Biogeochemistry

Marine Ecology & Ocean-Atmosphere Interactions

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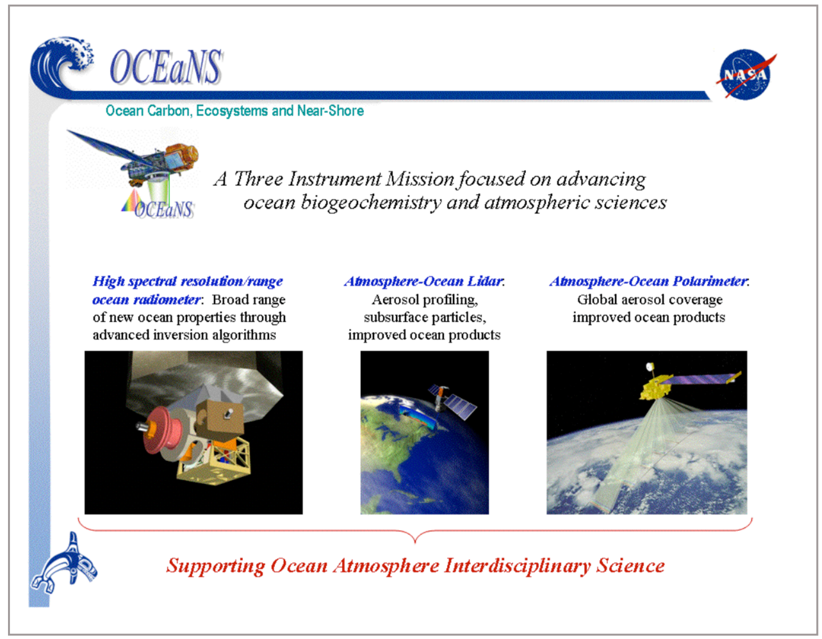
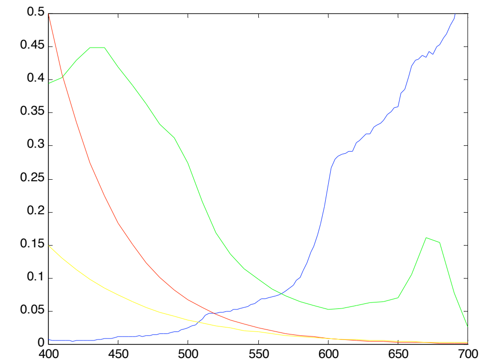
Joint Ocean – Atmosphere Mission History

- 2003 – Conception & HQ presentation of ocean mission concept with aerosol-targeted instrument
- 2004 – IMDC and ISAL analysis – Two instrument design: ACE & ORCA (GLAS/SeaWiFS extension)
- 2004 – International Science Team Meeting
- 2005 – Second ISAL study – Complete revision of radiometer and Lidar
- 2005 – Three instrument design: Ocean radiometer, Lidar, & polarimeter – expanded focus on interdisciplinary science – "OCEaNS"
- 2005 – Joint Ocean-Atmosphere Mission concept briefing at NASA HQ (Behrenfeld / Diner)
- 2005 – "OCEaNS" mission concept submitted as white paper to Decadal Survey call
- 2006 – ACE mission identified in Decadal Survey
- 2006 – GOCECP IMDC Study conducted



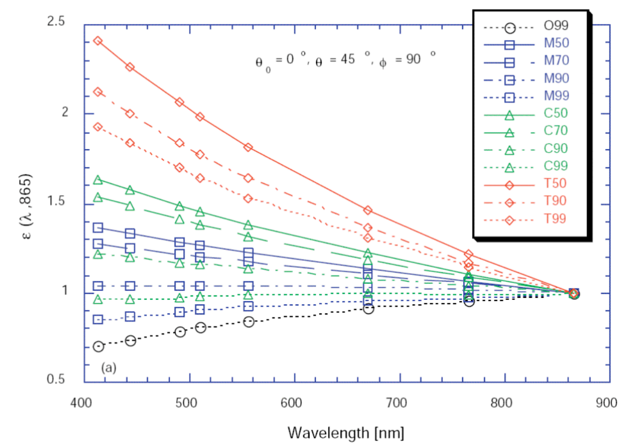
Joint Ocean – Atmosphere Mission History

- Chlorophyll concentration is not adequate for understanding climate-ocean biology feedbacks
- Bio-optical assumption is invalid
- Separate empirical algorithms for key properties not valid approach
- Development of spectral inversion algorithms
- Application of inversion products



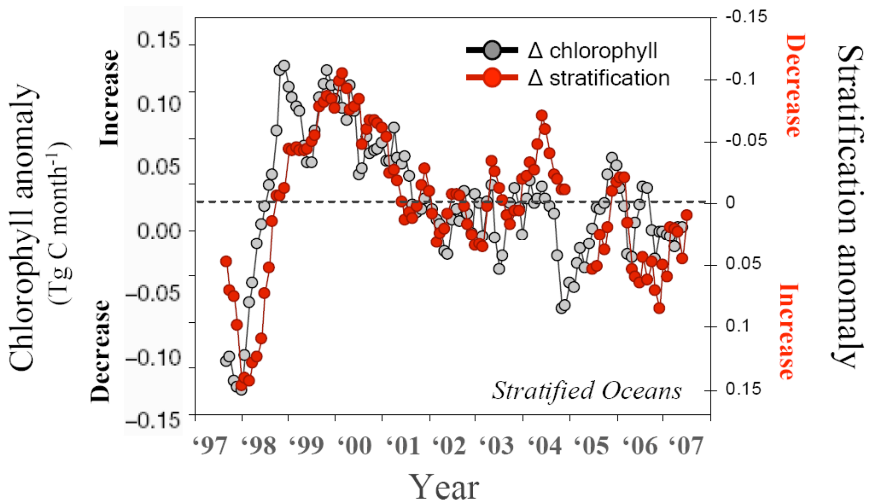
New Requirements:

- Better separation of optically-active components } extension into near-UV, higher spectral resolution
- Superior retrieval accuracy } Inversions are ‘unforgiving’
- Improved atmospheric corrections } spectral anchoring at short and long wavelengths, aerosol type and height



Immediate Objectives…

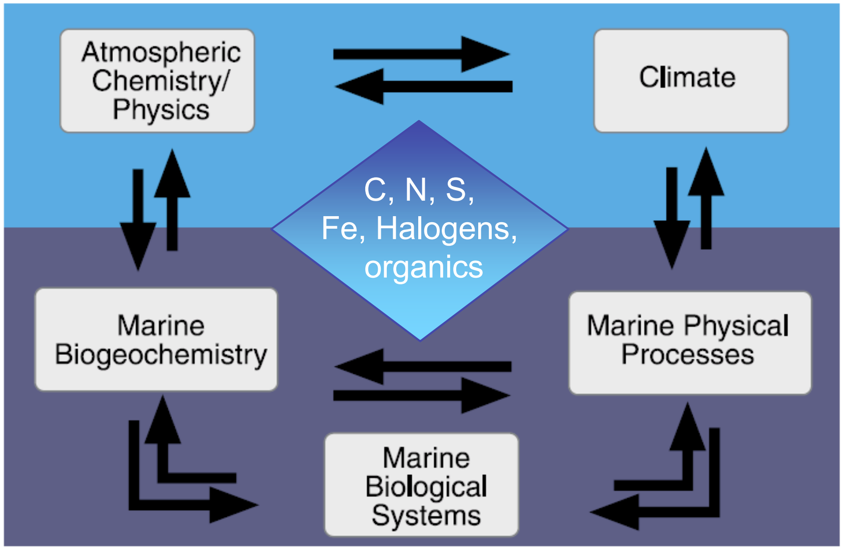
- Separation of phytoplankton pigments from colored dissolved organics (cDOM)
- Quantification of phytoplankton carbon and chlorophyll (physiology)
- Detection of taxonomic groups (N-fixers, calcite producers, carbon exporters, DMS producers, etc.)
- Improved chlorophyll fluorescence retrievals
- Detection of change:
  - ❖ climate effects on biomass *vs* physiology?
  - ❖ acidification effects on global calcite producers?
  - ❖ phytoplankton responses to iron enrichment events
  - ❖ cDOM responses to altered stratification and incident sunlight
  - ❖ coastal systems responses to nutrient loading



