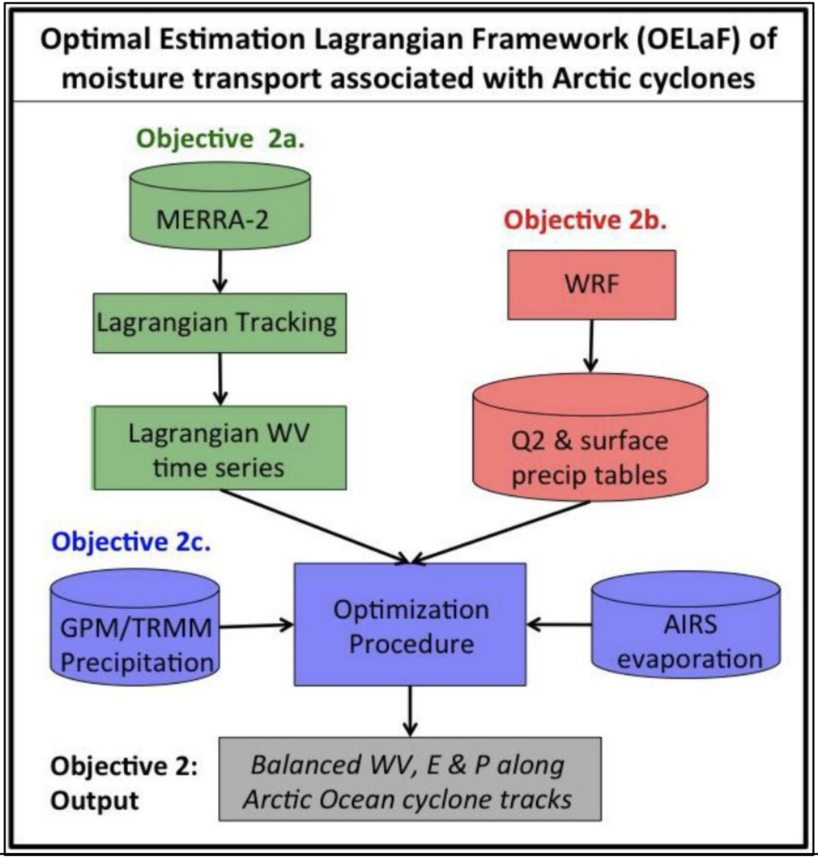
- As the New Arctic continues to undergo rapid change, observational data of P from GPM (IMERG) and E from AIRS [Boisvert et al., 2013; 2015] can give us critical information on:
  - Changes in (E-P) associated with cyclones
  - Their effects on the Arctic climate system & moisture processes therein.
- Process-oriented (E-P) observations can provide invaluable insight into the potential feedbacks of (E-P) changes in the future.



a) Daily E derived using AIRS data. b) Daily GPM surface P estimates overice-free oceans. The daily estimates are derived by averaging the GPROF daily gridded P estimates from 12 passive sensors. c) AIRS E - GPM P. d) Reanalysis E-P. Note that while there is good correlation between the satellite and reanalysis E-P, there are also significant magnitude differences. These differences are difficult to reconcile based on water vapor conservation principles because the water vapor is not conserved in reanalyses.

