Influence of monsoons on atmospheric CO_2 spatial variability and ground based monitoring over India

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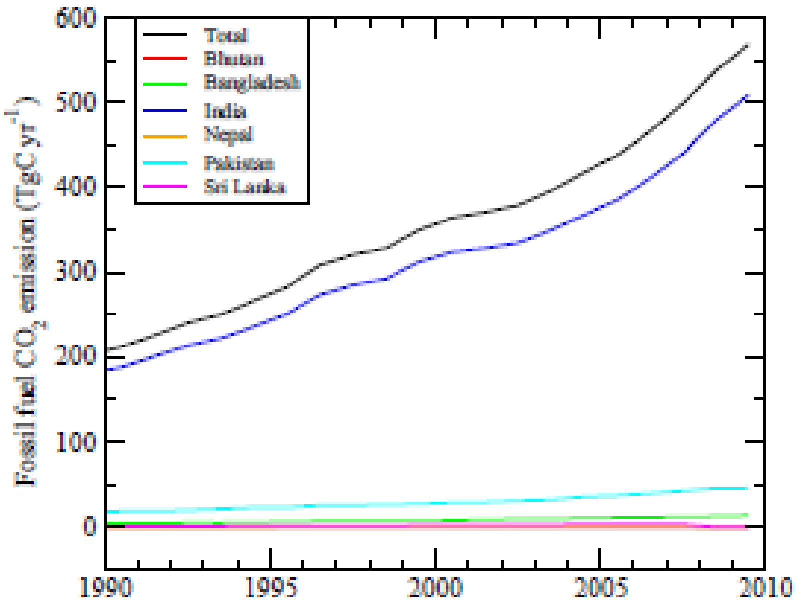
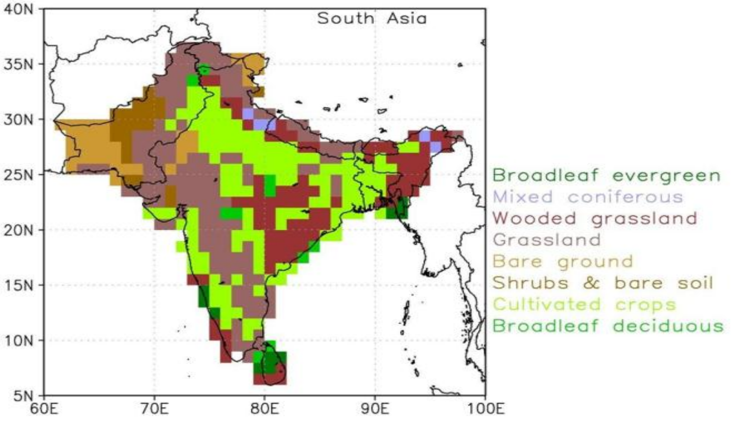
Prabir Patra, Chun ho Cho

CO_2 emissions from India

➢India has one of the largest and fastest growing economies in South Asia and is emerging as a major contributor to CO_2 emissions among developing nations.



Time series of CO_2 emissions over South Asia during 1990-2009 (Source:Boden,2011)



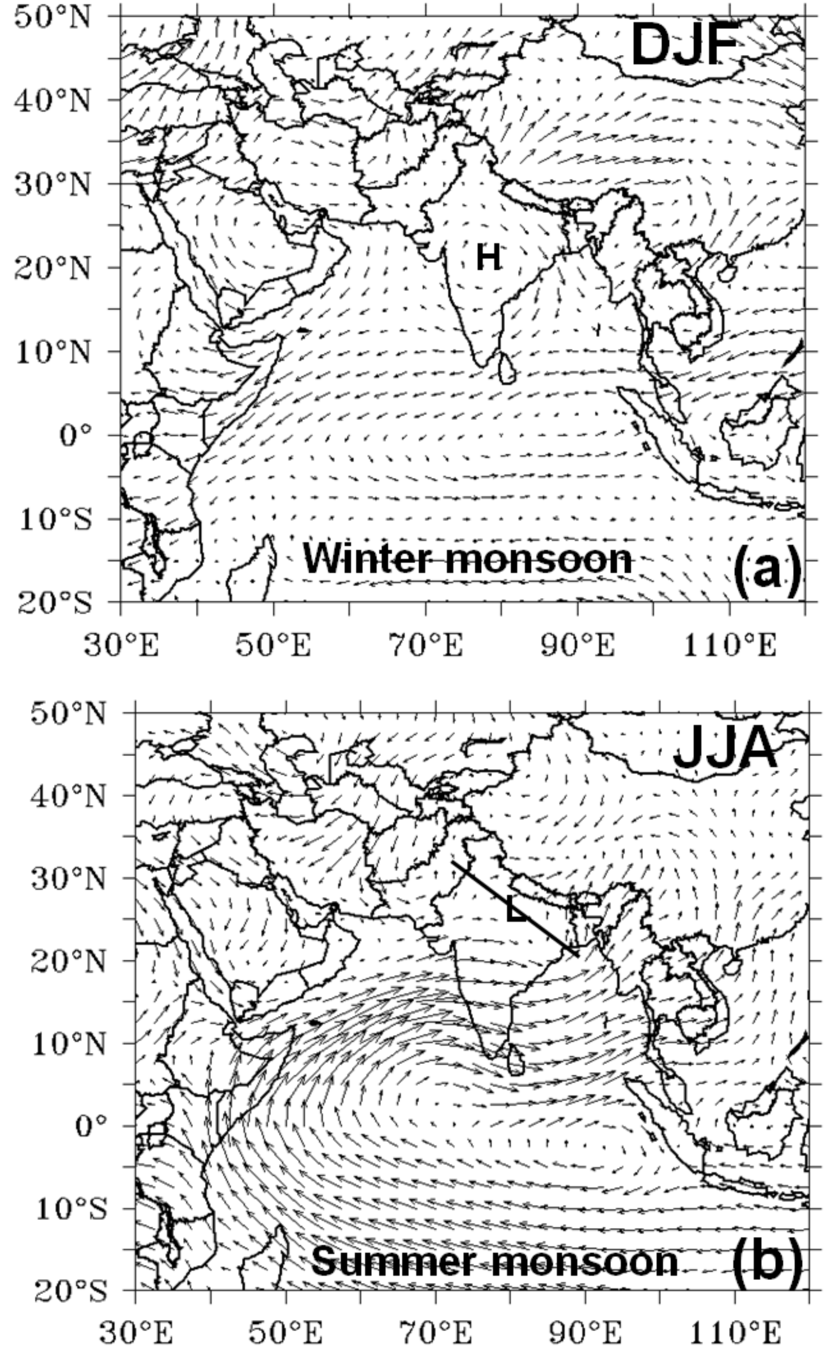
Landmass selected for the RECCAP South Asian Region Ref: Patra et al., 2013 (South Asian carbon budget)

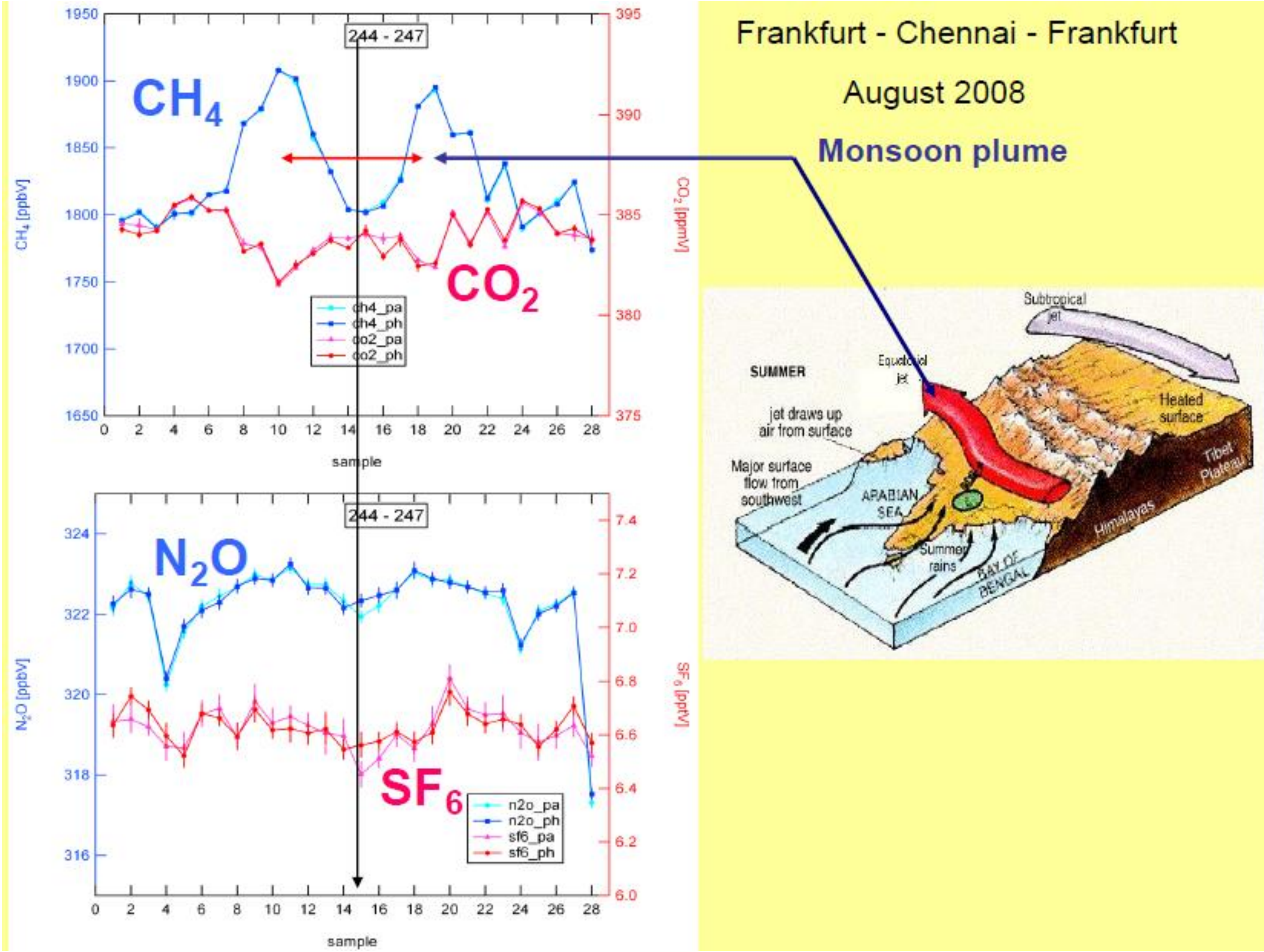
CO_2	TgC/yr
Bottom- Up	−191±186
Top –Down	−104±150
Best Estimate	−147±239 (NBP)
	+444 (fossil fuel)

➢Uncertainty of estimated emissions of CO_2 over above Asian region are larger due to the lack of sufficient CO_2 monitoring(Schuck et al., 2010, Peylin et al., 2012).

➢Towards a better understanding of CO_2 transport pathways, CO_2 sources and sinks over Indian subcontinent, need dense network and high quality CO_2 monitoring supplemented by a robust modeling techniques (Bhattacharya et al., 2009;Tiwari et al., 2011, Ravi et al., 2014).

