



Top-down estimates of European CH₄ and N₂O emissions using different inverse models and improved observations

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atmospheric measurements

InGOS NA2/3

standardize and improve historical (since 2000) and current in-situ measurements of atmospheric CH₄ and N₂O

- strict QC procedures
- estimates of repeatability and different systematic error components

inverse models

InGOS JRA3

different inverse modelling systems

- ensemble approach -> estimates of the overall model uncertainties
- model validation (²²²Rn, BLH)
- analysis of uncertainty reduction / synthetic inversions (synthetic observations)

CH₄ inversions

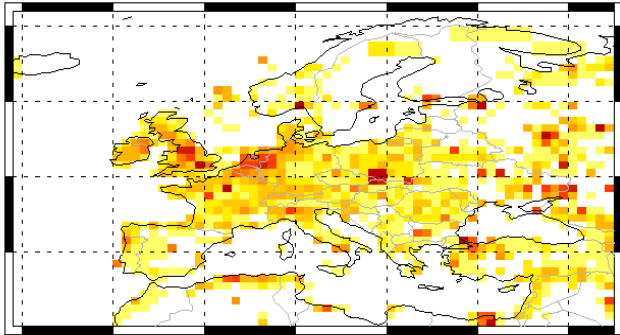


	station list	a priori inventory	period	InGOS data	NOAA+LSCE flask
S1-CH4	CH4_001B	EDGARv4.2FT-InGOS	2007-2011	preliminary	x
S2-CH4	CH4_002B	EDGARv4.2FT-InGOS	2010-2011	preliminary	x
S3-CH4	CH4_002B	no a priori	2010-2011	preliminary	x
S4-CH4	CH4_004	EDGARv4.2FT-InGOS	2006-2012	2014 release	x
S5-CH4	CH4_005	EDGARv4.2FT-InGOS	2010-2012	2014 release	x
S6-CH4	CH4_005	no a priori	2010-2012	2014 release	x
S7-CH4	CH4_007	EDGARv4.2FT-InGOS	2010-2012	2014 release	-

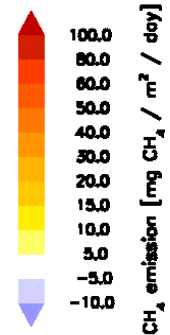
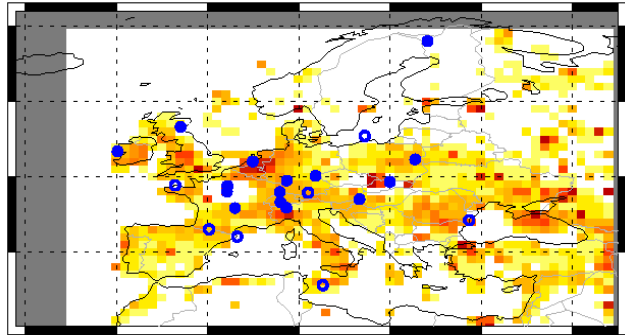
European CH₄ emissions 2010-2011 S2



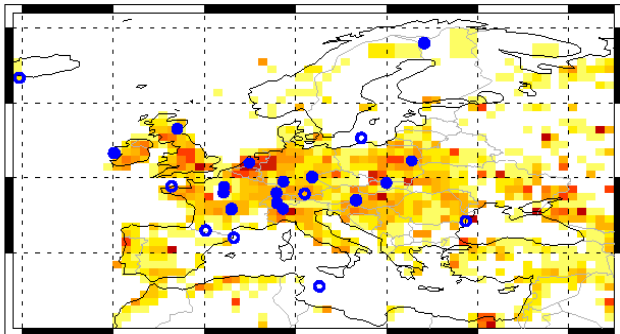
a priori 01/2010-12/2011 S2



FLEXPART 01/2010-12/2011 S2

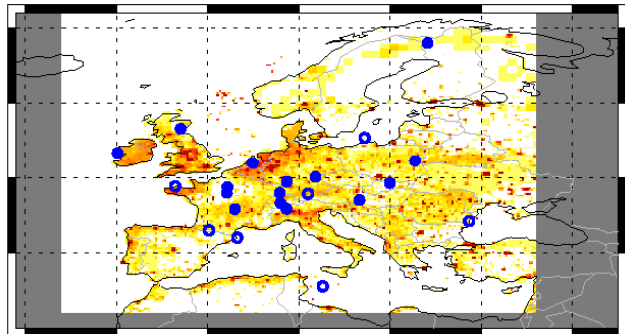


TM5-4DVAR 01/2010-12/2011 S2

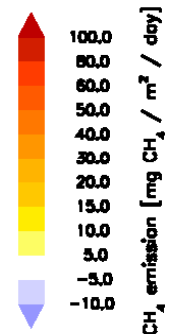


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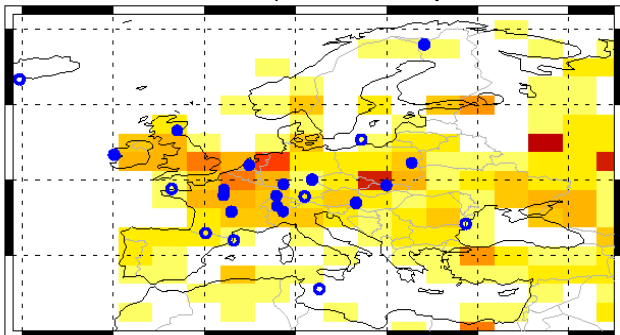
TM3-STILT 01/2010-12/2011 S2



TM3-STILT-CH4_expel_Fus_S2_v6_v6

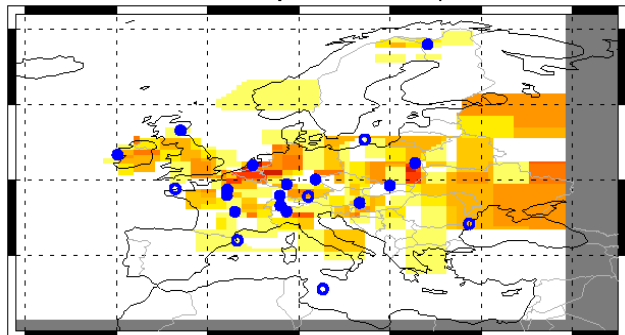


LMDZ 01/2010-12/2011 S2

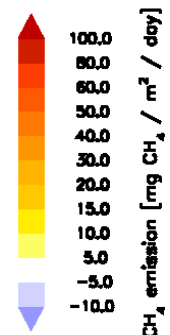


emb_mosmos_monthly_CH4_2009-12-01to2011-12-25.nc

NAME 01/2010-12/2011 S2



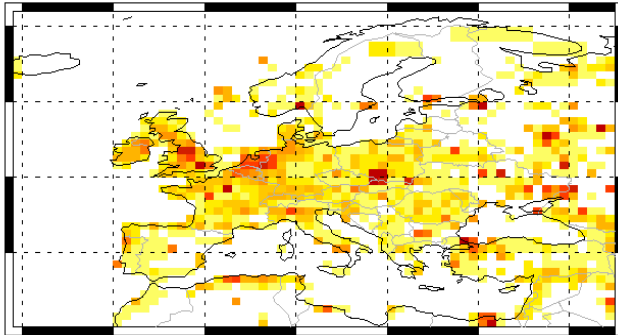
Exp2_emission_map-CH4_IntEM_YYYY_Fnc10_G_best



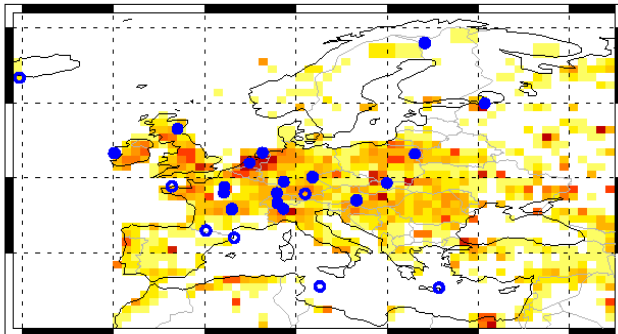
European CH₄ emissions 2010-2012 S5



a priori 01/2010-12/2012 S5

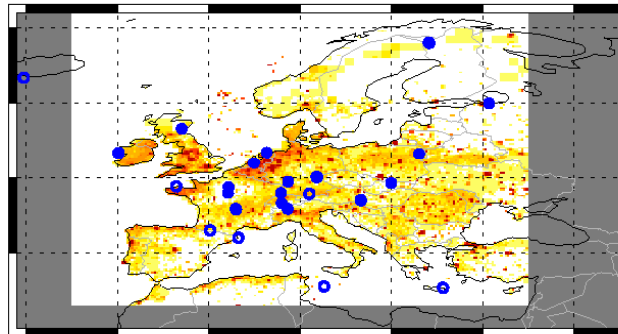


TM5-4DVAR 01/2010-12/2012 S5



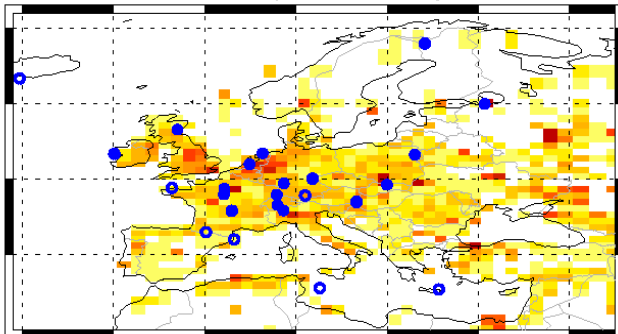
VR_L150_EC2_CH4_gpr_EU05_E42FL_R5_TM_EC_V16

TM3-STILT 01/2010-12/2012 S5

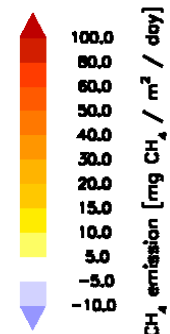
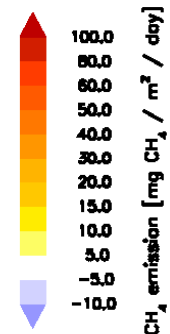


TM3-STILT_ch4_gpr_eu_S5_v0.0c

LMDZ 01/2010-12/2012 S5



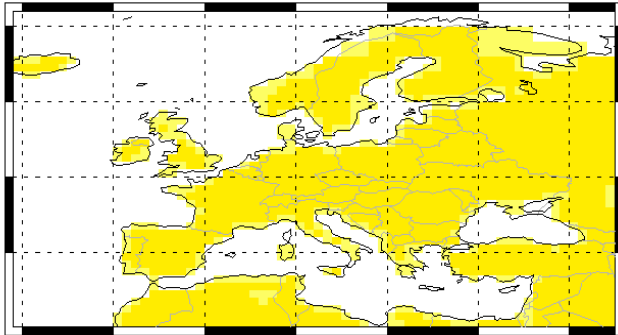
emis_moscat_monthly_CH4_2009-06-01to2012-12-25_S5_LMDZEU.nc



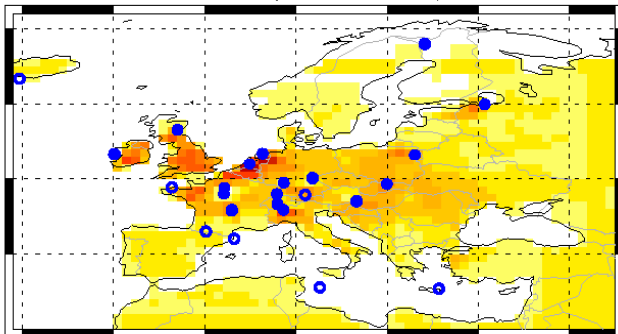
European CH₄ emissions 2010-2012 S6



a priori 01/2010-12/2012 S6

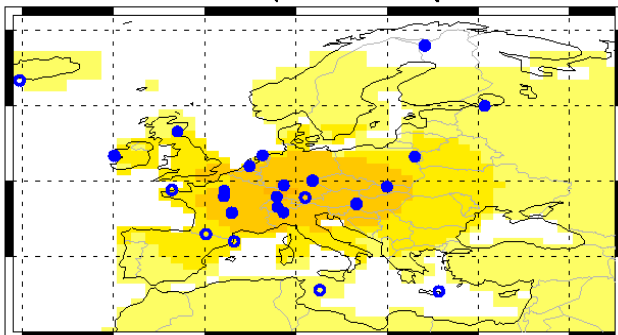


TM5-4DVAR 01/2010-12/2012 S6

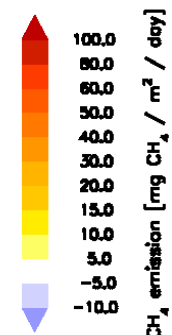
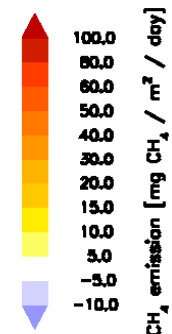


