National Aeronautics and Space Administration


# MODIS/VIIRS
# Land Surface Temperature and Emissivity

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# Outline

1. Algorithm and product updates
2. Validation
3. Product unification
4. Continuity

# Land Surface Temperature/ Emissivity (LST&E)

- LST&E are key variables for Earth Science:
  - Monitoring climate change
  - Land use/land cover change
  - Surface energy balance (e.g. ET)
  - Cryosphere

- Push for better understanding and utilization:
  - EarthTemp, GlobTemperature, ILSTE-Working groups
  - LST recognized as Essential Climate Variable (ECV) by GCOS!

- Requirements:
  - 1 K accuracy LST, 1.5% accuracy emissivity
  - Global daily (LEO), and 30-min (GEO)
  - <1 km spatial resolution
  - Long term stability and uncertainty characterization

# LST&E Algorithm Updates

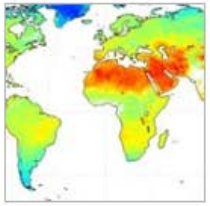
| LST&E Product Characteristics | MODIS (MOD21) | VIIRS (VNP21) |
|---|---|---|
| Algorithm | Temperature Emissivity Separation (TES) | Temperature Emissivity Separation (TES) |
| Bands used | 29 (8.55 µm)<br>31 (11 µm)<br>32 (12 µm) | 14 (8.55 µm)<br>15 (10.76 µm)<br>16 (12 µm) |
| Radiative Transfer Model | RTTOV | RTTOV |
| Atmospheric Profiles (T, RH) | MERRA-2 | MERRA-2 |
| Status | Complete: Tier-2 C6 (MODAPS) | Baselining in progress (LSIPS) |
| Data Product Types | L2, L2G Daily (1 km)<br>L3 8-day, (1 km) | L2, L2G Daily (750 m)<br>L3 8-day, (750 m) |
| Science Data Products | - LST<br>- Emissivity<br>(bands 29, 31, 32) | - LST<br>- Emissivity<br>(bands 14, 15, 16) |

Central Europe
03-12-2014

Low clouds in central California
01-24-2015

# MODIS Land Surface Temperature and Emissivity (MOD21)

## Overview



The new MODIS Land Surface Temperature and Emissivity (LST&E) product (MOD21) available in Collection 6 uses a physics-based algorithm to dynamically retrieve both the LST and Emissivity simultaneously for the three MODIS thermal infrared bands (29, 31 and 32) at a spatial resolution of 1 km at nadir. The MOD21 product addresses the documented cold bias of 3-5 K in the MOD11 heritage split-window products over arid and semi-arid regions.

The MOD21 algorithm is based on the ASTER Temperature Emissivity Separation (TES) algorithm, which uses full radiative transfer simulations for the atmospheric correction, and an emissivity model based on the variability in the surface radiance data to dynamically retrieve both LST and spectral emissivity. The TES algorithm is combined with an improved Water Vapor Scaling (WVS) atmospheric correction scheme to stabilize the retrieval during very warm and humid conditions. Simulations and validation results available in the ATBD have shown consistent accuracies at the 1 K level over all land surface types including vegetation, water, and deserts.

The MOD21 product will include a swath (scene) Level-2 daily product, and daily and eight-day Level 3 gridded products in sinusoidal projection.

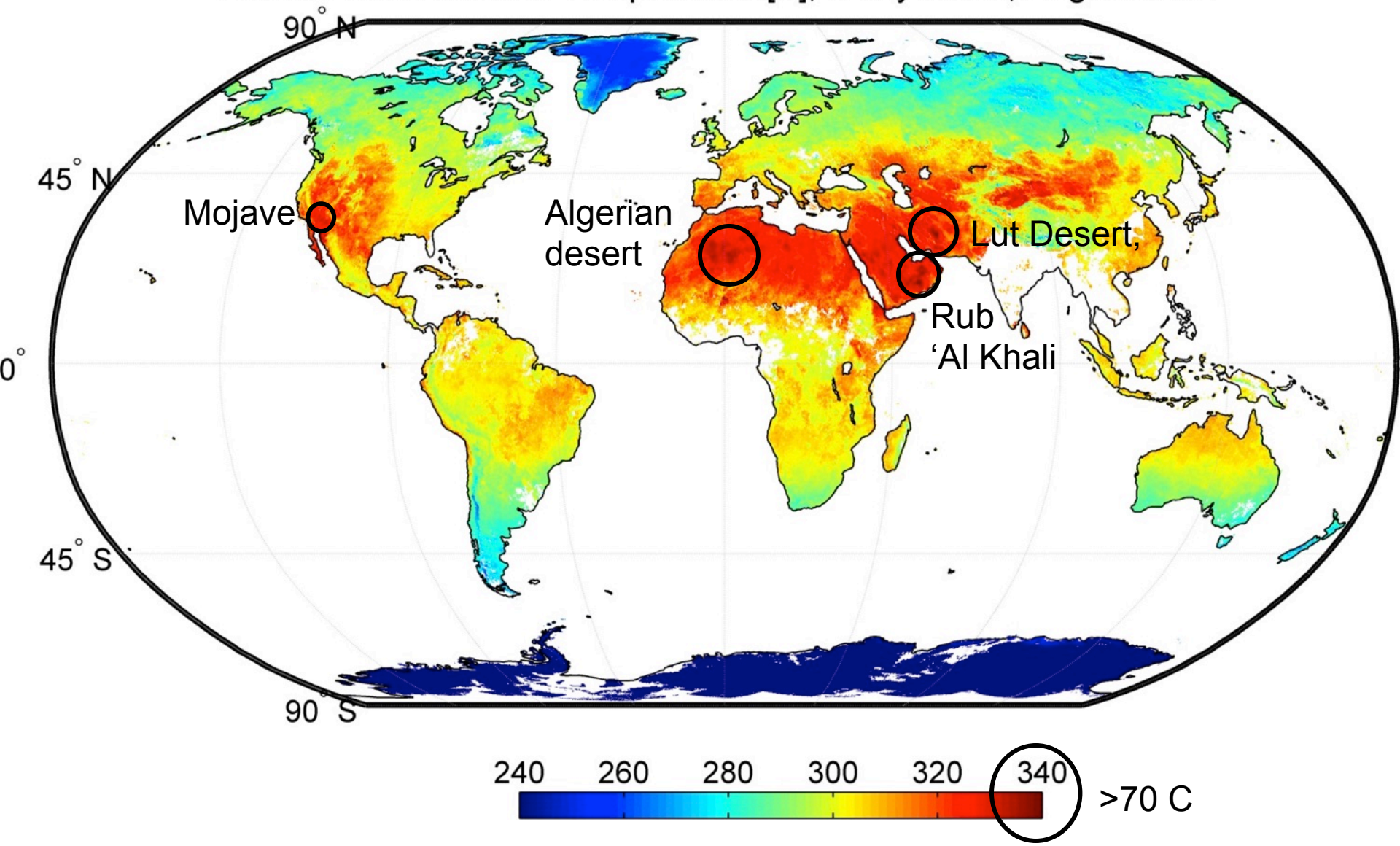
## Product Information

- Product PI: Glynn Hulley
  https://science.jpl.nasa.gov/people/Hulley/
- Validated Stage: Stage 1
- PI Product Page URL
- User Guide Download
- ATBD

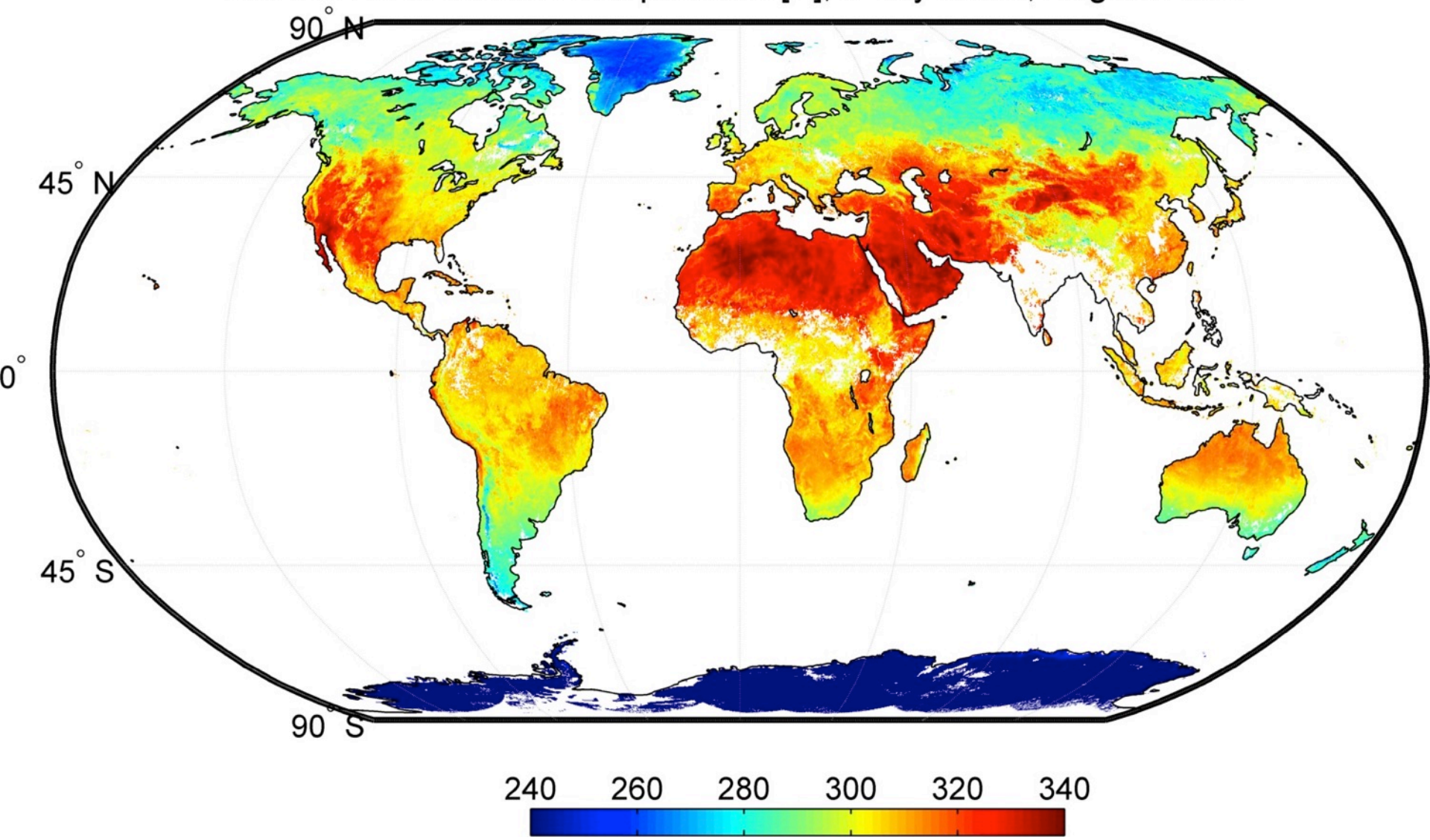
## Product Details

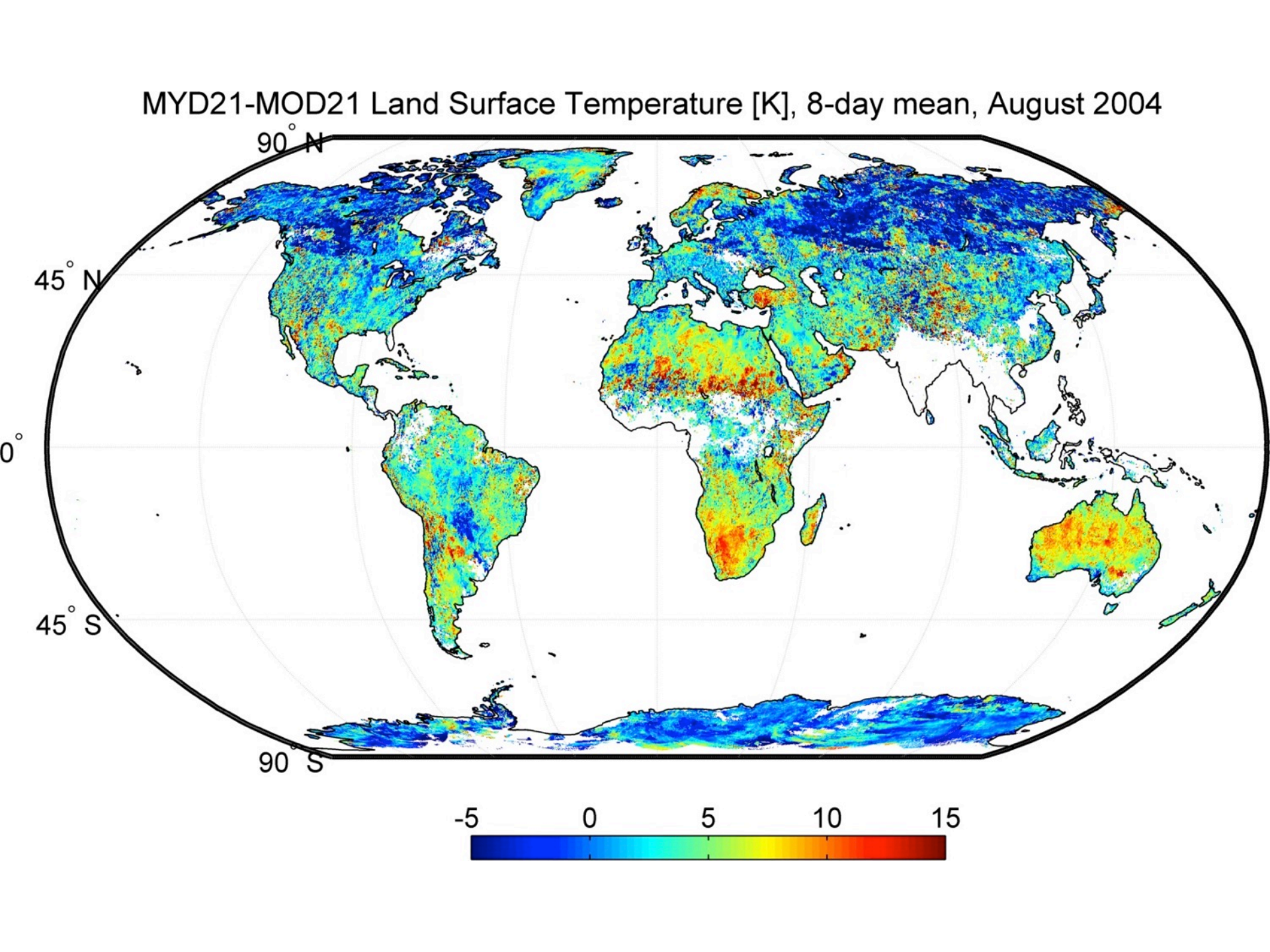
| Product Name | Terra Prod ID/ DAAC Link | Aqua Prod ID/ DAAC Link |
|---|---|---|
| Land Surface Temperature/Emissivity Daily 5-min L2 Swath 1km | MOD21_L2 | MYD21_L2 |
| Land Surface Temperature/Emissivity Daily L3 Global 1km | MOD21A1 | MYD21A1 |
| Land Surface Temperature/Emissivity 8-day L3 Global 1km | MOD21A2 | MYD21A2 |

