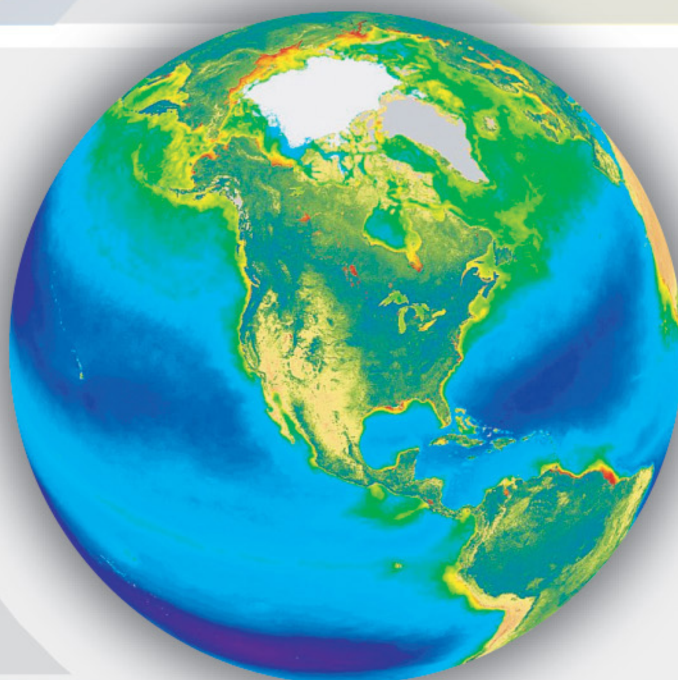
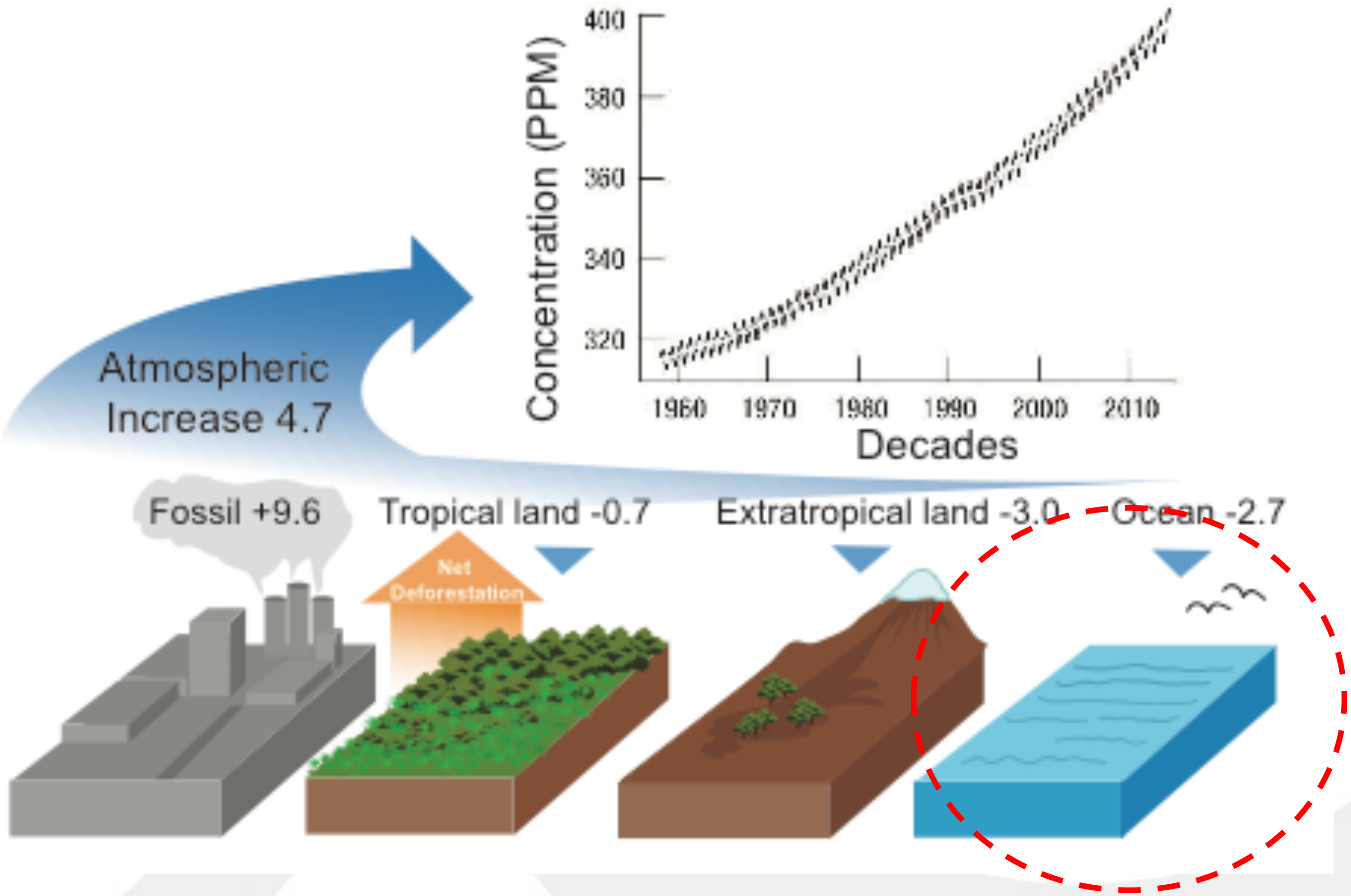
Flux towers in the sky: global ecology from space



US CLIVAR Summit (August 6-8, 2019)

