Global budgets of CH_4, N_2O:

their uncertainties and techniques to measure emissions at regional and country scales

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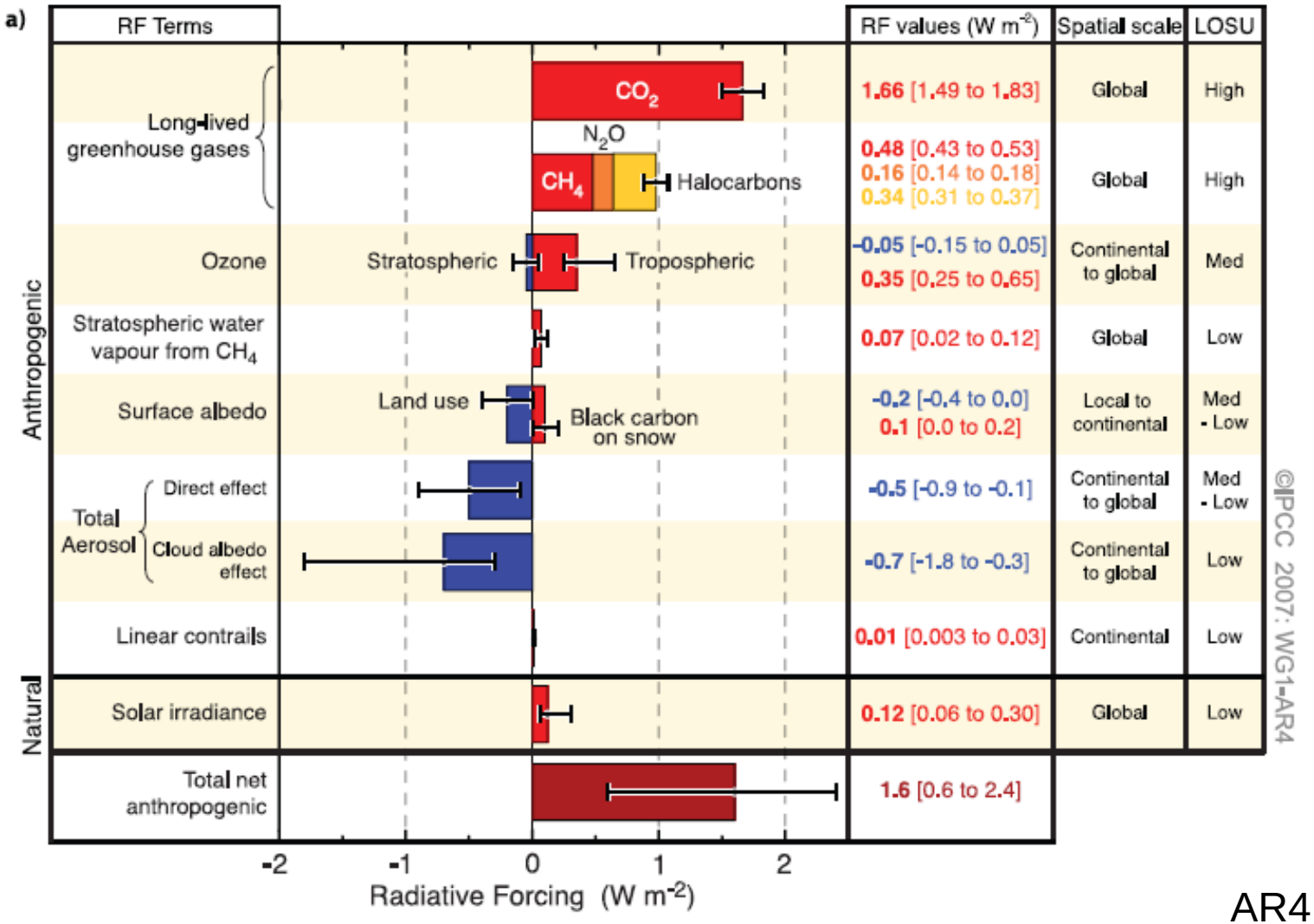
Outline

- Recent trends in global CH_4 and N_2O concentrations and their atmospheric budgets
- Sources and their uncertainty
- Direct measurements of country scale GHG emissions

Global Mean Radiative Forcings



AR4

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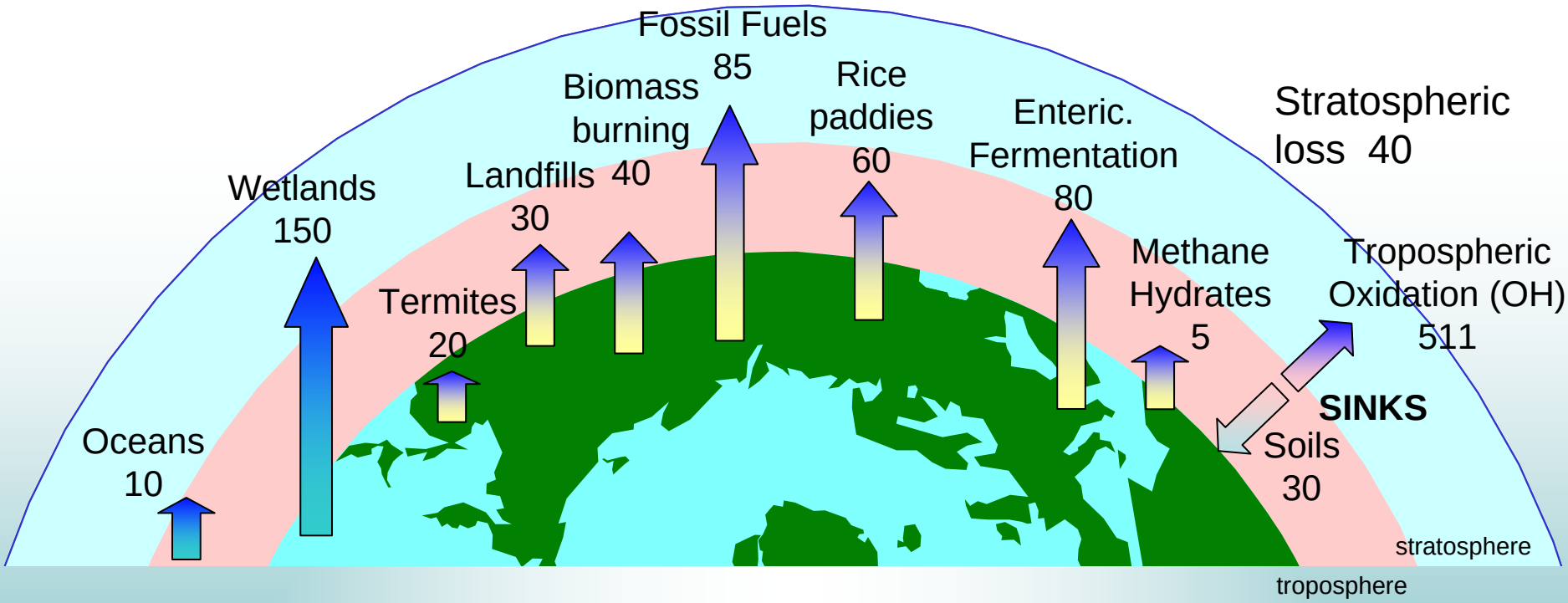
Methane

GLOBAL METHANE BUDGET (Mt)
AR4

Annual Source	582 Mt
Annual Sink	581 Mt



Uncertainties in Methane emissions Tg CH_4 per year

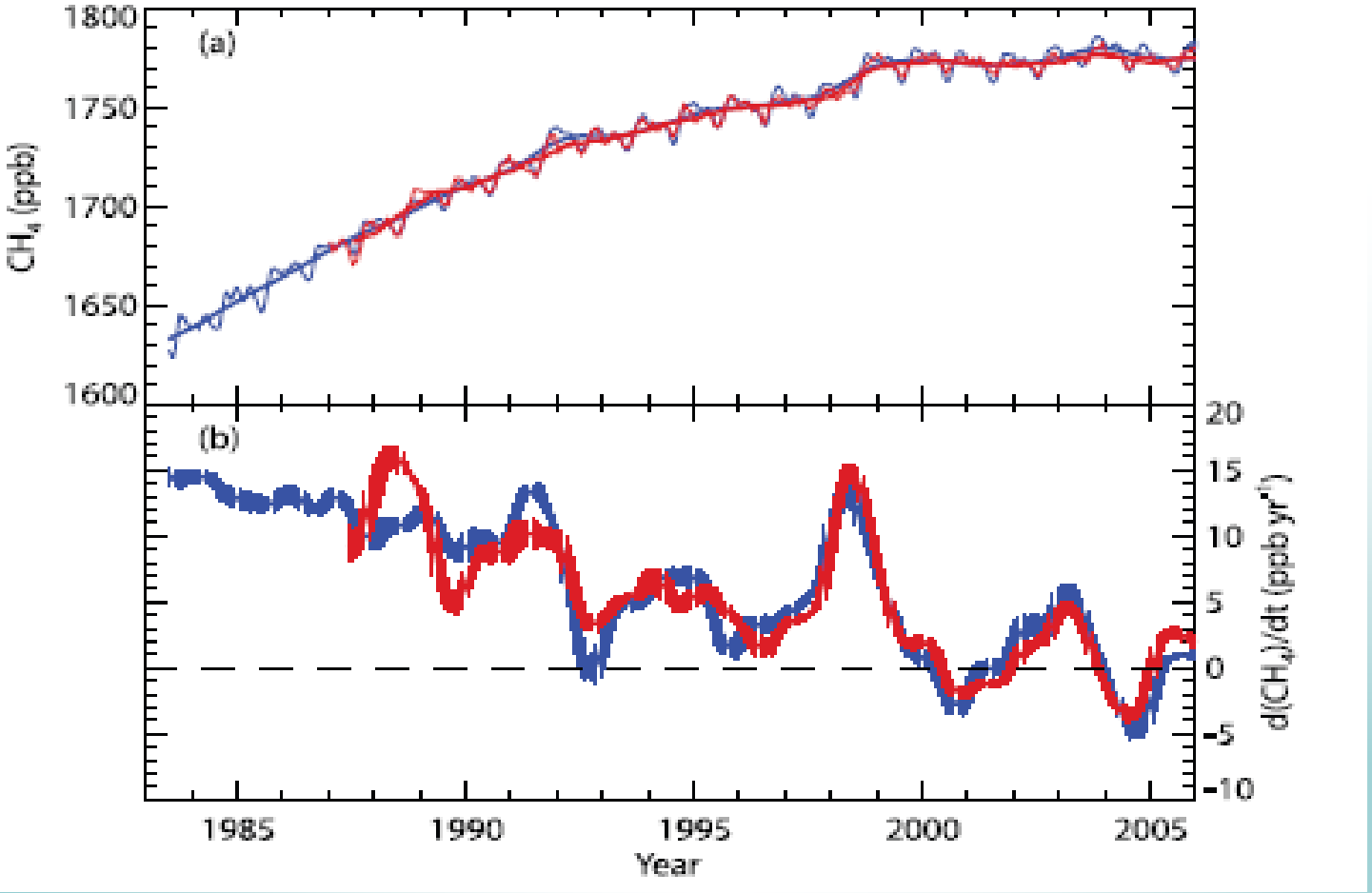
- Wetlands 150 (range 100-260)
- Rice Agriculture 60 (30-112)
- Ruminants 80 (76-92)
- Landfill 30 (35 – 69)
- Biomass burning 40 (14-88)
- Termites 20 (20-30)
- Gas, coal and industry 85 (90-120)

