ECOSTRESS

Level-2 Land Surface Temperature and Emissivity Product Status

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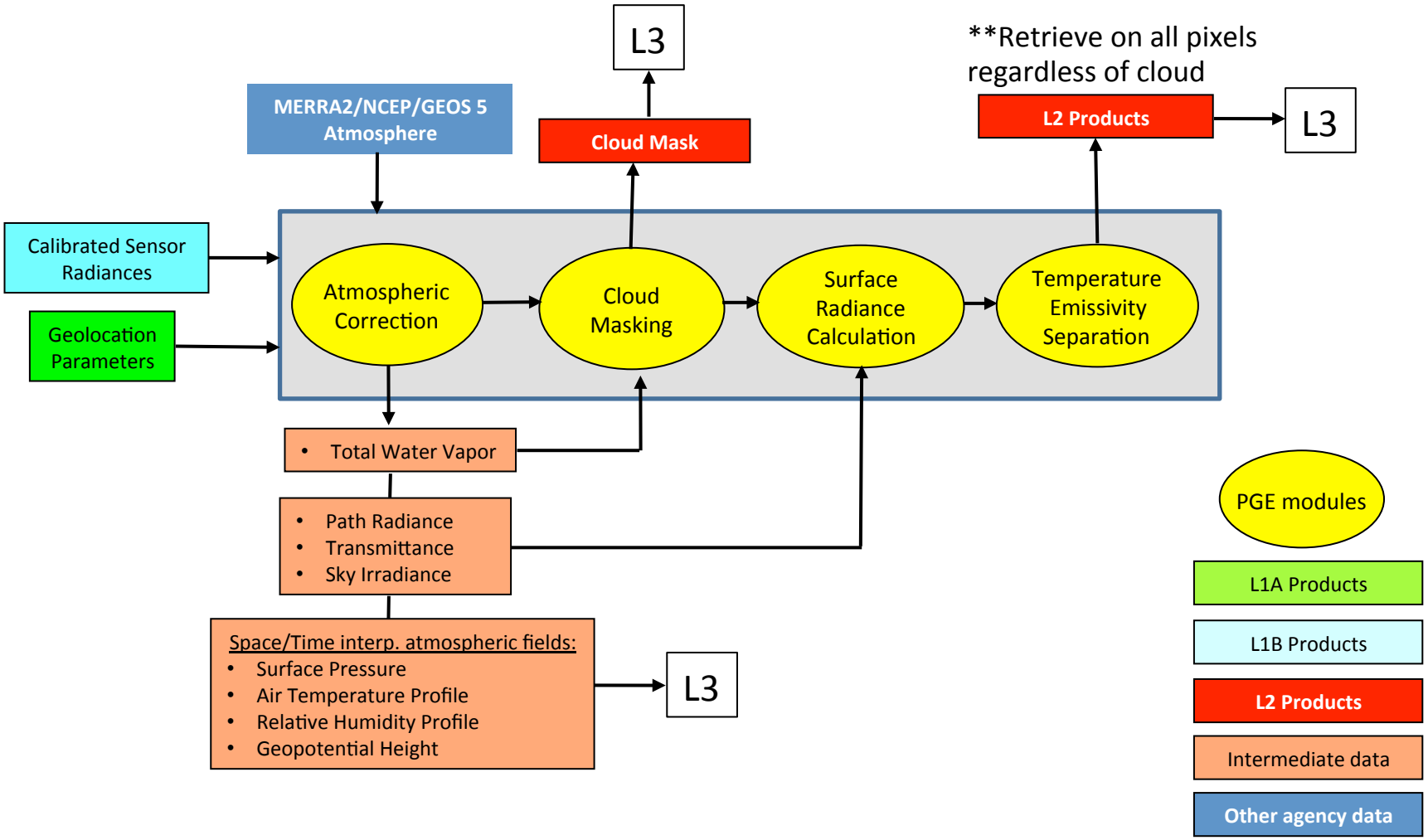
Outline

1. Level-2 Products
2. Level-2 Algorithm and Status
3. Band 4 shift uncertainty analysis
4. GEOS-5 FP Implementation/Testing/Validation
5. Summary

Level-2 Flow Schematic



Code: C++

Timing: ~5 minutes for one ECOSTRESS granule (~25 million pixels)

Runconfig: Multiple runtime options (cloud thresholds, atmospheric data, WVS model)

ECOSTRESS Level-2 Products

SDS	Long Name	Data type	Units	Valid Range	Fill Value	Scale Factor	Offse
Group	**L2 LSTE Data**						
LST	Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC	Quality control for LST and emissivity	uint16	n/a	0-65535	0	n/a	n/a
Emis1	Band 1 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis2	Band 2 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis3	Band 3 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis4	Band 4 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis5	Band 5 emissivity	uint8	n/a	1-255	0	0.002	0.49
LST_Err	Land Surface Temperature error	uint8	K	1-255	0	0.04	0.0
Emis1_Err	Band 1 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis2_Err	Band 2 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis3_Err	Band 3 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis4_Err	Band 4 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis5_Err	Band 5 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
EmisWB	Wideband emissivity	uint8	n/a	1-255	0	0.002	0.49

LST Uncertainty Analysis

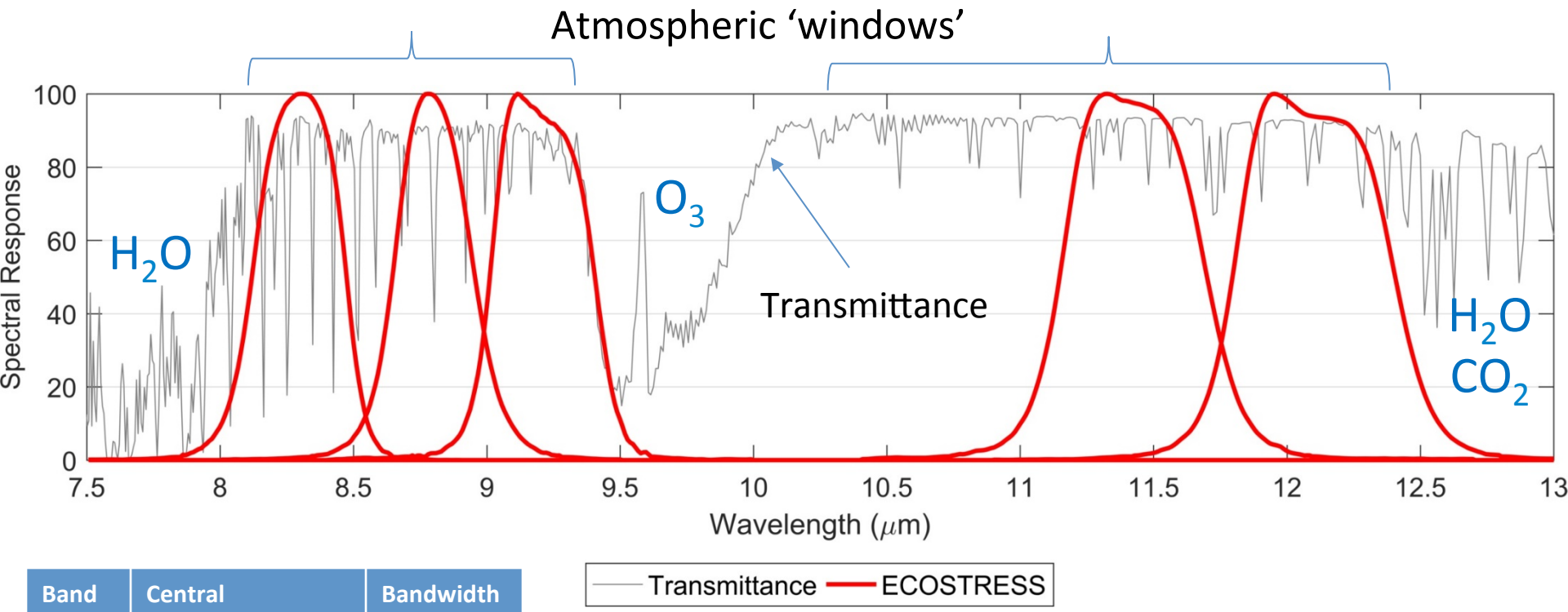
Hulley et al. 2012 (Uncertainty Analysis Study)			**LST Uncertainty (K)**	
Surface types	**Samples**	**MODTRAN Simulations**	**3-band TES**	**5-band TES**
Dense vegetation, Water, Ice, Snow	8	660,096	2.19	1.63
Rocks	48	3,960,576	1.44	1.45
Soils	45	3,713,040	0.89	0.91
Sands	10	825,120	1.12	0.99
Total	**111**	**9,158,832**	**1.49 K**	**1.13 K**