# TERRA – 10:30 am

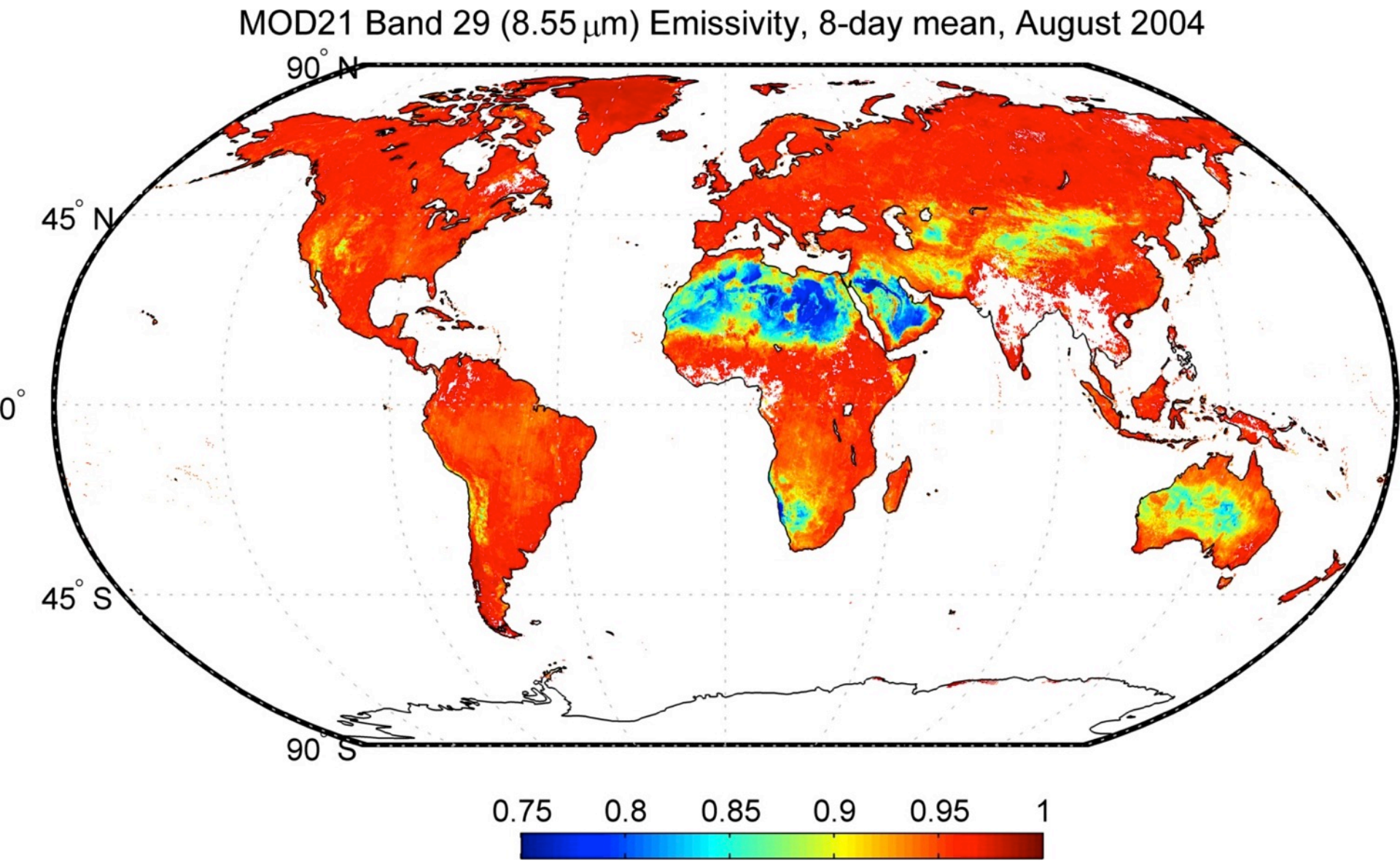


# AQUA – 01:30 pm


MYD21 Land Surface Temperature [K], 8-day mean, August 2004
90° N
45° N
0°
45° S
90° S
240
260
280
300
320
340


MYD21-MOD21 Land Surface Temperature [K], 8-day mean, August 2004
90° N
45° N
0°
45° S
90° S
-5
0
5
10
15

