Understanding relationships between satellite, model, and ground-based surface temperature characterizations from overcast to clear conditions

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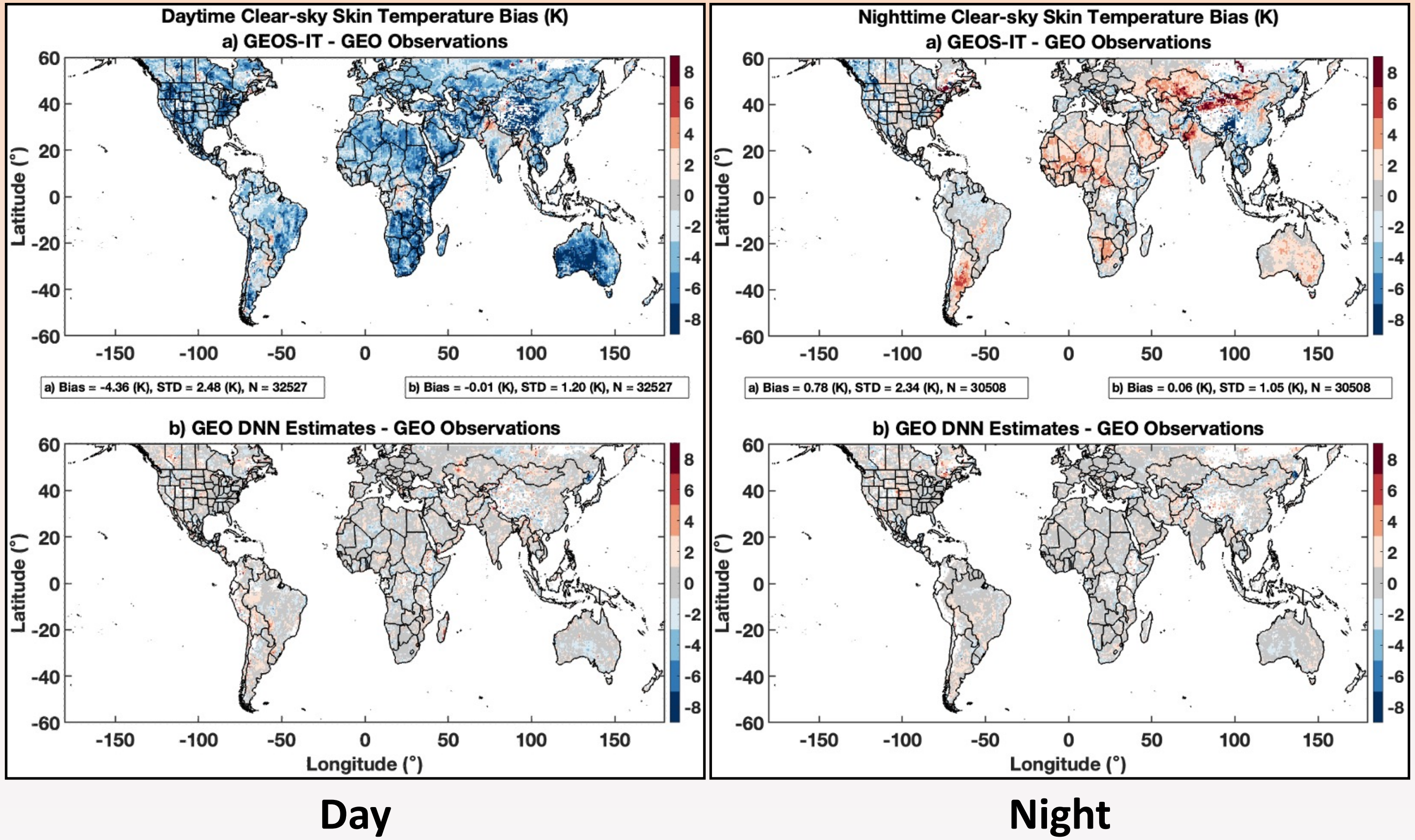
Background

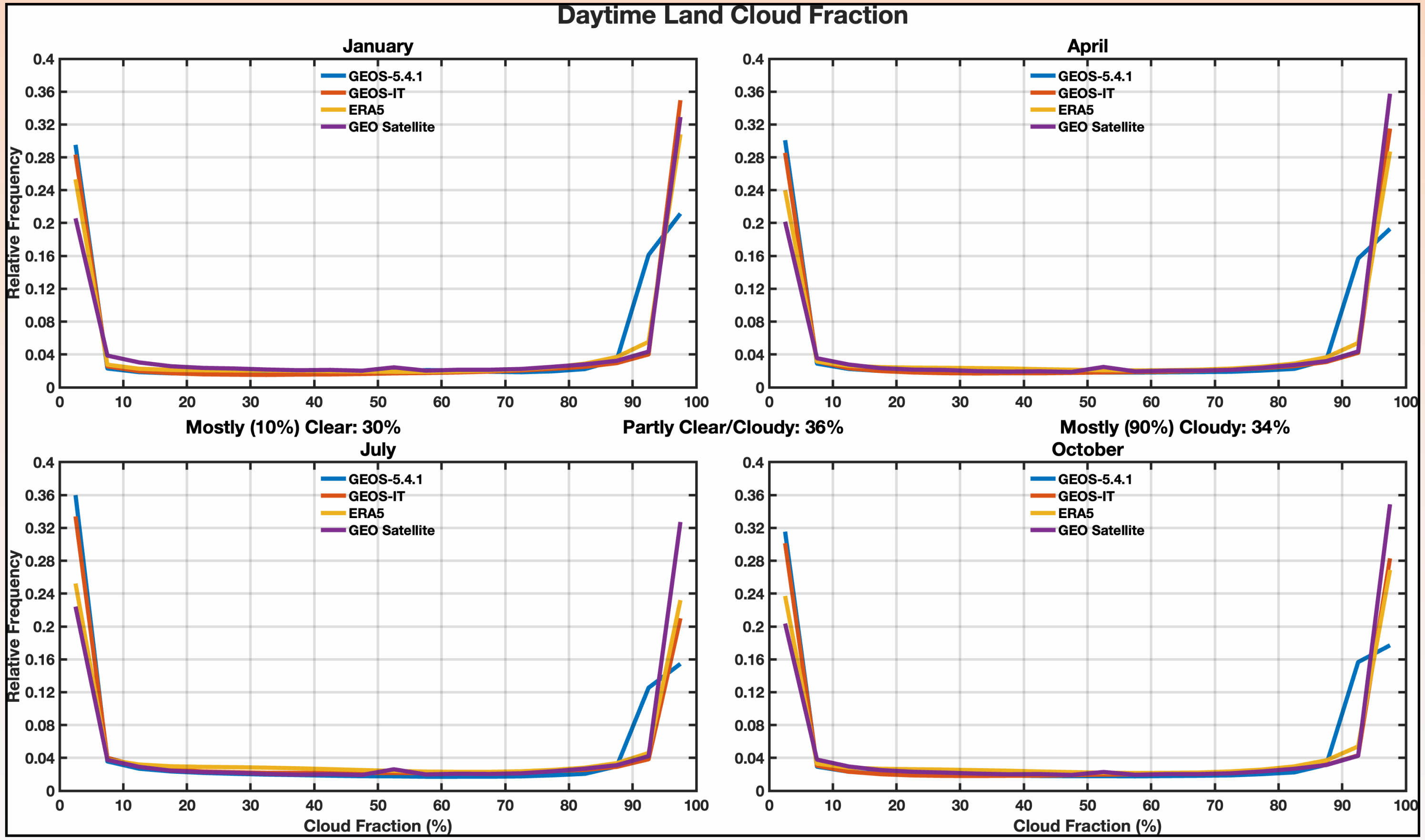
- Cloud mask threshold approaches rely on cloud-free skin temperature **(T_s)** estimate
- T_s in cloudy condition necessary for optical depth and height retrievals
- Downstream radiation budget calculations rely on clouds and on model T_s in cloudy condition
- High variance in observed + model T_s in all-sky conditions
- In GEO we estimate a cloud-free T_s with reasonably good accuracy using cloud-free observations, model 2-m air temperature **(T_a)**, and a deep neural network **(DNN)**



Can relationships between observed clear-sky T_s and modeled T_s+T_a help us estimate a more reliable all-sky T_s?

