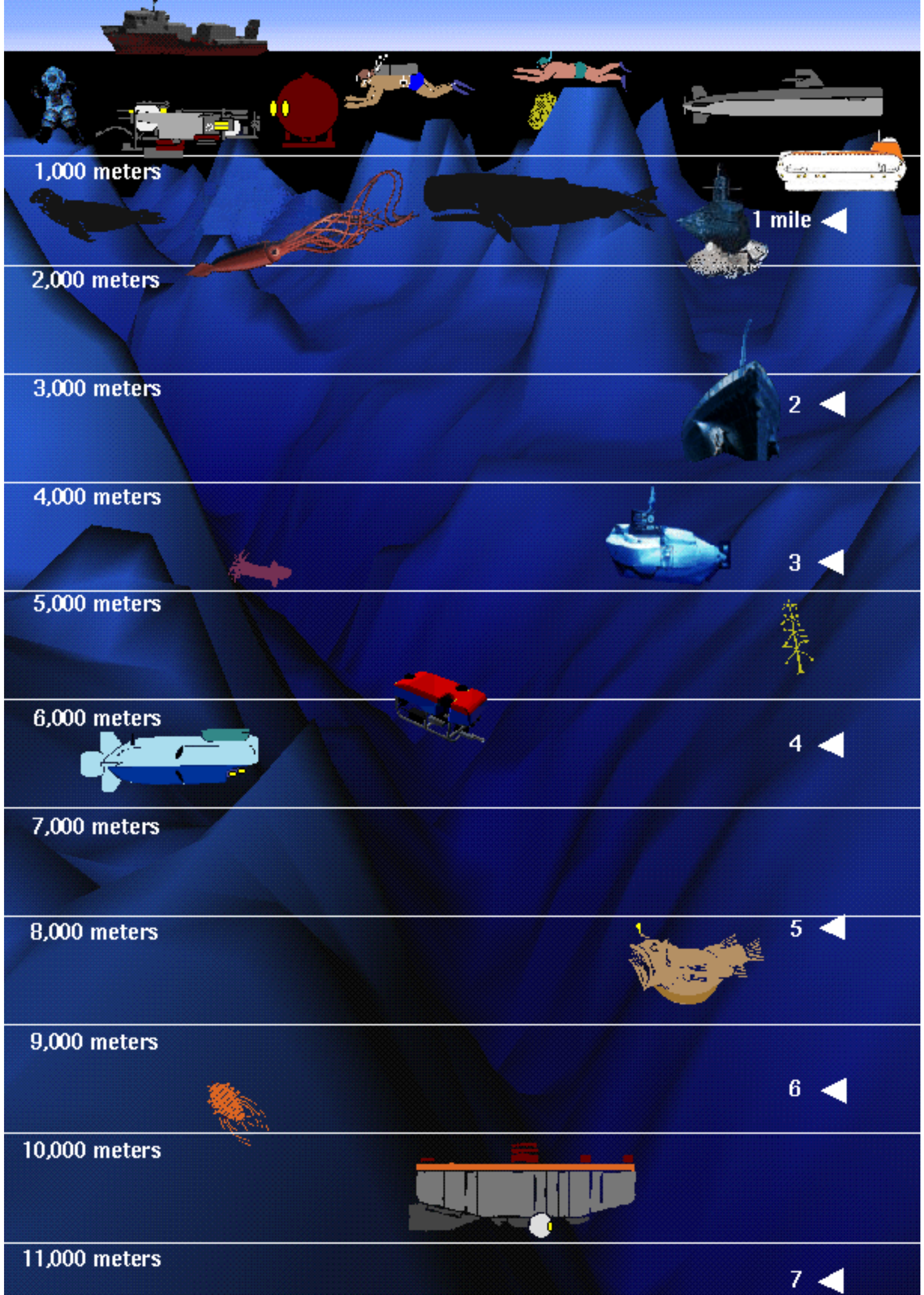
Imaging Earth's Ocean Gardens

Paula Bontempi
NASA Headquarters
(many thanks to Gene Feldman and Norman Kuring, NASA GSFC)

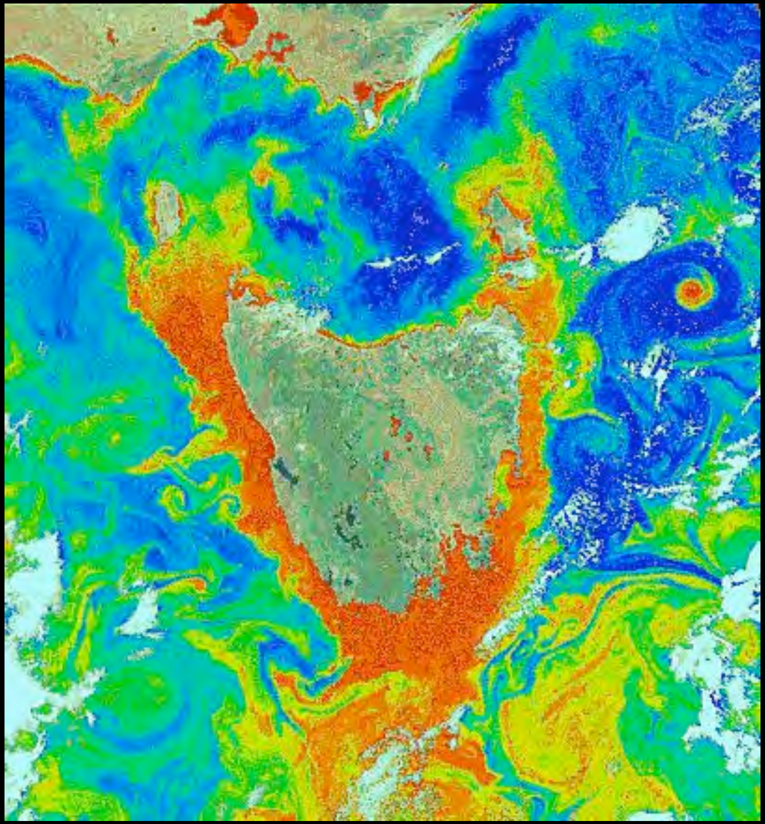
International Ocean Color Science Meeting
Lisbon, Portugal
15-18 May 2017


1,000 meters
1 mile
2,000 meters
3,000 meters
2
4,000 meters
3
5,000 meters
6,000 meters
4
7,000 meters
8,000 meters
5
9,000 meters
6
10,000 meters
11,000 meters
7

Historical Ocean Sampling

- The ocean is a very big place - ships don't move that fast.
- Conditions in the ocean can change pretty quickly – the ocean is enormous – SO the chances of really characterizing the conditions in any given place are pretty difficult.
- Being out at sea for any length of time can be pretty uncomfortable even under the best of circumstances.
- Ship-based oceanographers are still generally limited to sampling things in a pretty small area often with a great deal of difficulty.
- Autonomous technologies (vehicles, floats, drifters), sensors, batteries, etc. have opened up many new scales of observations and sampling options.

Satellite Ocean Sampling



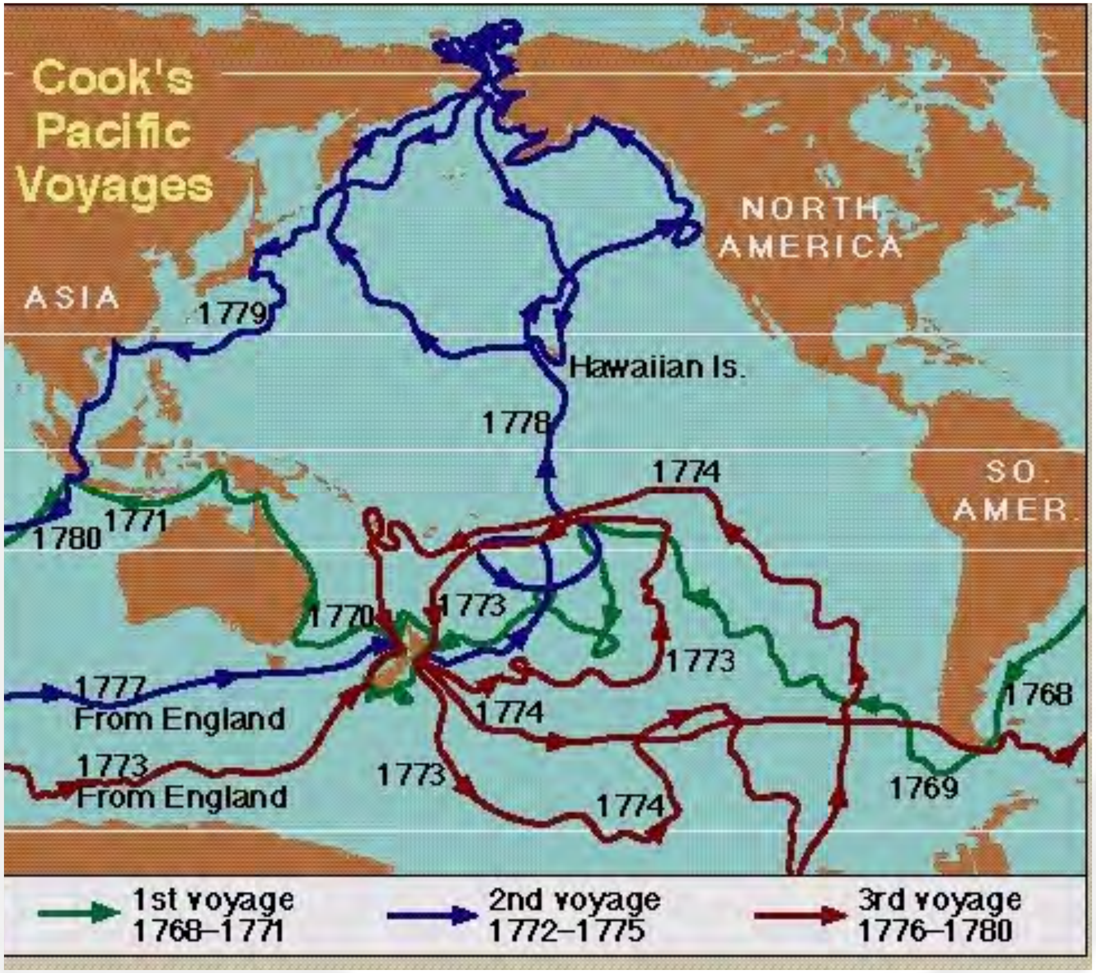
- Satellites look at very large areas of the world in a very short time (synoptic).
- Located off the southeast coast of Australia, Tasmania has currents that collide with one another around producing regions of intense mixing that ultimately result in very complex patterns of phytoplankton - Coastal Zone Color Scanner (CZCS) - 1981.

Physical Climate

Ocean Color

Captain James Cook (1728-1779)

Captain Cook by Nathaniel Dance, 1776

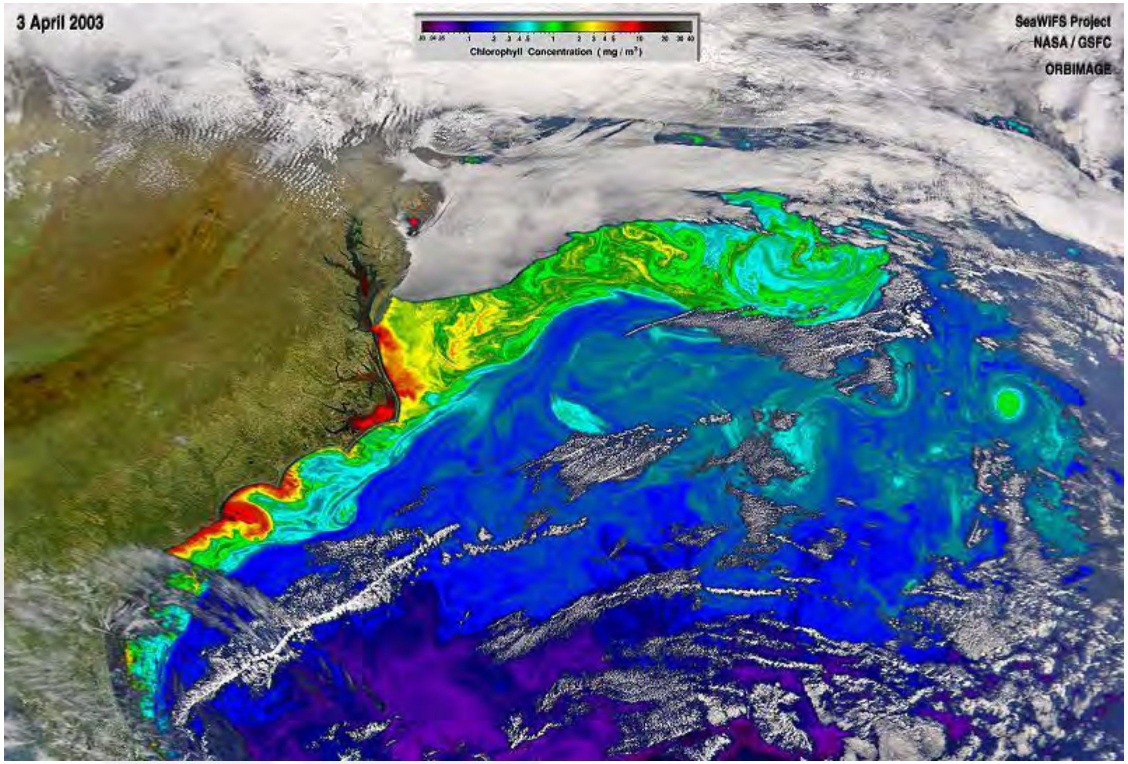


Cook's Three Voyages of Discovery (1768-1780)

- 3 Major Voyages of Exploration
- 1st truly scientific voyages

Franklin-Folger Map of the Gulf Stream - 1769

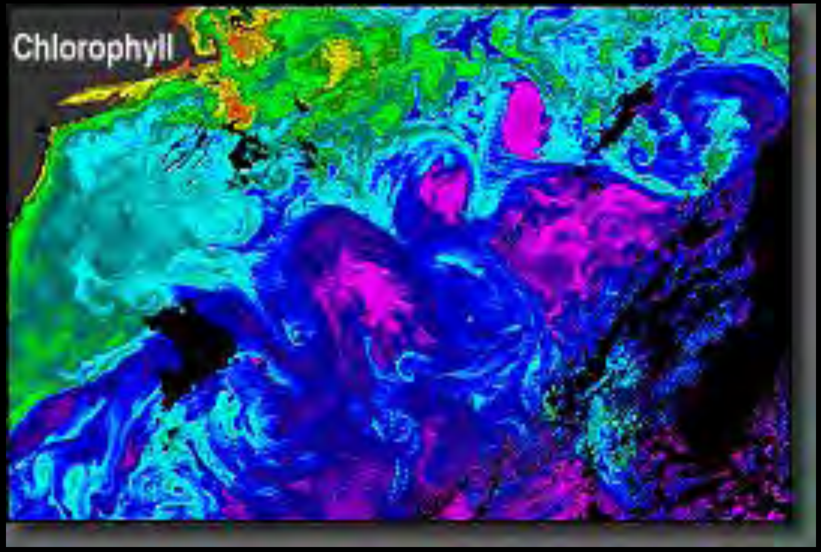
Map of the Gulf Stream (SeaWiFS - 2003)

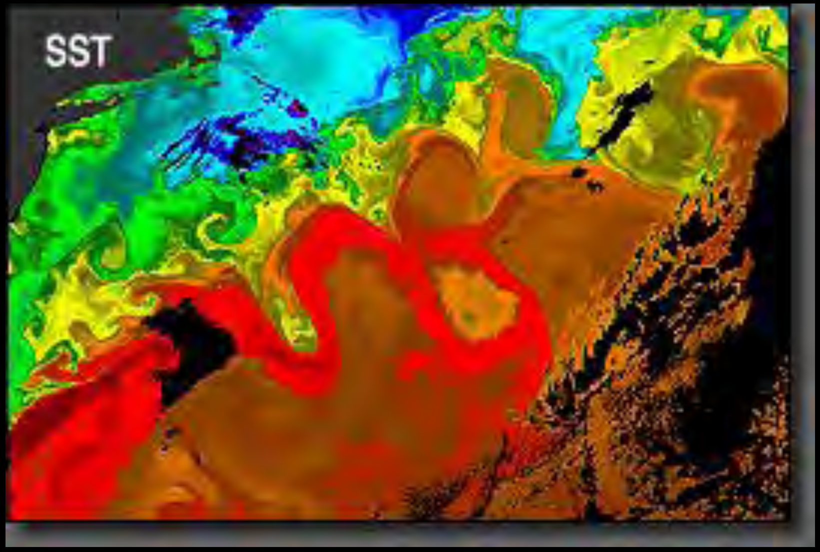


Probably the most dominant oceanographic feature of the western North Atlantic Ocean is the Gulf Stream. The northern edge of that current is clearly visible in the chlorophyll field. As the Gulf Stream flows eastward it forms meanders that occasionally pinch off to form clockwise-rotating warm-core rings to the north and counterclockwise- rotating cold-core rings to the south. Cold-core rings generally have higher chlorophyll concentrations (and lower surface temperatures) than the surrounding water, and a few of them can be defined in this image. Cold core rings tend to form in the east and then gradually migrate towards the southwest. Some have been reported to remain recognizable for up to two years.

