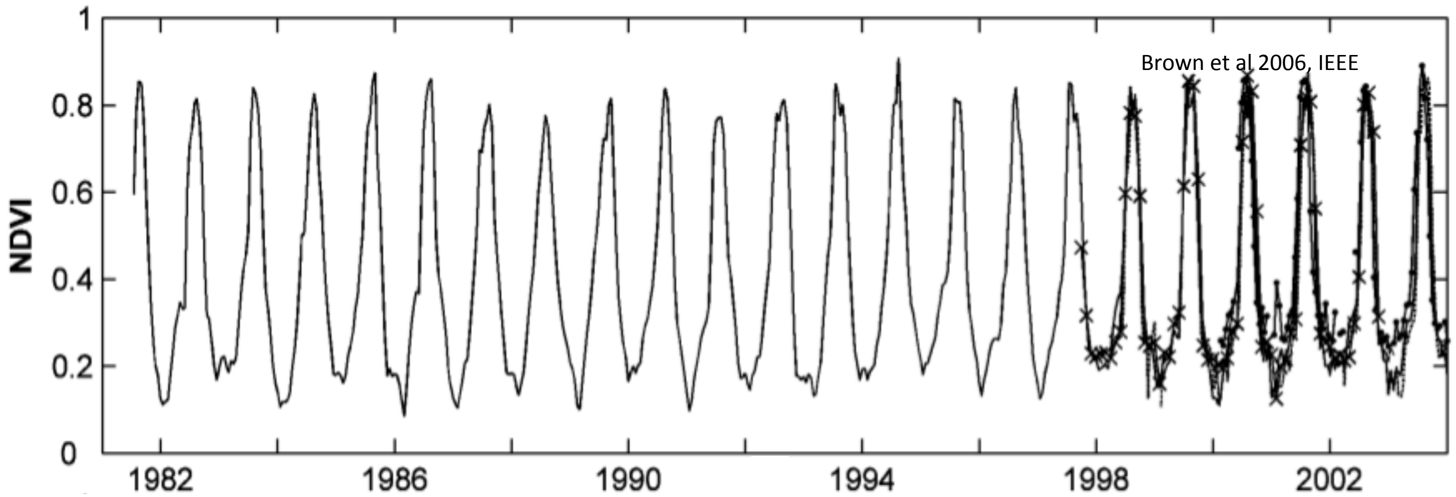
Compatibility of Imaging Spectroscopy and Broadband Multispectral Data



E. Natasha Stavros, Felix C. Seidel, Morgan L. Cable, Robert Green, Anthony Freeman

Jet Propulsion Laboratory, California Institute of Technology

Augmenting our multi-spectral reality with Imaging Spectroscopy

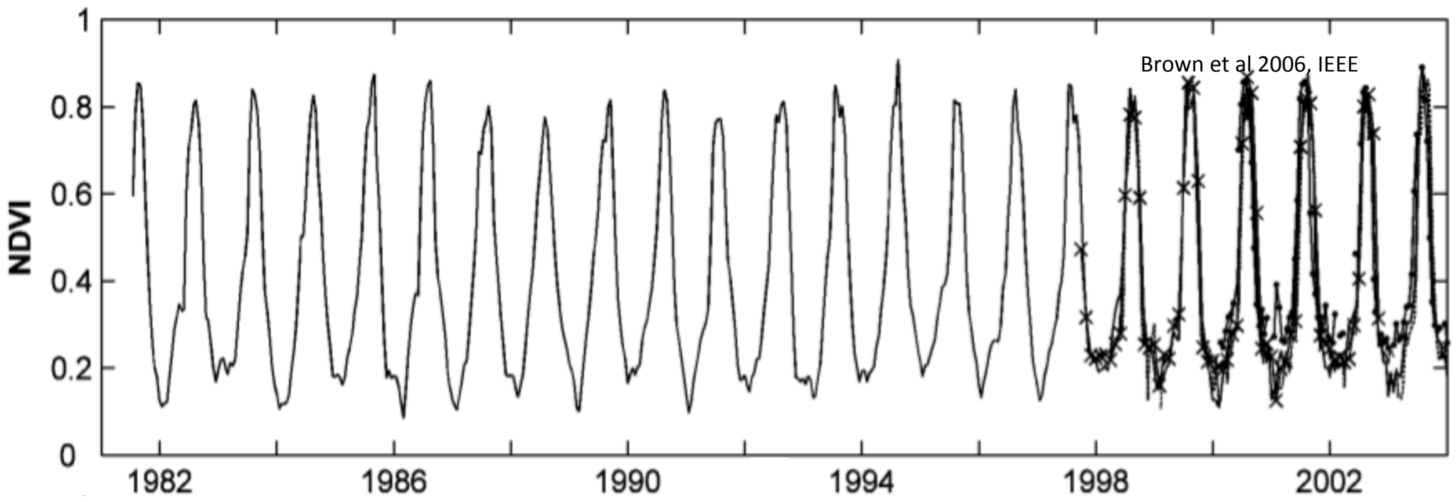
- Background/Motivation
- Objectives
- Methods
- Results
- Discussion
- Conclusions

