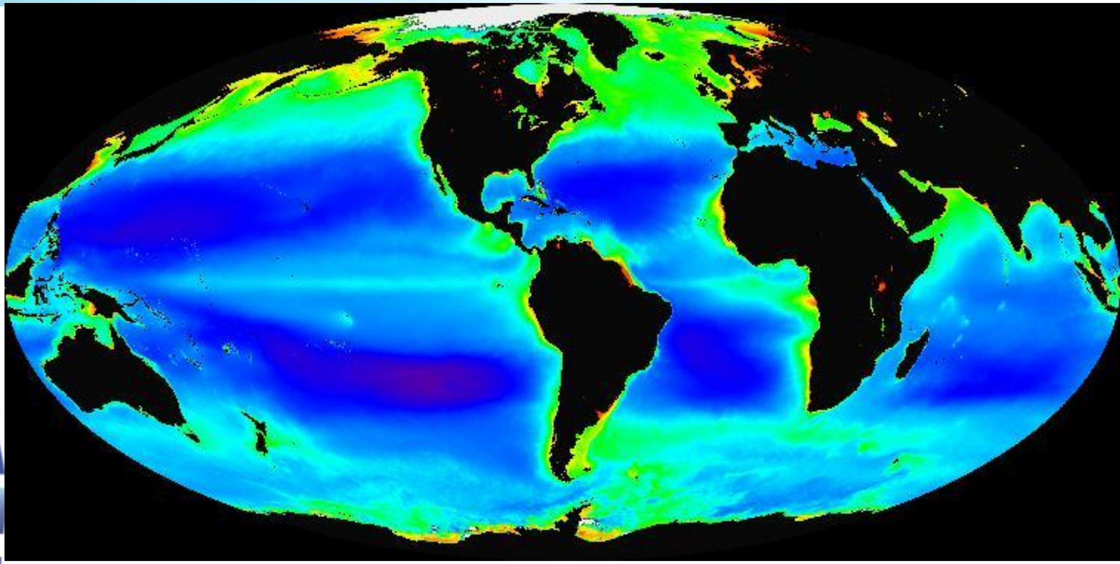


Understanding the Living Oceans from space

Pre-Aerosol, Clouds, & ocean Ecosystem

HySPiRI Meeting
June 3, 2015

Deputy Project Scientist: **Antonio Mannino**
Ocean Ecology Lab
NASA GSFC

Acknowledgements: Andre Dress, Jeremy Werdell & Carlos Del Castillo

PACE Fact Sheet

Organization

- Directed Mission to GSFC

Mission Elements

- Ocean Color Instrument:
  - In House Build
- Polarimeter Instrument:
  - JPL Provided
  - Contributed
  - Procured
- Spacecraft:
  - Procurement
  - In-House Build

Science Goals

- The PACE mission will make global ocean color measurements for ocean ecology and global biogeochemistry along with polarimetry measurements on clouds and aerosols:
  - **Primary:** Understand and quantify global biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change
  - **Secondary:** Understand and resolve/quantify the role of aerosols and clouds in physical climate

Mission Overview

- Pre-Phase A
- Design to Cost Mission
- $805M cost-cap for the mission
- Class C Mission
- 97° inclination; ~650 km altitude; sun sync
- Launch 2022 – 2023
- 3 years Phase E

Pre-Phase A Schedule

- TBD

PACE Pre-Phase A Project Organization Chart

Project Manager
Andre Dress
Deputy Project Manager
Kathy McIntyre
Deputy Project Manager Resources
Bill Sluder

Project Scientist
Jeremy Werdell
Deputy Project Scientist (Ocean)
Antonio Mannino
Deputy Project Scientist (Atmosphere)
Brian Cairns

Support Staff
Administration - Vacant
Plan/Sch – Bill Paradis
Config. Mgmt.– Vacant

Financial Manager
Marsha Gosselin

Contract Officers
Vacant

Observatory Manager
Beth Weinstein

Mission CSO
John Rauscher

Technical Authority Reporting

Ocean Color Instrument (OCI) Project Manager
Robby Estep
OCI Deputy Project Manager
Mike Hill & Phuc Nguyen

