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A discussion on the current status of CH_4 regional numerical models

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◆Outline

- Background
- Observational studies of CH_4
- Modeling studies of CH_4
- My work

◆Background

- CH_4 is the 2nd most important anthropogenic greenhouse gas after CO_2. And the global warming potential of CH_4 is 25 times that of CO_2. Lifetime for methane is 12 years (*IPCC,2007*).

- The global mixing ratios of CH_4 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*).

- Based on data in EPA's Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases report, in 2005, China's estimated anthropogenic methane emissions ranked 1st in the world. (*http://www.globalmethane.org/partners/china.aspx*)

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Methane sources

- **Natural sources** **145–260 Tg/a**
  - Wetlands 100–231
  - Termites 20–29
  - Oceans 4–15
  - Hydrates 4–5
  - Geological sources 4–14
  - Wild animals 15
  - Wildfires 2–5

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- **Anthropogenic sources** **264–428 Tg/a**
  - Energy & industry (fossil fuels) 74–106
  - Landfills & waste 35–69
  - Ruminants 76–92
  - Rice agriculture 31–112
  - Biomass burning 14–88

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- **Total sources** **503–610 Tg/a**

Methane sinks

- **Sinks** **492–577 Tg/a**
  - Tropospheric OH 428–507
  - Stratosphere (OH, Cl, O^1D, $h\nu$) 30–45
  - Soils 26–43

IPCC,2007

CO_2: No chemistry

CH_4: Reaction with OH

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●Methane oxidation mechanism in troposphere

- The mechanism for oxidation of CH_4 involves many steps and very complicate.

$$CH_4 + OH \rightarrow CH_3 + H_2O$$
$$CH_3 + O_2 + M \rightarrow CH_3O_2 + M$$

$$CH_3O_2 + HO_2 \rightarrow CH_3OOH + O_2$$
$$CH_3O_2 + NO \rightarrow CH_3O + NO_2$$

$$CH_3OOH + OH \rightarrow CH_2O + OH + H_2O$$
$$CH_3OOH + OH \rightarrow CH_3O_2 + H_2O$$
$$CH_3OOH + h\nu \rightarrow CH_3O + OH$$

$$CH_3O + O_2 \rightarrow CH_2O + HO_2$$

$$CH_2O + OH \rightarrow CHO + H_2O$$
$$CH_2O + h\nu \xrightarrow{O_2} CHO + HO_2$$
$$CH_2O + h\nu \rightarrow CO + H_2$$

$$CHO + O_2 \rightarrow CO + HO_2$$

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 CH3OOH, C(0) in CH_2O, 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)

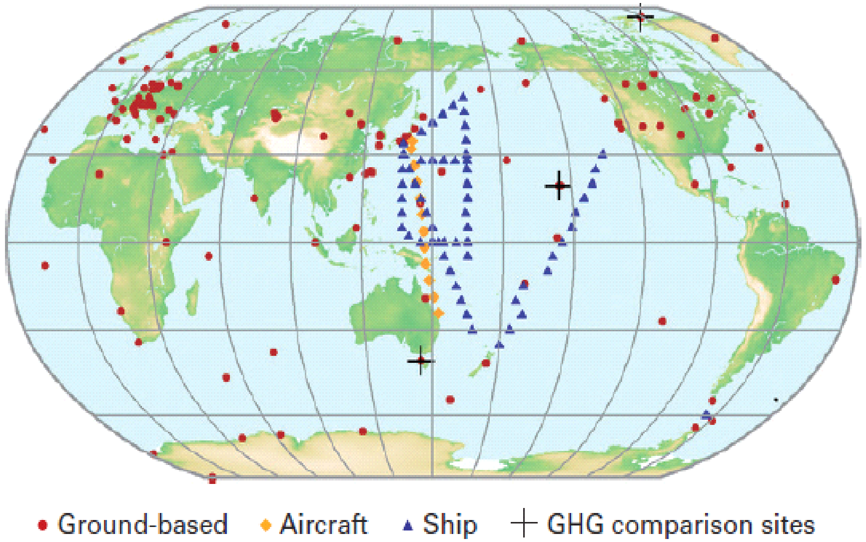

Fig.1 The GAW global network for carbon dioxide. There is a similar network for methane.

