SEASONAL VARIABILITY OF TROPOSPHERIC CO\textsubscript{2} BASED ON GLOBAL AND REGIONAL MODEL SIMULATION WITH SATELLITE OBSERVATION.

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Abstract: In this paper, we use GEOS Chem model to simulate the atmosphere surface CO\textsubscript{2} concentration Indian region to estimate the regional source and sink of atmospheric CO\textsubscript{2}. Satellite (GOSAT, OCO-2) and in situ observation are used to estimate CO\textsubscript{2} concentration and fluxes. We simulate the two different temporal and spatial resolutions: global (2° x 2.5°) and Indian region (0.25° x 0.3125°, nested grid) for period of 2013-2019. The model and in situ comparison has good coherent, Batul insitu location has 0.89 correlation with Nested model and Sundarbans location has 0.72 correlation with Nested grid location. The regional and global model surface atmospheric CO\textsubscript{2} compared with OCO-2 and GOSAT satellite observation over four different regions in the Indian land region. Sensitivity experiment conduct to use Terrestrial biosphere exchange over Indian region and with regional global model and satellite observation. The regional and global and sensitivity model simulations are near surface atmospheric CO\textsubscript{2} concentration is compared and get good correction with satellite observation. The analysis has good comparison and time series analysis shows us good coherent with atmospheric surface CO\textsubscript{2} with satellite and insitu observation. In the analysis observed seasonal and inter annual variation over four regions of box: North India (Box A), South India (Box B) and North east India (Box C) and south west region (Box D). In three model simulation has good agreement with GOSAT and OCO-2 satellite observation. GOSAT with Nested, Global and BBIO inserted Nested model simulation Correlation are 0.9, 0.88, 0.89 and OCO-2 with Nested, Global and BBIO inserted Nested model simulation Correlation are 0.93, 0.89, 0.89. The terrestrial biosphere experiment given good results with regional simulation of CO\textsubscript{2} and satellite observation. The mainly effect of seasonal and inter-annual increase depends on terrestrial biosphere.

Index Terms - GEOS-Chem, Carbon Dioxide, Greenhouse Gas, Seasonal Cycle, GOSAT, OCO-2.

I. INTRODUCTION

Atmospheric carbon dioxide (CO\textsubscript{2}) is the most important element in the carbon cycle and it is a major greenhouse gas that has a significant role in global warming. The greenhouse gases are can trap thermal radiation or heat of the earth emit to space. CO\textsubscript{2} concentrations have been increasing continuously since pre-industrial times, from 280 parts per million by volume (ppmv) to 413 parts per million by volume, primarily due to the increase in anthropogenic emissions like fossil fuel burning, deforestation etc. Globally among the highest CO\textsubscript{2} emitting countries, China is leading with (~9.8 Gt CO\textsubscript{2} yr\textsuperscript{-1}) and followed by USA (~5.3 Gt CO\textsubscript{2} yr\textsuperscript{-1}) then India with ~2.5 Gt CO\textsubscript{2} yr\textsuperscript{-1} in 2017 (e.g., Le Quere et al. 2018). Our understanding of the chemistry of the global troposphere has advanced significantly over the past twenty years. Quantitative understanding of the atmospheric carbon budget is very important for developing climate mitigation policies. Global studies have been carried out to understand Atmospheric CO\textsubscript{2} variability using different approaches using in-situ measurements, Satellite data and various modelling techniques. Many
studies have used atmospheric transport models with in situ CO₂ observations to surface fluxes of CO₂ (Baker et al., 2006a; Peters et al., 2007; Schuh et al., 2010; Feng et al., 2017; Basu et al., 2013; Deng et al., 2014; Lau-vaux et al., 2016) at various spatiotemporal scales. High spatial temporal resolution of transport model to improve and understanding the source and sink for the greenhouse gases (Yoshida et al. 2011). Major developments in the Atmospheric chemical transport modelling over the past decades has been helpful in overcoming the limitations of satellite and in-situ measurements in understanding the troposphere chemistry in a coupled manner (Land-Atmosphere-Ocean). Source process is where CO₂ is released into atmospheric from animal and planet decay, deforestation and the burning of fossil fuel (Coal or Gas). Sink is remove CO₂ from atmosphere such as vegetation and trees take up CO₂ for photosynthesis process. In Recent years regional-scale carbon emission based numerical models are being used significantly in improving the understanding of regional carbon cycles. Model simulations to quantify the sink and source of atmospheric CO₂ on regional scale, some model conducted some part of the Asian region CO₂ transport model (e.g., Patra et al. 2018; Tiwari et al. 2011). Ballav et al. (2012, 2016) explain advantage of high resolution regional model for CO₂ instead of the Global model. Ma et al developed a downscaled method for CO₂ using OCO2 column dataset. Balance biosphere emission (BBIO) is one of the most important parameter to control in ecosystem productivity of global and regional model simulation of atmospheric CO₂ variability in different time scales, climate and carbon cycle. For regions such as USA, Europe and China carbon budgets and associated cause of variability in C sources and sinks are more or less understood. However, regional scale C budget for India is not yet accurately assessed or understood despite the country has occupied large land mass (3.28 million km²) with sizeable forest cover (23%) of high biomass potential. In India mainly carbon cycle based on the primary productivity and biomass etc. CASA model simulation long term pattern of Balance biosphere (NEP) studied in spatial and temporal variability (Nayak et al., 2015). The terrestrial ecosystem is India work as net sink of the atmospheric CO₂ for the period of 1981-2006 with the budget of 20TgC. It has significant as interannual and seasonal variability of atmospheric CO₂ (nayak et al. 2015).

