Analysis and Validation of AIRS Tropospheric Carbon Dioxide Concentrations

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Abstract

This research aims at investigating the change in tropospheric carbon dioxide levels from 2002 to 2011 by utilizing NASA's Atmospheric Infrared Sounder (AIRS) instrument. Four images were used to demonstrate the change in carbon dioxide over the study period, 2002, 2005, 2009, and 2011. The products were then analyzed in order to calculate the December averages for each year, the amount of radiative forcing produced, and the total change in carbon dioxide concentrations. The results were validated through the acquisition of the Global Atmospheric Watch Program's data provided by the World Meteorological Organization (WMO). Quantitative analysis revealed that the validation of AIRS imagery is poorly correlated with the twenty WMO stations, which resulted in low R^2 values and high RMSE values. The low correlation is likely caused by the difference in data collection methods, and low resolution of the AIRS carbon dioxide product.

Keywords: remote sensing, greenhouse gases, carbon dioxide, AIRS

1. Introduction

Over the last few decades, there has been a major debate over the impacts of greenhouse gases on climate change. This study aims at understanding the relationship between the greenhouse gas, carbon dioxide (CO_2), and its effects on the troposphere. This research also examined the spatial distribution of the CO_2 concentrations on the surface of the Earth. CO_2 is the most abundant greenhouse gas in the atmosphere, and accounts for approximately 85% of all the greenhouse gases emitted by human activity in the United States (National Research Council, 2010). Greenhouse gases trap heat in the lower atmosphere, and as a result increase the amount of radiative forcing. Radiative forcing causes land surface temperatures to rise adversely affect human wellbeing and the environment.

2. Methodology

The purpose of this research is to utilize geospatial technology to investigate the change in global tropospheric carbon dioxide concentrations from 2002 to 2011, and to measure the impacts of increasing CO_2 levels on radiative forcing. Due to the fact that CO_2 is the most plentiful greenhouse gas, and has a lifespan of up to 200 in the atmosphere, it must be monitored rigorously. (Intergovernmental Panel on Climate Change, 2007). Imagery was collected from NASA's AQUA Atmospheric Infrared Sounder instrument (AIRS). AIRS's infrared bands are able to capture the spectral signatures of trace gases, including CO_2, throughout the lowest 11km-16km of the atmosphere. However, AIRS is most accurate at detecting CO_2 in the mid troposphere, which ranges from 4.5km to 9.1km (NASA, 2014). For this research, four AIRS images were collected from four separate years, 2002, 2005, 2009, and 2011. For an accurate comparison, all of the images represent monthly averages of CO_2 during the month of December. The AIRS imagery was validated against data collected from the World Meteorological Organization's (WMO) Global Atmospheric Watch program. CO^2 concentrations were collected from twenty stationary towers around the world (World Data Centre for Greenhouse Gases, 2014). The level of significance and the accuracy were evaluated for the AIRS data through calculating yearly averages, conducting a one to one plot with R^2 values, and annual root-mean-squared error (RMSE). The research also compared the WMO's overall monthly averages (all stations and data available) to the AIRS imagery.

3. Results

In December of 2002, the tropospheric CO_2 concentration was 363.70ppm with an estimated radiative forcing of 1.564W/m². Nine years later in December of 2011, the tropospheric CO_2 levels climbed to 382.69ppm with an estimated radiative forcing of 1.818Wm².Over the course of this study the annual increase was 2.109ppm CO_2 with an annual increase of .0302Wm² radiative forcing. The most dramatic increase occurred in the higher latitudes over Russia and the state of Alaska. The increase in CO_2 is mostly due to human activities and has already increased the radiative forcing of the atmosphere by 17.40%. If trends continue as they are predicted, the increase in both concentration of CO_2 and radiative forcing will continue to cause the atmosphere to warm. The AIRS imagery was validated against the WMO data first by calculating the averages and comparing the data. The average CO_2 concentration of WMO data was 377.23ppm in 2002, 383.97ppm in 2005, 390.97ppm in 2009, and 395.38ppm in 2011. The average CO_2 concentration of the AIRS data was 372.45ppm in 2002, 379.30ppm in 2005, 387.46ppm in 2009, and 391.70 in 2011. Next one to one plots were created with the calculated the R^2 value, 2002 had an R^2 value of 0.0444, 2005 had an R^2 value is 0.2944, 2009 had an R^2 value is 0.2812, and 2011 had an R^2 value is 0.1442. The root-mean-squared error (RMSE) was conducted for each year, 2002, 2005, 2009, and 2011, and the RMSE values were 7.75, 6.72, 6.66, and 6.30 respectively. The overall RMSE was 6.87. The December averages of the entire WMO's data set were 374.78ppm in 2002, 381.22ppm in 2005, 388.42ppm in 2009, and 392.69ppm in 2011. The RMSE of the entire data set compared to the satellite imagery was 1.855 with an R^2 of 0.9998.

