ECOSTRESS

Level-2 Land Surface Temperature and Emissivity

Glynn Hulley[1], Robert Freepartner[1], Robert Radocinski[1], Gerardo Rivera[1], Simon Hook[1] Frank Goettsche[2]

1. Jet Propulsion Laboratory, California Institute of Technology

2. Karlsruhe Institute of Technology

ECOSTRESS Science Team meeting, Ventura, CA, 11-13 February, 2020

Outline

1. L2 products
2. QC and Cloud Masking
3. Stage-2 Validation

Credit: NASA/SpaceX

ECOSTRESS Level-2 Science Data Sets (SDS)

SDS	Long Name	Units
LST	Land Surface Temperature	K
Emissivity	Emissivity (bands 1 -5)	n/a
QC	Quality Control (16-bit)	n/a
LST_err	LST Uncertainty	K
Emis_err	Emissivity Uncertainty (bands 1 – 5)	n/a
EmisWB	Wideband Emissivity (8 – 12.5 micron)	n/a
PWV	Precipitable Water Vapor	cm

Please read the User Guide and pay attention to QC! 🙏

https://lpdaac.usgs.gov/documents/423/ECO2_User_Guide_V1.pdf

Bits	Long Name	Description
1&0	Mandatory QA flags	00 = Pixel produced, best quality 01 = Pixel produced, nominal quality. Either one or more of the following conditions are met: 1. Emissivity in both bands 4 and 5 < 0.95, i.e. possible cloud contamination 2. Low transmissivity due to high water vapor loading (<0.4), check PWV values and error estimates 3. P… s… Reco… 10 = Pixel pr… 11 = Pixel no… should check…
3 & 2	Data quality flag	00 = Good q… 01 = Missing… 10 = not set… 11 = Missing…
5 & 4	Cloud/Ocean Flag	Not set. Plea… information.…
7 & 6	Iterations	00 = Slow co… 01 = Nomina… 10 = Nomina… 11 = Fast
9 & 8	Atmospheric Opacity	00 = >=3 (W… 01 = 0.2 - 0.3… 10 = 0.1 - 0.2… 11 = <0.1 (D…
11 & 10	MMD	00 = > 0.15 (… 01 = 0.1 - 0.1… 10 = 0.03 - 0… 11 = <0.03 (V…
13 & 12	Emissivity accuracy (Average of all bands)	00 = >0.02 (P… 01 = 0.015 - 0.02 (Marginal performance) 10 = 0.01 - 0.015 (Good performance) 11 = <0.01 (Excellent performance)
15 & 14	LST accuracy	00 = >2 K (Poor performance) 01 = 1.5 - 2 K (Marginal performance) 10 = 1 - 1.5 K (Good performance) 11 = <1 K (Excellent performance)

Bits	Long Name	Description
1&0	Mandatory QA flags	00 = Pixel produced, best quality 01 = Pixel produced, nominal quality. Either one or more of the following conditions are met: 1. Emissivity in both bands 4 and 5 < 0.95, i.e. possible cloud contamination 2. Low transmissivity due to high water vapor loading (<0.4), check PWV values and error estimates 3. Pixel falls on missing scan line in bands 1&5, and filled using spatial neural net. Check error estimates. Recommend more detailed analysis of other QC information 10 = Pixel produced, but cloud detected 11 = Pixel not produced due to missing/bad data or TES divergence, user should check data quality flag bits.

MODIS cloud mask tests

	Daytime Ocean	Nighttime Ocean	Daytime Land	Nighttime Land	Daytime Snow/ice	Nighttime Snow/ice	Daytime Coastline	Nighttime Coastline	Daytime Desert	Nighttime Desert
BT_{11} (Bit 13)	✓	✓								
$BT_{13.9}$ (Bit 14)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$BT_{6.7}$ & BT_{11} - $BT_{6.7}$ (Bit 15)	✓	✓	✓	✓	✓	✓	✓	✓	✓	○
$R_{1.38}$ (Bit 16)	✓		✓		✓		✓		✓	
$BT_{3.7}$ - BT_{12} (Bit 17)				✓		✓				✓
$BT_{8.6}$ - BT_{11} & BT_{11} - BT_{12} (Bit 18)	✓	✓	✓	✓			✓	✓	✓	✓
BT_{11} - $BT_{3.9}$ (Bit 19)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$R_{0.66}$ or $R_{0.87}$ (Bit 20)	✓		✓		✓		✓		✓	
$R_{0.87}/R_{0.66}$ (Bit 21)	✓		✓				✓			
Delete this row.										
$BT_{7.3}$ - BT_{11} (Bit 23)				○				○		○
Temporal Consistency (Bit 24)	○	○								○
Spatial Variability (Bit 25)	✓	✓								

Cloud Mask Challenges

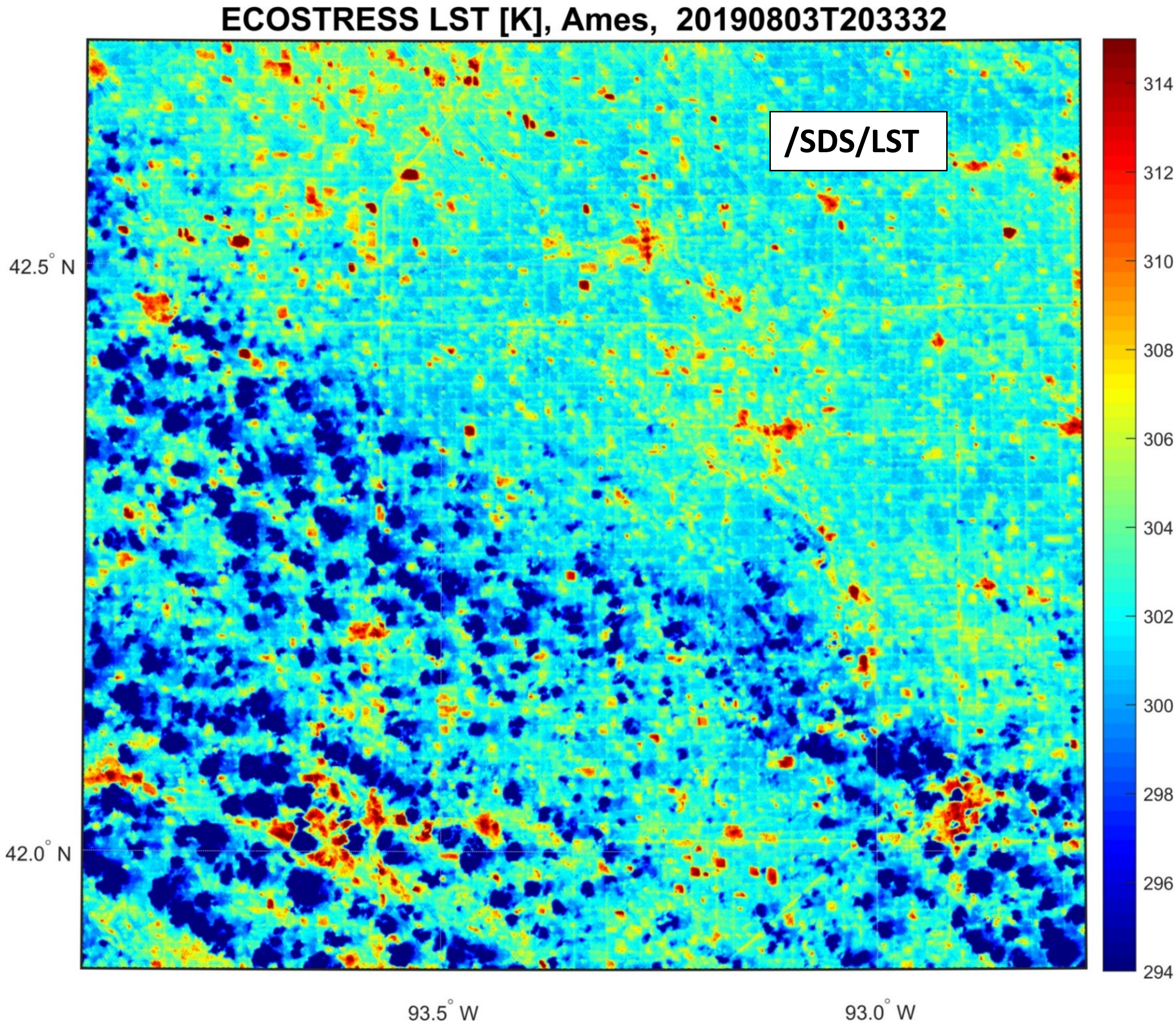
- ECOSTRESS has two cloud thermal tests:
  1. BT11: Band 4 brightness temperature threshold
     BT11 threshold (day/night, elevation)

  2. BT11 – BT12: Band 4 – 5 brightness temperature difference
     BT11 – BT12 (LUT based on band 4 brightness temperature)

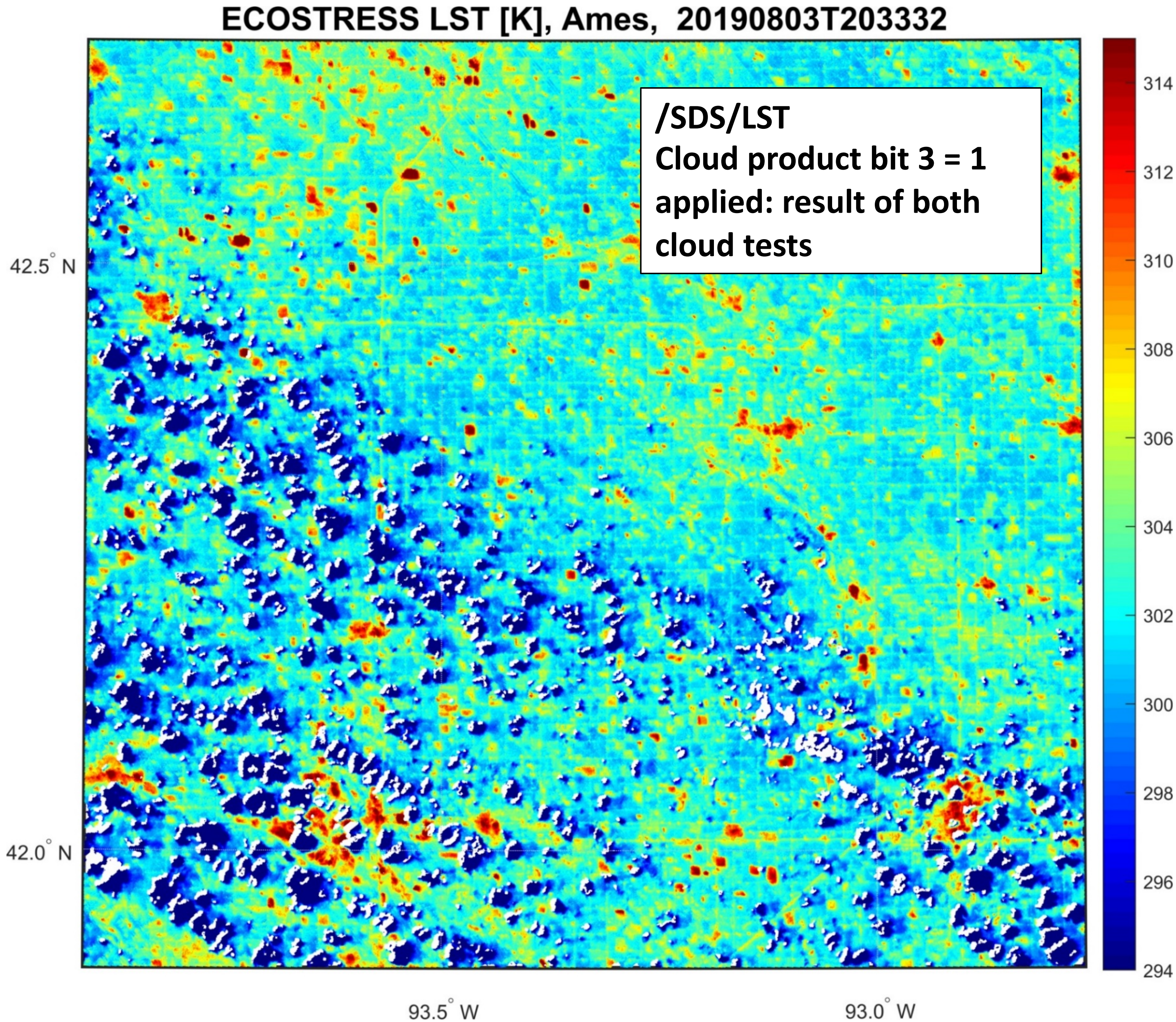
  <u>However, ideally:</u>

  1. BT11 threshold (location, time of day, time of year, elevation)

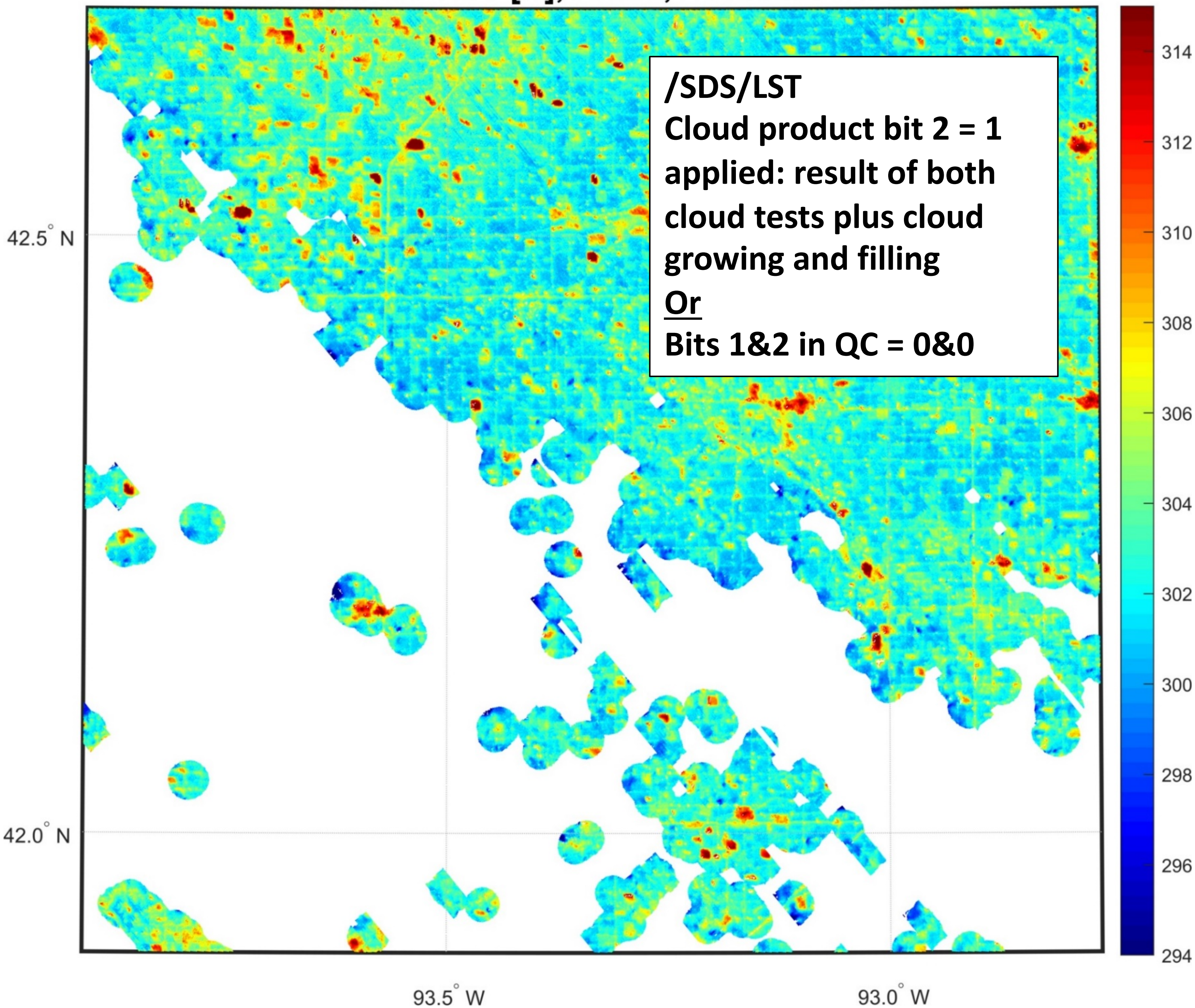
  – Work to be completed this summer and implementation in build 7 reprocessing



