Inverse modeling of European GHG emissions and verification of bottom-up inventories

P. Bergamaschi[1], M. Corazza[1], A. Segers[1], F. Dentener[1]

M. Krol[2], J.F. Meirink[3] J.v.Aardenne[1], S.Monni[1]

A. Vermeulen[4], A.J. Manning[5], M. Athanassiadou[5], P. Bousquet[6], R. Thompson[6], I.Pison[6]

M. Schmidt[6], M. Ramonet[6], C. Yver[6], E. Popa[4] L Haszpra[7], J. Moncrieff[8], R. Neubert[9], E.G Nisbet[10], R.E. Fisher[10], F. Meinhardt[11], T. Alto[12], M. Steinbacher[13], S. O'Doherty[14], F. Artuso[15], and E. Dlugokencky[16]

[1]EC-JRC-IES, [2]WUR, [3]KNMI, [4]ECN, [5]UK Mettoffice, [6]LSCE, [7]HMS, [8]UEDIN, [9]CIO-RUG, [10]RHUL, [11]UBA(D), [12]FMI, [13]EMPA, [14]AGAGE, [15]ENEA, [16]NOAA

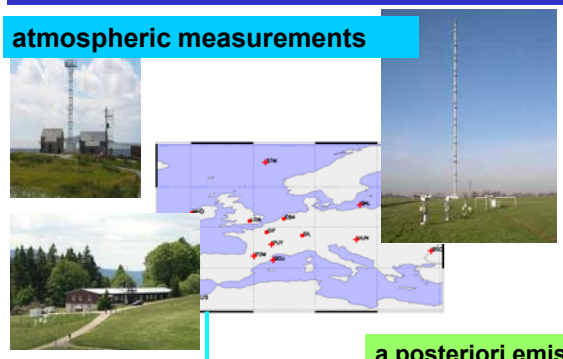
overview

- Introduction
- European CH_4 inversion 2001-2006 (TM5-4DVAR)
- Comparison of inverse models in NitroEurope project (2006-2007)

  CH_4, N_2O

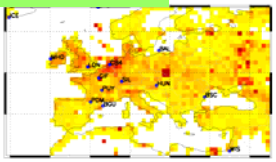
inverse modeling approach

atmospheric measurements

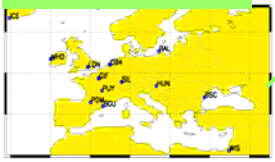


a priori inventory

EDGAR v4.0

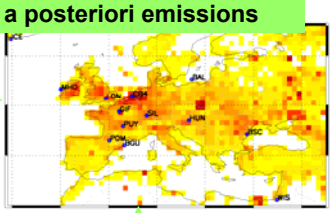


'free' inversion



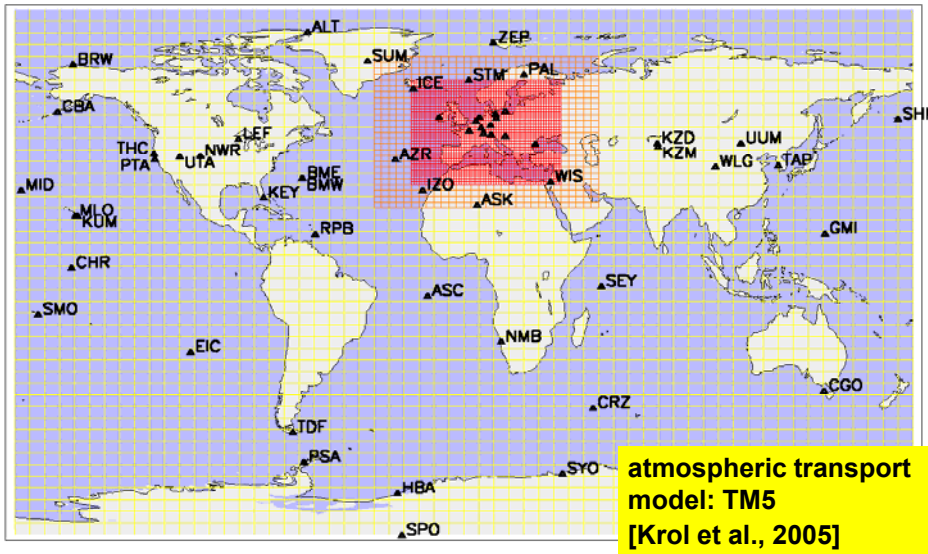
TM5-4DVAR

a posteriori emissions



UNFCCC

TM5 global model / zoom over Europe



atmospheric transport model: TM5
[Krol et al., 2005]

ECMWF meteorology (ERA-Interim)

