The Effect of Sastrugi on TOA Albedo From CERES

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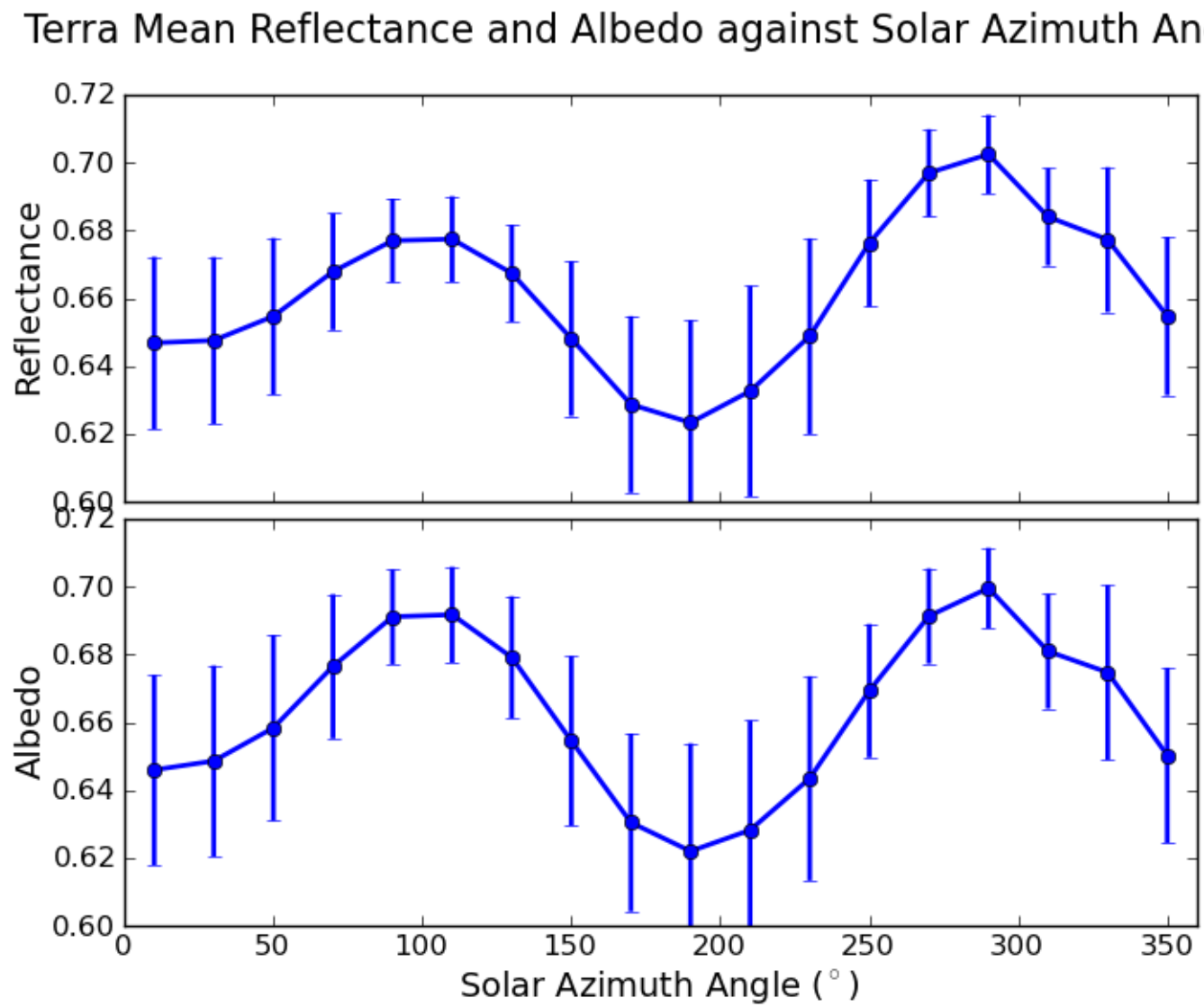
CERES Measurements

Lat: 88° - 89°
Lon: -93°- -101°
Month: DEC
SZA: 65°-70°
RAZ: 60°-70°
VZA: 50°-70°



ΔAlb ≈ ±0.04

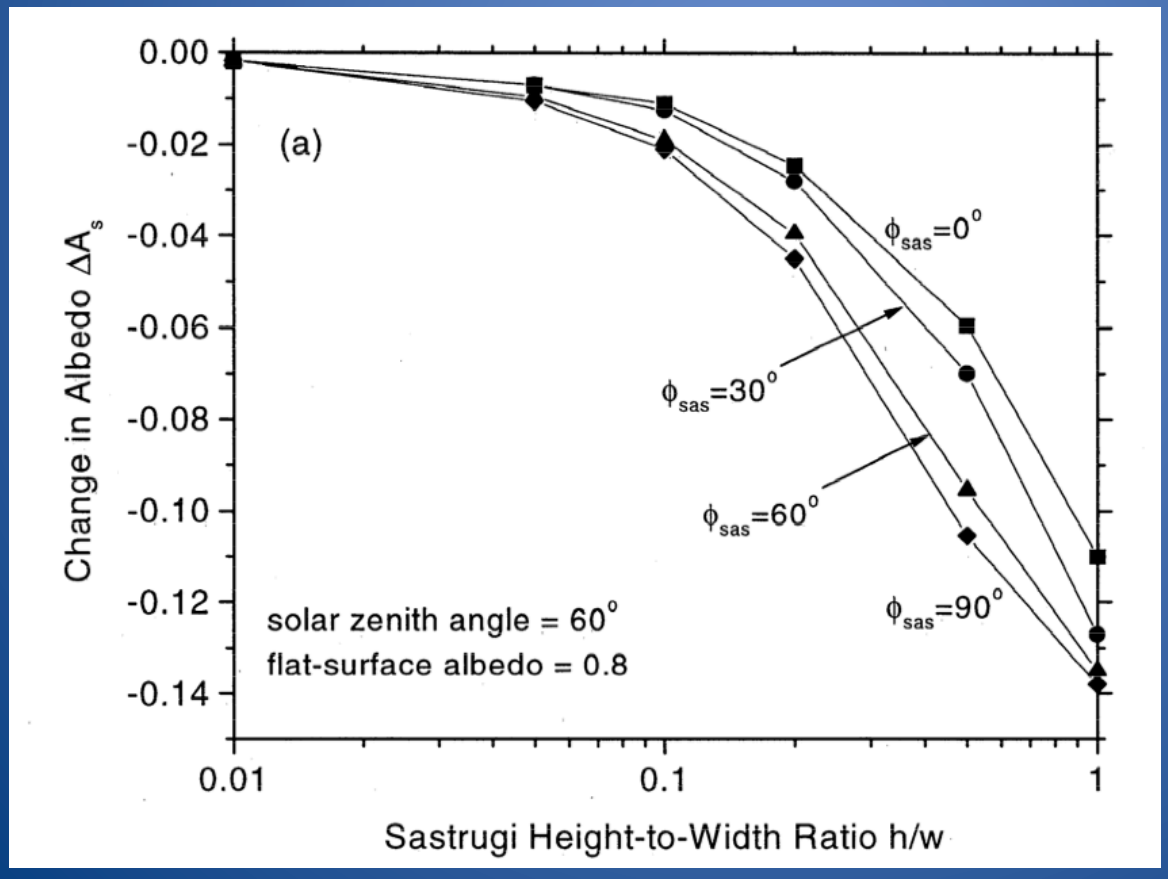
What are “sastrugi”….

