ECOSTRESS

Level-2 Algorithm Status, Simulated Data, and Cloud Detection

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Collaborators:
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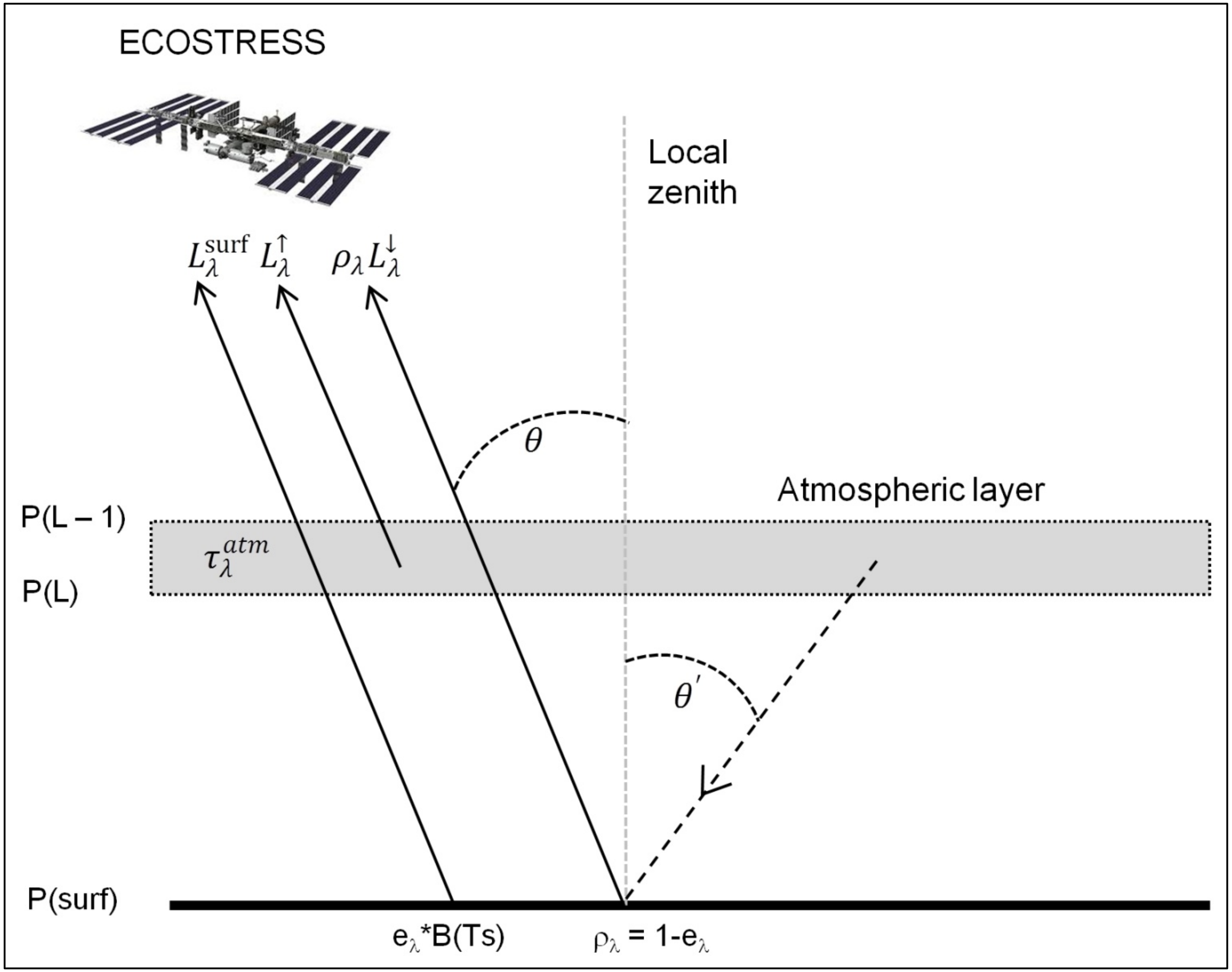
HyspIRI Science Workshop, Pasadena, CA, 18-20 October 2016

Outline

1. Level-2 algorithm status
2. Products
3. Simulated data
4. Cloud detection evaluation

Iteratively solve for surface radiance + Temperature/Emissivity

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



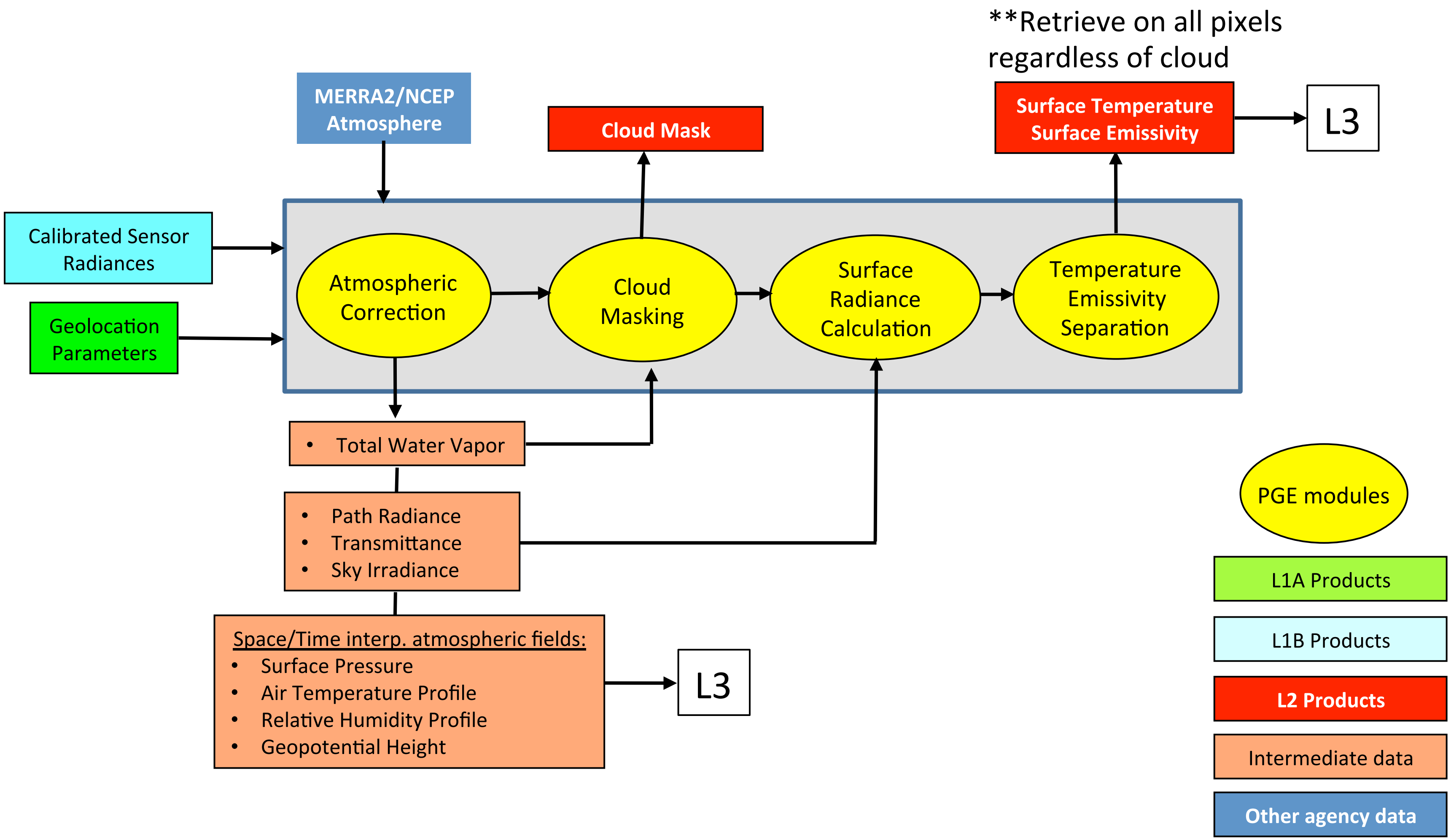
LST Uncertainty Analysis

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**

L2 error contributions = algorithm + measurement + atmosphere

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

Level-2 Flow Schematic



<u>Code:</u> C++ Unix system

<u>End-to-end timing:</u> ~3.5 minutes for one ECOSTRESS granule (~25 million pixels)

<u>Runconfig:</u> Multiple runtime options (cloud thresholds, atmospheric data, WVS model)

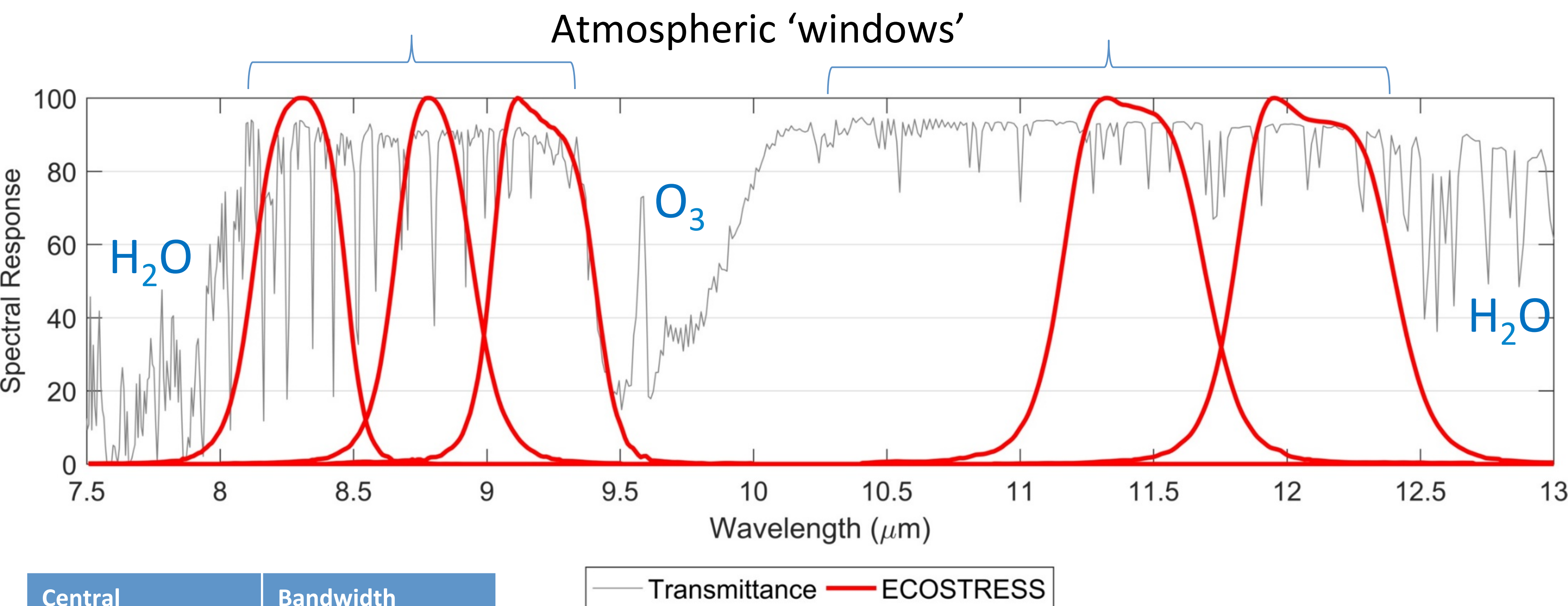
ECOSTRESS Level-2 TES Product

SDS	Long Name	Units
LST	Land Surface Temperature	K
Emissivity	Emissivity (bands 1 -5)	n/a
PWV	Precipitable Water Vapor (MERRA-2)	cm
QC	Quality Control	n/a
LSTerr	LST Uncertainty	K
Emis_err	Emissivity Uncertainty (bands 1 – 5)	n/a
Emis_bb	Broadband Emissivity	n/a

