On-Orbit Calibration of Geostationary Earth Orbit (GEO) Imagers

Curtiss O. Davis

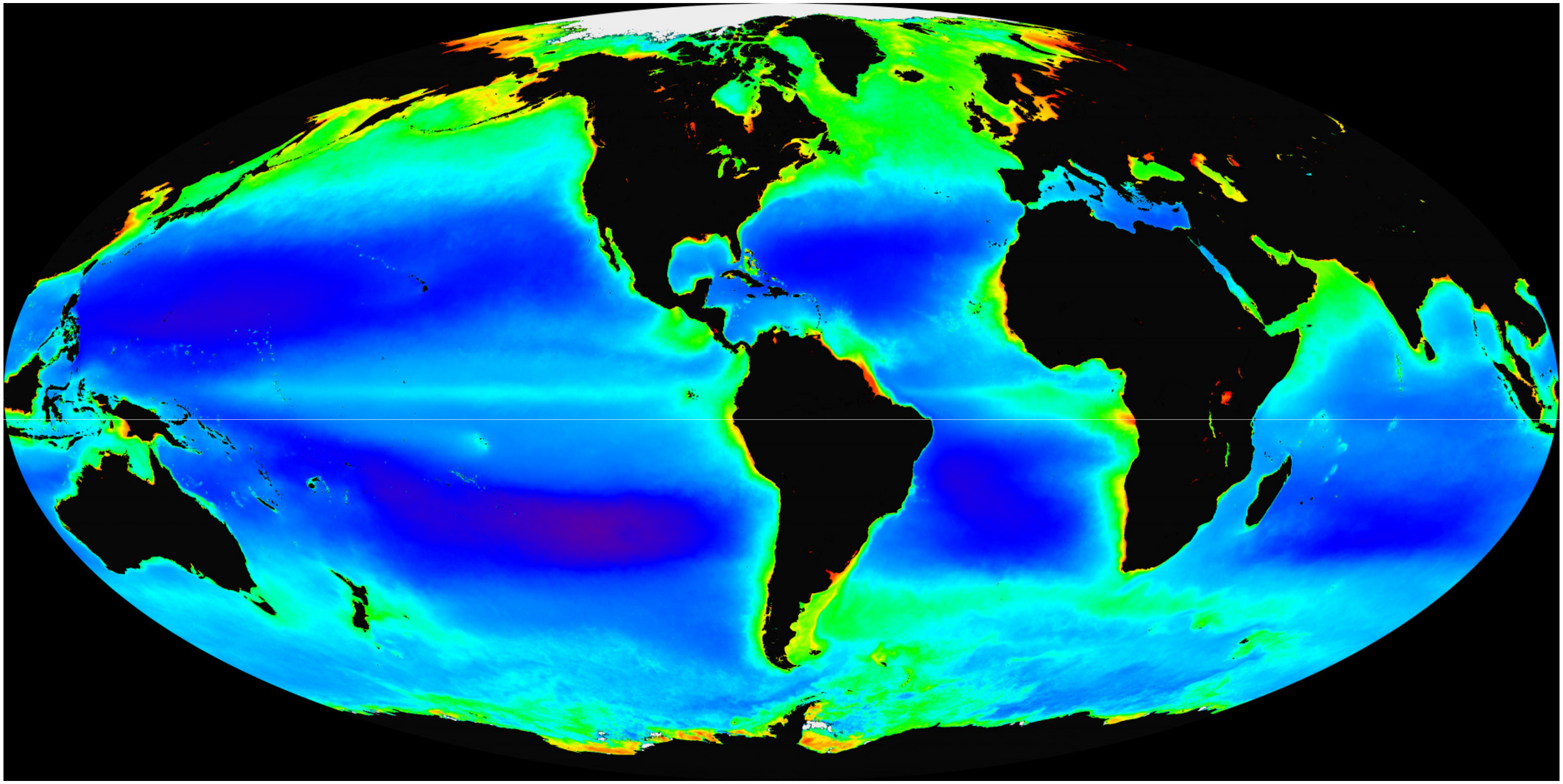
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331 USA
cdavis@coas.oregonstate.edu
001 541-737-5707

Outline of Presentation

- On-Orbit calibration
  - SeaWiFS history as an example
- On-Orbit Calibration Approaches for GEO Imagers
  - On-Board Calibrator
  - Moon Imaging
  - Vicarious calibration
  - Cross Calibration with LEO satellites
    - MODIS
    - MERIS
    - Hyperspectral Imager for the Coastal Ocean (HICO)
- Summary and conclusions

For this analysis I have assumed that the GEO Imager is a filter spectrometer similar to GOCI, and that it will be capable of full disk imaging.