TES 5-band approach meets ~1 K accuracy capability for **ECOSTRESS** (Requirement is 2 K)

L2 Algorithm Status

LEVEL-2 TASK	Completion
Simulate L1/L2 Products (VIIRS, ASTER)	01-31-2016
L2 Documentation (ATBD, PSD)	02-23-2016
L2 Code conversion to C++	07-22-2016
Installation of necessary libraries, radiative transfer models, Ancillary data (ASTER)	07-25-2016
Metadata, uncertainties, cloud mask, error logs	07-29-2016
L2 code testing on simulated data	08-15-2016
Baseline L2 PGE with Process Control System (PCS)	09-30-2016
Incorporate NCEP atmospheric data (backup)	12-15-2016
Implement Water Vapor Scaling (WVS) Model	1-25-2016
Documentation (Cloud ATBD, ASD, User Guide)	Ongoing
Cloud Mask evaluation/refinement	Ongoing
Test and implement GEOS-5 FP atmospheric data	Ongoing
Update algorithm coefficients/data for band 4 spectral shift	Ongoing

Spectral Response Functions
(best estimate as of 8.25.2016)

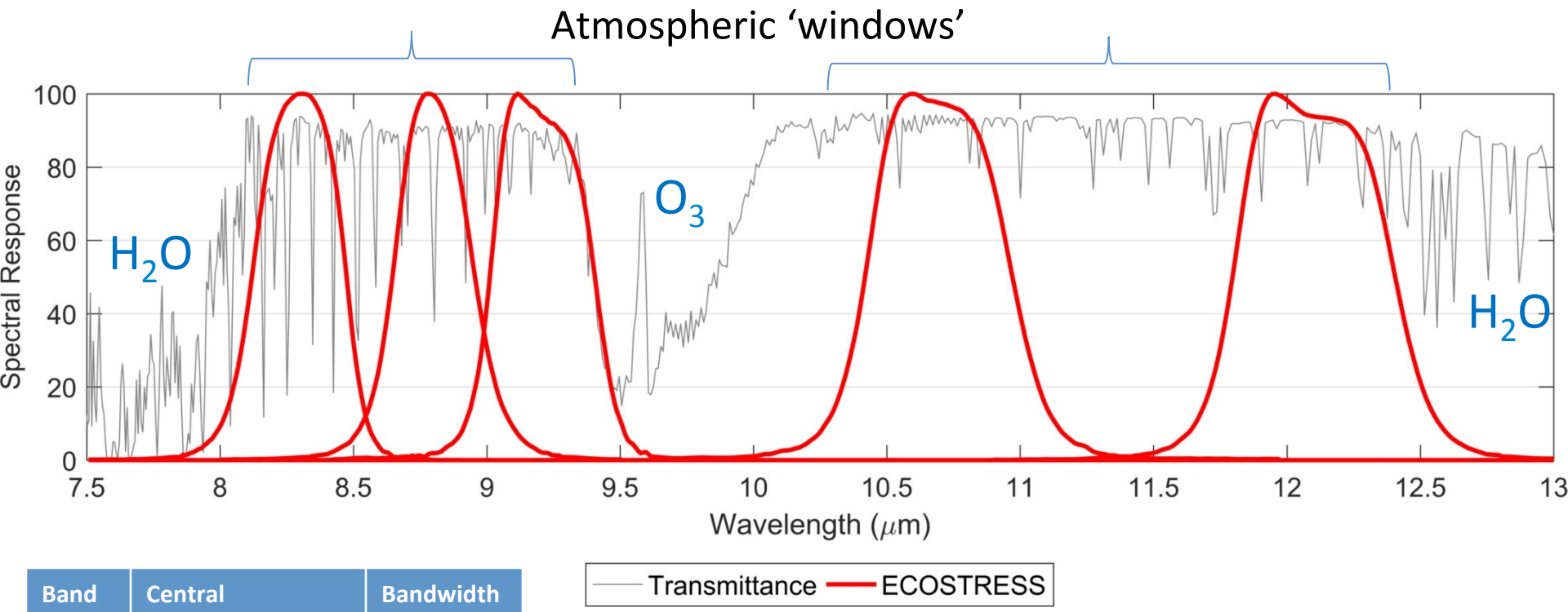


Band	Central Wavelength (μm)	Bandwidth (μm)
1	8.29	0.355
2	8.80	0.309
3	9.20	0.395
4	11.41 (10.6)	0.553
5	12.09	0.610

<u>SRF algorithmic dependencies</u>:

- Emissivity calibration curve
- Brightness temperature LUT's
- Radiance conversion LUT's
- RT model coefficient files
- Uncertainty estimates

Spectral Response Functions
(Expected shift 05.2017)