850 hPa mean winds





Source: Carl Brenninkmeijer, CARIBIC

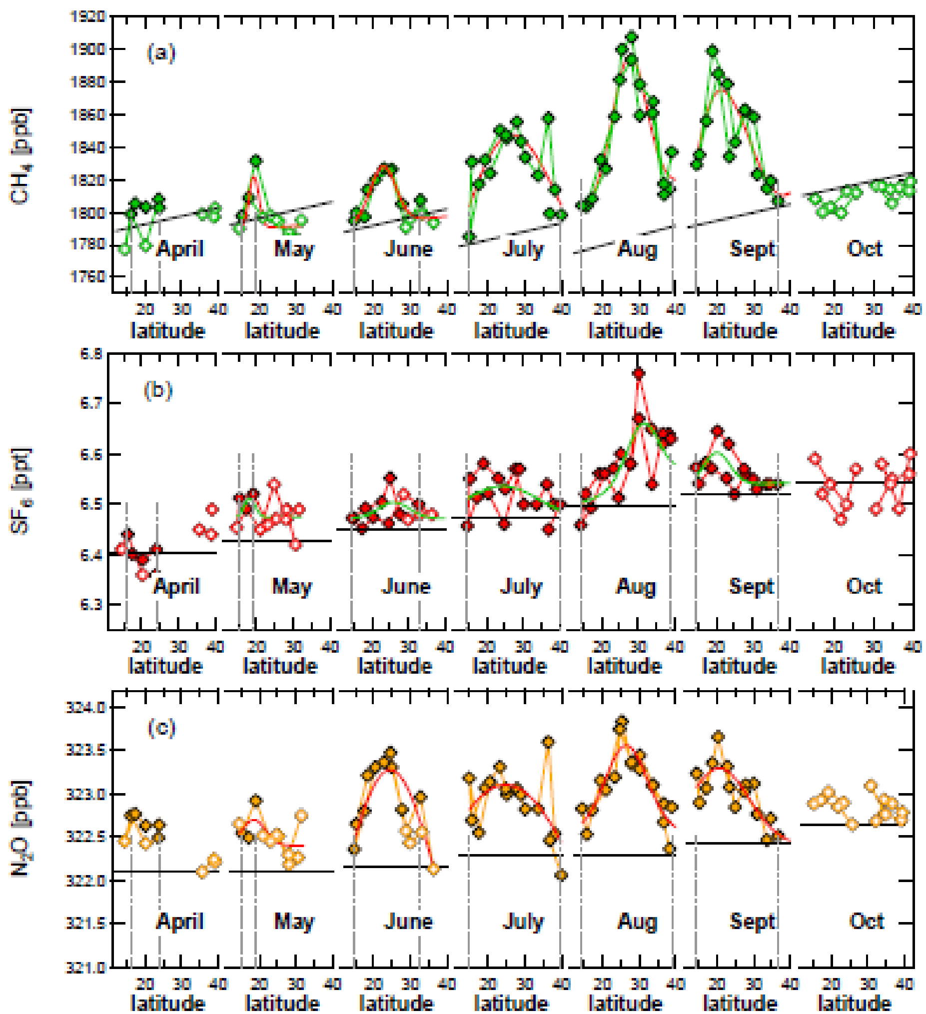


Fig. 8. Latitudinal distributions of CH_4 **(a)**, SF_6 **(b)**, and N_2O **(c)** for April–October 2008. For May–September a Gaussian has been fit to the data. Solid lines indicate background levels determined from the CARIBIC measurements in April and October for SF_6 and from the Mauna Loa Observatory for CH_4 and N_2O. All samples for which CH_4 mixing ratios are above the reference background are indicated by closed symbols, open symbols denote samples with lower CH_4 mixing ratios. The vertical dashed lines mark the integration limits used to calculate the increase in the monsoon plume.

Schuck et al., 2010, ACP

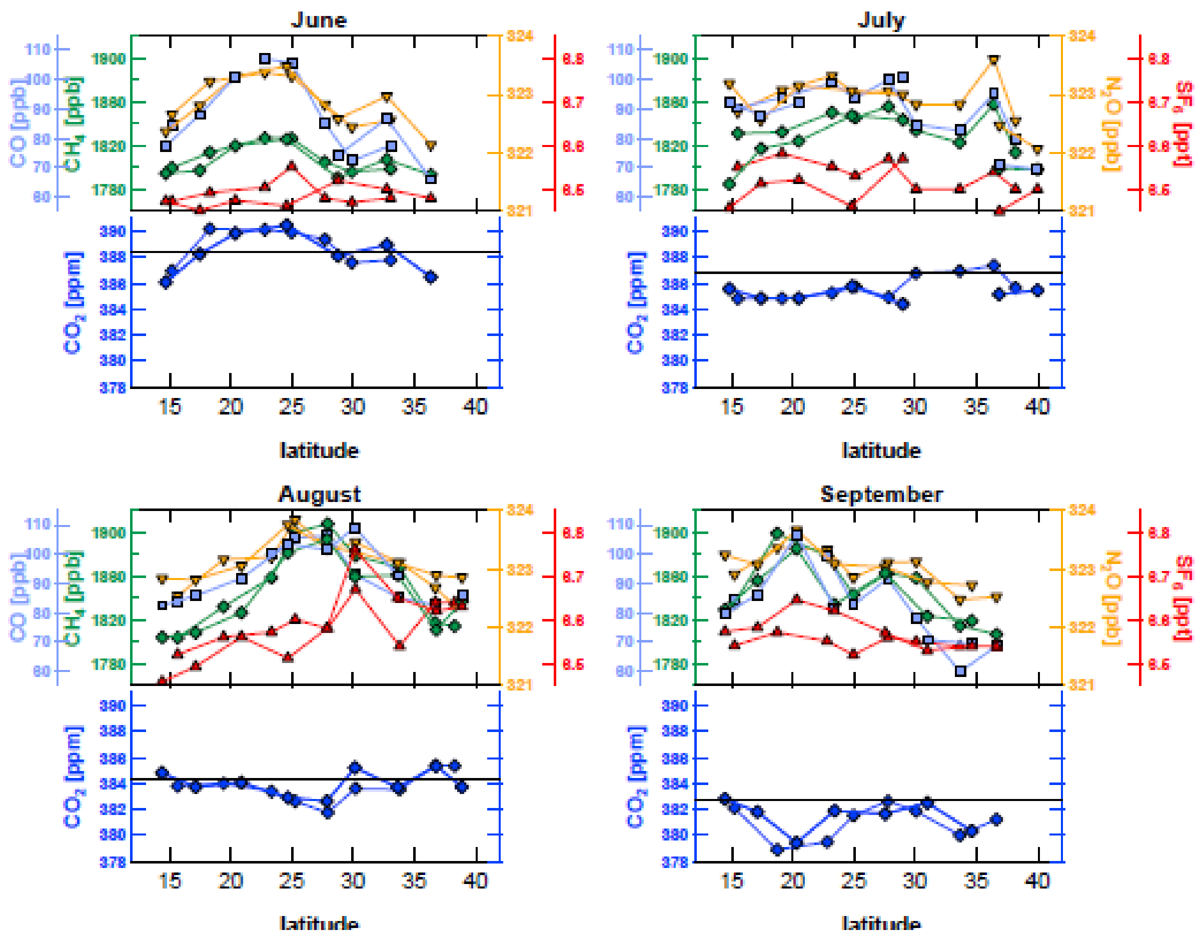
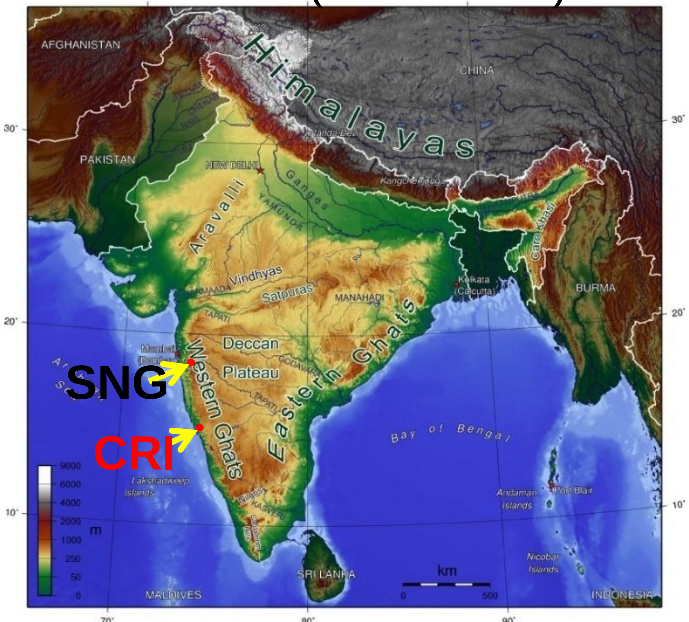


Fig. 5. Latitudinal distributions of CH_4, CO_2, N_2O, and SF_6 from air samples and on-line measured CO mixing ratios integrated over the sampling period for flights between Frankfurt and Chennai in June, July, August, and September 2008. For CO_2 the mean mixing ratio observed at Mauna Loa Observatory (19° N) is indicated by a solid line.

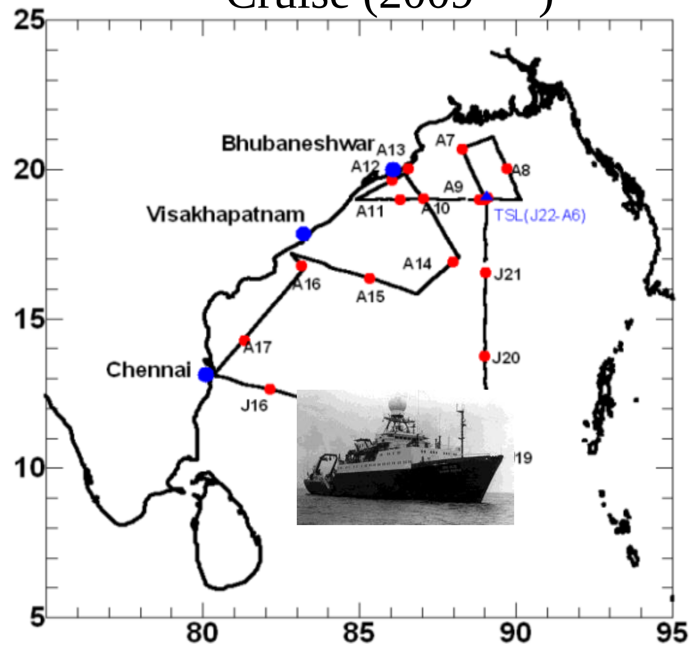
Schuck et al., 2010, ACP

GHG's observations: India

Surface (2009-2014)



Cruise (2009 -)



IITM,Pune- Sinhagad (SNG), 1600 m amsl

CSIRO, NIO -Cape Rama (CRI), 50 m amsl

Aircraft (2010, 2014)

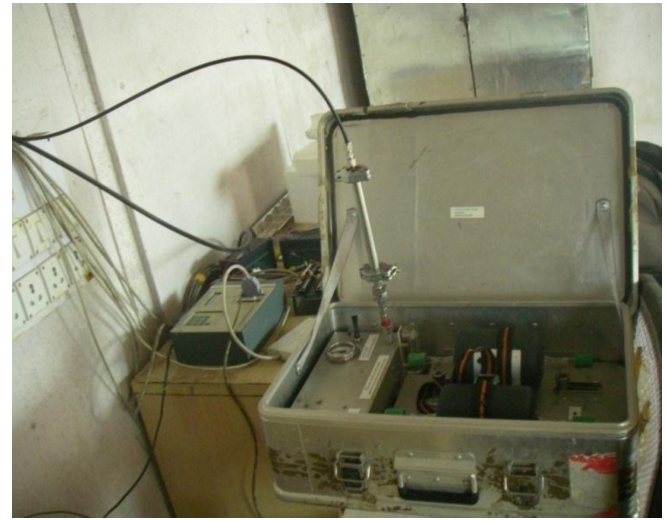
Surface monitoring sites

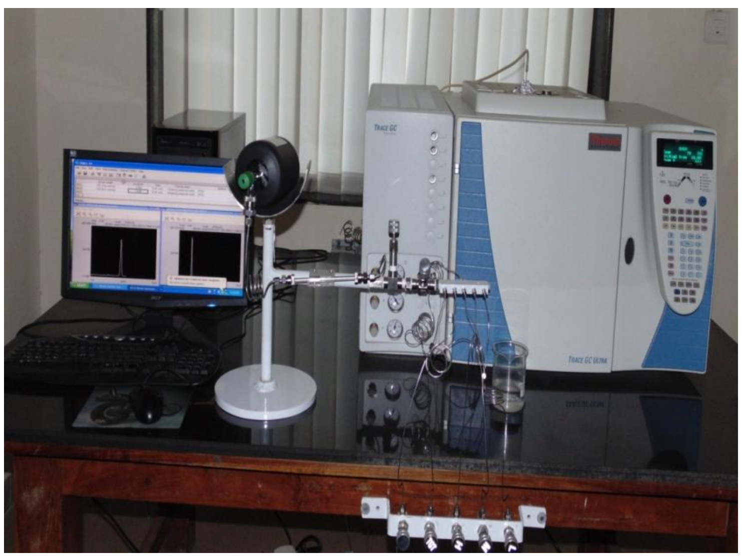
Surface monitoring site SNG, Pune, India

