The NW Indian Ocean's Biogeochemistry in Relation to a Changing Planet and Changing Concepts

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HORN POINT LABORATORY

Nomenclature

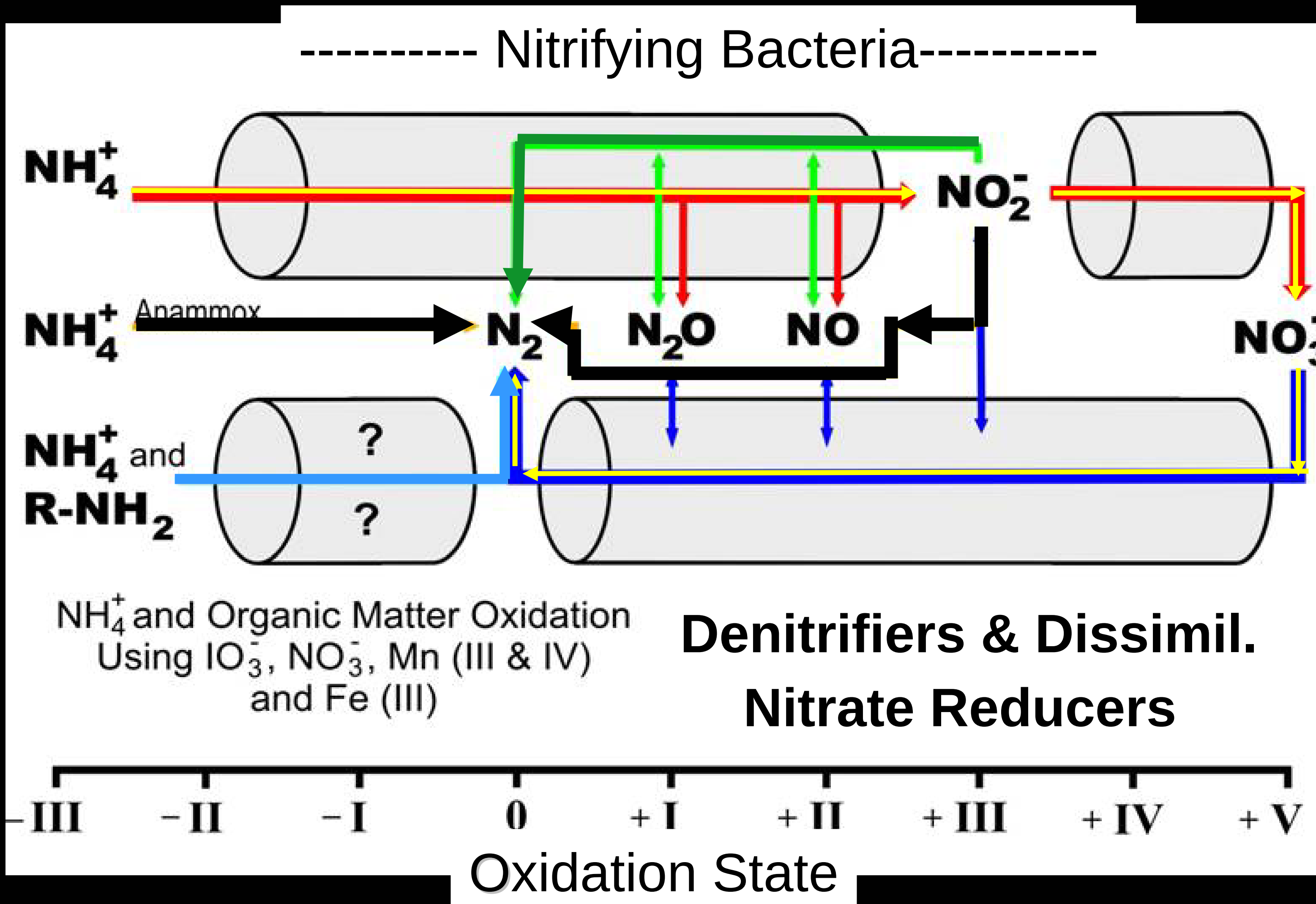
Canonical Denitrification: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

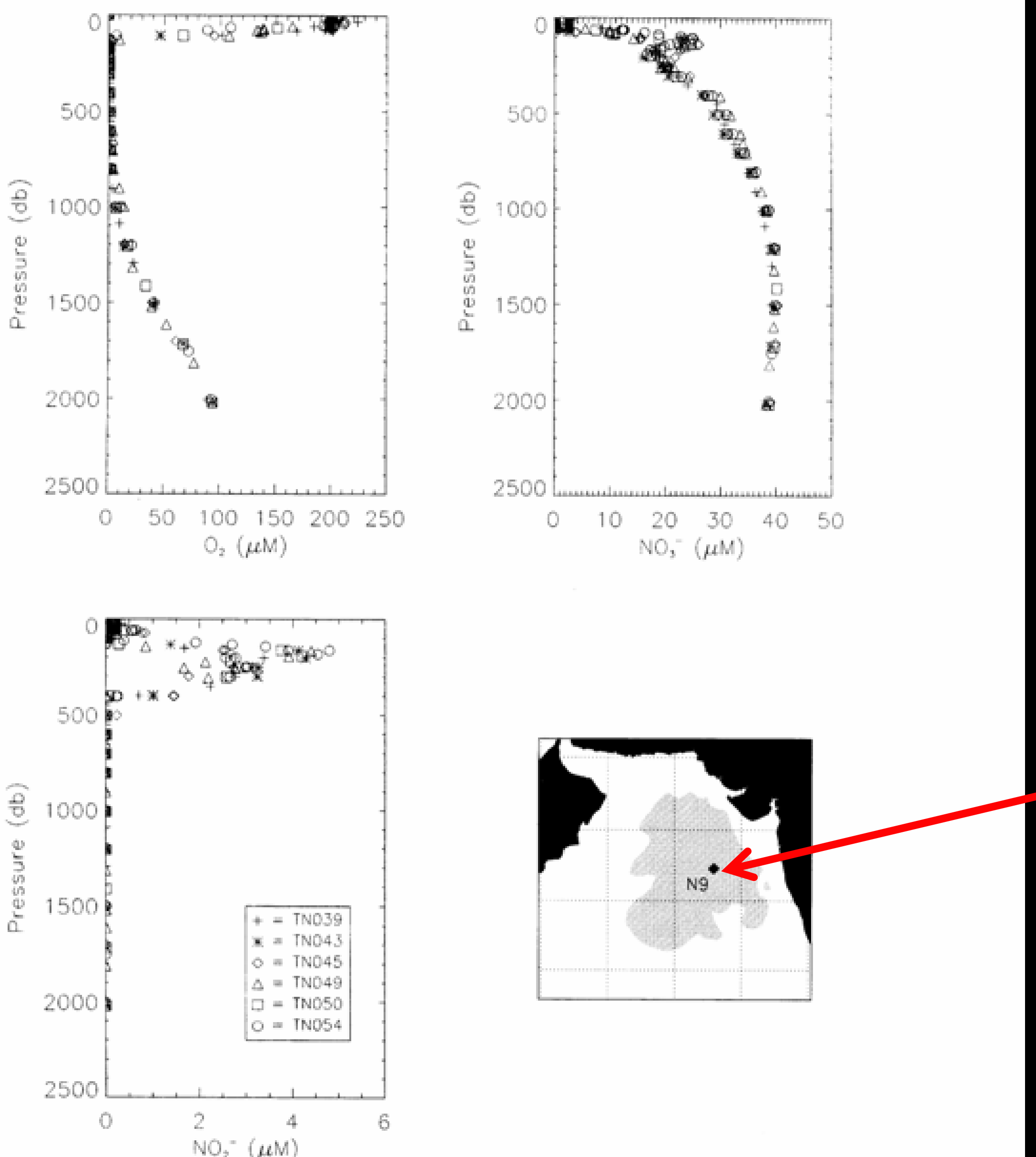
Denitrification: the ensemble of biological processes that convert fixed-N to N_2

This nomenclatural detour is made necessary because of the recent explosion of knowledge *vis a vis* biological pathways that produce N_2.

