REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: …Italy……

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Other researchers: …Francesco Apadula, Paolo Cristofanelli, Michela Maione ……

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Project Title: European emissions of CO_2 and CH_4 inferred from model inversion system and their comparison with annual national inventory reports

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** _____	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES **X**☐	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	4,000,000	4,000,000	4,000,000
Accumulated data storage (total archive volume)[2]	(GB)	25000	30000	35000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive xGB in year one and y GB in year two and don't delete anything you need to request x+ y GB for the second project year etc.

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

Introduction

Considerable grow of atmospheric greenhouse gases (GHG) (CO_2, CH_4, N_2O, halocarbons and other synthetic compounds) since preindustrial times due to anthropogenic activities are the main driving force of climate change [1]. Carbon dioxide (CO_2) and methane (CH_4) represent the two most important greenhouse gases (except for water vapour) with a combined radiative forcing of 2.3 [± 0.24] W/m2 on the global average (IPCC 2013). The uninterrupted increase in these two most notorious atmospheric GHG has lead of unprecedented concentration levels in at least the last 800,000 years. This trend has been unmistakable attributed to human emissions mainly coming from fossil fuel burning and land use changes [2][3]. Their effects, together with those of other anthropogenic drivers, have been estimated throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. In response to this, regulation and emission trading schemes have been adopted at the Paris Agreement (PA) at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris on 12 December 2015. The PA requires the majority of the global countries to contain anthropogenic global warming well below 2°C with respect to pre-industrial times and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial level. The PA commitments call for immediate measure of GHG emission reduction with a deep impact on the energy and transport sectors of the developed economies. For this purpose, the European Union pledged to cut its emissions below 1990 levels, by at least 40% and 80-95 % by 2030 and 2050 respectively [4][5]. A detailed quantification of GHG emissions by all Parties is needed in order to supervise if all countries attain their commitments, which will be achieving within the "transparency framework" established by the Paris Agreement.

The UNFCCC reporting guidelines on annual inventories for Parties, developed by Conference of the Parties (COP), require each Party to provide its annual GHG inventory and removal of direct GHGs included in so called Kyoto basket : carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3)) from five sectors (energy; industrial processes and product use; agriculture; land use, land-use change and forestry (LULUCF); and waste).

Bottom-up emission inventories, however, can have significant uncertainties, especially for CO2 related to Land Use Land-Use Change and Forestry (LULUCF) sector, and for CH4 regarding the agriculture and waste management sector [6]. In addition, Bergamaschi [7] shows that emissions of sources category with large spatial, temporal and/or site-to-site variability are characterized by high uncertainty.

Both the UNFCCC Reporting Guidelines for National Greenhouse Gas Inventories and the MMR (the "Monitoring Mechanism Regulation) request countries to improve over time their estimates of emissions by sources and removals by sinks, in line with the 2006 IPCC Guidelines for national greenhouse gas inventories and in line with the IPCC reporting principles of transparency, accuracy, consistency, completeness and comparability. A complementary approach to bottom up emission inventories method is represented by top down or inversion model techniques. This methodology, based on atmospheric measurements and modelling, can be applied to estimate global regional and national GHG emissions in support to the inventory compilation. A large number of studies demonstrate the top down approach as successful method to verify the consistency between bottom-up emission inventories [8] [9] [10]. Moreover, the Subsidiary Body for Scientific and Technological Advice (SBSTA) of UNFCCC [11], highlighted the importance of adopting the top-down methods for verification of reported bottom up inventories, to support the Paris Agreement. Already today, some countries, including Switzerland and UK include inverse modelling results in their National Inventory Report. This was also recently emphasized in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

The aim of this project is to check the consistency between CO2 and CH4 bottom-up national emission inventories and concentration measured in the atmosphere. Moreover, changes in emissions of CH4 and CO2, due to the lock down COVID-19 pandemic, will be investigate over Po basin. For this purpose, a model inversion techniques will be used to estimate the magnitude and trend over 10 years period, of emissions sources of CH4 and CO2 over the European domain. In order to do this, we will use a combination of atmospheric measurements, Lagrangian Particle Dispersion Model (LDPM) in conjunction with a Bayesian inversion algorithm.

