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CARBON CYCLE AND OCEAN MODELLING

Fluxes of greenhouse gases (GHG) between different compartments of the earth system – atmosphere, land and ocean – need to be quantified robustly before we can close the carbon budget of the planet. It is essential that we do this at good spatial and temporal scales because it is the cornerstone of our efforts to mitigate climate change by controlling anthropogenic emissions. There are two approaches to this effort and CSIR-4PI has made important contributions to both.

The bottom-up approach models includes 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. We do this by combining a state of the art biogeochemical model (TOPAZ) with an advanced 3D ocean circulation model (MOM). Climatological and inter-annual simulations of the carbon, nitrogen and oxygen cycles in the ocean have 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. This work is carried out under CSIR 12th FYP Projects ARiEES & INDIAS-IDEA, and SIBER Programme funded by MoES.

The top-down approach inverts very accurate GHG measurements to yield robust fluxes. Data from three stations, Hanle, Pondicherry and Port Blair have been collected and analysed. A fine resolution model to simulate the transport of GHG is under development. A new GHG station with primary standards is under commissioning at Hoskote near Bengaluru under the CSIR 12th FYP Project ARiEES.

Decadal scale variation of sea surface temperature (SST) in space and over time has become increasing important in recent times. Changes in warm pools in low latitudes have major consequences on cloud formation and precipitation over vast areas. A new method proposed by K S Yajnik uses the representation of annual SST cycle as a point in a 12-dimensional state space and this study shows the average growth rate of warm pool area during 1951-2010 is rather high (~1 to 2% per decade).

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1.1 Atmospheric CO_2 monitoring at Hanle

The record of continuous CO_2 measurements at Hanle, India from 2005 – 2011 has been analysed carefully. Hanle is part of a cold desert in the Himalayas at an elevation of 4500 m. It is ideally suited to be a background reference station as it is influenced minimally by local effects. The measurements were made with an instrument called Caribou which is based on the LICOR LoFlo analyser. Precise control of temperature, pressure and flow rate is maintained by the use of computer controlled valves. The absolute accuracy of the instrument is ensured by frequent calibration with 6 standards. A reference gas is passed hourly to correct for the short-term drift of the NDIR analyzer and a target gas is passed twice a day to monitor the stability of the instrument. The site is also equipped with an automatic weather station with wind (speed and direction), temperature, pressure and humidity sensors.

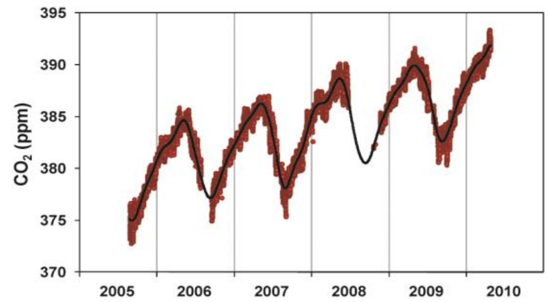

Figure 1.1 CO_2 measurements at Hanle. Each red circle corresponds to an hourly mean, whereas the thick line represents the smooth curve.

