



# Inverse modeling of CH<sub>4</sub> emissions: examples of derived emissions from the assimilation of ground-based measurements and satellite retrievals

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Frankenberg<sup>5</sup>, Maarten Krol<sup>3,4</sup>, Jan Fokke Meirink<sup>2</sup>, Frank  
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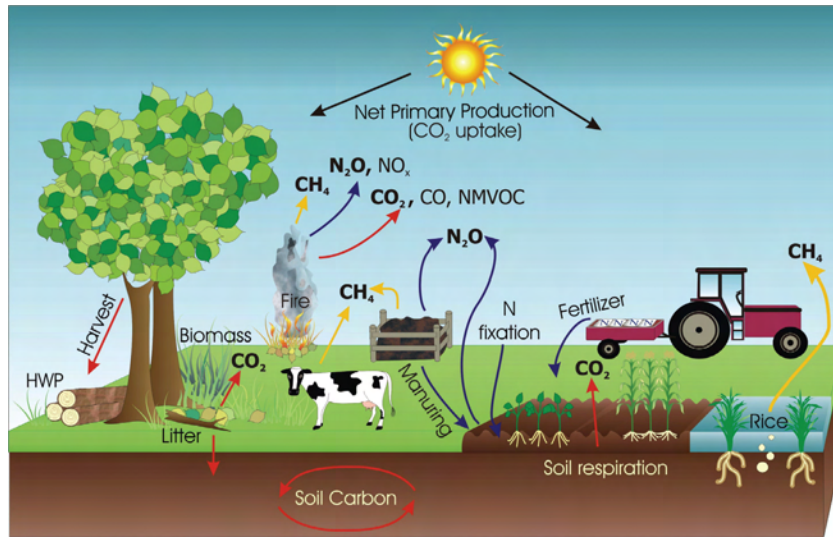
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[3] Wageningen University and Research Centre, Wageningen, The Netherlands

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from IPCC Guidelines for National GHG Inventories

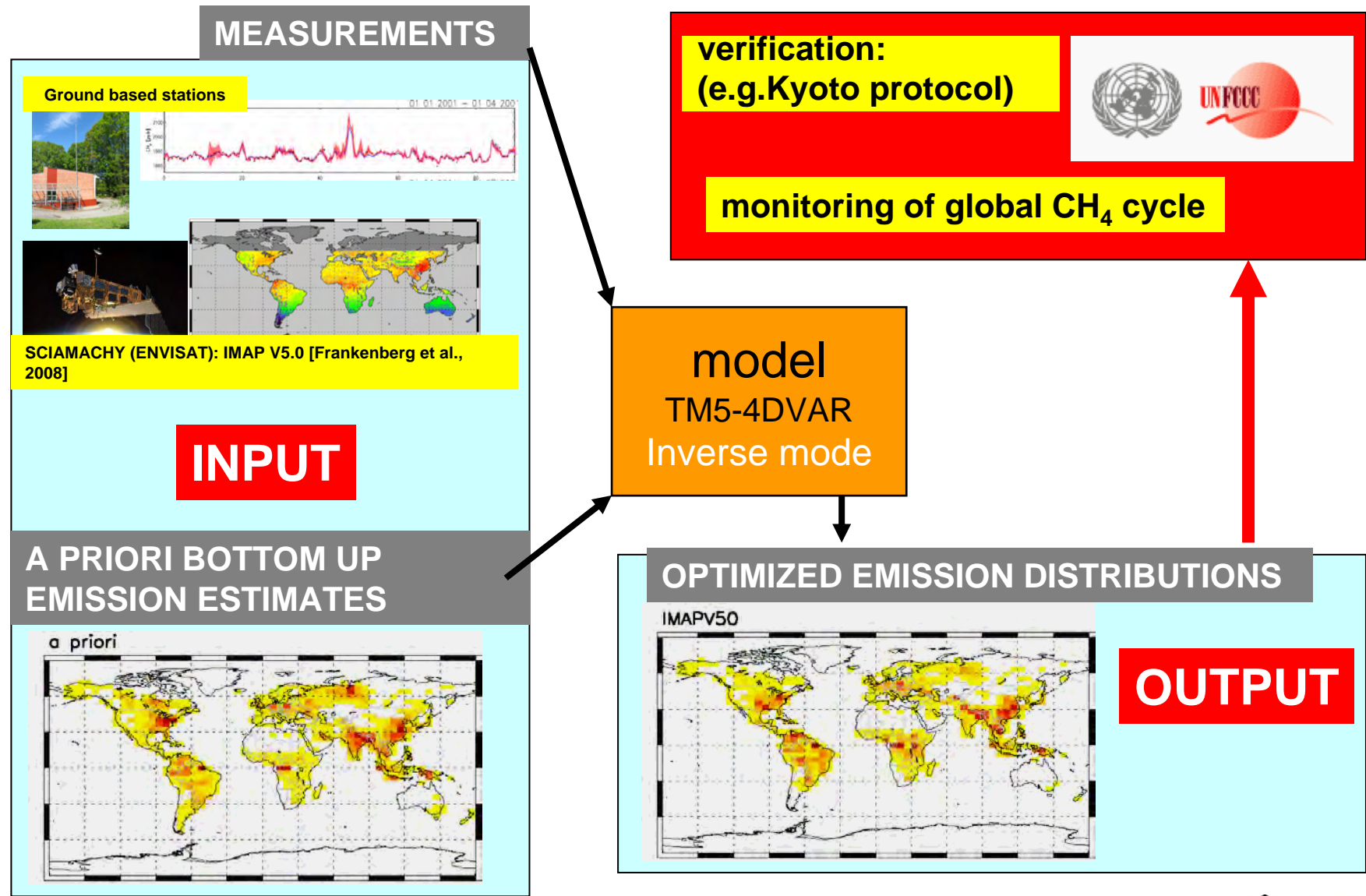
## Major Sources:

