Title: 5 years of trace gas observations over the Indian subcontinent: a study based on surface flask measurements

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Abstract: With the rapid population growth and economic development, the emissions of greenhouse gases (GHGs) over the Indian subcontinent have sharply increased during the current decade. However, evaluation of regional fluxes of GHGs and characterization of their spatial and temporal variations remain uncertain due to the sparse atmospheric surface observation network. Three new atmospheric stations were recently established in India as part of the cooperation between C-MMACS and LSCE, France - at Hanle (HLE), Pondicherry (PON), and Port Blair (PBL) - to monitor various long-lived trace gases and regionally constrain their fluxes between the biosphere and the atmosphere. Here we present temporal variations of multiple trace gases (CO_2, CH_4, N_2O, SF_6, CO, H_2) flask measurements at HLE, PON, and PBL during the period 2007–2011. For each species at each station, the mean seasonal cycle is analyzed, and related to seasonal variations in terrestrial ecosystem fluxes, anthropogenic emissions, and monsoon circulation, including convection. Back-trajectories analyses of the three stations during the sampling period show the dominant air flow patterns in different seasons. The covariance between different species pairs is also examined to identify the dominant sources of synoptic variability over the region. The measurements of multiple long-lived trace gases at the three stations have the potential to improve the atmospheric transport model and constrain the inversions of fluxes over the Indian subcontinent. The network of ground stations needs further extension to different parts of this region for better understanding of the carbon cycle.

GHGs observations over the Indian subcontinent

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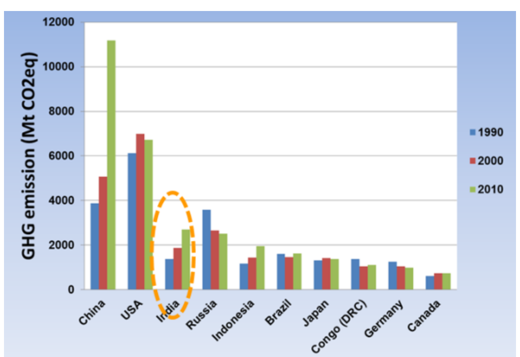
Outline

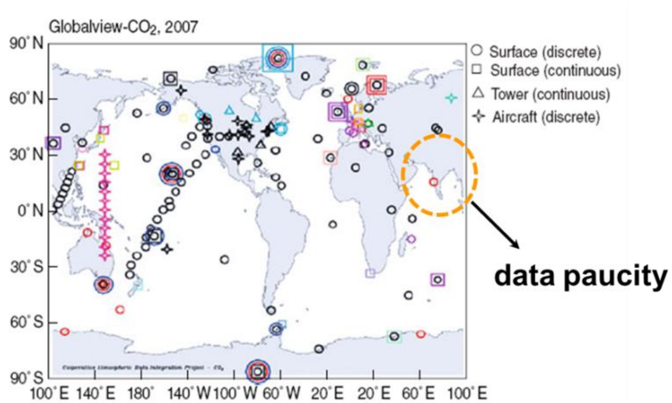
- Background
- Objectives
- Datasets
- Results of flask measurements

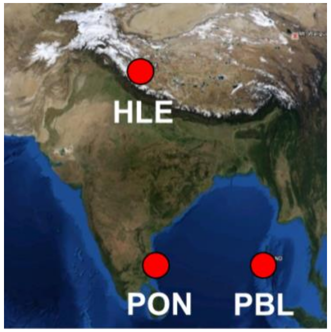
Background

- Sharp increases in GHG emissions over India with booming industry and economy (2691.66 Mt CO_2eq in 2010)
- Large uncertainties of regional carbon fluxes due to sparse atmospheric observation network
- Newly-established atmospheric stations at Hanle (HLE), Pondicherry (PON), and Port Blair (PBL) in India open opportunities to measure trace gases and constrain regional carbon fluxes



Sources: Emission Database for Global Atmospheric Research (EDGAR), release version 4.2

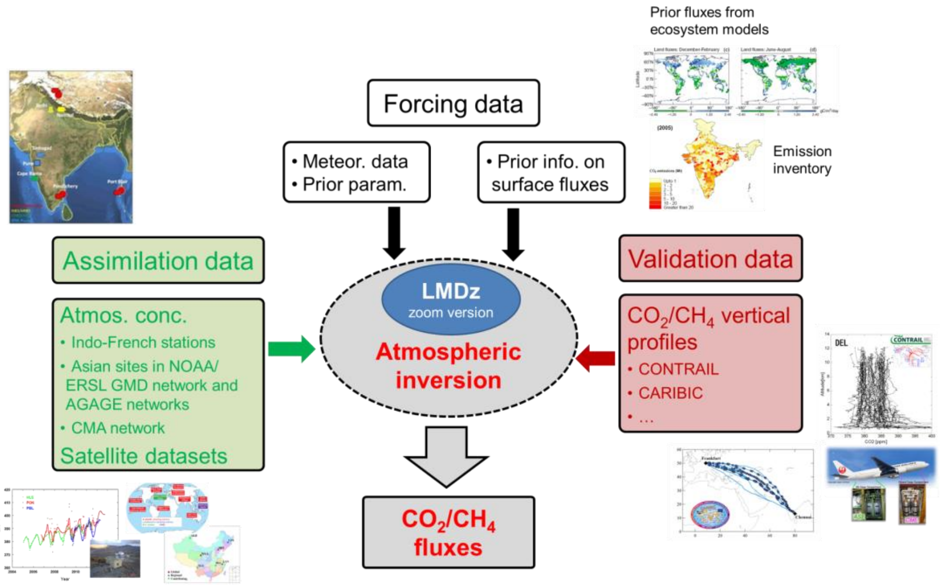




Objectives

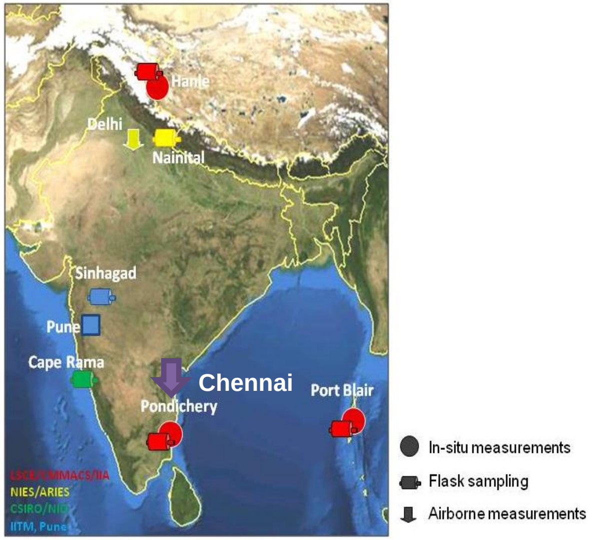
- The aim of the study will be to use new atmospheric network to improve our knowledge of regional distribution of sources and sinks of GHGs in India and their variability

