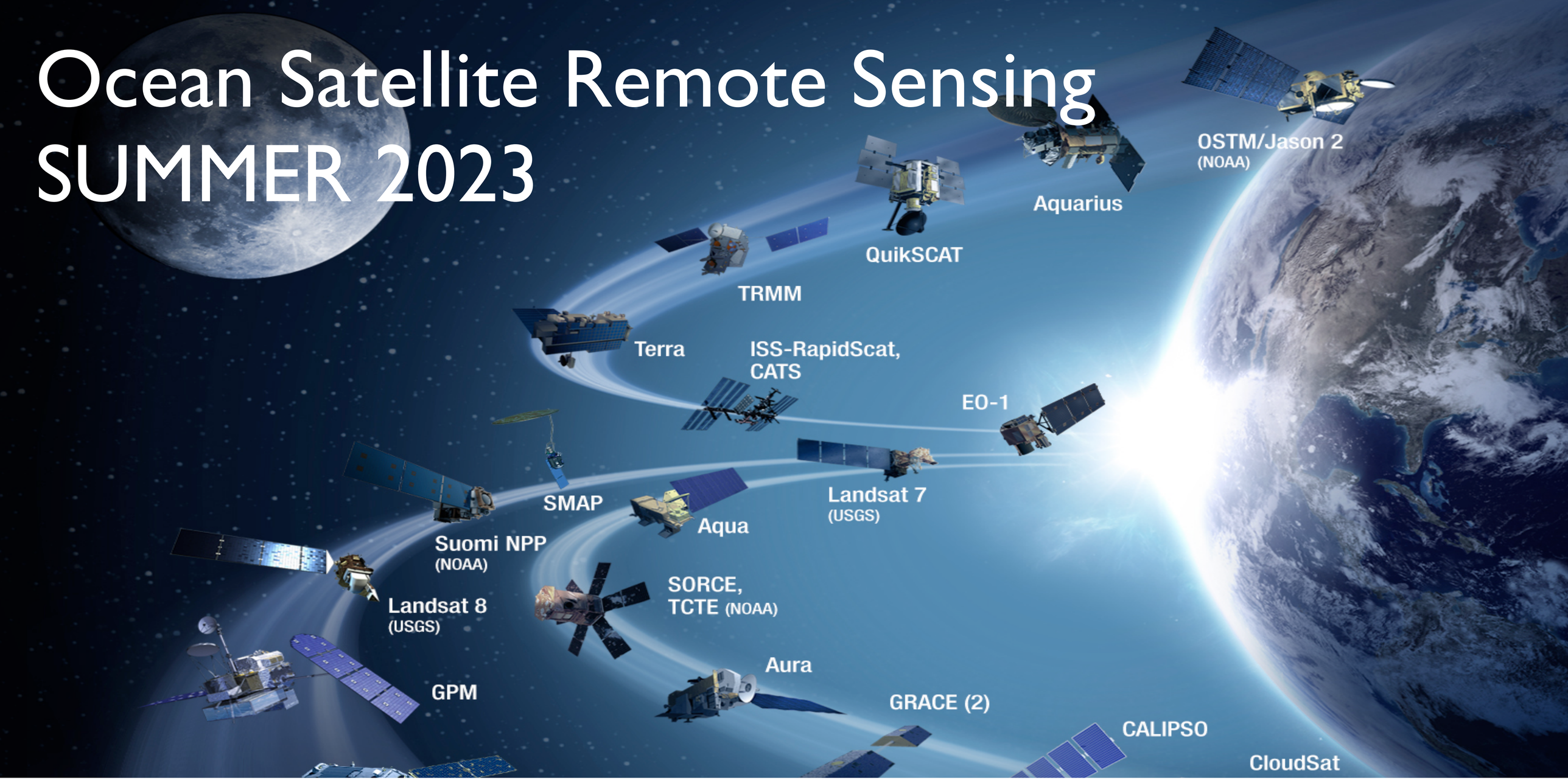
Ocean Satellite Remote Sensing
SUMMER 2023



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Workshop Goals…

1. **Develop good Python programming skills** that are needed to effectively make use of satellite image data to answer important oceanographic questions.
2. Gain strong familiarity with the use of NASA's **SeaDAS software** to derive mapped imagery of geophysical parameters (e.g., chlorophyll or CDOM) from data obtain through the Ocean Color Web Data Server.
   - An important feature of the course involves **running SeaDAS with pre-written Python scripts** to batch process large quantities of data.
3. Be able to import and visualize satellite imagery of 1) sea surface temperature, 2) ocean wind speed and 3) sea surface height.
4. **Build a Vocabulary** that will allow you to access (i.e., read/understand) a significant amount of the peer-reviewed ocean remote-sensing literature.

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Outline

1. Python Programming Methods *(computer work)*
2. Background Fundamentals *(lectures)*
   - Bio-Optics
   - Pigment Algorithms
   - Primary Production Algorithms
   - Atmospheric Correction

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3. Ocean Color Missions *(lectures)*
4. Ordering Ocean Color Data *(computer work)*
5. Using SeaDAS Software *(computer work)*
   - Working in Interactive Mode
   - **Working Within Python Scripts**

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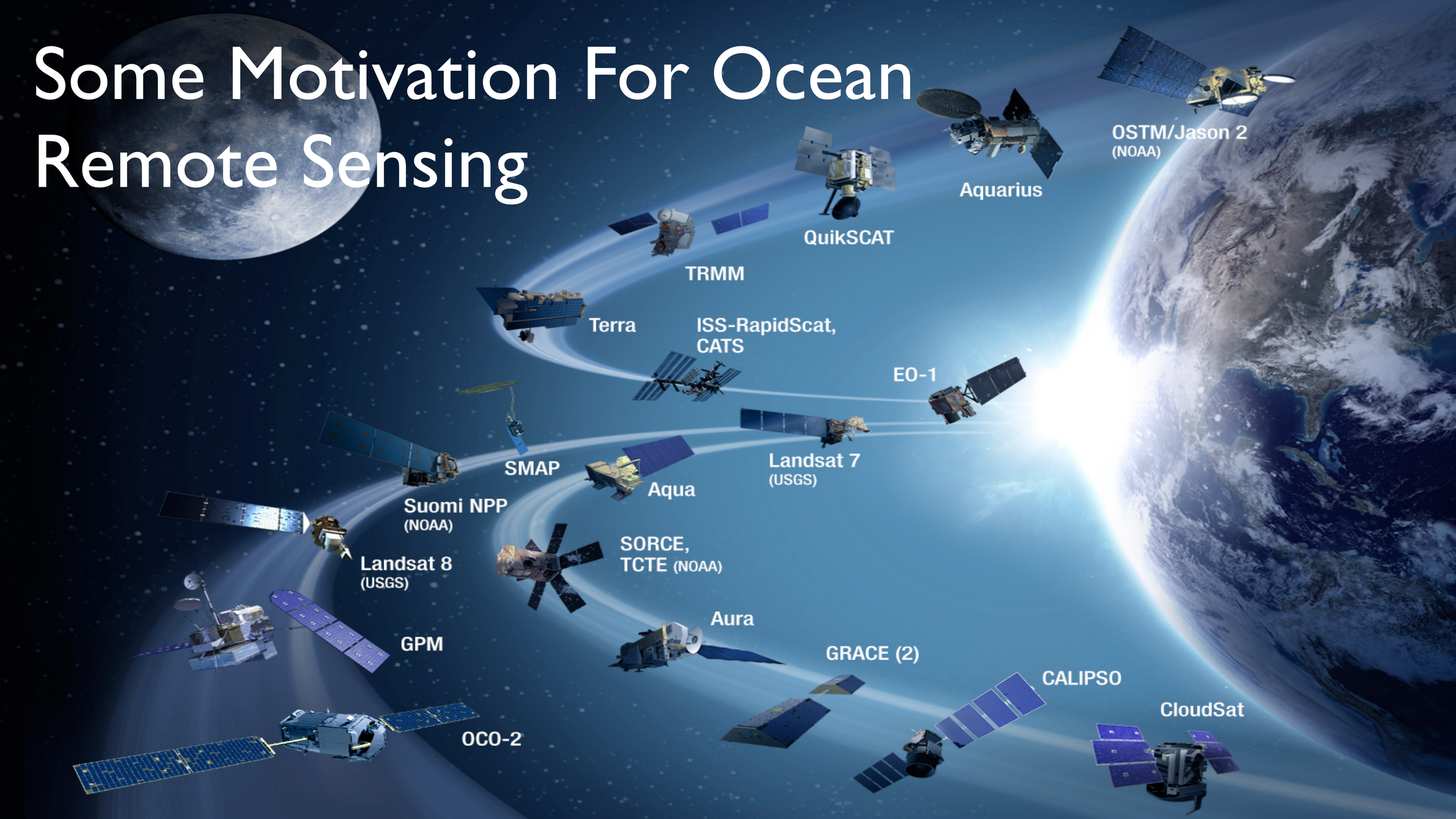
6. Background Theory of the Measurement, Data Download and Imaging For:
   - SST, Wind and Altimetry
7. Empirical Orthogonal Function (EOF) Analysis of Satellite Image Time Series

Some Motivation For Ocean Remote Sensing



NASA DAAC (*data distribution*) System

Site Map

http://nasadaacs.eos.nasa.gov/sitemap.html

NASA Langle...ive Center) EOS NASA GISS: ...s E. Hansen NOAA Coast...ata Access hydrophobicity stuff Google CU Lib

DAAC Alliance About | Data: Search Tools | News/Features | Education | Site Map

Site Map

Data Center Quick Links Alphabetical Topic List Site Organization

Data Center Information

Data Center	Data Search URL	USO Email
Alaska Satellite Facility (ASF DAAC)	ASF Data Products	asf@eos.nasa.gov
GSFC Earth Sciences (GES DAAC)	GES DAAC Search and Order	help@daac.gsfc.nasa.gov
Global Hydrology Resource Center (GHRC)	GHRC Data	ghrc@eos.nasa.gov
Langley Atmospheric Sciences Data Center (LaRC DAAC)	LaRC DAAC Home	larc@eos.nasa.gov
Land Processes (LP DAAC)	Ordering LP DAAC Products	edc@eos.nasa.gov
National Snow and Ice Data Center (NSIDC DAAC)	NSIDC DAAC Data Catalog	nsidc@nsidc.org
Oak Ridge National Laboratory (ORNL DAAC)	ORNL DAAC Data Products	ornldaac@ornl.gov
Physical Oceanography (PO DAAC)	PO DAAC Catalog and Order Form	podaac@podaac.jpl.nasa.gov
Socioeconomic Data and Applications Center (SEDAC)	SEDAC Query Build	ciesin.info@ciesin.columbia.edu

OceanColor WEB

ABOUT MISSIONS DATA DOCS SOFTWARE & TOOLS SERVICES GALLERY FORUM

OCEAN BIOLOGY DISTRIBUTED ACTIVE ARCHIVE CENTER

NASA's OceanColor Web is supported by the Ocean Biology Processing Group (OBPG) at NASA's Goddard Space Flight Center. As a Science Investigator-led Processing System (SIPS), our responsibilities include the collection, processing, calibration, validation of ocean-related products from a large number of operational, satellite-based remote-sensing missions providing ocean color, sea surface temperature and sea surface salinity data to the international research community since 1996. As a Distributed Active Archive Center (DAAC), known as the Ocean Biology DAAC (OB.DAAC), we are responsible for the archive and distribution of satellite ocean biology data produced or collected under NASA EOSDIS, including those from historical missions and partner space organizations.

Ocean Color Feature

Salton Sea

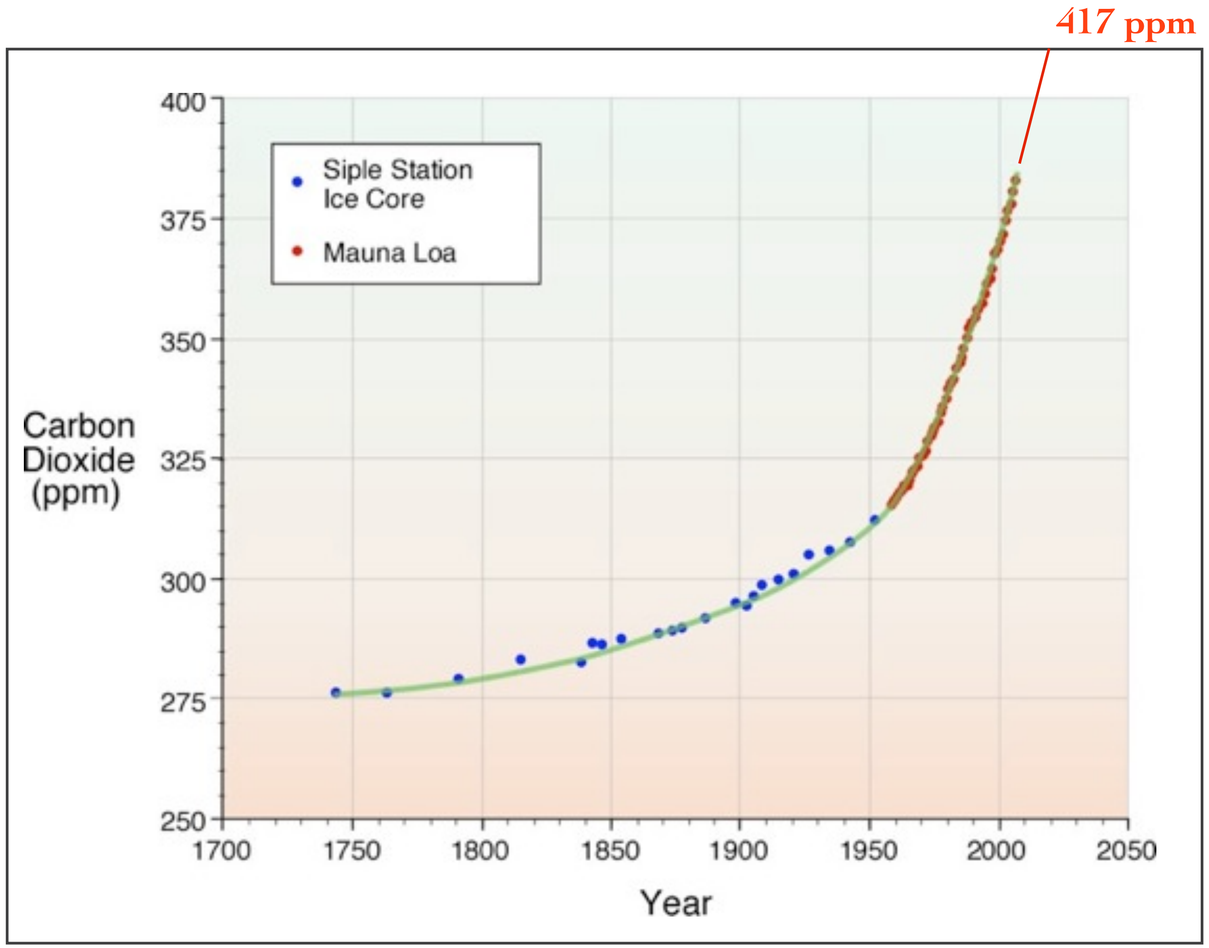
Some Examples of Using Satellite Data…

Outline

- <u>Global Scale</u>
  - Global Carbon Cycle and Climate Change
  - Coral Bleaching/Death and Conservation Management
- <u>Ocean Basin Scale</u>
  - Spring Phytoplankton Blooms in the North Atlantic
- <u>Regional Scale</u>
  - Gulf of Maine Zooplankton Dynamics

Climate Change

Concentration of Atmospheric CO_2 Since the Beginning of the Industrial Era… An increase of 40%



A Super Important Point

Atmospheric CO_2 concentration is increasing by about 2 to 3ppm each year

So in less than 20 years it will be 450 ppm.