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 for MERRA2), ECMWF?	Ongoing
Implement Water Vapor Scaling (WVS) Model	Ongoing
Documentation (Cloud ATBD, ASD’s)	Ongoing
Cloud Mask evaluation/refinement	Ongoing

Spectral Response Functions
(best estimate as of 8.25.2016)

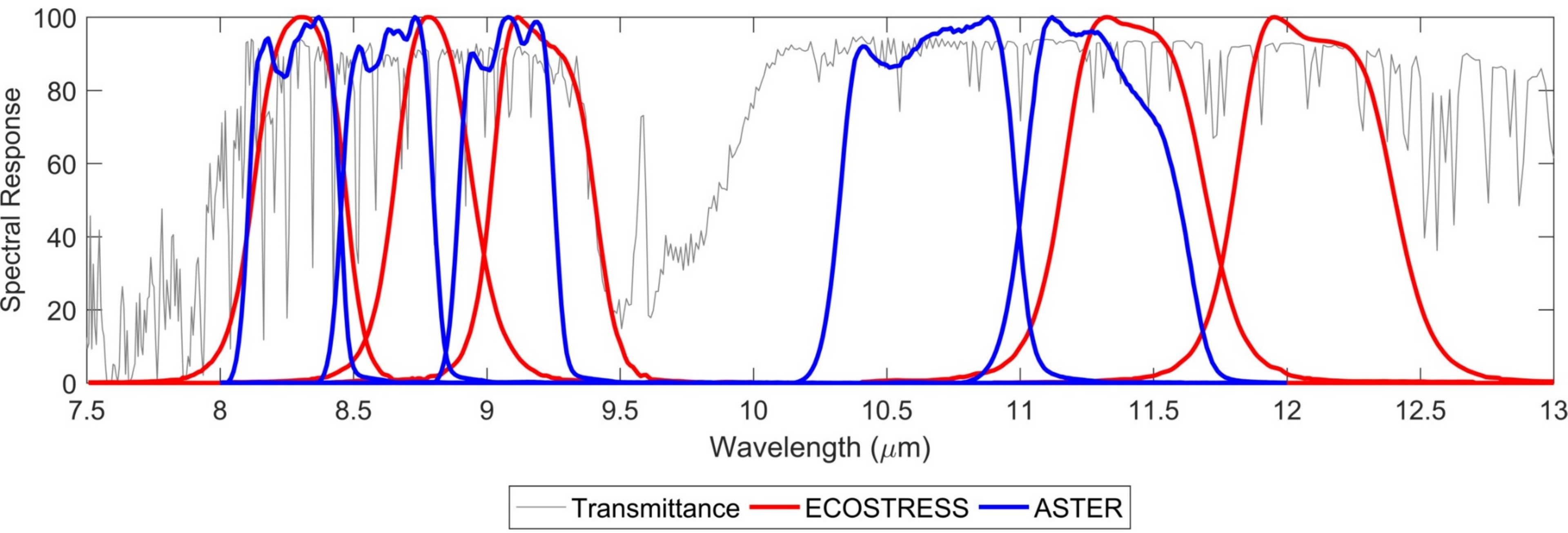


Central Wavelength (μm)	Bandwidth (μm)
8.29	0.355
8.80	0.309
9.20	0.395
11.41	0.553
12.09	0.610

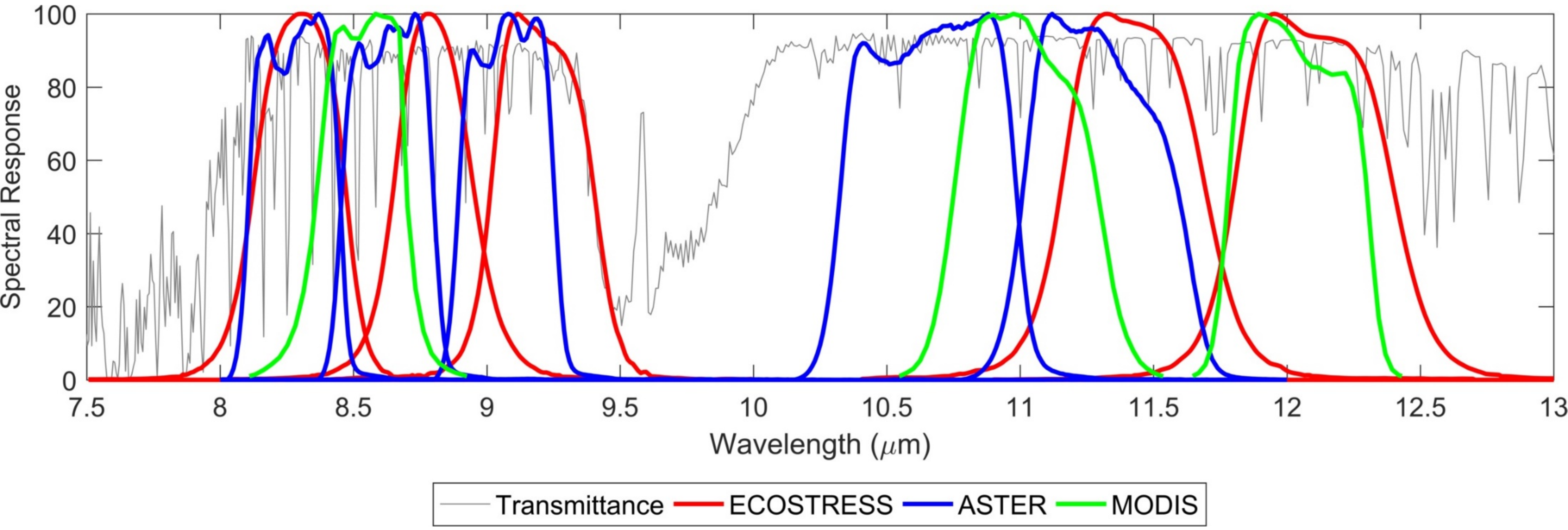
<u>SRF dependencies</u>:

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

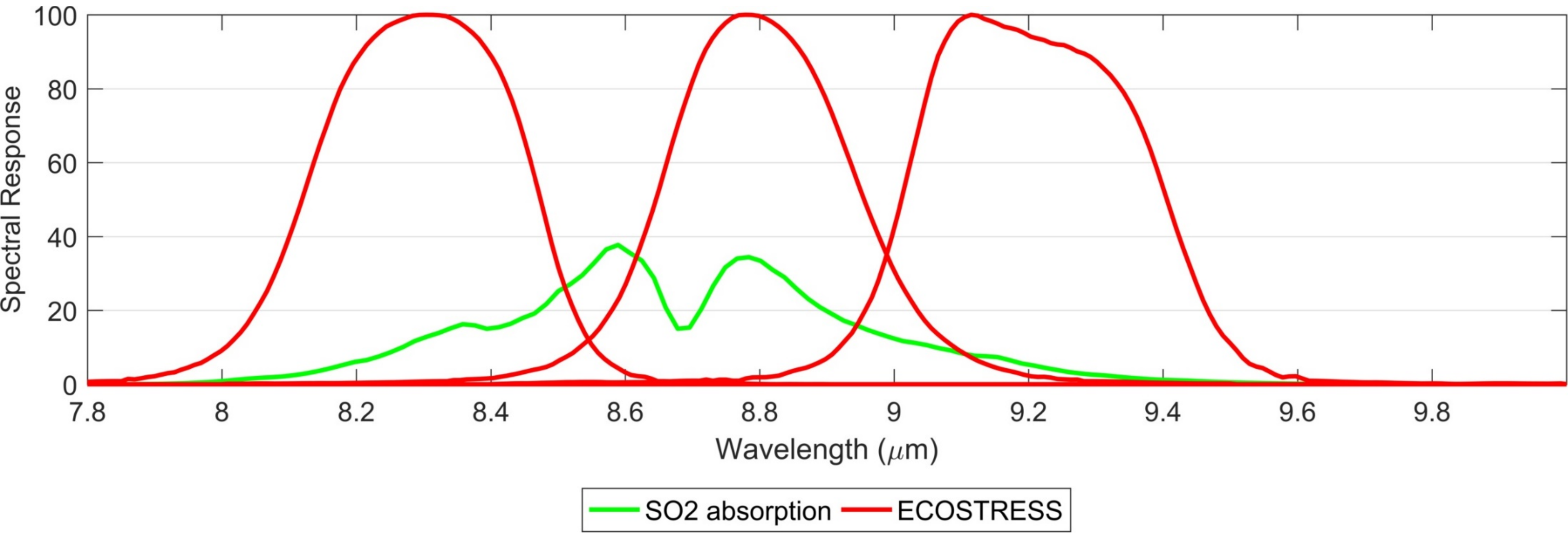
Spectral Response Functions
(best estimate as of 8.25.2016)



Spectral Response Functions
(best estimate as of 8.25.2016)

