



**REanalysis of the TROpospheric chemical composition
over the past 40 years
A long-term global modeling study of tropospheric chemistry
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RETRO Working Group report on the status and strategy of emissions data
sets and modelling

Work Package 1, Deliverable D1-1

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Contents

1.	Introduction	4
2.	Classification of emissions	4
3.	Work programme for natural emissions	7
3a.	Ocean emissions	
3b.	Volcanic emissions	
3c.	Biogenic emissions	
3d.	Dust and sea salt emissions	
3e.	Lightning NO _x production	
3f.	Natural methane emissions	
4.	Work programme for biomass burning emissions	12
5.	Work programme for all other anthropogenic emissions	15

References

Annex: Preliminary RETRO dataset format and conventions

1. Introduction

Changes in the atmospheric budget of trace gases and aerosols are driven to a large extent by changes in the emissions of these compounds or their precursor species. Human activities (in particular combustion processes) have begun to exert a noticeable influence on the atmospheric chemical composition and as a consequence also on the physical climate system (IPCC, 2001). The RETRO project aims at an understanding of the factors controlling the budgets of ozone and ozone precursor species, and of tropospheric aerosols during the past 40 years, and at identifying the anthropogenic influence on the abundance of these compounds. Therefore, in addition to assessing the meteorological variability during this time period, a key objective of the project is the quantification of emission changes and the interannual, and seasonal variability of emissions.

While the scientific understanding of emissions is a very ambitious goal on its own, the RETRO project also wants to generate information which is useful for policy makers, i.e. past emission control regulations and future options will be assessed in targeted sensitivity studies. This is reflected in the work programme structure of the project, which foresees close interactions between the 5 work packages of the RETRO project (see RETRO project description, available at <http://retro.enes.org/>). The emission data sets produced in work package 1 form an important piece of information for the modelling studies in work packages 3 and 4. On the other hand, the past and future policy options analysed in work package 5 define to some extent the set-up of sensitivity experiments in work package 3, and the level of detail required in the source sector definitions of the emission data sets. The strategy described in this document has been developed in discussions between all project partners during the first RETRO project meeting in Dourdan, France (22-23 April 2003) and with the help of external advisors to the project.

The document is structured in terms of specific work programmes for the various types of emissions, each of which begins with a short description of the state-of-the-art. These specific sections are preceded by a general definition of terms and source sector aggregations. The appendix describes the RETRO data format and standard units to be used.

2. Classification of emissions

To avoid duplication of previous work and to produce information that is useful for scientific and policy purposes, the RETRO consortium decided to focus on the categorisation schemes adopted by the United Nations Framework Convention on Climate Change (UNFCCC) / International Panel on Climate Change (IPCC) common reporting format (CRF), and the Nomenclature for Reporting (NFR) applicable for the Convention on Long-Range Transboundary Air Pollution (CLRTAP). However, for modelling purposes to be practical, this detailed categorisation of source sectors is used

in an aggregated manner. We identified three major factors, that have caused significant changes in emissions over the past 4 decades:

- Changes in world-wide energy consumption patterns among industrialised regions, including shifts in the type and quantities of fuels used,
- the introduction of catalytic converters for road traffic and the increase in road traffic in developing countries, and
- changes in land-use in concert with climate variability influencing the controlled and uncontrolled burning of vegetation

The source sector aggregation described below accommodates the investigation of these issues by ensuring that:

- the different fuel types (oil, gas, coal, biofuel) are traceable in the emission data sets produced for the project, so that sensitivity studies can be performed testing different fuel use scenarios,
- road traffic emissions are listed separately in order to allow the development of scenarios with different fractions of the automobile fleet equipped with catalytic converters or different types of fuel used,
- vegetation fire emissions are segregated at the top level by broad ecosystem class, namely a distinction is made between fires in different savanna and forest regions. The final ecosystem and forest-use classifications used in this project will be distributed along with the emission data sets.

For technical reasons, emissions occurring above about 50 m altitude (large point sources and aircraft) are grouped into separate categories. Finally, all emissions, which are primarily of natural origin are given special attention in order to allow for the distinction between controllable and uncontrollable emissions.

