# *Issues in Developing and Validating Satellite Land Surface Temperature Product*

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# Outlines

- LST Algorithm Basics
- Issues in LST algorithm development
- Issues in LST product validation
- Summary

# LST Algorithm Basics

$$T_s = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}+T_{12}) + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}-T_{12}) + D(T_{11}-T_{12})(\sec\theta - 1)$$

Wan & Dozier (1996); Becker & Li (1990).

$$T_s = C + A_1\frac{T_{11}}{\varepsilon} + A_2\frac{T_{12}}{\varepsilon} + A_3\frac{1-\varepsilon}{\varepsilon} + D(T_{11}-T_{12})(\sec\theta - 1)$$

Prata & Platt (1991); modified by Caselles *et al.* (1997).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3(1-\varepsilon_{11}) + A_4\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$$

Coll & Valor (1997).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\frac{1-\varepsilon}{\varepsilon} + A_4\frac{\Delta\varepsilon}{\varepsilon^2} + D(T_{11}-T_{12})(\sec\theta - 1)$$

Vidal (1991).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3(T_{11}-T_{12})\varepsilon_{11} + A_4T_{12}\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$$

Price (1984).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$$

Ulivieri & Cannizzaro (1985).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\frac{\Delta\varepsilon}{\varepsilon} + D(T_{11}-T_{12})(\sec\theta - 1)$$

Sobrino *et al.* (1994).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3(1-\varepsilon) + A_4\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$$

Ulivieri *et al.* (1992).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3(T_{11}-T_{12})(T_{11}-T_{12}) + A_4(1-\varepsilon_{11}) + A_5\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$$

Sobrino *et al.* (1993).

$$T_s = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}+T_{12}) + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}-T_{12})$$

Wan & Dozier (1996); Becker & Li (1990).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon$$

Ulivieri & Cannizzaro (1985).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3(1-\varepsilon) + A_4\Delta\varepsilon$$

Ulivieri *et al.* (1992).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12}) + A_5(T_{11}+T_{12})\Delta\varepsilon$$

Modified from Ulivieri & Cannizzaro (1985).

$$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12}) + A_5\Delta\varepsilon$$

Modified from Ulivieri & Cannizzaro (1985).

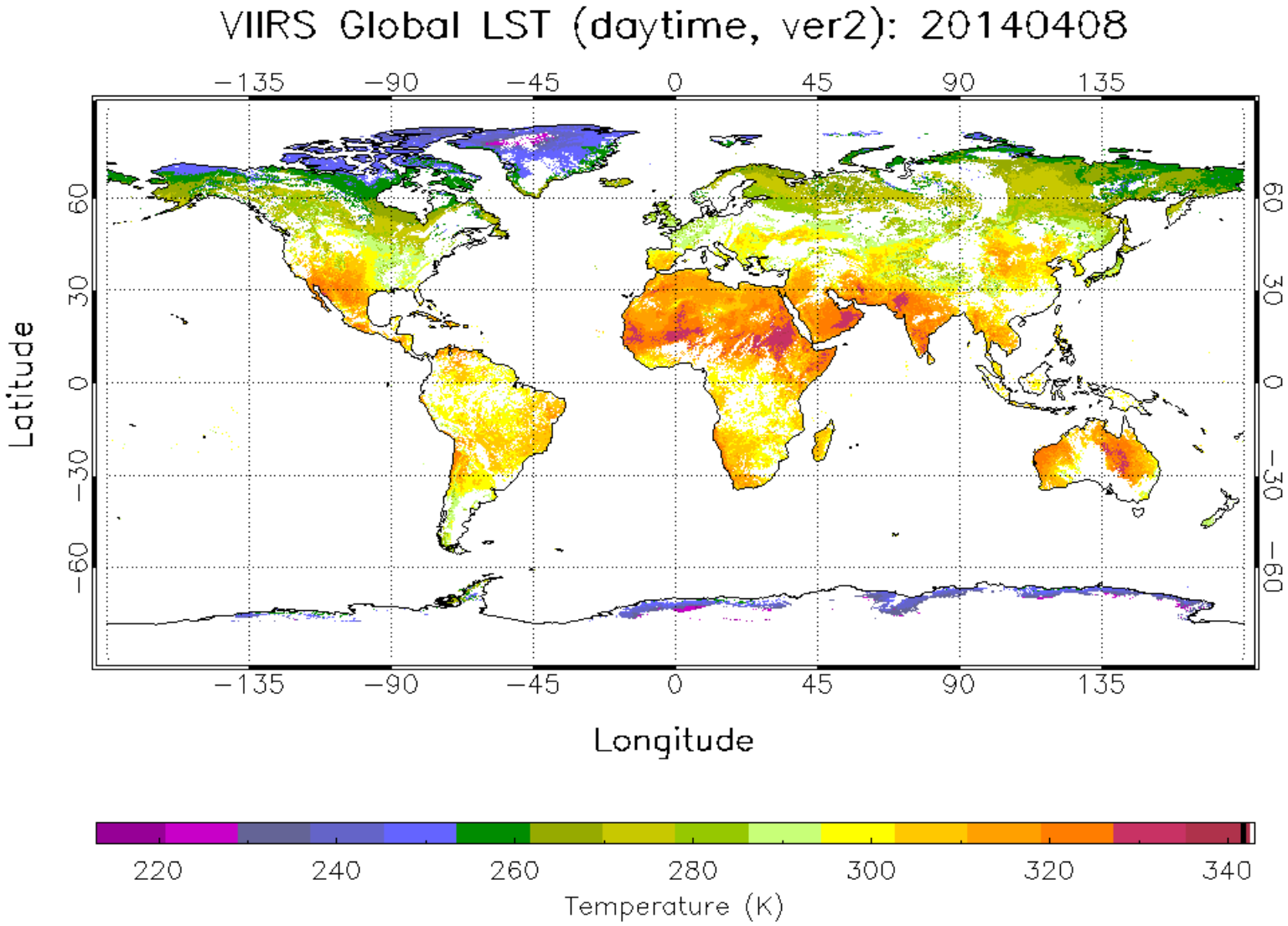
## Algorithm Evaluation

LST retrieval algorithms were mostly inherited from SST retrieval technique using a split-window regression approach. Simulation studies indicate that different regression formula provide similar retrieval quality under ideal condition.

| Site | Record No. | Bias | STD | RMSE |
|---|---|---|---|---|
| VIIRS | 1802 | -0.61 | 2.31 | 2.39 |
| 1 | 1802 | -0.16 | 2.40 | 2.40 |
| 2 | 1802 | 0.18 | 2.59 | 2.60 |
| 3 | 1802 | -0.21 | 2.44 | 2.45 |
| 4 | 1802 | -0.19 | 2.43 | 2.44 |
| 5 | 1802 | -0.81 | 2.53 | 2.66 |
| 6 | 1802 | -0.19 | 2.45 | 2.45 |
| 7 | 1802 | -0.21 | 2.44 | 2.45 |
| 8 | 1802 | -0.22 | 2.44 | 2.45 |
| 9 | 1802 | -0.19 | 2.48 | 2.48 |
| 1’ | 1802 | -0.10 | 2.37 | 2.37 |
| 6’ | 1802 | -0.13 | 2.41 | 2.41 |
| 8’ | 1802 | -0.15 | 2.41 | 2.41 |
| 11 | 1802 | -0.16 | 2.33 | 2.35 |
| 12 | 1802 | -0.16 | 2.33 | 2.34 |

