ABRUPT LOSS OF PHYTOPLANKTON BIODIVERSITY IN THE ARABIAN SEA – NEW INSIGHTS FROM THE INDO-US COLLABORATIVE STUDY

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FIELD STUDIES IN THE ARABIAN SEA
MARCH – APRIL 2008

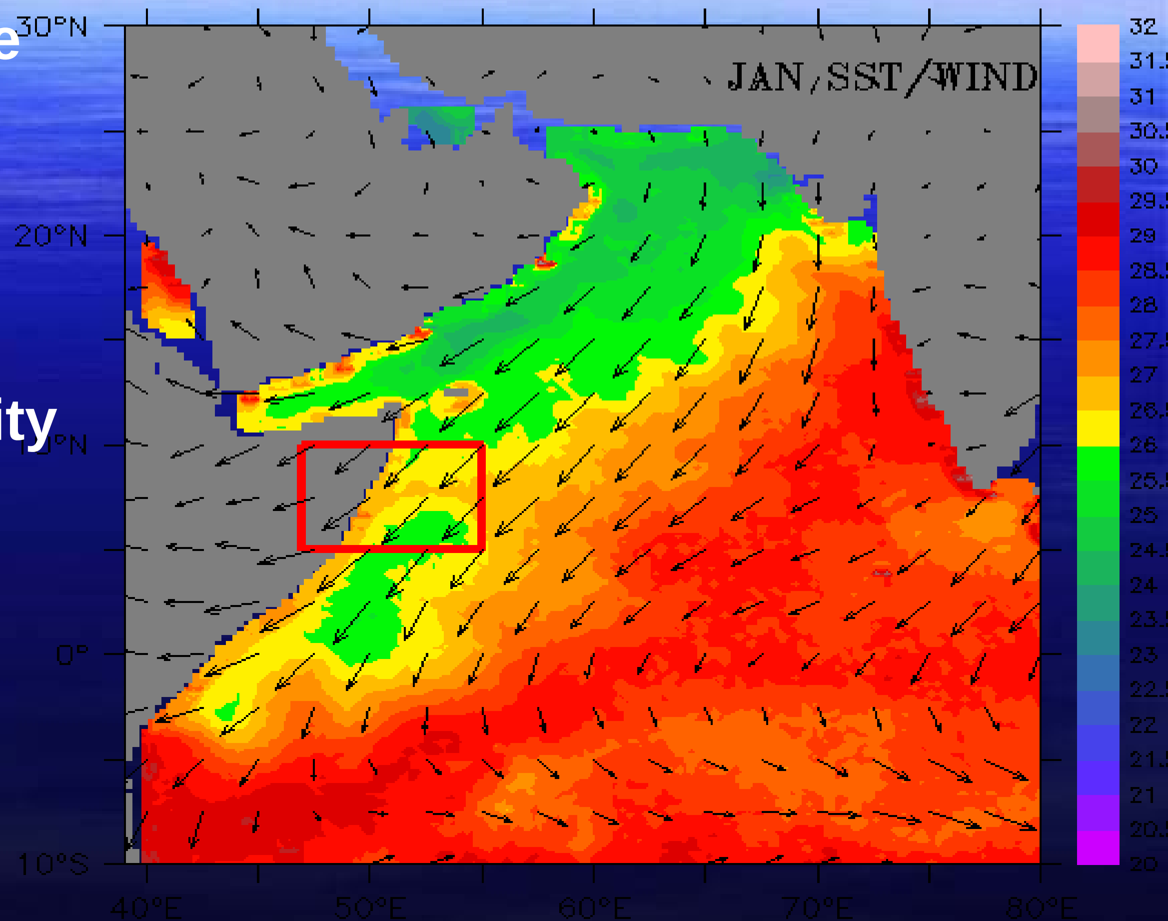
SAGAR KANYA

FORV SAGAR SAMPADA

ARABIAN SEA - A UNIQUE ECOSYSTEM

Comes under the influence of seasonally reversing monsoon winds

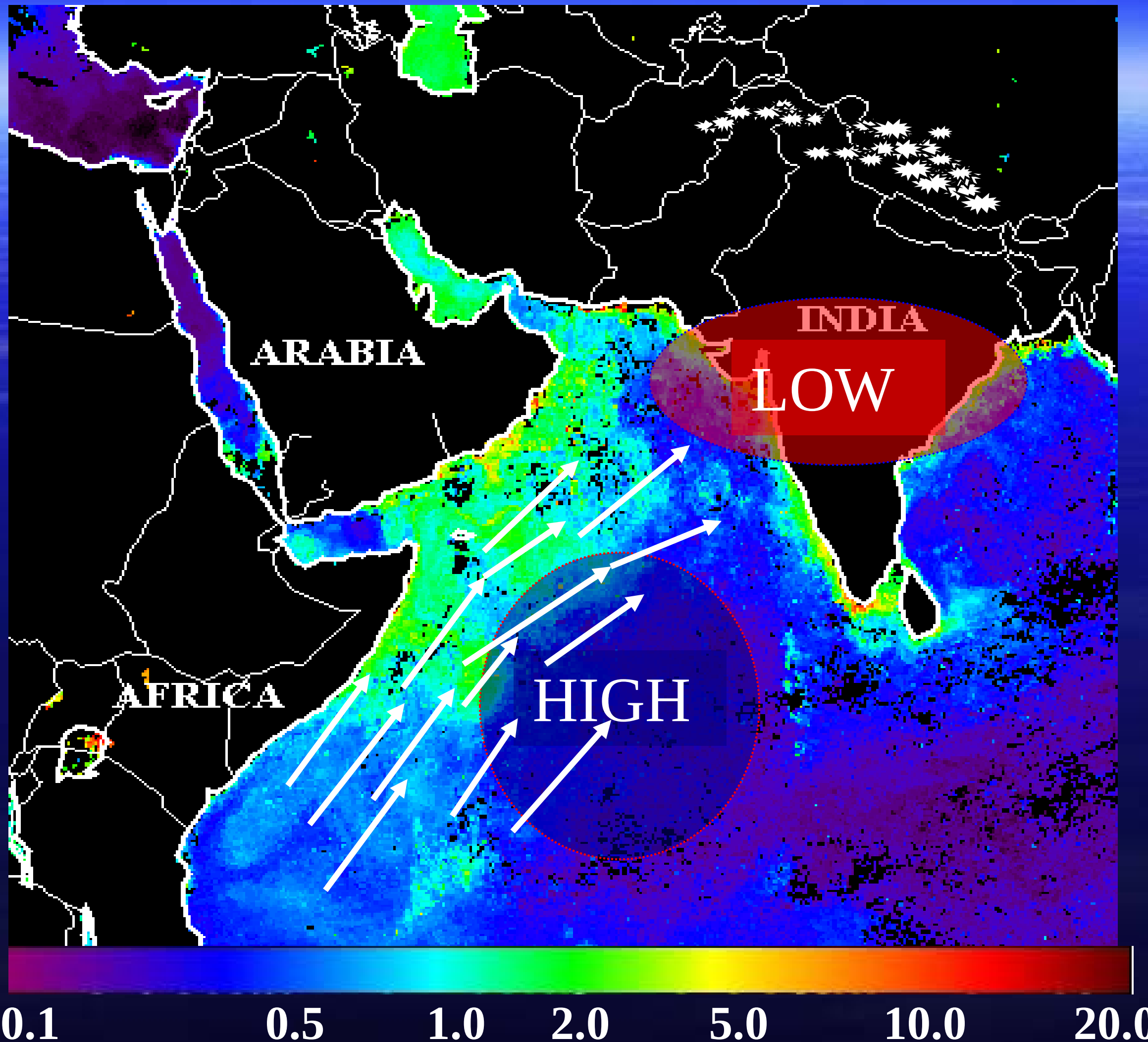
Winds drive one the most energetic current systems and the greatest seasonality in phytoplankton productivity and carbon fluxes observable in all oceans



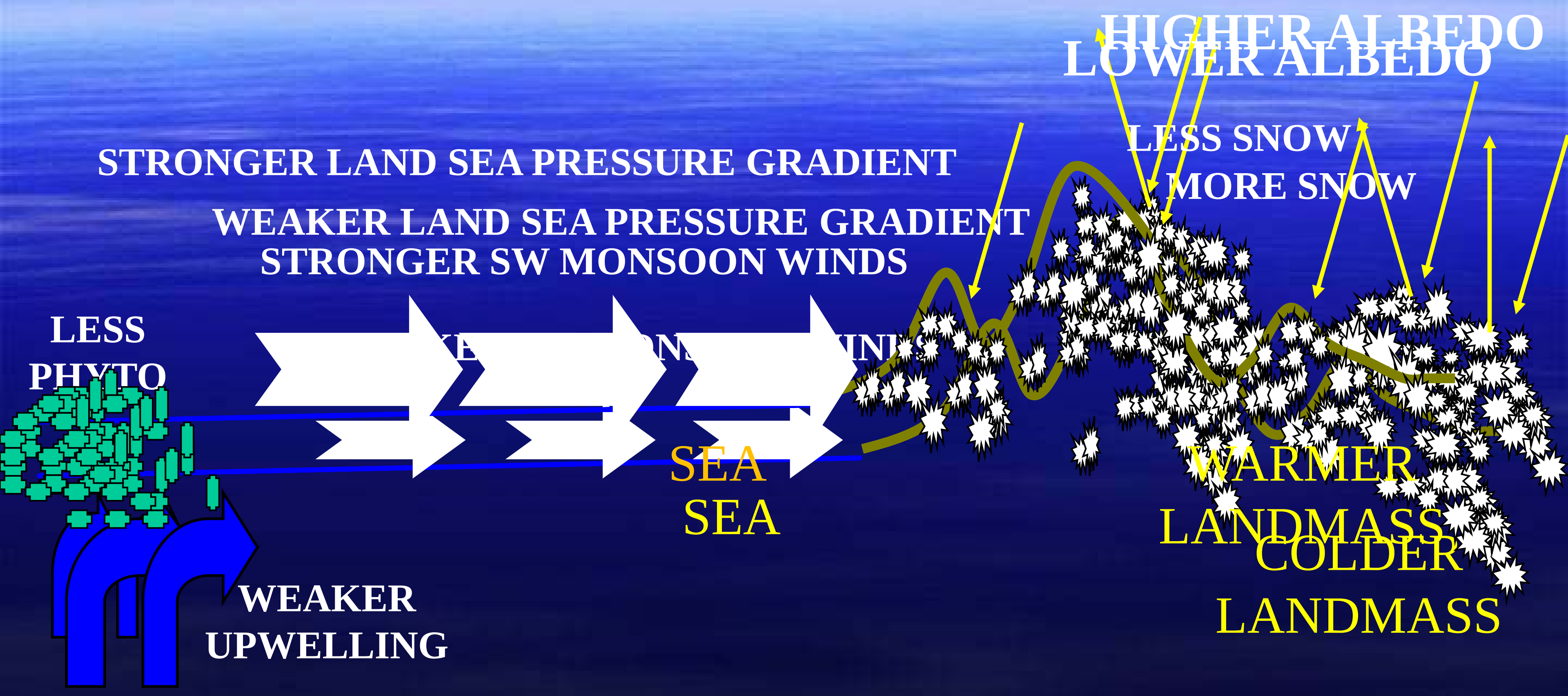
Intensity of winds is regulated by thermal gradient between land and the sea