Table 1 specifies one categorisation scheme, which can be used for the RETRO simulations. This scheme is similar to the classification scheme currently used in the EDGAR project [Olivier et al., 2001]. Since most models are using emissions data based on the EDGAR scheme, this provides a good starting point.

Table 1. Example categorisation scheme for RETRO simulations.

<i>Class</i>	<i>Relevant IPCC Sectors¹</i>	<i>Comments</i>
fossil fuel		
f-oil	1A1, 1A2, 1A4, 1A5, 1B2a, c (fugitive emissions)	oil combustion processes other than transport and large point sources, including fugitive emissions. Oil includes crude oil, gasoline, kerosene, gas/diesel oil
f-coal	1A1, 1A2, 1A4, 1A5, 1B1 (fugitive emissions)	coal combustion processes other than transport and large point sources, including

¹ IPCC sectors indicated here covering the identified classes. A more precise classification will be carried out case-by-case.

		fugitive emissions
f-gas	1A1, 1A2, 1A4, 1A5, 1B2b, c (fugitive emissions)	(natural) gas combustion other than transport, including fugitive emissions
f-other	1A1, 1A2, 1A4, 1A5, 1B2b (fugitive emissions)	combustion of other fossil fuels (liquefied petroleum gas, ethane, naphtha, ...)
f-road transport	1A3b	fossil fuel combustion (and NMVOC evaporation) associated with road transport
f-rail	1A3c	
f-aviation	1A3a, 1A5 (military aviation)	fossil fuel combustion from international and national aviation
f-marine	1A3d, 1A4c (fishing)	fossil fuel combustion from marine vessels
f-point	parts of 1A1, 1A2	fossil fuel combustion (oil, coal, other) with emissions from smokestacks. In general, these are power plants with energy generation > 300 MW and other sources as listed in NFR
biofuel		
b	1A, 6D	waste, paper, wood etc.
	1A	ethanol,
	1A	fuel wood combustion- both non-CO ₂ and CO ₂ (<i>Under IPCC rules, only non-CO₂ emissions from fuel woods are accounted for</i>) ² .
industrial processes (non-combustion) and solvent use		
I	2A-D, 3A-D	
agriculture (including prescribed burning of savannas and field burning of agricultural residues)		
l	4 (except 4D)	Enteric fermentation, manure management, rice cultivation,
l-croplands	4F	field burning of residues
l-soils	4D	soil emissions (natural and fertilizer induced)
l-savanna	4E	savanna burning-prescribed fires and wildfires;- CO ₂ and non-CO ₂ emissions. <i>Under IPCC rules, only non-CO₂ emissions from prescribed burning of savannas are accounted. We aim to include all species emissions from all fires in savannas (prescribed and unprescribed.). The distinction between prescribed and unprescribed fires will be given low priority.</i>

² Fuel wood emissions will be estimated with two independent methods. One will be based on reported numbers, the second one uses estimates of the per-capita consumption and constrains this with the available fuel estimated by the LPJ biosphere model.

Land-use Change and Forestry	5A	harvesting and plantation of forest biomass stocks for commercial timber and fuel wood consumption. Also includes burning of post-harvest slash.
	5B	Forest and grassland conversion (includes vegetation clearing, regrowth of cleared vegetation, and burning of cleared vegetation)
	5E	wildland and prescribed burning of forests (tropical, temperate, boreal) and other major vegetation types.
waste handling		
w	6	solid waste disposal, waste water handling, waste incineration (and other)
	6	municipal solid waste, industrial waste
natural sources		
n-ocean	7	ocean release of volatile organic compounds including DMS, C ₂ H ₄ , C ₃ H ₆ , Acetone, etc.
n-volcanoes	7	slowly degassing volcanoes and individual major eruptions
n-biogenic	7, 5A	production and release of isoprene, terpenes, and other NMVOC from living vegetation ³ (parameterised source)
n-dust		volatilisation of mineral dust. Also includes release of sea salt (parameterised source)
n-lightning	7	NO _x production from lightning (parameterised source) ⁴

During the the further development of emission data, consistency checks will be carried out depending on the applied sector definitions.