VR_L15L_EC2_CH4_gpr_EU05_HQHQ_TM_EC_V18

LMDZ 01/2010-12/2012 S6



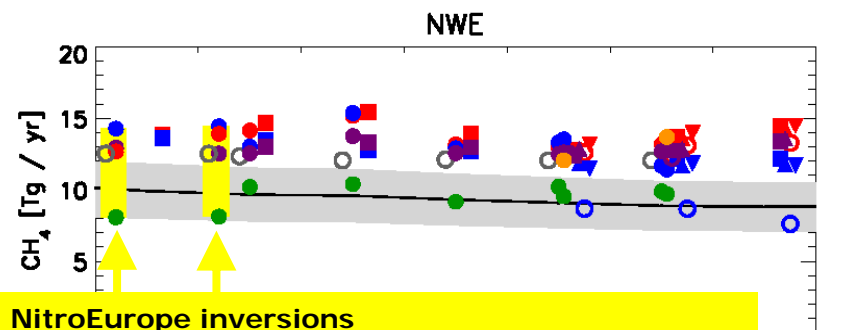
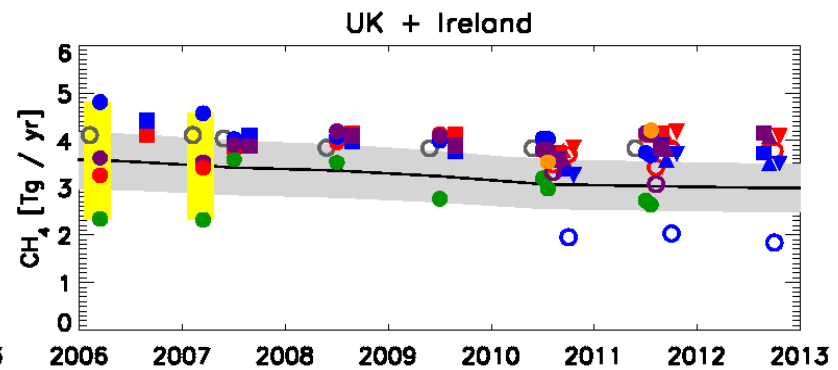
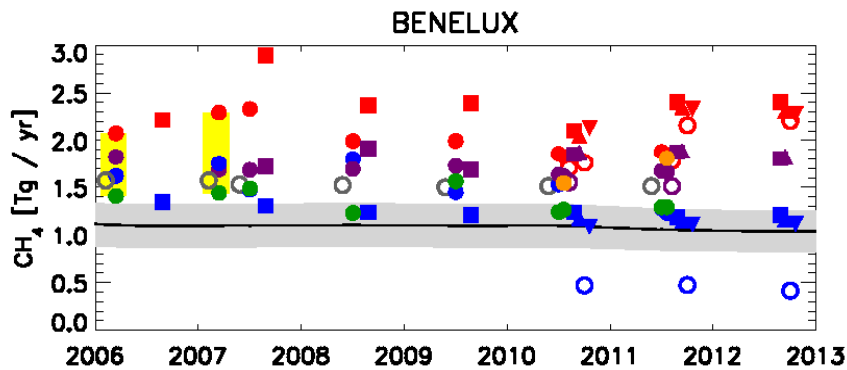
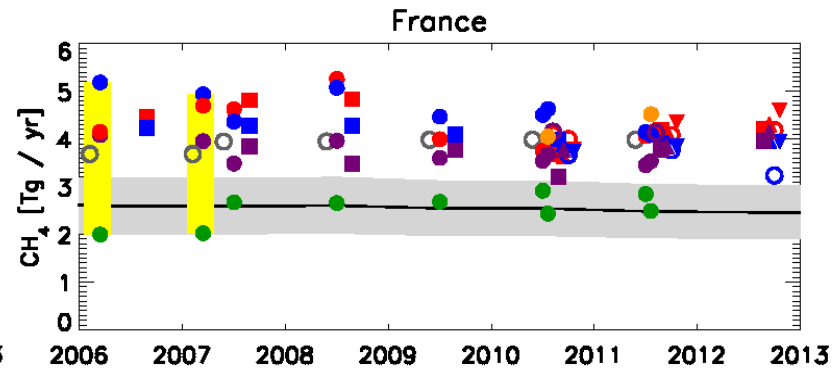
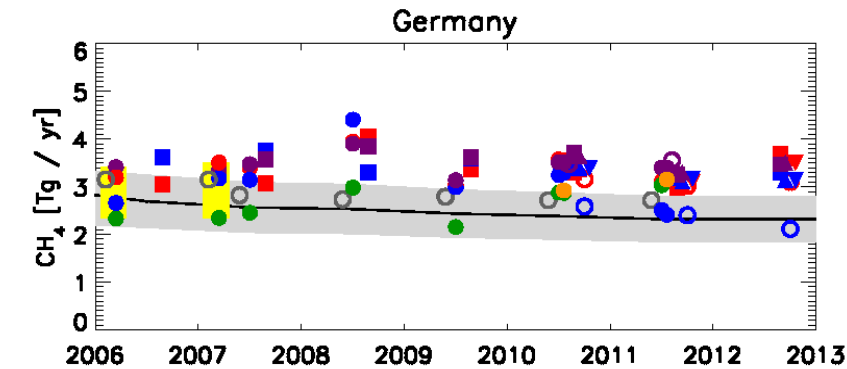
emis_mosser_monthly_CH4_2009-06-01to2012-12-25_S6_LMDZEUre



European CH₄ emissions - country totals NWE



NWE: North-Western European countries
Germany, France, BENELUX, UK+Ireland



NitroEurope inversions
[Bergamaschi et al., ACPD, 2014]

S1 S2 S3 S4 S5 S6 S7

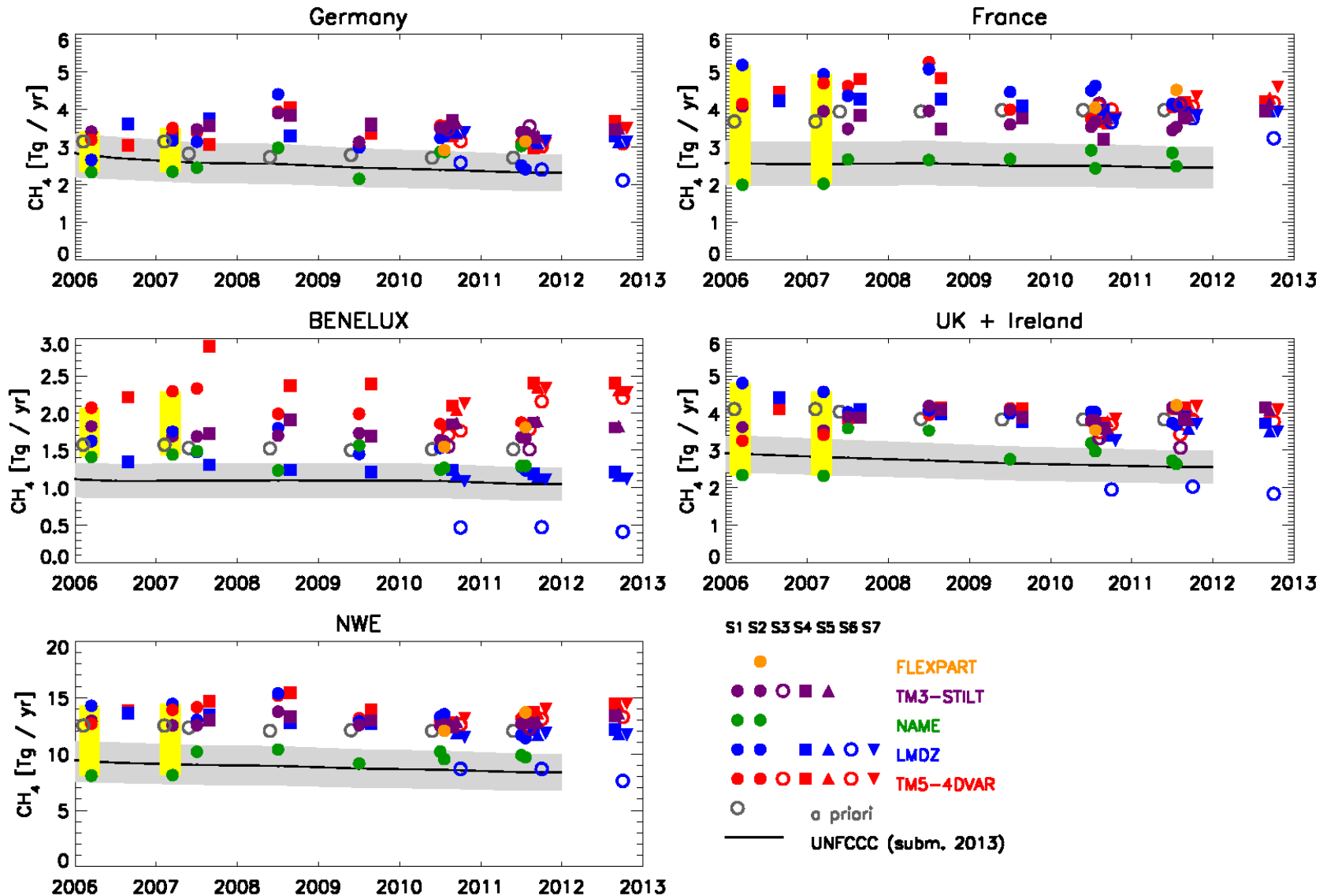
- FLEXPART
- TM3-STILT
- NAME
- LMDZ
- TM5-4DVAR
- a priori
- UNFCCC (subm. 2014)

2013

European CH₄ emissions - country totals NWE



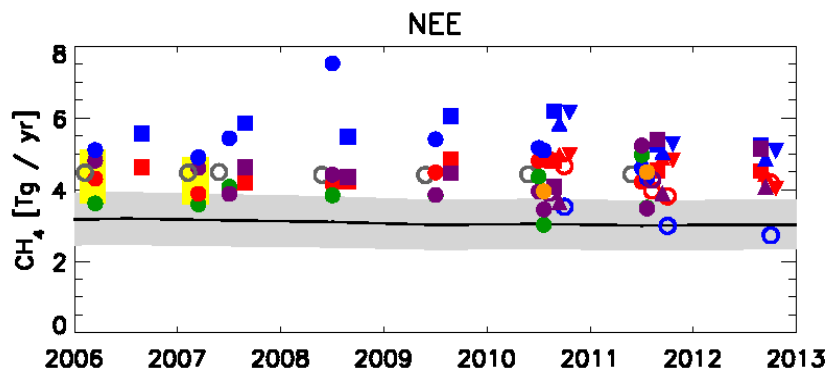
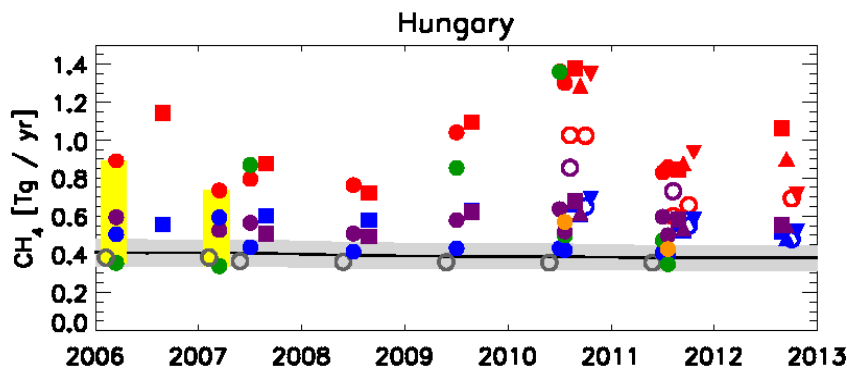
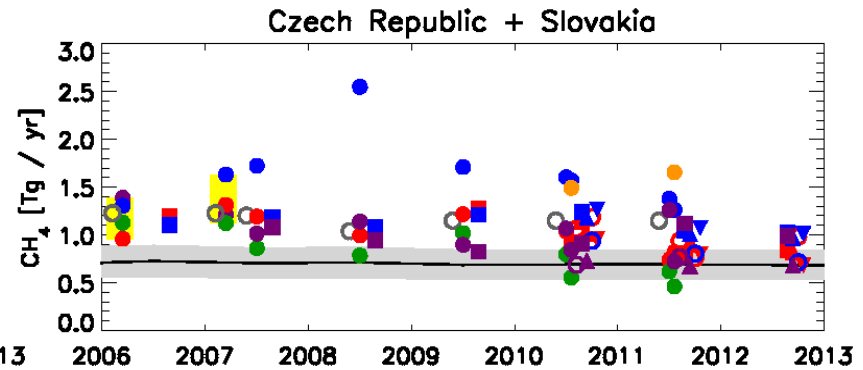
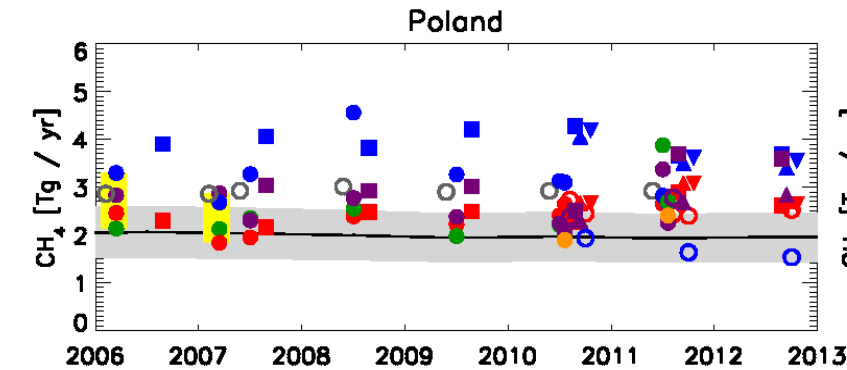
NWE: North-Western European countries
Germany, France, BENELUX, UK+Ireland



