Continuing efforts on greenhouse gases monitoring and modeling in India

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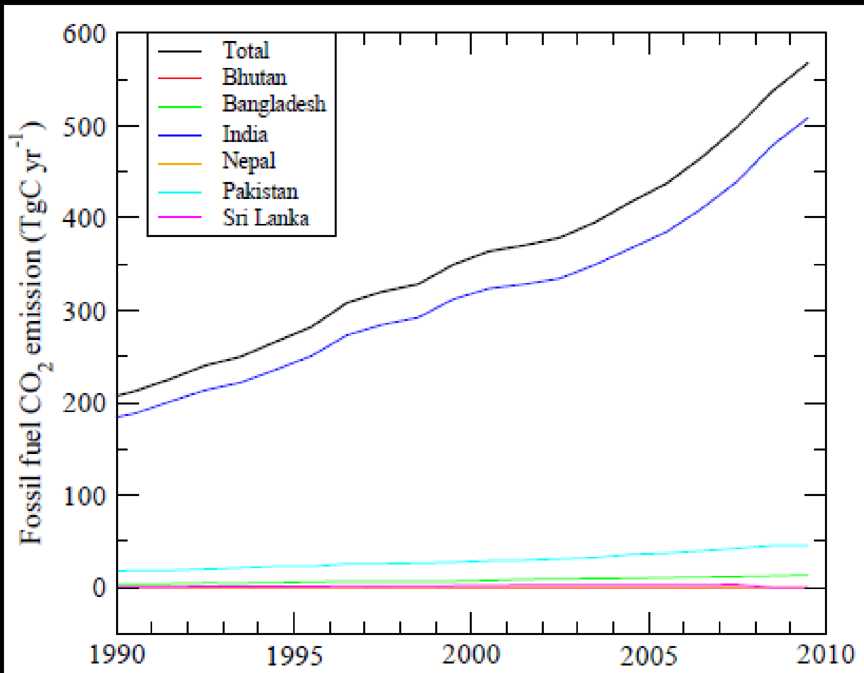
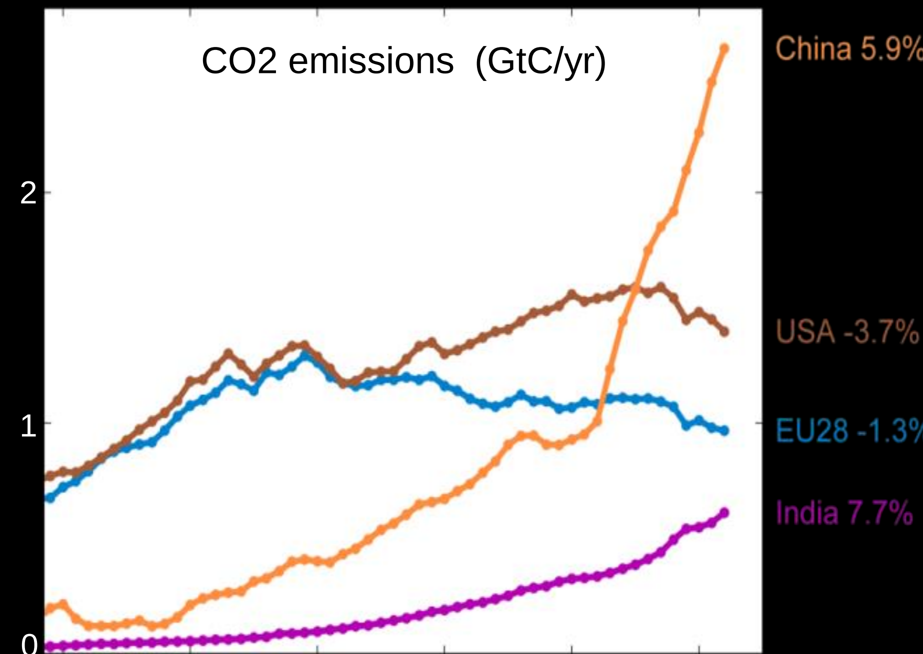
(Ministry of Earth Sciences, Govt. of India)

CO_2 emissions from India



CO_2 emissions due to fossil fuel and cement production over South Asia during 1990-2009 (Source: Boden et al,2011)



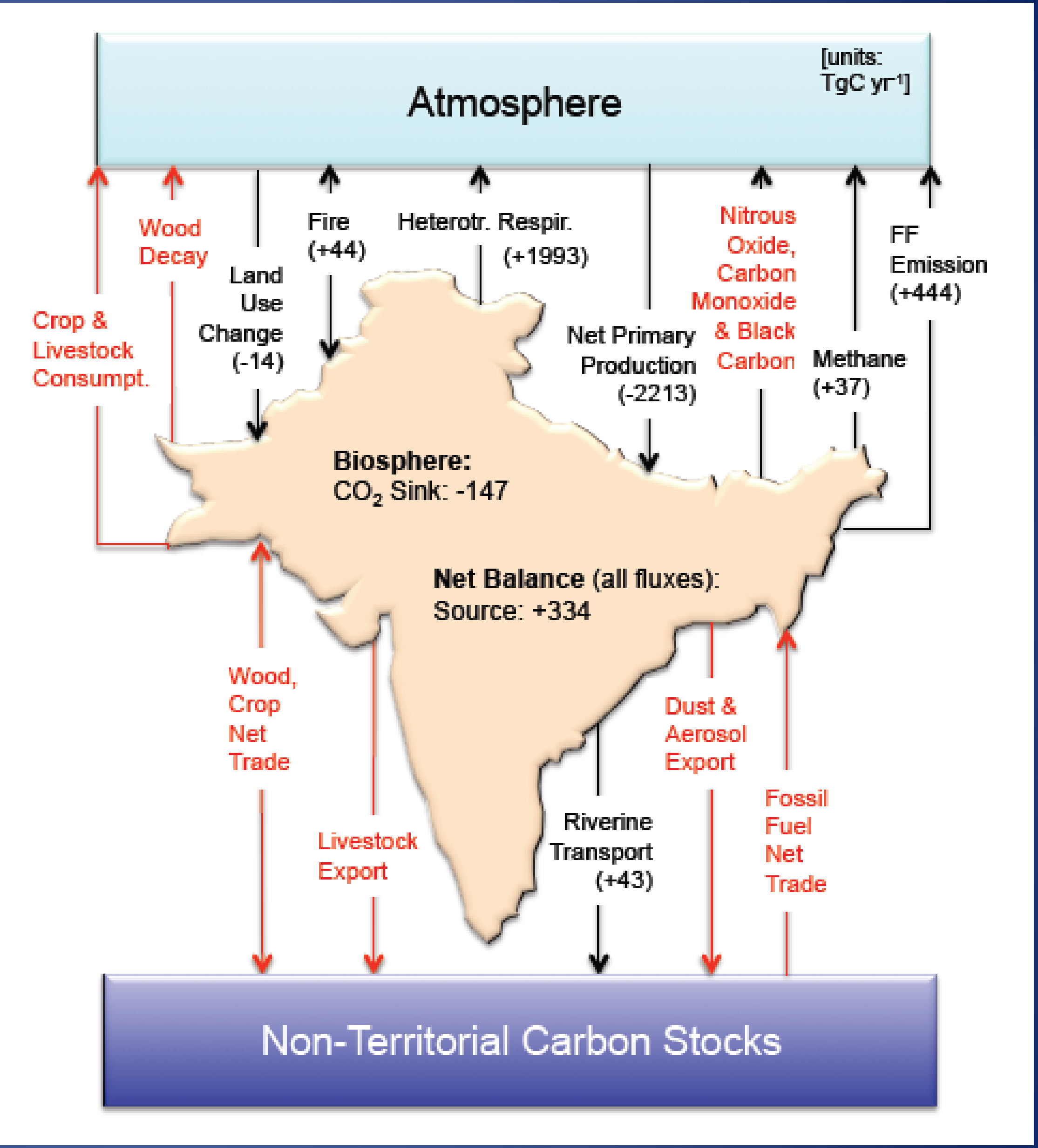
Le Quéré et al 2013; Global Carbon Project (GCP) 2013

- 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; Patra et al, 2013).

- 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, 2014; Ravi et al., 2014).

Major fluxes of CO_2, CH_4, N_2O and related species in the South Asian region

(Source: Patra et al, 2013)

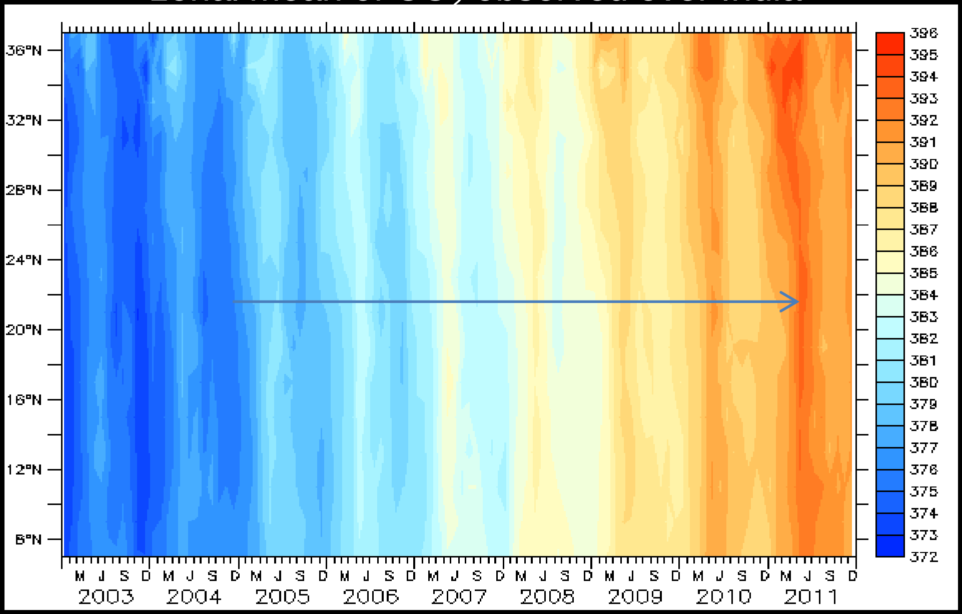


CO_2 from space (satellite)

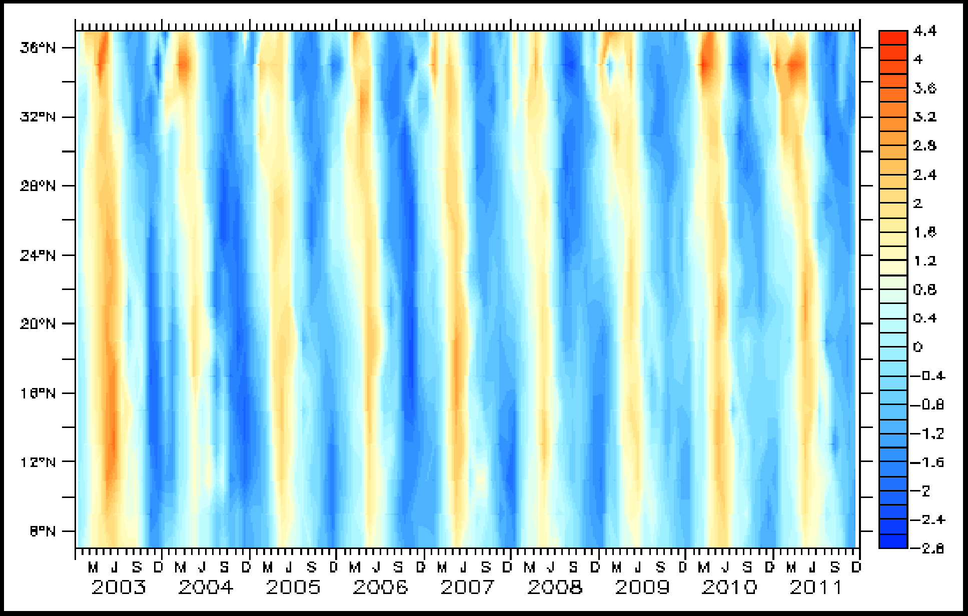
- AIRS CO_2 -Source (NASA)