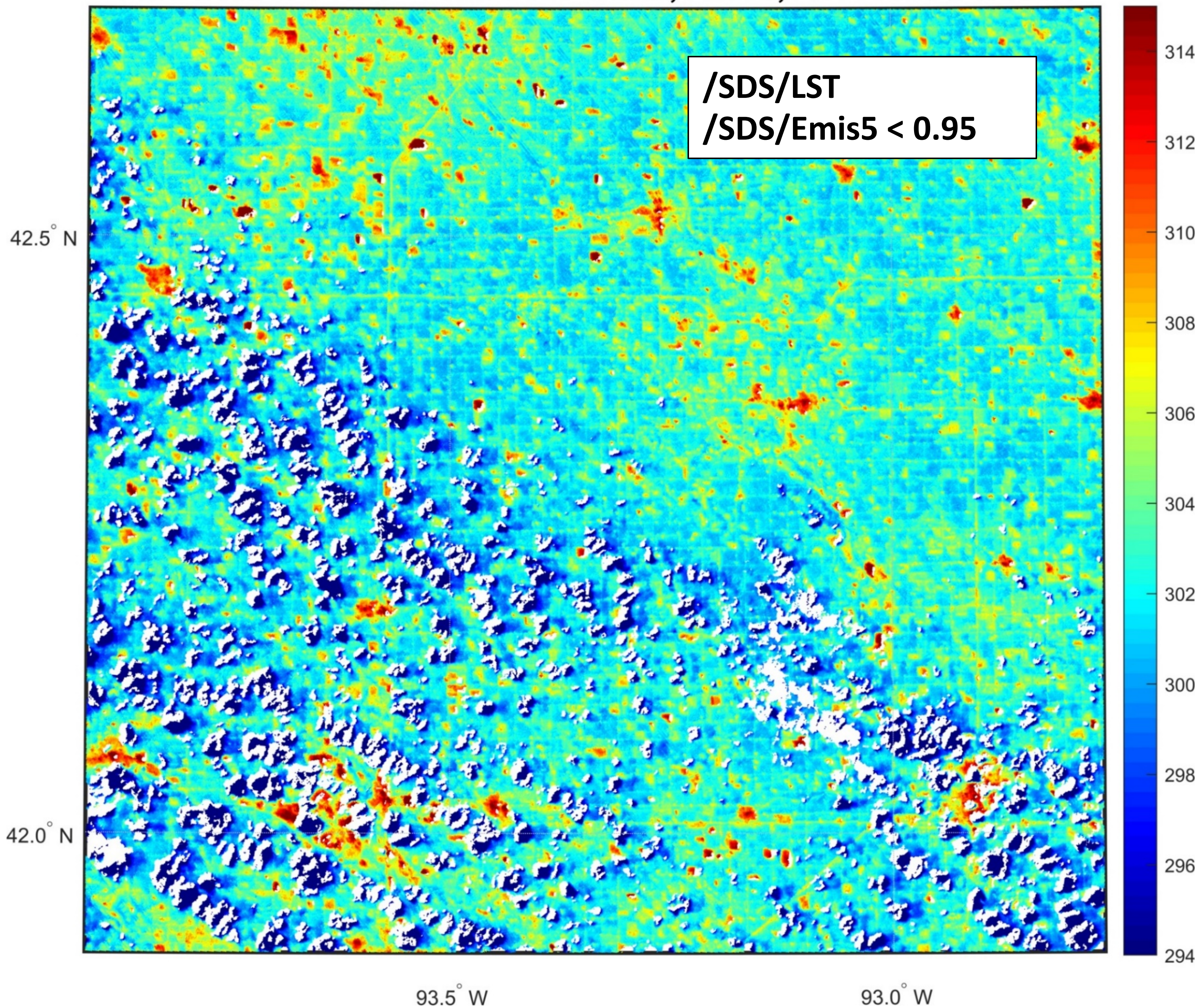
ECOSTRESS LST [K], Ames, 20190803T203332
/SDS/LST
42.5° N
42.0° N
93.5° W
93.0° W
314
312
310
308
306
304
302
300
298
296
294


ECOSTRESS LST [K], Ames, 20190803T203332
/SDS/LST
Cloud product bit 3 = 1
applied: result of both
cloud tests
42.5° N
42.0° N
93.5° W
93.0° W
314
312
310
308
306
304
302
300
298
296
294

ECOSTRESS LST [K], Ames, 20190803T203332

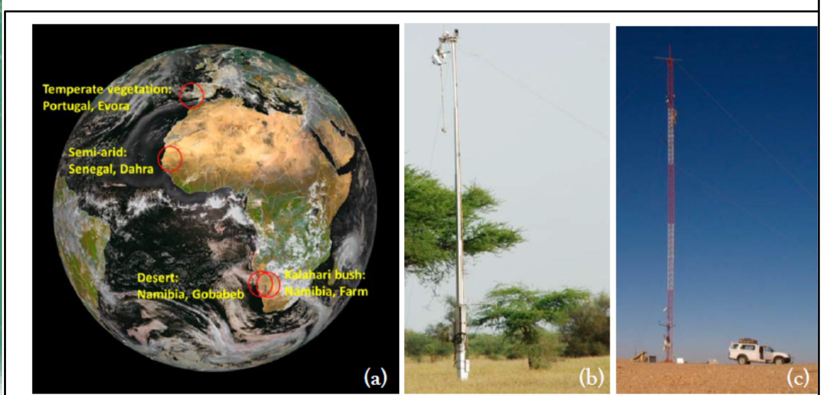


ECOSTRESS LST - Emis5 for cloud, Ames, 20190803T203332



CEOS LST validation best practices

1. Temperature-based validation
2. Radiance-based validation
3. Sensor LST product intercomparisons
4. Time-series analysis

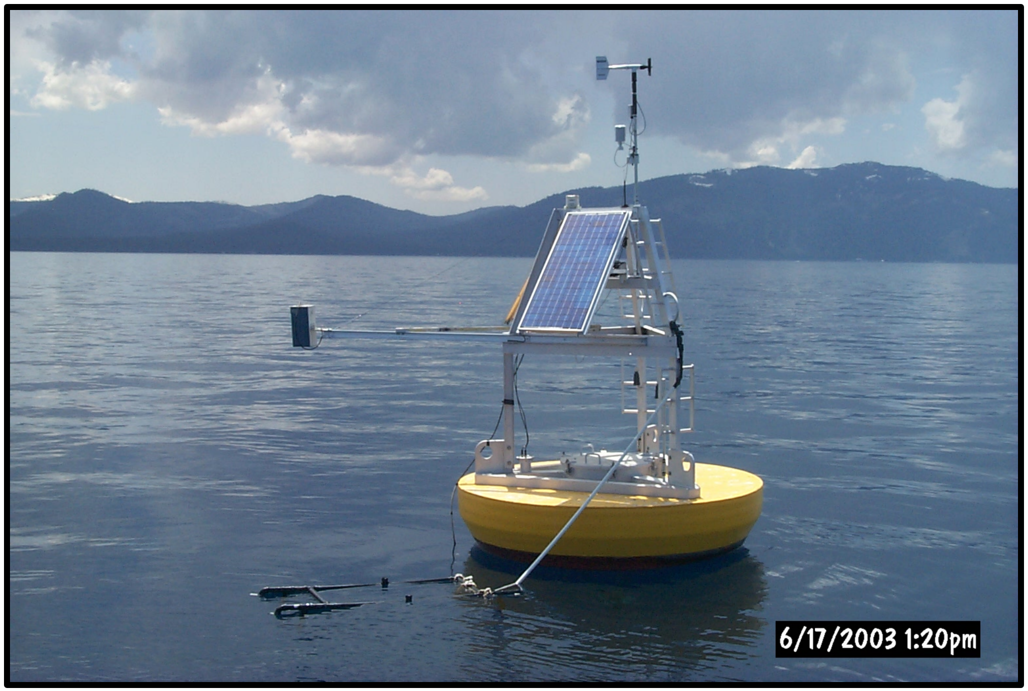


Status: LST instrumented validation Sites

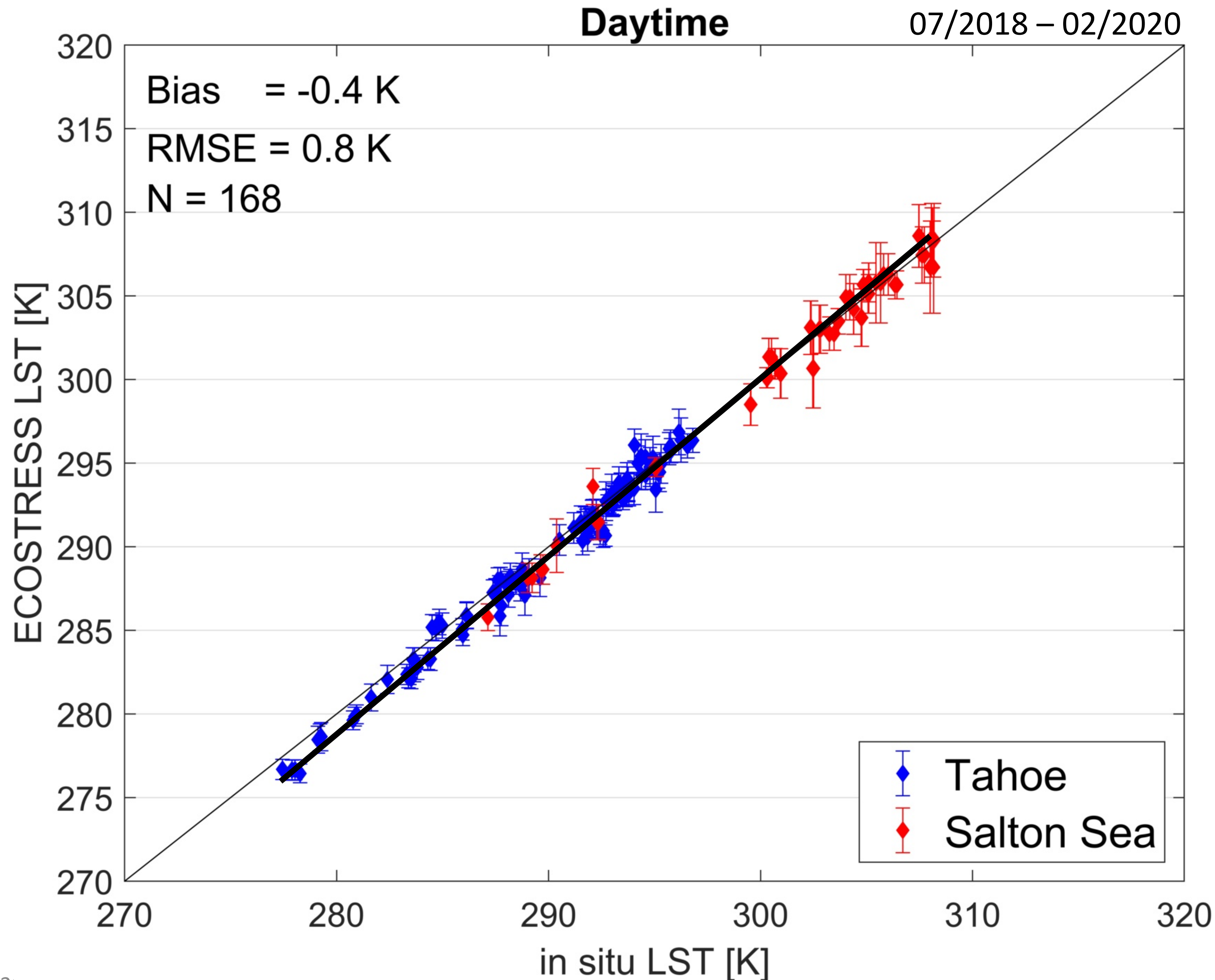
Site Name	State/ Prov	Country	Contact	Network / Organisation	Instruments
Lake Tahoe (4 buoys)	CA/NV	USA	Simon.j.hook@jpl.nasa.gov	JPL	Radiometer (in-house development)
Salton Sea	CA	USA	Simon.j.hook@jpl.nasa.gov	JPL	Radiometer (in-house development)
Table Mountain, Boulder	CO	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Fort Peck	MT	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Desert Rock	NV	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Sioux Falls	SD	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Goodwin Creek	MS	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Bondville	IL	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
Penn State	PA	USA	Jeff.Privette@noaa.gov	SurfRad	Pyrgeometer, Eppley
ARM SGP	OK	USA	Jeff.Privette@noaa.gov	ARM	KT19.85 (Heitronics), Pyrgeometer (Eppley)
ARM NSA	AL	USA	Jeff.Privette@noaa.gov	ARM	Pyrgeometer, Eppley
Lake Constance (ferry)		Germany - Switzerland	frank.goettsche@kit.edu	KIT NEW	KT15.85 IIP, Heitronics
Evora		Portugal	frank.goettsche@kit.edu	KIT	KT15.85 IIP, Heitronics
~~Dahra~~		~~Senegal~~	~~frank.goettsche@kit.edu~~	~~KIT~~	~~KT15.85 IIP, Heitronics~~
Farm Heimat (Kalahari)		Namibia	frank.goettsche@kit.edu	KIT	KT15.85 IIP, Heitronics
Gobabeb Windmast (GBB Wind)		Namibia	frank.goettsche@kit.edu	KIT	KT15.85 IIP, Heitronics
Gobabeb Plains (GBB Plains)		Namibia	frank.goettsche@kit.edu	KIT	KT15.85 IIP, Heitronics
Neumayer Station III (Germany)		Antarctica	Gert.Koenig-Langlo@awi.de	BSRN	Pyrgeometer, Eppley
CRN sites		USA	Jeff.Privette@noaa.gov	NOAA CRN	SI-111, Apogee
BSRN		Global	respective site owner	BSRN	broadband hemispherical radiances
Valencia		Spain	cesar.coll@uv.es	University of Valencia	SI-121, Apogee (8-14µm)
Barrax		Spain	Jose.Sobrino@uv.es	University of Valencia	IR120, Campbell Scientific; Apogee (8-14µm)
Doñana		Spain	Jose.Sobrino@uv.es	University of Valencia	IR120, Campbell Scientific; Apogee (8-14µm)
Cabo de Gata		Spain	Jose.Sobrino@uv.es	University of Valencia	IR120, Campbell Scientific; Apogee (8-14µm)
OzFlux ASM site		Australia	James.Cleverly@uts.edu.au	TERN	CNR1, Kipp & Zonen (broadband hemispherical radiances)
Etna		Italy	fabrizia.buongiorno@ingv.it	INGV	
Almeria (2 sites)		Spain	Jose.Sobrino@uv.es	University of Valencia	