The validation of AIRS imagery with the twenty WMO stations is poorly correlated with low R^2 values and high RMSE values. This may be due to the fact that the AIRS imagery has a low resolution of 2.5º by 2.5º, which averages are calculated over a very large area compared to the WMO data collected at a single point. Another important factor associated with the low correlation is the altitude at which the data is collected. The AIRS data is an average of the entire column of air throughout the troposphere, and WMO data is collected only at a specific altitude in the atmosphere. However, when comparing the entire WMO data set to the entire satellite imagery the RMSE was reduced and the R^2 increased significantly. Both of these factors should be investigated further, and higher resolution imagery is needed to make a more accurate comparison of carbon dioxide concentrations in the atmosphere.

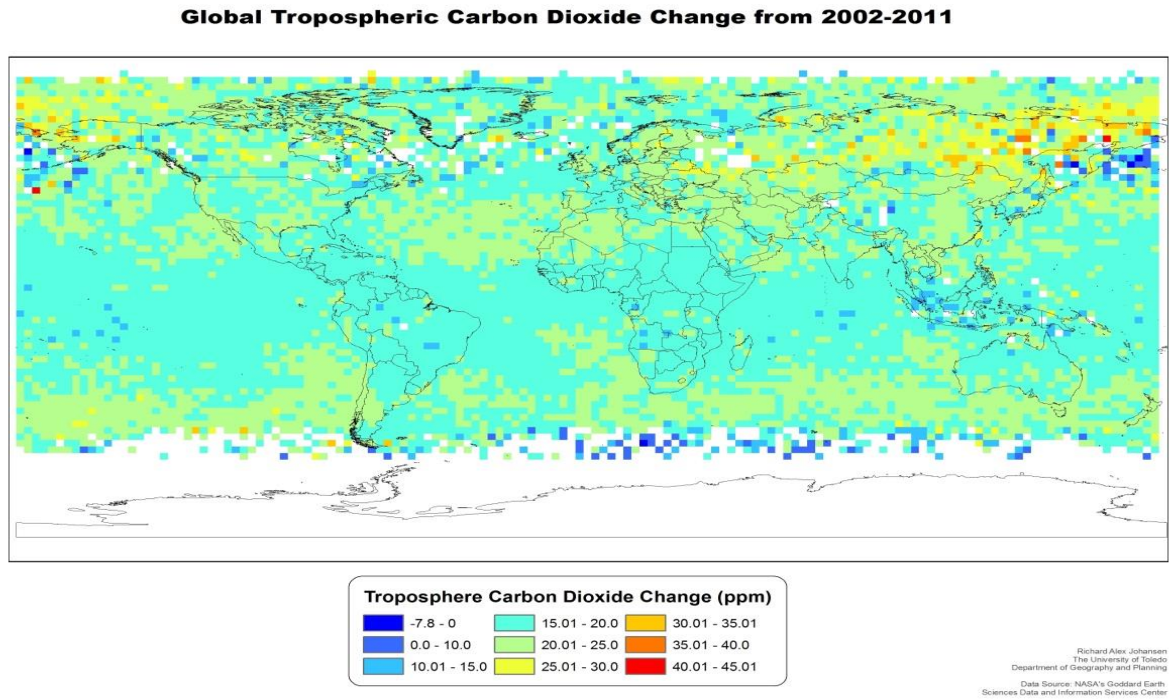

Figure 1: The global change in average December carbon dioxide levels measured in parts per million from 2002-2011.

