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CARBON CYCLE & OCEAN MODELLING

The sources and sinks of greenhouse gases (GHG) need to be estimated robustly, both in space and time, before we can come up with meaningful limitations in emissions. Large data gaps exist in world-class WMO-standard measurements of GHGs which lead to large uncertainties in estimated fluxes.

The bottom-up approach models all the processes of the marine carbon, nitrogen and oxygen cycles essential to get basin-wide estimates of the air-sea fluxes as well as the estimation of oxygen minimum zones which have a large impact of the marine ecosystem. Climatalogical and interannual simulations of the carbon, nitrogen and oxygen cycles in the ocean captured several observed phenomena-existence of subsurface chlorophyll maxima, biological productivity, temperature and salinity profiles, presence and extent of oxygen minimum zones - in the Indian Ocean, especially the Arabian Sea. Sensitivity experiments with parameters that control iron-limitation yielded some insights into the processes which control biological productivity. These simulations are perhaps the most sophisticated as they combine a state of the art biogeochemical model (TOPAZ) with an advanced ocean general circulation model (Modular Ocean Model).

The top-down approach inverts GHG measurements to yield robust fluxes. We have compiled weekly-biweekly flask measurements of GHG gases made with a gas-chromotograph complying with WMO standards from three stations, Hanle, Pondicherry and Port Blair. The measurements clearly reveal the impact of the monsoons on GHG concentrations, with lows in the SW monsoon and highs during NE monsoon. Back-trajectories from these stations show that Hanle is mostly influenced by winds from Central Asia while the other two are influenced by the monsoons. Correlation between methane and carbon monoxide show common origin of the two species (biomass and waste burning).

Inside

1.1 Flask measurements of greenhouse gases at Hanle, Pondicherry and Port Blair

We have recently completed 5 years of flask measurements, conforming to WMO-standards, of carbon dioxide, methane, carbon monoxide, nitrous oxide, sulphur hexafluoride, and hydrogen from clean background sites, Hanle (32.78 °N, 78.96 °E, 4517 m a.s.l., HLE), Pondicherry (12.01 °N, 79.86 °E, 20 m a.s.l, PON) and Port Blair (11.65 °N, 92.76 °E, 20 m a.s.l., PBL). The 5-day back-trajectories of the air masses reaching these stations are shown in Figure 1.1.

Hanle mostly samples air from Central Asia, Middle East and North Africa while the other two stations sample air from both Southwest and Northeast monsoons. Flask samples in Hanle were collected (weekly-biweekly) in the mornings while in the other two, they were collected in the afternoon after the sea breeze set in. The samples are representative of the background concentration, unaffected by immediate local sources.

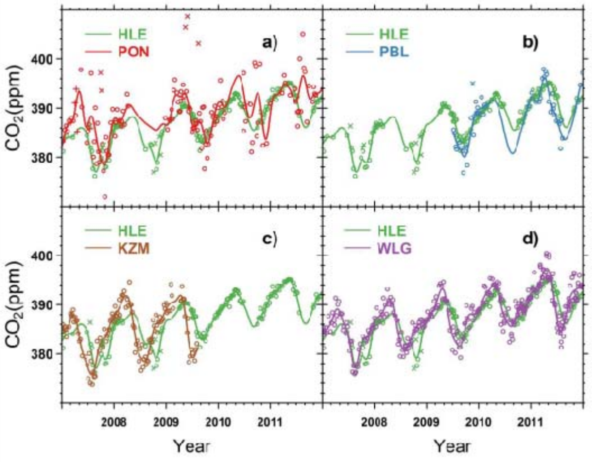

Figure 1.2 **Time series of carbon dioxide flask measurements. Two Asian stations (Kazhakstan, KZM and Mt. Waligaun WLG) are also shown.**

The measurements of carbon dioxide at the three sites along with two other measurements at other Asian stations (KZM, Kazhakstan, WLG – Mt. Wauligan, China) are shown in Figure 1.2. The smoothed curves in all the figures are based on a standard procedure which includes a first-order polynomial for the growth rate and two harmonics for the annual cycle as well as a low pass filter with 80 and 667 days as short-term and long-term cutoff values, respectively. The anomalies are the residuals