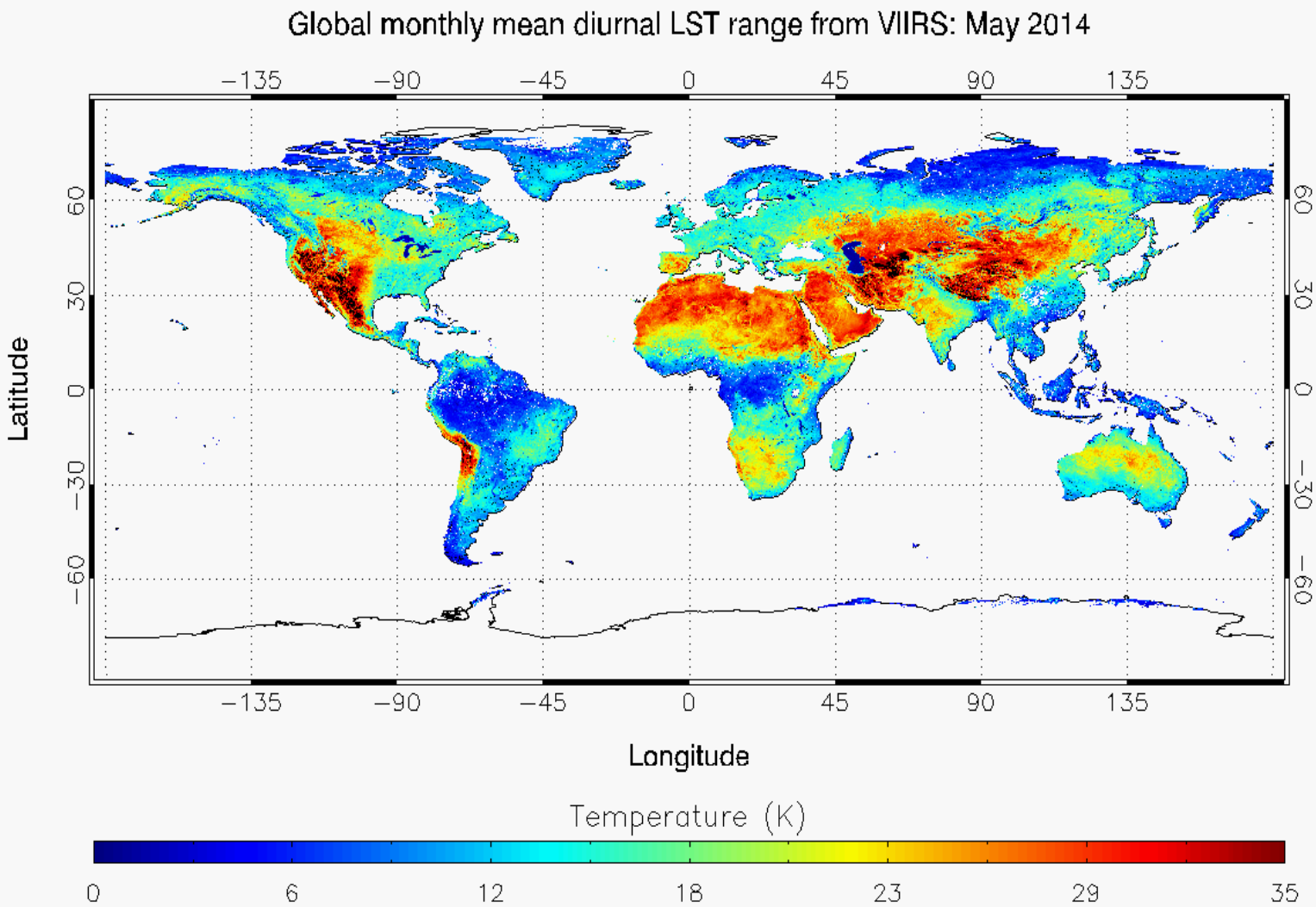
# Issues in LST Algorithm Development

## ---- Spatial Variation



# Issues in LST Algorithm Development

## ---- Temporal Variation



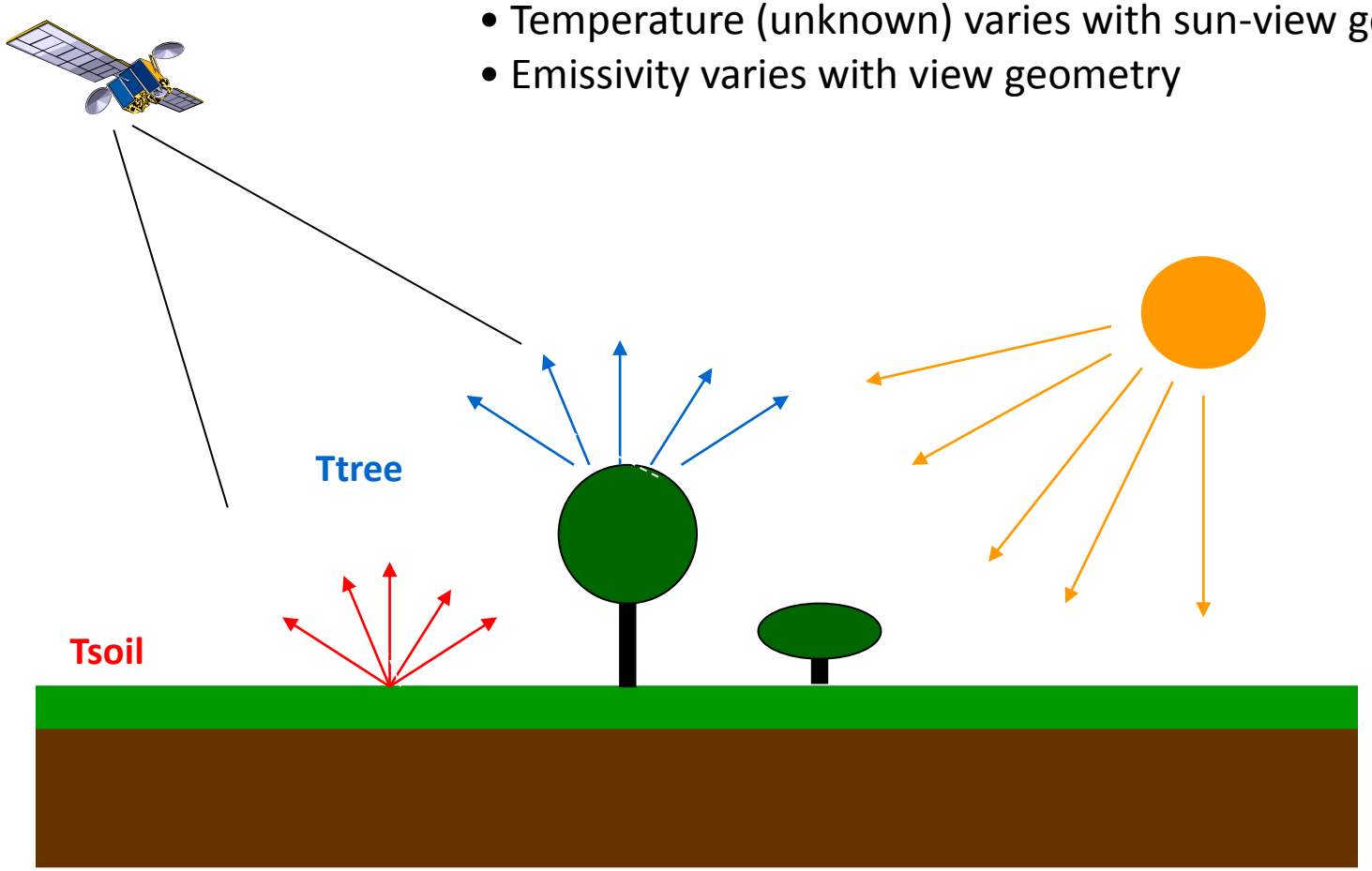
# Issues in LST Algorithm Development

## ---- Directional Impact

Angular Anisotropy is Currently Ignored in Most LST

2 Effects:

- Temperature (unknown) varies with sun-view geometry
- Emissivity varies with view geometry



# Issues in LST Algorithm Development

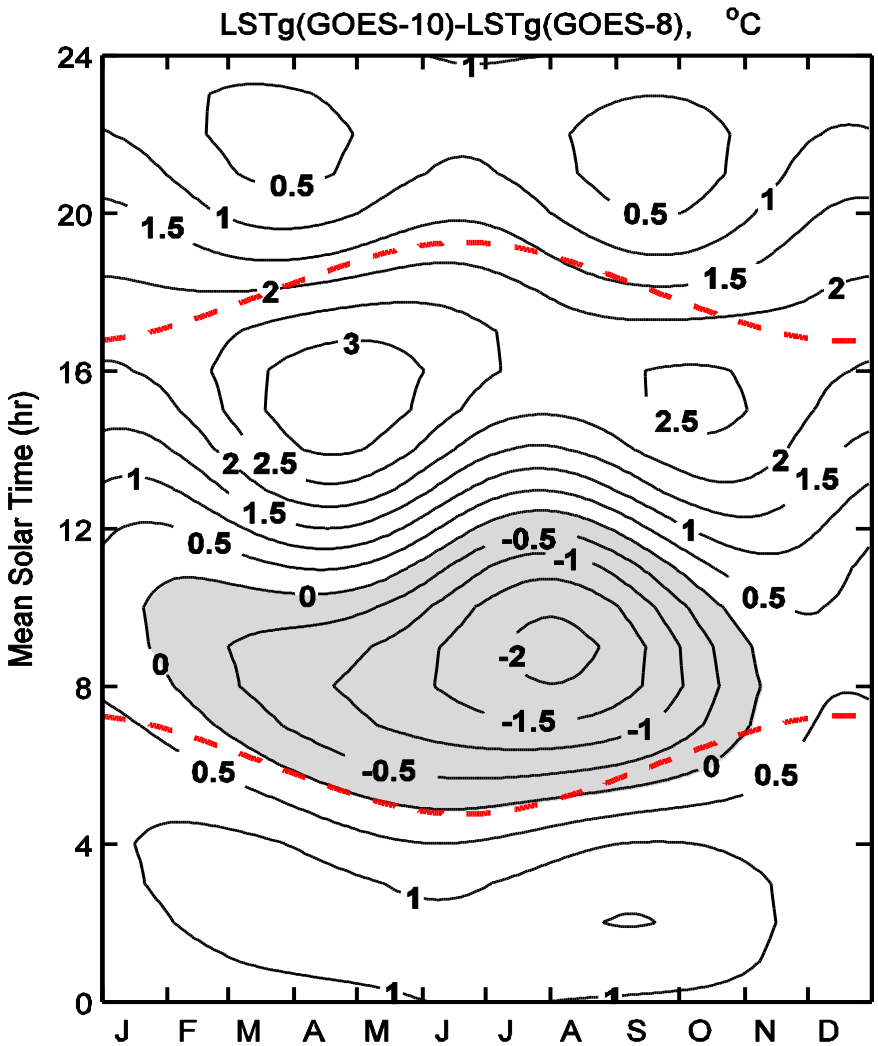
## ---- Directional Impact

## LST Directional Effect in GOES-8 and -10 Imager

**Difference of LSTs observed by GOES-10 and GOES-8 imager at the same location of SURFRAD station Desert Rock, NV, 36.63ºN, 116.02ºW. The simultaneous observation pairs are about 2096.**