4DVAR for inverse modelling

4DVAR for inverse modelling

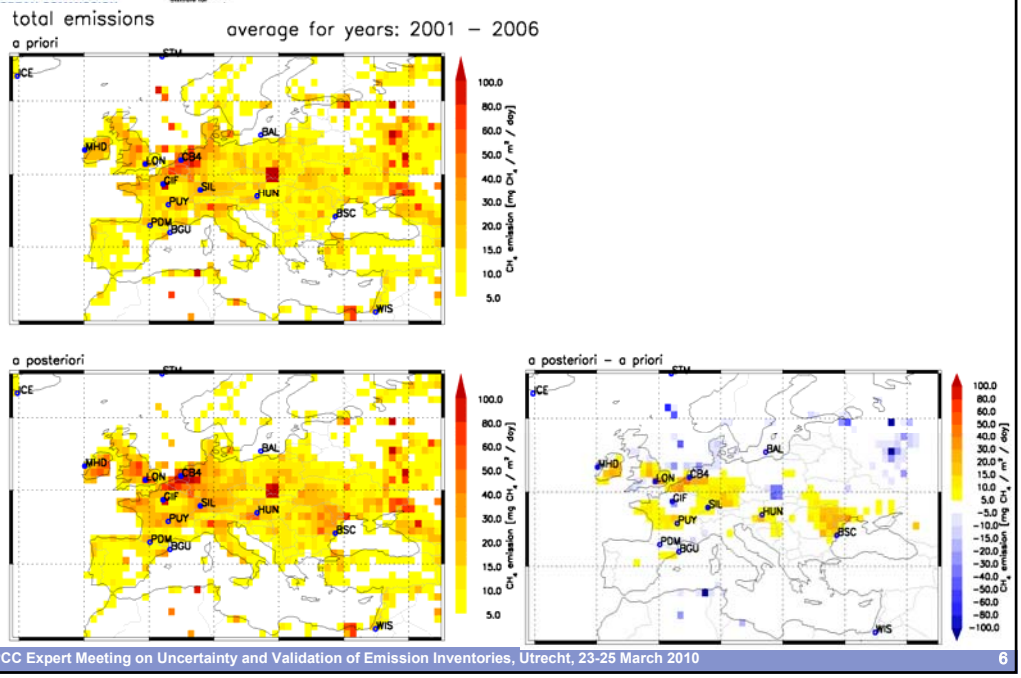
iterative technique, originally developped for NWP

allows optimization of systems with very larger numbers of parameters **AND** observations (n ~ 10^6-10^8)

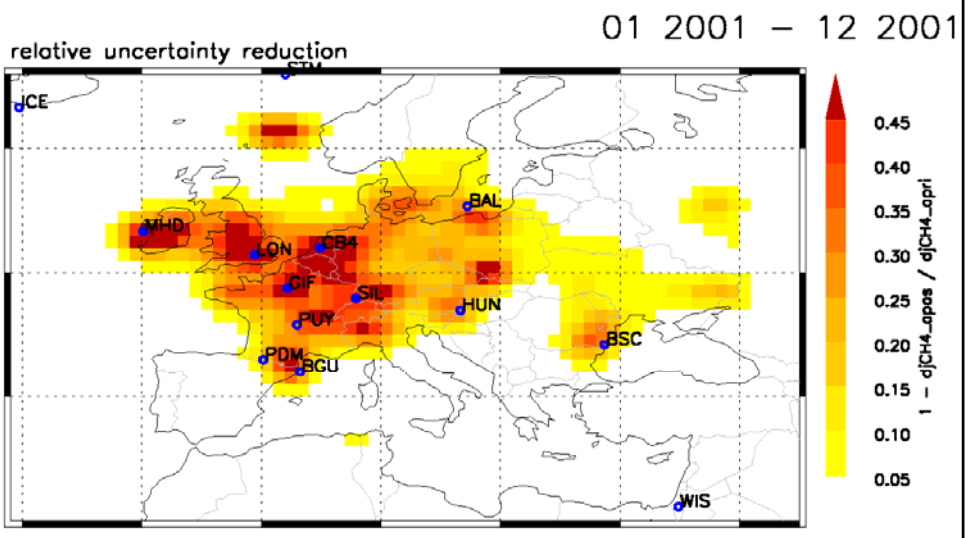
-> Optimization of emissions from individual model grid cells

-> Use of large observational data sets (continuous in-situ measurements, satellite data)

