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Fusion of multi-source near-surface CO_2 concentration data based on high accuracy surface modeling

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ABSTRACT

Under the background of growing greenhouse gas emissions and the resulting global warming, researches about the spatial-temporal variation analysis of the concentration of carbon dioxide in the regional and global scale has become one of the most important topics in the scientific community. Simulating and analyzing the spatial-temporal variation of the carbon dioxide concentration on a global scale under limited observation data has become one of the key problems to be solved in the research field of spatial analysis technology. A new research approach based on high accuracy surface modeling data fusion (HASM-DF) method was proposed in this paper, in which the output of the CO_2 concentration of the GEOS-Chem model were taken as driving field, and the observation values of CO_2 concentration at ground observation station were taken as accuracy control conditions. The new approach's objective is to fulfill the fusion of the two kinds of CO_2 data, and obtain the distribution of CO_2 on a global scale with a higher accuracy than the results of GEOS-Chem. Root mean square error (RMSE) was chosen as the basic accuracy index, and the experimental analysis shows that the RMSE of the result of the proposed approach is 1.886 ppm, which is significantly lower than that of the GEOS-Chem's 2.239 ppm. Furthermore, compared with the results created by the interpolation methods used the observation values at stations; the fusion results keep a good spatial heterogeneity similar to the results of GEOS-Chem. This research analyzed the spatial distribution and time series variation of the near-surface CO_2 based on the fusion result on a global scale. And it can found that areas such as East Asia, Western North American, Central South America and Central Africa and other region show a relatively high value of the near-surface CO_2 concentration. And we also found that the near-surface CO_2 concentration changes with season, especially in North America and Eurasia, the near-surface CO_2 in summer was significantly lower than winter in these areas.

1. Introduction

The continues growth of carbon dioxide (CO2) in the earth's atmosphere caused a growing absorption of the long wave radiation, and thereby speeding up the process of global warming. This problem has already become one of the most important and far-reaching global environmental problems. Greenhouse gas emission reduction worldwide through optimization of industrial structures and development of new green energy has become the important measure to slow down the process of global warming (Integovernmental Panel on Climate Change, 2007). And accurate simulation of the spatial-temporal variations of the CO2 provide an important foundation for adopting carbon emission reduction policies and refining the evaluation system of CO2 emission reduction effectiveness.

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At present, there many techniques to observe the concentration of CO_2 in the atmosphere. Ground station observation is the traditional method to observe CO_2 concentration, which can obtain CO_2 concentration values with high accuracy. However, the limited observation stations in the worldwide is far from enough to analyze the spatial-temporal variation of the CO_2 concentration at global scale. Retrieval calculation by satellite spectral data can obtain CO_2 concentration of large area rapidly, and has become an important method to observe the CO_2 concentration at global scale. The CO_2 data sets from several satellites which are equipped with related sensors provide sufficient data for scientists to simulate and analyze the variations of the CO_2 concentration at global scale, and a series of meaningful results have been obtained. Relevant scholars (Buchwitz, 2005, 2007; Schneising, 2008) analyzed the spatial pattern of dry-air column averaged mixing ratios of carbon dioxide (XCO_2) cocentration at the global scale and its regularity of perennial variations used the Scanning Imaging Absorption spectrometer for atmospheric Chartography (SCIAMACHY) XCO_2 products; at the same time, the error characteristics of the SCIAMACHY-XCO_2 were discussed. Some scholars (Hammerling et al., 2012) estimated the atmospheric XCO_2 concentration in the global land area and meanwhile discussed the results's uncertainty used the Greenhouse gases observing satellite (GOSAT) XCO_2 products. Regression relations between GOSAT-XCO_2 and Gross Primary Production (GPP) from MODIS project were built in different continents, despite the limited accuracy, these regression relations still indicate that the spatial pattern of XCO_2 cocentration is to follow certain rules at global scale. In addition, lots of researches focussed on the spatial-temporal variation at regional and national scale were carried out, for instance, the seasonal variation of XCO_2 concentration in East Asia and its influence factors were studied (Guo et al., 2012; Shim et al., 2013; Guo et al., 2013; Liu et al., 2012), and the spatial-temporal variation of XCO_2 concentration in China were discussed (Zeng et al., 2013; Xu et al., 2013; Lei et al., 2014). Although these retrieval XCO_2 data paly an important role in the study about the spatial pattern and dynamic change of CO_2 concentration at different scale, its accuracy still need to be improved in order to explore the carbon sources and sinks better.

