Supplementary material - Description of data products

Short hand: **Abril**
Field(s): 1a' (b)
Description: CH_4 fluxes from rivers, lakes, estuaries, marshes and peatlands
Spatial extent: Watersheds draining into the Atlantic Ocean, Artic, Baltic, North, Mediterranean and Black sea
Temporal extent: Publications from the period 1978 to 2007 were compiled in a single data product, hence, the temporal extent of the product is undefined.
Observations: CH_4 release factors were taken from an extensive overview of published literature see references in Saarnio et al. (2009).
Accounting boundaries: The estimate excludes fjords and other coastal waters.
Processing: See Saarnio in this Supplementary Material.
Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.
Post-processing: None.
Bias correction: The spatial extent of this data product exceeds the area of interest, total flux estimates were divided by the surface area of aquatic ecosystems of the data product. Subsequently, average fluxes were multiply by the surface area of aquatic ecosystems given by CORINE for the region of interest to obtain a flux estimate for spatial extent within this study. CORINE does not account for small lakes and rivers which are thought to globally account for 45% of the aquatic surface area (Downing *et al.*, 2006). The CORINE surface area was corrected for this bias. The data product is temporally undefined, nevertheless, the estimates were assigned to the period 2001-2005.

Short hand: **Bastviken**

Field(s): 1a' (a)

Description: CH_4 outgassing and carbon burial in rivers and lakes.

Spatial extent: Temperate, boreal and arctic freshwaters.

Temporal extent: Observations from the period 1990 to 2010 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Observations: Estimate A: data from 18 publications and 74 systems. Estimate B: 24 papers reporting data from 295 systems (Bastviken *et al.*, 2011). River estimate: (Lilley et al., 1996;Deangelis and Scranton, 1993;Hope et al., 2001;Jones and Mulholland, 1998;Kling et al., 1992;Middelburg et al., 2002)

Accounting boundaries: It should be recognized that there are few data points behind these numbers and that CH_4 measurements suffer from the use of many non-comparable approaches so these numbers are uncertain at this point. For example even if Estimate B seems to be robust on data from 295 systems, ebullition being the most important open water flux component was only measured in around 20 systems from relevant biomes globally. The reason many estimates are similar is that they are all based on more or less the same limited dataset. Flux though plants at lake margins were not included, hence, the estimate should be considered conservative.

Processing: Estimate A is based on models in Bastviken et al. (2004) applied to the European freshwater area. Since European reservoirs are relatively old and because little data are available, reservoirs were assumed to emit as much as lakes. River emissions were based on average temperate, boreal and arctic river emission data multiplied with river area. Estimate B is based on temperate, boreal and subarctic data in a database (Bastviken *et al.*, 2011) Diffusive flux was estimated by simple multiplication of average times area. For ebullition and emission of accumulated water column methane upon lake circulation the fact that these emission pathways are most important from shallow water (ebullition) and in small wind sheltered systems was accounted for. The River estimate is the same as in Estimate A.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: The spatial extent of this data product exceeds the area of interest, total flux estimates were divided by the surface area of aquatic ecosystems of the data product. Subsequently, average fluxes were multiply by the surface area of aquatic ecosystems given

by CORINE for the region of interest to obtain a flux estimate for spatial extent within this study. CORINE does not account for small lakes and rivers which are thought to globally account for 45% of the aquatic surface area (Downing *et al.*, 2006). River and lake emissions were assumed to be representative for estuary which are not included in CORINE. The CORINE surface area was corrected for these biases. The data product is temporally undefined, nevertheless, the estimates were assigned to the period 2001-2005.

Short hand: **Bastviken**

Field(s): 1a (a), 9j

Description: CO_2 outgassing and C burial in rivers and lakes.

Spatial extent: Temperate, boreal and arctic freshwaters.

Temporal extent: Observations from the period 1990 to 2010 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Observations: Literature compilations (see below)

Accounting boundaries: C-burial estimates are based on very little observational evidence.

Processing: Outgassing and C burial for lakes and impoundments are based on the literature reviewed by Tranvik et al. (2009). In this review, the long-term average carbon burial rates in lakes are estimated to be between 4.5 and 14 g C m^{-2} y^{-1} (Dean and Gorham, 1998;Stallard, 1998;Cole et al., 2007). C-burial in impoundments has been estimated at 1000 g C m^{-2} y^{-1} (Downing *et al.*, 2008). Outgassing from rivers is based on Battin et al. (2008).

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: The spatial extent of this data product exceeds the area of interest, total flux estimates were divided by the surface area of aquatic ecosystems of the data product. Subsequently, average fluxes were multiply by the surface area of aquatic ecosystems given by CORINE for the region of interest to obtain a flux estimate for spatial extent within this study. CORINE does not account for small lakes and rivers which are thought to globally account for 45% of the aquatic surface area (Downing *et al.*, 2006). River and lake emissions were assumed to be representative for estuary which are not included in CORINE. The CORINE surface area was corrected for these biases. The data product is temporally undefined, nevertheless, the estimates were assigned to the period 2001-2005.

Short hand: **Bastviken**

Field(s): 1a”’(a)

Description: N_2O outgassing from rivers and lakes (Schulze *et al.*, 2010).

Spatial extent: Temperate, boreal and arctic freshwaters.

Temporal extent: Observations from the period 1990 to 2010 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Observations: Literature compilation from (Clough et al., 2006;Cole and Caraco, 2001;de Wilde and de Bie, 2000;Garnier et al., 2009;Garnier et al., 2006;Harrison and Matson, 2003;Harrison et al., 2005;Hemond and Duran, 1989;Hendzel et al., 2005;Hirota et al., 2007;Huttunen et al., 2004;Huttunen et al., 2003a;Huttunen et al., 2003b;Huttunen et al., 2002;McMahon and Dennehy, 1999;Mengis et al., 1996, 1997;Miyajima et al., 1997;Reay et al., 2003;Silvennoinen et al., 2008;Stow et al., 2005)

Accounting boundaries: All river numbers in the dataset comes from eutrophic rivers in agricultural primarily temperate areas and emissions should be much lower for rivers in boreal forest areas with low amounts of nitrogen being present

Processing: Emission estimates were compiled for temperate, boreal and arctic freshwaters. The river average was multiplied with the river area (Schulze *et al.*, 2010). Several of the literature sources showed clear evidence that emissions from central parts of water bodies are negligible and that only shallow littoral parts release significant amounts of N_2O (some of the boreal lakes were actually N_2O sinks). Therefore, the area fraction having a depth of less than 1 m was estimated for different size classes of lakes (Carpenter, 1983) as a proxy for the shallow littoral parts. This area fraction ranged from 25 % in the smallest lakes to 1.8 % in the largest lakes. The estimated littoral areas was multiplied with the average lake N_2O emission. Reservoirs and ponds were treated like lakes. The sum of all emissions (from rivers, lakes, reservoirs and ponds) was 0.25 Tg N_2O yr^{-1}. River emissions accounted for 99 % of the emissions. This likely represents an overestimate since all river numbers in the dataset come from eutrophic rivers in agricultural primarily temperate areas and emissions should be much lower for rivers in boreal forest areas with low amounts of nitrogen being present.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: The spatial extent of this data product exceeds the area of interest, total flux estimates were divided by the surface area of aquatic ecosystems of the data product.

Subsequently, average fluxes were multiply by the surface area of aquatic ecosystems given by CORINE for the region of interest to obtain a flux estimate for spatial extent within this study. CORINE does not account for small lakes and rivers which are thought to globally account for 45% of the aquatic surface area (Downing *et al.*, 2006). The CORINE surface area was corrected for this bias. The data product is temporally undefined, nevertheless, the estimates were assigned to the period 2001-2005.

Short hand: **Bousquet**

Field(s): 14a'

Description: Monthly methane (CH_4) total surface fluxes (emissions and soil uptake) gridded in Tg CH_4 yr^{-1} for the period 1984-2008 (Bousquet et al., 2006;Bousquet et al., 2011). Measurements of CH_4 concentrations in the atmosphere are used in models of atmospheric transport. The distribution of sources and sinks at the land surface is derived by minimizing the difference between simulated and observed concentration measurements, taking account of their respective errors and of a prior knowledge of their magnitude.

Spatial extent: Global

Temporal extent: 1984 - 2008

Observations: Monthly-averaged data from up to 68 sites from different networks were collected and used; 75% was contributed by the NOAA network. A total of 16,000 monthly observations from 1984 to 2008 was used.

Accounting boundaries: The model extents up to 30 km high in the atmosphere. The inversion is based on a prior knowledge of all known sources and sink of atmospheric methane.

Processing: Atmospheric CH_4 measurements can be linked quantitatively to regional sources and sinks by inverse modelling. For the period 1984–2008, the CH_4 concentration responses to the action of OH sinks and regional surface sources were simulated each month with the three-dimensional chemistry transport model LMDz-INCA (Hauglustaine *et al.*, 2004). The model was forced with interannual analysed winds (Uppala *et al.*, 2005) and interannually varying OH concentrations (Bousquet *et al.*, 2005). Emissions of CH_4 from different large regions of the globe and from distinct processes (emissions from bogs, swamps, tundra, termites, fossil fuel and industry, gas, bio-fuel, ruminant animals, landfills and waste, and soil uptake), together with the photochemical sinks, were inferred, and their uncertainties reduced, by matching atmospheric observations within their uncertainties in a Bayesian formalism (Bousquet *et al.*, 2005). Clearly, uncertainties in the variations of OH concentrations limit our ability to infer accurately fluctuations in regional CH_4 emissions. The removal of CH_4 by OH nearly balances the sum of all surface sources, making the atmospheric CH_4 highly sensitive to OH changes. Thus, we constrained first the interannual variability of OH through a preliminary inversion of methyl chloroform atmospheric observations (Bousquet *et al.*, 2005). Contributions of monthly surface CH_4 sources and pre-optimized monthly OH sinks were then combined to fit optimally monthly averages of CH_4 measurements from a global network of 68 sampling sites. Long-term measurements of the $^{13}C/^{12}C$ ratio in CH_4 ($\delta^{13}C\text{-}CH_4$) were also used as an additional constraint for the partitioning of microbial-, biomass-burning- and

fossil-fuel-related CH_4 sources.

Available uncertainty estimates: We performed a control inversion, supplemented by an ensemble of 17 sensitivity inversions (Bousquet *et al.*, 2006). Annual residual uncertainties after inversion are calculated by the inverse procedure. However, these uncertainties are known to be underestimated because of some assumptions made in the inversion e.g. perfect atmospheric transport, aggregation error due to the large-region grouping, choice of prior distribution of sources and sinks etc. Therefore, the standard deviation of the 17 sensitivity inversions provides an additional uncertainty partly representing the unresolved uncertainties.

Post-processing: Conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: None.

Short hand: **Byrne**

Field(s): 2l, 9i

Descriptikon: CO_2 and CH_4 fluxes from undisturbed peatlands

Spatial extent: SWE, FIN, DEU and GBR

Temporal extent: 2000-2002

Observations: Site observations were compiled by Byrne et al. (2004) and presented in their table 4.

Accounting boundaries: The available data are strongly biased towards Finland. Only data from natural mires were used.

Processing: A literature review was performed to gather all available information on measured GHG fluxes.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Average fluxes were multiply by the population of the region of interest to obtain a flux estimate for the spatial extent within this study.

Bias correction: None.

Short hand: **CDIAC**

Field(s): 5a

Description: Annual fossil-fuel CO_2 emissions

Observations: Compilation of global, regional, and national fossil-fuel CO_2 emissions (http://cdiac.ornl.gov/trends/emis/overview_2008.html)

Spatial extent: Global

Temporal extent: 1751-2008

Accounting boundaries: Andres et al. (this issue) describe the limitations of national and global fossil fuel CO_2 data sets. Of particular interest here is that global totals do not equal the sum of national totals due to the internationally accepted conventions of fossil fuel accounting. For example, bunker fuels (i.e., those fuels used to conduct international trade) are not accountable to any one nation and thus do not appear in national totals, but do appear in global totals. One ramification of this is that if one were to produce a map of all emissions to the atmosphere from European lands and waters, perhaps in an effort to reconcile known inputs and exports to/from the European atmosphere with atmospheric measurements of that atmosphere, the map would be incomplete if all that were plotted were national fossil fuel CO_2 emissions. In this particular example, missing would be the bunker fuel emissions of international shipping and aircraft.

Processing: The Carbon Dioxide Information Analysis Center (CDIAC) estimates carbon dioxide emissions from the consumption of fossil fuels for all nations of the world by the methods described in Marland and Rotty (1984) and Andres et al. (1999). To calculate CO_2 emissions, statistics of the mass or volume of fuel consumed in each country are multiplied by the carbon content of the fuel and the combustion efficiency. These data are available in tabular form from http://cdiac.ornl.gov/trends/emis/overview_2008.html. These tabular emissions can also be expressed in geographic form by mapping the emissions on a one degree latitude by one degree longitude grid using the methodology of Andres et al. (1996). This methodology preserves national and global totals while distributing the within country distribution by a fixed population proxy. The gridded data are available from http://cdiac.ornl.gov/epubs/ndp/ndp058/ndp058_v2010.html.