European CH₄ emissions - country totals NEE



NEE: North-Eastern European countries
Poland, Hungary, Czech Rep. + Slovakia



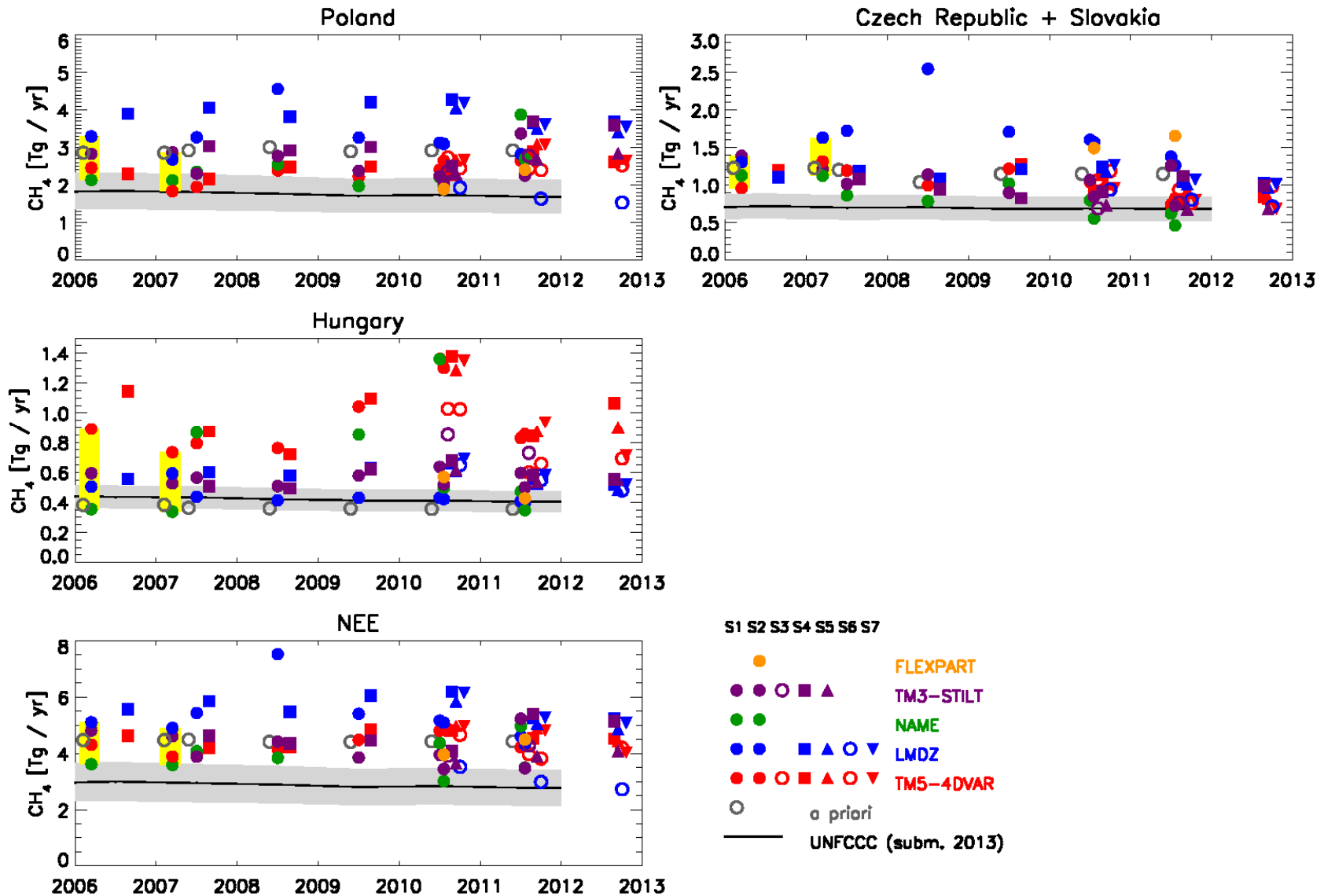
S1 S2 S3 S4 S5 S6 S7

- FLEXPART
- ○ ▲ TM3-STILT
- NAME
- ▲ ○ ▼ LMDZ
- ○ ▲ ▼ TM5-4DVAR
- a priori
- UNFCCC (subm. 2014)

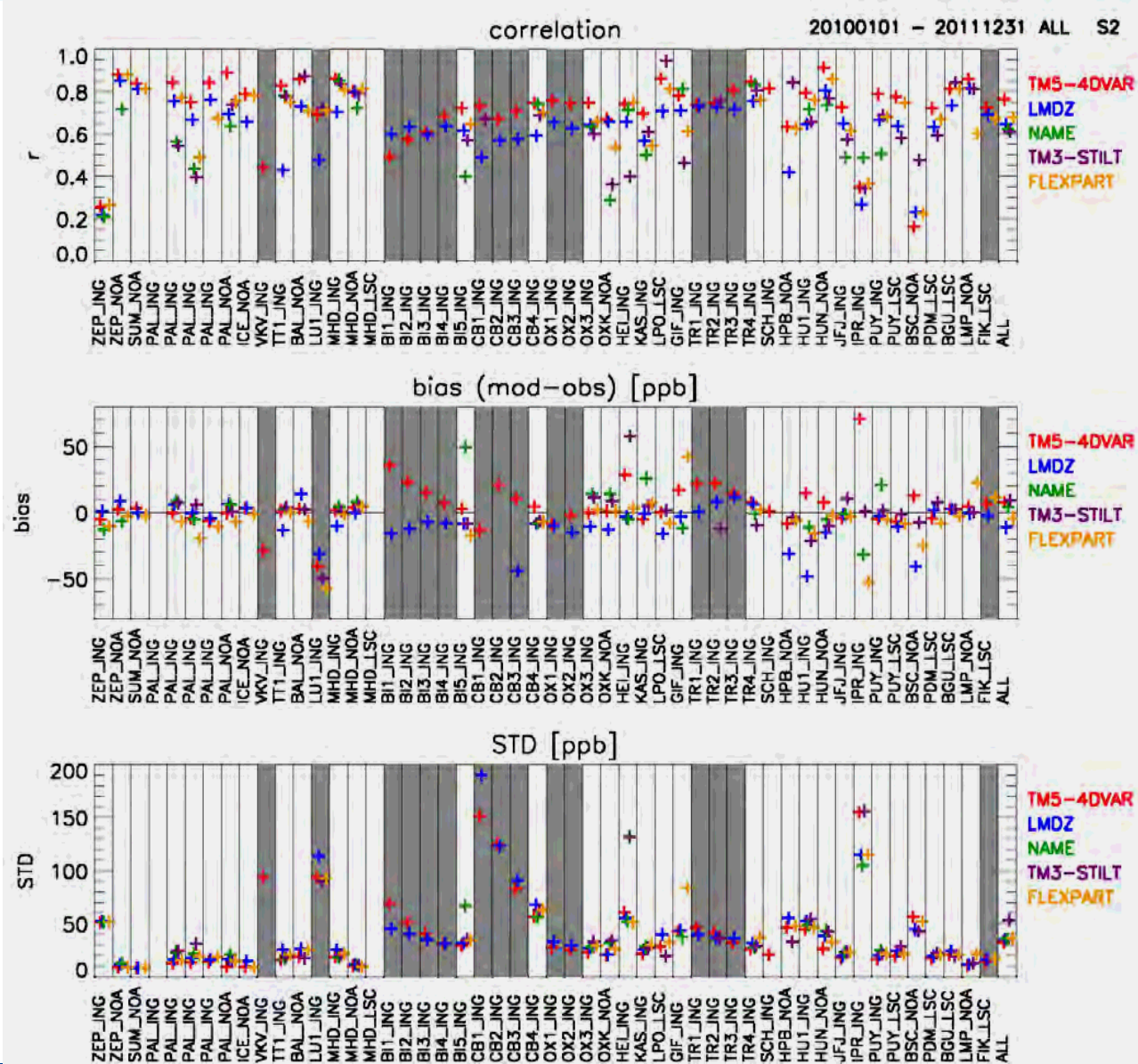
European CH₄ emissions - country totals NEE