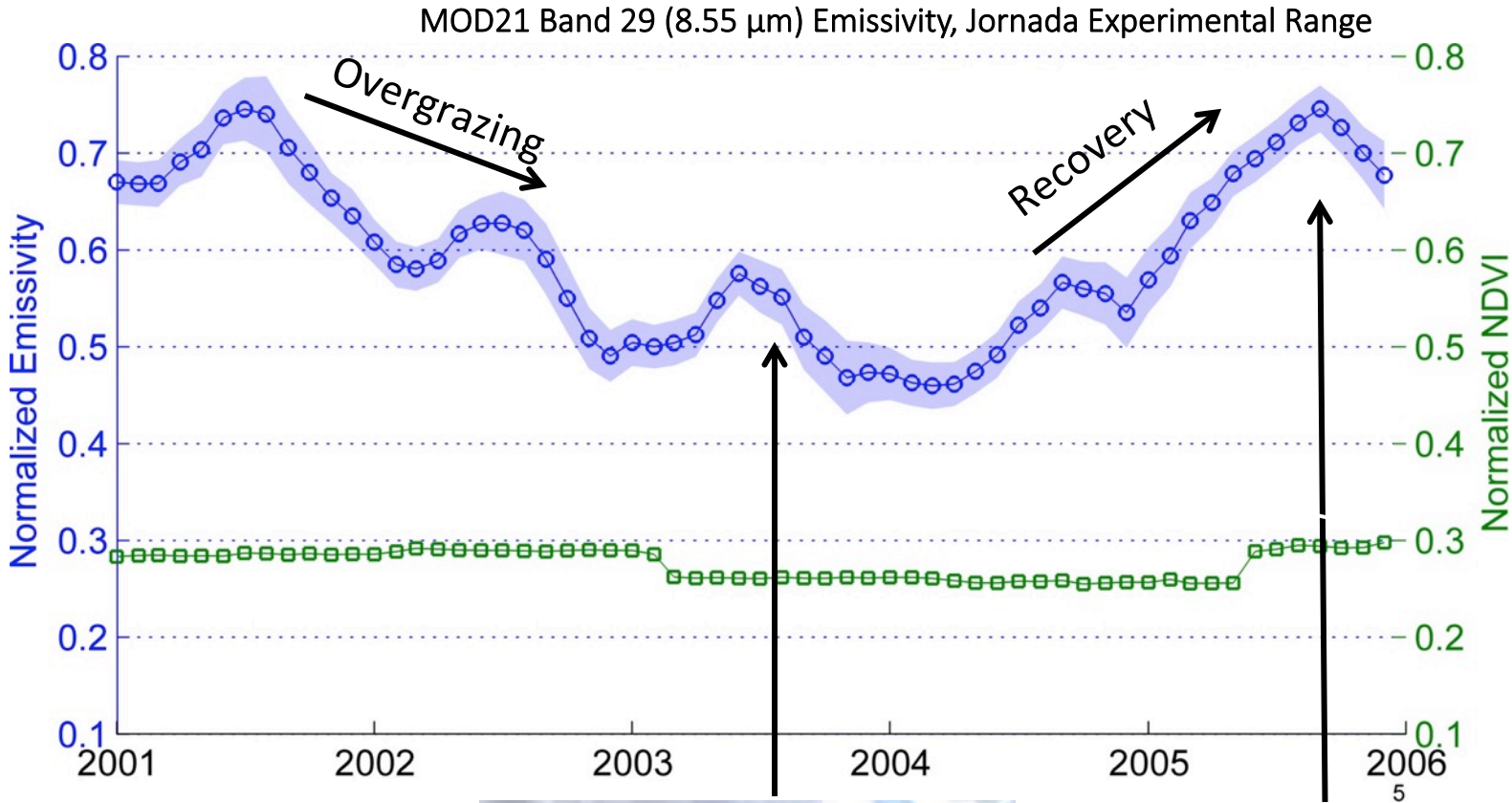
# MOD21 Band 29 Emissivity – 1km



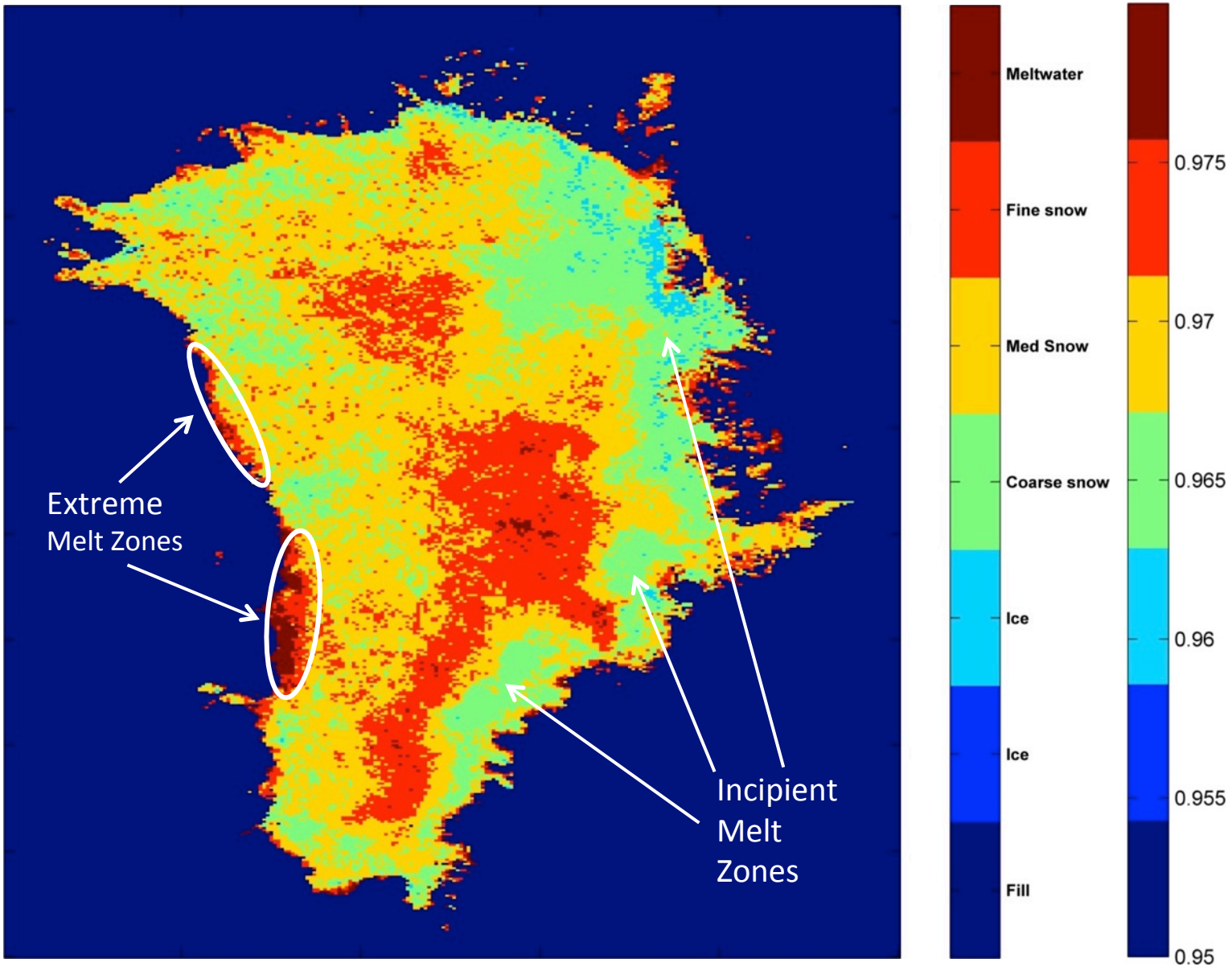

Generated using prototype MOD21 algorithm at MODAPS

# New thermal-based techniques for land cover change detection in climate sensitive zones

*Hulley et al. 2014*




# MOD21 Band 32 (12 µm) Emissivity, Greenland, August 2004



# Outline

1. Algorithm and product updates
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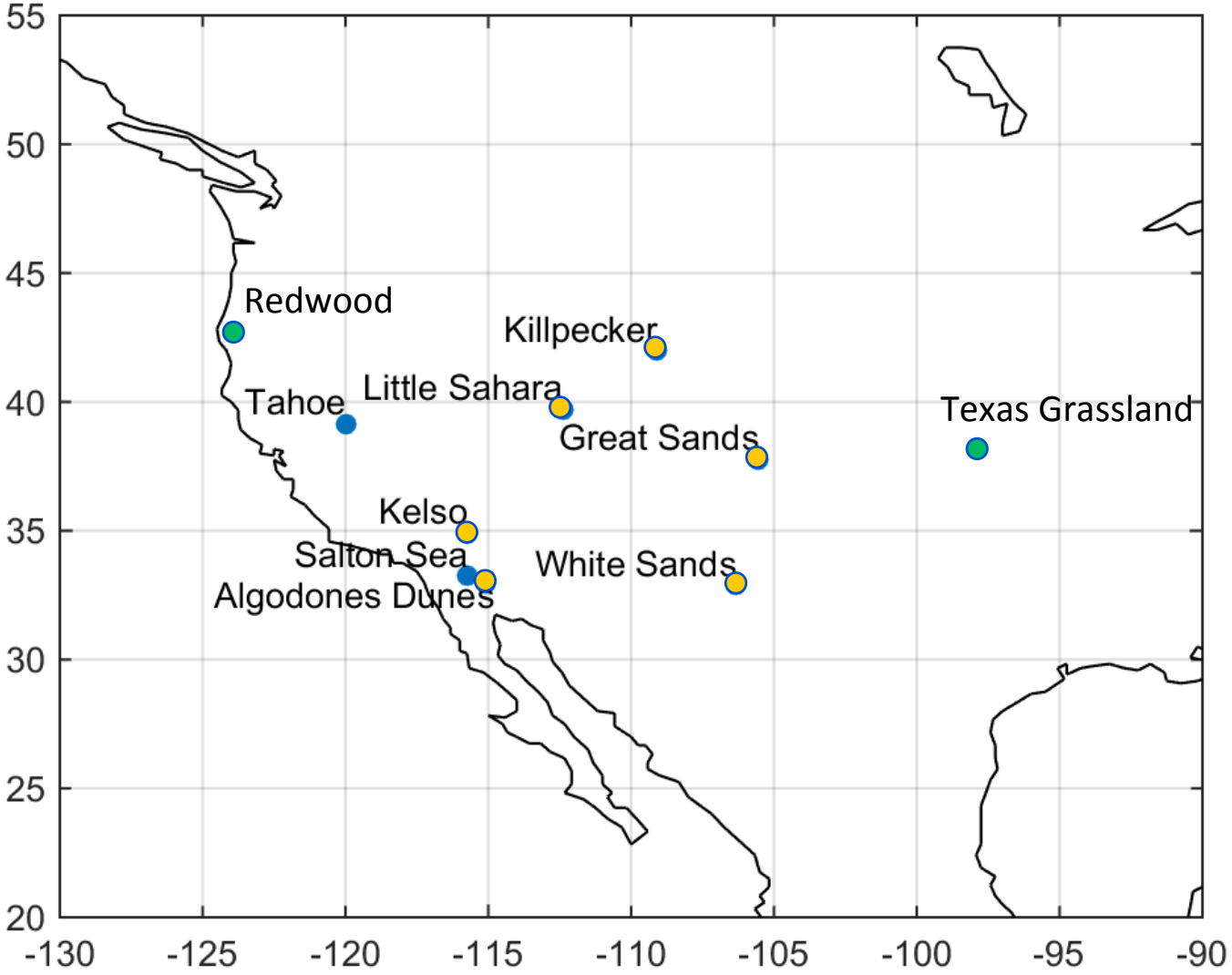
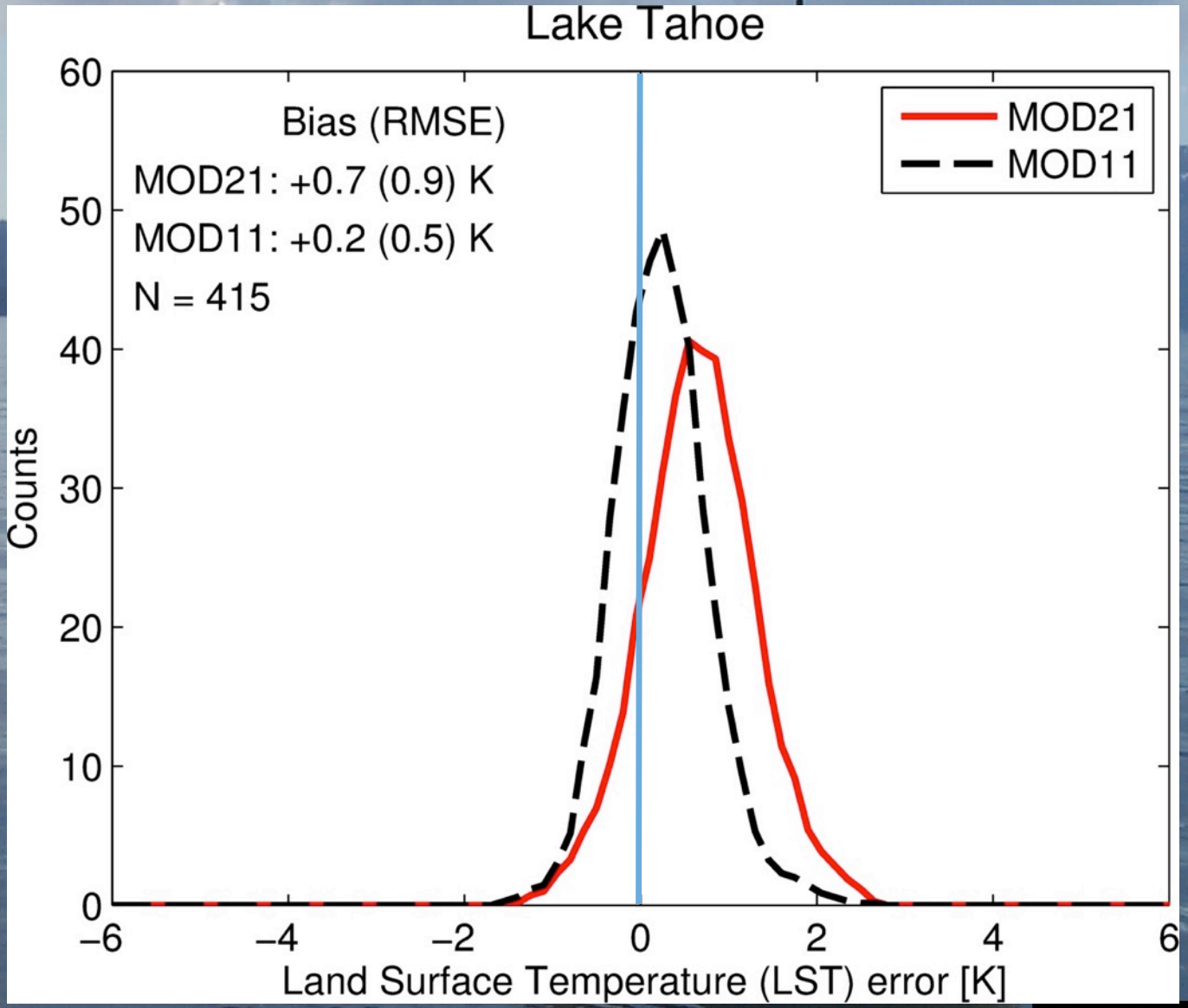
# LST&E Validation Sites (Stage 1)




## Temperature-based and Radiance-based validation methods

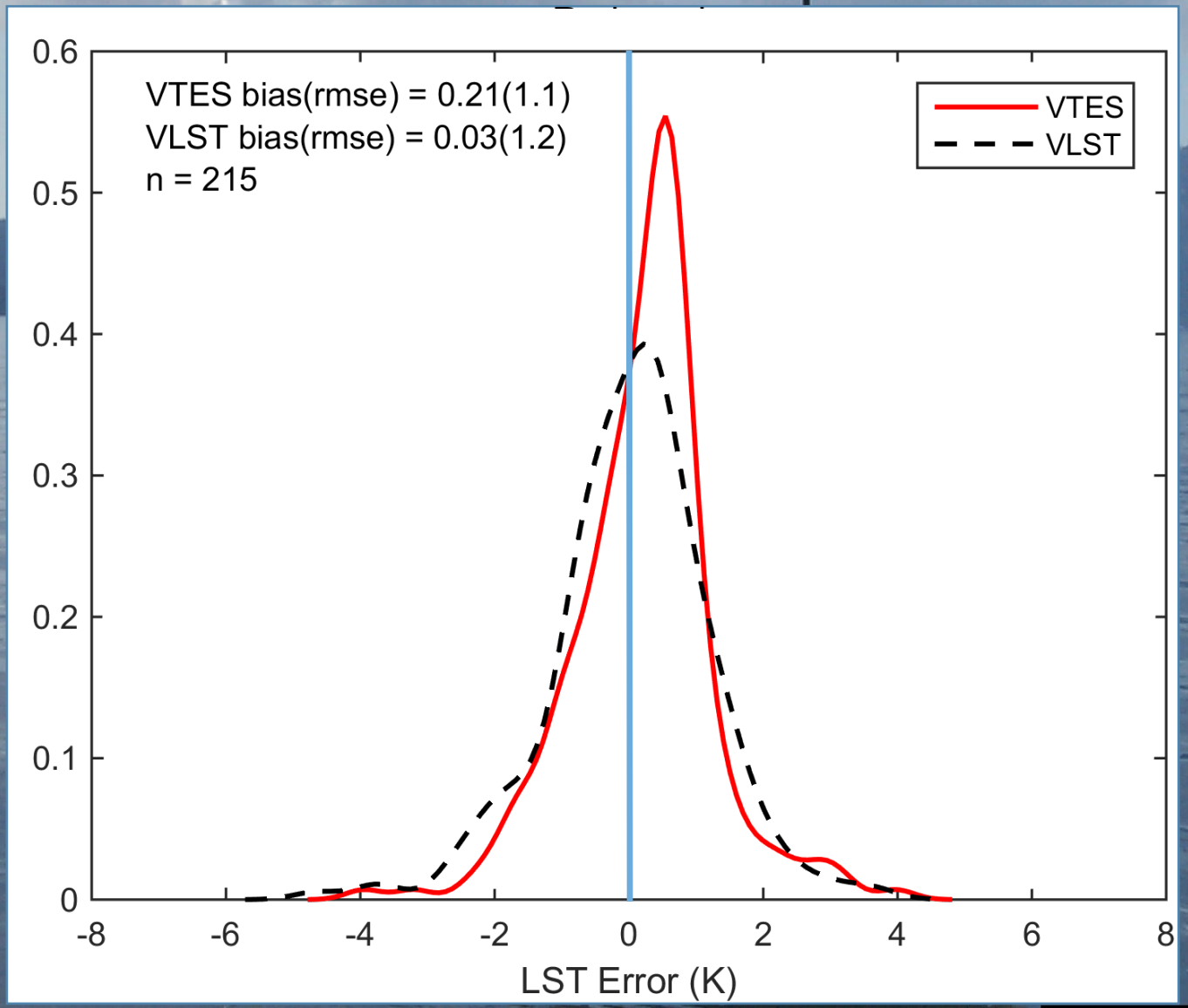
*(Wan et al. 2008, Guillevic et al. 2012, Schneider et al. 2013, Hulley et al. 2012, Hook et al. 2007)*