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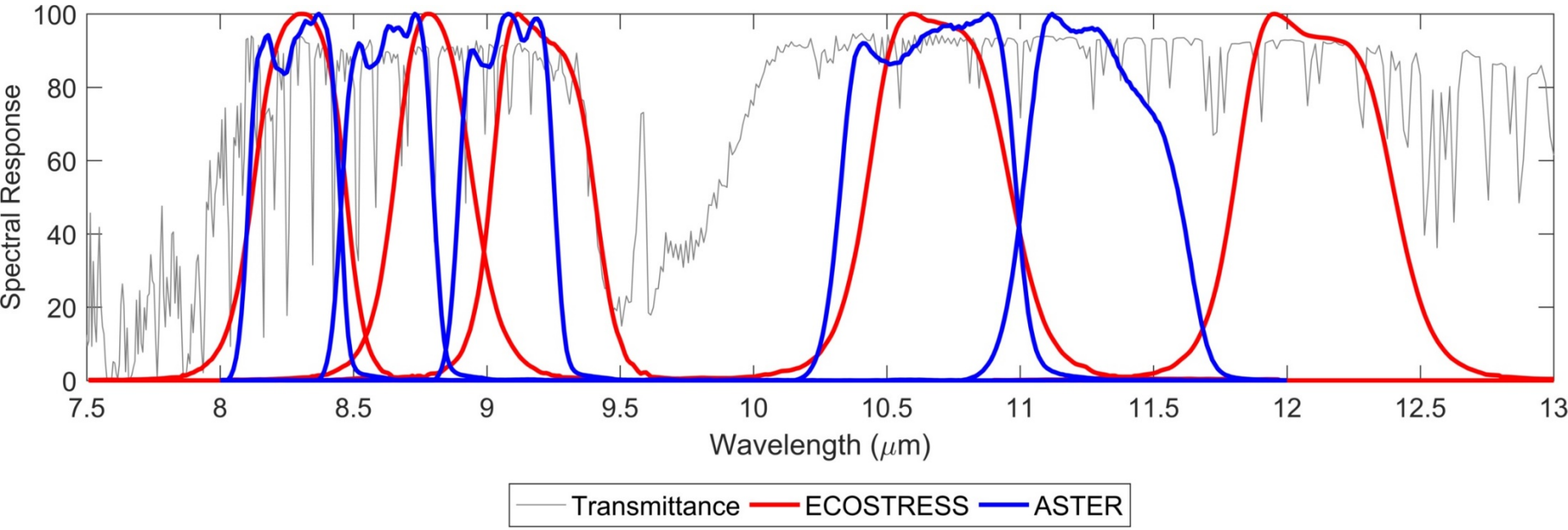
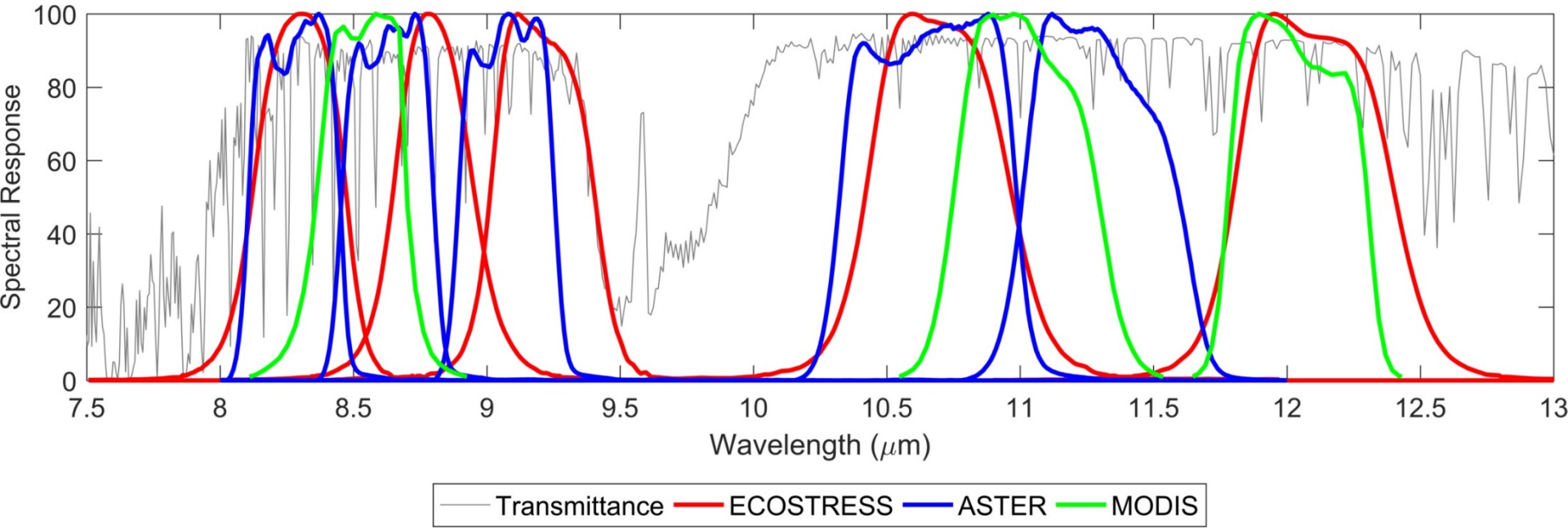
Spectral Response Functions



Spectral Response Functions



TES Algorithm performance with Band 4 shift

- MODTRAN Radiance Simulations
- ECOSTRESS TES algorithm
- Global Radiosonde profiles (SeeBor)
- ASTER spectral library for emissivity

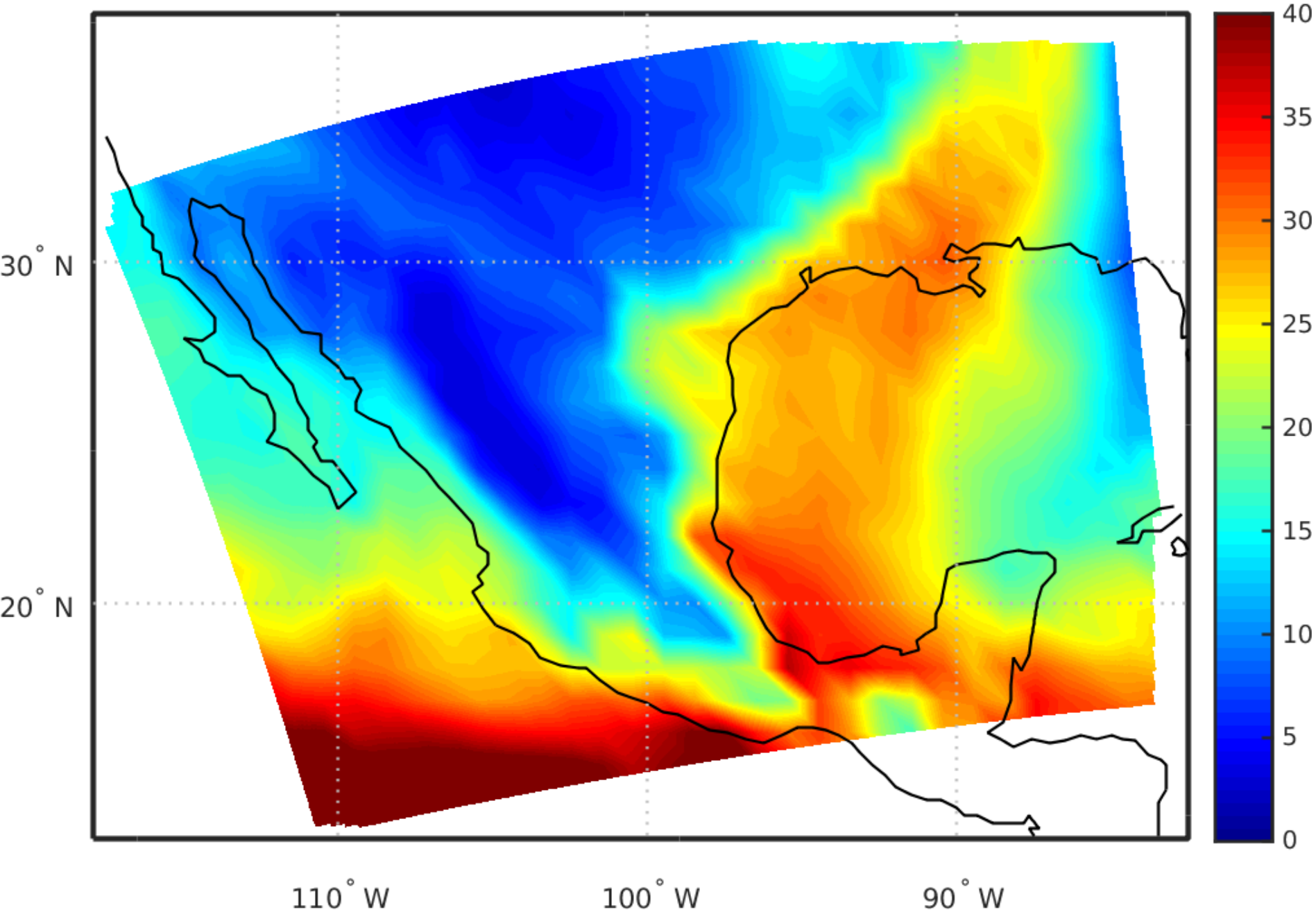
	LST RMSE	
Surface types	**V1***	**V2* (band 4 shift)**
Graybody (Veg, Water, Snow)	0.555 K	0.542 K
Barren (sands, soils, rocks)	0.974 K	0.958 K
Total	**0.79 K**	**0.78 K**