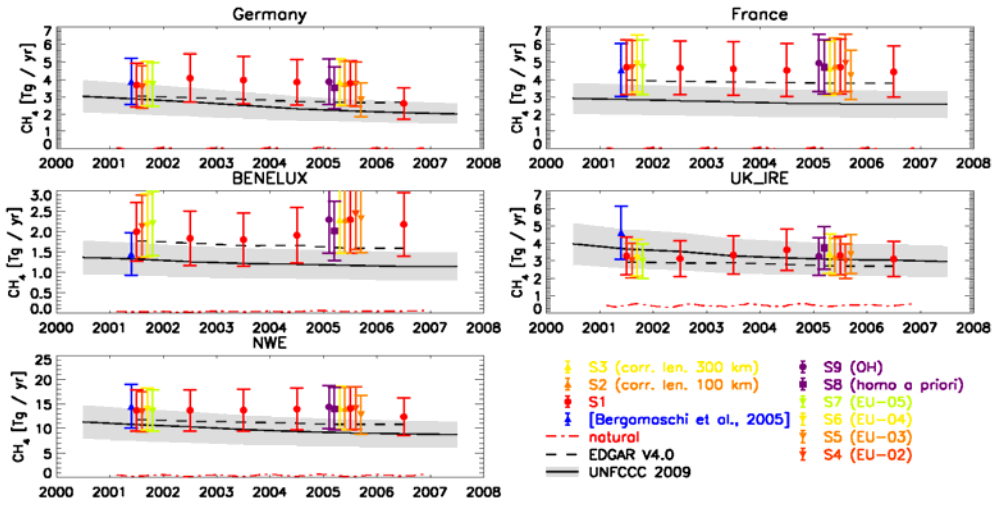
European emissions 2001-2006 average



network sensitivity

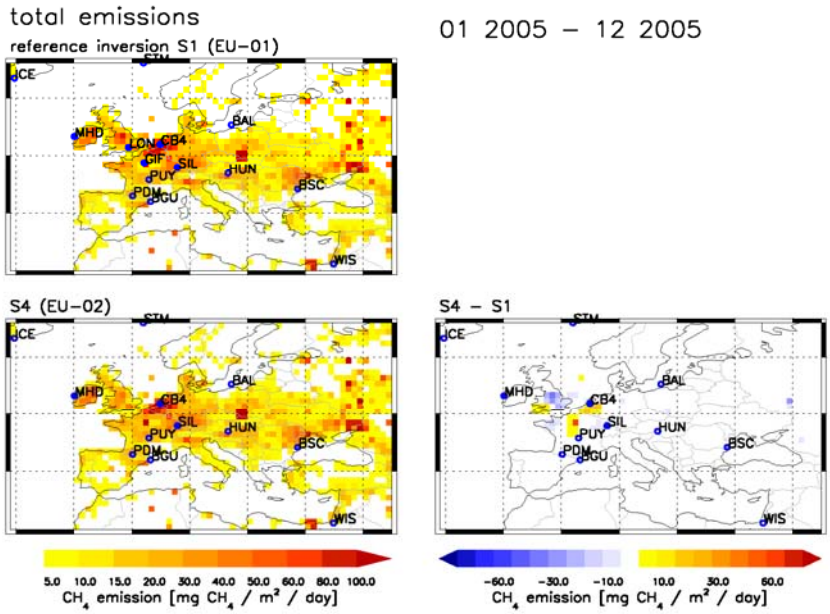


European CH_4 - country totals

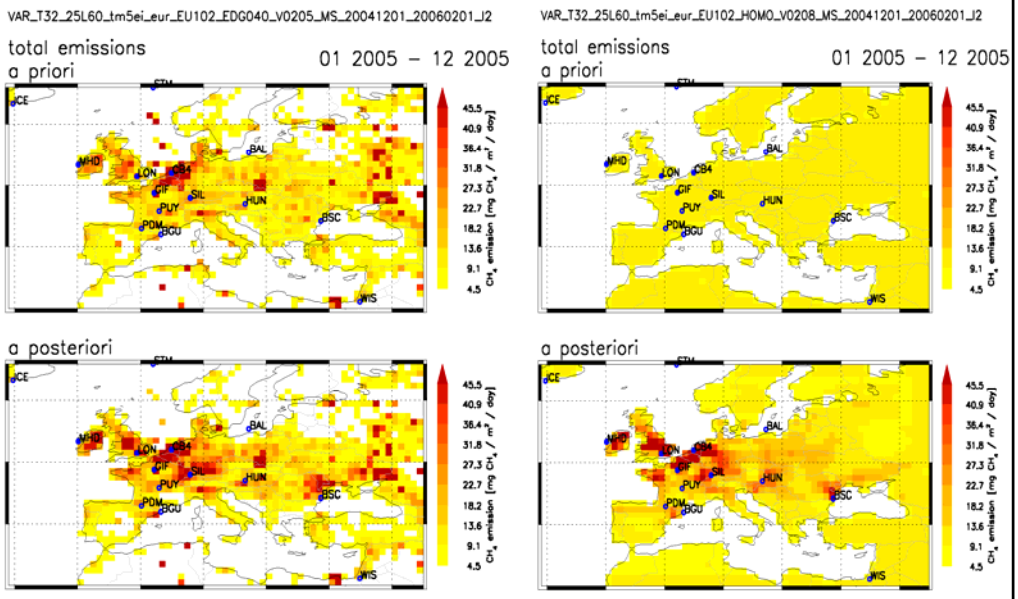


[Bergamaschi et al., *submitted to JGR*, 2010]

