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Model simulations of atmospheric methane and their evaluation using AGAGE/NOAA surface- and IAGOS-CARIBIC airborne observations, 1997-2014

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The concentration of the atmospheric greenhouse gas methane (CH4) has been growing by about 1%/yr since the beginning of the Anthropocene in the 19th century and its climate forcing potential is estimated at ∼35% of that of CO_2. In this study the global CH4 budget and trends have been simulated with the ECHAM/MESSy Atmospheric Chemistry (EMAC) model for the period 1997-2014, distinguishing eleven CH4 source categories and applying atmospheric chemical and soil microbial sinks. Simulated CH4 has been compared to observations from five AGAGE and NOAA surface stations and 327 intercontinental CARIBIC flights. Source segregated simulation results have been optimized to the station records, especially with respect to the interhemispheric CH4-gradient (ΔNS).

Simulating inter-annually constant sources and sinks reproduces the observations during the no-methane-trend period from 1997-2006 in magnitude as well as seasonal and synoptic variability. The measured average all station CH4 mixing-ratio of 1.789ppmv is approximated within a root mean square deviation range (RMS) of 9.6ppbv, and the corresponding coefficient of determination R2=0.83 implies that 83% of the observed variability is explained by the model. Tagged simulations with eleven source categories were carried out to analyze global CH4 observations and derive steady state lifetimes for the different sources.

The atmospheric CH4 abundance is linearly dependent on the source strengths, which allows an a posteriori rescaling of individual emissions with proportional effects on the corresponding inventories. Under the condition to reproduce the observed ΔNS, Amazon wetland emissions have been enhanced by about 34Tg/y with a corresponding reduction of anthropogenic fossil CH4 emissions. As a result, the model exactly fits the observed ΔNS of 119.3ppbv and the RMS improves by 5.2% .

The 95 intercontinental CARIBIC flight data for the no-trend period up to 2007 are accurately reproduced by the model. The 740 air samples were mostly taken during northern hemispheric flights at ∼10km altitude near the tropopause. The average CH4 -volume mixing-ratio of 1785.36 ppbv is simulated by the model within a 1.1% RMS deviation range and with R2=0.64.

To explain the renewed growth of CH4 since 2007, a 30Tg/yr larger global CH4 emission needed to be assumed. Two additional tagged sources, one representing natural emissions from wetlands in the Amazon and the other anthropogenic shale gas production emissions in North America, have been invoked to investigate their role in the CH4 trend. A comparable contribution by both sources explains the observed ΔNS, e.g. 122.6ppbv in 2013. Based on linear optimization a 55% contribution of the 30Tg/yr emission increase is assigned to Amazon wetlands and 45% to the northern American shale gas sources. The all station average RMS of 7.1ppbv and the corresponding R2=0.91 indicate even better agreement than the no-trend results.

The 4287 samples collected at 232 CARIBIC flights after 2007 provide a comprehensive statistical data base, and the simulation average with an RMS=1.3% and R2=0.8 indicate that the model accurately reproduces observed CH4 near the tropopause.