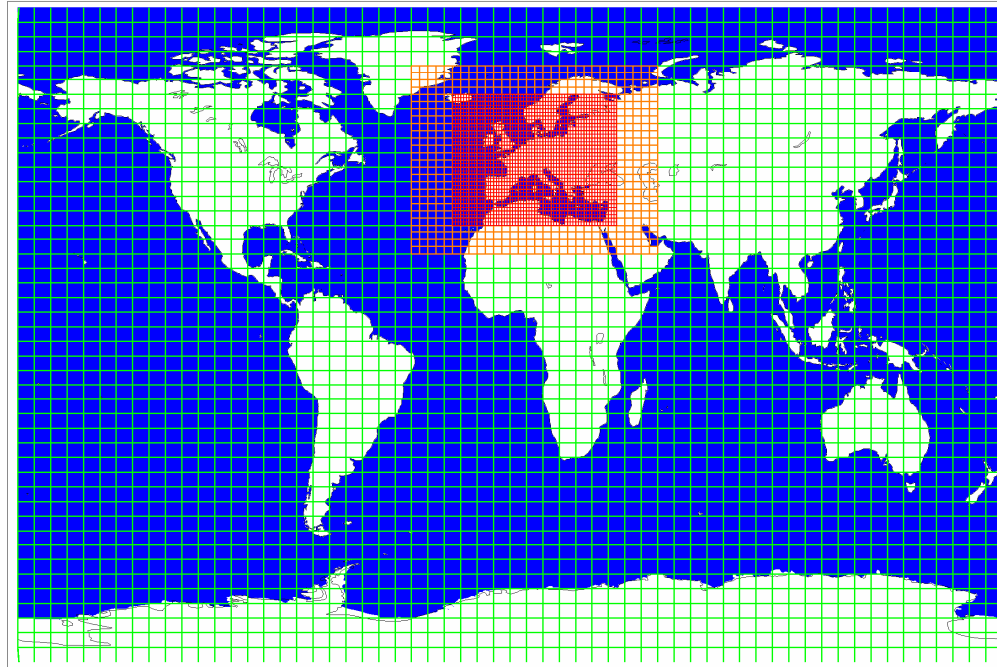
- landfills (12%)
- livestock (18%)
- rice cultivation (12%)
- biomass burning (4%)
- wetlands (34%)

- Long lived: local sources -global distribution
- After CO<sub>2</sub>, second most important anthropogenic GHG: Kyoto Protocol.
- It has increased of a factor of 2.5 compared to pre-industrial levels.
- Surface observations and satellite data available

# TM5-4DVAR INVERSE MODELING

Joint Research Centre





Universiteit Utrecht



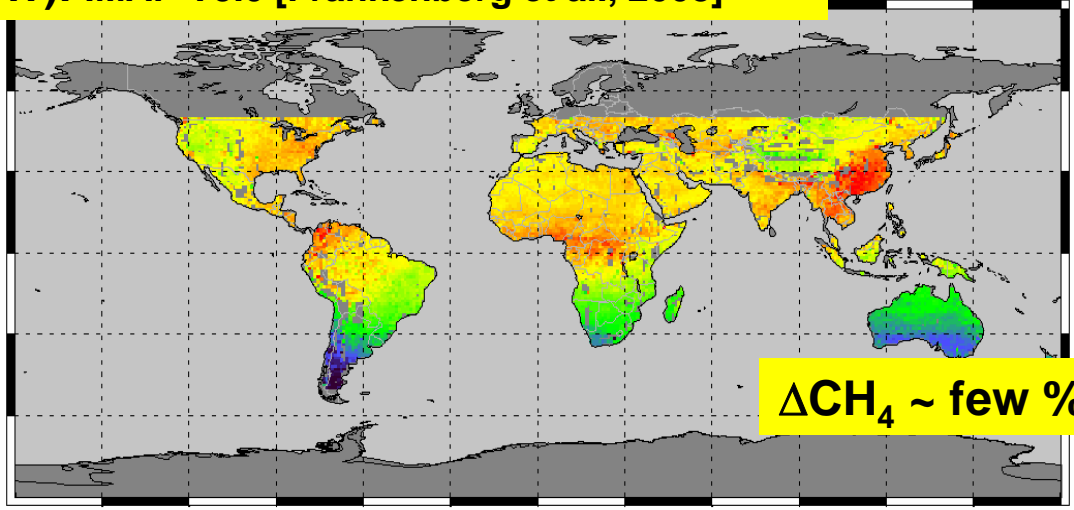
- TM5 offline atmospheric transport model (Krol et al., 2005)
- meteo from ECMWF
- global simulation 6° x 4°
- zooming 1° x 1° (Europe, ...)