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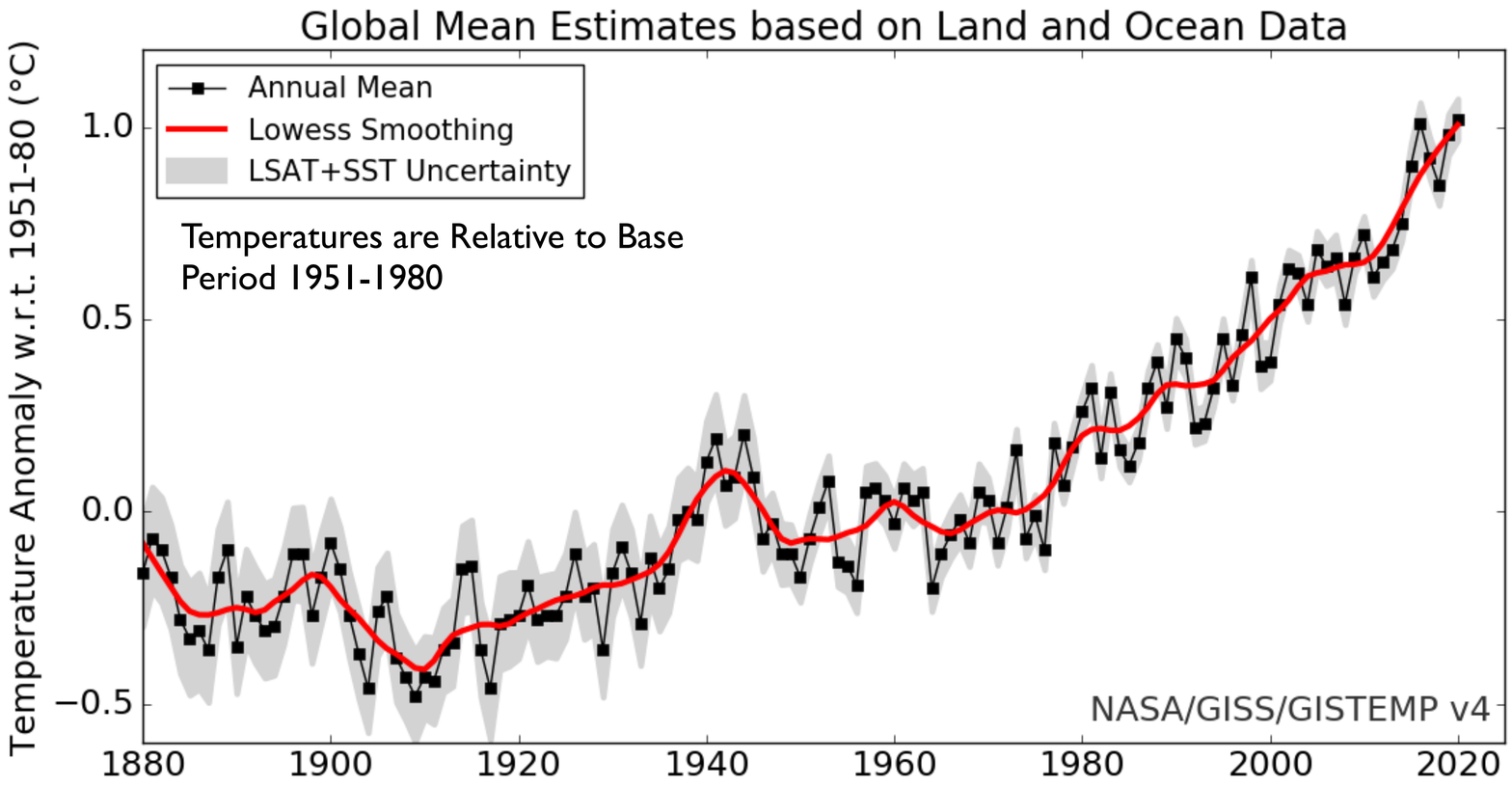
Global Temperature Anomalies Since the Industrial Era

1.1 °C Rise in Global Average Temperature



Two Important Points…

1. Limiting global warming to **1.5°C** above pre-industrial levels is the widely accepted upper limit of warming expressed by the international community.

2. To give you some perspective… **during the the last ice age** there was one kilometer of ice laying on top of Ithaca and global average temperatures were just **4 °C** colder

http://data.giss.nasa.gov/gistemp/graphs/

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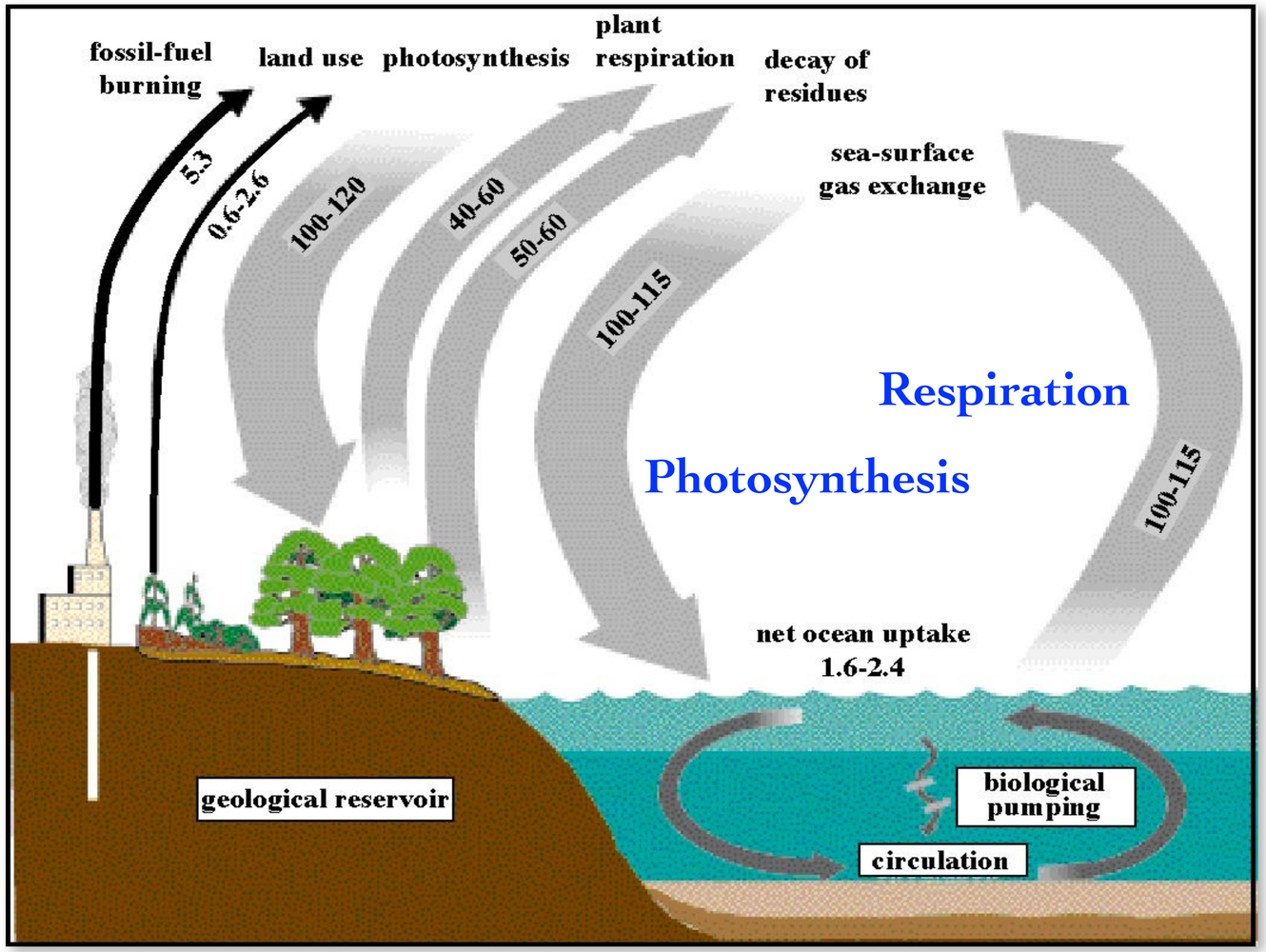
Ocean Biology Plays an Important Role in the Global Carbon (CO_2) Cycle

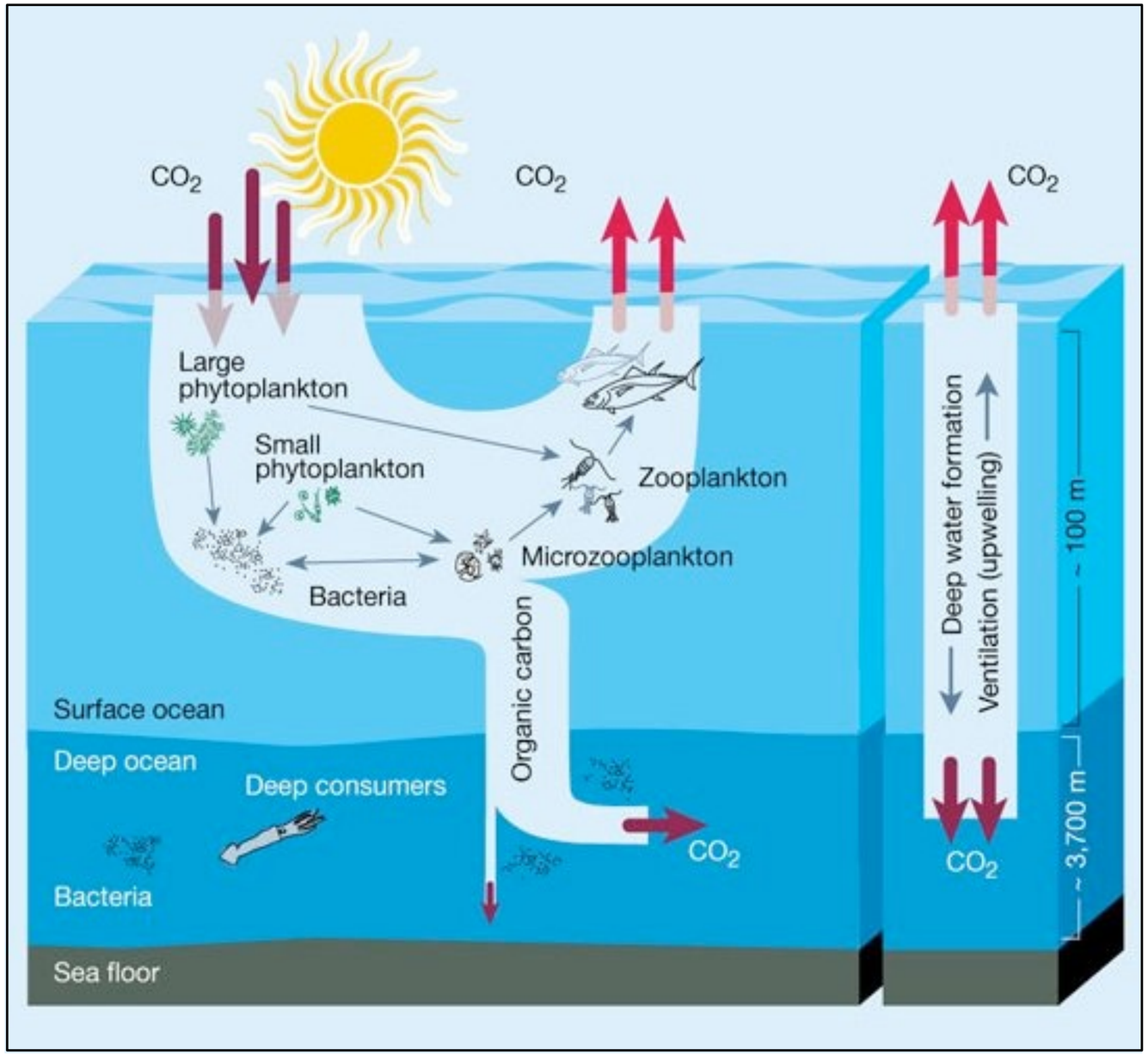
1. **Photosynthesis** consumes carbon dioxide to form the particulate carbon of algae
2. **Respiration** by all organisms produces carbon dioxide.
3. The difference between photosynthesis and respiration by all of the organisms is what sinks to the ocean floor

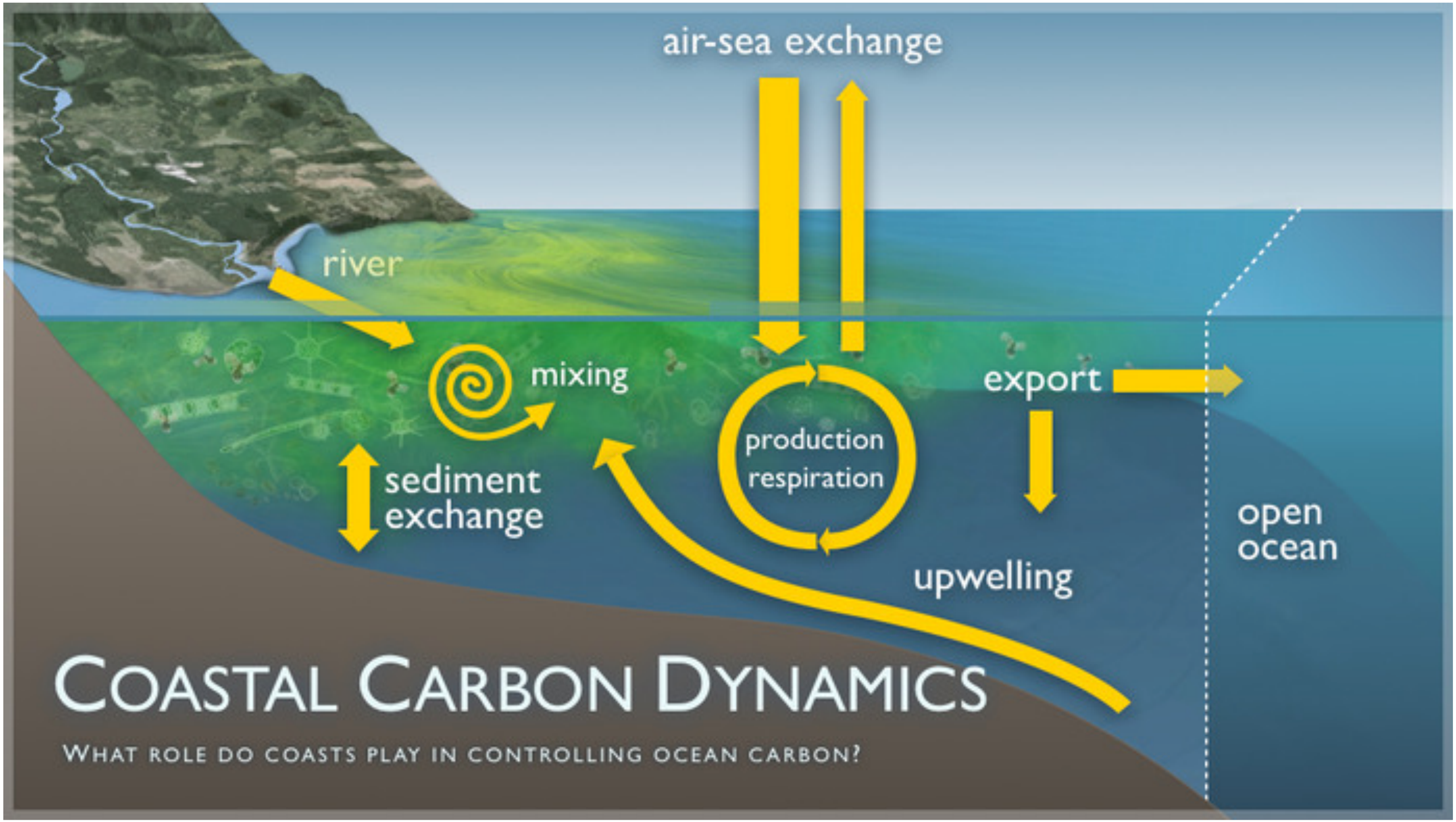


Magnitude of CO_2 flux between Land and Ocean Reservoirs

Biological Carbon Pump and the Solubility Pump

Moves carbon dioxide from the atmosphere to the deep ocean waters where it is stored for about 2,000 years or into marine sediments where it is stored on geologic time scales