Methodology and analysis techniques

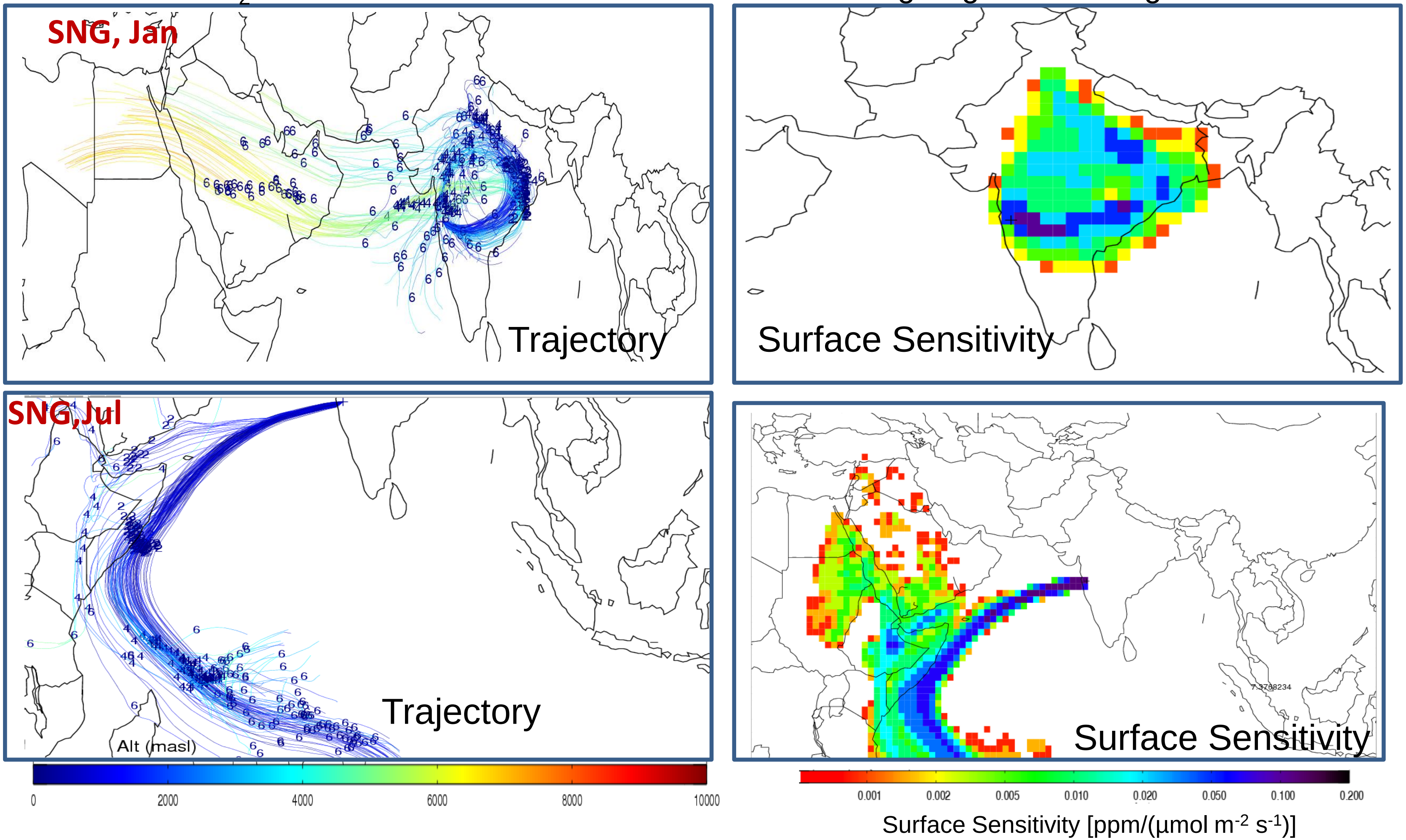
Met sensors and Intet pump

Air sampler





CO_2 sources at the observation sites based on Lagrangian modeling

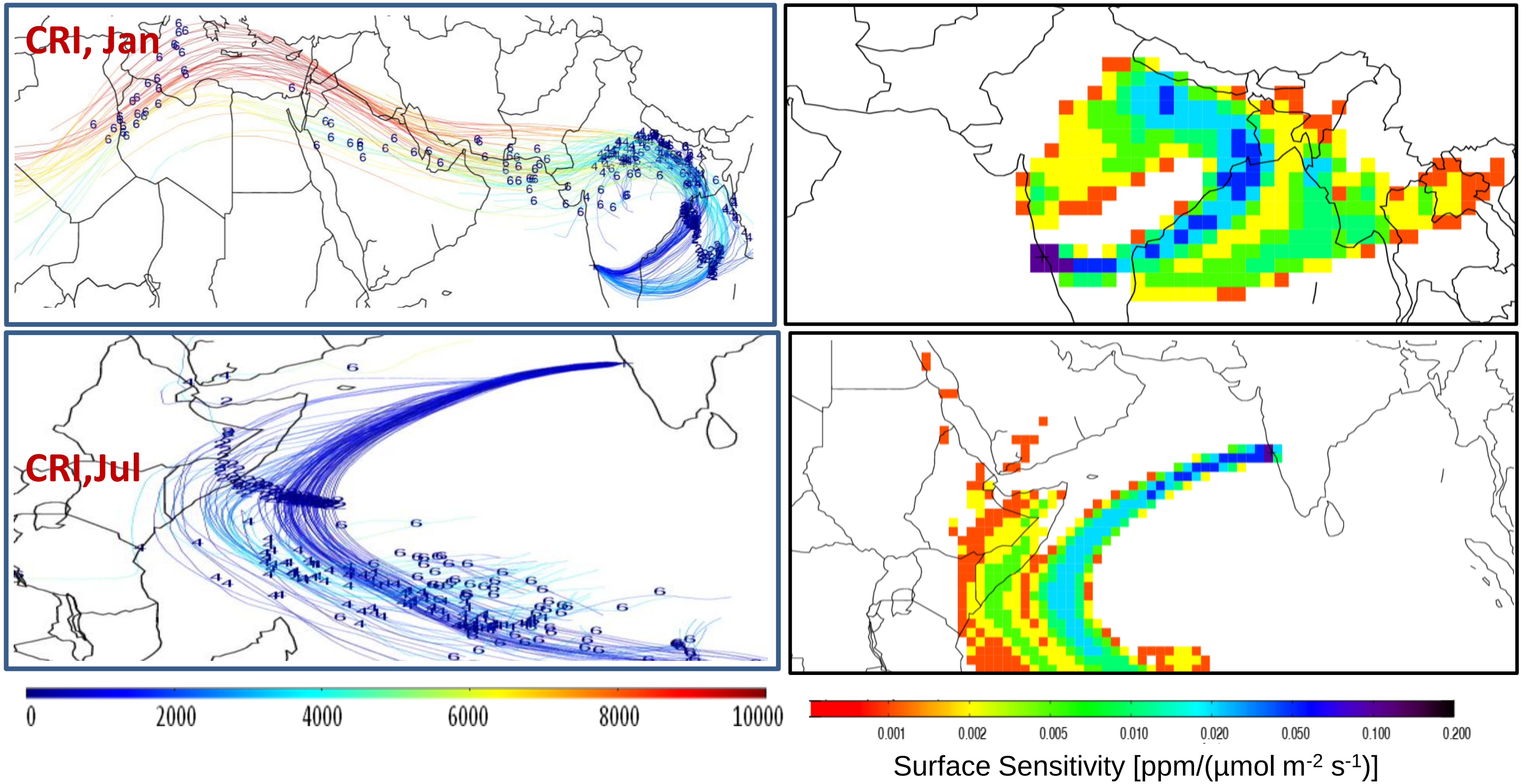


Although the particles are transported from the western part of Asia in January, they are primarily transported by the northeasterly winds within the planetary boundary layer (PBL) over India as they reach SNG.

Impact of marine layer CO_2 fluxes is rather significant on the receptor at SNG.

Ref : Yogesh K.Tiwari, V. Valsala, R. K. Vellore, and **K. Ravi Kumar** (2013): Effectiveness of surface monitoring stations in capturing regional CO_2 emissions over India. Climate Research, 56, 121-129.

Cape Rama

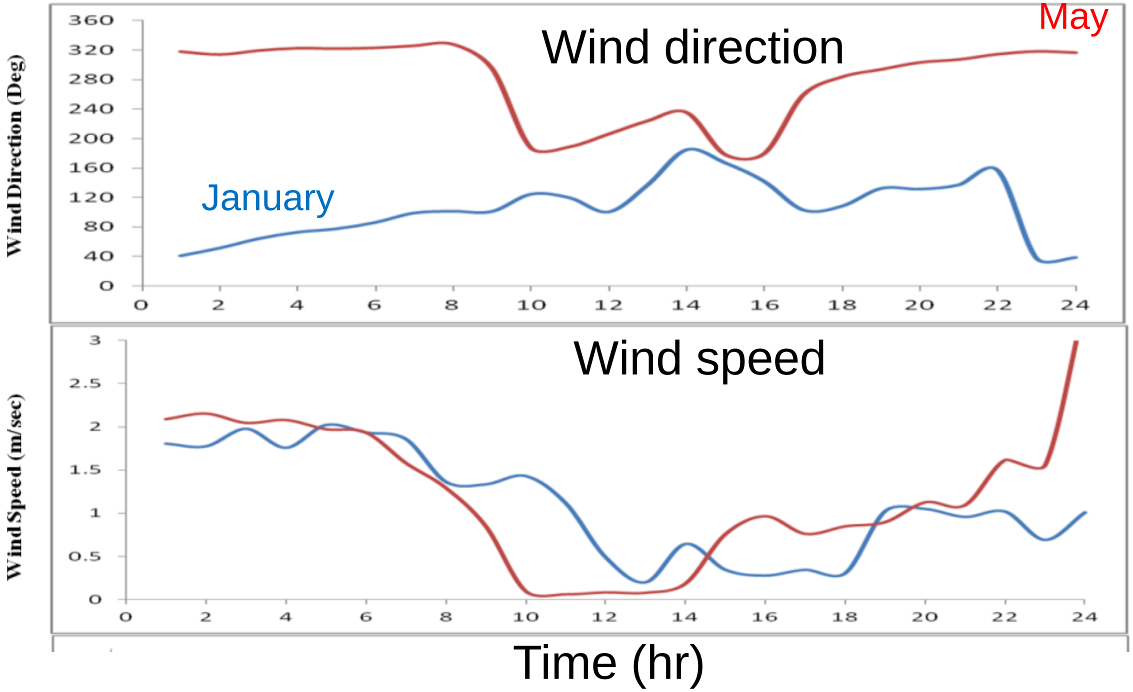


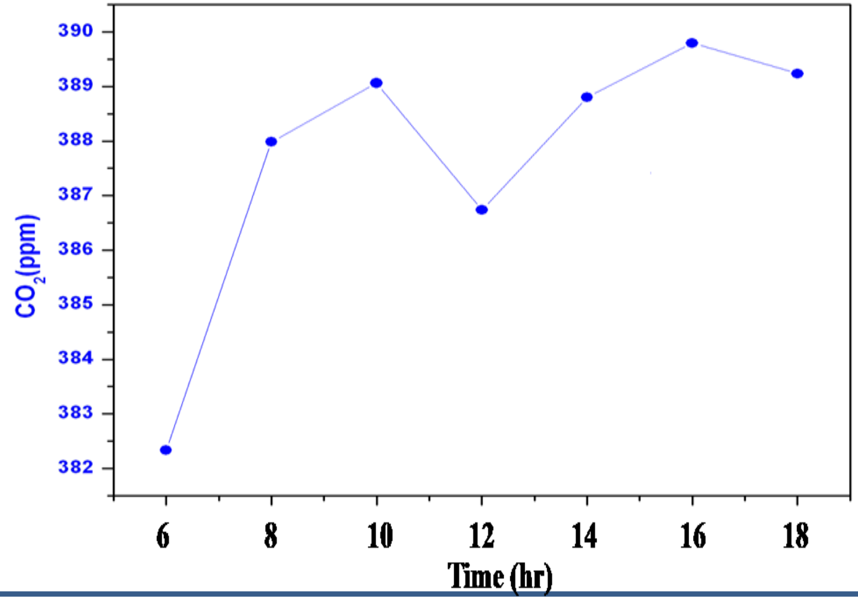
❖During January, higher surface sensitivity is seen over the central and east coast of India as well as over the foothills of the Himalayas. In contrast, the surface sensitivity magnitudes are significant over the central Arabian Sea in July.

❖The concentrations can be more sensitive to local terrestrial (marine/oceanic) fluxes in January (July).

Ref : Yogesh K.Tiwari, V. Valsala, R. K. Vellore, and **K. Ravi Kumar** (2013): Effectiveness of surface monitoring stations in capturing regional CO_2 emissions over India. Climate Research, 56, 121-129.

