Using remotely sensed data from AIRS to estimate the vapor flux on the Greenland Ice Sheet:

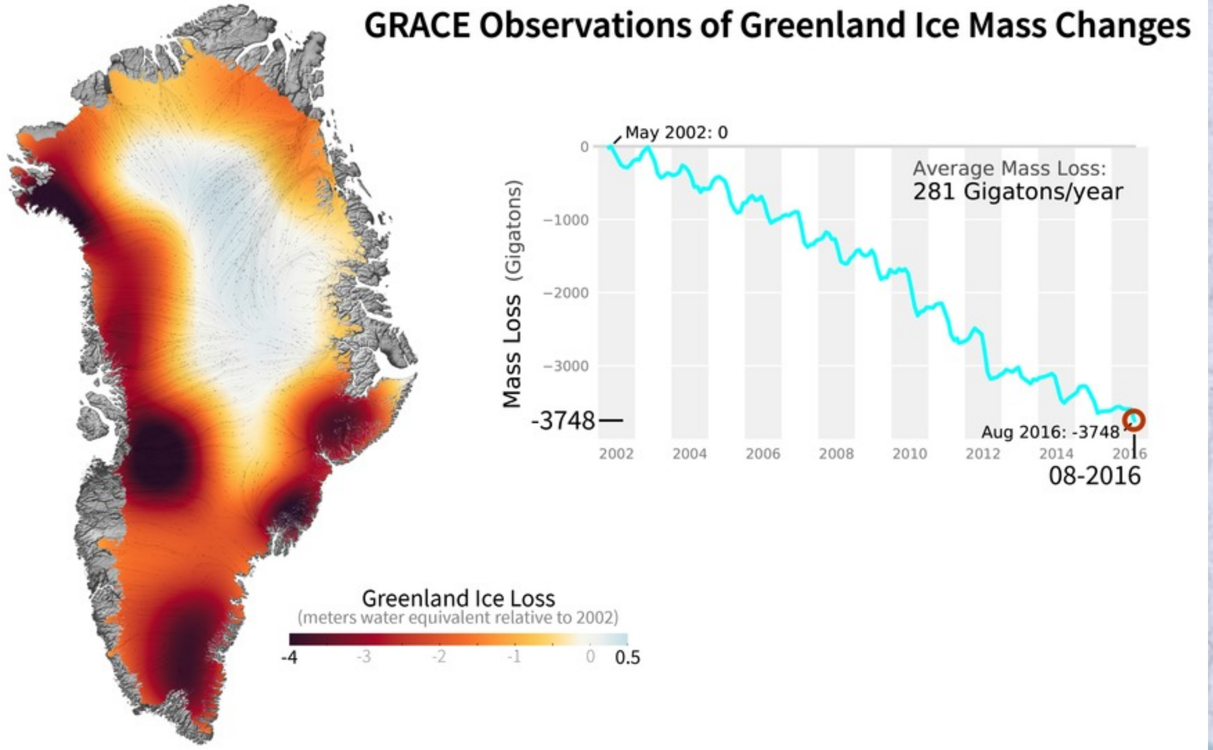
comparisons with observations and a regional climate model

Linette N. Boisvert, Jae N. Lee, Jan T. M. Lenaerts, Brice Noël, Michiel R. van den Broeke, and Anne W. Nolin

JGR Atmos. doi: 10.1002/2016JD025674

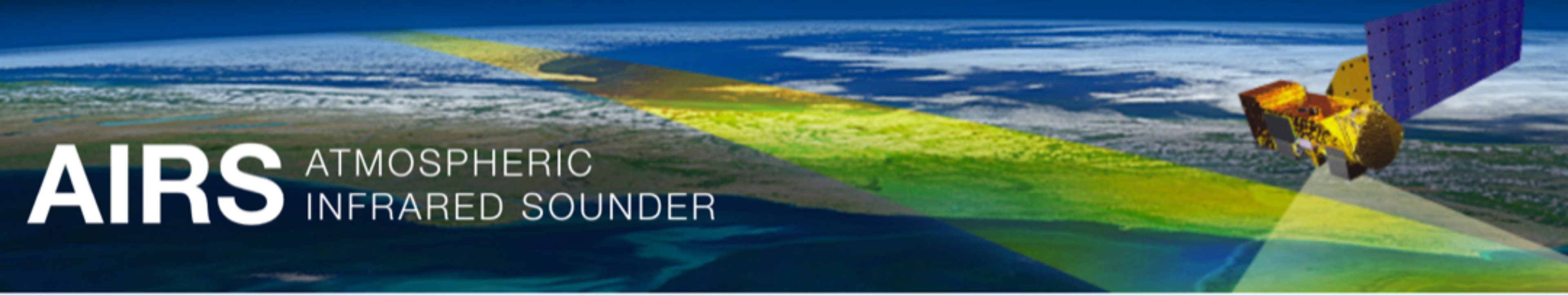
Motivation

- Mass loss from GrIS is accelerating, with runoff from surface melt dominating SMB since 2008 [*Enderlin et al.*, 2014].
- **SMB = Precipitation – Evaporation/Sublimation – Runoff**
  – Precipitation & surface runoff are the dominant source & sink terms of the GrIS SMB.
    - Been studied extensively
    - Relatively little attention has been given to the smallest component of GrIS SMB.
  – Future contribution & magnitude of this term to the overall SMB remains uncertain.



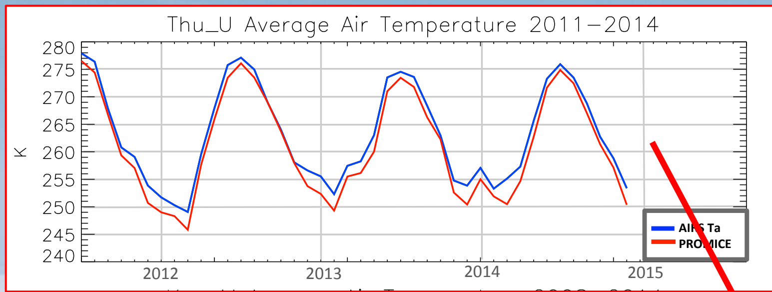
Motivation

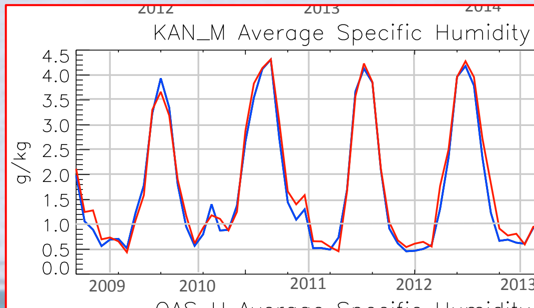
- In recent years, satellite data have shown considerable improvements in estimating near-surface air temperature & humidity using new retrieval techniques [*Dong et al.*, 2010], but remain highly underutilized.
- Here we introduce a **new, independent GrIS vapor flux dataset between 2003-2014** that is produced using AIRS data & a model adapted from *Boisvert et al.,* [2013] that was created for use over Arctic sea ice.
  - Compared with in situ observations & also an independent regional atmospheric climate model: RACMO.

