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Satellite Mapping of CO_2 Emission from Forest Fires in Indonesia Using AIRS Measurements

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Abstract

Results from the analysis of the retrieved carbon dioxide (CO_2) columns in the free troposphere are presented for one year (2005) obtained by the Atmospheric Infrared Sounder (AIRS) included on the EOS Aqua satellite launched on May 4, 2002. Providing information for several greenhouse gases, CO_2, CH_4, CO and O_3 is one goal of the AIRS instrument as well as to improve weather prediction and study the water and energy cycle. Carbon Dioxide (CO_2) is the most prominent Greenhouse gas in Earth's atmosphere and plays a key role in earth's climate. It is emitted into the air as humans exhale, from burning fossil fuels for energy and deforestation of the planet. The aim of this study is to generate Monthly CO_2 Distribution maps and to investigate the effects of Indonesia forest fires on CO_2 distributions over Peninsular Malaysia, north Sumatra and Singapore for 2005. The CO_2 concentration map of the study area was generated by using mole_fraction of CO_2 in free troposphere, obtained from AIRS/Aqua Level 3 monthly CO_2 retrieval product (AIRS+AMSU) V005 (AIRX3C2M) at GES DISC. Considerable variations were demonstrated in the annual changes of rainfall and drought patterns in various seasons (dry & wet season). Variations in the biomass burning and CO_2 emissions where noted over the study area, while the highest CO_2 occurred over industrial and congested urban zones and a greater draw down of CO_2 occurred in the pristine marine environment over northeast coasts of Sumatra during 2005. In particular, we observe a quasi-biennial variation in CO_2 emissions from study area with two peaks, the natural peak occurring at the end of each dry season (February to April), when biomass burning occurs, and the second peak at wet season (July to September), because of the influence of Indonesia forest fire. Examining satellite measurements, the results showed that the enhanced CO_2 emission correlates with occasions of less rainfall during dry season.

Keywords: Carbon dioxide, AIRS, Forest fire

1. Introduction

Many gases occur naturally in the atmosphere, while other from industrial wastes emissions. Our reliance on fossil fuels has been firmly solidified and global population has increased, so emissions of these gases have risen. While gases such as carbon dioxide occur naturally through the terrestrial biosphere and the ocean, humankind has altered the natural carbon cycle (through burning forest lands, oil, natural gas, wood or mining and burning coal) artificially move carbon from solid storage to its gaseous state, eighty-five percent of all human-produced carbon dioxide emissions come from the burning of fossil fuels like coal, natural gas and oil, including gasoline,(33% power plants, 22%cars and trucks, 12%major transportation, 33% Factories, home and heating systems). In the last half of the 20th century, carbon dioxide was the first greenhouse gas manifested to be increasing in atmospheric concentration with the first eventual measurements. Before the industrial revolution, concentrations were fairly stable at 280ppm, today they are around 370ppm and keeps rising steadily (Y. K. Tiwari et al., 2005). The increase from developing countries was three times that from developed countries, Middle East carbon dioxide emissions from burning of fossil fuels increased 35%, Africa increased 12% and Eastern Europe increased by 75% from 1990-1995(Greenhouse Gases, 2008). CO_2 is toxic in higher concentrations: 1% (10,000 ppm) will make some people feel drowsy, concentrations of 7% to 10% cause dizziness, headache, visual and hearing dysfunction and unconsciousness within a few minutes to an hour. Carbon dioxide in the atmosphere is low, it is not practical to obtain the gas by extracting it from air. Some CO_2 is obtained from the combustion of coke or other carbon-containing fuels, while most commercial carbon dioxide is recovered as a by-product of other processes, such as the production of ethanol by fermentation and the manufacture of ammonia (Shakhashiri, 2008).

