

An aerial satellite image of a coastal region, likely the San Francisco Bay Area. The image shows a large body of water on the left, with a complex network of channels and bays extending inland. The land is a mix of green vegetation and brownish/tan areas, possibly indicating urban development or agricultural land. The overall scene is captured from a high altitude, providing a wide view of the geography.

Surface Biology and Geology (SBG)

Observing Terrestrial Thermal Emission Radiometer (OTTER)





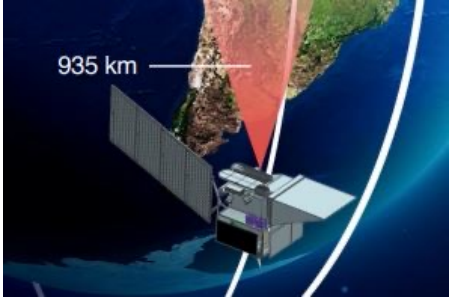
Level-2 Surface Temperature, Emissivity, and Cloud Mask

Glynn Hulley
Robert Freepartner
SBG-TIR R&A Team

NASA Jet Propulsion Laboratory, California Institute of Technology, USA



NASA Surface Temperature and Emissivity Algorithm Heritage

	ASTER (2000)	MODIS (2000/2002) VIIRS (2011/2017/2022)	ECOSTRESS (2018)	HyTES (2013)	Surface Biology Geology OTTER (2027)
					
Platform	Terra	Aqua, Terra, S-NPP, NOAA-20, NOAA-21	International Space Station	Twin Otter/ER2	OTTER
TIR bands	5	3	5	256	6 (+2 MIR)
Algorithm	TES	TES	TES	TES	TES: land surfaces Split-window: water surfaces
Temporal	16 day	Twice Daily (1:30am/pm)	3-5 days	Campaigns	3 days
Spatial	90 m	1000 m	70 m	1- 10 m	60 m

TES = Temperature Emissivity Separation (TES) algorithm [Gillespie et al. 1998]





SBG OTTER Level-2 product data layers

SBG OTTER LEVEL-2 ATBD

JPL D-XXXXXX

Surface Biology and Geology (SBG) Observing Terrestrial Thermal Emission Radiometer (OTTER)

Level 2 Algorithm Theoretical Basis Document (ATBD)

Version 1
June 24, 2023

Glynn Hulley
Jet Propulsion Laboratory
California Institute of Technology

JPL D-XXXXXX

© 2023 California Institute of Technology. Government sponsorship acknowledged.

Paper copies of this document may not be current and should not be relied on for official purposes. The current version is in the SBG DocuShare Library (*) at [insert url]
(* Access limited to user group)

National Aeronautics and
Space Administration
JPL
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109-8099
California Institute of Technology

Units
K
n/a
n/a
n/a
n/a
n/a
n/a
n/a
n/a
n/a
n/a
K
n/a
n/a
n/a
n/a
n/a
n/a
n/a
n/a
cm
1=water 0=land
1=cloud 0=clear
meters
meters
degrees



Glynn Hulley
Darren Ghent

Taking the Temperature of the Earth



Steps Towards Integrated Understanding of Variability and Change

3

LAND SURFACE TEMPERATURE

Glynn C. Hulley*, Darren Ghent[†], Frank M. Göttsche[‡],
Pierre C. Guillevic[§], David J. Mildrexler[¶], César Coll^{||}
*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States. [†]Department of Physics and Astronomy, National Centre for Earth Observation, University of Leicester, Leicester, United Kingdom. [‡]Karlsruhe Institute of Technology (KIT), Institute of Meteorology and Climate Research (IMK-ASF), Eggenstein-Leopoldshafen, Germany. [§]Department of Geographical Sciences, University of Maryland, College Park, MD, United States. [¶]Department of Forest Ecosystems and Society, College of Forestry, Oregon State University, Corvallis, OR, United States. ^{||}Department of Earth Physics and Thermodynamics, Faculty of Physics, University of Valencia, Burjassot, Valencia, Spain

CHAPTER OUTLINE

- 3.1 Introduction 58
- 3.2 Thermal Infrared Theory 60
 - 3.2.1 Thermal Emission 60
 - 3.2.2 Emissivity and Kirchhoff's Law 62
 - 3.2.3 Thermal Infrared Radiative Transfer 64
- 3.3 LST Retrieval Algorithms 69
 - 3.3.1 Deterministic Approaches 70
 - 3.3.2 Nondeterministic Approaches 76
- 3.4 Validation 85
 - 3.4.1 Introduction 85
 - 3.4.2 LST Determination Using TIR Field Radiometers 87
 - 3.4.3 LST Validation Examples 90
- 3.5 Satellite Data and Availability 93
 - 3.5.1 Capabilities and Features of LST Satellite Instruments 93
 - 3.5.2 Satellite Data Specifications 96
 - 3.5.3 Satellite Data Availability 99
- 3.6 Science and User Applications 103
 - 3.6.1 Introduction 103
 - 3.6.2 Ecological Applications 104
 - 3.6.3 Vector-Borne Diseases 112
 - 3.6.4 Surface Energy and Radiation Budget 113

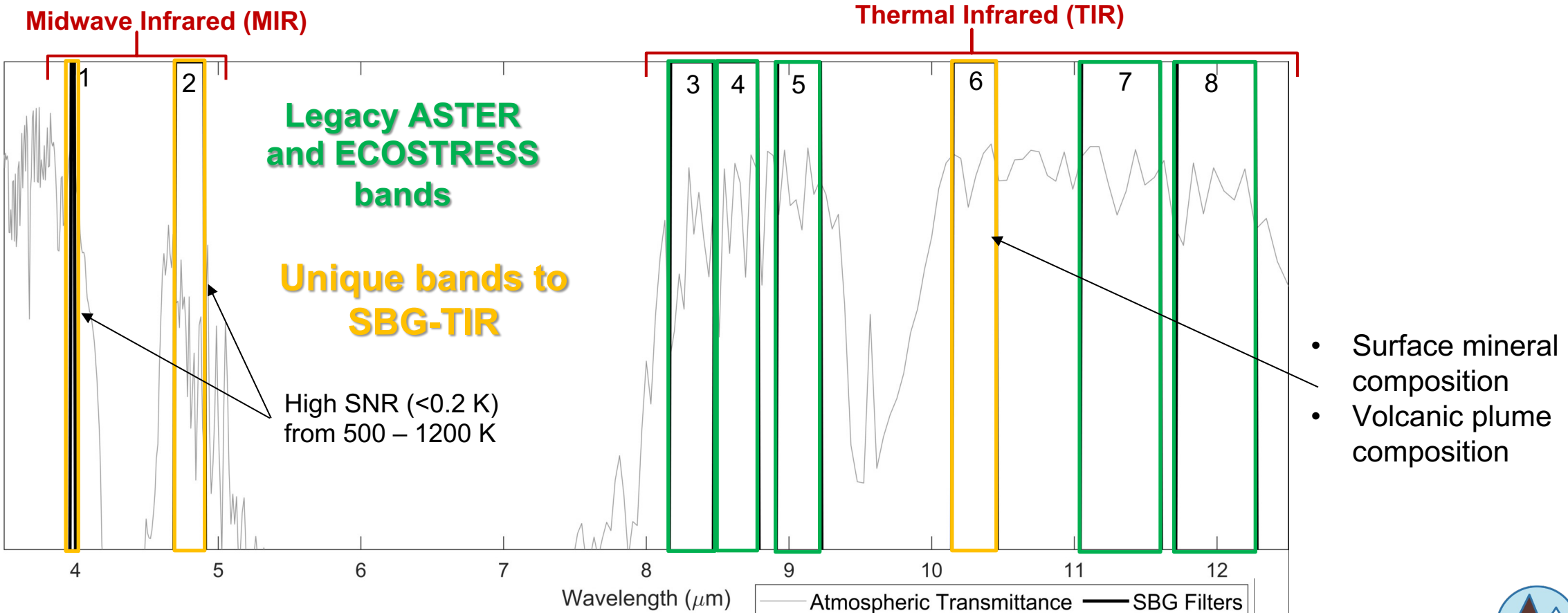
Taking the Temperature of the Earth. <https://doi.org/10.1016/B978-0-12-414455-1.00003-4>
© 2013 Elsevier Inc. All rights reserved.