Objectives

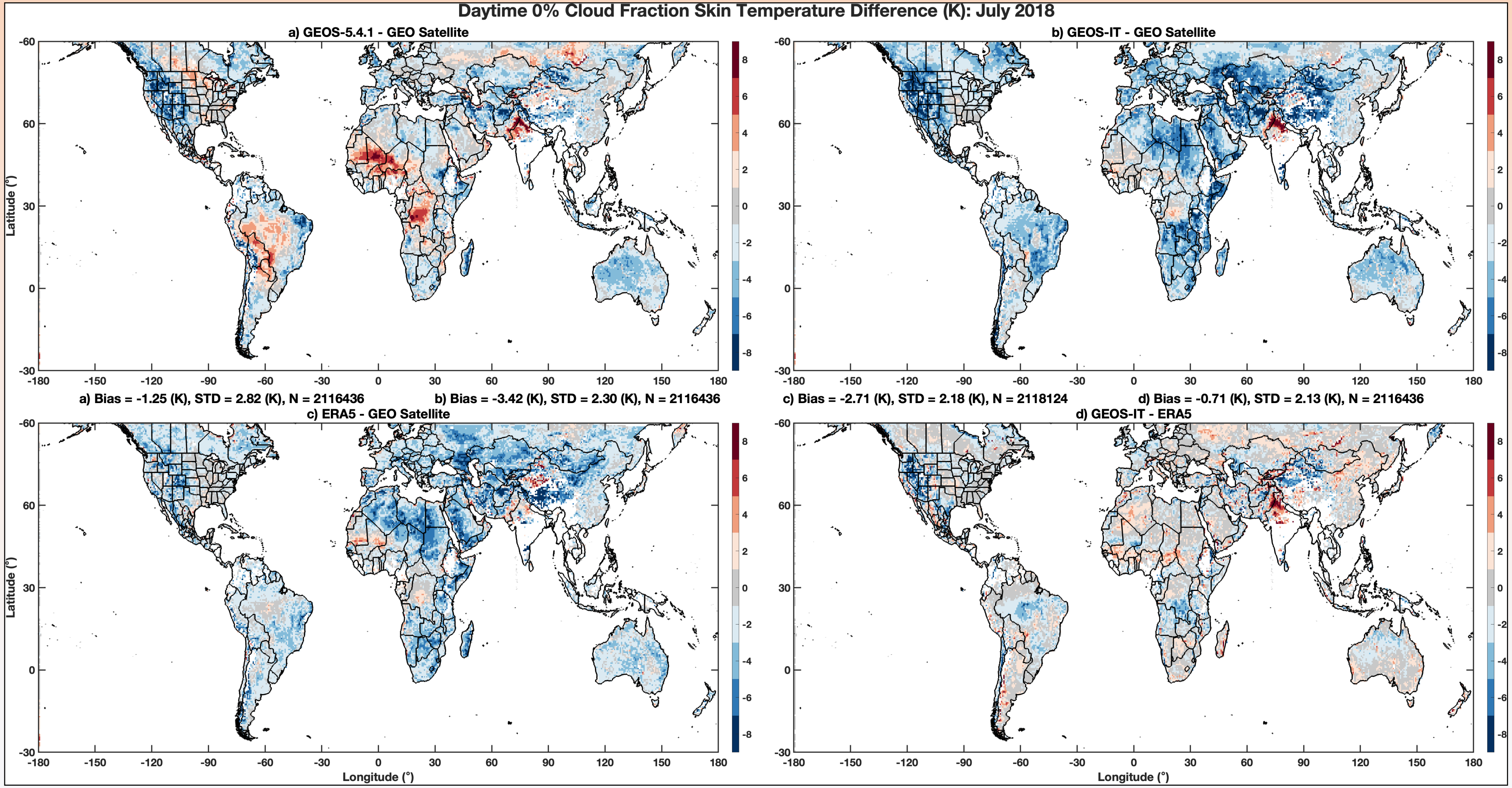
- Highlight cloud-fraction-dependent relationships of:
  - Model T_s and satellite T_s
  - Model T_s and model T_a
  - Model T_a and station T_a
- Suggest paths toward an observation-linked all-sky T_s solution
- Highlight GEO clear-sky T_s DNN developments and explain limitations



~1/3 of land is "partly cloudy" – how to estimate an expected T_s for all-sky conditions ?

Model T_s – Satellite T_s Differences: Day

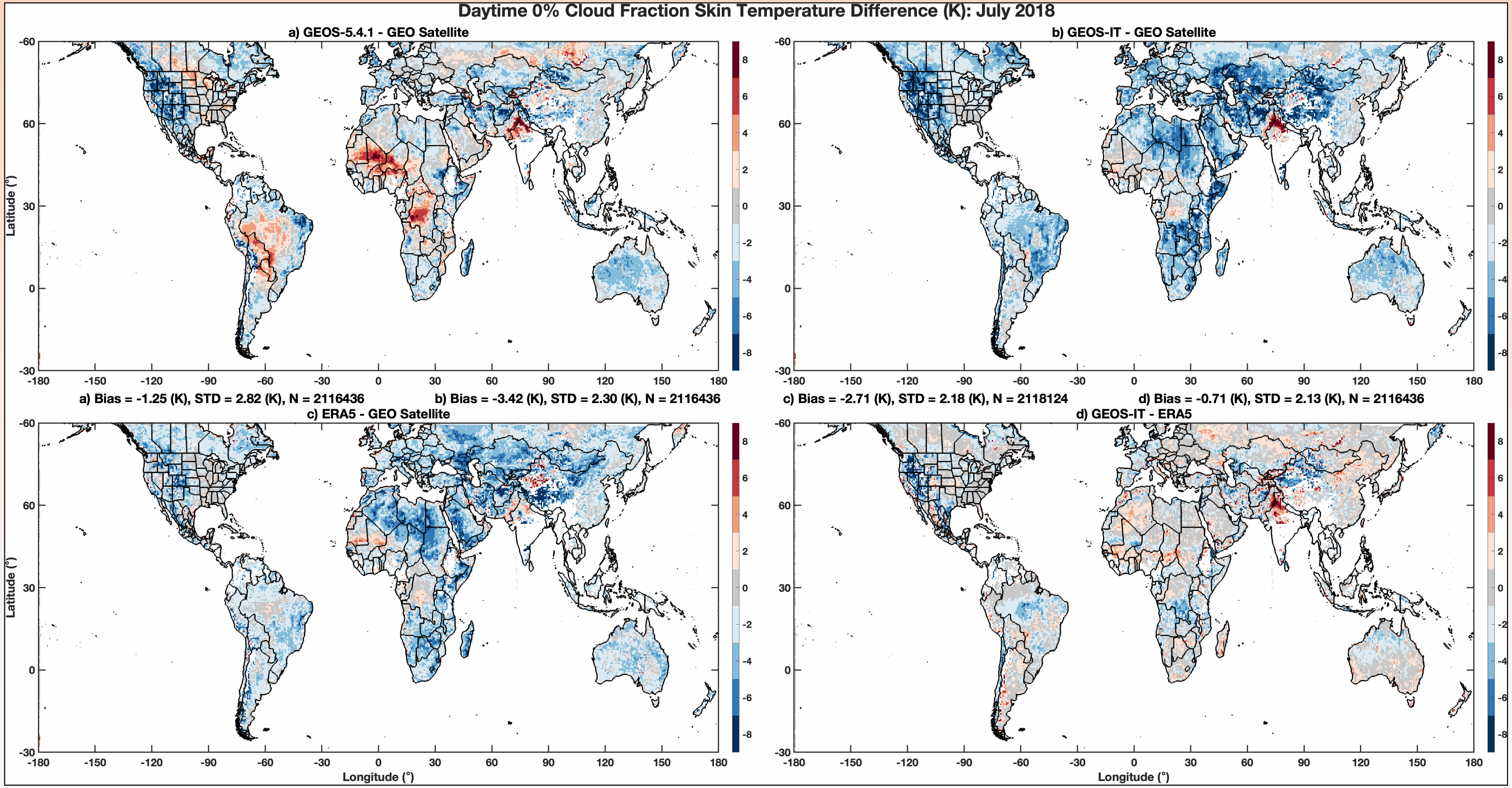
- 0% satellite cloud fraction at 0.5°x0.5°
- Pronounced, positive regional biases in GEOS-5.4.1 – broadly negative biases in GEOS-IT and ERA5
- Relatively comparable GEOS-IT and ERA5 biases, although still distinct (especially where often cloudy)



High daytime variance in regional T_s agreement between different models and satellites observations

Model T_s – Satellite T_s Differences: Day

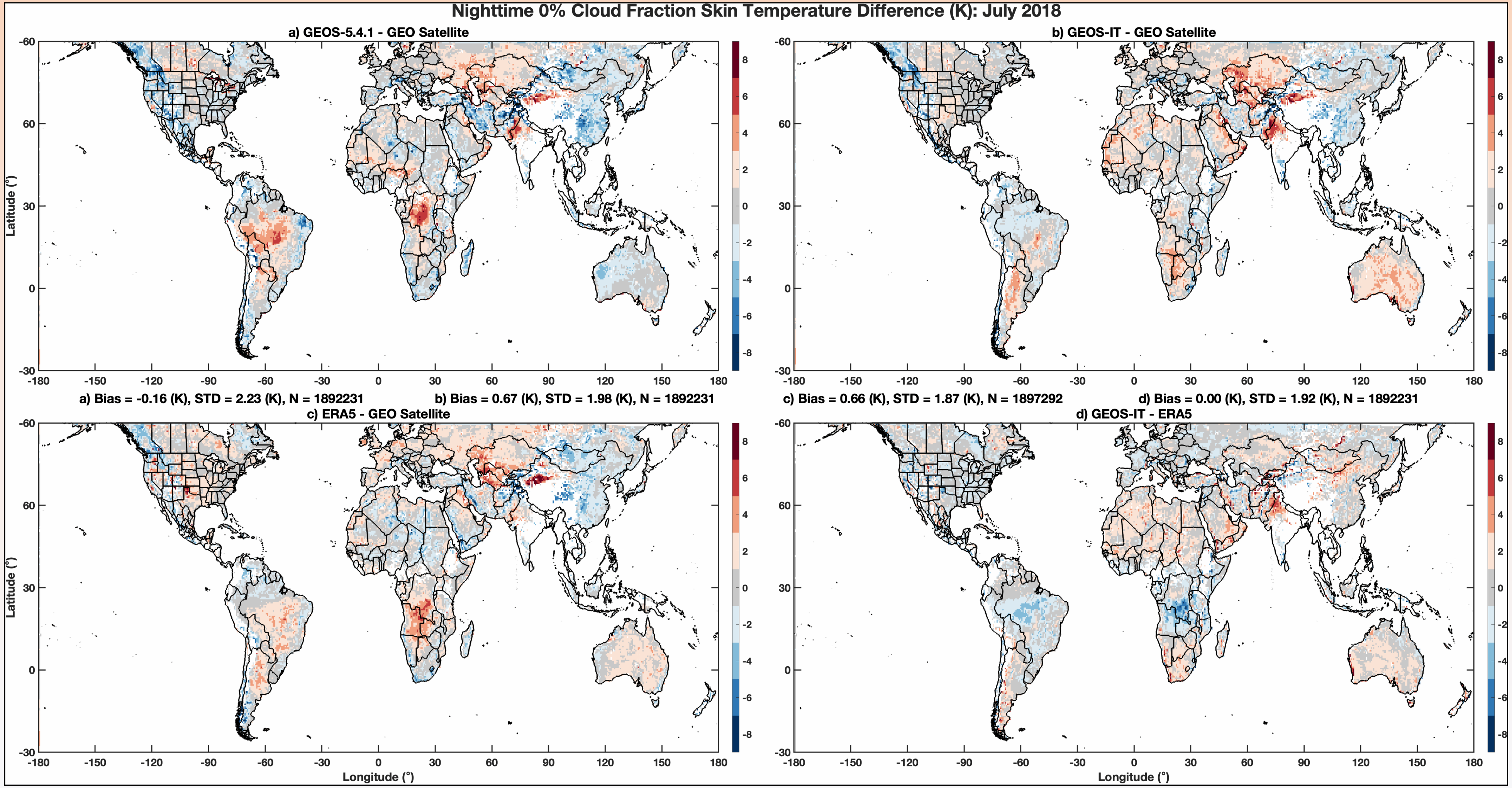
- For increasing satellite cloud fraction
- Would expect <u>cooler</u> daytime all-sky model T_s as cloudiness increases
- Daytime cloud contamination significantly impacting clear-sky observations in all-sky grid tiles



