Optimization of Instrument Requirements for NASA's GEO-CAPE Coastal Mission Concept Based On Sensor Capability And Cost Studies

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Background

NASA's GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission concept recommended by the U.S. National Research Council (2007) focuses on measurements of atmospheric trace gases and aerosols and aquatic coastal ecology and biogeochemistry from geostationary orbit (35,786 km altitude). GEO-CAPE is currently in pre-formulation (pre-Phase) A with no established launch date. NASA continues to support science and engineering studies to reduce mission risk. Instrument design lab (IDL) studies were commissioned in 2014 to design and cost two implementations for geostationary ocean color instruments (1) Wide-Angle Spectrometer (WAS) and (2) Filter Radiometer (FR) and (3) a cost scaling study to compare the costs for implementing different science performance requirements.

Instrument Study Objectives

- Obtain high fidelity cost estimates for various GEO-CAPE ocean color sensor capabilities to inform NASA and the GEO-CAPE team.
- Generate credible bounds on instrument costs to demonstrate to NASA that mission is viable financially (as well as technologically).
- Evaluate the impact of various science requirements, including spatial and spectral resolution, multi-spectral versus hyperspectral, SWIR bands, scanning rate and SNR on the instrument cost.
- Multiple instrument concepts were examined to capture a broader range of costs that might be associated with different instrument concepts.
  - Multi-spectral filter radiometer (FR)
  - Hyperspectral wide-angle spectrometer (WAS)
  - Hyperspectral multi-slit spectrometer (COEDI)
  - Hyperspectral single-slit spectrometer (SSS)

Why geostationary for ocean color?

- Capability to image the same regions multiple times per day.
- Maximize daily spatial coverage due to diurnal variability in cloud cover and gaps in orbital coverage gaps.
- Permits staring at a region (iFOV) to gain sufficient SNR to retrieve ocean reflectances during low light conditions (early morning and late afternoon) and at high view angles (e.g., high latitudes).
- To quantify physical, biological and biogeochemical processes that react on short time scales from minutes to days.
- High frequency observations will advance our knowledge of the rates of biological and biogeochemical processes including primary productivity (carbon cycle, climate change, & water quality research).

Science

- Track riverine/estuarine plumes, tides, fronts and eddies
- Follow the evolution of phytoplankton blooms (log-phase to post-senescence)
- Reduce uncertainties in primary productivity and other biogeochemical processes
- Quantify surface currents to track sediments, carbon pools, pollution, etc.
- Capability for nearly continuous coverage of coastal hazards or other events
- High frequency observations to improve coastal models
  - To evaluate biogeochemical model performance
  - Satellite data assimilation to improve model forecasting

NASA Application Sciences Relevance

- Post-storm Assessments (e.g., flood detection); sediment transport (navigation)
- Detection and tracking of oil spills and other disasters
- Water Quality Indicators and management of water resources in lakes and coastal waters
- Better monitoring, predictions and early-warnings for HABs; fisheries management
- Air Quality in Coastal Cities and impacts of anthropogenic air pollution on human health
- Mapping and assessment of carbon dynamics, sources and fluxes & integration into climate models
- Overall: Improve assimilation of satellite data into operational models to (i) assess/improve management of coastal resources, and (ii) improve forecasting/predictions.

Process in GEO-CAPE Pre-Formulation

- Define mission science objectives
- Define measurement and instrument requirements to meet science objectives
- Conduct engineering studies to determine technological and cost feasibility
- Conduct science studies in parallel to refine requirements
- Iterate between science and engineering to optimize mission science and sensor data

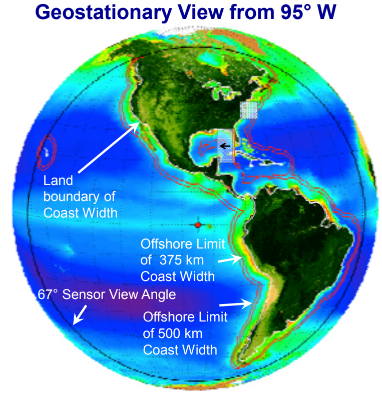
Instrument Capability Trades

	Hyperspectral Spectrometers	Multi-spectral Filter Radiometer
Spatial Resolution	**250, 375 and 500 m**	**250, 375 and 500 m**
Spectral Resolution	0.4 and 2 nm	5 nm
Spectral Range	340-1050 nm	50 bands: 340-1050
SWIR Bands	1245, 1640, 2135 nm	1245, 1640, 2135 nm
SNR (UV-Vis; 10 nm bands)	1000	1000

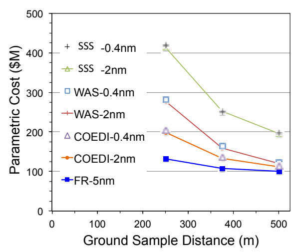
GEO-CAPE Ocean Color Requirements

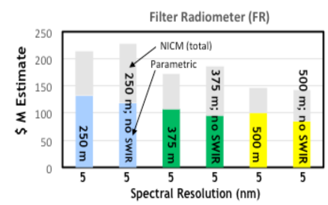
	Threshold (min.)	Baseline (goal)
Temporal Resolution Targeted Events	<1 hour	<0.5 hour
Survey Coastal U.S.	<2 hours	<1 hour
Inland & Other Coastal	>1 Region 3 times/day	<3 hours
Spatial Resolution (nadir)	<375 m x 375 m	<250 m x 250 m
Spectral Range	345-1050 nm; 1245 & 1640 nm	340-1100 nm; 1245, 1640 & 2135 nm
Spectral Resolution	**≤5 nm (UV-VIS-NIR)**; ≤0.8nm (400-450nm; NO_2); ≤20-40 nm (SWIR)	**≤0.75 nm (UV-VIS-NIR)**; ≤20-50 nm (SWIR)
Signal-to-Noise Ratio (SNR) @ Ltyp 70° solar zenith angle	1000:1 for 350-800 nm (10nm FWHM)	1500:1 for 350-800 (10 nm FWHM)
Coastal Coverage (inland to offshore)	375 km width	500 km width
Pointing Stability	<25% pixel	<10% pixel