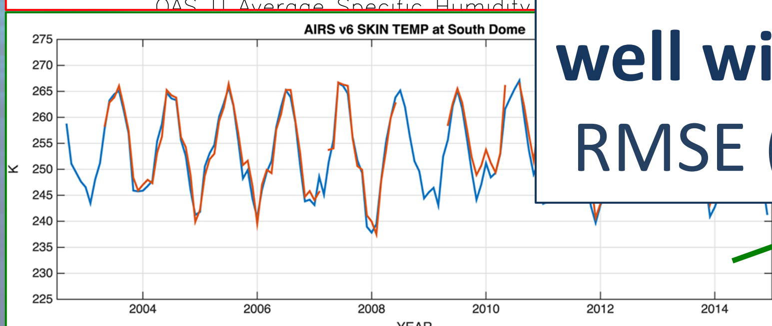


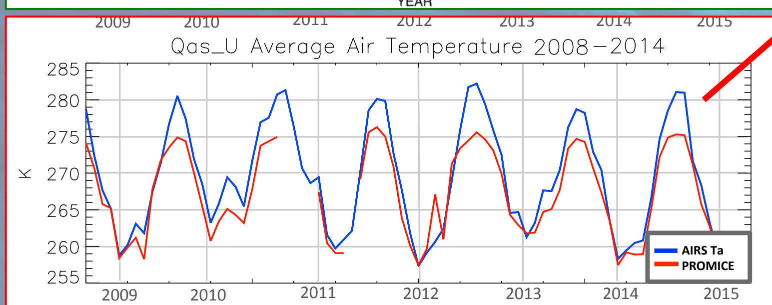
- AIRS is a cross-track high spectral resolution infrared sounder onboard NASA’s Aqua satellite, launched on May 4, 2002.
- **Data used in this study**: skin temperature, near surface air temperatures & specific humidity depending on pressure level (1000, 925, 850, 700 & 600 hPa dependent on surface elevation from ICESat) & associated geopotential heights.

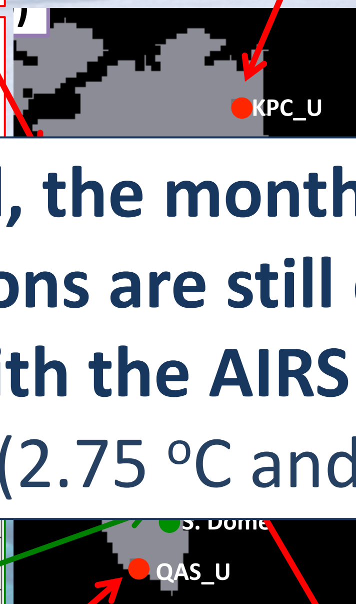
Quality of AIRS data

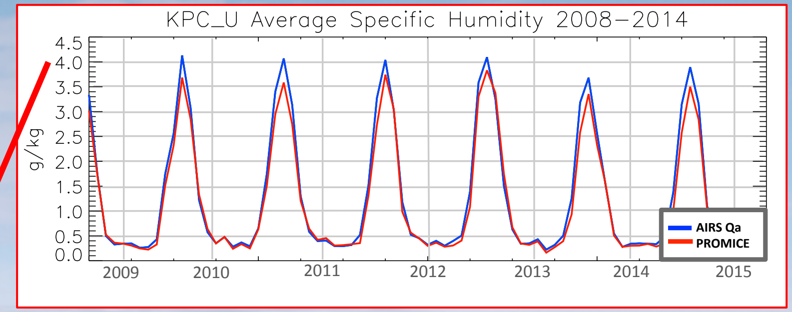


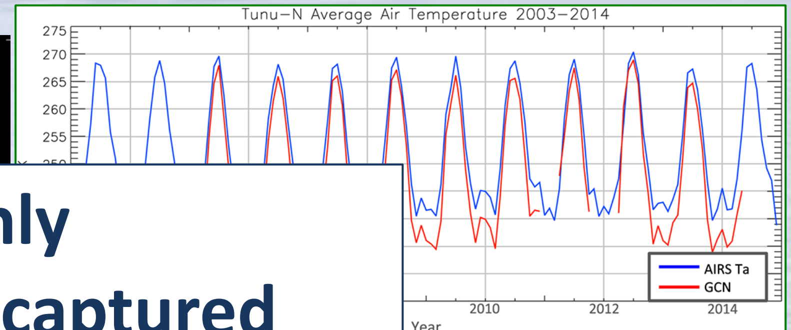


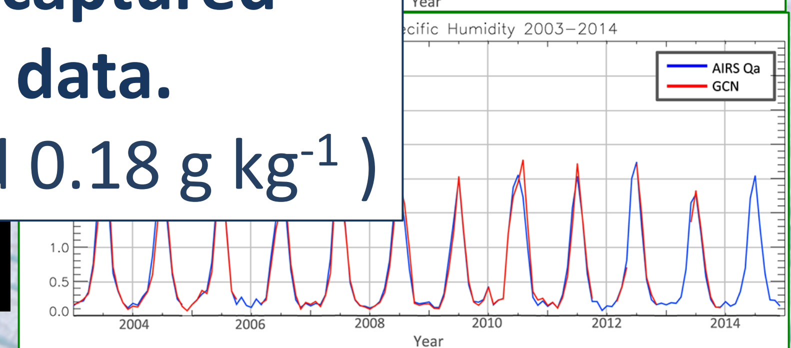


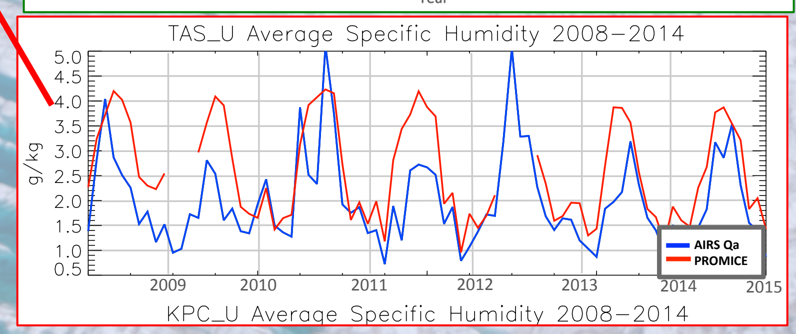












Overall, the monthly variations are still captured well with the AIRS data.

