National Aeronautics and Space Administration

Level-2 Products, Processing, Simulated Data, Cal/Val

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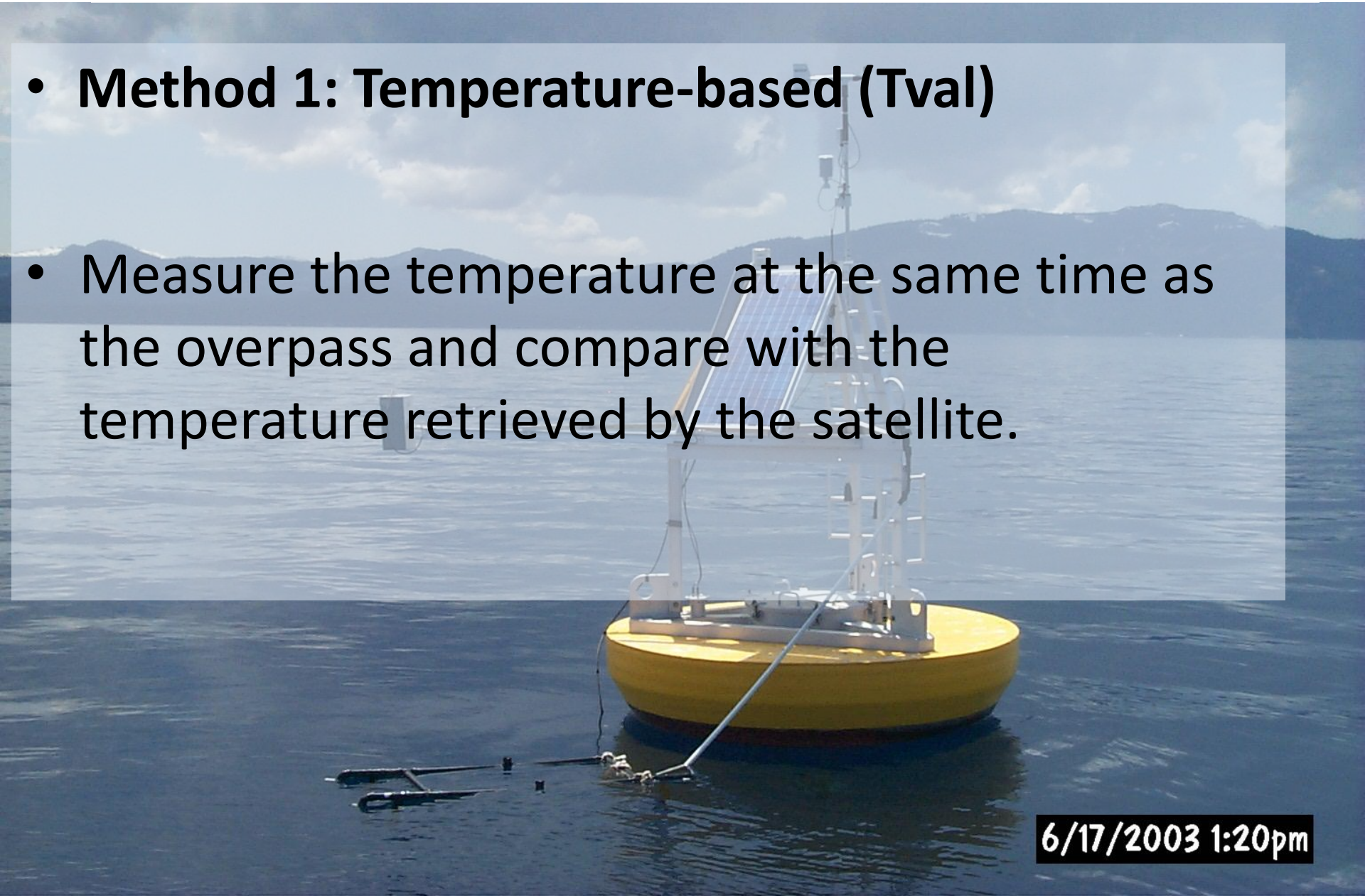
Outline

1. L2 Science Data Products and Heritage
2. L2 Algorithm Architecture
3. Atmospheric Correction
4. Uncertainty Analysis
5. Simulated ECOSTRESS L2 products (MASTER)

Temperature Validation

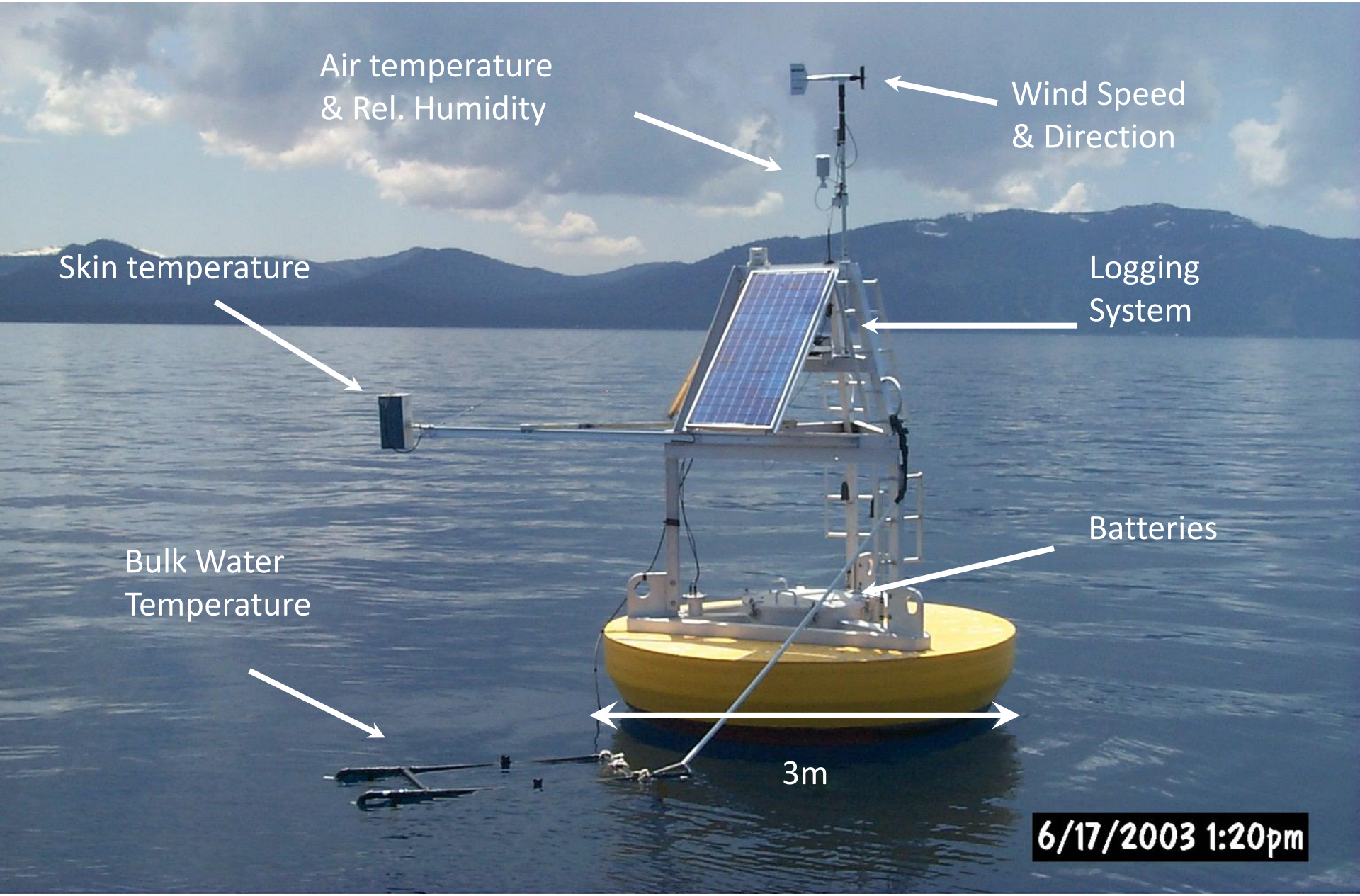


- **Method 1: Temperature-based (Tval)**

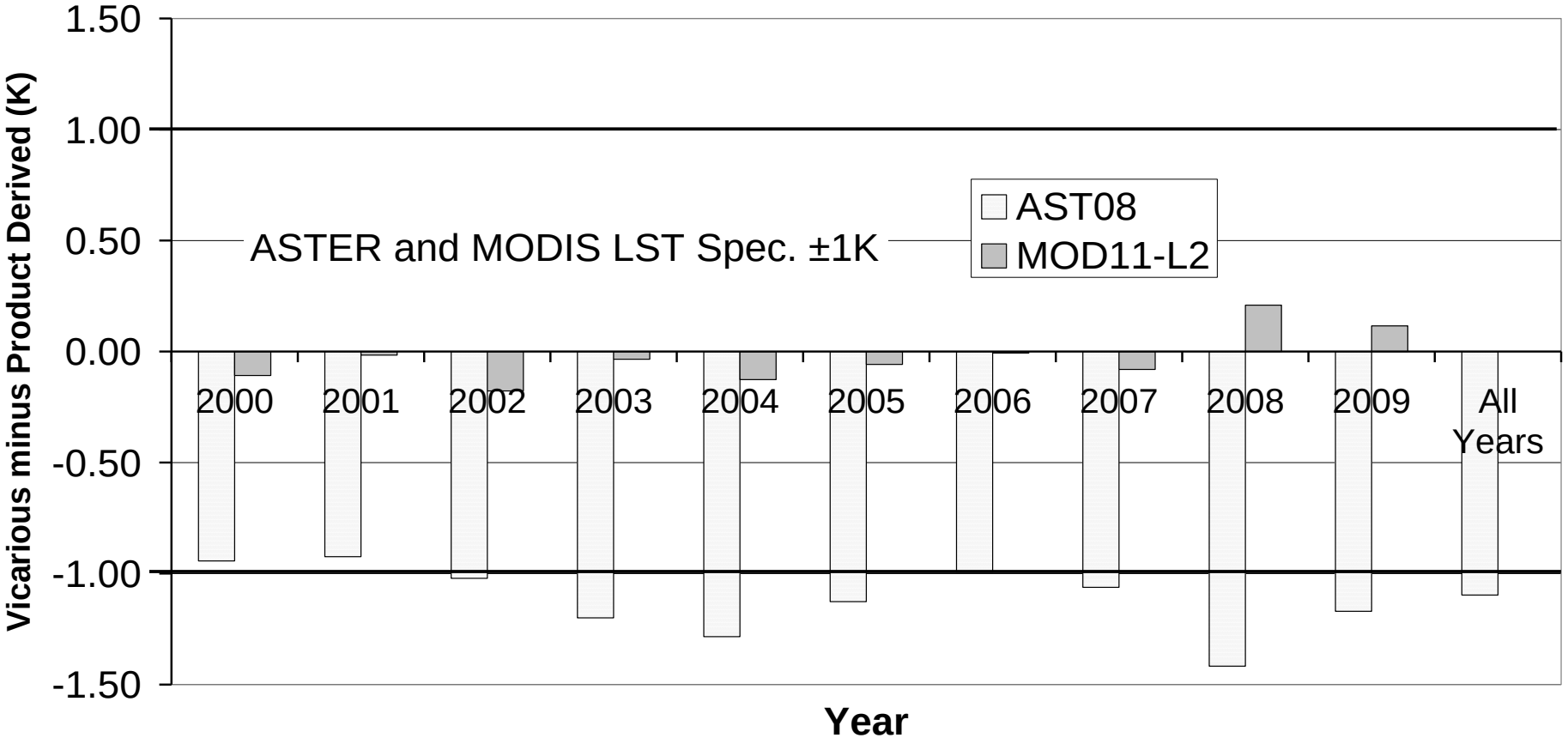
- Measure the temperature at the same time as the overpass and compare with the temperature retrieved by the satellite.