In the 1990s, the US spent $50M

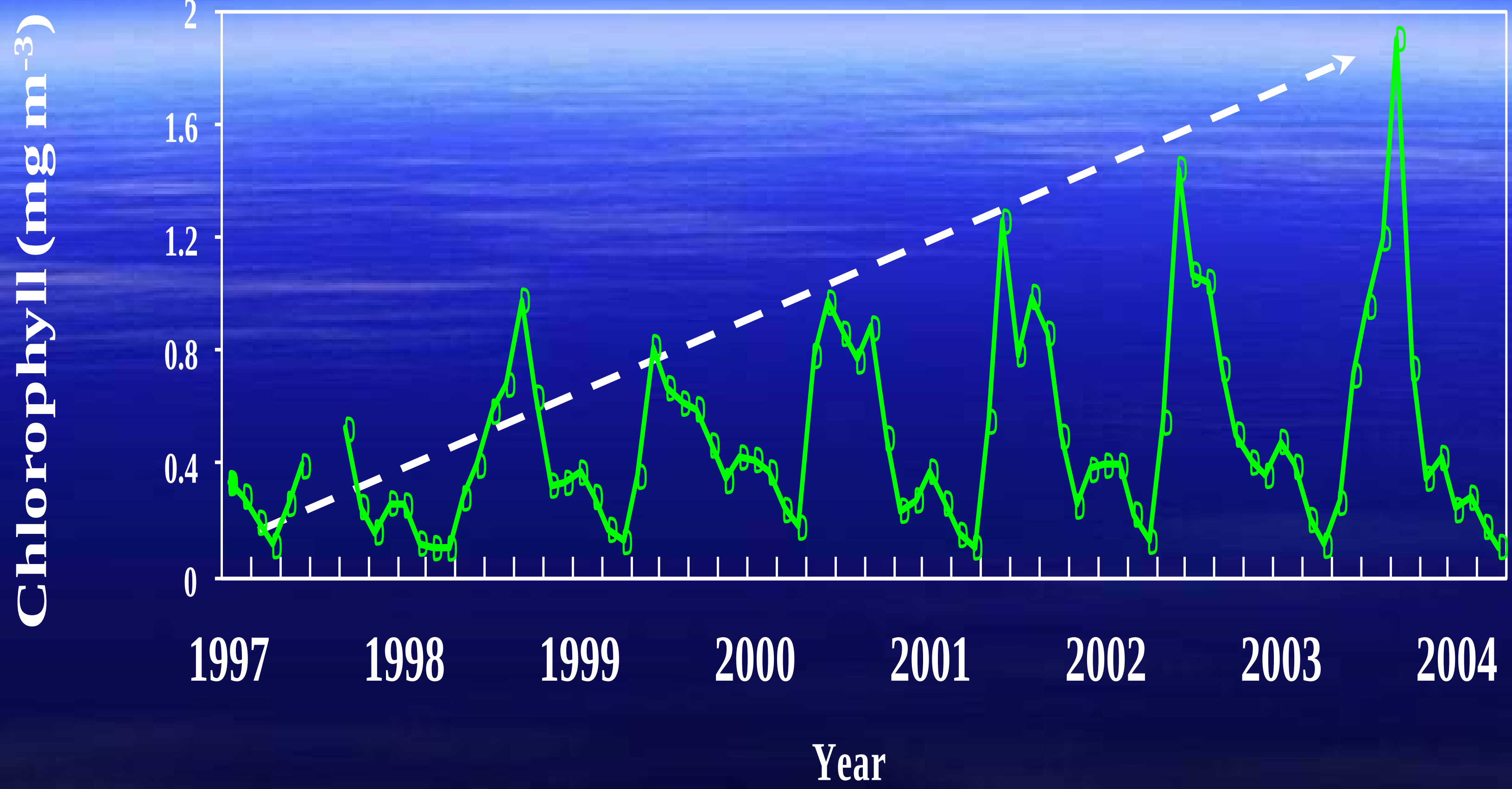
SUMMER MONSOON



Schematic showing the reversal in wind direction during the southwest monsoon (Jun-Sept), superimposed on satellite derived chlorophyll fields

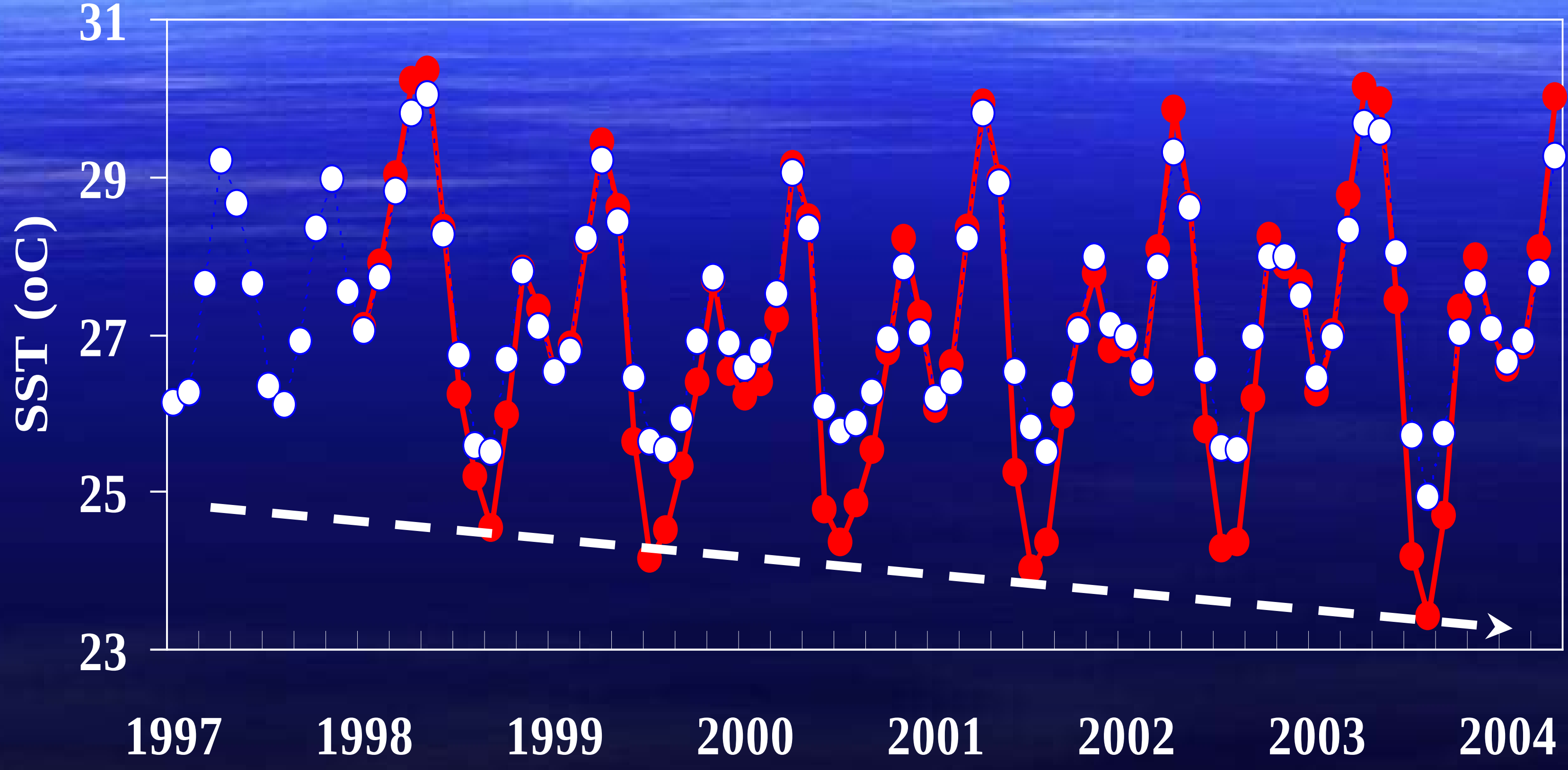


Schematic showing the SW Monsoon response of the Arabian Sea to snow cover over the Himalayan-Tibetan Plateau

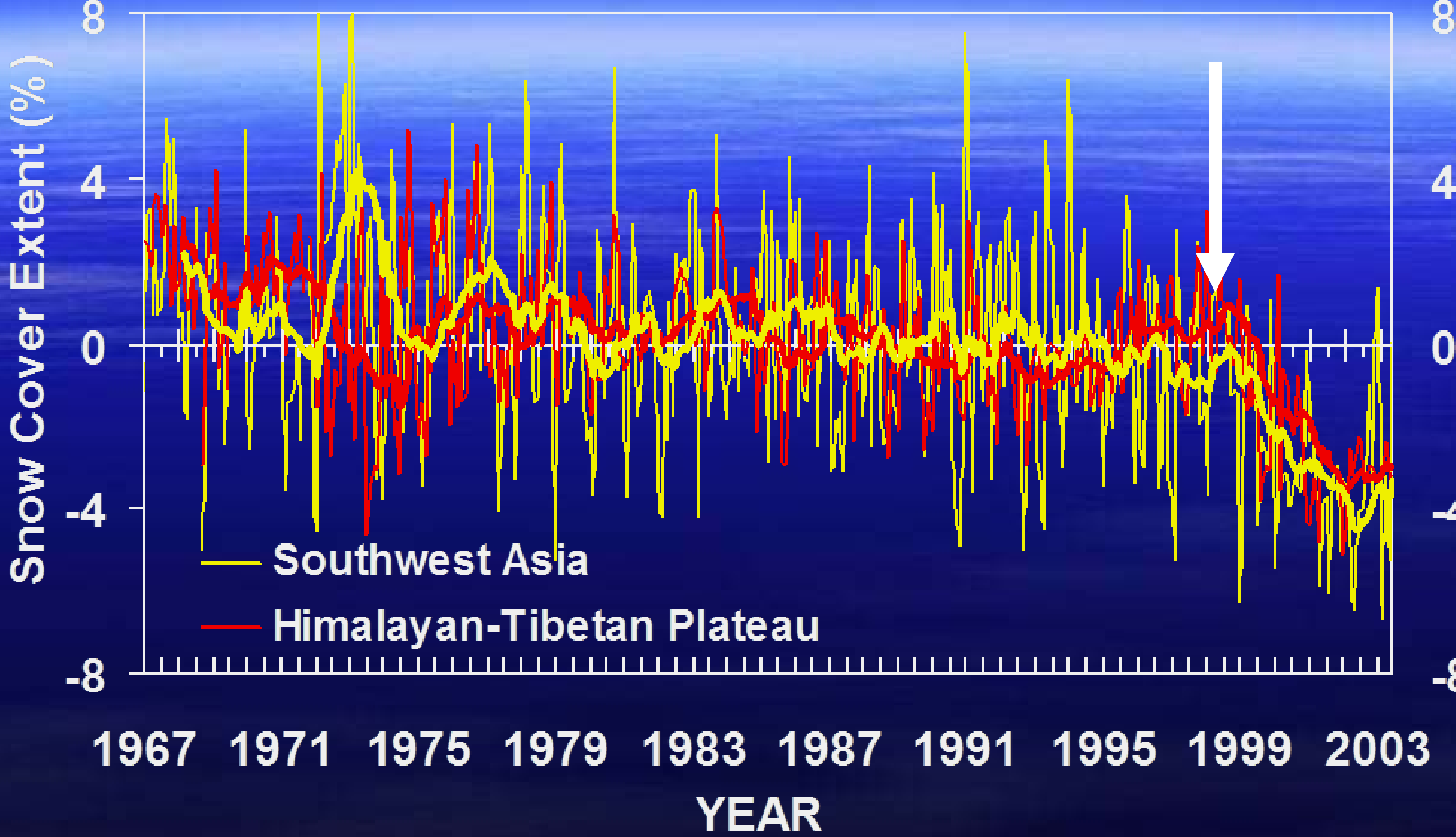


Interannual changes in chlorophyll in the core of upwelling region along coast of Somalia linked to the intensification of SW monsoonal winds