RMSE (2.75 ^{o}C and 0.18 g kg^{-1})

BMF13 Model

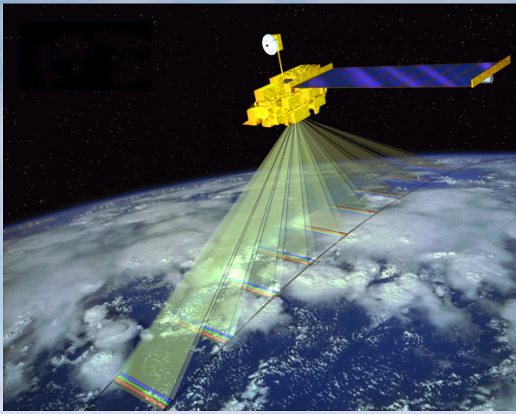
- GrIS vapor flux (E) is estimated from the *Boisvert et al*. [2013] moisture flux model (herein BMF13) with a few adaptations made for Greenland:

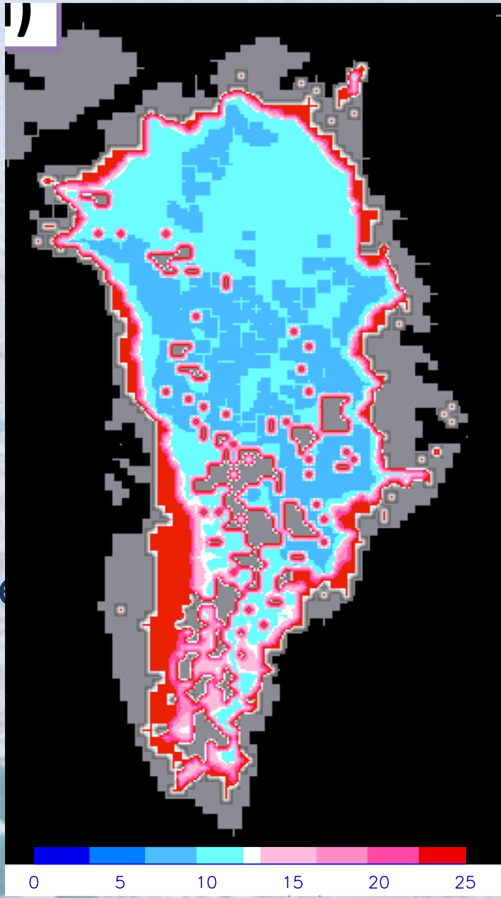
$$E = \rho C_{Ez} S_r (q_{s,i} - q_z) \quad (1)$$

- E is estimated from (1) using Monin-Obukhov similarity theory & an iterative calculation scheme based on *Launiainen and Vihma* [1990]
- Modifications:
  - The flux algorithm of *Grachev et al* [2007] for stable conditions over ice.
  - The effective wind speed, which includes a parameter for gustiness that is different in stable & unstable boundary conditions [*Andreas et al.*, 2010].

BMF13 Model

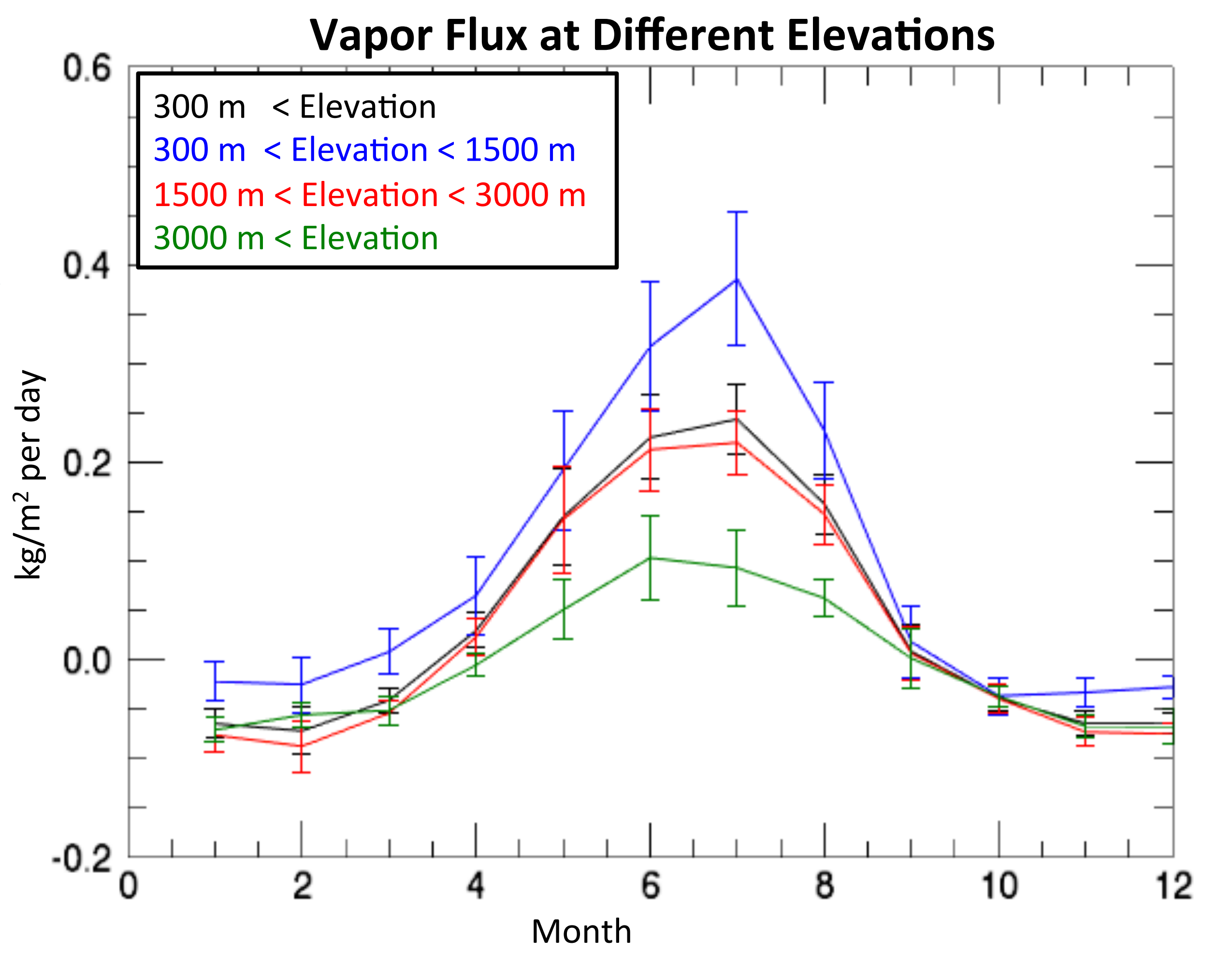
- On GrIS, surface roughness is created by glacier dynamics & surface-atm interactions.
  - Affects boundary layer processes through the aerodynamic roughness length.
- A **surface roughness data product** from the Multi-angle Imaging SpectroRadiometer (MISR) [*Nolin et al.,* 2002] is used to calculate C_{Ez} in (1).
  - Created via MISR angles of ± 60 degrees & nadir
  - Valid during the sunlit season with average roughness values ranging from 11 cm in April to roughly 20 cm in July.
    - For the remainder of the year 10 cm was used because in winter the surface is not as rough due to snow covering the bare ice.
- 10 m wind speeds taken from ERA-Interim.