3. Work programme for natural emissions

3a. Ocean emissions

Measurements from various ship and aircraft field campaigns have shown that the oceans act as a significant source of several trace gases. Exchange of trace gases between the oceans and the atmosphere affects the atmospheric content and cycling of a range of chemical species, which are related to climate change, ozone layer depletion, acid deposition, eutrophication, atmospheric particle formation, photo oxidants, trace metals, and persistent organic compounds (e.g. Pacyna et al., 1998). In many cases, the specific source mechanisms are not well understood (c.f. Frost and Upstill-Goddard, 1999), but there is general agreement that the dominant fraction of marine emissions originates from

³ The degradation of dead plant material (litter) may also constitute a significant source of emissions, but is likely less relevant than the emissions from living plants.

⁴ Global annual total assumed 5TgN for 1997

the marine biosphere. While oceanic emissions are generally small compared to present-day terrestrial sources, they may have a sizeable impact on the global budgets of a number of ozone and aerosol precursors, such as DMS, C₂H₄, C₃H₆, Acetone, and organic halogens. In addition, local and regional impacts can be significant, in particular when considering coastal regions, which often emit species in higher quantities than the open oceans (Pacyna and Hov, 2003). Current inventories of oceanic emissions are largely focusing on global budgets and are based on individual scientific studies analysing the small body of available measurements. In a few cases, ocean biogeochemistry models have been used in the attempt to formulate a consistent approach for modelling.

Given the relatively minor importance of most oceanic emissions on the global scale, their small interannual variability, and the scarcity of new data sets to improve the knowledge about these processes, the RETRO consortium has decided to limit its efforts to comparing the existing inventories and to decide on a common standard for the long-term simulations in work package 4. This standard data set will be developed during the 2nd RETRO project meeting. Other activities carried out in the framework of RETRO may include some simulations of the oceanic emissions of individual trace compounds using a coupled ocean atmosphere model, or a model based assessment of the potential implications of oceanic halocarbons on the concentrations of tropospheric ozone, which can be used for better quantification of the uncertainties of the RETRO simulations (where halocarbons are generally not considered).

3b. Volcanic emissions

Volcanic emissions are of importance predominantly for the global sulfur cycle. However, a few major eruptions, which have transported dust and sulfur into the lower stratosphere, also exert an influence on stratospheric temperatures and ozone concentrations and on the UV radiation penetrating in the troposphere.

A 100-year dataset of annual volcanic gas input has been compiled by M. Halmer (Halmer et al., 2001). This data set comprises emission estimates for SO₂ and derived estimates for other compounds such as HCl, H₂S, OCS, CS₂, HF, and HBr. We will try to obtain this data set for use in the aerosol simulations. Alternatively, a climatological data set of volcanic sulfur emissions is available at the MPI-Met, which will be augmented by literature information on major volcanic eruptions.

3c. Biogenic emissions

The current state-of-the-art for modelling emissions of isoprene, terpenes, and other NMVOC (e.g. methanol, acetone, acetaldehyde, ethane, ethanol) from living vegetation is described by Guenther et al. (1995). The release of these compounds is very much species dependend and controlled by the ambient temperature and light intensity. An interactive algorithm has been developed and implemented in several chemistry transport models

participating in RETRO. The other models are using monthly mean values for these emission fluxes, which have been computed using the same algorithm.

The physical parameters needed from the models are: near surface air temperature, solar radiation (including information on cloud cover), foliar density or leaf area index, vegetation type (in the Guenther et al. (1995) parameterisation, the Olson (1992) scheme with 57 classes is used). Historical changes in vegetation type will be assessed in close coordination with the work programme on biomass burning emissions, where these changes are also addressed. Recent updates of input data sets and algorithms will be reviewed and implemented where necessary.

Emissions of nitrogen oxides and other species from soils are of microbial origin, and account for significant fractions of the total nitrogen oxide emissions in particular in less industrialised regions. Currently, no coherent description of soil emissions is available on the global scale, which would allow for a reliable assessment of changes in these emissions over the past 40 years. The emission rate depends on meteorological parameters and on the environmental conditions of the soils. It is estimated that currently about 50% of all soil NO_x emissions are due to fertilizer use. If sufficient data on historical and geographical trends of fertilizer usage are available, this factor will be included. Otherwise, we will limit our efforts to sensitivity studies assessing the potential impact of such changes.