- 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



Greenhouse gases monitoring techniques we use

1) Discrete
2) In-situ

Greenhouse gases monitoring platforms we work

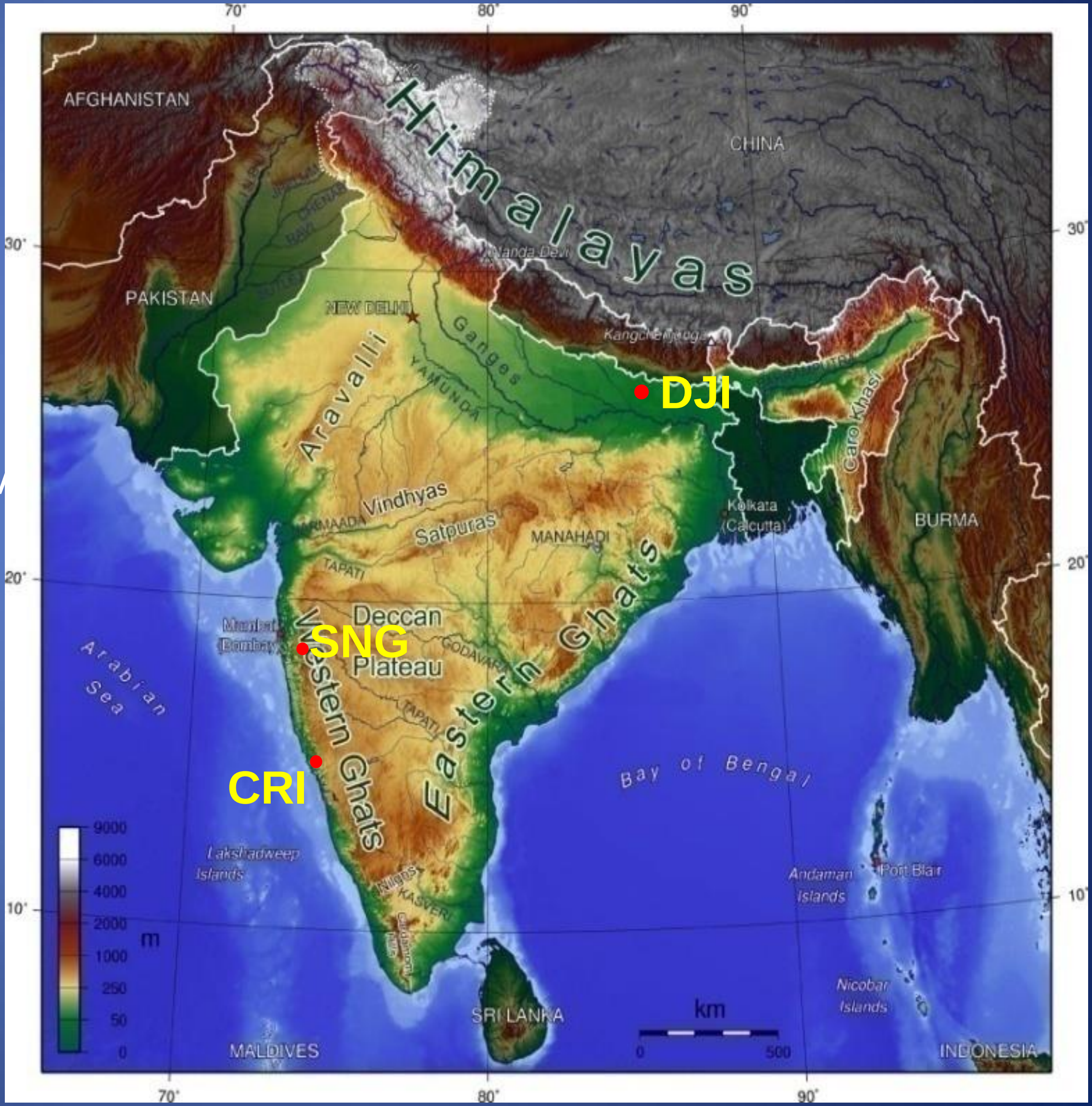
1) Surface
2) Aircraft
3) Ship

1) Surface sites:

Sinhagad **(SNG)** – Yogesh Tiwari (2009 – continue)

Cape Rama **(CRI)** – Marcel (1993-2002, 2009-2013)

Darjeeling **(DJI)** – Anita, Bristol Univ (2010- 2013)



(SNG)


SNG-tower
सिंहगड
Image © 2010 DigitalGlobe
© 2010 Google
Google
Imagery Date: May 16, 2006
18°21'54.75" N
73°45'19.45" E
elev 4276 ft
Eye alt 8087 ft

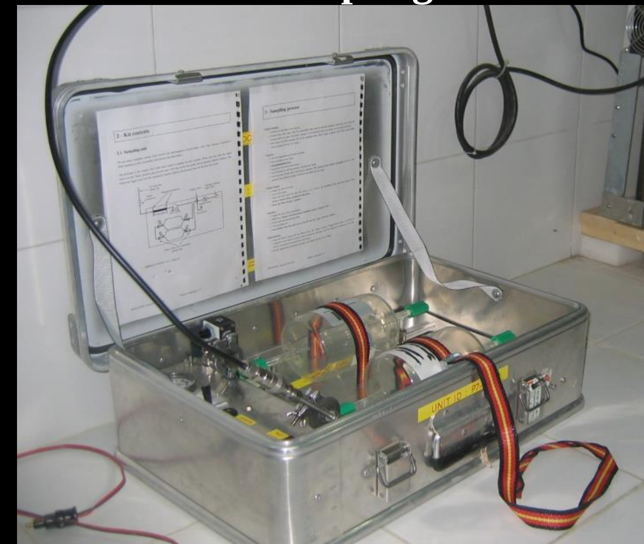

(SNG)
SNG-tower
Image © 2010 DigitalGlobe
© 2010 Google
©2008 Google
Imagery Date: May 16, 2006
18°21'57.78" N
73°45'16.03" E
elev 4275 ft
Eye alt 4927 ft