- Small scale grooves or ridges of snow.
- Formed by deposition and erosion of snow by the wind.
- Generally aligned parallel to prevailing wind direction.
- Range of sizes – 1-10’s of m long, cm to m high.

…and how do they affect albedo?

- Alter the angle of incidence from horizontal.
- Increase inter-sastrugi reflections
- Depends on orientation relative to the sun

Modeled Albedo



From Warren et al 1998

Sastrugi also affect the directional reflectance

- Important for CERES albedo estimates

Minimum albedo

Minimum reflectance

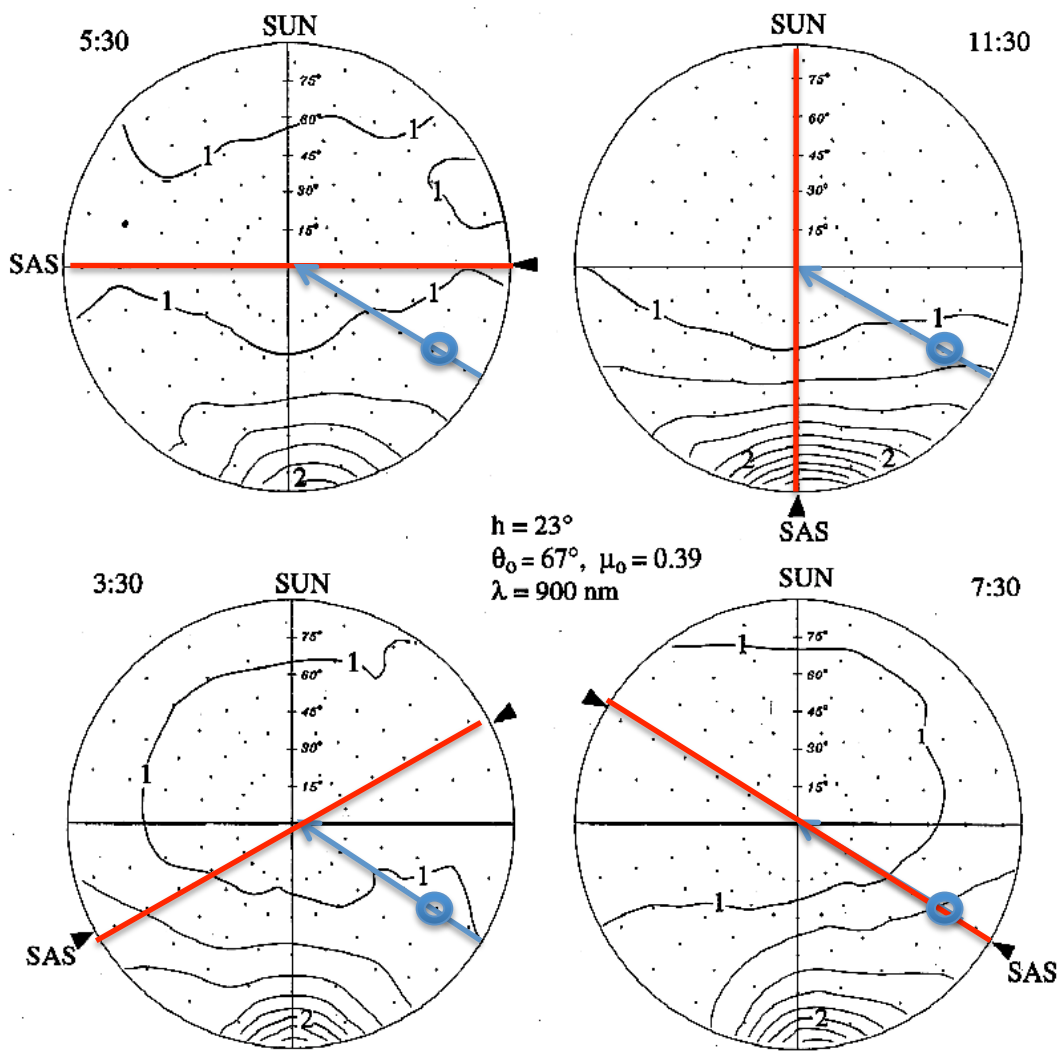


Figure 5. Anisotropic reflectance factor for h=23°, λ=900 nm, for four different Sun-sastrugi azimuth angles. The orientation of the sastrugi axis is indicated by SAS. The universal time of each pattern is indicated. Adapted from Figure 1 of *Brandt et al.* [1991].

Maximum albedo

Example CERES viewing geometry:
- VZA = 60°
- Raz = 60°

Maximum reflectance

Warren et al 1998

What do the CERES measurements show?