Opportunity for Interdisciplinary Science…

Requirements for improved atmospheric correction leads to an instrument complement suited for tackling important ocean-atmosphere-climate problems

- Atmospheric dust – ocean productivity
- Aerosol profiling – subsurface particle profiling
- Ocean biology/photochemistry – sulfate aerosols
- Ocean methane/N_2O – greenhouse warming
- Solar radiation changes – ocean / atmosphere changes



- ➢ Direct impact on ocean biology and photochemistry
- ➢ Altered production of sulphate gases, organo-halogens (Cl, Cl_2, Br, BrO_3, IO, etc), CO, hydrocarbons, volatile organic compounds, methane, CO_2
- ➢ Consequences for tropospheric & stratospheric chemistry and cloud formation

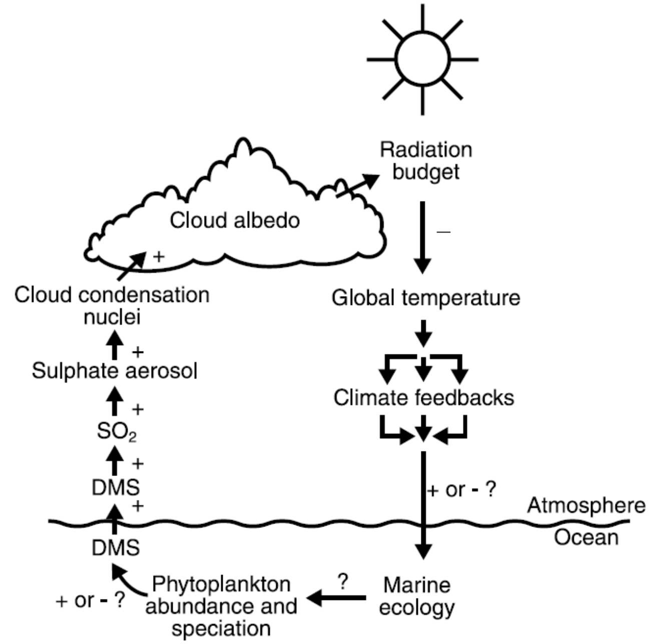
Feedbacks Scenarios…

Scenario: Change in spectral quality and dose of solar radiation (ozone depletion, changes in cloud cover, aerosols, ocean stratification) } Change in cDOM photo-oxidation ↔ change in subsurface UV dose } change in ocean CO_2 budget from community responses to light/UV changes + trace metal changes + heterotrophic respiration + direct CO_2 release from organics photo-oxidation } impact on atmospheric radiative forcing

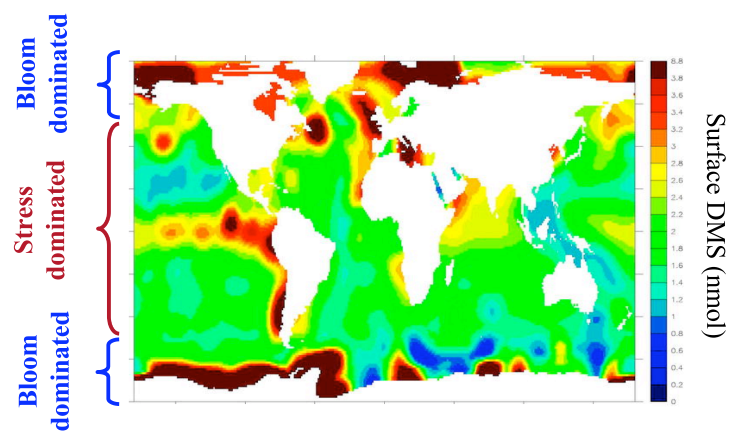
- cDOM is primary absorber of UV light in surface ocean
- Photochemical breakdown of dissolved organic carbon directly to CO_2 estimated to be of similar magnitude as carbon sequestration through export ocean production
- Phototransformation can convert refractory material into labile material
- oxygen and organic radicals can influence trace metal bioavailability

Feedbacks Scenarios…

Scenario: Climate-driven changes in ocean circulation, stratification, and incident light alter phytoplankton distributions, composition, production, and oxidative stress } Space-time change in dimethylsulphoniopropionate (DMSP) production } alters dimethylsulphide (DMS) production exchange with atmospheric } modifies sulphate aerosols load of remote marine atmosphere } influences cloud albedo } alters incident light } affects phytoplankton production, CO2 uptake, radiatively important gas emissions, community composition } alters climate and DMS production



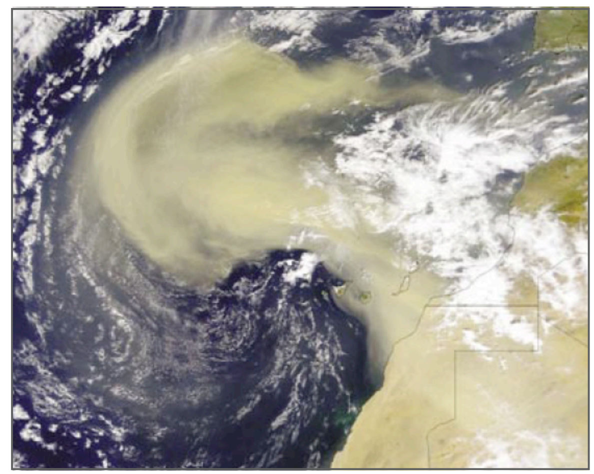
- Elaboration of CLAW Hypothesis [Charlson, Lovelock, Andreae, Warren (1987)]
- Some pieces have been observed (e.g., 2x cloud concentration above large southern ocean bloom than outside bloom)
- Many pieces still require verification
- Water column production is always light limited
- Taxonomy important – some species contain order-of-magnitude greater DMS precursor
- Strong latitudinal differences – high latitude ‘bloom’ driven, low latitude ‘stress’ driven
- Significant lag can exist between blooms and DMS production – UV strongly correlated



Feedbacks Scenarios…

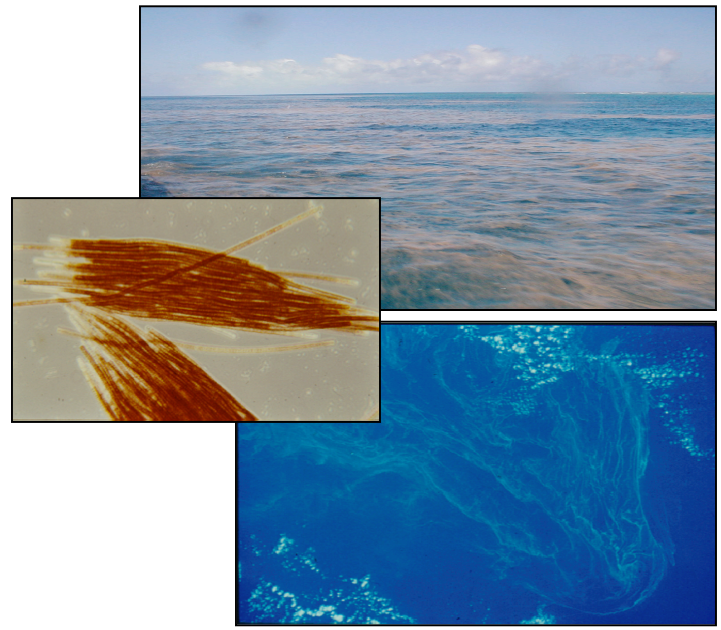
Scenario: Climate change alters desert area, global wind fields, atmospheric circulation, & space-time aerosol deposition on ocean } change in nutrient budget } alters phytoplankton productivity, community structure in low-iron regions } impacts carbon uptake & biogenic gas release } feedback on atmospheric radiative forcing

- Dust is an important source of new iron for phytoplankton
- Iron enrichment dependent on iron content, atmospheric chemistry (pH, wet-dry cycles, etc), particle size, air-sea boundary chemistry, etc.
- Iron response dependent on macronutrient load
- Significant iron response can result with no detectable change in chlorophyll (i.e., strictly physiological)
- Great remote sensing contribution, but tracking dust is not enough – need information on plume altitude, particle sizes, processes affecting iron mobilization, wet/dry deposition
- Phytoplankton responses to Asian dust have been observed, but only when dust passed through urban/industrial pollution – illustrating the importance of aerosol interactions



