Stratégies

GEO-CAPE INTELLIGENT OBSERVATION STUDIES @GSFC

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GEO-CAPE Workshop
September 1, 2015

http://geocape.herokuapp.com
### STRATEGIES OVERVIEW

*Based On Current Assumptions That Need To Be Validated*

<table>
<thead>
<tr>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
<th>Strategy 4</th>
<th>Strategy 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Scheduler</td>
<td>Ground Scheduler</td>
<td>Ground Scheduler</td>
<td>Onboard Scheduler and</td>
<td>Smart Onboard Scheduler and onboard Image</td>
</tr>
<tr>
<td>With Simple</td>
<td>With Cloud Forecast</td>
<td>With Sub-area</td>
<td>Onboard Cloud Detection</td>
<td>Processing to Reduce Downlink Costs</td>
</tr>
<tr>
<td>Priorities</td>
<td>Forecast</td>
<td>Forecast</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Potentially Acquired Scenes per hour

- Strategy 1: < 10 scenes
- Strategy 2: ~14 scenes
- Strategy 3: ~16 scenes
- Strategy 4: ~19 scenes
- Strategy 5: ~19.2 scenes

#### Complexity:

- Strategy 1: ★★★★★
- Strategy 2: ★★★★★
- Strategy 3: ★★★★★
- Strategy 4: ★★★★★
- Strategy 5: ★★★★★

#### Cost:

- Strategy 1: 🈹️
- Strategy 2: 🈹️
- Strategy 3: 🈹️
- Strategy 4: 🈹️
- Strategy 5: 🈹️
OBJECTIVES OF GSFC STUDY ELEMENTS

Analyze And Summarize Strategies To Improve Science Data Collection

Smart Cloud Forecasting

Onboard Cloud Detection

Ground/Onboard Scheduling with Robust Executive
Assumptions

+ Mission
+ Instruments
+ Study Selection
+ Scheduling
MISSION ASSUMPTIONS

Optimize Acquisition of “Cloud Free” Scenes At Lowest Cost

Mission Life Time: 5 years

~16 hours of Operations per day

Survey Mode

U.S Coastal Waters: East Coast, Gulf Coast, West Coast, Puerto Rico, Great Lakes

Targeted Events As Necessary

Regions of Interests

Other Coastal Waters of North & South America

Anywhere within Field of Regard
MISSION ASSUMPTIONS

Optimize Acquisition of “Cloud Free” Scenes At Lowest Cost

Standard (Threshold) Survey Mode (60min Repeat Frequency)

High Repeat (Baseline) Mode (30mn Repeat Frequency)

Targeted Events and Regions of Special Interest

Engineering Tasks and Special Window Events (Sun interference…)

Some scenes will be requested by external users and subject to Science Team Approval