Uncertainties in Methane sinks

- Soils 30 (26-34)
- Tropospheric OH 511 (420-511)
- Stratospheric loss 40 (30-40)

Recent trends in CH_4

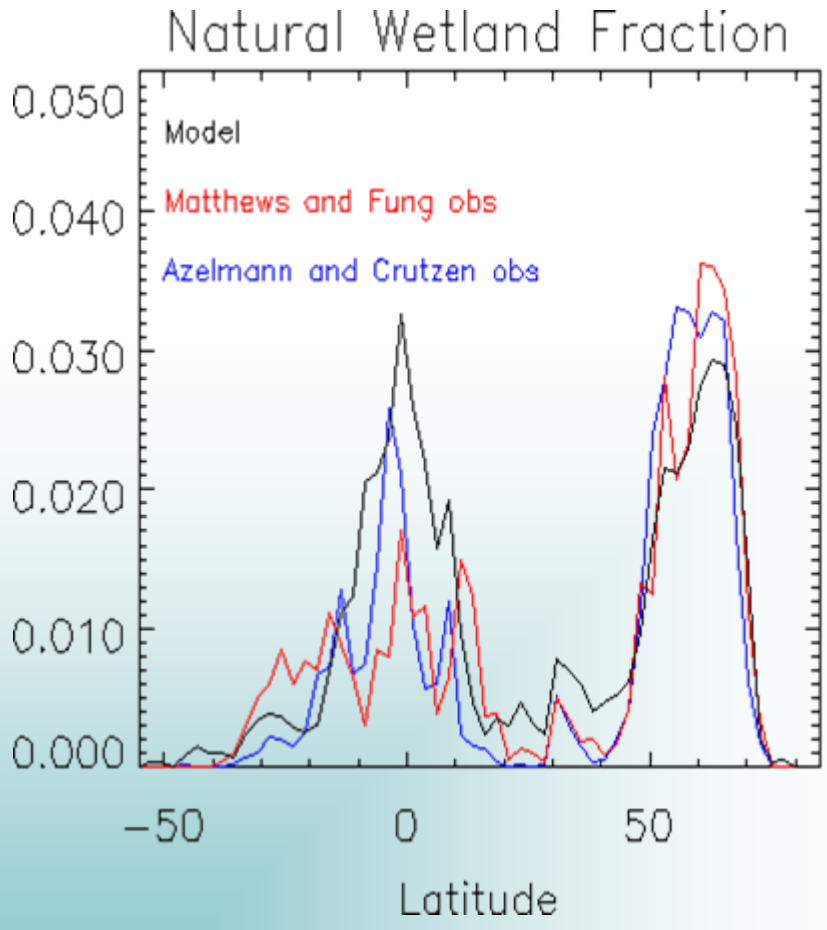
Why has the rate of change in global CH_4 concentration been so variable?

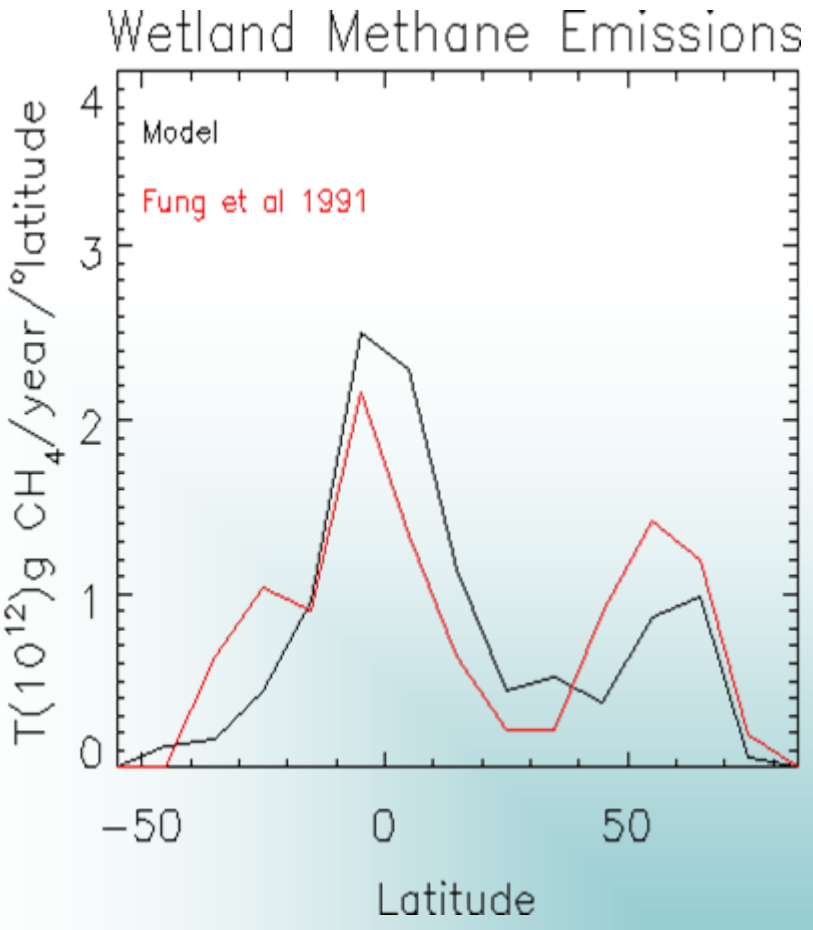


Global Methane trends

- The trends in global CH_4 since 1990, remain largely unexplained
- Thus sources and sinks for global CH_4 remain a research priority
- There is much to do in validating regional emission estimates measuring fluxes in the main source regions, especially wetlands both high and low latitude

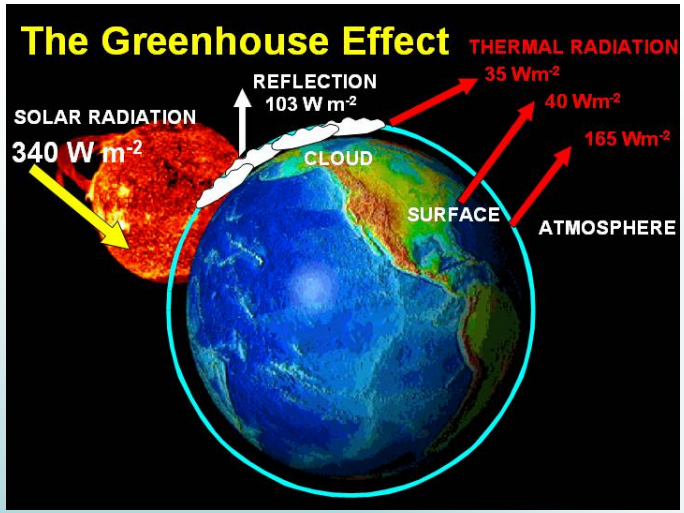
Modelled zonal mean wetland area and methane emissions