NEE: North-Eastern European countries
Poland, Hungary, Czech Rep. + Slovakia



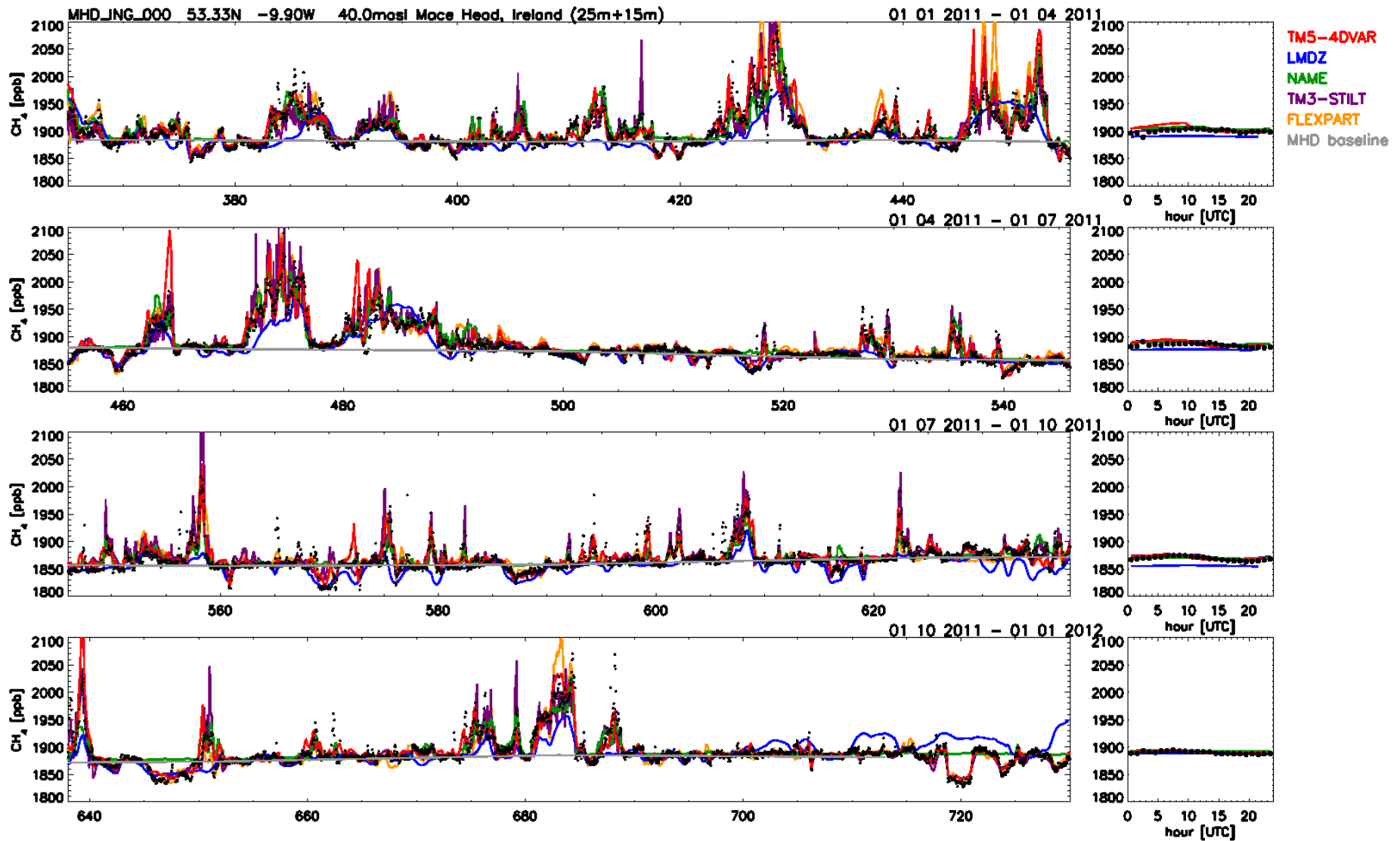
statistics S2-CH4 2010-2011



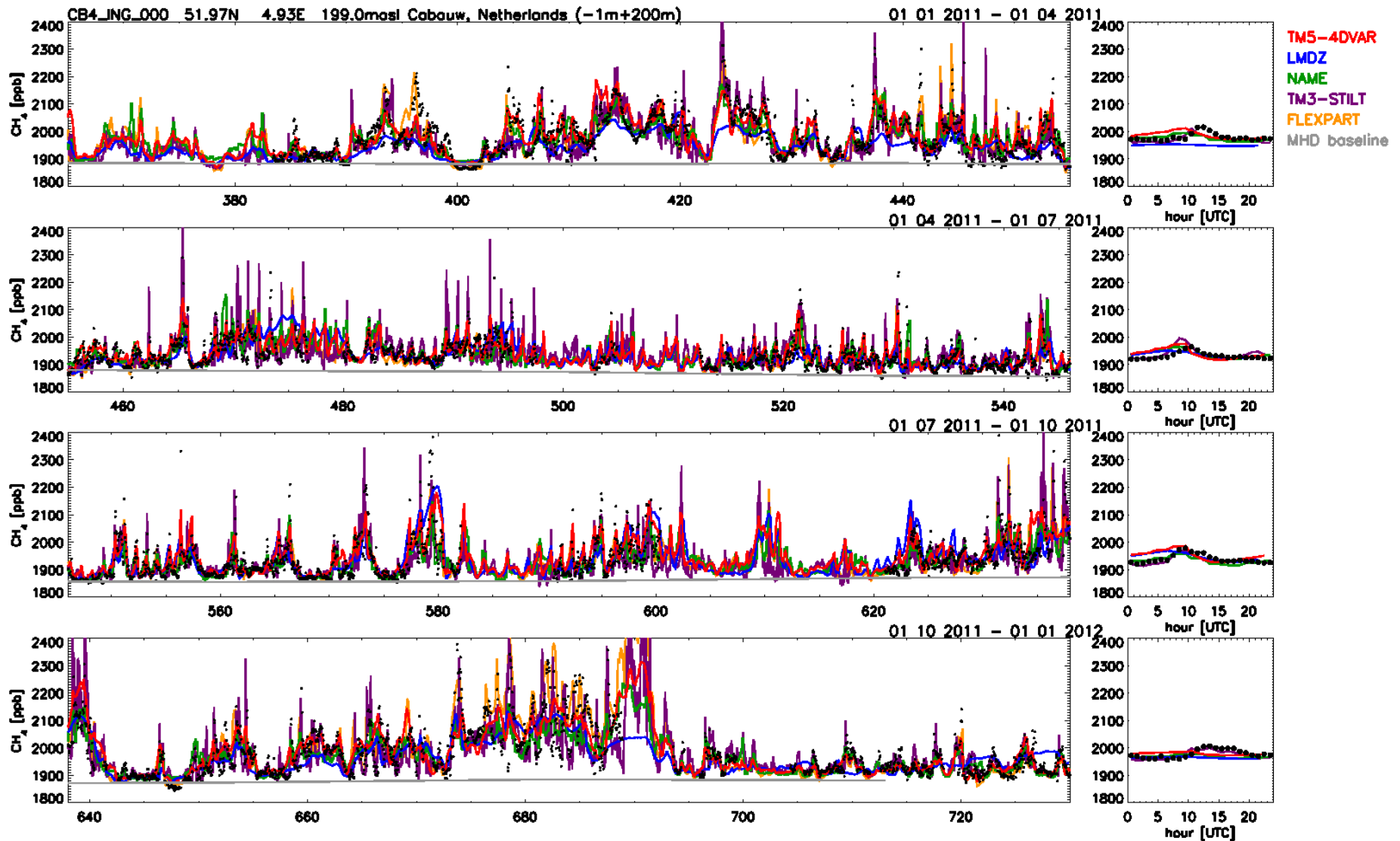
all data (24h)

assimilated stations
validation stations

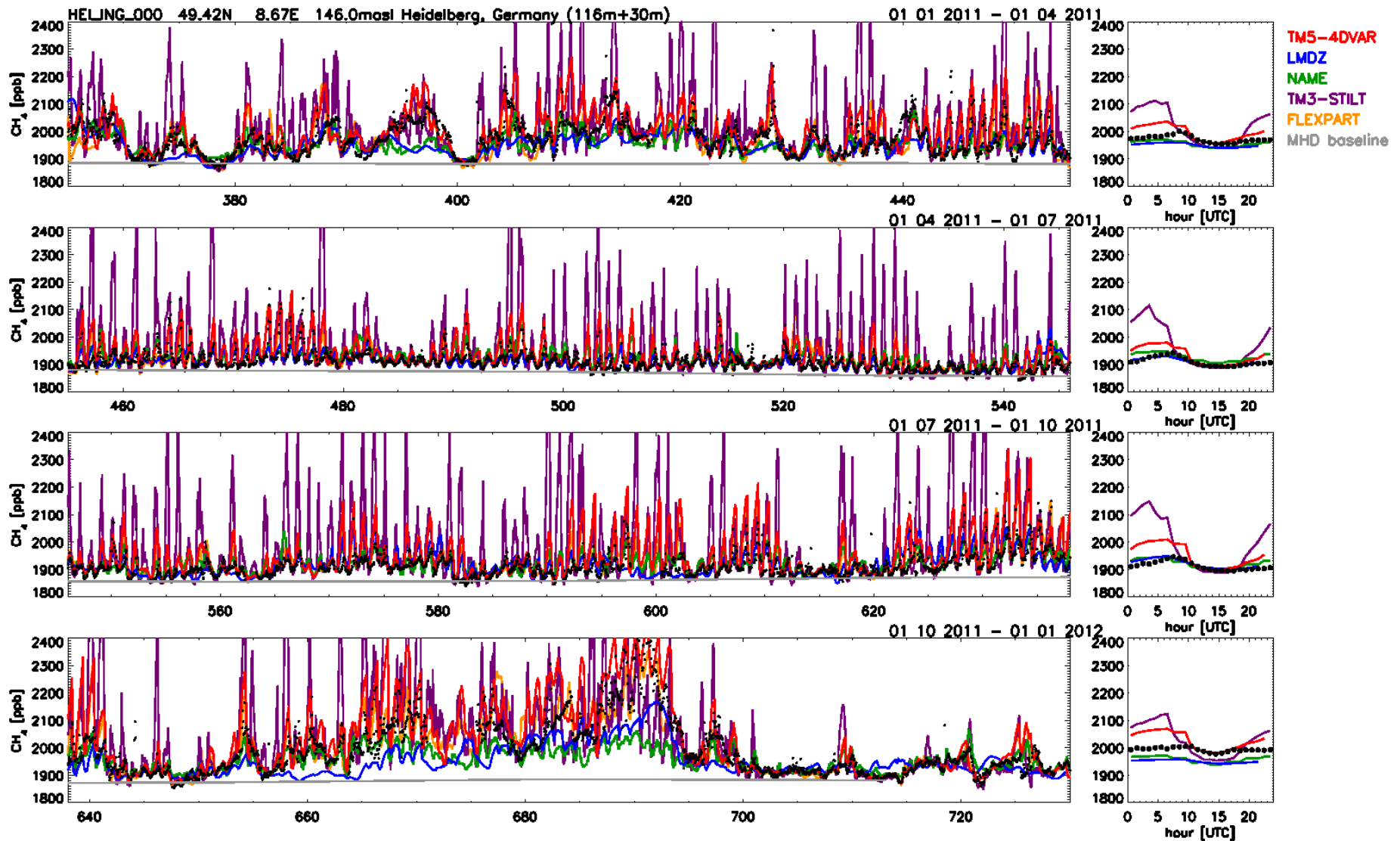
CH₄ station timeseries MHD 2011 S2



CH₄ station timeseries CB4 2011 S2



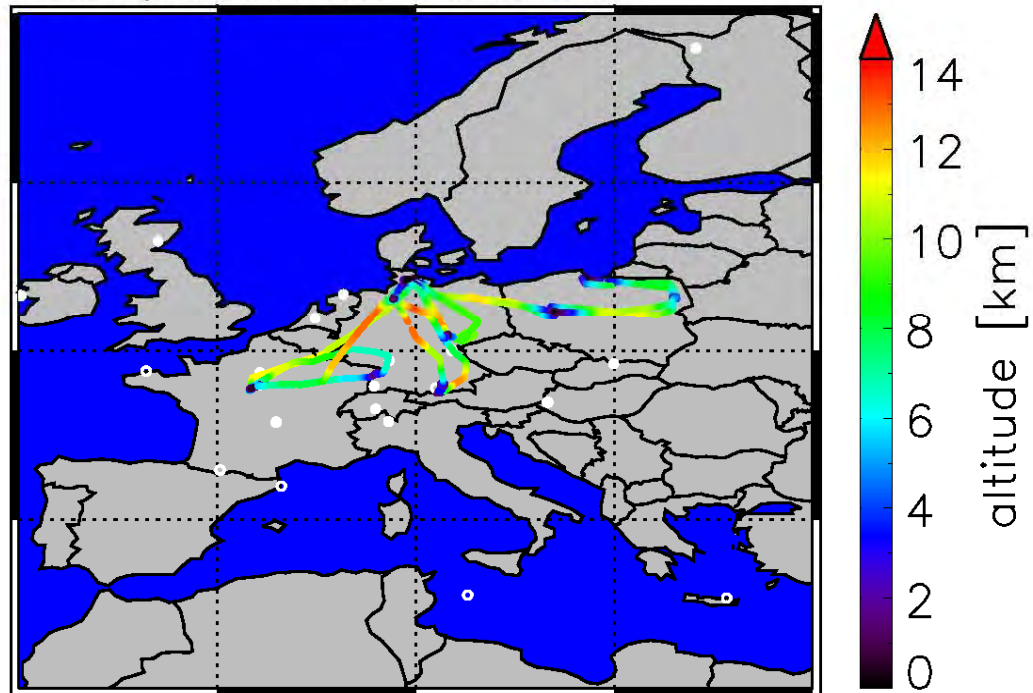
CH₄ station timeseries HEI 2011 S2



CH₄ inversions: validation IMECC aircraft



IMECC flights: 30 09 2009 – 09 10 2009



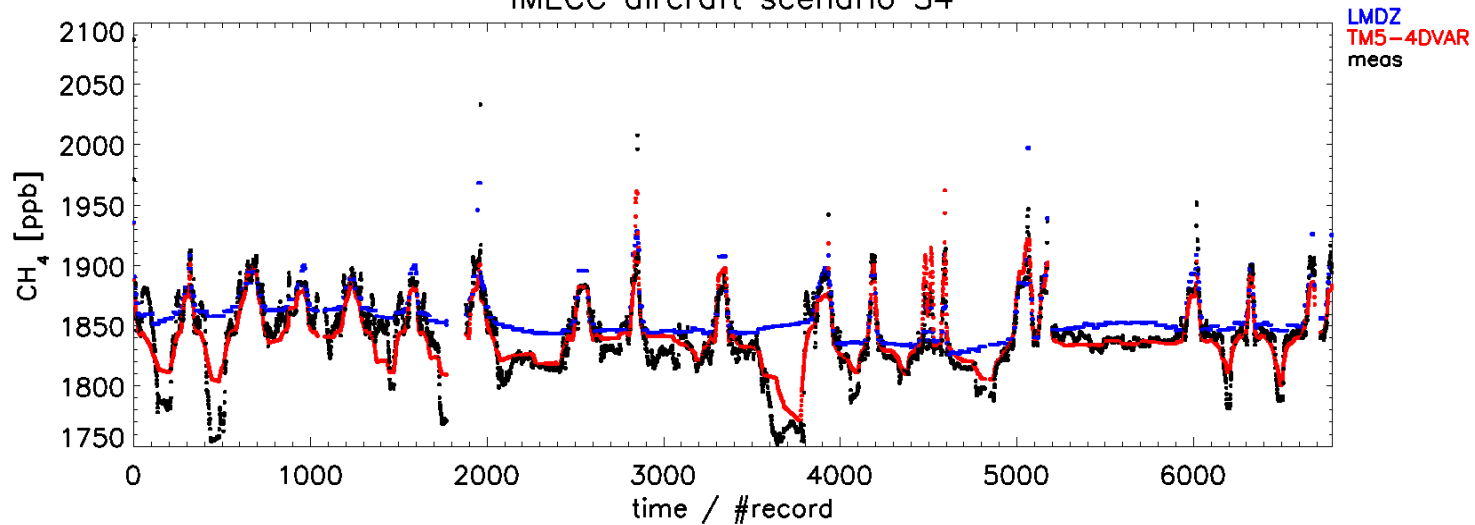
IMECC data: D. Feist, MPI-BGC
[Geibel et al., ACP, 2012]

