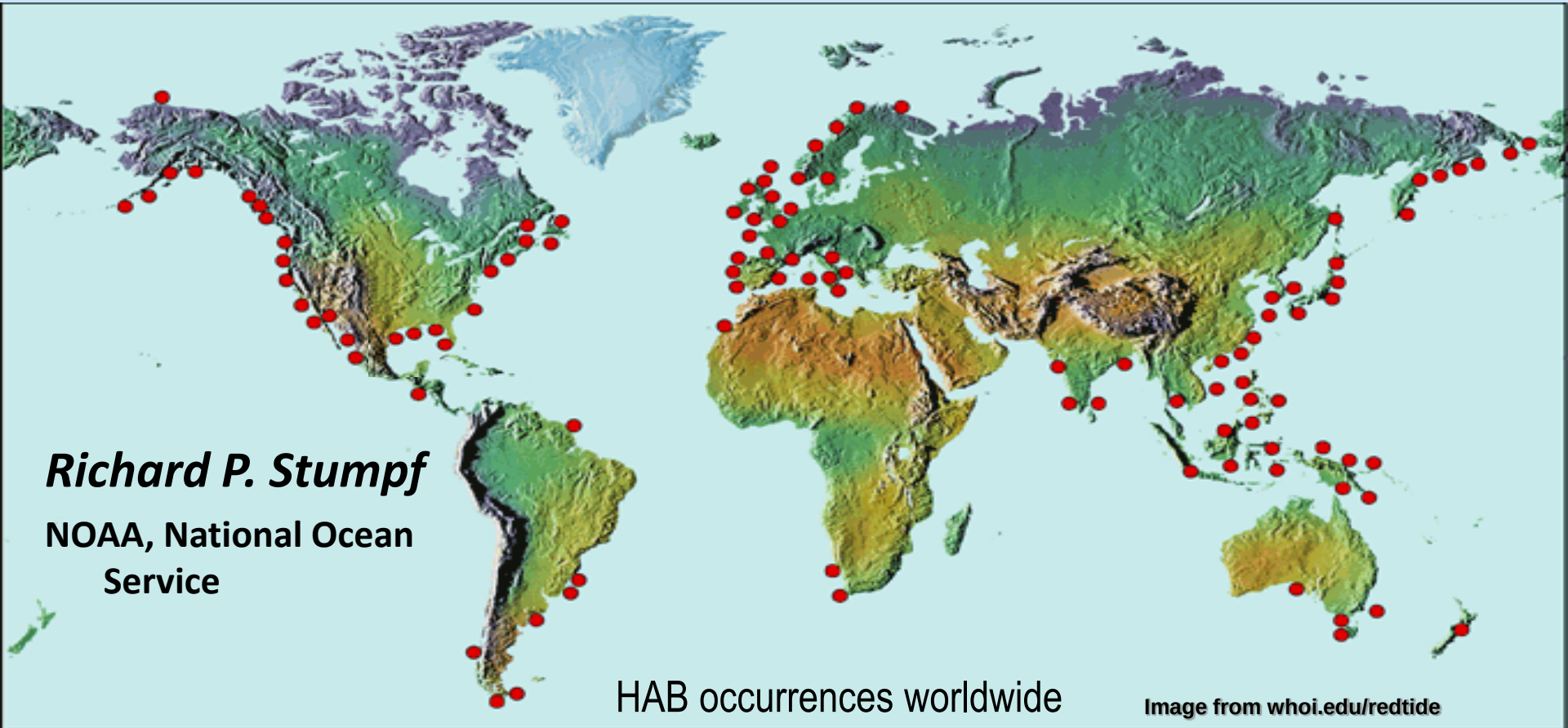


Harmful Algal Blooms (HABs)



Impacts of Harmful Algal Blooms

- Molluscan shellfish losses
- Fish kills (threat to aquaculture)
- Endangered species
- Tourism
- Public health
- US \$1billion in loss over 10 years
- \$1 Billion industries at risk in east Asia & Europe