air-sea exchange
river
mixing
sediment
exchange
production
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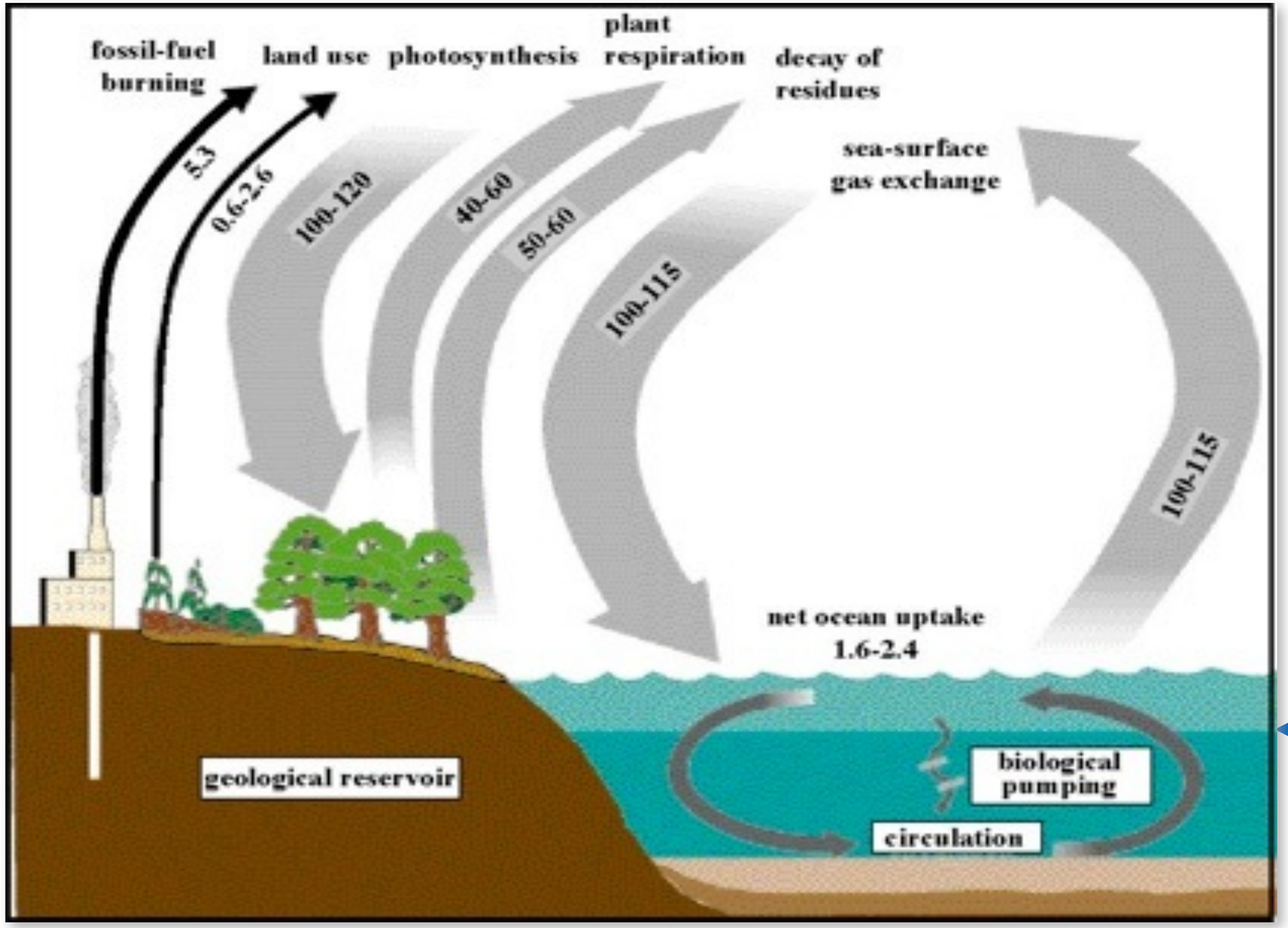
export
upwelling
open
ocean
COASTAL CARBON DYNAMICS
WHAT ROLE DO COASTS PLAY IN CONTROLLING OCEAN CARBON?

Impact of Global Warming on Global Ocean Net Primary Production

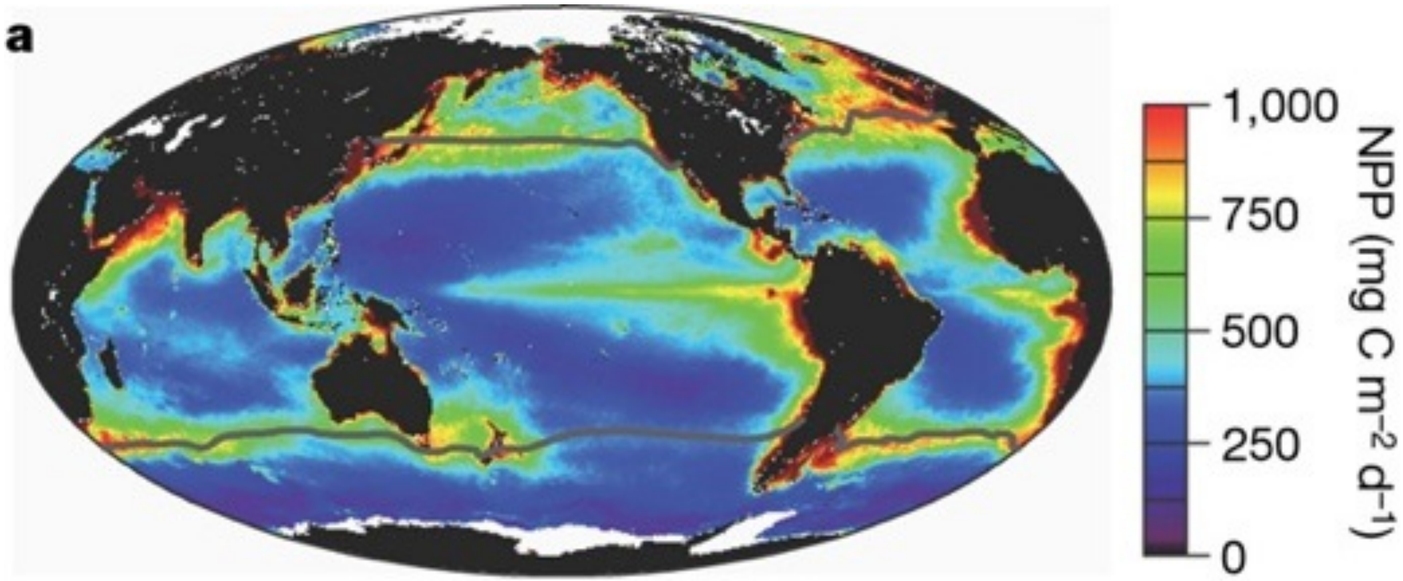
1. Much of the global ocean primary production takes place in the large low chlorophyll subtropical gyre regions
2. This region has a permanent thermocline that acts to isolate deep ocean water rich in plant nutrient from the upper ocean water that is rich in sunlight

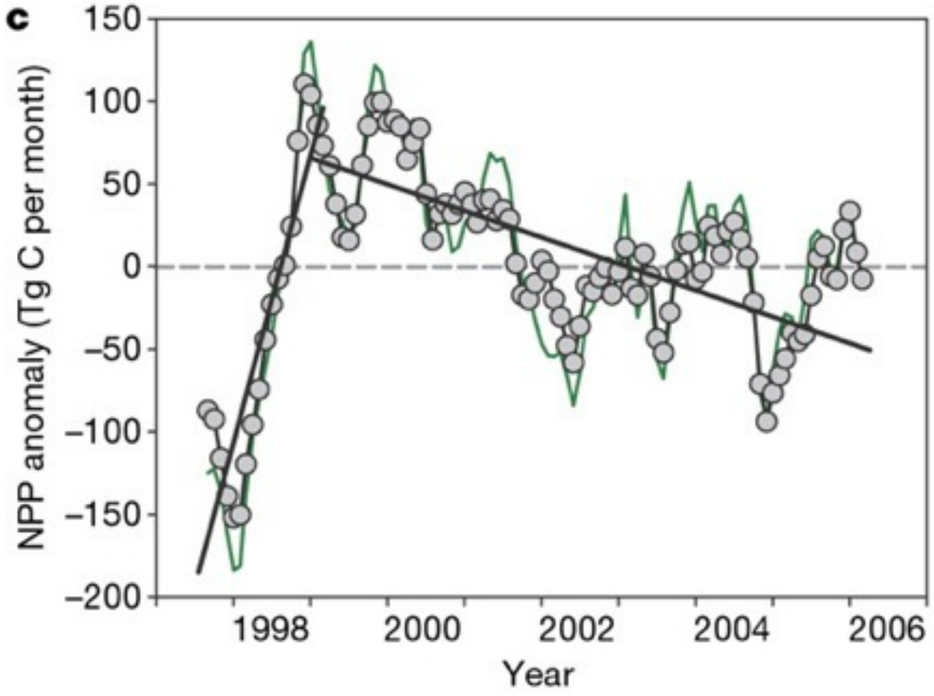


NOTE

1. The thermocline acts to hold phytoplankton near the sunlit surface ocean
2. The thermocline also acts as a significant barrier to upward mixing of nutrient rich deep water. The stronger the thermal stratification the strong the inhibition of nutrient mixing

Decline in Net Primary Production in Subtropical Ocean Regions





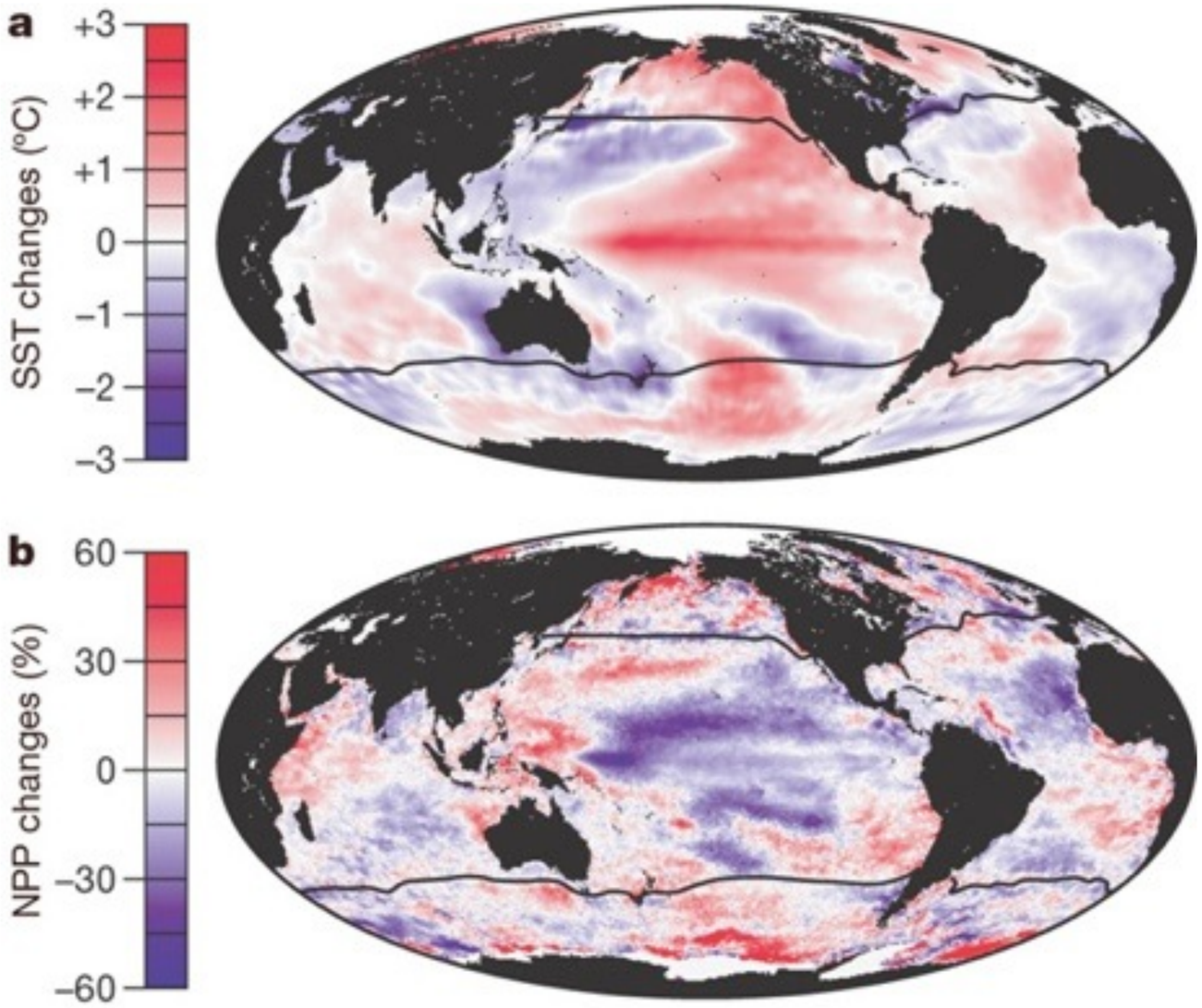
The trend is said to be a global warming signal and the oscillations about the trend is from El Nino to La Nina events…

Behrenfeld et al. (2006)
Climate-driven trends in contemporary ocean productivity.
Nature, Vol 444, 752-755

Inverse Relationship Between Surface Warming and Net Primary Production

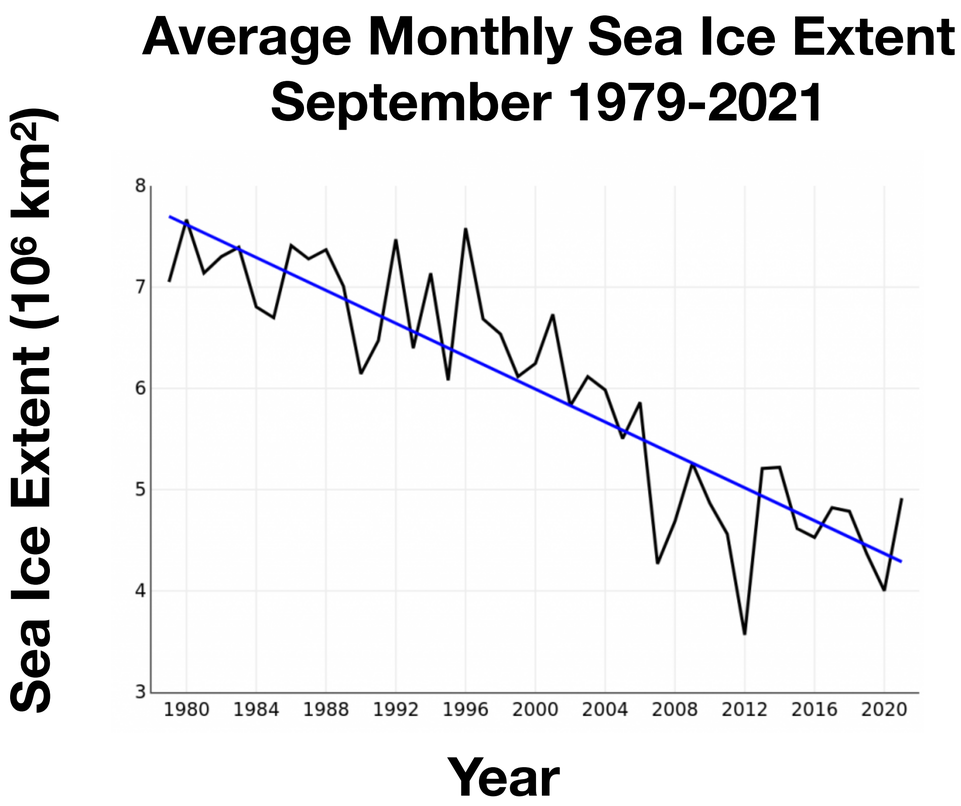
Sea Surface Temperature Anomalies

Net Primary Production Anomalies



Changes in the Arctic Ocean Due to Global Warming

In 2007 the fabled Northwest Passage opened for the first time in human history. It has opened again several times since then…



http://nsidc.org/arcticseaicenews/2021/10/

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Trends in Sea Ice Persistence (1998-2009)