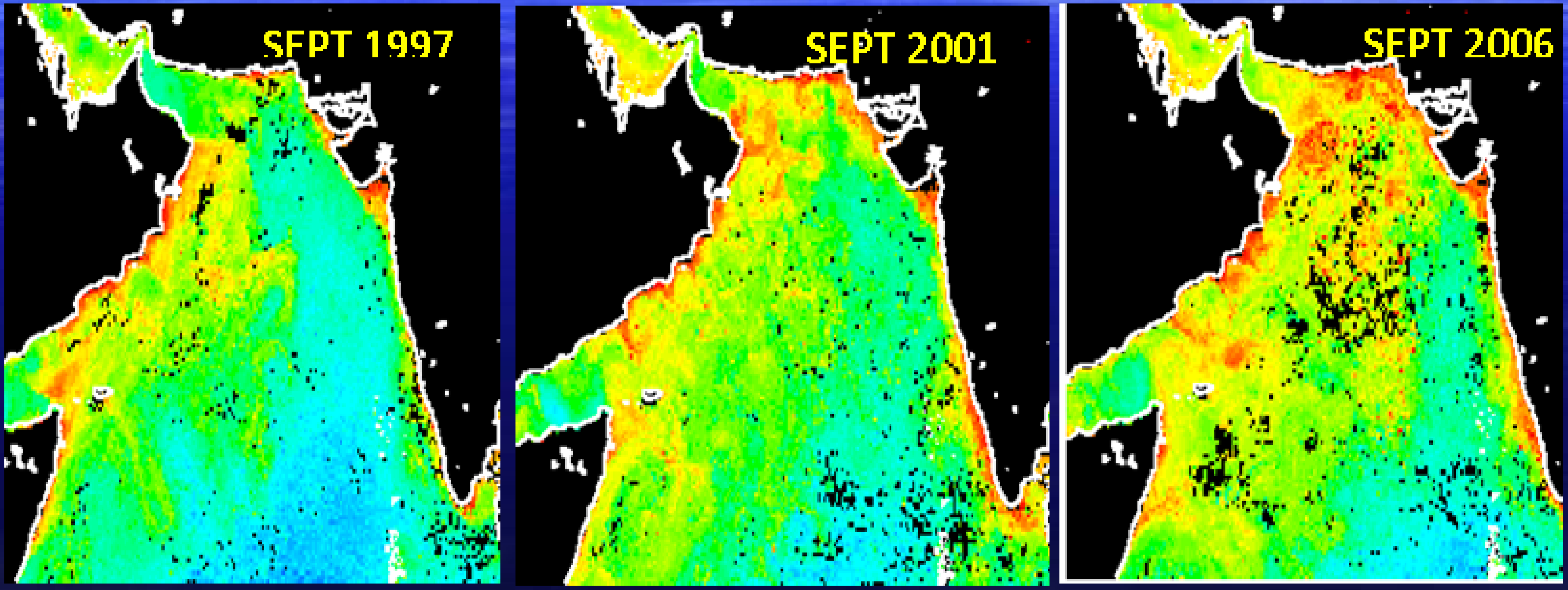
Goes et al. (2005) - Science



Interannual variability in SST along the coast of Somalia

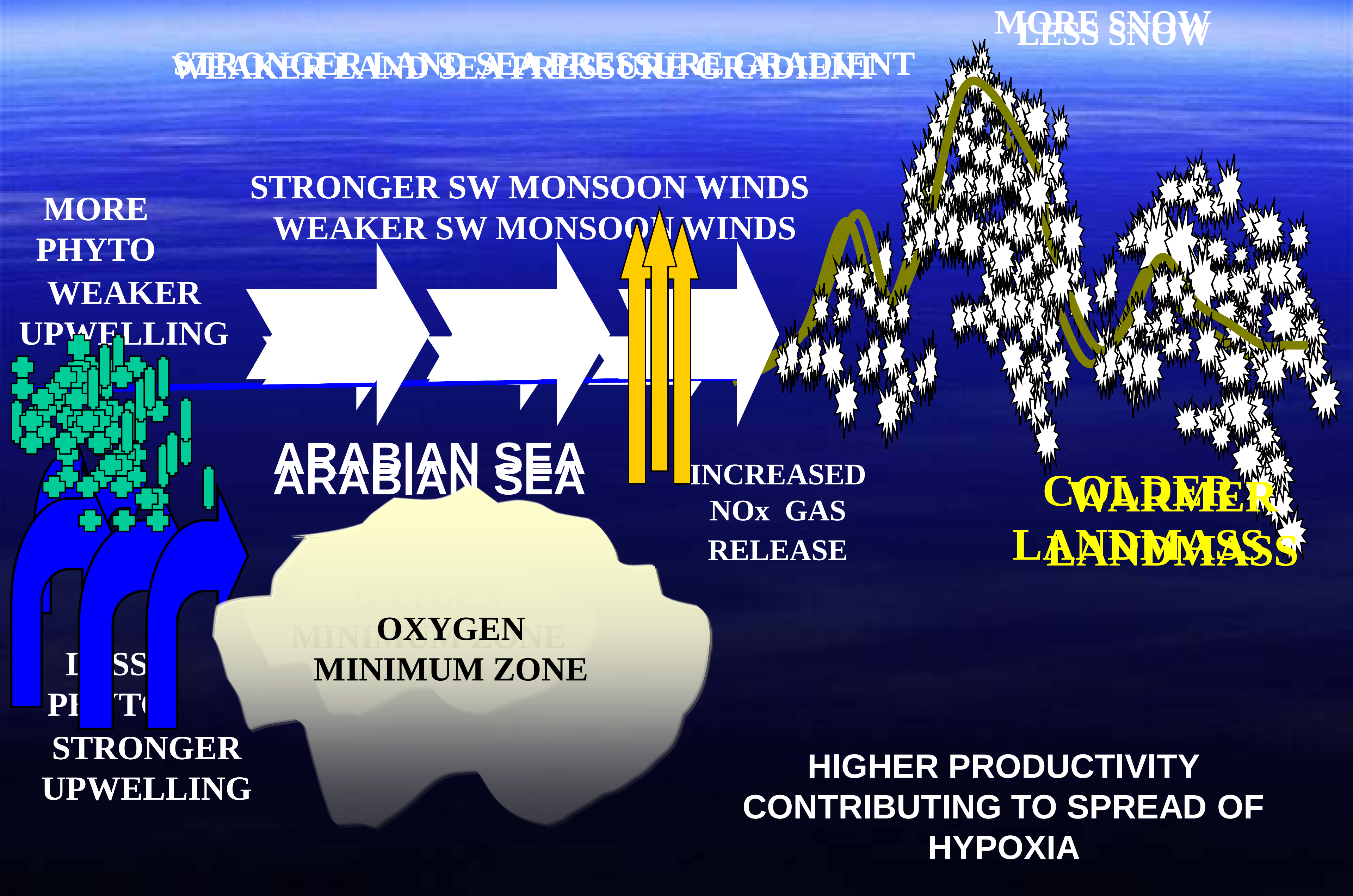


Trend line showing anomalies (departures from monthly means) of snow cover extent over Southwest Asia and Himalayas-Tibetan Plateau between 1967 and 2003.

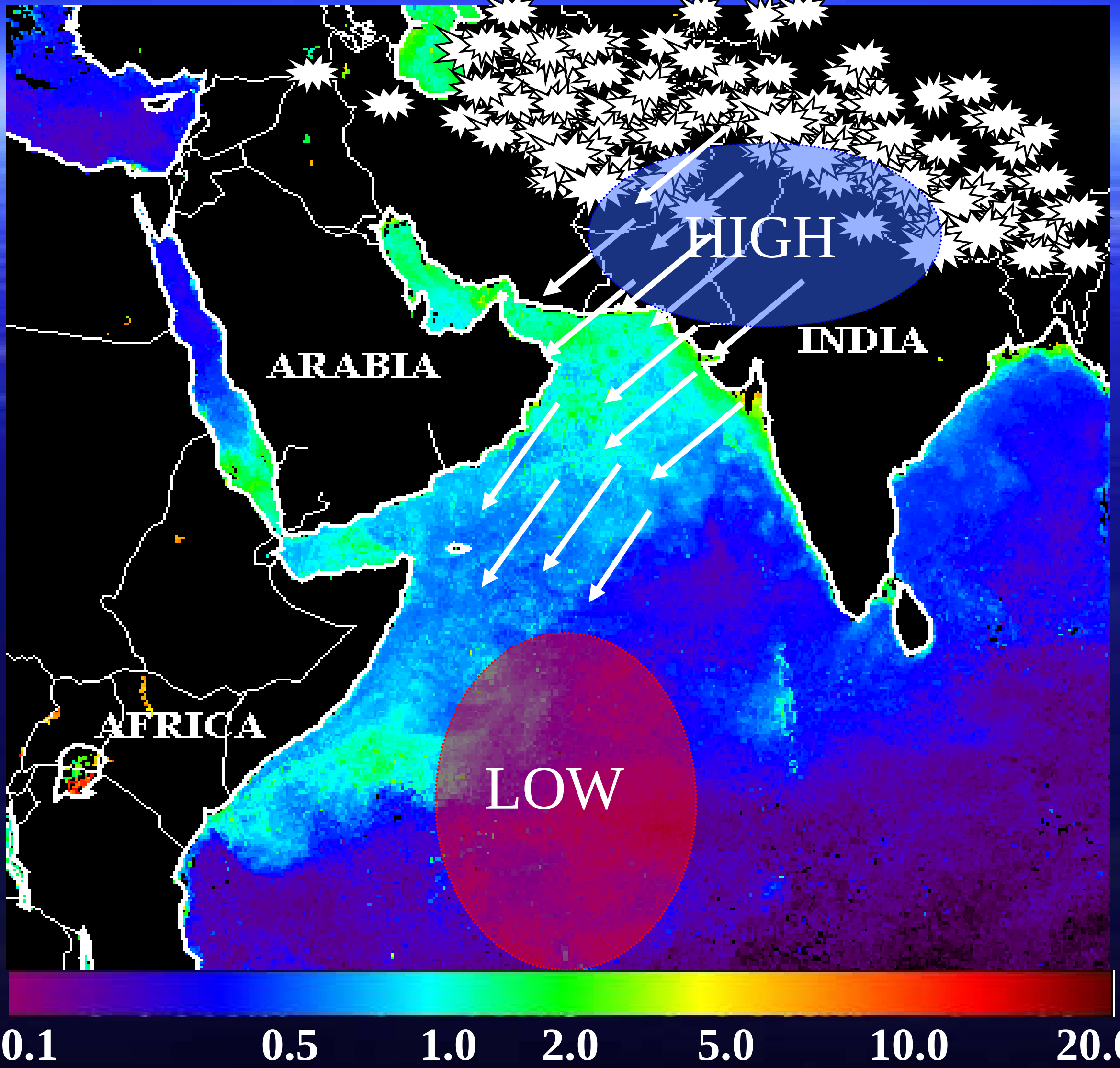


Chlorophyll fields during the peak southwest monsoon seasons of 1997, 2001 and 2006 showing continued increase in phytoplankton biomass due to intensification of winds and coastal upwelling