Proposal Plan

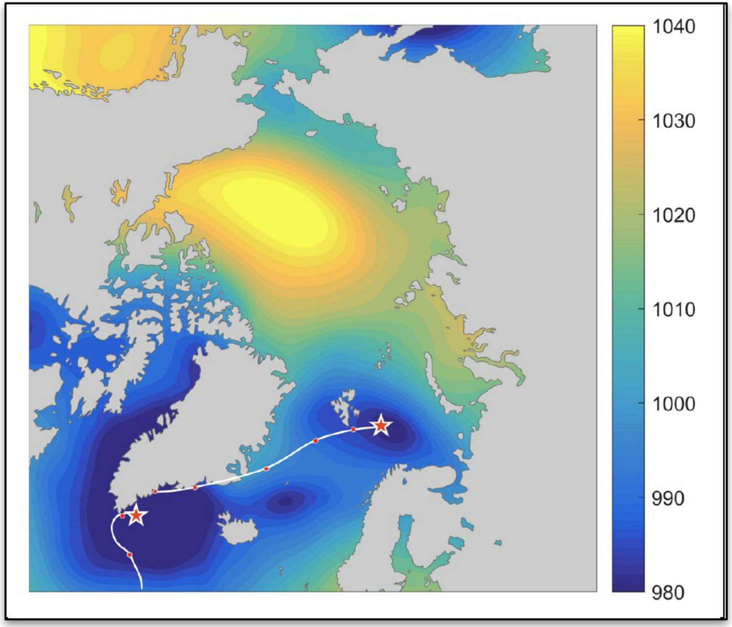
- Lagrangian framework to track Arctic moisture from cyclones and adjust the moisture term at each timestep to observational E-P.
    - provides more intuitive insight into physical processes
    - Integration of GPM precipitation estimates & AIRS based evaporation product into the analysis.
- Backwards integration of reanalysis transport and conservation equation starting at the end of the Arctic cyclone trajectories
- GPM P & AIRS E along the trajectories will be attached to the Lagrangian series and used in an optimal estimation framework to provide the most likely q estimates in agreement with both GPM P and AIRS E.



<u>Outcome:</u> more accurate Arctic cyclone moisture transport and optimally balancing the moisture transport along cyclone tracks, where this could not have been done previously using just reanalysis data alone.

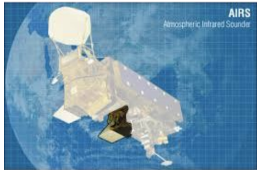
Cyclone Tracker

- Using the Melbourne University cyclone tracking scheme (Simmonds & Murray, 1999) in a Lagrangian framework
  - Computed the Laplacian of the SLP fields, local maxima are identified
  - Must meet the 'concavity criterion' for 'strong cyclones': Laplacian values of 0.7 hpa/degree latitude (Simmonds et al., 2008)
  - Tracking follows Zhang et al. [2004], distances between timesteps are compared with a location probability distribution map
- 6-hourly Sea Level Pressure (SLP) data taken from NASA MERRA-2



December 31, 2014: Location of two strong cyclones (stars) with their previous location in 12-hourly timesteps (red dots) tracked along the white lines going back to December 28, 2014.

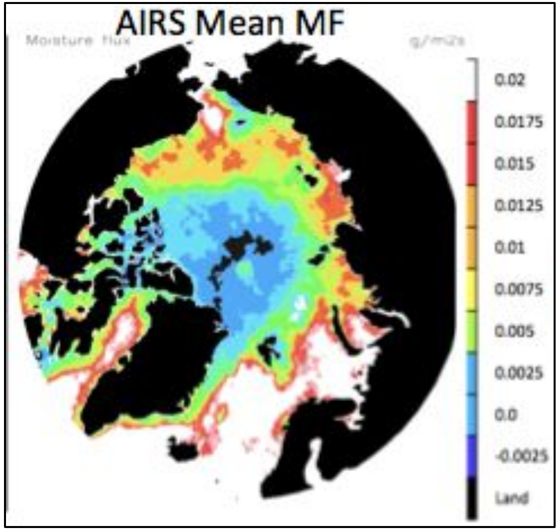
Evaporation with AIRS



Variable	Unit	Source
Skin Temperature	K	AIRS
1000 hPa Air Temperature	K	AIRS
1000 hPa Relative Humidity	%	AIRS
1000 hPA Geopotential Height	m	AIRS
10 m wind speed	m/s	MERRA-2
Ice Concentration	%	SSMI