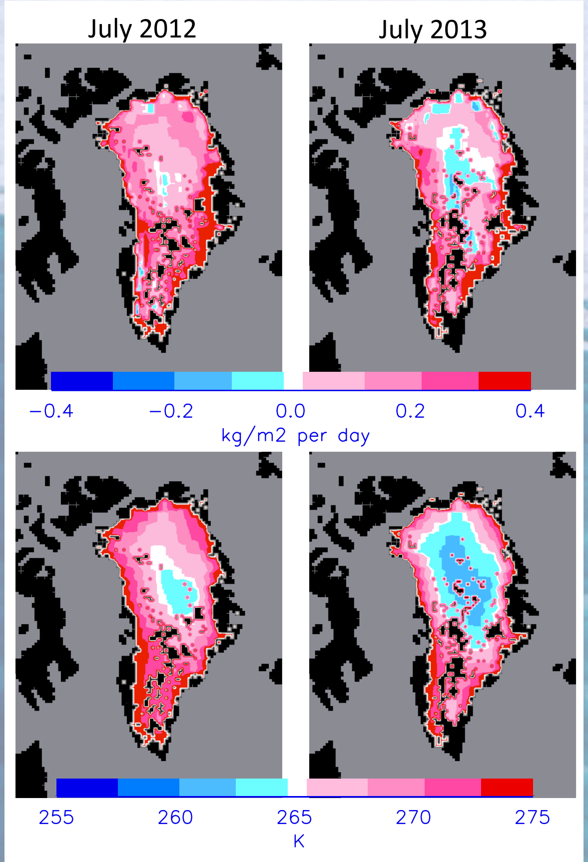
BMF13 Vapor Flux Climatology 2003-2014

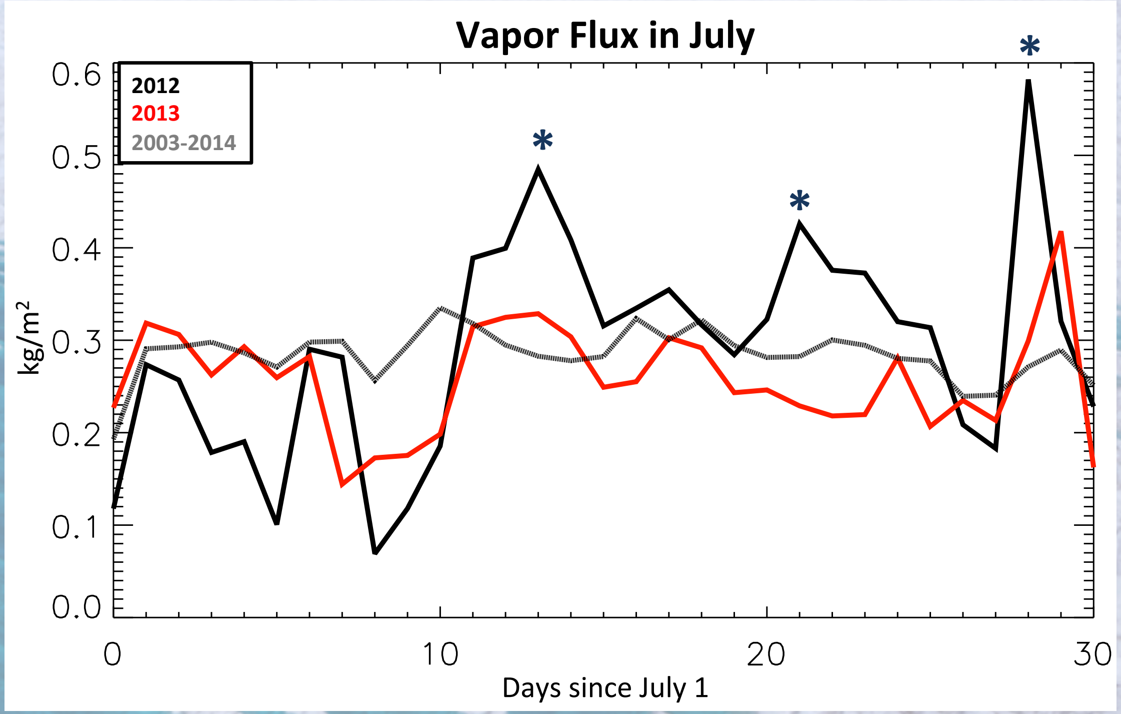
- Largest interannual variability occurs in the summer (0.067 Gt day^{-1}), & smallest variability occurs in the winter (0.020 Gt day^{-1}).
  - Positive vapor flux (summer) is about five times the magnitude of the deposition (winter).
  - The largest vapor flux deviation occurs in elevations between 0.3 km -1.5 km (near the edge of the ice sheet)
  - Smaller deviations occur at higher elevations.



Comparing July 2012 (high melt) and 2013 (average melt)

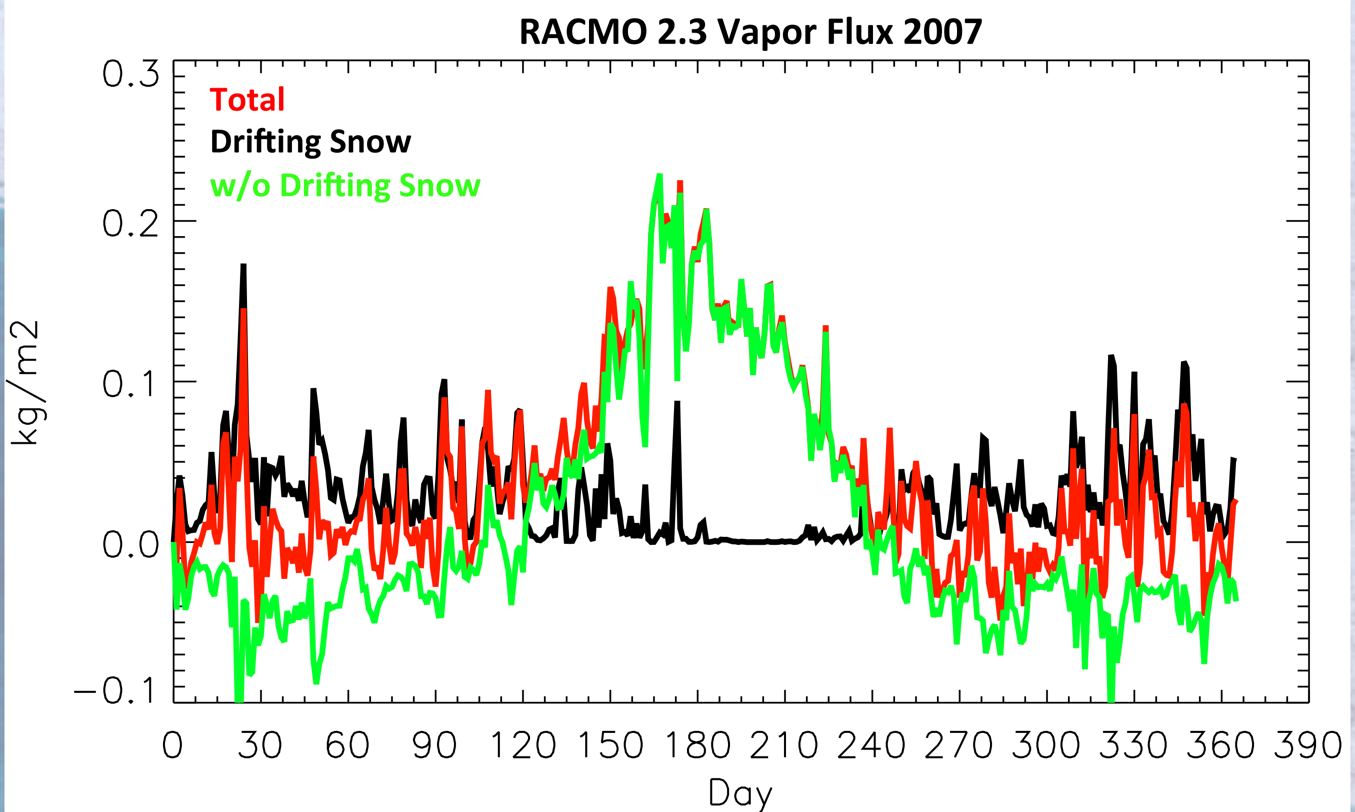
- **July 2012:** 0.88 Gt more mass lost by the vapor flux than the average (2003-2014), & 1.53 Gt more than in 2013 (more along ice edge & at higher elevations).
- **July 2013:** more snowfall, & less mass loss to sublimation than 2012.
  - Contributed to an overall smaller mass loss in 2013 compared to 2012.
  - 2013 Vapor flux was very similar to the 2003-2014 average.
- 2012 vapor flux produced three high sublimation spikes around 12 July, 22 July & 29 July.
  - Consistent with the findings from *Nghiem et al.* [2012], who showed concurrent large melt events covering the majority of the ice sheet.