Scenes will need some kind of a priority scheme for scheduling
<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>Filter Radiometer FR</th>
<th>Filter Radiometer FR</th>
<th>Wide Angle Spectro-meter WAS</th>
<th>Multi-Slit Spectro-meter COEDI</th>
<th>Multi-Slit Spectro-meter COEDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution (m) (nadir)</td>
<td>250</td>
<td>375</td>
<td>375</td>
<td>375</td>
<td>250</td>
</tr>
<tr>
<td>Spectral Resolution (nm)</td>
<td>5 nm</td>
<td>5 nm</td>
<td>0.4 nm</td>
<td>0.4 nm</td>
<td>0.4 nm</td>
</tr>
<tr>
<td>Spectral Range (nm)</td>
<td>Multispectral (50) 340-1050; 1245, 1640, 2135</td>
<td>Multispectral (50) 340-1050; 1245, 1640, 2135</td>
<td>340-1050; 1245, 1640, 2135 nm</td>
<td>340-1050 1245,1640 nm</td>
<td>340-1050 1245,1640 nm</td>
</tr>
<tr>
<td>Scan Rate (km²/min)</td>
<td>100,105</td>
<td>100,105</td>
<td>48,200</td>
<td>43,200</td>
<td>28,800</td>
</tr>
<tr>
<td>Mass CBE (kg)</td>
<td>190.4</td>
<td>126.3</td>
<td>309.4</td>
<td>202.8</td>
<td>358.6</td>
</tr>
<tr>
<td>Power CBE (W)</td>
<td>200.1</td>
<td>161.2</td>
<td>341.3</td>
<td>192.5</td>
<td>257.7</td>
</tr>
<tr>
<td>Volume (m x m x m)</td>
<td>1.5 x 1.46 x 1.02</td>
<td>1.0 x 0.97 x 0.68</td>
<td>2.6 x 1.8 x 1.5</td>
<td>1.5 x 1.7 x 1.1</td>
<td>2.2 x 2.5 x 1.7</td>
</tr>
<tr>
<td>Telemetry CBE (kbps)</td>
<td>15,900</td>
<td>10,600</td>
<td>23,832</td>
<td>23,854</td>
<td>35,765</td>
</tr>
<tr>
<td>Detector Size</td>
<td>4k X 4K</td>
<td>2730 X 2730</td>
<td>8k X 1k</td>
<td>2k X 1k (x 2)</td>
<td>3k X 1k (x 2)</td>
</tr>
<tr>
<td>Real Detector Size</td>
<td>4096 x 4096</td>
<td>Line scanner (8K)</td>
<td>2 line scans 2048 20 pixels apart</td>
<td>2 line scans 3072 20 pixels apart</td>
<td></td>
</tr>
</tbody>
</table>
• Detector Size 2730 x 2730

• Subsampled 2x2 – initial spatial resolution 187.5m -> 375m final

• Scan Rate: 100,134 km²/min -> 157 seconds per scan

• Scan Rate:
  \[2730 \times 2730 \times 0.1875 \times 0.1875 \times 60/157 = 100,134 \text{ km}^2/\text{min}\]

• Final Scene Size: 1365 x 1365 pixels
  (512km x 512km)

• Total Time including mirror displacement = 157s + 1s = 158s

• 50+3 bands ??? @ 2bytes/pixels

• Scene Size: 53*2*1365*1365 = 197.5 MB

• Data Ingest Rate: 197.5 / 158 = 1.250 MB/s

• Estimated Daily Storage/Downlink:
  21 scenes/hr. * 16hr/day * 444.6MB = 65.7 GB

• Estimated Monthly Downlink: 1.97 TB

Example of Instrument Analysis for each of 4 options
Strawman 18 Coastal/Lakes Survey Scenes Using FR

Source: GSFC analysis via GUI Editor, assuming spherical Earth – Satellite at 95W
## Instrument Analysis Comparison

<table>
<thead>
<tr>
<th></th>
<th>FR</th>
<th>FR</th>
<th>COEDI</th>
<th>WAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>250m</td>
<td>375m</td>
<td>375m</td>
<td>375m</td>
</tr>
<tr>
<td>Scene Size</td>
<td>512 x 512 km</td>
<td>512 x 512 km</td>
<td>768 x 535.5 km</td>
<td>1536 x 375 km</td>
</tr>
<tr>
<td>Scene Storage</td>
<td>446.6MB</td>
<td>197.5 MB</td>
<td>304.15 MB</td>
<td>434.2 MB</td>
</tr>
<tr>
<td>High Repeat Baseline (30min)</td>
<td>11 scenes</td>
<td>11 scenes</td>
<td>8 scenes</td>
<td>2 scenes</td>
</tr>
<tr>
<td>Threshold (1hr)</td>
<td>22 scenes</td>
<td>22 scenes</td>
<td>17 scenes</td>
<td>4 scenes</td>
</tr>
<tr>
<td>CONUS Coverage</td>
<td>18 scenes</td>
<td>18 scenes</td>
<td>15 scenes</td>
<td>13 scenes</td>
</tr>
<tr>
<td>Data Rate</td>
<td>2.814 MB/s</td>
<td>1.25 MB/s</td>
<td>1.46 MB/s</td>
<td>0.57 MB/s</td>
</tr>
<tr>
<td>Parametric Cost ($M)</td>
<td>$132M</td>
<td>$108M</td>
<td>136.2M</td>
<td>165.2M</td>
</tr>
<tr>
<td>Daily Storage/Downlink</td>
<td>150 GB</td>
<td>65.7 GB</td>
<td>102.2 GB</td>
<td>145.9 GB</td>
</tr>
<tr>
<td>Monthly Downlink</td>
<td>4.5 TB</td>
<td>1.97 TB</td>
<td>3.1 TB</td>
<td>4.38 TB</td>
</tr>
</tbody>
</table>
Clouds