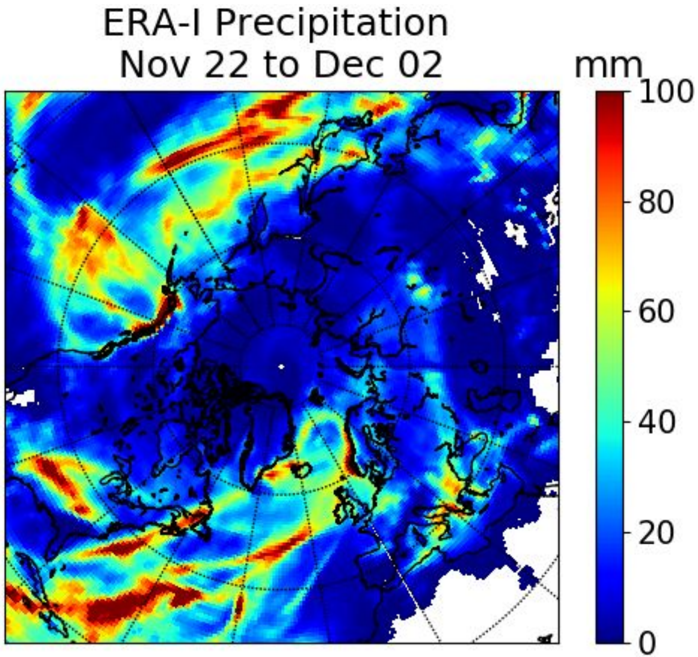
Table of variables used to compute E.

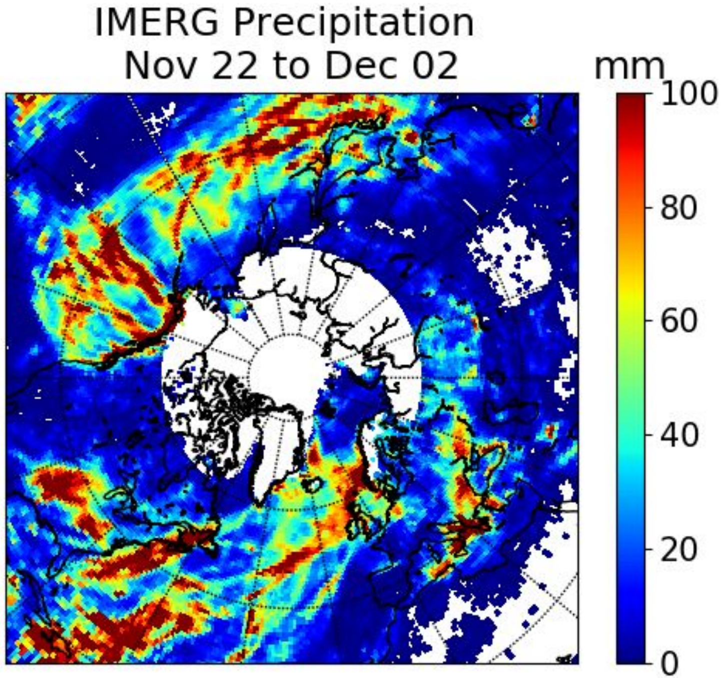
- AIRS is a cross-track high spectral resolution infrared sounder on NASA's Aqua satellite.
- AIRS has daily, global coverage & allows for accurate retrievals under most cloud conditions
    - Important in the Arctic where data is sparse and clouds are prevalent.
- AIRS V6 Ts and q data produce accurate estimates in the Arctic when compared to in-situ data
- E is estimated with the bulk-aerodynamic method using Monin-Obukhov Similarity Theory (MOST) and an iterative calculation scheme based on Launiainen and Vihma [1990] with a few modifications tailored to boundary conditions and roughness of sea ice in the Arctic. [Boisvert et al., 2013]