Gulf Stream Dynamics

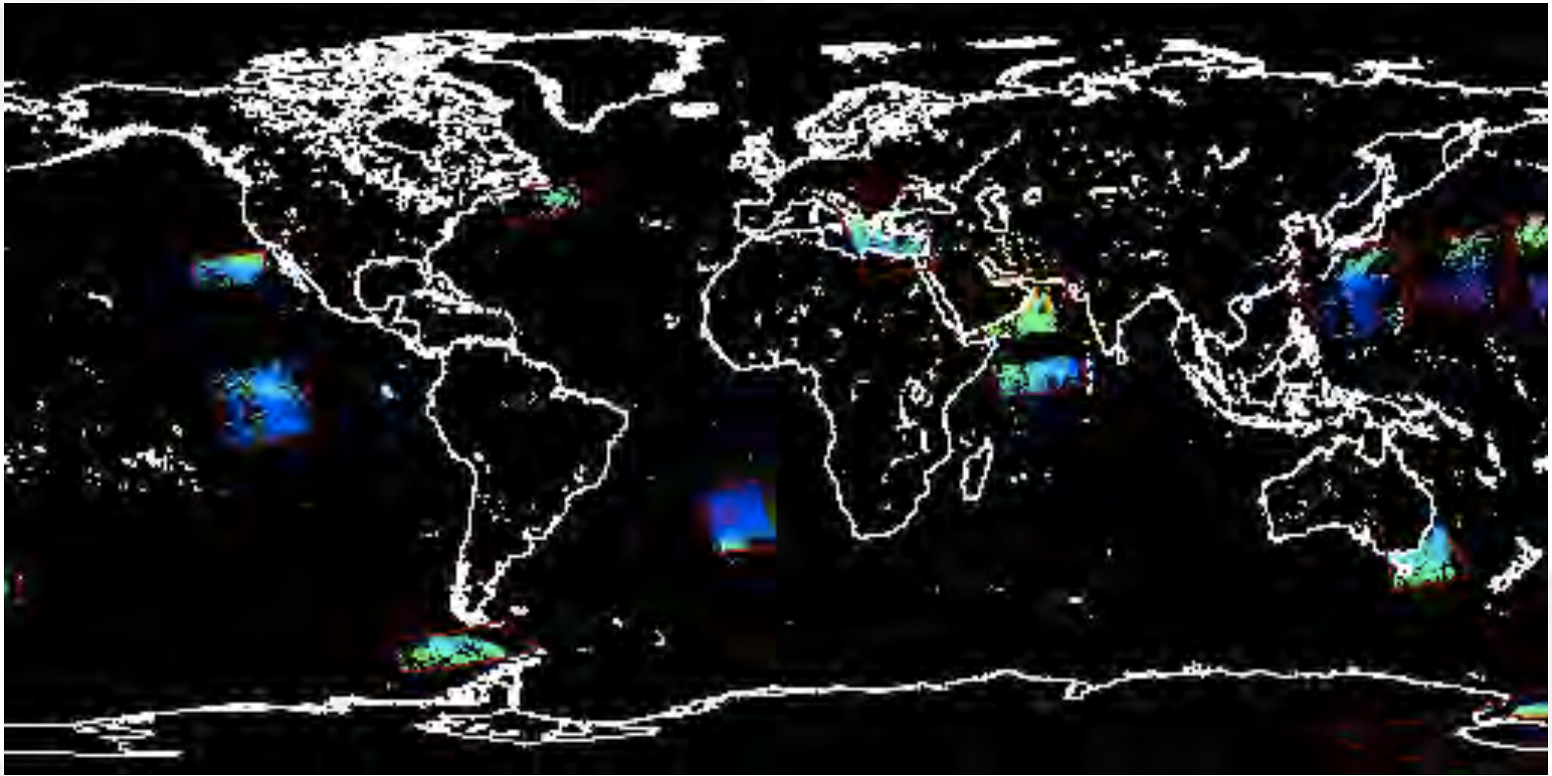
(MODIS-Aqua - 2005)





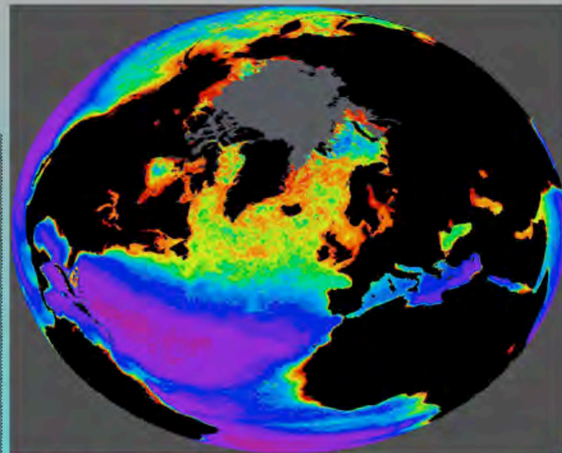
Coastal Zone Color Scanner (CZCS) 1978 – 1986

- experimental "proof of concept" mission
- shared onboard resources limited coverage
- no thought of routine global coverage
- system designed to process ONLY 10% of data collected
- targets chosen by a "select" few
- very limited and 'difficult' data access

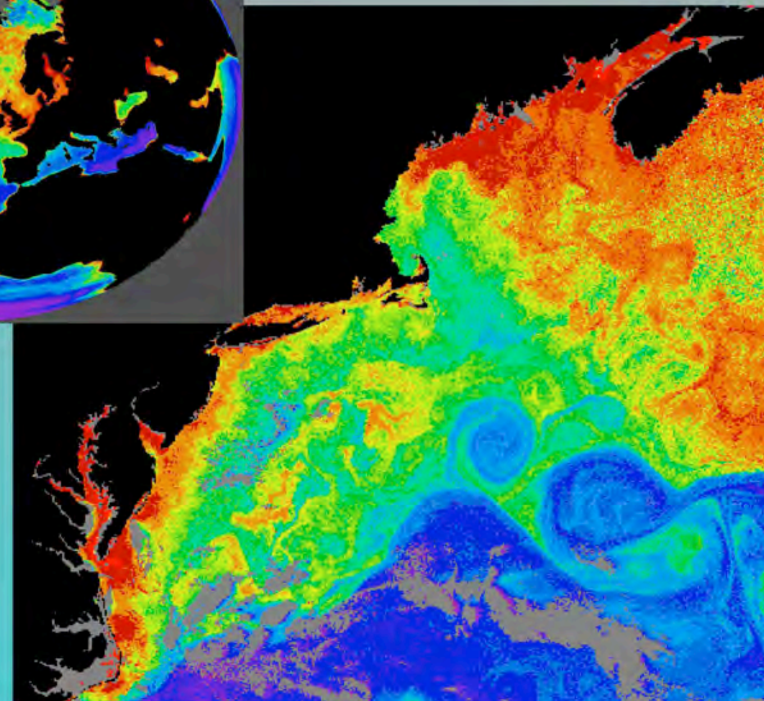


The Earth from Space

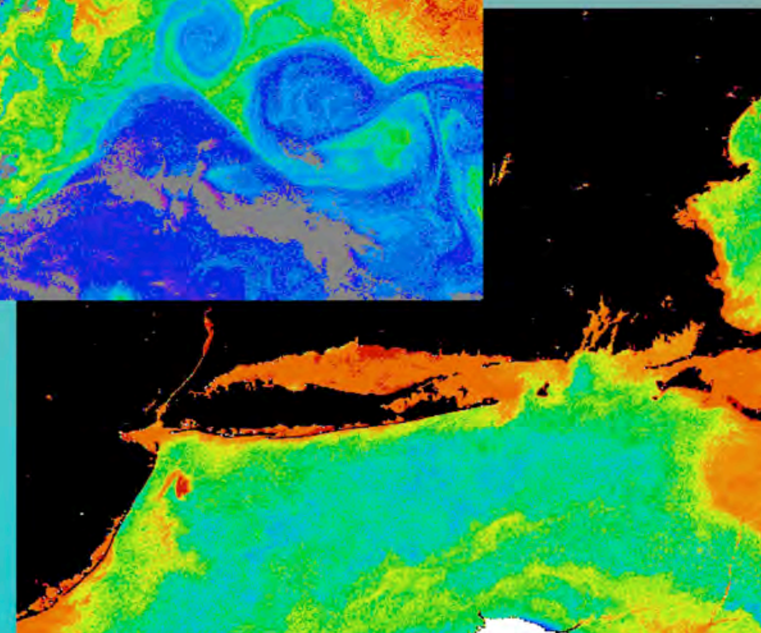
Spanning Key Time and Space Scales



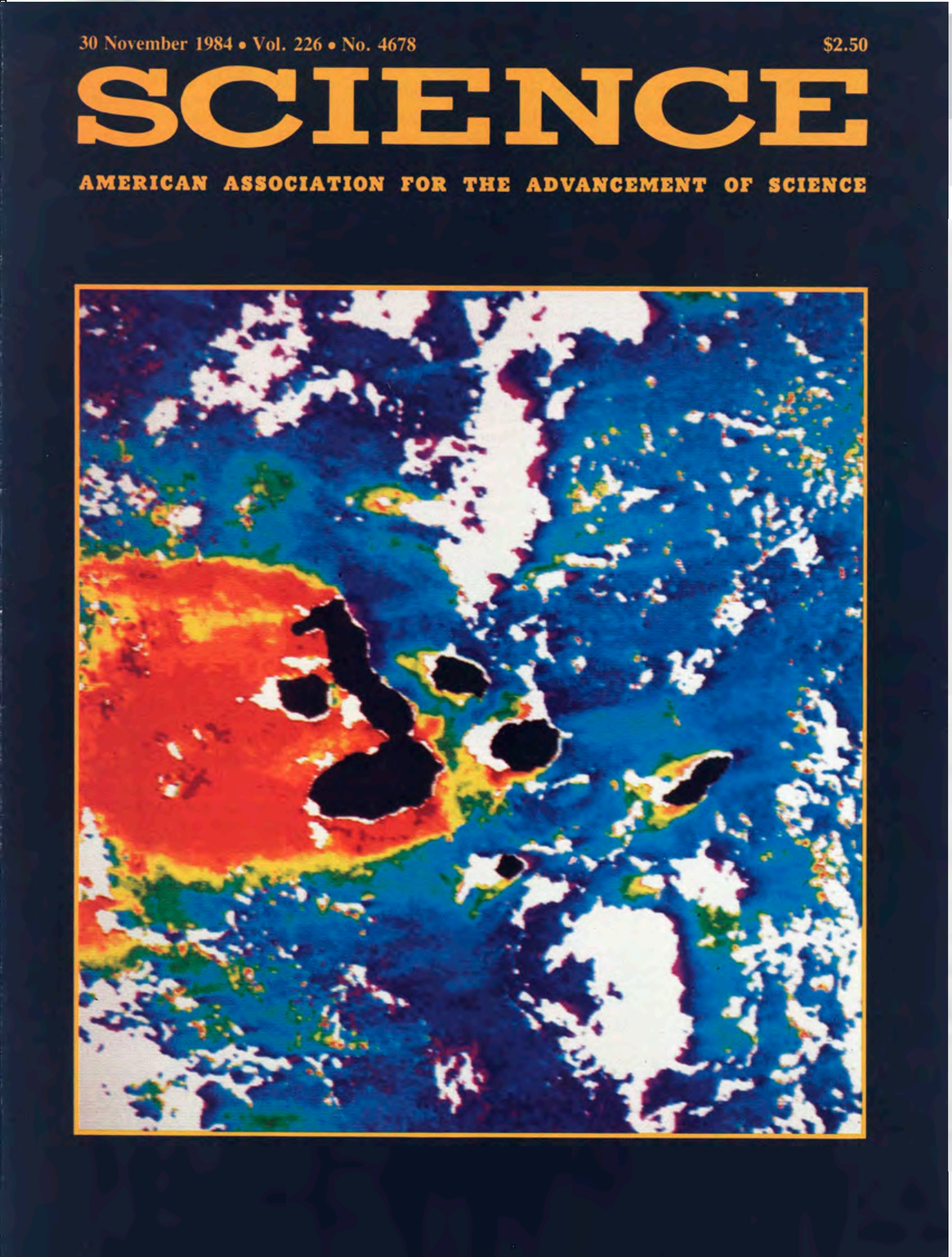
Global



Regional



Local



El Niño – productivity collapsing then redistributed - revisited in 1997-98 El Niño

El Niño en las Islas Galápagos: El Evento de 1982-1983. pp. 125-130
Fundación Charles Darwin para las Islas Galápagos, Quito, Ecuador, 1985