<http://www.phys.uu.nl/~tm5/>



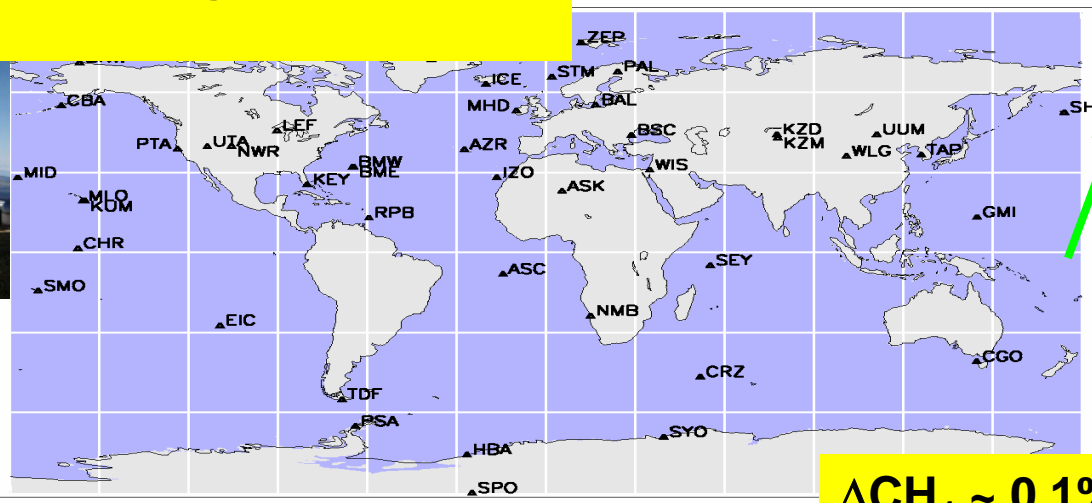
# Coupled Inversion: SCIAMACHY + NOAA surface measurements

SCIAMACHY (ENVISAT): IMAP V5.0 [Frankenberg et al., 2008]



$\Delta\text{CH}_4 \sim \text{few \%}$

surface background monitoring sites (NOAA/ESRL)

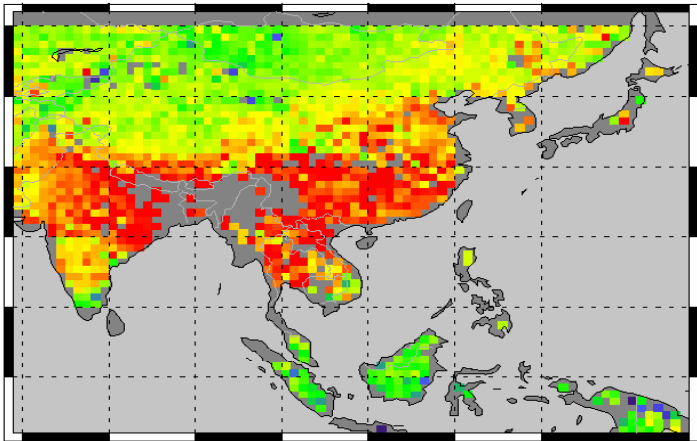


TM5-4DVAR

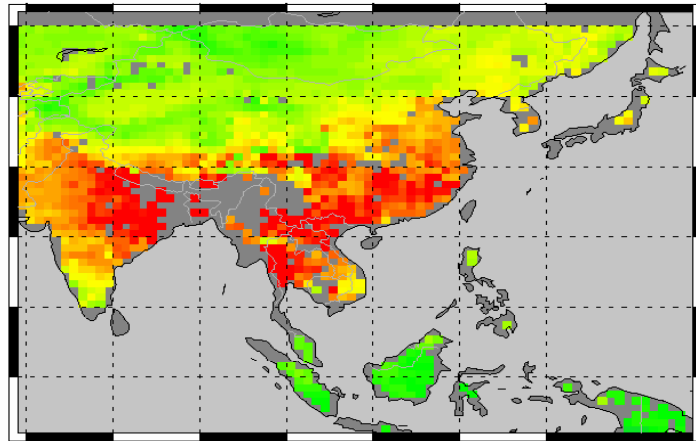
$$\vec{x} = \begin{bmatrix} \vec{x}_{\text{ATM}} \\ \vec{x}_{\text{EMIS}} \\ \vec{x}_{\text{PARA}} \end{bmatrix}$$

$\Delta\text{CH}_4 \sim 0.1\%$

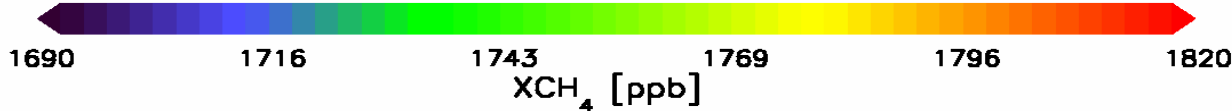
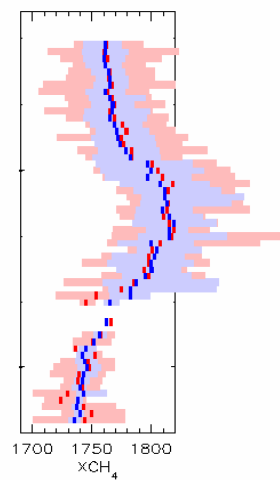
SCIAMACHY