# Lake Tahoe, CA (2003-2005)



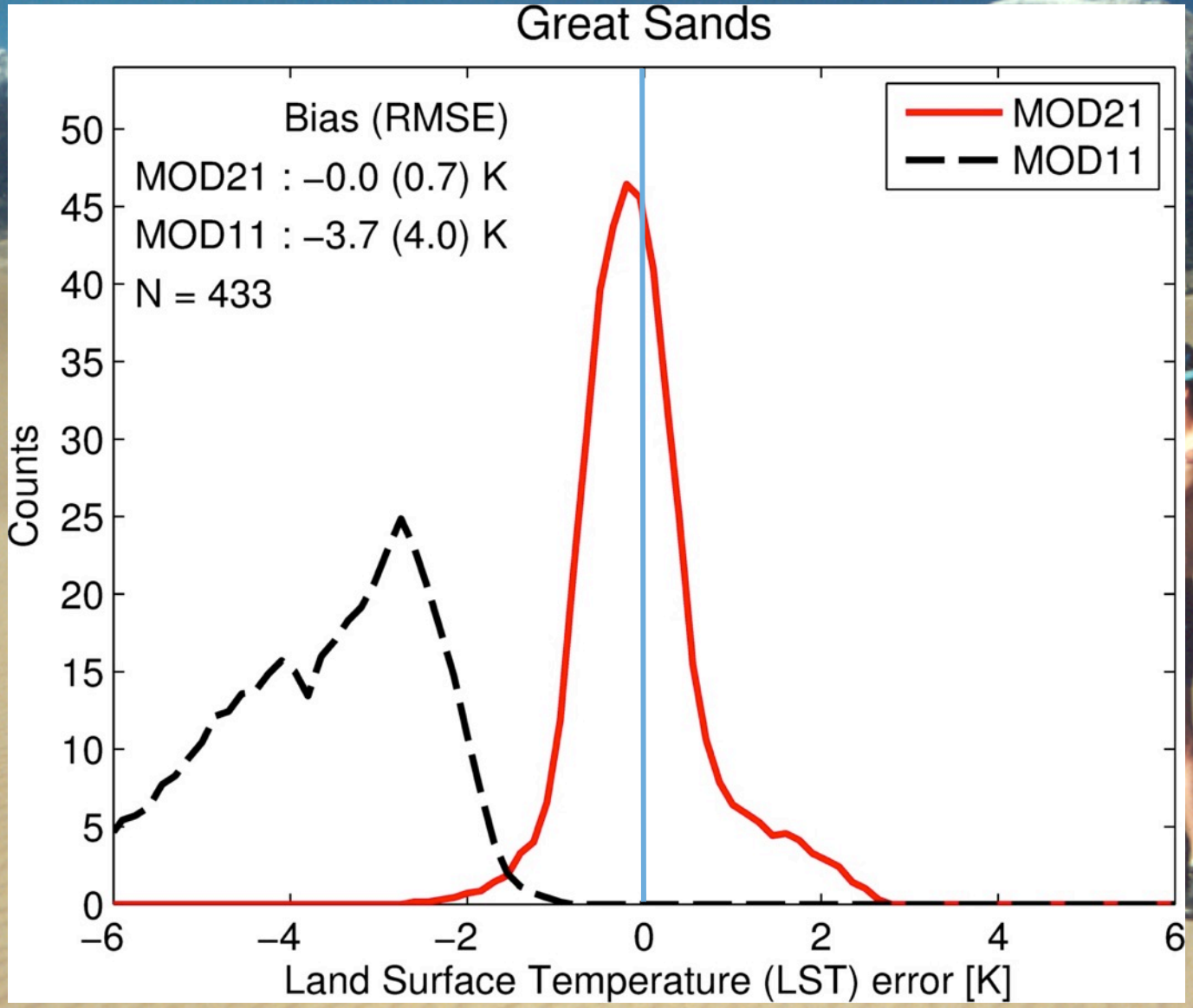

6/17/2003 1:20pm

# Lake Tahoe, CA (2003-2005)

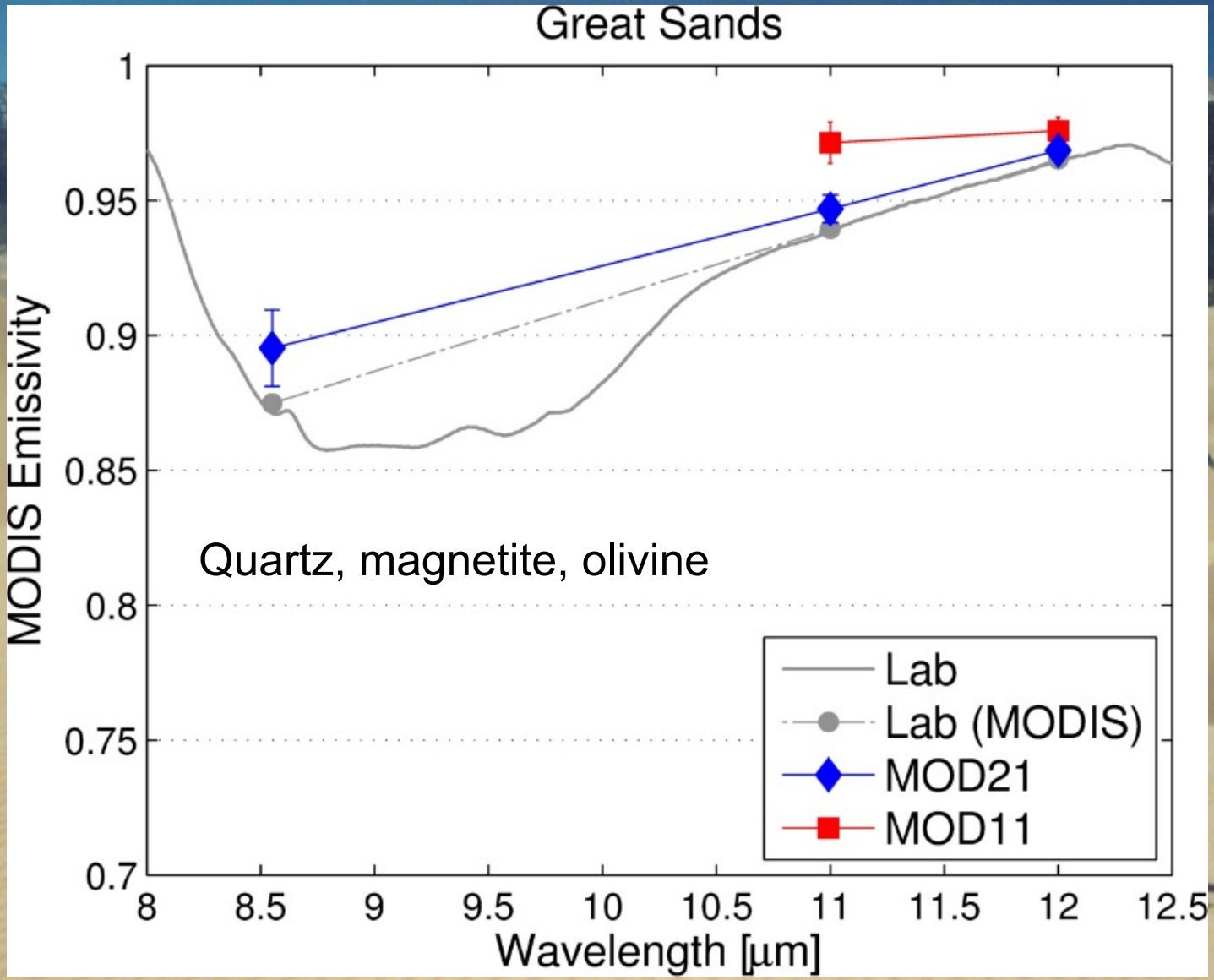



6/17/2003 1:20pm

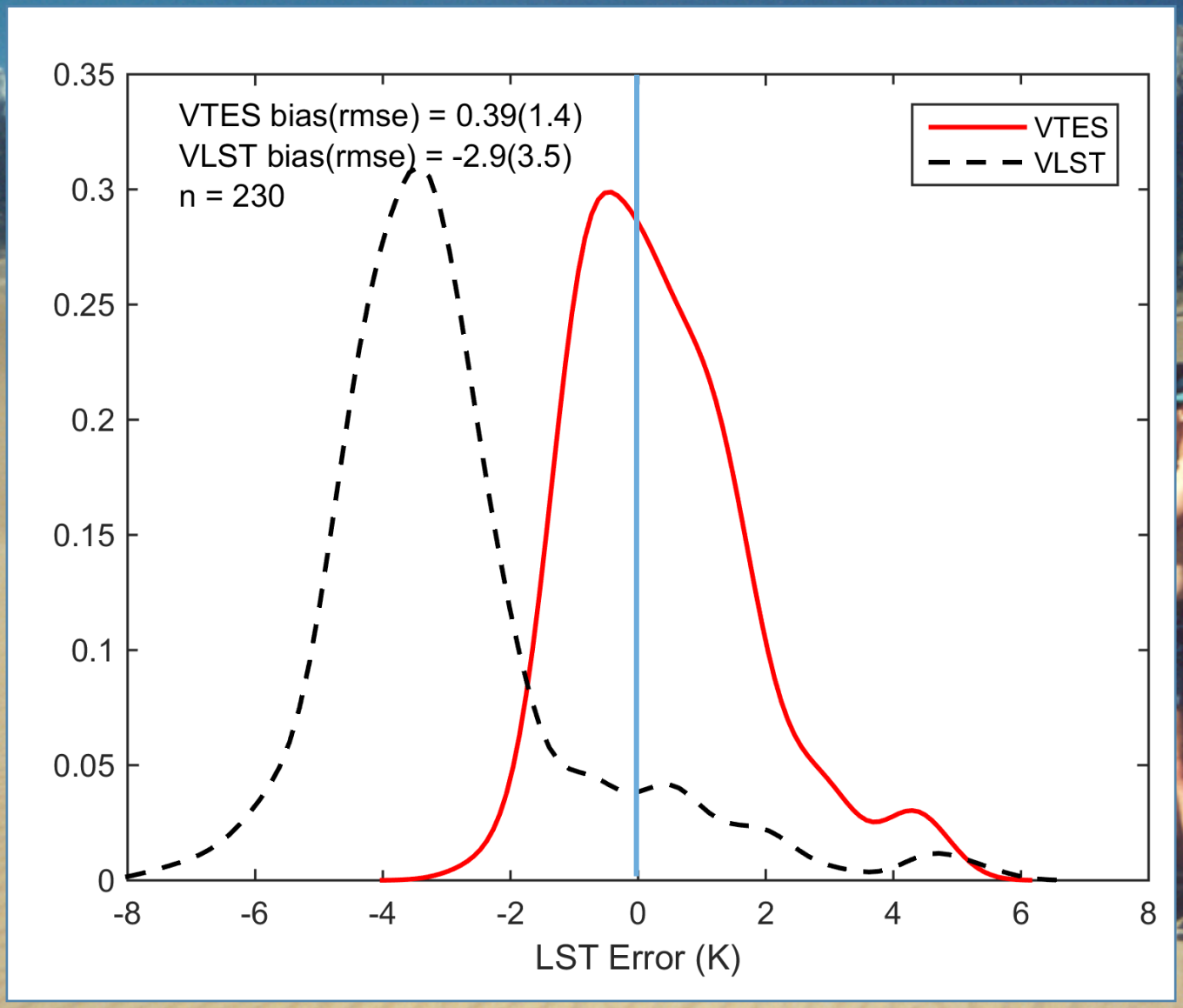
# Great Sands, CO (2003-2005)



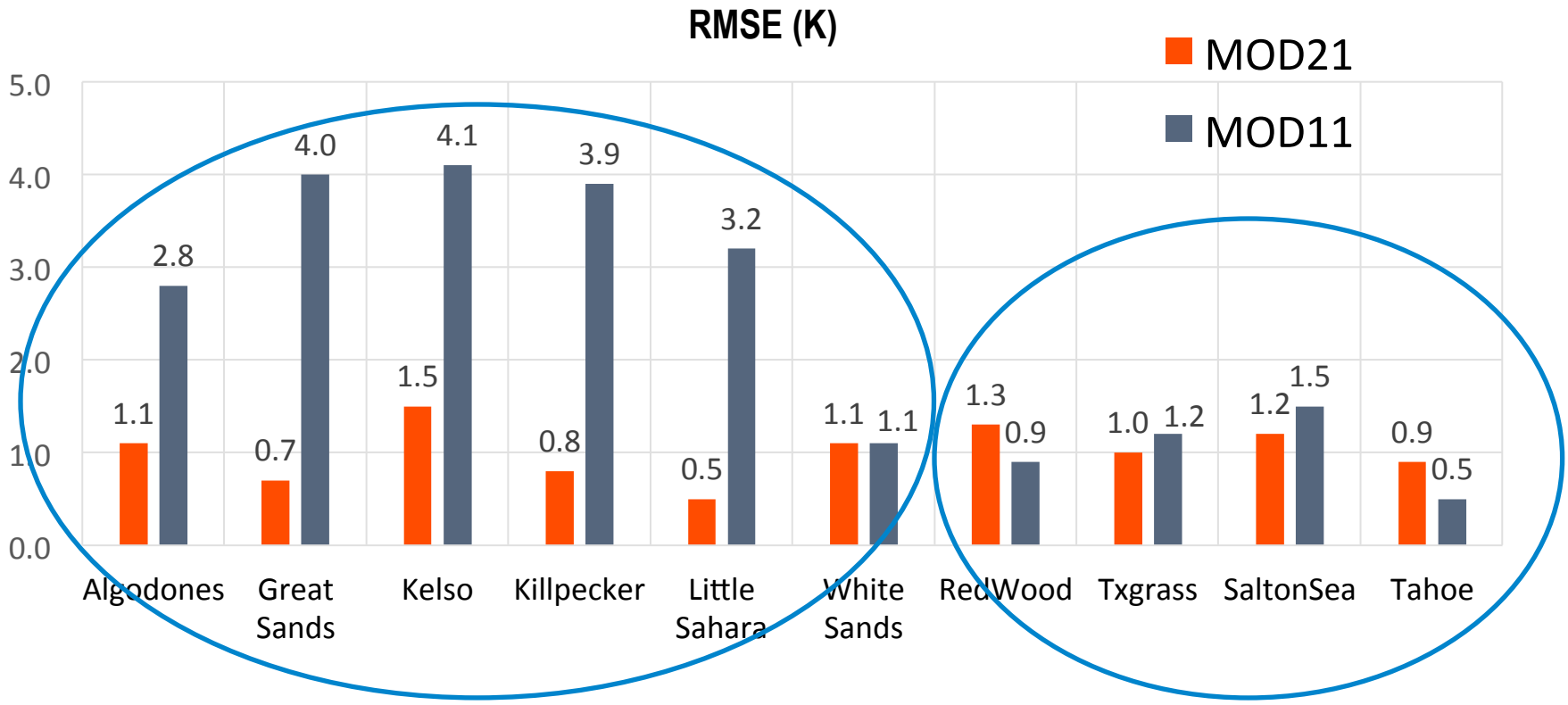
# Great Sands, CO (2003-2005)



# Great Sands, CO (2003-2005)



# MODIS LST Validation Summary




MOD11 larger uncertainty over bare regions (3-5 K)

MOD11 more stable over graybodies (higher precision)

# Outline

1. Algorithm and product updates
2. Validation
3. Product unification (MOD11+MOD21)
4. Continuity

# LST Uncertainty Model

*Hulley et al. 2012*

$$\delta LST_{MODIS} = a_o + a_1 TCW + a_2 \mathrm{SVA} + a_3 TCW \cdot SVA + a_4 TCW^2 + a_5 SVA^2 \quad (10)$$

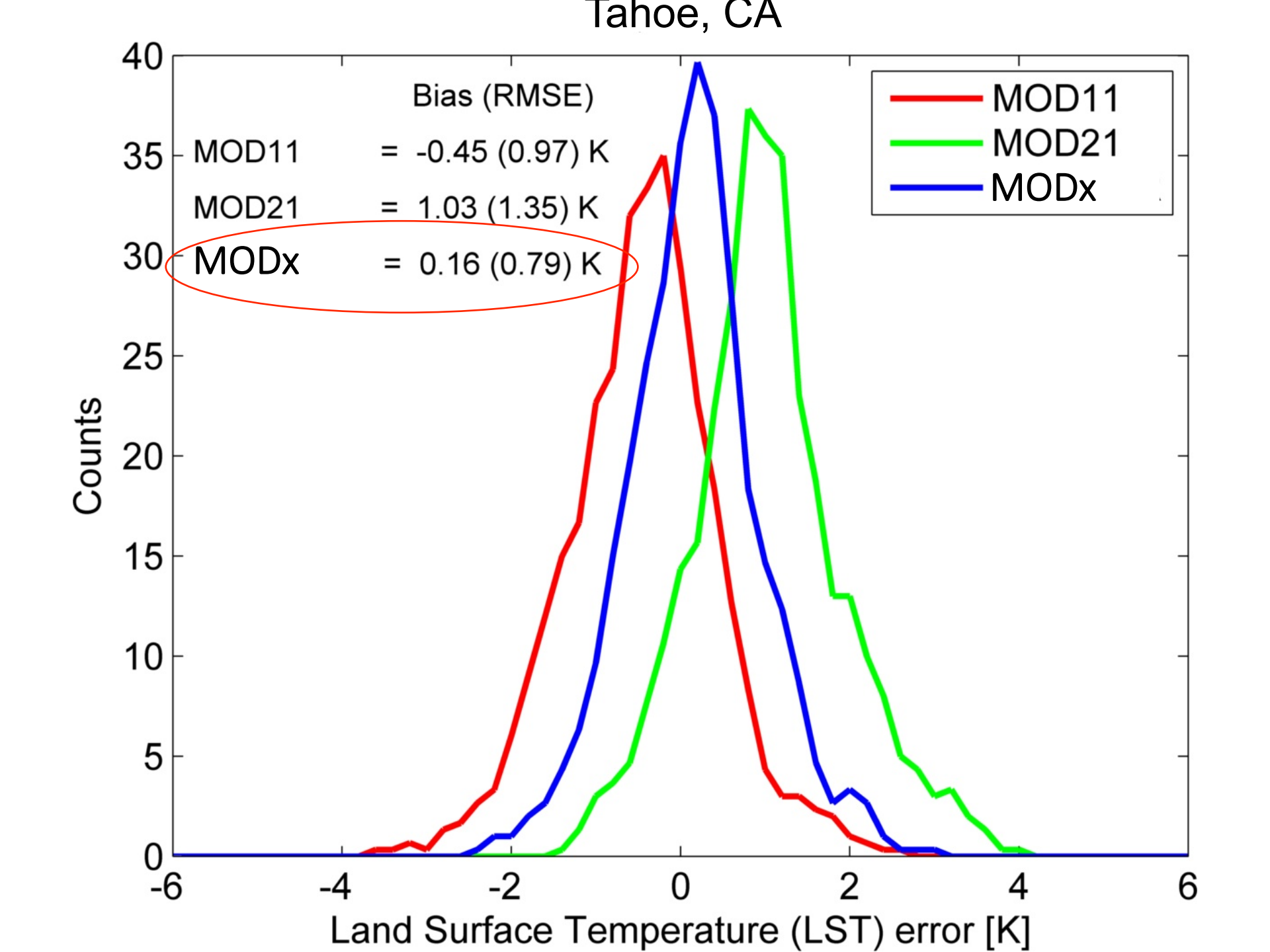
$\boldsymbol{a_i}$ = Regression coefficients dependent on surface type (gray, bare, transition)
$\boldsymbol{SVA}$ = Sensor view angle
$\boldsymbol{TCW}$ = Total column water estimate (cm), e.g. from MOD07, NCEP