**View zenith of GOES-8: 60.14$^0$**

**View zenith of GOES-10: 46.81$^0$**



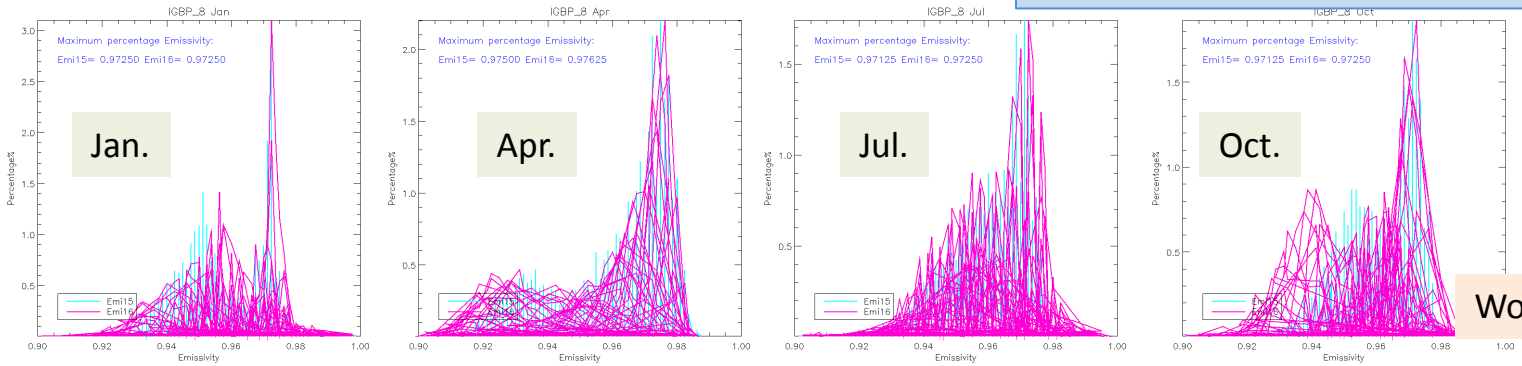

LST difference observed from GOES-8 and GOES-10 Imagers.

# Issues in LST Algorithm Development

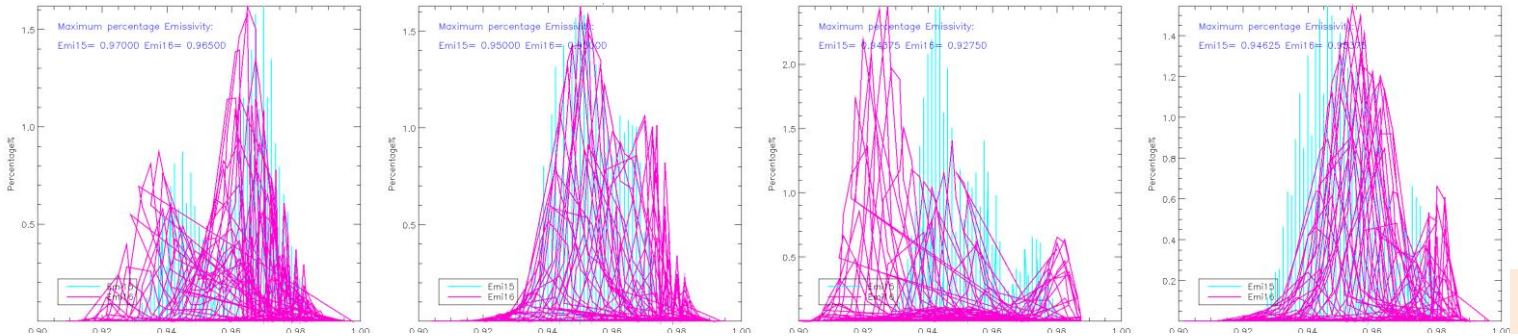
## ---- Emissivity Variation Impact

- *Considerable seasonal emissivity variation over some surface types*
- *Considerable emissivity variation within cover types*

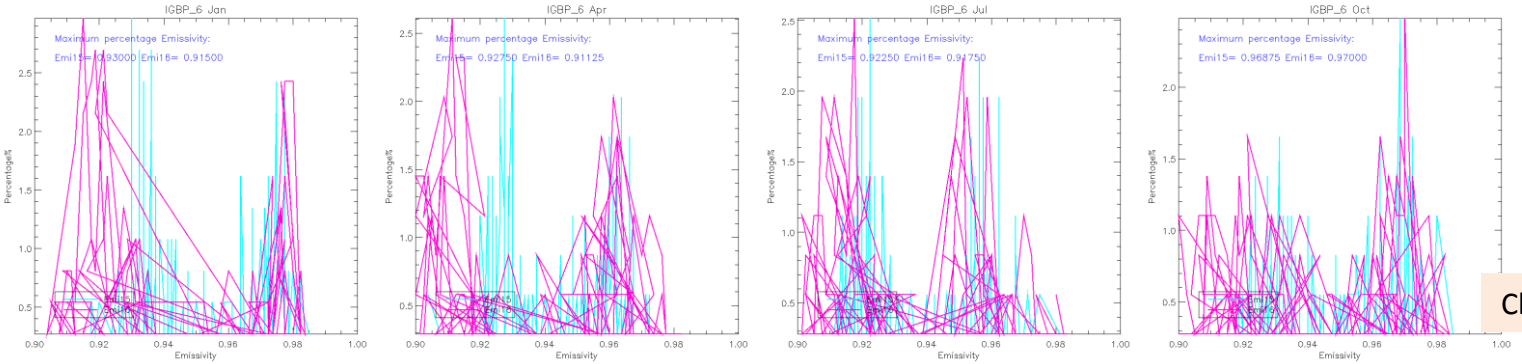
## Emissivity Impact to LST




Woody Savannas (2012)




Grassland(2011)




Closed Shrub lands (2012)

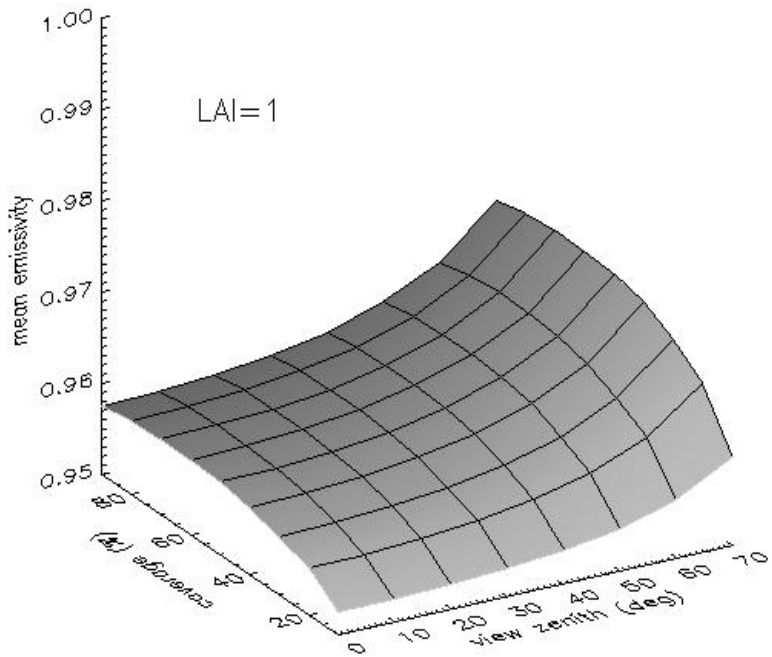
# Issues in LST Algorithm Development

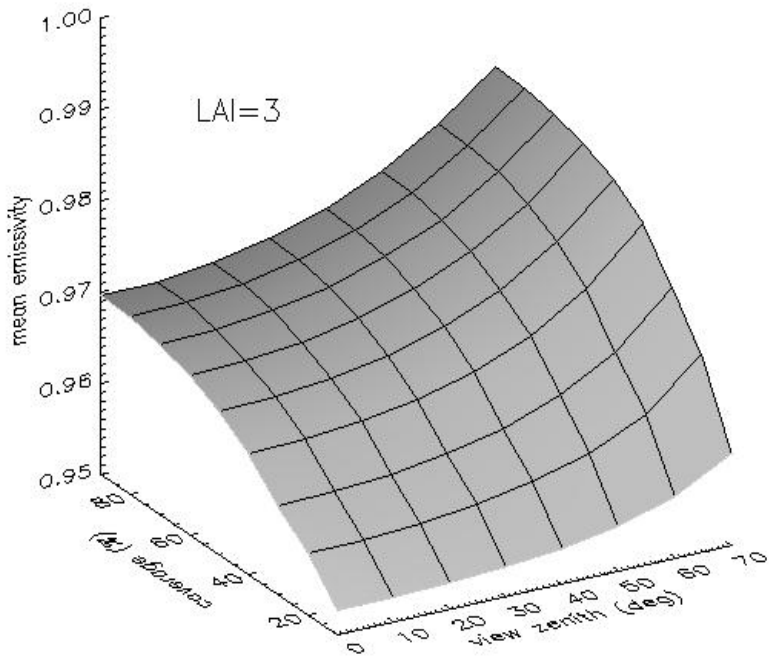
## ---- Emissivity Variation Impact

Directional Emissivity Variation Example from a MGP model

Vegetation surface: Green needle Forest ; Background: bare soil

Mean Emissivity=$(\varepsilon_1+\varepsilon_2)/2$, where $\varepsilon_1$ and $\varepsilon_2$ are the spectral emissivities at MODIS bands 31 and 32, respectively.



