A discussion on the current status of CH$_4$ regional numerical models

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Outline

- Background
- Observational studies of CH₄
- Modeling studies of CH₄
- My work
Background

- CH₄ is the 2nd most important anthropogenic greenhouse gas after CO₂. And the global warming potential of CH₄ is 25 times that of CO₂. Lifetime for methane is 12 years (IPCC, 2007).

- The global mixing ratios of CH₄ in the atmosphere have been increasing more than doubled since the pre-industrial period, rising from around 750 ppb in 1800 (Simpson et al., 2002; Dlugokencky et al., 2003) to the current level of around 1825 ppb (WMO, 2011).

Methane sources

- **Natural sources**
  - Wetlands: 100–231 Tg/a
  - Termites: 20–29
  - Oceans: 4–15
  - Hydrates: 4–5
  - Geological sources: 4–14
  - Wild animals: 15
  - Wildfires: 2–5

- **Anthropogenic sources**
  - Energy & industry (fossil fuels): 74–106
  - Landfills & waste: 35–69
  - Ruminants: 76–92
  - Rice agriculture: 31–112
  - Biomass burning: 14–88

- **Total sources**
  - 503–610 Tg/a

Methane sinks

- **Sinks**
  - Tropospheric OH
    - 428–507
  - Stratosphere (OH, Cl, O1D, hv)
    - 30–45
  - Soils
    - 26–43

- CO2: No chemistry
- CH4: Reaction with OH

IPCC, 2007
Methane oxidation mechanism in troposphere

The mechanism for oxidation of CH$_4$ involves many steps and very complicate.

\[ CH_4 + OH \rightarrow CH_3 + H_2O \]
\[ CH_3 + O_2 + M \rightarrow CH_3O_2 + M \]

\[ CH_3O_2 + HO_2 \rightarrow CH_3OOH + O_2 \]
\[ CH_3O_2 + NO \rightarrow CH_3O + NO_2 \]

\[ CH_3OOH + OH \rightarrow CH_2O + OH + H_2O \]
\[ CH_3OOH + OH \rightarrow CH_3O_2 + H_2O \]
\[ CH_3OOH + h\nu \rightarrow CH_3O + OH \]

\[ CH_3O + O_2 \rightarrow CH_2O + HO_2 \]
\[ CH_2O + OH \rightarrow CHO + H_2O \]
\[ CH_2O + h\nu \rightarrow CHO + HO_2 \]
\[ CH_2O + O_2 \rightarrow CO + H_2 \]
\[ CHO + O_2 \rightarrow CO + HO_2 \]

In this overall reaction sequence the C(-IV) atom in CH$_4$ (the lowest oxidation state for carbon) is successively oxidized to C(-II) in CH$_3$OOH, C(0) in CH$_2$O, C(+II) in CO, and C(+IV) in CO$_2$ (highest oxidation state for carbon).
Observational studies of CH$_4$

- Surface stations.
- Airborne measurement.
- Satellite measurement.
  - Mid-IR(IASI, TES, AIRS)
  - Near-IR(GOSAT, SCIAMACHY)

Fig. 1 The GAW global network for carbon dioxide. There is a similar network for methane.

- Yale-NUIST Center for AE: CH$_4$ measurements at Lake Taihu (MLW) and NUIST Campus (using PICARRO) since 2012.
Fig. 2 Globally averaged CH$_4$ mole fraction (a) and its growth rate (b) from 1984 to 2011. Annually averaged growth rate
(from 2011 WMO GHG bulletin)

Fig. 3 CH$_4$ Retrievals from GOSAT (Hartmut Boesch et al 2010)

What causes the variability?
What pattern does CH$_4$ look like over the Yangtze River Delta region?
◆ Modeling studies of CH$_4$

• Global models for CH$_4$
  □ TM5: Global chemistry- transport model 5
  □ GEOS-Chem: Goddard Earth Observing System-Chemistry transport model
  □ MOZART: Model for Ozone And Related chemical Tracers

• These global models include many chemistry mechanism, but it simulates CH$_4$ with relatively simple chemistry. In WRF-GHG, CH$_4$ transported online in a passive way (i.e. without any chemical reaction).

• Global models have coarse resolution compared to regional models, That can't reflect the sub grid meteorological characteristics. A model inter-comparison study over Europe suggested, that the fine-scale features are better resolved at the increased horizontal resolutions (Geels et al., 2007).
Table 1 Comparison between three global model for CH₄

<table>
<thead>
<tr>
<th>Model</th>
<th>Meteorology</th>
<th>Horizontal resolution (°)</th>
<th>Vertical layers</th>
<th>Anthro. emissions</th>
<th>Biomass burning</th>
<th>wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM5</td>
<td>ECMWF ERA interim</td>
<td>6×4 (1×1)</td>
<td>25 (60)</td>
<td>EDGAR V4.0</td>
<td>GFEDv2</td>
<td>‘JK’ or ‘BW’</td>
</tr>
<tr>
<td>GEOS-Chem</td>
<td>GEOS-5 analyzed meteorological data</td>
<td>2×2.5 (can reach 0.5×0.67)</td>
<td>47 (72)</td>
<td>EDGAR V4.0</td>
<td>GFEDv2</td>
<td>Kaplan</td>
</tr>
<tr>
<td>MOZART</td>
<td>NCEP</td>
<td>2.8×2.8 (can reach 0.7×0.7)</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bergamaschi et al. (2005) used TM5 model to estimate national level emissions for Europe. They found that emissions reported by some nations to the UN Framework Convention on Climate Change (UNFCCC) were underestimated by 50–90% compared with the model inversion.