TM5-4DVAR

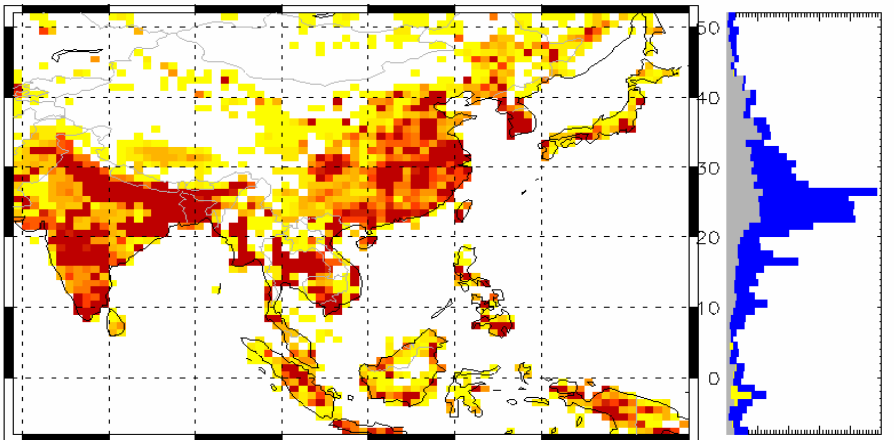


01 09 2004 – 30 09 2004

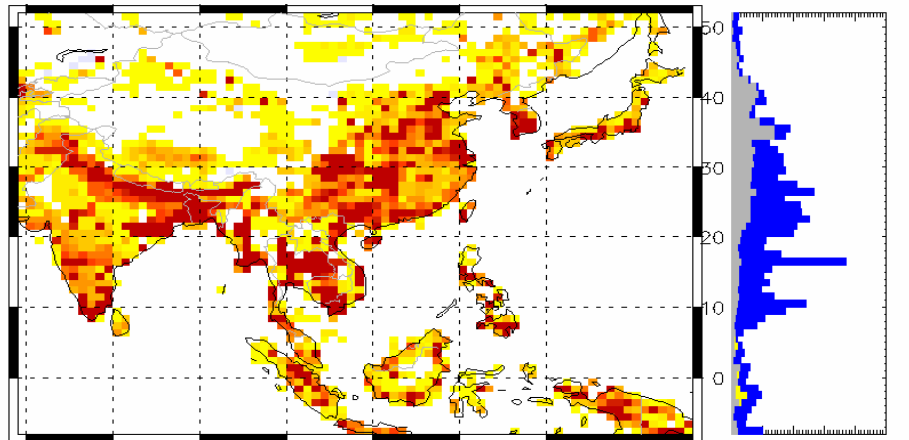


SCIA  
TM5

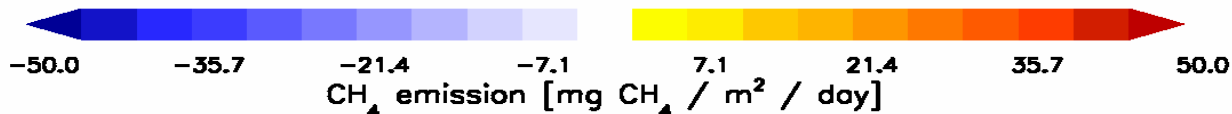
a priori



a posteriori

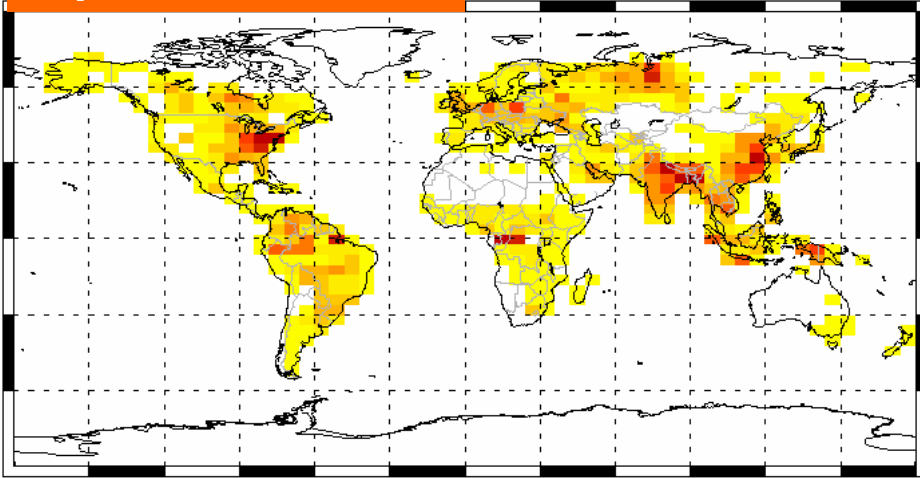


(Bergamaschi et al. 2009)