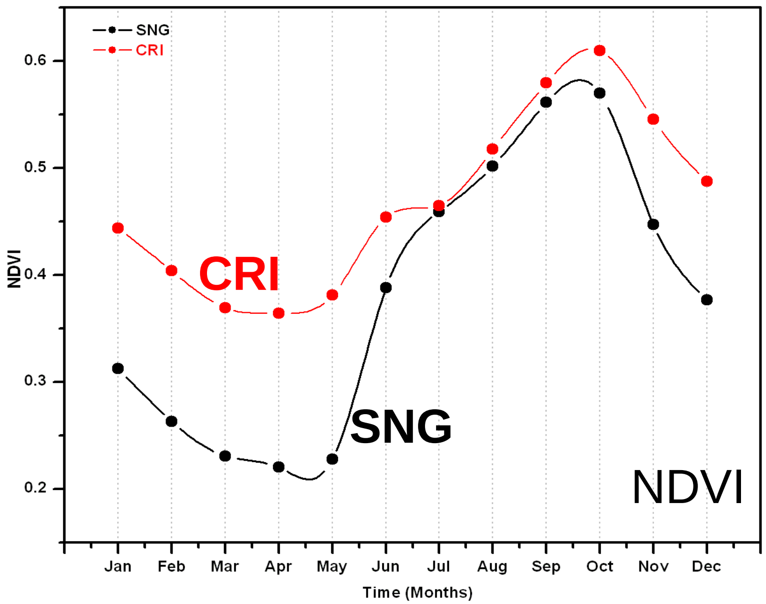
Surface CO_2 observations and meteorology at SNG site

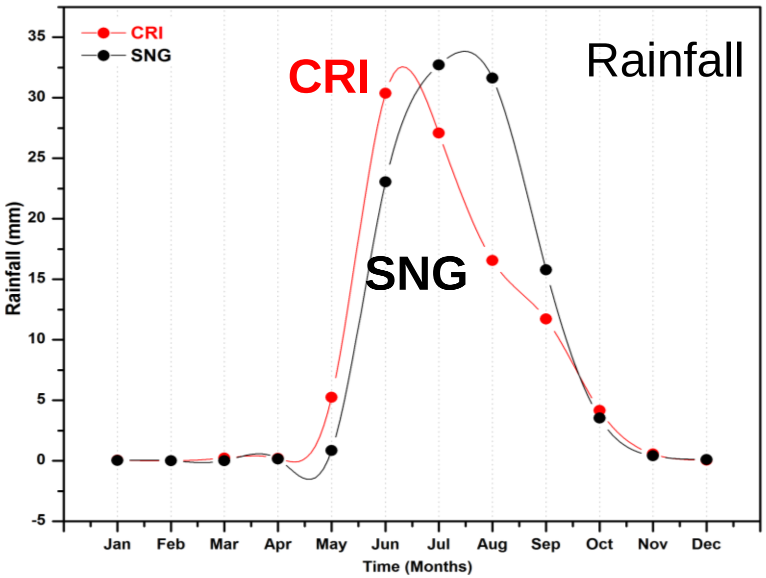




- ➢Wind speed is minimum during the sampling time.
- ➢Wind direction is observed mostly southwesterly at the sampling location during both seasons.
- ➢The daytime variability is observed ~ 7ppm

Seasonal cycle of NDVI (Normalized Difference Vegetation Index) and Rainfall at SNG and CRI

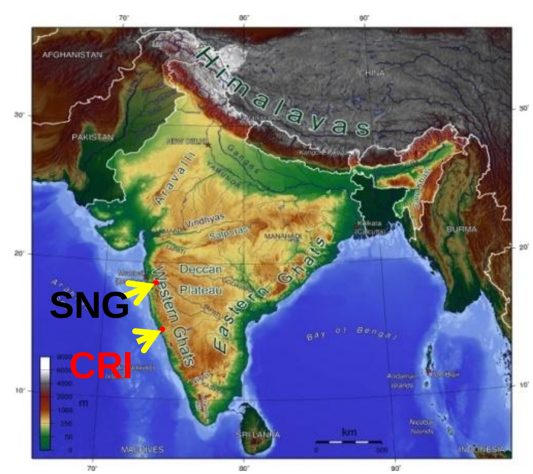


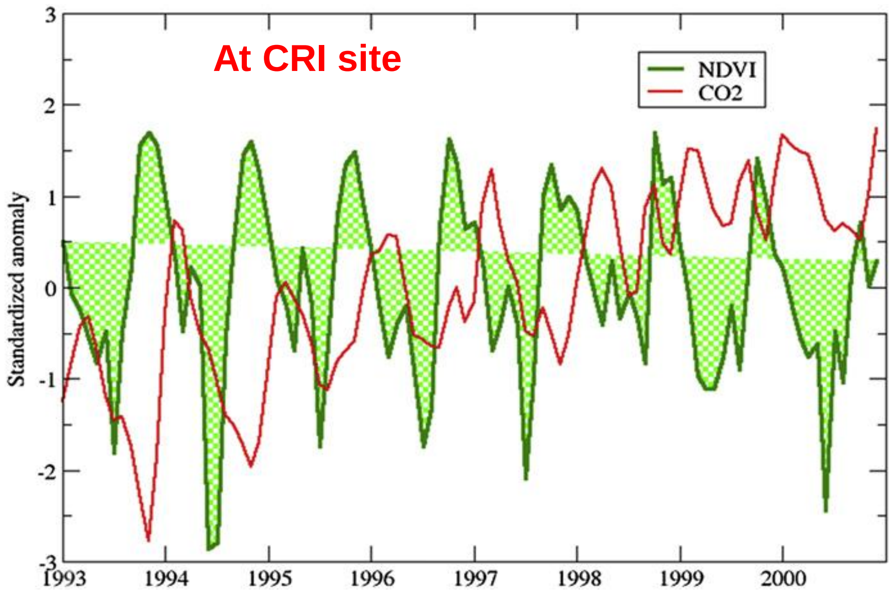


➢NDVI shows a minimum value at SNG to represent bare soil during April to May, which contrasts the maximum in October to represent the loss of vegetation canopy.

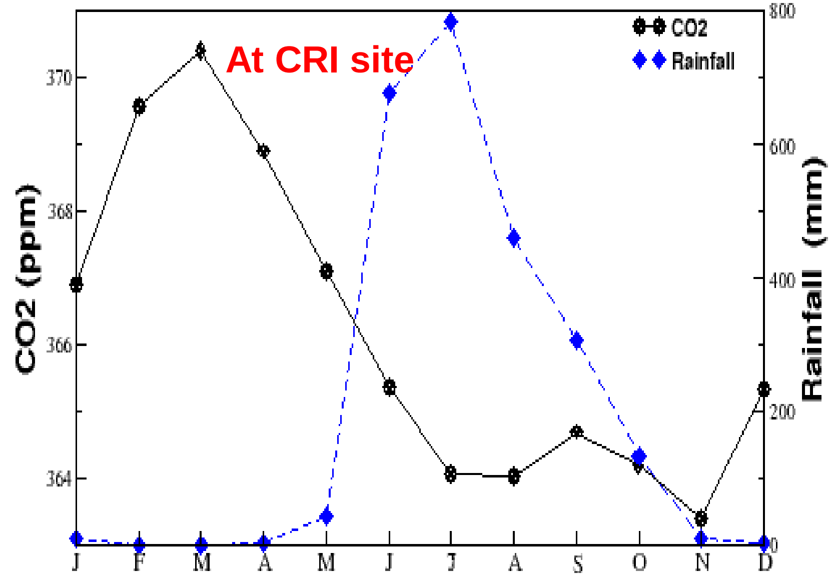
➢Although the NDVI magnitude at CRI is larger, the month-to-month variability in the vegetation cover is found to be weaker at CRI as compared to SNG. This suggests that crop harvesting in the vicinity of SNG appears to play a role ahead of the summer monsoon season.

➢The annual cycle of vegetation at both sites follows the annual cycle of rainfall.





Annual cycle of CO_2 (ppm) superimposed with annual cycle of NDVI over Cape Rama based on the data for 1993-2002.



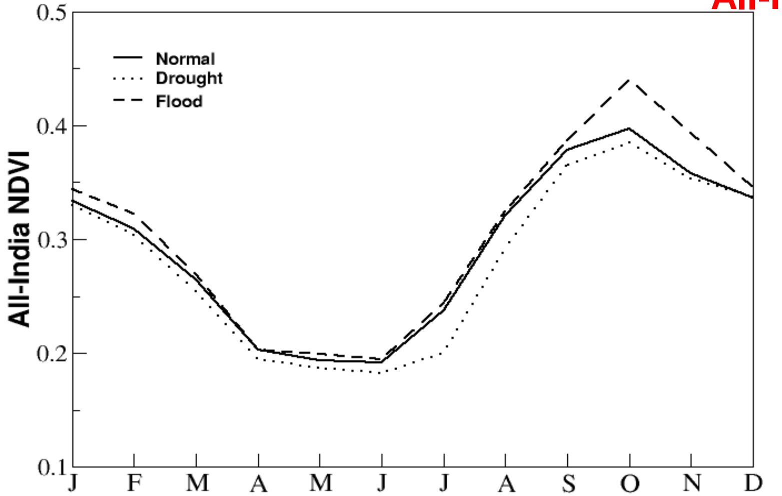
Annual cycle of CO_2 (ppm) superimposed with annual cycle of Rainfall (mm) over Cape Rama based on the data for 1993-2002.

- Annual cycles of vegetation and CO_2 concentration show clear opposite patterns in their monthly values, except during May, June and July.

- Amplitude of decreasing phase of vegetation is higher than the amplitude of increasing phase. Opposite features are seen in standardized anomalies of Carbon Dioxide.

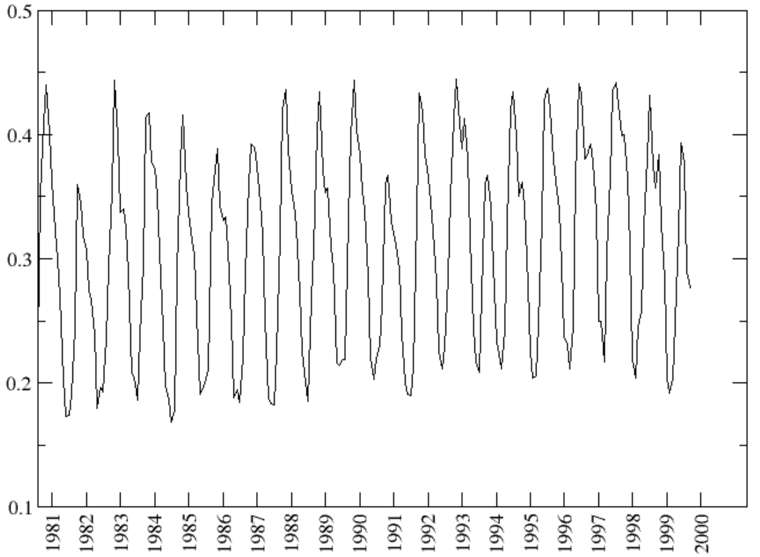
Ref: Yogesh K.Tiwari., J. V. Revadekar, and **K. Ravi Kumar** (2013): Variations in atmospheric Carbon Dioxide and its association with rainfall and vegetation over India, *Atmospheric Environment*, Volume, 68, April 2013, Pages 45–51..

All-India NDVI



Annual cycle of all-India monthly mean NDVI during 1981-2000, drought and flood years

➢ During drought years, there is a decrease in all-India NDVI for all months. Opposite features are seen during flood years; however, the incremental change during flood years up to the month of September is comparable with normal years, but there is a substantial increase in all-India NDVI in the month of October onwards compared to a normal year.

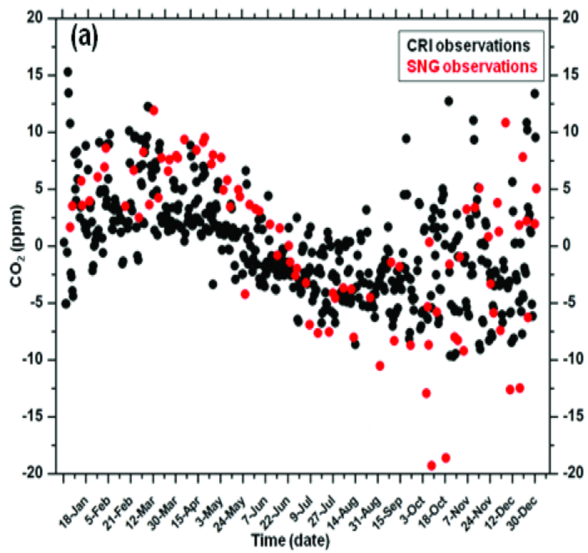


Inter-annual variability of all-India NDVI for the period from July 1981 to Dec 2000.

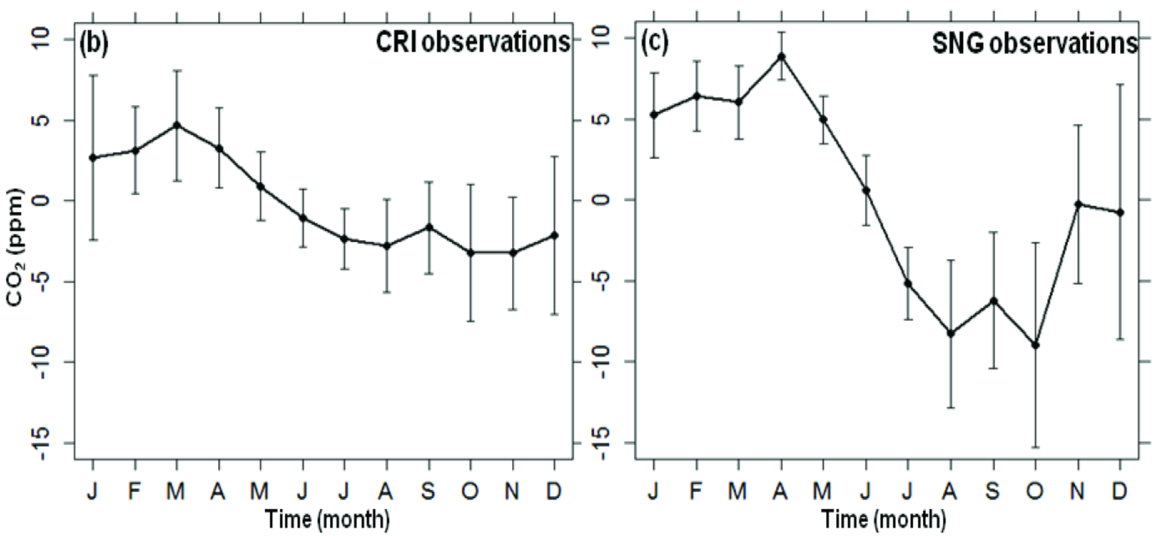
➢During the drought years 1982, 1986 and 1987, there is a decrease, while the flood year 1983 showed an increase in all- India NDVI. Although rest of the years is normal monsoon rainfall years, the inter-annual variability of NDVI corresponds well with the negative and positive rainfall anomalies.

