Decadal Survey Tier 2 Mission Study
Summative Progress Report

Geo-CAPE
Ocean Science and STM

Antonio Mannino

November 15, 2010

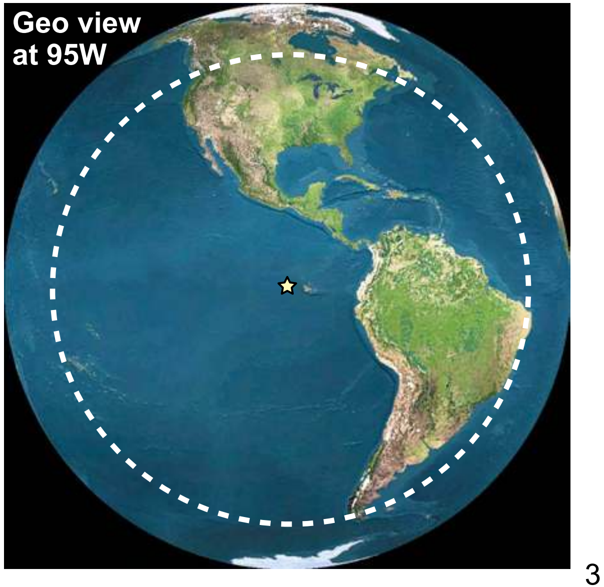
Advantages of Coastal Observations from Geo

- Observations analogous to “weather” for coastal waters
  - water quality, primary production, harmful blooms, etc.
- Discriminate **physical** from **biological** forcing
  - Rates of processes possible:

    Primary productivity, photooxidation, transport of materials, etc.
- Resolve sub-mesoscale processes (lateral scales <1km)
- Study short time scales associated with dynamic coastal processes (tides, wind-driven currents, storm surges, algal blooms)
- More opportunities for cloud-free viewing
- High signal-to-noise at finer spatial resolution (~300m) can be achieved by longer integration time
- Opportunity to monitor hazardous events on high frequency time scales (oil slicks, HABs, etc.)

Summary of Accomplishments

- Developed Science Traceability Matrix
- Supported Instrument Design Lab study
- Supported Mission Design Lab study
- Atmospheric correction studies
- Additional science studies underway to inform on requirements
- Joint ACE/Geo-CAPE Ocean product assessments
- Completed draft white paper



Geo-CAPE Coastal Ocean Ecosystem STM

Science Focus	Science Questions
Short-Term Processes	**1** **How do short-term coastal and open ocean processes interact with and influence larger scale physical, biogeochemical and ecosystem dynamics?** (OBB1)
Land-Ocean Exchange	**2** **How are variations in exchanges across the land-ocean interface related to changes within the watershed, and how do such exchanges influence coastal and open ocean biogeochemistry and ecosystem dynamics?** ‡ (OBB1 & 2)
Impacts of Climate Change & Human Activity	**3** **How do natural and anthropogenic changes including climate-related forcing impact coastal ecosystem biodiversity and productivity?** ‡ (OBB1, 2 & 3)
SYNERGY Impacts of Airborne-Derived Fluxes	**4** **How do airborne-derived fluxes from precipitation, fog and episodic events such as fires, dust storms & volcanoes significantly affect the ecology and biogeochemistry of coastal and open ocean ecosystems?** (OBB1 & 2)
Episodic Events & Hazards	**5** **How do episodic hazards, contaminant loadings, and alterations of habitats impact the biology and ecology of the coastal zone?** (OBB4)

Approach	Maps to Science Question
PRODUCTS Standing Stocks: Aquatic chlorophyll a, POC, DOC, PIC, DIC*, inherent & apparent optical properties, total suspended matter, phytoplankton biomass*, pigments* and key functional groups, terrigenous DOC*, & black carbon*. Rate Measurements: Aquatic primary productivity, respiration*, air-sea CO2 fluxes*, photooxidation, phytoplankton fluorescence responses*, phytoplankton vertical migration*, net community production of DOC* and POC*, and other associated trophic responses* Hazards: Aquatic HABs, petroleum-derived hydrocarbons, and other pollutants*. ***Products not currently derived from ocean color observations.**	
Targeted, high-frequency, episodic event-based monitoring and evaluation of tidal and diurnal variability of Standing Stocks, Rate Measurements and Hazards from river mouths to the coastal ocean (and lakes).	1, 2, 4, 5
Routine sampling of seasonal and interannual variations in the Standing Stocks, Rate Measurements and Hazards for estuarine and continental shelf regions with linkages to open-ocean processes at appropriate spatial scales.	2, 3, 5
Observe coastal region at sufficient spatial scales to resolve near-shore processes, coastal fronts, eddies, and track carbon pools and pollutants.	1, 2, 5
Integrate GEO-CAPE observations with field measurements, models and other satellite data: 1. To derive coastal carbon budgets and determine whether coastal ecosystems are sources or sinks of carbon to the atmosphere	1, 2
2. To quantify the responses of coastal ecosystems and biogeochemical cycles to river discharge, land use change, airborne-derived fluxes, hazards and climate change.	1, 2, 3, 4, 5
3. To estimate fishery yields, extent of oxygen minimum zones, and ecosystem health (including ocean acidification).	3, 5

Measurement Requirements

Water-leaving radiances in the near-UV, visible & NIR for separating absorbing & scattering constituents & chlorophyll fluorescence

Product uncertainty TBD

Temporal Resolution:
Targeted Events:
- Threshold: 1 hour
- Goal: 0.5 hour

Routine Coastal U.S.:
- Threshold: ≤3 hours
- Goal: 0.5 hour

Regions of Special Interest (RSI): Threshold: 1 RSI 3 scans/day
- Goal: multiple RSI 3 scans/day

Other Coastal N. & S. America 50°N to 45°S:
- Threshold: 4 times/yr
- Goal: ≤3 hours

Spatial Resol. (nadir):
- Threshold: 375 x 375 m
- Goal: 250 x 250 m

Field of Regard for Ocean Color Retrievals[1]: 50°N to 45°S; ~145°W to 45°W

Coastal Coverage: width from coast to ocean:
- Threshold: 375 km
- Goal: 500 km

RSI: Amazon & Orinoco River plumes, Peruvian upwelling, Cariaco Basin, Bay of Fundy, Rio Plata, etc. (TBD)

Instrument Requirements

Spectral Range: Hyperspectral UV-VIS-NIR
- Threshold: 345-900 nm; 3 SWIR bands 1245, 1640, 2135 nm
- Goal: 340-1100 nm; 3 SWIR bands 1245, 1640, 2135 nm

•Spectral Resolution:
- Threshold: UV-VIS: 0.5 nm FWHM; NIR: 1 nm; SWIR: 20-50 nm
- Goal: UV-VIS: 0.25 nm FWHM; NIR: 0.5 nm; SWIR: 20-50 nm
  - Retrieval of NO_2 and O_2 A-band for atm. corrections? (TBD)

Signal-to-Noise Ratio (SNR):
- Threshold: 1000:1 for 10 nm FWHM (380-800 nm); 600:1 for 40 nm FWHM in NIR; 300:1 to 100:1 for SWIR bands (20-50nm FWHM)
- Goal: 1500:1 for 10 nm (380-800 nm); 600:1 for 40 nm FWHM in NIR; 300:1 to 200:1 for SWIR bands (20-50nm FWHM); 400:1 NO_2 band (TBD)

see Measurement Requirements for Temporal & Spatial Resolutions and Field of View.

Field of Regard:
- ±9° N to S & E to W imaging capability from nadir for Lunar & Solar Cals.