Curtesy of http://townlink.com/augmented-reality/

Background/Motivation

- Highly desired are long-term continuous data records of geophysical variables (NRC Decadal Survey, 2013, 2008)
- In this room, we do not debate that an imaging spectrometer can recreate multi-spectral broadbands
  - "*just* spectrally convolve"
- BUT, why has this message failed to "stick" with the multi-spectral community?
- Last AGU – I set out to find out why…

- Many considerations for creating a long-term record:
  - Differences in instrument capabilities: signal-to-noise ratio (SNR), spatial and spectral sampling and coverage, etc.
  - Even with the same instrument specifications, there are changes through time: orbit drifts, changes in spectral response of filters, and other sensor degradations
- Those factors affect the quality of the measurements from which geophysical variables derived
- There has been much attention on the consistency of multi-spectral data (AVHRR, MODIS, Landsat, etc.), so it's no surprise they are not an easy sale



- Furthermore, most of our attention has focused on how imaging spectroscopy augments information spectrally
- With little consideration for broad-band community difficulties in creating the long term record

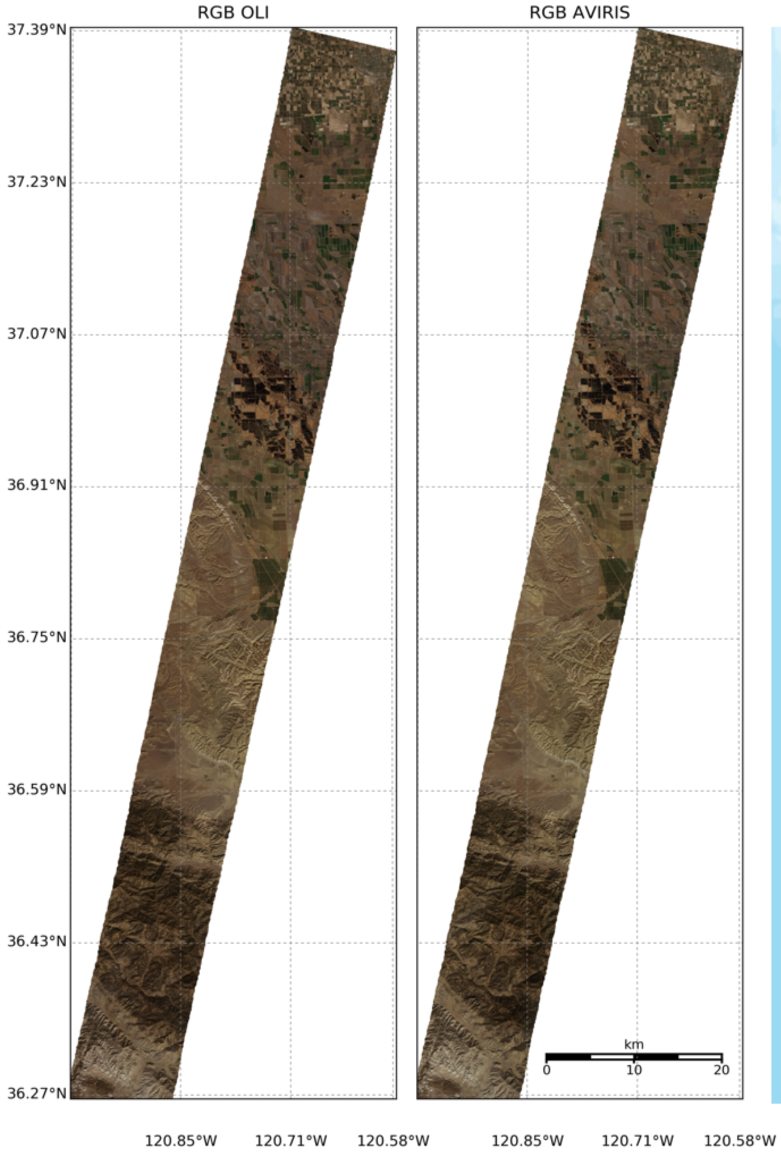
Overview of applications enabled or augmented by imaging spectroscopy