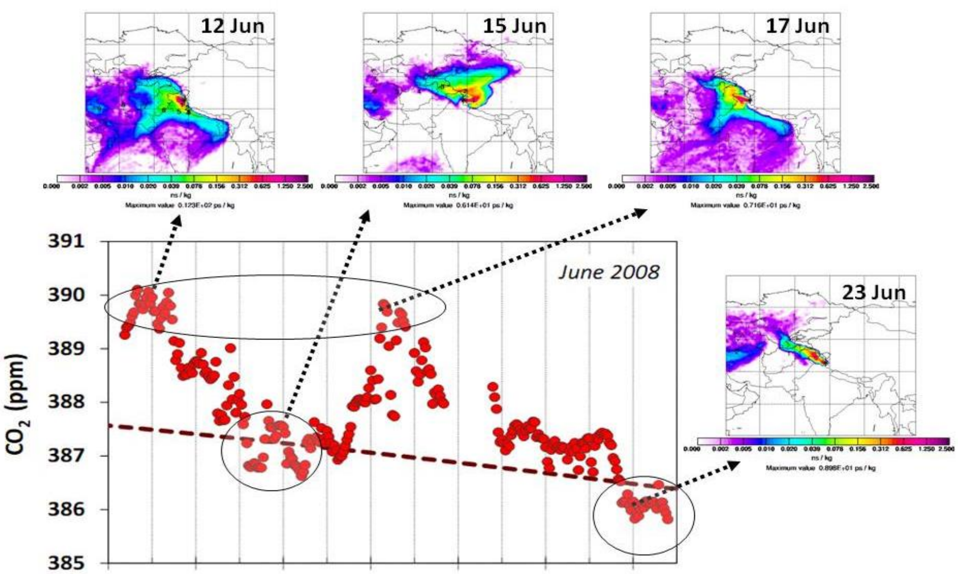

Figure 1.2 CO_2 variability in June 2008 associated to the air masses origins. The dashed line represents the smooth fitting curve.

Hourly-mean and standard deviation values are first computed from the high frequency measurements. The procedure developed by ESRL, Boulder is then applied to process the data to yield hourly and daily averages (Figure 1.1). The short-term CO_2 variability has been correlated with the origin of air masses reaching Hanle. When the air-masses originate from the populated regions of Pakistan and Uttar Pradesh, the CO_2 signal is large and when they originate from the Tibetan side, CO_2 is lower (Figure 1.2). Wind at Hanle is predominantly from the south or south-west and CO_2 values are well correlated with the wind-speed indicating a stronger remote influence than a local one. The diurnal amplitude is only about 0.5 ppm indicating that local vegetation has a very small effect (Figure 1.3).

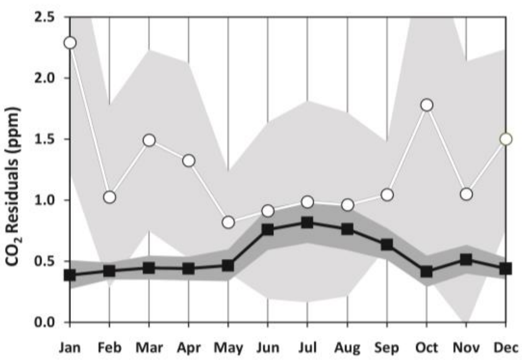

Figure 1.3 **Two weeks of CO_2 and meteorological measurements at Hanle in October 2009. Top: Hourly CO_2 averages (grey circles) and standard deviations (black area); Middle: Wind speed (grey area) and wind direction (black line); Bottom: atmospheric pressure (grey line) and temperature (dotted line).**

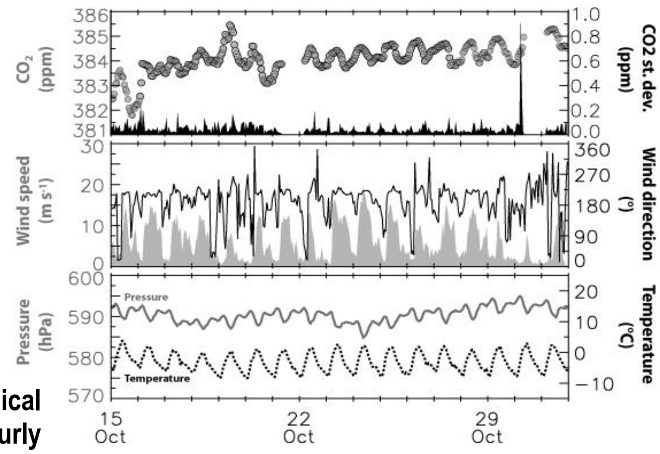

Figure 1.4 Mean CO_2 residuals at Hanle (2005-2010) in black squares, and Cape Rama (1993-2002) in circles.