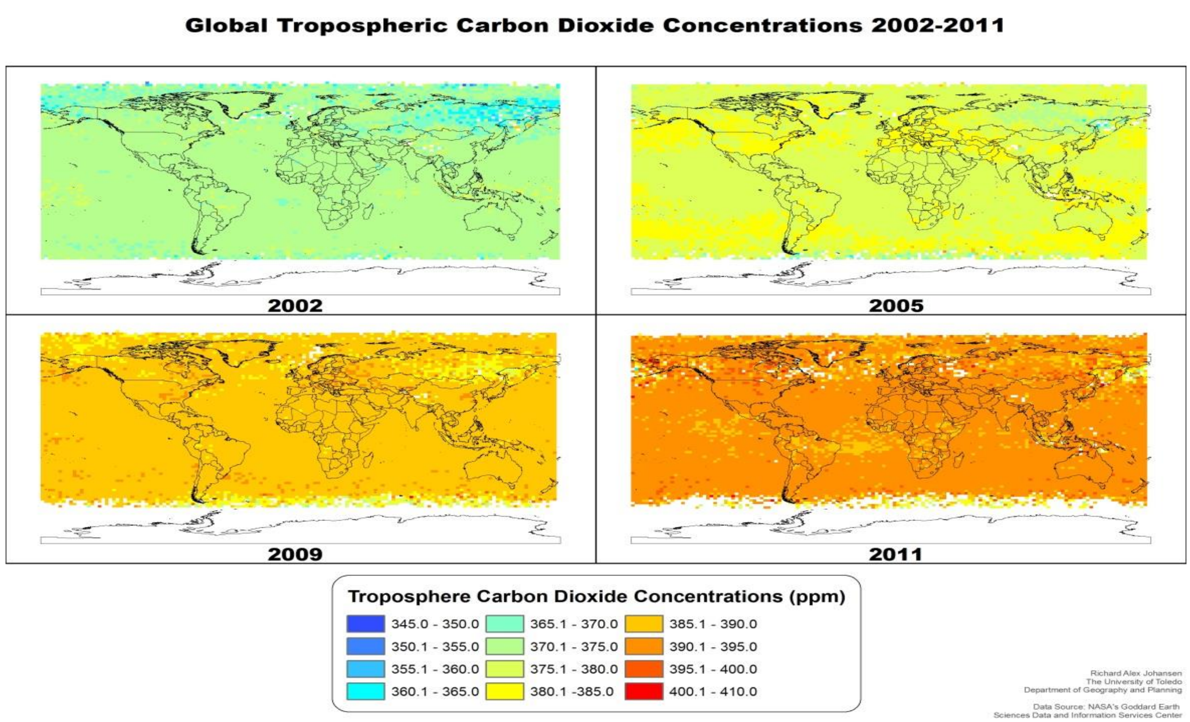

Figure 2: The global average December carbon dioxide concentrations levels measured in parts per million by year.

References

Central Intelligence Agency. (2011). *The World Factbook.* Retrieved from Industrial Growth Rate: https://www.cia.gov/library/publications/the-world-factbook/fields/2089.html#116

Intergovernmental Panel on Climate Change. (2007). *Summary for Policymakers. In Climate Change 2007: The Physical Science Basis.* Cambridge, UK and New York, USA: Cambridge University Press.

NASA. (2014, March 28). *AIRS Carbon Dioxide Data.* Retrieved from AIRS Weather and Climate from Space: http://airs.jpl.nasa.gov/data/get_airs_co2_data/

National Oceanic & Atmospheric Administration. (2013, Summer). *Earth System Research Laboratory Global Monitoring Division*. Retrieved from The NOAA Annual Greenhouse Gas Index (AGGI): http://www.esrl.noaa.gov/gmd/aggi/aggi.html

National Research Council. (2010). *Advancing the Science of Climate Change.* Washington, DC, USA: National Academies Press.

World Data Centre for Greenhouse Gases. (2014, 04 04). *Map Search*. Retrieved from WMO Global Atmosphere Watch: http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/map_search.cgi