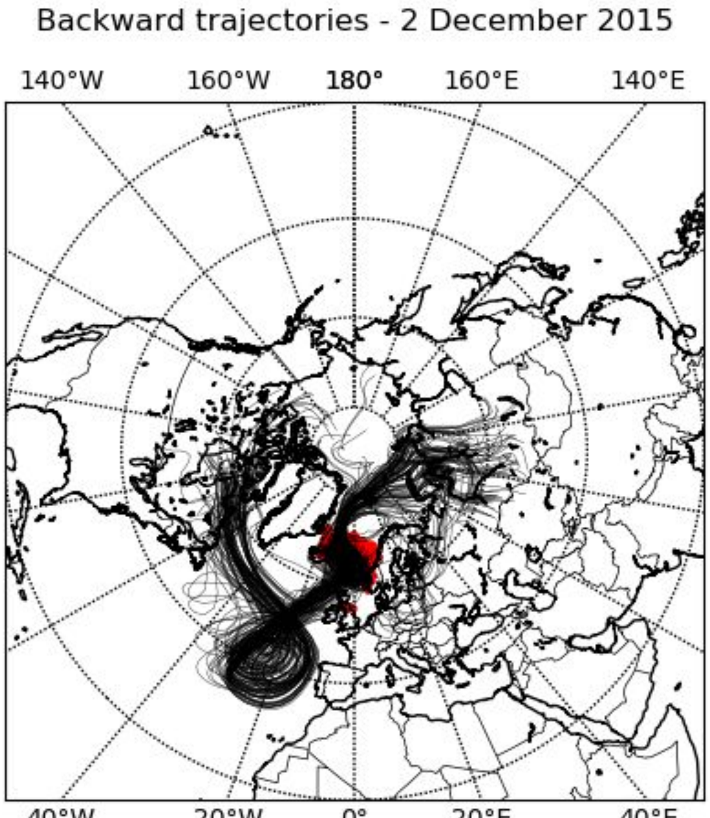
AIRS Mean moisture flux (MF), equivalent to mean evaporation for September 2003-2012. Units are in g/m^2s. Positive values are form the surface to atmosphere.