sensitivity of emissions on atmos. network



influence of a priori inventory



UNFCCC uncertainty estimates

		UK	IRE	NL	BEL	France	Germany	NWE
solid fuel								
emission (2001-2006)	Tg CH4 / yr						0.37	0.65
rel. uncertainty	%						138.7	83.3
abs. uncertainty	Tg CH4 / yr	0.03	0.00	0.00	0.00	0.00	0.51	0.54
oil + gas								
emission (2001-2006)	Tg CH4 / yr						0.35	0.81
rel. uncertainty	%						64.7 - 75.5	37.7
abs. uncertainty	Tg CH4 / yr						0.22	0.31
ent ferm								
emission (2001-2006)	Tg CH4 / yr						0.84	3.90
rel. uncertainty	%						5.9	23.7
abs. uncertainty	Tg CH4 / yr						0.05	0.93
manure management								
emission (2001-2006)	Tg CH4 / yr	0.14	0.11	0.13	0.08	0.67	0.26	1.39
rel. uncertainty	%	30.0	11.2	69.7	41.2	50.2	11.6	39.0
abs. uncertainty	Tg CH4 / yr	0.04	0.01	0.09	0.03	0.34	0.03	0.54
solid waste								
emission (2001-2006)	Tg CH4 / yr						0.59	2.42
rel. uncertainty	%						12.5	38.9
abs. uncertainty	Tg CH4 / yr						0.07	0.94
waste water								
emission (2001-2006)	Tg CH4 / yr	0.04	0.00	0.01	0.01	0.06	0.01	0.12
rel. uncertainty	%	50.0	31.6	32.0	72.8	104.4	45.3	75.0
abs. uncertainty	Tg CH4 / yr	0.02	0.00	0.00	0.00	0.06	0.00	0.09
total								
total 'major categories'		2.58	0.63	0.79	0.33	2.55	2.41	9.29
total all anthropogenic		2.65	0.64	0.85	0.35	2.70	2.46	9.65
total uncertainty	Tg CH4 / yr	0.55	0.07	0.15	0.08	0.67	0.56	1.56
rel. uncertainty	%	21.3	11.0	18.5	24.9	26.5	23.4	16.8
rel. uncertainty	%	23		16-25				

solid fuel: 13% (UK) - 139% (D)

oil + gas: 10% (IRE) - 76% (D)

ent. fermentation: 6% (D) - 40% (F)

solid waste: 12% (D) - 54% (F)

2σ uncertainties

total uncertainties: 11% (IRE) - 27% (F)

UNFCCC vs. EDGAR

average 2001-2005

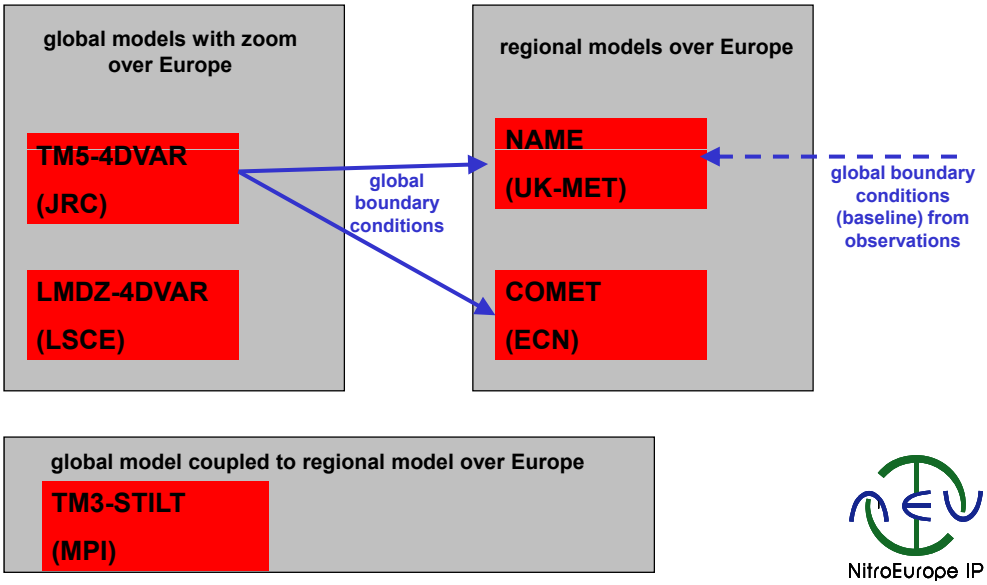
	solid fuel Tg CH_4/yr	oil and gas Tg CH_4/yr	ent ferm + man Tg CH_4/yr	waste Tg CH_4/yr	other Tg CH_4/yr	total Tg CH_4/yr	difference EDGAR / UNFCCC %
UK							
UNFCCC	0.26	0.32	0.92	1.14	0.07	2.70	
EDGAR	0.14	0.67	1.21	0.11	0.04	2.16	-20.0
Ireland							
UNFCCC	0.00	0.01	0.55	0.07	0.01	0.64	
EDGAR	0.00	0.07	0.56	0.01	0.00	0.64	0.6
BENELUX							
UNFCCC	0.00	0.06	0.70	0.39	0.08	1.24	
EDGAR	0.00	0.27	0.78	0.62	0.04	1.70	37.7
France							
UNFCCC	0.04	0.09	2.05	0.38	0.16	2.72	
EDGAR	0.02	1.43	1.77	0.48	0.15	3.86	41.8
Germany							
UNFCCC	0.39	0.35	1.11	0.63	0.05	2.53	
EDGAR	0.29	0.39	1.45	0.67	0.10	2.89	14.4
NWE							
UNFCCC	0.69	0.83	5.33	2.62	0.37	9.83	
EDGAR	0.45	2.83	5.76	1.89	0.33	11.26	14.6

model uncertainties

	calc. uncertainty	potential additional uncertainty	overall uncertainty
	%	%	%
UK+Ireland	14.1	~30	~33
BENELUX	20.5	~30	~36
France	13.7	~30	~33
Germany	15.2	~30	~34
NWE	6.6	~30	~31