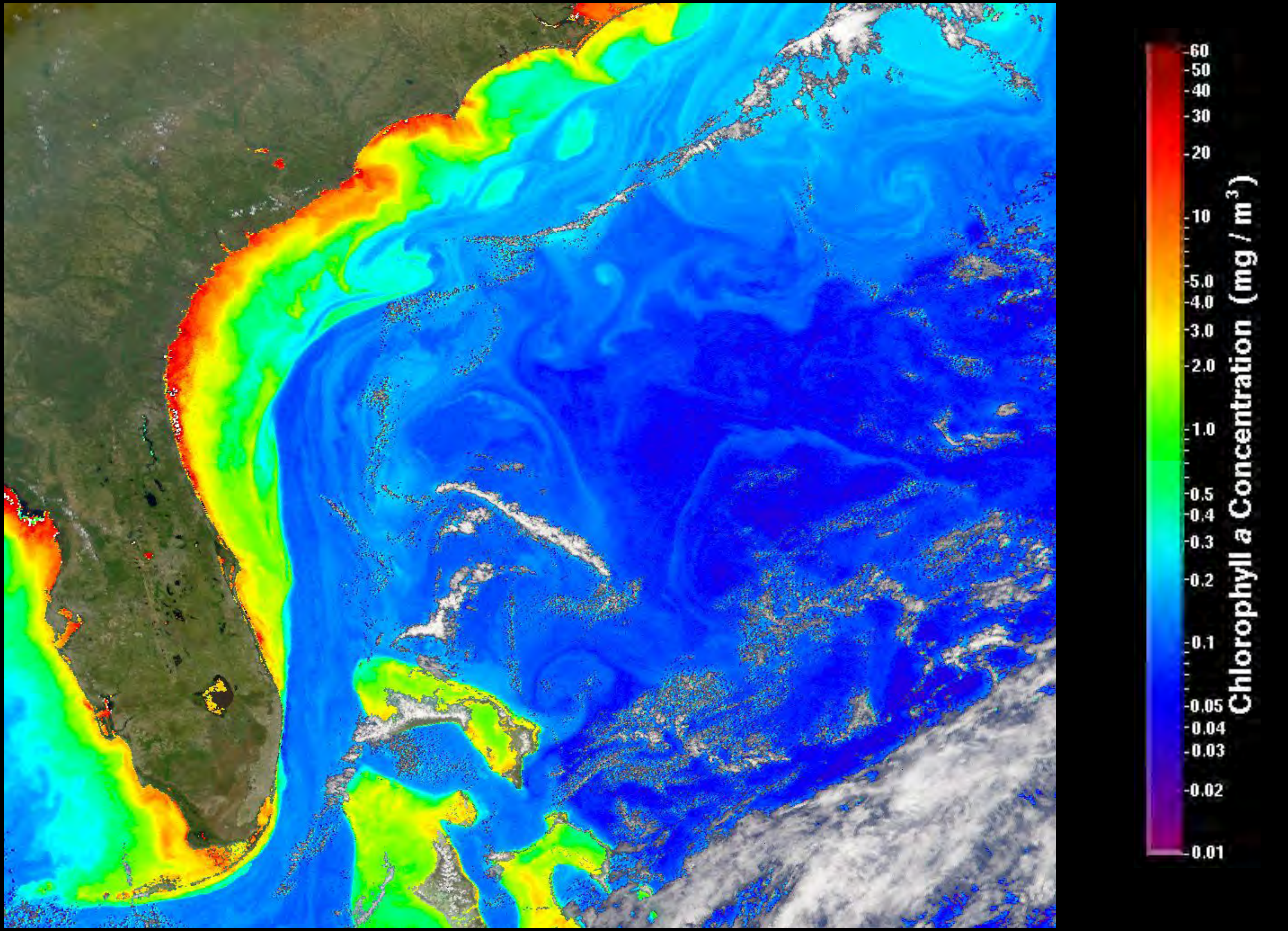
SATELLITES, SEABIRDS, AND SEALS*

Gene Feldman
Marine Sciences Research Center
State University of New York at Stony Brook
Long Island, New York 11794

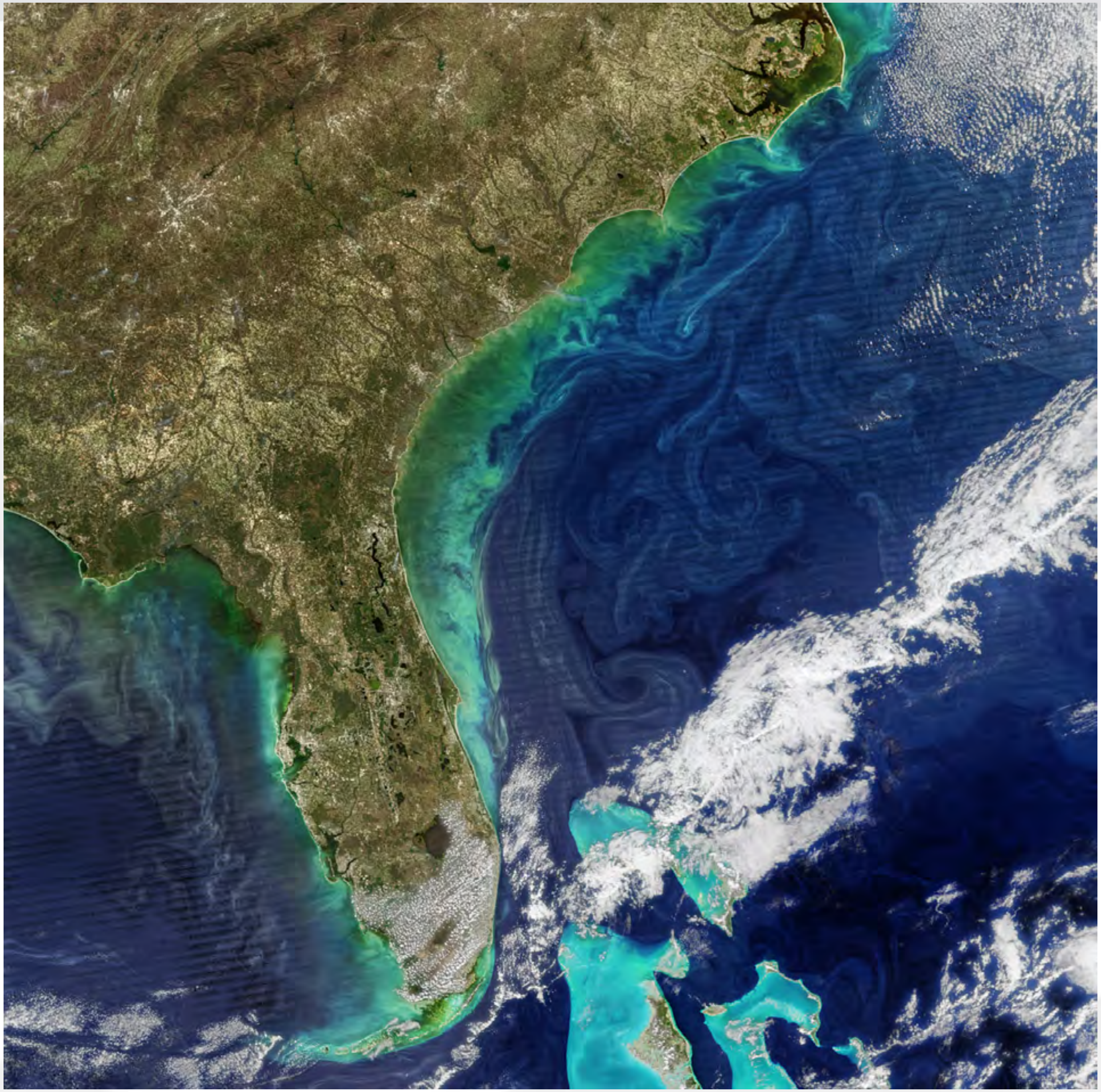
The conditions for, and the unique character of, life on the Galápagos Islands is directly related to the oceanographic setting and the biological productivity of the surrounding waters. Variations in ocean conditions have been shown to have profound effects on the biota of these islands, particularly during times of El Niño (Boersma, 1978). A recent investigation, utilizing satellite ocean color observations and complemented with coincident oceanographic measurements has demonstrated the tight coupling that exists between the distribution of phytoplankton populations around the Galápagos Islands and the oceanographic conditions observed during the 1982-83 El Niño (Feldman, Clark, & Halpern 1984). The reversal of winds and ocean currents during February-March, 1983 is associated with a major redistribution of food resources around the archipelago. This redistribution, combined with a decrease in primary productivity of the region (Barber & Chavez, 1983), might explain the observed reproductive failure of seabirds and marine mammals on the Galápagos Islands during this El Niño.

South Atlantic Bight

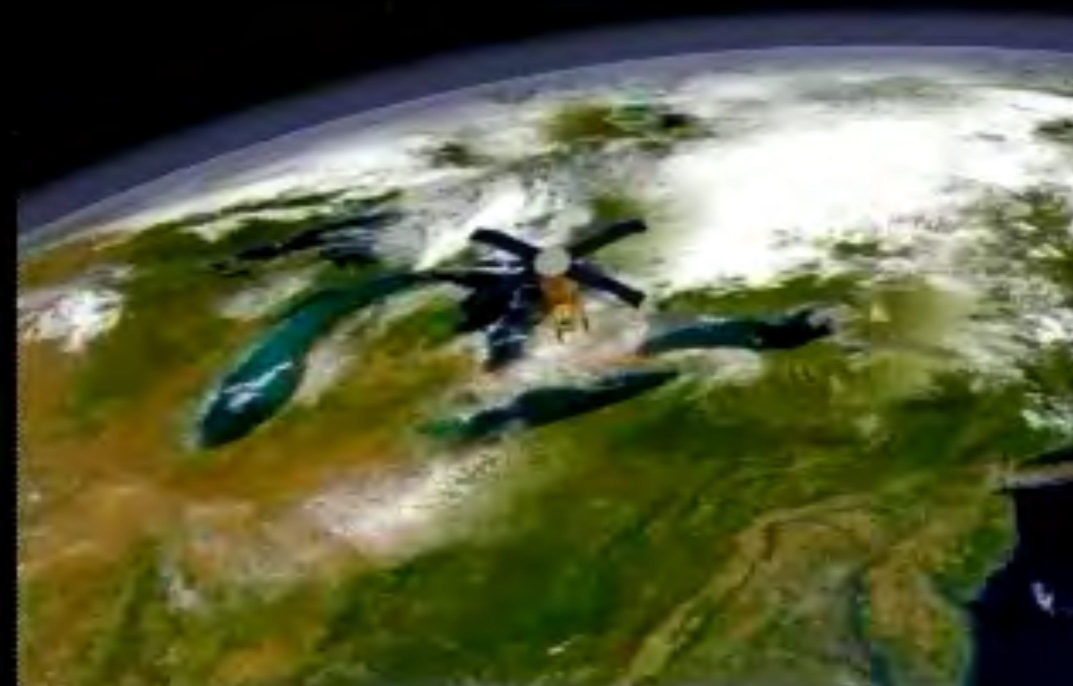
(Ocean Color and Temperature Scanner, OCTS & SeaWiFS - 1997)



South Atlantic Bight (Suomi NPP VIIRS – 2017)