The global carbon cycle

Human forcing, land and ocean uptake
A challenge to all modes of remote sensing



Aquatic satellite mission timeline

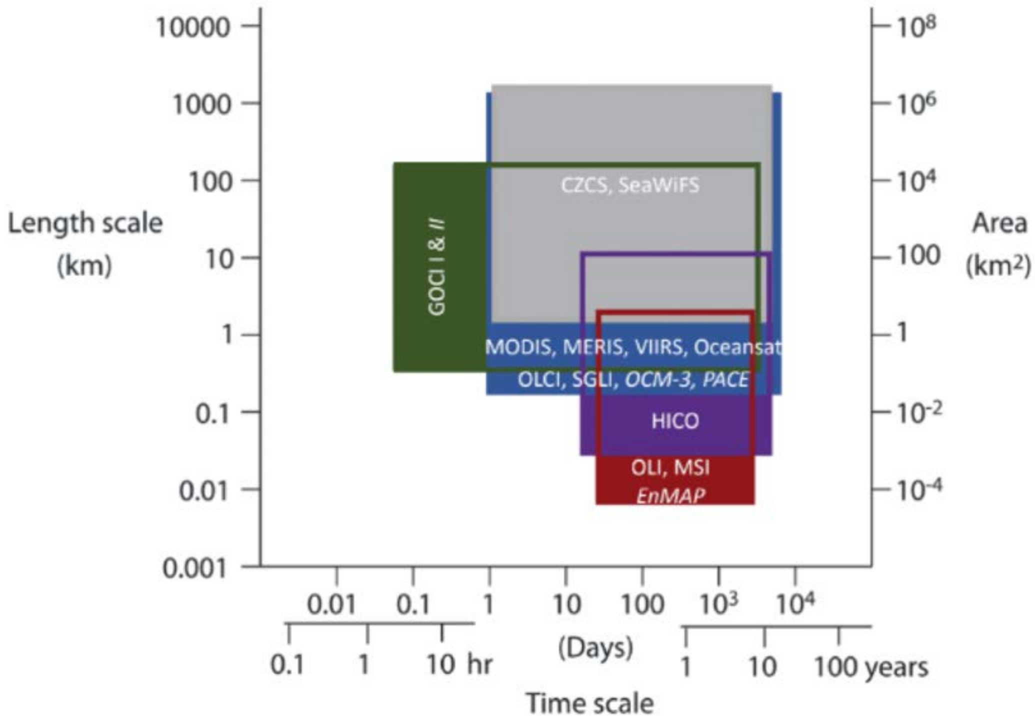
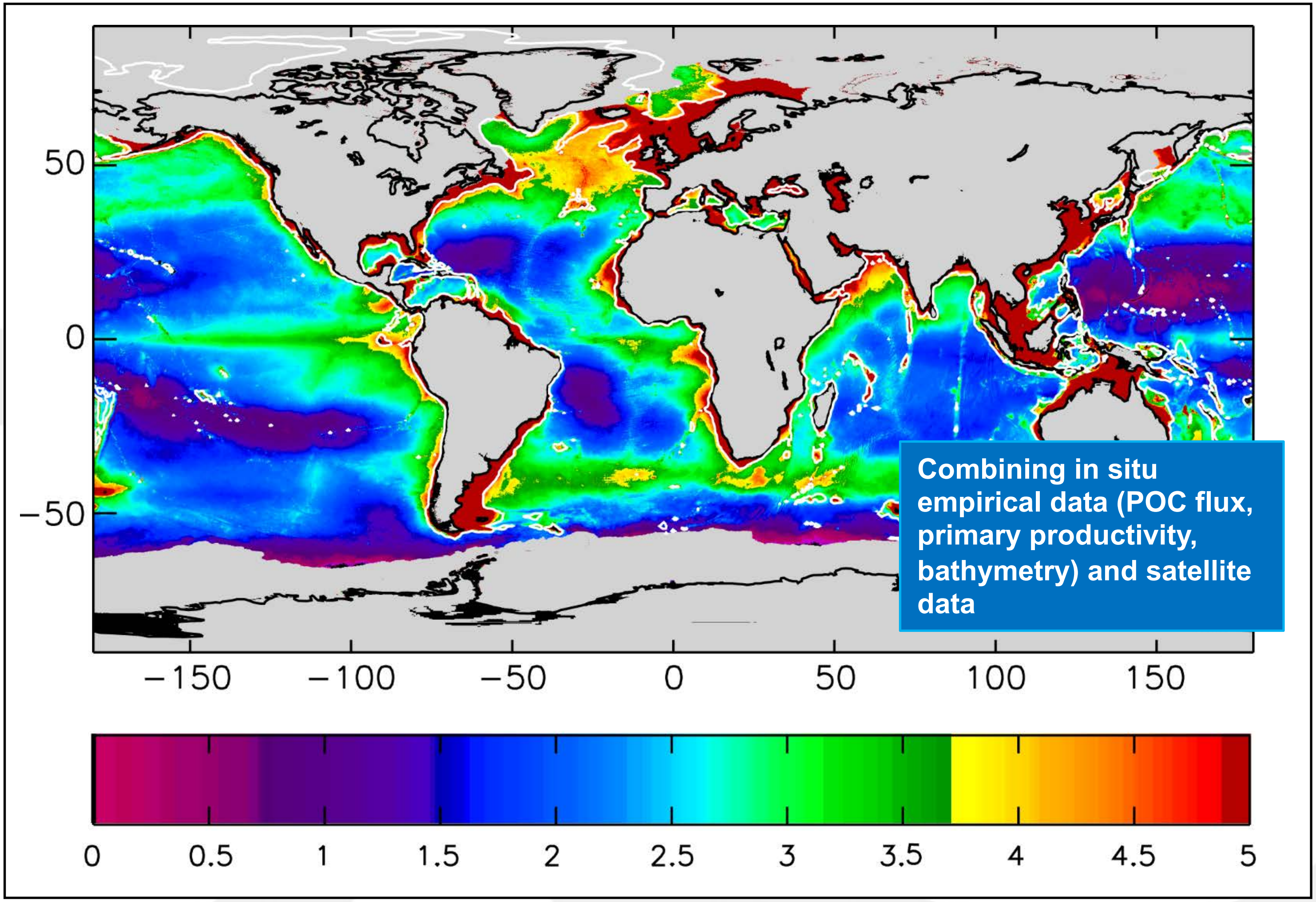


Figure 2.6 Spatial and temporal resolution of heritage, current and planned ocean colour satellite sensors. Planned sensors and missions are italicized. Note: OLI and MSI are instruments developed for terrestrial observations that have demonstrated success in some coastal applications. Adapted from Mouw et al. (2015).

Approximately half of the world's net annual photosynthesis occurs in the oceans (~48 Pg C y^{-1})

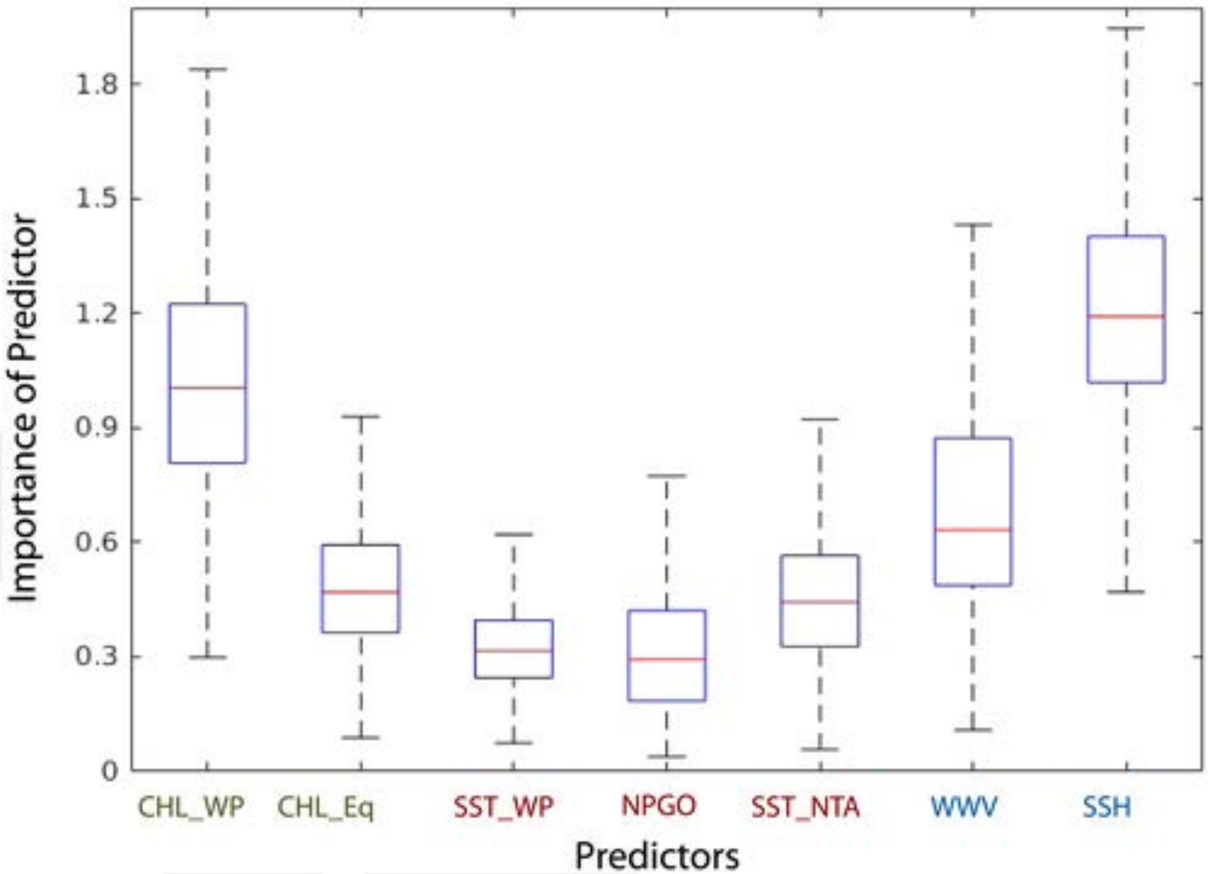


Combining in situ empirical data (POC flux, primary productivity, bathymetry) and satellite data

Average annual POC flux [g C m^{-2} y^{-1}] to bottom of the ocean (1998 – 2001)

Muller-Karger et al. 2005. The importance of continental margins in the global carbon cycle. GRL, Vol. 32.