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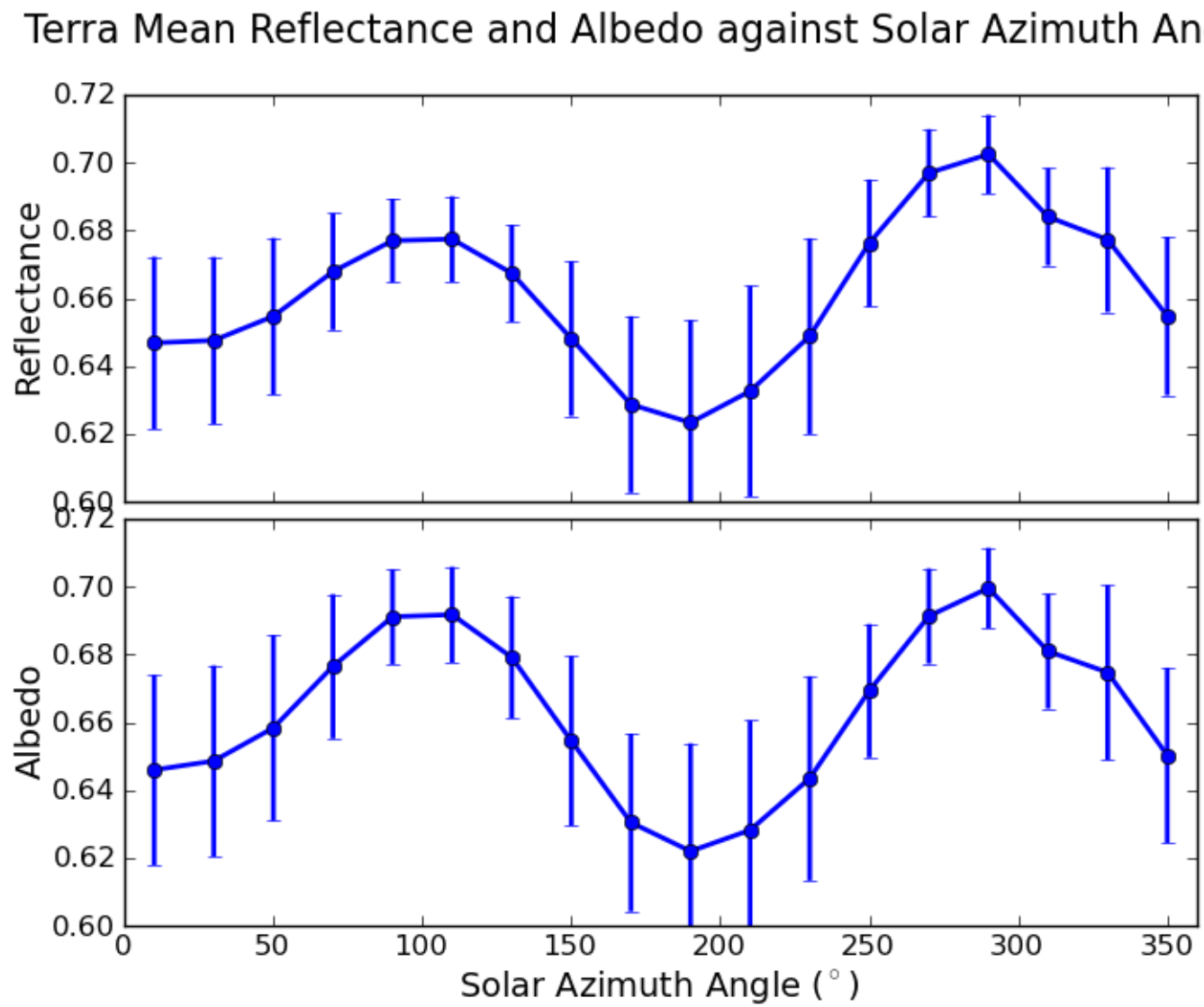
$\Delta Alb \approx \pm 0.04$



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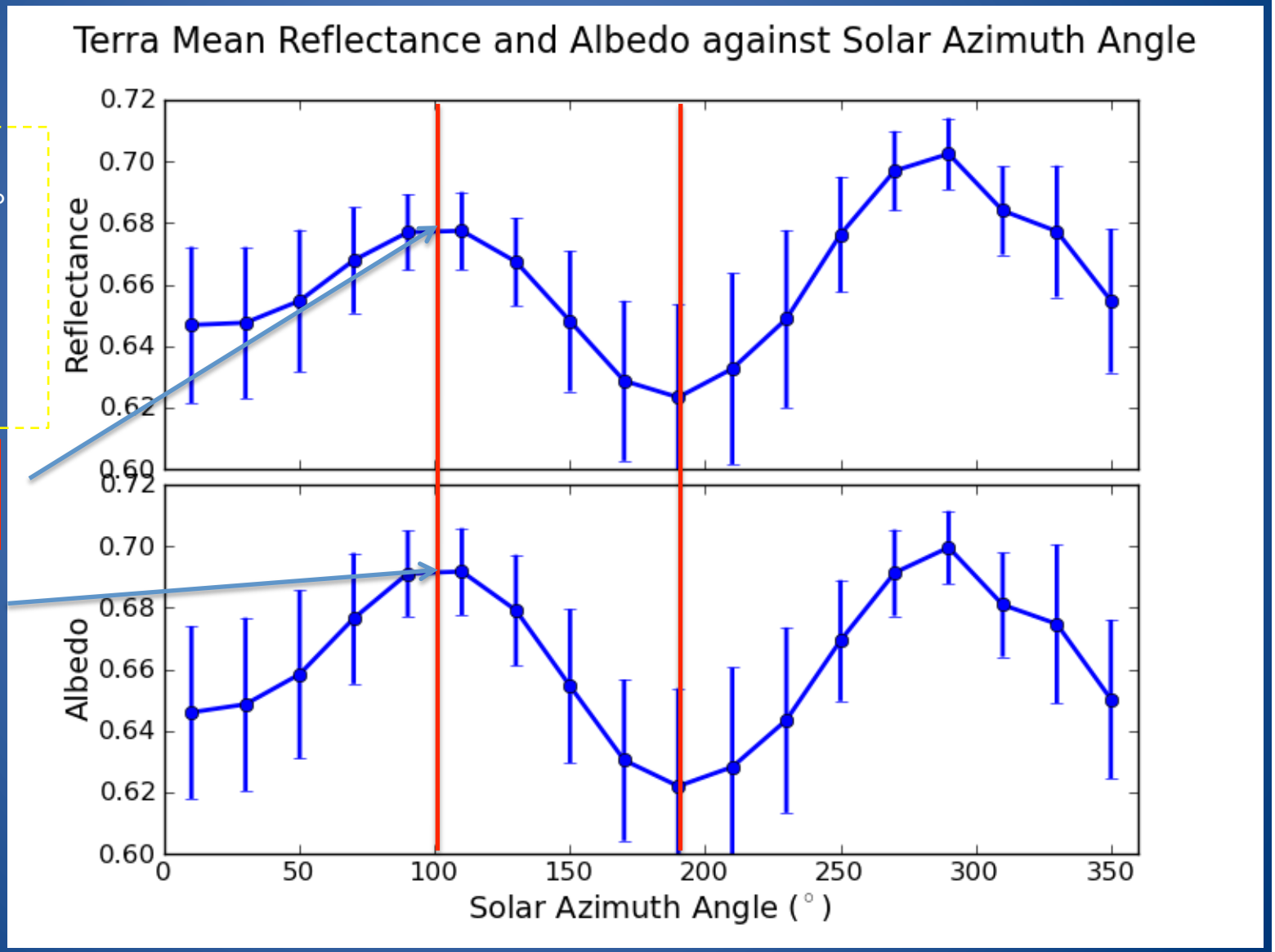
Max reflectance

Max albedo

ΔAlb ≈ ±0.04

$$A(\theta_0) = \frac{\rho(\theta_0, \theta_v, \phi)}{R(\theta_0, \theta_v, \phi)}$$



Are the albedo estimates possibly biased?