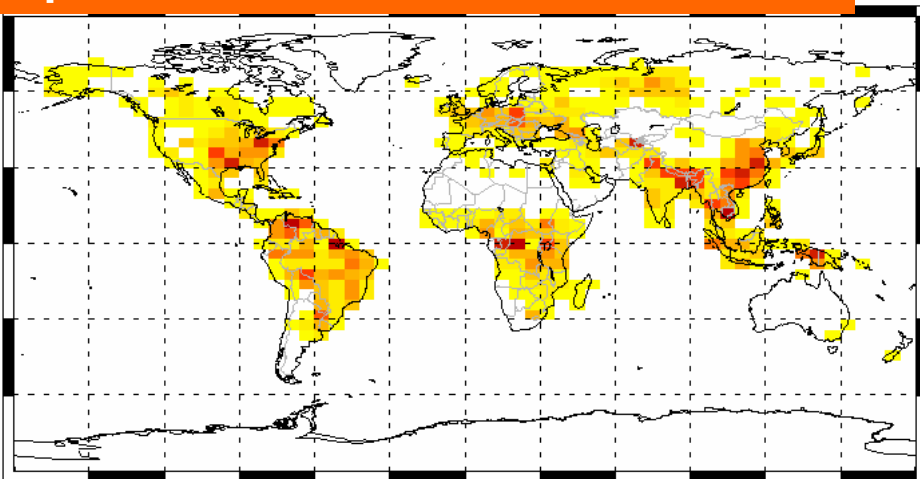
remain emission  
 biomass burning  
 wetlands rice

## A priori emissions

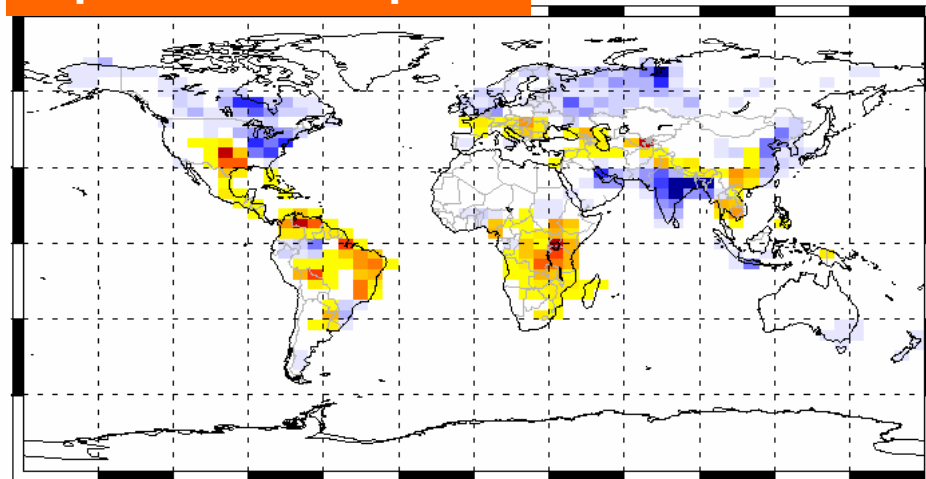


- Satellite gives lots of additional information
- Can change estimated emissions by up to 50 %

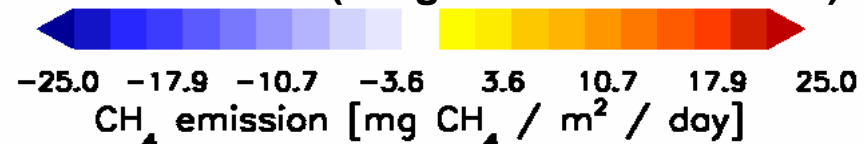
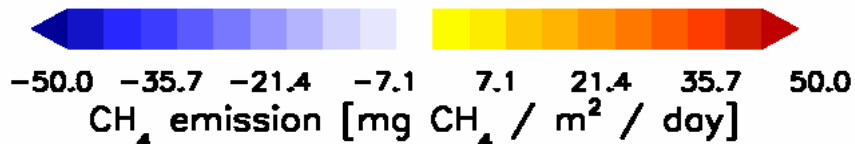
## A posteriori emissions with IMAPv50



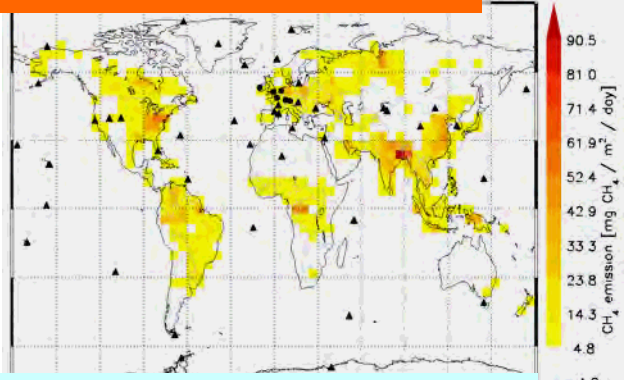
## A posteriori – a priori



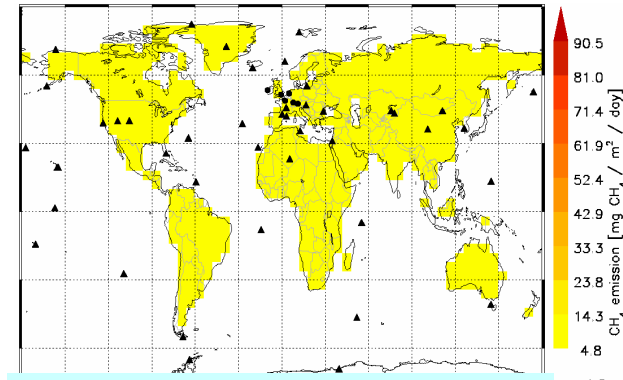
(Bergamaschi et al. 2009)