Ocean Chlorophyll as a Precursor of ENSO: An Earth System Modeling Study

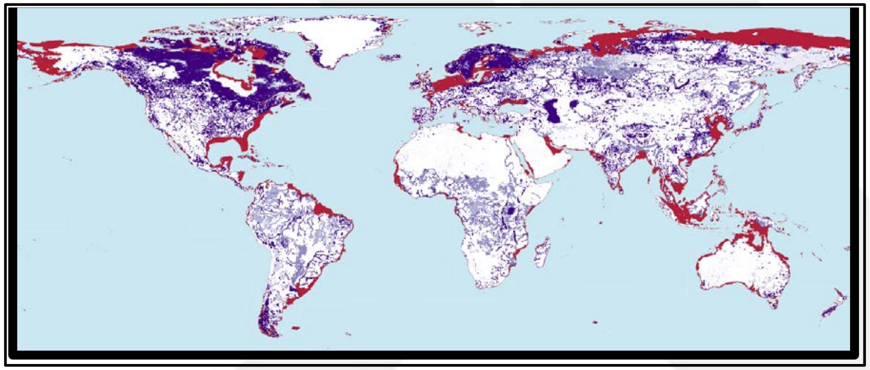


- A regression model based on an ensemble learning approach is applied to assess the importance of these biological and physical predictors.
- **Results show that the two chlorophyll-based indices are generally ranked higher than the SST-based indices. The importance of chlorophyll is similar to that of warm water volume and sea surface height, supporting that the underlying mechanisms of chlorophyll and subsurface heat anomalies are based on the same physical process.**

Park, J-Y, J.P. Dunne, C.A. Stock (2018). Ocean chlorophyll as a precursor of ENSO: An Earth System Modeling Study. GRL, doi://10.1002/2017GL076077

What are the science gaps?

- Grand challenges identified in the 2017 NASA Ocean Biology and Biogeochemistry Advanced Science Plan Draft:
  - **Life on the edge**
    - *How are the diversity, function, and geographical distribution of aquatic boundary habitats changing?*
  - **Expansive ecosystems**
    - *What processes drive change in ecosystem structure and biodiversity and how do contemporary changes in these globally expansive ecosystems inform improved management practices, predictions of change, and global ocean stewardship?*
  - **Ocean Biogeochemistry and the Earth System**
    - *How do carbon and other elements transition into, between and out of ocean pools? What are the quantitative links between ocean biogeochemical cycles and climate?*
  - **Transient Hazards and Natural Disasters**
    - *How can knowledge of the spatial extent, dispersion, intensity, and frequency of transient hazards and natural disasters in the aquatic environment improve forecasting and mitigation?*

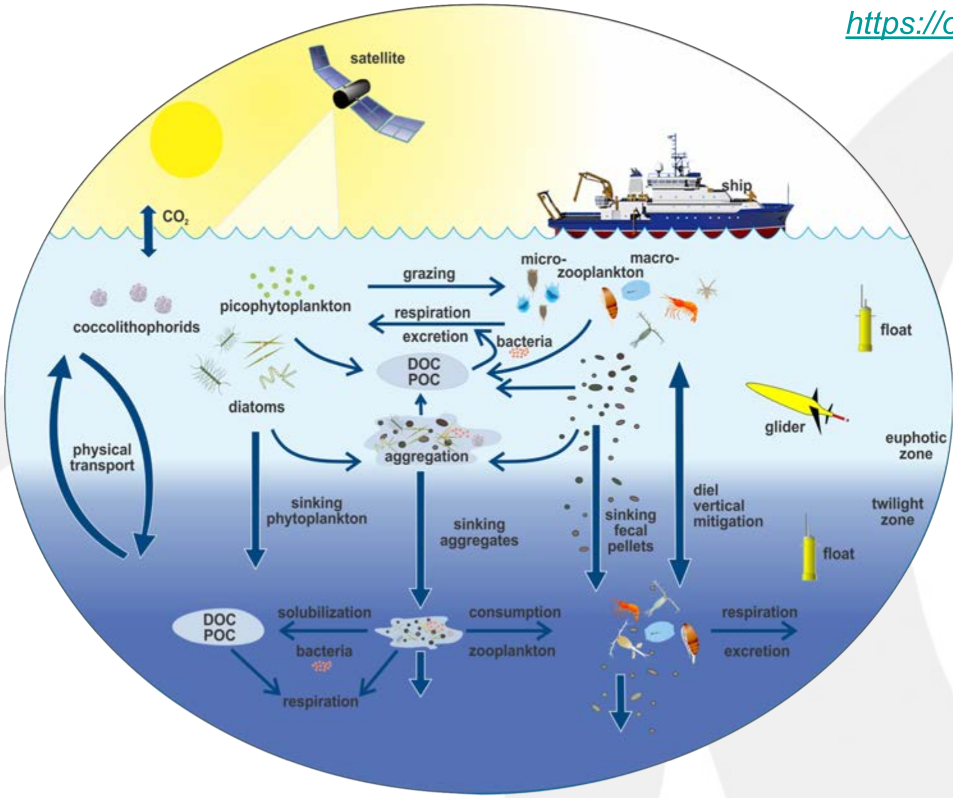


Global distributions of coastal and inland aquatic ecosystems. Red indicates regions where water depth is less than 50 m and where land elevation is less than 50 m. Light to dark violent gives the concentration of inland wetlands, lakes, rivers and other aquatic systems.

Focus on Pathways…

EXPORTS (EXport Processes in the Ocean from RemoTe Sensing) Field Campaign

https://oceanexports.org/



Three Science Questions

How do upper ocean ecosystem characteristics determine the vertical transfer of organic matter from the well-lit surface ocean?

What controls the efficiency of vertical transfer of organic matter below the well-lit surface ocean?

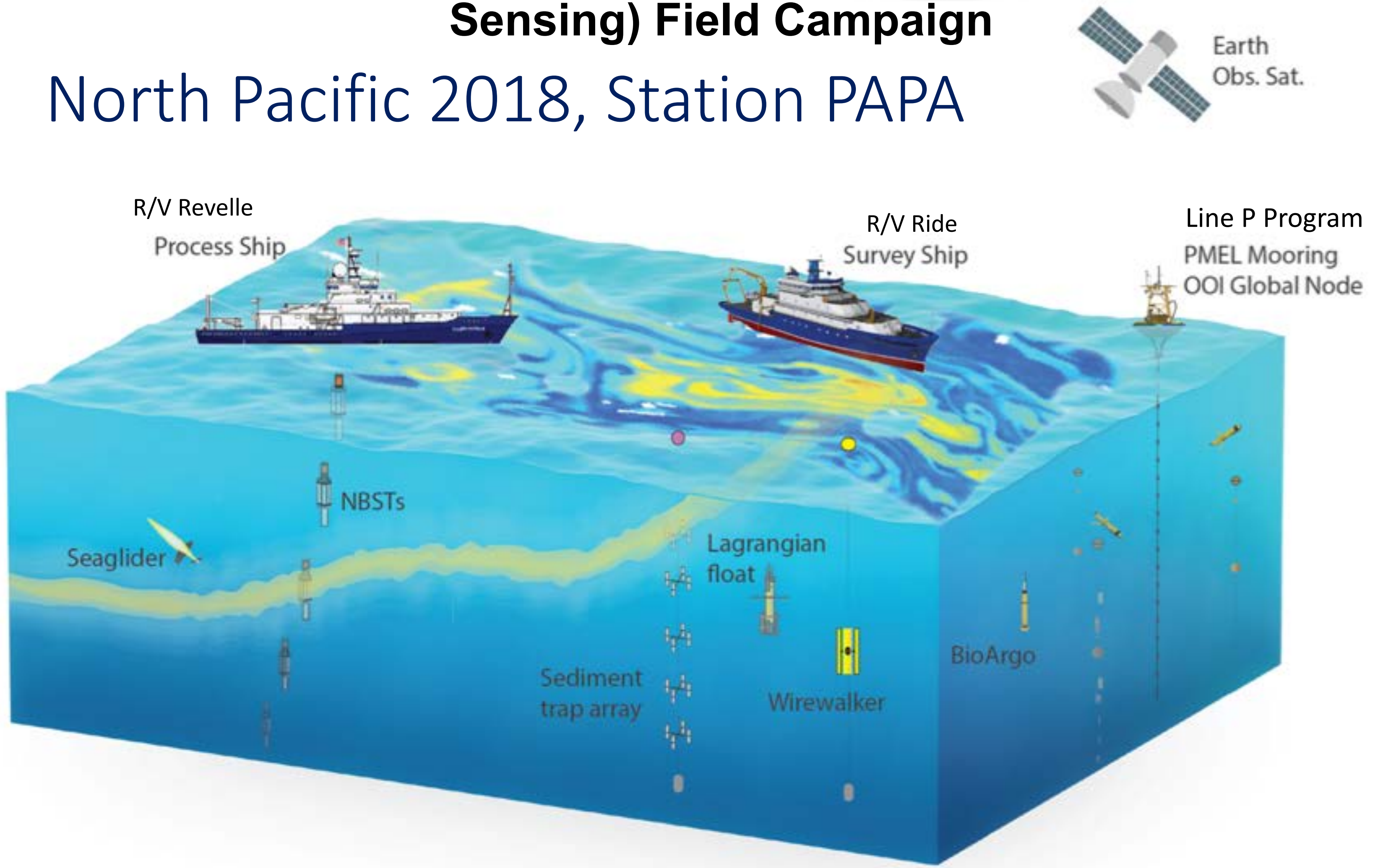
How can the knowledge gained be used to reduce uncertainties in contemporary & future estimates of the export and fates of NPP?