Mission System Engineer
Peter Spidaliere
Deputy MSE
Leslie Hartz

Polarimeter Instrument Manager
Tom Dixon

Mission Operations & Ground Operations Manager
Robert Schweiss

Concept Studies

OCI Studies
Robby Estep

Polarimeter Studies Lead
Tom Dixon

Spacecraft Studies in House Lead
Beth Weinstein

Spacecraft Studies out of House Lead
Beth Weinstein

Launch Vehicle Studies Lead
Kathy McIntyre

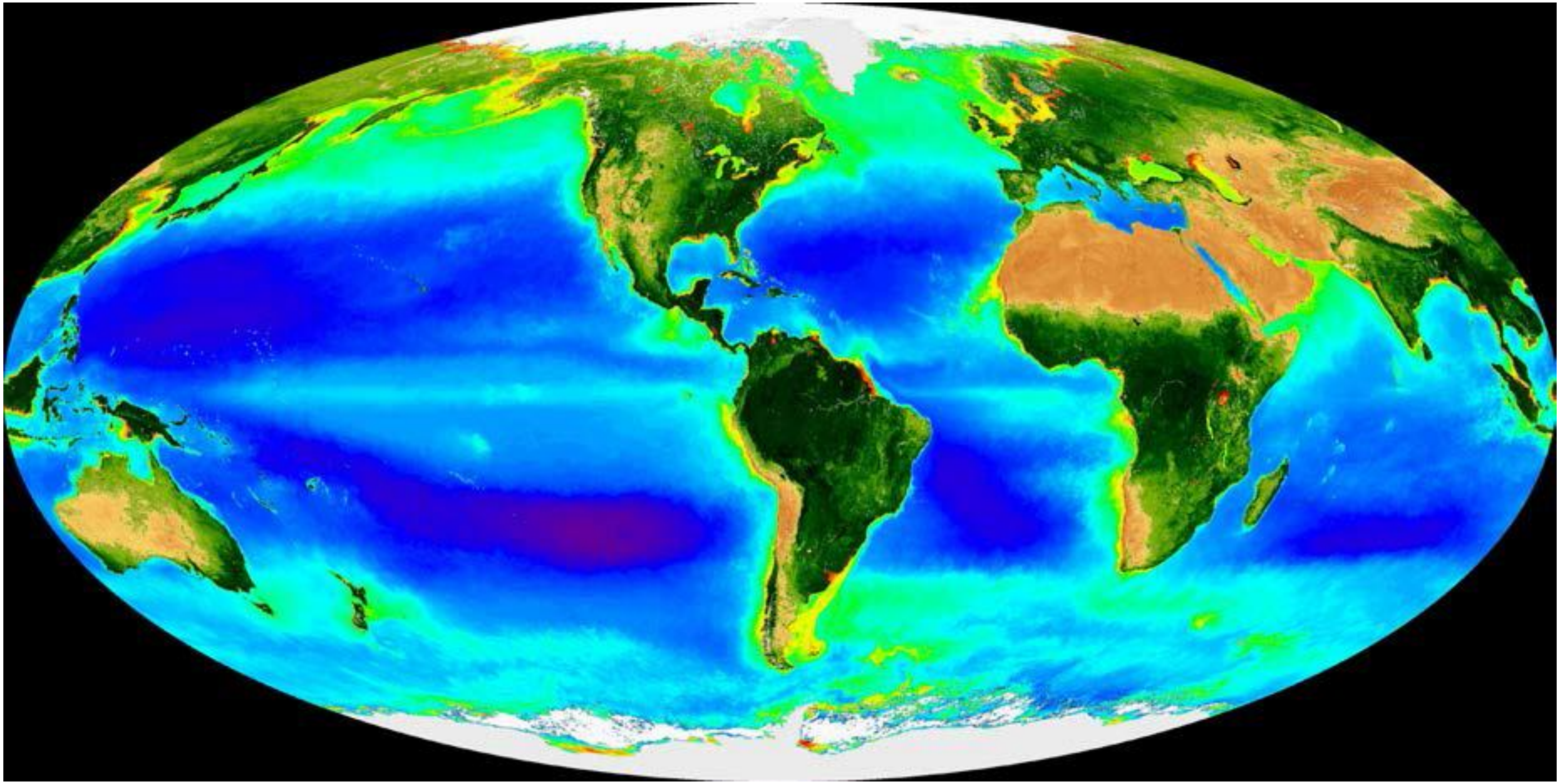
OPS & Ground Studies Lead
Robert Schweiss

Architecture & Requirements Studies Lead
Pete Spidaliere

Cost Capped Mission

- Cap is $805M and includes the following:
  - Project team at GSFC
  - Spacecraft bus
  - Launch vehicle
  - Instrument payload
  - 3 years of mission operations
  - Mission Science
    - Calibration/validation (hardware & execution)
    - Science team support (pre- & post launch)
    - Data processing/analysis to be performed by GSFC's Ocean Biology Processing Group (OBPG)

Ocean Color – Main Science Objective

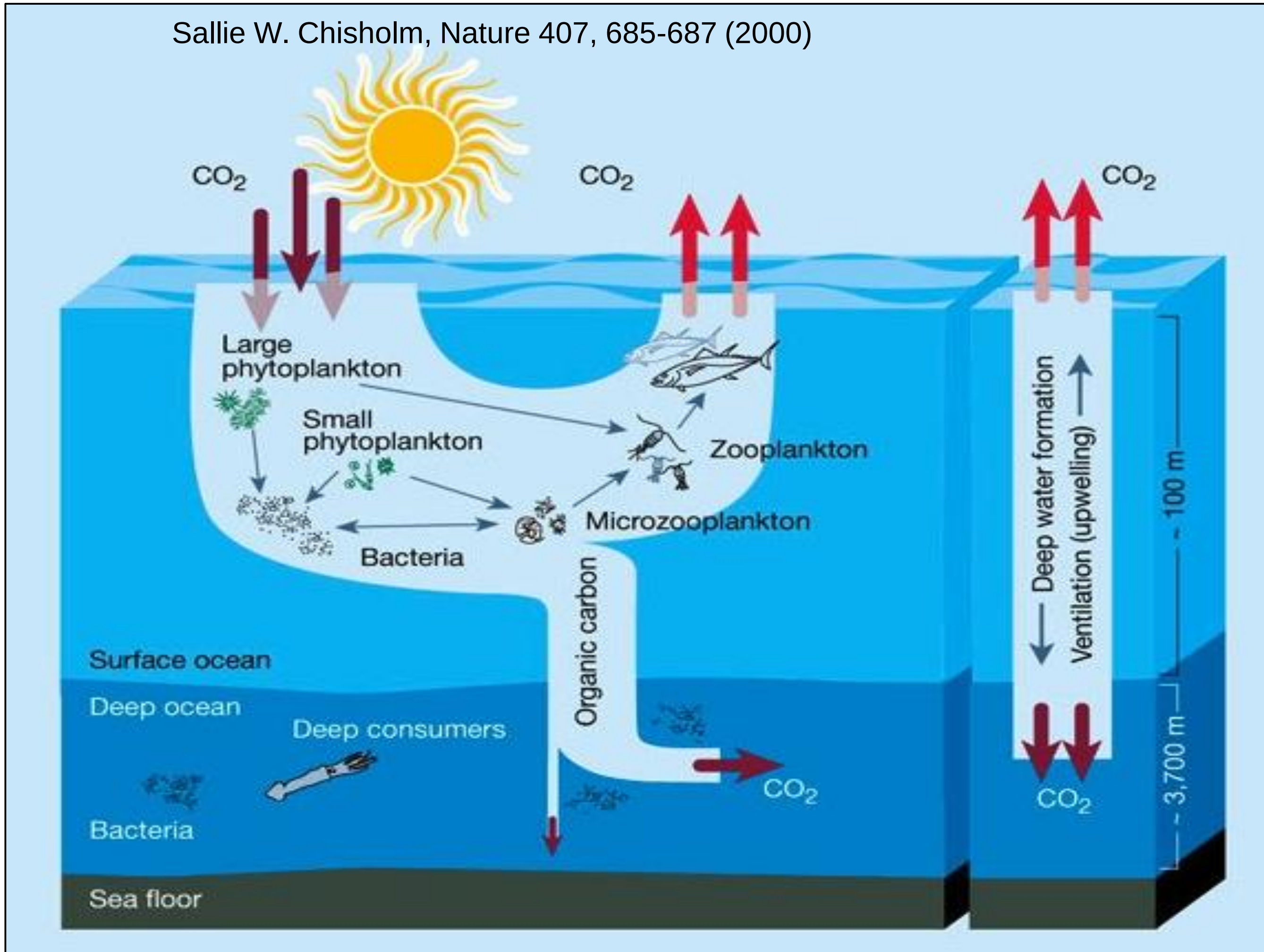


WHY are ecosystems changing, **WHO** within an ecosystem are driving change, **WHAT** are the consequences & **HOW** will the future ocean look?