## Emission distributions:

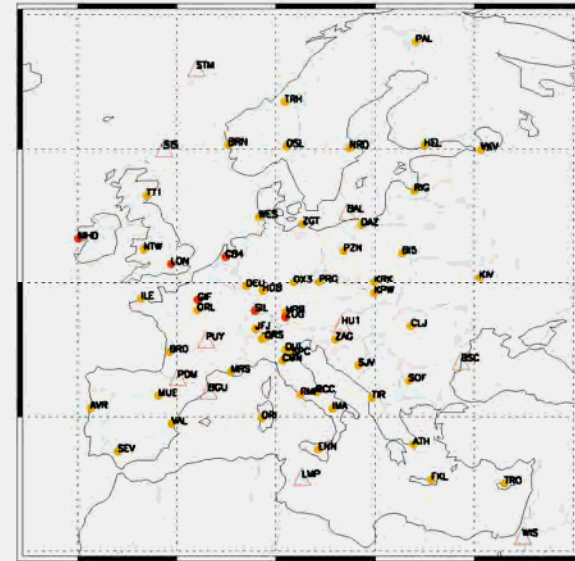
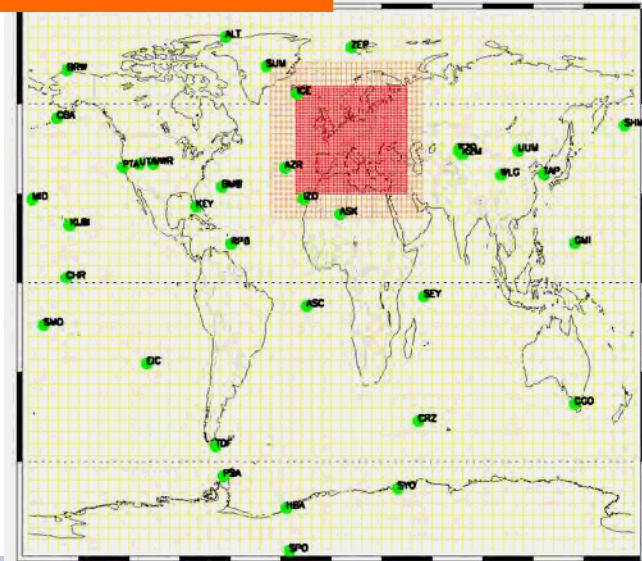


True emissions [forward run]

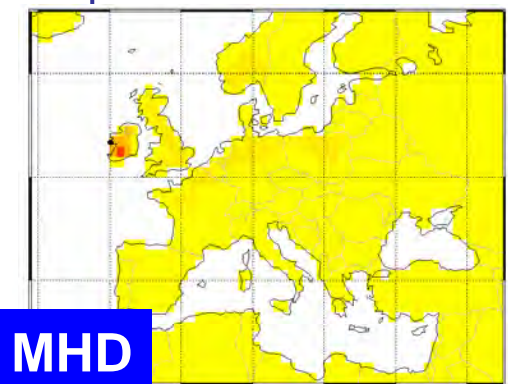


A priori emissions [4D-Var]

## Sites location:

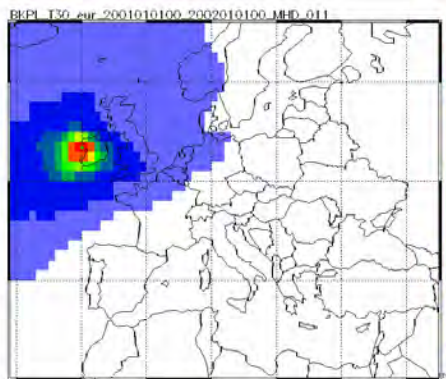


(Villani et al. 2009)