Feedbacks Scenarios…

Scenario: Climate effects on dust (as previous) and stratification } change in nitrogen fixation } alters phytoplankton productivity, community structure } impacts carbon uptake & biogenic gas release } feedback on atmospheric radiative forcing



- Several lines of evidence suggest that nitrogen fixation has increased over the past two decades in the subtropical Atlantic and Pacific oceans and Caribbean Sea

- Physical changes in the mixed layer appear responsible for North Pacific changes

- Increased iron deposition appears responsible for changes in the Atlantic and Caribbean

Feedbacks Scenarios…

Scenario: Increasing atmospheric reduced nitrogen loads } enhance nitrogen deposition to surface ocean } eutrophication in coastal waters, shifts in oceanic productivity, interactions with nitrogen fixation rates, tipping point between nitrogen and iron limited ecosystems, altered community structure } change in carbon sequestration & biogenic gas release } feedback on atmospheric radiative forcing

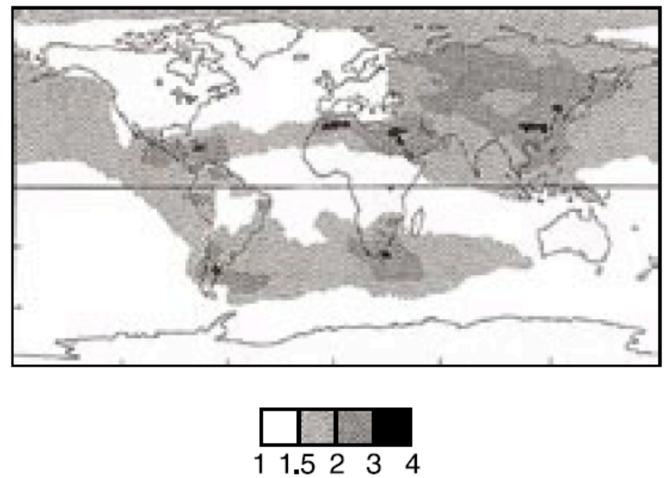
- Atmospheric nitrogen deposition to coastal waters of Europe and N. America increased 50% to 200% over past 50 years

- Atmospheric nitrogen loading to open ocean systems is small fraction of total budget, but comes in highly episodic, often large, pulses –different ecological consequences than a chronic trickle

- Nitrogen fixation is inhibited by addition of reduced nitrogen

- Forms: NO_3, NO_2, NH_4, organic N

Change in reactive nitrogen deposition: 1980-2020



Factor of…

Feedbacks Scenarios…

- Biogeochemical feedback processes remain one of the greatest uncertainties in climate change scenarios

- Some pieces of each feedback path have been demonstrated, but most have not

- The synergistic nature of the ACE mission observations provides a unique opportunity to investigate these biogeochemical links on a truly global scale

STM Ocean – Atmosphere Science Questions…

How do climate and habitat changes influence the productivity and elemental cycles of the global oceans?

How do aerosols deposited on the ocean surface influence nutrient levels and stressors for ecosystems?

How do ocean biological processes influence aerosols and cloud distributions?

What are the standing stocks, transformation rates, and fates of marine organic carbon pools, as well as inorganic particles?

Ocean Approaches: Pigments & cDOM

Issue: Accurate separation of absorption by cDOM and phytoplankton pigments

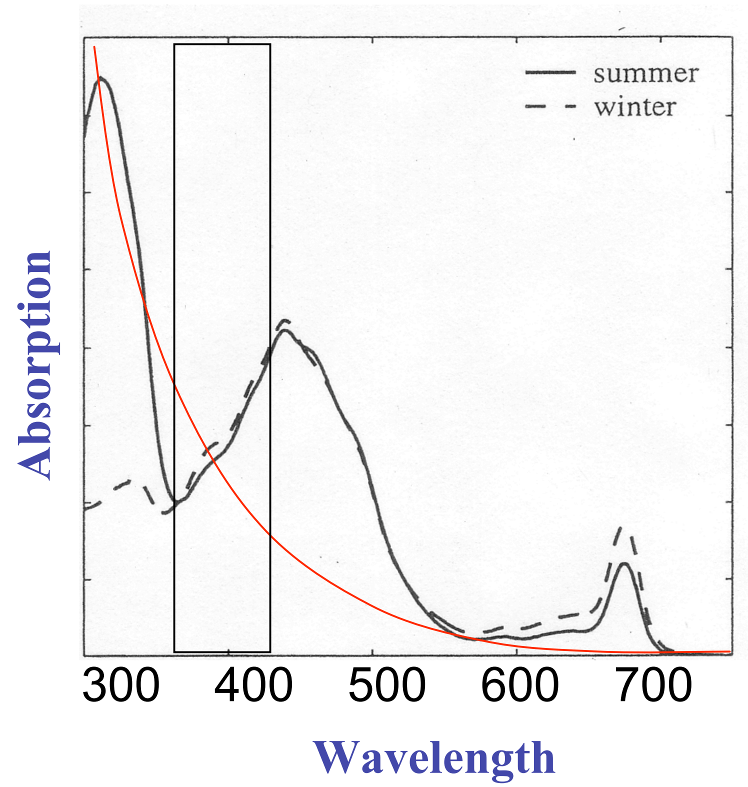
Status: Difference between ocean productivity estimates based on standard empirical chlorophyll product and spectral matching product can exceed 15 Pg C y-1 (annual total = 50 Pg C y-1)

Approach: Expansion of observations into near-ultraviolet

Minimum requirement: 2 near-UV bands, 20 nm bandwidth, 360 & 380 nm center

Optimal: 5 nm resolution 345 – 400 nm

Value added: improved productivity estimates, feedbacks (, UV protective?)



Ocean Approaches: Biomass, Physiology, Productivity, Taxonomy

Issue: Distinction between phytoplankton carbon biomass and physiology changes

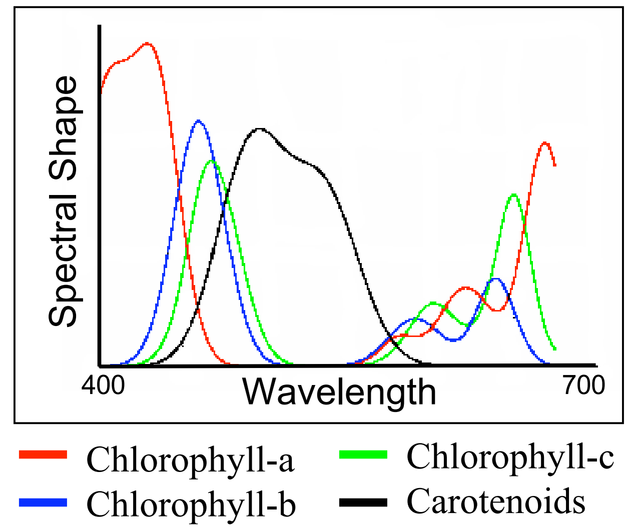
Status: Chlorophyll is a complex expression of biomass and physiology. Particulate scattering provides carbon biomass. Scatter:Chl provides physiology. Carbon estimate requires information on particle size distribution.

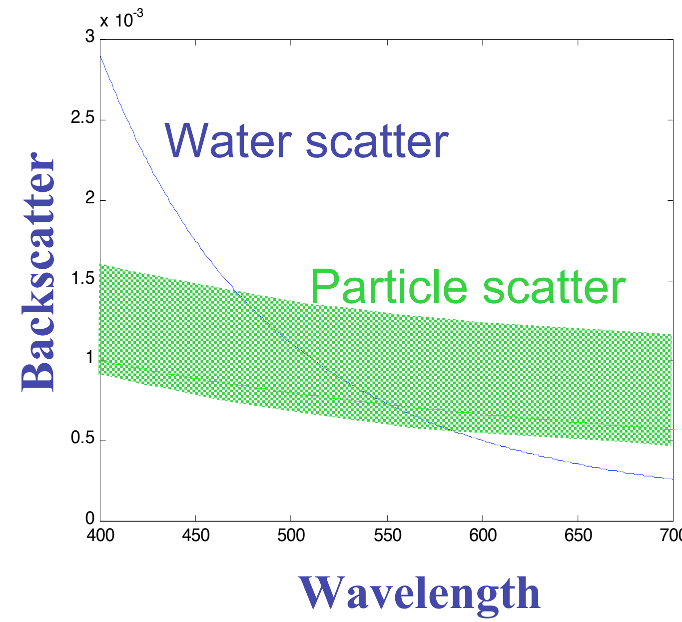
Approach: High VIS spectral resolution, backscatter coefficient & slope, phytoplankton pigments – variable absorption spectrum

Minimum requirement: Aggregate bands every 20 nm from 400 – 600 nm

Optimal: 5 nm resolution 400 – 600 nm

Value added: flexible aggregation for inter-sensor comparison, feedbacks, HABs, coastal applications, functional groups





…. Biomass, Physiology, Productivity, Taxonomy (cont.)