No obvious correlation between regional biases and sample sizes (not shown)

Model T_s – Satellite T_s Differences: Night

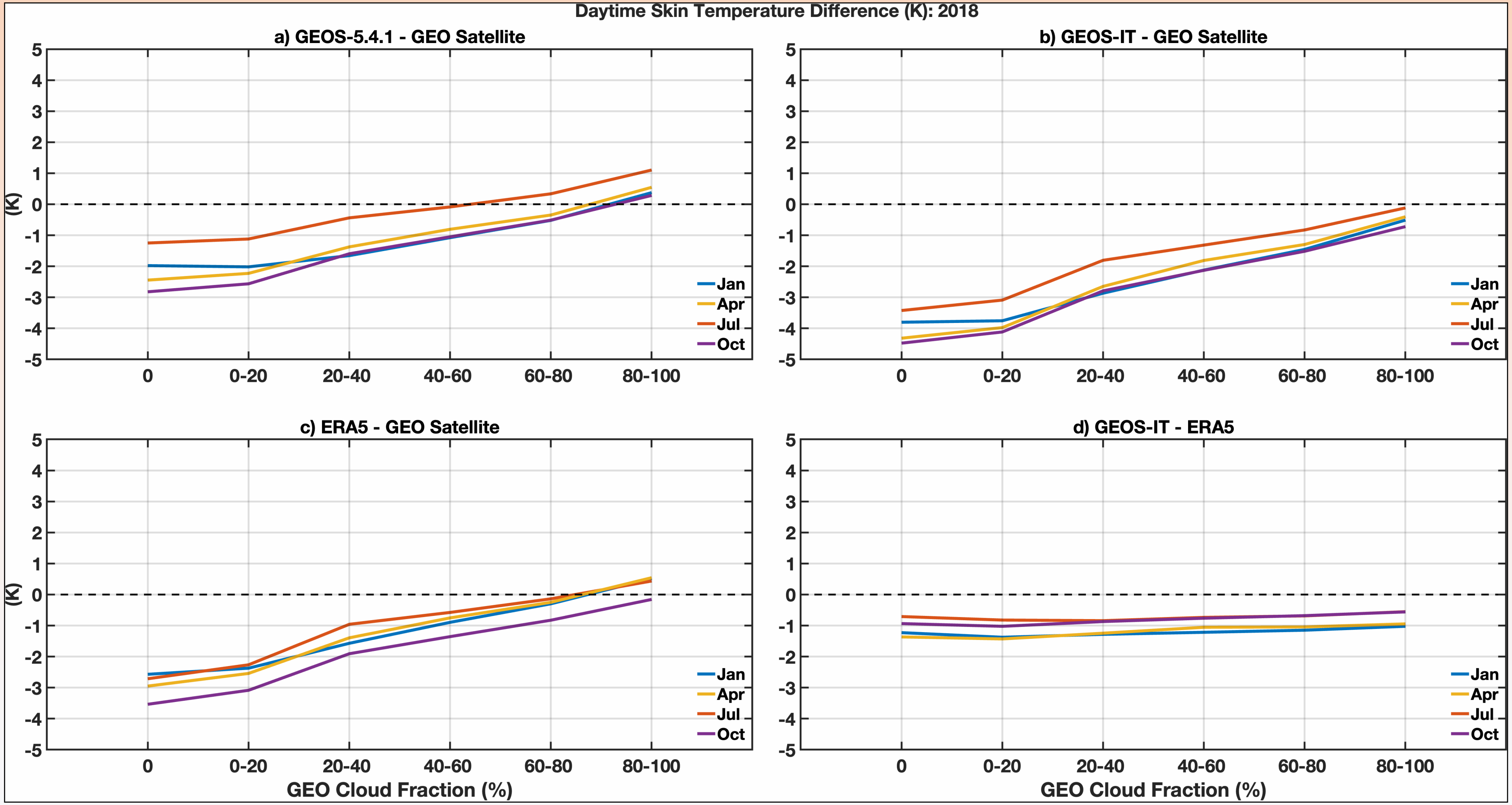
- For increasing satellite cloud fraction
- Would expect warmer nighttime all-sky model T_s as cloudiness increases
- Warm bias tendency compounded by cloud contamination of clear-sky observations



Not *obvious* to conclude whether GEOS-IT is "better" than GEOS5.4.1, or if ERA5 is "better" than GEOS-IT

Model T_s – Satellite T_s Differences: Summary

- All months share these tendencies, although with different offsets
- Driven primarily by imperfect cloud masking (highlights need?)
- GEOS-IT – ERA5 relationship uninfluenced by cloud fraction



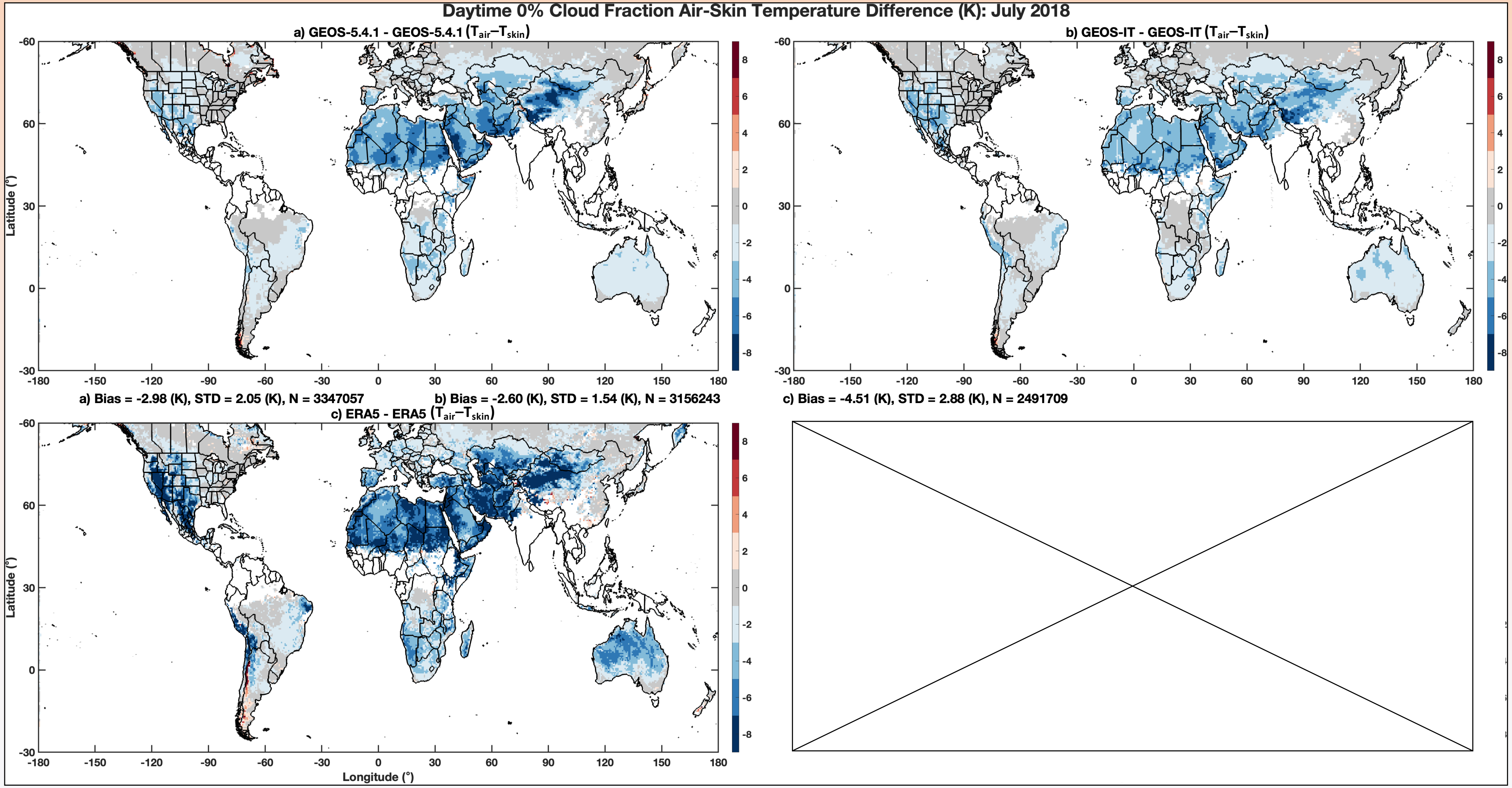
Variance increases with increasing cloud fraction

Model T_a – Model T_s Differences: Day

- Can understanding model T_a–T_s relationships help inform reliable all-sky T_s estimates