Radiometer Calibration

Tval over water (Lake Tahoe)



Tahoe LST validation



The MODIS product is accurate to (± 0.2K), while the ASTER product has a bias of 1-2 K due to residual atmospheric correction effects

Temperature Validation

- **Method 2: Radiance-based (Rval)**

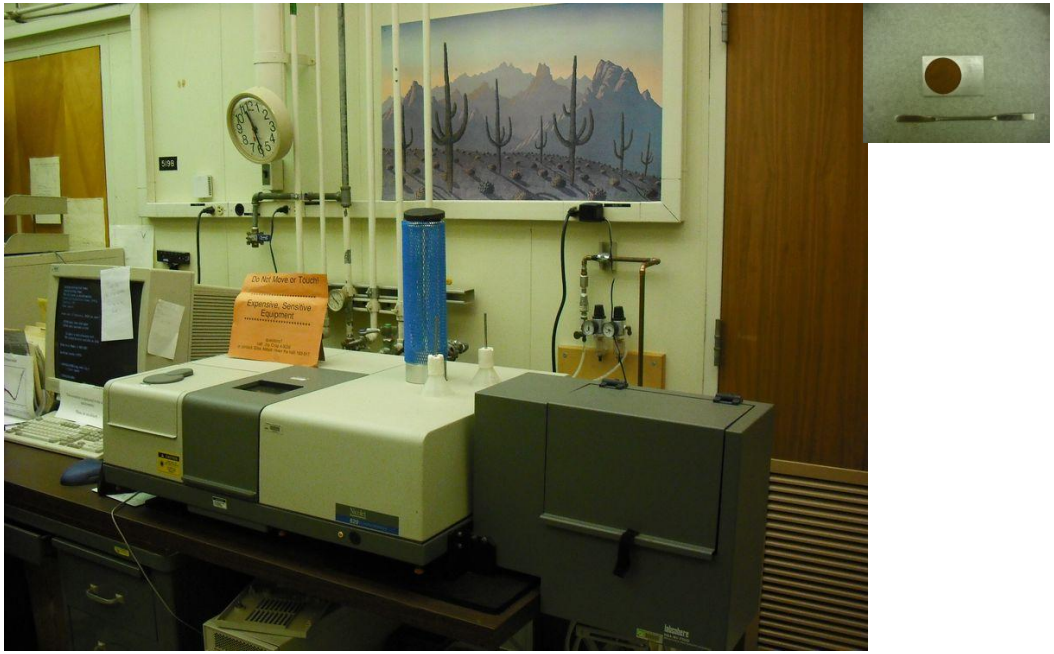
- Measure the emissivity and use an independent atmospheric profile (e.g. radiosonde). Forward calculate the ground temperature needed to match the at-sensor radiance and compare to retrieved temperature.

Emissivity Validation

- Requires compositionally homogeneous pixels (e.g. sand dunes) with known emissivity/mineralogy
- Surface sand samples are gathered at random within the footp of pixel to be validated
- Samples are measured with Nicolet spectrometer in the lab at to get reflectance, which is converted to emissivity
- Lab-measured emissivity convolved and compared to sensor product

Sand samples collected in field

Reflectance measured using Nicolet 520 FTIR spectrometer



JPL

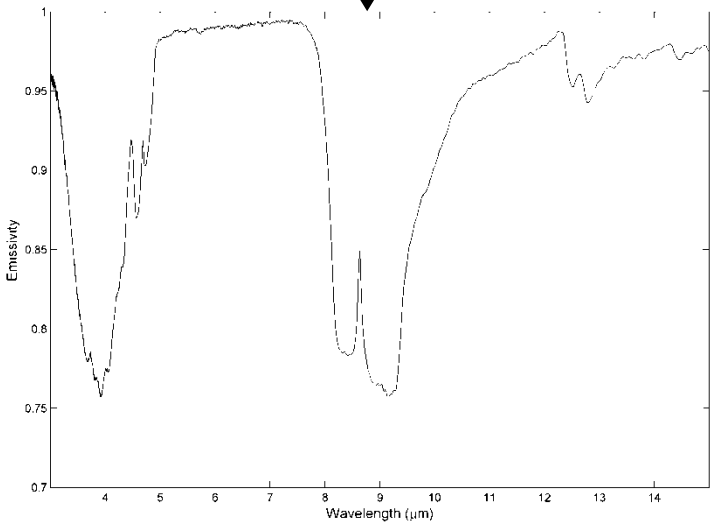
LAB MEASUREMENTS

$\varepsilon = 1 - r$

spectral range: 2.5 – 15 μm

spectral resolution: 4 cm^{-1}

1000 scans in 10 minutes

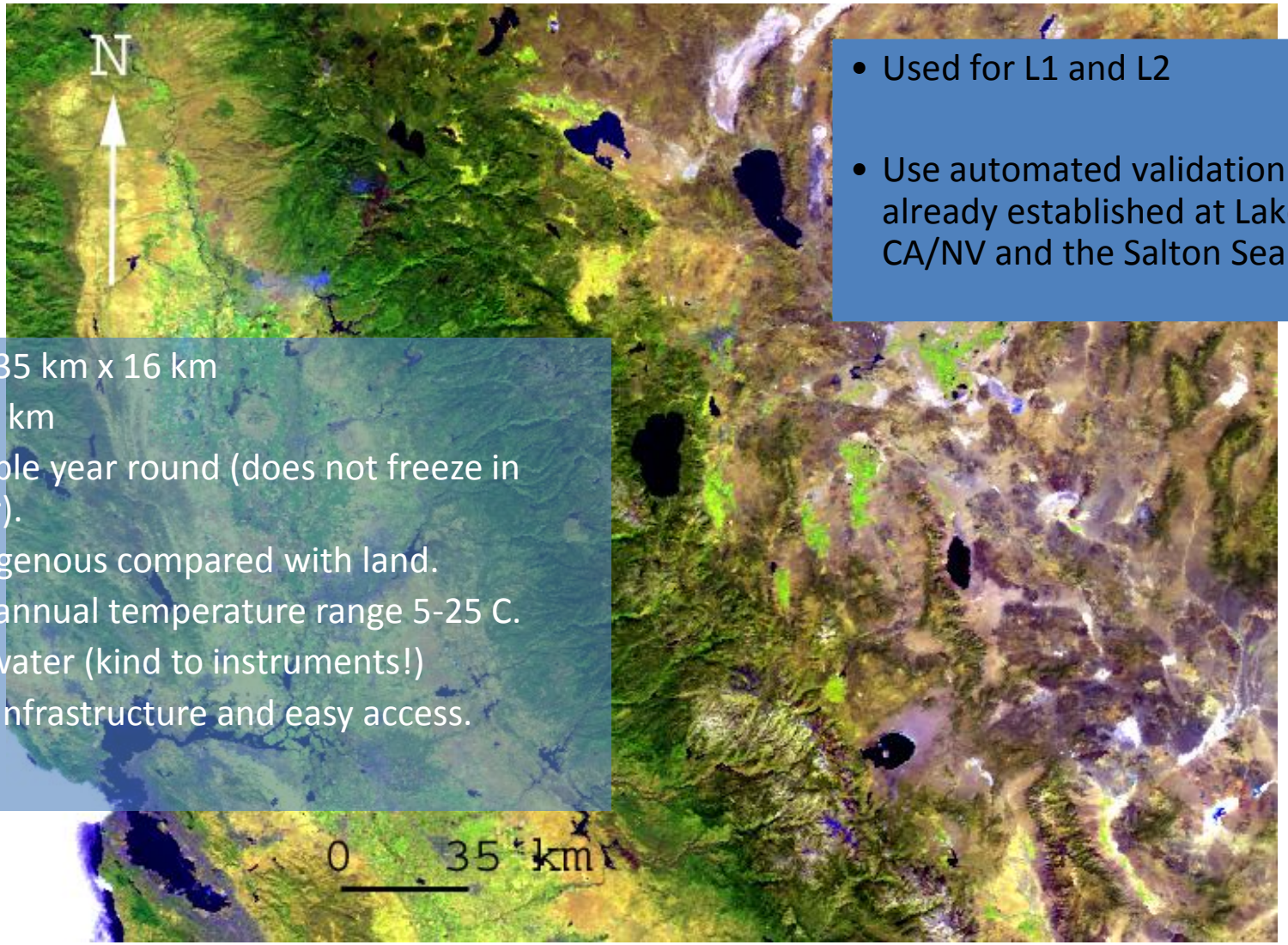


Pros and Cons of Temperature Validation Approaches

Method	Requirements	Advantages	Disadvantages
T-val	Accurate radiometer measurement(s) at the same time of overpass	• Direct comparison • Can also be used to validate calibration of sensor	• Requires in situ measurement at time of overpass • Difficult to perform over targets where temperatures vary rapidly over short distances
R-val	• Surface emissivity measurement (not coincident with overpass) • Atmospheric profile at the time over overpass	Does not require in situ emissivity measurement at time of overpass	• Requires atmospheric profile at time of overpass • Requires surface emissivity measurement • Indirect measurement cannot be used to validate calibration of sensor

Both approaches are typically used over homogenous targets (either in temperature or emissivity)