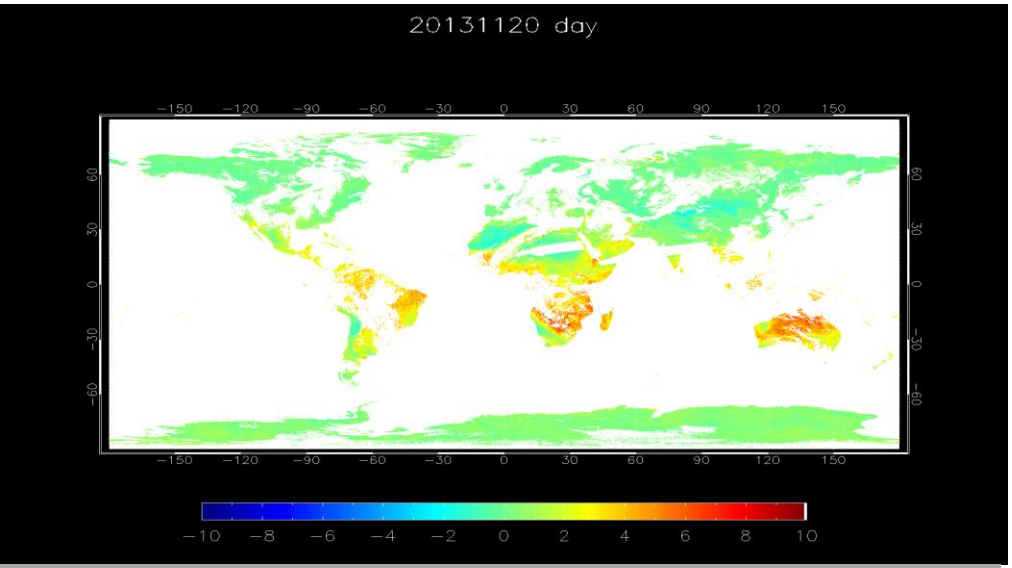




LUT dimension: vegetation type, cover%, LAI, soil background, view zenith

# Issues in LST Algorithm Development

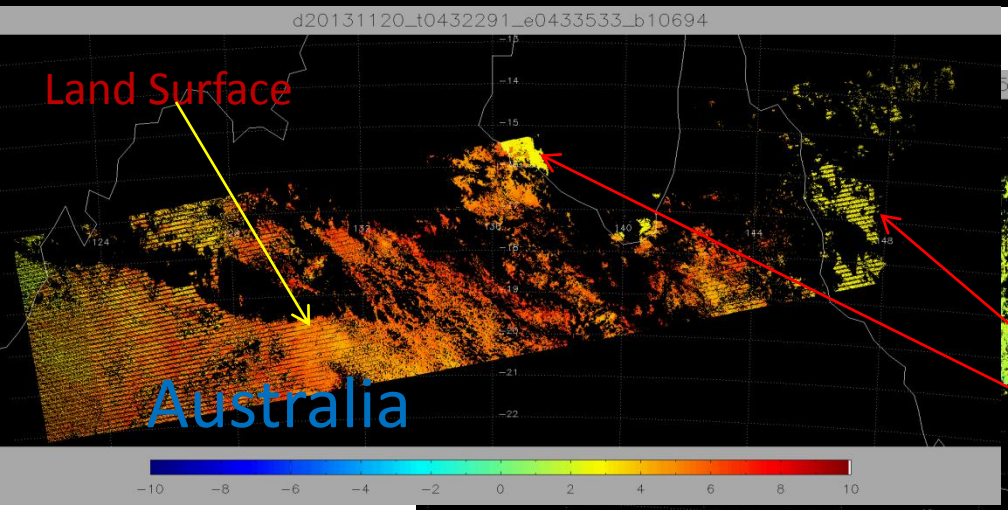
## ---- Atmospheric Correction

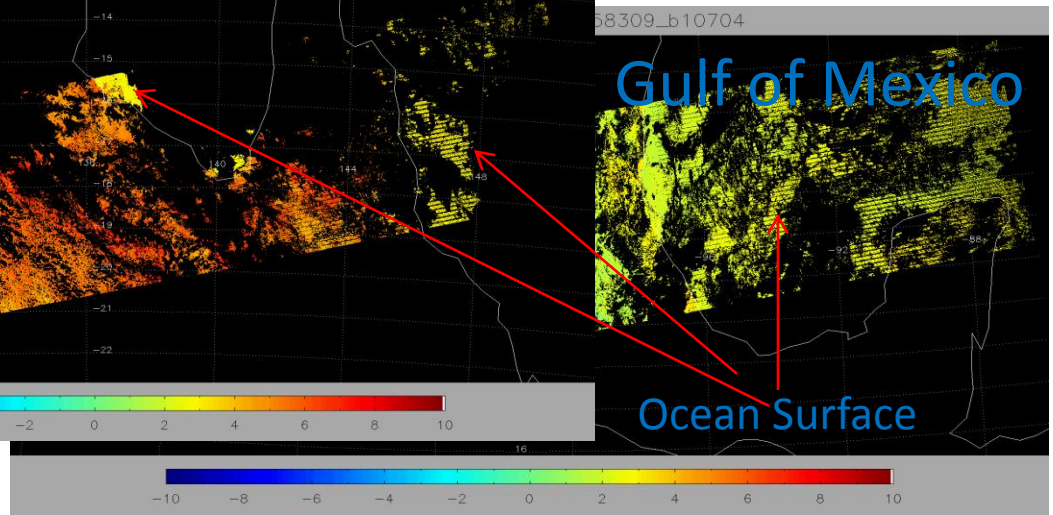
## BT difference for atmospheric correction




Split-window algorithm feature: brightness temperature (**BT**) difference at 11 and 12 μm is used for atmospheric correction. It is the SST heritage. However, the BT difference can be very different over land. Additional measure is needed.

*BT difference at daytime*



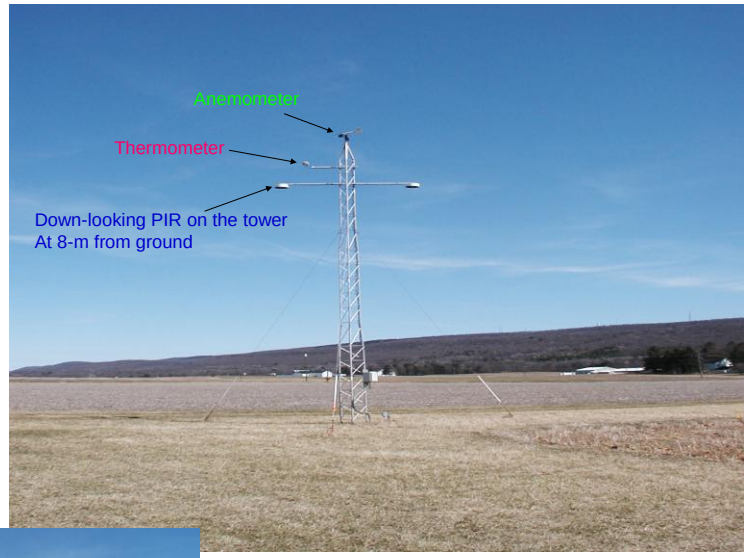

Left: Significant BT differences over land and sea water surface. The BT difference is much smaller over sea surface

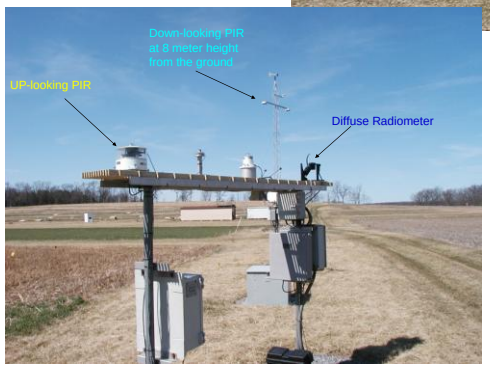
# Issues in LST Product Validation

## ---- In-situ Validation

### LST Validation Difficulties

- *In Situ* data limitation
  - Measurement difficulty
  - Emissivity Directional impact
  - Cloud contamination impact
- Spatial and temporal variations
  - Spot vs pixel difference
  - Accurate match-up process (in space and in time)
- Others (e.g., angle effect)



Surface heterogeneity is shown in a 4km x 4km Google map (1km x 1km, in the center box) around the Bondville station area