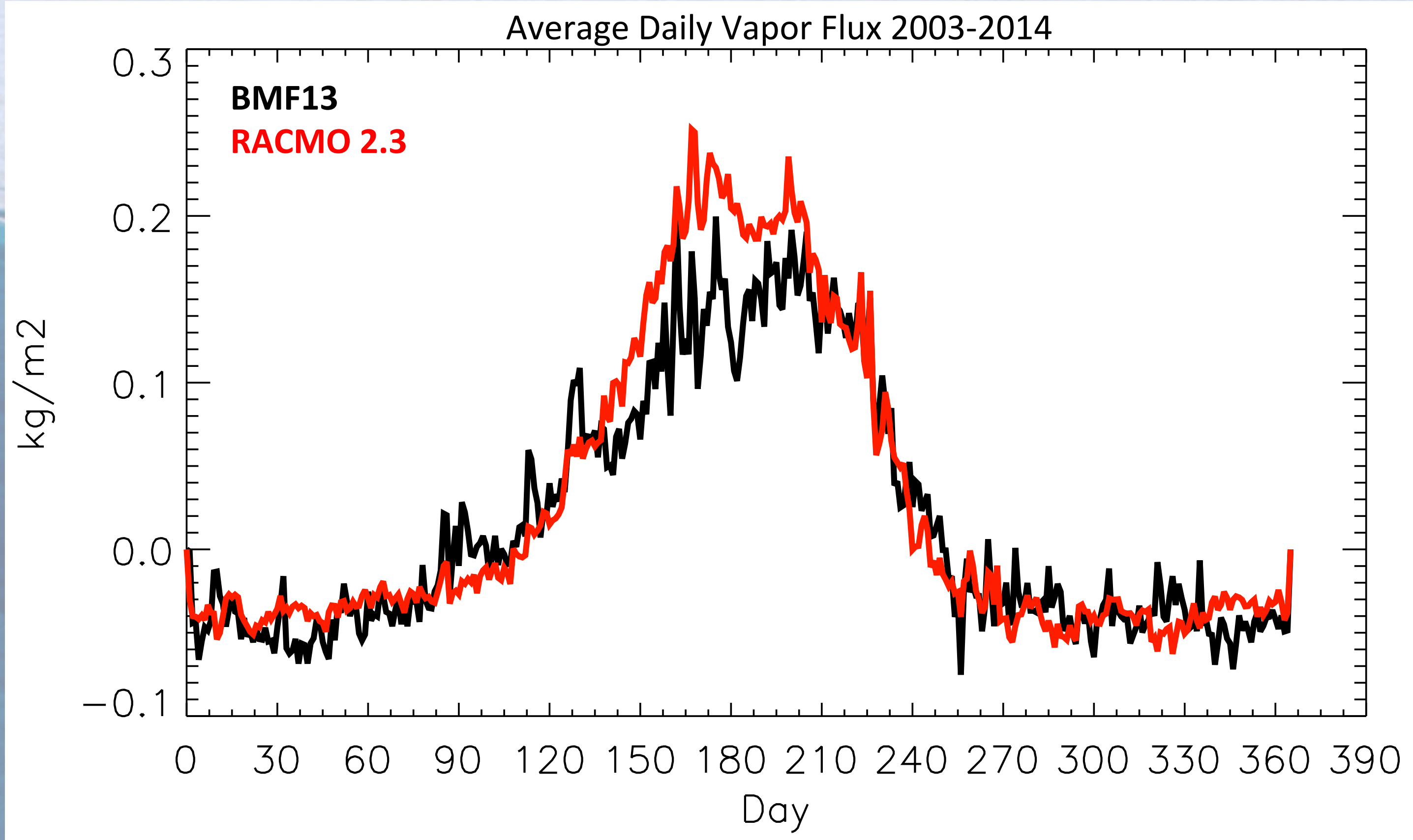
RACMO2.3

- Regional Atmospheric Climate Model version 2.3 (RACMO2.3) focused on the GrIS [*Noël et al.*, 2015] is used to compare with the BMF13 product.
- RACMO2.3 is forced by ERA-Interim at its lateral boundaries & combines 2 weather prediction models: dynamics from the High Resolution Limited Area Model (HIRLAM) [*Unden et al.*, 2002] & physical processes from ECMWF [*ECMWF-IFS*, 2008].
- RACMO2.3 vapor flux product that we use here **DOES NOT** include drifting snow sublimation [*Lenaerts et al*., 2012].
- Thus in order to compare accurately with the BMF13 model we will only use data points where there is no drifting snow sublimation present in RACMO2.3.