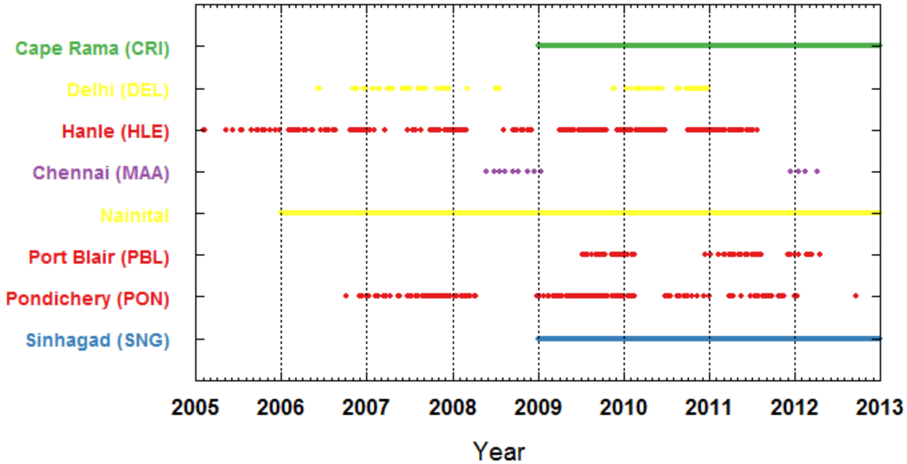
  - To analyze flask measurements of multiple trace gases at the 3 stations in India during the recent years
  - To develop LMDZ Indian zoom model
  - To infer CO_2 and CH_4 fluxes and uncertainties over India using the inversion system and LMDZ Indian zoom model



Datasets: atmospheric observations

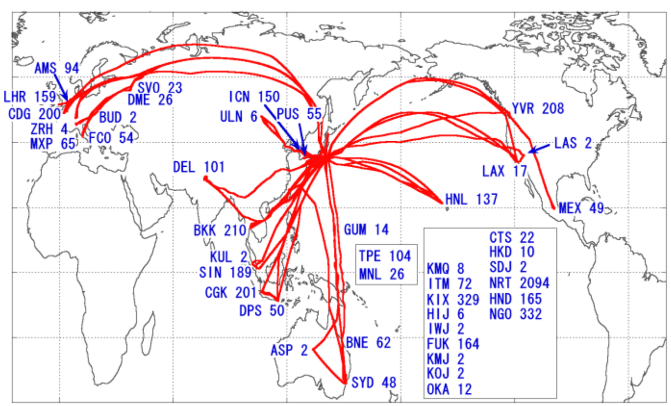
- Networks in India
  - By sampling approach
    - In-situ measurements
    - Flask sampling
    - Airborne measurements
  - By institute
    - **LSCE, CMMACS, IIA, NIOT…**
    - **NIES, ARIES, JAL…**
    - **IITM**
    - **CSIRO, NIO**
    - **MPI, Lufthansa**
  - Monitoring trace gas species
    - CO_2, CH_4, N_2O, SF_6, CO, H_2

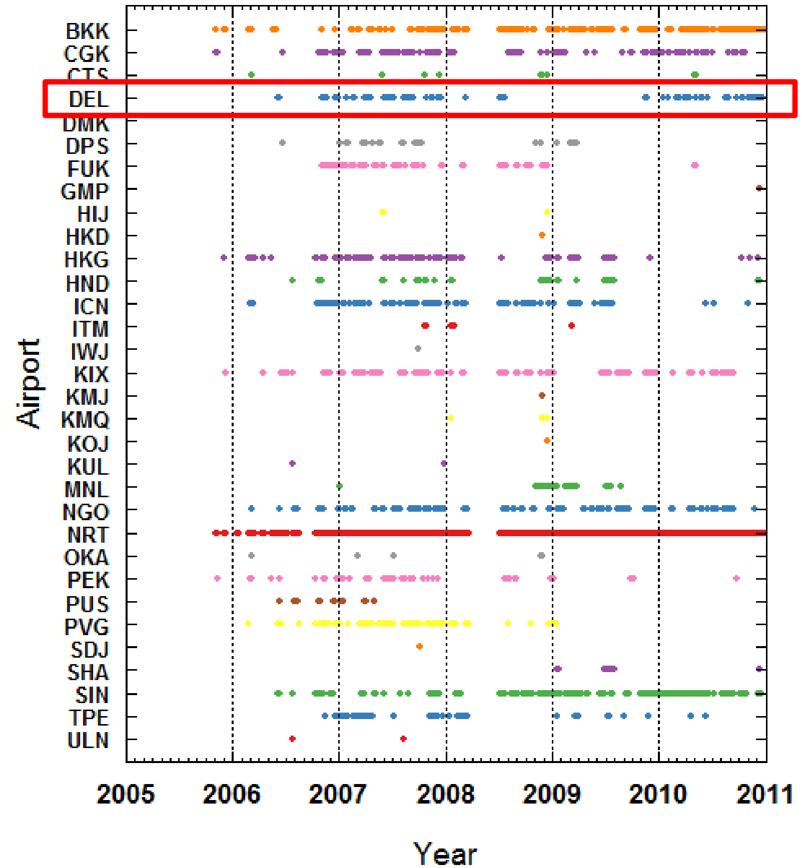




Datasets: atmospheric observations

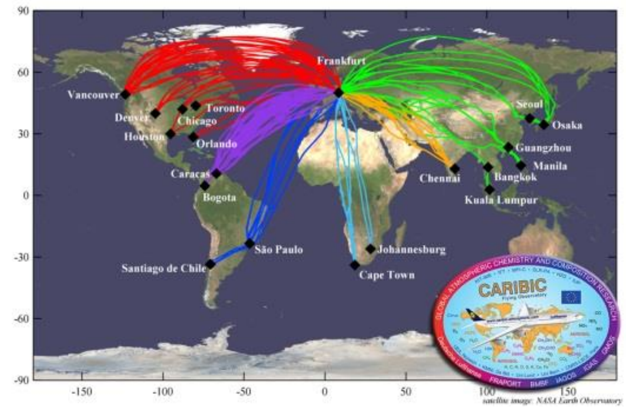
- CONTRAIL (Comprehensive Observation Network for Trace gases by AIrLIner)
  - Jointly conducted by NIES, MRI, JAL
  - CO_2 in-situ and flask measurements during ascending, level flight and descending

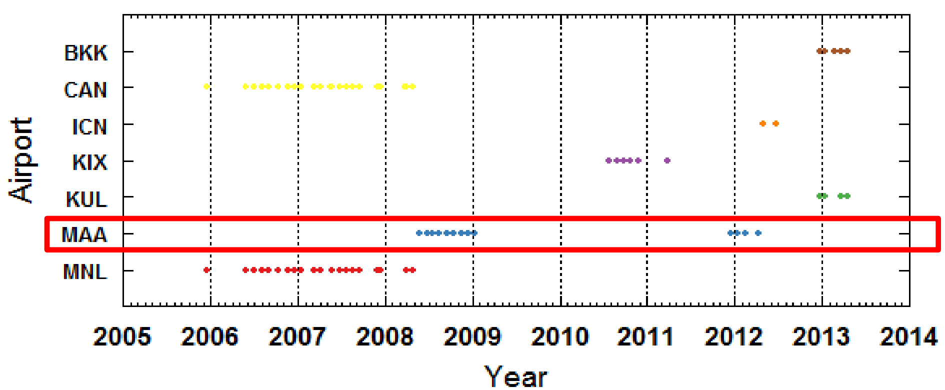


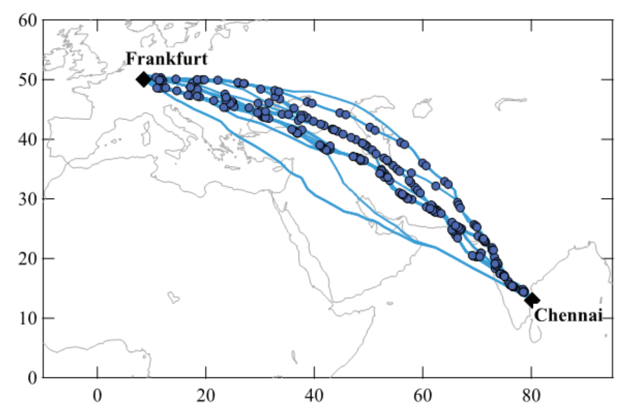


Datasets: atmospheric observations

- CARIBIC (Civil Aircraft for the Regular Investigation of atmosphere Based on an Instrument Container)
  - Jointly conducted by MPI with Lufthansa
  - In-situ and flask measurements of CO_2, CH_4, N_2O, SF_6 and CO