CH₄ inversions: validation IMECC aircraft

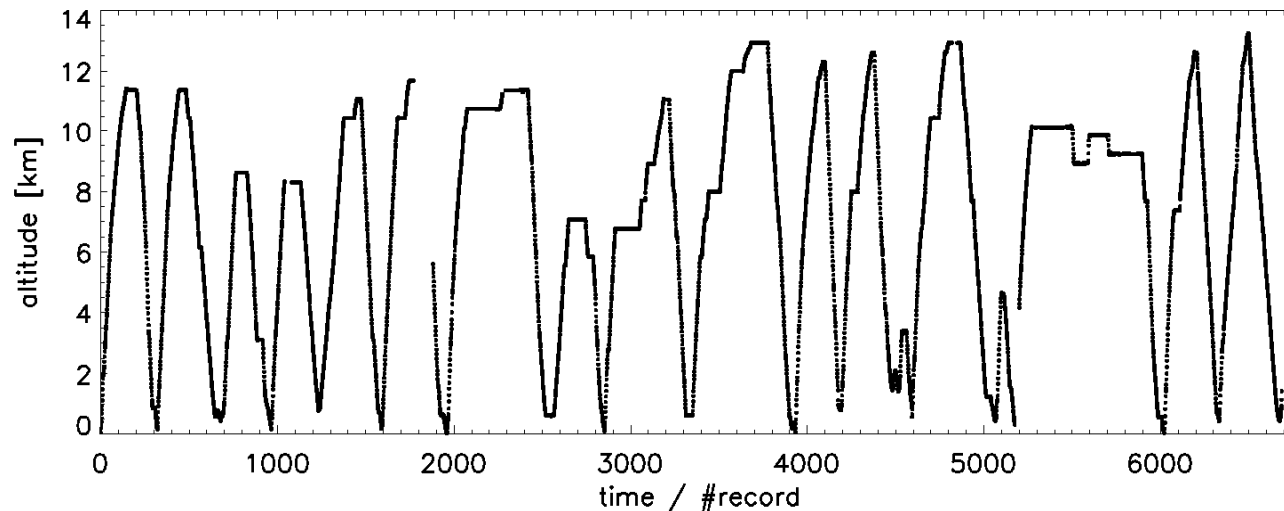


30 09 2009 – 09 10 2009

IMECC aircraft scenario S4



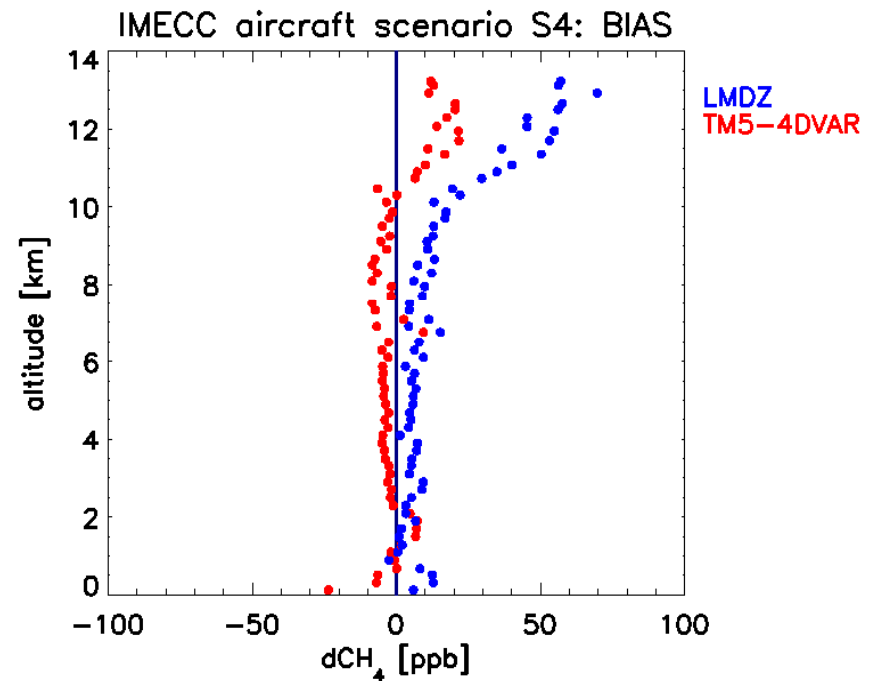
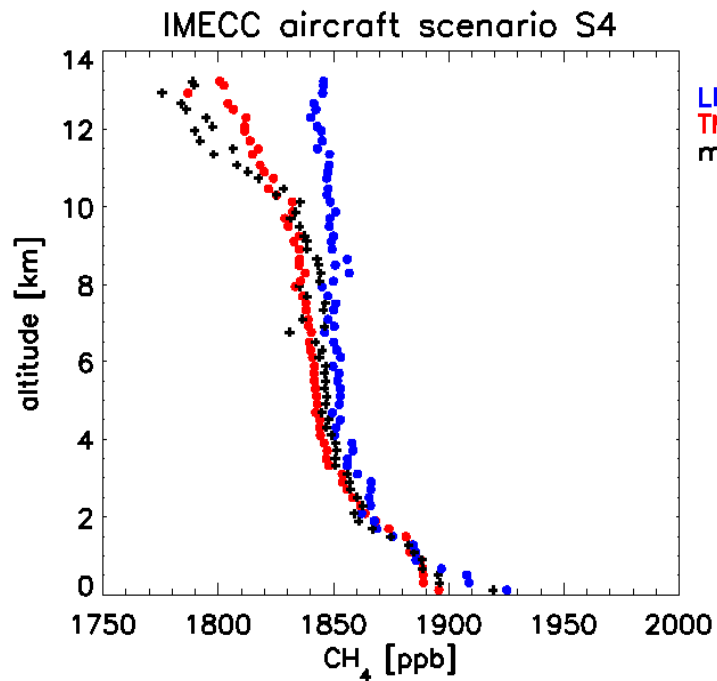
IMECC aircraft



CH₄ inversions: validation IMECC aircraft



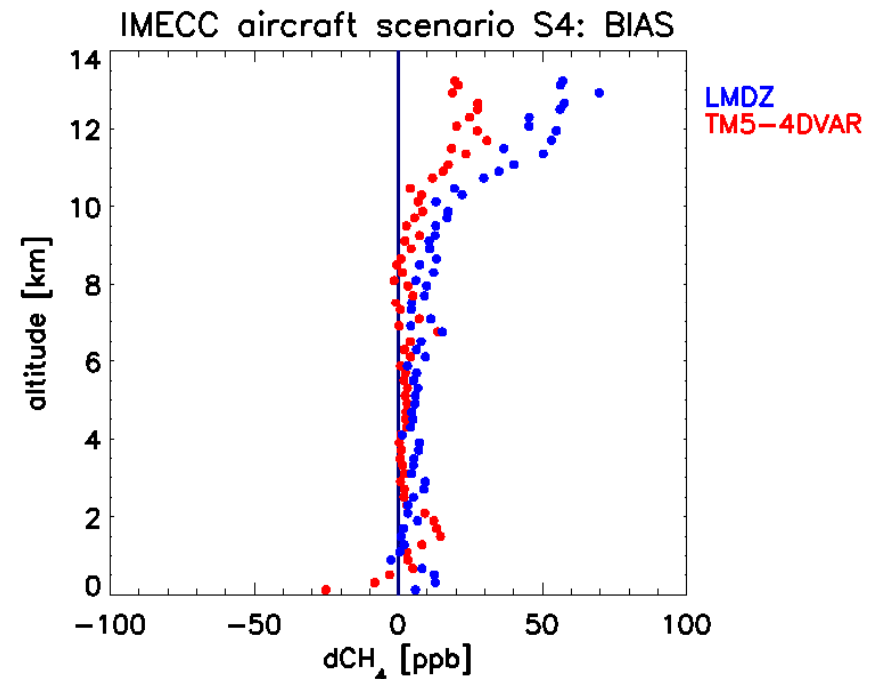
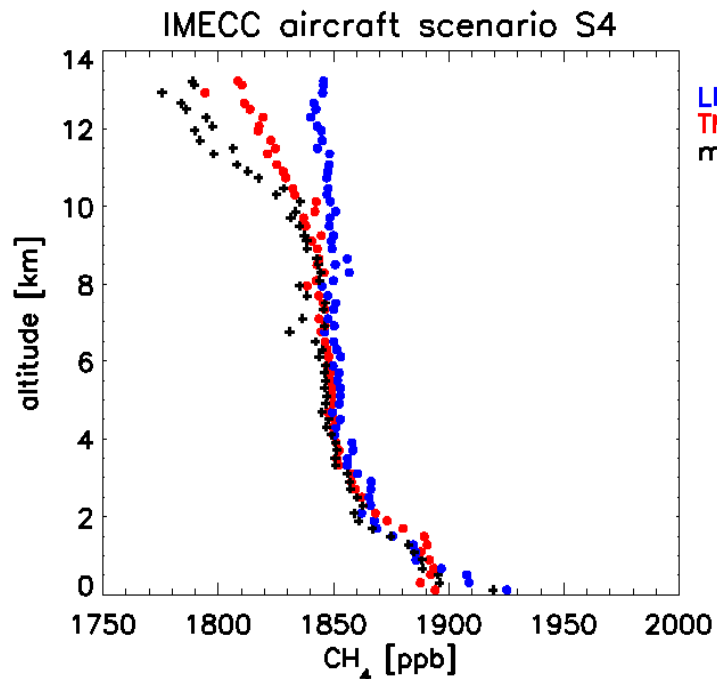
30 09 2009 – 09 10 2009



CH₄ inversions: validation IMECC aircraft



30 09 2009 – 09 10 2009



TM5:

new convective fluxes based on

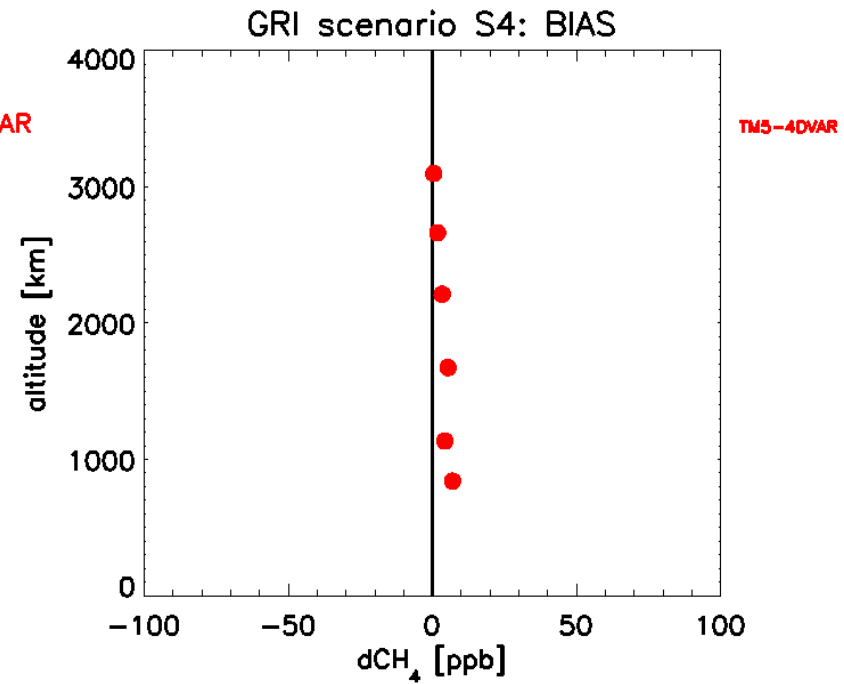
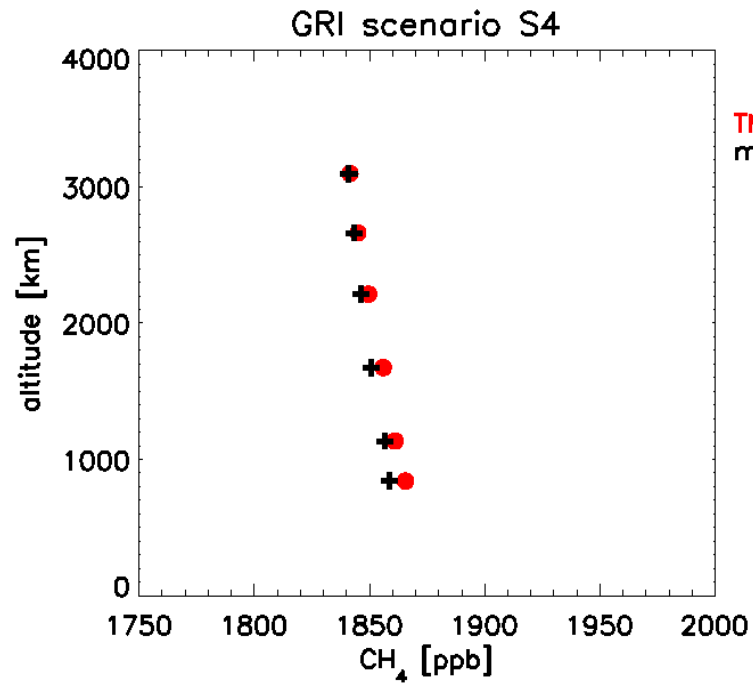
'new': ECMWF ERA-Interim (Berrisford et al, 2011)

(instead of [Tiedke])