* V1 = ECOSTRESS spectral response from best estimate 08/25/16
V2 = ECOSTRESS V1 with simulated band 4 shift from 11.2 to 10.6 micron

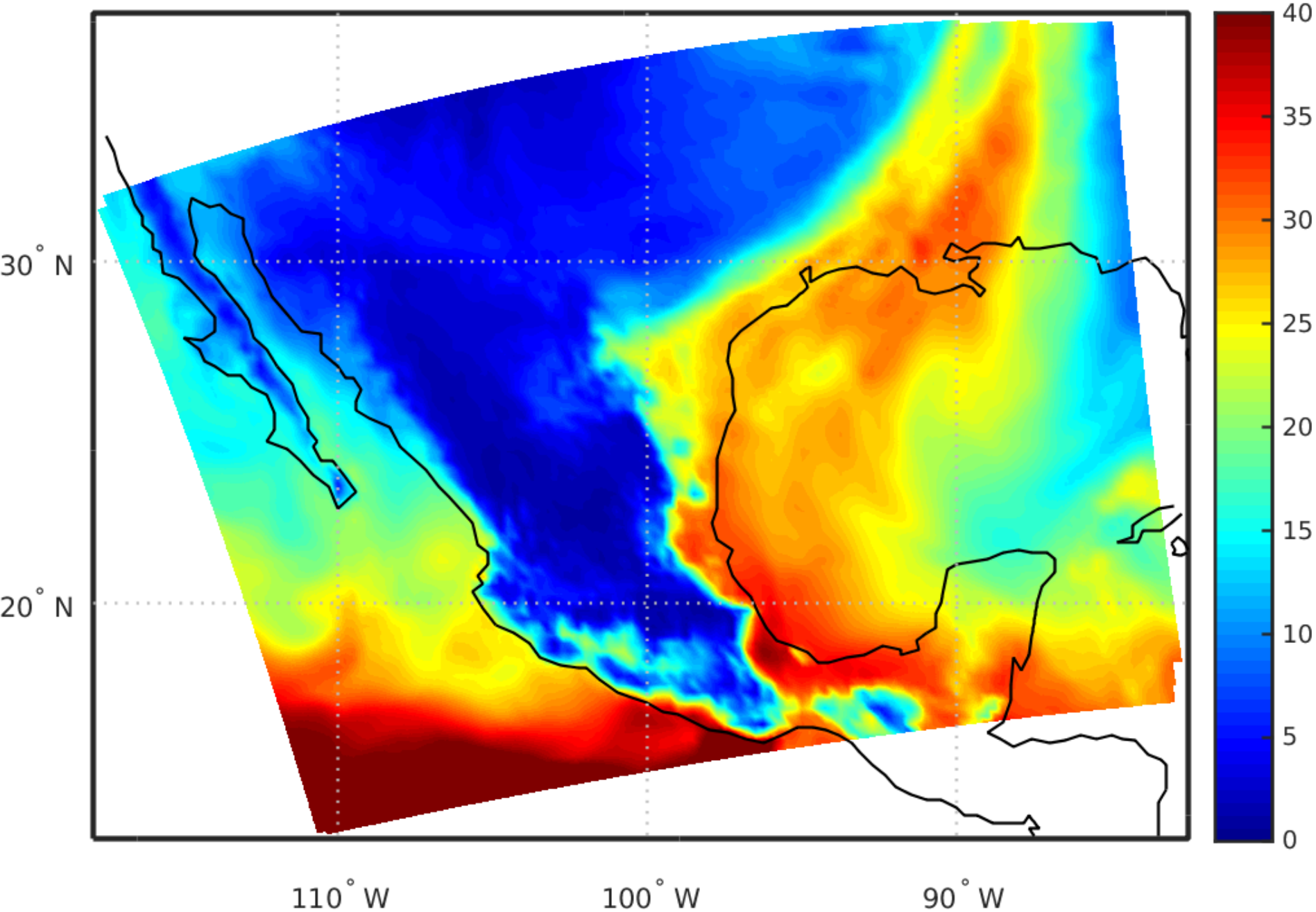
Numerical Weather Prediction (NWP) Models used for ECOSTRESS Atmospheric correction

	NCEP GDAS	MERRA-2	GEOS-5 FP
Description	Reanalysis from 1979-present	Reanalysis from 1979-present	Analyses and forecasts in near real-time using recent GEOS-5 model
Spatial Resolution	1.0 degree (~100 km)	0.5 degree (~50 km)	0.25 degree (~25 km)
Temporal Resolution	6 hourly	6 hourly	3 hourly
Vertical Resolution	26 pressure levels	42 pressure levels	42 pressure levels
Latency	Daily	1 month	Daily