Multiple Pathways to N_2

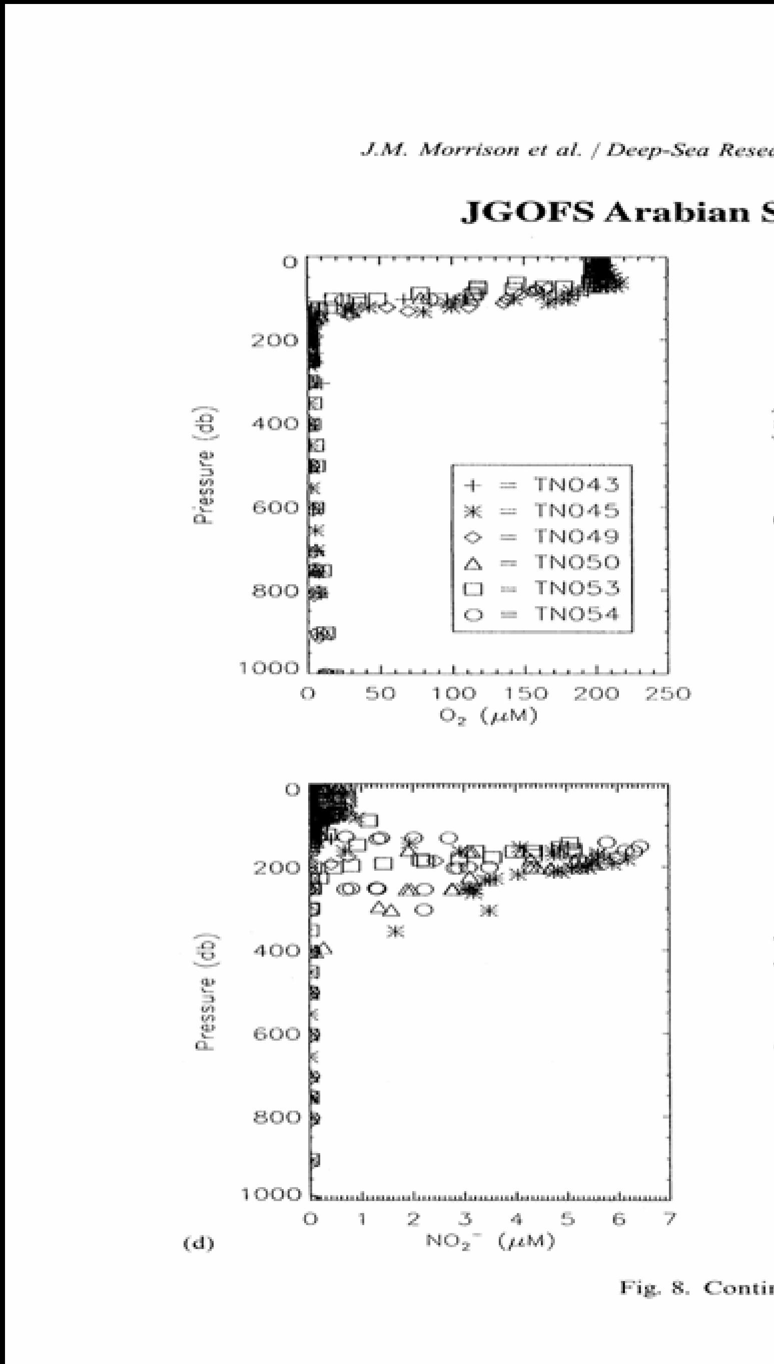
What happens to NH_4^+ flux from sediments to suboxic water?





Data from 6 US JGOFS Cruises that attempted to resolve the seasonal cycle

Station N9 in quasi-permanent secondary nitrite max (shaded region)

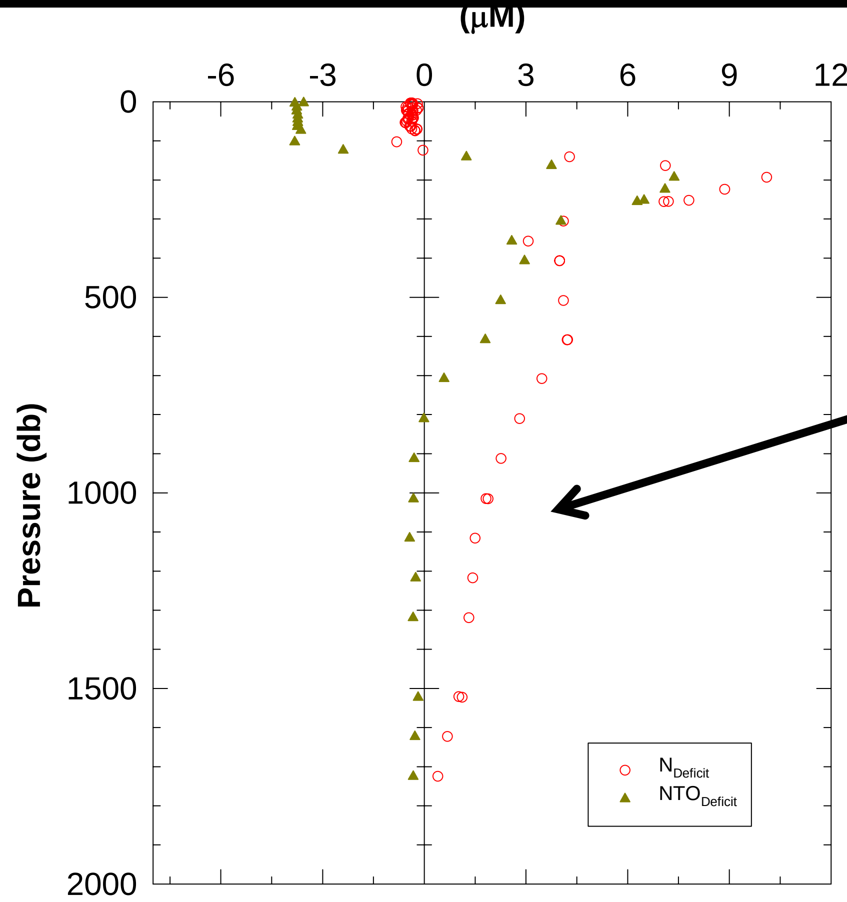


Low oxygens extend considerably deeper (several hundred db) than nitrite maximum.

Existing denitrification estimates assume that denitrification is confined to the nitrite max layer. Is this so?

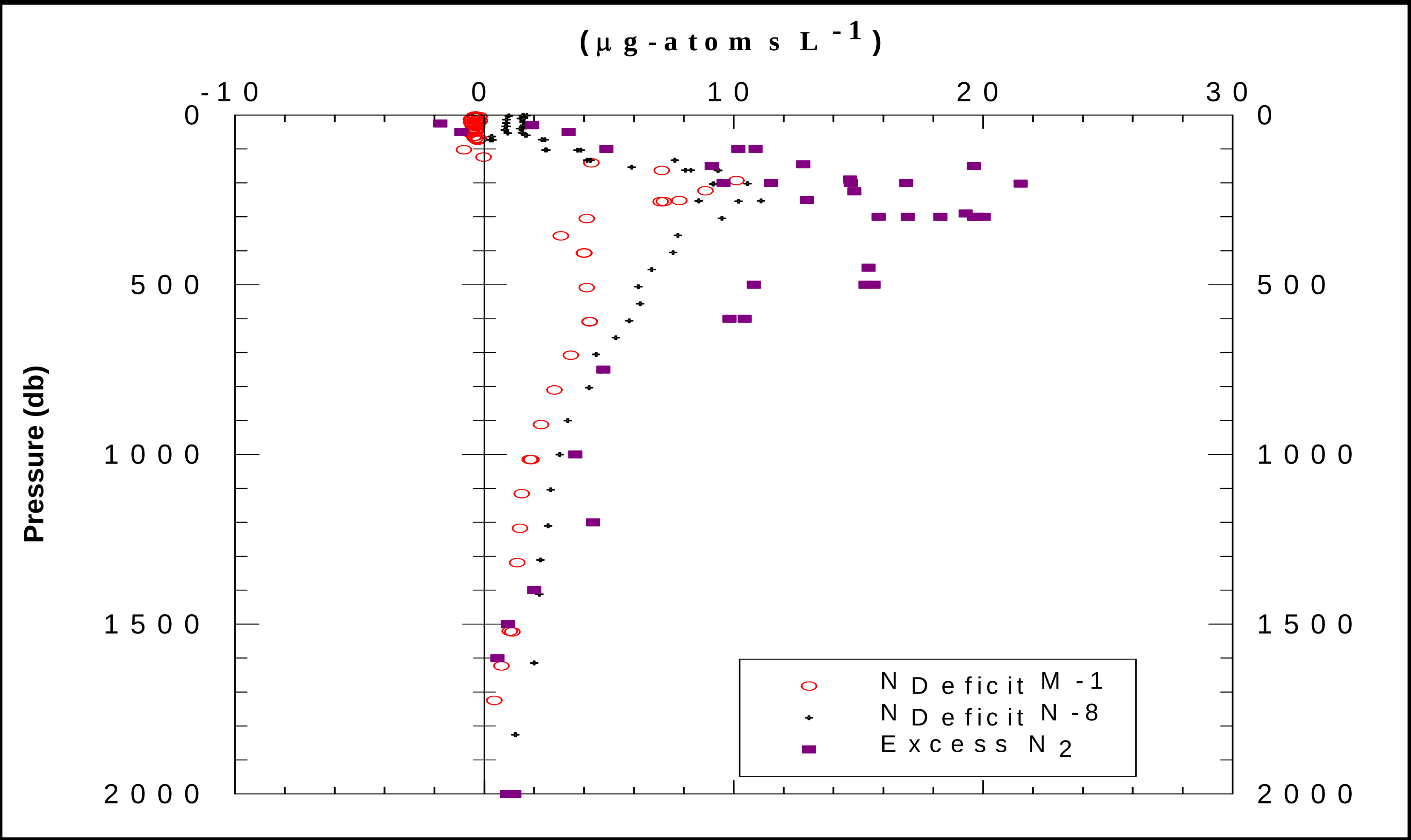
We need a better understanding of the distribution of N-transformations in the 0-10 micromolar range.

