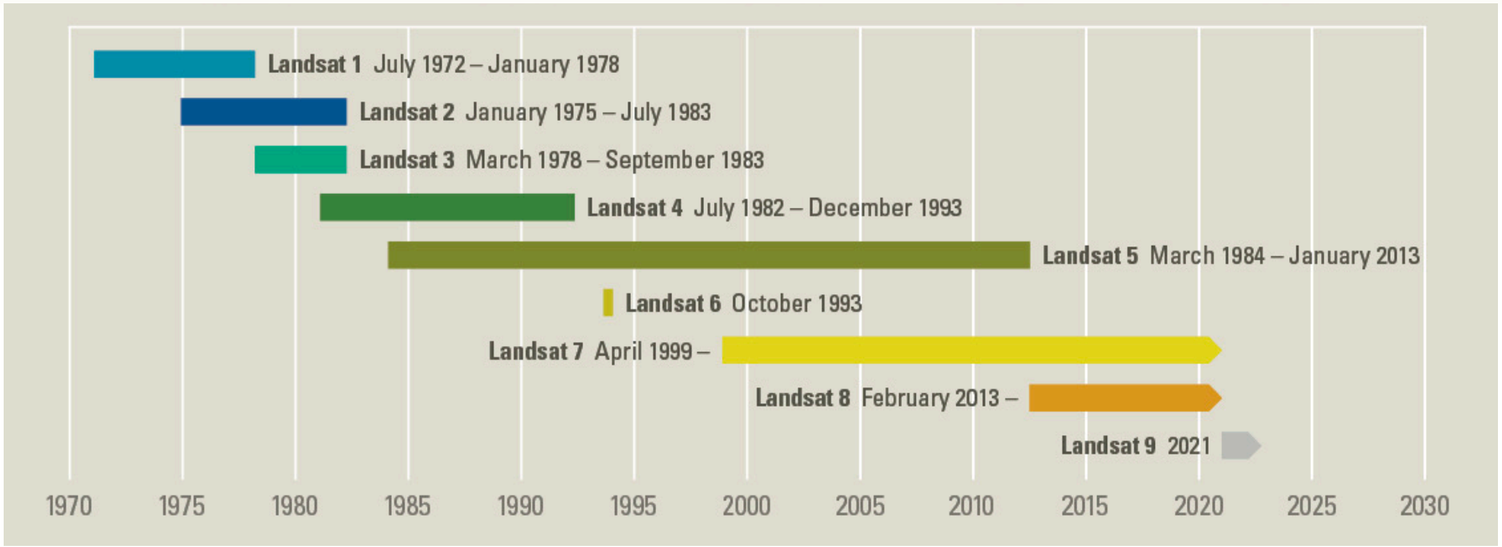
Applying lessons learned from Landsat 8 and 9 Thermal Infrared Sensor calibration for future thermal missions

Brian N. Wenny[1], Kurtis Thome[2], Sarah Eftekharzadeh[1], Matt Montanaro[3], Norvik Voskanian[1], Mohammad Tahersima[1], and Mehran Yarahmadi[1]

1 Science Systems & Applications, Inc., Lanham, MD USA
2 NASA Goddard Space Flight Center, Greenbelt, MD USA
3 Rochester Institute of Technology, Rochester, NY USA

Landsat 8 & 9 Basics

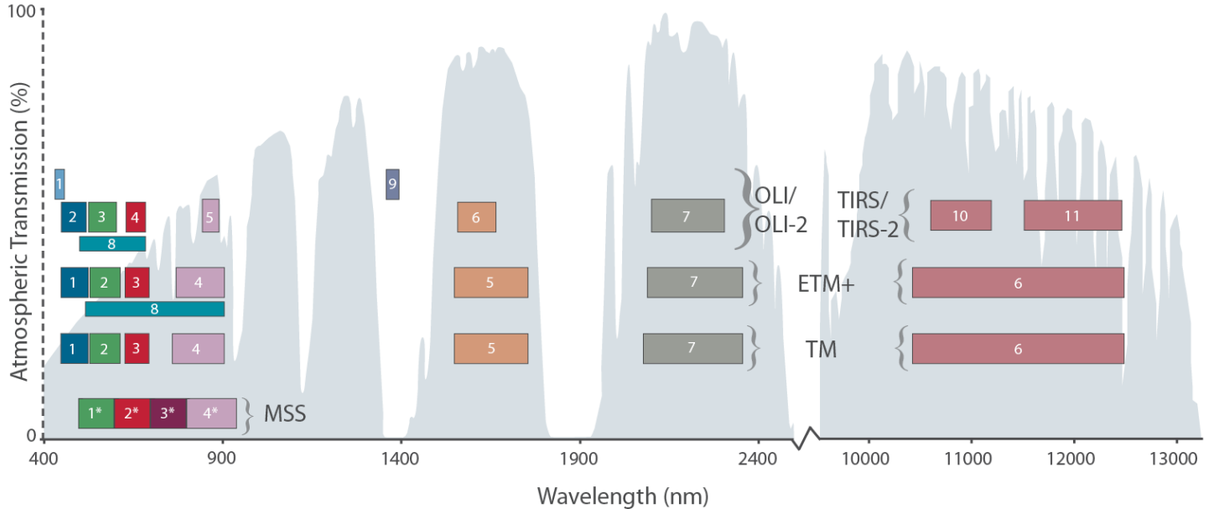
Launched on Feb. 11, 2013

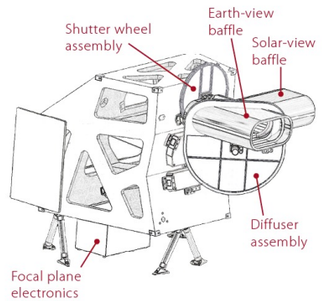


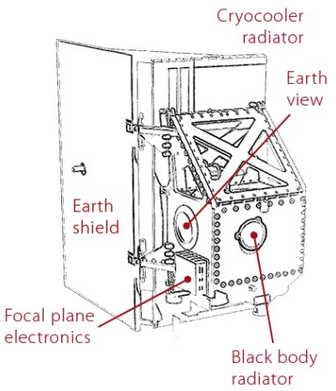
Launched on Sept. 27, 2021

Near identical instrument build for the two platforms

- Operational Land Imager (OLI)
- Thermal Infrared Sensor (TIRS)

