1

CARBON CYCLE AND OCEAN MODELLING

Measurement and modelling of the carbon cycle are key components in understanding the science and mitigation options of global warming. At CSIR-4PI (erstwhile C-MMACS) we have been involved in a comprehensive study of the carbon cycle which covers atmospheric, terrestrial and oceanic components. The key processes involved in the oceanic carbon cycle, especially the role of iron in photosynthesis has been studied by embedding a complex biogeochemical model in an ocean general circulation model. The presence and extent of oxygen minimum zones in the ocean have also been modelled. The modelling of atmospheric transport of green house gases combined with accurate measurements of green house gases has provided robust fluxes from basin-scale regions to complete the budgets of carbon. Temperate Eurasia was shown to be a robust sink to the tune of 1.5 gigatonnes of carbon. A new transport model based on LMDZORINCA was developed for future use in inversion.

Inside

- *Seasonal and Interannual Variability of Marine Ecosystem in the North Indian Ocean*
- *Forward Modelling of Carbon Dioxide Transport with LMDZORINCA*

1.1 Seasonal and Interannual Variability of Marine Ecosystem in the North Indian Ocean

We have investigated the climatological and interannual variability of biogeochemical cycles in the north Indian Ocean with simulations of TOPAZ (Tracers of Phytoplankton with Allometric Zooplankton) during 1949-2009. This model has twenty five tracers and incorporates several processes like multinutrient limitations including the micronutrient iron, nitrification-denitrification, regeneration of nutrients, dynamic elemental ratios etc. and is embedded in an ocean General Circulation Model (Modular Ocean Model MOM4). 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, interannual and spatial variations of SST and surface chlorophyll (Chl) during 1998-2007 in the AS and the BOB using the satellite data. Monthly variations of SST are compared with satellite data from TMI, MODIS-A and ERSST (Extended Reconstructed Sea Surface Temperature) data during 1997 to 2009 at seven stations in the AS and nine stations along the 88º E and coastal transects made by NIO during BOBPS Cruise carried out in the Bay of Bengal. Comparison of model results with the data at two stations in the BOB and at two stations in AS are shown in Figure 1.1. It can be seen that the model is able to capture the trend seen in the observed data but SST is underestimated during June to November at all locations during most of the years in the BOB and SST is underestimated during SIM (Spring Inter Monsoon-April, May, June) and FIM (Fall Inter Monsoon – September, October, November) and overestimated during SWM (South West Monsoon – June, July, August) sometimes at all locations during most of the years in the AS. In general, SST from TMI is higher than ERSST and SST from the model is close to the MODIS data at many locations during many months.

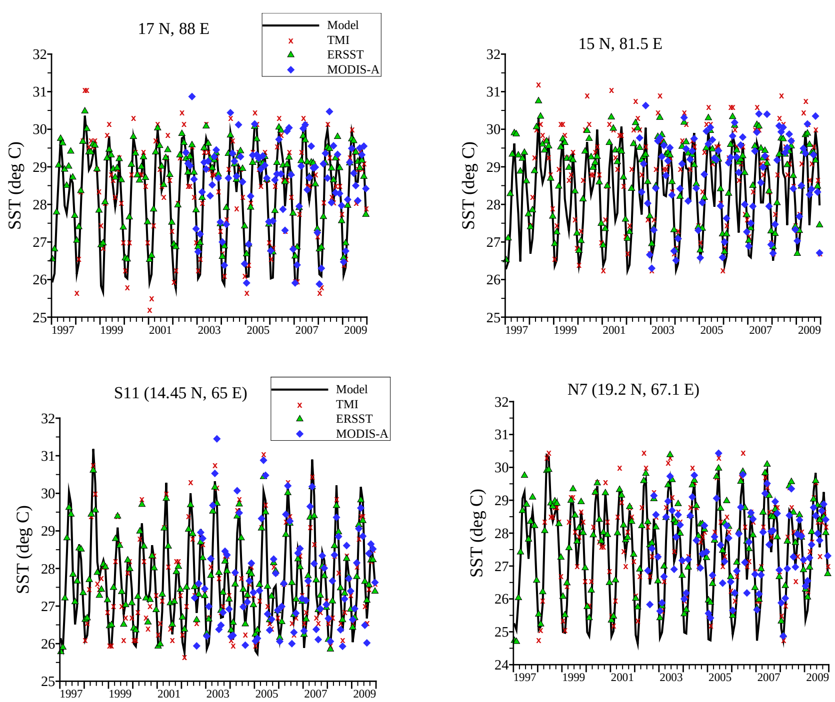

Figure 1.1 Monthly variations for SST for the period 1997-2009 at 2 stations in the Bay of Bengal and 2 stations in the Arabian Sea

