Using AIRS data to estimate sublimation/deposition on the Greenland ice sheet:

Comparisons and Climatology

Dr. Linette Boisvert

ESSIC/ NASA-GSFC

Previous Work with AIRS

Geophysical Research Letters

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The Arctic is becoming warmer and wetter as revealed by the Atmospheric Infrared Sounder

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... Environmental
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Key Points:
- AIRS data reveal a warmer and wetter Arctic
- Arctic atmospheric changes drive melt onset a

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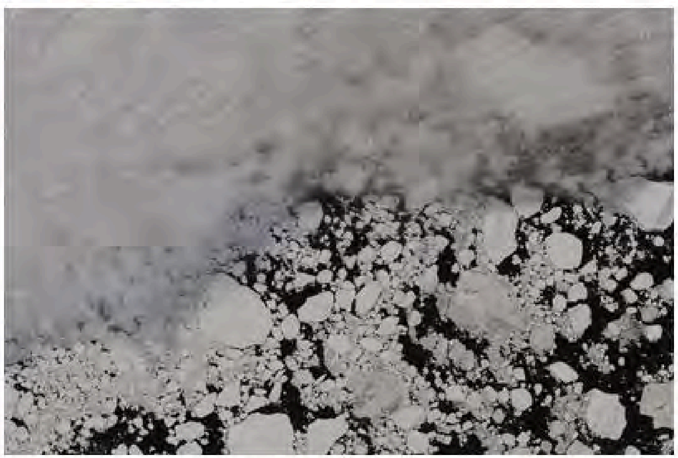
As sea ice shrinks, the Arctic gets warmer and wetter, study finds

Alaska Dispatch News

Yereth Rosen | August 9, 2015



This June 21, 2014 satellite image shows sea ice in the Greenland Sea
NASA Earth Observatory

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The Arctic became warmer and wetter since the beginning of the 21st century, a self-reinforcing trend likely to continue because it is linked to sea-ice melt and more persistent open-water conditions in the world's northern ocean, a newly published study concludes.

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Data from NASA shows that average surface temperatures across the Arctic Ocean increased an average of 0.16 degrees Celsius per year from 2003 to 2013, and air temperatures rose 0.09 degrees Celsius annually over the same period, says the study, published online in Geophysical Research Letters.

EARTH The Science Behind the Headlines

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Arctic climate change marked by warmer, wetter conditions

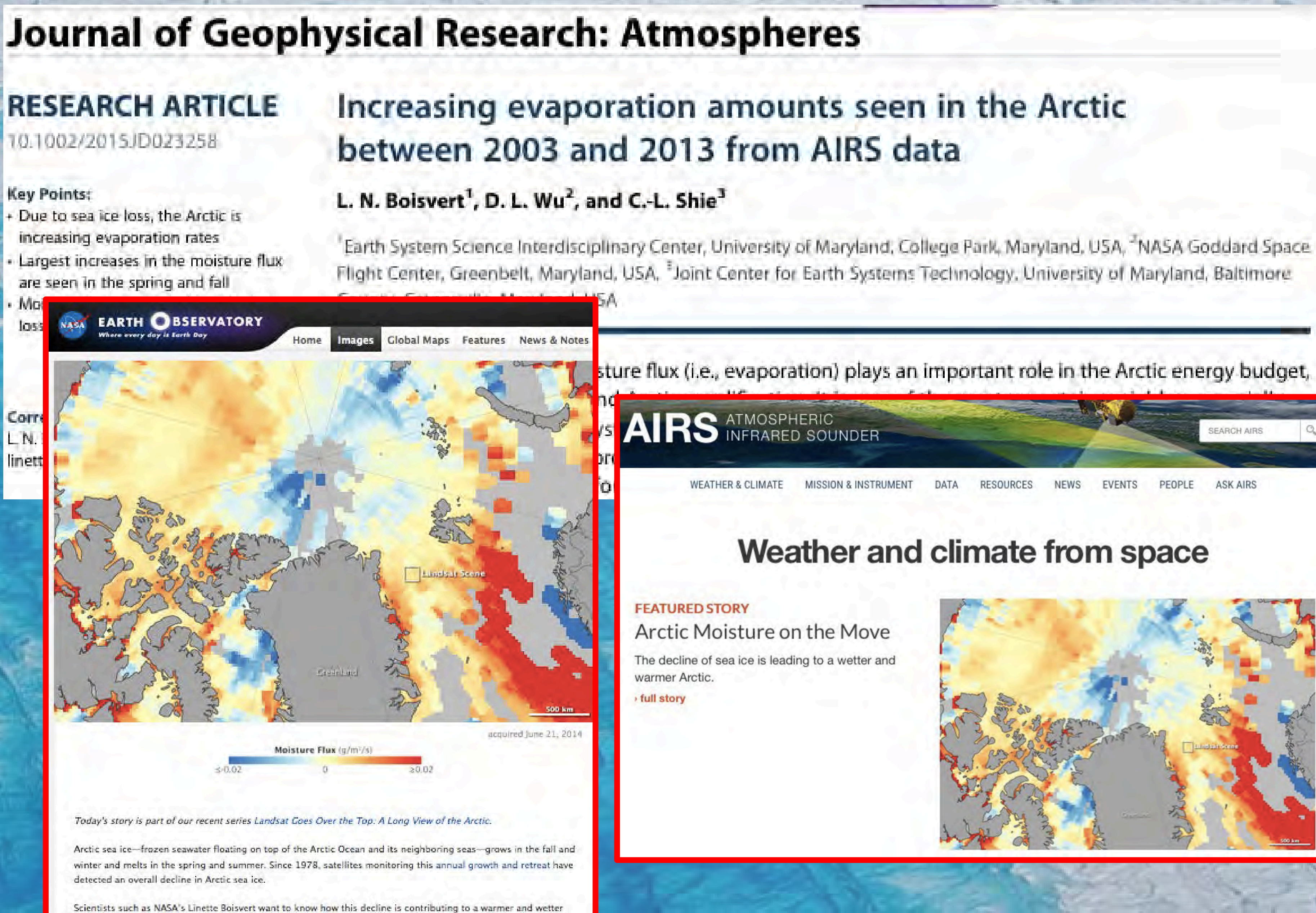
New satellite data show that the skies over the Arctic Ocean are warming, which is increasing humidity and cloud cover over the region. Credit: NASA/Kathryn Hansen

At least since satellite observations began four decades ago, climbing temperatures have chipped away at Arctic sea ice, causing earlier spring melting and later autumn freezing. Because ice reflects more sunlight than water does, shrinking sea-ice cover means that Arctic waters soak up more solar energy, which affects climate both regionally and globally. Now, a new study has documented how Arctic warming leads to wetter air and increased cloud cover, particularly during autumn and winter, which spurs even more warming in a self-reinforcing cycle.

Researchers analyzed the first decade's worth of data collected over the Arctic by the Atmospheric Infrared Sounder (AIRS) aboard NASA's Aqua satellite between 2003 and 2013. During that period, average air temperatures above the Arctic Ocean rose by 1.5 degrees Celsius while the temperature at the sea and ice surface rose by 2.5 degrees. Evaporation from the ocean surface increased as well, adding an average of 0.81 kilograms of water vapor per square meter to the lower atmosphere, which increased the humidity in the region.