JPL Cal/Val sites: Lake Tahoe and Salton Sea, CA

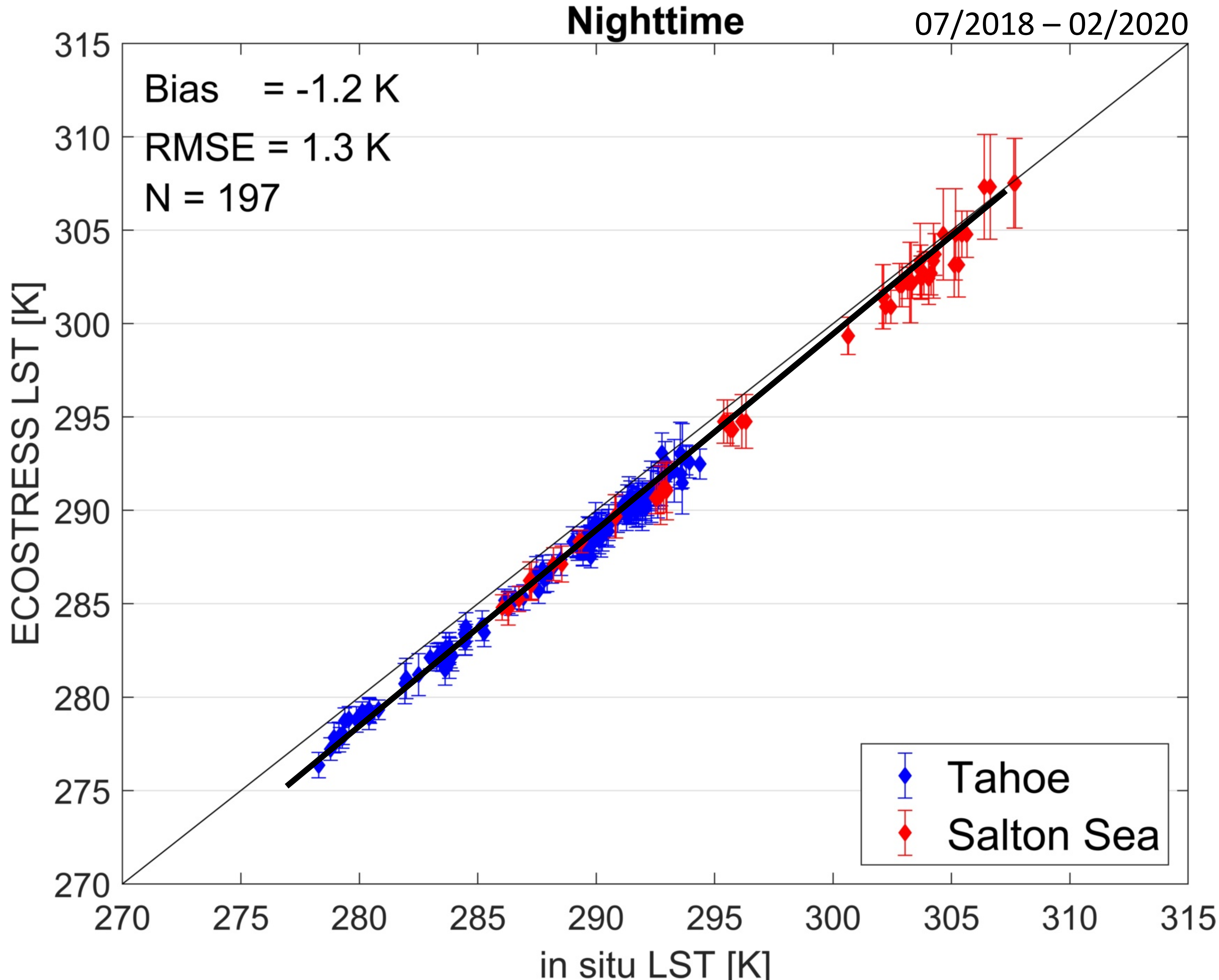
Lake Tahoe operating 24x7 since 1999



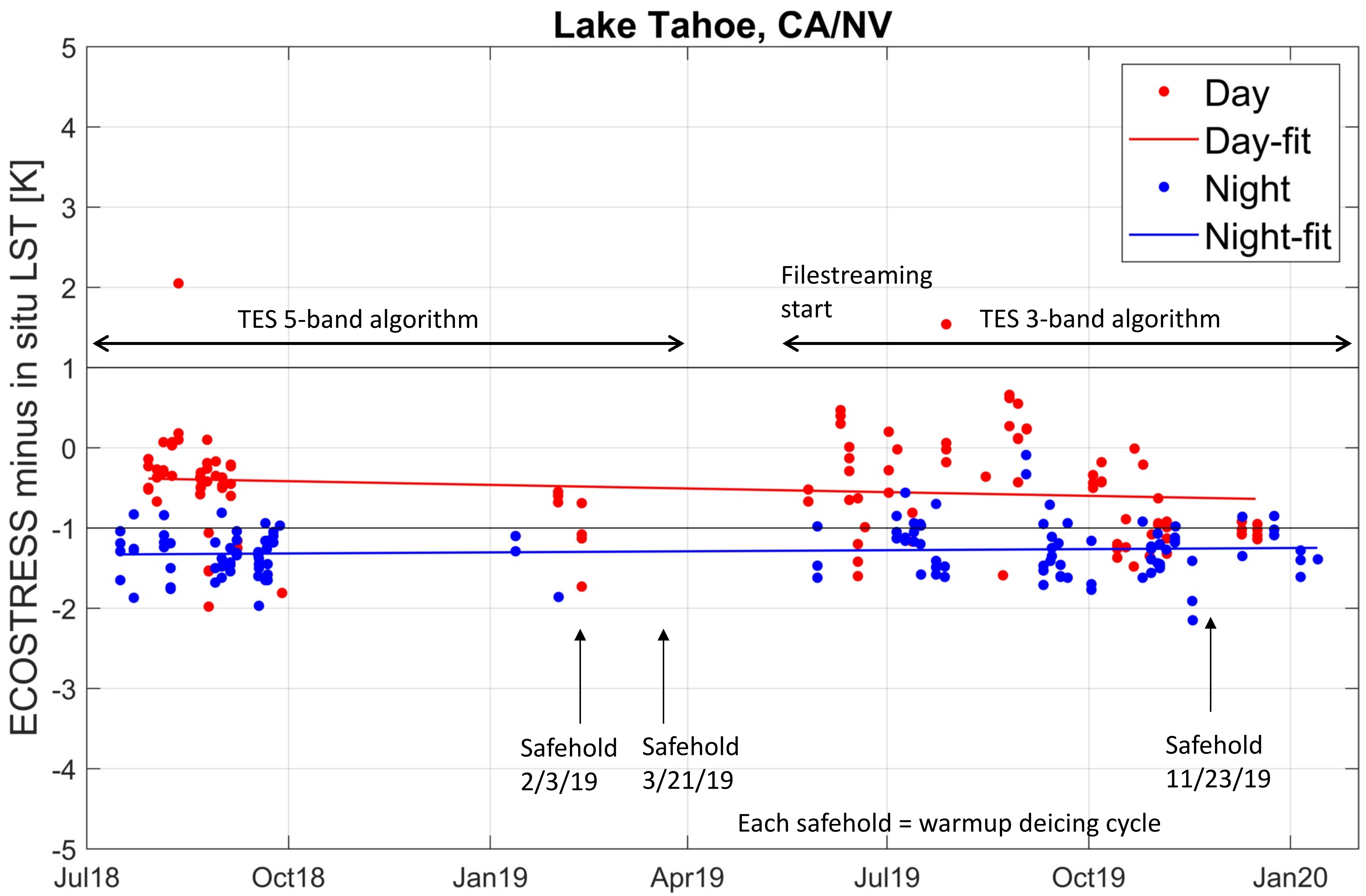
Salton Sea since 2007



Daytime
07/2018 – 02/2020
Bias = -0.4 K
RMSE = 0.8 K
N = 168
ECOSTRESS LST [K]
in situ LST [K]
320
315
310
305
300
295
290
285
280
275
270
270
280
290
300
310
320
Tahoe
Salton Sea



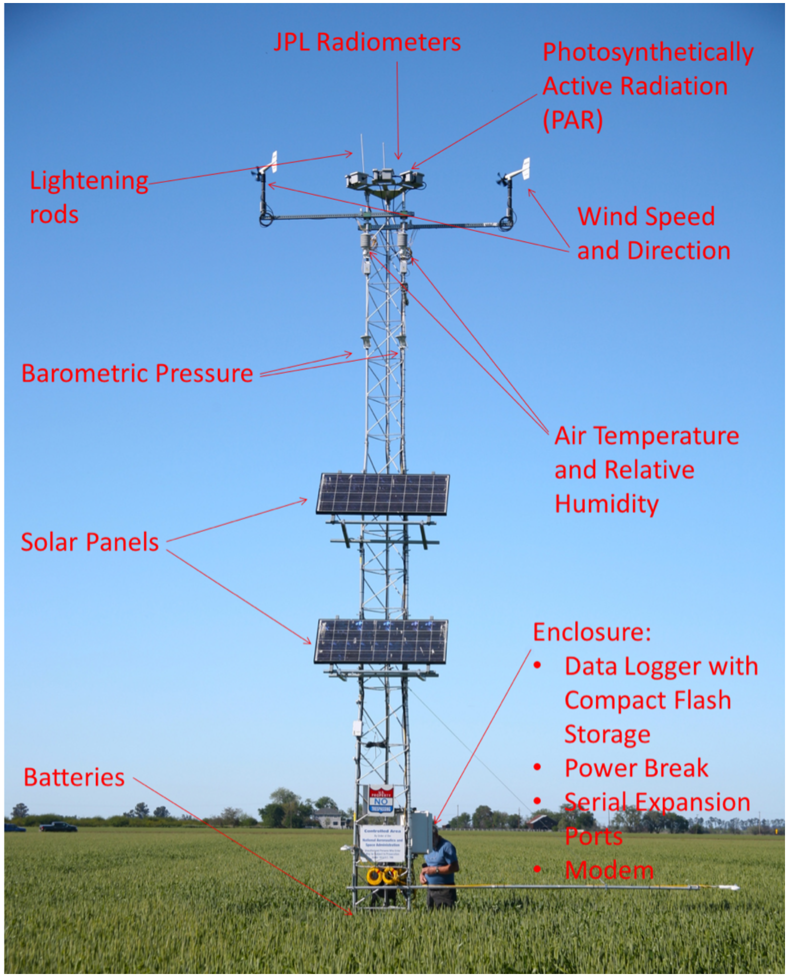
Nighttime
07/2018 – 02/2020
Bias = -1.2 K
RMSE = 1.3 K
N = 197
ECOSTRESS LST [K]
in situ LST [K]
Tahoe
Salton Sea
270
275
280
285
290
295
300
305
310
315



Lake Tahoe, CA/NV
ECOSTRESS minus in situ LST [K]
5
4
3
2
1
0
-1
-2
-3
-4
-5
Jul18
Oct18
Jan19
Apr19
Jul19
Oct19
Jan20
Day
Day-fit
Night
Night-fit
TES 5-band algorithm
Filestreaming start
TES 3-band algorithm
Safehold 2/3/19
Safehold 3/21/19
Safehold 11/23/19
Each safehold = warmup deicing cycle

JPL Cal/Val sites: Russell Ranch, CA

Instrument/Sensor Description	Data Collected
Wind speed indicator (MET)	The values are in counts and are converted to meters per second (ms^{-1})
Wind direction indicator (MET)	The values are in counts and are converted to degrees with respect to magnetic north
Air Temperatures with Gill radiation shield (MET)	The values are in counts and are converted to degrees Celsius (the air temperatures and relative humidity sensor are integrated together)
Relative Humidity (RH) (MET)	The values are in counts and are converted to percent
Barometric Pressure with Pressure Port (MET)	The values are in counts and are converted to hectopascals or millibars (hPa or mBar). The pressure port is used to prevent any errors in pressure due to wind over the sensor
Li-COR Photosynthetically Active Radiation (PAR) sensor	Sensor measures Photosynthetic Photon Flux Density (PPFD) in both natural and artificial light
Net Radiometer	Incoming solar radiation (short wave), reflected solar radiation, incoming far infrared radiation (long wave), outgoing far infrared radiation, sky temperature and ground temperature
JPL-built Radiometer	Land surface temperature
Eddy Covariance System	Air temperature, sonic air temperature, barometric pressure, absolute carbon dioxide and water vapor densities and the orthogonal wind components (three-dimensional)