+ Forecasting
+ Sub-Gridding
+ Cloud Detection
+ Onboard Detection Algorithms
Example FR Scene Forecast Schedule

**Red** scenes fail cloud threshold and are not scheduled

**Green** scenes pass cloud threshold and are scheduled

**Orange** scenes are marginal and are scheduled for more evaluation onboard
Two Cloud Thresholds: *Green, Orange*

- **Below Green Threshold**: Cloud Coverage is Acceptable For Science Team, Scene is *Green*

- **Above Orange**: Scene Is Not Even Scheduled On the Ground, Scene is *Red*

- **Between Green And Orange**: Scene Can Be Scheduled, But Will Be Checked On Board. It May Become *Green*

This Allows Higher Threshold Values For Use by Ground Scheduler

After Acquisition, Onboard Cloud Detection Is Used To Check Scene Against *Green* Thresholds. Scenes Can Then Be Accepted or Rejected.

- ~20% Chance to Accept Marginal Scenes and increase Scene Marginal Return
- ~20% Chance to Reject Marginal Scenes and Optimize Data Downlink/Storage

The ~20% acceptance/rejection of marginal scenes is based on studies done for HyspIRI, GEWEX and other analysis listed in the reference backup.
Cloud Forecast Optimization Strategy

**Rationale:** Focus Cloud Forecast on Sub-areas of the Scene (sub-grids)

Forecast is obtained at the center of sub-area of interest (and not on a pixel by pixel basis). This is faster and cheaper.

Scene Forecast is then calculated by averaging the forecasts of sub-areas.
ONBOARD CLOUD DETECTION

Strategy to Resolve Orange (marginal) Scenes using Scene Sub-grids

Rationale: Determine if the orange scheduled scenes were actually within the acceptable green threshold for science quality in order to make decisions about downlinking and rescheduling.

Approach: Evaluate only coastal zone sub-grids (masking out sub-grids over land, for example) and average those results to determine if the green threshold is met; if successful downlink those observations; if too cloudy, delete to reduce downlink costs.
### SPECTRAL BANDS USED FOR CLOUD DETECTION BY OTHER SENSORS COMPARED TO THE BANDS AVAILABLE ON GEO-CAPE

#### Instrument (Spat. Resol.)
- **Landsat-7 (30 m):** 7 Bands
- **Landsat-8 (30 m):** 11 Bands
- **EO1 Hyperion (30 m):** 220 Bands
- **EO1 Multispectral (30 m):** 7 Bands
- **GOES (1 km, 4 km, 2.5 km, 8 km):** 5 Bands
- **MODIS (250m/500m, 1.2km: 3-7,1000nm: 8-36):** 36 Bands

#### GEO-CAPE OPTIONS
- **Roll Cameras (2):** 1 Band/for each camera
- **Filter Radiometer (FR):** 30 Bands

#### Band number | Central wavelength (nm) | Bandwith (nm) | Spatial resolution (m)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>443</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>490</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>560</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>665</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>705</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>740</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>783</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>842</td>
<td>115</td>
<td>10</td>
</tr>
<tr>
<td>8b</td>
<td>865</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>945</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>1380</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>1610</td>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>2190</td>
<td>180</td>
<td>20</td>
</tr>
</tbody>
</table>

**Notes:**
- **Thermal bands distinguish clouds from ice.**
- SWIR band 1375nm (used by EO-1 / Landsat-8 / Sentinel 2) is the most critical to detect high cirrus clouds that contaminate scenes, especially in Coastal Areas.
Scheduling Ops Demo

+ Architecture
+ Strategies
+ KISS
+ Schedule Layout
+ Visualization

http://geocape.herokuapp.com
USER SCENARIO TO SUBMIT NEW REQUESTS

• Science team members are provided user front end GUI to add/remove scenes and edit scene attributes

• They enter scene parameters including location, size, priority, number of collects, cloud coverage thresholds, etc...

