Influence of monsoons on atmospheric CO$_2$ spatial variability and ground based monitoring over India

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Credits: K. Ravi Kumar, Vinu Valsala, Ramesh Vellore, Marcel van der Schoot, Prabir Patra, Chun ho Cho
India has one of the largest and fastest growing economies in South Asia and is emerging as a major contributor to CO\textsubscript{2} emissions among developing nations.

![Time series of CO\textsubscript{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\textsubscript{2} TgC/yr
  - Bottom- Up $-191\pm186$
  - Top –Down $-104\pm150$
  - Best Estimate $-147\pm239$ (NBP)

Towards a better understanding of CO\textsubscript{2} transport pathways, CO\textsubscript{2} sources and sinks over Indian subcontinent, need dense network and high quality CO\textsubscript{2} monitoring supplemented by a robust modeling techniques (Bhattacharya et al., 2009; Tiwari et al., 2011, Ravi et al., 2014).
850 hPa mean winds
Frankfurt - Chennai - Frankfurt
August 2008
Monsoon plume

Source: Carl Brenninkmeijer, CARIBIC
Fig. 8. Latitudinal distributions of CH$_4$ (a), SF$_6$ (b), and N$_2$O (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$_2$O. 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.
Fig. 5. Latitudinal distributions of CH₄, CO₂, N₂O, and SF₆ 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 CO₂ the mean mixing ratio observed at Mauna Loa Observatory (19°N) is indicated by a solid line.
GHG’s observations: India

Surface (2009-2014)

- IITM, Pune - Sinhagad (SNG), 1600 m amsl
- CSIRO, NIO - Cape Rama (CRI), 50 m amsl

Cruise (2009 - )

Aircraft (2010, 2014)
Surface monitoring sites
Surface monitoring site SNG, Pune, India

Wet condition

Dry condition
Methodology and analysis techniques

Met sensors and Intet pump

Air sampler
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.

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).

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 cycles of vegetation and CO₂ 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.

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.

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.

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.

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

**CO$_2$**

**CH$_4$**
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.
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 CO₂.
Cruise observations: Land-ocean contrast of surface CO₂

- The spatial pattern of mean CO₂ from the CarbonTracker simulations averaged from the start to the end of the cruise period.

- The sharp land-ocean contrast in atmospheric CO₂ at the surface (1000 hPa) can be seen in the CarbonTracker simulations.

Ref: K. Ravi Kumar., Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO₂ over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)
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)
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 CO₂ fluxes.

Monsoon atmospheric circulation plays a pivotal role in advecting the CO₂ fluxes from the land towards the ocean.

Ref: K. Ravi Kumar., Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO₂ over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)
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.

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

The cruise data clearly demonstrated the land-to-ocean contrast of atmospheric CO\(_2\) and this served as a validation tool for transport models.

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

Conclusions: An assessment of future climate warrants routine CO\(_2\) monitoring over India.
- Terrestrial biosphere plays an pivotal role in regulating the CO\(_2\) signals along the west coast of India.
Thank You!!
Satellite retrievals of CO₂

- AIRS CO₂ - Source (NASA)
- Zonal average (65°E-100°E) of satellite retrieved over India shows a monotonous increase at each latitude band.
- Satellite retrievals of CO₂ show almost a 24ppm increase with an average growth rate of 2 ppm/yr during 2003-2011 over the Indian region.
- Zonal average satellite de-trended CO₂ shows clear seasonality from year to year.