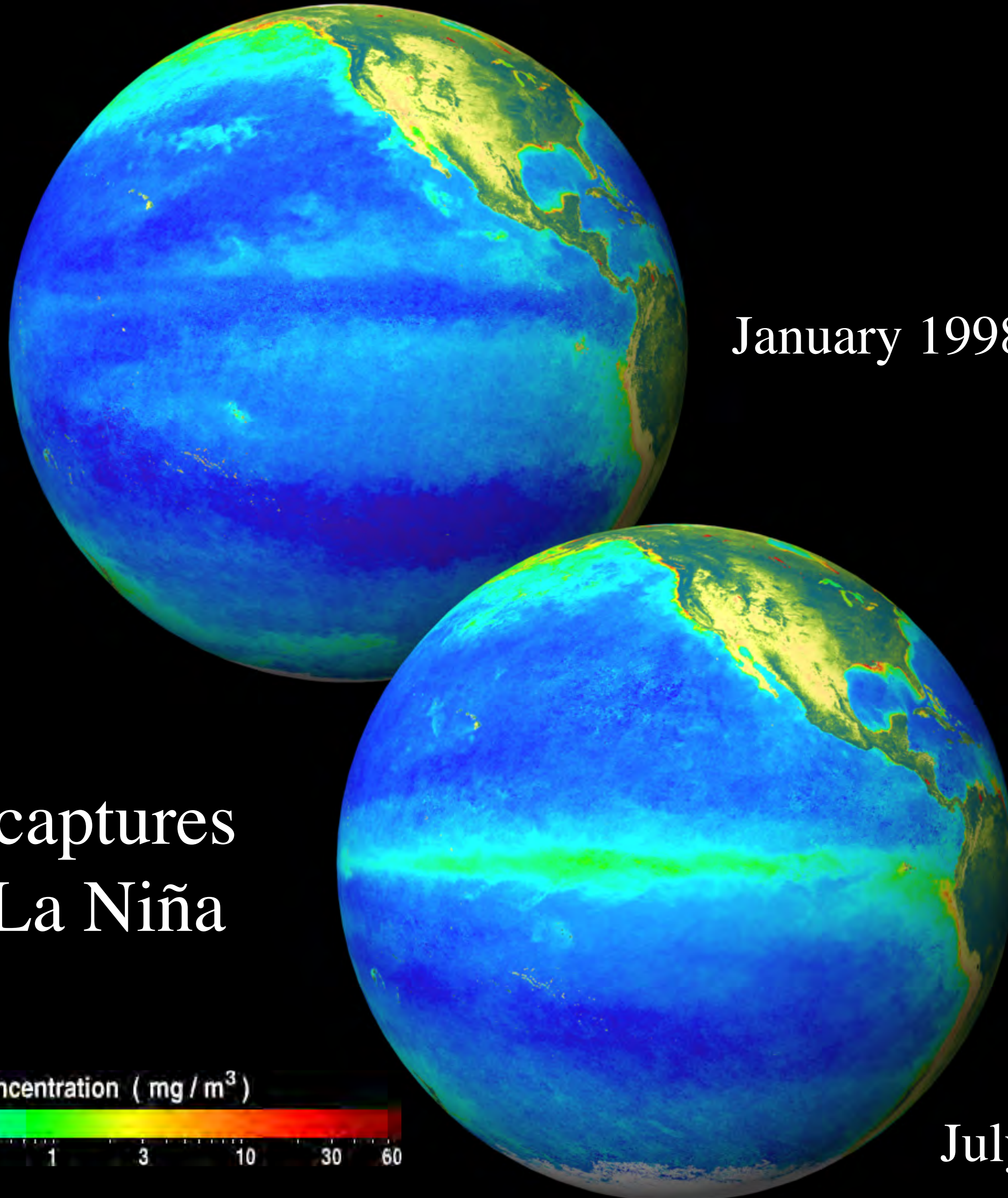


SeaWiFS: A View from Above



Launched:
August 1, 1997

Routine Data Began:
September 1997



January 1998

July 1998

SeaWiFS captures El Niño / La Niña transition

1997-1998
El Niño-La Niña

Warm Phase

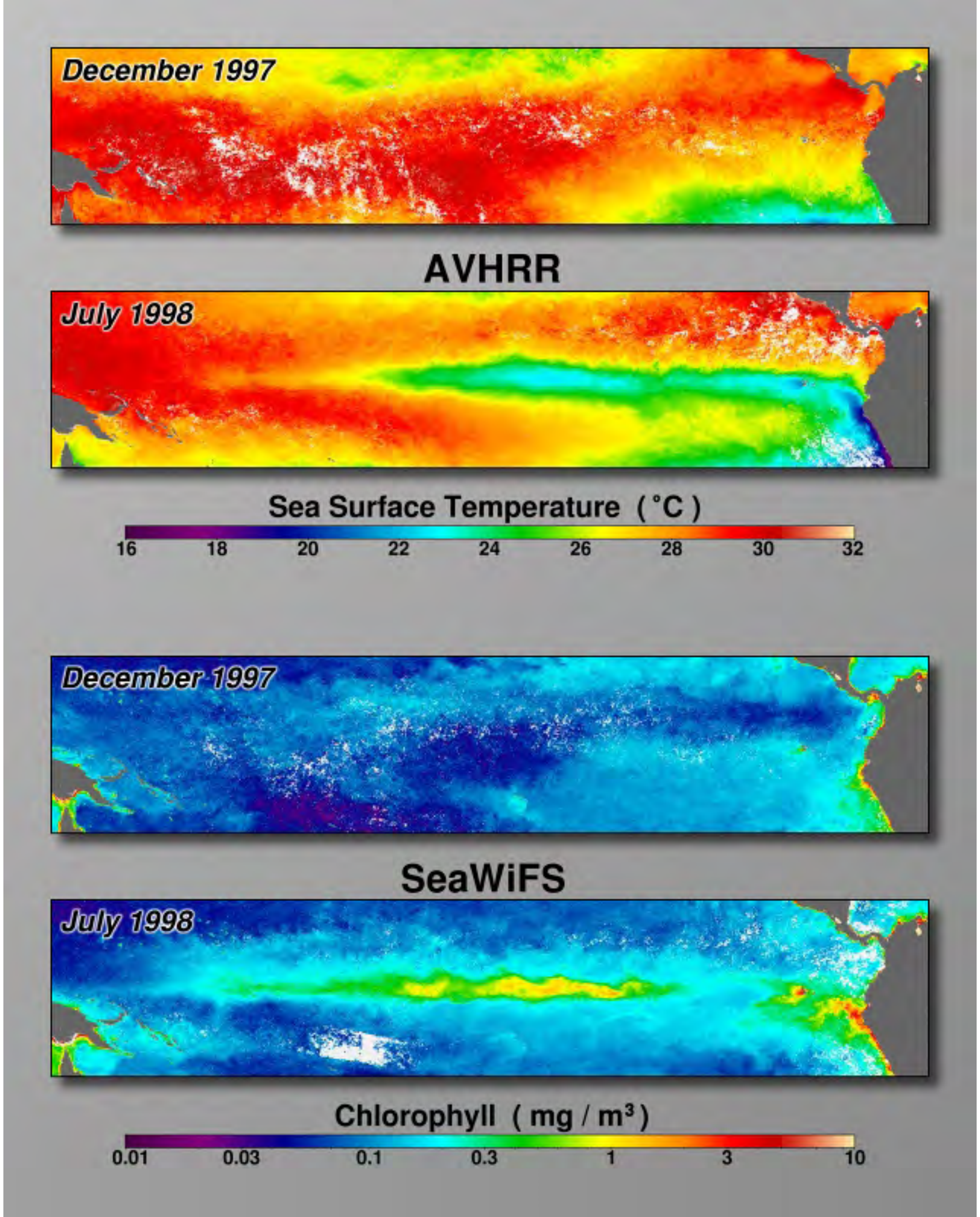
SST

Cold Phase

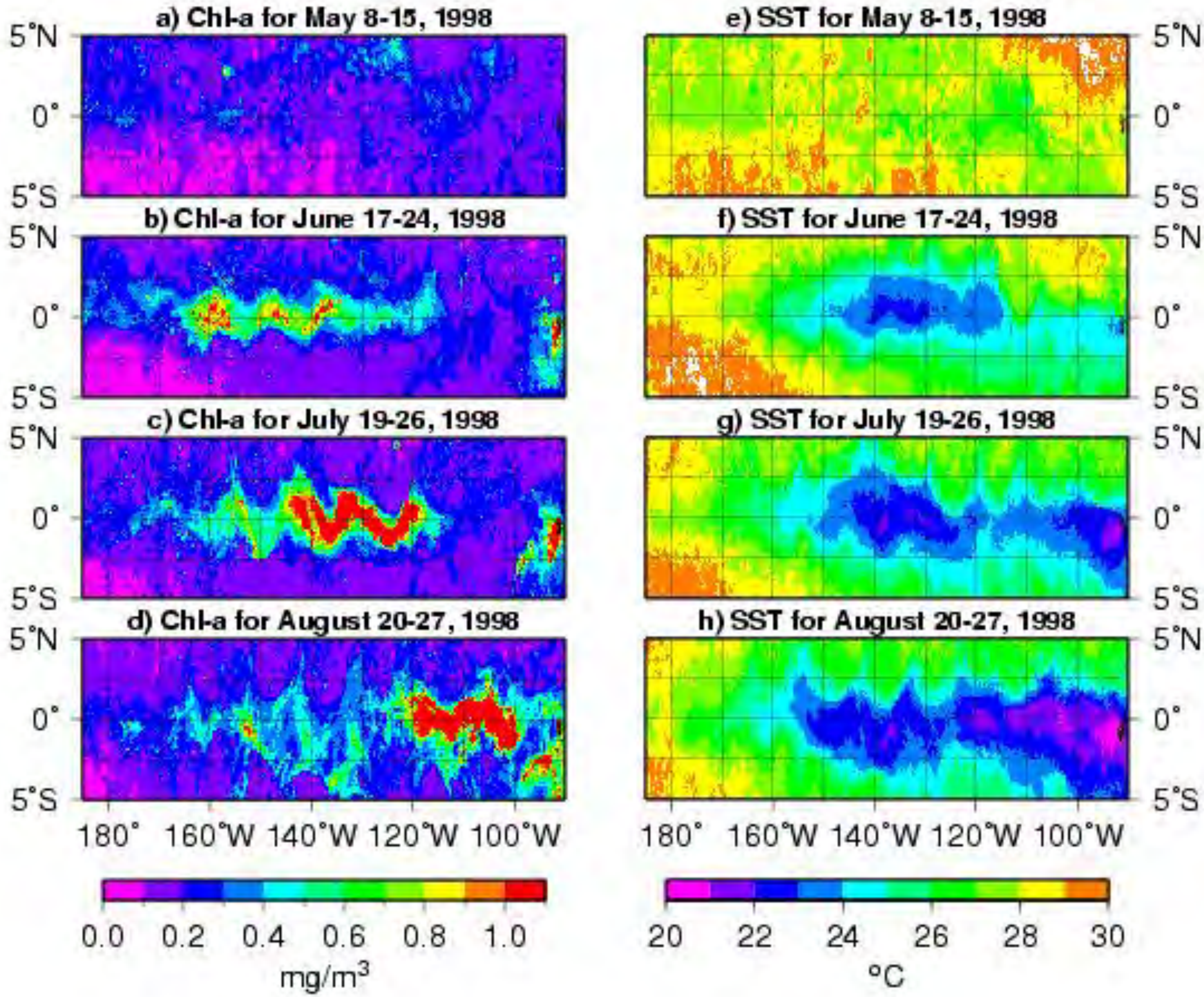
Warm Phase

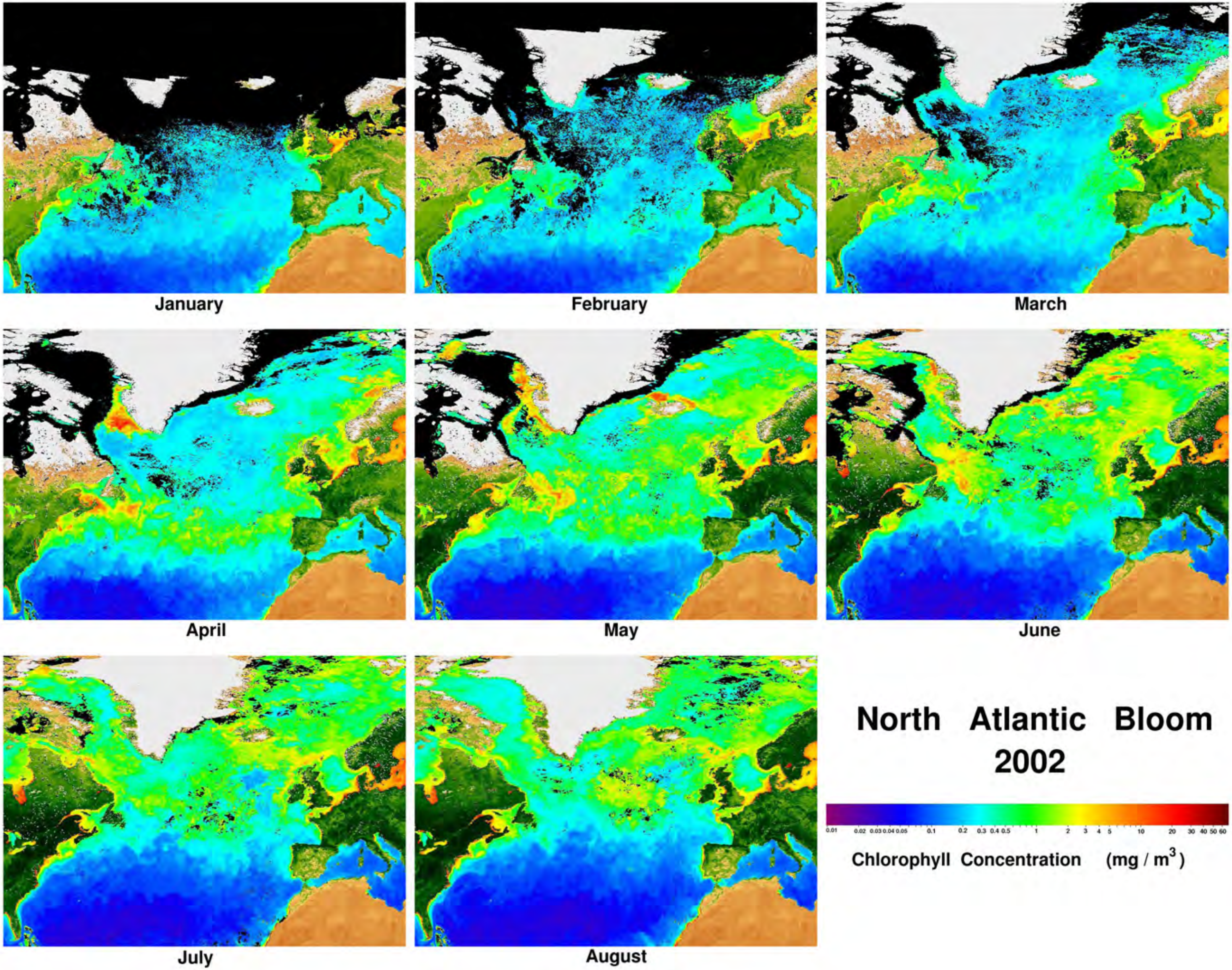
Chlorophyll-a

Cold Phase



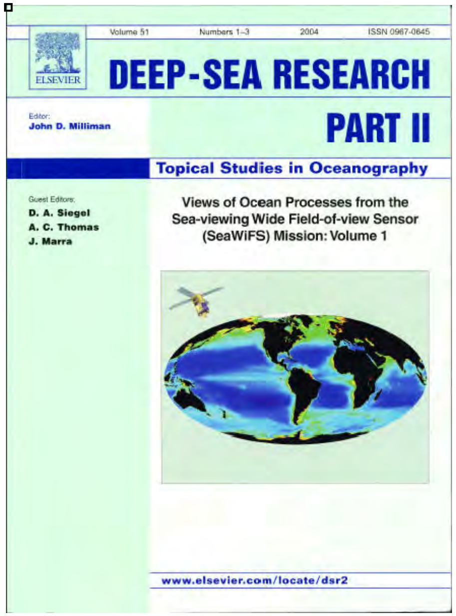
1998 La Niña Bloom Genesis & Propagation

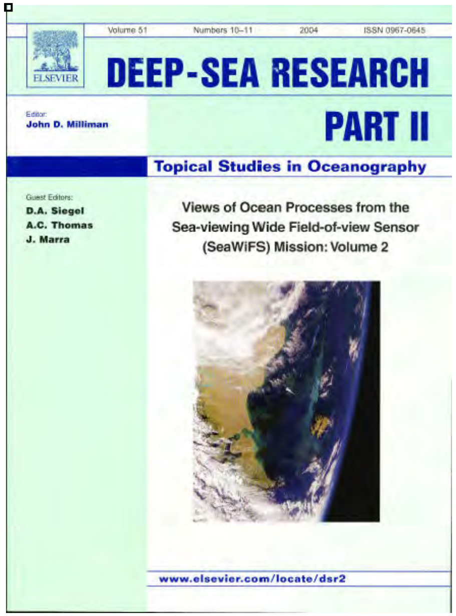


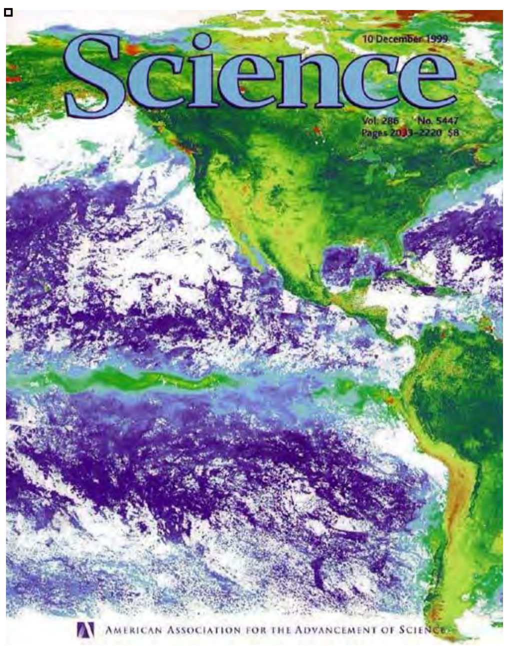

January
February
March
April
May
June
July
August
North Atlantic Bloom
2002
0.01 0.02 0.03 0.04 0.05 0.1 0.2 0.3 0.4 0.5 1 2 3 4 5 10 20 30 40 50 60
Chlorophyll Concentration (mg / m³)

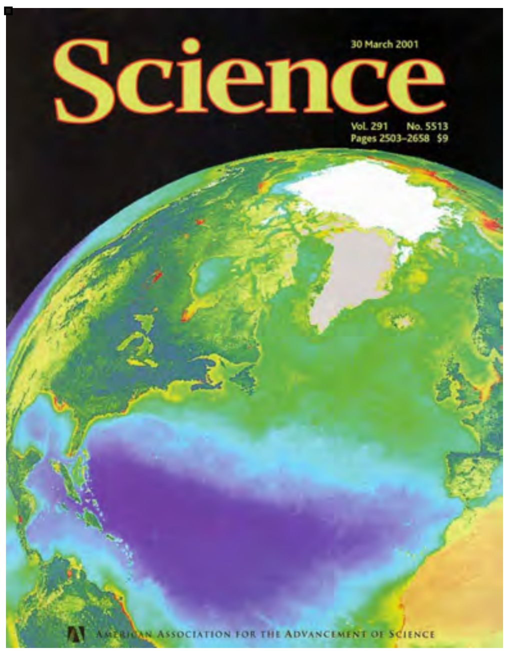
Science from SeaWiFS

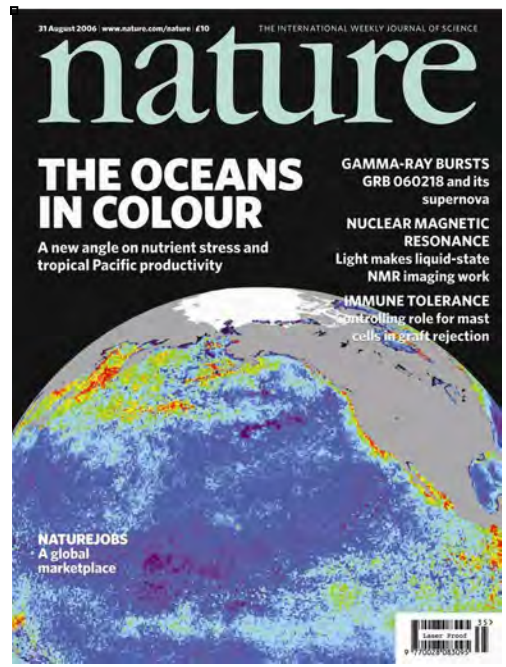
Web of Knowledge: 1741
(journal & conference papers)