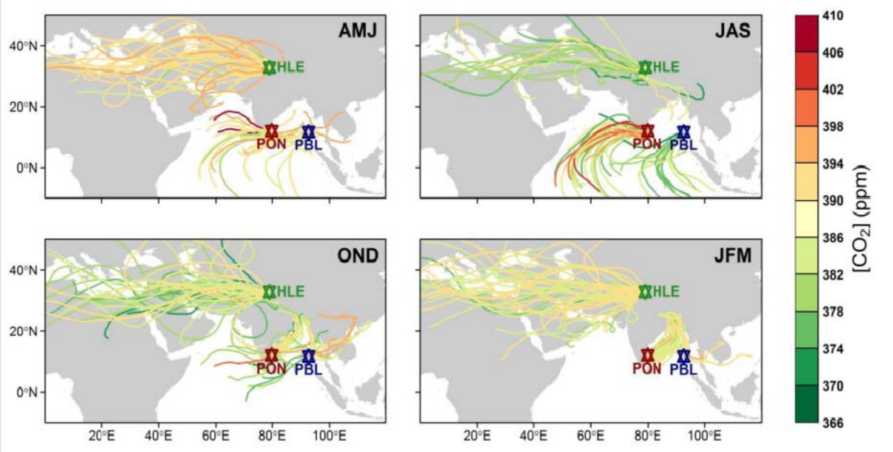

Figure 1.1 **Five-day back-trajectories and concentrations generated using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) model driven by wind fields from the Global Data Assimilation System (GDAS) archive data based on National Centers for Environmental Prediction (NCEP) model output (https://ready.arl.noaa.gov/gdas1.php). Back-trajectories are coloured according to individual carbon dioxide measurements on corresponding sampling dates.**

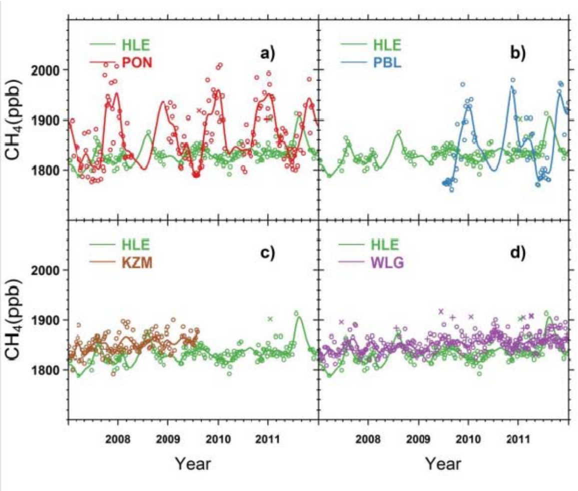

Figure 1.3 Time series of methane flask measurements. Two Asian stations (Kazhakstan, KZM and Mt. Waligaun WLG) are also shown.

of the data from the smoothed curves. HLE observed an increase in CO_2 mole fractions from 382.3±0.3 ppm to 391.4±0.3 ppm between 2007 and 2011, with annual mean values being lower (by 0.2–1.9 ppm) than KZM and WLG. At PON, the annual mean CO_2 mole fractions were generally higher than at HLE, with differences ranging between 1.9–4.3 ppm (Figure 1.2a). The annual mean CO_2 gradient between PON and HLE reflects the altitudinal difference of the two stations, and the larger influence of CO_2 emissions at PON, mostly from South India. Seasonal cycles at PON and PBL reflecting the effect of monsoon circulation can be clearly seen. Measurements of methane are shown in Figure 1.3. At HLE, annual mean CH_4 increased from 1814.8±2.9 to 1849.5±5.2 ppb between 2007 and 2011. The multiyear mean CH_4 value at HLE was lower than at KZM and WLG on average by 25.7±3.1 and 19.6±7.8 ppb.

The seasonal cycle in methane is more pronounced in Pondicherry and Port Blair due to agriculture and biomass burning than at Hanle which is in a cold desert. Correlations between the anomalies of methane and carbon monoxide measurements can be seen in Figure 1.4. It can be seen that the two are closely correlated indicating sources of common origin, usually incomplete combustion of biomass.