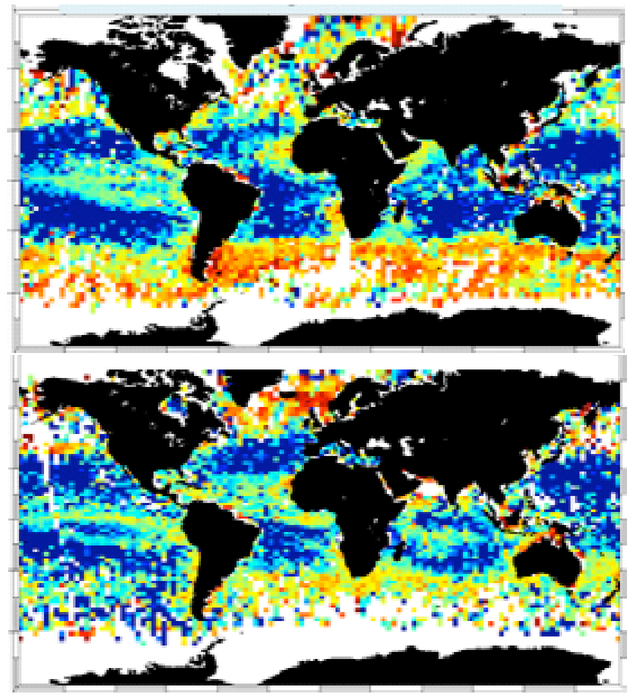
Issue: Independent measure of backscatter and particle profiling

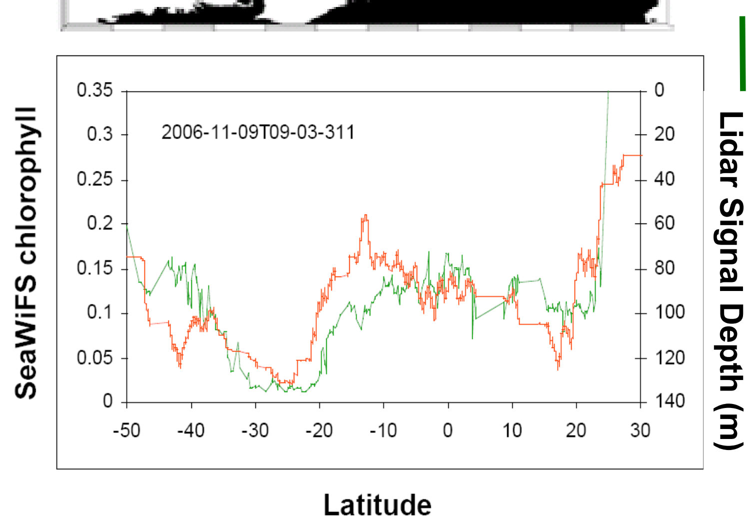
Status: CALIOP demonstration of particulate backscattering retrieval & significant penetration depth

Approach: Optimization of lidar configuration for subsurface returns, including 1 m vertical resolution

Minimum requirement: CALIOP repeat with greater vertical resolution

Value added: Improvements in inversion products





Ocean Approaches: Complex Coastal Waters

Issue: Separating biotic & abiotic constituents in coastal waters

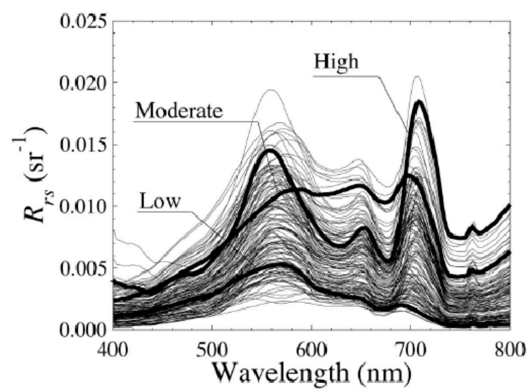
Status: Key properties of optically complex coastal waters can be retrieved through analysis of water leaving radiances outside ‘traditional’ ocean color bands

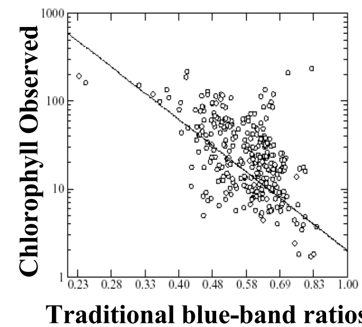
Approach: Greater spectral resolution in visible-near infrared

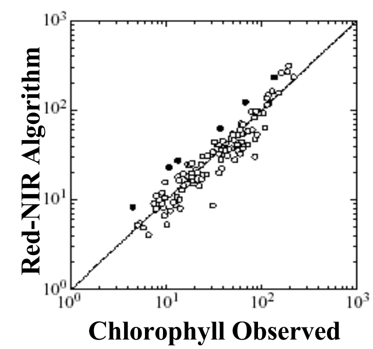
Minimum requirement: Aggregate bands every 20 nm from 500 – 800 nm

Optimal: 5 nm resolution 500 – 800 nm

Value added: coastal eutrophication, carbon sequestration hot-spot, nutrient loading effects (rivers, atmospheric N)







Ocean Approaches: Iron & Phytoplankton

Issue: Responses to iron enrichment
- dust, subsurface, fertilization
- physiology / pigment / biomass

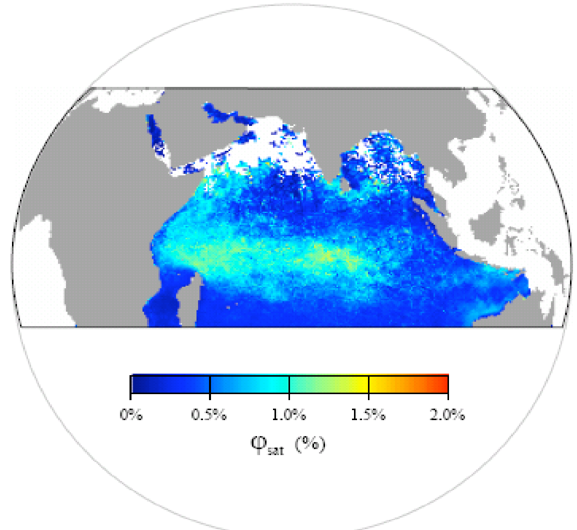
Status: Scientific understanding of iron stress effects matured. Response detection requires phytoplankton biomass, Pigment:C ratio, & fluorescence measurements

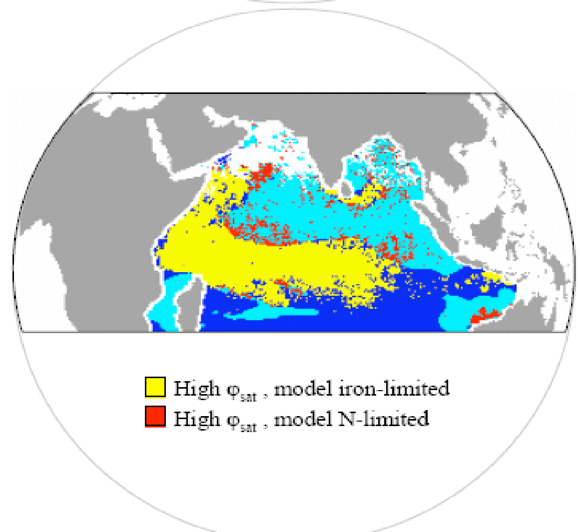
Approach: Inversion provides C & Pigment, fluorescence line height measurements

Minimum requirement: Inversion requirements for C & pigment as above, 10 nm fluorescence bands at 667, 678, 748 nm, 2 day global coverage

Optimal: 5 nm resolution 650 – 750 nm

Value added: coastal applications, HABS, strong ocean-atmosphere link





Ocean Approaches: Functional Groups

Issue: Calcite organisms & Nitrogen fixation responses to atmospheric events and ocean acidification

Status: Unique scattering signals of key functional groups.

