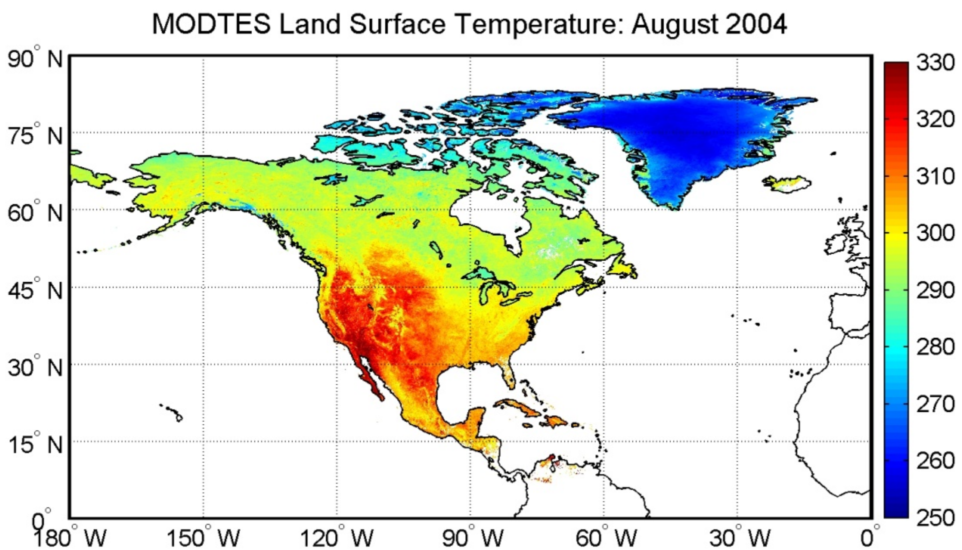
ECOSTRESS L1 and L2 Calibration and Validation



Simon J. Hook and the ECOSTRESS Team

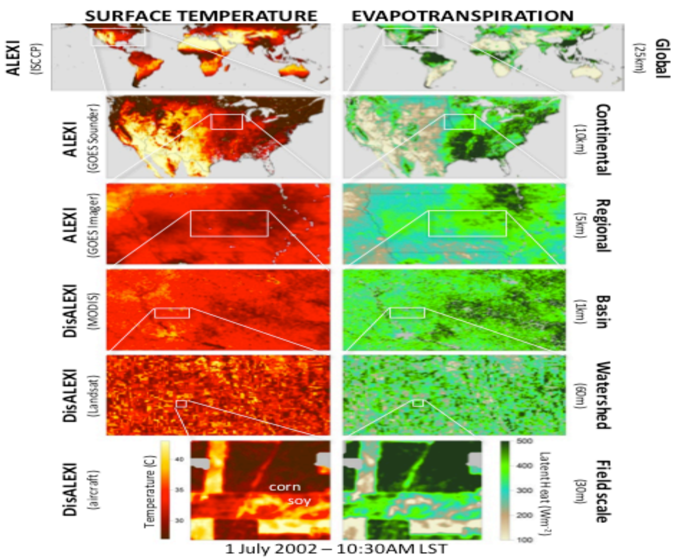
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Outline

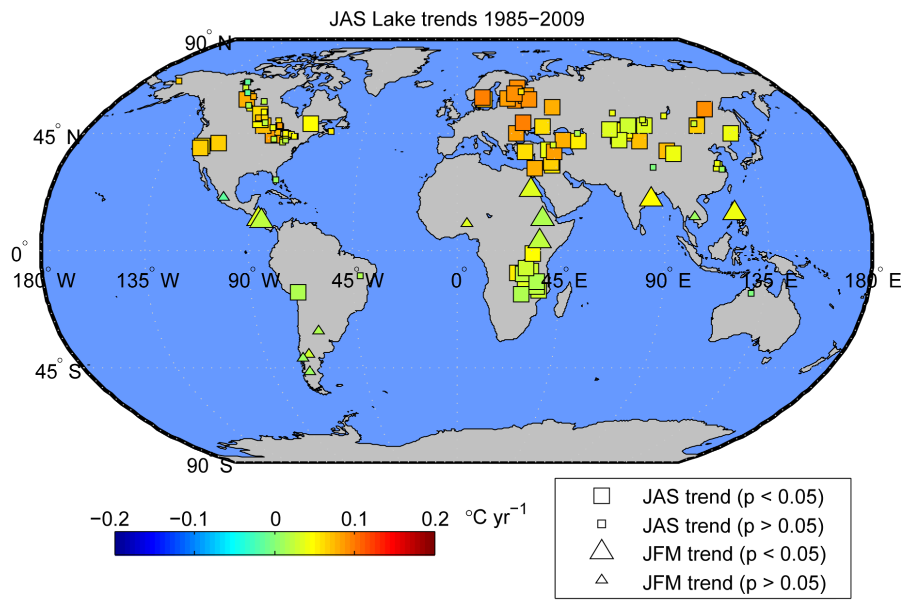
- Introduction
  - Science Use
- Theoretical Basis
  - Methods
- L1 and L2 Product Flow
- Validation
  - T-val
  - R-val
- Uncertainties
- Summary and Conclusions

Earth Science Use of LST&E

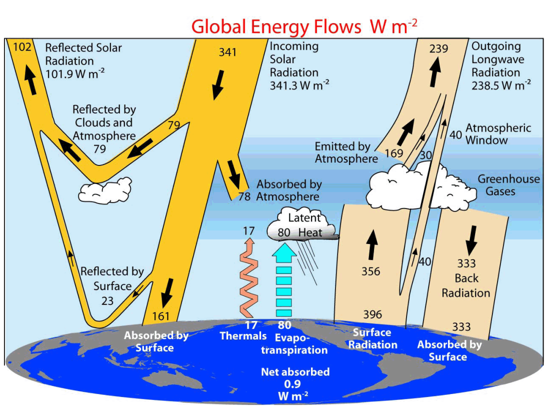
Evapotranspiration (drought monitoring)



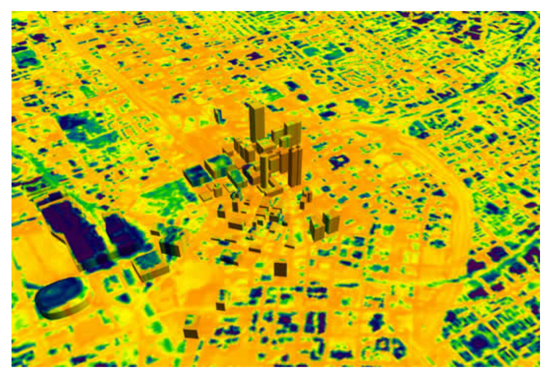
Understanding Climate Change



Surface Energy Balance Models



Urban Heat Island Studies



Theoretical Basis: Planck Formula

$$B_\lambda = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right)-1\right]}$$

where :

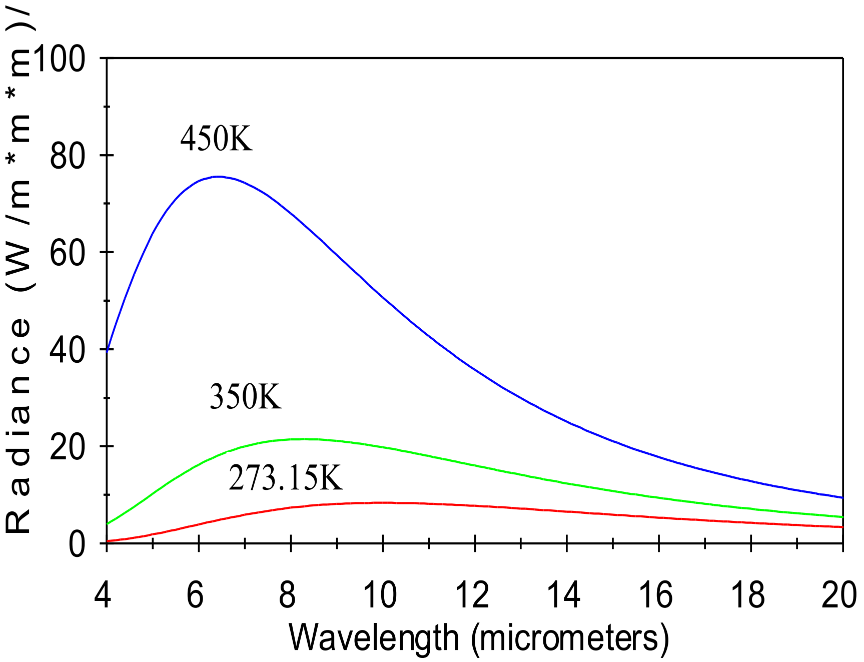
B_λ = blackbody spectral exitance.

λ = wavelength

T = absolute temperature.

C_1 = first radiation constant.

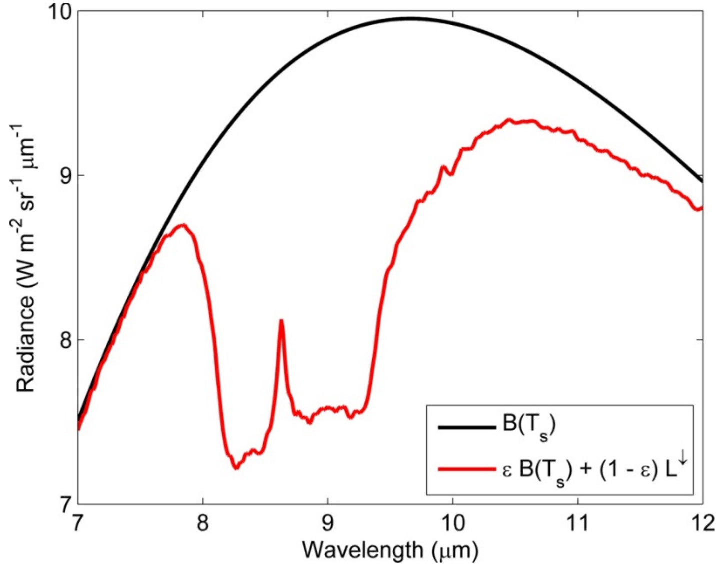
C_2 = second radiation constant.



As the temperature increases the peak in the Planck function shifts to shorter and shorter wavelengths

Theoretical Basis: Temperature and Spectral Emissivity

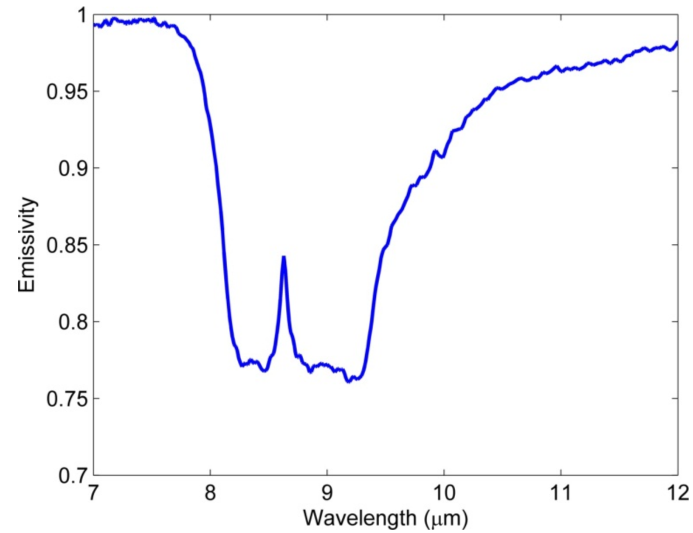
Materials are not perfect blackbodies, but instead emit radiation in accordance with their own characteristics. The ability of a material to emit radiation can be expressed as the ratio of the spectral radiance of a material to that of a blackbody at the same temperature. This ratio is termed the spectral emissivity:



$$\varepsilon_{\lambda} = L_{\lambda}(\text{Material}) / L_{\lambda}(\text{Blackbody})$$

