Top down atmospheric and bottom up estimates of the European GHG balance

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Importance of methane and nitrous oxide for Europe's terrestrial greenhouse-gas balance

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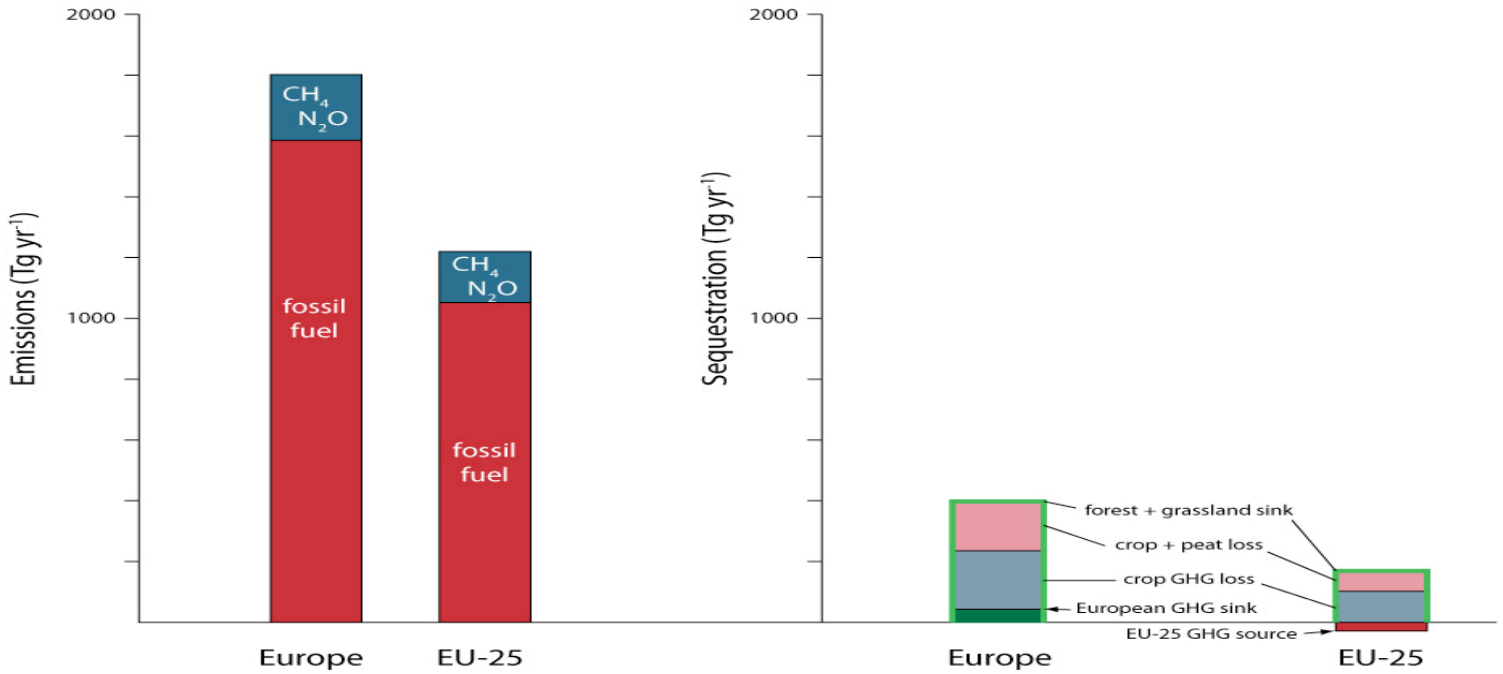