Economic impact of HABs

Example in Florida

- Early 1970's estimate: \$20 million
- The 1995-96 red tide problem cost Florida "at least double that amount."
- Economic study: \$6.5 million *per month* in one county (Larkin et al.). Typical bloom 3-5 counties/ 2-4 months
- Loss of fish and shellfish: \$6 million dockside for clams and oysters in 2002-2003 (Florida Department of Agriculture.)
- Loss of beach usage



World Distribution of Major HAB toxic events

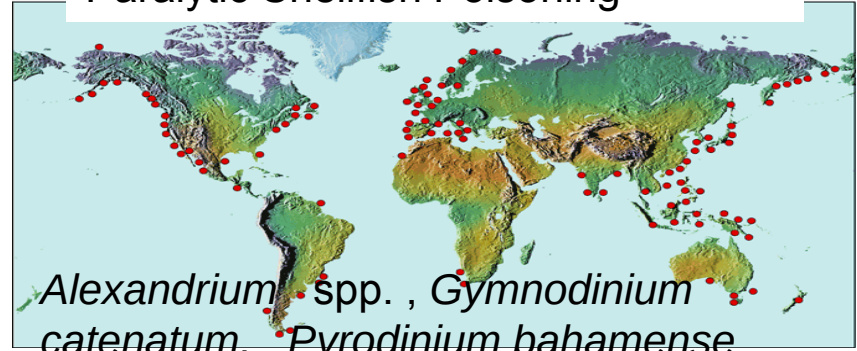
Amnesiac Shellfish Poisoning

• P



Paralytic Shellfish Poisoning

• SP



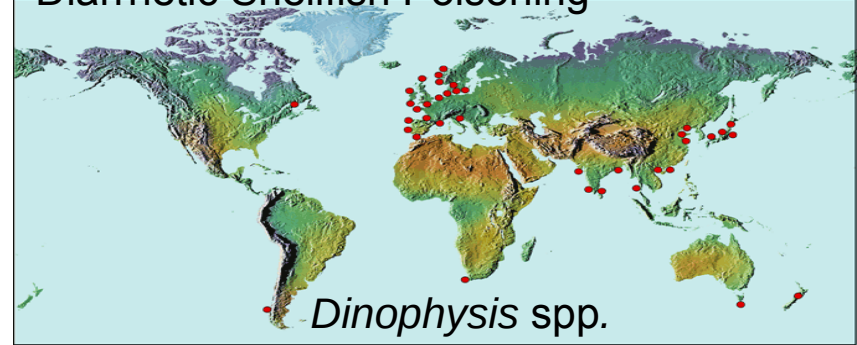
Neurotoxic Shellfish Poisoning

• NSP



Diarrhetic Shellfish Poisoning

• DSP



Some HABs detected with optics or remote sensing

HAB Species	Region	Sensing Type	Impact
<i>Pseudo-nitzschia spp.</i>	Upwelling regions	SST, chlorophyll	ASP, variable
<i>Karenia brevis</i>	Gulf of Mexico	Chlorophyll, optical ratio, absorption spectra	NSP, respiratory, fish toxin
<i>Karenia mikimotoi</i>	Coastal ocean (Hong Kong, Ireland, New Zealand)	SST chlorophyll	NSP
<i>Gymnodinium catenatum</i>	Estuaries, coastal ocean, upwelling	SST chlorophyll	PSP
<i>Alexandrium spp.</i>	Coastal ocean (Gulf of Maine, Gulf of Alaska)	SST	PSP
<i>Gonyaulax</i>	Upwelling regions	Chlorophyll, possible UV absorption	Fish toxin
<i>Cochlodinium</i>	Coastal ocean (British Columbia, Korea)	SST, color	Shellfish toxin
<i>Nodularia, Microcystis</i>	Enclosed Brackish	Color	Hepatotoxin

Other major HABs not clearly monitored with remote sensing

<i>Dinophysis</i>	Ireland, Portugal, Norway	Maybe SST However optical in situ	Shellfish toxin

