NASA's Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission

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Acknowledgements: Jay Al-Saadi, GEO-CAPE Ocean Science Working Group, Goddard IDL Team, Dirk Aurin

Outline

- Background on GEO-CAPE
- GEO-CAPE Mission Science
- Scientific Benefits of Geostationary
- Requirements
- Recent Activities
  - Scientific
  - Engineering
- TEMPO
- GOCI-II

GEO-CAPE Mission and Evolution

- **GEO-CAPE mission concept from 2007 Decadal Survey**
  - "Dedicated" NASA geostationary mission for air quality and ocean color
  - Air-quality and ocean color instruments on one satellite
- **An updated mission study was conducted in 2010**
  - With Payload that achieved all GEO-CAPE measurements
  - Estimated cost ~$1.5B => *not affordable*
- **GEO-CAPE stakeholders developed an alternative implementation concept (Fishman et al., BAMS, 2012)**
  - Ocean & atmosphere measurements can be independent
  - Implement mission as 2 or 3 commercially hosted payloads
    - Phased implementation is responsive to budget uncertainties
    - Reduce risk and cost compared to one dedicated mission

GEO-CAPE Science Overview

- Provide first-ever high temporal, spatial, & spectral resolution observations from GEO to resolve the diurnal evolution of North American air quality and ocean color.
  - Ozone, NO_2, aerosol, & precursor observations that are critical for managing air quality & short-lived climate forcers.
  - Address water quality, ocean biogeochemistry, and ecological science questions in coastal waters and their response to climate or environmental variability and change.
- Western Hemisphere contribution to integrated global observing systems for air quality and coastal biogeochemistry.

GEO-CAPE Ocean 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?

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

- 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?

Impacts of Airborne-Derived Fluxes

- 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?

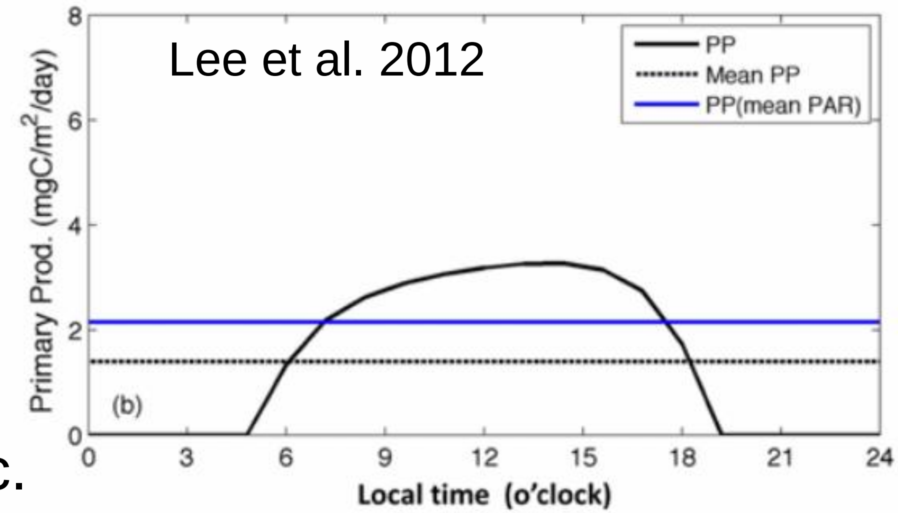
Episodic Events & Hazards

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

Questions are traceable to OBB advance planning document, CCSP, decadal survey.

Scientific Applications of Geostationary OC

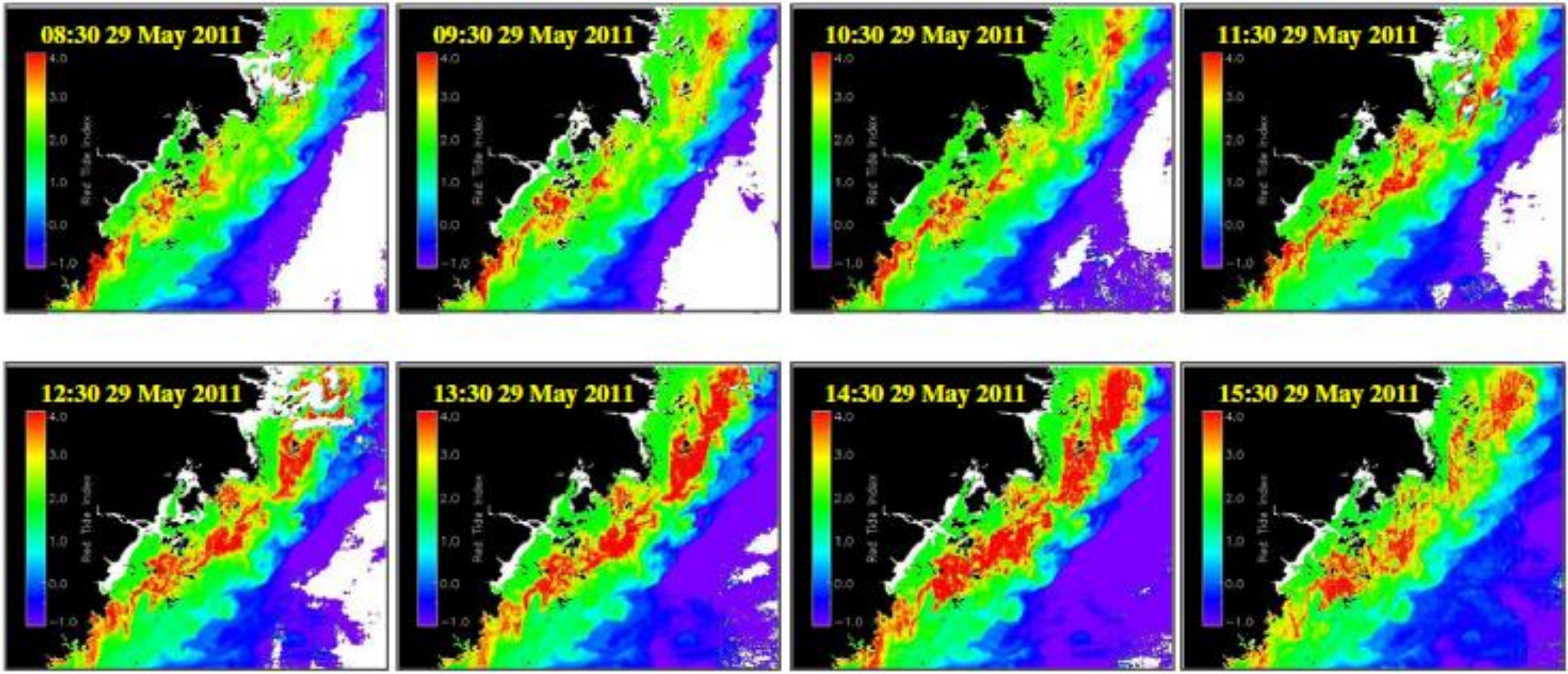
- Track riverine/estuarine plumes, tides, fronts and eddies
- Follow the evolution of phytoplankton blooms (from initial log-phase to post-senescence)
- Reduce uncertainties in primary productivity and other biogeochemical processes