JPL validation tower at Russell Ranch, CA

- Crops are sown in ~April (usually tomatoes)
- Harvesting occurs in late September
- Tower has a visible camera taking daily snapshots of field condition
- Two radiometers pointing perpendicular to crop rows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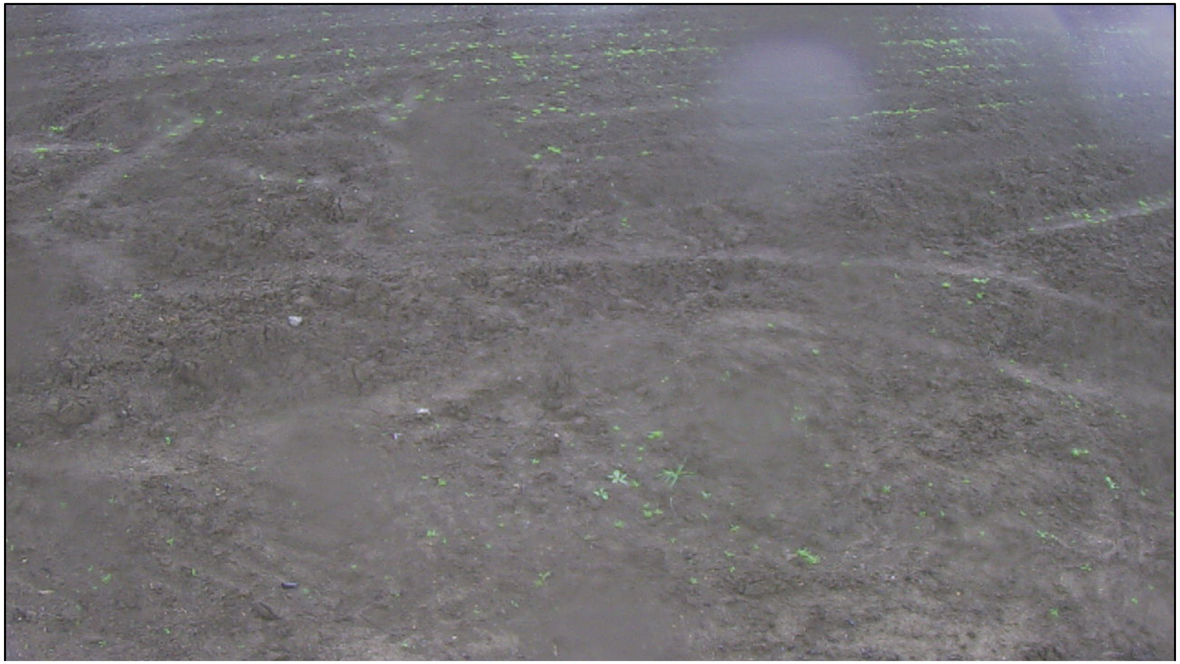
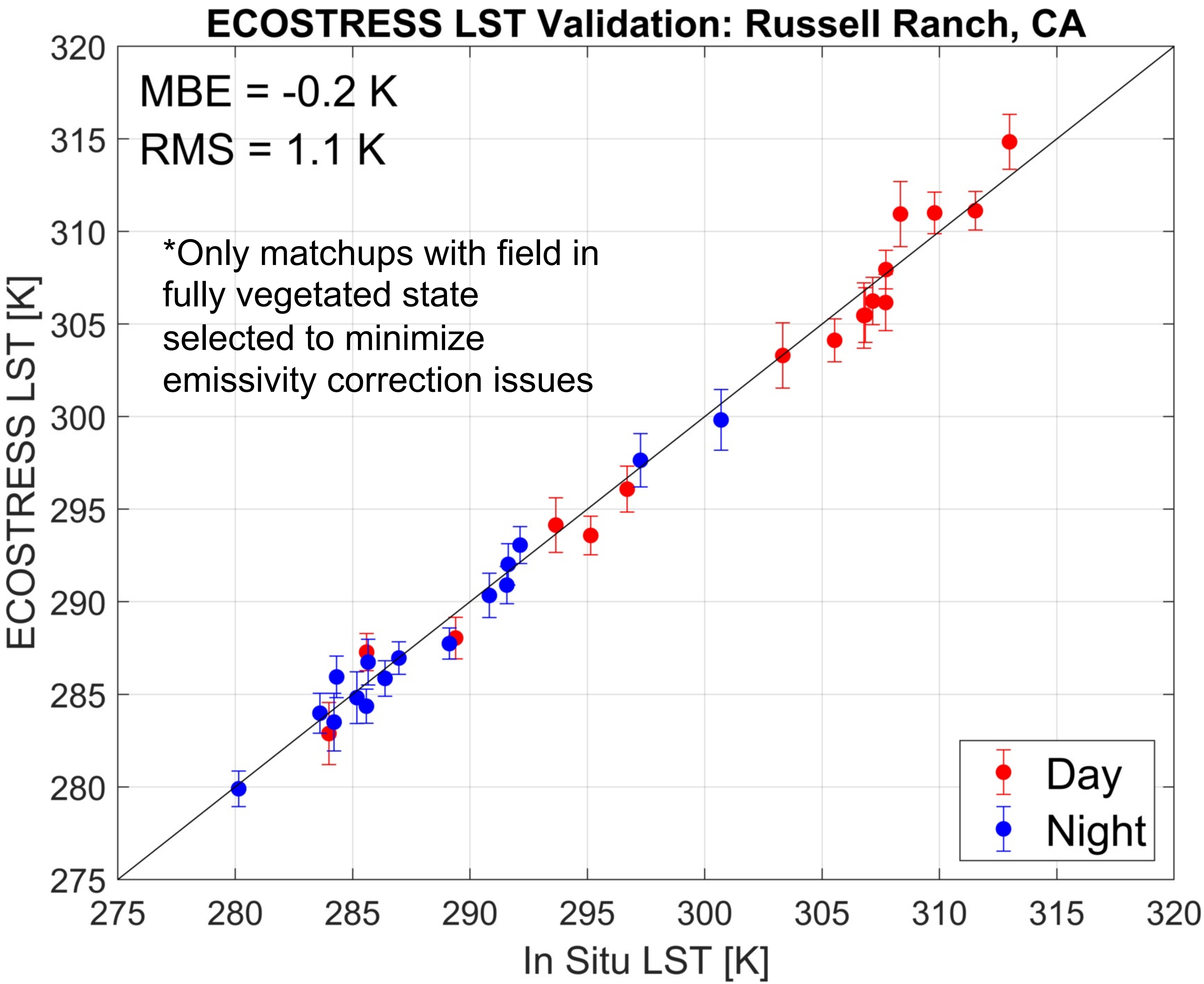
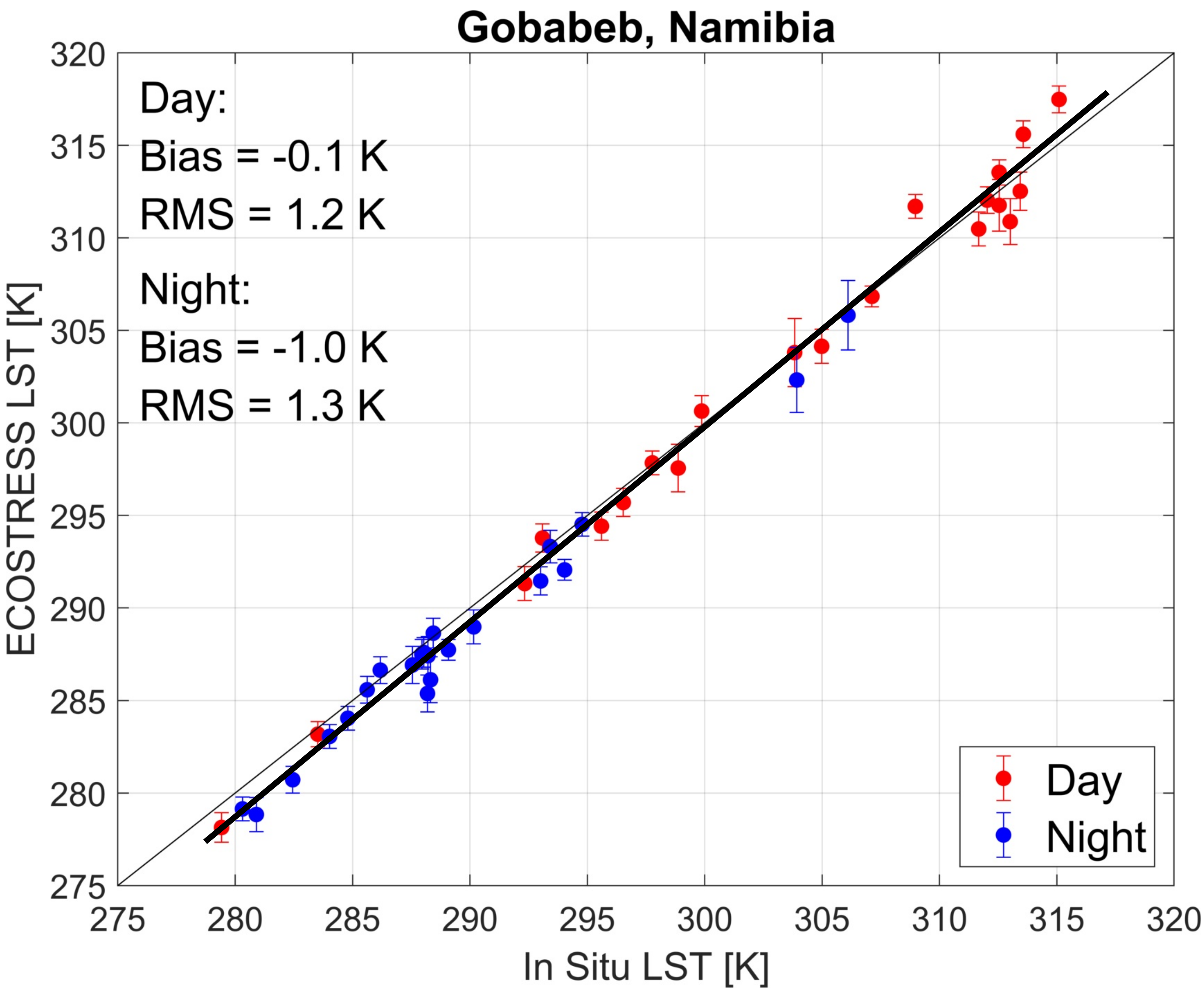
National Aeronautics and
Space Administration
Unauthorized Persons Who Enter
May be Subject to Prosecution
Under 18 U.S.C. 799

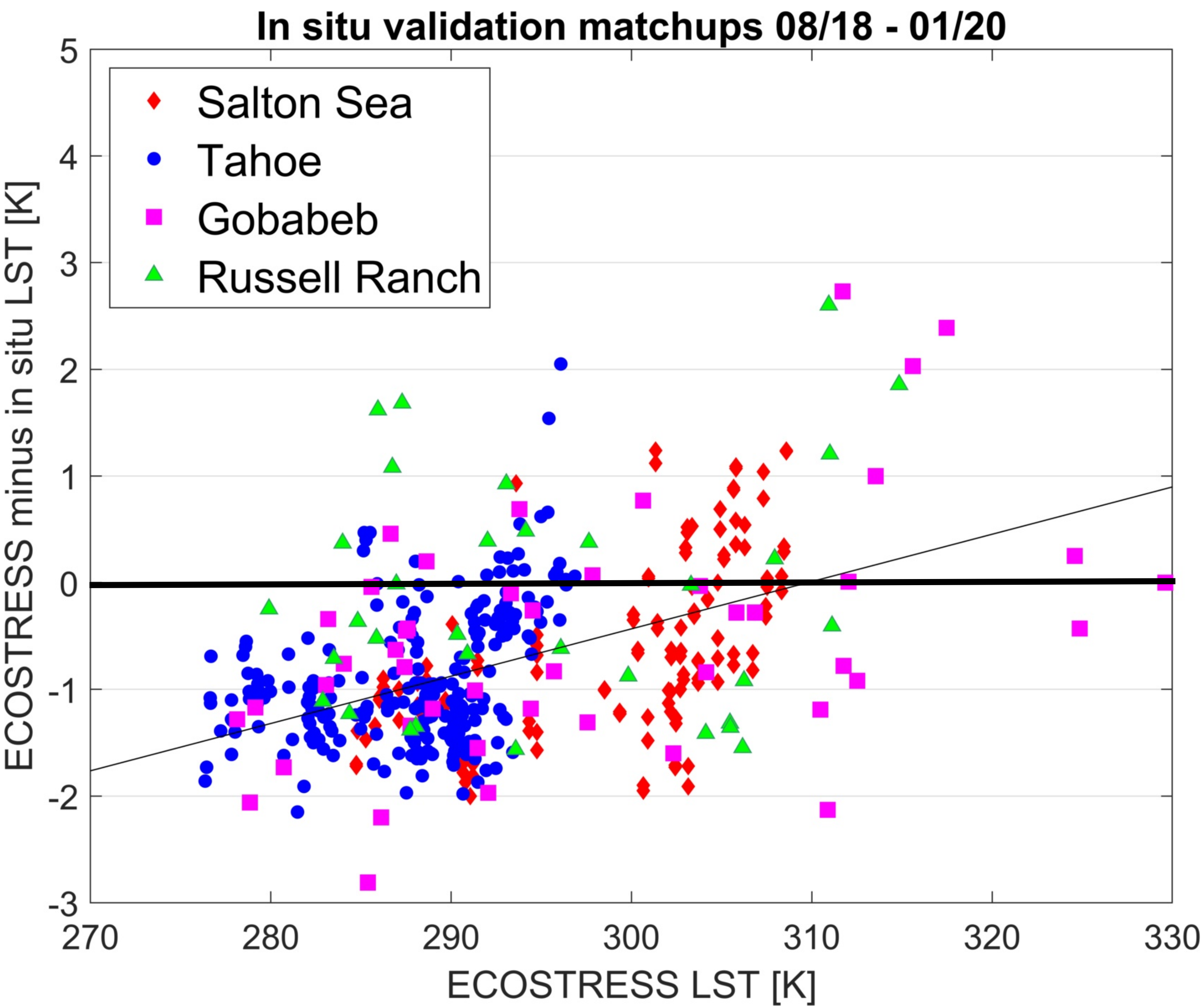



ECOSTRESS LST Validation: Russell Ranch, CA
MBE = -0.2 K
RMS = 1.1 K
*Only matchups with field in
fully vegetated state
selected to minimize
emissivity correction issues
ECOSTRESS LST [K]
In Situ LST [K]
Day
Night
275
280
285
290
295
300
305
310
315
320

Karlsruhe Institute of Technology



Gobabeb, Namibia
Day:
Bias = -0.1 K
RMS = 1.2 K
Night:
Bias = -1.0 K
RMS = 1.3 K
ECOSTRESS LST [K]
In Situ LST [K]
275
280
285
290
295
300
305
310
315
320
Day
Night



In situ validation matchups 08/18 - 01/20
Salton Sea
Tahoe
Gobabeb
Russell Ranch
ECOSTRESS minus in situ LST [K]
ECOSTRESS LST [K]
5
4
3
2
1
0
-1
-2
-3
270
280
290
300
310
320
330

Radiance-Based Temperature Validation

Compare radiances:
CALC1 – OBS?