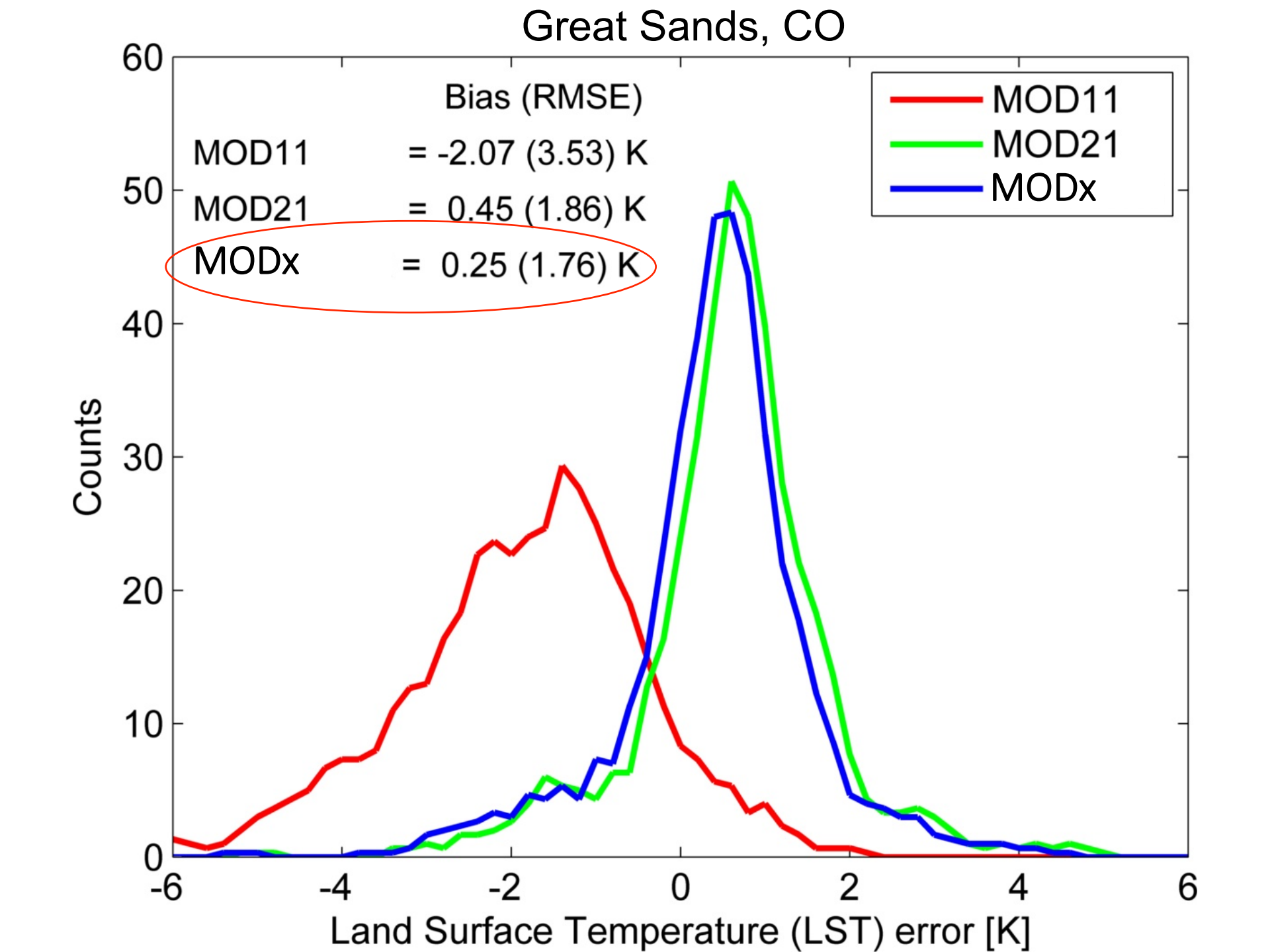
# Combined LST is weighted mean:

$$\overline{LST} = \frac{1}{(w1 + w2)} (w1 \cdot LST1 + w2 \cdot LST2) \quad (1)$$

$$w = 1/\delta^2$$

TCW


Tahoe, CA
Bias (RMSE)
MOD11 = -0.45 (0.97) K
MOD21 = 1.03 (1.35) K
MODx = 0.16 (0.79) K
MOD11
MOD21
MODx
Counts
Land Surface Temperature (LST) error [K]
0
5
10
15
20
25
30
35
40
-6
-4
-2
0
2
4
6


Great Sands, CO
Bias (RMSE)
MOD11 = -2.07 (3.53) K
MOD21 = 0.45 (1.86) K
MODx = 0.25 (1.76) K
MOD11
MOD21
MODx
Counts
Land Surface Temperature (LST) error [K]
0
10
20
30
40
50
60
-6
-4
-2
0
2
4
6

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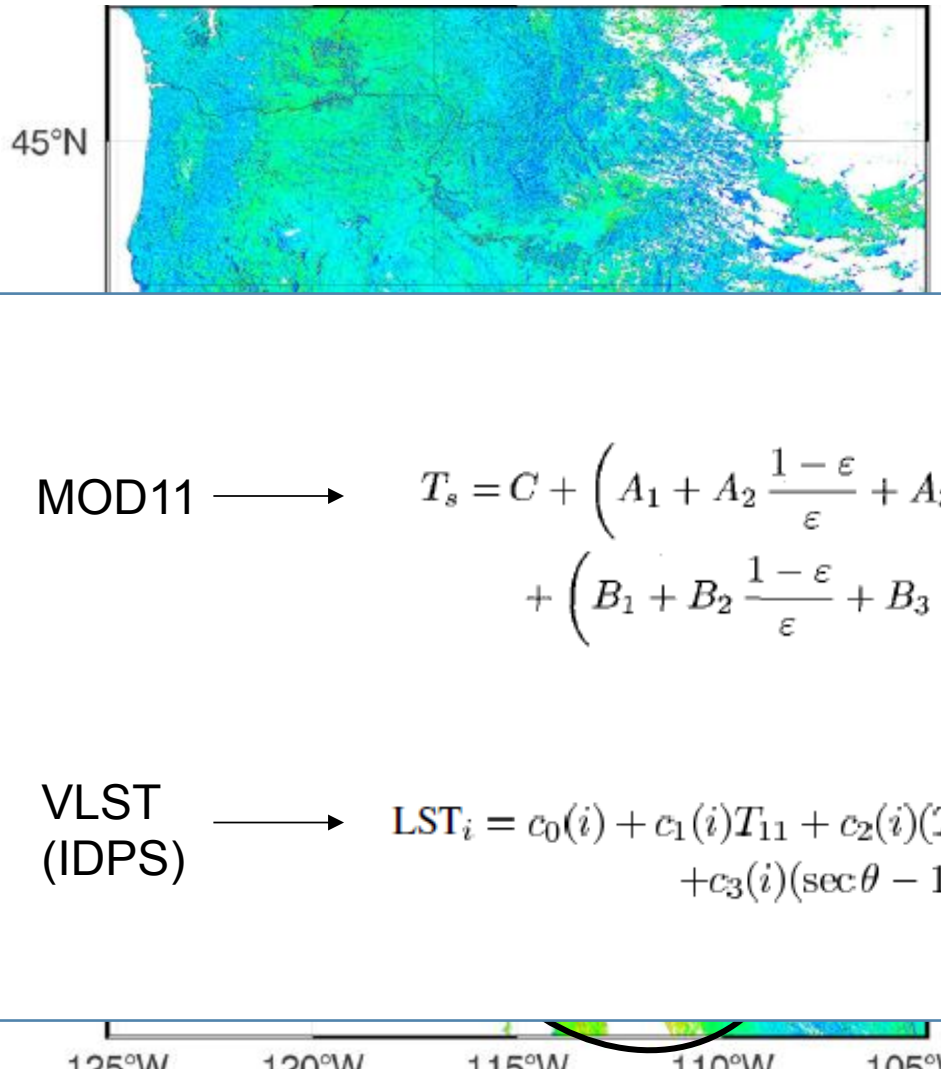
# VLST – MOD11 C5 LST (08-11-2012, SNO)
# Split-Window products




Criteria:

1. Time: <10 min
2. Angular separation: <2°
3. View angles < 10º

MOD11 ⟶

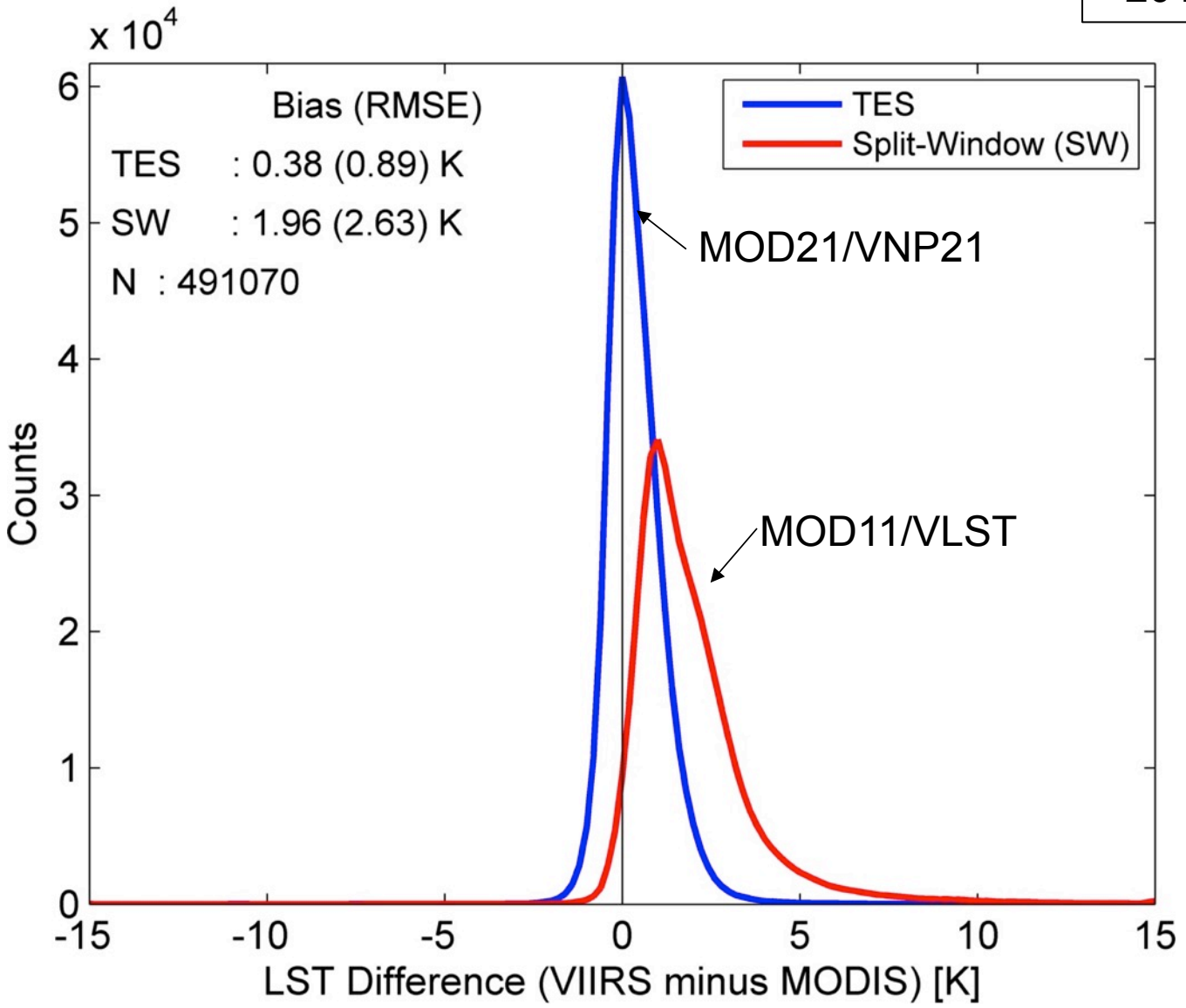
$$T_s = C + \left(A_1 + A_2 \frac{1-\varepsilon}{\varepsilon} + A_3 \frac{\Delta\varepsilon}{\varepsilon^2}\right) \frac{T_4 + T_5}{2} + \left(B_1 + B_2 \frac{1-\varepsilon}{\varepsilon} + B_3 \frac{\Delta\varepsilon}{\varepsilon^2}\right) \frac{T_4 - T_5}{2}. \quad (15)$$