SeaWiFS 10th Anniversary Top Tens (1976-2007)

10. Planetary waves can be seen in the distribution of plant biomass due to their influence on plant nutrients
9. The heat budget of the ocean is significantly impacted by the absorption of sunlight by microscopic ocean plants (phytoplankton)
8. One half of (the Earth's) biosphere production occurs in the ocean
7. Phytoplankton blooms in the northern Indian Ocean are linked to snow cover in the nearby mountains
6. Low iron concentrations in the equatorial Pacific cause changes in plant pigments; led to local overestimates of productivity by one billion tons of carbon or more per year
5. Die-offs in seabirds along the US coastline can be caused by episodic blooms in phytoplankton (such as those observed in the Bering Sea after a bloom of coccolithophorids)
4. Subtle changes in the color of the ocean can be used to map out the distribution of important species' influence on carbon budgets, such as nitrogen fixers and organisms that form hard parts made of calcium carbonate (chalk)
3. By separating satellite measured ocean color in to the constituents of different light absorbing and scattering compounds we can greatly Improve our ability to understand the ocean carbon cycle, including mapping organic carbon locked up in particles and determine phytoplankton growth rates
2. Measuring changes in phytoplankton in the Equatorial Pacific is Central to predicting El Nino events
1. The biological production or health of the ocean and its ability to absorb CO_2 from the atmosphere is directly controlled by climate – when the ocean warms, CO_2 uptake goes down, when it cools, CO_2 uptake increases

SeaWiFS 10th Anniversary Top Tens

Die-offs in seabirds along the US coastline can be caused by episodic blooms in phytoplankton (such as those observed in the Bering Sea after a bloom of coccolithophorids) Hunt, G. L. and P. J. Stabeno. 2002. Climate change and the control of energy flow in the southeastern Bering Sea. *Progress in Oceanography* 55:5-22

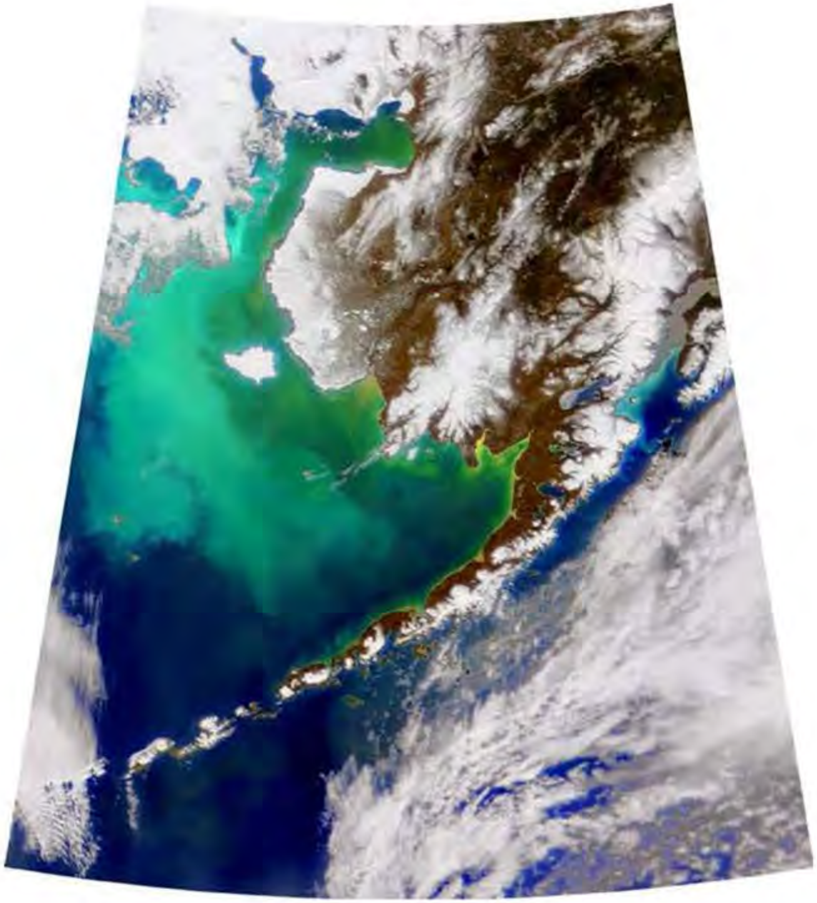
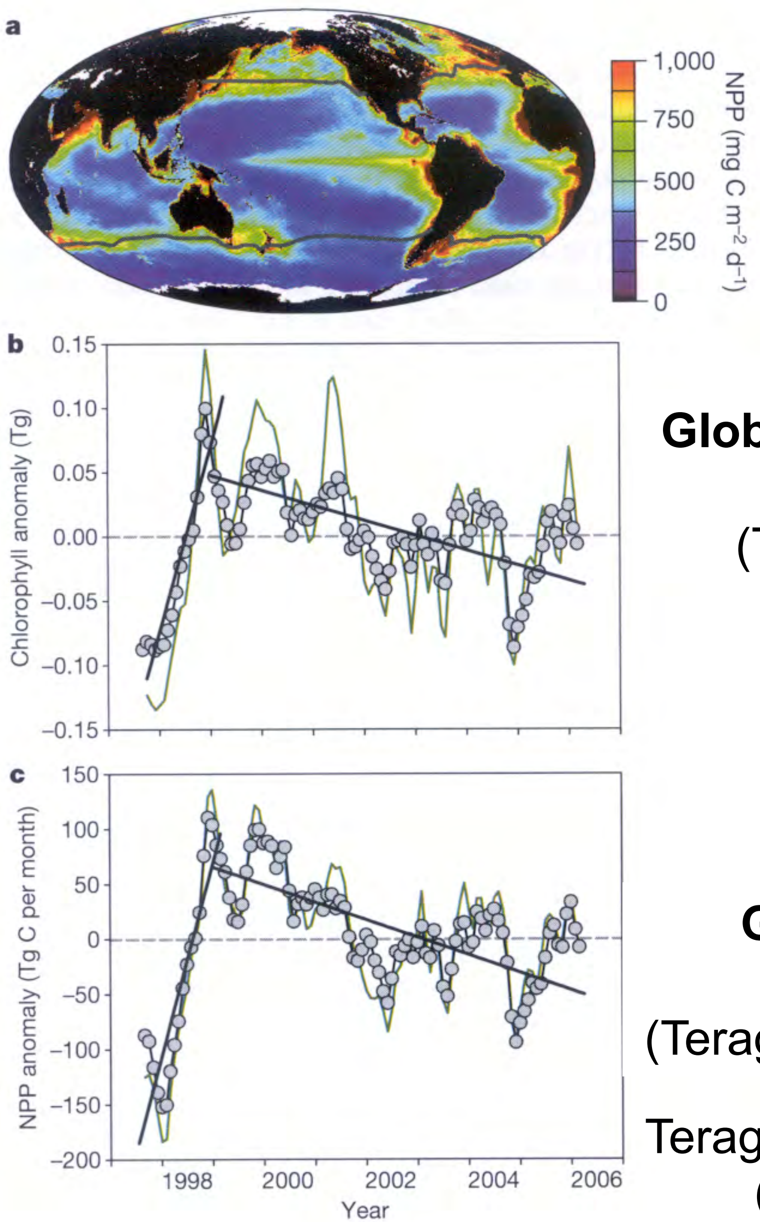


Fig. 8. Bering Sea coccolithophore blooms. During the summer and fall of 1997, a large coccolithophore bloom persisted in the eastern Bering Sea (Vance et al., 1998). Such blooms are very unusual in the Bering Sea and caused widespread starvation of marine birds and mammals and also severely affected fisheries which use the adjacent Alaskan rivers for spawning. The bloom reappeared the following spring and was vividly captured in this 25 April 1998 SeaWiFS image.

Global Patterns of Net Primary Production 1998-2005



Global Mean Net Primary Production (mg C/ m^2/ day)

Black Lines: Boundary of permanently stratified ocean

Global Total Chl-a anomaly
(Teragrams)

Anomaly: Global average minus monthly value

Green Line: Global Vertically Integrated Anomaly

Circles & Black Line: Vertically Integrated Anomaly within permanently stratified ocean

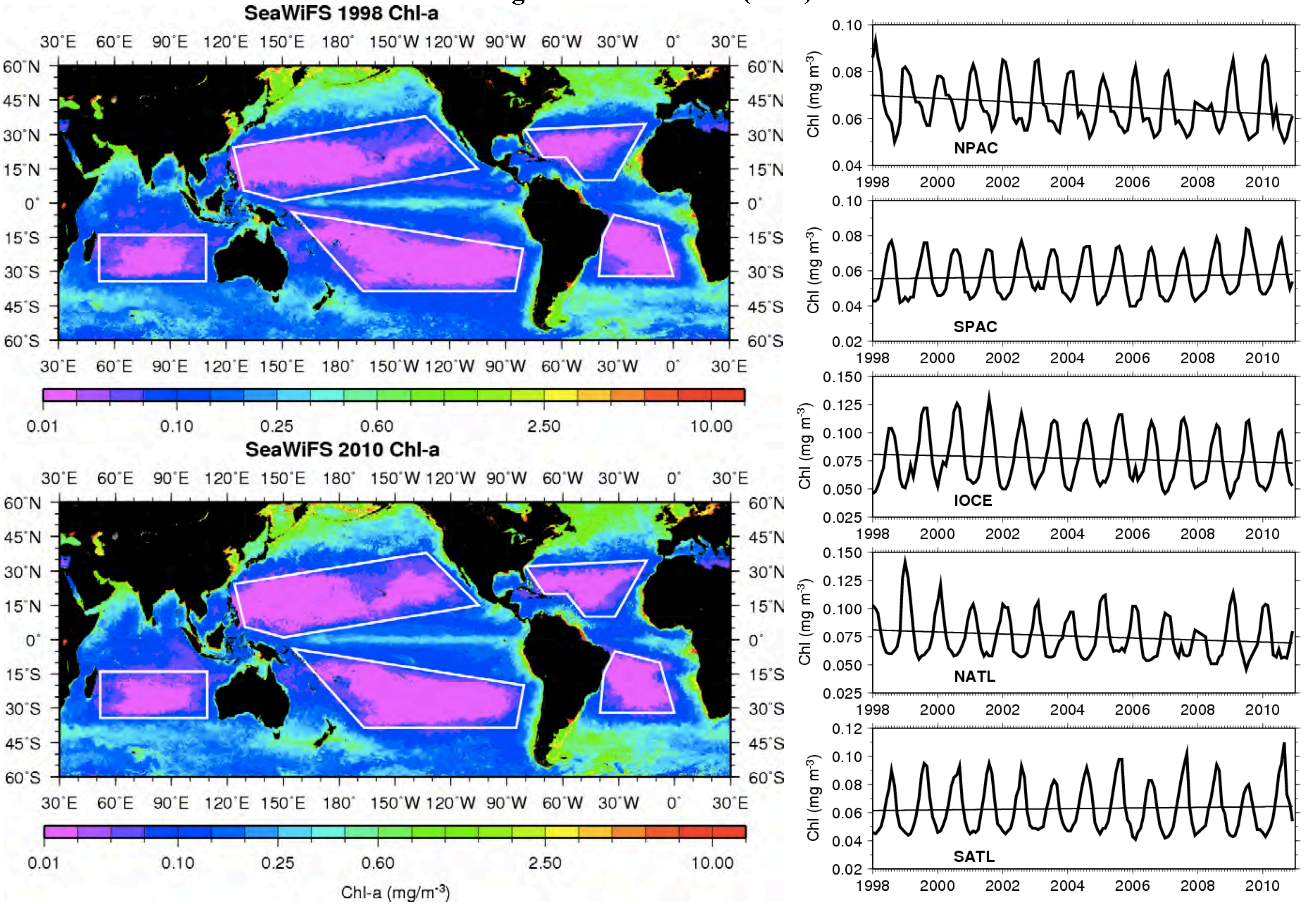
Global NPP anomaly
(Teragrams C/month)

Teragram = 10^{12} grams (1000 billion)

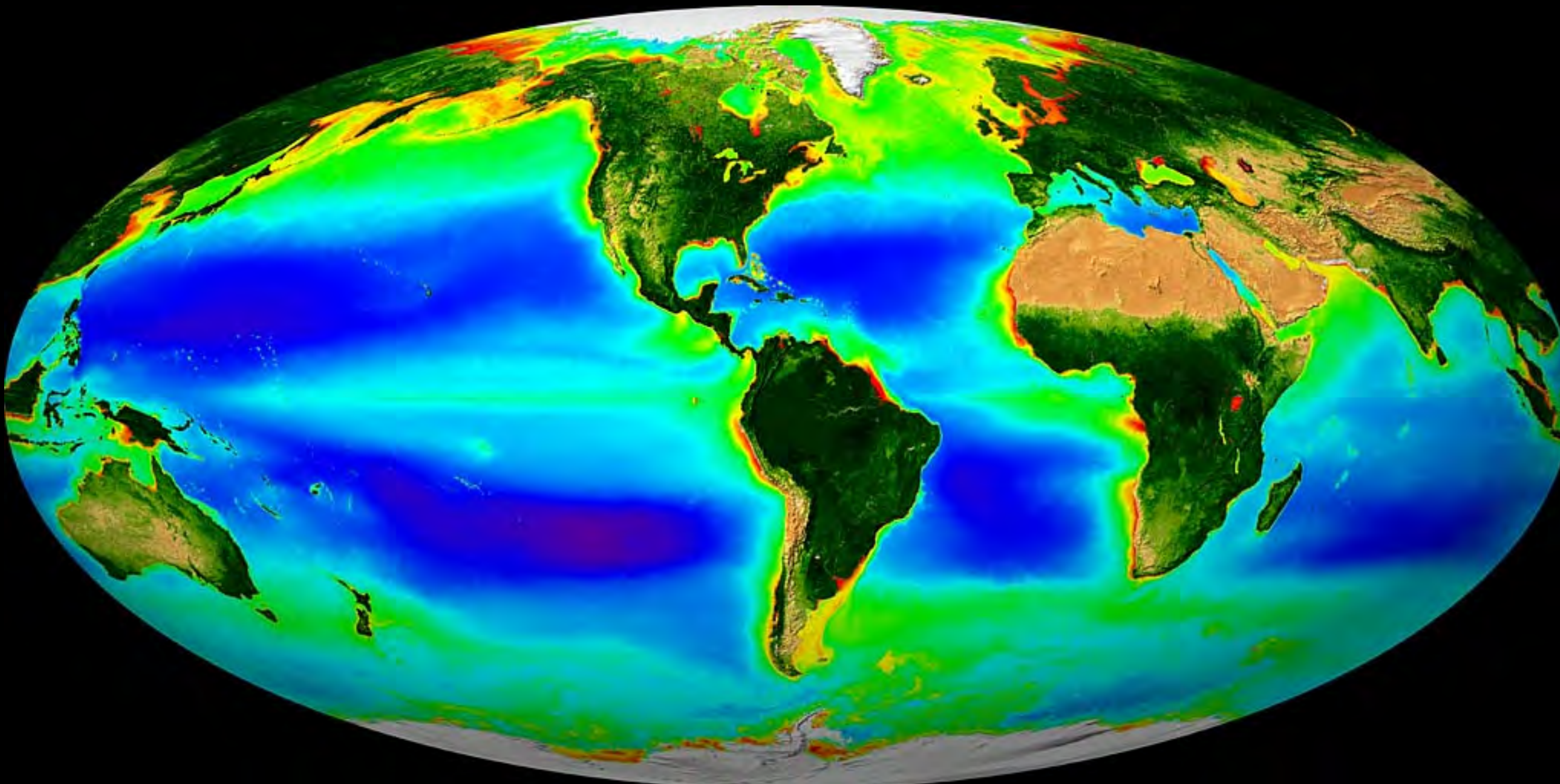
Behrenfeld, M., et al., Climate-Driven trends in contemporary ocean productivity, *Nature*, 444, 752-755, 2006. & Behrenfeld, M. et al., Revaluating ocean warming impacts on global phytoplankton *Nature CC*, 6, 323–330, 2016.