SeaWiFS Global Ocean Chlorophyll

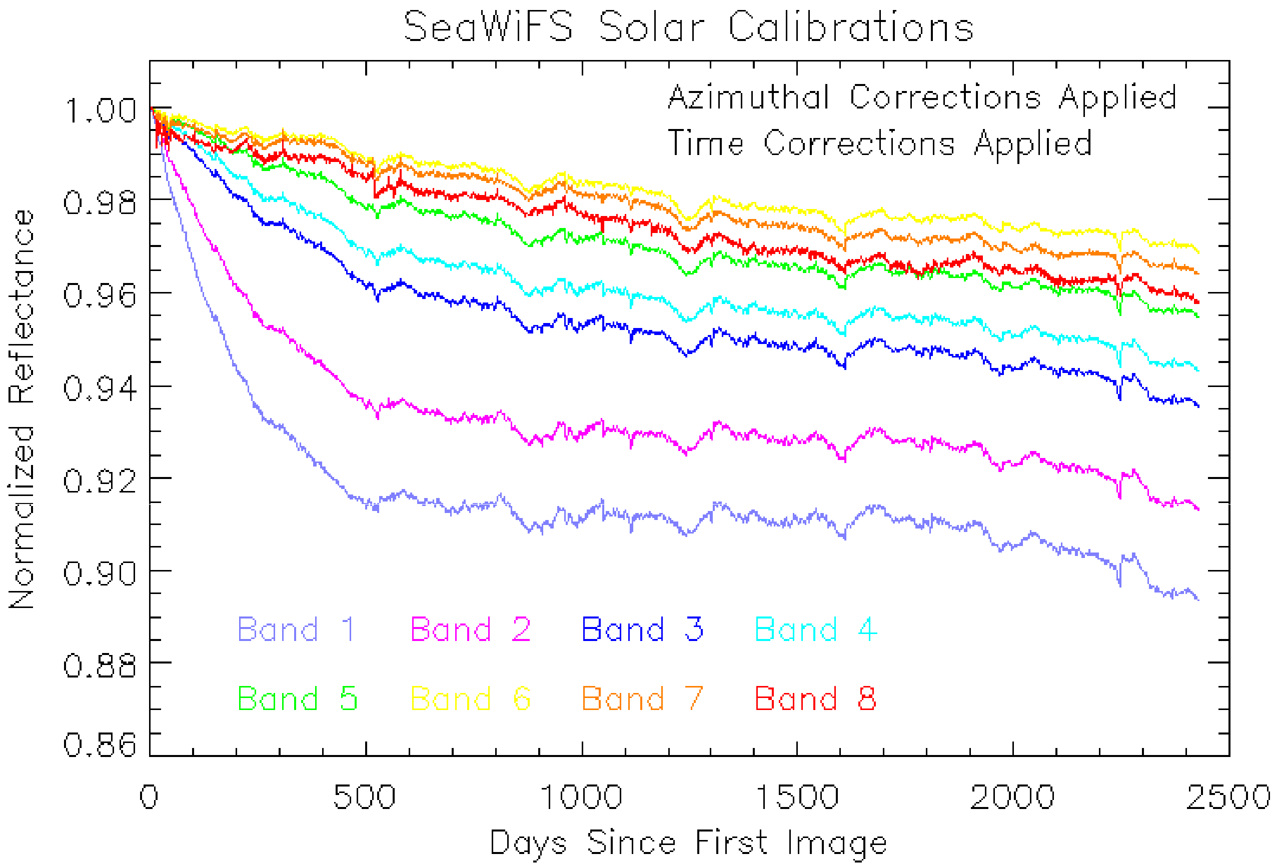


Seven year composite of the global distribution of chlorophyll from SeaWiFS data (blue low and yellow high concentrations). SeaWiFS has been highly successful for addressing NASA goals to better understand the global ocean carbon cycle and climate change.

SeaWiFS Overall Calibration Approach

- Pre- Launch detailed laboratory calibration and characterization. (Barnes, et al. 1994, NASA Tech Memo.104566, Vol. 23.)
- Transfer of pre-launch calibration to orbit.
  - Measurements of the solar irradiance using the solar diffuser made on the ground before launch and compared to on-orbit diffuser measurements. The ratio of the measurements shows any changes during launch. (Barnes, et al. 2000, Appl. Opt. 39:5620-5630.)
- Routine on-orbit calibration with solar diffuser.
- Monthly moon imaging to track sensor degradation.
- Vicarious calibration with Marine Optical BuoY (MOBY).
  - MOBY radiances (+/- 2% for water leaving radiance) used with atmospheric model to provide sensor radiance calibration accuracy of +/- 0.2%.
- Overall calibration accuracy of +/- 0.3% refined with vicarious calibration and maintained routinely with monthly moon imaging.
- Maintained for a decade of operations.