Sea-Viewing Wide Field of View Sensor (SeaWiFS) image from http://oceancolor.gsfc.nasa.gov/

Phytoplankton & our changing climate

phytoplankton productivity = ~50 Pg C/yr (~half of global PP)



PACE OCI Requirements & Trade Studies

Threshold Requirements

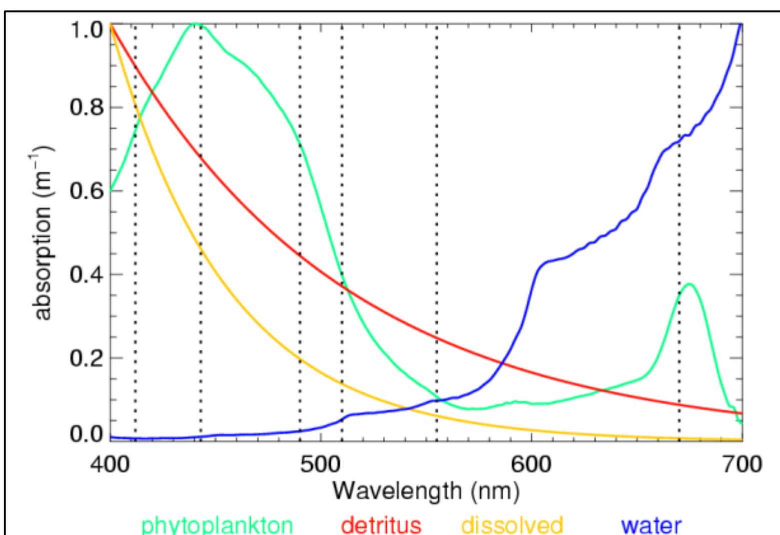
- 1 km^2 spatial resolution
- 2-day global coverage
- Orbit w/ equatorial crossing near local noon
- Hyperspectral open ocean water-leaving reflectances for 350-800 nm at 5 nm resolution
- 2 NIR, 4 SWIR and a 350 nm band for atmospheric correction
- Monthly lunar calibration
- Image striping <0.5%
- AOD and fraction of visible OD by fine mode aerosol over dark water
- cloud top pressure, water path, optical thickness & effective radius

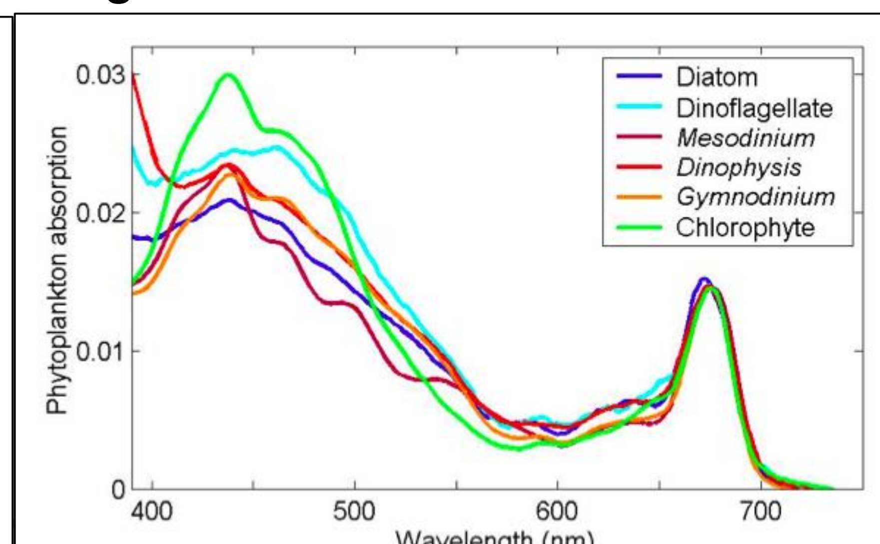
Trade Studies for OCI

- Global sensor
    - Red edge spectral sub-sampling (5nm bands at 1-2nm intervals)
    - 250 to 500m spatial resolution
    - Hyperspectral <350 nm & to 900 nm
    - Spectral resolution <5 nm
- Coastal sensor
    - 100 to 250m spatial multi- or hyperspectral
    - 350-900 nm spectral range
    - 10 to 20 nm bandwidth

PACE will improve our understanding of ocean ecosystems and carbon cycling through its…

- <u>Spectral Resolution</u> – 5 nm resolution to characterize phytoplankton communities & nutrient stressors
- <u>Hyperspectral and Spectral Range</u> – UV to NIR covers key ocean spectral features and for separation of ocean constituents
- <u>Atmospheric Corrections</u> – UV bands allow ‘spectral anchoring‘, SWIR for turbid coastal systems. A *<u>polarimeter</u> option for advanced aerosol and cloud characterization.*
- <u>Strict Data Quality Requirements</u> – Reliable detection of temporal trends and assessments of ecological rates