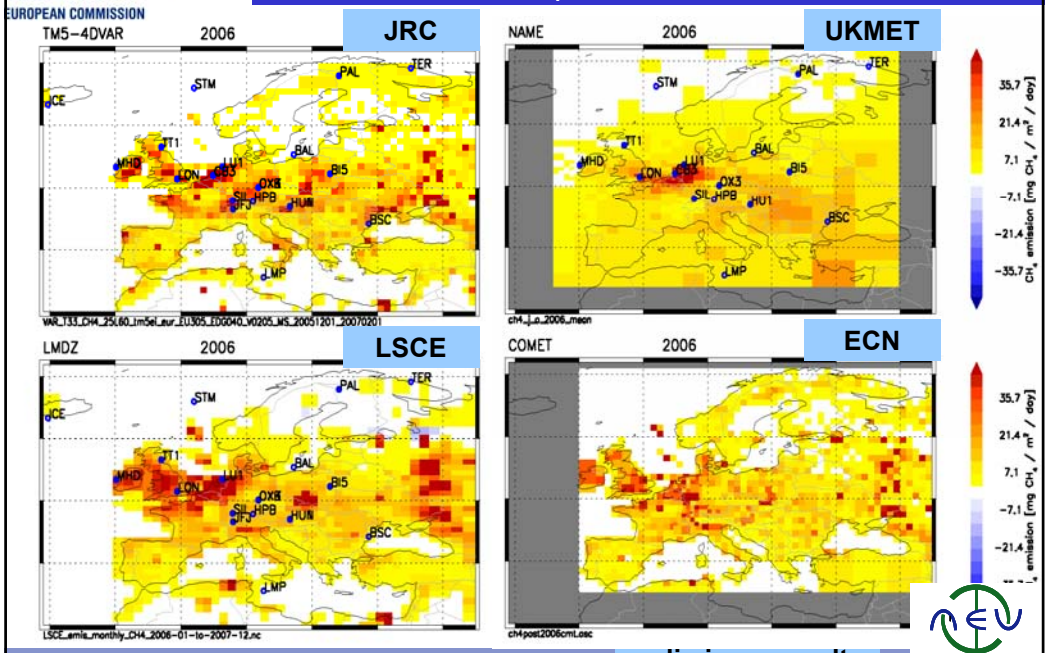
2σ uncertainties

5 inverse models



NitroEurope IP

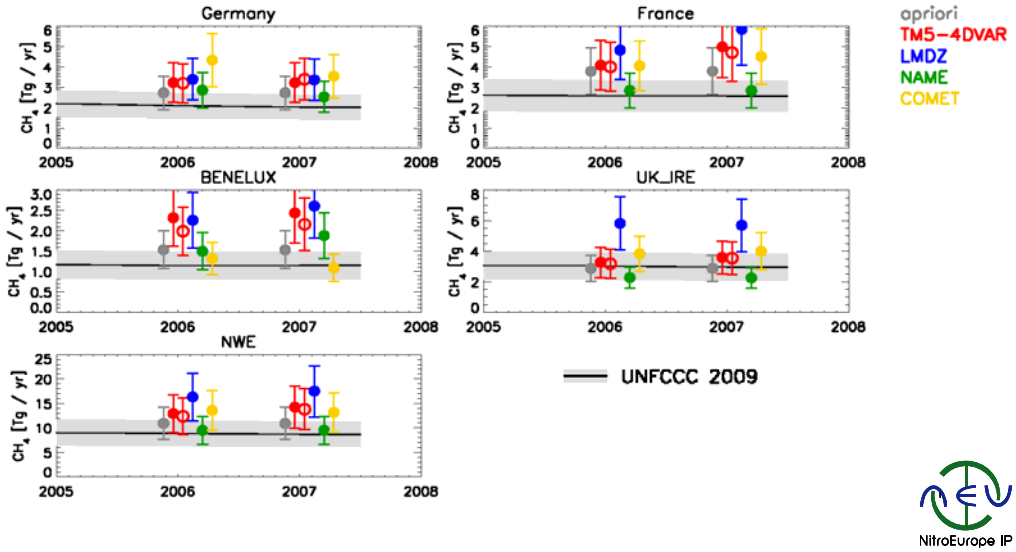
CH_4 inversion 2006



IPCC Expert Meeting on Uncertainty and Validation of Emission Inventories, Utrecht, 2 **preliminary results**