➤ Yale-NUIST Center for AE: CH_4 measurements at Lake Taihu (MLW) and NUIST Campus (using PICARRO) since 2012.

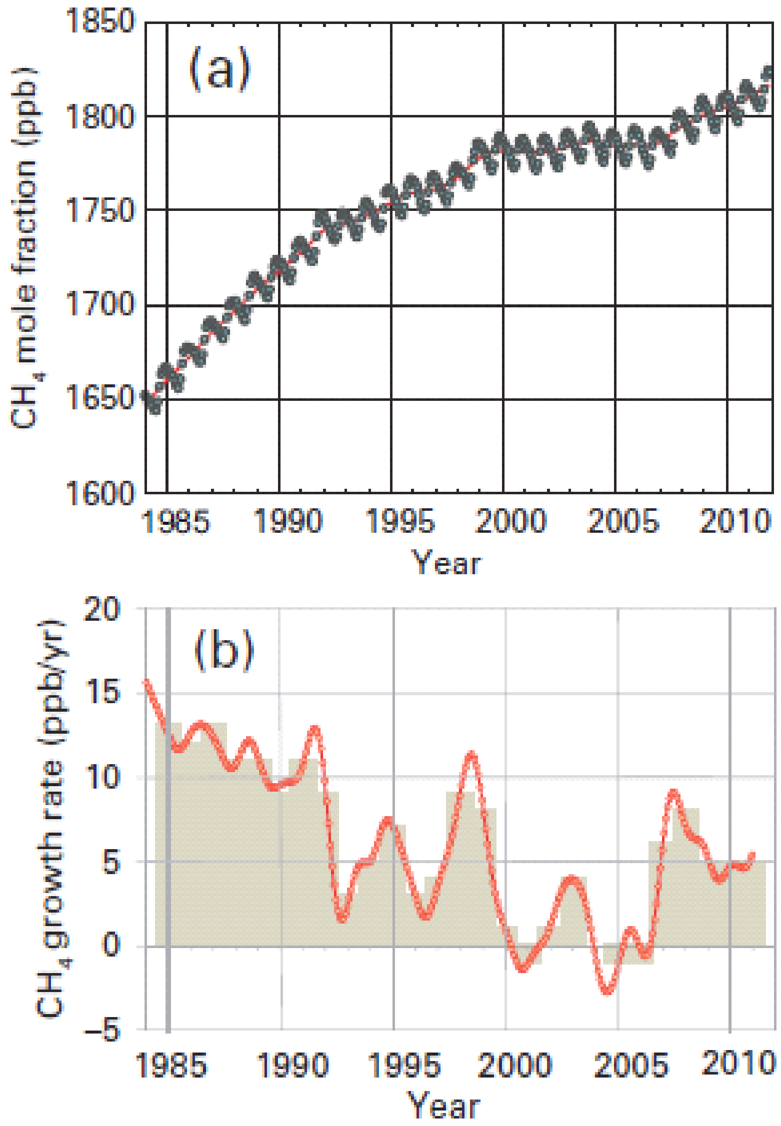

Fig.2 Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2011. Annually averaged growth rate

(from 2011 WMO GHG bulletin)