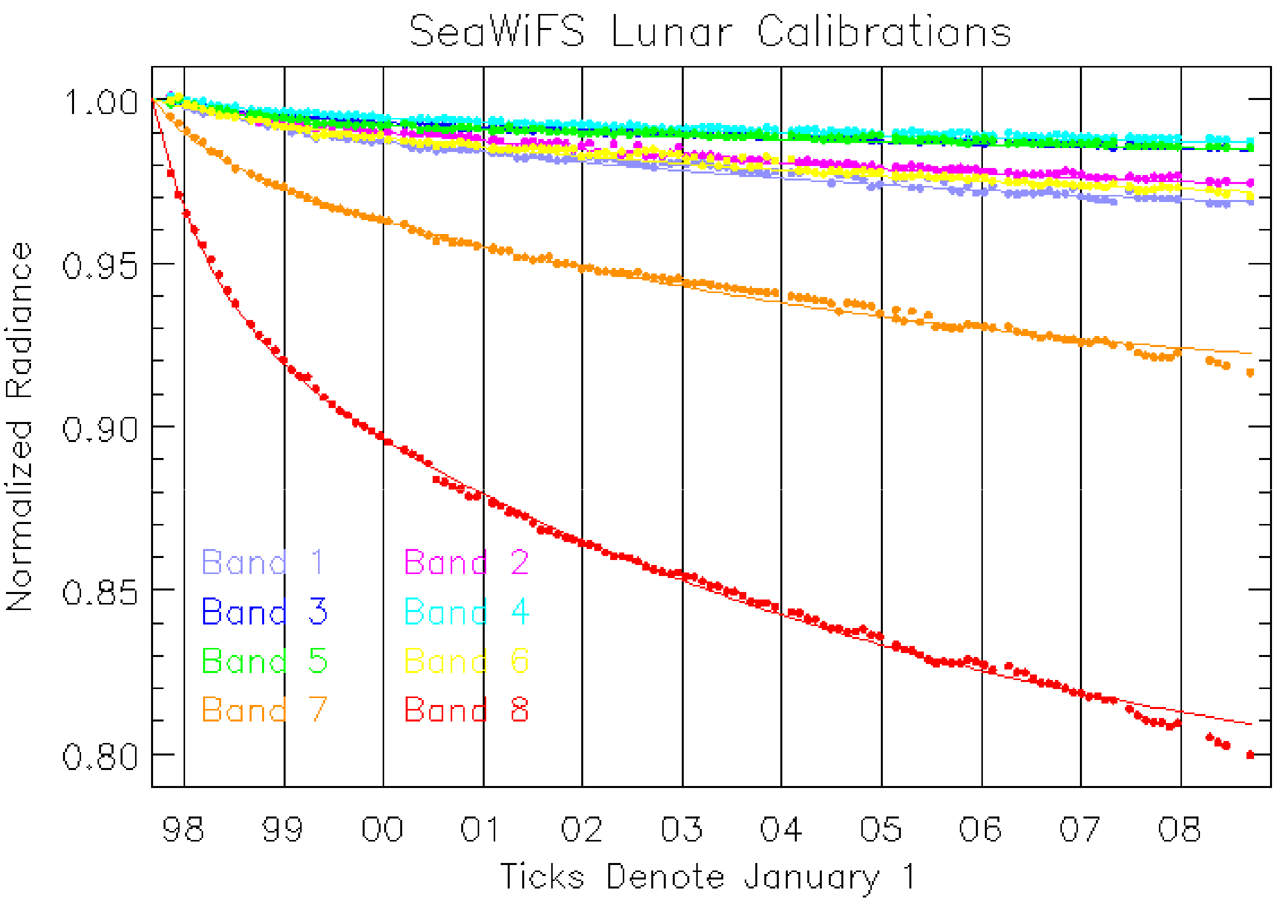
SeaWiFS On-Orbit Calibration with the Solar Diffuser



http://oceancolor.gsfc.nasa.gov/SeaWiFS/On_Orbit/scal/

Frequent solar calibrations track changes in the sensor, but also show changes in the diffuser and in the BRDF of the diffuser as the sun angle varies on the diffuser. Diffuser based calibration traced to NIST standards and good to +/- 3%.

SeaWiFS uses monthly Lunar calibrations to maintain calibration to < 0.3%



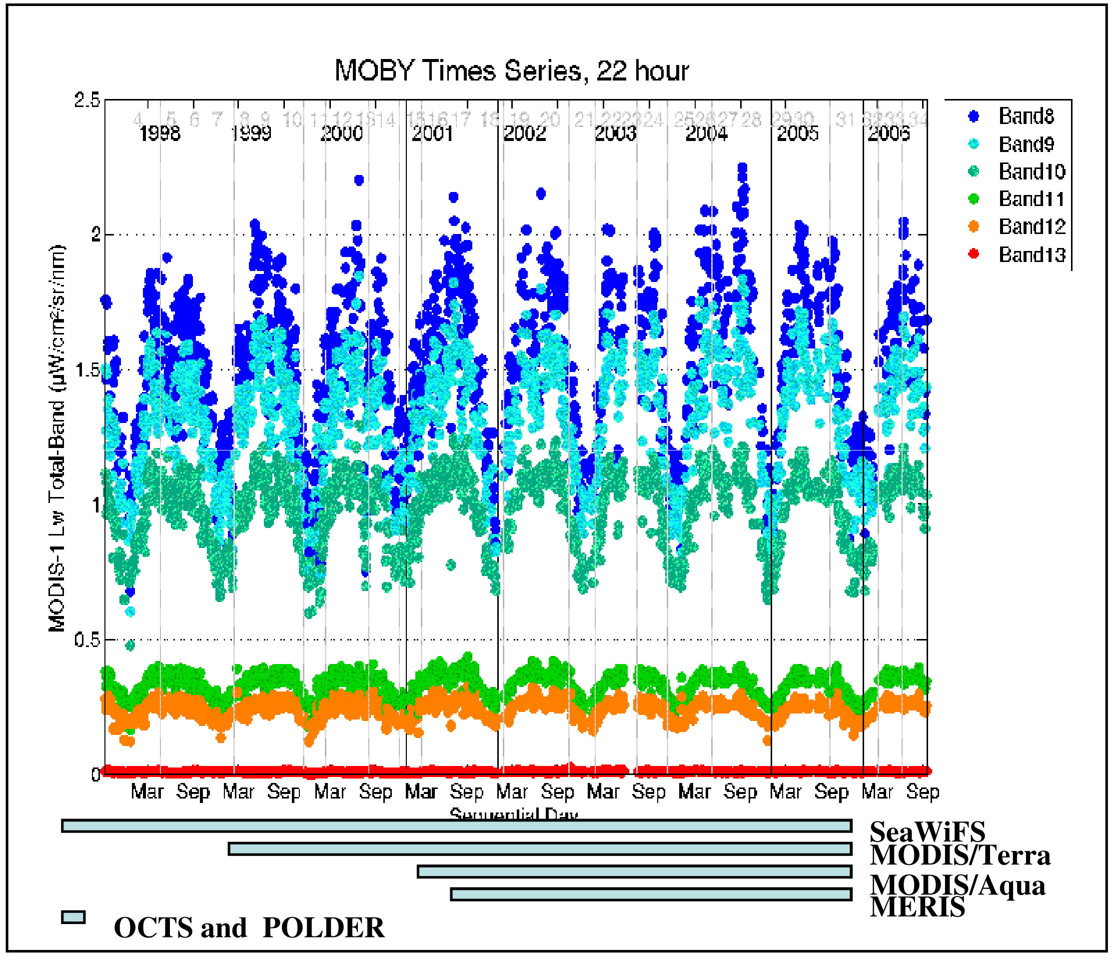
http://oceancolor.gsfc.nasa.gov/SeaWiFS/On_Orbit/lcal/