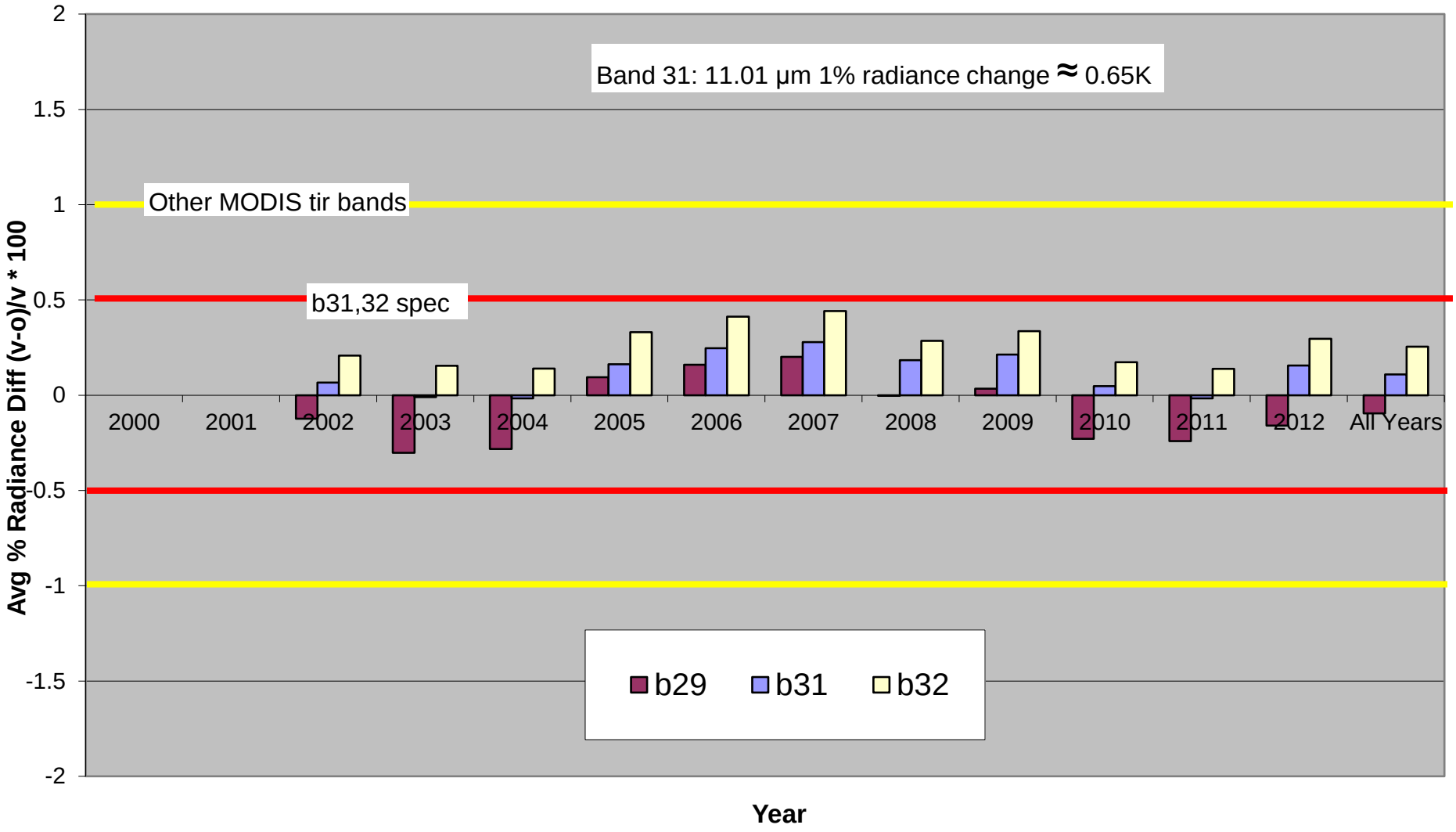
T-val - Use Automated Validation Sites



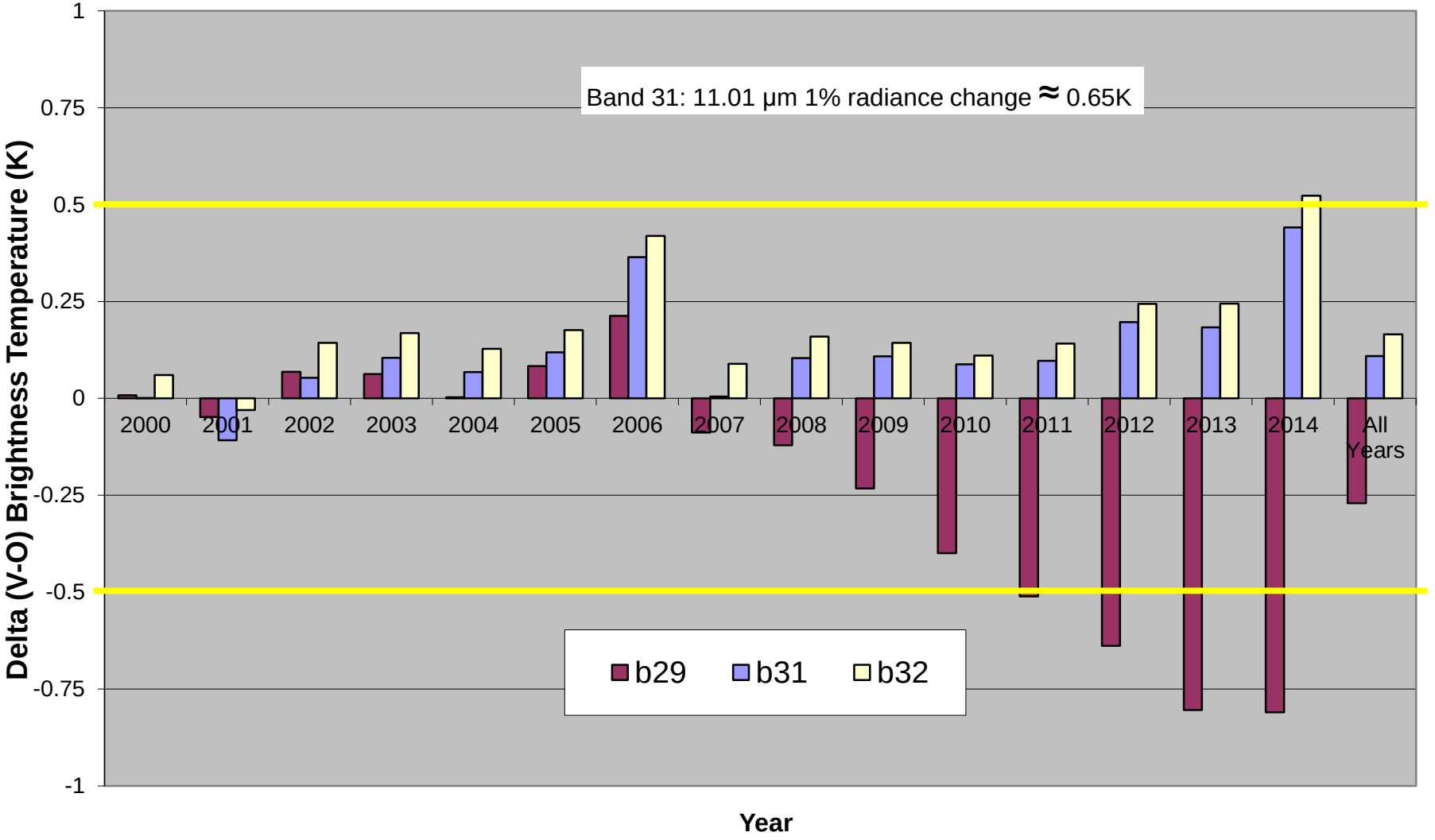
- Used for L1 and L2
- Use automated validation sites already established at Lake Tahoe CA/NV and the Salton Sea

- Large 35 km x 16 km
- High 2 km
- Available year round (does not freeze in winter).
- Homogenous compared with land.
- Large annual temperature range 5-25 C.
- Freshwater (kind to instruments!)
- Good infrastructure and easy access.

% Radiance Change in TIR Channels for MODIS Aqua at Lake Tahoe and Salton Sea CY2000-2012, vz0-30 v5.x



Delta Brightness Temperature in TIR Channels for MODIS Terra at Lake Tahoe and Salton Sea CY2000-2014 vz0-7 v5.x



Excellent calibration until 2009. Since 2009 channel 29 calibration started to degrade

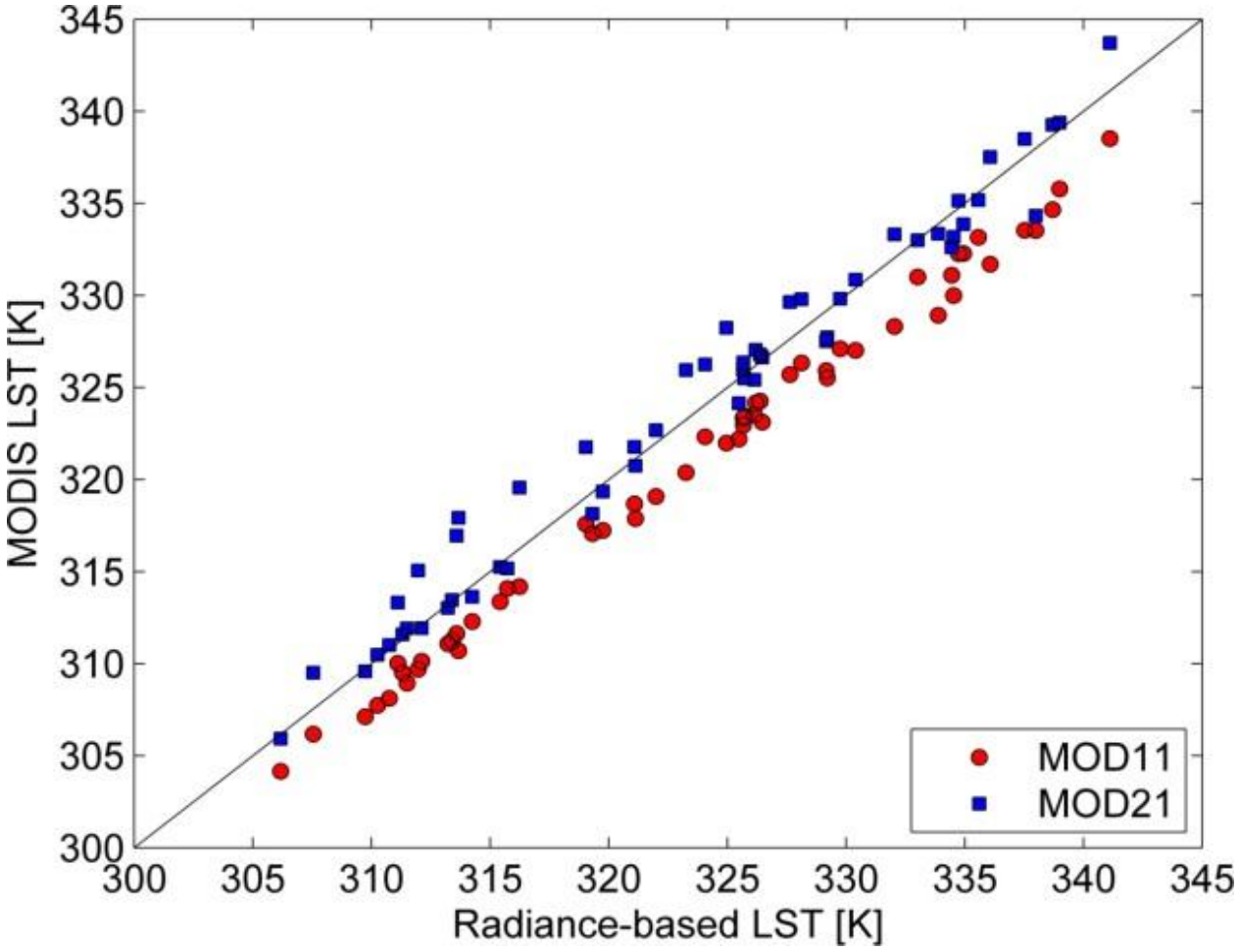
Radiance-Based LST Validation

- Requires compositionally homogeneous pixels (e.g. sand dunes) with known emissivity
- Radiative closure simulation:
  - Atmospheric profiles (e.g. NCEP, ECMWF)
  - In situ emissivity data
  - Retrieved LST
  - input to RT model (e.g. MODTRAN, SARTA)