In this paper we analysis the spatial and temporal variation of atmospheric CO₂ using GEOS Chem transport model GEOS Chem transport model use to simulate Global and regional model simulation of atmospheric CO₂ compared with satellite and different insitu measurements. Due to insitu observation data available over Indian region after 2012 onwards, by using satellite retrievals data of CO₂ column average user to showing variability of regional scale and source and sink are estimate. In the evaluation of model performance through four different sensitivity experiments, most commonly used statistical tools such as correlation coefficient (r), root mean square error (RMSE), standard deviation, bias are applied to the entire time series spanning from 2013-2019.

2. Data and methods

2.1 GEOS CHEM Model

Atmospheric Chemical Transport Models are based on the continuity equation describing chemical species' mass conservation. GEOS-Chem is a global 3-D chemical transport model (CTM) for atmospheric composition driven by meteorological input from the Goddard Earth Observing System (GEOS) of the NASA Global Modelling and Assimilation Office. Besides the meteorology fields, GEOS-Chem is driven by surface (boundary fluxes) of CO₂ over the land, over the oceans and anthropogenic sources of CO₂. The land surface fluxes are estimated based on regionalized version of the CASA terrestrial ecosystem model (land modules) and sea - air fluxes are estimated from the data of del pCO₂ and other ocean surface parameters based on the simple empirical model for the gas dissolution mechanism. Anthropogenic sources of CO₂ coming from several inventories data and global databases. The model can be run with full chemistry component, however our current focus is on CO₂ species only.