Plot of the current SeaWiFS lunar calibration time series showing how the radiometric response of the instrument changes with time.

SeaWiFS Vicarious Calibration with MOBY

- Vicarious calibration with Marine Optical BuoY (MOBY).
  - MOBY radiances (+/- 2% for water leaving radiance) used to model at sensor radiances by inverting the atmospheric correction model.
  - This is done periodically to refine the sensor calibration.
  - As the atmosphere is over 90% of the signal this can lead to sensor radiance calibration accuracy of +/- 0.2%.

(Eplee, et. al. 2001, Appl. Opt. 40:6701-6718.)



On-Board Solar Diffuser Calibration System

Solar diffuser system should included for on-orbit calibration:

- Example: GOCI In-orbit Absolute Calibration

– Solar Diffuser (SD) + DAMD (Diffuser Aging Monitoring Device)

– SD and DAMD are identical except for the size. (155mm : 70mm [dim])

– Features

- QVD (Quasi Volume Diffuser) : Heritage - Aura, GOME-2/MetOp

– Strong to UV radiation, Smaller spectral response fluctuation

[from Ahn presentation Feb. 13, 2008 to the IOCCG]

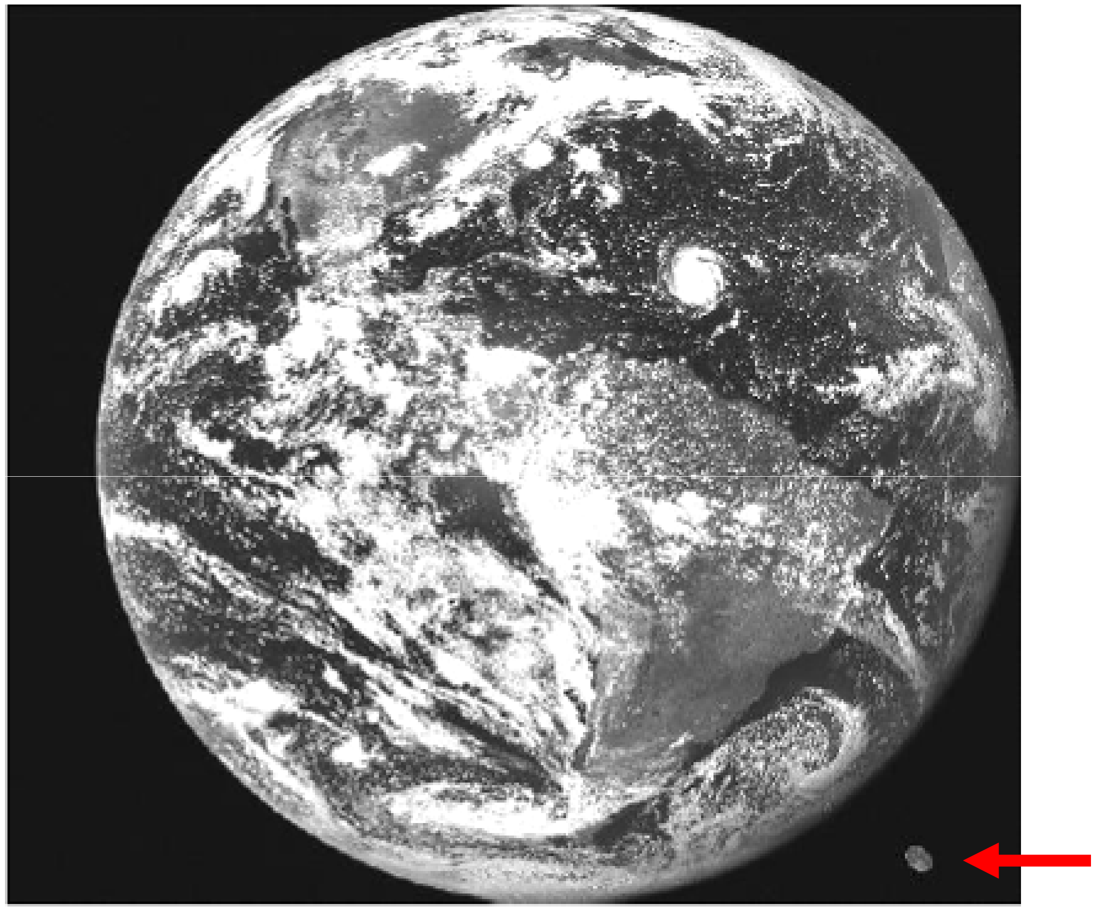
Should be able to maintain +/- a few percent calibration like SeaWiFS. Excellent to monitor short term changes, however, SeaWiFS experience is that moon imaging is most reliable for long term trend monitoring and correction.