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  - Would depend on solar-viewing-sastrugi geometry.

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- What about mean monthly - regional albedos (i.e. level 3 data products)?
  - Depends on:
    - A) if sastrugi are present in a region, and
    - B) the range of solar-viewing-sastrugi geometry's sampled.

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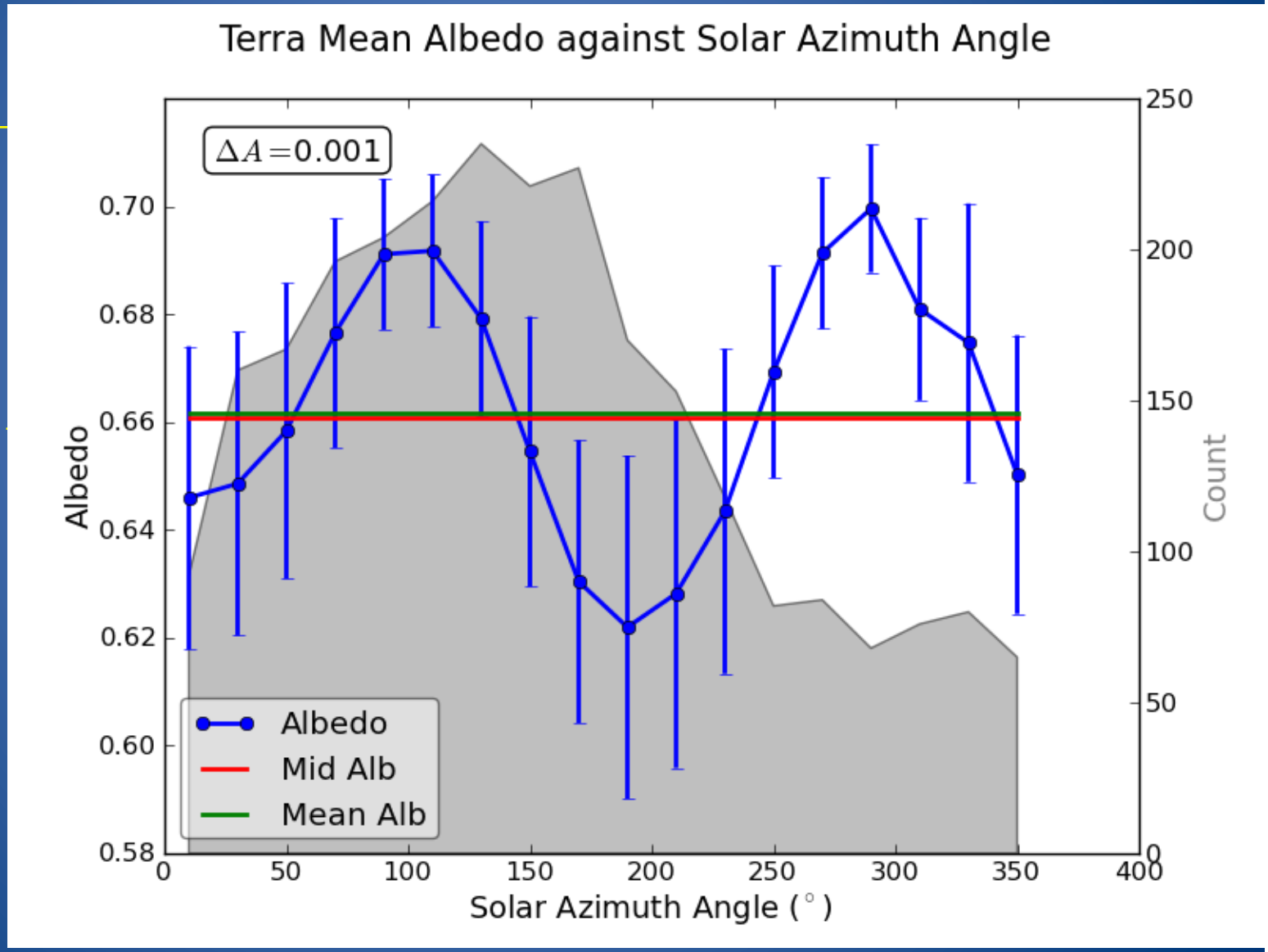
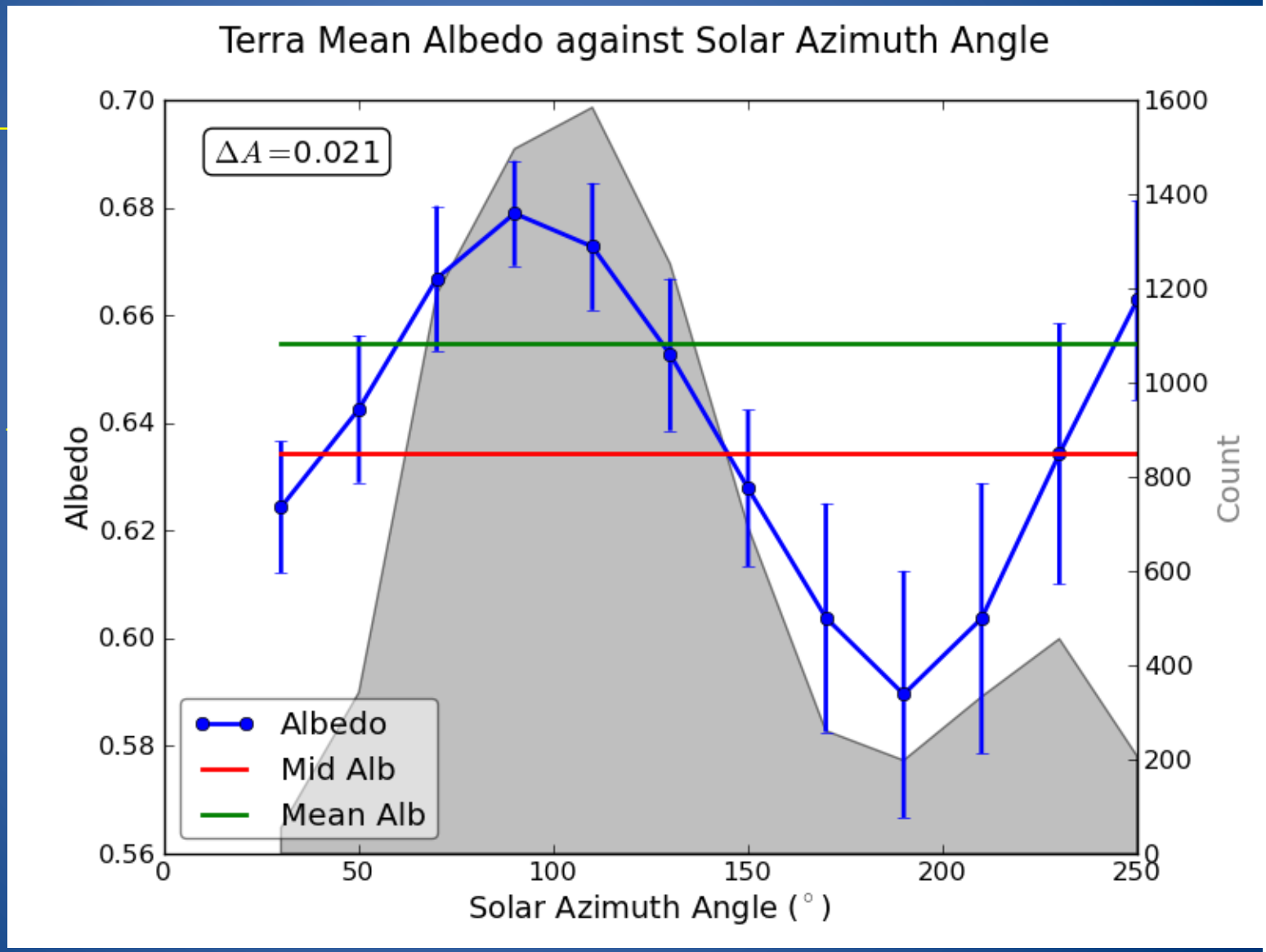