Siegel et al. *Frontiers in Marine Science* [2016]

Focus on Pathways…

EXPORTS (EXport Processes in the Ocean from RemoTe Sensing) Field Campaign

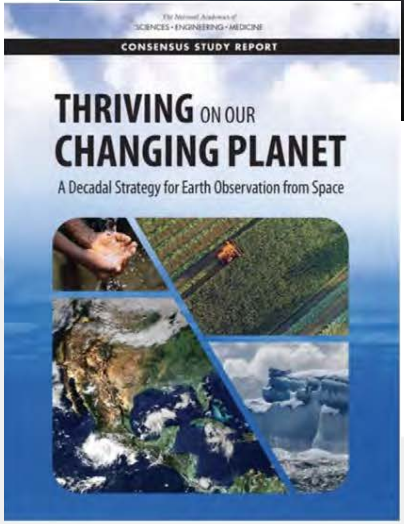
North Pacific 2018, Station PAPA



Planned/Future Remote Missions to Address Other Science Gaps

NASA

- 2022 –Plankton, Aerosol, Cloud and ocean Ecosystem (PACE)
- 2025 – EVI Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR)
- ~2027 – Surface Biology and Geology
    - Designated mission in the 2017 Decadal Survey
    - Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits, and algal biomass



International

- EnMap
- PRISMA
- HISUI (ISS)
- DESIS (ISS)

Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) Mission

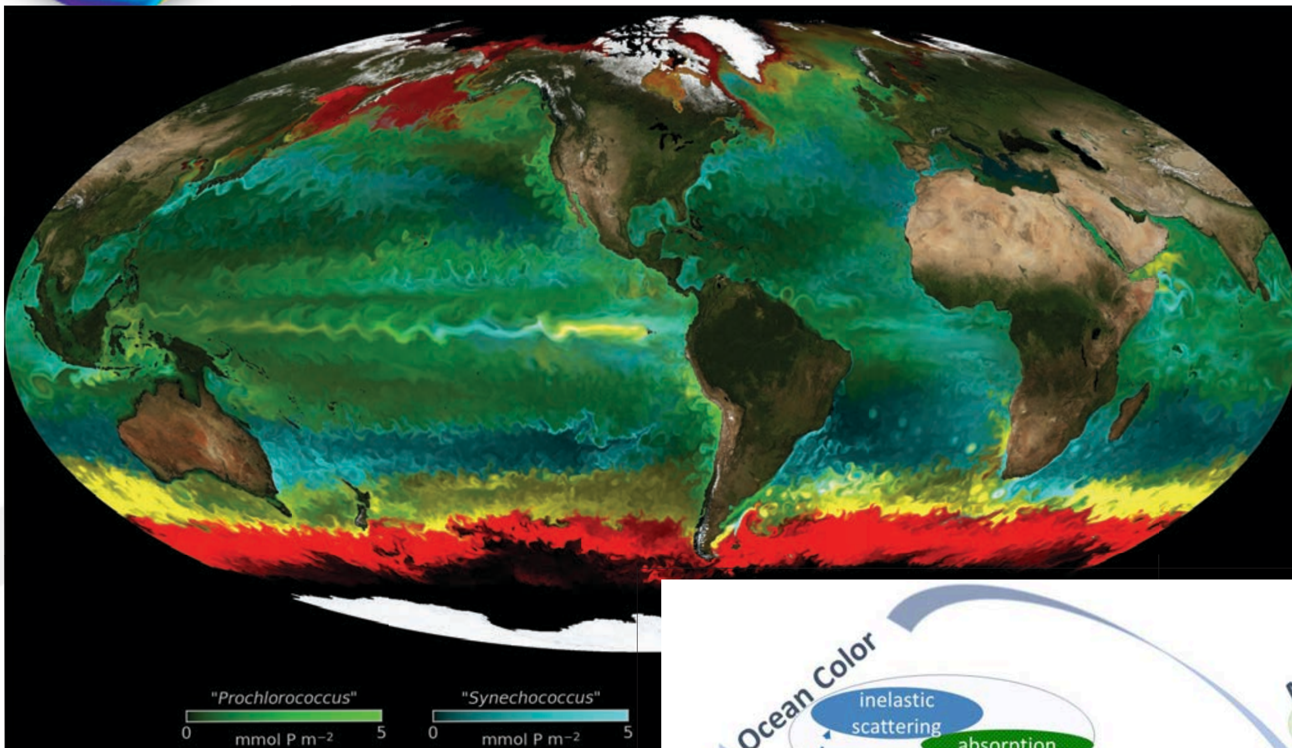
Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) is an ocean color, aerosol, and cloud mission identified in the 2010 report "Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space Science".

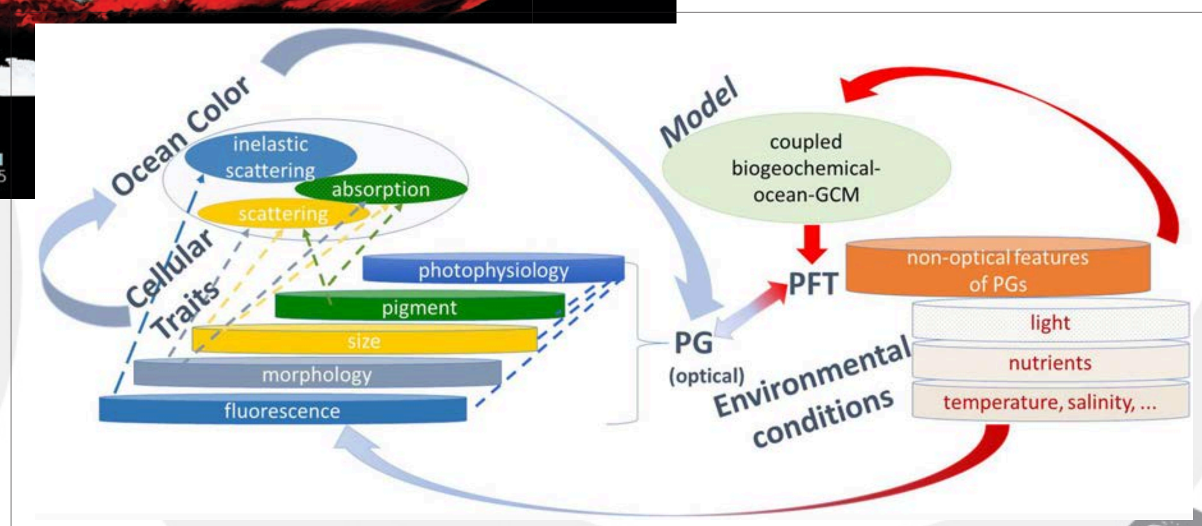
Science Objectives

- **Primary:** Understand & quantify global aerosol & cloud dynamics, aerosol-ocean interactions, ocean biogeochemical cycling, and ecosystem function due to natural & anthropogenic forcings from environmental/climate variability and change: **OCI (expanded SeaWiFS, MODIS heritage)**
- **Primary:** Extend key Earth system data records on global ocean ecology, ocean biogeochemistry, clouds, and aerosols **(SeaWiFS, MODIS heritage)**
- **Secondary:** Understand and resolve/quantify the role of aerosols and clouds in physical climate (the largest uncertainty): **polarimeter (MISR heritage)**
- **Applied Sciences:** enable carbon monitoring and management, contribute to better weather forecasting, and delineate the impacts of weather events on coastal ecosystems to enable resource management (**early returns for ACE mission**)

