Model Analysis of the Factors Regulating the Trends and Variability of Methane, Carbon Monoxide and OH: 1. Model Validation

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Introduction

- Methane (CH_4) is the second most important anthropogenic greenhouse gas (GHG). Its 100-year global warming potential (GWP) is 25 times larger than that for carbon dioxide. The 100-yr integrated GWP of CH_4 is sensitive to changes in OH levels.

- Methane's atmospheric growth rate was estimated to be more than 10 ppb yr^{-1} in 1998 but less than zero in 2001, 2004 and 2005 (Kirschke et al., 2013). Since 2006, the CH_4 is increasing again. This phenomena is yet not well understood.

- Oxidation of CH_4 by OH is the main loss process, thus affecting the oxidizing capacity of the atmosphere and contributing to the global ozone background.

- Current models typically use an annual cycle of offline OH fields to simulate CH_4. The implemented OH fields in these models are typically *tuned* so that simulated CH_4 growth rates match that measured. For future and climate simulations, the OH tuning technique may not be suitable. In addition, running full chemistry, multi-decadal CH_4 simulations is a serious challenge and currently, due to computational intensity, almost impossible.

Aim of this Work

- Develop, implement and validate a computationally-efficient, interactive parameterization of the CH_4-CO-OH system into the NASA GEOS chemistry climate model (CCM).

- Investigate the CH_4,CO and OH temporal and spatial variability and try to shed some light on their variations and trends.

Modelling Approach

NASA GEOS-5 Chemistry Climate Model (CCM, Rienecker et al. (2008), Pawson et al. (2008), Ott et al. (2010), and Molod et al. (2012)**):**

Model simulations:
- CTL_iOH:
  - Simulation Period: 1988-2008
  - Resolution: 2.5°×2° (longitude × latitude)
  - CH_4 Emissions: Transcom (Patra et al., 2011) CTL scenario (partial IAV)
  - Chemistry: full interactive CH_4-CO-OH code. CH_4, CO, and OH tracers are radiatively inactive (i.e., they do not influence the dynamics of the AGCM through radiative forcing. We do this to reproduce the same meteorology in all simulations.

- EXTRA_iOH: Similar to CTL_iOH but using the Transcom EXTRA scenario (full IAV).

- CTL_GMI_offOH: Similar to CTL_iOH but using *offline OH annual cycle* fields from full chemistry chemical transport model simulation, i.e., only CO-CH_4 system is interactive (conditions that are typically used by other models *but without tuning OH*).

Results and Discussion

- **OH zonal mean**
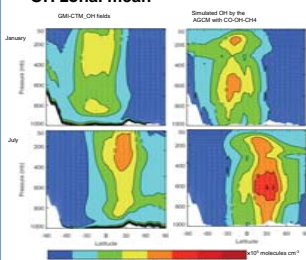
- Simulated OH levels by the GMI are much lower (~17%) compared to the GEOS CCM with the interactive CH_4-CO-OH code.
- Methylchloroform (CH_3CCl_3) global mean lifetime with relative to tropospheric OH:
  - CH_4-CO-OH: 6.1 year (5.5 NH, 6.7 SH) (OH: 0.92 ×10^{6} molecules cm^{-3}).
  - GMI-CTM_OH: 7.1 year (OH: 0.78 ×10^{6} molecules cm^{-3}).
  - Measured (e.g., Khalil and Rasmussen, 1984): 6 (±1.5) year (OH: 0.8 (±0.6) ×10[6] molecules cm^{-3}).
- These low OH offline values lead to higher CH_4 growth rate than observed (see Fig. 2).
- Typically, other models tune the OH levels so that the CH_4 growth rates match that measured.

Fig. 1: Zonal mean of simulated OH (10[6] molecules cm^{-3}) by the full chemistry GMI-CTM model (left) and that simulated by the GEOS CCM model with the CH_4-CO-OH code (right).

Comparison with NOAA ESRL Global Monitoring Division (GMD)

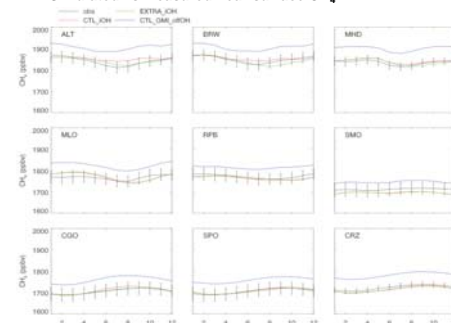- **Simulated vs Measured near-surface CH_4**

Fig. 2: Measured (GMD) and simulated near-surface CH_4 monthly average (1988-2008) for different stations in the northern hemisphere (upper panels, ALT (82N,62W), BRW(71N,156W), MHD (53N, 10W)), tropics (middle panels, MLO (20N, 155W), RPB (13N, 59W), SMO (14S,170W)) and southern hemisphere (bottom panels, CGO (45S, 145E), SPO (90S, 25W), CRZ (46S, 52E)).