Sensor Radiance
(CALC1)

Sensor Radiance
(CALC2)

```
Tr = interp1([CALC1 CALC2],
             [T1 T2],
             OBS);

Terror = Tr – T1
```

Atmospheric Profile (ECMWF) (Tair, RH)

Retrieved Temp (T1)
Measured Emissivity

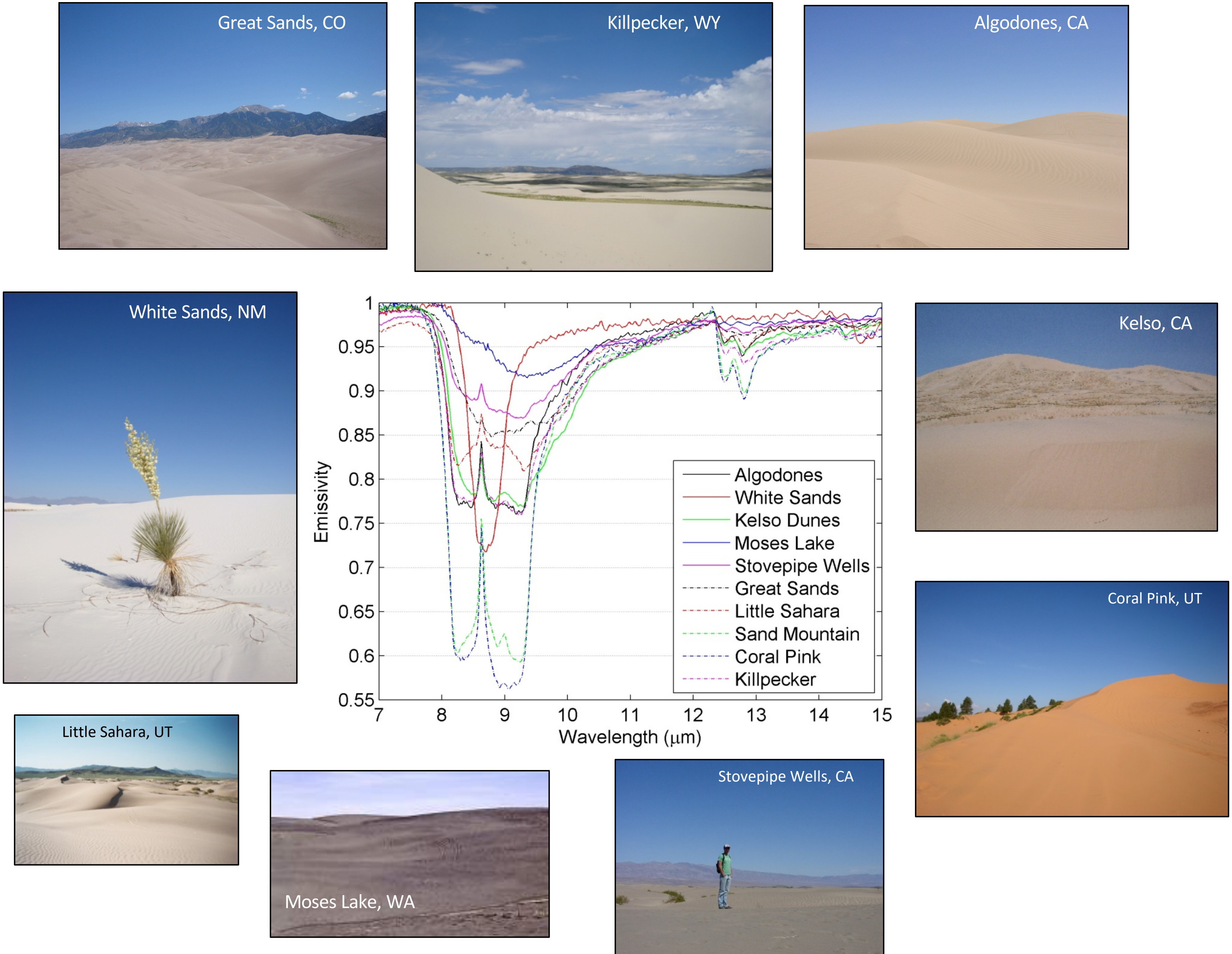
T2 = T1 ± 2 K
Measured Emissivity

<u>Requirements:</u>

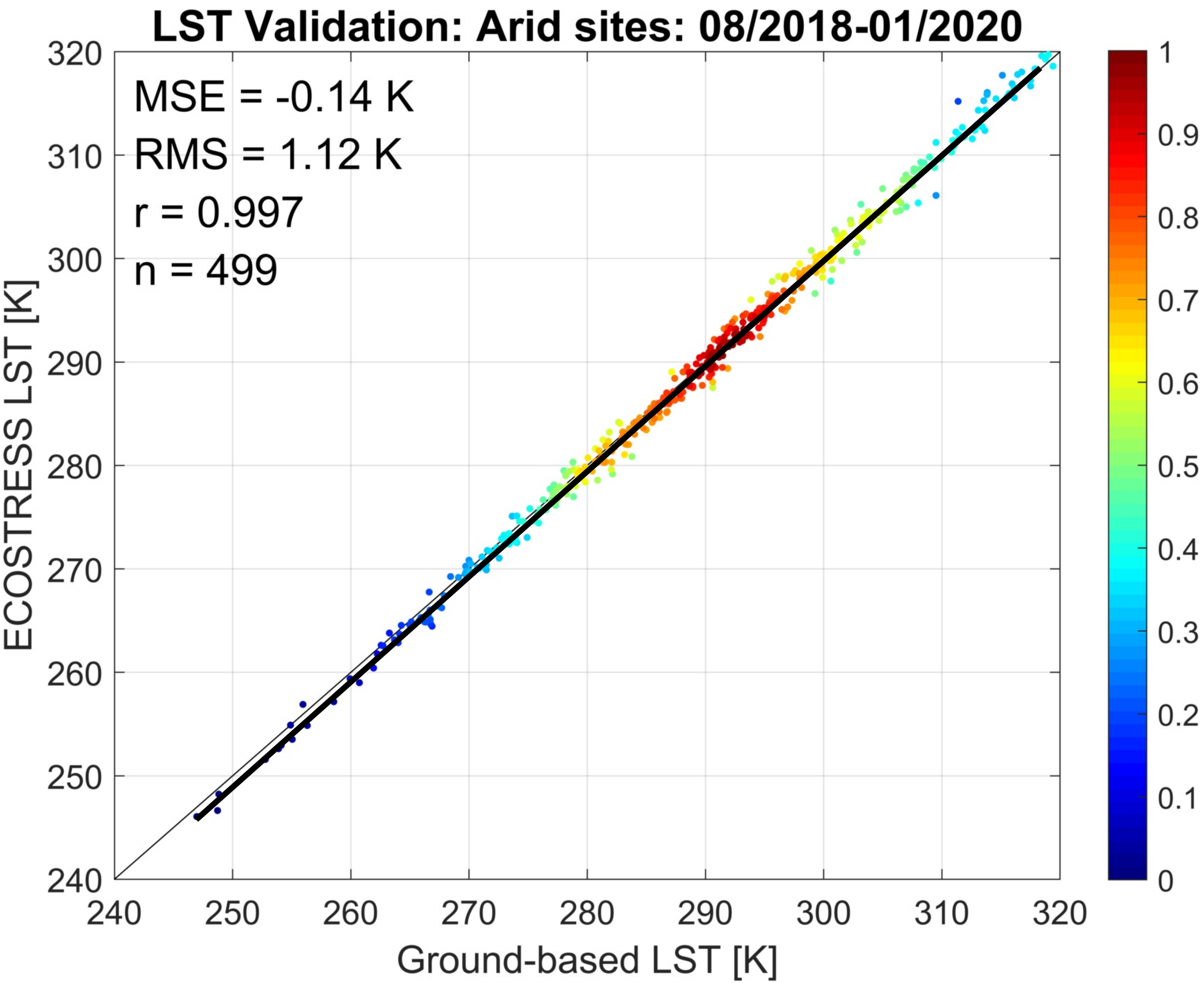
- Accurate Emissivity
- Accurate Profile:

Td(calc) = Tb(11μm) – Tb(12μm)
Td(obs) = Tb(11μm) – Tb(12μm)

Td(calc) – Td(obs) <0.5 K

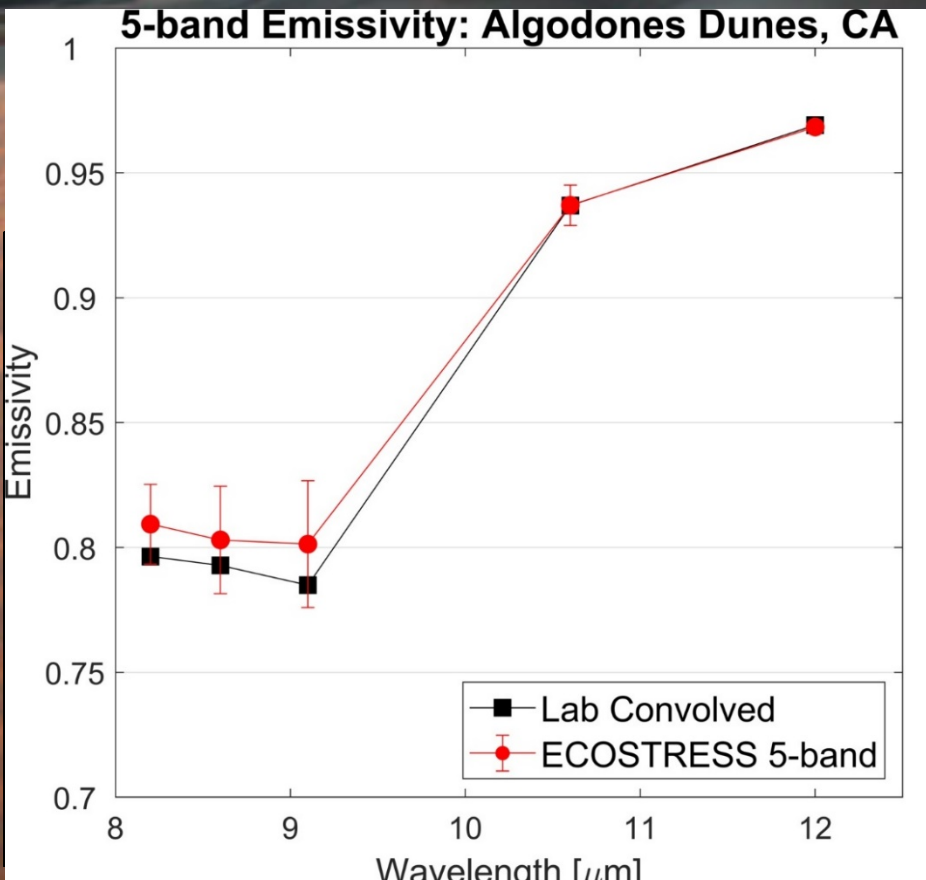


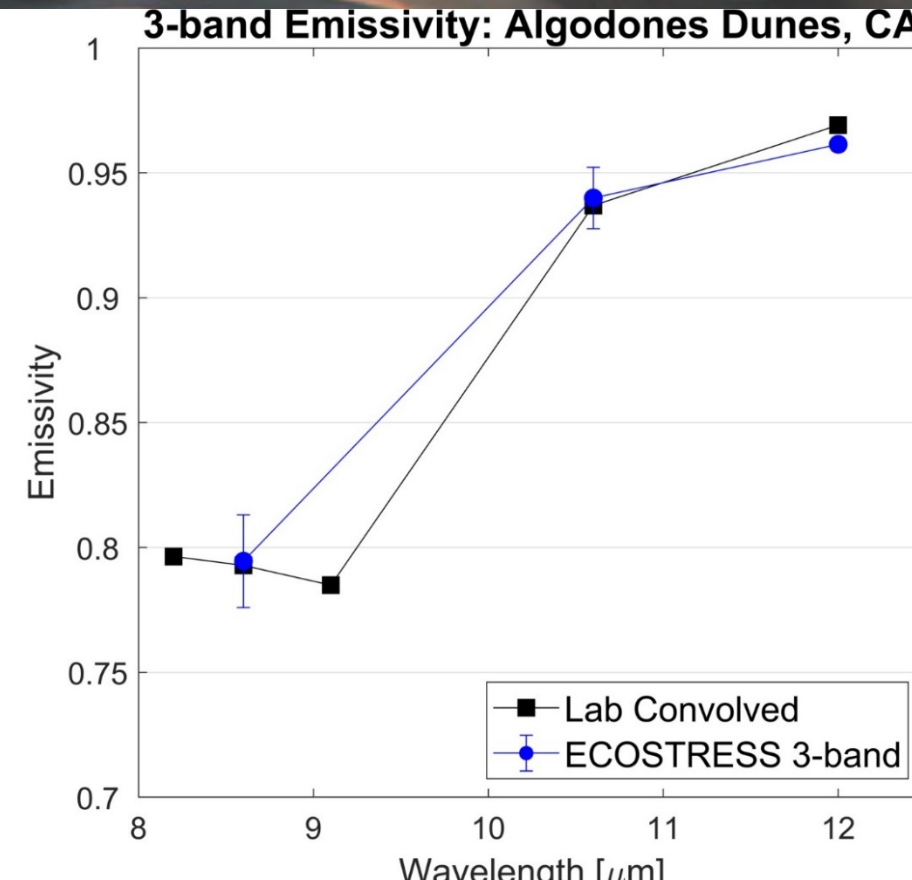
Great Sands, CO
Killpecker, WY
Algodones, CA
White Sands, NM
Kelso, CA
Coral Pink, UT
Little Sahara, UT
Moses Lake, WA
Stovepipe Wells, CA
Emissivity
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
7
8
9
10
11
12
13
14
15
Wavelength (μm)
Algodones
White Sands
Kelso Dunes
Moses Lake
Stovepipe Wells
Great Sands
Little Sahara
Sand Mountain
Coral Pink
Killpecker



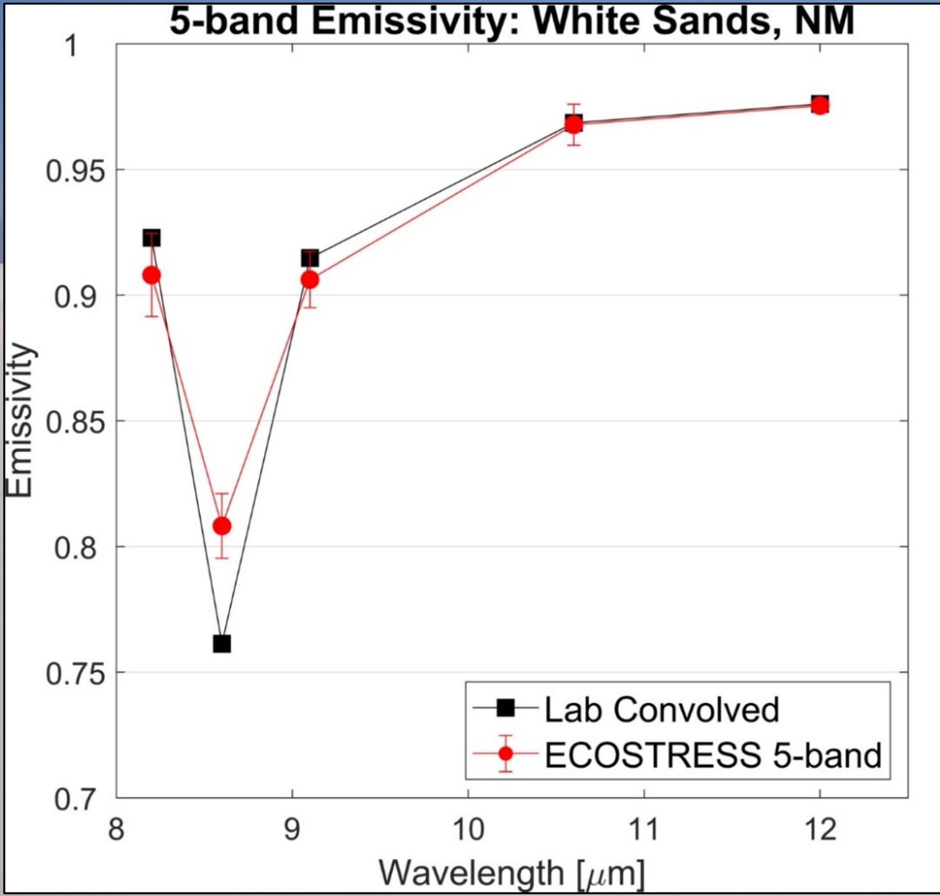
LST Validation: Arid sites: 08/2018-01/2020
MSE = -0.14 K
RMS = 1.12 K
r = 0.997
n = 499
ECOSTRESS LST [K]
Ground-based LST [K]
240
250
260
270
280
290
300
310
320
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