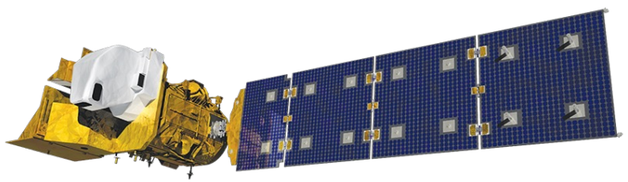




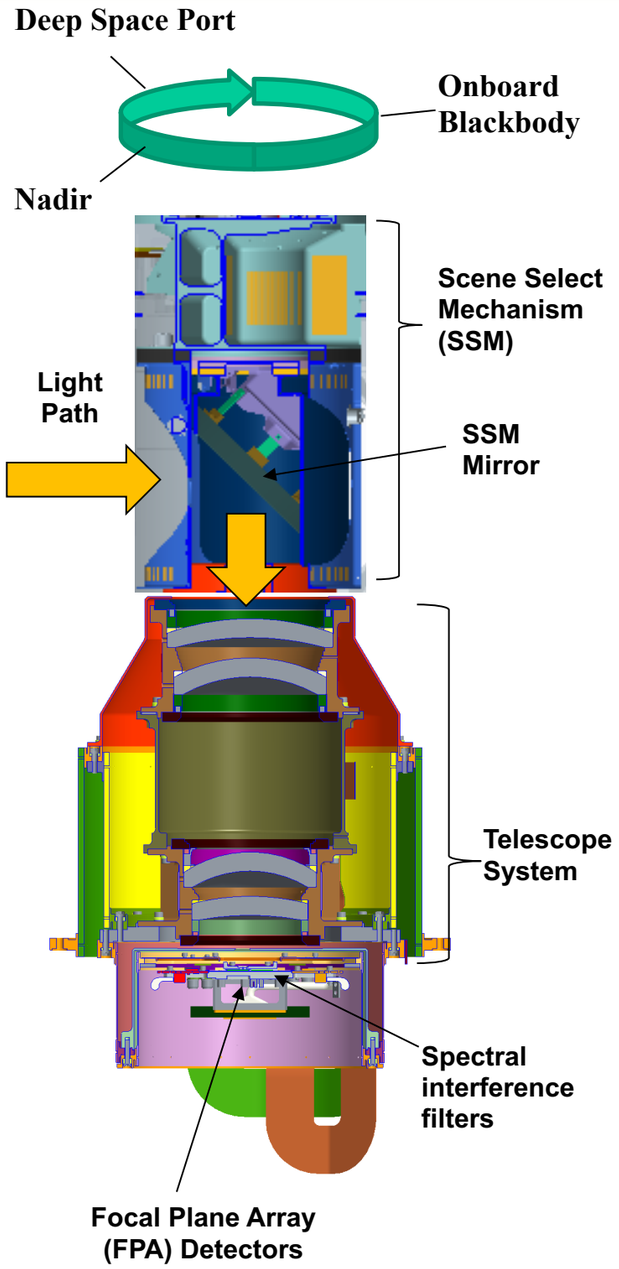


Orbits

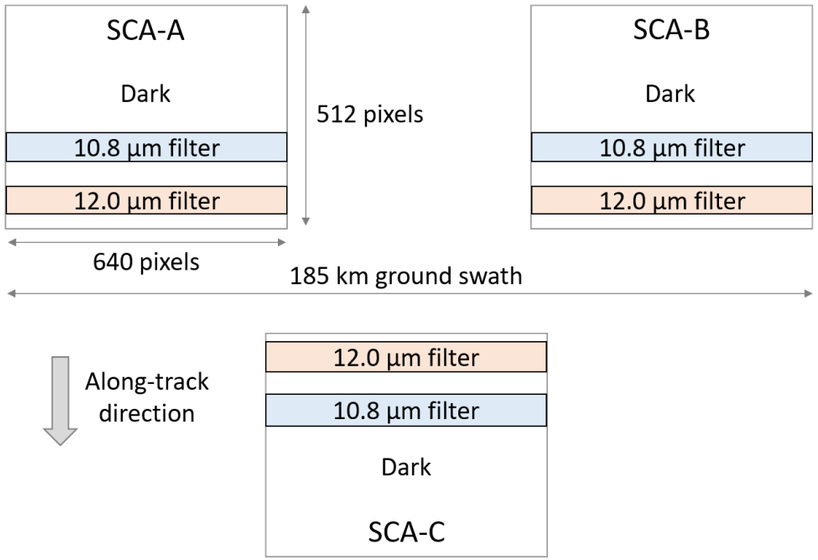
- 705 km
- Sun-synchronous
- 98.2° Inclination
- 8 days out of phase



TIRS Instrument Basics



- Push-broom mode, 3 detector arrays, 185 km wide swath



- 10.8um (band 10) and 12.0um (band 11) channels
- Onboard calibration sources: Deep Space port and Onboard Blackbody Calibrator (OBC)
- Image acquisition of onboard sources before and after every Earth interval

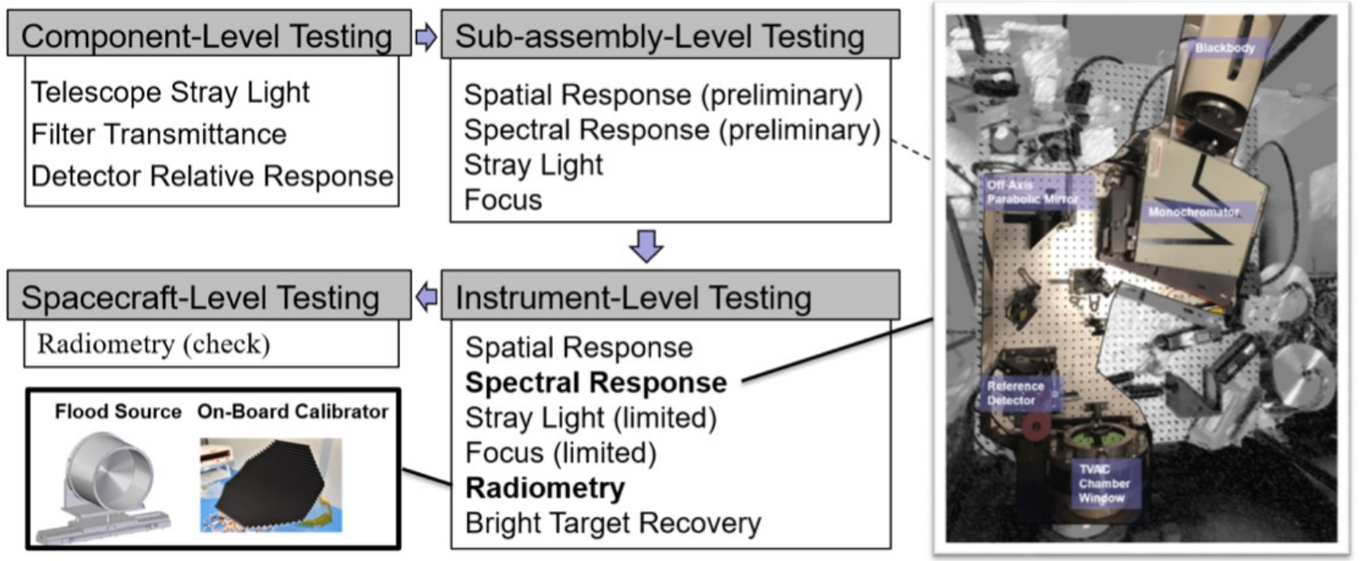
J. Hair et al., "Landsat 9 thermal infrared sensor 2 architecture and design," in Proceeding of IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 8841–8844, (2018)

TIRS Pre-launch Calibration Testing

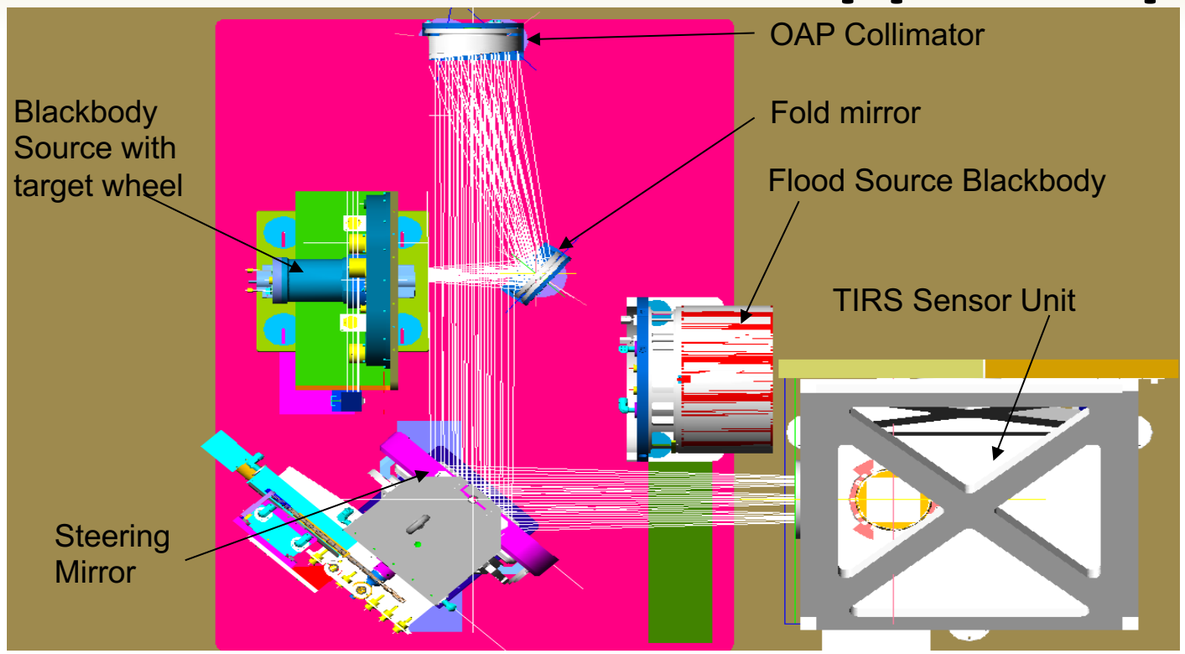
- TIRS was designed, built and tested at NASA Goddard Space Flight Center

- Landsat 9 TIRS incorporated slight design changes
  - Additional baffles to reduce stray light
  - Expanded electronic redundancies to avoid single point failures

