

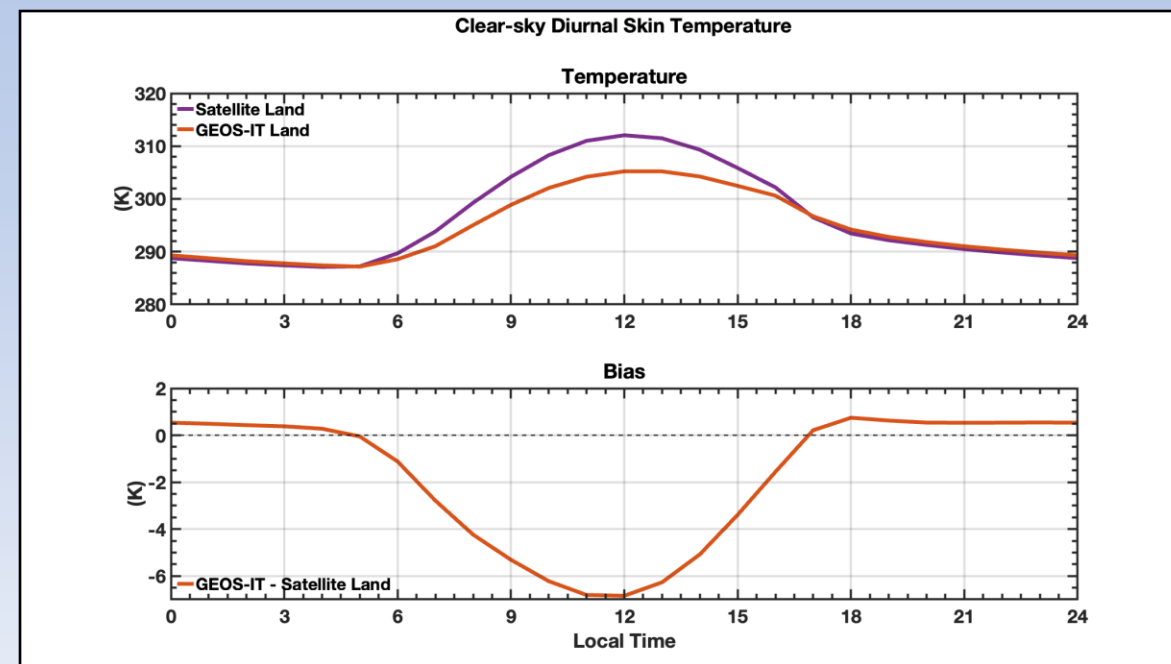
# Understanding relationships between satellite, model, and ground-based surface temperature characterizations from overcast to clear conditions

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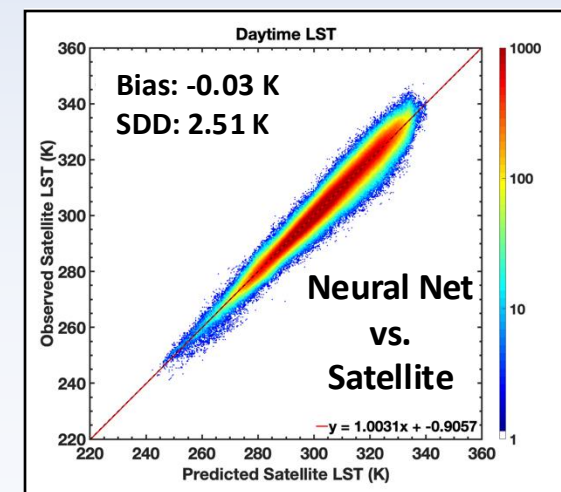
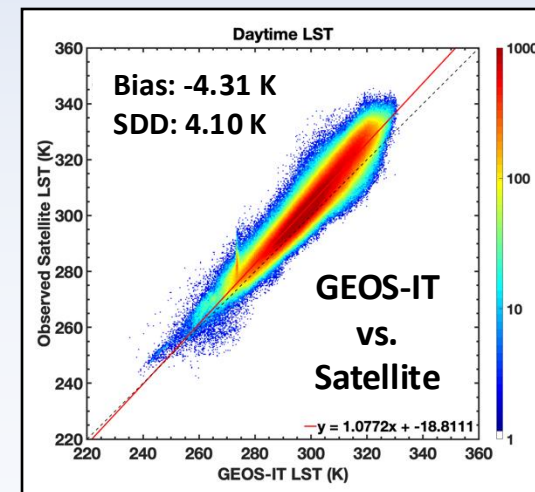
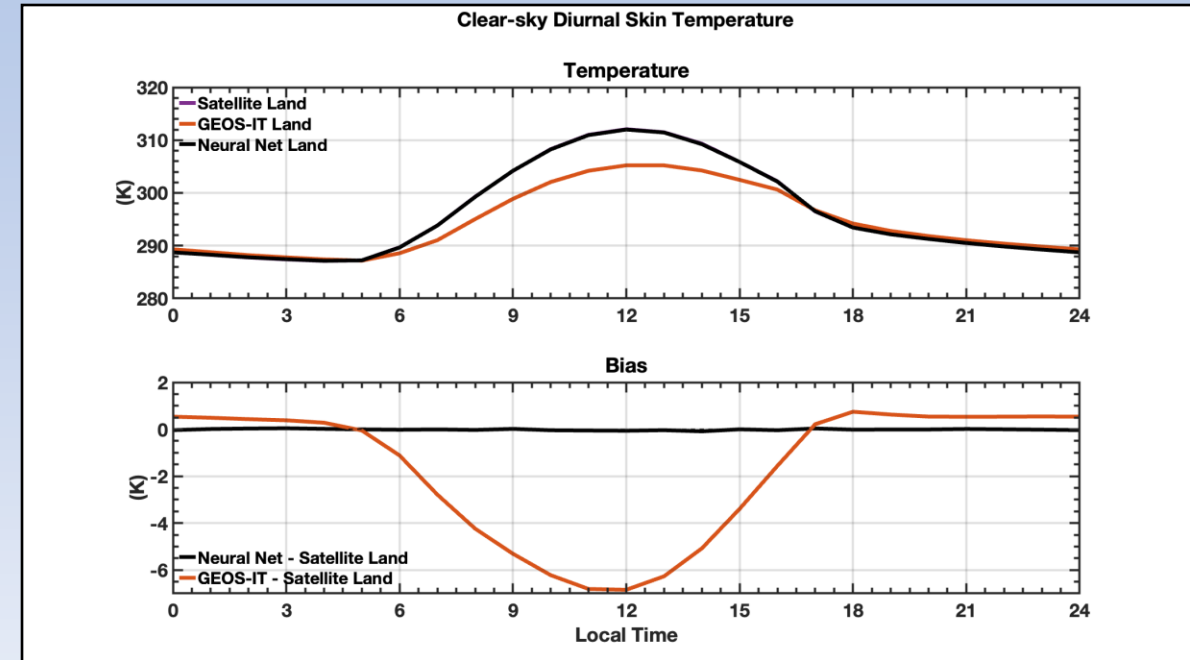
- Cloud mask threshold approaches rely on cloud-free skin temperature ( $T_s$ ) estimate
- $T_s$  in cloudy condition necessary for optical depth and height retrievals
- Downstream radiation budget calculations rely on clouds and on model  $T_s$  in cloudy condition
- Need for stability in  $T_s$  estimates for clear and cloudy skies
- $T_s$  and surface air temperature ( $T_a$ ) estimates vary significantly between different reanalyses
- Differences between reanalyses and satellite-derived  $T_s$  can be extreme



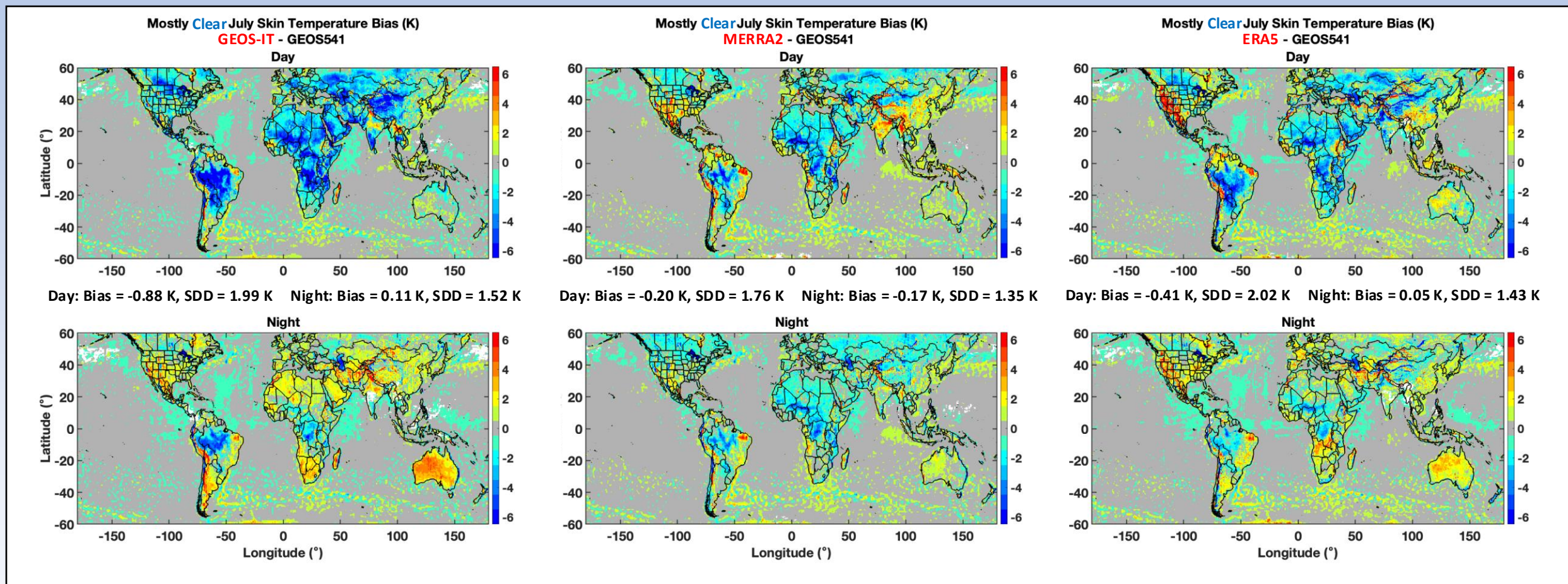
**Large diurnal dependence  
in reanalysis land  $T_s$  bias**

- Explore the consistency of  $T_s$  and  $T_a$  temperature across different reanalysis datasets, relative to...
  - ...one-another
  - ...global surface station observations
  - ...satellite
- Explore deep neural network (DNN) approach to produce consistent  $T_s$  estimates given any reanalysis dataset
  - Estimate one reanalysis dataset from another
  - Estimate satellite observation from reanalysis