- 0% <u>model</u> cloud fraction at 0.5°x0.5°

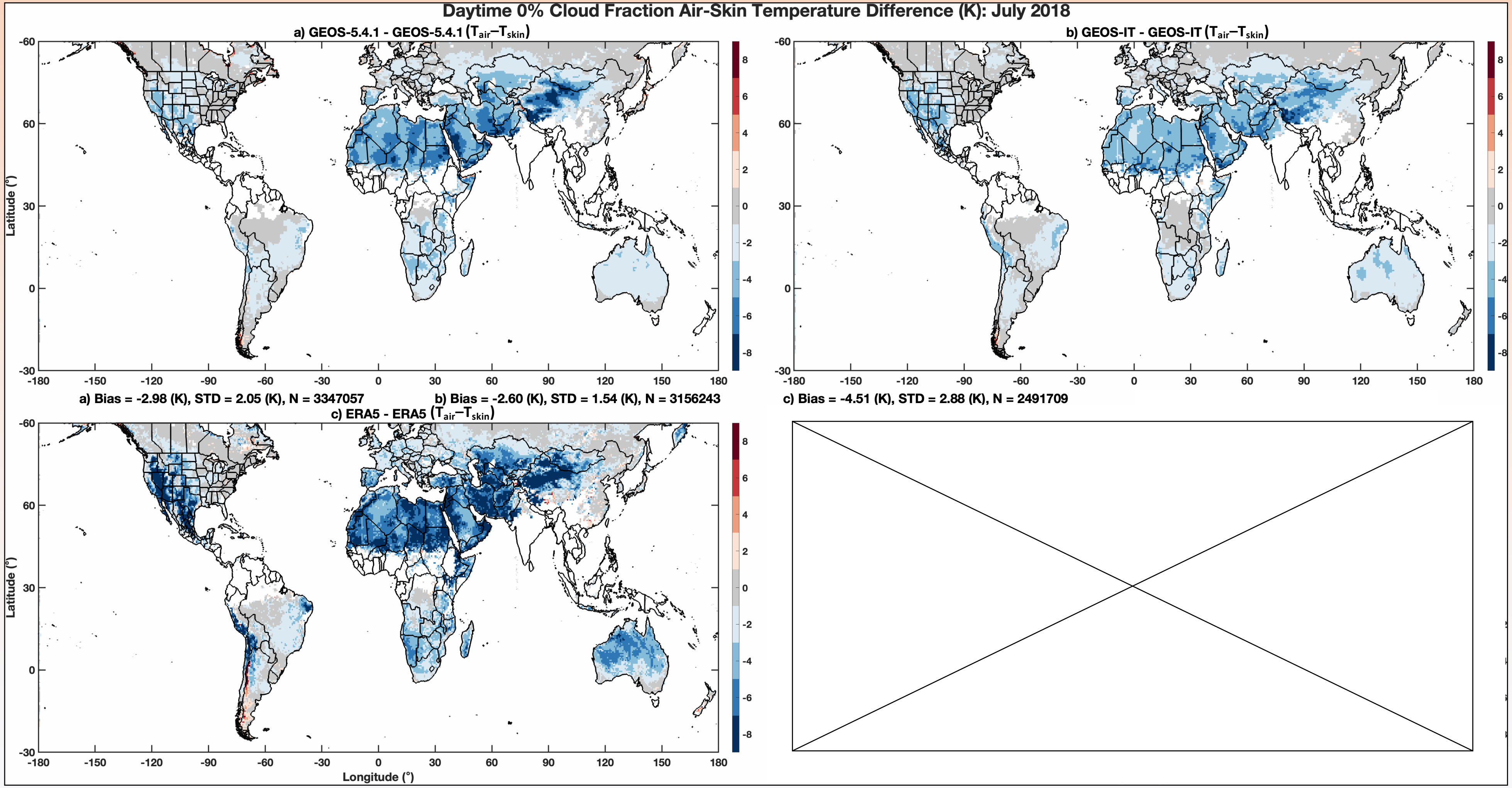
- Daytime 2-m T_a significantly colder than T_s, often where dry or mountainous



GEOS-IT T_a–T_s more often neutral than ERA5 difference, which is >5 K over much of world

Model T_a – Model T_s Differences: Day

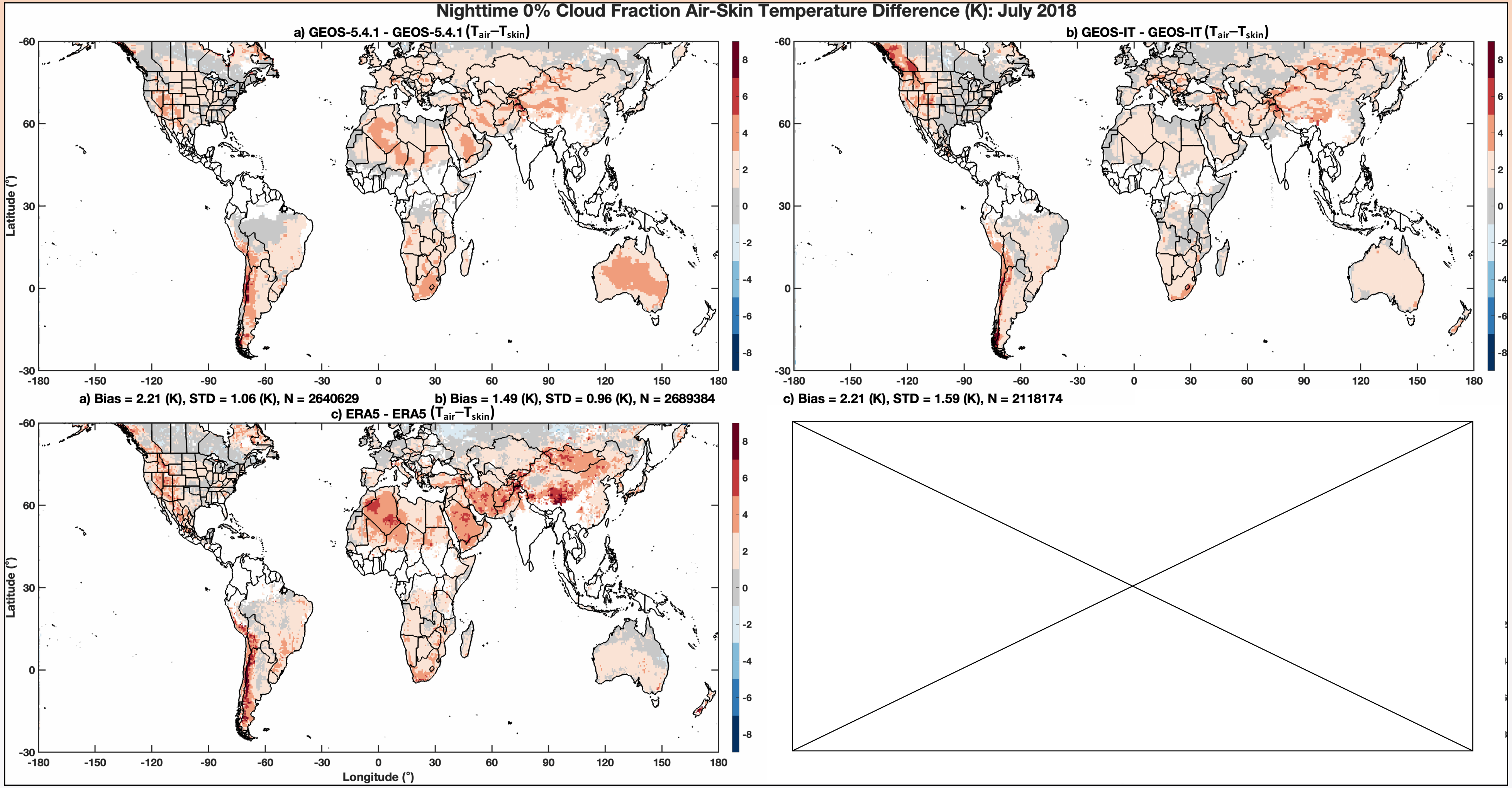
- For increasing model cloud fraction
- Tendency toward 0 K bias as cloudiness ↑
- GEOS-5.4.1 not often claiming 100% overcast



Clear → overcast differences in model T_a–T_s may inform expected T_s bias in cloudy conditions

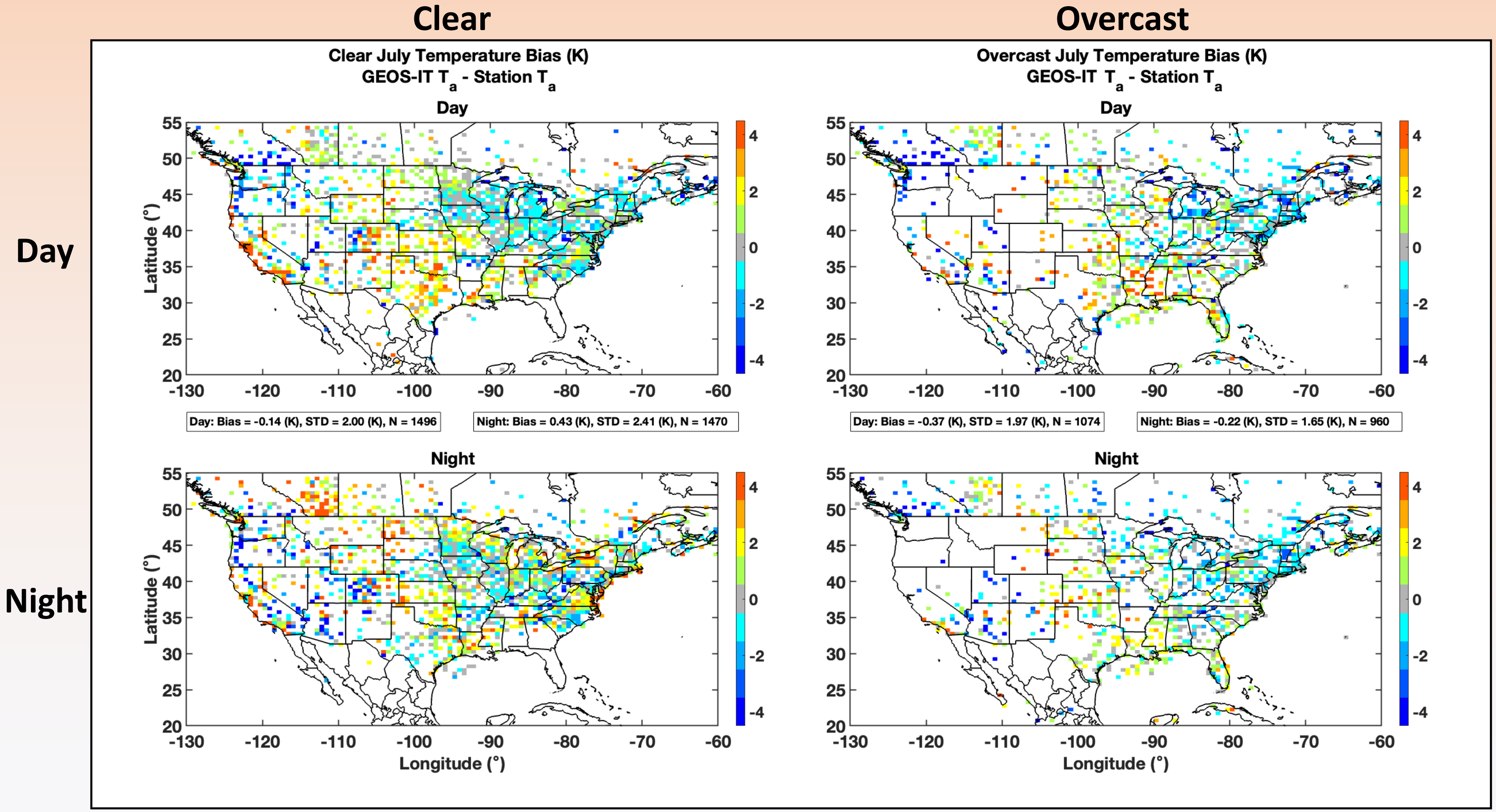
Model T_a – Model T_s Differences: Night

