Review of "The 2009–2010 step in atmospheric CO2 inter-hemispheric difference" by R. J. Francey and J. S. Frederiksen (Biogeosciences Discuss., 12, 15087ff, 2015)

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This paper calculated inter-hemispheric gradients (IHG) in CO2 concentrations and ^{13}C-CO_2 isotopes between the Mauna Loa Observatory, Hawaii (MLO) and South Pole Observatory (SPO) / Cape Grim Observatory (CGO). The authors report an interesting step change in 2010 in the CO2 IHGs, and attribute this change to a possible change in inter-hemispheric transport through the so called "the equatorial upper troposphere duct". The idea is certainly interesting and quite well presented and doesn't need minor revision for the paper to be published in Atmos. Chem. Phys. However, I cannot agree fully with the authors that this step change in CO_2 IHG indeed due to a change in dynamics alone. Given below are my lines of argument. Therefore, the paper require a major revision, if any, before it can be published in Atmos. Chem. Phys., unless the authors successfully refute my criticism. I am returning a signed review just in case my contact is useful.

Figure 1 shows the JAMSTEC's ACTM (Patra et al., 2009) simulated CO_2 IHGs in comparison with NOAA measurements at 4 site pairs. ACTM simulations are prepared using repeating seasonal cycle (cyclostationary or CYC for 2008; blue line) and inter-annually varying (IAV, for 2000-2011 and 2011 repeats thereafter; red line) fluxes of the terrestrial biosphere and oceanic exchange (referred to as biosphere). Both model simulations used a common interannually varying fossil fuel (FF) emission. The model meteorology is nudged with the NCEP2 reanalysis horizontal winds and temperature at 6-hourly intervals varying from year to year.

It is clear that MLO minus CGO/SPO IHGs are simulated well when IAV inversion fluxes are used, which indicate that for the given FF emission the biosphere sink has to increase in the northern hemisphere (NH). The FF emissions increased from 8.8 PgC/yr to 9.46 PgC/yr in 2011 and most of this increase occurred in the NH, thus overestimating the MLO-SPO or MLO-CGO IHGs when CYC inversion fluxes are used. No clear differences are found for ALT-MLO gradient suggesting no significant change has taken place between the extra-tropics and the northern high-latitude CO_2 fluxes between the 2008 (CYC) and IAV fluxes, and CO_2 concentration signals is fairly

uniformly distributed in the latitude regions of ALT and MLO. For ALT-SPO gradients, ACTM using IAV fluxes better simulate the observed variabilities than using the CYC fluxes. In summary, the ACTM meteorology and FF emissions are not sufficient to simulate the observed CO_2 gradients without incorporating the variations in biospheric fluxes. It should be reiterated here that these results hold good with an intrinsic assumption that the model transport is accurately represented in ACTM.