Measurement data

To estimate the emissions fluxes on national scale, high spatial and temporal resolution measurement data of CO2 and CH4 are required. For this aim, we will retrieved data from the Integrated Carbon Observation System (ICOS) and World Data Centre for Greenhouse Gases (WDCGG) networks . Fig 1 shows the location of European ICOS and WDCGG measurement stations. Atmospheric measurements are carried out on the top of tall towers, in mountain terrains or in remote environments. These measurement stations are commonly not too much influenced by local phenomena but are rather exposed to atmospheric transport and processes covering larger areas. This important feature allows to retrieved information on regional source and sink of the measured species. Table 1 shows the stations Name, and the period of which the CH4 and CO2 data are available. The total number of year available are 135 and 113 years for CO2 and CH4 respectively. However, we will not use all the data for our estimates, as some stations, mainly in the center of the domain, will have similar sources influence. We will perform several sensitivity test to evaluate the model performance of different stations, and then decide which stations will be include on the inversions for all period.

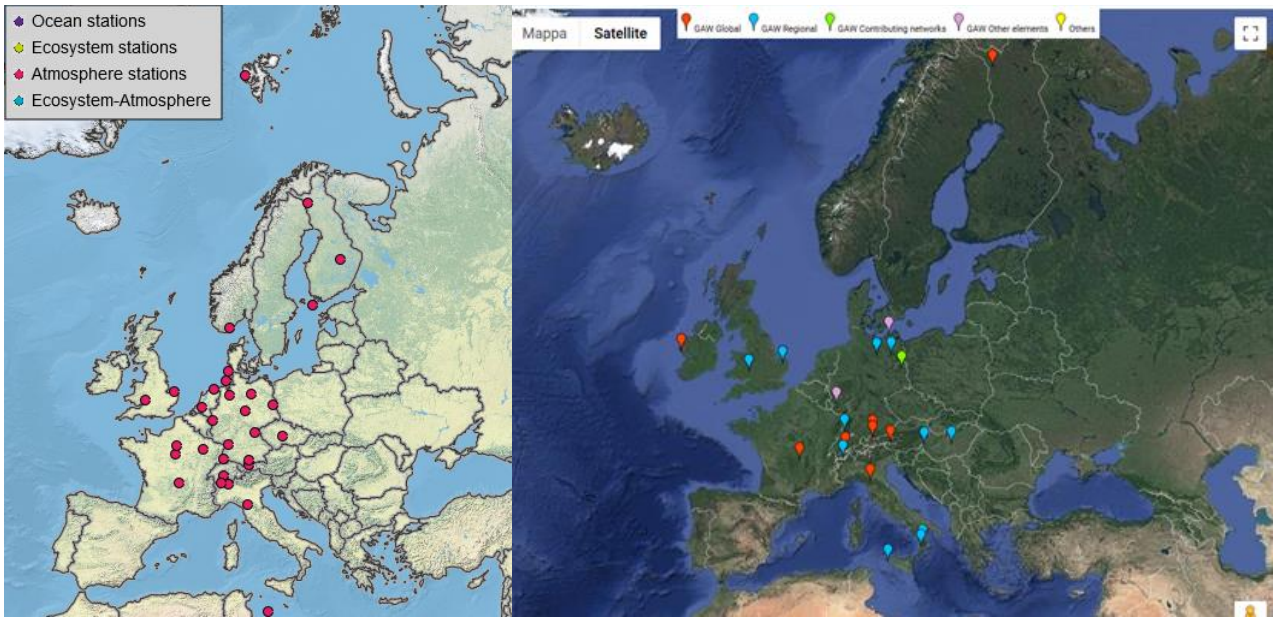

Fig 1. Map showing the location of the ICOS (left panel) and WDCC (right panel) atmospheric stations.