First Ocean Color of an algal bloom, NIR, 1974

letters to nature

Nature **250**, 213 - 214 (19 July 1974); doi:10.1038/250213a0

Remote sensing and lake eutrophication

ROBERT C. WRIGLEY^{*} & ALEXANDER J. HORNE[†]

AN infrared photograph of part of Clear Lake, California (Fig. 1) shows beautiful, complex patterns of blue-green algal blooms which were not observed by conventional limnological techniques. Repeated observations of patterns such as these can be used to chart the surface movement of these buoyant algae and can also be used to help control algal scums in eutrophic lakes.

Satellite biological “oceanography” started with Landsat

Boland, DHP | Blackwell, RJ, 1975, The LANDSAT-1 Multispectral Scanner as a Tool in the Classification of Inland Lakes (among others) in:
Proceedings of the NASA Earth Resources Survey Symposium June 1975,
Technical Session Presentations, Agriculture-Environment, Volume I-A. Report
No. NASA TM X-58168. Symposium held June 9-12, 1975, Houston, Texas

B. Öström of SMHI used Landsat MSS in 1975 (Öström, B., Fertilization of the Baltic by nitrogen-fixation in the blue-green alga *Nodularia spumigena*.
Remote Sensing of Environment, 4, 305-310, 1976)

Horstmann U. (1975) Eutrophication and mass occurrence of blue-green algae in the Baltic. *Merentutkimuslait. Julk./Havsforskningsinst Skr.* 239:83–90

Satellite Ocean Color and HABs, *the image*

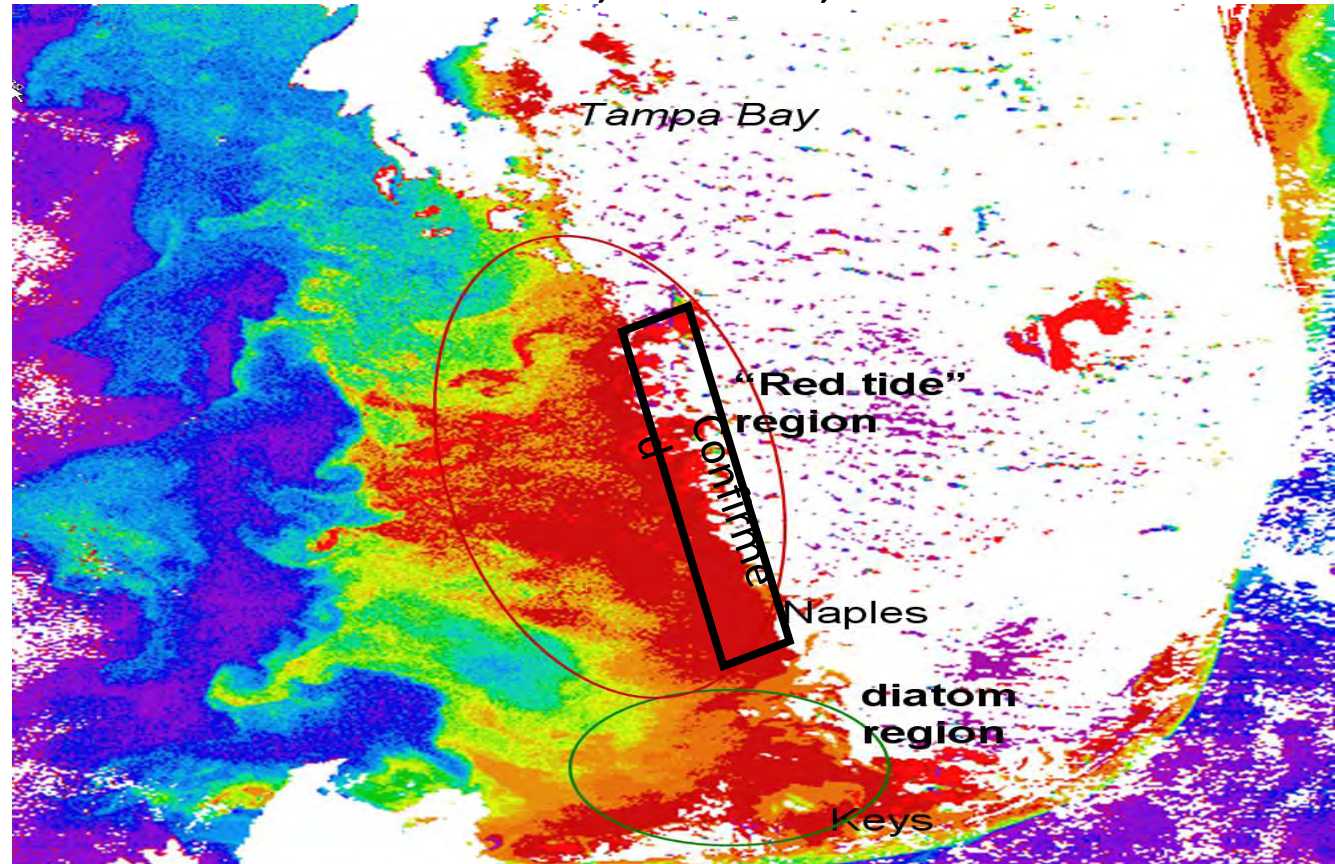
Coastal Zone Color Scanner, Nov 14, 1978