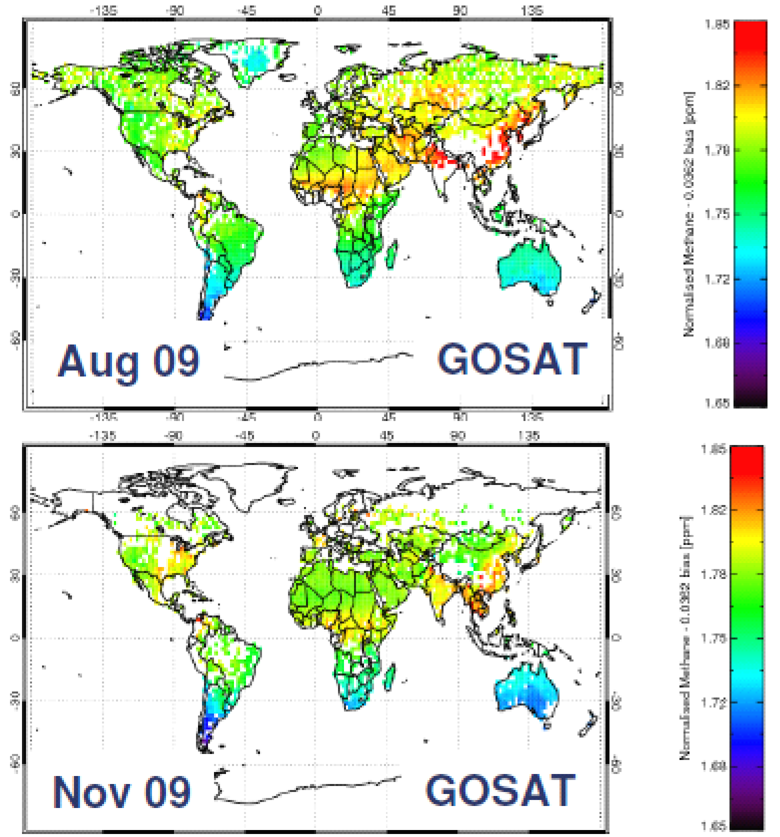

Fig.3 CH_4 Retrievals from GOSAT
(*Hartmut Boesch et al 2010*)

What causes the variability?

What pattern does CH_4 look like over the Yangtze River Delta region?

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◆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*).

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Table.1 Comparison between three global model for CH_4

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

Data from P.Bergamaschi,.et al,2005,2007,2010; L.Emmons,.et al,2010; Pickett-Heaps et al. (2011).

- *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 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.