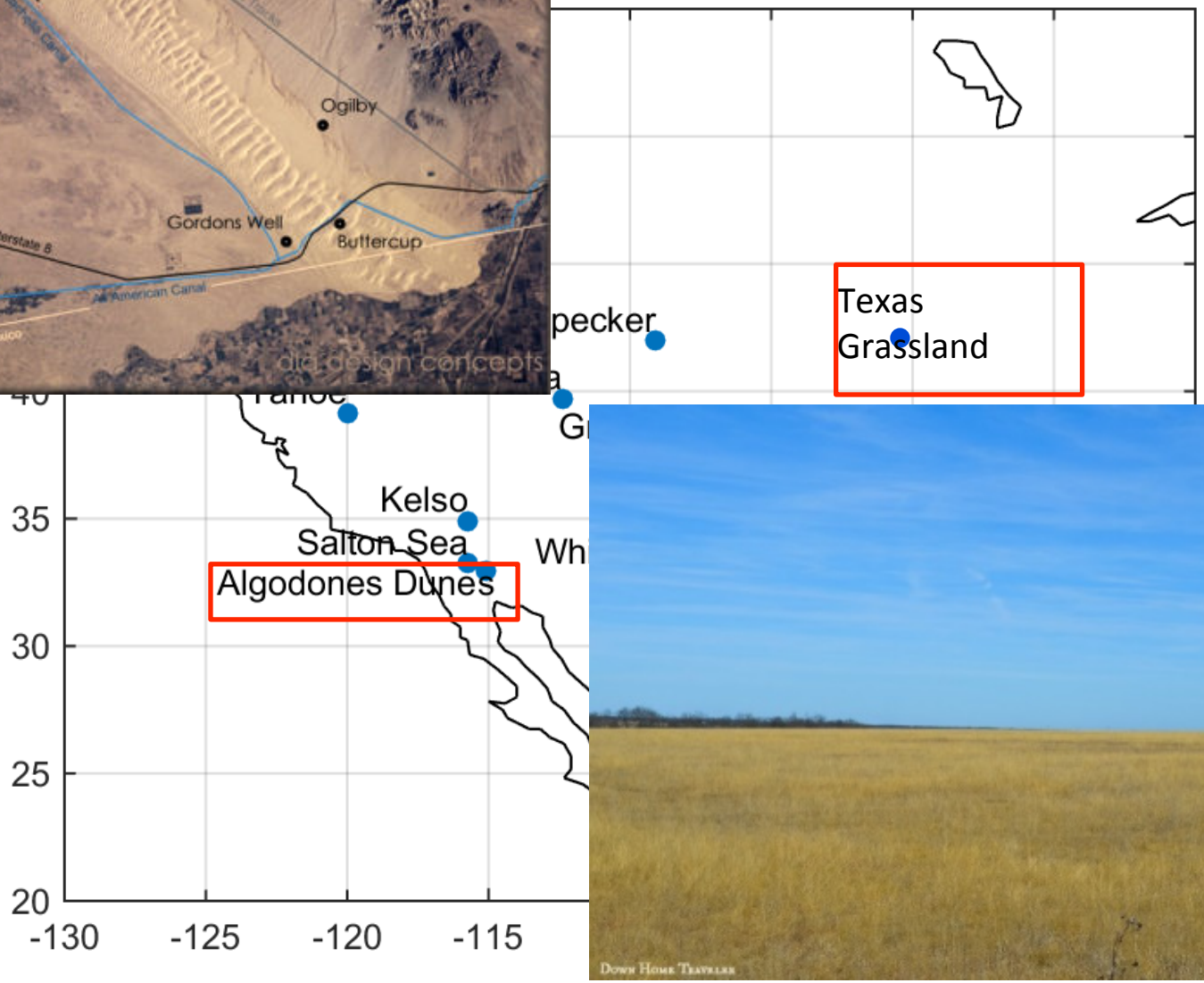
MERRA-2 Total Water Vapor (mm) 0.5x0.625 deg (~50 km)