Monthly variations of surface Chl are compared with satellite data from SeaWiFS and MODIS-A during 1997 to 2009. Comparison of model results with the data at two stations in the AS and

BOB are shown in Figure 1.2. It can be seen Chl values from the model are always higher than the satellite data at all locations during all the years in the BOB. The model is able to capture the trend seen in the observed data, whereas it is unable to capture high values of Chl during SWM and NEM (North East Monsoon – December, January, February) during most of the years in the AS.

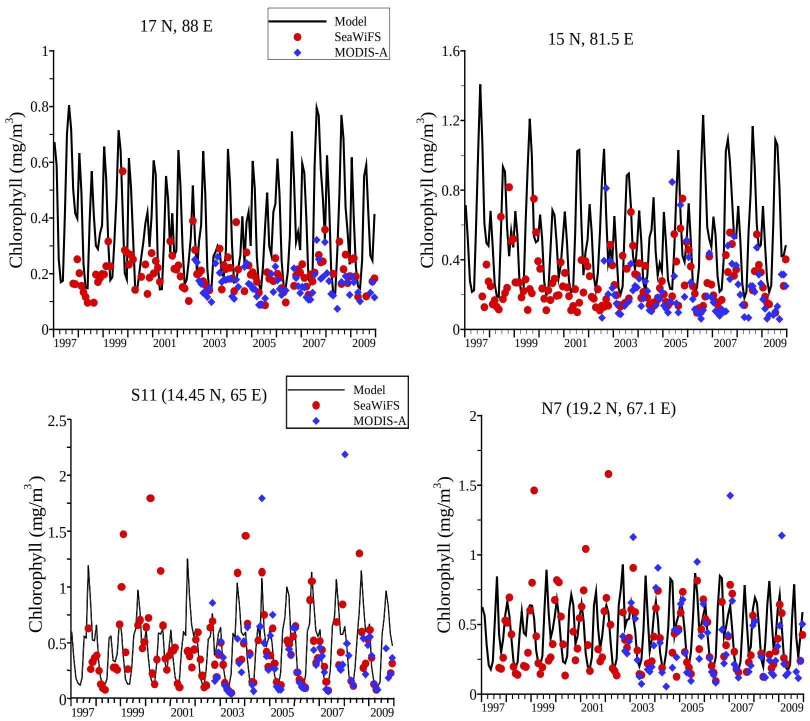

Figure 1.2 Monthly variation of chlorophyll for the period 1997-2009 at 2 stations in the Bay of Bengal and 2 stations in the Arabian Sea

Model simulations are able to capture most of the features that are observed in the satellite data in the North Indian Ocean for both SST and surface Chl. This kind of model validation studies are required to identify and understand in detail the significant marine ecosystem processes in the north Indian Ocean for estimation of primary productivity and carbon flux.

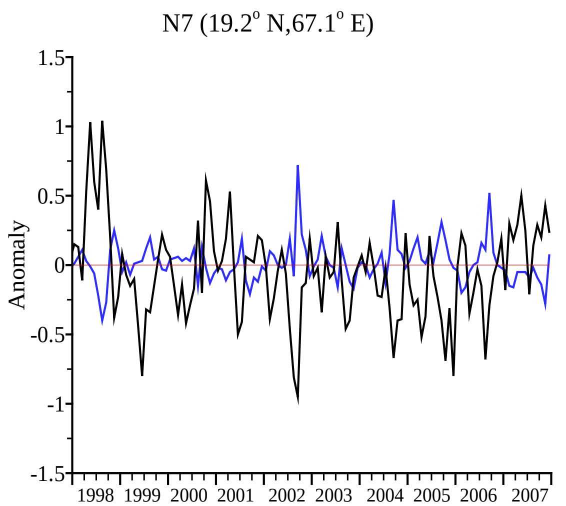

Figure 1.3 Surface Chl anomaly (mg/m3) scaled by 2 and SST (^{0}C) anomaly in the interannual simulations (1998-2007)

