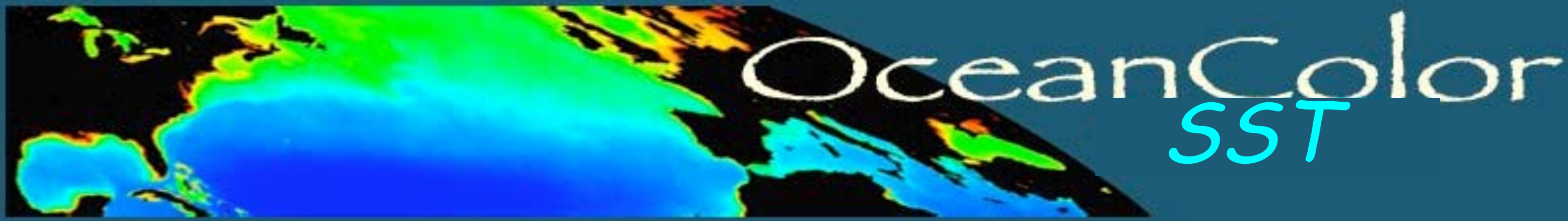


Satellite Remote Sensing of Ocean Color and Temperature

Bryan Franz

NASA Ocean Biology Processing Group

NASA's Goal

To make available the highest quality ocean color (and sst) data to the broadest user community in the most timely and efficient manner possible.

NASA Ocean Biology Processing Group

- Ocean Color

- Missions to Measurements
  - Sensor calibration/characterization
  - Product validation (SeaBASS MDB)
  - Algorithm development and evaluation (NOMAD)
  - User processing and display (SeaDAS)
  - User support (Ocean Color Forum)

- Global processing & distribution
  - SeaWiFS
  - MODIS
  - CZCS
  - OCTS

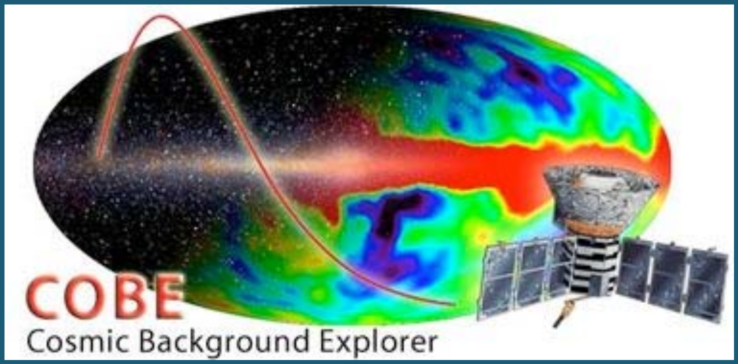
- SST processing for MODIS

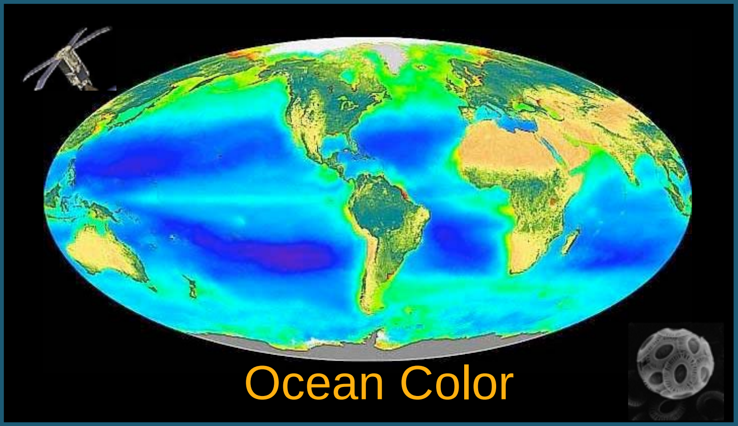
My Background

Aeronautical Engineering
aerodynamic design

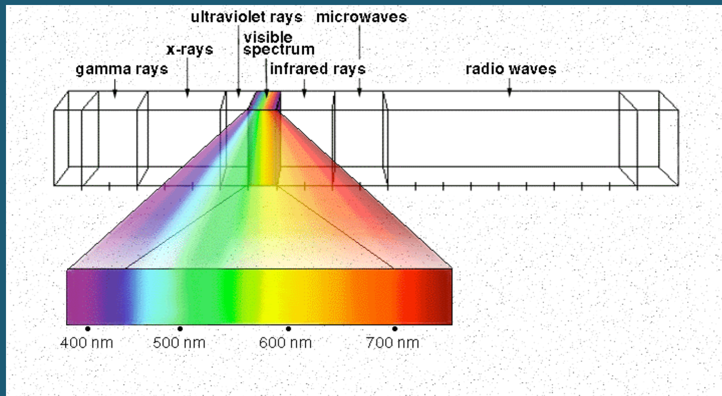
Space Science
interplanetary dust modeling
instrument calibration

Earth Science
atmospheric correction
calibration & validation
sensor intercomparison

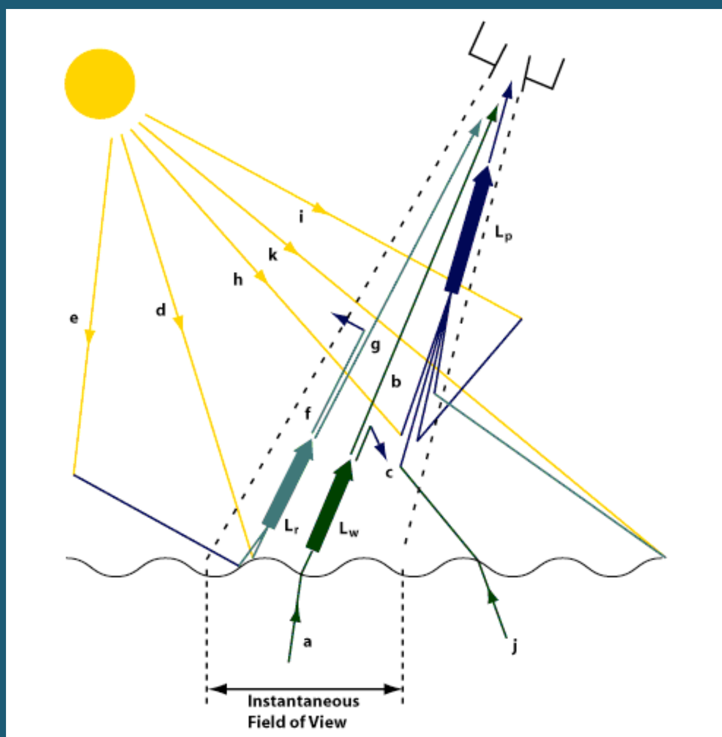




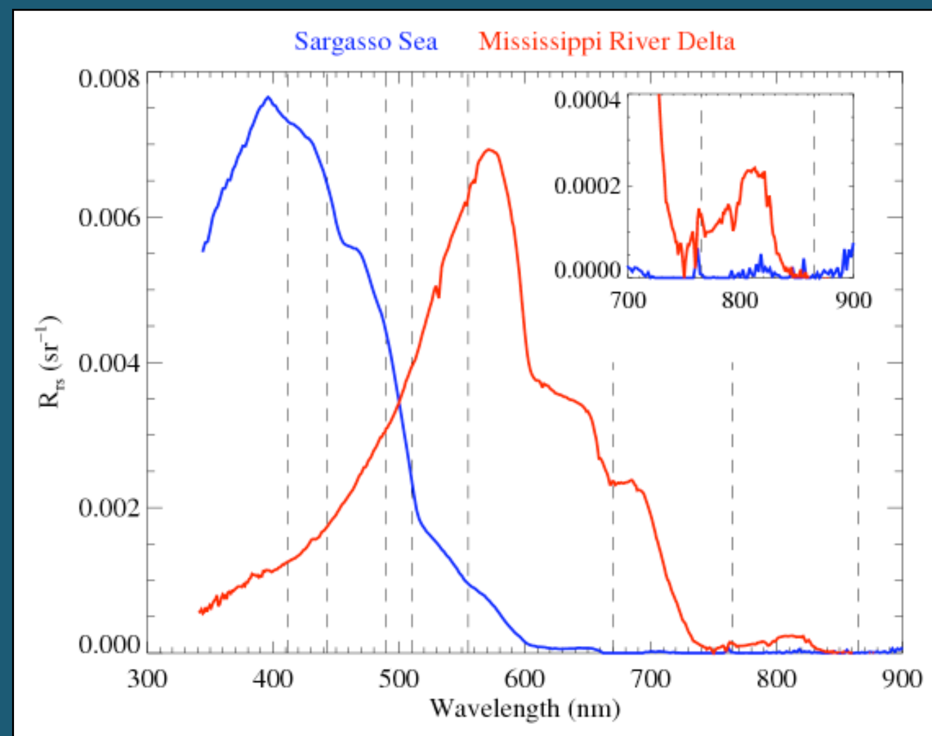
What is ocean color?



Ocean color is the measurement of spectral distribution of radiance (or reflectance) upwelling from the ocean in the visible regime.



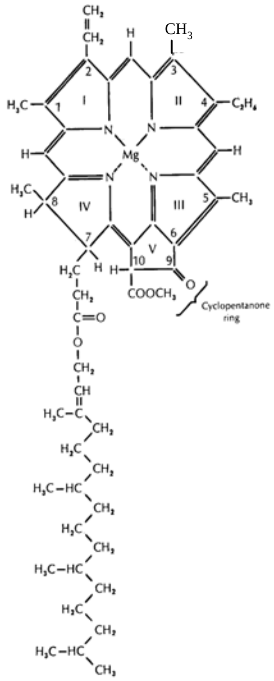
Marine Spectral Reflectance

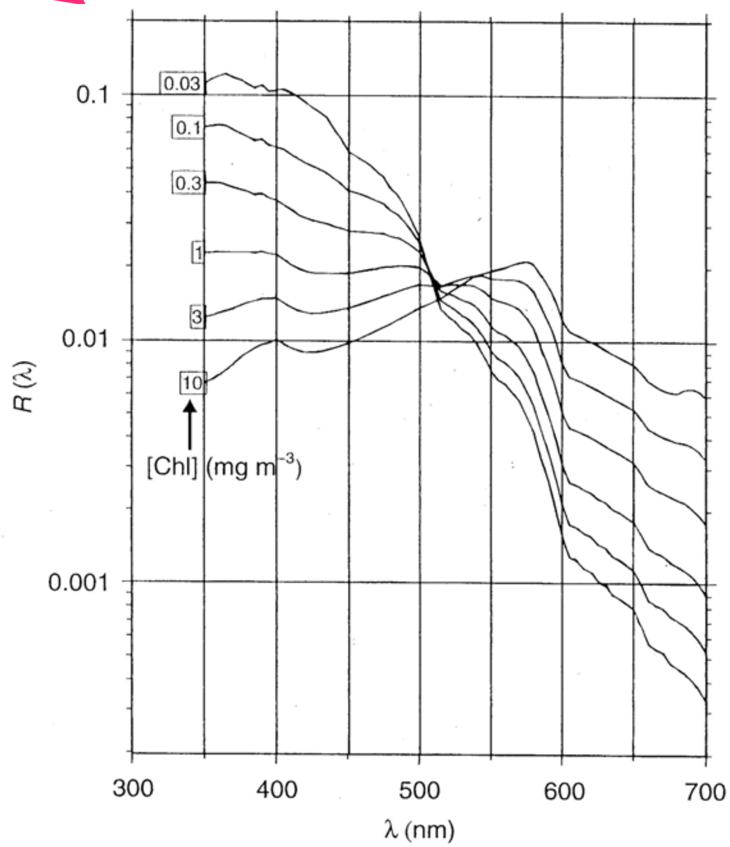


Spectral Wavelength (λ)

Quantifying Phytoplankton Processes Remotely

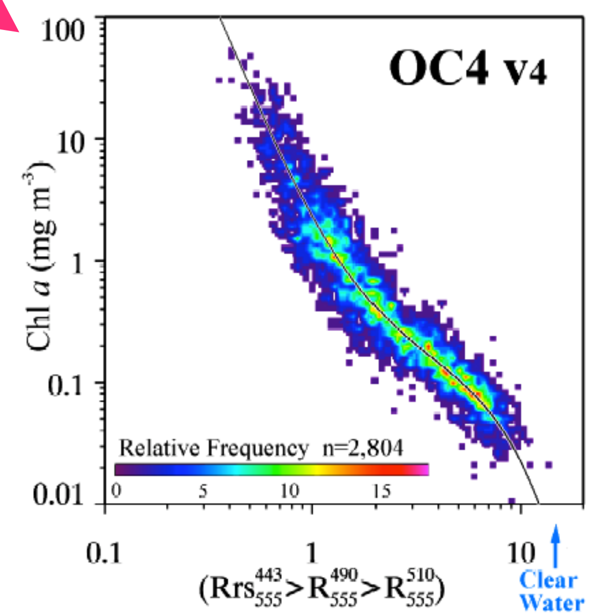
Chlorophyll-a





Marine Spectral Reflectance

Chlorophyll Algorithm



Phytoplankton

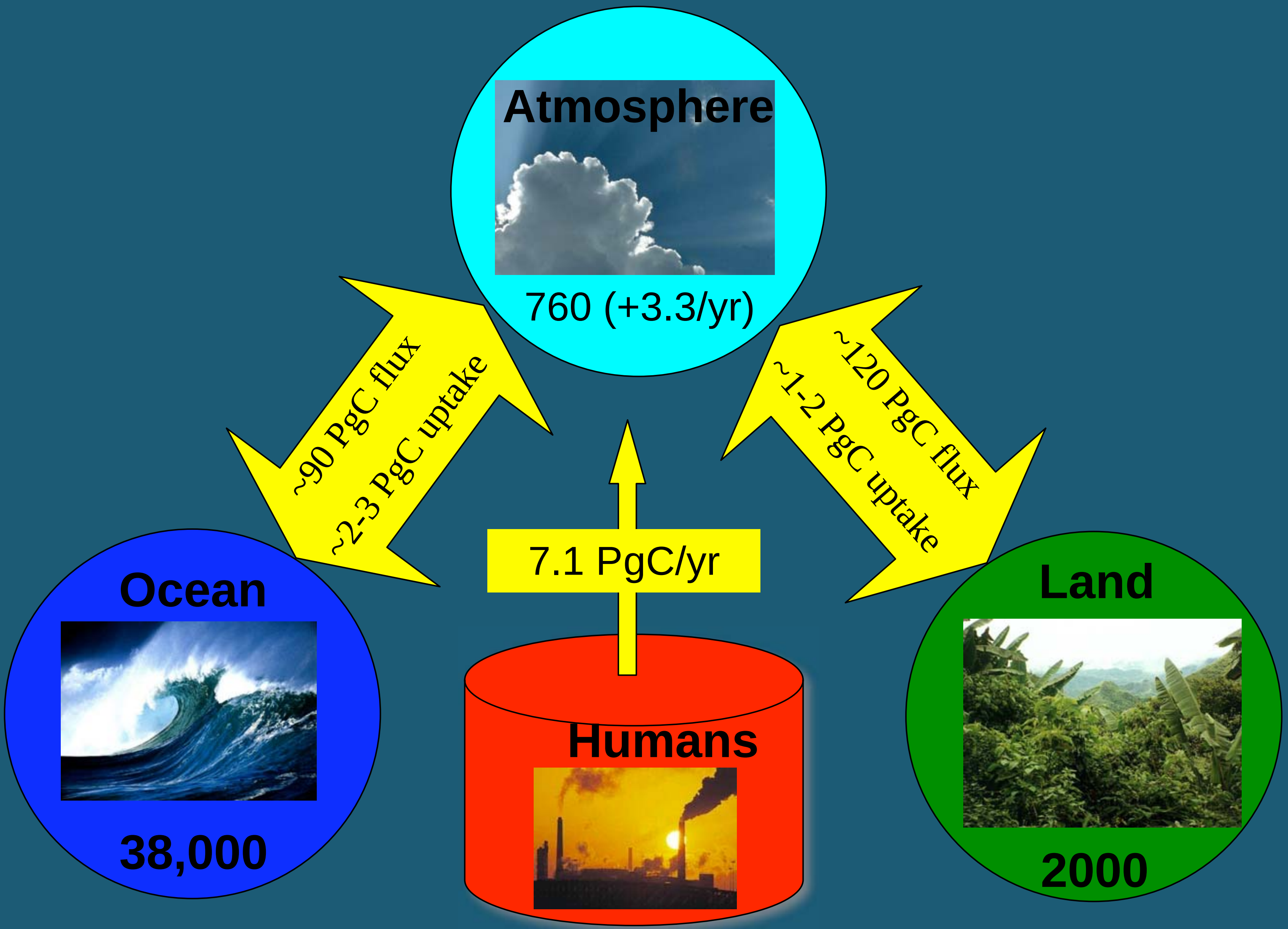
the chlorophyll concentration that we observe is associated with the distribution of phytoplankton

phytoplankton are microscopic plants that represent the first link in the marine food chain

the patterns of distribution are related to both physical and biological processes

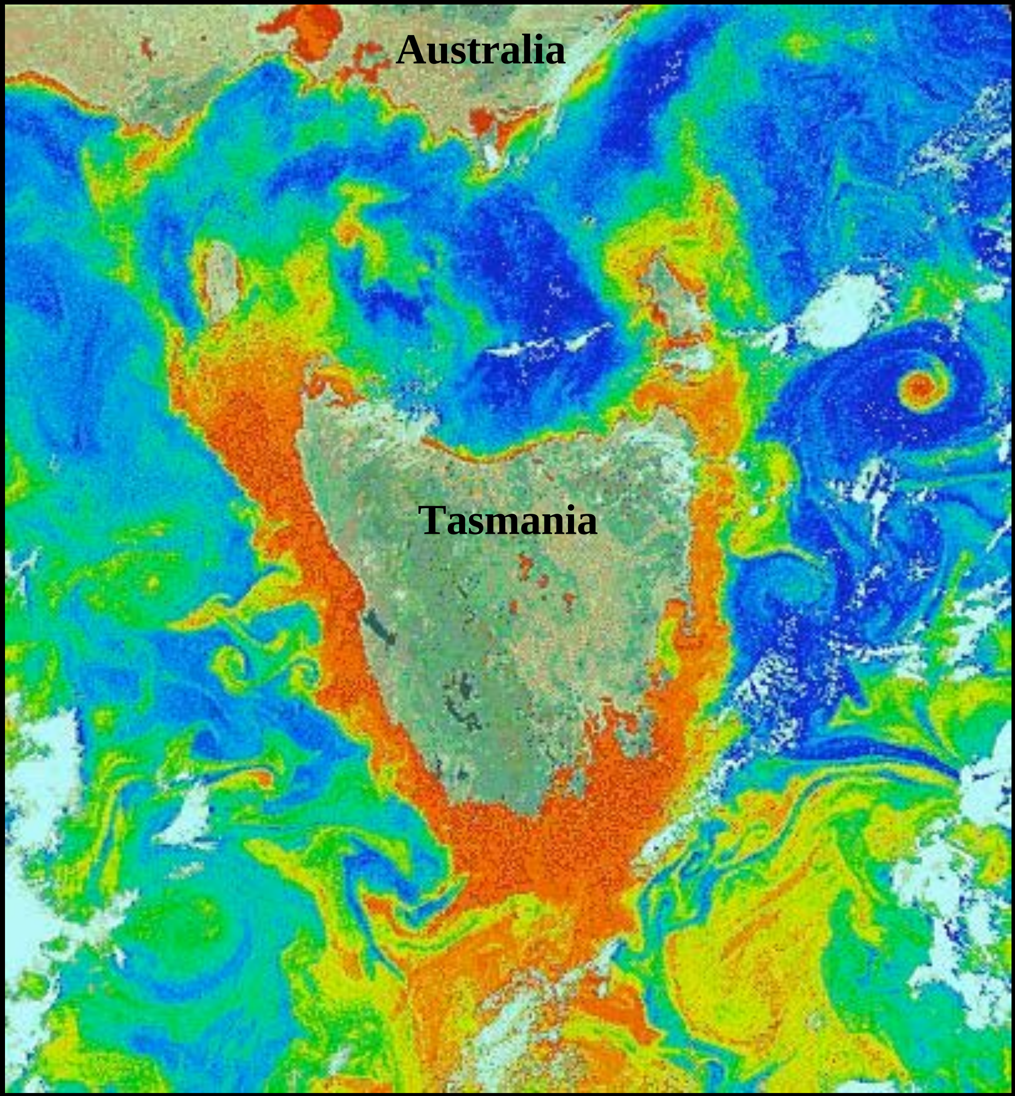
phytoplankton require light, water, nutrients, and carbon dioxide to grow

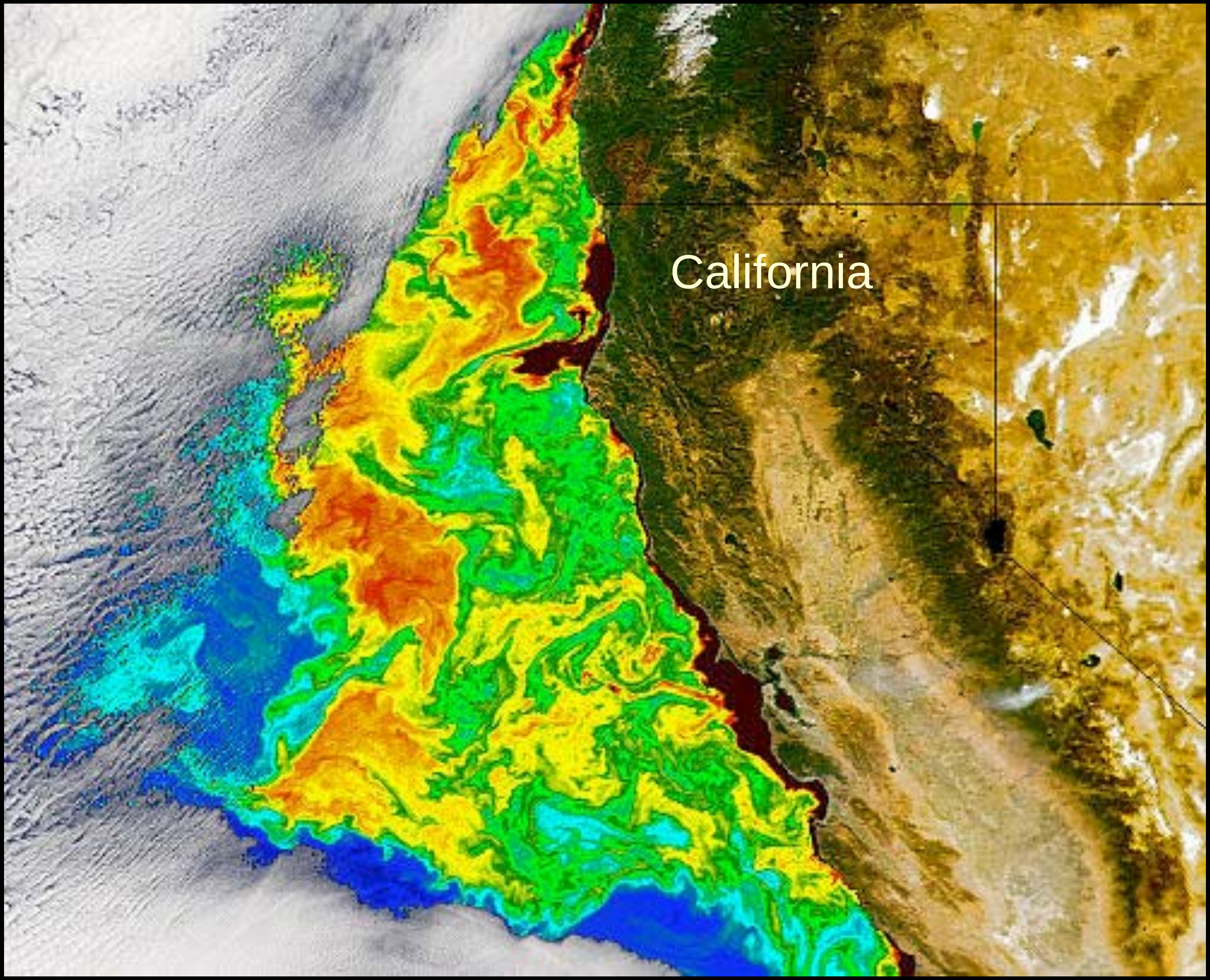
Global Carbon Budgets

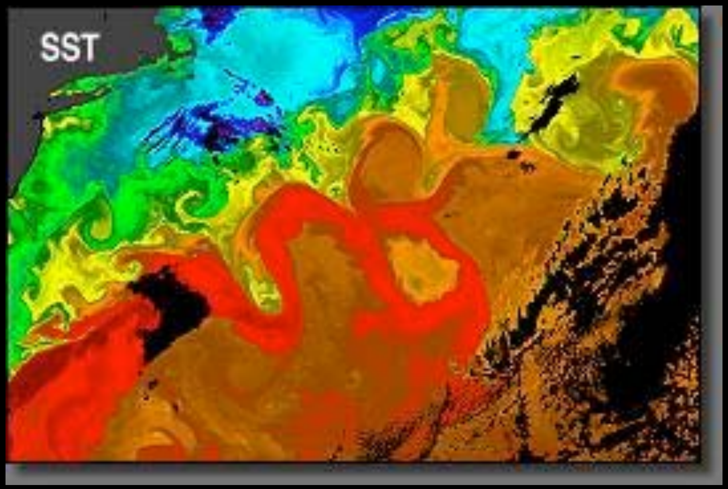


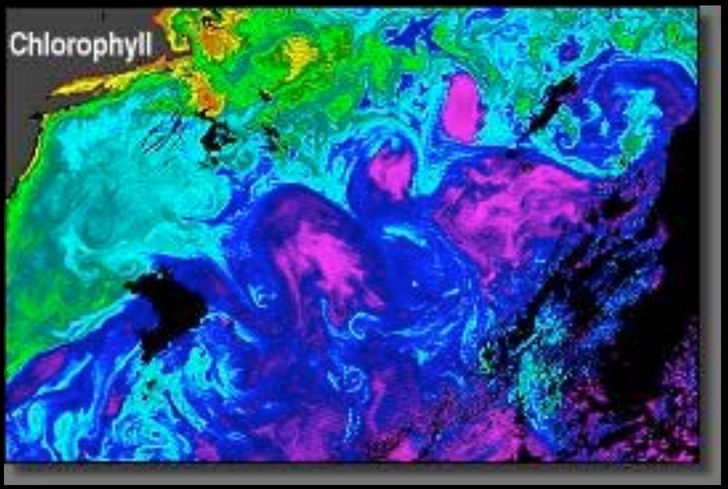
Petagrams (Pg) of Carbon

Why measure phytoplankton from space?