“Red Tide” HAB of *Karenia brevis*

(then *Gymnodinium breve*)

Demonstrated the potential value of ocean color (Used by **Steidinger and Haddad, 1981**)

(a year earlier Jim Mueller flew CZCS simulator over Florida “red tide”)



What is “Harmful”?

Are they **Toxic, Noxious, or Nuisance?**

- Phycotoxins (direct and indirect effects) many species
 - Most critical, public health, aquaculture
- Mechanical (irritation) *Chaetoceros*
 - Fisheries
- Starvation *Aureococcus*
 - Scallops, etc.
- Physical (secretions interfering with fish) *Chatonella*
 - Aquaculture
- NH_4 toxicity (*Noctiluca*)
- Anoxia (Many species, depends on concentration and mixing)

Karenia brevis, Florida > 500,000 cells L^{-1}

What is a “Bloom”?

- 1) An increase in concentration of the organism
- 2) If harmful, a persistent high concentration

A species does not have to achieve high biomass, or high population densities to be in a bloom state
(Smayda, 1997)

Only a few thousand cells/L can cause toxicity in shellfish (e.g. *Alexandrium fundyense*, *Karenia brevis*)

What is a “Bloom”?

- 1) Microcystis, Microcystin levels (20 $\mu\text{g/L}$ in recreational water (WHO) for adults; 1 $\mu\text{g/L}$ in drinking water (extremely rare in properly treated water; chlorine is effective on microcystin)
 - 1) Practical, 10^5 cells/mL If harmful, a persistent high concentration
- 2) Karenia 10^3 cells/L
- 3) Saxitoxin, mouse bio-assay, also 80 $\mu\text{g}/100\text{ g}$
- 4) Domoic acid, 20 ppm, mouse bio-assay

Mouse bio-assay, saxitoxin: A mouse unit is the amount necessary to kill a 20 g mouse in 15 minutes with 1 ml of extract. (Nollet, Handbook of Water Analysis)

Ecological Conditions

Many types of blooms. Broad categories

Dinoflagellates, calmer conditions, occur in “succession” after diatoms.
Why? Diatoms grow fast, dinos don't; dinos can swim vertically to nutrients.
(This applies to other flagellates also)

Cyanos, calm and warm. Calm favors species that float, calm water removes diatom competitors

Diatoms: Pseudo-nitzschia species, toxin on US west coast, linked to upwelling phenomena, recent for toxicity is debated, linked to micro-nutrients.

Ecological Conditions

Dinoflagellates concentrate at fronts, so dense concentrations are possible (potential for other flagellates).