CH_4 and N_2O emissions by agriculture offset C sinks in forest and grasslands

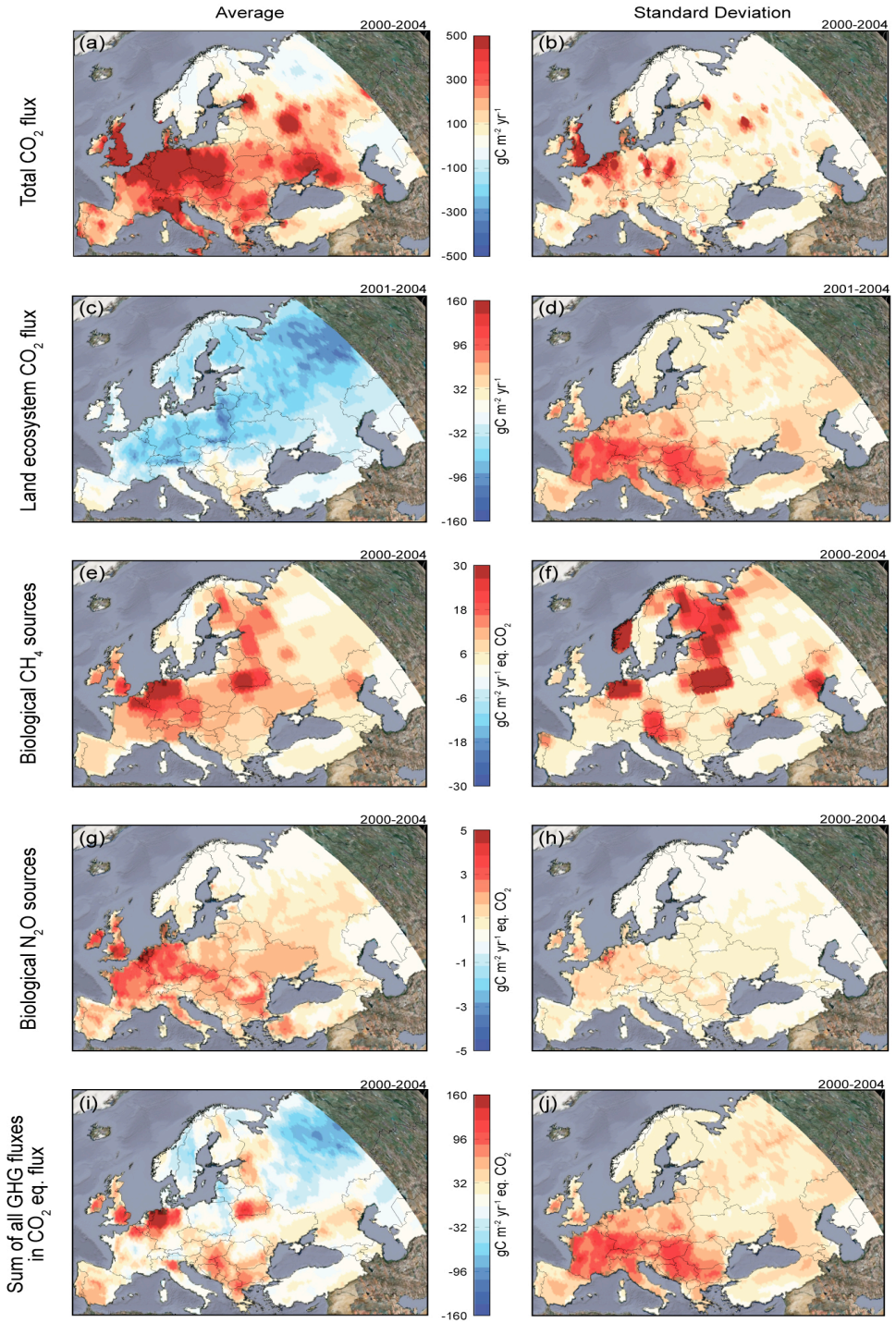
Total CO2 flux

land ecosystems
CO2 flux

land ecosystems
CH4 flux

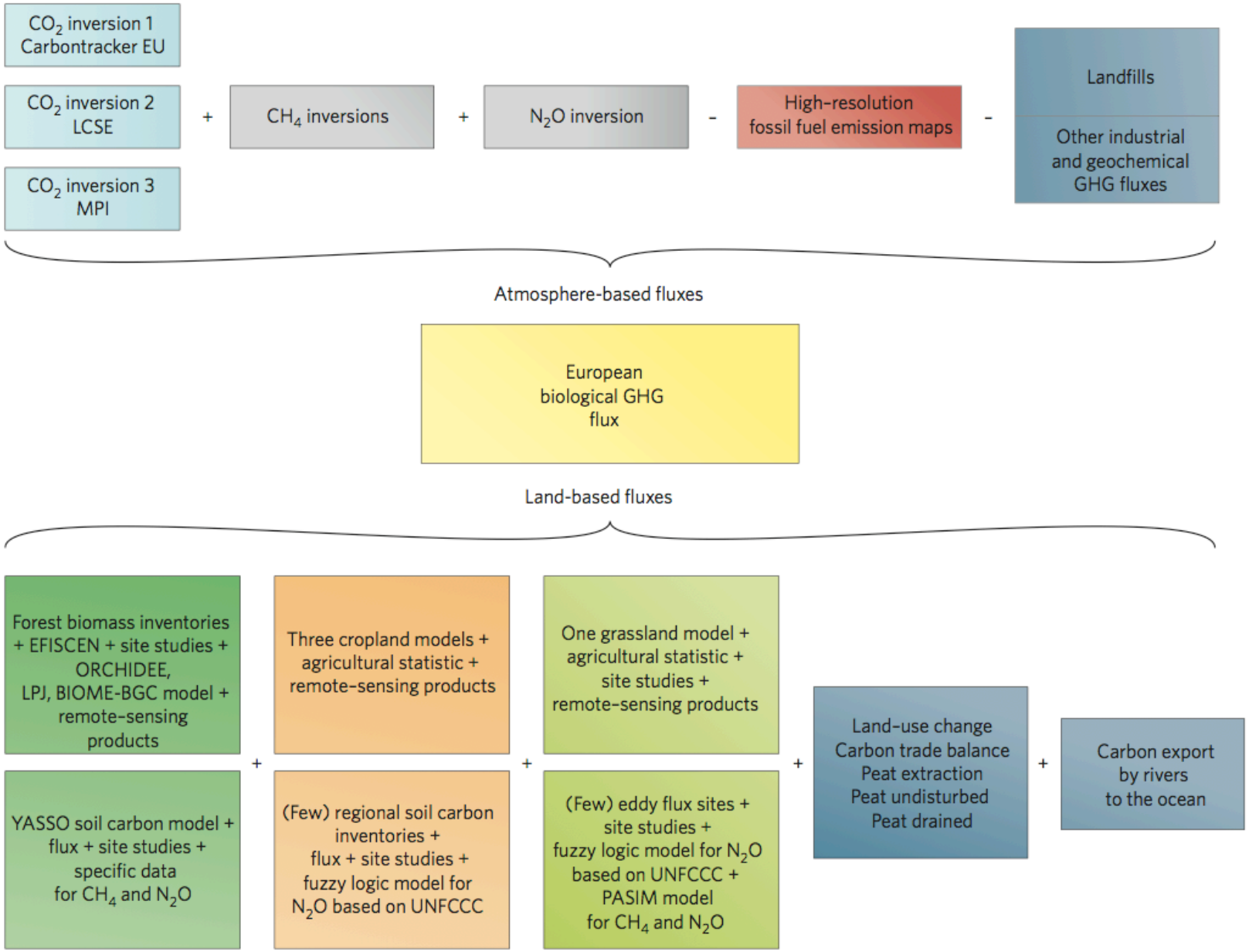
land ecosystems
N2O flux

land ecosystems
GHG flux in CO2eq



uncertainties

Methods


CO_2 inversion 1 Carbontracker EU
CO_2 inversion 2 LCSE
CO_2 inversion 3 MPI
+
CH_4 inversions
+
N_2O inversion
-
High-resolution fossil fuel emission maps
-
Landfills
Other industrial and geochemical GHG fluxes
Atmosphere-based fluxes
European biological GHG flux
Land-based fluxes
Forest biomass inventories + EFISCEN + site studies + ORCHIDEE, LPJ, BIOME-BGC model + remote-sensing products
YASSO soil carbon model + flux + site studies + specific data for CH_4 and N_2O
+
Three cropland models + agricultural statistic + remote-sensing products
(Few) regional soil carbon inventories + flux + site studies + fuzzy logic model for N_2O based on UNFCCC
+
One grassland model + agricultural statistic + site studies + remote-sensing products