Australia
Tasmania


California





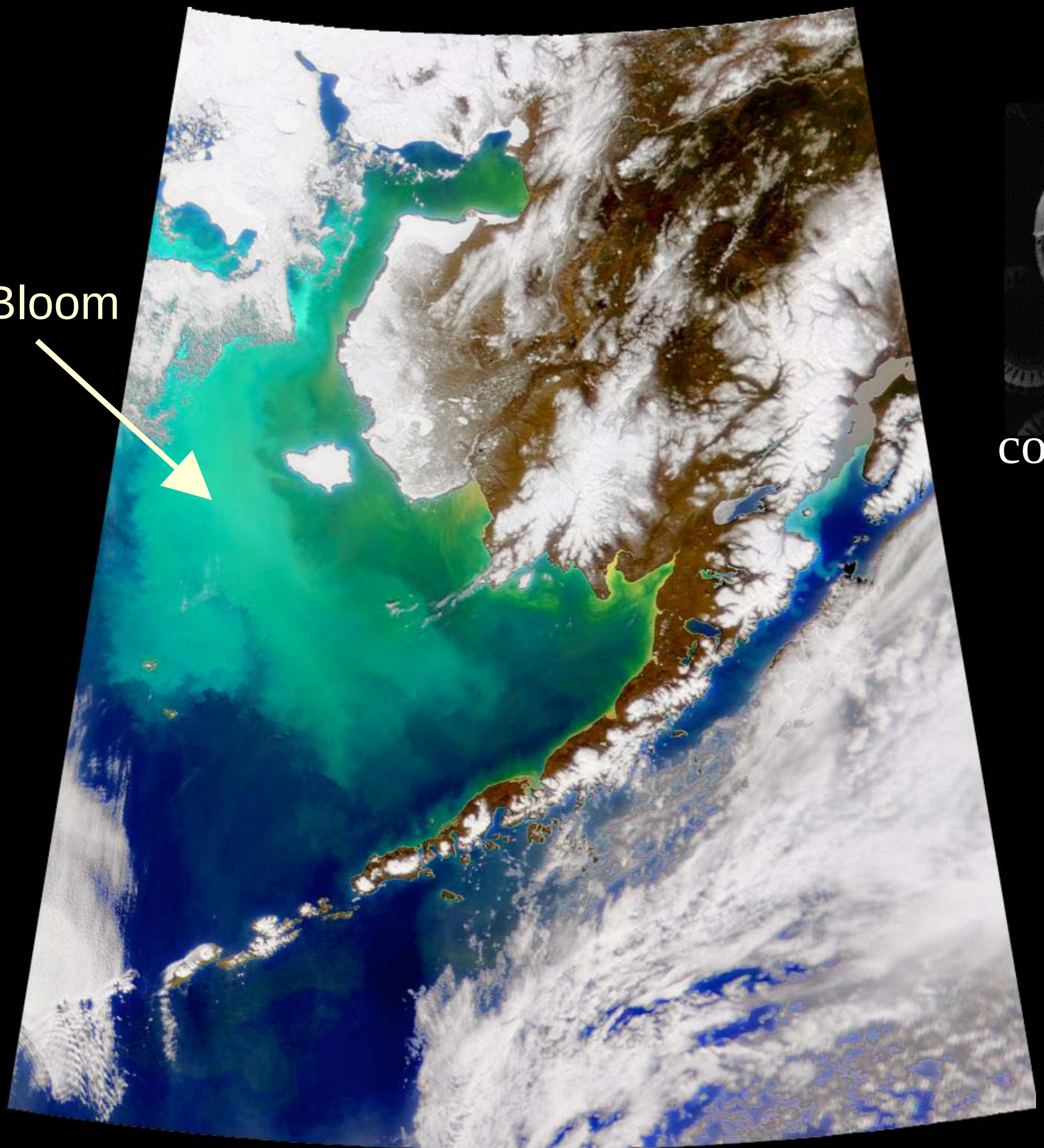
The warm heart of the Gulf Stream is readily apparent in the top SST image. As the current flows toward the northeast it begins to meander and pinch off eddies that transport warm water northward and cold water southward. The current also divides the local ocean into a low-biomass region to the south and a higher-biomass region to the north.

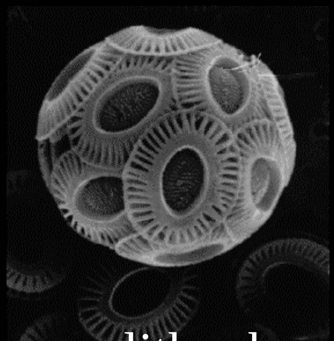
The data were collected by MODIS aboard Aqua on April 18, 2005.

Impact to Human Health

A toxic bloom of the cyanobacteria nodularia spumigena was reported in the Baltic Sea. On 24 July 2003, SeaWiFS captured this view of the bloom.

Impact to Fisheries





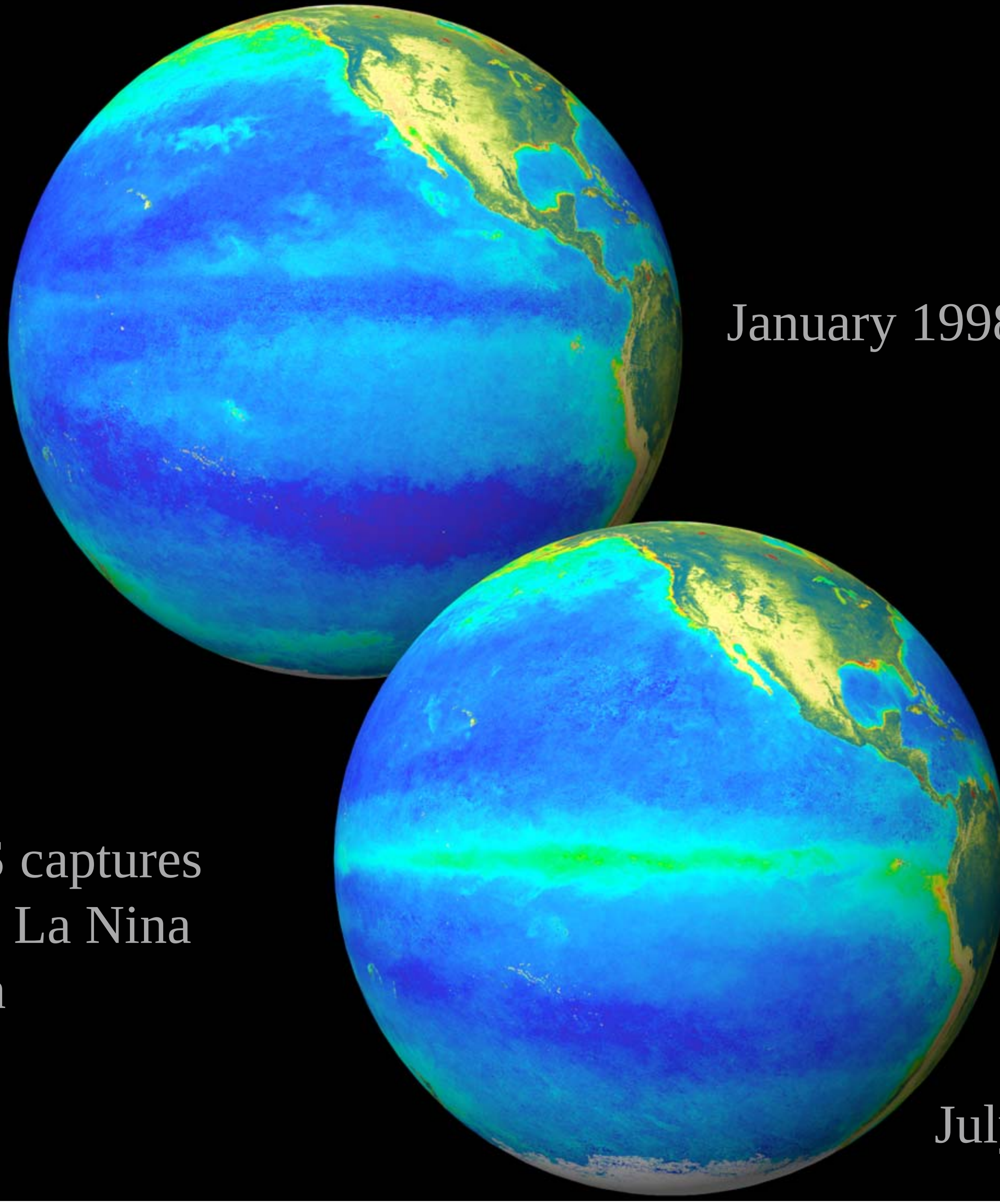
coccolithophore

Impact of Natural Disasters

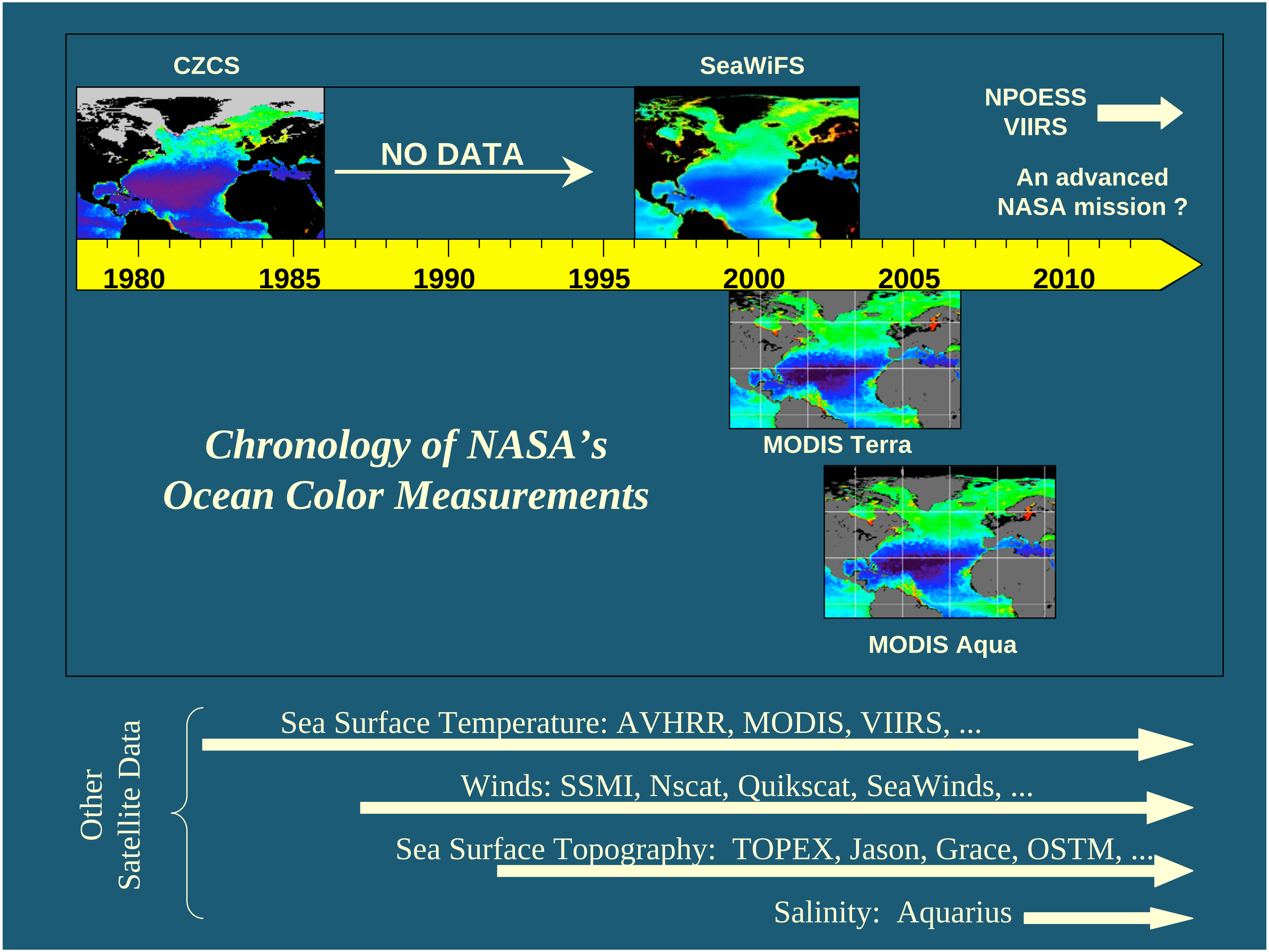
Hurricane Floyd

- massive flooding
- rivers carried
  - sediment
  - sewage
- discharged into coastal areas
- resulted in anoxic conditions in bay

Sept. 23, 1999



SeaWiFS captures El Nino / La Nina transition

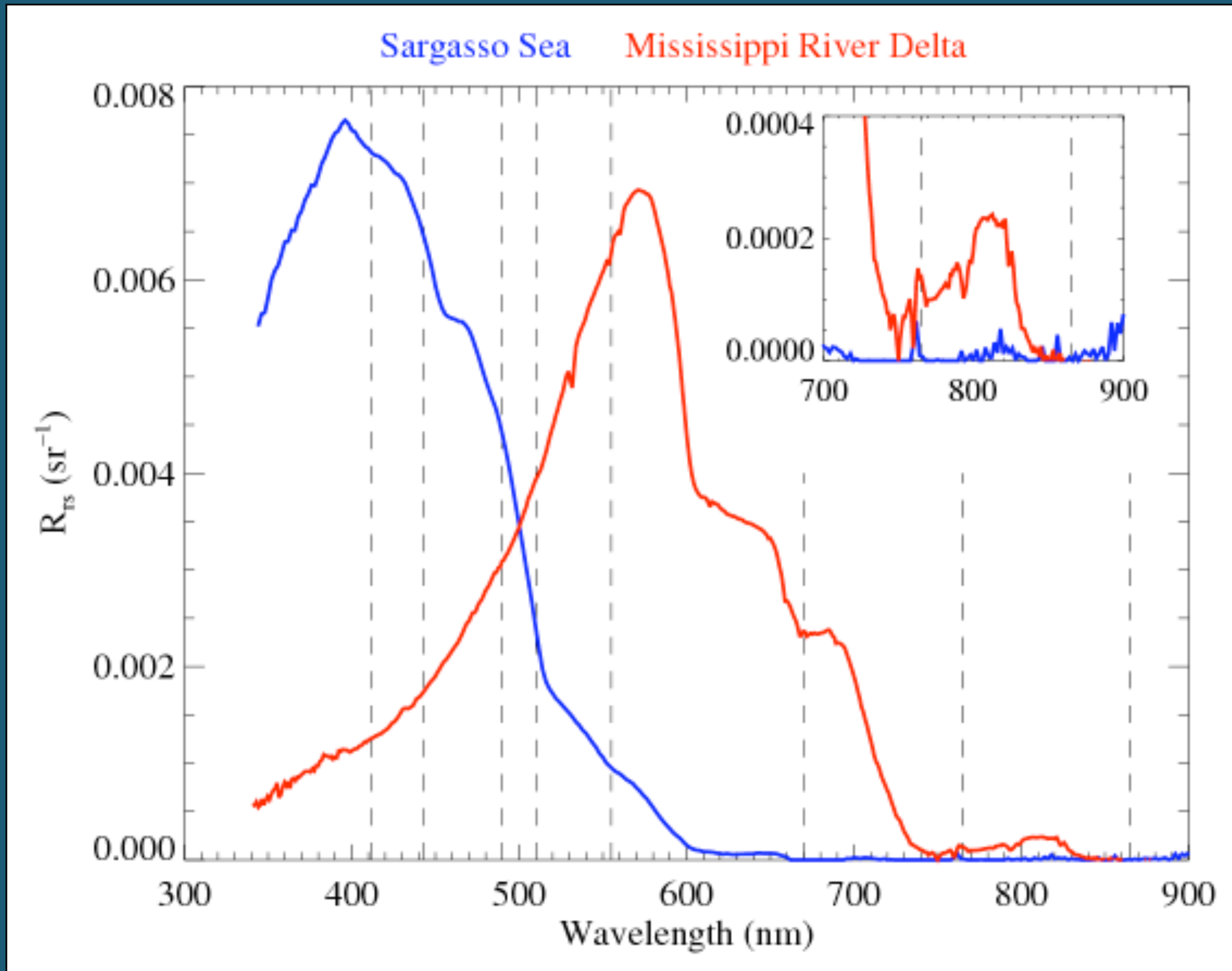

CZCS
SeaWiFS
NPOESS
VIIRS
NO DATA
An advanced
NASA mission ?
1980
1985
1990
1995
2000
2005
2010
MODIS Terra
MODIS Aqua
Chronology of NASA's
Ocean Color Measurements
Other
Satellite Data
Sea Surface Temperature: AVHRR, MODIS, VIIRS, ...
Winds: SSMI, Nscat, Quikscat, SeaWinds, ...
Sea Surface Topography: TOPEX, Jason, Grace, OSTM, ...
Salinity: Aquarius

Operational MODIS Ocean Band Suite

VIS/NIR

Ocean Color

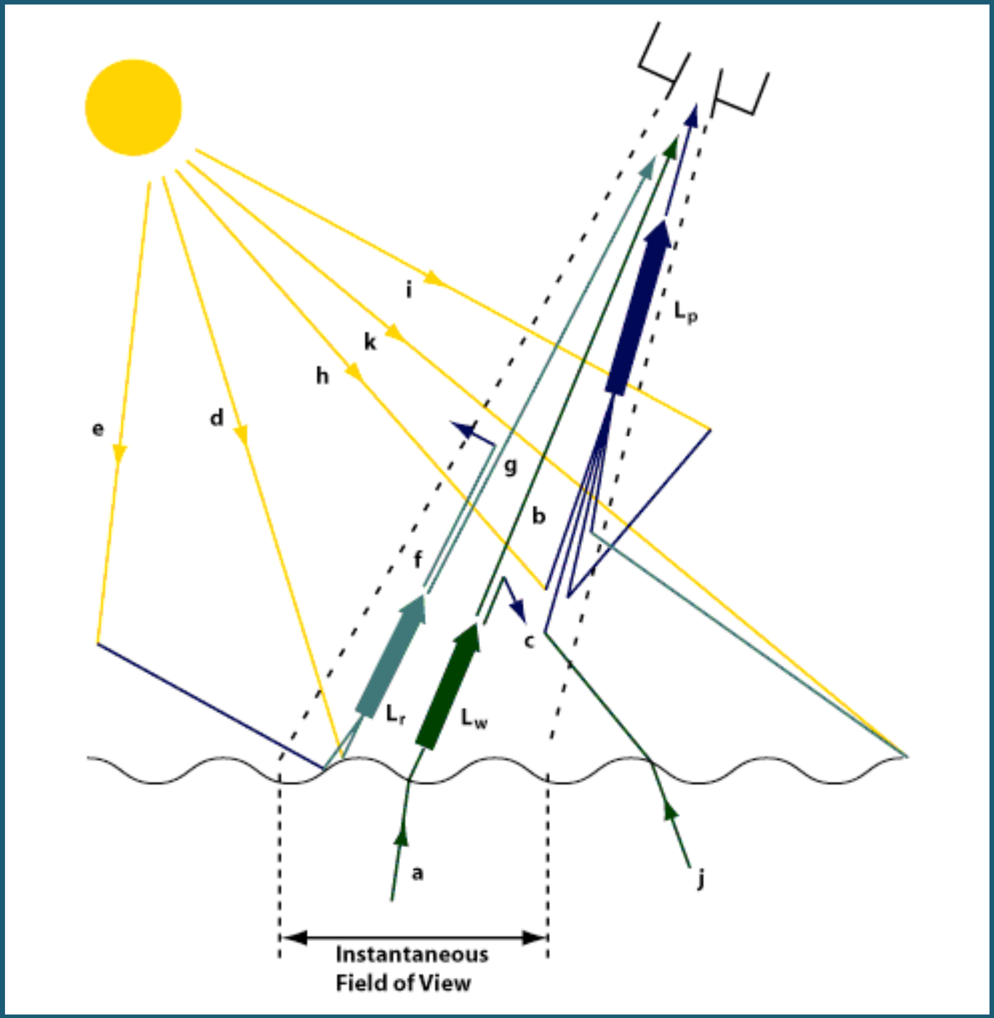
Band Number	Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)	SNR at L_{typ}	L_{typ} mW cm^{-2} μm^{-1} sr^{-1}	L_{max} mW cm^{-2} μm^{-1} sr^{-1}
8	412	15	1000	1773	7.84	26.9
9	443	10	1000	2253	6.99	19.0
10	488	10	1000	2270	5.38	14.0
11	531	10	1000	2183	3.87	11.1
12	551	10	1000	2200	3.50	8.8
13	667	10	1000	1962	1.47	4.2
14	678	10	1000	2175	1.38	4.2
15	748	10	1000	1371	0.889	3.5
16	869	15	1000	1112	0.460	2.5



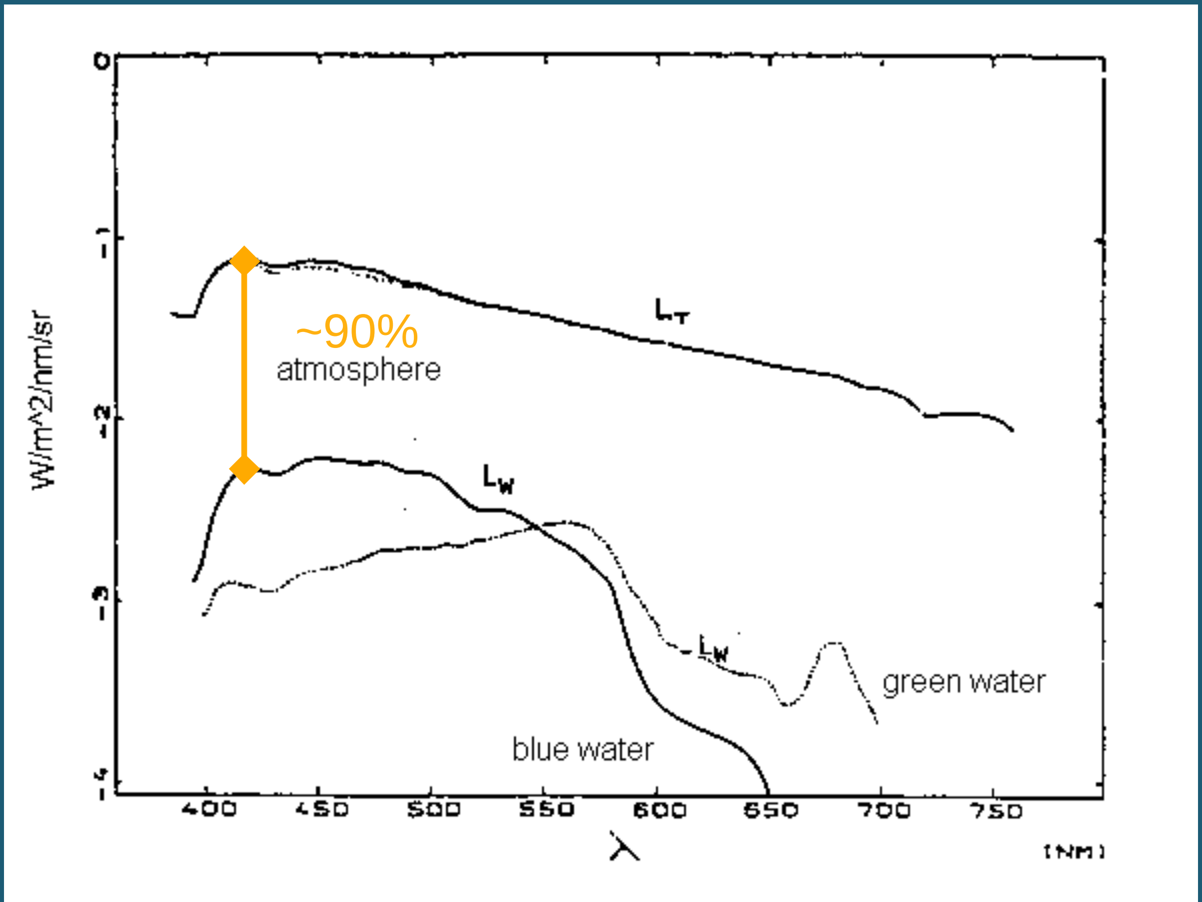
Sargasso Sea
Mississippi River Delta
0.008
0.006
0.004
0.002
0.000
R_{rs} (sr^{-1})
300
400
500
600
700
800
900
Wavelength (nm)
0.0004
0.0002
0.0000
700
800
900

Light Paths to the Sensor

Scattering and Attenuation of Reflected Solar Bands



Ocean Color from Space



1% error in instrument calibration or atmospheric model
~10% error in water-leaving radiance

Effects of the Atmosphere

- Gaseous absorption (ozone, water vapor, oxygen)
- Scattering by air molecules (Rayleigh)
- Scattering and absorption by aerosols (haze, dust, pollution)
- Polarization (MODIS response varies with polarization of signal)

Rayleigh (80-85% of total signal)

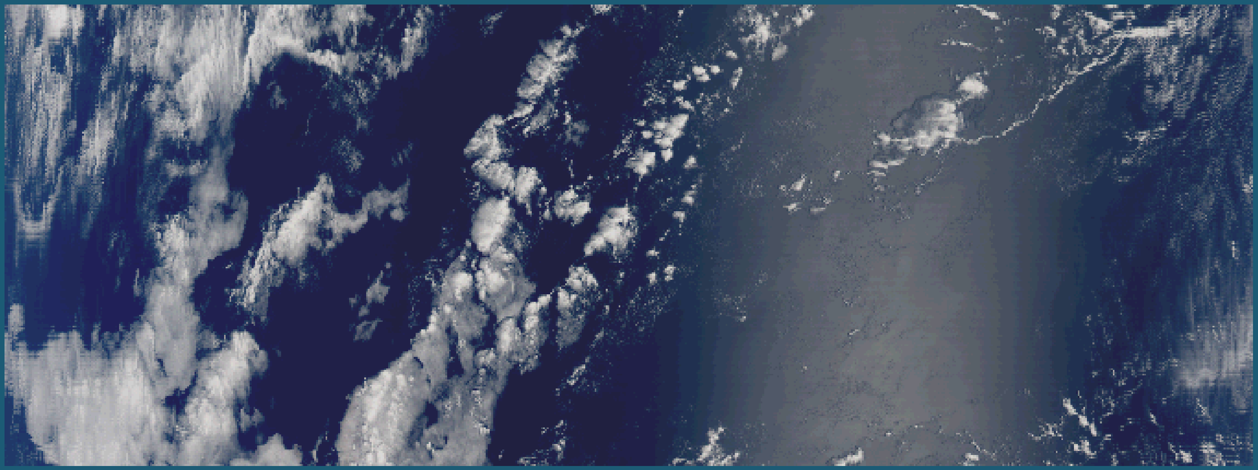
- small molecules compared to nm wavelength, scattering efficiency decreases with wavelength as λ^{-4}
- reason for blue skies and red sunsets
- can be accurately approximated for a given atmospheric pressure and geometry (using a radiative transfer code)

Aerosols (0-10% of total signal)

- particles comparable in size to the wavelength of light, scattering is a complex function of particle size
- whitens or yellows the sky
- significantly varies and cannot be easily approximated

Surface Effects

Sun Glint



White Caps

Corrections based on statistical models (wind & geometry)

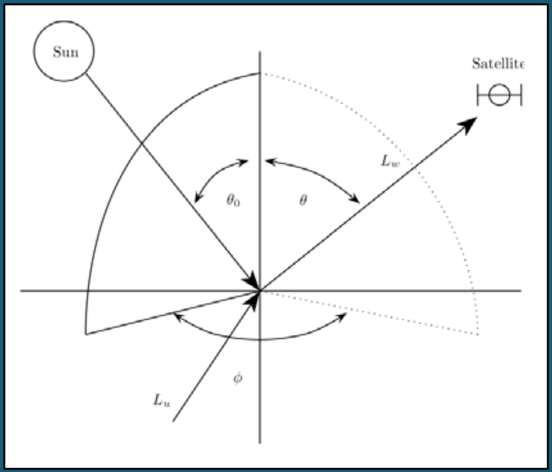
Atmospheric Correction

TOA gas pol glint whitecap air aerosol

$t_d(\lambda)\ L_w(\lambda) = L_t(\lambda) / t_g(\lambda) / f_p(\lambda) - TL_g(\lambda) - tL_f(\lambda) - L_r(\lambda) - L_a(\lambda)$

brdf Sun

$nL_w(\lambda) = L_w(\lambda)\ f_b(\lambda) / t_{d0}(\lambda)\ \mu_0\ f_0$



But, we need aerosol to get $L_w(\lambda)$

$L_w(\lambda=NIR) \approx 0$ and can be estimated (model extrapolation from VIS) in waters where C_a is the primary driver of $L_w(\lambda)$.