We have used the 9-02 version of GEOS-Chem 3D chemical transport model which is driven by GEOS meteorological fields with Nested South Asia 0.3125°x0.25° spatial resolution, with 47 vertical levels extending from 1006 hPa to 0.01 hPa(surface level) from the NASA Global Modelling and Assimilation Office (GMAO) along with surface boundary fluxes and anthropogenic emissions from different sources. For Nested model (regional) boundary conditions are taken from the GEOS-Chem global simulations performed at the horizontal resolution of coarser grid 2°x2.5°. Coarser grid has 47 vertical levels extending from 1006 hPa to 0.01 hPa(surface level). Nested grid model simulate troposphere CO₂ over (regional model) India at 3 hourly intervals for the period of 2013-2019, output of regional model stored in daily vertical mean. In Nested grid simulation All GEOS meteorological fields and Emissions fields are Downscaled from Global set. The first version of GEOS-Chem CO₂ mode including the atmospheric CO₂ fluxes from biomass burning, biofuel
burning, fossil fuel combustion and cement production, ocean exchange and terrestrial biosphere exchange was developed by Suntharalingam et al. (2004). Later it was updated by Nasser et al. (2010) by improving the CO₂ flux inventories, CO₂ emissions from international shipping and aviation (3D). The CO₂ emissions from fossil fuel burning and cement manufacture were based on the inventory developed at the Carbon Dioxide Information and Analysis Centre (CDIAC) of the Oak Ridge National Laboratory (ORNL) with regional and seasonal variability that spans 1950-2007 (Andres et al., 2011). The CO₂ emissions from biomass burning used year-specific Global Fire Emission Database version 2 (GFEDv2) (van der Werf et al., 2006). The biofuel burning CO₂ contribution used the annual mean inventory by Yevich and Logan (2003). The CO₂ ocean fluxes are from Takahashi et al. (2009) with monthly variations, which are based on the 3,000,000 non-El Nino measurements of the pressure of CO₂ dissolved in ocean water.

Table 1 represented Regional and Global simulation of atmospheric CO₂ and retrieval satellite observation of CO₂ data type and resolution.

<table>
<thead>
<tr>
<th>Model / Satellite</th>
<th>Time period</th>
<th>Data type and resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nested grid</td>
<td>Apr 2012-2019</td>
<td>Meteorology field (GEOS-FP), 0.25°x0.3125° (daily)</td>
</tr>
<tr>
<td>Global</td>
<td>2012-2019</td>
<td>Meteorology field (GEOS-FP), 2°x2.5° (daily)</td>
</tr>
<tr>
<td>CASA inserted Nested</td>
<td>2013-2018</td>
<td>Meteorology field (GEOS-FP), 0.25°x0.3125° (daily)</td>
</tr>
<tr>
<td>GOSAT</td>
<td>2013-2017 oct</td>
<td>CO₂ surface with level L4 (daily) and level L3 (monthly), 2.5°x2.5°</td>
</tr>
<tr>
<td>OCO-2</td>
<td>Sep 2014-2019</td>
<td>OCO2 L2 level date (daily)</td>
</tr>
</tbody>
</table>

In this paper regional (Nested) grid model simulation anthropogenic and natural emission files and input meteorology field (GEOS FP) downscaled by using Bilinear interpolation from coarse resolution to high resolution, this interpolated method described in section 2.6 and input parameters downscaled shown is table 2. The three different model simulation have done i.e Global and regional and New CASA emission inserted in regional model for atmospheric CO₂. This three simulation are compared with satellite observation.

The table 2 show us the input Meteorology field downscaled and emission files with 0.25°x0.3125° (daily or monthly) resolution.

<table>
<thead>
<tr>
<th>Input</th>
<th>Original data resolution (Global simulation)</th>
<th>Downscaling data resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorology field (GEOS-FP)</td>
<td>2°x2.5° (daily)</td>
<td>0.25°x0.3125° (daily)</td>
</tr>
<tr>
<td>Fossil Fuel Emission</td>
<td>2°x2.5° (month)</td>
<td>0.25°x0.3125° (month)</td>
</tr>
<tr>
<td>Biomass Burning</td>
<td>0.5°x0.5° (month)</td>
<td>0.25°x0.3125° (month)</td>
</tr>
<tr>
<td>Biofuel Emission</td>
<td>1°x1° (month)</td>
<td>0.25°x0.3125° (month)</td>
</tr>
<tr>
<td>Balanced Biosphere</td>
<td>2°x2.5° (daily)</td>
<td>0.25°x0.3125° (daily)</td>
</tr>
<tr>
<td>Ocean Exchange</td>
<td>2°x2.5° (month)</td>
<td>0.25°x0.3125° (month)</td>
</tr>
</tbody>
</table>
2.3 Satellite observation (GOSAT, OCO-2) and Insitu location