- Quantify surface currents
  - Track sediments, C, pollution, etc.
- Capability for nearly continuous coverage of coastal hazard or other event (*e.g.*, 2010 Deepwater Horizon oil spill)
- High frequency observations to improve coastal models
  - To evaluate biogeochemical model performance
  - Satellite data assimilation to improve model forecasting

Scientific Applications of Geostationary OC

- Improve monitoring and forecasting of harmful algal blooms



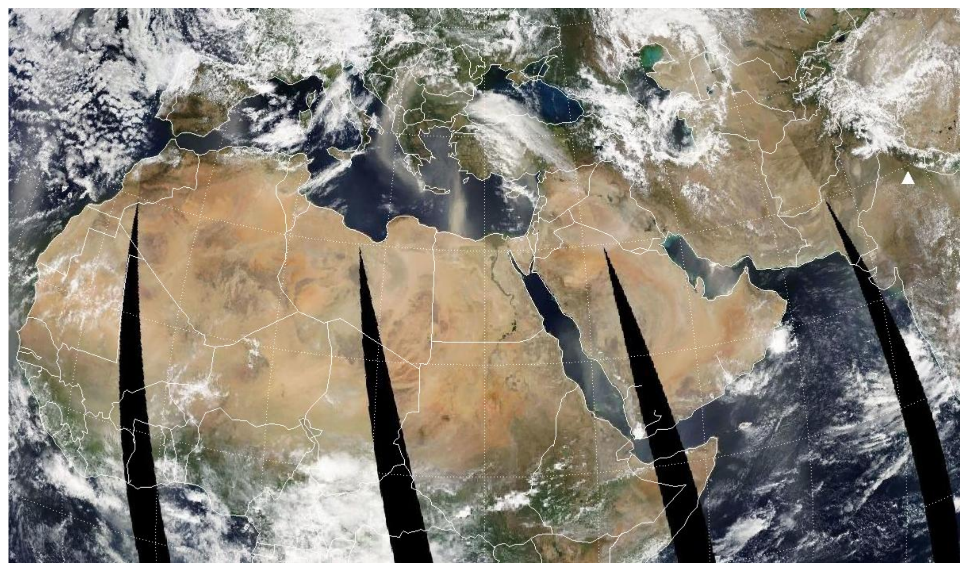
GOCI-observed diurnal changes of HAB *Prorocentrum donghaiense* along the East China's coast.

Lou and Hu (2014)

See presentation by Maria Tzortziou for more details on Applications

Other Benefits of Geostationary

- Capability to increase integration time to boost SNR to capture particular processes or features.
- Greater coverage compared to LEO sensors (except polar regions)
  - Time geo observations to avoid cloud cover that varies diurnally
  - LEO sensors have orbital gaps and high sensor view angles (>60°) every orbit