• Requests are submitted and can be accepted or rejected by the scheduling system. Every 6 hours the front end assembles the scenes to be imaged, including engineering tasks and activity blackouts, and gathers the cloud forecast for each scene

• The scenes are scheduled based on scene attributes and cloud forecasts. The schedule may be reviewed by the science team and potentially rejected. Scene attributes may have to be tweaked and ingested by the scheduling system to generate a new plan

• Approved schedule is generated and uplinked after science team approval
SCHEDULE LAYOUT CONCEPT

Priorities

2

Special Event

Special Event

1

High Repeat Events

Standard Survey Mode

0

10:30

11:00

11:30

12:00
**SCHEDULE EXAMPLE**

**FR Schedule**

**Based on actual forecast data for June 15, 2015 and cloud threshold criteria per region**
SCHEDULE VISUALIZATION SNAPSHOT
GROUND PROCESSING

- Calibration
- Atmospheric Correction
- Ortho-Rectification
- Co-Registration
- [Vectorization]
- Distribution
### scene_14

<table>
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<tr>
<th>Field</th>
<th>Value</th>
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<tr>
<td>id</td>
<td>913a9c64c24d8d281637df053e3653a20e32fda</td>
</tr>
<tr>
<td>Date</td>
<td>2015-06-16T09:00:00.000Z</td>
</tr>
<tr>
<td>Description</td>
<td>GEOCAPE scene_14</td>
</tr>
<tr>
<td>Status</td>
<td>complete</td>
</tr>
<tr>
<td>Image</td>
<td><img src="image_url" alt="Image" /></td>
</tr>
</tbody>
</table>

**BROWSE SNAPSHOT**

**Full Access to Final Product(s) & MetaData**

**Easy To Share And Distribute to Community of Interest**

**Realtime User Notifications**
Summary:

Key Findings

- GEO-CAPE Observation Operations Simulator developed
- Hosted Payload data handling and potential cost savings examined
- Candidate cloud detection algorithms identified, including value of SWIR band 1375nm
- Feasibility established for
  - Cloud threshold settings and forecast constraints, incorporating marginal scene handling
  - Onboard processing of cloud detection to not downlink marginal observations that fail cloud threshold (reduce data handling costs)
  - Cost of onboard processing capability with 2015 technology

Use GSFC Observation Ops Simulator Tool (http://geocape.herokuapp.com)

- Examine “What If” scenarios incorporating actual cloud forecast data for example/fixed targets
- Characterize instrument scene based on footprint center point to generate target observation requests

Possible Follow-on Activities

- Integrate scheduler with simulator to enable live simulations with dynamic targets (1-2 month)
- Update Simulator tool per user feedback (days to weeks)
- Analyze VNIR Band Study for High Cloud Detection (1-2 months)
- Research Commercial Vendor Communication Capabilities, Cost & API (1-2 months)
“Now is no time to think of what you do not have. Think of what you can do with what there is.”
— Ernest Hemingway

http://geocape.herokuapp.com

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stuart.w.frye@nasa.gov
BACKUP SLIDES
COMMERCIAL DOWNLINK COST (DOD)

This table reflects current DOD prices for Commercial Satellite Access. NASA costs have been assumed to be comparable.

<table>
<thead>
<tr>
<th>Current Satellite Type</th>
<th>AOR</th>
<th>MHz</th>
<th>Mbps</th>
<th>Cost</th>
<th>Cost per MHz</th>
<th>Mbps to MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS-20</td>
<td>Ext Ku</td>
<td>AFG</td>
<td>60</td>
<td>100</td>
<td>$200,000</td>
<td>$3,333</td>
</tr>
<tr>
<td>IS-17</td>
<td>Ku</td>
<td>ME Inroutes</td>
<td>8.1</td>
<td>13.5</td>
<td>$27,000</td>
<td>$3,333</td>
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<tr>
<td>IS-17</td>
<td>Ku</td>
<td>ME Outroutes</td>
<td>24.2</td>
<td>31.5</td>
<td>$63,000</td>
<td>$2,603</td>
</tr>
<tr>
<td>IS-17</td>
<td>C</td>
<td>ME - Oman</td>
<td>36</td>
<td>64</td>
<td>$128,000</td>
<td>$3,556</td>
</tr>
</tbody>
</table>