Trends in Annual Primary Production (1998-2009)

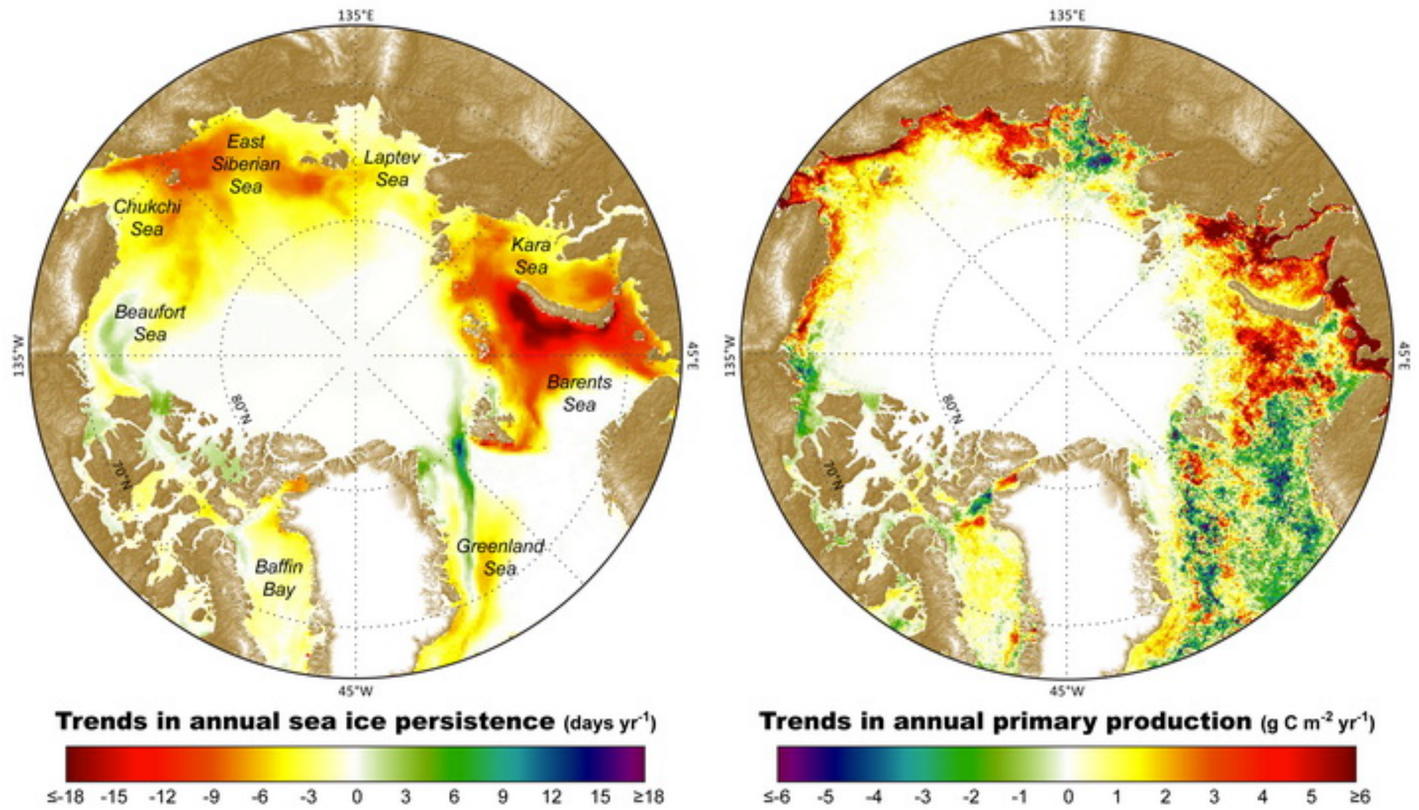

Fig. ME2. Trends in annual sea ice persistence (left) and total annual net primary production (right) across the Arctic Ocean and its adjacent shelf seas from 1998-2009. Sea ice persistence data (based on a 15% sea ice concentration threshold) are derived from Special Sensor Microwave/Imager passive microwave radiances (Cavalieri et al., 2008) and primary production data are from Arrigo and van Dijken (2011).

http://www.arctic.noaa.gov/report11/primary_productivity.html

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Changes in the Antarctica

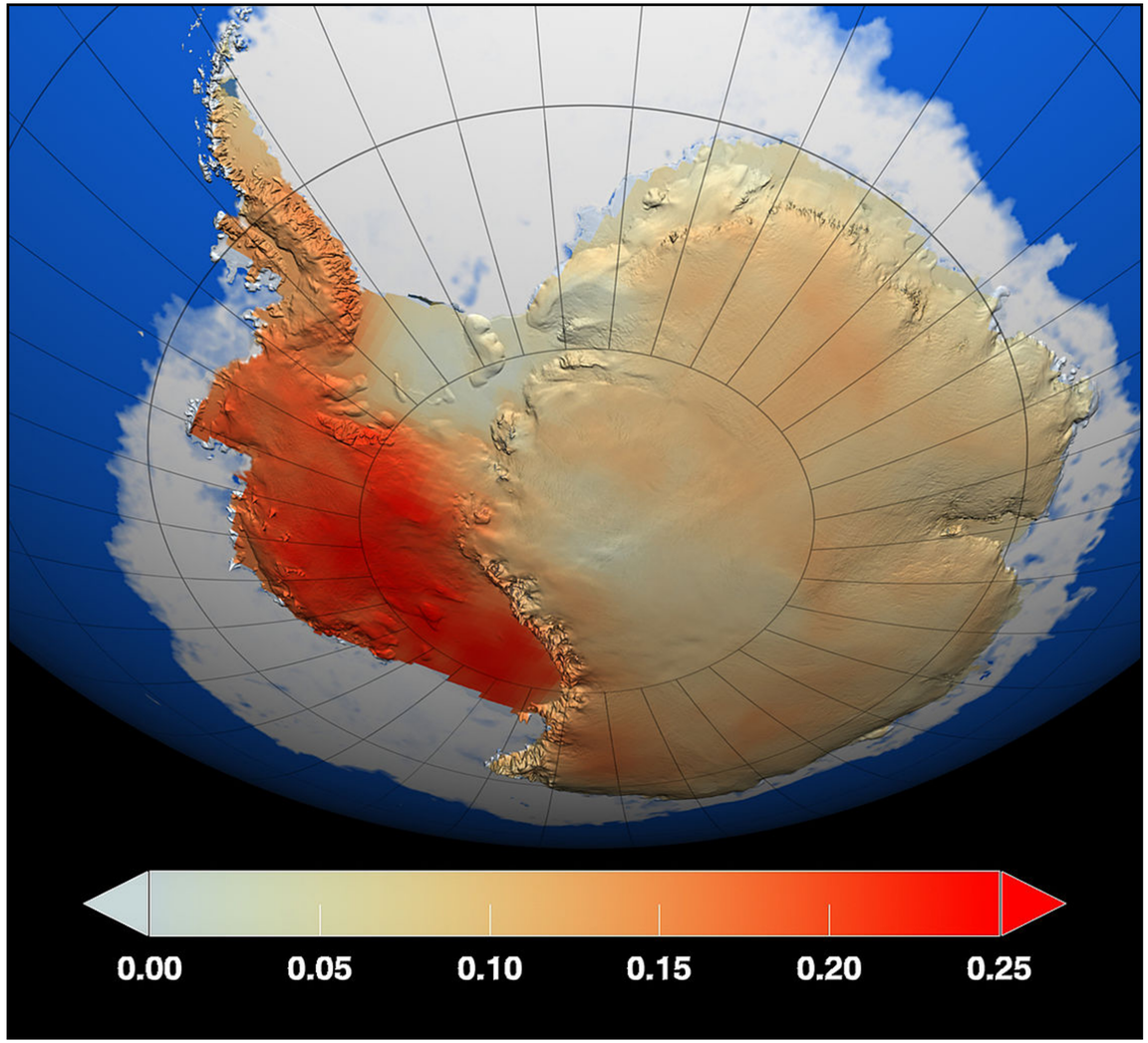
1. Some stations in East Antarctica show some cooling, but in general Antarctica is warming up.

2. The **West Antarctic Peninsula** is one of the fastest warming areas on Earth, with only some areas in the Arctic experiencing faster rising temperatures.

3. **The West Antarctic Ice Sheet is losing mass, likely due to warmer water deep in the ocean near the coast.**

4. West Antarctica has lost 18% of is ice sheet volume over the last two decades.

http://www.sciencemag.org/news/2015/03/antarctica-rapidly-losing-its-edge



Antarctic surface temperature trends for 1957-2006.

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Ecosystem Changes in West Antarctica

1. Krill is a Keystone Species on the Southern Ocean: Food for a broad array of predators

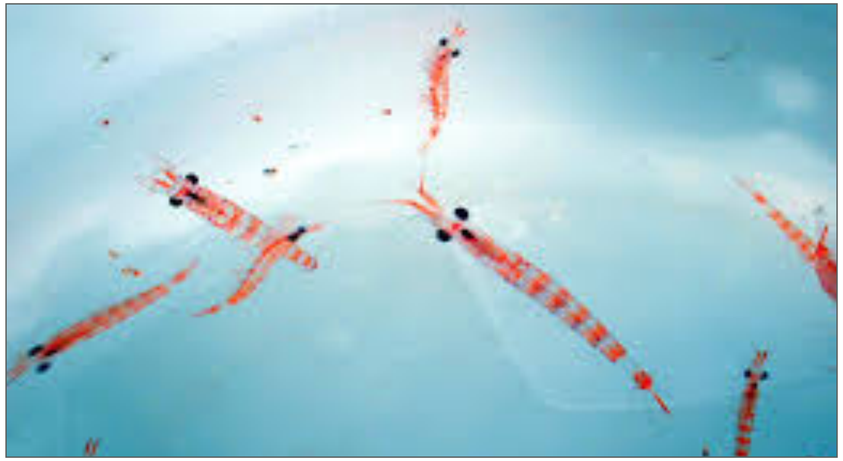
2. Most Antarctic krill are found in an area from the Weddell Sea to the waters around the Antarctic Peninsula

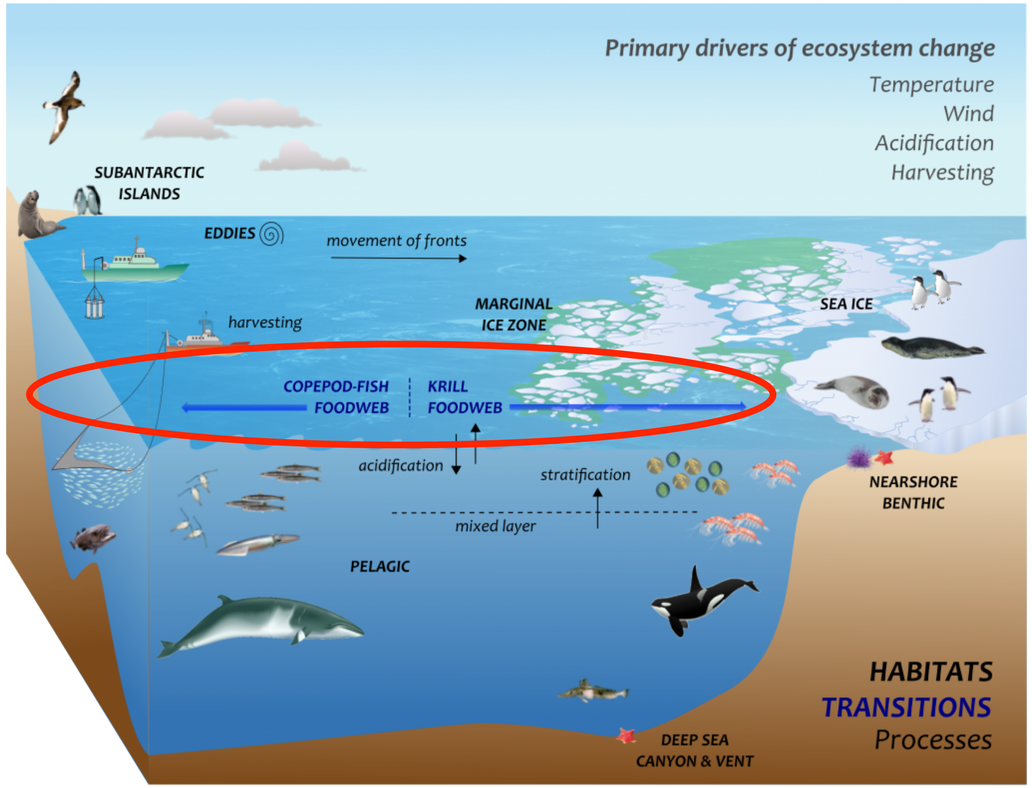
3. **Over the past 40 years**, populations of adult Antarctic krill have declined by **70 to 80 percent** in these areas.