$N_{Deficit}$ VS. $NTO_{Deficit}$

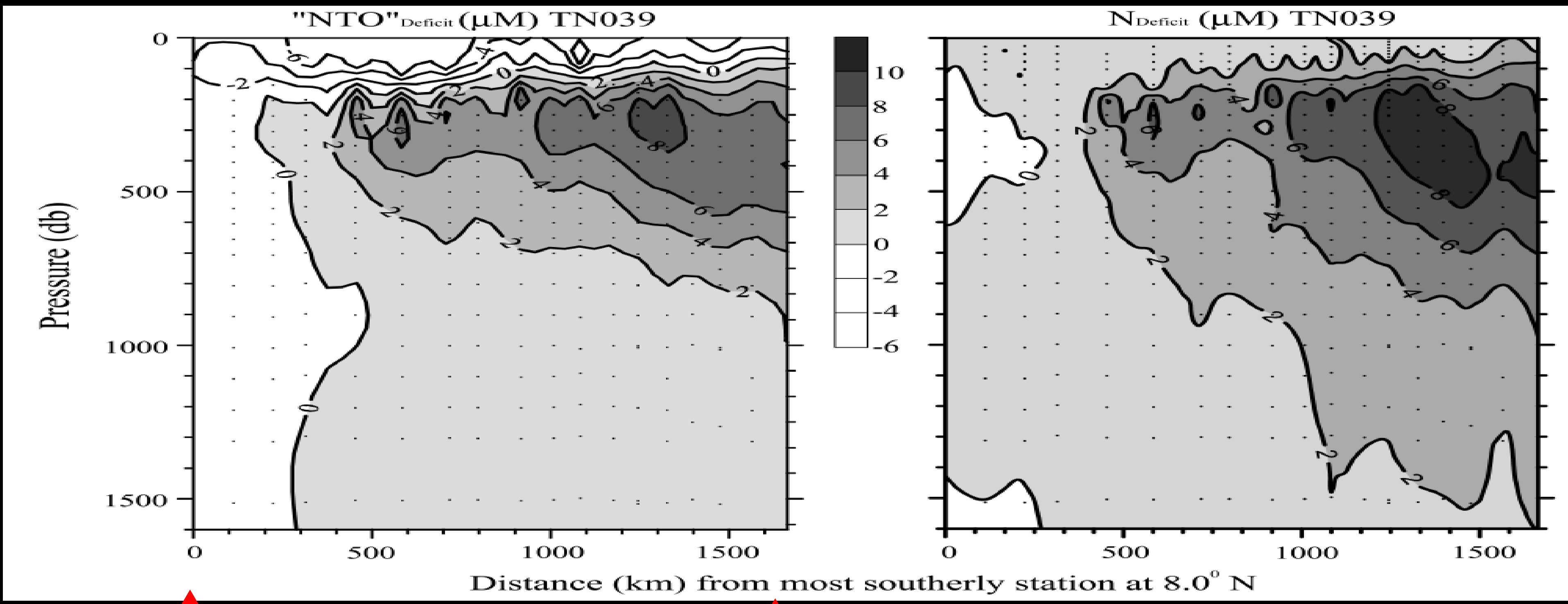


Produced locally, elsewhere or some combination? Anammox in particles?

Excess N_2 + $N_{Deficit}$ vs. Depth

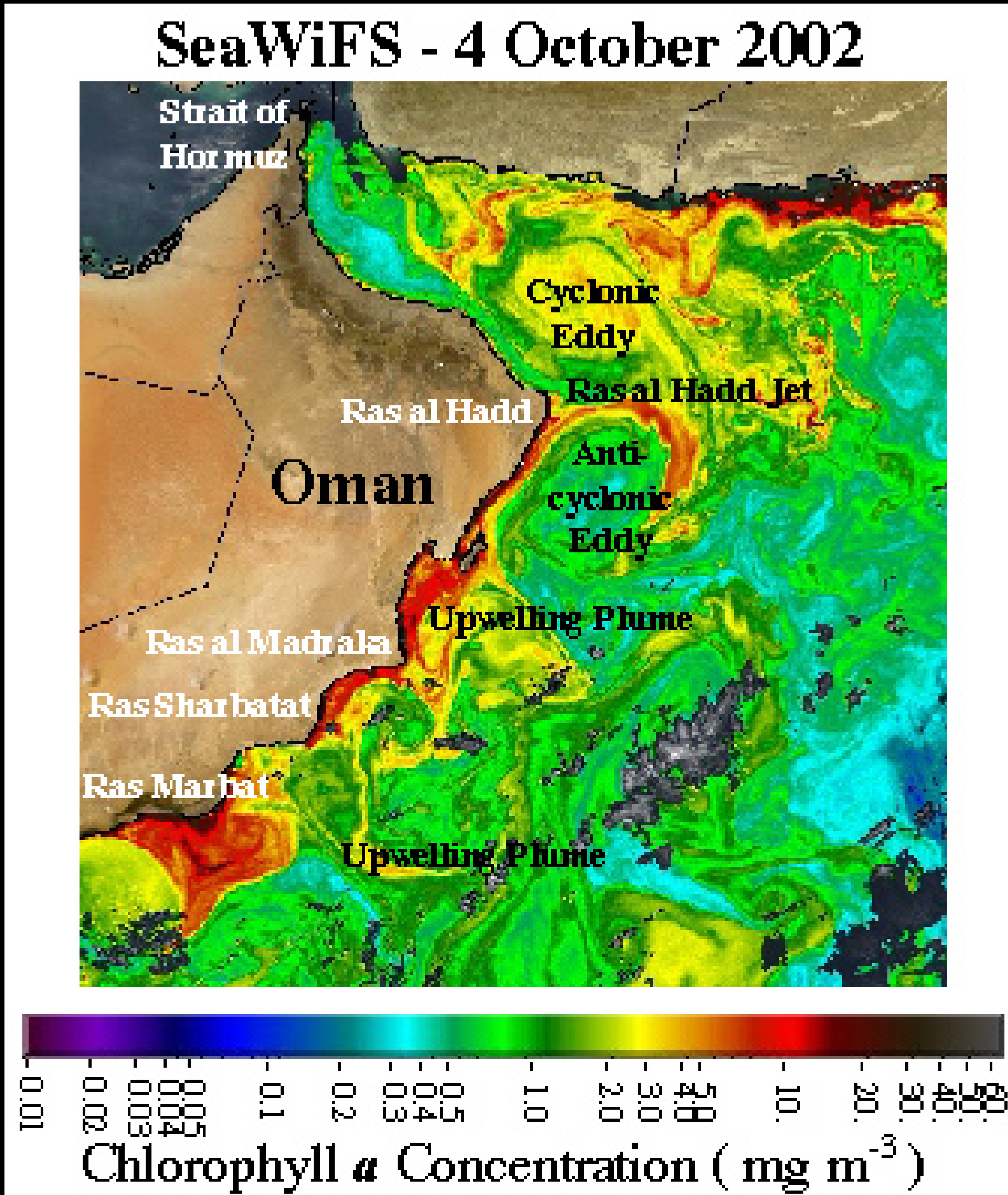


~ North-South Arabian Sea Sections for NO based and N/P Based Deficits



8°N

22-23°N



Do the Ras al Hadd Jet, and Associated Eddies and biology, help to “feed” the suboxic layer?

In any event, this region and Gulf of Oman “light up” in some satellite color images.

This Figure is From John Morrison’s SIBER PPT that I can make available.

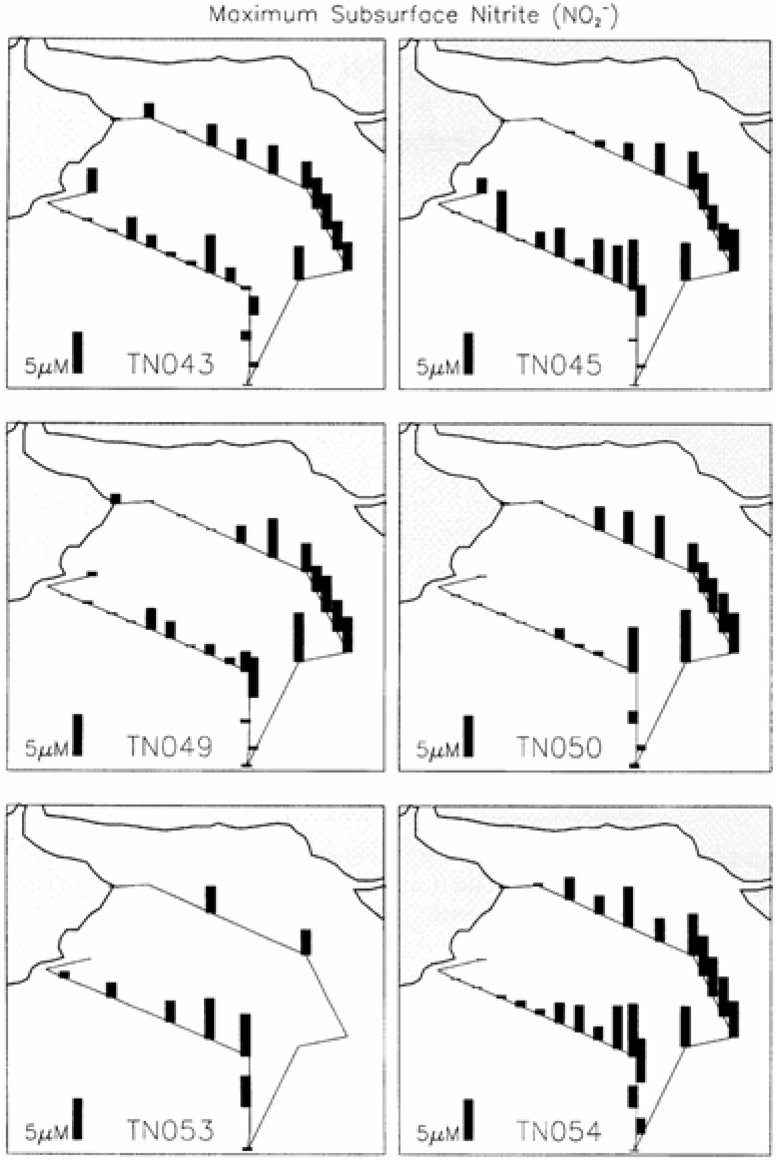


Fig. 13. Maximum nitrite concentrations (µM) at any depth ≥ 100 db.