Risk	• 8705.4 Payload Risk Class C
Launch	• 2022/2023, budget and profile driven
Orbit	• 97° inclination; ~650 km altitude; sun synchronous
Duration	• 3 years
Payload	• Ocean color instrument; potential for a polarimeter
LCC	• **$805M Cost Cap**

Phytoplankton Diversity from Space





Bracher, A., et al (2017), Obtaining phytoplankton diversity from ocean color: a scientific roadmap for future development. Frontiers in Marine Science, doi:10.3389/fmars.2017.00055

Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR)

Identified: *An urgent need for high frequency, hyperspectral observational capabilities for coastal ocean science, resource management, and hazard mitigation (HABs, Hypoxia, & Oil Spills)*

Response: ***GLIMR*** *– a hyperspectral ocean color radiometer capable of delivery high frequency data from geostationary orbit.*

Science Goals: GLIMR develops new knowledge relevant to coastal aquatic biogeochemistry, ecosystem health, human health, and resource management advancing two major NASA Earth Science Division goals of:

- *Detecting and predicting changes in Earth's ecological and biogeochemical cycles, including biodiversity, and the global carbon cycle, and*
- *Furthering the use of Earth system science research to inform management decisions.*

GLIMR ADDRESSES KEY SCIENCE AND APPLICATIONS OBJECTIVES

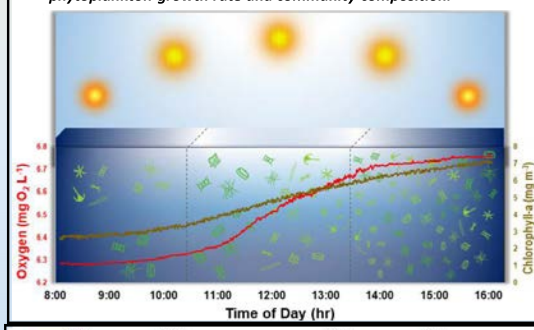
Investigation Overview:

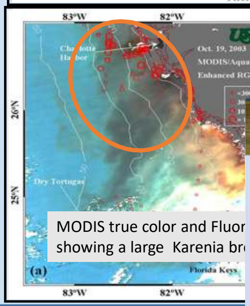
GLIMR provides…

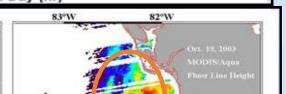
- Science Data: 15+hours of daily observations
- Hyperspectral: UV-VIS-IR 340-1040nm
- High spatial resolution: 300m at nadir
- Fast temporal scanning: ~70 Minute GoM coverage
- Highly calibrated: Ground, On-orbit, Atmospheric Correction, & vicarious calibrations applied
- Configurable to respond to episodic events and hazards of national importance
- Societal Benefits: Economic benefits to tourism, fisheries, oil & gas, shipping, and recreational users

1. ***Short Term Coastal Processes: how high frequency fluxes of sediments, organic matter, and other materials between and within coastal ecosystems regulate the productivity and health of coastal ecosystems.***

2. ***Understanding processes contributing to rapid changes in phytoplankton growth rate and community composition.***





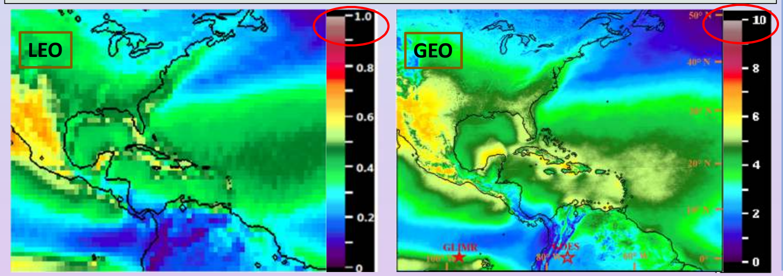


MODIS true color and Fluor… showing a large Karenia br…

No other sensor can achieve the degree of scientific understanding we propose with GLIMR

GLIMR provides many times more data per region per day than polar orbiting sensors!

The mean proportion of cloud-free observations during a day for polar-orbiting LEO sensors (left panel; ~0.3 to 0.6/ day in the Gulf of Mexico) based on MODIS observations between 2006 and 2011 compared to the much higher mean number of cloud-free hourly observations during a day (4 to 6/day in the Gulf of Mexico) from GOES East (right panel), based on cloud cover data between 2006 and 2011. The higher spatial and temporal resolution of GLIMR will confer a higher probability of cloud-free observations as compared to GOES and MODIS. (Red circles highlight the different scales used). Nominal location for GLIMR (98°W) is annotated in the GEO figure on right (from Feng et al. 2017).

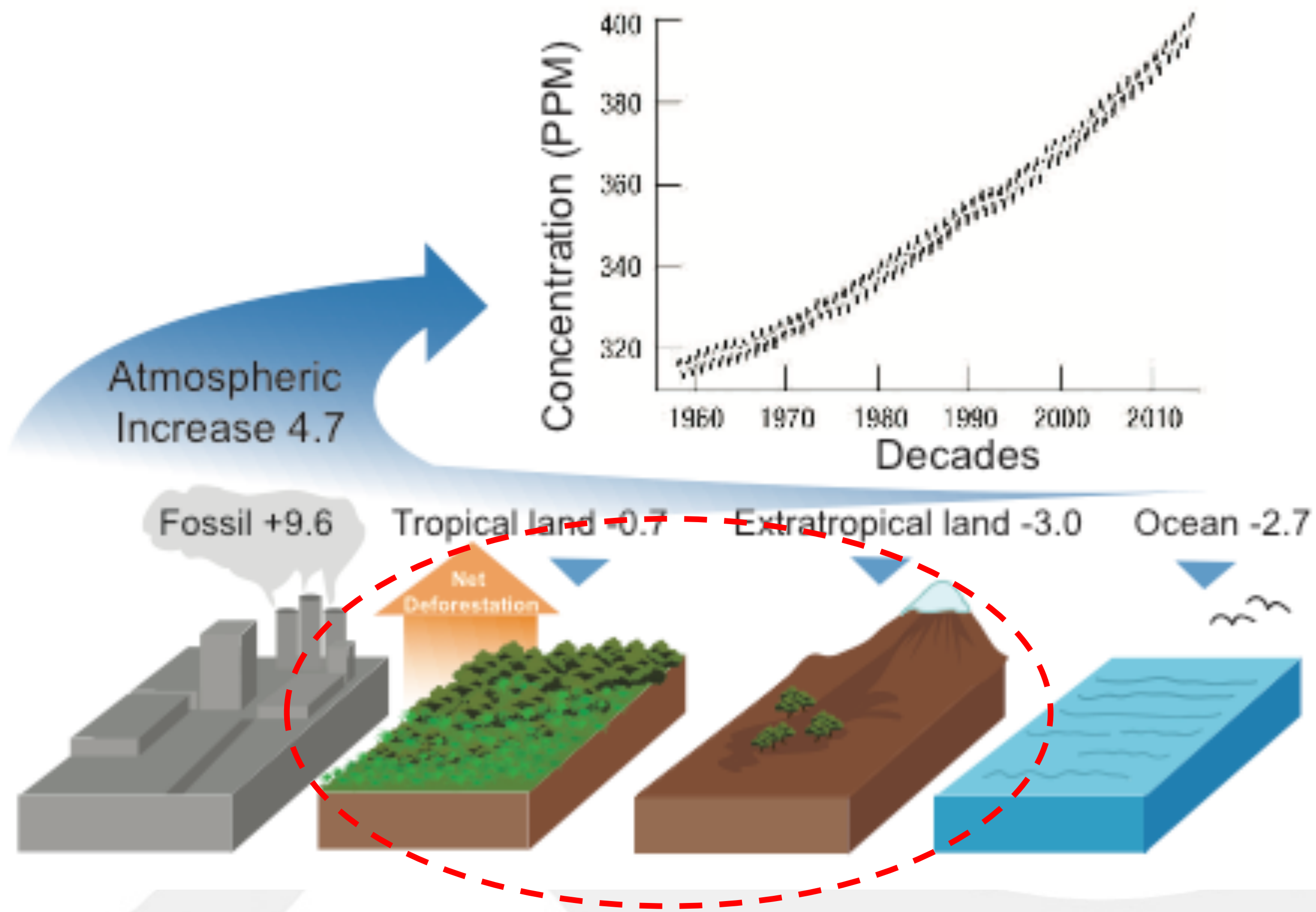


GLIMR – spatial, temporal, and spectral resolution capability uniquely suited to observing dynamic coastal ocean processes like no other current or planned mission.