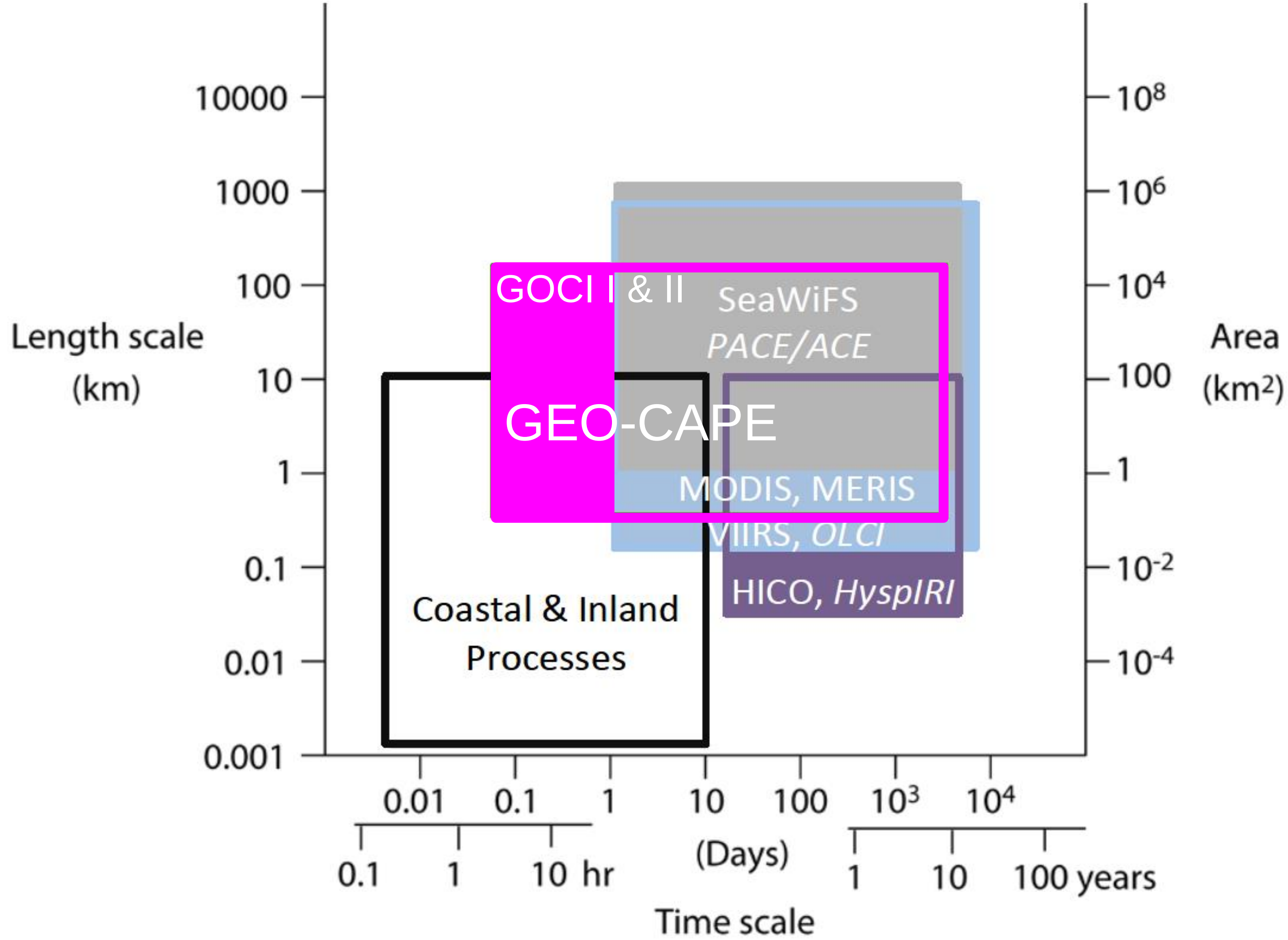


PACE - end-to-end mission concept

- A mission architecture that includes
  - continuous post-launch calibration
    - solar & lunar calibration
    - vicarious calibration (field-based)
  - algorithm development and maintenance
  - field validation
    - measurement collections at sea
    - AERONET-ocean color
    - measurement protocol activities
  - proven science data system
    - SeaWiFS, MODIS, VIIRS, Aquarius

Ocean color comprises up to ~10% of the top-of-atmosphere radiances, hence the rigor required in pre-launch characterization and post-launch calibrations along with field validation and algorithm development activities.

Time & Space Scales of OC Relevant Missions



from Mouw et al. 2015, Remote Sens. Environ

NASA’s GEO-CAPE Mission

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Ocean Ecology Laboratory
NASA Goddard Space Flight Center

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

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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.

GEO-CAPE Status

- **Currently in pre-formulation (pre-Phase A)**
  - No launch date (post-2023)
  - ***Current estimated cost of ocean color mission: <$500M***
  - Science & engineering studies to continue in FY15 & FY16
  - TEMPO - geostationary atmospheric chemistry mission selected under Earth Venture Instrument
    - Launch date ~2018-2019
    - Global geo constellation for atm. chemistry enabled with Korean GEMS and European Sentinel 3 missions.
- **Continuing collaboration with Korean GOCI team**
  - GOCI - 1st and only geo ocean color sensor
  - GOCI processing within SeaDAS 7 enabled
  - Distribution of GOCI L1 and NASA standard products awaiting Korean ministry approval (NASA USPI award)

GEO-CAPE Activities

- **Upcoming Workshops**
  - GEO-CAPE Aug. 31-Sept. 2, 2015 (Triangle Park, NC)
  - Data Synthesis workshop Sept. 2-3, 2015
- **Field Campaigns**
  - Chesapeake Bay - July 2011 (CBODAQ)
  - Gulf of Mexico - September 2013 (GoMEX)
  - Korean coastal waters - May-June 2016 (KORUS-OC)
    - 14-day oceanographic campaign to be coordinated with KORUS-AQ
- **Recent Instrument Design Studies**
  - FY14 Instrument Cost vs Capability study
  - FY15 Functional 50-band filter wheel study

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

1. 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 & Envir. Change on Productivity & Biodiversity

2. 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

3. 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

4. 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.