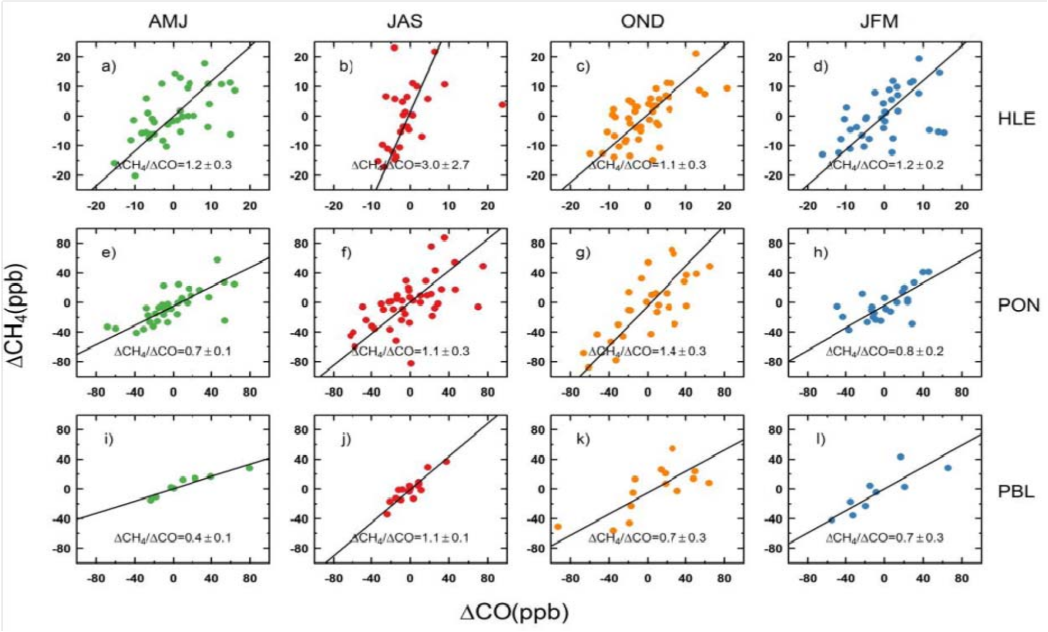

Figure 1.4 Scatter plot of carbon monoxide and methane residuals

This data will provide a valuable base for constraining India's sources and sinks of greenhouse gases.

N K Indira, P S Swathi, V K Gaur, Prashant Meti, Nagaraj Naik, Akash Choudhury, Shambulinga, Prabhat Prabhu, B C Bhatt*, M V Reddy*, D Angchuck*, S S Jorphail*, M V Reddy#, S Balakrishnan#, S Patnaik#, M Begum**, S Durairaj**, S Kirubagaran **, X Lin^, M Ramonet^, M Delmotte^, M Schmidt^
*Indian Astronomical Observatory, Hanle
#Pondicherry University
**NIOT
^LSCE

1.2 Carbon cycle study in the north Indian Ocean

The major objective is to understand the physical-biological-chemical processes in the ocean which influence the primary productivity and carbon flux across the air-sea interface. This study is carried out by incorporating biological and chemical process models in the ocean general circulation model and evaluating the results of a three dimensional physical-biological-chemical model (TOPAZ) using data from different sources for spatial, monthly, seasonal and interannual variations. Model simulations have been carried out with climatological and interannual fluxes forcings and the results have been evaluated by using the available data from different sources in the Arabian Sea (AS) and the Bay of Bengal (BOB).

Initially, the model (TOPAZ) simulation results are evaluated for seasonal, inter annual and spatial variations of SST and surface chlorophyll (Chl) in the AS and the BOB using the satellite data. Simulation results on Temperature, Salinity, Chlorophyll, Nitrate, Oxygen, Silicate are compared with the Cruise Data from Indian JGOFS programme. Spatial variations of different biogeochemical variables with depth along 65° E Transect have been studied using the climatological simulations of the TOPAZ model and Indian JGOFS Cruise data.

Depth Profiles of temperature, salinity, nitrate, dissolved inorganic carbon (DIC), oxygen, chlorophyll and primary productivity (PP) from the climatologi-

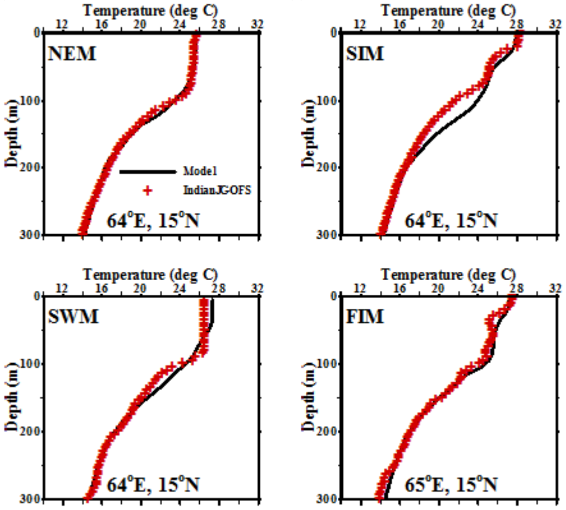

Figure 1.5 Comparison of depth profiles of temperature (° C) from model with Indian JGOFS data at (15° N, 65° E) during four seasons