- Clear-sky bias patterns cover similar regions, but reverse of day
- Same tendency toward neutral bias with ↑ clouds
- Models provide all-sky T_s for a grid tile, but we don't have global all-sky ground truth



Can we interpret model clear → overcast T_a–T_s relationships to produce a more accurate cloudy T_s?

Model T_a – Station T_a Differences

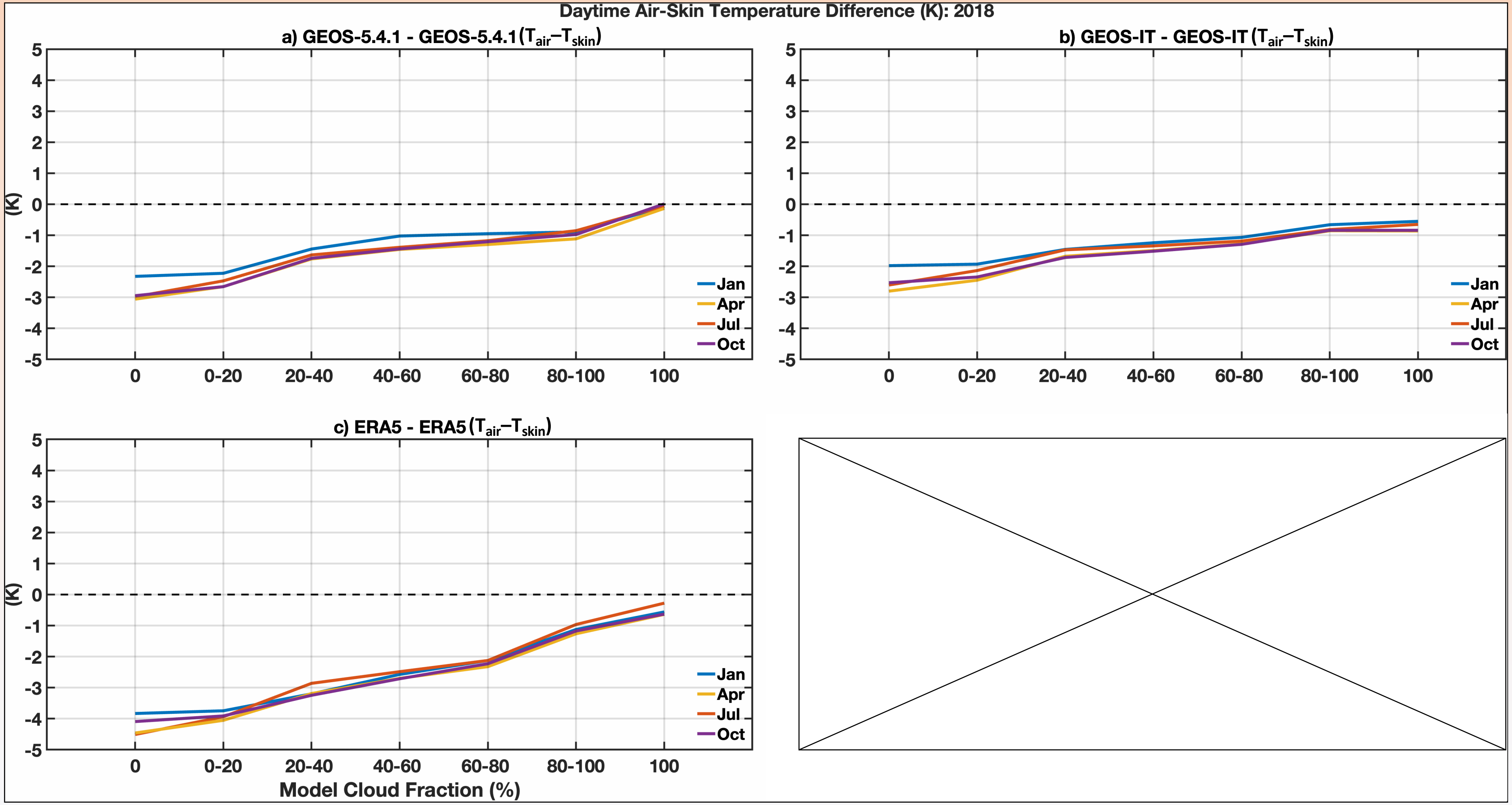


- We know model-satellite clear-sky consistency is poor
- With station data, we can test model T_a consistency for clear → overcast

Overcast model-station consistency about the same as that for clear

Model T_a – Model T_s Differences: Summary

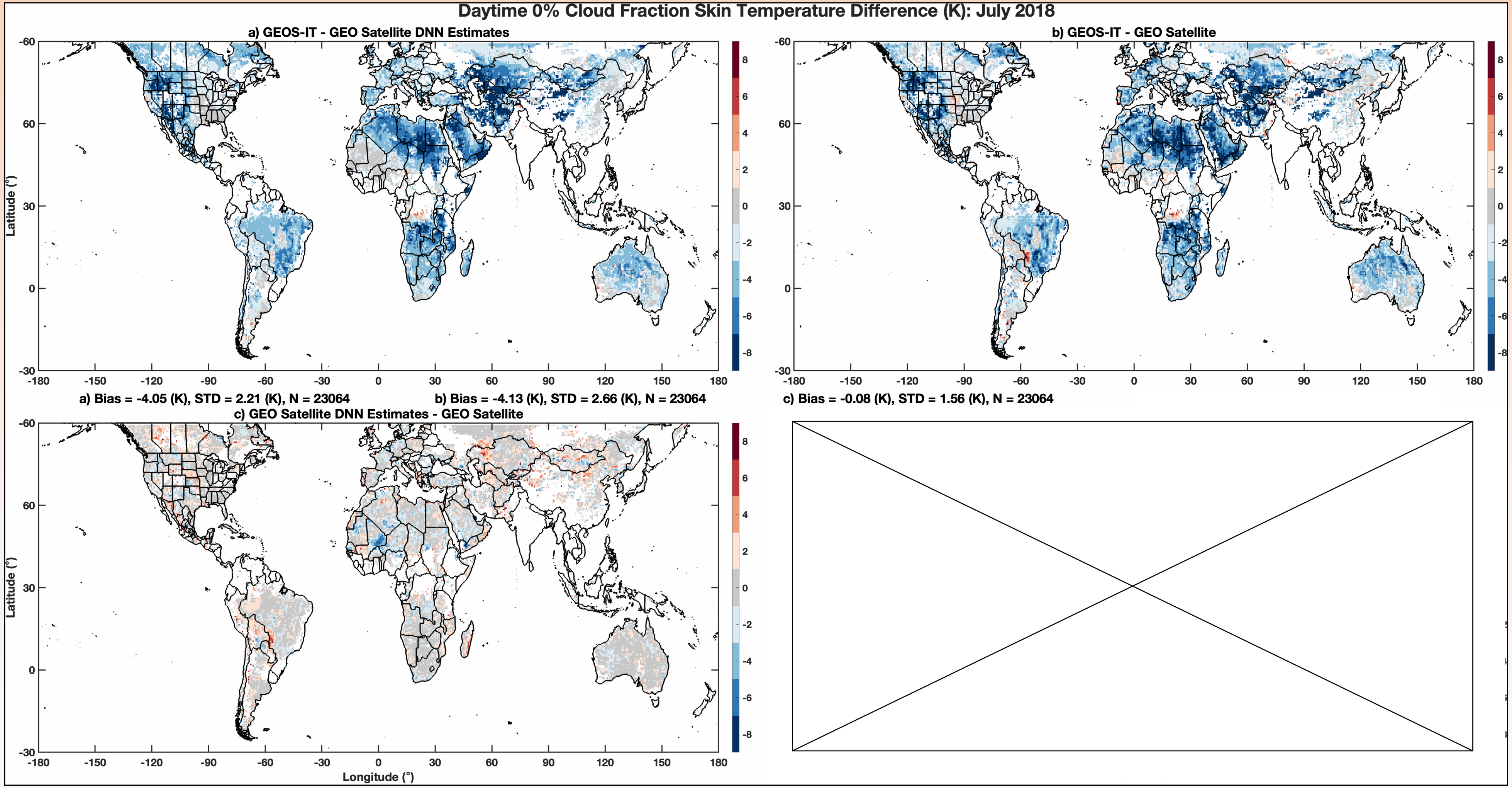
- As clear → overcast, T_s → T_a
- True, on average, for all months, day and night
- Variance decreases with increasing cloud fraction
- Anchor clear-sky satellite estimates to curves in a model – later tie in optical thickness estimate



A good first-order assumption?