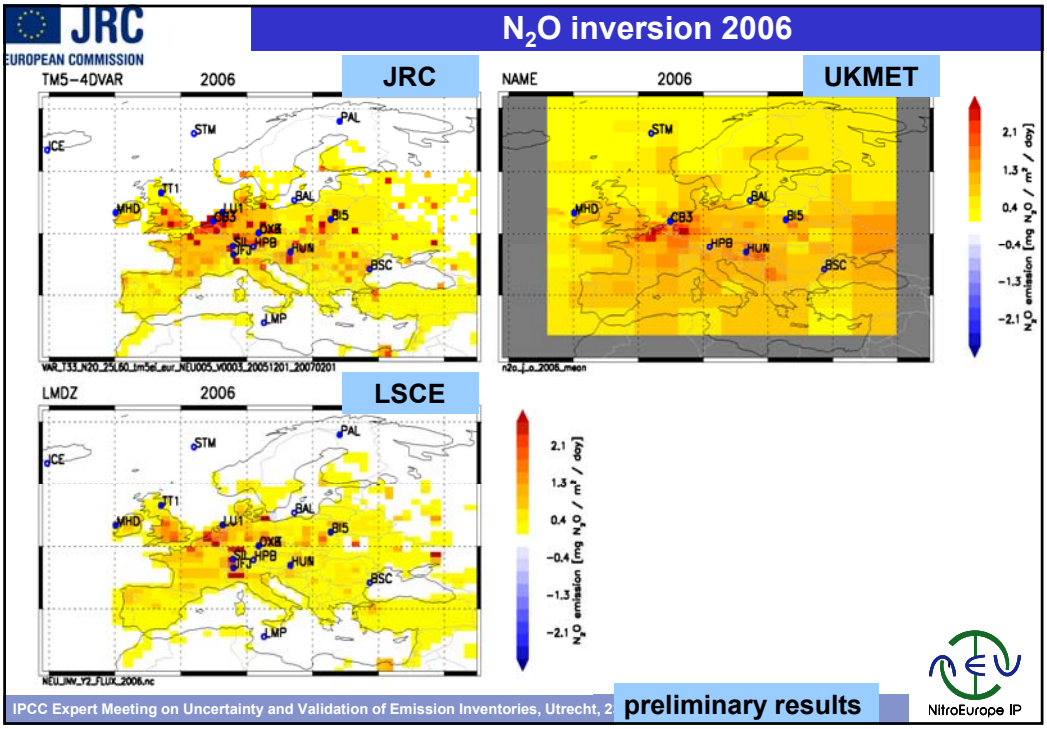
NitroEurope IP

European CH_4 emissions - country totals NWE



NitroEurope IP

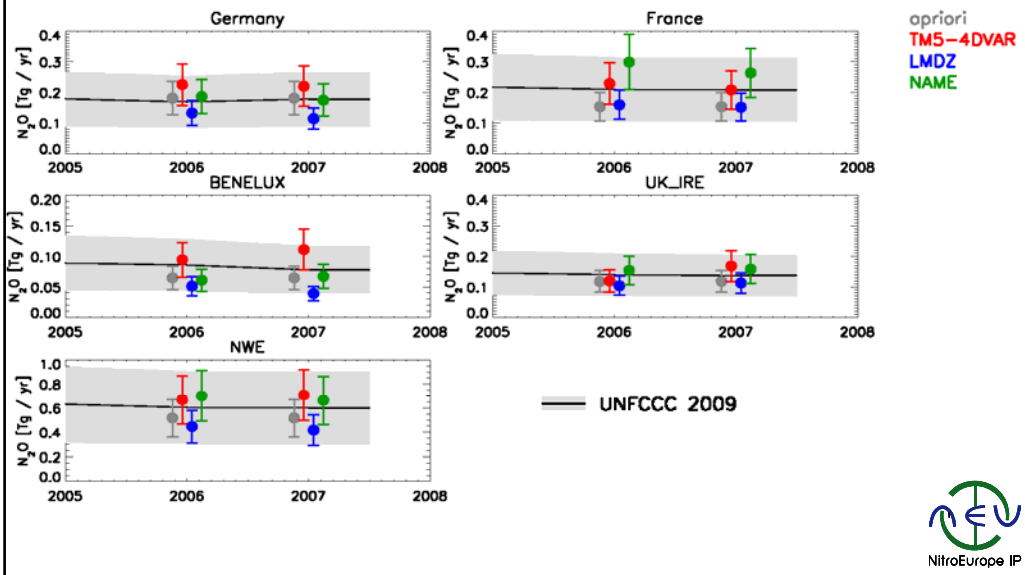
N_2O inversion 2006



preliminary results

NitroEurope IP

European N_2O emissions - country totals NWE



NitroEurope IP

preliminary results

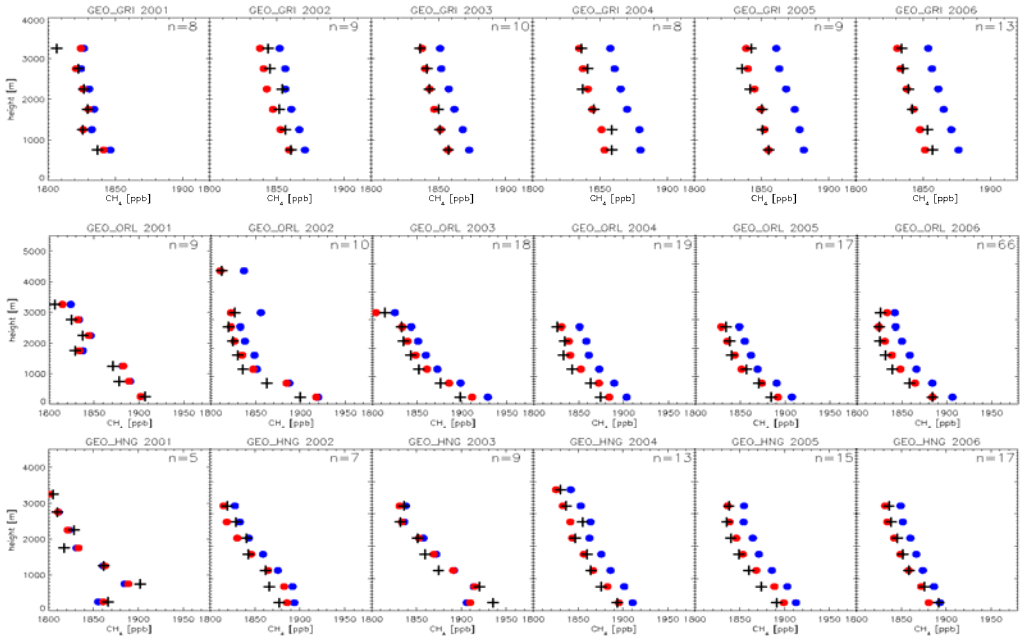
Conclusions

- TM5-4DVAR: CH_4 emissions NWE (2001-2006):
- 40% higher than UNFCCC (France: 71%, BENELUX: 64%, D: 49%)
- 21% higher than EDGARv4.0
- NitroEurope inverse models: tendency to somewhat higher top-down CH_4 emission estimates for NWE compared to UNFCCC (3 of 4 models)
- conclusions about consistency between bottom-up and top-down depend on assumed uncertainties
- UNFCCC uncertainties shows large differences among countries; total uncertainties generally relatively low