**Desire for consistent initial  $T_s$  regardless of reanalysis source**



# Global (non-polar) Reanalysis Skin Temperature Differences



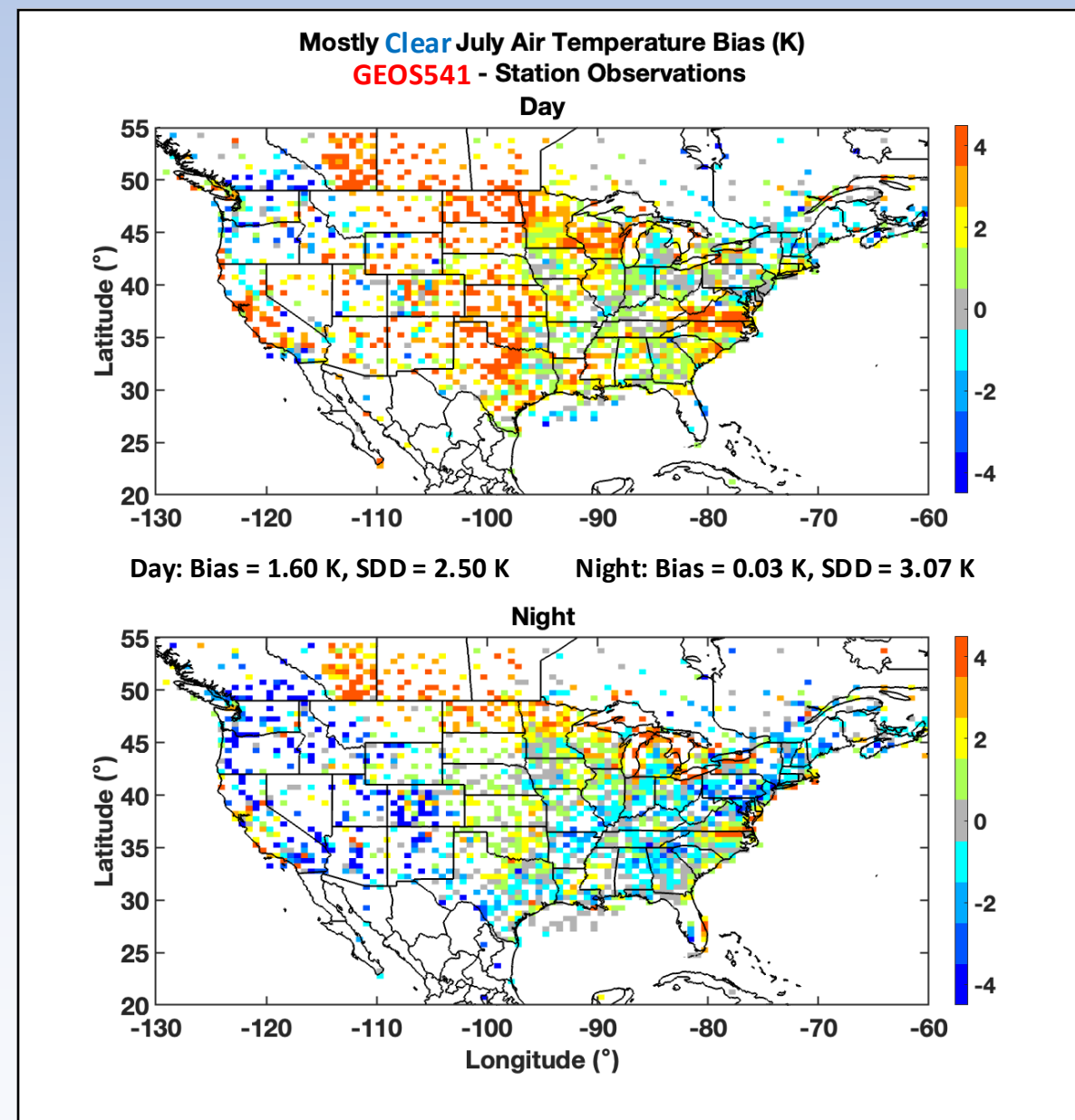
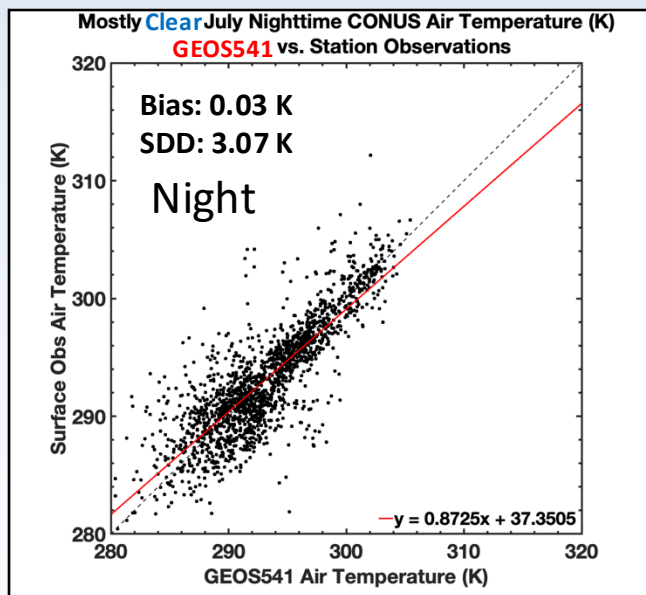
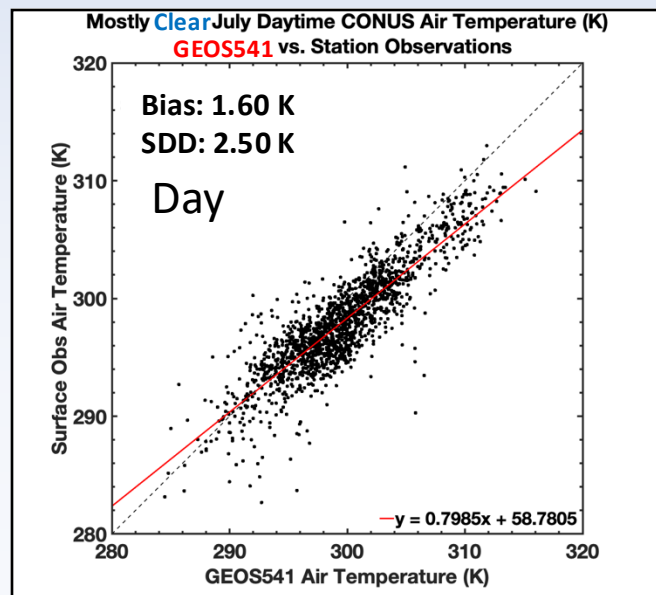
- Seasonal, regional, and diurnal dependencies complicate reanalysis  $T_s$  bias accounting
- Land difference can easily swing by 1 K on average – easily more than 6 K instantaneously

**A change in reanalysis  $T_s$  will influence the cloud mask**

# Reanalysis vs. Observed Air Temperature

- Ground validation of  $T_s$  is limited, but surface  $T_a$  observations are global
- GMAO does not assimilate station  $T_a$  –  $T_s$  and  $T_a$  tied to numerical models of near-surface processes

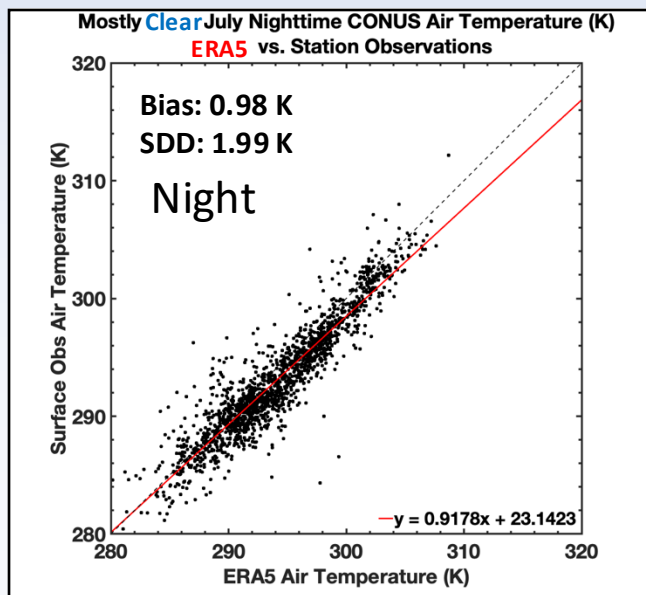
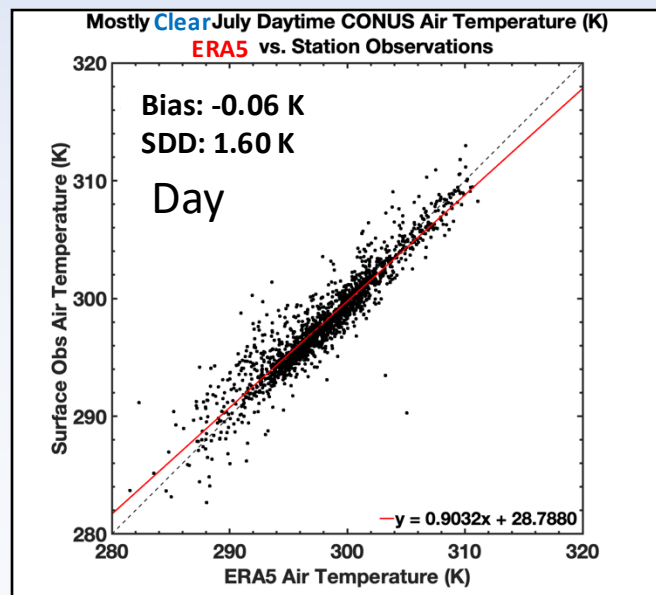
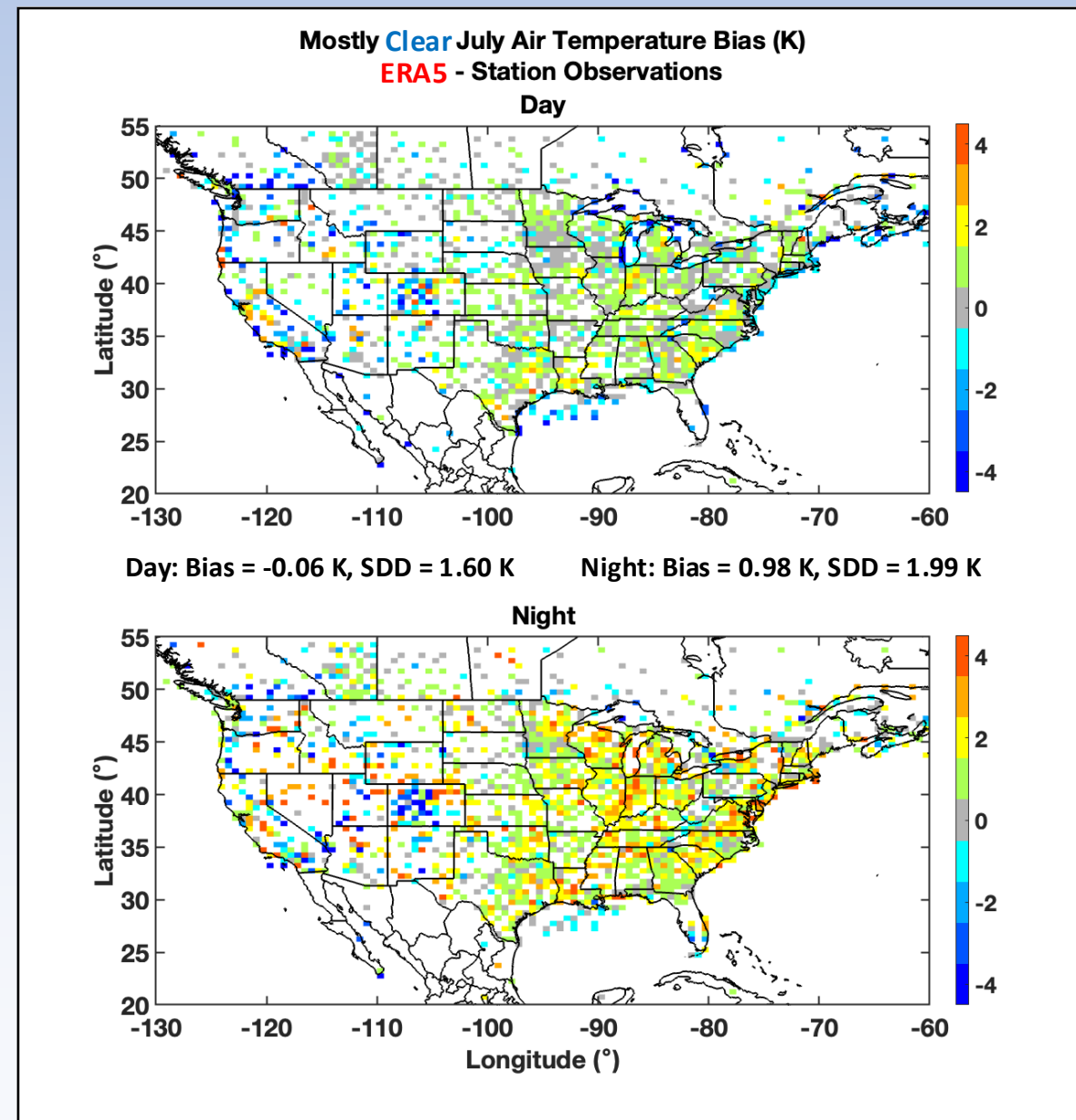
Assessing bias in  $T_a$  can help interpret bias in  $T_s$