or for a material at a given wavelength

$$L = \varepsilon \, B\,(\mathrm{T})$$



Thermal Infrared Radiative Transfer

Surface Radiance

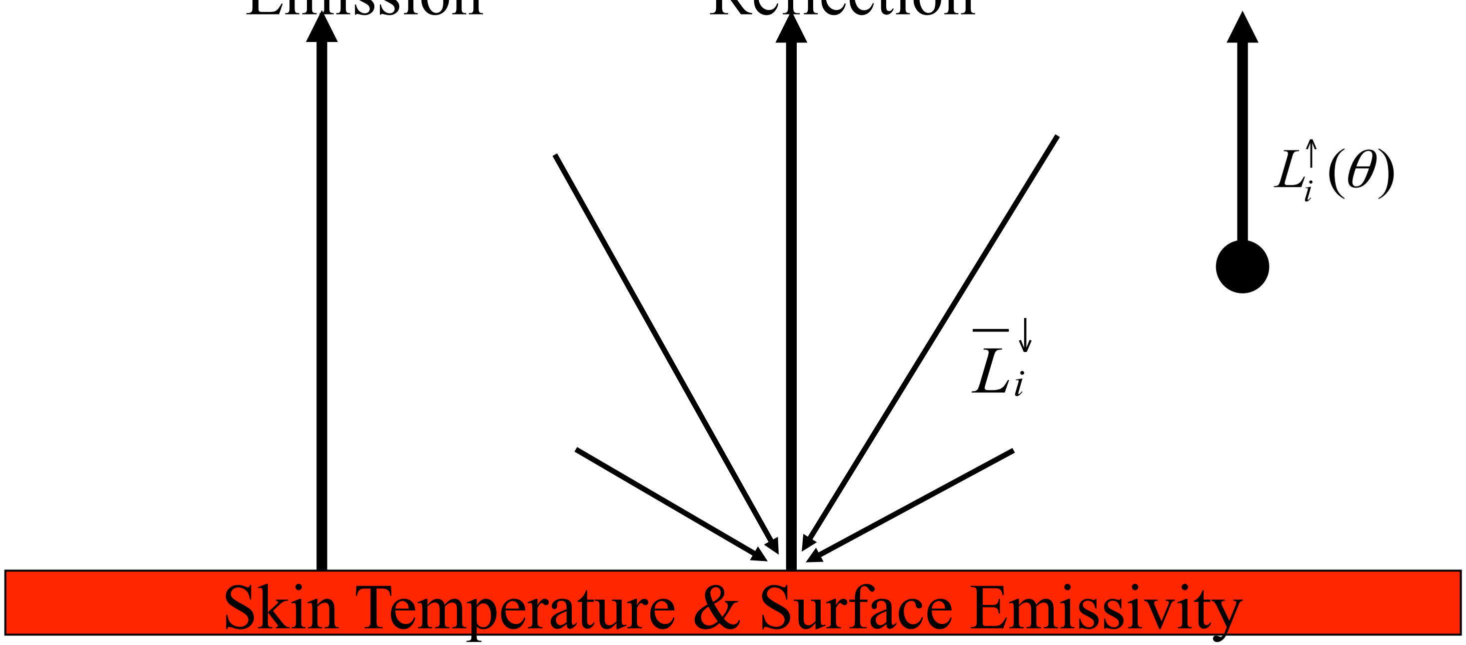
TOA Radiance

$$L_i(\theta) = \underbrace{\tau_i(\theta)\cdot e_i \cdot B_i(T_S)}_{\text{Surface Emission}} + \underbrace{\tau_i(\theta)\cdot(1-e_i)\cdot \overline{L}_i^{\downarrow}}_{\text{Surface Reflection}} + \underbrace{\int B_i(T(P))\,d\tau_i}_{\text{Atmospheric Emission}}$$

Surface Emission

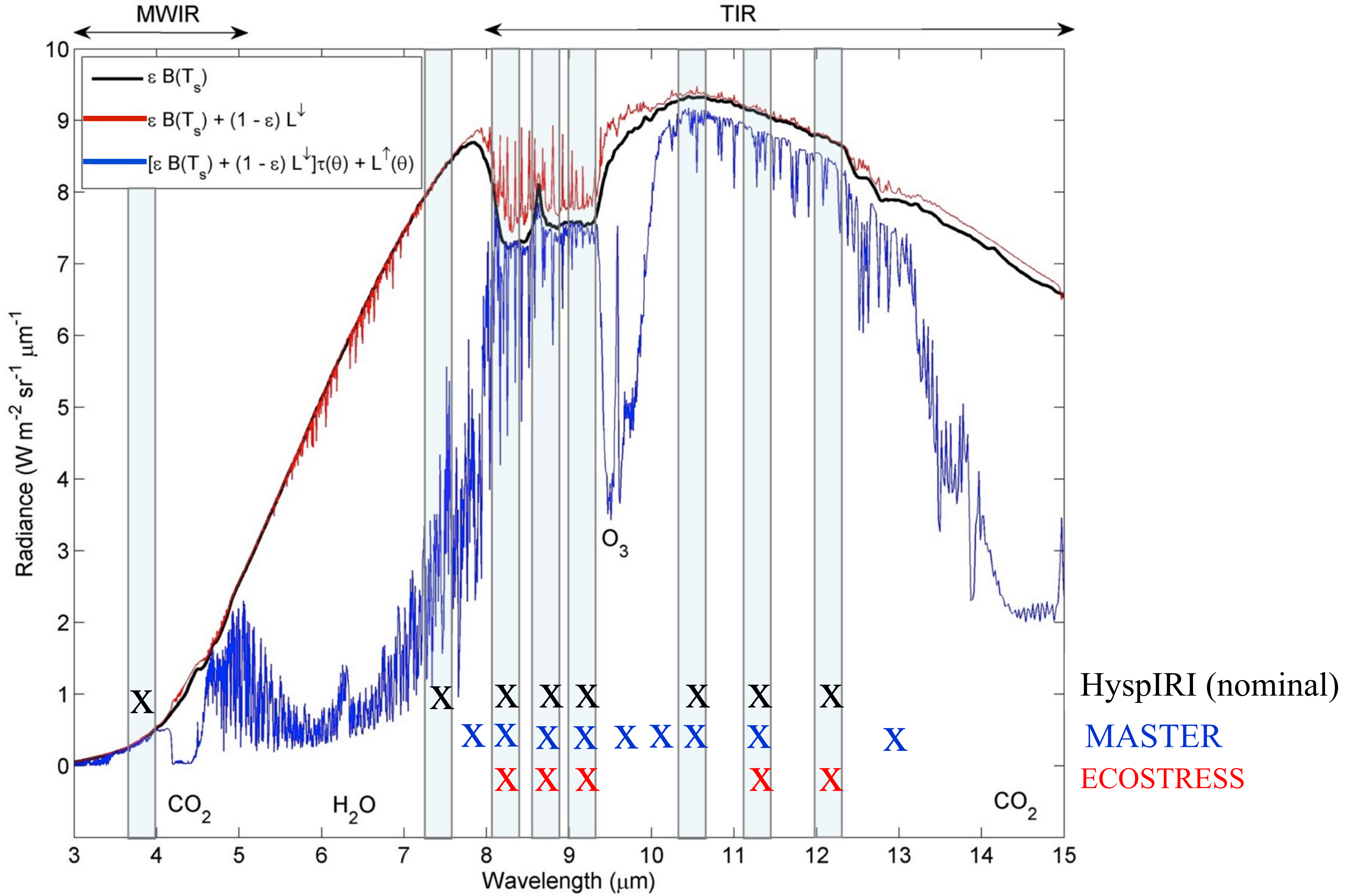
Surface Reflection

Atmospheric Emission

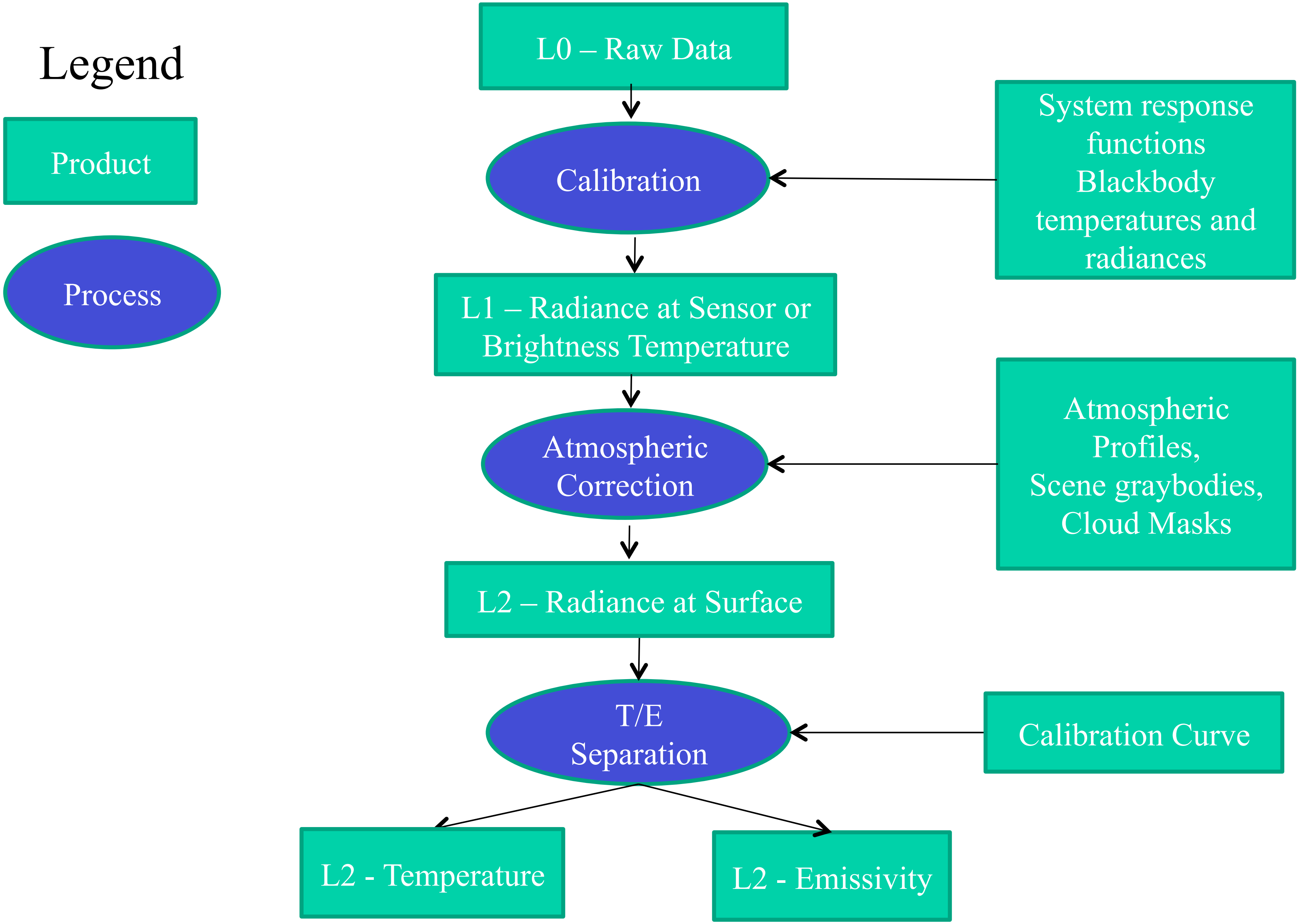


Thermal Infrared Physics

$$L_{sat,\lambda} = \left[\varepsilon_\lambda B_\lambda(LST) + (1 - \varepsilon_\lambda) L^{\downarrow}_{sky,\lambda}\right] \tau_\lambda + L^{\uparrow}_{sky,\lambda}$$



ECOSTRESS L1/L2 Product Flow



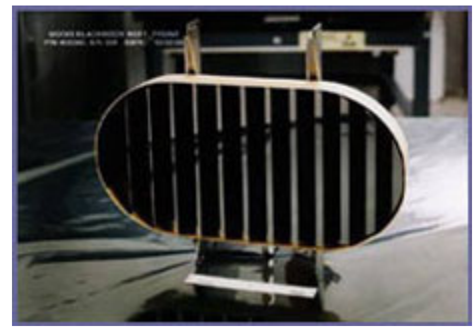
NASA L2 LST&E Product Characteristics

	ECOSTRESS (ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station)	ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	MODIS* (Moderate Resolution Imaging Spectroradiometer)	AIRS (Atmospheric Infrared Sounder)
Satellite	ISS (2017)	Terra (2000)	Terra/Aqua (2000/2002)	Aqua (2002)
Algorithm	TES Calibration Curve with WVS	TES Calibration Curve with WVS	TES Calibration Curve with WVS	Regression plus retrieval
Temporal sampling	5 day repeat (varying times)	16 day repeat (1030 AM/PM)	Twice-daily (10:30/1:30 AM/PM)	Twice-daily (10:30 AM/PM)
Nadir Spatial resolution	40 x 60 m	90 m	1 km	13 km
Spectral resolution	5 TIR bands (8-12 μm)	5 TIR bands (8-12 μm)	7 MIR/TIR bands (3.7-14 μm)	39 'hinge-points' (3.7-15.4 μm)
Swath Width	384 km	60 km	2330 km	1650 km

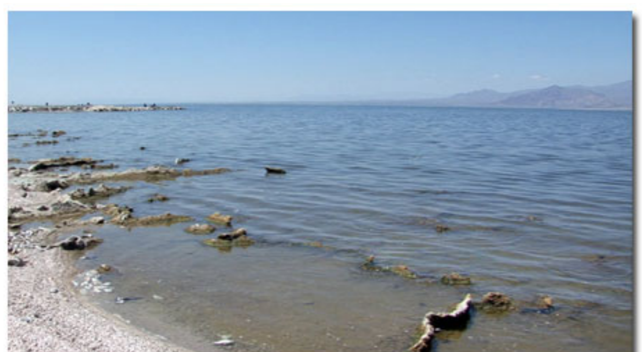
* VIIRS also available at 1 km

L1 Calibration and Validation

- Calibration
  - Two blackbodies, one temperature controlled



- Validation
  - Water targets



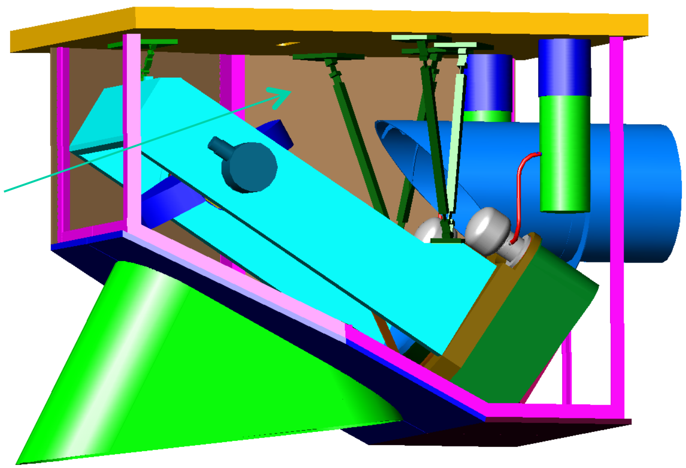
Lake Tahoe CA/NV

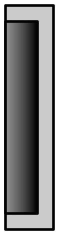
Salton Sea CA

PHyTIR Test Configuration

- Instrument is in air. Vacuum enclosure around focal-plane is evacuated (to be described in detail in mechanical presentation). Scan mirror rotating.