Surface monitoring site SNG, Pune, India

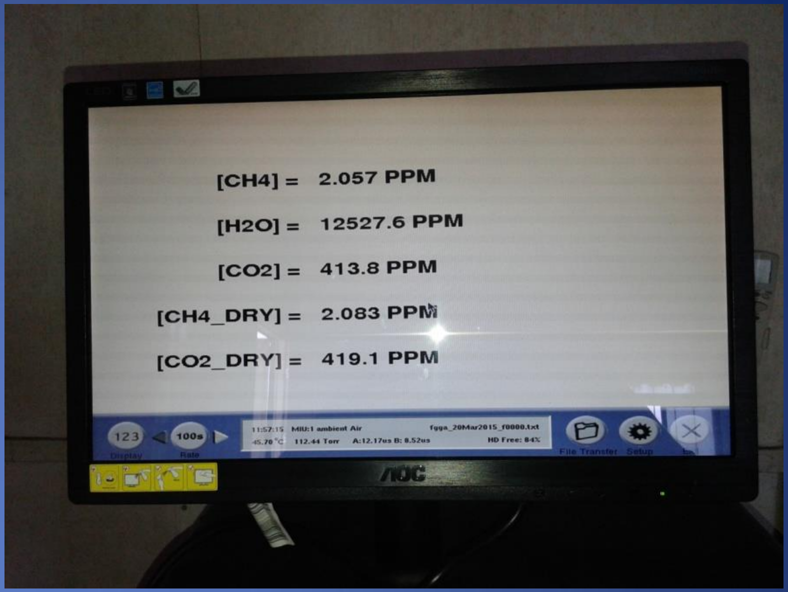
Methodology and analysis techniques

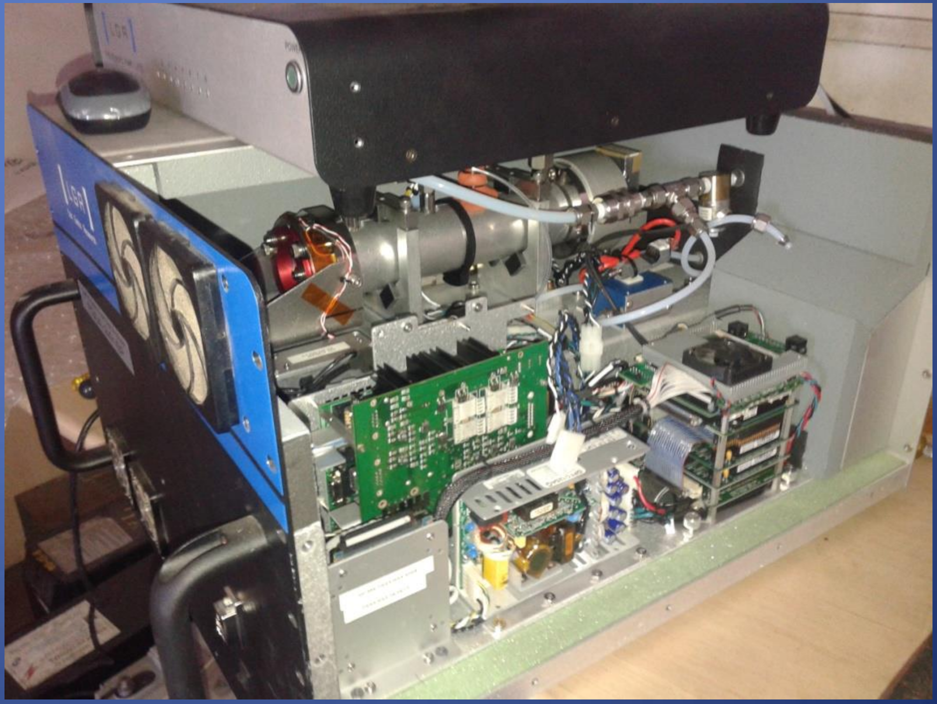
Met sensors and Intet pump

Flask sampling unit

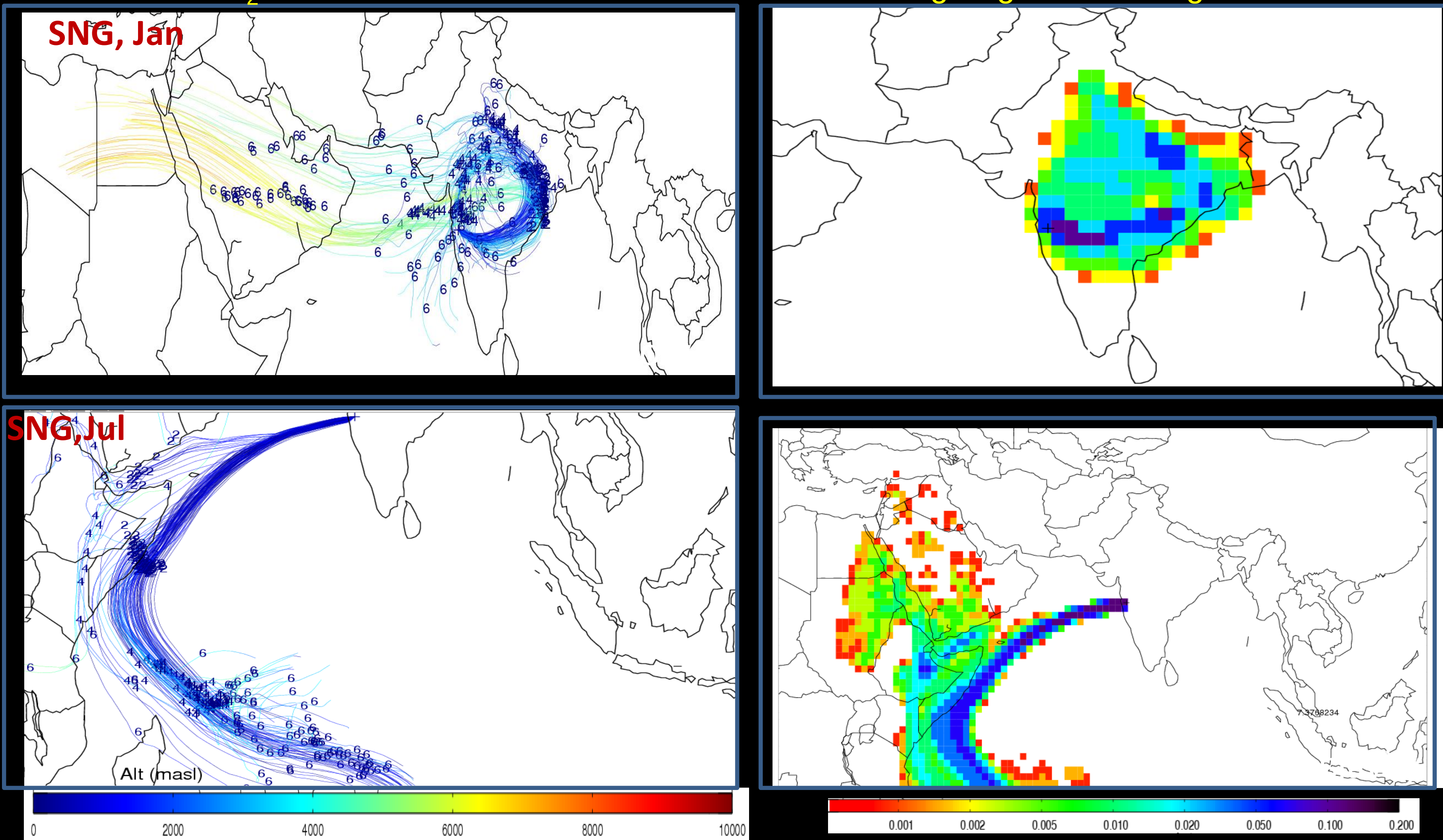


Continuous in-situ measurements of CO_2, CH_4, H_2O at Sinhagad (SNG) site





CO_2 sources at the observation sites based on Lagrangian modeling

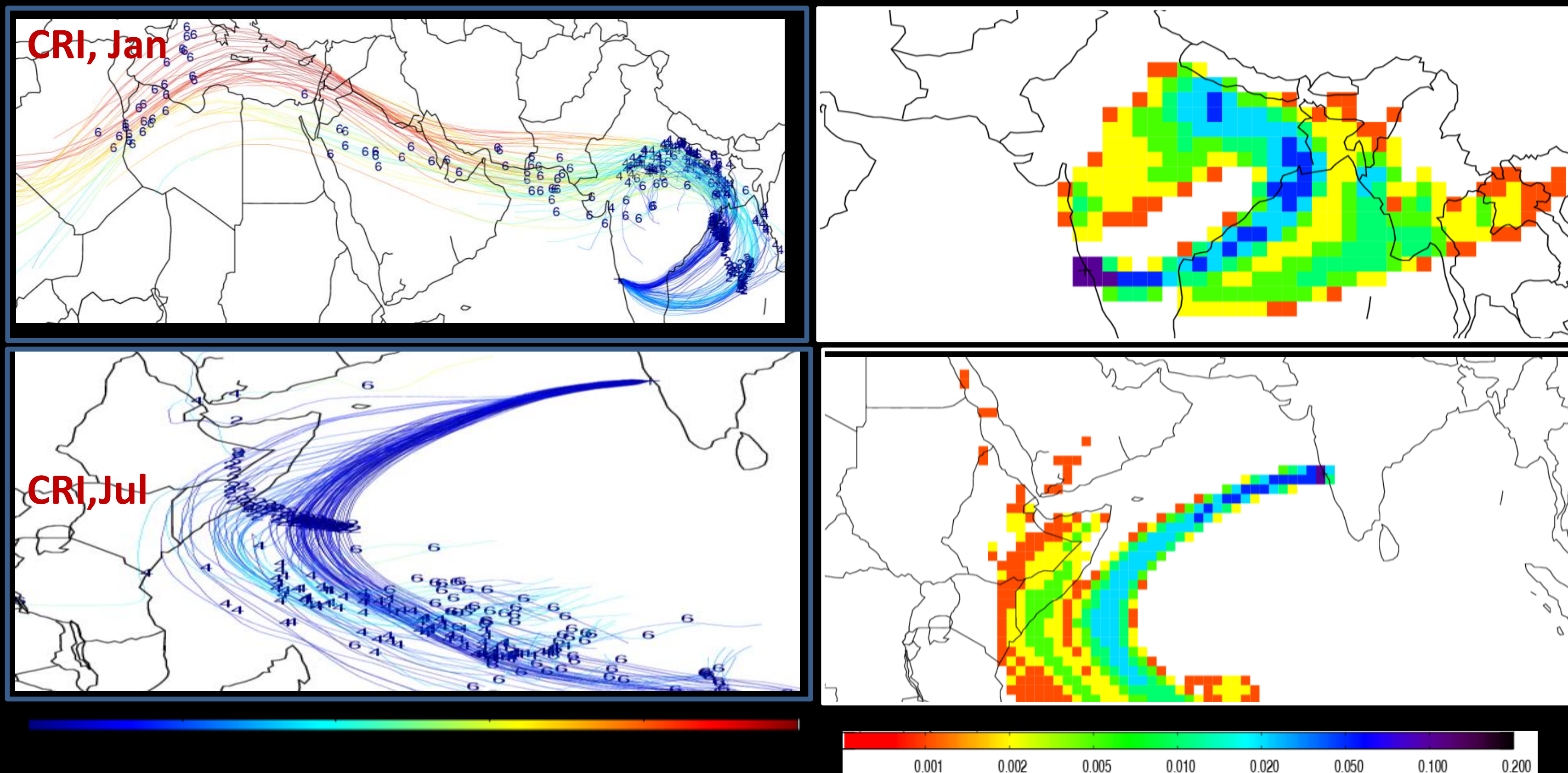


Surface Sensitivity [ppm/(µmol m^{-2} s^{-1})]

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



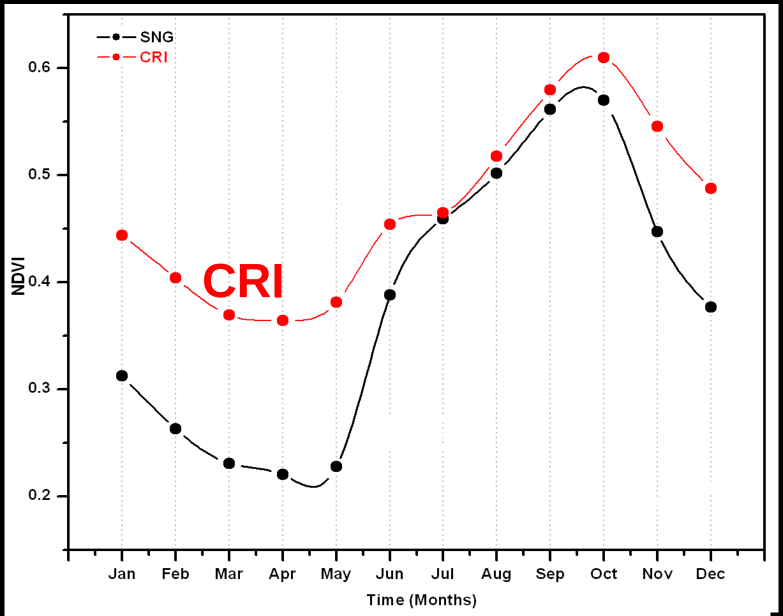
Surface Sensitivity [ppm/(μmol m^{-2} s^{-1})]

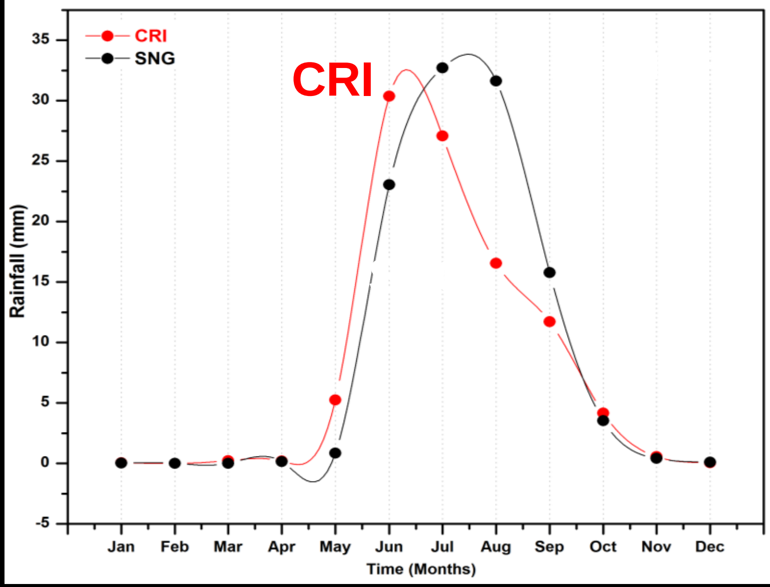
❖During January, higher surface sensitivity is seen over the central and east coast of India as well as over the foothills of the Himalayas. In contrast, the surface sensitivity magnitudes are significant over the central Arabian Sea in July.

❖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.

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





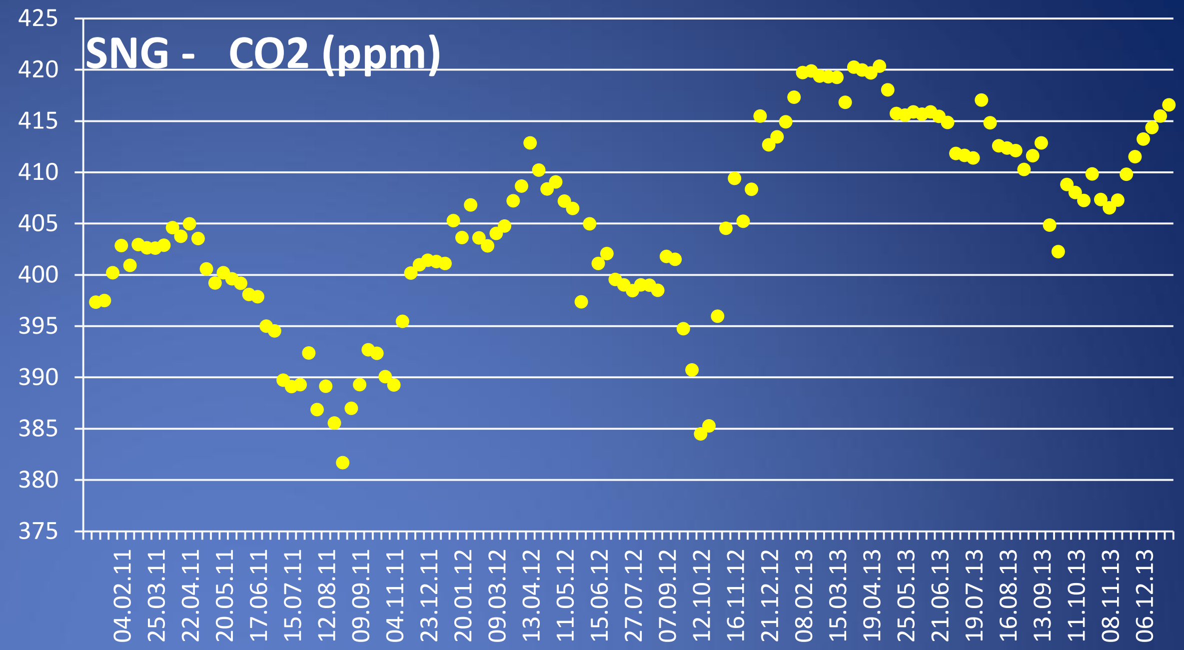
➢NDVI shows a minimum value at SNG to represent bare soil during April to May, which contrasts the maximum in October to represent the loss of vegetation canopy.

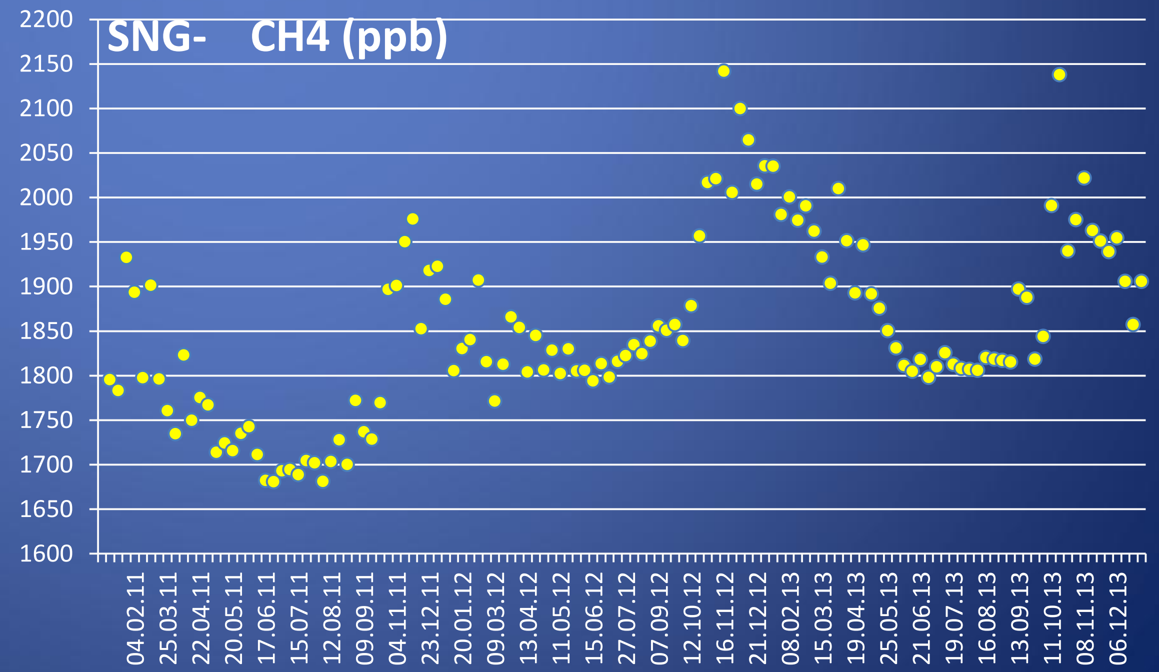
➢Although the NDVI magnitude at CRI is larger, the month-to-month variability in the vegetation cover is found to be weaker at CRI as compared to SNG. This suggests that crop harvesting in the vicinity of SNG appears to play a role ahead of the summer monsoon season.