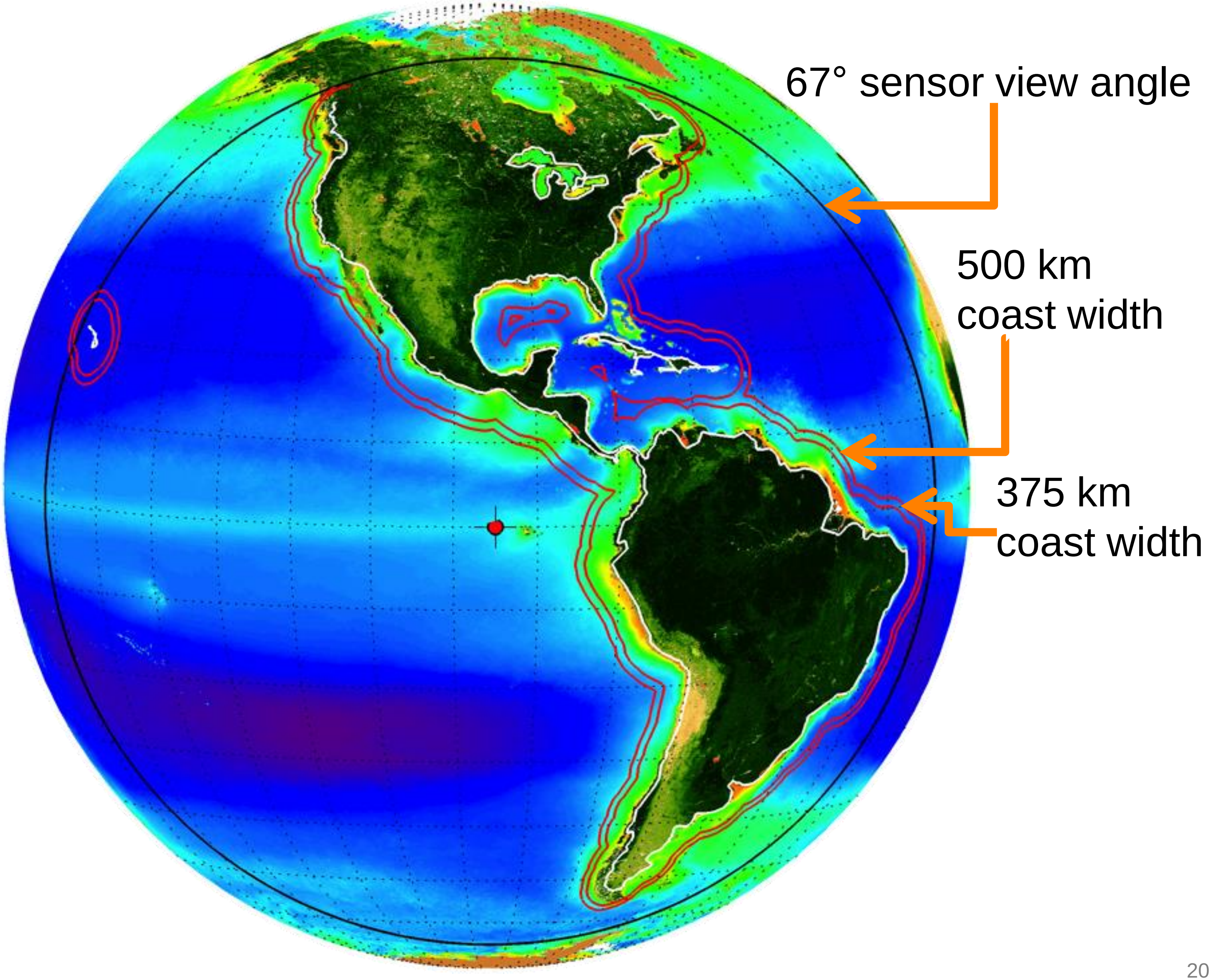
Science Applications of Geo OC

- 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

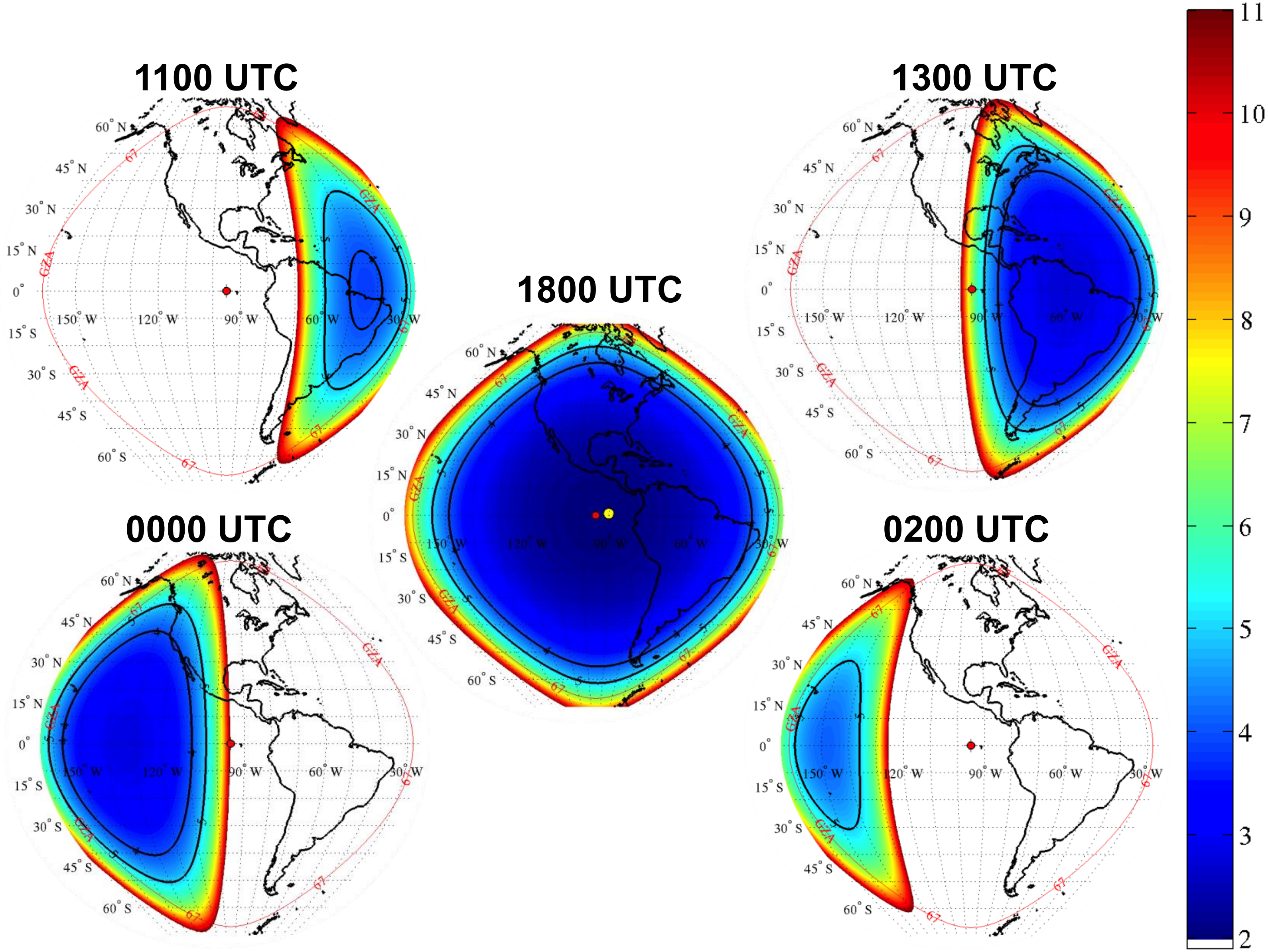
Requirements

	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 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 for 350-800 (10 nm FWHM); 100:1 for 2135nm (50nm FWHM); NIR, SWIR and NO_2 same as threshold
Coastal Coverage	375 km width	500 km width

