CHAPTER 8

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The Indian Ocean experiences seasonal reversal in the wind system, which is unique to this area. The wind induced current system causes upwelling and subsequently results in high primary productivity. This region is one of the most productive regions among the world’s oceans. DMS is an important gas with implications to climate change. The Indian Ocean is climatically and biogeochemically dynamic but no systematic studies had been made on reduced sulphur gas before this study was undertaken. This study is aimed to understand the distribution and factors controlling DMS and DMSP in the Indian Ocean, and to quantify the emission of non-sea salt sulphur to atmosphere. A total of 11 oceanic expeditions were undertaken in the Arabian Sea, Bay of Bengal and the Central Indian Ocean covering 352 stations. Time series observations were carried out at specific coastal and open sea locations and a few laboratory experiments were conducted to study the stability of DMSP in air and seawater. The highlights of this present study are as follows.

8.1. Summary

Intense spatial variability in DMS has been found in the North Indian Ocean.
- **Extremes in DMS** – Very high DMS and DMSP are generally found in coastal waters of the Arabian Sea from non-detectable to over 526 nM and 916 nM, respectively.

- **Low DMS in intermonsoons** – DMS concentrations are low in the intermonsoons in the Arabian Sea when bacteria seem to dominate the biological regimes. This is because of large siphoning of DMSP to form methanethiol.

- **Higher DMS with a time lag after nutrient pumping** – We found a time lag between the occurrences of higher biological production driven by nutrient pumping to surface layers, resulting from winter convection or southwest monsoonal upwelling, and maximal DMS concentrations in seawater. This is primarily because of the time required for secondary producers (grazers) to arrive on the scene.

- **Very high DMS in coastal domains of sub-oxia** – Intense biogeochemical activity following very high biological production after the southwest monsoonal occurrence appears to lead to the maximal concentrations (DMSP = 916 nM and DMS = 526 nM) in coastal waters off the west coast. These are among the highest values known to occur in the world oceans.

- **Lower DMS in the Bay of Bengal** – We found lower DMS values to occur in the Bay of Bengal compared to that in the Arabian Sea and Central Indian Ocean. This might have been due to relatively less
biological production and trophic diversity in the bay as also can be seen from generally lower DMSP levels in the bay.

**Very strong time series variability of DMS has been found from diurnal to inter-annual time scales.**

- **Higher DMS values in the afternoon** - Diurnal variability studies have shown that DMS values peaked in the water column in the afternoon. The variability is $\geq 50\%$.

- **Enhanced DMS/DMSP levels under stormy conditions** – Studies during a storm in the Bay of Bengal revealed higher contents of DMSP and DMS because of the upward pumping of nutrients from subsurface layers that resulted in higher biological activities.

- **Cloud cover influenced chlorophyll production** – Time series study during a cyclonic storm on board ORV Sagar Kanya revealed that the cloud cover enhanced chlorophyll production under the conditions of nutrient availability. There was a clear negative relation between the incident UV radiation and chlorophyll in seawater.

- **Strong monthly variability** - DMS in Dona Paula bay showed strong seasonal variability with higher values occurring in southwest monsoon season. This is because of the increase in biological activity during the southwest monsoon driven by upwelling.

- **Significant inter-annual variability** – Studies in the Central Indian Ocean during the winter season of 1998 and 1999 showed clear annual variations in DMS and DMSP concentrations in the water column,
which were higher in 1999 due to changes in biology triggered by turbulent mixing.

The factors regulating DMS in seawater were found to be multiple.

- **Pulses of salinity** – Sudden changes in salinity in the ocean are found to induce enhanced DMSP and DMS production in plankton cells. This has been confirmed by our laboratory experiments.

- **DMSP production does not depend on nitrate availability** – Relations between DMSP and nitrate have not revealed any specific dependency of the former production on the latter. Although negative relation could be seen between these two parameters this appears to result from differences in vertical behaviours.

- **Decoupling found between chlorophyll and DMS maxima** – Although chlorophyll at times shows positive relationship with DMS the vertical profiles of the two show a clear decoupling. While peak in DMS occurs closer to the sea surface that of chlorophyll is deeper. This implies that at a given location the DMS content in seawater is not a function of biological activity alone.

- **Shallow mixed layers favour higher DMS levels** – The results revealed that shallower mixed layer depths in the ocean are favourable to DMS production.

- **Higher UV radiation lowers phytoplankton and bacterial populations** – We found evidence for the suppression of
phytoplankton and bacterial counts at higher intensity of incident UV on
the sea surface.

- **Higher UV incidence enhances DMS production** – Higher DMS
  concentrations in the surface ocean were found to be favoured by
  increased incident UV radiation since bacterial activity is suppressed
  when exposure is intense.

Export fluxes of sulphur compounds are important from Indian Ocean
since this is one of the most turbulent regions, with regular occurrence
of monsoons, in world oceans.

- **DMSP in marine aerosols** – Ours is the first report on the occurrence
  of DMSP in marine aerosols.

- **Export of DMSP derived NSS gases** – Export of non-sea salt sulphur
  gases, resulting from break down of DMSP in marine aerosols and
  surface microlayer, could be comparable to DMS diffusive fluxes,
  particularly under rough weather conditions.

- **Normal diffusive DMS fluxes** - Diffusive fluxes of DMS from the
  Indian Ocean are comparable to other regions of the world.

8.2. Recommendations for future research

- **Role of DMSP in biochemical and biophysical functions of
  plankton cells** - Many workers have found that plankton cultures
  supplemented with nitrate concentrations produced less DMSP in
  comparison to those which were nitrate deficient. One possible reason
  is that there could be production of glycinebetaine (GBT), which is an
alternative to DMSP. Production of GBT requires lesser energy in comparison to that to be spent for DMSP synthesis. Conflicting views about this assumption are, however, known. Our knowledge of real functions of DMSP in plankton cells is not satisfactory and should be unraveled.

- **Long term time series measurements** - Actually a time series study is needed in this area where one can study right from the input of nutrients in the surface waters to increase in primary production and then how these changes in the water column characteristics bring about changes in DMSP and DMS concentrations with respect to phytoplankton population and speciation.

- **Phaeocystis occurrence and role to be probed** - The Ocean's microalgae play a key role in the cycling of elements that determine to a large extent the global climate. Prymnesiophyceae is a family of marine algae of which Phaeocystis is one of the most important species involved in biogeochemical cycles. This species is found to occur in the central Arabian Sea during southwest monsoon and might play an important role in cycling of materials. Therefore, investigations should be carried out to study DMS in the Arabian Sea during the prevalence of Phaeocystis blooms since the research elsewhere revealed higher DMS abundance associated with this species.

- **DMS – an essential ingredient in ocean-atmosphere interactions** – Since DMS has a major source in the ocean with implications to
indirect atmospheric cooling this should find focus in all national and international programmes in the Indian Ocean since this region is one of the most dynamic in regard to ocean atmosphere interactions.

- **Coastal investigations have to be intensified** – Since DMS variability is too large and the influence of biological variability along the coast is not very well known it is important that future DMS studies should be closely linked to carbon dioxide and biological studies.

- **Mechanisms of DMSP decomposition in seawater and air** – The pathways of DMSP decomposition is not fully known. Whether the degradation pathways in seawater and air are the same or different are unknown. This is the most demanding and challenging aspect in understanding the dynamics of DMS compounds in nature and therefore needs to be given top priority.