Bergamsachi et al. (2010) used inversion modeling method, and found that anthropogenic emissions of \( \text{CH}_4 \) from northwest Europe were 40% greater than the values reported to the UNFCCC during the period 2001–2006. This is a significant discrepancy and emphasizes the need for verification of emissions.

C. A. Pickett-Heaps et al. (2011) used the GEOS-Chem model quantify the HBL(Canada) methane emissions found that the model only reproduces well the observations in summer and estimate methane emissions is several-fold higher than previous estimates.
Fig. 4 (a) TES Tropospheric CH₄ estimates. The TES estimates have been reduced by 26.3 ppb.
(b) Corresponding GEOS-Chem CH₄ estimates, adjusted with the TES instrument operator.
(c) Difference between TES and GEOS-Chem

Regional model: WRF-GHG for CH$_4$

Global model TM5 or GEOS-chem

Chem.ICS/LBCs

Prep_sources_chem

Anthropogenic (EDGAR V4.2 ) and Natural emissions (Kaplan inventory, termite, soil uptake, vegetation)

WPS preprocess

Real.exe
Met. ICS/LBCs

WRF-Chem

Chemical transport module

verification

NCEP or ECMWF data and Surface param.

Observational data
Online calculated fluxes

- CH₄ fluxes from wetland: Kaplan inventory

  Kaplan wetland inventory is based on a diagnostic approach to determine CH₄ emissions from wetlands as a percentage of the heterotrophic respiration. In addition, an external carbon pool (from LPJ model [Sitch et al., 2003]) and a wetland map are necessary input fields.

  \[
  k_r = \frac{1}{\tau_0} \cdot g(T) \cdot f_{SM} \\
  f_{SM} = 0.25 + 0.75 \cdot \frac{sm}{sm_{sat}} \\
  g(T) = \exp \left(308.56 \cdot \left(\frac{1}{56.02} - \frac{1}{T + 46.01}\right)\right)
  \]

  \(k_r\) is carbon decomposition rate; \(\tau_0\) is a factor accounting for the turnover time of the fast carbon pool; \(f_{SM}\) is soil moisture factor; \(sm\) is the mean value of the first two layers of the WRF model; \(sm_{sat}\) is the saturation value of the soil moisture depending on the soil type; \(g(T)\) is temperature dependence.
- **Termite CH$_4$ fluxes**: use the termite database of *Sanderson*(1996) based on WRF-Chem vegetation types.

- **Soil uptake CH$_4$ fluxes**: the soil uptake model developed by *Ridgwell et al*(1999). Meteorological drivers including soil moisture, precipitation and potential evaporation from WRF-Chem.

- **CH$_4$ flux from vegetation**: in WRF-GHG a CH$_4$ vegetation source has been implemented for hypothesis testing. Using the values of GEE and RESP from VPRM model to calculate emissions.

More details please see WRF-GHG tech. report
External fluxes data sets

- **Biomass burning emissions for CH$_4$:** calculated as daily emissions based on satellite fire spots by a WRF-Chem preprocessor (*Prep_chem_sources*) developed by Karla Longo and Saulo Freitas.

- **Anthropogenic emissions for CH$_4$:** Emission Database for Global Atmospheric Research (EDGARv4) and data from the Reanalysis of the TROpospheric chemical composition (RETRO).

- **CH$_4$ fluxes from wetlands-Walter model:** It is a process-based model to calculate CH$_4$ emissions from wetlands. *more details please see Walter et al., 1996, 2000, 2001.*
Fig. 5 Comparison of observed CH₄ mixing ratios (a1,b1) to the WRF simulated CH₄ concentrations (a2,b2) in vertical cross-sections along the flight path of the airplane for two flights in the Amazon region during the BARCA project. The grey lines denotes the vertical “path” of the airplane flown, where the mixing ratios have been measured. The observations are interpolated in the same way as the WRF-GHG results which had been extracted along the flight path of the airplane. CH₄ concentration is indicated by the color scale.

Fig. 6 Extracted tagged tracer for different CH$_4$ emission processes along the flight path for two flights in the Amazon during the BARCA project.

End of the dry season

End of the wet season

My work

- To set up the WRF/GHG simulations over the Yangtze River Delta region.

- To investigate the impact of land-use and land-cover change, especially wetland change on atmospheric CH₄ concentrations over the YRD region over the past decades.

- To examine the impact of anthropogenic emission changes on CH₄.
What should I do

- Learning WRF first, then WRF-Chem, last WRF-GHG, through class and user’s guide. Can run some simple cases.

- To check the CH$_4$ data we need (from Carbon Tracker, EDGAR) and analysis the data we measure from PICARRO.

- Learn to draw graph by NCL. (http://www.ncl.ucar.edu/Applications/)

- Continue literature reading about CH$_4$ modeling.
Thank You!