Geostationary view from 95°W



Diurnal Coverage from 95°W



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

How can we use GEO-CAPE for terrestrial ecology and other aquatic applications?

antonio.mannino@nasa.gov

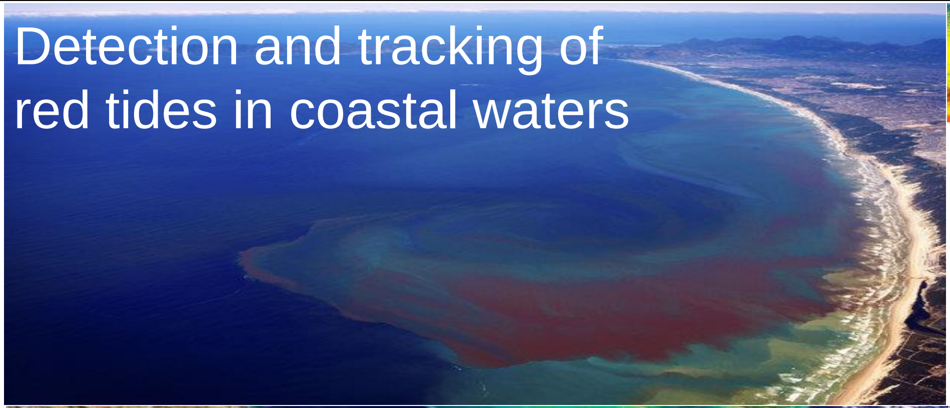
BACKUP

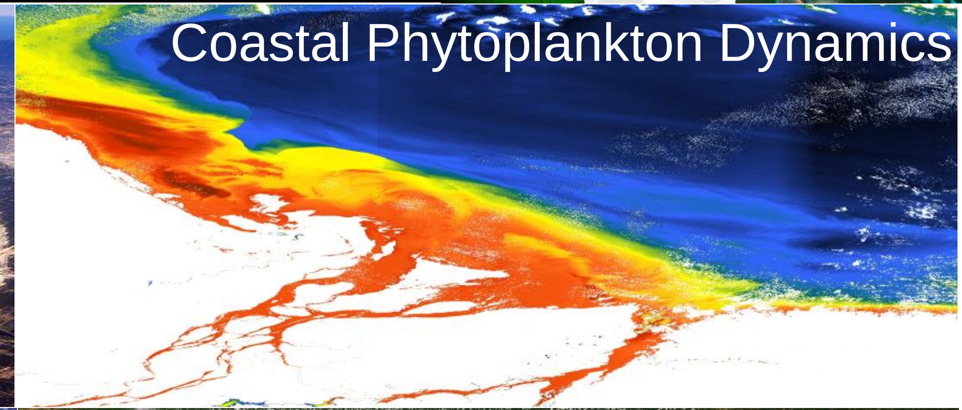
Instrument Capability vs Cost

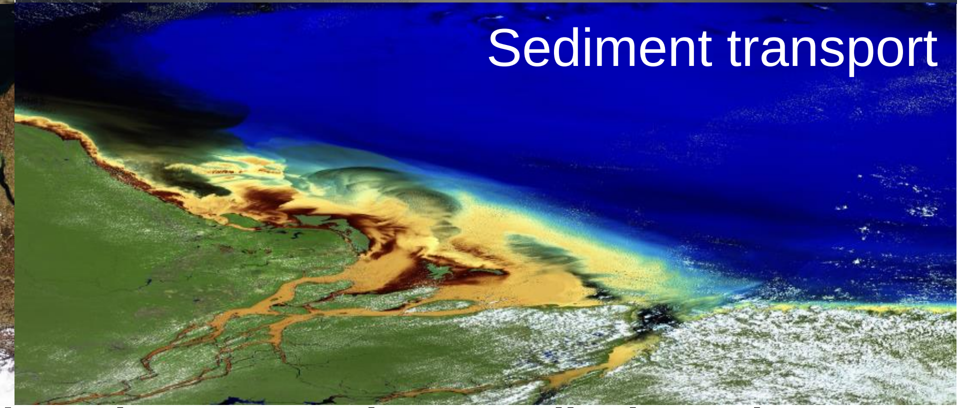
GEO-CAPE
Air quality & Ocean color from space

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)	Multispectral (50) 340-1050; 1245, 1640, 2135	Multispectral (50) 340-1050; 1245, 1640, 2135	340-1050; 1245, 1640, 2135 nm	340-1050 1245,1640 nm	340-1050 1245,1640 nm
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**	**$200.1**
NICM Sub-System Cost ($M)	**$128.7**		**$179.3**		