Mission	Hourly Imaging	300m Spatial Resolution	Full Spectral Coverage
GLIMR	✓	✓	✓
MODIS & VIIRS			
OLCI		✓	
GOCI	✓	✓	
PACE			✓
GOES	✓		
HyspIRI (SBG ?)		✓	✓

The global carbon cycle

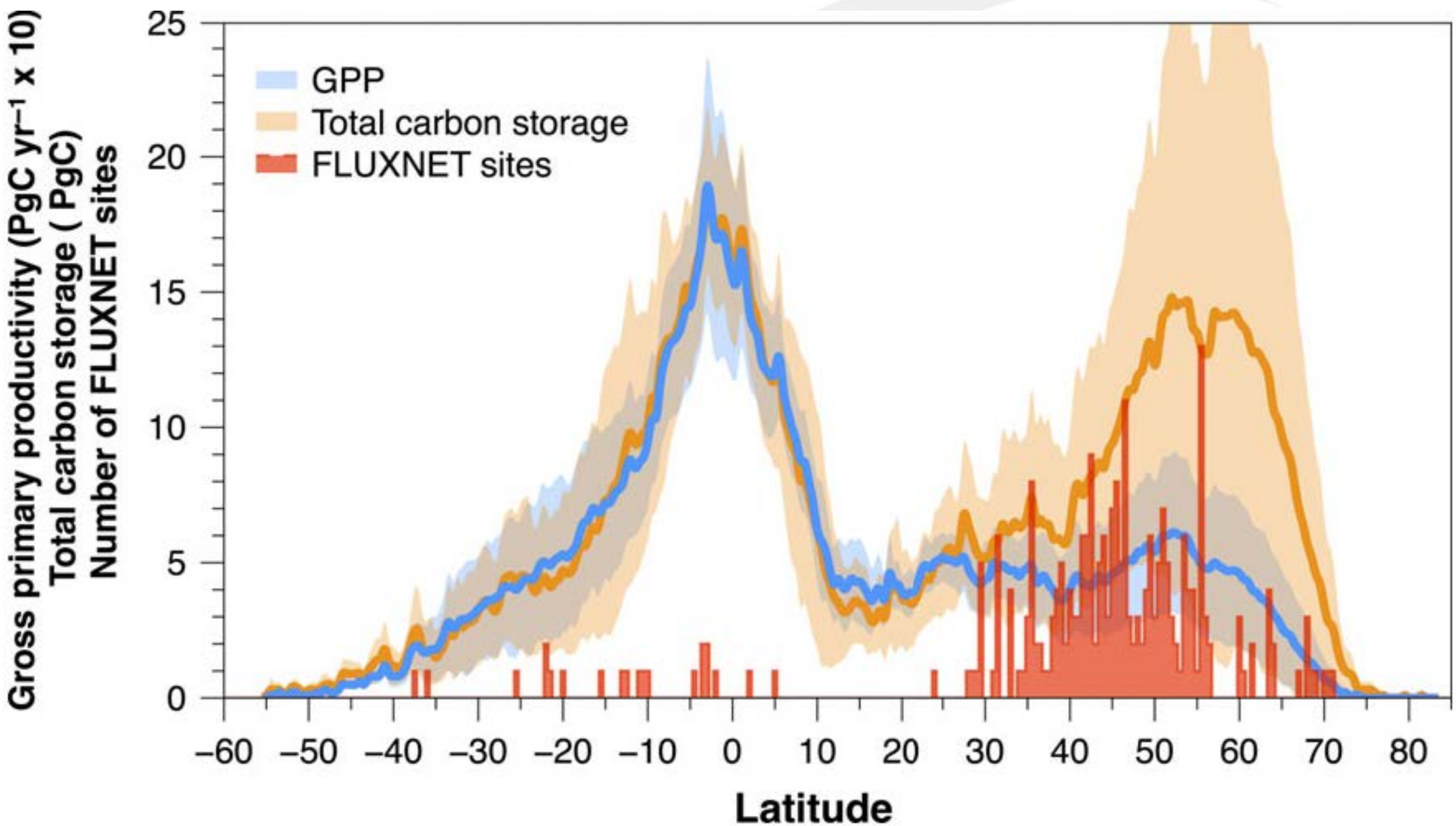
Human forcing, land and ocean uptake
A challenge to all modes of remote sensing



The data gap

"The two poles of the carbon cycle"

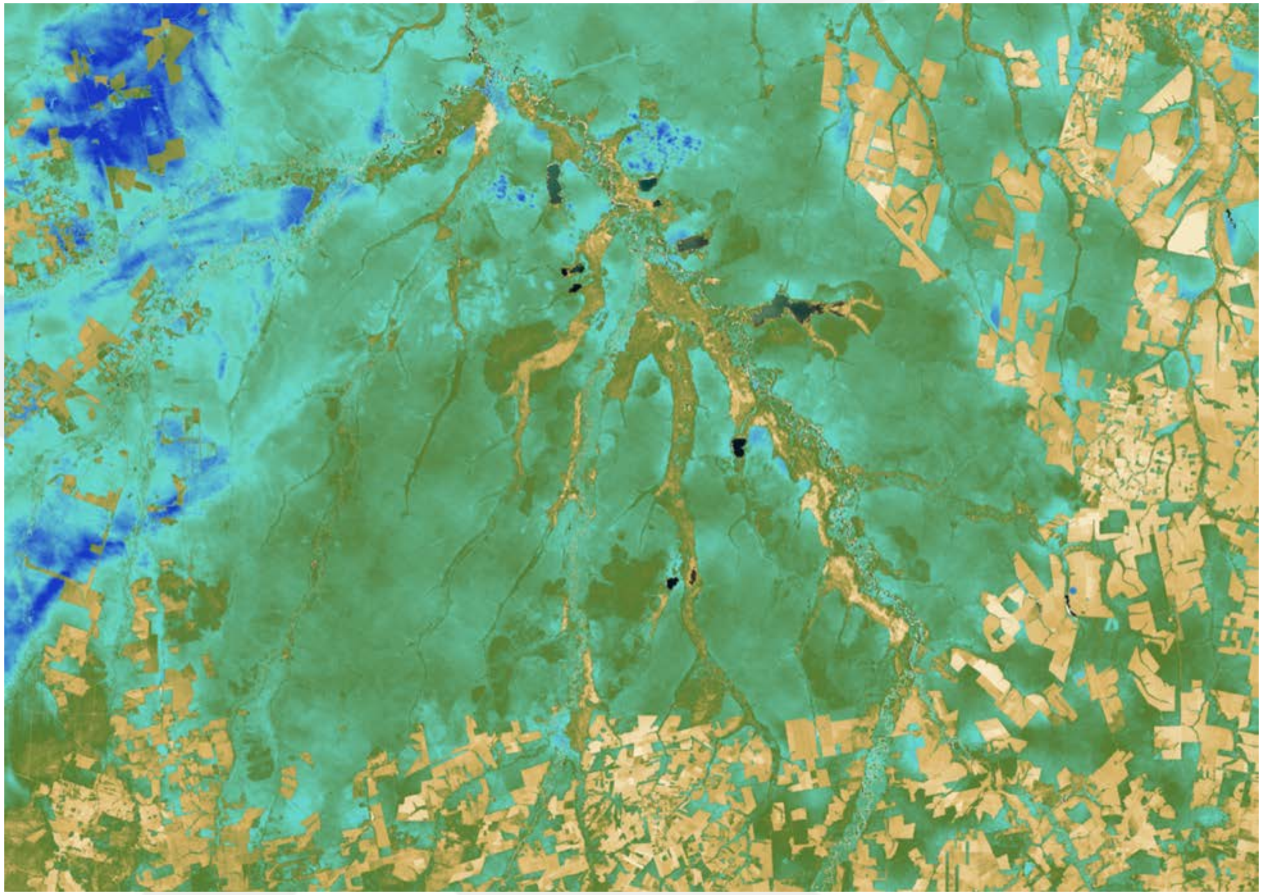
The most active regions are the least sampled *in situ*



Future of terrestrial biogeochemistry

- For decades, we have had two global measures from space for terrestrial carbon, greenness (NDVI) and land use change
- Now, and increasing in the near future, we have multiple quantitative retrievals of terrestrial biogeochemistry,
- Some (Vegetation Optical Depth) for scaling reasons, have no direct in situ counterpart,
- Others are more accurate remotely than in situ (canopy height),
- Today’s terrestrial and land surface models originated in the “NDVI” era and are ill-suited to comparison, ingestion and assimilation of new observables,
- A scale mis-match remains between carbon assimilation model length scale (~500 km) and in situ (~1 km).