Anomalies of surface Chl from model simulation results and SeaWiFS for the period 1998-2007, surface Chl and SST anomalies with MODIS-A for the period 2003-2007 are studied. It is seen that there is a negative surface Chl anomaly during a positive SST anomaly i.e., when there is an increase in SST, surface Chl decreases. To emphasize this trend a few locations in the AS and BOB are studied in detail using model simulations. Figure 1.3 illustrates the two anomalies from the model for a location in the AS (Blue –Chl Anomaly*2, Black- SST Anomaly). Studies on anomalies of SST and surface Chl from model and satellite data will help in analysing the impact of climate change on ecosystem and carbon cycle.

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 at 3 Stations in AS, namely S4 (59.8°E, 17.2°N), S7 (62° E, 16° N) and N7 (19.2º N, 67.1º E) for monthly variations with depth. It is noticed that at 2 stations S4 and S7, PP and Chl increase, NO_3 and pCO_2 decrease during January-March and September-December, when $(Fe{:}N)_{irr}$ is reduced. However at N7, PP, Chl, NO_3 and pCO_2 did not show any change 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 AS (Figure 1.4).

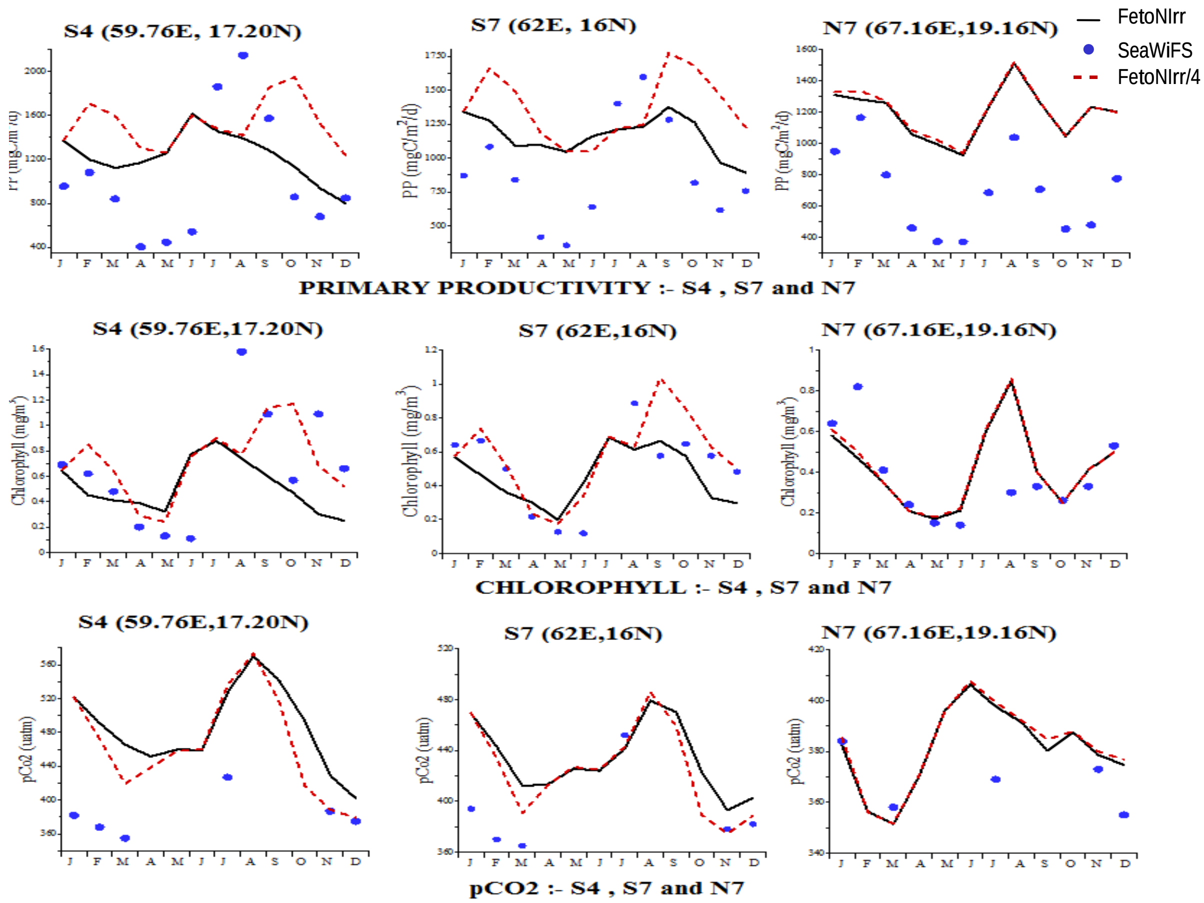

Figure 1.4 Monthly variations of Primary Productivity (mgC /m² /d) over the euphotic zone, surface Chlorophyll (mg /m³) and sea surface pCO_2 (uatm) for the locations S4 (59.76E,17.20N), S7 (62E,16N) and N7(67.16E,19.16N)

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 coupled with MOM4p1 has been used to carry out the numerical simulations for

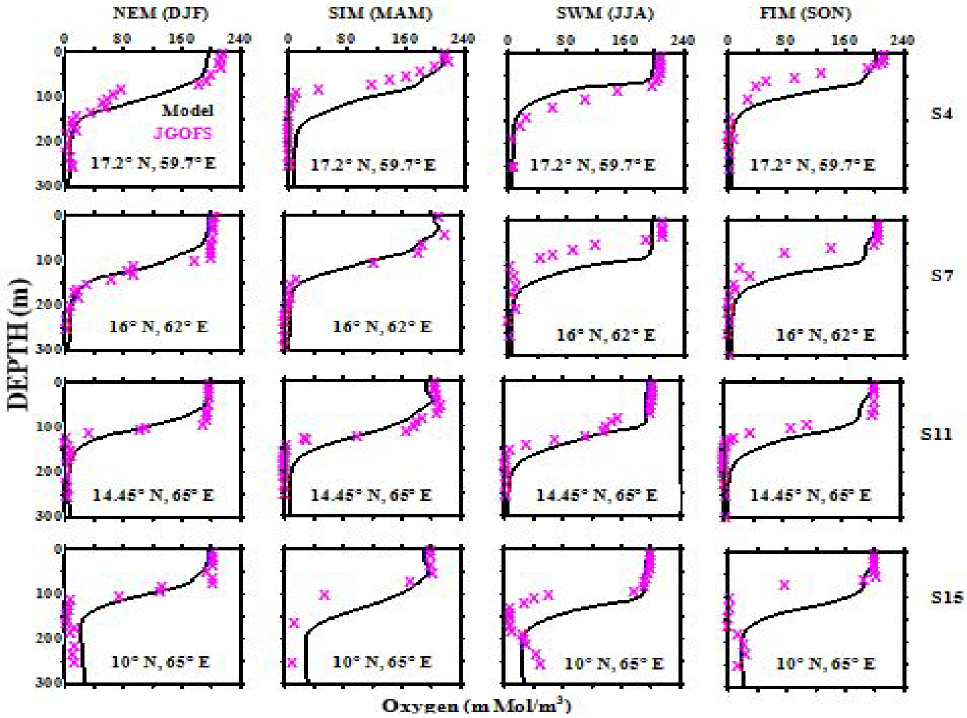

Figure 1.5 (a) Comparison of Oxygen (mMol/m³) from Model with USJGOFS observations during four seasons at 4 stations in the Arabian Sea