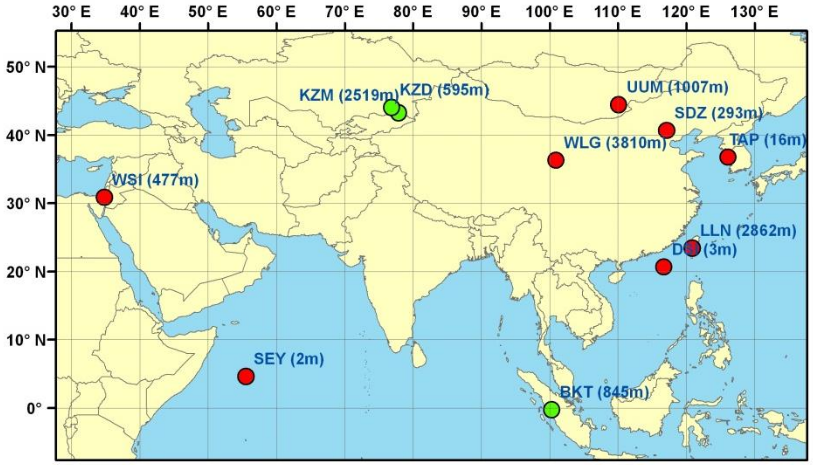


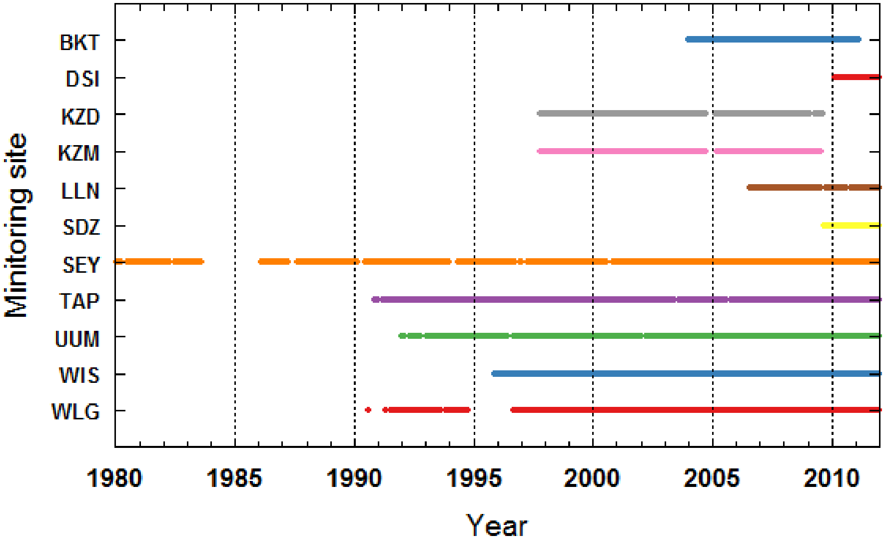




Datasets: atmospheric observations

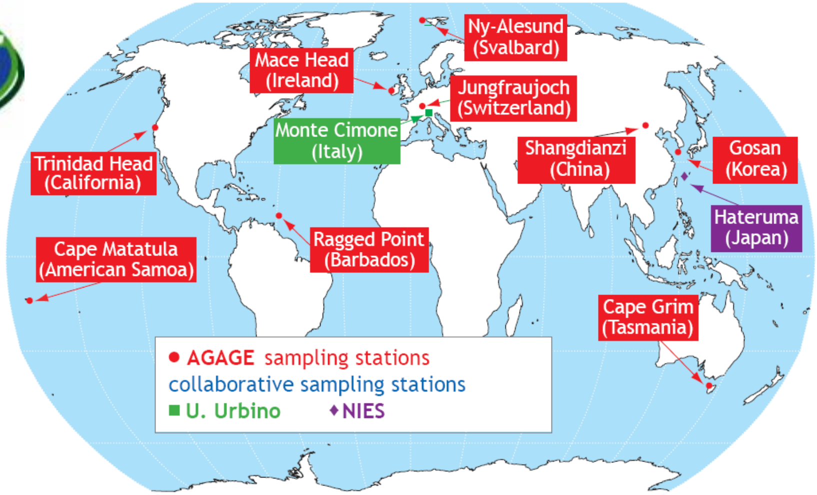
- NOAA/ERSL GMD (Earth System Research Laboratory Global Monitoring Division)
  - In-situ and/or flask measurements of CO_2, CH_4, N_2O, SF_6 and H_2