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

Results:

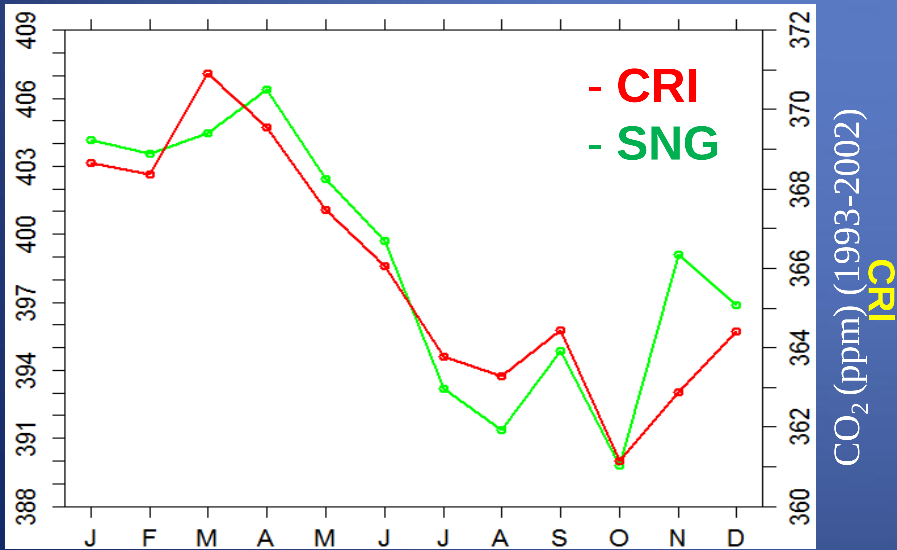
GHGs observations at Sinhagad (SNG) monitoring site (2011-2013)

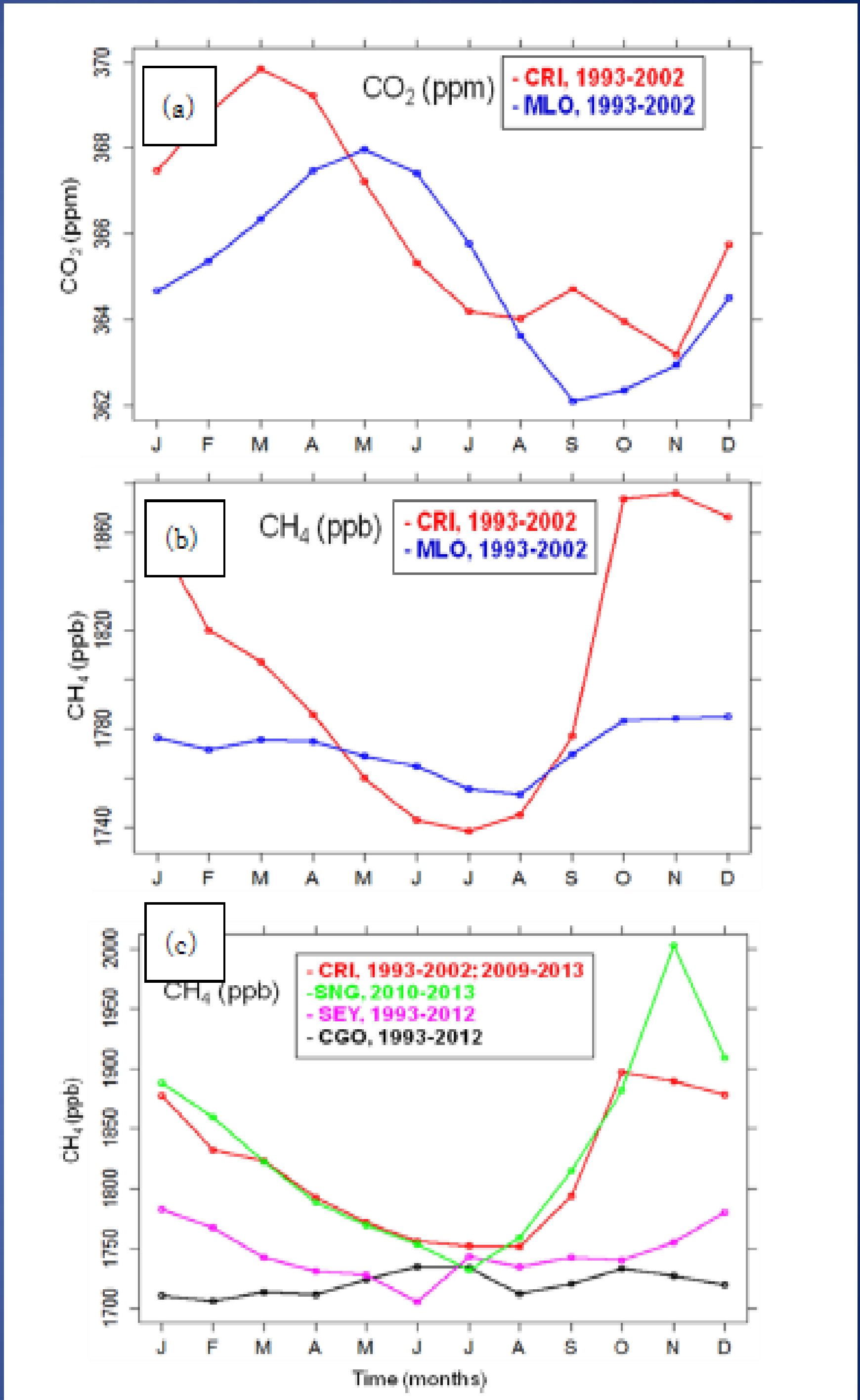




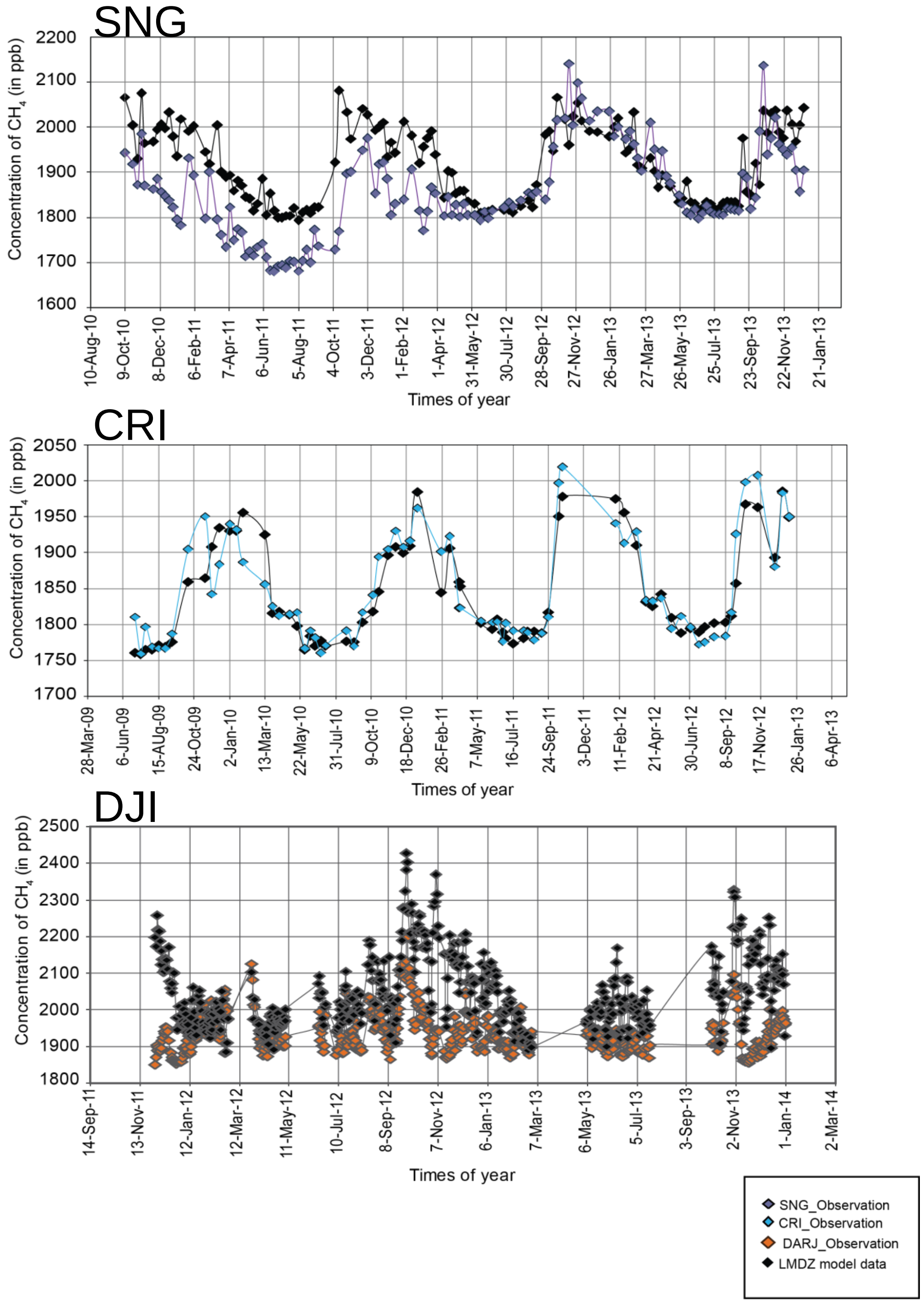
Climatological mean of
Observed CH4 & CO2 concentrations.

Comparison with northern and
Southern hemisphere global
Monitoring sites



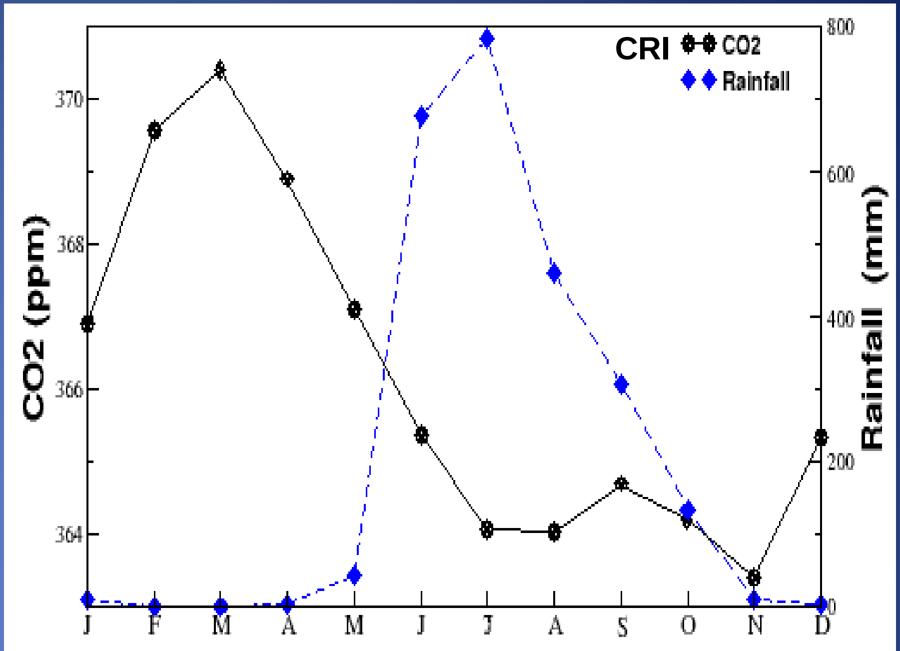


CH_4 observations and comparisons with model simulation at three Observational sites in India



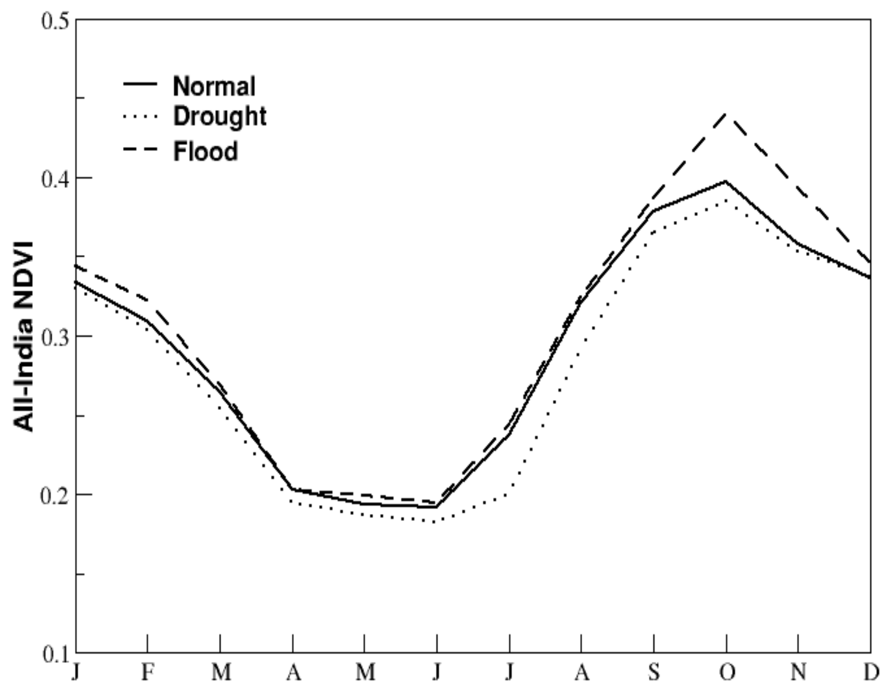
Annual cycle of CO_2 (ppm) superimposed with annual cycle of Rainfall (mm) over Cape Rama based on the data for 1993-2002

(Ref.: **Yogesh K. Tiwari**, J. V. Revadekar, K. Ravi Kumar, 2013, Variations in atmospheric Carbon Dioxide and its association with rainfall and vegetation over India. *Atmospheric Environment,* Vol.68 (2013), pp 45-51, DOI: 10.1016/j.atmosenv.2012.11.040)

