Disagreement in Observed and Simulated Cloud Perimeter Distributions

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Cloud perimeters as a control on fluxes

Simulation of clouds in climate models remains problematic due to the complexity of processes involved, despite improvements in model physics. To attack this problem, recent work has turned to the large-scale boundary conditions and their overall thermodynamic constraints. Cloud perimeters, as the boundary across which clouds grow or shrink laterally, have emerged as primarily important in controlling the mean cloud state [1].

Perimeter distributions: expectation

- In [1], cloud perimeter distributions are derived assuming all perimeter classes have equal total flux.
- The result implies the number n density of cloud perimeters p is linear in logarithmic space with slope -1:

$$\frac{dn}{d\log p} \propto p^{-\beta} \tag{1}$$

$$\beta = 1 \tag{2}$$

- Cloud areas are similarly power-law distributed and a fractal dimension converts area and perimeter [5]

Image edge bias

- Significant disagreement in previously calculated area distributions:
  - from a slope of 0.3 in [2] to 0.87 in [3]
  - Scale break at 0.28 km^2 [4] or, alternatively, 10^6km^2 [3].
- Clouds touching the edge of the image have been previously underappreciated, but cause significant bias (Figure 1)
- Can be accounted for by omitting large bins

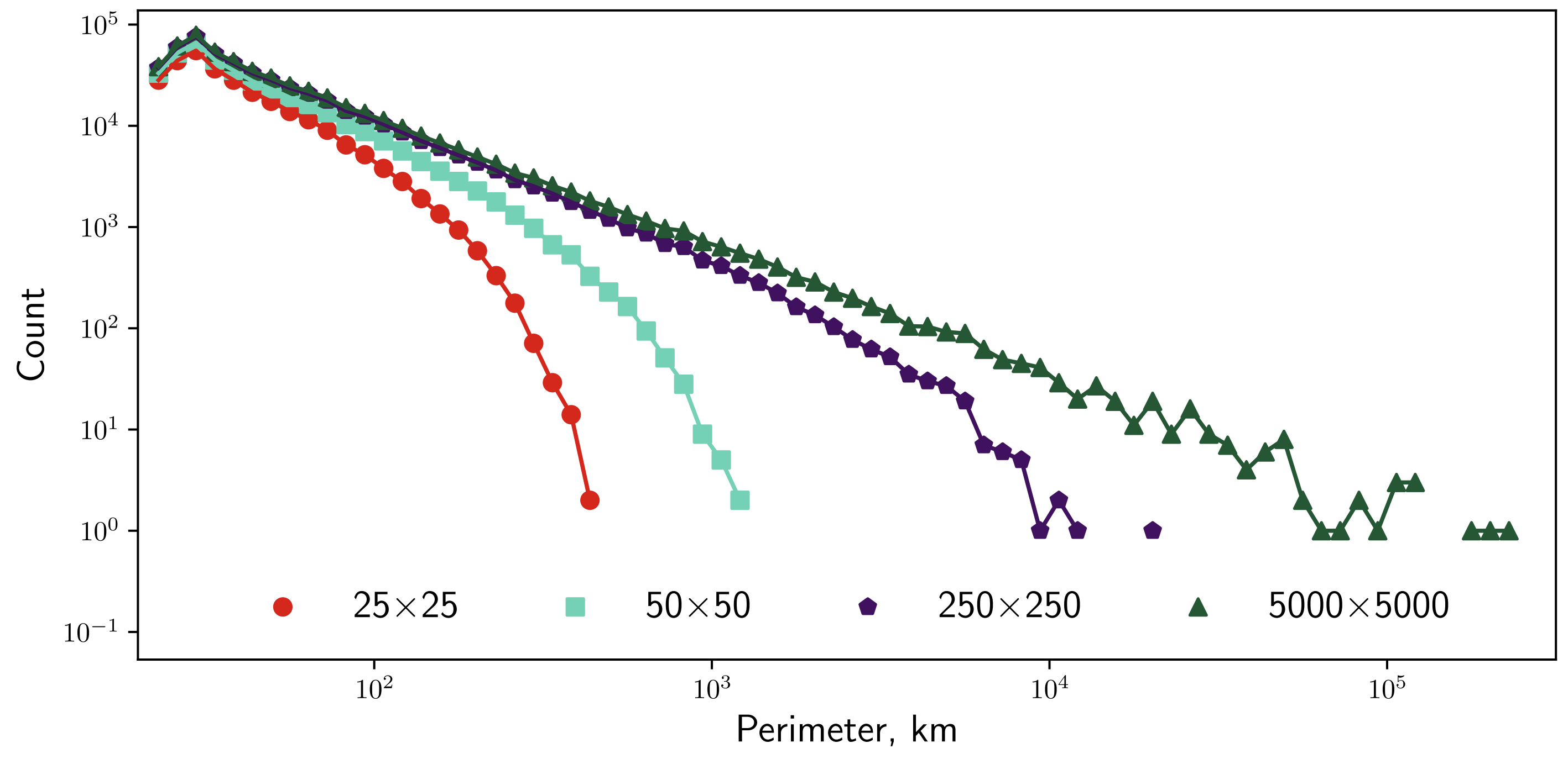

Figure 1: Histograms of clouds from GOES WEST. Each image is broken up into smaller subdomains, listed in units of pixels, and clouds touching the subdomain edge removed. For example, the 25×25 series simulates images taken with a sensor approximately 50km × 50km. While each histogram is made from the same original data, as the image gets smaller, the edge effect becomes stronger and can be misinterpreted as a scale break.