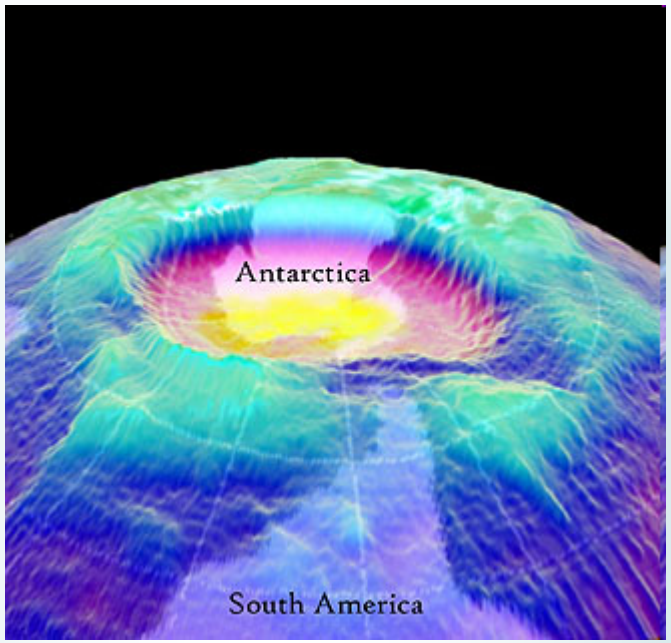




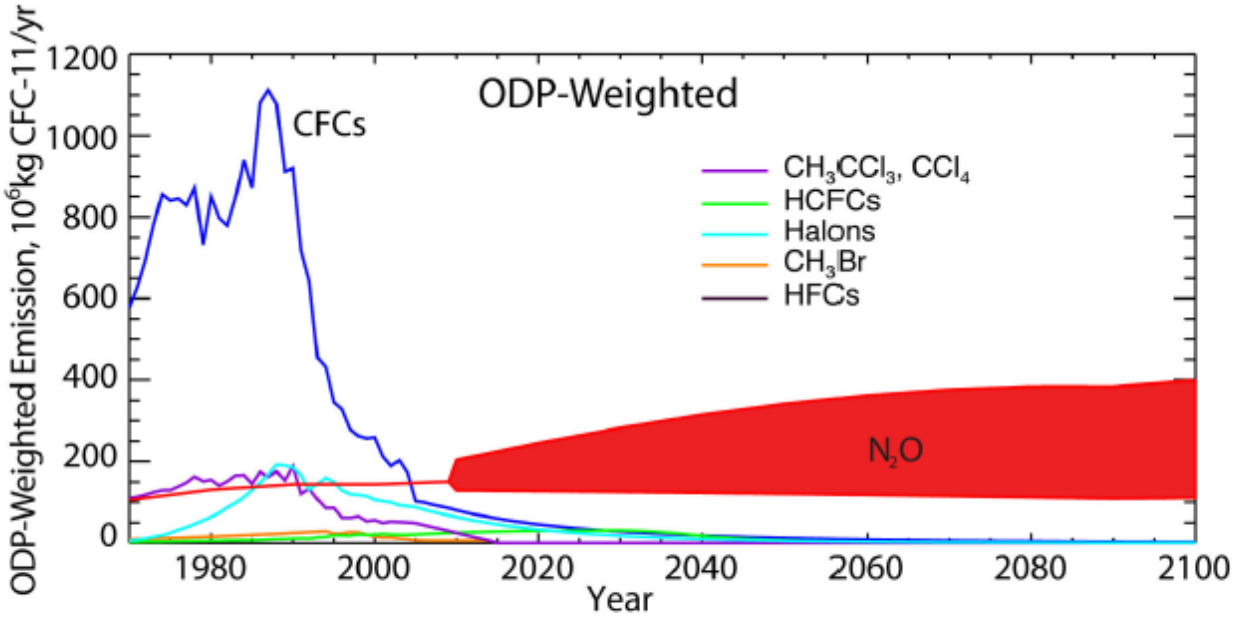
Nitrous Oxide

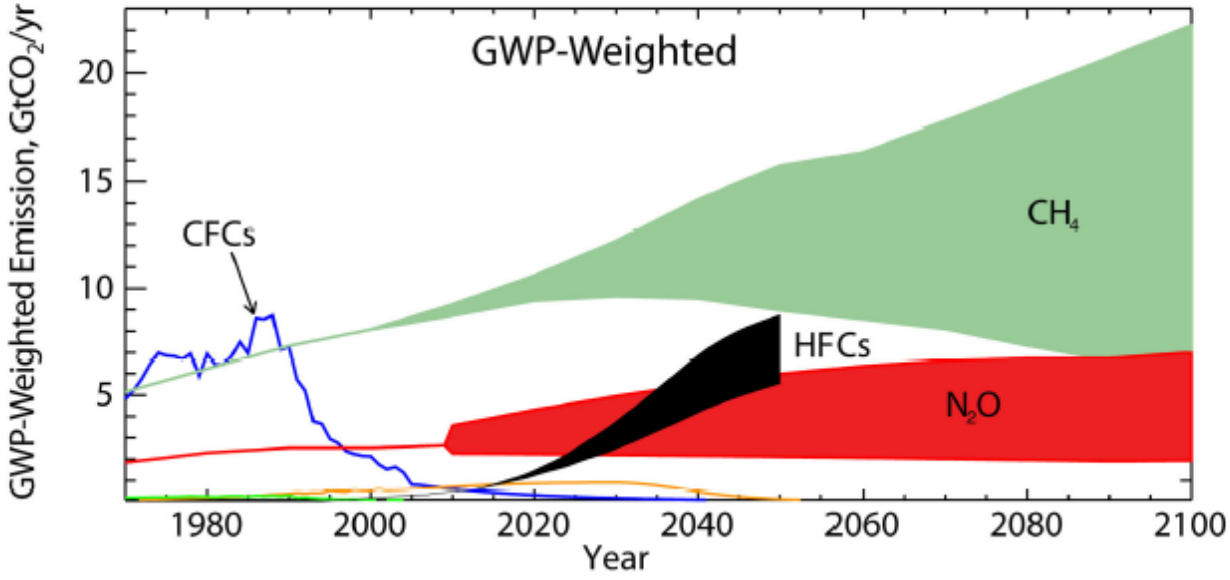
- Radiatively active
- Stratospheric Ozone depleting gas



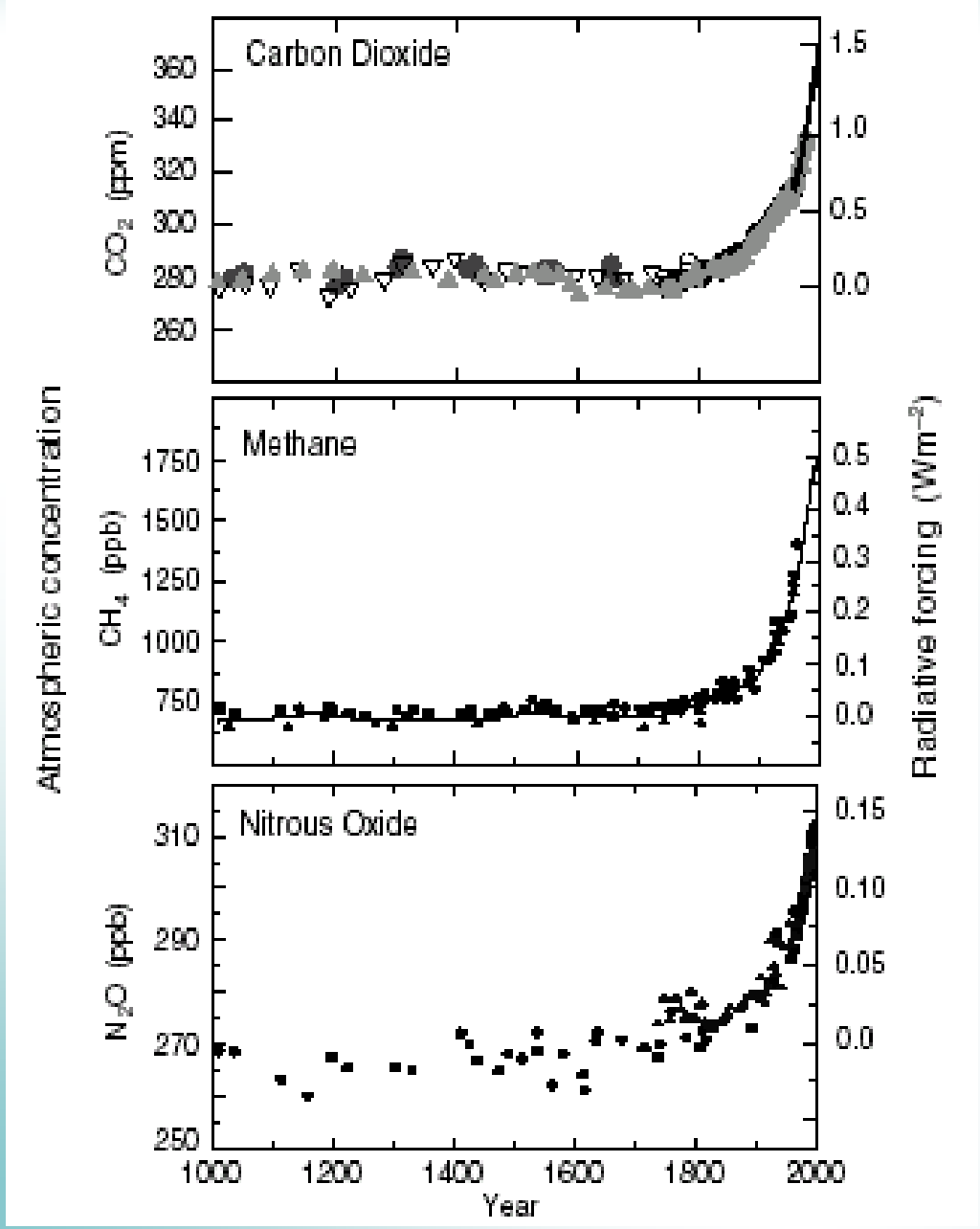


View of the South Pole from NASA's TOMS (Total Ozone Mapping Spectrometer) satellite. Blue and green indicate relatively large amounts of ozone. Red and yellow mark the "ozone hole", an area of decreased ozone. Credit: NASA





Sciencexpress / www.sciencexpress.org / 27 August 2009 / Page 4 / 10.1126/science.1176985
A. R. Ravishankara,* John S. Daniel, Robert W. Portmann



Long term trends derived from ice cores

CO_2 +40%

CH_4 +160%

N_2O +18%

270 ppb pre-industrial value now 320 ppb

N_2O trend 1980-2006 (AR4)