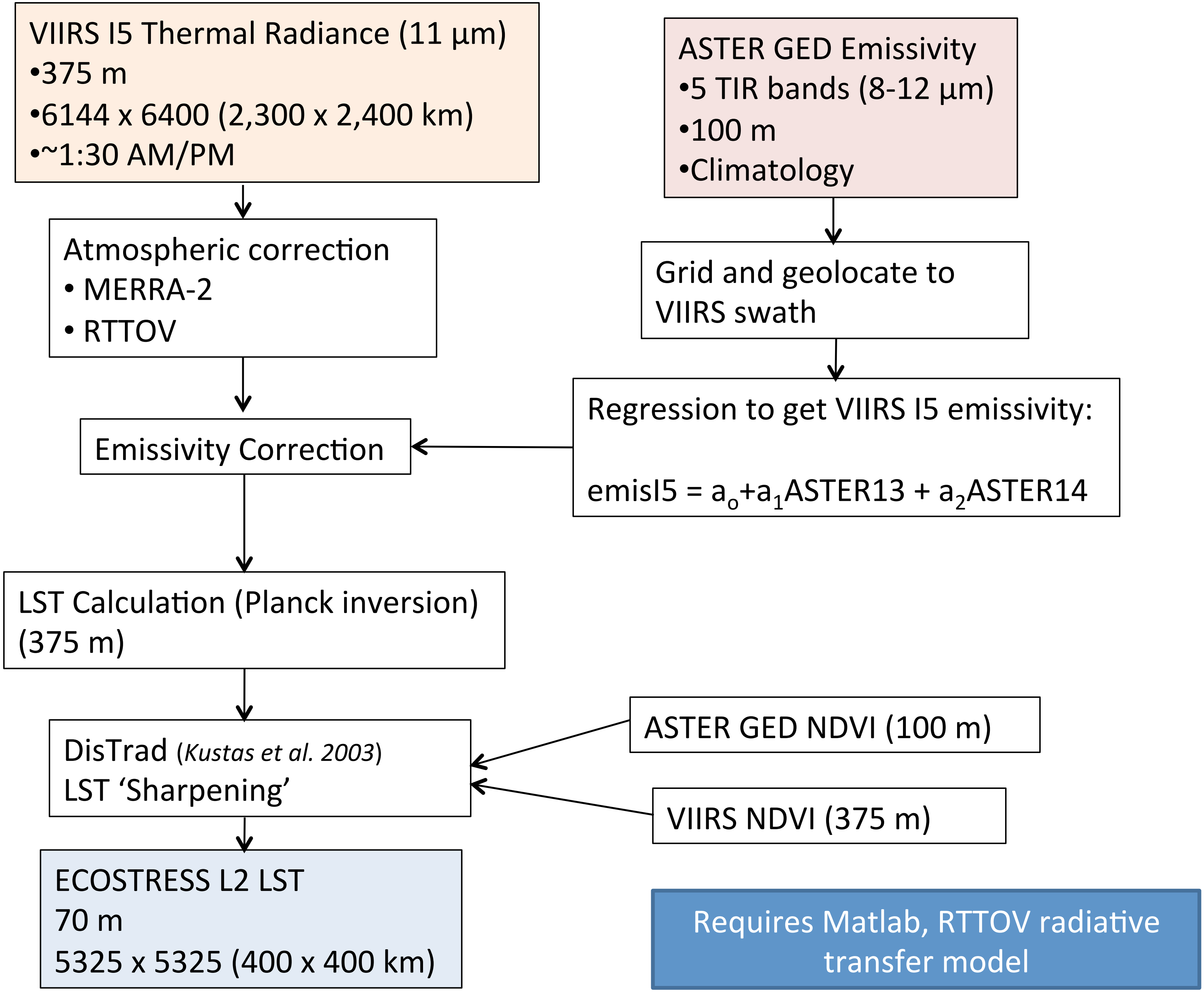


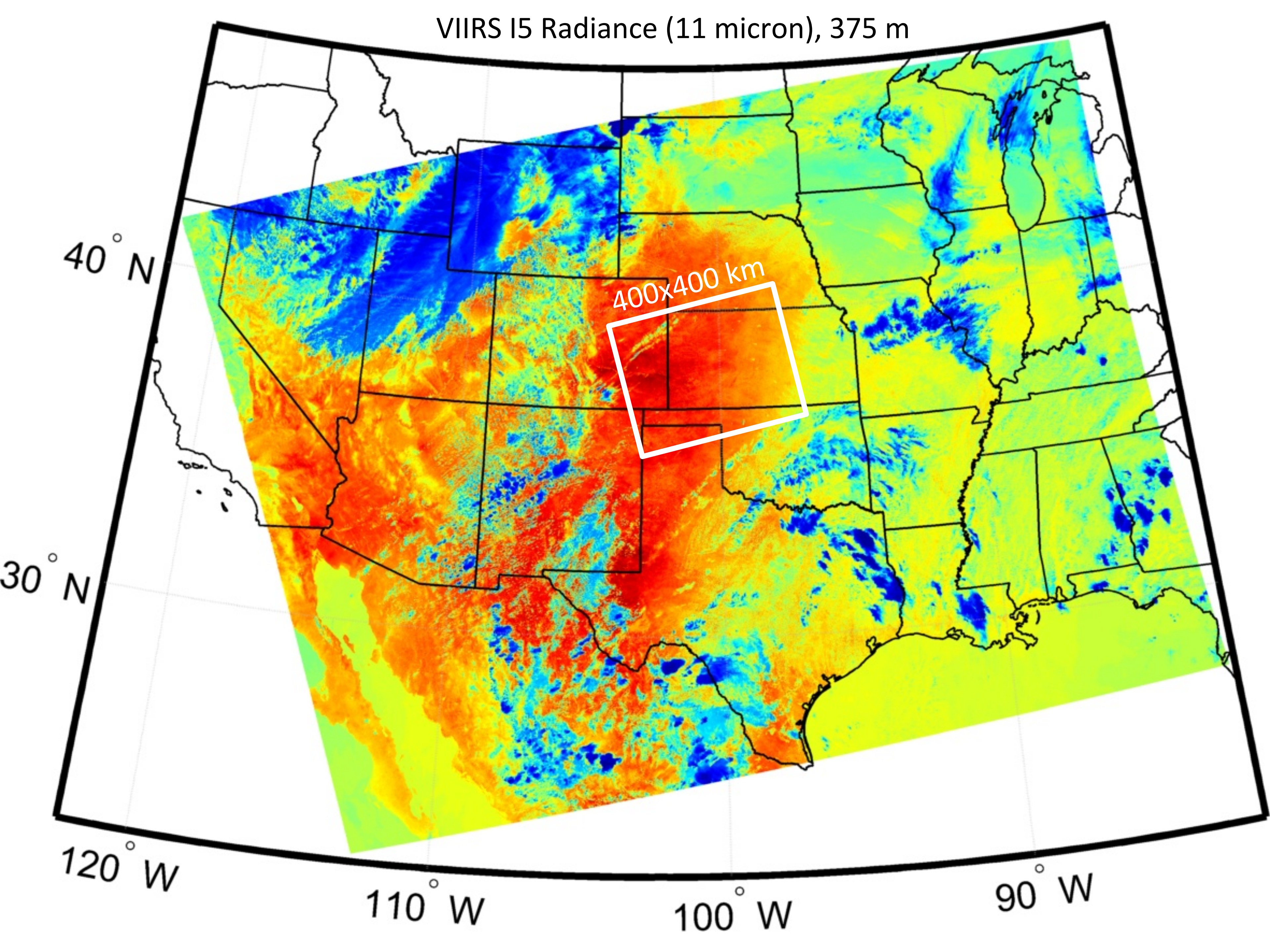
SO2 Detection



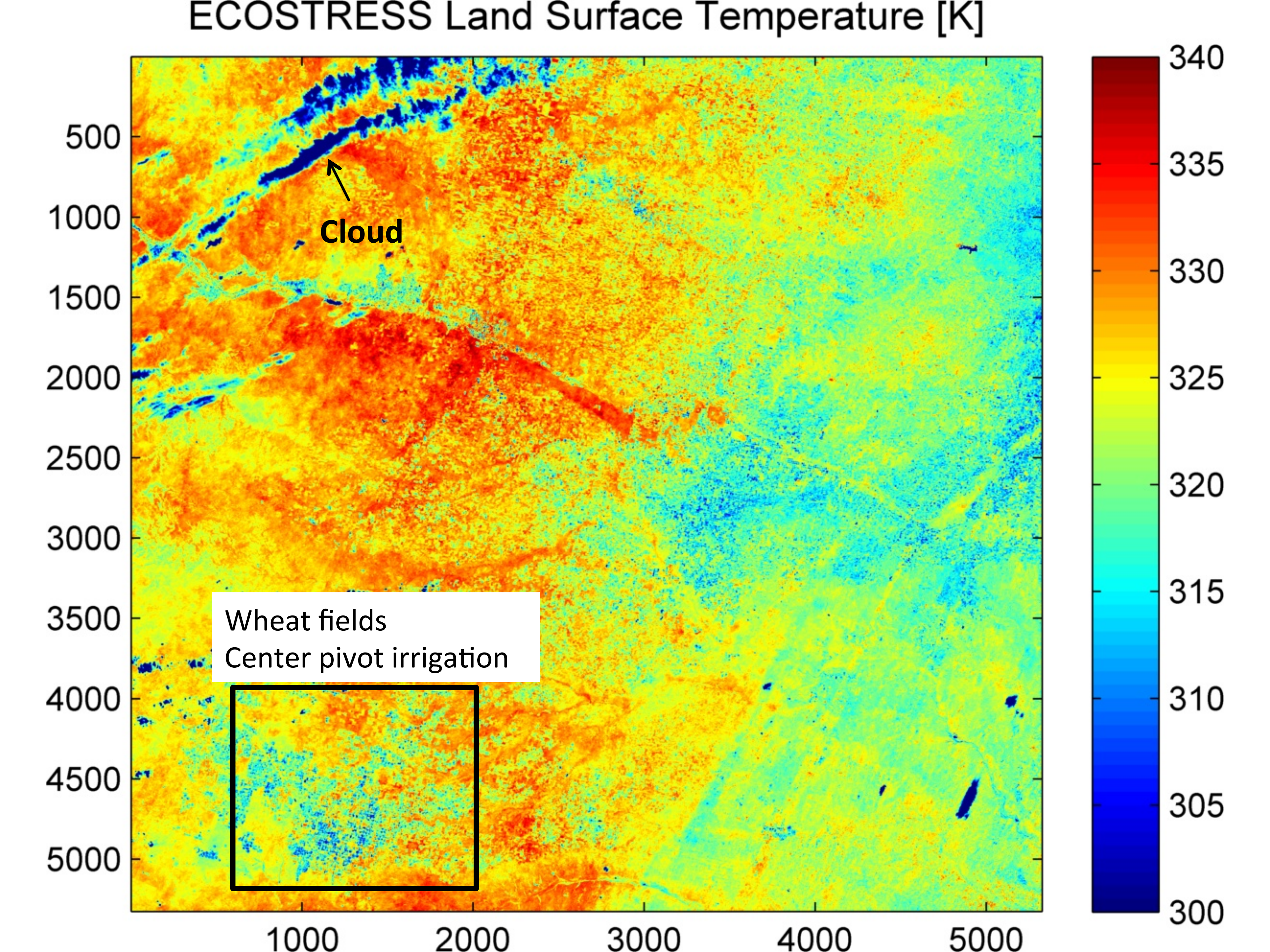
ECOSTRESS L2 Simulated Data

- Simulate L2 products at native ECOSTRESS resolution (~400x400 km swath, 70 m)
- VIIRS (375m) and ASTER (100m) thermal data
- L2 Simulated Data Workshop, July 2016
- Uses:
  - Forward calculate observed radiances (L1B)
  - Test production algorithms, timings, memory usage
  - Early adopters, e.g. NASA DEVELOP, Earth Uni, Costa Rica, UC Davis