**Two-measurement model :**

$$LST_{satellite} = LST_{truth} + Noise_{satellite}$$

$$LST_{ground} = LST_{truth} + Noise_{ground}$$

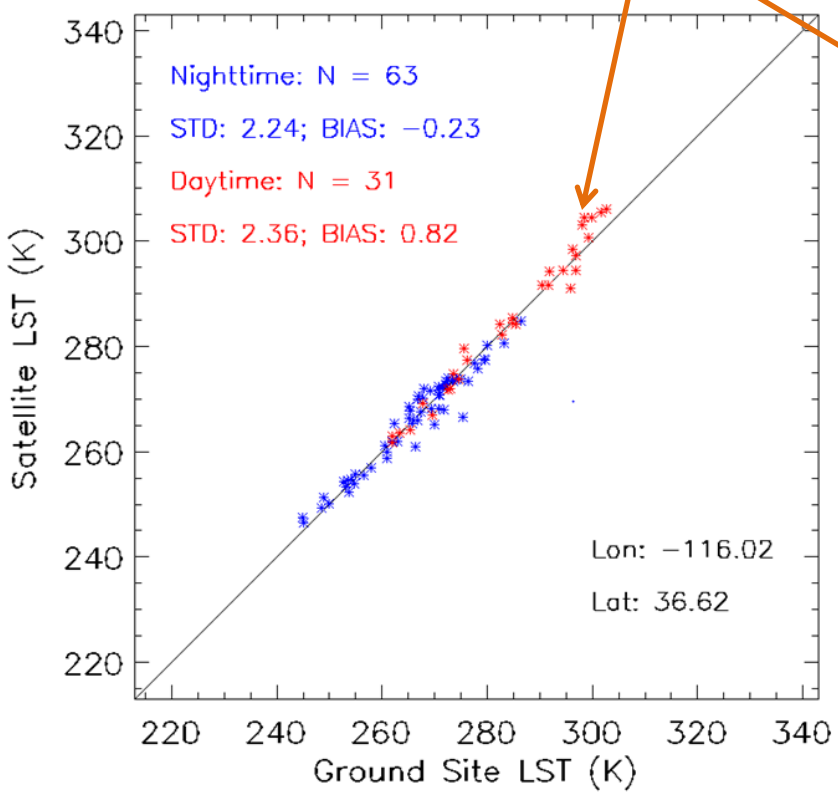
Understanding $Noise_{ground}$ is crucial for understanding $Noise_{satellite}$

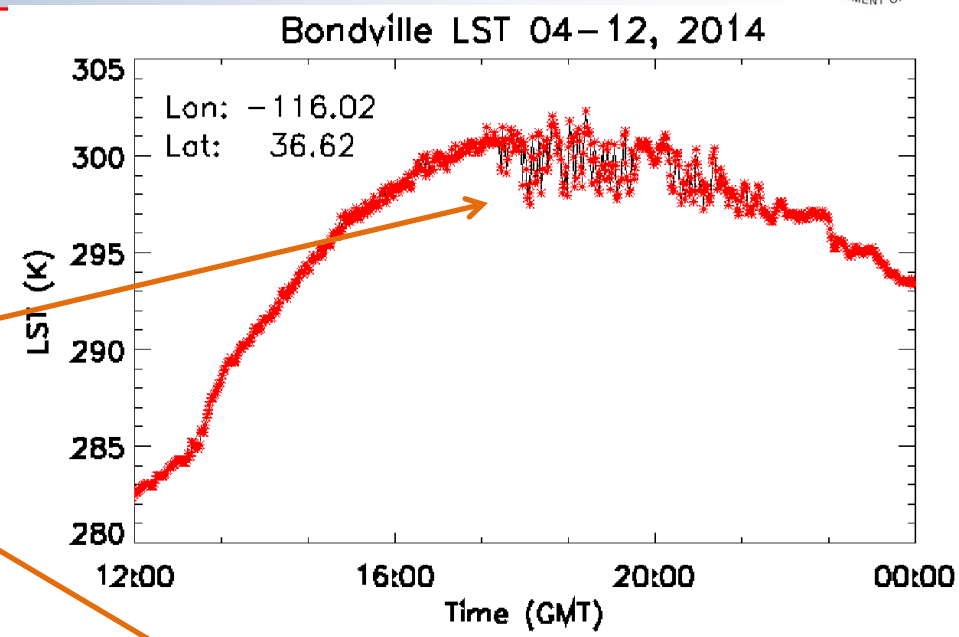
# Issues in LST Product Validation

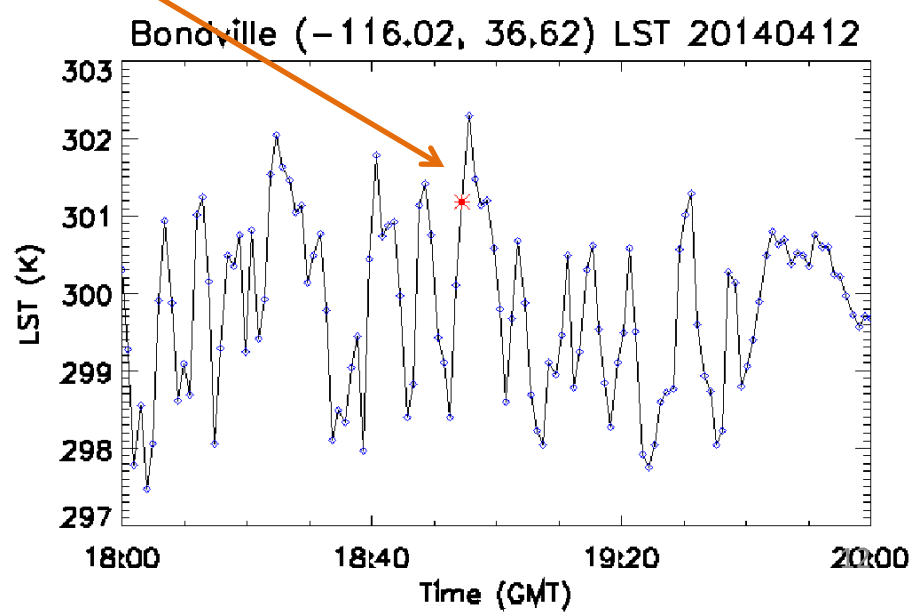
## ---- In-situ Validation

## Impact of Ground Data Fluctuation

The ground LST estimate can be fluctuated significantly, resulting big match-up uncertainty ( ~6K)