Application	References
Identification of invasive species	Underwood et al. 2003, 2006, 2007; Asner and Vitousek 2005; Noujdina and Ustin 2008; Khanna et al. 2011, 2012; Hestir et al. 2012; Beland et al. 2016; Santos et al. 2016
Habitat mapping and habitat suitability: including species and biodiversity mapping	Beland et al., 2016; Fagan et al., 2015; Féret and Asner, 2011; Ferreira et al., 2016; Gu et al., 2015; Roberts et al., 1998b; Santos et al., 2016a, 2016b
Vegetation functional traits and diversity	Asner et al., 2015; Féret and Asner, 2014; Jetz et al., 2016; Singh et al., 2015; Susan L Ustin and Gamon, 2010
Mapping ecosystem condition (e.g., mortality/dormancy and stress)	Coates et al., 2015; Roberts et al., 2015
Phytoplankton diversity, such as algal blooms, which require information from pigment- or spectra shape-specific (i.e., not band ratio) analysis	Kudela et al., 2015; Palacios et al., 2015; Ryan et al., 2014
Mapping coral reef benthic communities	Hochberg and Atkinson, 2003, 2000

Objective: demonstrate conversion of imaging spectroscopy data to fully compatible bands with multi-spectral observations

1. Document a replicable procedure for simulating OLI data from AVIRIS data
2. Evaluate influencing factors on the retrieved radiance
3. Test the <u>hypothesis:</u> Imaging spectroscopy spectral data is compatible with a multi-spectral sensor to within ±5% radiometric accuracy, as desired to continue the long-term record

Datasets: Coincident AVIRIS and OLI data calibrated radiance to reducing confounding illumination effects



- **Data Collected:** October 21, 2014
  - OLI instrument on Landsat 8 (Path 43, rows 34-35)
  - AVIRIS on NASA's ER-2 at ~20km

- **Time of Acquisition**:
  - AVIRIS: 18:32:05 UTC (11:32:05 Local Daylight Time) -18:44:48 UTC (11:44:48 LDT)
  - OLI overpass at 18:40:00 UTC (11:40:00 LDT)

- **Flightline** heading of 195˚ (where 0˚ is True North)
- **Solar elevation** at 40˚
- **Solar azimuth** at 159˚

Pre-Processing: a how-to manual (Objective 1)

TOA = Top-of-Atmosphere

AVIRIS processing

1) Download AVIRIS flightline (f141021t01p00r07rdn_b) **Level 1B:**

a. Radiance from "flightline_org_img"
b. Central wavelength by band from "flightline_sc##_ort_img.hdr"
c. Gain (scaling factor) from "flightline.gain"
d. Information about which original pixel (i.e., not rotated) occupies which output pixel in the final product from "flightline_ort_glt"
e. Geographic latitude and longitude of original data from "flightline_org_img"
f. Solar and viewing geometry, and the path length between ER-2 and the surface from "flightline_obs_ort"

2) Preprocessing AVIRIS data

a. Re-scale Radiances: L1B_rdn_ort * scale factor
b. Rescale from μW/cm^2/nm/sr to W/m^2/μm/sr
c. Determine pixel locations by projecting 1e. from the original pixel location to the actual (geo-corrected) location using 1d.

3) Spectral Convolution

a. Linear interpolation: AV_{orig} to AV_{1nm}
b. AV_{1nm} * OLI Spectral Response Function: AV_OLI_{1nm}
c. Spectral integration to OLI bands using Five Point Newton-Cotes method (SOLI – simulated OLI)

4) Calculate TOA Radiance:

a. Using 6s radiative transfer model calculate at-sensor radiance ($6S_{ER2}$) at 20-km (ER-2 flight altitude) and at top-of-atmosphere ($6S_{TOA}$) for each AVIRIS viewing angle across-track assuming a single view zenith angle (VZA) by sample (assumes stable aircraft)
b. Calculate $SOLI_{TOA} = SOLI_{ER2} + (6S_{TOA} – 6S_{ER})$

5) Spatial Co-location to OLI geolocation and grid: Assign AVIRIS pixels (2c.) to the OLI pixel grid. If multiple AVIRIS pixels fit an OLI pixel, then assign the mean $SOLI_{TOA}$ to the OLI pixel

OLI processing

1) Download OLI data:

- LC08_L1TP_043035_20141021_20170303_01_T1
- LC08_L1TP_043034_20141021_20170303_01_T1
- OLI Spectral Response Functions

2) Pre-processing OLI data:

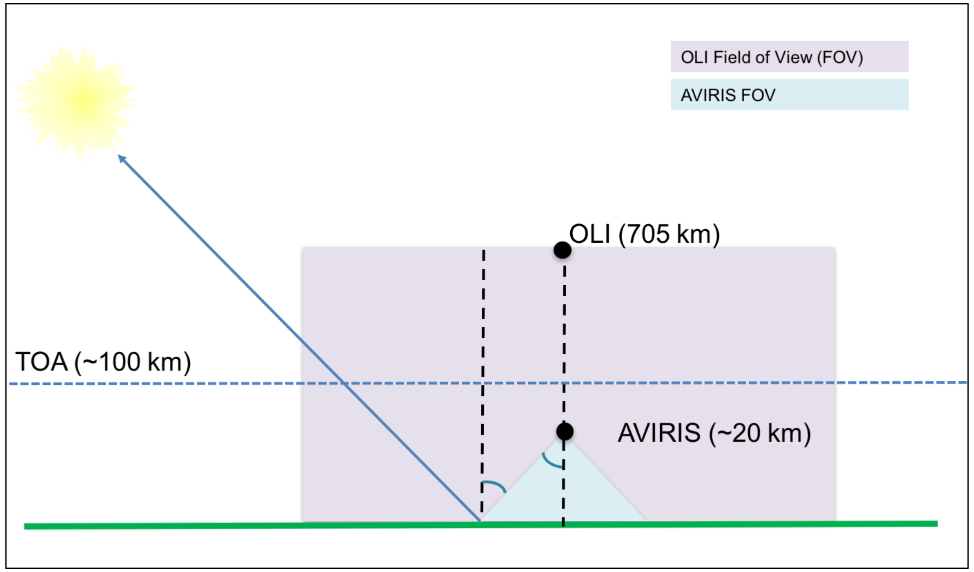
a. Combine scenes into single image
b. Clip to Region of Interest (ROI) where all AVIRIS bands have data

3) Calculate TOA Radiance: using 6s radiative transfer model calculate at-sensor, top-of-atmosphere radiance (OLI_{TOA}) for the nadir viewing OLI

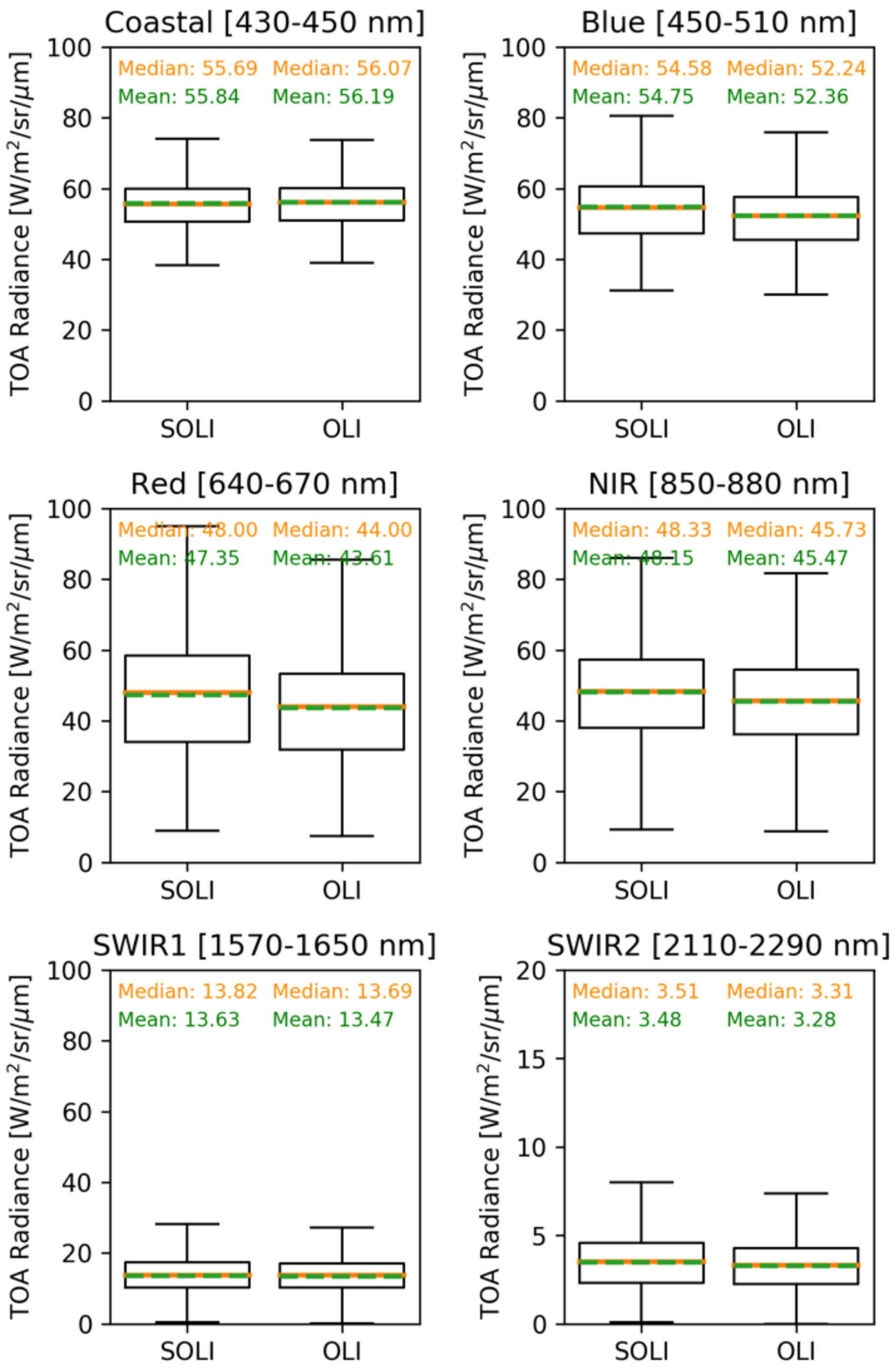
NOTE: we can't just spectrally convolve!