3d. Dust and sea salt emissions

Dust emissions

Although considerable progress has been made in the last decades our understanding of the physics of dust emissions, attempts at establishing a global source of dust have been hampered by the lack of information on local soil properties such as soil grain size distribution and local roughness height. Topographical lows have been shown to act as active dust source although their relative importance compared to other surfaces has not clearly been established. A global formulation of dust sources based upon a source scheme where threshold velocities and emission factors are computed over arid and semi-arid regions is proposed e.g. by Ginoux et al. [2001] and Balkanski et al [2003]. In the latter work threshold velocities were derived by associating a value which was calculated with detailed data in North Africa to each dominant FAO soil type and extrapolated globally. The source strengths of 12 individual arid areas were deduced on the basis of the retrieval of the aerosol optical depth from TOMS data. Satellite data have opened the way for validation of dust emission schemes and of atmospheric dust distribution. Where most needed, i.e., in the vicinity of source regions, a reliable quantitative estimate of the aerosol burden remain evasive. Nonetheless, the conjunction of multi-spectral captors and active sensors have created new directions of research for a quantification of the dust emissions.

Sea salt emissions

Some recent estimates to illustrate the range of sea salt fluxes to be expected with the source functions described in Schulz et al. [2003] are presented in table 2. The compilation shows that only a few source functions have been used to derive a global sea salt emission flux. But also those that seem to use the same source function are hardly comparable. The major reason is that the upper maximum of the size distribution is a critical parameter. The fact that a substantial amount of the emitted sea salt mass is produced as coarse aerosol particles, renders the comparison difficult because of the different size ranges used in the models. Schulz et al [2003] have split for illustration the total emissions of the work of (Guelle et al., 2001) into two contributions. It becomes clear that the coarse aerosol mode with a mass mean radius of approximately 5.5 μm dominates over the “fine” aerosol mode, described mainly by M86.

Table 2. Global sea salt emission flux estimates.

Reference	Source function used	Global sea salt flux (Tg yr^{-1})	Size range for particle radius (μm)
Erickson and Duce, 1988	E86	10000-30000	Lognormal distribution, mnr vary 3-7,5 μm (E88)
Tegen et al., 1997	E86	5900	6 bins between 2-16 μm using E88
Takemura et al., 2000	E86	3530	10 bins between 0.1-10 μm using E88
Gong et al., 1998	M86	3300	8 bins between 0.03 – 8 μm
Erickson III et al., 1999	M86	2779	8 bins between 0.03 – 8 μm
Grini et al., 2002	M86+S93	6500	16 bins between 0.03-25 μm
Guelle et al., 2001	M86+SH98	2680	mode 1 (mnr ~ 1 μm)
		17100	mode 2 (mnr ~ 5.5 μm)

E86: Erickson and Duce, 1988. / M86: Monahan et al, 1996. / S93: Smith et al, 1993. / SH98: Smith and Harrison, 1998.

The studies which have used the concentration-wind speed relationship of E86 bear specific uncertainties. While surface concentrations might be well represented in these models, the total flux is dependent on the resolution and on the vertical dispersion and dry deposition fluxes. Any large flux removing sea salt tracer from the surface layer within a time step implies large emission fluxes as compensation to maintain concentrations. The parameterisation itself had not taken into account that a fraction of the observed sea salt concentration is due to advected sea salt from long range transport. Thus, the small particle flux is rather overestimated by this parameterisation. It is interesting to note that the uncertainty of the removal flux in the model is dependent on the accuracy with which the wind data are available. Problems of surface wind speed data are translated into the sea salt size distribution emitted.

Finally, the wind speed data used in the global estimates pose a problem, because different climate models and wind reanalysis products are expected to have rather different surface wind speed distributions over oceanic areas. It

is difficult to know which part of the difference in source emissions documented in table 2 is due to this effect.