4. **Model projections* predict that by 2100 suitable habitat for young krill will decline by up to 80%.**

* A. Piñones and A. Fedorov

Geophysical Research Letters, 10.1002/2016GL069656





http://www.climatecentral.org/news/climate-change-could-put-tiny-krill-at-risk-20641

Oceanography

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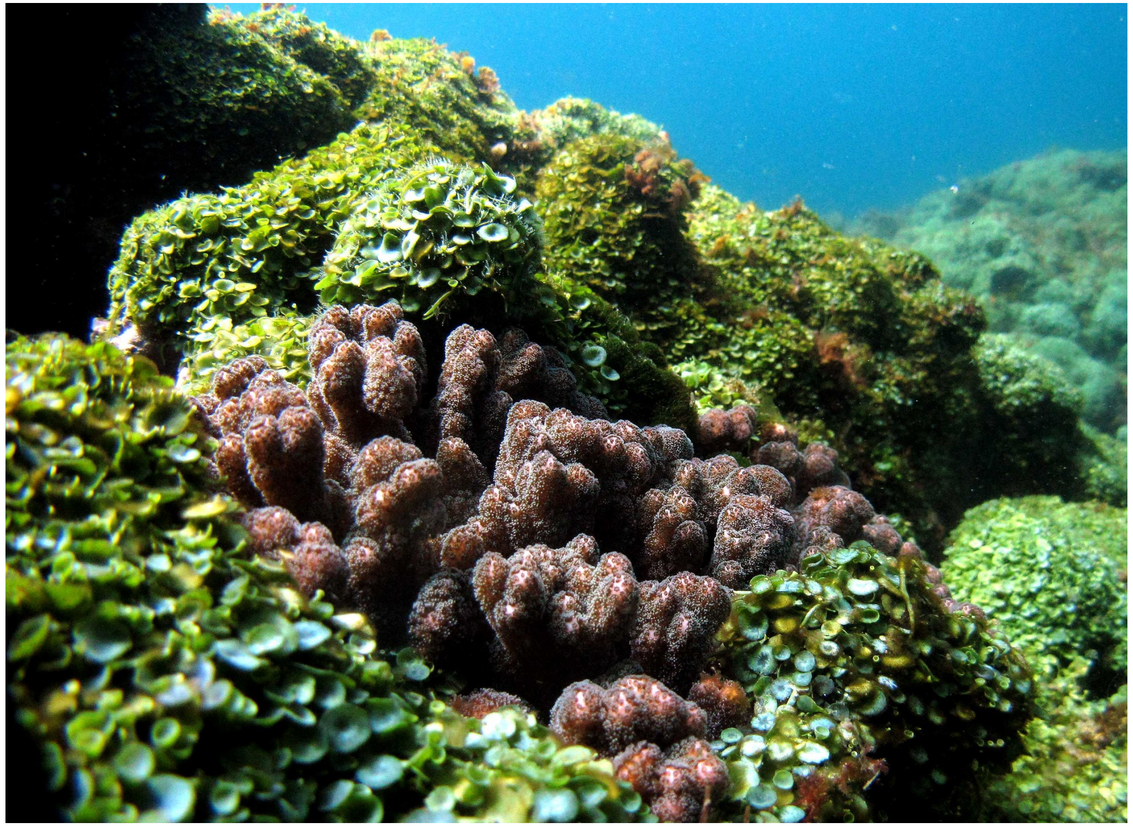
Coral Reefs

Corals Compete for Space:

They Compete With Other Corals *and* With Macroalgae



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Coral Competition with Macroalgae in High Nutrient Waters

The competitive advantage for taking over space is shifted in favor of macroalgae when nutrients from agricultural activities run off the coast and onto coral reefs

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Coral Bleaching

1. It is the zooxanthellae algae that give corals all of their beautiful natural colors

2. Coral bleaching is the name given to an event where corals expel their symbiotic zooxanthellae algae due to environmental stress such as unusually warm water

3. Corals can recover and regain their zooxanthellae if the stress is small or short-lived (a couple of weeks)

4. Coral death follows if the stress is *extreme* and/or *prolonged*.

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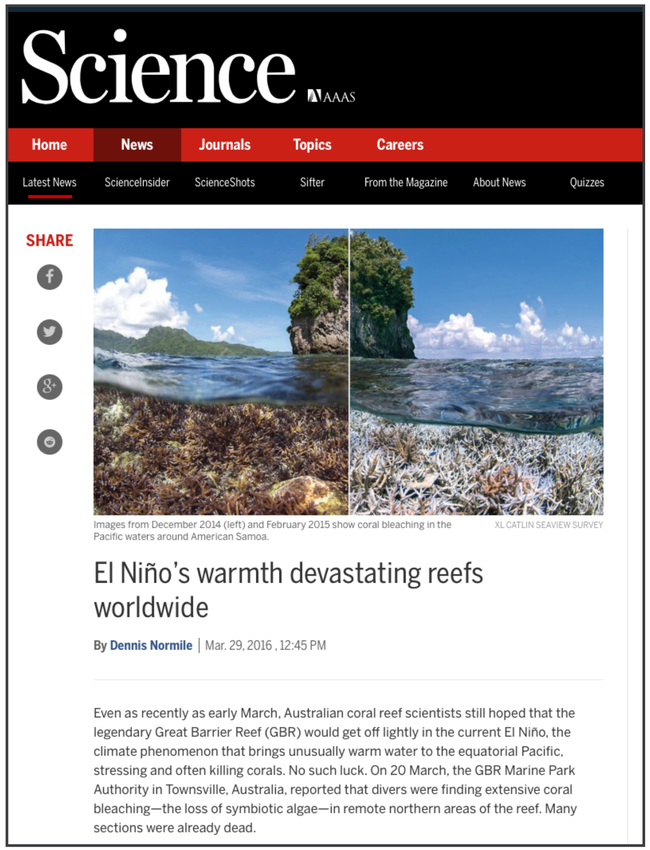
The 2015-2016 El Nino Warming Effect, When Super-Imposed on the Multi-Decadal Global Warming Trend, Was Disastrous for Coral Reefs!!



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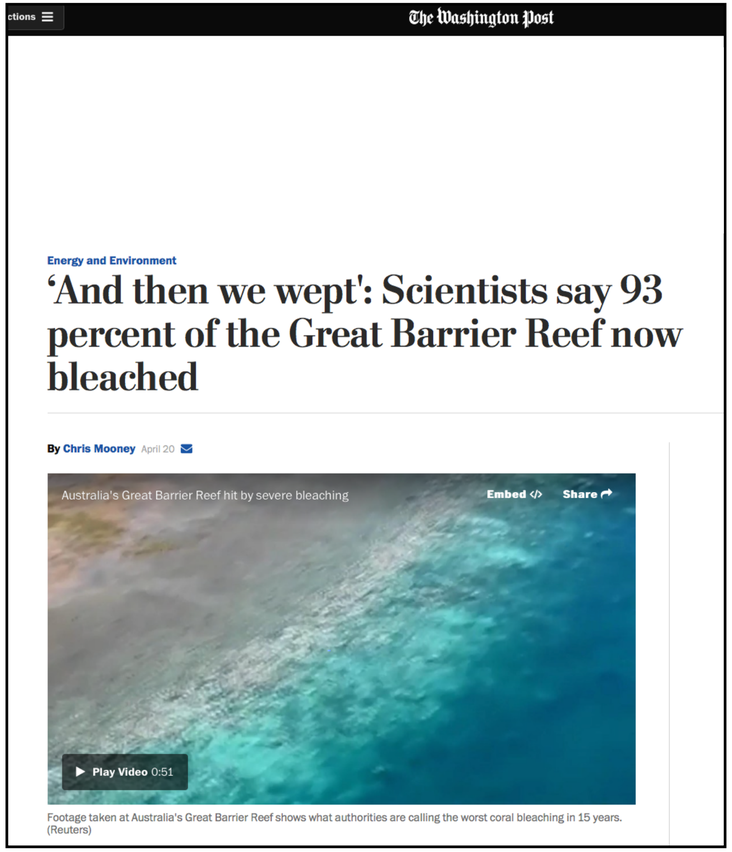
Images from December 2014 (left) and February 2015 show coral bleaching in the Pacific waters around American Samoa. XL CATLIN SEAVIEW SURVEY

El Niño's warmth devastating reefs worldwide

By Dennis Normile | Mar. 29, 2016 , 12:45 PM

Even as recently as early March, Australian coral reef scientists still hoped that the legendary Great Barrier Reef (GBR) would get off lightly in the current El Niño, the climate phenomenon that brings unusually warm water to the equatorial Pacific, stressing and often killing corals. No such luck. On 20 March, the GBR Marine Park Authority in Townsville, Australia, reported that divers were finding extensive coral bleaching—the loss of symbiotic algae—in remote northern areas of the reef. Many sections were already dead.



The Washington Post

Energy and Environment

'And then we wept': Scientists say 93 percent of the Great Barrier Reef now bleached

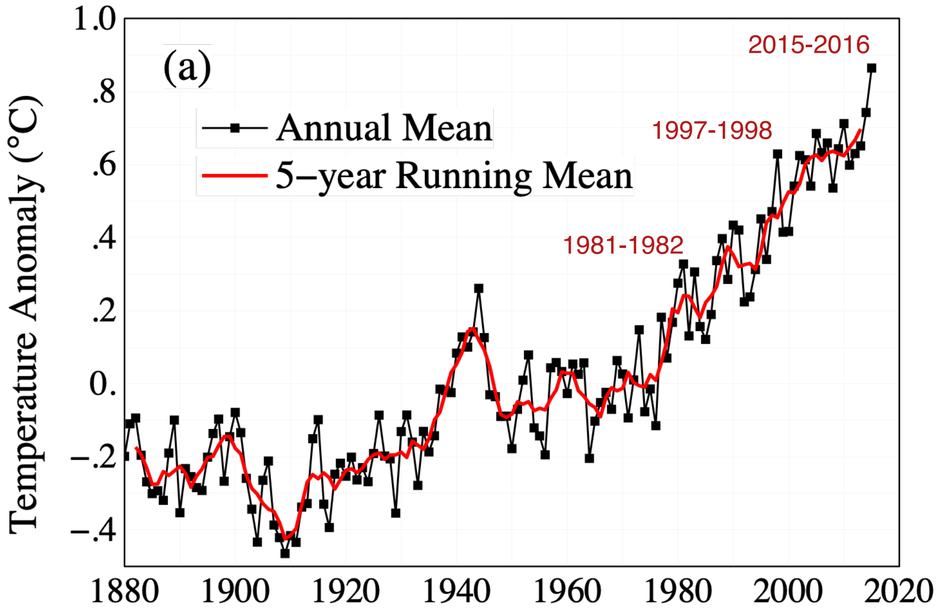
By Chris Mooney April 20

Australia's Great Barrier Reef hit by severe bleaching

Embed Share

Play Video 0:51

Footage taken at Australia's Great Barrier Reef shows what authorities are calling the worst coral bleaching in 15 years. (Reuters)



El Ninos are nothing new. They temporarily raise global average temperatures. However, when these temporary warming events are super imposed on the human-caused multi-decadal warming they have increasingly devastating effects on coral reef mortality

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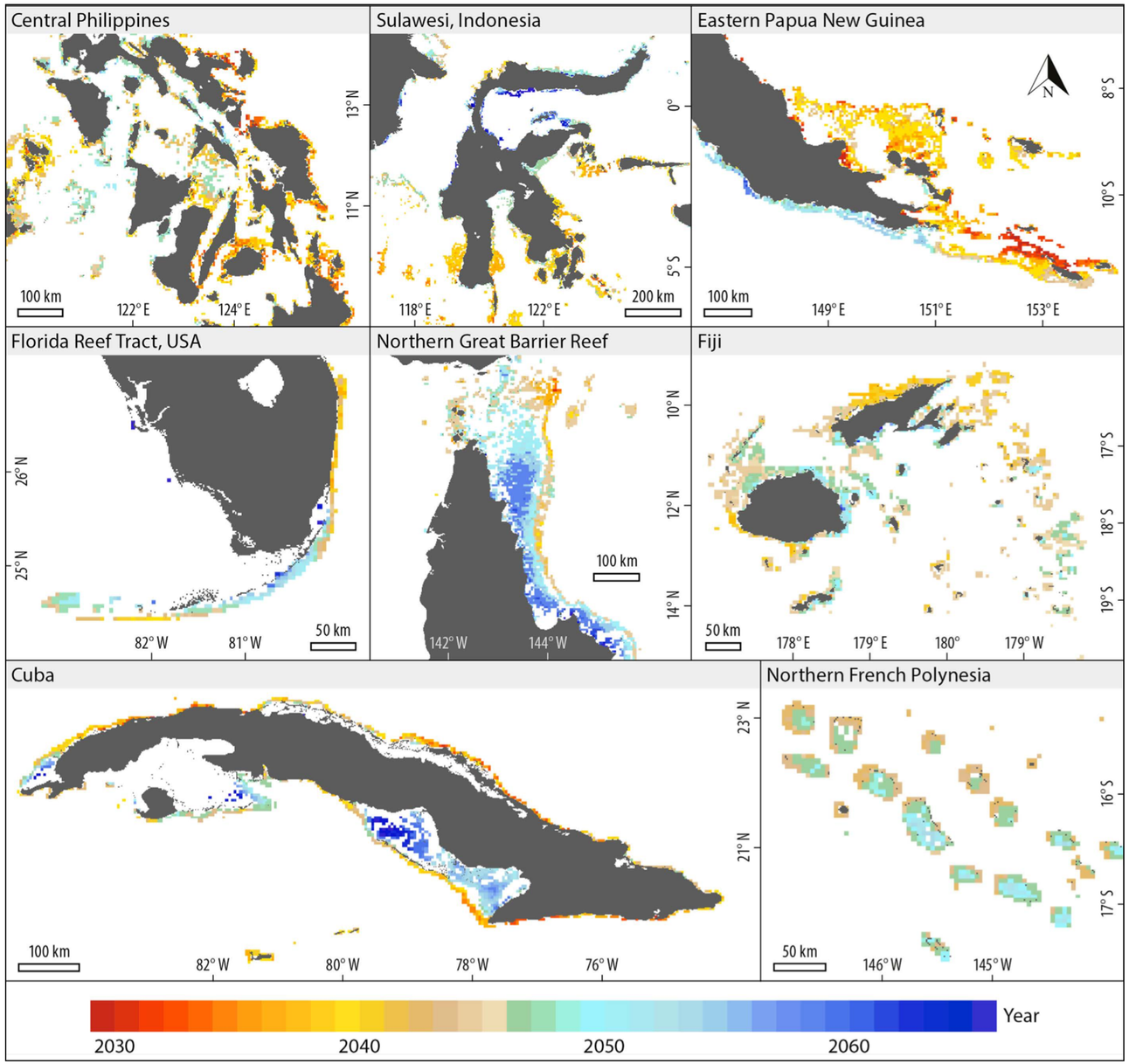
Modeled onset of annual severe bleaching under *Business as Usual* emissions scenario

1. Red regions will see regular beaching by 2030 (***less than 15 years***)
2. Orange and Yellow regions indicate onset of regular bleaching by 2040 (***about 25 years***)
3. Blue regions have until 2050-2060 (***about 35 to 45 years***)
4. Note: COP-21 Pledges will add an additional 10 years onto the onset dates above, but will not prevent severe annual bleaching from occurring…



van Hooidonk et al (2016), Nature, 6:39666, doi: 10.1038/srep39666

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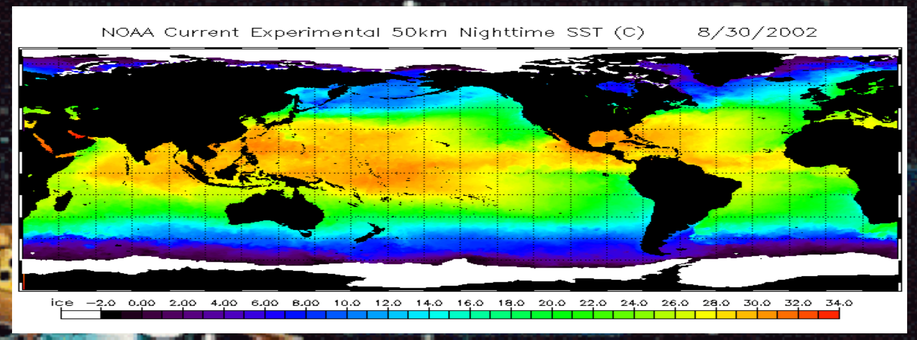
NOAA Coral Reef Watch Program

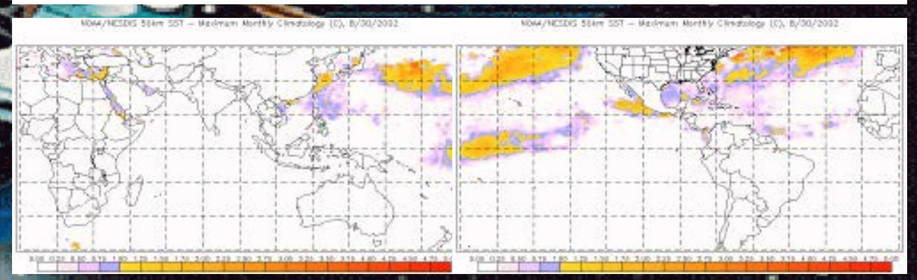
Satellite Near Real-Time Coral Bleaching HotSpot Products

(Twice-weekly at 50km resolution)