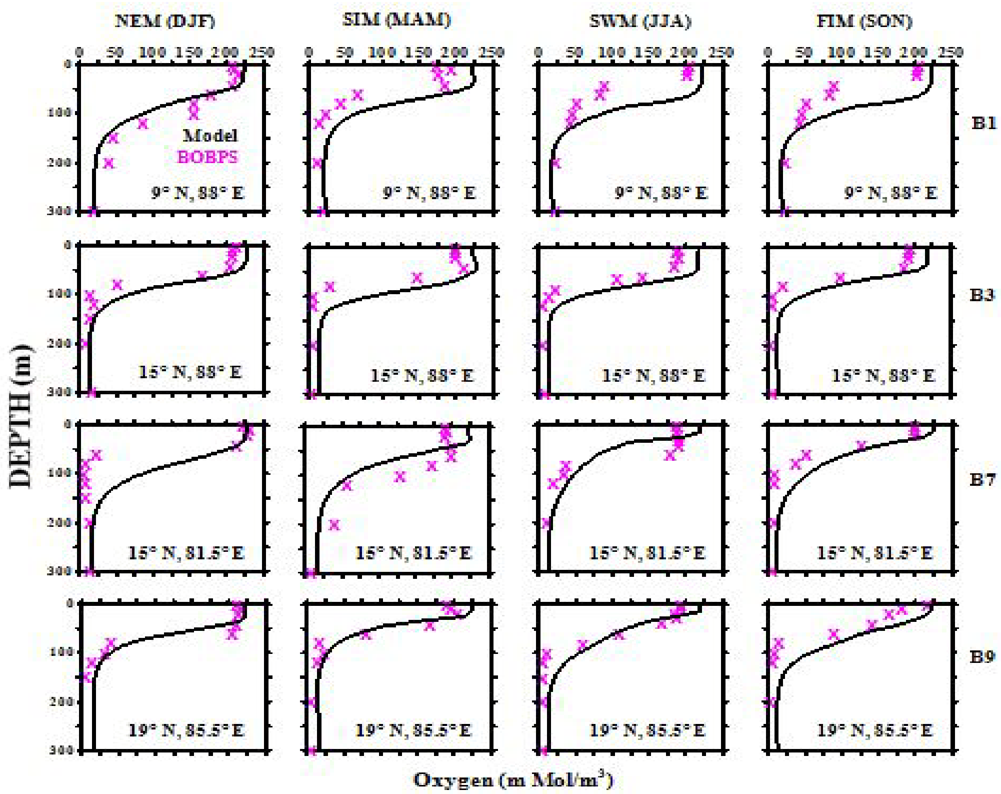

Figure 1.5 (b) Comparison of Oxygen (mMol/m³) from Model with BOBPS observations during four seasons at 4 stations in the Bay of Bengal

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. 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 US JGOFS Cruises at four stations in the AS and with BOBPS data at four stations in the BOB (Figure 1.5). 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 both in the AS and BOB, but the oxygen concentration from the model is more than the observed by 5 to 10 units.

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.

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2.2 Forward Modelling of Carbon Dioxide Transport with LMDZORINCA

We have setup a model for global atmospheric transport of carbon dioxide (CO_2) using LSCE's LMDZORINCA model with the following features: a zoom over India and China of 0.5^0 resolution centered over India and China and a total grid count of 144*142*19. The model couples LMDZ for transport with ORCHIDEE, a biosphere model and INCA a chemistry and aerosol model.

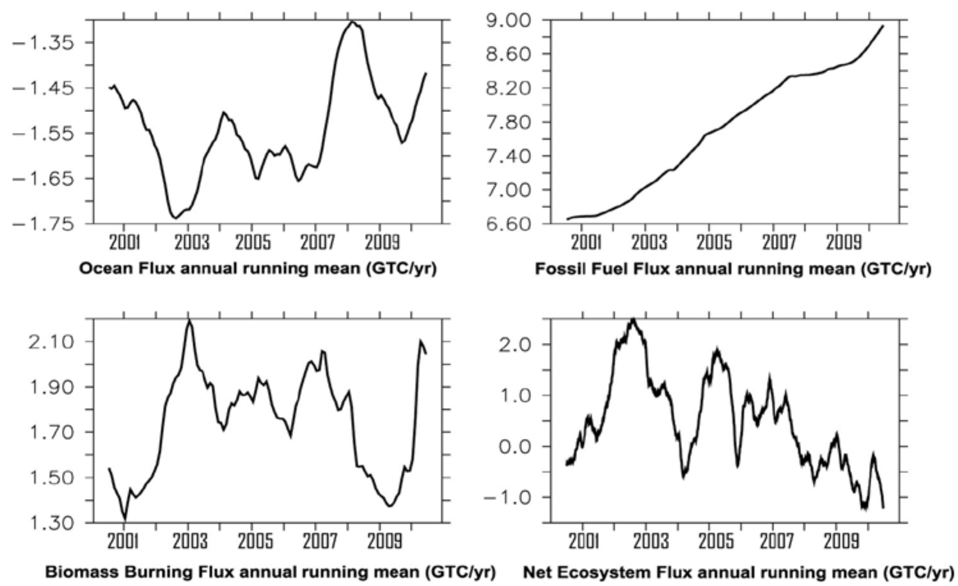

Figure 1.6 Global totals of surface fluxes forcing the transport model

The surface fluxes of CO_2 from (i) anthropogenic emissions (monthly) are taken from the CARBONES programme (www.carbones.eu), (ii) biomass burning (monthly) from Global Fire Emission Data base (GFEDV3.1) ,(iii) land biosphere (daily) from ORCHIDEE, CARBONES and (iv) ocean fluxes (monthly) from NOAA/AOML product. The model is integrated from 2000-