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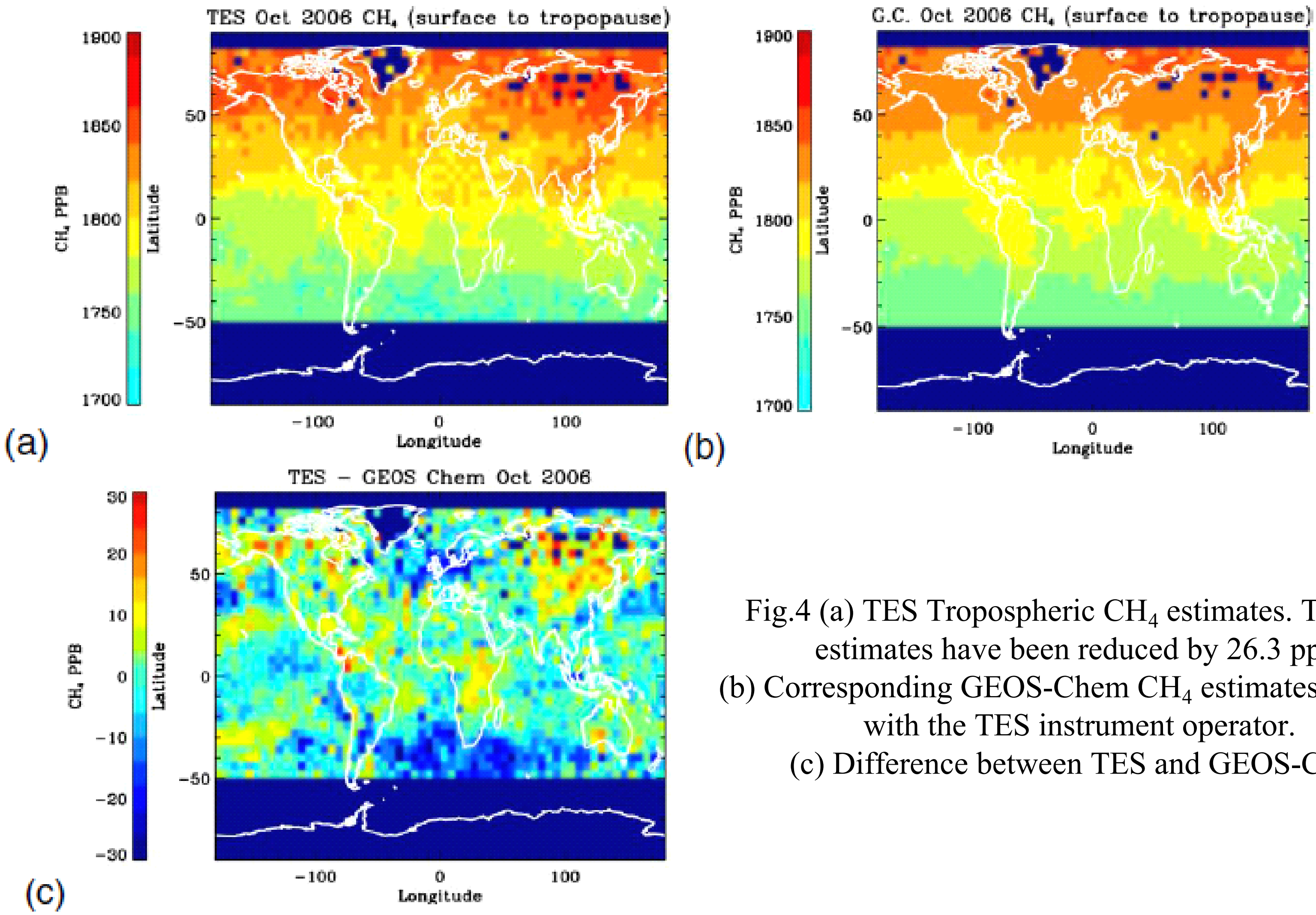

Fig.4 (a) TES Tropospheric CH_4 estimates. The TES estimates have been reduced by 26.3 ppb.
(b) Corresponding GEOS-Chem CH_4 estimates, adjusted with the TES instrument operator.
(c) Difference between TES and GEOS-Chem