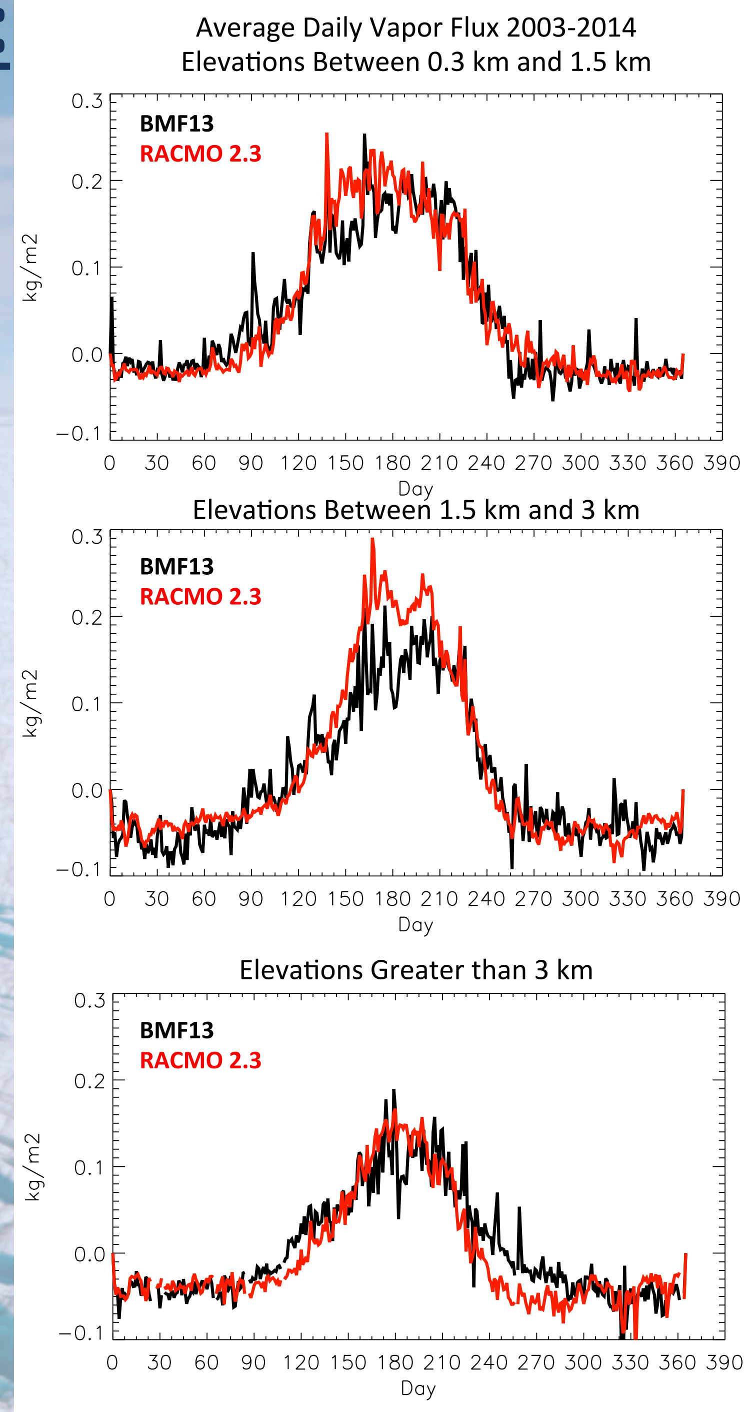
Comparison with RACMO2.3

- RACMO2.3 & BMF13 are similar in shape & magnitude of the annual cycle, except in June-July.
- Wintertime deposition is slightly stronger in BMF13 (Feb & Dec)
- Yearly vapor flux average: BMF13 & RACMO2.3 differ by 7.1 Gt yr^{-1}.
  - Due to the larger flux in the summer months from RACMO2.3, 0.05 Gt day^{-1} larger than in BMF13.

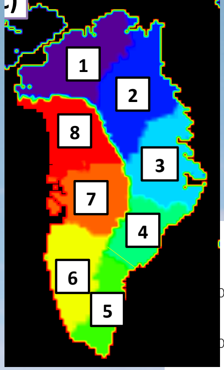


Comparison with RACMO2.3: Different Elevations

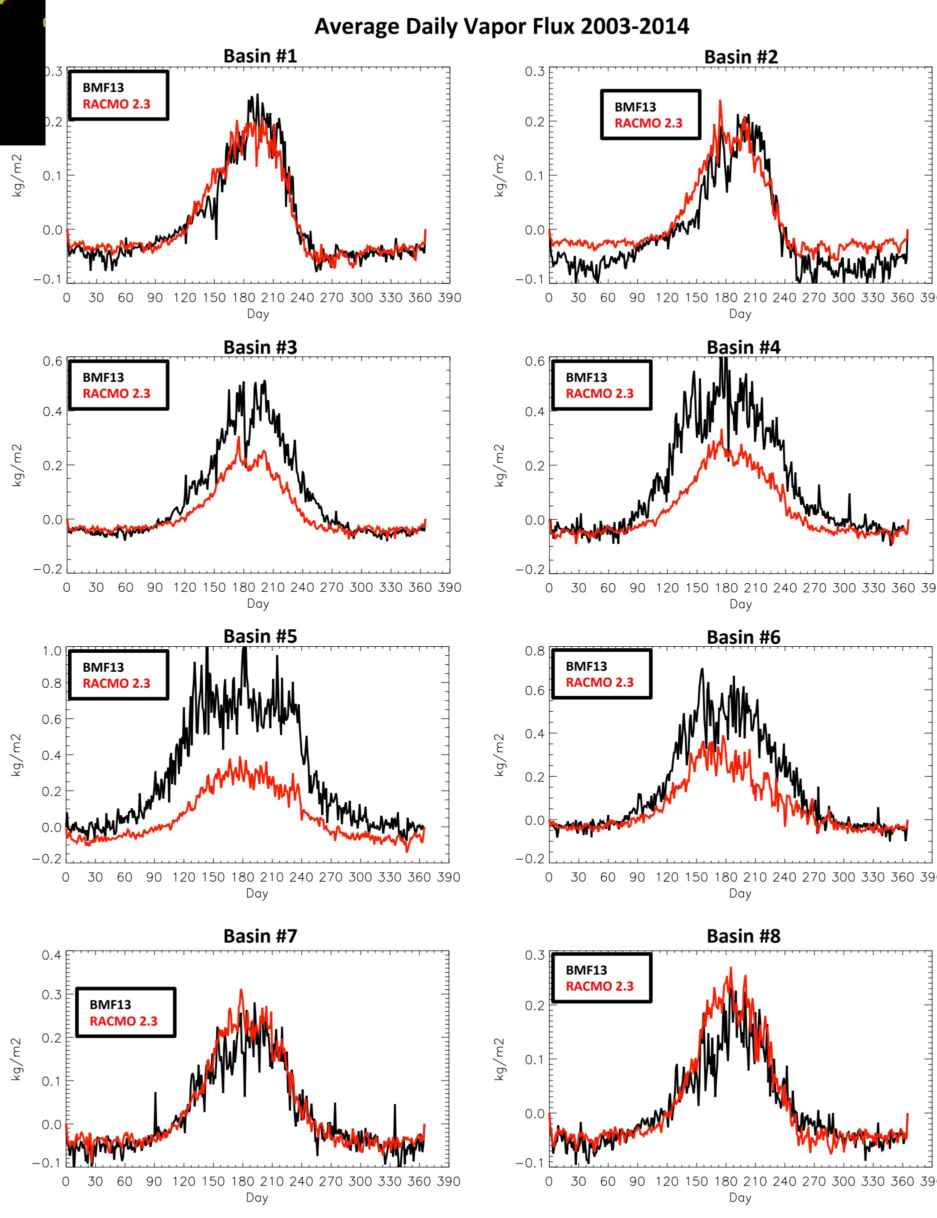
- The vapor flux differences vary across ice sheet elevations, with largest differences in the summertime.
  - Elevations **300 - 1500 m a.s.l** (along the edges of the ice sheet): annual vapor differ by 1.9×10^{-3} Gt day^{-1}. Deposition very close to zero.
  - Elevations **1500 - 3000 m a.s.l** (majority of the ice sheet): RACMO2.3 is slightly larger than BMF13.
    - Summer: sublimation rates were 3.05×10^{-2} Gt day^{-1} larger in RACMO2.3
    - Winter: Deposition rates 1.15×10^{-2} Gt day^{-1} less than BMF13.
  - Elevations greater than **3000 m a.s.l**, the annual vapor flux is close to zero, with BMF13 being slightly positive & RAMCO2.3 being slightly negative.