- Both interactive OH simulations with CTL (CTL_iOH) and EXTRA (EXTRA_iOH) scenarios compare well. EXTRA scenario is doing better in the northern hemisphere, which is due to the full inter-annual variability (IAV) of the implemented CH_4 emissions.
- Offline annual OH cycle (CTL_GMI_offOH) simulations significantly overestimate CH_4 growth rates (low OH), due to the too low OH levels (see Fig.1).

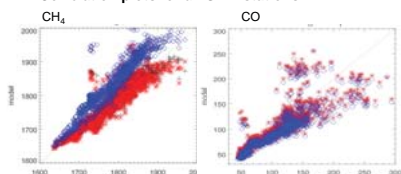- **Correlation plots for all GMD stations**

Fig. 3: correlation plots for mean annual measured and simulated CH_4 (left) and CO (right) for all GMD stations.

- CTL_iOH
- EXTRA_iOH
- CTL_GMI_offOH

- Simulated surface CH_4 levels using interactive CH_4-CO-OH code (X_iOH) compares well to GMD measurements.
- Simulated surface CO levels compare well to GMD measurements. Some points (to be investigated).
- Simulation using annual offline OH cycle (CTL_GMI_offOH) tends to overestimate CH_4 and underestimate CO, due to the very low OH levels.
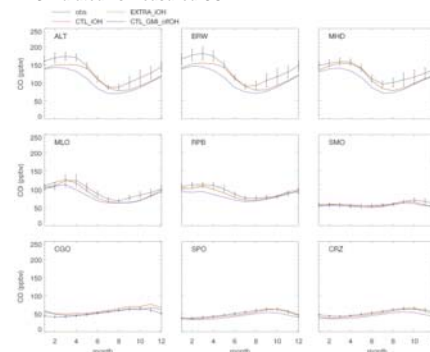
- **Simulated vs Measured CO**

Fig. 4: Same as Fig. 2 but for CO.

- Simulated surface CO monthly mean (1988-2008) using interactive CH_4-CO-OH code (X_iOH) compares well to most of the GMD measurement stations, except NH high-latitude values are biased low..
- Simulations using annual offline OH cycle (CTL_GMI_offOH) tends generally to underestimate CO.

Comparison with ENVISAT Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY).

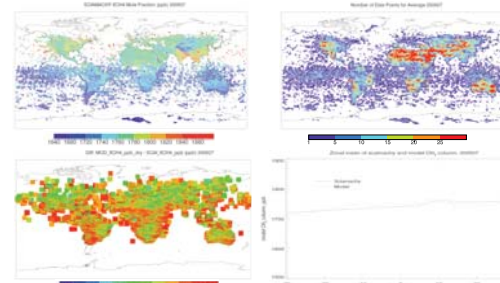- **Simulated vs Measured CH_4**

Fig. 5: Column averaged dry air mole fractions (ppbv) of SCIAMACHY data (upper left) and the number of data points averaged for July, 2005 (upper right). The difference between the model (CTL_iOH scenario) and the sciamachy data is shown In the bottom panel (left), while the monthly zonal mean of both model and sciamachy is shown in the bottom panel (right).

- Simulated CH_4 column with GEOS CCM model with CH_4-CO-OH code (CTL_iOH) compare reasonably well.

- **Seasonal distribution**

2008, April | July | October
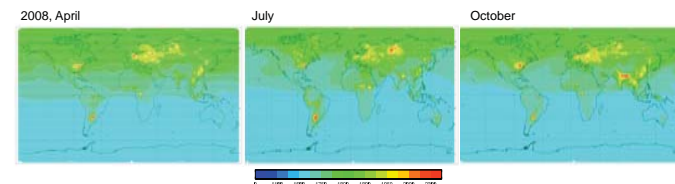
- October: CH_4 production from energy, rice production and wetlands is apparent.
- July: CH_4 production from biomass burning and wetlands is also apparent.
- April: CH_4 production from biomass burning, energy, wetlands and other sources.

- CH_4 seasonal distribution seems to be well simulated with the CH_4-CO-OH code.

Conclusion

- Simulated CH_4 levels using the CH_4-CO-OH system compare reasonably well with GMD ground-based measurements and SCIAMACHY satellite data.
- Simulated CO levels compare reasonably well with GMD ground-based data.
- Seasonal distribution of simulated CH_4 seems reasonable.

Future and on-going work

- The computationally-efficient CH_4-CO-OH code will allow us to run 1980-2050 simulations as well as perform the necessary sensitivity runs to investigate the CO, OH and CH_4 trends and variability.
- We will also implement online emissions for biomass burning, anthropogenic emissions as well as interactive wetland emission parameterization (Walter et al., 2001).

References

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