J. Worden,.et al,2012

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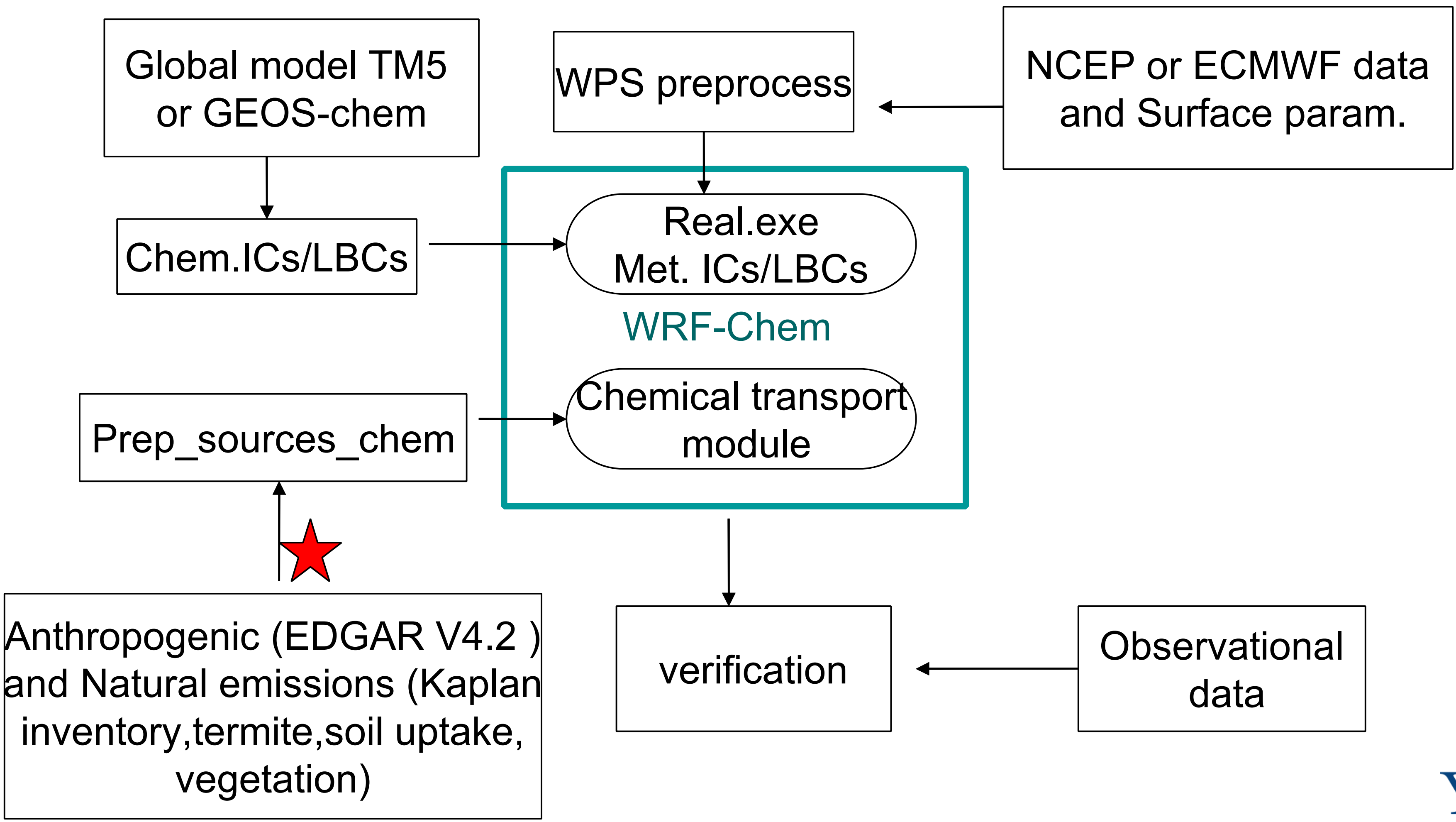
◆Regional model: WRF-GHG for CH_4



Online calculated fluxes

- CH_4 fluxes from wetland: Kaplan inventory

➢ Kaplan wetland inventory is based on a diagnostic approach to determine CH_4 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.

$$k_r = \frac{\frac{1}{\tau_0} \cdot g(T) \cdot f_{SM}}{12 \cdot 24 \cdot 30}$$

$$f_{SM} = 0.25 + 0.75 \frac{sm}{sm_{sat}}$$

$$g(T) = \exp\left(308.56 \cdot \left(\frac{1}{56.02} - \frac{1}{T + 46.01}\right)\right)$$

K_r is carbon decomposition rate; τ_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

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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*.

