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

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Introduction

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

EMC has started to incorporate 4-D 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 radiance data assimilation. Particularly for climate reanalysis this method will help to produce more realistic climate signals.

Topics covered in this poster: variability of CO2 and CH4; construction of time dependent 3d monthly means for GSI use; sensitivity of Community Radiance 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 CO_2 and CH_4

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 http://www.wmo.int/pages/prog/arep/gaw/ghg/ghgbull06_en.html

(2)CO2 concentration simulated by a state-of-art numerical prediction model GEOS_GCM. 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 6-10 km. Data period covers from Sept. 2002 to Oct. 2010 (data source: GESDISC/NASA).

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

CH4 data sets:

(1) ESRL/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/ccgg/about/global_means.html

(2) Simulated by a Chemistry Transport Model (data source: Global Modeling Initiative, GMICTM,NASA).
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 (Engelen at ECMWF)

Consensus of CO2 variation cross the data sets:

i. Annual trend in global mean: around 1.9ppmv 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 the North Hemisphere
iv. Land-ocean contrast

The analysis and comparison of these four data sets are documented at:
"https: //www.emc.ncep.noaa.gov/gc_wmb/ryang/CO2PLOTS/co2datacomp.htm"

Ch4 variation

i.Annual growth for the period of 1980s to current (except 1999 to 2006, ESRL data)
ii. Seasonal variation is weak compared with CO2 (ESRL and AIRS retrieval)
Iii. Gradient from the Southern Hemisphere to Northern Hemisphere

Time dependent monthly mean CO_2 and CH_4 formulation for the GSI

Time dependent climate CO_2 data should include the averaged/statistical features in CO_2 data/product, since those features are the dominant signals.

Method: To start from zonally mean field, use WMO surface CO_2 observation as the constraint for near surface CO_2 amount and use vertical structure in the GMAO GCM model.
The vertical structure reflects the role of atmospheric circulation on the transportation of CO_2 given surface CO_2 sources and sinks prescription.
Similarly we reconstruct the CH4 data for GSI.

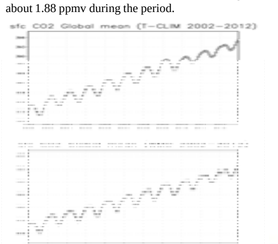
Feature of this time-dependent monthly mean CO_2 data (denote as climate_GSI):

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

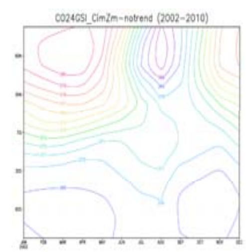
(b) The longitude/time structure resembles the"consensus" features of the various data sets.

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

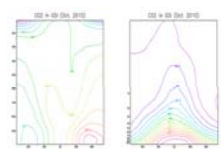
Comparison of global means between climate_GSI (top) and WMO observation (bottom). Global annual growth is about 1.88 ppmv during the period.



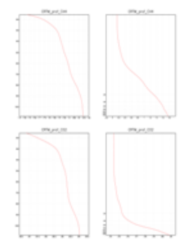
Climatological monthly means derived from Clim_GSI (the linear estimated annual trend for the period of 2002-2010 is subtracted).
typical values:
Max seasonal variation: NH: ~13ppmv; SH: < 3 ppmv
Gradient: max: 11 ppmv at March, 3 ppmv at Aug
Note the gradient reversed during the seasonal transition.



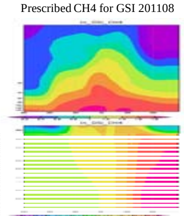
Y-Z plot of climate-GSI for Oct. 2010

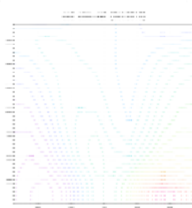


Global mean constant CO2 (top) and CH4 profiles used in the reference run (REF)

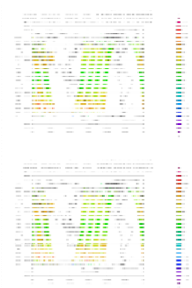


Prescribed CH4 for GSI 201108





Difference between climate_GSI and reference CO2 profile



Differences (*100) in brightness temperature between EXP and REF for AIRS channel 110 (top) and channel 105. Both channel's peak function is around 800mb.