Jitter
- Threshold: <25% pixel size during single exposure
- Goal: TBD

Non-saturating detector array(s) at Lmax

On-board Calibration:
- Monthly Lunar Calibration at ≤7° phase angle
- Solar Calibration (TBD)

Polarization: <0.5%

Relative Radiometric Precision:
- Threshold: 1% through mission lifetime
- Goal: 0.5% through mission lifetime

Mission lifetime: Threshold: 3 years; Goal: 5 years

Intelligent Payload Module: Near Real-Time satellite data download from other sensors (GOES, etc.) for on-board autonomous decision making: (TBD)
- To bypass scanning mostly cloudy scenes; Targeting events (e.g., HABs)

Pre-launch characterization: to achieve radiometric precision above on orbit

Solar Zenith Angle Sensitivity[1]: Threshold: <70°; Goal: <75°

Platform Requirem.

Geostationary orbit to permit sub-hourly observations of coastal waters adjacent to the continental U.S., Central and South America

Storage and download of full spatial data and spectral data.

Ancillary Data Requirem.

Western hemisphere data sets from models, missions, or field observations:

Measurement Requirements
(1) Ozone
(2) Total water vapor
(3) Surface wind velocity
(4) Surface barometric pressure
(5) NO2 concentration
(6) Vicarious calibration & validation - coastal
(7) Full prelaunch characterization

Science Requirements
(1) SST
(2) SSH
(3) PAR
(4) UV
(5) MLD
(6) CO2
(7) pH
(8) Ocean circulation
(9) Tidal & other coastal currents
(10) Aerosol & dust deposition
(11) run-off loading in coastal zone
(12) Wet deposition in coastal zone

Validation Requirements
Conduct high frequency field measurements and modeling to validate GEO-CAPE retrievals from river mouths to beyond the edge of the continental margin.

‡ Climate change-related science questions

GEO-CAPE Science Questions are traceable to NASA's OBB Advanced Planning Document ….

* Coverage area within field-of-view (FOV) includes major estuaries and rivers such as Chesapeake Bay & Lake Pontchartrain/Mississippi River delta, e.g., the Chesapeake Bay coverage region would span west to east from Washington D.C. to several hundred kilometers offshore (total width of 375 km threshold).

Draft v.2.7 – March 24, 2010

[1] **Corrections Nov. 2010**

Geo-CAPE Ocean Science Questions

Draft v.2.7 - March 24, 2010

Short-Term Processes

1. How do short-term coastal and open ocean processes interact with and influence larger scale physical, biogeochemical and ecosystem dynamics?

Land-Ocean Exchange

2. How are variations in exchanges across the land-ocean interface related to changes within the watershed, and how do such exchanges influence coastal and open ocean biogeochemistry and ecosystem dynamics?

Impacts of Climate Change & Human Activity

3. How do natural and anthropogenic changes including climate-related forcing impact coastal ecosystem biodiversity and productivity?

Impacts of Airborne-Derived Fluxes

4. How do airborne-derived fluxes from precipitation, fog and episodic events such as fires, dust storms & volcanoes significantly affect the ecology and biogeochemistry of coastal and open ocean ecosystems?

Episodic Events & Hazards

5. How do episodic hazards, contaminant loadings, and alterations of habitats impact the biology and ecology of the coastal zone?

Science Questions are traceable to Decadal Survey and NASA's OBB Advanced Planning Document

Studies Enabled by Geo-CAPE

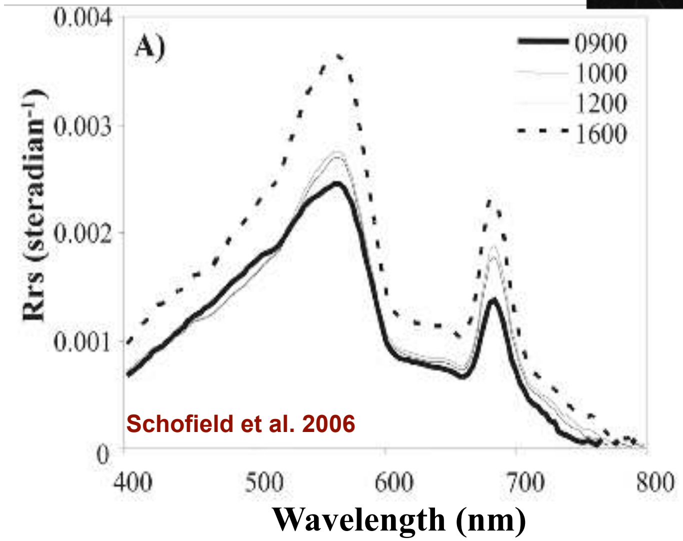
What cannot be achieved with existing sensors but possible with Geo-CAPE?

- Estimate surface oil film thickness (with multi-angle illumination)
- Study vertical migration of harmful and non-harmful algae
- Trace origin and evolution of hazardous events more effectively
- Assess impacts more precisely (e.g., changes in species)

Changes in color contrast are due to changes in solar/viewing angles

Oil spill volume assessment possible

HAB detection from diurnal vertical migration of the toxic Karenia brevis



Ocean Data Products

Mission Critical Products (drive requirements; algorithms exist)

- Spectral remote sensing reflectances (& water-leaving radiances)
- Chlorophyll-a, Primary Productivity
- Particulate Organic Carbon, Dissolved Organic Carbon, Particulate Inorganic Carbon (coccolithophore blooms)
- Total Suspended Matter
- Absorption coefficients of Colored Dissolved Organic Matter, Particles & Phytoplankton; Particle backscatter coefficient
- Water clarity (k_d[490nm]; euphotic depth)
- Photosynthetically Available Radiation
- Fluorescence Line Height, Phytoplankton Carbon
- Trichodesmium, Harmful Algal Bloom detection & magnitude
- *Aerosol & other atmospheric products for atmospheric corrections*

Highly Desirable Products (experimental products)

- Particle size distributions & composition, other plant pigments, Functional/taxonomic group distributions, Phytoplankton physiological properties, Vertical migration detection
- Net Community Production, Export production, Respiration
- Air Sea CO_2 fluxes, pCO_2(aq)
- Terrigenous Dissolved Organic Carbon
- Petroleum detection and thickness, Photooxidation

Approach

- Survey mode for evaluation of diurnal, seasonal and interannual variability
  - *U.S. coastal waters*
  - *Regions of special interest*
  - *All other coastal waters from 50°N to 45°S*
- Targeted observations of high-frequency and episodic events including evaluation of tidal and diurnal variability
- High spatial resolution to resolve near-shore processes, fronts, eddies, and track carbon pools and pollutants

- Integrate Geo-CAPE observations with field measurements, models and other satellite data:
  - *To **derive coastal carbon budgets** and determine whether coastal ecosystems are sources or sinks of carbon to the atmosphere.*
  - *To **quantify the responses of coastal ecosystems and biogeochemical cycles** to river discharge, land use change, airborne-derived fluxes, hazards and climate change.*
  - *To improve estimates of **fishery yields**, extent of **oxygen minimum zones**, and **ecosystem health** (including ocean acidification).*