The Oceans Biological Deserts are Expanding

Signorini & McClain (2011)

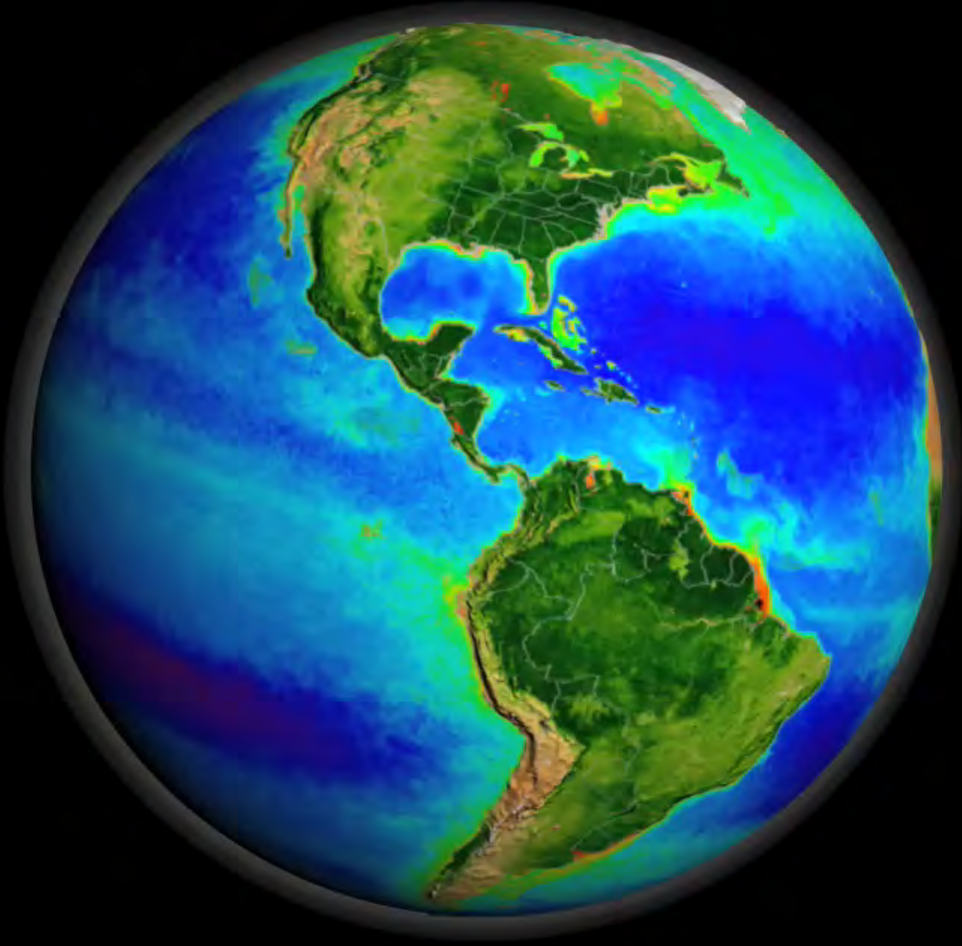


Percent of total area with Chl-a concentration < 0.07 mg/m^3



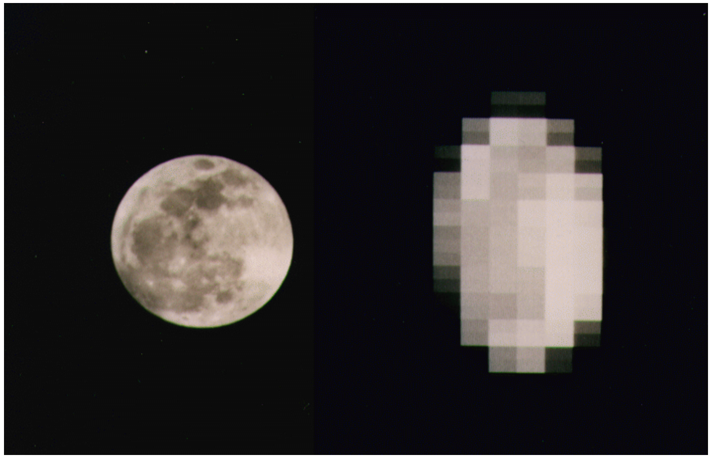
SeaWiFS Global Biosphere (1997 – 2010)

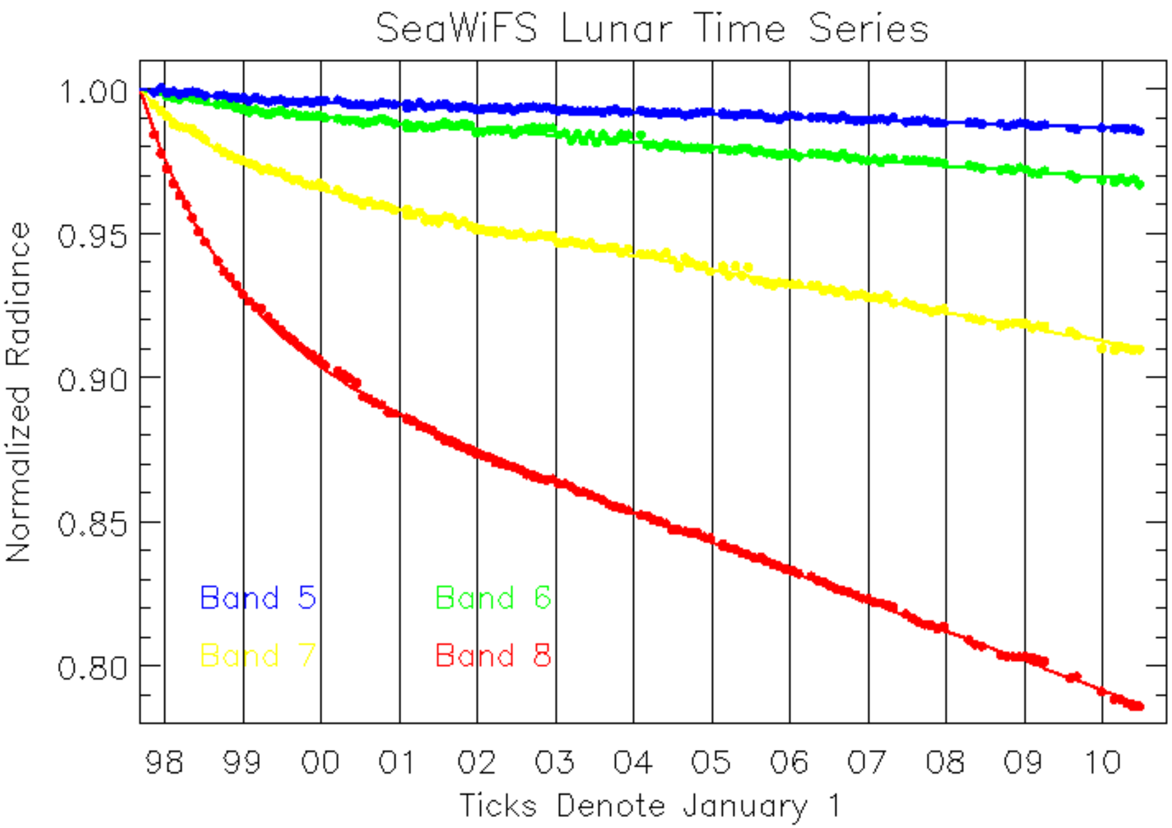
SeaWiFS Biosphere Data Over the North Atlantic



SeaWiFS Temporal Degradation

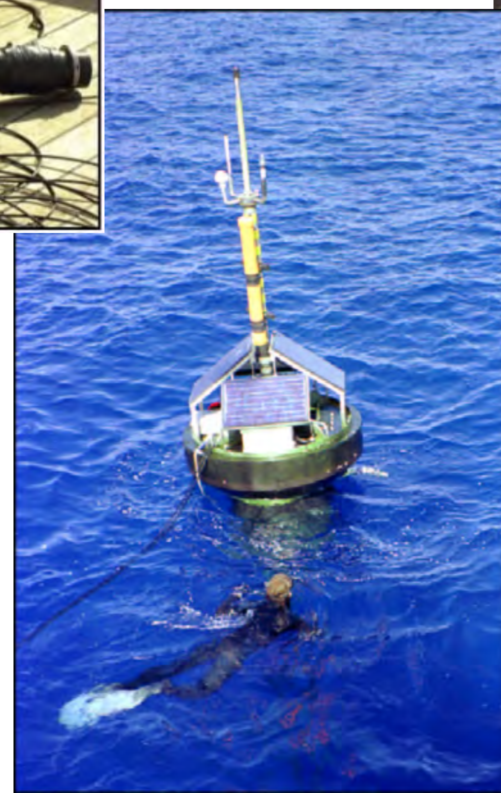
Once a month, the SeaWiFS satellite (Orbview-2) was pitched to observe the Moon at a phase angle ~ 7°.