Sensitivity of CRTM to changes in prescribed CO2 and CH4

Sensitivity of BT computed by CRTM due to changes in CO_2 shows similar magnitudes as the perturbation tests in selected channels (Maddy, personal communication), typically

for δCO_2=1 ppmv BT changes about 0.01-0.03K with respect to a mean CO_2= 370 ppmv

Sensitivity channels (E. Maddy, 2007):

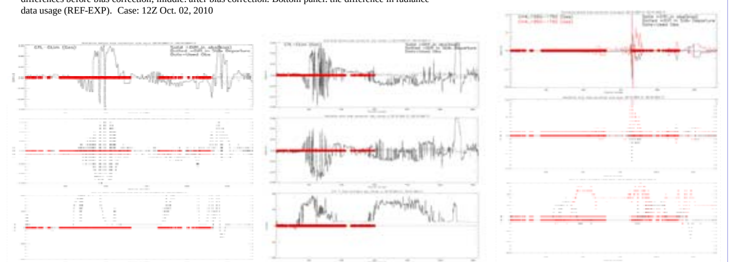
For AIRS the most sensitive channels to CO_2 (least interference from H_2O and O_3 etc) are in the wave number range of 712.45 to 792.10 (cm^{-1}) .
For IASI: 680.75 –791.75 (cm^{-1}) In GSI we use most of these channels.

Four pairs of stand alone GSI runs are performed for four cases: Dec. 2010, April 2011, June 2011, Oct. 2011

Figures show the sensitivity of CRTM BT to the changes in CO_2 and CH_4 profiles (at an analysis time)*

Top two panels: difference in the magnitudes of global mean bias (Solid) and standard deviation (dashed line) between Reference and Experimental runs (REF-EXP). The X-axis is channel number used in GSI (not same as the real instrument channel number), and the Y-axis is Brightness Temperature in K. The red dots denote the channels assimilated in GSI. Left: AIRS instrument; Right: IASI instrument. Top: the differences before bias correction; middle: after bias correction. Bottom panel: the difference in radiance data usage (REF-EXP). Case: 12Z Oct. 02, 2010

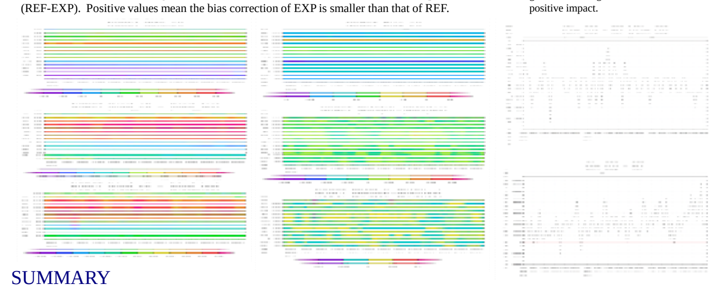
Similar to left figure, but for CH4 sensitivity with two pairs runs: EXP1 CH4=1550, EXP2: CH4=1950 (ppbv). The REF's CH4=1750



Impact of changes in trace gases on satellite data assimilation

For AIRS: Left: for CO2 experiment; Right: for CH4 experiment. Top: bias in REF' Middle and bottom: differences in the magnitude of bias correction between REF and EXP for Sept. and Oct. 2010 (REF-EXP). Positive values mean the bias correction of EXP is smaller than that of REF.

For CO2 experiment: Difference in satellite radiance Jo/n,(top panel) and radiance data usage (bottom) between EXP and REF. Jo/nIs a gross measurement of observation fit to model guess field. Negative values means positive impact.



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 consistently smaller than that of the reference runs in AIRS and IASI IR channels. The reduction in bias correction is about 10[th] 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 constant value of the reference run is very close to the global mean of Climate-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 these channels when they will be used.
3. Geographical distribution of the differences in BT follows that of changes in input CO2 and CH4. In CO2 experimental runs, the differences in BT is comparable with that resulted from the perturbation test in selected sensitivity channels for AIRS and IASI.

Acknowledgement:
Data providers: **WMO** observed CO_2 data; **Steve Pawson** and **Z. Zhu** of GMAO/GSFC NASA; **Suhung Shen** of ESC/GSFC.
R. Engelen of ECMWF; **X. Xiong** of NESDIS, AIRS retrieval,ESRL/NOAA. Thanks to Eric Maddy of NESDIS for providing weighting functions of AIRS and IASI, CO_2 sensitivity bands.