- model uncertainties: model intercomparison gives range of ~±30%
- N_2O: top-down emission estimates for NWE close to UNFCCC
- NitroEurope CH_4 and N_2O intercomparison results still preliminary, will be refined and complemented in 2010

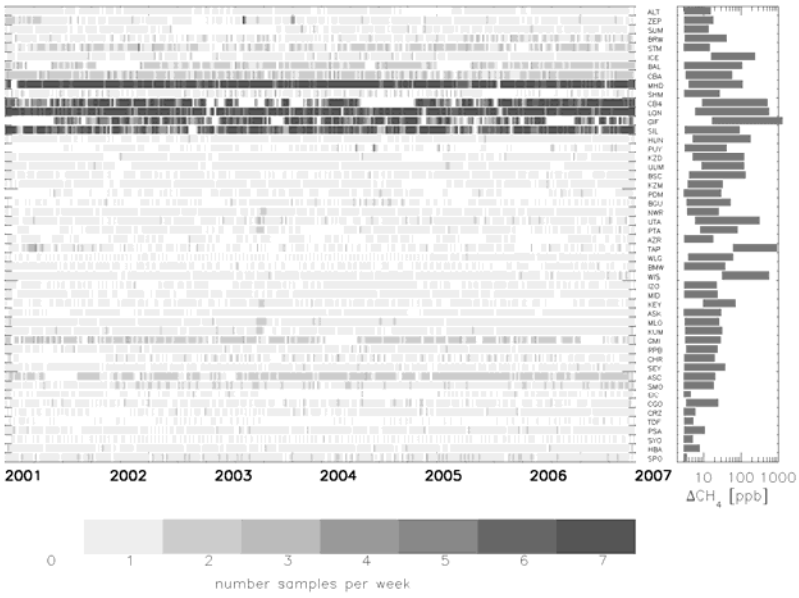
Some issues

- atmospheric models
  - model transport (in particular vertical mixing)
  - representation of different station types by atmospheric models
- inversion methods
  - use of a priori information
  - weighting of a priori information <-> weighting of observational data
- atmospheric measurements
  - quality of measurements, potential calibration offsets
  - potential impact of local sources
  - network density

validation of vertical gradient

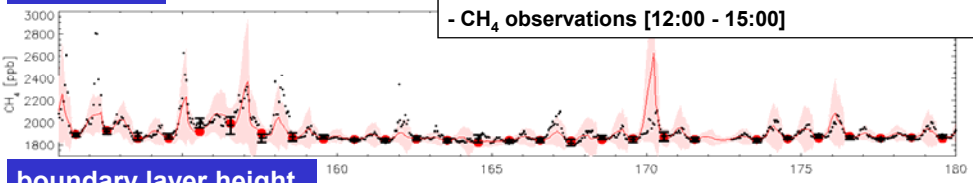


data coverage



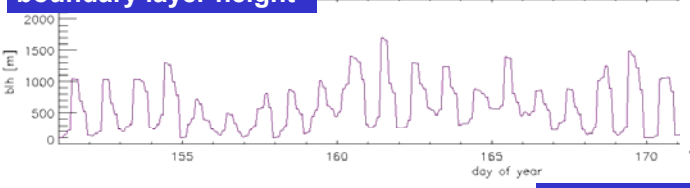
model representativeness error / sampling