(Few) eddy flux sites + site studies + fuzzy logic model for N_2O based on UNFCCC + PASIM model for CH_4 and N_2O
+
Land-use change
Carbon trade balance
Peat extraction
Peat undisturbed
Peat drained
+
Carbon export by rivers to the ocean

Atmosphere - based estimates

Top down inversions
C-tracker
Peylin et al.
Rödenbeck et al.

-

Bottom-up

=

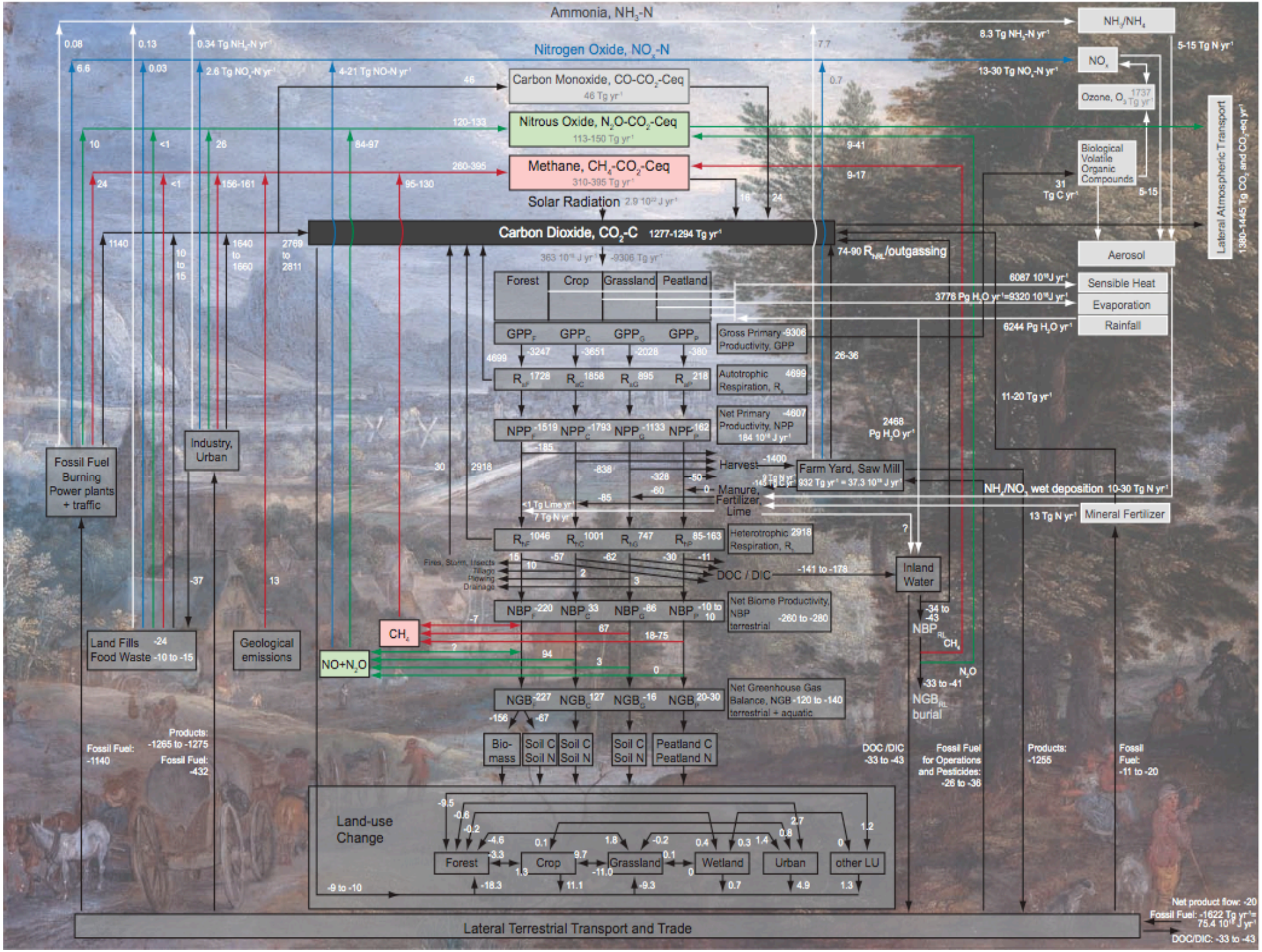
		EU-25 Flux ($Tg\ C\ yr^{-1}$)	EU-25 Uncertainty ($Tg\ C\ yr^{-1}$)
	Inversion fluxes		
1.	Top-down CO_2 flux (rows 12 + 5 + 28 + 6 + 7)	960	176
2.	Top-down CH_4 flux*,†	170	67
3.	Top-down N_2O flux*,†	90	58
4.	Subtotal	1,220	195
	Industrial and geological GHG fluxes‡		
5.	Fossil fuel CO_2 emissions	1,052	53
6.	Volcanic and geothermal CO_2 flux§	10	3
7.	Products and landfills	−3	2
8.	CH_4 industry*,‖	61	31
9.	CH_4 geological*,‖	6	3
10.	N_2O industry*,‖	32	16
11.	Subtotal	1,158	63
	Atmosphere-based biological fluxes		
12.	CO_2 flux¶	**−120**	73#/150**
13.	CH_4 flux (2 − 8 − 9)	103	54#/50**
14.	N_2O flux (3 − 10)	58	40#/45**
15.	GHG flux (12 + 13 + 14)	40	100#/164**