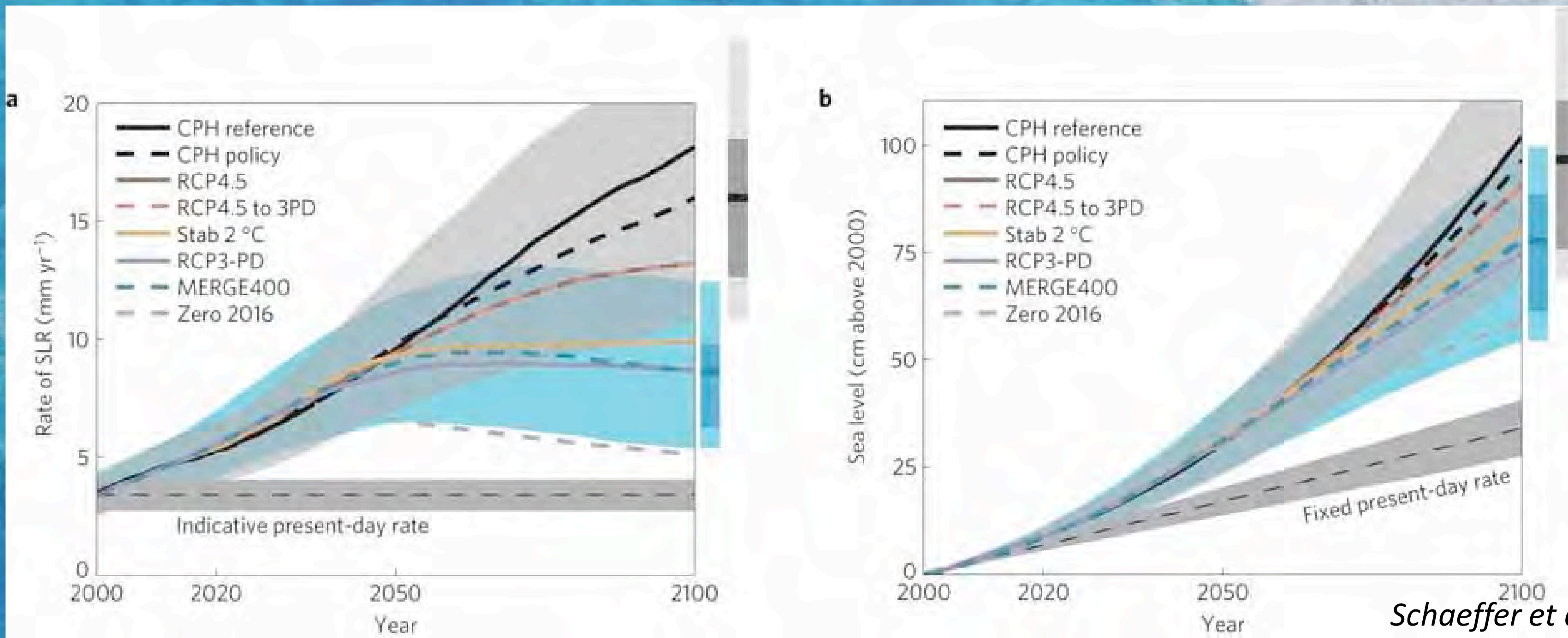
Warmer air and ice-surface temperatures mean that sea ice typically begins melting earlier in the spring than it once did, which lengthens the portion of the year in which much of the Arctic Ocean is ice-free. This causes the Arctic to absorb more sunlight, adding heat to the ocean and causing the increased evaporation, reported Linette Boisvert, a research scientist at NASA's Goddard Space Flight Center in Greenbelt, Md., and Julienne

Previous Work with AIRS



Sea Level Rise

- Melting of the ice sheet will cause global sea level rise anywhere between 3 to > 7 meters
  - Total amount is uncertain (~30% i.e. *Rignot et al., 2011*)
  - Lack of in situ observations
  - Harsh environment
  - Difficulty in measuring snowfall amounts, sublimation and glacial runoff



Schaeffer et al., 2012

- Way to estimate past and present sea level rise is through mass loss
- **Greenland mass loss**
  - **1990-2008**: attributed equally to
    - Solid discharge through outlet glaciers
    - Enhanced runoff from surface melt
  - **2008-present**: dominated by surface processes

Surface Mass Balance (SMB)

SMB = Precipitation – Sublimation - Runoff

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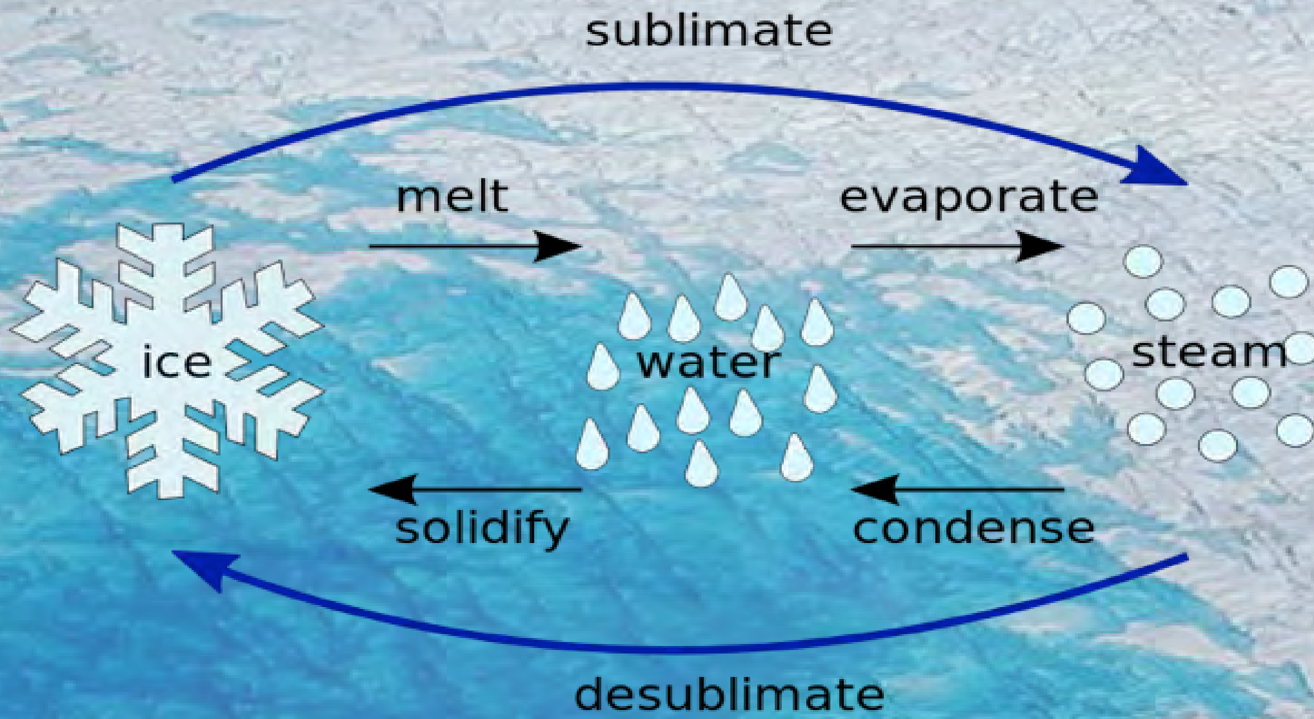
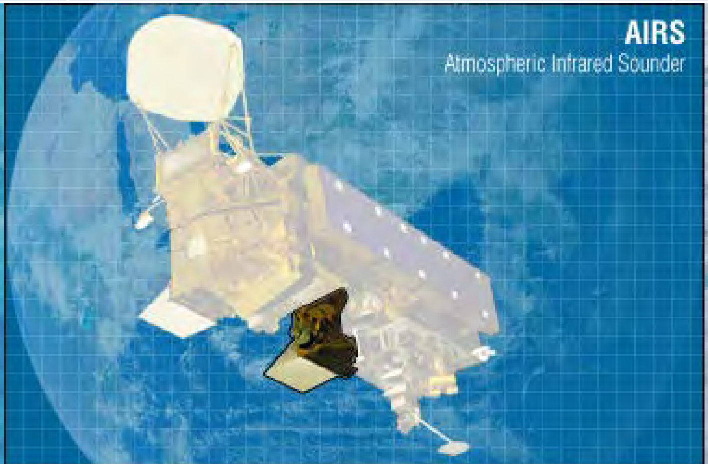


- Want to reduce the uncertainty of this term using improved data and methods
  - Use modified sublimation model from *Boisvert et al., 2013; 2015*
  - Use AIRS version 6 level 3 data
  - Compare with in situ measurements
  - Compare with a regional climate model

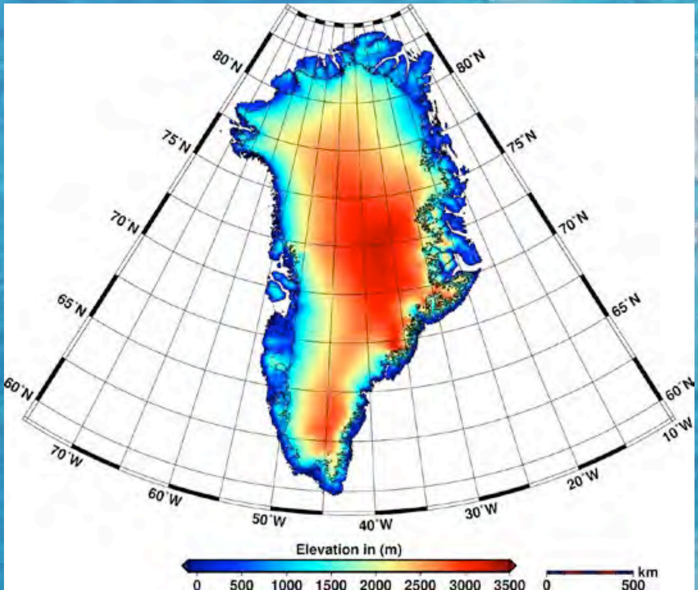
Data

Data Source	Variable	Variable Height	Unit
AIRS	Skin Temperature	Surface	K
AIRS	Air Temperature	Blended product from: 1000, 925, 850, 700 & 600 hPa	K
AIRS	Relative Humidity	Blended product from: 1000, 925, 850, 700 & 600 hPa	%
AIRS	Geopotential Height	Blended product from: 1000, 925, 850, 700 & 600 hPa	m
ERA-Interim	Wind Speed	10 m	m/s
GLAS on IceSat	Digital Elevation Model	Surface	m
MISR	Surface Roughness	Surface	cm