SCHEMATIC SHOWING THE IMPACTS OF INCREASING PRODUCTIVITY ON THE ARABIAN SEA

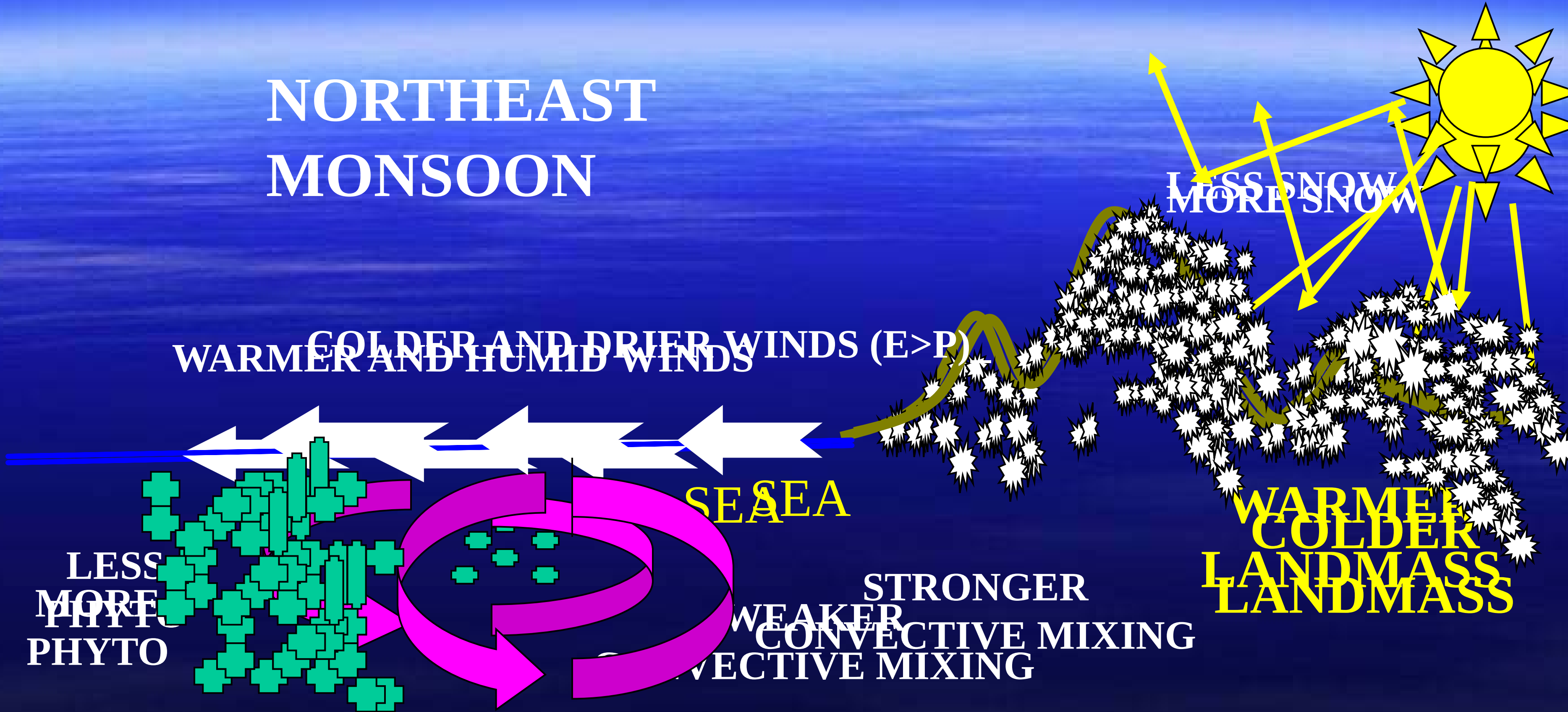


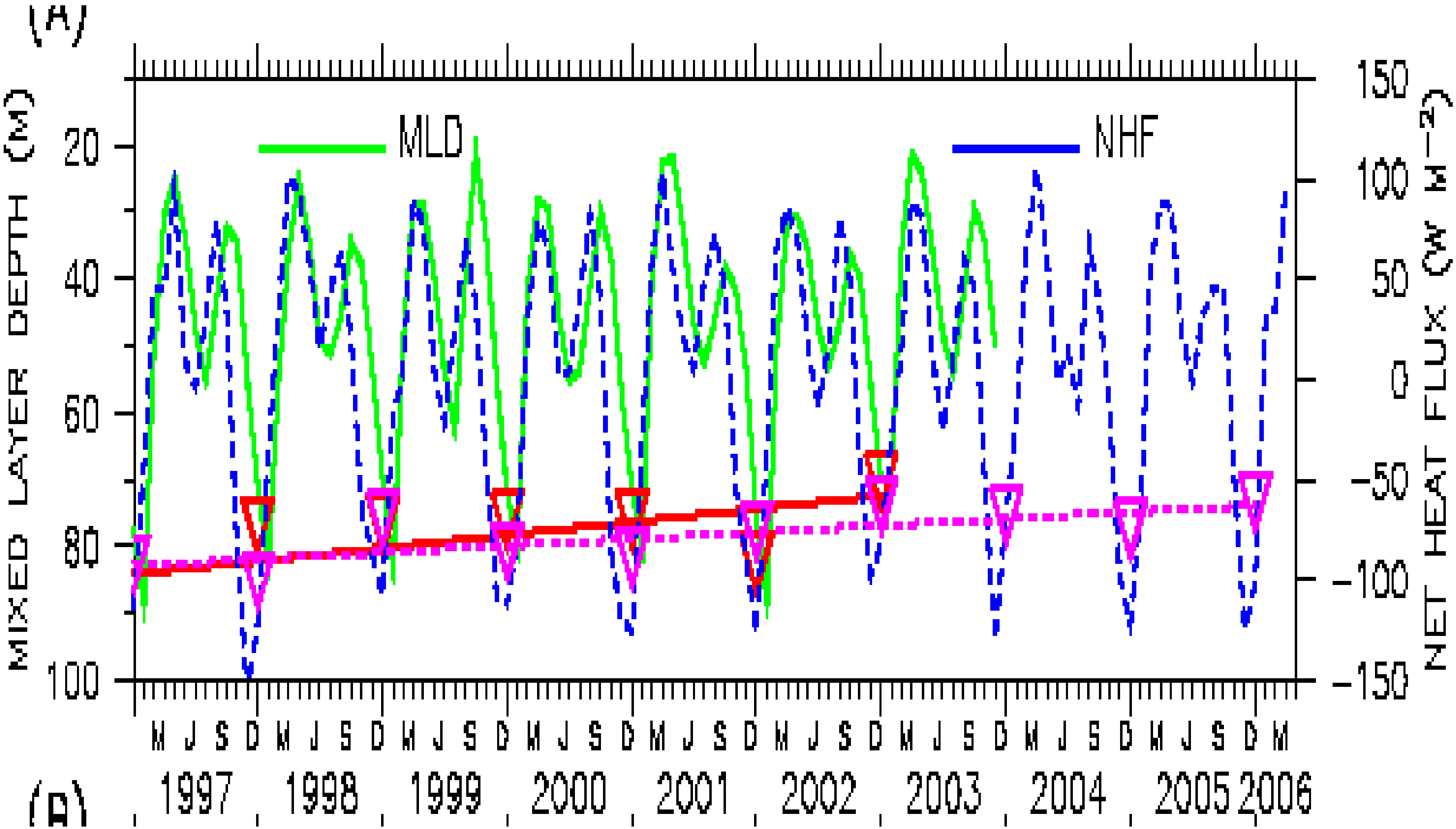
WINTER MONSOON



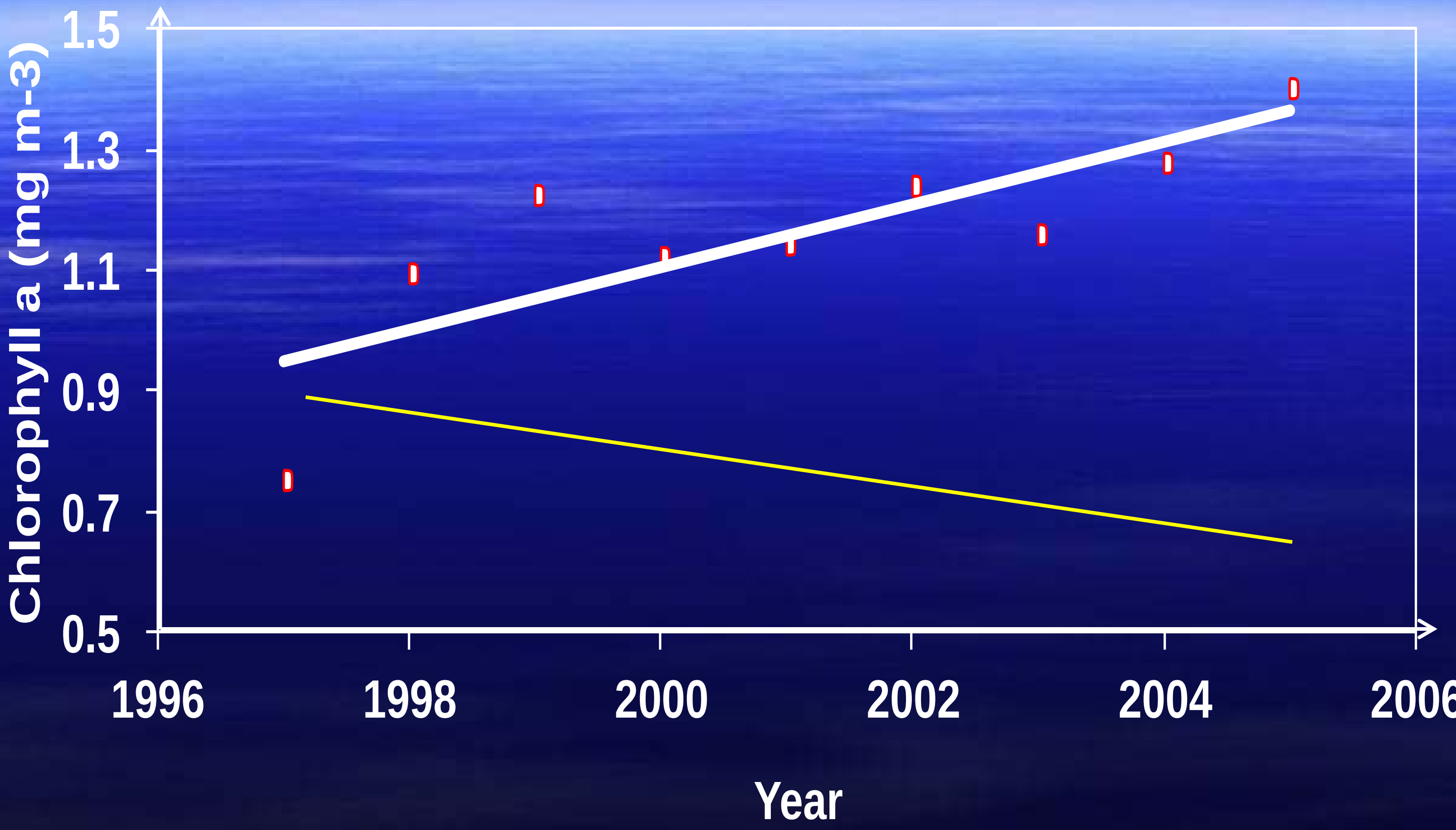
Schematic showing snow cover extent and wind direction superimposed on an ocean color chlorophyll image for the northeast monsoon season (Nov-Feb).

NORTHEAST MONSOON



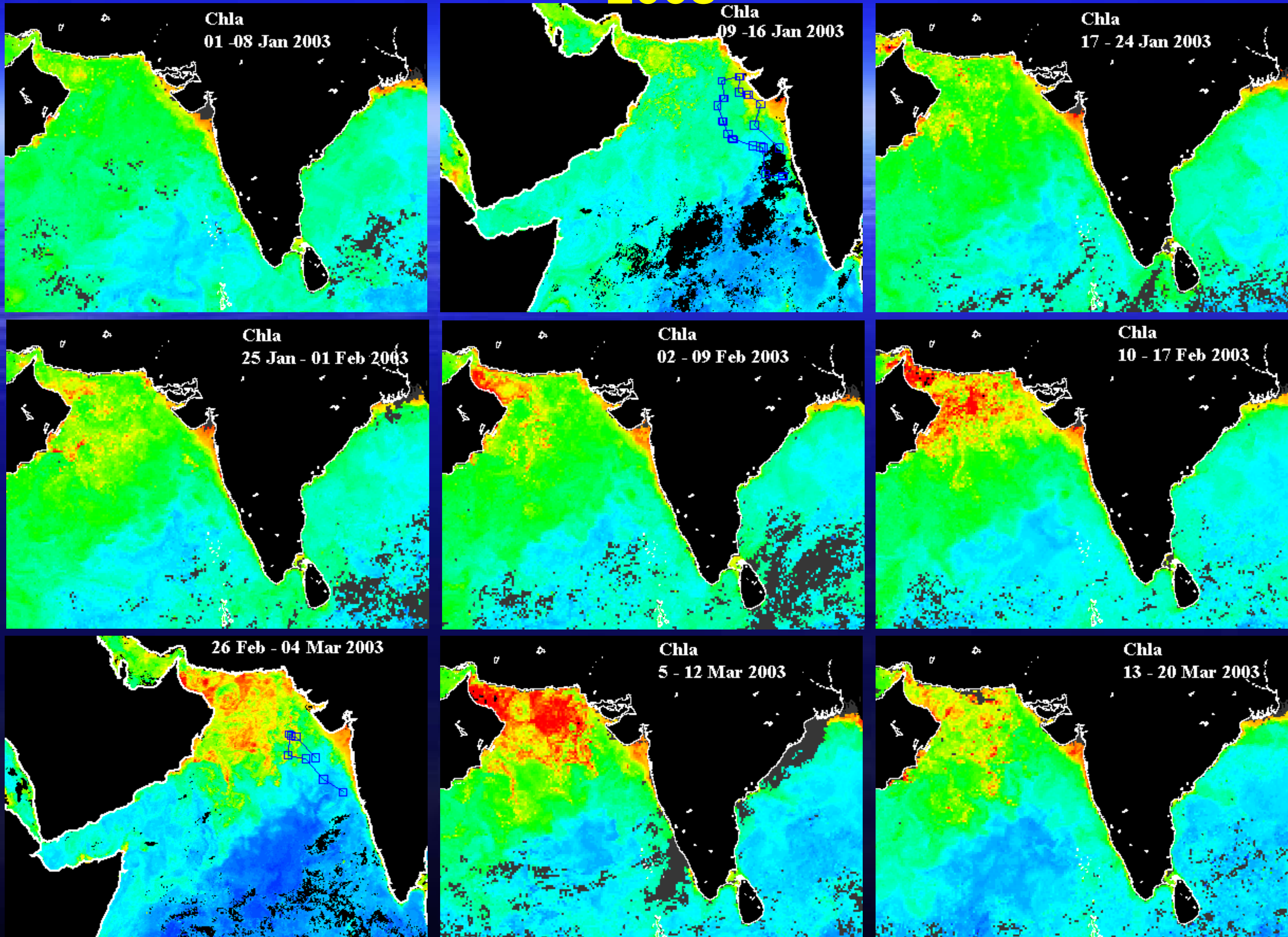


Annual trends of net heat flux (NCEP-NCAR) (60-70°E, 14°N-25°N) and Mixed Layer Depth (XBT, JEDAC, USA) indicating weakening of winter convective mixing during the NE monsoon



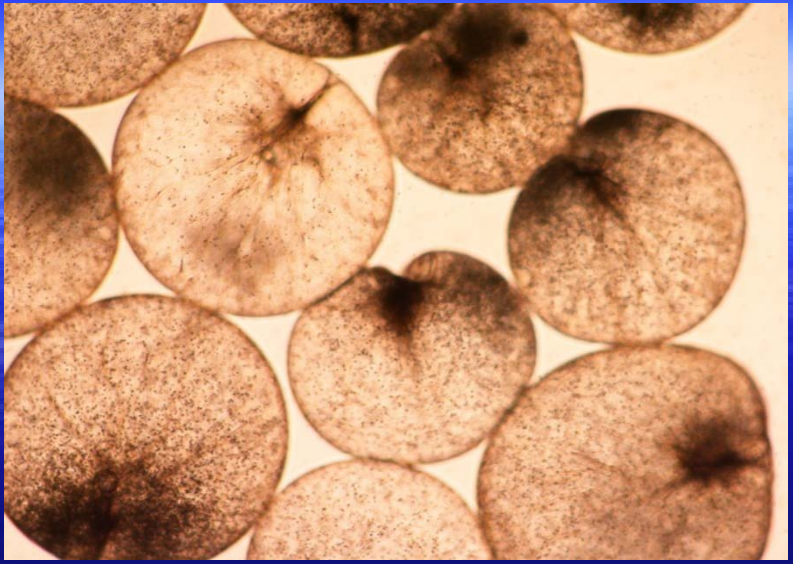
Winter mean SeaWiFS Chl *a* averaged over the Arabian Sea (55°E-70°E, 15°N-24°N).