GOSAT was launched on 23 January 2009 by the Japanese Aerospace Exploration agency (JAXA). It operates in the SWIR (shortwave infrared) at 0.76, 1.6, 2.0-micrometer sensitivity to the near surface. GOSAT has two types of instruments, TANSO-FTS and TANSO-CIA. TANSO-FTS (thermal and near infrared sensor for carbon observation - Fourier transform spectrometer) has four bands, one is thermal IR channel from 5.5 to 14.3 micrometer remain three are spectral channels with 0.27/cm resolution at 0.76,1.6,2.0 micrometre, in this bands not only CO₂ retrieval and also CH₄, H₂O and O₂. CO₂ absorption is high in near 1.6 μm and 2 μm bands near the lower troposphere. In this study CO₂ concentration near surface layer monthly using for period of 2013 and 2017 with 2.5⁰ x 2.5⁰. Spatial resolution form JAXA(Yokota et al., 2009; Yoshida et al., 2011; https://data.gosat.nies.go.jp). We used the GOSAT FTS SWIR L4B daily of 2009 to 2017 with grid resolution of 2.5⁰ x 2.5⁰. (Level 3 data product available is monthly average of 2009 to 2018 for over a grid 2.5⁰ x 2.5⁰. The data were missing for the period June, December months in 2014 and January, September months 2015 in GOSAT FTS SWIR Level 3). The details of the products and processing methods are described in https://data.gosat.nies.go.jp. GEOS-CHEM data were projected into grids of GOSAT observations both for horizontal and vertical levels.

Orbiting Carbon Observatory -2 (OCO-2) launched by American environmental science on 2 July 2014 (crisp et al 2017), replacement for the orbiting Carbon Observatory, in 2009 OCO fist launch failed to reach orbit. This OCO-2 second successful high precision observing satellite after GOSAT. OCO-2 is three band spectrometer which are measured two spectral band for column measurements of carbon dioxide (weak band 1.61 microns, strong band 2.06 microns) and one spectral band measurement column of Oxygen (A band 0.76 microns). In this paper we used OCO-2 X CO₂ version 9r algorithm use for retrieval Odell et al 2012. The OCO-2 XCO₂ retrieval and temporal resolution 16 days so we use monthly mean composite of Xco2 for atmospheric surface, and retrieval co2 used to comparison to Model from the seasonal and interannual variations.

The two insitu location are available Betul and Sundarbans eddy covariance under instilled under ISRO Geosphere Biosphere program to measures atmospheric CO₂. Betul flux tower location in the forestry area in Madhya Pradesh in India. Sunderban flux tower available location west Bengal, this location 7m above the sea level, details of the data processing and calibration procedure given in Rodda et al. 2016 and krishnapriya et al. 2020. The table 1 shows us model simulation and Satellite observation time period.

2.4 COMPUTATION OF SEASONAL AND NO SEASONAL CYCLES

The dominant oscillating signals of wind vectors with annual and semi-annual periodicity were found in the Fast Fourier Transformation (FFT) analysis. Time-series of the surface wind velocity A(t) are fitted with annual and semi-annual harmonics based on least square methods for calculation of the seasonal contributions PS (t) in the time series at each pixel level as they were the most prominent signals (Nayak et al. 2013). The time series A (t) can be expressed as

\[ A(t) = A_0 + A_a \cos(w_at + \Phi_a) + A_as \cos(w_as t + \Phi_as) + e(t) \]  

Where the stationary component A₀ represents the climatological mean, (Aₐ , Aₐs) and (Φₐ , Φₐs) correspond to the amplitude and phase angles of annual and semi-annual harmonics, respectively, e represents the residual term and white noise. The nonseasonal time series is the residual of mean seasonal cycle from the original time-series data of surface wind velocity. It is important to note that this procedure can remove only the mean component of the seasonal variability. Hence nonseasonal contribution is composed of intra-seasonal variability and inter-annual variability. The changes in seasonal cycles during the study period contribute to inter-annual variability, while changes occurring within a seasonal time scale are called intra-seasonal variability.
2.5 Sensitivity experiment for Terrestrial biosphere emission