VIIRS I5 Thermal Radiance (11 µm)
•375 m
•6144 x 6400 (2,300 x 2,400 km)
•~1:30 AM/PM
ASTER GED Emissivity
•5 TIR bands (8-12 µm)
•100 m
•Climatology
Atmospheric correction
• MERRA-2
• RTTOV
Grid and geolocate to VIIRS swath
Regression to get VIIRS I5 emissivity:
emisI5 = a_o+a_1ASTER13 + a_2ASTER14
Emissivity Correction
LST Calculation (Planck inversion) (375 m)
DisTrad (*Kustas et al. 2003*)
LST 'Sharpening'
ASTER GED NDVI (100 m)
VIIRS NDVI (375 m)
ECOSTRESS L2 LST
70 m
5325 x 5325 (400 x 400 km)
Requires Matlab, RTTOV radiative transfer model

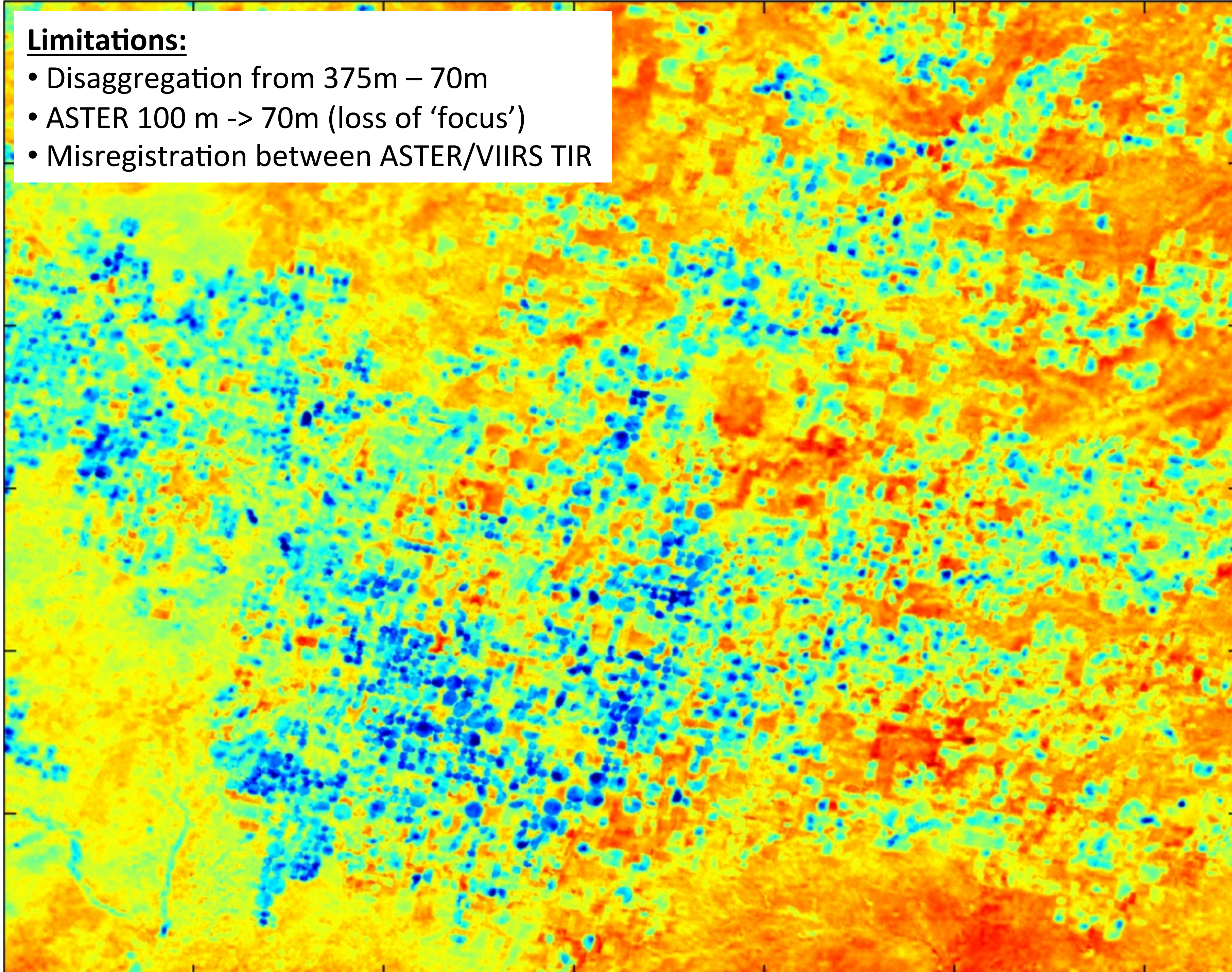


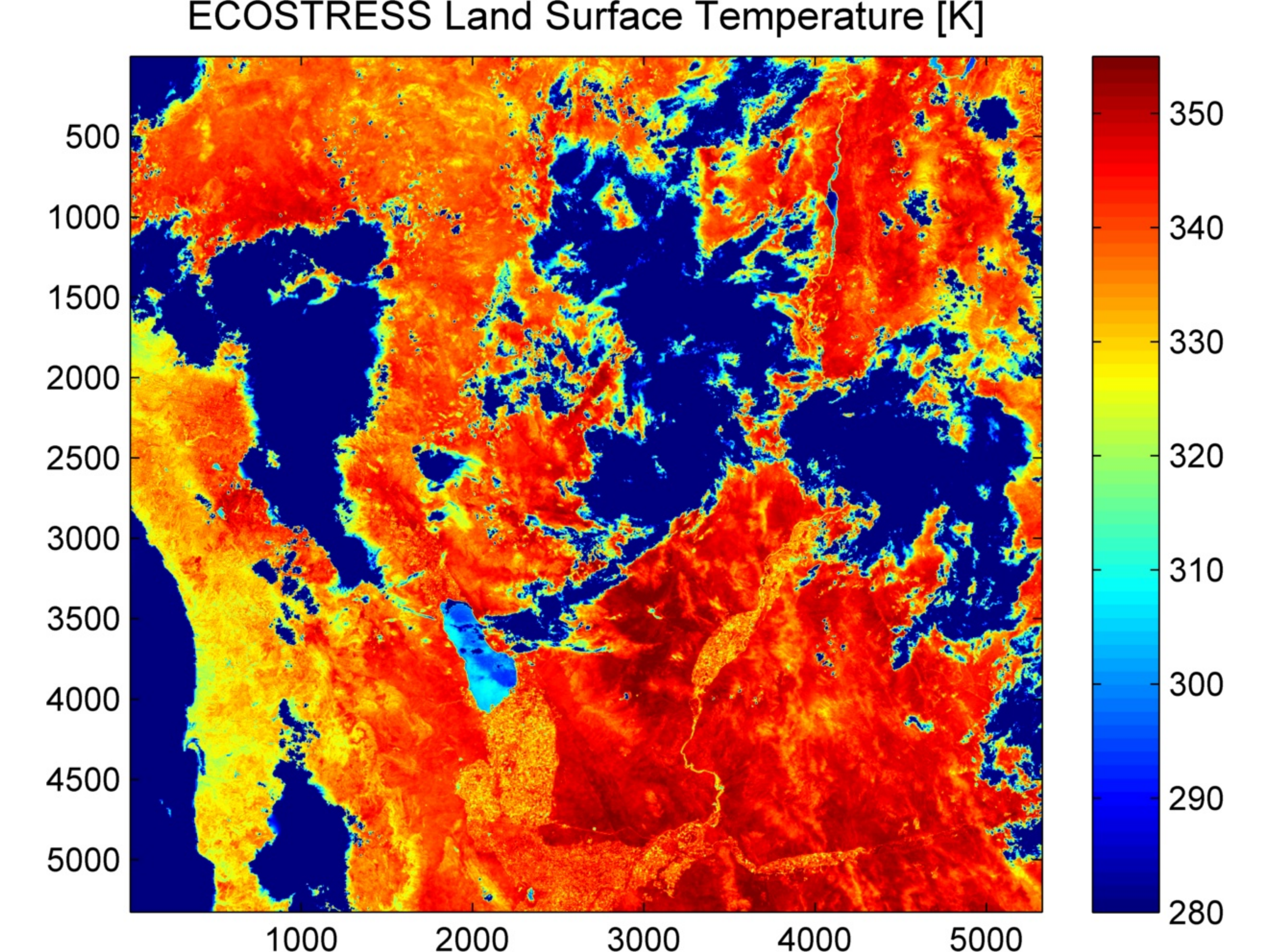
VIIRS I5 Radiance (11 micron), 375 m
400x400 km
40° N
30° N
120° W
110° W
100° W
90° W


ECOSTRESS Land Surface Temperature [K]
Cloud
Wheat fields
Center pivot irrigation
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1000
2000
3000
4000
5000
340
335
330
325
320
315
310
305
300