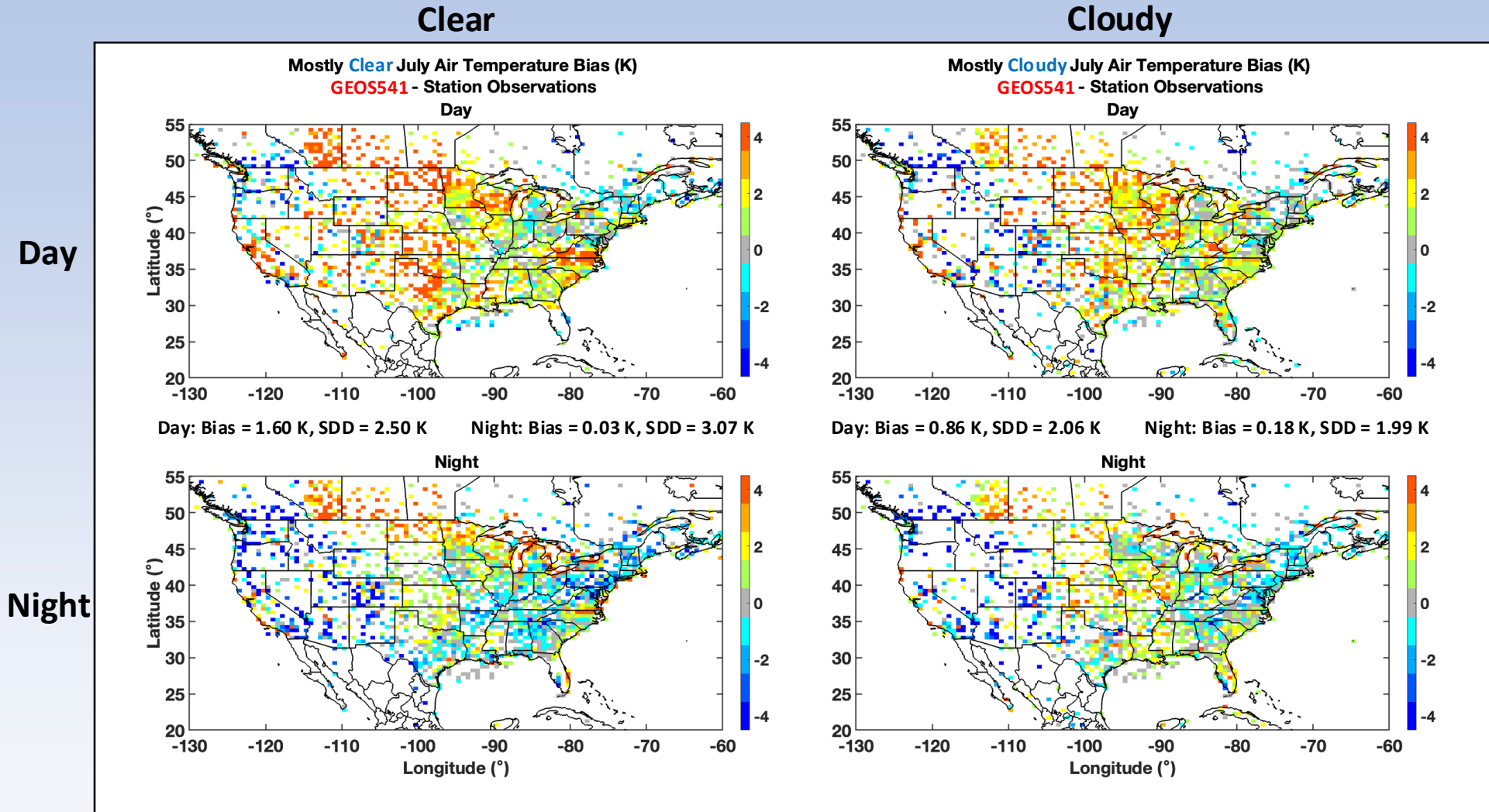
# Reanalysis vs. Observed Air Temperature

- ERA5 assimilates station  $T_a$  over land
- Variation reduced by 1 K for day and night

Neural Net efforts  
initially focused on  $T_a$   
input rather than  $T_s$



# Reanalysis vs. Observed Air Temperature



- Strong biases in both clear and cloudy conditions
- Overcast bias nearly as bad as clear because station  $T_a$  not assimilated

**Clear and cloudy differences in  $T_a$  may inform expected  $T_s$  bias in cloudy conditions**

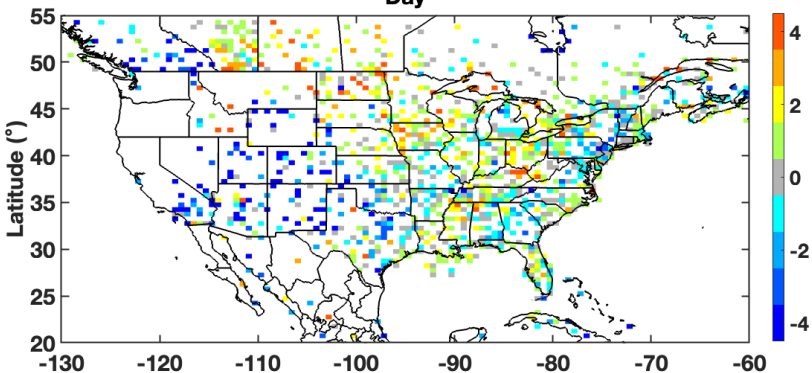
# Overcast Temperature Biases



GEOS541  $T_a$  – Observed  $T_a$

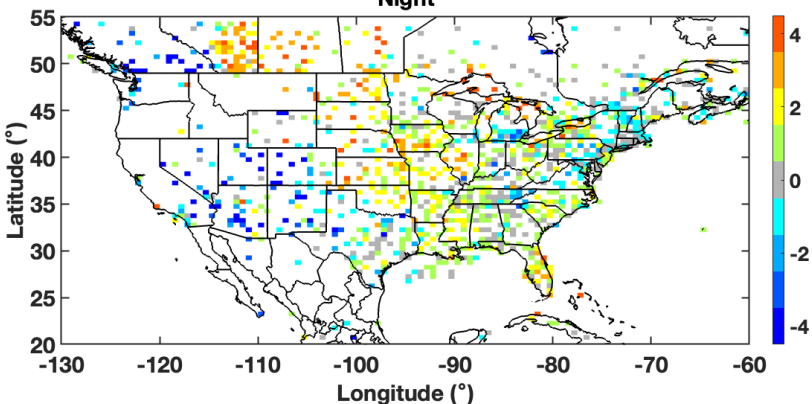
Overcast July Temperature Bias (K)  
GEOS541  $T_a$  - Station  $T_a$  Observations

Day



Day: Bias = 0.02 K, SDD = 2.37 K      Night: Bias = 0.55 K, SDD = 1.96 K

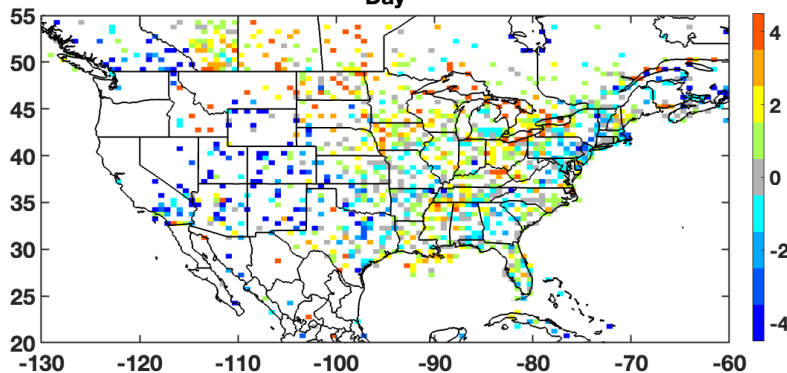
Night



GEOS541  $T_s$  – Observed  $T_a$

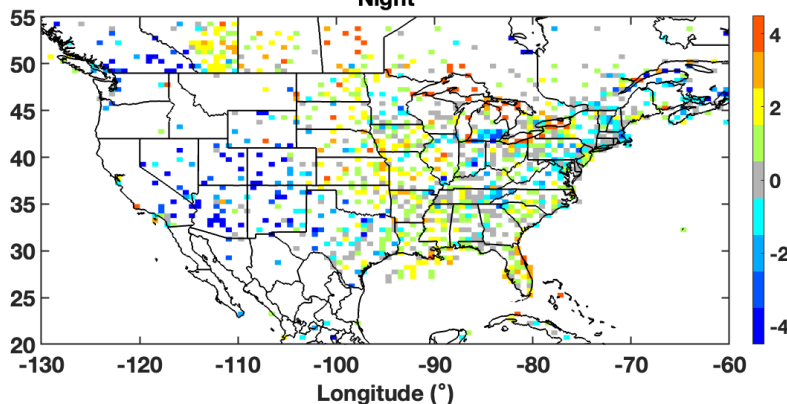
Overcast July Temperature Bias (K)  
GEOS541  $T_s$  - Station  $T_a$  Observations