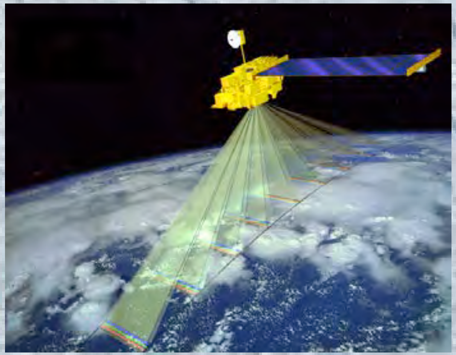
Data: Blended AIRS products

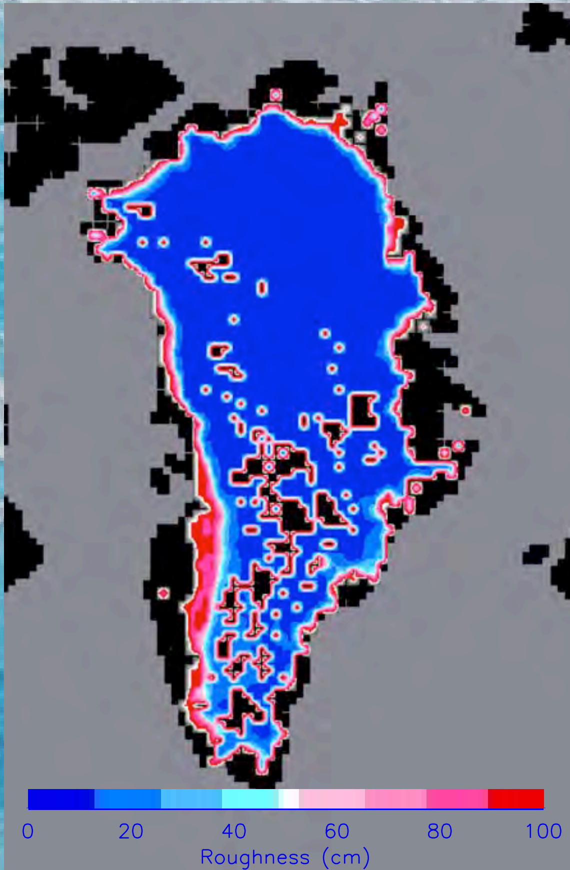
- Due to high and changing elevations of the ice sheet we can't take lowest hPa values of temperature and humidity
- For each Pixel:
  - Find at what hPa level the geopotential height is higher than the elevation of the ice sheet (GLAS DEM)
  - Use that hPa level value of temperature, humidity and geopotential height
  - Compute new height above surface = geopotential height - DEM



Data: Surface Roughness Product

- Surface roughness is created by glacial dynamics, and surface-atmospheric interactions
  - Affects boundary layer processes through aerodynamic roughness length
- Created from Multi-angle Imaging SpectroRadiometer (MISR)
  - Using +/- 60 degree angles and nadir calibrated against ATM flight lines.
  - Data available for March-July (sunlit months) for 2003-2014





Sublimation Model

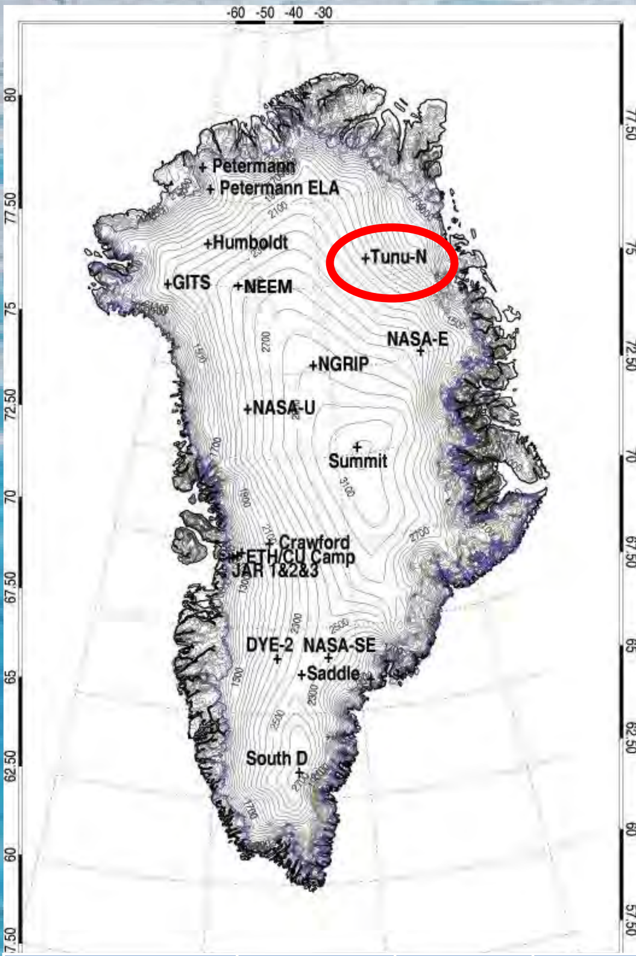
$$E = \rho\, C_{Ez}\, S_r\, (\, q_{s,i} - q_z\,)$$

- Estimated using Monin-Obukhov Similarity Theory and an iterative calculation scheme based on *Launiainen and Vihma* [1990].
- **Modifications**:

  1.) Use the flux algorithm of *Grachev et al* [2007] for stable conditions over ice.

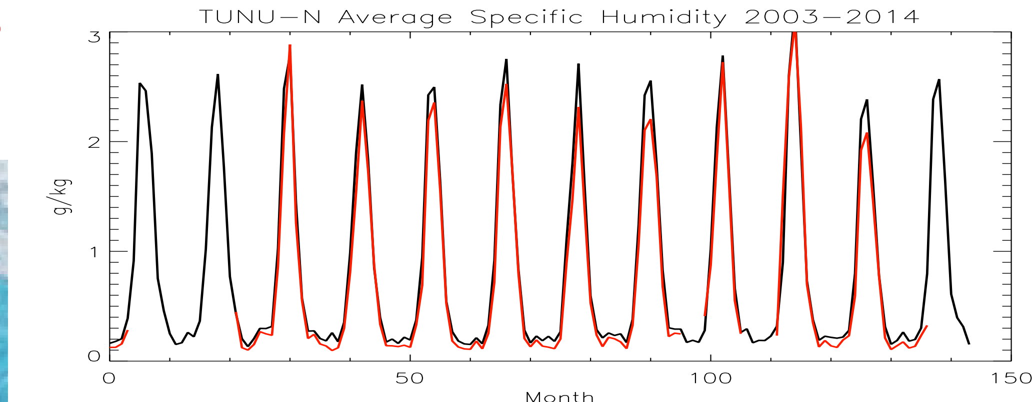
  2.) Use the effective wind speed, which includes a parameter for gustiness that is different in stable and unstable boundary conditions [*Andreas et al.*, 2010].
- The iterative method allows for the use of input variables (i.e. air temperature, relative humidity and wind speed) to be measured at varying heights above the surface.
  - Uses input variables and together with the information on their observed heights (i.e. the surface elevation minus the geopotential height), determines what they would be at the reference height, which in this case we take to be 2 meters.