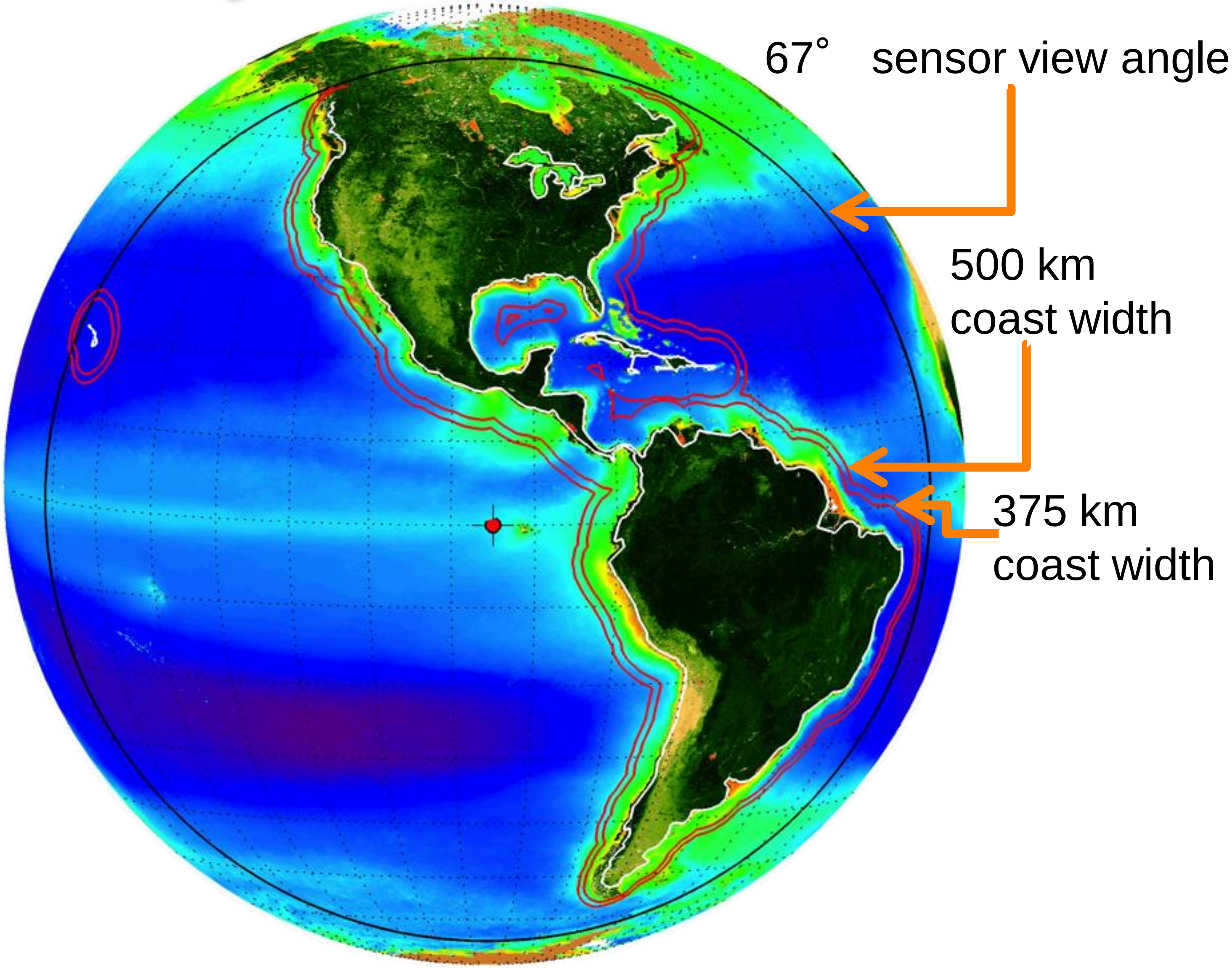


- Constant view angle so native pixel size doesn't change locally
  - MODIS pixels range from $\sim 1\,km^2$ at nadir to $>7\,km^2$ for sensor

Measurement & Instrument Requirements

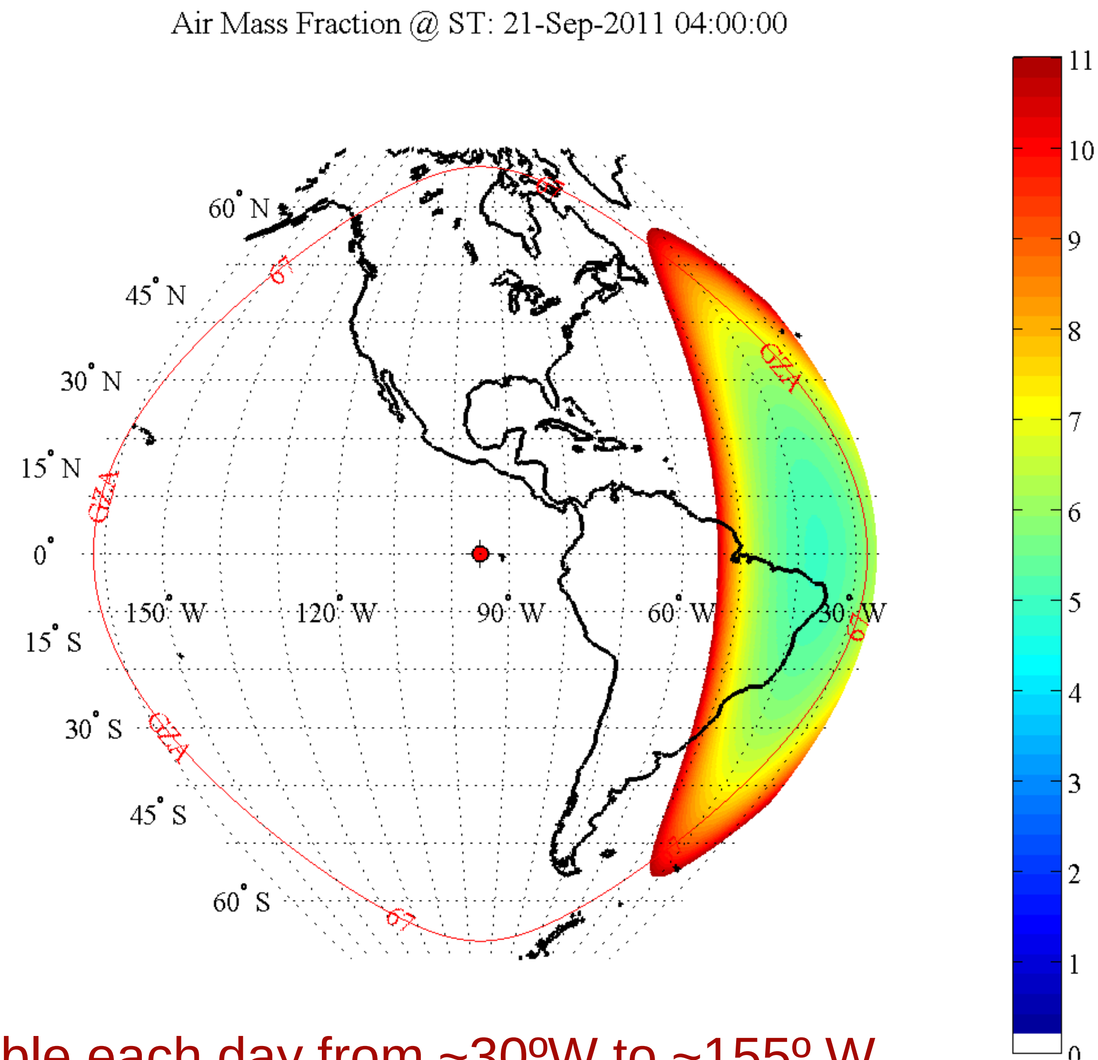
	Threshold (minimum)	Baseline (goal)
Temporal Resolution Targeted Events	**<1 hour**	**<0.5 hour**
Survey Coastal U.S.	**<3 hours**	**<1 hour**
Region of Special Interest	≥1 RSI at 3 scans/day	
Spatial Resolution (nadir)	**375 m x 375 m**	**250 m x 250 m**
Coastal Coverage (coast to ocean)	**375 km**	**500 km**
Spectral Range	**345-1050 nm;** **2 SWIR bands 1245 and 1640 nm**	340-1100 nm; 3 SWIR bands 1245, 1640, 2135 nm
Spectral Resolution	**UV-VIS-NIR: ≤5 nm;** **400-450nm: ≤0.8nm (NO_2);** SWIR: ≤20-40 nm	UV-VIS-NIR: ≤0.75 nm; SWIR: ≤20-50 nm
Signal-to-Noise Ratio (SNR) @ Ltyp for 70° solar zenith angle	**1000:1 for 350-800 nm (10nm FWHM)**; 600:1 for NIR (40nm FWHM); 250:1 & 180:1 for 1245 & 1640 nm (20 & 40nm FWHM); ≥500:1 NO_2	1500:1 (350-800 nm); 100:1 for 2135nm (50nm FWHM); NIR, SWIR and NO_2 same as threshold
Pointing Stability	<50% of pixel size	<10% of pixel size

Geostationary view from 95° W



• Within AMF ≤ 5, where atmospheric correction is feasible, coverage extends to ~60º latitude in summer and ~50º in winter and from ~30ºW to ~155º W (at equator).