Day



Day: Bias = 0.13 K, SDD = 2.93 K      Night: Bias = 0.32 K, SDD = 2.41 K

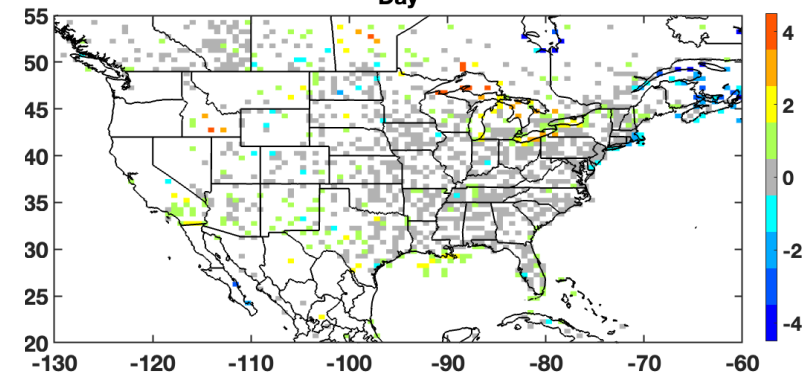
Night



GEOS541  $T_s$  – GEOS541  $T_a$

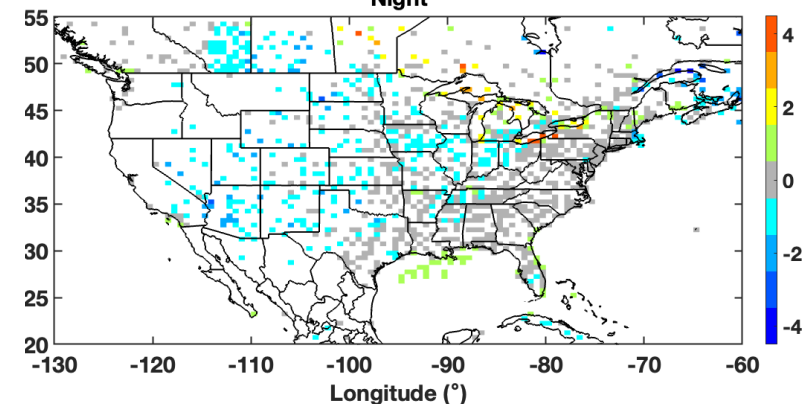
Overcast July Temperature Bias (K)  
GEOS541  $T_s$  - GEOS541  $T_a$

Day



Day: Bias = 0.11 K, SDD = 1.10 K      Night: Bias = -0.24 K, SDD = 0.92 K

Night

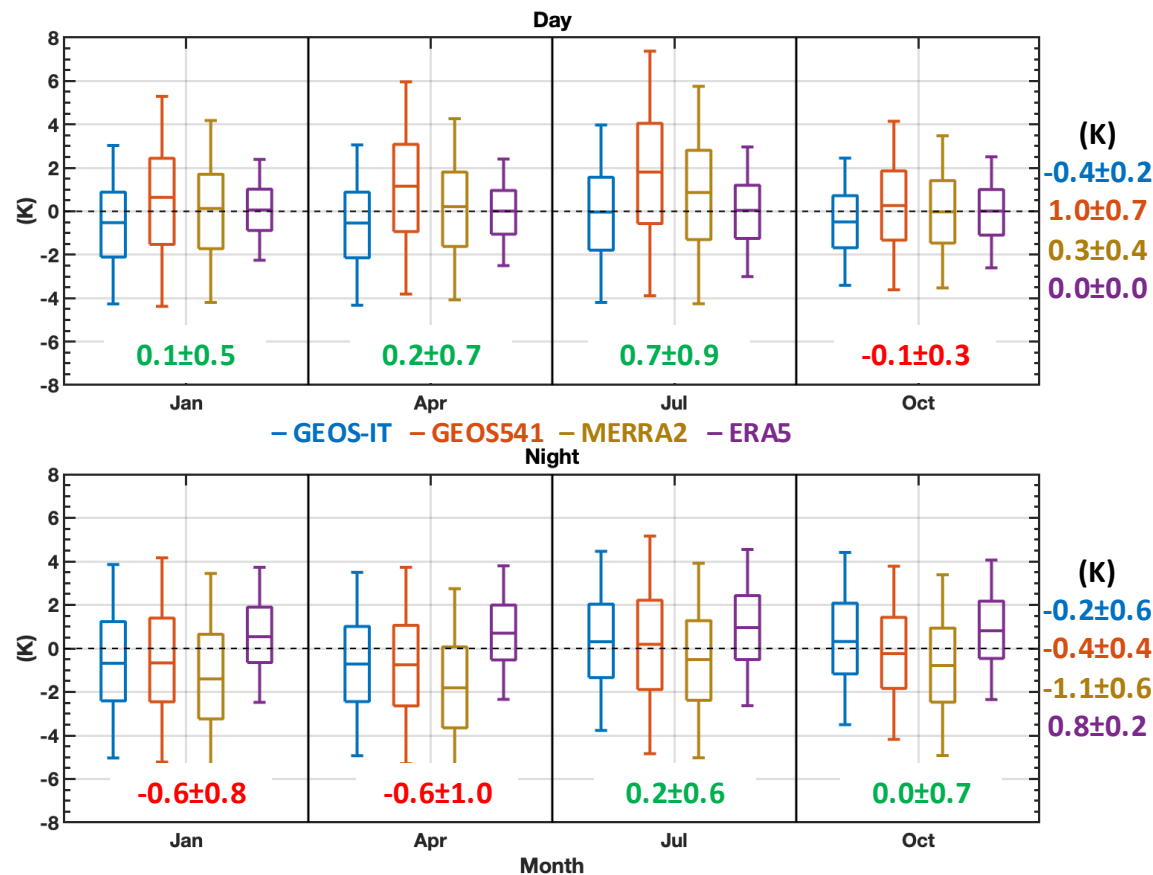


- Cloudy bias needs consideration
  - Influences flux calculations
  - No satellite truth
- GMAO  $T_s$  and  $T_a$  are reasonably close in overcast conditions

**Further Study: Can  $T_a$  observations lead to reliable  $T_s$  estimates in cloudy conditions?**

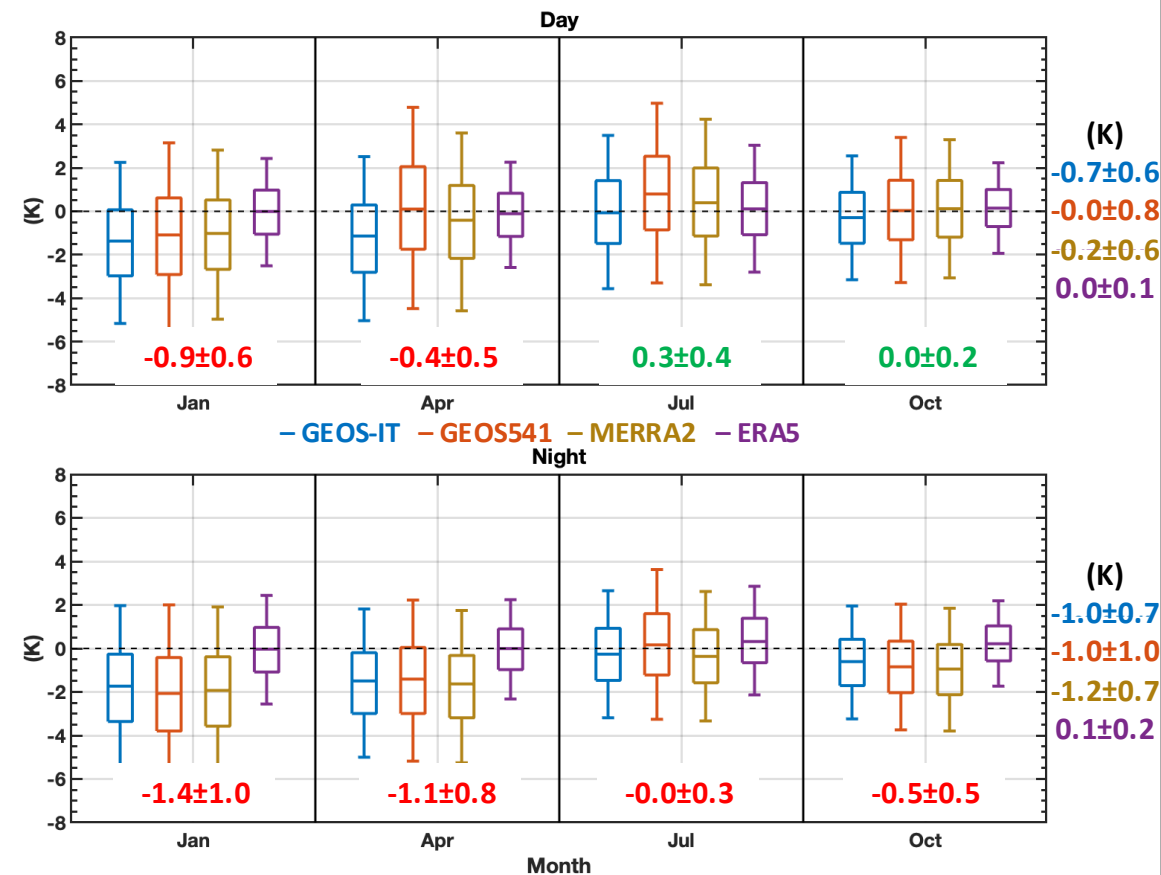
# Seasonal Station Observation Comparisons

Mostly **Clear** CONUS Air Temperature Bias  
Reanalysis - Station Observations



- Large average bias and seasonal variation in GEOS541 daytime clear-sky
- MERRA2 1+ K too cold at night with ~0.6-K month-to-month variance
- ERA5 is the most certain and consistent – although too warm at night

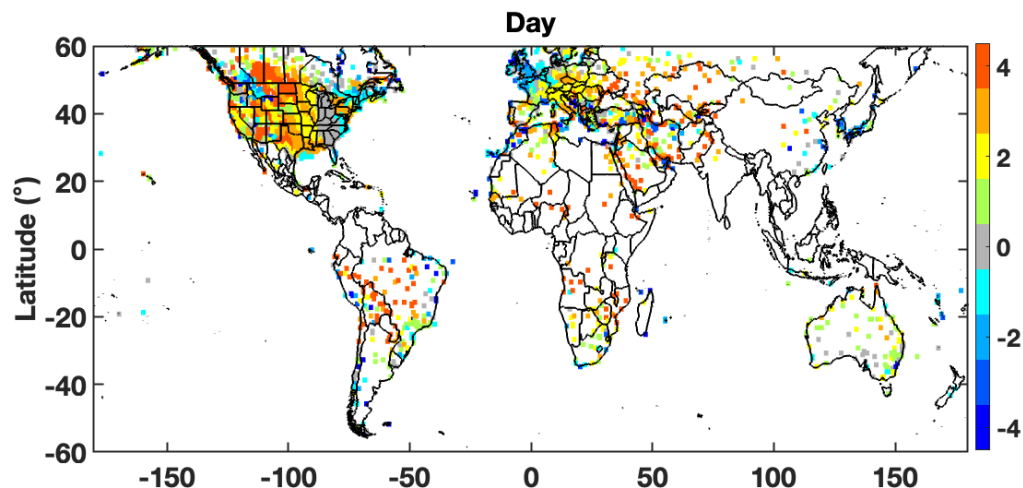
Mostly **Cloudy** CONUS Air Temperature Bias  
Reanalysis - Station Observations



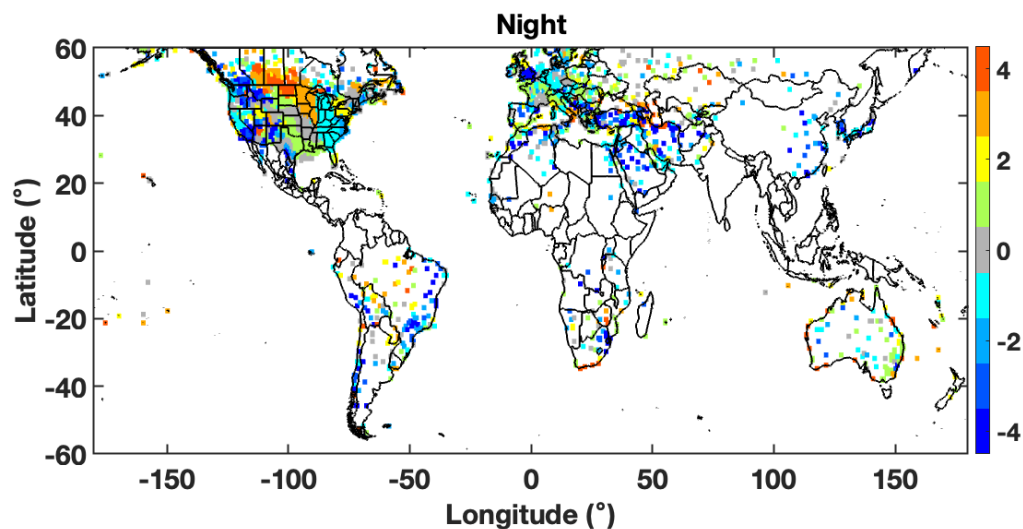
- Overall larger month-to-month variation in cloudy conditions
- GMAO too cold in Jan and Apr – Oct at night
- Nighttime ERA5 improved when cloudy – daytime accuracy remains