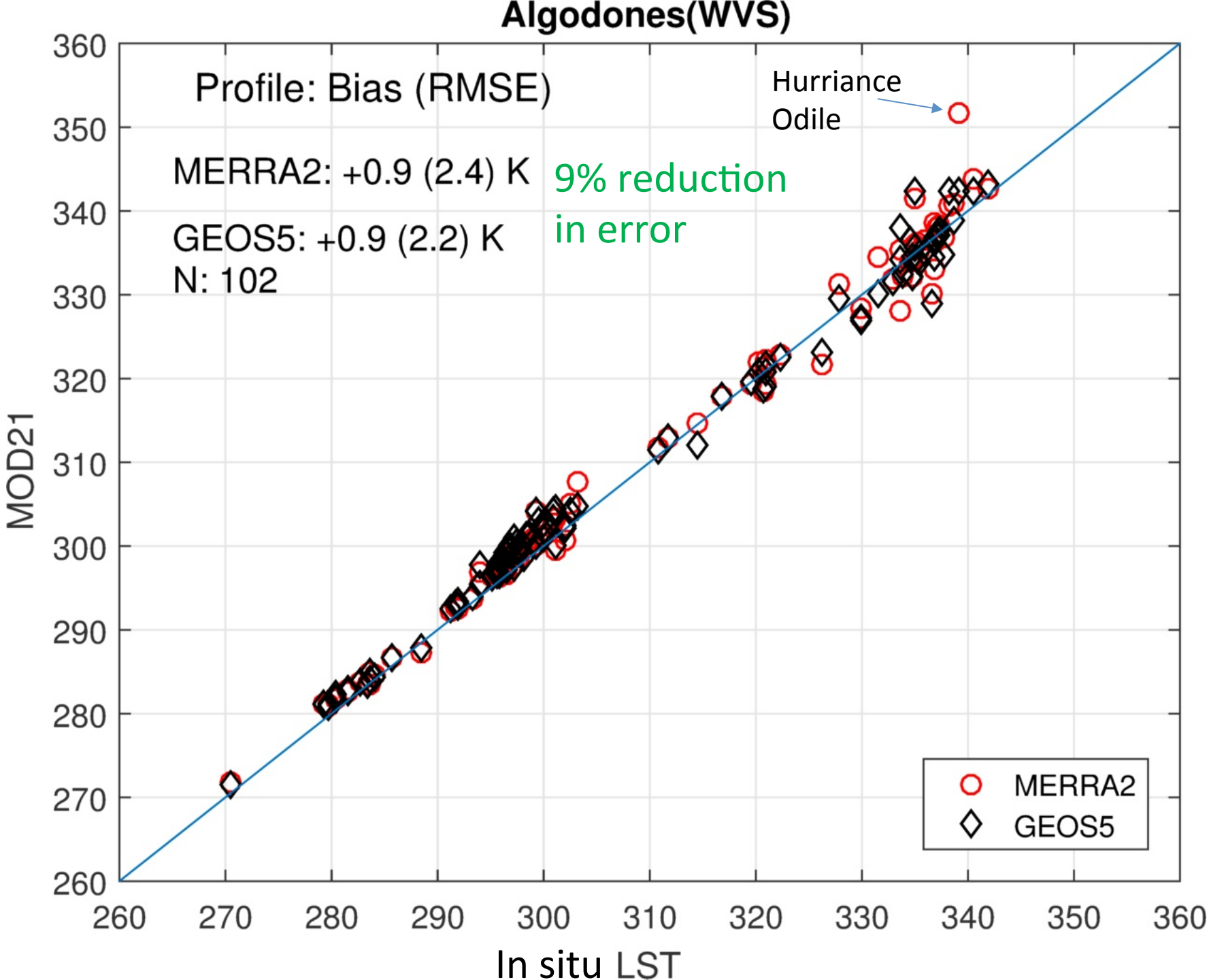


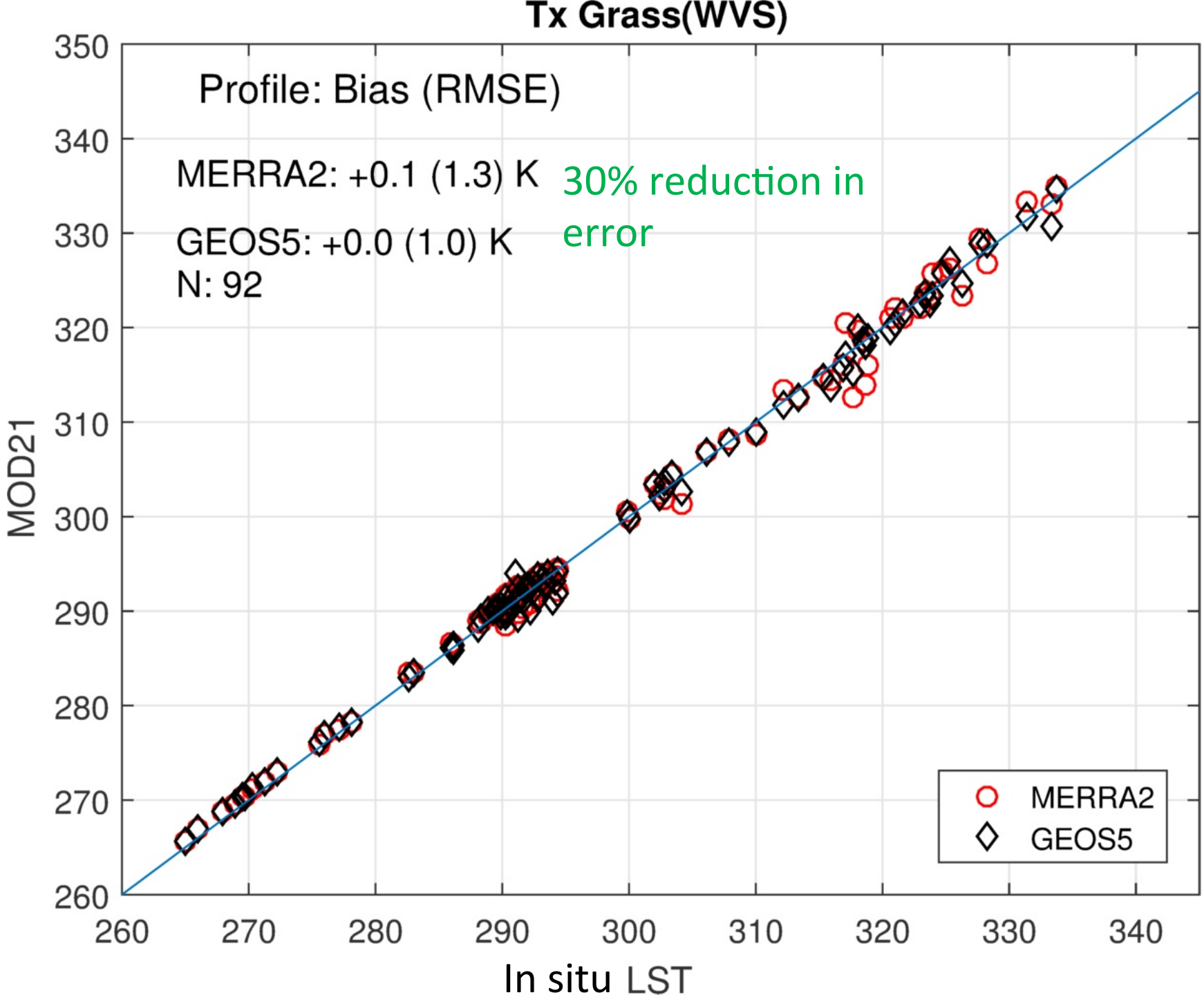
GEOS5-FP Total Water Vapor (mm) 0.25 deg (~25 km)



Sites (Stage 1, ‘Testing’)




Algodones(WVS)
Profile: Bias (RMSE)
MERRA2: +0.9 (2.4) K
GEOS5: +0.9 (2.2) K
N: 102
9% reduction
in error
Hurriance
Odile
MERRA2
GEOS5
MOD21
In situ LST
260
270
280
290
300
310
320
330
340
350
360


Tx Grass(WVS)
Profile: Bias (RMSE)
MERRA2: +0.1 (1.3) K
GEOS5: +0.0 (1.0) K
N: 92
30% reduction in error
MERRA2
GEOS5
MOD21
In situ LST
350
340
330
320
310
300
290
280
270
260
260
270
280
290
300
310
320
330
340

Summary

- ECOSTRESS L2 Products:
  - Land Surface Temperature (LST)
  - Spectral Emissivity (5 bands)
  - Broadband Emissivity
  - Cloud Mask
- Well defined and strong algorithm heritage (ASTER/MODIS/VIIRS/MASTER)
- L2 C code tested and baselined in SDS
- Band 4 shift has no effect on L2 accuracy
- Using higher resolution GEOS5-FP results in 10-30% higher accuracy of retrieved LST

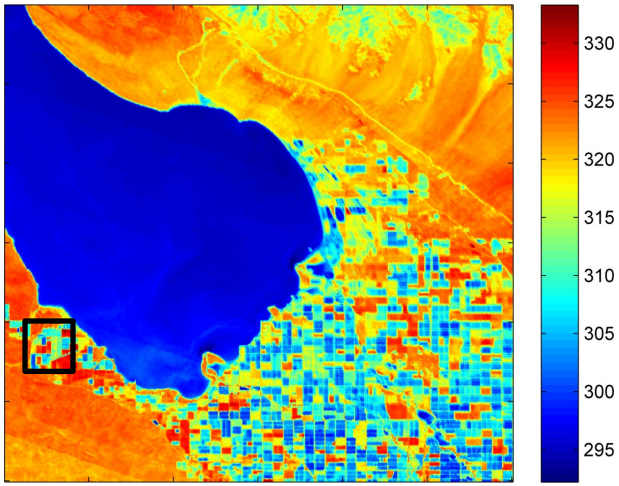
Cloud Mask Output

- 8-bit product

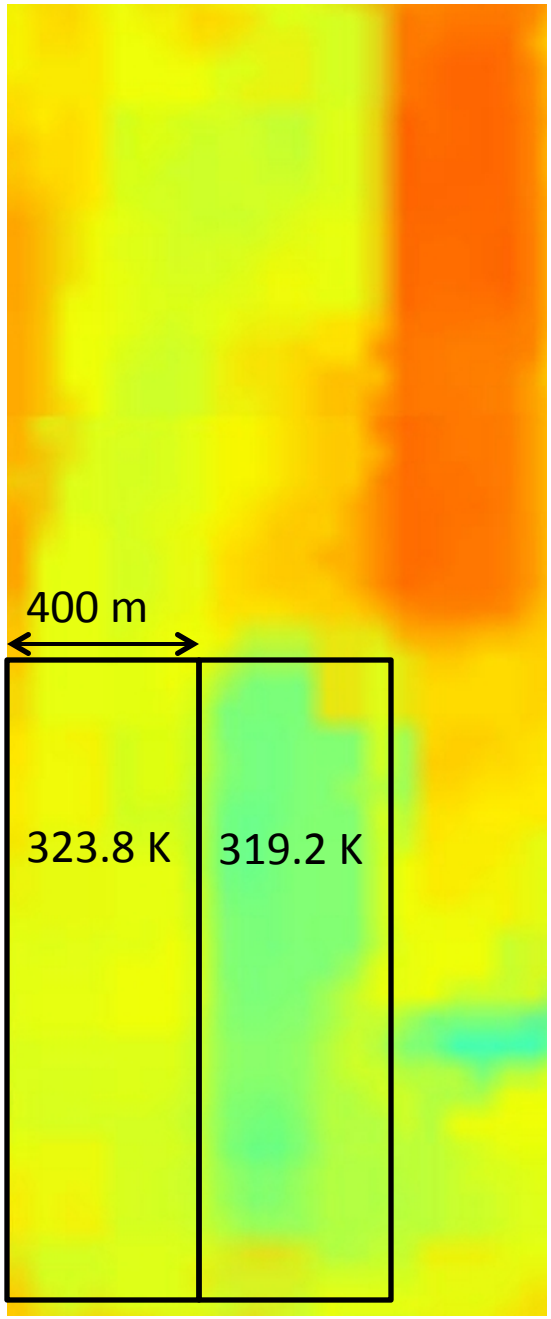
Bits	Long Name	Description
0	Cloud mask flag	0 = determined 1 = not determined
1	Cloud	0 = no 1 = yes
2	Cloud extended	0 = no 1 = yes
3	BTdiff test	0 = no 1 = yes Careful consideration of land surface emissivity required
4	VSWIR test	0 = no 1 = yes Uncalibrated band – dynamic threshold required per scene
5	BT11 test	0 = no 1 = yes May overestimate over most land surfaces
6	spare	
7	spare	

Table 3. 8 bit Level 2 Cloud Mask Product.