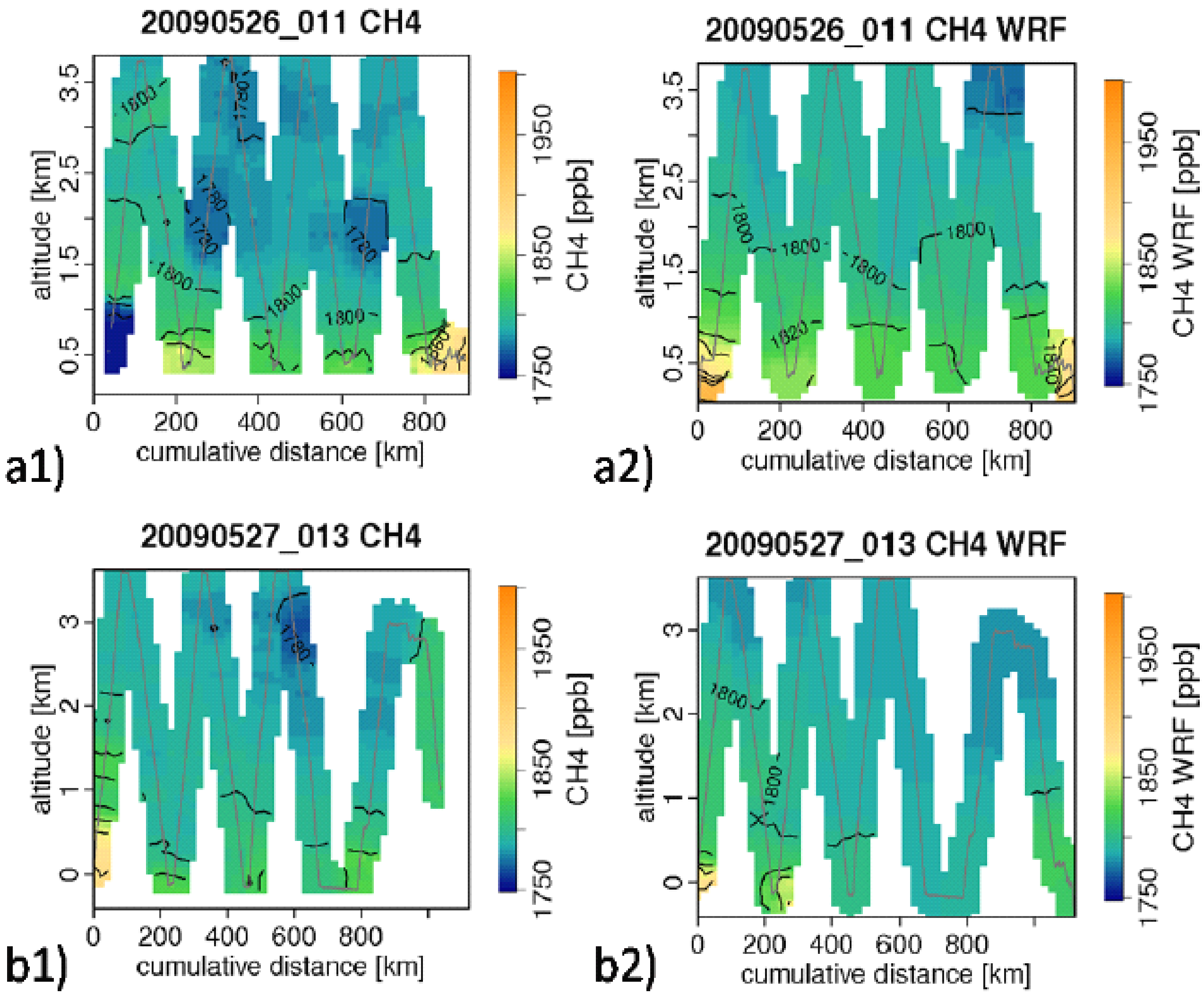

Fig.5 Comparison of observed CH_4 mixing ratios (a1,b1) to the WRF simulated CH_4 concentrations (a2,b2) in vertical cross-sections along the flight path of the airplane for two flights in the Amazon region during the BARCA project. The grey lines denotes the vertical “path” of the airplane flown, where 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. CH_4 concentration is indicated by the color scale.