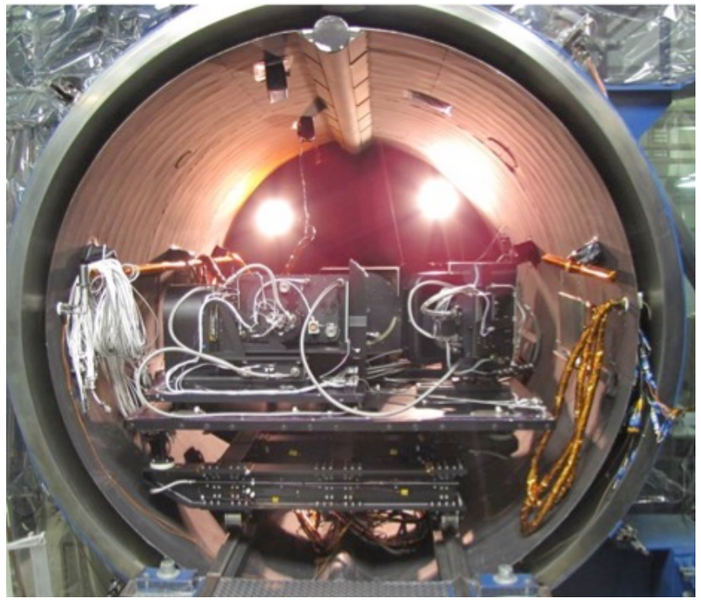
- TIRS characterized at component, subassembly, instrument and spacecraft level
  - Test as you fly, fly as you test philosophy



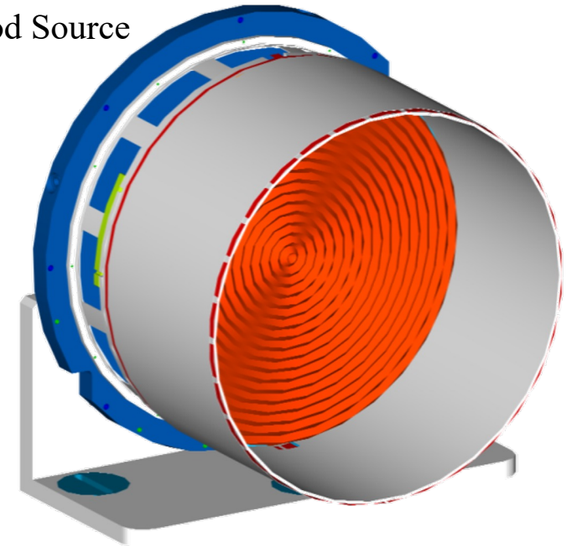
Calibration Ground Support Equipment



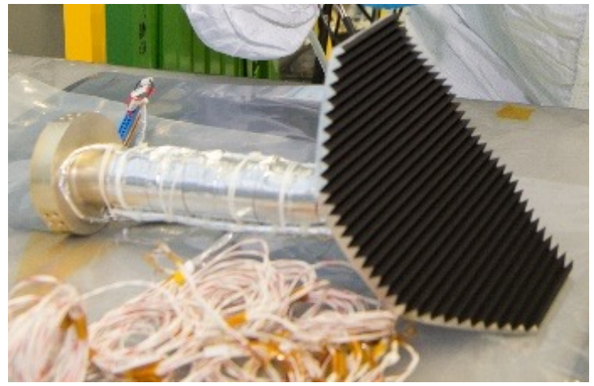
- Custom built calibration equipment
  - ‘Flood Source’ - Full-aperture, variable temperature used for radiometric characterization
  - ‘IRSM’ – Blackbody source with target wheel
- SI traceability of the Flood source established by the Space Dynamics Lab (SDL) through their NIST-traceable blackbody source & transfer radiometer with uncertainty of 0.2%.



Flood Source



Onboard Blackbody Calibrator (OBC) Source

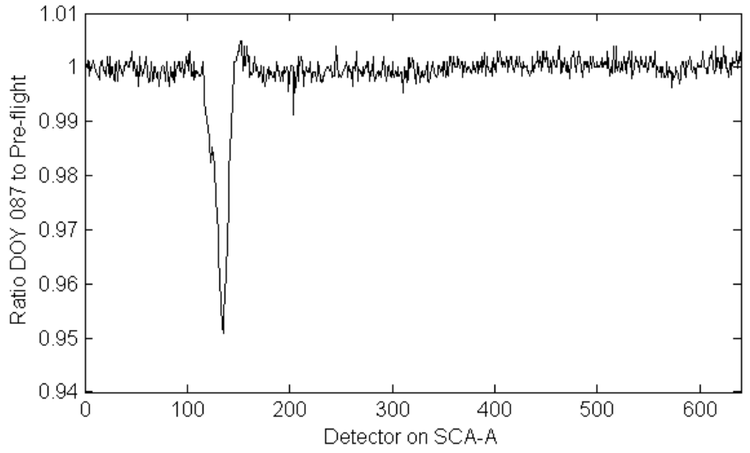


A. Pearlman, M. Montanaro, B. Efremova, J. McCorkel, B. Wenny, A. Lunsford, and D. Reuter. “Prelaunch Radiometric Calibration and Uncertainty Analysis of Landsat Thermal Infrared Sensor 2,” in IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 4, pp. 2715-2726, 2021. doi: 10.1109/tgrs.2020.3008655

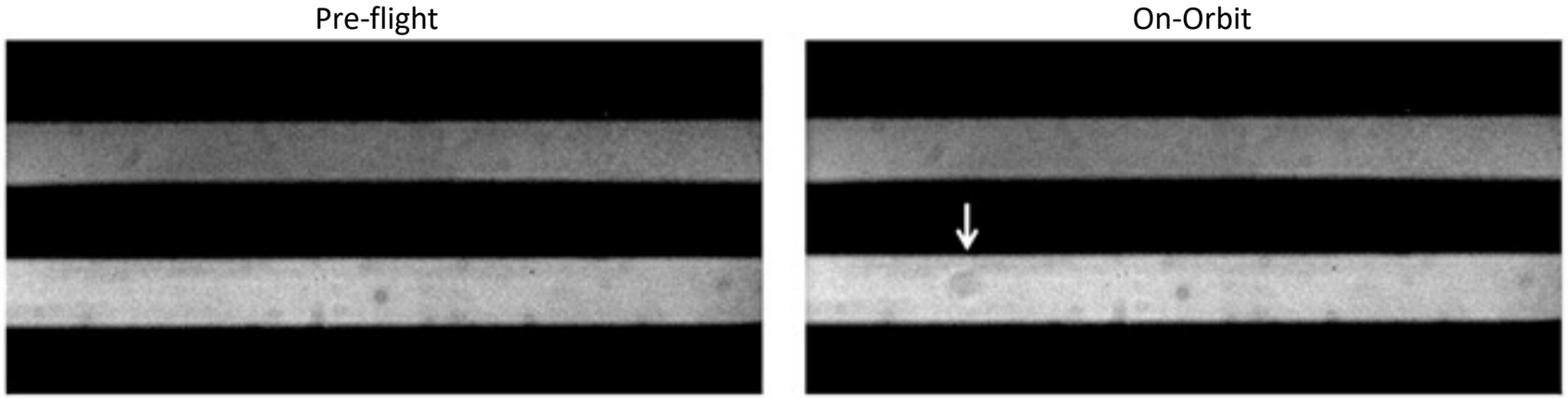
Not able to predict when a sensor will misbehave

- Shortchanging pre-launch sensor calibration and characterization induces risk to on-orbit data quality and ultimately to mission success

- Reducing preflight and onboard calibration may reduce cost and schedule, but a comprehensive characterization is needed to allow understanding of on-orbit sensor behavior and calibration, particularly when anomalies occur