- Retrieved LST is adjusted until calculated radiances match o
  - ➢ LST uncertainty = retrieved LST minus adjusted LST

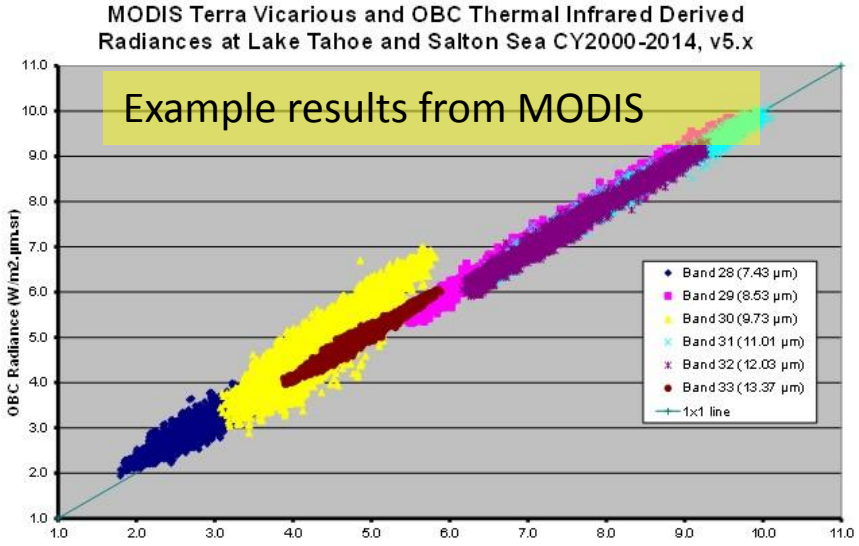
- ECOSTRESS will use the Algodones Dunes and Gobabebi, Na

Radiance-based LST Validation at Algodones Dunes

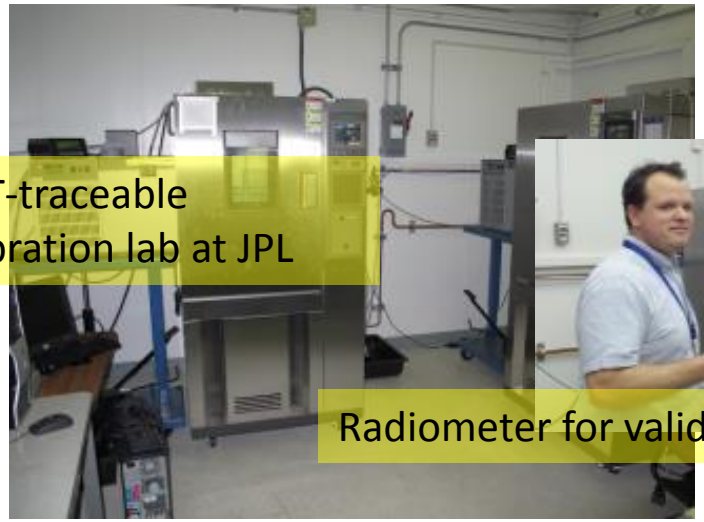


Brightness Temperature at Sensor : On-orbit Validation

Validation site at Lake Tahoe

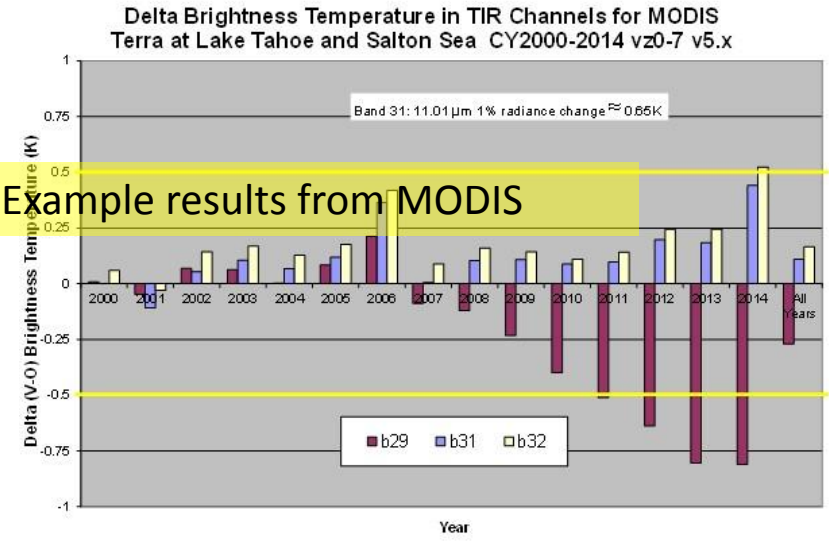


Example results from MODIS

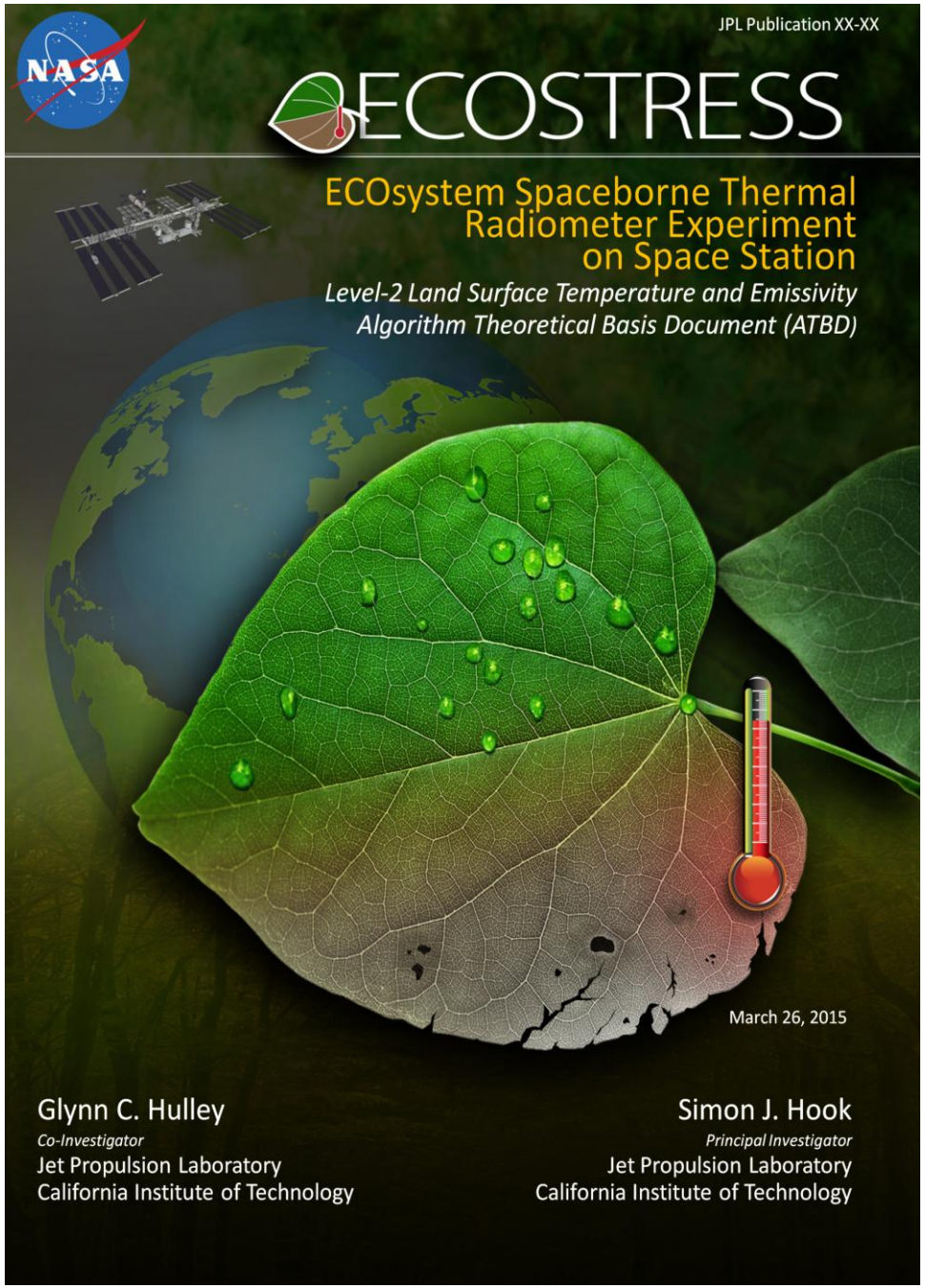


NIST-traceable calibration lab at JPL

Radiometer for validation



Example results from MODIS

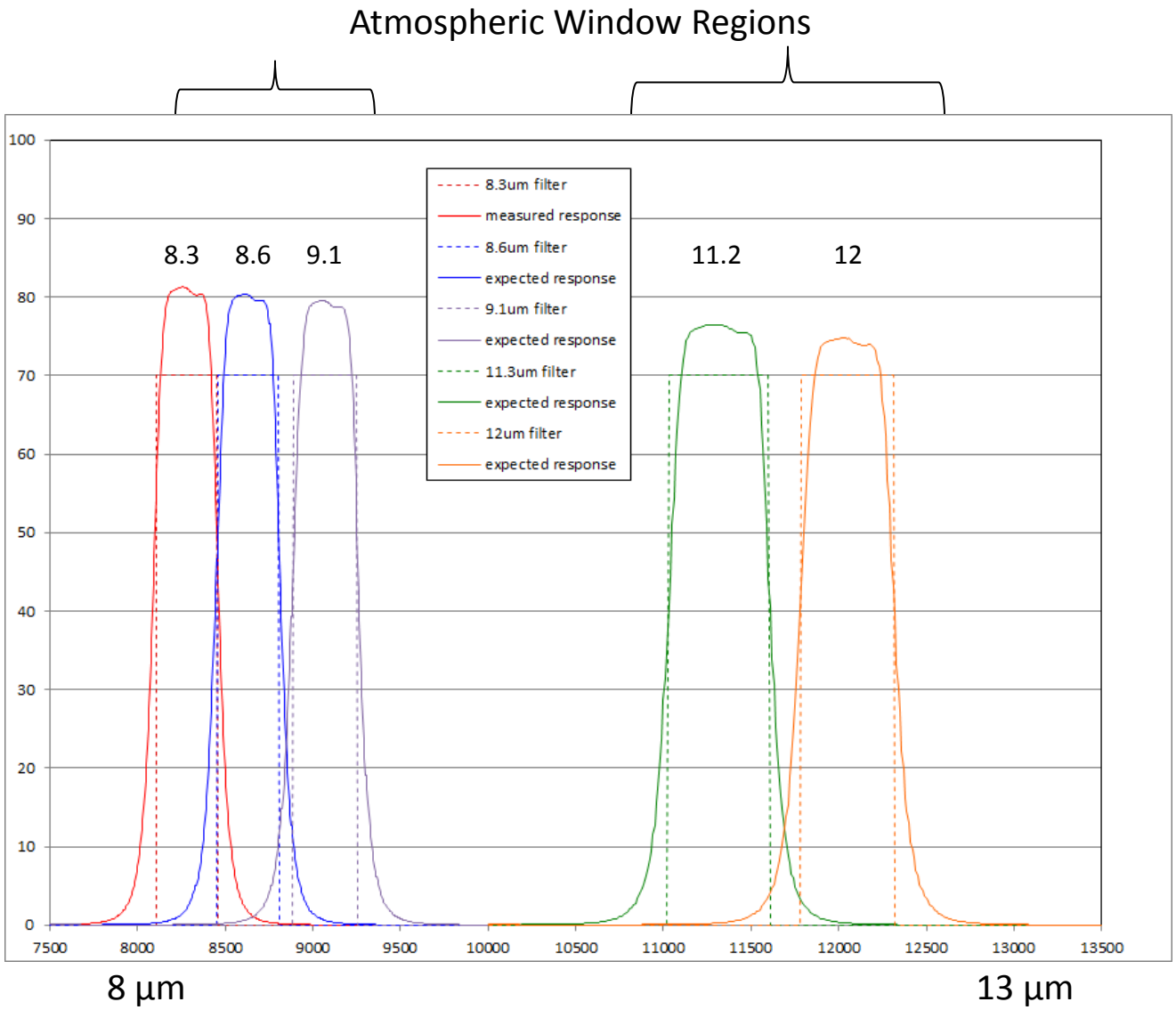


ECOSTRESS L-2 Algorithm Theoretical Basis Document (ATBD)