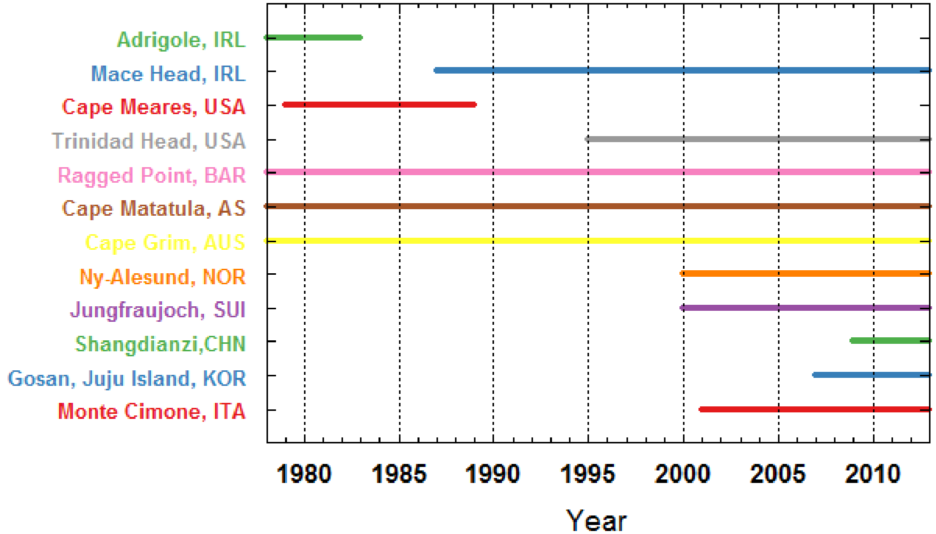




Datasets: atmospheric observations

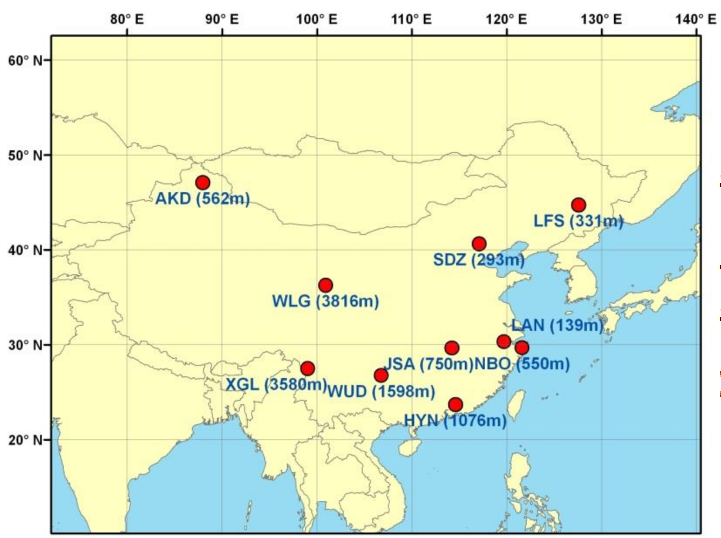
- AGAGE (Advanced Global Atmospheric Gases Experiment)
  - Measurements of almost all of the important gases in Montreal Protocol (e.g. CFCs and HCFCs) and the significant non-CO_2 gases in Kyoto Protocol (e.g., HFCs, CH_4, N_2O)

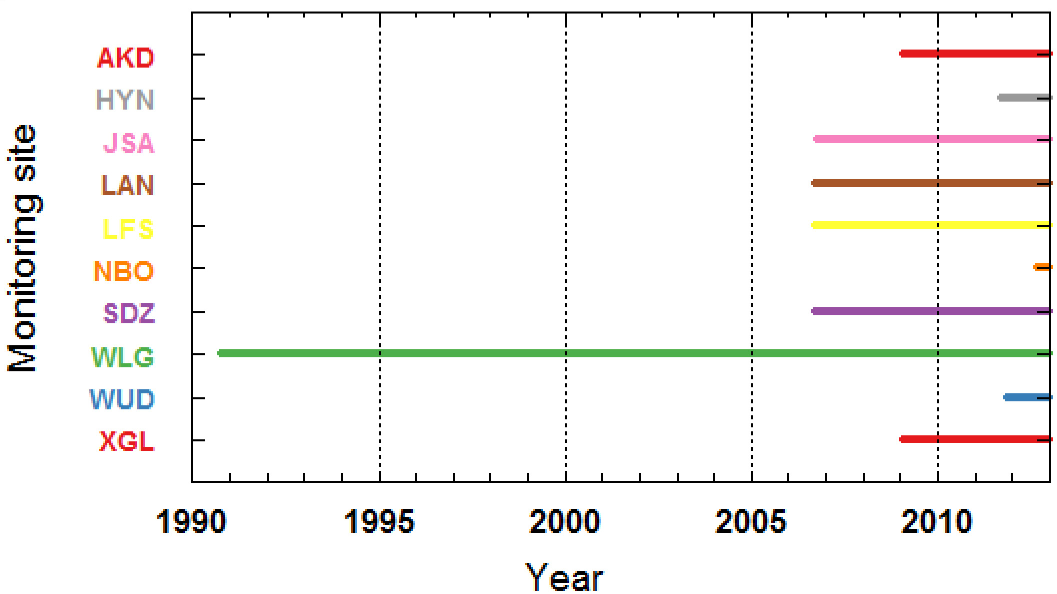




Datasets: atmospheric observations

- CMA (China Meteorological Administration) GHGs network
  - In-situ and flask measurements of CO_2, CH_4, N_2O, SF_6 and other halo-generated GHGs





Datasets: emission inventories

GHG emissions over 1985-2005 (Tg)

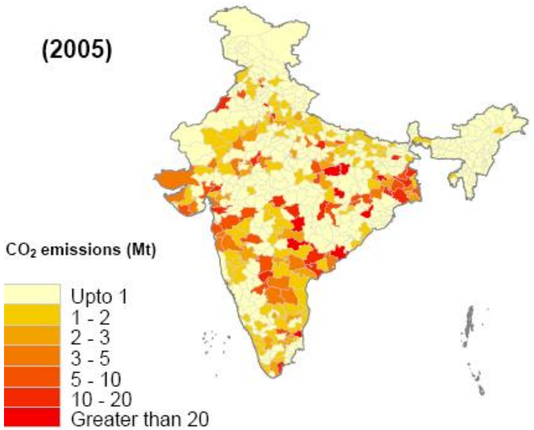
GHG gases	1985	2000	2005	CAGR%	Main contributors
CO_2	440	1032	1229	5.3	• **Coal consumption (mainly from power sector) (66%)** • Oil product combustion (mainly from transport sector)
CH_4	17.21	19.61	20.08	0.8	• **Enteric fermentation (~50%)** • Paddy cultivation • Biomass burning for energy
N_2O	0.134	0.217	0.253	3.2	• **Synthetic fertilizer use (~60%)** • Field burning of agriculture crop residue • Manure management
SF_6	—	0.1	2	88.7	• Use for insulation of high-voltage equipment
CO	33.7	40.3	41.7	1.1	• Incomplete biomass burning (mainly from rural households)

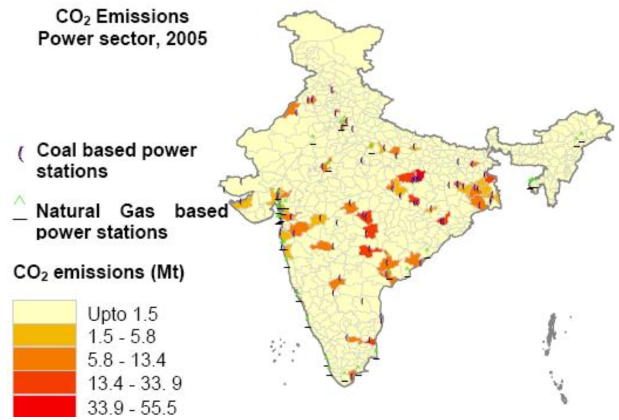
CAGR: compounded annual growth rate
Source: Garg *et al.* (2006)

GHG emissions in India at the district level

Total emission | Emission from main contributor

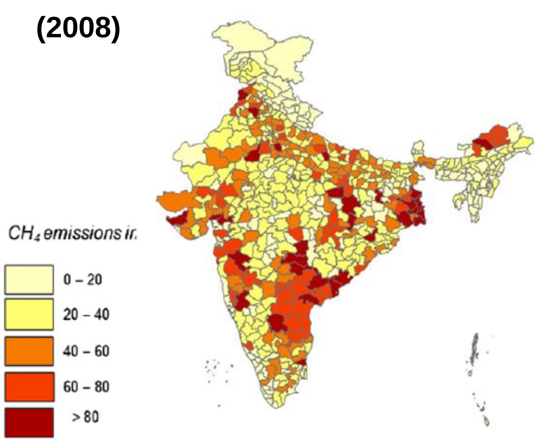
CO_2

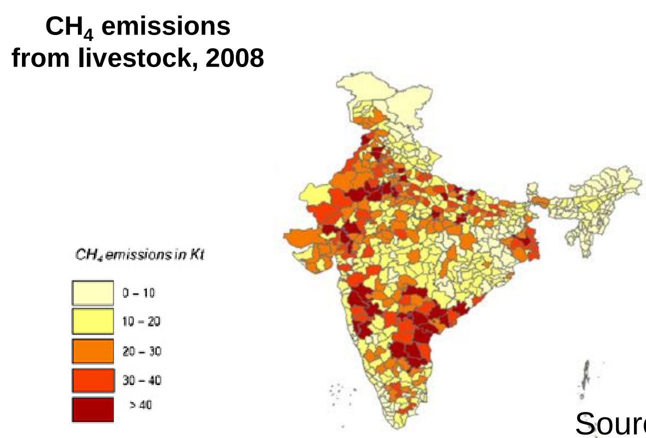




Source: Shukla *et al.* (2008)