Ref: Revadekar, J. V., Y. K. Tiwari, and **K. Ravi Kumar** (2012): Impact of climate variability on NDVI over the Indian region during 1981-2010, *International Journal of Remote Sensing*, 33:22,7132-7150.

CO_2 variability at SNG and CRI observing sites

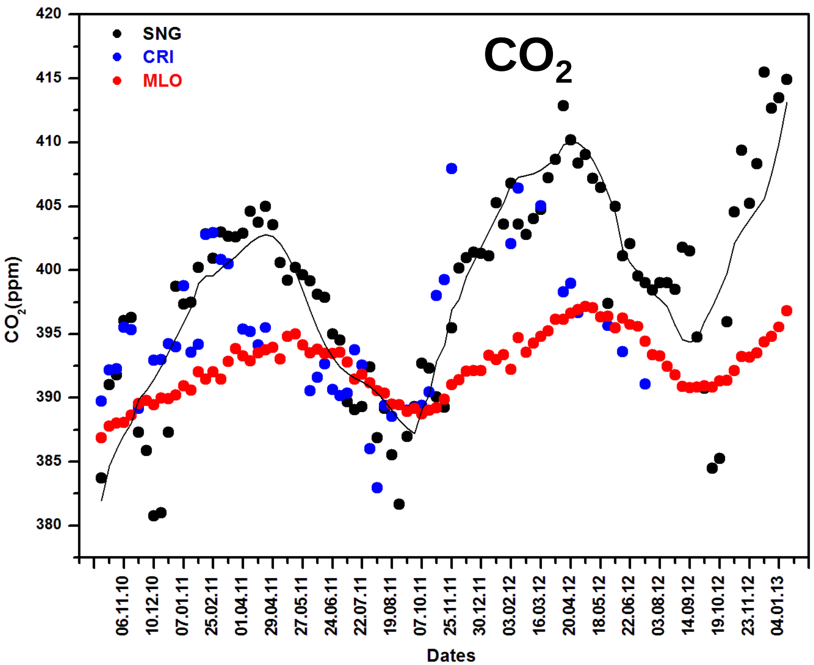


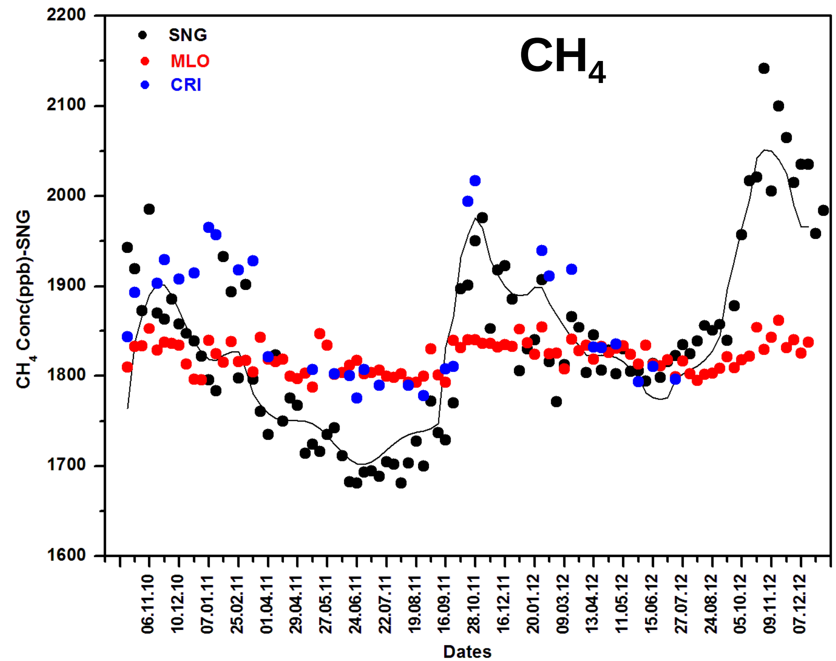
There is a smaller CO_2 variability (8–10 ppm) during summer monsoon months (JJAS) compared to values greater than 15 ppm for the remainder of the year. This is in part due to higher vegetation cover in these months due to intermittent precipitation spells. The observational record also indicated larger variances seen at SNG during post-monsoon months (later than September) than seen at CRI.

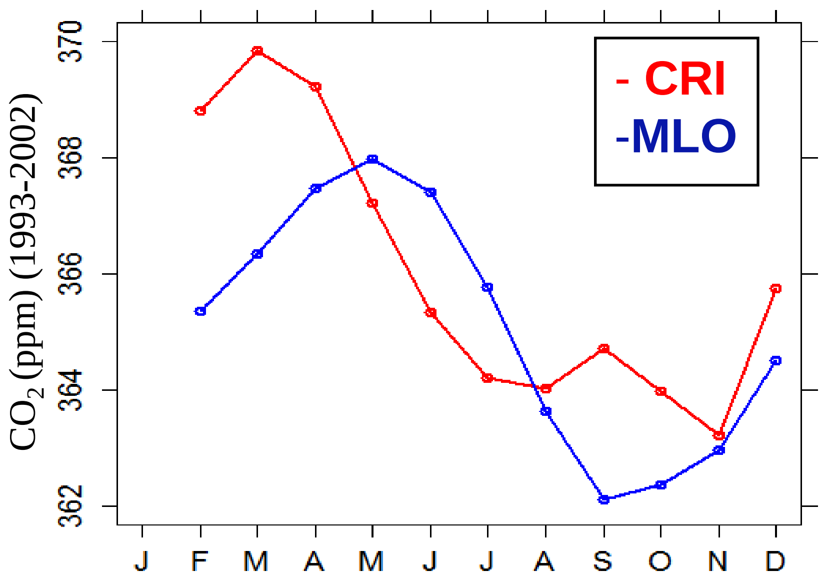


Yogesh K. Tiwari, Ramesh K. Vellore, **K Ravi Kumar**, Marcel Vander Schoot, and Chun-Ho Cho (2014) Influence of monsoons on atmospheric CO_2 spatial variability and ground-based monitoring over India. ***Science of the Total Environment*** 490 (2014) 570–578.

CO_2 observations: Sinhagad, Cape Rama, and global site Mauna Loa





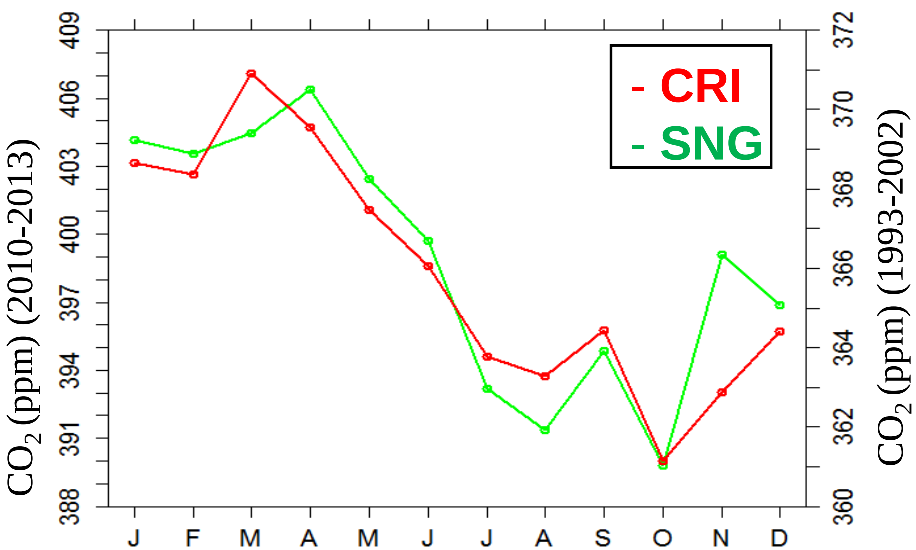


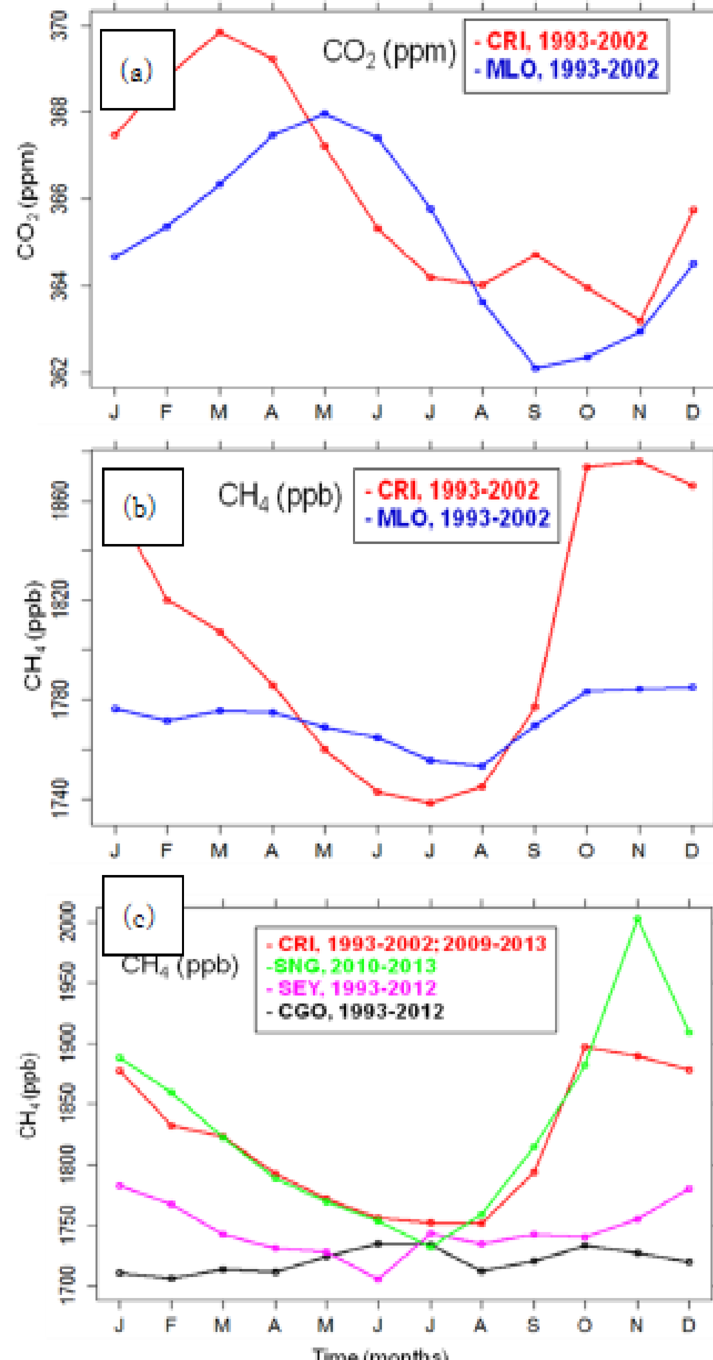
➢SNG and CRI show similar pattern in trend and seasonality, however amplitudes are different as compared to the Mauna Loa(MLO)

➢During the monsoon season CO_2 signals are Lower than seen at the MLO site – which suggests that the terrestrial ecosystems play a role in regulating the greenhouse gases.

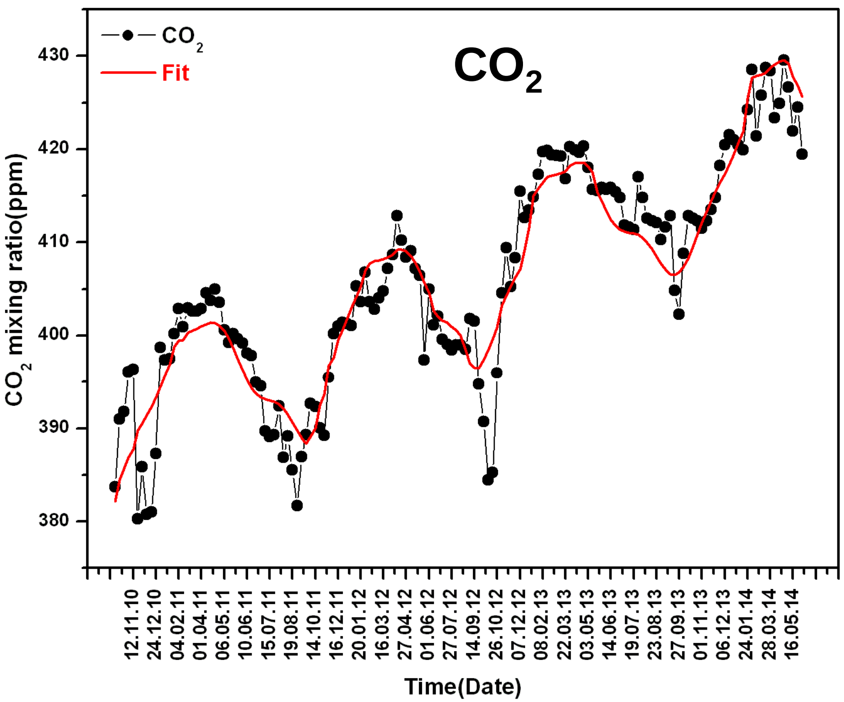
Climatological mean of
Observed CH4 & CO2 concentrations.