Precipitation Products

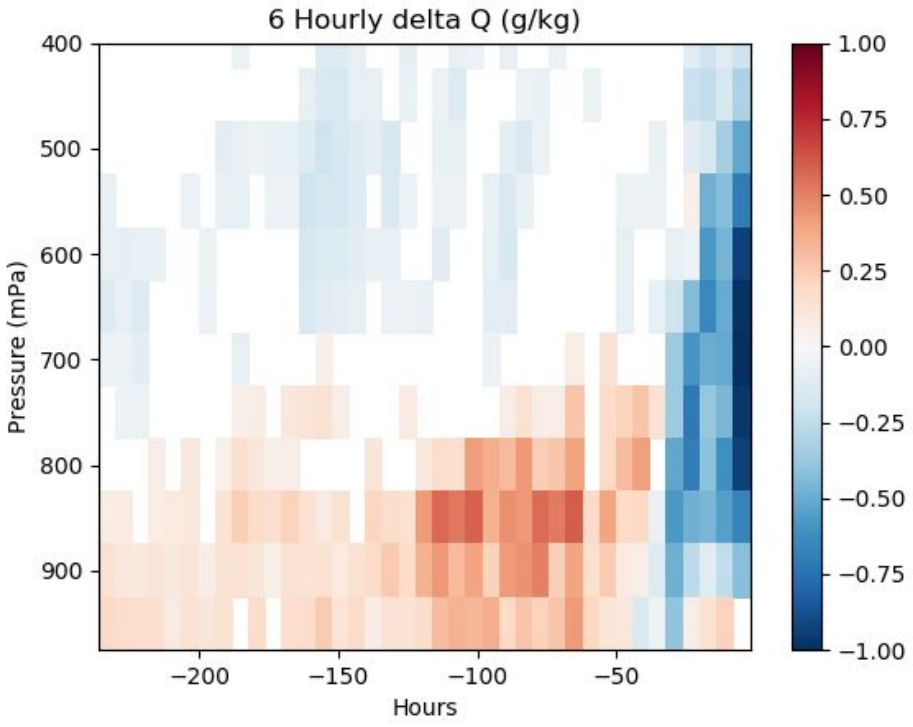




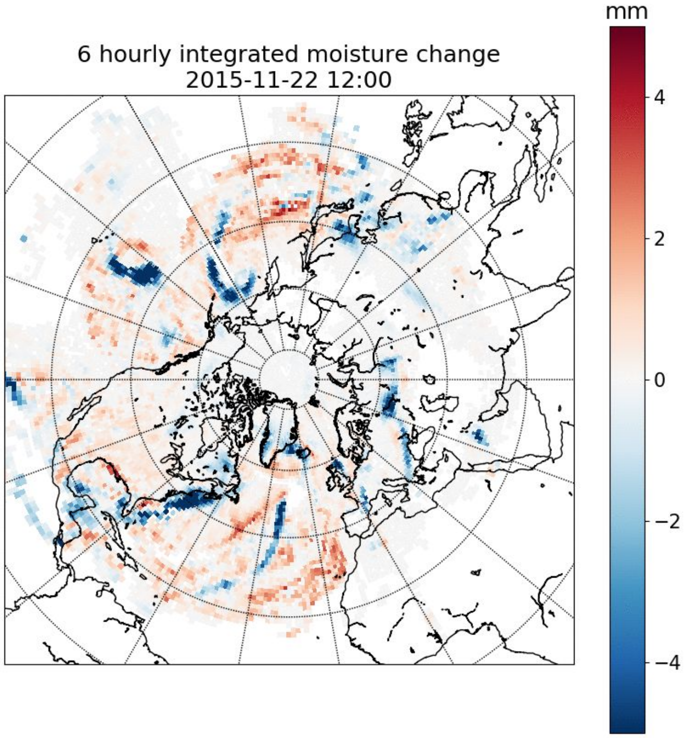
Backwards trajectories



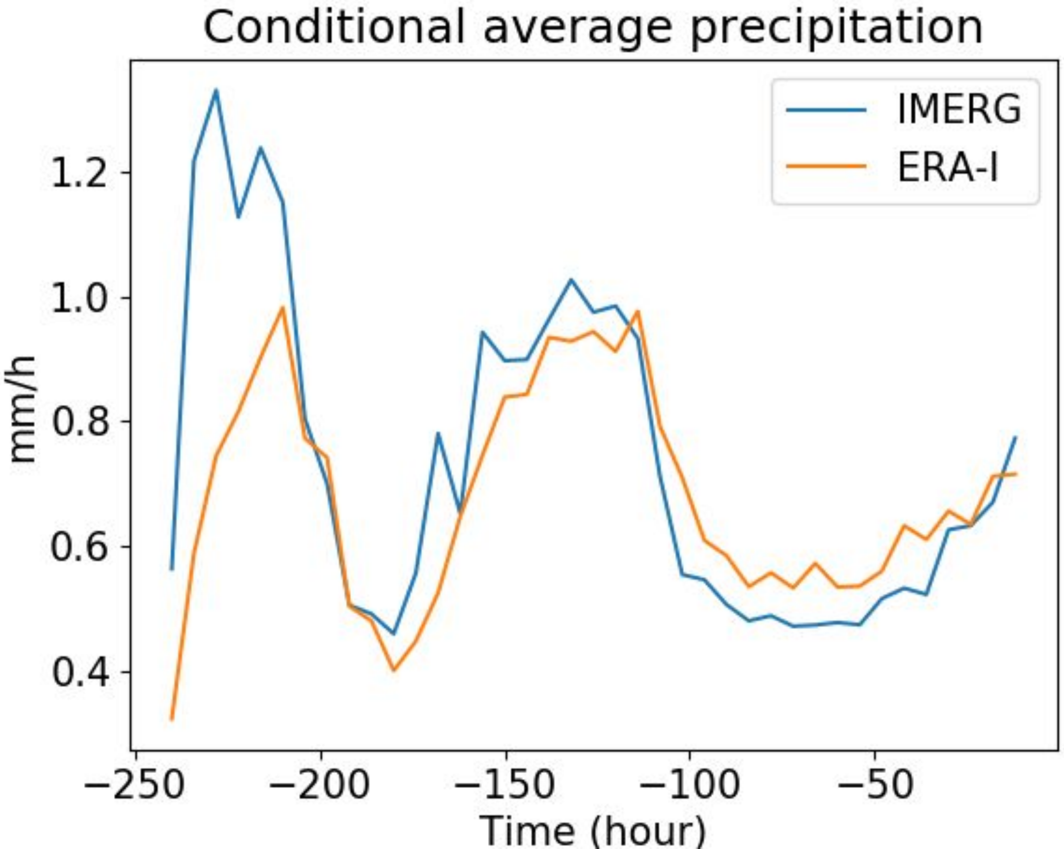
10-day composite moisture changes



Vertically integrated 6 hourly water vapor changes



ERA-5 and IMERG particle-averaged precipitation



Summary

- A Lagrangian transport scheme has been used to track the transport of moisture into a North Atlantic cyclone.
- Reanalysis and IMERG precipitation associated with the tracked atmospheric flows have been analyzed and found to exhibit notable differences.
- A similar analysis will be carried out for the reanalysis and satellite evaporation products.
- The analysis tools are automatized and ready for production
- Systematic differences will be investigated and the water vapor transport dq/dt will be updated using an optimal estimation procedure.

Future Work

1. Development of an Arctic cyclone trajectory database for 2003-2020.

2. Development and implementation of the OELaF in order to track and balance moisture associated with Arctic cyclones.

3. Utilization of NASA GPM and AIRS data to constrain moisture transport from reanalysis along Arctic cyclone trajectories.