RETRO strategy for dust and sea salt emissions

Since a major part of the interannual variability of the source of sea salt and dust comes from changing wind fields driven by the evolution of climate, the source described by Balkanski et al. [2003] and Schulz et al. [2003] has been implemented in the LMDzT-INCA and ECHAM global circulation model in an interactive mode. The sources formulated as described will be used for a reference simulation of the ERA40 period. Currently intensive validation efforts are underway, which might necessitate to correct the source parameterisations in the course of the RETRO project.

3e. Lightning NO_x production

The production of NO_x from lightning flashes is still a major uncertainty in the global NO_x budget. Current estimates range from 2 to 20 TgN/year (Lawrence et al., 1995; Price et al., 1997), and model studies suggest a sensitivity to climate variability of 5-14%/K (Price and Rind, 1994; Stenke and Grewe, 2002). Most models participating in RETRO use the parameterisation by Price and Rind (1993) to estimate the column lightning NO_x production, which is then distributed vertically according to standard profiles developed by Pickering et al. (1998). This parameterisation yields a reasonable distribution of lightning flashes, but the absolute magnitude of NO_x produced depends on the physical parameterisations of the model and its grid resolution. Therefore, in most modelling studies, a tuning parameter is introduced, which scales the computed column NO_x production to yield a global annual total between 3 and 7 TgN/yr. For the purposes of the RETRO project, we have adopted a target value of 5 TgN/yr for the year 1997, which will be used in the initial RETRO test simulations. The so-derived tuning parameter will then be held constant throughout the long-term simulations (WP 4) in order to allow for assessing the interannual variability of the lightning NO_x production. The global source of NO_x from lightning and its (2D) geographical distribution will be stored as output from the models and evaluated after the long-term simulations will be completed.

3f. Natural methane emissions

Because of the long lifetime of methane in the atmosphere and the difficulties to achieve a balanced global budget of methane sources and sinks, which must also reflect the observed trends in the methane concentration, we will not attempt to improve current estimates of natural methane emissions. Instead, interpolated measurements of near-surface concentrations will be used in the models as boundary condition. For the 1990s, such a data set has been already compiled in the European POET project (No. EVK2-1999-00011). This data set will be adopted and extended to earlier years.

4. Work programme for biomass burning emissions

Interannual variability in emissions from biomass burning can have important implications for the global budgets of various trace compounds [e.g. Schultz, 2002; Duncan et al., 2003]. However, trend estimates are notoriously difficult, because of the complex interactions between terrestrial vegetation, the climate system, and socio-economic factors.

RETRO sets out with a very ambitious program and attempts to answer several questions in respect of biomass burning emissions:

- How did biomass burning contribute to global emissions of aerosol and trace gases during 1960-2000?
- What were the seasonal and long-term dynamics of biomass burning and its interaction with vegetation and climate?
- How did socio-economic factors such as land-use change contribute to patterns in biomass burning?

While the scope of the work performed here will be global, not all possible factors and feedbacks will be assessed. Because of the complexity of this topic, RETRO will have to restrict itself to investigate some key changes, for which acceptable data are available. Examples for specific subjects, which will be addressed in the framework of this project, are cropland changes and tropical deforestation trends.

Broadly speaking, emission sources from biomass burning may be organised into one of two categories: in-situ burning of vegetation (vegetation-related fires), and combustion of waste biomass and fuel wood. The fire behaviour (and thus the emissions) is dependent on the ecosystem and on the prevailing meteorological conditions. For the purpose of the project, we will distinguish nine significantly different ecosystem classes:

Table 3. Different fire behaviour related to ecosystem classes.

Vegetation-related fires		Waste biomass and fuel wood combustion
Ecosystem class	Type of fire	
1. Savanna-tropical	surface	1. Burning of agricultural crop residue
2. Savanna-temperate	surface	2. Burning of slash in managed forests
3. Forest-tropical	surface	3. Burning of cleared vegetation as part of forest to agricultural or grassland conversion
4. Forest-temperate	surface + crown	4. Fuel wood combustion
5. Forest-boreal	surface + crown	
6. Forest-shrublands		
7. Heathlands and general shrublands	surface + crown	
8. Arid-zone vegetation (< 500 mm MAP)	surface	
9. Peat/wetlands	sub-surface	

Fires within each of the nine ecosystem types may be further broken down into different land use types. For example, temperate forests could be plantations, used for timber production, or conservation reserves. Further work will investigate appropriate land use classifications based on available data.