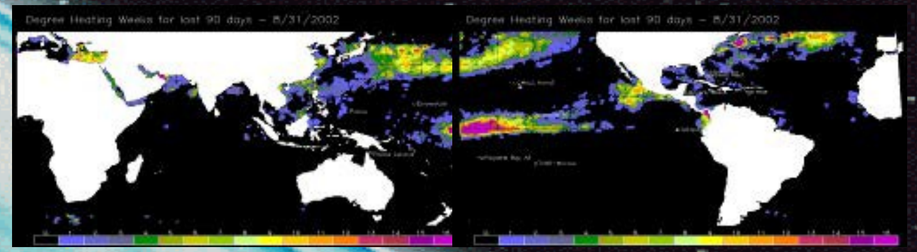
Sea Surface Temperature
(Night-time only)



Bleaching HotSpots

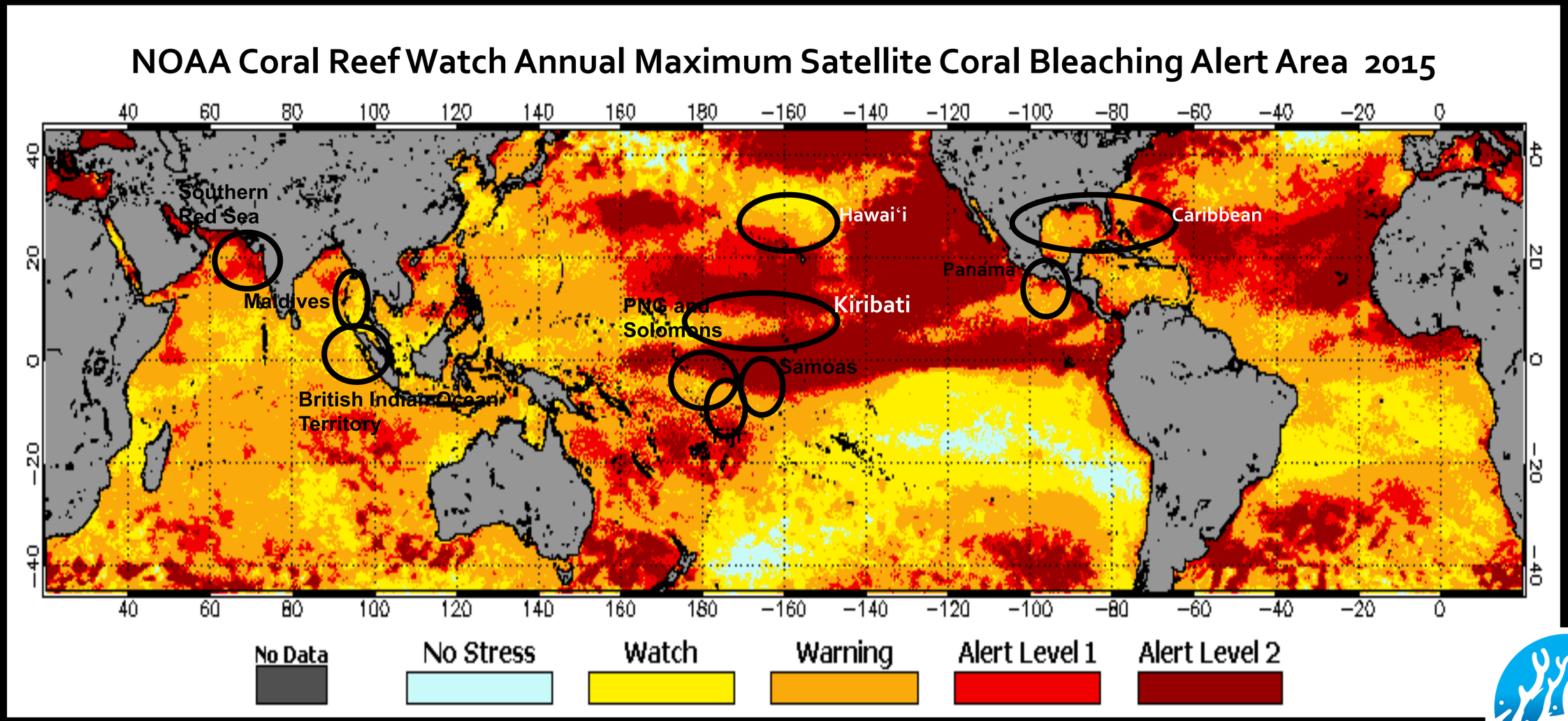


Degree Heating Weeks (DHW)



http://coralreefwatch.noaa.gov

Global Bleaching: 2015

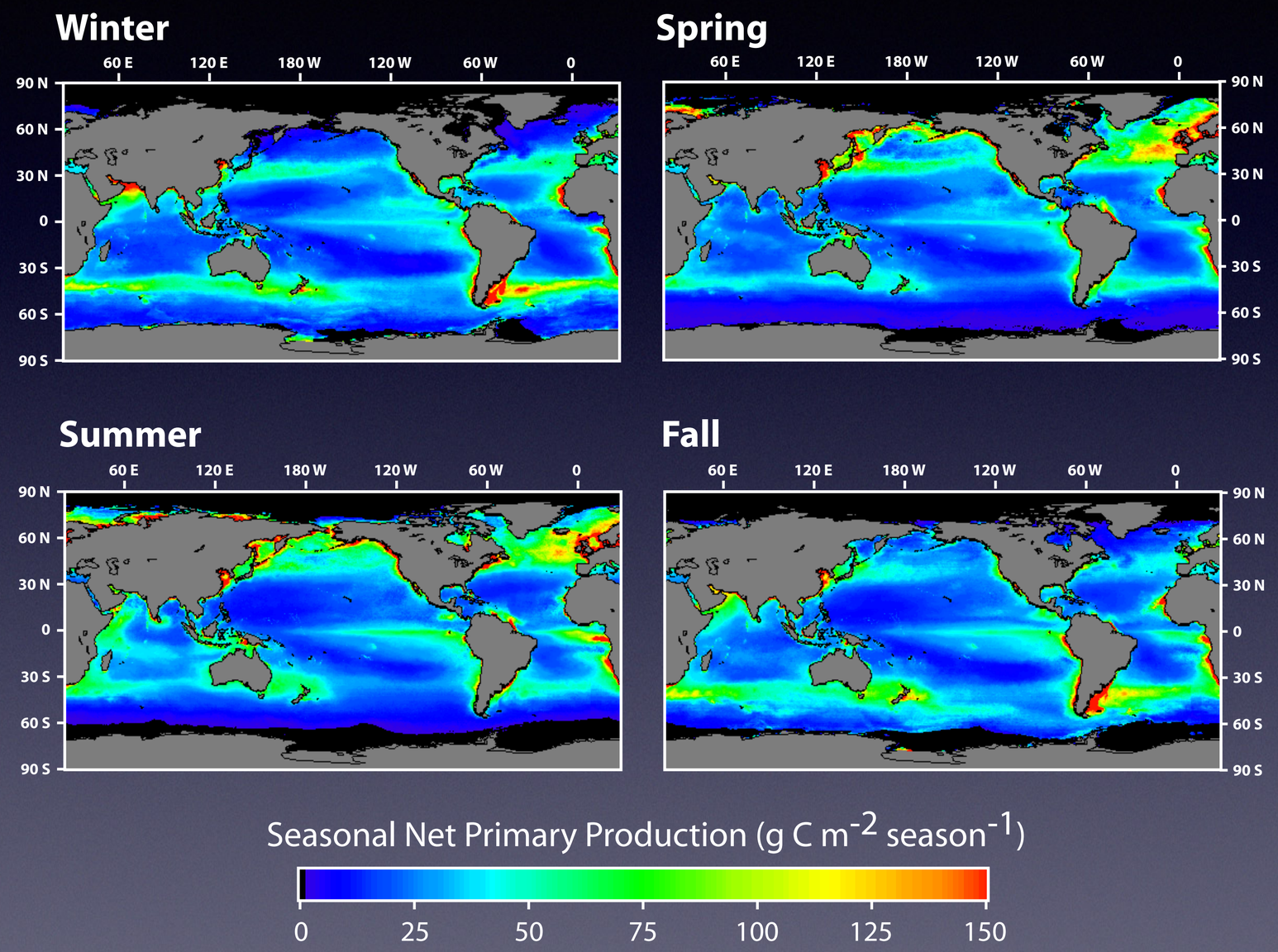


NOAA CORAL REEF CONSERVATION PROGRAM

NAO Impact on North Atlantic Spring Phytoplankton Blooms

An Example of Using Satellite Data Quantitatively

Seasonal Variation in Primary Production

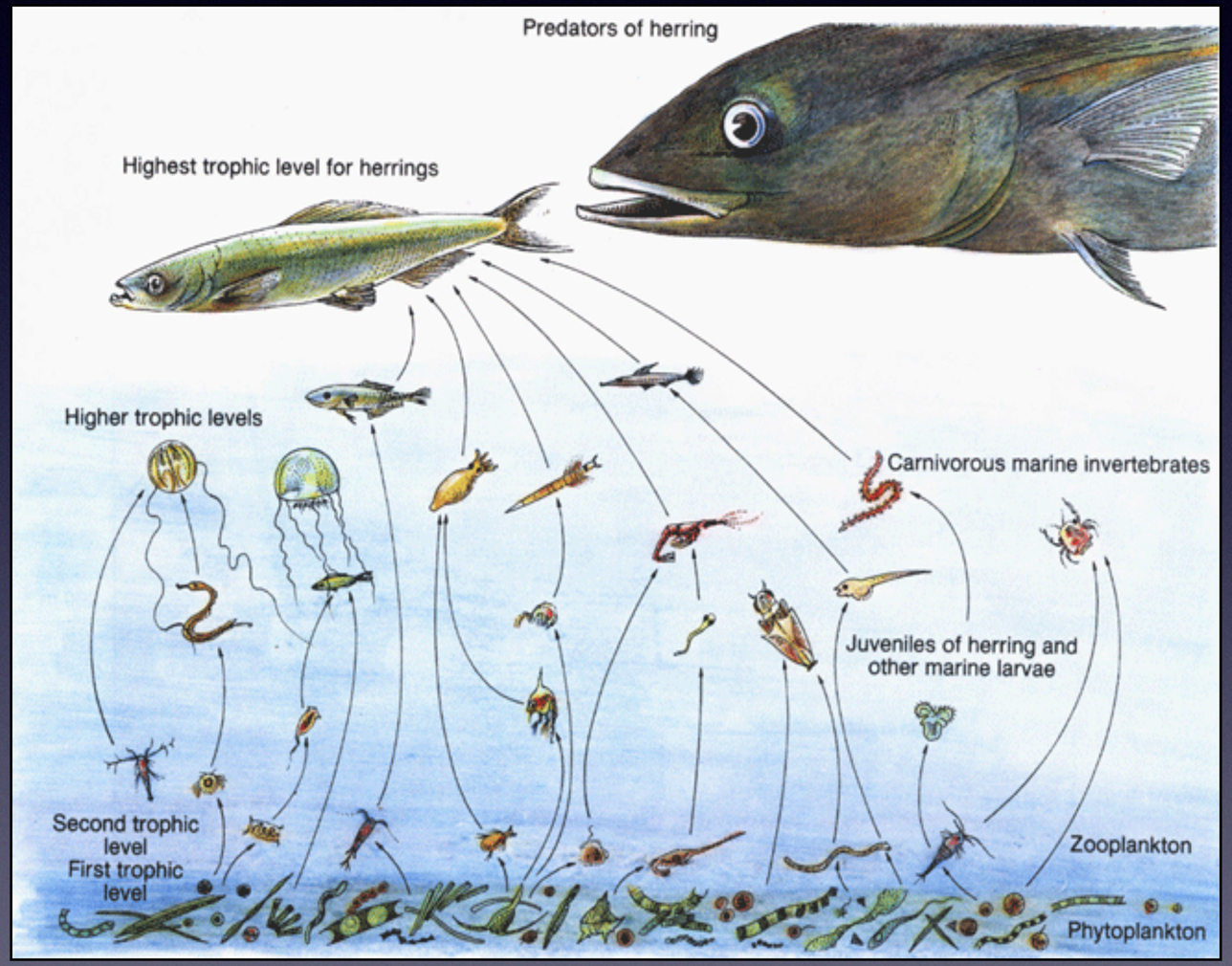


NPP Derived Using Behrenfield & Falkowski (1997) VGPM

Timing, Magnitude and Duration of the Seasonal Increase in Phytoplankton Abundance Can Have Important Impacts on Zooplankton Populations and Subsequent Trophic Levels…

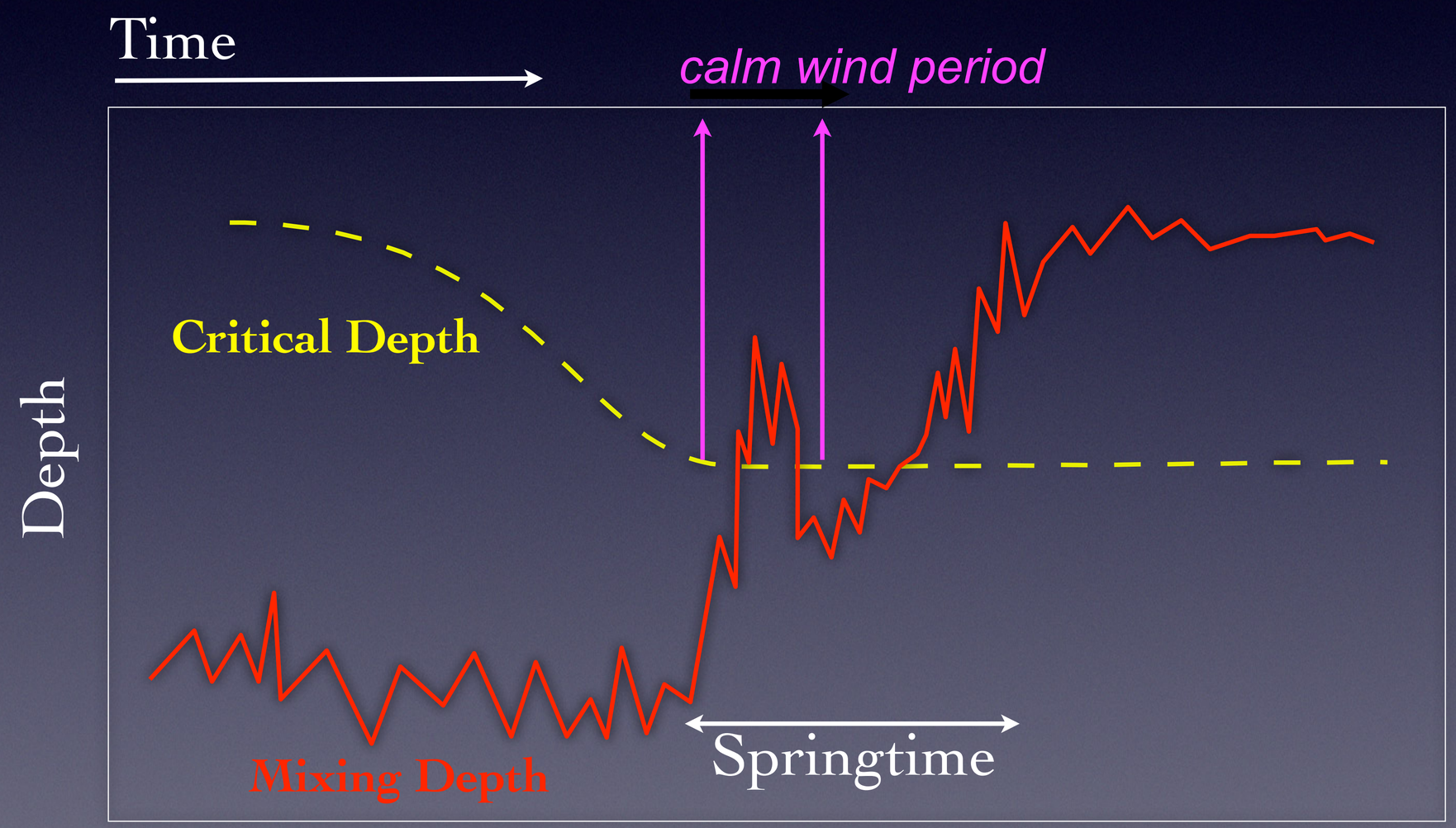
1. match-mismatch between the timing of bloom onset and timing of zooplankton emergence from diapause