Are the albedo estimates possibly biased?

Lat: 85° - 86°
Lon: -54 °- -59°
Month: DEC
SZA: 65°-70°
RAZ: 60°-70°
VZA: 30°-70°



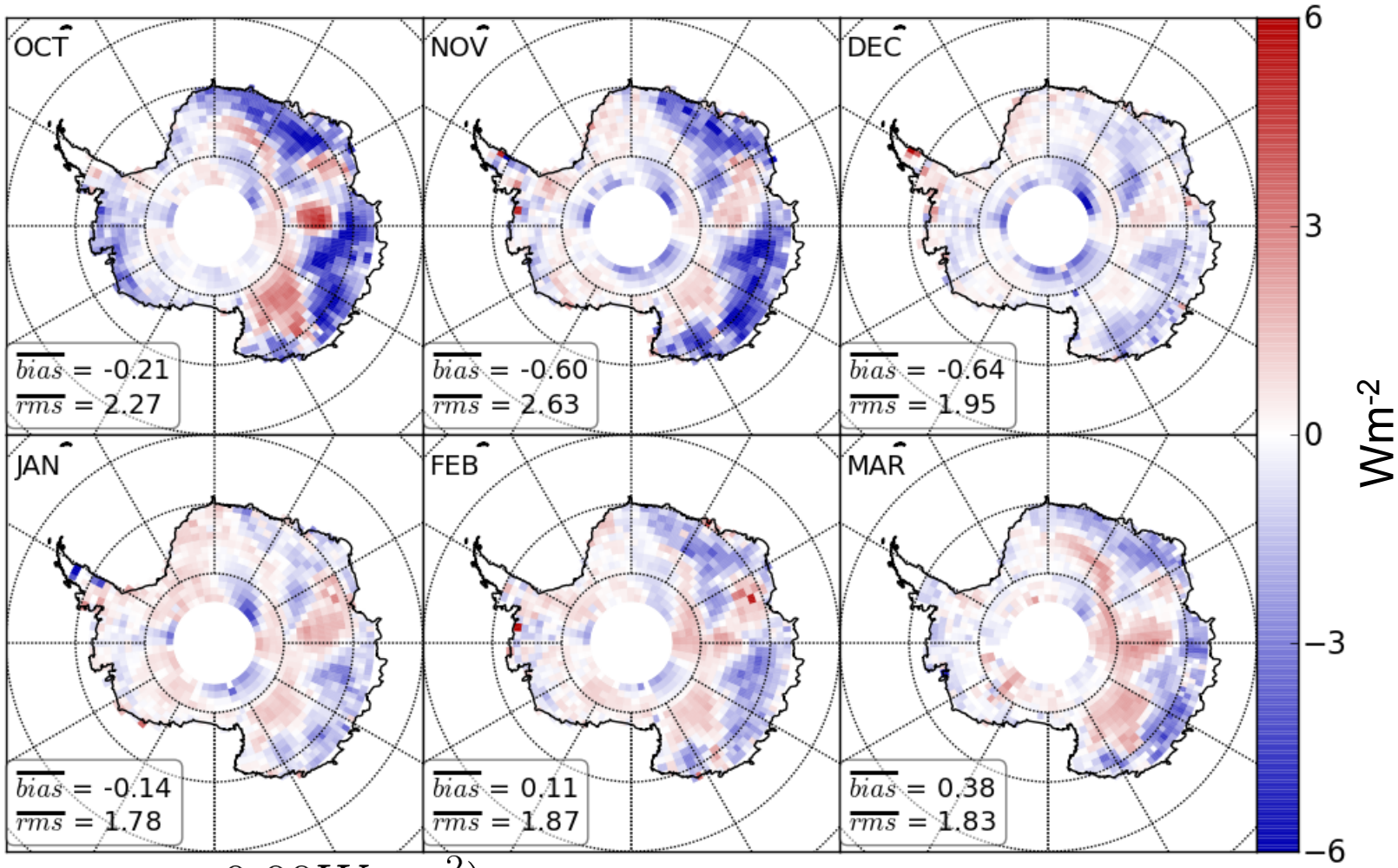
Are all the albedo estimates possibly biased?