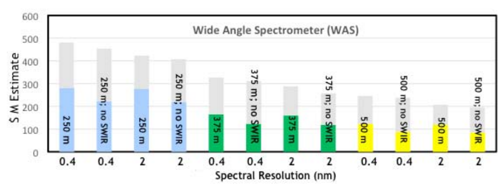
Geostationary View from 95° W

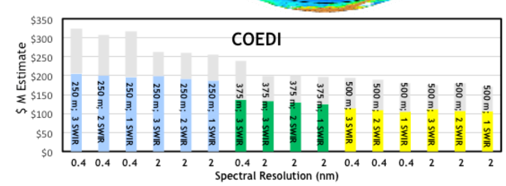


Results: Capability vs. Cost



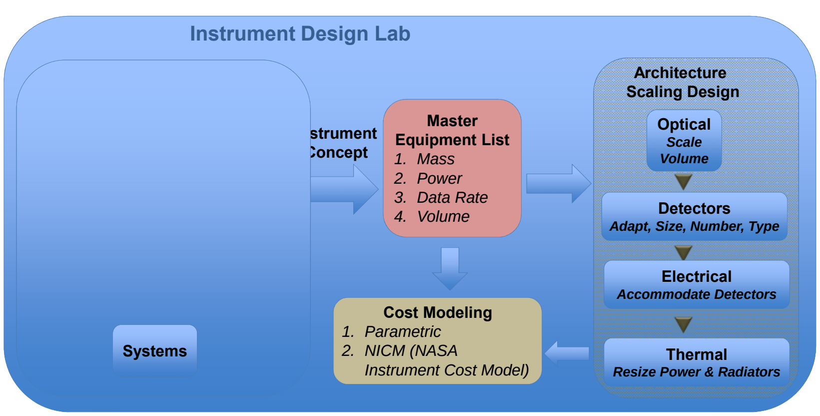






Instrument Type	Filter Radiometer FR		Wide Angle Spectrometer WAS	Multi-Slit Spectrometer COEDI	
Spatial Resolution	**250 m**	**375 m**	**375 m**	**375 m**	**250 m**
Spectral Resolution	5 nm	5 nm	0.4 nm	0.4 nm	0.4 nm
Spectral Range (nm) (2135 not req)	Multi-spectral (50 bands total) 30-1050 & 1245, 1640, 2135	Multi-spectral (50 bands total) 340-1050 & 1245, 1640, 2135	Hyperspectral: 340-1050; 1245, 1640, 2135 nm	Hyperspectral: 340-1050; 1245, 1640	Hyperspectral: 340-1050; 1245, 1640
Scan Rate (km^2/min)	100,105	100,105	48,200	43,200	28,800
Mass CBE (kg)	190.4	126.3	309.4	202.8	358.6
Power CBE (W)	200.1	161.2	341.3	192.5	257.7
Volume (m x m x m)	1.5 x 1.46 x 1.02	1.0 x 0.97 x 0.68	2.6 x 1.8 x 1.5	1.5 x 1.7 x 1.1	2.2 x 2.5 x 1.7
Telemetry CBE (kbps)	15,900	10,600	23,832	23,854	35,765
NICM Cost ($M)	$213.4	$172.9	$325.2	$238.8	$308.0
Parametric Cost ($M)	**$131.7**	**$107.7**	**$165.2**	**$136.2**	**$200.1**
NICM Sub-System ($M)	**$128.7**		**$179.3**		

Instrument Design Lab



Wag on GEO-CAPE OC Mission Cost Estimate

Instrument:	$200M
Project Mngmt, S&E, & SMA (10%)	$45M
Ground Sys., Mission Ops (13%):	$60M
Host fees (launch, I&T, data):	$80M (TBD)
Science & Applications:	$65M
Reserves (10%):	$45M
TOTAL:	**$495M**

Conclusions

- Multiple GEO-CAPE ocean color sensor concepts are feasible technologically and financially.
- Spatial resolution is most costly capability followed by SWIR bands; spectral resolution does not impact parametric costs. NICM results confounded by data rate limitations of this model.
- Multi-spectral (FR) designs are less costly and provide twice the scanning rate than spectrometers.
- NICM cost estimates are likely too high because database lacks geo sensors (GOCI was costed as $85M in 2014 $, but actual cost was <half).
- Alternate telescope and spectrometer optical designs could yield smaller and less costly sensors.
- Hosting GEO-CAPE OC sensor reduces costs (typical NASA LEO S/C & launch are ~40% of cost)
- Iterative process between science and engineering can lead to cost effective solutions for geo OC.

IDL Team: Aron Brall, Bobby Nanan, Bryan Monosmith, Cabin Samuels, Cathy Marx, Carl Kotecki, Cheryl Salerno, Dick McBirney, Elizabeth Matson, Eric Stoneking, Greg Bowers, Jay Smith, Jeff Bolognese, Jennifer Bracken, John Panek, Jonathan Verville, JP Swinski, Kequan Luu, Mark Wilson, Mike Choi, Mike Clark, Mark Secunda, Martha Chu, Paul Earle, Sanjay Verma/Costing, Sharon Seipel, Tammy Brown (IDL lead). **Program Scientists**: Jay Al-Saadi & Paula Bontempi; **Program Executive**: Betsy Edwards

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