Geostationary view from 95°W

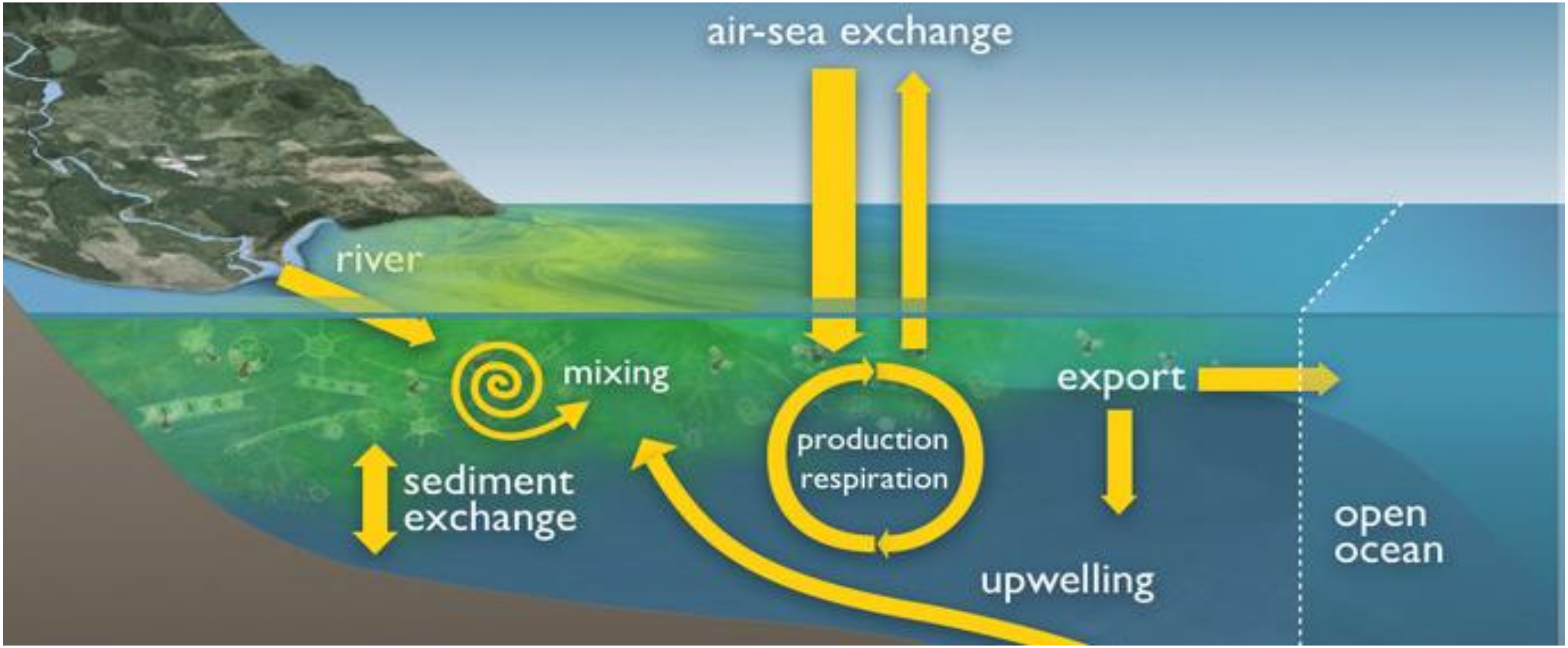






Link data to models and decision-support tools and processes (e.g., predict hypoxic regions, fisheries mngmt, ocean acidification, water-quality forecasting)

GEO-CAPE Applications Objectives in Coastal Areas



- 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 C 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.

Feasibility of Geo OC mission

- Mature instrument technologies (no tall poles)
  - GOCI 4-yr in orbit; GOCI-II launch in 2019
  - Several GEO-CAPE instrument design studies
- Instrument costs and capabilities understood
- Hosted payload on commercial com-sat constrains mission costs

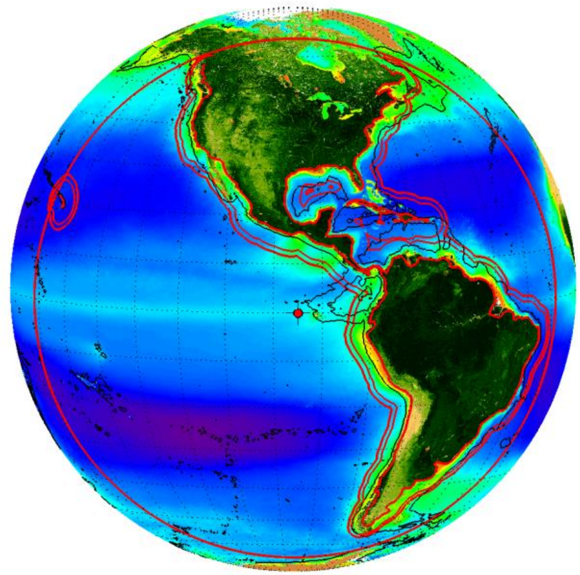
Instrument:	$150M
Project Mngmt, S&E, SMA, GS:	$50M
Host fees (launch, I&T, data):	$80M
Science & Applications:	$100M
Reserves (25%):	$95M
TOTAL:	**$475M**

- Earth Venture possibility (e.g. TEMPO)

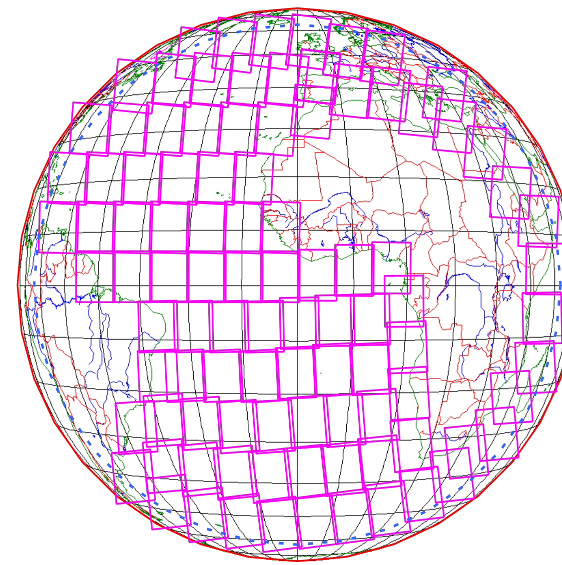
Feasibility of Geo OC mission

- Other nations planning Geo ocean color missions: Korea (follow-on), Europe & India.