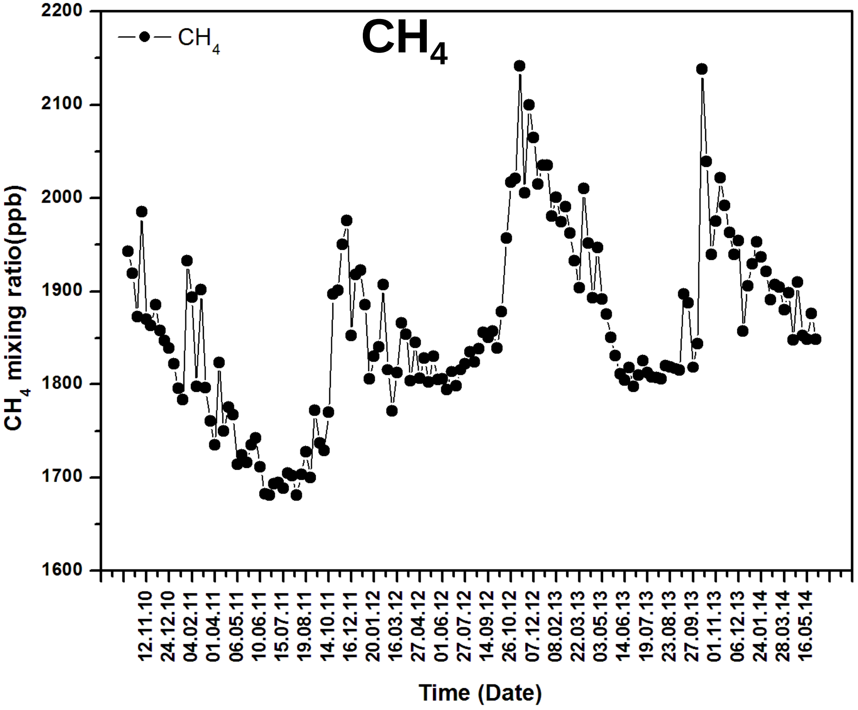
Comparison with northern and
Southern hemisphere global
Monitoring sites



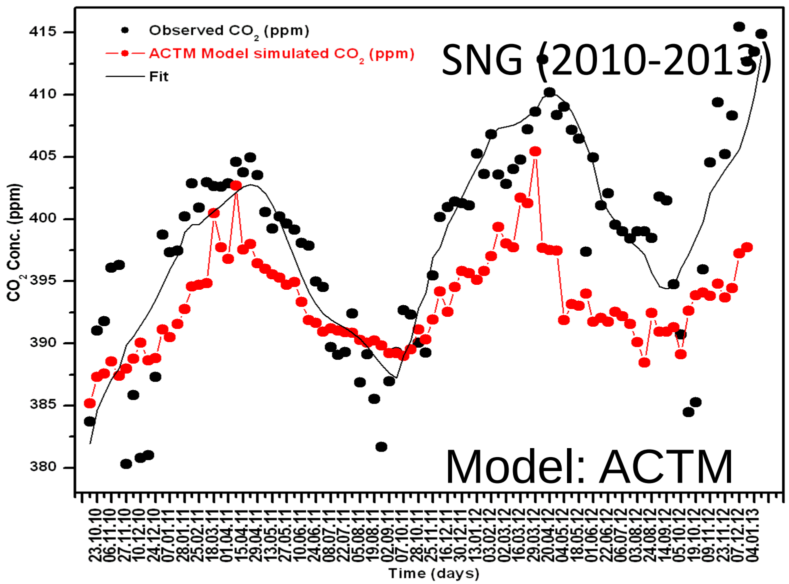


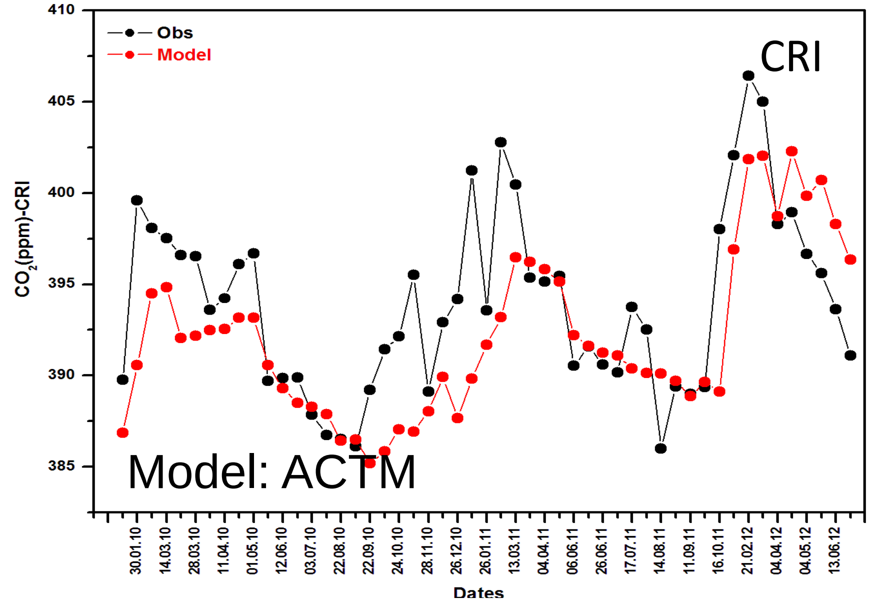
Observations at SNG site – updated up to May 2014

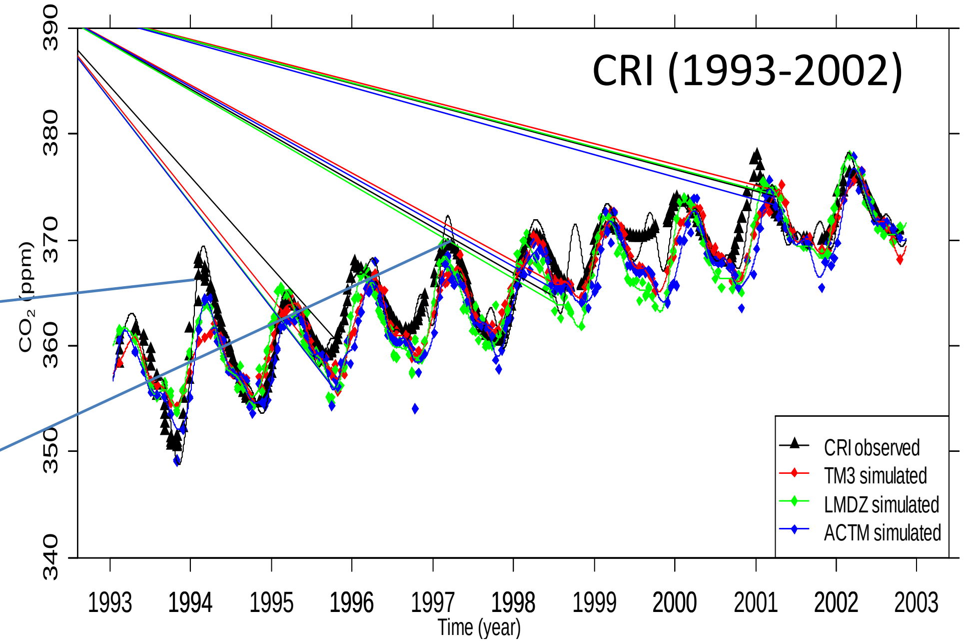




Observations and model simulations of CO_2 at SNG and CRI





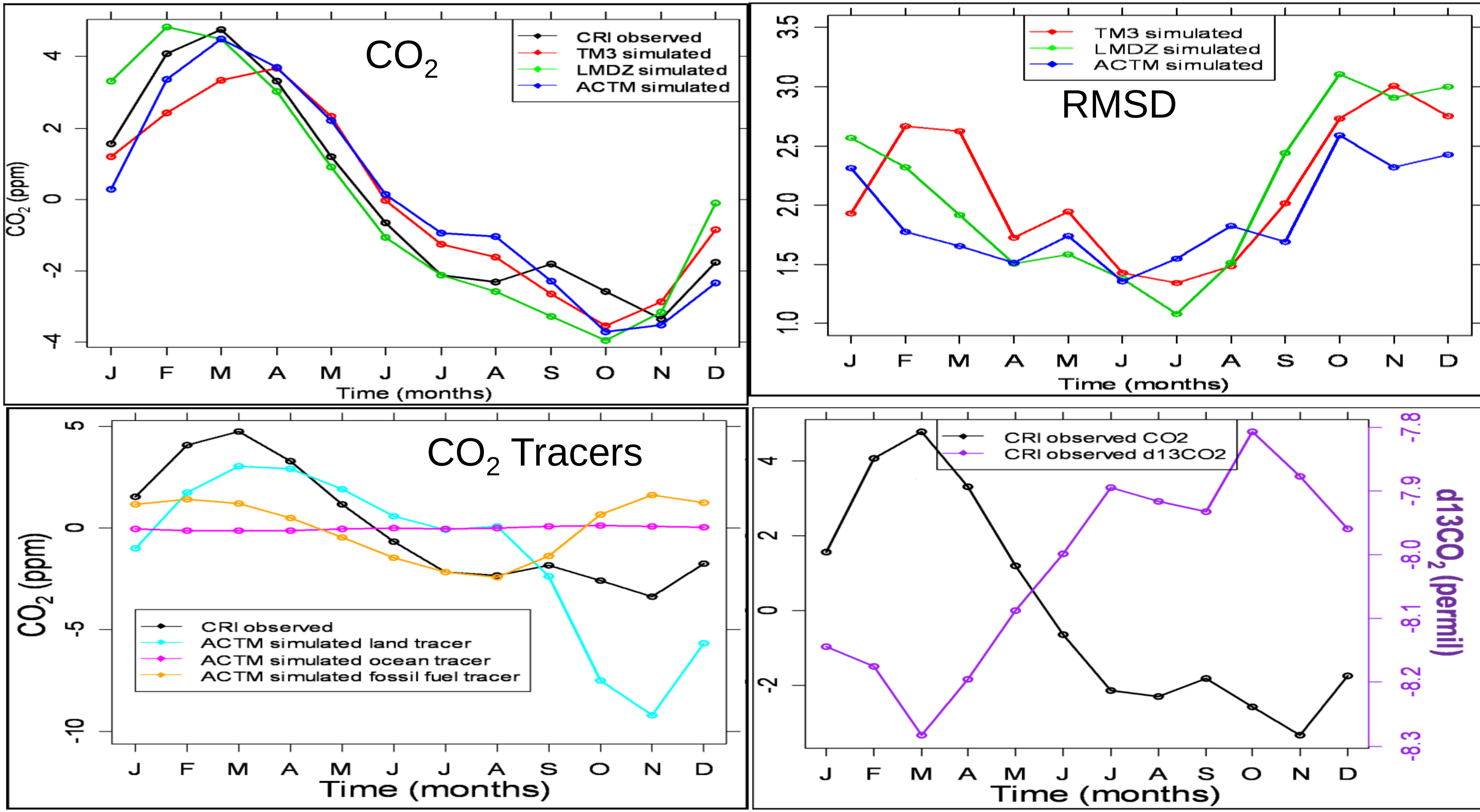


- Observations at SNG and CRI are in good agreement with the model simulations in seasonality

- The CRI and SNG sites indicated lower signatures of CO_2 during the summer months as CO_2 signatures richer in continental winds than in the marine winds

- The CRI seasonality appears particularly large in 1994/95 (20 ppm) and 1997/98 (13 ppm), which is not reflected in the simulations, but these periods were marked by unusual ***global wildfire activity*** particularly at low latitudes.

Seasonal cycle of CO_2 from observations and model simulations at CRI



❖ During summer monsoon months (June–September), the agreement between model and observed seasonal cycle is better represented (RMS values within ~1.5 ppm) than that of winter months (RMS values of 2–3 ppm).