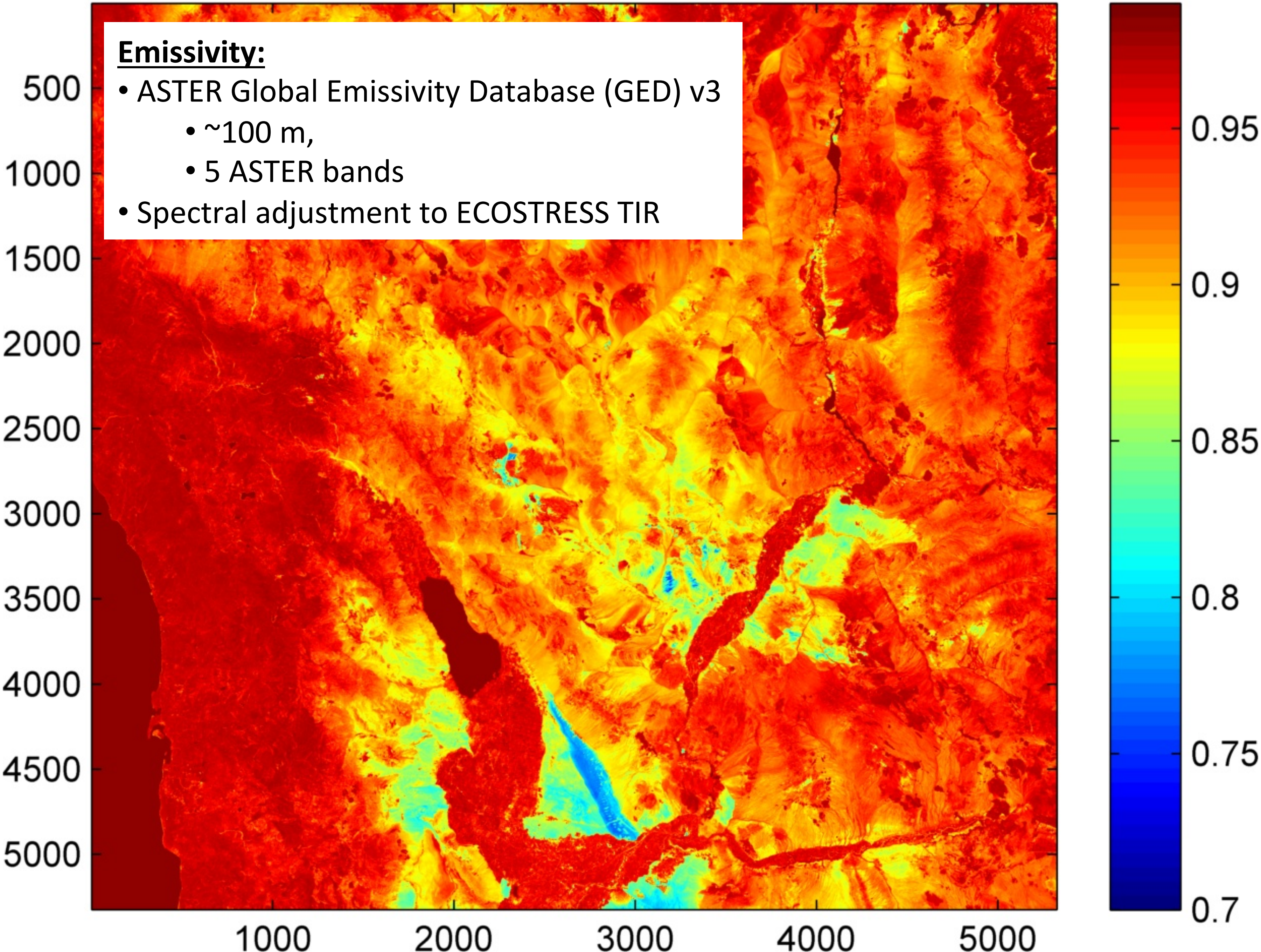
Limitations:

- Disaggregation from 375m – 70m
- ASTER 100 m -> 70m (loss of ‘focus’)
- Misregistration between ASTER/VIIRS TIR




ECOSTRESS Land Surface Temperature [K]
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1000
2000
3000
4000
5000
350
340
330
320
310
300
290
280

ECOSTRESS Emissivity Band 1 (8.3 μm)



NASA DEVELOP Project - Costa Rica Agriculture Summer 2016

Objective: To utilize simulated ECOSTRESS data products to estimate the changes in water stress in crops over a daily cycle using the Priestly-Taylor-JPL model and to evaluate the utility of future ECOSTRESS data streams for supporting agricultural water resources management.

Team: *Gregory Halverson, Mark Barker, Savannah Cooley, Steven Pestana (*indicates Team Lead)

Mentors: Dr. Christine Lee, Dr. Joshua Fisher

Partners at EARTH University: Dr. Johan Perret, Jose Eduardo Villalobos Leandro, Karim Abdalla Bolanos, Carol Lucia Fuentes Fallas

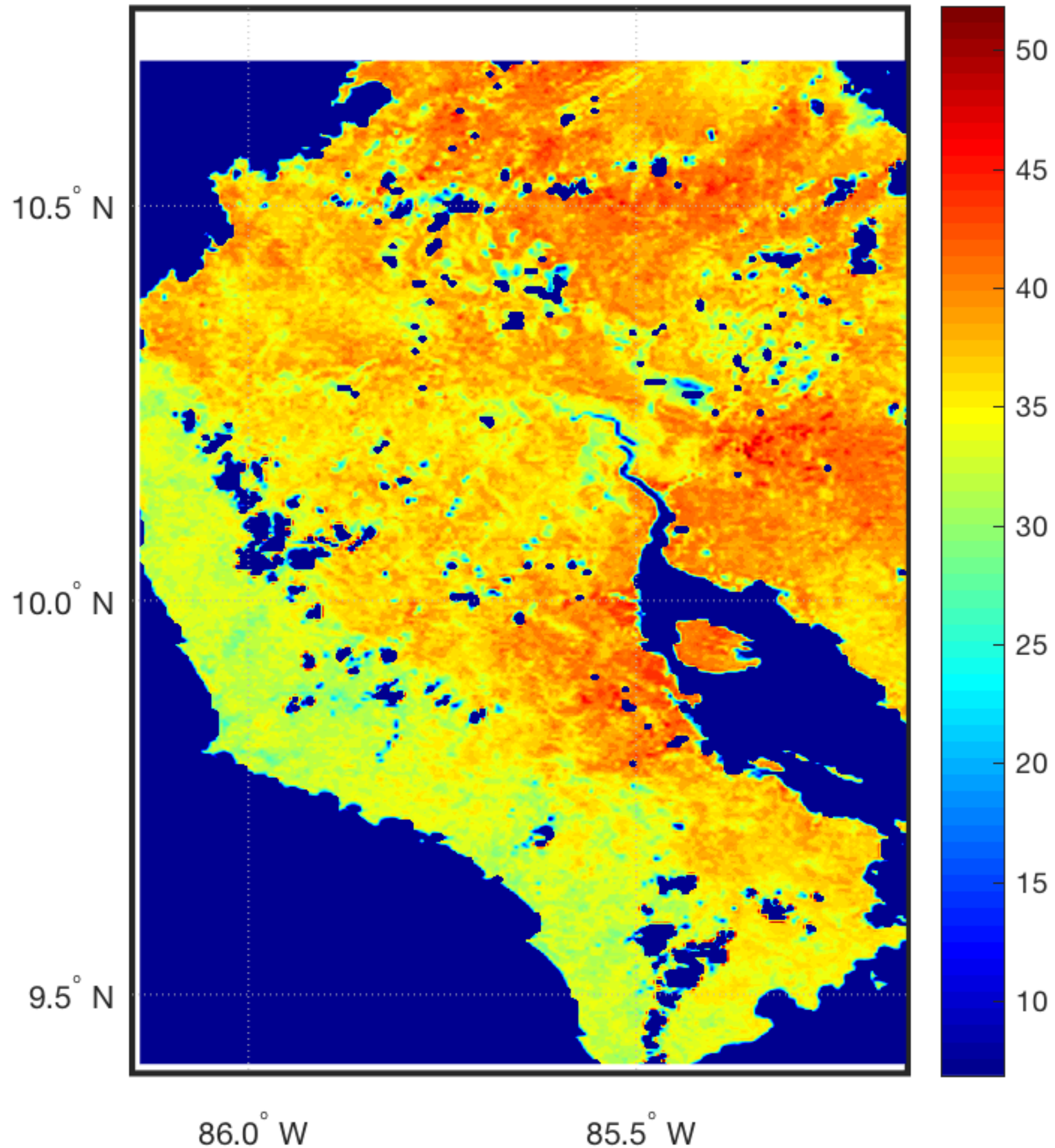
Upcoming Events

2016 HyspIRI Science and Applications Workshop
Oct 18, 2016 - Oct 20, 2016 — Pasadena, CA

ECOSTRESS Science and Applications Team Meeting
Dec 06, 2016 - Dec 07, 2016

Upcoming events…

ECOSTRESS L2 Land Surface Temperature Simulated Image – Costa Rica
Generated by Steven Pestana



ECOSTRESS Cloud Mask Evaluation

Roel Rodriguez (Caltech, SURF)

- Evaluation over all conditions using MODIS
- Compare to MOD35 standard
- Identify issues
- Optimize thresholds
- Update ATBD

ECOSTRESS cloud mask

- Based on MODIS cloud detection heritage

- Group I: Thick high clouds;
  (**BT11**, **BT13.9**, and **BT6.7**)

BT11 = Brightness Temperature at 11 micron

- Group II: Thin clouds;
  (**BT11-BT12**, **BT8.6-BT11**, **BT11-BT3.9**, and **BT11-BT6.7**)

- Group III: Low clouds – VSWIR reflectance tests ($\mathbf{r_*}$)

- Group IV: High thin clouds;
  ($\mathbf{r_{1.38}}$, **BT11-BT12**, **BT12-BT4**, and **BT13.7-BT13.9**)

ECOSTRESS cloud tests

Cloud Test 1

- If **BT11** > threshold (land, ocean, day, night)