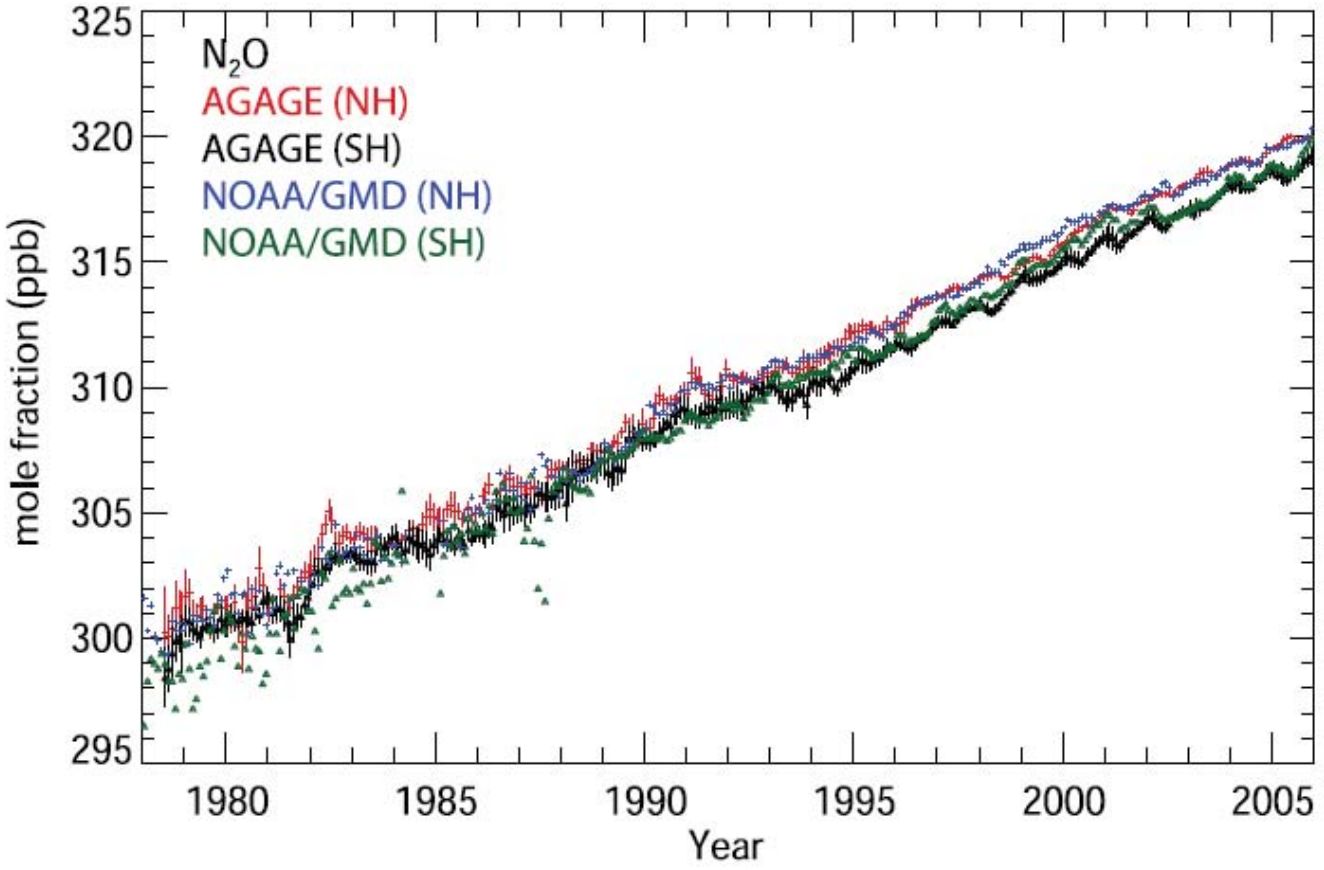
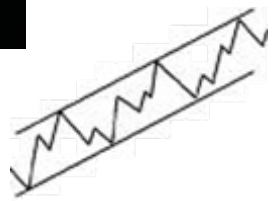


Figure 2.5. *Hemispheric monthly mean N_2O mole fractions (ppb) (crosses for the NH and triangles for the SH). Observations (*in situ*) of N_2O from the Atmospheric Lifetime Experiment (ALE) and GAGE (through the mid-1990s) and AGAGE (since the mid-1990s) networks (Prinn et al., 2000, 2005b) are shown with monthly standard deviations. Data from NOAA/GMD are shown without these standard deviations (Thompson et al., 2004). The general decrease in the variability of the measurements over time is due mainly to improved instrumental precision. The real signal emerges only in the last decade.*

***Knowns*:**

Stratospheric destruction	8.7 Tg-N y^{-1}
Annual increase	3.0 – 4.5 Tg-N y^{-1}
Total	11.7 – 13.2 Tg-N y^{-1}



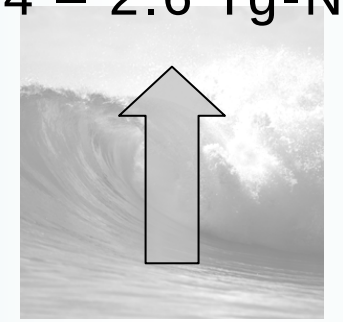
Natural source:

(from ice-core data)

8.1 Tg-N y^{-1}

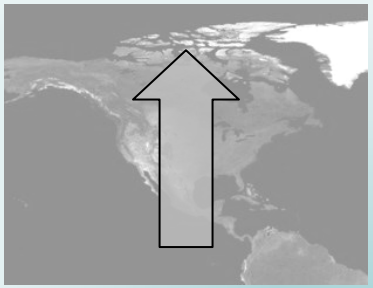
Oceans

1.4 – 2.6 Tg-N y^{-1}



Continent

5.5 – 6.7 Tg-N y^{-1}

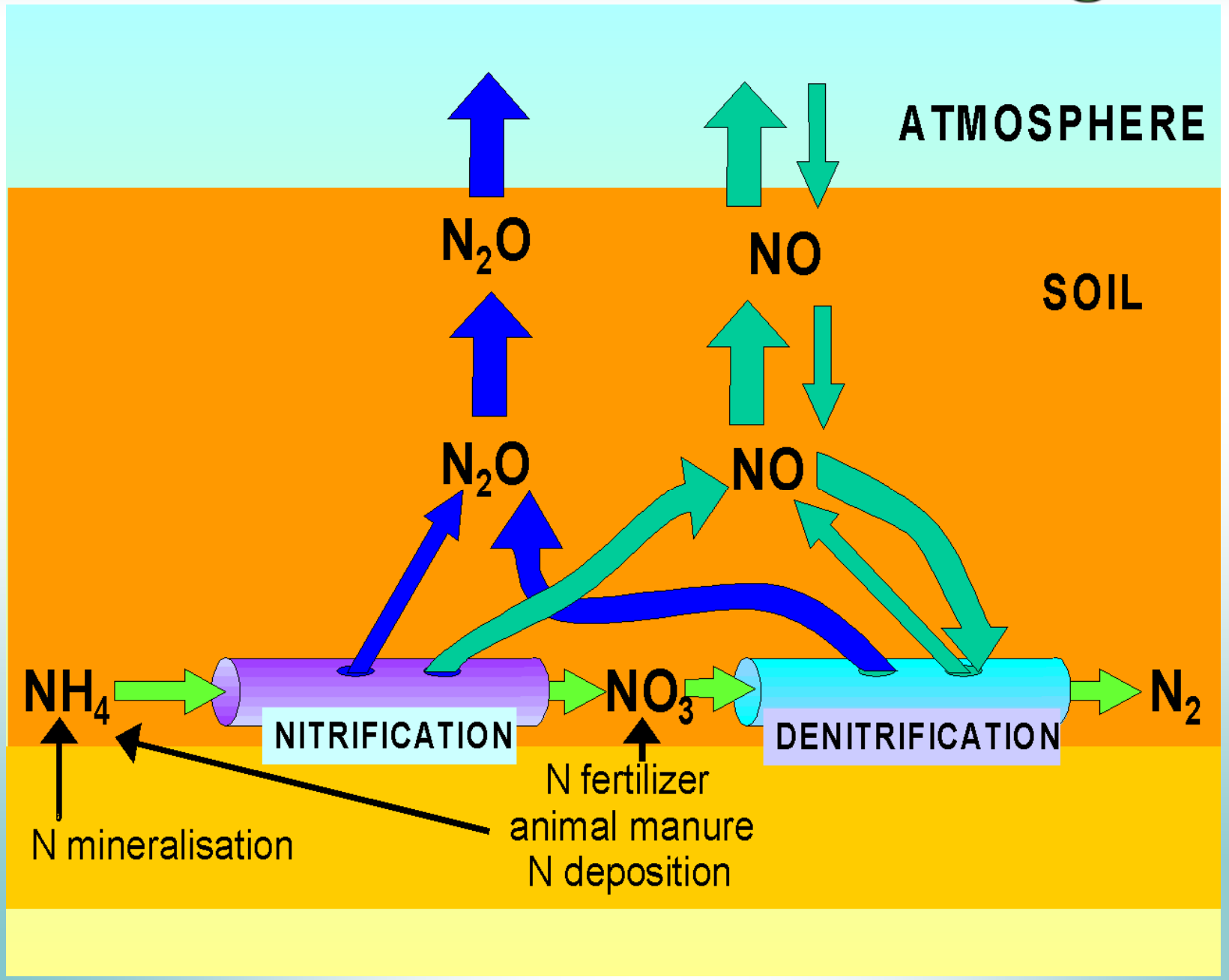


***Anthropogenic sources*:** 3.6 to 5.1 Tg-N y^{-1}

(by difference)

Sources of N_2O

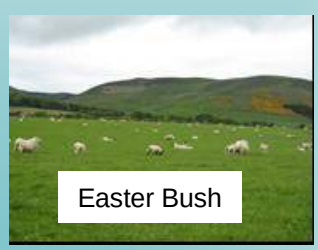
- Soils, agricultural and natural
- Industry (fertilizer, HNO_3 and nylon production)
- Catalyst equipped cars

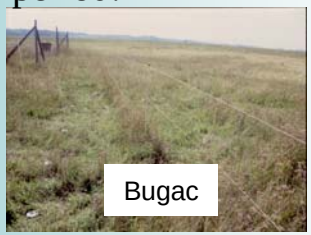

ATMOSPHERE
SOIL
N_2O
NO
N_2O
NO
NH_4
NITRIFICATION
NO_3
DENITRIFICATION
N_2
N mineralisation
N fertilizer
animal manure
N deposition

A preliminary calculation of greenhouse gas fluxes from some NEU Level 3 sites.

Ecosystem	Site	CO_2	CO_{2eqN2O}	CO_{2eqCH4}	Total GHG
		kg $ha^{-1}y^{-1}$	kg $ha^{-1}y^{-1}$	kg $ha^{-1}y^{-1}$	t ha^{-1} y^{-1}
Forest	FI-Hyy	-6078	117	-246	-6.2
	DK-Sor	-3987[1]	211	- 96	-3.9
Grassland	UK-EBu	-3788[2]	5840	42[3]	2.1
	HU-Bug	-3691	75	6	-3.6
Arable land	FR-Gri	-19114[2]	126	0	-18.9
Wetland	FI_Lom	-800[1]	42	5000	4.2
	UK-AMo	-4250	0	61	-4.2

[1]Average of measurements for 12 months 08/06 -07/07, [2]export of C by harvest (vegetation, animals) is not included,[3] CH_4 emissions from sheep are not included. The global warming potential used for N_2O was 298 and for CH_4 25, over the 100 year time period.