VLST (IDPS) ⟶

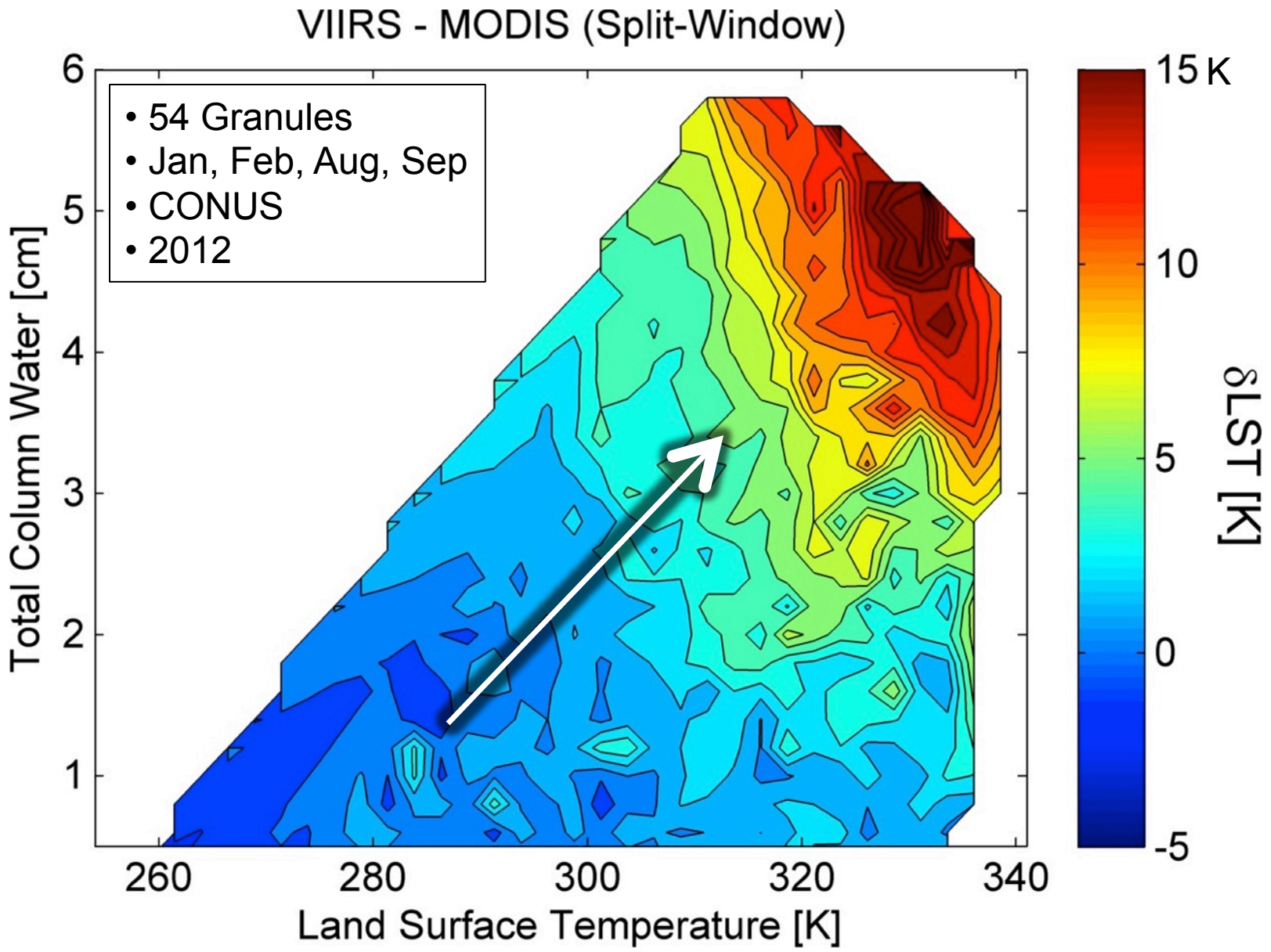
$$\mathrm{LST}_i = c_0(i) + c_1(i)T_{11} + c_2(i)(T_{11} - T_{12}) + c_3(i)(\sec\theta - 1) + c_4(i)(T_{11} - T_{12})^2 \quad (3)$$

# VIIRS – MODIS LST Difference

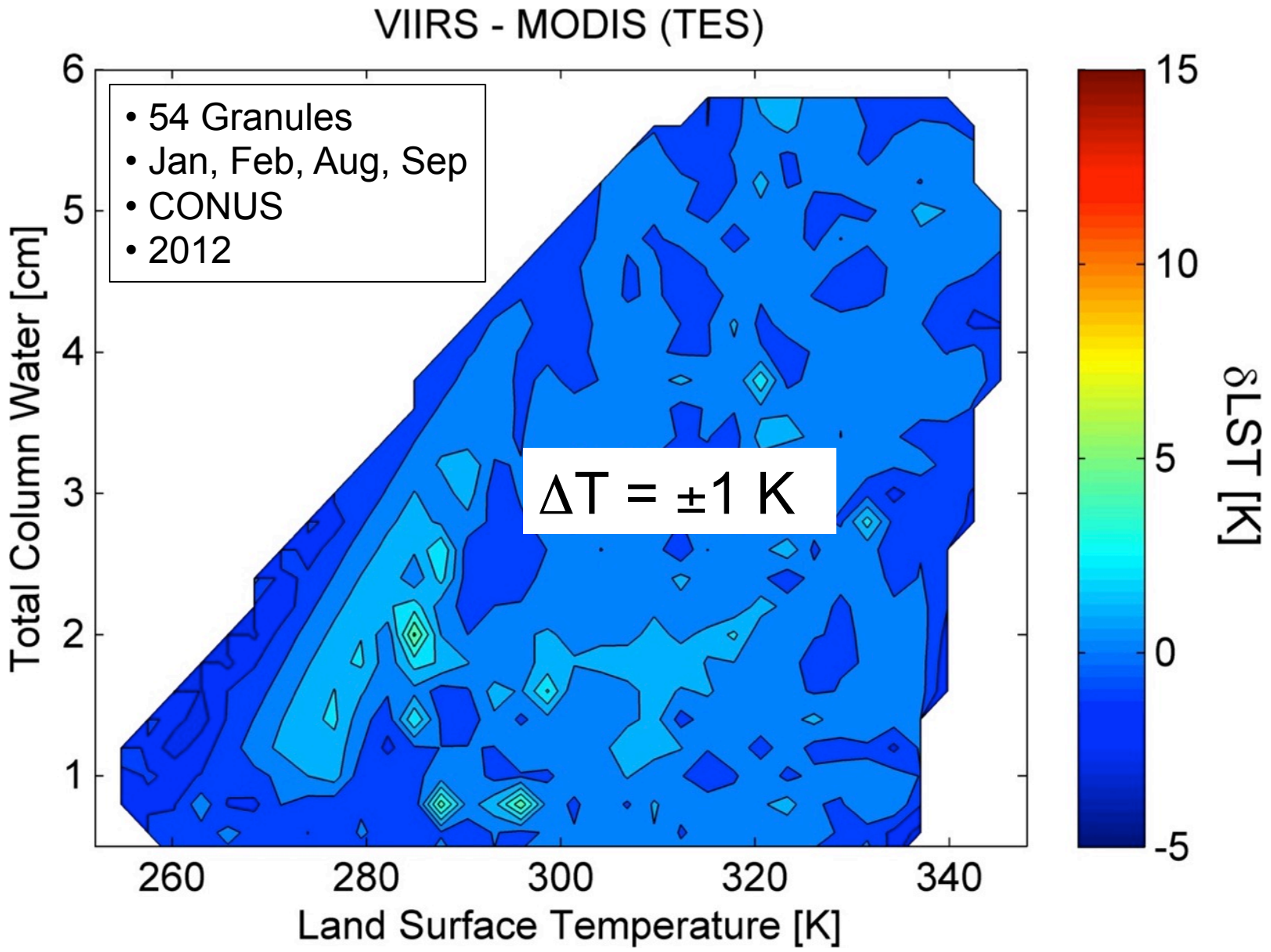
- 54 Granules
- Jan, Feb, Aug, Sep
- CONUS
- 2012



# Split-Window Products (MOD11, VLST/IDPS)



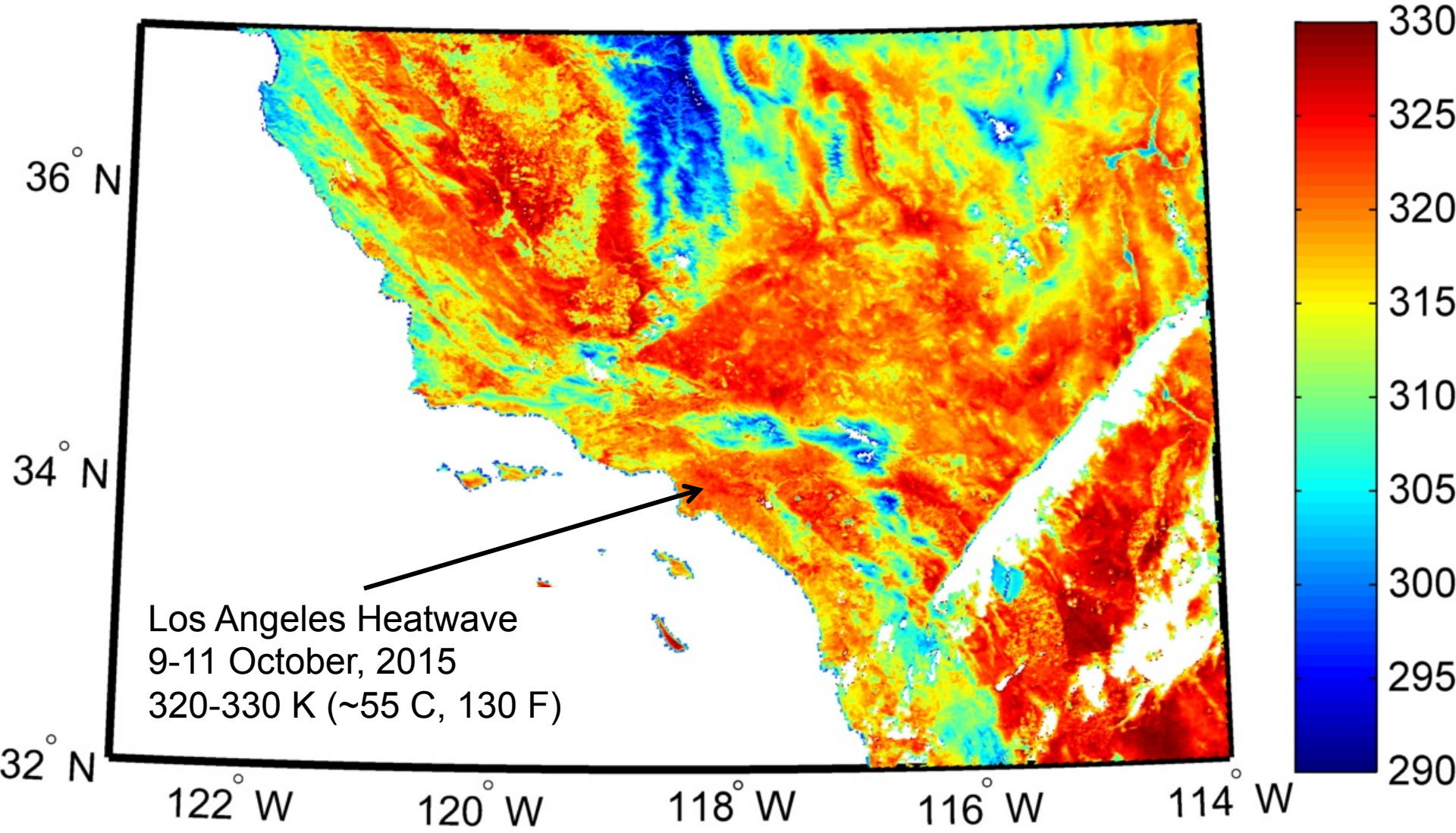
# JPL TES Products (MOD21 and VNP21)



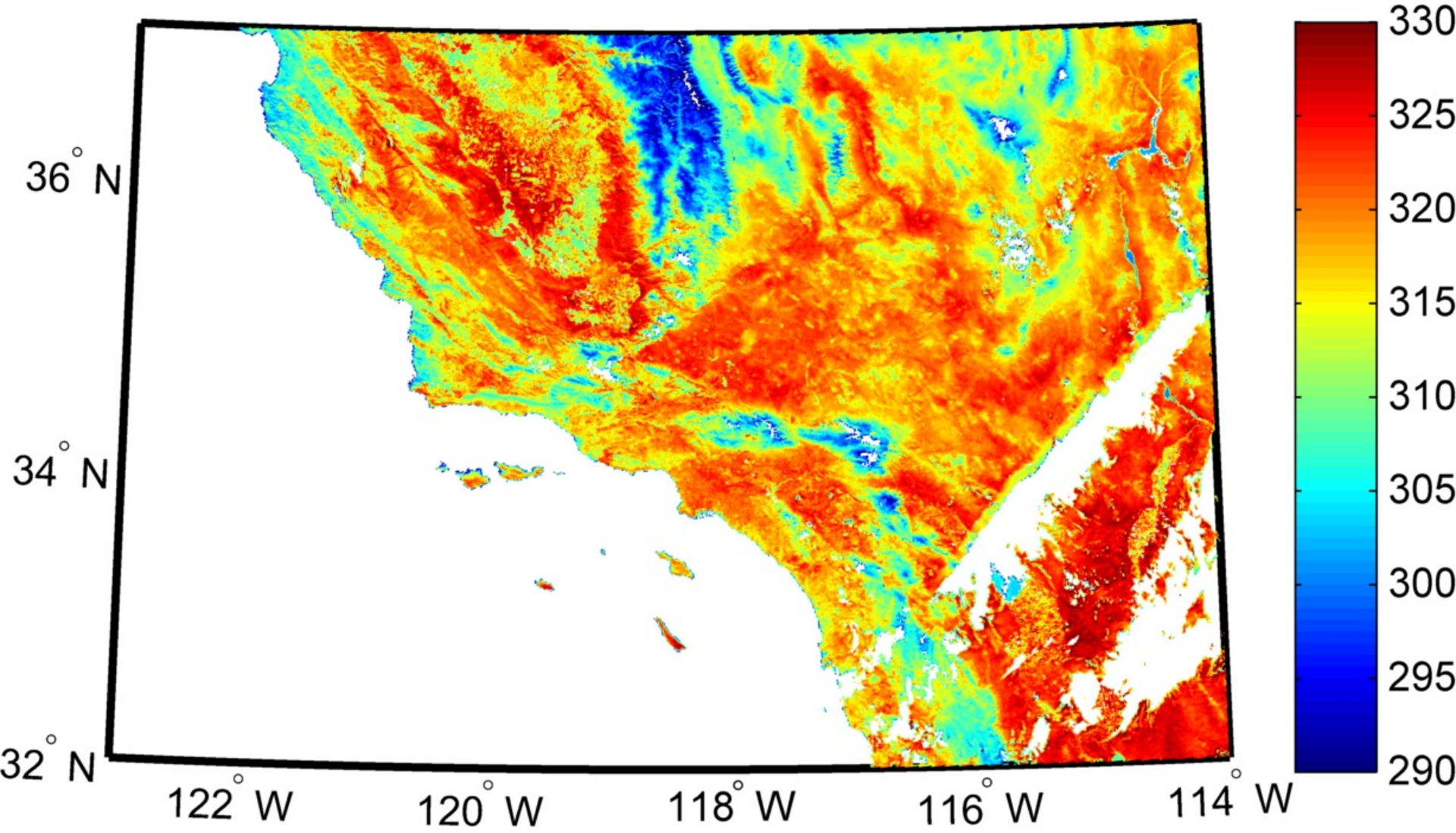
# Summary

1. MXD21 and VNP21 algorithms implemented at MODAPS and Land-SIPS (mature)
   - Baselining and testing almost complete for MXD21
   - Baselining in progress for VNP21
2. MXD21/VNP21 uncertainties at ~1 K level for LST and ~1% for emissivity
3. MXD21/VNP21 continuity demonstrated at the ~0.5 K level (Climate enabling)
4. Future endeavor is to merge MXD21/MXD11 reduce uncertainty and overall number of LST products