Analysis: influencing factors to differences (Objective 2) and within ±5% radiometric accuracy (Objective 3)

- Examine differences between OLI_{TOA} and $SOLI_{TOA}$ radiance by band
- Account for differences in path-length through the atmosphere (from VZA differences)



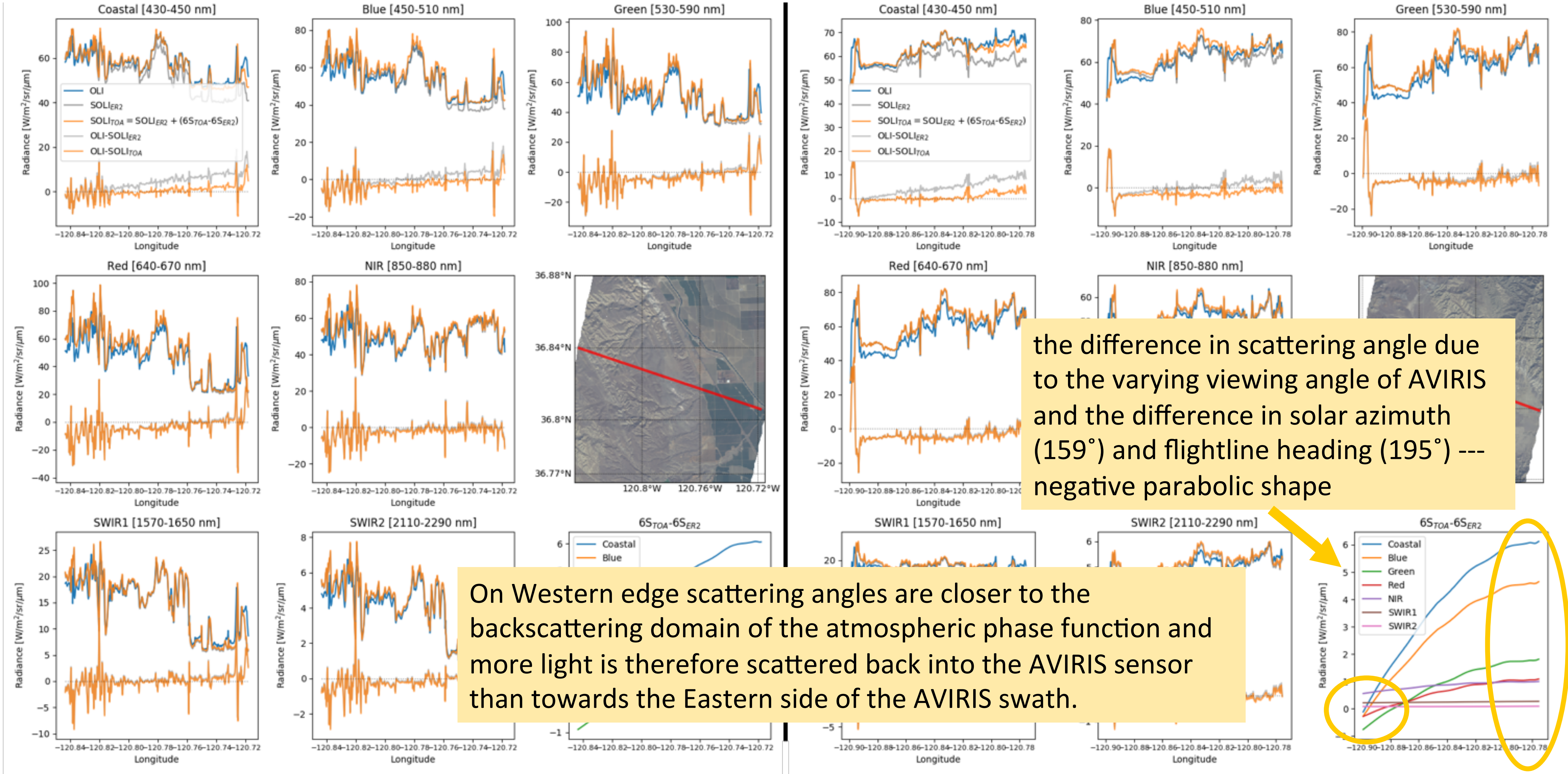
- Eliminate image-level sensor calibration differences via systematic bias-adjustment
- Use Normalized Difference Index (NDVI) to Examine differences from spatial resampling and effects on bi-directional reflectance distribution function (BRDF)
- Evaluate SNR