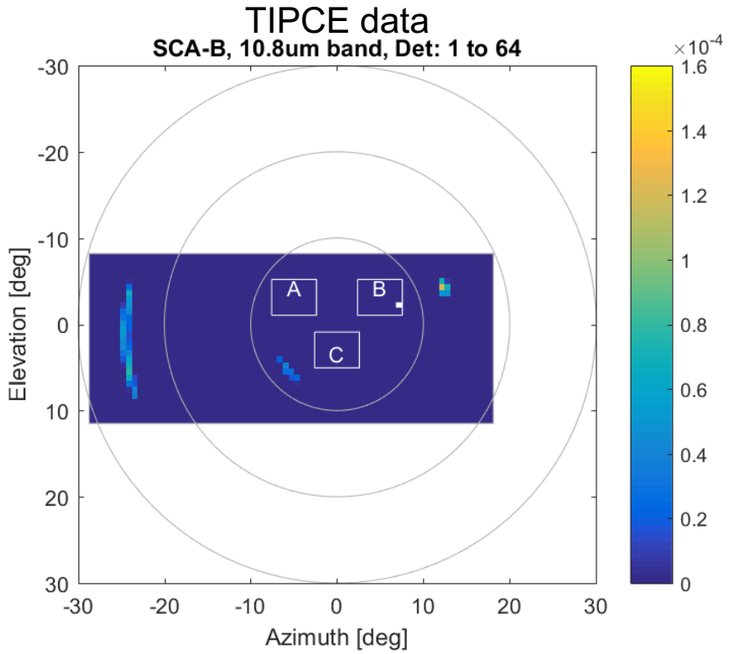


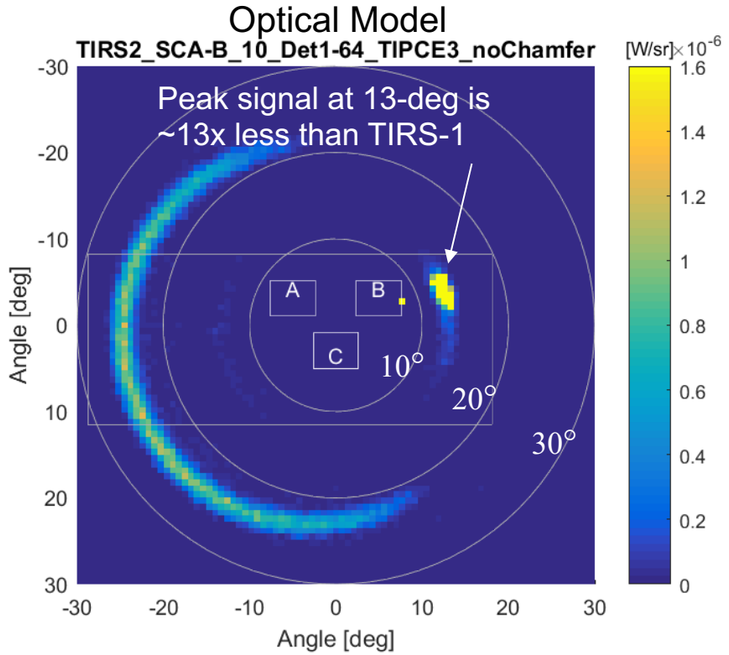
Landsat-8 TIRS focal plane data



Trust, but Verify

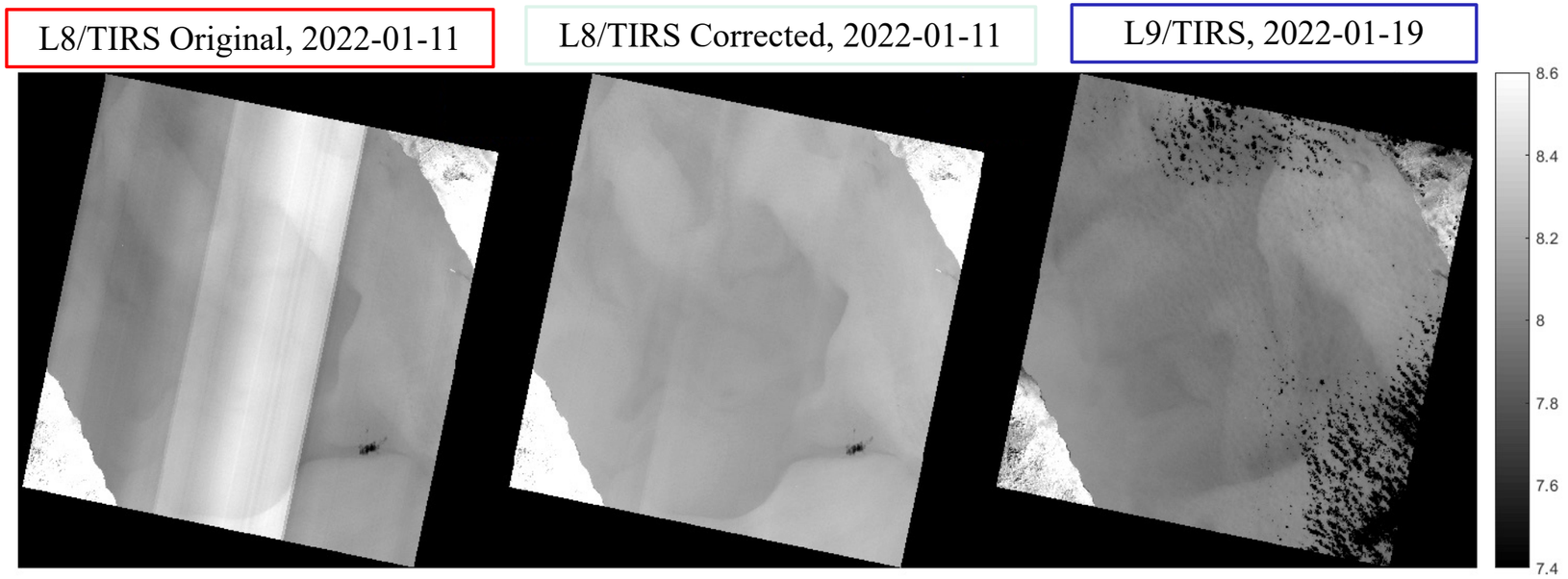
- Instrument models useful tool for understanding optical artifacts
- Landsat 8 TIRS stray light artifact observed in TVAC testing not seen in instrument model analysis
  - Assumed model was correct and cause was the Calibration GSE
  - On-orbit showed the assumption was incorrect
- Landsat 9 TIRS included additional baffles
  - Updated instrument model predictions of out-of-field scattering measurements confirmed with a dedicated component-level TVAC test





• TIRS Stray Light Mitigation

- Landsat 8 TIRS dependent on software to fix a hardware problem
- Mechanical baffles added to optical system resulted in a 30x reduction in stray light for Landsat 9 TIRS
- Landsat 9 TIRS Earth imagery does not exhibit stray light artifacts.

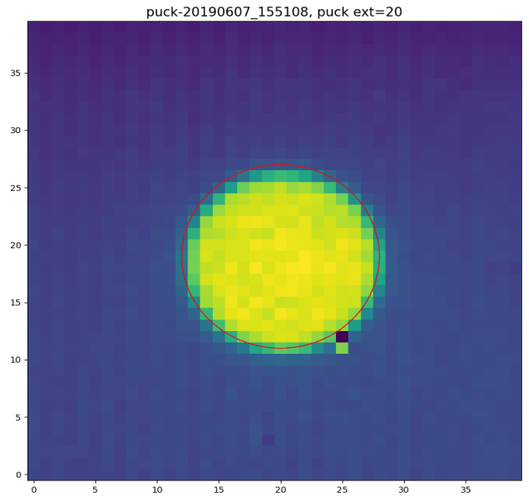


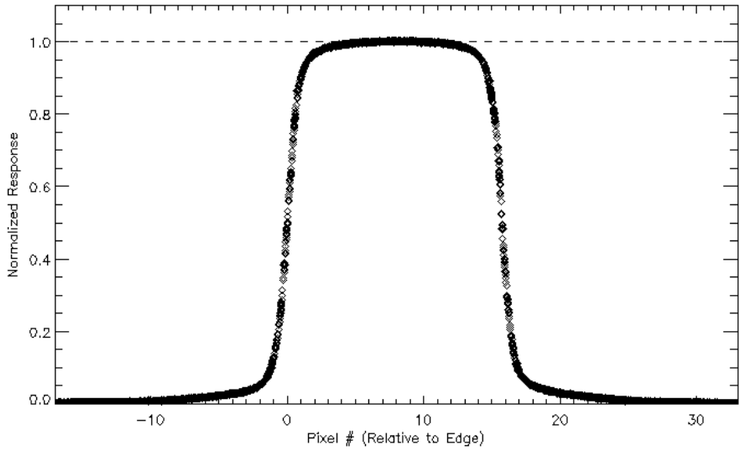
Red Sea, WRS2 path 173/row 42, Band 11

M. Montanaro, J. McCorkel, J. Tveekrem, J. Stauder, E. Mentzell, A. Lunsford, J. Hair, and D. Reuter. "Landsat 9 Thermal Infrared Sensor 2 (TIRS-2) Stray Light Mitigation and Assessment," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-8, (2022), Art no. 5002408. doi: 10.1109/TGRS.2022.3177312.