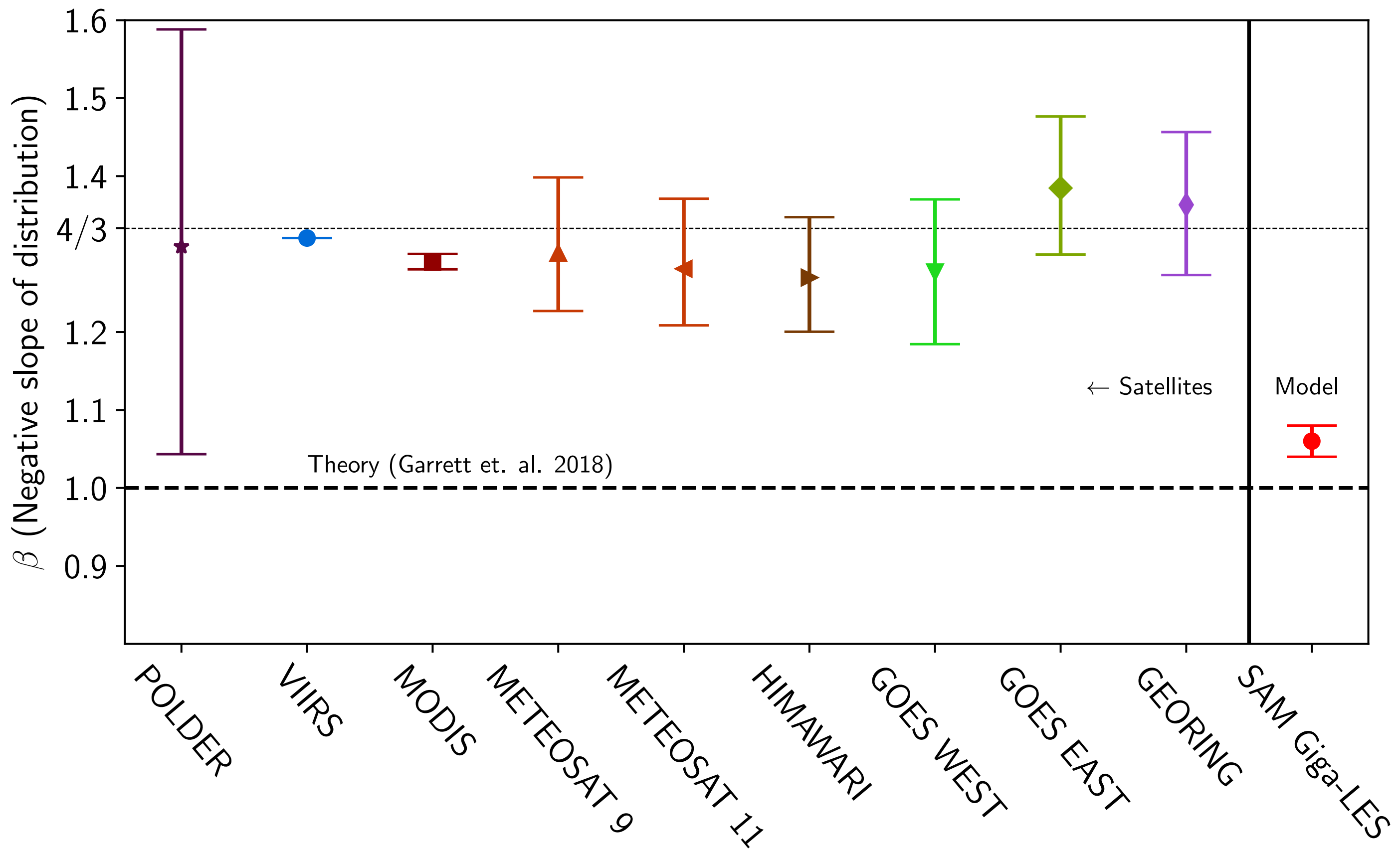

Figure 2: Slopes of the histograms in figure 3 compared to theory. β is the slope of the histogram; see equation 1. There is broad agreement between satellites around a value of $\beta \approx 4/3$, significantly above that of SAM and theory.

Why the disagreement?

The slope β is notably close to the fractal dimension $D = 4/3$, suggesting perimeter p needs to be replaced with p^D in the theory presented in [1]. This also suggests model cloud perimeters, calculated at model resolution, are too small.

After accounting for a novel source of bias, satellite-measured cloud size distributions significantly disagree with model-derived parameters and theory

More Information

https://www.inscc.utah.edu/~u1020524/pan-gass/poster-info.html

This project funded by NSF award 2022941

References: [1] Garrett et. al. 2018; [2] Koren et. al. 2008; [3] Wood & Field, 2011; [4] Calahan & Joseph 1989; [5] Lovejoy, 1982