TOA gas pol glint whitecap air water

$L_a(\lambda=NIR) = L_t(\lambda) / t_g(\lambda) / f_p(\lambda) - TL_g(\lambda) - tL_f(\lambda) - L_r(\lambda) - t_d(\lambda)\ L_w(\lambda)$

Aerosol Determination in Visible Wavelengths

Given retrieved aerosol reflectance at two λ, and a set of aerosol models fn(θ,θ_0,ϕ).

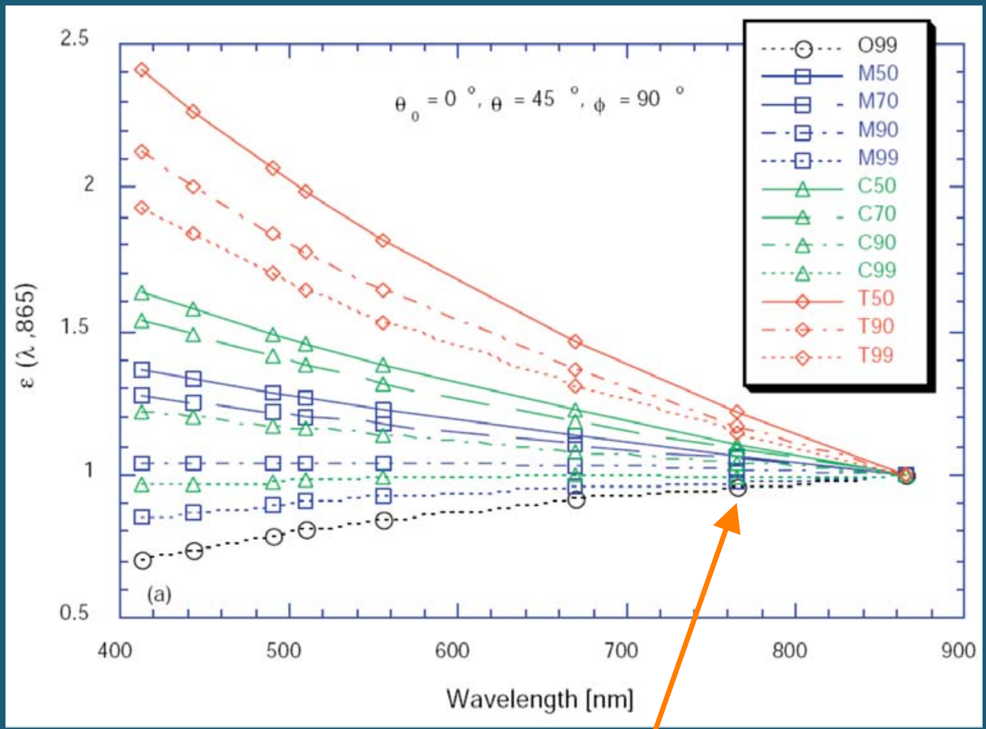
$$\rho = \frac{\pi L}{F_0 \cdot \mu_0}$$

$\rho_a(748)$ & $\rho_a(869)$

$$\rho_a(\mathrm{NIR}) \overset{\text{model}}{\Rightarrow} \rho_{as}(\mathrm{NIR})$$

$$\varepsilon\,(748{,}869) = \frac{\rho_{as}(748)}{\rho_{as}(869)}$$

$$\varepsilon\,(\lambda{,}869) = \frac{\rho_{as}(\lambda)}{\rho_{as}(869)}$$



$\varepsilon\,(748{,}869)$

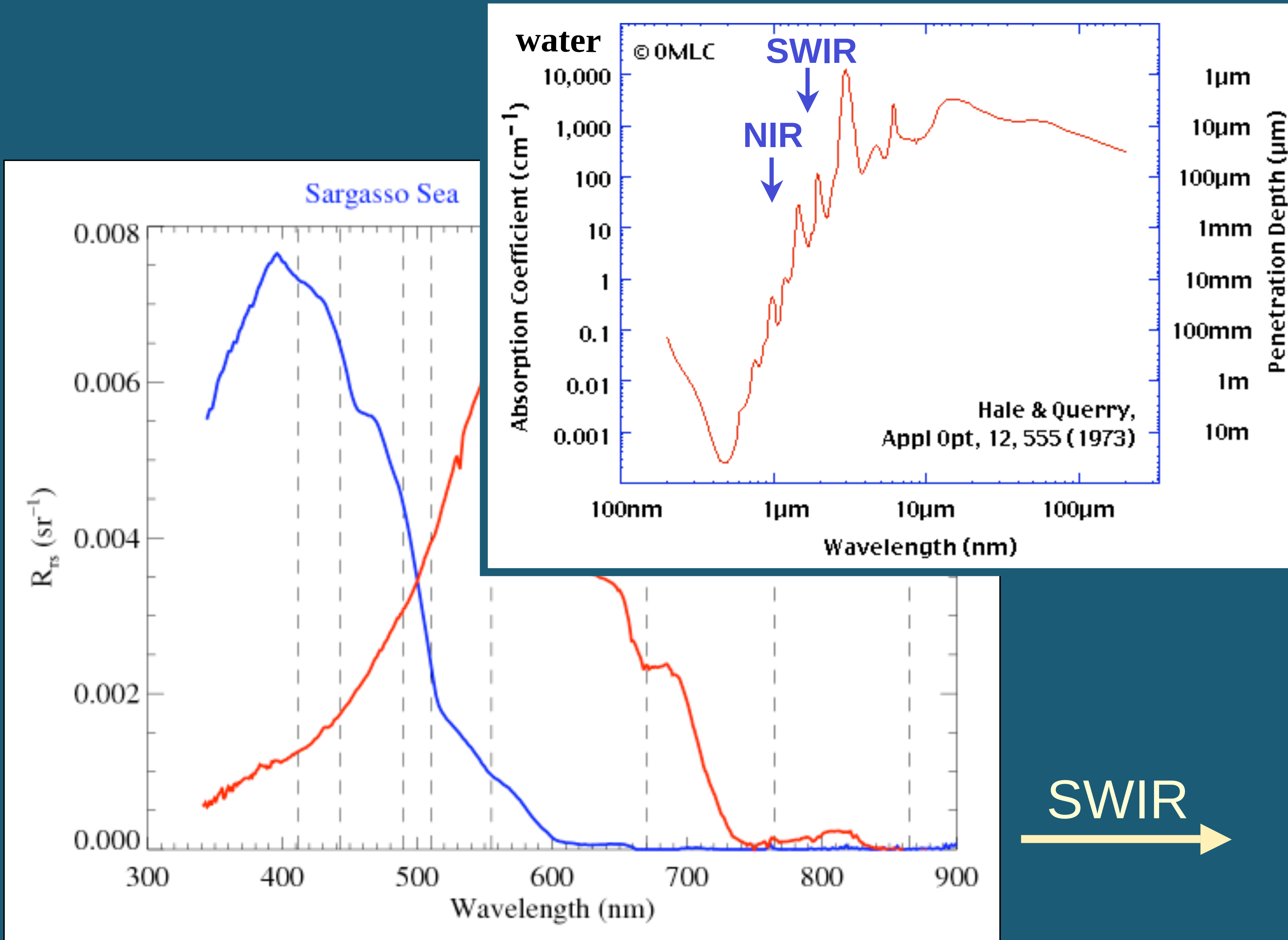
Atmospheric Correction

TOA gas pol glint whitecap air aerosol

$$t_d(\lambda)\ L_w(\lambda) = L_t(\lambda) / t_g(\lambda) / f_p(\lambda) - TL_g(\lambda) - tL_f(\lambda) - L_r(\lambda) - L_a(\lambda)$$

brdf Sun

$$nL_w(\lambda) = L_w(\lambda)\ f_b(\lambda) / t_{d0}(\lambda)\ \mu_0\ f_0$$



SWIR →

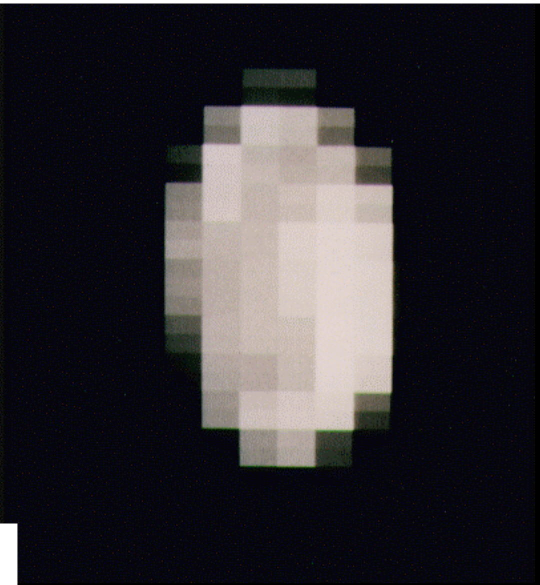
P.J. Werdell, 2007

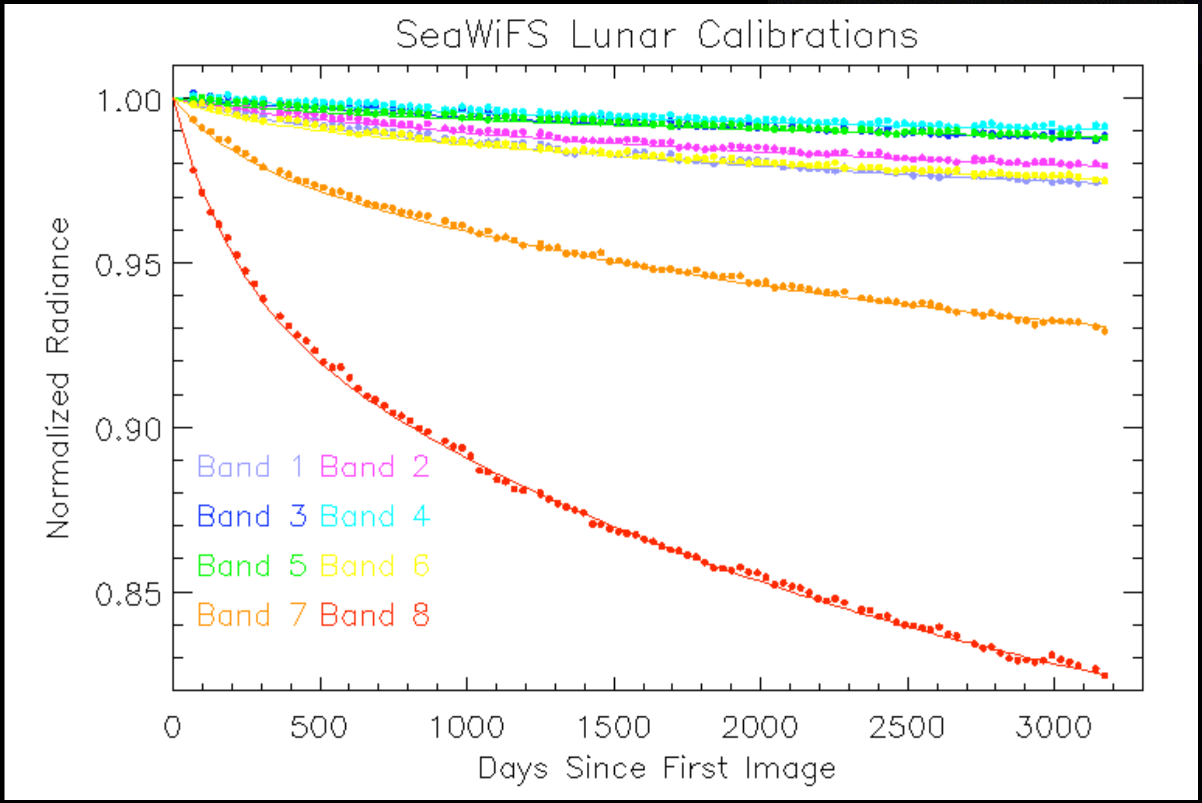
Level-2 Ocean Color Processing

1. Determine atmospheric and surface contributions to total radiance at TOA and subtract.
2. Normalize to the condition of Sun directly overhead at 1 AU and a non-attenuating atmosphere (nLw or Rrs = nLw/F_0).
3. Apply empirical or semi-analytical algorithms to relate the spectral distribution of nLw or Rrs to geophysical quantities.
4. Assess quality (set flags)

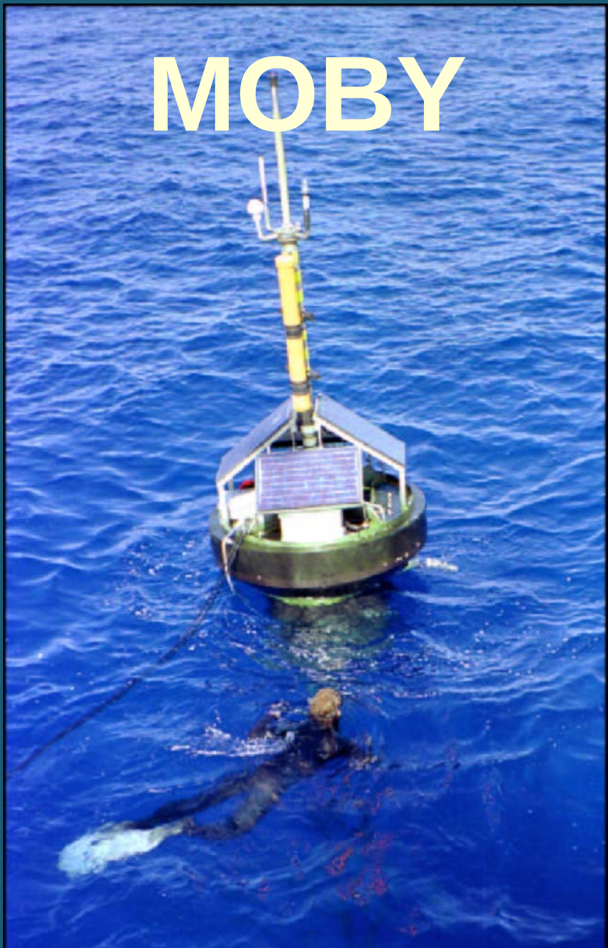
Calibration

Temporal Calibration



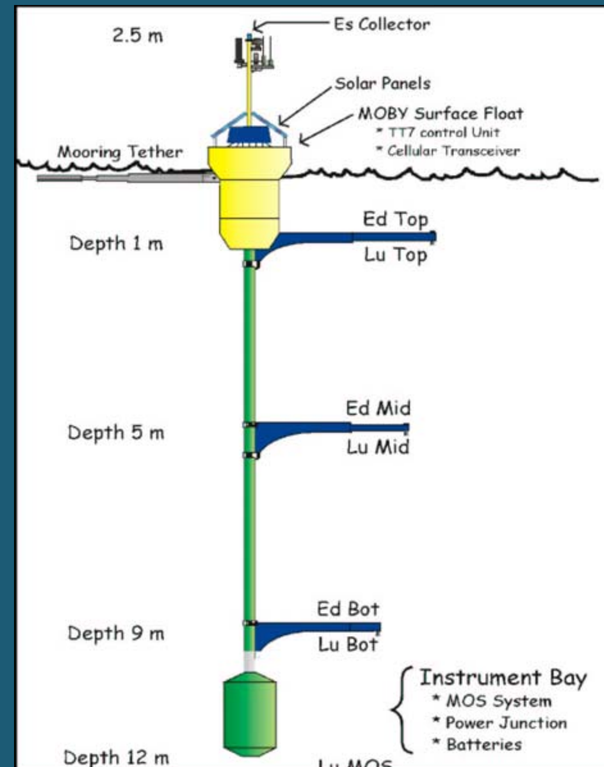


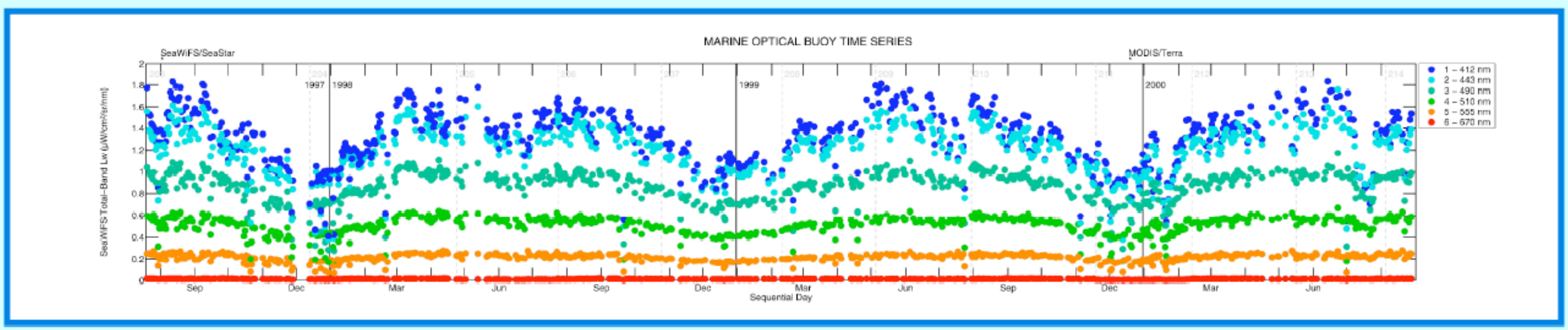
SeaWiFS Band	SeaWiFS λ (nm)
1	412
2	443
3	490
4	510
5	555
6	670
7	765
8	865



Vicarious Calibration

MOBY is used to adjust prelaunch calibration for visible bands using satellite-buoy comparisons.





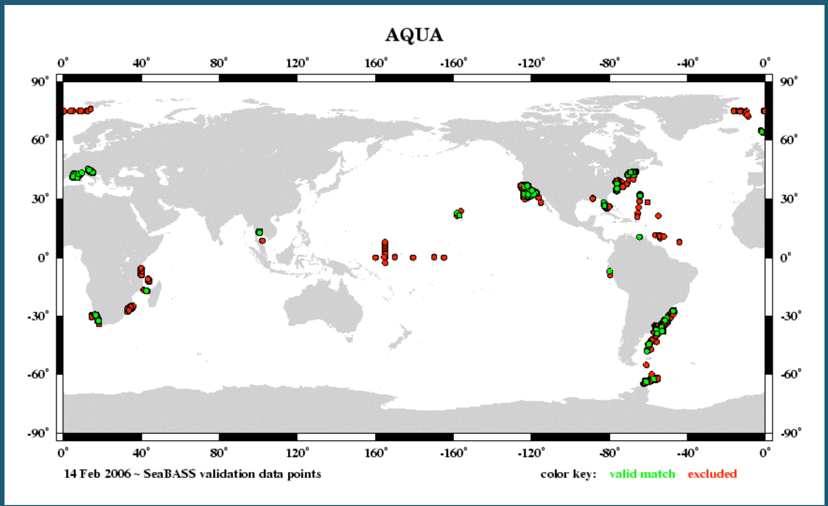
Are the results valid?

SeaBASS

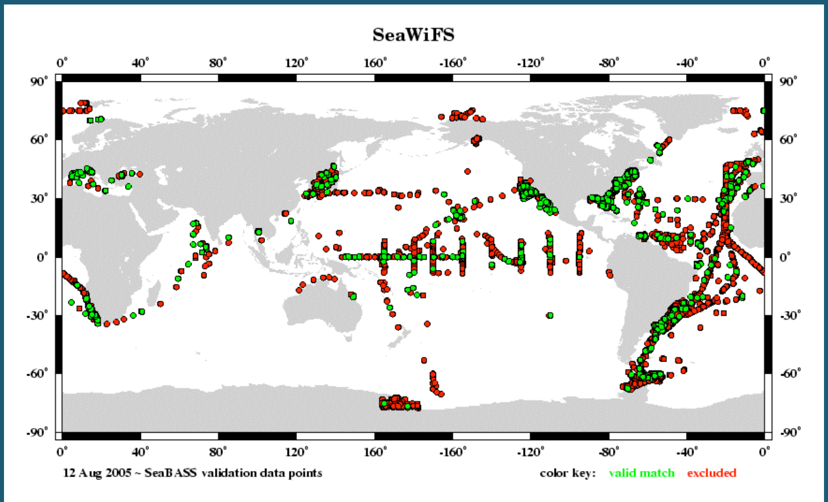
The SeaWiFS Bio-optical Archive and Storage System

Available *In Situ* Match-Ups by Mission

MODIS/Aqua
July 2002 - Present

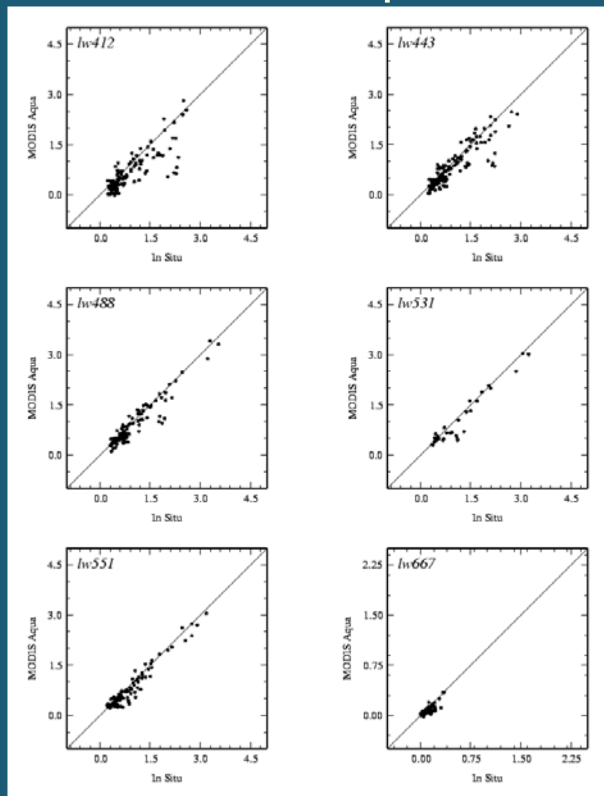


SeaWiFS
Sept 1997 - Present

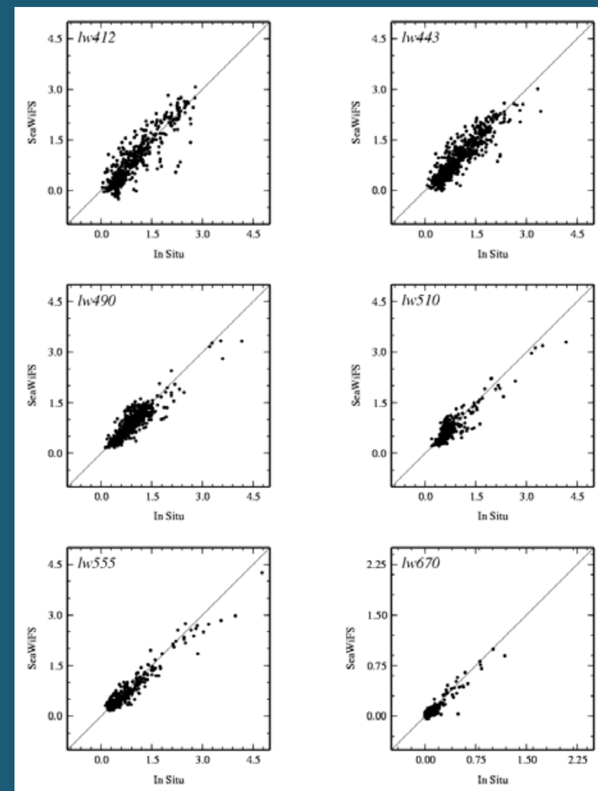


Comparison of Water-Leaving Radiances to *In Situ*

MODIS/Aqua



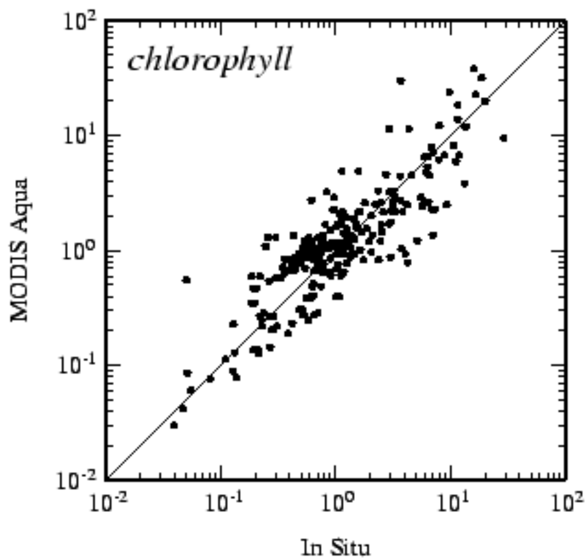
SeaWiFS



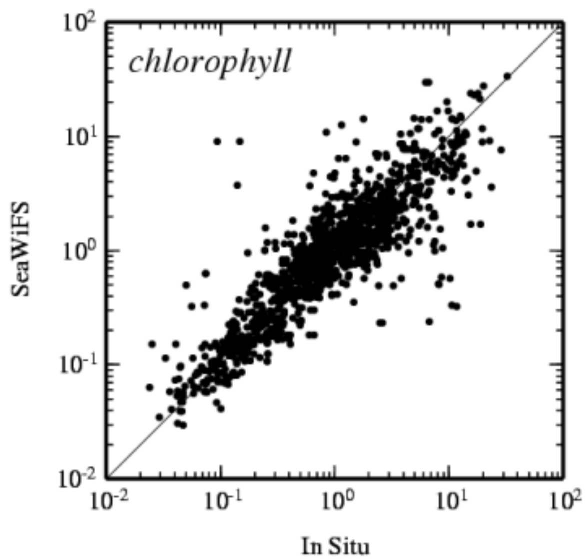
Wavelength		# Matches		Mean Ratio*		% Difference**		r^2	
MODIS	SeaWiFS	MODIS	SeaWiFS	MODIS	SeaWiFS	MODIS	SeaWiFS	MODIS	SeaWiFS
412	412	120	553	0.747	0.905	30.898	24.098	0.742	0.827
443	443	133	702	0.862	0.915	18.811	17.480	0.815	0.830
488	490	109	660	0.923	0.918	14.563	15.101	0.907	0.821
531	510	32	479	0.933	0.918	11.178	13.739	0.934	0.849
551	555	120	702	0.940	0.915	12.255	16.878	0.943	0.931
667	670	107	666	0.682	0.920	36.392	45.717	0.735	0.876