Southeast Asia is experiencing a similar rapid economic growth to that in Northeast Asia, is also a large source of several air pollutants, and may make an important contribution to regional and global pollution because of increasing anthropogenic emissions associated with biogenic emissions from large tropical forests, the greater oxidizing capacity in tropical regions due to higher UV intensity and humidity and rapid development and industrialization (Kato N, Akimoto H 1992; Streets DG et al., 2001). Because satellite remote sensing allows consistent, frequent, and comprehensive data collection at global scales and regional, scientists have discovered its use in studying biomass burning and fire emission. Parameters concluded from satellite data include fire counts, aerosol index, biomass density and burnt area (Cooke et al., 1996; Delmas et al., 1991). Carbon dioxide is the important trace gas retrieved by AIRS for the study of anthropogenic effects on climate.

The AIRS instrument is included among several instruments mounted on the (EOS) Earth Observing System Aqua satellite launched on 4 May 2002, with its partner, Advanced Microwave Sounding Unit (AMSU-A) are characterizing and observing the entire atmospheric column from the surface to the top of the atmosphere in terms of temperature and surface emissivity, cloud amount and height, atmospheric temperature and humidity profiles, and the spectral outgoing infrared radiation. The infrared brightness values coming up from Earth's surface and from the atmosphere are measure by AIRS. Their scan mirrors revolve around a central axis along the line of flight and directs infrared energy from the Earth into the instrument (Parkinson et al., 2003). The AIRS instrument, includes 2378 infrared spectral channels provides spectral coverage in the 3.74–4.61µm, 6.20–8.22µm, and 8.8–15.4µm infrared wavebands at a nominal spectral resolution of $\lambda/\Delta\lambda$=1200. The term "sounder" in the instrument's name refers to the fact that water vapor and temperature are measured as functions of height. The AIRS instrument also contains four visible/near-IR (Vis/NIR) channels between 0.40 and 0.94 µm, with a 2.3-km FOV. The most important minor gases retrieved from AIRS spectral radiances is CO_2 in the 712-750 cm^{-1} region (mid troposphere at a nadir resolution of 90km×90km), uses an analytical method based on the properties of partial derivatives. The AIRS broad swath makes it able to map the global distribution of CO_2 every day (Hartmut H. Aumann et al., 2003).

Immense plumes of the gas emitted from forest and grassland burning in Indonesia forest fires in 2005 caused a serious air pollution in Malaysia, northern Sumatra and Singapore. In Malaysia, air pollution reached extremely hazardous levels and forced schools and an airport to close. NOAA recorded 5420 hotspots from satellite images over the area between mid-July and mid-August. This study is based on CO_2 retrievals from a research version of the current AIRS operational physical algorithm, used Standard Level-3 Monthly gridded product (AIRX3C2M) Version 5 data, in the free troposphere using AIRS IR and AMSU, without-HSB, to investigate Monthly Distribution map of carbon dioxide over Peninsular Malaysia, north Sumatra and Singapore for 2005. By using Retrieved mole fraction of CO_2 in free troposphere, the CO_2 concentration map of the Peninsular Malaysia, northern Sumatra and Singapore was conducted, map were generated by using Photoshop CS & SigmaPlot 11.0 software to assess the effect of Indonesia forest fire August on atmosphere Carbon dioxide distribution.

2. Study Area and Data

An area covering 1.045X10^6 km^2, which includes the Peninsular Malaysia and northern Sumatra (centered at 100.755º E and 2.429º N) was selected for this study because a series of large fires occurred in the area in the August of 2005 (Figure 1).The extent of the domain was chosen so that it was sufficiently large to contain CO_2 plumes from severe fires in the area. The dimensions of the study domain are 1100 km E-W and 950 km N-S. The time period from January to December 2005 was selected to study the CO_2 distribution for 2005 covered the development of fires in the area since mid-June to mid-August was the period with the most number of detected fires.