SBG OTTER bands and science uses

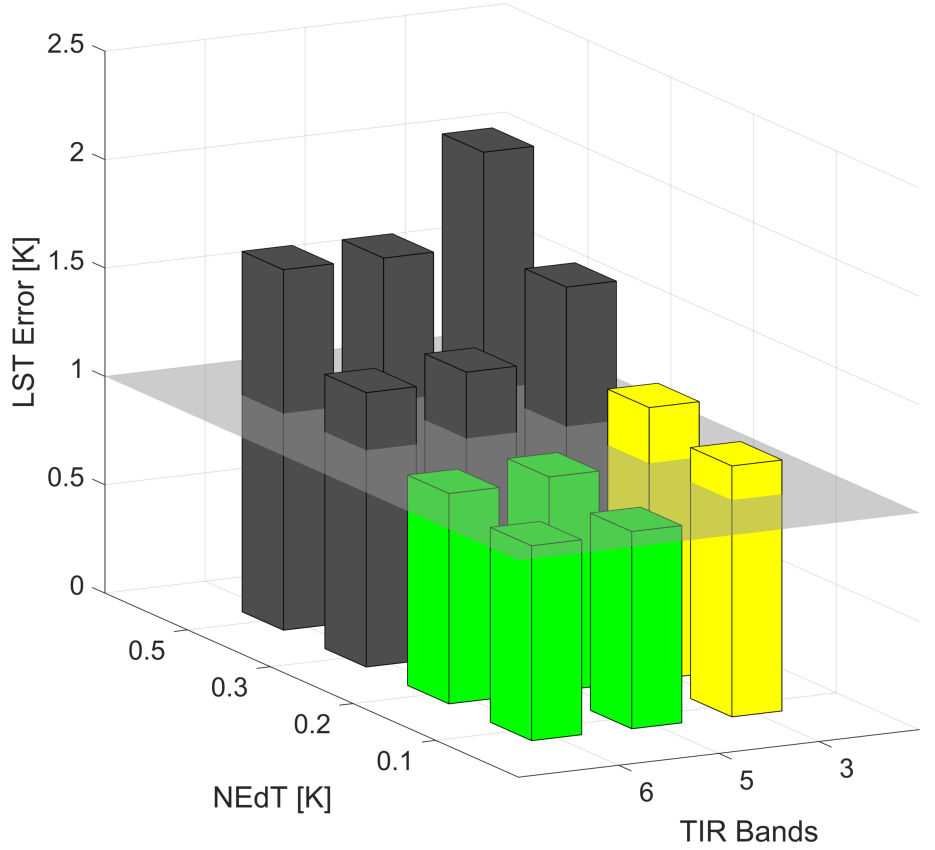
- Band uses
- Surface temperature/emissivity: 1, 3, 4, 5, 6, 7, 8
 - Evapotranspiration: 3, 4, 5, 6, 7, 8
 - Volcanic activity: 1, 2, 3, 4, 5, 6, 7, 8
 - Surface composition: 1, 3, 4, 5, 6, 7, 8
 - Elevated Temperature Features: 1, 2, 7, 8



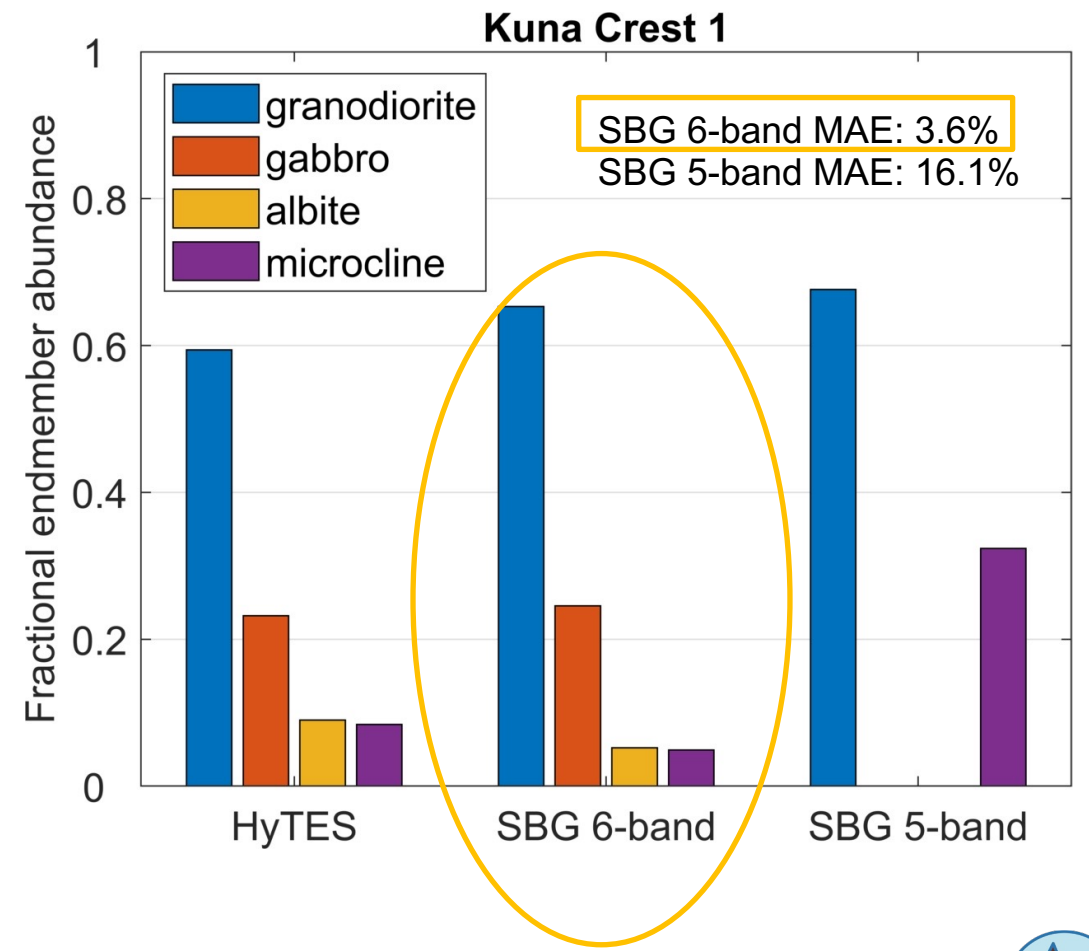
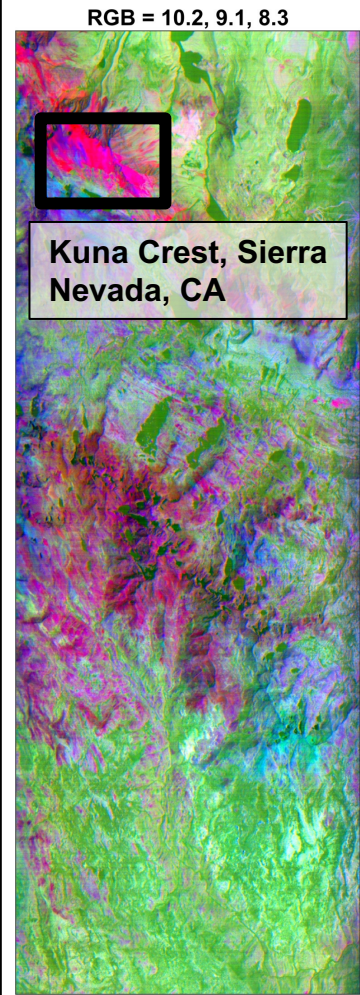