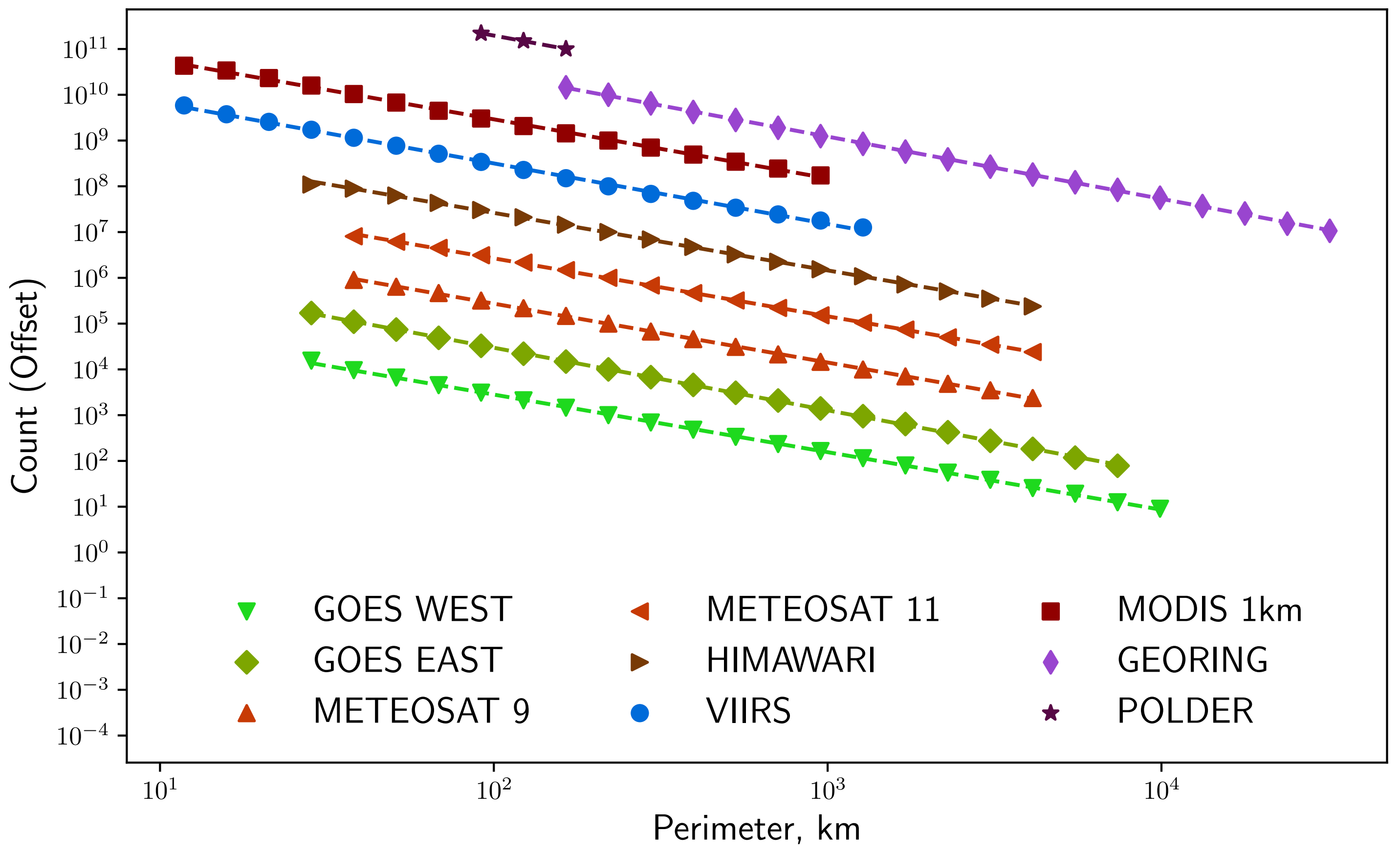

Figure 3: Perimeter distributions derived from satellite data and the SAM Giga-LES model, accounting for edge biases shown in figure 1.

Seasonality, latitude, and surface type

Satellite-measured perimeters show robust disagreements with theory and model across surface types, latitudinal bands, and seasons (figures 4 and 5)

