Changing productivity in the Arabian Sea linked to shrinking snow caps – How satellites helped connect the dots

Joaquim I. Goes and Helga Gomes  
Bigelow Laboratory for Ocean Sciences

Prasad Thoppil  
Naval Research Laboratory, Stennis Space Centre

Prabhu Matondkar and Sushma Parab  
National Institute of Oceanography

Adnan Al Azri  
Sultan Qaboos University
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NASA, NSF - USA and SAC - India
Estimating Nitrate In The World’s Oceans and its utility to study environmental regulation of nitrate based new production in the Arabian Sea

Nitrate fields generated using MODIS Terra Chl a and SST

Goes et al., EOS (2004)
ARABIAN SEA WIND FIELDS

Sea surface winds reverse direction seasonally

Development and intensity regulated by thermal gradient between land and sea

Winds responsible for convective mixing during winter monsoon and coastal upwelling during summer monsoon
Schematic showing snow cover extent and wind direction superimposed on an ocean color chlorophyll image for the northeast monsoon season (Nov-Feb).
NITRATE INPUTS IN THE ARABIAN SEA DUE TO WINTER CONVECTIVE MIXING DURING NORTHEAST MONSOON
Schematic showing the reversal in wind direction during the southwest monsoon (Jun-Sept), superimposed on satellite derived chlorophyll fields.
NITRATE INPUT DUE TO UPWELLING DURING THE SOUTHWEST MONSOON

JUNE 2002
JULY 2002
AUG 2002
SEPT 2002
OCT 2002
NOV 2002

Nitrate ($\mu$M)

NITRATE INPUT DUE TO UPWELLING DURING THE SOUTHWEST MONSOON
Comparison between shipboard and satellite derived sea surface nitrate concentrations in the Arabian Sea
INTERANNUAL CHANGES IN SEA SURFACE NITRATE CONCENTRATIONS DURING THE SW MONSOON
Schematic showing the SW Monsoon response of the Arabian Sea to snow cover
Anomalies (departures from monthly means for period between 1996-2002) of Eurasian Snow Cover (x10^6 km^2). Trend line shown in bold is 14 point moving average.
Annual snow cover trends suggest a marked decrease in snow accumulation north of the Arabian Sea.

May snow cover trends are largely negative all over Eurasia reflecting an earlier and stronger spring melt-off.
Trend line (14 point moving average) showing anomalies (departures from monthly means) of snow cover extent over Southwest Asia and Himalayans-Tibetan Plateau between 1967 and 2003. Note especially the runaway decline in snow cover extent after 1997.
The warming of SW Eurasia mirrors the global-land signal, but recent warm anomalies are >50% larger than for the global temperatures.
Left Panel - 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. Right top panel – Interannual variability of Wind Speed and Wind Stress Curl. Right bottom panel – Decrease in SST along the coast of Somalia.
Interannual changes in chlorophyll along coast of Somalia since 1997
Annual trends of satellite derived chlorophyll $a$ and zonal wind stress in the offshore western Arabian Sea.
Scatter plots showing the impact of the decline in Eurasian snow on phytoplankton in the Arabian Sea
southwest monsoon growth season of 1997 and 2003
NORTHEAST MONSOON

WARMER AND HUMID WINDS

COLDER AND DRIER WINDS

LESS PHYTO

MORE PHYTO

WEAKER CONVECTIVE MIXING

STRONGER CONVECTIVE MIXING

WARMER LANDMASS

COLDER LANDMASS

LESS SNOW

MORE SNOW
Relative humidity and Air-temperature for the northern Arabian Sea (60°E-70°E, 14°N-25°N).
Annual trends of Mixed Layer Depth (XBT, JEDAC, USA) and net heat flux (NCEP-NCAR) (60-70°E, 14°N-25°N).
Comparisons of observed and model-derived MLD for winter (Jan – Feb), and model derived Sea Surface Salinity (SSS, psu) during Jan – May for the 60°E-70°E, 14°N-25°N. Model derived fields are obtained from the ECCO-JPL Kalman Filter Assimilation project.
Winter mean SeaWiFS Chl $a$ averaged over the Eastern Arabian Sea (EAS, 66°E-70°E, 15°N-24°N) and in the western Arabian Sea (WAS, 55°E-62°E, 17.5°N-22.5°N).
SeaWiFs derived chlorophyll anomaly plots for the winter monsoons of (A) Nov 2002 to Feb 2003 and (B) Nov 2005 to Feb 2006.
Sea Surface Height Anomalies (SSHA, cm, contours) and geostrophic current vectors computed from the SSHA for the period 22-25 February 2003 superimposed on a weekly (18-25 February 2003) averaged SeaWiFS chlorophyll $a$ image.
Eddies and the OMZ
Eddy kinetic energy for the region off the coast of Oman for the period from 2001 to 2006.
Eddy kinetic energy for the region off the coast of Oman for the period from 2001 to 2006.
Area averaged chlorophyll for the Gulf of Oman
Are recent changes in the productivity of the Arabian Sea related to other modes of climate variability?

How will changes in species diversity and biological productivity impact:

- Carbon delivery to deeper layers of the Arabian Sea
- Bacterial processes
- Denitrification rates
- The Oxygen Minimum Zone and
- Coastal Fisheries?

significance of eddies in the Arabian Sea?
“Nothing in the sea falls haphazard; if we cannot predict, it is because we do not know the cause, or how the cause works...”

Henry Bryant Bigelow