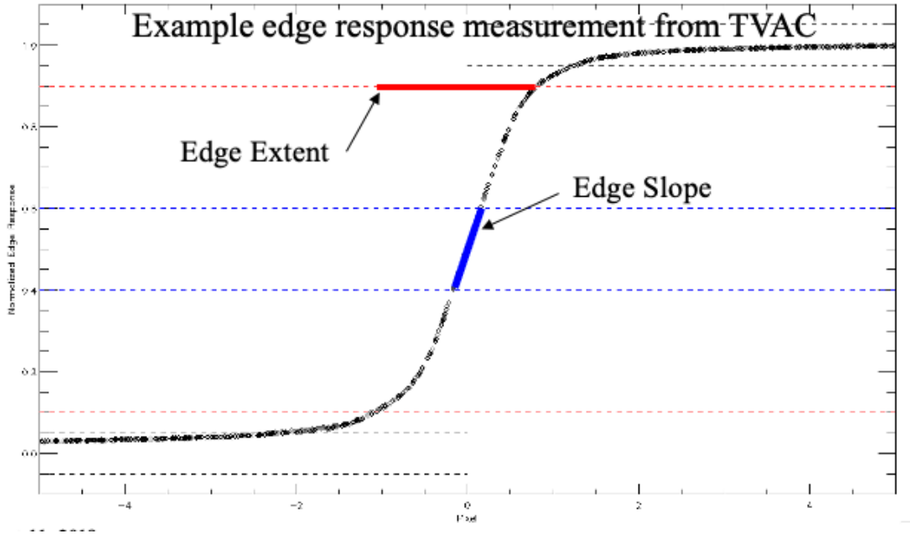
TIRS Spatial Performance

- Radiometric calibration performance critical for mission success.
  - Spatial response performance is also important for understanding small scale features and harmonizing multiple sensors.
- TIRS spatial performance requirement metric defined in terms of edge response.
  - Data collected at instrument-level TVAC at all expected on-orbit operational conditions and pre- and post-vibration
- Pre-launch derived edge response nearly identical for both TIRS





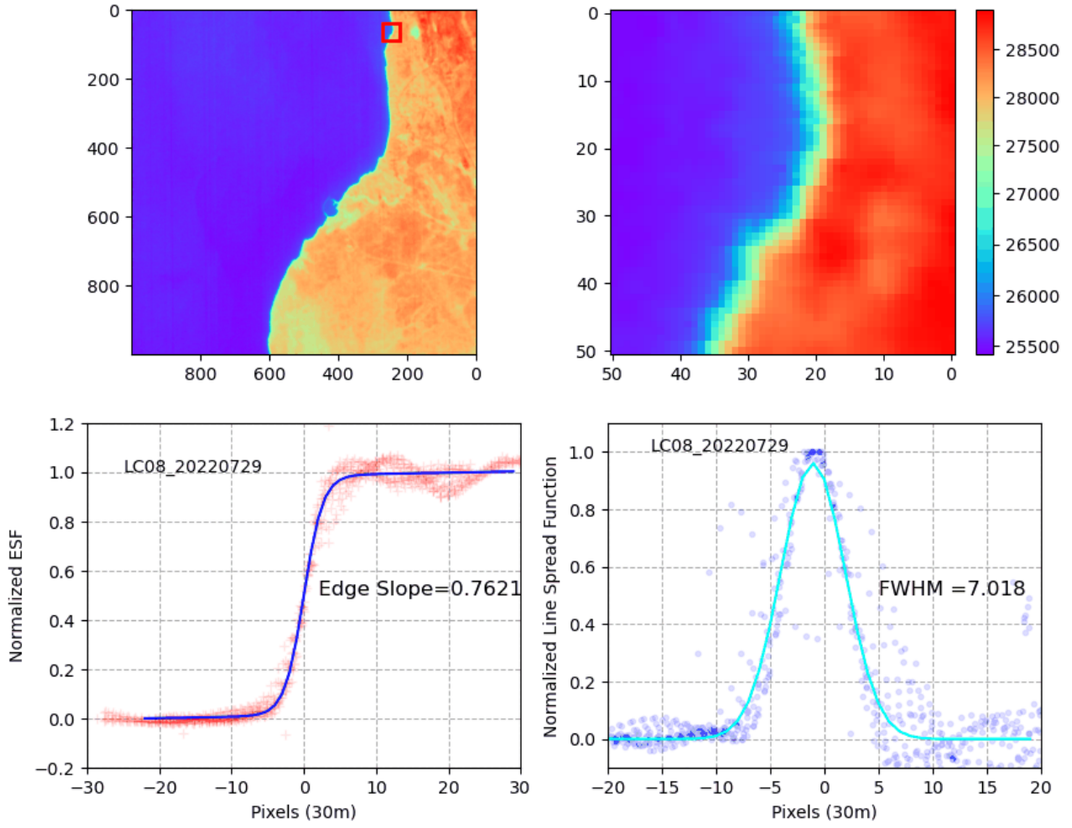
Collected cross sections shifted to common reference frame



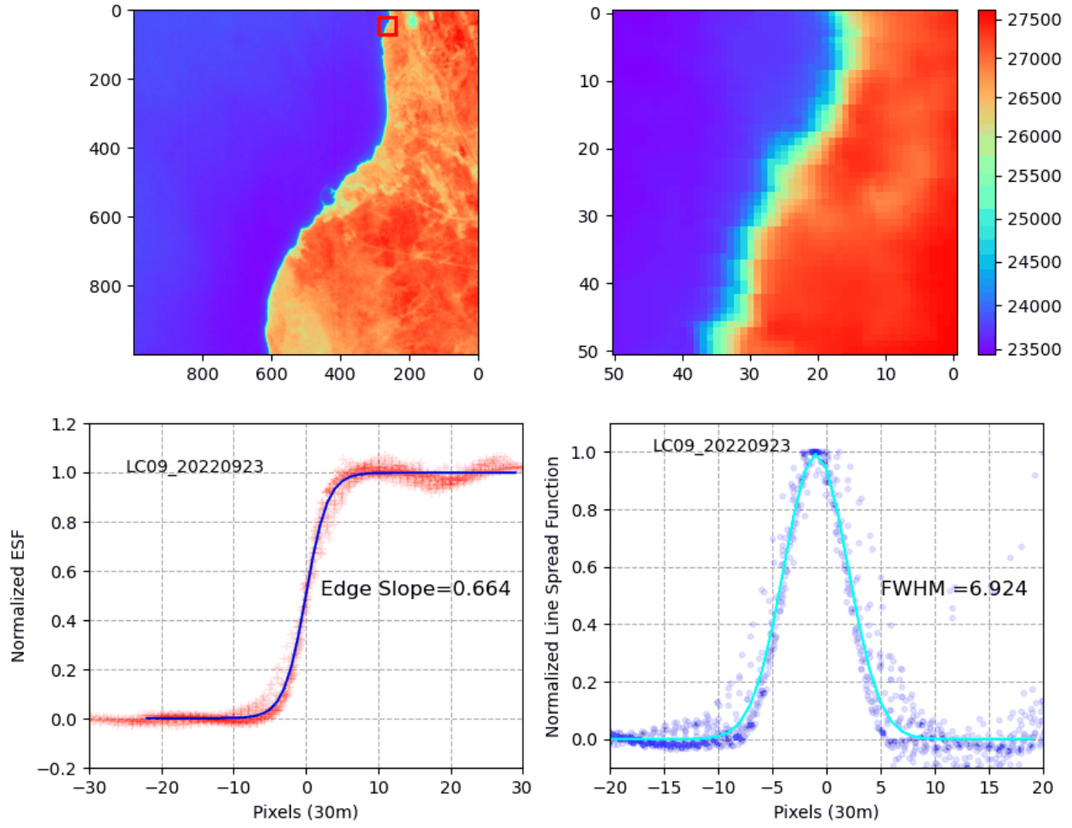
TIRS On-orbit Spatial Performance

- Landsat 8 TIRS on-orbit assessment of similar edge slope metric using technique developed for high temperature contrast coastlines near deserts. A similar approach applied to Landsat 9 TIRS allows comparison.