Vegetation-related fires may also be classified as i) human-caused; and ii) lightning-caused (i.e. natural). For example, recent estimates for Russia indicate that 10% of the observed fires are of natural origin, but due to their remoteness, these fires can contribute up to 37% to the total burnt area (Korovin and Romanovich, 1996). Data on the use of fire in different regions of the world are sparse, so that finer classifications of human-caused fires into, for example, prescribed for management purposes, accidental and arson will not be accounted by RETRO.

Emissions from combustion of waste wood and fuel wood will be investigated using an inventory-based approach using available data in the scientific literature and in reports from individual or groups of countries (e.g. OECD). Emissions trends from agricultural waste burning will be assessed using two alternative methods: (1) the EDGAR methodology (as implemented in the HYDE data set), which relies on changes in activities, (2) an attempt to correlate satellite data of burnt areas, crop statistics, and a relationship between crop yields and burnt material. However, in general, we are limited in the types of analyses we can apply to data on combustion of waste biomass or fuel wood. Time-series records do not span the whole 40 year period, are biased to industrialised countries, and the socio-economic drivers affecting these types of emissions (principally, economic markets and human behaviour) are complex, and quite beyond the scope of the current study.

A considerable research effort will be spent estimating vegetation-related fire emissions and their interannual variability and possible longer-term trends. Similar work at the global scale has not been previously attempted. This work will be based on a careful evaluation of historic and recent satellite data sets to estimate burnt areas on the one hand, and on the continued development of a mechanistic regional fire model (reg-FIRM), which has been coupled to the Lund-Potsdam-Jena (LPJ) dynamic global vegetation model (DGVM) (Sitch et al., 2003).

In the inventory-type approach, the emissions from vegetation fires (open fires in savanna and forest regions) will be computed using the newly developed Global Wildfire Emission Model (GWEM) (Hoelzemann et al., 2003), which uses the following data sets as input:

- monthly maps of burnt areas, e.g. from the 8x8 km² AVHRR Pathfinder data set (1982-2001). From the comparison of data sets with different resolution, a scale factor map will be derived to estimate the fraction of area burnt for each burnt pixel,

- annual fuel load maps from the LPJ-DGVM, segregated into the compartments for aboveground litter, leafs, wood (including coarse roots), and fine roots,
- ecosystem classification according to IGBP including historic trends where feasible,
- a climatological map of combustion completeness for individual ecosystem types
- emission factors from Andreae and Merlet (2001) with updates (M. Andreae, personal communication 2003)

By allowing for the use of different data sets for burnt areas, vegetation classes, and available biomass, the GWEM model allows for an assessment of the most significant uncertainties in global scale fire emission estimates. For example, the AVHRR Pathfinder burnt area data for 1996-2001 will be evaluated with finer resolution data sets from the GBA-2000, GLOBSCAR, and GLOBCARBON projects and with the forthcoming MODIS burnt area data set.

The inventory-based methods for analysing fire activity using satellites need to be complemented by extensive simulation modelling of fire at a global scale because the satellite record covers only about one-half of the study period, and because satellite based fire detection can be affected e.g. by forest canopy cover. In general, there is a dearth of burnt area observations before the 1980s for most parts of the globe. Simulation modelling therefore presents the only way to estimate vegetation fire emissions and their interannual variability during the first half of the past 4 decades. The foreseen simulation approach also permits scenario-based investigations of the factors affecting fire activity and emissions.