Results

For all bands, except for the coastal band, $SOLI_{TOA}$ mean and median radiance are biased high as compared to OLI

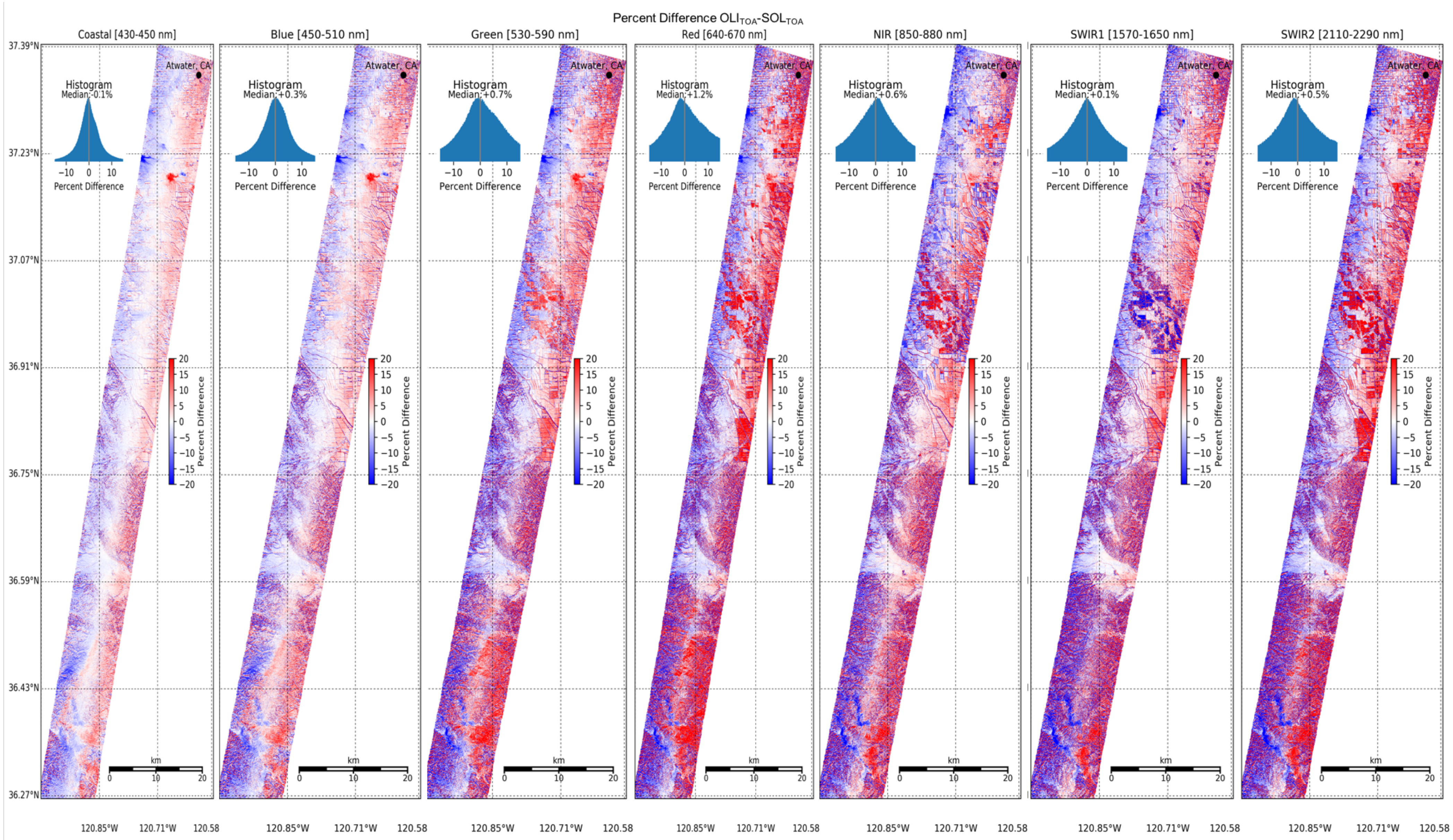
Results: Account for differences in path-length through the atmosphere (altitude and VZA), but still an upward trend remains, likely because:



the difference in scattering angle due to the varying viewing angle of AVIRIS and the difference in solar azimuth (159˚) and flightline heading (195˚) --- negative parabolic shape