SATELLITE INTERNET COST (IDIRECT)

Coverage CONUS

Source: http://www.groundcontrol.com/US_Canada_Satellite_Internet.htm

750GB/month, 40 sites $56K/month

$0.14 per MB
# CLOUD DETECTION ALGORITHMS DETAILS

## LANDSAT-7 BANDS USED FOR CLOUD DETECTION

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (Range)</th>
<th>Spatial Resolution (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.52-0.60</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>0.63-0.69</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>0.77-0.90</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>1.55-1.75</td>
<td>30</td>
</tr>
<tr>
<td>6 (Thermal IR)</td>
<td>10.40-12.50</td>
<td>60 (30 after 02/2010)</td>
</tr>
</tbody>
</table>

## Landsat-8 Bands Used for Cloud Detection

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (Range)</th>
<th>Spatial Resolution (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.53 - 0.59</td>
<td>30 m</td>
</tr>
<tr>
<td>4</td>
<td>0.64 – 0.67</td>
<td>30 m</td>
</tr>
<tr>
<td>5</td>
<td>0.85 – 0.88</td>
<td>30 m</td>
</tr>
<tr>
<td>6</td>
<td>1.57 – 1.65</td>
<td>30 m</td>
</tr>
<tr>
<td>9</td>
<td>1.36-1.38</td>
<td>30 m</td>
</tr>
<tr>
<td>10</td>
<td>10.60 – 11.19</td>
<td>100 m * (30 m)</td>
</tr>
<tr>
<td>11</td>
<td>11.50 – 12.51</td>
<td>100 m * (30 m)</td>
</tr>
</tbody>
</table>

* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product.

## EO-1/Hyperion Bands Used for Cloud Detection

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (Central)</th>
<th>Spatial Resolution (in meters)</th>
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</thead>
<tbody>
<tr>
<td>21</td>
<td>0.56</td>
<td>30</td>
</tr>
<tr>
<td>31</td>
<td>0.66</td>
<td>30</td>
</tr>
<tr>
<td>51</td>
<td>0.86</td>
<td>30</td>
</tr>
<tr>
<td>110</td>
<td>1.25</td>
<td>30</td>
</tr>
<tr>
<td>123</td>
<td>1.38</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>1.65</td>
<td>30</td>
</tr>
</tbody>
</table>

## GOES Bands Used for Cloud Detection

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (Range)</th>
<th>Spatial Resolution (in kilometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3.8 – 4.0</td>
<td>4 km</td>
</tr>
<tr>
<td>4</td>
<td>10.2 – 11.2</td>
<td>4 km</td>
</tr>
<tr>
<td>5</td>
<td>11.5 – 12.5</td>
<td>4 km</td>
</tr>
<tr>
<td>6</td>
<td>12.9 – 13.7</td>
<td>4 km</td>
</tr>
</tbody>
</table>

## MODIS Bands Used for Cloud Detection

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (Central)</th>
<th>Spatial Resolution (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.645</td>
<td>250 m</td>
</tr>
<tr>
<td>2</td>
<td>0.858</td>
<td>250 m</td>
</tr>
<tr>
<td>5</td>
<td>1.240</td>
<td>500 m</td>
</tr>
<tr>
<td>6</td>
<td>1.640</td>
<td>500 m</td>
</tr>
<tr>
<td>7</td>
<td>2.130</td>
<td>500 m</td>
</tr>
<tr>
<td>20</td>
<td>3.750</td>
<td>500 m</td>
</tr>
<tr>
<td>31</td>
<td>11.030</td>
<td>500 m</td>
</tr>
<tr>
<td>26</td>
<td>1.375</td>
<td>500 m</td>
</tr>
</tbody>
</table>
REFERENCES (1 of 2)


Doggett et al, Correspondences with Thomas Doggett, January-April, 2008.