2011. Figure 1.6 shows the global totals (1 year running mean) of all the surface fluxes. Note that anthropogenic emissions have steadily increased from 6.6 GTC in 2000 to nearly 9.0 GTC in 2011 while other components show large interannual variability. The land biospheric component shows both positive emissions as well as uptake after 2008.

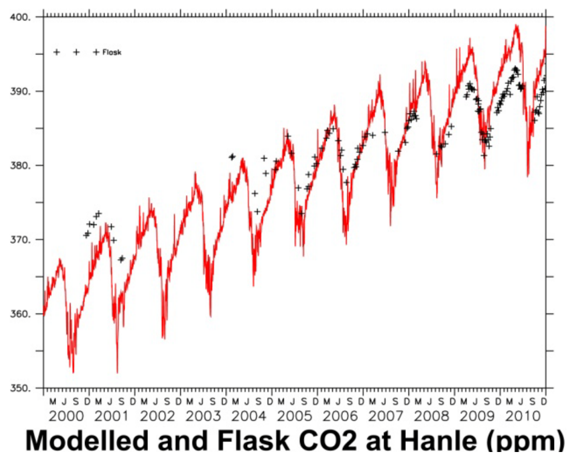

Figure 1.7 Model-data comparison at Hanle

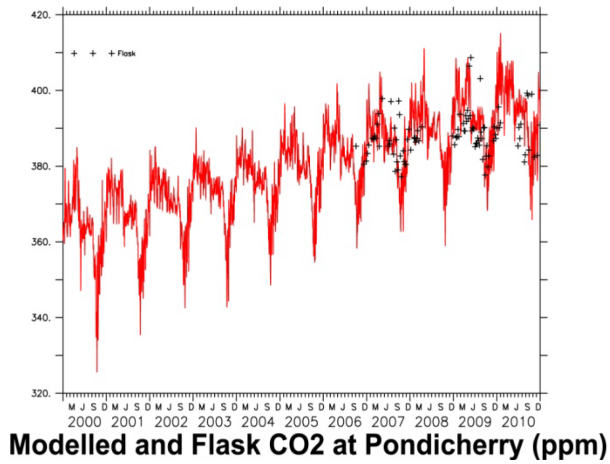

Figure 1.8 Model-data comparison at Pondicherry

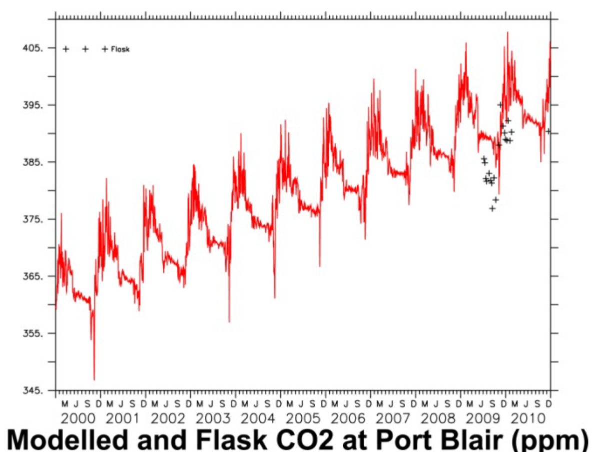

Figure 1.9 Model-data comparison at Port Blair

CSIR-4PI (erstwhile C-MMACS) has been running a detailed measurement programme of greenhouse gases at 3 sites, Hanle, Pondicherry and Port Blair for the past few years. The measurements conform to WMO standards and are the best available in the country. The output from the above model is compared with discrete flask data, collected at uniform intervals (weekly to bimonthly) at each site. Figure 1.7 shows the comparison at Hanle and it can be seen that both the model and data have a very pronounced seasonal cycle and a marked annual trend which are both higher in the model than in the data. The results at Pondicherry (Figure 1.8) and Port Blair (Figure 1.9) show similar features though there are structural differences among the three sites which reflect the combined effects of prevailing winds and surface emissions.

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