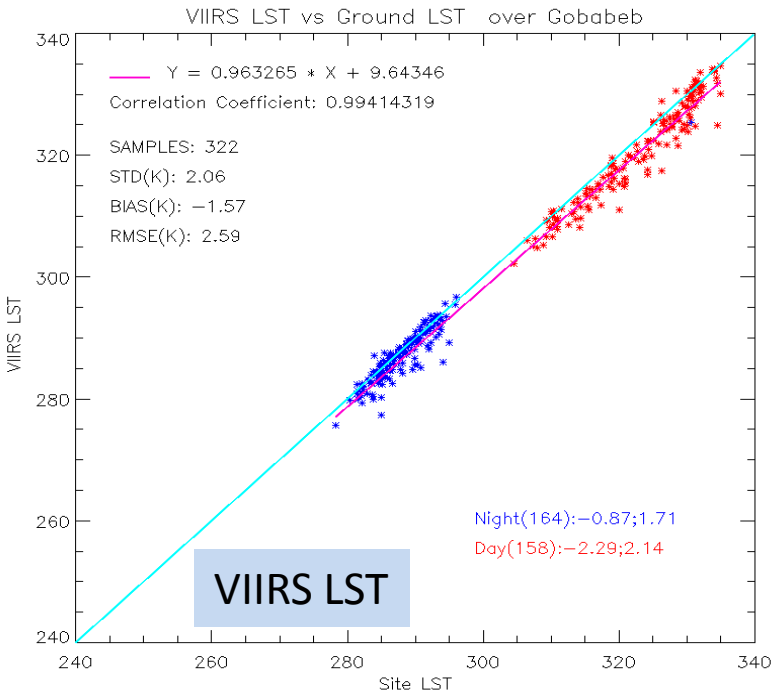


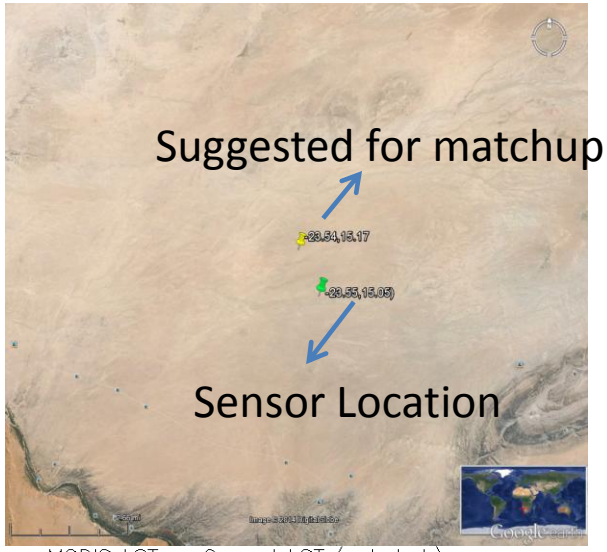



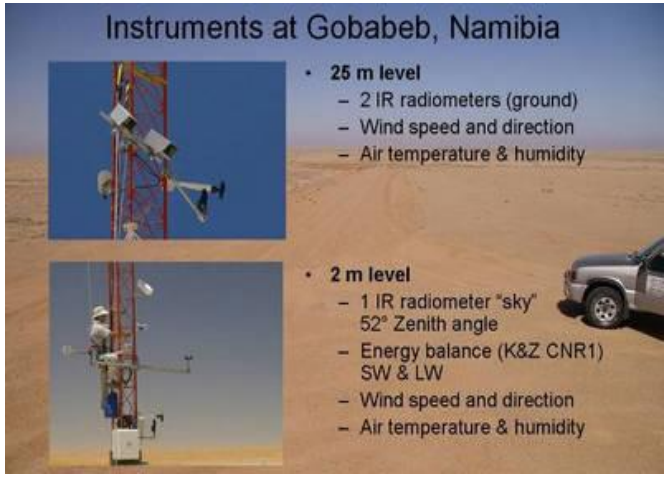
# Issues in LST Product Validation

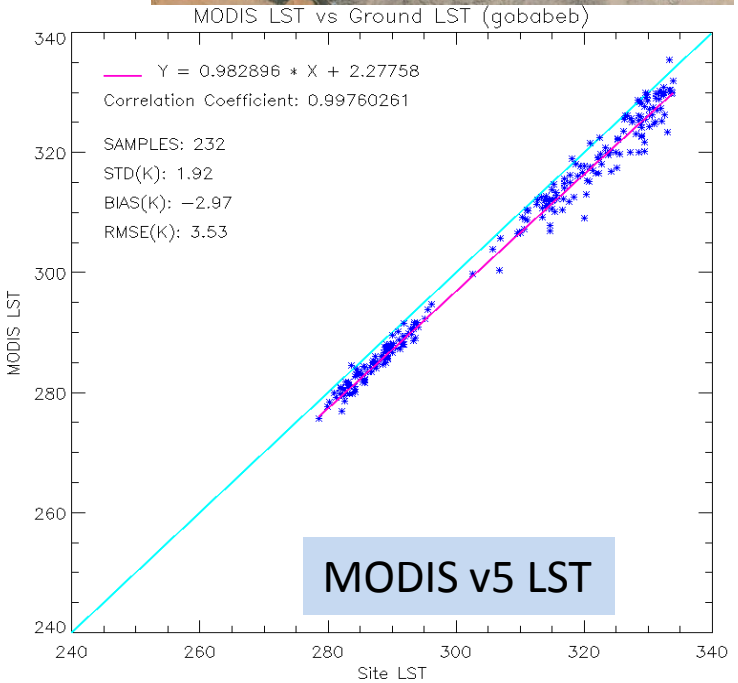
## ---- In-situ Validation




A case study of in-situ data comparison in Africa (Gobabeb, Namibia)



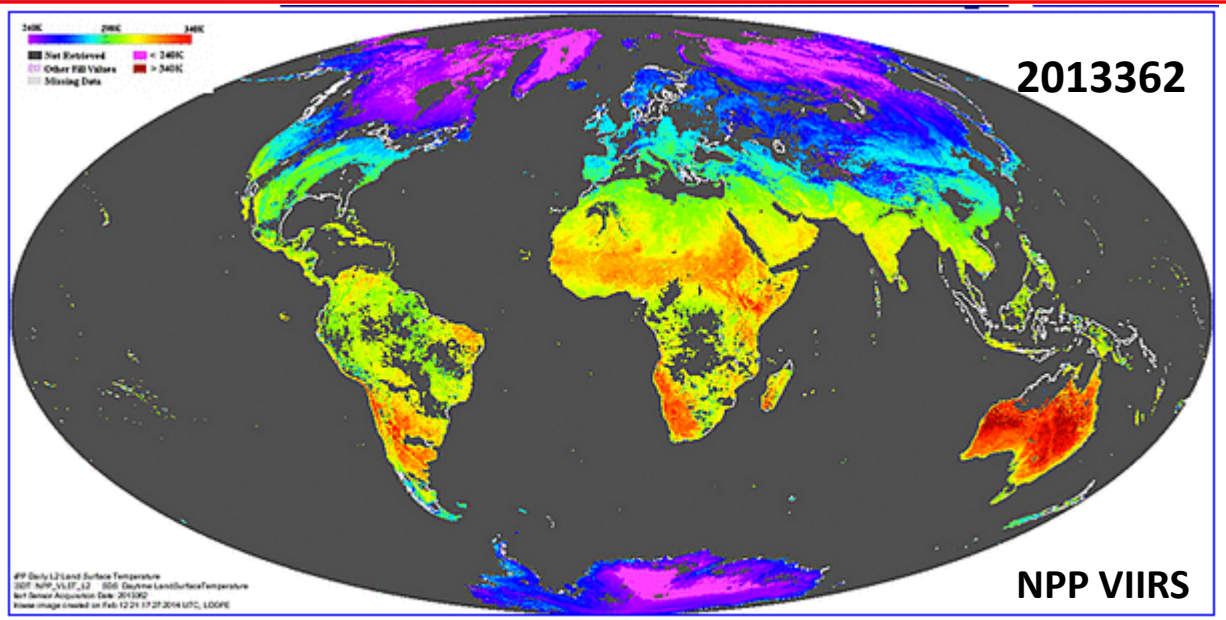



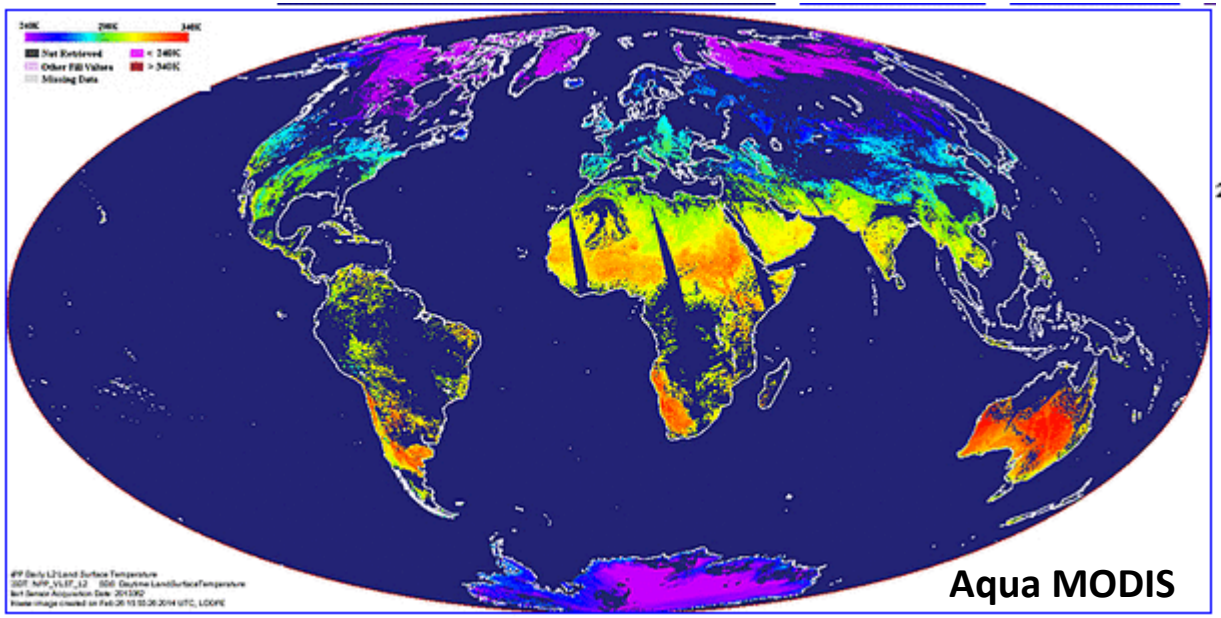




*the Africa site data provided by Frank Goettsche (KIT & EUMETSAT Land SAF), through LST validation collaboration