Beck, V .,et al (2012)

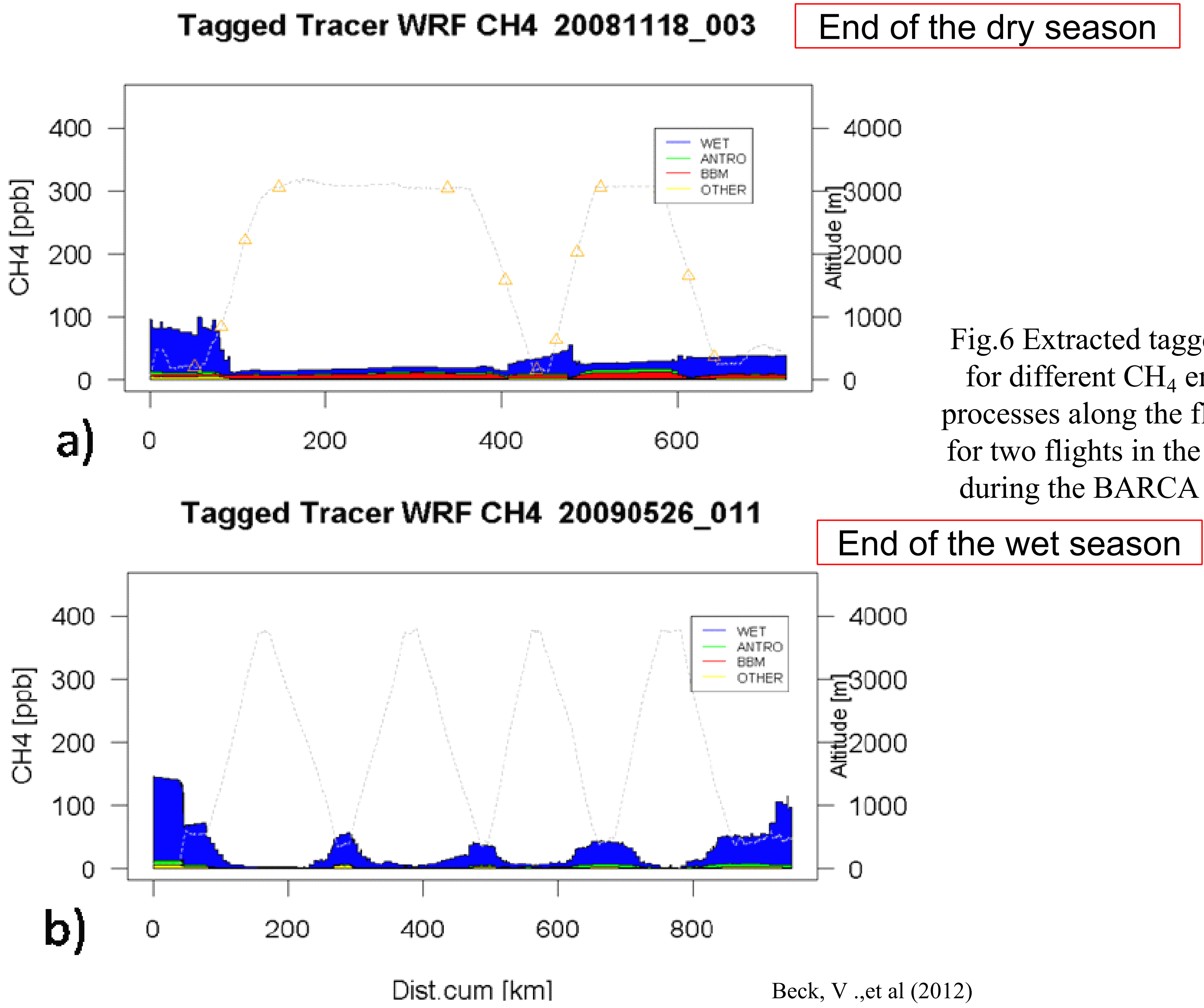

Fig.6 Extracted tagged tracer for different CH_4 emission processes along the flight path for two flights in the Amazon during the BARCA project.

Beck, V .,et al (2012)

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◆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 CH_4 concentrations over the YRD region over the past decades.
- To examine the impact of anthropogenic emission changes on CH_4 .

◆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!