MODIS-TES (MOD21) Land Surface Temperature (K)
10 October 2015

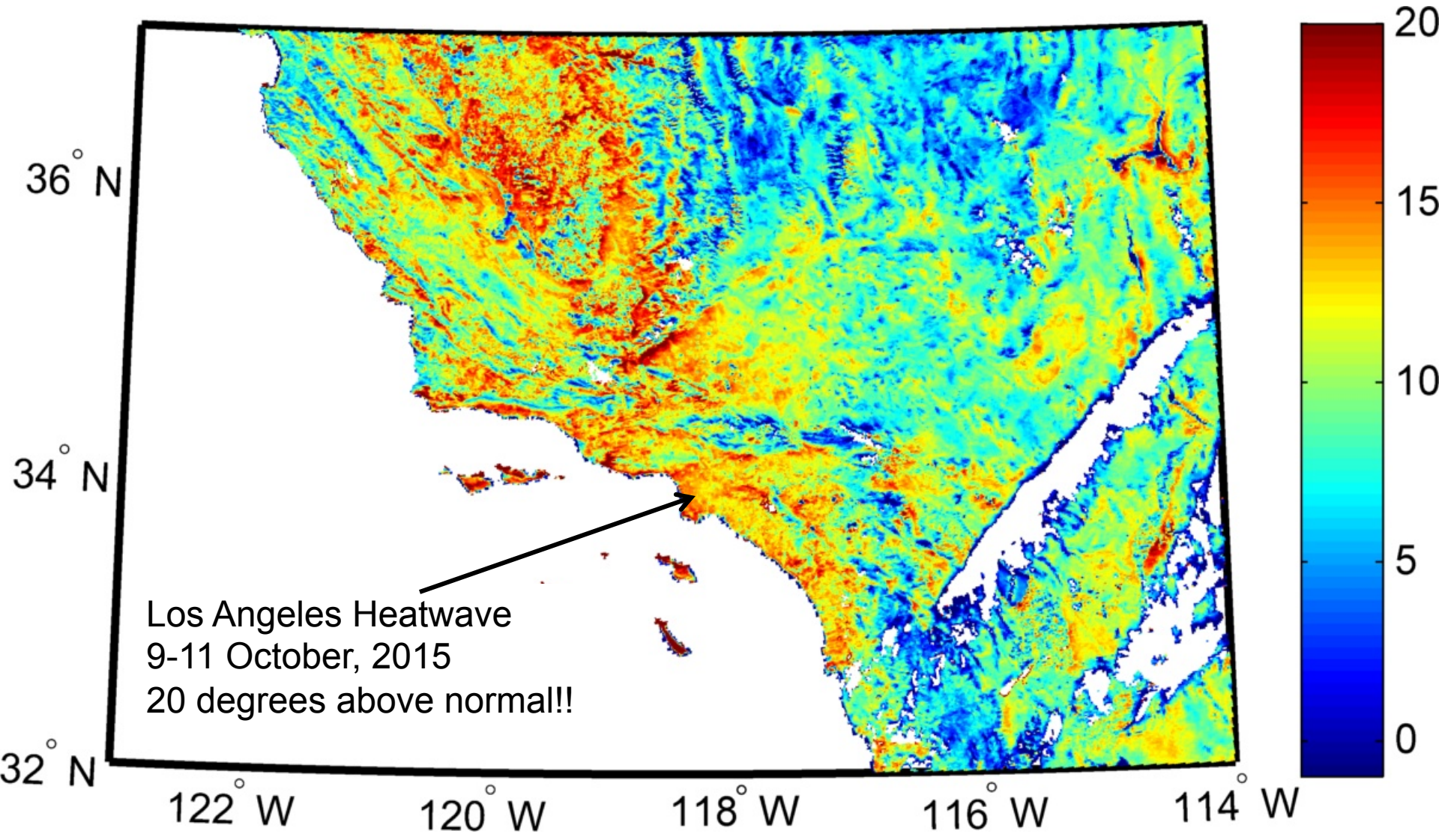


VIIRS-TES Land Surface Temperature (K)
10 October 2015



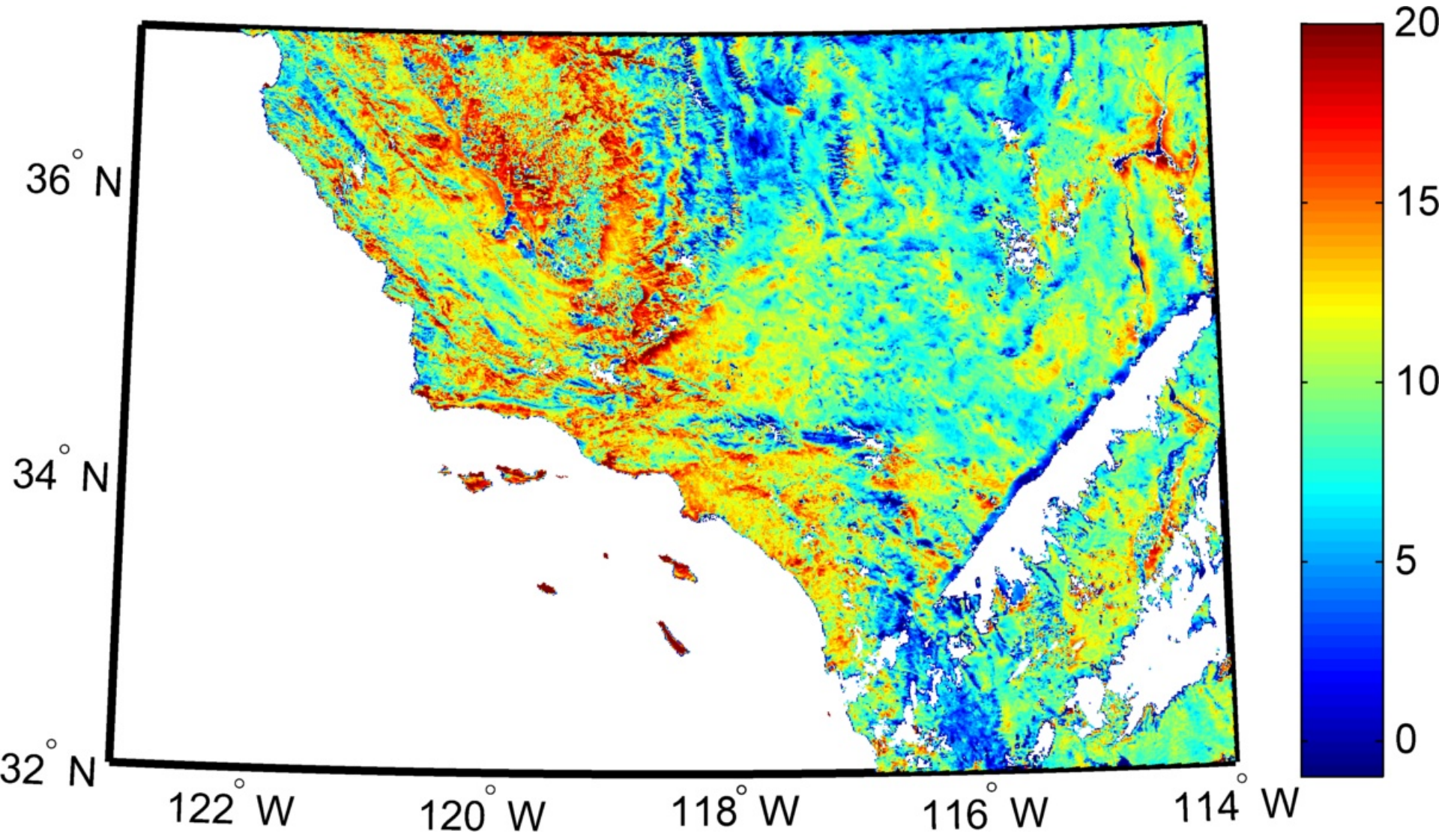
# VIIRS-TES LST Anomaly

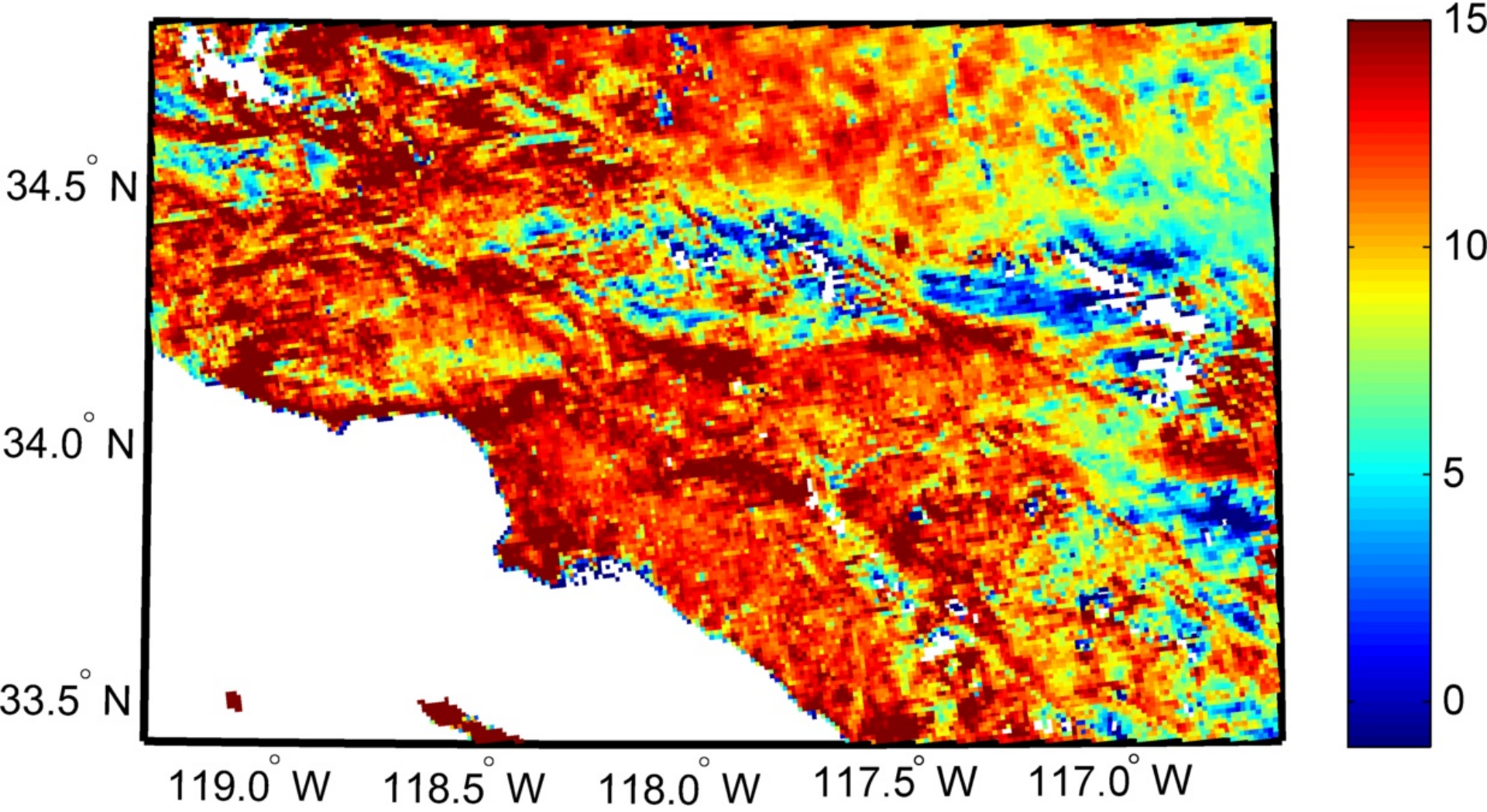
(2000-2014 October baseline)