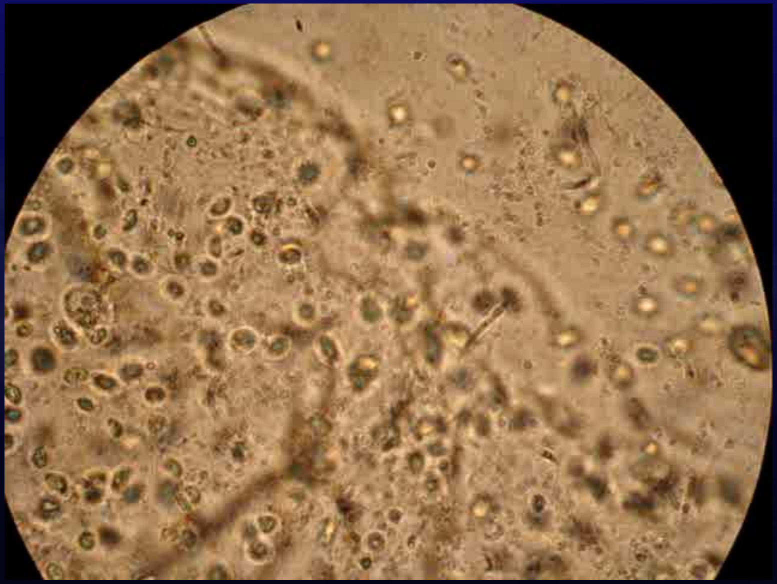
2003

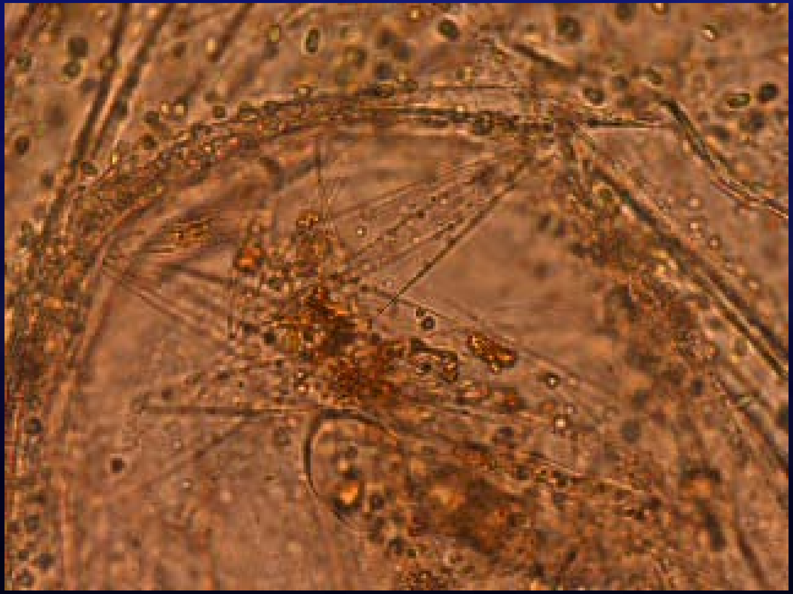


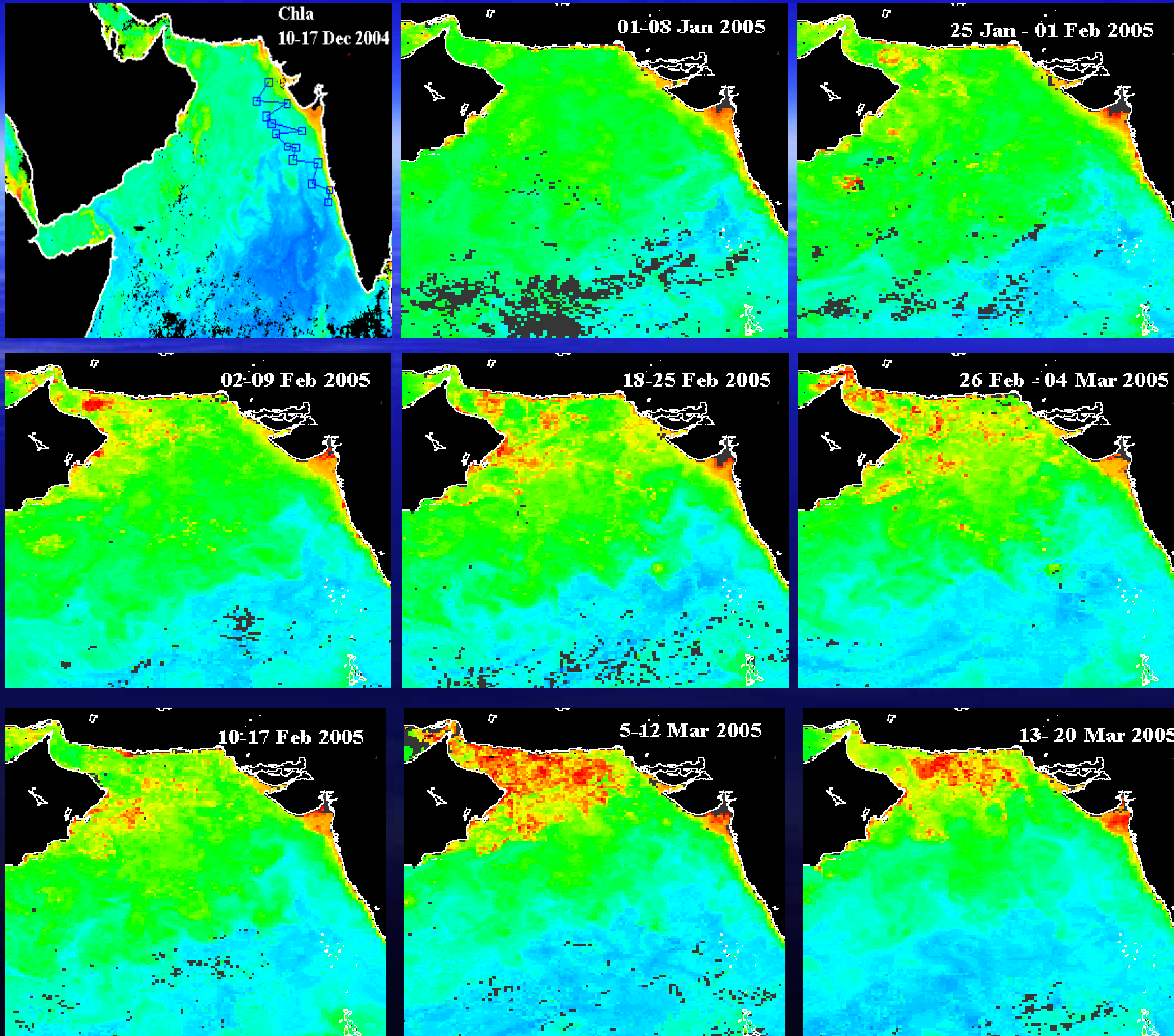
DESPITE WEAKENING CONVECTING MIXING, ARABIAN SEA IS WITNESSING UNPRECEDENTED BLOOMS OF PHYTOPLANKTON