Cyanos concentrate near surface (if they float), concentrate at shore and at fronts.

Diatoms: must grow to concentration.

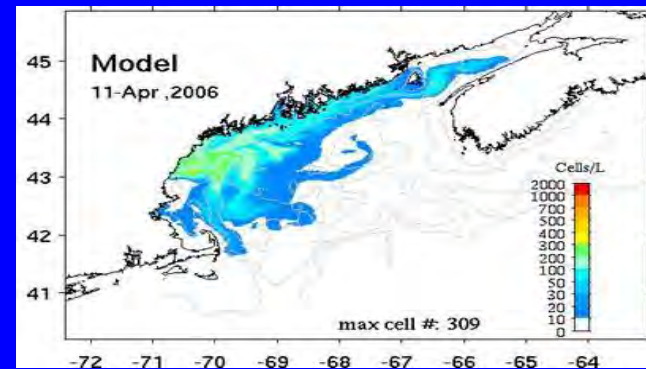
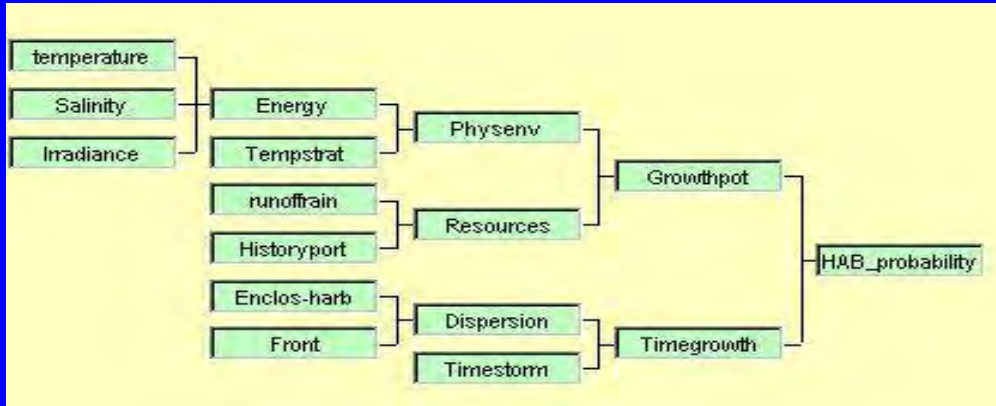
Ecological Models

- 3-D Hydrodynamic/Ecological
- e.g. Gulf of Maine model, has ecological initiation from
- cysts (then used as a transport model)

No optics (cannot see *Alexandrium*)

Heuristic (expert “fuzzy” logic)

e.g. HABES project (*Alexandrium* inputs)



3-D: Norway moncoze model for flagellates (*Chatonella*, however not useful for major *Alexandrium* and *Dinophysis*)



Research vs Operational

Research	Operations
Case Study	Current problem
Develop Algorithm	Apply algorithm
Hindcast, selective validation	Real-time validation
Months for analysis	Days for analysis
Best imagery	Available imagery