2.5.1 Spatial pattern of annual mean Balanced biosphere emission (BBIO) for Indian region and time series.

Terrestrial biosphere exchange consists of two components. The first is the “balanced biosphere” and it is from model of the Carnegie-Ames-Stanford Approach (CASA) model (Randerson et al., 1997, Olsen and Randerson, 2004), the sum of the Gross Primary Production (GPP) and total ecosystem respiration (Re) is taken to represent Net Ecosystem Productivity (NEP) for 2000. The GEOS Chem taken using NEE for 2000 for simulation for global resolution. GEOS Chem model consist of balanced biosphere (BBIO) is based on CASA model. In Global model and Nested model run Net Ecosystem productivity (NEP) for 2000, in the global GEOS chem Model simulation it take same year repeat for remain year. Balanced biosphere give no net annual uptake/release of CO₂ (no anthropogenic interfacing). The CASA NEP output is used as Net Ecosystem Exchange (NEE) in our model simulation. Fig show us a comparison between global NEP (BBIO) for the year 2000 and CASA model output NEP (BBIO) for the year of 2013-2018 annual mean with three different regions. We observed Model BBIO and regional CASA BBIO have some difference in Amplitude and phase shift and both datasets show us similar seasonality. In this paper we are using 2 data sets, one is GEOS chem BBIO has daily 0.25°×0.3125° resolution and CASA 0.03°×0.03 resolution monthly. The CASA Model BBIO is Monthly data converted into daily in linear interpolation method for period of 2013-2018. The daily CASA Model BBIO upscaled to Model resolution.

Fig1 show us Harmonic analysis of GEOS Chem Model NEP (BBIO) and CASA model NEP (BBIO) of Mean climatology, annual and semi-annual harmonic analysis (krishnapriya et all.2020, Nayak et al.2016). Mean Climatology of the Model NEP and Casa output BBIO has observed difference in north east state and Kerala region. In Model BBIO observed Panjab and south region some difference. Annual harmonic high amplitude observed in Middle Indian and North east states in GEOS Chem model. In CASA BBIO Arabian coast and Bengal and north east also observed high amplitude. Semi annual amplitude Delhi and Himachal Pradesh has observed high amplitude and Bengal and Panjab and Arabian coastal region has high amplitude. The figure 2 show seasonal variability of BBIO of GEOS Chem model input emission and CASA Model BBIO output. North India some amplitude and phase different observed in GEOS chem BBIO maximum amplitude observed in APR but in CASA July max amplitude in south India also we observed some different in phase and amplitude and northeast also amplitude difference we observed.
Figure 1a shows us Spatial Patterns of Climatology, Annual and Semi-annual harmonics BBIO (gCm²-month⁻¹). Left two panel: upper panel is Mean climatology of GEOC Chem BBIO, down panel is CASA new data inserted BBIO, middle upper panel is Annual amplitude of Model BBIO and lower panel is CASA model and right upper panel is Model BBIO semiannual amplitude and down panel is CASA BBIO semiannual.
The figure 1b, show a time series analysis for two different terrestrial biosphere, black line shows us GEOS Chem biosphere red line shows us CASA new inserted Biosphere:

Figure 2 The study region shows the four different location over Indian region, box A Indogenous region box B southern peninsular region, box C Desert region, box D is green forest region. The map is created from http://www.google.com/maps.

2.6 Downscaled method for Coarse to high resolution

In nested grid model simulation we have used bilinear interpolation method for downscaling. In this method calculating values of grid location is based on nearby grid cells. Using the four nearest neighbouring cells, assigns the output cell value by taking the weighted average, closer cell being given higher weights. The table 2 shows us the parameter is downscaled to coarser to finer resolution. The input meteorological filed and different emission are downscale to high resolution shows in table 2.