Because the atmosphere is 90% of the signal need to do vicarious calibration to achieve < 0.3% accuracy needed for ocean color imaging, especially for climate data records.

Moon Imaging possible from a Geostationary Orbit

The field of regard for full-disk imaging is 20.8° E–W $\times$ 19° N–S, while the Earth disk diameter is about 17.4° from geostationary orbit, resulting in margins of 1.7° and 0.8° respectively. From geostationary orbit the Moon's diameter ranges between 0.44° and 0.51°, thus for the GOES visible imagers with 1 km GSD the full Moon at perigee will be imaged in 318 N–S lines by 556 E–W pixels.

Stone, et al., 2005, Proceedings of SPIE Vol. 5882OP, 1-9.

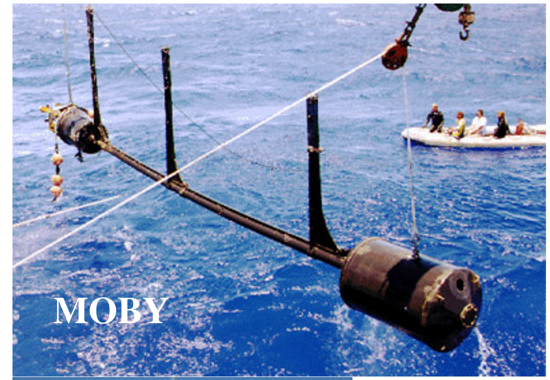


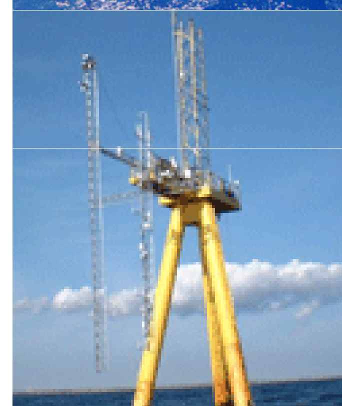
GOES-12 Visible channel full disk Image acquired 2004 August 30, 17:45:14 UTC. The nearly full moon is captured in the lower right corner.

Vicarious Calibration Sites

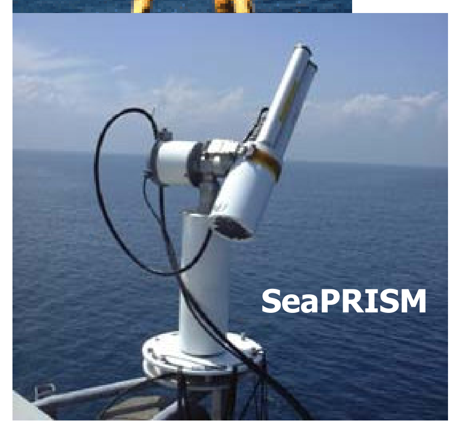
- MOBY U.S. buoy near the Hawaiian Islands. Has provided accurate water leaving radiances for over a decade.
  http://physoce.mlml.calstate.edu/moby/moby241/index.html
- BOUSOLLE French Buoy providing accurate radiances in the Mediterranean Sea.
  http://www.obs-vlfr.fr/Boussole/html/project/introduction.php
- AERONET sites with SeaPRISM. On towers or platforms. Provides good validation of coastal products, but none for vicarious calibration.
  http://aeronet.gsfc.nasa.gov/new_web/ocean_levels_versions.html
- Observations of clear water sites in the South Pacific and Indian Ocean Gyres (Franz, et al, 2007, Appl. Opt. 46: 5068-5082.)
- Vicarious calibration works to refine the combined calibration and atmospheric correction and only provides calibration data for the ocean channels.

Depending on the Satellite location one or more of these sites could be visible for a GEO Imager.





MVCO



Cross-Calibration with LEO Ocean Color Sensors

- Advantages of using Low Earth Orbit (LEO) ocean color sensors:
  - Can match data collection with GEO Imager coverage.
  - Can match a full scene covering a variety of environments and sea truth locations.
  - LEO sensors use vicarious calibration and can transfer that advantage to the GEO imager if it cannot image a vicarious calibration site.
- The challenge is to select the best sensor for matchup with GEO Imager:
  - Need to match channels to GEO Imager channels:
    - Spectrometers easier to match to GEO Imager filter channels than other filter channel instruments.
  - Need to match Ground Sample Distance (GSD) and sampling locations
    - Smaller GSD that can be binned to Geo Imager GSD is a big advantage.
  - Most LEO sensors in sun-synchronous orbits – one match time of day
    - Non sun-synchronous orbit could provide matches at various times of day.

