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Geosynchronous Ocean-color Hyperspectral Imager

Jeffery J. Puschell, John Silny and Lacy Cook
Raytheon Space and Airborne Systems, El Segundo, California USA

Summary

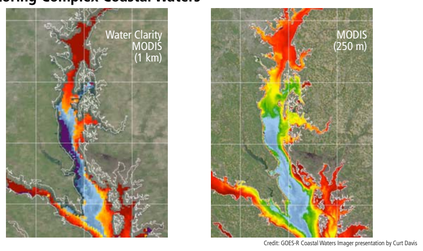
- This paper describes recent design studies of a Geosynchronous Ocean-color and land Imager (GOI) (pronounced "joy"). GOI would provide hyperspectral data with ~200 m spatial resolution at nadir. Contiguous high SNR spectral samples at a ~3.4 nm interval would be collected in each spatial resolution element across a 380–910 nm spectral region. This relatively wide (~2.5 deg) FOV imaging prism spectrometer approach meets expected Earth coverage, spatial sampling and radiometric sensitivity requirements derived from previous mission studies.
- GOI measures key parameters needed for coastal water studies with high sensitivity and relatively high spatial resolution. This hyperspectral GEO imager offers flexible spatial, spectral and radiometric sensitivity characteristics that can be tailored for specific applications.
- Additional work is needed to study approaches for accommodating GOI on candidate spacecraft, providing onboard calibration sources and developing more detailed understanding of baseline structural, thermal, electronics and onboard processing approaches to enable more detailed trade studies.

A Geosynchronous Ocean-color Imager (GOI) Measures Key Data Products Needed For Coastal Water Monitoring

- Water-leaving radiances in near-ultraviolet, visible and near-infrared for separation of absorbing and scattering constituents and for calculation of chlorophyll fluorescence
  - High spatial resolution (~300 m) needed for coastal water studies
- Total radiances in UV, NIR and, with additional cost and complexity, SWIR spectral regions for atmospheric corrections
- Cloud radiances for assessing instrument stray light
- Applications include: water quality monitoring, coastal hazard assessment, public health, ecosystem management, climate change monitoring and forecasts, land use changes, coral reef health appraisal, nowcasting and forecasting coastal ocean conditions

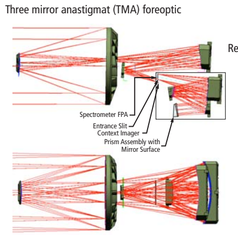
Why hyperspectral? Understanding complex coastal water requires hyperspectral imaging, especially if the bottom is visible. Hyperspectral GOI could cross calibrate all polar-orbiting ocean color sensors.

Higher Spatial Resolution Is Critical to Monitoring Complex Coastal Waters



Credit: GOES-R Coastal Waters Imager presentation by Curt Davis

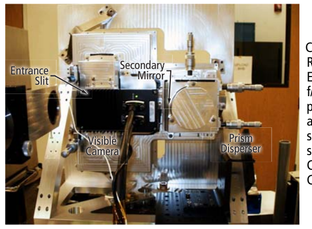
Recent Dispersive Spectrometer Designs Enable Wide Field of View GOI Approaches



Opto-mechanical packaging concept derived from recent work at Raytheon

(U.S. Patent # 5,260,767, Lacy Cook)

Raytheon's CIRCE Wide Field of View (36.8 Deg) Spectrometer Helps Establish GOI Feasibility



Cost-effective Imager for Real-time Chromatic Exploitation (CIRCE) is an f/3.0 breadboard imaging prism spectrometer operating across the 450 to 900 nm spectral range at ~6 nm spectral resolution using a COTS 8192 x 96 pixel format CCD array