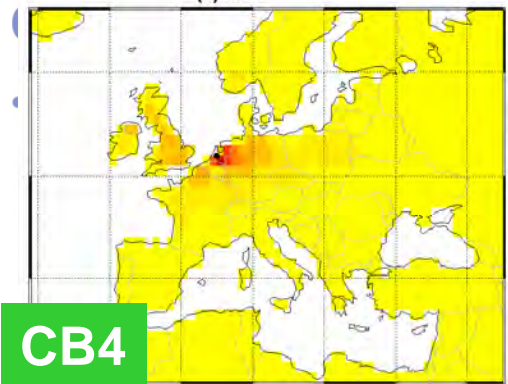


**MHD**

(a) MHD

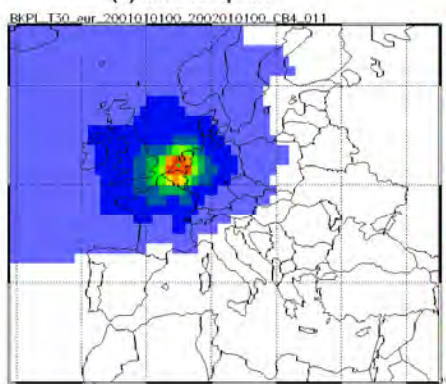


(d) MHD footprint

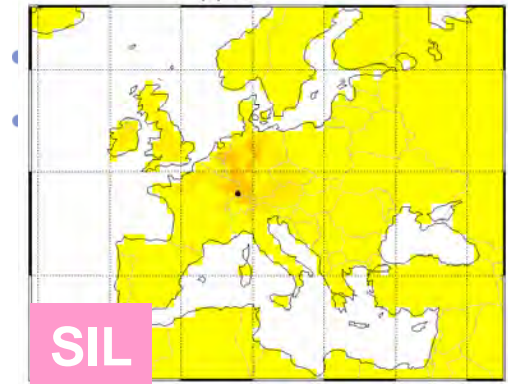


**CB4**

(b) CB4

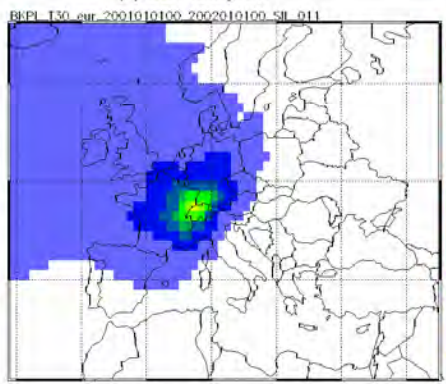


(e) CB4 footprint

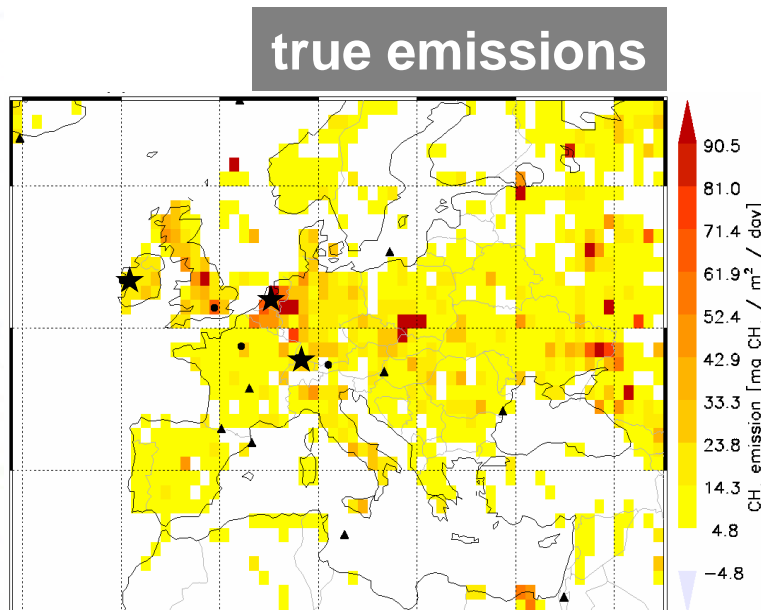


**SIL**

(c) SIL



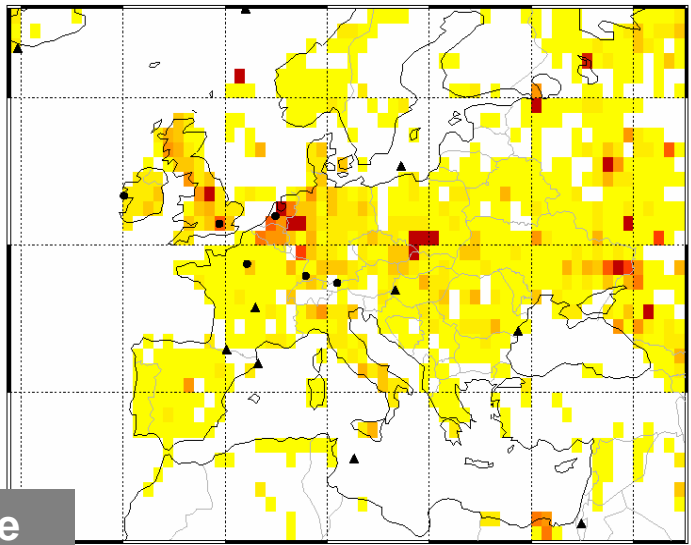
(f) SIL footprint



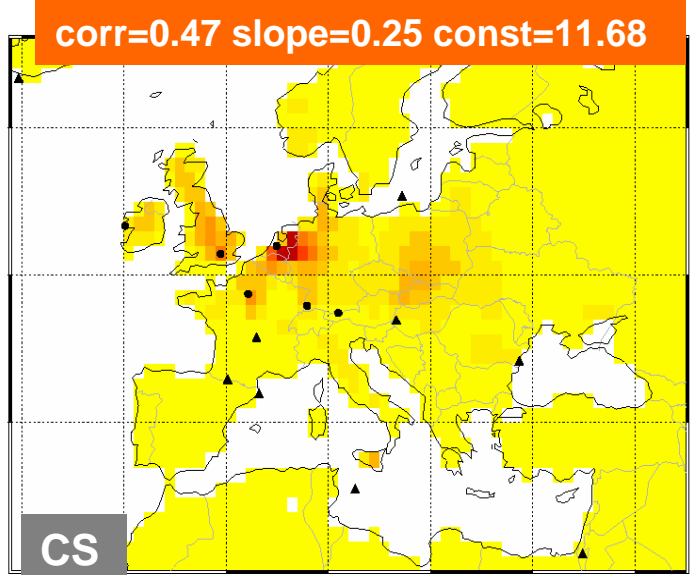
**true emissions**

(Villani et al. 2009)