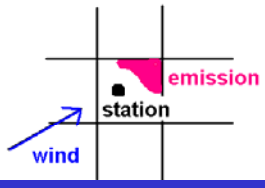
CH_4



- CH_4 (a posteriori) with estimated model repr. error
- CH_4 observations [12:00 - 15:00]

boundary layer height

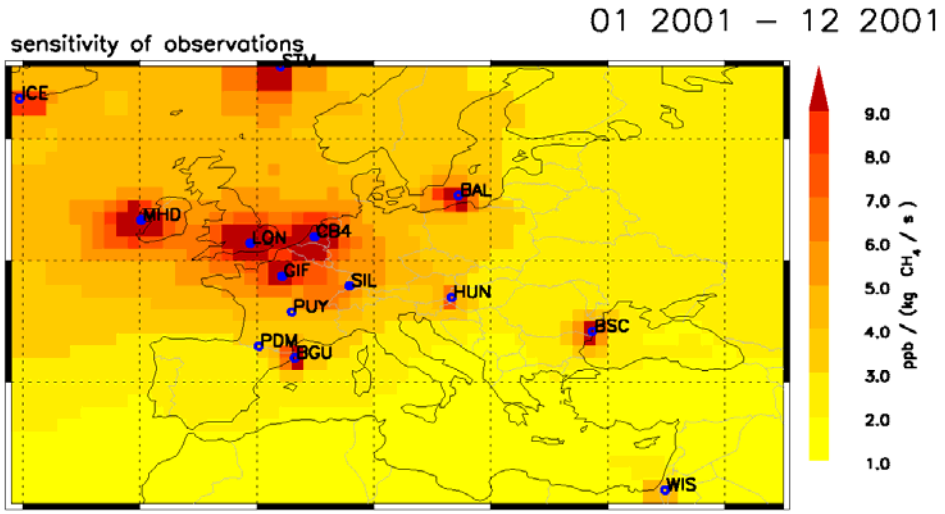




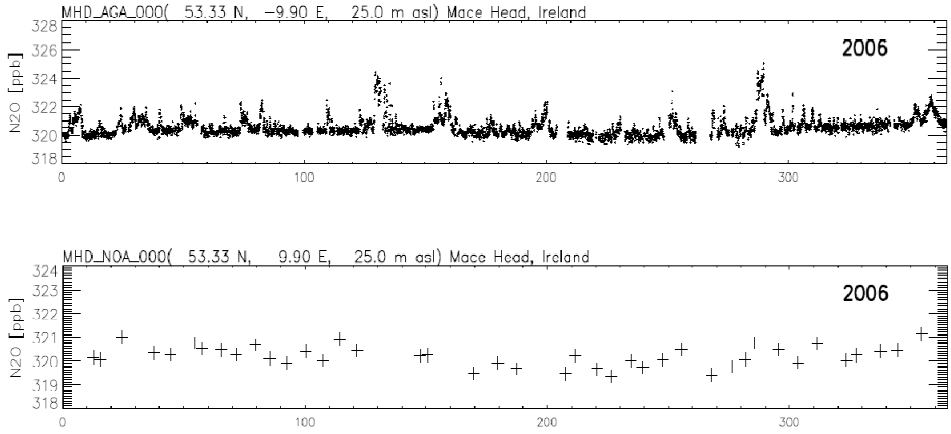
estimate model representativeness error

(due to subgridscale variability of emissions)

sensitivity of network



N_2O calibration offset (MHD)



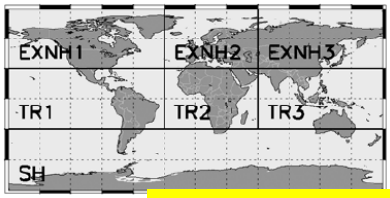
N_2O calibration offset

	Comparison hourly obs	TM5-4DVAR
NOAA	Reference	Reference
Pallas (FMI)	0.5 ±0.3 (n=36)	0.5
Angus (CHI)		0.9
Lutjevad (CHI)		-1.4
Mace Head (AGA)	-0.1 ±0.3 (n=36)	0.0
Bialystok (CHI)		0.3
Cabauw (CHI)		0.1
Ochsenkopf (CHI)	1.0 ±0.4 (n=5)	1.1
Schauinsland (WDC)		0.4
Hegyhatsal (CHI)	1.0 ±1.2 (n=23)	1.0
Schneefernehaus		-
Jungfraujoch (EMP)		-0.4

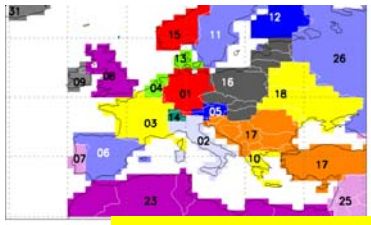
units: ppb N_2O

previous inverse modelling systems

synthesis inversion / 'big-region' inversion



[Bergamaschi et al., 2007]



[Bergamaschi et al., 2005]

[Mikaloff Fletcher et al., 2004]

[Bousquet et al., 2006]