Temporal and Spatial Variation in Trace Gases and Their Impact on satellite Radiance Data Assimilation

Runhua Yang1, Andrew Collard1, John Derber2, Yu-Tai Hou2

1: IMSG, 2: EMC/NWS/NOAAID

Introduction

For reanalysis problems it is essential to account for the climatological variation in trace gases, because 1) some important sounding bands from AIRS/AMSRs/AMSs are sensitive to trace gases; 2) the variation in the trace gases over the lifetime of some satellites (10-20 years) can be significant.

EMC has started to incorporate 4-5 time dependent fields of CO2 and CH4 into the grid-point Statistical interpolation (GSI) data assimilation system, replacing the previous method of using global constant CO2 and CH4 profiles in simulating satellite radiance data. By taking account of climatological variation in the prescribed input trace gases, we expect to reduce the error in simulating brightness temperature (BT) and further to reduce bias correction in satellite sounding data assimilation. Particularly for climate reanalysis, this method will help to produce more realistic climate signals.

Topics covered in this paper: variability of CO2 and CH4; construction of time dependent 3d monthly mean for GSI use; sensitivity of Community Radiation Transfer Model (CRTM) to changes in the prescribed trace gases, and the impact of changes in trace gases on satellite radiance data assimilation.

Climatological variations in monthly mean CO2 and CH4

Four CO2 data sets:

1. WMO CO2 surface observation (records start from 1750, but the data before 1956 is estimated based on ice core data). A global network for carbon dioxide is given by WMO Greenhouse Gas bulletin

2. CO2 concentration simulated by a state-of-art numerical prediction model GEOS_CCM. The model runs with observation-based climatological CO2 surface source/sink for three years. We consider the last year’s CO2 field as an approximation of climate field. (data source: GMAO/NASA)

3. Free troposphere CO2 concentration derived from AIRS. The peak levels are within the range of 360-400 ppm. Data period covers from Sept. 2002 to Oct. 2010. (data source: GESDIS/CNASA)

4. ECMWF/MAAC reanalysis of the whole column CO2 concentration, covering the period of Jan. 2003-Dec. 2007. (data source: Engleke at ECMWF)

CH4 data sets:

1. ESLB/NOAA MBL/CH4: Only data from sites where the sampled air is representative of large well-mixed marine air are used to construct the data. http://www.esrl.noaa.gov/gmd/ceg/about/global_means.html

2. Simulated by a Chemistry Transport Model (data source: Global Modeling Initiative, GMAO/NCAR/NOAA). Model runs with prescribed surface sources and sinks of available trace gases for 2001-2008. The monthly means of last four years data are considered as climatology.

3. NESDIS/NOAA AIRS retrieval (data source: Xiong at NESDIS)

4. ECMWF CH4 reanalysis (Engleke at ECMWF)

Consensus of CO2 variation across the data sets:

i. Annual trend in global mean: around 1 ppmv averaged in the data period

ii. Strong seasonal variation: larger in winter season and smaller in summer season

iii. Gradient from the South Hemisphere to Northern Hemisphere

iv. Land-ocean contrast

The analysis and comparison of these four data sets are documented at: https://www.emc.ncep.noaa.gov/ge -------------------------------------------------------------------------

Time dependent monthly mean CO2 and CH4 formulation for the GSI

Time dependent climate CO2 data should include the averaged/statistical features in CO2 data/product, since those features are the dominant signals. The vertical structure reflects the role of atmospheric circulation on the transportation of CO2 given surface CO2 sources and sinks prescription.

Similarly we reconstruct the CH4 data for GSI.

Feature of this time-dependent monthly CO2 data (denote as climate_GSI):

(a) A given month of the year, the global mean within the surface layers is the same as the global mean of the WMO surface observation.

(b) The longitude/time structure resembles the consensus features of the various data sets.

(c) The vertical structure is same as in the GCM

Climatological monthly means derived from Clim_GSI (the linear estimated annual trend for the period of 2001-2010 is subtracted). The analysis and comparison of these four data sets are documented at: http://www.esrl.noaa.gov/gmd/ceg/about/global_means.html

Comparison of global means between climate_GSI (top) and WMO observation (bottom). Global annual growth is about 1.9ppmv/y during the period.

Finding is information of climatological annual trend for the period of 2001-2010.

Prescribed CH4 for GSI 201108

Climatological monthly mean derived from Clim_GSI for CH4 (2001-2010). Global mean of Climate-GSI for this selected year is about 1.7 ppmv higher than the reference run is very close to the global mean of Clim-GSI for this selected year.

For AIRS: Left: for CO2 experiment; Right: for CH4 experiment. Top: bias in REF’; Middle and Bottom: Standard deviation in the bias correction between REF and EXP for Sep. and Oct. 2010

Impact of changes in trace gases on satellite data assimilation

For AIRS: Top left figure shows the sensitivity of CRTM BT to changes in CO2 and CH4 profiles (at an analysis time)*

Sensitivity of CRTM to changes in prescribed CO2 and CH4

Sensitivity of BT computed by CRTM due to changes in CO2 shows similar magnitudes as the perturbation tests in selected channels (Moddy, personal communication), typically for 0.5-1 ppmv BT change about 0.01-0.02K with respect to a mean CO2~370 ppmv

Sensitivity channels (e. Moddy: 2005)

For AIRS the most sensitive channels to CO2 (least interference from H2O and O3 etc.) are in the wave number range of 712.41 to 792.10 cm-1.

For UARS 680.71, 791.72 cm-1 ISMF use one out of these channels.

Four parts of each data set: EXP are performed for four cases: Dec. 2010, April 2011, June 2011, Oct. 2010

Figure shows the sensitivity of CRTM BT to this change in CO2 and CH4 profiles (at an analysis time)*

SUMMARY

1. The impact of using the time dependent monthly mean CO2 on satellite data assimilation is neutral or slightly better. The bias correction is considerably smaller than that of the reference run in AIRS and ISMF BT channels. The reduction in bias correction is about 10th of the bias field. The radiance data usage in EXP is slightly higher than in REF run. The small impact is not surprising because the global contribution of the reference run is very close to the global mean of Clim-GSI for this selected year of 2010.

2. For CH4 experiment, the reduction in bias correction is unexpectedly small, probably because most of the CH4 channels are not used in GSI. Further study is needed to infer the impact on those channels when they will be used.

3. Geographical distribution of the differences in BT follows that of changes in input CO2 and CH4. In U2D experimental runs, the differences in BT are comparable to that resulted from the perturbation test in selected sensitivity channels for AIRS and ISMF.

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Figure shows the sensitivity of CRTM BT to changes in CO2 and CH4 profiles (at an analysis time)*