**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)
  - Hyperpectral wide-angle spectrometer (WAS)
  - Hyperspectral multi-slit spectrometer (COEDI)
  - Hyperspectral single-slit spectrometer (SSS)

**Why geostationary for ocean color?**

- Capacity to image the same regions multiple times per day.
- Maximize daily spatial coverage due to diurnal variation in cloud cover and gaps in orbital coverage gaps.
- Permits staring at a region (FOV) to gain sufficient SNR to retrieve ocean reflectance (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 near continuous coverage of coastal hazards or other events
- High frequency observers 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.

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**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**

<table>
<thead>
<tr>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>SWIR Bands</th>
<th>SNR (UV-VIS: 10 nm bands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250, 375 and 500 m</td>
<td>0.4 and 2 nm</td>
<td>1245, 1640, 2135 nm</td>
<td>1000</td>
</tr>
<tr>
<td>250, 375 and 500 m</td>
<td>5 nm</td>
<td>1245, 1640, 2135 nm</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Results: Capability vs. Cost**

- Hyperspectral Spectrometers
- Multi-spectral Multi-slit Radiometer
- Multi-slit Spectrometer

**GEO-CAPE Ocean Color Requirements**

<table>
<thead>
<tr>
<th>Threshold (min.)</th>
<th>Baseline (goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal Resolution</td>
<td>Targeted Events</td>
</tr>
<tr>
<td>Survey Coastal U.S.</td>
<td>&gt;2 hours</td>
</tr>
<tr>
<td>Inland &amp; Other Coastal</td>
<td>&gt;1 Region 3 times/day</td>
</tr>
<tr>
<td>Spatial Resolution (nadir)</td>
<td>&lt;375 m x 375 m</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>345-1050 nm; 1245 &amp; 1640 nm</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>55 nm (UV-VIS-NIR); 0.85 nm (400-4000 nm); 2.00 nm (SWIR)</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio (SNR) @ Lsp 70° solar zenith angle</td>
<td>1000:1 for 360-800 nm (10 nm FWHM)</td>
</tr>
<tr>
<td>Coastal Coverage</td>
<td>&lt;375 km width</td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>&lt;25% pixel</td>
</tr>
</tbody>
</table>

**Wag on GEO-CAPE OC Mission Cost Estimate**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Mgmt, S&amp;E, &amp; SMA (10%)</td>
<td>$45M</td>
</tr>
<tr>
<td>Ground Sys., Mission Ops (13%)</td>
<td>$60M</td>
</tr>
<tr>
<td>Host fees (I&amp;T &amp; D)</td>
<td>$60M (TBD)</td>
</tr>
<tr>
<td>Science &amp; Applications</td>
<td>$65M</td>
</tr>
<tr>
<td>Reserves (10%)</td>
<td>$45M</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$495M</td>
</tr>
</tbody>
</table>

**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.
- Hyperspectral (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 costing $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 S/C & launch are ~40% of cost)
- Iterative process between science and engineering could lead to cost-effective solutions for GEO-OC

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**Instrument Design Lab**

- Systems
- Architectural Design
- Optical Scale Volume
- Detectors
- Electrical Accommodate Detectors
- Thermal Radiometer and Radiators

**Master Equipment List**

1. Parametric
2. NICM (NASA Instrument Cost Model)

**Cost Modeling**

- Project/Engineering (P/E)
- NICM (NASA Instrument Cost Model)

**Optical Scale Volume**

- OVL: 200M
- Host fees: (NASA S/C & Launch) $60M (TBD)
- TOTAL: $495M

**Diagram**

- [Diagram of Instrument Design Lab]

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**Design Concept**

- [Diagram of System Design Concept]

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