Uncertainties show the range of most likely inversion results. The standard deviation of a uniform distribution needs to be multiplied by 3.45 to obtain the minimum–maximum range.

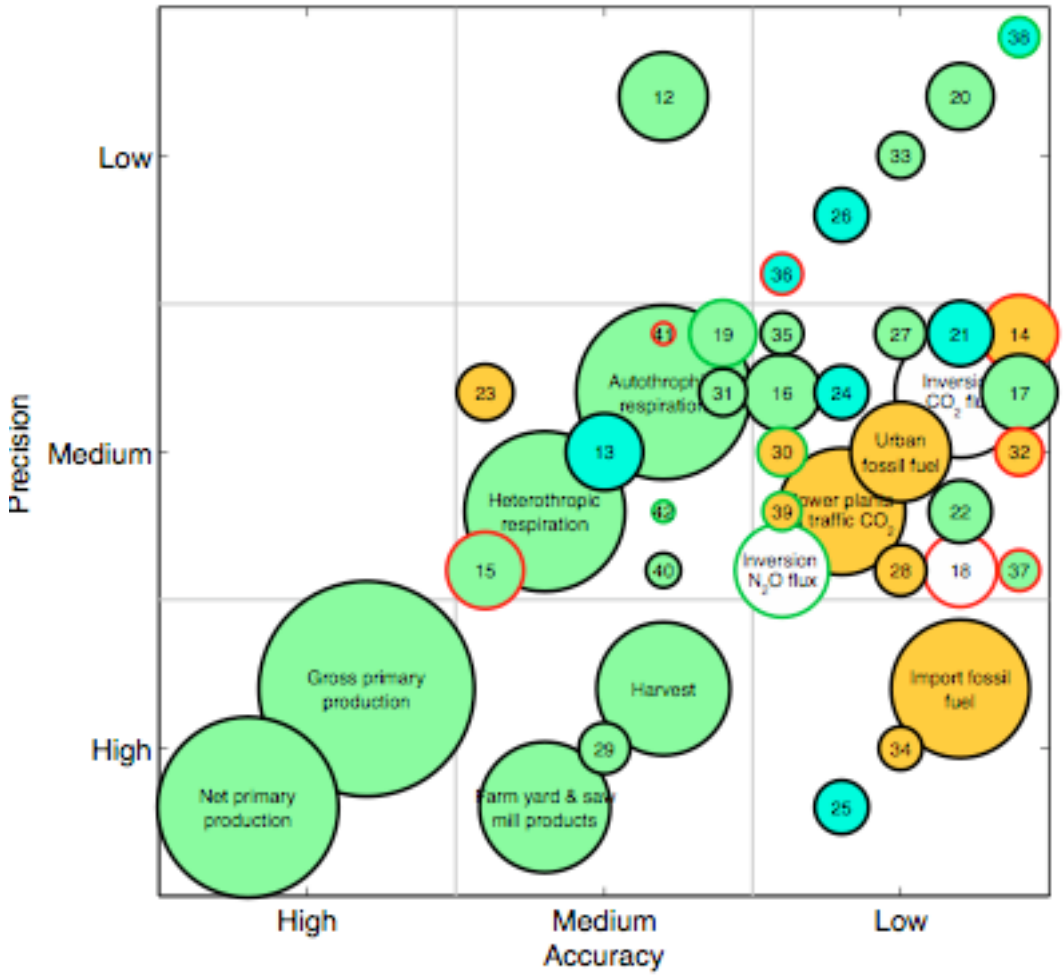
** Gaussian uncertainty of individual simulations. The range of model outcomes and the Gaussian uncertainty of an inversion are not independent.

Land - based estimates

		EU-25		
		Area (million km²)	Flux (Tg C yr⁻¹)	Uncertainty (Tg C yr⁻¹)
	Ecosystem CO_2 fluxes			
16.	Forest biomass	1.45	−80	14#
17.	Forest soil		−29	5#
18.	Other wooded land	0.16	−5	3
19.	Grassland	0.57	−32	4#
20.	Cropland ††	1.08	11	2#
21.	Peat undisturbed	0.09	−3	2
22.	Peat drained	0.15	13	7
23.	Subtotal	3.50	−125	17
	Additional CO_2 fluxes			
24.	Land-use change‡‡		−20	10
25.	Carbon trade balance		24	4
26.	Carbon export by rivers to ocear		−10	3
27.	Peat extracted		7	1
28.	Fossil fuel agriculture§§		22	11
29.	Subtotal		23	16
	Biological GHG fluxes			
30.	CH_4 agriculture*,‖		51	26
31.	CH_4 wetlands*		13	7
32.	CH_4 oxidation*		−4	2
33.	N_2O agriculture*,‖		70	35
34.	Subtotal		130	44
	Land-based biological GHG flux			
35.	CO_2 flux (23 + 29)		**−102**	23
36.	CH_4 flux (30 + 31 + 32)		**60**	26
37.	N_2O flux (33)		**70**	35
38.	GHG flux (35 + 36 + 37)		28	49