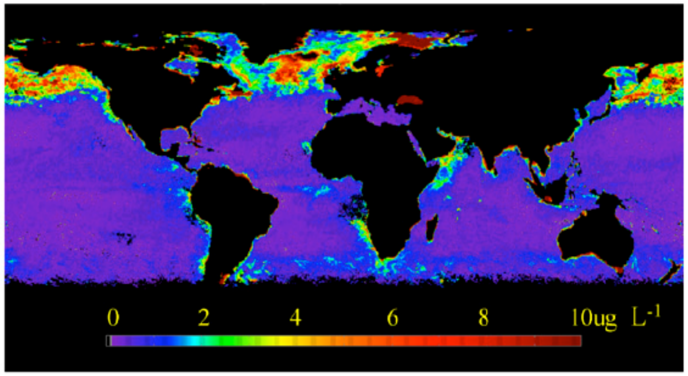
Approach: Empirical 'presence index' or inversion retrievals

Minimum requirement: 20 nm aggregate bands through visible, 2 day global coverage

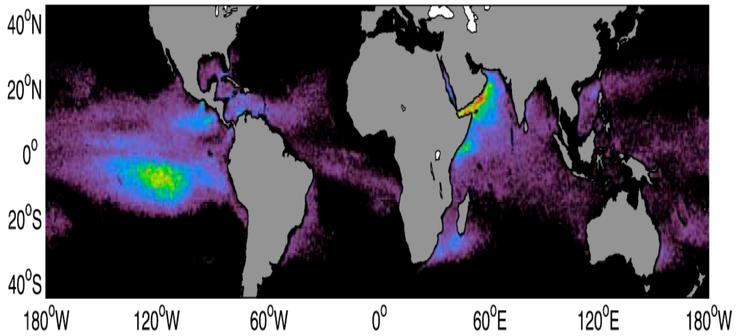
Optimal: 5 nm advantage unclear?

Value added: strong ocean-atmosphere link

Calcite



Nitrogen Fixers (*Trichodesmium*)



Ocean Approaches: Harmful Algal Blooms

Issue: Detect and monitor harmful algal blooms and bloom frequency

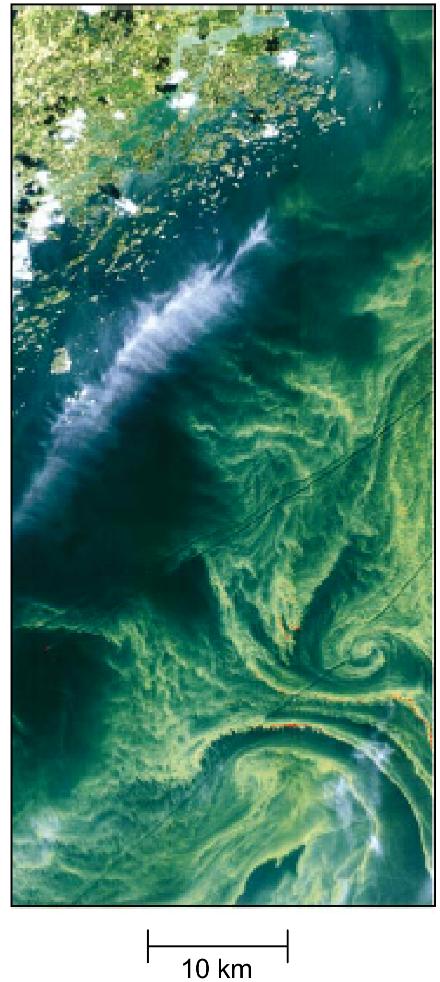
Status: Few HABs have been identified with globally unique optical properties, but regional approaches have been developed for identification and tracking. Many of these 'diagnostic' features require spectral resolution of 10 nm or better

Approach: High spectral resolution measurements in visible band

Minimum requirement: 10 nm resolution

Optimal: 5 nm resolution

Value added: health issues, links to climate change

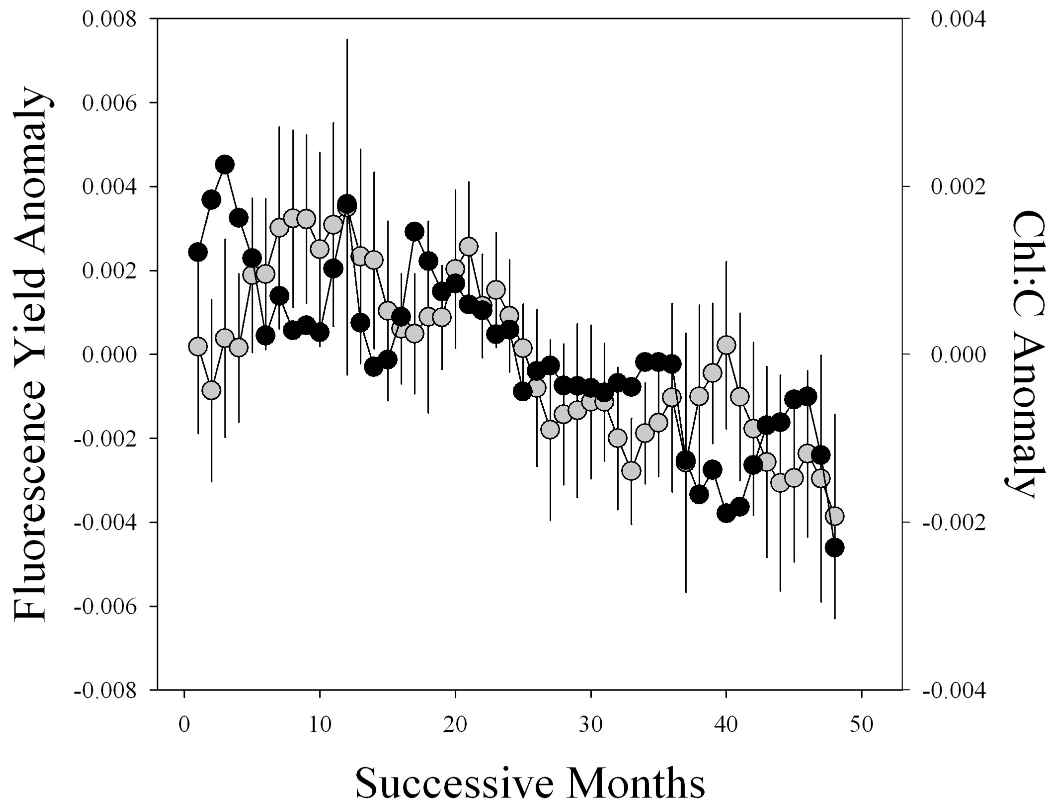


Massive cyanobacterial bloom in the Baltic Sea (July 2002) as seen by the Advanced Land Imager (Kutser et al 2004). Cyanobacteria have high concentrations of phycocyanin which gives an absorption peak near 625 nm that can be used as a bloom marker (e.g., Kutser 2004, Simis et al. 2005)

Ocean Approaches: Summary

- Inversion & fluorescence products ‘unforgiving’
  (implications on radiometric and atmospheric correction requirements)
- Subsurface lidar retrievals - carbon assessment & vertical profiling
- Product suite requires 345 – 800 nm spectral range, 5 nm resolution (optimal)
- Deposition events, bloom dynamics, and cloud clearing require 2-day global coverage
- Temporal trends – accurate sensor degradation characterization

Temporal Trends…



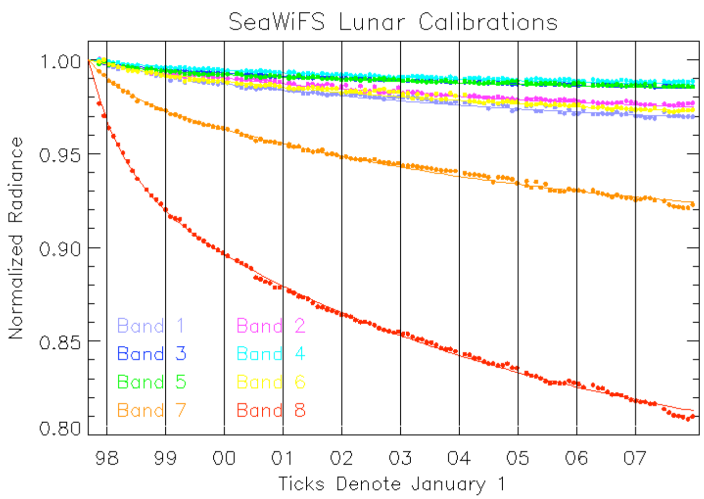
Bottom Line: **SeaWiFS remains the only ocean color sensor yet to produce a climate-quality data record.**