Clear-sky T_s DNN Estimates: Day

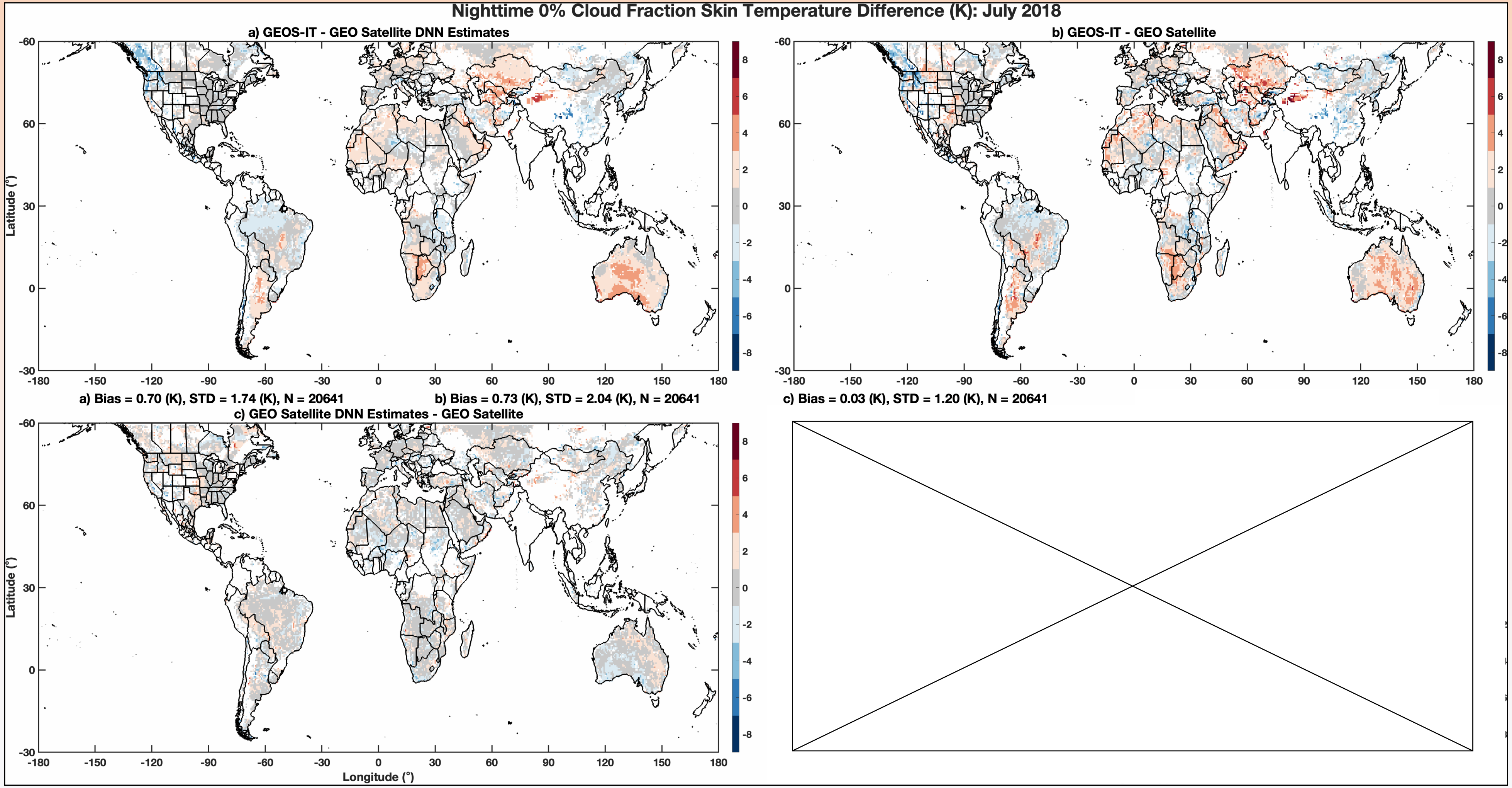
- Clear-sky DNN T_s estimates should be minimally affected by cloud contamination
- Trace cloud contamination where especially cloudy may have influenced training data (a)
- May explain why (a) weighted bias does not decrease further with ↑ cloud fraction



GEO DNN T_s value may be a more reliable clear-sky estimate than observations when partly cloudy

Clear-sky T_s DNN Estimates: Night

- Expect (a) to warm as emitted cloud radiance increases in the model
- Immediately offset by increased dominance of cloudy high elevation regions
- Cloudy mountains seemingly modeled colder than satellite measurements

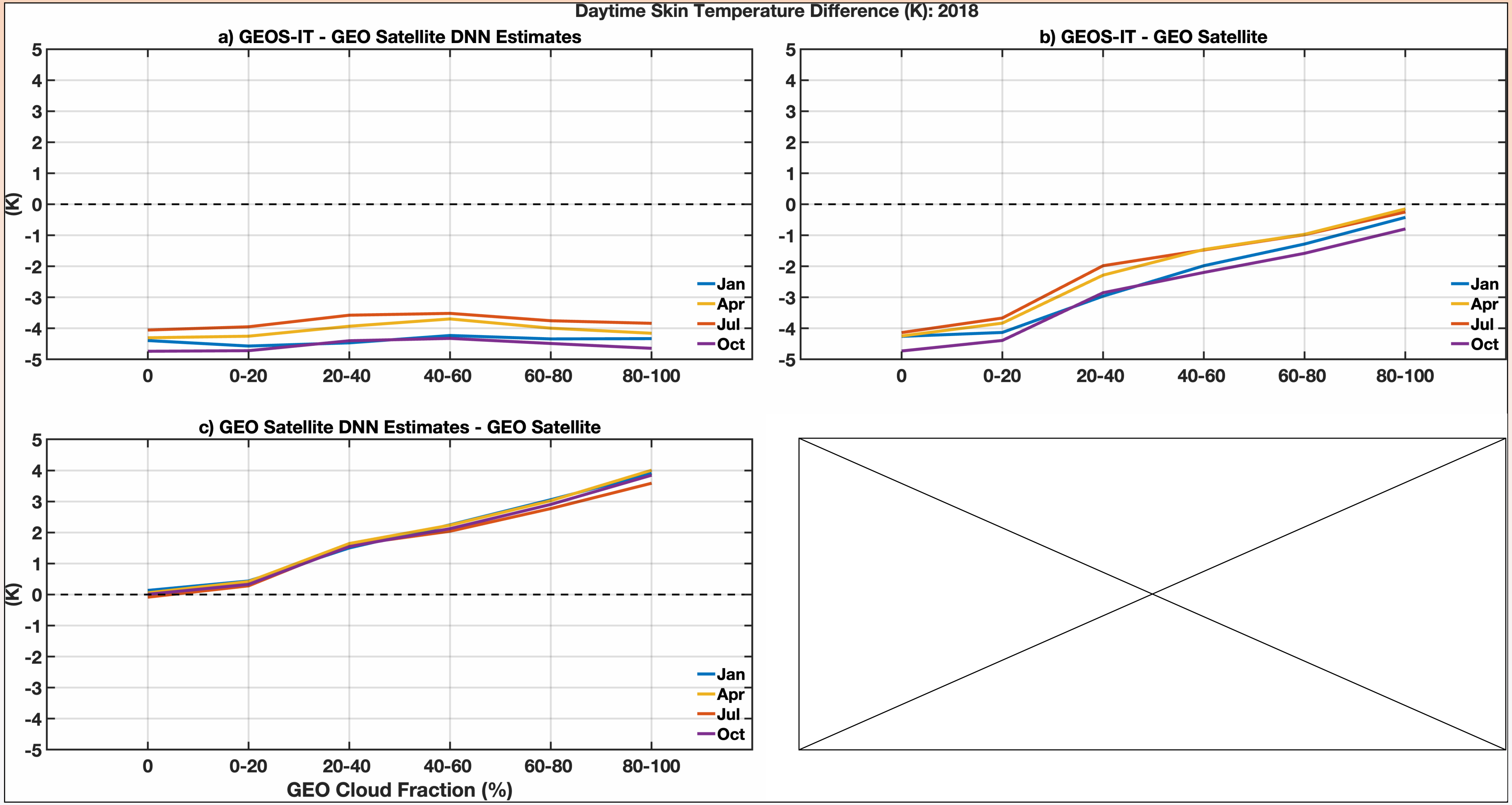


Nighttime GEO DNN T_s also appears to dodge cloud contamination issue

Clear-sky T_s DNN Summary

- For daytime (a), trace cloud contamination initially, then model temperature drops

- For nighttime (a), immediate influence from cold mountainous regions, then thermal emittance strengthens