NOCTILUCA - MICROSCOPY



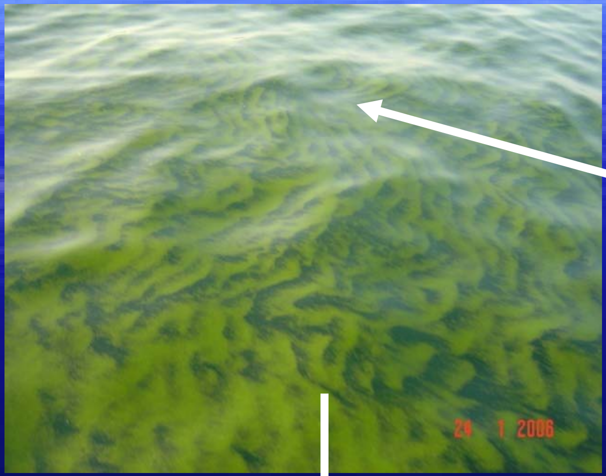




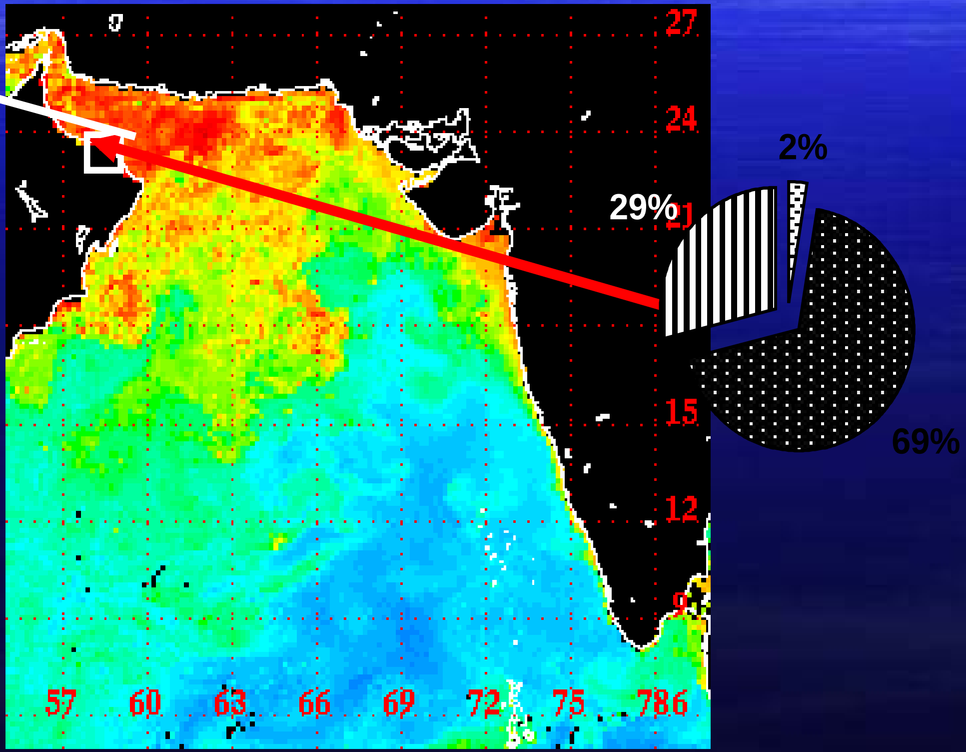


PHYTOPLANKTON BLOOM OF 2005

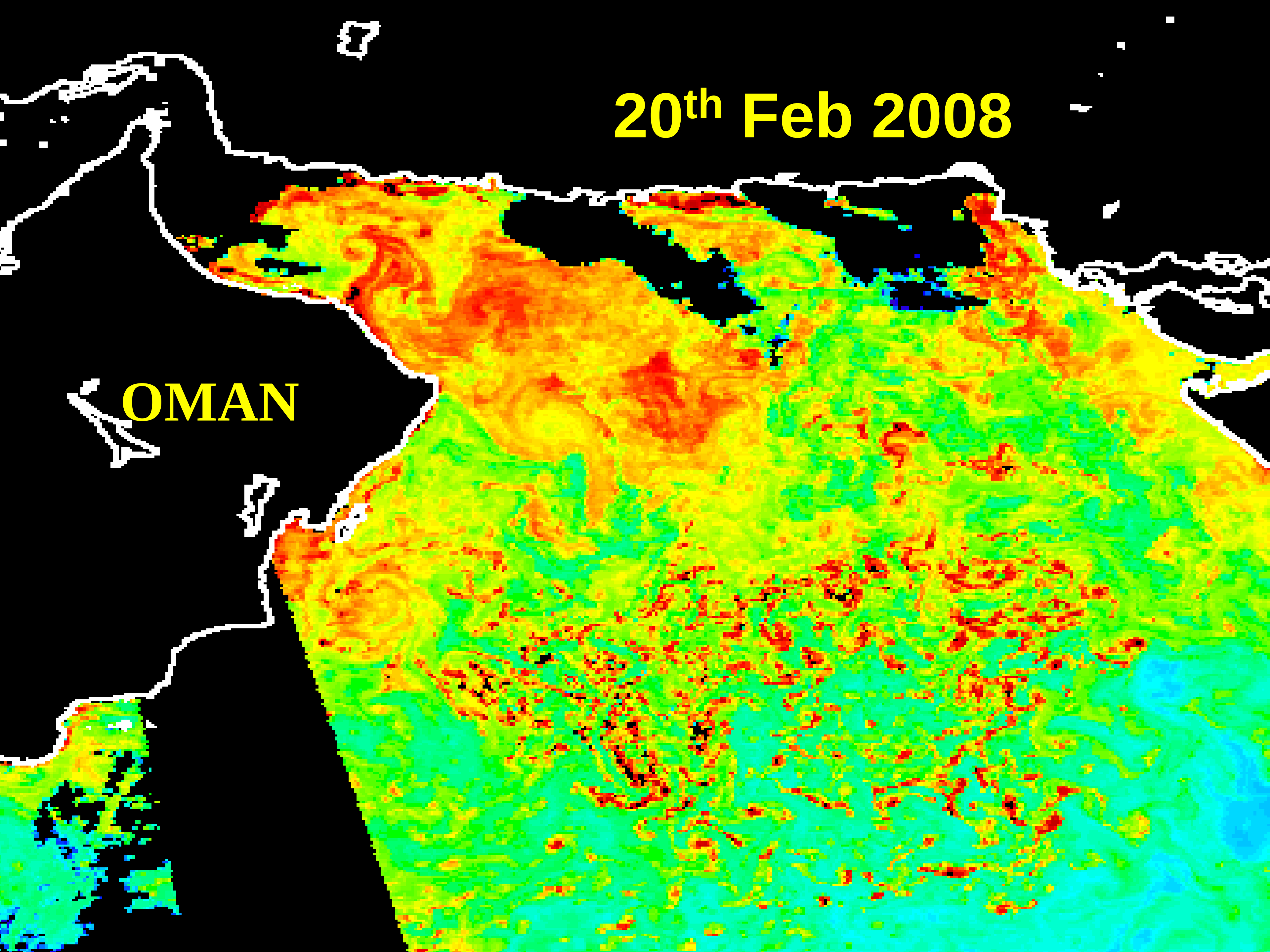
NOCTILUCA MILIARIS BLOOM OF 2006 IN OMAN