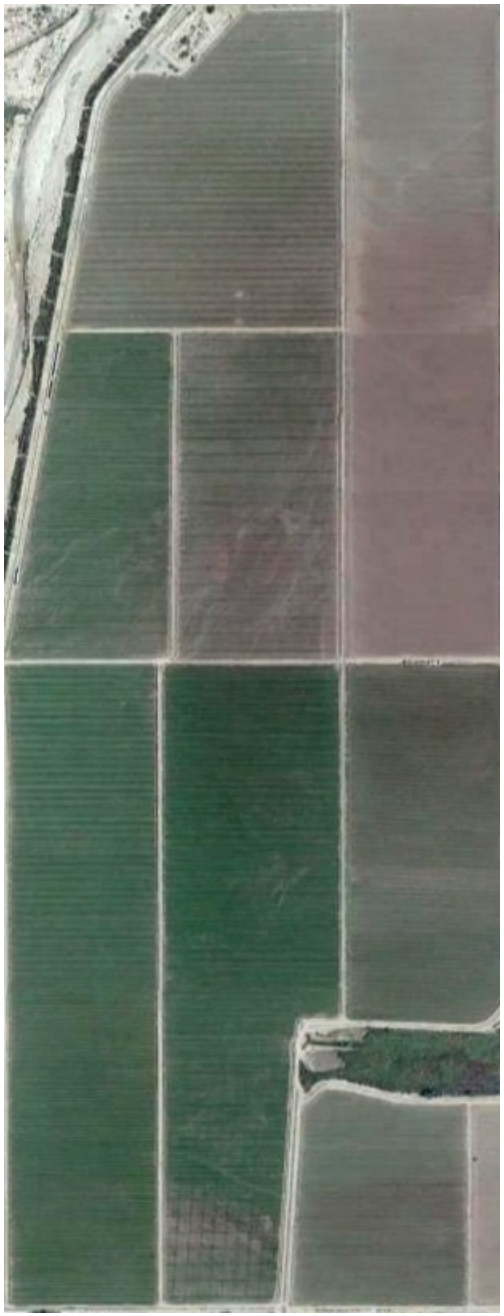
ECOSTRESS Simulated LST - 67m



MASTER LST: 08/26/2014



Google Earth: 08/28/14



1. **Signatures of vegetation stress are manifested in the LST signal *before* any visible deterioration of vegetation cover occurs.**

2. **The surface moisture state can be *deduced directly* from the remotely sensed LST.**

Theoretical Basis: Surface Temperature

Radiometric ('Brightness') Temperature

$$T_\lambda(\theta) = B_\lambda^{-1}\left(L_\lambda(\theta)\right)$$

Land Surface ('Skin') Temperature (LST)

$$T_s = B_\lambda^{-1}\left(\frac{L_\lambda(\theta) - \rho_\lambda L^{\downarrow}}{\varepsilon_\lambda}\right)$$

where:

B_λ = blackbody spectral radiance

λ = wavelength

T_s = Surface Temperature

$T_\lambda(\theta)$ = Surface Brightness Temperature

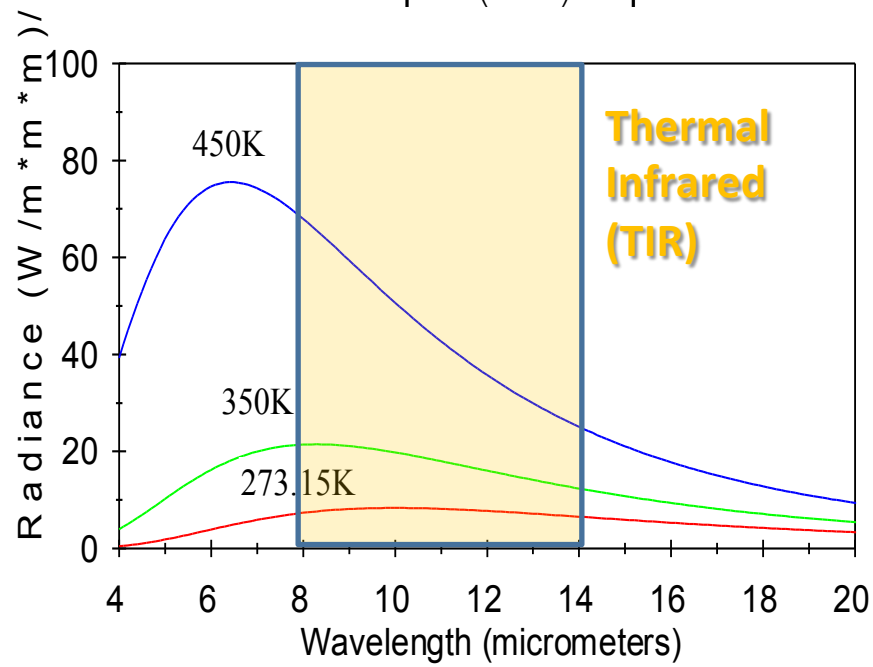
ρ_λ = Surface Reflection

$L^{\downarrow}$ = Downwelling Sky Irradiance

ε_λ = Emissivity

Planck Function

$$B_\lambda = \frac{c_1}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T_s}\right) - 1\right]}$$



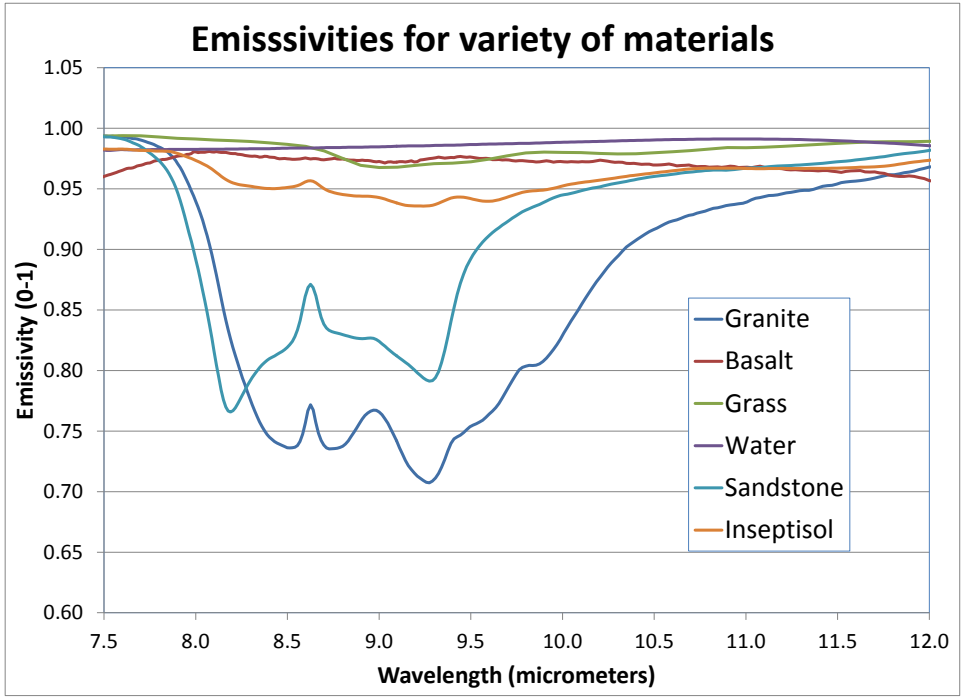
in the Planck function shifts to shorter and shorter wavelengths