Available uncertainty estimates: Uncertainty estimates on global totals are on the order of 5-10% (two sigma). At the national level, two sigma uncertainties start at 3-5% for least uncertain countries to 50% or more for the most uncertain countries. For Europe, the two sigma uncertainty on annual fossil fuel emissions is 6.59%. Uncertainties with gridded fossil fuel CO_2 emissions are much more difficult to quantify due to the lack of independent

measurements at the appropriate spatial and temporal scales. Andres et al. (this issue) discuss uncertainties with these data products in more detail.

Post-processing: None

Bias correction: None

Short hand: **Chevallier**

Field(s): 14a

Description: The space-time distribution of CO_2 fluxes at the Earth's surface is inferred from measurements of CO_2 mixing ratio made at a series of surface stations. The ill-posed inverse problem is regularised with prior maps of those fluxes. An atmospheric transport model links the flux variables and the mixing ratio variables within the inverse system. The system takes the error of each information piece into account.

Spatial extent: Global

Temporal extent: 1988 to 2008.

Observations: The surface measurements used as input to the inversion system are mixing ratios of CO_2 (expressed as dry mole fractions) either collected in flask air samples at various places in the world over land (from fixed sites) and over ocean (from commercial ships), or performed in situ by automatic analyzers. 128 station records are used from three data sources representing cooperative efforts from many laboratories around the globe: the NOAA/ESRL archive (ftp://ftp.cmdl.noaa.gov/ccg/co2/), the CarboEurope atmospheric archive (http://ce-atmosphere.lsce.ipsl.fr/database/index_database.html) and the WDCGG archive (http://gaw.kishou.go.jp/cgi-bin/wdcgg/catalogue.cgi). Records from 3 additional stations were extracted from the LSCE database. All data have been downloaded on 28 September 2009.

Accounting boundaries: the CO_2 source from the oxidation of CO is attributed to the surface.

Processing: Tracer transport is simulated with the LMDZ4 model (Hourdin *et al.*, 2006) on a 3.75°x2.5° (longitude-latitude) horizontal grid and with 19 layers between the surface and the top of the atmosphere. Grid point fluxes are estimated on this horizontal grid for eight-day segments, with prescribed variations at shorter time scales. The 21-year inversion consisted of a 30-iteration minimization of a Bayesian cost function with a conjugate gradient algorithm. For numerical efficiency, the adjoint of LMDZ is exploited. The whole minimization lasted 35 days with eight Itanium2 CPUs at 1.6 GHz running in parallel. A detailed description of the system and of its results can be found in Chevallier et al. (2007;2010;2005) or at http://www.carboscope.eu/?q=co2_inv_lsce_var. The results have been validated with aircraft mixing ratio measurements.

Available uncertainty estimates: Formal Bayesian uncertainty can be computed on demand for target quantities.

Post-processing: None

Bias correction: None

Short hand: **Ciais**

Field(s): 1b, 2c, 9i

Description: Lateral transport of C from terrestrial ecosystems to fresh water ecosystems and subsequently from fresh water ecosystems to the ocean including burial and outgassing of CO_2 from fresh water ecosystems.

Observations: Organic and inorganic carbon concentrations in inland water and river discharge were compiled using the main European rivers database (Meybeck and Ragu, 2006).

Spatial extent: European watershed draining into the Artic Sea, Baltic Sea, North Sea, Atlantic Ocean, Mediterranean sea and Black sea.

Temporal extent: Observations from the period 1980 to 2000 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Accounting boundaries: Measurements were not normalized in sampling position along the fresh water – salt water continuum within the estuaria, delta or fjord. Hence, the accounting boundary of ocean discharge is ill defined. Further, autochthonous carbon production within freshwater ecosystems is not accounted for resulting in overestimating the C-subsidy of terrestrial systems to fresh water ecosystems.

Processing: Organic and inorganic carbon concentrations in inland water and river discharge were compiled using the main European rivers database (Meybeck and Ragu, 2006) and extrapolated for the European sea's catchments ($8.2\ 10^6$ km^2) on the basis of runoff, land cover and rock types similarities (Ciais *et al.*, 2008). The additional carbon loss as CO_2 outgassing from rivers, lakes and estuaries was derived from a previous estimate at the European scale (Ciais *et al.*, 2008) that considered the ecosystem's typical average water–air CO_2 fluxes and river, lakes and estuaries surface areas (Lehner and Döll, 2004). This sum was then corrected by the ratio of organic over total carbon concentrations in inland water (Ciais *et al.*, 2007). Leaching of carbon from terrestrial ecosystems was calculated as the sum of CO_2 outgassing and the carbon load in inland waters. The number represents the average estimate and the contributions of forests, grasslands and croplands cannot be separated.

Available uncertainty estimates: There are no formal quantitative uncertainty analysis available for this product.

Post-processing: The estimate for the lateral flux included DIC from weathering. We subtracted estimates 6a and 6d to avoid double counting within our accounting framework. Simply subtracting 6a and 6d from assumes that all the DIC from weathering ends-up in the rivers and lakes. This is unlikely, hence our estimate probably underestimates the contribution

of terrestrial ecosystems.

Bias correction: The spatial extent of this data product exceeds the area of interest, total flux estimates were divided by the surface area of aquatic ecosystems of the data product. Subsequently, average fluxes were multiply by the surface area of aquatic ecosystems given by CORINE for the region of interest to obtain a flux estimate for spatial extent within this study. CORINE does not account for small lakes and rivers which are thought to globally account for 45% of the aquatic surface area (Downing *et al.*, 2006). The CORINE surface area was corrected for this bias. The data product is temporally undefined, nevertheless, the estimates were assigned to the period 2001-2005.

Short hand: **Ciais**

Field(s): 9b

Description: Soil inventory based changes in soil carbon under cropland

Spatial extent: AUT, BEL, DNK, FIN, FRA, GBR and some regions in DEU.

Temporal extent: Observations from the period 1980 to 2000 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Observations: C-content changes from repeated soil inventories

Accounting boundaries: The available data are confined to humid temperate systems and are most likely not representative for the region under study because Mediterranean systems are underrepresented as are less intensively managed croplands in Eastern Europe. The interval between two inventories varied between 10 and 50 years.

Processing: Ciais et al (2010) compiled changes in cropland soil carbon stock from regional inventories over AUT, BEL, DNK, FIN, FRA, GBR and some regions in DEU. Altogether, these inventoried regions represent over 30% of the total cropland area within the study region. Details of the compilation are given in Table 3 (Ciais *et al.*, 2010). Total flux estimates were divided by the land surface area of the data product. Surface areas were based on Corine land cover data (http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes) estimating the total surface area of 'arable land & permanent crop' at 1,246,570 km^2.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: The spatial extent of this data product is limited to AUT, BEL, DNK, FIN, FRA, GBR and some regions in DEU. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. For upscaling total cropland area (1,246,570 km^2) was corrected for cropland on drained peatlands (29,700 km^2) which were separately accounted for. This estimate was assigned to the period 2001-2005.

Short hand: **Ciais**

Field(s): 9d

Description: Soil inventory based changes in soil carbon under pasture

Spatial extent: BEL, FRA and GBR.

Temporal extent: Observations from the period 1980 to 2000 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Observations: C-content changes from repeated soil inventories

Accounting boundaries: The available data are confined to humid temperate systems and are most likely not representative for the region under study because Mediterranean systems are underrepresented as are less intensively managed pastures in Eastern Europe. The interval between two inventories varied between 10 and 40 years.

Processing: Changes in cropland soil carbon stock were compiled from regional inventories over Belgium (Lettens et al., 2005;Goidts and Wesemael, 2007), France (Soussana *et al.*, 2004) and GBR (Bellamy *et al.*, 2005). Altogether, these inventoried regions represent just under 30% of the total pasture area within the study region. Surface areas were based on Corine land cover data (http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes) estimating the total surface area of 'pasture and mosaics' at 909,788 km^2.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: The spatial extent of this data product is limited to BEL, FRA and GBR. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. This estimate was assigned to the period 2001-2005.

Short hand: **Corazza**

Field(s): 14a'''

Description: measurements of N_2O concentrations in the atmosphere are used in models of atmospheric transport. The distribution of sources and sinks at the land surface is derived by minimizing the difference between simulated and observed concentration measurements, taking account of their respective errors.

Spatial extent: global with a European zoom (1° x 1°)

Temporal extent: 2006

Observations: 9 European measurement stations with quasi-continuous measurements, complemented by European and global measurements from the NOAA global cooperative air sampling network (Dlugokencky *et al.*, 1994).

Accounting boundaries: the model is global and uses 25 vertical layers, with about 5 layers representing the boundary layer, 12 layers the free troposphere and 8 the stratosphere. It includes the major known natural and anthropogenic emissions. 4 sources categories (soil emission, biomass burning, ocean, and 'all other' emissions) are optimized independently, using a spatial correlation of 200 km, and a temporal correlation of zero for soil emission , biomass burning, ocean, and 9.5 months for 'all other' emissions.

Processing: The TM5-4DVAR inverse modelling system used in this work for N_2O is described in detail by Corazza et al. (2011). It is based on the two-way nested atmospheric zoom model TM5 (Krol *et al.*, 2005). In this study we apply the zooming with 1° × 1° resolution over Europe, while the global domain is simulated at a horizontal resolution of 6° × 4°. TM5 is an offline transport model, driven by meteorological fields (using the ERA-Interim reanalysis) from the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecast System (IFS) model.

The N_2O version of the TM5-4DVAR system is a further development of the system originally developed for CH_4 (Bergamaschi et al., 2010;Meirink et al., 2008). Major updates include: (i) the implementation of the chemical sink in the stratosphere (photolysis and reaction with $O(^1D)$ radicals, based on the ECHAM5/MESSy1 model (Brühl *et al.*, 2007), (ii) the a priori inventories for 13 different source categories, using EDGARv4.0 for most of the anthropogenic emissions, GFEDv2 (van der Werf *et al.*, 2004) for biomass burning, and GEIA (Bouwman *et al.*, 1995) for the natural emissions, and (iii) a novel bias correction scheme to correct for measurement biases among different laboratories. A bias correction has been applied for measurements from different laboratories, assuming a constant bias over the whole assimilation period (1 year). It has been demonstrated that the N_2O bias corrections

determined in the TM5-4DVAR system agree within ~0.1 ppb with the bias derived from the measurements at monitoring stations where parallel NOAA discrete air samples are available (Corazza *et al.*, 2011).

Available uncertainty estimates: The formal Bayesian uncertainties of derived emissions can be estimated based on a conjugate gradient algorithm (Corazza et al., 2011;Meirink et al., 2008). In addition, the overall uncertainty has been evaluated in a comprehensive model comparison within the NitroEurop project.

Post-processing: conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: None

Short hand: **Decay function**

Field(s): 11b

Description: Food stock in land fills

Spatial extent: EU-27

Temporal extent: 2008

Observations: Eurostat data on generation of waste in the EU-27 – Animal and vegetal waste

Accounting boundaries: Currently, the data collected under the Waste Statistics Regulation is not of sufficient detail on a country by country basis to relate to the definition of biowaste used here. However, for the European Waste Code (EWC) for animal and vegetal wastes, which also includes manure and the like, European wide data is available. The parameters of the decay function were assumed static, hence, changes in waste production and life-time are not accounted for.

Processing: Eurostat reported a total of 115,590,000 tonnes of biodegradable waste was produced in the EU-27 (http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/wastestreams/biowaste). When correcting for the spatial bias (see below), the total production is estimated at 124,290,000 tonnes. About 57% of this waste component ends up in landfills (http://resourcities.acrplus.org/waste_resources/europe_waste.htm). The UNFCCC reported that for the region under study annually 6 Tg of C is lost from landfills (see UNFCCC in section 3.4.3). We calculated the food stock that accumulated over the last 50 years by adjusting the decomposition rate such that the C-efflux from food decomposition is half the UNFCCC estimate, thus assuming the other half comes from wood decomposition. Given that the estimated waste production contains dry and fresh waste, a C content of 0.15 g C g^{-1} waste was assumed.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: The spatial extent of this data product is limited to EU-27. Prior to processing EU-27 waste production was divided by population of the EU-27. Subsequently, average waste production was multiplied by the population of the region of interest to obtain a flux estimate for the spatial extent within this study. The estimate for 2008 was assigned to the 2001-2005 period.

Short hand: **Dechow**

Field(s): 2j (a), 2j (b)

Description: N_2O fluxes from grassland and cropland management derived from on a fuzzy logic model using spatially explicit variables for upscaling site observations to the region level.