CH_4



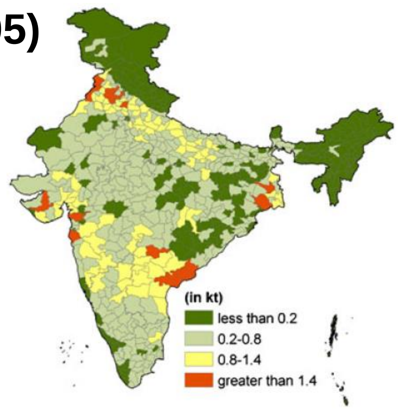


Source: Garg *et al.* (2011)

GHG emissions in India at the district level

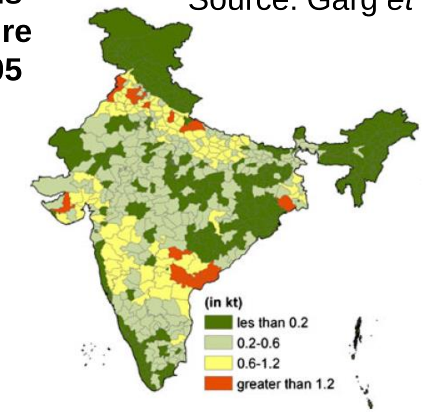
Total emission | Emission from main contributor

N_2O (2005)

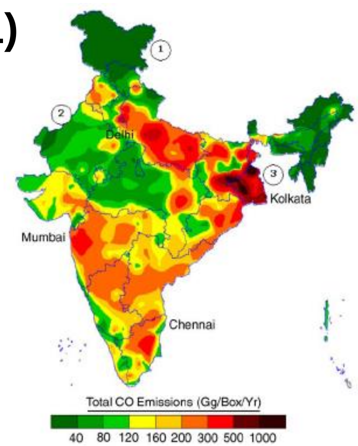


N_2O emissions from agriculture activities, 2005

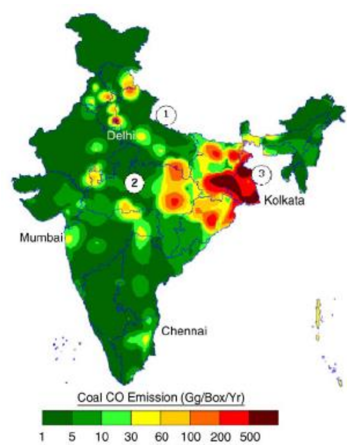
Source: Garg *et al.* (2012)



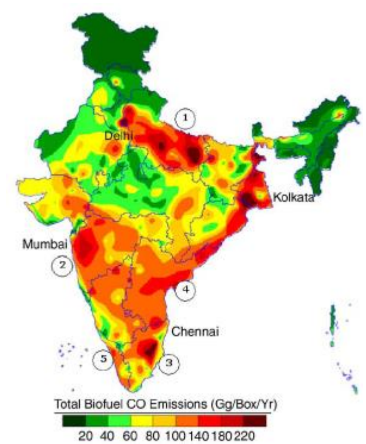
CO (2001)