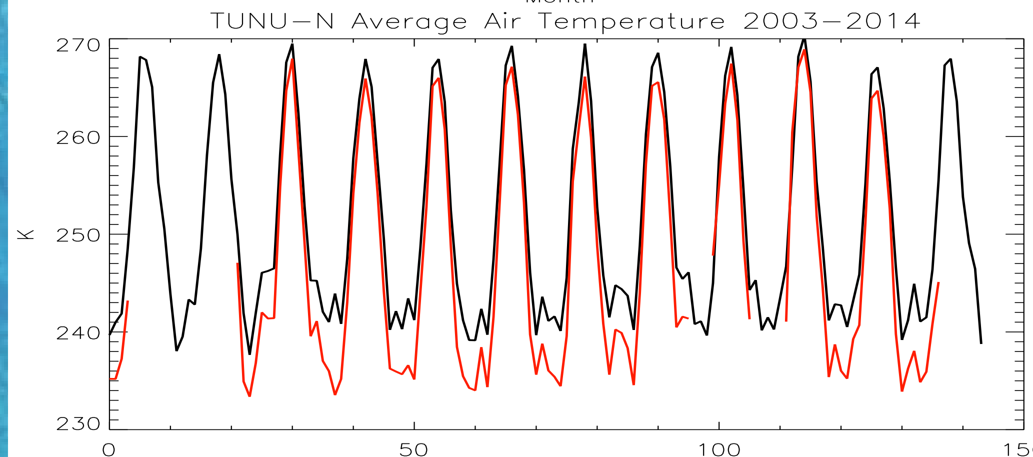
Comparison with GC-Net Data

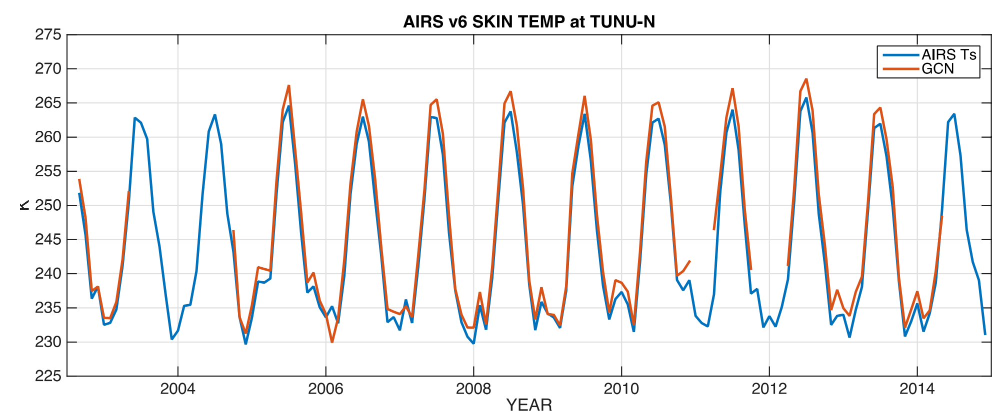


GC-NET

AIRS

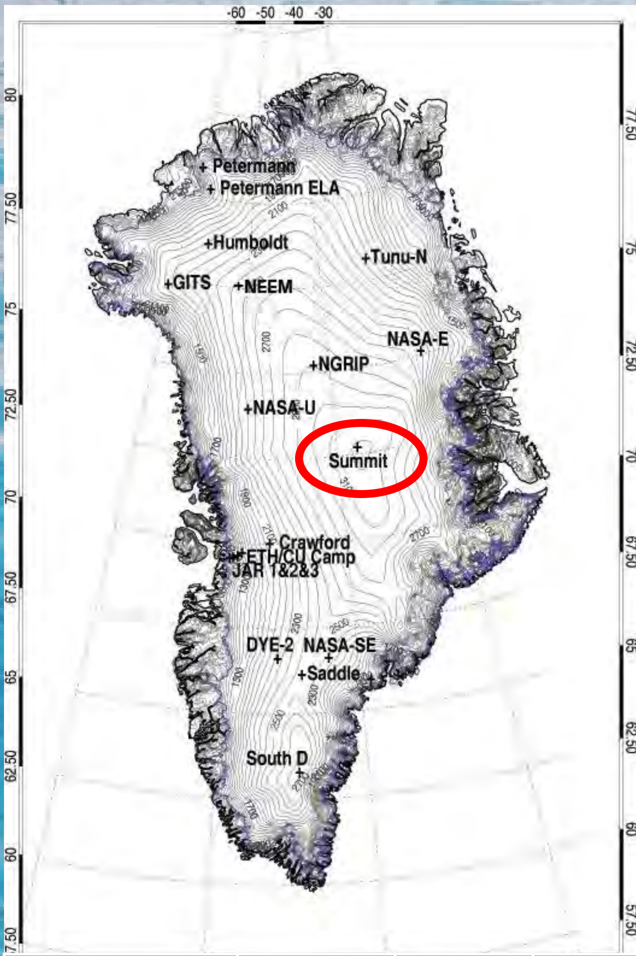






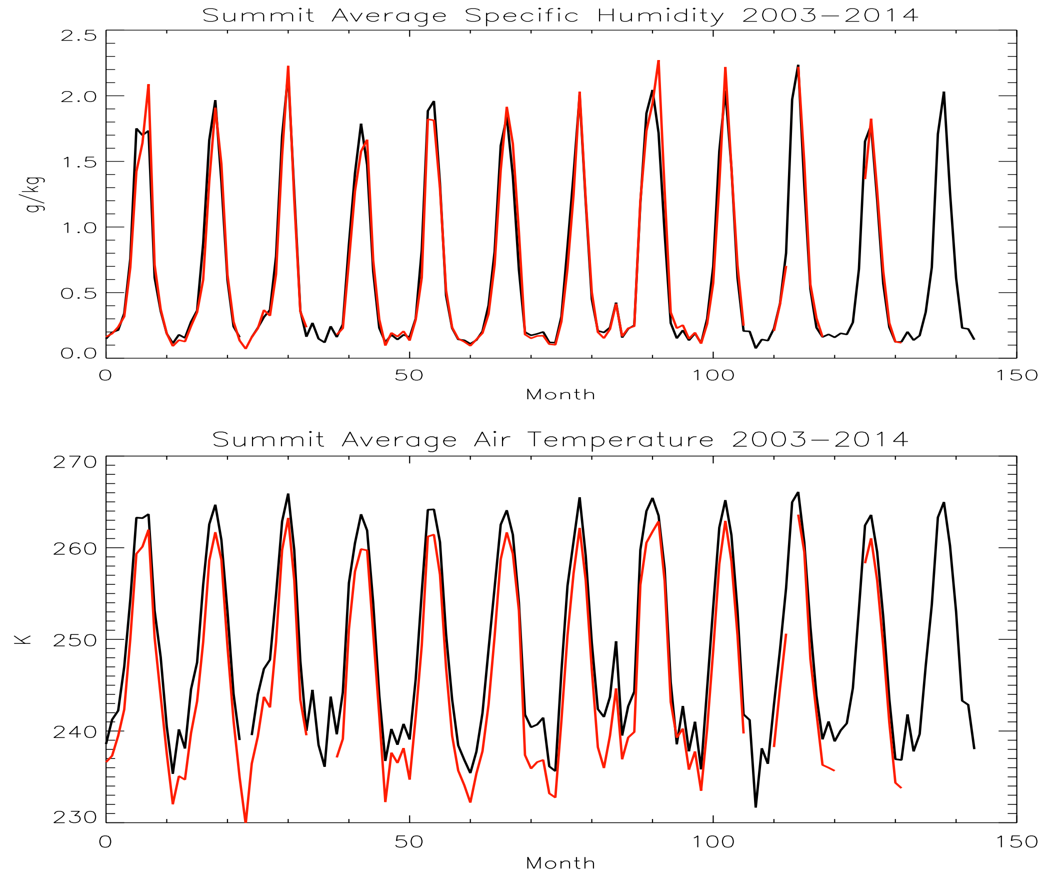
Tunu-N	Mean	STD	Bias	RMSE
Skin Temp	244.28	11.28	-1.75	2.01
Air Temp	251.29	10.28	1.54	3.15
Spec. Hum	0.84	0.86	-0.107	0.067