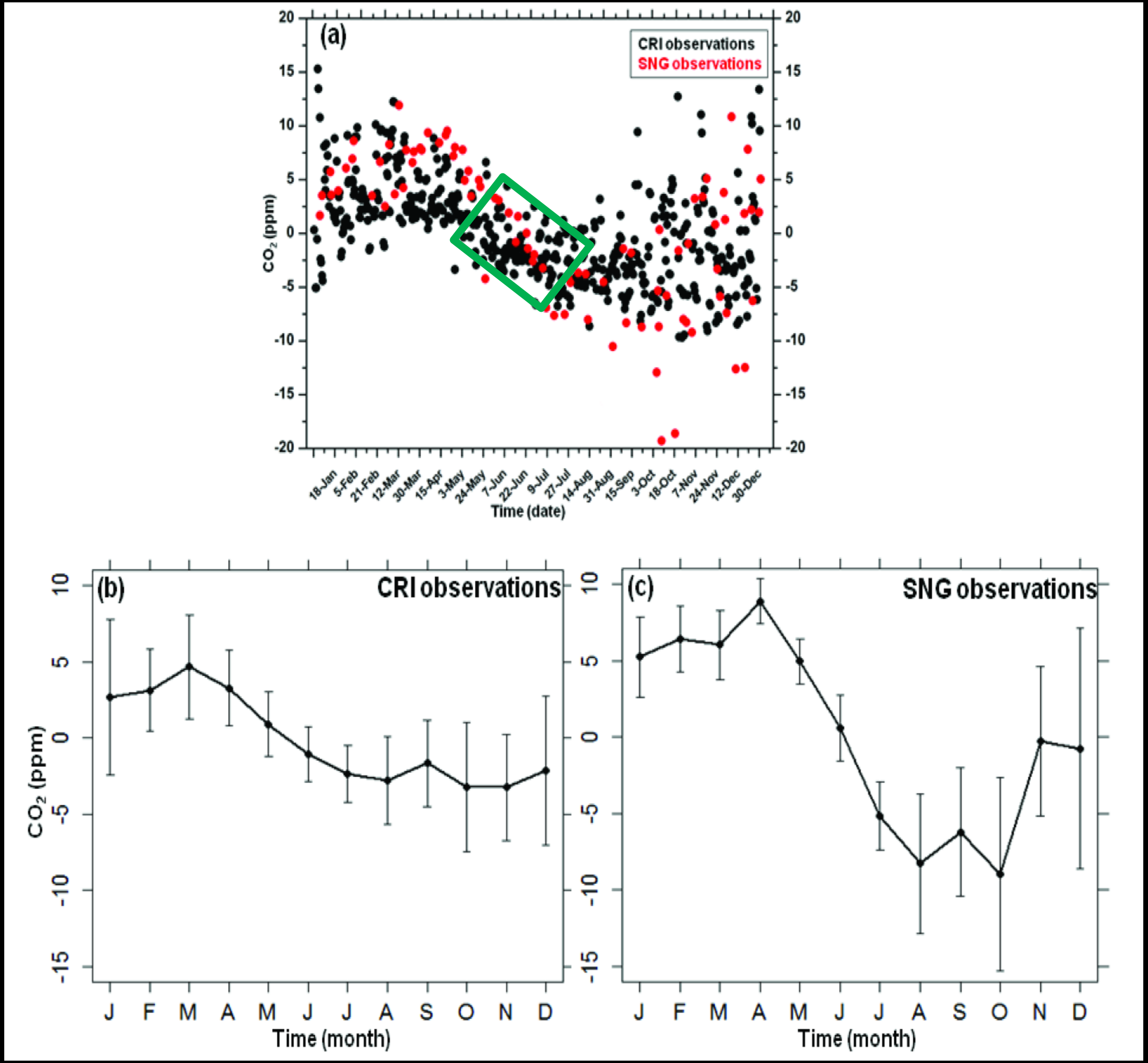


Annual cycle of all-India monthly mean Vegetation index (NDVI) during drought and flood years over the period 1981–2000

(Ref.: J. V. Revadekar, **Yogesh K. Tiwari**, K. Ravi Kumar, 2012, Impact of climate variability on NDVI over Indian region during1981-2000. *International Journal of Remote Sensing*, Vol.33, No.22, 2012, 132-7150, DOI: 10.1080/01431161.2012.697642)



CO_2 variability at SNG and CRI observing sites



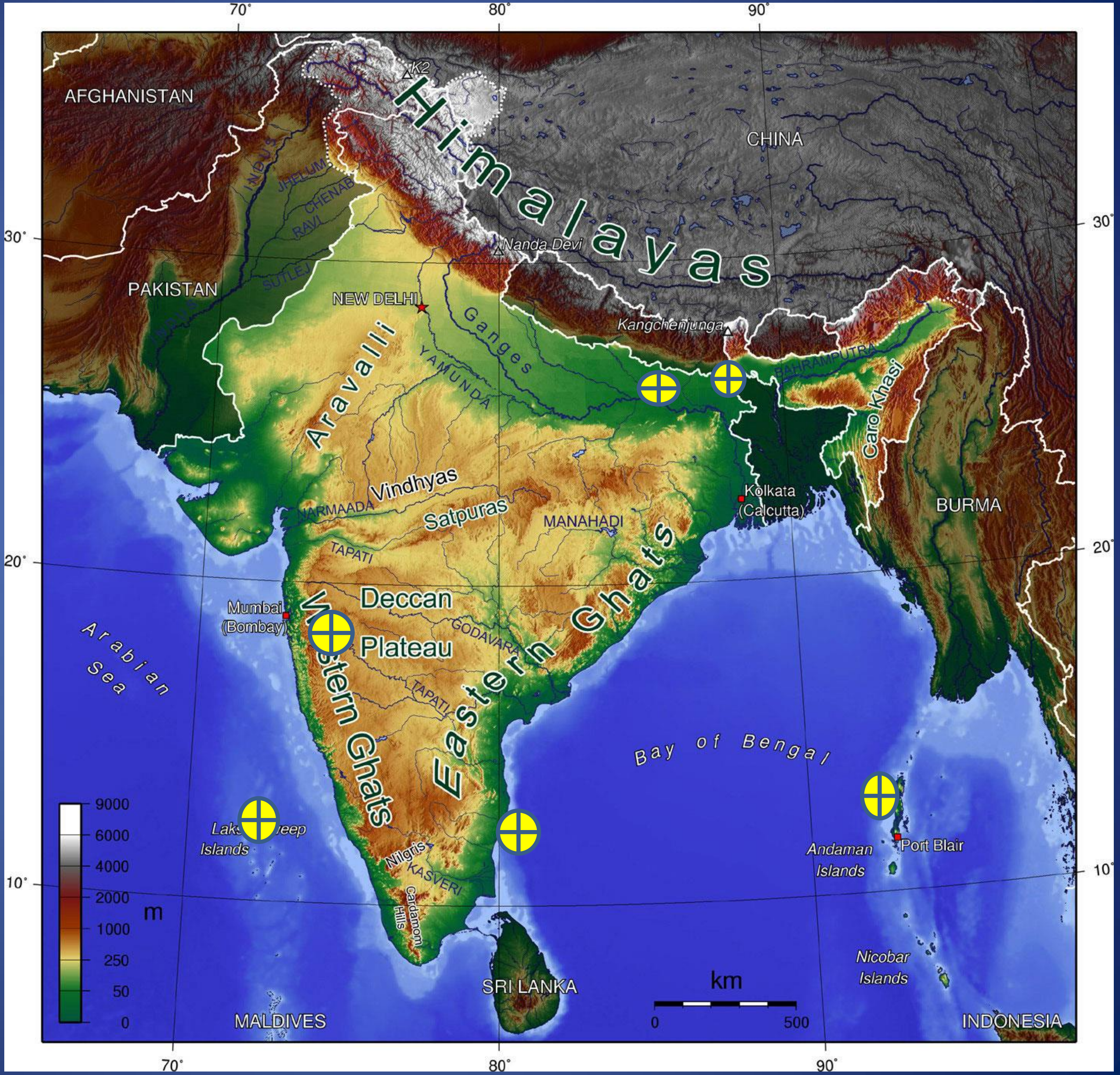
There is a smaller CO_2 variability (8–10 ppm) during summer monsoon months (JJAS) compared to values greater than 15 ppm for the remainder of the year. This is in part due to higher vegetation cover in these months due to intermittent precipitation spells.

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.

Carbon flux Measurement Netwrok in India (FLUXNET)

-IITM operates Six sites for Carbon flux Measurements In India



Carbon flux measurement (fluxnet):

- Multi-level instrumentation

1. Eddy Covariance (EC) systems at two levels consisting of fast-response 3D sonic anemometer-thermometer, closed-path CO_2-H_2O analyzer and data logger
2. soil temperature sensor at 5 levels
3. heat flux plates at 2 levels
4. multi-component weather sensors at 4 levels
5. infra-red thermometer
6. Photosynthetic Active Radiation (PAR) quantum sensor
7. net radiometer

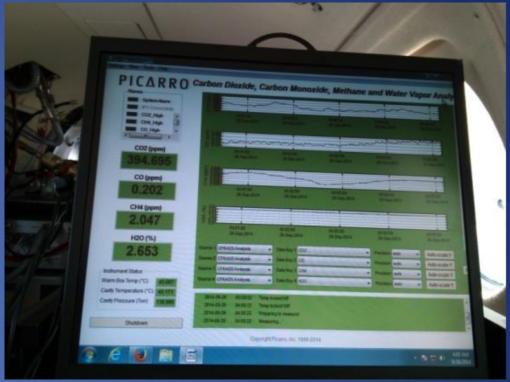
Credits: Pramit

2) Airborne GHGs monitoring: 2010, 2014, 2015

- **Instrumentation**

CRDS instrument

Data display



•Cavity Ring Down Spectroscopy (CRDS) for measuring CO2, CH4, CO, H2O concentrations in the air

•CRDS is a linear optical absorption technique for measuring trace levels of a target compound in air

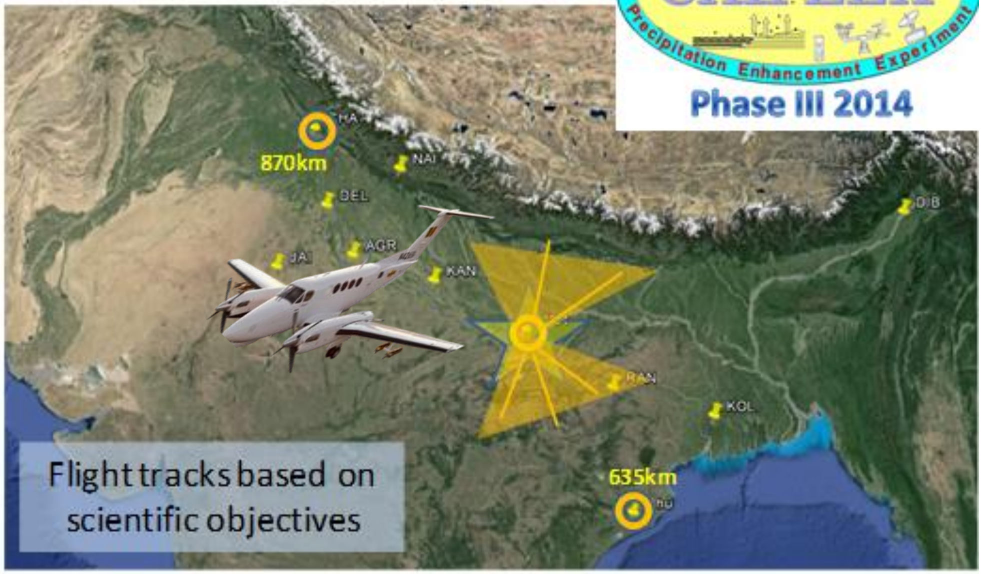
•Linear optical absorption technique is a process of passing light through a gas sample and measuring the amount of light absorbed.

Calibrations…….

Beechcraft King Air B200: Sept 2014 at Varanasi

Cloud Aerosol Interaction and Precipitation Enhancement Experiment
CAIPEEX
Phase III 2014

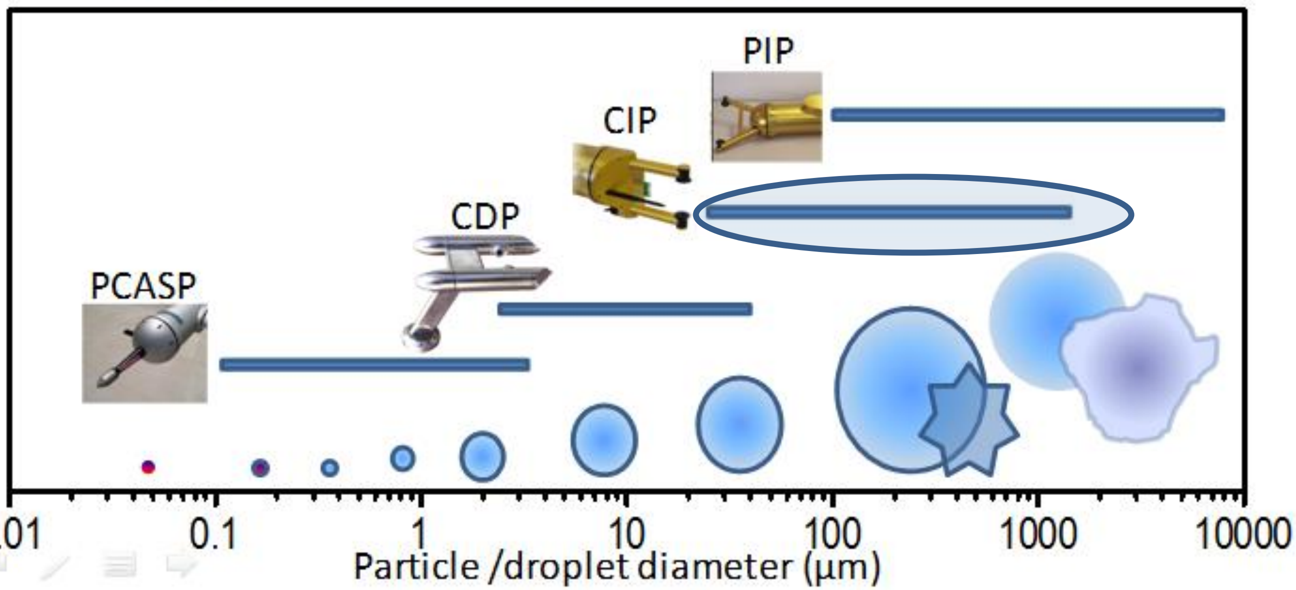
Crew	2 pilots + 2 scientists
Gross weight	> 12,500 lbs
Payload	> 1000 lbs
Cabin Volume	>6 m³
Minimum operating altitude	500-1000 ft AMSL
Minimum operating altitude	25000 to 28000 ft AMSL
Cruising Speed	230 - 260 knots
Sampling Speed	80-120 m/s
Ascent rate	>800 ft /min
Endurance	4 - 5 hours
Range	2000 km minimum



Other Instruments:

- CCN counter
- Hot-Wire Liquid Water Sensor (LWC-100)
- TWC probe
- Air Data Probe (winds, temperature, RH)
- PILS with Auto Sampler
- Photoacoustic Extinctiometer (PAX) – aerosol scattering and absorption
- CRDS gas analyzer (CO_2, CH_4, H_2O, CO)

Aerosol and Cloud Physics Instruments



Credits: Thara P.