Measurement & Instrument Requirements

	Threshold	Goal
Spatial Resolution (nadir)	375 m x 375 m	250 m x 250 m
Temporal Resolution		
Targeted Events	1 hour	0.5 hour
Survey Coastal U.S.	≤3 hours	0.5 hour
Region of Special Interest (RSI) & Other Coastal waters 50°N-45°S	1 RSI at 3 scans/day	≤3 hours
Field of Regard for Ocean Color science retrievals	50°N to 45°S; ~145°W to 45°W	same as threshold
Coastal Coverage coast to ocean	375 km	500 km
Spectral Range	345-900 nm; 1245, 1640, 2135 nm	340-1100 nm; 1245, 1640, 2135 nm
Spectral Resolution	UV-VIS: 0.5 nm FWHM; NIR: 1 nm; SWIR: 20-50 nm	UV-VIS: 0.25 nm FWHM; NIR: 0.5nm; SWIR: 20-50nm
Signal-to-Noise Ratio (SNR)	**1000:1 for 10 nm FWHM (380-800 nm)**; 600:1 for 40 nm FWHM in NIR; 300:1 to 100:1 for SWIR bands (20-50nm FWHM)	1500:1 for 10 nm (380-800 nm); 600:1 for 40 nm FWHM in NIR; 300:1 to 200:1 for SWIR bands (20-50nm FWHM)
Pointing stability (line-of-sight)	<25% of pixel size	within 10% of pixel size
Lunar Calibration	Monthly at 7° phase angle	same as threshold
Relative Radiometric Precision	1% through mission lifetime	<0.5% mission lifetime

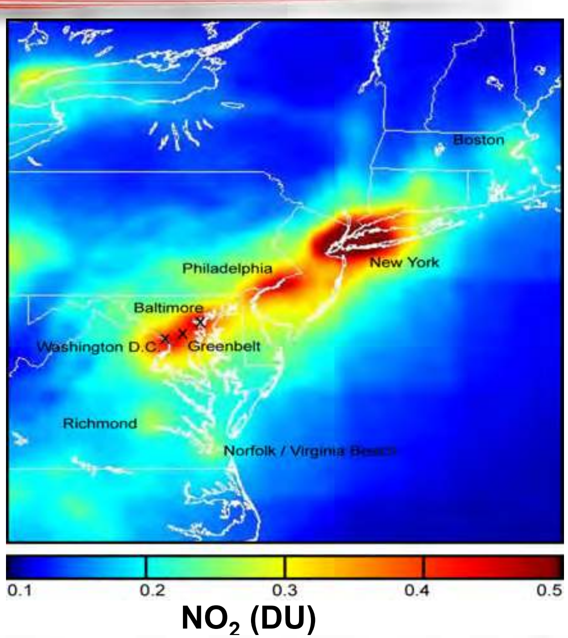
Science Studies for Evaluation of Requirements

Spatial & Temporal measurement requirements

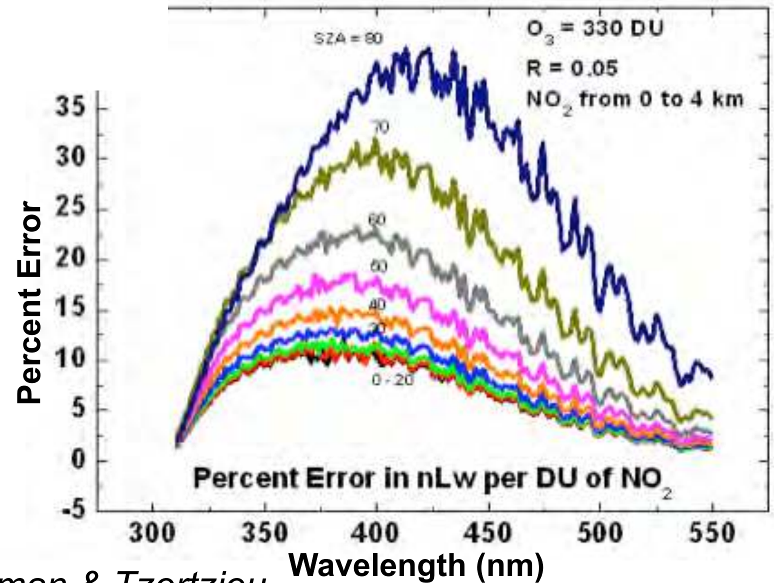
- GOCI, high latitude polar orbiters, and HICO data analysis
- Dissipation/dispersion of phytoplankton, contaminants and sediments
  - *Lagrangian experiments show particle stocks and turnover times tracking net community production. (Salisbury)*
- Exchange across land-sea interface
  - *Tidal exchange yields optical & biogeochemical variability at hourly time scales. (Tzortziou)*
  - *Optical signature from tidal marsh is distinguishable to 1km distance.*
- Sensitivity studies on observing strategies
- Diurnal phytoplankton physiology from fluorescence - dawn to dusk sensitivity
- Atmosphere-ocean synergistic science
- Vertical migration of phytoplankton
- Process observations for algorithm development
- Atmospheric correction studies for ocean color

Atmospheric Correction Studies

- Considerable day-to-day and diurnal variability in total column ozone.
  - *Real-time ozone correction will lead to <0.3% error in water-leaving radiances at 551nm, while climatology could result in 0.5 to 3% error.*
- Variability of NO_2 can exceed 0.5 DU over a period of an hour at near-coastal land sites.
  - *Such changes in NO_2 results in ~15-20% error in water leaving radiances at 410nm for larger solar zenith (>40°) and look angles expected with GEO-CAPE.*



NO_2 and possibly ozone must be measured nearly simultaneously with ocean color measurements to reduce errors in water-leaving radiances.



1 DU = 2.69×10^{16} NO_2 molecules cm^{-2}

courtesy of Herman & Tzortziou

Algorithm Assessment & Development Plan

- Develop advanced algorithms to take advantage of full spectral range & high spectral resolution
  - Initial approach to emulate SeaWiFS, MODIS and MERIS algorithms
  - Joint activity with PACE and ACE missions
  - Apply near real-time atmospheric correction
    - Coincident NO_2, O_3, aerosols, etc.
- Joint ACE/Geo-CAPE Ocean product assessments
  - Field ocean product uncertainty documentation
  - Planned satellite ocean product uncertainty assessment
- Further development work identified
  - Planning field activities with specific observational objectives
  - in situ sensor development (spectral range and resolution)

Cal/Val Plans & Requirements

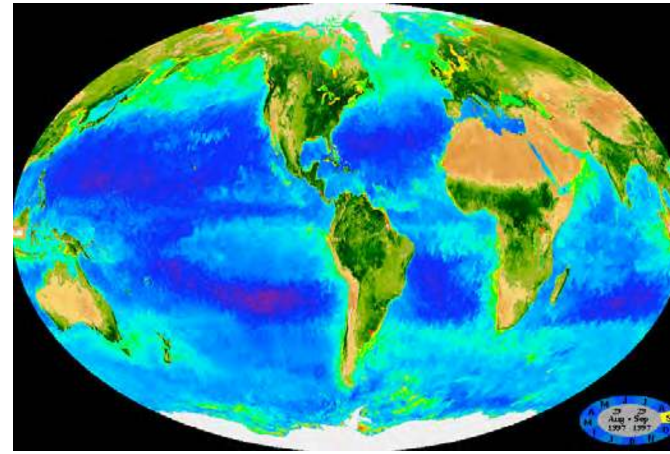
- Calibration: Radiometric, Spectral, and Spatial
  - Follow approaches for SeaWiFS and MODIS
  - Extensive pre-launch calibration and characterization
  - Hyperspectral spectrometer enables the use of solar Fraunhofer spectrum for on-orbit spectral calibration
  - Post-launch (in-orbit) vicarious calibration
    - Requires continuous field vicarious calibration site
  - Post-launch stability monitoring (lunar, solar and stable target)

- Validation
  - Directed field campaigns
    - Optical closure experiments
    - Diurnal variability
  - Existing observation networks
  - Opportunistic validation (research cruises, buoys, moorings)