Comparison of Chlorophyll Retrievals to *In Situ*

MODIS/Aqua



SeaWiFS

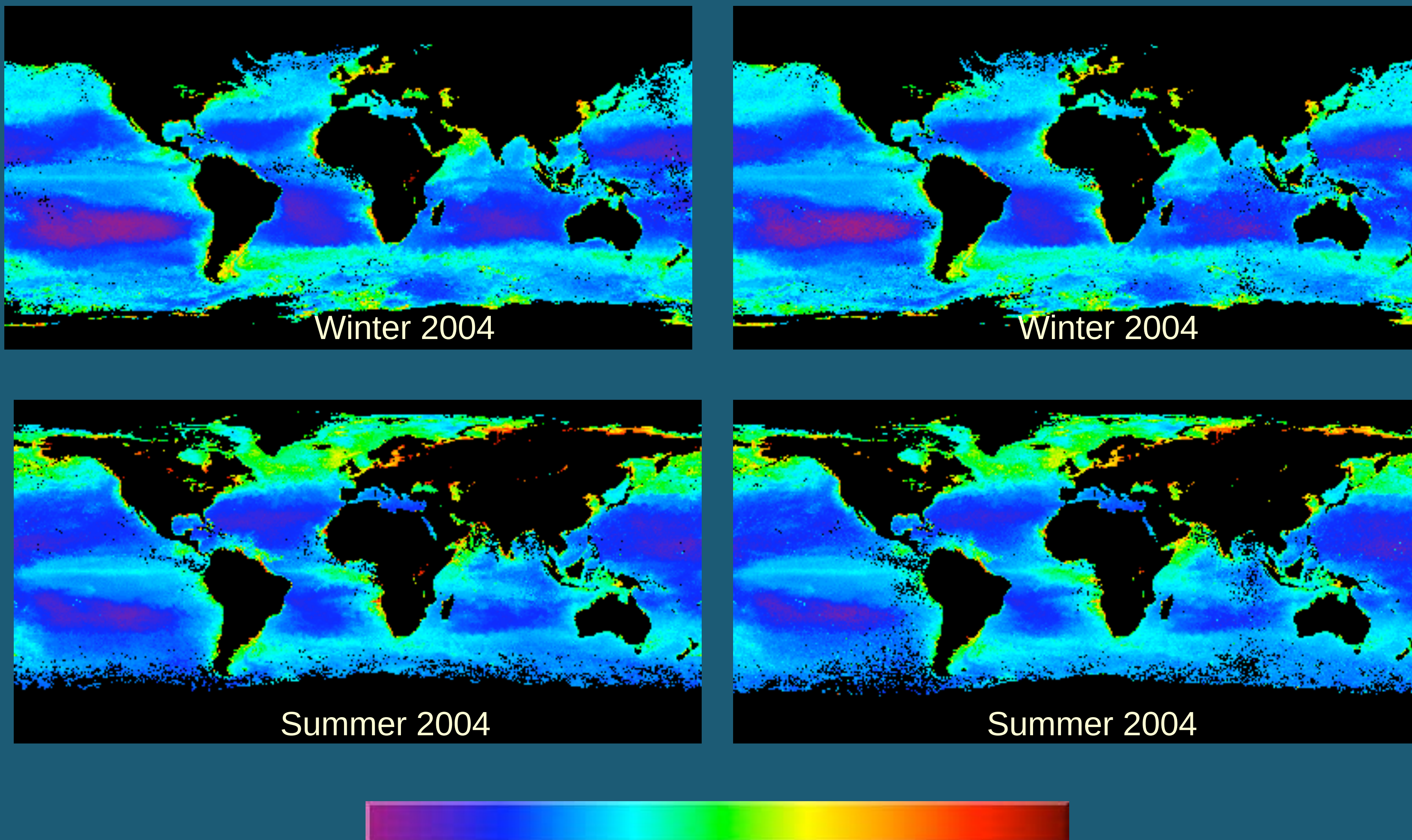


Sensor	# Matches	Mean Ratio	% Diff	r^2
SeaWiFS	1293	0.998	33.1	0.796
MODIS/Aqua	263	1.084	40.4	0.780

Seasonal Chlorophyll Images

MODIS/Aqua

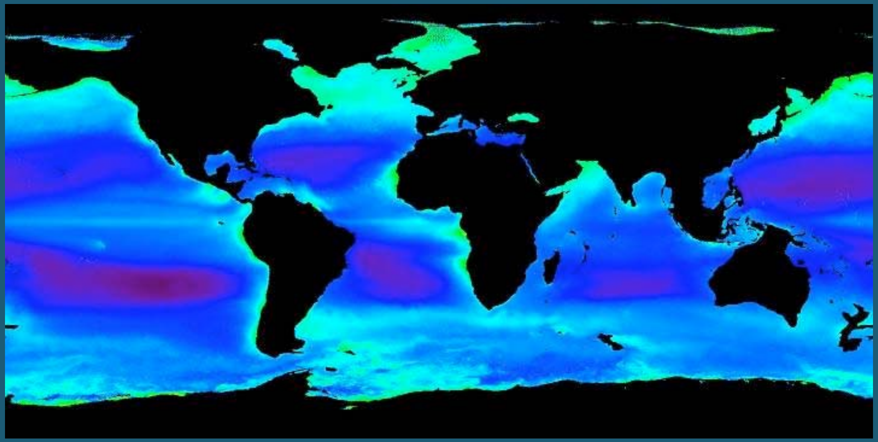
SeaWiFS



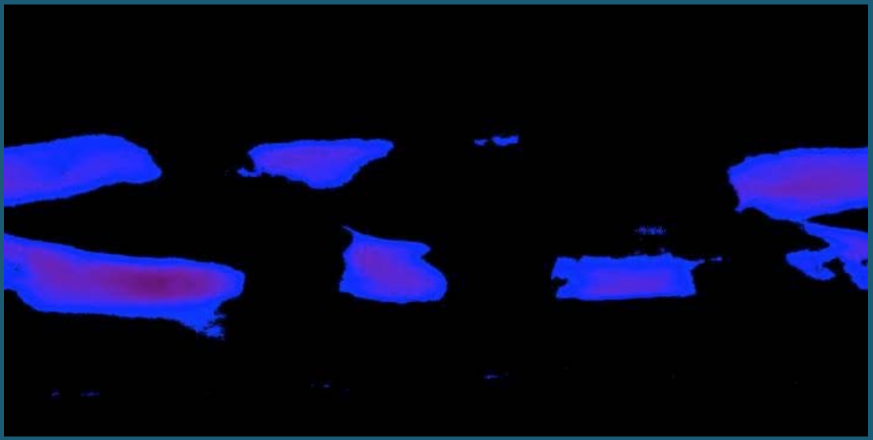
0.01-64 mg m^{-3}

Definition of Trophic Subsets

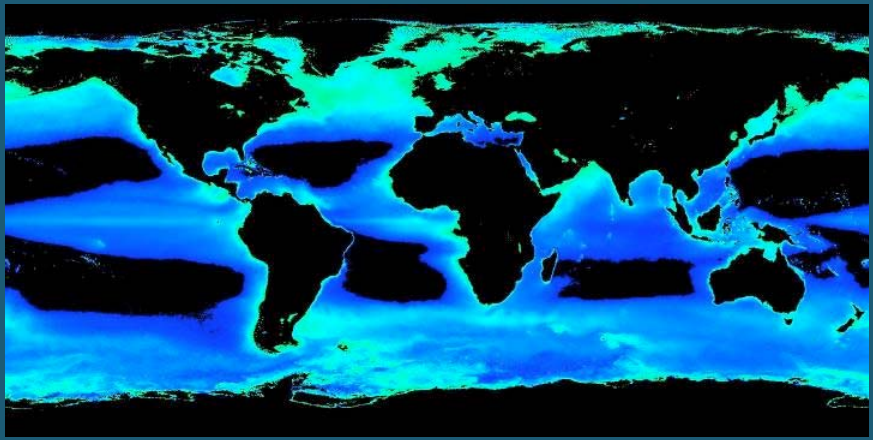
Deep-Water (Depth > 1000m)



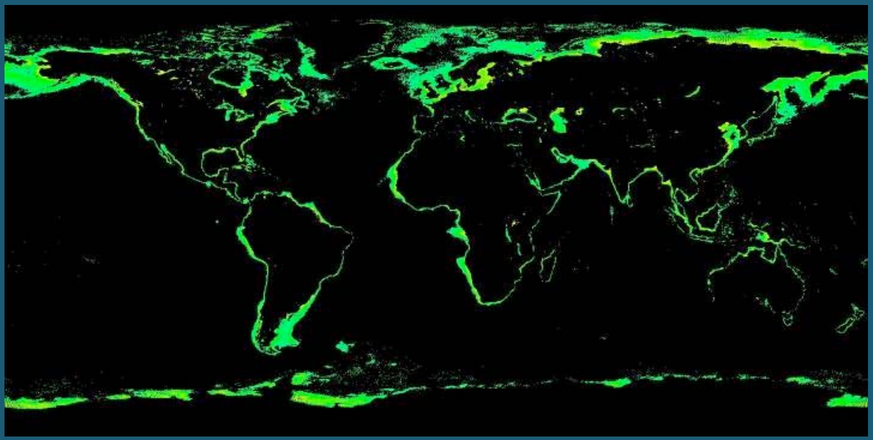
Oligotrophic (Chlorophyll < 0.1)



Mesotrophic (0.1 < Chlorophyll < 1)

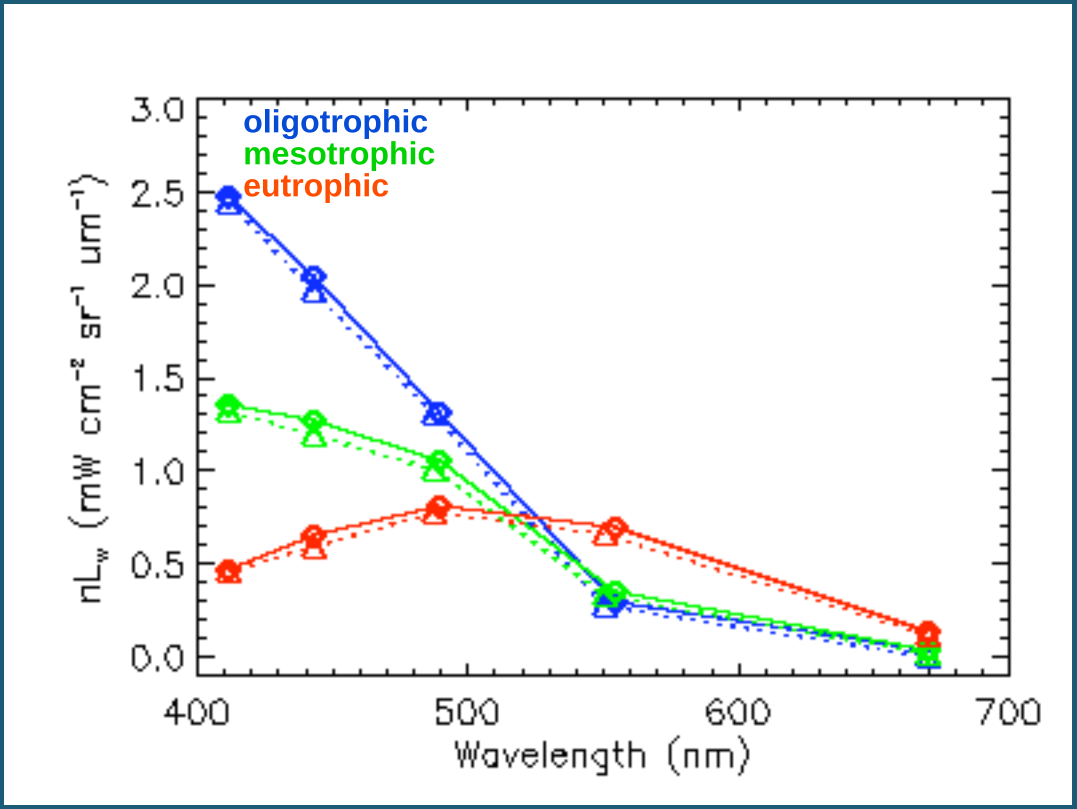


Eutrophic (1 < Chlorophyll < 10)

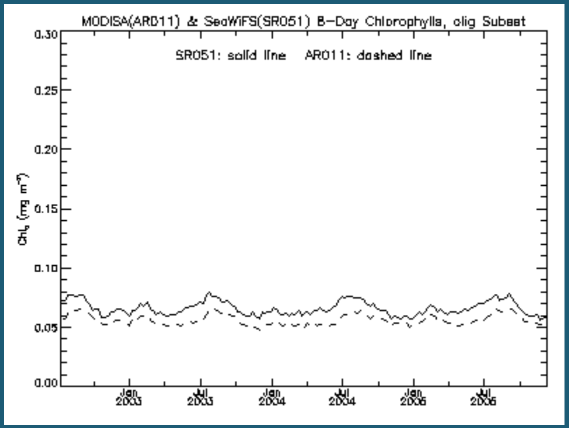
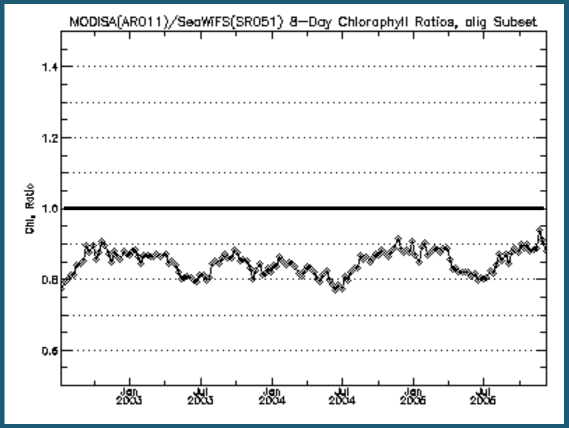
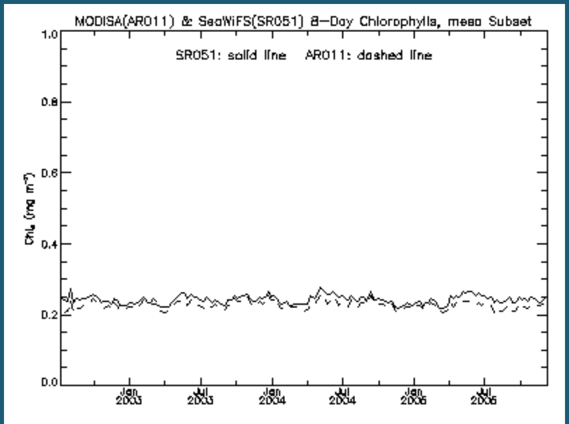
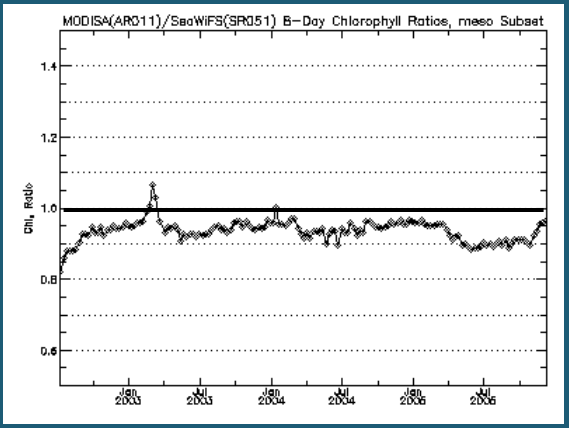
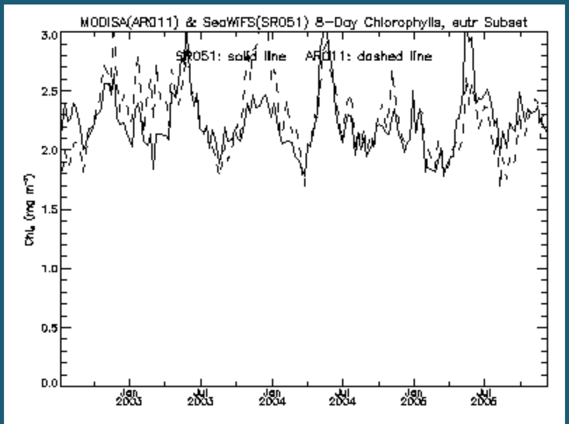
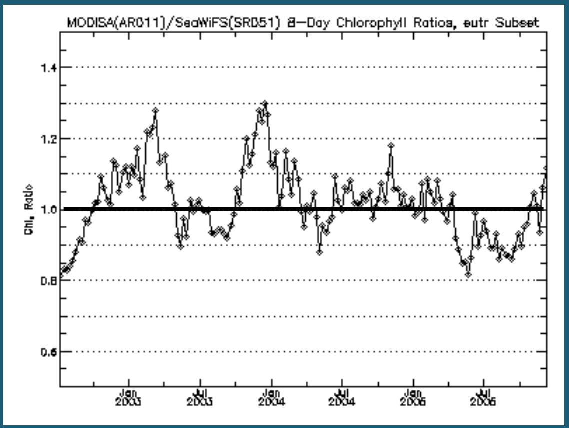


Comparison of Spectral Distribution Trends

MODIS & SeaWiFS Mean nLw



Chlorophyll Comparisons

	MODIS & SeaWiFS	MODIS / SeaWiFS
Oligotrophic		
Mesotrophic		
Eutrophic		

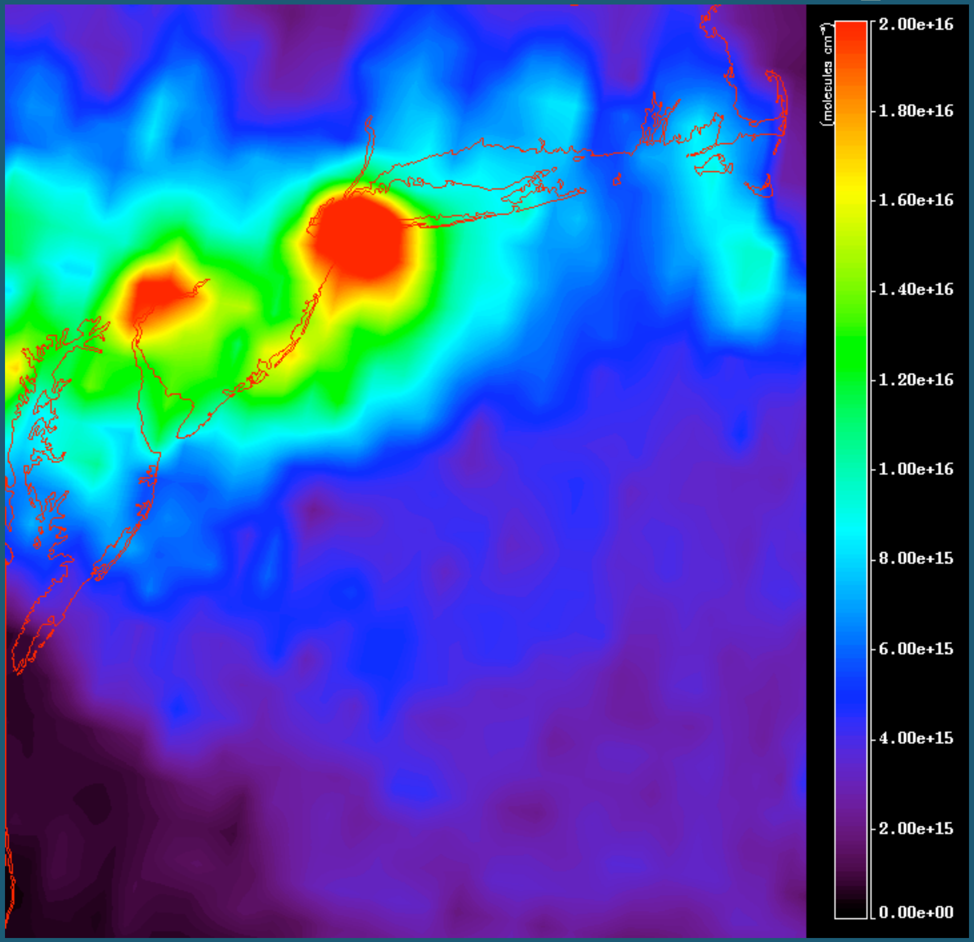
Challenges to Remote Sensing of Coastal Waters

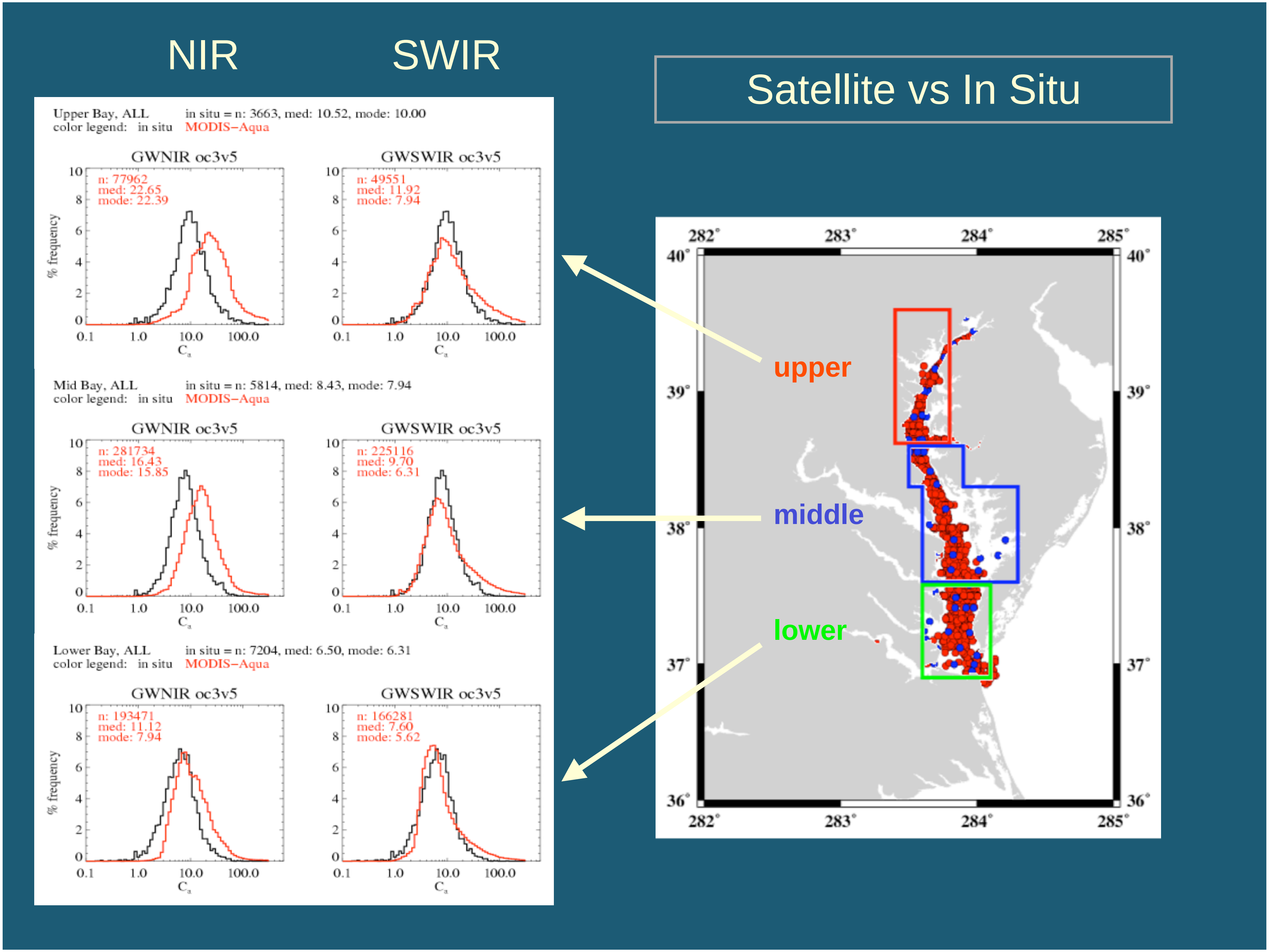
- Temporal and spatial variability
- Straylight contamination from land
- Non-maritime aerosols (dust, pollution)
  - Region-specific models required
  - Absorbing aerosols
- Anthropogenic emissions
- Suspended sediments and CDOM
  - Invalid estimation of Lw(NIR), model not fn(C_a)
  - Saturation of observed radiances
- Bottom reflectance

Correction for NO_2 Absorption

MODIS/Aqua RGB

OMI/Aura Tropospheric NO_2



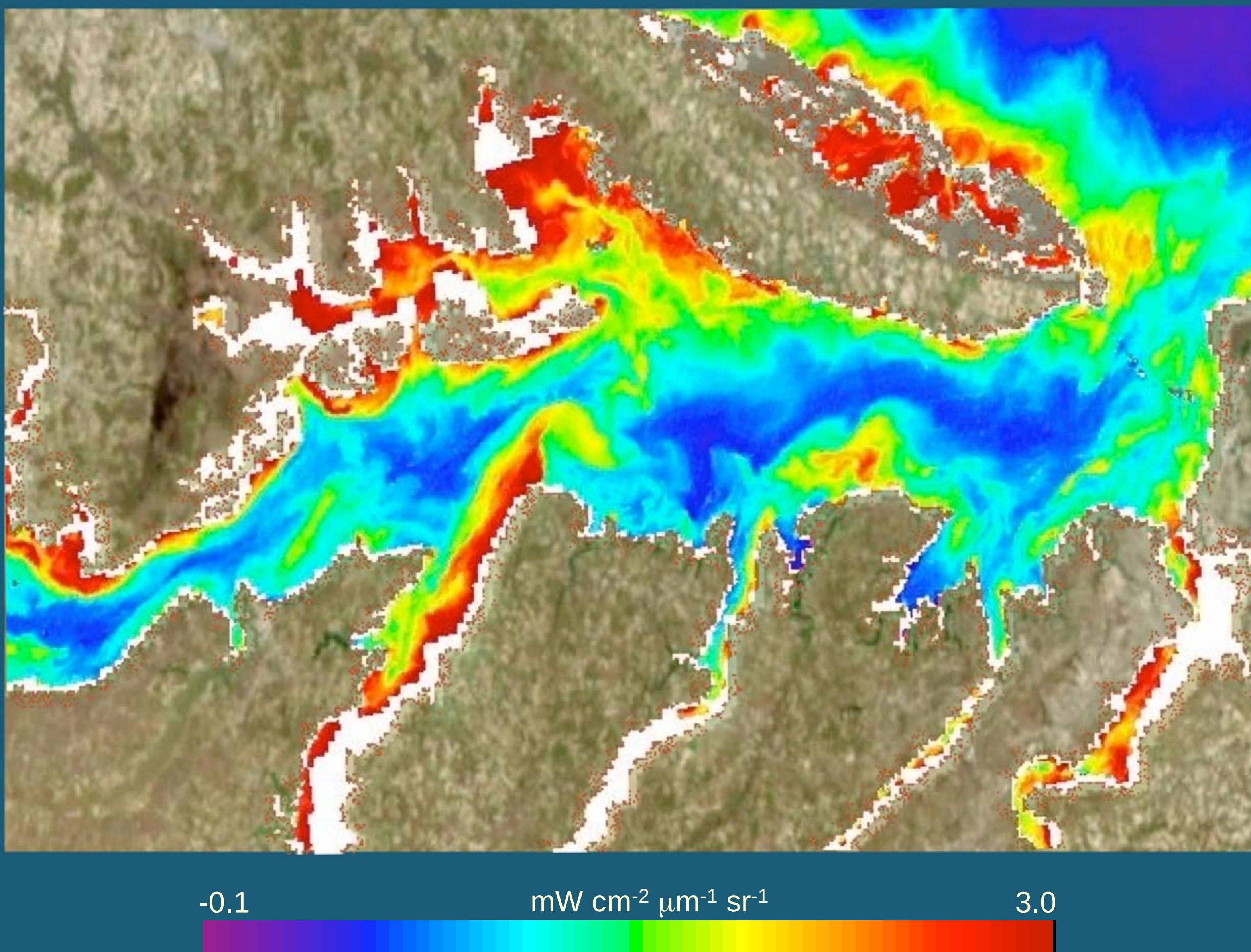

NIR
SWIR
Satellite vs In Situ
Upper Bay, ALL
in situ = n: 3663, med: 10.52, mode: 10.00
color legend: in situ MODIS−Aqua
GWNIR oc3v5
n: 77962
med: 22.65
mode: 22.39
GWSWIR oc3v5
n: 49551
med: 11.92
mode: 7.94
Mid Bay, ALL
in situ = n: 5814, med: 8.43, mode: 7.94
color legend: in situ MODIS−Aqua
GWNIR oc3v5
n: 281734
med: 16.43
mode: 15.85
GWSWIR oc3v5
n: 225116
med: 9.70
mode: 6.31
Lower Bay, ALL
in situ = n: 7204, med: 6.50, mode: 6.31
color legend: in situ MODIS−Aqua
GWNIR oc3v5
n: 193471
med: 11.12
mode: 7.94
GWSWIR oc3v5
n: 166281
med: 7.60
mode: 5.62
% frequency
C_a
upper
middle
lower
282°
283°
284°
285°
40°
39°
38°
37°
36°