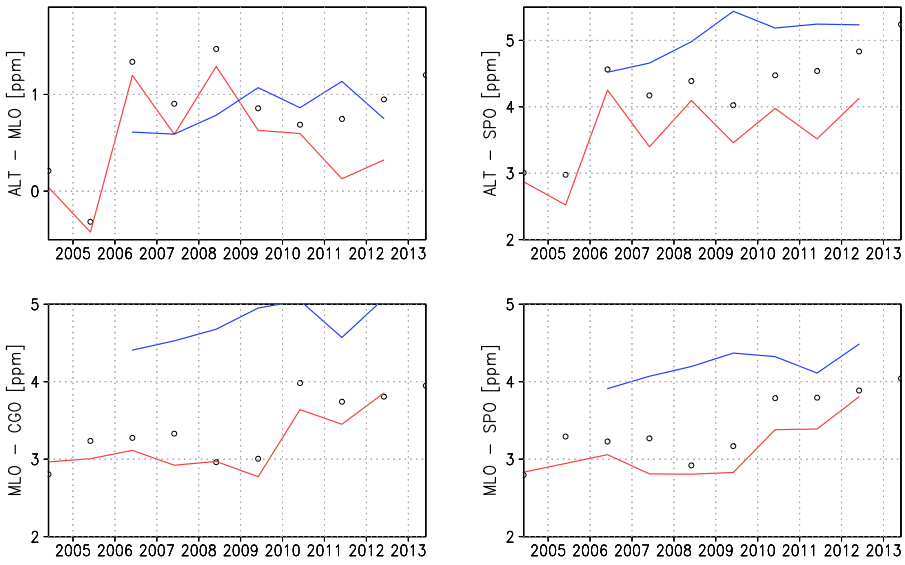

Figure 1: CO_2 inter-site differences as simulated by ACTM using inversion fluxes from Patra et al. (2011) (blue line), and Saeki et al. (in prep.) (red line) and EDGAR42FT2010 fossil fuel emissions (global total emissions scaled to the CDIAC numbers; data sources: http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2010; http://cdiac.ornl.gov/trends/emis/meth_reg.html). The model results are shown in comparison with NOAA measurements (circle) (data source: ftp://aftp.cmdl.noaa.gov/data/trace_gases/co2/flask/surface/).

The authors have used various other chemical species (CH_4, CO, H_2) in support of their argument for a dynamical change. However, the choice of tracers may not be the most appropriate because all these species also have biospheric emission which often covary with those of CO_2, e.g., due to biomass burning, FF consumption. The transport modeling community makes use of SF_6 for diagnosing inter-hemispheric transport (IHT) in models, and ACTM has successfully passed the tests for having quite accurate IHT for simulating long-lived chemical species (Patra et al., 2009, 2013).

Figure 2 shows measured SF_6 concentrations, IHGs, atmospheric growth rate (from NOAA HATS) in comparison with CO_2 IHG for the matching period of 2005-2012 (from

Francey and Frederiksen, 2015). From these plots (bottom-left) it may be suggested that the IHG has speed up after 2009 as the gradients stabilized since about 2009 while the concentrations continued to rise. The IHG of long-lived species SF_6 (chemically inert in the troposphere) is governed mainly by two factors; 1. inter-hemispheric exchange time due to transport, and 2. gradient in hemispheric total emissions (Patra et al., 2014).