Complementary Science Missions

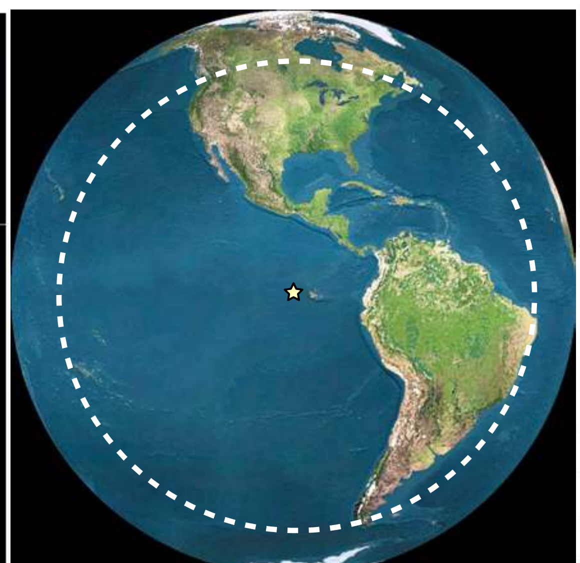
- Global ocean color missions:
  - *PACE (2018),* ACE (>2020)
    - Joint Cal/Val activities
  - *JAXA S-GLI; ESA MERIS-follow-on*
- Geo constellation:
  - *Korean GOCI-2*
  - *ESA's OCAPI*