Comparison with GC-Net Data



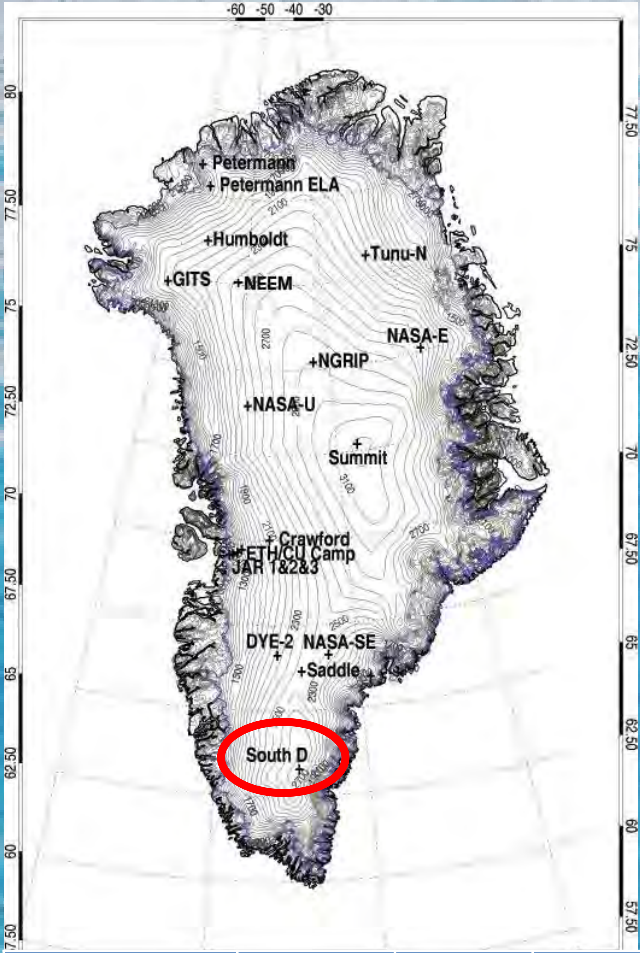
GC-NET

AIRS



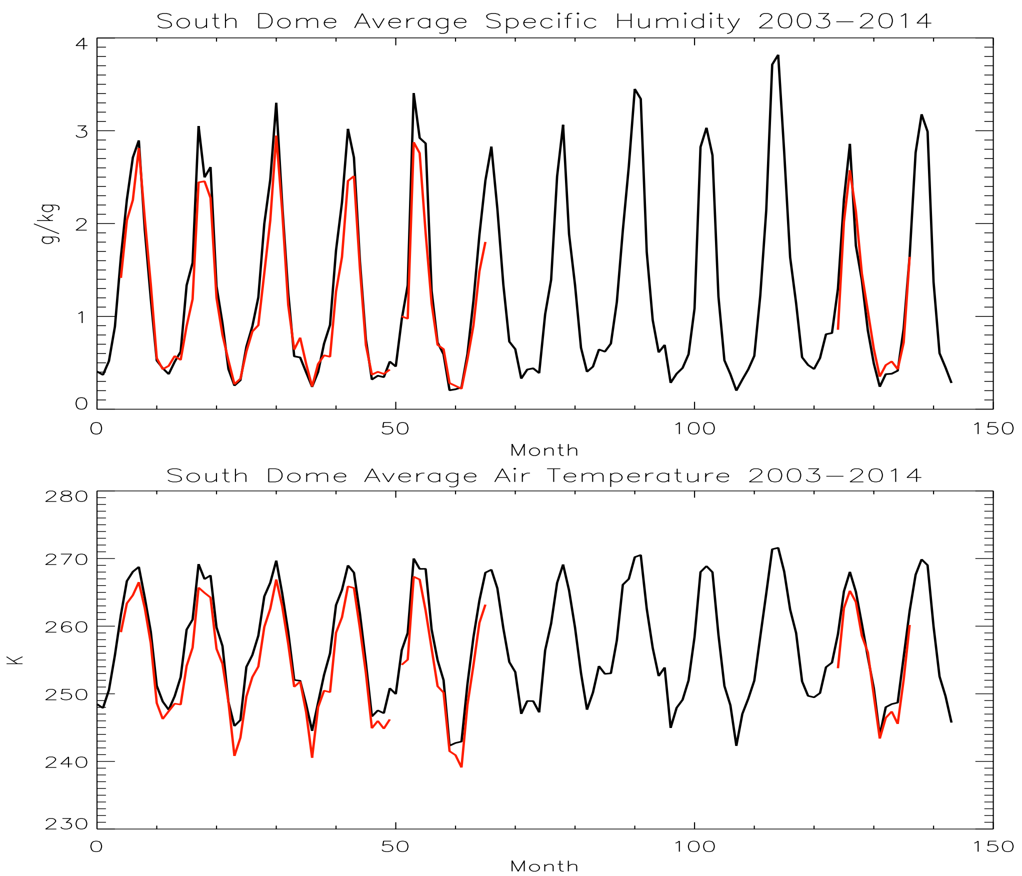
Summit	Mean	STD	Bias	RMSE
Skin Temp	243.09	9.84	-1.40	2.00
Air Temp	248.85	9.86	3.01	3.26
Spec. Hum	0.66	0.64	0.020	0.15

Comparison with GC-Net Data



GC-NET

AIRS



South D.	Mean	STD	Bias	RMSE
Skin Temp	253.39	8.01	-0.79	2.00
Air Temp	257.00	8.16	2.68	3.01
Spec. Hum	1.29	0.99	0.154	0.28

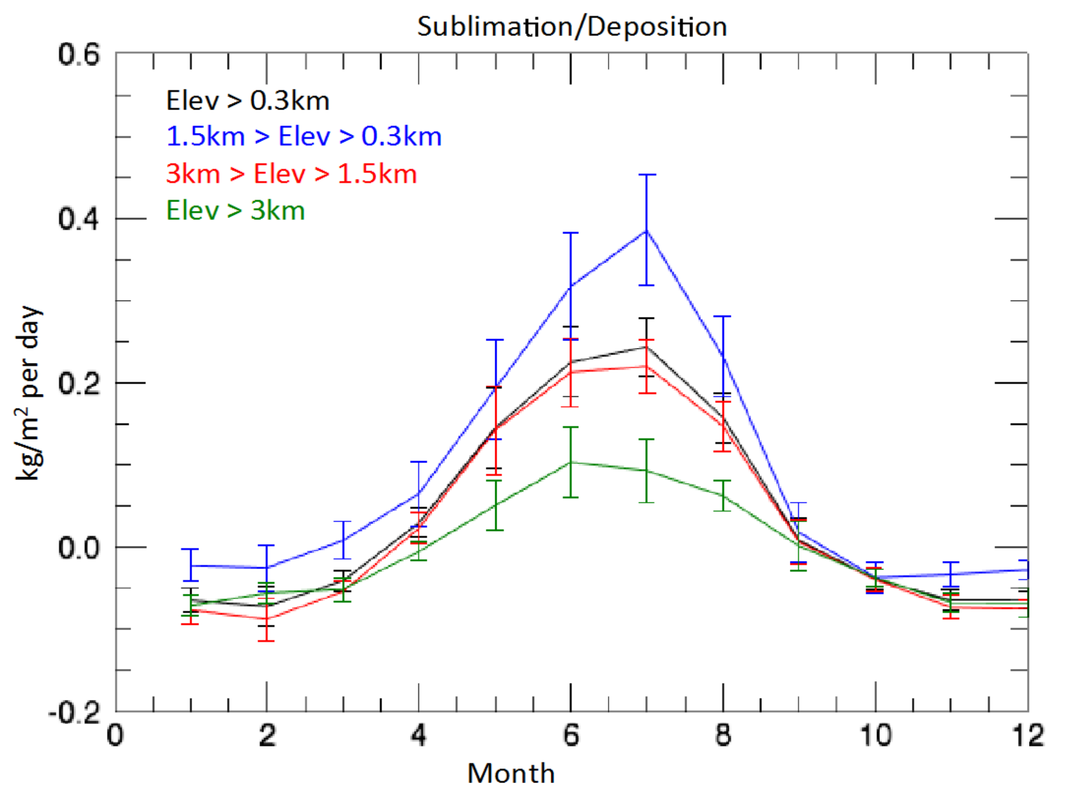
Error Analysis

- Point vs 25km^2 pixel size comparisons
- We assumed that the variables are uncorrelated, and this has allowed for us to make an error estimate by using:

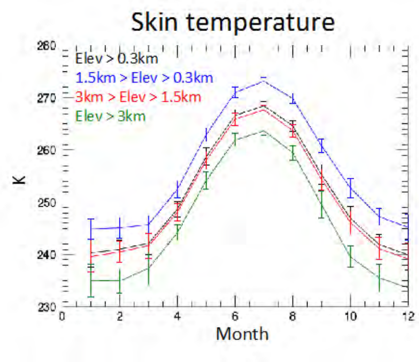
$$\sigma_E^2 = \sum \sigma_x^2 \left(\frac{dE}{dx}\right)^2$$

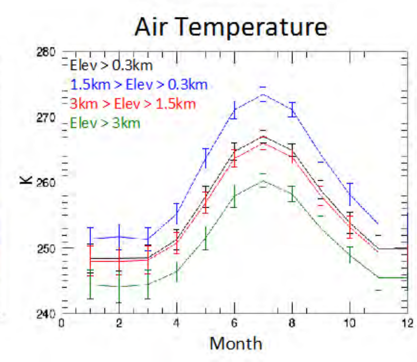
- Error of the sublimation/deposition for the GrIS;
  - **3.53 × 10^{-3} kg m^{-2} day^{-1}, or 12.6%.**
  - Small when compared to the range of variability during 2003–2014.