MODIS Land/Cloud Bands of Interest

Band	Wavelength	Resolution	Potential Use
1	645 nm	250 m	sediments, turbidity, IOPs
2	859	250	aerosols
3	469	500	C_a, IOPs, $CaCO_3$
4	555	500	C_a, IOPs, $CaCO_3$
5	1240	500	aerosols
6	1640	500	aerosols
7	2130	500	aerosols

RGB Image: 250-meter Resolution

nLw(645): 250-meter resolution



Data Products and Distribution

Standard Ocean Products

- Ocean Temperature (MODIS only)
  - Long-wave SST (11-12 μm), day and night
  - Short-wave SST (3.9 - 4.0 μm), night only
  - SST quality level

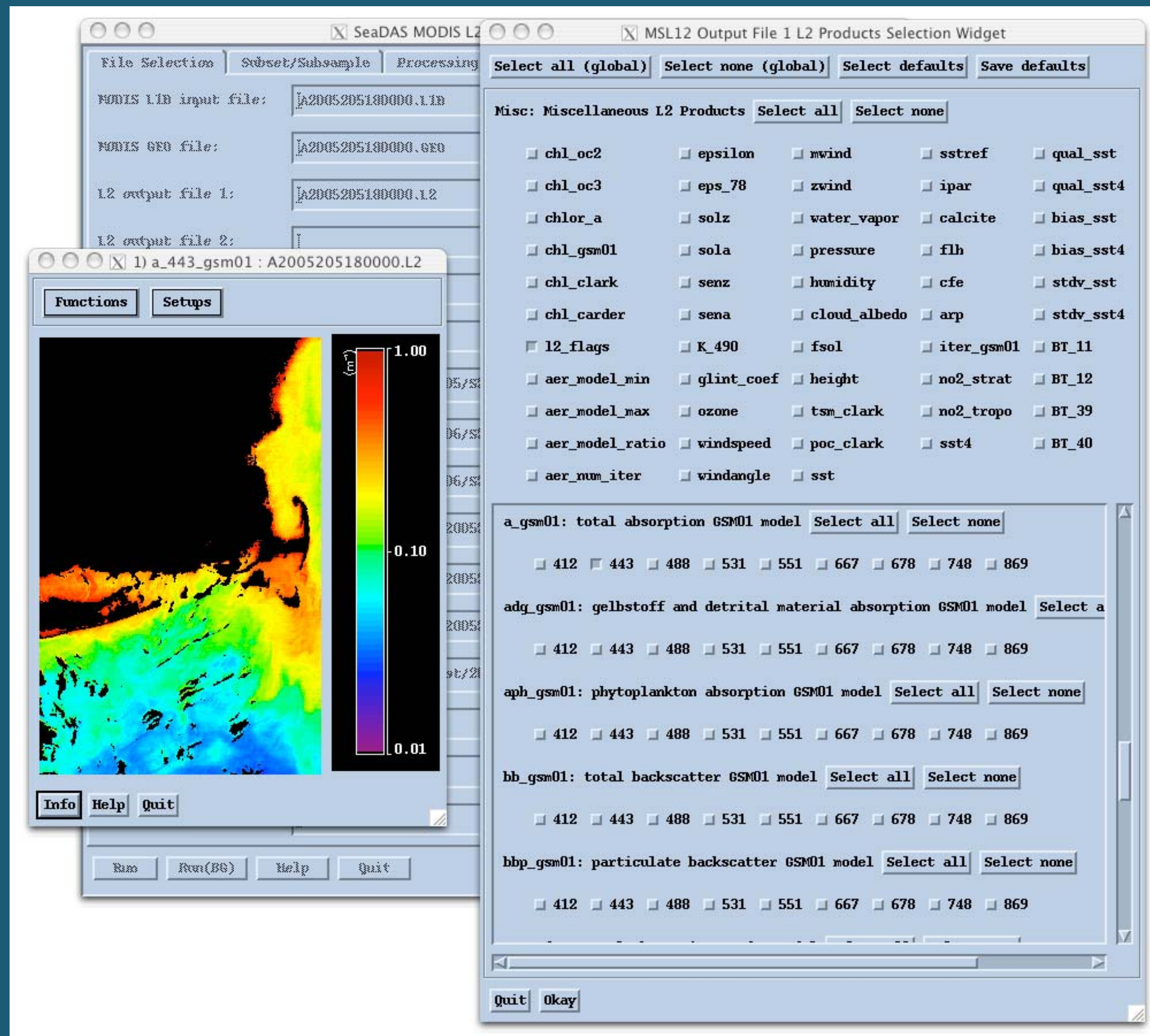
- Ocean Color
  - Normalized water-leaving radiances, nLw(λ)
  - Chlorophyll, C_a
  - Diffuse attenuation, $K_d(490)$
  - Aerosol type and concentration
  - Processing flags

- Data Types
  - Level-1: observed radiances (swath-based)
  - Level-2: retrieved geophysical parameters (swath-based)
  - Level-3: global gridded composites (daily, 8-day, monthly, merged)

SeaDAS

Data Processing, Analysis, and Display Software

- free
- multi-mission
- display tools
- analysis tools
- processing
- open source



Examples of Non-standard Ocean Products

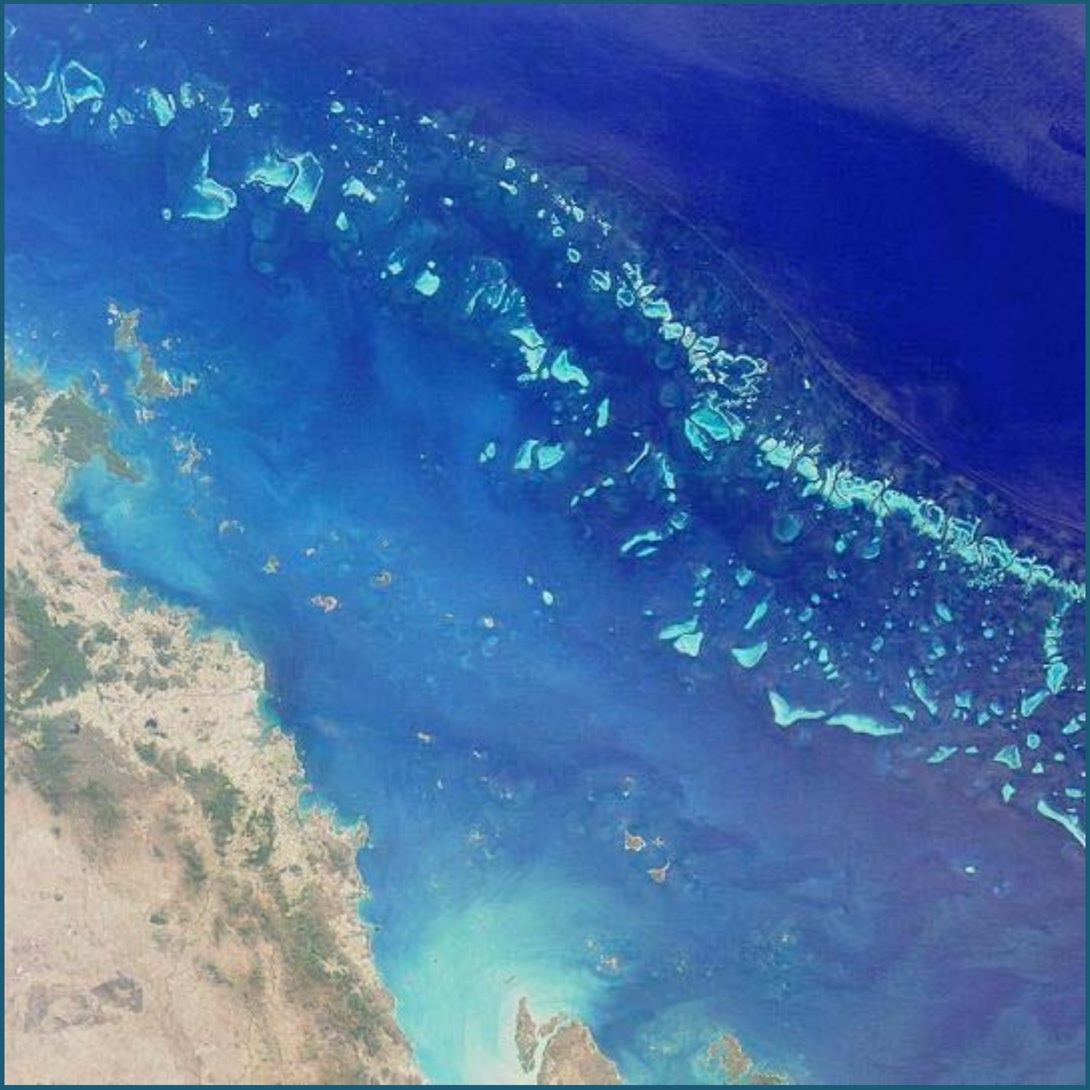
- Alternate C_a and K_d algorithms
- Chlorophyll fluorescence, FLH
- Particulate inorganic carbon, Calcite
- Inherent optical properties (various bio-optical models)
  - absorption (total, phaeophytin, dissolved matter)
  - backscatter (total, particulate)
- Euphotic depth (Z_{eu}, Z_{sd})
- Spectrally integrated diffuse attenuation, K_d(PAR)

Data Distribution

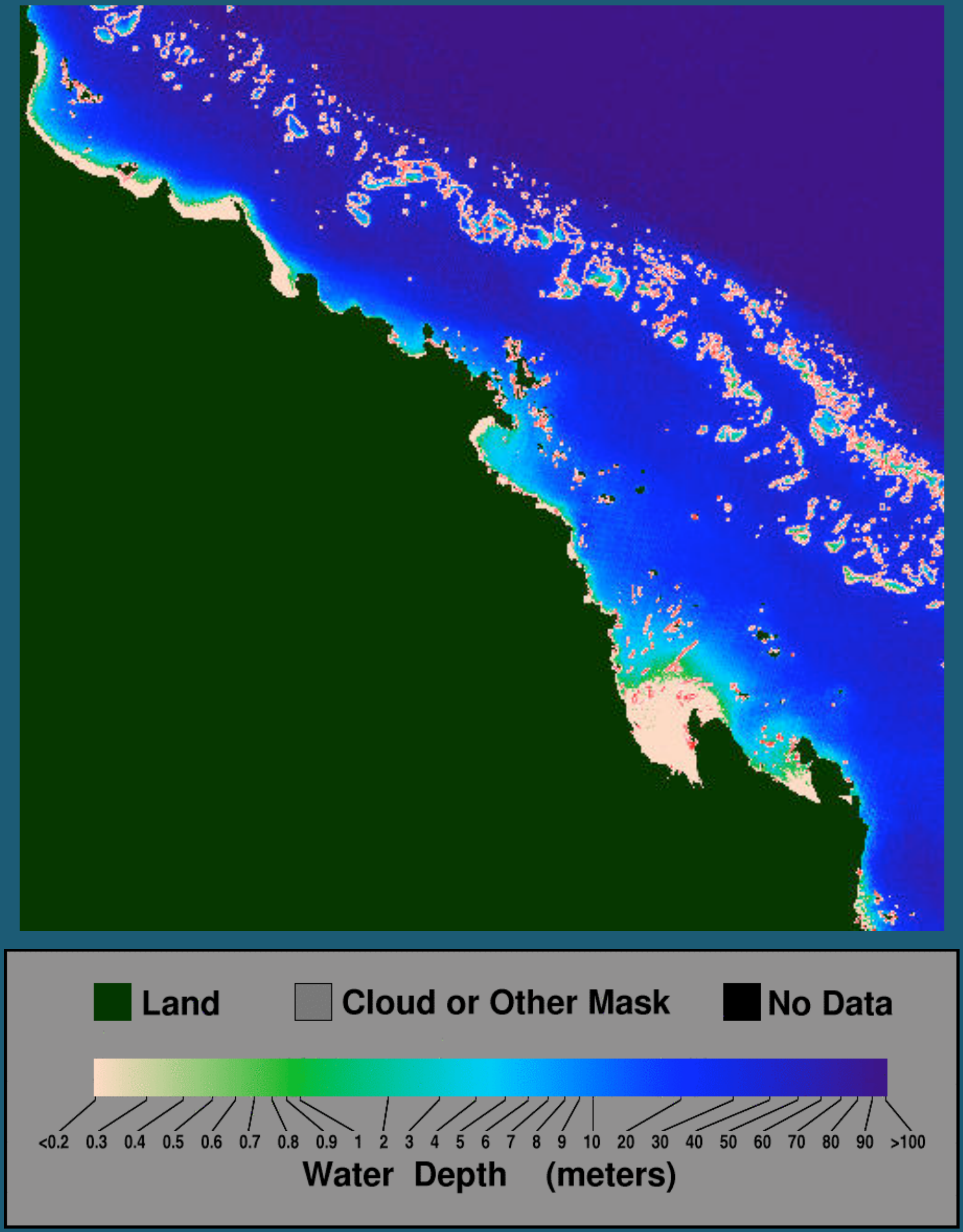
- Free and open data distribution policy
  - Level-1, Level-2, and Level-3
  - ocean color and SST
  - CZCS, OCTS, SeaWiFS, MODIS
- Web-based browsing and direct ftp access
- Automated ordering system
- Subscription services
- Geographic and parameter sub-setting

Remote Sensing of Coral Reefs

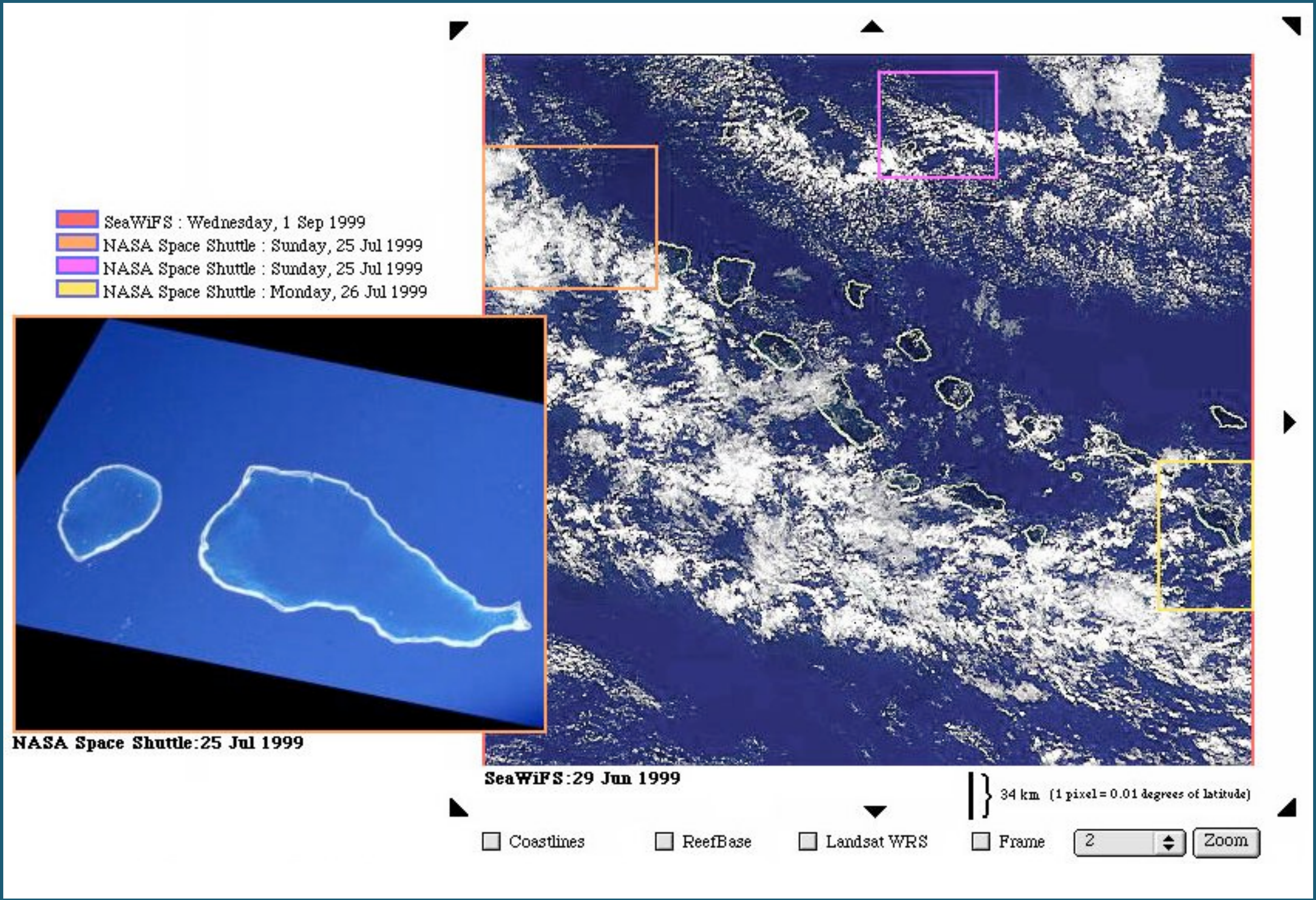
http://oceancolor.gsfc.nasa.gov/cgi/reefs.pl



Water Depth Classification from SeaWiFS

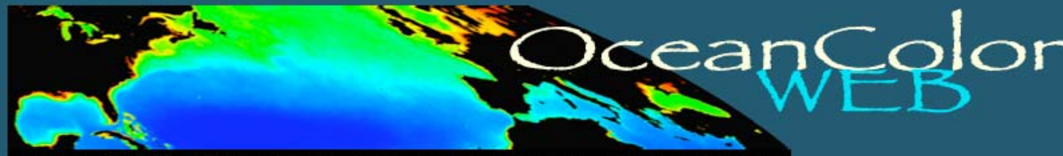


http://oceancolor.gsfc.nasa.gov/cgi/reefs.pl



http://oceancolor.gsfc.nasa.gov/cgi/reefs.pl

http://oceancolor.gsfc.nasa.gov/



MODIS SeaWiFS IOCCG Products News People Documents Validation Questions

Data Access

Data Production and Distribution Status

All systems nominal

NOTE: FTP connections must be made in PASSIVE mode

Level 1 and 2 Browser

Visually search the ocean color data archive and directly download and/or order data from single files to the entire mission. Extensive online HELP and tutorials available.

Level 3 Browser

Browse the entire Level 3 global ocean color data set for many parameters and time periods and download either JPEG images or digital data in HDF format. View time series plots of selected SeaWiFS parameters for selected regions of the globe.

Data Subscriptions

Request a subscription for Aqua data to be staged on an FTP site. You can check the status of an existing subscription. Requires a Support Services username and password.

Data by FTP

The Project maintains several FTP sites containing the most popular data products including the complete Level 3 data archive.

Giovanni

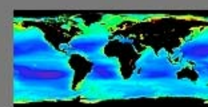
A GES DISC DAAC tool to provide users with an easy-to-use, Web-based interface for the visualization and analysis of the Earth Science data.

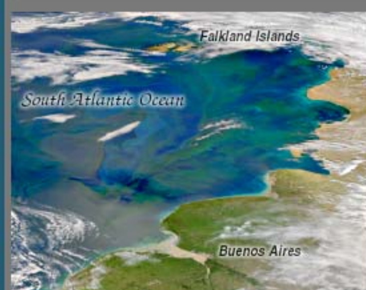
Ocean Color Web Feature

Recent topics and imagery of interest to the OceanColor community.

AQUA/SeaWiFS Merged Chlorophyll Data

The OBPG now produces a merged Level-3 chlorophyll product derived from SeaWiFS and MODIS/Aqua. The products are being created routinely for daily, 8-day, monthly, seasonal and annual time periods. Details about this new product can be found **HERE**





Some of the authors of a recent paper describing the timing of coccolithophore blooms in the South Atlantic Ocean off the coast of Argentina are once again at sea in this area endeavoring to improve our understanding of the phytoplankton communities that add so much color to these waters.

Click on the above 26 October 2006 MODIS image for a larger version or click here for the full-sized (98.6 megabyte) image.

Image Gallery

Ocean Color Distribution Statistics

Support Services

SeaDAS

A comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.

SeaBASS

An archive of in situ data, both oceanographic and atmospheric, used for algorithm development and satellite validation.

Register for Support Services

Register for support services, including:

- SeaWiFS data access authorization
- Access to Near Real Time image support
- Request a new password or change email address
- Ocean Color Forum
- Ocean Color Mailing List

Support Services

- Overflight predictions
- Near real-time imagery and data for cruise support

Data Processing

The ODPS site contains information related to the ocean color data production system.

Employment Opportunities
(IOCCG listings)

Acknowledgements

- Scarla Weeks and the CMS

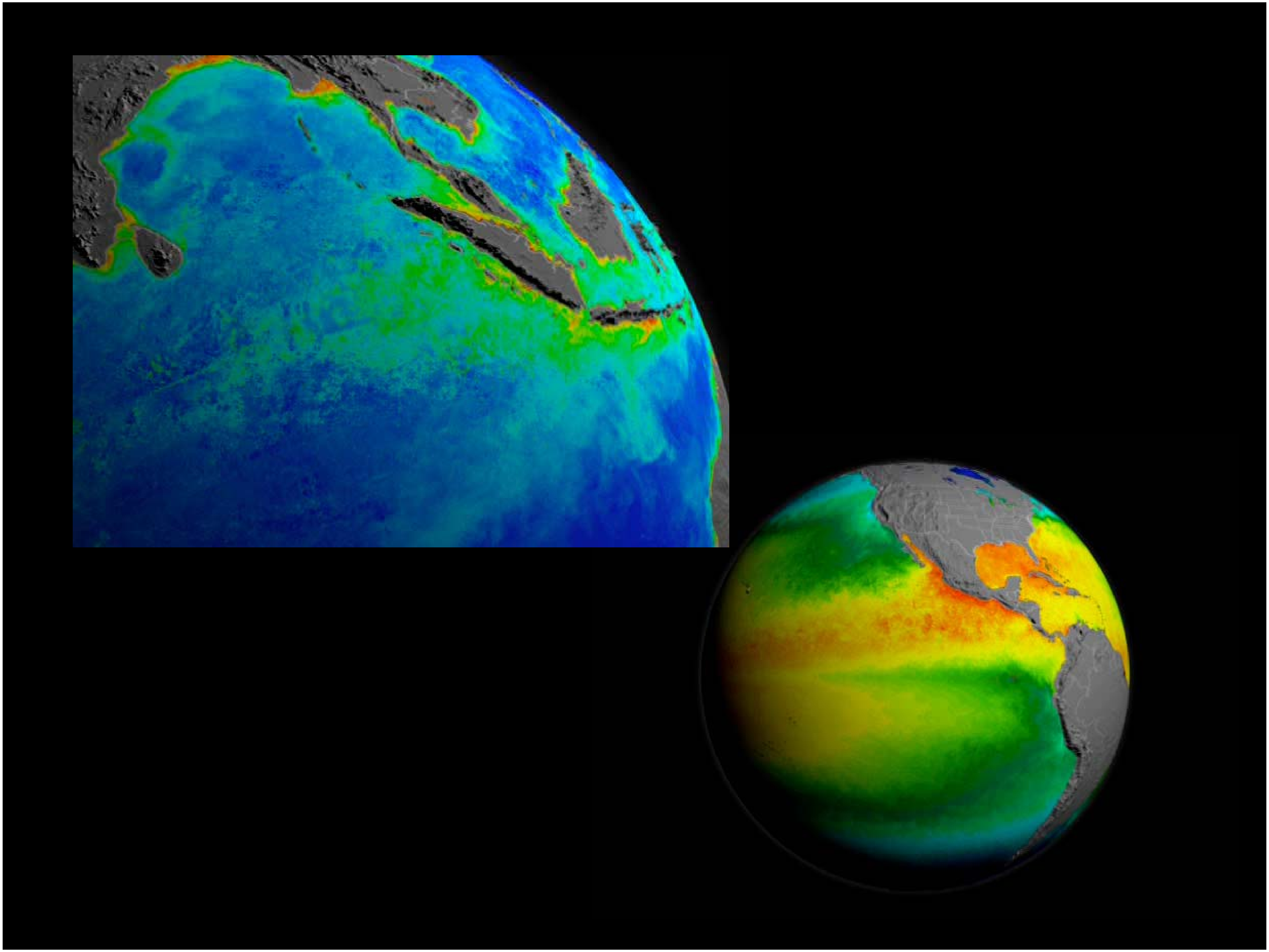
  thanks for the invite

- Chuck McClain and Gene Feldman of NASA

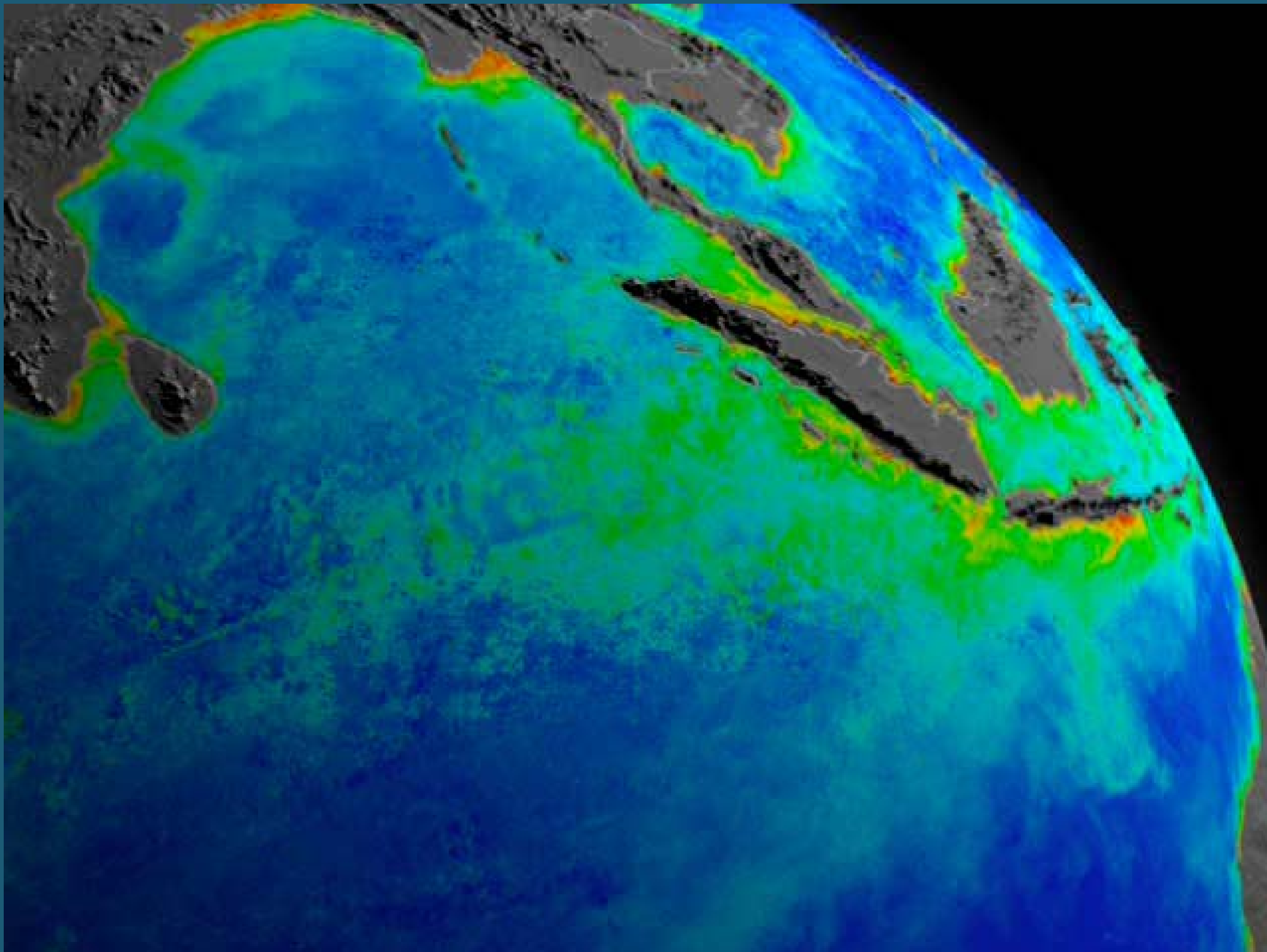
  thanks for paying the bill

- The Ocean Biology Processing Group

  thanks for doing all the work



Thank You!