Blackbodies Added for ISS

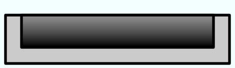




Room-temperature reference blackbody. Flat plate with corrugated, painted surface. Emissivity <1 acceptable.

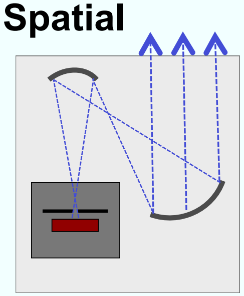
Test Sources Placed Within PhyTIR Scan Range

Radiometric



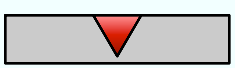
Variable-temperature blackbody: ≥ room temperature. Flat plate with corrugated, painted surface. Emissivity <1 acceptable.

Spatial



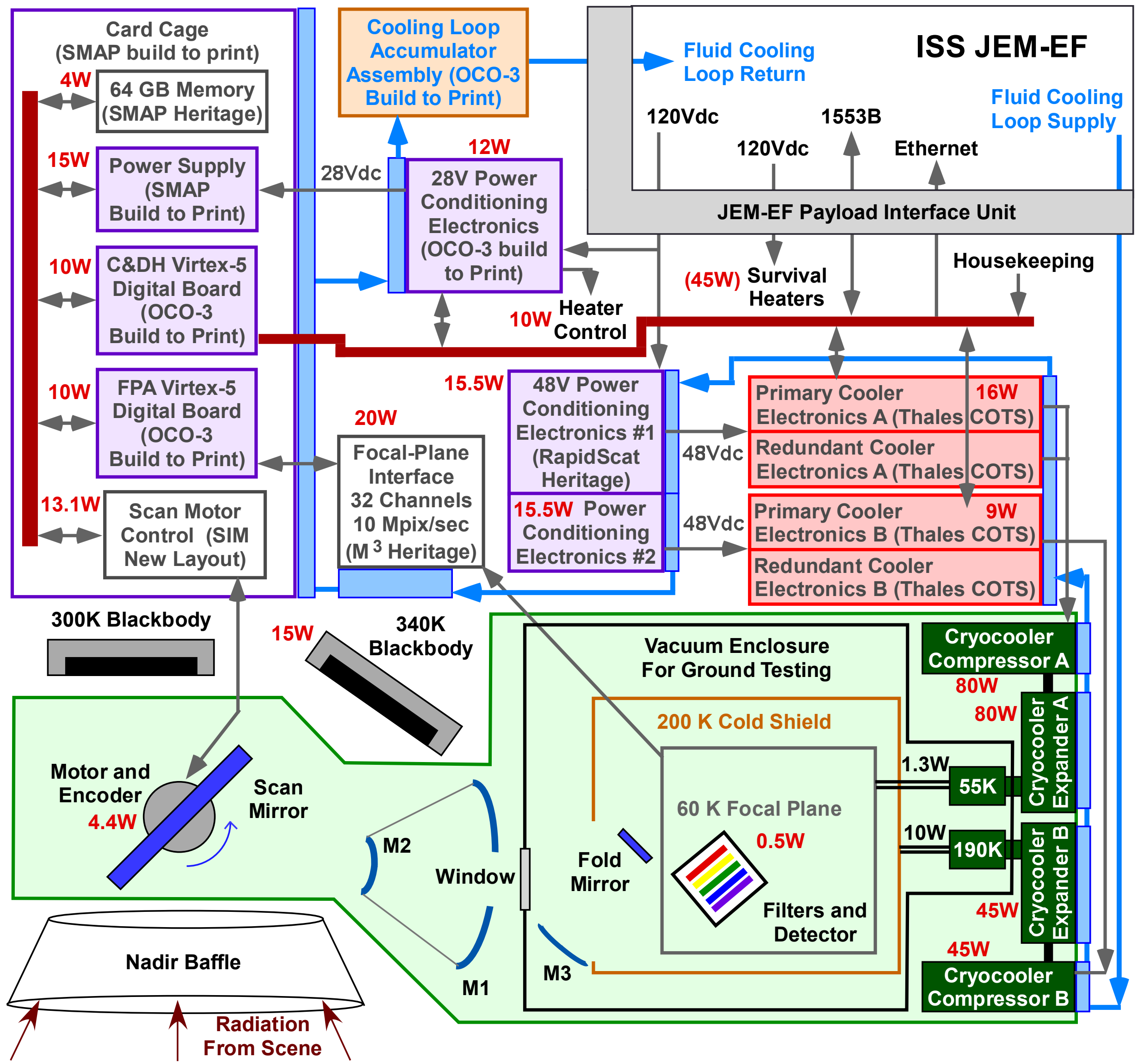
MCS Target Projector with slit source. Will underfill PHyTIR aperture.

Saturation

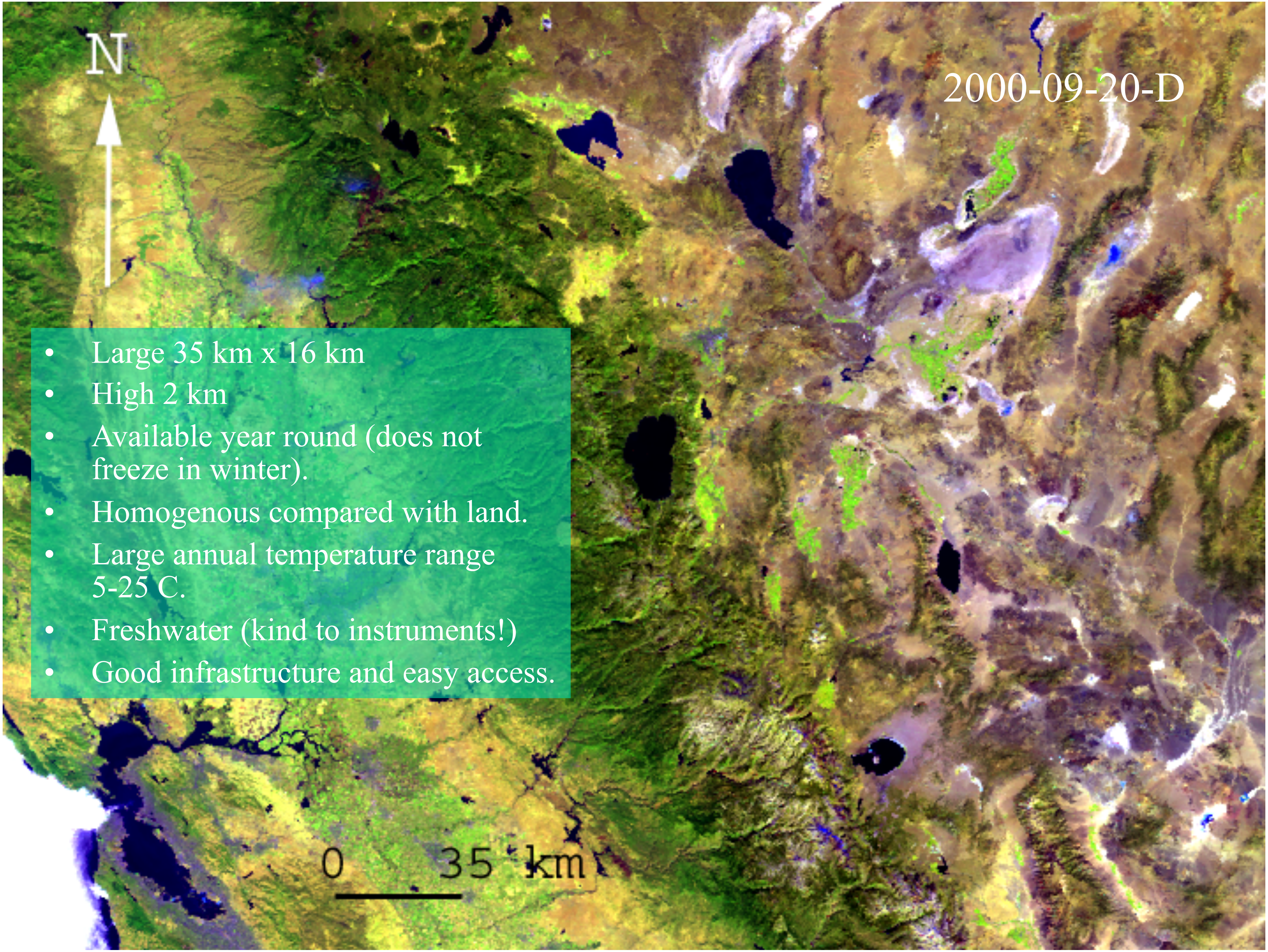


Small hot source. 295K to > 500 K.

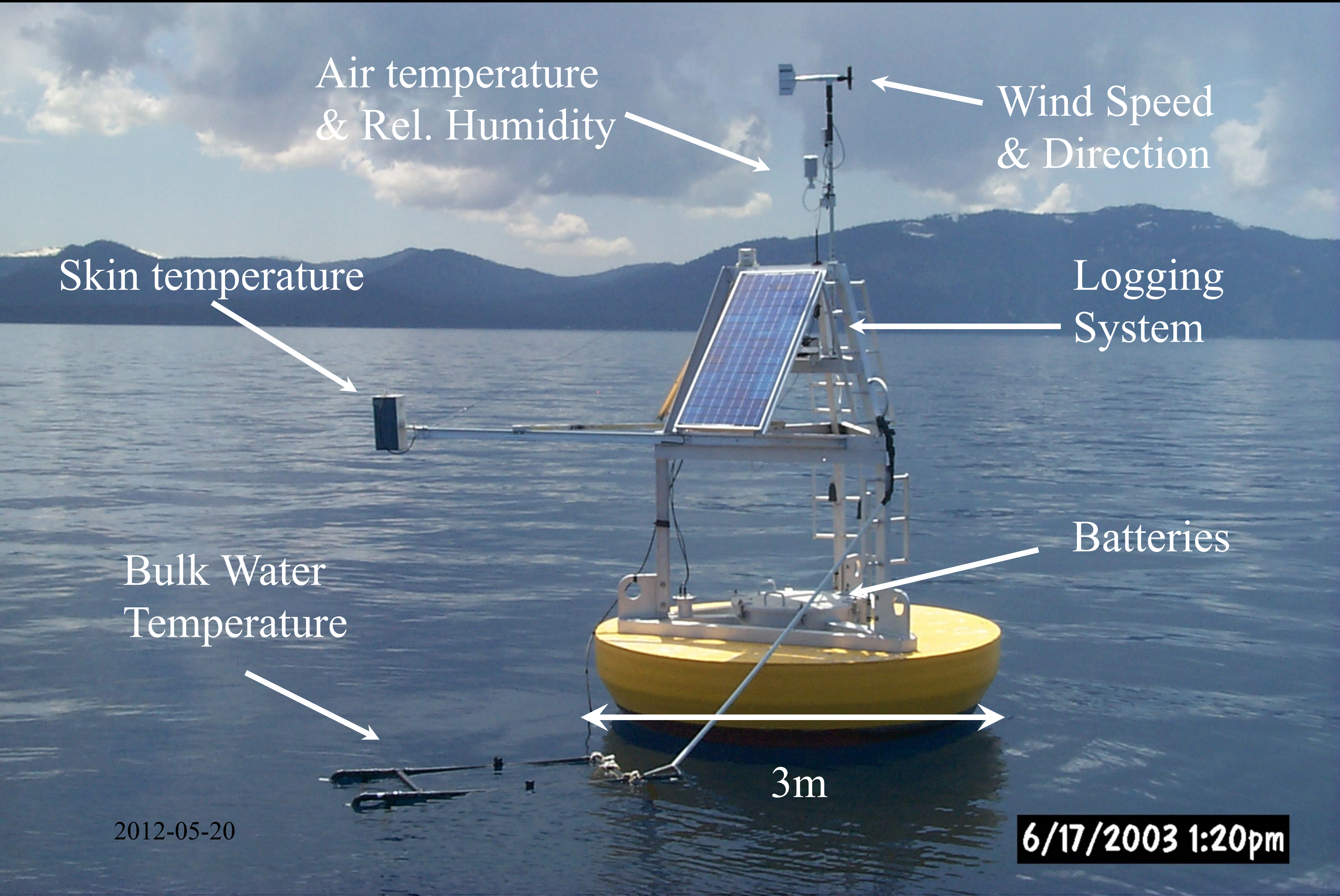
ECOSTRESS Design Layout



Existing Radiometer | Build to print electronics | COTS electronics | Build to print accumulator assembly | New design or layout based on heritage