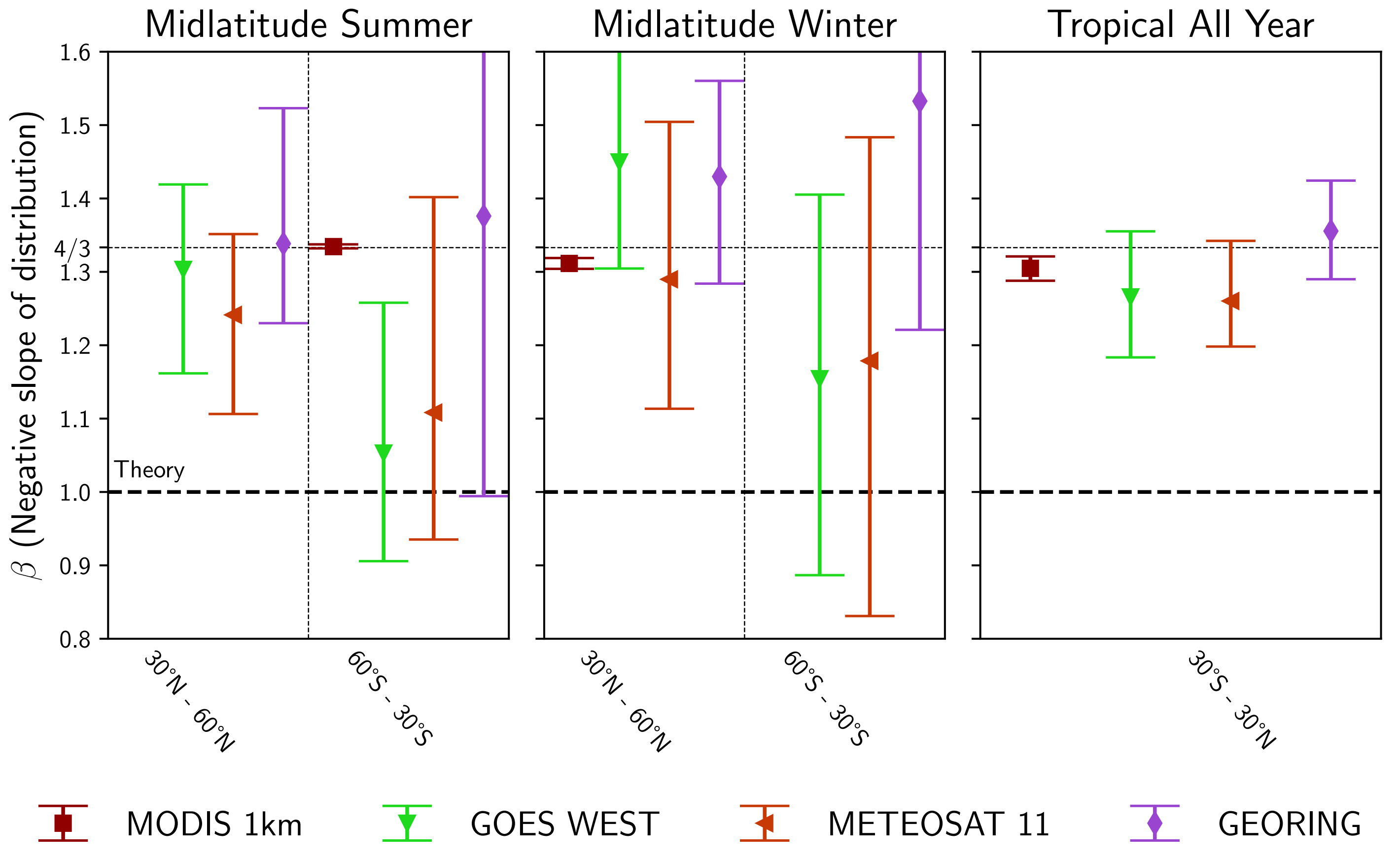

Figure 4: β by season and latitude band