Skiba et al, Agriculture, Ecosystems and Environment 133 (2009) 139–149

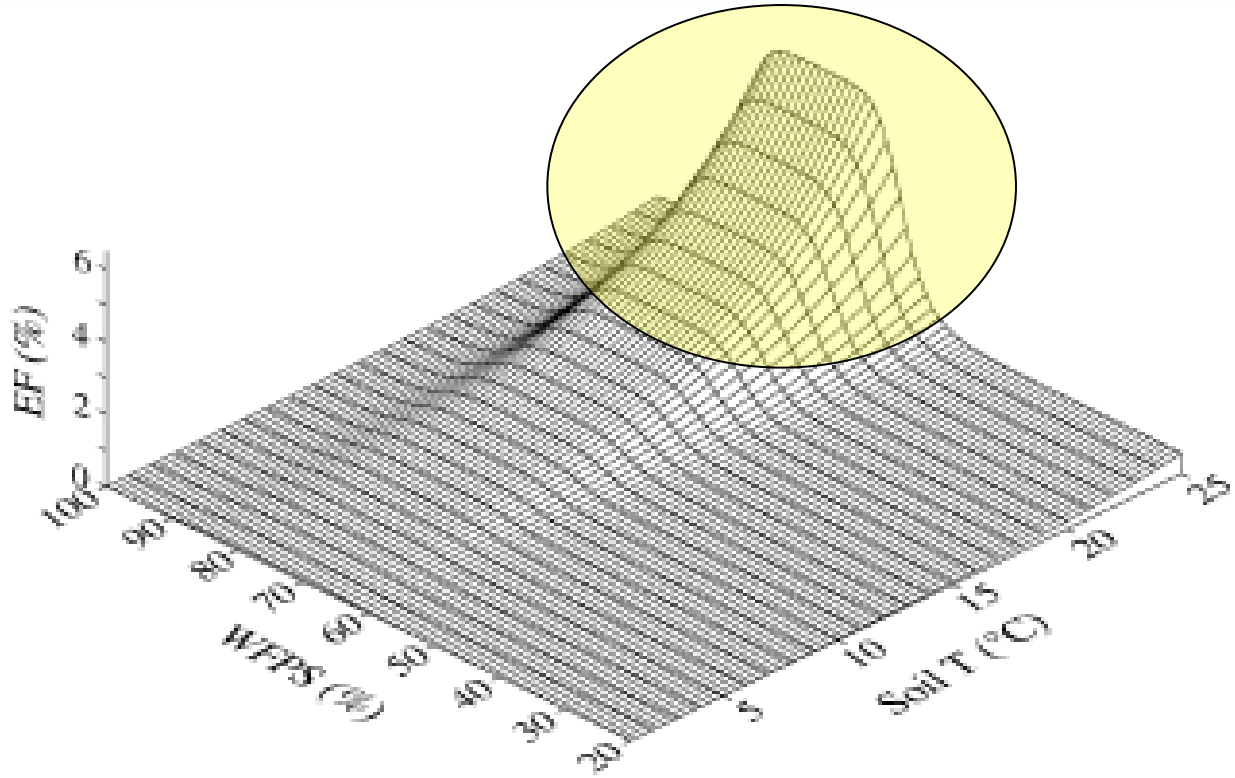


Fig. 7. Fitted response of the emission factor (EF) from fertilizer to soil temperature and WFPS, assuming a monthly rainfall of 50 mm (after Eq. (4)).

C.R. Flechard et al. / Agriculture, Ecosystems and Environment 121 (2007) 135–152

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N_2O

- Spatial and temporal variability in N_2O emission is very large
- The available data to show that a more complex treatment of N_2O in national inventories is better than the default value at the country scale, is lacking

How good are national CH_4 inventories ?

- UK annual emissions of CO_2, CH_4, N_2O
- These are ‘bottom up’ inventories calculated from activity / emission factor data, for N_2O almost all country data is provided by the assumption of default (1% N applied)
- There is no systematic validation

Validation methods available for country scale emissions

- Tall towers (~200m)

(Including Flux towers)

- Aircraft sampling to measure the mass budget of GHG over a region
- Satellite remote sensing

Tall Towers

- Long term, high precision measurements of CO_2, CH_4, N_2O, CO, NO_x, etc and inverse modelling to deduce regional surface-atmosphere fluxes.

ICOS will make the existing network denser and more accurate

(John Grace *et al* Edinburgh Univ)

- Principle = the atmosphere is a fast but incomplete mixer of surface sources and sinks
- High accuracy, long-term monitoring of CO_2 concentrations at atmospheric stations, inversion to estimate sources and sinks using atmospheric models
- Innovative methodologies using tracers and isotopes to attribute CO_2 sources to fossil, oceanic, and terrestrial processes

Angus Tall tower, CO_2 signal

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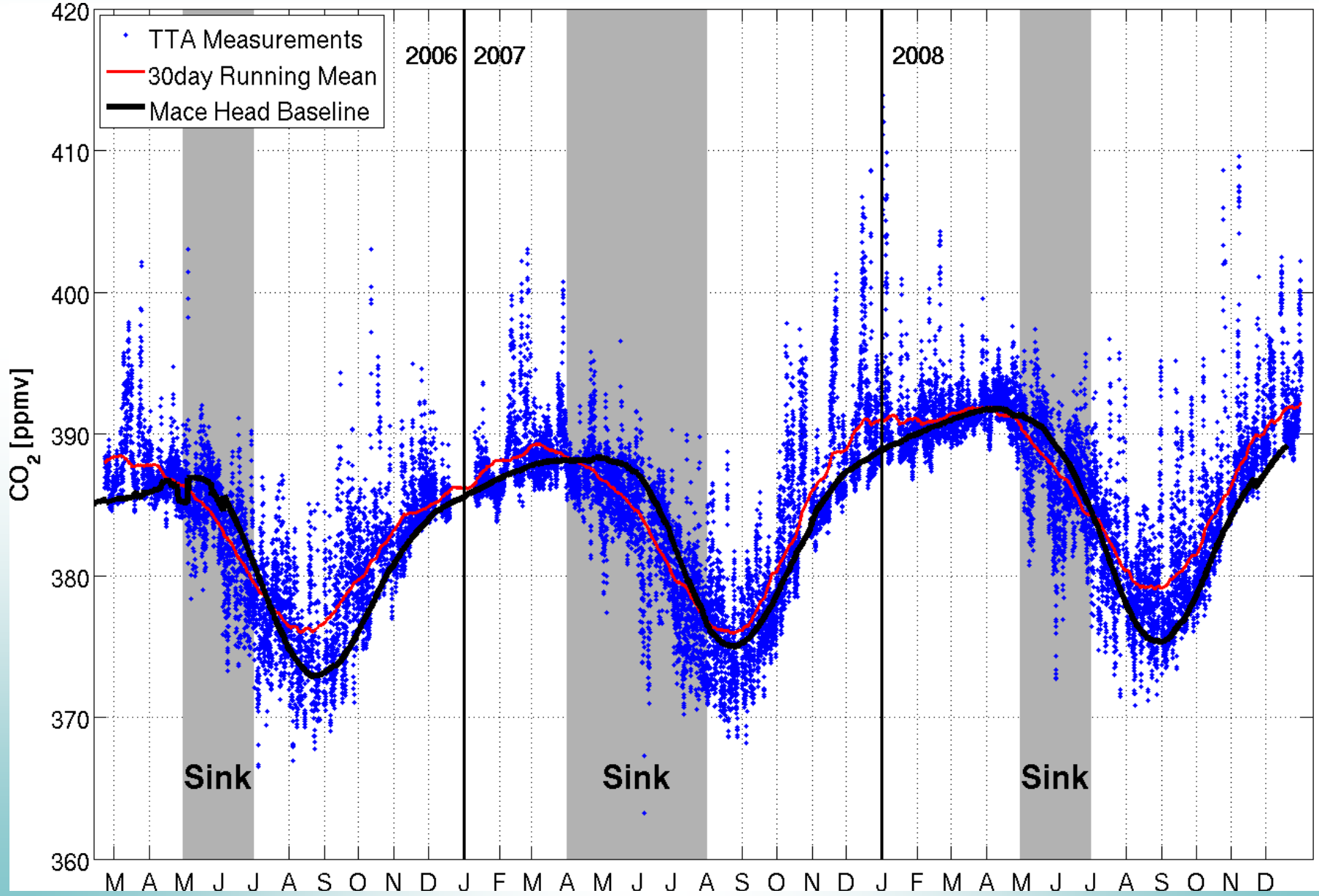

Funded through Carboeurope-IP and DEFRA/CEH, John Moncrieff, Rob Clement, Paul Parrish

Modelled country scale fluxes for Scotland from concentrations at Mace head and in Eastern Scotland (Angus)