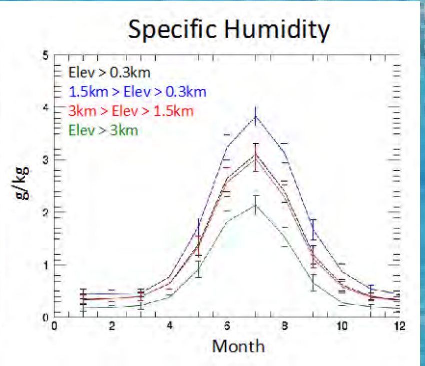
Sublimation Climatology



- Largest sublimation & range in summer, largest deposition & smallest range in winter.
  - More variability with clouds, storm tracks, influence from ice-free ocean
  - Largest sublimation near edge of ice sheet (lower elevations)







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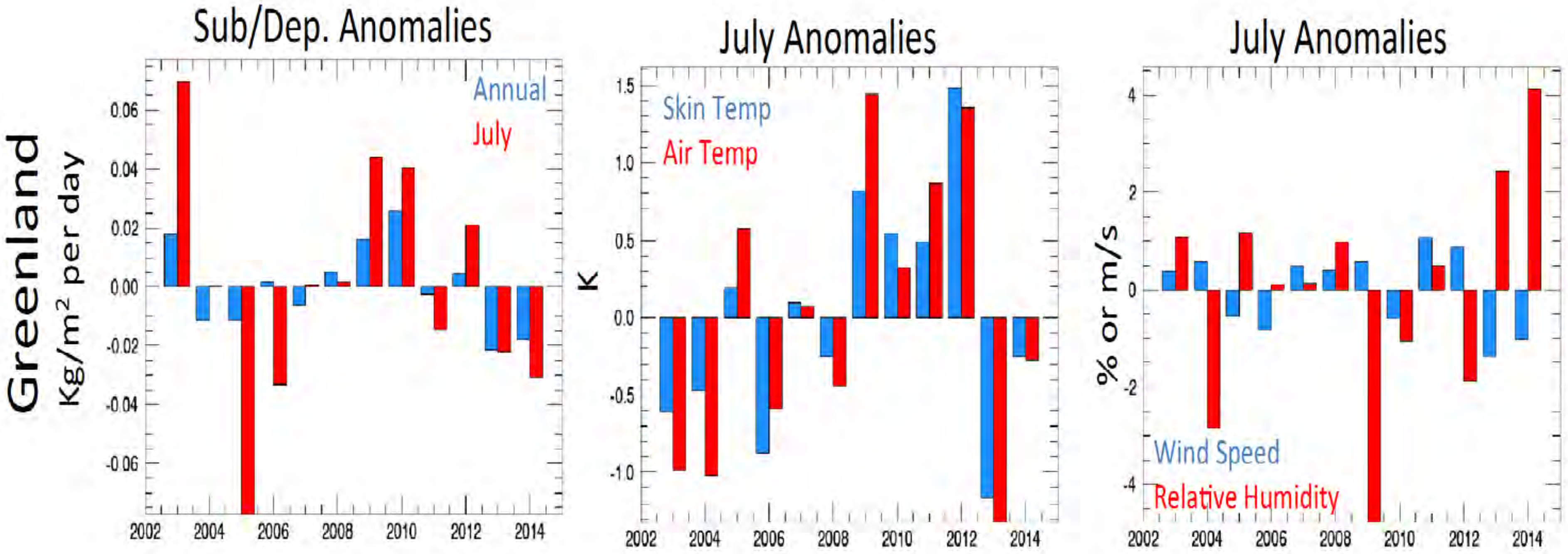
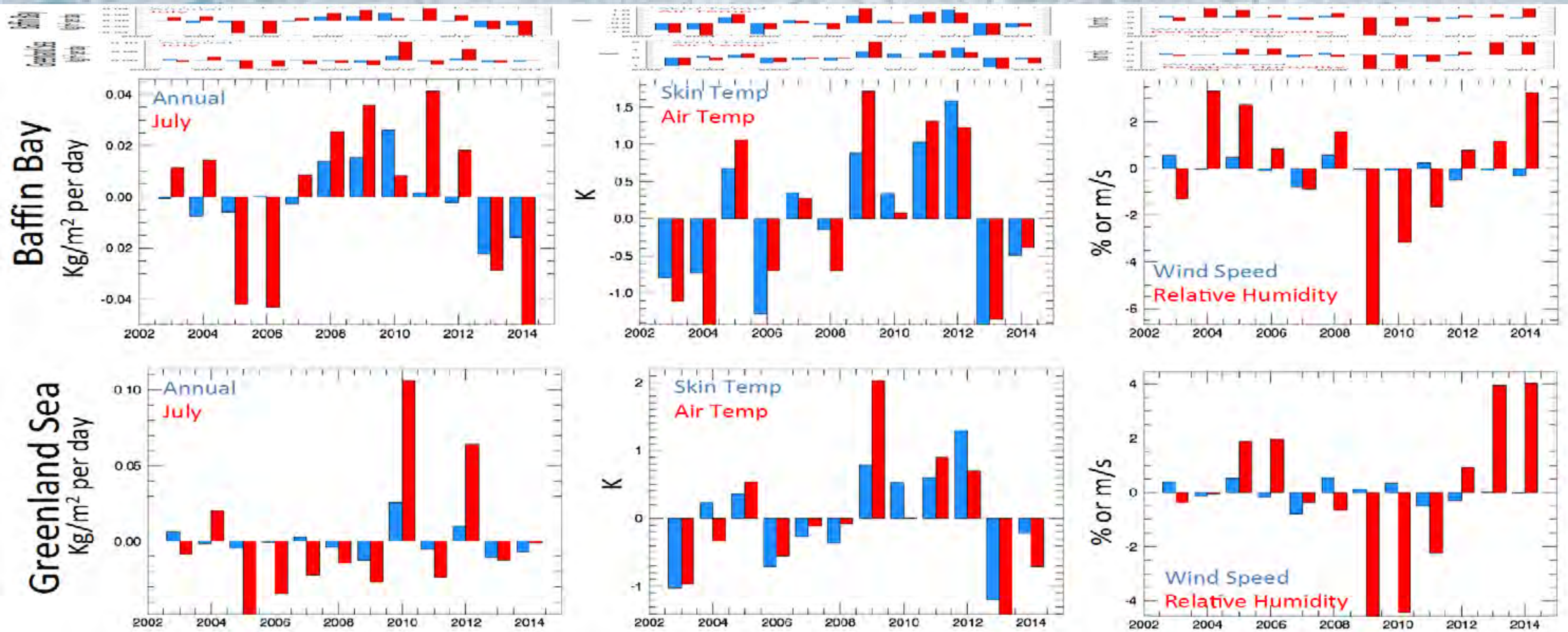
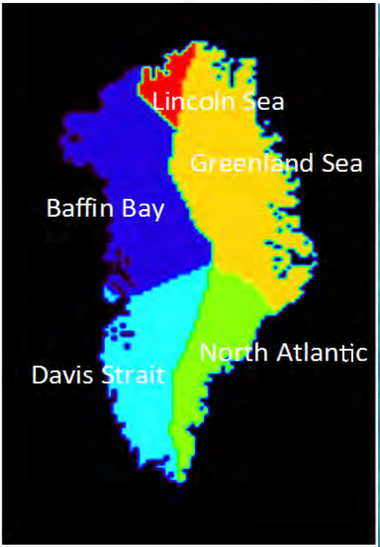


- Positive anomalies: 2003,2009,2010,2012
  - Low humidity, high skin and air temps.
- Negative anomalies: 2005,2006,2011,2013,2014
  - High humidity, low skin and air temps.