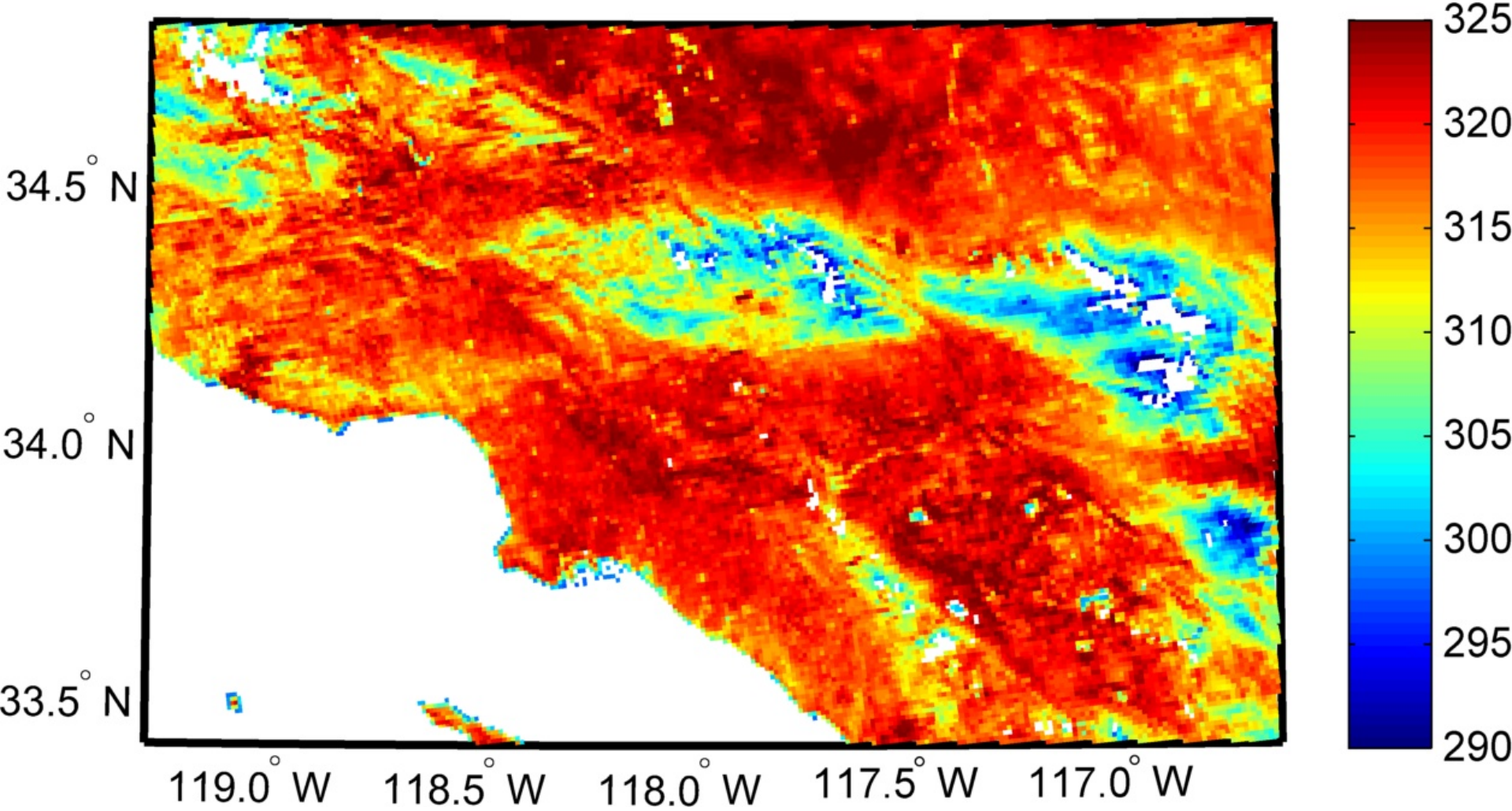


# MODIS-TES LST Anomaly

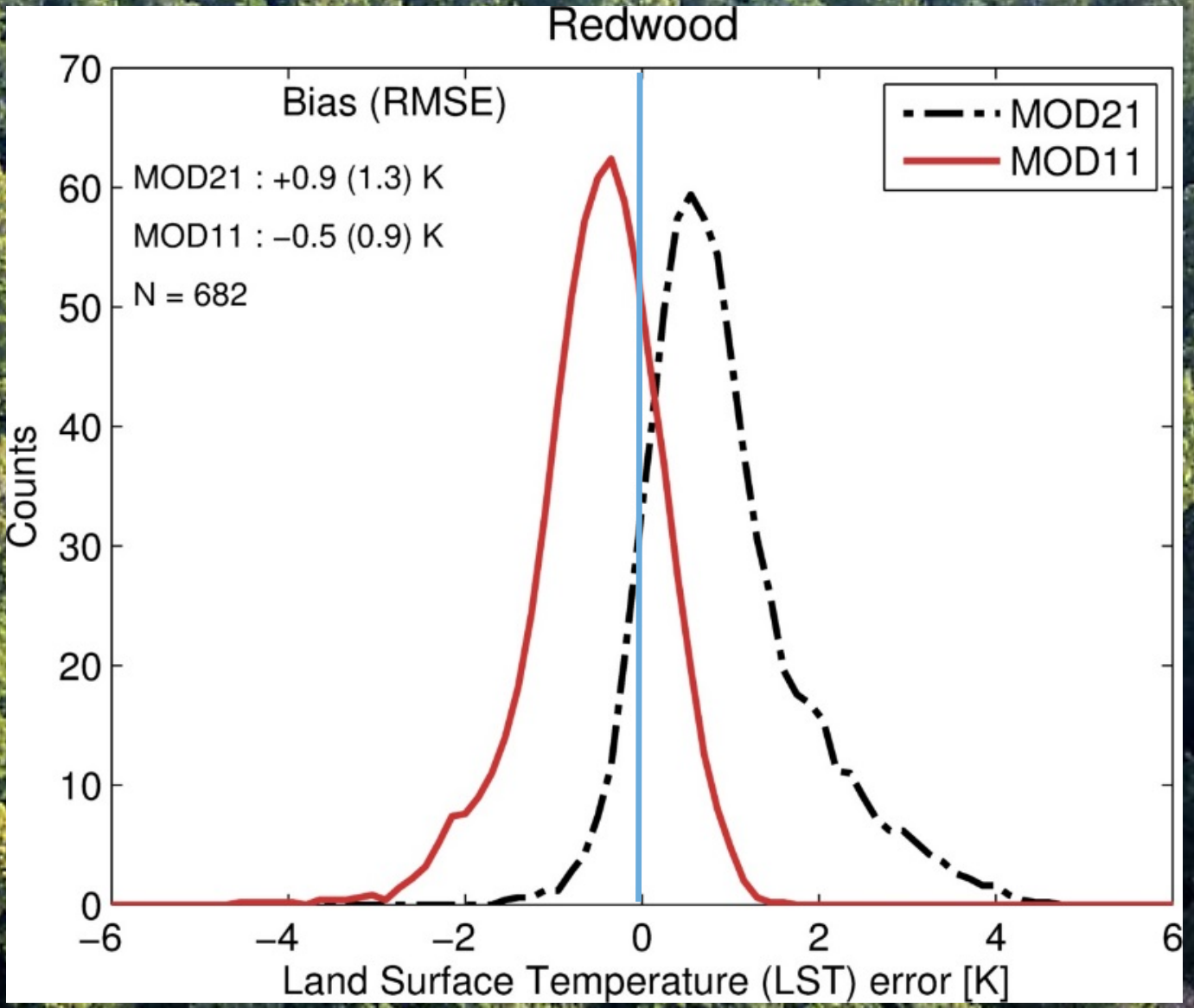
(2000-2014 October baseline)



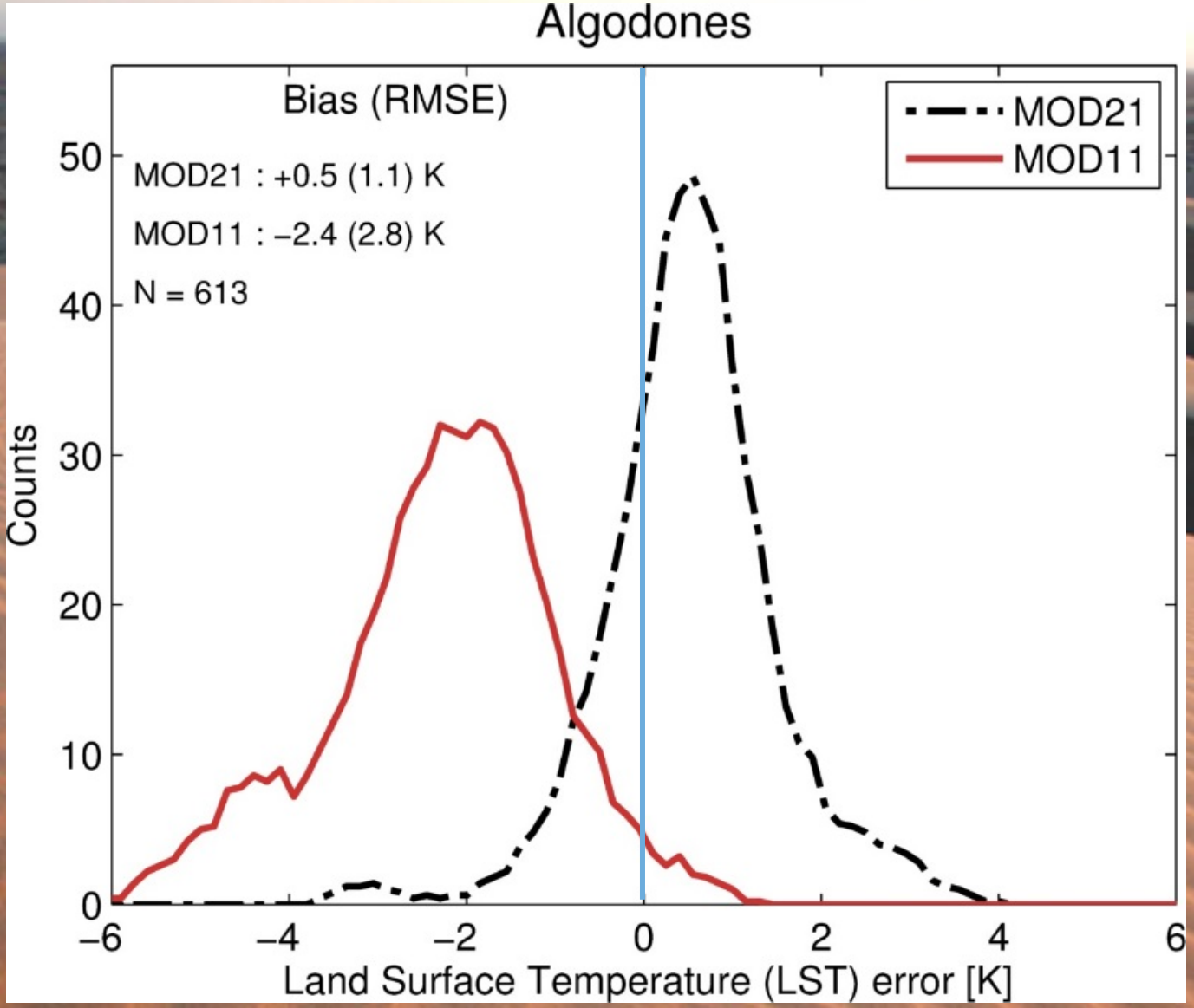

34.5° N
34.0° N
33.5° N
119.0° W
118.5° W
118.0° W
117.5° W
117.0° W
15
10
5
0


34.5° N
34.0° N
33.5° N
119.0° W
118.5° W
118.0° W
117.5° W
117.0° W
325
320
315
310
305
300
295
290

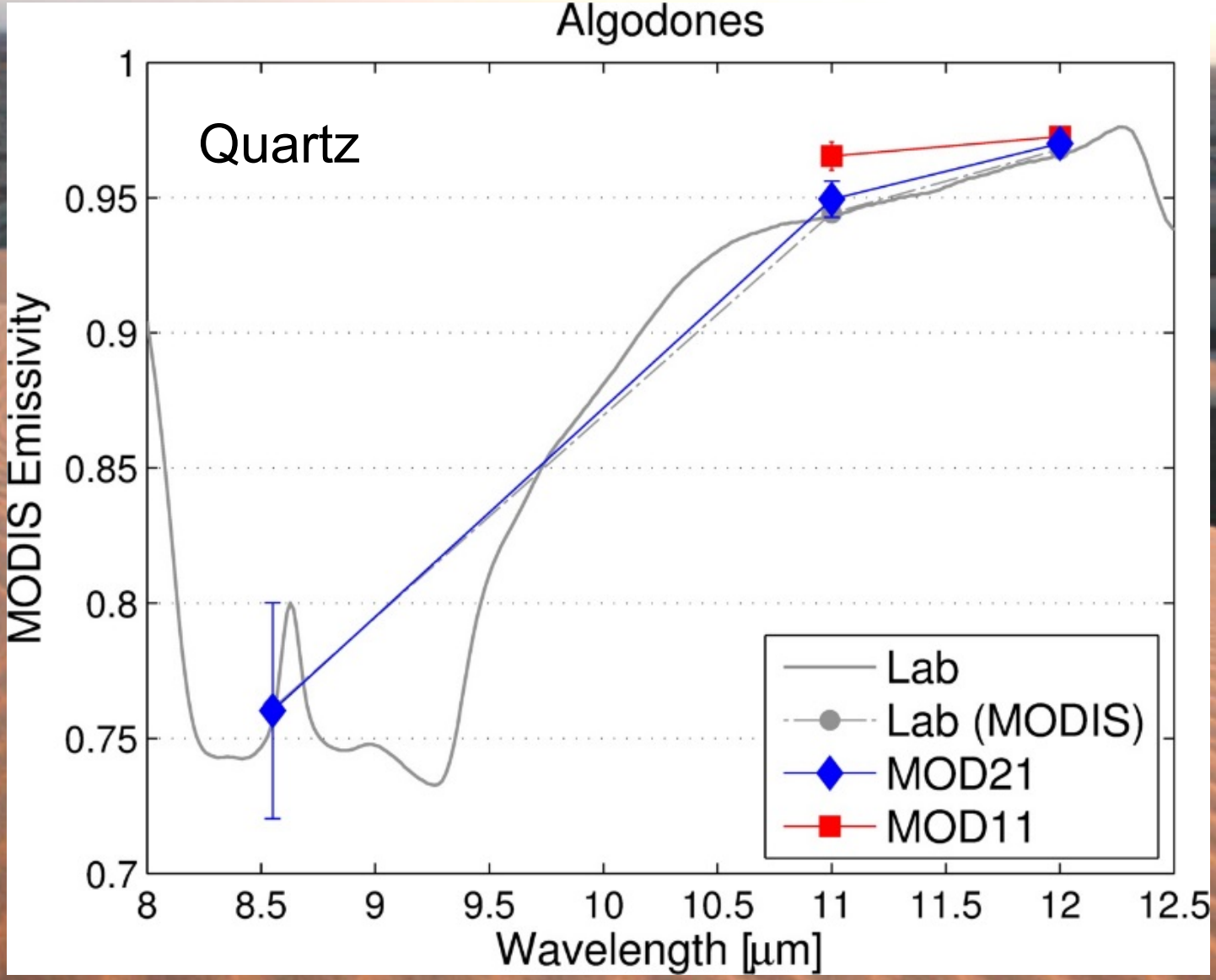
# Redwood Forest, CA (2003-2005)



# Algodones Dunes, CA (2003-2005)



# Algodones Dunes, CA (2003-2005)




NOAA National Calibration Center
NPP vs. AQUA
Return to SNO Predictions >>

MODIS Aqua/VIIRS Matchups for 2012 over Contiguous US:

Winter (Jan, Feb): 24 granules
Summer (Aug, Sep): 30 granules

Observation Criteria:

1. Time: <10 min
2. Angular separation: <2°
3. View angles < 10º