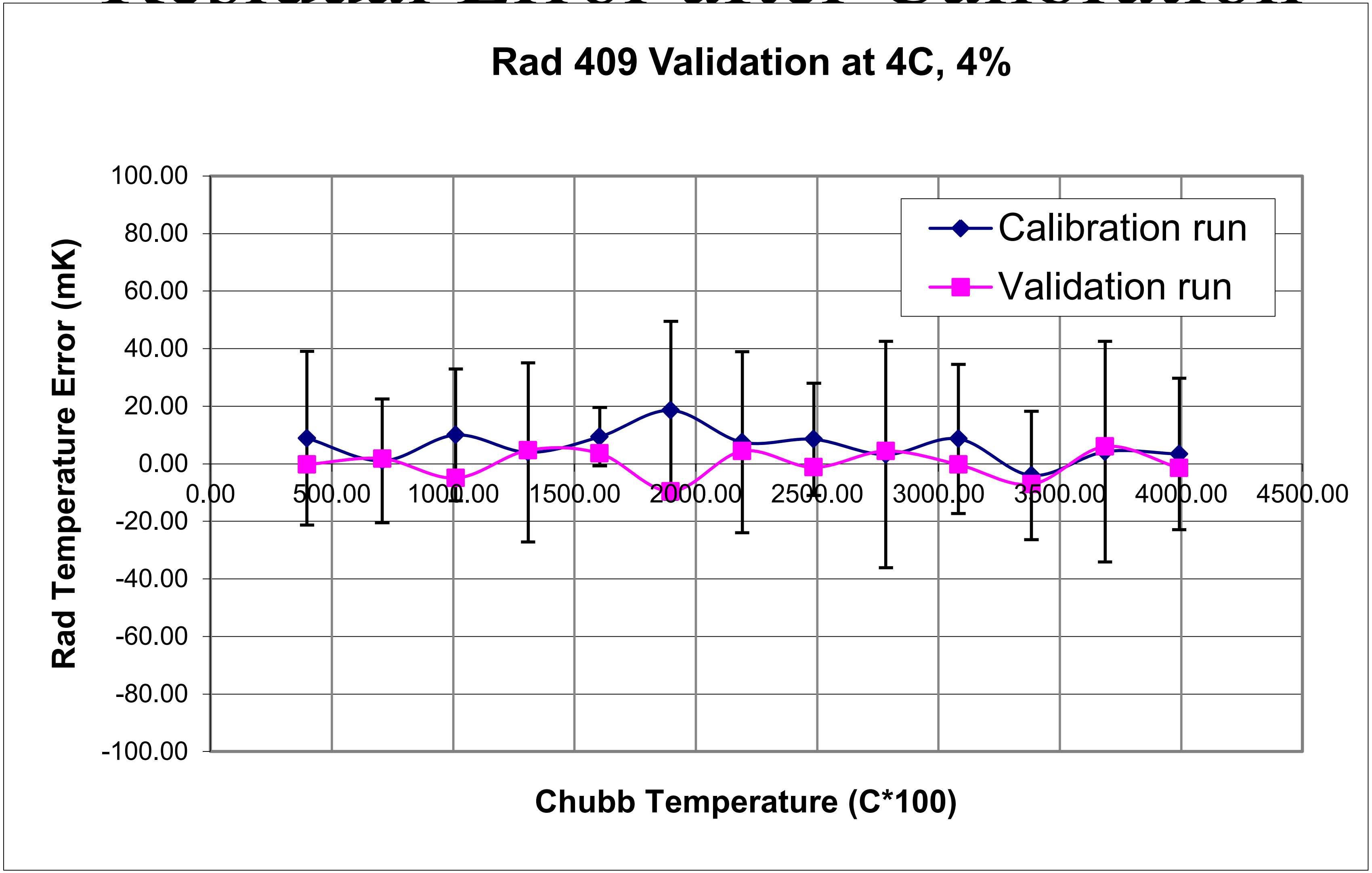

N
2000-09-20-D
• Large 35 km x 16 km
• High 2 km
• Available year round (does not freeze in winter).
• Homogenous compared with land.
• Large annual temperature range 5-25 C.
• Freshwater (kind to instruments!)
• Good infrastructure and easy access.
0 35 km

TB3 Installed 11-04-2002



Radiometer Calibration

Residual Error after Calibration



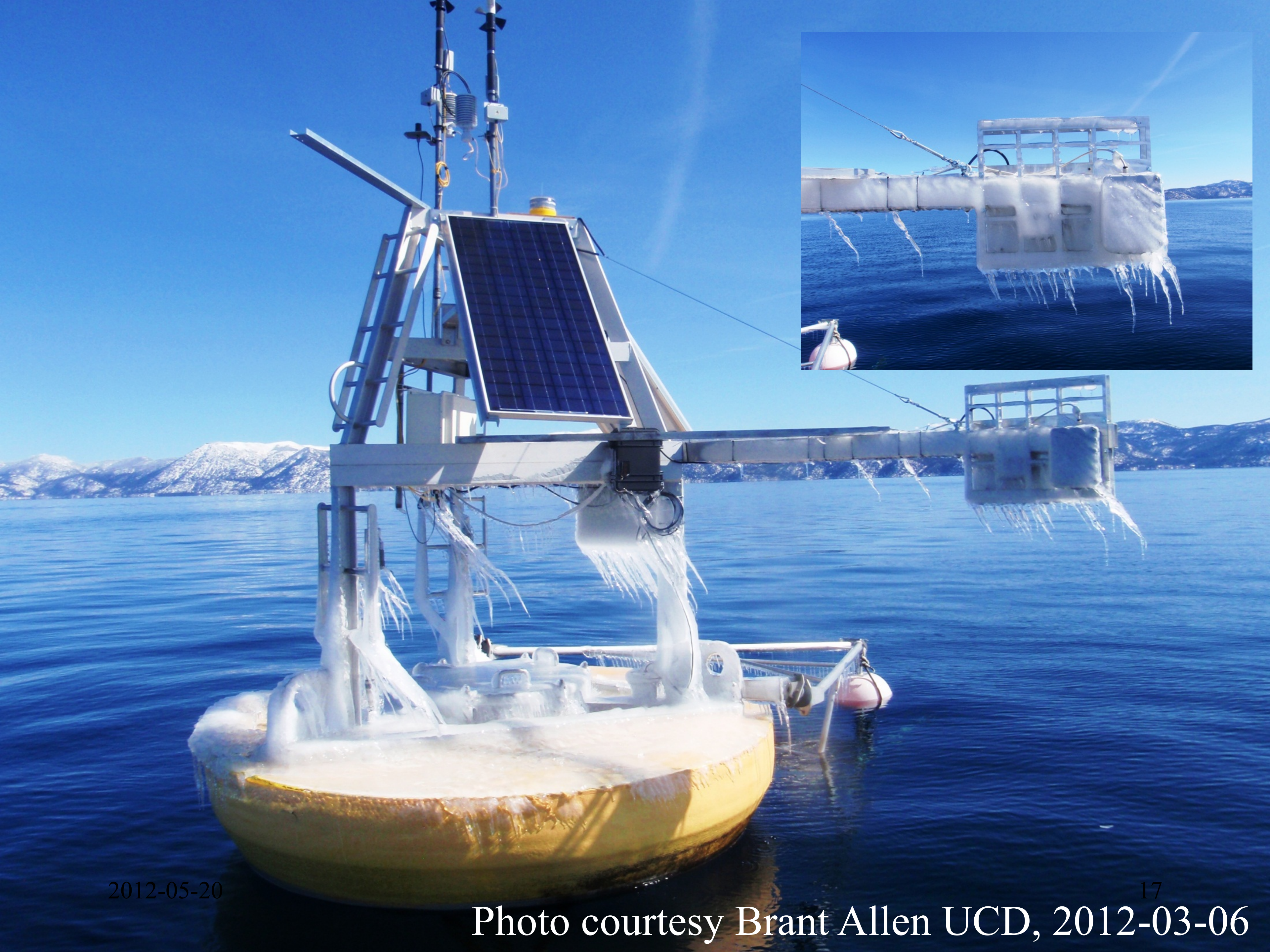
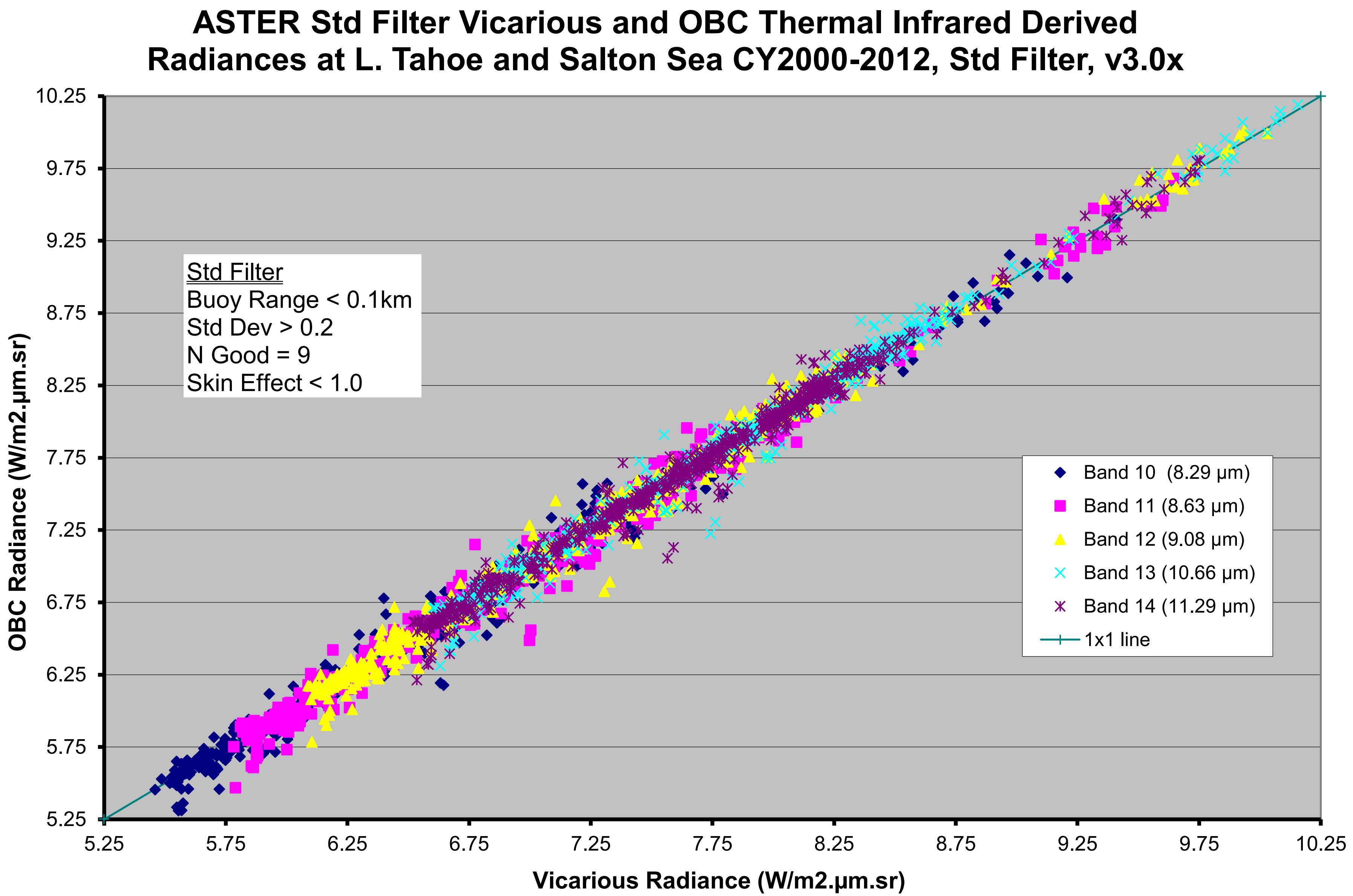
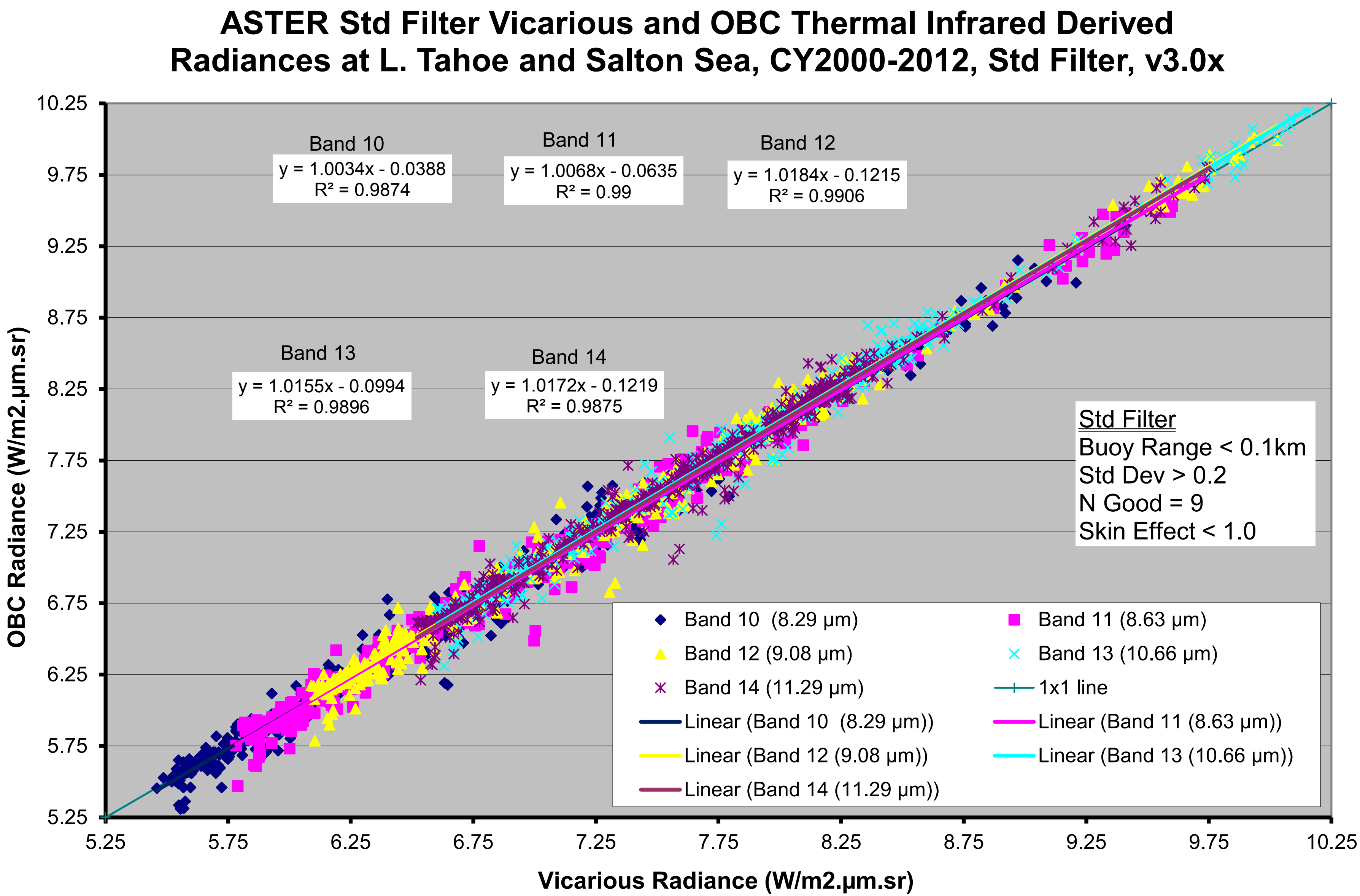