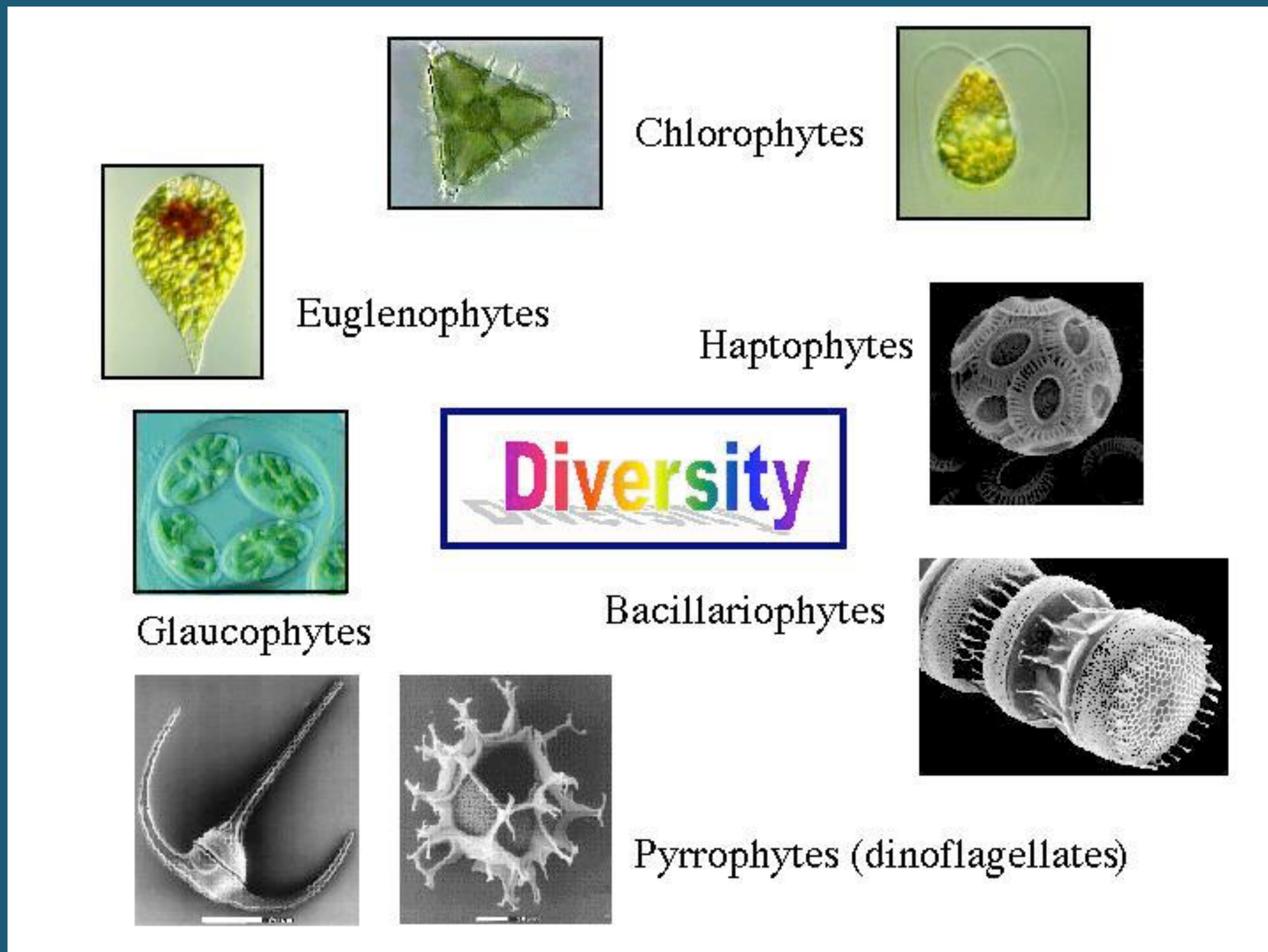
Thank You!

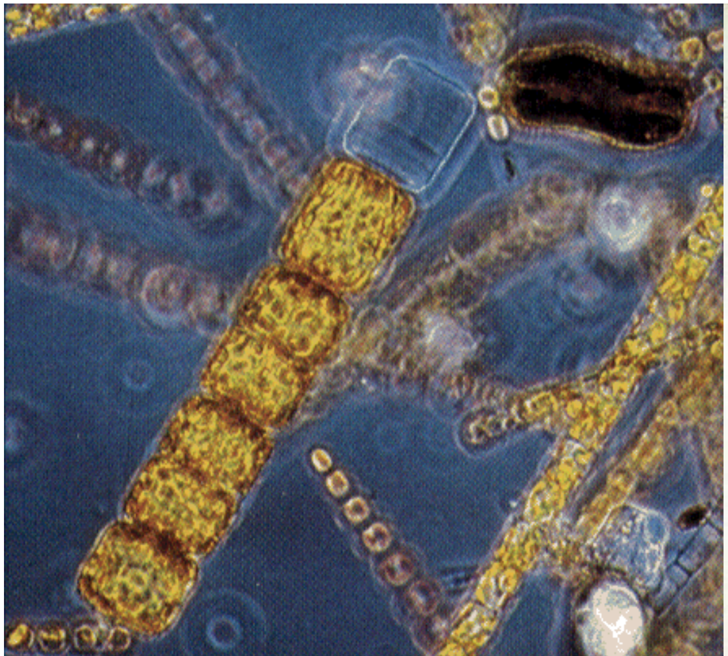
Multi-Mission Approach

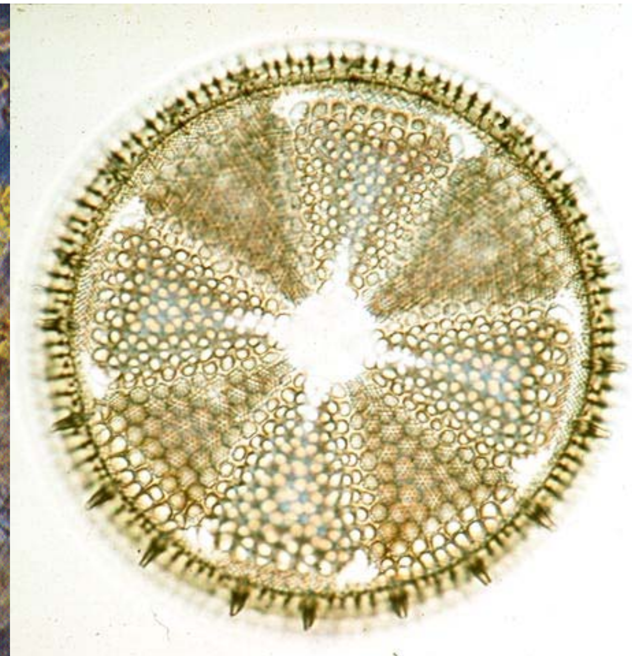
- Common software for Level-1 through Level-3
  - reduces potential for algorithm and implementation differences
  - sensor-specific issues consolidated in i/o function and external tables
- Mission-independent, distributed processing system
  - controls staging/sequencing of processing jobs for max through-put
  - 150x global reprocessing for MODIS, 1600x for SeaWiFS
- Standard procedures for calibration and validation
  - temporal calibration via On-Board Calibration system (OBC)
  - vicarious calibration to MOBY (instrument + algorithm calibration)
  - validation against SeaBASS *in situ* archive
  - temporal trending analysis of Level-3 products

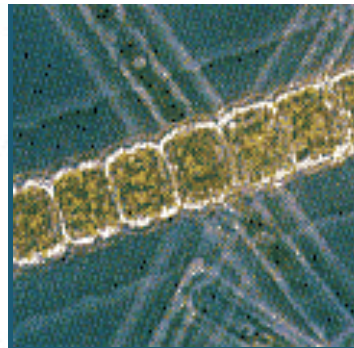
Expanded MODIS Ocean Band Suite

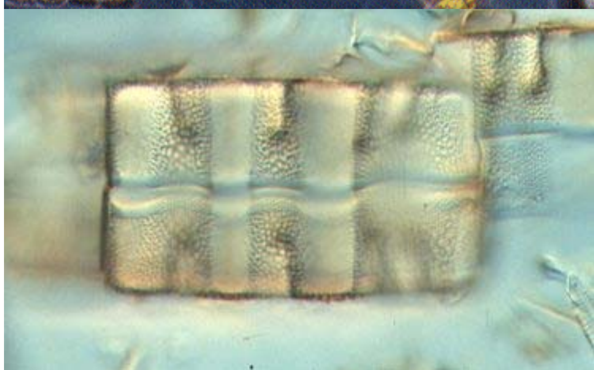
Band Number	Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)	SNR at L_{typ}	L_{typ} mW cm^{-2} μm^{-1} sr^{-1}	L_{max} mW cm^{-2} μm^{-1} sr^{-1}
8	412	15	1000	1773	7.84	26.9
9	443	10	1000	2253	6.99	19.0
3	469	20	500	556	6.52	59.1
10	488	10	1000	2270	5.38	14.0
11	531	10	1000	2183	3.87	11.1
12	551	10	1000	2200	3.50	8.8
4	555	20	500	349	3.28	53.2
1	645	50	250	140	1.65	51.2
13	667	10	1000	1962	1.47	4.2
14	678	10	1000	2175	1.38	4.2
15	748	10	1000	1371	0.889	3.5
2	859	35	250	103	0.481	24.0
16	869	15	1000	1112	0.460	2.5
5	1240	20	500	25	0.089	12.3
6	1640	35	500	19	0.028	4.9
7	2130	50	500	12	0.008	1.7


Chlorophytes
Euglenophytes
Haptophytes
Diversity
Glaucophytes
Bacillariophytes
Pyrrophytes (dinoflagellates)





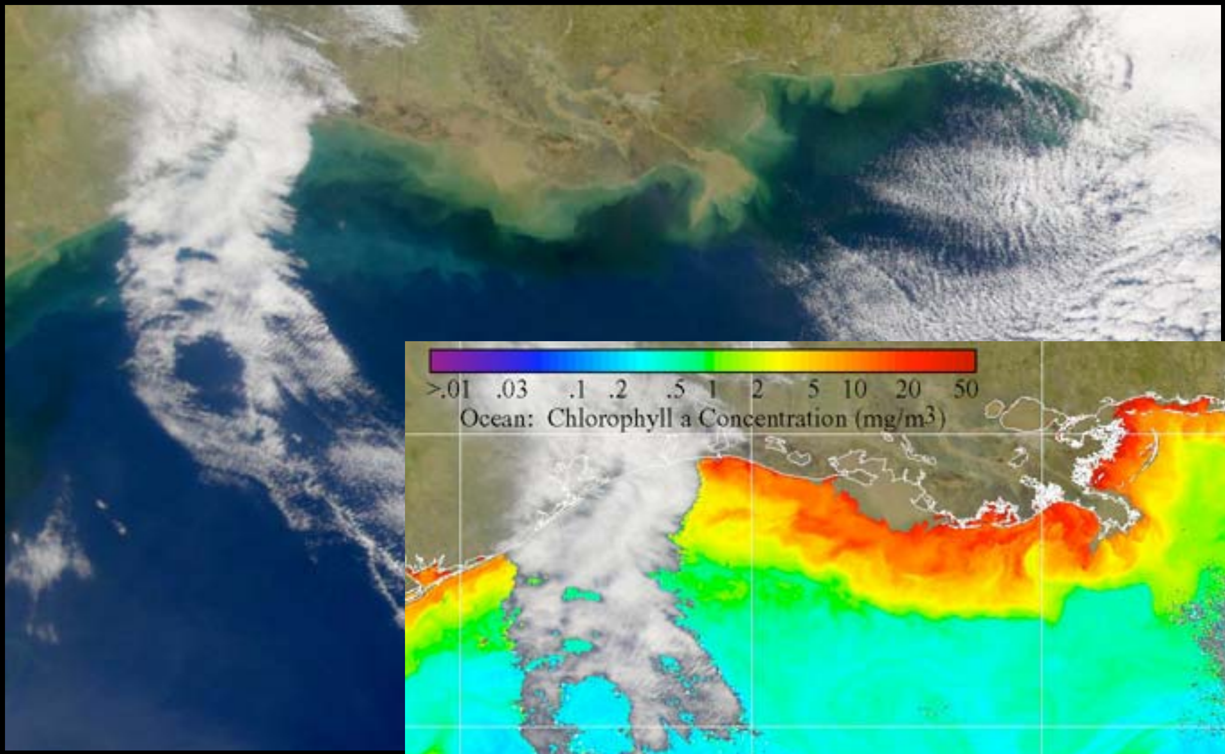




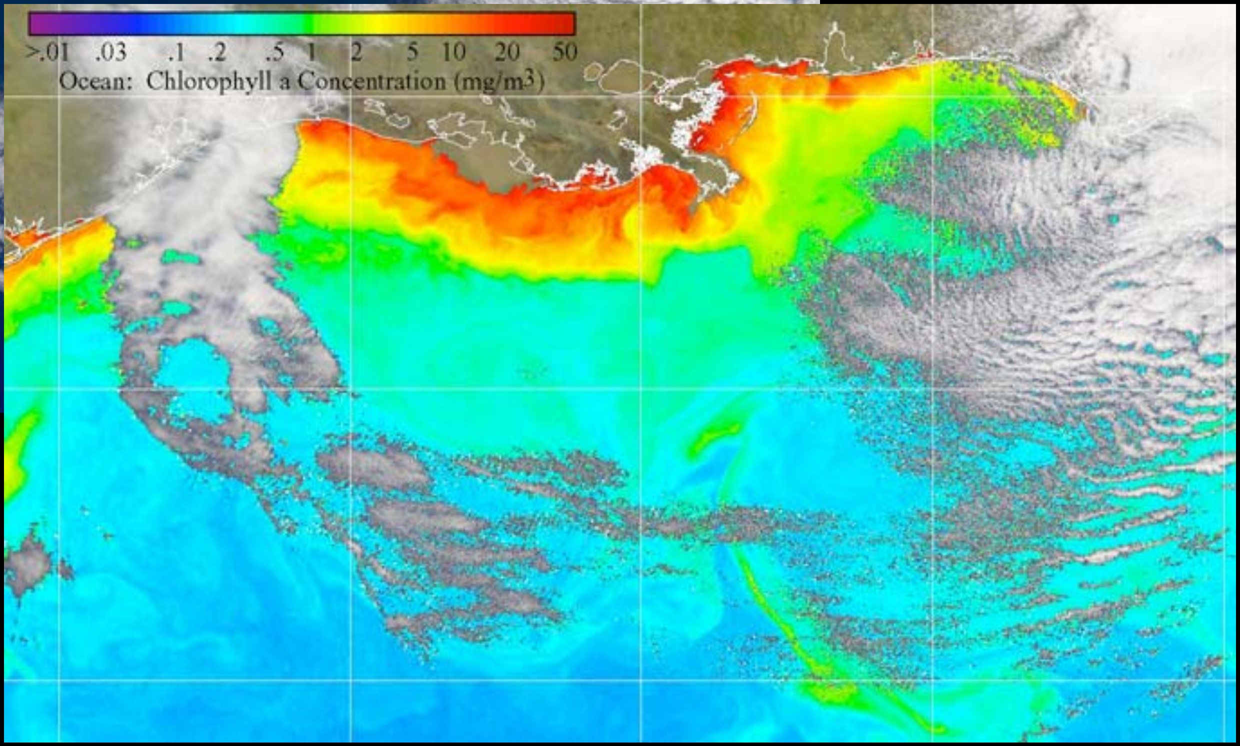
Phytoplankton – the principal source of organic matter in the oceans which sustains the marine food chain, a biological pump which sequesters carbon dioxide from the atmosphere into the deep ocean

Green color of plants, including phytoplankton, is a result of plant pigments, primarily chlorophyll a.

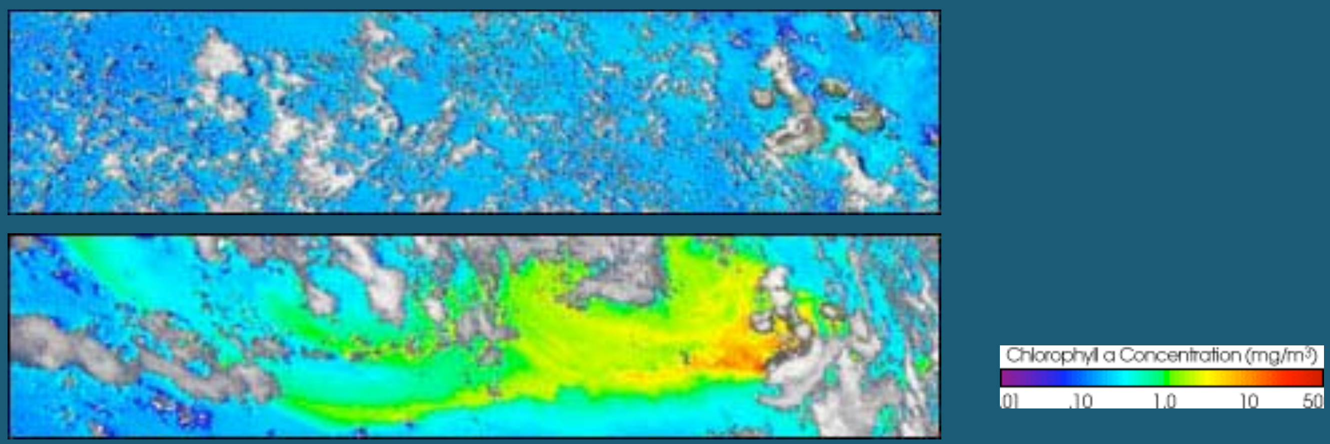
Algal Blooms

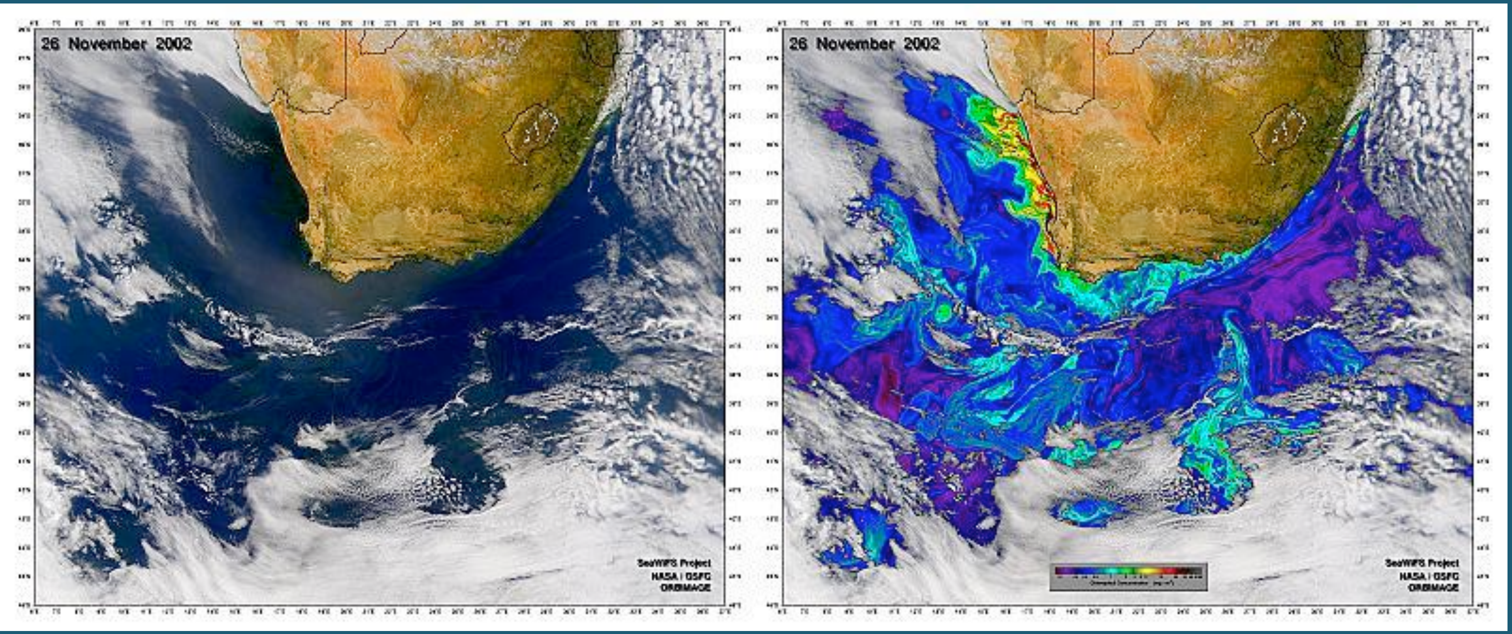


Feb. 25, 1999



Sea-viewing Wide Field-of-view (SeaWiFS) images of the Galapagos islands and surrounding waters from May 9, 1998 (top) and May 24, 1998 (bottom). The equatorial current shut down by El Niño reappeared over a period of days, indicated by the high concentrations of phytoplankton chlorophyll streaming to the west in the later image.

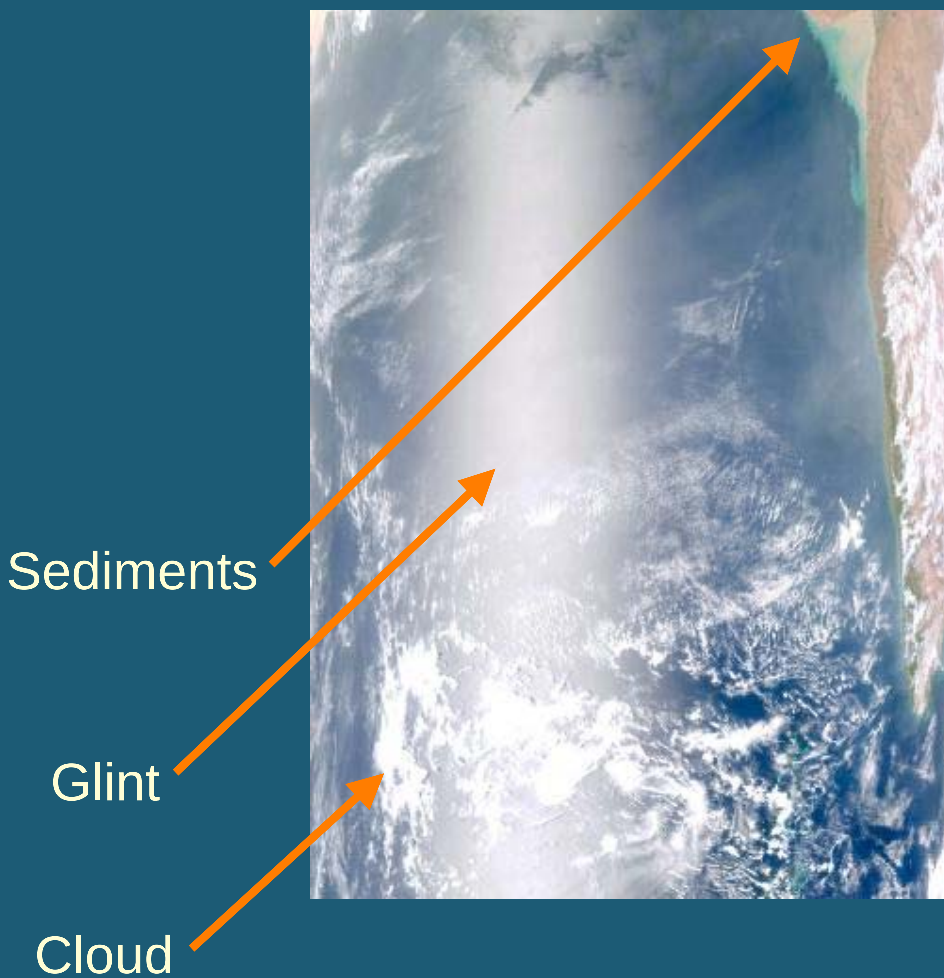




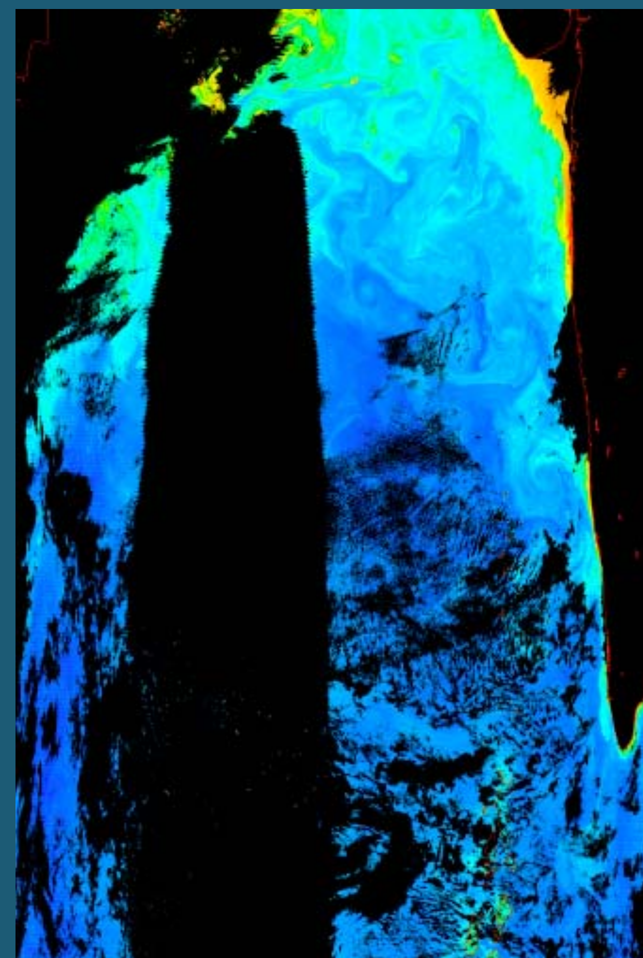
On November 26, 2002, SeaWiFS captured this relatively clear view of southern Africa and the seas around it. Phytoplankton distributions that are barely discernible in the quasi-true-color image become much clearer in the image of computed chlorophyll concentrations. In the second image, the lower chlorophyll concentrations associated with the Agulhas Current ar visible along the southeastern coast of the continent. When this current meets the Antarctic Circumpolar Current, it gets retroflexed back towards the east and forms the meanders and eddies visible in the lower right quadrant of the image. Higher chlorophyll concentrations along the west coast of Africa result from upwelling associated with the Benguela Current which flows northward along the western edge of the continent.