Air Mass Fraction at Equinox for 95°W



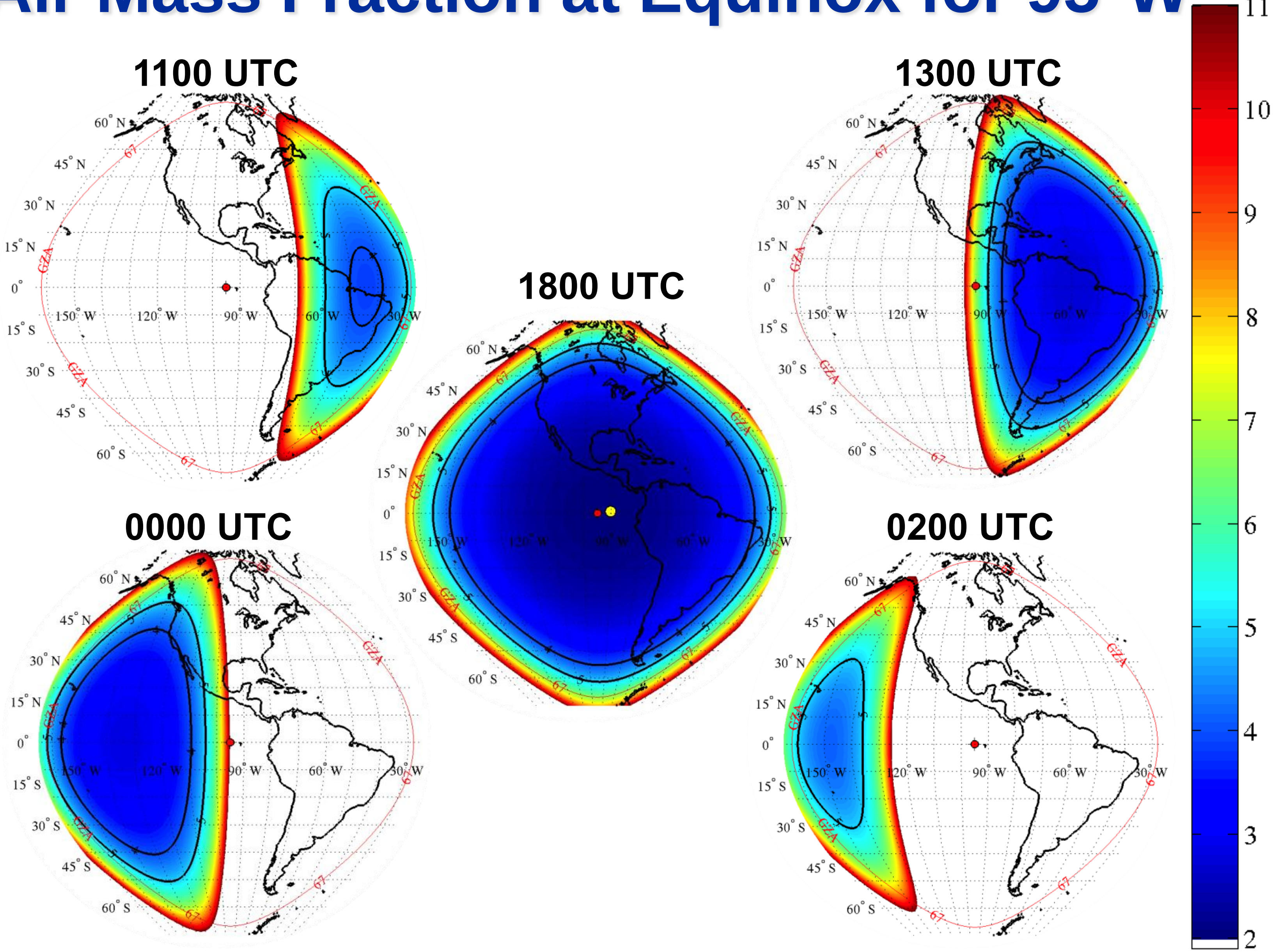
- Scan Atlantic coastal & deep ocean waters in early morning

- Scan Pacific coastal & deep ocean waters in late afternoon

~16 hours of scan time available each day from ~30ºW to ~155º W.

- GEO-CAPE in combination with S-GLI, OLCI & PACE could provide multiple observations per day over open ocean and improve rate measurements (PP).

Air Mass Fraction at Equinox for 95°W



• GEO-CAPE in combination with S-GLI, OLCI & PACE could provide multiple observations per day over open ocean and improve rate measurements (PP).