Ammonia, NH3-N
Nitrogen Oxide, NOx-N
Carbon Monoxide, CO-CO2-Ceq
46 Tg yr-1
Nitrous Oxide, N2O-CO2-Ceq
113-150 Tg yr-1
Methane, CH4-CO2-Ceq
310-395 Tg yr-1
Solar Radiation 2.9 10^22 J yr-1
Carbon Dioxide, CO2-C 1277-1294 Tg yr-1
363 10^18 J yr-1 -9306 Tg yr-1
74-90 RRL/outgassing
NH3/NH4
NOx
Ozone, O3 1737 Tg yr-1
Biological Volatile Organic Compounds
31 Tg C yr-1
Aerosol
Lateral Atmospheric Transport
1380-1445 Tg CO2 and CO2-eq yr-1
8.3 Tg NH3-N yr-1
13-30 Tg NOx-N yr-1
5-15 Tg N yr-1
6087 10^18 J yr-1
Sensible Heat
3776 Pg H2O yr-1=9320 10^18 J yr-1
Evaporation
6244 Pg H2O yr-1
Rainfall
2468 Pg H2O yr-1
NHx/NOy wet deposition 10-30 Tg N yr-1
13 Tg N yr-1
Mineral Fertilizer
Forest
Crop
Grassland
Peatland
GPP
Gross Primary Productivity, GPP
Autotrophic Respiration, Ra
Net Primary Productivity, NPP
184 10^18 J yr-1
Harvest
Farm Yard, Saw Mill
932 Tg yr-1 = 37.3 10^18 J yr-1
Manure, Fertilizer, Lime
<1 Tg Lime yr-1
7 Tg N yr-1
Heterotrophic Respiration, Rh
Fires, Storm, Insects
Tillage
Plowing
Drainage
DOC / DIC
Inland Water
Net Biome Productivity, NBP terrestrial -260 to -280
NBPRL
CH4
N2O
NGBRL burial
Net Greenhouse Gas Balance, NGB -120 to -140 terrestrial + aquatic
Bio-mass
Soil C Soil N
Peatland C Peatland N
Land-use Change
Forest
Crop
Grassland
Wetland
Urban
other LU
Fossil Fuel Burning Power plants + traffic
Industry, Urban
Land Fills -24
Food Waste -10 to -15
Geological emissions
CH4
NO+N2O
Fossil Fuel: -1140
Products: -1265 to -1275
Fossil Fuel: -432
DOC /DIC -33 to -43
Fossil Fuel for Operations and Pesticides: -26 to -36
Products: -1255
Fossil Fuel: -11 to -20
Net product flow: -20
Fossil Fuel: -1622 Tg yr-1 = 75.4 10^18 J yr-1
DOC/DIC: -33 to -43
Lateral Terrestrial Transport and Trade

Precision & accuracy



12 Terrestrial net biome production,
13 Dissolved (in)organic carbon,
14 Urban emissions CH_4,
15 Terrestrial CH_4,
16 Forest biomass,
17 Carbon in manure
18 Change in atmospheric CH_4,
19 Terrestrial N_2O,
20 Terrestrial net greenhouse gas balance,
21 Aquatic outgassing,
22 Forest soils,
23 Fossil Fuel CO,
24 Aquatic net biome production,
25 Export of dissolved (in)organic carbon,
26 Aquatic net greenhouse gas balance,
27 Biological volatile organic compounds,
28 Farm yard fossil fuel,
29 Disturbance,
30 Urban emissions N_2O,
31 Land fills CO_2,
32 Power plants and traffic CH_4,
33 Import products,
34 Fertilizer fossil fuel,
35 Respiration from food waste,
36 Aquatic CH_4,
37 Geological CH4,
38 Aquatic N_2O,
39 Power plants and traffic N_2O,
40 Land use change,
41 Land fills CH_4,
42 Land fills N_2O

Substantial improvements in the European carbon balance are expected by either
Increasing the accuracy by confirming the present magnitude with an independent estimate of the component flux
Increasing the precision by rigourous measurements and representative sampling networks or both.

Fossil fuel emission accuracy

Table II.2 Different estimates (in MtC) of CO2 emissions from fossil-fuel consumption for the United States, Canada, and Mexico.

Country	1990		1998		2002	
United States	CDIAC	1305	CDIAC	1501	CDIAC	1580
	IEA	1320	IEA	1497	IEA	1545
	USEPA	1316	USEPA	1478	USEPA	1534
Canada	CDIAC	112	CDIAC	119	CDIAC	139
	IEA	117	IEA	136	IEA	145
	Canada	117	Canada	133	Canada	144
Mexico	CDIAC	99	CDIAC	96	CDIAC	100
	IEA	80	IEA	96	IEA	100
	Mexico	81	Mexico	96	Mexico	NA

Notes:
Many of these data were published in terms of the mass of CO_2, and these data have been multiplied by 12/44 to get the mass of carbon for the comparison here.
All data except CDIAC include oxidation of non-fuel hydrocarbons.
All data except IEA include flaring of gas at oil and gas processing facilities.
Sources: CDIAC (Marland *et al.*, 2005), IEA (2005), USEPA (2005), Canada (Environment Canada, 2005), and Mexico (2001).