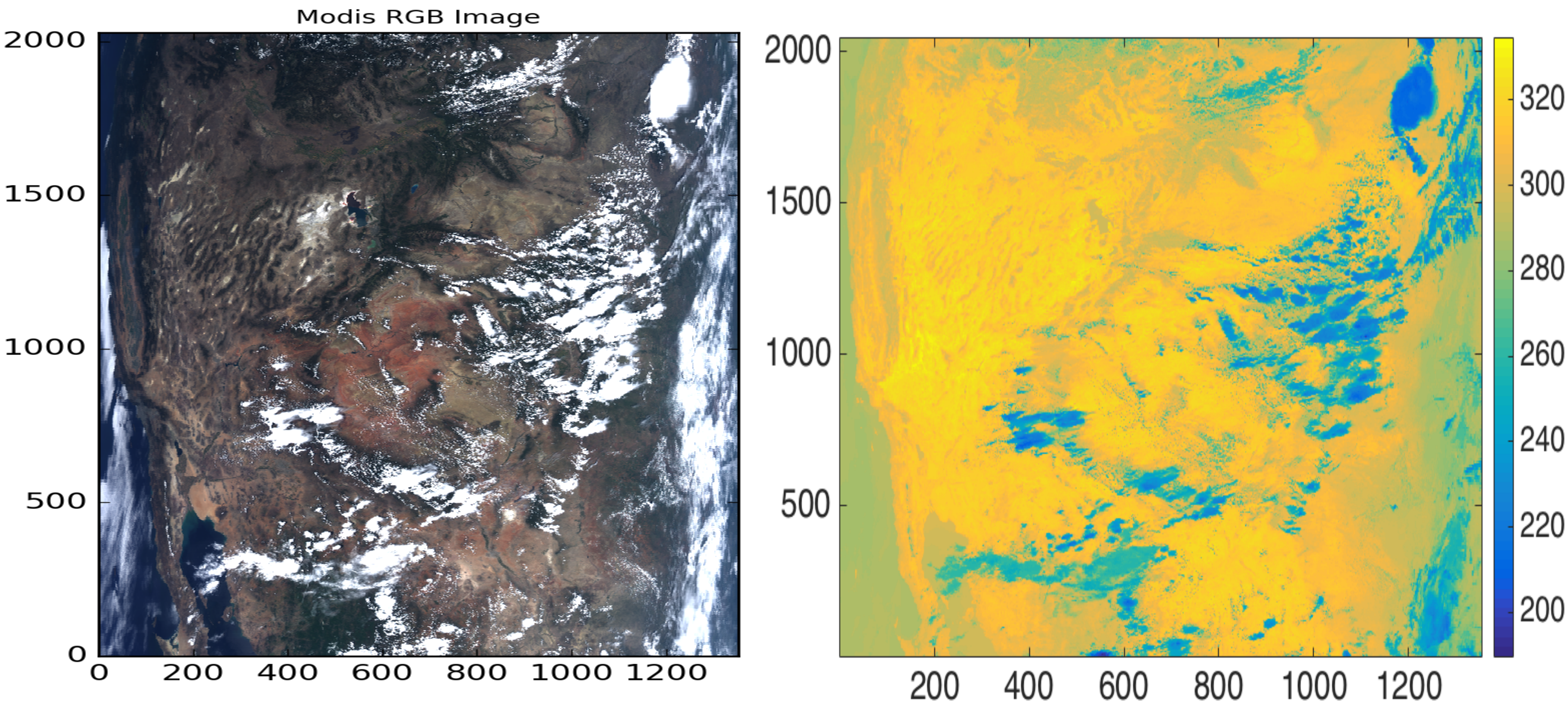
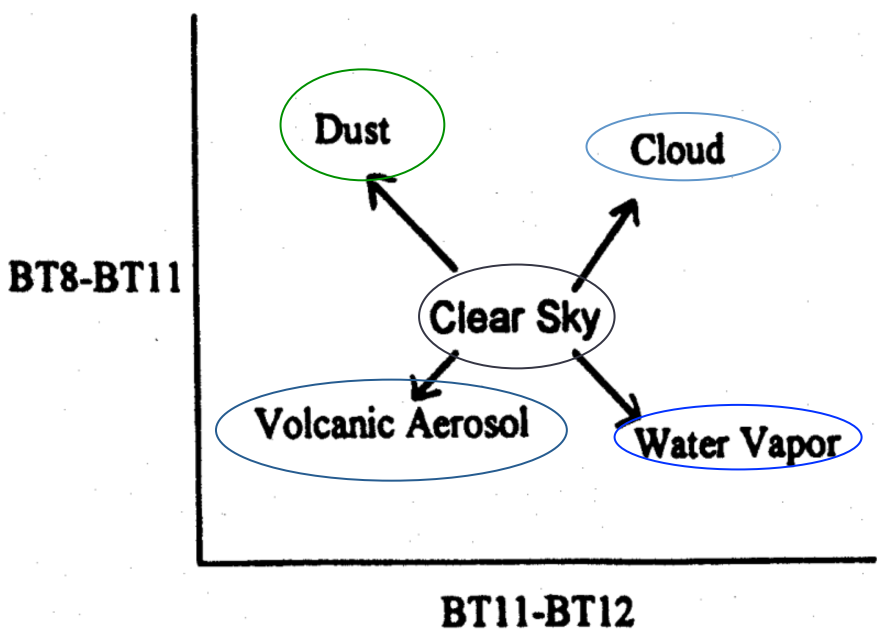


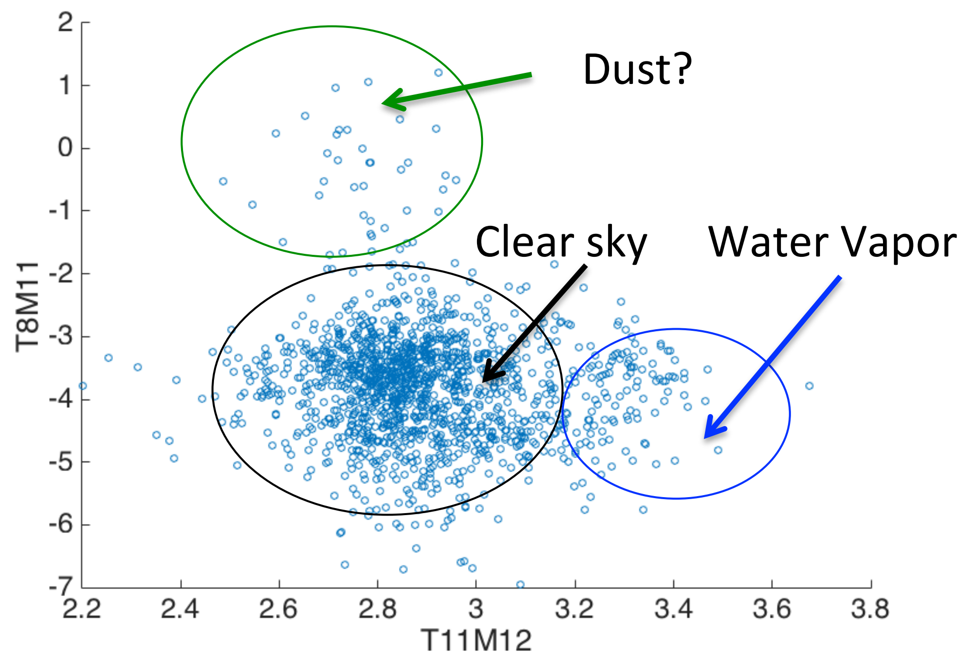
Figure 1. MODIS visible image (left) and 11 µm band brightness temperature (right) using MODIS data on 7 August 2004.

Cloud Test 2

- Tri-spectral combination of 8.6, 11, and 12 micron bands suggested by *Ackerman et al.* (1990)

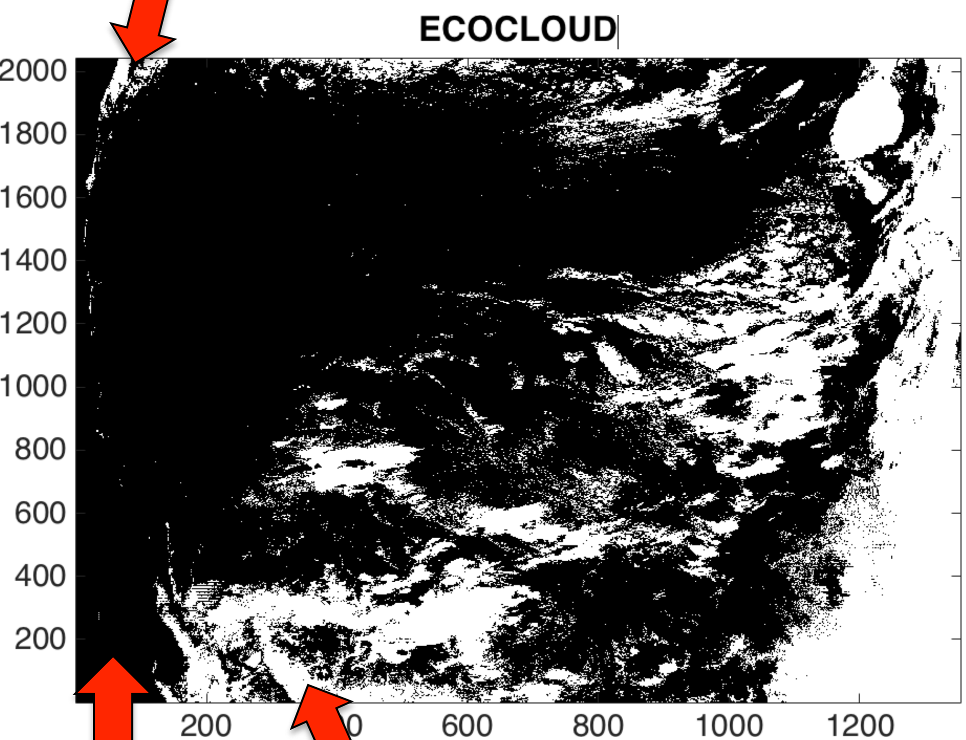
$$\mathrm{T8M11} = c1 + c2 \cdot \log(\mathrm{PW}) \qquad \mathrm{T11M12} = d1 + d2 \cdot (\mathrm{PW})$$