Observations: N2O emission database (Stehfest and Bouwman, 2006)

Spatial extent: All exc. ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK & CHE

Temporal extent: 1991-2000

Accounting boundaries: All relevant N_2O fluxes are considered. The statistical approach is based on annual N_2O observations and input data with seasonal to annual resolution. Inter annual system dynamics are not simulated. The influences of some specific management options (fertilizer type, application practice, tillage, inter crops) on N_2O fluxes are not considered.

Processing: A fuzzy logic model developed by Dechow et al. (2011) was used to calculate direct N_2O emissions. It is a sequence of 'IF-THEN' rules that aims to estimate N_2O emissions based on a combination of input factors. Training of the model finds the most suitable combination of information about soil properties (texture, organic carbon and organic nitrogen), climatic conditions and management options (amount of mean applied N, type of applied fertilizer) in order to match direct annual N_2O emissions known at the site level. Validation was performed by excluding a subset of sites from the calibration dataset. Training and validation data come from 50 sites with 240 plots that were extracted from the N_2O emissions database (Stehfest and Bouwman, 2006). Western and central Europe are well represented by measurements while the density of plot scale measurements in Eastern and Southern Europe is low. Factors used for up-scaling to the EU-25 level were the amount of applied N, sand content, pH, crop type (cereals, roots and vegetables, fallow, other), mean autumn precipitation and winter temperature of the precedent year. Nitrogen addition via fertilizer in 1990–1999 was extrapolated from CAPRI-Dynaspat data for the year 2000 (Leip *et al.*, 2008) and country budgets from the EUROSTAT database. Seasonal precipitation and temperature were derived from simulations with the REMO model (Vetter *et al.*, 2005). Local distribution of cropland areas for the year 2000 originates from a two-step regression approach (Leip *et al.*, 2008) taking into consideration environmental factors (climate, soil properties, land cover, etc.), statistical data of the CAPRI database with information at NUTS 2 Level and the Land Use/Cover Area Frame Statistical Survey (Kempen *et al.*, 2007). This data was extrapolated to the time period 1990–1999 using statistics from FAO. N_2O emissions

from histosols were calculated using national emission inventories from Drösler et al. (2008). Other direct and indirect sources came from UNFCCC statistics. N_2O flux estimate provided is the mean value over the 1990s decade.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None

Bias correction: The spatial extent of this data product does not include ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK and CHE. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Eggers**

Field(s): 10a, 11a

Description: C stock in wood products and wood in landfills

Spatial extent: All exc. CYP, EST, ISL, LVA, LTU, MLT

Temporal extent: 2000

Observations: FAO and EUROSTAT statistics for felling and commodities and country specific processing efficiencies. For more details see Eggers (2002 and references therein).

Accounting boundaries: From 1990 the model uses already modelled data as input to its own computations. Therefore, natural disturbances since 1990 were not accounted for. Also the parameters of the model were static, hence, changes in processing efficiency and life-time are not accounted for.

Processing: The contribution of wood-based products in absorbing atmospheric carbon is estimated for the Europe (see spatial extent). Based on past wood use, carbon stocks in wood products from 1990 are estimated with an existing wood product model (Karjalainen *et al.*, 1994) which has been slightly modified to support a coupling with EFISCEN (Eggers, 2002). The carbon in harvested timber runs through several stages and storages with country and product specific life-times until it is finally released again into the atmosphere. The fluxes of carbon are yearly processes whereas the stocks may sequesters the carbon for some years to several decades. In addition to the estimate of the initial carbon stock in 1990, scenarios of the future development of the carbon stock in wood products were run up to 2050. In this study we report the estimates for the business-as-usual scenario in 2000.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None

Bias correction: The spatial extent of this data product does not include CYP, EST, ISL, LVA, LTU and MLT. Total flux estimates were divided by the population represented by the data product. Subsequently, average fluxes were multiply by the population of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Etiope**

Field(s): 6b

Description: Geological-CO_2 emissions are almost exclusively related to geothermal and volcanic areas (high-temperature fluid-rock interactions, crustal magma and mantle degassing). So they may be referred to as "geothermal-volcanic CO_2 emissions". In these areas CH_4 concentration in the emissions is generally < 2% (typically a few ppmv).

Observations: Flux data were compiled from limited literature sources: Etiope et al. (2007 and references therein) Agustsdottir and Brantley (1994), Gıslason (2000) and Aiuppa et al. (2006).

Spatial extent: CZE, DEU, ESP, GRC, HUN, ISL & ITA.

Temporal extent: Owing to rather sparse observations, all available observations were bulked in a single data product, irrespective of the sampling year. Hence, the temporal extent of this data product is undefined.

Accounting boundaries: Significant changes in volcanic emissions over a short time span emphasize the need of a prudent extrapolation of spot measurements to the derivation of long-term time averages of CO_2 volcano degassing. For example, the CO_2 emission rates of Etna volcano varied by a factor 40 during only one year of observations from 2004 to 2005 (Aiuppa *et al.*, 2006). Geothermal emissions (independent of volcanic activity) seem to be much less variable.

Processing: In Europe, three types of degassing systems must be accounted for: (1) volcanoes including both crater and flank degassing, (2) non-volcanic geothermal vents such as mofettes, CO_2-springs and submarine vents and (3) non-volcanic geothermal diffuse degassing from soil. A literature survey has been made to collect available flux data on such three geological CO_2 source categories in Europe. Following our definition of Europe, we only considered the terrestrial (onshore) geological CO_2 sources. The following emission factors were derived: (1) For 11 active volcanoes, CO_2 flux is typically in the order of 10^4-10^5 ton/year. Etna volcano dominates the overall volcanic degassing being in the order of 10^6-10^7 ton/year. (2) Non-volcanic vents occur mainly in Italy (presumably more than 100 sites), Greece, Germany, Czech republic, Hungary, Romania, France. Individual flux is typically in the order of 10^3-10^4 ton/year (Etiope *et al.*, 2007). Considering that the area and size of a vent zone is much smaller than a volcano, the specific flux (ton km^{-2} y^{-1}) of vents is much higher than that of volcanoes. (3) Large areas around vents or even soil in geothermal areas without the presence of vents (visible manifestations), emit a diffuse exhalation of CO_2 which is superimposed on soil respiration. Data based on closed-chamber measurements show fluxes

typically one to three orders of magnitude higher than normal soil respiration (which is around 3000 g m^{-2} $year^{-1}$ in temperate drylands) in areas with a heat flow above 80–90 mW m^{-2}, which is the case in regions of Cenozoic volcanism and active tectonic belts. In the Mátraderecske area (Hungary) soil CO_2 fluxes have been up to ~1700 g $m^{-2}d^{-1}$, with average values of ~200 to 400 g $m^{-2}d^{-1}$ (NASCENT, 2005).

Available uncertainty estimates: The main uncertainty lies in the knowledge of the actual extent of the total area (km^2) in European soils affected by diffuse CO_2 degassing. Large scale regional estimates are available only in Italy and, partially, in Germany. Spot and site observations were not extrapolated to the study area. Given that data on diffuse soil degassing, in almost all the 28 countries hosting geothermal systems, are lacking, the provided estimate must be considered as conservative and provisional. There are no formal quantitative uncertainty analysis available for this product.

Post-processing: None

Bias correction: None

Short hand: **Etiope**

Field(s): 6b'

Description: Geological-CH_4 emission or more precisely onshore natural hydrocarbon seepage and geothermal exhalations, are mainly related to gas seepage in petroleum-bearing sedimentary basins (either visible macro-seepage or invisible diffuse microseepage of hydrocarbons produced in sedimentary rocks) and diffuse or focused gas exhalation in geothermal areas (where gas is dominated by CO_2). In the sedimentary basins CO_2 concentration in natural gas is quite low (generally <5%).

Observations: CH_4 fluxes from onshore natural hydrocarbon seepage and geothermal exhalations were acquired by using traditional techniques including closed-chamber system, inverted funnel system, flux-meters associated with gas-chromatographic, semiconductor, infra-red or laser sensors. Emission estimates were acquired from the reviews by Etiope et al (2009;2007).

Spatial extent: ALB, AUT, BGR, CHE, CZE, DEU, DNK, ESP, FRA, GBR, GRC, HUN, ISL, ITA, NLD, POL & ROU.

Temporal extent: Owing to rather sparse observations, all available observations were bulked in a single data product, irrespective of the sampling year. Hence, the temporal extent of this data product is undefined.

Accounting boundaries: The data product does not include CH4 fluxes (unknown) related to episodic eruptions of magmatic volcanoes and sedimentary (mud) volcanoes (events of higher degassing).

Processing: A variety of geological sources, often associated with oil and/or natural gas reservoirs, potentially or actually emit geological (i.e. fossil, either thermogenic or microbial) CH_4 : they include onshore and offshore macro-seeps such as mud volcanoes (or sedimentary volcanoes; Etiope, 2009), diffuse microseepage, submarine seepage and geothermal gas manifestations (Etiope, 2009;Etiope et al., 2008). Following our definition of Europe, we only considered the terrestrial (onshore) geological methane sources being aware that the offshore sources of the North Sea and the Black Sea may be significant at the continental scale. Onshore fluxes are based on direct field measurements using traditional techniques as described, among others, by Klusman et al. (2000) and Etiope et al. (2004) and up-scaling procedures following the recommended EMEP/CORINAIR Emission Inventory Guidebook related to emission factor and area approaches (Etiope et al., 2009;Etiope et al., 2007). The emission calculation from the invisible microseepage is based on averaging field contribution from identifiable homogeneous areas. The definition of the area used for emission calculation

depends on the recognition of homogeneous identifiable areas and the spatial variability of the measured flux. Basically, the investigated area is divided into different sectors with different levels of flux; in case of a wide range of flux, the levels may correspond to different orders of magnitude (10^1, 10^2, 10^3 ,mg m^{-2} d^{-1}).

Available uncertainty estimates: The uncertainty estimates are reported in the EMEP/EEA air pollutant emission inventory guidebook, where "Geological seepage" is described as "code 110900" (EMEP/EEA, 2009). Uncertainty of local flux measurements may range from 5 to 20 %. The uncertainty of emission factors can be assumed to be in the order of 10–50 %. The certainty of the 'typical value' is considerably better than the total emission range. The main uncertainty is related to the actual extent of dry-lands affected by diffuse and invisible exhalation of CH_4, called "microseepage", which is critical in estimating the European terrestrial carbon sinks. It has been reported that dry soil is not always a net CH_4 sink; wide grassland areas show positive CH_4 fluxes from soil, because methanotrophic consumption is not always sufficient to consume CH_4 migrating from the subsoil. So dry soil can be a greenhouse-gas source in petroliferous areas (Etiope and Klusman, 2010). Microseepage shows seasonal variations (the fluxes are higher in winter and lower in summer) due to the variable methanotrophic activity in the soil.

Post-processing: Conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: None

Short hand: **FAO**

Field(s): 3a (b)

Description: charcoal production and wood removals for wood fuel

Observations: Items 1627, 1628 and 1630 from http://faostat.fao.org based on national statistic as declared by the nation to the FAO.

Spatial extent: All counties except UNK

Temporal extent: 2001-2010

Accounting boundaries: No detailed information was found on how the different countries collected and processed their national data. It is not clear whether the statistics account only for commercial wood fuel removals or also accounts for personal wood fuel removals.

Processing: The volume of wood fuel and mass of charcoal was taken from http://faostat.fao.org

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: FAO statistics report the volume of wood removals, volume was converted to mass by assuming a wood density of 0.4g cm^{-3} and a carbon content of 0.48 gC g^{-1} wood. The roundwood equivalent of charcoal was calculated using a factor of 6.0 to convert from weight (tonnes) to solid volume units (m3).

Bias correction: The spatial extent of this data product does not include UNK. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **FAO**

Field(s): 4a (b), 4a' (b), 4a'' (b)

Description: CO_2, CH_4 and CO emissions from charcoal production and wood fuel

Observations: Items 1627, 1628 and 1630 from http://faostat.fao.org. Based on national statistic as declared by the nation to the FAO.

Spatial extent: All counties except UNK

Temporal extent: 2001-2010

Accounting boundaries: No detailed information was found on how the different countries collected and processed their national data. It is not clear whether the statistics account only for commercial wood fuel removals or also accounts for personal wood fuel removals.

Processing: The volume of wood fuel and mass of charcoal was taken from http://faostat.fao.org

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: FAO statistics report the volume of wood removals, volume was converted to mass by assuming a wood density of 0.4g cm^{-3} and a carbon content of 0.48 gC g^{-1} wood. When burning this woody biomass as a fuel it was assumed that 100% of the C entered the atmosphere as CO_2, 10% as CO and 3% as CH_4. These ratio were taken from the modelled fire emission (van der Werf *et al.*, 2004). The roundwood equivalent of charcoal was calculated using a factor of 6.0 to convert from weight (tonnes) to solid volume units (m3). Subsequently the same conversion and emission factors were applied as for wood fuel.