Exercise

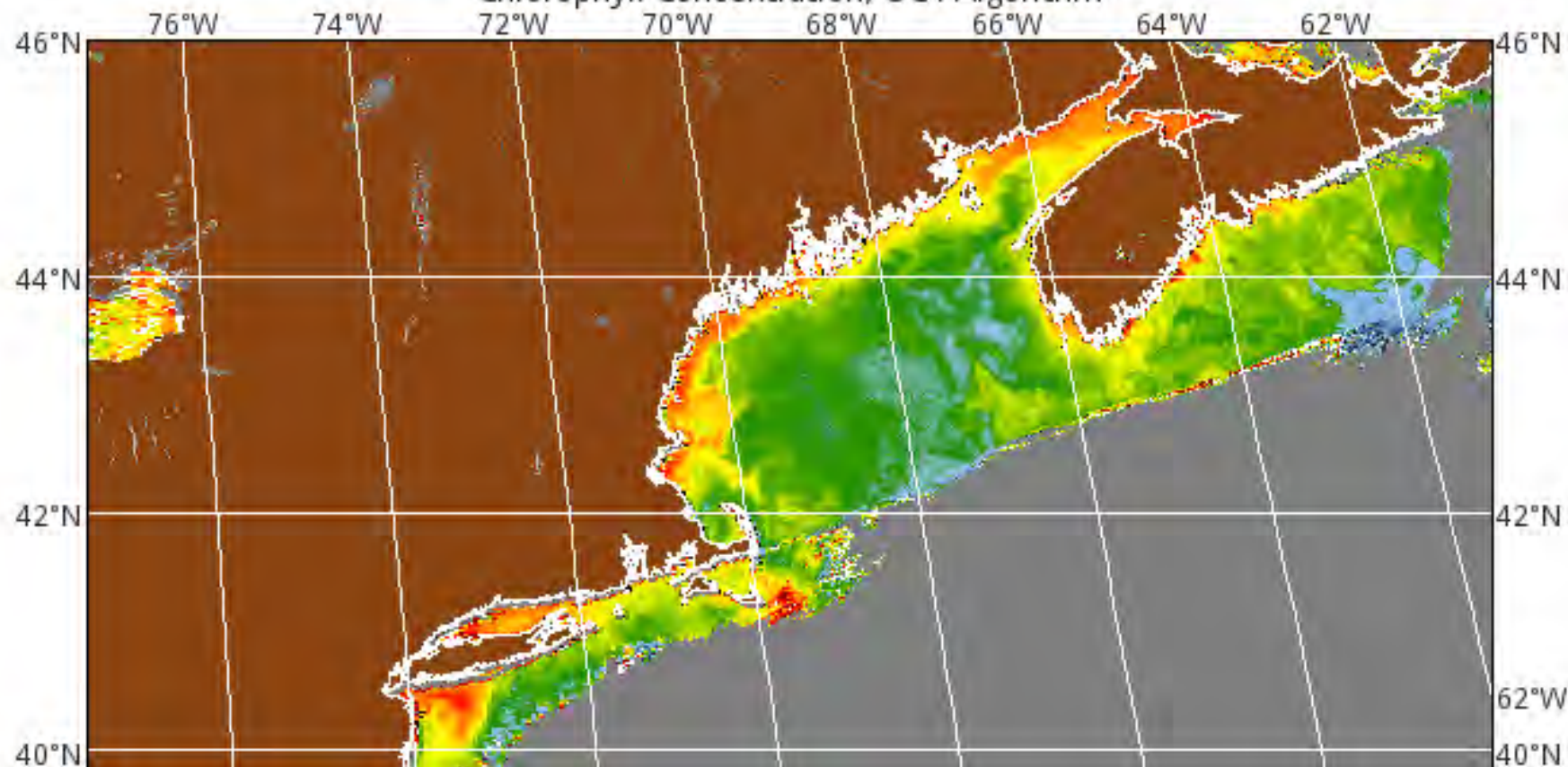
Late May. You have just started working at the University of Maine. A severe red tide has been reported in the western Gulf of Maine, starting in mid-May.

What is your plan of action?

Images are provided.