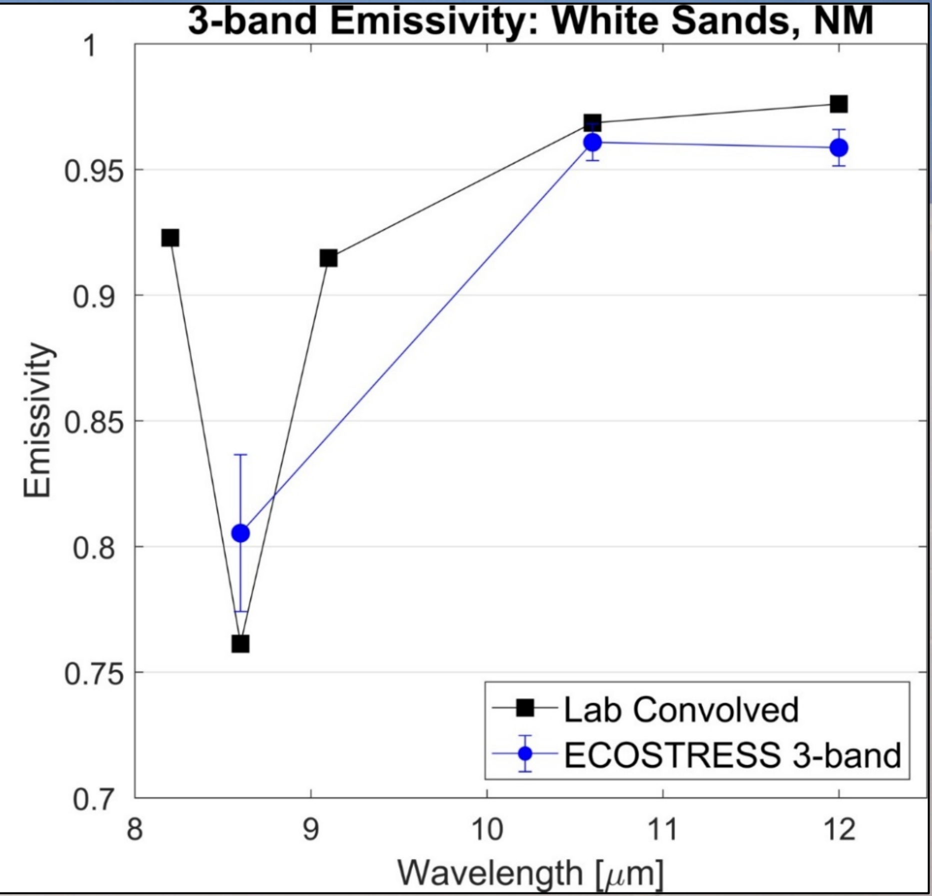
Algodones Dunes, CA





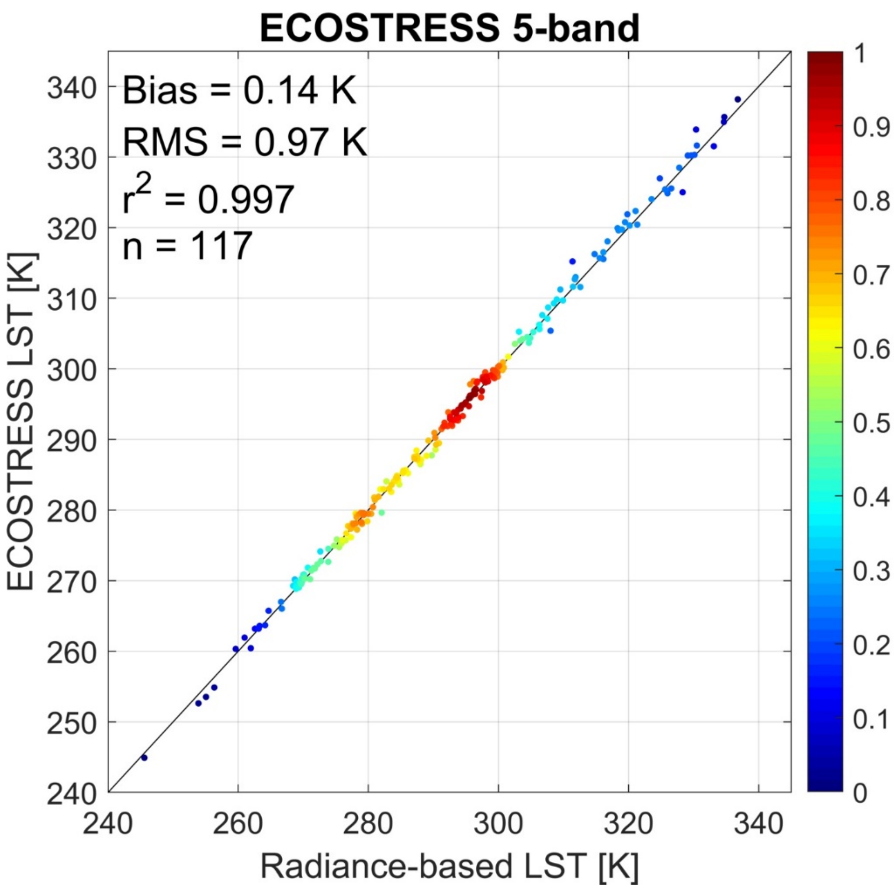
White Sands, NM



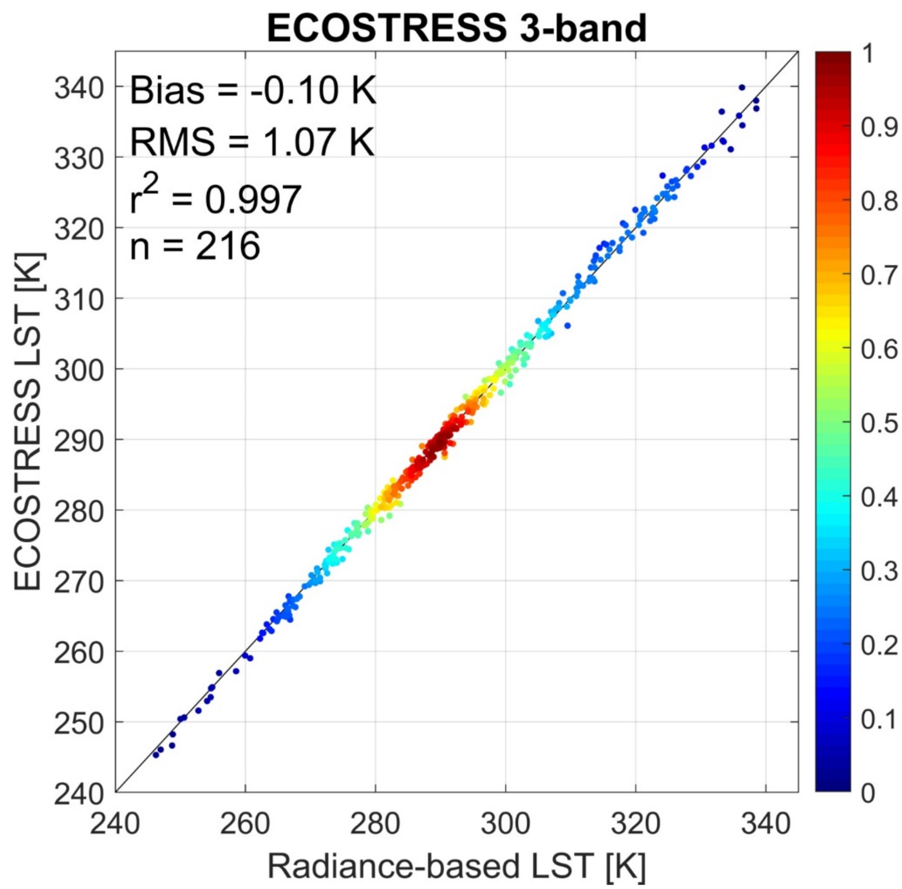


ECOSTRESS 3 vs 5-band TES accuracy

07/2018 – 3/2019

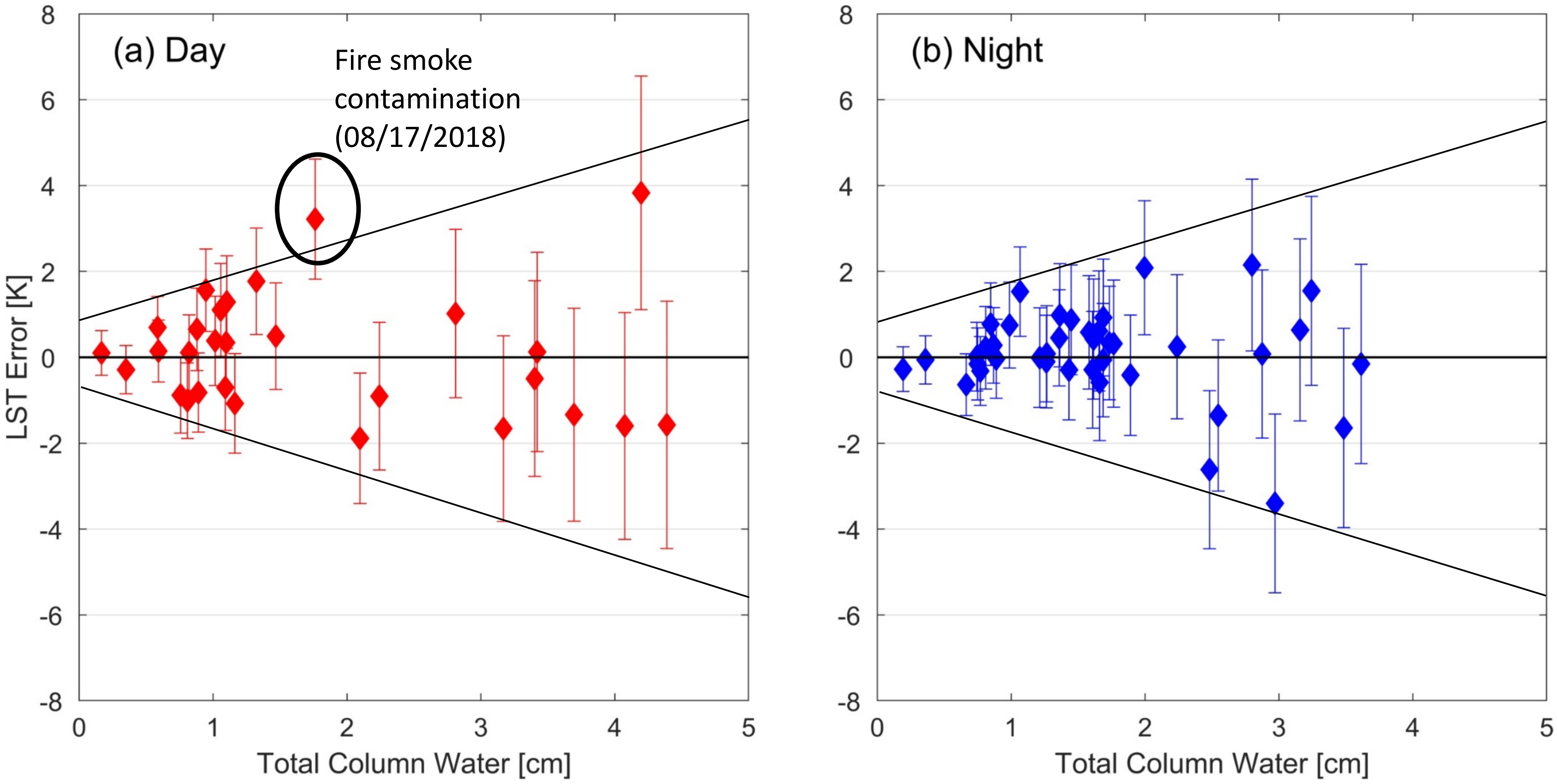


05/2019 – 02/2020

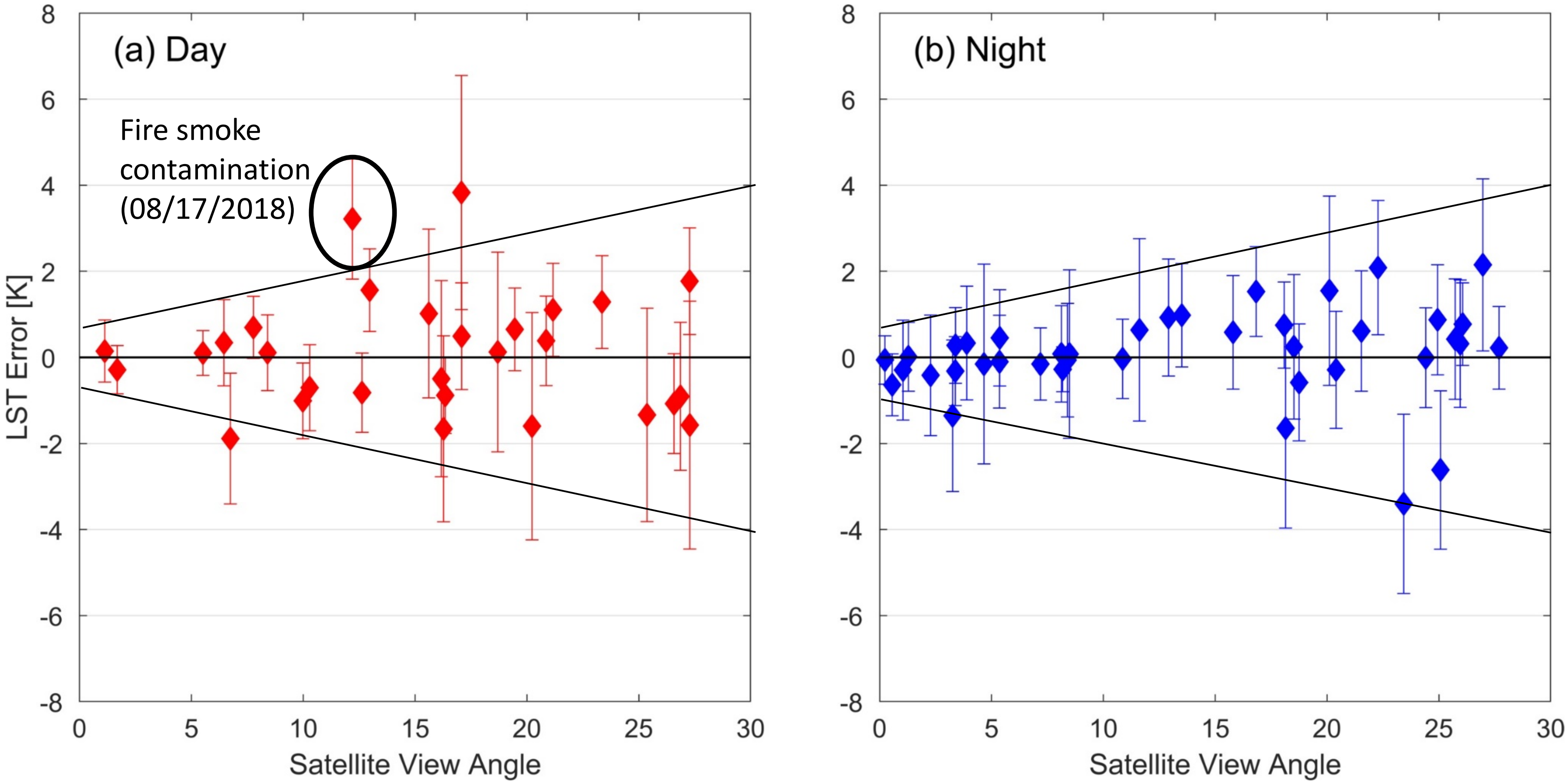


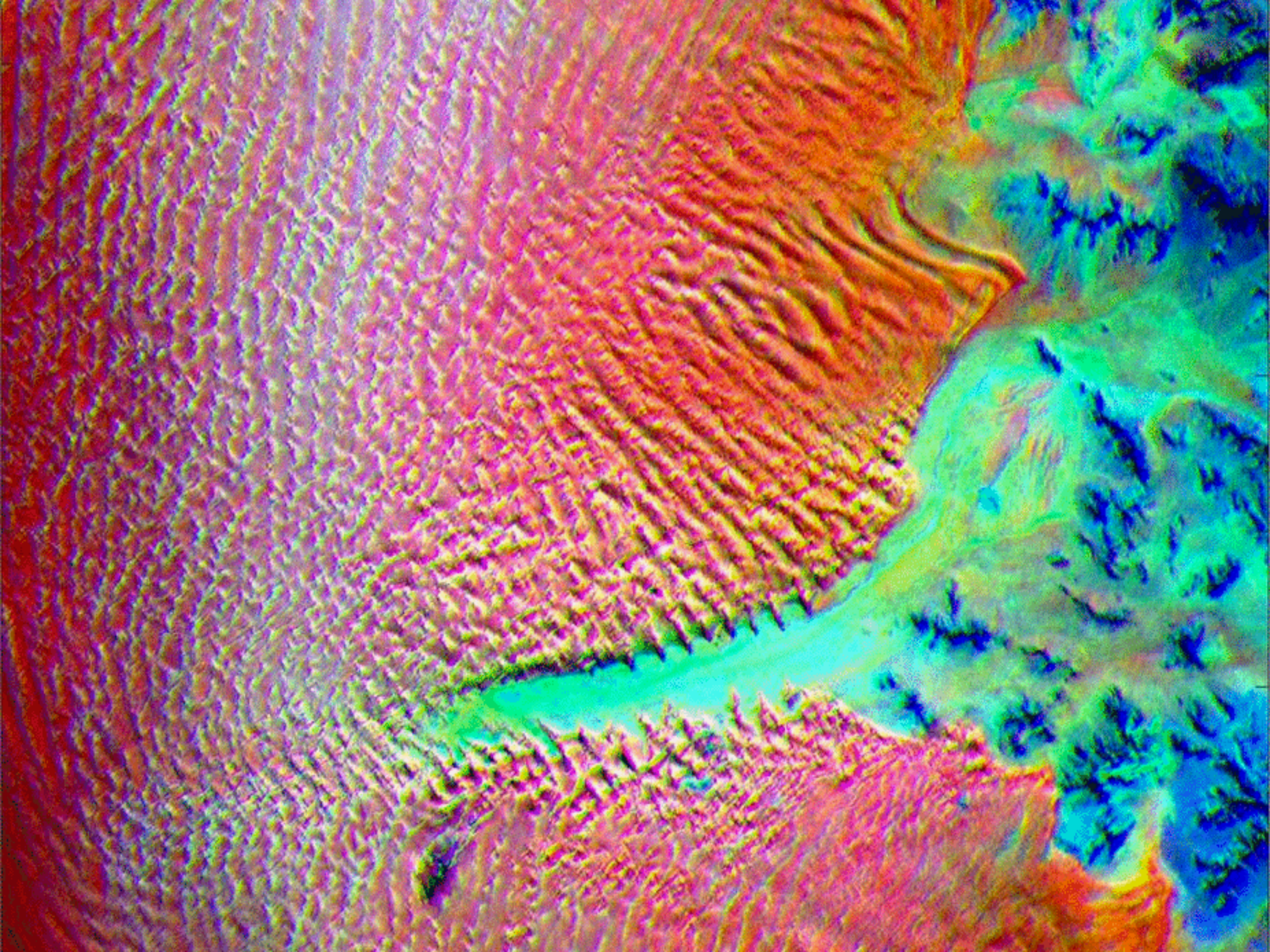
0.1 K higher error for 3-band TES, negligible change in Bias

LST error vs atmospheric water vapor (Algodones dunes, CA)



LST error vs satellite view angle





CEOS LST Validation Recommendations

1. Temperature-based validation
   – Ground instrumented sites
   – Sensor LST matched to ground temperature measurements with NIST traceable standards

- Advantages:
  – Most direct and accurate method of validation
  – Can also be used for calibration purposes