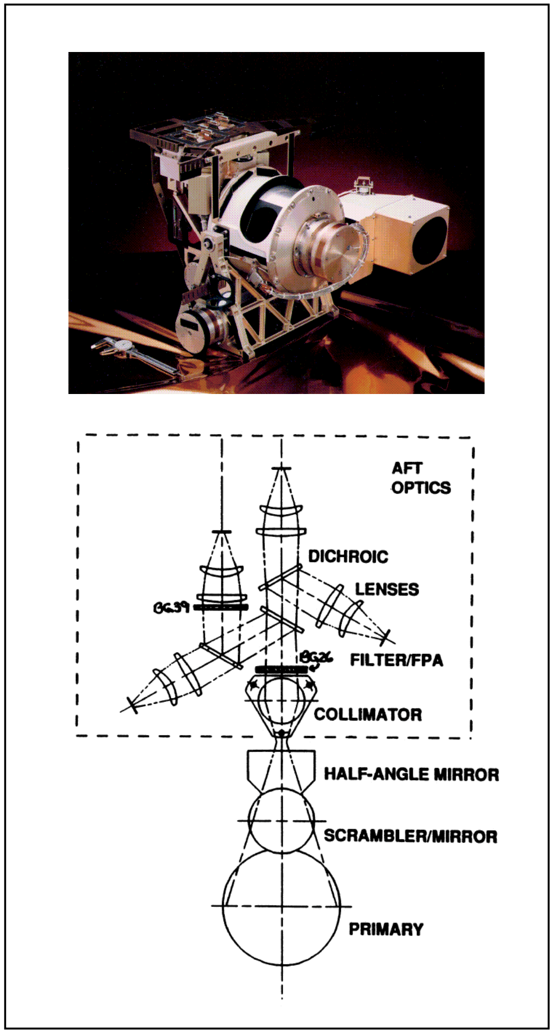
Take-home Message: ***Learn from Past Successes!***

Lessons Learned

Requirements for ACE

- Routine lunar viewing through same observational port as ocean observa[illegible]s
- Time-delay-integration des[illegible] (T[illegible] simplifies optics a[illegible] calibra[illegible]
- Thoro[illegible] [illegible]zation
- [illegible]
- [illegible] optical cross-talk
- [illegible]aturated over bright targets
- Sun-glint avoidance
- Regular data reprocessing post-launch



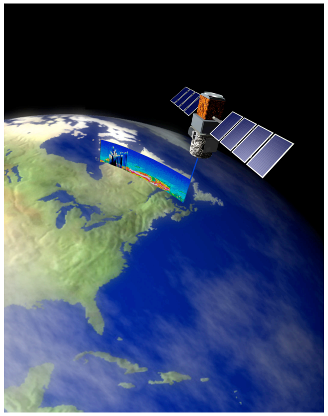


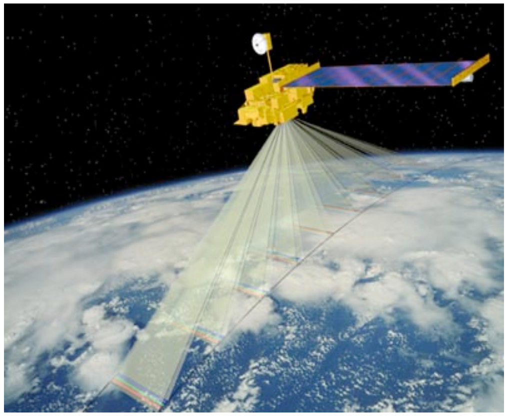
Atmospheric correction

• Advance product suite based on inversions and fluorescence requires significant improvements in atmospheric corrections
• Measurement into the UV spectral range where atmosphere is less transparent than in the visible.
• Global aerosol optical depths, heights, and absorption attributes for broad swath of ocean radiometer (Lidar & Polarimeter)
• Spectral anchoring at short and long wavelengths
• Observations in SWIR for bright coastal systems

Details to be provide by Chuck!

Atmosphere-Ocean Lidar: Aerosol profiling, subsurface particles, improved ocean products





Atmosphere-Ocean Polarimeter: Global aerosol coverage improved ocean products

Ocean Biology STM

Category	Focused Questions	Approach	Measurement Requirements	Instrument Requirements	Platform Requirements
Ocean Biology	• How do aerosols deposited on the ocean surface influence nutrient levels and stressors for ecosystems? • How do ocean biological processes influence aerosol and cloud distributions? • What are the standing stocks, transformation rates, and fates of marine organic carbon pools as well as inorganic particles. • How do climate and habitat changes influence the productivity and elemental cycles of the global oceans?	• Estimate atmospheric aerosol (dust) deposition to the ocean.Characterize the responses of marine ecosystem stocks and rates to aerosol inputs. • Compare historical atmospheric correction algorithms with results for a fully-resolved aerosol load and distribution. • Define environmental factors regulating the release of important atmospheric aerosols (e.g. DMS) and quantify flux and spatial distribution • Quantify carbon-standing stocks within global ocean ecosystems and their uncertainties. • Quantify ocean primary productivity and loss pathways to assess carbon export. • Estimate elemental fluxes from terrestrial to ocean margin to open ocean environments. • Characterize elemental fluxes between the upper water column and deeper ocean layers (including the near-shore sedimentary layer) • Distinguish key particle types and phytoplankton functional groups. • Determine how optically complex near-shore waters influence uncertainties in remote sensing data products. • Test and improve satellite-derived products and processes through comparison with field sea-truth data and modeling.	Measurement of water leaving radiances allowing the separation of absorbing and scattering constituents in the near ultraviolet and visible bands Measurement of water leaving radiances red and near-infrared for calculation of fluorescence line heights. . Measurement of total radiances in UV, NIR, and SWIR for atmospheric corrections. Measurement of cloud radiances to account for instrumental stray light	**Multi-wavelength radiometer** ozone column measurements to 5% Measurements from 345 nm to 800 nm with 5 nm resolution. 1000 to 1500 SNR for UV through visible for 20 nm aggregate bands, 180 to 750 SNR for 10 to 40 nm aggregate bands in the NIR and SWIR 0.5% radiometric accuracy 0.1% relative radiometric stability 58.3^{0} cross track scanning +20 to -20 degree sensor tilt for glint avoidance	Orbit at 650 km for 2 day coverage Sun synchronous 10:30AM to 2:30 PM crossing time .
			Measurement of aerosol heights and optical thickness to identify and correct for absorbing aerosols in the calculation of water-leaving radiances	**Lidar (as with Air Quality)**	
			Measurements of aerosol heights over a wide swath to identify and correct for absorbing aerosols in the calculation of water-leaving radiances Measurement of oceanic polarized return to improve typing of oceanic particles.	**Polarimeter (as with Air Quality)**	

Thank You

VIIRS Issues

➢**List <u>not</u> in priority order:**

1- VisNIR IFA Optical Crosstalk*

2- VisNIR ROIC Static Electronic Crosstalk

3- VisNIR Dynamic Crosstalk

4- LWIR/SMWIR Static Crosstalk and/or Ghosting

5- Gain Switch Noise and Linearity

6- Stray Light Contamination

7- Reflective Bands Uniformity

8- Emissive Bands Calibration

9- Relative Spectral Response (RSR) Measurements – characterization data receipt in a timely fashion

10- End-to-End Calibration (SD-SAS-SDSM)

11- Sensor Stability (Temperature, SC voltage, EMI/EMC)

12- Response Versus Scan (RVS) Angle

13- Characterization of Polarization Sensitivity

14- Ambient to T/V to On-orbit Spatial Performance

➢ **In addition….**

VIIRS has fewer visible bands than SeaWiFS or MODIS, and no fluorescence capability

VIIRS data will have same striping issues as MODIS

VIIRS on NPP will not have lunar viewing capability through its ocean observation port

Lunar Calibration Maneuvers are not even considered for NPOESS C1 and beyond: no lunar roll, SD yaw, or deep space pitch maneuvers

VIIRS field Cal-Val plan is underdeveloped

Bottom Line: the ability of VIIRS on NPP and beyond to meet the Ocean Color science requirements for climate quality data is severely compromised.