ECOSTRESS L2 Products

SDS	Long Name	Units
LST	Land Surface Temperature	K
Emis	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

ECOSTRESS Spectral Response Functions

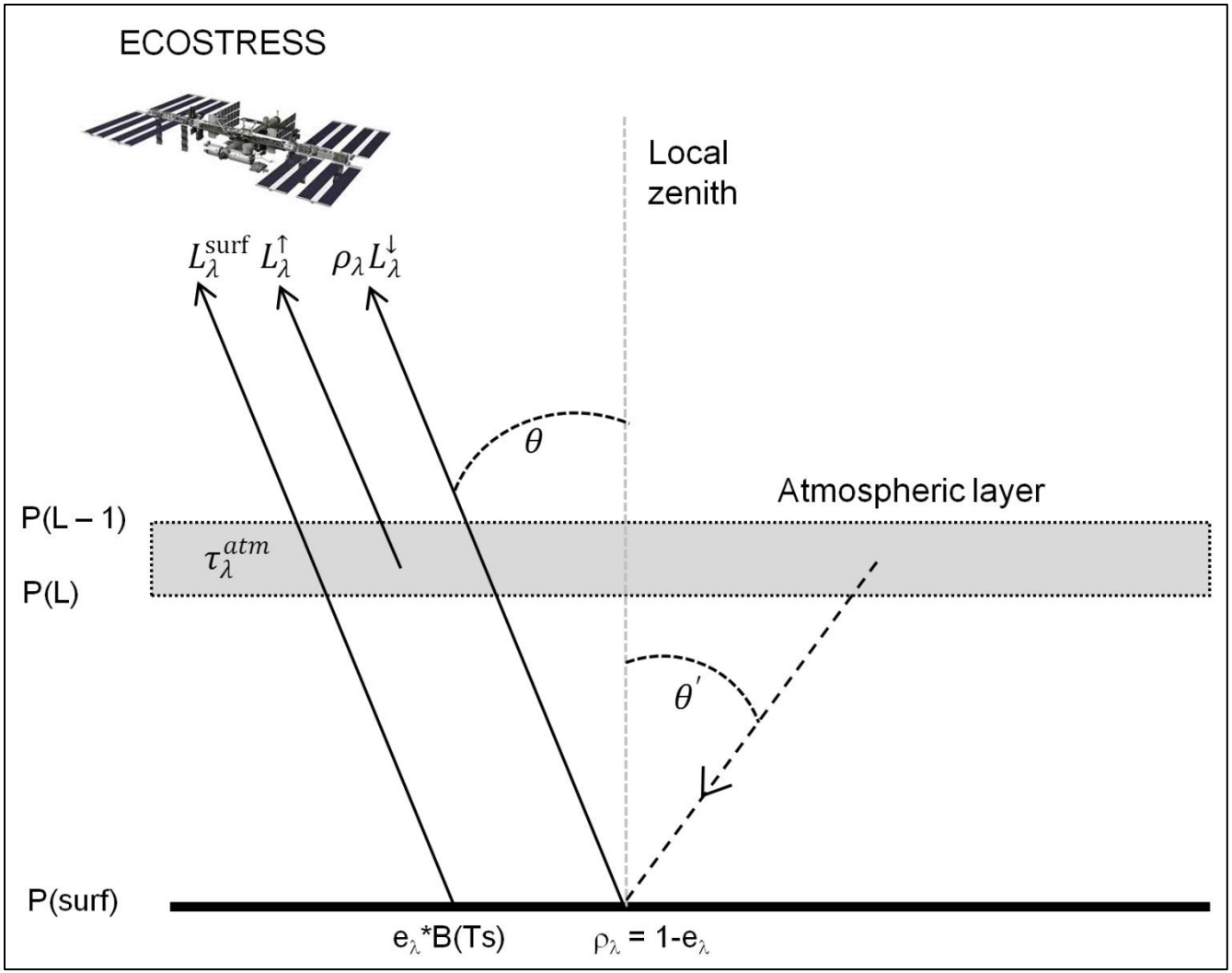


ECOSTRESS L2 Algorithm Heritage

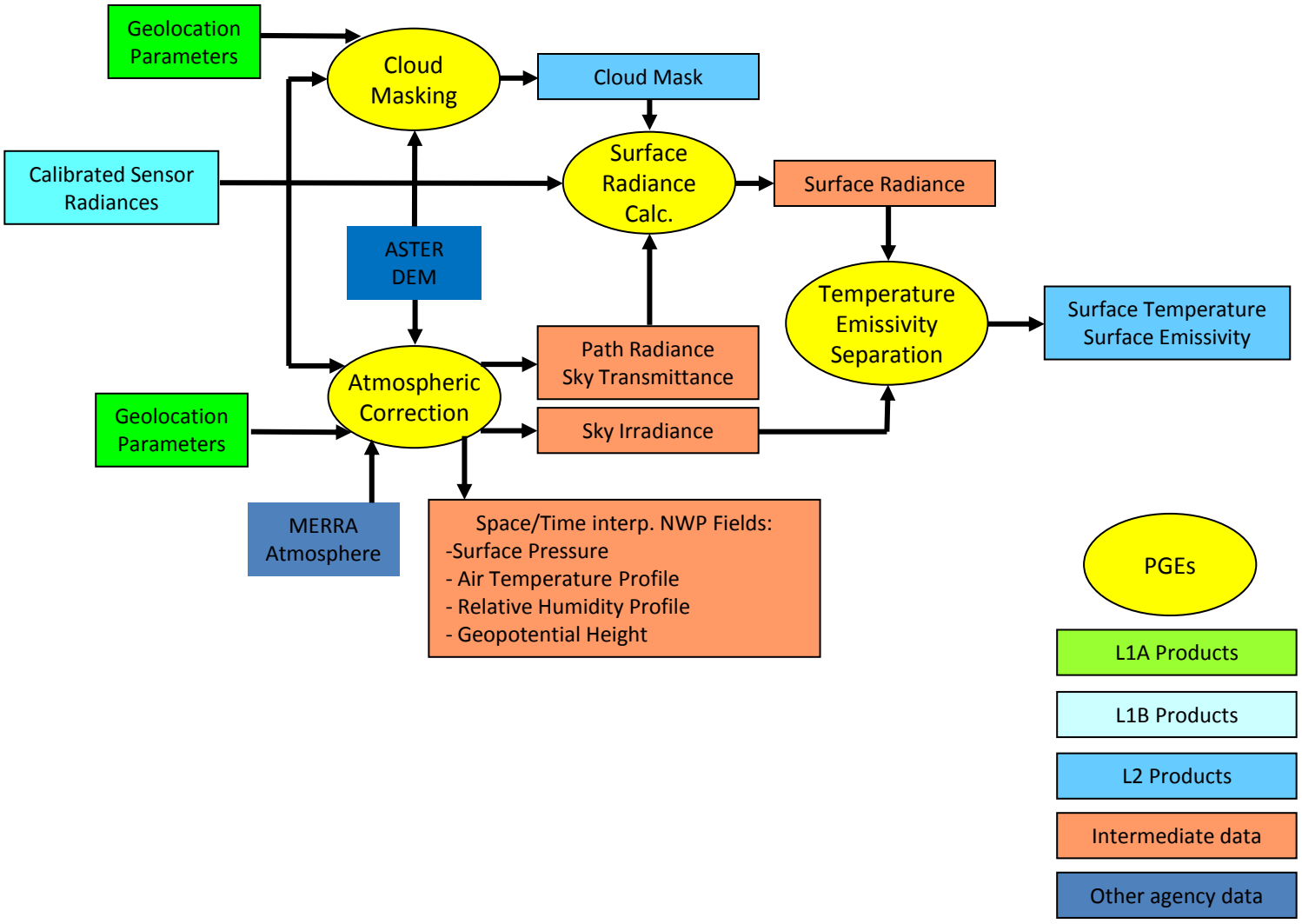
LST&E Product Characteristics	ASTER *Terra - 2000*	MODIS *Terra – 2000* *Aqua - 2002*	VIIRS *NPP - 2011*	ECOSTRESS *ISS - 2017*
Algorithm	TES	TES	TES	TES
Product	AST05/08 - 2000	MOD21 (JPL) - 2016	VLST (JPL) - 2017	ECO-L2 (JPL) - 2018
Bands used	10 (8.3 µm) 11 (8.6 µm) 12 (9.1 µm) 13 (10.6 µm) 14 (11.3 µm)	29 (8.55 µm) 31 (11 µm) 32 (12 µm)	14 (8.55 µm) 15 (10.76 µm) 16 (12 µm)	2 (8.3 µm) 3 (8.6 µm) 4 (9.1 µm) 5 (11.2 µm) 6 (12 µm)
Radiative Transfer Model	MODTRAN	RTTOV	RTTOV	RTTOV
Atmospheric Profiles	NCEP/MOD07	MERRA-2 WVS model	MERRA-2 WVS model	MERRA-2 WVS model
Spatial and Temporal Resolution	90 m 16-day	1-km Twice daily (am/pm)	750 m Twice daily (am/pm)	70 m Variable (CONUS – 5 day)
Science Data Products	- LST - Emissivity (bands 10-14)	- LST - Emissivity (bands 29, 31, 32)	- LST - Emissivity (bands 14, 15, 16)	- LST - Emissivity (bands 2-6)

Iteratively solve for surface radiance + TE separation (TES)