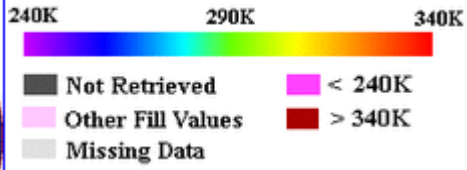
# Issues in LST Product Validation

## ---- Cross-Satellite Comparison




A Case Study of LPEATE Global Browse Images of Day LST

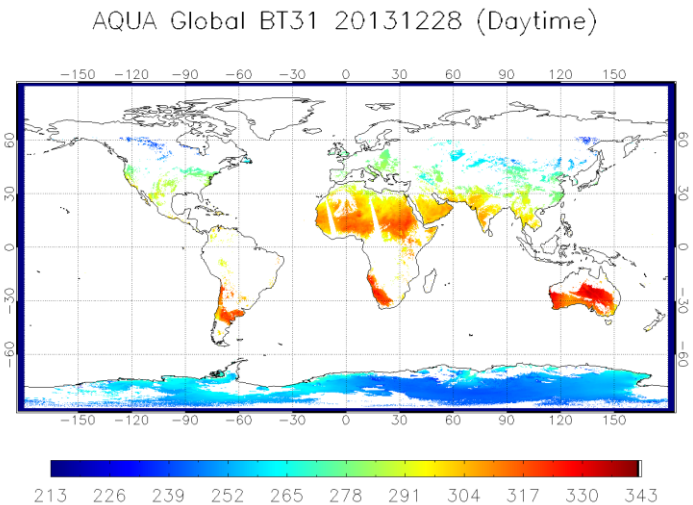


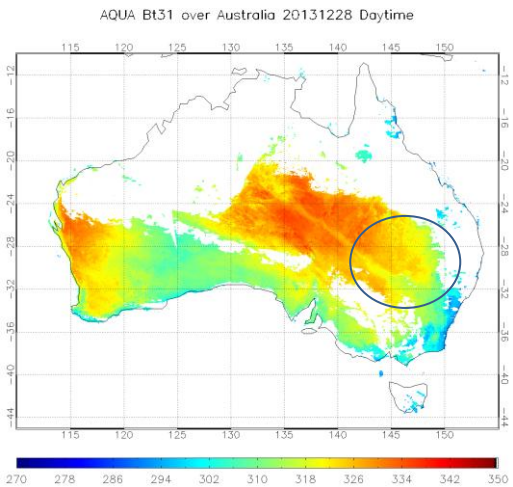

**Global images are generated**
*by courtesy of NASA/GSFC LPEATE*

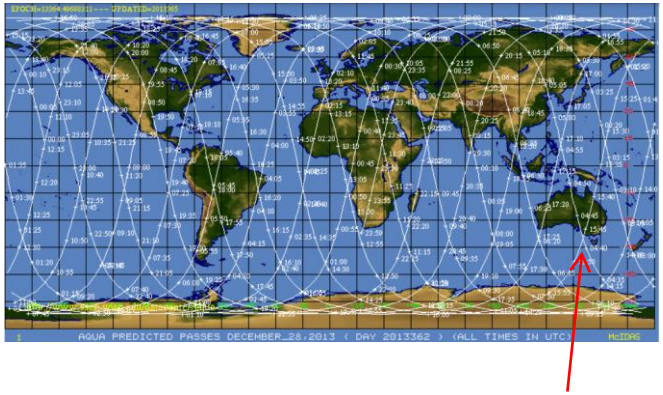
# Issues in LST Product Validation

## ---- Cross-Satellite Comparison

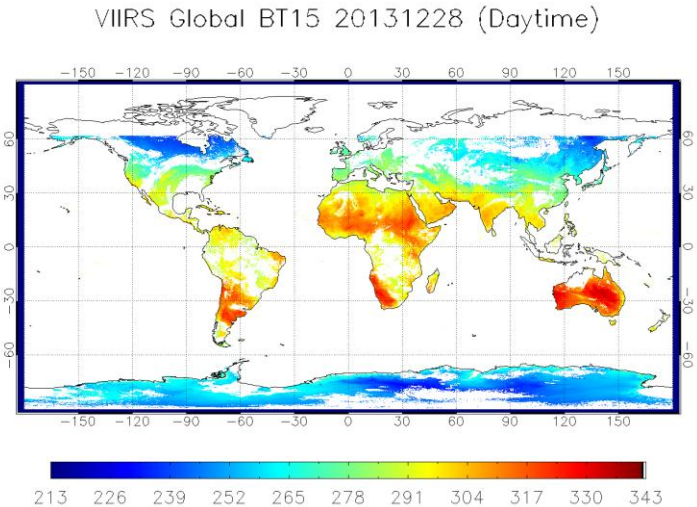
## Impact of time difference in cross-satellite comparison