**GEOS-IT and GEOS541 diurnal relationships consistent with changes in heat capacity – seasonal relative distributions more consistent in clear conditions**

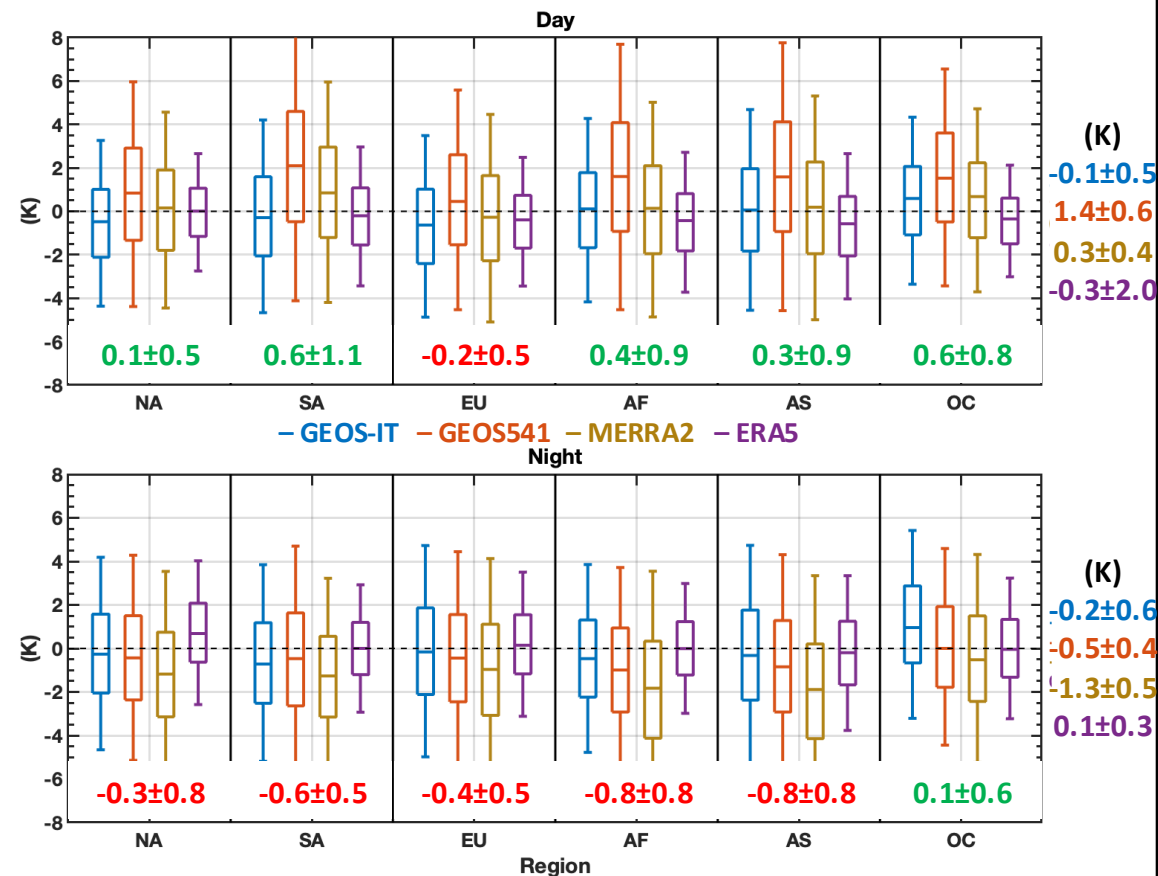
Mostly **Clear** July Air Temperature Bias (K)  
**GEOS541** - Station Observations



Day: Bias = 1.50 K, SDD = 2.61 K      Night: Bias = -0.39 K, SDD = 3.06 K



Mostly **Clear** Air Temperature Bias  
 Reanalysis - Station Observations

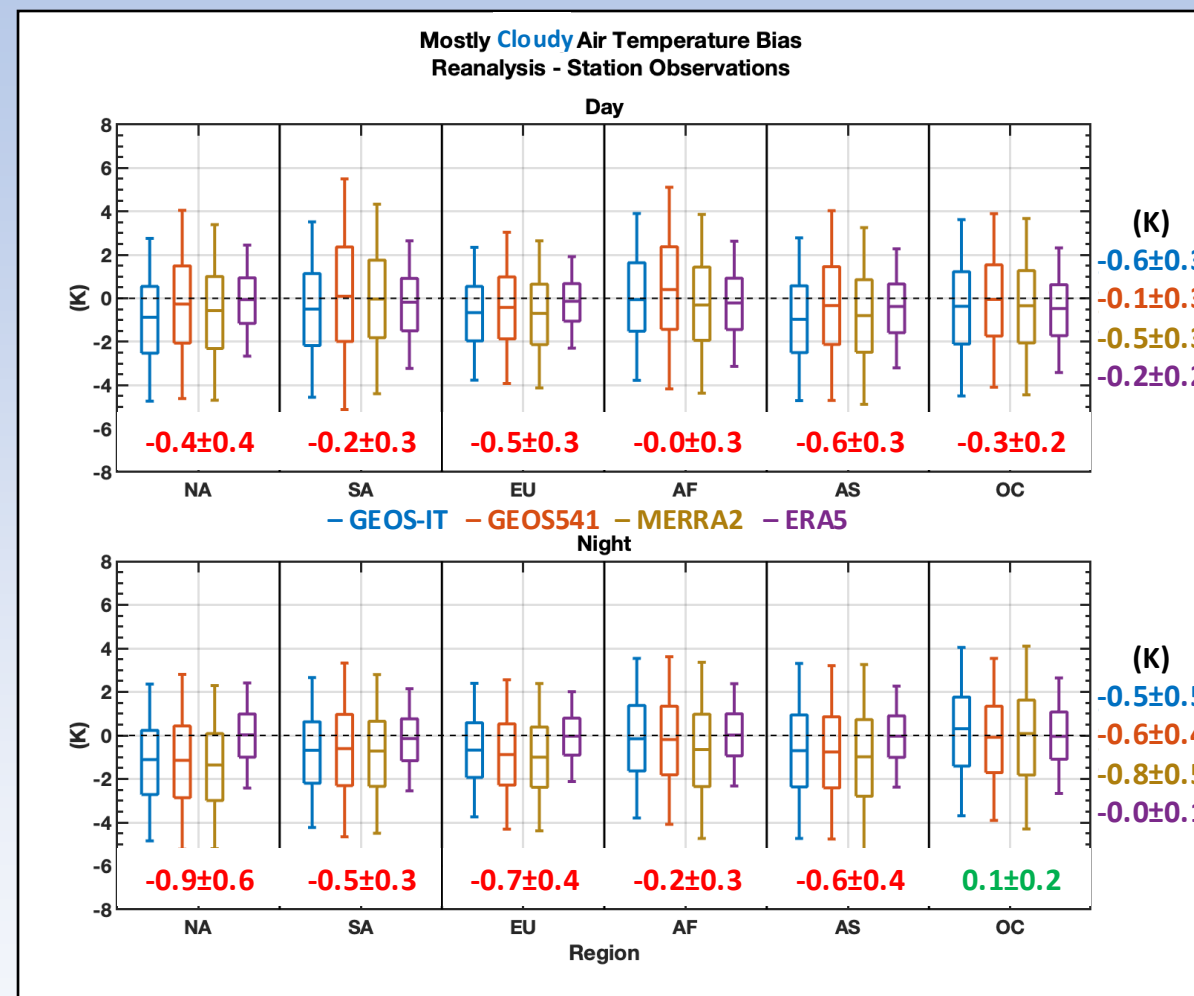


- GEOS-IT overall small bias and uncertainty compared to GEOS541 and MERRA2
- ERA5 fairly consistent – although NA seems out-of-family (especially at night)

# Regional Station Observation Comparisons

- Overall smaller region-to-region variation in cloudy conditions
- GEOS-IT less consistently accurate when cloudy
- GMAO largely too cold over land
- Relatively good ERA5 regional consistency, especially at night – although daytime AS and OC are noticeably too cold

**Assimilation  
most beneficial  
where overcast**

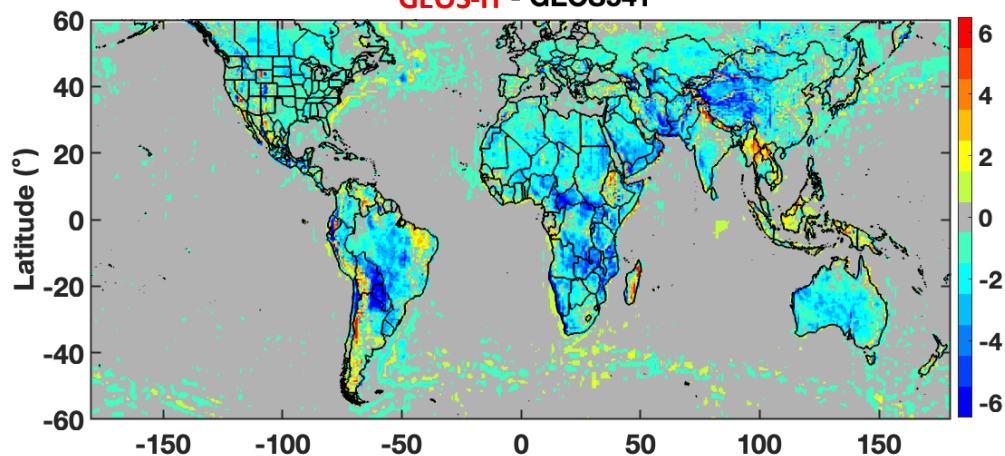


Day

Night

Daytime All-sky Skin Temperature Bias (K)