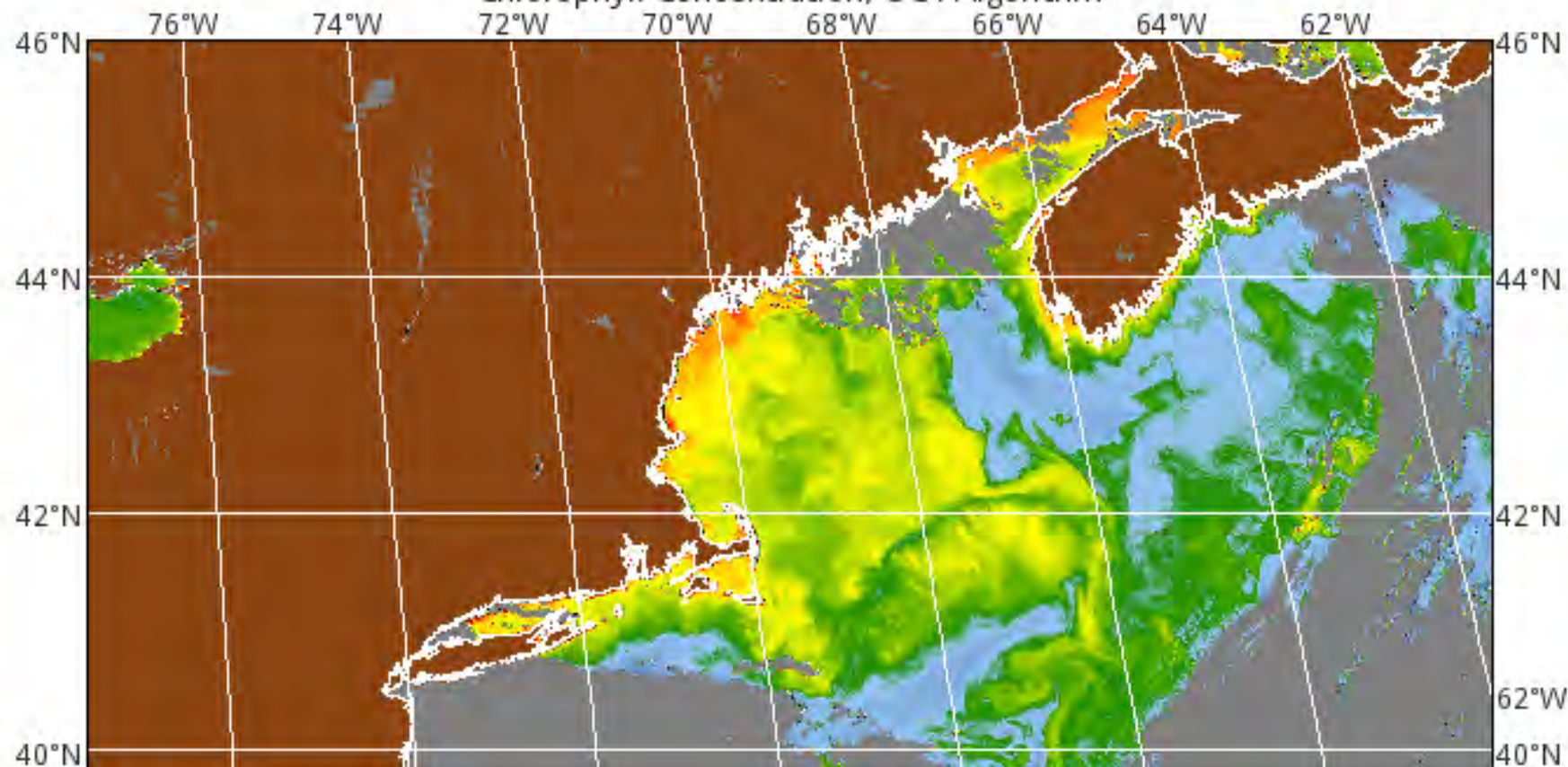
orbview-2.2005099.0409.165814.D.L3.seawifs.NE1.v09.1100m.hdf Sat Apr 9 16:58:14 2005