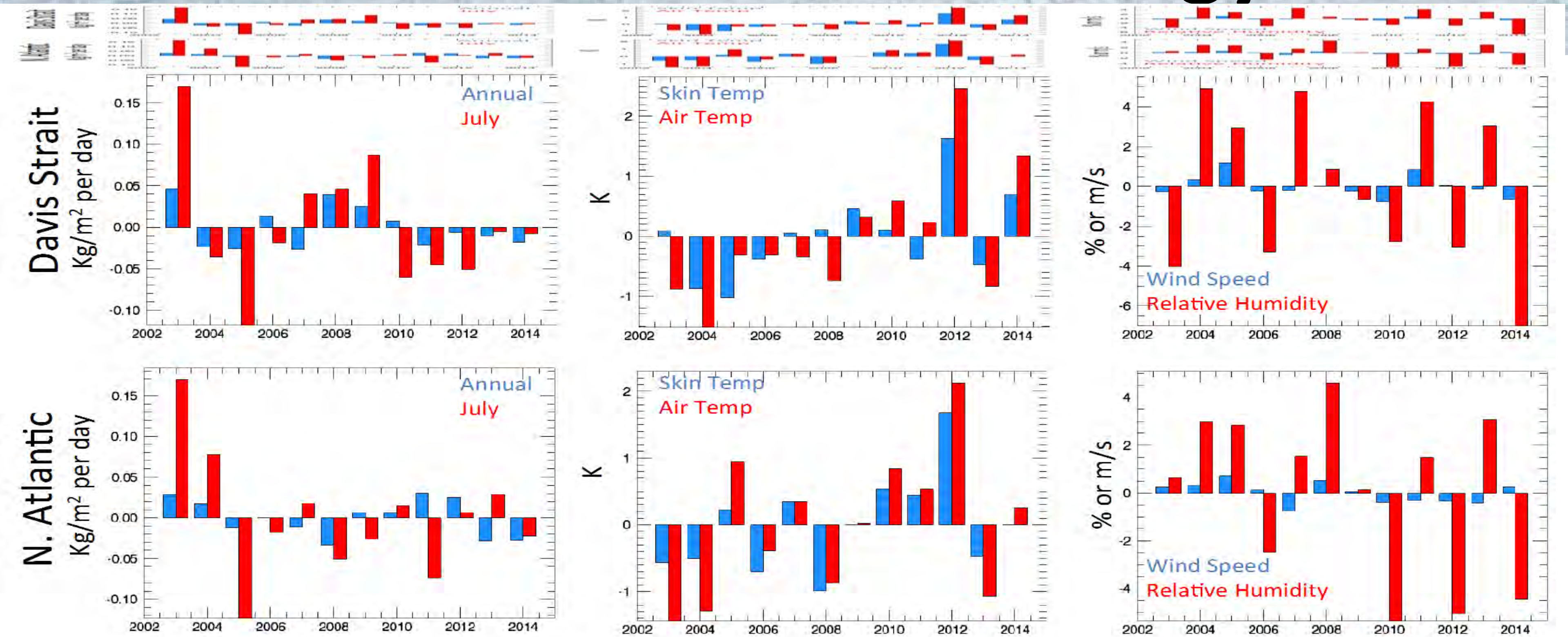
Sublimation Climatology

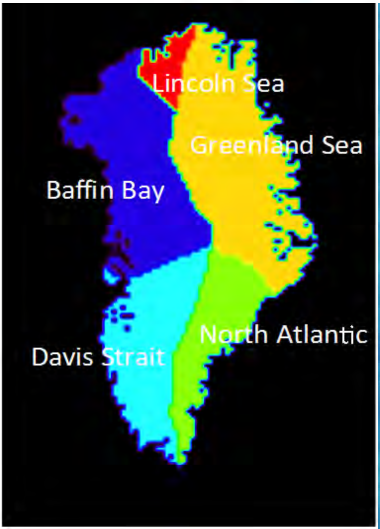




- Northern regions similar atmospheric anomalies
  - Since 2010 dramatic increase in humidity

Sublimation Climatology



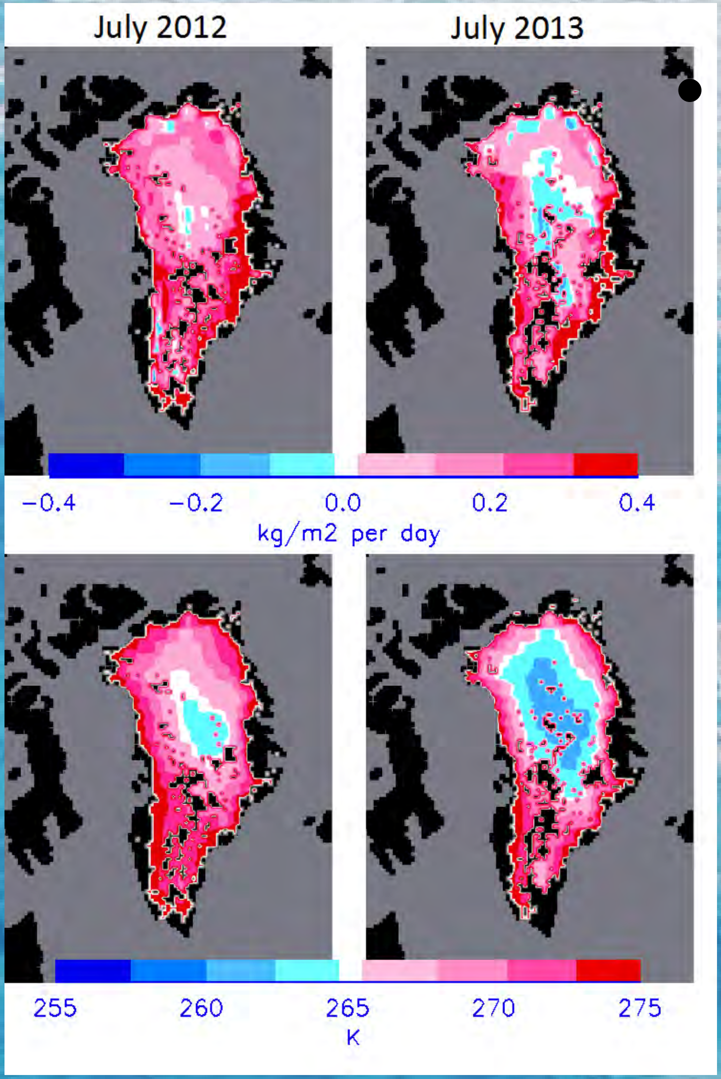


- Southern regions similar atmospheric anomalies: warming temps 2003-2012
    - Affected by storm tracks, and surface melt each year

High surface melt (July 2012) vs. Low surface melt (July 2013)

2012

- NAO: Negative (anomously low)
  - Warmer temperatures, less clouds = lower humidity
  - 1.53 Gtons more lost to sublimation
  - Large mass loss



2013

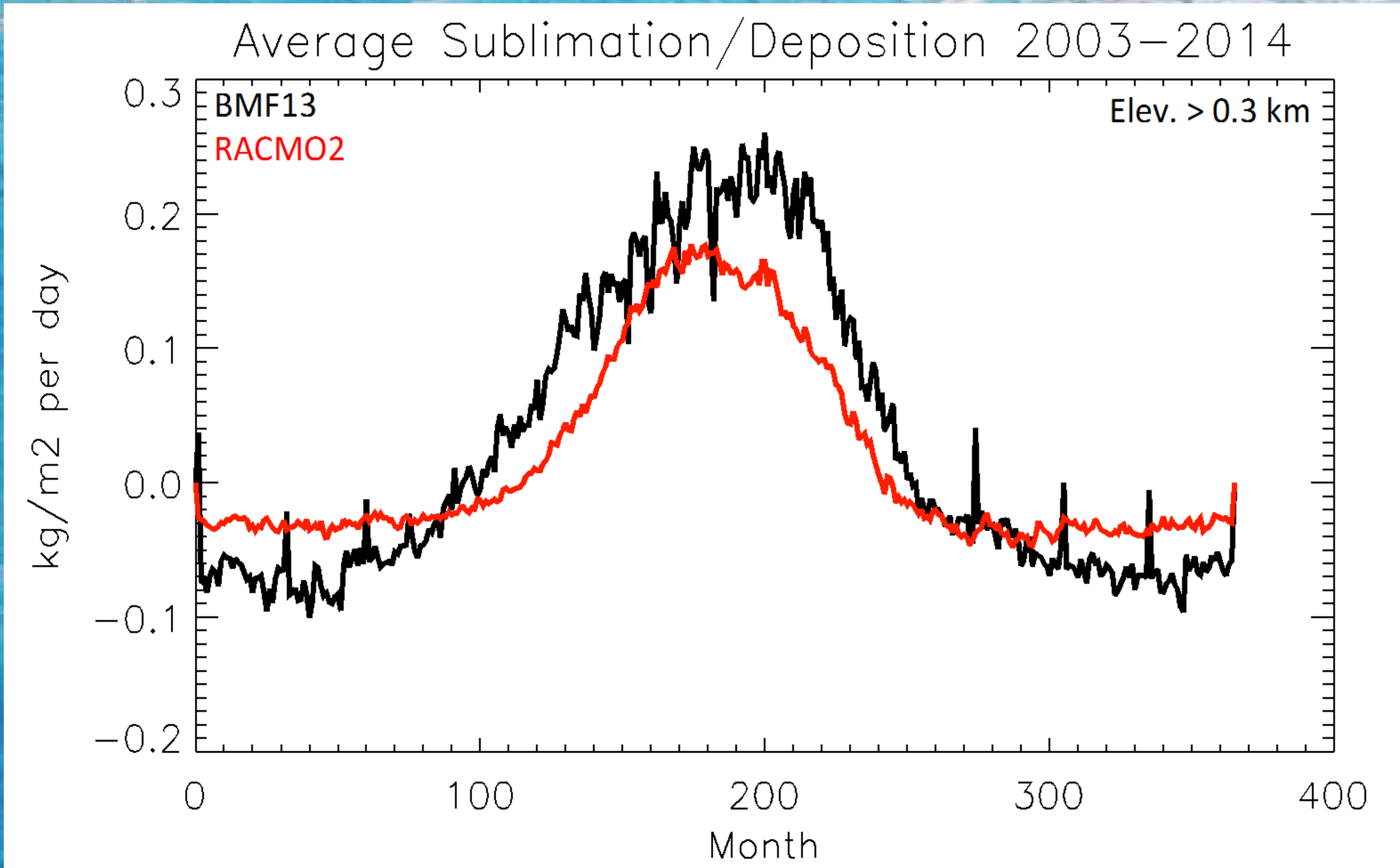
- NAO: Positive
  - Cooler temperatures (1K), more precipitation = higher humidity (3%)
  - Less sublimation
  - Smaller mass loss