Photo courtesy Brant Allen UCD, 2012-03-06



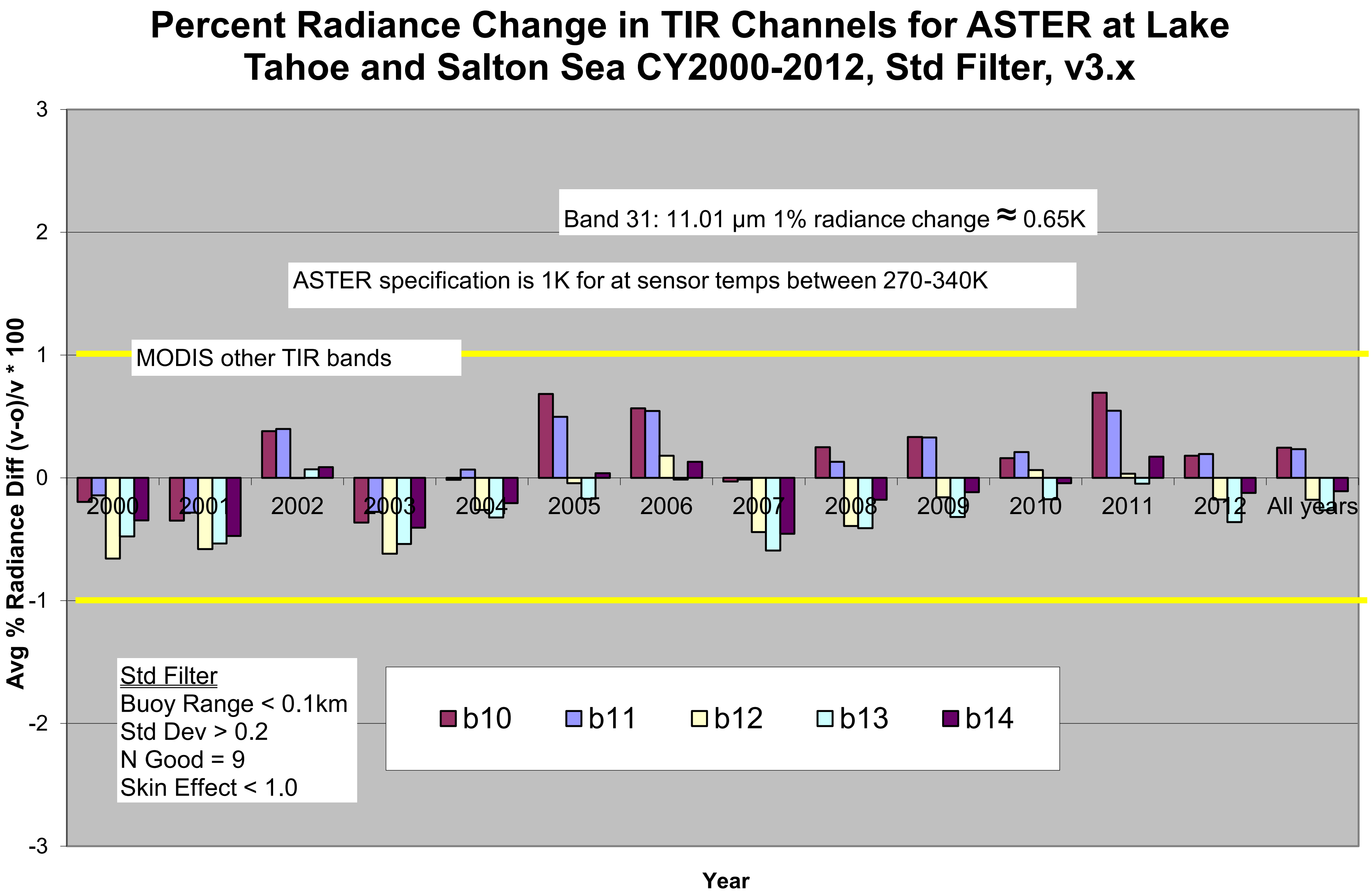
Data clearly fall on 1x1 line. High radiance values from Salton Sea



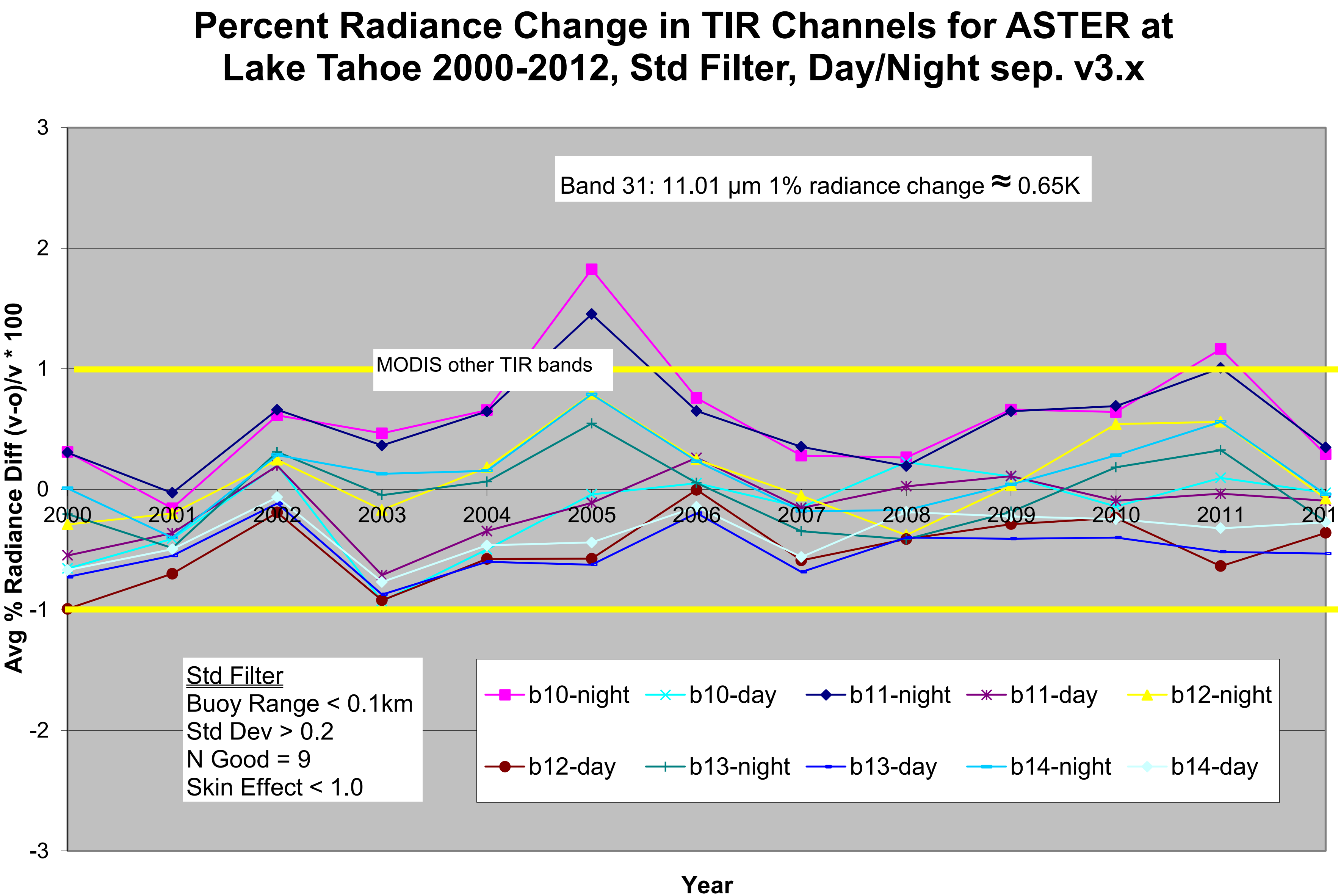
Excellent best fit lines obtained in all bands. Rsquared is typically 0.98. Data follow 1x1 line.

Delta Vicarious and OBC Brightness Temp. for ASTER TIR Channels at L. Tahoe and Salton Sea CY2000-2012, Std Filter v3.x

If you look at the individual points they typically scatter between +/- 1K with a few outliers. ASTER specification for 270-340K is 1K. Need to check outliers more!

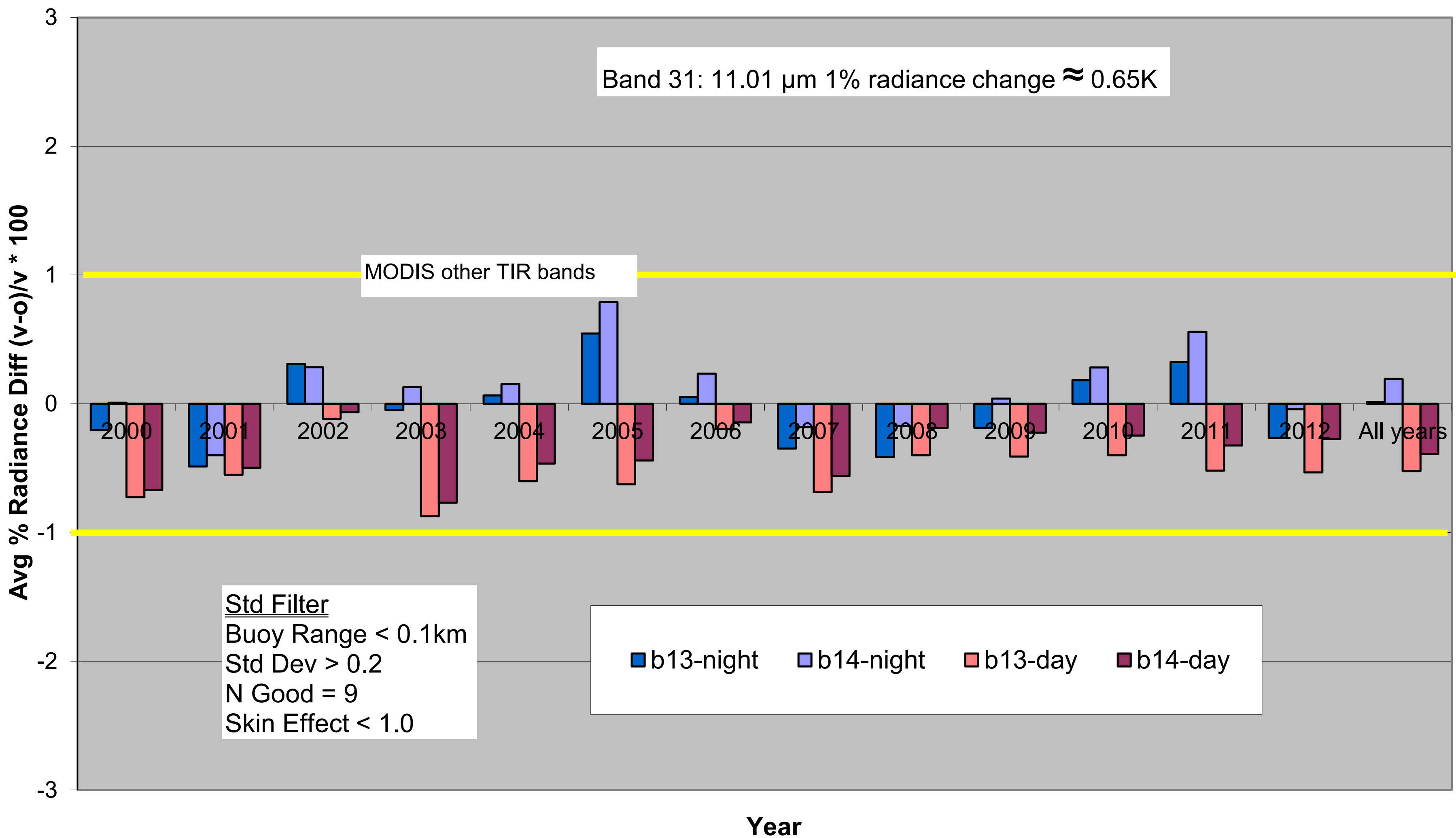


If look at mean radiance differences for each year they are typically less than 0.5% or 0.3K.