Certainly, the RAH jet and eddies are in the right neighborhood

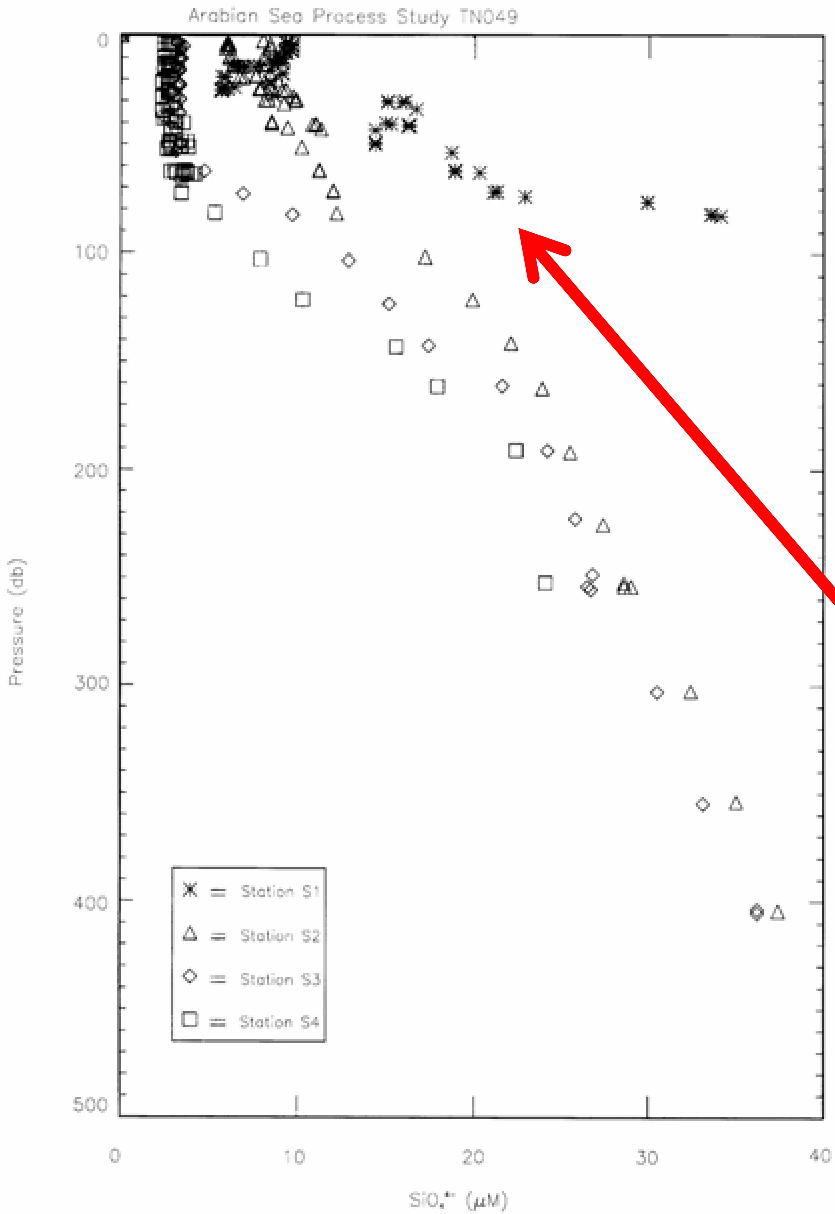
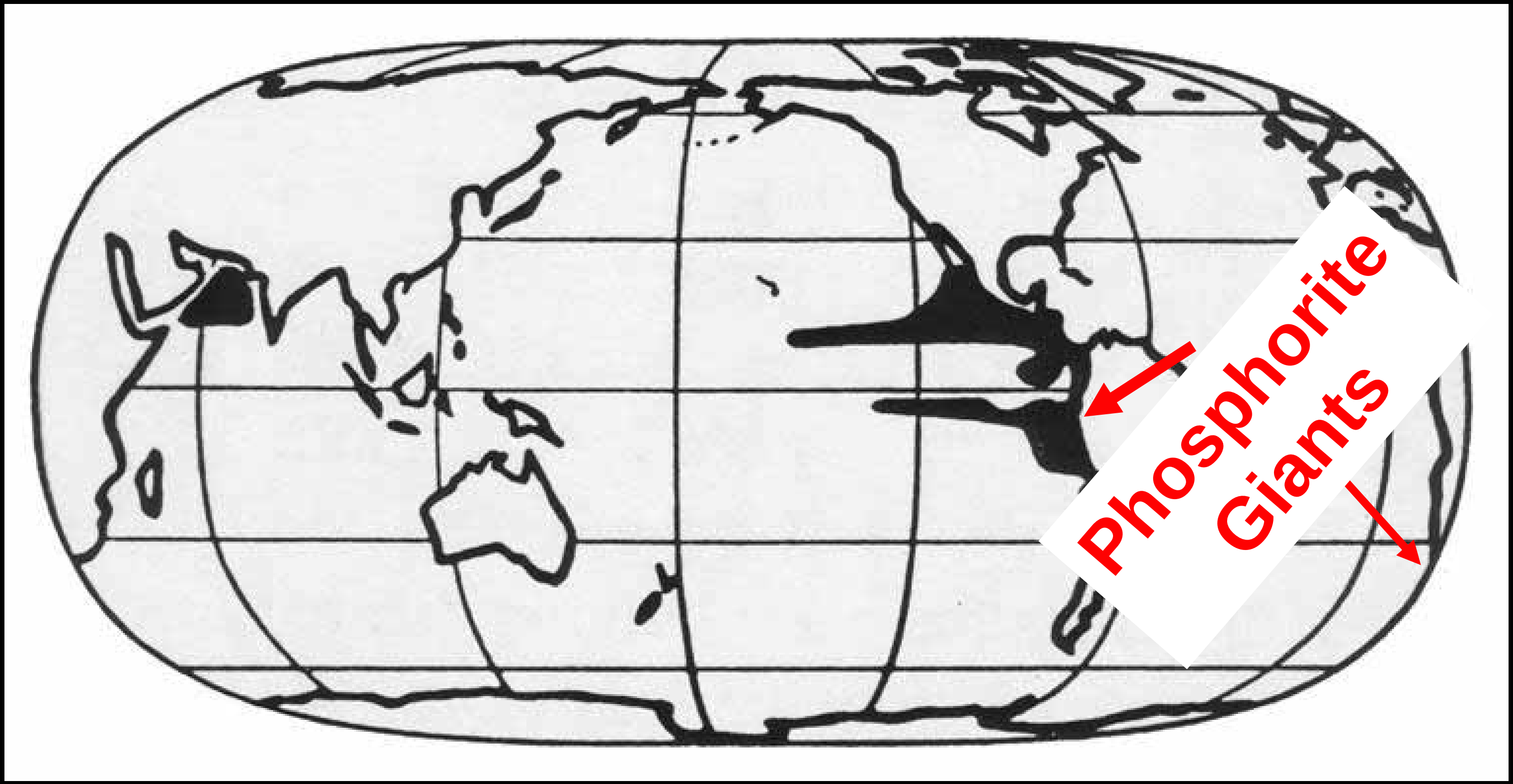


Fig. 29. Anomalously high reactive silicate (μM) values at station S-1 during cruise TN049, suggesting enhanced retention and regeneration of silicate over the shelf during coastal upwelling.