Demonstrated need for more TIR bands

Improved LST accuracy <1 K



Improved surface composition mapping

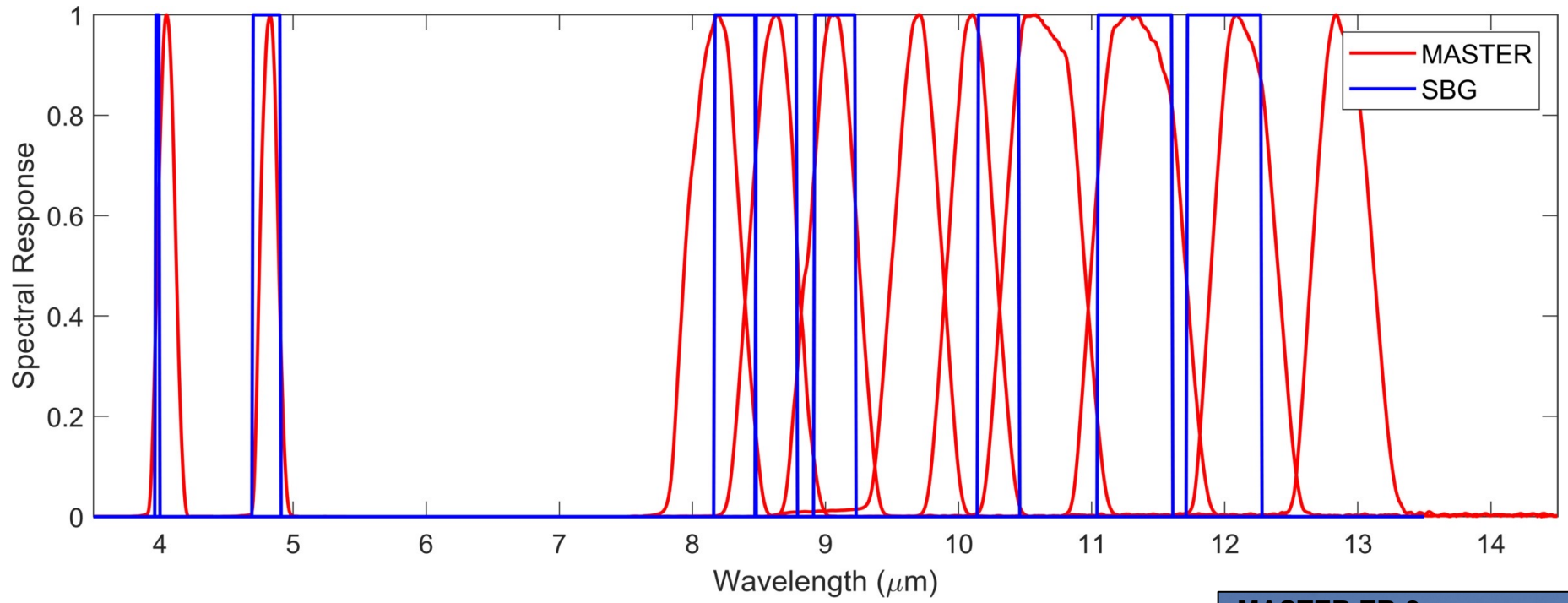




Simulated SBG TIR data from MASTER airborne

MASTER IR bands

Band	Wavelength (micron)
32	4.05
37	4.82
42	8.15
43	8.59
44	9.02
45	9.64
46	10.1
47	10.6
48	11.32
49	12.14
50	12.85



Example regression for two bands:

$$\epsilon_{SBG\ 1} = c1 \epsilon_{MASTER\ 32} + c2$$

$$\epsilon_{SBG\ 6} = b1 \epsilon_{MASTER\ 46} + b2 \epsilon_{MASTER\ 47} + b3$$

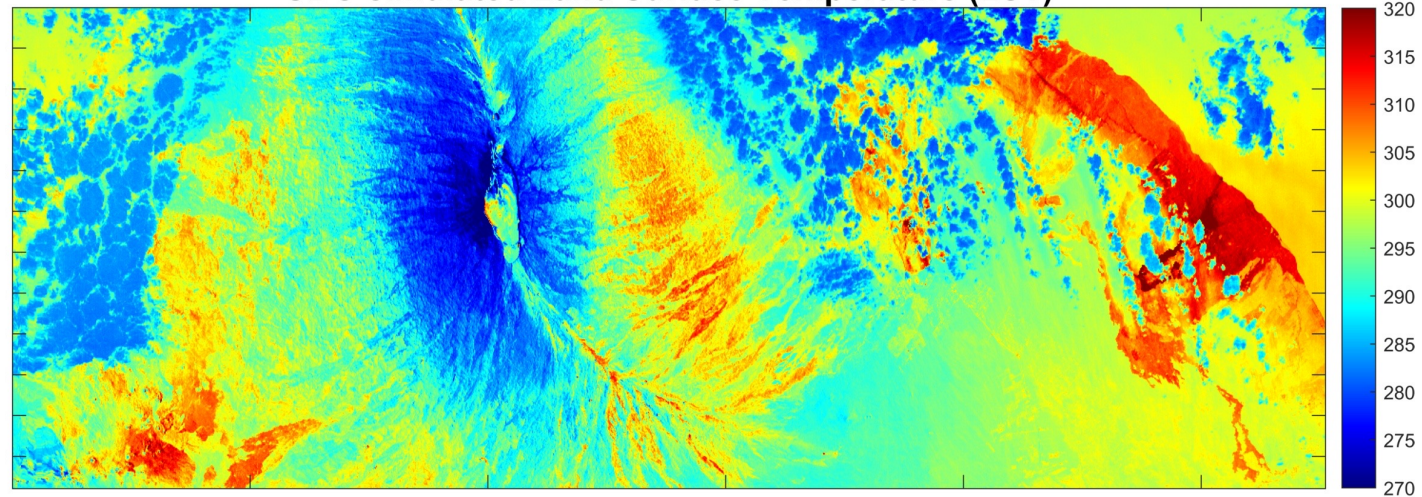




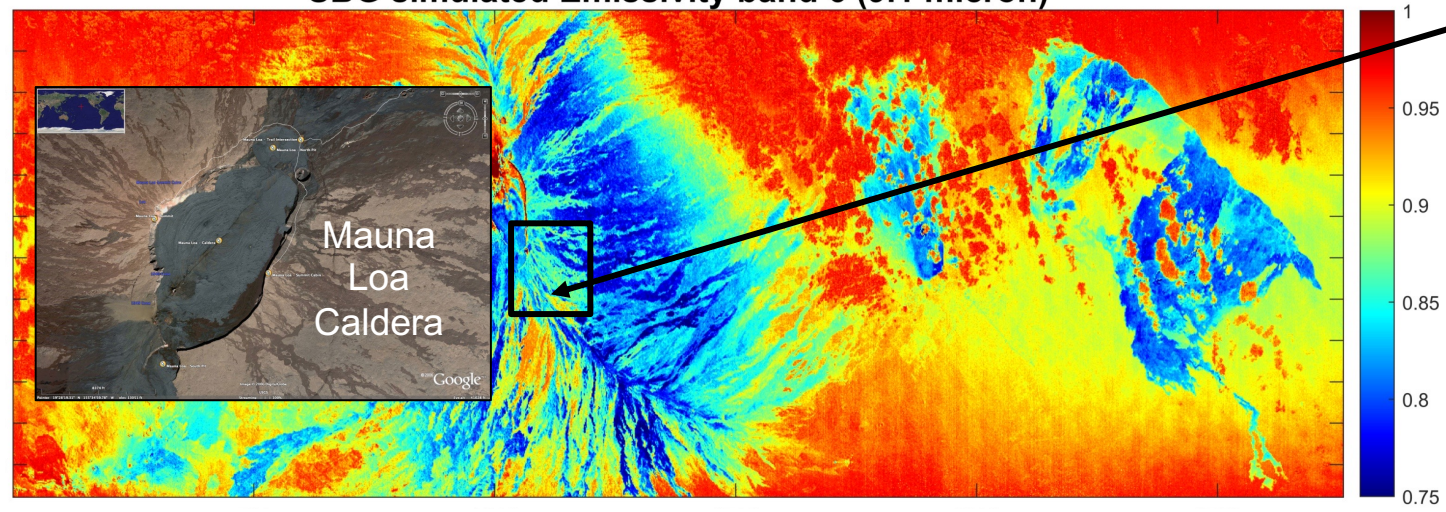
Simulated SBG TIR data from MASTER airborne



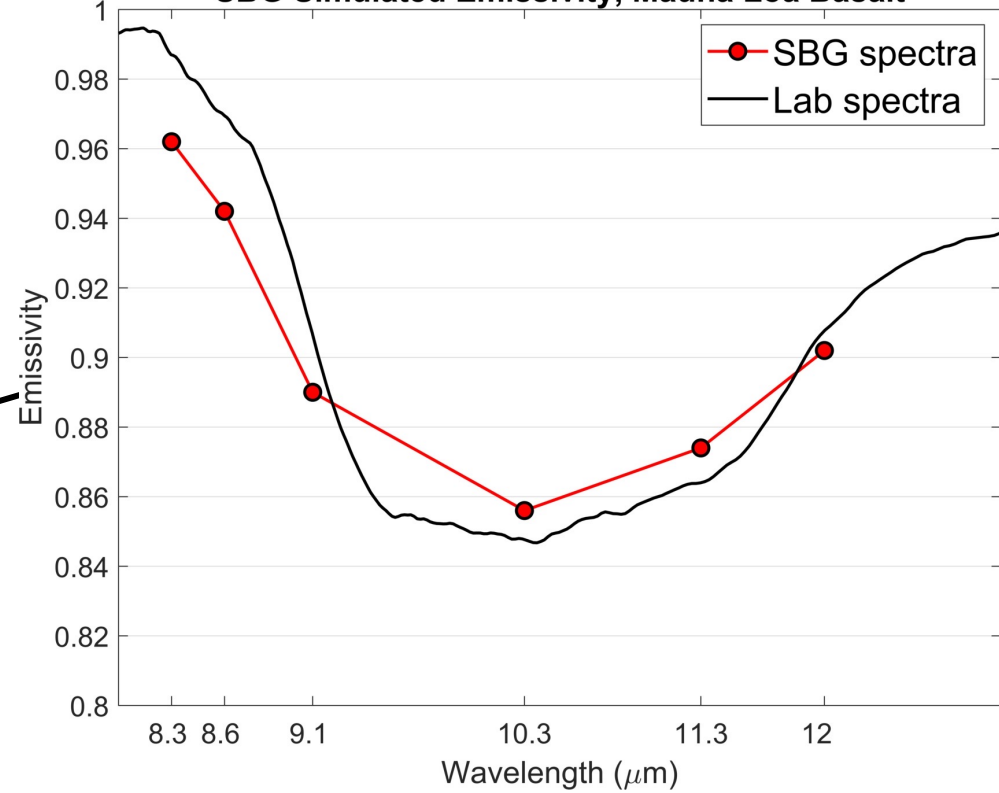
SBG simulated Land Surface Temperature (LST)

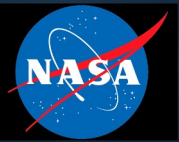


SBG simulated Emissivity band 6 (9.1 micron)