Bias correction: The spatial extent of this data product does not include UNK. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Fortems-Cheiney**

Field(s): 14a''

Description: Monthly carbon monoxide (CO) surface fluxes and losses (oxidation to CO_2), gridded respectively in TgCO yr^{-1} and TgC yr^{-1}, for the period 2002-2009 (Fortems-Cheiney *et al.*, 2011).

Spatial extent: Global 3.75° x 2.5° (longitude, latitude)

Temporal extent: 2000 to 2009

Observations: The main observational constraint comes from the 700 hPa level CO MOPITT retrievals (Version 4 of Level 2, see descritpion at http://www.acd.ucar.edu/mopitt/), associated with their averaging kernels, downloaded at https://wist.echo.nasa.gov. Moreover, CO is the main species reacting with OH in the troposphere. In the absence of sufficient direct observations of OH, indirect information from methylchloroform (MCF) measurements is exploited to constrain the OH concentrations. A set of stations that measured MCF nearly continuously has been selected from the AGAGE and NOAA/ESRL networks, available on the World Data Centre for Greenhouse Gases (WDCGG) site.

Accounting boundaries: The chemistry transport model LMDz-SACS (for Simplified Atmospheric Chemistry System) used in our study has been conceived as a simplification of LMDz-INCA: LMDz refers here to Version 4 of the general circulation model of the Laboratoire de Meteorologie Dynamique (Hourdin *et al.*, 2006) and INCA stands for Interaction with Chemistry and Aerosols (Hauglustaine et al., 2004;Folberth et al., 2006). The simplification consists in explicitly solving the main reactions of a limited set of four species only: CH4, CO, formaldehyde (HCHO) and MCF.

Processing: LMDz-SACS is run at horizontal resolution 3.75° x 2.5° (longitude, latitude) and with 19 verticals levels between the surface and the mid-stratosphere. Grid point fluxes are estimated on this horizontal grid for eight-day segments. Measurements of CO concentrations in the troposphere are used as top-down constraints in our inversion system, which aims at adjusting the emissions, in such a way they become consistent both with atmospheric observations and with some prior state, given their respective uncertainties. The 8-year period is processed in consecutive 13-month chunks with a 1-month overlap from one chunk to the next. About 25 iterations are needed to reduce the norm of the gradient of a Bayesian cost function by 95% with the M1QN3 minimizer (Gilbert and Lemaréchal, 1989). A detailed description of the system and of its results can be found in Fortems-Cheiney et al. (2011). The results have been validated with several sets of independant measurements: surface measurements, aircraft and satellite.

Available uncertainty estimates: We estimated the inversions one-sigma uncertainty from the spread of the regional emissions of several sensitivity tests.

Post-processing: None.

Bias correction: None.

Short hand: **FRA**

Field(s): 9g

Description: Changes in biomass stock for semi-natural vegetation

Spatial extent: All counties except UNK

Temporal extent: 2000

Observations: Statistics reported by the nations to the FAO.

Accounting boundaries: Changes in soil and litter stock are not accounted for in this product

Processing: Surface areas were based on Corine land cover data (http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes) estimating the total surface area of 'semi-natural vegetation' at 408,783 km^2. We used the estimate for 'other wooded land' as a proxy for 'semi-natural vegetation'. The Forest Resource Assessment report, estimated the surface area of 'other wooded land' in Europe at 39 million ha (Table S1 in) and the annual biomass increment for this region at 8.4 million m3 wood. We calculated the changes in biomass stock per unit area by assuming a wood density of 0.4g cm^{-3} and a carbon content of 0.5g C g^{-1} wood.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None

Bias correction: None

Short hand: **GFRA**

Field(s): 3b (b)

Description: Industrial roundwood removals

Observations: Based on national statistic as declared by the nation to the FAO.

Spatial extent: All counties except UNK and CYP

Temporal extent: 2005

Accounting boundaries: Most likely harvest for personal use is not declared and therefore not included in the national statistics. No detailed information was found on how the different countries collected and processed their national data.

Processing: The volume of removed industrial roundwood in 2005 was taken from the Global Forest Resource Assessment (FAO, 2006). FAO worked closely with countries and specialists in the design and implementation of the Global Forest Resource Assessment (FAO, 2006)- through regular contact, expert consultations, training for national correspondents and ten regional and subregional workshops. The outcome is better data, a more transparent reporting process and enhanced national capacity in data analysis and reporting.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: FAO statistics report the volume of wood removals, volume was converted to mass by assuming a wood density of 0.4 g cm^{-3} and a carbon content of 0.5 gC g^{-1} wood. For the EU-15 it was estimated that 79% of the removed wood enters the atmosphere (Eggers, 2002). This conversion factor was applied to the total domain.

Bias correction: The spatial extent of this data product does not include CYP and UNK. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. The estimate for 2005 was provided. These emissions were applied to the period 2001-2005.

Short hand: **Grassi**

Field(s): 2fgh

Description: Mean CO_2 equivalent emissions from land-use change (LUC) for 2000 to 2009 as reported to the United Nation Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP).

Observations: Land-use changes come from remote sensing, statistics and administrative inventories. The emission factor is generally based on real measurement, or in some case on IPCC default factors. In general, the source for the input data to estimate GHG from LUC is country-specific.

Spatial extent: All exc. ALB, BIH, CYP, MKD, MLT, UNK & SCG

Temporal extent: 2000 - 2009

Accounting boundaries: Following Guidance (IPCC, 2006), LUC in UNFCCC/KP context is defined as any transition between six land uses: forest, cropland, grassland, wetland, settlements and other lands. In this study only the fluxes from the major transitions were accounted for i.e. all land converted to forest, forest converted to other land, grassland converted to cropland and cropland converted to grassland.

Processing: The emissions from LUC are estimated as the product of the converted land area and emission factors. Specific country-specific emission factors are applied for different conversions. All Annex-1 (industrialized) countries report annual GHG inventories to UNFCCC, including emissions and removals from Land Use, Land Use Change sector (LULUCF) from 1990 to the reporting year -2 (i.e. in 2011, time series ranged from 1990 to 2009). For the countries which ratified the KP, additional reporting requirements are in place for the period 2008- 2012. Although the accuracy, comparability and completeness of the UNFCCC/KP inventories can still improve for many countries, the value of these inventories is that they condense a large amount of information from national statistics (which on LUC is often not easily accessible to the scientific community), and that an independent UN expert team reviews annually such estimates for their adherence to the IPCC methodological guidance (IPCC, 2003). The reporting of LUC differs between the UNFCCC and the KP. The UNFCCC reporting should in theory cover all land use changes; by default lands remain in 'conversion status' for 20 years (e.g. the sink of a "cropland converted to forest" in 1984 is counted in the LUC flux till 2003), but different periods may also be used. By contrast, under the KP, the reporting of land use changes is mandatory only for conversions from/to forests, and it refers to land use changes occurred since 1990. In the context of RECAPP, the UNFCCC reporting was used as the source of data from conversions between croplands and

grasslands, while the KP reporting was used as a basis for conversions from/to forests (in general, KP reporting allows better comparability among countries). GHG from Afforestation/reforestation for the yrs 2008 and 2009 are taken directly from KP reporting.
Available uncertainty estimates: Not many countries provide explicit uncertainty estimates for GHG from LUC. Based on the available information, the JRC estimated, for the 15 old EU Member States, an uncertainty around 25% for conversion from/to forests, and around 50% for conversions from/to croplands and from/to grasslands (EU-NIR, 2011).
Post-processing: None
Bias correction: The spatial extent of this data product does not include ALB, BIH, CYP, MKD, MLT, UNK & SCG. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Haberl & Krausmann**

Field(s): 2dd'd'', 3b (c), 3b (d), 3c, 3d, 3cd, 3e (c)

Description: Modelled annual human use of terrestrial net primary production around the year 2000.

Observations: Statistical data on wood and crop harvest as reported by the countries to the FAO (UN-ECE and FAO, 2000;FAO, 2004)

Spatial extent: Global at the country level

Temporal extent: 3- to 5-yr averages centred on the year 2000

Accounting boundaries: C contained in NPP was estimated, decomposition of produce was not separated in CO_2 and CH_4 fluxes.

Processing: We defined human use of net primary production (NPPh) as all biomass harvested or destroyed during harvest within 1 yr. Calculations of NPPh were based on statistical data on wood and crop harvest (UN-ECE and FAO, 2000;FAO, 2004) and were calculated as 3- to 5-yr averages centered on the year 2000 to reduce the impact of stochastic events, such as unusually good or bad harvests. Biomass harvest on cropland and permanent cultures was derived from the FAO agricultural production database by using factors to extrapolate biomass fractions not reported in the statistics, such as straw, stover and leaves (see SI Text and SI Table 7 in Haberl *et al.*, 2007). Harvest of forestry products was calculated by using the TBFRA2000 database (UN-ECE and FAO, 2000) for 52 temperate and boreal countries and FAO statistics (FAO, 2004) for all other countries. Factors used to extrapolate biomass fractions not reported in these statistics (e.g., bark, roots, or leaves) were derived from (Pulkki, 1997) and the TBFRA2000 database (see also SI Text and Table 8 in Haberl *et al.*, 2007). The amount of biomass consumed by ruminants on grazing land is assessed on the basis of country-level feed balances which estimate the demand for grazing as the difference between supply of commercial feed and fodder crops (reported in FAO statistics) and the aggregate demand of livestock. Feed demand was calculated separately for 11 livestock species for which country-specific data on stock and production are provided by the FAO (see also SI Text and Table 9 in Haberl *et al.*, 2007). Grazed biomass was calculated as the difference between feed demand and the supply of market feed, nonmarket feed from cropland, and feed from crop residues. Grazed biomass is allocated to the grazing land layer on the basis of the grazing land quality map presented in Erb et al. (2007), assuming that all quality classes are grazed. In contrast to cropland and forestry, no belowground NPPh was assumed to occur on grazing land because plant roots are mostly not killed during mowing or grazing (O'Neill *et al.*, 2007). The assessment of the biomass flows related to human-induced

fires, based on data reported by the FAO and the Global Burned Area 2000 Project and integral part of the aggregate estimate of global NPPh was revised and published in Lauk and Erb (2009). On-site backflow to nature, i.e., unused crop residues, roots or other harvest losses on cropland and in forestry, and livestock feces dropped during grazing were calculated assuming appropriate factors (see also SI Text in Haberl *et al.*, 2007).

Available uncertainty estimates: There are no formal quantitative uncertainty analysis available for this product.

Post-processing: National estimates for 'human induced fires', 'harvested primary crops', 'grazed biomass' and 'net trade' were aggregated for the countries contained in the study area. The estimates for Belgium-Luxemburg were split into separate estimates for Belgium and Luxemburg according to a 95/5 ratio in line with the population of the countries. Similar, estimates for Serbia-Montenegro were split according to a 90/10 ratio. The decay of products outside landfills (i.e. 3e(c)) was estimated as the residual of 3b +3cd -3e(a) –3e(b) -3e'-4b -4b' -'b''-10a -11a -11b.

Bias correction: None

Short hand: **Hartmann & Moosdorf**

Field(s): 6a, 6d

Description: CO_2 consumption and carbon fluxes by chemical weathering

Spatial extent: global 1km x 1km grid

Temporal extent: Long term mean run-off is used.

Observations: 382 river chemistry datasets from Japan (Harashima et al., 2006;Kobayashi, 1960), representing typical ranges range of weathering rates for representative lithological classes (Hartmann et al., 2009;Hartmann, 2009). For carbon fluxes from carbonate rock, an equation reported by Amiotte-Suchet et al. (1995), based on observations from river catchments in France was used.

Accounting boundaries:

Processing: Based on observations CO2-consumption/carbon flux equations were empirically developed to estimate the carbon flux in dependence of lithology and runoff (Hartmann et al., 2009;Hartmann, 2009) and were applied using a global long-term average runoff grid dataset (cell size: 0.5 degree; Fekete *et al.*, 2002) and a global vector based lithological map with 15 lithological classes (Dürr *et al.*, 2005). Carbonate abundant in other rocks than represented by the lithological class "carbonate sedimentary rocks" was recognized. It was assumed that half of the carbon fluxes originating from carbonate weathering stems from the lithosphere (Field 6d), while the other half and all carbon from silicate weathering originates from soil/atmospheric CO_2 (Field 6a).

Available uncertainty estimates: There are no formal quantitative uncertainty analysis available for this product. However, similar studies suggest an uncertainty of about 35% (based on the two sigma of all estimates: Moosdorf *et al.*, 2011) , which is rendered a conservative estimate by comparison with regional scale studies.

Post-processing: The original global dataset with a resolution of 1 km x 1 km (Hartmann *et al.*, 2009) was aggregated to the target resolution and clipped to the required spatial boundaries (Figure 1).

Bias correction: None.