- Disadvantages
  – Requires accurately matched measurements
  – Site and instrument maintenance is costly

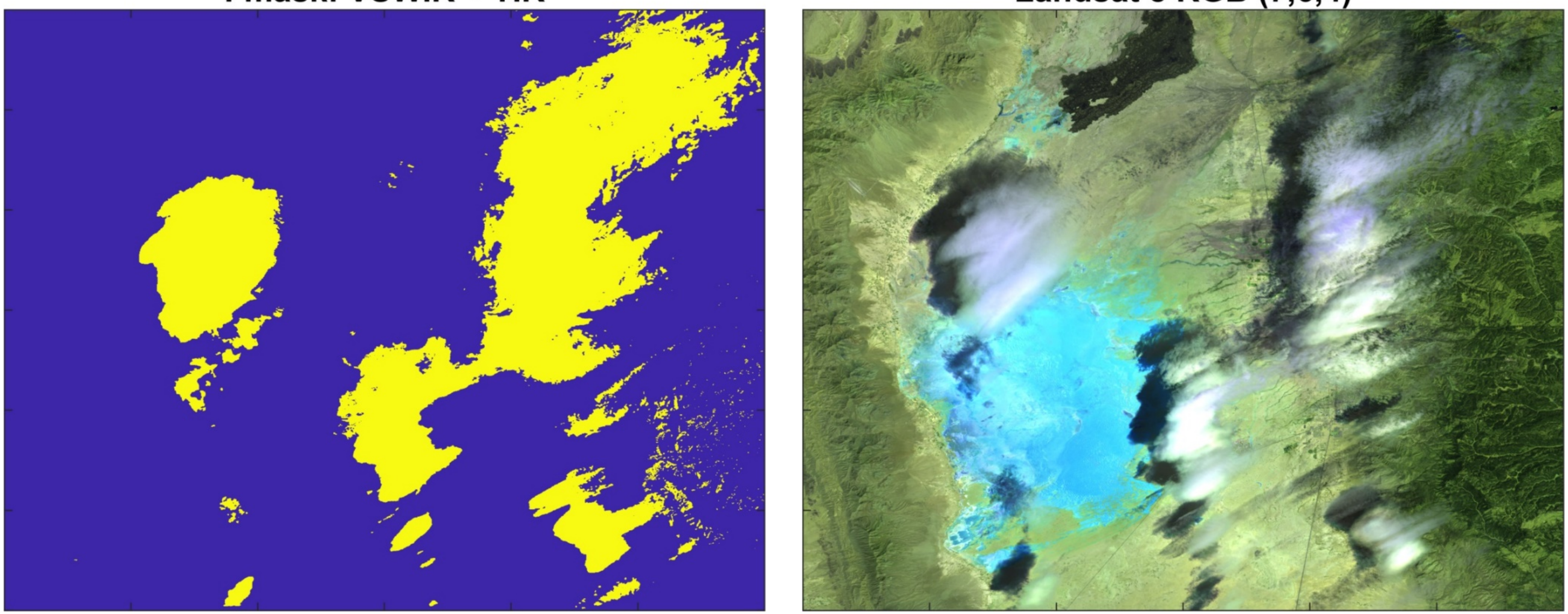
CEOS LST Validation Recommendations

2. Radiance-based validation
   - Radiative closure simulation experiment
   - Requires accurate site emissivity data and atmospheric profiles (NWP or radiosonde)

- Advantages:
  - Can be used to validated coarser resolution sensors
  - Can be applied on global scales day and night
- Disadvantages
  - Requires accurate atmospheric profiles and emissivity
  - Requires sensor with at least two bands at 10-12 micron

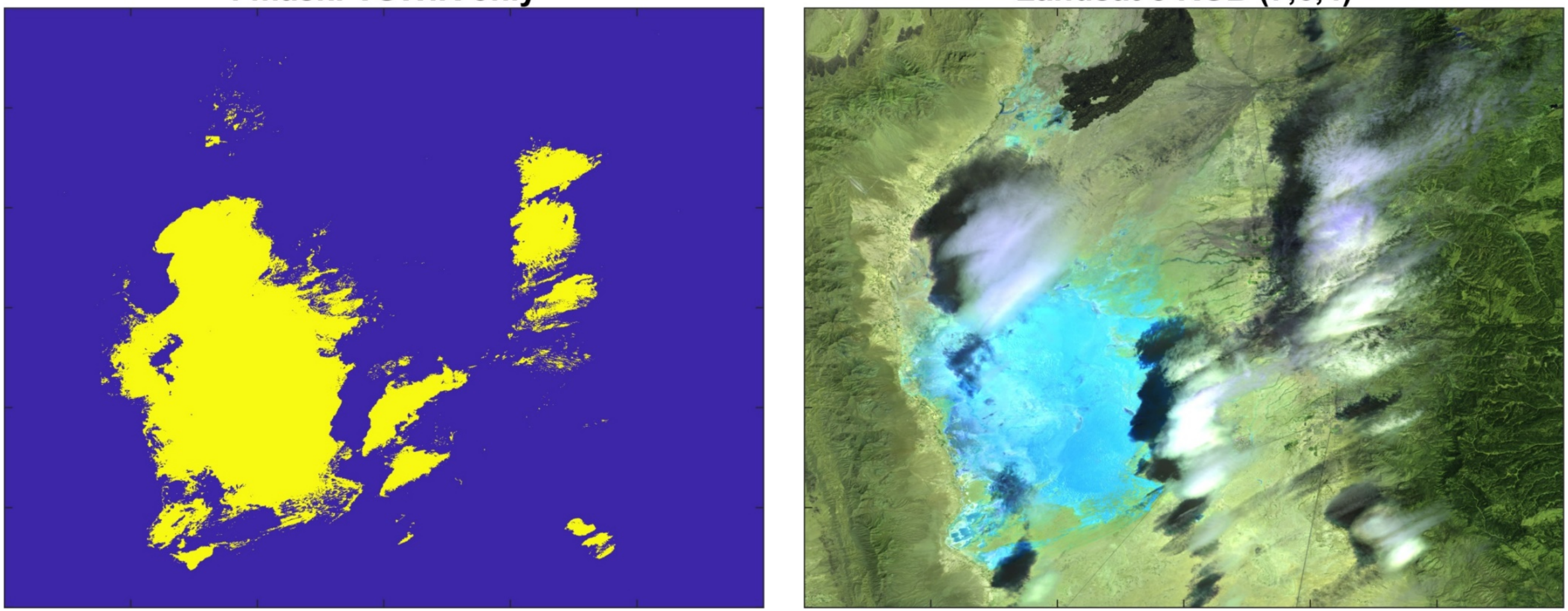
Fmask: VSWIR + TIR

Landsat 8 RGB (7,6,4)

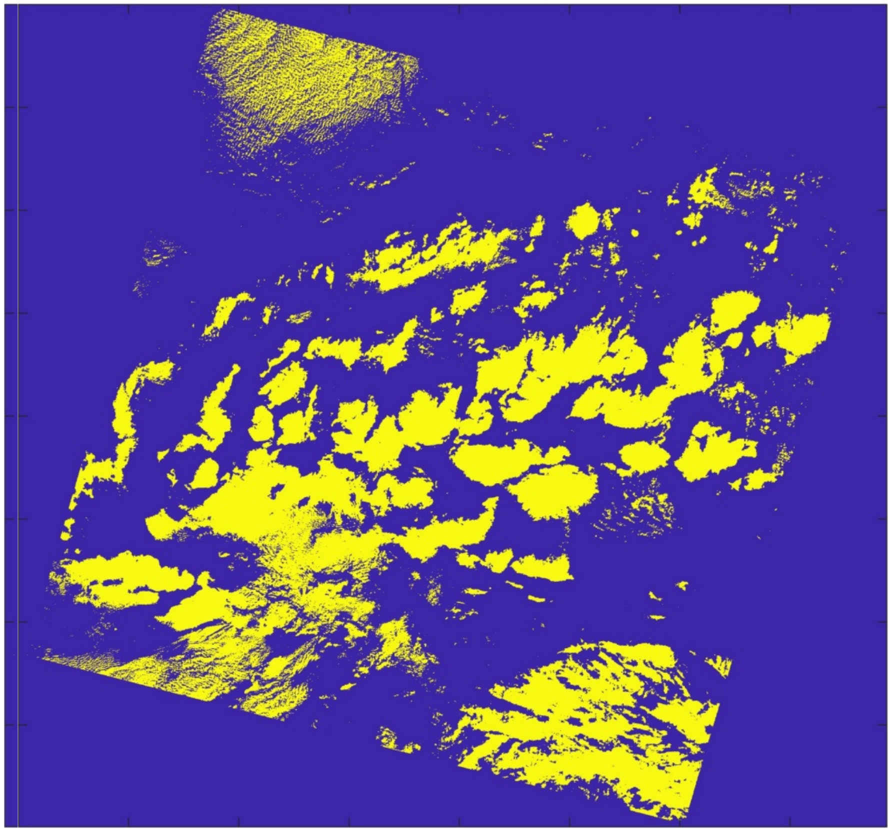


Fmask: VSWIR only

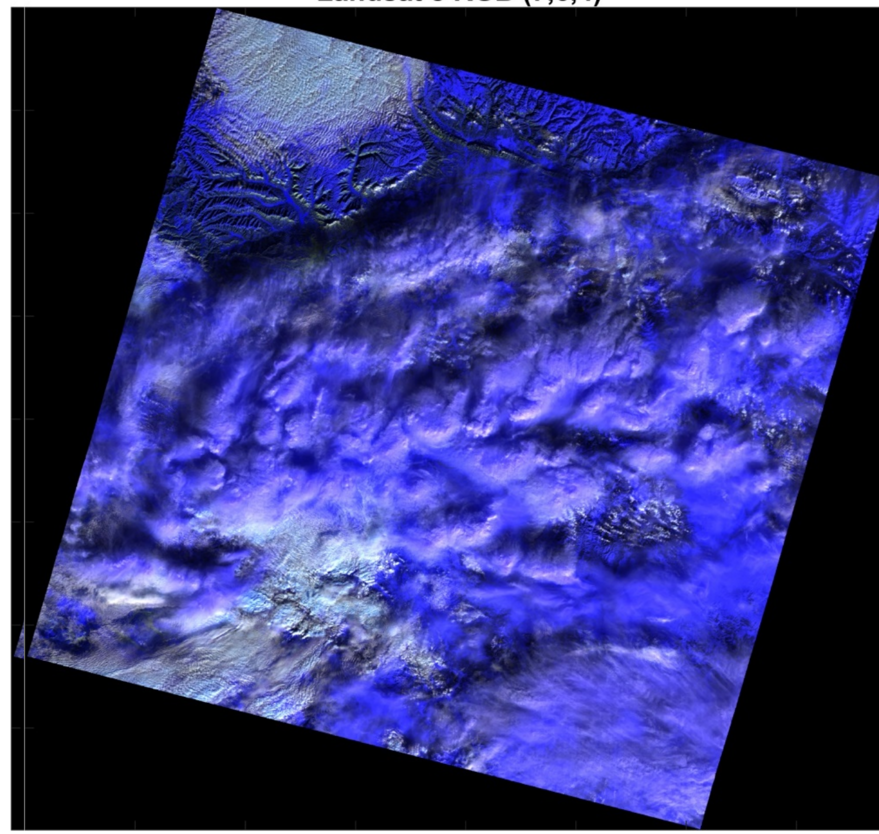
Landsat 8 RGB (7,6,4)