2. phytoplankton blooms of modest intensity that persist for an extended period of time may be more beneficial to zooplankton populations than blooms that are intense, but short-lived



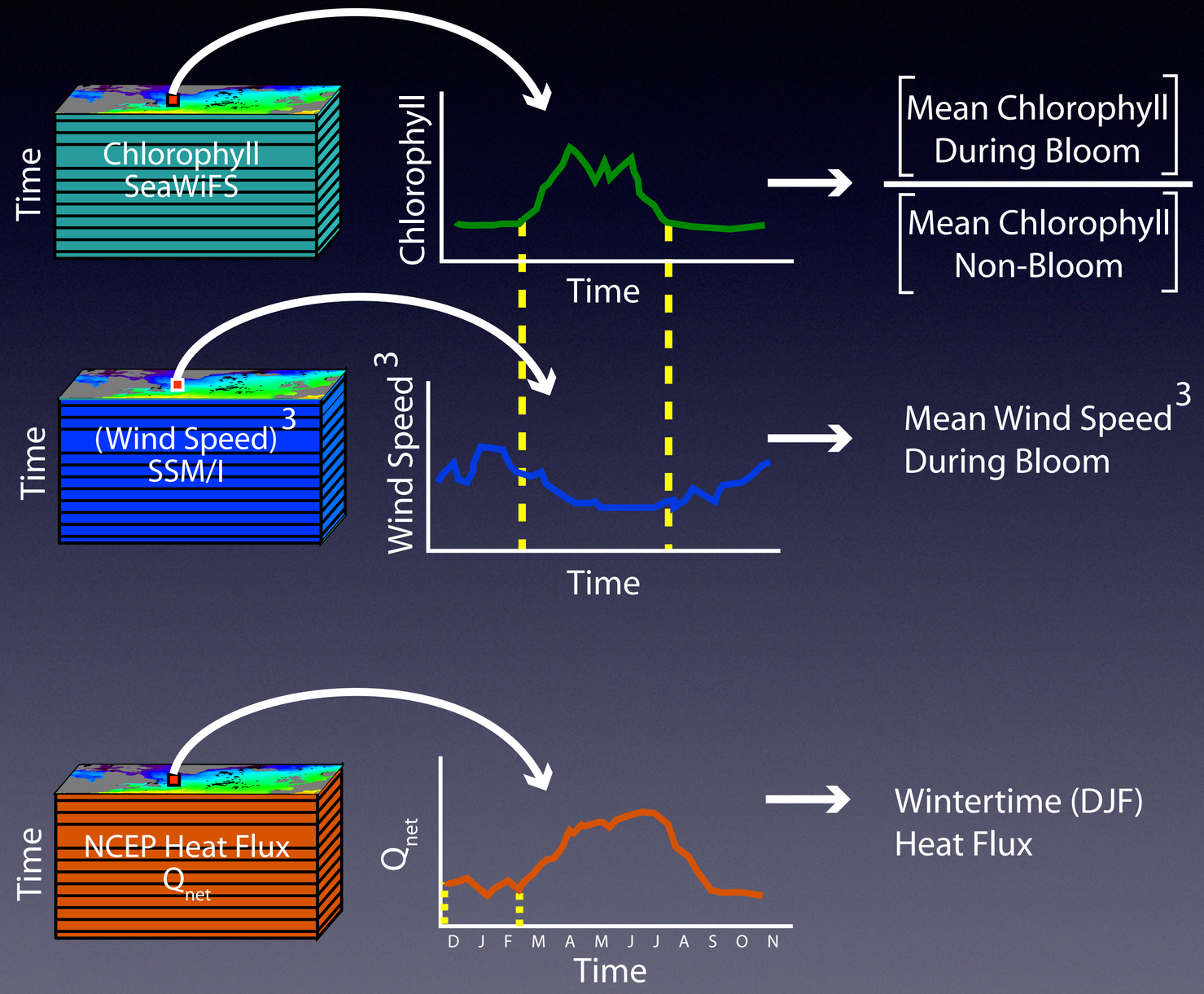
Impact Wind Mixing on the Timing of Bloom Onset

Spring Blooms Can Occur Earlier than Usual in Years with Anomalously Calm Wind Conditions

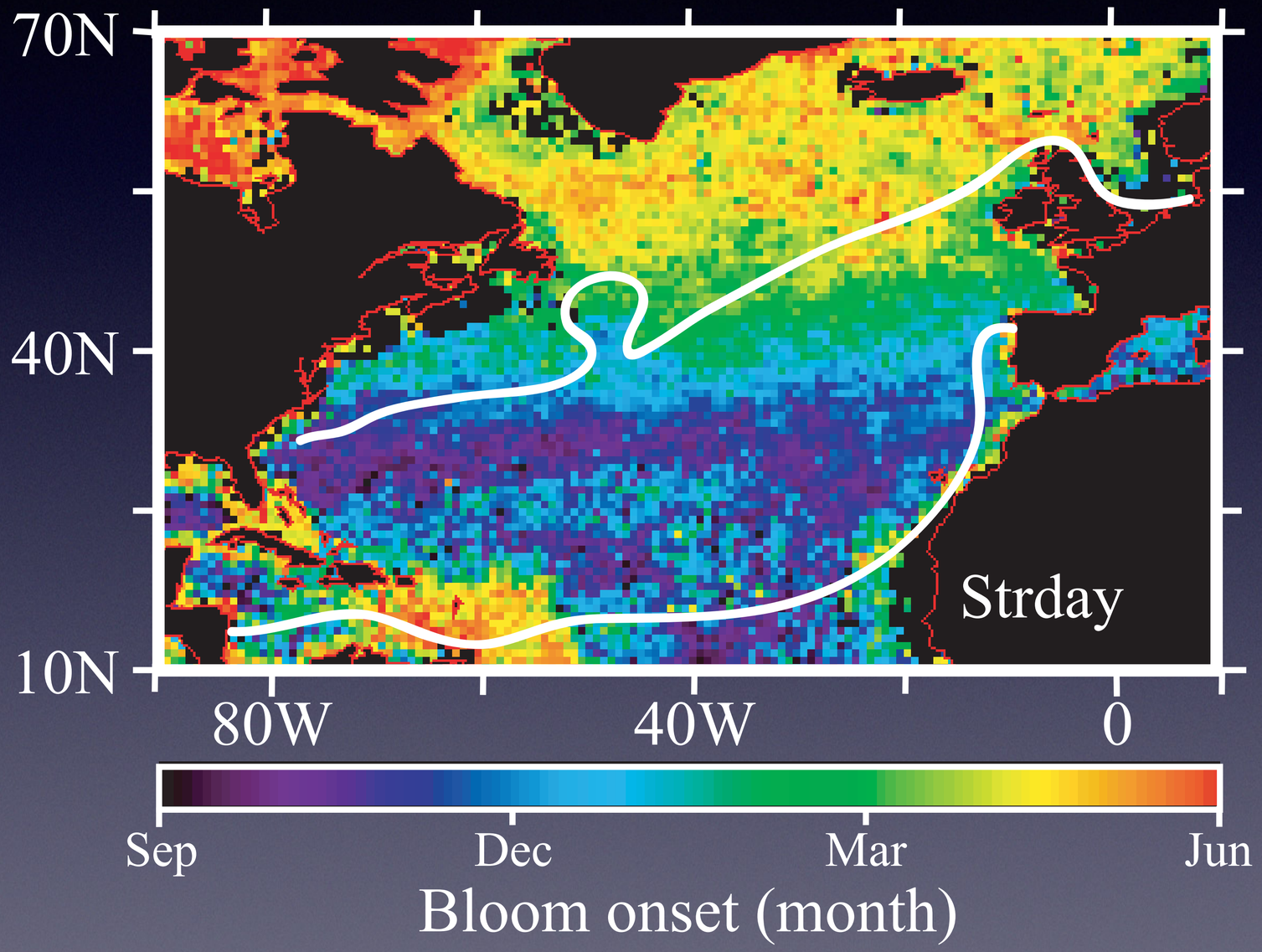


Observations And Analysis…

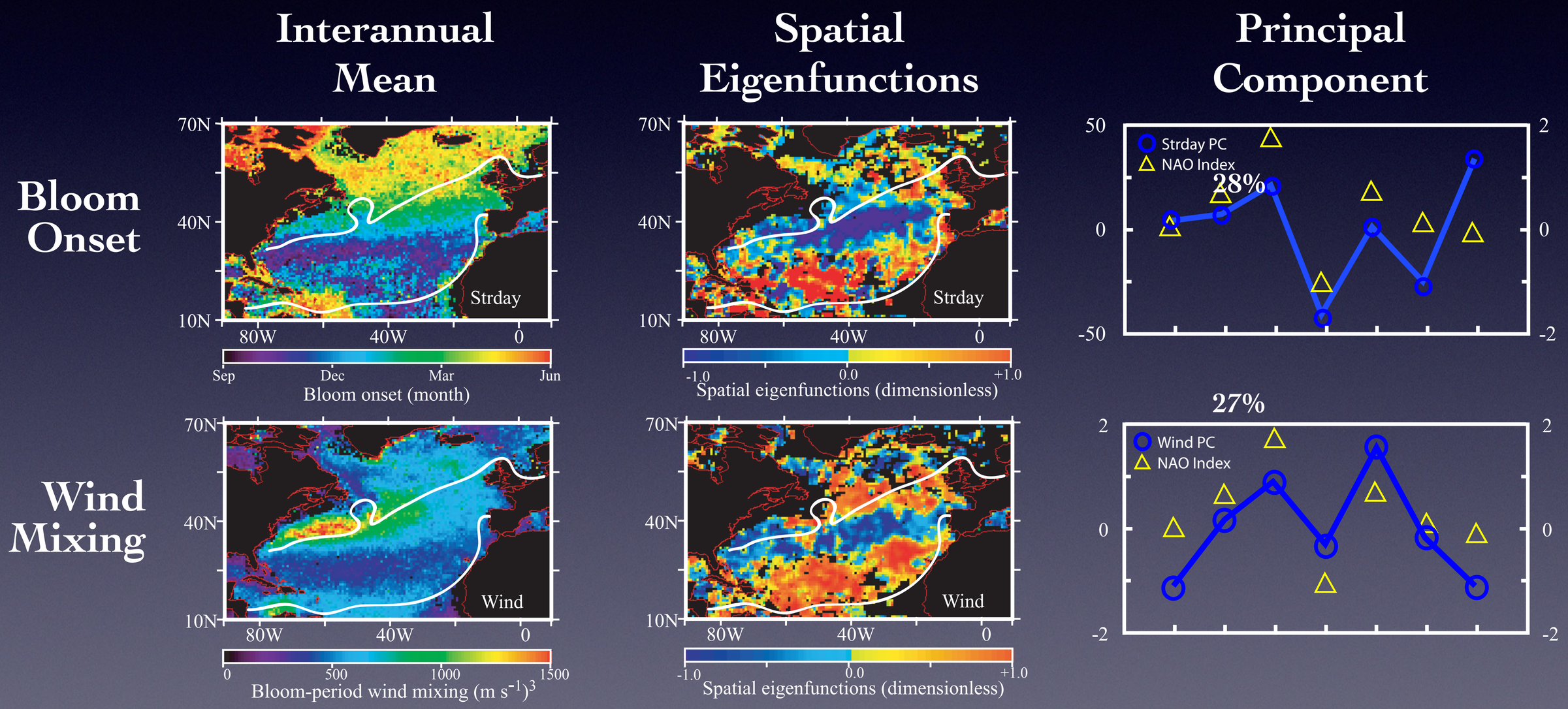
Data Methods...



Timing of Seasonal Bloom Onset: Mean Pattern (1998-2004)



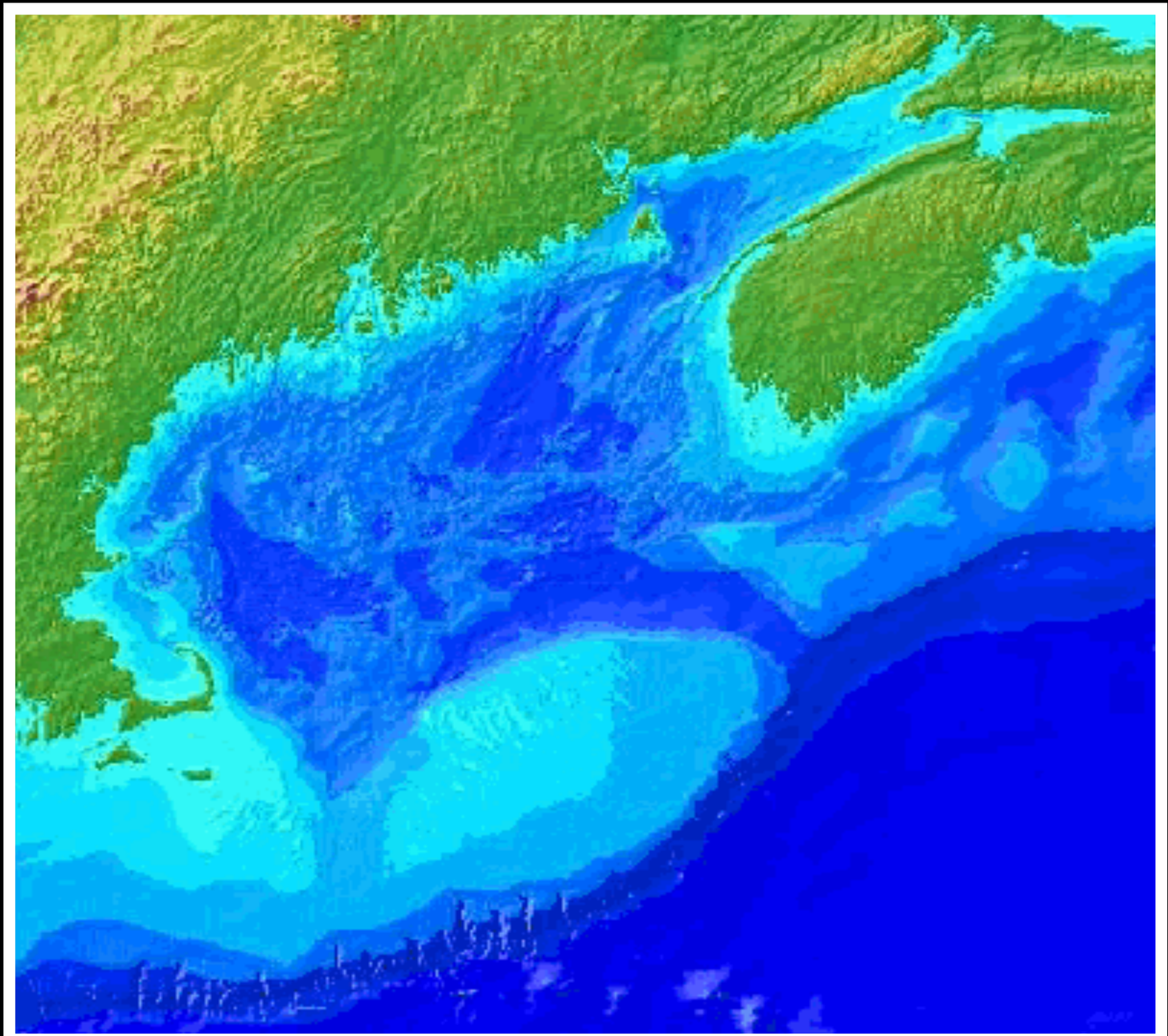
Interannual *Variability* in the Timing of Bloom Onset From EOF Analysis