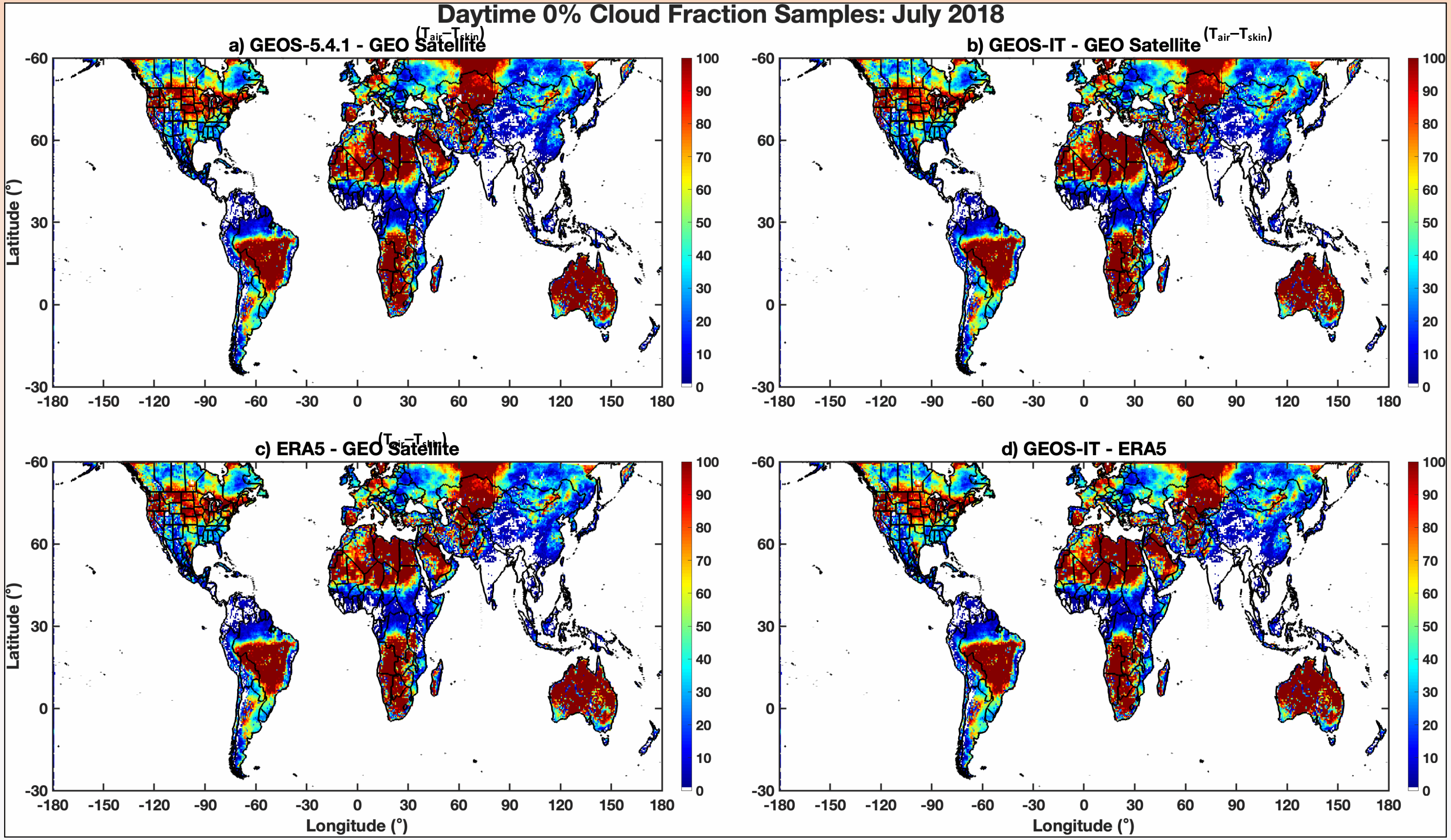
Patterns are consistent across seasons

Summary

- Models deviate significantly from observed surface temperatures in all clear/cloudy conditions
- Satellite-based clear-sky T_s estimates can help produce a more regionally consistent cloud mask
- There is no global ground truth for all-sky/overcast conditions
- Maybe good enough to just use ERA5 because of assimilation practices, but not available in CERES – still shows satellite-relative bias like other models
- Perhaps tendency for $T_s \rightarrow T_a$ as clear → overcast is a *good first-order assumption* for improving all-sky T_s (anchored to expected satellite clear-sky T_s)
- Clear-sky DNN T_s estimates are a good starting point for testing this effort

Additional Slides

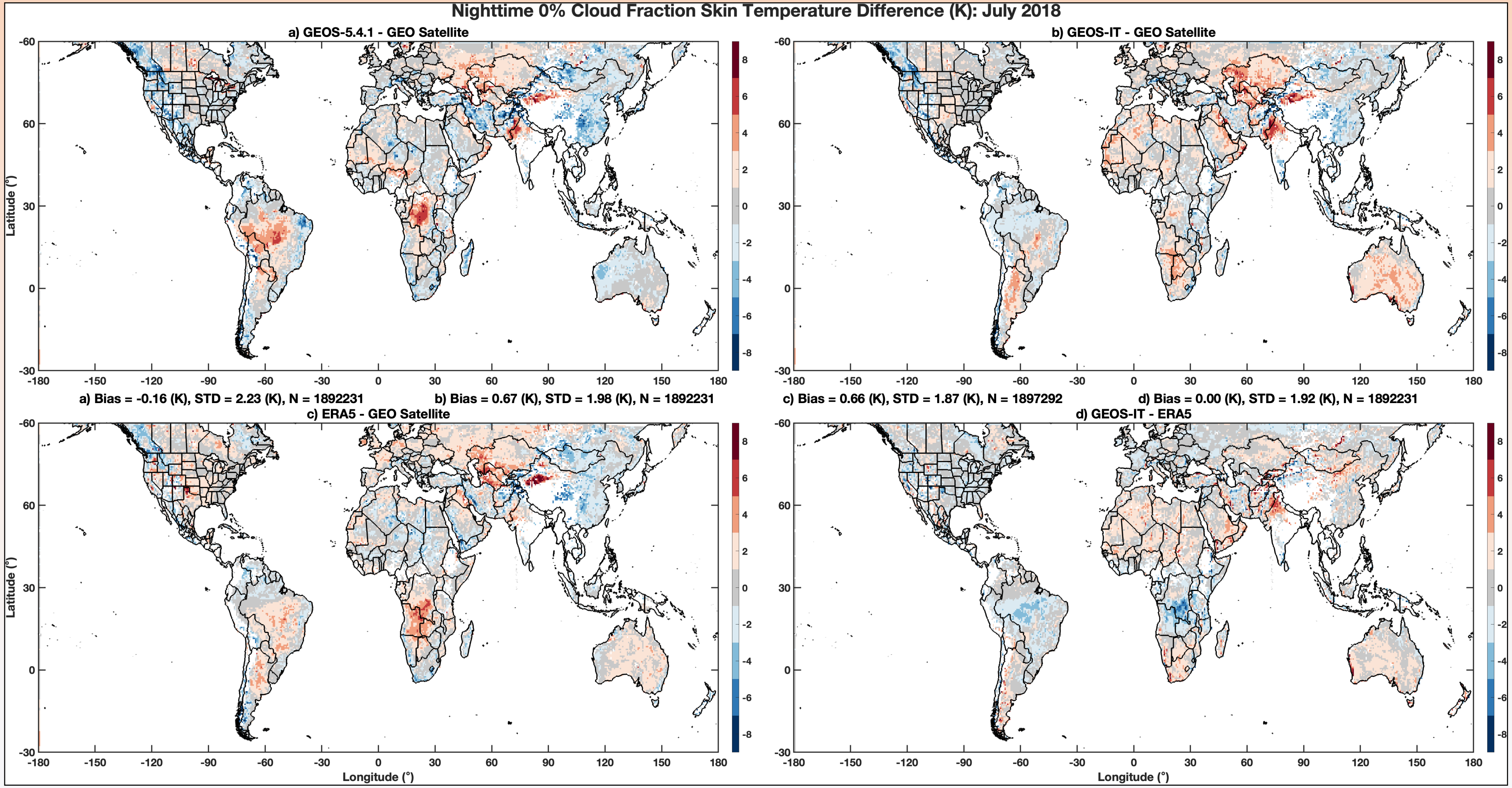
Model T_s – Satellite T_s Differences: Samples



No obvious correlation between regional biases and sample sizes

Model T_s – Satellite T_s Differences: Night

- 0% satellite cloud fraction at 0.5°x0.5°
- Overall more neutral, but all models show strong regional biases
- GEOS-IT and ERA5 have greater similarity than during the day



Whether day or night, not *obvious* to conclude if GEOS-IT is “better” than GEOS5.4.1, or if ERA5 is “better” than GEOS-IT

Model T_a – Model T_s Differences: Night

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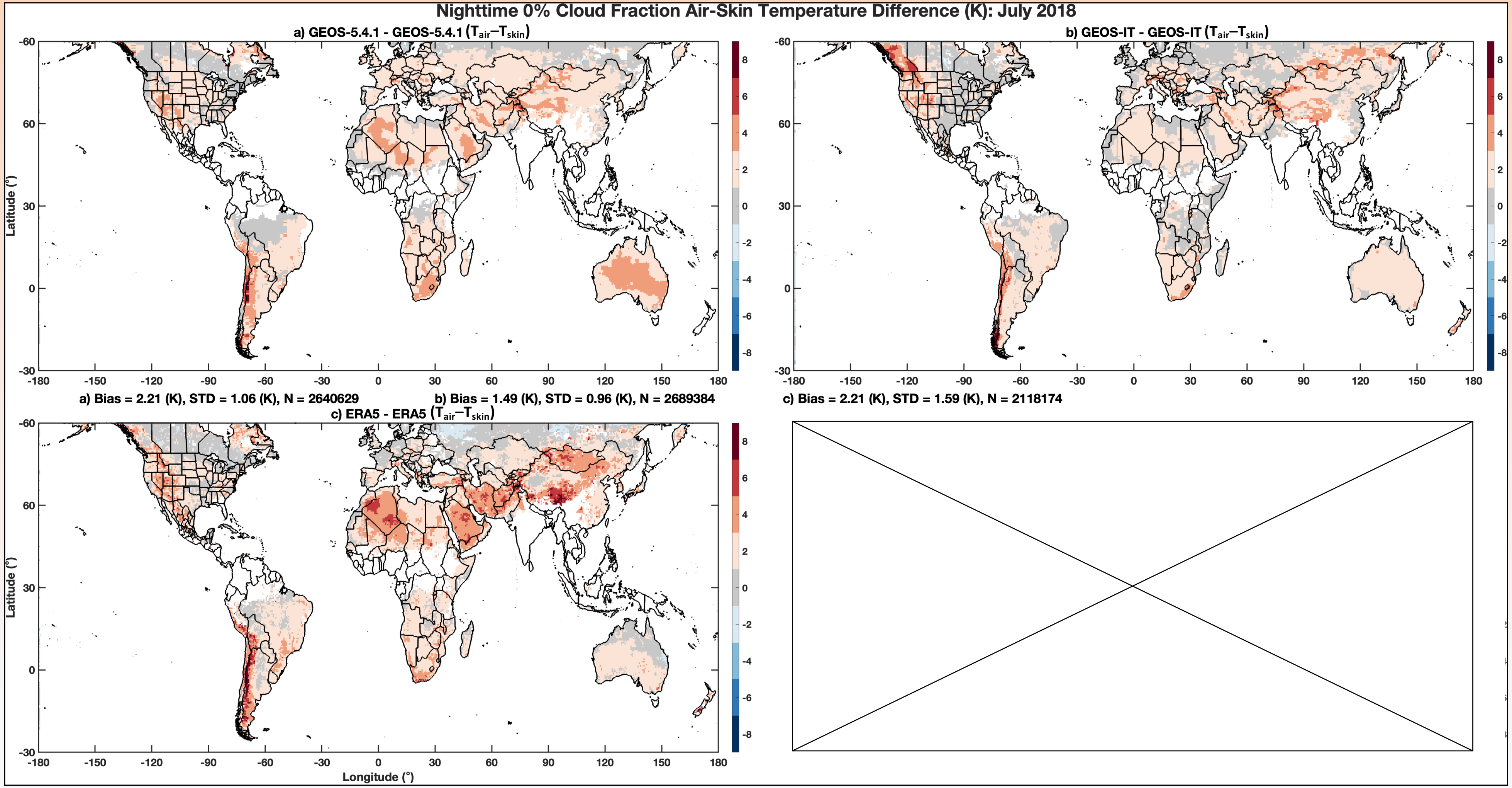