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



Science Data System (SDS)
L2 Data Flow



MERRA-2 (GEOS-5.12.4), 0.5° x 0.625° L72 to 0.01 hPa

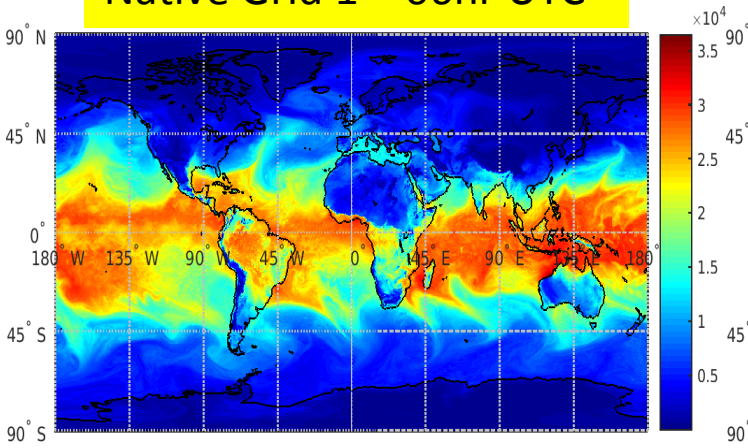
Reanalysis Progression

	MERRA	MERRA-2	Next Target
System vintage	2008	2014	2017
Release	2009	mid 2015	late 2018
Scope	Atmosphere	Atmosphere, including aerosols and land correction	Atmosphere-ocean-ice-land
Resolution	0.5°×0.66° L72	0.5°×0.625° L72 (C180 cubed sphere)	0.25°×0.3125° L137 (C360 cubed sphere) + 25-km ocean
Analysis	3D-Var atmos	3D-Var atmos	4D EnsVar atmos + EnKF land + EnOI ocean

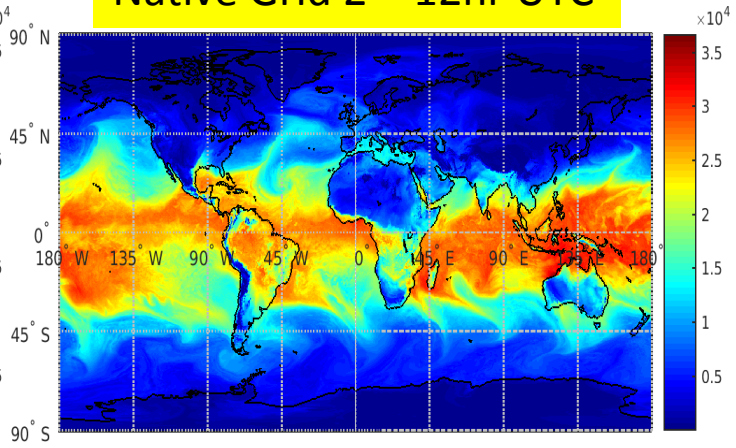
MERRA Global Water Vapor Field

(Water vapor at 2m, ppmv)

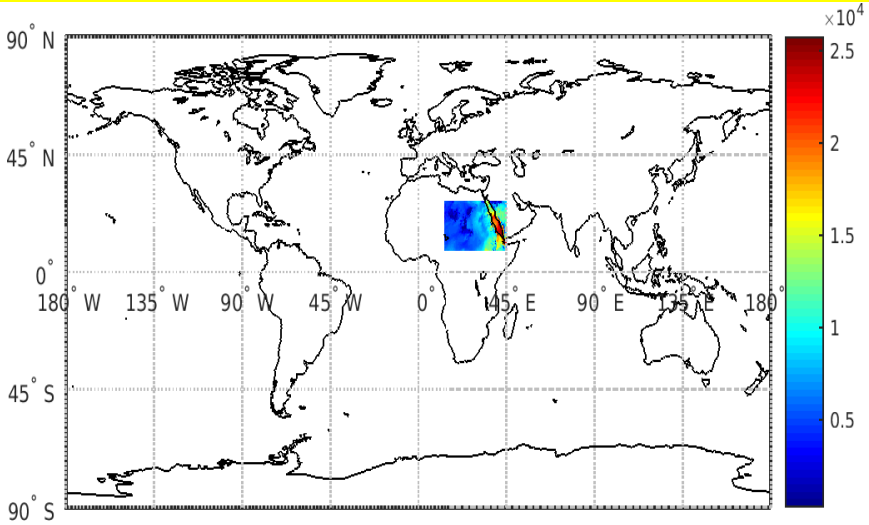
Native Grid 1 – 06hr UTC



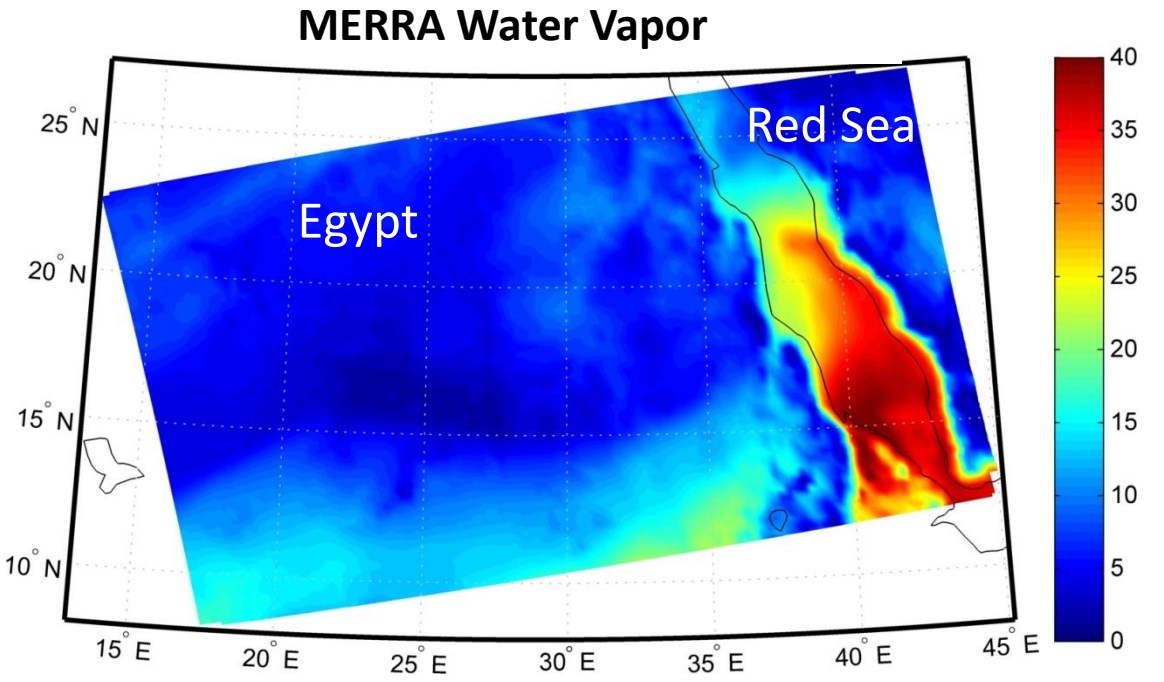
Native Grid 2 – 12hr UTC

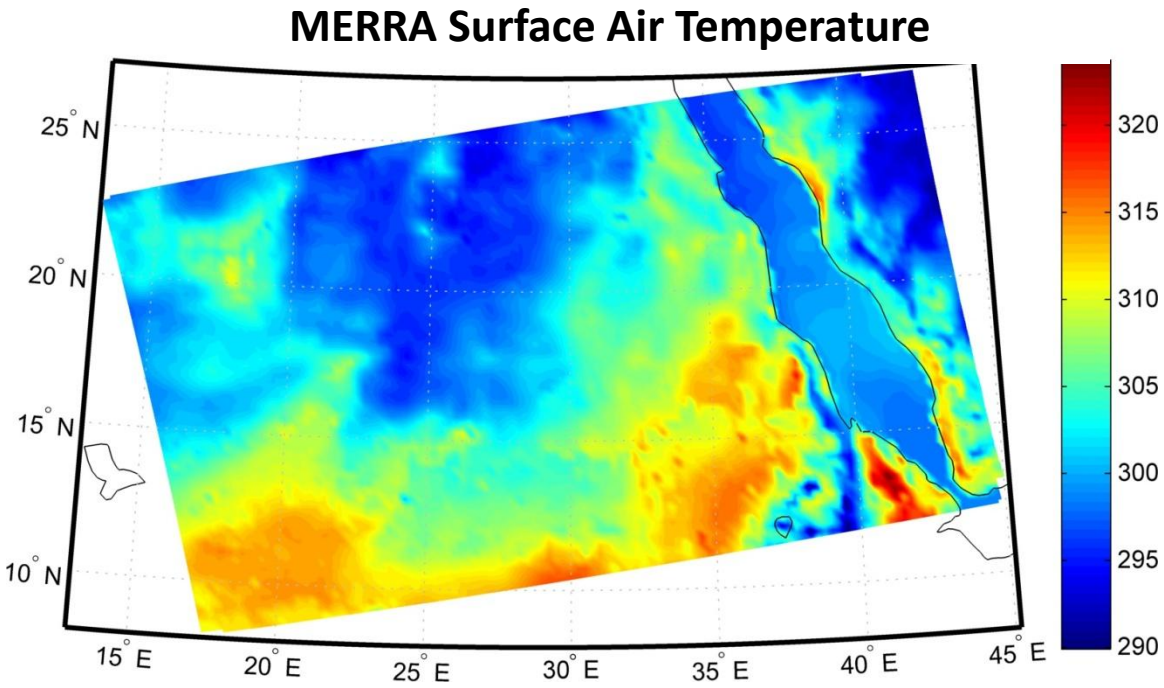


Native Grid 3 – Clipped and time-interpolated to ECOSTRESS scene at 11hr UTC



VIIRS Example Granule:
2300x3200 pixels
750 m resolution





LST Algorithm Uncertainty Analysis

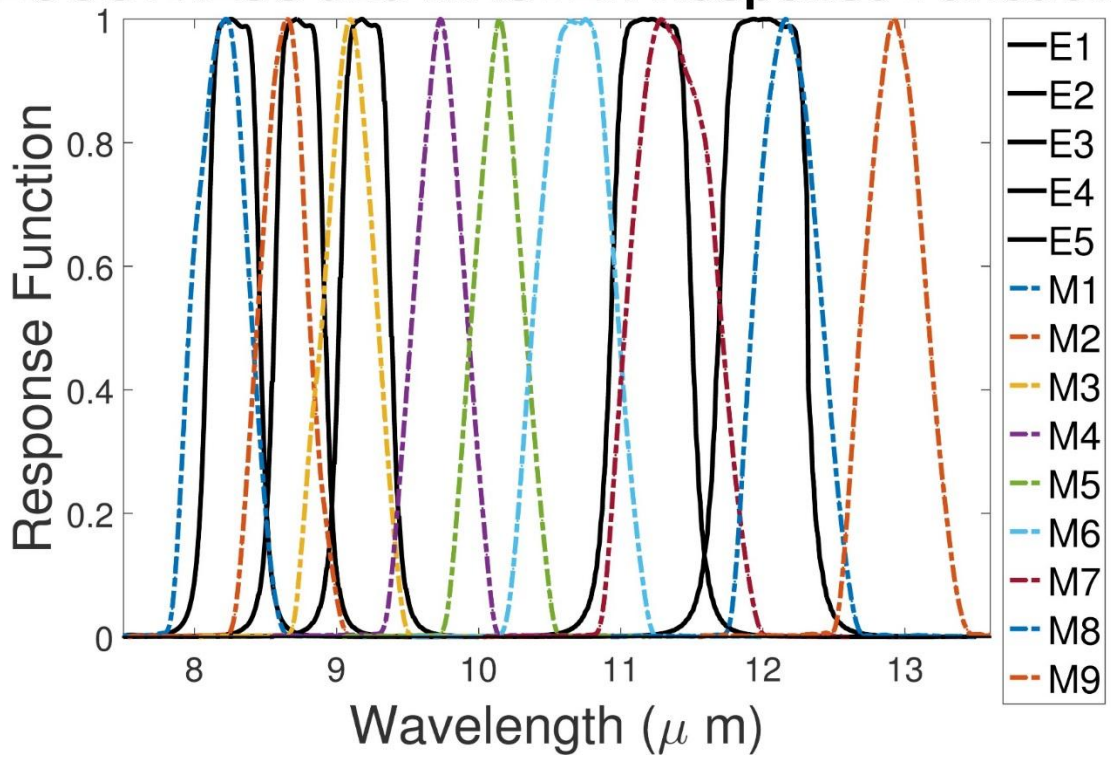
Test algorithms with global radiosonde database (SeeBor)