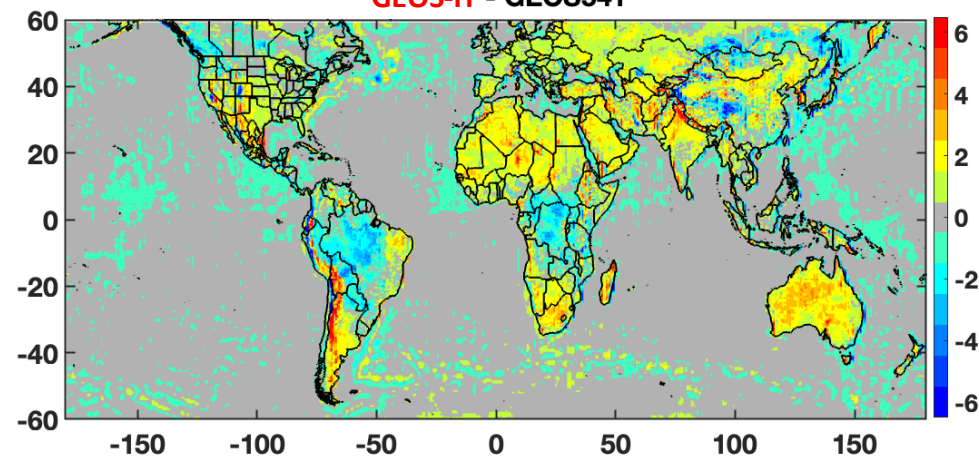
GEOS-IT - GEOS541



Original: Bias = -0.46 K, SDD = 1.18 K    Predicted: Bias = 0.05 K, SDD = 0.89 K

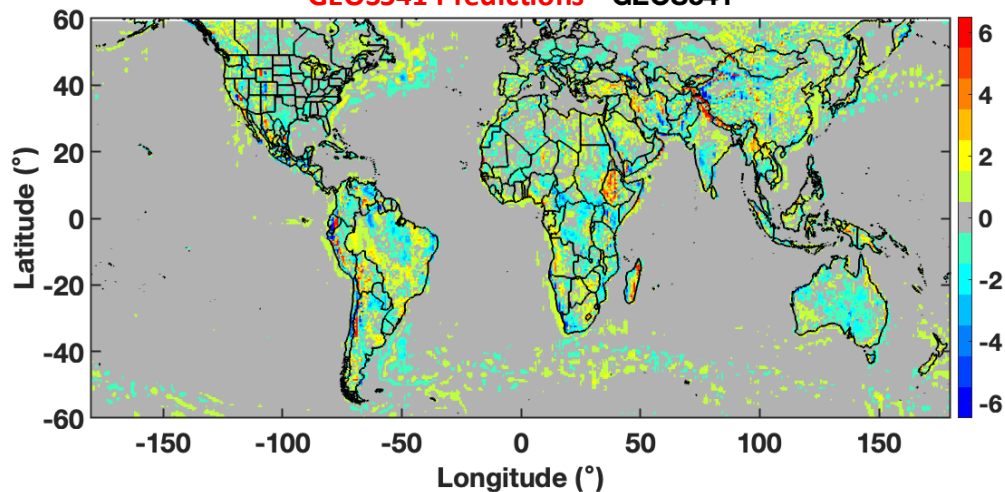
Nighttime All-sky Skin Temperature Bias (K)

GEOS-IT - GEOS541

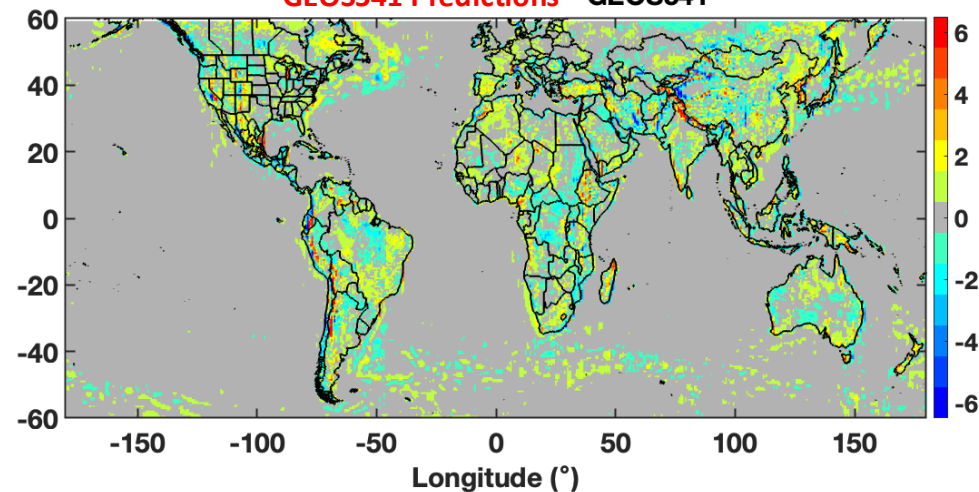


Original: Bias = -0.03 K, SDD = 1.20 K    Predicted: Bias = 0.06 K, SDD = 0.90 K

GEOS541 Predictions - GEOS541



GEOS541 Predictions - GEOS541

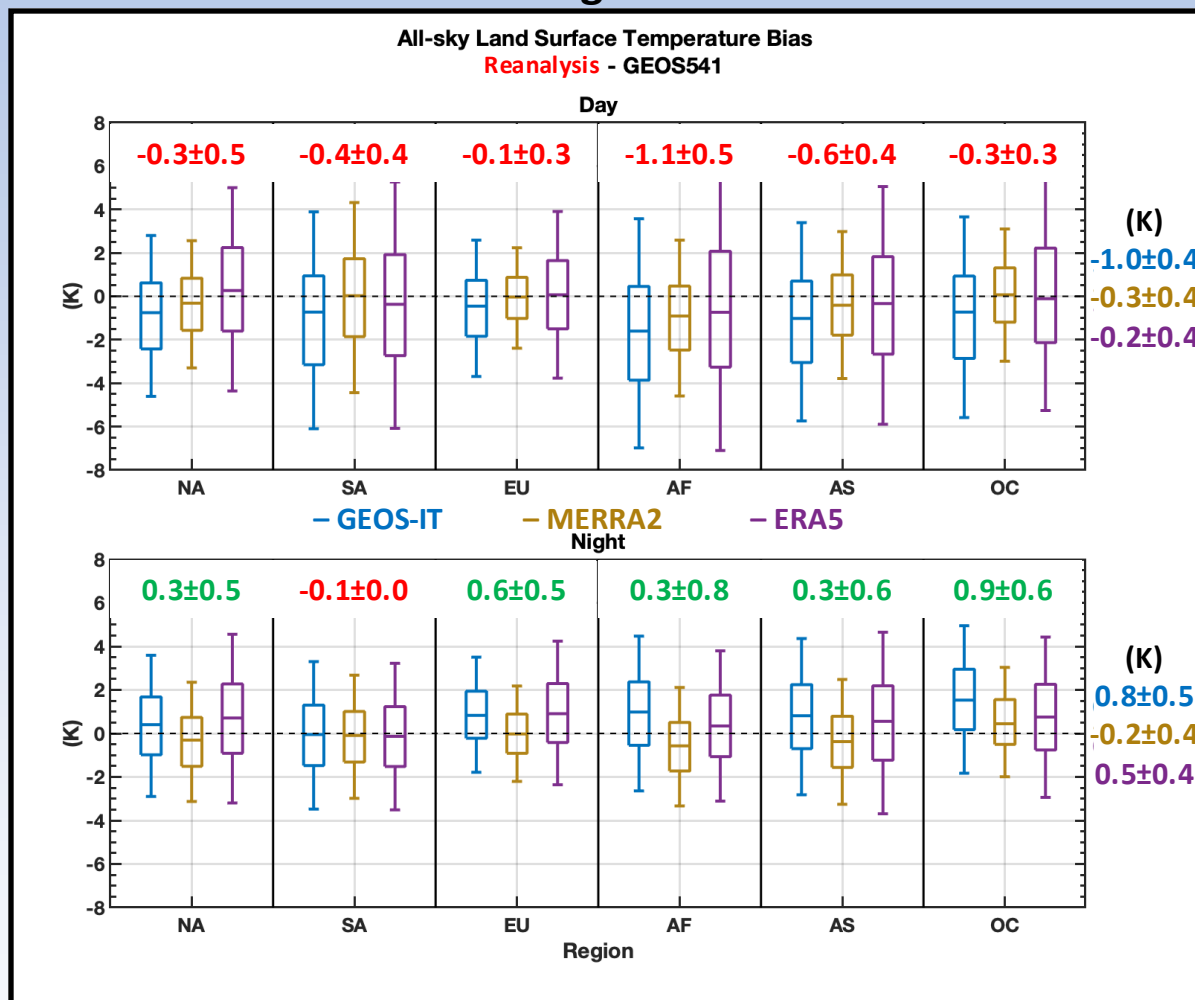


Original

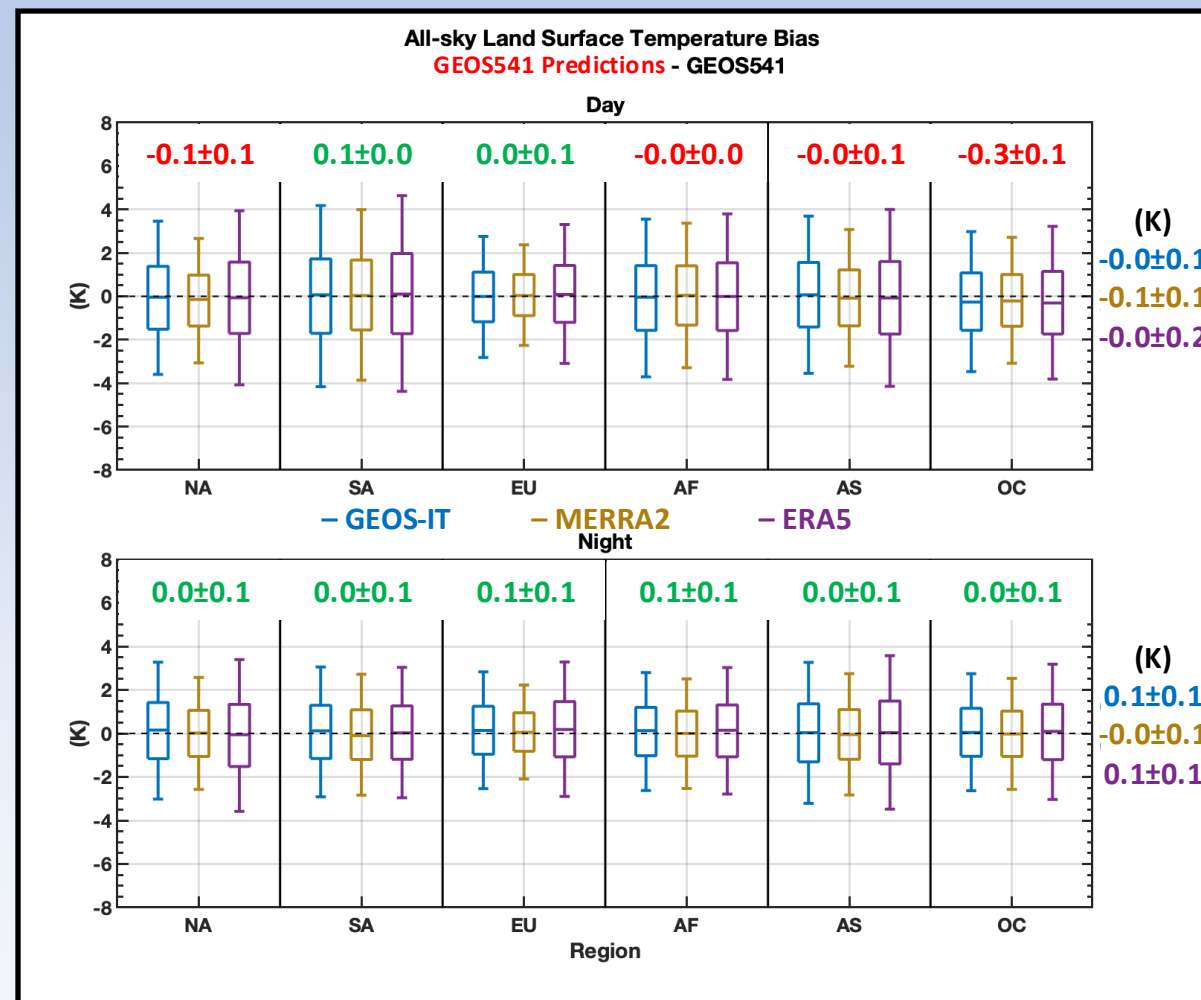
With DNN

# Deep Neural Network to Estimate Reanalysis Skin Temperature

## Original

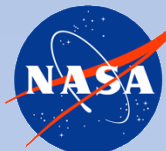


## With DNN



- Model relationships are multi-variate and complex
- DNN can help unravel and more consistently simulate all-sky GEOS541  $T_s$  from different GMAO inputs