Comparison with RACMO2

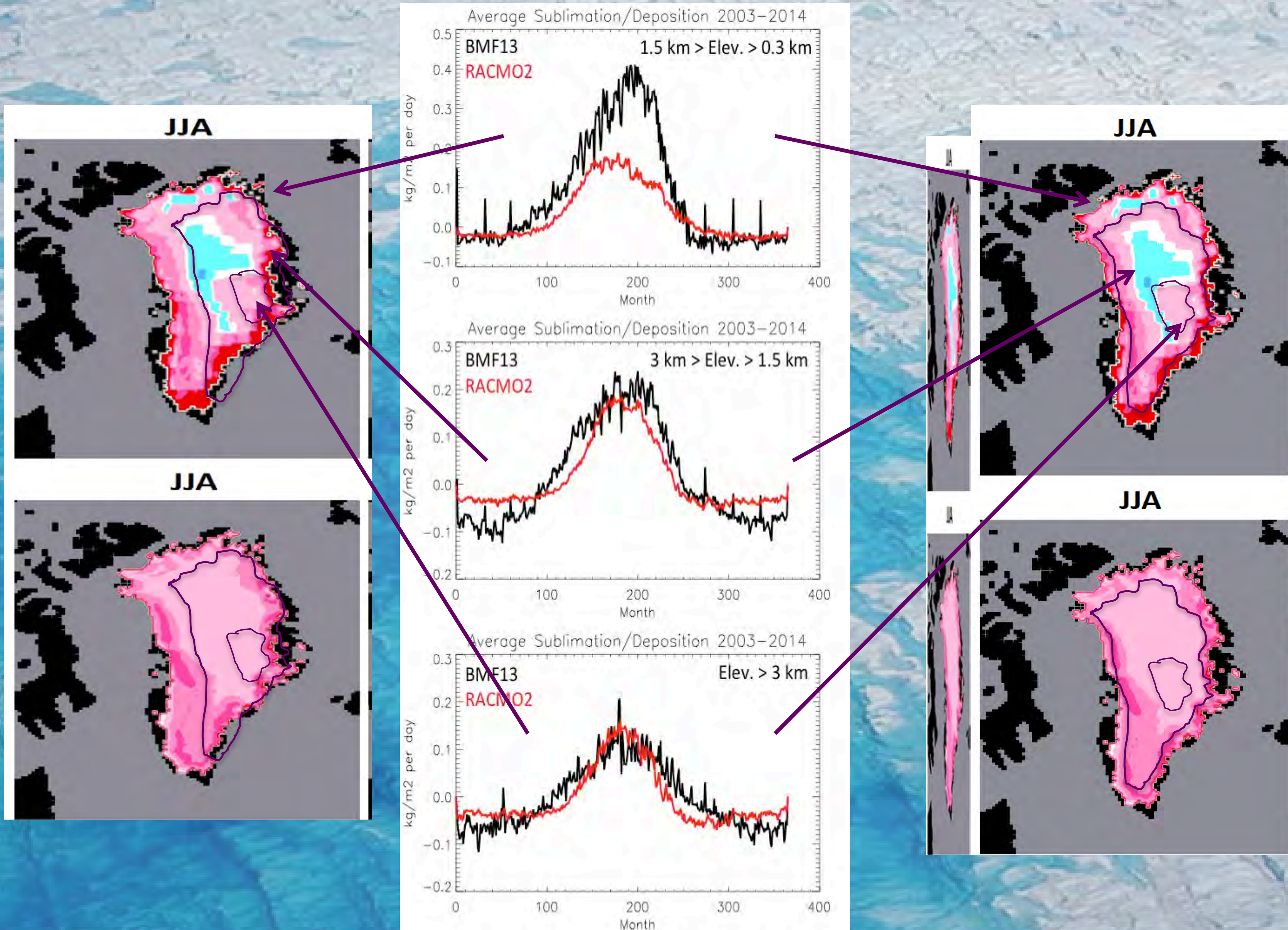
- In the Polar Regions, where in situ observations are sparse, near-surface data products are not guaranteed to be more accurate than a satellite product
- **Regional Atmospheric Climate MOdel version 2 (RACMO2)**
  - Combines dynamics from HIRLAM and physical processes from ECMWF
  - Forced by ERA-Interim at lateral boundaries
- RACMO2 is capable of simulating the Greenland ice sheet temperature, wind speed [*Ettema et al.*, 2010a] and SMB [*Noel et al.*, 2014], but a detailed evaluation of sublimation has been hampered by the limited availability of observational data.

Comparison with RACMO2

- Taking the average loss of mass for 2003-2014 due to sublimation/deposition from the ice sheet,
  - 23.8 Gt/yr from AIRS and our model (10.4% of SMB)
  - 14.2 Gt/yr from RACMO2 .(6.2% of SMB)



Comparison with RACMO2

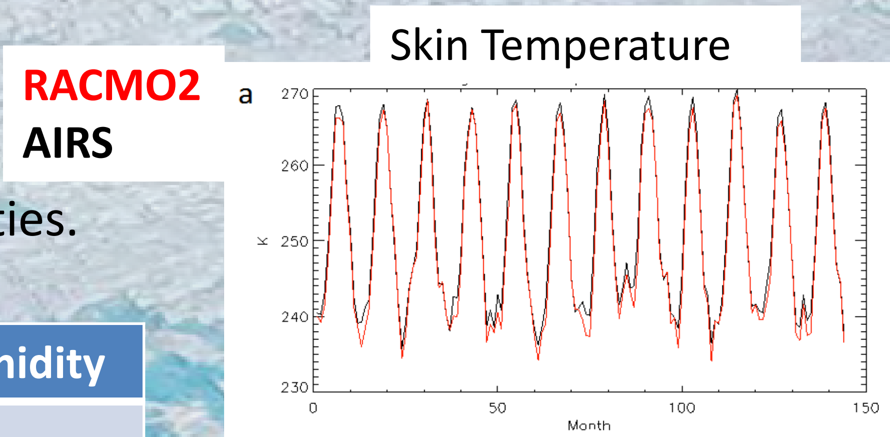


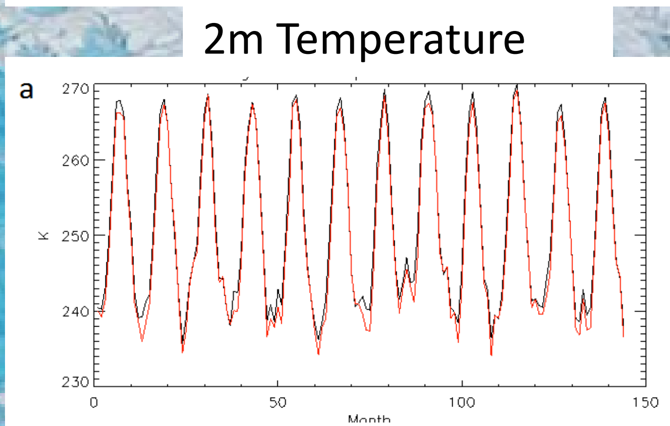
Comparison with RACMO2

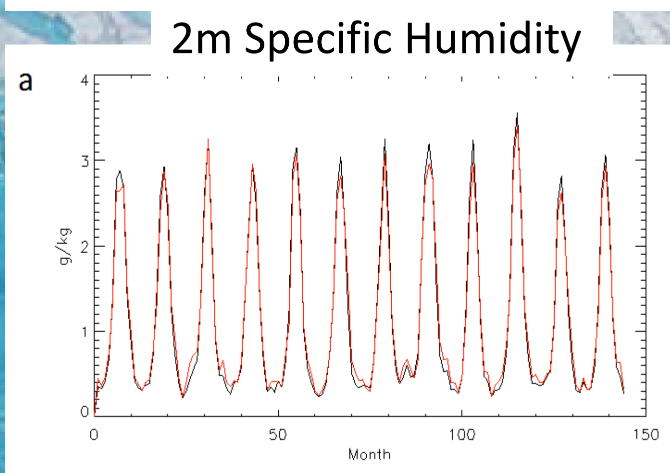
- Differences between the sublimation/deposition:
  - Errors in the temperatures and humidities.
  - Differences in the two model's physics.

RMSE	2m Temperature	2m Specific Humidity
AIRS	3.14 K	0.17 g/kg
RACMO2	2.30 K	0.26 g/kg

- In the summer:
  - Inclusion of evaporation,
  - The surface roughness product
    - Largest roughness values along the edges of the ice sheet
- In the winter:
  - Errors in the input variables
  - Drifting snow sublimation
    - In RACMO2, when drifting snow sublimation is activated, surface deposition is set to zero. Drifting snow occurs most often in the winter months and most frequently at lower elevations [*Lenaerts et al.,* 2012].







Conclusions

- In the future with a warming climate, the length and area that the Greenland ice sheet undergoes melt each summer is expected to increase.
  - The amount of sublimation could increase, especially with increases in the amount of evaporation.
    - Will contribute to the surface mass loss by mitigating increases in precipitation (changes are uncertain).
- Data products from AIRS can be useful for estimating the sublimation on the Greenland ice sheet.