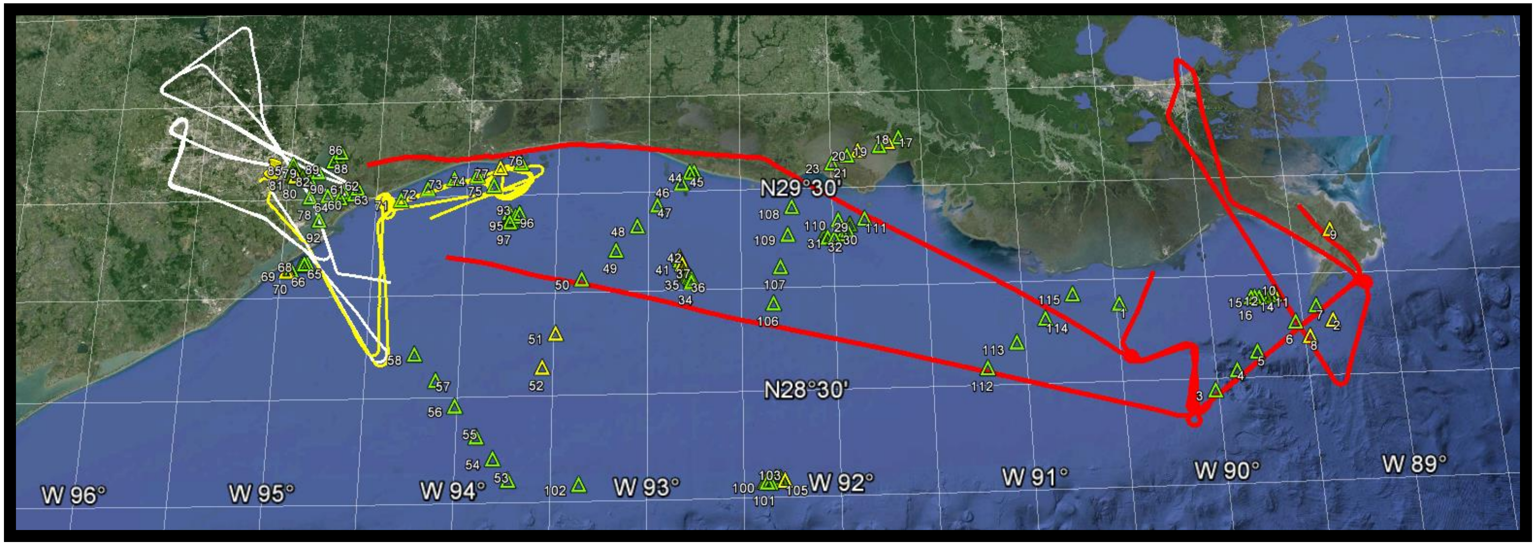
Science Studies

- Various science studies supported annually
- Chesapeake Bay field campaign in July 2011 (CBODAQ)
  - 10-days of aquatic and atmospheric sampling and measurements from a small research vessel
  - coordinated with DISCOVER-AQ
- Northern Gulf of Mexico field campaign in September 2013
  - in coordination with DISCOVER-AQ (EV-S on air quality)
- Science Value Matrix under development
  - Link science prioritization to cost to assign a value to the science

http://geo-cape.larc.nasa.gov/

Gulf of Mexico Campaign in Sept. 2013

- Transects along gradients - address spatial variability
- Tracking water masses (follow instrumented drogue)
  - diurnal evolution of biology & biogeochemistry
- Small boat operations (more optically complex waters)
- Diurnal ship-based sampling ~every 90 minutes
- Continuous underway IOPs
- Complete datasets: aquatic radiometry, C, nutrients, IOPs, NPP, GPP, respiration, & algal taxonomy plus atmospheric measurements: aerosol properties and trace gases properties



Lines represent flight paths by airborne sensors

Consistent with Requirements

- **Temporal resolution:** <3 hr frequency needed; <1-2 hr desirable
- **Spatial resolution:** <500x500m (local) needed; 250x250m desirable
- **Spectral resolution** of 0.8 nm (sampling of 0.4 nm) would be required, at least in the 400-450 nm spectrum, for NO_2 correction.
- Retrieval of aerosol properties (SSA and aerosol layer height) critical for nLw retrievals.
    - Detection (& correction) of absorbing aerosols necessary
- *If uncorrected, atmospheric variability (aerosols,* NO_2*, etc.) will lead to a false estimate of time-dependent underwater processes.*

- **Need for *in situ* data sets** with high temporal resolution (15-30 min) & spectral resolution (2-5nm) and range (up to 750nm); above water *Rrs* to 1670nm.

Applications Traceability Matrix

Agency	Applications	Satellite products	Spatial requirements	Temporal requirements
NOAA	Habitat assessment, fisheries management water quality, HABS, ecological forecasting, pollution monitoring, coral health, acidification	Chlorophyll, Rrs(λ), abs(λ), HABs, K_{490}, K_{PAR}	100m – 4km	3hrs - daily
EPA	Sustainable coastal resources; air, climate and energy research; healthy and sustainable coastal communities	Chlorophyll, Rrs(λ), abs(λ), abs(cdom, phy, det), HABs, SPM, K_{490}, K_{PAR} and more	<250m – 500m	0.5 hrs – 3hrs
US Navy	Surface currents, instrument assessments, bathymetry, visibility, coastal oceanography, navigation	Chlorophyll, Rrs(λ), abs(λ), abs(cdom, phy, det), bbp(λ), HABs, SPM, K_{490}, K_{PAR} currents, etc.	250m – 1km	1hr - daily
Gulf of Mexico Fishery Management Council	Habitat quality, fisheries conservation, coral conservation	Chlorophyll, NPP, currents	Not specified	Not specified
BOEM	Ecological models, sediment transport, current trajectory, oil detection and thickness	Chlorophyll, NPP, currents, cdom, SPM	Not specified	Not specified

Engineering Studies - Ocean Color

- January 2010 - Instrument Design Study (CEDI)
- 2011 - Instrument pointing line-of-sight study
  - Existing hardware and processes capable of supporting science data products down to ~1km GSD
  - Benefit to vibration isolation from the host spacecraft
  - Host spacecraft roll about the nadir axis is a significant source of instrument pointing errors
- 2013-2014 - continuing pointing analysis studies
- Summer 2014 - Ball completes a 3-yr NASA Instrument Incubator project for a multi-slit spectrometer
- January-August 2014 - Sensor capability versus cost instrument design study

Sensor Capability versus Cost Study

GEO-CAPE Ocean Sensor Requirement	Filter Radiometer (*e.g.*, GOCI)	Wide-Angle Spectrometer 8K detector array	Multi-Slit Spectrometer	Single-slit spectrometer
Spatial GSD at nadir	T = 375 m B = 250 m	D = 500 m T = 375 m B = 250 m	D = 500 m T = 375 m B = 250 m	D = 500 m T = 375 m
Spectral range[1] D = 350-900 nm T = 340-1050 nm	Multi-spectral[2] 16 or more bands	Hyperspectral D or T	Hyperspectral D or T	Hyperspectral D or T
SWIR Bands D = 1640 nm T = 1245, 1640 nm B = 1245, 1640, 2135nm	0, 1 (D) or 2 (T) bands	1 (D), 2 (T) or 3 (B) bands	1 (D), 2 (T) or 3 (B) bands	1 (D) or 2 (T) bands
UV/Vis/NIR Spectral Sampling/Resolution	D = 10 nm	T = 2/5 nm B = 0.4/0.8 nm	T = 2/5 nm B = 0.4/0.8 nm	T = 2/5 nm B = 0.4/0.8 nm

T = Threshold requirements from STM (but not including the NO_2 requirements)
B = Baseline Requirements from STM (includes the NO_2 requirements)
D = Descope option
[1] SNR >1000 for UV-Vis (at 10nm FWHM)
[2] Multispectral: ~MERIS bands plus 360, 385 & 1020 nm. SWIR additional.