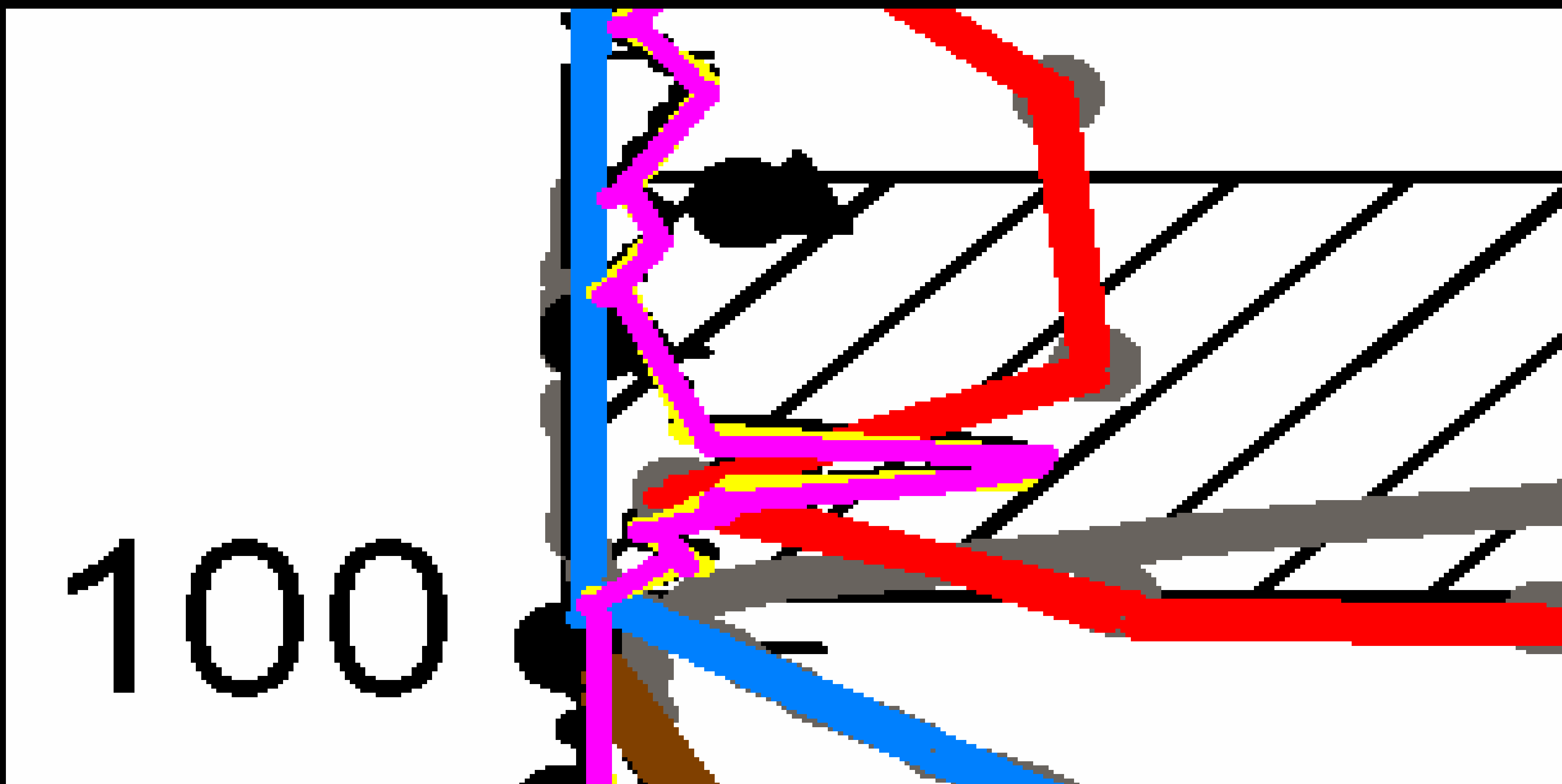
Does Si regeneration over the shelf, make the shelf a site of enhanced diatom production? Is this phytoplankton community advected northward in a coastal jet, and then swept seaward over the suboxic zone in the RAH jet?

Local nutrient trap

Shaded regions = DO concentrations <~20μM (from Deuser). Suboxic regions (DO < 3 μM) within the shaded areas are major denitrification sites.



With respect to sedimentary P deposition or loss, I think that there is a major difference between, suboxic and anoxic conditions.



Bacteria that Oxidize Sulfide With Nitrate

"The More We Look, The More We Find!!!

Denitrification Sites Not Yet Dreamt of in Our Philosophy?

Asimetrias introducidas por la operacion del la energia external en sequencias de sdeimentos y de poblaciones

Ramon Margalef

“..... of a bias introduced by the very structure of the world. It records and tells only one side of the story.”

7. Brine pockets in ice

The Holocene is Sooo Over!
Welcome to the Anthropocene!

From < 1 billion to > 6 billion in a Few Hundred Years: 2050 UN Projections 8-10 billion

Change

Change

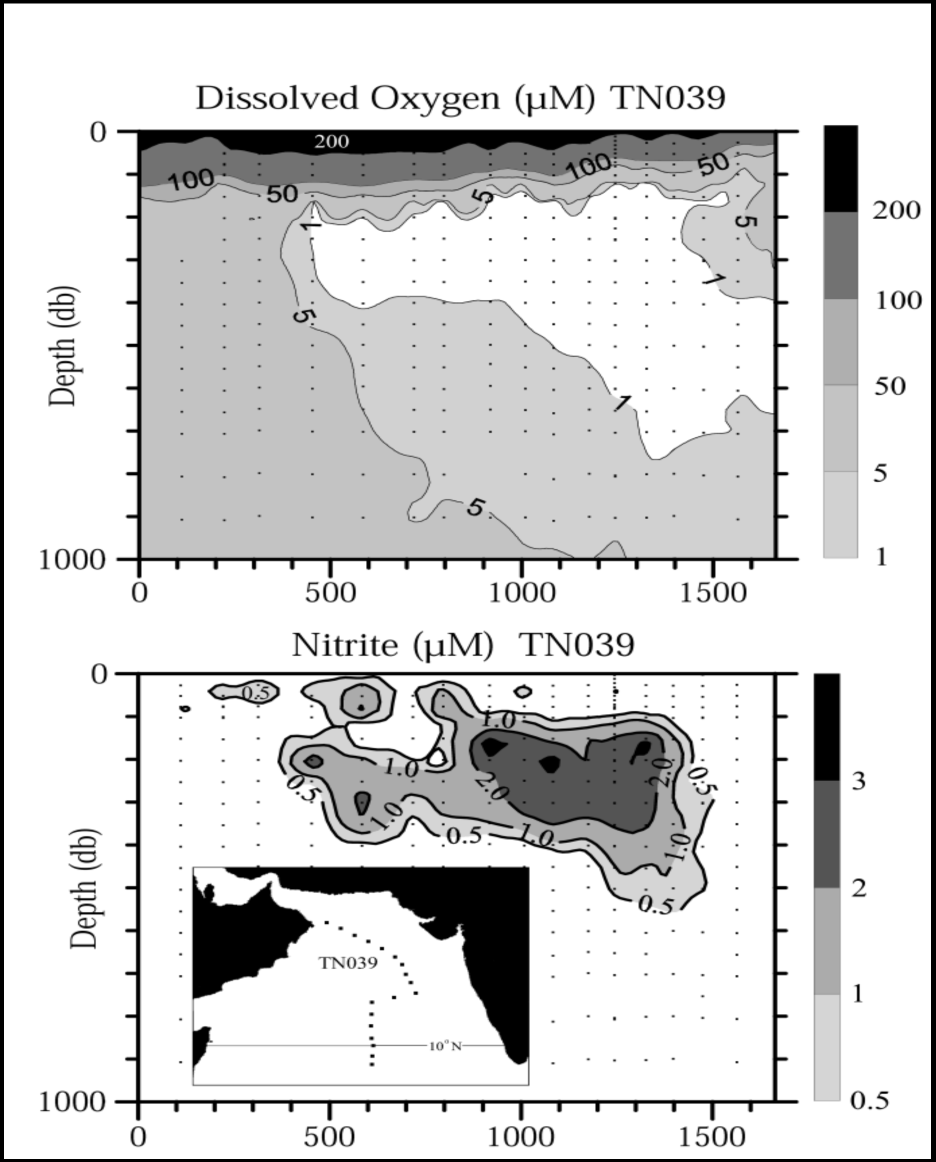
Change

10-20% increase in the flux of nitrogen to estuaries by 2030

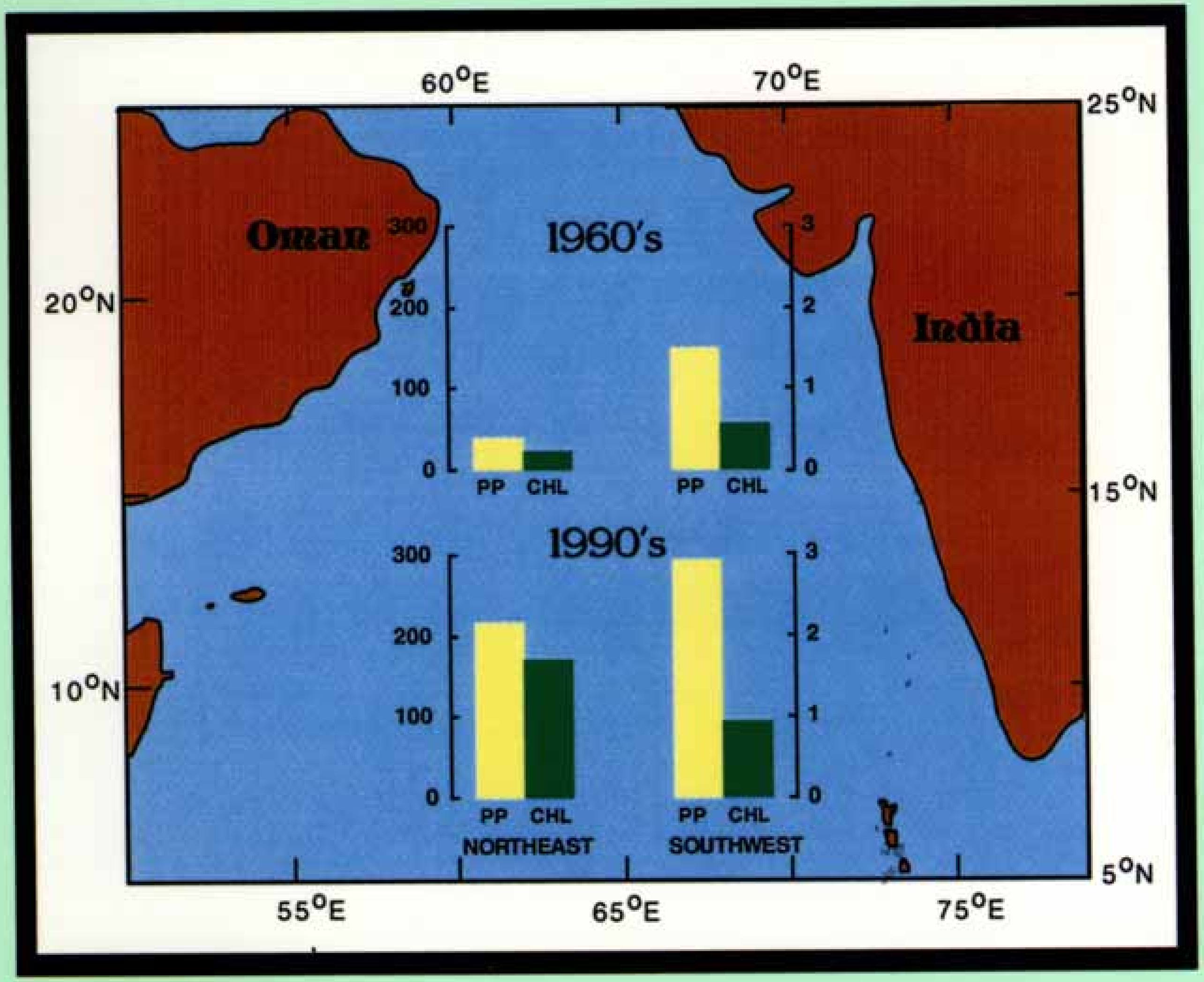
25% of global continental shelf swept by bottom trawls every year, etc.