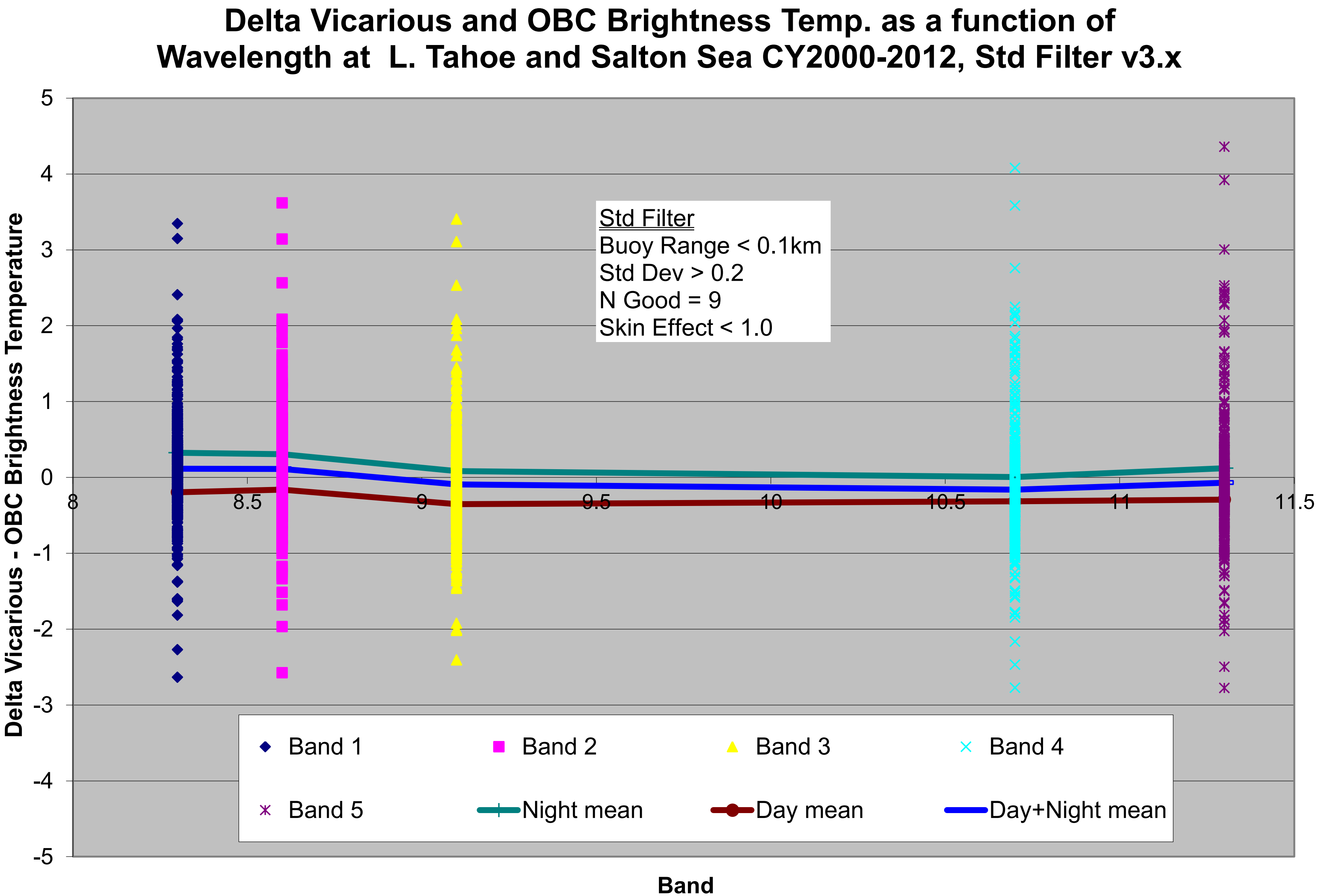


If look at individual bands see that night data problem in 2005

Percent Radiance Change in TIR Channels for ASTER at Lake Tahoe and Salton Sea CY2000-2012, Std Filter v3.x

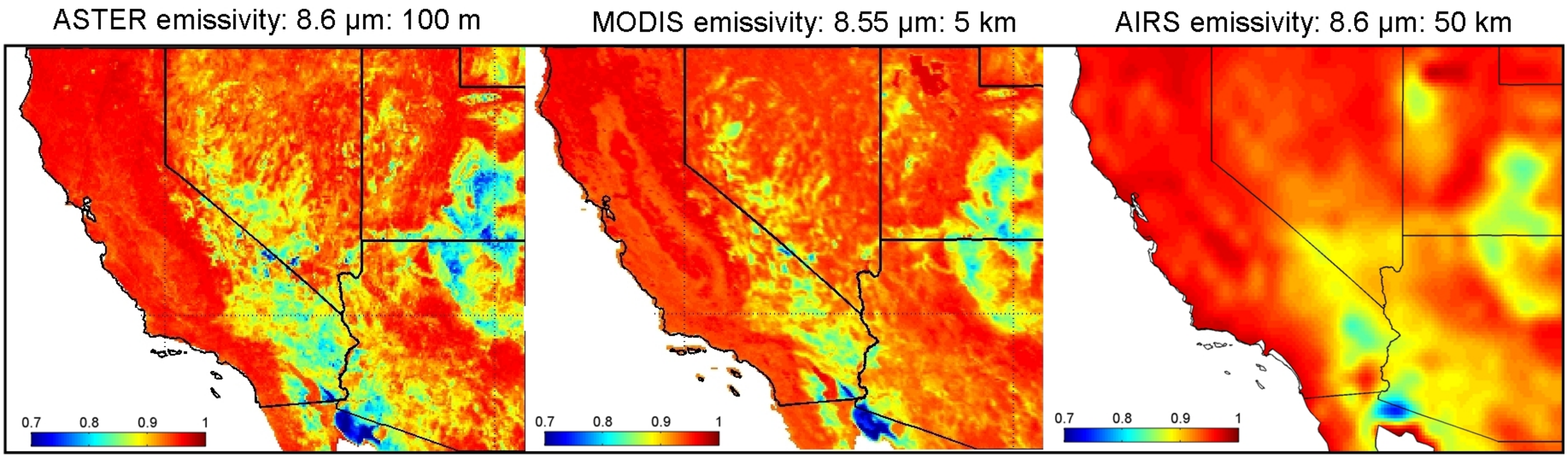


If look at different between day and night for two clear TIR channels (minimum atmospheric effect) see that daytime values tend to be lower than nighttime. Cause for this is unknown but is observed with other sensors, e.g. Landsat. Likely explanation is RT model or bulk-skin effect.



Channels 13 and 14 used to check bias since least affected by the atmosphere. Band 10 is most affect by the atmosphere.

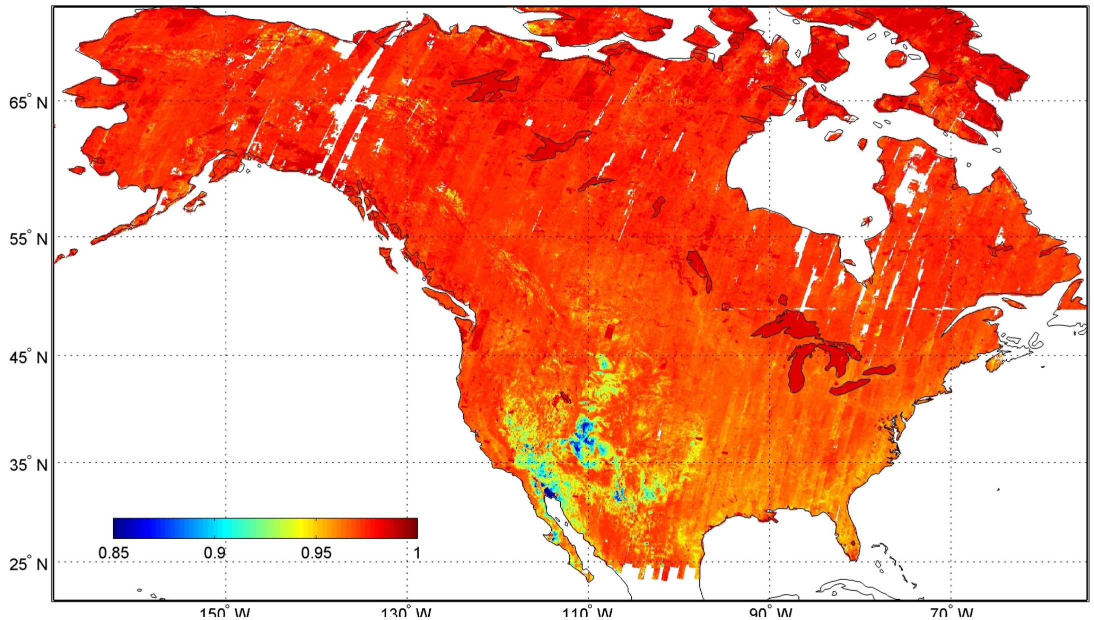
Level 2 Validation – Temperature and Emissivity



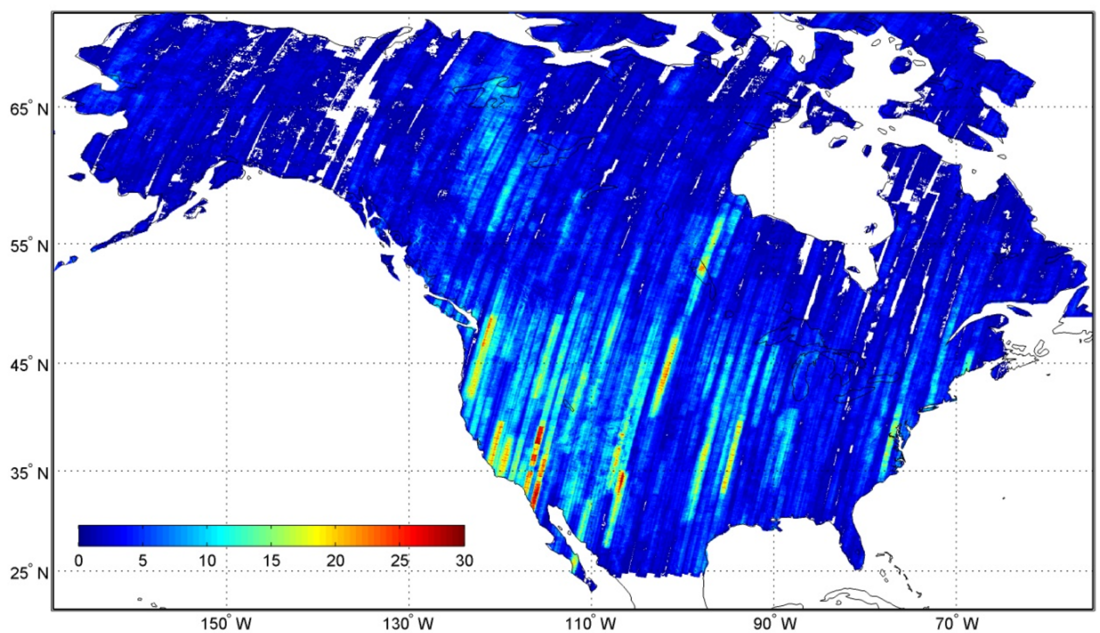
- Good correlation at regional scale, but differences when look in detail. Differences due to different spatial, spectral, and temporal characteristics of the sensors, including algorithmic differences.
- Currently validate data LST&E data from ASTER, MODIS, AIRS, Landsat, VIIRS, will use same techniques with ECOSTRESS