Calibration and post-processing:

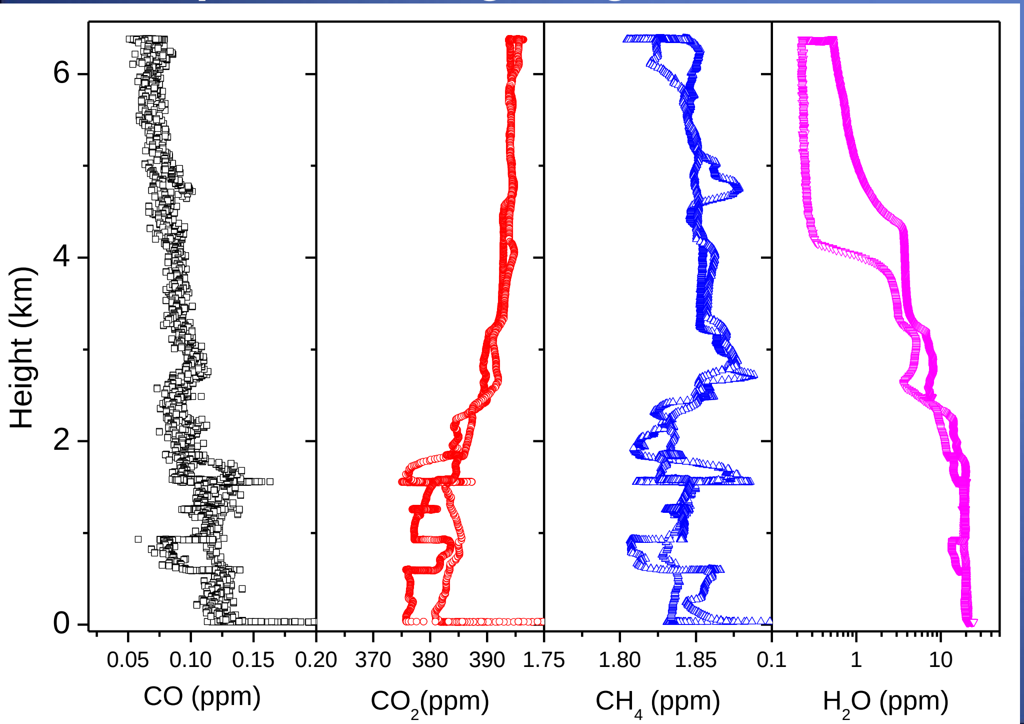
• Three standards, from WMO certified lab NOAA ESRL USA, are used to calibrate observations

• Calibration is done at the ground before airborne observations

•Output data are stored at every two second interval

• Post-processing is done with the help of co-located met data from other instruments