CH₄ inversions: validation LSCE aircraft - GRI



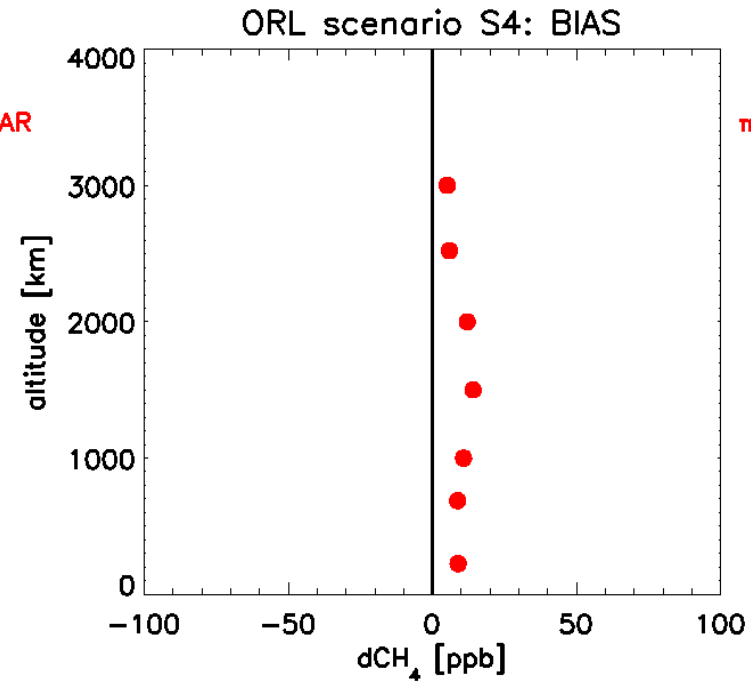
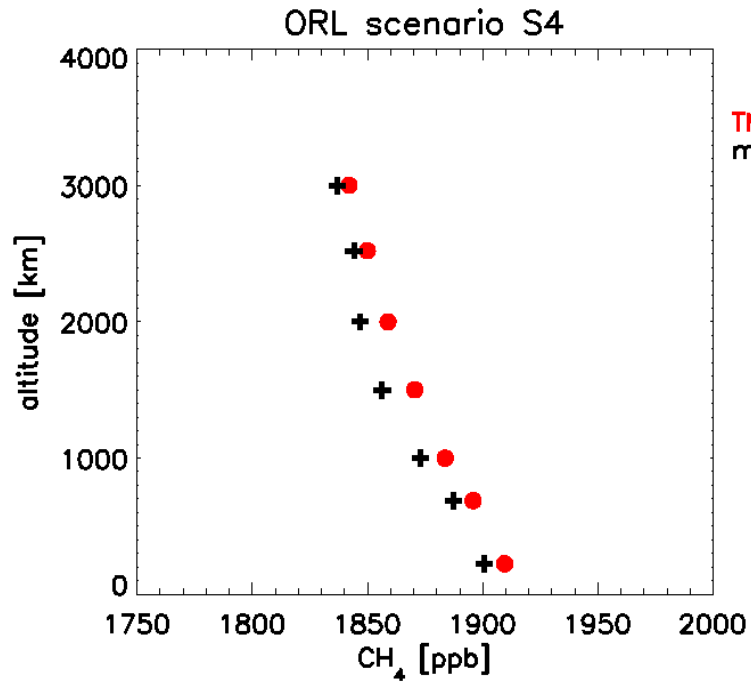
average: 20060101_20121231



CH₄ inversions: validation LSCCE aircraft - ORL



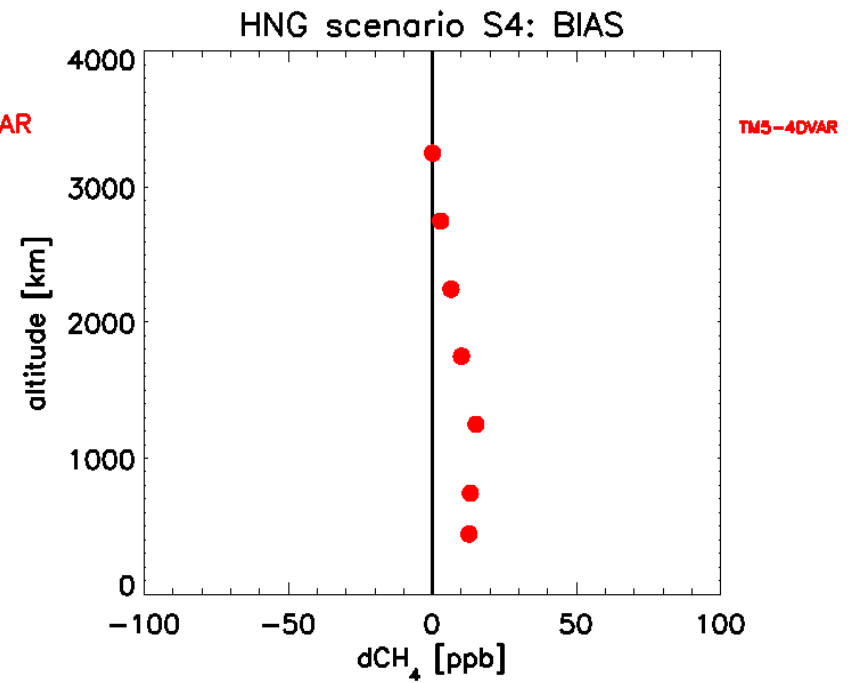
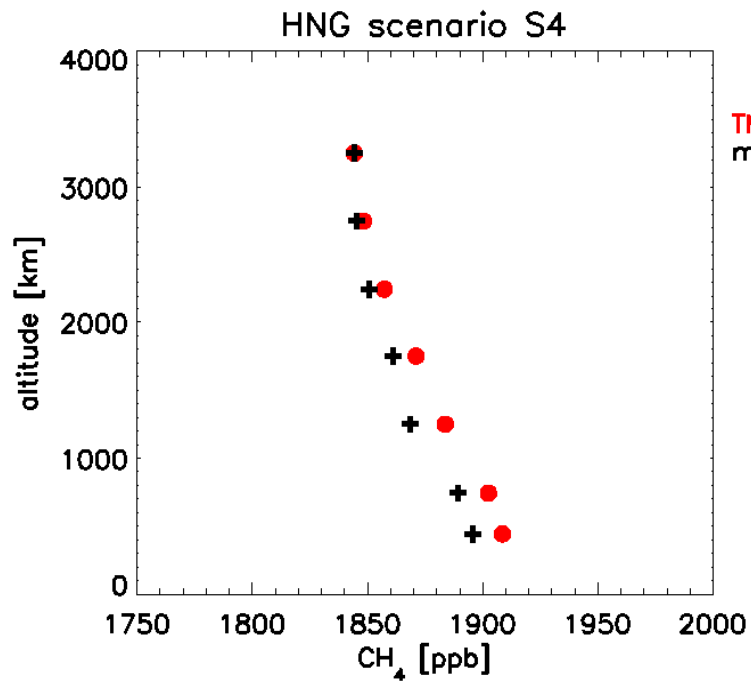
average: 20060101_20121231



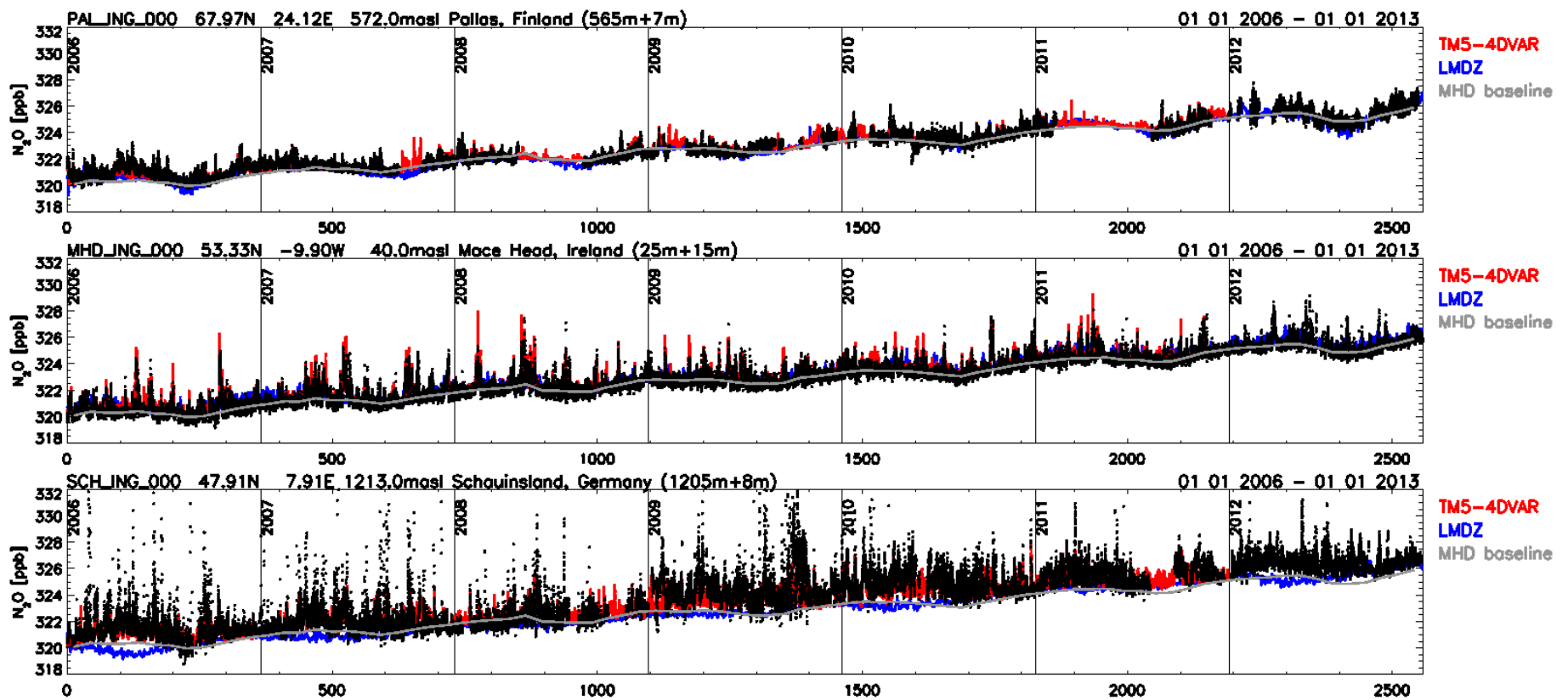
CH₄ inversions: validation LSCCE aircraft - HNG



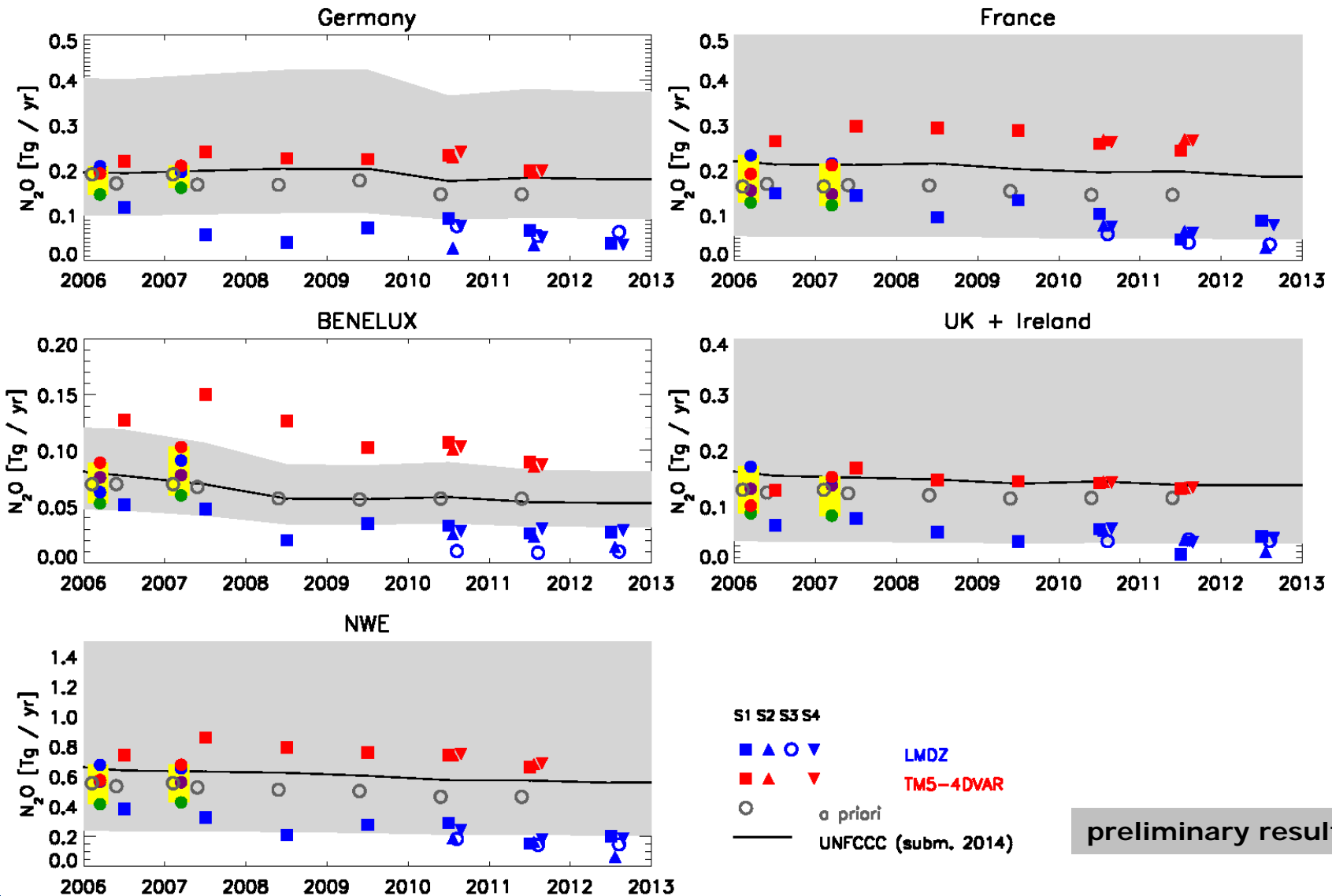
average: 20060101_20121231



N₂O inversions station time series



European N₂O emissions - country totals NWE



preliminary results

model validation: BLH daytime



BLH radiosonde measurements:

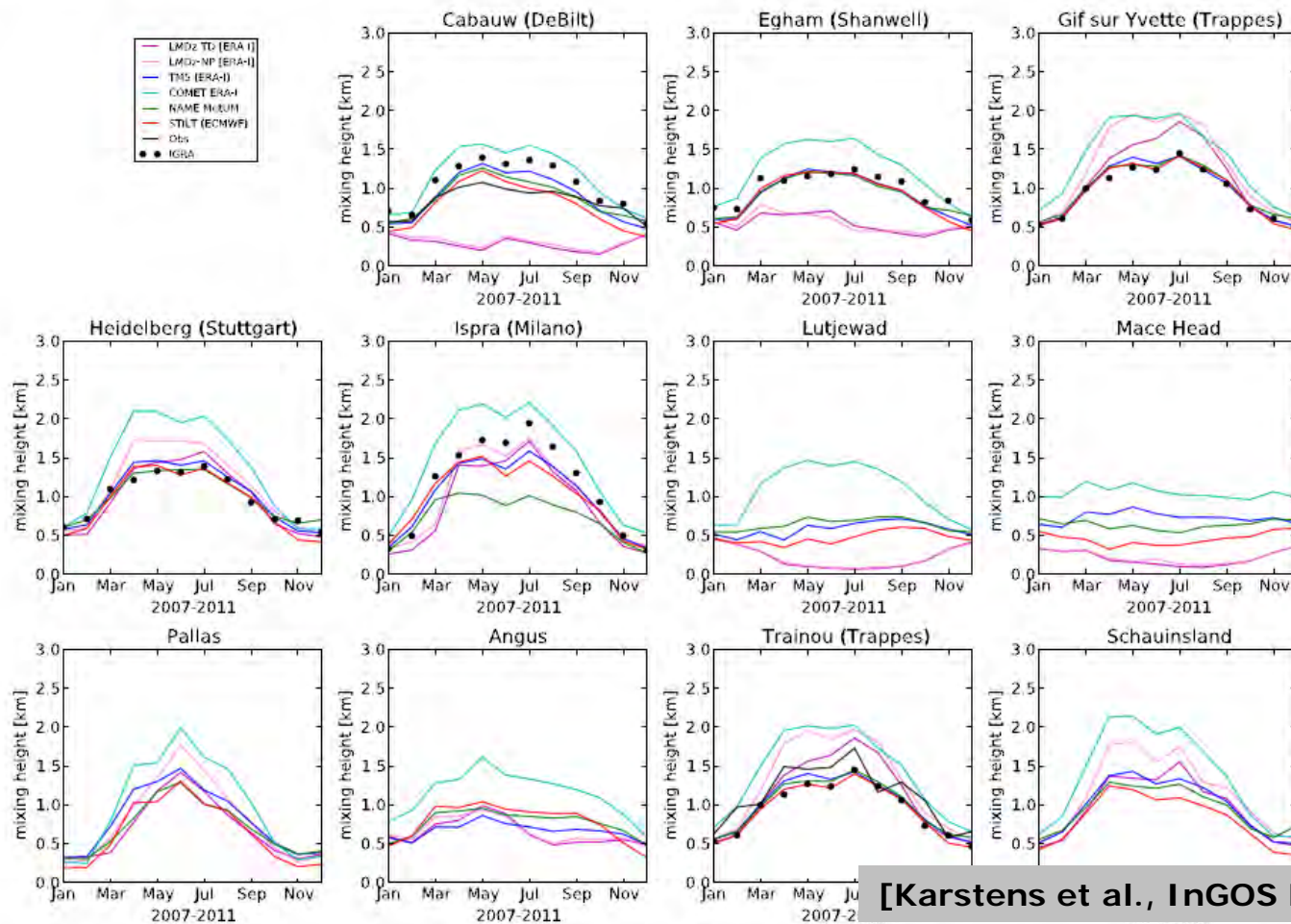
NOAA Integrated Global Radiosonde Archive (IGRA).

Cabauw: ceilometer

Trainou: lidar system (ALS/300-Leosphere)

Figure 5: Mean seasonal cycle of (a) daytime and (b) night transport models (for 2007-2011) and lidar-derived mixing (2009) and Trainou (for 2011). Radiosonde-derived mixing nearest IGRA station are also included where available.

a)

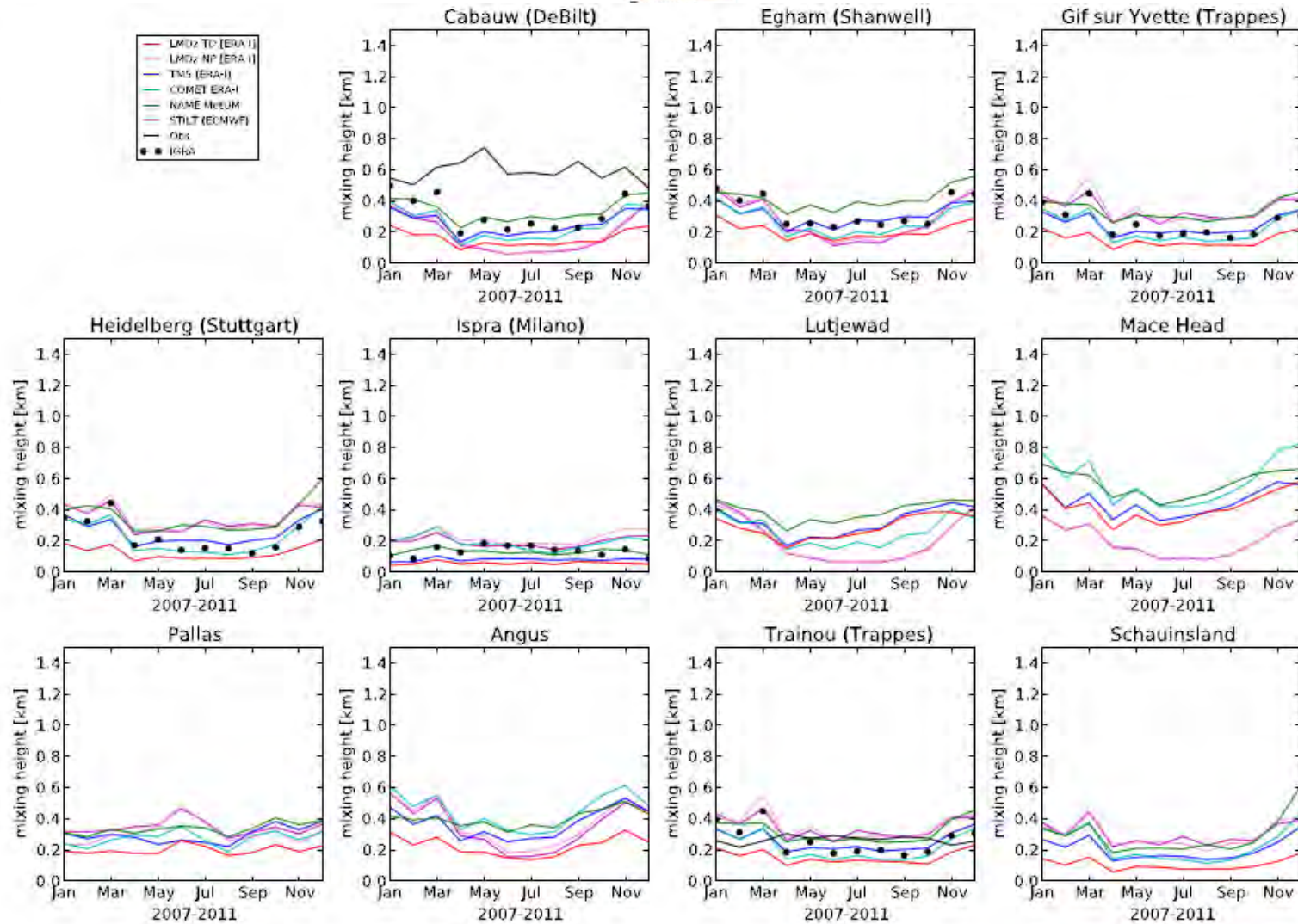


[Karstens et al., InGOS D15.5 report, 2014]

model validation: BLH nighttime

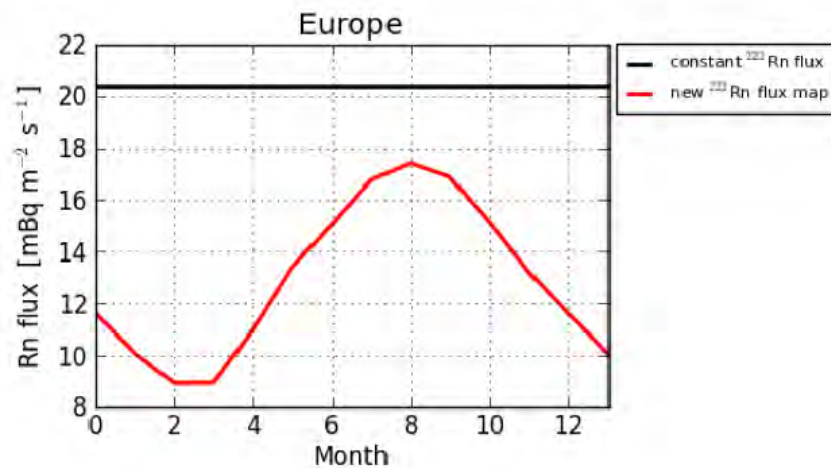
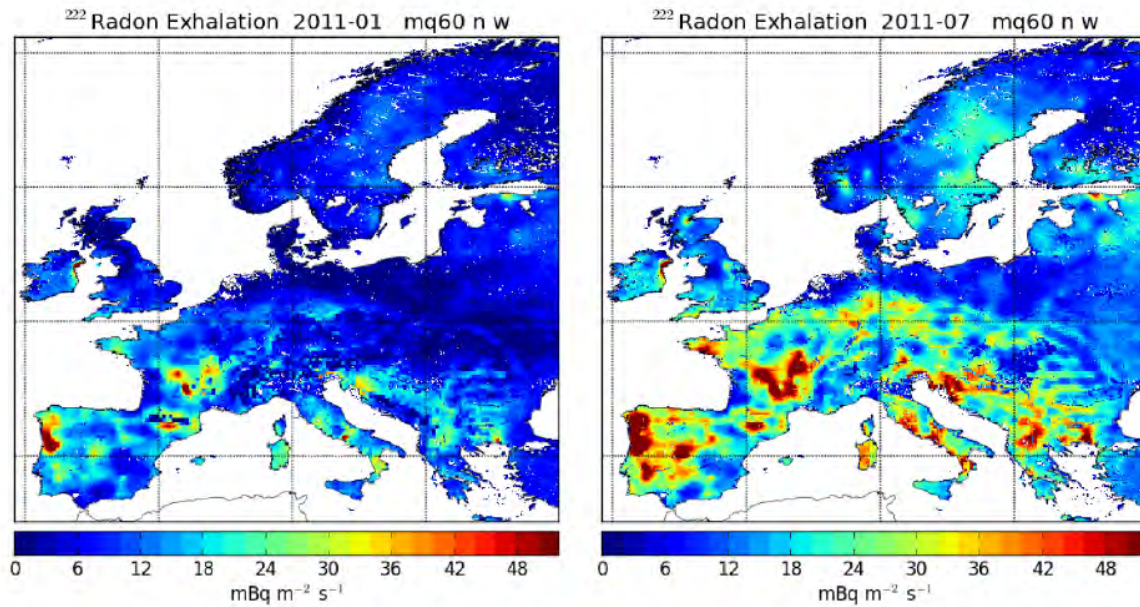


b)