- Instantaneous
  - Would depend on solar-viewing-sastrugi geometry.
- What about mean monthly - regional albedos (i.e. level 3 data products)?
  - Depends on:
    - A) if sastrugi are present in a region, and
    - B) the range of solar-viewing-sastrugi geometries sampled.
- For regions with poor solar azimuth sampling:
  - Estimate the bias by:

$$bias = \bar{A}(\theta_v) - \bar{A}(\theta_v < 20^\circ)$$

Regional clear sky flux biases

FM1 and FM2 Mean Clear Sky Flux Bias 2001-2009 (Wm^2)

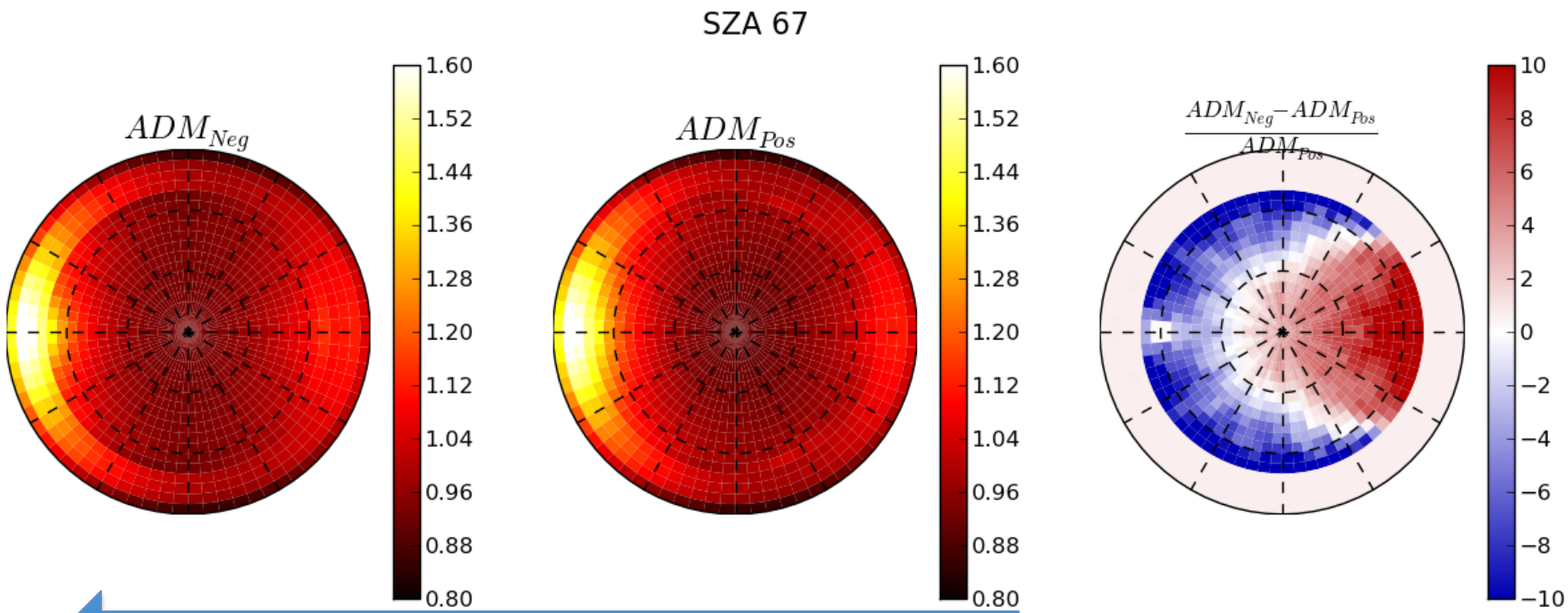


$(\overline{bias}_{global,yearly} = 0.00 Wm^{-2})$

Are these biases really caused by sastrugi?

- Its hard to to be entirely sure.
- Ways to check:
  - 1) compare anisotropy between regions of negative and positive bias
  - 2) use wind direction as a proxy for sastrugi orientation

The anisotropy is different between the two regions



Forward Scatter ⇐ ***Sun*** ⇐ Back scatter

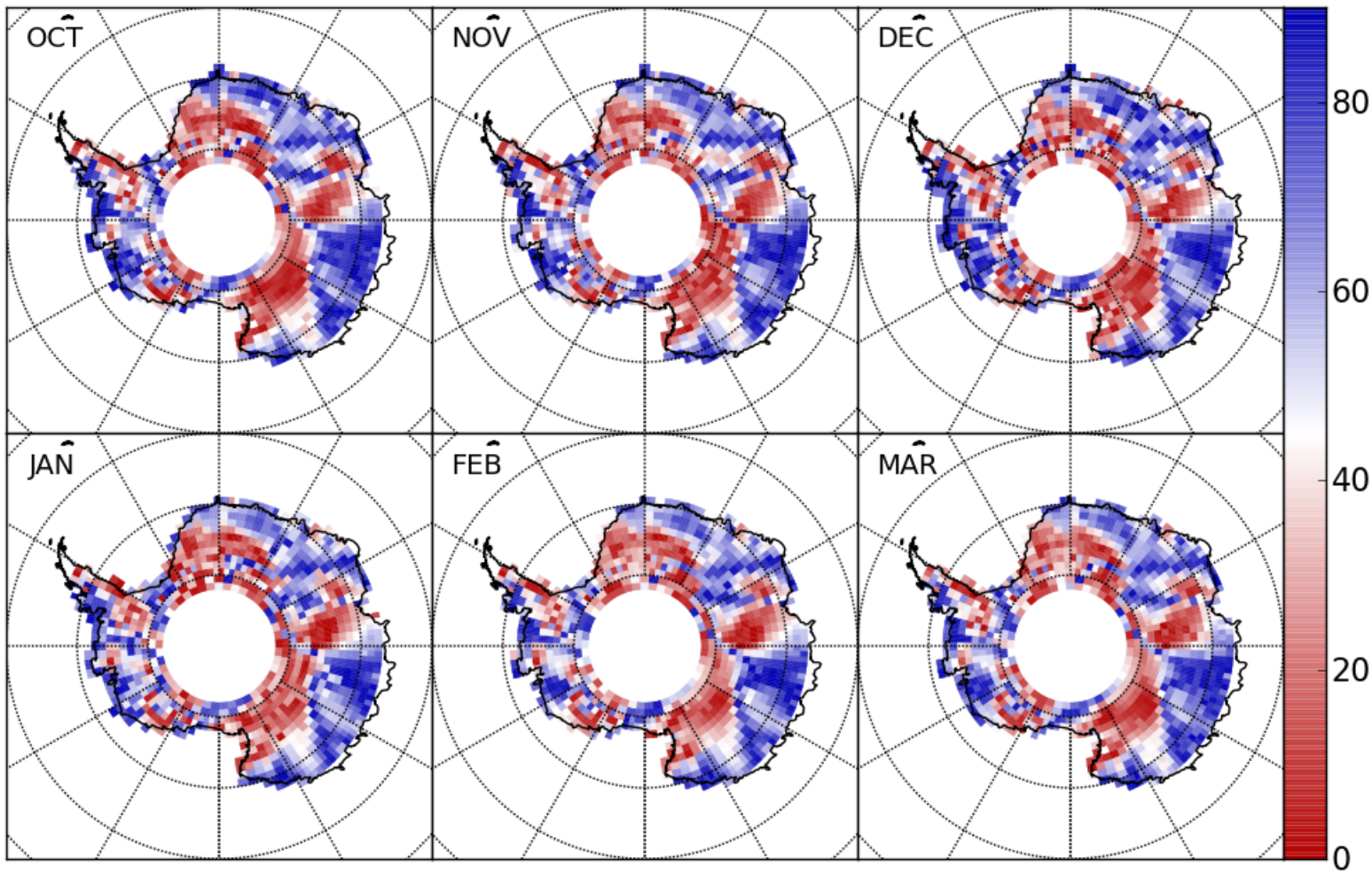
ADM_{Neg} = Negative regions
ADM_{Pos} = Positive regions

ADM_{Neg} : Lower forward peak and higher back peak
- Sastrugi orientation ***perpendicular***.