Preliminary Results for Capability vs Cost

- Cost drivers from most costly to least costly:
  Spatial resolution > spectral resolution > SWIR bands
- 2D frame capture (“filter radiometers”) multi-spectral sensors are least costly
- Wide-angle (8K detector array) and multi-slit spectrometers are moderate cost
- Single-slit (1K to 2K detector array) spectrometers most costly

Preliminary Results for Capability vs Cost

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- Single-slit (1K to 2K detector array) spectrometers most costly

What's Next:

- Optical design for 16+ band multi-spectral and hyperspectral wide-angle spectrometer (WAS).
- 2-week Instrument Design Lab studies - on two concepts from COEDI, multispectral or WAS
  - NICM sub-system and parametric costing

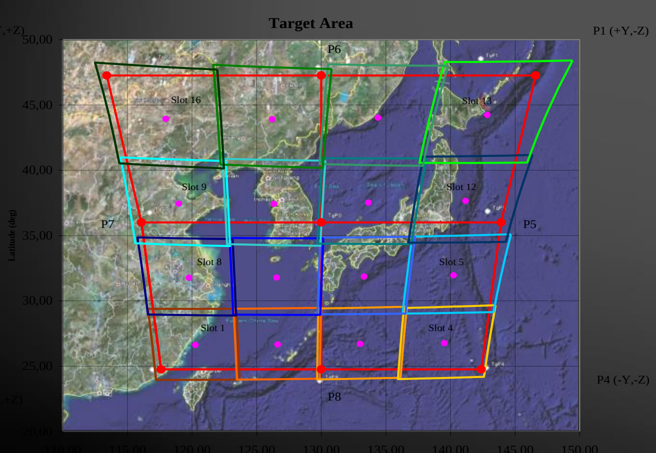
What does TEMPO mean for GEO-CAPE?

- TEMPO selected Nov. 2012 as NASA's first Earth Venture Instrument - provides hourly atmospheric pollution from geo
- TEMPO will provide a significant part of the GEO-CAPE atmospheric measurement: launch ~2019
- Remains to be seen whether TEMPO will be a GEO-CAPE precursor, or the initial component of GEO-CAPE
- TEMPO will demonstrate the use of commercially-hosted payloads to accomplish Earth science, hopefully enabling affordable earlier implementation of a complete GEO-CAPE mission
  - Full suite of simultaneous atmospheric measurements
  - Coastal ocean ecosystem science mission

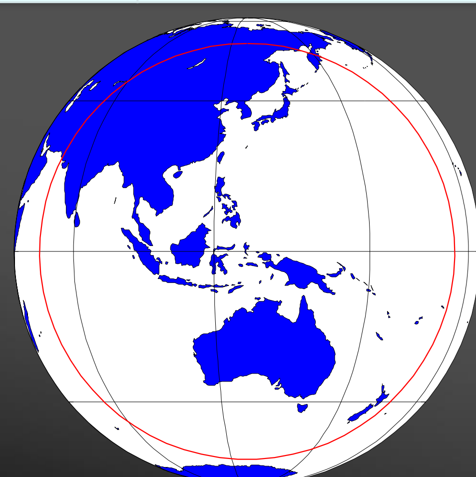
GOCI-II

	GOCI	GOCI-II
Band Number	8 bands	**12+1 bands**
Local Spatial Resolution	500m	**250m**
Observations	8 times/ day	**10 times/ day**
Coverage	Local Area	**Local Area + Full Disk**

Band	Band Center	Bandwidth
1	380 nm	20 nm
2	412 nm	20 nm
3	443 nm	20 nm
4	490 nm	20 nm
5	510 nm	20 nm
6	555 nm	20 nm
7	620 nm	20 nm
8	660 nm	20 nm
9	680 nm	10 nm
10	709 nm	10 nm
11	745 nm	20 nm
12	865 nm	40 nm
13	PAN	515 nm



LA (Reference Local Area)



FD (Red Circle)

Material courtesy of Young-Je Park

GeoKompsat-2B : GOCI-II & GEMS - 2018 launch

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Backup

GEO-CAPE Oceans STM

Draft v.4.6 - Feb. 28, 2013

Science Focus

- **Short-Term Processes**
- **Land-Ocean Exchange**
- **Impacts of Climate Change & Human Activity**
- **Impacts of Airborne-Derived Fluxes**
- **Episodic Events & Hazards**

Science Questions

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

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? (OBB 1 & 2; CCSP 1 & 3)

3 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)

4 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)

5 How do episodic hazards, contaminant loadings, and alterations of habitats impact the biology and ecology of the coastal zone? (OBB 4)

Approach (Maps to Science Question)

GEO-CAPE will observe coastal regions at sufficient temporal and spatial scales to resolve near-shore processes, tides, 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. [Maps to: 1, 2, 3, 4; 1, 2, 4, 5]

Measurement objectives for both modes include:

(a) Quantify dissolved and particulate carbon pools and related rate measurements such as export production, air-sea CO2 exchange, net community production, respiration, and photochemical oxidation of dissolved organic matter. [Maps to: 1, 2, 3]

(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. [Maps to: 1, 2, 3, 4, 5]

(c) Measure the inherent optical properties of coastal ecosystems: absorption and scattering of particles phytoplankton and detritus, CDOM absorption. [Maps to: 1, 2, 3, 4]

(d) Estimate upper ocean particle characteristics including particle abundance and particle size distribution. [Maps to: 5; 1, 2, 3]

(e) Detect, quantify and track hazards including HABs and petroleum-derived hydrocarbons. [Maps to: 5]

GEO-CAPE observations will be integrated 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, [Maps to: 2, 3]

(2) to quantify the responses of coastal ecosystems and biogeochemical cycles to river discharge, land use change, airborne-derived fluxes, hazards and climate change, and [Maps to: 1, 2, 3, 4, 5]

(3) to enhance management decisions with improved information on the coastal ocean, such as required for Integrated Ecosystem Assessment (IEA), protection of water quality, and mitigation of harmful algal blooms, oxygen minimum zones, and ocean acidification. [Maps to: 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
- Baseline: ≤0.5 hour

Survey Coastal U.S.:
- Threshold: ≤3 hours
- Baseline: ≤1 hour

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

Other coastal and large inland bodies of water within ocean color FOR:
- Baseline: ≤3 hours

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

Field of Regard for Ocean Color Retrievals:
60°N to 60°S;
155°W to 35°W

Coastal Coverage*:
width from coast to ocean:
- Threshold: min 375 km
- Baseline: min 500 km