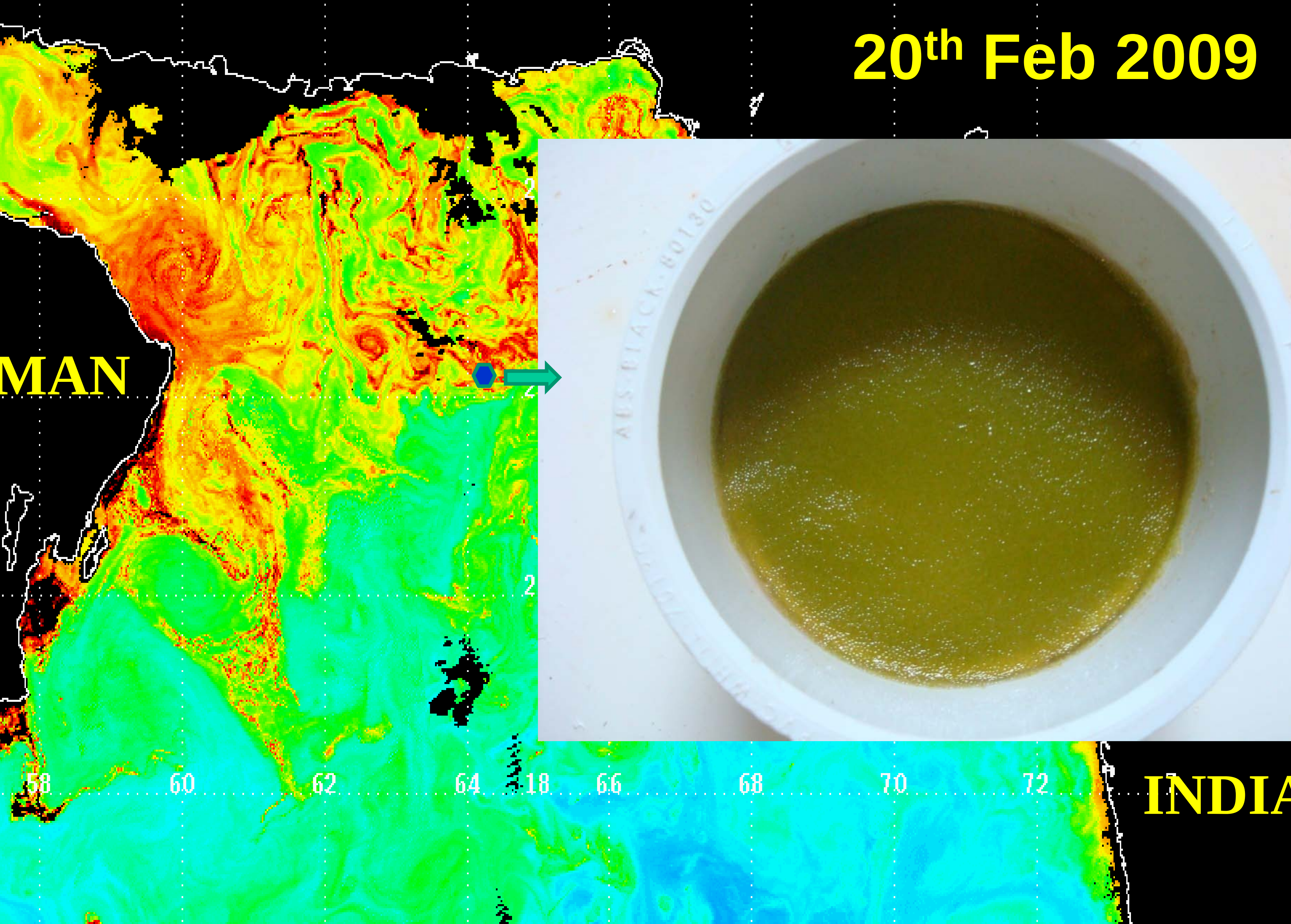
Pedinomonas noctilucae

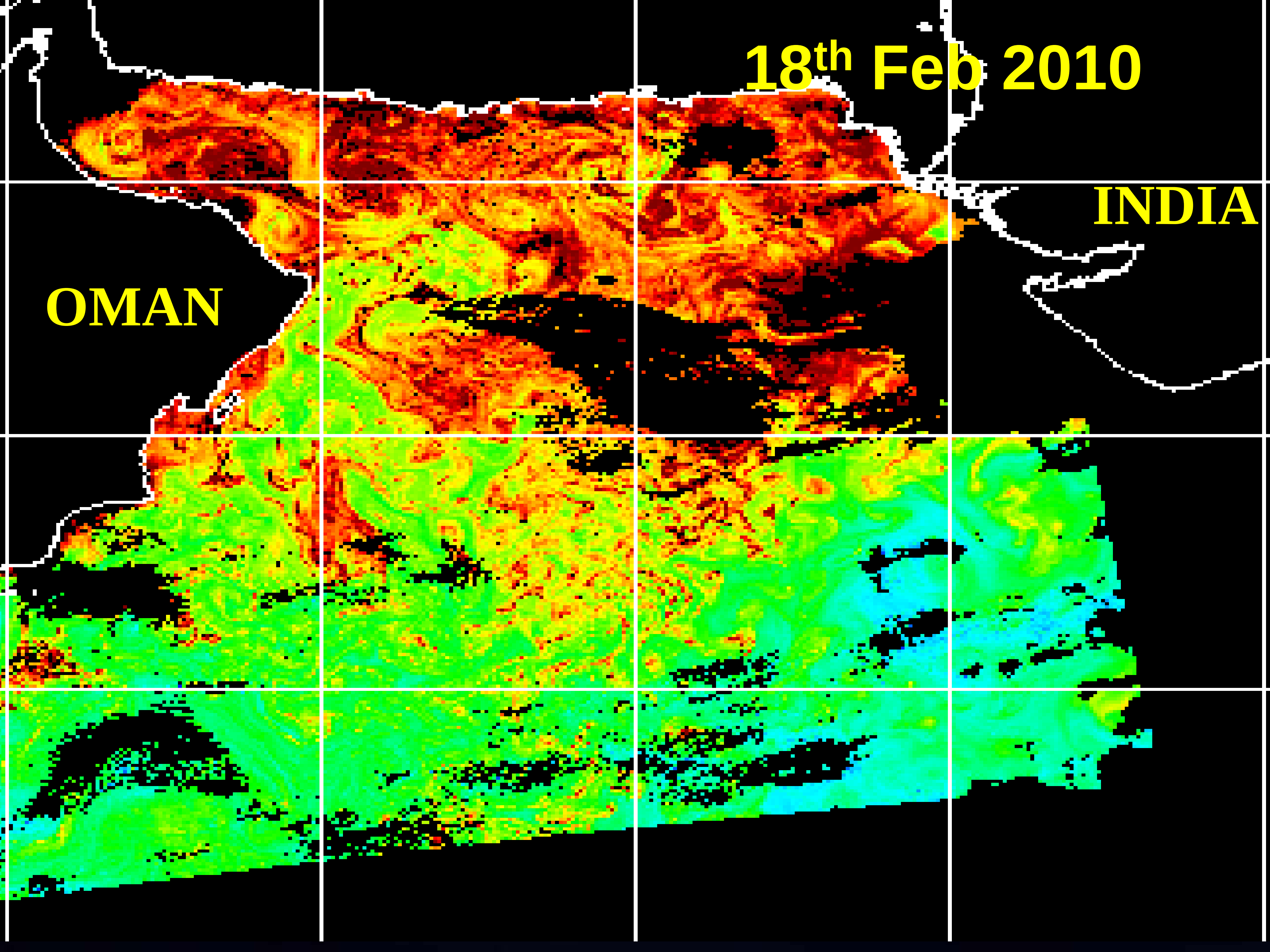


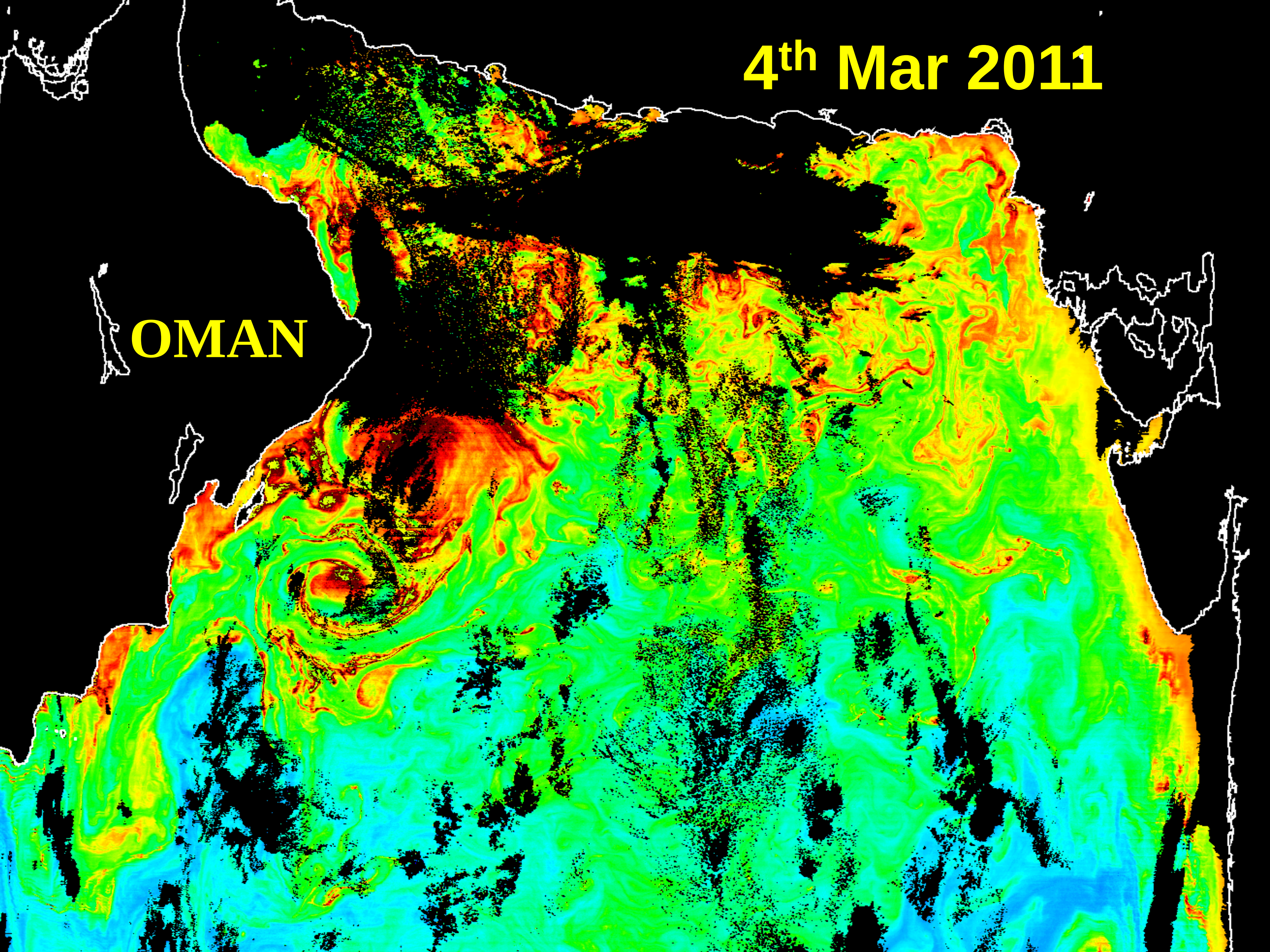
Dinoflagellate, thrives in (cold) <22^{o}C, nutrient rich and oxygen poor waters


20th Feb 2008
OMAN

20th Feb 2009




18th Feb 2010
INDIA
OMAN


4th Mar 2011
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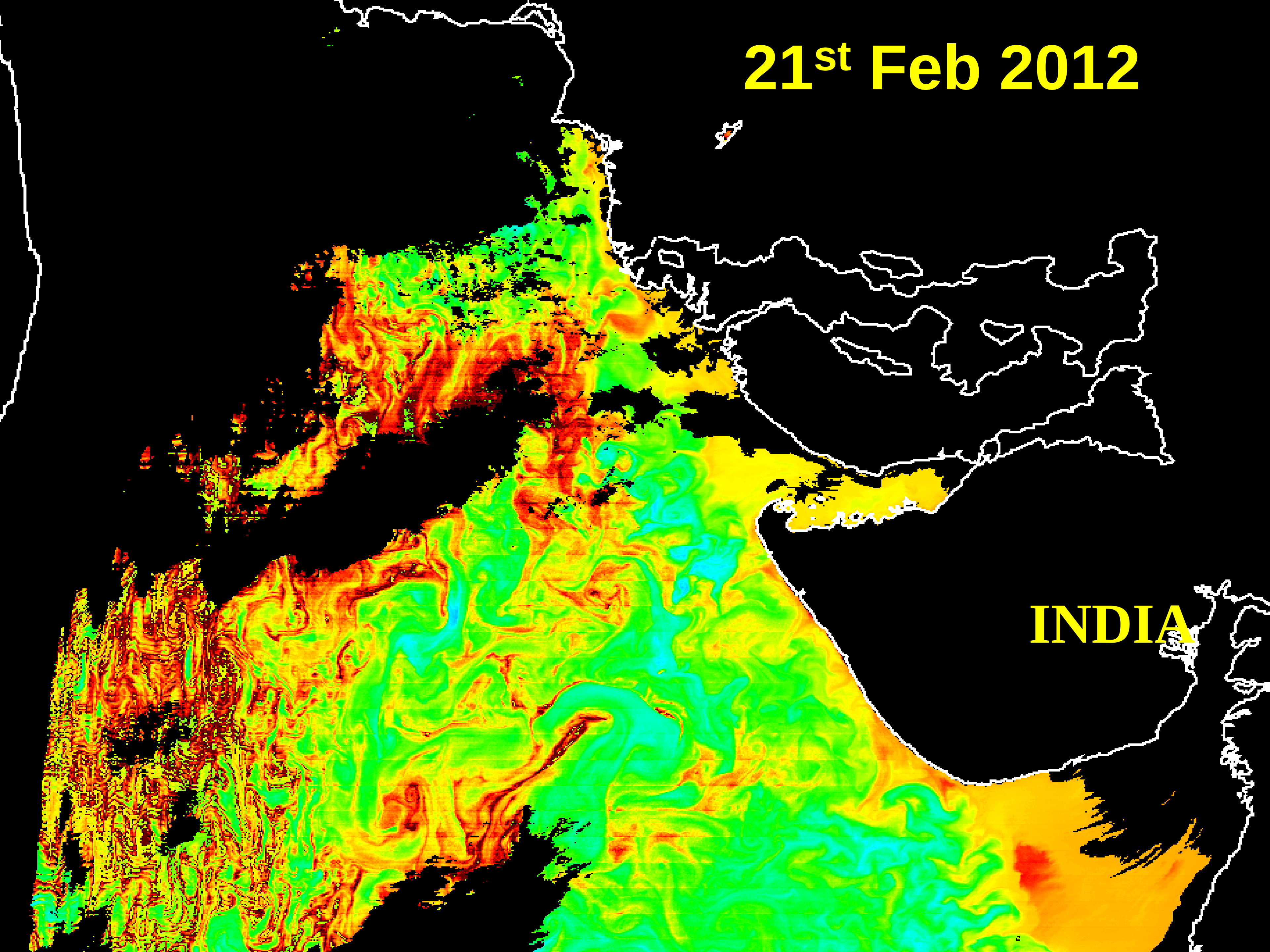
21st Feb 2012
INDIA

Ocean Color Inversion to obtain PFTs

Application to *Noctiluca miliaris* blooms in the Arabian Sea

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Dept. of Earth and Ocean. Science

Bowdoin College

Analytic Inversion of Ocean Color Spectra to Inherent Optical Properties

$$R(\lambda) = \frac{f}{Q}\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}$$

$$a(\lambda) = a_w(\lambda) + a_\phi(\lambda) + a_{NAP}(\lambda) + a_{CDOM}(\lambda)$$

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda)$$

$$a_\phi(\lambda) = C_\phi a_\phi^*(\lambda)$$

- Reflectance, *R*(λ), is a function of spectral absorption, and backscattering, *a*(λ) and $b_b(\lambda)$
- Absorption and backscattering are the sum of their constituents
- Constituent *a* and *b* are the product of concentration and concentration-specific IOPs, $a^*(\lambda)$ and $b_b^*(\lambda)$
- For example: C_ϕ = chl and $a^*_\phi(\lambda)$ = chl-specific phytoplankton absorption spectrum

Full Reflectance Equation

$$R(\lambda) = \frac{f}{Q} \frac{b_{bw}(\lambda) + b_{bp}(\lambda)}{a_w(\lambda) + a_{CDM}(\lambda) + a_\phi(\lambda) + b_{bw}(\lambda) + b_{bp}(\lambda)}$$

- where

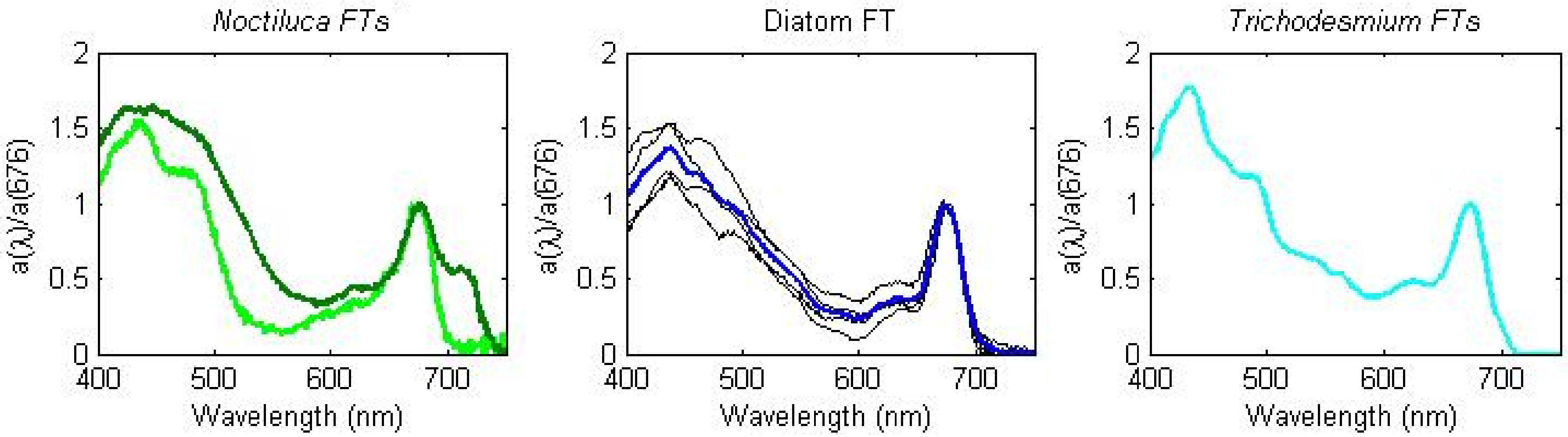
$$b_{bp}(\lambda) = b_{bp}(440)\left(\frac{\lambda}{440}\right)^\eta$$

$$a_\phi(\lambda) = C_\phi a_\phi^*(\lambda)$$

$$a_{CDM}(\lambda) = a_{CDOM}(\lambda) + a_{NAP}(\lambda) = a_{CDM}(440)\exp(-S*(\lambda - 440))$$

The phytoplankton absorption spectrum is represented as the sum of the absorption spectra for pigment-based taxonomic groups (PFTs)

$$a_{\phi}(\lambda) = C_{Nm} a^{*}_{\phi Nm}(\lambda) + C_{Dt} a^{*}_{\phi Dt}(\lambda) + C_{TR} a^{*}_{\phi Tr}(\lambda)$$

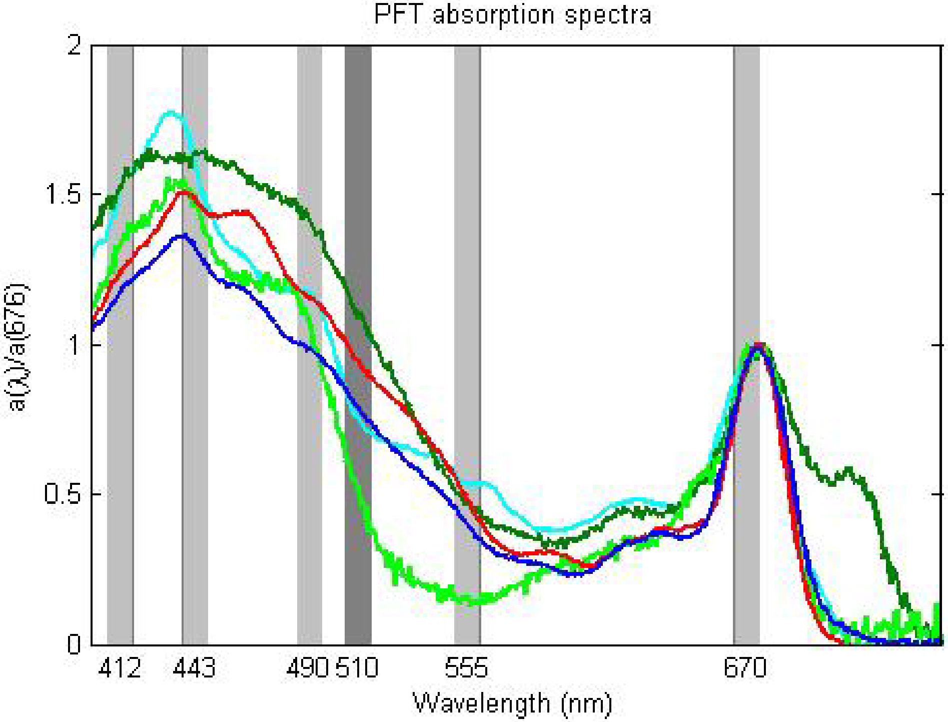


N. miliaris measured **early** and **late** in a bloom, 2011 and 2009, respectively

Range of cultured diatom absorption spectra (Proctor and Roesler 2010)