ADM_{Pos} **:** Higher forward peak and lower back peak
- Sastrugi orientation ***parallel***.

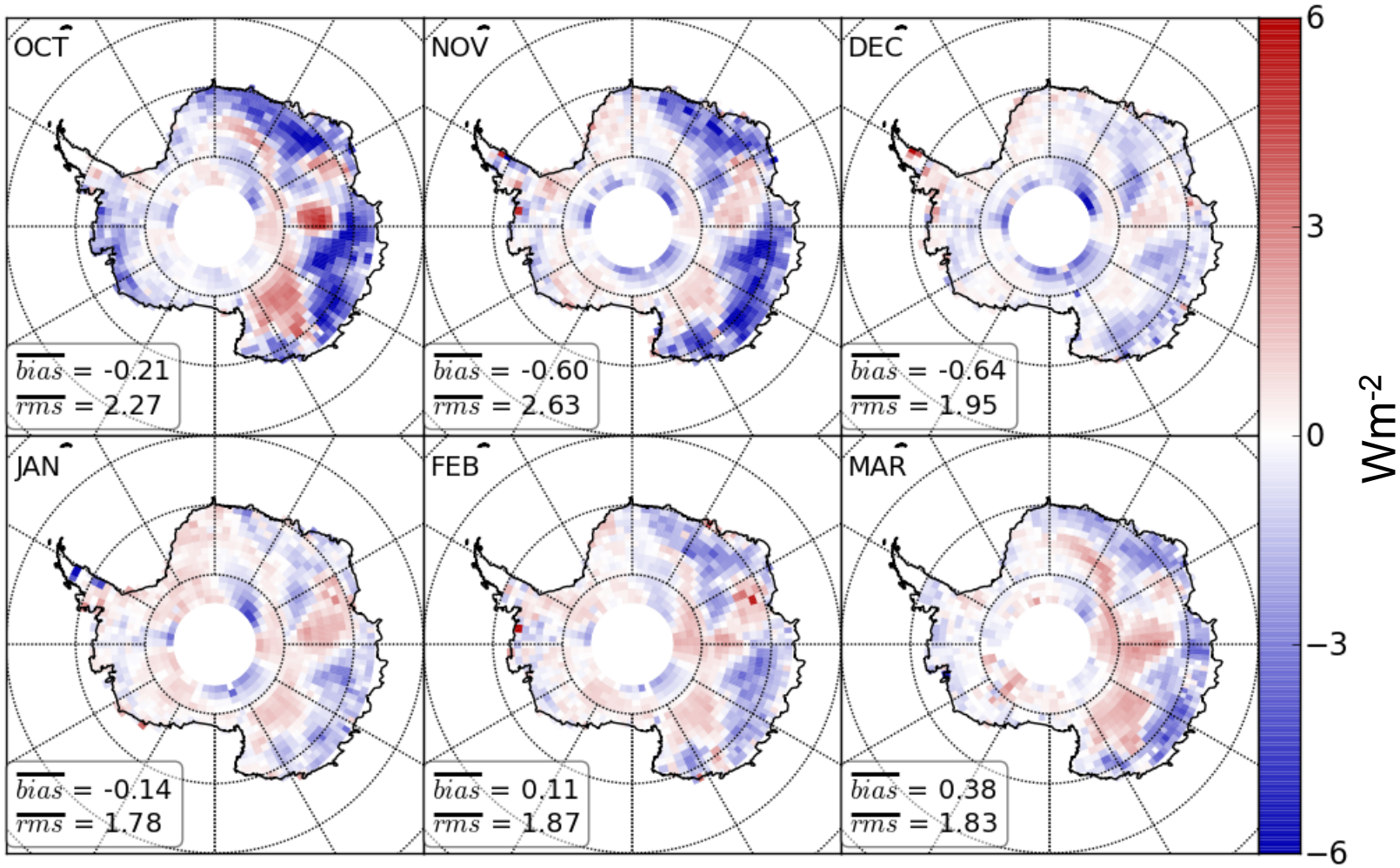
The difference between wind direction and solar azimuth angles

Most Freq Wind Direction - Most frequent solar azimuth 2001-2004 ($\Delta\phi_{ws}$)