This method has low quality and good quality. If we using this algorithm the final pixel can obtained using the linear interpolation in vertical and horizontal directions. Bilinear interpolation method is it useful for its computational efficiency and image quality (Pawar Ashwini Dilip et al. 2014).

The basic algorithms the bilinear interpolation method is a linear interpolation in one direction, and repeating the same for the other direction also. As shown in Figure, P(i, j), P(i+1,j), P(i,j+1), and P(i+1,j+1) are the four nearest neighbour pixels of the original image with i = [0, 1, 2, ... N] and j = [0, 1, 2, ... M]. Here, N is pixel point in horizontal direction and M is point in latitude point. missing pixels is \( P(x', j) \) and \( P(x', j+1) \) are created by linear interpolation in horizontal direction and can be calculated as

\[
P(x', j) = (1 - xf) \times P(i, j) + xf \times P(i+1, j)
\]

\[
P(x', j+1) = (1 - xf) \times P(i, j+1) + xf \times P(i+1, j+1)
\]

where \( xf \) is the scale parameter in horizontal direction.

After interpolating in horizontal direction, the values of temporary pixels \( P(x', j) \) and \( P(x', j+1) \) are generated. The resulting output pixel \( P(x', y') \) can be obtained by one more linear interpolation in the other direction. Alternatively, the output can be produced by implementing linear interpolation in the vertical direction and can be calculated as

\[
P(x', y') = \[(1-yf)\times P(i,j)+yf\times P(i+1,j)]\times(1-yf)+[(1-yf)\times P(i,j+1)+yf\times P(i+1,j+1)]\times yf
\]

where \( yf \) is the scale parameter in vertical direction.
3. Results and Discussion

3.1 Time series analysis of Model simulation and satellite observation

Seasonal cycle, spatial and temporal cycle is Comparison of model CO₂ with satellite observation for Time series analysis. The Fig 4 show the temporal variations of Model simulated troposphere columnar CO₂ concentration and OCO-2 observation and GOSAT L4A for five different region over Indian land region for the period 2013-2019, table 2 shows is Global and Regional (Nested grid) Model simulations and observation grid their resolution and during time period. The temporal characteristics of atmospheric CO₂ concentration is strong seasonal variation observed and rising trend over Indian land region. The four region are box A represented cropland dominance Indo Gangetic plain and this area away from from the marina environment. box B is southern peninsular region and evergreen tress. Box C is grassland dominance of Rajasthan and Thar Desert. Box D is evergreen forest region. As shown in fig GEOS Chem global and regional modelled CO₂ concentration lower tropospheric columnar mean is better agreement with GOSAT and OCO-2 observation. Yoshida et al described the SWIR band of the GOSAT surface layer CO₂ concentration is more sensitive. The all data set shows a similar range of CO₂ between 390 to 410 ppmv, linear growth rate 2.25 ppmv yr⁻¹. GEOS chem Model comparison of three data set comparison with lower troposphere columnar mean has better agreement with OCO-2 and GOSAT observation.

In the figure 4 observed the model has a cold bias of 3.1 ppm compared with satellite observation because of model initial condition. The temporal and seasonal variation in atmospheric CO₂ concentration include intense increasing trend over four different regions over India. The interannual oscillation observed in the atmospheric CO₂ in the year 2017 and 2019 and minimum observed in 2015, 2016. Low and Simmonds 1996 explained interannual variability and latitudinal gradient occurs mainly in CO₂ surface changes. The global and Nested region model simulation of Atmospheric CO₂ good correlation with OCO-2 and GOSAT observation. CASA inserted BBIO has lower correlation compared to global and Nested grid Model with satellite observation. Correlation coefficient with model vs observation shows in table. Fig 5 show us spatial correlation between the model vs satellite observation. In this spatial correlation most of the regions has more then 0.8 correlation and less correlation observed where data is unavailable region. GOSAT and OCO-2 satellite some region data not present because of clouds.
Figure 4 shows time-series analysis of Global and regional and CASA inserted regional model simulation of atmospheric CO$_2$ is compared GOSAT and OCO-2 satellite observation with four different location show in fig2 four Box A, B, C and D.