PACE

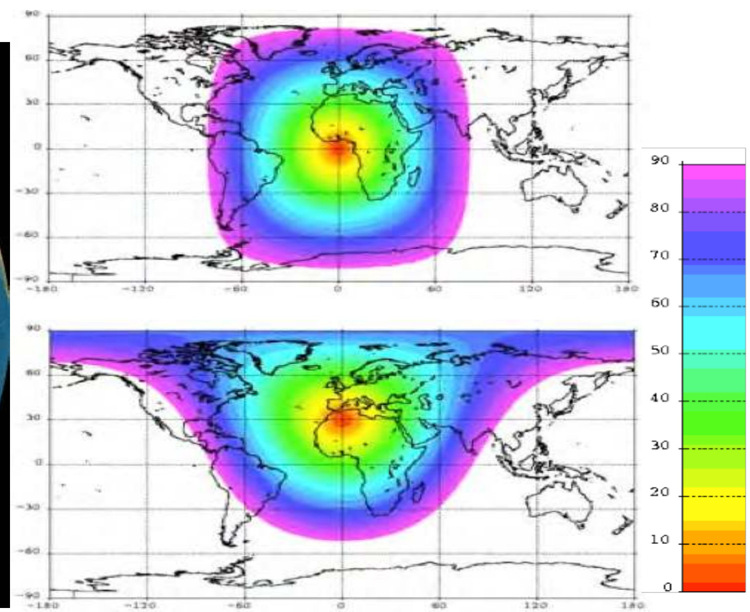


GOCI-II: 2018-2019

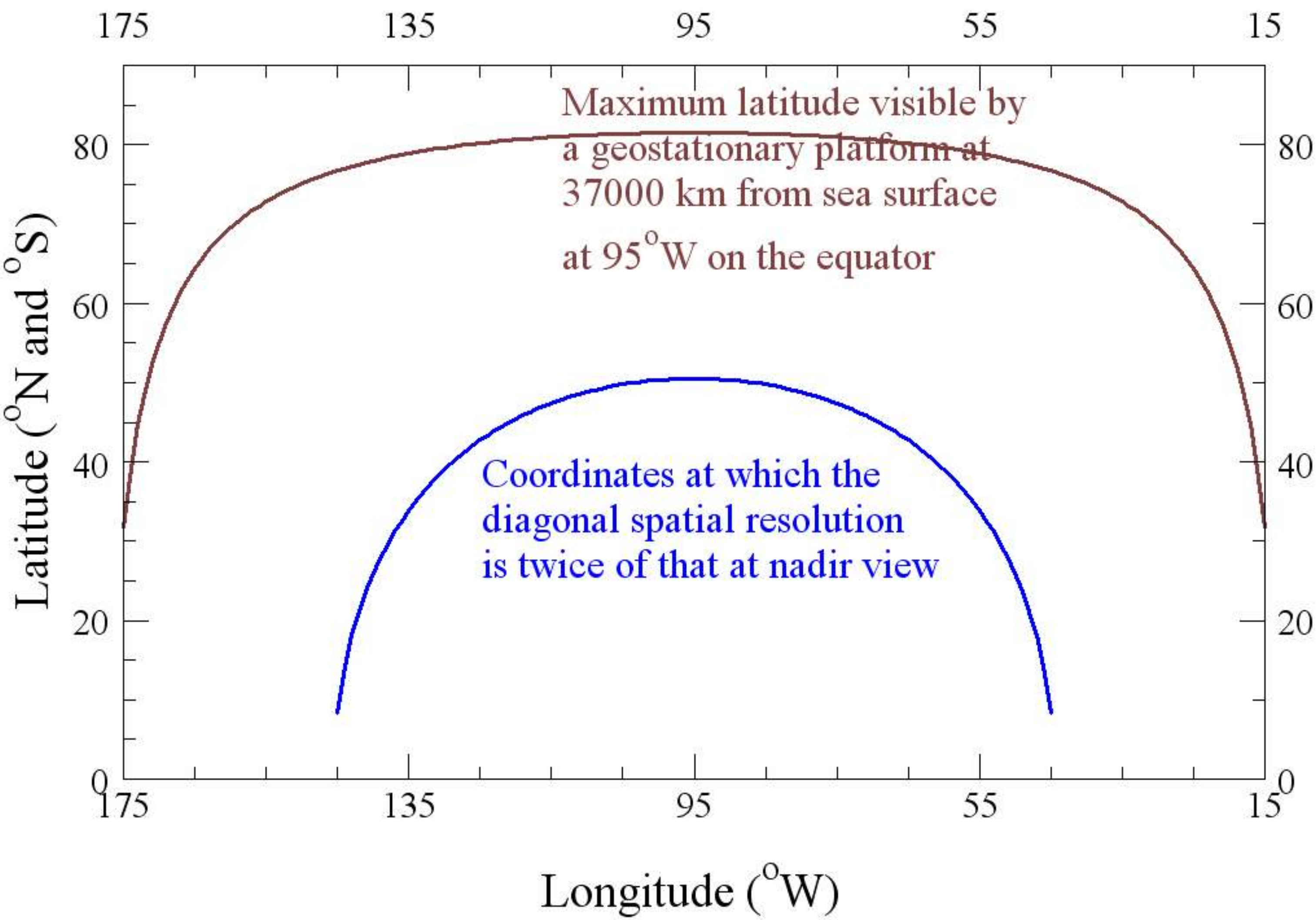
Geo-CAPE: >2020



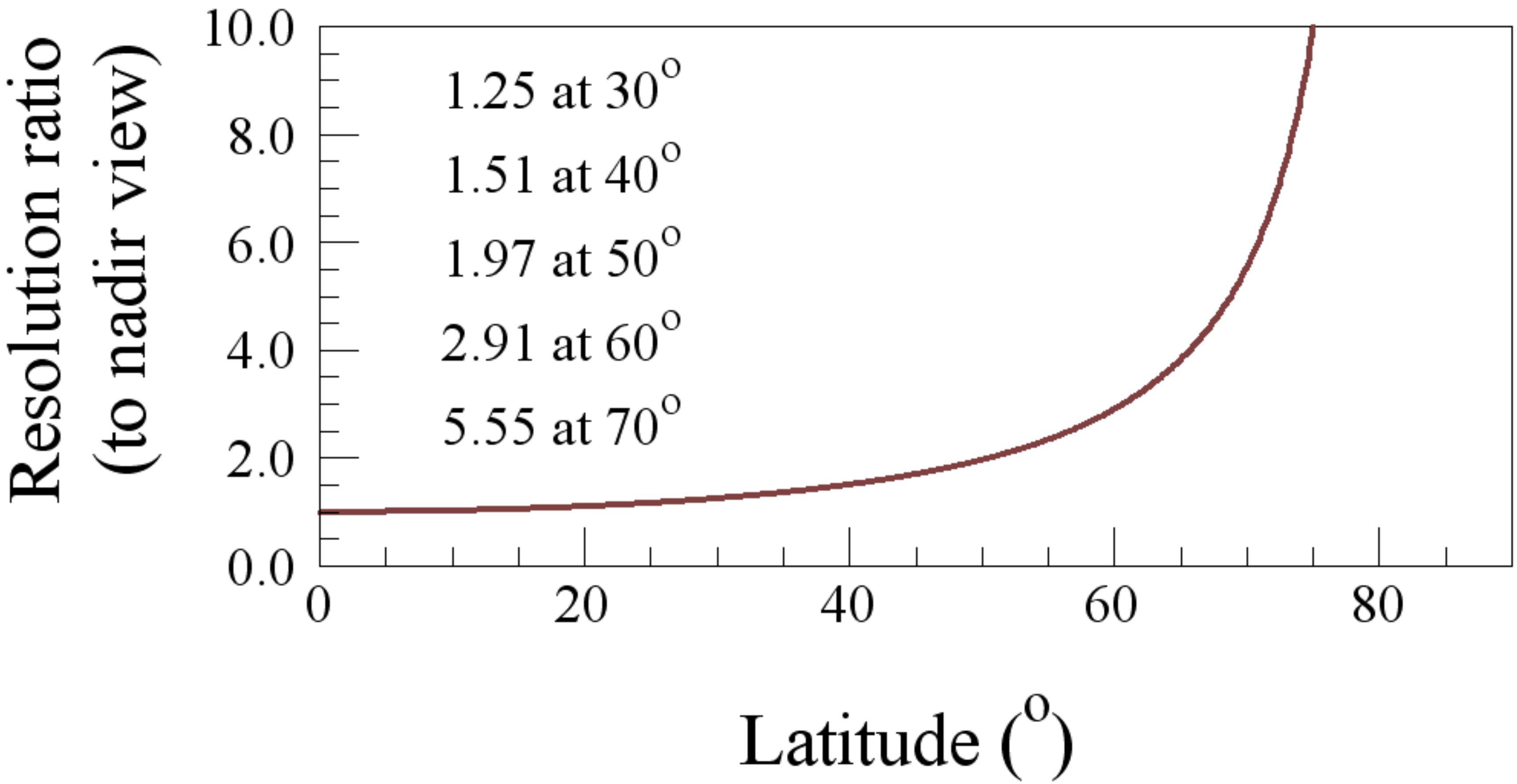
Geo-OCAPI: 2019 ?



View Limit and Resolution



Resolution at 95W



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Summative Progress Report

Geo-CAPE
Instrument Design Lab Study (GSFC)
Coastal Ecosystem Dynamics Imager (CEDI)

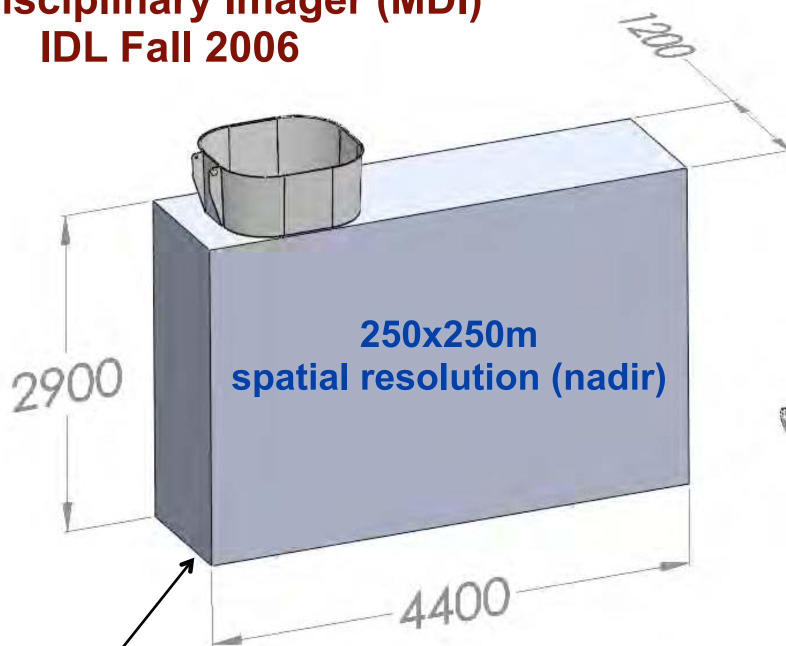
Antonio Mannino

November 15, 2010

Instrument Design Lab Study Goals

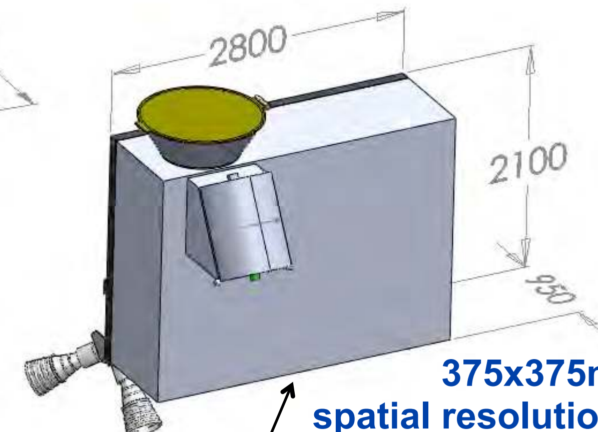
(1) to develop an instrument design that meets requirements established in the Coastal Oceans STM
(2) to reduce size and cost from a previous IDL design concept

Multi-Disciplinary Imager (MDI)
IDL Fall 2006



Geo-MDI
15.3 cubic meters
(includes calibration assy. Volume)

Coastal Ecosystem Dynamics Imager (CEDI)
IDL January 2010

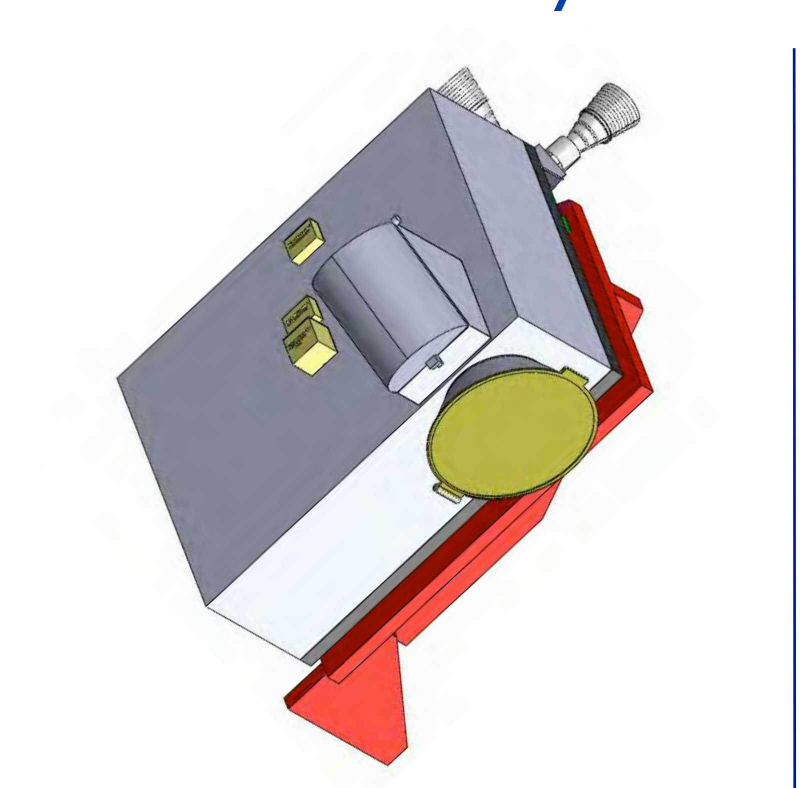


375x375m
spatial resolution (nadir)