NAALSED Summertime Emissivity (Jul-Sep 2000-2010), Band 12 (9.1 μm), 5km

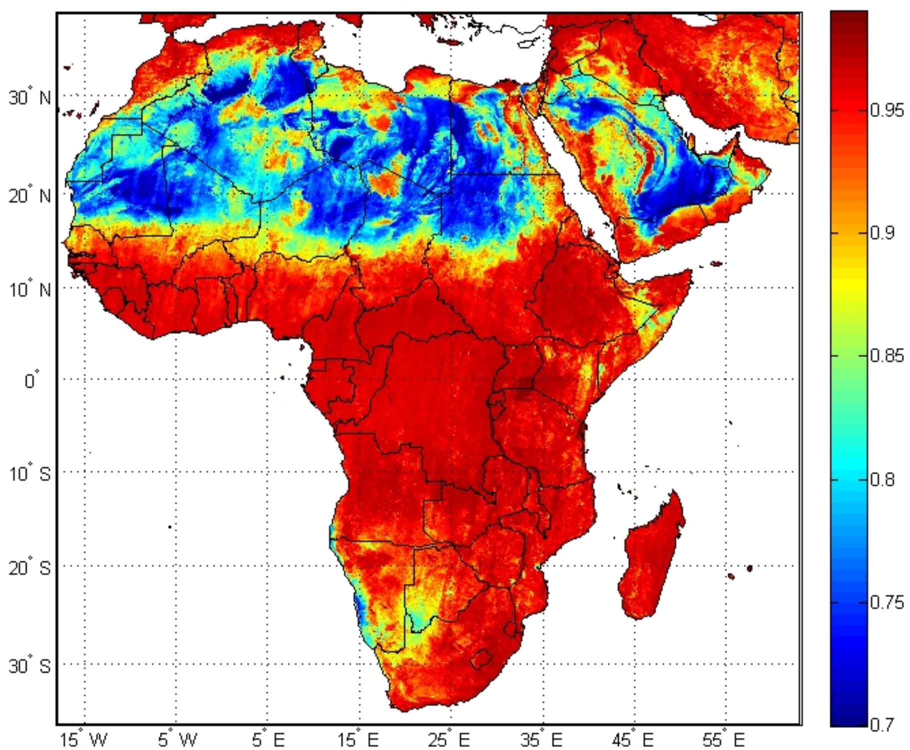
Lowest emissivity over southwest

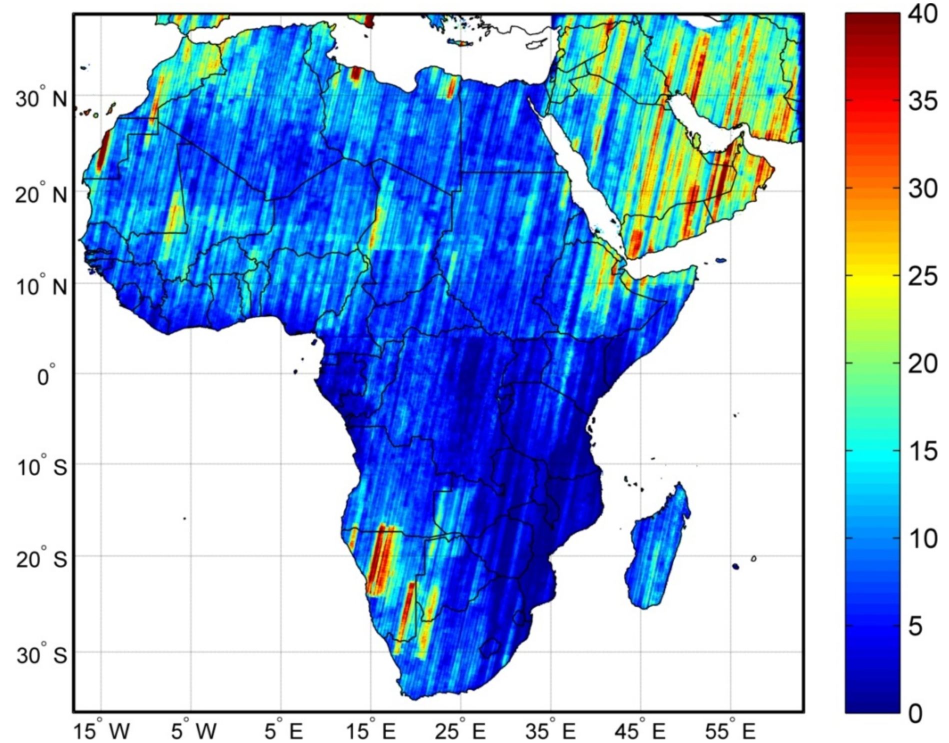


Number of pixels averaged for a given location ->



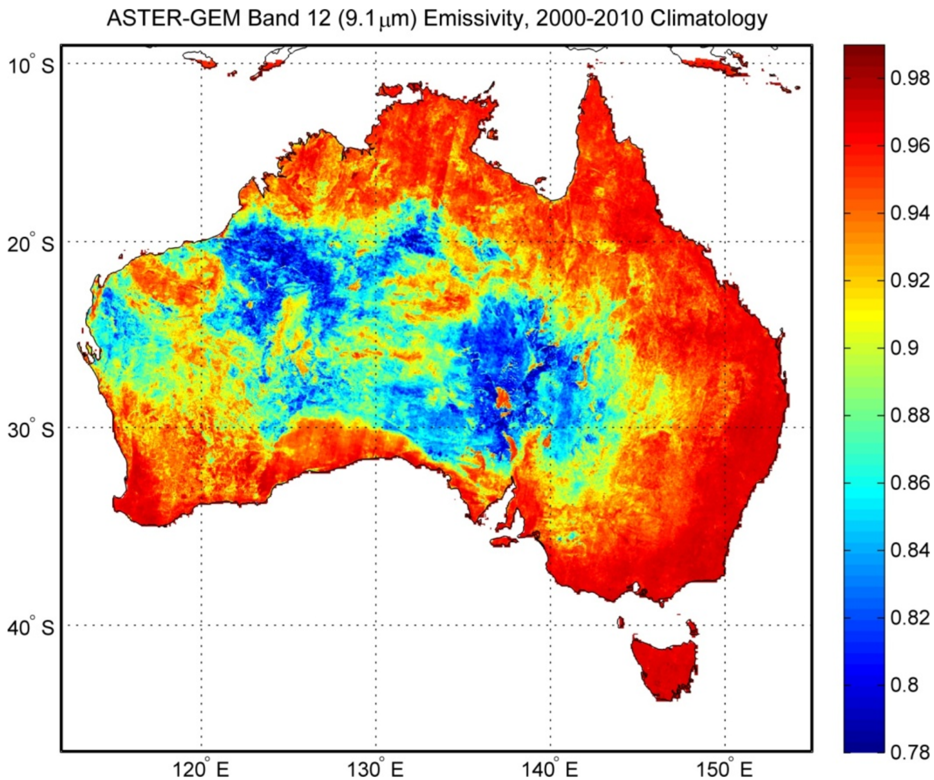
ASTER-GEM Band 12 emissivity (9.1 μm)
5km resolution: 2000-2010 (~112,000 scenes)

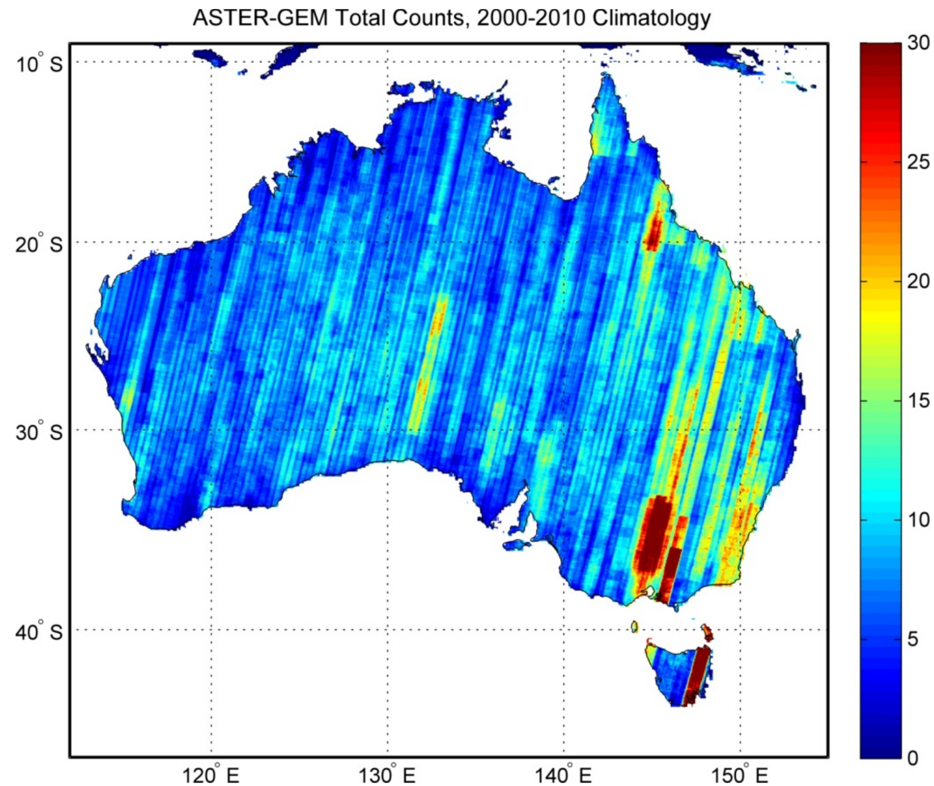




Certain regions have far more coverage than others!

ASTER-GEM Band 12 emissivity (9.1 μm)
5km resolution: 2000-2010 (~57,446 scenes)





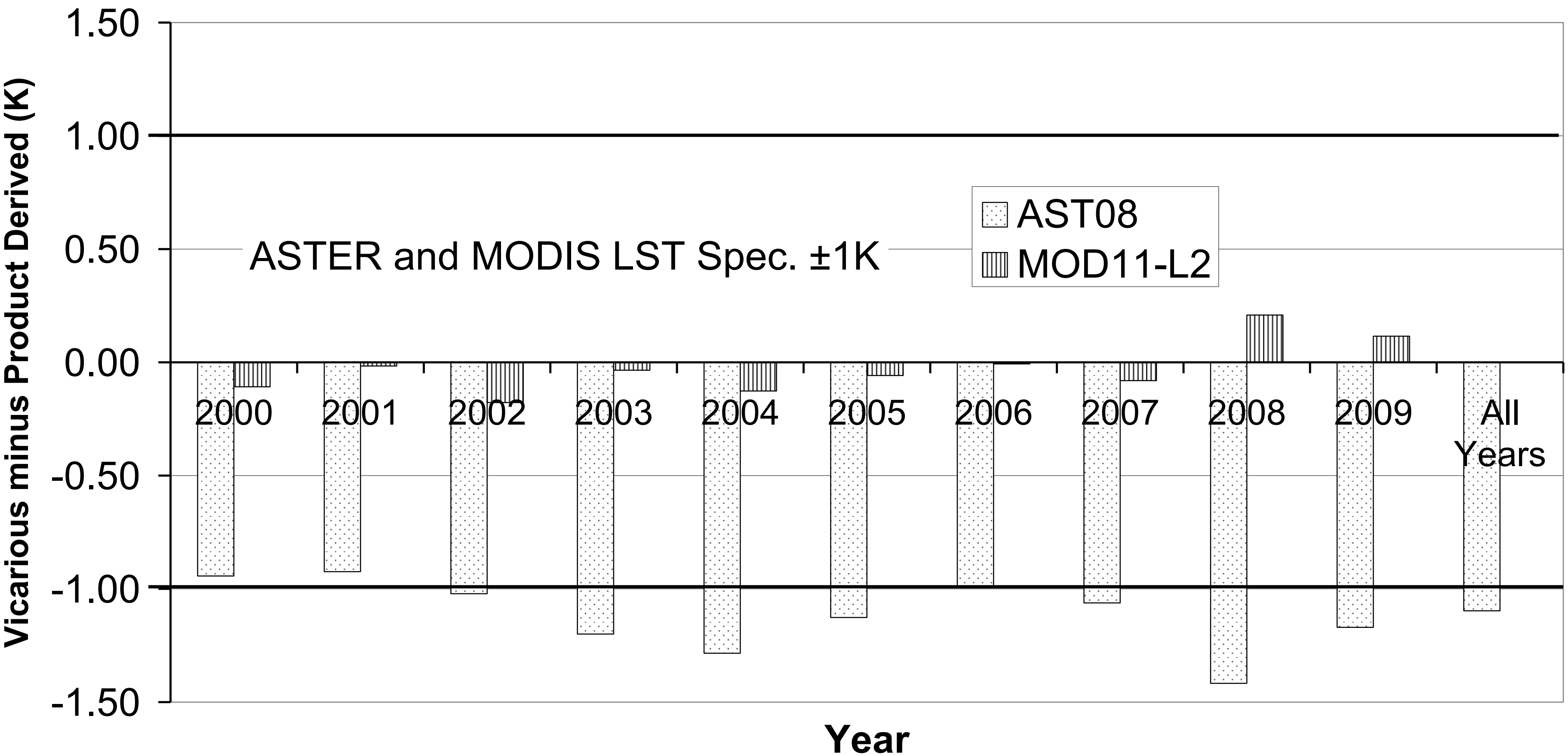
L2 Validation

- Two methods:
  - Temperature validation (Tval) – measure the temperature at the same time as the overpass and compare with the temperature retrieved by the satellite
  - Radiance validation (Rval) – measure the emissivity and the atmospheric profile independently. Forward calculate the ground temperature needed to match the at-sensor radiance and compare to retrieved temperature.