A 5% accuracy is obtained, or better
National Agencies use more detailed factors than international / global analysis

Global Change Biology (2009), doi: 10.1111/j.1365-2486.2009.02098.x

The European carbon balance revisited. Part 4: fossil fuel emissions

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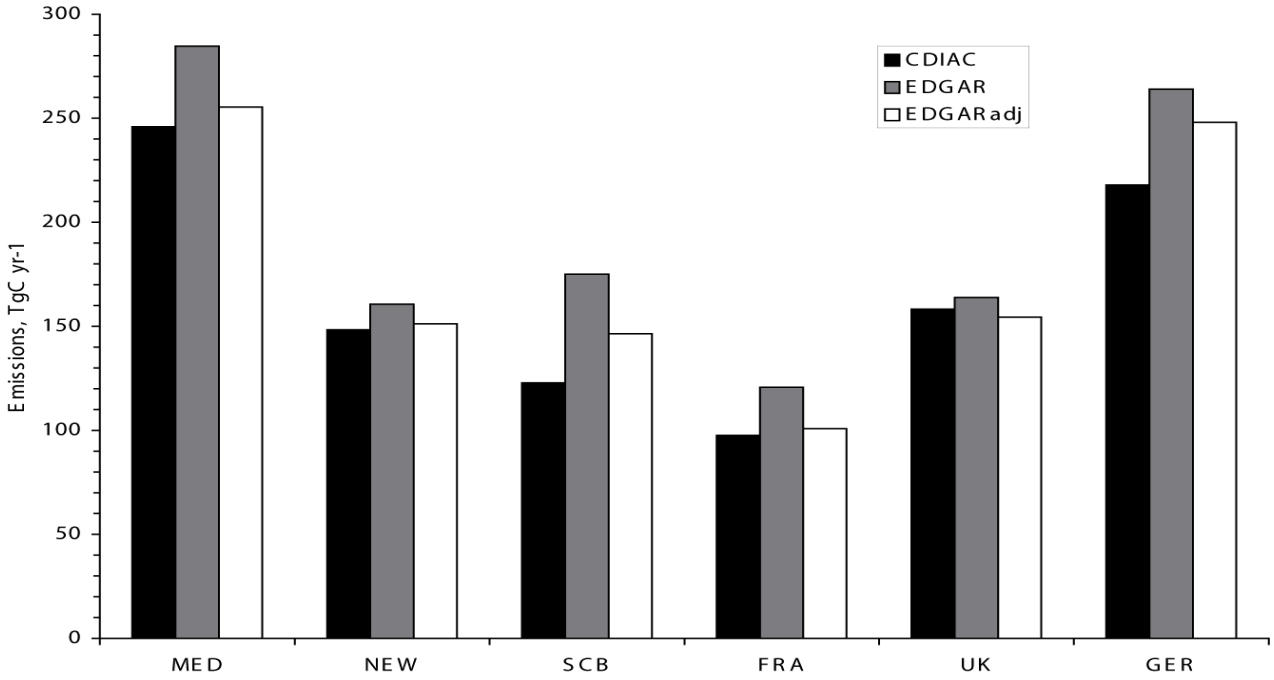
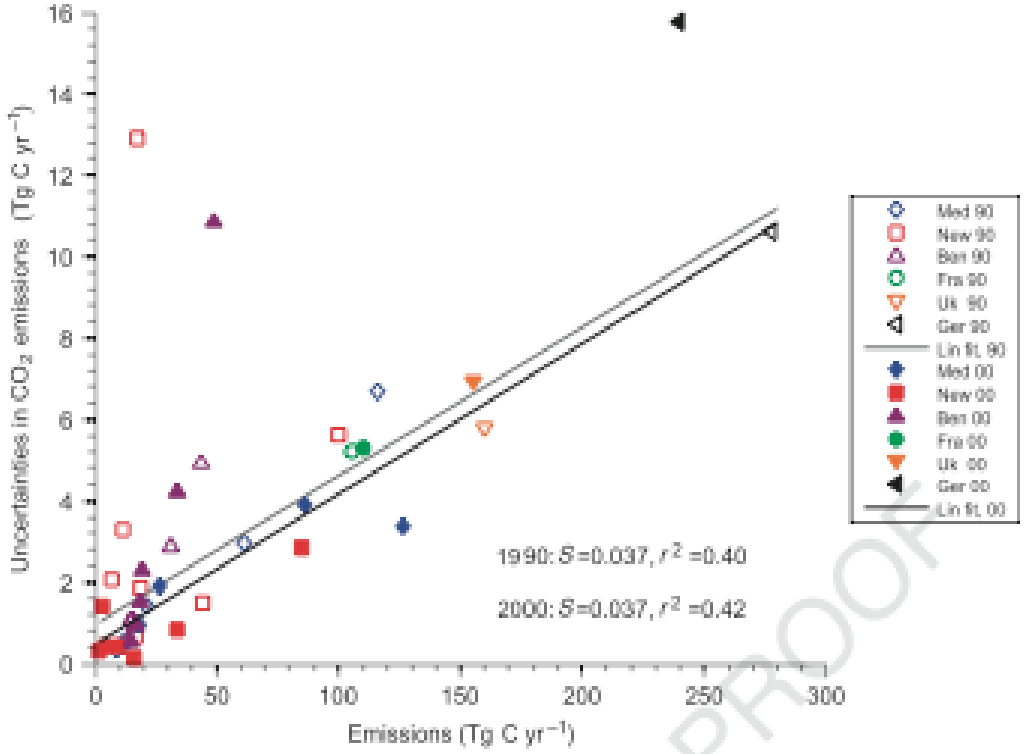