The data used for this study include CO_2 data from AIRS and ground Station data; they were extracted for the study area and were processed to match in terms of space and time. The CO_2 data were derived from Atmospheric Infrared Sounder (AIRS) Version 5 Level 3 data available from the Goddard Earth Science Data and Information Services Center (GES DISC), as well as auxiliary data including the corresponding location and time along the satellite track in a HDF (Hierarchical Data Format) format on monthly basis. Using the location information, CO_2 data were gridded monthly at Geospatial Resolution of 2 degrees x 2.5 degrees (lat x lon). Twelve months composites (mean) were made to obtain near-complete coverage for 2005. The above-ground data were obtained from the Bukit Koto Tabang station is roughly 120 km north of Padang which the capital of the province West Sumatra, Indonesia, which is located in the tropical zone on the ridge of a high Barisan plateau at an altitude of 864.5 m a.s.l., latitude 0.20Sº longitude 100.32º and 40 km off the western coastline.

3. Acquisition and Specification

The AIRS spectrometer is devised to operate in synchronism with the microwave instruments AMSU-A1, AMSU-A2 and HSB. Its science objectives is to determinate the factors that control the global energy and water cycles, inquisition of atmosphere-surface interactions, improving numerical weather prediction, evaluating climate variations and feedbacks and diagnosis of the effects of increased carbon dioxide, methane, ozone and other greenhouse gases (J.Le Marshall et al., 2006). Table 1 describes AIRS Technology – Specifications. We use Standard (Version 5.0), from Collection (AIRX3C2M), AIRS/Aqua Level 3 monthly CO_2 retrieval product in the free troposphere (AIRS+AMSU), and available at website: http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings/by-data product/airsL3_C2M.shtml. AIRS radiance data in the regions at 700 cm-¹ and 2400 cm-¹ were used to retrieve mid-tropospheric CO_2 at nadir resolution of 90 km X 90 km (Hartmut H. Aumann et al., 2003). The AIRS mid-tropospheric CO_2 Level 3 Monthly Gridded Retrieval Product contains standard retrieval means, standard deviations and input counts as well as the latitude and longitude arrays giving the centers of the grid boxes. Each file covers a calendar month. The mid-tropospheric CO_2 retrievals have been averaged and binned into 2.5°x 2° grid cells, from -180.0° to +180.0° longitude and from -60.0° to +90.0° latitude. The global, space-based measurements of the column-averaged CO_2 dry-air mole fraction, CO_2 could dramatically improve our understanding of the environmental processes that control the atmospheric CO_2 budget (Olsen, S. C., and Randerson, 2004).

4. Results and Discussion

The six maps in Figures 2a-2f illustrate the extent of AIRS monthly coverage of mid-tropospheric CO_2, the nominal peak of AIRS vertical sensitivity and the magnitude of the seasonal variations in free tropospheric CO_2 over Peninsular Malaysia, north Sumatra and Singapore for a dry season (November - April) of 2005. A quasi-biennial variation in CO_2 over study area, plainly evident the high values of CO_2 occurred over northern and middle of Malaysia and southern and northern Sumatra, higher value was (380.751 ppm) at (lat. 4º - long. 100º) for December, and 381.636 ppm lat. 4º - long. 95º for November. During the late dry season between January and April, Observed CO_2 are lowest in the southern regions, increase at the northern regions, and are highest in the north of peninsular Malaysia 379.285 ppm at lat. 8º - long. 97.5º in April. The ~3.5 ppm higher CO_2 in the north than at south regions has mainly been attributed to long-range of air masses blowing from northeast and from western Asia (Pochanart P et al., 2003) as well as biomass burning occurs during these months, especially in the late dry season (boreal springtime), biomass burning pollution is raised by deep convection to the upper and middle troposphere, hold by the sub-tropical westerly flow, and transported to the central western Pacific.