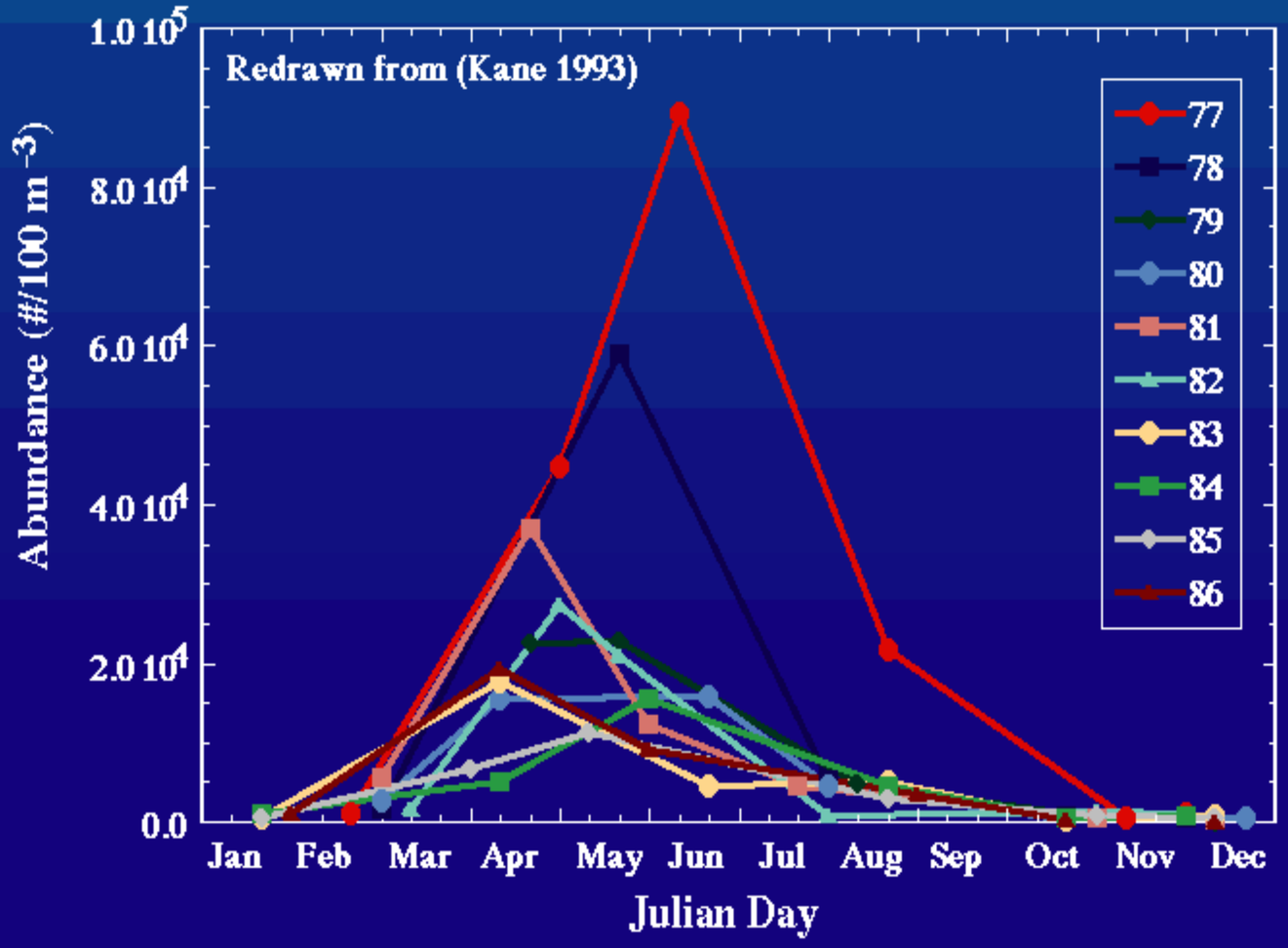
Regional Scales

1. Zooplankton Dynamics in the Gulf of Maine
2. Ecosystem Monitoring

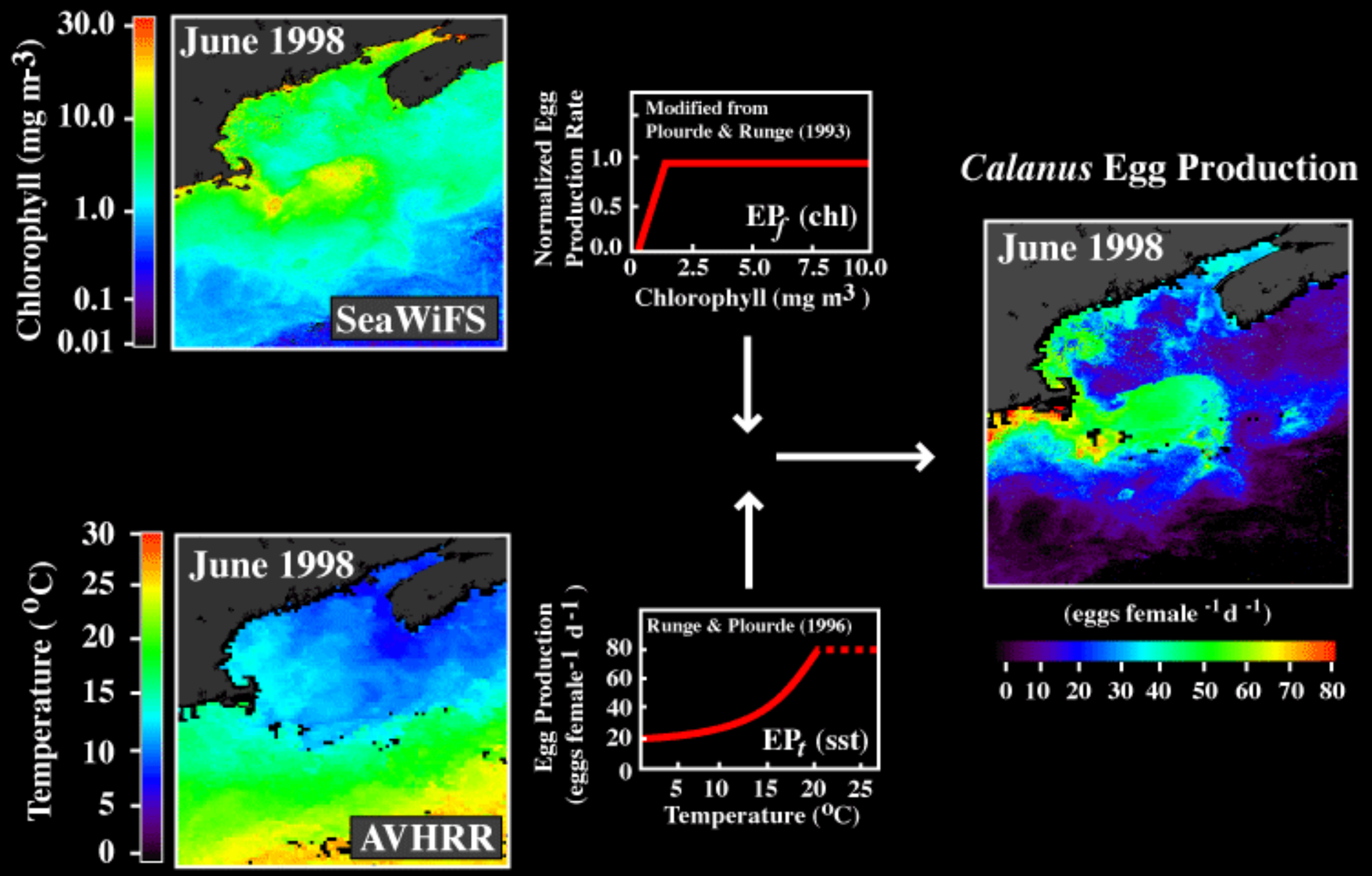
Bathymetry of the
Gulf of Maine Region



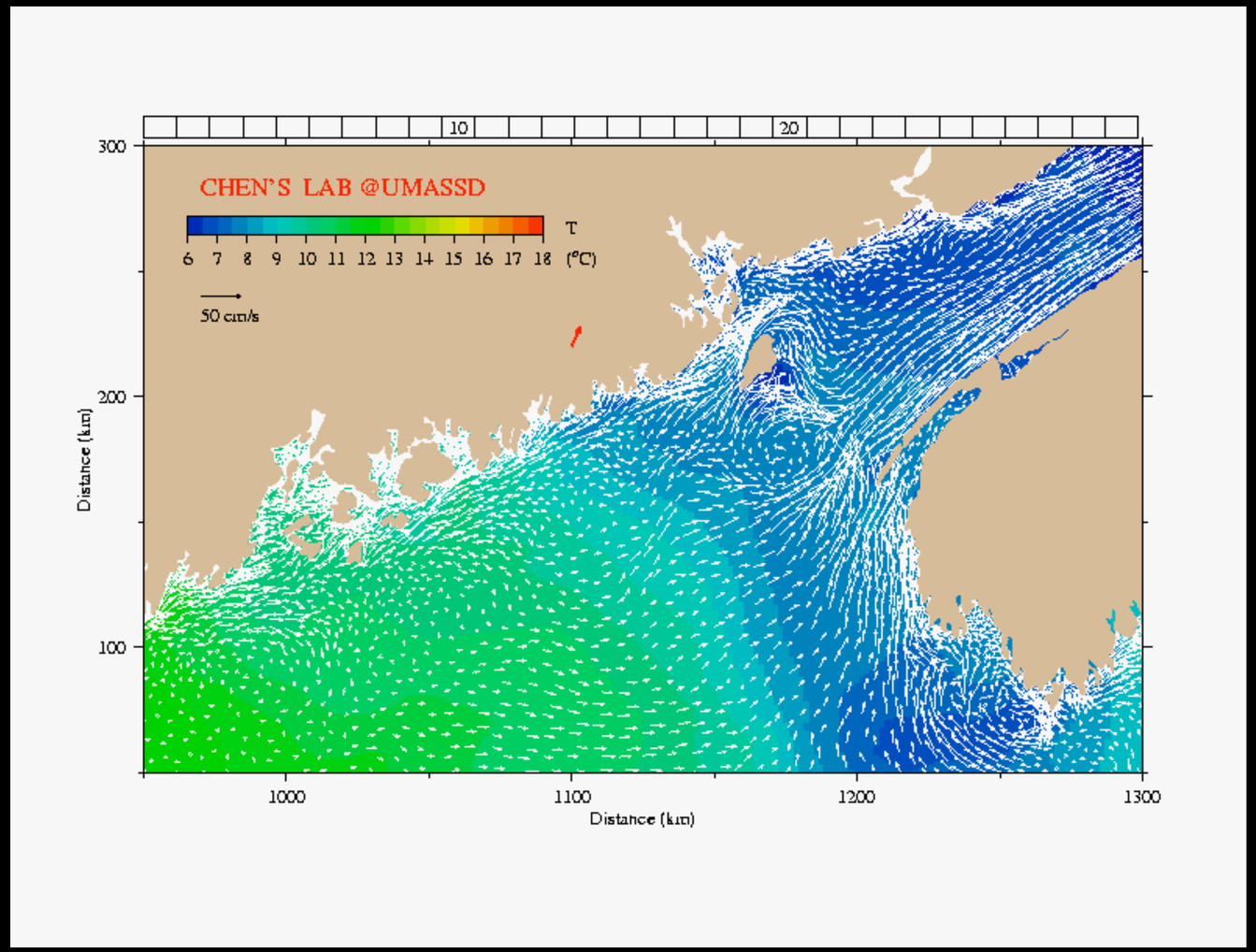
Interannual Variability in *Calanus* Abundance over Georges Bank (1977-1986)



Computing Egg Production Rates from SST and Chlorophyll Satellite Products

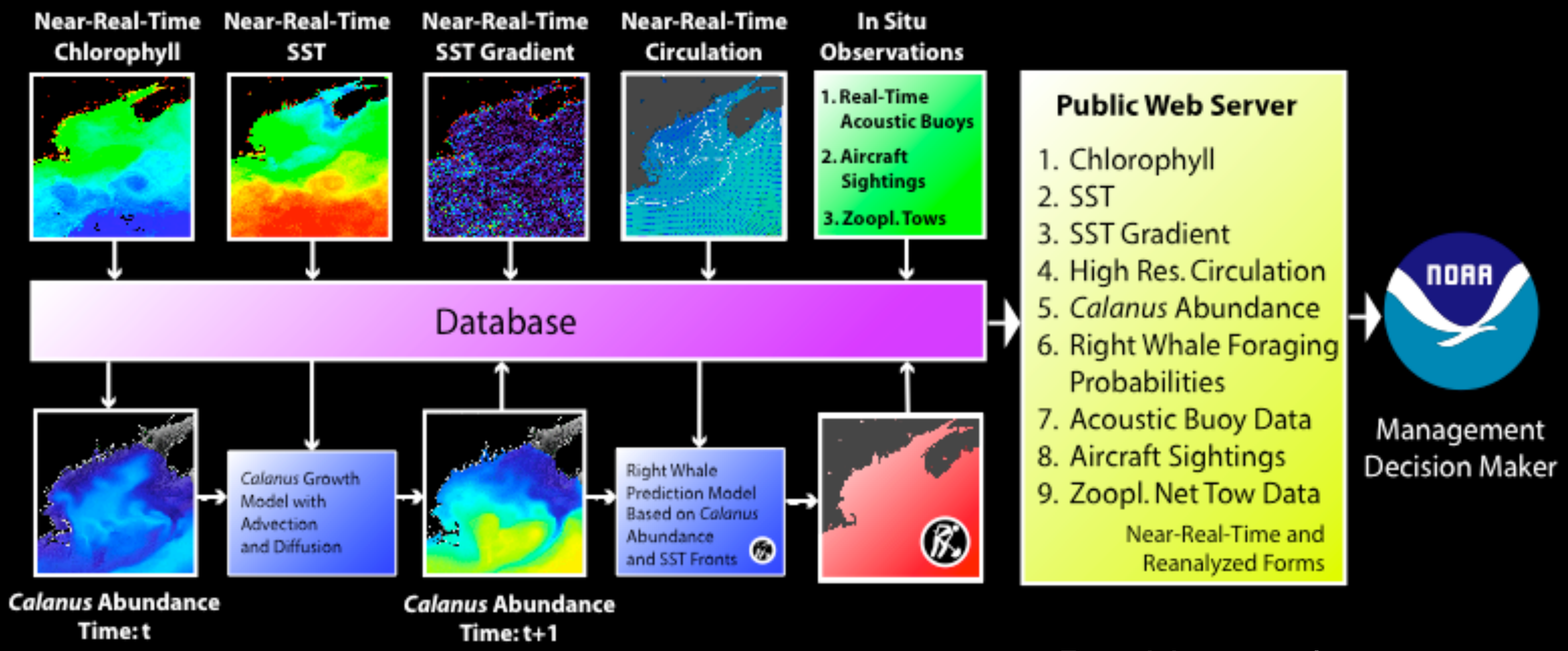


High Resolution Flow Fields using Finite-Volume Coastal Ocean Circulation Model (FVCOM) Forced with the Fifth-Generation Mesoscale Regional Weather Model (MM5)



Changsheng Chen

Schematic of How Environmental Data and Model Predictions of Right Whale Foraging Areas Will be Delivered to NOAA Decision Makers in Near-Real-Time



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