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

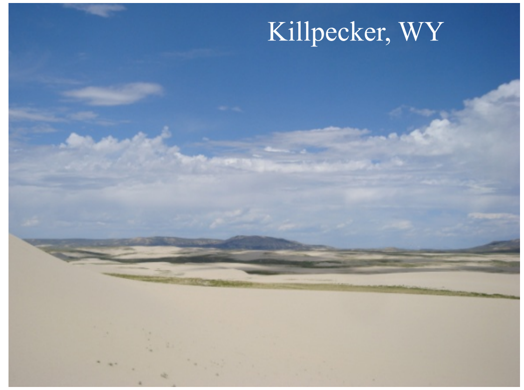
Both approaches are typically used over homogenous targets (either in temperature or emissivity)

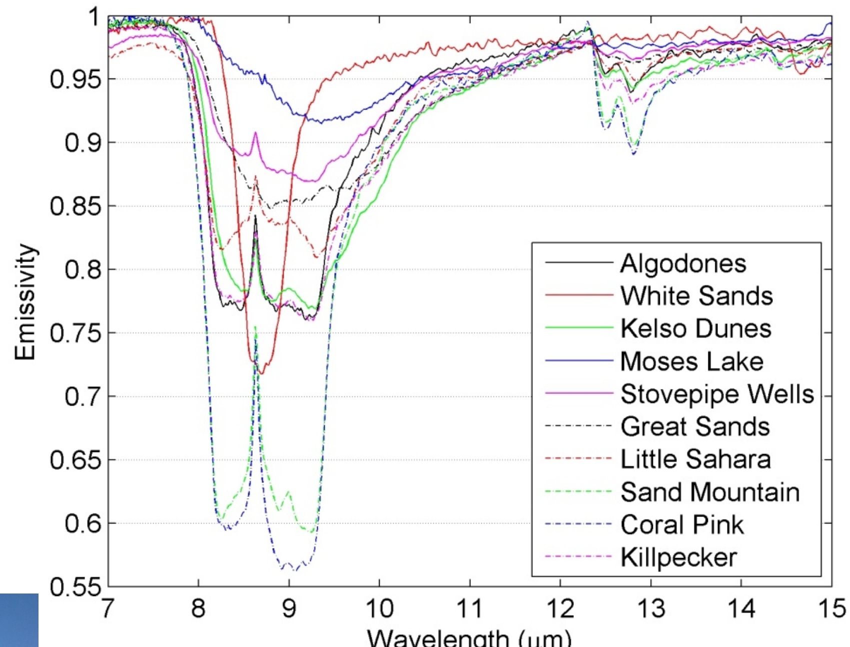
Tahoe LST validation

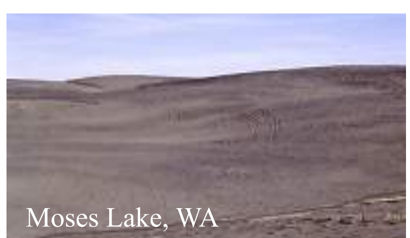


The MODIS product is accurate to (± 0.2K), while the ASTER product has a bias of 1-2 K due to residual atmospheric correction effects

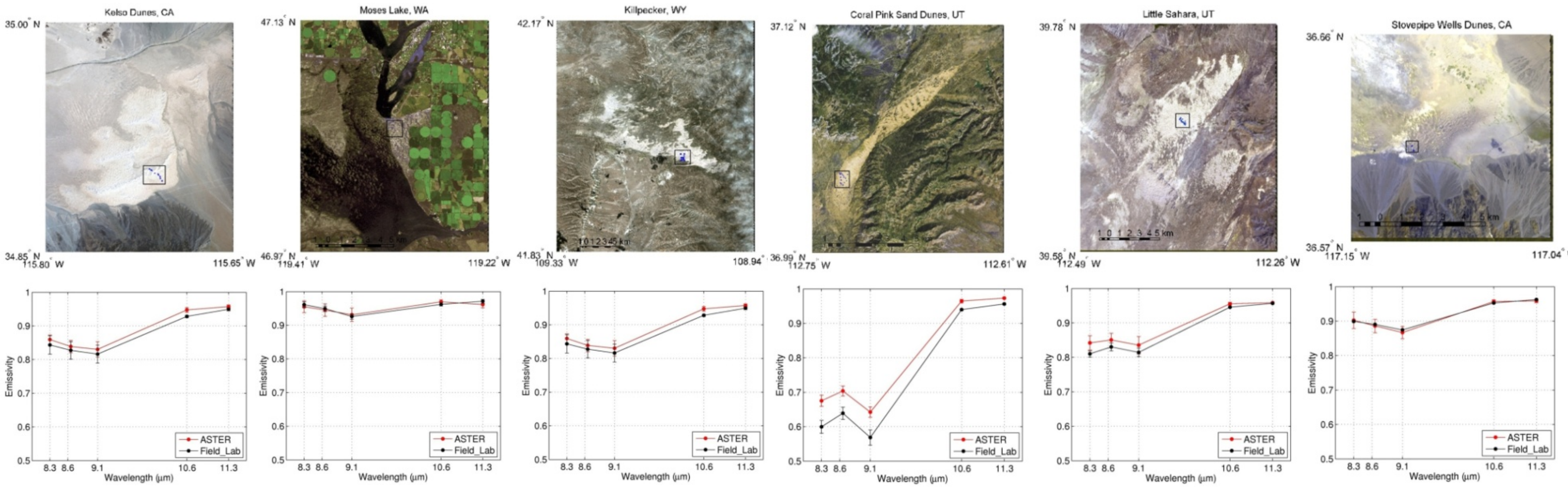
Pseudo-invariant sand dune validation sites

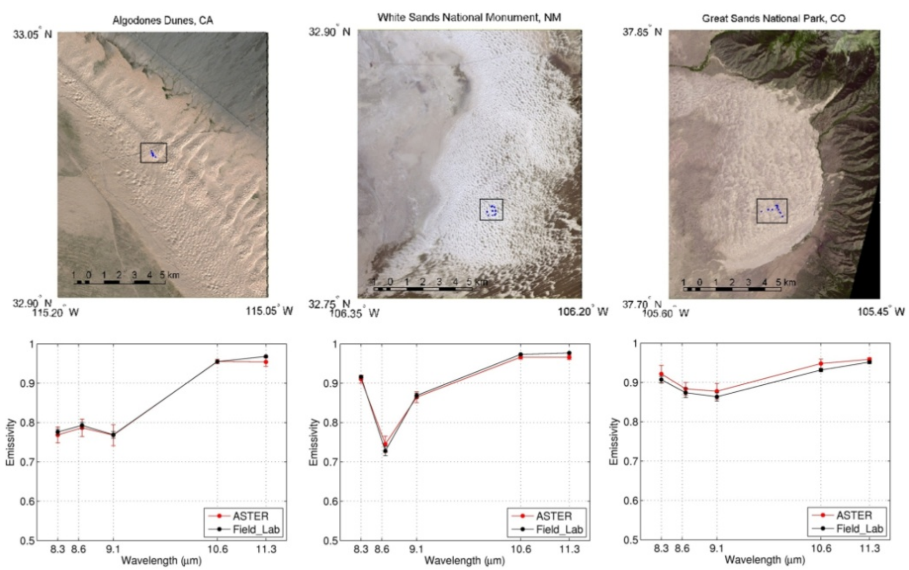






Pseudo-Invariant Sand Dune Validation Sites



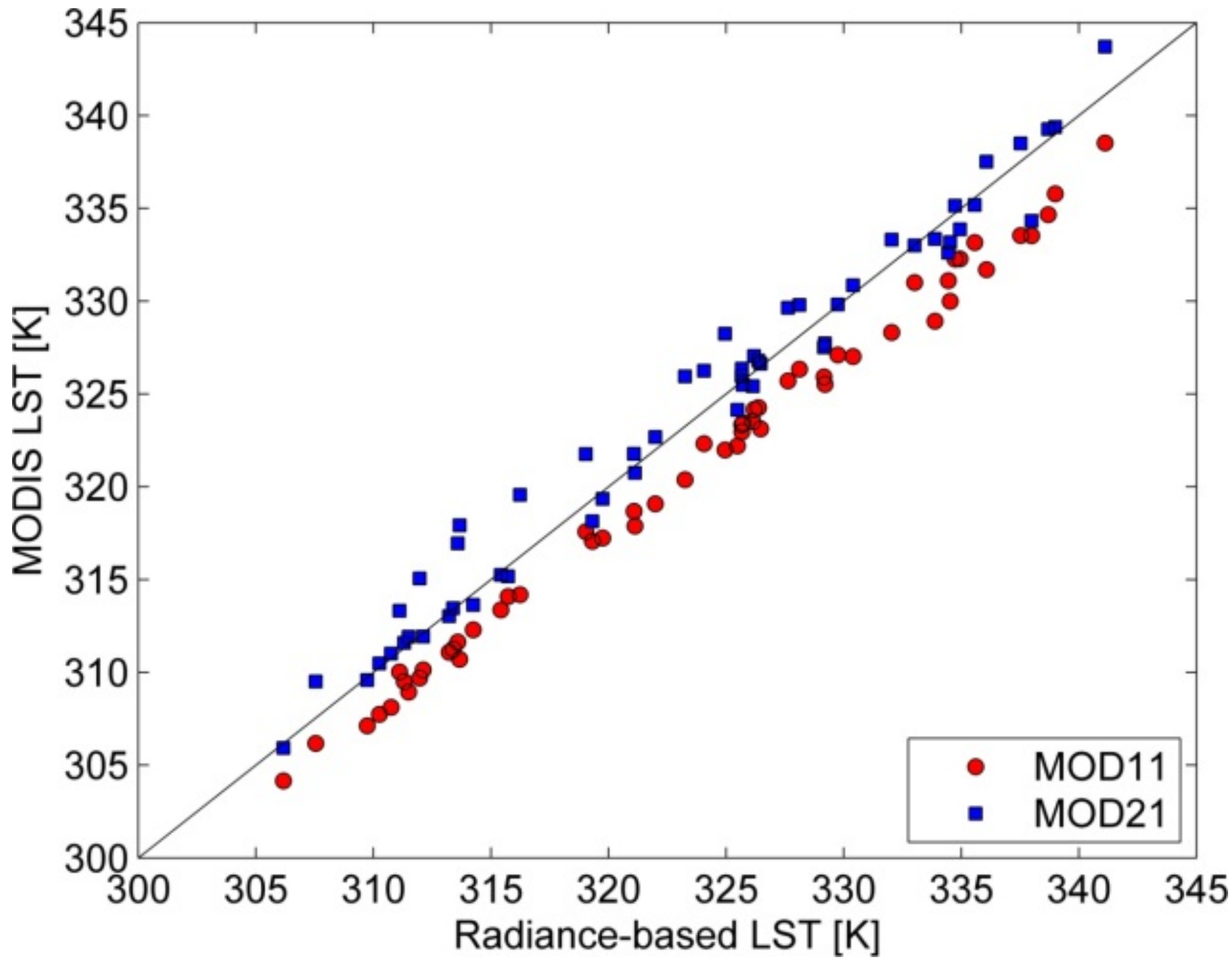


	ASTER MINUS LAB EMISSIVITY (%)					
Dune site	**Band 10**	**Band 11**	**Band 12**	**Band 13**	**Band 14**	**Mean**
Algodones	0.68	0.60	0.13	0.02	1.40	**0.57**
Stovepipe Wells	0.17	0.77	1.02	0.34	0.37	**0.53**
White Sands	0.34	2.76	0.16	0.92	1.08	**1.05**
Kelso Dunes	1.57	1.04	1.33	1.91	0.81	**1.33**
Great Sands	1.44	0.97	1.42	1.64	0.69	**1.23**
Moses Lake	0.69	0.52	0.42	0.61	1.01	**0.65**
Sand Mountain	7.74	6.47	9.01	1.82	1.10	**5.23**
Coral Pink	7.48	6.44	7.32	2.50	1.70	**4.90**
Little Sahara	3.55	2.39	2.60	0.96	0.19	**1.94**
Killpecker	2.34	1.99	2.26	1.33	0.81	**1.75**

< 1.6% (~1 K)

Hulley, G. C., Hook, S. J., and A.M. Baldridge, Validation of the North American ASTER Land Surface Emissivity Database (NAALSED) Version 2.0, *Remote Sensing of Environment* (2009), accepted

Radiance-based LST Validation at Algodones Dunes



Summary and Conclusions

- Land surface temperature and emissivity (LST&E) are important measurements for understanding the earth system. They are used in a wide variety of studies from measuring evapotranspiration to predicting volcanic eruptions.
- LST&E measurements are available at a variety of spatial, spectral and temporal resolutions and generated using multiple algorithms. Different algorithms result in one product performing better in one region and a different product performing better in a different region.
- Well understood procedure to calibrate to L1 data using 2 blackbodies but must also validate in-flight to obtain independent validation. Will use large lakes to validate L1 radiance at sensor
- L2 LST&E data can be validated using two approaches T-val and R-val. Approaches complement each other and allow validation over a broader range of cover types.

Questions?

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California