Short hand: **IPS**

Field(s): 3a (a), 3b (a)

Description: Peat removal for energy and horticultural usage

Observations: Production statistics as reported by the WEC (2010)

Spatial extent: data are available for CZE, EST, FIN, DEU, HUN, IRL, LTU, NOR, POL, SWE & GBR which includes the main producers for the region under study.

Temporal extent: Different data sources have been used resulting in a data product with and undefined temporal extent.

Accounting boundaries: The estimates were not corrected for import and export

Processing: The WEC (2010) compiled data from the WEC Member Committees, 2000/2001, Energy Statistics Yearbook, 1998, United Nations; Survey of Energy Resources 1992 and 1998 and direct communications from International Energy Agency and International Peat Society.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Production was reported in m^3. Subsequently reported values were multiplied by 0.4 ton peat m^{-3} and 0.57 g C g^{-1} peat to obtain the C-content of the peat production.

Bias correction: No spatial bias correction was applied as the major peat producing nations were include. These fluxes were applied to the period 2001-2005.

Short hand: **IPS**

Field(s): 4a (a), 4a' (a), 4a'' (a)

Description: CO_2, CH_4 and CO emissions from peat fuel

Observations: Production statistics as reported by WEC (2010)

Spatial extent: data are available for CZE, EST, FIN, DEU, HUN, IRL, LTU, NOR, POL, SWE & GBR which includes the main producers for the region under study.

Temporal extent: Different data sources have been used resulting in a data product with and undefined temporal extent.

Accounting boundaries: The estimates were not corrected for import and export

Processing: WEC (2010) compiled data from the WEC Member Committees, 2000/2001, Energy Statistics Yearbook, 1998, United Nations; Survey of Energy Resources 1992 and 1998 and direct communications from International Energy Agency and International Peat Society

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Production was reported in m^3. Subsequently reported values were multiplied by 0.4 ton peat m^{-3} and 0.57 g C g^{-1} peat to obtain the C-content of the peat production. When burning this peat biomass as a fuel it was assumed that 100% of the C entered the atmosphere as CO_2, 10% as CO and 3% as CH_4. These ratio were taken from the modelled fire emission (van der Werf *et al.*, 2004).

Bias correction: No spatial bias correction was applied as the major peat producing nations were include. These emissions were applied to the period 2001-2005.

Short hand: **Jena Inversion**

Field(s): 14a

Description: Measurements of CO_2 concentrations in the atmosphere are used in models of atmospheric transport. The distribution of sources and sinks at the land surface is derived by minimizing the difference between simulated and observed concentration measurements, taking account of their respective errors.

Spatial extent: global

Temporal extent: 1994-2008

Observations: 602,064 CO_2 measurements

Accounting boundaries: None

Processing: The Jena inversion system solves for daily CO_2 fluxes at pixel resolution (□4□ □5□), with a focus on temporal variations. Fluxes in the period 1994-2008 are optimized against atmospheric CO_2 data from 51 long-record sites operated by many institutions worldwide, including 10 sites in and around Europe. The inversion uses hourly in-situ measurements or weekly flask sampling, as available (602,064 data points). Except for pre-subtracted fossil fuel emissions, Bayesian a priori fluxes do not involve detailed spatio-temporal structure, the flux estimates are then as directly related to the information in the atmospheric data as possible. Spatial and temporal a priori correlations are applied to bridge between the spatially and temporally discrete data points, thereby smoothing the flux field. Full documentation is given by Rödenbeck (2005), Rödenbeck et al. (2003) or at http://www.bgc-jena.mpg.de/~christian.roedenbeck/download-CO2/.

Available uncertainty estimates: Currently two uncertainty measures are available: (1) spread of ensemble of runs and (2) formal Bayesian a-posterior uncertainties (which can be provided for predefined target quantities).

Post-processing: None

Bias correction: None

Short hand: **Jung**

Field(s): 2ab

Description: Net ecosystem exchange of CO_2 between terrestrial ecosystems and their overlaying atmosphere derived from eddy covariance measurements and interpolated by means of an ensemble of regression trees.

Observations: Half hourly net ecosystem exchange observations of CO_2 from almost 1000 site-years of 253 eddy covariance sites in all five continents. However, the observational network is strongly biased towards Western Europe and the USA. Observations were made from 1994 until 2006 with more observations being made towards the end of this period.

Spatial extent: Global

Temporal extent: Monthly fluxes from 1982 to 2008

Accounting boundaries: The current network is not dense nor well designed and therefore does not meet the full potential of the eddy covariance method. Although few towers have been established in urban areas and over inland water, the size of the network does not permit credible upscaling. Therefore, fluxes 1a, 1b, 1d, 2i and 3e (Table 1) are not monitored by the current eddy-covariance network. Further, the current network is biased towards maturing and mature ecosystems and is therefore believed to largely overlook the fluxes following land-use change denoted as 2f, 2g and 2h (Table 1). Finally, the network is too sparse to accurately represent fluxes owing to infrequent disturbances such as storms, insects pests (2e) and fires (2d).

Processing: The overall upscaling procedure involves three main steps: (1) processing and quality control of the FLUXNE data, (2) training MTEs for each monthly biosphere-atmosphere flux of interest using site-level explanatory variables and fluxes, and (3) applying the established MTEs for global upscaling, using gridded data sets of the same explanatory variables. We forced 25 individual model trees for each biosphere-atmosphere flux using gridded monthly inputs from 1982 to 2008. The best estimate of a biosphere-atmosphere flux for further analysis is the median over the 25 estimates for each pixel and month. Ensembles of model trees were generated by coupling TRIAL (The model Tree Induction) to the ERROR (Evolving tRees with RandOm gRowth) algorithm (Jung et al., 2009;Jung et al., 2011). We processed half-hourly FLUXNET eddy covariance measurements using standardized procedures of gap filling and quality control (Moffat et al., 2007;Papale et al., 2006), and the data were subsequently aggregated into monthly means. We used 29 explanatory variables of four types to train the model tree ensemble to predict biosphere-atmosphere fluxes globally (see also Table 1 in Jung *et al.*, 2011), including (1) monthly fAPAR from the SeaWiFS

sensor, precipitation, and temperature (both in situ measured); (2) annual changes of the fPAR that describe properties of vegetation structure such as minimum, maximum, mean, and amplitude; (3) mean annual climate such as mean annual temperature, precipitation, sunshine hours, relative humidity, potential evapotranspiration, climatic water balance (precipitation–potential evaporation), and their seasonal dynamics; and (4) the vegetation type according to the IGBP classification plus a flag regarding the photosynthetic pathway (C3, C4, C3/C4) (in situ information). Some otherwise pertinent data for upscaling were ignored because either corresponding site information or respective global data sets do not exist or are insufficient. Examples include information on land use history, disturbance history, soil moisture, and fertility. We evaluated the performance of our approach based on fivefold cross validations. We conducted two experiments where (1) entire sites were removed from the training (~20%), and (2) consecutive parts of the time series of the sites were removed.

Available uncertainty estimates: Cross validation errors were estimated at RMSE = 0.54 gC m^{-2} day^{-1} or for the mean NEE of a site = 197 gC m^{-2} yr^{-1} (see Fig.1 in Jung *et al.*, 2011). Uncertainties were estimated by repeating a given calculation for each of the 25 tree outputs and computing a measure for the deviation. Our uncertainty estimates reflect a structural uncertainty of the model trees, i.e., the mapping of X to Y. Other sources of uncertainty such as measurement uncertainties of eddy covariance fluxes (Lasslop et al., 2008;Richardson et al., 2006a;Richardson et al., 2008) or uncertainties of global gridded data of explanatory variables (Zhao et al., 2006;Hicke, 2005) are not accounted for in this uncertainty measure.

Post-processing: Monthly NEE estimates from the ensemble of regression trees were averaged and aggregated at the annual scale to obtain separate annual estimates for the years 2000 to 2008.

Bias correction: The mean NEE for 2000 to 2008 was used as an estimate for the entire accounting period 2000 to 2009.

Short hand: **Lathière**

Field(s): 2i

Description: Global emissions of biogenic volatile organic compounds: isoprene, monoterpenes, methanol, acetone, acetaldehyde, formaldehyde and formic and acetic acids.

Observations: Episodic data from nine field campaigns in Canada, USA, Congo, Brazil, Italy and Finland. For details see Table 4 in Lathière et al. (2006) and references therein.

Spatial extent: Global 1°x1° grid

Temporal extent: 1983 - 1995

Accounting boundaries: Only mostly emitted BVOCs are considered in these fields. Other reactive biogenic VOCs, such as sesquiterpenes, for which global emissions are low but which could be important for atmospheric chemistry processes, are not considered. BVOC emission change over the 1983-1995 period is only related to changes in climate conditions. The evolution of vegetation distribution in relation with land-use change, that one can consider moderate over this time-scale, is not taken into account.

Processing: A biogenic emission scheme, based on Guenther et al. (1995) parameterizations, has been incorporated into the dynamic global vegetation model ORCHIDEE (Krinner *et al.*, 2005). Relevant parameters, such as emission factors, are prescribed for each plant functional type and each BVOC considered (Krinner *et al.*, 2005). This distinction is of great importance since the nature and the amount of the biogenic VOCs emitted are very different from one vegetation type to another. In addition to isoprene and monoterpenes, we also explicitly estimate the emissions of methanol, acetone, acetaldehyde, formaldehyde, formic and acetic acids, which are usually considered as a family of compounds and estimated as bulk emissions. VOC biogenic emissions are calculated every 30 minutes, based on the Guenther et al. (1995) parameterizations, and integrate additional features such as the leaf age influence on isoprene and methanol emissions. The generic formula is:

$F = LAI \times s \times Ef \times CT \times CL \times La$. Where F is the flux of the considered biogenic species, given in µgC/m2/h and LAI the leaf area index in m2/m2, calculated at each time step by the model. The specific leaf weight s in gdm/m2 (dm: dry matter) is prescribed in ORCHIDEE depending on the considered PFT. Ef is the emission factor in µgC/gdm/h prescribed for each PFT and biogenic compound (see Table in Lathière et al. (2006)). Isoprene, and monoterpenes emission factors are based on Guenther et al. (1995) and adapted to the PFTs considered in ORCHIDEE. For methanol, we use emission factors from Guenther et al. (2000) and Mac-Donald and Fall (1993), crops being the highest methanol emitters. For the other VOCs (acetone, aldehydes and acids), we use emission factors from Kesselmeier and Staudt (1999)

and Janson and De Serves (2001).

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for these products.

Post-processing: None

Bias correction: The mean estimate for the period 1983 to 1995 was provided. These emissions were applied to the period 2001-2005.

Short hand: **Lohila**

Field(s): 9c

Description: Changes in soil, litter and biomass carbon stock of drained peatlands under agricultural management

Spatial extent: FIN, SWE, NLD, NOR, GBR

Temporal extent: Owing to rather sparse observations, all available observations were bulked in a single data product, irrespective of the sampling year. Hence, the temporal extent of this data product is undefined.

Observations: year-round flux studies

Accounting boundaries: Lateral C-fluxes such as BVOC emissions and DOC leaching are not accounted for.

Processing: The C stock change for drained peatlands in agricultural use was estimated from year-round flux studies conducted in crop- and grasslands in Finland (Lohila et al., 2004;Maljanen et al., 2001;Maljanen et al., 2004), the Netherlands (Veenendaal et al., 2007), Norway (Gronlund *et al.*, 2008), and U.K.(Lloyd, 2006). The stock change was obtained by summing up the CO_2 fluxes and harvested biomass, and components of C-balance, like CH_4 exchange or manure application, if available. Flux studies were summarized separately for crop- and grasslands, and the area-weighted average was used reported.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. This estimate was assigned to the period 2001-2005.

Short hand: **Lohila**

Field(s): 9f

Description: Changes in soil, litter and biomass stock of forest planted on drained peatlands

Spatial extent: Observations were confined to Finland.

Temporal extent: Data from 1990 to 2008 were combined

Observations: A large amount of soil heterotrophic respiration measurements on different peat forests, measurements on below-ground litter production and the tree growth measurements and models

Accounting boundaries: Observations were confined to Finland however in Europe most forest on drained peatland occur in Finland and Sweden. Given the nature of this study emission savings of CH_4 were accounted for in units carbon.

Processing: The areas for forestry-drained peatlands, 105,378 km^2, has been taken from Joosten (2010). The area was assumed unchanged during 1990-2008. For the area of peatland forests in Sweden, the estimate of Joosten (2010), 30000 km2, clearly differs from that of Swedish EPA (2011), which was 44000 km2 for all peatland forests and 10000 km2 for drained ones. However, as the C pool changes have been assumably reported for the larger area, the estimate of Joosten (2010) settles nearly between these two estimates, and was considered an appropriate estimate of the area of forestry-drained peatlands in Sweden in this paper. Statistics Finland (2010) has recently published a detailed description of sectorial GHG emissions in Finland including forested peat soils. The total estimate of the C balance of forestry-drained peat soils is the sum of the tree CO_2 uptake (biomass increment), litter biomass increase (dead organic matter), and peat decomposition (soil organic matter). The calculation is based on a large amount of soil heterotrophic respiration measurements on different peat forests, measurements on below-ground litter production and the tree growth measurements and models. Average of the years 1990-2008 has been used.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None.