A comparison of the CO_2 residual between Hanle and Cape Rama (CRI) near Goa shows striking features. While the residuals are lowest at CRI during SW monsoon, indicating the presence of oceanic air, it is highest at Hanle during the same season reflecting the fact that this air has picked up CO_2 from the mainland (Figure 1.4).

1.2 Greenhouse gas reference station in IIA, Hosakote

CSIR-4PI has set up a Greenhouse gas (GHG) reference station in the CREST campus of IIA at Hoskote. Two instruments - a Picarro 2301 measuring CO_2, CH_4 and a LGR measuring N_2O, CO were installed inside a cabin. The station is equipped with 6 primary standards (smaller cylinders in the Figure 1.5) from NOAA as well as working standards covering a range of concentrations of all the gases listed above. The figure below shows the instruments and the cylinders which are connected through a computer-controlled multiport valve-system (Valco). Ambient air is drawn from a 32 meter tower with a flushing pump, dehumidified by passing through a cooling system and fed to the one of the ports of the Valco box.

The secondary working standards (seen in the figure with the green top) were first calibrated against the primary standards using a NOAA-approved procedure. Each cylinder (primary and secondary) was used for 20 minutes, first in an ascending sequence and then in a descending sequence and this procedure was repeated 3 times. Only data from the last 15 minutes of each cylinder were used to allow for stabilization. The measurements were very stable with standard deviations of less than 0.02 ppm CO_2 in minute averages. A linear fit between the measured and standard values of the primary cylinders was first determined and this was used to calibrate the secondary's which are used routinely. All our measurements are now traceable to NOAA primary standards.

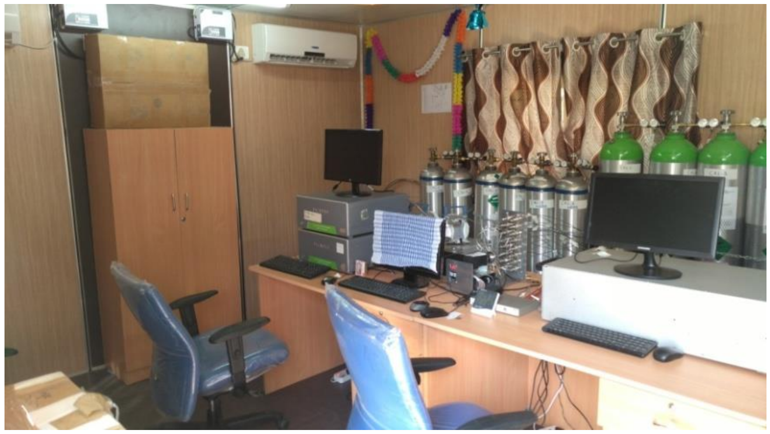

Figure 1.5 Reference Station at IIA, Hoskote

We plan to make this facility available to other researchers in India to calibrate their instruments and working standards.

1.3 Analysis of satellite data in the north Indian Ocean

Data on Net Primary Productivity (PP), Surface Chlorophyll (Chl), and Sea Surface Temperature (SST) from different satellites have been analyzed in detail for spatial, seasonal, climatological