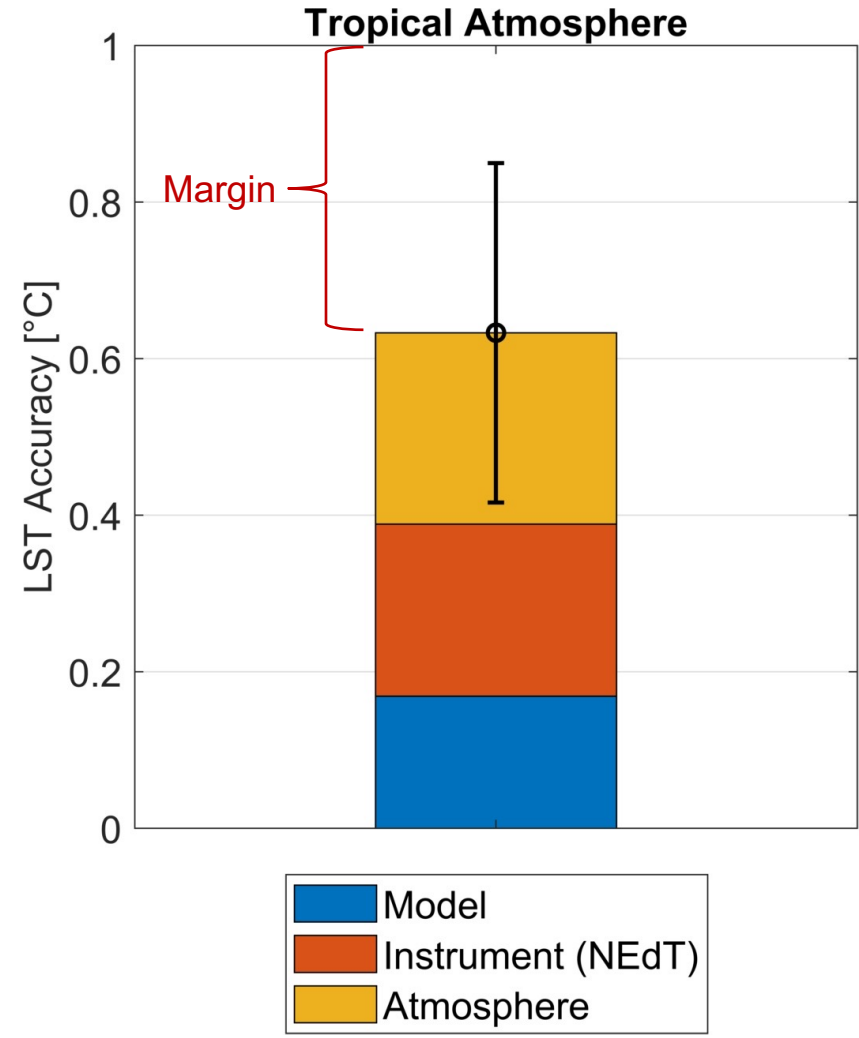
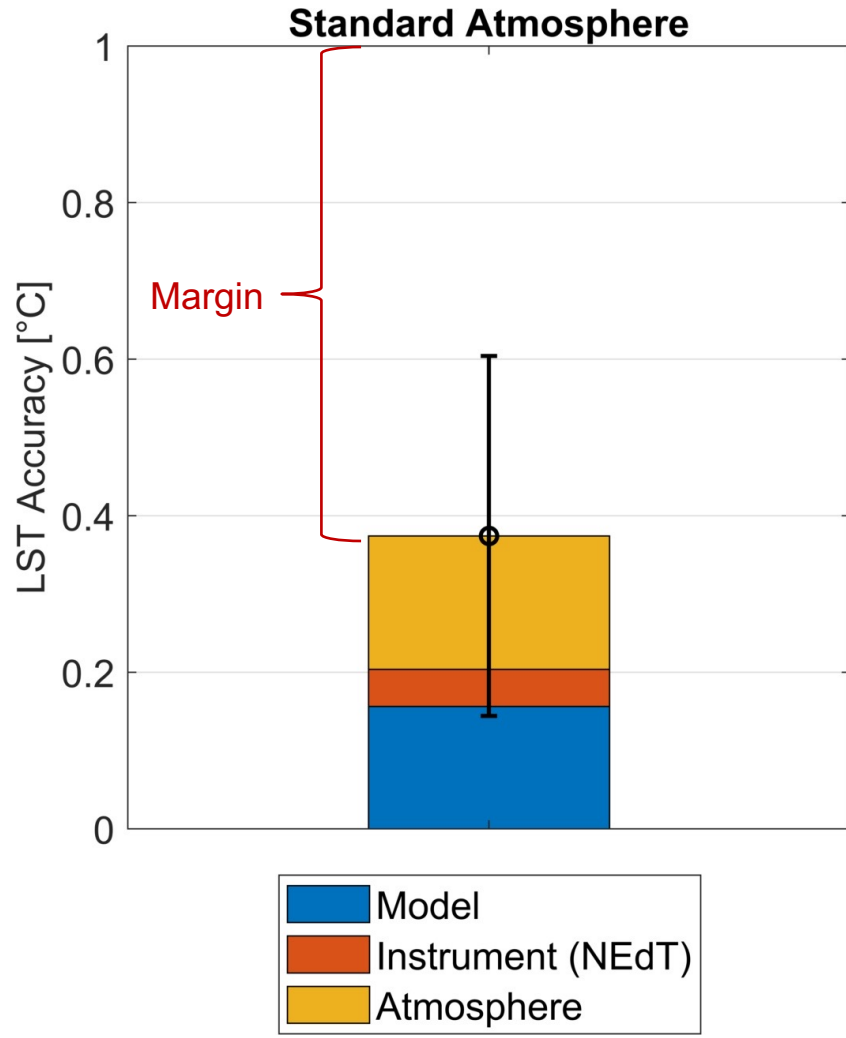


SBG Simulated Emissivity, Mauna Loa Basalt





LST&E Uncertainty Quantification



Simulation run details:

150 rocks, soils, sands, vegetation spectra from ECOSTRESS spectral library
10,000 Monte Carlo simulations with 10% and 1 K random error on humidity and air temperature, respectively.
NEdT = 0.2 K per band (instrument noise)

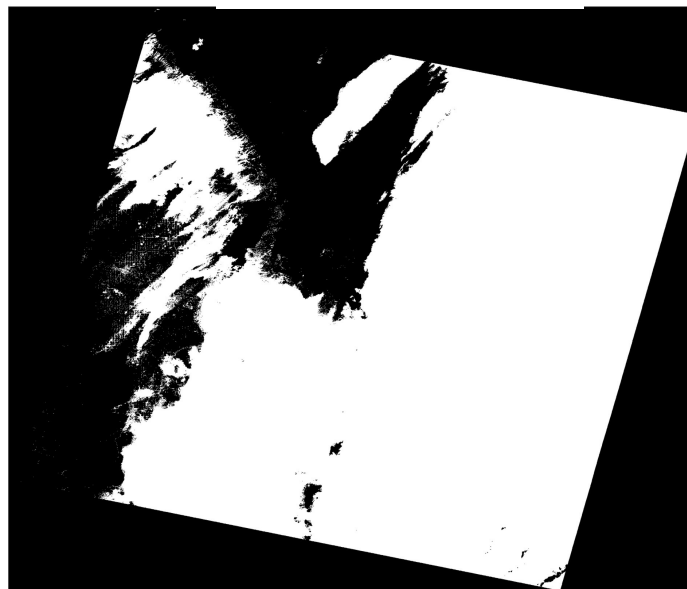
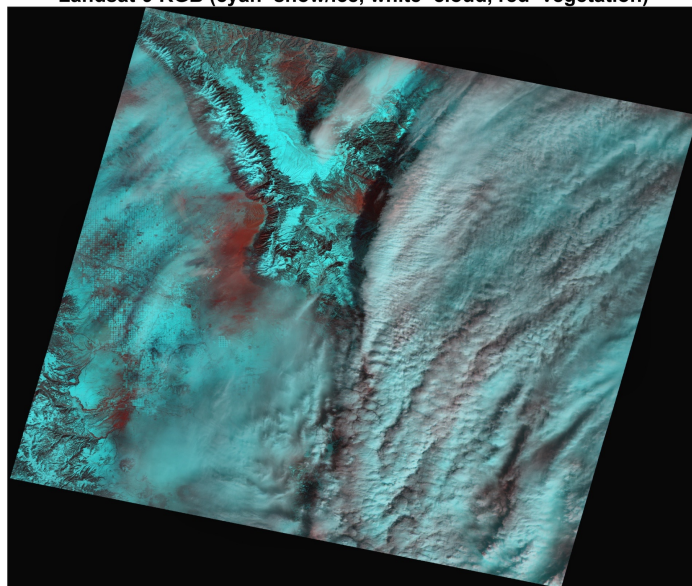
See details in *Hulley et al., (2023) SBG L2 ATBD, Temperature Emissivity Uncertainty Simulator (TEUSim)*





SBG OTTER Cloud Mask

Landsat-9 RGB (cyan=snow/ice, white=cloud, red=vegetation)