Landsat 8 B10 – Oman
07.29.2022



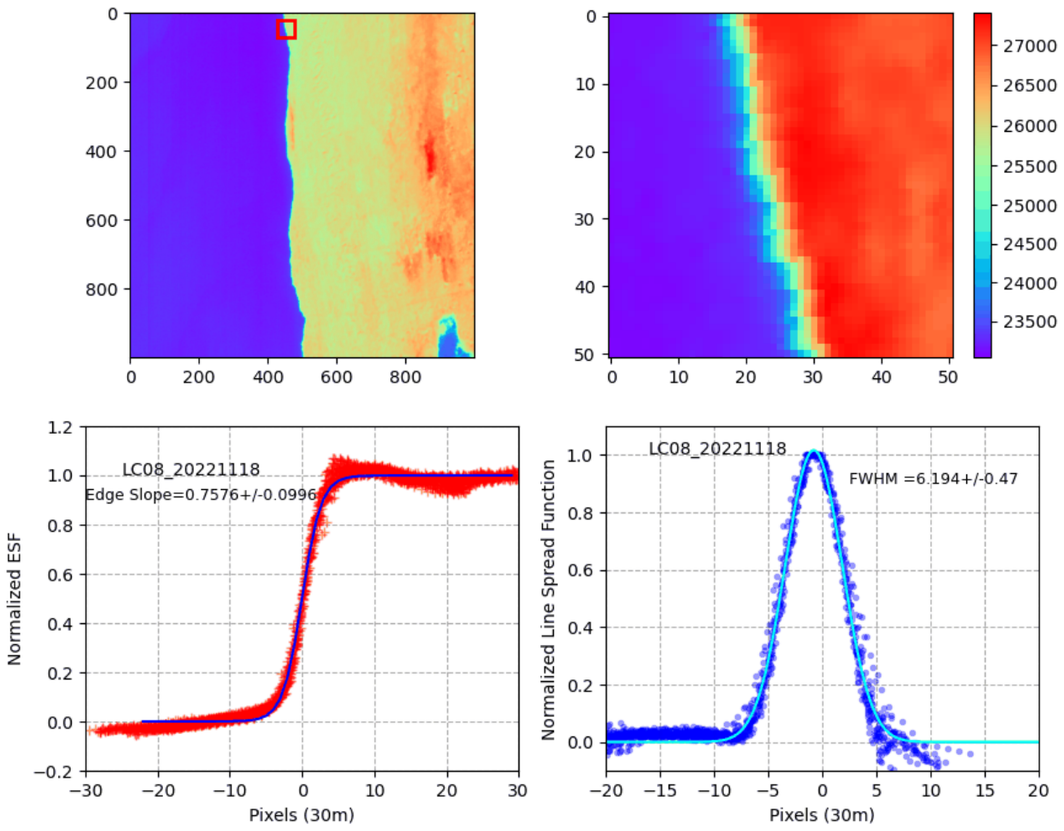
Landsat 9 B10 – Oman
09.23.2022



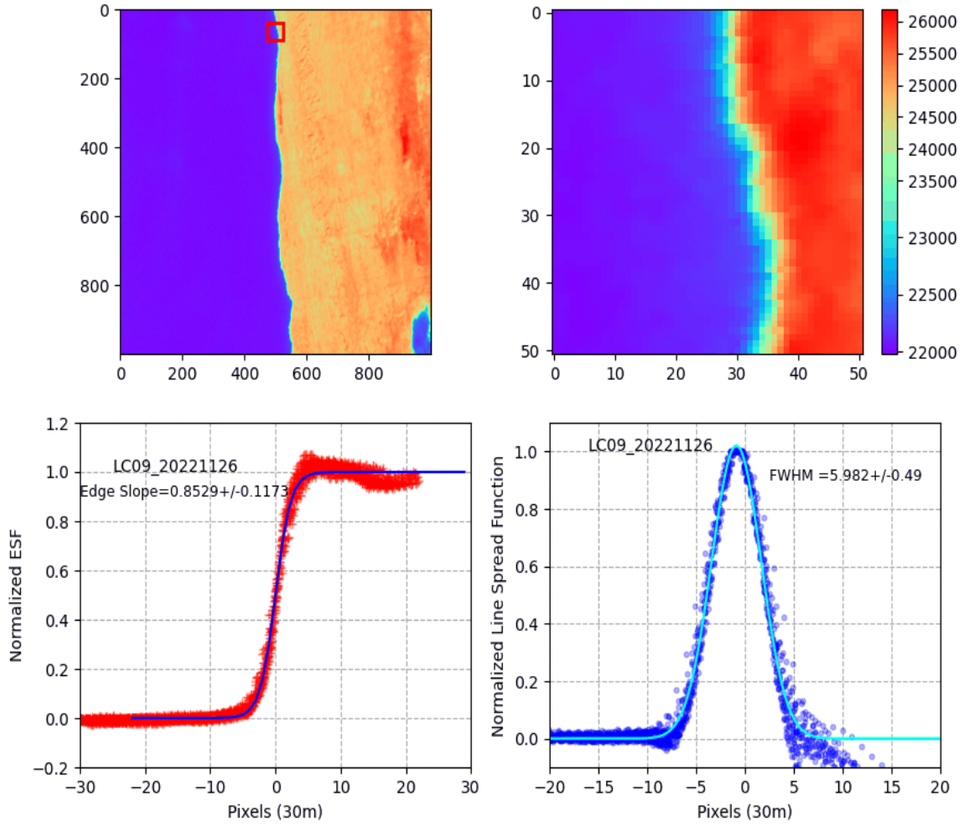
TIRS On-orbit Spatial Performance

- Choice of coastline orientation enables assessment in both cross-track and along-track directions

Landsat 8 B11 – Western Sahara
11.18.2022



Landsat 9 B11 – Western Sahara
11.26.2022

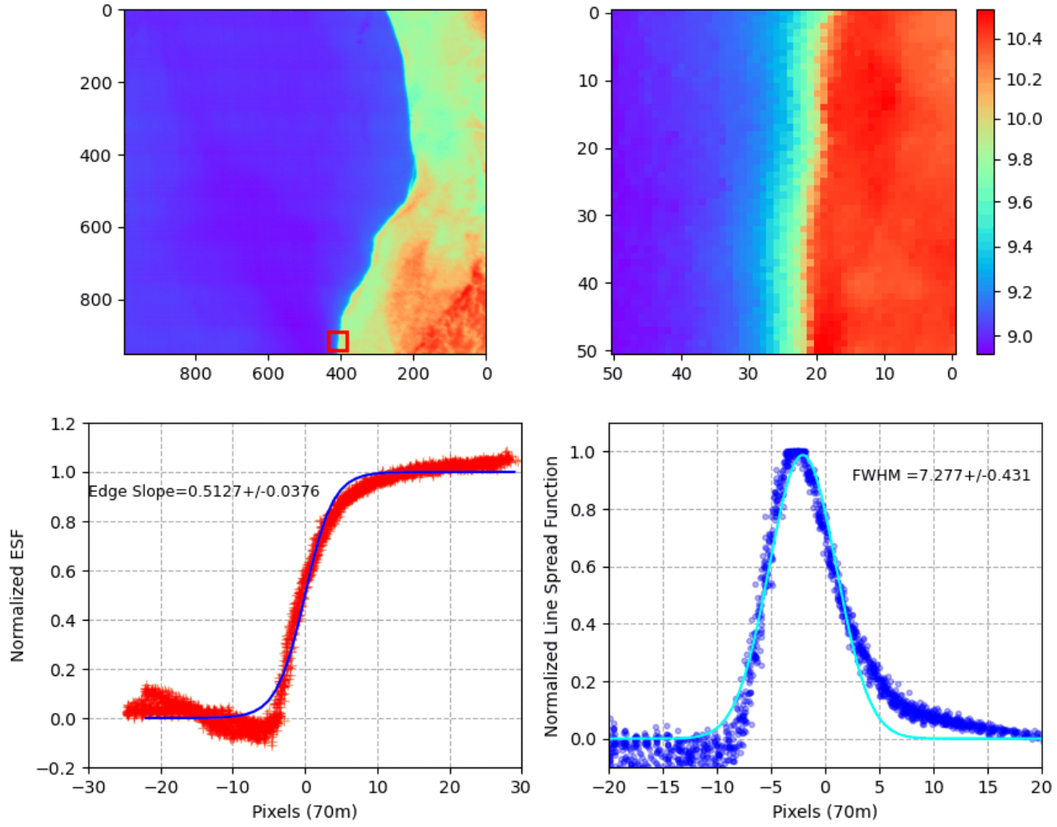


ECOSTRESS Spatial Performance

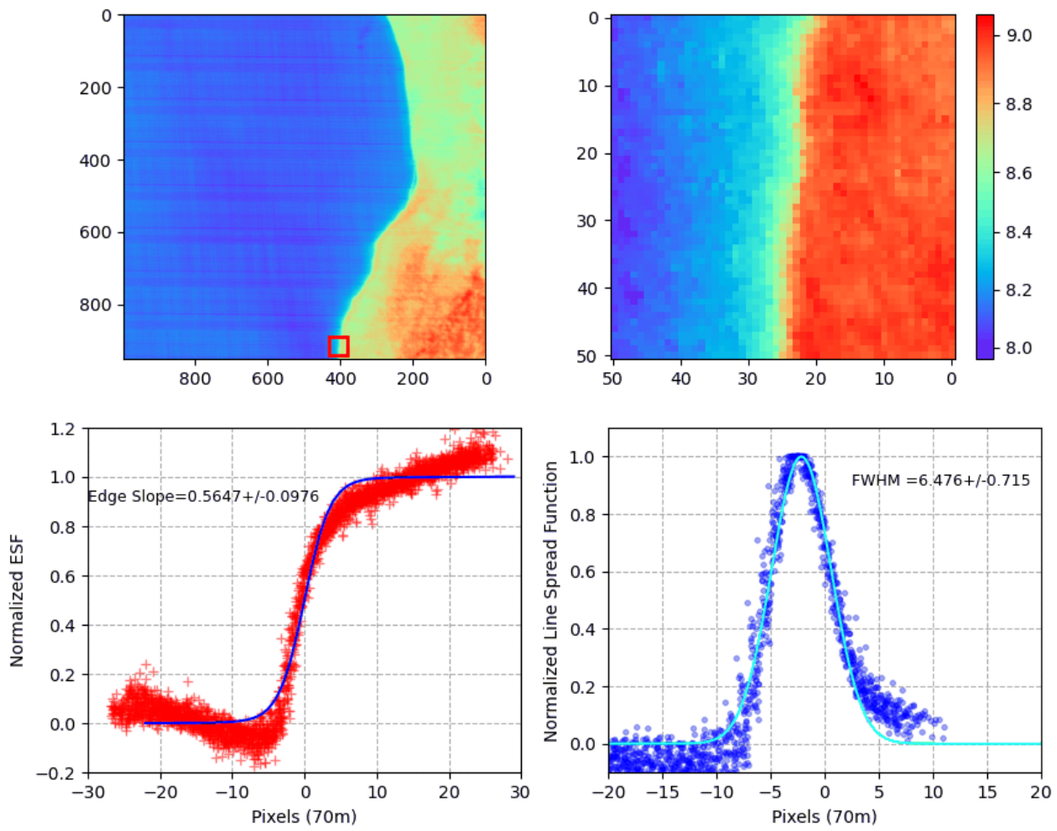
- Coastline technique applied to ECOSTRESS as test of strategy for SBG TIR