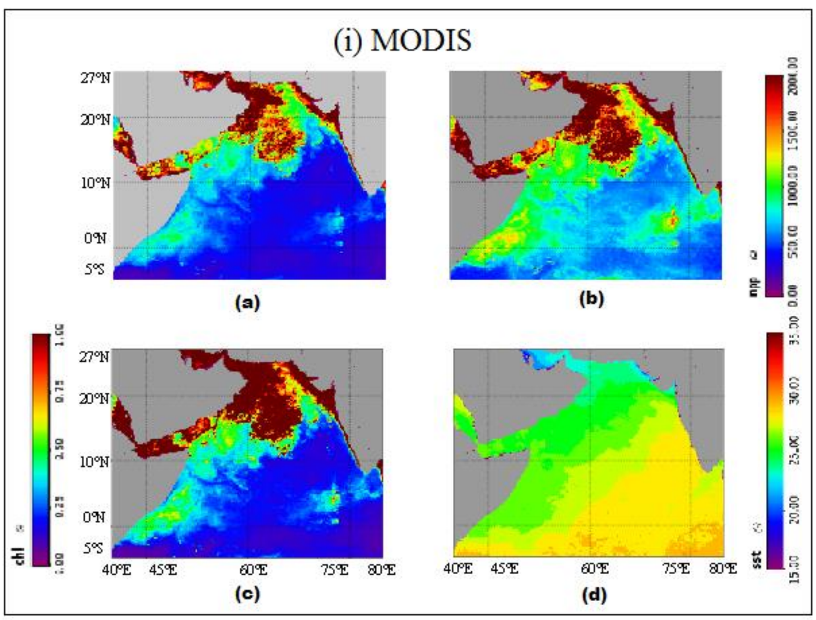

Figure 1.6 Spatial variation of (a) PP (mg C/ m²/day) estimated using Standard VGPM (b) PP (mg C/m²/day) estimated using Eppley VGPM (c) Chlorophyll (mg/m³) and (d) SST (degree C) in the Arabian Sea during 2004

and interannual variations in different regions of the Arabian Sea (AS) and Bay of Bengal (BOB) during 1997-2009. Marine biogeochemical model (TOPAZ) simulation results are evaluated using these data. Data on PP is derived from Chlorophyll from SeaWiFS and MODIS satellites using three algorithms, namely, Eppley VGPM (Vertically Generalized Production Model), Standard VGPM and CbPM.

Relation of PP with Chl and SST: Spatial variation of PP (estimated from Eppley and Standard algorithms), Chl and SST from MODIS during 2004 in Arabian Sea are shown in the Figure 1.6. It can be observed that high Chl and low SST in the north Arabian Sea results in high PP. Chl and PP are low in the south Arabian Sea where SST is high. A trend similar to that of MODIS is observed for SeaWiFS data but SeaWiFS PP and Chl show lower values compared to MODIS.

1.4 Study of physics of the Arabian Sea

General Ocean Turbulence Model (GOTM) (a one-dimensional water column model) simulations are carried out at the site of the WHOI mooring (15.5°N, 61.5°E) in the Central Arabian Sea using mooring observations for one year. The model is forced with temperature, salinity, shortwave radiation and precipitation minus evaporation rate obtained from WHOI Arabian Sea buoy data as input. Net surface heat flux and surface momentum fluxes computed from WHOI Arabian Sea buoy data are given as the boundary conditions. Detailed analysis of model simulation results are done for one year starting from 16th October 1994 to 17th October 1995. Several numerical simulations are carried out using different forcing and boundary conditions.

These numerical experiments lead us to conclude that horizontal advection of heat, various physical forcing, the turbulence model and the boundary conditions play an important role in the upper ocean dynamics of the Arabian Sea.

1.5 Decadal scale warming of the ocean surface

Decadal scale variation of sea surface temperature (SST) in space and over time has become increasing important in recent times. Gradients of SST are a major forcing for air and sea circulation. SST variation affects seasonal melting of sea ice in high latitudes. Changes in warm pools (SST> 28.5C) in low latitudes have major consequences on cloud formation and precipitation over vast areas. However, the detection of such changes is challenging due to larger changes on seasonal or inter-annual scales. A new method which uses the representation of annual SST cycle as a point in a 12-dimensional state space is used for this study. Decadal scale change then appears as a drift of the state point in the projections of SST annual cycle trajectory on 2-D planes (Mar-Sep and Jul-Dec). Two results are noteworthy: (1) The average growth rate of warm pool area during 1951-2010 is rather high (~1 to 2% per decade). (2) A Fourier-like decomposition is given in which parameters of normal modes can vary from year to year, and which is applicable to other areas.