Coal CO emissions, 2001



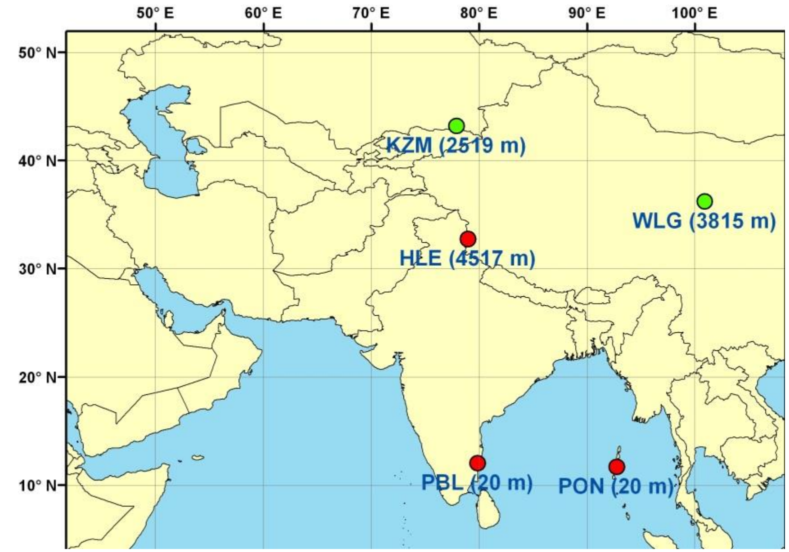
Biofuel CO emissions, 2001

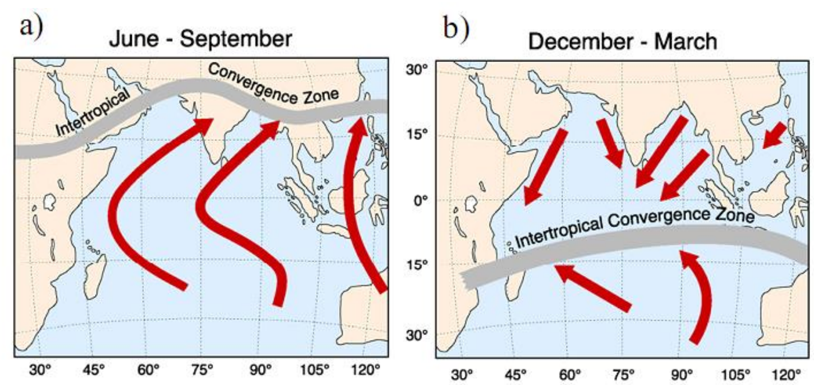


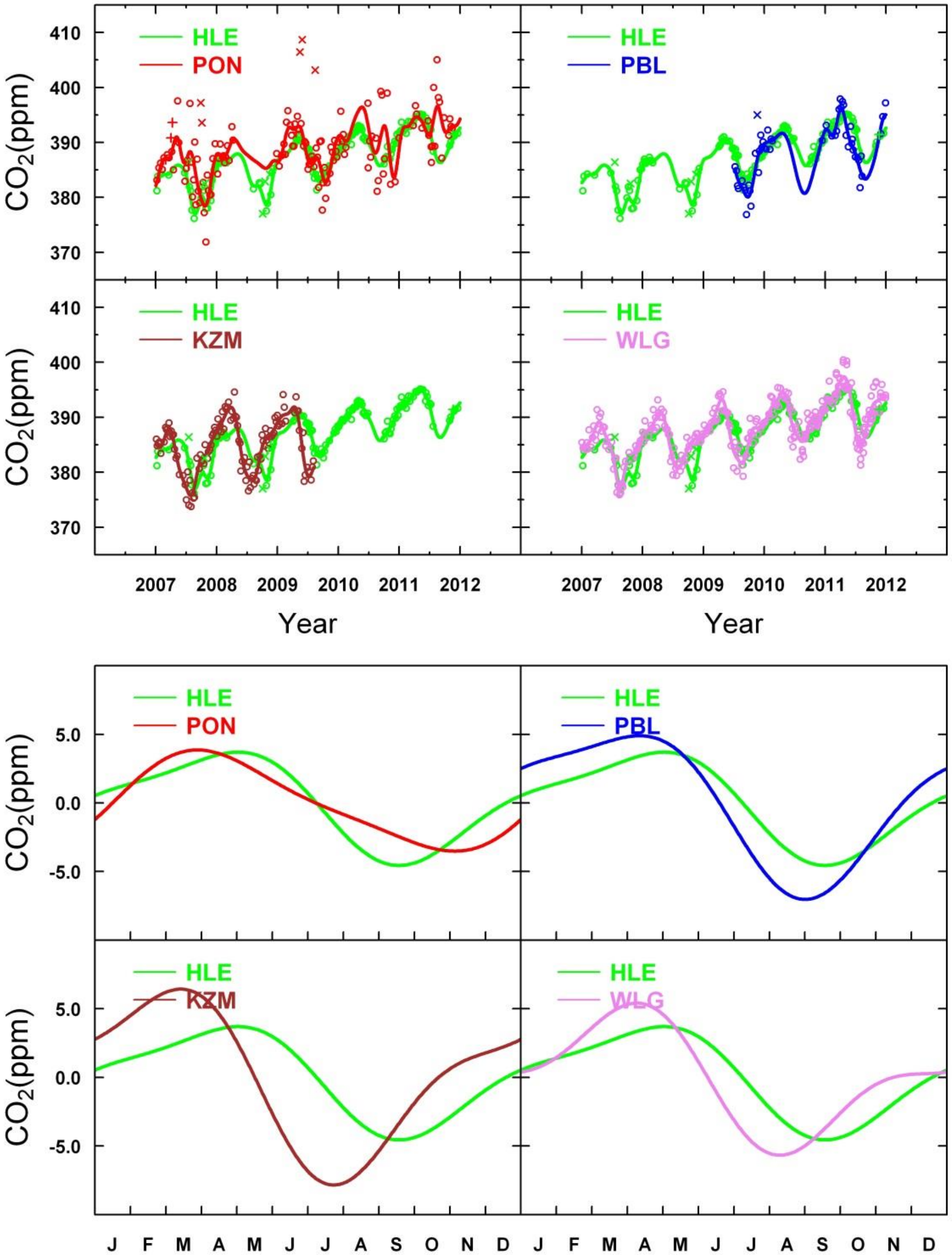
Source: Dalvi *et al.* (2006)

Results of flask measurements

- Time series of multiple GHGs observations at 3 Indian sites and 2 NOAA/ERSL sites
  - Trace gas species include:
    - CO_2, CH_4, N_2O, SF_6, CO, H_2
  - 3 Indian sites: HLE, PON, PBL
  - 2 NOAA sites: KZM, WLG
  - For each species at each station, annual mean and mean season cycle are analyzed, and related to seasonal variations in:
    - biological activities
    - anthropogenic emissions
    - monsoon circulation, including convection.
  - Methods to analyze the data:
    - Curve fitting method: CCGVU (Thoning *et al.*, 1989)
    - Back-trajectory analysis: HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model (Draxler and Hess, 1997)