Bias correction: The spatial extent of this data product is limited FIN and SWE. About 60% of the drained peatland forests in Europe are located in Finland and 30% in Sweden. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. This estimate was assigned to the period 2001-2005.

Short hand: **Pan**

Field(s): 8a, 8b

Description: C contained in biomass, dead wood and forest stock change

Spatial extent: All exc. UNK

Temporal extent: Mean for 1990-1999 an 2000-2007

Observations: The data for Europe were obtained from the country reports prepared by 41 European countries for the Global Forest Resources Assessment of 2010 (FAO, 2010).

Accounting boundaries: Only limited data are available for dead wood, litter and soil C stocks (see below).

Processing: The estimates for carbon in living biomass in Europe are generally based on field surveys from national forest inventories that measure growing stock volume. Growing stock volume is converted to biomass, and biomass to carbon, using national factors developed by country specific research or from IPCC's Good Practice Guidance (IPCC, 2003). The quality of these data is good. The availability of data on carbon in dead wood is more restricted; approximately half of all European countries lack these data for at least one reporting year. Where data were missing, carbon in dead wood was estimated by applying ratios of dead wood carbon per hectare to forest area. For countries that lacked data for some year(s), these ratios were extrapolated based on data for other years. For countries entirely lacking data, these ratios were adopted from the country with the most similar climate and forest-use history. In these cases, the estimated ratios were constant and based on data from 1990. Due to data deficiencies, the accuracy and precision of the regional estimates of the dead wood C stock are weaker than the corresponding estimates for living biomass. The availability of data on C stocks in litter and soils is also limited. Of the 41 European countries included in the analysis, 27 reported soil C for at least one year (1990-2010). Nearly all European countries that report soil C use forest area based extrapolations. These estimates are constructed by either applying a constant ratio of soil C per hectare to total forest area, or by applying ratios specific to soil type and soil type areas. Three countries deviate from this practice. In Austria and Sweden, soil C estimates are based on inventory data. In Finland, soil C stocks are principally estimated using the Yasso model. The soil depth at which soil C was measured varied between countries. Of the countries that had data, 17 used a soil depth of 30 cm. In the remaining 10 countries, the soil depth applied in estimates varies from 20 cm (in Belgium) to 100 cm (in Finland and the UK). In this study, the C stocks in litter and soils for countries that lacked data were estimated by using area-based litter and soil C ratios. For countries that lacked data for some year(s), these ratios were extrapolated based on data for other years. For

countries entirely lacking data, these ratios were adopted from the country with the most similar climate and forest use history. In these cases, the estimated ratios were constant and based on data from 1990. Available estimates were adjusted to a standard depth of one meter if a different depth was used, based on a model of soil C by depth reported in Jobbagy and Jackson (2000). Estimates of the HWP C stock changes were derived using the method described earlier in the general methods section.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Estimates for European boreal and temperate forest were combined in a single estimate. Forest in Sweden, Norway and Finland were considered to be part of the European Boreal zone. All other forests were considered temperate.

Bias correction: The spatial extent of this data product includes Ukraine and Belarus. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Papale**

Field(s): 2ab

Description: Net ecosystem exchange of CO_2 between terrestrial ecosystems and their overlaying atmosphere derived from eddy covariance measurements and interpolated by means of an artificial neural network.

Observations: Half hourly net ecosystem exchange observations of CO_2 from almost 1000 site-years of 253 eddy covariance sites in all five continents. However, the observational network is strongly biased towards western Europe and the USA. Observations were made from 1994 until 2007 with more observations being made towards the end of this period. Before ANN training data have been gapfilled and aggregated to a monthly time resolution.

Spatial extent: global

Temporal extent: 1990-2008

Accounting boundaries: The current network is not dense and ad-hoc designed and therefore does not meet the full potential of the eddy covariance method. Although few towers have been established in urban areas and over inland water, the size of the network does not permit credible upscaling. Therefore, fluxes 1a, 1b, 1d, 2i and 3e (Table 1) are not monitored by the current eddy-covariance network. Further, the current network is biased towards maturing and mature ecosystems and is therefore believed to largely overlook the fluxes following land-use change denoted as 2f, 2g and 2h (Table 1). Finally, the network is too sparse to accurately represent fluxes owing to infrequent disturbances such as storms, insects pests (2e) and fires (2d).

Some otherwise pertinent data for upscaling must be ignored because either corresponding site information or respective global data sets do not exist or are insufficient. Examples include information on land use history, disturbance history, soil moisture, and fertility.

Processing: An artificial neural network similar to the one described in Papale & Valentini (2003) and Sulkava et al. (2011) was used as a spatial interpolator of the site-level eddy covariance measurements to the entire land surface. A feed-forward back-propagation artificial neural network (ANN) was trained using the Levenberg- Marquardt algorithm. For this data product, the monthly spatially explicit climatic variables used as input data of the ANN were air temperature, precipitation, shortwave downward flux, fraction of the photosynthetic absorbed radiation (FAPAR) and the product between FAPAR and Top of Atmosphere incoming radiation. A different ANN has been trained for each Plant Functional Type. The ANN training makes use of 10 data sets, composed by randomly splitting the data in three groups: training set (60%), test set (20%) and validation set (20%). For each of these

10 training data sets, 8 different ANN with different structures are trained 30 times each using different sets of initial weights (selecting the best of each structure). The values of the driver variables of the training set pass through the ANN and produce an output. This output is then compared with the expected output and the error in prediction is back- propagated in the ANN to adjust the weights of the neurons in the ANN in order to minimize it and improve the prediction capacity. The test set was used to validate the ANN during training calculating the error of unseen data and prevented overfitting by terminating the training once the error of the test set no longer improved.

The eight ANNs that were trained have been then used to simulate the validation set (not used in the training phase) and the ANN with the lowest error and simpler structure (less degrees of freedom) was selected to be used for interpolation. In this way 10 different ANNs were selected (one for each dataset extracted) and used to compute the mean and uncertainties of the upscaling results.

Available uncertainty estimates: When being upscaled, there are four main sources of uncertainty in the eddy covariance data: uncertainty in the data used to train the neural network, uncertainty in the climate data used for upscaling, uncertainty in the representativeness of the network and uncertainty in the model structure and parameterization. Despite the recent progress in estimating the uncertainty and consistency of the eddy covariance data (Lasslop et al., 2008;Luyssaert et al., 2009;Moffat et al., 2007;Papale et al., 2006;Richardson et al., 2006b), the uncertainty of the neural network which is used to upscale these data has not been determined yet. A proxy for the neural network uncertainty was calculated for 32 sites in Europe. The neural network was trained with one year of data for 31 sites, the trained network was then used to estimate the NEE at the site that had been removed from the training set. This approach mimics the uncertainty in the observations and representativeness of the network but does not deal with uncertainty in the climate data used for upscaling. Also, this proxy for uncertainty is estimated at the site level. Compensation of site-level errors during upscaling may result in similar or lower uncertainties at the regional than that at the site level.

Post-processing: Monthly NEE estimates from 10 different ANN (see above) were aggregated at the annual scale to obtain separate annual estimates for the years 1999 to 2008.

Bias correction: The mean NEE for 2000 to 2008 was used as an estimate for the entire accounting period 2000 to 2009.

Short hand: **Peters**

Field(s): 14a

Description: Measurements of CO_2 concentrations in the atmosphere are used in models of atmospheric transport. The distribution of sources and sinks at the land surface is derived by minimizing the difference between simulated and observed concentration measurements, taking account of their respective errors.

Spatial extent: Global

Temporal extent: 2000 to 2008, with 2001 to be discarded as spin-up year.

Observations: typically ~70 sites per week totalling to 70,000 atmospheric CO_2 measurement from flask samples and tall tower observations from NOAA ESRL, CSIRO, NCAR, Environment Canada, and CarboEurope between 2000 and 2008.

Accounting boundaries: Atmospheric observations from aircraft not included, only surface samples and inlets. Optimization targets only the exchange with terrestrial biosphere and oceans, fossil fuel emissions and biomass burning are prescribed based on monthly mean inventory data. For the terrestrial biosphere uncorrelated scaling factors are used for the 19 ecoregions within each TransCom region. Except for tropical areas where all ecoregions within a TransCom region are correlated by an exponential distance relationship (L = 2000 km) to accommodate the lack of observations. Similar ecoregions in different TransCom regions are correlated exponentially with L=2000km.

Processing: The Carbon Tracker Europe system optimizes weekly net carbon fluxes around the globe drawing on observations from several CO_2 monitoring networks (Peters et al., 2007;Peters et al., 2010). Flask samples and tall tower observations from NOAA ESRL, CSIRO, NCAR, Environment Canada, and CarboEurope-IP are assimilated over the period 2000 to 2008 totalling nearly 70,000 atmospheric CO_2 values. In the data assimilation process, a set of scalars is derived that make the hourly 1º x 1º net ecosystem exchange (NEE) from the CASA biosphere model consistent with the atmospheric record. Each scalar is tied to (and solved for) a large eco-region and multiplies the detailed flux pattern in space and time. The European domain has 18 eco-regions; for example: crop lands, coniferous forest and wetlands. Ocean exchange is included (Jacobson *et al.*, 2007) and also optimized across 30 ocean basins. The seasonal fuel emissions and carbon release from fires (van der Werf *et al.*, 2004) are prescribed to the system and not explicitly estimated. Transport of CO_2 through the atmosphere is estimated with the two-way nested transport model TM5 (Krol *et al.*, 2005) with a horizontal resolution of 1º x 1º over Europe (about 90 x 60 km). A detailed description of the data assimilation and its results can be found at www.carbontracker.eu.

Available uncertainty estimates: Currently two uncertainty measures are available: (1) spread of ensemble of runs with altered assumptions on input data and model system and (2) formal Bayesian uncertainty available as covariance matrices for every weekly estimated set of parameters.

Post-processing: 1º x 1º degree NEE maps are created by convolving the optimized set of weekly parameters (258 in total) with the original 1º x 1º 3-hourly NEE patterns. NEE was thus never estimated at the 1º x 1º degree model resolution.

Bias correction: None.

Short hand: **Raymond**

Field(s): 1c

Description: Lateral transport of DOC, POC and DIC from fresh water ecosystems to the ocean.

Spatial extent: For all three carbon species, carbon loads to the coast were aggregated to coastal segmentation regions (i.e., COSCAT; Meybeck et al., 2006). For Europe this included COSCAT regions 401-408 and 410-418 (Meybeck et al., 2006; Figure 2).

Temporal extent: DOC and POC loads were modelled largely using drivers corresponding to the year 2000, though some parameters and the observed loads are based on data spanning the previous two decades. DIC modelled estimates represent a mean for approximately 1970-2000. Thus, carbon loads may be characterized as representing conditions for the period 1980-2000.

Observations: The lateral transport of carbon to the coast was estimated using the Global Nutrient Export from WaterSheds (NEWS) model framework (Mayorga et al., 2010).

Accounting boundaries: None

Processing: The carbon species models are hybrid empirically and conceptually based models that include single and multiple linear regressions developed by the NEWS effort and Hartmann et al. (2009), and single-regression relationships assembled from the literature. For DOC and POC, we used output from Mayorga et al. (2010) corresponding to observed hydro-climatological forcings with 2000 as the reference year. For DIC (corresponding to bicarbonate exports), the statistical relationships developed by Hartmann et al. (2009) were adjusted in highly weathered tropical soils (ferralsols) to 25% of the modelled values found in Hartmann et al. (2009) to account for overestimates relative to observed river exports (J. Hartmann and N. Moosdorf, unpublished); adjusted grid-cell scale exports were aggregated to the basin scale using NEWS basin definitions (Mayorga et al., 2010), then reduced by applying NEWS-based basin-scale consumptive water removal factor from irrigation withdrawals (Mayorga et al., 2010).

Post-processing: None

Bias correction: None.

Short hand: **Saarnio**

Field(s): 1d', 2kl

Description: Outgassing of CH_4 from rivers, lakes, estuaries and wetlands (marshes and peatlands).

Observations: CH_4 release factors were taken from an extensive overview of published literature see references in Saarnio et al. (2009)

Spatial extent: All countries except SCG

Temporal extent: Publications from the period 1978 to 2007 were compiled in a single data product, hence, the temporal extent of the product is undefined.

Accounting boundaries: The estimate excludes estuary, fjords and other coastal waters.