VIIRS Issues

Limits in NASA's role imposed by the Level-1 requirements (signed off 2003):

2.1.2.1 The Science Data System (SDS) shall be designed with the assumption that the operational IPO IDPS generated NPP EDRs do not require reprocessing or re-computation in order to support climate research needs. Consequently, the SDS will not be designed to routinely generate climate data products which require long-term archival in ADS.

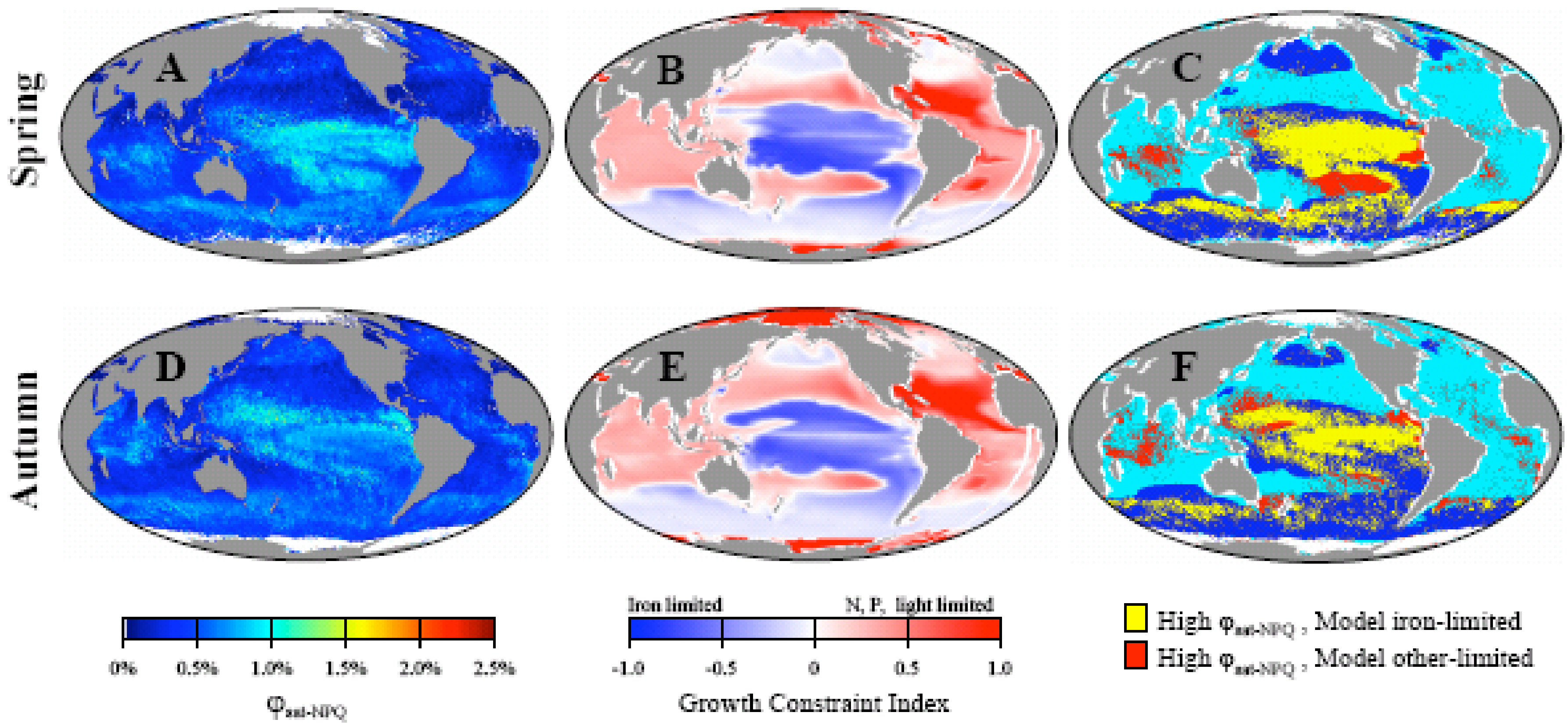
2.1.2.3 In developing the SDS, the Project shall assume that EDRs produced by the IDPS are climate quality and put in place the capability to test that hypothesis in order to contribute to improving the quality of future EDRs. The SDS shall provide suggested algorithm improvements to the IDPS.

Note:

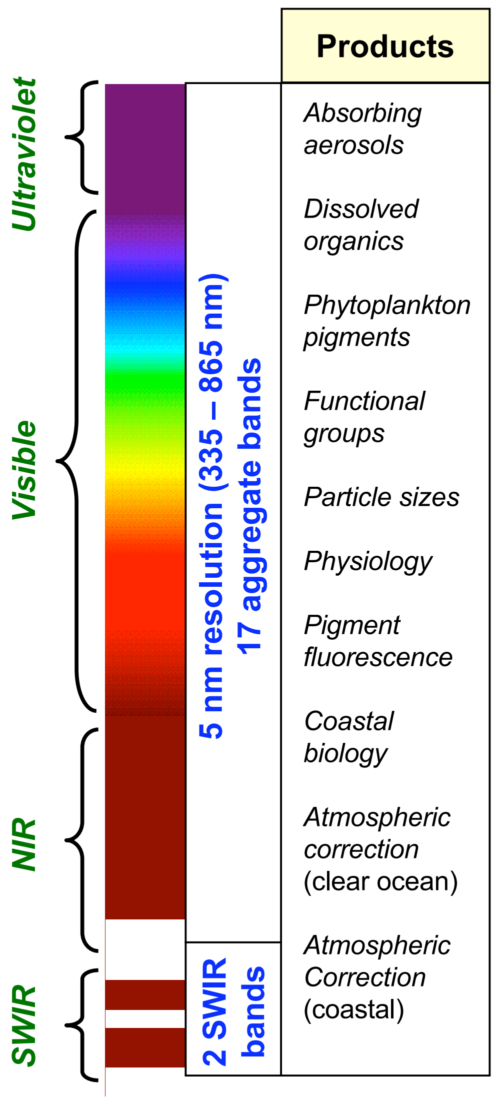
1) The assumption underlying these requirements is demonstrably false, since no satellite sensor has ever produced research-quality data without reprocessing; and

2) NASA NPP Project (SDS) funding is not to produce better products than the EDRs.

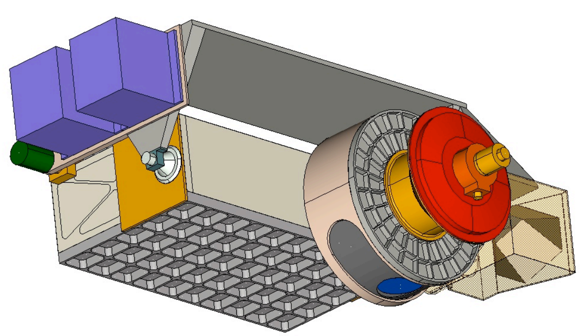
Global Fluorescence

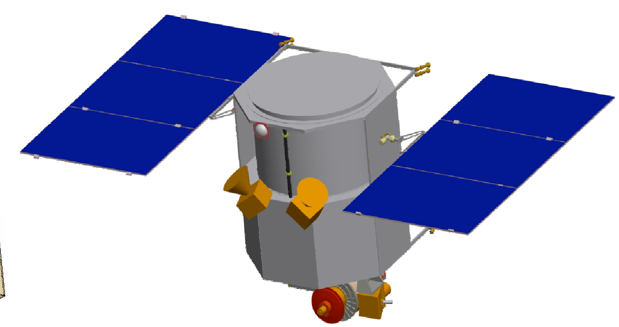


GOCECP



- Spectral Range: 340 to 1400 nm, 5 nm resolution, 20 aggregate bands
- Improved fluorescence detection
- Sun synchronous orbit, noon descending node
- Monthly Lunar calibration maneuver and measurements through ocean observation port
- Daily Solar Calibration (pole)
- Spectral calibration (solar based)
- Sun glint avoidance
- 0.1% radiometeric accuracy on orbit
- < 1% polarization sensitivity
- Data collected to 70° latitude of subsolar point
- Spatial resolution: 1 km