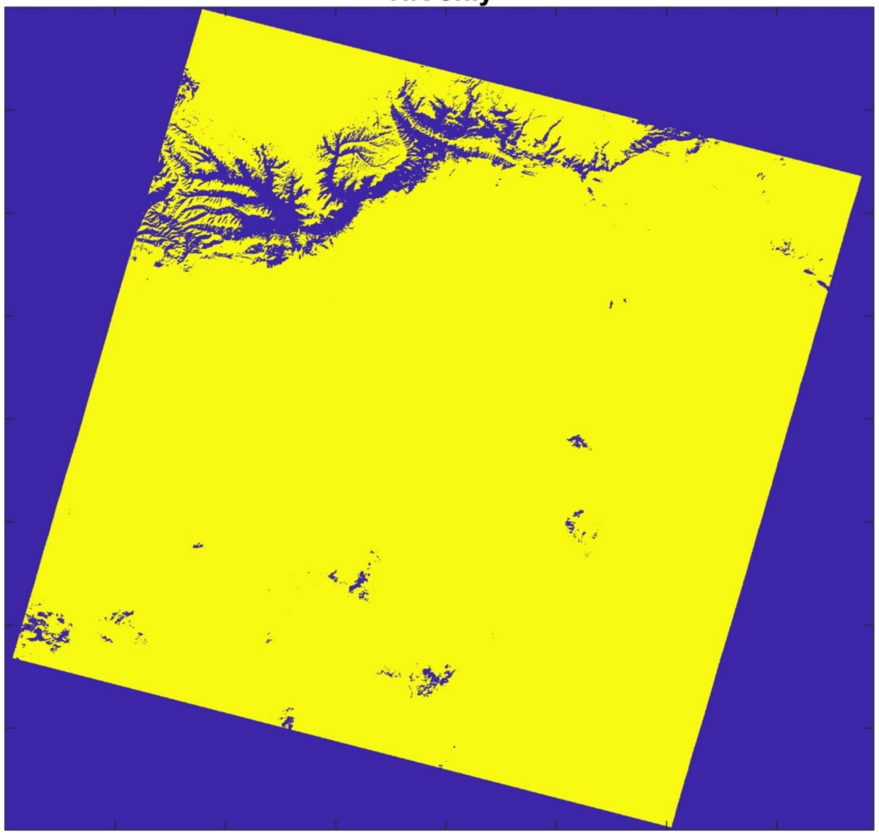
Fmask: VSWIR + TIR



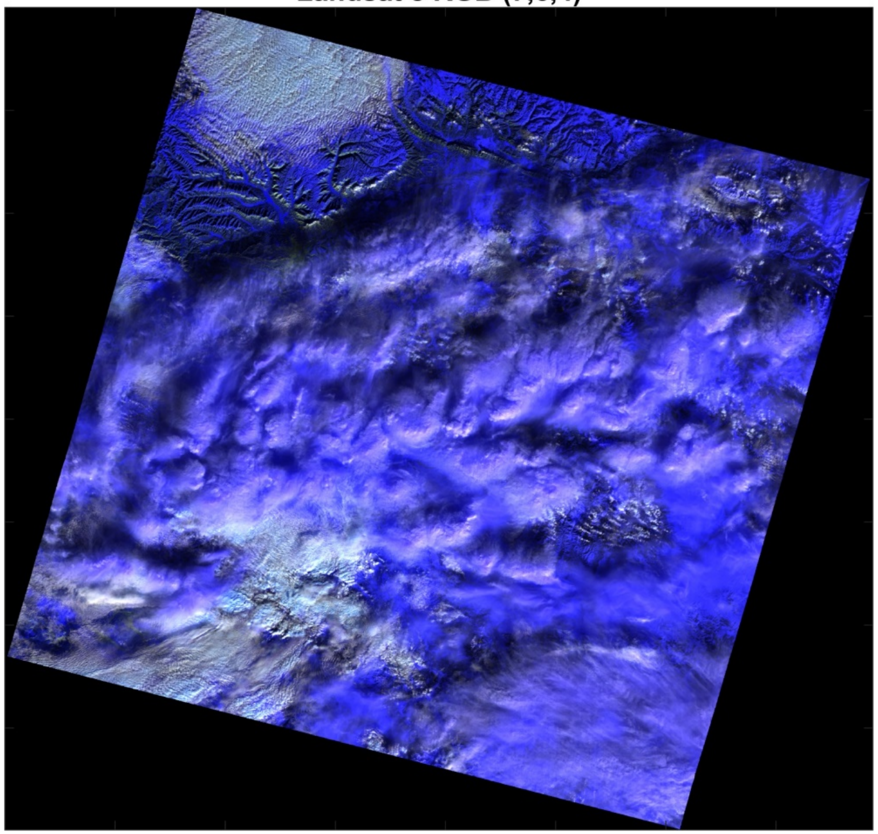
Landsat 8 RGB (7,6,4)



TIR only



Landsat 8 RGB (7,6,4)



CEOS LST Validation Recommendations

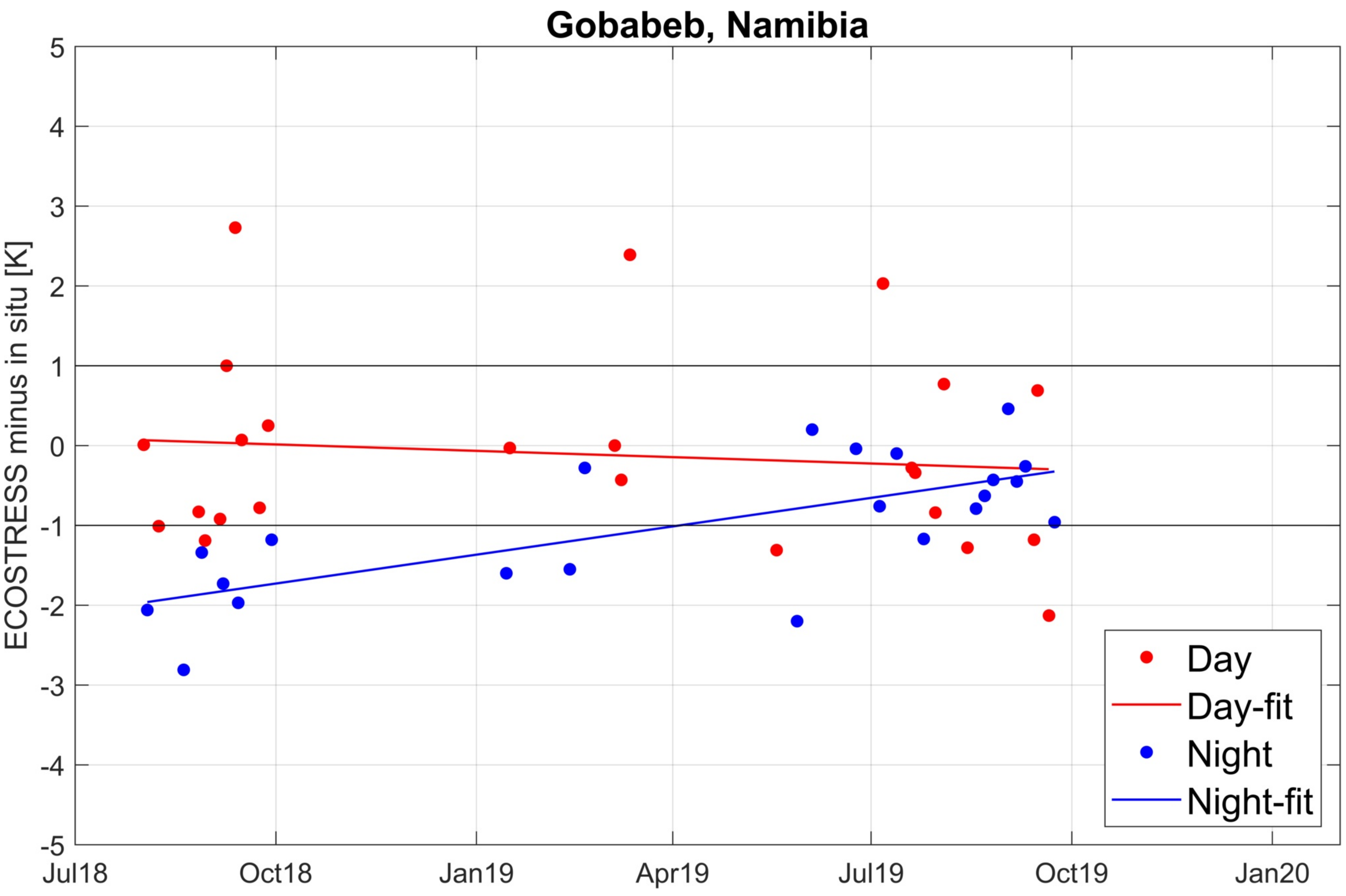
3. Sensor LST scene intercomparisons
   – Comparisons with contemporaneous LST from other well calibrated/validated sensors
   – e.g. Landsat vs ASTER, or Landsat vs GOES-16

4. Time-series comparisons
   – Comparisons between LST products over time to identify sensor drift, calibration, cloud detection issues

CEOS WGCV Validation Stages

Table 8. The CEOS WGCV Land Product Validation Stages.

Stage 0 Validation	No validation results have been reported.
Stage 1 Validation	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in situ or other suitable reference data.
Stage 2 Validation	Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.
Stage 3 Validation	Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
Stage 4 Validation	Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.



Gobabeb, Namibia
ECOSTRESS minus in situ [K]
5
4
3
2
1
0
-1
-2
-3
-4
-5
Jul18
Oct18
Jan19
Apr19
Jul19
Oct19
Jan20
Day
Day-fit
Night
Night-fit

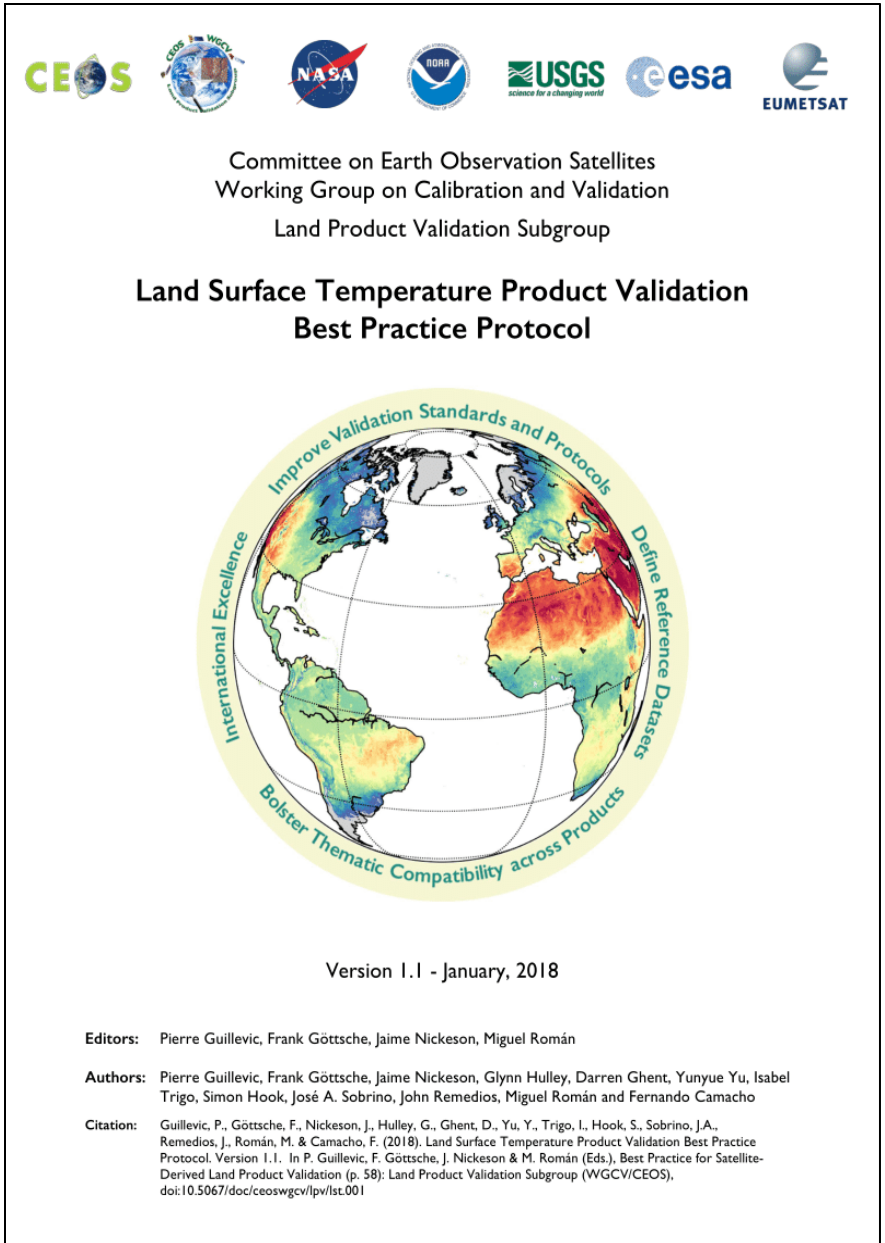
- Spatial representativeness is key
- Sites should be homogeneous at a scale of <u>at least</u> 3x3 satellite pixels

Before the harvest

After the harvest

Bondville SURFRAD site measures different proportions of vegetation depending on time of year making it unsuitable for LST validation

LST validation good practices


Committee on Earth Observation Satellites
Working Group on Calibration and Validation
Land Product Validation Subgroup

Land Surface Temperature Product Validation
Best Practice Protocol

Version 1.1 - January, 2018

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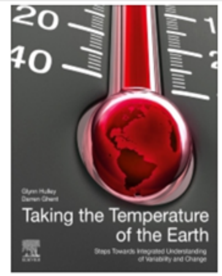

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