Scanning Priority:
•Threshold:
1. U.S. Coastal Waters* 3 to 8 times per day
2. Other coastal and large inland bodies of water
3. Open ocean waters within FOR

Instrument Requirements

Spectral Range:
Hyperspectral UV-VIS-NIR
- Threshold: 345-1050 nm; 2 SWIR bands 1245 & 1640 nm
- Baseline: 340-1100 nm; 3 SWIR bands 1245, 1640, 2135 nm

•Spectral Sampling & Resolution:
- Threshold: UV-Vis-NIR: ≤2 & ≤5nm; 400-450nm: ≤0.4 & ≤0.8nm (for NO_2 at spatial resolution of 750x750m at nadir); SWIR resolution: ≤20-40 nm
- Baseline: UV-ViS-NIR: ≤0.25 & 0.75 nm; SWIR: ≤20-50 nm

Signal-to-Noise Ratio (SNR) at Ltyp(70˚ SZA):
- Threshold: ≥1000 for 10 nm FWHM (350-800 nm); ≥600 for 40 nm FWHM (800-900 nm); ≥300 for 40 nm FWHM (900-1050 nm); ≥250 and ≥180 for 1245 & 1640 nm (20 & 40 nm FWHM); ≥500 NO_2 band.
- Baseline: ≥1500 for 10 nm (350-800 nm); NIR, SWIR and NO_2 bands same as threshold; ≥100 for the 2135nm (50nm FWHM)
- Threshold: Aggregate SWIR bands to 2x2 GSD pixels to meet SNR; Baseline: No aggregation.

Scanning area per unit time: Threshold: ≥25,000 km²/min; Baseline: ≥50,000 km²/min

Field of Regard:
- Full disk: 20.8° E-W and 19° N-S imaging capability from nadir for Lunar & Solar Calibrations

Error (as % of nadir pixel)	Threshol	Baselin
Pointing Knowledge LOS	<50%	<10%
Pointing Accuracy LOS	<100%	<25%
Pointing Stability LOS	<50%	<10%
Geolocation Reconstr.	<100%	<10%

Non-saturating detector array(s) at Lmax

On-board Calibration:
- Lunar: Threshold: minimum monthly; Baseline: same as threshold
- Solar: Threshold: none; Baseline: daily

Polarization Sensitivity: <1.0%

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

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

Intelligent Payload Module Baseline only: Near Real-Time satellite data download from other sensors (GOES, etc.) for on-board autonomous decision making.

Pre-launch characterization: Adequate to achieve the required on-orbit radiometric precision

Platform Requirem.

Geostationary orbit at 95W longitude to permit sub-hourly observations of coastal waters adjacent to the continental U.S., North, Central and South America

Storage (up to 1 day) 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) Vicarious calibration & validation - coastal
(6) Full prelaunch characterization
(7) Cloud cover

Science Requirements
(1) SST
(2) SSH
(3) PAR
(4) UV solar irradiance
(5) MLD
(6) Air/Sea pCO2
(7) pH
(8) Ocean circulation
(9) Tidal & other coastal currents
(10) Aerosol deposition
(11) run-off loading in coastal zone
(12) Wet deposition in coastal zone
(13) Wave height & surface wind speed

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.

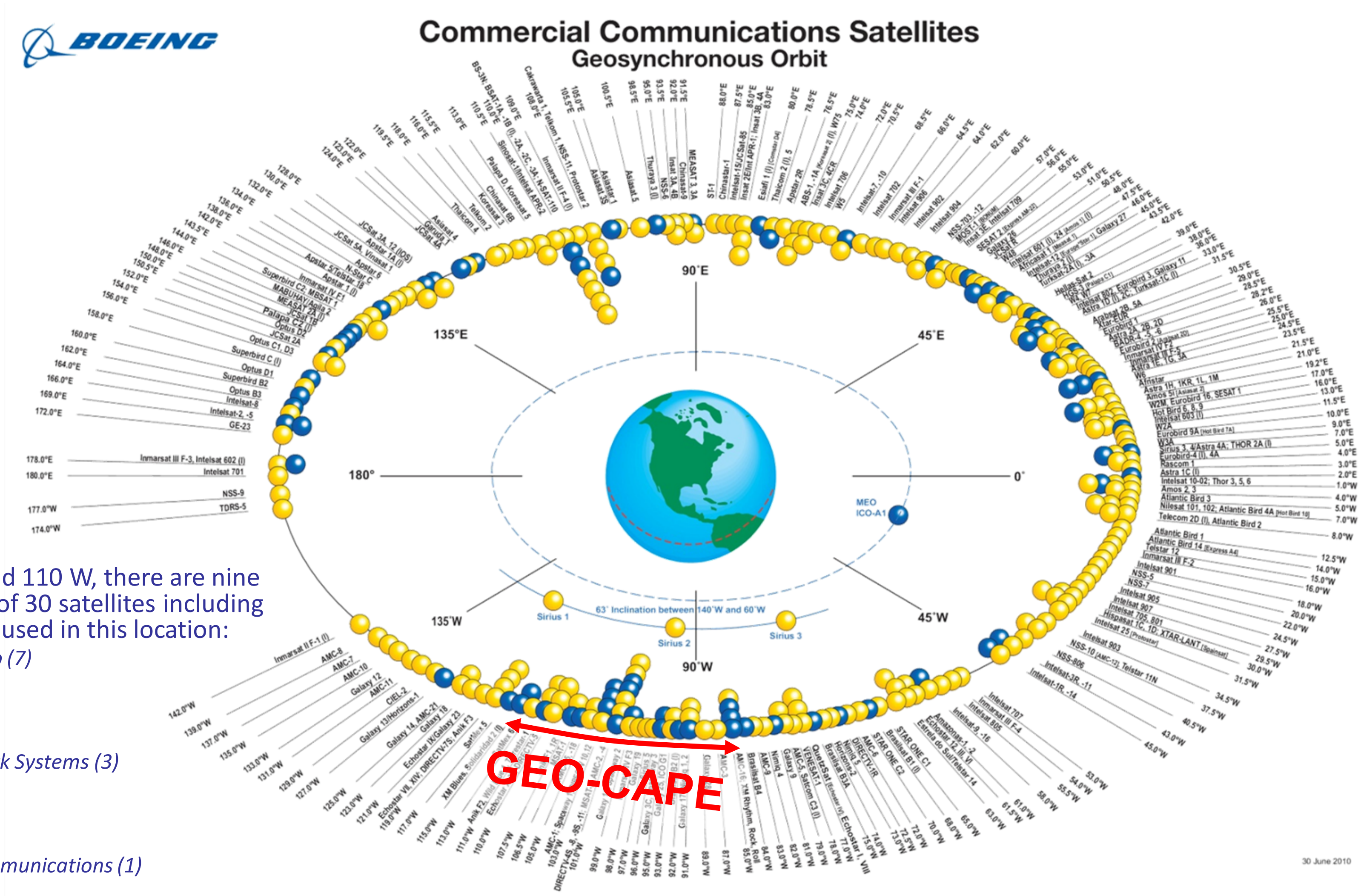
GEO-CAPE Science Questions are traceable to NASA's OBB Advanced Planning Document (OBB) and the U.S. Carbon Cycle Science Plan (CCSP).