Figures 3a-3f illustrate the extent of AIRS monthly coverage of mid-tropospheric CO_2 during wet season (May – October) of 2005 with high values in the north and low value in the middle region. Maximum values of CO_2 over the northern regions of Malaysia occur in June to September with minima over Sumatra occurs in May and October. Plainly evident in the monthly average, differences in the CO_2 spatial patterns for each of the peak months, variations are visible for other geographic regions, but none is as regular during these six months as those over Malaysia. During the wet season, Southeast Asia is governed by marine air masses from the middle and low latitudes of the Southern Hemispheric Indian Ocean, which bring small to moderate amounts of air pollution to continental Southeast Asia. There is no clear observational evidence that the transport of air pollution exerts a strong effect on Southeast Asia, partly due to the transport attributes of the region, as well as previous study and investigations showed minima values of CO_2 occurred in wet season (Tsusumi Y and Matsueda H, 2000). In contrast, the highest observed CO_2 occurs during wet season 2005, plainly evident the impact of Indonesia forest fire August 2005 making opposite process at July to September. The ~2.5 ppm higher CO_2 in wet season than at dry season, especially occurs precisely in a region that experienced extensive fires over northern area of Peninsular Malaysia, nearest to the fire regions, this extended from Riau to north Sumatra in Indonesia affected 10,000 hectares of peat forest, smoke from forest fires were badly affected and caused serious air pollution, as the wind carried the smoke further afield from July to September 2005.

From Figures 2 & 3, with the exception of the forest fire influence, the highest CO_2 occurs over Industrial and congested urban zones and a greater draw down of CO_2 occurs in the pristine marine environment over southwest coasts of Peninsular Malaysia and west coasts of Sumatra. Variation in CO_2 over study area in 2005 is plainly evident in the monthly average AIRS CO_2 maps presented. Maximum values of CO_2 occur in June, July, and August, with minima in January, February, and March.

Figure 4 illustrates the annual average distribution of CO_2 for 2005. The local CO_2 maximum just north of Peninsular Malaysia (379.044ppm ,area above latitude 4) occurs precisely in a region that experienced extensive Indonesia forest fire in 2005. In contrast, the figure shows much less CO_2 over the middle and northeast coasts of Sumatra. Looking carefully at Figure 4, two very localized areas stand out against their backgrounds: Kuala Lumpur (3N, 101.5E) and Johor (1.5N, 103.5E), although, considered as broad Industrial and congested urban zones but their CO_2 values are still less than over the northern regions and this situation was mainly attributed to Indonesia forest fires. Also note, that a greater draw down of CO_2 occurs in the pristine marine environment over northeast coasts of Sumatra during 2005.

The variation of CO_2 values for 2005 from Bukit Koto Tabang station measurement (near the surface, Sumatra, Indonesia) and the corresponding mid-tropospheric column from AIRS are illustrated in Figure 5.Note two peaks for CO_2 measurement from ground station, the natural peak occurred in the late dry season between February and April, and the CO_2 values had a large seasonal cycle whose amplitude was largert near the surface than column average CO_2 as a result of biomass burning. The second peak which occurred between July to September was caused by the Indonesia forest fire and thus phenomenon did not appear in the previous years. While from May to January the column average CO_2 was greater than surface CO_2, exceeded ~2-6 ppm.

5. Conclusion

As demonstrated here, AIRS' monthly observations of free troposphere CO_2 above the study area enable detailed analyses of both the spatial and temporal variations in emissions and the visualization of subsequent transport, AIRS can successfully detect CO_2 emission from large forest fires. We have investigated the wealth of information contained in the one year of AIRS data. AIRS/Aqua Level 3 monthly CO_2 retrieval Standard (Version 5.0) products in the free troposphere (AIRS+AMSU) V005 (AIRX3C2M), were used to evaluate the monthly CO_2 distributions, caused by the Indonesia forest fires.

Plainly evident the highest values of CO2 occurred during biomass burning in the late dry season and over Industrial and congested urban zones. The local CO2 maximum in the north Peninsular Malaysia occurs in a region that experienced the effect of extensive Indonesia forest fire in 2005. A greater draw down of CO2 occurs in the pristine marine environment over northeast coasts of Sumatra during 2005.