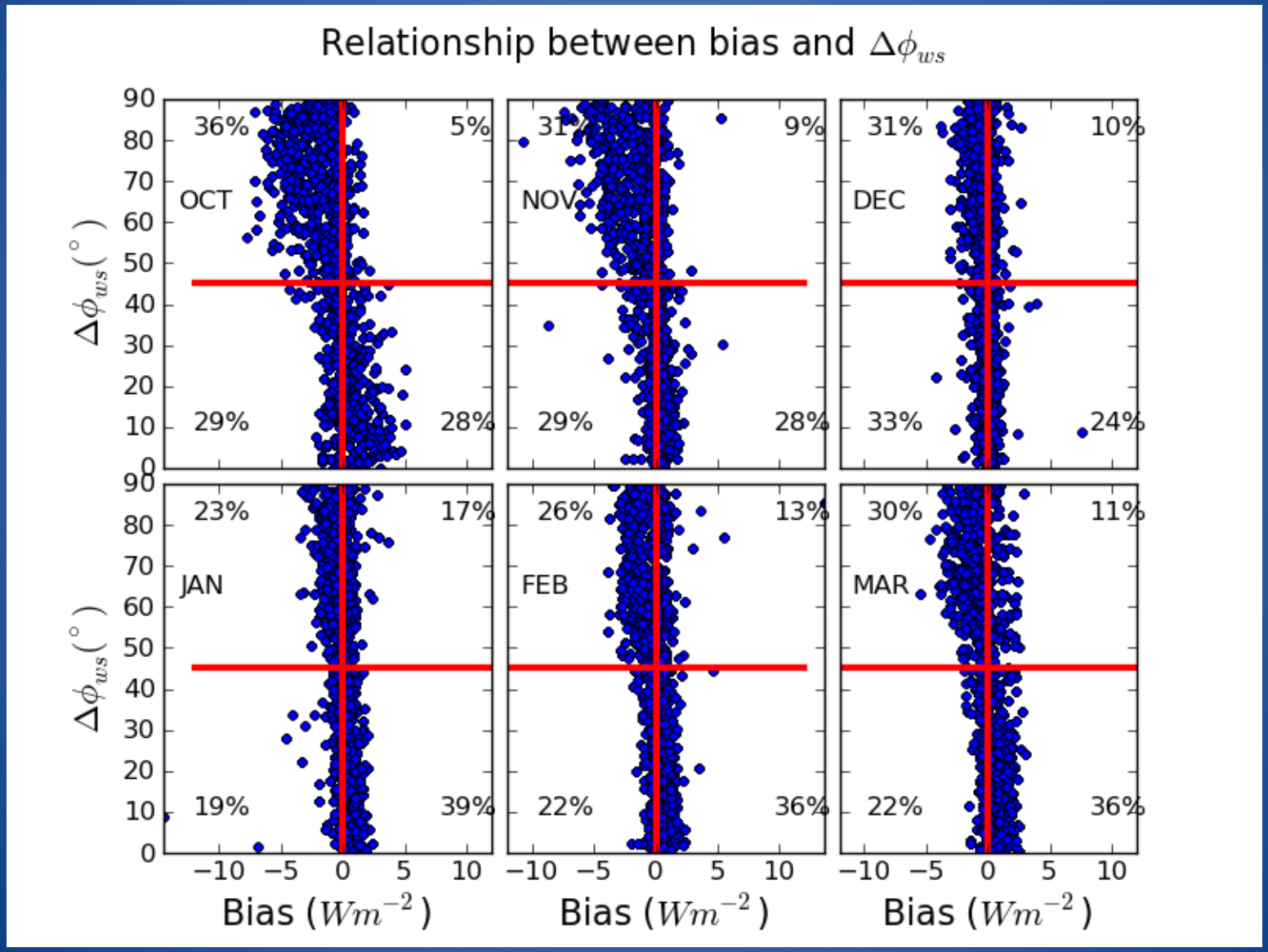


Comparing with Clear Sky flux biases shows some agreement

FM1 and FM2 Mean Clear Sky Flux Bias 2001-2009 (Wm^2)

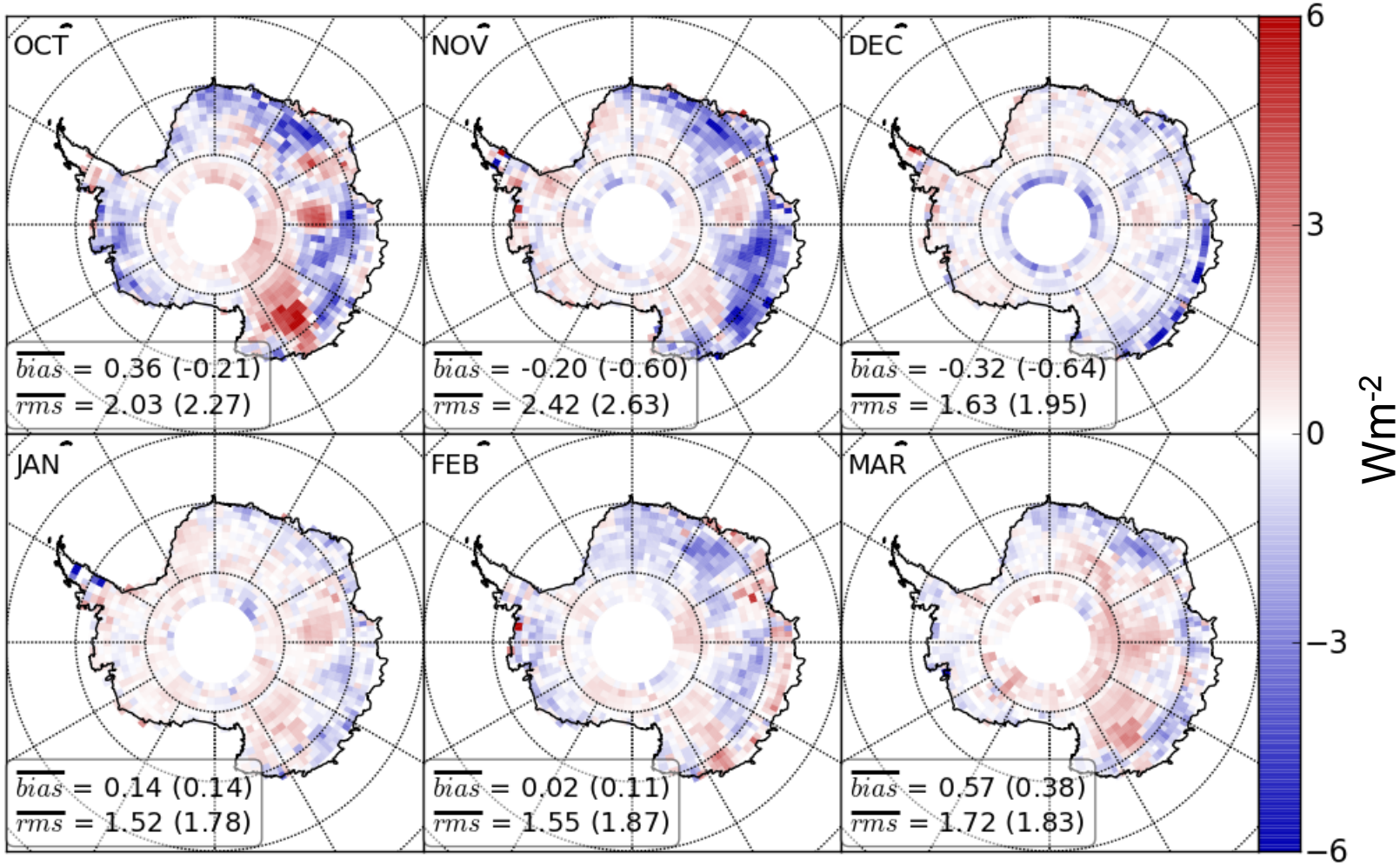


Bias and wind-sun orientation



Is this a better way to construct the ADMs?

ADM$_2$ Mean Clear Sky Flux Bias 2001-2009 (Wm^2)



Conclusions

- It appears sastrugi introduce a bias into CERES TOA albedo/flux measurements.
- Size depends on temporal and spatial averaging
  - Instantaneous:
    - bias unknown, depends on geometry
  - Monthly-regional:
    - Clear sky < ±5 Wm^{-2}
  - Yearly - global:
    - Clear Sky ~ 0.00 Wm^{-2}
- Explicitly attempting to account for sastrugi in angular models shows no improvement.

Thank You!

What about all-sky?

FM1 and FM2 Mean All Sky Flux Bias 2001-2009 (Wm^2)

$$\overline{bias}_{6months} = -0.17$$