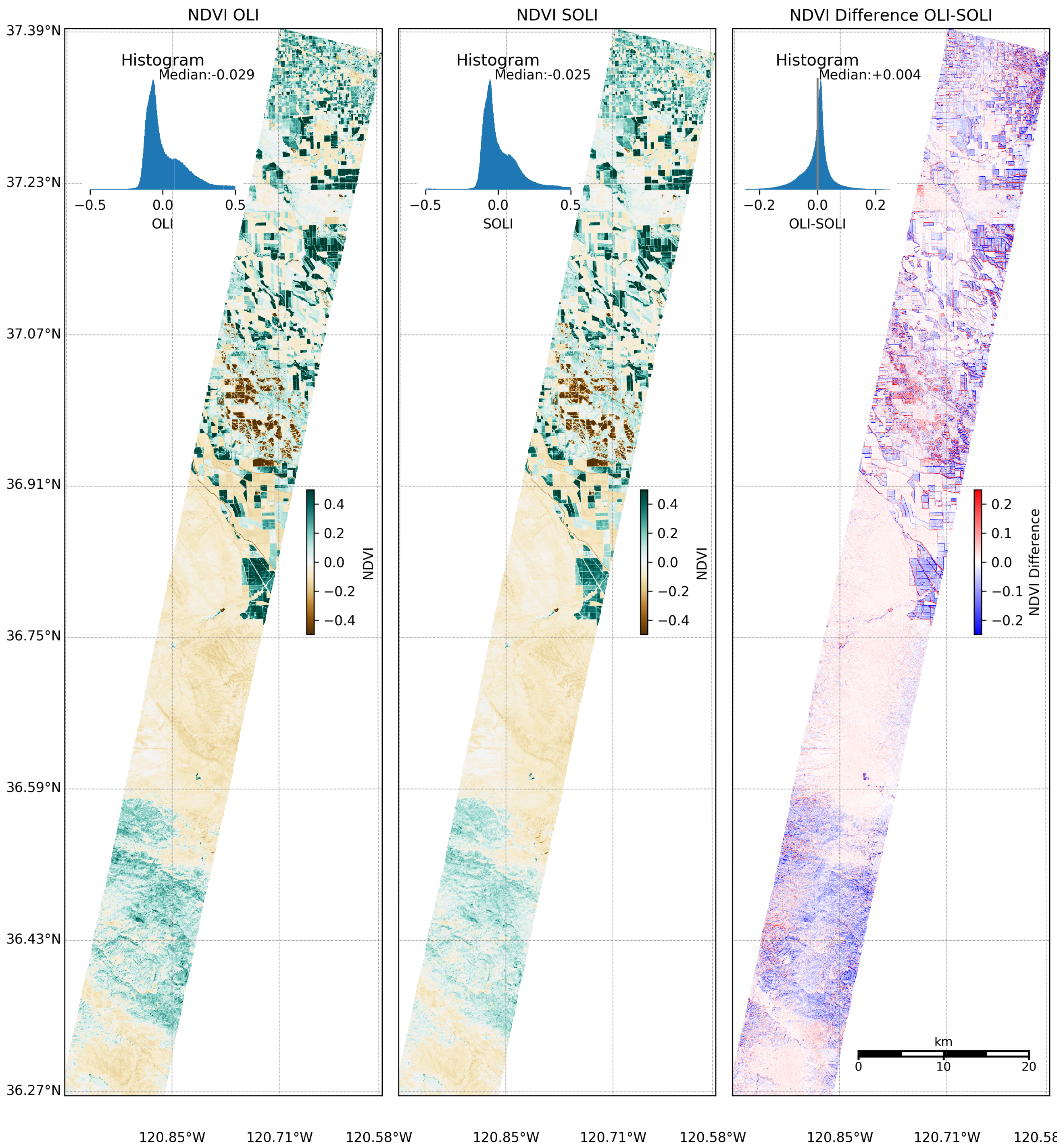
On Western edge scattering angles are closer to the backscattering domain of the atmospheric phase function and more light is therefore scattered back into the AVIRIS sensor than towards the Eastern side of the AVIRIS swath.

Results: Eliminate image-level sensor calibration differences, by applying systematic bias-adjustment by band to match median $SOLI_{TOA}$ to OLI_{TOA}