Trichodesmium sp. (Dupuoy et al. 2010)

The spectral variations of these PFTs is shown with the SeaWiFS and MODIS AQUA bands

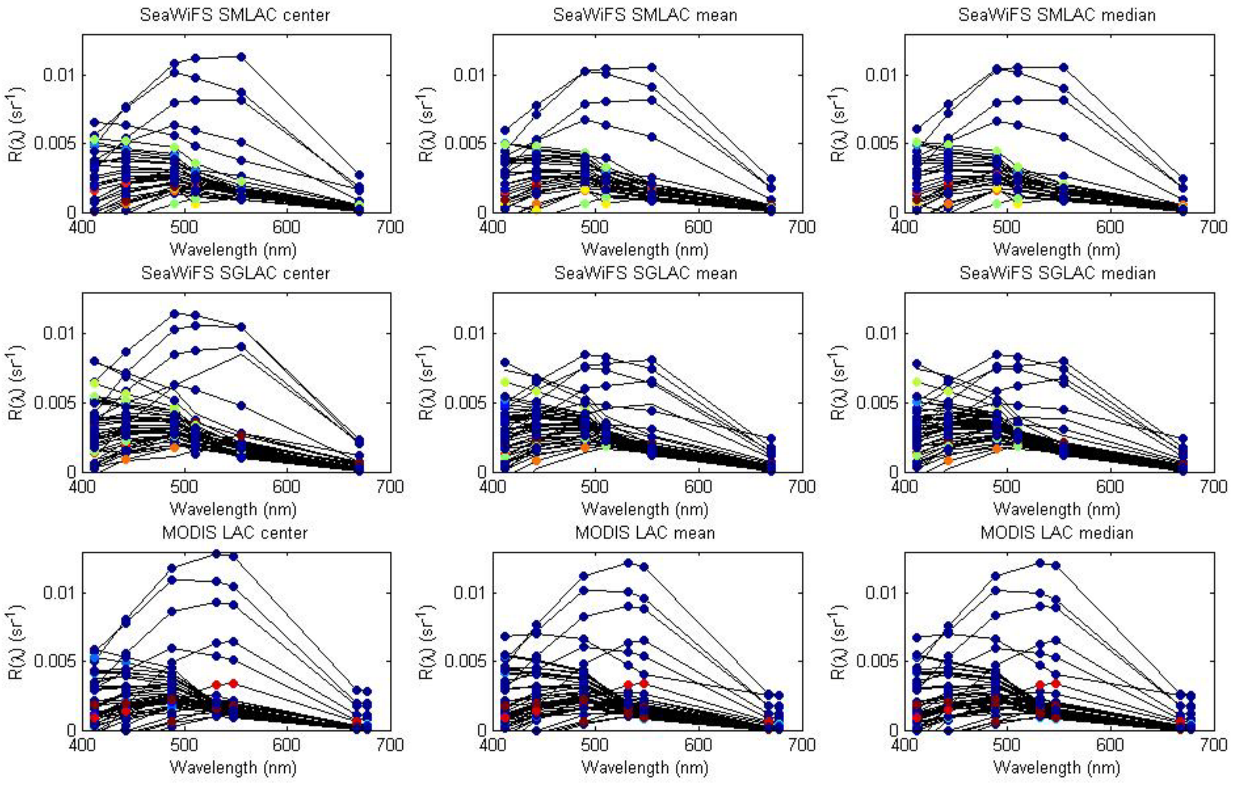


Matchups

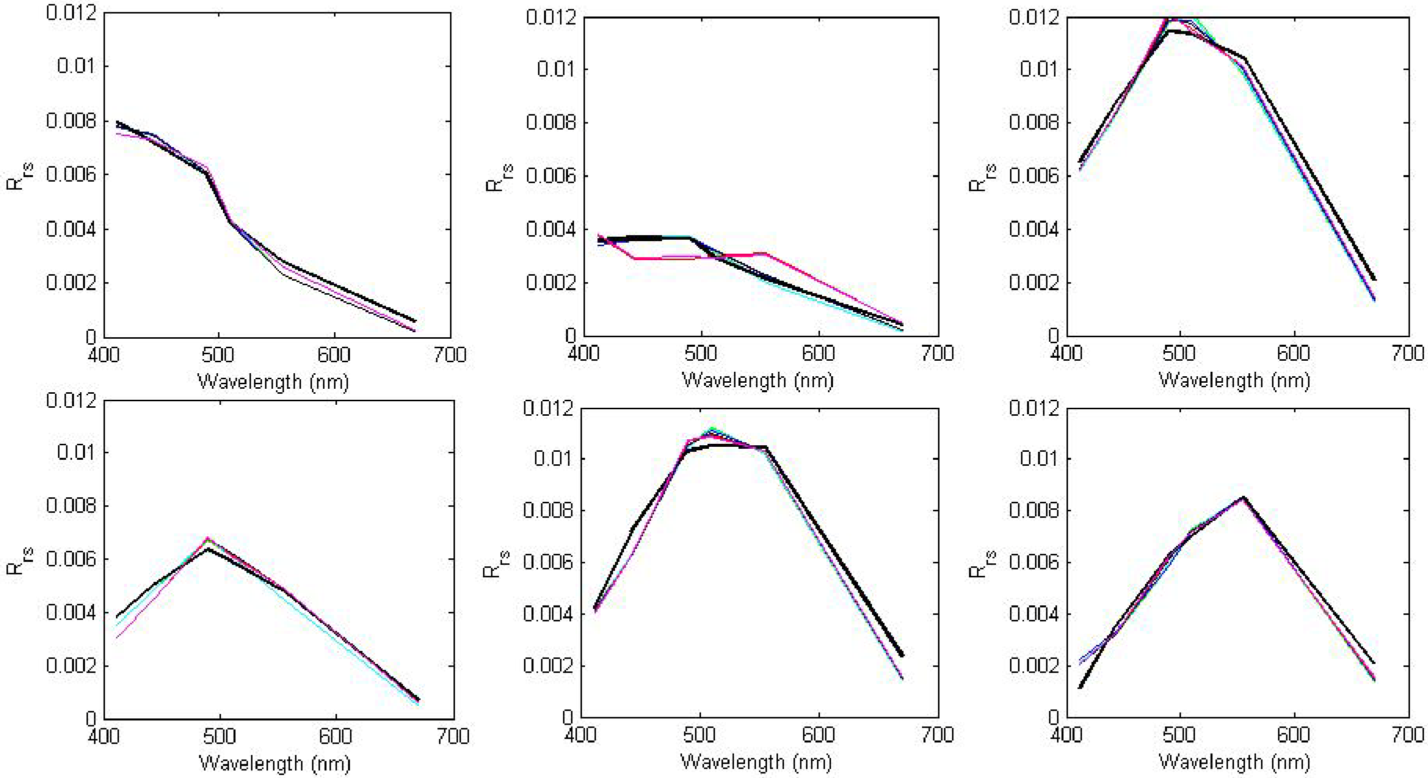
SeaWiFS LAC

SeaWiFS GAC

MODIS LAC



Iterative Non-linear Inversion Results



- satellite measure reflectance (black)
- modeled reflectance using range of PFT eigenvectors (100% N. miliaris – green to 100% diatom – red)
- reasonable fit obtained with either eigenvector

Exact Solution Linear Matrix Inversion

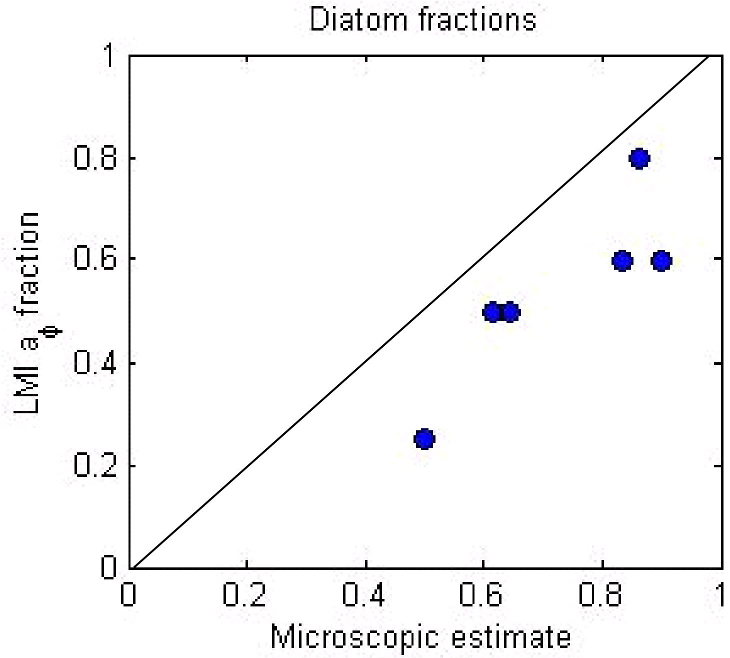
$$a_{CDM}(\lambda)+a_{\phi}(\lambda)+b_{bp}(\lambda)*\left(1-\frac{f}{Q*R(\lambda)}\right)=\left(b_{bw}(\lambda)*(\frac{f}{Q*R(\lambda)}-1)\right)-a_{w}(\lambda)$$

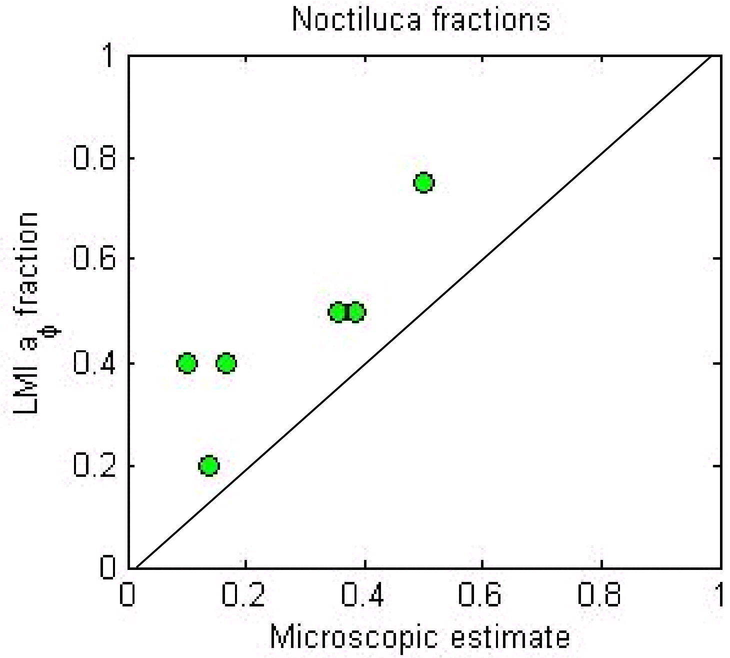
- solve the reflectance equation
- known on right, unknowns on left
- multiple linear regression
- single solution for constituent IOPs

Following Boss, Peng and Roesler 2005

- Solve LMI for a range of eigenvectors
- e.g. allow
  - slope of b_{bp} to vary
  - slope of a_{cdm} to vary
  - spectral shape of a_{ϕ} to vary from 1:0:0 to 0:1:0 to 0:0:1 diatom:Noctiluca:Trichodesmium
- consider only retrievals with R_{mod} with <10% error R_{meas}
- compute median and standard deviation of retrieved eigenvalues

Comparison of retrieved to measured fractions of diatoms to *Noctiluca*





ACKNOWLEDGMENTS

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THANK YOU