**Note: Yet to prove that this DNN approach will result in more consistent cloud retrievals**



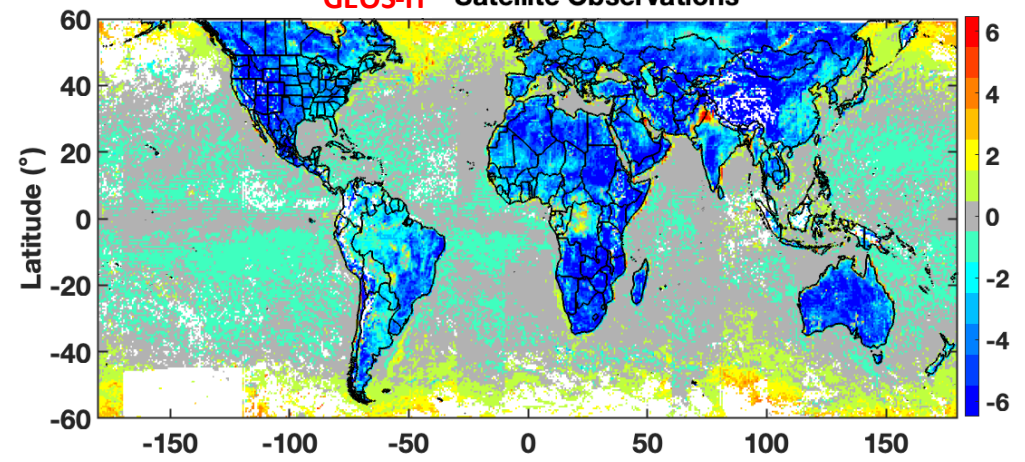
# Deep Neural Network to Estimate Satellite Skin Temperature

Day

Night

Daytime **Clear-sky** Skin Temperature Bias (K)

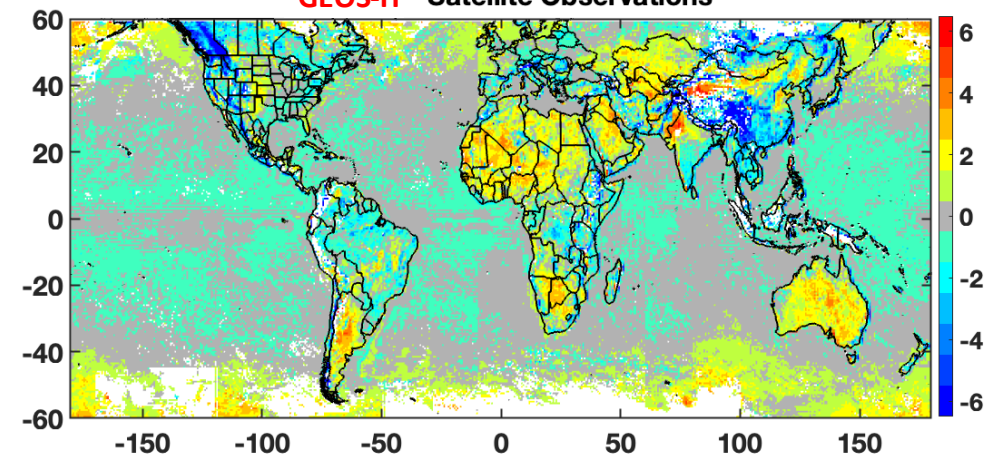
**GEOS-IT - Satellite Observations**



Original: Bias = -2.64 K, SDD = 2.70 K    Predicted: Bias = -0.03 K, SDD = 1.01 K

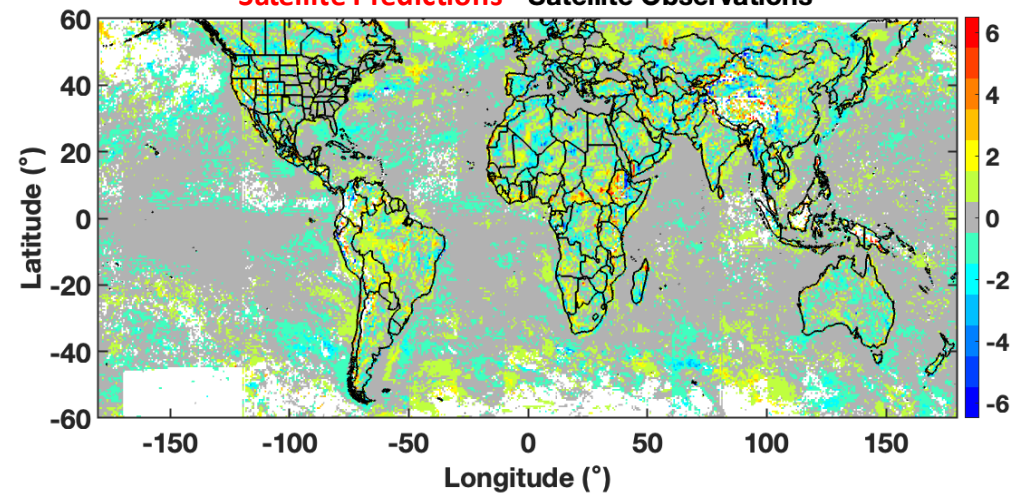
Nighttime **Clear-sky** Skin Temperature Bias (K)

**GEOS-IT - Satellite Observations**

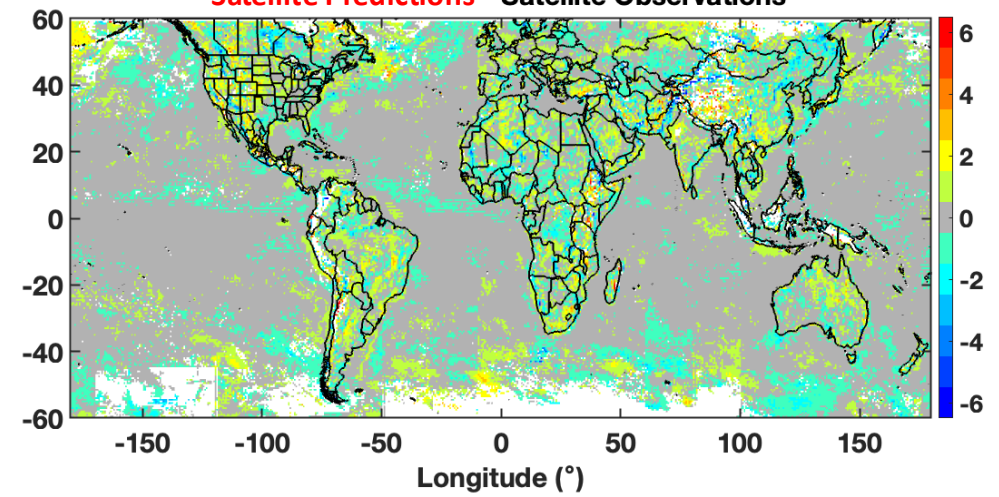


Original: Bias = 0.13 K, SDD = 1.55 K    Predicted: Bias = -0.00 K, SDD = 0.82 K

**Satellite Predictions - Satellite Observations**



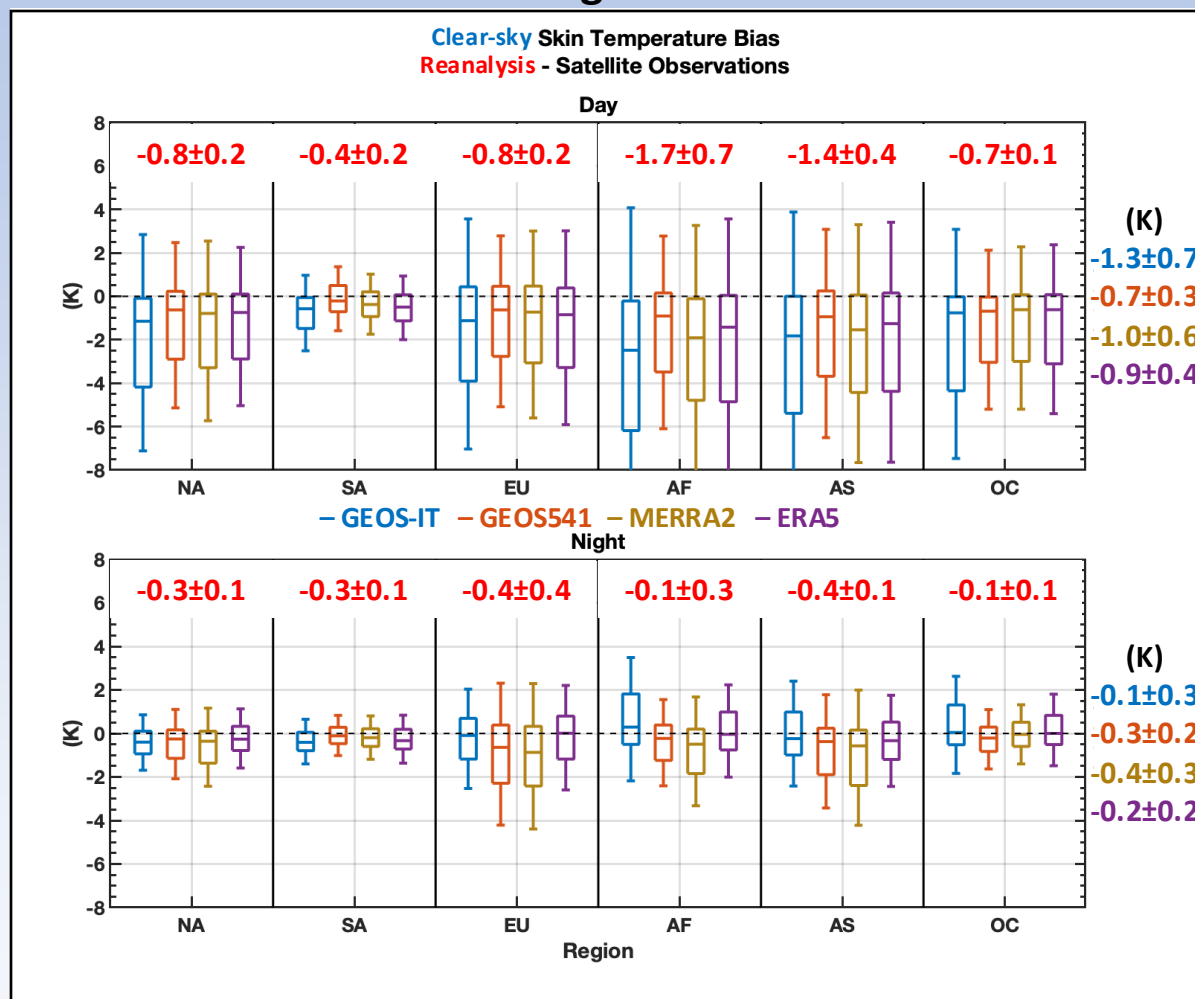
**Satellite Predictions - Satellite Observations**