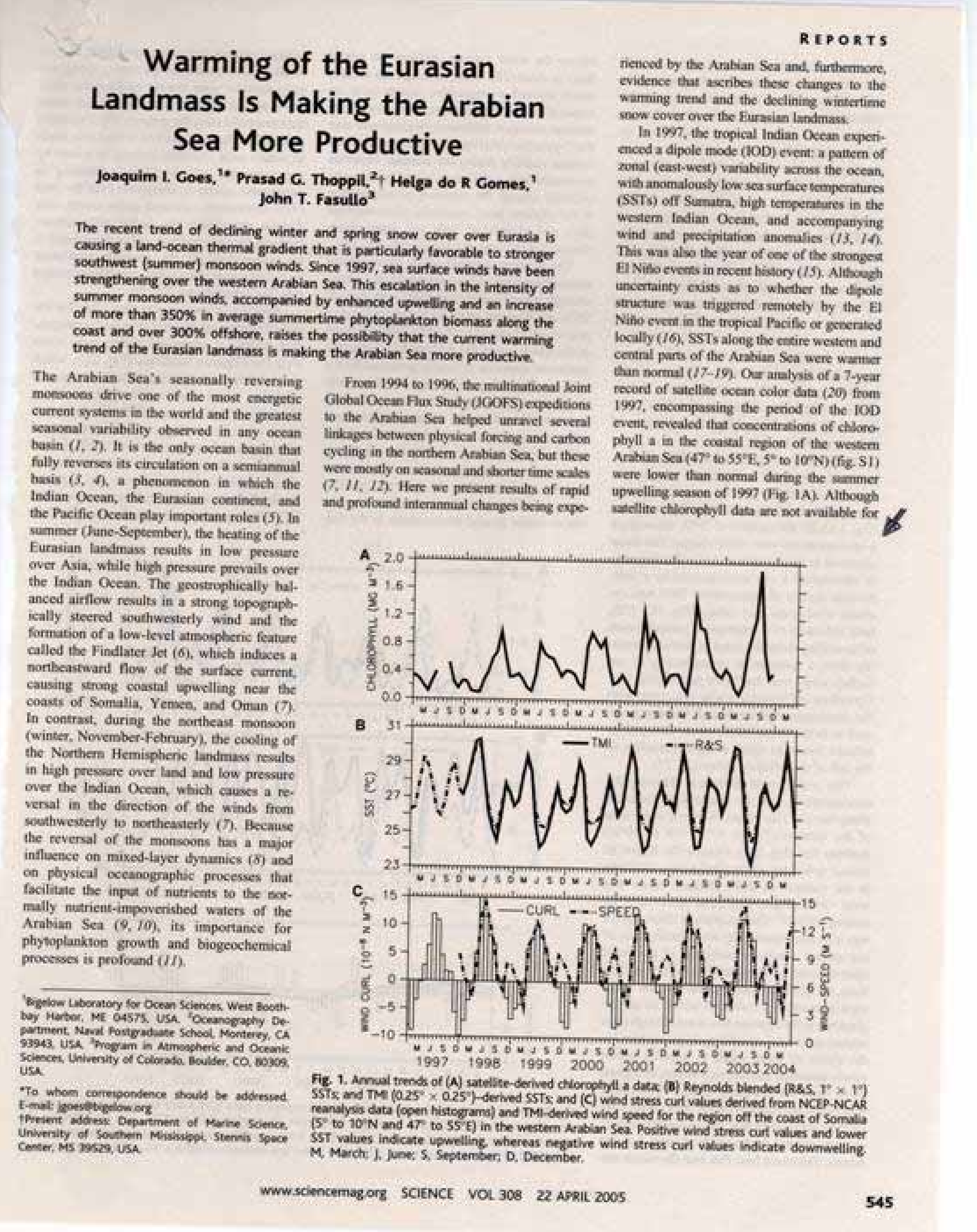
Arabian Sea

Suboxic conditions apply in only ~0.1-0.2 % of the oceanic water column's volume. Thus, minor changes in the ocean can cause large % changes in the suboxic volume.



It is important to realize that we are under-sampling a time variable system and that different types of estimates have different time scales!!!! <u>Portions of the Bay of Bengal are on the verge of suboxia</u>.


60°E
70°E
25°N
20°N
15°N
10°N
5°N
55°E
65°E
75°E
Oman
India
1960's
1990's
300
200
100
0
3
2
1
0
PP
CHL
NORTHEAST
SOUTHWEST



Warming of the Eurasian Landmass Is Making the Arabian Sea More Productive

Joaquim I. Goes,[1*] Prasad G. Thoppil,[2†] Helga do R Gomes,[1] John T. Fasullo[3]

The recent trend of declining winter and spring snow cover over Eurasia is causing a land-ocean thermal gradient that is particularly favorable to stronger southwest (summer) monsoon winds. Since 1997, sea surface winds have been strengthening over the western Arabian Sea. This escalation in the intensity of summer monsoon winds, accompanied by enhanced upwelling and an increase of more than 350% in average summertime phytoplankton biomass along the coast and over 300% offshore, raises the possibility that the current warming trend of the Eurasian landmass is making the Arabian Sea more productive.

The Arabian Sea's seasonally reversing monsoons drive one of the most energetic current systems in the world and the greatest seasonal variability observed in any ocean basin (1, 2). It is the only ocean basin that fully reverses its circulation on a semiannual basis (3, 4), a phenomenon in which the Indian Ocean, the Eurasian continent, and the Pacific Ocean play important roles (5). In summer (June-September), the heating of the Eurasian landmass results in low pressure over Asia, while high pressure prevails over the Indian Ocean. The geostrophically balanced airflow results in a strong topographically steered southwesterly wind and the formation of a low-level atmospheric feature called the Findlater Jet (6), which induces a northeastward flow of the surface current, causing strong coastal upwelling near the coasts of Somalia, Yemen, and Oman (7). In contrast, during the northeast monsoon (winter, November-February), the cooling of the Northern Hemispheric landmass results in high pressure over land and low pressure over the Indian Ocean, which causes a reversal in the direction of the winds from southwesterly to northeasterly (7). Because the reversal of the monsoons has a major influence on mixed-layer dynamics (8) and on physical oceanographic processes that facilitate the input of nutrients to the normally nutrient-impoverished waters of the Arabian Sea (9, 10), its importance for phytoplankton growth and biogeochemical processes is profound (11).

From 1994 to 1996, the multinational Joint Global Ocean Flux Study (JGOFS) expeditions to the Arabian Sea helped unravel several linkages between physical forcing and carbon cycling in the northern Arabian Sea, but these were mostly on seasonal and shorter time scales (7, 11, 12). Here we present results of rapid and profound interannual changes being experienced by the Arabian Sea and, furthermore, evidence that ascribes these changes to the warming trend and the declining wintertime snow cover over the Eurasian landmass.

In 1997, the tropical Indian Ocean experienced a dipole mode (IOD) event: a pattern of zonal (east-west) variability across the ocean, with anomalously low sea surface temperatures (SSTs) off Sumatra, high temperatures in the western Indian Ocean, and accompanying wind and precipitation anomalies (13, 14). This was also the year of one of the strongest El Niño events in recent history (15). Although uncertainty exists as to whether the dipole structure was triggered remotely by the El Niño event in the tropical Pacific or generated locally (16), SSTs along the entire western and central parts of the Arabian Sea were warmer than normal (17–19). Our analysis of a 7-year record of satellite ocean color data (20) from 1997, encompassing the period of the IOD event, revealed that concentrations of chlorophyll a in the coastal region of the western Arabian Sea (47° to 55°E, 5° to 10°N) (fig. S1) were lower than normal during the summer upwelling season of 1997 (Fig. 1A). Although satellite chlorophyll data are not available for

Fig. 1. Annual trends of (A) satellite-derived chlorophyll a data; (B) Reynolds blended (R&S, 1° × 1°) SSTs; and TMI (0.25° × 0.25°)–derived SSTs; and (C) wind stress curl values derived from NCEP-NCAR reanalysis data (open histograms) and TMI-derived wind speed for the region off the coast of Somalia (5° to 10°N and 47° to 55°E) in the western Arabian Sea. Positive wind stress curl values and lower SST values indicate upwelling, whereas negative wind stress curl values indicate downwelling. M, March; J, June; S, September; D, December.