The mechanistic fire model Reg-FIRM has been developed in a first version and tested for the simulation of number of fires and burnt areas in the Iberian peninsula (Venevsky et al 2002). Further development until March 2004 will continue with case studies using finer resolution data from the Iberian peninsula, Australian tropical savannas, semi-arid zone and temperate forests, and then Alaskan boreal forests, Western USA and Brazil. Our focus will be on improving the following aspects of reg-FIRM: simulation of fire frequency as a function of population density and land use; probability of successful ignition in relation to fuel moisture characteristics; modelling the spread of fires both among surface fuels and tree crowns- the latter under conditions of high fire intensity; simulating plant mortality in relation to fire intensity; and modelling combustion of dead and live fuels.

Plant Functional Types (PFTs) within the LPJ-DGVM framework and the Rothermel series of fire spread equations (see, for example, Pyne et al 1996) will be utilised for this work. Several components of LPJ will need to be revised concurrently as part of this work. For example, algorithms for above ground litter production will be changed to account for additional dead fuel classes. Allocation rules for compartmentalising woody biomass in LPJ will be changed to enable additional live fuel pools to be specified. Above ground

litter moisture will be linked to inputs from a soil hydrology module currently being developed by PIK Potsdam. The model will then be extended to global coverage based on inputs from several sources, namely, revised litter production, decay and soil moisture modules in the current version of LPJ-DGVM, and global weather fields (CRU and ECMWF). Satellite-based data acquired as part of GWEM development will be used to test reg-FIRM predictions within the last 20 years outside of case study regions. Emissions factors used in GWEM will be the same as those used in reg-FIRM.

A hitherto only very poorly characterised source of atmospheric trace gases are emissions from peat fires. Peat fires occur often underground and are therefore generally not detectable by satellite observations. Information on the annual amount of peat burnt globally are practically not available. Estimates exist only for specific episodes such as the Indonesian fires in 1997/98 (e.g. Page et al., 2002). Peat is also not currently a PFT within LPJ. Accounting for emissions from sub-surface fires, which are characteristic of peat, will be a research challenge, and it is yet unclear how much progress we will be able to achieve on this aspect within RETRO.

5. Work programme for all other anthropogenic emissions

The RETRO activities with respect to fossil and biofuel emissions will be based on the available data sets from EDGAR (version 3.2, <http://arch.rivm.nl/env/int/coredata/edgar/>) with extensions to cover the period 1990-2000 from the European POET project (NO EVK2-1999-00011, data available at <http://nadir.nilu.no/poet/>), and on the historical emissions data set EDGAR-HYDE 1.3/1.4 by Aardenne et al. (2001) (also available at <http://arch.rivm.nl/env/int/coredata/edgar/>), and on the European TROTREP project (EVK2-CT-1999-00043).

RETRO concentrates on simulations of tropospheric ozone and ozone precursors as well as aerosols. This implies that most attention will be given to emission data sets for the following species: CO, NO_x, NMVOC, and SO₂. While reasonable confidence has been achieved for some of these emissions, considerable uncertainties remain in the following areas:

- emission factor changes over the time period covered by the RETRO simulations
- speciation of non-methane volatile organic compound emissions (NMVOC)
- seasonality and diurnal emission patterns

The work within RETRO will concentrate on the latter two aspects in order to use the available resources with maximum efficiency. The approach will be similar to that of the TNO-LOTOS model and its database where factor maps are used as a postprocessor to clustered emission data.

Another data set to include in the RETRO-work will be the reporting of particulate matter for the Co-ordinated European Programme on Particulate

Matter Emission Inventories, Projections and Guidance (CEPMEIP) as a part of the national reporting. This data base, which has been developed according to the CRF sector specifications, will be used mainly to refine the information on particulate matter (soot) as a precursor. As a reference, annual data from international reporting obligations (UNFCCC) will be used for scaling/comparison purposes.

Activity 1:

Developing an underlying structure for production of gridded emission data, based on various sector definitions/fuel sources, regions.

Activity 2:

retrieve EDGAR-HYDE data set and update CO, NO_x, and NMVOC emissions to incorporate the refined source sector definitions and revised activity data of EDGAR 3.2. In order to improve the global consistency, conversion matrices for activity source categories according to IPCC / EMEP will have to be prepared.