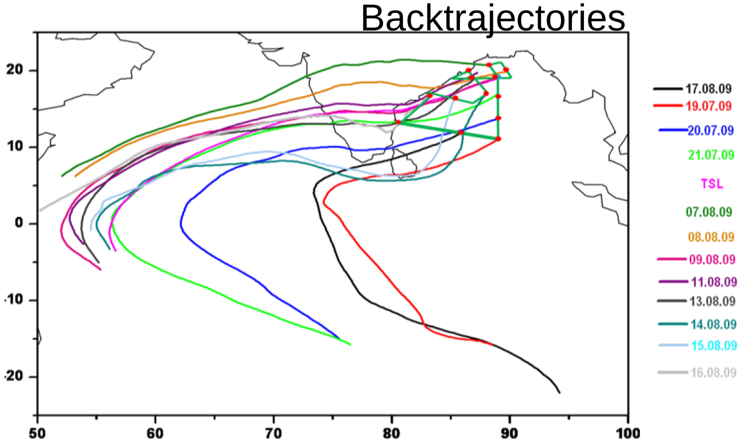
❖The seasonal forcing at CRI clearly comes from the terrestrial biosphere. This is also corroborated from the strong anti-correlation of the seasonal cycles of δ 13C and CO_2 .

Cruise observations : Land-ocean contrast of surface CO_2

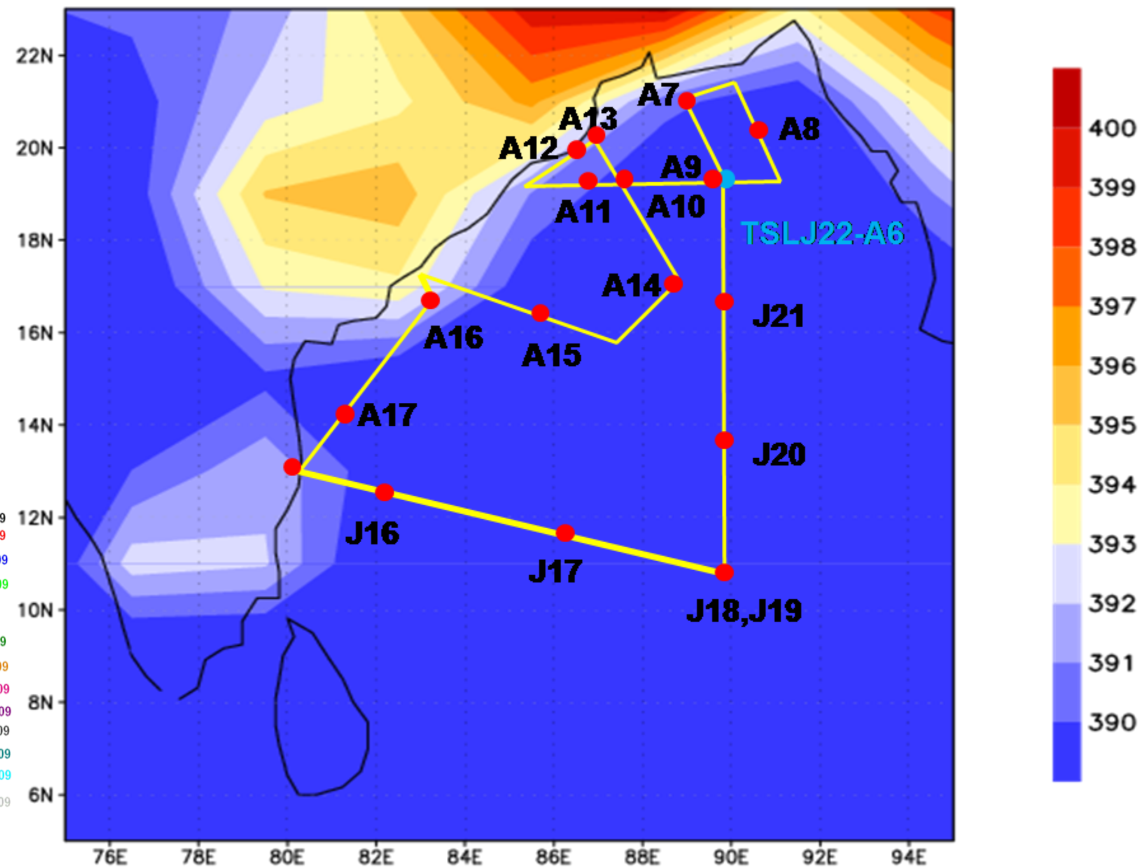
- The spatial pattern of mean CO_2 from the CarbonTracker simulations averaged from the start to the end of the cruise period.

- The sharp land-ocean contrast in atmospheric CO_2 at the surface (1000 hPa) can be seen in the CarbonTracker simulations.

Backtrajectories

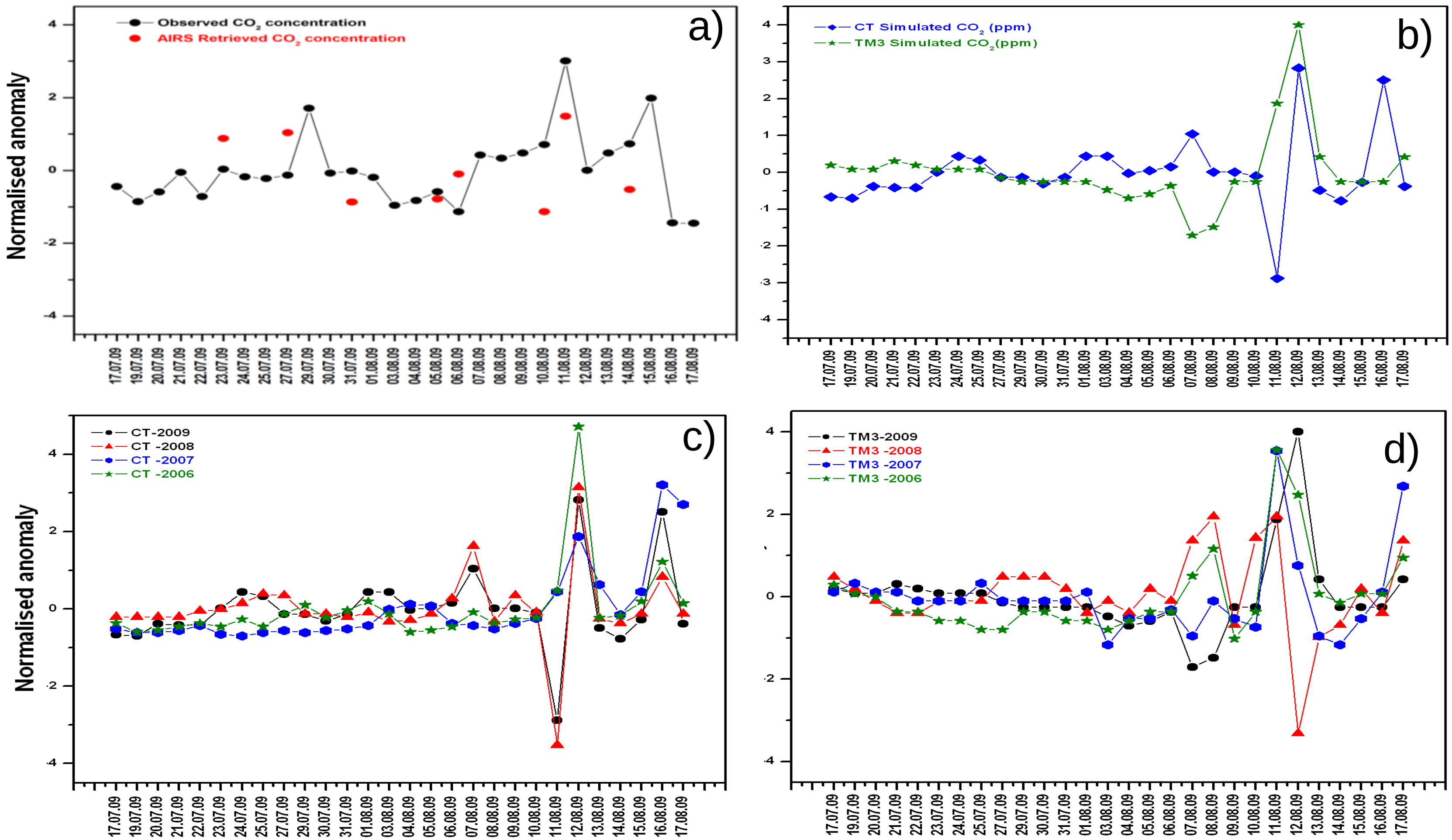


CruiseTrack and mean CO_2 (ppm; shaded) of the cruise period from Carbon Tracker model



Ref: **K. Ravi Kumar.**, Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO_2 over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)

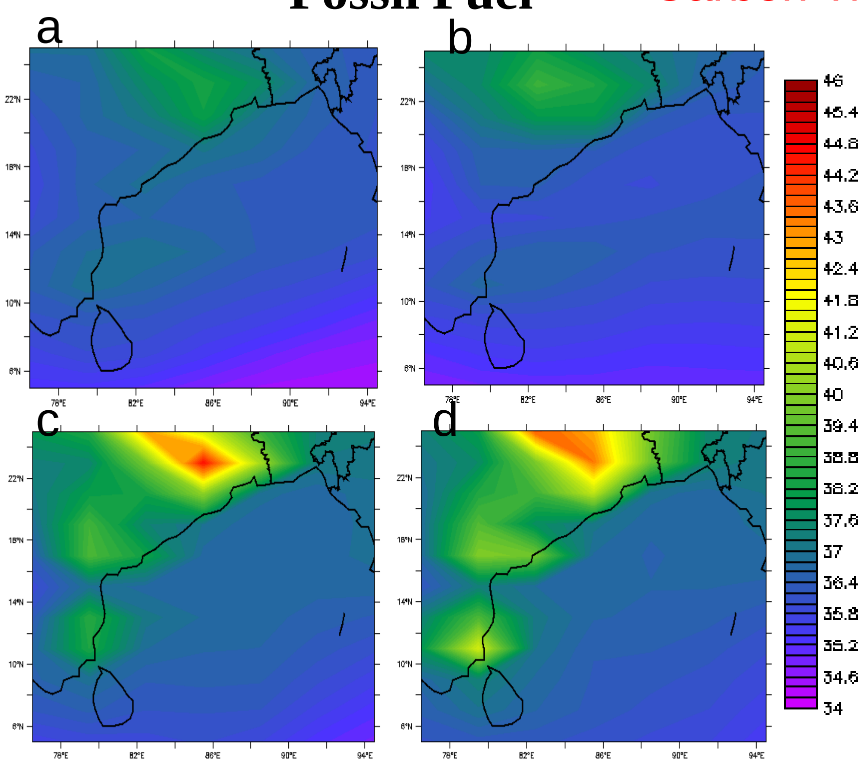
Comparison of observations and model simulations over Bay of Bengal

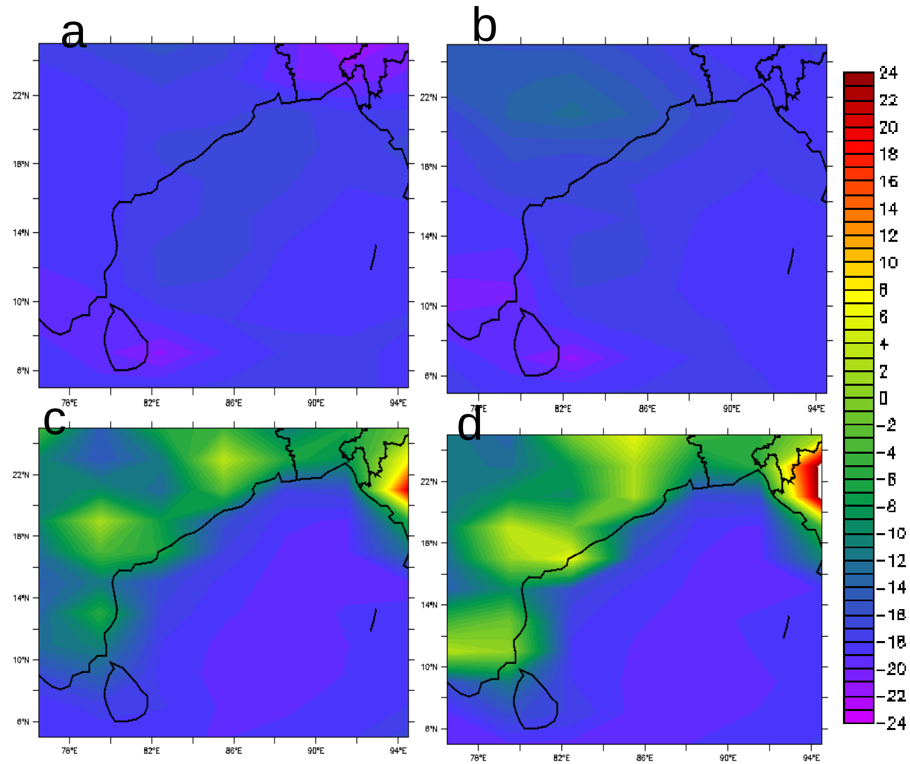


The land –ocean contrast is observed in the observations of CO_2 over BoB. such land-ocean contrast in CO_2 prevails during the same period of every year.