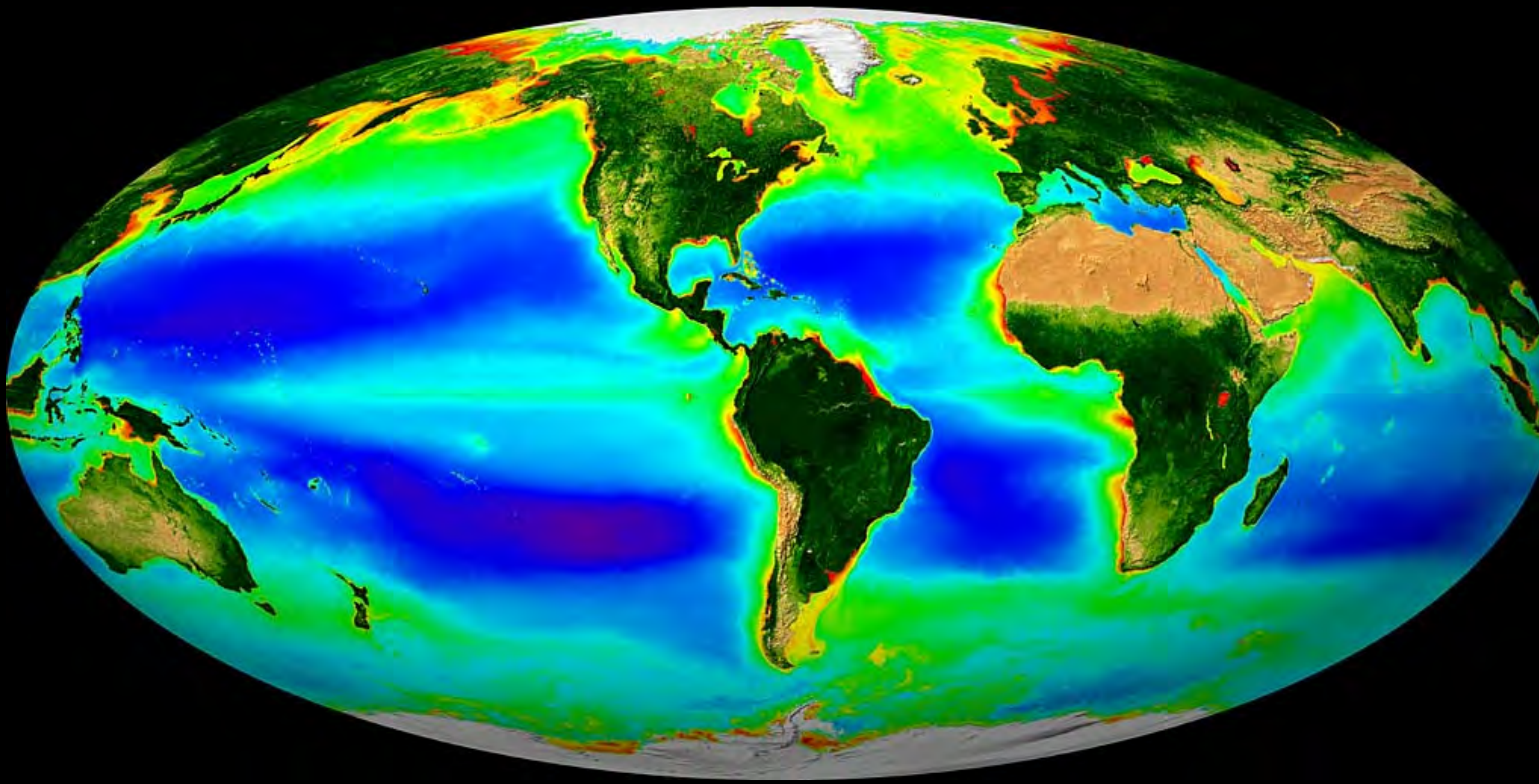




SeaWiFS Band	SeaWiFS λ (nm)
1	412
2	443
3	490
4	510
5	555
6	670
7	765
8	865

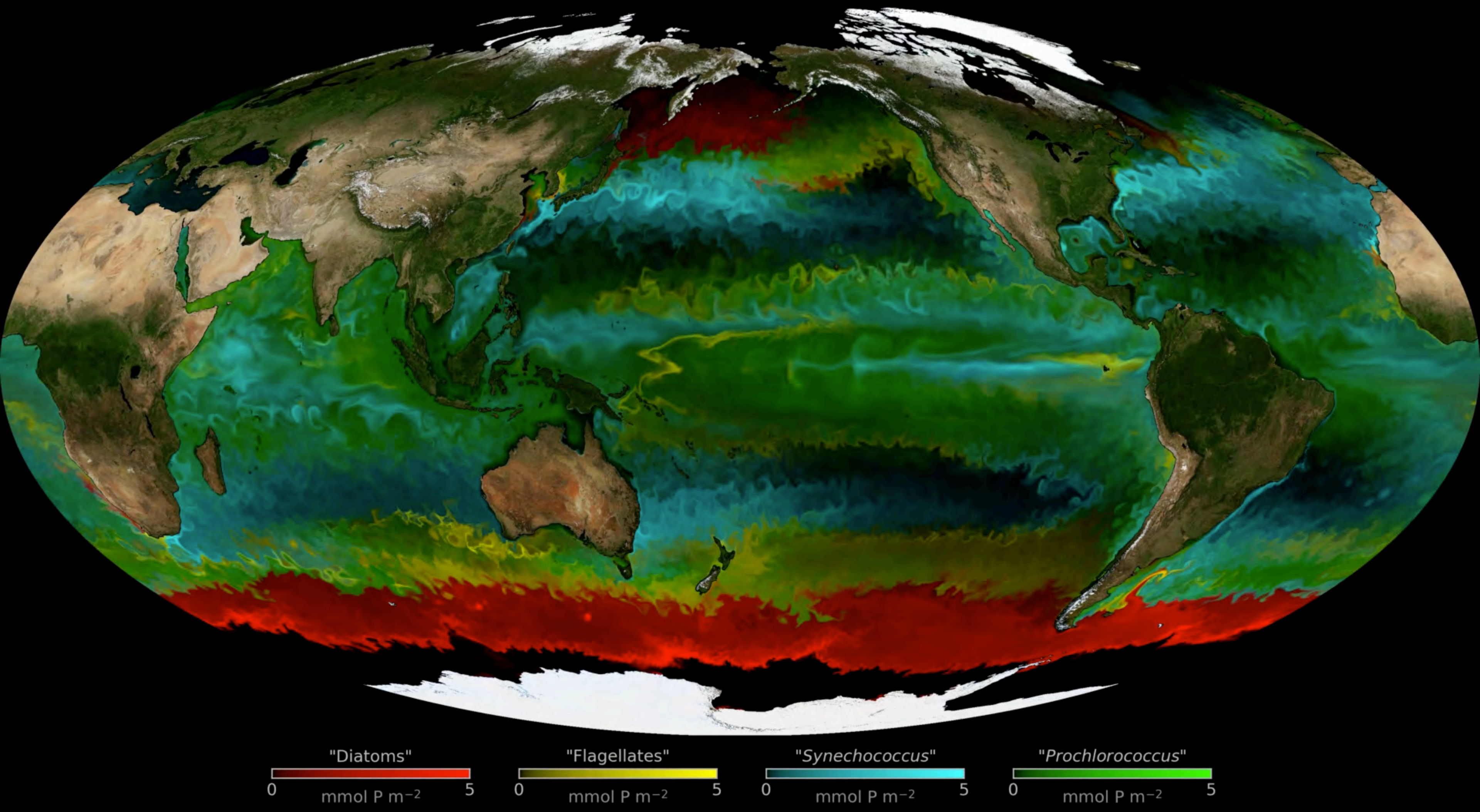
Degradation in Bands 1-4 relatively small – not shown.

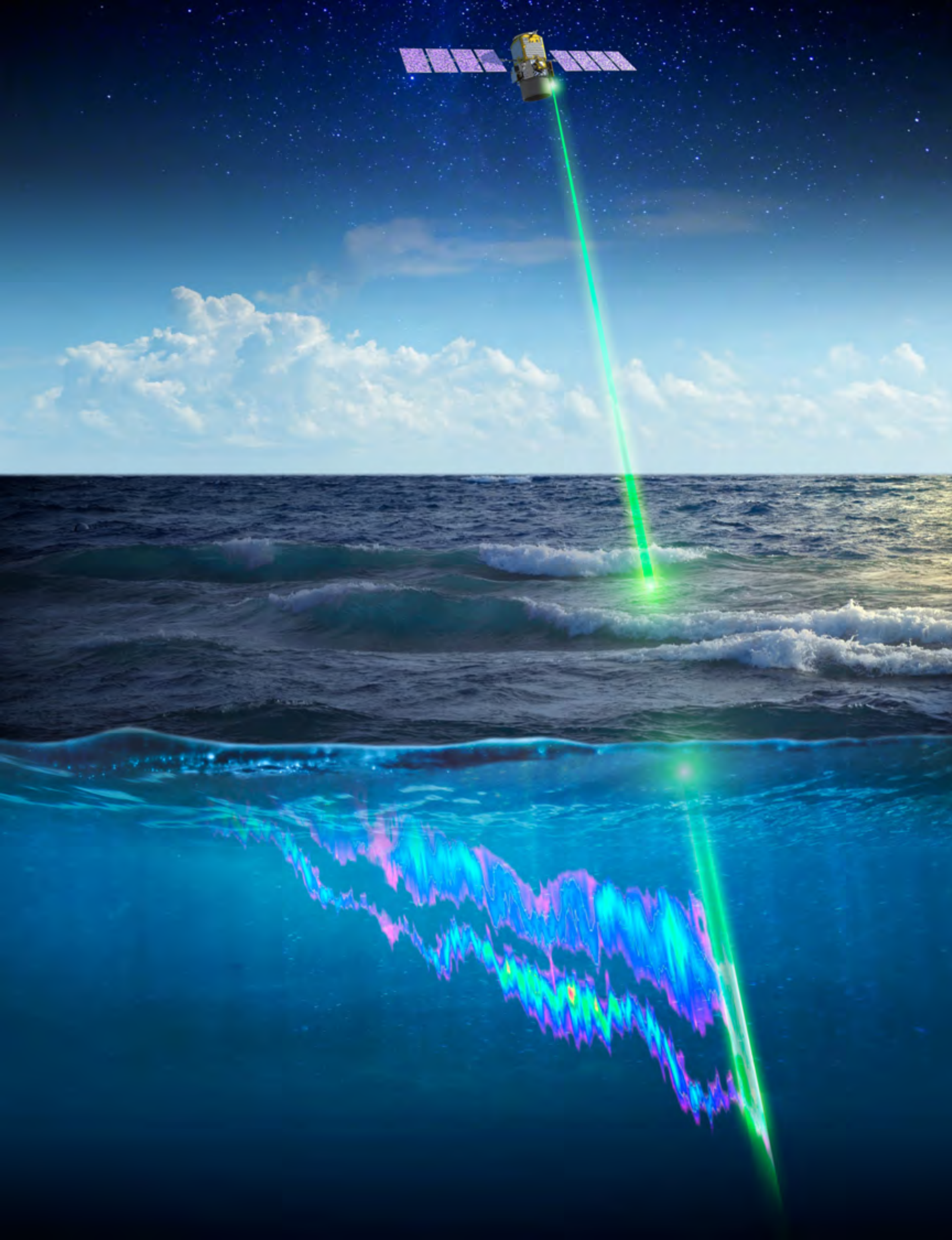




SeaWiFS Global Biosphere (1997 – 2010)

ECCO-2/Darwin Modeled Phytos (1994 – 1998)





nature geoscience | ARTICLES
PUBLISHED ONLINE: XX MONTH XXXX | DOI: 10.1038/NGEO2861

Annual boom–bust cycles of polar phytoplankton biomass revealed by space-based lidar

Michael J. Behrenfeld[1*], Yongxiang Hu[2], Robert T. O'Malley[1], Emmanuel S. Boss[3], Chris A. Hostetler[2], David A. Siegel[4], Jorge Sarmiento[5], Jennifer Schulien[1], Johnathan W. Hair[2], Xiaomei Lu[2], Sharon Rodier[2] and Amy Jo Scarino[2]

Polar plankton communities are among the most productive, seasonally dynamic, and rapidly changing ecosystems in the global ocean. However, persistent cloud cover, periods of constant night, and prevailing low solar elevations in polar regions severely limit traditional passive satellite ocean colour measurements and leave vast areas unobserved for many consecutive months each year. Consequently, our understanding of the annual cycles of polar plankton and their interannual variations is incomplete. Here we use space-borne lidar observations to overcome the limitations of historical passive sensors and report a decade of uninterrupted polar phytoplankton biomass cycles. We find that polar phytoplankton dynamics are categorized by 'boom–bust' cycles resulting from slight imbalances in plankton predator–prey equilibria. The observed seasonal-to-interannual variations in biomass are predicted by mathematically modelled rates of change in phytoplankton division. Furthermore, we find that changes in ice cover dominated variability in Antarctic phytoplankton stocks over the past decade, whereas ecological processes were the predominant drivers of change in the Arctic. We conclude that subtle and environmentally driven imbalances in polar food webs underlie annual phytoplankton boom–bust cycles, which vary interannually at each pole.

Nature Geoscience 10, 118–122 (2017) doi:10.1038/ngeo2861

Not all phytoplankton are green. Most of them are harmless, some can bloom in large numbers and produce toxins that can be quite harmful to marine life and to humans. When phytoplankton growth is stimulated by an overabundance of nutrients from sources such as sewage discharge or runoff of agricultural fertilizers used on land, the consequences can be serious. Dense blooms of phytoplankton can block sunlight from reaching the bottom in shallow areas of bays or estuaries, and can cause massive decline in Submerged Aquatic Vegetation that has been taking place in places like Chesapeake Bay. These grasses are vital nursery grounds for fish and invertebrates; their loss can have dire ecological results. When blooms die and cells sink to the bottom, bacterial decomposition of this organic matter strips the water of oxygen. Fish, shellfish and most other living things require oxygen to survive ,and decaying phytoplankton blooms have been the cause of massive fish kills over the years.

Gulf of Mexico Harmful Algal Bloom Bulletin

27 October 2005

National Ocean Service

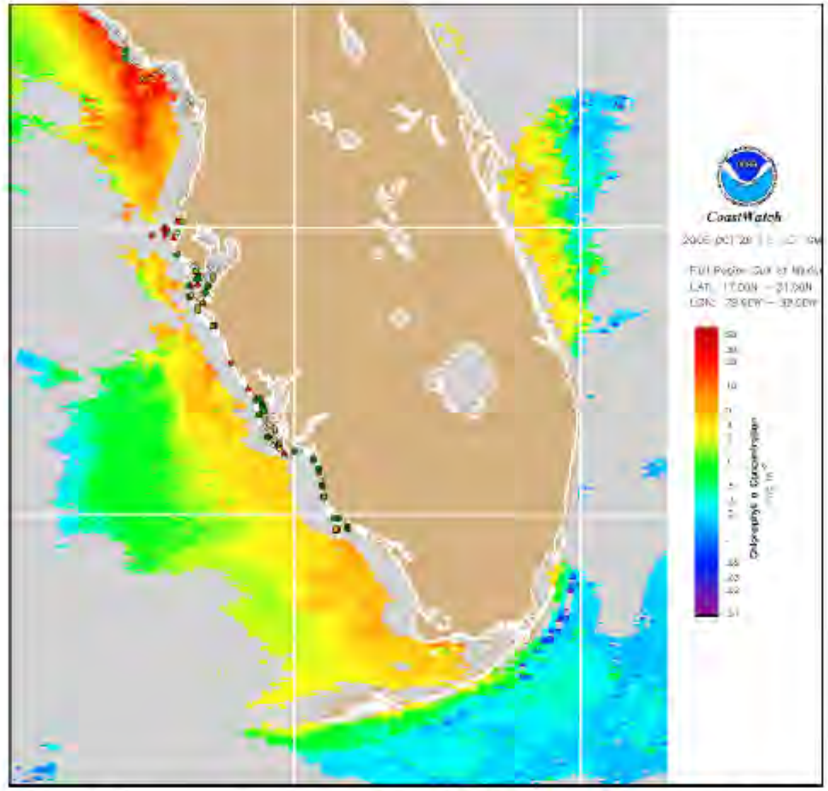
National Environmental Satellite, Data, and Information Service

Last bulletin: October 24, 2005

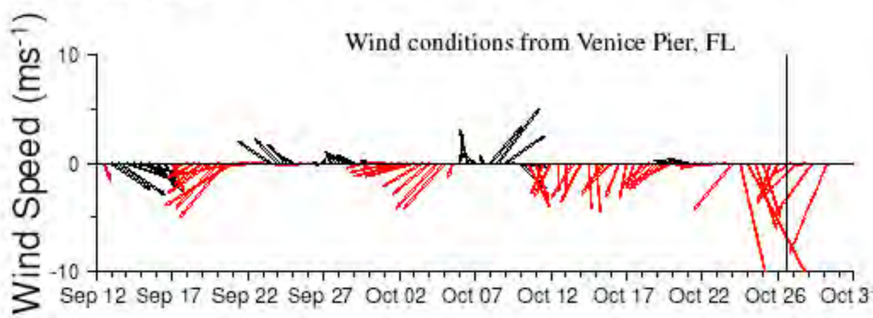
Conditions: Harmful algal blooms have been identified in Pinellas County, Dixie to Levy County and in very small patches from Manatee to Collier County in Florida. A secondary bloom has been identified in patches along Alabama and the Florida Panhandle. No impacts are expected along the coast from Pinellas to Collier County or from Dixie to Levy County today through Sunday. Patchy very low to low impacts are possible from Wakulla to Okaloosa County, FL and Baldwin to Mobile County, AL today through Sunday. Dead fish have been reported in Bay and Okaloosa Counties over the past few days. Dead fish smell, while unpleasant, does not produce the same respiratory irritation as red tide.

Analysis: The harmful algal bloom continues to dissipate along the SW Florida coastline; however very small remnant populations of *K. brevis* may still be present in patches from Pinellas to Collier County. Low *K. brevis* concentrations remain offshore of Bunces Pass in southern Pinellas County. Previous low *K. brevis* concentrations in Sarasota County have decreased to background levels (FWRI 10/20-26). Chlorophyll levels are elevated all along the Florida coast due to resuspension produced by Hurricane Wilma; thus bloom extent analysis is limited. Results of a wind transport model indicate possible bloom movement 20-30km southward since October 24. No recent samples have been reported from Levy to Dixie Counties. Sampling is recommended. Persistent northeasterlies will minimize coastal impacts through Sunday. Continual dissipation of the bloom is expected. Reports of discolored water are likely.

˜Fisher, Bronder



Chlorophyll concentration from satellite with HAB areas shown by red polygon(s). Cell concentration sampling data from October 19, 2005 shown as red squares (high), red triangles (medium), red diamonds (low b), red circles (low a), orange circles (very low b), yellow circles (very low a), green circles (present), and black "X" (not present).