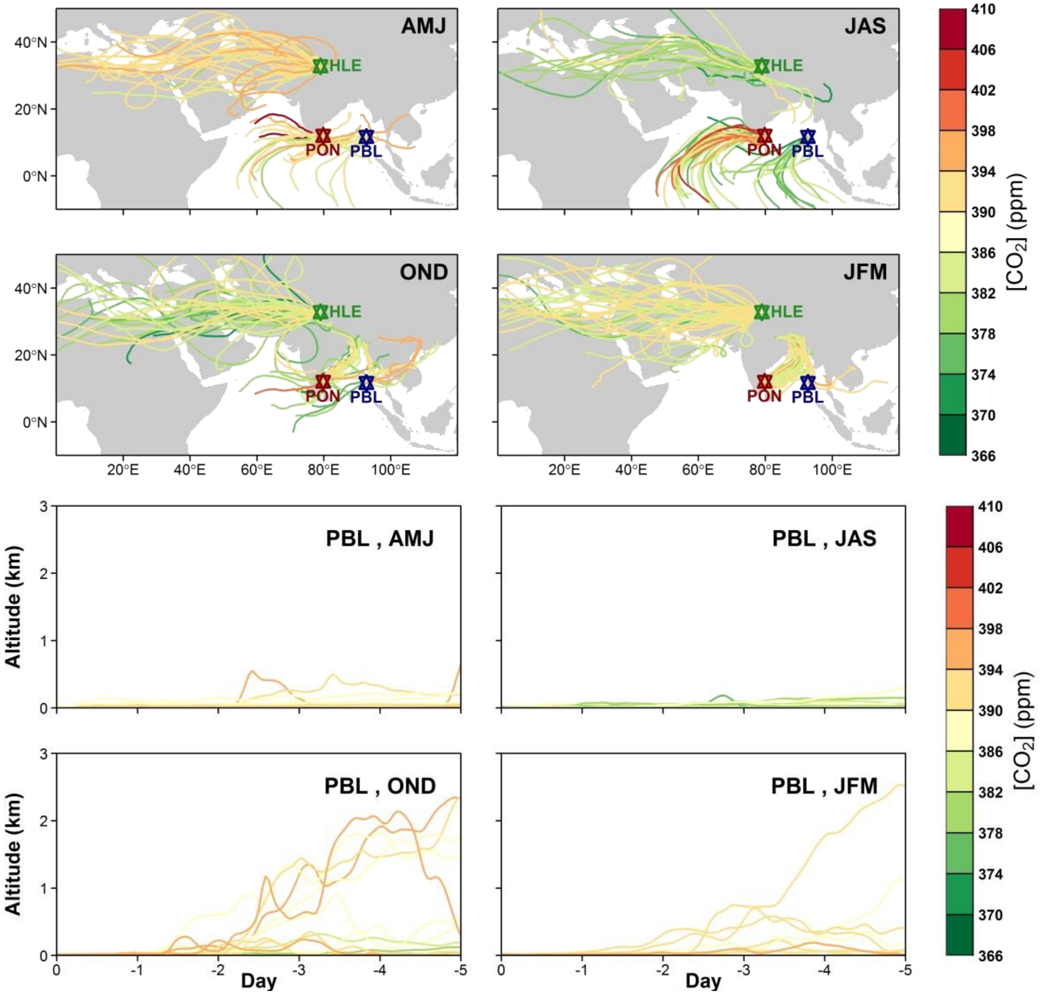




CO_2 time series

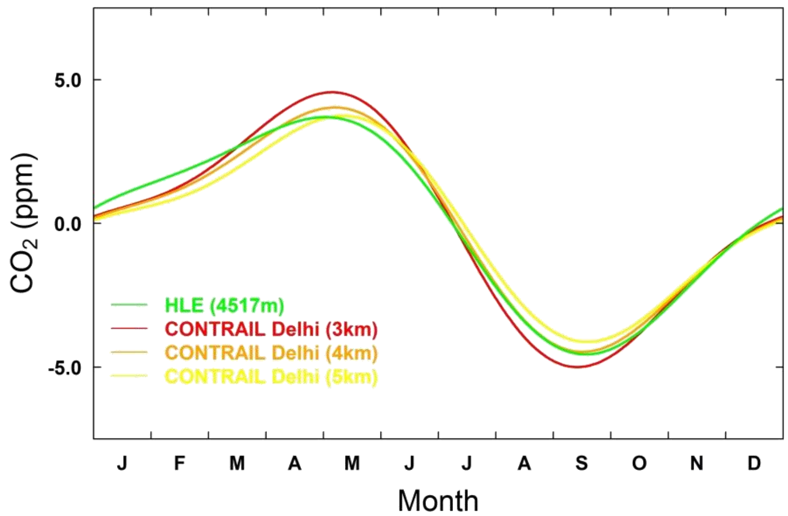
- Annual mean values
  - PON higher than HLE by up to 3 ppm with large variability
  - PBL < HLE by ~1.5 ppm, strong CO_2 uptake in summer
  - KZM, WLG: similar to HLE
- Mean seasonal cycles
  - HLE: CO_2 decreases since early May, reaches the min. in mid-Sep.
  - A lag in CO_2 drawn down phase between HLE and PON, PBL, KZM and WLG
  - The average peak-to-peak amplitude of HLE is smaller than PBL, KZM and WLG

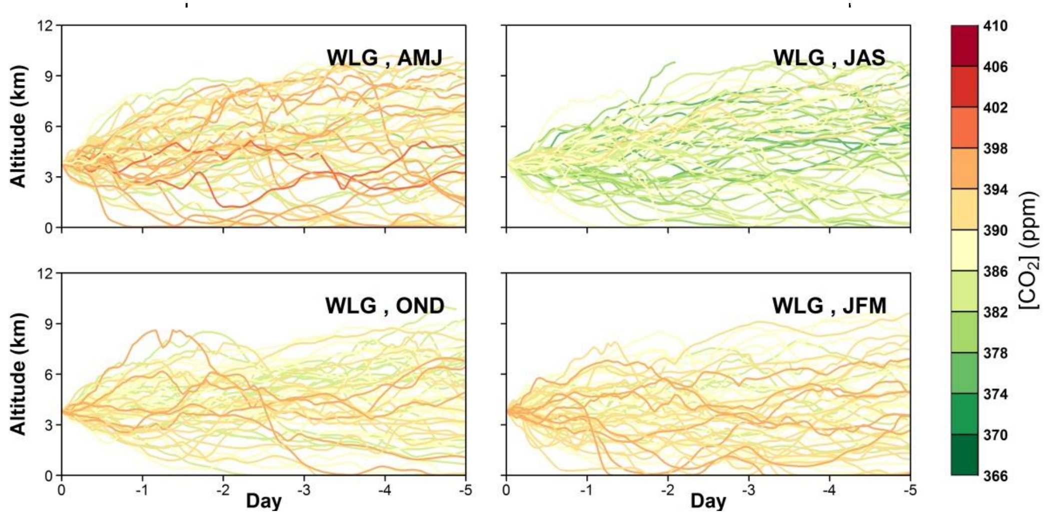
CO_2 time series



- Back-trajectories for HLE, PON, PBL
- Annual mean values
  - PON > HLE
    - CO_2 from both surface sources and subsidence of polluted air coming from SW direction
  - PBL < HLE, strong CO_2 uptake in summer
    - Strong surface uptake in PBL
    - Altitudinal gradient
  - KZM, WLG: similar to HLE
    - Background sites