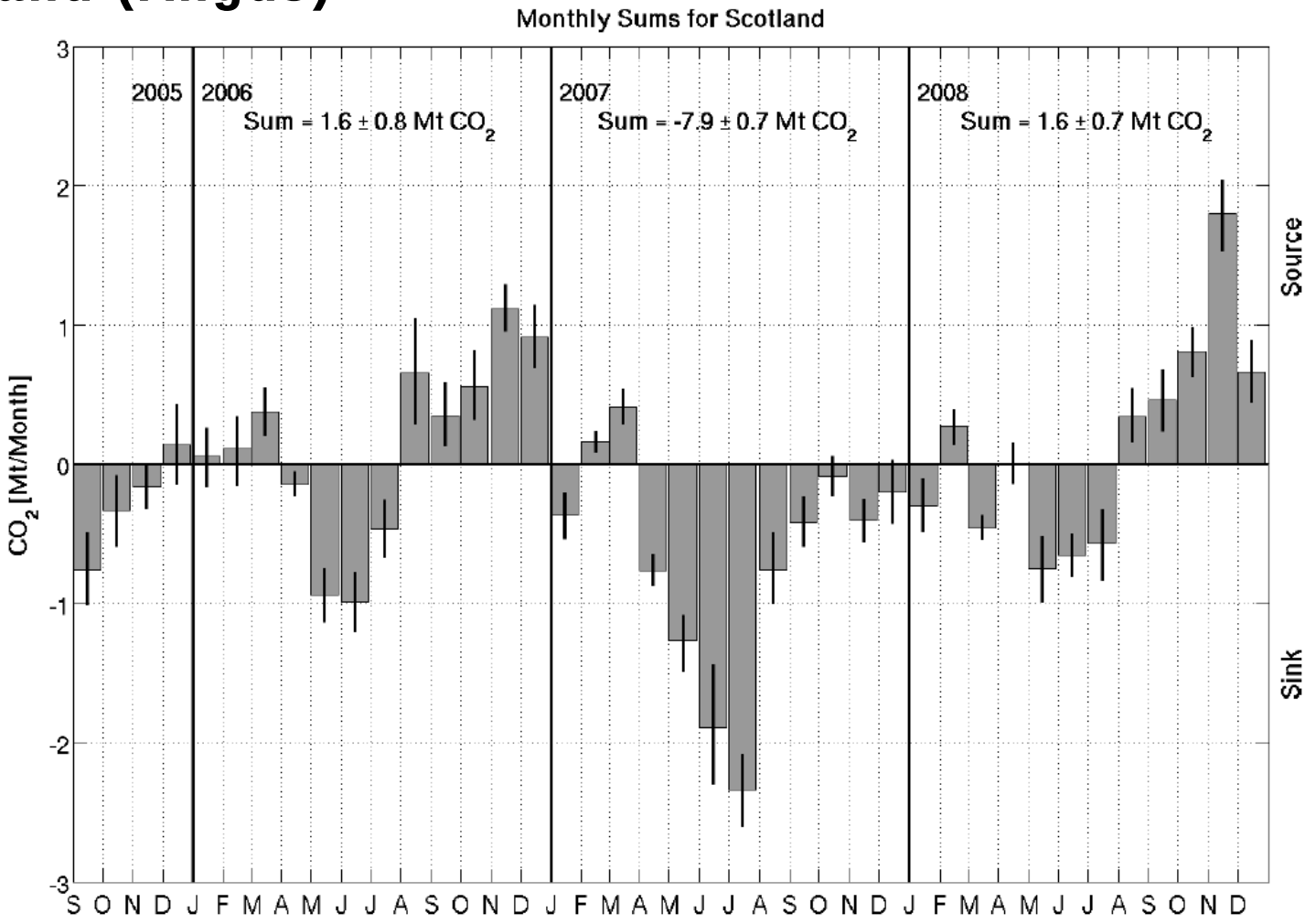

Figure 10: *[Incomplete plot: will be adding a montly representative box plots at the bottom to illustrate the amount of data that the montly sums are based on.]* Calculated net regional exchange (mass) estimates for Scotland, with 95% confidence intervals.

Parrish *et al* (in prep)

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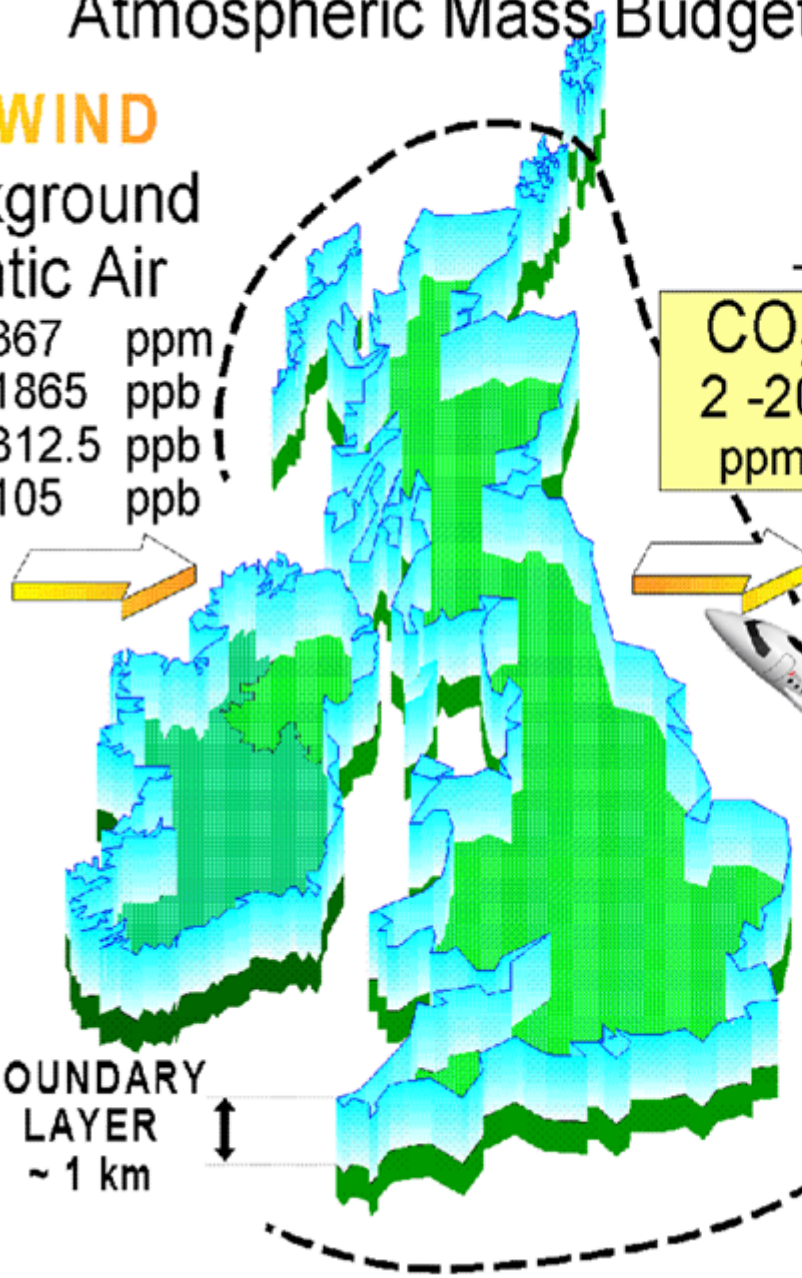
Boundary layer budget at the country scale using aircraft

Atmospheric Mass Budgets at Regional Scales



UPWIND

Background Atlantic Air

CO_2	367	ppm
CH_4	1865	ppb
N_2O	312.5	ppb
CO	105	ppb

DOWNWIND

+'veΔ BOUNDARY LAYER ENHANCEMENT

CO_2	CO	CH_4	N_2O
2 -20 ppm	10 -100 ppb	20 -150 ppb	0.5 - 4 ppb

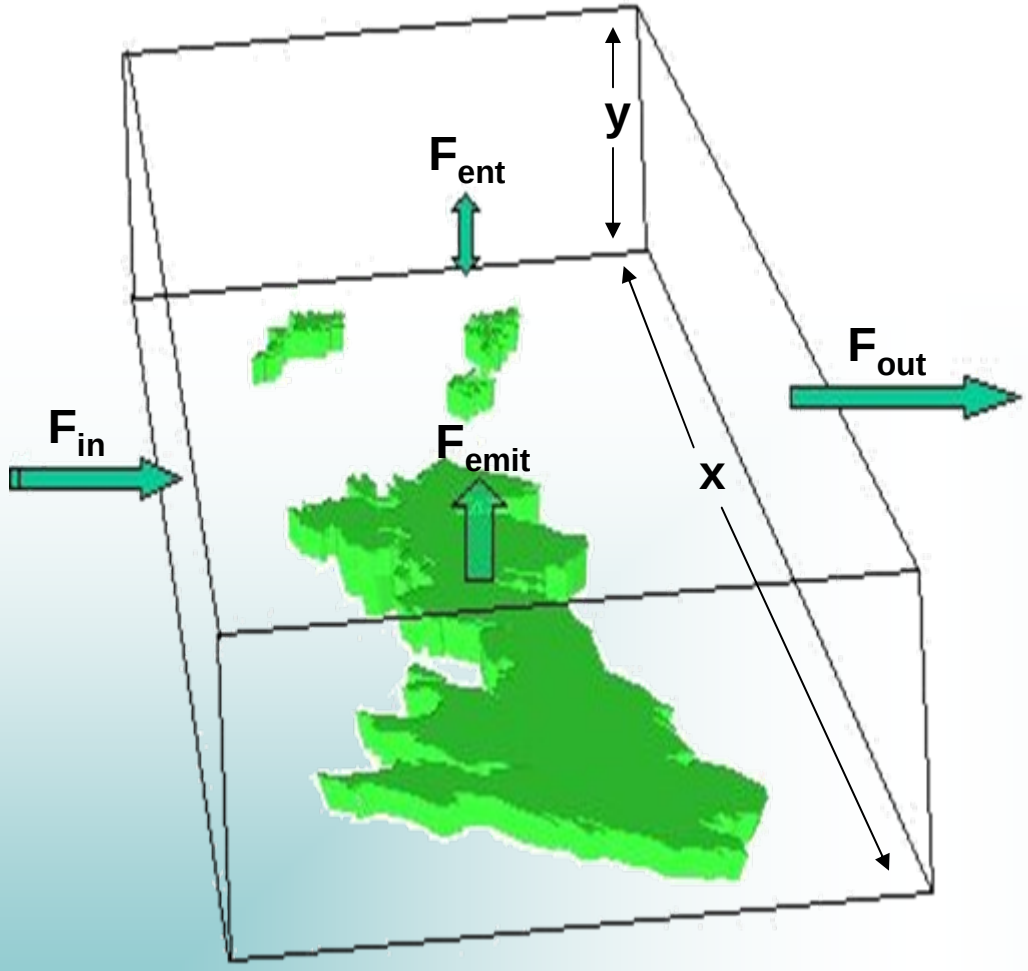
sampling at 30 m, with profiles every 100 km along trajectory

BOUNDARY LAYER ~ 1 km

REQUIRES

- clearly defined boundary layer
- no deep convection
- no frontal activity along trajectory
- steady boundary layer winds (3-15 ms^{-1})

Estimating Annual Emissions – Box Technique



- $F_{emit} = F_{out} – F_{in} – F_{ent}$
- $F_{in} = \iint u_{in}(y,z)c(y,z)dydz$
- $F_{out} = \iint u_{out}(y,z)c(y,z)dydz$
- $F_{ent = 0}$