Cross Calibration with LEO Ocean Color Sensors

Comparison of Spectral Channels

SeaWiFS	MODIS	GEO I	HICO	MERIS	MERIS Application
	411nm	412 nm	Hyperspectral	412.5 nm	CDOM
443 nm	442 nm	443 nm	380 -1000 nm	442.5 nm	chlorophyll
	487 nm	490 nm	at 5.2 nm	490 nm	Chl and other pigments
520 nm	530 nm		Can match	510 nm	turbidity
550 nm	547 nm	555 nm	Any GEO I	560 nm	Chl, suspended sediments
			channel	620 nm	Suspended sediments
670 nm	665 nm	660 nm		665 nm	Chl absorption
	677 nm	680 nm		681.25 nm	Chl fluorescence
				705 nm	Blooms, Red edge
750	746 nm	745 nm		753.75 nm	O_2 abs. ref., ocean aerosols
Beyond				760 nm	O_2 abs.
Planned				775 nm	Aerosols, vegetation
Lifetime.	866 nm	865 nm		865 nm	Aerosols over the ocean
Little data				890 nm	Water vapor reference
In 2008				900 nm	Water vapor absorption

Cross Calibration with MODIS

- MODIS on Aqua continues to operate well and provide stable well calibrated data. http://modis.gsfc.nasa.gov/
  - However, Aqua is at end of planned lifetime; service could end if there is a problem with the satellite or sensor.
- Generally a good match for channel centers and width.
- However, MODIS has filter channels with specific shapes like a GEO Imager. These never match exactly unless from the same filter run.
- MODIS has two sided scan mirror with some variable polarization effects.
  - NASA has developed good correction tables and can produce accurate at sensor radiances.
- Vicarious calibration with MOBY. Calibrates the combined sensor calibration and atmospheric correction to give accurate water leaving radiances.
- 1000 m GSD not an ideal match for anticipated GEO Imager 300-500 m GSD data.

Cross Calibration with MERIS

- MERIS continues to operate well and provide stable well calibrated data. http://envisat.esa.int/handbooks/meris/
  - Operations officially extended to 2014.
  - Follow-on sensors planned for Sentinel 3 satellites to extend time series for decades.
- Reasonable match between MERIS and GEO Imager channels.
- MERIS is a high resolution spectrometer binned to the selected channels.
  - This approach gives regular channel shape and is more readily matched to GEO Imager filter shapes.
- Can request MERIS 300 m GSD data to better match GEO Imager pixel size.
- MERIS is calibrated against BOUSOLLE buoy data.
  - Provides a calibration of the water leaving radiances.
  - Calibrates the combination of sensor calibration and atmospheric correction.

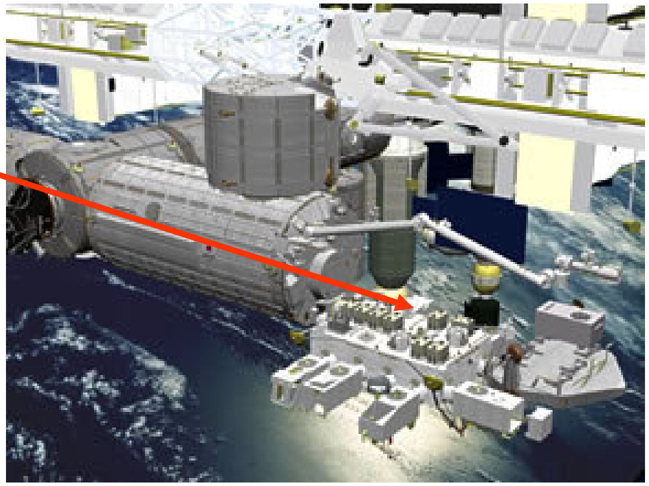
Hyperspectral Imager for the Coastal Ocean (HICO)

- In the Spring of 2007, the Naval Research Laboratory's HICO and RAIDS Experiment Package (HREP) was manifested for the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.

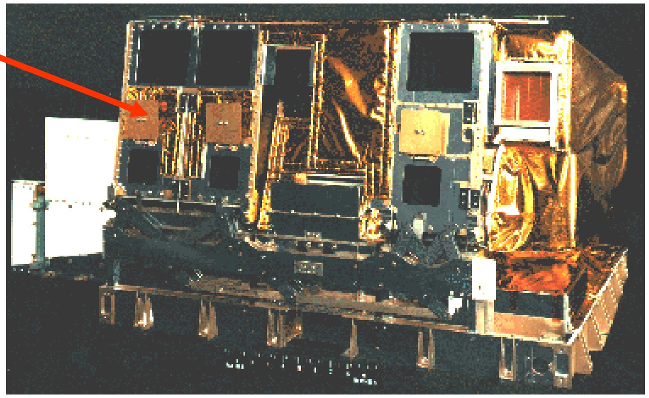
Payload Instruments:

- HICO – the topic of this presentation
- RAIDS (Remote Atmospheric and Ionospheric Detection System)
  - designed to perform a comprehensive study of upper atmospheric airglow emissions
  - developed at the NRL Space Science Division