[Karstens et al., InGOS D15.5 report, 2014]

model validation: ^{222}Rn

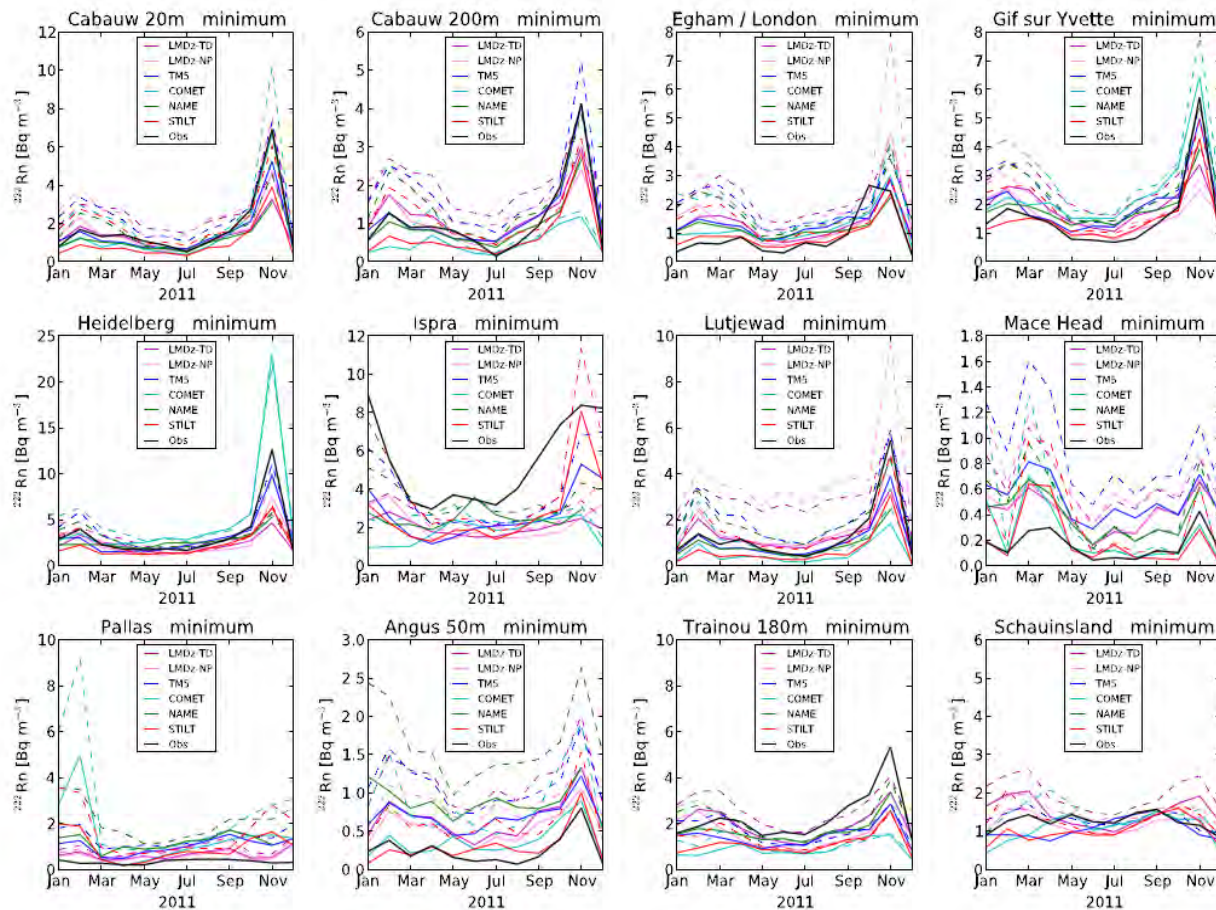


[Karstens et al., InGOS D15.4 report, 2014]

model validation: ^{222}Rn - seasonal variation of daily minimum



Figure 7: Modelled and observed monthly mean of daily minimum ^{222}Rn concentrations at all sites. Model simulations based on the new ^{222}Rn emission map (full lines) and simulations based on constant ^{222}Rn fluxes (dashed lines).



[Karstens et al., InGOS D15.4 report, 2014]

conclusions



- preliminary InGOS CH₄ inversions
 - > tendency to higher CH₄ emissions compared to UNFCCC
- evaluation model performance
 - in general synoptic variability relatively well represented
 - deficiencies to simulate diurnal cycle, especially at continental surface stations (with low sampling heights above ground)
- validation of modelled CH₄ gradients vs. aircraft profiles (IMECC; LSCE profiles sites)
TM5: small tendency to overestimate CH₄ in the altitude range 1-2 km
- validation of model BLH vs NOAA IGRA radiosondes / LIDAR
better relative agreement (MOD/OBS) for daytime BL than for nighttime BL
(however poorer agreement for coastal sites / coarse resolution models)
- validation using 222Rn
better agreement MOD vs OBS for most sites when using InGOS 222Rn inventory
MOD/OBS (222Rn) vs. MOD/OBS not always consistent
- further evaluation of simulation of BLH dynamics and vertical gradients essential

supplementary material



Bottom-up CH₄ emissions and their uncertainties: UNFCCC - EDGAR



			Germany	France	UK + Ireland	BENELUX	Hungary	Poland	CZE + SVK	NWE	NEE	NWE + NEE
Solid Fuels (1B1)												
emission (2005)	EDGARv4.1 ¹	Tg CH ₄ yr ⁻¹	0.54	0.02	0.14	0.008	0.008	1.69	0.18	0.71	1.88	2.59
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	0.36	0.02	0.08	0.007	0.009	1.71	0.16	0.47	1.87	2.34
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.21	0.01	0.13	0.002	0.001	0.43	0.19	0.35	0.62	0.97
emission range	UNFCCC	Tg CH ₄ yr ⁻¹	0.13–0.29	N/A ²	0.11–0.14	0.001–0.002	0.001–0.001	0.22–0.64	0.16–0.21	0.25–0.45	0.38–0.85	0.64–1.30
relative uncertainty	UNFCCC		37.4%	N/A ²	13.0%	19.8%	10.4%	48.6%	13.2%	27.8%	37.9%	34.2%
Oil and natural gas (1B2)												
emission (2005)	EDGARv4.1	Tg CH ₄ yr ⁻¹	0.37	1.44	0.66	0.26	0.08	0.15	0.07	2.73	0.30	3.03
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	0.27	1.49	0.61	0.28	0.08	0.15	0.08	2.64	0.31	2.95
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.28	0.05	0.27	0.06	0.10	0.21	0.07	0.66	0.38	1.03
emission range	UNFCCC	Tg CH ₄ yr ⁻¹	0.25–0.32	0.04–0.06	0.22–0.32	0.04–0.07	0.05–0.15	0.20–0.22	0.04–0.09	0.55–0.76	0.29–0.46	0.84–1.23
relative uncertainty	UNFCCC		11.4%	18.0%	17.1%	30.2%	50.0%	5.3%	40.0%	15.9%	23.2%	18.5%
Enteric fermentation (4A)												
emission (2005)	EDGARv4.1	Tg CH ₄ yr ⁻¹	1.06	1.39	1.50	0.50	0.09	0.58	0.22	4.45	0.89	5.34
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	1.04	1.37	1.48	0.50	0.09	0.58	0.21	4.40	0.88	5.27
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.99	1.36	1.20	0.48	0.08	0.44	0.14	4.04	0.66	4.70
emission range	UNFCCC	Tg CH ₄ yr ⁻¹	0.66–1.32	1.15–1.58	0.98–1.42	0.39–0.58	0.07–0.09	0.29–0.59	0.11–0.17	3.17–4.91	0.47–0.85	3.64–5.76
relative uncertainty	UNFCCC		33.4%	15.8%	18.7%	20.3%	13.3%	34.4%	20.5%	21.5%	29.0%	22.6%
Manure management (4B)												
emission (2005)	EDGARv4.1	Tg CH ₄ yr ⁻¹	0.35	0.36	0.25	0.25	0.03	0.15	0.04	1.21	0.21	1.42
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	0.35	0.35	0.25	0.25	0.03	0.14	0.03	1.20	0.20	1.40
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.26	0.48	0.24	0.19	0.07	0.16	0.03	1.17	0.26	1.43
emission range												
relative uncertainty												
Solid waste disposal												
emission (2005)												
emission (2006–2007)												
emission (2006–2007)												
emission range												
relative uncertainty												
Waste water (6B)												
emission (2005)												
emission (2006–2007)												
emission (2006–2007)												
emission range												
relative uncertainty												
total												
total major categories	EDGARv4.1	Tg CH ₄ yr ⁻¹	3.08	3.47	3.79	1.49	0.34	3.10	0.68	11.84	4.12	15.96
total major categories	EDGARv4.2	Tg CH ₄ yr ⁻¹	2.70	3.76	3.60	1.45	0.34	3.01	0.71	11.50	4.06	15.57
total major categories	UNFCCC	Tg CH ₄ yr ⁻¹	2.51	2.43	2.76	1.00	0.42	1.68	0.67	8.70	2.77	11.47
total all categories	UNFCCC	Tg CH ₄ yr ⁻¹	2.65	2.56	2.83	1.07	0.43	1.83	0.71	9.11	2.97	12.08
total uncertainty	UNFCCC	Tg CH ₄ yr ⁻¹	0.52	0.55	0.47	0.21	0.07	0.44	0.15	1.68	0.63	2.27
relative uncertainty	UNFCCC		20.6%	22.8%	16.8%	20.6%	17.0%	26.1%	22.9%	19.3%	22.8%	19.8%

UNFCCC: countries report uncertainties per source category

calculate uncertainties of total emissions assuming

- uncertainties of different categories are uncorrelated
- uncertainties of sub-categories are correlated
- uncertainties reported by different countries for same category are correlated

Bottom-up CH₄ emissions and their uncertainties: UNFCCC vs EDGAR: fossil fuels

European
Commission

NWE: Germany, France, BENELUX, UK+Ireland

NEE: Hungary, Poland, CZE+SVK

			NWE	NEE	NWE + NEE
Solid Fuels (1B1)					
emission (2005)	EDGARv4.1 ¹	Tg CH ₄ yr ⁻¹	0.71	1.88	2.59
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	0.47	1.87	2.34
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.35	0.62	0.97
emission range	UNFCCC	Tg CH ₄ yr ⁻¹	0.25–0.45	0.38–0.85	0.64–1.30
relative uncertainty	UNFCCC		27.8%	37.9%	34.2%
Oil and natural gas (1B2)					
emission (2005)	EDGARv4.1	Tg CH ₄ yr ⁻¹	2.73	0.30	3.03
emission (2006–2007)	EDGARv4.2	Tg CH ₄ yr ⁻¹	2.64	0.31	2.95
emission (2006–2007)	UNFCCC	Tg CH ₄ yr ⁻¹	0.66	0.38	1.03
emission range	UNFCCC	Tg CH ₄ yr ⁻¹	0.55–0.76	0.29–0.46	0.84–1.23
relative uncertainty	UNFCCC		15.9%	23.2%	18.5%

UNFCCC uncertainties (2σ) << difference UNFCCC-EDGAR

EDGAR: ~50% of oil and natural gas emissions NWE+NEE from France (for which much higher emission factor is applied for leakage from gas pipelines)

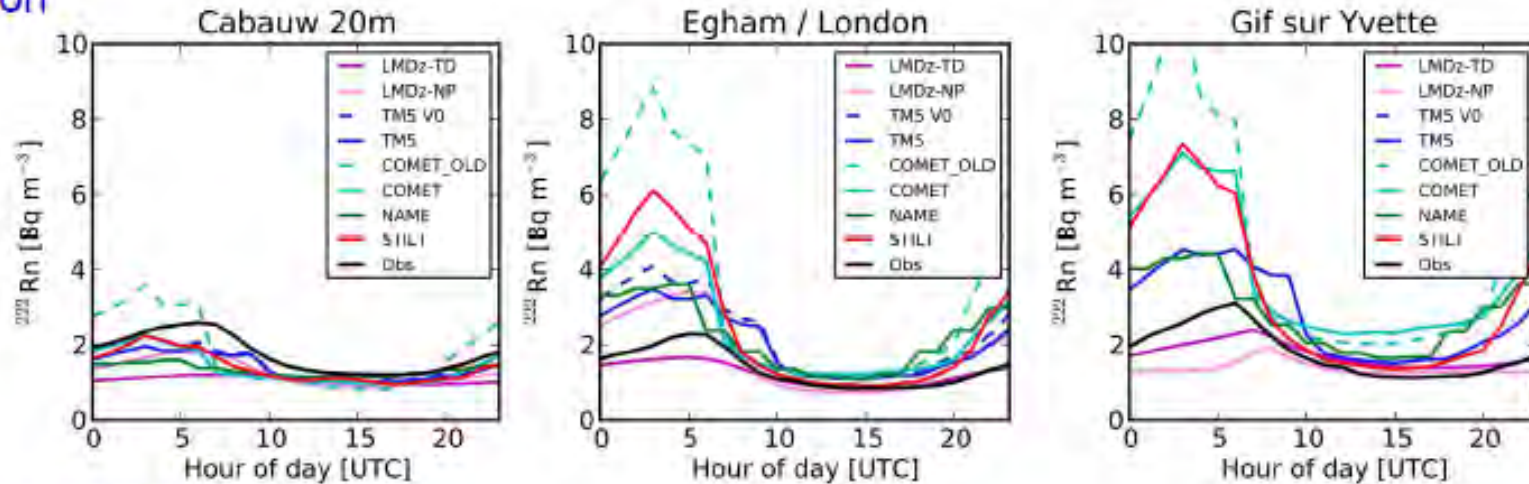
[Bergamaschi et al., ACPD, 2014]

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Diurnal cycle of ^{222}Rn and mixing height



Radon



Mixing height