Notional Subset of GOI Requirements

- Ground Instantaneous FOV and sample distance: 200 m at nadir
  - Provides ~300 m GIFOV at U.S. latitudes, a frequently cited requirement for U.S. coastal water and ocean color imagers
- Spectral Coverage: ~380–910 nm
  - Could be extended to 2,500 nm, using different detector technology and cryogenic cooling – with additional cost and complexity
- Spectral sample: dλ ~ 5 nm
  - Similar to recent hyperspectral imagers, although latest GEO-CAPE mission studies require 10× better spectral resolution (Antonio Mannino, NASA OCRT Meeting, May 2010)
- SNR for ocean radiance in each VNIR multispectral channel: 900 or ~1.5× SeaWiFS
  - Reaches for GOES-R Coastal Waters Imager goal (Curt Davis, et al. 2009) while keeping in mind Davis et al. threshold SNR of 300
- CONUS coastal waters revisit time: <60 min
  - GOES-R Coastal Waters Imager goal (Curt Davis, et al. 2009)
- Detector saturation not allowed up to maximum scene spectral radiances associated with brightest clouds and glint
  - Enables correcting nearby spatial samples for crosstalk and scattered light effects
- Flight system would have many other requirements for MTF, repeatability, calibration, simultaneity, stability, jitter, etc.

Mission Requirements Drive GOI Design

200 m GSD at ~900 nm with SNR~900 Goal in Most Multispectral Reference Bands	~0.6 m Telescope Diameter
	Simple, Slow Earth Scan
	Wide Field-of-View Sensor to Minimize Number of Swaths
380–910 nm Coverage	Full Range Can Be Covered with Multiple Orders from One Spectrometer or with One Broadband Spectrometer
dλ ~ 5 nm	Dispersive Spectrometer (Grating or Prism) or FPI

Goal Requirements Compete with Each Other

For a strongly signal-photon-noise-limited system like GOI, SNR is approximately equal to the square root of the number of signal photoelectrons or n_s

$$n_s = L_{typ}/hv * A\,\Omega * d\lambda * \Delta t * \eta$$

- L_{typ}/hv: Typical photon spectral radiance determined by measurement need
- $A\,\Omega$: Etendue defined by collection aperture area times IFOV solid angle
- $d\lambda$: Spectral bandwidth defined by measurement need
- Δt: Integration time constrained by refresh rate, area to be covered, electronics and pointing
- η: Photon conversion efficiency should be good across spectrum, except possibly at wavelengths beyond 700 nm and in the UV

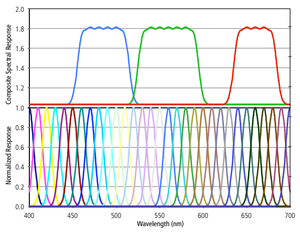
Demand High SNR, Aim for High Spatial resolution and fast refresh

Balance maximizing etendue to increase SNR and improve image quality with minimizing IFOV to achieve higher spatial resolution and making system as small as possible to minimize cost and impact on spacecraft

Maximize swath width ⟷ Minimize Earth area that needs to be refreshed

Balance high refresh rate that takes advantage of GEO's persistence with high SNR and spatial resolution

Data from GOI Could Be Used to Create Virtual Multispectral Channels



- Linear Combination of Hyperspectral Channels can Create Legacy and New Multispectral Channels
- Hyperspectral Channels (400 to 700 nm)

Sensitivity Is Constrained by Radiometric Performance in These Multispectral Reference Bands