Chlorophyll Concentration, OC4 Algorithm



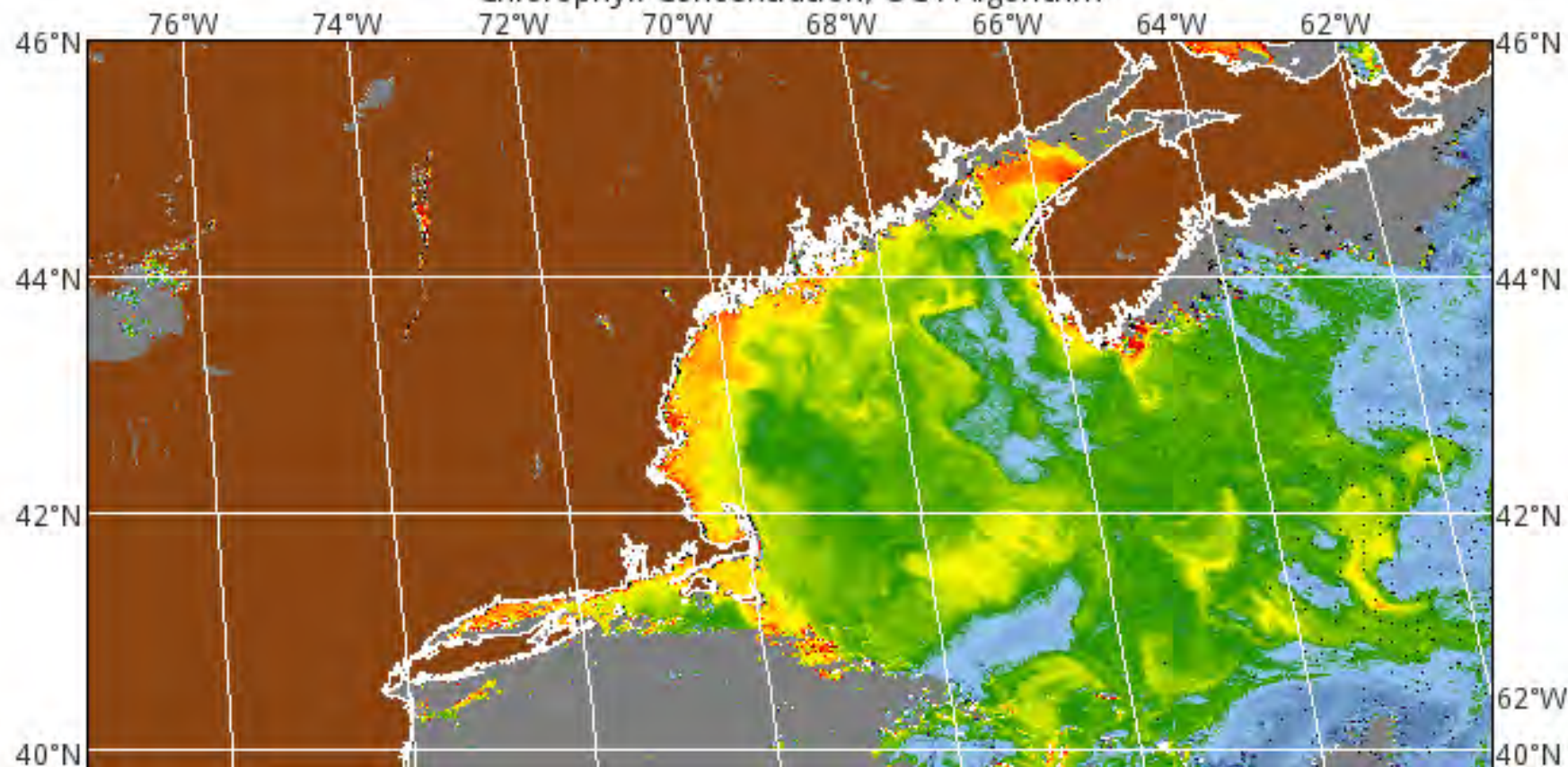
orbview-2.2005119.0429.172057.D.L3.seawifs.NE1.v09.1100m.hdf Fri Apr 29 17:20:57 2005

Chlorophyll Concentration, OC4 Algorithm



orbview-2.2005125.0505.180643.D.L3.seawifs.NE1.v09.1100m.hdf Thu May 5 18:06:43 2005

Chlorophyll Concentration, OC4 Algorithm



orbview-2.2005132.0512.175458.D.L3.seawifs.NE1.v09.1100m.hdf Thu May 12 17:54:58 2005

Chlorophyll Concentration, OC4 Algorithm