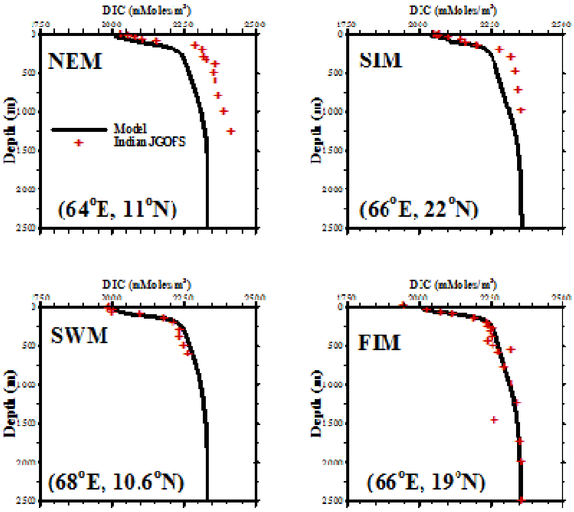

Figure 1.6 Comparison of depth profiles of Dissolved Inorganic Carbon (mMoles/m^3) from model with Indian JGOFS data for four seasons

cal model simulations are compared with the Indian JGOFS data at many (more than 10) locations for four seasons (NEM, North East Monsoon – December, January, February; SIM, Spring Inter Monsoon – March, April, May; SWM, South West Monsoon – June, July, August; FIM, Fall Inter Monsoon-September, October, November). Figure 1.5 shows the comparison of depth profiles of temperature from the model with Indian JGOFS data at one station during four seasons and it is noted that temperature obtained from the model compares well with the data. It is noted that spatial variation of temperature with depth from the model is able to capture many of the features observed during Indian JGOFS cruises (Report and Research Papers related to Indian JGOFS Cruise) Comparison of DIC with depth (Figure 1.6) at various stations shows that DIC from the model is less than the cruise data during NEM and SIM but is close to the data during SWM and FIM.

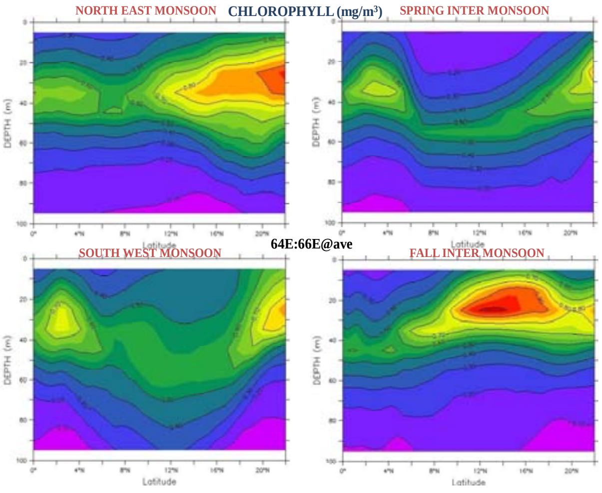

Figure 1.7 Latitudinal variation of Chlorophyll (mg/m^3) with respect to depth along 65° E transect

Spatial variation of Chl with depth along 65° E transect (Figure 1.7) shows that subsurface maximum exists during all seasons. Chl values are higher in the regions north of 16° N and maximum values of Chl are obtained during FIM and NEM. Chl values are lower in the regions between 6° N and 16° N during all seasons.

Spatial variations of temperature, nitrate and Chlorophyll along the 65° E transect clearly indicate that regions with low temperature have high nitrate and chlorophyll concentration during different seasons.

Parameter sensitivity study

Numerical simulations of TOPAZ are carried out for three different values of a parameter related to iron limitation namely, $(Fe:N)_{irr}$. Initially the model results are evaluated for some of the biogeochemical components using data from World Ocean Atlas-05 (WOA-05). Then, the results of the simulations are examined in detail for spatial and seasonal variations of different biogeochemical components. It is noticed that when $(Fe:N)_{irr}$ is reduced (For Exp b, value of $(Fe:N)_{irr}$ is 1/4th of the value used in Exp a) PP and Chl increase, NO_3 and pCO_2 decrease in the northwest AS, during January-March and August-December (Figure 1.8). But PP, Chl, NO_3 and pCO_2