This paper has provided evidence for the impact of remote biomass burning and forest fire on Carbon Dioxide pollution levels above study area and enhanced our knowledge on AIRS detection of CO_2 emission from forest fire, the accuracy of remotely sensed tropospheric CO_2 columns and abundances from AIRS.

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Table 1. AIRS Technology – Specifications

Instantaneous Field of View (IFOV)	1.1°
Spectral Resolution	13.5x13.5 km in the nadir
coverage	pole-to-pole & covers the globe two times a day
orbit	438 miles (705.3km) polar, sun synchronous, 98.2+/- .1 degrees inclination, ascending node 1:30pm +/- 15 minutes, period 98.8 minutes
Ground Coverage	+/- 49.5 degrees around nadir
Ground Footprint	90 per scan, 22.4 ms footprint
Temporal Coverage	Global, twice daily swath (daytime and nighttime)
Radiometric Calibration	+/- 3% absolute error
Spatial Coverage	Scan Angle: +/- 49.5 around nadir IFOV: 0.185
Power / Mass	256 W / 166 kg
Swath Width	1650 km

Figure 1. The Study area

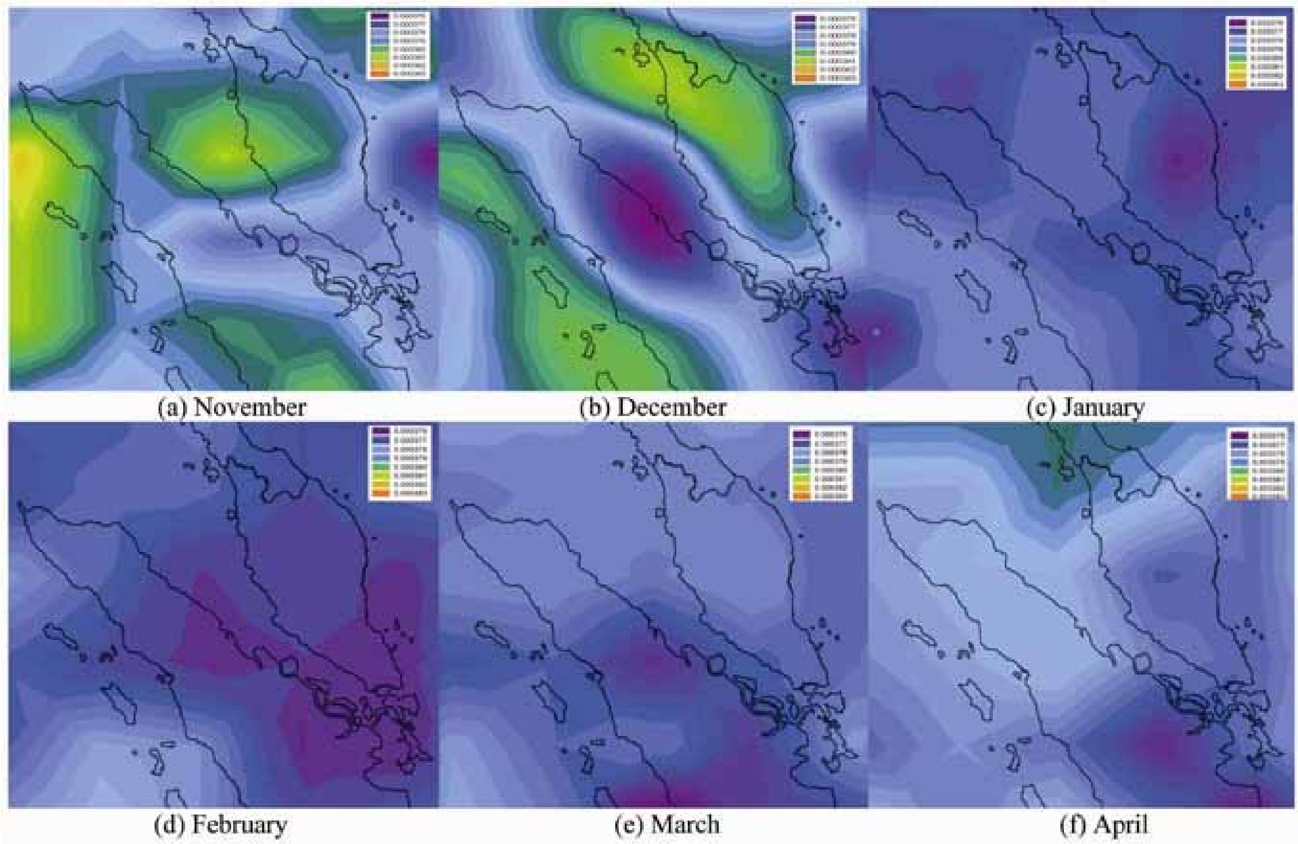

Figure 2. AIRS monthly coverage of mid-tropospheric CO_2, from November to April 2005