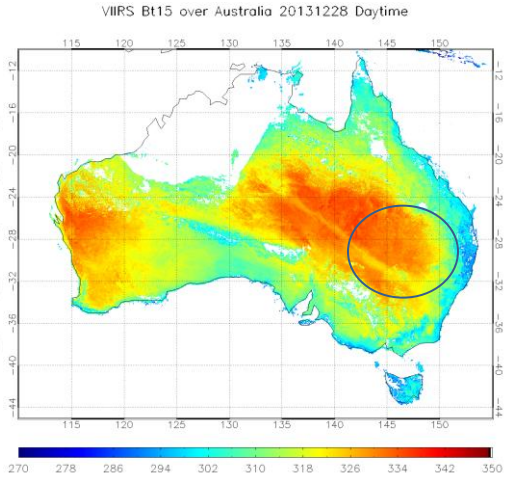


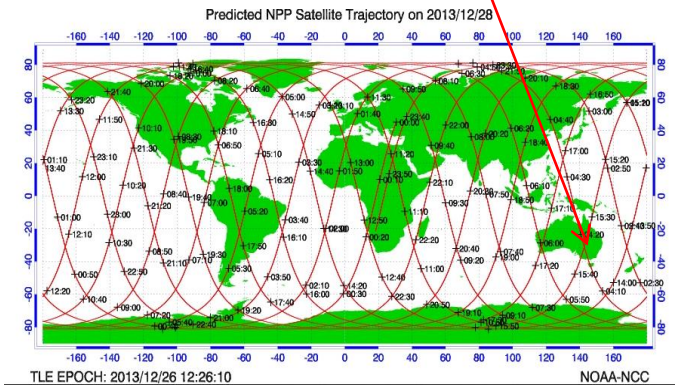




About 25 min difference between VIIRS and MODIS

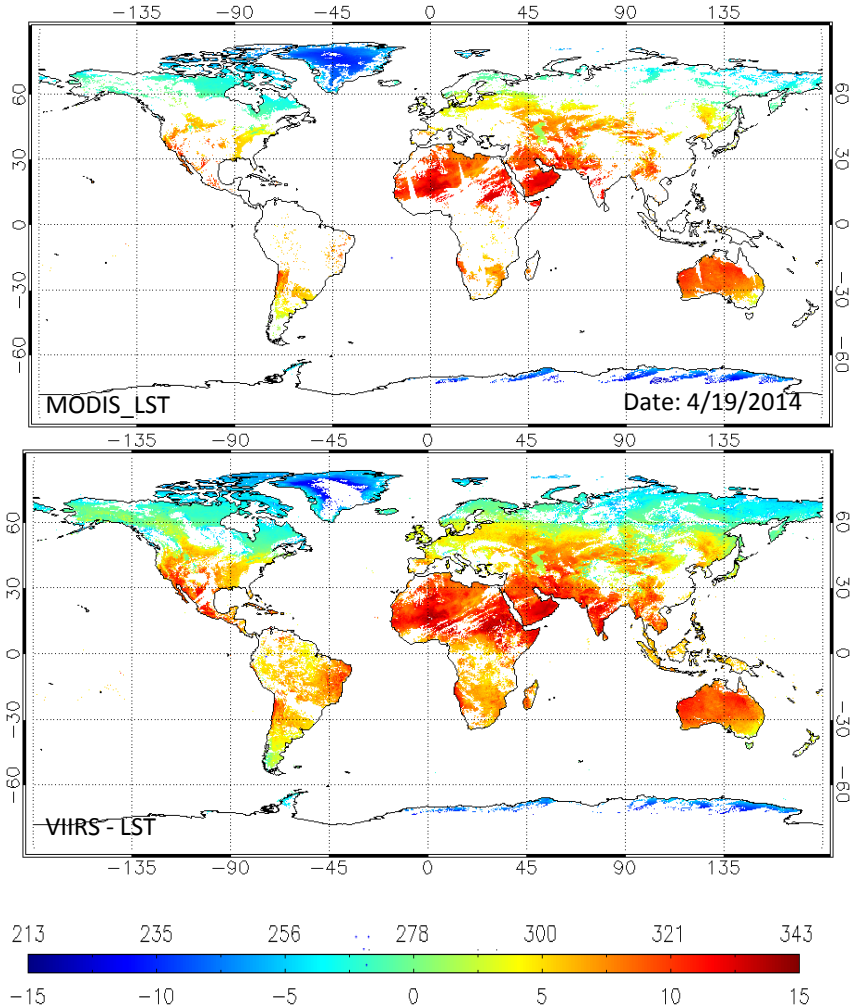


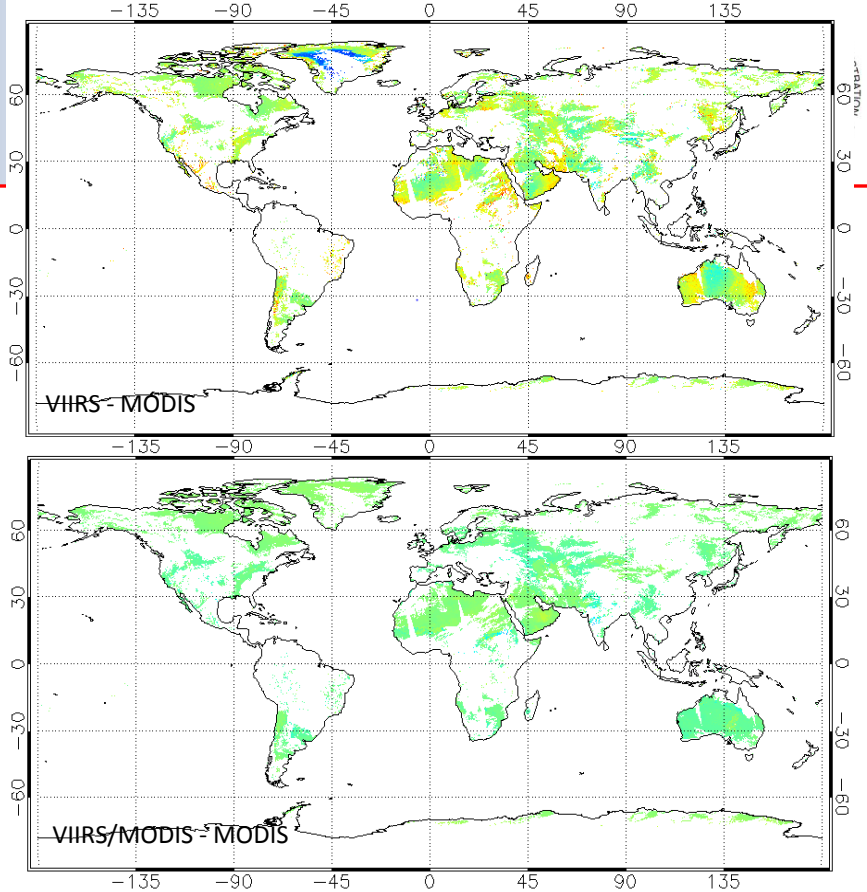



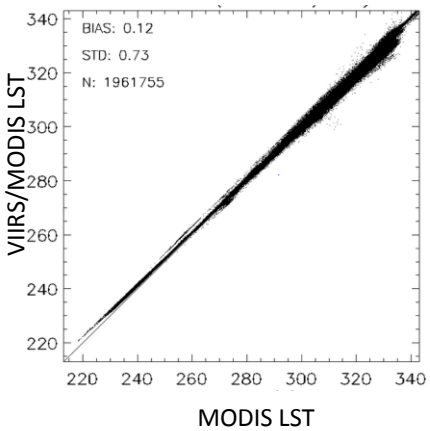



# Cross-Satellite Comparison

## Cross-satellite Comparison: dataset difference



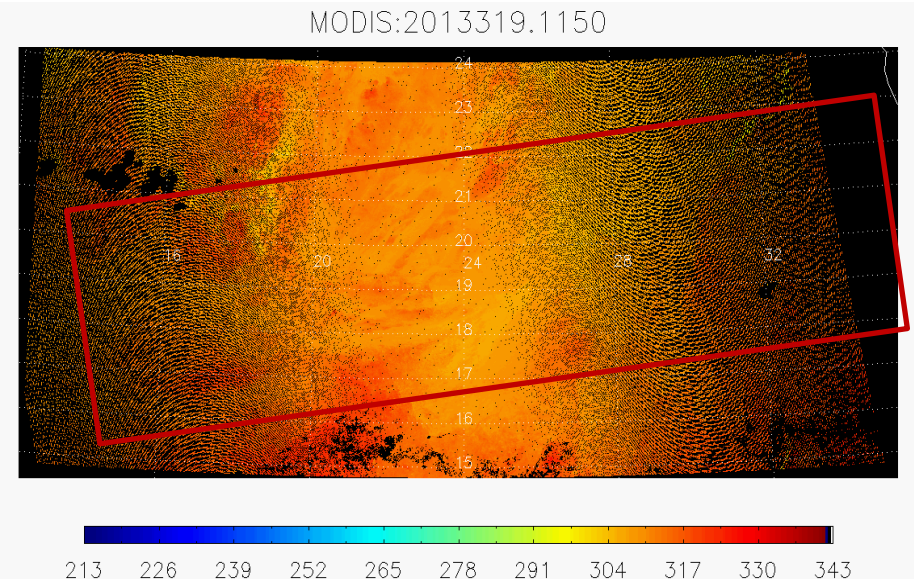



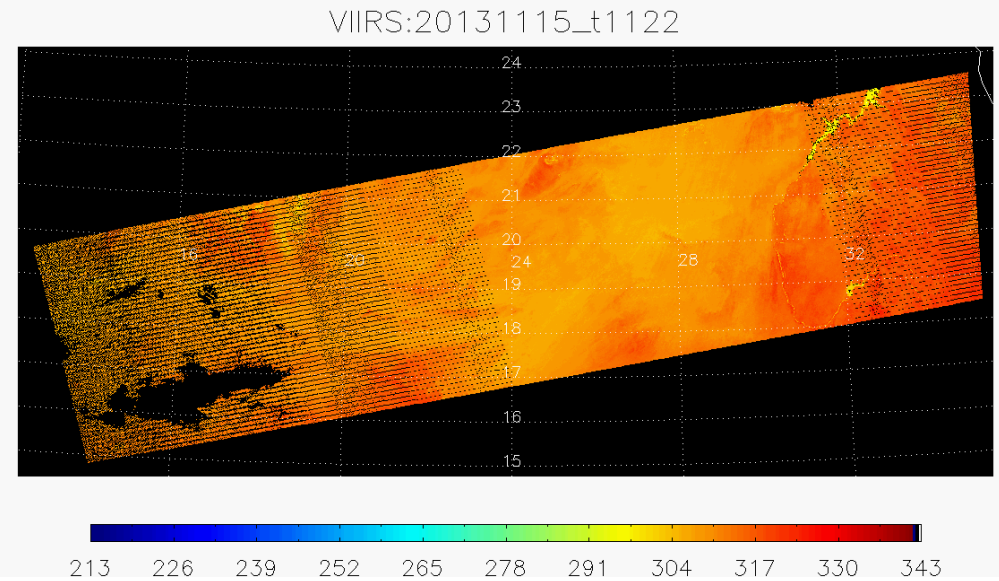

Cross-satellite LST comparison is used in VIIRS LST evaluation.

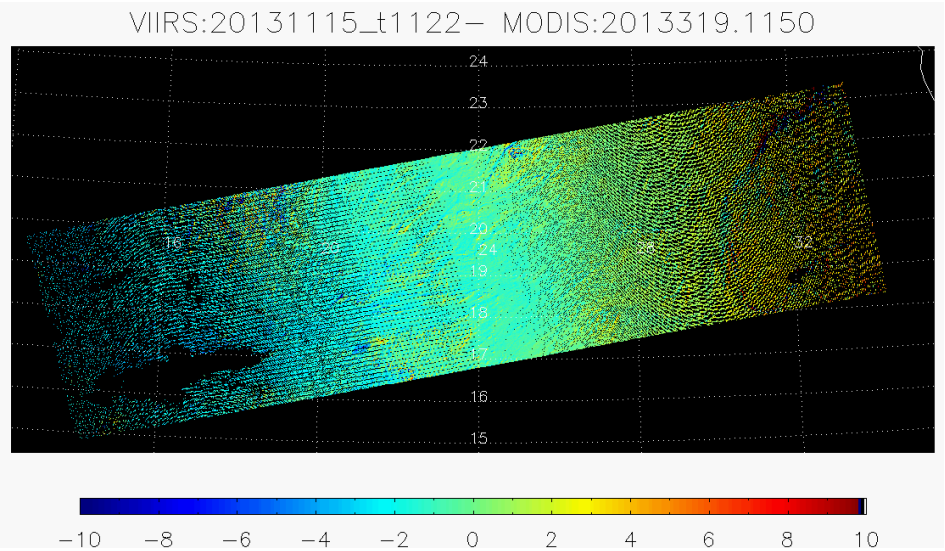
Caution: Time difference is a significant impact; granule level comparison is needed.

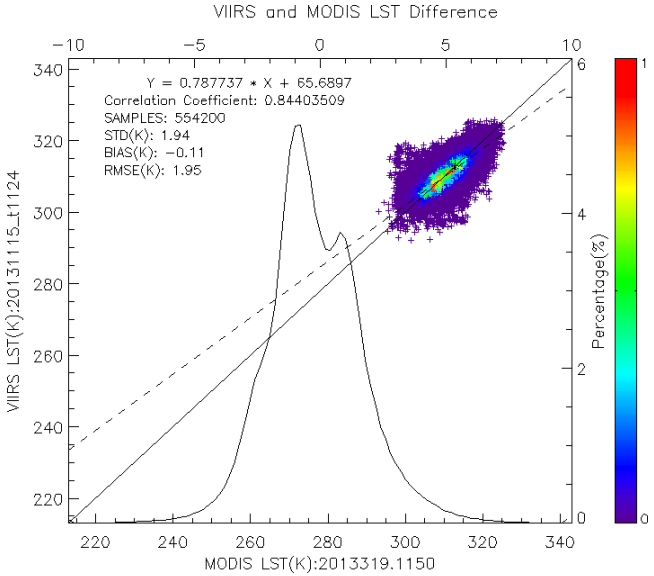
# Issues in LST Product Validation

## ---- Granule level Cross-Satellite Comparison



# Summary

## *Issues in LST Algorithm Development*

- Emissivity sensitivity
- Spatial heterogeneity
- Temporal variation
- Atmospheric difference
- Cloud contamination

## *Issues in LST Product Validation*

- In-situ validation
  - Spatial heterogeneity: spot-pixel difference
  - Temporal variation: time match restriction
  - In-situ LST estimation: data quality, emissivity issue
- Cross-satellite comparison
  - Data gridding: aggregation process
  - Time match
  - BRDF impact