N°Stations	Name	GAW ID	Country	CO2	CH4	CO2 N° year since 2010	CH4 N° year since 2010
1	Capo Granitola	CGR	IT	2015-2020	2015-2020	5	5
2	Hegyhatsal*5	HUN	HU	1995-2020	----------	10	----------
3	Jungfraujoch	JFJ	CH	2005-2020	2005-2020	10	10
4	Pallas	PAL	FI	1998-2020	1998-2020	10	10
5	Plateau Rosa	PRS	IT	1992-2020	1992-2020	10	10
6	Puy De Dome	PUY	FR	2000-2020	1991-2020	10	10
7	Ridge Hill	RGL	UK	2012-2020	2012-2020	8	8
8	Sonnblick	SNB	AU	2002-2019	2012-2018	10	8
9	Schauinsland	SSL	DE	2000-2020	1992-2020	10	10
10	Tacolneston*2	TAC	UK	2012-2020	2002-2020	10	10
11	Zugspitze	ZSF	DE	2002-2020	2002-2020	10	10
12	Diabla Gora / Puszcza Borecka	DIG	PL	2002-2020	----------	10	----------
13	Lecce Environmental-Climate Observatory	ECO	IT	2015-2020	2015-2020	5	5
14	Giordan Lighthouse	GLH	MT	2013-2020	2013-2020	7	7
15	Izana (Tenerife)	IZO	ES	1992-2020	1992-2020	10	10

Table 1. Table showing , the **N°** of Stations, the **Name** of stations, the ***** indicate tower sampling and the following number the number of sampling point on tower; the **GAW ID**, the **Country** name, and CO2 and CH4 the period of available data, and the **N°** of years of data available since 2010 for the two species.

Dispersion model and Meteorological data

The inversion method proposed here, is based on backward simulations with the LPDM "FLEXible PARTicle" FLEXPARTv10.4 ([12] see also http://transport.nilu.no/flexpart). FLEXPART was validated through continental-scale tracer experiments [13] and has been used in a large number of model inversion studies on global and regional scale [14] [15][16][17][18][19].The dispersion model is driven by meteorological data which yields a description of atmospheric state of atmosphere as function of space and time. As in the top down regional emission estimate the transport errors remain a major concern, a high spatial and temporal resolution wind field is needed to reduce the error on inversion results. For this purpose, a global wind filed of 1° latitude x 1° longitude, and 137 vertical levels and time step of 2 hours will be retrieved from ERA5 ECMWF (European Centre for Medium-Range Weather Forecasts). As our project is focused on European domain, a nest wind field ERA5

of 0.25° latitude 0.25 ° longitude resolution grid and 137 vertical levels will be used. Large transport errors are generate over complex topography areas, for this reason a further nested wind field of 0.1 ° latitude x 0.1 longitude resolution, from Operational Field of ECMWF, with 137 vertical levels, will be tested over Alpine region. The ECMWF data will be retrieved using flexextractv7.1 version. To estimate the reduction of anthropogenic activities in the Po Valley, due the lockdown during the COVID-19 pandemic, shorter wind field interval (1 hour) will be adopted for the model simulations.

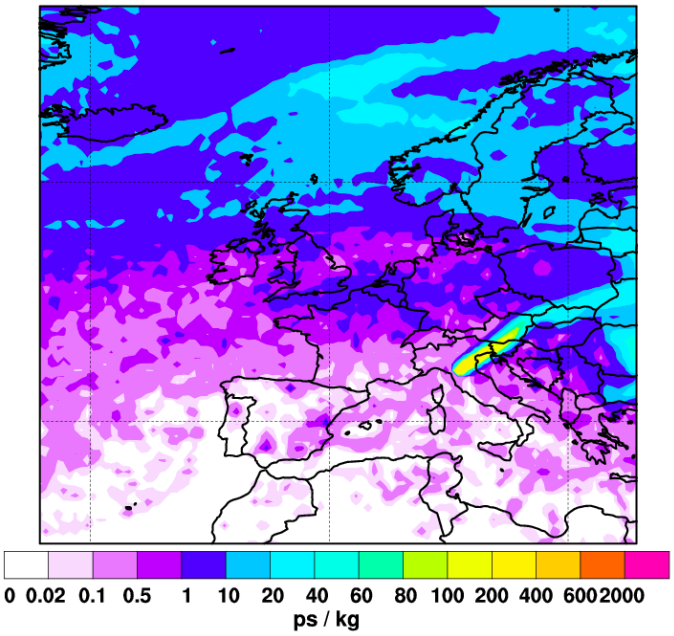

Fig 2 Footprint emission sensitivity in picoseconds per kilogram (ps kg−1) obtained from FLEXPART 20-day backward calculations from CMN station.

FLEXPART calculates the trajectories of particles using the mean wind interpolated from the analysis fields, and parametrizes the sub grid-scale atmospheric motions unresolved by the meteorological input data, adding random fluctuations based on Langevin equations for the particle velocity components. Moreover, the last version of the model, FLEXPARTv10.4, a vertical particle velocity include skewed turbulence and a vertical density gradient can be set as option on model runs. Even if a larger computational cost is entailed for that option, higher resolution of vertical velocity turbulence is needed to reproduce the characteristic features of CBL dispersion. In order to optimize the *effectiveness* of computer resources we will choice the parametrization values that allow an accurate turbulence description with reasonable computer costs.

However, due the large number of stations and the long period exanimated, before extending the model runs to all period and for all stations, several preliminary test will be conducted to evaluate the model performance achieved using different parametrization values, as explained on "Model inversion" part. From each measurement site, 60.000 virtual particles every hour are released and followed for 15 days backward in time, to calculate an emission sensitivity, and a named source-receptor-relationship (SRR) as by Seibert et al [20]. Fifteen days is considered a proper timescale for regional domain, considering that contribution from various regions become more and more well mixed and start forming the baseline after several days. The SRR at every grid cell is proportional to the particle residence time in that cell and gives the direct influence of mass emission from a source location to receptor point. The SRR of CO2 will calculate without considering loss process, meanwhile, the CH4 simulation will simulate loss process due to oxidation by OH radicals along the trajectories using pre-calculated OH fields from the GEOS-Chem model [21]. However, over the 15-day simulation period the loss is generally small. As the main CO_2 and CH_4 sources are ground based, we will extrapolate the SRR layer close to the surface 0-100 m (so-called "footprint"), as input for our inversion methodology.

A priori emission field

The GHG gridded emission inventories provides an accurate input to model inversion. We will test several a priori emission fields on our preliminary test, in order to find the reference a priori emission field, which will be adopt on all investigated period. Our reference-inverted emission will be

performed by a priori emission field, which shows the best agreement (r^2) between observations and a priori time series.

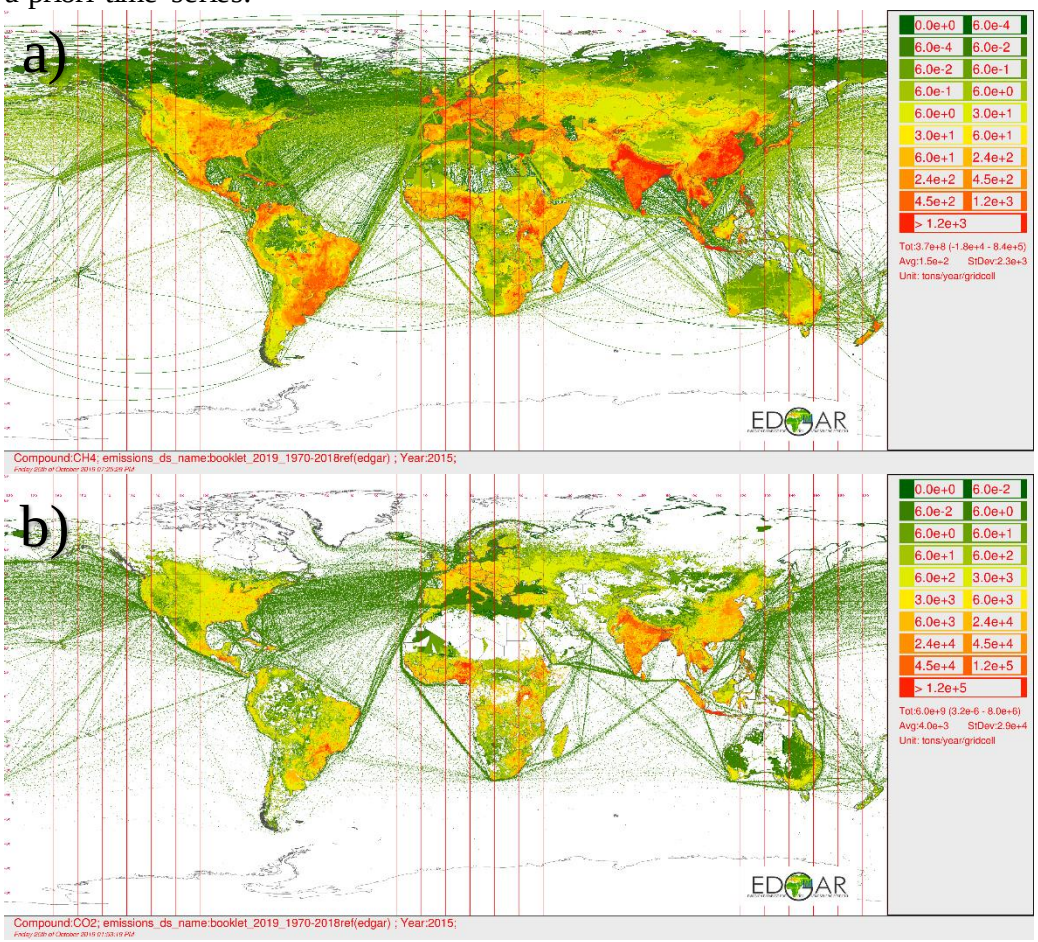

Fig 3 EDGARv5.0 grid maps for the year 2015 of CH4 (a panel) and CO2 (b panel) with spatial resolution of 0.1° x 0.1° latitude and longitude.

For anthropogenic emission fluxes, we will include on our a priori filed the European Commission's in-house database, the "Emissions Database for Global Atmospheric Research" (EDGAR) [22] (Fig 3). EDGARv5.0 provide a 1970-2015 global grid-maps for CO2, CH4 for all emission sources excluding the large-scale biomass burning sector (such as forest fires or savannah burning) and the land use, land-use change and forestry (LULUCF) sector. Furthermore, the scientist has led efforts on global GHG emission inventory. An important inventory for modelling community is a global gridded inventory of both species, CH4 and CO2, with time series of more than 6 decades provided by Community Emissions Data System (CEDS) [23]. Lamarques et al., [24] created a CH4 (and other compounds) gridded dataset for Climate Model Intercomparison Programme CMIP5. A spatial gridded format of CO2 emissions is provided by ODIAC [25] based on Carbon Dioxide Information Analysis Centre (CDIAC) [26][27]. We will not use UNFCCC database on our a priori emission field, as no gridded emission are available on it.

Model inversion

In order to derive the CH4 and CO2 source regions and to check the consistency between top down estimates and emission inventories, a Bayesian inversion framework FLEXINVERT will be used. This inversion method is based on FLEXPART dispersion model; it is described in Thompson and Stohl [28] and has been applied for CH4 inversions [29][30]. The Bayesian inversion algorithm identify the optimal emission fluxes by minimizing the mismatch between modelled and observed mixing ratios from the measurement sites, taking in to account the model simulations, measurements data, a priori emissions fluxes and the gridded uncertainty on emissions. The first part of the project will be devote to assess the influence of different input values to the model performance. The main input variable are the a priori emission field, the wind field resolution (spatial and temporal), model dispersion setting, and the observations adopted in the model inversion cascade. As an example, we will investigate how a flat a priori emission field (emission field homogenously distributed over land)

can affect our inversion results. For the mountain stations, an important preliminary test will be conducted to investigate the more suitable release altitude. In fact, due to the limited horizontal model resolution and the complex topography in the domain drive differences between the model surface altitude and the real station sampling altitude. As the choice of particle release height in the model can significantly change the model performance, several model performance test will be conducted for each mountain stations to select the most representative height above model ground. We will determine the influence of higher resolution wind field over Alpine regions with different the time step. Moreover, we will evaluate how sensitivity fields generated by different receptor geometries (removing one station at time) affect the model inversion system. Through the geometry test, we will able to select the most representative receptors of the study domain. This will allow us to acquire an accurate emission estimation over the domain with reasonable computer costs.
The inversion estimates provided by this project may contribute to constrain the atmospheric budget of the two most important GHGs on a regional scale. Furthermore, in order to investigate the not well-understood biogenic source budget an emission seasonal cycle will be performed for both species. In addition, large resolution will be implemented on model cascade to investigate the CO2 and CH4 emissions variation during the lockdown period due to the COVID-19 pandemic

Technical Requirements

As the aim of this project is to calculate the magnitude of CO_2 and CH_4 emissions on national scale, over the period of 10 years, this work is computationally expensive. However, we will adopt the technical feature to reduce and optimize the computational cost through preliminary test. It is not easy to establish a prior how many stations will we used for the inversions, as the exact number of receptors will be decide after preliminary test. However, based on our experience 11 stations, instead of 15 (reducing the years to simulate to 107 instead of 135) over the domain could be enough to get high-resolution national country emissions values for both species. Here the foreseen stations used and in bracket the number of years of CO_2 (CH_4 has always equal or minor data, see table 1) data available for each stations : GLH (7 yr), ECO (5 yr),DIG (10 yr),TAC(10 yr), SSL(10 yr), PUY(10 yr), ORS(10 yr), PAL(10 yr), JFJ(10 yr),HUN (10 yr), CGP(5 yr), IZO(10 yr) .We plan to simulate ten days backward runs for each stations, for both gasses. One year of this simulations (with most probable model setting), cost 72000 SBU, so we will require 72000*107 (n° of years)=7.7*10^6 SBU, plus 1,300,000 SBU to test the set-up to ensure that the simulations are run exactly as desired, and to run the sensitivity test described above needed to evaluate the inversions performance. We can run both species on a single simulation, so no additional computational cost is planned for run two species. Moreover, based on our experience, we estimate 3*10^6 SBU needed for inversions. The amount of storage for the simulation is equal to 3.5 Tb. The first year of the project will dedicate to retrieved the meteorological field data, test the model cascade simulation setting and run the first years of inversions. The second year of the project will be dedicated to investigate the lock down period using high resolution setting, and extending the simulations period; the last year of the project with planned to complete all the model simulations for both species and to get the final results.

References

[1] Intergovernmental Panel on Climate Change (IPCC) (2013) Climate Change 2013—The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York

[2] Keeling CD (1993) Global observations of atmospheric CO2. In: Heimann M (ed) The global carbon cycle. Springer, New York, pp 1–29

[3] World Meteorological Organization (WMO) (2017) Greenhouse Gas Bulletin: The state of greenhouse gases in the atmosphere based on global observations through 2016. WMO, Geneva

[4] European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions - A policy framework for climate and energy in the period from 2020 to 2030, COM(2014) 15 final, http://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX:52014DC0015, 2014

[5] European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions - A

Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0112, 2011
[6] Umweltbundesamt, Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2018, National Inventory Report for the German Greenhouse Gas Inventory 1990 - 2016, 2018.
[7] Bergamaschi, P., A. Danila, R. F. Weiss, P. Ciais, R. L. Thompson, D. Brunner, I. Levin, Y. Meijer, F. Chevallier, G. Janssens-Maenhout, H. Bovensmann, D. Crisp, S. Basu, E. Dlugokencky, R. Engelen, C. Gerbig, D. Günther, S. Hammer, S. Henne, S. Houweling, U. Karstens, E. Kort, M. Maione, A. J. Manning, J. Miller, S. Montzka, S. Pandey, W. Peters, P. Peylin, B. Pinty, M. Ramonet, S. Reimann, T. Röckmann, M. Schmidt, M. Strogies, J. Sussams, O. Tarasova, J. van Aardenne, A. T. Vermeulen, F. Vogel, Atmospheric monitoring and inverse modelling for verification of greenhouse gas inventories, EUR 29276 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-88938-7, doi:10.2760/759928, JRC111789
[8] Keller, C. A, Hill, M., Vollmer, M. K., Henne, S., Brunner, D., Reimann, S., O'Doherty, S., Arduini, J., Maione, M., Ferenczi, Z., Haszpra, L., Manning, A. J., Peter, T., 2012. European Emissions of Halogenated Greenhouse Gases Inferred from Atmospheric Measurements. Environ. Sci. & Technol. 46, 217-225.
[9] Manning, A. J., O'Doherty, S., Jones, A. R., Simmonds, P. G., Derwent, R. G., 2011. Estimating UK methane and nitrous oxide emissions from 1990 to 2007 using an inversion modeling approach. J. Geophys. Res. 116(D2), D02305.
[10] Graziosi, F., Arduini, J., Furlani, F., Giostra, U., Kuijpers, L. J. M., Montzka, S. A., Miller, B. R., O'Doherty, S. J., Stohl, A., Bonasoni, P., and Maione, M., 2015. European emissions of HCFC-22 based on eleven years of high frequency atmospheric measurements and a Bayesian inversion method. Atmos. Environ. 112, 196-207.
[11] SBSTA, Subsidiary Body for Scientific and Technological Advice Forty - seventh session Bonn, 6-15 November 2017 https://unfccc.int/resource/docs/2017/sbsta/eng/l21.pdf, 2017.
[12] Stohl, A., Forster, C., Frank, A., Seibert, P., Wotawa, G., 2005. Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2. Atmos. Chem. Phys. 5, 2461–2474.
[13] Stohl, A., Hittenberger, M., Wotawa, G., 1998. Validation of the Lagrangian particle dispersion model FLEXPART against large scale tracer experiment data. Atmos. Environ. 32, 4245–4264.
[14] Stohl, A., Seibert, P., Arduini, J., Eckhardt, S., Fraser, P., Greally, B. R., Lunder, C., Maione, M., Mühle, J., O'Doherty, S., Prinn, R. G., Reimann, S., Saito, T., Schmidbauer, N., Simmonds, P. G., Vollmer, M. K., Weiss, R. F., Yokouchi, Y., 2009. An analytical inversion method for determining regional and global emissions of greenhouse gases: Sensitivity studies and application to halocarbons, Atmos. Chem. Phys. 9, 1597-1620.
[15] Stohl, A., Kim, J., Li, S., O'Doherty, S., Mühle, J., Salameh, P. K., Saito, T., Vollmer, M. K., Wan, D., Weiss, R. F., Yao, B., Yokouchi, Y., and Zhou, L. X., 2010. Hydrochlorofluorocarbon and hydrofluorocarbon emissions in East Asia determined by inverse modeling, Atmos. Chem. Phys. 10, 3545-3560.
[16] Maione, M., Graziosi, F., Arduini, J., Furlani, F., Giostra, U., Blake, D.R., Bonasoni, P., Fang, X., Montzka, S.A., O'Doherty, S., Reimann, S., Stohl, A., and Vollmer, M.K., 2014. Estimates of European emissions of methyl chloroform using a Bayesian inversion method. Atmos. Chem. Phys. 14, 9755-9770.
[17] Henne, S., Brunner, D., Oney, B., Leuenberger, M., Eugster, W., Bamberger, I., Meinhardt, F., Steinbacher, M. and Emmenegger, L., 2016. Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling. Atmos. Chem. Phys. 16, 3683-3710.
[18] Graziosi, F., Arduini, J., Furlani, F., Giostra, U., Kuijpers, L. J. M., Montzka, S. A., Miller, B. R., O'Doherty, S. J., Stohl, A., Bonasoni, P., and Maione, M.: European emissions of HCFC-22 based on eleven years of high frequency atmospheric measurements and a Bayesian inversion method, Atmos. Environ., 112, 196, 2015.
[19] F. Graziosi, J. Arduini, P. Bonasoni, F. Furlani, U. Giostra, A. J. Manning, A. McCulloch, S. O'Doherty, P. G. Simmonds, S. Reimann, M. K. Vollmer and M. Maione "Emissions of Carbon Tetrachloride (CCl_4) from Europe", Atmos. Chem. Phys doi:10.5194/acp-2016-326, doi:10.5194/acp-16-12849-2016.

[20] Seibert, P. and Frank, A., 2004. Source-receptor matrix calculation with a Lagrangian particle dispersion model in backward mode. Atmos. Chem. Phys. 4, 51–63.
[21] Bey, I., Jacob, D. J., Logan, J. A., and Yantosca, R. M.: Asian chemical outflow to the Pacific in spring: Origins, pathways, and budgets, J. Geophys. Res., 106, 23073–23095, 2001
[22] Janssens-Maenhout, G., M. Crippa, D. Guizzardi, M. Muntean, E. Schaaf, F. Dentener, P. Bergamaschi, V. Pagliari, J. G. J. Olivier, J. A. H. W. Peters, J. A. van Aardenne, S. Monni, U. Doering, and A. M. R. Petrescu, EDGAR v4.3.2 Global Atlas of the three major Greenhouse Gas Emissions for the period 1970–2012, Earth Syst. Sci. Data Discuss., doi:10.5194/essd-2017-79, 2017.
[23] Hoesly, R. M., S. J. Smith, L. Feng, Z. Klimont, G. Janssens-Maenhout, T. Pitkanen, J. J. Seibert, L. Vu, R. J. Andres, R. M. Bolt, T. C. Bond, L. Dawidowski, N. Kholod, J. I. Kurokawa, M. Li, L. Liu, Z. Lu, M. C. P. Moura, P. R. O'Rourke, and Q. Zhang, Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), Geosci. Model Dev., 11(1), 369-408, doi:10.5194/gmd11-369-2018, 2018.
[24] Lamarque, J. F., T. C. Bond, V. Eyring, C. Granier, A. Heil, Z. Klimont, D. Lee, C. Liousse, A. Mieville, B. Owen, M. G. Schultz, D. Shindell, S. J. Smith, E. Stehfest, J. Van Aardenne, O. R. Cooper, M. Kainuma, N. Mahowald, J. R. McConnell, V. Naik, K. Riahi, and D. P. van Vuuren, Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application, Atmos. Chem. Phys., 10(15), 7017-7039, doi:10.5194/acp-10-7017-2010, 2010.
[25] Oda, T., and S. Maksyutov, A very high-resolution (1 km×1 km) global fossil fuel CO2 emission inventory derived using a point source database and satellite observations of nighttime lights, Atmos. Chem. Phys., 11(2), 543-556, doi:10.5194/acp-11-543-2011, 2011.
[26] Andres, R. J., T. A. Boden, F. M. Bréon, P. Ciais, S. Davis, D. Erickson, J. S. Gregg, A. Jacobson, G. Marland, J. Miller, T. Oda, J. G. J. Olivier, M. R. Raupach, P. Rayner, and K. Treanton, A synthesis of carbon dioxide emissions from fossil-fuel combustion, Biogeosciences, 9(5), 1845-1871, doi:10.5194/bg-9-1845-2012, 2012.
[27] Boden, T. A., G. Marland, and R. J. Andres, Global, Regional, and National Fossil-Fuel CO2 Emissions, doi:10.3334/CDIAC/00001_V2017, 2017.
[28] Thompson, R. L. and Stohl, A.: FLEXINVERT: an atmospheric Bayesian inversion framework for determining surface fluxes of trace species using an optimized grid, Geosci. Model Dev., 7, 2223–2242, doi:10.5194/gmd-7-2223-2014, 2014.
[29] Thompson, R. L., Stohl, A., Zhou, L. X., Dlugokencky, E., Fukuyama, Y., Tohjima, Y., Kim, S. -Y., Lee, H., Nisbet, E. G., and Fisher, R. E.: Methane emissions in East Asia for 2000–2011 estimated using an atmospheric Bayesian inversion, J. Geophys. Res.-Atmos., 120, doi:10.1002/2014JD022394, 2015.
[30] Thompson, R. L., Sasakawa, M., Machida, T., Aalto, T., Worthy, D., Lavric, J. V., Lund Myhre, C., and Stohl, A.: Methane fluxes in the high northern latitudes for 2005–2013 estimated using a Bayesian atmospheric inversion, Atmos. Chem. Phys., 17, 3553– 3572, https://doi.org/10.5194/acp-17-3553-2017, 2017.