ECOSTRESS – Oman
04.02.2023

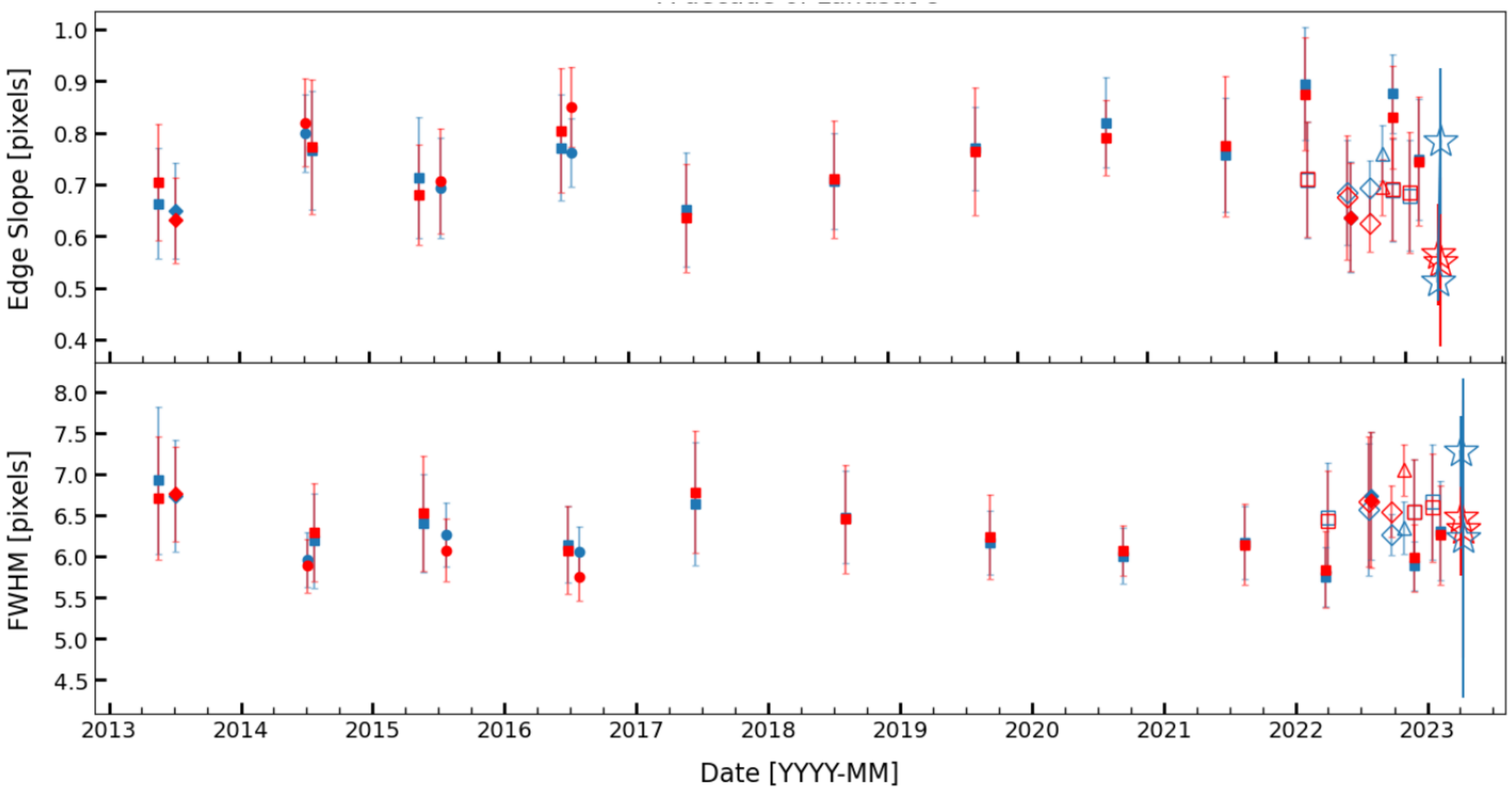
Site/date:Oman-ECOSTRESS_L1B_MAP_RAD_26867_006_20230402T072203-10.5um