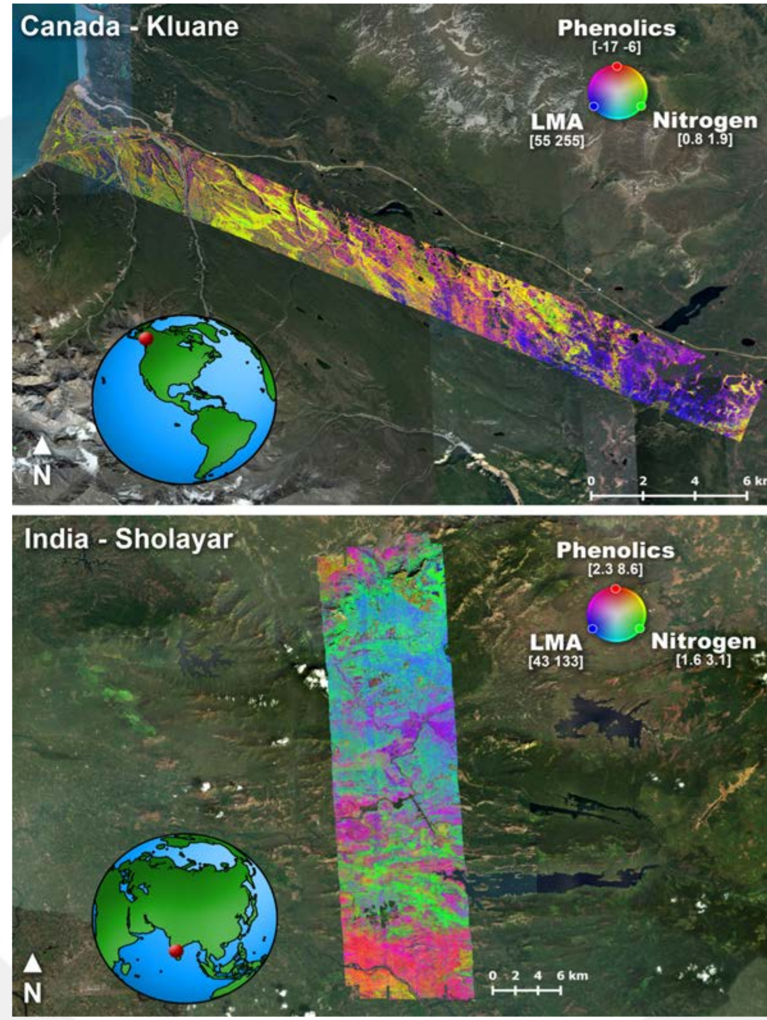
ECOSTRESS: Evapotranspiration over the Amazon



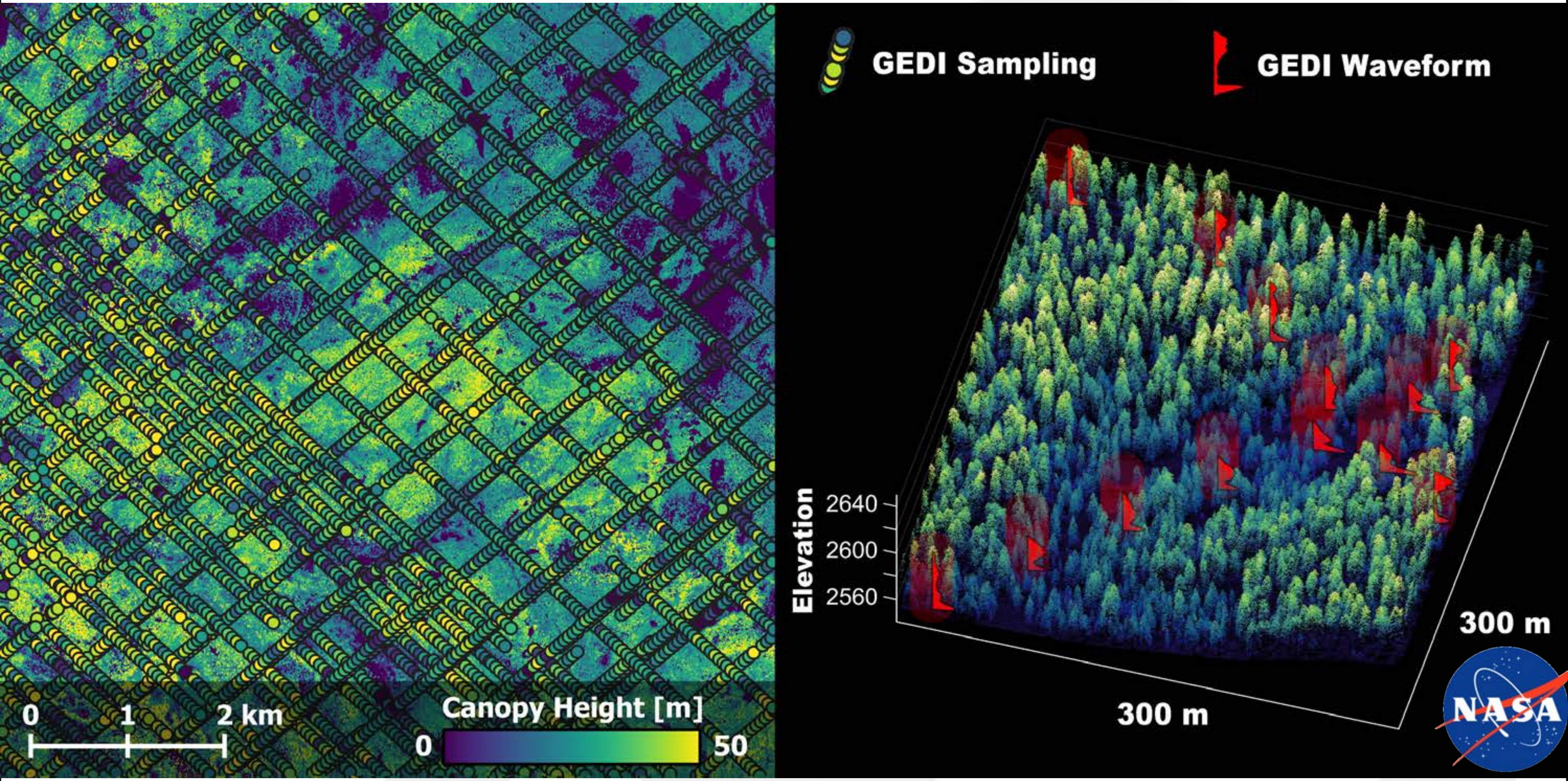
Plant Diversity from Space

Imaging spectroscopy for plant canopy functional traits determining physiological rates

Functional Trait	Units	Normalized Uncertainty, Retrieved (Singh et al 2015)
LMA	g/m^2	11%
Nitrogen	% dry mass	16%
Chlorphyll	ng/mg	8%
Lignin	% dry mass	12%
Phosphorus	% dry mass	16%