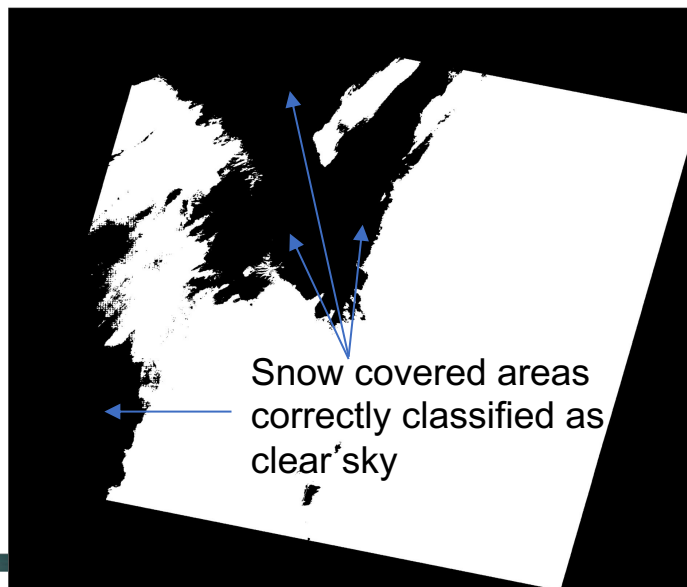


Landsat-9 FMask

VSWIR+TIR bands
Threshold based approach

	Landsat Fmask ('truth')	ECOCLOUD
Percent cloud	71.4%	72.1%
Commission error	0%	5.7%
Omission error	0%	4.8%

Negligible differences at the Landsat Fmask uncertainty level (~5%)



SBGCLOUD

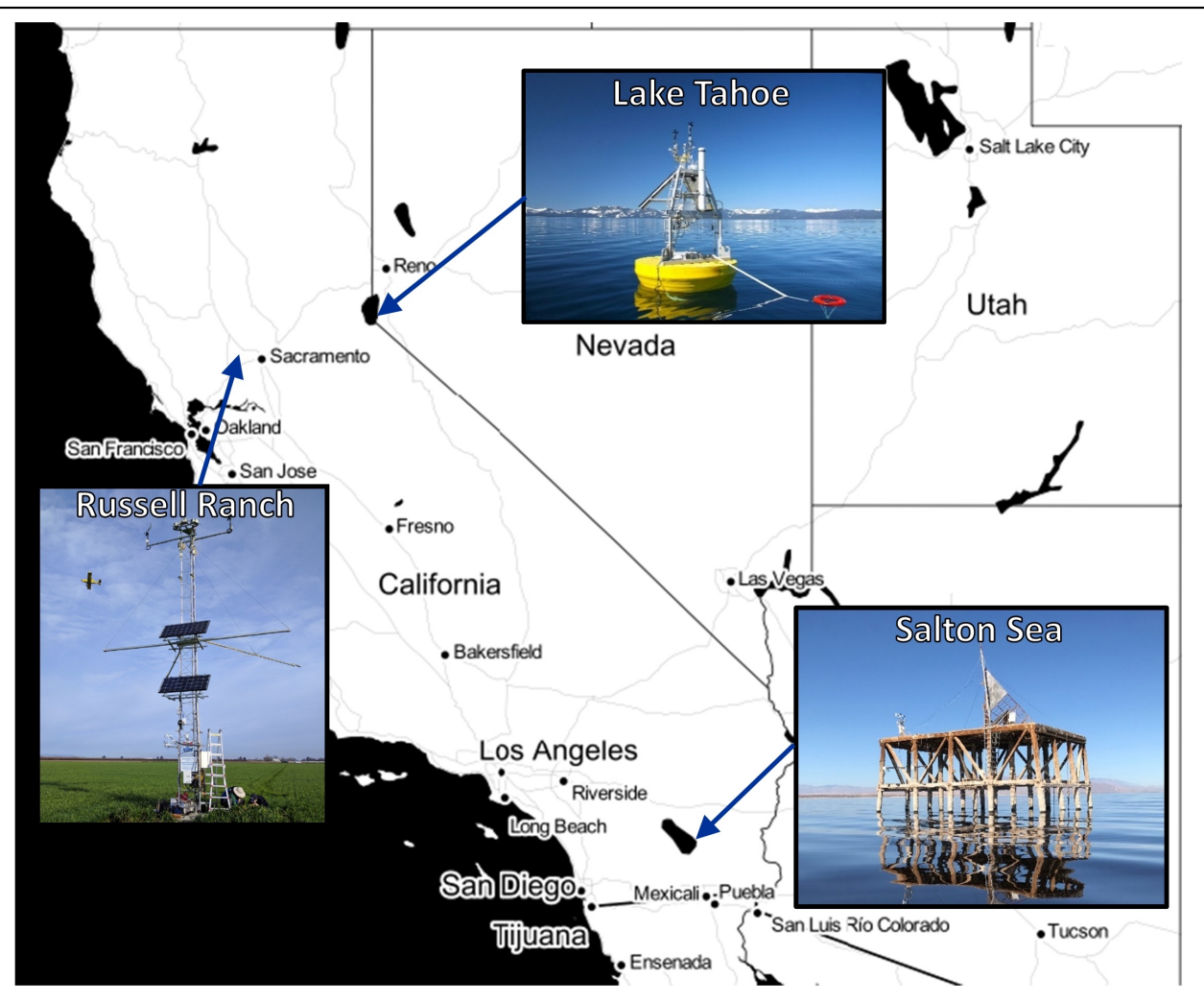
2 VNIR + 2 TIR bands
ML approach
(Random forest)