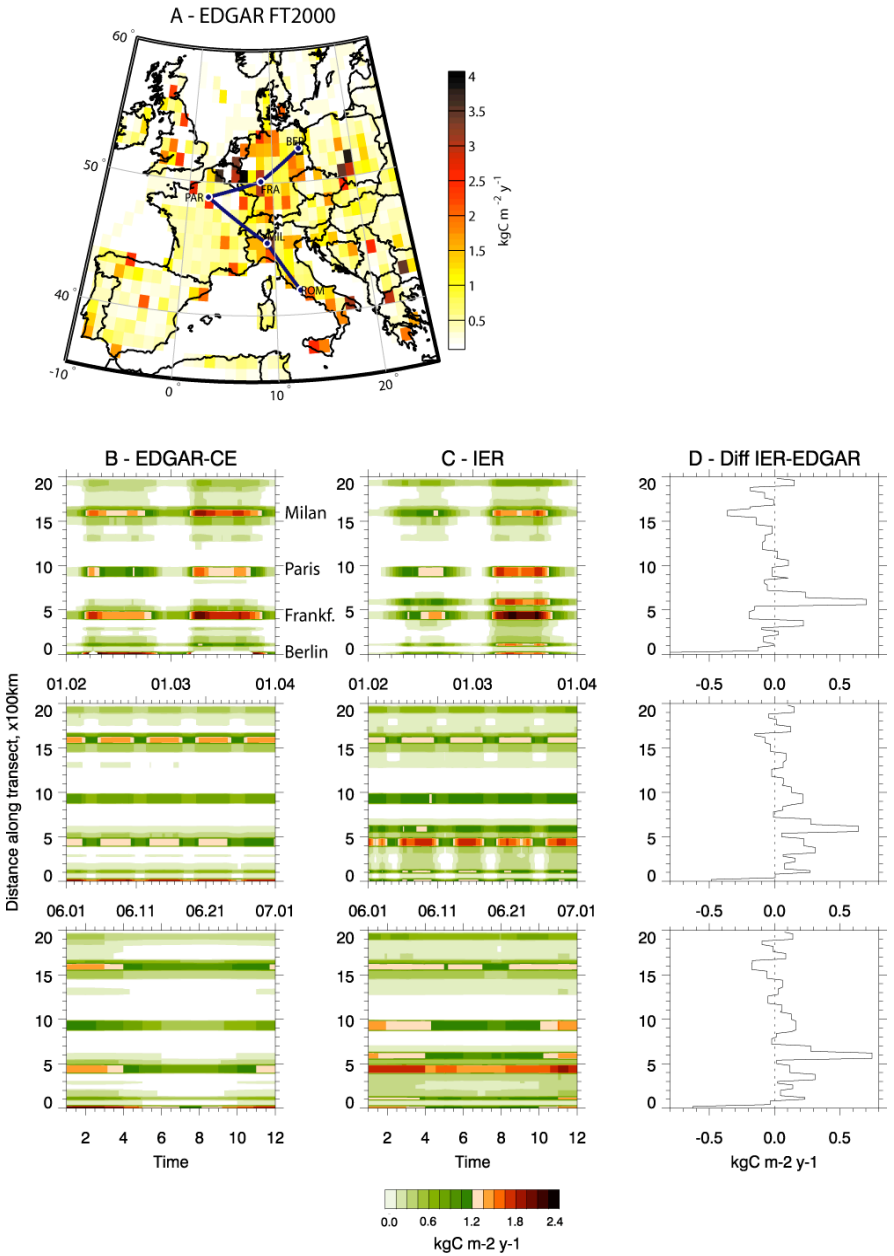
Example of systematic error in emissions for EU-25, indicated by differences between the CDIAC and EDGARv3.2 datasets. EDGAR adjusted has removed bunker fuels and nonfuel-use related emissions, which were not included in the CDIAC system boundary. None of the fossil-fuel emission inventories include cement production here.

Accuracy of emission estimates

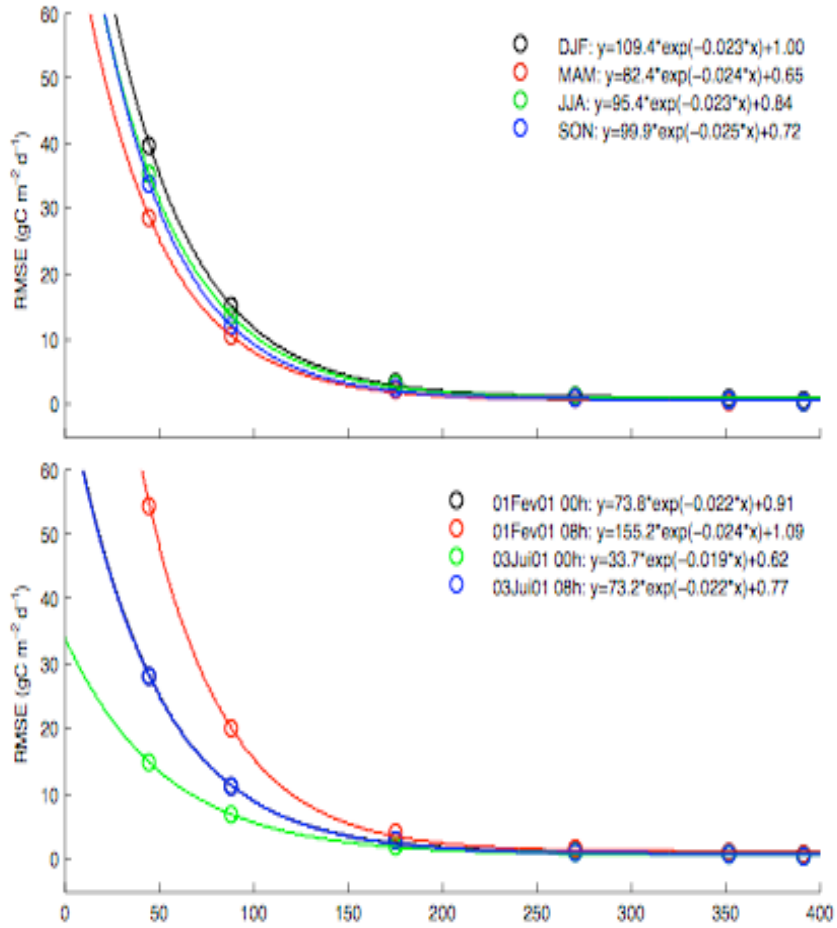
Accuracy
std from four inventories
Cdiac, edgar, gains, UNFCCC



