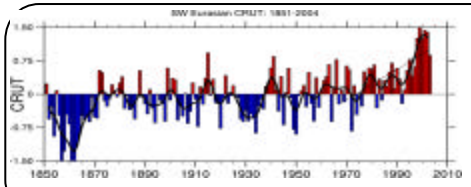
Climate Change Impacts on Phytoplankton Biodiversity and Its Consequences for the Ecosystem of the Arabian Sea

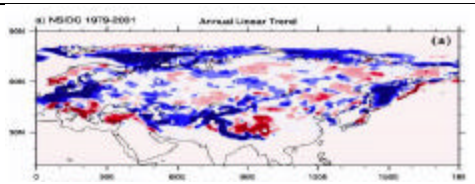
J. I. Goes[1], H. do R Gomes[1], P. G. Thoppil[2], S. G. P. Matondkar[3], A. N. Al-Azri[4], R. M. Dwivedi[5], J. T. Fasullo[6], F. Chai[7], S. deRada[2], J. T. Kindle[2], R. T. Barber[8]

[1]Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME, 04575, USA, [2]Naval Research Laboratory, Stennis Space Center, MS 39529, USA, [3]National Institute of Oceanography, Dona Paula, Goa, 403004 India, [4]Sultan Qaboos University, Al-Khod, 123,Oman, [5]Space Applications Centre, Indian Space Research Organization, Ahmedabad, India, [6]National Center for Atmospheric Research, Boulder, CO 80305, [7]University of Maine, Orono, ME, 04469, USA, [8]Duke University, Beaufort, NC, 28516, USA

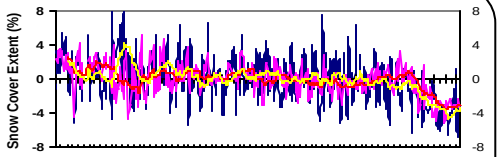
ABSTRACT: Over the past few years the Arabian Sea has witnessed a rapid increase in summer-time phytoplankton blooms due to strengthening of the southwest monsoon winds and intensification of coastal upwelling. In a study based primarily on satellite-based datasets we showed that these changes were linked to the warming trend over Eurasia and a decline in snow cover over the Himalayan-Tibetan Plateau region. Our recent observations suggest that the warming trend is undermining convective mixing responsible for nutrient inputs during the boreal winter component of the monsoon cycle. More recently, we have been able to combine satellite data with shipboard observations to show the Arabian Sea may be experiencing a loss of phytoplankton biodiversity, with traditional winter-time diatom populations being replaced by unprecedented blooms of the heterotrophic dinoflagellate *Noctiluca miliaris*. At the moment, it remains unclear whether these changes are related to the warming trend. One of the difficulties is that, unlike the other major ocean basins, long-term shipboard observations in the Arabian Sea are lacking and continue to be a major impediment to a better understanding of the relationships between the oceanographic processes and biological productivity as they relate to climate change. As part of our studies funded by NASA, we have been working to overcome this shortcoming through the development of a coupled physical-biological model. A detailed analysis of atmospheric data from the region being undertaken simultaneously will be used to identify salient trends in climate and in conjunction with the coupled physical-biological model, for a coherent diagnosis of climate variability on the ecosystem of the Arabian Sea.



CRUT data depicting the warming of SW Eurasia. Anomalies are >50% larger than for the global temperatures.

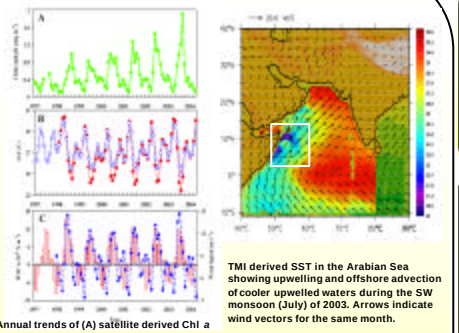


NSIDC Annual snow cover trends suggest a marked decrease in snow accumulation north of the Arabian Sea.



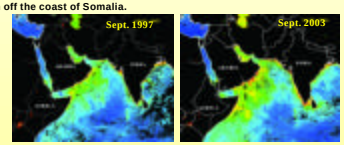
Departures from monthly means of snow cover extent over Southwest Asia and Himalayas-Tibetan Plateau between 1967 and 2003.

SOUTHWEST MONSOON

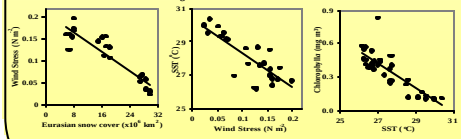


Annual trends of (A) satellite derived Chl a (B) Reynold's blended (1°x 1°) SST and TMI (0.25°x 0.25°) derived SST (C) Wind Stress Curl derived from NCEP-NCAR reanalysis data and TMI derived Wind Speed for the region off the coast of Somalia.