Site/date:Oman-ECOSTRESS_L1B_MAP_RAD_26867_006_20230402T072203-12.0um



On-orbit Edge Response History



Landsat 8

Landsat 9

ECOSTRESS

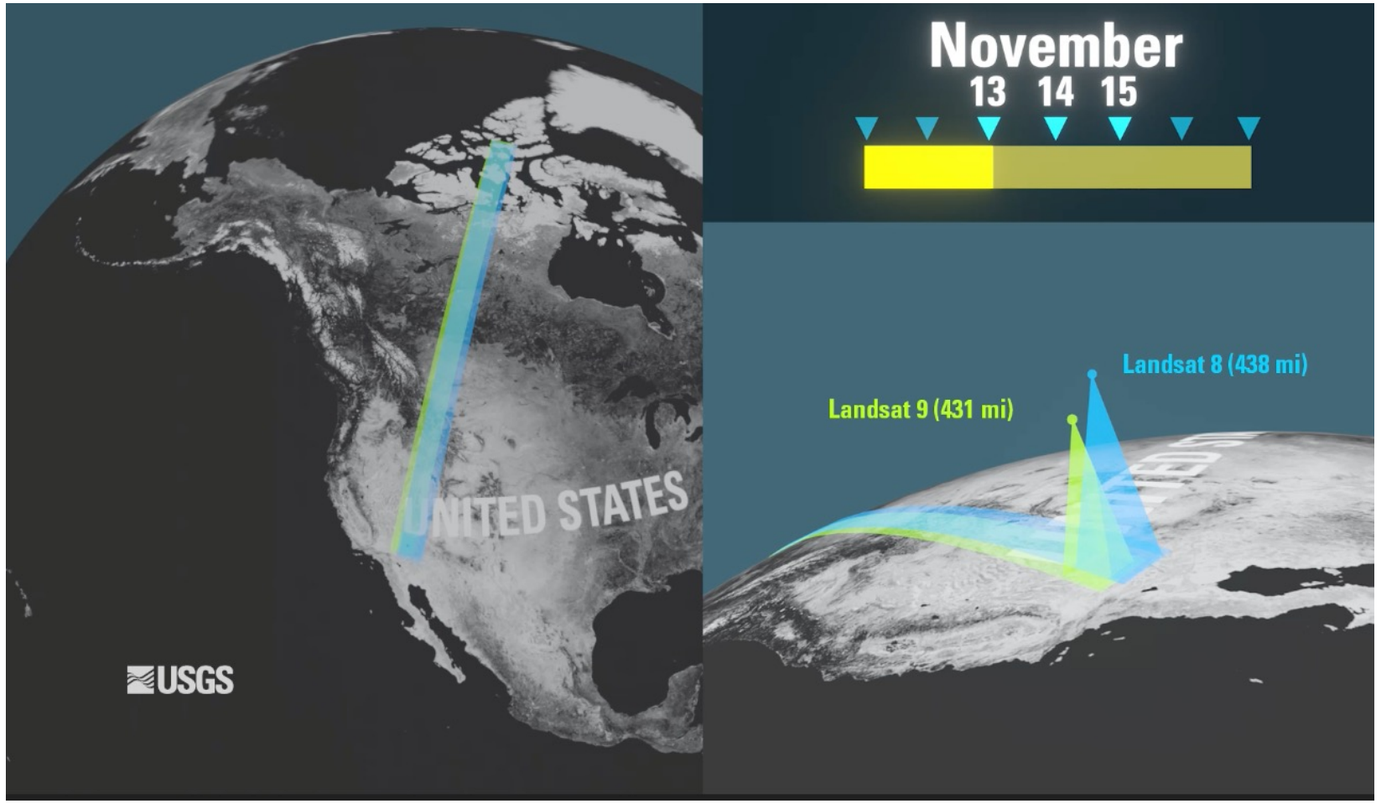
Blue: 10.8 μm, Red: 12 μm,

◆: Oman ■:Sahara ●: Libya ▲: Yemen

Leverage any opportunity for sensor characterization

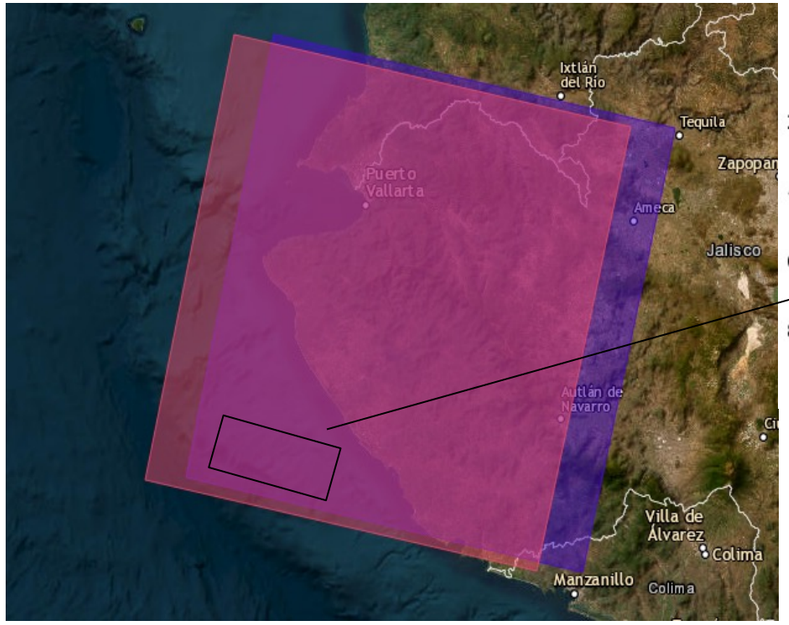
- As Landsat 9 was maneuvered into its final orbit, the spacecraft was purposefully placed directly under the orbit of Landsat 8 for several days allowing collection of collocated and coincident Earth view scenes

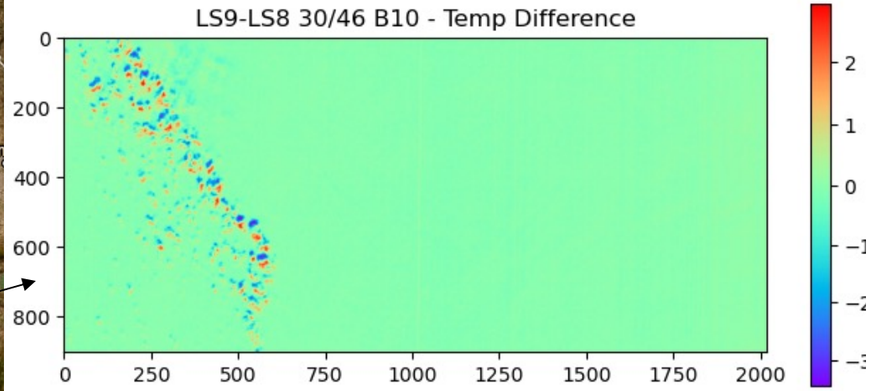
- Can be incorporated as part of operational process during orbital insertion of any platform
- Does not require additional resources
- No reason not to do it if at all feasible
- Provides a quick check on sensor performance – collecting data over a range of surface types and conditions
- Co-ordinated ground/airborne campaigns add value to any underfly opportunity

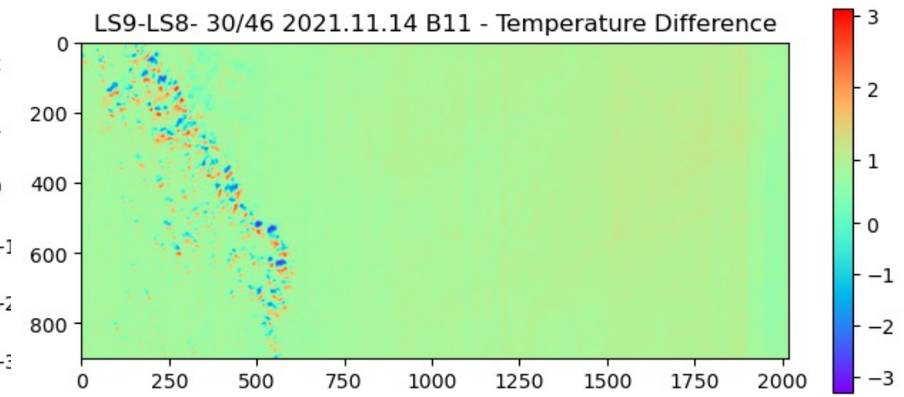


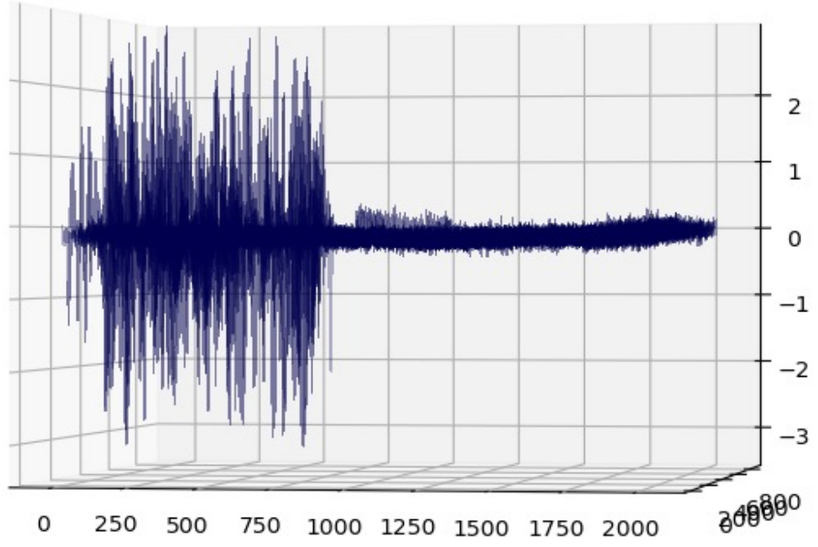
TIRS Underflight

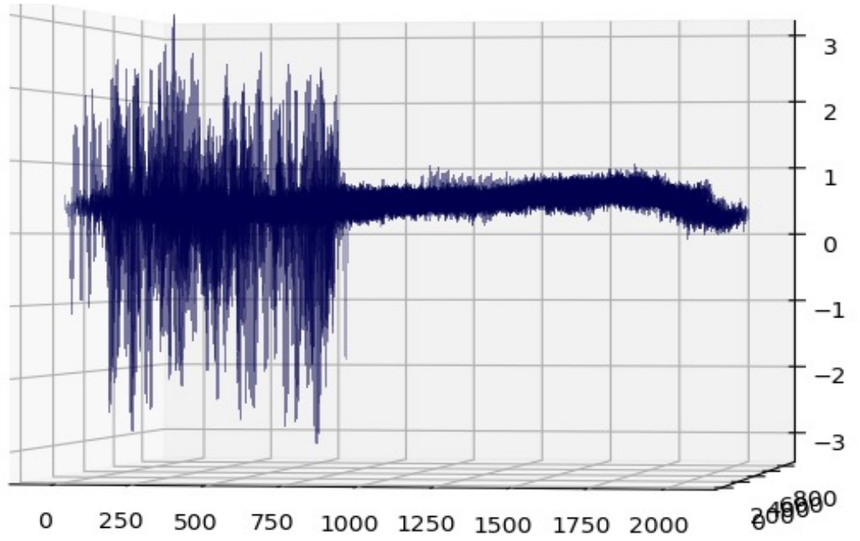
- Useful method for early on-orbit assessment of sensor performance and harmonization potential. Quick look example below shows good agreement between coincident L8 and L9 TIRS for clear skies with a generally uniform surface type.











TIRS Lessons Learned Take Home Message

- Don’t shortchange calibration and characterization at pre-launch
  - Test as you fly, fly as you test
  - Flexibility in testing
  - Don’t rely on software to fix hardware problems.
  - Radiometric calibration should be primary objective, but don’t neglect spatial & spectral characterization.

- Trust, but verify instrument models.

- Leverage any opportunity to gain insight on sensor