Figure 5 shows us Spatial correlation for Global and Nested with satellite observation of GOSAT and OCO-2.
Table 3a shows satellite observation and model simulation for four different regions (A, B, C, D) with OCO-2.

<table>
<thead>
<tr>
<th>Region</th>
<th>Nested</th>
<th>Global</th>
<th>BBIO inserted Nested model</th>
<th>Nested</th>
<th>Global</th>
<th>BBIO inserted Nested model</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.93</td>
<td>0.88</td>
<td>0.89</td>
<td>1.25</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>B</td>
<td>0.89</td>
<td>0.88</td>
<td>0.89</td>
<td>1.5</td>
<td>1.6</td>
<td>1.45</td>
</tr>
<tr>
<td>C</td>
<td>0.93</td>
<td>0.91</td>
<td>0.91</td>
<td>1.1</td>
<td>1.2</td>
<td>1.14</td>
</tr>
<tr>
<td>D</td>
<td>0.79</td>
<td>0.73</td>
<td>0.73</td>
<td>2.2</td>
<td>2.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 3b shows satellite observation and model simulation for four different regions (A, B, C, D) with GOSAT.

<table>
<thead>
<tr>
<th>Region</th>
<th>Nested</th>
<th>Global</th>
<th>BBIO inserted Nested model</th>
<th>Nested</th>
<th>Global</th>
<th>BBIO inserted Nested model</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.93</td>
<td>0.88</td>
<td>0.77</td>
<td>1.2</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>B</td>
<td>0.93</td>
<td>0.92</td>
<td>0.84</td>
<td>1.1</td>
<td>1.25</td>
<td>1.35</td>
</tr>
<tr>
<td>C</td>
<td>0.97</td>
<td>0.96</td>
<td>0.92</td>
<td>0.8</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>D</td>
<td>0.93</td>
<td>0.84</td>
<td>0.77</td>
<td>1.2</td>
<td>2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Figure 6 shows us comparison between simulated CO₂ and in situ observation at Sundarbans and Betul flux tower station location. Comparison has been done three ways and two different units such as volume mixing ratio in ppmv and mass density (milli moles m⁻³) and tendency (time rate change of CO₂) details explained in krishnapriya et al. 2020. The two in situ location the model data extracted in surface layer and compared with in situ. First one is Sundarban location during April 2012 March 2013 period data available. The fig shows decreasing trend during spring and summer season and increasing trend in autumn and winter in global and Nested grid simulation shows us similar variability of increasing and decreasing trend. krishnapriya et al 2020 explained Sundarbans and global model simulation comparison correlation coefficient 0.71 with regional model simulation 0.72. Regional (Nested grid) model CO₂ and Sundarbans location fig shows mass density and tendency comparison also got good agreement compared to global model simulation. Betul location during 2013 year. In fig shows us increasing trend in the Oct-Dec 2013 during this period in global and regional simulation, dip observed in April-May 2013. Global simulation compared Betul in situ location got correlation coefficient 0.88 and nested simulation got 0.89. Very good agreement between the nested and Betul flux tower location. In seasonal cycle decreasing values observed in global and regional simulation in Feb-May 2013 and decreasing trend in month of September. The Decreasing phase main reason for this is regional vegetation uptake and transport phenomena. In winter season CO₂ act as sink in ecosystem region. In comparison between the tendency CO₂.
Figure 6 Left panels show comparison between Sundarban insitu and simulated near surface layer atmospheric CO$_2$ at ppmv (upper panel), in milli mole m$^3$ in middle panel, and tendency in milli mole m$^3$ month$^{-1}$ in the bottom panel. The right panels show the same as that in the left panels for Betul Flux tower station. krishnapriya et al. 2020 explain about insitu and global simulation.