Geo-CEDI
7.5 cubic meters
(includes calibration assembly volume)

Note: dimensions in millimeters

Summary of Geo-CEDI



Instrument Concept

- Enables scientific objectives of coastal ocean and atmospheric retrievals.
- Capable of pointing anywhere on Full Disk.
- Spatial Resolution: 375 m x 375 m (nadir)
- Telescope focal length set for 1:1 Offner Spectrograph
- Effective focal length = 1717.7 mm, F/3.44 focal ratio
- Employs three focal planes
  - (1) 345-600 nm, (2) 600-1100 nm
    - Two Teledyne custom HyViSi ROIC: 1k (spectral) x 2k (spatial) detectors (UV-A or NIR coating)
  - (3) 1225-2160 nm
    - One HgCdTe Hawaii-2RG ROIC: 2k x 2k detector (SWIR)
- All detectors have 18 μm pixels
- Spectral Resol: 0.5 nm (UV-NIR) and 2.5 nm (SWIR)

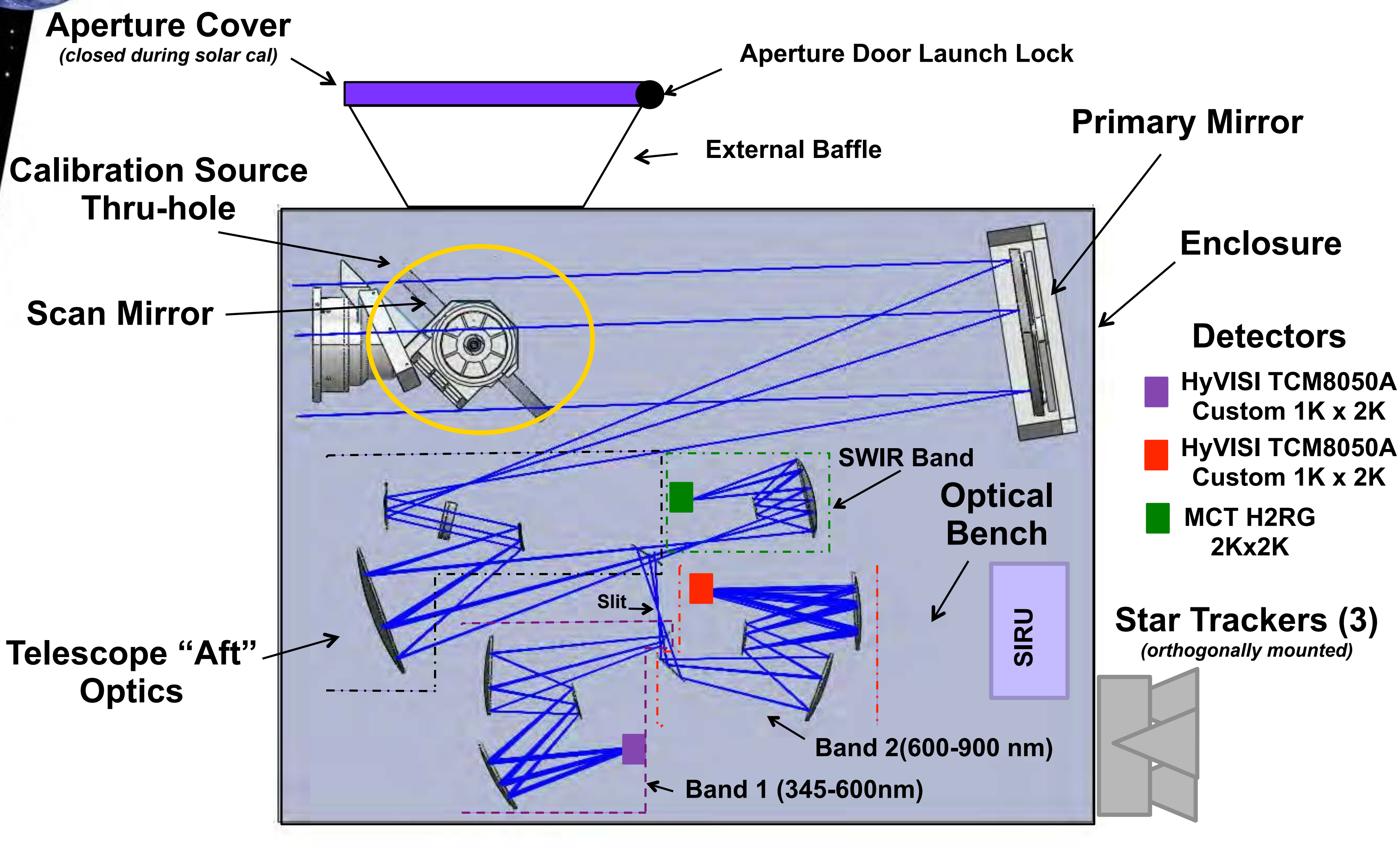
Instrument Characteristics

- Volume - 7.5 m^3
- Mass - 621.4 kg
- Power - 392 W
- Data Rate - 88.4 Mbps
- Scene: 750 km N-S x variable E-W
- Scene Integration Time: 9-17 min
- Pointing - ~0.5 arc-sec
- Lifetime - 3 yr (design); 5 yr (goal)

Technology Development Needs

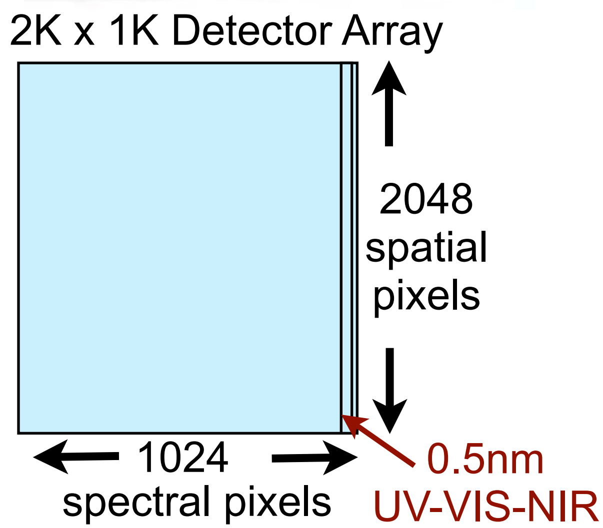
- Scan mirror pointing mechanism requires further study and technology enhancements.
- Dedicated effort required to investigate, characterize, and mitigate all sources of disturbances to scan mirror.
- 100Hz Attitude Determination may exceed existing proven technologies (133MHz BAE Rad750).