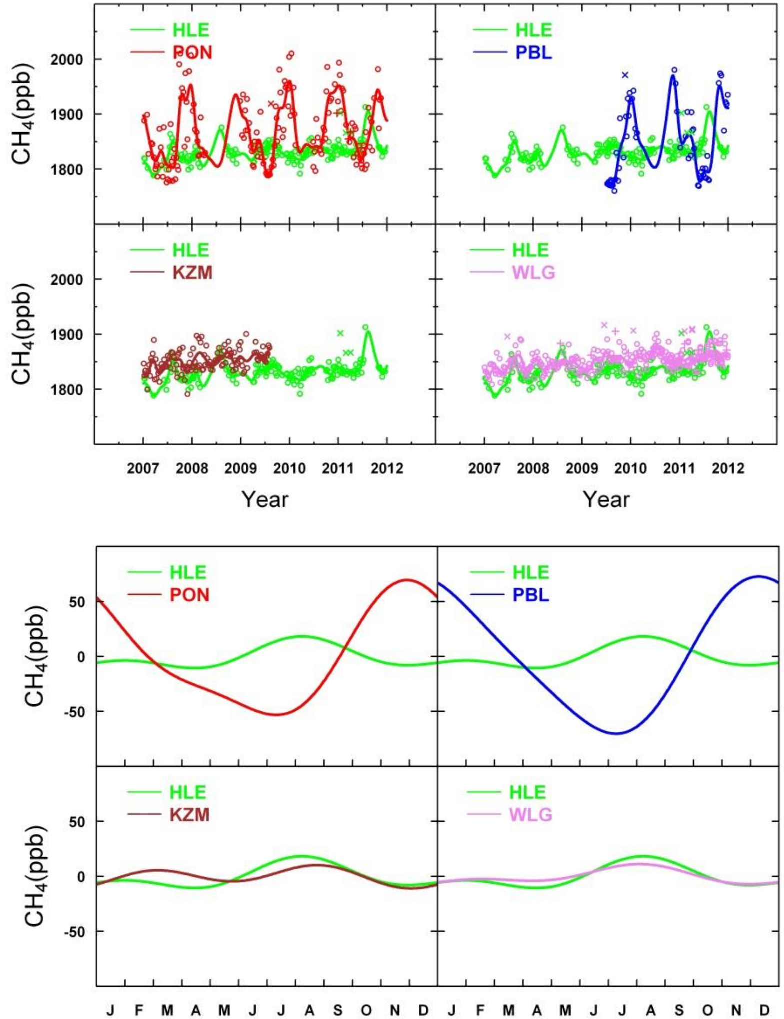
CO_2 time series



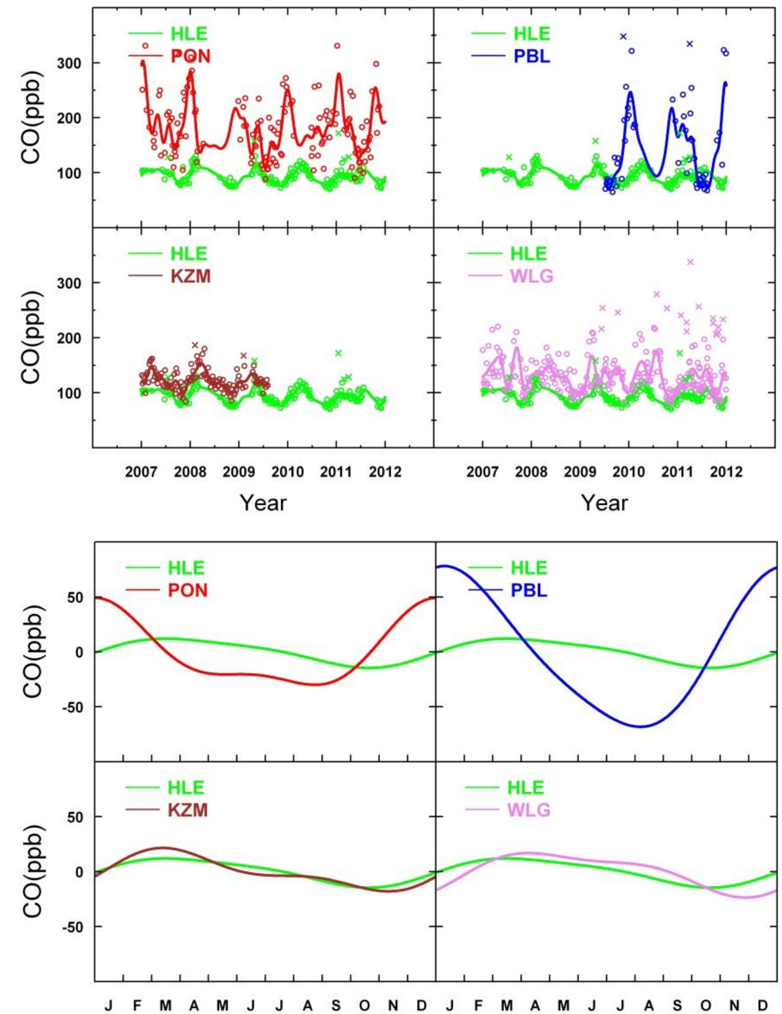


- Mean seasonal cycles
  - HLE: CO_2 decreases since early May, reaches the min. in mid-Sep.
    - Also confirmed by CONTRAIL aircraft vertical profile over Delhi
    - CO_2 drawn-down phase occurs when SW monsoon prevails and intense precipitation stimulates active vegetation growth and uptake
  - Lag in CO_2 drawn down phase
    - Influenced by SW monsoon
    - Less influenced by surface fluxes
  - Smaller amplitude
    - The peak-to-peak amplitude dampens with altitude

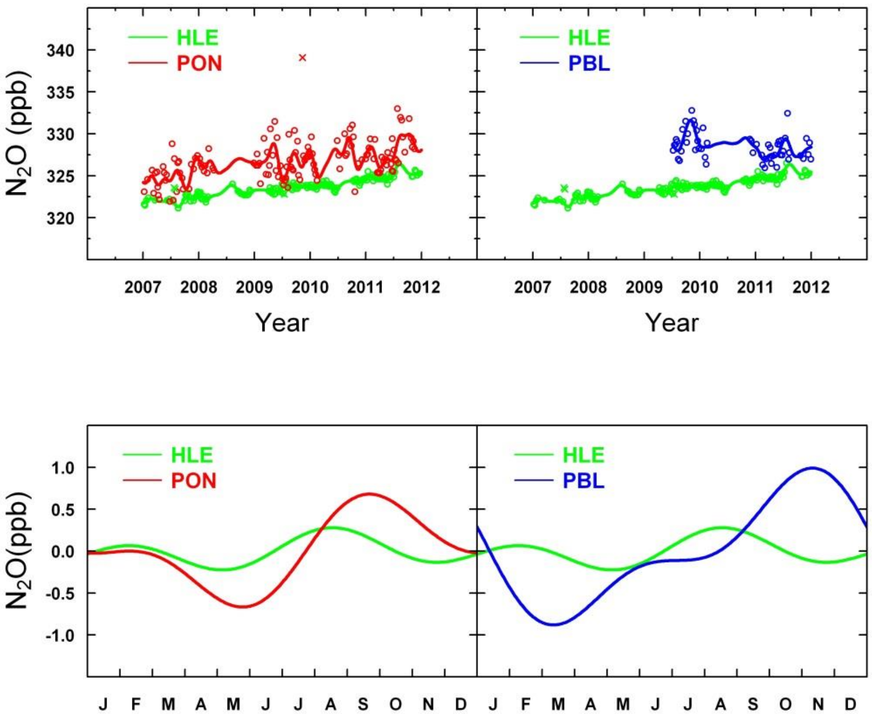
CH_4


HLE
PON
PBL
KZM
WLG
CH4(ppb)
2000
1900
1800
50
0
-50
2007
2008
2009
2010
2011
2012
Year
J F M A M J J A S O N D

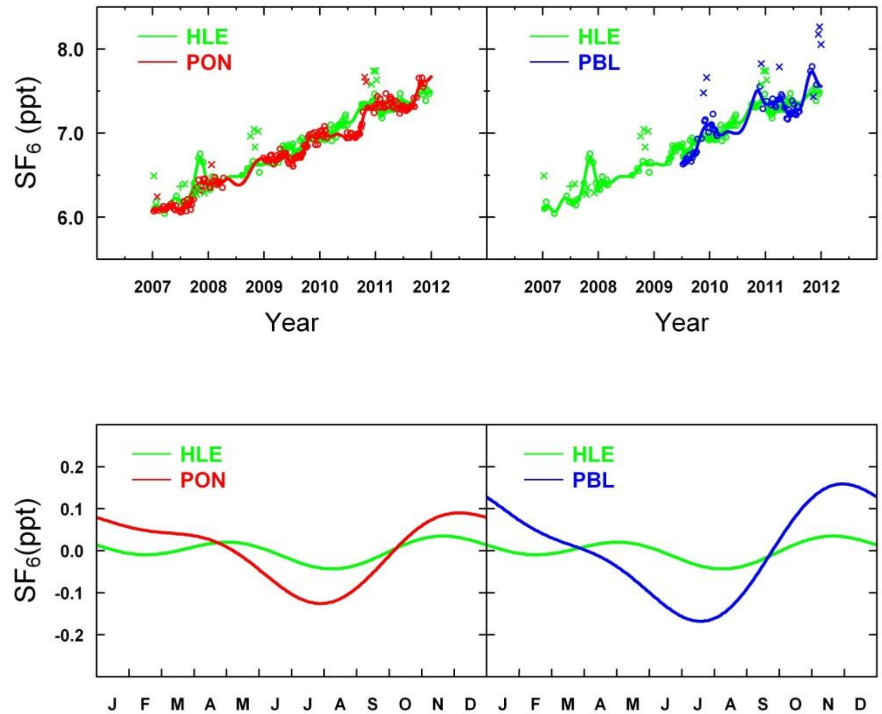
CO


HLE
PON
PBL
KZM
WLG
CO(ppb)
300
200
100
50
0
-50
2007
2008
2009
2010
2011
2012
Year
J F M A M J J A S O N D

N_2O


HLE
PON
HLE
PBL
N2O (ppb)
340
335
330
325
320
2007 2008 2009 2010 2011 2012
Year
N2O(ppb)
1.0
0.5
0.0
-0.5
-1.0
J F M A M J J A S O N D

SF_6


HLE
PON
HLE
PBL
SF6 (ppt)
8.0
7.0
6.0
2007 2008 2009 2010 2011 2012
Year
SF6(ppt)
0.2
0.1
0.0
-0.1
-0.2
J F M A M J J A S O N D

Next steps

- Further interpret the gradients between sites for other species
- Run LMDZ Asian zoom model forwardly with CO_2 and CH_4 fluxes to see if the model can reproduce the gradients

Thank you very much for your attention!

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