* 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).

Recent International Activities

- Substantial discussions between KOSC and NASA Goddard
  - GOCI and GOCI-II PI meeting - Jan. 2012
  - KOSC delegation visit to Goddard - Aug. 2012
  - KOSC delegation participation at GEO-CAPE Workshop at NASA Ames - May 2013
  - KOSC personnel visit to Goddard - Jan. 2014
  - Franz and Mannino participation in GOCI PI meeting - April 2014
- Discussion on international geostationary ocean color collaboration at GEO-CAPE Workshop - May 2013
- Splinter session on geo ocean color at International Ocean Color Science Meeting (May 2013)

Geostationary Orbit Opportunities



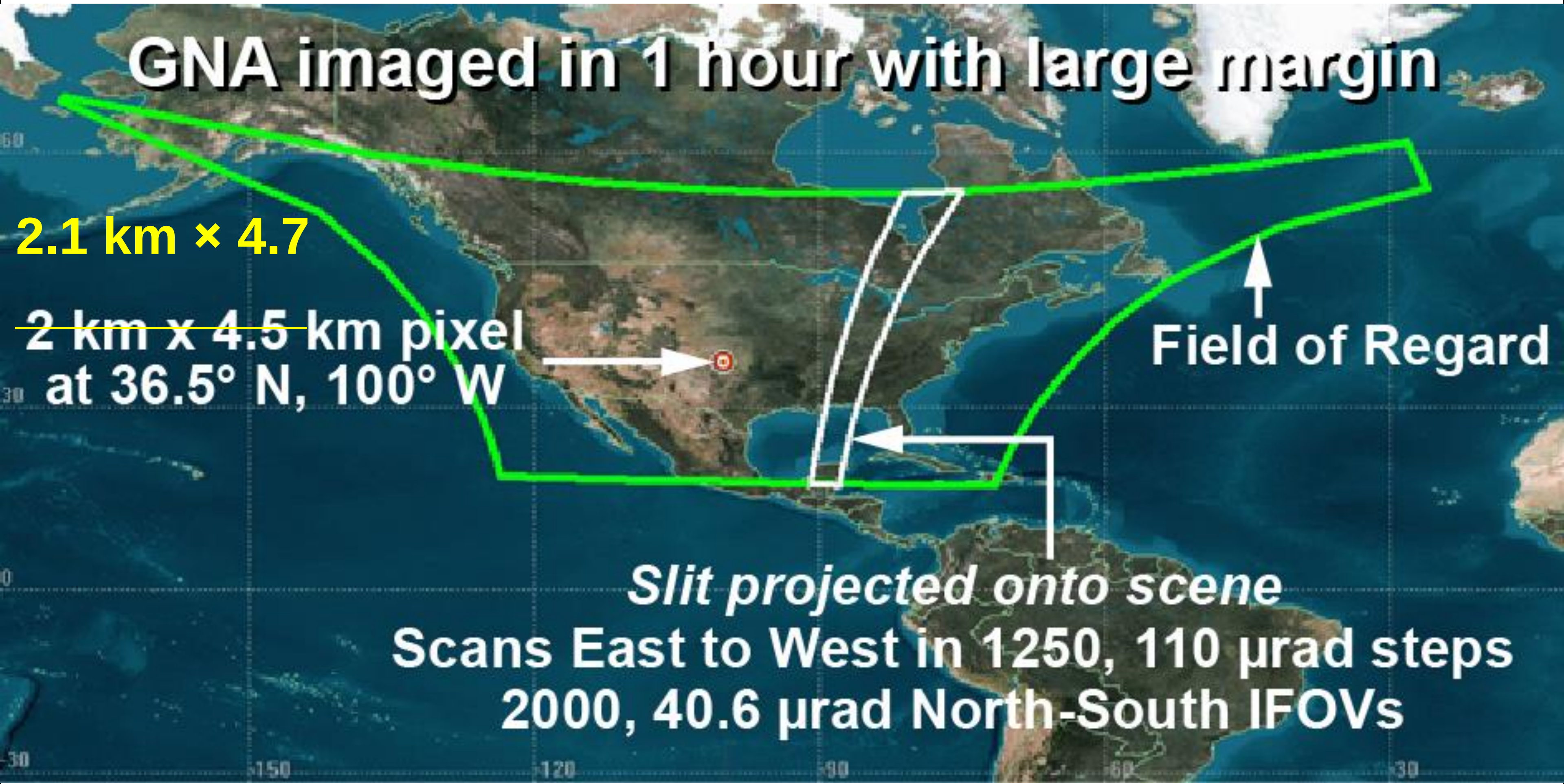
Between 90 W and 110 W, there are nine owner operators of 30 satellites including older models still used in this location:

- *Direct TV Group (7)*
- *AGS (5)*
- *Intelsat (5)*
- *Telesat (4)*
- *Hughes Network Systems (3)*
- *Echostar (2)*
- *SkyTerra (2)*
- *Inmarsat (1)*
- *ICO Global Communications (1)*

As older satellites are replaced there will be many hosted payload opportunities in the orbit locations most useful for GEO-CAPE observations

TEMPO - Tropospheric Emissions: Monitoring of Pollution

- TEMPO selected Nov. 2012 as NASA's first Earth Venture Instrument - provides hourly atmospheric pollution from geo



Each 2.1 km × 4.7 km pixel is a 2K element spectrum from 290-740 nm
GEO platform selected by NASA for viewing Greater North America