Coastal Ecosystem Dynamics Imager (CEDI) Block Diagram



CEDI Conceptual Scanning Plan

- **>72 scenes per day (~750km x 375km nadir)**
  - ~18 hours of operation per day
  - ~4 scenes per hour (15 minutes each)
  - 1000+ iFOV scans per scene



- **Avoid scanning cloudy scenes**

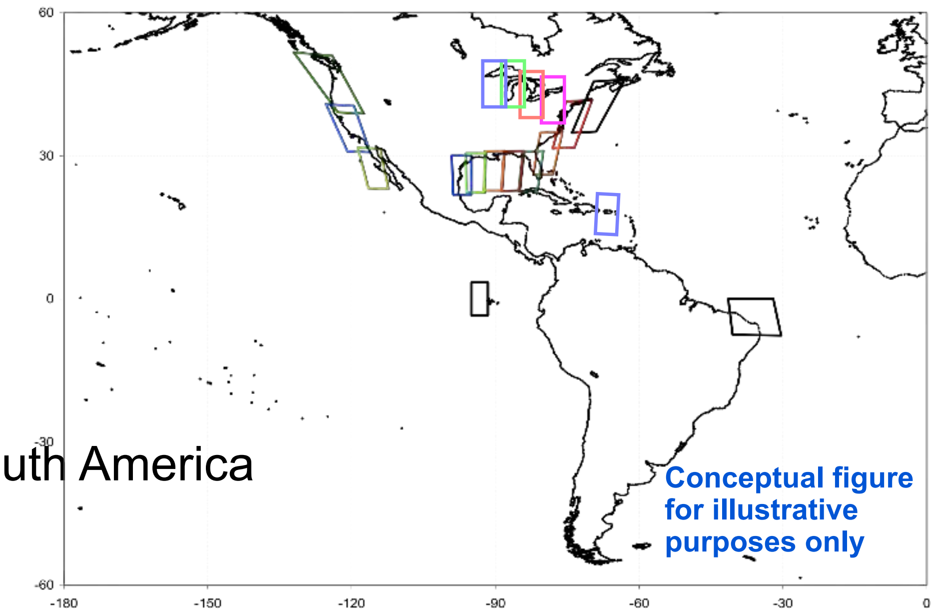
- **Targeted Events** - scheduled as necessary
- **Survey Mode**

U.S. Coastal Waters

- East Coast – 4 scenes (3-4x/day)
- Gulf Coast – 4 scenes (3-4x/day)
- West Coast – 3 scenes (3-4x/day)
- Puerto Rico – 1 scene (3-4x/day)
- Great Lakes – 4 scenes (3x/day)

Regions of Interest

- Other coastal waters of North & South America
- Anywhere within Field of Regard (50°N to 45°S; ~145°W to ~45°W)



Radiometry Requirements & Results
70° Solar Zenith Angle case

λ_o - Bands	FWHM	W/m^2-$\Delta\lambda$um-ster		Req'd	Well_Capacity	Averages	Ltyp	Lmax	eff		Req'd	Ltyp
nm	$\Delta\lambda$ – nm	Ltyp	Lmax	Dynamic Range	Dynamic Range	$\Delta\lambda$	Well_Volume	Well_Volume	Opt. Tx	Det. QE	SNR_{req}	SNR_{actual}
350	15	39.26	117.5	2.99	21.49	60.00	46,538	139,247	0.24	0.65	500	1512
360	15	38.00	124.1	3.27	16.71	60.00	59,840	195,393	0.31	0.65	500	1750
385	10	32.16	125.7	3.91	17.65	40.00	56,656	221,513	0.31	0.68	1000	1385
412	10	41.77	198.7	4.76	8.65	40.00	115,662	550,095	0.43	0.72	1000	2061
425	10	40.63	193.1	4.75	8.70	40.00	114,935	546,085	0.42	0.73	1000	2054
443	10	37.51	219.1	5.84	9.61	40.00	104,106	608,151	0.39	0.74	1000	1947
460	10	33.14	238.9	7.21	10.60	40.00	94,319	679,962	0.38	0.75	1000	1844
475	10	30.25	238.3	7.88	10.96	40.00	91,250	718,621	0.39	0.75	1000	1811
490	10	29.25	226.4	7.74	10.45	40.00	95,675	740,472	0.41	0.75	1000	1859
510	10	24.23	218.8	9.03	13.08	40.00	76,441	690,354	0.38	0.75	1000	1641
532	10	20.09	214.8	10.69	15.96	40.00	62,645	669,884	0.36	0.75	1000	1467
555	10	16.11	212.2	13.17	18.57	40.00	53,862	709,431	0.37	0.75	1000	1345
583	10	14.56	205.9	14.14	22.22	40.00	45,007	636,418	0.33	0.74	1000	1210
617	10	11.25	192.1	17.07	22.34	40.00	44,758	764,026	0.33	0.9	1000	1206
640	10	9.39	186.1	19.82	25.53	40.00	39,177	776,529	0.33	0.91	1000	1114
655	10	8.33	176.6	21.20	26.51	40.00	37,718	799,554	0.35	0.91	1000	1088
665	10	7.83	176.9	22.59	25.58	40.00	39,087	882,988	0.38	0.91	1000	1112
678	10	7.37	171.3	23.24	26.66	40.00	37,510	871,697	0.38	0.91	1000	1085
710	15	5.36	161.4	30.10	35.39	60.00	28,256	850,622	0.38	0.9	1000	1114
748	10	4.89	147.5	30.17	36.82	40.00	27,156	819,179	0.38	0.9	600	887
765	40	3.62	141.9	39.18	51.32	160.00	19,486	763,516	0.36	0.9	600	1428
820	15	2.82	129.7	46.04	62.24	60.00	16,067	739,677	0.36	0.89	600	766
865	40	4.50	139.0	30.89	37.36	160.00	26,770	826,886	0.36	0.88	600	1758
1245	20	0.88	59.5	67.61	67.72	368.00	1,477	99,843	0.336	0.85	300	637
1640	40	0.29	17.6	60.69	156.00	736.00	641	38,903	0.336	0.85	250	514
2135	50	0.08	4.7	58.75	424.41	920.00	236	13,843	0.336	0.87	100	263