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My experience and reading leads
me to believe that undersampling, sampling problems and incubation problems lead to underestmates
of PP.

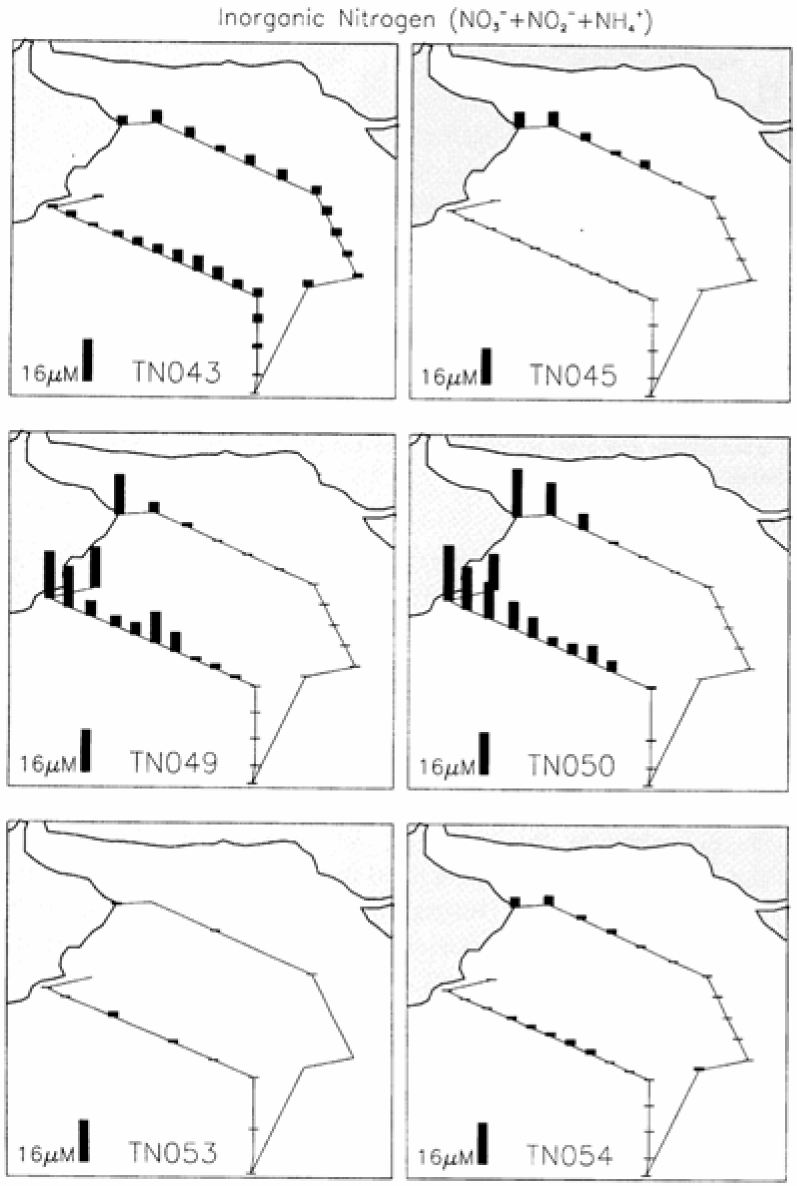
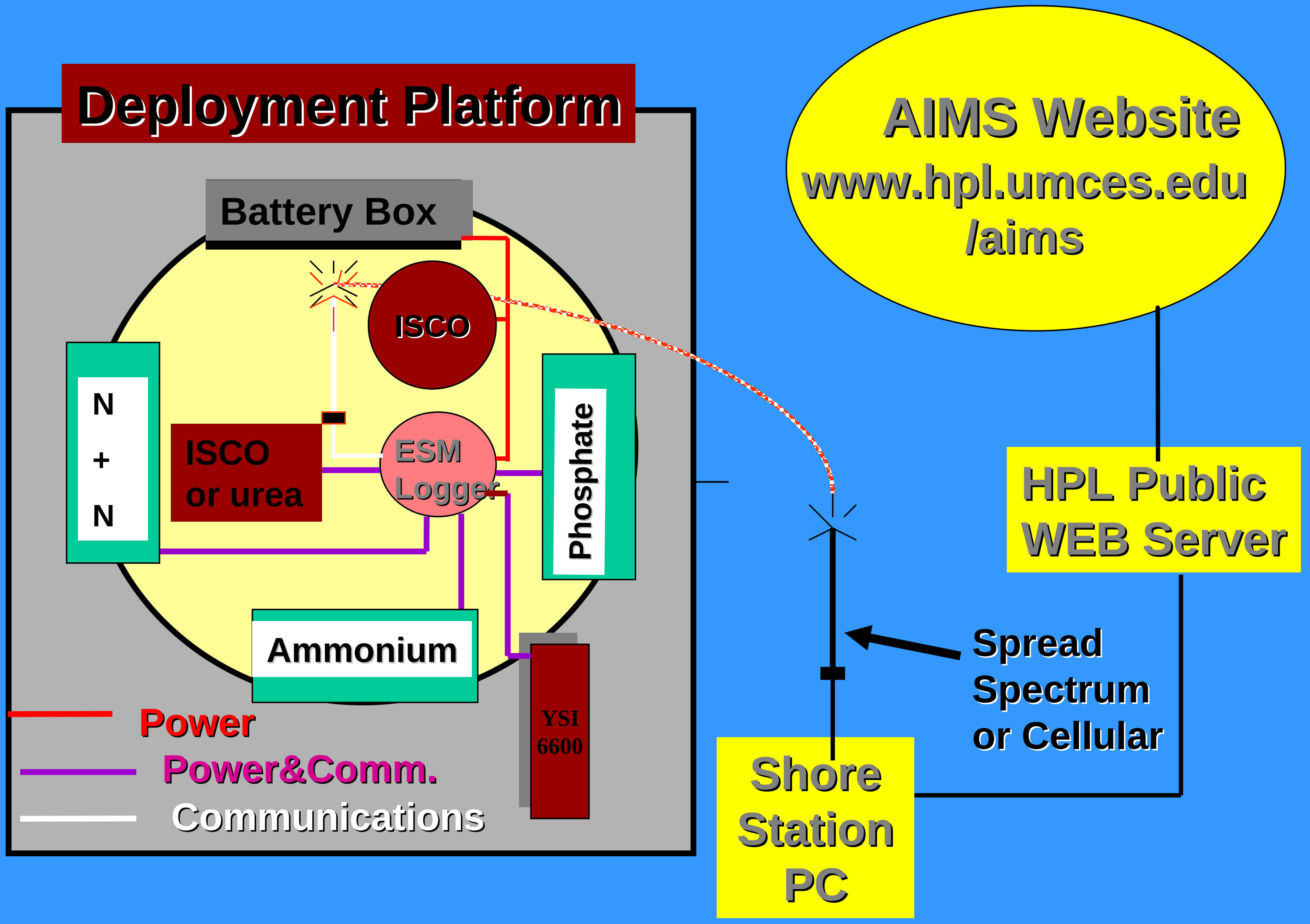


Fig. 9. Average inorganic nitrogen concentrations ($NO_3^- + NO_2^- + NH_4^+$) in the 0–25 db layer during cruises TN043, TN045, TN049, TN050, TN053, and TN054. Concentrations are in μM.

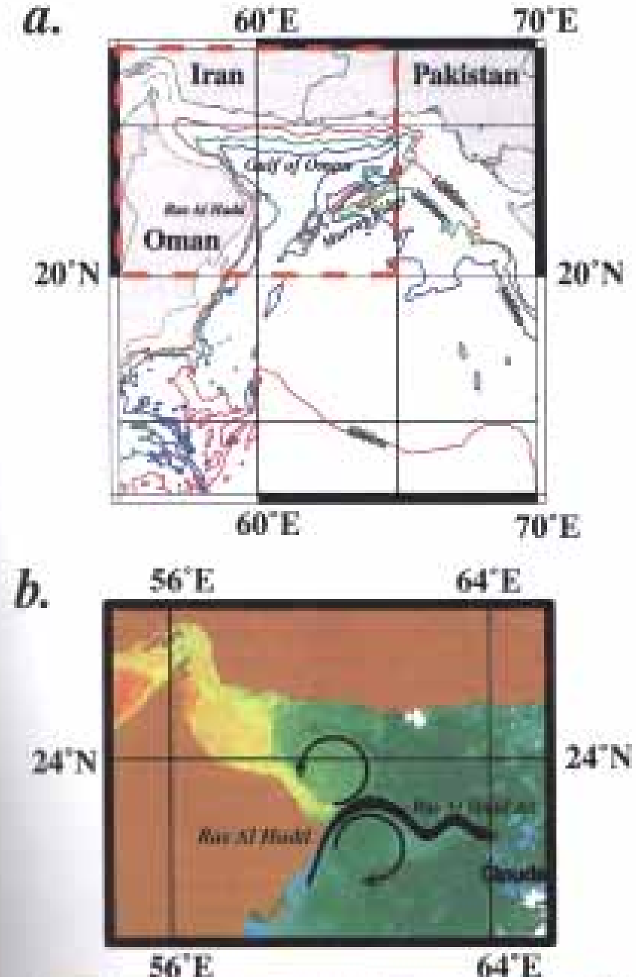
Have we paid enough attention to PP during the NE Monsoon? Does the widespread nutrient enrichment over the secondary nitrite max. during TN 043 suggest another process that feeds the suboxic zone?