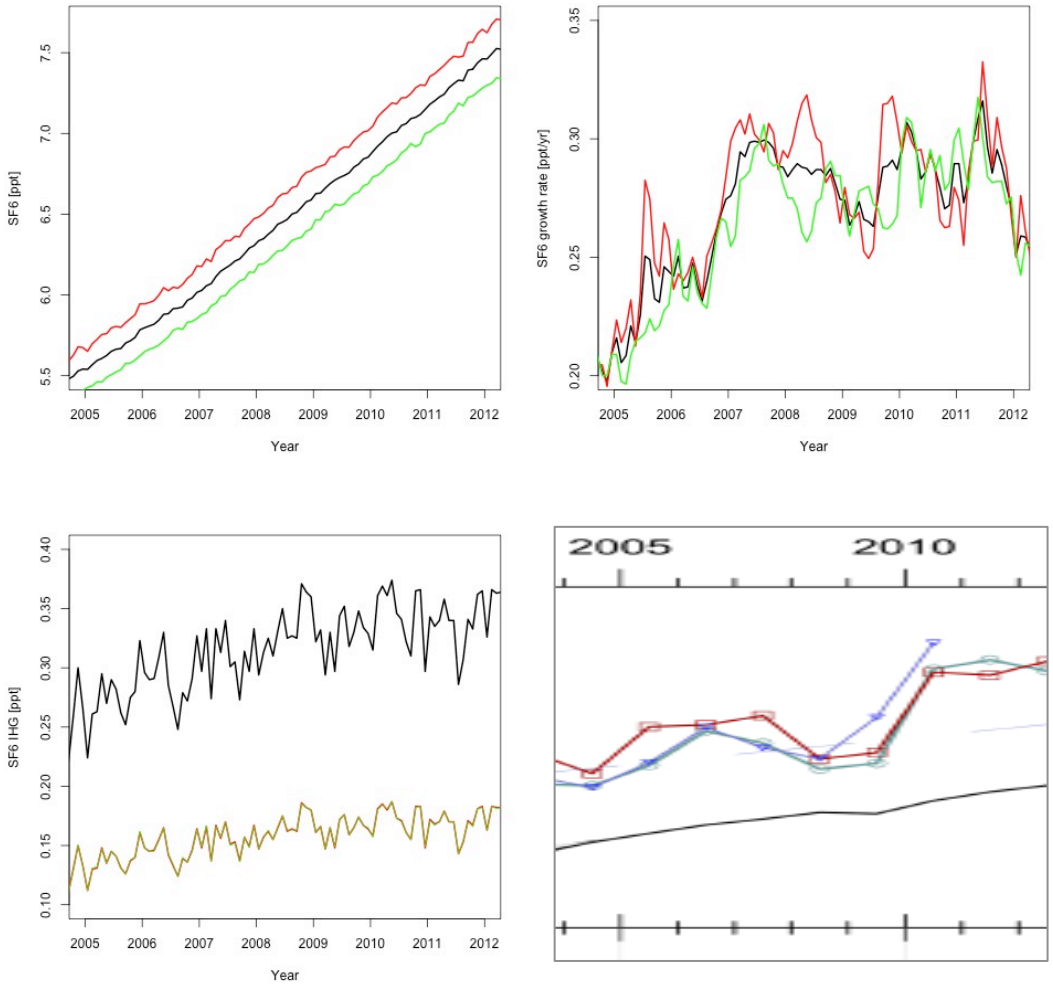

Figure 2: (a, left-top) Sulphur hexafluoride (SF_6) mean concentrations for global (black), northern hemisphere (red) and southern hemisphere (green) as measured by the NOAA Halogen and Other Trace Species (HATS) network (ftp://ftp.cmdl.noaa.gov/hats/sf6/flasks/Otto/global/global_SF6_MM.dat). (b, bottom-left) shows the inter-hemispheric gradient (IHG) in SF_6 as the difference between the NH - SH (black), NH - global and global - SH (green). (c, top-right) SF_6 growth rate in the atmosphere, indicating the global total emission increase. (d, bottom-right) CO_2 IHG (ΔC) as shown in Figure 1a of Francey and Frederiksen (2015) for the period 2005-2012.

Further analysis suggests that the measured SF_6 growth rate in practically stabilized in the atmosphere since about 2007 (Fig. 2c; top-right), which is only possible in case of no increase in the rate of SF_6 release to the atmosphere. Thus it is likely that the step change in CO_2 IHG is more due to a change in CO_2 fluxes. It is well known that the global total fossil fuel CO_2 emissions went down in 2009 compared to 2008, mainly due to the decrease in emissions from the North America and Europe (data source: http://cdiac.ornl.gov/ftp/Global_Carbon_Project/Global_Carbon_Budget_2014_v1.1.xlsx). However, the global total FF CO_2 emission rate returned to the normal pace (244 TgC/yr mean over 2005-2008) with an annual increase of about 280 TgC/yr during 2010-2013. The dip in CO_2 IHG in 2008 and 2009 (Fig. 2d; bottom-right) could have been caused by the temporal decrease/pause in FF emission growth rate.

Finally, it should be possible to check whether the chemistry-transport models transport tracers through the equatorial upper troposphere duct, which I hope will be taken up following publication of this paper. As mentioned earlier SF_6 is an ideal tracer for IH transport, but artificial tracers with different decay time and emissions in different latitude bands can be formulated for identifying transport through the duct at short (e.g., tropical convective) and long (e.g., inter-hemispheric) time scales.

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