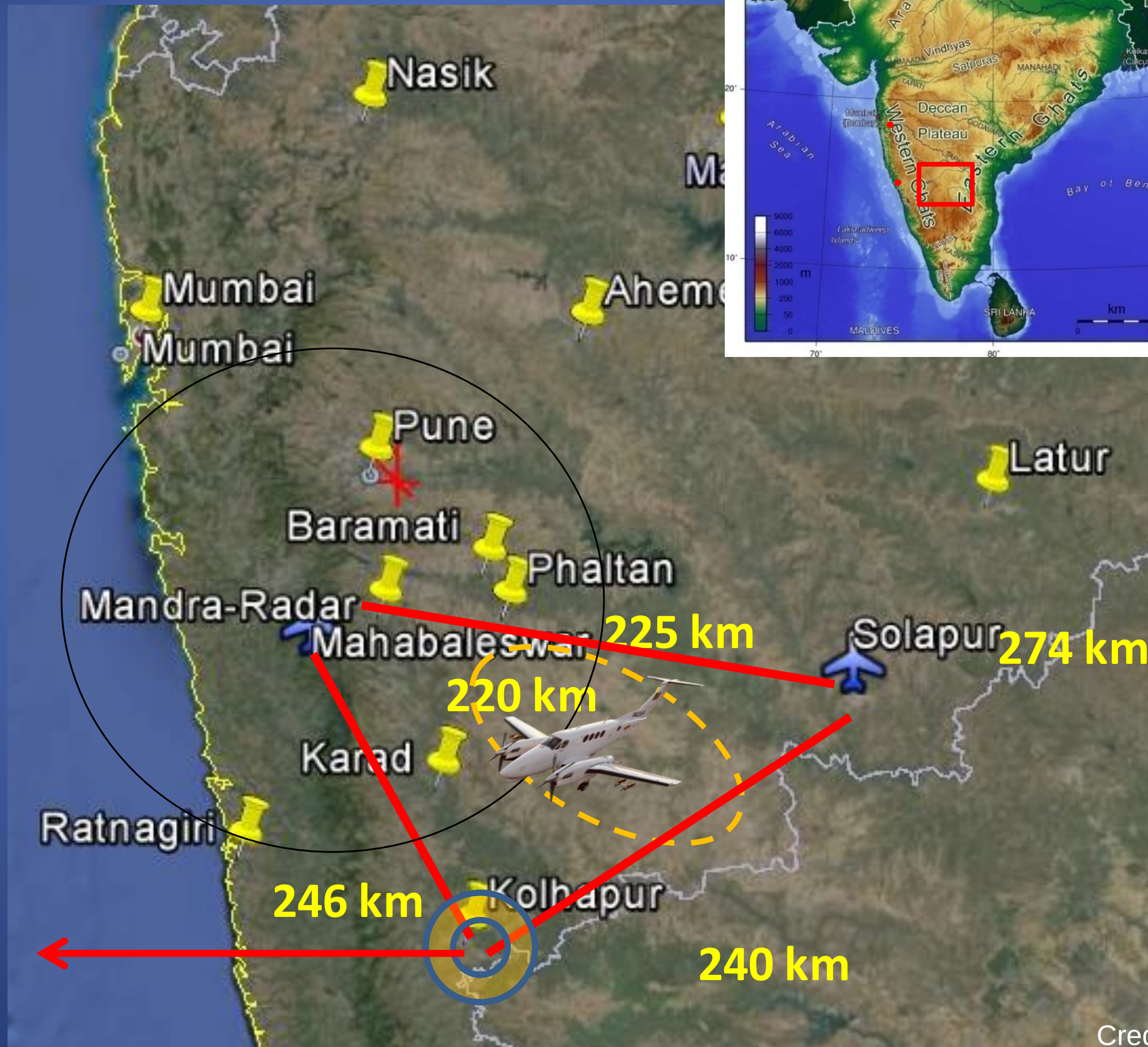
Vertical profile during a flight

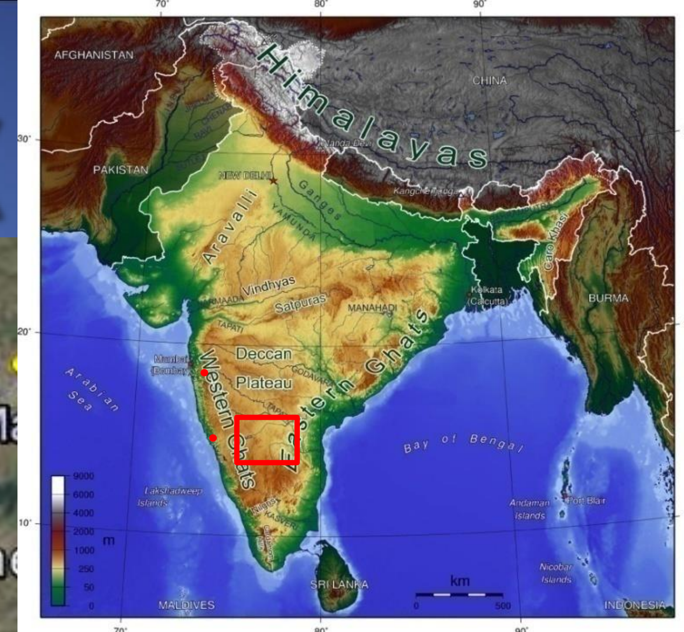


CAIPEEX

Phase III 2015

2015

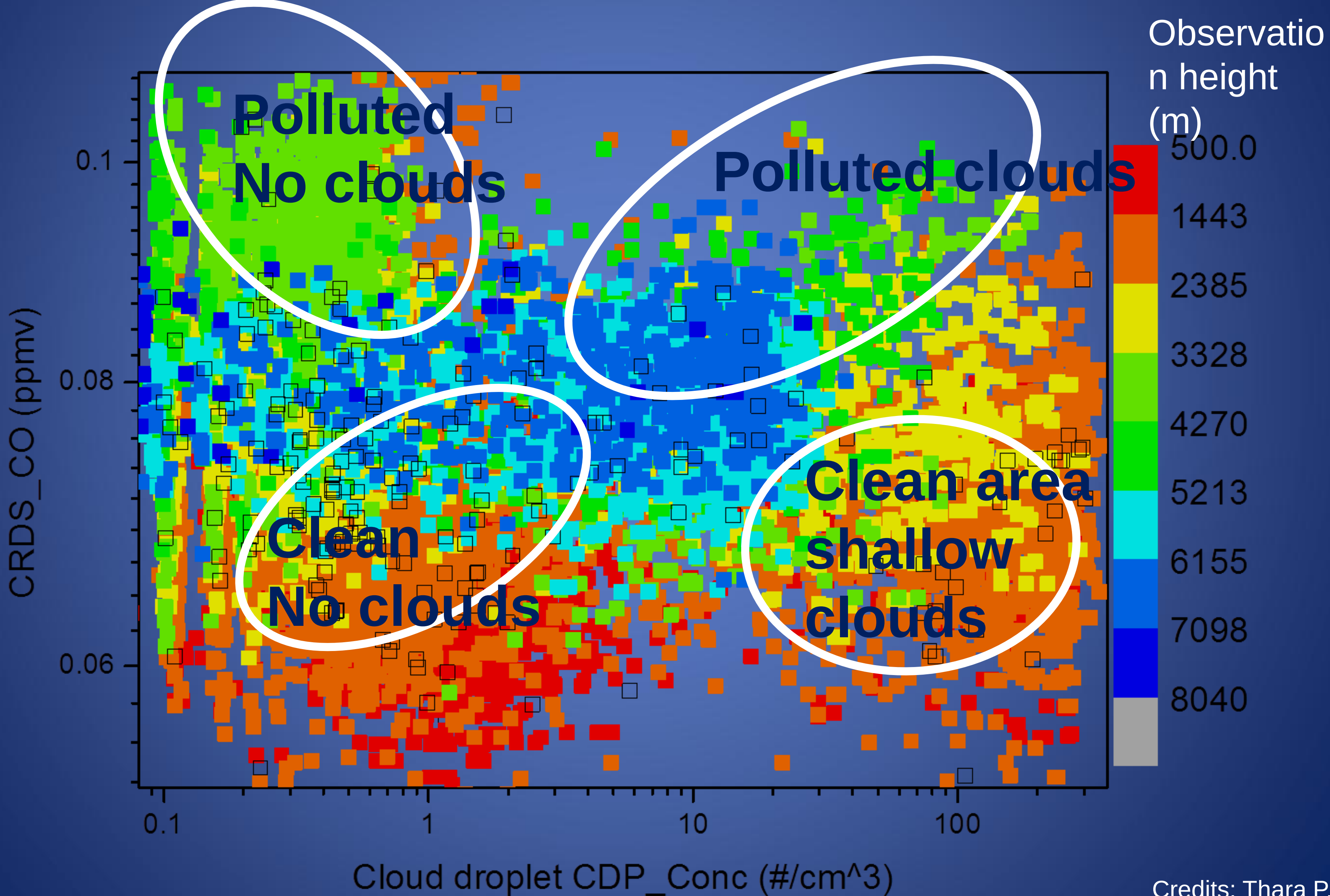




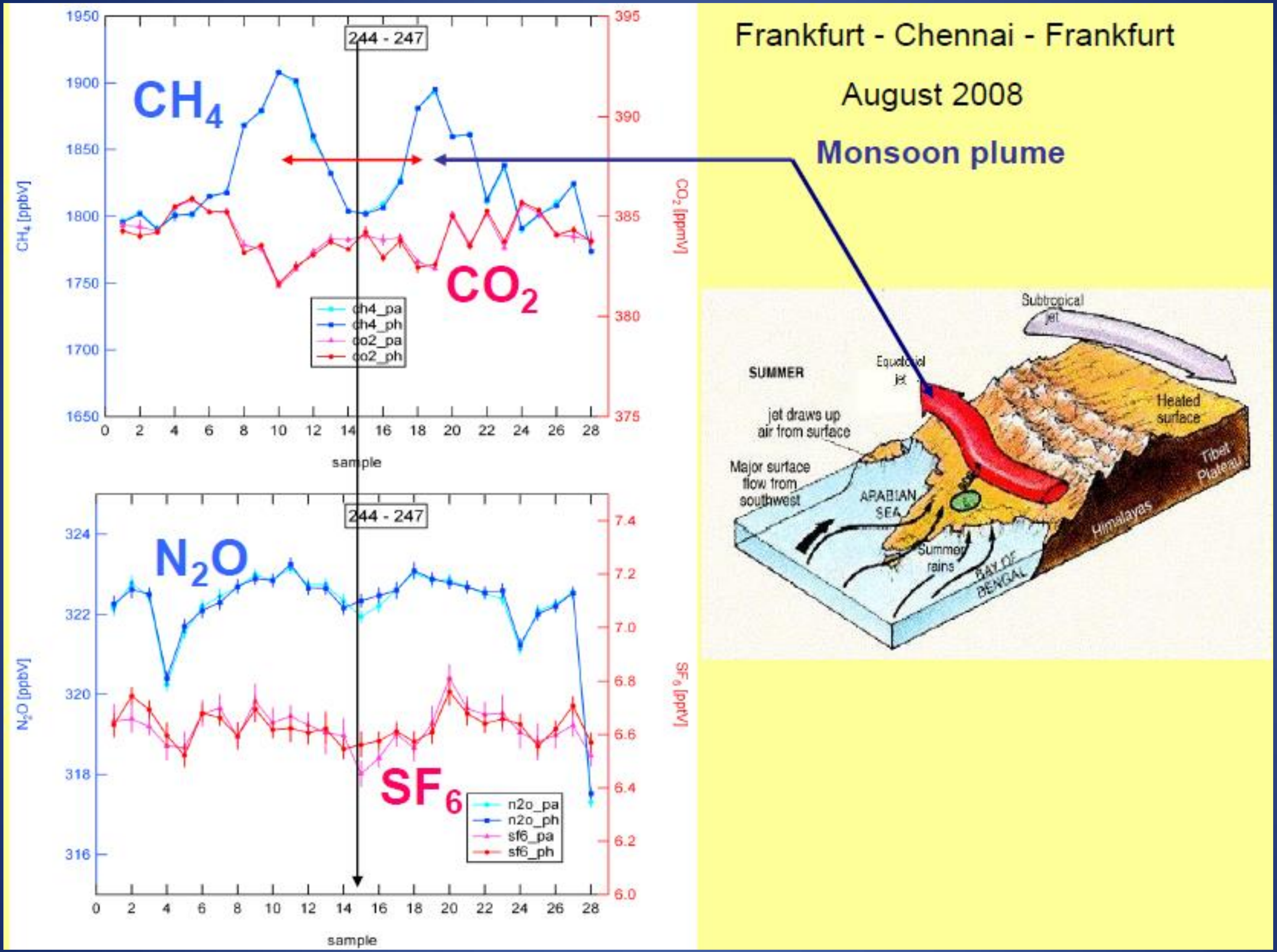
Credits: Thara P.

Relationship between in-situ CO pollution and Cloud droplet number concentration over Arabian sea and inland

Phase III 2015



Credits: Thara P.



Source: Carl Brenninkmeijer, Max Planck

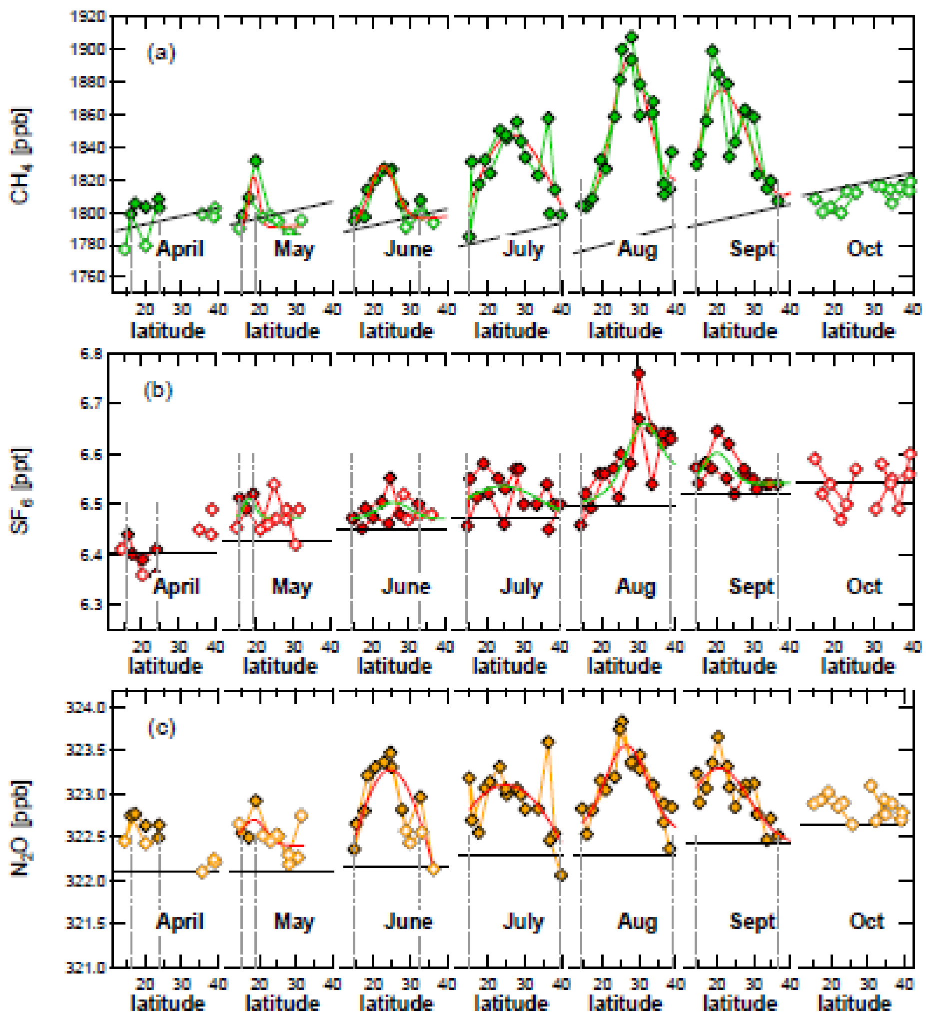


Fig. 8. Latitudinal distributions of CH_4 **(a)**, SF_6 **(b)**, and N_2O **(c)** for April–October 2008. For May–September a Gaussian has been fit to the data. Solid lines indicate background levels determined from the CARIBIC measurements in April and October for SF_6 and from the Mauna Loa Observatory 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

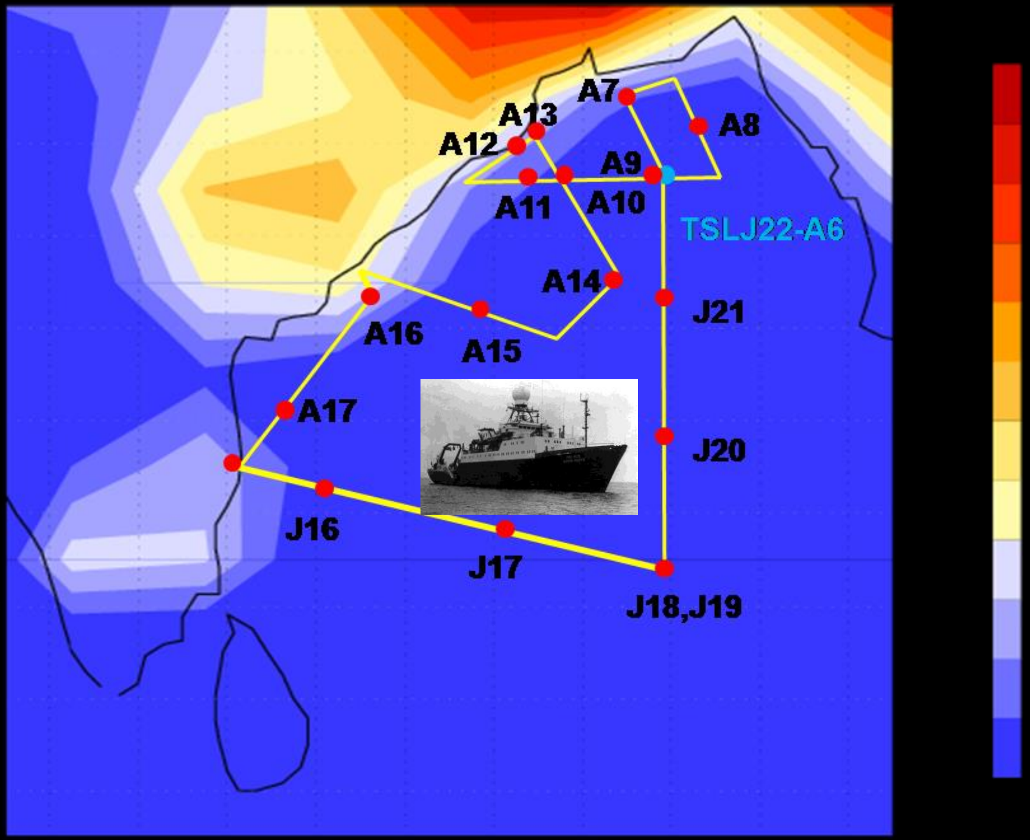
3) GHGs monitoring at the ship deck :

Land-ocean contrast of surface CO_2

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

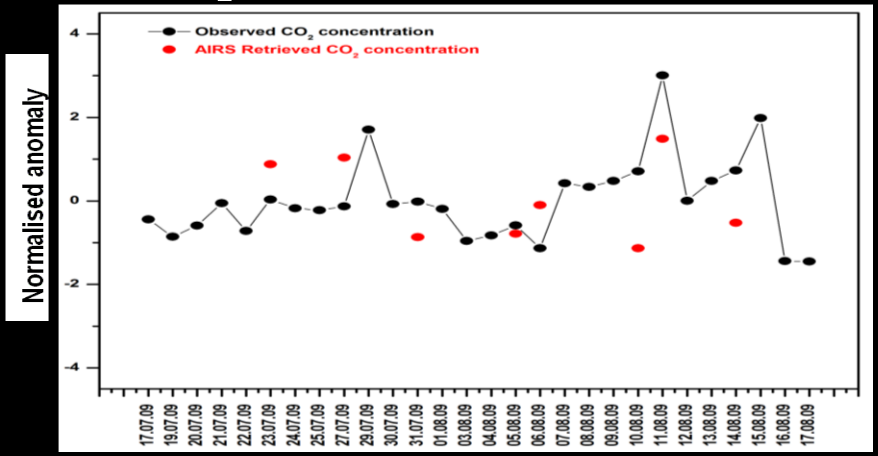
- The spatial pattern of mean CO_2 from the CarbonTracker simulations averaged from the start to the end of the cruise period.

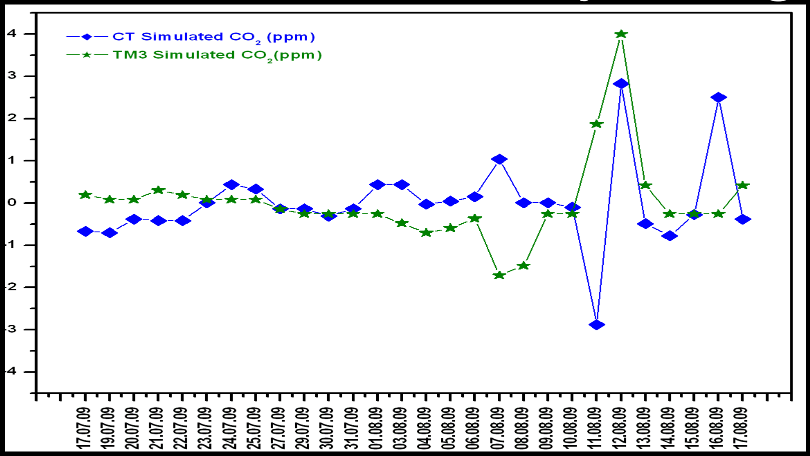
- The sharp land-ocean contrast in atmospheric CO_2 at the surface (1000 hPa) can be seen in the CarbonTracker simulations.