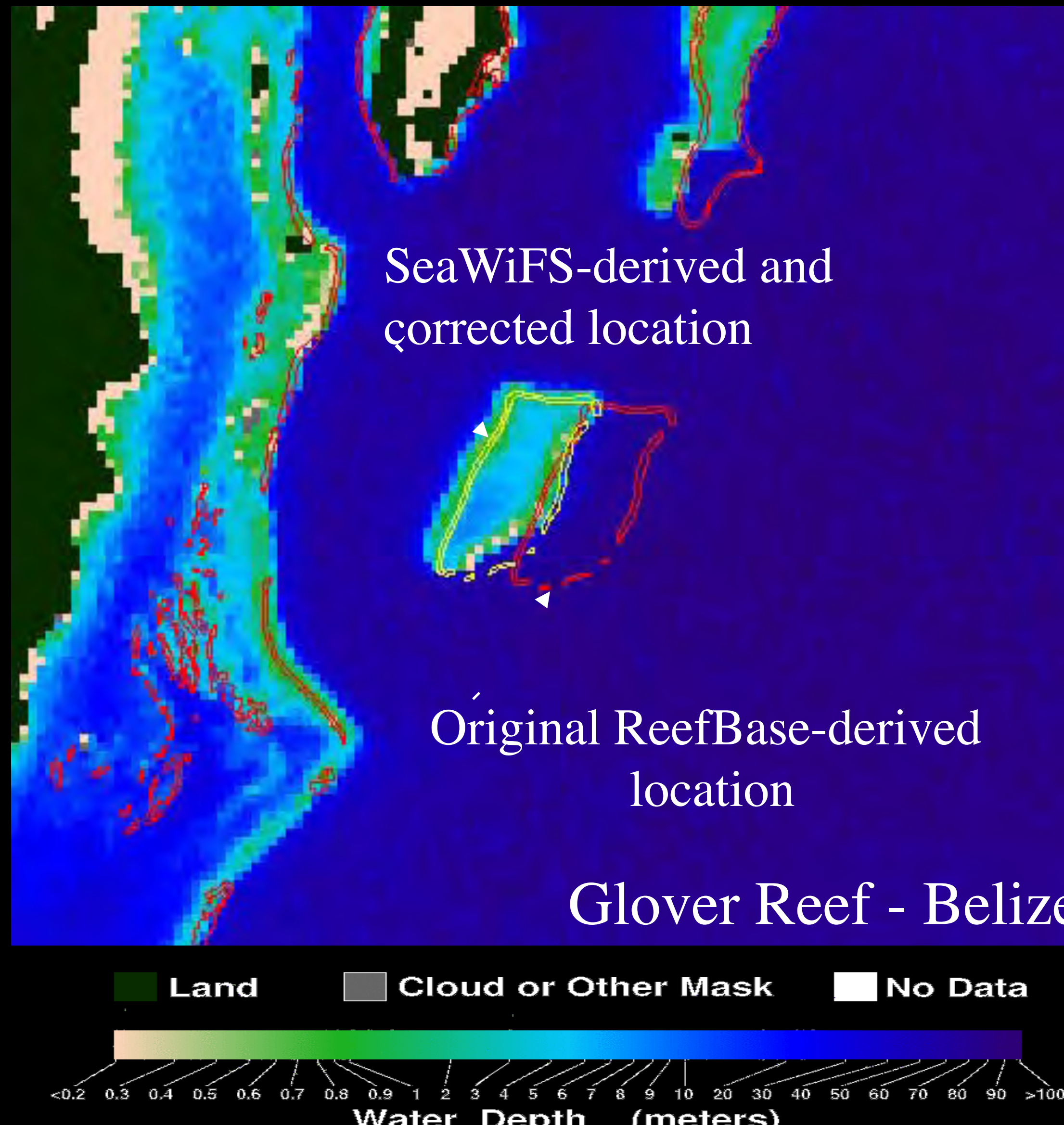
Wind speed and direction are averaged over 12 hours from measurements made on buoys. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

SW Florida: Moderate (10-15kts, 5-8m/s) northeasterly winds today will continue through Sunday;

Improved Global Reef Map

Collaborative effort between NASA, NOAA and WCMC to create the most accurate global map of potential coral reef habitats

- Accurate to 1 km.
- Nearly 44,000 SeaWiFS images processed
- Online web-based tool
- 1779 reefs or reef groups corrected based on SeaWiFS data



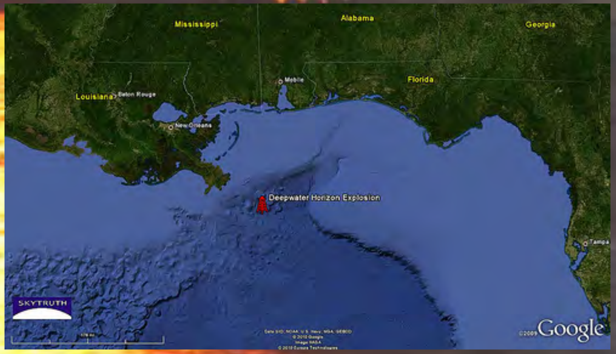
Chesapeake Bay – Case Study
Eutrophication

Gulf of Mexico Oil Spill
Spring – Summer 2010

Deepwater Horizon
Tragic blowout: April 20, 2010
Final capping: July 15, 2010

63,000 barrels per day

Total: 4.4 million barrels = 184.8 Million gallons

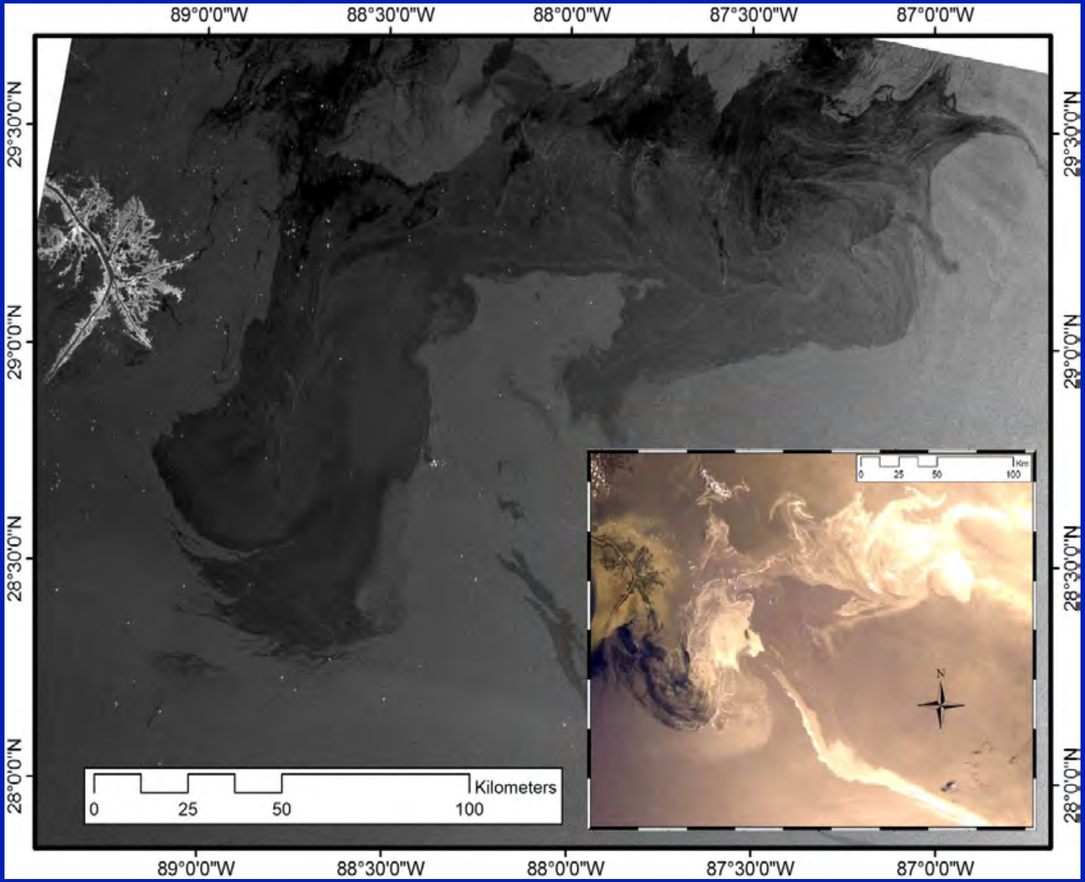


Remote Sensing of Surface Oil
(C. Hu, USF)

Two fundamental questions: Where is the oil? How much?

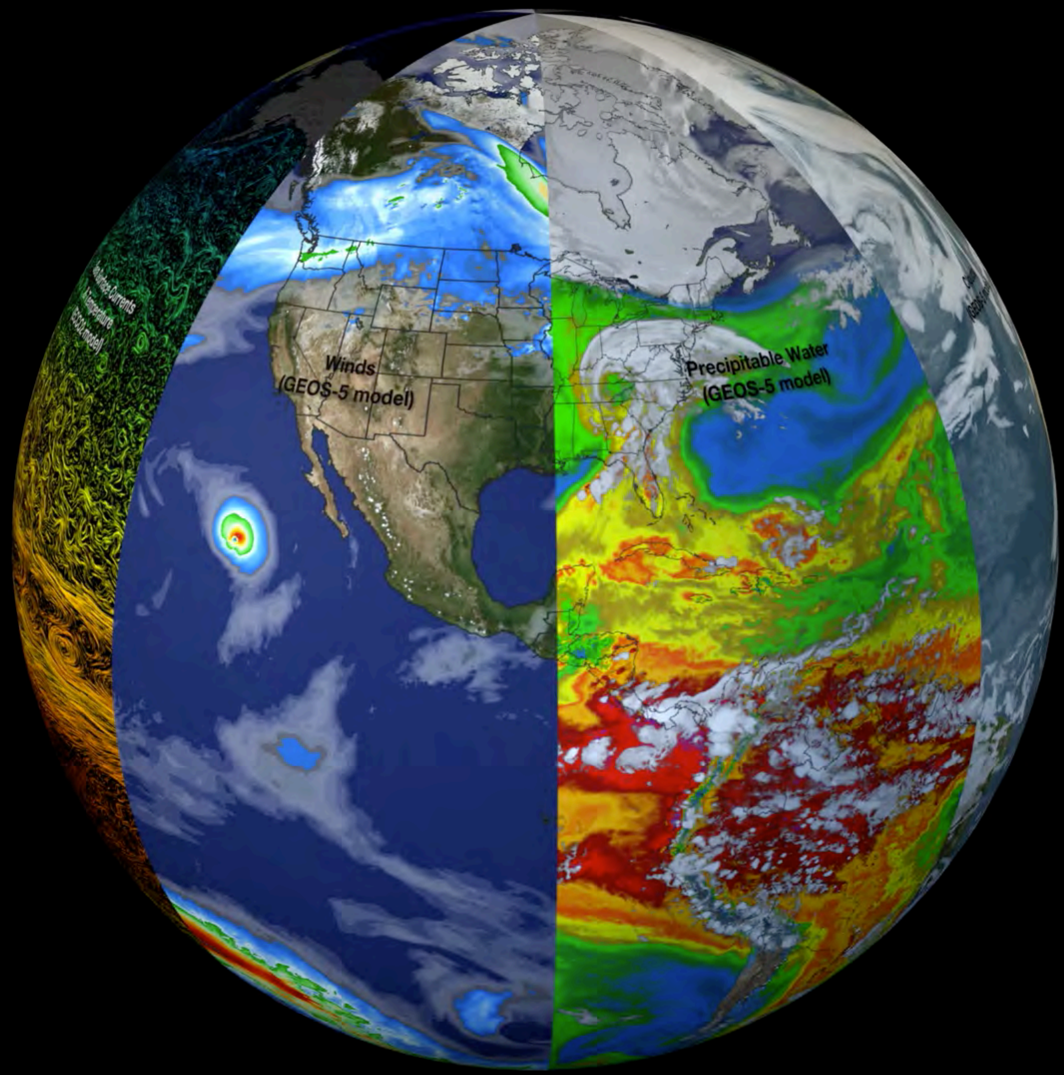
Most used technique:
- SAR

Other techniques
- Optical (UV-VIS-NIR)
- Infrared
- What next?

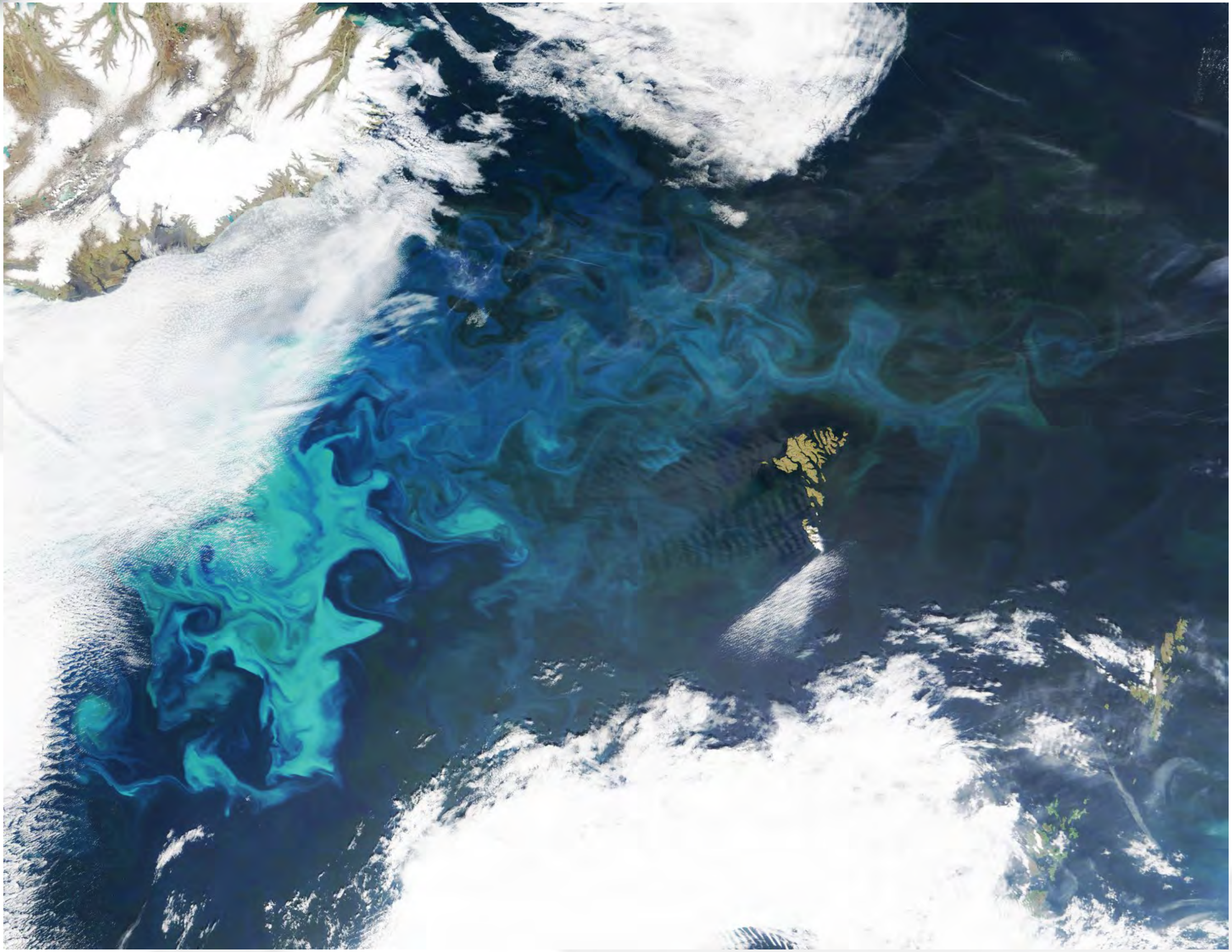


24 May 2010, ALOS (L-Band) SAR, and MERIS

From Garcia-Pineda et al. (2013)


Winds
(GEOS-5 model)
Precipitable Water
(GEOS-5 model)

Washington Post (2016)
(The Ocean by Van Gogh – MODIS-Terra)




Earth
Forever
USA
2016