Atmospheric CO_2 data assimilation is a technology that combined the CO_2 concentration observation data and the atmosphere translation model to simulate the carbon sources/sinks of CO_2 in continents and the ocean (Kaminski et al., 2002). This approach estimates the dynamic change of the carbon sources/sinks by adjust the difference of the observation value and the output of the atmosphere translation to minimize the difference, and it has become one of the most important methods in the carbon cycle fields (Krol et al., 2005; Kaminski et al., 2002; Bousquet et al., 2000). Data assimilation is widely applied to studies about concentration variations of atmospheric trace gases on global scale (Kopacz et al., 2009; Zhang et al., 2009; Walker et al., 2012; Singh et al., 2011). However, studies on CO2 used this method was limited to North America, Europe, and part of Asia because of the model's complexity in principle and input parameters (Peter et al., 2007; Peters et al., 2010; Zhang et al., 2013).

In this paper, HASM-DF is introduced to perform the data fusion of different CO_2 data. For this approach, CO_2 from GEOS-Chem is defined as driving field and it provides approximate initial value at each space position for HASM-DF; CO2 from ground stations are defined as precision control points, and it provides accuracy value at specific position in space; HASM-DF's mission is to merge the driving field and the precision control points, and produce CO_2 distribution in space with accuracy level between the two kinds of CO_2 data. Sufficient tests are performed in order to demonstrate HASM-DF's validity. Besides, this paper also discussed the spatial-temporal variation of the fusion results. The main purpose of this paper is to establish a simple but with high accuracy approach to simulate the CO_2 concentration at global scale.

2. Methods and data

2.1. GEOS-Chem

GEOS-Chem is a global tropospheric chemistry transport model, which is widely used in the researches about atmospheric composition and their dynamic change analysis, such as O_3 (Wu et al., 2007), SO_2 (Lee et al., 2009), CO (Koike et al., 2006) and so on. GEOS-Chem can simulate the change process of different chemical substances in three dimensional spaces over time, and the model is drove by the assimilation of meteorological data produced by Goddard Earth Observing System (GEOS) that affiliated to Global Modeling Assimilation Office (GMAO). GEOS-Chem is mainly composed by emission module, the transmission module and the chemical reaction module, and the version of the GEOS-Chem used in this paper is v9-01-03.

The CO_2 simulation module in GEOS-Chem was first developed by Parv Suntharalingam (Suntharalingam et al., 2004), and then Ray Nassar and B.A. Jones from University of Toronto made important improvement (Nassar et al., 2010). The improved module reserved six kinds of CO_2 flux in the former version, which is fossil fuel, ocean carbon exchange, biomass burning, burning biofuels, terrestrial carbon balance exchange and the net annual terrestrial carbon exchange. At the same time, several other CO_2 sources were included, such as CO_2 emissions from international shipping and air, and the CO_2 oxidized by other atmospheric composition, CO for example. Lots of studies about the CO_2 were performed worldwide based on the GEOS-Chem with CO_2 module, such as influences of different emission sources on the concentration of CO_2 (Feng et al., 2009), effects of human activities on the fluxes of CO_2 (Suntharalingam et al., 2003), and analysis on the characteristics of carbon source/sinks at continent scale (Palmer et al., 2008).

2.2. HASM-DF

A surface is determined by the first and the second fundamental coefficients based on differential geometry. Suppose a surface can be expressed as$z = f(x,y)$, the first fundamental coefficients E,F,G can be expressed as formula (1), and the second fundamental coefficients L, M, N can be expressed as eq. (2).

$$E = 1 + f_x^2, F = f_x \cdot f_y, G = 1 + f_y^2 \quad (1)$$

$$L = \frac{f_{xx}}{\sqrt{1 + f_x^2 + f_y^2}}, M = \frac{f_{xy}}{\sqrt{1 + f_x^2 + f_y^2}}, N = \frac{f_{yy}}{\sqrt{1 + f_x^2 + f_y^2}} \quad (2)$$

In which f_x represents the first order partial derivative of the function $z = f(x,y)$ with respect to x, f_y represents the first order partial derivative with respect to$y$, f_{xx} represents the second order partial derivative with respect to x, f_{yy} represents the second order partial derivative with respect to y, and f_{xy} represents the mixed partial derivative first with respect to x and then with respect to y. The entire derivative can be calculated using finite difference methods (Zhao and Yue, 2012; Zhao et al., 2014).

Partial differential equations of the surface theory require E,F,G,L,M,N to satisfy the following Gauss equations (Somasundaram, 2005; Toponogov, 2006; Yue, 2011):