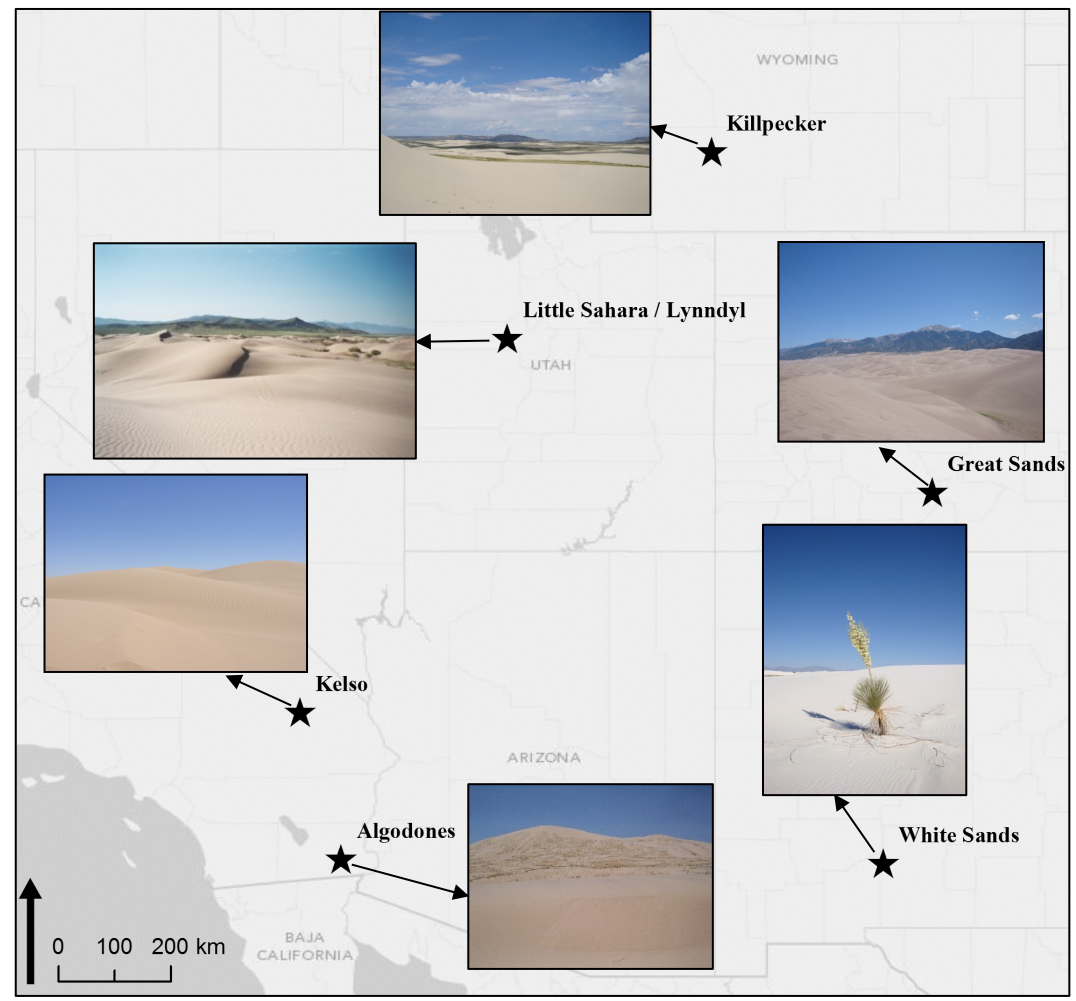


SBG LST&E Validation

JPL automated cal/val sites



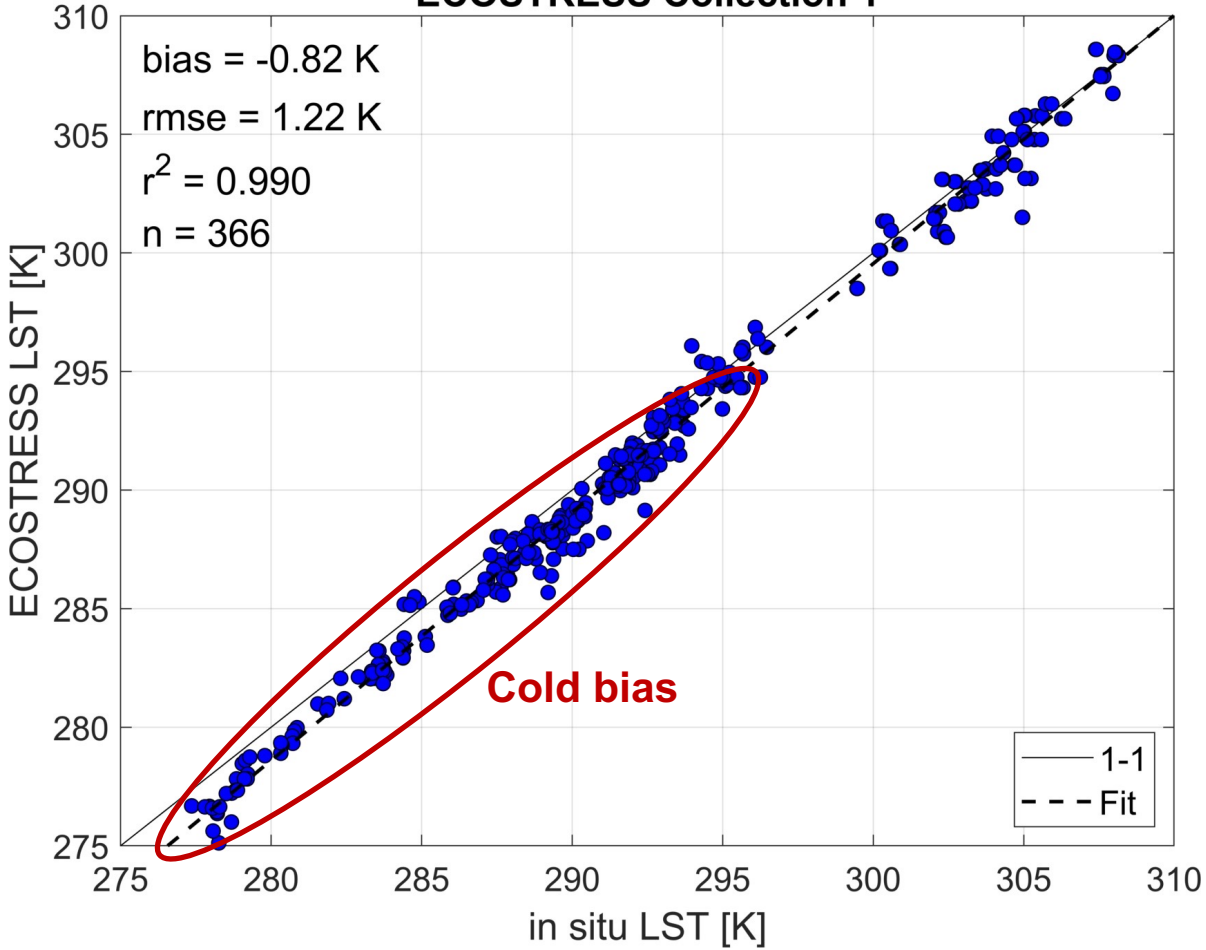
Pseudo-invariant sand dune sites



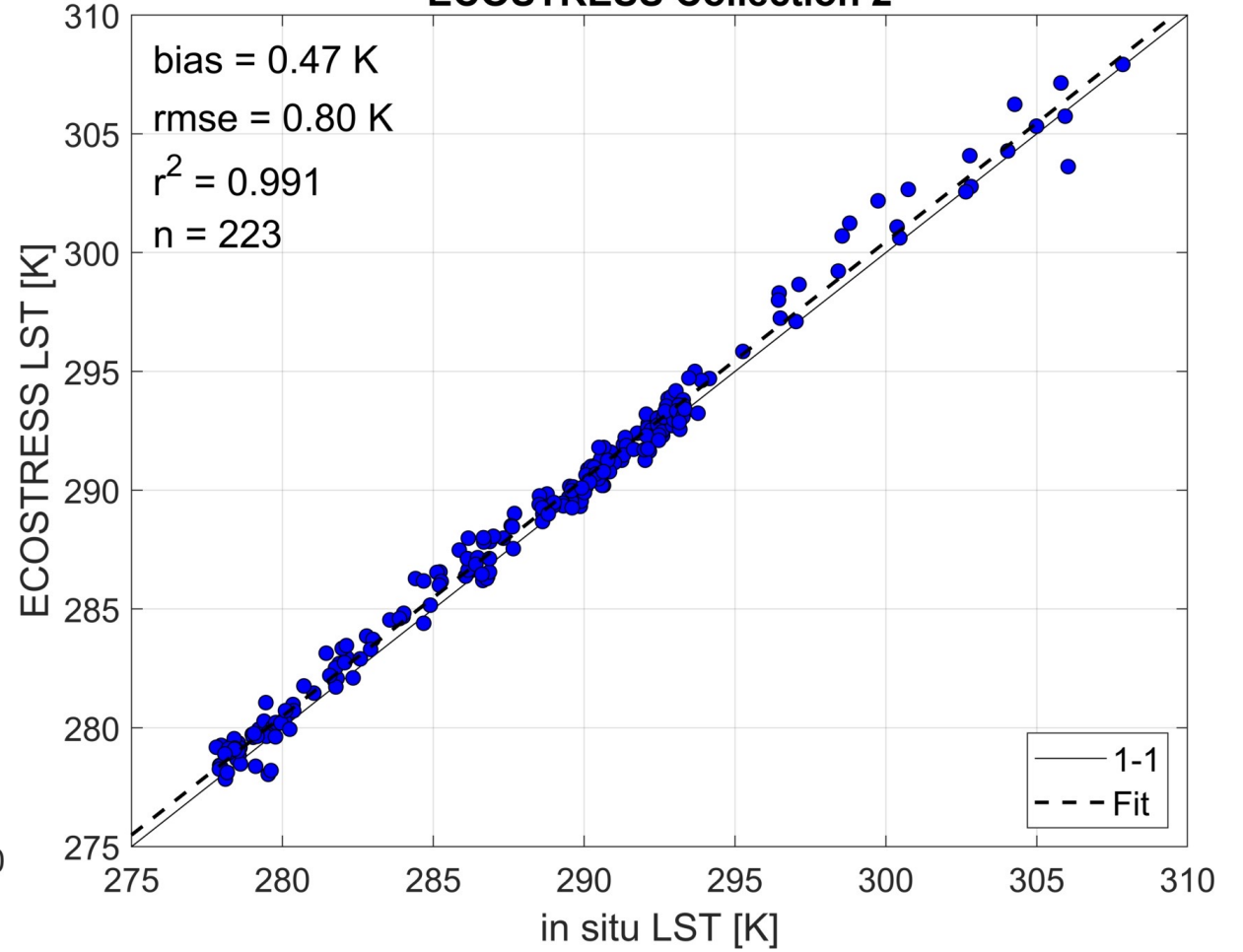


SBG LST&E Validation

ECOSTRESS Collection 1



ECOSTRESS Collection 2

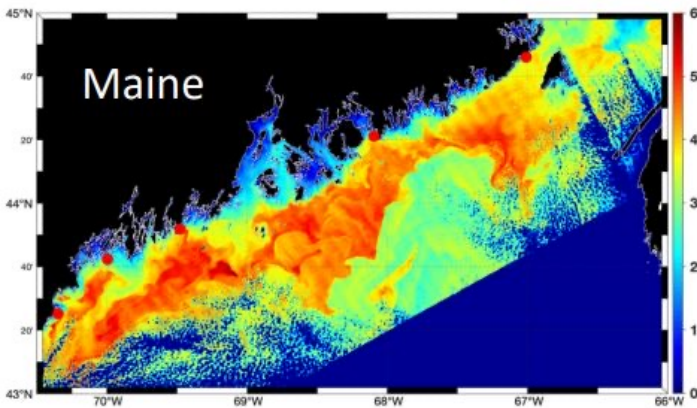
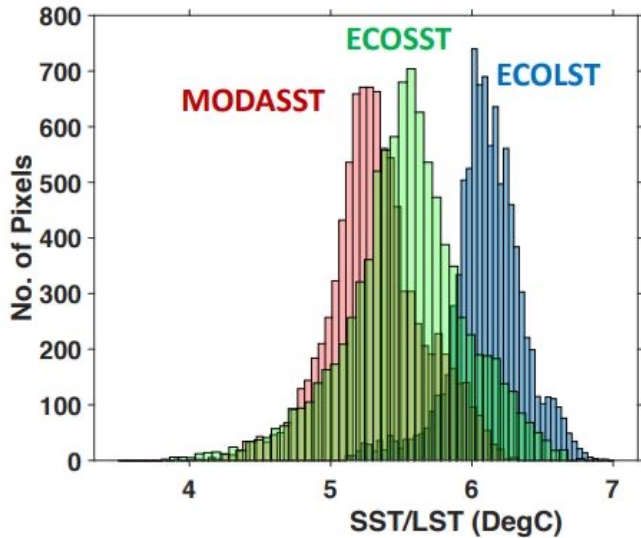




LST&E Algorithm Improvements for SBG

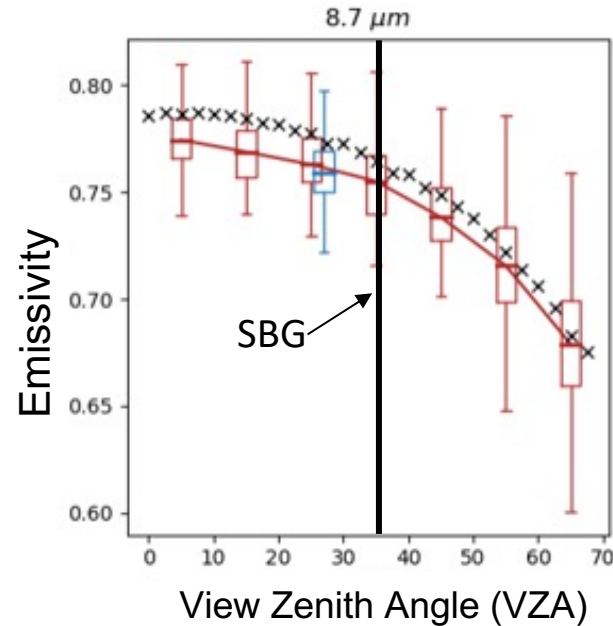