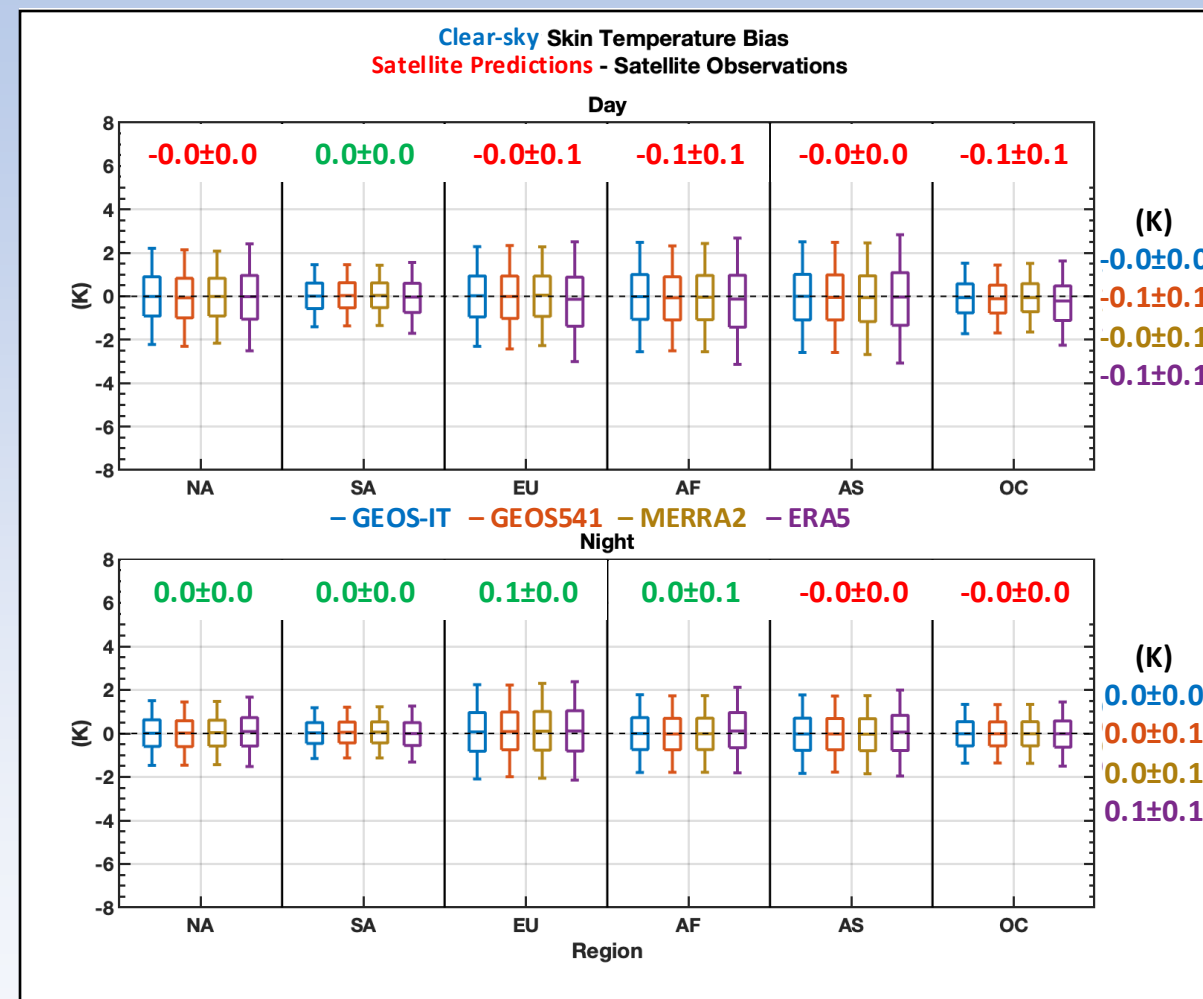
Original

With DNN

## Original



## With DNN



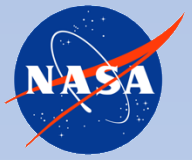
- Observation relationships show greater complexity
- DNN can exploit predictor correlations to arrive at a consistent, observations-based answer

Reanalyses  $T_s$  not designed to match Satellite  $T_s$ ,  
but a deep neural network can help achieve that

- Clear and cloudy differences in  $T_a$  may inform expected  $T_s$  bias in cloudy conditions
- Varying relative performance between GMAOs across different seasons, regions, day+night, and cloud condition complicates  $T_s$  bias accounting
- ERA5  $T_a$  is seasonally and (mostly) globally consistent
  - Except nighttime clear over NA and daytime AS and OC
  - Overcast conditions are especially accurate
- A deep neural network is effective at simulating a reference  $T_s$  that is consistent given any reanalysis dataset

**Next Step: Use a DNN with GMAO inputs to correct GMAO  $T_a$  to observed  $T_a$  in sufficiently cloudy conditions**

**– i.e., use  $T_a$ -informed estimated  $T_s$  for better cloud optical depth and height retrievals and flux calculations**



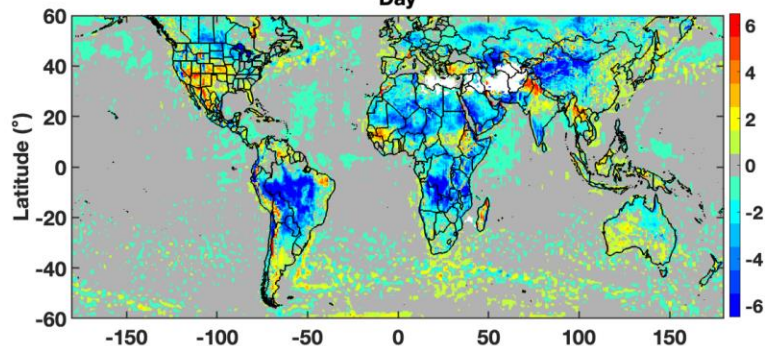
# Additional Slides

# Global Reanalysis Skin Temperature Differences

Mostly **Cloudy** July Skin Temperature Bias (K)

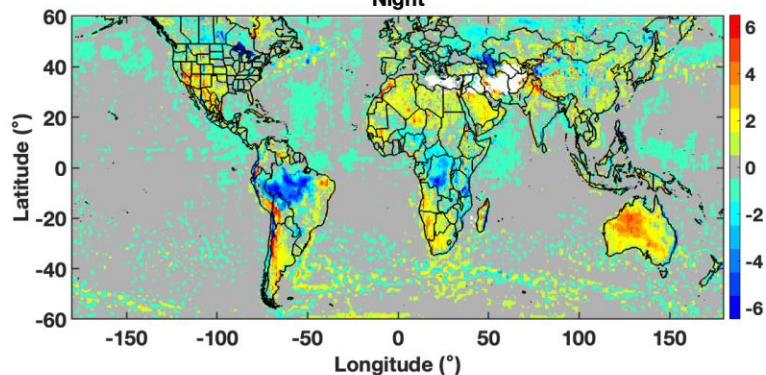
**GEOS-IT** - GEOS541

Day



Day: Bias = -0.30 K, SDD = 1.30 K Night: Bias = -0.14 K, SDD = 1.03 K

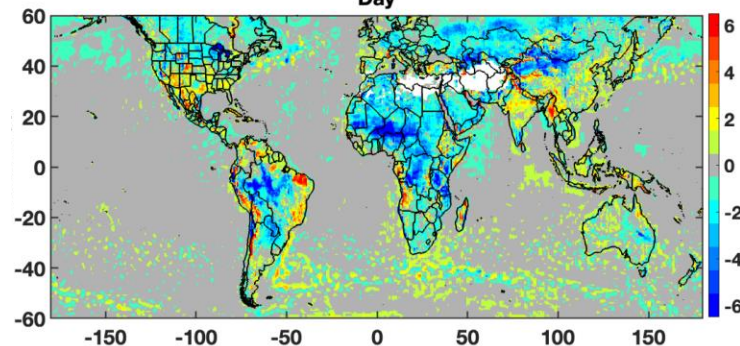
Night



Mostly **Cloudy** July Skin Temperature Bias (K)

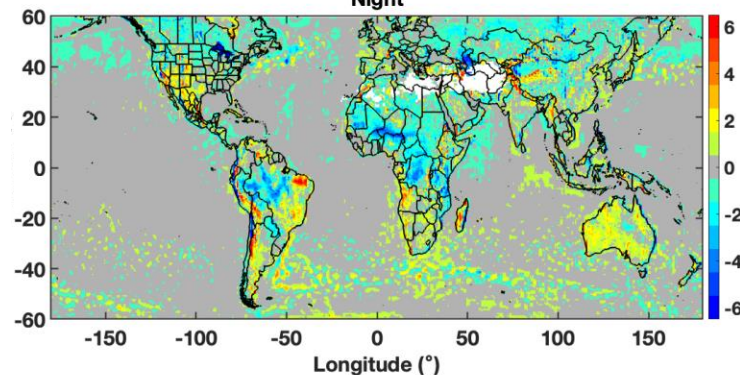
**MERRA2** - GEOS541

Day



Day: Bias = -0.19 K, SDD = 1.26 K Night: Bias = -0.06 K, SDD = 0.95 K

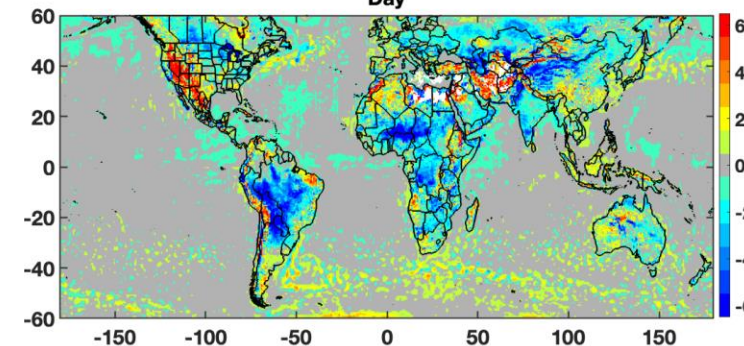
Night



Mostly **Cloudy** July Skin Temperature Bias (K)

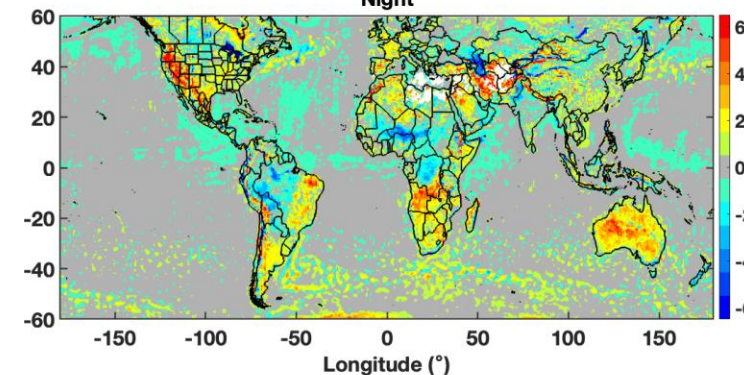
**ERA5** - GEOS541

Day



Day: Bias = -0.28 K, SDD = 1.53 K Night: Bias = 0.00 K, SDD = 1.09 K

Night



- Relationships change depending the reanalysis cloud conditions
- $T_s$  tied to model's accuracy in predicting clouds

**Resolving these degrees of freedom  
is a nonlinear consideration**