Activity 3:

improve gridding of HYDE data set by taking into account changes in the urbanisation. Interpolate between existing data sets with decadal time resolution to achieve annual resolution (e.g. based on CO₂ emission trends in order to account for drastic changes such as breakdown of Soviet Union in 1992, Kuwaiti oil fires in 1991)

Activity 4:

improve the speciation of NMVOC emissions by factor maps. In particular, emissions shall be detailed for C₂H₆, C₂H₄, C₃H₈, C₃H₆, acetone, formaldehyde, benzene. For other compounds, the emissions shall be grouped in alkanes, alkenes, aromatics, and oxygenated compounds.

Activity 5:

develop gridded factor maps to estimate the diurnal and weekday patterns of emissions.

Table 4. Trends in aircraft emissions (Lee et al, 2003)

year	seat km offered by airlines [10 ⁹ km]
1960	250
1965	500
1970	800
1975	1000
1980	1500
1985	1700
1990	2300
1995	3500

Trends in aircraft emissions will be taken into account by using a simple scaling approach, which may include estimates for historic changes in the engine efficiency if feasible. The scaling will be based on results from the AEROCHEM project (*Meteorologische Zeitschrift*, 11 (3), 139ff, 2002). The following table (from Figure 1 of Lee et al., 2003) provides a first estimate of the magnitude of change to be expected from this source. The WMO 1998 Ozone assessment lists the following estimates of global NO_x emissions: 1976 = 0.3 TgN, 1984 = 0.39 TgN, 1992 = 0.51 TgN, 2015 = 1.26 TgN.

Trends in ship emissions will be treated with a similar scaling approach. Data on historic ship traffic could in principle be obtained from Lloyd's register, however the cost and effort to make good use of these data exceeds the resources of the RETRO project by far. We expect that a simple non-linear increase in time will be sufficiently accurate for the purpose of this project.

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Annex: Preliminary RETRO data set format and conventions

In order to facilitate the exchange of data sets between RETRO partners and with the general (scientific) community, the project has adopted a common data format. The availability of processing tools, the previous stability of the format, and its self-descriptive properties have led to the adoption of the netcdf binary format (<http://www.unidata.ucar.edu/>) as the primary standard. All emission data sets will be produced in this format in a resolution of 0.5°x0.5°.

The conventions for netcdf attributes generally follow the CF standard, which is currently developed within the European network of Earth System Modeling (ENES), but will be somewhat less stringent in order to facilitate the development of processing tools and to encourage widespread use of the netcdf format. The following rules lay out the naming conventions and attributes, which should be used in all RETRO data sets. Additional attributes are recommended in order to enhance the descriptiveness and consistency of the data sets. Emission data will be stored in separate files per species and may contain several variables describing emissions of individual source sectors or fuel types. These definitions will be refined throughout the first year of the project, taking into account the new developments within PRISM and other input, e.g. from the ASSET programme.

Preliminary RETRO netcdf rules:

1. All *dimensions* of the netcdf file must have an associated *dimension variable* (i.e. a 1-dimensional variable containing the values for that dimension) with the same name. Example: the dimension lon shall be accompanied by a variable lon(lon) containing the longitude (grid) coordinates in “degrees_east”.
2. All variables in the netcdf file must have a *units* attribute containing the physical unit of the variable. Standard units are: “degrees_east” for lon(gitude), “degrees_north” for lat(itude), “km” or “hPa” or “Pa” for altitude or pressure levels, respectively, “days since 1900-01-01 00:00:00” for time, “mole/m2/s” for emission fluxes.
3. Variable names shall be all lower case and contain no special characters other than “_”. A variable name must begin with a letter. All variables should have a *long_name* attribute describing the variable in sufficient detail.
4. The global attributes shall at a minimum consist of the following:
 - *title*: a string describing the contents of the data set
 - *author*: a string with the name of the person who created the data set
 - *institution*: a string with the name of the institution where the data set was created
 - *history*: a string containing the creation date of the data set
 - *grid*: a string defining the grid type of the data set (e.g. “0.5x0.5”, “1x1”, etc.)
5. The use of the following additional global attributes is encouraged:
 - *project*: a string with “RETRO, EVK2-CT-2002-00170, EU 5th framework programme”