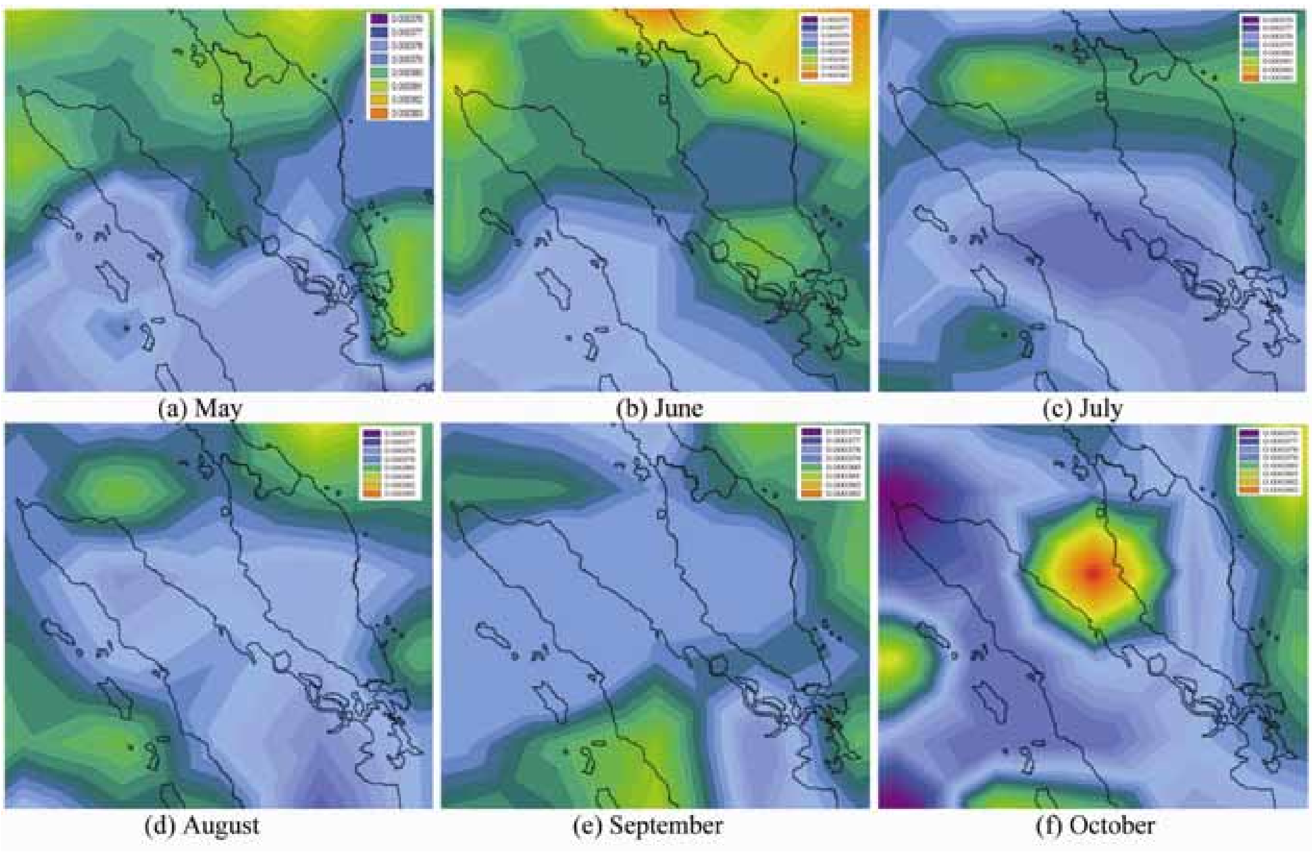

Figure 3. AIRS monthly coverage of mid-tropospheric CO_2, from May to October 2005