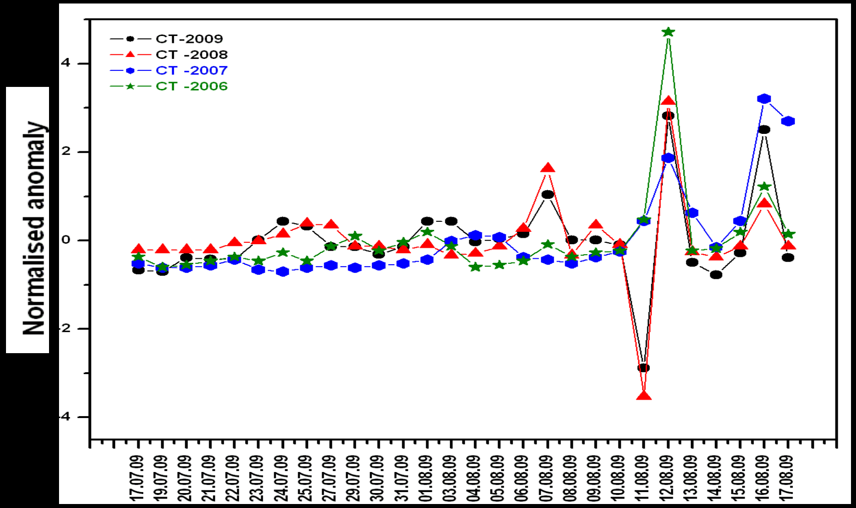


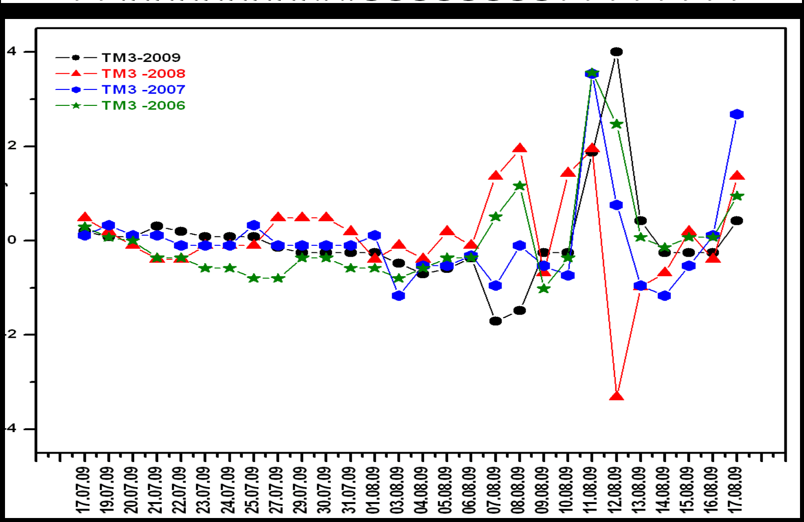
Ref: **K. Ravi Kumar.**, Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO_2 over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)

Comparison of observations and model simulations over Bay of Bengal







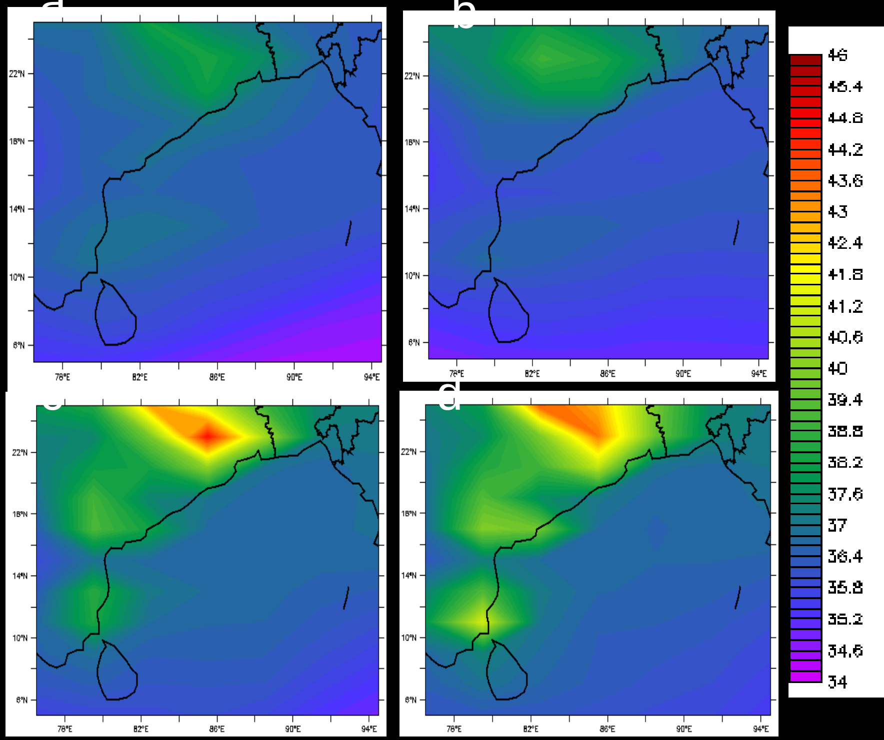


The land –ocean contrast is observed in the observations of CO_2 over BoB. such land-ocean contrast in CO_2 prevails during the same period of every year.

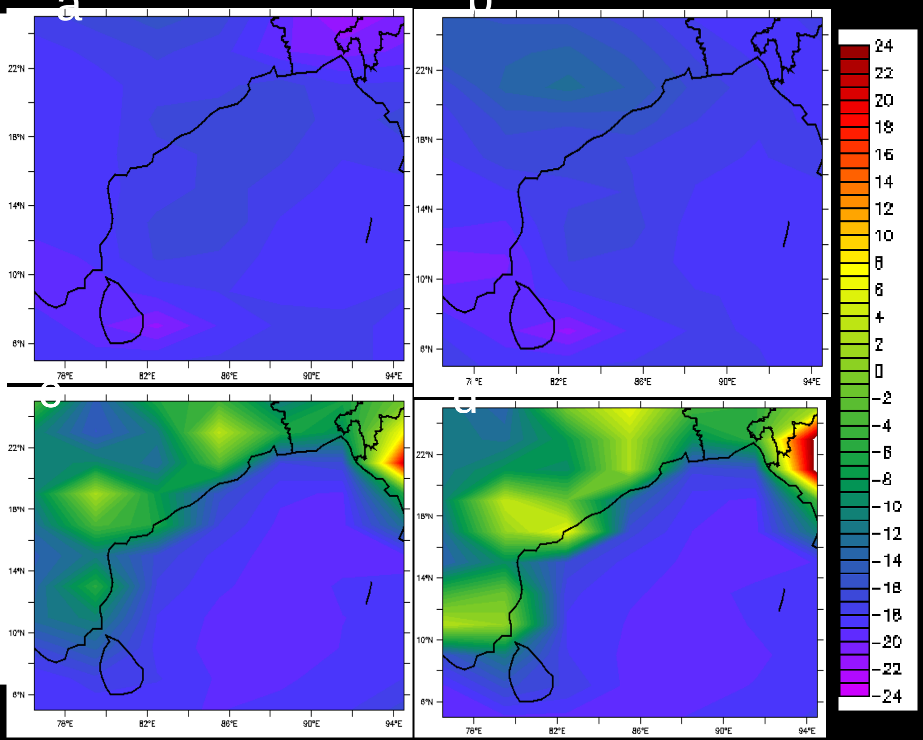
Ref: **K. Ravi Kumar.**, Y. K. Tiwari, V. Valsala, and R. Murtugudde (2014); On understanding of land-ocean contrast of atmospheric CO_2 over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)

Carbon Tracker CO2

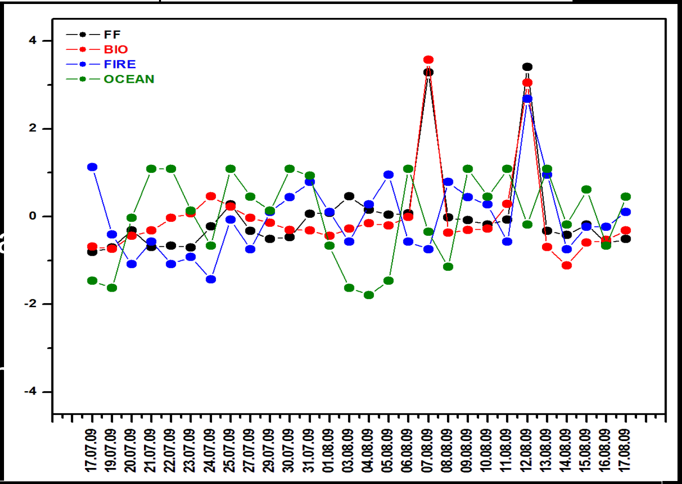
Fossil Fuel



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 tha the land-ocean contrast is induced by the terrestrial vs. oceanic CO_2 fluxes.
- ➢Monsoon atmospheric circulation plays a pivotal role in advecting th CO_2 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 CO_2 over Bay of Bengal: A case study during 2009 summer monsoon (Environmental Science and Pollution Research)

KMA team visited IITM Pune India:

• **KMA scientists and engineers visited IITM Gas Chromatograph (GC) lab during 19-23 Sept.2015**

•**Worked on CO2 and CH4 monitoring at the IITM GC lab**

•**Monitoring of Sulfur Hexafluoride (SF6) and Nitrous Oxide (N2O) at Gas Chromatograph (GC) lab at the IITM Pune.**

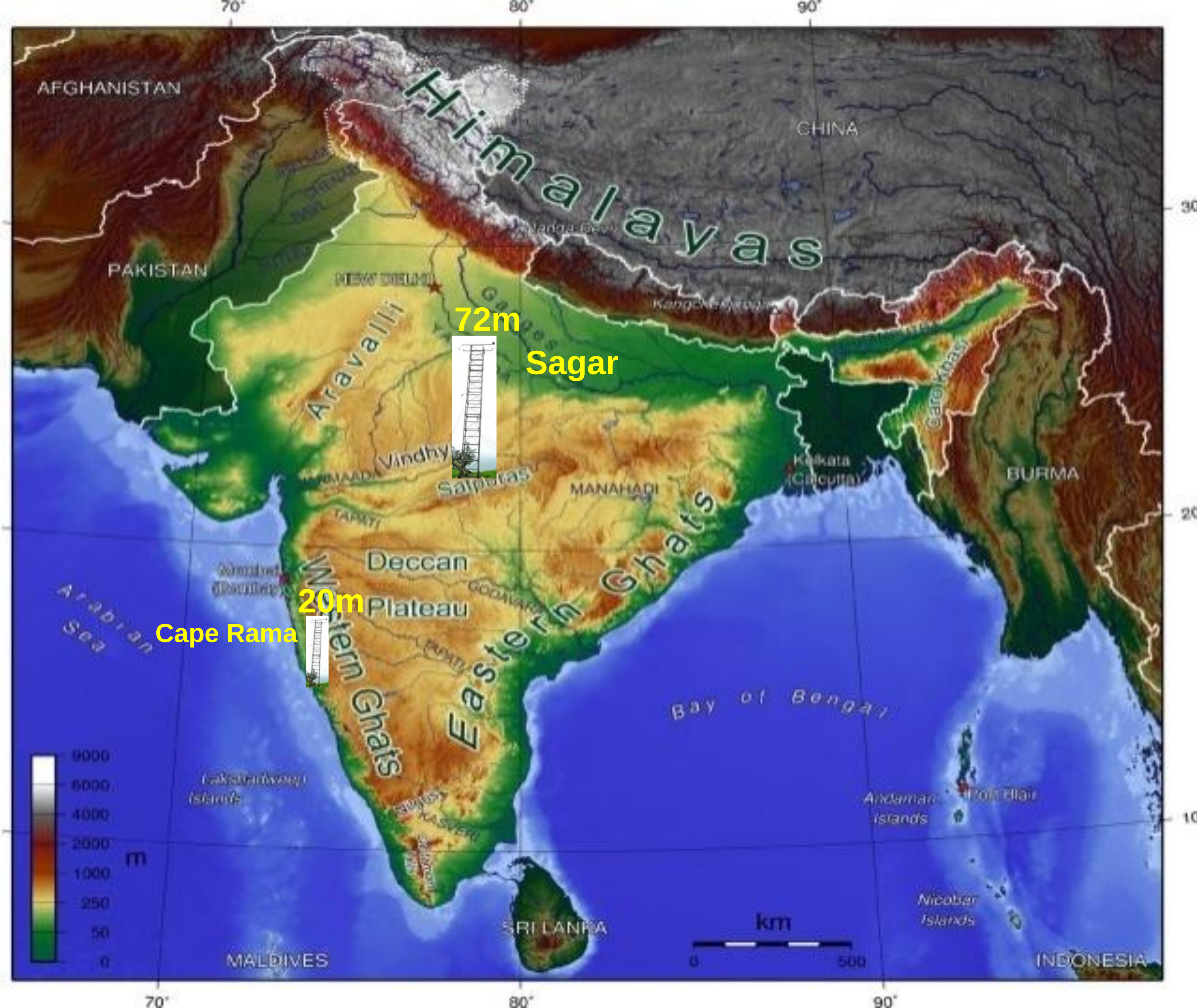
• **Collaborations on GHG's monitoring in India**

Inter-comparison of CH4 calibration standards:

Korea (KMA) - India (IITM) - Japan (JMA)

In the intercomparison project, two cylinders containing air of known CH_4 mole fractions are circulated among above participants

New observational sites – starting early next year



AFGHANISTAN
CHINA
Himalayas
PAKISTAN
NEW DELHI
72m
Sagar
Aravalli
Vindhya
Satpuras
MANAHADI
Kolkata (Calcutta)
BURMA
Deccan Plateau
Western Ghats
Eastern Ghats
20m
Cape Rama
Arabian Sea
Bay of Bengal
Andaman Islands
Port Blair
Nicobar Islands
SRI LANKA
MALDIVES
INDONESIA
km
0
500
9000
6000
4000
2000
1000
250
50
0
m
70°
80°
90°
30°
20°
10°

Thank You !!