Processing: The geographical distribution and total area coverage of ombrotrophic mires and minerotrophic mires, freshwater marshes and saltwater marshes were taken from CORINE 2000, for all other countries Global Land Cover 2000 (JRC) was used. The area of waterbodies (lakes, rivers) was estimated from the ESRI database, Europe Water Layer (ESRI, 2003), providing a spatial resolution of 25 m. Smaller water bodies are considered to be negligible. Differentiation between lakes and rivers was done by using aspect ratios of the respective water body, i.e., rivers were identified by their long shorelines with respect to their surface area. CH_4 release factors were taken from an extensive overview of published literature and were specific for the different categories of wetlands, rivers and lakes.

Available uncertainty estimates: Minerotrophic and omrotrophic mires determine almost all emission for wetlands. Therefore we applied their uncertainty (class B ranging between 20 and 60%; Saarnio *et al.*, 2009) to the entire data product. The uncertainty for inland waters was higher (class D ranging between 100-300%; Saarnio et al., 2009). There are no formal quantitative uncertainty analyses available for these products. Only quantitative sensitivity analyses were provided.

Post-processing: Conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: The spatial extent of this data product does not include SCG, total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for spatial extent within this study. The data product is temporally undefined, the estimates was used as the average value for the period 2001-2005.

Short hand: **Schelhaas**

Field(s): 2e

Description: (Lateral) C-flux due to biotic and abiotic disturbances excluding fire

Observations: The basis of this study is a literature review by Schelhaas et al. (2003, and reference therein).

Spatial extent: All exc. CYP, EST, ISL, LVA, LTU, MLT

Temporal extent: Mean for 1950 to 2000

Accounting boundaries: Most types of damage seem to be increasing. This is partly an artefact of the improved availability of information. The most likely explanations for an increase in damage from disturbances are changes in forest management and resulting changes in the condition of the forest. Forest area, average volume of growing stock and average stand age have increased considerably, making the forest more vulnerable and increasing the resources that can be damaged. Since forest resources are expected to continue to increase, it is likely that damage from disturbances will also increase in future. Due to salvage logging it is expected that the majority of damaged wood stock (exc. Fire) is already accounted for in the wood harvest estimate.

Processing: Schelhaas et al. (2003) report that annually 35 million m3 of wood is damaged by abiotic and biotic disturbances of which 16% is caused by fire. Damage by fire was excluded from this estimate because it has been accounted for in more detail in the product labelled 'van der Werf'.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: We calculated the losses in biomass stock by assuming a wood density of 0.4g cm^{-3} and a carbon content of 0.5g C g^{-1} wood.

Bias correction: The spatial extent of this data product does not include CYP, EST, ISL, LVA, LTU and MLT. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. The mean estimate for 1950-2000 was provided and this flux was applied to the period 1996-2000.

Short hand: **Szopa**

Field(s): 7a

Description: Oxidation of non-CO_2 gasses

Spatial extent: Global 1.9° x 3.75°grid

Temporal extent: Mean for 1995 – 2005

Observations: The basis of this estimate is a concatenation of up-to-date bottom-up emissions for natural and anthropogenic sources. No direct use of observations is made (however most of the emissions factors are determined experimentally).

Accounting boundaries: The anthropogenic emissions account for agricultural practices and agricultural waste burning emissions, residential and commercial combustion, energy production and distribution, industrial processes and combustion, land transport, waste treatment and disposal, solvent production and use, ship emissions and biomass burning. They are described in Lamarque et al. (2010). The ORCHIDEE vegetation model has been used to calculate biogenic surface fluxes of isoprene, terpenes, acetone and methanol as described by Lathière et al. (2006). The emissions of CH_4 due to wetlands and termites are based on the study by Fung et al. (1991) for spatial distribution. The total of wetland emission is rescaled to 150Tg (according to the IPCC-AR4 recommendations).

Processing: The part of reactive carbon containing compounds which are oxidized in CO2 is not computed on line with a chemistry transport model using these emissions but is estimated using a previous study done by Folberth et al. (2006). The oxidation ratio considered is 66%.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product but the uncertainties are known to be high (> a factor 2).

Post-processing: The flux of non-CO_2 gasses CH_4, CH_3OH, C_2H_5OH, C_2H_6, C_3H_8, alkanes, C_2H_4, C_3H_6, C_2H_2, alkenes, CH_2O, aromatics, CH_3CHO, CH_3COCH_3, methylethylketones, methylvinylketones, CH_3COOH, isoprene, terpenes and CO was multiplied by an oxidation ratio of 66% as indicated by Folberth et al. (2006)

Bias correction: The mean estimate for 1995-2005 was provided and this flux was applied to the period 2001-2005.

Short hand: **Thompson**

Field(s): 14a'''

Description: measurements of N_2O concentrations in the atmosphere are used in models of atmospheric transport. The distribution of sources and sinks at the land and ocean surface is derived by minimizing the difference between simulated and observed concentration measurements, taking account of their respective errors.

Spatial extent: global with zoom over Europe to 1x1 degrees.

Temporal extent: 2005-2007 (with 2005 considered as the spin-up year)

Observations: NOAA (43 stations), AGAGE (1 stations), and CHIOTTO (7 stations),. Uncertainties assigned to the observations incorporate not only the measurement error but also the error in representing the observations due to limitations in the atmospheric transport model, such as the finite resolution and errors in horizontal and vertical transport.

Accounting boundaries: the model is global with the uppermost vertical bound in the upper stratosphere at 3 hPa.

Processing: The prior surface flux estimates were compiled from the anthropogenic flux estimates of EDGAR v4.0, natural soil emissions of (Bouwman *et al.*, 1995), biomass burning emissions of GFED v2 (van der Werf *et al.*, 2004) and ocean fluxes of GEIA (Nevison *et al.*, 1995). The relationship between the fluxes and the observations is described by the atmospheric transport operator. Here the transport operator is an offline version of the general circulation model of the Laboratoire de Météorologie Dynamique with a 'zoom' capability (LMDz) (Hourdin and Armengaud, 1999). This offline version uses archived fields of winds, convection mass fluxes, and planetary boundary layer (PBL) exchange coefficients that were compiled from prior integrations of the full model, which was nudged towards ECMWF winds. In this study, LMDz was run on a Eulerian grid with a zoom over Europe of 1.0° x 1.0° (longitude by latitude) and 19 sigma-pressure levels in the vertical. In addition to the transport, simple chemical reactions were added to the offline model to account for the loss of N_2O in the stratosphere. The loss of N_2O (due to photolysis and reaction with O1D) is calculated in every grid cell at each time step using pre-calculated fields of O1D and reaction cross-sections of photolysis from the full LMDz model coupled to the Interaction with Chemistry and Aerosols (INCA) model (Hauglustaine *et al.*, 2004). The model was initialized with a 3D field of N_2O mixing ratio taken from prior integrations of the full LMDz model, which had been run long enough to establish a quasi-steady-state. However, to give the inversion freedom from these initial fields, scalars for the total column of the initial field were included as parameters to be optimized. In addition, the total loss of N2O was scaled using a

separate scalar for each vertical column in 4 latitudinal bands (90 – 30°N, 30°N – Eq, Eq – 30°S, and 30 – 90°S). An initial value of 0.66 was assigned to all the scalars (all months and latitudinal bands), which resulted in a global loss of N_2O in the forward model runs consistent with a lifetime of 122 years (Volk *et al.*, 1997). These scalars were optimized in the inversion at monthly resolution, to avoid biases in the surface fluxes arising from incorrect assumptions about the lifetime. A further parameter was also optimized, namely the scale-offsets between independent in-situ sites and networks, to avoid these offsets (which are still poorly defined for N2O) from biasing the inversion results.

Available uncertainty estimates: posterior flux uncertainties were calculated from a Monte-Carlo ensemble of inversions, where each member of the ensemble contained random perturbations consistent with the prior error estimates for surface fluxes and observations.

Post-processing: conversion to global warming potential and C contained in the CO_2 equivalents.

Bias correction: no spatial bias correction was applied. As a temporal bias correction, the mean for 2006-2007 was used for the entire period.

Short hand: **Tupek**

Field(s): 9e

Description: Changes in soil, litter and biomass carbon stock of forest (Tupek *et al.*, 2010)

Spatial extent: EU-27

Temporal extent: 2000 to 2005

Observations: Forest area available for wood supply, tree growing stock and net annual increment collected from national forest inventories conducted between the 1980s and the year 2001

Accounting boundaries: Changes in soil and litter stocks are based on model assumptions. Natural disturbances are not accounted for.

Processing: The EFISCEN (European Forest Information SCENario) model is a large-scale model that projects forest resource development on regional to European scale. The model is described in detail by Schelhaas et al. (2007). EFISCEN describes the state of the forest as an area distribution over age- and volume-classes in matrices, based on data on the forest area available for wood supply (FAWS), average tree growing stock and net annual increment collected from national forest inventories conducted between the 1980s and the year 2001 (Nabuurs et al., 2007;Schelhaas et al., 2006). EFISCEN inventory data for Ireland and Portugal were limited to coniferous tree species only. Transitions of area between matrix cells during simulation represent different natural processes and are influenced by management. First, a basic forest management regime defines the period during which thinning can take place and a minimum tree age for final felling. Secondly, the demand for wood is specified for separately thinning and for final felling. This determines the intensity with which forests are managed. EFISCEN projects stemwood volume, increment, age classes and wood removals for 5-year time steps. To assess biomass carbon stocks, stemwood volume is converted into carbon in stems, branches, foliage, coarse and fine roots, using basic wood densities, a generic carbon content of 0.5, and age-dependent biomass distributions. Information on litterfall rates and unused harvest residues are input to the soil module YASSO (Liski *et al.*, 2005), which simulates litter fractionation and decomposition based on 30 years (1961–1990) average climate data (Mitchell and Jones, 2005) for every EFISCEN region.

Available uncertainty estimates:

Post-processing: None.

Bias correction: The spatial extent of this data product is limited to EU-27. Total flux estimates were divided by the land surface area of the data product. Subsequently, average

fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study. For upscaling, total forest area (1,784,719 km^2) was corrected for forest on drained peatlands (105,378 km^2) which were separately accounted for. This estimate was assigned to the entire period 2001-2005.

Short hand: **UNFCCC**

Field(s): 3e, 3e', 3e'''

Description: CO_2, CH_4 and N_2O emissions from product decomposition

Observations: Items 6A, 6B, 6C and D grouped under the header 'waste' from the UNFCCC GHG database (http://unfccc.int)

Spatial extent: All exc. ALB, BIH, CYP, MKD, MLT, UNK & SCG

Temporal extent: 1990-2009

Accounting boundaries: The emissions represent the total emissions from solid waste disposal on land, wastewater, waste incineration and any other waste management activity. Any CO_2 emissions from fossil-based products (incineration or decomposition) are not included here. CO_2 from organic waste handling and decay are not included here.

Processing: The GHG data are data officially reported by Parties to the UNFCCC secretariat, the exact data sources are given by country in the National Inventory Reports. Waste production statistics are multiplied by waste-specific emission factors. Different countries may use different emission factors.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product. Different countries may report different expert-based uncertainty estimates.

Post-processing: None

Bias correction: The spatial extent of this data product does not include ALB, BIH, CYP, MKD, MLT, UNK and SCG. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **UNFCCC**

Field(s): 5a, 5a', 5a'', 5a'''

Description: CO_2, CH_4, CO and N_2O emissions from fossil fuel burning and product use

Observations: Items 1, 2, 3, 4 and 7 from the UNFCCC GHG database (http://unfccc.int)

Spatial extent: All exc. ALB, BIH, CYP, MKD, MLT, UNK & SCG

Temporal extent: 1990-2009

Accounting boundaries: The emission estimate comprises; (a) emissions from fuels combusted by the fuel extraction or energy producing industries; (b) emissions from the combustion and evaporation of fuel for all transport activity; (c) by-product or fugitive emissions of greenhouse gases from industrial processes; (d) emissions from fuel combustion in industry are included under (a); (e) emissions resulting from the use of solvents and other products containing volatile compounds and (f) all other non-energy emissions not included under Industrial Processes are included in (e). This estimate excludes: (g) regardless of the sector, emissions from fuel sold to any air or marine vessel engaged in international transport (international bunker fuels); (h) all anthropogenic emissions from agriculture except for fuel combustion; (i) total emissions and removals from forest and land use change activities.

Processing: Statistics of fuel consumption and fossil fuel use for produce are multiplied by process or product-specific emission factors. Different countries can use different emission factors. The GHG data are data officially reported by Parties to the UNFCCC secretariat, the exact data sources are given by country in the National Inventory Reports.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product. Different countries may report different expert-based uncertainty estimates.

Post-processing: None

Bias correction: The spatial extent of this data product does not include ALB, BIH, CYP, MKD, MLT, UNK and SCG. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **UNFCCC**

Field(s): 6c

Description: CO_2 emissions from cement and lime production

Observations: Items 2.A.1 and 2.A.2 under 2A 'Mineral products' and 2 'Industrial processes' from the UNFCCC GHG database (http://unfccc.int)

Spatial extent: All exc. ALB, BIH, CYP, MKD, MLT, UNK & SCG

Temporal extent: 1990-2009

Accounting boundaries: The emission estimate comprises the energy used to break the rock material and the CO_2 released during breakage

Processing: Cement and lime production statistics are multiplied by process-specific emission factors. Different countries can use different emission factors. The GHG data are data officially reported by Parties to the UNFCCC secretariat, the exact data sources are given by country in the National Inventory Reports.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product. Different countries may report different expert-based uncertainty estimates.

Post-processing: None

Bias correction: The spatial extent of this data product does not include ALB, BIH, CYP, MKD, MLT, UNK and SCG. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiplied by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **van der Werf**

Field(s): 2d, 2d', 2d'', 2d''', 2dd'd''

Description: Monthly burned area and fire emissions for total carbon, CO_2, CO, CH_4 and N_2O

Observations: Terra Moderate Resolution Imaging Spectroradiometer (MODIS), Tropical Rainfall Measuring Mission (TRMM), Along Track Scanning Radiometer (ATSR)

Spatial extent: Global

Temporal extent: 1997 – 2010, monthly

Accounting boundaries: All open landscape fires that burn at least half the 500-meter grid cell can potentially be detected. The product therefore is more capable of detecting large fires than smaller ones, and is thus probably biased low (van der Werf *et al.*, 2010). This is especially the case in areas dominated by relatively small fires, for example agricultural areas. The burned area is multiplied with actual fuel loads and combustion completeness calculated by a modified version of the CASA model.

Processing: CASA, a satellite-driven vegetation model, was run at 0.5° × 0.5° spatial resolution, forced by climate and land cover datasets. Carbon released through forest fire emissions (F) was estimated by coupling burned area from the Terra Moderate Resolution Imaging Spectroradiometer (Giglio *et al.*, 2010) with the fire module of the CASA model (van der Werf *et al.*, 2006). Fire emissions were estimated monthly for the period 1997-2010. For the pre-MODIS period (November 2001 in this case), ATSR and TRMM active fire detections scaled to burned area were used (Giglio *et al.*, 2010). The burned area product has been validated for a small number of regions (Giglio *et al.*, 2009) and fuel or biomass loads have been compared to both point measurements and large-scale biomass assessments for the Amazon, but no formal uncertainty assessment has been carried out.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for these products. Only quantitative sensitivity analyses were provided.

Post-processing: Regridded the estimates on a 1°x1° grid and aggregated the monthly estimates to obtain separate annual totals. CH_4 emissions were converted to global warming potential and C contained in the CO_2 equivalents

Bias correction: None

Short hand: **Vuichard**

Field(s): 2j (b)

Description: N_2O fluxes from grasslands based on the PASIM model

Observations: Emission factors regressed from in situ flux data by Bouwman (1996) and Freibauer and Kaltschmitt (2003)

Spatial extent: All exc. ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK & CHE

Temporal extent: mean 1990's climate with 1993 intra-annual variability

Accounting boundaries: We did not consider organic N-applications since relevant information was not available at the European level, which causes N_2O emissions to be under-estimated.

Processing: N_2O emissions across the EU-25 territory was simulated by a process-oriented model (PASIM) specifically designed for managed grassland ecosystems. The PASIM model, initially developed and applied to simulate C and N-related fluxes for pasture and meadows (Riedo *et al.*, 1998), had previously been extended to calculate N_2O production from denitrification and nitrification, N_2O concentrations in the soil air and N_2O emissions to the atmosphere (Schmid *et al.*, 2001). It was evaluated against representative sites in Vuichard et al. (2007b) for C pools and fluxes and integrated at the scale of the European continent to calculate GHG fluxes in equilibrium with climate and CO_2 for the year 1993, using climate and soil input data at a resolution of 1° by 1° (Vuichard et al., 2007b;Vuichard et al., 2007a). PASIM calculated the geographical distribution of meadows (i.e. cut grasslands) and pastures (grazed grasslands) using simple management rules that assumed an optimal animal density in each grid point. In order to model the effects of variable N fertilizer applications on N_2O emissions within each grid point, we performed two end-members simulations over EU-25 using PASIM: a first run called FER in which all the pastures and meadows received an annual amount of N-fertilizer equivalent to the national average for fertilized grasslands given by the FAO (2002) agricultural statistics, and another run with no fertilizers called NOFER. The relationship between N_2O emission and N-fertilizers input as calculated by PASIM (0.009) for each grid cell of Europe has been compared with emission factors regressed from in situ flux data by Bouwman (1996) and Freibauer and Kaltschmitt (2003). The slope obtained with the simulation model is lower than those empirically determined by Bouwman (0.0125), and Freibauer and Kaltschmitt (0.015). The modeled intercept is also significantly lower than in the two previous studies.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: Maps of N_2O from the two end-members simulations were combined into a best estimate map of N_2O, using national ratios of fertilized to non-fertilized grasslands given by FAO (2002).

Bias correction: The spatial extent of this data product does not include ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK and CHE. Total flux estimates were divided by the land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Wang**

Field(s): 4a, 4a', 4a''

Description: CO_2, CH_4 and CO emissions from biomass burning

Spatial extent: global 0.1° x 0.1° grid

Temporal extent: 2007

Observations: Consumption of firewood, straw, and dung cake for cooking and heating, combustion of biogas in energy production, industry and residential/commercial sector, biodiesel used by vehicles, burning of biomass in wildfires from International Energy Agency Energy Statistics and Balances and FAO Statistical Database, China Energy Statistics Yearbook (CESY) province-by-province data, Tata Energy Directory and Data Yearbook 2007 (New Delhi, India, 2008), Ravindranath *et al.* (2005), Streets *et al.* (2005), Bond *et al.* (2004), Zhang *et al.* (2009), Yevich *et al.* (2003), and van der Werf (see above).

Accounting boundaries: The biomass component of this data product includes: solid agricultural waste, biogas, biodiesel, firewood, straw, dung cakes, forest fire, deforestation fire, woodland fire, savannah fire and peat fire.

Processing: National/sub-national fuel data were disturbed within the national boundaries as a function of the rural population. Biomass burned in wildfires were allocated to 0.5°×0.5° grids using the CO emission proxy from GFED database, and further refined to 0.1°×0.1° grids using 0.8×0.8 km^2 biomass (grass/trees) distributions (Friedl *et al.*, 2002). Biomass mass and volumes (as reported in the statistics) were converted to CO2 emissions by making use of fuel-specific emission factors from Van der Werf (see above), IPCC (1996), URS Corporation EME (2003) and US-DoE (US-DOE, 2000).

Available uncertainty estimates: Monte Carlo simulation (1000 runs) was conducted to characterize the uncertainties for fuel consumptions and CO_2 emissions. The variations in inputs were quantified by coefficients of variations (CVs) of given distributions. CVs for normally distributed fuels in wildfire (20%) were from the literature (van der Werf et al., 2010). CVs for uncombusted ratios and emission factors (normal distribution) were 20 and 5%, respectively. To address uncertainties in population aggregation, CVs assigned to individual countries depend on their areas. 1000% was used for Asian Russia (225829 grids). CV for other countries were calculated by 1000%*log(N)/log(225829), where N is country grid number. For normally distributed global, regional, or national total CO_2 emissions or fuel consumptions, the uncertainties are presented as 95% confidence intervals. For grid mapping, emissions were not normally distributed and the uncertainties are presented either absolutely as R_{90} or relatively as R_{90}/M.

Post-processing: To avoid double counting we subtracted CO_2 emissions from peat burning, wood and charcoal burning and ecosystem fires from the CO_2 emissions estimated by Wang. When burning biomass as a fuel it was assumed that 100% of the estimated C entered the atmosphere as CO_2, 10% as CO and 3% as CH_4. These ratio were taken from the modelled fire emission (van der Werf *et al.*, 2004). This approach is acceptable because Wang applied emission factors to obtain the CO_2 emissions. CH_4 emissions were converted to global warming potential and C contained in the CO_2 equivalents

Bias correction: This estimate was assigned to the entire period 2001-2005.

Short hand: **Wattenbach**

Field(s): 2j (a), 2j (b)

Description: N_2O fluxes from grasslands and croplands derived from UNFCCC downscaled by means of data from European Fertilizer Association on fertilizer consumption in the EU between 2006 and 2007.

Observations: N_2O emission as reported to the UNFCCC and fertilizer statistics as reported by the European Fertilizer Association on fertilizer consumption in the EU between 2006 and 2007

Spatial extent: All exc. ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK & CHE

Temporal extent: discrete time steps 1990, 2000 and 2005

Accounting boundaries: We did not now the actual split of mineral fertiliser between crop and grasslands and use the default European rate as a prior which was updated for each country by least square optimization.

Processing: UNFCCC statistics report national N_2O emissions from agricultural soils by different sectors. According to the agricultural sector considered, N_2O emitted by cropland and grassland soils were split as follows. The categories synthetic fertilizer-related emissions (4.D.1.1 in UNFCCC nomenclature), N_2O emissions falling into the animal manure category (4.D.1.2) and nitrogen fixation emissions (4.D.1.3) were split according to rules for region- and crop type-specific nitrogen demand on cropland with the remainder being allocated to grassland. This procedure follows state-of the- art approaches by Freibauer (2003) and CAPRIDynaspat. The resulting allocation factors for N input to cropland vary between 480% in Hungary, Finland and Sweden to 50% of the N input in Austria, Germany and the Netherlands. N_2O emissions from histosols (4.D.1.5) were attributed to croplands according to the emissions from cropland and grassland (Drösler *et al.*, 2008). In average, 43% of the total N_2O emissions from agricultural histosols in EU-25 were assigned to croplands, and the rest attributed to grasslands. N_2O emissions falling in the other direct and indirect emissions categories of the UNFCCC were all attributed to croplands, except for pasture emissions (4.D.2) and nitrogen fixation emissions (4.D.1.3) that were all attributed to grasslands. UNFCCC statistics for the years 1990 until 2000 have been used.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product.

Post-processing: None

Bias correction: The spatial extent of this data product does not include ALB, BIH, HRV, CYP, ISL, MKD, MLT, SCG, NOR, UNK and CHE. Total flux estimates were divided by the

land surface area of the data product. Subsequently, average fluxes were multiply by the surface area of the region of interest to obtain a flux estimate for the spatial extent within this study.

Short hand: **Willey**

Field(s): 7f, 7g

Description: Dissolved carbon in rainwater

Spatial extent: global mean

Temporal extent: Owing to rather sparse observations, all available observations were bulked in a single flux estimate, irrespective of the sampling year. Hence, the temporal extent of this data product is undefined.

Observations: Field observations of rainwater composition for Sweden, New Hampshire and New York in the USA, the Netherlands, Puerto Rico and Costa Rica (Willey *et al.*, 2000 and references therein).

Accounting boundaries: None

Processing: The published continental rainwater DOC fluxes (Willey *et al.*, 2000 and references therein) spans a rather narrow range, considering the large variations in collection time, climate, annual precipitation, vegetation, sample preservation and analytical techniques. Because these flux values do not vary over many orders of magnitude, continental rain DOC flux was estimated. The average continental or coastal rain DOC flux is 2.3 g C m^{-2} y^{-1}.

Available uncertainty estimates: There are no formal quantitative uncertainty analyses available for this product. For the limited number of field sites, the spatial heterogeneity appeared to be small and ranged between 1.5 and 3.0 g C m^{-2} y^{-1}.

Post-processing: Using a land area of 4,899,425 km^2 and a inland water area of 135,722 km^2 based on Corine land cover data (http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes) the C-flux in rainwater was estimated. The global DOC/DIC ratio (Willey *et al.*, 2000) was used to convert the DOC into the total dissolved carbon flux in rainwater.

Bias correction: None.

Short hand: **Yue**

Field(s): 7b

Description: C contained in dust deposition and emission

Observations: Dust particle size distribution, dust concentrations, logarithmic total deposition and aerosol optical thickness observations (Yue et al., 2009).

Spatial extent: global 4° x 5° grid, aggregated values were reported for Europe but the spatial extent of Europe was not detailed.

Temporal extent: 20 years mean for unspecified period.

Accounting boundaries:

Processing: A global transport model of dust was implemented within a general circulation model, using comprehensive parameterizations of the emissions and deposition processes (Wang et al., 2000). Parameterization was modified to match the surface conditions and meteorological fields of the climate model. Model simulations were validated against dust particle size distribution, dust concentrations, logarithmic total deposition and aerosol optical thickness (Yue et al., 2009).

Post-processing: The dust flux was assumed to contain 1% of carbon. Such a low value seems justified because the bulk of this flux over Europe comes from Sahara desert sand. A dust source with most likely a very low C-content.

Bias correction: Due to the magnitude of the flux (0.5 Tg C y^{-1}) no effort was made to apply bias corrections for the spatial extent. Nevertheless, the estimate is likely an overestimate for Europe as defined in RECAPP.

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