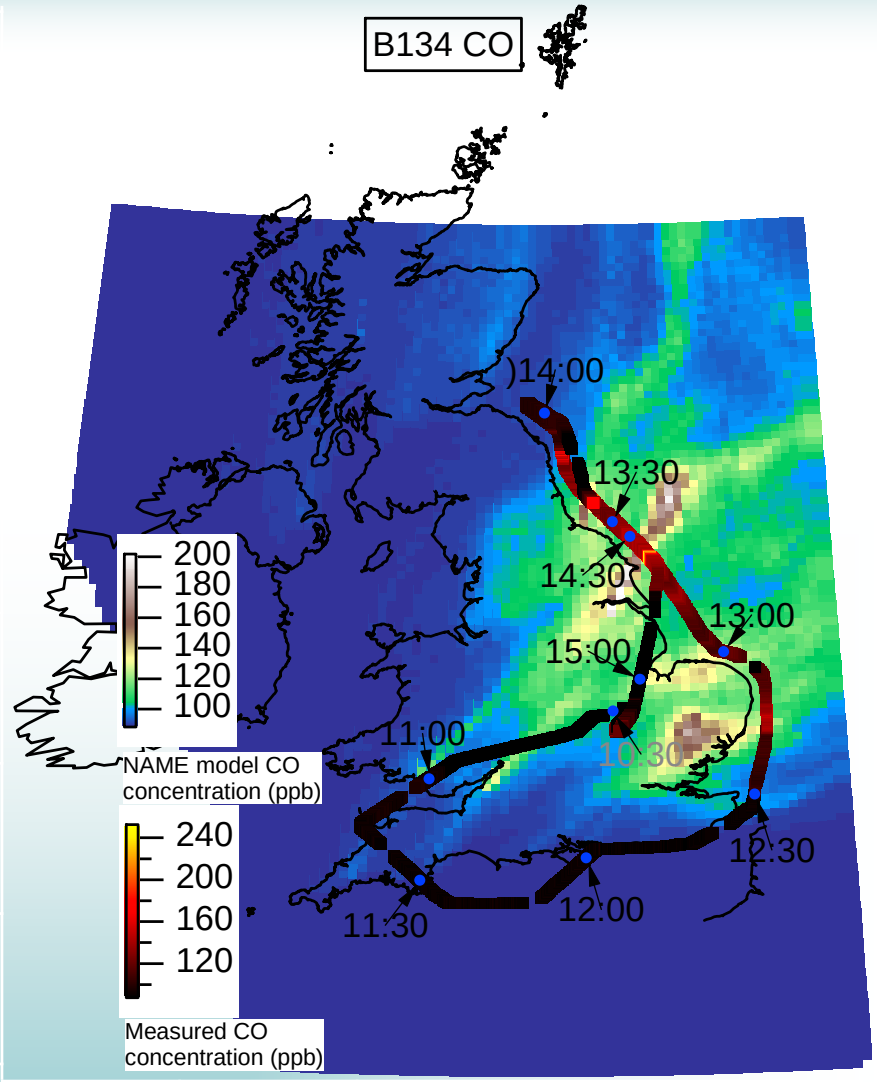
F_{emit} = Flux emitted

F_{in} = Flux in

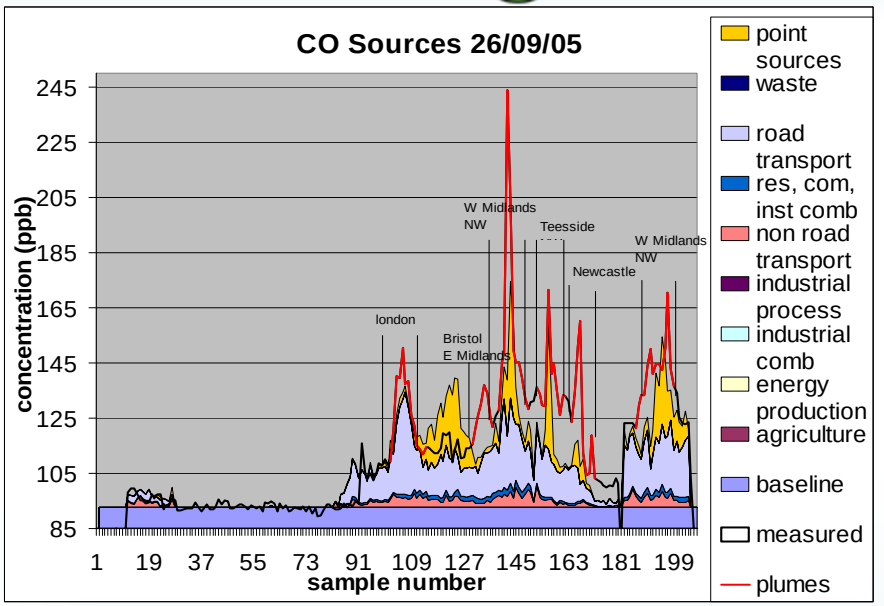
F_{out} = Flux out

u = wind speed

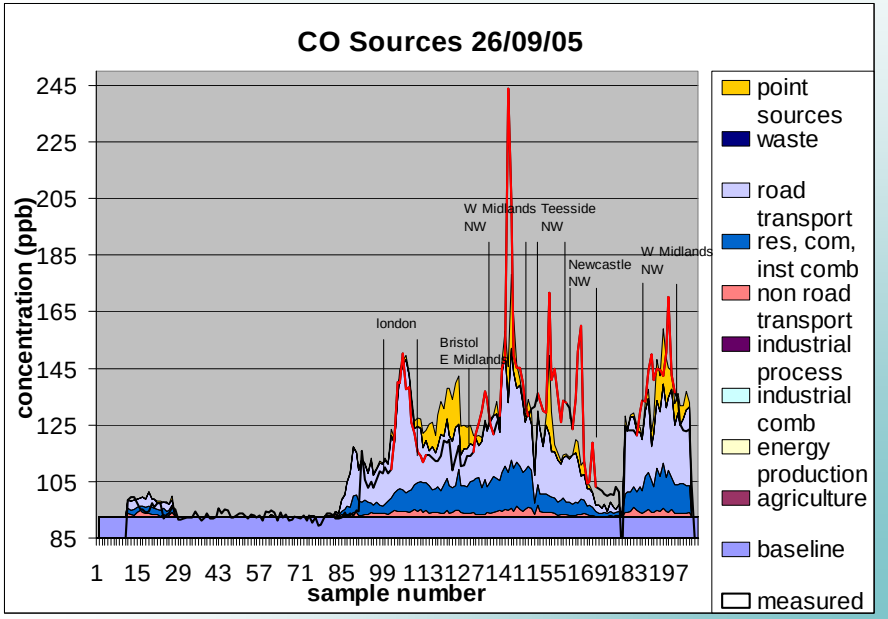
c = concentration



Original emissions



Adjusted emissions



UK Facility Airborne Atmospheric Measurement (FAAM): BAe-146

Flight duration: max. 5:30 hours

Results: NAME Sectorial Emission Adjustment Technique

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	CO (kT/y)	CO_2 (kT/y)	N_2O (kT/y)	CH_4 (kT/y)
NAEI (2003)	2757	572196	130	1933
B92	1900 ± 147	490000 ± 68500	880 ± 456	*8700 $\pm^{7770}_{6870}$
B97	3700 ± 605	470000 ± 117000	540 ± 427	4600 ± 1190
B102	2700 ± 250	410000 ± 93000	620 ± 334	*****
B111	*3000 ± 202	*1200000 ± 181000	*930 ± 223	*****
B112	1700 ± 292	620000 $\pm^{222000}_{130000}$	*2200 $\pm^{1260}_{239}$	9600 ± 3440
B113	2800 ± 847	840000 ± 319888	*2900 ± 893	12000 ± 6910
B118	800 ± 141	650000 ± 87266	320 ± 199	*****
B119	1900 ± 102	510000 ± 145000	190 ± 106	*****
B126	3300 ± 66	620000 ± 130000	3800 $\pm^{3760}_{3938}$	9300 ± 2730
B130*	2400 ± 48	420000 ± 82800	200 ± 72	1900 $\pm^{661}_{231}$
B132*	1600 ± 43	330000 ± 127000	390 ± 64	1600 ± 210
B134	4700 ± 167	510000 ± 75200	320 ± 186	6500 $\pm^{4070}_{3510}$
B136	2900 ± 334	580000 ± 246000	620 ± 532	*2800 $\pm^{1570}_{1390}$
AVERAGE	2400 ± 226	560000 $\pm^{139000}_{133000}$	350 ± 208	4000 $\pm^{1400}_{1290}$

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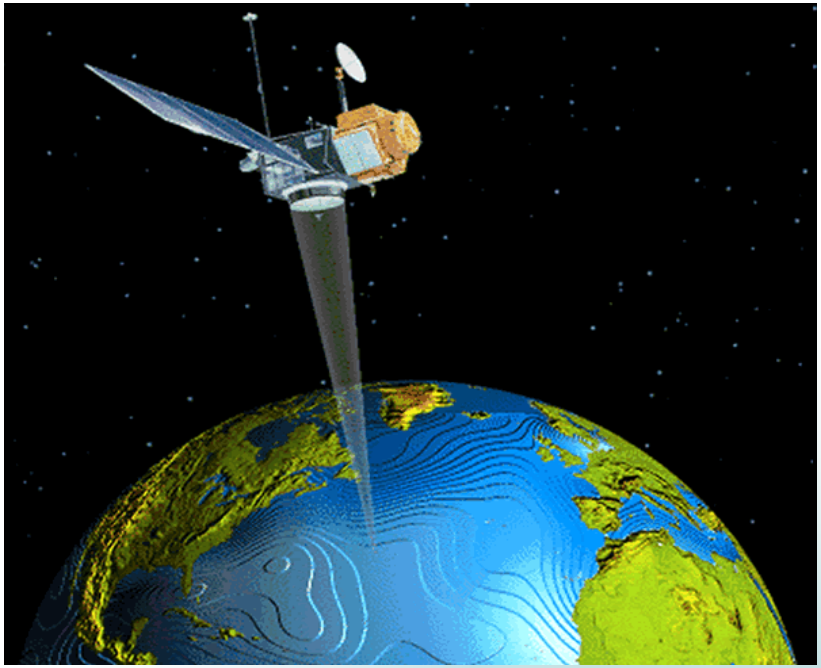
Summary of Annual Emissions Estimates (kt yr^{-1})