Spectral Radiance Units are mW cm^{-2} sr^{-1} µm^{-1}

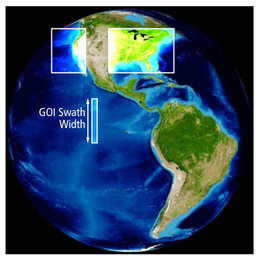
Center Wavelength (nm)	Bandwidth (nm)	Reference Scene Spectral Radiance L_{typ}	Maximum Scene Radiance L_{max}	Applications
385	15	6.11	38.1	CDOM - chlorophyll separation; strong NO_3 absorption
412	20	7.86	60.2	CDOM - chlorophyll separation; similar to SeaWiFS and MODIS bands; strong NO_3 absorption
443	20	6.95	58.5	Chlorophyll-a absorption peak; similar to SeaWiFS and MODIS bands; strong NO_3 absorption
477	20	6.19	72.2	Chlorophyll and other pigments; Similar to GOES ABI band
490	20	5.31	68.6	Similar to SeaWiFS and MODIS bands; ratioed with chlorophyll bands
510	20	4.58	66.3	Similar to SeaWiFS band: chlorophyll-a band ratio; strong O_3 absorption
532	20	3.92	65.1	Similar to MODIS band; aerosol lidar transmission band; strong O_3 absorption
555	20	3.39	64.3	Similar to SeaWiFS and MODIS bands; chlorophyll band ratios; strong O_3 absorption
640	20	1.90	56.4	Similar to GOES ABI band; between O_3 and water vapor absorption
665	10	1.60	53.6	Fluorescence line baseline; bandwidth constrained by water vapor absorption and 678 nm band
678	10	1.45	51.9	Fluorescence line height; band center offset fluorescence peak by oxygen absorption
748	20	0.93	44.7	Atmospheric correction - MODIS band, between O_2 A-band and water vapor absorption peaks
765	20	0.83	43.0	Atmospheric correction - SeaWiFS band, O_2 A-band absorption
865	20	0.45	33.3	Atmospheric correction; narrower width implementation of SeaWiFS and GOES ABI bands - close to MODIS band
905	35	0.10	20.0	Atmospheric correction; aerosol lidar band; MODIS band; absorbed by water vapor

References: 2009 May 4 ACC overview by Chuck McClain (GSFC); GOES-R Coastal Waters Imager by Curt Davis (Oregon State)

One Possible Set of GOI Imaging Prism Spectrometer Characteristics

Telescope	60 cm diameter at f/4.3
Cross Scan FOV	2.5 deg
Projected IFOV at Nadir	200 m (5.6 µrad from GEO)
Spectral Bands	~380–910 nm
Spectral Sample Size	~3.4 nm
Prism Spectrometer	Fused silica and SF57 crown/flint glass
Detector Element Size	14.4 µm
Array Format Size	8,000 (cross) x ~110 (spectral) for GOI
Array Dimensions	11.5 cm (cross) x ~ 0.16 cm (spectral)
Detector Operating Temperature	Stabilized ambient with Si FPA
Electron Well Capacity per Unit Cell	~4.8 Me- (varies with spectral channel)
Effective Number of Bits	14
Required Readout Rate	11 Hz
CONUS Coastal Waters Coverage Time	25 min (17 min Eastern, 8 min Western)
SNR Radiometric Sensitivity	900 (goal at L_{typ})
Peak Data Rate	135 Mbps

GOI Could Reach East Coast and West Coast Waters Along with the Great Lakes from a GEO Slot at ~90 W

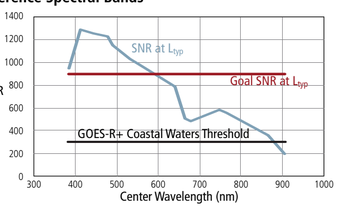


- Coastal Waters Covered in Two Operating Regions Using One Swath Optimized for Refreshing Data in Both Regions in Minimum Time
  - Eastern Region Includes Atlantic Coast, Gulf Coast and the Great Lakes (1030 sec)
  - Western Region includes Pacific Coast from Baja California to Vancouver Island (460 sec)

Credit: Earthview website by John Walker at http://www.fourmilab.ch/

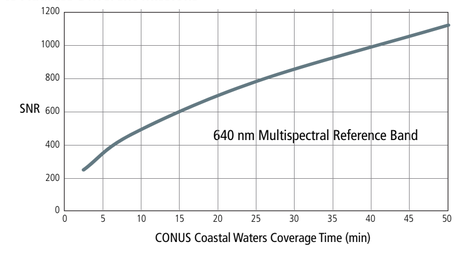
Telescope for Actively Scanned Dispersive Spectrometer Moves Across Field of Regard

Performance Exceeds Goal SNR at L_{typ} in Most Reference Spectral Bands



- Predicted SNR in 905 nm band falls below threshold for GOES-R+ Coastal Waters Imager (Davis, et al. 2009)
  - Based on very preliminary performance expectations

SNR Can Be Traded with Earth Coverage Rate to Address Different Missions



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