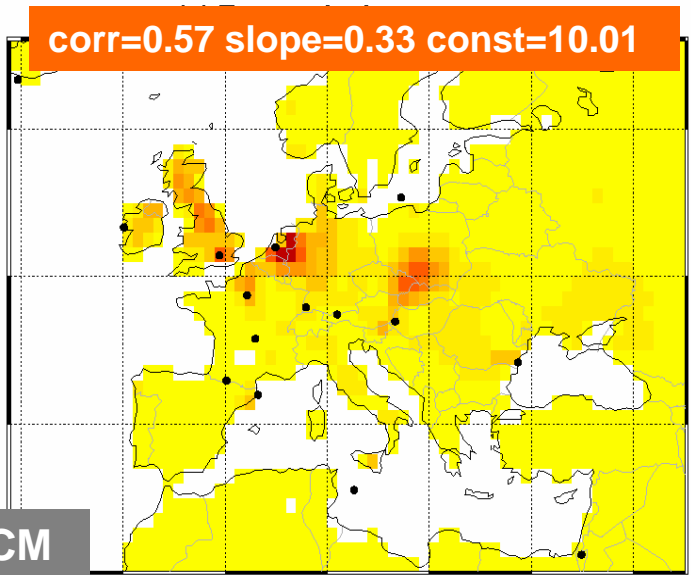
Joint Research Centre



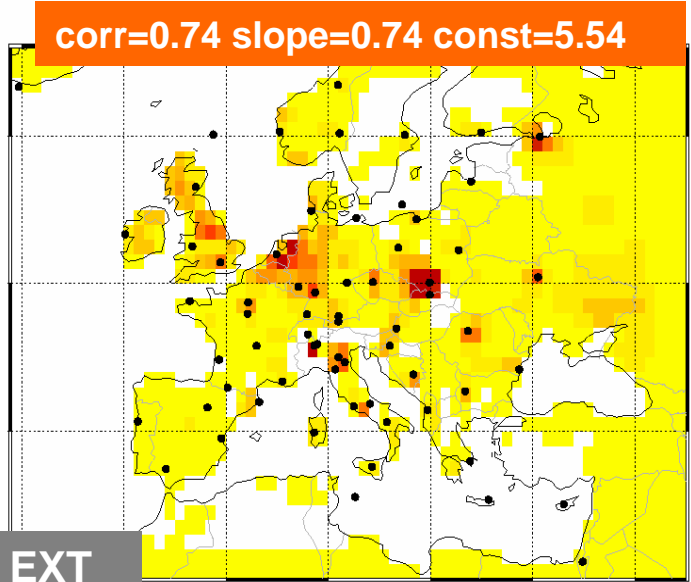
True



CS



CS-CM



EXT

(Villani et al. 2009)

- Methane emission estimates can be improved with the implementation of inverse modeling techniques (**modeling+ measurements**)
- We expect a larger role for CH<sub>4</sub> data from satellites (global coverage)
- Coupling to high-accuracy surface observations may be used to (partially) correct for systematic biases of satellite data
- We need a careful selection of representative stations
- We need a larger extension of the current observing network

## TM5-4DVAR System:

- Bergamaschi, P., C. Frankenberg, J.F. Meirink, M. Krol, M.G. Villani, S. Houweling, F. Dentener, E.J. Dlugokencky, J.B. Miller, A. Engel, and I. Levin (2009), Inverse modeling of global and regional CH<sub>4</sub> emissions using SCIAMACHY satellite retrievals, *Journal of Geophysical Research*, D- Atmosphere.
- Krol, M. C., S. Houweling, B. Bregman, M. van den Broek, A. Segers, P. van Velthoven, W. Peters, F. Dentener, and P. Bergamaschi (2005), The two-way nested global chemistry-transport zoom model TM5: algorithm and applications, *Atmos. Chem. Phys.*, 5, 417-432.
- Meirink, J. F., P. Bergamaschi, and M. Krol (2008a), Four-dimensional variational data assimilation for inverse modelling of atmospheric methane emissions: Method and comparison with synthesis inversion, *Atmos. Chem. Phys.* , 8, 6341–6353.
- Villani M.G., Bergamaschi P., Krol M., Meirink JF., and F. Dentener, 2009, Inverse modeling of European CH<sub>4</sub> emissions: Sensitivity to the observational network, *ACPD*, acp-2009-524

## Data Assimilation:

- ECMWF data assimilation training courses / lecture notes [http://www.ecmwf.int/newsevents/training/lecture\\_notes/index.html](http://www.ecmwf.int/newsevents/training/lecture_notes/index.html)
- Bouttier and Courtier, Data assimilation concepts and methods, ECMWF
- M. Fischer, 3D VAR, 4D VAR, ECMWF
- Kasibhatla, Heimann, Rayner, Mahowald, Prinn, Hartley (Eds.), Inverse methods in global biogeochemical cycles, AGU, Geophysical Monograph 114, 2000