Level-2 Flags and Masking

RGB Image

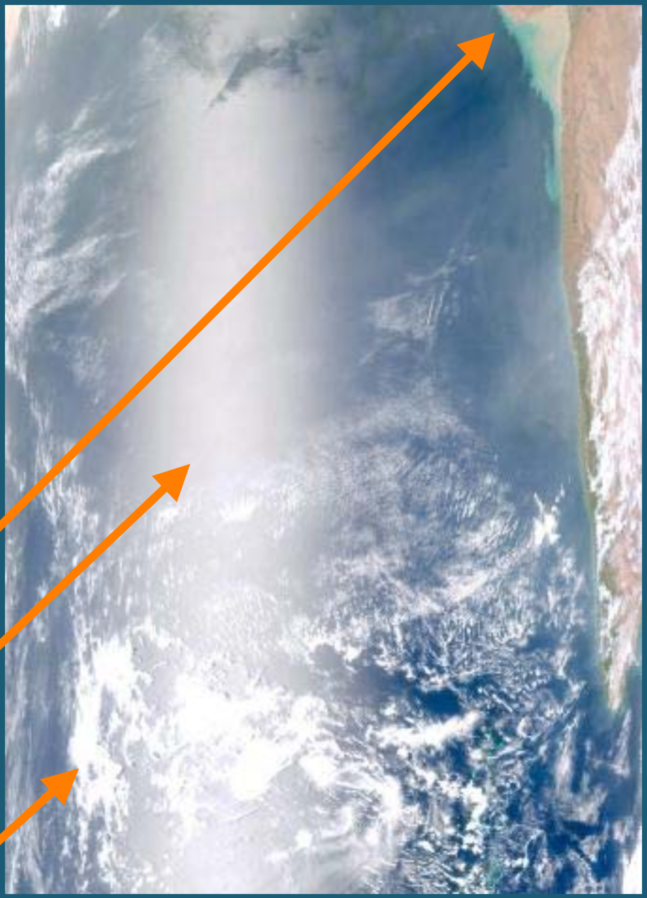


Chlorophyll



Level-2 Flags and Masking

RGB Image

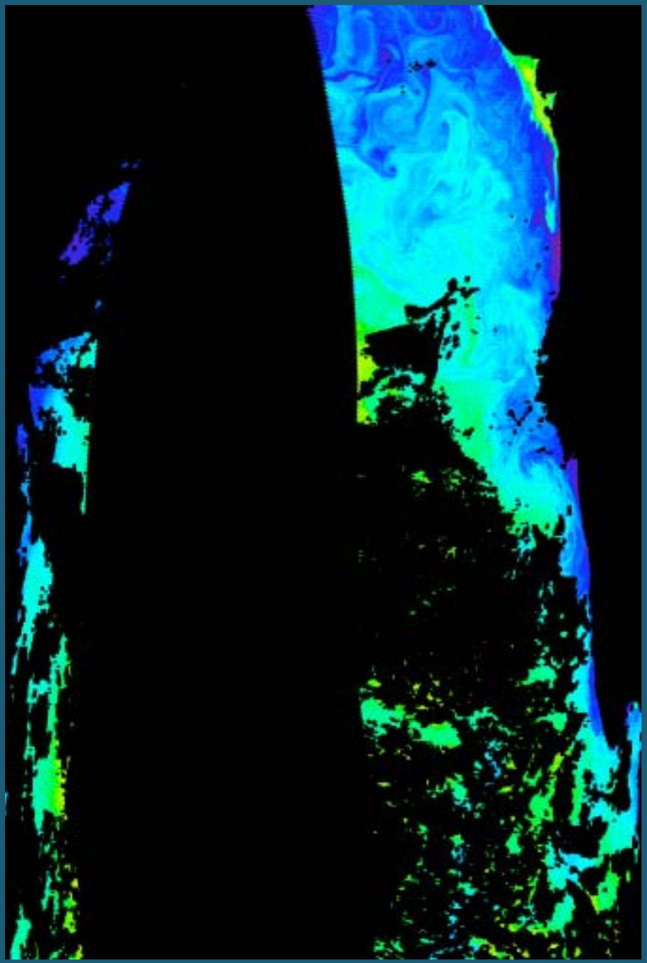


Sediments

Glint

Cloud

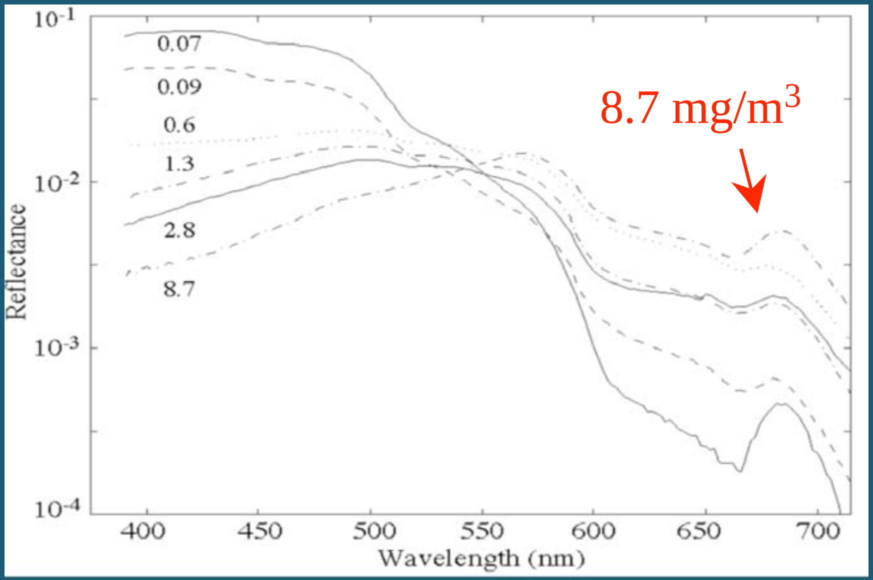
nLw (443)



Add masking for straylight

Aerosol Determination in High Chlorophyll

- High chlorophyll waters (or turbid coastal water) may contain significant L_w contribution in the NIR



- Atmospheric correction is applied iteratively using NIR reflectance modeling based on consecutive chlorophyll and reflectance retrievals (green & red)

- The modeling assumes
  - NIR absorption to be due to water only, and
  - NIR backscatter to be a function of particulates, colored dissolved organic matter, and detritus

Iterative Correction for Non-zero L_w(NIR)

1) Assume Lw(NIR) = 0
2) Compute La(NIR)
3) Compute La(VIS) from La(NIR)
4) Compute Lw(VIS)
5) Estimate Lw(NIR) from Lw(VIS) + model
6) Repeat until Lw(NIR) stops changing

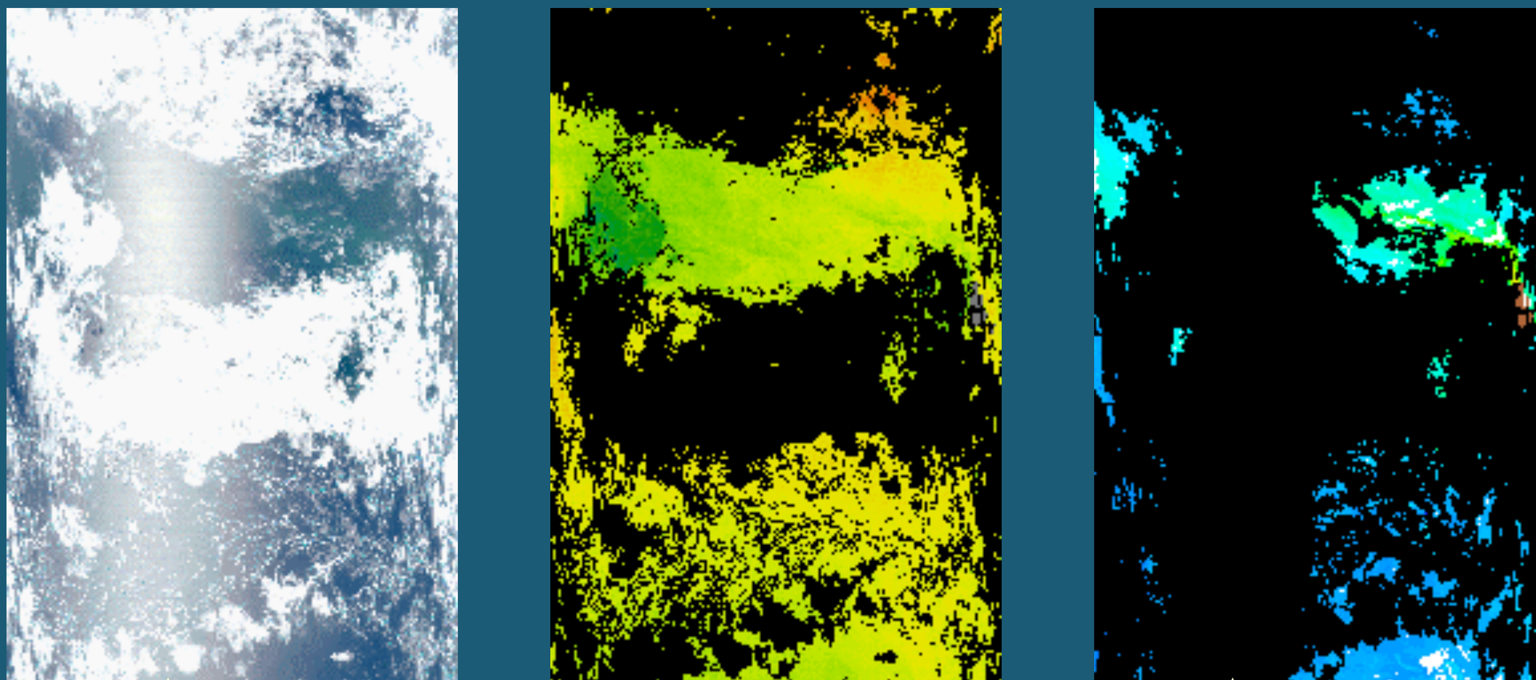
Iterating up to 10 times

MODIS Land/Cloud Bands of Interest

Band	Wavelength	Resolution	Potential Use	
1	645 nm	250 m	sediments, turbidity, IOPs	
2	859	250	aerosols	
3	469	500	C_a, IOPs, $CaCO_3$	
4	555	500	C_a, IOPs, $CaCO_3$	
5	1240	500	aerosols	SWIR
6	1640	500	aerosols	
7	2130	500	aerosols	

Retrieval Coverage Differences Between SST and OC

RGB Image | SST | Chlorophyll



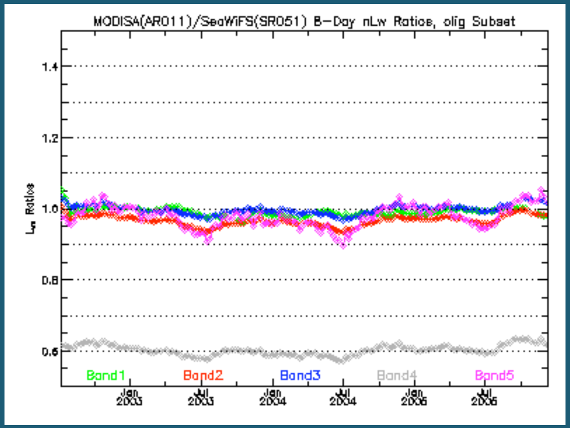
Sun glint

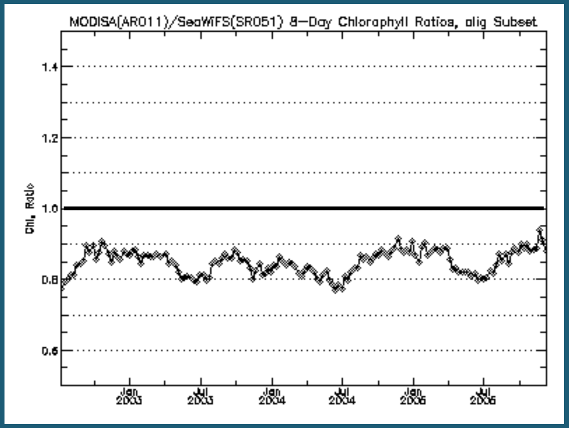
Sun glint

MODIS/SeaWiFS Ratio Trends

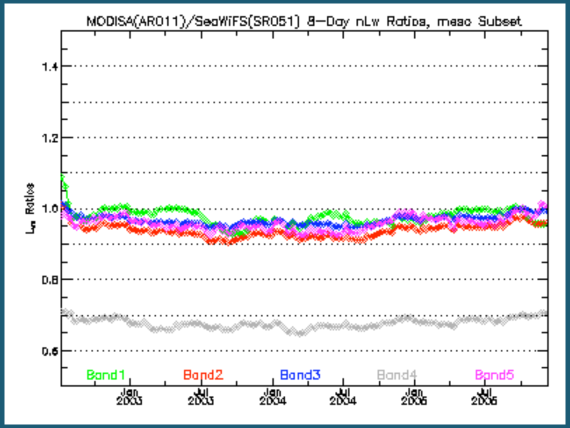
nLw Ratios | C_a Ratios

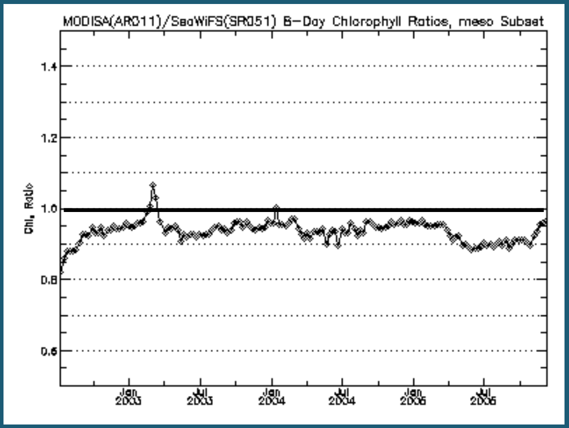
Oligotrophic



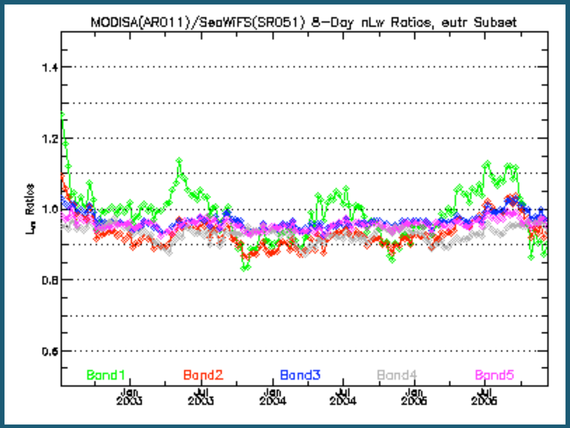


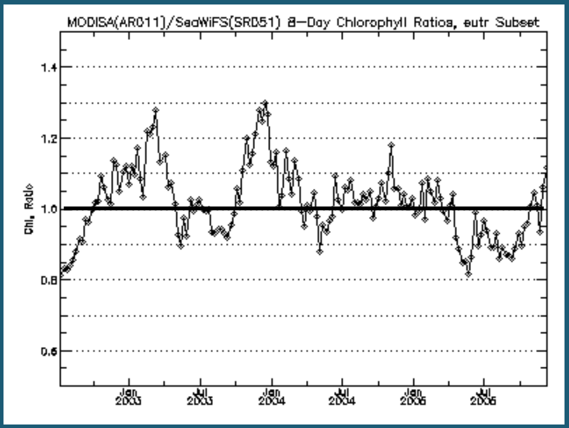
Mesotrophic



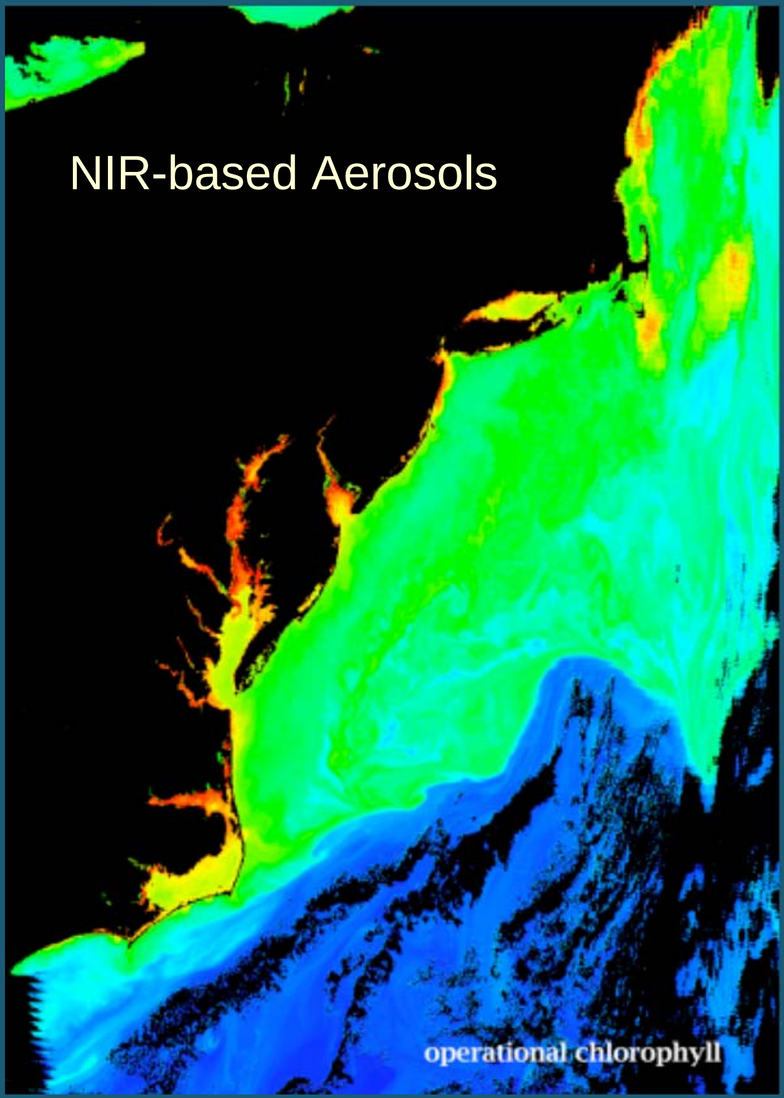


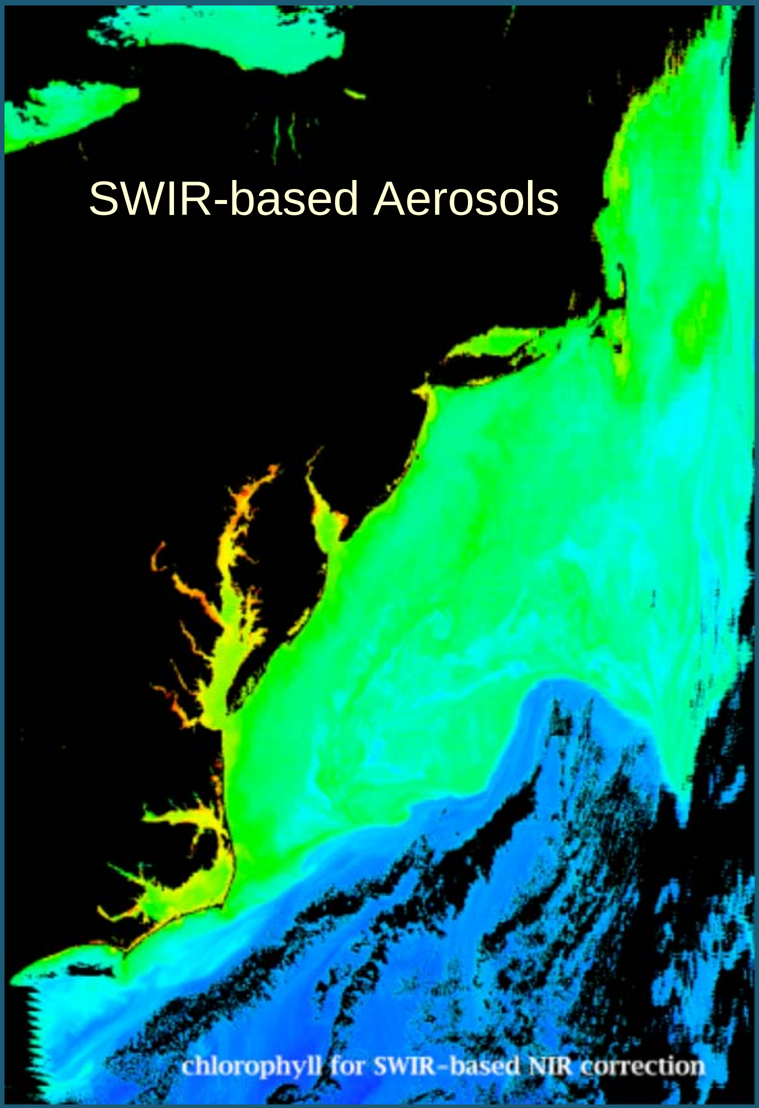
Eutrophic





Change in Chlorophyll Retrieval
with Alternate Aerosol Determination Methods

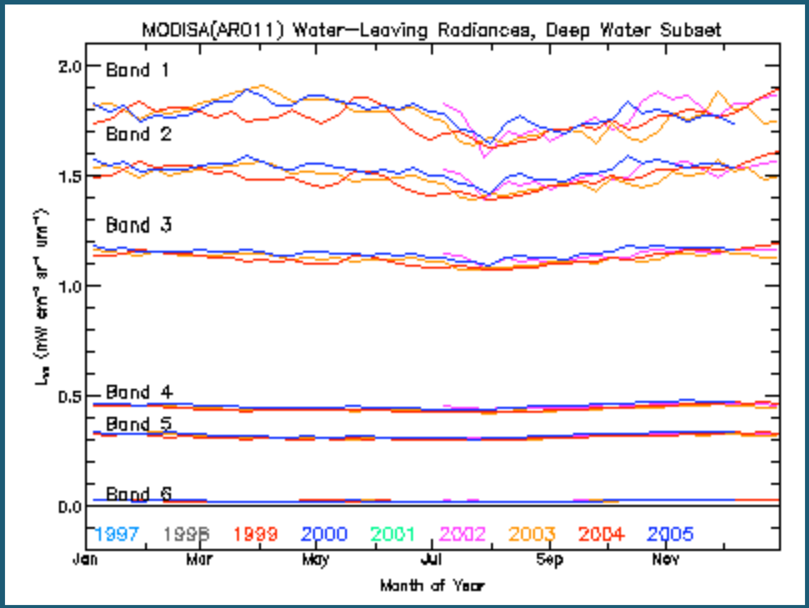




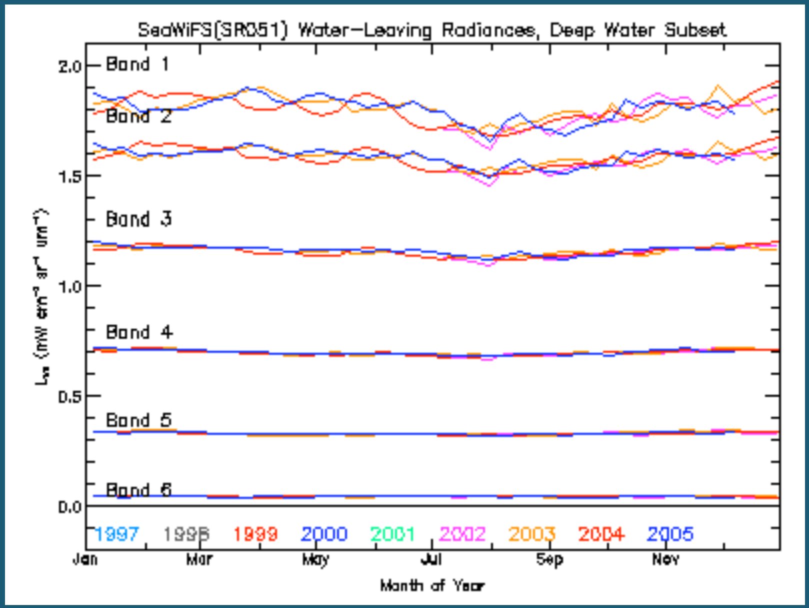
Comparison of Relative Temporal Stability in nLw

Deep-Water, 8-Day Composites, Common Bins

MODIS/Aqua



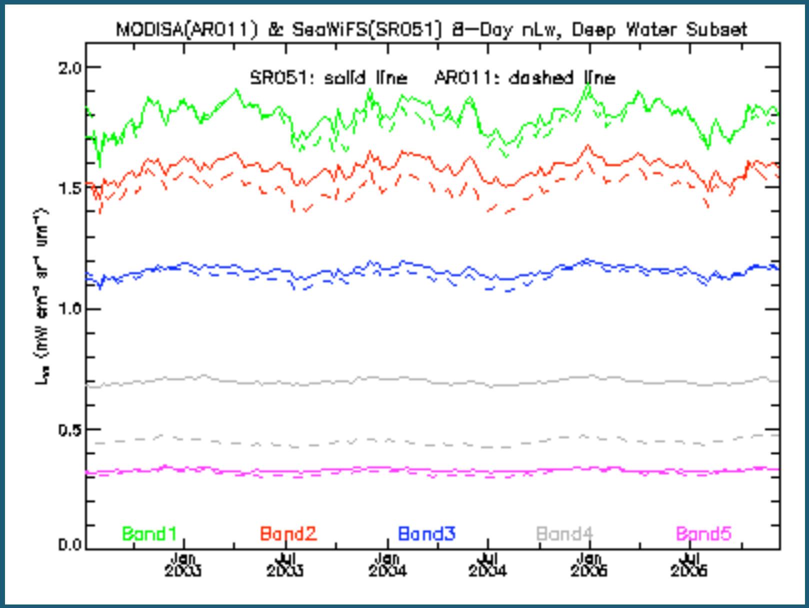
SeaWiFS



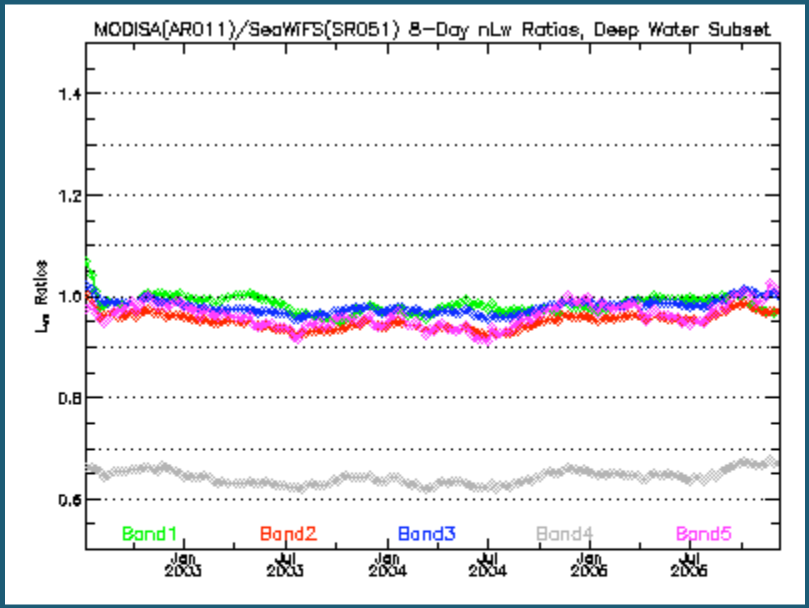
Direct Comparison of Satellite nLw Retrievals