Inaccuracy in emission downscaling (compare IER vs Edgar+CE)



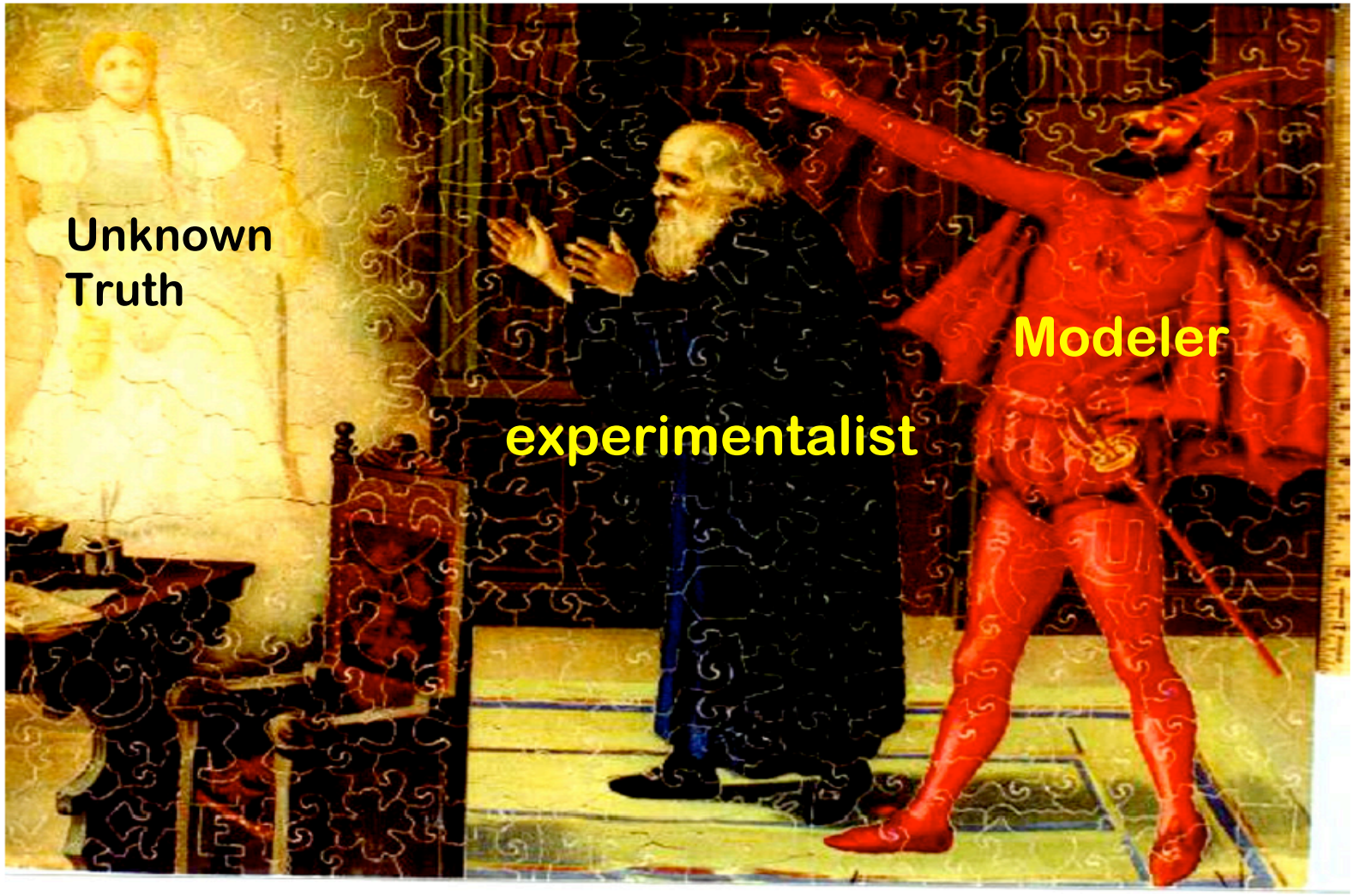
Emission error



Aggregation scale (km)

Conclusions

- Overall accuracy of the continental GHG balance can be assessed from the difference between the top-down and bottom-up estimates
- Convergence of these largely independent approaches increases confidence in our GHG balance.
- Although component fluxes obtained by a single method typically come with a well-defined accuracy, estimates of the uncertainty in different methods are often inconsistent.
- Even if all component fluxes had consistent uncertainty estimates, integration would be hampered by conceptual issues such as how to weight representativeness against the accuracy of point measurements (e.g. forest inventories with a wide spatial sample, against more accurate but probably poorly representative flux tower observations)


Unknown
Truth
Modeler
experimentalist