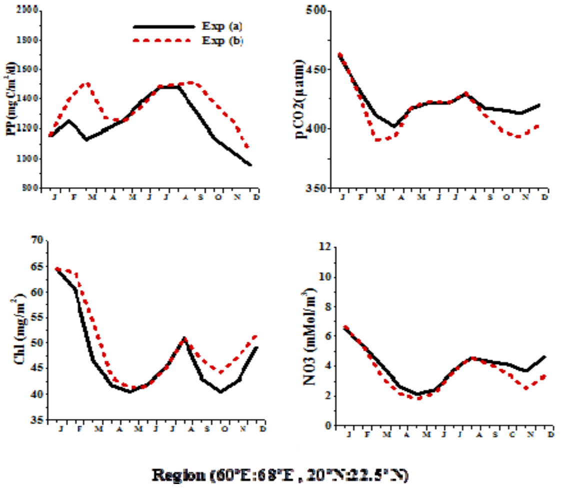

Figure 1.8 Monthly variation of depth integrated Primary Productivity (mgC/m^2/d) and Chlorophyll (mg/m^2), Nitrate averaged over top 50m (m Moles/ m^3) and surface pCO_2 in northwest Arabian Sea

did not show any change in the east AS and most of BOB when (Fe:N)$_{irr}$ is varied. Model results show that iron limitation has significant influence on PP, Chl as well as pCO$_2$ at some of the regions in the west AS. Model results are being analysed to understand the effect of iron limitation on primary productivity due to different phytoplankton and regeneration processes.

Modelling and simulation of subsurface oxygen distribution in the north Indian Ocean

The focus of this study is to understand the processes related to nitrogen and carbon cycles in the oxygen-depleted environments from literature, data and numerical simulations of the existing biogeochemical models. The biogeochemical model TOPAZ developed at GFDL (Dunne et al., 2010) coupled with MOM4p1 has been used to carry out the numerical simulations for climatological and interannual variability in the global domain. Initially, model results on the annual average value of oxygen concentration at deeper depths are compared with the World Ocean Atlas in the global domain. It is noticed that model is able to capture all the Oxygen Minimum zones well (not shown). Variation of oxygen with respect to depth from the model is compared with the data from Indian JGOFS Cruises at many stations in the AS. It can be noticed that there is a considerable decrease in oxygen below 100m. Model simulations are able to capture the oxygen minimum zone well in the AS as observed in Indian JGOFS Programme, but the oxygen concentration from the model is more than the data by 5 to 10 units. Spatial variation of Oxygen with depth along the 65º E transect (Figure 1.9) shows that, oxygen concentration is less than 20 Mol/m^3 in the regions north of 10º N and is 5 Mol/m^3 between 16º and 20º N during all seasons.

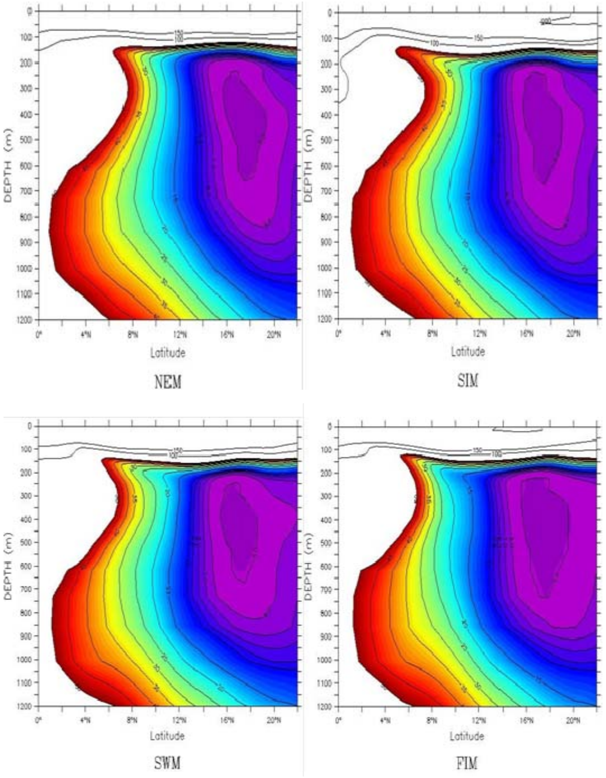

Figure 1.9 Latitudinal variation of Oxygen (m Moles/m^3) with respect to depth along 65º E transect

Results of the model simulations for climatological and interannual variability are being analysed and evaluated using data, for different biogeochemical components to get a better understanding of the processes and model parameters in the oxygen minimum zone in the north Indian Ocean.

M K Sharada, C Kalyani Devasena, M V Sundara Deepthi, M K Shelva Srinivasan, P S Swathi, K S Yajnik