HICO is integrated and flown under the direction of DoD's Space Test Program



Graphic of JEM-EF on Station



RAIDS

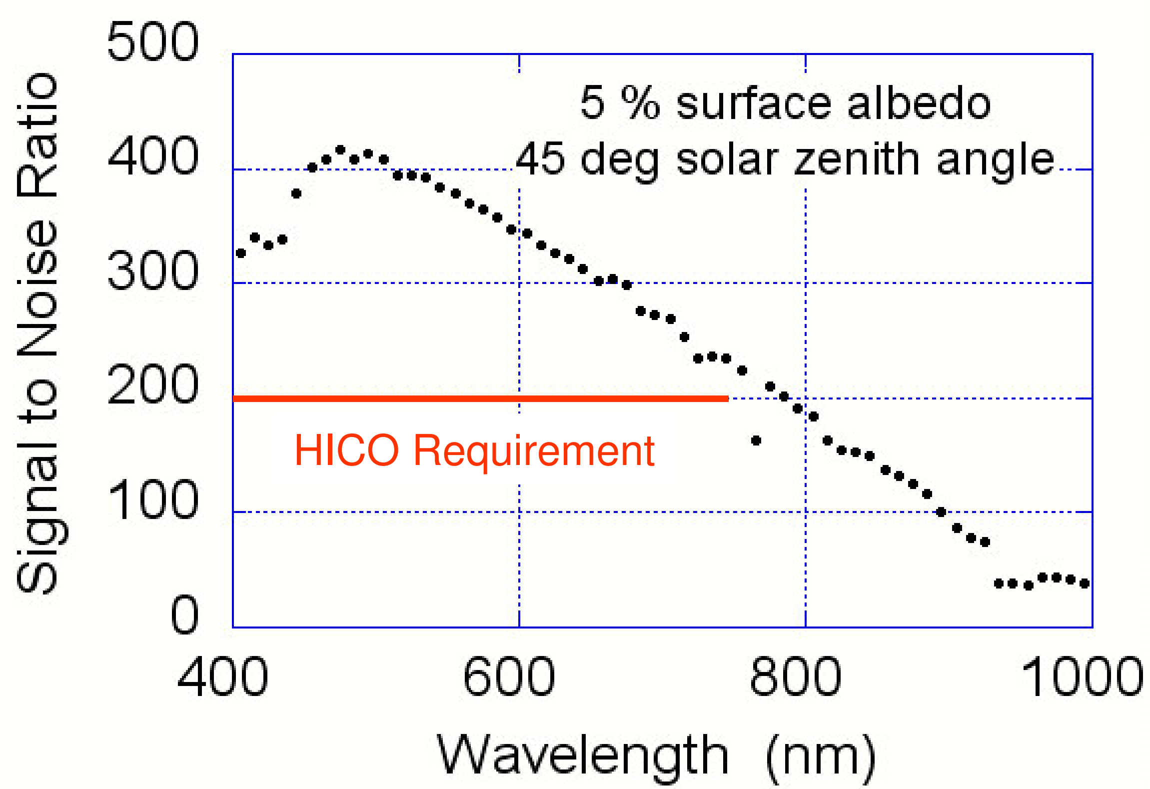
THE SPACE-BASED HYPERSPECTRAL IMAGER FOR THE COASTAL OCEAN (HICO)

HICO is designed to demonstrate characterization of coastal environments Worldwide. Baseline HICO on-orbit imaging system performance confirmed by preflight calibration and characterization.

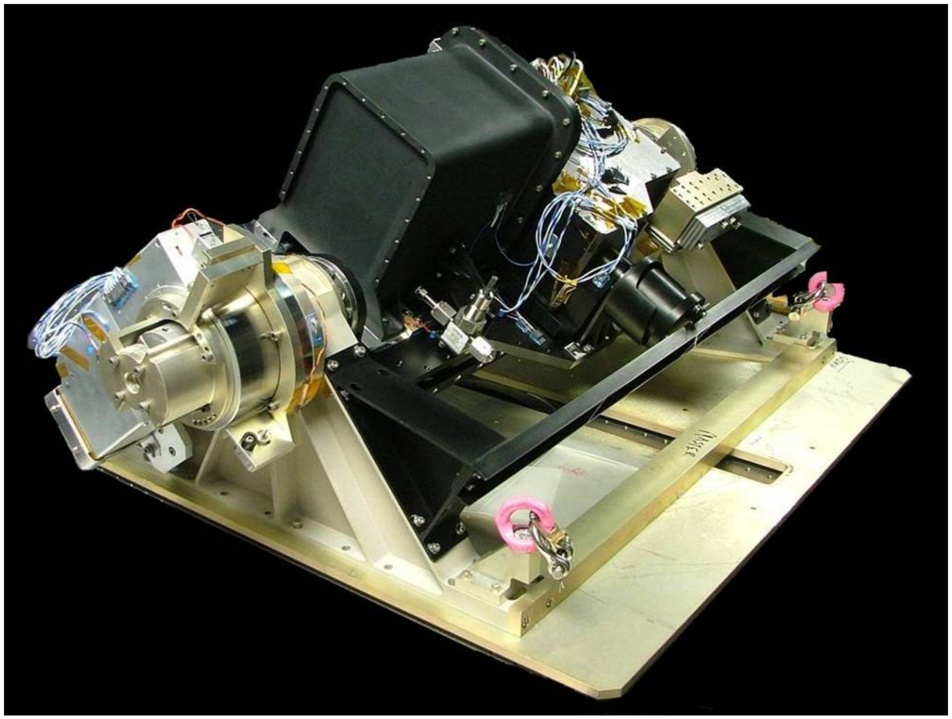
- Ground Sample Distance: 100 m at nadir.
  - Sufficient for many coastal environmental features.
- Spectral coverage: 380 -1000 nm.
  - Includes all water-penetrating wavelengths.
- Spectral binning: 5.7 nm spectral bin width.
  - Sufficient to resolve spectral features in coastal scenes.
- Signal to Noise Ratio (SNR): greater than 200 to 1 for water-penetrating wavelengths, assuming 5 percent effective surface albedo and 0.011 micron spectral bins.
  - Required for sufficient residual SNR after atmospheric correction.