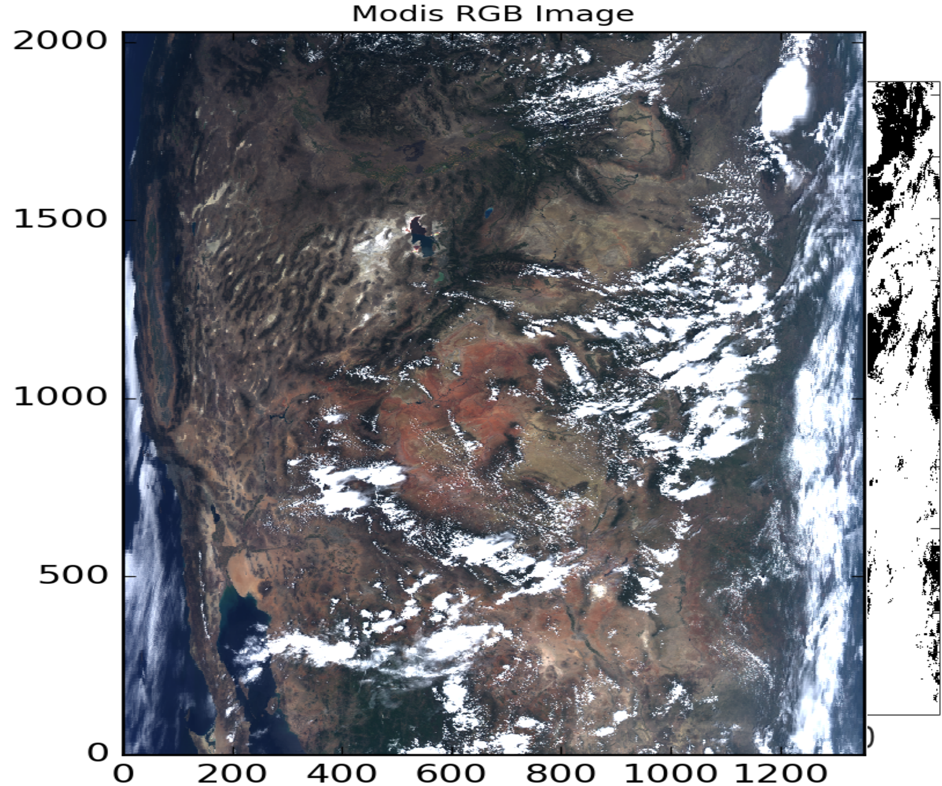




Performance versus MODIS

False positives





False positives

Low cloud over ocean missed

% Cloud Overestimated (Compared to MODIS)	% Cloud Missed (Compared to MODIS)
8.6%	9.9%

Cloud Mask Output

- 8-bit product

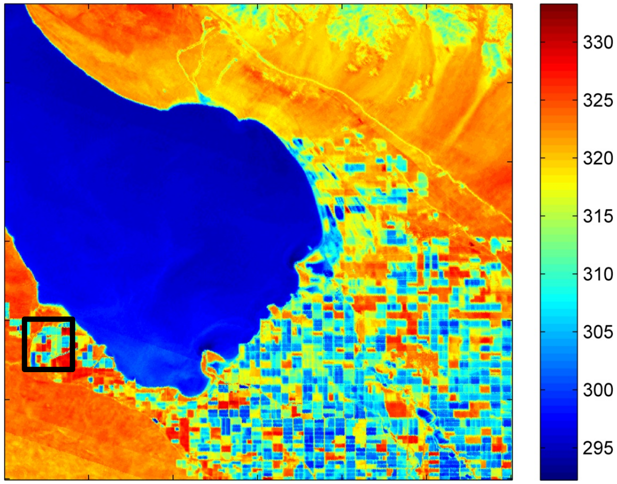
Bits	Long Name	Description
0	Cloud mask flag	0 = determined 1 = not determined
1	Cloud	0 = no 1 = yes
2	Cloud extended	0 = no 1 = yes
3	BTdiff test	0 = no 1 = yes Careful consideration of land surface emissivity required
4	VSWIR test X	0 = no 1 = yes Uncalibrated band – dynamic threshold required per 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.

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)
- L2 Code tested and baselined in SDS
- Simulated ECOSTRESS L2 Products
- Cloud mask evaluation and optimization

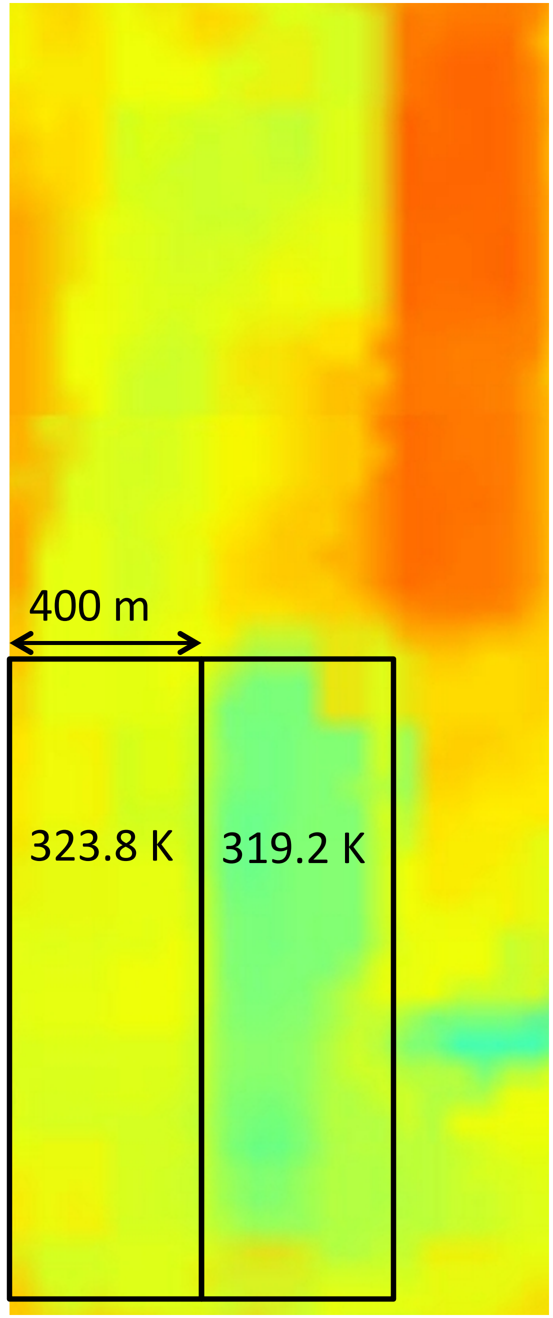
ECOSTRESS Simulated LST - 67m



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

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

MASTER LST: 08/26/2014



Google Earth: 08/28/14

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

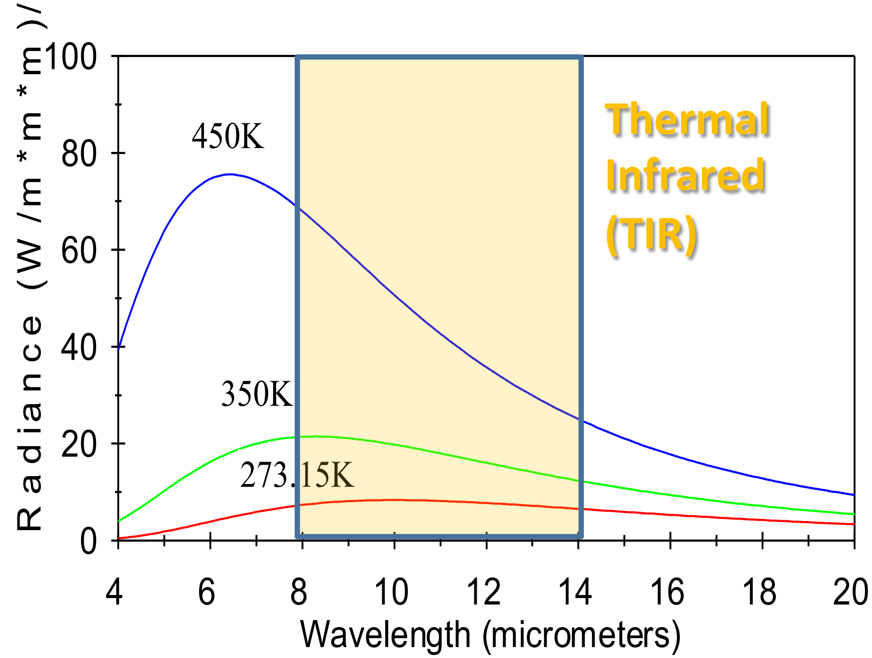
ρ_λ = Surface Reflection

$L^\downarrow$ = Downwelling Sky Irradiance

ε_λ = Emissivity

Planck Function

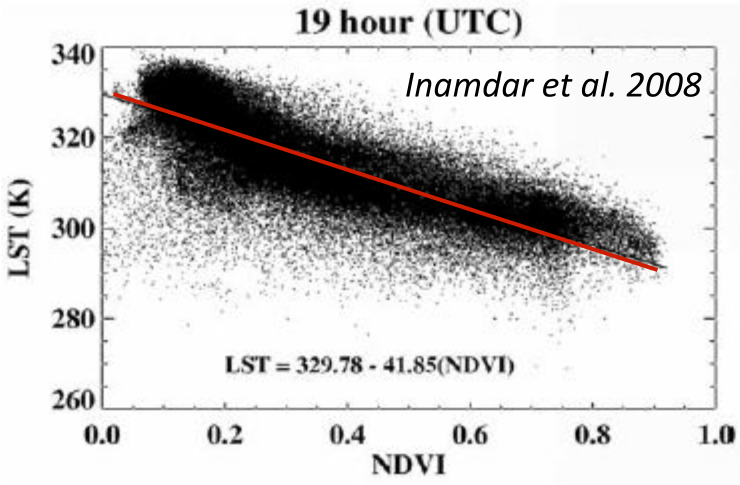
$$B_\lambda = \frac{c_1}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T_s}\right) - 1\right]}$$



in the Planck function shifts to shorter and shorter wavelengths

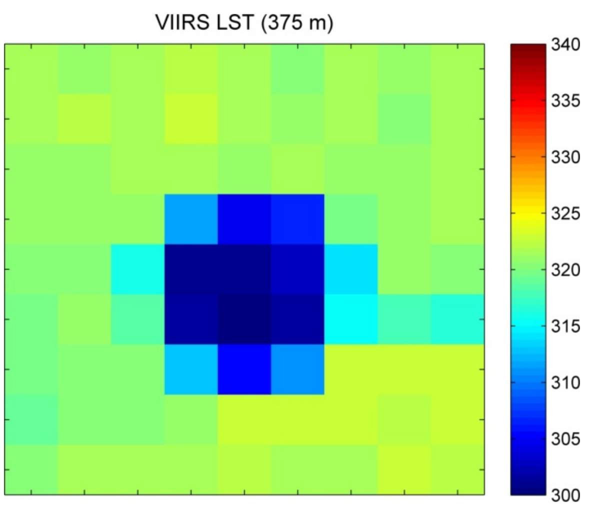
LST Disaggregation Approach (375 m ->70 m)