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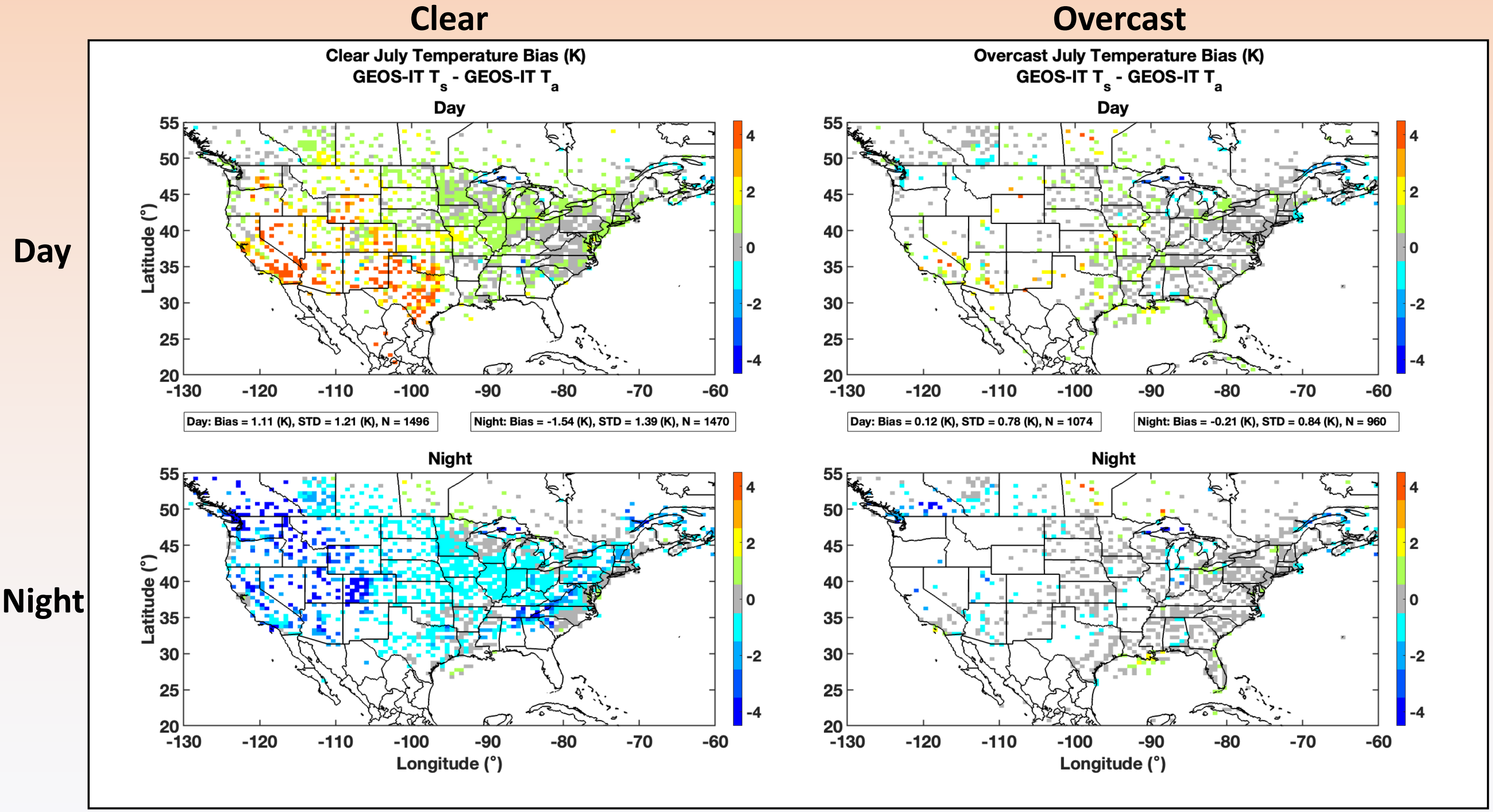
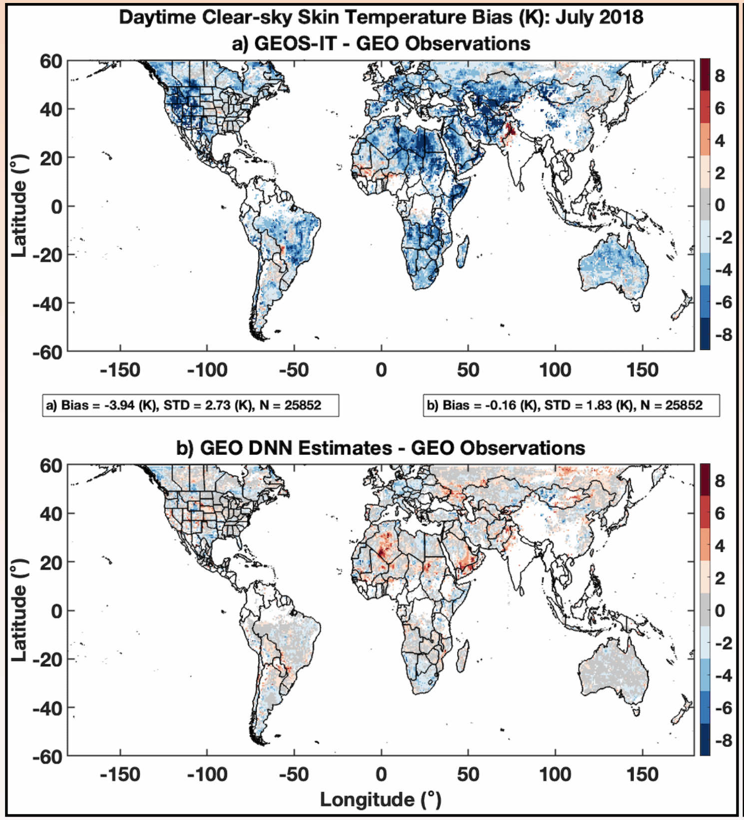
Model T_s – Model T_a Differences



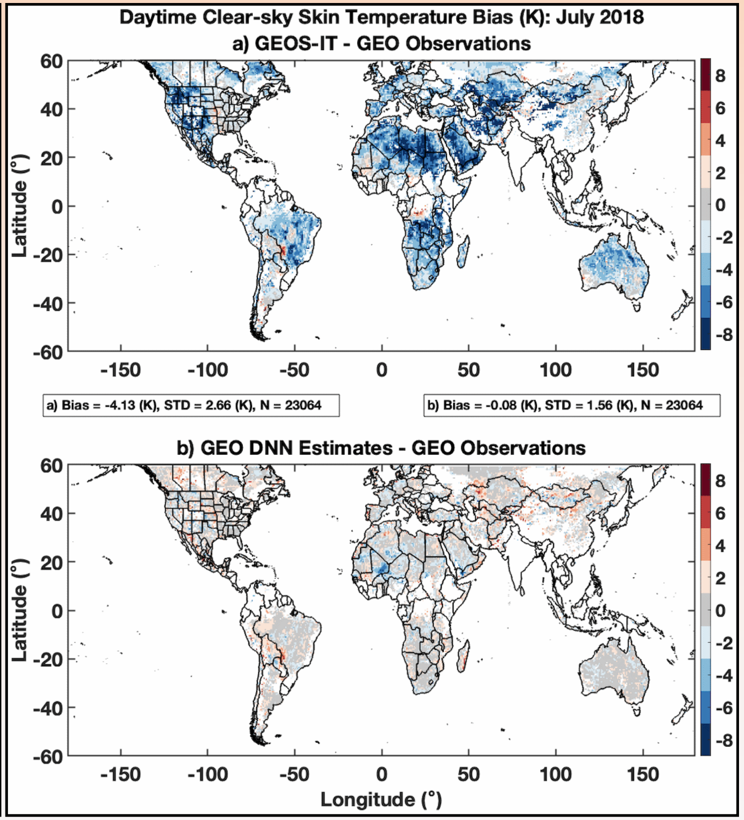
Model T_s and T_a are reasonably close in overcast conditions at surface sites

Clear-sky T_s DNN Developments/Limits

- Previous DNN:
  - Predictors: GEOS-IT T_a, Latitude, Longitude, Local Time, SZA, IGBP, day-of-year, and snow flag
  - Skillful on average, regional biases strongly tied to model biases (suggests data representation issue)
- New DNN:
  - Substitutes month for day-of-year
  - Adds water percentage and GEOS-IT cloud fraction
  - Better engineered training/validation/testing splitting
  - An improvement, but persistent representation issue suggests more years of training data are necessary



Previous DNN



New DNN

Above testing set results represent 10% of available July days