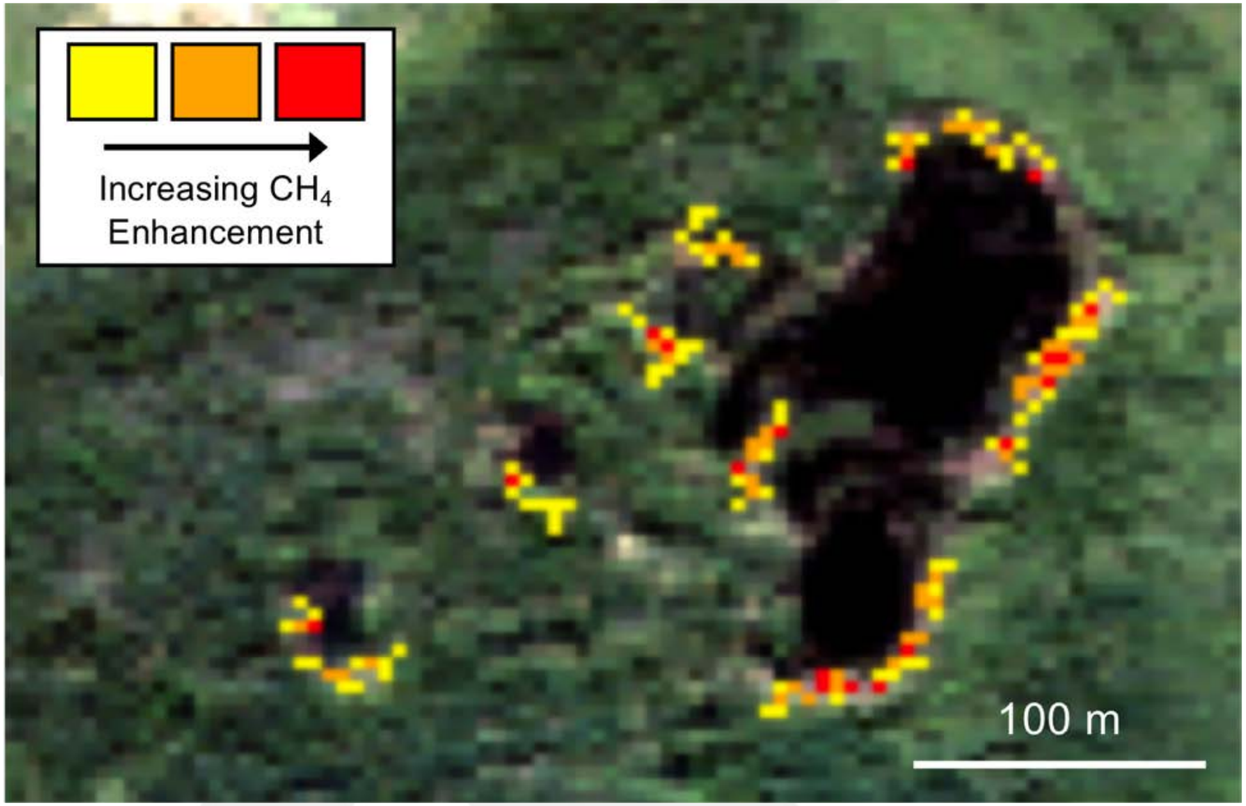


GEDI: Forest structure and biomass over the Sierra Nevada



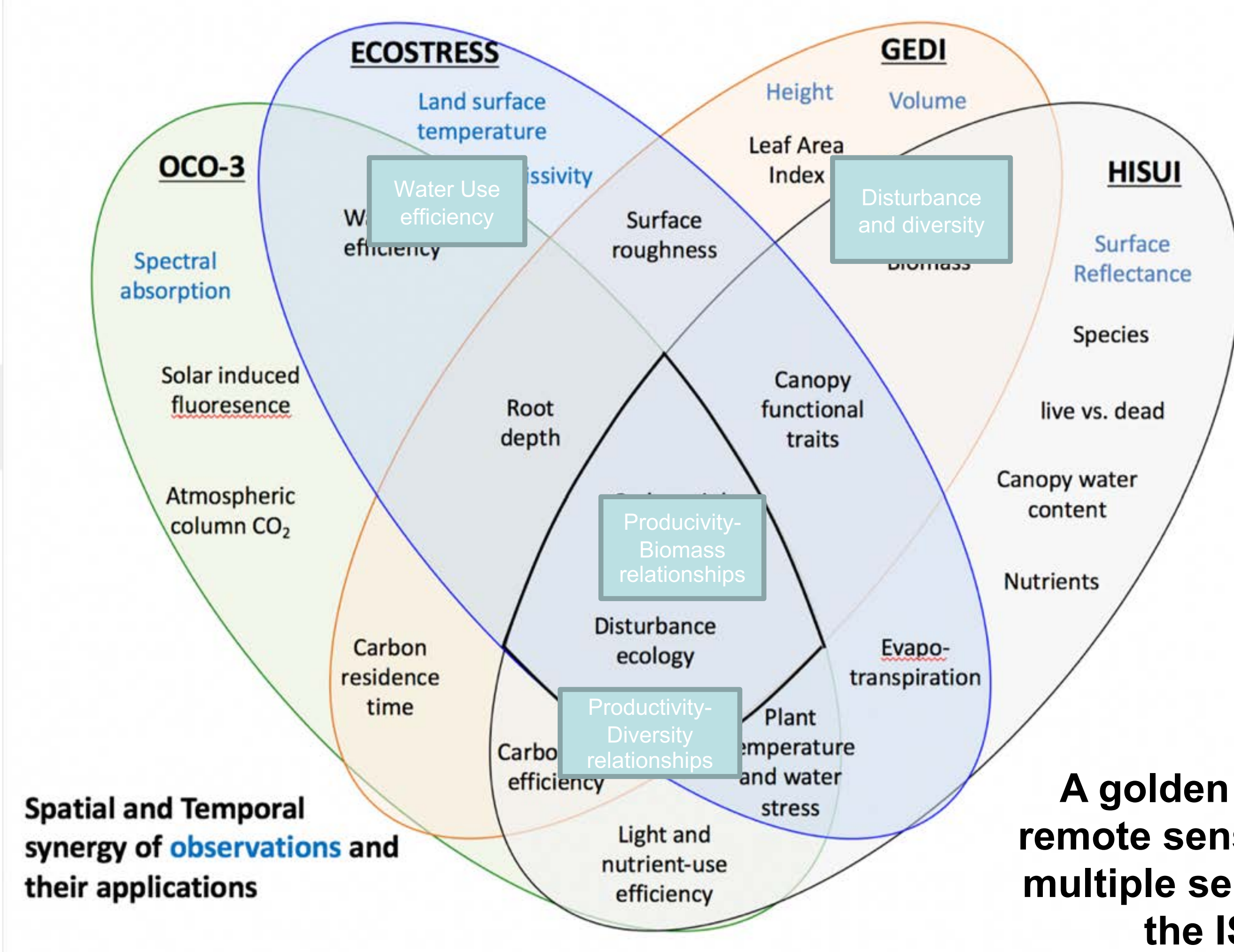
Methane Detection

AVIRIS sees natural patterns of methane emission around Arctic lakes: addresses the decades-old scaling challenge.



CH_4 emissions occur at lake margins, wet and with ample supplies of carbon

Fusion of data products



A golden Age of remote sensing with multiple sensors on the ISS

Recommendations

- **Validation**
  - More data is needed to validate remote sensing products, especially biogeochemical and biological. Particularly critical in optically complex waters and in data poor regions (e.g. mesopelagic).
- **Technology development (in situ/remote)**
  - Role of cubesats
  - Bio-Argo expansion
- **Numerical Modeling**
  - Model applications – promotion of OCR as a necessary input to NWP models (heat exchange etc.) and, as more standard, ecosystem models
  - Disconnect between modeler needs and research data/products – scale, number and location of observations.
  - Uncertainties in data products (esp. for stakeholders)

Recommendations

- **Science (Observations, approaches, technology, models, etc.)**
  - Vertical structure of the ocean – role of new technologies (lidar, tie to Bio-Argo to resolve physical properties (MLD, PAR, Zeu) to get at sources, sinks, stocks and fluxes (aquatic carbon from space)
  - Scales of motion – merge in situ and remote data in a seamless linkage
  - Quantification and sampling for carbon inventory
  - Plastics
  - Sub-mesoscale – not just the temporal resolution, but the spatial
  - High latitude/ice related studies
  - Leverage on non-OCR specific missions – e.g., Discovr, ICESat-2, potential with SAR/Sentinel/commercial combinations to achieve CLIVAR objectives
  - Multi-platform and sensor data fusion for Earth Science