(1) Hybrid LST/SST algorithm

Otis and Hulley, 2021



(2) Emissivity anisotropy

Ermida and Hulley, 2020

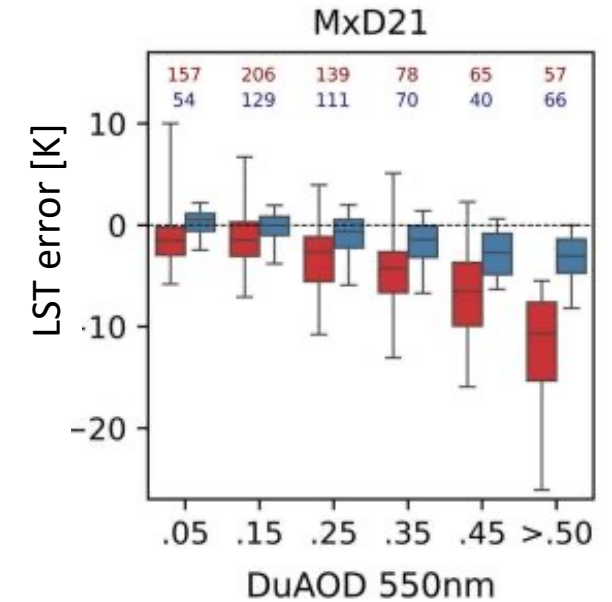


VZA-dependent TES calibration curve:

$$\epsilon_{min} = a_1 + a_2 MMD^{a_3 + b_2} VZA^{b_3}$$

(3) High aerosol dust loading

Stante et al. 2023



Improve atmospheric correction:

- RTTOV radiative transfer model
- AOD information (models, satellite)
- Uni. of Lisbon collaboration