	CO	CO_2	N_2O	CH_4
UK Inventory	2,757	572,196	130	1,933
Ireland Inventory	239	43,469	31	607
NAME	2,400 ± 226	$560{,}000 \pm {}^{139{,}000}_{133{,}000}$	350 ± 208	$4{,}000 \pm {}^{1400}_{1290}$
Box Approach	2,700 ± 898	670,000 ±294,000	310 ± 217	4,200 ± 2,130

Remote sensing

- Satellite remote sensing provides opportunities to deduce regional or continental scale GHG fluxes



SCIAMACHY methane (CH4) columns

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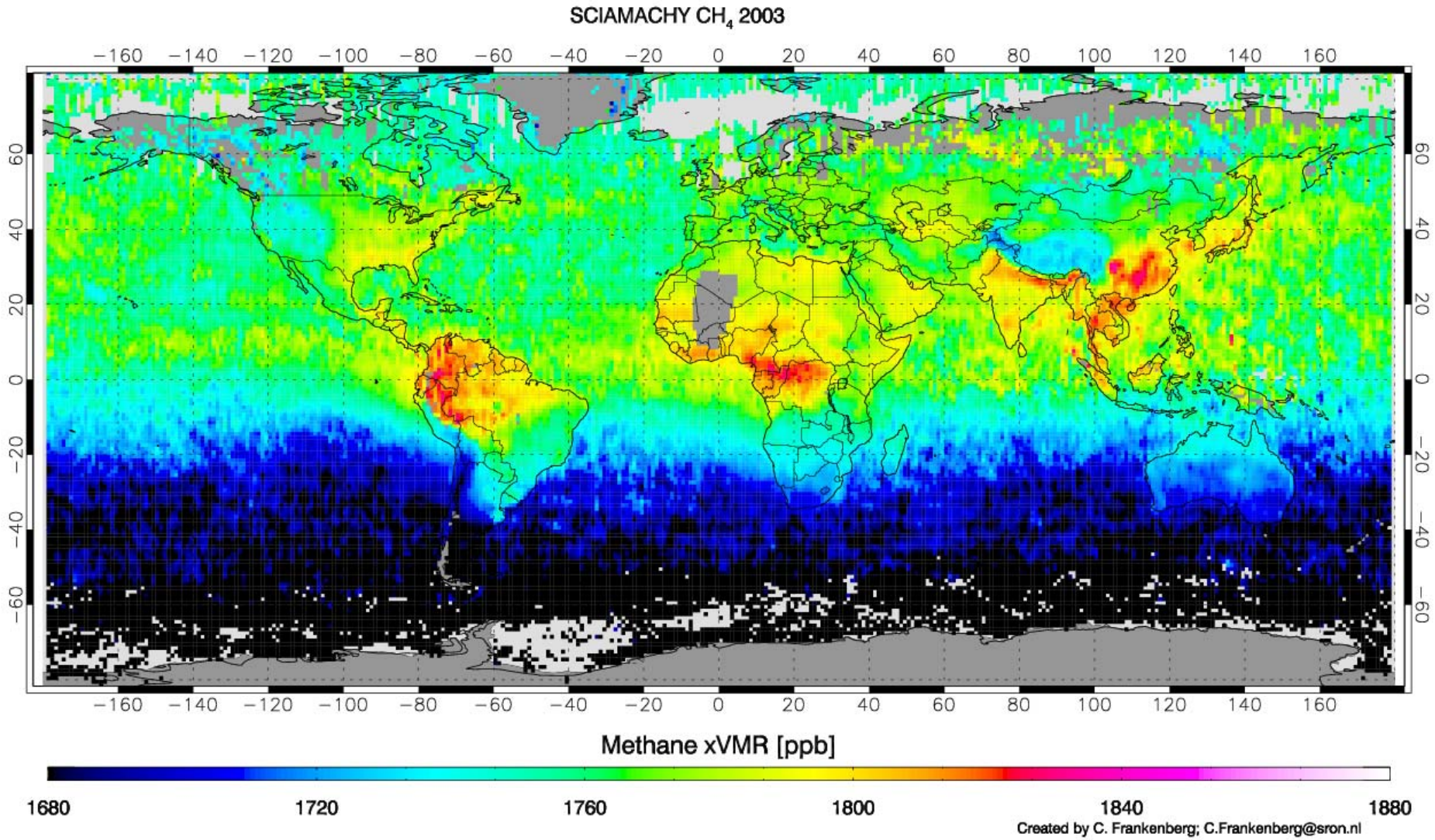
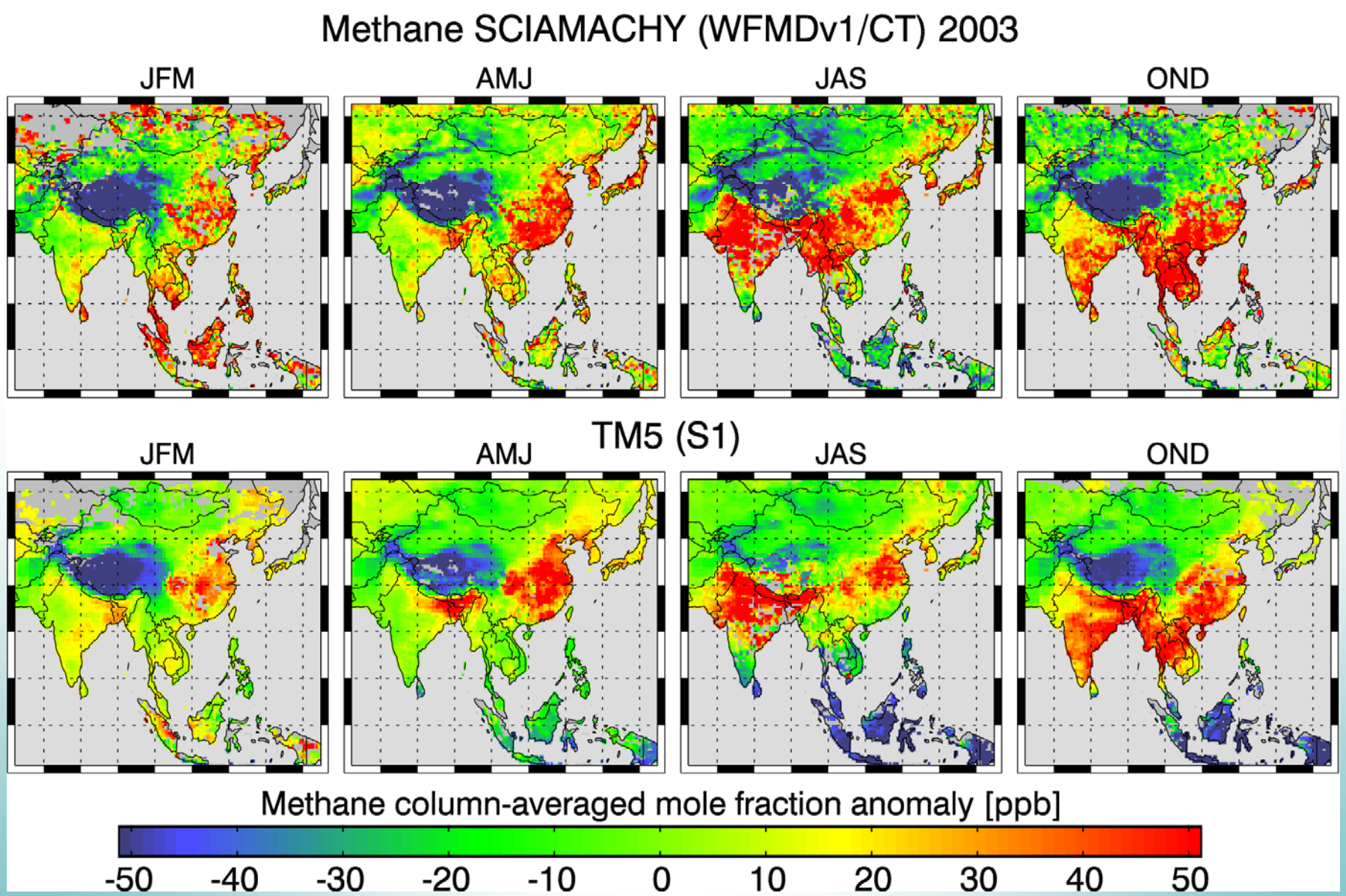


Frankenberg et al.

SCIAMACHY CH4: China & India



Schneising et al., ACPD, 2008

- Three years of SCIAMACHY CO_2 and CH_4 retrievals (2003-2005) have been analysed
- CO_2 (WFMDv1.0; Schneising et al., ACP, 2008a):
  - Reasonable to good agreement with NOAA's CarbonTracker (annual increase, seasonal cycle NH, regional pattern); retrieved variability higher
  - Strong indications for up to several ppm error due to subvisual cirrus (e.g., seasonal cycle SH)
  - Advanced retrieval algorithm under development
- CH_4 (WFMDv1.0 Schneising et al., ACPD, 2008b; v1.1):
  - Good agreement with TM5/JRC except tropics (inversion ongoing at JRC)
  - 2003-2005 data reprocessed (v1.1) using new spectroscopic H_2O and CH_4 line parameters (see Frankenberg et al., GRL, 2008)
  - Analysis ongoing; Preliminary conclusions: Qualitatively we confirm the findings of Frankenberg et al. (e.g. lower tropical methane with new spectroscopy)

Conclusions

- Given the importance of GHG emissions for global climate, it is surprising that systematic validation of national emissions is not a requirement
- Methods for validation are reasonably well advanced, and a range of techniques need to be used
- Tall towers, with flux measurements and inverse modelling appear to provide the most cost effective approach
- Aircraft and remote sensing from satellite are also needed to aid interpretation and for global coverage respectively