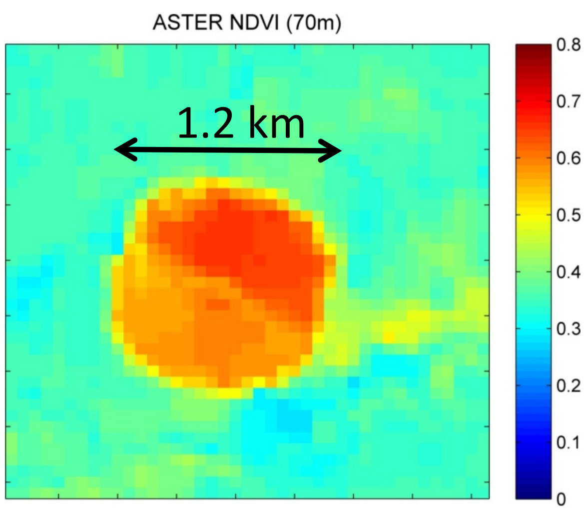
- Disaggregation procedure for radiometric surface temperature (DisTrad), *Kustas et al. 2003*
- Based on assumed relationship between vegetation 'greeness' and temperature

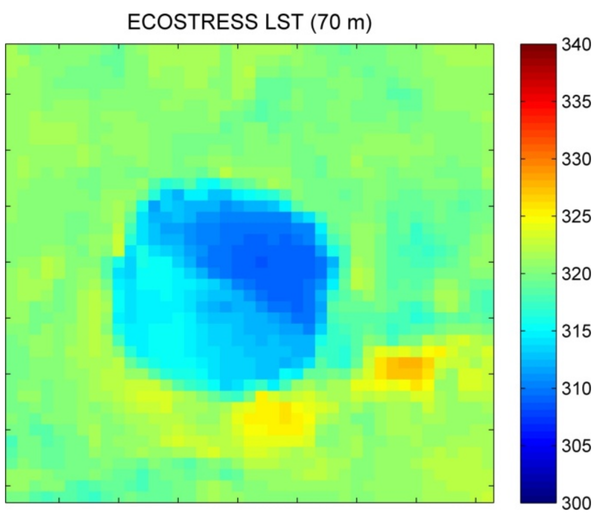


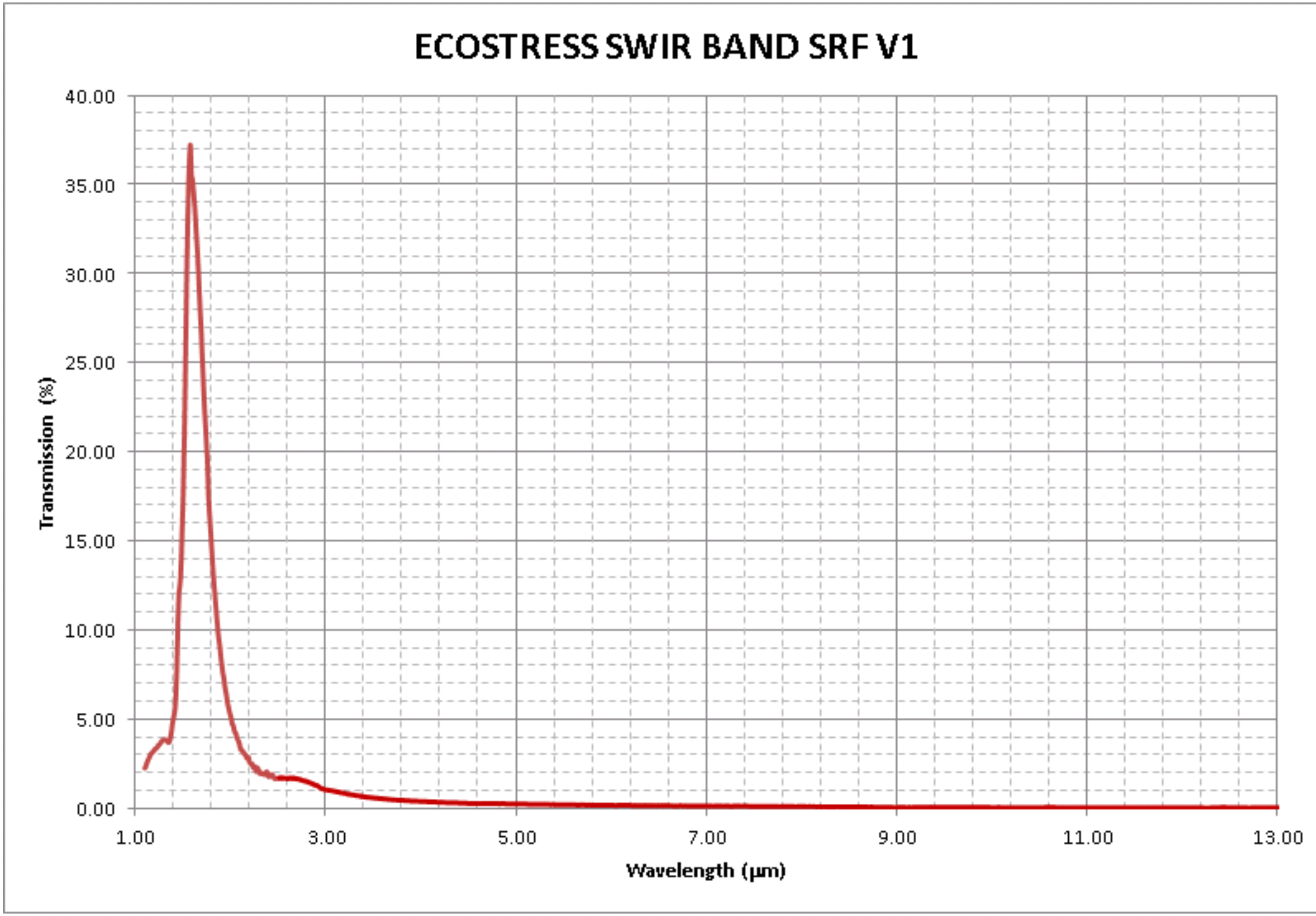
Requires:
LST at 375 m (VIIRS)
NDVI at 375 m (VIIRS)
NDVI at ~70 m (ASTER)

Corn field









1.6 micron band used for geolocation (<u>uncalibrated</u>)

ECOSTRESS L-2 and Cloud Mask Algorithm Theoretical Basis Document (ATBD)

Temperature Emissivity Separation (TES) Algorithm ‘ASTER approach’

T-E separation is under-determined:

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

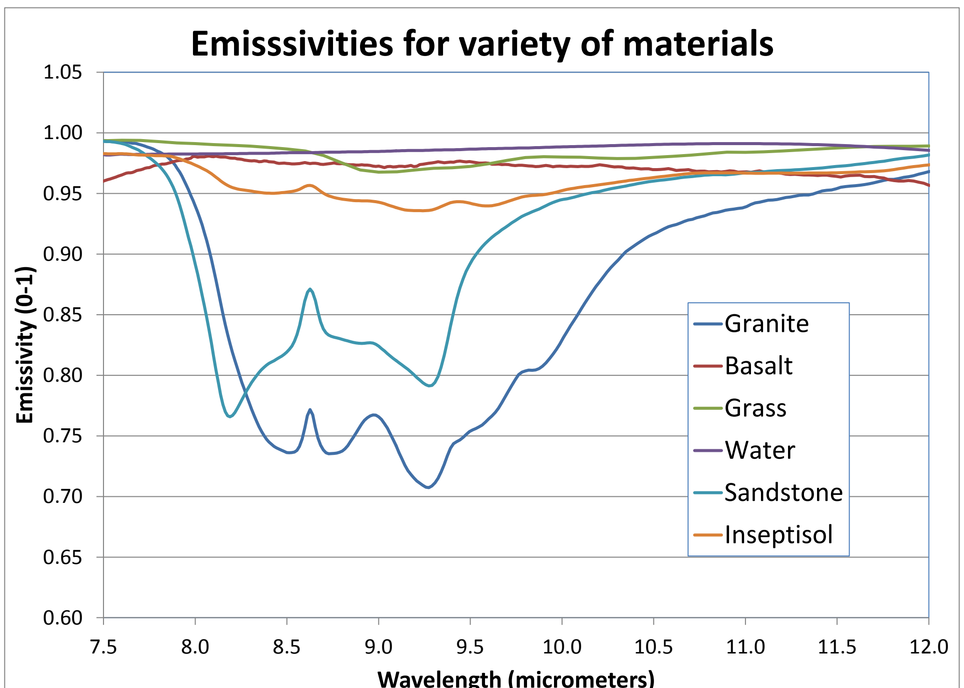
Radiance Band 1 = T + emissivity_1

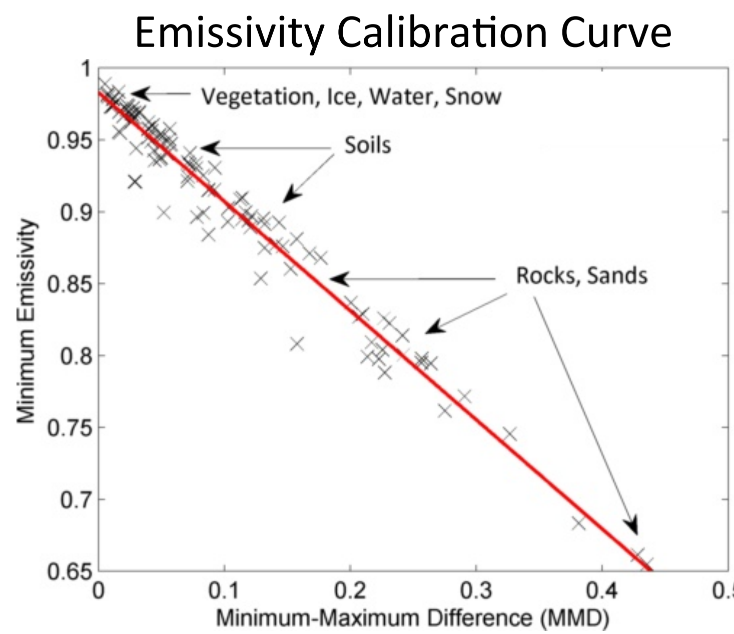
Radiance Band 2 = T + emissivity_2

Radiance Band 3 = T + emissivity_3

Radiance Band 4 = T + emissivity_4

Radiance Band 5 = T + emissivity_5





Carbonate mapping