Comparison with RACMO2.3: Accumulation & Ablation Zones

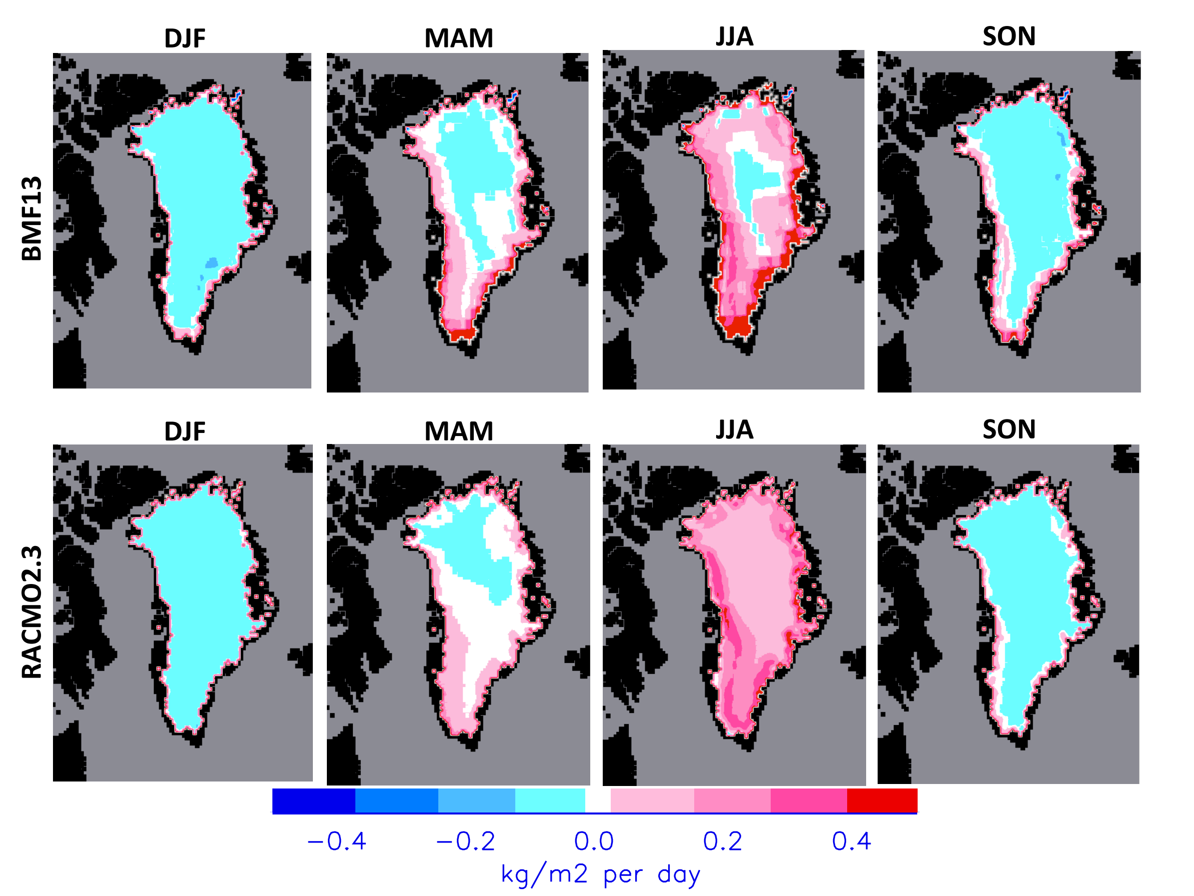


- Northern half of GrIS (regions **1**, 2, **7** & **8**) vapor flux is very similar for both models.
- Southern end of GrIS (3, 4, **5** & 6) show larger discrepancies.
  - Winter are very similar, but in summer BMF13 is higher (roughly double) than RACMO2.3 values.
- Coastal areas grid boxes with the most surface heterogeneity show the largest differences.
  - Due to larger footprint & resolution from AIRS.



Comparison with RACMO2.3:
Spatial Differences

- Spatially BMF13 & RACMO2.3 are very similar.
  - **JJA:** RACMO2.3 shows sublimation over the entire ice sheet, whereas the BMF13 model produces a small amount of deposition at higher elevations (between 1500 - 3000 m a.s.l) over the central ice sheet.
  - **SON & DJF:** magnitude of deposition is similar except for a few areas of larger deposition rates in the BMF13 product along the southern edge of the ice sheet.