Hulley et al. 2012 (ESDR Uncertainty Analysis)			**LST Uncertainty (K)**		
Surface types	**Samples**	**MODTRAN Simulations**	**Split-Window (MOD11)**	**3-band TES (MOD21)**	**5-band TES (ECOSTRESS)**
Dense vegetation, Water, Ice, Snow	8	660,096	1.59	2.19	1.63
Rocks	48	3,960,576	4.31	1.44	1.45
Soils	45	3,713,040	1.27	0.89	0.91
Sands	10	825,120	2.38	1.12	0.99
Total	**111**	**9,158,832**	**2.66 K**	**1.49 K**	**1.13 K**

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

Simulated ECOSTRESS L2 Products From MASTER L2

1. Mosaic and grid MASTER L2 data flight lines
   - ASTER GED Gridding algorithm
2. Degrade MASTER 50 m to ECOSTRESS ~70 m
3. Estimate ECOSTRESS band emissivity by regression from MASTER TIR bands
   - Using ASTER spectral library data and MASTER/ECOSTRESS response functions



$$\epsilon(ECOSTRESS)_1 = 1.1705\ \epsilon(MASTER)_1 - 0.1660$$

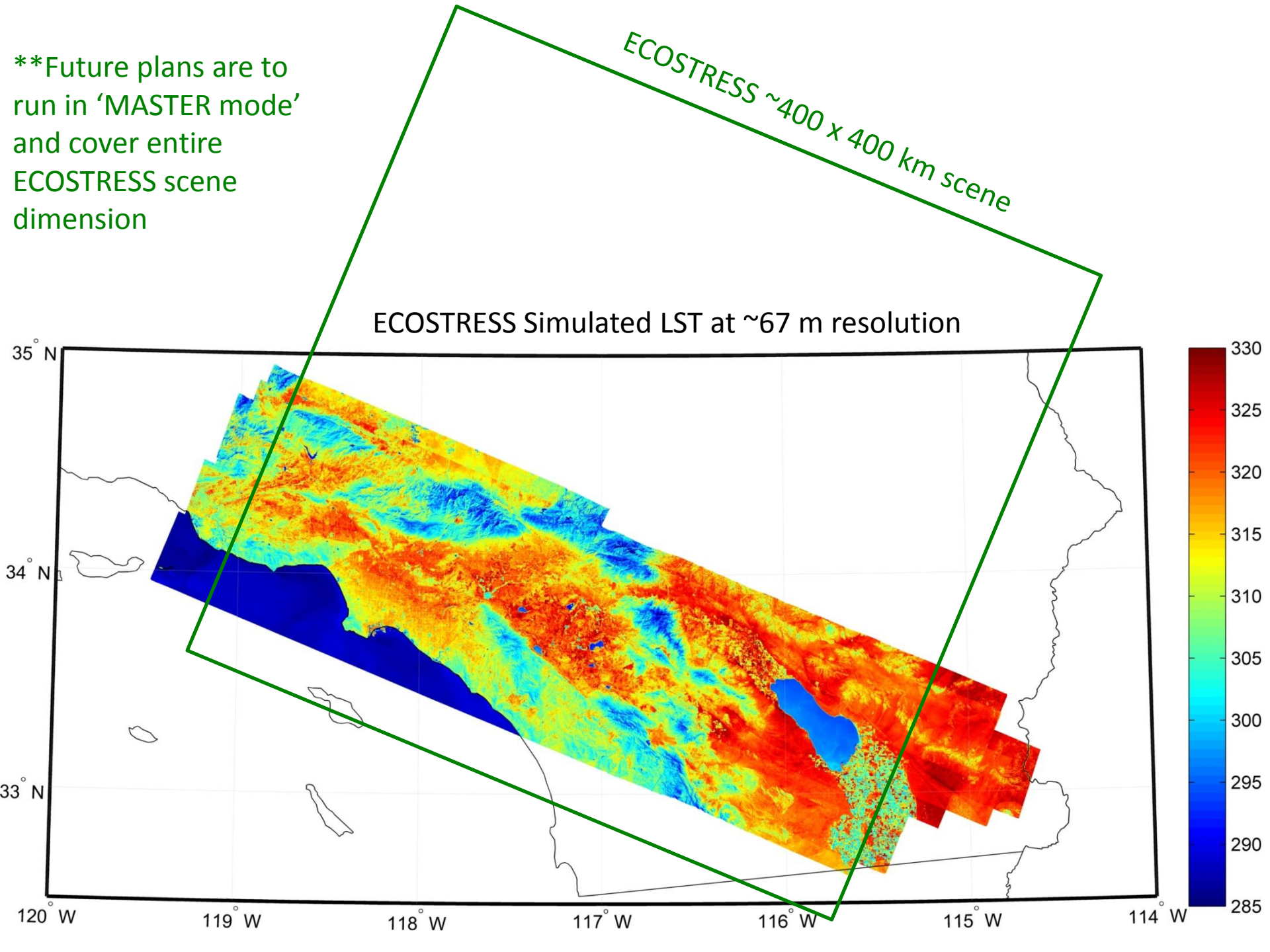
$$\epsilon(ECOSTRESS)_2 = 1.0189\ \epsilon(MASTER)_2\ - 0.0190$$

$$\epsilon(ECOSTRESS)_3 = 0.9889\ \epsilon(MASTER)_3 + 0.0096$$

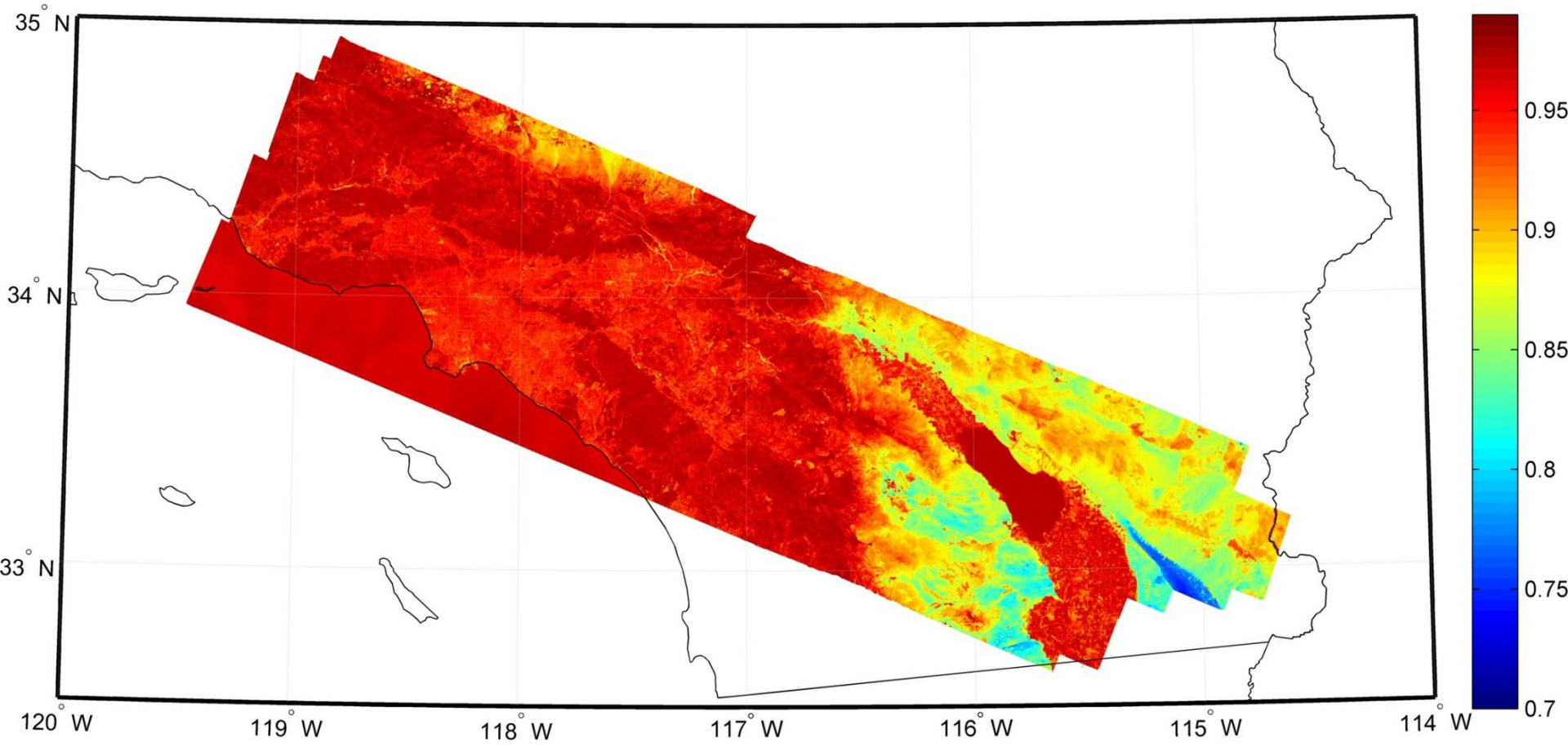
$$\epsilon(ECOSTRESS)_4 = 0.1364\ \epsilon(MASTER)_6 + \ 0.3737\ \epsilon(MASTER)_7\ + 0.4811$$