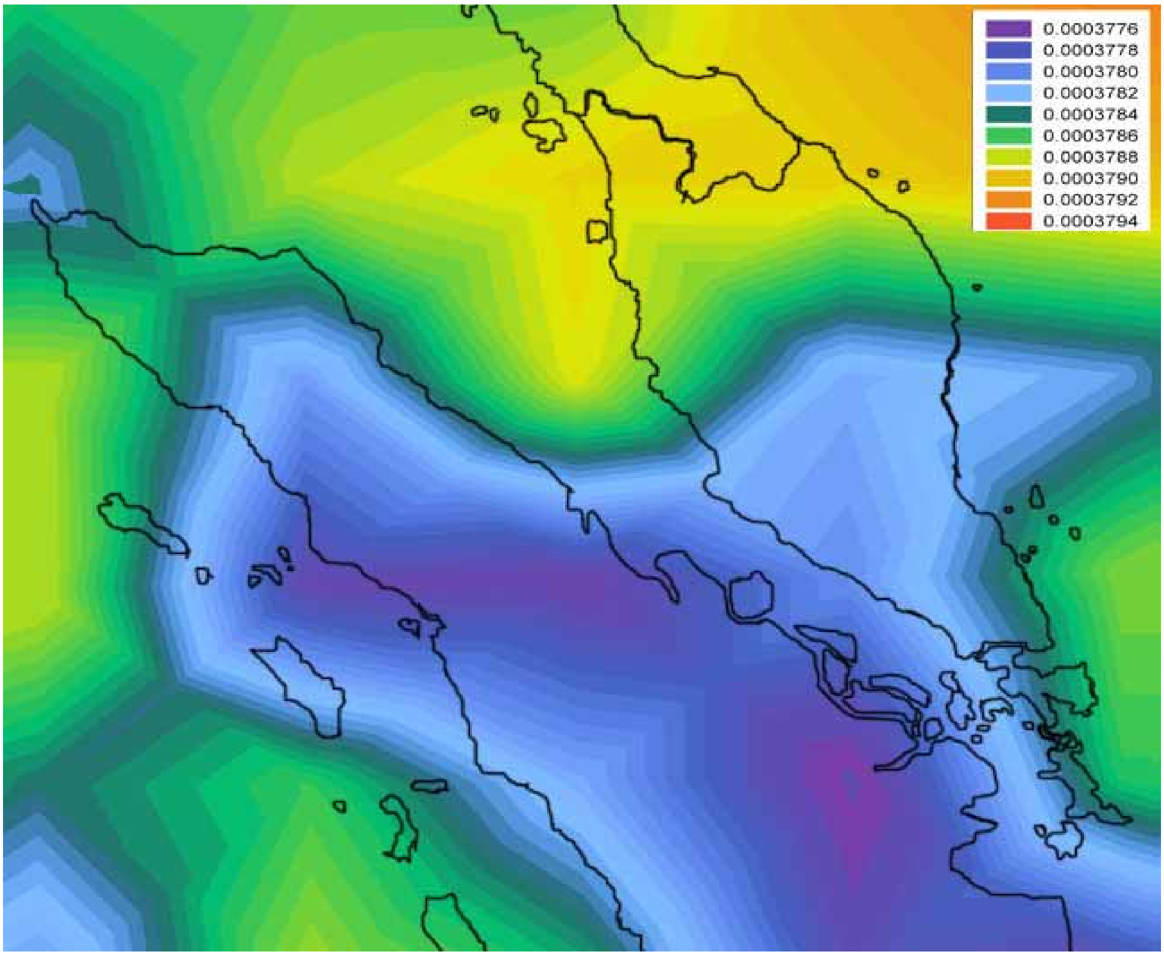

Figure 4. Presents the 2005 average distribution of CO_2

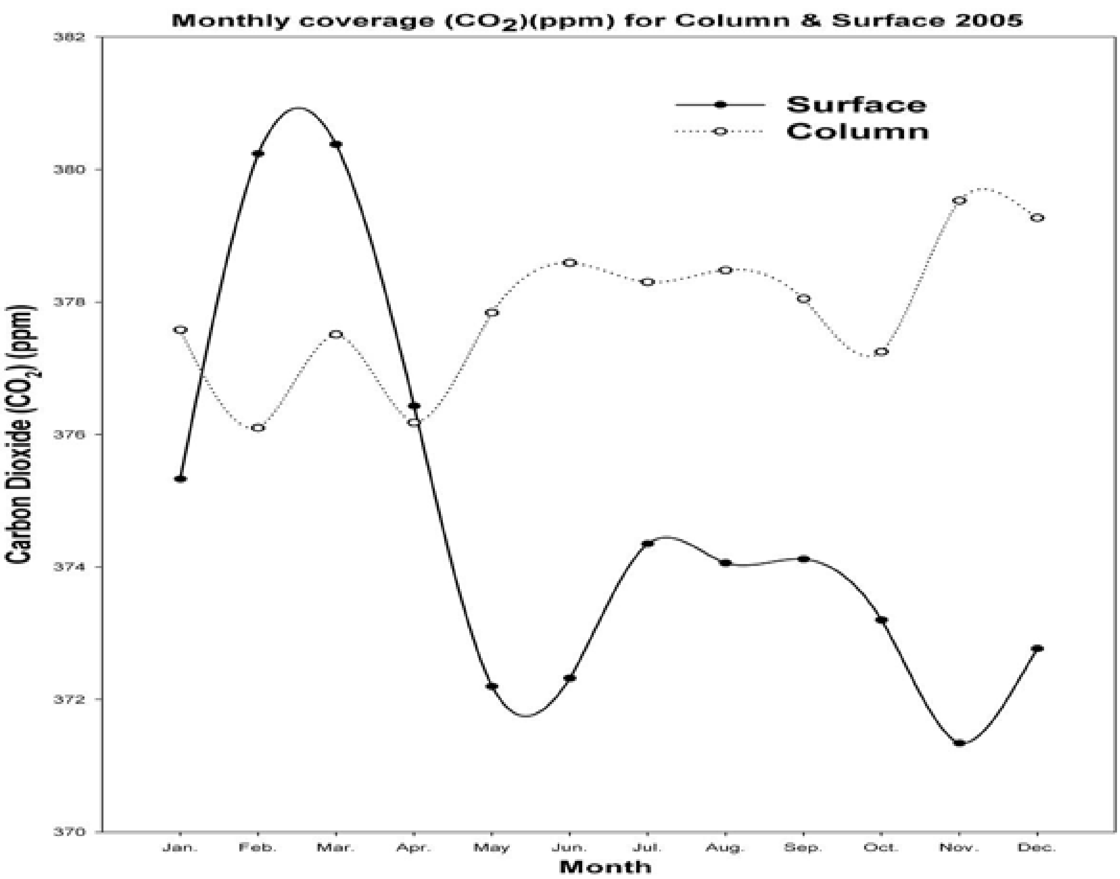

Figure 5. Monthly coverage carbon dioxide (CO2) (ppm) at (100.32 E, 0.20 S) for column from AIRS (dashed line) and Surface (solid line)