Modeled HICO Signal to Noise Ratio

- Modeling assumes:
  - Measured performance parameters of spectrometer and camera.
  - above-atmosphere spectral radiance from MODTRAN.
    - 5% earth surface albedo, 45 degree solar zenith angle.



HICO Flight Hardware Delivered for Integration



- Radiometric accuracy: 5% or better.
- Polarization sensitivity: 5% or less.
- Scene size: 50 x 200 km (nominal)
  - Appropriate for coastal scene sizes.
- On-orbit lifetime: one year minimum
  - Required to collect data over all seasons.

HICO Flight Hardware Completed July 2008. HICO is manifested for a September 2009 launch to the Japanese Experiment Module – Exposed Facility on the International Space Station. First data expected in October 2009.

Cross Calibration with HICO

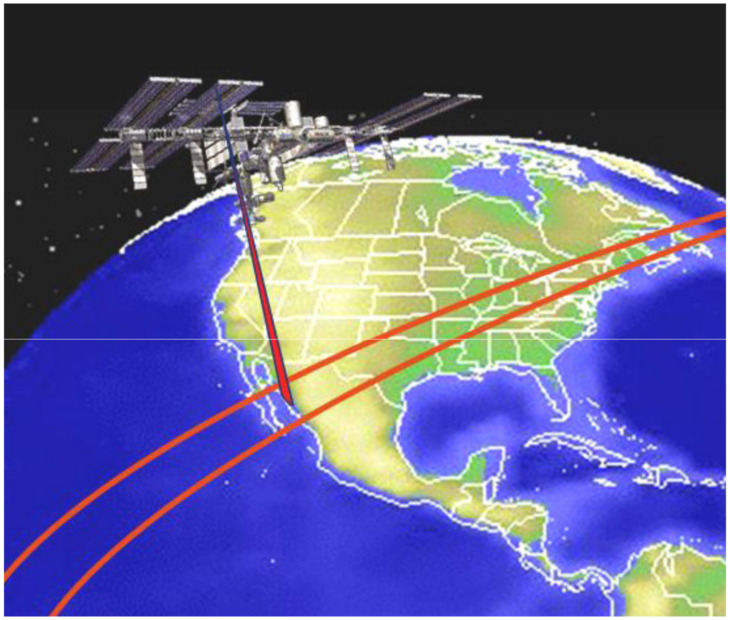
- The Hyperspectral Imager for the Coastal Ocean (HICO) to be flown on the International Space Station in September 2009.
- Advantages
  - HICO is an imaging spectrometer can directly match GEO Imager channels.
  - HICO has 100 m GSD; can bin pixels to accurately match GEO Imager pixels.
  - HICO on ISS 52 deg. orbit - not sun-synchronous.
    - Image at all times of day to match GEO Imager.
    - Look at changes in phytoplankton, chlorophyll, fluorescence and CDOM production as a function of time of day.
- Disadvantage - HICO will be new sensor launched in September 2009.
  - HICO does not have the calibration history that MODIS and MERIS have.
  - HICO will be cross-calibrated with MODIS and MERIS.
  - HICO will do vicarious calibration using MOBY.

Recommendations

- GEO Imager should include a solar diffuser type on-board calibrator.
  - Learn from experience with GOCI.
- GEO Imager should be capable of full disk scanning.
  - Address a wide range of environments.
  - Image vicarious calibration sites including South Pacific and Indian Ocean central gyres.
  - Image the moon monthly.
- Use vicarious calibration to refine calibration factors.
- Maintain the calibration with solar diffuser and moon imaging with calibration refined with vicarious calibration.
- Cross calibration with LEO imagers:
  - Check calibration over coastal and open sites, not just the vicarious calibration site.
  - LEO imagers can be used to cross calibrate between GEO imagers to provide a uniform global image from GEO.

Summary

- Reviewed calibration of SeaWiFS as an example of a successful calibration approach for ocean color imagers.
- Assessed approaches for calibration of GEO Imagers.
  - On-orbit calibration with solar diffuser.
  - Moon imaging
  - Vicarious calibration
  - Cross calibration with LEO sensors.
- Cross calibration with LEO sensors.
- MERIS is a well calibrated stable sensor.
- HICO is manifested for the International Space Station – Launch September 2009.
- HICO could provide the ideal data for cross-calibration with GEO I data.
  - Spectral data binned to match GEO I.
  - 100 m GSD can bin to GEO I pixels.
  - Image any time of day.



HICO on the ISS