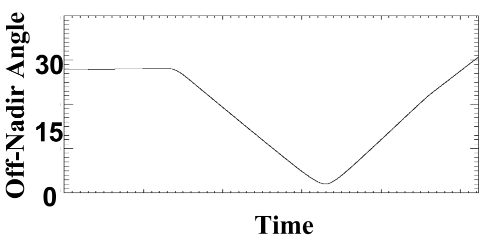


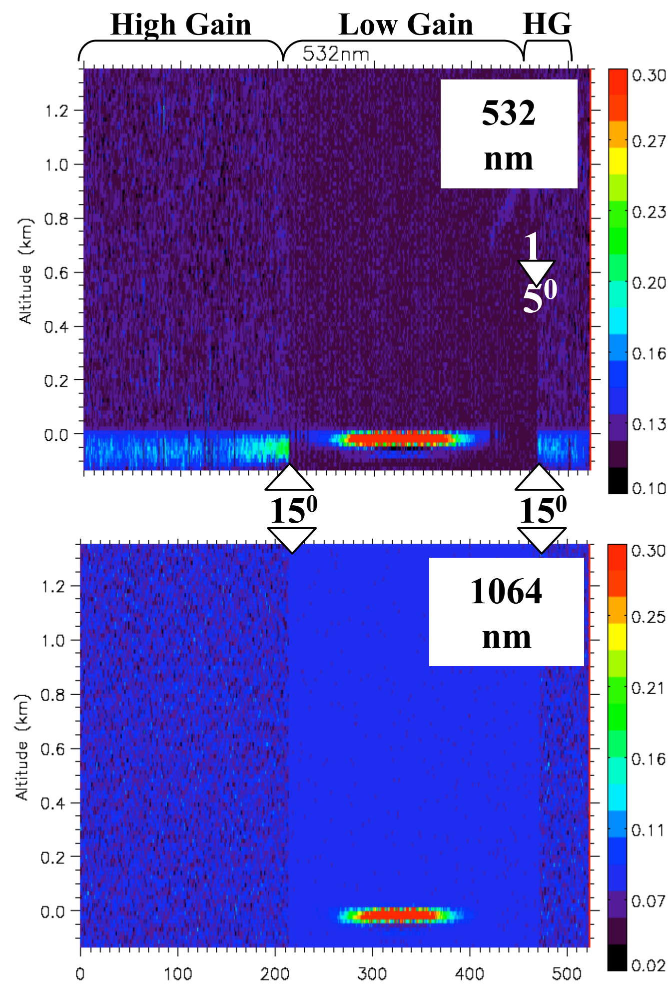


Shootin' lasers at Mother Earth

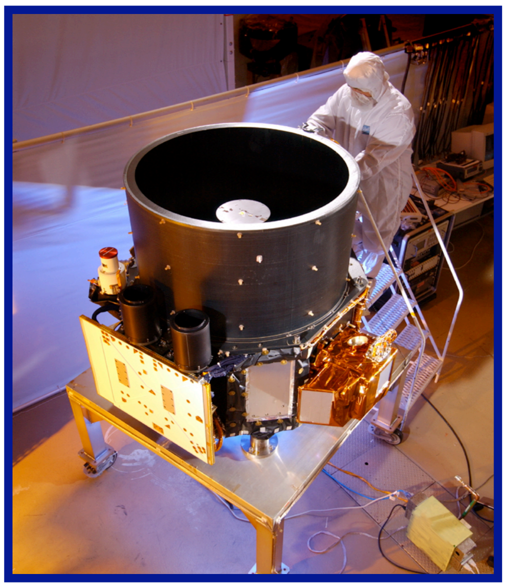
Lidar In-space Technology Experiment (LITE)

- 3-wavelength Nd-Yg lidar
- Space Shuttle in 1994
- Multi-angle (+/-30^0) maneuvers over Lake Superior and Gulf of California





Shootin' lasers at Mother Earth

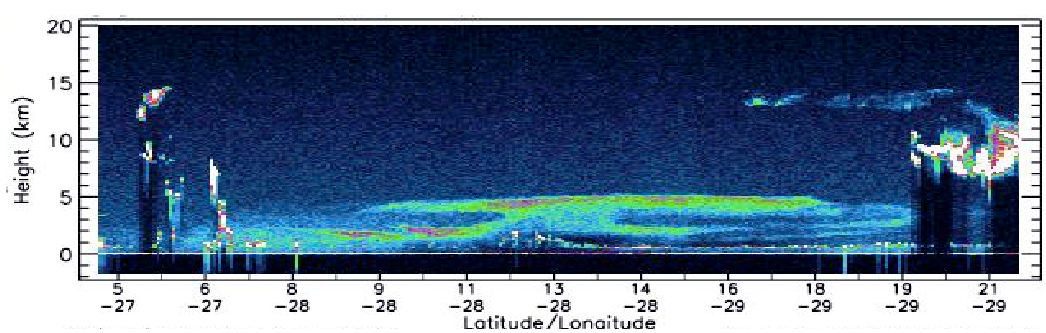


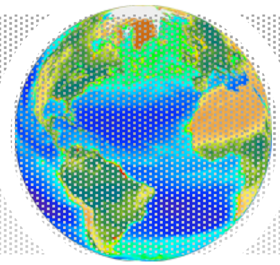
CALIPSO's CALIOP lidar

CALIOP

Cloud-Aerosol Lidar with Orthogonal Polarization

- 2-wavelength, 3-channel (5322, 532ζ, 1064)
- 110 mJ Nd:Yg laser (@532 & 1064)
- Repetition rate = 20.25 Hz
- 1 m telescope
- Footprint/FOV = 100 m / 130 :rad
- Variable vertical resolution to approximately 30 m in air
- Aerosol height and thickness for AOD > 0.005



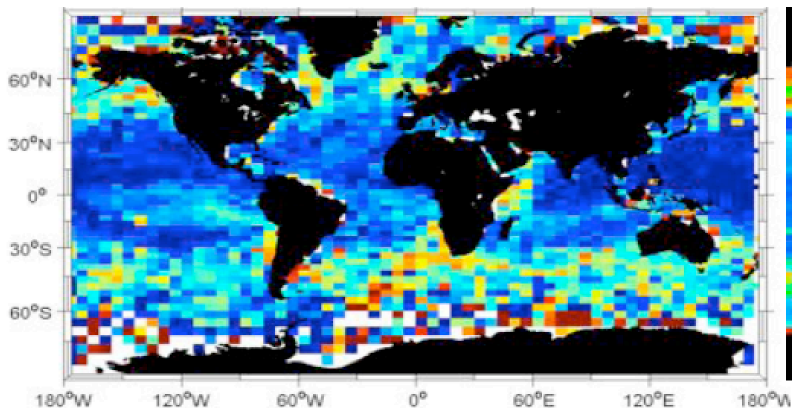


Shootin' lasers at Mother Earth

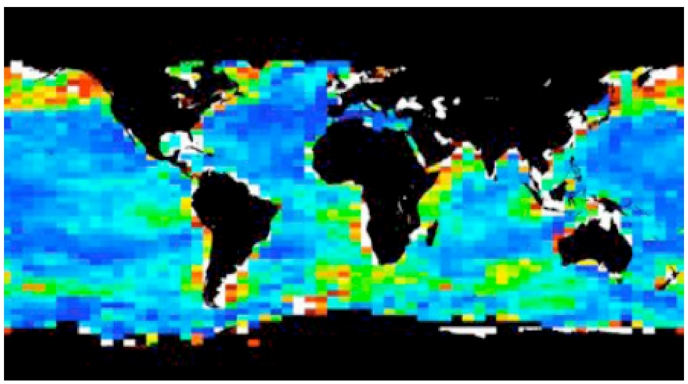
First Result: Ocean Particulate Backscatter

*Study conducted by **Dr. Yong Hu**, NASA Langley Research Center*

CALIOP subsurface backscatter



SeaWiFS backscatter from GSM model



1. ***Statistics:*** roughly 3600 lidar shots per 3^0X6^0 grid box
2. ***Application:*** an independent, active measurement of particle abundance for estimating particulate organic carbon (POC), phytoplankton carbon biomass, and for cross-calibration with passive ocean color inversion products

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