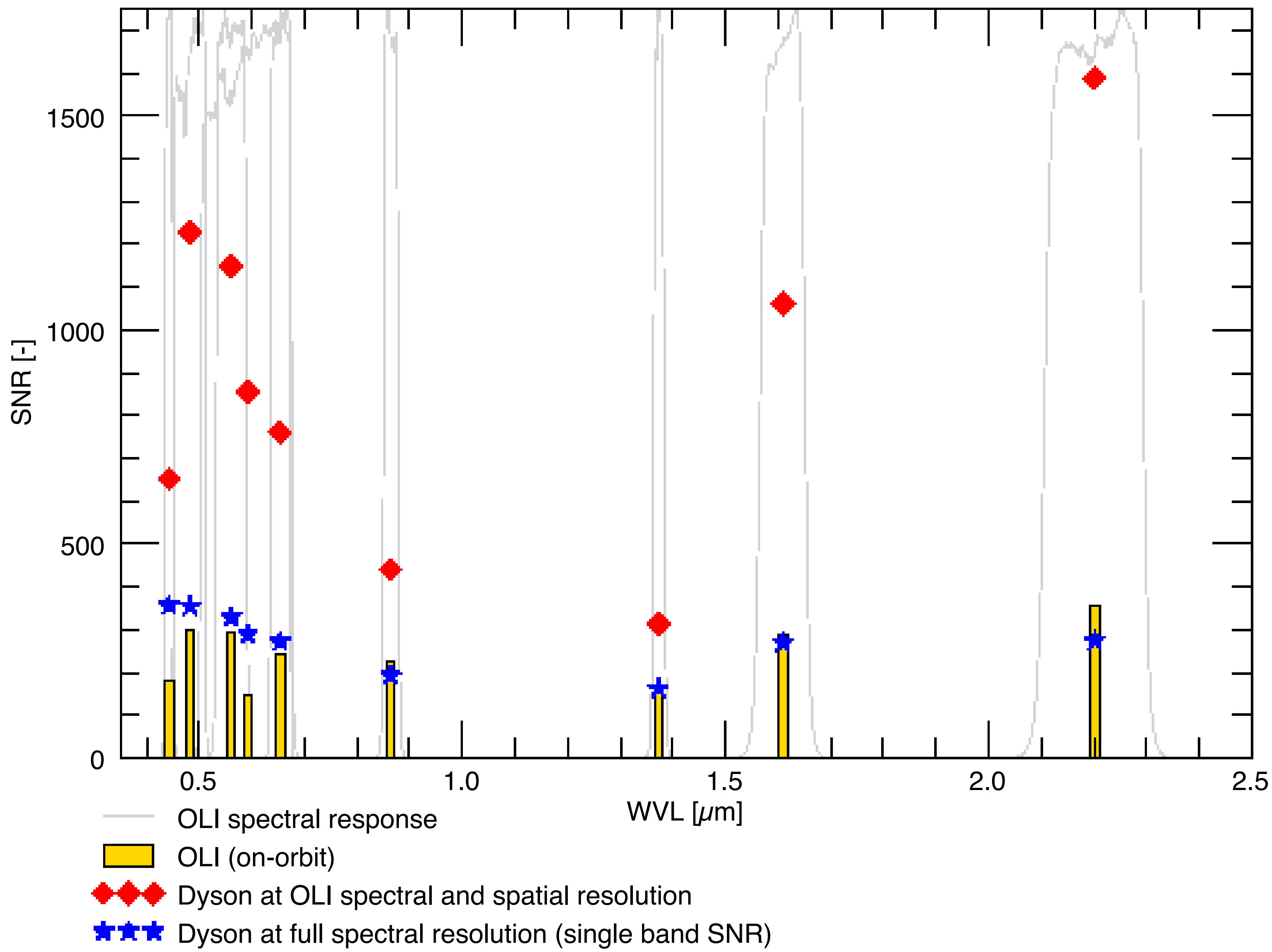
All bands within the required 5% accuracy for compatibility between sensors!!!

KEY: 5% is the community standard, as determined from creating records from AVHRR, MODIS and Landsat



Results: using NDVI the remaining difference can be attributed to spatial resampling from coregistration and consequent effects on pixel-level bi-directional reflectance distribution function (BRDF)

- Edge Effects in heterogeneous areas
- Topography



Results: SNR between a realistic optical design of an orbital version of AVIRIS (a Dyson Imaging Spectrometer) and OLI shows that in nearly all cases, an orbital imaging spectrometer would have equivalent or improved SNR values

Conclusions

- **Evaluate the influencing factors on the retrieved radiance including confounding factors**: VZA, View azimuth angle relative to solar azimuth angle, and field of view, resulting error from geolocation discrepancies and spatial convolution required for co-registering two images
- **Imaging spectroscopy not only augments the land imager record spectrally, but also temporally as it is possible to recreate previous multi-spectral bands**
  - Demonstrate the median radiometric percent difference for each band is no more than 1.2% radiometric percent difference with any OLI band after cross-calibration; This is well within the community-accepted standard ±5%!
- **Provide a How-To manual for non-Imaging Spectroscopy experts**
- **Demonstrate that cross-calibration from a spectrometer to a radiometer is, in principle, more straightforward than between different radiometers** (e.g., ETM+ vs. OLI) because imaging spectrometers can recreate the bands for any two radiometers and alleviate any differences in spectral response functions by band

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

Seidel FC, Stavros EN, Cable ML, Green R, Freeman A (in review) Imaging spectrometer emulates Landsat: A case study with Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and Operational Land Imager (OLI) data. *Remote Sensing Environment*.