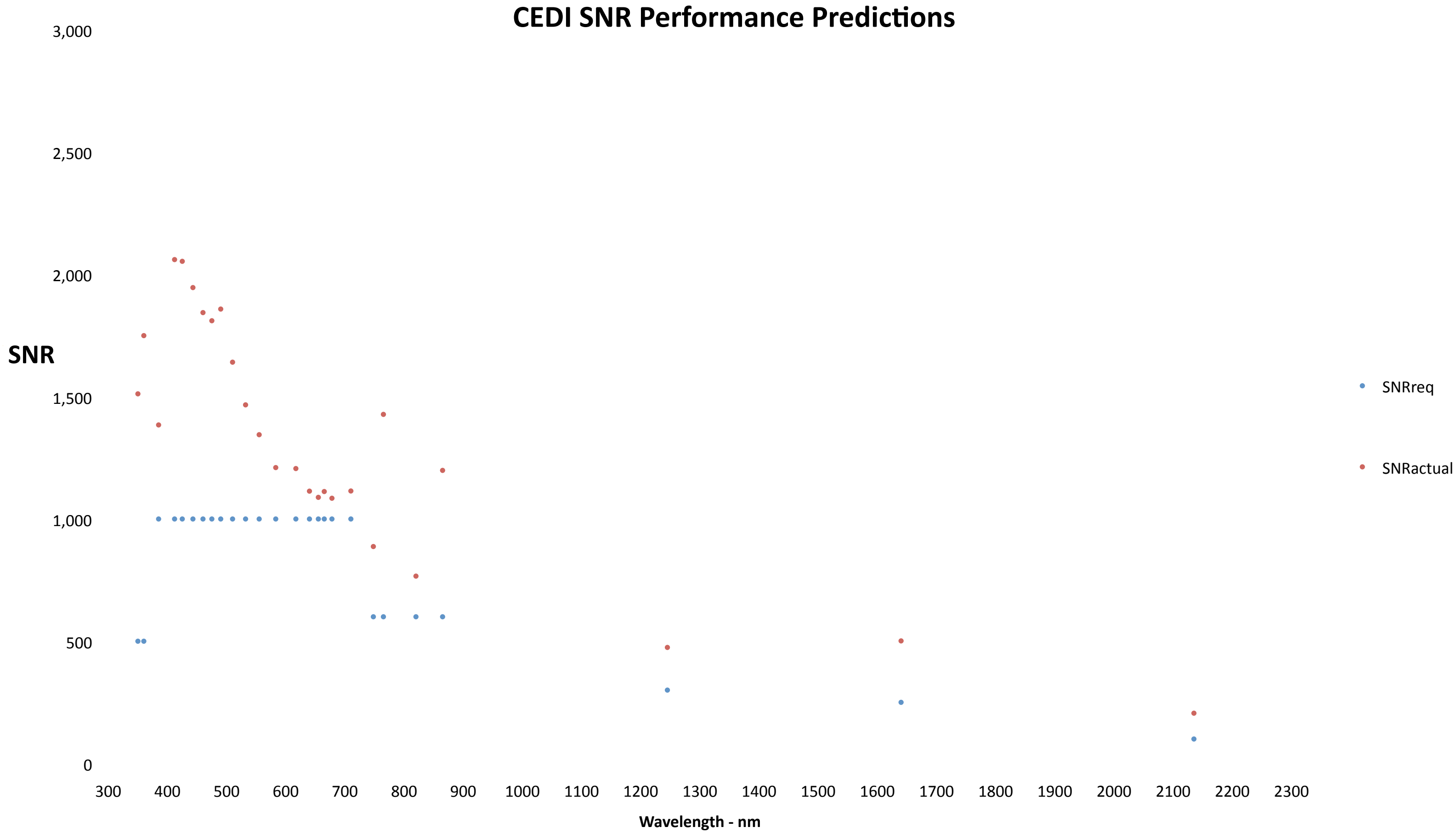
Challenge to overcome ocean requirements of high sensitivity (SNR) without saturating the detectors.

Conclusions

- Geo-CAPE Oceans STM requirements are achievable with CEDI or similar class of instrument.
- Scan mirror pointing mechanism requires further study and technology enhancements.
  - *e.g., SCH_2OO_3NERS IIP-heritage fast scanning mirror concept*
  - *Dedicated effort required to investigate, characterize, and mitigate all sources of disturbances to scan mirror.*
- Additional design studies recommended
  - *To reduce instrument size and cost*
  - *To extend design to meet goal requirements for temporal and spatial resolution*

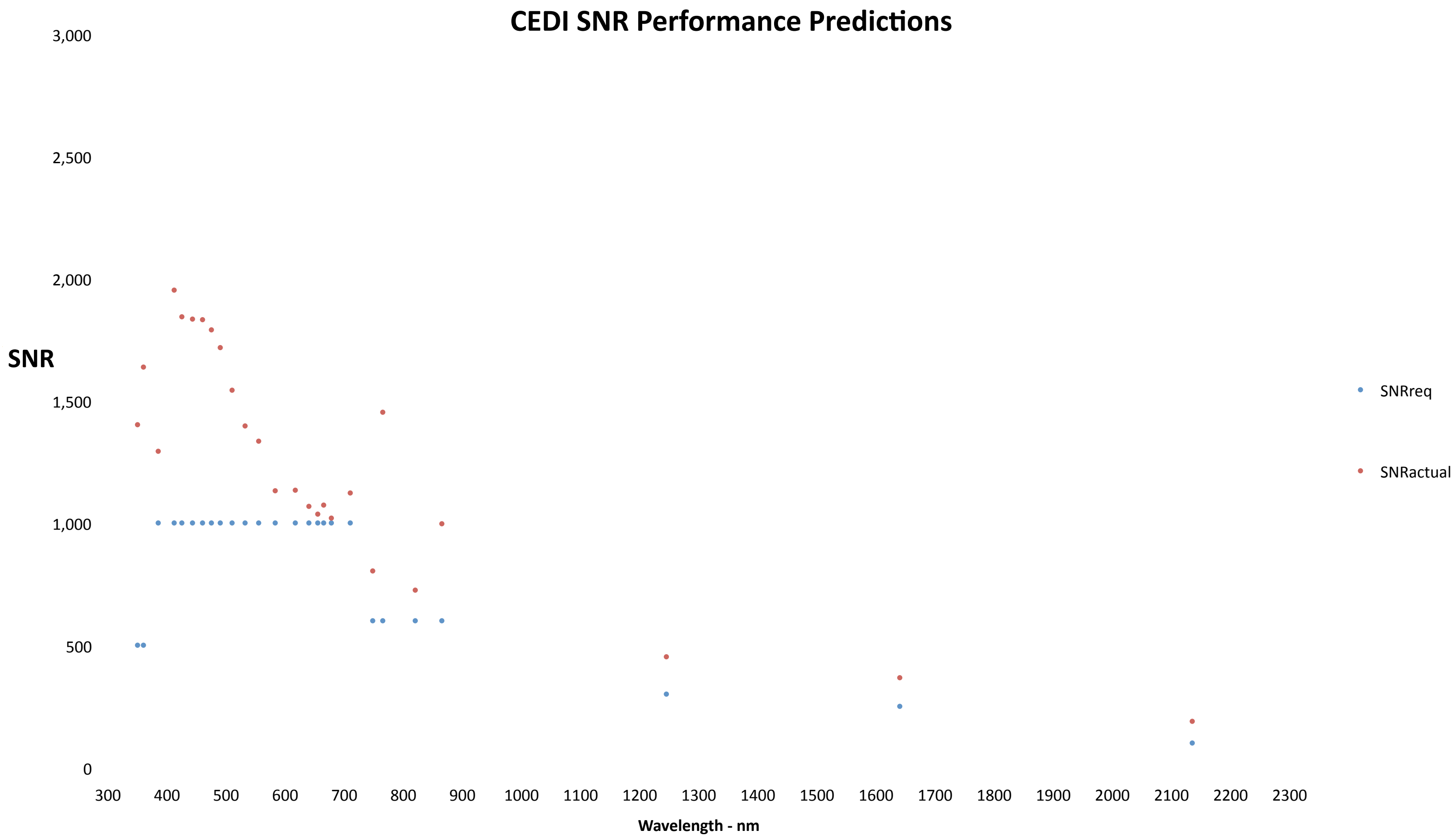
EXTRA SLIDES

Ltyp = ~TOA Radiances at 70° SZA*



Total integration time = ~17.1 min per scene
0.8 sec integration time per scan line
Co-add 2 frames for UV-VIS-NIR & 46 for SWIR

Ltyp & Lmax equivalent to SeaWiFS values



Total integration time = ~10.3 min per scene

0.4 sec integration per scan line

Co-add 3 frames for UV-VIS-NIR & 23 for SWIR

Saturation of 1245 and 1640nm bands possible for extremely bright scenes.

Lmax(Barnes) based on SeaWiFS data, only 0.2% of pixels saturated