Deep-Water, 8-Day Composites, Common Bins

SeaWiFS & MODIS



MODIS / SeaWiFS

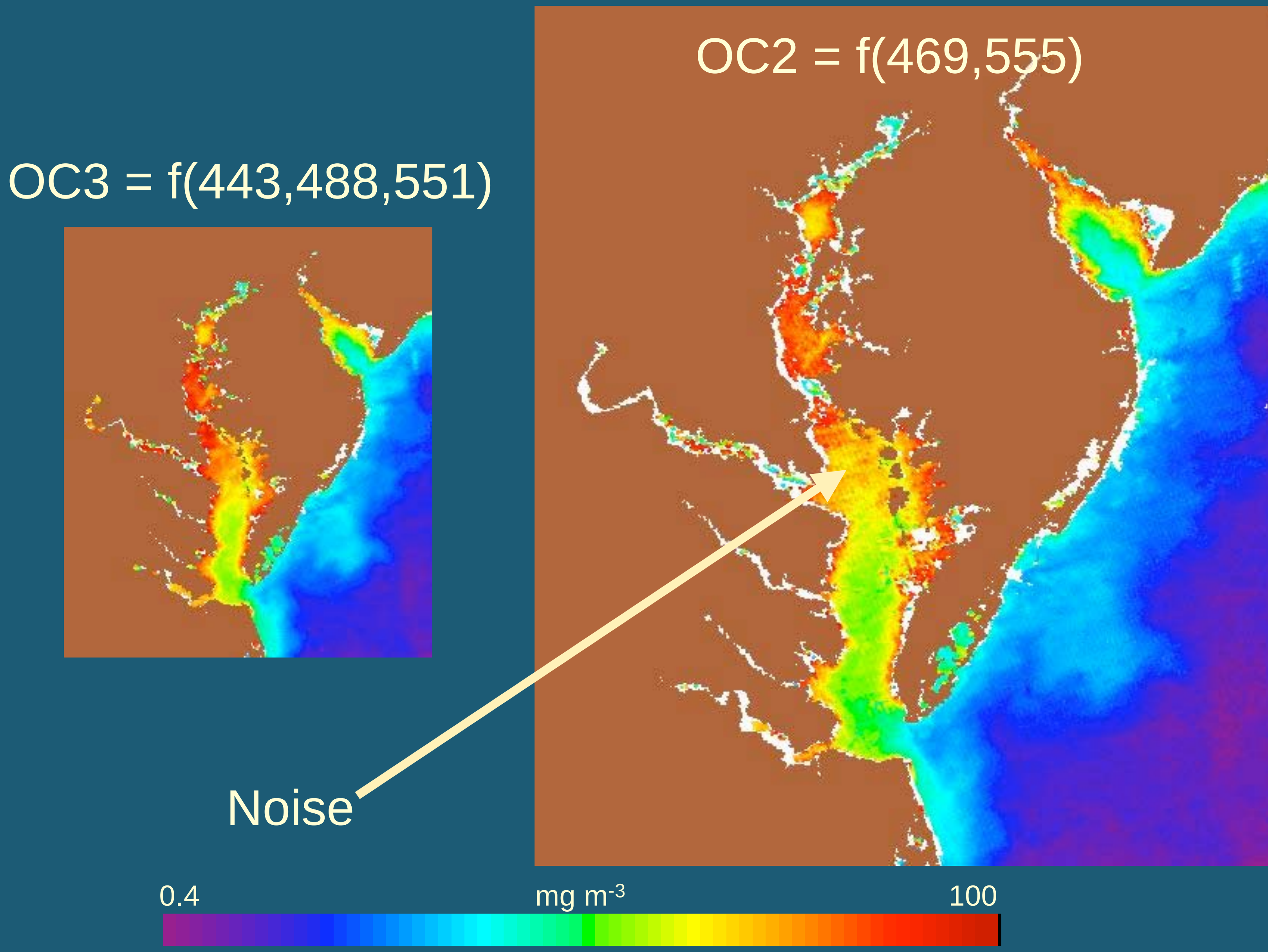


MODIS Land/Cloud Bands of Interest

Band	Wavelength	Resolution	Potential Use
1	645 nm	250 m	sediments, turbidity, IOPs
2	859	250	aerosols
3	469	500	C_a, IOPs, $CaCO_3$
4	555	500	C_a, IOPs, $CaCO_3$
5	1240	500	aerosols
6	1640	500	aerosols
7	2130	500	aerosols

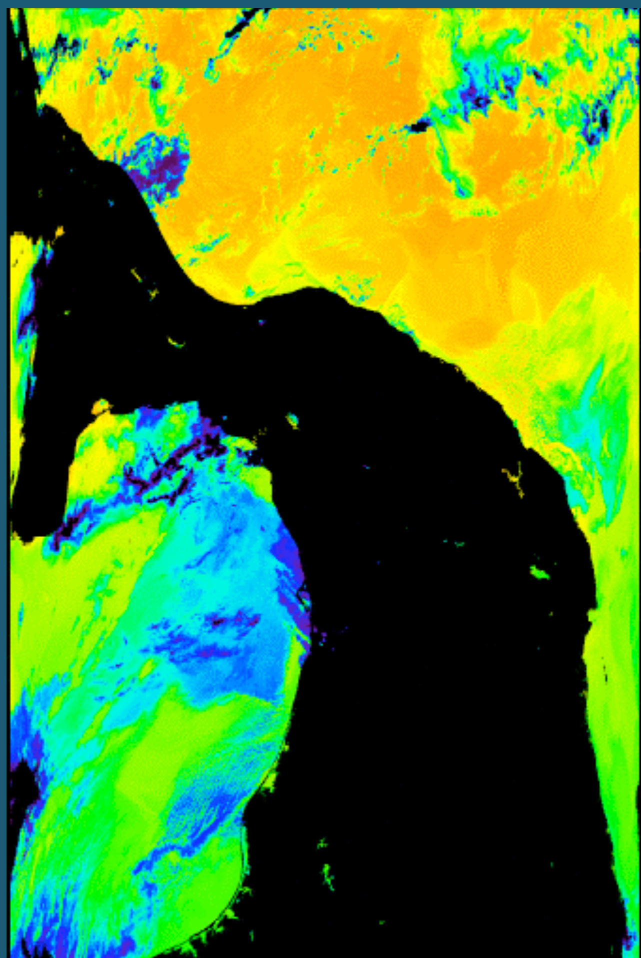
spatial resolution and expanded dynamic range come at the cost of increased digitization error (reduced sensitivity at ocean radiances) and reduced signal to noise

Chlorophyll: 1000 & 500-meter

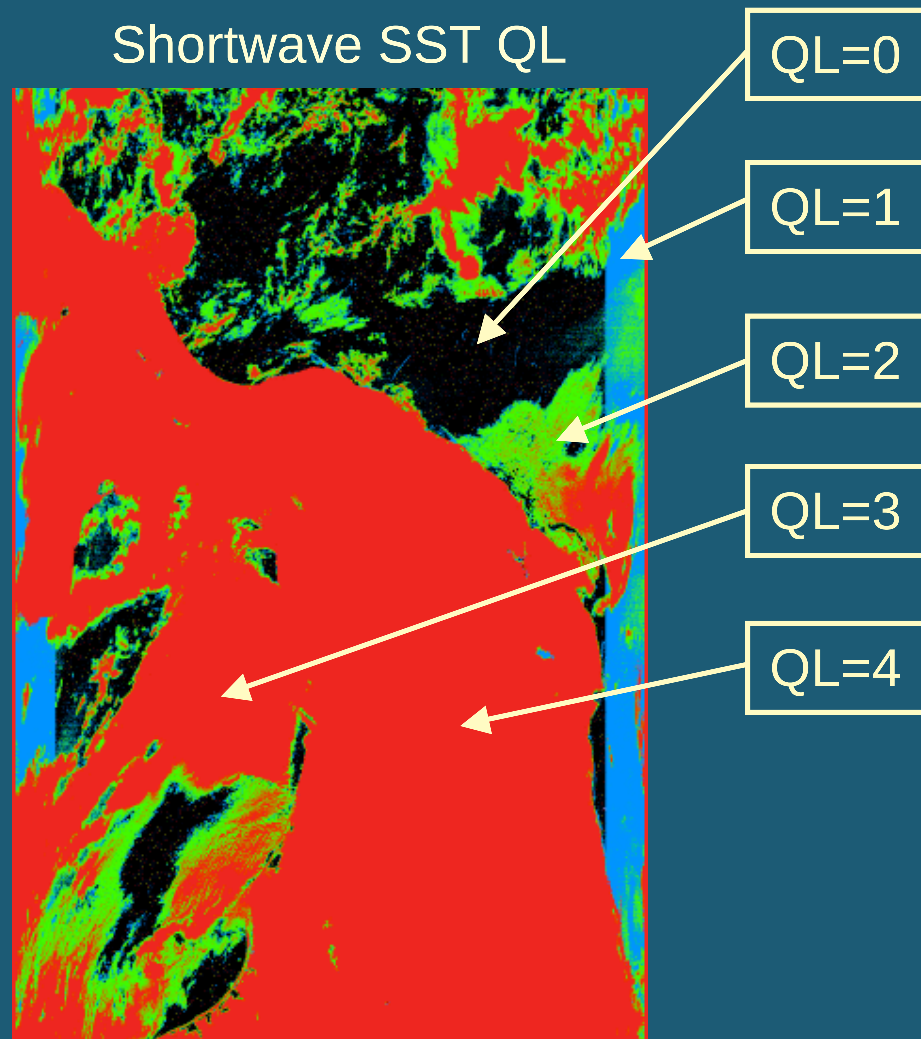


SST Quality Levels

Shortwave SST



Shortwave SST QL



Sea Surface Temperature

Operational MODIS Ocean Band Suite

VIS/NIR

Ocean Color

Band Number	Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)	SNR at L_{typ}	L_{typ} mW cm^{-2} µm^{-1} sr^{-1}	L_{max} mW cm^{-2} µm^{-1} sr^{-1}
8	412	15	1000	1773	7.84	26.9
9	443	10	1000	2253	6.99	19.0
10	488	10	1000	2270	5.38	14.0
11	531	10	1000	2183	3.87	11.1
12	551	10	1000	2200	3.50	8.8
13	667	10	1000	1962	1.47	4.2
14	678	10	1000	2175	1.38	4.2
15	748	10	1000	1371	0.889	3.5
16	869	15	1000	1112	0.460	2.5

Thermal

SST

Band Number	Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)	NEdT
22	3959	60	1000	0.07
23	4050	60	1000	0.07
31	11000	60	1000	0.05
32	12000	60	1000	0.05

Level-2 SST Processing

1 Convert observed radiances to brightness temperatures (BTs)

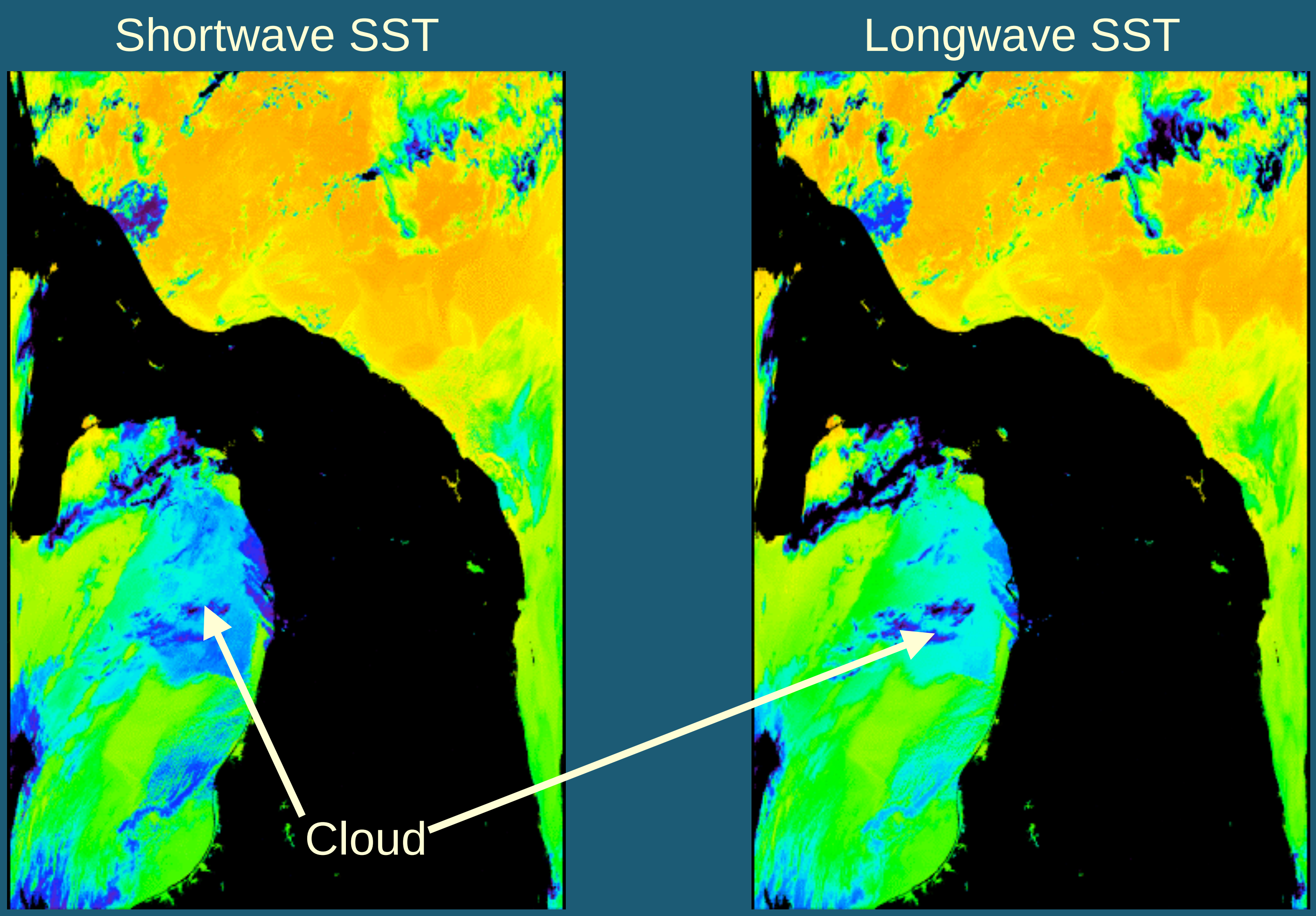
2 Apply empirical algorithm to relate brightness temperature in two wavelengths to SST (regression against in situ buoy data)

$$sst = a0 + a1*BT_1 + a2*(BT_2-BT_1) + a3*(1.0/\mu-1.0)$$

3 Assess quality (0=best, 4=not computed)

- e.g., cloud or residual water vapor contamination
- no specific "cloud mask"

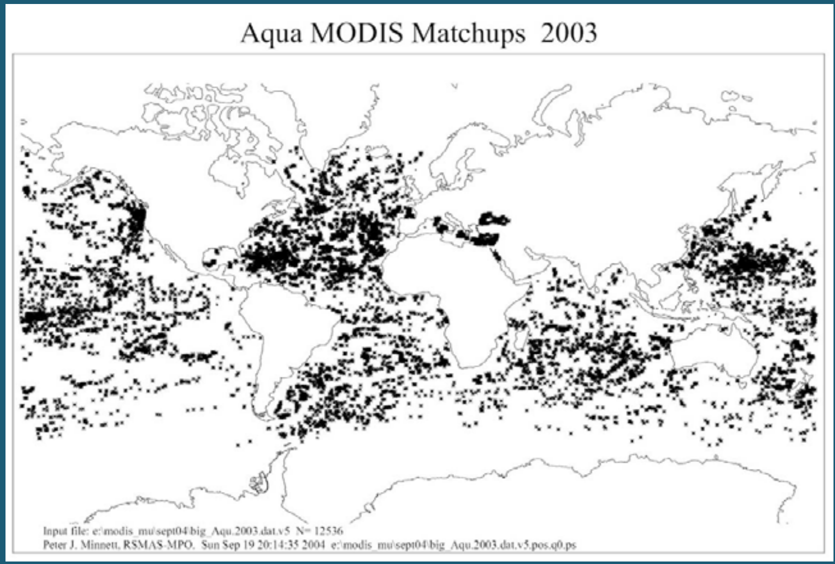
Nighttime SST Products

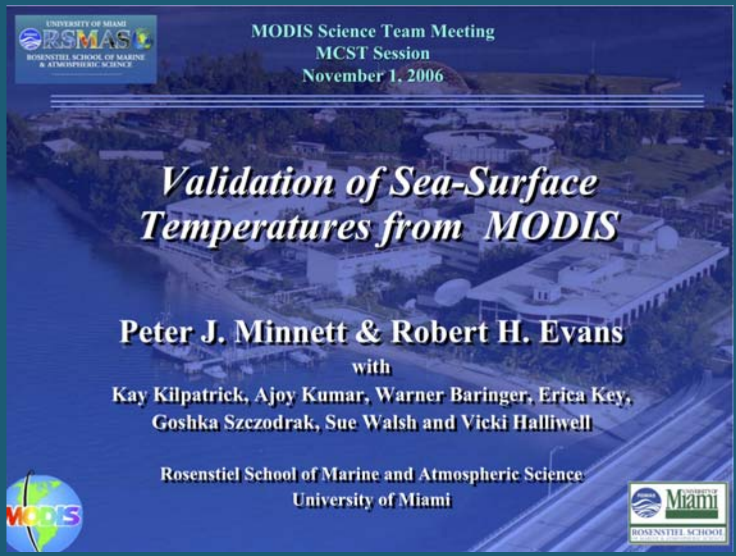


SST Validation

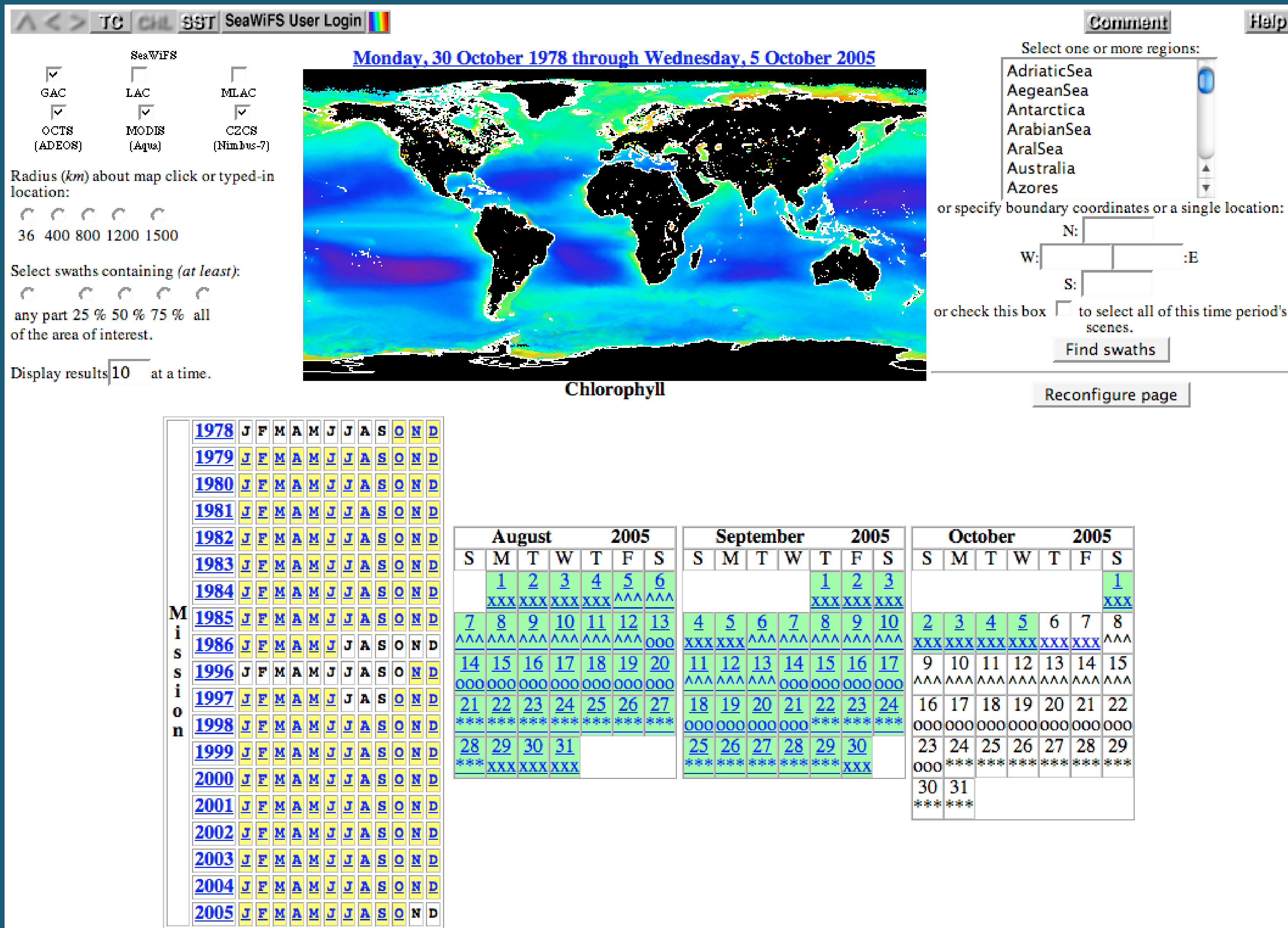
Buoy Measurements

SST 11-12 µm	TERRA					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2000	-0.139	0.797	3091	-0.186	0.794	1800
2001	-0.262	1.430	6321	-0.228	0.707	4935
2002	-0.135	0.621	9244	-0.204	0.580	6935
2003	-0.086	0.607	15685	-0.190	0.558	11058
2004	-0.068	0.579	24964	-0.167	0.559	16943
2005	-0.110	0.549	39826	-0.213	0.519	28460
2006	-0.105	0.574	32495	-0.208	0.524	23149
all years	-0.108	0.650	131626	-0.200	0.555	93280
SST 11-12 µm	**AQUA**					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2002	-0.153	0.538	10293	-0.235	0.499	5906
2003	-0.133	0.577	22988	-0.224	0.508	12977
2004	-0.137	0.562	26415	-0.219	-0.484	15471
2005	-0.152	0.539	40941	-0.235	0.461	25083
2006	-0.135	0.550	34687	-0.205	0.452	22187
all years	-0.142	0.553	135324	-0.222	0.475	81624
SST 4µm	**TERRA**			**AQUA**		
Year	night			night		
	mean	RMS	Count	mean	RMS	Count
2000	-0.161	0.829	1993			
2001	-0.220	0.663	5397			
2002	-0.191	0.528	7580	-0.224	0.449	6429
2003	-0.176	0.500	12006	-0.217	0.455	14095
2004	-0.178	0.493	18452	-0.214	0.426	16765
2005	-0.178	0.471	31130	-0.223	0.414	27280
2006	-0.174	0.473	25294	-0.208	0.404	24140
all years	-0.179	0.505	101852	-0.216	0.423	88709

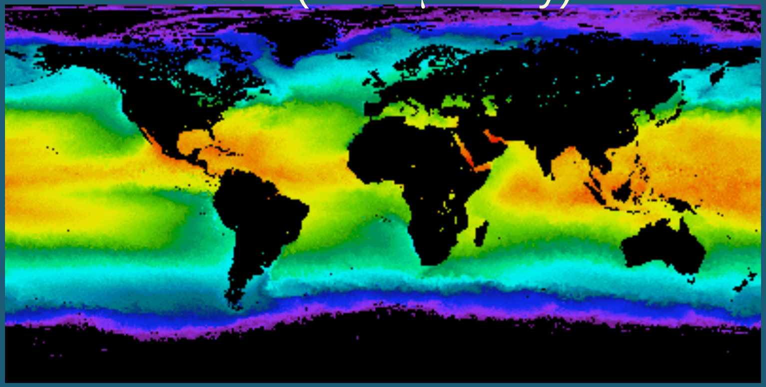




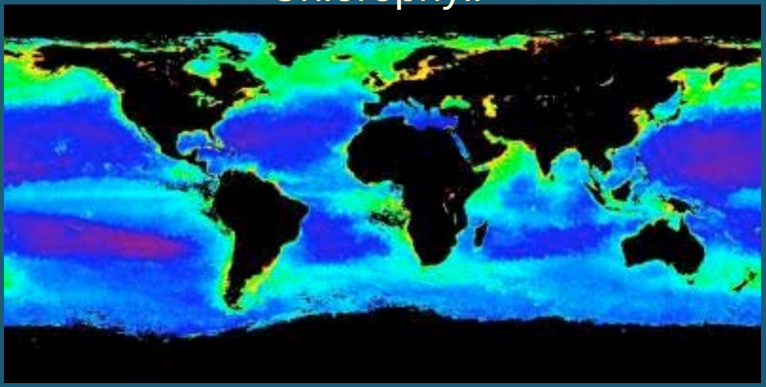
http://oceancolor.gsfc.nasa.gov/



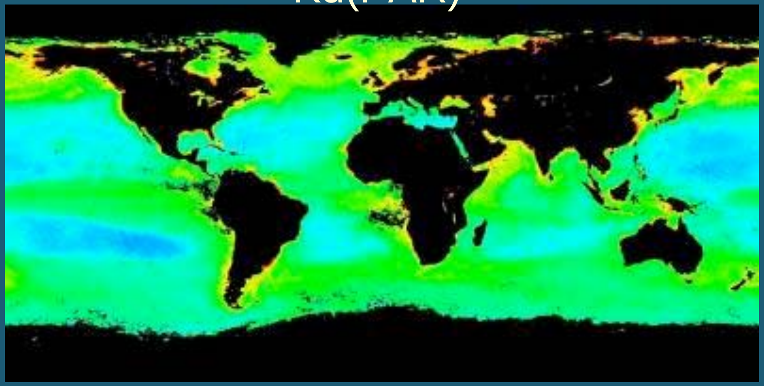
SST (11-12μm day)



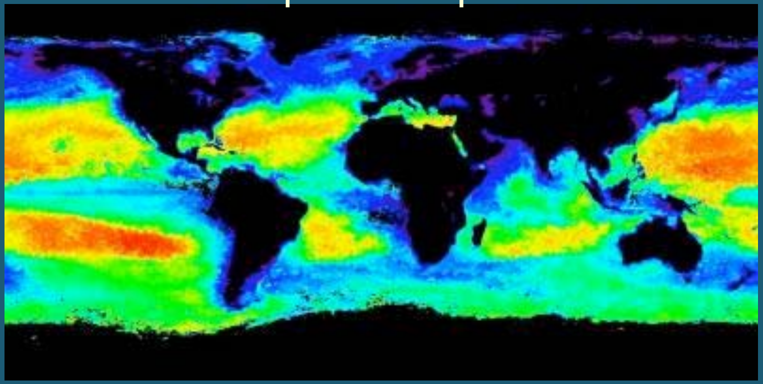
Chlorophyll



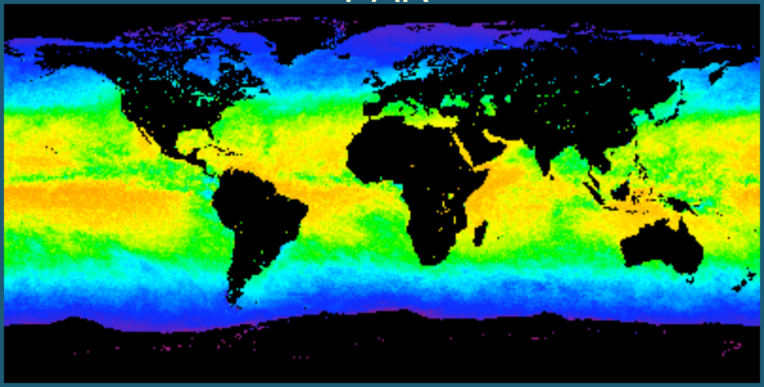
Kd(PAR)

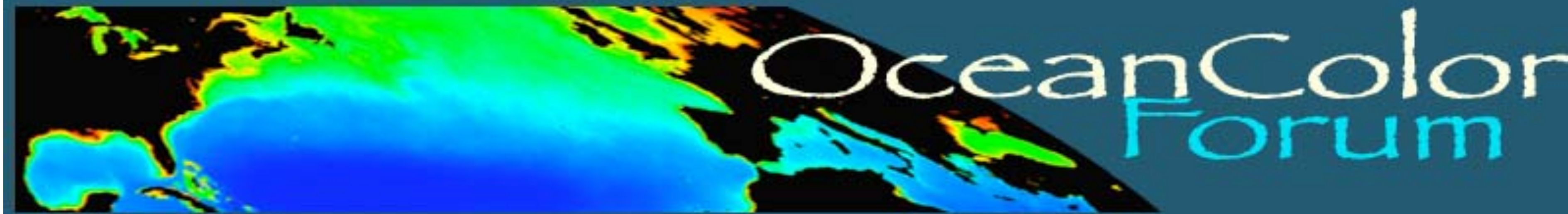


Euphotic depth



PAR





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