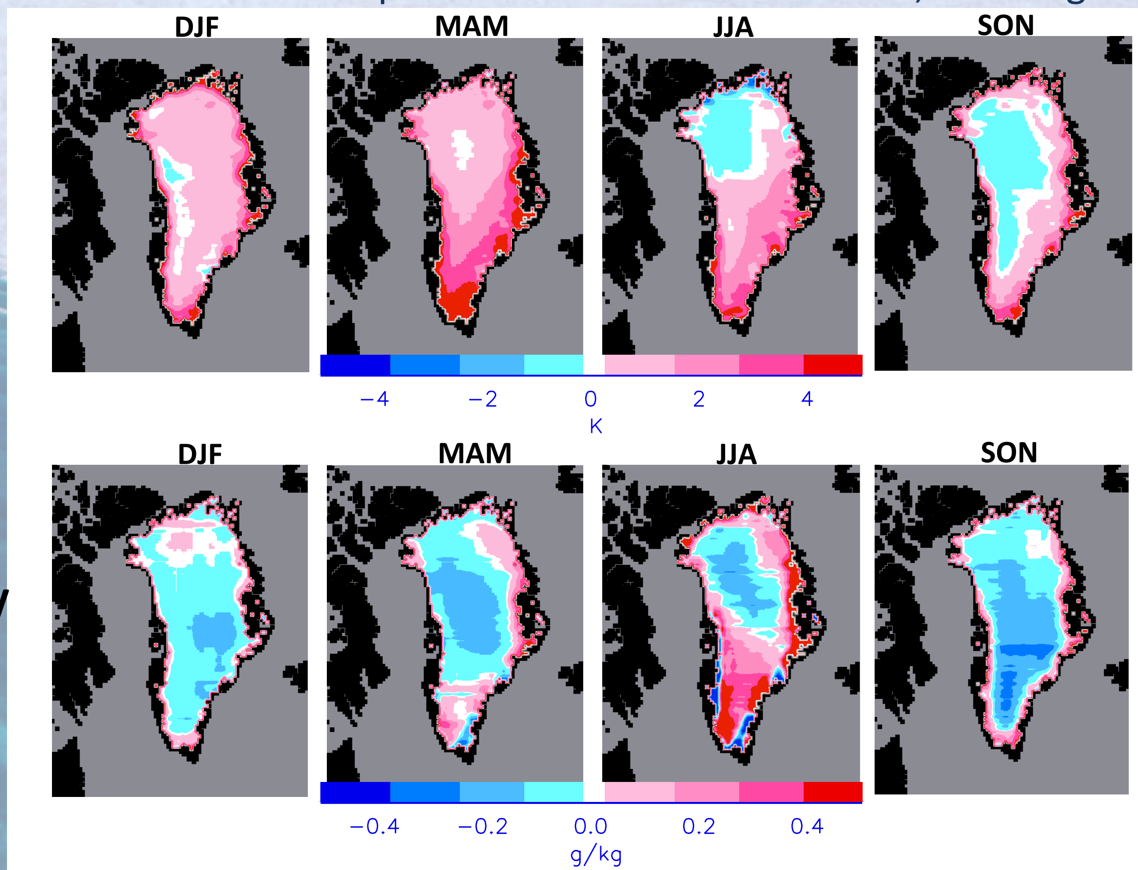


Reasons for Differences: Input Data

- Specific humidity from AIRS tends to be lower in all seasons at elevations greater than 3000 m a.s.l, & for all elevations in the winter months.
- AIRS shows higher humidity in MAM & JJA, along the southern tip of the ice sheet, corresponding with comparisons of specific humidity at the South Dome GC-Net Station & QAS_U & TAS_U PROMICE stations.
- Skin temperatures from AIRS are higher MAM & JJA, but lower in SON.
- Despite these differences, the magnitudes & behavior of the vapor flux at all elevations are very similar. Differences at the surface tend to be comparable with differences at 2 m, resulting in a similar gradient.

Skin Temperature (AIRS-RACMO)

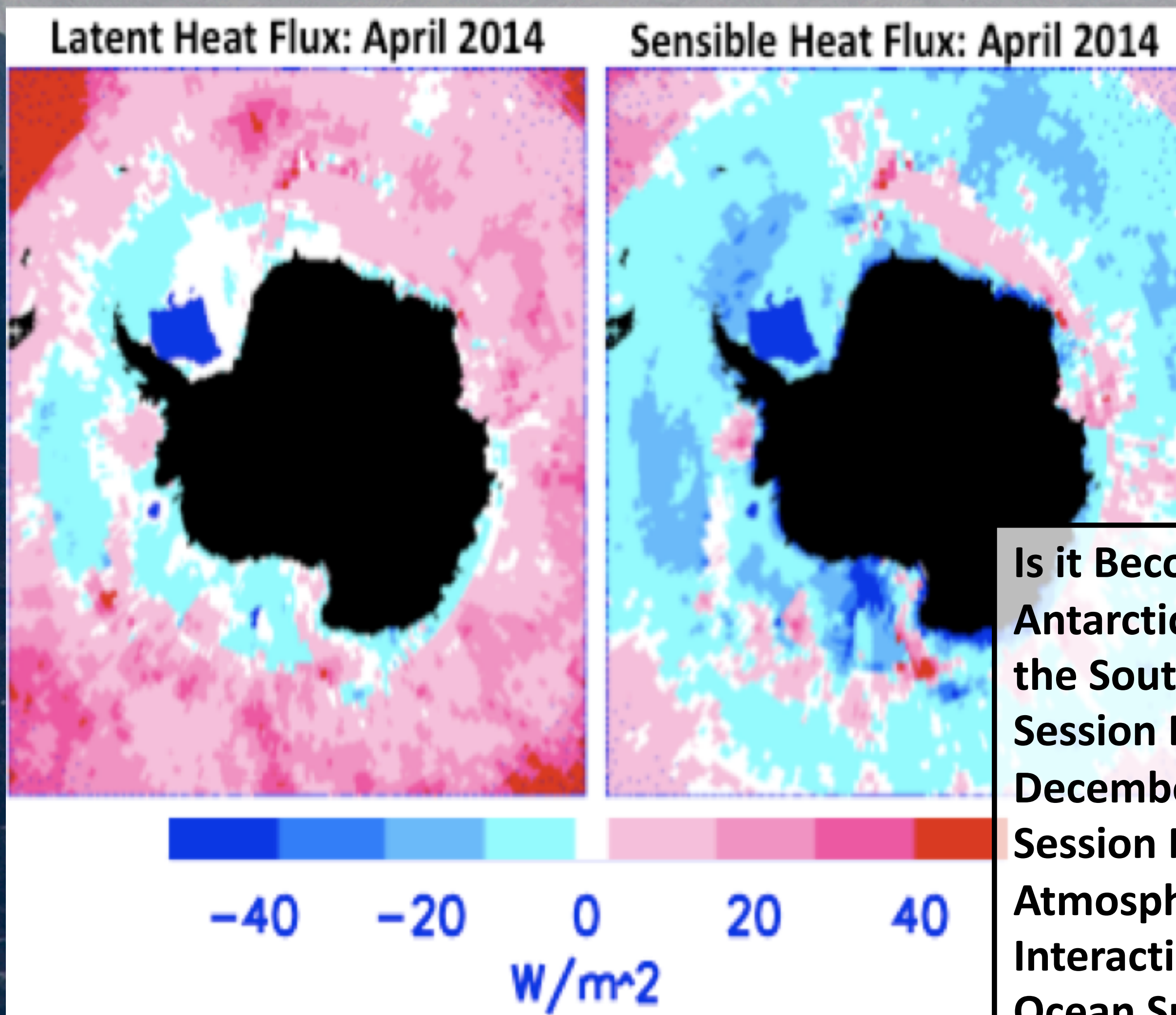
2m Specific Humidity (AIRS-RACMO)



Conclusions

- **Goal:** Produce a vapor flux data set for GrIS using remotely sensed data from AIRS.
  - **AIRS Pros: 1)** Full coverage of the entire ice sheet, compared to point measurements from AWS
  - **2)** AIRS has small errors compared with the GC-Net and PROMICE in situ observations.
    - A combined uncertainty of 44% in the BMF13 vapor flux product was found, & not including the southeast coastal stations the RMSE is reduced to 25%.
  - **3) Independent comparison** with regional climate models, which use reanalysis data as boundary conditions.
  - **4)** When compared with RACMO2.3, results agreed qualitatively well on both a spatial & temporal scale.
- No single method to estimate the vapor flux is expected to be perfect & many uncertainties remain.
  - **AIRS Cons: 1)** footprint is much larger than that of RACMO2.3, footprint contamination
  - **2)** Temporal scale is only twice daily thus probably misses some variations in the temperature and humidity that RACMO2.3 captures.
- **Vapor Flux: 14.6 ± 3.6 Gt/year in 2003-2014**, equivalent to **6 ± 2% of the SMB between 2003-2014**.
  - Although no trends in the vapor flux were found over the 2003-2014 period, there were large interannual variations.
- The vapor flux is important for future projections of mass loss from GrIS and its contribution to sea level rise.

Current Work: To be shown at AGU 2017



Is it Becoming Warmer and Wetter in th Antarctic? A Look at Evaporation from the Southern Ocean

Session Date and Time: Friday, 15 December 2017; 13:40 - 15:40

Session Number and Title: A53L: Polar Atmospheric Processes and Their Interactions with the Land, Ice, and Ocean Surface