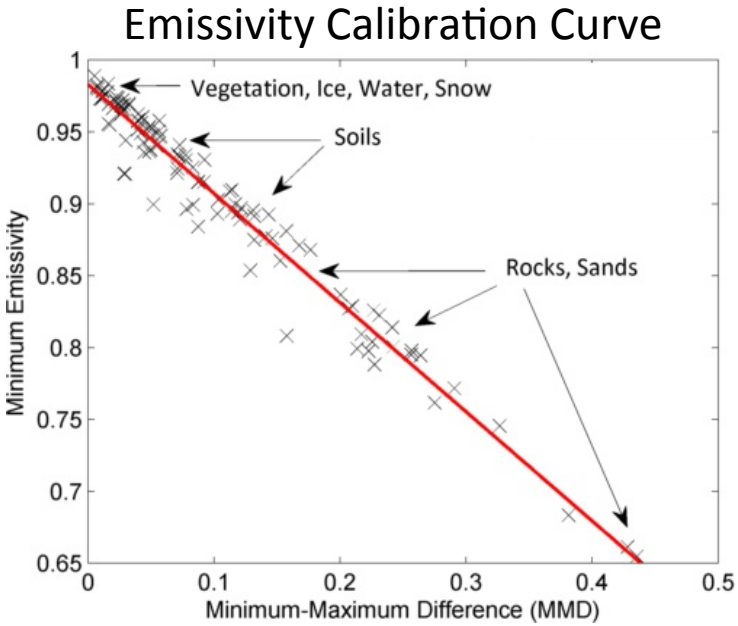
Temperature Emissivity Separation (TES) Algorithm 'ASTER approach'

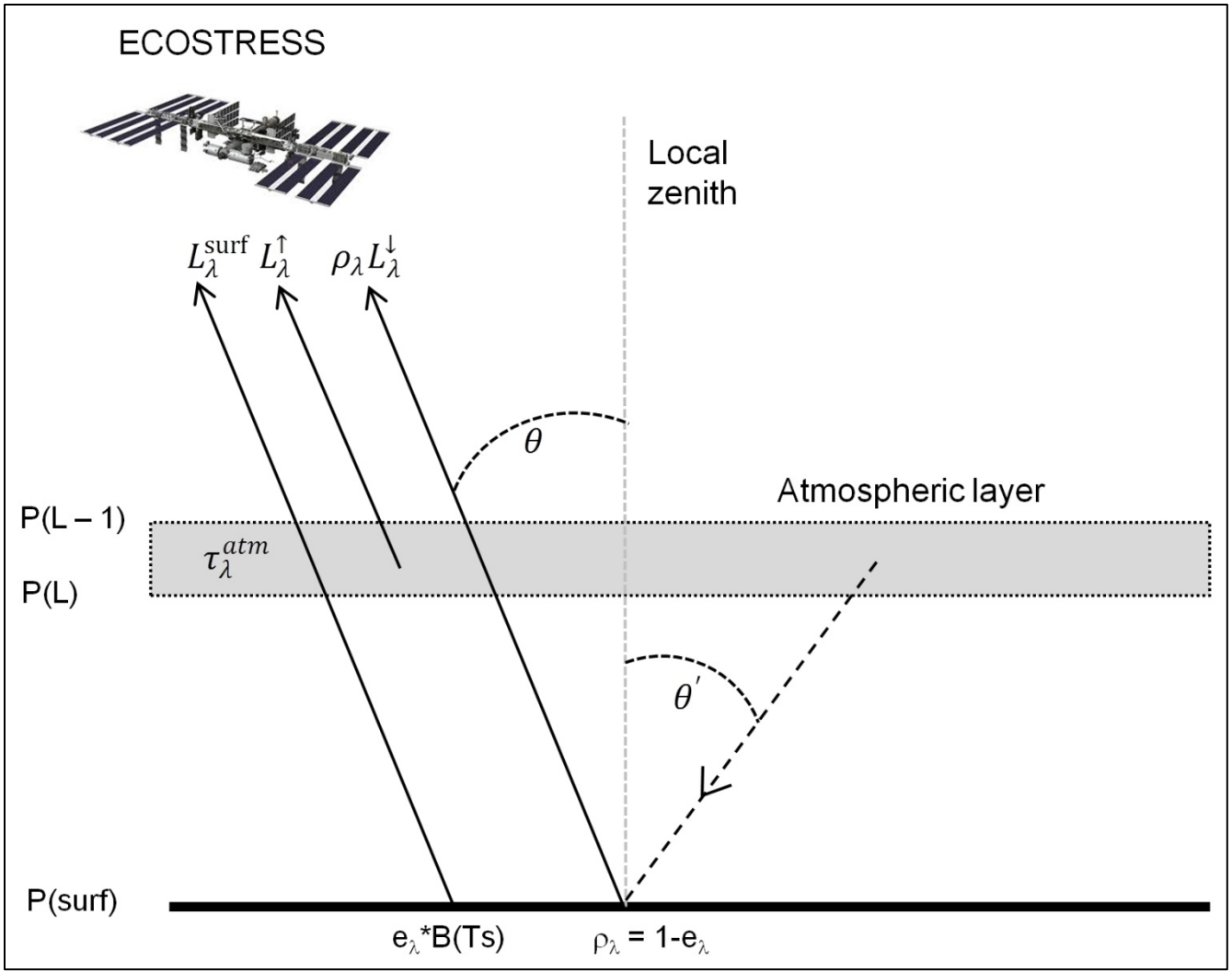
T-E separation is under-determined:

<u>If have N measurements, always have N+1 unknowns:</u>

Radiance Band 1 = T + emissivity_1
Radiance Band 2 = T + emissivity_2
Radiance Band 3 = T + emissivity_3
Radiance Band 4 = T + emissivity_4
Radiance Band 5 = T + emissivity_5





Iteratively solve for surface radiance + Temperature/Emissivity

$$L_\lambda(\theta) = \boxed{\tau_\lambda(\theta)}\left[L_\lambda^{surf} + (1-\varepsilon_\lambda)\boxed{\overline{L}_\lambda^{\downarrow}}\right] + \boxed{L_\lambda^{\uparrow}} \qquad L_\lambda^{surf} = \varepsilon_\lambda B(Ts)$$