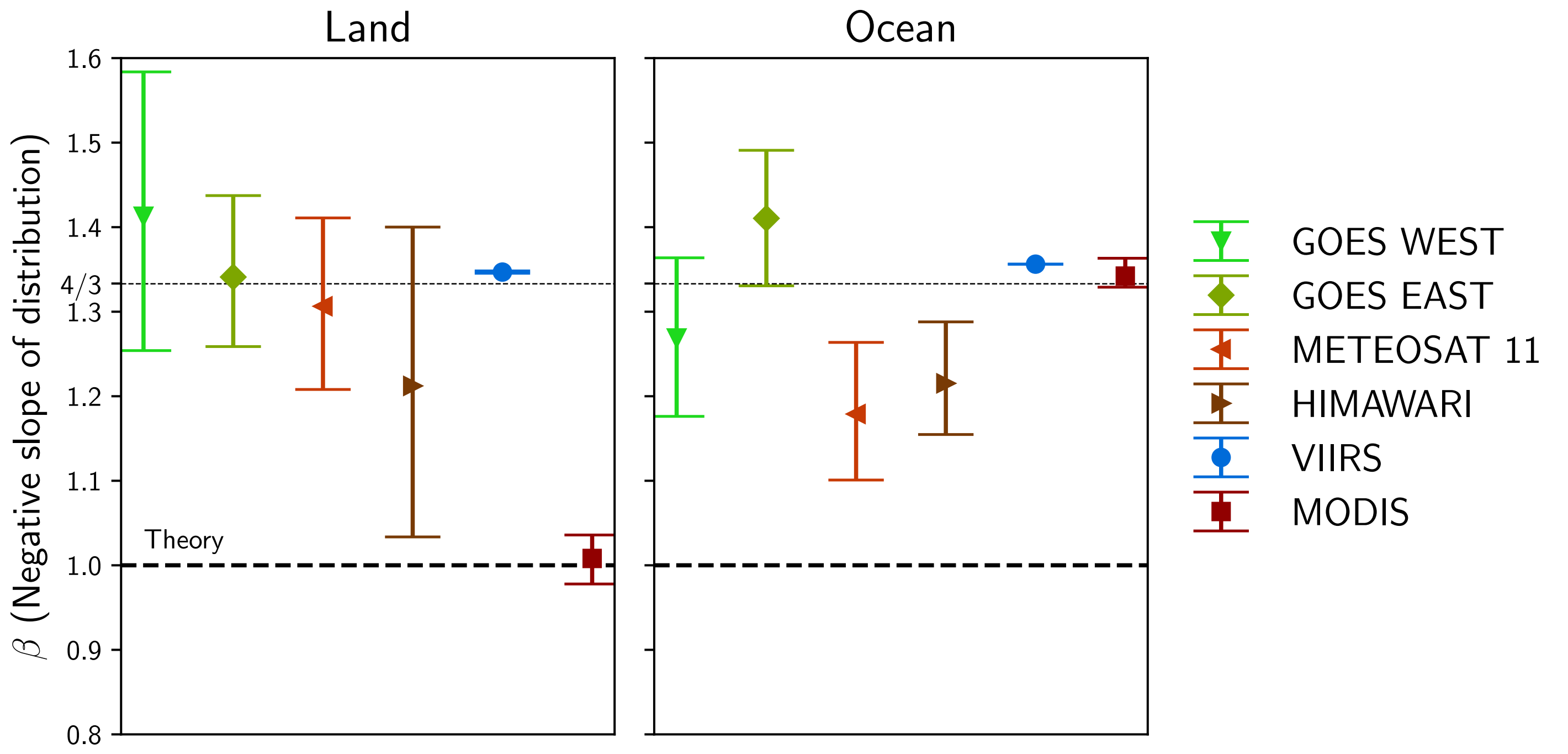

Figure 5: β by surface type