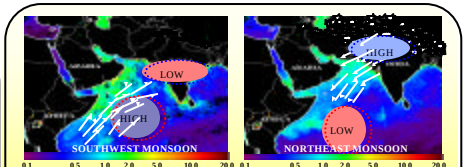
TMI derived SST in the Arabian Sea showing upwelling and offshore advection of cooler upwelled waters during the SW monsoon (July) of 2003. Arrows indicate wind vectors for the same month.



SeaWiFS derived chlorophyll fields during the peak southwest monsoon growth season of 1997 and 2003



Scatter plots of (a) resultant wind stress and Eurasian snow cover (b) SST and resultant wind stress (c) Satellite Chl a and SST (°C). Oceanographic data are for region (10°N-5°S, 52-57°E) and Eurasian snow cover are from the Northern Hemisphere EASE grid.



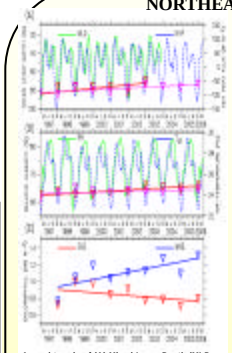
Schematic showing snow cover and wind direction superimposed on ocean color chlorophyll images for the southwest (Jun-Sept) and the northeast monsoon (Dec-Feb).

The Arabian Sea's seasonally reversing monsoons drive one of the most energetic current systems in the world and the greatest seasonal variability in phytoplankton biomass observed in any ocean basin. In summer, the heating of the Eurasian land mass, creates conditions for the development of southwesterly winds which cause strong coastal upwelling off Somalia, Yemen, and Oman. During the northeast monsoon, the cooling of the northern hemispheric land mass results in high pressure over land and low pressure over the Indian Ocean, which causes a reversal in the direction of the monsoon winds from southwesterly to northeasterly. These cold dry winds are responsible for winter convective mixing during winter.

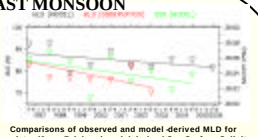
The declining winter snow cover over Eurasia is creating a land-ocean thermal gradient that is particularly favorable to stronger southwest monsoon winds. Since 1997, sea surface winds have strengthened in the western Arabian Sea. This escalation in the intensity of upwelling favorable summer monsoonal winds has led to a >350% increase in average summer time phytoplankton biomass along the coast, of Somalia and Oman and a >300% offshore making the Arabian Sea more productive during the summer.

In contrast since 1998, the northern Arabian Sea has been experiencing a steady weakening of winter convective mixing, evident from the progressive shallowing of mixed layer depths. Over the period from 1998 to the present, the northern Arabian Sea has experienced a ~30 W m^{-2} reduction in wintertime net heat flux (NHF) due to an increase in temperatures and the relative humidity of the northeasterly winds. Consistent with the weakening trend of convective mixing, chlorophyll concentrations have been on the decline but only in the eastern Arabian Sea, In the western Arabian Sea, chlorophyll concentrations have been on the rise, due to unprecedented blooms of *N. miliaris* off the coast of Oman, which are being observed with increased frequency in waters which are subsaturated with respect to dissolved oxygen. The appearance of *N. miliaris* in bloom proportions during winter raises the intriguing possibility that the warming trend is causing a shift in phytoplankton biodiversity in the Arabian Sea.

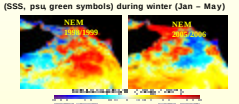
NORTHEAST MONSOON



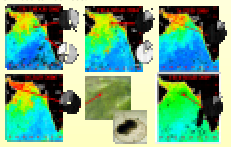
Annual trends of (A) Mixed Layer Depth (MLD, and net heat flux (NHF, W m^{-2}); (B) Relative humidity (RH, %,) and Air temperature (°C,) for the northern Arabian Sea (60°E-70°E, 14°N-25°N); (C) Winter mean SeaWiFS derived Chl a in the eastern Arabian Sea (EAS, 66°E-70°E, 15°N-24°N) and in the western Arabian Sea (WAS, 55°E-66°E, 17.5°N-22.5°N)



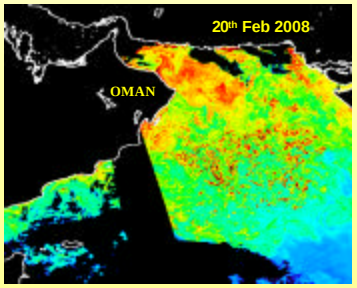
Comparisons of observed and model-derived MLD for winter (Jan – Feb.) and model derived Sea Surface Salinity (SSS, psu, green symbols) during winter (Jan – May)



SeaWiFS derived chlorophyll anomaly plots for the winter monsoons of (A) Nov 2002 to Feb 2003 and (B) Nov 2005 to Feb 2006.



Increase in Chl a related to appearance of unusual blooms of *Noctiluca miliaris (synonm scintillans)*.



Bloom of *Noctiluca miliaris (synonm scintillans)* of the NEM of 2008 as seen by MODIS-Aqua

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