Adaptive and Integrated Monitoring System (AIMS)



Conclusion

- *Thus if we are to understand the productivity of this region, it is essential to resolve the dynamics at scales of less than 10 km.*


a.
60°E
70°E
Iran
Pakistan
Gulf of Oman
Ras Al Hadd
Oman
20°N
20°N
60°E
70°E
b.
56°E
64°E
24°N
24°N
Ras Al Hadd
56°E
64°E

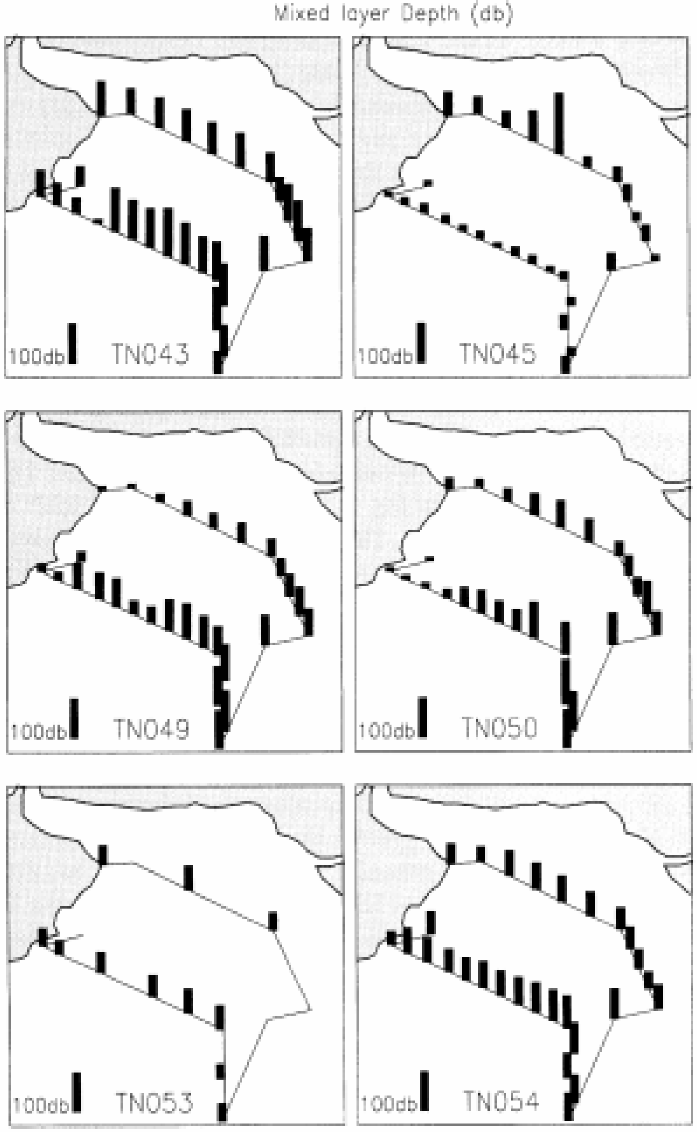


Fig. 7. Mixed layer depths cruises TN043, TN045, TN049, TN050, TN053, and TN054.

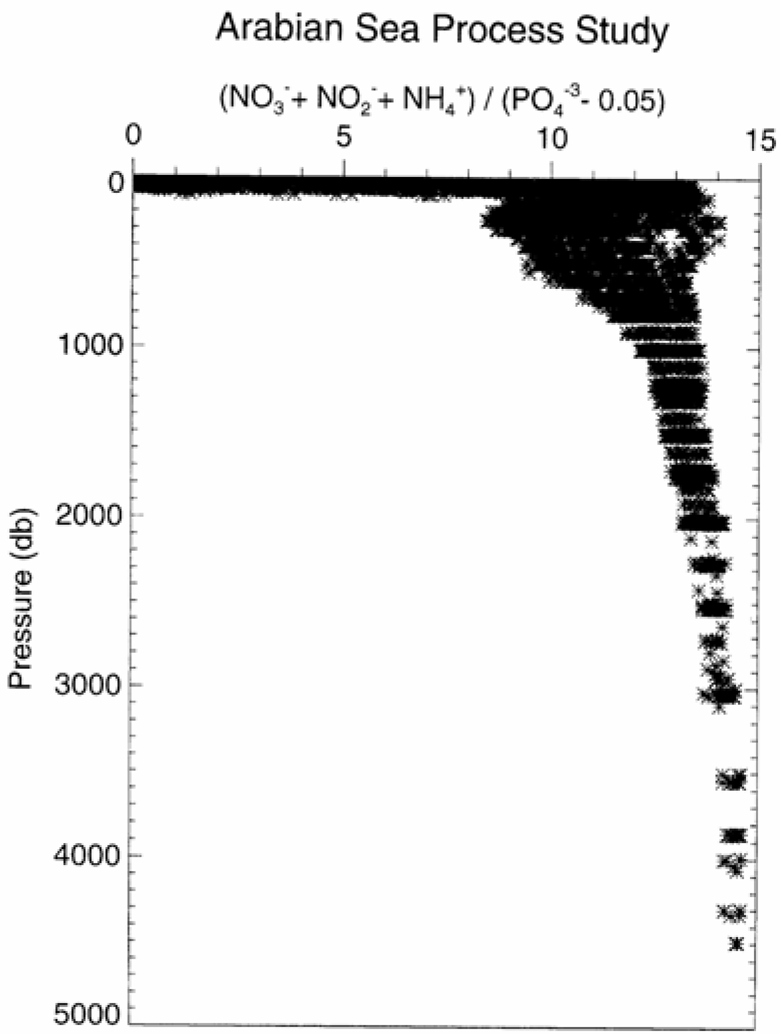


Fig. 12. Inorganic nitrogen ($NO_3^- + NO_2^- + NH_4^+$) to phosphate ratios from all data collected during the US JGOFS Arabian Sea Process Study in the Arabian Sea. Phosphate concentrations have been reduced by 0.05 μM to account for arsenate interference.

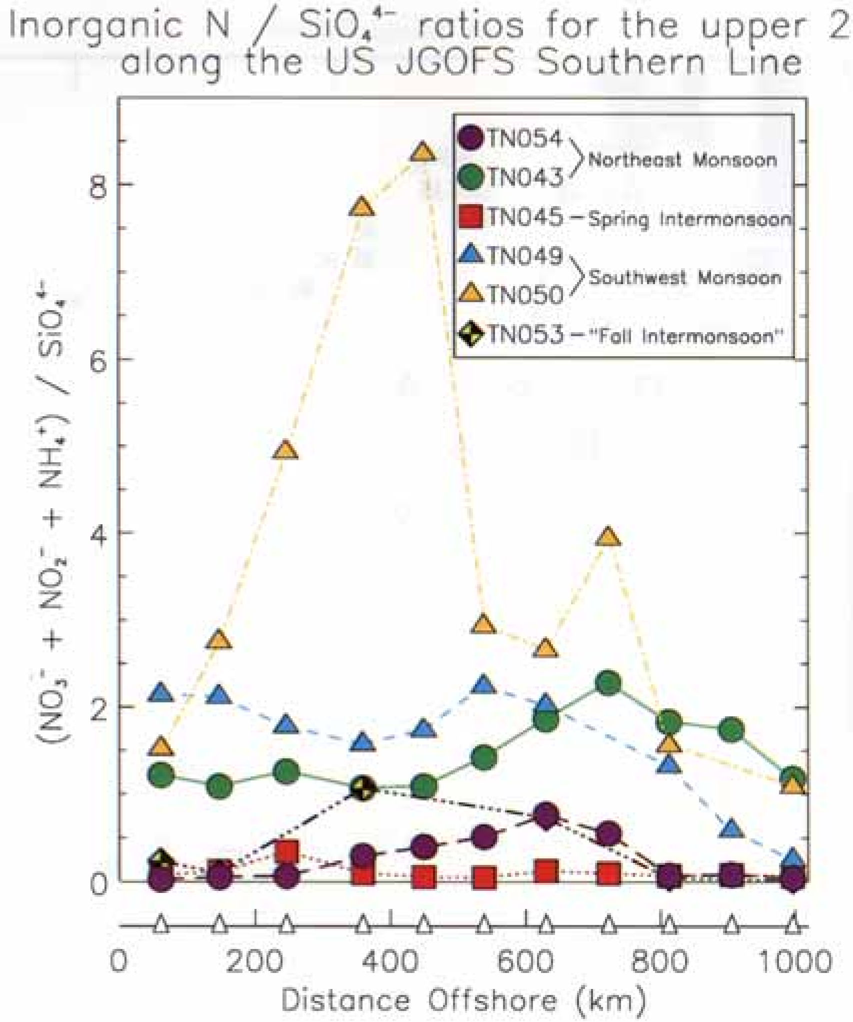


Fig. 28. Temporal and spatial distribution of average inorganic nitrogen ($NO_3^- + NO_2^- + NH_4^+$) to silicate ratios in the 0–25 db layer along the southern line (stations S-1–S-11).

Comparing $N_{Deficit}$ for two Arabian Sea cruises

Note that N deficits based on N/P ratios extend much deeper in water column than NO based deficits.