GOCI-II 2019



GEO-CAPE

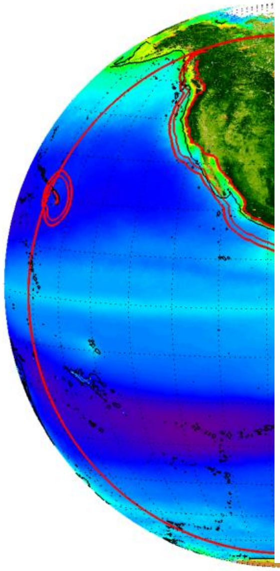


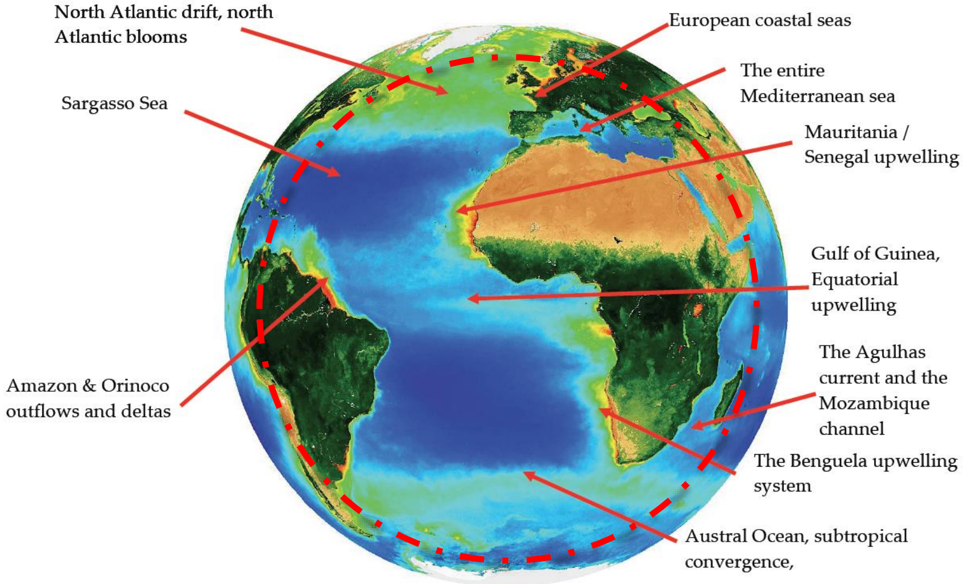
Geo-OCAPI

- Harmonization through constellation promotes consistent global assessment of coastal ecosystems and carbon fluxes.
- Synergies with PACE: improve global productivity measurements, on-orbit cross-calibration, joint cal/val activities, etc.

Feasibility of Geo OC mission

- Other nations planning Geo ocean color missions: Korea (follow-on), Europe & India.

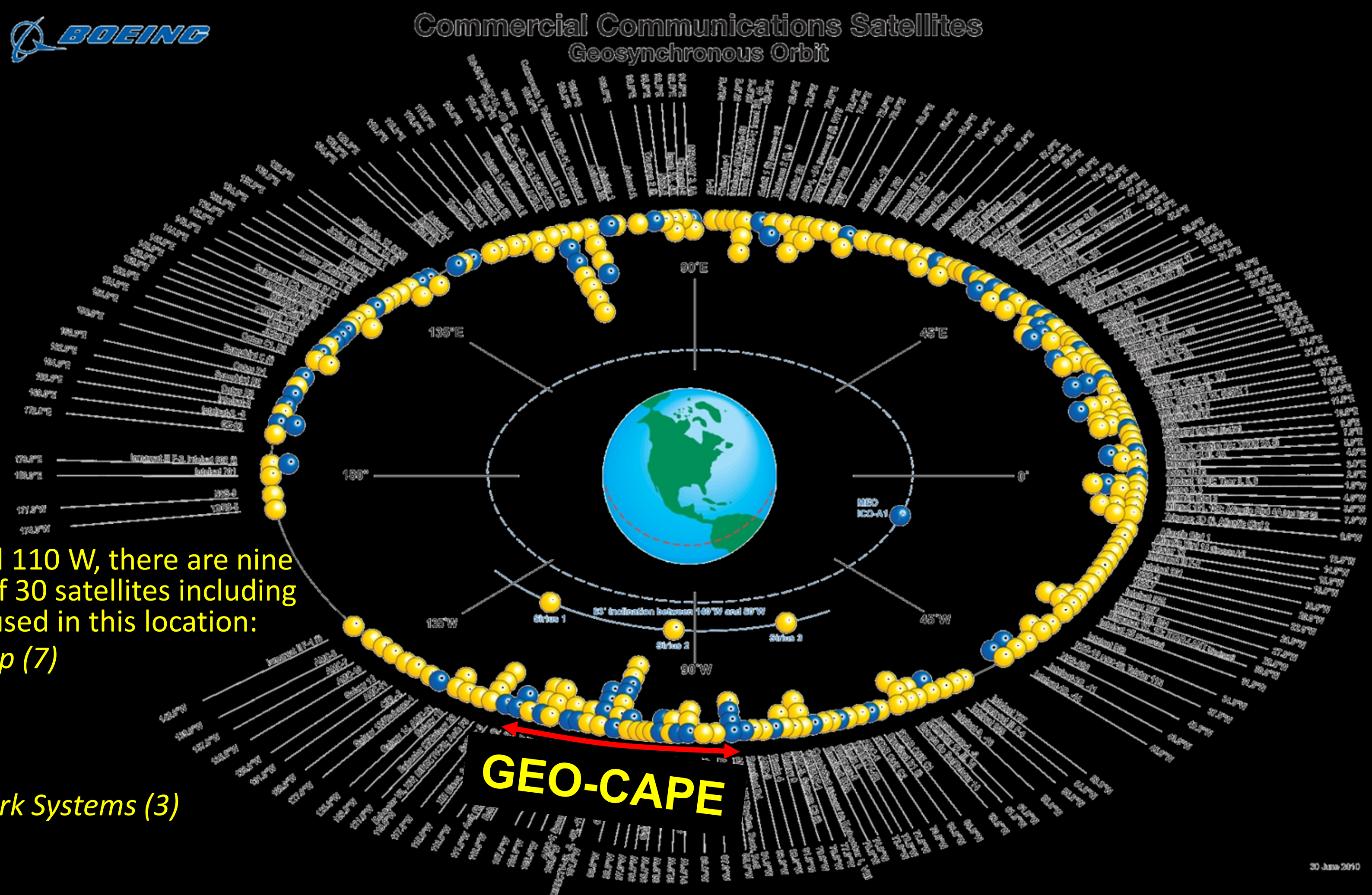




GOCI-II 2019 **GEO-CAPE** **Geo-OCAPI**

- Harmonization through constellation promotes consistent global assessment of coastal ecosystems and carbon fluxes.
- Synergies with PACE: improve global productivity measurements, on-orbit cross-calibration, joint cal/val activities, etc.

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)*
- *ICO Global Communications (1)*
- *Inmarsat (1)*

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