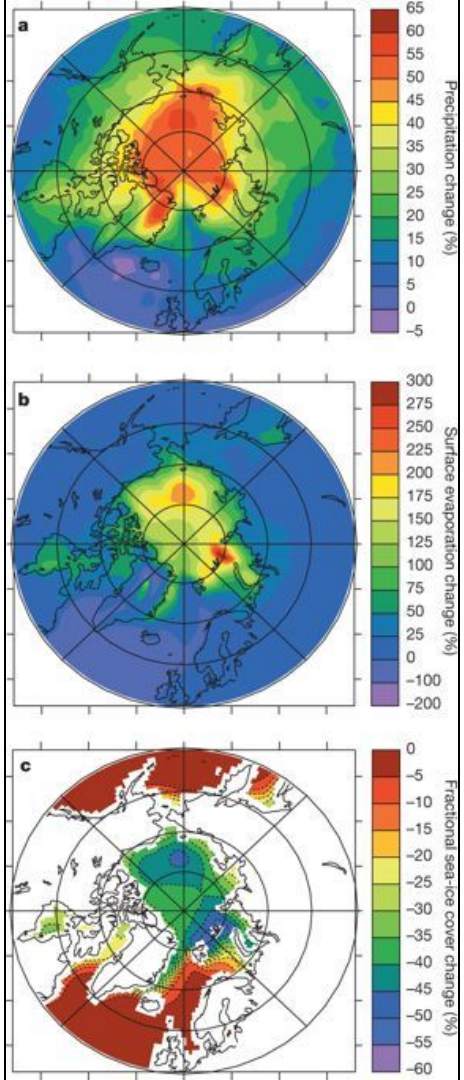
4. Multiple scientific studies dealing with strong cyclone precipitation, behavior (intensity, frequency, phase), and the impact on the Arctic sea ice pack.

5. Improved understanding of precipitation and moisture processes associated with strong cyclones in the Arctic.

Backup slides

Implications for the future

- Future climate scenarios: Global climate models project that Arctic cyclone activity and precipitation will increase [IPCC AR5 Stocker et al., 2013].
- How will moisture transport associated with cyclones change in the future with increased warming?
  - Warming temperatures are also associated with a moistening of the atmosphere leading to perhaps more intense P associated with cyclones [Toreti et al.; 2013; Kharin et al., 2013]
  - Larger moisture gradients between lower and higher latitudes leading to enhanced moisture transport into the Arctic via cyclones [Barnes and Polvani, 2015]



Changes (based on the difference between the means over 2091–2100 and 2006–2015) in precipitation (a), surface evaporation (b) and sea-ice extent (c), for the strong forcing scenario (RCP8.5). Taken from Bintanja and Selten, 2014 Nature.