Ref: **K. Ravi Kumar.**, Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO_2 over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)

Fossil Fuel — Carbon Tracker CO2 — Bio tracers



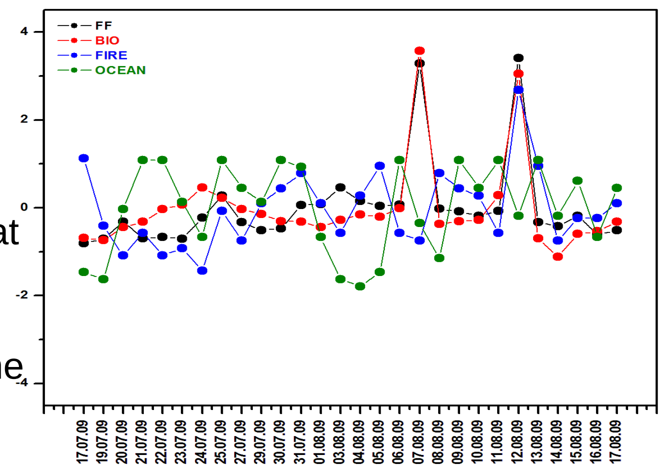


Open ocean – a) 19.07.09 and b) 21.07.09

Coastal ocean - c) 11.08.09 and d) 12.08.09

➢The peaks seen here are clearly contributed by the terrestrial biospheric fluxes (BIO) and fossil fuel (FF), and this also confirms that the land-ocean contrast is induced by the terrestrial vs. oceanic CO_2 fluxes.

➢Monsoon atmospheric circulation plays a pivotal role in advecting the CO_2 fluxes from the land towards the ocean.



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Ongoing aircraft experiment (Picarro : CO_2, CH_4, CO, H_2O)
(Aug-Sep-Oct-Nov, 2014)

Conclusions : An assessment of future climate warrants routine CO_2 monitoring over India

We

- monitored and analyzed three consecutive seasonal cycles of CO_2 data obtained from the new continental site (Sinhagad near Pune) routinely operated by the IITM.
- Also sampled and analyzed marine environmental CO_2 over Bay of Bengal (BoB) from a cruise experiment.

- The cruise data clearly demonstrated the land-to-ocean contrast of atmospheric CO_2 and this served as a validation tool for transport models.

Using the new land-station data

- Comparison with previously exiting longer record over India as well as from the global observations, we found that the seasonality of CO_2 cycle at this station is similar while amplitudes are different
- The observations showed clear indications of the linkage of local ecosystem and monsoon circulation
- Simulations using transport models at this receptor are in good agreement with the observations which provided a basis for CO_2 modelling over India

- CO_2 transport along the west coast of India is influenced by both local and remote sources

- Examination of CO_2 data with climate parameters (e.g., vegetation cover and rainfall) demonstrated an inverse relationship between the vegetation and CO_2

- Terrestrial biosphere plays an pivotal role in regulating the CO_2 signals along the west coast of India.

Implications

- The current monitoring at Sinhagad (SNG) and Cape Rama(CRI) provided insights and the results of this study can serve as a guideline to climate studies and carbon cycle modelling over monsoon region.
- Also this provides an important roadmap to future CO_2 (e.g., high frequency) observations over India

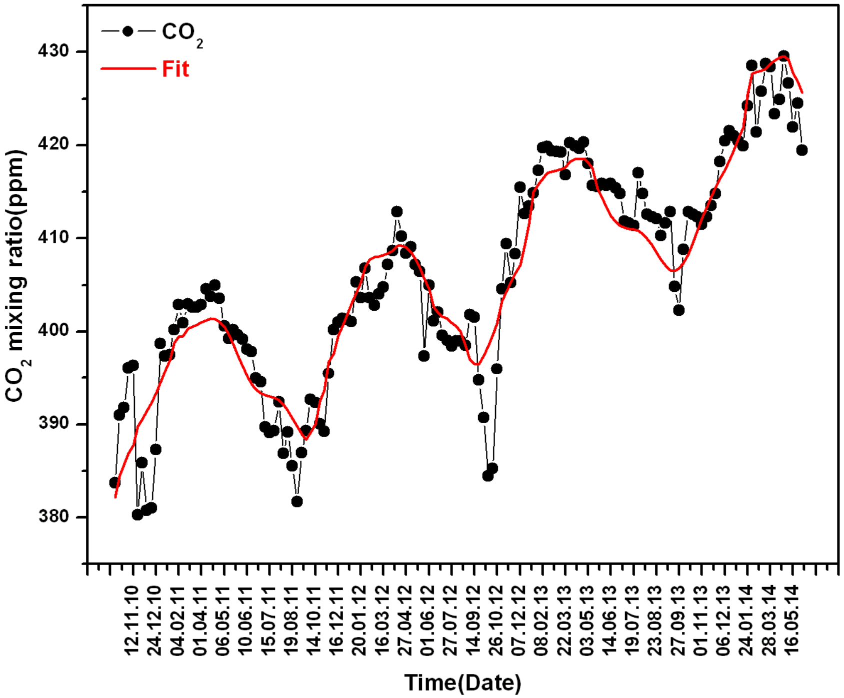
Thank You !!

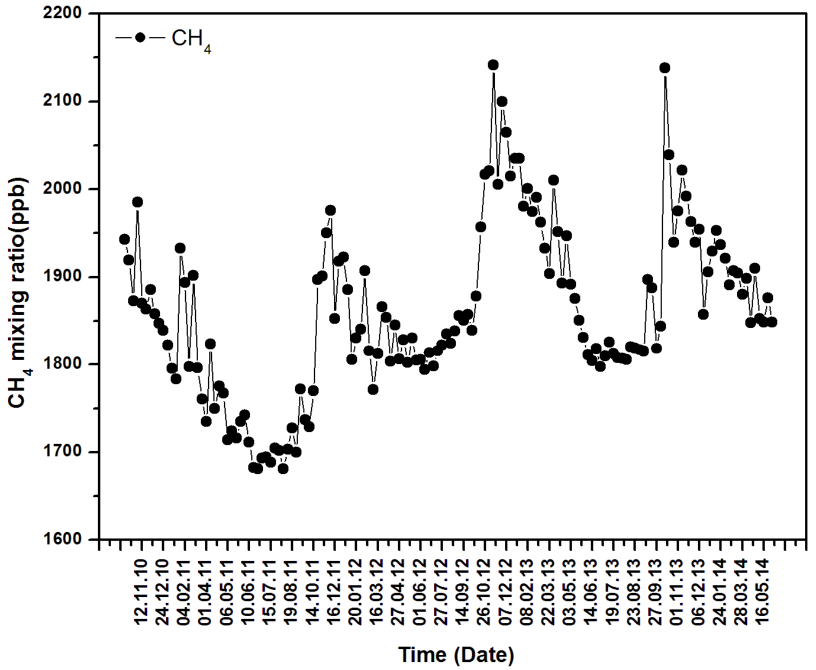


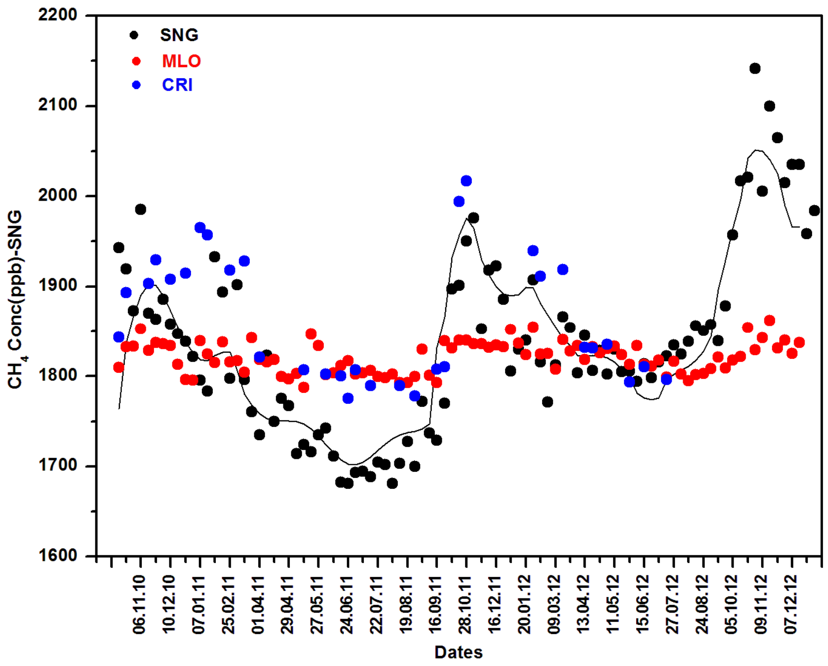




Observations at SNG site – up to May 2014





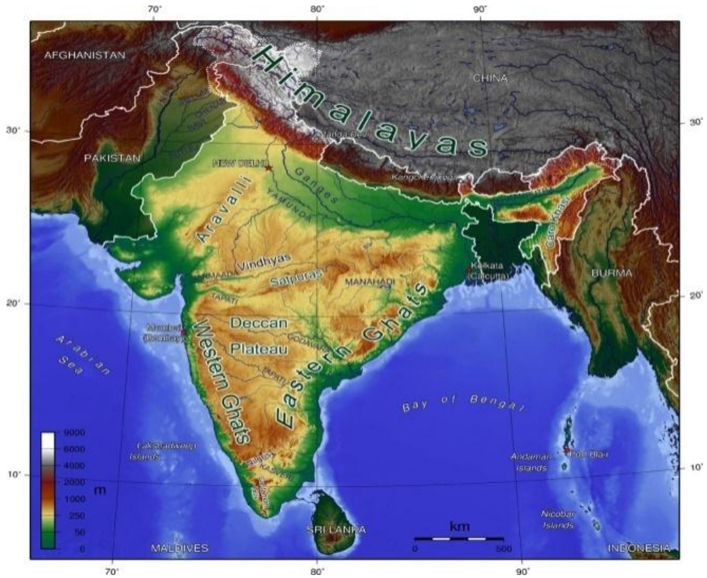


SNG
MLO
CRI
CH4 Conc(ppb)-SNG
2200
2100
2000
1900
1800
1700
1600
06.11.10
10.12.10
07.01.11
25.02.11
01.04.11
29.04.11
27.05.11
24.06.11
22.07.11
19.08.11
16.09.11
28.10.11
16.12.11
20.01.12
09.03.12
13.04.12
11.05.12
15.06.12
27.07.12
24.08.12
05.10.12
09.11.12
07.12.12
Dates

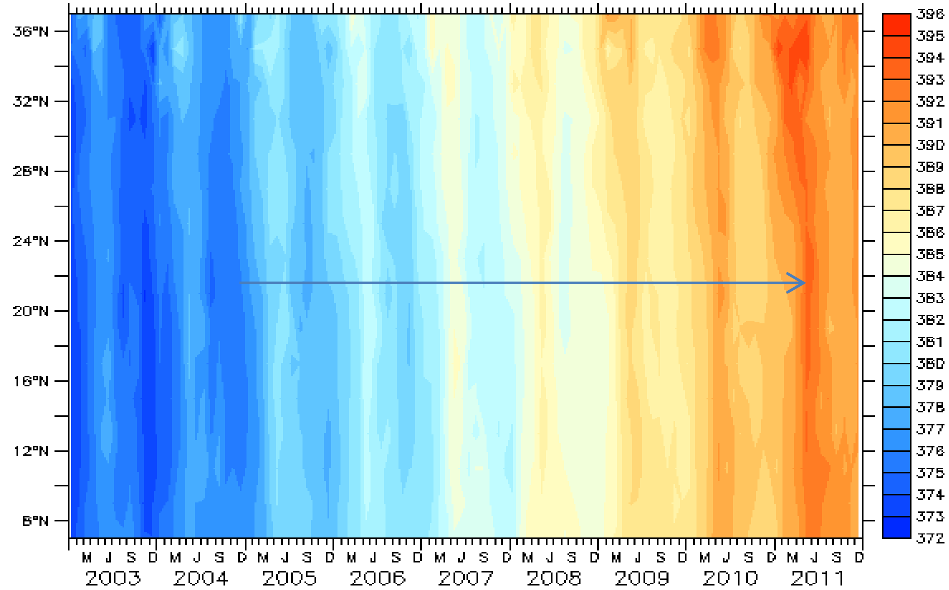
Satellite retrievals of CO_2

- AIRS CO_2 -Source (NASA)

- Zonal average(65°E-100°E) of satellite retrieved over India is shows monotonous increase at each latitude band.
- Satellite retrievals is shows almost 24ppm of CO_2 increase with an average growth rate of 2 ppm/yr during 2003-2011 over Indian region.
- Zonal average satellite de-trended CO_2 shows clear seasonality from year to year.



zonal mean of CO_2 observed over India



(zonal average) Detrended CO_2