Correspondences with Michael K. Griffin, MIT Lincoln Laboratory, August 2010.


Hyperion cloud detection algorithm (General Overview): http://eo1.gsfc.nasa.gov/new/validationReport/Technology/SensorWebs/Final%20Rpt_Appendix_Cloud%20Cover%20Val.ppt


ACCA algorithm (General Overview): http://landsathandbook.gsfc.nasa.gov/pdfs/ACCA_slides.pdf
REFERENCES (2 of 2)


Landsat facts: http://geo.arc.nasa.gov/sge/landsat/l7.html


**References for Cloud Predictions:**


- Empirical experience from EO-1 tasking. Formal simulation may be required to firm up the threshold numbers
GEO-CAPE Ocean STM

Draft v.4.6 - Feb. 28, 2013

Science Focus | Science Questions | Approach | Measurement Requirements | Instrument Requirements | Platform Requirements | Ancillary Data Requirement
---|---|---|---|---|---|---
Short-Term Processes | How do short-term coastal and open ocean processes interact with and influence larger scale physical, biogeochemical and ecosystem dynamics? (OBB 1) | GEO-CAPE will observe coastal regions at sufficient temporal and spatial scales to resolve near-shore processes, lidar coastal fronts, and eddies, and track carbon pools and pollutants. Two complementary operational modes will be employed: (1) survey mode for evaluation of diurnal to interannual variability of constituents, rate measurements and hazards for estuarine and continental shelf and slope regions with linkages to open-ocean processes at appropriate spatial scales, and (2) targeted, high-frequency sampling for observing episodic events including evaluating the effects of diurnal variability on upper ocean constituents, assessing the rates of biological processes and coastal hazards. Measurement objectives for both modes include: (a) quantify dissolved particulate ocean pools and related rate measurements such as export production, air-sea CO2 exchange, net community production, respiration, and photochemical oxidation of dissolved organic matter. (b) quantify phytoplankton properties: biomass, pigments, functional groups (size/taxonomy/Harmful Algal Blooms (HABs)), daily primary productivity using bio-optical models, vertical migration, and chlorophyll fluorescence. (c) measure the inherent optical properties of coastal ecosystems: absorption and scattering of particles, phytoplankton and detritus, CDOM absorption. (d) estimate upper ocean particle characteristics including particle abundance and particle size distribution. (e) detect, quantify and track hazards including HABs and petroleum-derived hydrocarbons. | Water-leaving radiances in the near-UV, visible & NIR for separating absorbing & scattering constituents & chlorophyll fluorescence | Product uncertainty TBD | | Western hemisphere data sets for models, missions, or field observations | Measurement Requirements | (1) Ozone | (2) Total water vapor | (3) Surface wind speed | (4) Surface barometric pressure | (5) Vicarious calibration & validation - coastal | (6) Full prelaunch characterization | (7) Cloud cover

Land-Ocean Exchange | 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? (OBB 1 & 2; CCSP 1 & 3) | | | | | |

Impacts of Climate Change & Human Activity | How are the productivity and biodiversity of coastal ecosystems changing, and how do these changes relate to natural and anthropogenic forcing, including local to regional impacts of climate variability? (OBB 1, 2 & 3; CCSP 1 & 3) | | | | | |

Impacts of Airborne-Derived Fluxes | How do airborne-derived fluxes from precipitation, fog and episodic events such as fires, dust storms & volcanoes affect the ecology and biogeochemistry of coastal and open ocean ecosystems? (OBB 1 & 2; CCSP 1) | | | | | |

Episodic Events & Hazards | How do episodic hazards, contaminant loadings, and alterations of habitats impact the biology and ecology of the coastal zone? (OBB 4) | | | | | |

GEO-CAPE Science Questions are traceable to NASA’s OBB Advanced Planning Document (OBB) and the U.S. Carbon Cycle Science Plan (CCSP). * Coastal coverage within field-of-view (FOV) includes major estuaries and rivers such as Chesapeake Bay, Lake Pontchartrain/Mississippi River delta and the Laurentian Great Lakes, 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).