3.2 Mean Seasonal of Global and Nested (Regional ) model simulation of atmospheric CO$_2$ concentration.

The figure 7a shows us the global and Nested (regional ) grid model simulation has seasonal mean CO$_2$ concentration in the south Asia for 2013-2019. The seasonal distribution of the CO$_2$ concentration is similar in all seasons and some areas with high concentration of CO$_2$ observed because of high anthropogenic emission and terrestrial system (BBIO). The simulated CO$_2$ concentration is the highest in autumn season(September –November), with the maximum CO$_2$ concentration exceeding 407 ppmv and the minimum CO$_2$ concentration below 398 ppmv in north India. CO$_2$ concentration smaller in summer (JJA). It is mainly because the terrestrial ecosystems show a higher photosynthesis rate in summer and growing the vegetation in this season.
The figure 7b shows seasonal Co2 concentration distribution of zonal mean of atmospheric CO3 and vertical pressure level of Indian study region for the four different seasons (-40°E;110°E). The surface pressure level (1006 hPa) has more Co2 concentration observed in all seasons. The atmospheric Co2 higher concentration observed in North East region. In summer and autumn Co2 concentration values are decreases with air parcel is updraft. In global and nested region has spatial variability is observed. Satellite observation (OCO-2 level 2 and GOSAT) are retrieved for near troposphere surface level (650hP) and model also up to troposphere surface level. Scatter plot between GOSAT and three different model simulations for four different regions over Indian region. As shown fig the GOSAT satellite observation corresponding to four different region over India has good agreement with NESTED model (r =0.93) simulation followed by GLOBAL (r =0.8) and CASA (r =0.77) inserted model simulation. GOSAT good agreement near box c region with three model simulation data sets.
The Fig 8 shows the scatter plot between OCO-2 and three different model simulations for four different regions over Indian region. As shown the GOSAT satellite observation corresponding to four different regions over India has good agreement with NESTED (Red) model simulation followed by CASA (Blue) inserted model simulation and GLOBA (Green).

The Figure 8 about the scatter plot between OCO-2 and three different model simulations for four different regions over Indian region. As shown the OCO-2 satellite observation corresponding to four different regions over India has good agreement with NESTED model simulation followed by CASA inserted model simulation and global. The following table 3a, 3b shows the correlation values and RMSE values of GOSAT and OCO-2 with Nested, Global and BBIO inserted CASA for four different locations of box shows in the figure 2. The good agreement between the model with satellite observation.

4 Summary and Conclusion

A high-resolution GEOS-Chem atmosphere transport model has been set up for Indian Region and studied the seasonal dynamics and interannual variability of surface layer atmosphere CO2 in four different regions in Indian land region. In Model run are Global and Nested and BBIO inserted Nested runs were performed to evaluate the role of Balance Biosphere (BBIO) characterizing the seasonal cycle of CO2. The simulated CO2 from three model run has been compared with OCO-2, GOSAT, and in situ observations. They show good agreement between them and exhibit distinct seasonal cycles and inter-annual variability across four different regions. The mean climatology exhibits a strong latitudinal gradient with a high concentration in the north and decreases towards the southern tropical Indian Ocean. The interannual variation of the terrestrial fluxes has main crucial parameter in the surface CO2 concentration. The terrestrial biosphere fluxes in Indian region has been main impact and understanding of the interannual variation of atmospheric CO2 and understanding effect
of uncertainty in the BBIO fluxes in GEOS Chem chemical transport model of atmospheric surface CO2. The model simulation surface CO2 concentration increasing Over Indian land region 2013-2019 trend of the 2-3 ppmv per year and model has cold bias 3.1 ppm. The in situ measurement at two flux tower station i.e Betul and Sundarban, it has represented the surface layer CO2 variability of model simulation. The model simulation is some variation observed with In situ tower location because of model initial and input date sources and spatial resolution at global and regional model.

Reference:


