GlobEmission

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User Requirements Document

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1 Introduction

1.1 Purpose and scope

This document will describe the user requirements for the GlobEmission service. It is based on the input of the main users of GlobEmission and the issues discussed at the User Workshops of the first phase of GlobEmission. Also requirements from the modeling community and other available user requirements will be included in the document.

2 Documents

2.1 Reference documents

[RD-1] GlobEmission User Consultation Requirement Documents

[RD-2] van der Werf, G.~R., J. T. Randerson, L. Giglio, G. J. Collatz, M. Mu, P. S. Kasibhatla, P. S., D. C. Morton, R. S. DeFries, Y. Jin, and T. T. van Leeuwen : Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997-2009), Atmos. Chem. Phys. Discuss., 10, 16153-16230, 2010.

[RD-3] Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527-554, doi:10.5194/bg-9-527-2012, 2012.

[RD-4] Richard H. Moss, Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, Steven K. Rose, Detlef P. van Vuuren, Timothy R. Carter, Seita Emori, Mikiko Kainuma, Tom Kram, Gerald A. Meehl, John F. B. Mitchell, Nebojsa Nakicenovic, Keywan Riahi, Steven J. Smith, Ronald J. Stouffer, Allison M. Thomson, John P. Weyant & Thomas J. Wilbanks, The next generation of scenarios for climate change research and assessment, Nature 463, 747-756(11 February 2010), doi:10.1038/nature08823

[RD-5] van Vuuren DP, JA Edmonds, M Kainuma, K Riahi, AM Thomson, K Hibbard, GC Hurtt, T Kram, V Krey, J-F Lamarque, T Masui, M Meinshausen, N Nakicenovic, SJ Smith, and S Rose . 2011a. The representative concentration pathways: an overview Climatic Change, 109: 5-31. DOI: 10.1007/s10584-011-0148-z

[RD-6] Martin, R. V., C. E. Sioris, K. Chance, T. B. Ryerson, T. H. Bertram, P. J. Wooldridge, R. C. Cohen, J. A. Neuman, A. Swanson, and F. M. Flocke (2006), Evaluation of space-based constraints on global nitrogen oxide emissions with regional aircraft measurements over and downwind of eastern North America, J. Geophys. Res., 111, D15308, doi:10.1029/2005JD006680.

[RD-7] Zhao, C. and Y. H. Wang (2009), Assimilated inversion of NOx emissions over east Asia using OMI NO_2 column measurements, Geophys. Res. Lett., 36, L06805, doi:10.1029/2008gl037123.

[RD-8] Kurokawa, J.I., K. Yumimoto, I. Uno, and T. Ohara, Adjoint inverse modeling of NOx emissions over eastern China using satellite observations of NO2 vertical column densities, *Atmos. Environ* 43, pp. 1878–1887, 2008.

[RD-9] Stavrakou, T., J. F. Müller, K. F. Boersma, I. De Smedt, and R. J. van der A (2008), Assessing the distribution and growth rates of NOx emission sources by inverting a 10-year record of NO2 satellite columns, Geophys. Res. Lett., 35, L10801, doi:10.1029/2008GL033521.

[RD-10] Napelenok, S. L., R. W. Pinder, A. B. Gilliland, and R. V. Martin (2008), A method for evaluating spatially-resolved NOx emissions using Kalman filter inversion, direct sensitivities, and space-based NO2 observations, Atmos. Chem. Phys., 8, 5603-5614.

[RD-11] Konovalov, I. B., M. Beekmann, A. Richter, and J. P. Burrows (2006), Inverse modelling of the spatial distribution of NOx emissions on a continental scale using satellite data, Atmos. Chem. Phys., 6, 1747-1770, doi:10.5194/acp-6-1747-2006.

[RD-12] Evensen, G. (2003), The Ensemble Kalman Filter: theoretical formulation and practical implementation, Ocean Dynamics, 53, 343-367, doi: 10.1007/s10236-003-0036-9

[RD-13] Stavrakou, T., A. Guenther, A. Razavi, L. Clarisse, C. Clerbaux, P.-F. Coheur, D. Hurtmans, F. Karagulian, M. De Mazière, C. Vigouroux, C. Amelynck, N. Schoon, Q. Laffineur, B. Heinesch, M. Aubinet, anf J.-F. Muller, First space-based derivation of the global atmospheric methanol emission fluxes, Atmos. Chem. Phys. Discuss., 11, 5217-5270, 2011.

[RD-14] Stavrakou, T., A. Guenther, A. Razavi, L. Clarisse, C. Clerbaux, P.-F. Coheur, D. Hurtmans, and J.-F. Muller, First space-based derivation of the global atmospheric methanol emission fluxes, Poster presentation at European Geosciences Union General Assembly 2011, Vienna, 3-8 April 2011.

[RD-15] Veefkind, P. F. Boersma, R. van der A, G. Hoek, P. Levelt, Monitoring the NOx emissions for the EC national emissions ceiling directive using satellite remote sensing, Poster presentation at European Geosciences Union General Assembly 2011, Vienna, 3-8 April 2011.

[RD-16] Mijling, B. and Van der A, R.J., NOx emissions in China constrained by satellite observations: a new inversion approach, Oral presentation at European Geosciences Union General Assembly 2011, Vienna, 3-8 April 2011.

[RD-17] Sofiev, M., Siljamo, P., Ranta, H., Linkosalo, T., Jaeger, S., Jaeger, C., Rassmussen, A., Severova, E., Oksanen, Karppinen, A., Kukkonen, J. (2009a) From Russia to Iceland: an evaluation of a large-scale pollen and chemical air pollution episode during April and May, 2006. Aerobiological Monographs, Vol. 1, in press.

[RD-18] Boersma, K.F., and OMI team, An improved retrieval of tropospheric NO_2 columns from the Ozone Monitoring Instrument, presented at the European Geosciences Union General Assembly, Vienna, 3-8 April 2011

[RD-19} Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K., Yan, X., and Hayasaka, T.: An Asian emission inventory of anthropogenic emission sources for the period 1980–2020, Atmos. Chem. Phys., 7, 4419-4444, doi:10.5194/acp-7-4419-2007, 2007

[RD-20] van Donkelaar A, Martin RV, Brauer M, Kahn R, Levy R, Verduzco C, et al. 2010. Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application. Environ Health Perspect 118:847-855. http://dx.doi.org/10.1289/ehp.0901623

3 Existing Emission databases

3.1 Current status of bottom-up emission inventories

Table 1 Relevant bottom-up emission inventories

Inventory	Spatial resolution	Temporal resolution	Last update	Period	Remarks
Global inventories					
ACCMIP	0.5 x 0.5 °	Annual	2010	1850-2000	Developed in support of IPCC AR5
EDGAR 4.2	0.1 x 0.1 °	Annual	2012	1970-2008	anthropogenic emissions GHGs (CO2, CH4, N2O, HFCs, PFCs, SF6) and air pollutants: CO, NOx, NMVOC, SO2 and NH3, updated every 5 years
GEIA v.1	1 x 1°	annual	1995	1985	
GFED v.3	1 x 1 °	monthly	2010	5 year	fire emissions, satellite data involved
FAS	0.5 x 0.5 ° 0.1 x 0.1 °	daily	2010	2000-2010	fire emissions (global and European)
GICC	1 x 1 °	monthly	2010	1997-2005	biomass burning
MACC	0.5 x 0.5 °	monthly	2010	1990-2010	under construction
MEGAN	1 x 1 °	monthly	2009	2000	biogenic emissions
POET	1 x 1 °	annual/monthly	2003	1990-2000	
RETRO	0.5 x 0.5 °	monthly	2005	1960-2000	
UNFCCC	per country	annual	2008	1990-2008	greenhouse gases

Regional inventories: Europe					
EMEP	50 x 50 km	annual	2007	1970-2020	Country total emissions updated yearly, spatial distribution updated every 5 years
TNO-MACC	0.125° x 0.0625°	annual	2007	2003-2007	EMEP country totals and gap filling with improved spatial distribution
Regional inventories: Asia					
INTEX-B	0.5 x 0.5 °	annual	2006	2006	
REAS	0.25 x 0.25 °	annual	2007	2000-2008	with predictions for 1980-2020
MEIC	0.25 x 0.25 °	monthly	2014	2000-2010	
SAFAR_India	1 x 1 °	annual		1991, 2001 and 2011	CO and NOx
Regional inventories: North America					
CGEIC	1 x 1 °	annual	1985	1985	part of EDGAR
NEI (EPA)	USA state	annual	2008	2008	updated every 3 years

The development of information for an emissions inventory can be carried out with two methods. One method is often referred to as the top-down approach. In the case of a top-down approach, generalized factors such as total fuel use, total population, total housing units, and total manufacturing jobs, for example, are used as indicators of emissions. Emission factors are developed that predict emissions per unit energy use or per person or such. The product of the emission factor with the relevant emissions indicator provides an estimate of emissions. If the data become much more activity and location specific, e.g. type of fuel used in well-described technological engine classes (such as the European emission standards for road transport) on specific roads, the emission inventory is bottom-up. So, A bottom-up approach means you estimate emissions for individual sources and sum all sources to obtain city-, state- or national-level estimates. The top-down approach is usually used when local data are not available, the cost to gather local information is prohibitive, or the end use of the data does not justify the cost of collecting detailed site-specific data. In practise it means an anthropogenic emission inventory is often a combination of both

approaches as key sources will be collected bottom-up but minor sources may be estimated top-down. To make an emission inventory suitable for modelling purposes it needs to be spatially distributed. This can be achieved by linking source sectors to specific distribution proxies (e.g. population density, road network) or by the so-called land use regression methodology, which uses a land use map to allocate emissions from source categories to spatial patterns. In both cases we call the resulting (gridded) emission maps “down-scaled” emission inventories. The underlying emission inventory is (mostly) bottom-up but at a coarser (national) resolution than the resulting spatially distributed emission map.
Another source of information to derive emission inventories from are earth observation data. Again we can distinguish a top-down and a bottom-up approach. Bottom-up is for example when satellite imagery is used to derive activity data with specific spatial allocation such as burned area or fire radiative power. The activities are than combined with (land-use) specific emission factors to derive e.g. fire emissions (e.g. GFED; van der Werf et al., 2010) MACC-GFAS; Kaiser et al, 2012). A top-down approach is when the observed columns of reactive gases or aerosol are combined with inverse modelling to derive emission source strengths of regions. Usually no source sector details can be derived from such top-down approaches, unless a region is strongly dominated by one source only, like shipping at seas. For scenario calculations some databases (e.g. EMEP, REAS) are extrapolated to future periods. For the global scale the ACCMIP database has been projected to 2100 following four so-called Representative Concentration Pathways (RCPs, Moss et al., 2010; van Vuuren et al., 2011). The RCP emissions database (not mentioned in Table 1) was constructed as input for the CMIP5 (Coupled Model Intercomparison Project 5) study, a set of coupled chemistry-climate simulations which will (at the time of writing) be used as input for the IPCC fifth assessment report (AR5) which is due to be published in 2013.

Table 1 shows the most important emission inventories. Bottom-up anthropogenic emission inventories, to a large extent based on specific activity data or statistics, are often lagging behind in time. Most reporting periods for global inventories end in 2000. Regional inventories are generally more up to date, e.g. 2005-2008 but a lag of 2 years to present is the minimum.

3.2 Current status of emission estimate techniques based on satellite observations

Satellite instruments measure high resolution radiance spectra at wavelengths in the ultraviolet, visible or infrared, which provide valuable information on the chemical composition of the atmosphere for various trace gases and aerosols. From their sun-synchronous orbit at a height of ~800 km they have a global coverage within 1-5 days at a 10-50 km resolution. The homogeneity and global coverage of the satellite retrievals are ideal to estimate top-down emissions. To achieve this, the retrieved tropospheric column concentrations of a trace gas are compared with the simulated concentrations from a chemistry transport model, based on a bottom-up emission inventory. The difference between observed and modelled concentrations contains information on how to adjust the underlying trace gas emissions. This is an inverse problem which is computationally challenging because the non-local relation (sensitivity) between emission and concentration has to be found. Due to transport away from the source, life-time information of the pollutant is crucial.

Several approaches have been developed, which are applied to different time scales and emission inventory resolutions. Shorter assimilation intervals ask for fast data assimilation algorithms, while transport issues become important for high spatial resolution. To discuss the different techniques NO_2 inversion will be used as an example. The methods differ in their emission domain (global or regional), the used satellite data, and the used chemical transport model. More importantly, the approaches differ in how the sensitivity is determined.

Martin et al. (2006) were one of the first to develop top-down estimates of NOx emissions from space. They assumed a direct relation between emissions and concentrations within a model grid cell (local sensitivity). Neglecting transport is allowed if the model grid resolution is large compared to the lifetime of the species. They used optimal estimation to weigh the *a priori* emission inventory with the top-down estimates, resulting in an *a posteriori* inventory with error estimates. This technique cannot be applied iteratively, because the error propagation through the model is unknown. Furthermore, zero emission areas in the *a priori* inventory remain zero; inferred emissions for these areas are attributed to surrounding non-zero emission sources.

Non-linear and non-local relations between emission and concentration can be indirectly solved by applying the method iteratively (e.g. *Zao and Wang* (2008)), although *a posteriori* inventory error estimates are lost. Again, zero emissions remain zero.

If the adjoint model code of the used chemistry transport model is available, it can be used to calculate the sensitivities, see e.g. *Kurokawa et al.* (2008), *Stavrakou et al.* (2008) who use the adjoint model together with 4DVAR techniques in their assimilation scheme.

Performing multiple model runs with different random perturbations on the emission inventory (Monte Carlo method) is another approach to solve the sensitivities. *Konovalov et al.* (2006) use 100 different model runs to calculate the sensitivities in a 5×5 grid box around a grid cell, allowing for transport of sufficiently short-lived chemical species.

A popular data assimilation method is the Ensemble Kalman Filter (*Evensen*, 2003), which is does not require an adjoint model and is relatively easy to implement. As an extension of the Kalman filter, it employs a Monte Carlo approach to represent the uncertainty of the model system with a large stochastic ensemble. Whenever the filter requires statistics such as mean and covariance, these are obtained from the sample statistics of the ensemble.

At the EGU General Assembly 2011, state-of-the-art inversion techniques were presented by several of the partners in this GlobEmission proposal. *Stavrakou et al.* (2011a, 2011b) showed their configuration of the global chemical transport model IMAGESv2 and its adjoint code to perform global inversions of NMVOCs (e.g. formic acid and methanol) from IASI retrievals. The same configuration will also be used for global emission estimates of other NMVOCs such as formaldehyde and glyoxal, and CO and NO_x.

Veefkind et al. (2011) presented a direct method to estimate country totals of NOx emissions from OMI retrievals. For high resolution emission estimates, *Mijling et al.* (2011) presented a new and fast assimilation approach. By applying a simplified, two-dimensional transport scheme, the need of adjoint model code or ensemble techniques is avoided. The chemical transport model is treated as a black box, which eases implementation of data assimilation applications based on other models or other model domains. Using the Kalman filter, the algorithm can invert daily emissions from satellite data of short-lived trace gases as NO_2, SO_2, and HCHO.

Sofiev et al., (2009) developed the emission estimation algorithm for the wild-land fires using the satellite-retrieved fire radiative power (FRP). Combing the MODIS FRP L2 products with the SILAM dispersion model computations, the scaling of FRP to PM emission was obtained for the main land-use classes and then verified for a series of fire episodes.

4 Users

4.1 Identified user groups

Emission inventories of greenhouse gases (GHGs), reactive gases and aerosols are needed as input for climate and atmospheric chemistry and transport models (CTMs) to be able to assess and predict the climate impacts, air pollution concentrations or deposition of elements to ecosystems. Emission inventories also provide the link to sources which can be mitigated by implementing policies to reduce emissions and thereby avoid or mitigate undesirable environmental impacts. Therefore emission inventories are used by policy makers as well as climate modellers and atmospheric modellers.

From these users, ESA selected several committed end-users that were for CCN1 added or replaced by several other users. They are representative for the wishes among users of emission inventories. These users will be introduced in chapter 4.2. During the project we will promote our data products to other users on international meetings and by the link with the TEMIS web-site, which already has a high number of visitors. Therefore, the data products will be designed to be accessible for a broad community of users.

During the project we will stay in contact with the data providers and user community of the MACC project and the developers of the Global Fire Emission Database (GFED). Within MACC an inventory of emission estimates will be made for methane, which is of interest to our users. Therefore these results will be linked to the GlobEmission web-site. The GFED database is developed by Dr. Guido van der Werf (VU University of Amsterdam) and co-workers, who have a long experience on global fire emission estimates based on satellite data. GFED became the standard emission inventory used in global studies by many modelling groups. van der Werf and co-workers aim at improving the understanding the global biogeochemical cycles by combining remote sensing data with biogeochemical modelling, and atmospheric studies. This with special interests in the role fires play in carbon cycling, including its effect on atmospheric CO_2 and CH_4. Consistent estimates of concentrations of fire-emitted species (CO, formaldehyde, CH_4) are needed. In addition, consistency is expected between different trace gases, algorithms and data formats.

4.2 Committed end-users

4.2.1 European Environment Agency

The European Environment Agency (EEA) is an agency of the European Union. Its task is to provide sound, independent information on the environment. The EEA is a major information source for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public. Currently, the EEA has 32 member countries.

The EEA holds a core role in the reporting of official emission inventory data for the EU to international conventions for both air pollution and climate change. It works closely with countries and the European Commission in receiving, compiling, reporting and dissemination of emissions inventory datasets. The emission data sets as provided by the member states serve two purposes:

a) assessing progress and compliance with present and future policy commitments.

b) serving as input to air quality modeling activities, including near real time forecasting

EEA is interested in obtaining improved emission knowledge for Europe and its surrounding countries based on remote sensing data to:

a) To support countries in improving the quality of emission inventory data submitted to the European commission and EEA under existing and future policy commitments.

b) To allow for improved verification of national emission inventory data

c) To provide improved emission inventory data for use in air quality model applications (retrospective analysis, scenarios as well as real time forecasting) through e.g. better spatial resolution or a better representation of intra- and interannual variability.

EEA can ensure linkages between the GlobEmission project and other ongoing projects in which the EEA is involved in. These include for example EEAs EU greenhouse gas inventory compilations for the UNFCCC, work on the air pollutant inventory within UNECE-TFEIP, the GMES MACC work programme as well as FAIRMODE working group 2. In the latter three TNO plays a key role as well, ensuring a good connection between EEA and glob-emission.

EEA has indicated that it would happily contribute in kind to the project (as far as resources allow). For example, EEA contributions could occur through provision of advice concerning the definition and consolidation of planned project activities, facilitating access to existing emission inventories, ensuring linkages to EEA activities within GMES. Finally, EEA could assist in the evaluation of the delivered products.

4.2.2 Satellite Environment Center, MEP of China

The Satellite Environment Centre, part of The Ministry of Environmental Protection of the People's Republic of China (SEC, China MEP), applies remote sensing techniques for environmental monitoring and assessment. They also supply service information to the authorities for environmental management.

SEC needs data of distribution and magnitude of emission of pollutants such as PM10, PM2.5, NO_x, SO_2, CO, CO_2, CH_4. These data are used for emission reduction policy.

Top-down emission estimates help to study the effect of pollutant emission reduction strategies, and facilitate a more objective policy for future pollution control.

SEC operates the HJ-1 satellite which is capable of monitoring aerosols. The Environmental Satellite Centre also uses satellite data of MODIS and NOVAA to study pollution events such as biomass burning. The results of the GlobEmission project will be used in research of pollutant sources and air quality prediction.

SEC will cooperate in validation activities once data of the GlobEmission project becomes available. Furthermore, SEC is committed to

- provide expert advice in the definition of the project activities, as requested;
- advise the project team in the consolidation of the user requirements during the initial phase of the project;
- facilitate access to existing data (e.g. emission inventories, in-situ data), if available, that may be useful for the project;
- contribute to the validation of the newly generated emissions inventories at the midterm and final reviews;
- perform an evaluation of the delivered products at the mid-term and final reviews.

4.2.3 Indian Institute of Tropical Meteorology

The Indian Institute of Tropical Meteorology (IITM) functions as a National Centre for basic and applied research in tropical meteorology. Its mission is to promote, guide and conduct research in the field of meteorology and air pollution in all aspects and to function as a national centre for basic and applied research in monsoon meteorology. Urban air pollution, chemical transport modelling and middle atmospheric dynamics is one of the major scientific programmes of IITM. The objective of this program is to

- study the processes governing distribution of chemical constituents in the atmosphere and impact assessment for climate change under the global and regional chemical transport modelling
- to develop emission inventory of atmospheric constituents for mitigation strategies
- to monitor ambient air pollutant to study the short-term and long-term variability over rural and urban environments.

Independent top-down emission inventory for NO_x and CO for India are needed, preferable with seasonality. Emission estimates from various source categories (eg. anthropogenic, biomass, soils, etc). Lack of accurate statistics and region specific emission factors is a source of uncertainty for India's bottom-up emission inventories (international (e.g. EDGAR and POET), and Indian). Therefore it is limited in providing a better picture to the policy-makers to mitigate the pollutants and their associated impacts. Also, model simulations show only limited success in reproducing observed concentrations of O_3 and its precursors over the Indian region due to the uncertainty in emission inventories and lack of seasonality in emission inventories.

It will provide the IITM an opportunity to give a better picture to the Indian policy-makers to mitigate the pollutants and their associated impacts. More specifically, the expected benefits are:

- To develop region specific (for various regions of India) emission estimates for mitigation strategies.
- To track the emission from the mitigate zones.
- To characterize emissions from the newly developing urban zones and power plants
- To verify and update current emission estimate from various national and international bottom up and top-down emission inventories for India.
- To improve the simulation for ozone distribution over India region.
- To develop pollution forecasting for highly polluted zone of India using GlobEmission products as input to regional CTM.

Currently, IITM is developing a top-down emission estimate for NOx emission with the specific focus on India using satellite data products, and is trying to compare the results with existing national and international bottom-up emission inventories.

On behalf of IITM, Dr. Sachin Ghude will provide access to available information about the emissions from India for validation purpose and quality assessment. Furthermore, he is committed to

- provide expert advice in the definition of the project activities, as requested;
- advise the project team in the consolidation of the user requirements during the initial phase of the project;
- facilitate access to existing data (e.g. emission inventories, in-situ data), if available, that may be useful for the project;
- contribute to the validation of the newly generated emissions inventories at the midterm and final reviews;
- perform an evaluation of the delivered products at the mid-term and final reviews.

4.2.4 South African National Space Agency

The South African National Space Agency (SANSA) has taken over the role of South African Weather Service (SAWS) in partnership with the South African Department of Water and Environmental Affairs (DWEA) as a user of GlobEmission.

SANSA …. (TBD)

4.2.5 National Institute for Environmental Studies

The National Institute for Environmental Studies (NIES) is Japan's primary institute for comprehensive research in environmental science, especially for climate change, sustainable material cycles, environmental risk, and the Asian environment. In the Asian Environment Research Group, a core research project, "Development of Methods for Evaluating Air Quality in Asia" (FY2006-2010), is now being conducted. This project develops methods for evaluating air quality by combining observational and modeling studies in order to establish the necessary systems for air quality management and integrate scientific knowledge on air quality in the Asian region through international collaboration. The development and improvement of emission inventories in Asia is an essential task in this project.

NIES has been developing and updating the regional emission inventory in Asia (REAS) and also performing the model simulation with REAS inventory for analysis of temporal and spatial variations of air quality in Asia. However, there are not enough observations and information to validate emission data and model simulated results. In addition, the base year of bottom-up emission inventory is generally a couple of years behind. Therefore, the satellite observation and satellite-derived emission data are required for improvements of bottom-up emission inventories of the Asian region.

In order to understand the spatial and temporal variations of air quality in the Asian region, model simulations with accurate emission inventories for target years are essential. However, bottom-up emission inventories which NIES is using now have relatively large uncertainties and the newest base year is generally a couple of years behind due to the limitations of statistics. In addition, there are not enough observations to validate the emission data and model simulated results. NIES expects that satellite observation and satellite-derived emission data over Asia by GlobEmission products are available for solving the above problems.

In a strategic research project (FY2009-2013) under the "Global Environment Research Fund" of Ministry of Environment, Japan, NIES works on an update of the the REAS inventory. A minor update is planned in the next 1 or 2 years and a major one in 2 or 3 years using the output of satellite observation data and satellite-derived emission data from the GlobEmission project. NIES will provide their products of updated bottom-up inventories to the GlobEmission project. Emission tables and gridded data of REAS version 1.1 (Ohara et al., 2007) are available from REAS home page:
http://www.jamstec.go.jp/frcgc/research/p3/emission.htm.

4.2.6 Laboratoir Atmospheres, Millieux, Observations Spatiales

Laboratoir Atmospheres, Millieux, Observations Spatiales (LATMOS) is a research laboratory of the Institute Pierre Simon Laplace in Paris, France. LATMOS focuses on three main research themes: physical and chemical processes in the Earth's atmosphere and interactions between atmosphere and the Earth's surface; study of planets and smaller objects in the solar system; physics of heliosphere, exosphere of the planets and plasma in the solar system.

As for the Earth environment the main goals are in improving the understanding and description of the physical processes, which contribute to energy and mass transfer in the atmosphere and near the surface. Special attention is given to processes contributing to the transport of heat and momentum, to the water cycle, to radiative effects, and to air composition (troposphere, stratosphere). In order to meet these objectives, LATMOS participates on development of experimental approaches, mainly based on remote sensing, including design of the instruments and analysis of observations. Along with experimental research, LATMOS has an expertise in use and improvement of numerical models studying meteorological phenomena in the atmosphere, as well as physical and chemical processes in troposphere and stratosphere. In support to numerical models, LATMOS develops emission inventories of atmospheric compounds emitted from both anthropogenic and natural sources.

As part of the Monitoring Atmospheric Chemistry and Climate (MACC) project, at our institute we have created a bottom-up global emission inventory of biogenic VOCs by applying the MEGAN (Model of Emissions of Gases and Aerosols from Nature) model. Unfortunately, the bottom-up BVOC emissions are still very uncertain mainly due to insufficiently detailed description of the vegetation distribution and composition, and due to selection of appropriate emission factors.

The flux measurements at the surface are scarce and usually concentrate on short period of time. Use of satellite data and inversion modeling technique is a promising way of evaluation of emission inventories as it provides a consistent picture in space and time. The satellite-derived emission data of CO and NMVOC from the GlobEmission project would be a useful dataset that could help us to improve our bottom-up inventory. It can highlight locations where the bottom-up emissions are not consistent with the satellite observation. The GlobEmission dataset would be used for comparison with the bottom-up inventory and in evaluation of the inventory in the chemical transport model.

4.2.7 Qatar Environment and Energy Research Institute

The Qatar Environment and Energy Research Institute (QEERI) is a member of the Qatar Foundation for Education, Research and Community Development. QEERI plays a key role in supporting Qatar's grand challenges. Atmospheric and climate change research at QEERI focus on impact assessment and mitigation of air quality and climate change within arid environments.

4.2.8 Inha University

Inha University has been closely collaborated with KNIER (Korean National Institute of Environmental Research) in reviewing accuracies of the source inventories of Korea and neighboring regions. Furthermore, Inha University is cooperating the national air quality in forecasting including PM and ozone and therefore interested in updating the emission inventories more frequently to handle fast changing emissions characteristic in the region and also interested to take into account the incidental emissions such as wild fires, sand and desert storms.

Inha University will evaluate the GobEmission products by comparing with the Korean source inventory compiled by taking a bottom-up approach in the first year And the GlobEmission products will be incorporated into the air forecasting modeling system operated by Inha University to improve the model performance possibly in the second and third year.

5 User requirements for the emission products

5.1 Global Emission product requirements

BIRA-IASB will provide global emission data for CO and NMVOC. The VU University Amsterdam and NIES confirmed that they are still willing to use these emission data. Moreover the South African Weather Service mentioned they would like to use NMVOC emission data on a regional scale that can be provided by BIRA.

The VU University Amsterdam is interested in consistent estimates of concentrations of fire-emitted species (CO, formaldehyde, CH_4) for global carbon cycle modeling, including production of the Global Fire Emissions Database (GFED).

The National Institute for Environmental Studies (NIES) is in charge of the development and improvement of emission inventories in Asia. Therefore NIES is especially interested in anthropogenic NMVOC emission data (on a monthly basis) and in NOx, CO, SO_2, black Carbon, Organic Carbon, PM, NH_3, and CO_2 emission data for Asian region (including Russian Asia).

The South African National Space Agency (SANSA) is interested in all trace gases of relevance for atmospheric modeling (including CO and NMVOC) and high spatial resolution 1 km x 1 km for the South African region.

Laboratoir Atmospheres, Millieux, Observations Spatiales (LATMOS) is interested in global NMVOC emissions, in particular biogenic isoprene, and CO emissions

Table 2 summarizes the requirement for CO, isoprene and NMVOC of these four users.

Table.2 User requirements for CO, isoprene and NMVOC

Quantity	**User Requirement**
Region coverage	Global, with special focus on Asian and South African region
Time period coverage	2009-2010 with possible extension from 2006 2005-2013 for LATMOS
Accuracy	Highest possible for VU University of Amsterdam 50-100% for NIES For other users is more important that the error is properly reported
Spatial resolution	Aggregated to ¼ or ½ degree for VU University of Amsterdam ½ x ½ degree or better for NIES and LATMOS

	From 30 minute to 0.5 degree for SANSA
Temporal resolution	Monthly for VU University of Amsterdam and LATMOS Monthly for NIES, if possible information on weekly or diurnal variations Weekly to monthly for SANSA
Availability	All groups mentioned that a delay of one month is acceptable. For LATMOS a delay of 6 months is enough.
Data format	HDF, NetCDF or text, to be defined with the user

5.2 Regional Emission product requirements

5.2.1 Regional emissions requirements for China

Table.3 User requirements from SEC-MEP for regional emissions in China.

Quantity	**User Requirement**
Region coverage	South East Asia with focus on China
Time period coverage	From 2005 to present
Accuracy	80%
Spatial resolution	From 1 x 1 km to 10 x 10 km
Temporal resolution	1 day
Availability	Two hours after measurement
Data format	Geotiff, HDF or NetCDF

The GlobEmission product will be used to get a better understanding of the distribution and magnitude of emissions in China. The top-down emission estimates will help to study the effect of pollutant emission reduction strategies, and facilitate a more objective policy for future pollution control.

5.2.2 Regional emissions requirements for Korea

Table.4 User requirements from Inha Universtity for regional emissions in Korea.

Quantity	User Requirement
Parameters	NO_x, CH_4, CO, PM, SO_2, NMVOC, NH_3 etc.
Region coverage	East Asia focused on Korean Peninsula
Time period coverage and temporal resolution	From 2005 to present, and daily averages
Spatial resolution	From 10 x 10 km(Korean Peninsula) to 40 km x 40 km(China, Japan, Asian Part of Russia)
Accuracy	50%
Availability (how long after the actual measurement the data are needed)	1~4 week
Data format	NetCDF is preferred, but ASCII is acceptable

The GobEmission products for Korea will be incorporated into the air forecasting modeling system operated by Inha University to improve the model performance.

5.2.3 Regional emissions requirements in India

Table.5 User requirements for regional emissions in India.

Quantity	User Requirement
Region coverage	South Asia with focus on India
Time period coverage	From 2001 to present
Accuracy	Not specified
Spatial resolution	0.25 x 0.25 or 0.5 x 0.5
Temporal resolution	6 months

Availability	6 months
Data format	NetCDF or ASCII

KNMI will provide regional emission estimates for NOx. The product will be used by IITM to update/improve their own top-down NOx estimate over the Indian region. Also, it will also be used as input data for a regional chemical transport model to study the processes behind the distribution of chemical constituents in the atmosphere, and impact assessments for climate change under the global and regional chemical transport modelling.

5.2.4 Regional emission requirements for South Africa

SANSA requires regional emission inventories of the trace gases CO, SO_2, NOx, NH_3, NMVOCs and other trace species relevant in atmospheric modeling. Also an emission inventory of particulate matter PM10 and/or PM2.5 is required. Further requirements are summarized in the table below.

Table 6: User requirements as provided by the South African National Space Agency

Quantity	**User Requirement**
Region coverage	Africa south of the equator with a South African nested domain. Due to the need to include biomass burning emissions north of South Africa, SANSA would require a significantly large sub-Saharan domain to be considered.
Time period coverage	From 1997 to present
Accuracy	-
Spatial resolution	1 km or better for the South African nested domain
Temporal resolution	Monthly availability will be required at the start and more regular intervals will be explored as needs arise from users
Availability	
Data format	HDF, NetCDF and text format

The GlobEmission product will be used by the South African National Space Agency (SANSA), South African Weather Service and the South African Department of Water and Environmental Affairs (DWEA) as an emission inventory module in the South African Air Quality Information System (SAAQIS). Depending on the timing of the release of the national emission inventory that currently is being developed, the GlobEmission products will inform and guide the development of the national inventory or be used to validate the data in the inventory. Unless the national emissions inventory is made available in time, GlobEmission inventory will be used in the future SAAQIS air quality forecasting system.

5.2.5 Regional emission product requirements for the Middle East

The Qatar Environment and Energy Research Institute (QEERI) requires emission estimates for NO2, CO & CH4. If possible PM, VOC & SO2 need to be included as well.

Table 7: User requirements as provided by the Qatar Environment and Energy Research Institute.

Quantity	**User Requirement**
Region coverage	Middle East with focus on the Arabian Peninsula
Time period coverage	From 2000 to present
Accuracy	Highest possible
Spatial resolution	Smallest possible (1 km x 1 km to 10 x 10 km)
Temporal resolution	Daily
Availability	As soon as possible for historical data Near real-time for modeling (AIMS-Q)
Data format	HDF or NetCDF & ASCII (format to be agreed upon with QEERI)

Atmospheric and climate change research at QEERI focus on impact assessment and mitigation of air quality and climate change within arid environments.

5.3 European emission product requirements

EEA is interested in obtaining improved emission knowledge for Europe and its surrounding countries based on remote sensing data to:

1. To support countries in improving the quality of emission inventory data submitted to the European commission and EEA under existing and future policy commitments.
2. To allow for improved verification of national emission inventory data

3. To provide improved emission inventory data for use in air quality model applications (retrospective analysis, scenarios as well as real time forecasting) through e.g. better spatial resolution or a better representation of intra- and interannual variability.

This means that the GlobEmission results will be used by teams responsible for national emission inventories as well as by air quality modeling teams. As the requirements for these users are different EEA has formulate product requirements for both applications. A summary of the requirements is given in Table 8.

The study should focus on those components for which methods/algorithms have been demonstrated in terms of their ability to provide scientific and policy-relevant emission information, and on those components for which independently calculated emission inventory estimates are available at various scales (for terms of verification). Thus, EEA lists that NO_x, CH_4, and CO are important components, and also if possible PM, SO_2, NH_3, N_2O etc. If CO_2 methodology exists, then this is also an EEA priority. Note that in GlobEmission project NO_x has been given priority, followed by SO_2.

The area under focus is primarily the European Union, and neighboring regions including West Balkans. For inventory verification, aggregated annual emission estimates are requested. For modeling purpose the user requirements are set more ambitious. The full European domain is requested at a 10x10 km resolution or better, preferably with information on temporal behavior. To be policy and scientifically relevant, the data should ultimately aim to be at least as accurate as 'traditional' inventory datasets. For country wide annual emission totals an accuracy <50% for most pollutants, and <10% for pollutants such as SO_2 and CO_2 is requested. For the spatially disaggregated data no real quality target is given, which we interpret as a request for data better than presently available.

Availability in time is not critical for purposes of inventory verification (12 months following measurement could be appropriate). For air quality modeling, more timely availability is required down to near real time availability.

Table.8 User requirements for emission inventory data for the European region and surrounding countries.

Quantity	**User Requirement**
Parameters	NO_x, CH_4, CO, CO_2 are important, and also if possible PM, SO_2, NH_3, N_2O etc.
Region coverage	Primarily Europe, and neighboring regions
Time period coverage and temporal resolution	For inventory verification, aggregated annual emission estimates. For air quality modeling the project might explore feasibility of providing daily emission temporal profiles, or weekly, monthly aggregated emission profiles.
Spatial resolution	For inventory verification, aggregated annual emission estimates available by country for all member states.

	For air quality modeling purposes, gridded emission maps at 10x10 km or better.
Accuracy	at least as accurate as ‘traditional’ inventory datasets: <10% for pollutants such as SO_2 and CO_2. <50% accuracy for most other pollutants
Availability (at which after the actual measurement the data are needed)	For inventory verification, after about a year For modeling, ideally in near real time.
Data format	Not specified

5.4 Aerosol-related emission product requirements

Table.9 User requirements for aerosols (PM).

Quantity	**User Requirement**			
User	EEA	SEC	NIES	SANSA
Product	PM	PM10, PM2.5	PM	PM10 and/or PM2.5
Region coverage	Primarily Europe and neighbouring regions incl. the west Balkans	SE Asia, China	Region: Asia, including Russian Asia. Countries: All countries in Asia, especially China, South Korea, and Japan.	Africa south of the equator; for biomass burning emissions a large sub-Saharan domain needs to be considered
Time period coverage	Not specified	Not specified	Not specified	1997-present
Accuracy	at least as accurate as ‘traditional’inventory data sets: <50%	80%	50-100% for aerosols	-
Spatial resolution	for inventory verification: by country for AQ modeling gridded maps of 10x10 km^2 or better	1x1 km^2 to 10x10 km^2	It is useful for users if several resolutions can be selected for each data. (e.g. from 30 minute by 30 minute to 0.5 degree by 0.5 degree)	1 km or better

Temporal resolution	aggregated annual for inventory verification; for AQ modeling daily, or weeky, monthly aggregates	1 day	Monthly; if possible weekly and daily	-
Availability	NRT (for AQ forecasting); 12 months for inventory verification	NRT (after 2 hours)	Two levels with respect to release timing and accuracy: - first level data are released almost immediately after the actual measurement with relatively low accuracy - second level data are provided half a year after the measurement with high accuracy.	Monthly initially and more frequent as needs arise.
Data format	country totals in text file	geotiff, hdf	text file or HDF	HDF, NetCDF and text formats

In addition to table 9 one can find the user requirements of QEERI for regional aerosols to be discussed in section 5.2.5.

An aerosol is a suspension of solid particles and/or liquid droplet including the medium in which they are suspended. In the atmosphere the medium is the air. Usually the term “aerosol” is used to indicate only the suspended particles / droplets. Here we will follow this and refer to the aerosols as particles, irrespective of whether they are in solid or liquid state.

The GlobEmission users are interested in PM2.5 or PM10, which refer to the particulate mass, i.e. the mass of the particles, with a diameter smaller than 2.5 µm (PM2.5) or 10 µm (PM10) where the mass is determined for dry particles, i.e. in environment where the relative humidity (RH) is smaller enough so all water vapour has evaporated from the particles (usually RH < ~40%).

Aerosol particles are either directly emitted into the atmosphere, examples are sea spray droplets, dust particles, particulate combustion products, or formed from their precursor gases through a chain of chemical and physical reactions. PM consists of a mixture of all particles present in the atmosphere, irrespective of their formation mechanism. PM may therefore consist of particles of very divers chemical and physical properties, including the optical properties which determine how we can see the particle with optical instruments such as those used in Earth Observation (EO) for the retrieval of properties of aerosols and gases. Yet PM2.5 can be obtained from satellite observations as was recently demonstrated by van Donkelaar et al. (2010).

However, because PM is not directly emitted, but results from direct emissions and emission of trace gases, followed by a myriad of transformation processes in the atmosphere affecting their properties and thus also PM, the emission of PM cannot be directly derived. This can only be through a model in which the various processes leading to the observed PM are well described. The PM2.5 or PM10 emissions provided to GlobEmission users are thus indirect variables consisting of the sum of individual components.

There are four committed end-users (EEA, SEC, NIES and SANSA) who have expressed their interest in PM2.5 or PM10 emissions, with different use of the data and different requirements for the delivery of the products as indicated in Table 7.

The use of the data for each user:

EEA:

- exploring application in inventory verification
- exploring application in contributing to improved AQ modeling
- assessing progress and compliance with present and future policy commitments;
- serving as input to air quality modeling activities, including near real time forecasting
- supporting countries in improving the quality of emissions inventory data submitted to the European Commission and EEA under existing and future policy commitments
- allowing improved verification of national emission inventory data
- allowing improved emission inventory data for use in air quality and near real time air quality modeling activities through, e.g., improved spatial resolution of emissions, improved interannual temporal emission trends etc.

SEC:

- the spatial distribution, density of sources and amount of PM emitted; preferably also the pollution source. Provide information for environmental management and emission reduction policy and evaluate the effects of emission reduction. SEC offers help with the validation of GlobEmission products.

NIES

- Emission data and related information from GlobEmission products will be used to improve REAS data set. The updated REAS data and global gridded emission data will be used for regional and global atmospheric chemistry models.
- Observation data will be used to validate and analyze the results of model simulations as well as input data for inverse model.

SANSA

- GlobEmission system will serve as an emission inventory module in the South African Air Quality Information System (SAAQIS)
- As GlobEmission products will be available before a national emissions inventory has been developed, the products will inform and guide the development of the national inventory
- SAAQIS GlobEmission inventory will be available for atmospheric dispersion modeling to SAWS and other local atmospheric modelers
- Unless the national emissions inventory is made available in the enxt two years, GlobEmission inventory will be sued in future SAAQIS air quality forecasting system

5.5 Fire-related emission product requirements

Table.10 User requirements for fire emissions.

Quantity	User Requirement
User	VU Univ. Amsterdam and LATMOS
Product	CO, NO_2, formaldehyde, CH_4
Region coverage	Global
Time period coverage	Multi-year: 1997-present
Accuracy	Highest possible
Spatial resolution	Aggregated to ½ degree
Temporal resolution	monthly
Availability	No need for NRT, delays of months is okay
Data format	HDF or NetCDF

There are two committed end-users (LATMOS and VU Univ. Amsterdam) who have expressed their interest in fire emissions, with requirements for the data that are indicated in Table 10.

The use of the data:

- Global fire emissions estimates based on satellite data (half degree resolution, daily time step, 1997 – present)
- Validation of Global Fire Emissions Database

6 User requirements for the GlobEmission system

Although there are no specific requirements from the users about the system, we envision building a system which can be used by a wide range of users. This means that the data dissemination will be done by a single web-site with distributed data processing. The possibility for data dissemination by ftp will be available on request of the users. The web-site will have a uniform look-and-feel and, if possible, using a single data format.