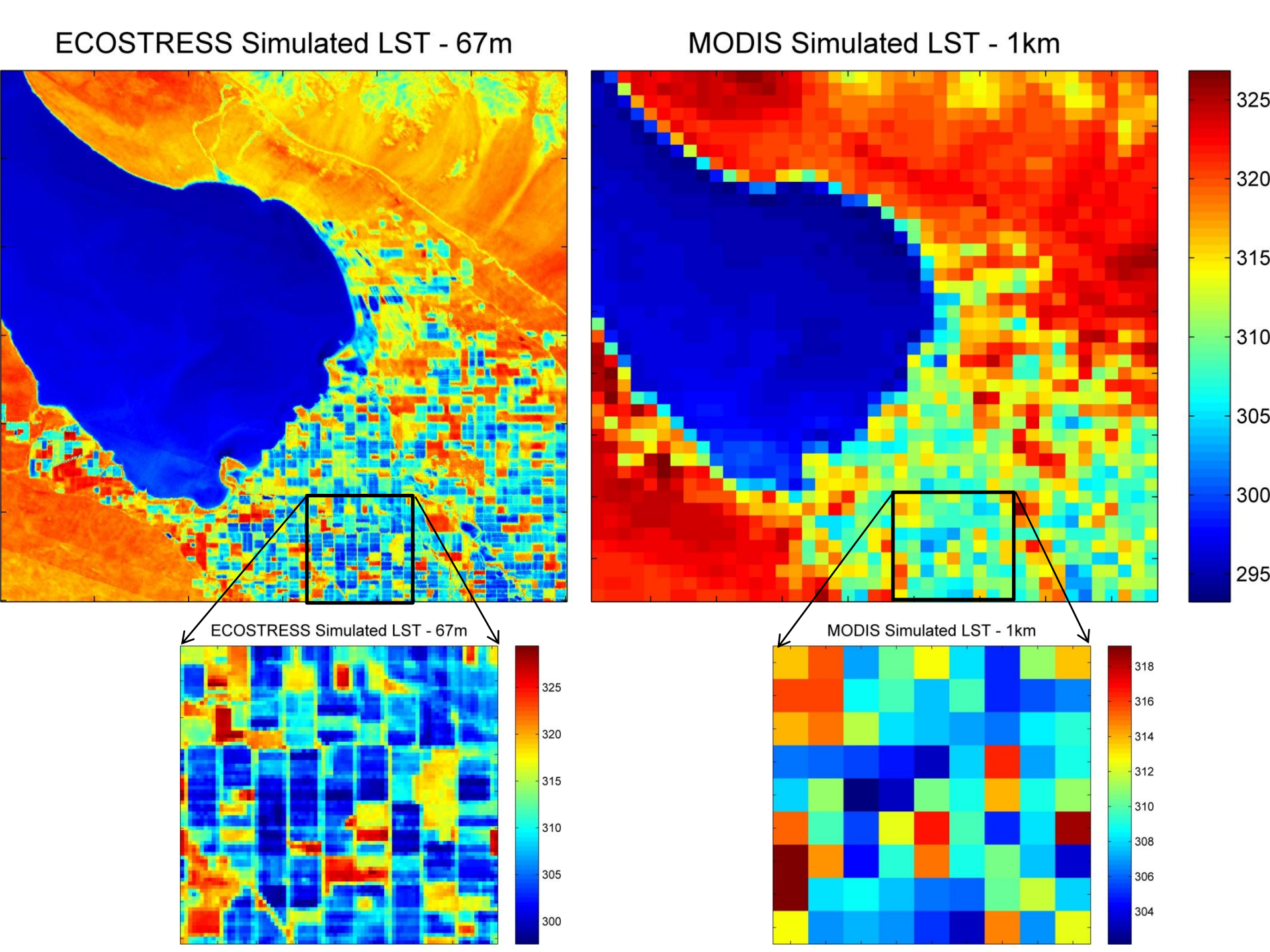
$$\epsilon(ECOSTRESS)_5 = 1.1633\ \epsilon(MASTER)_7 - 0.0870\ \epsilon(MASTER)_8 - \ 0.0741$$

**Future plans are to run in 'MASTER mode' and cover entire ECOSTRESS scene dimension

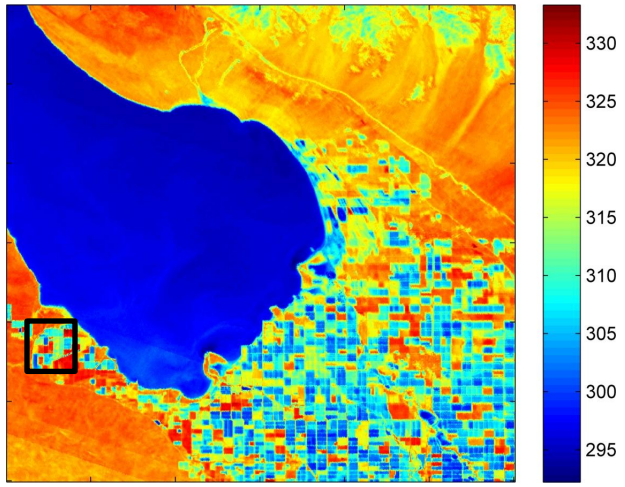


ECOSTRESS Simulated Emissivity (9.1 micron) at 67 m resolution




ECOSTRESS Simulated LST - 67m
MODIS Simulated LST - 1km
325
320
315
310
305
300
295
ECOSTRESS Simulated LST - 67m
325
320
315
310
305
300
MODIS Simulated LST - 1km
318
316
314
312
310
308
306
304

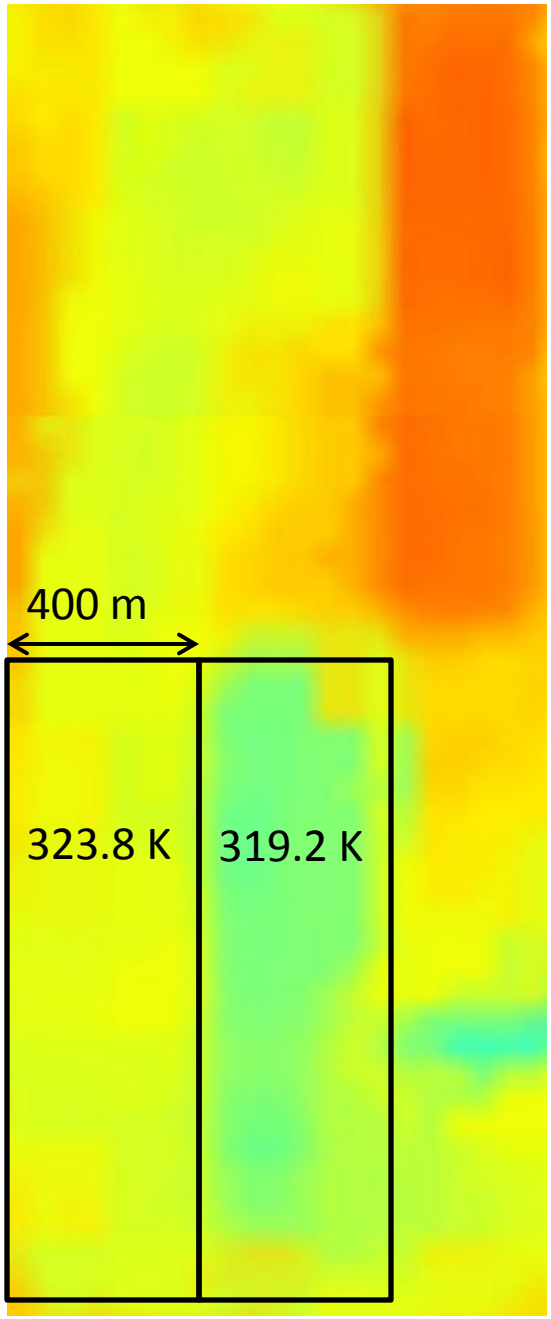
ECOSTRESS Simulated LST - 67m



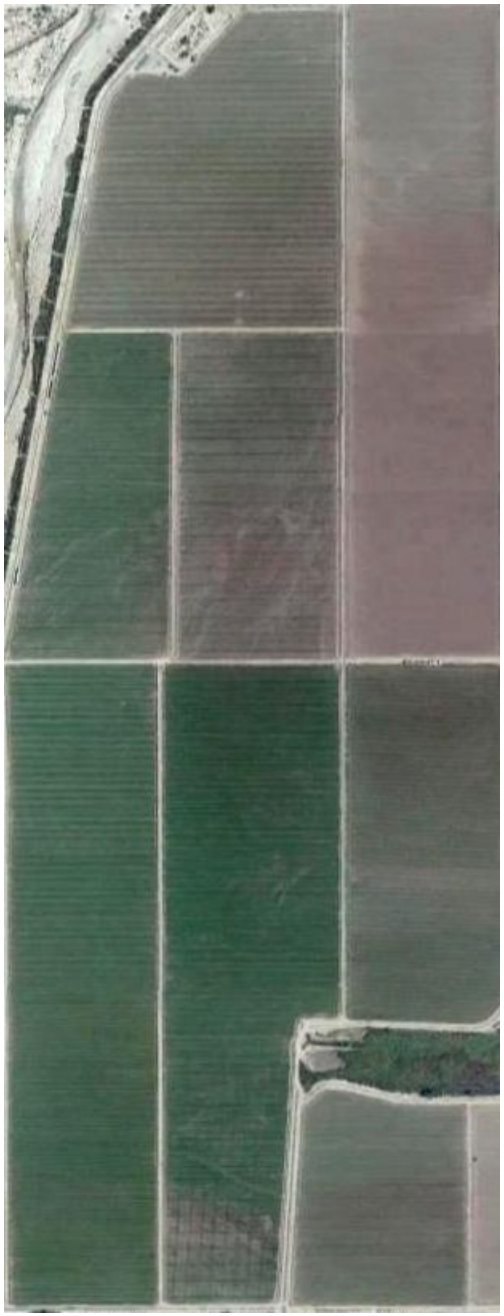
1. **Signatures of vegetation stress are manifested in the LST signal *before* any visible deterioration of vegetation cover occurs.**

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

MASTER LST: 08/26/2014



Google Earth: 08/28/14



Summary

- ECOSTRESS L2 Products:
  - Land Surface Temperature (LST)
  - Spectral Emissivity (5 bands)
  - Broadband Emissivity
- Well defined and strong algorithm heritage (ASTER/MODIS/VIIRS)
- Uncertainty Analysis Completed (~1 K accuracy)
- Algorithm optimization underway: C++
- Simulated ECOSTRESS L2 Products using MASTER TIR for end-user testing/support

ECOSTRESS Products

Data Products	Description	Information Required	Plans for Validation/Reprocessing
Level-0	Reconstructed, unprocessed instrument data at full resolution; any communication artifacts removed.	Raw science data packets	Automated process, no reprocessing needed.
Level-1A	Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients.	Level-0 raw data	Automated process, minimal reprocessing.
Level-1B	Level 1a data that have been processed to sensor units by applying the coefficients for radiometric calibration and geometric resampling	Level-1A & radiometric and geometric coefficients	Automated process, with full reprocessing as needed. Validation of at-sensor radiance using data from autonomous Lake Tahoe and Salton Sea cal/val sites.
Level-2	LST and spectral emissivity	Level-1B data, cloud mask, NWP atmospheric profiles, ASTER digital elevation data.	Automatic process, with full reprocessing as necessary (e.g. algorithm changes). Validation (T-based and R-based) using a global set of sites including water, vegetation, sand dunes, grasslands, and soil land cover types.
Level-3	Evapotranspiration (ET),	Level-2 products, VNIR data from Landsat, met. data from NCEP.	Reprocessing as needed based on Level 2 reprocessing. Validation with eddy covariance data from FLUXNET sites (global).
Level-4	Water Use Efficiency (WUE), Evaporative Stress Index (ESI)	Level-3 products, GPP	Reprocessing as needed based on Level 2 and 3 reprocessing. Validation with eddy covariance data from FLUXNET sites (global).