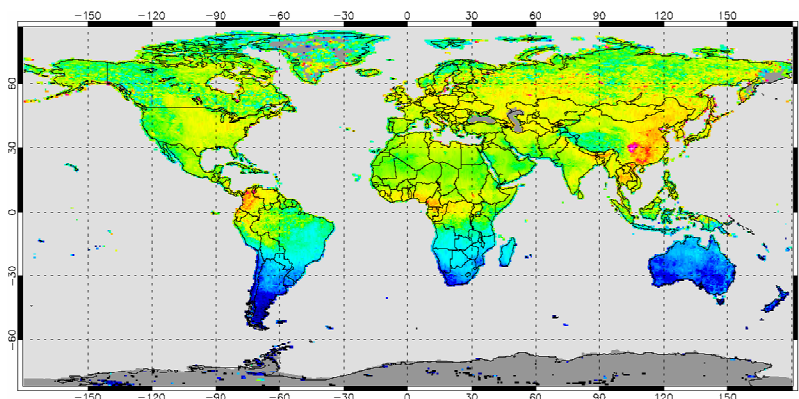


# HYMN

HYdrogen, Methane and Nitrous oxide:  
Trend variability, budgets and interactions with the biosphere



Specific Targeted Research Project (STREP)

## Part B

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**Proposal summary page**

# HYMN

## HYdrogen, Methane and Nitrous oxide: Trend variability, budgets and interactions with the biosphere

**6<sup>th</sup> Framework Programme Area I, Sub-Priority 1.1.6.3 Global Change and Ecosystems.**

**Topics addressed:**

- Atmospheric pollutants and their regional impacts
- Atmospheric composition change of methane, nitrous oxide and molecular hydrogen

**Proposal abstract**

The global atmospheric cycles of methane, nitrous oxide and hydrogen, are coupled and include various interactions with the biosphere. Apart from classical surface observations of these gases that are part of the GAW and CMDL networks, new detailed information on the regional scale about methane and nitrous oxide can and will be obtained from recently become available satellite observations by SCIAMACHY and IASI and from remote sensing observations by FTIR. In Hymn these observational data sets will be homogenised and evaluated against each other in order to derive consistent long-term time series. The error statistics of the observations will be carefully determined. By subsequently applying advanced emission inversion and data assimilation techniques to the validated observations in atmospheric chemistry models coupled to a new biosphere model, the sources and sinks of these gases will be quantified on regional scales (up to 1x1 degree). The coupling between the cycles of these gases and OH will be investigated focussing on presently not well understood relations between variations in their trends.

The new models will furthermore be applied to investigate the effects of a future transfer to a *hydrogen economy* and of the associated reduction in fossil fuel burning emissions (NO<sub>x</sub>, CO, VOCs) on the coupled cycles of H<sub>2</sub>, CH<sub>4</sub>, OH, and O<sub>3</sub> taking into account interactions with the biosphere.

## B.1 Scientific and technological objectives of the project and state of the art

### B1.1 Scientific and technological objectives

Ever-extending human activities on a global scale are the cause of the rising concentrations of several long-lived gases in the atmosphere, including the greenhouse gases methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). The possible transition to a so-called 'hydrogen economy' in the coming decades is likely to cause a significant increase in future atmospheric molecular hydrogen (H<sub>2</sub>) levels. The HYMN project will focus on the impact and mechanisms of three important gases: H<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, in direct response to the present call within the EU 6<sup>th</sup> Framework Programme, sub-priority "Global Change and Ecosystems", Area I on the "Impact and Mechanisms of Greenhouse Gas Emissions and Atmospheric Pollutants on Climate, Ozone Depletion, and Carbon Sinks". In this proposal we refer to these three gases as the 'HYMN gases'.

Recently, the Kyoto Protocol has been ratified. Concrete ceilings have been set for the 2012 greenhouse gas emissions of the participating countries, including the EU. The gases targeted by the Kyoto Protocol include CO<sub>2</sub>, the HYMN gases CH<sub>4</sub>, N<sub>2</sub>O, and the fully human-made HFCs, PFCs and SF<sub>6</sub>. For the EU this implies a targeted reduction of 12 % in 2012 relative to 1990 levels. A significant contribution to this target is expected to be made by reductions in CH<sub>4</sub> (about 32 %) and N<sub>2</sub>O (about 12%) emissions. Atmospheric molecular hydrogen (H<sub>2</sub>) is receiving increased attention because of the perturbations of its budget in a prospective *hydrogen economy*. In the future, hydrogen emissions could double compared to the present, and consequent impacts on climate forcing, air quality and ozone depletion have been hypothesized.

For the post-Kyoto era new regulations will be required. The need for a quantitative reduction in anthropogenic greenhouse gas emissions is internationally recognised – less agreement exists on methods to achieve such reductions. For the climate gases with both natural and anthropogenic components (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) a thorough assessment of their budgets is needed as a starting point for future regulations. Furthermore, different abatement strategies will have different potential, efficiency and impact. Finding the optimal strategy for reductions in greenhouse gas emissions is complex, and different trade offs can be made. For example, the efficacy of methane emission regulation to mitigate climate forcing has been reported to be relatively high, also because of its impact on tropospheric ozone (Hansen et al., 2005).

Emission regulation is important for different environmental issues such as anthropogenic climate change, air quality degradation and ozone depletion. Methane emissions as well as pollutant emissions of NO<sub>x</sub>, CO and VOCs contribute to tropospheric O<sub>3</sub> which is a toxic gas, an important oxidant and contributor to photochemical smog formation as well as a potent greenhouse gas. HYMN will provide necessary input information for assessments to provide guidance to policy making with respect to future emission regulations related to climate change, air quality degradation and ozone depletion.

In order to find optimal abatement strategies for the HYMN gases, in-depth knowledge is required of the budgets and biogeochemical cycles of the gases, including their geographical distribution, the magnitude and variability of their sources, sinks and dispersion, and the feedbacks that connect land-biosphere processes with the life cycles of these gases through atmospheric chemistry and long-range transport. HYMN will integrate knowledge on all these aspects.

The overall project-objectives of HYMN are:

- To improve the process modelling of the land-biosphere-atmosphere exchange of the HYMN gases and to provide global and regional estimates of their natural sources and sinks

- To contribute to global monitoring by provision of multi-year global satellite data sets of the CH<sub>4</sub> and CO distribution and long-term time series for CH<sub>4</sub> and N<sub>2</sub>O at a range of observing stations
- To provide advice on the further optimisation of monitoring networks for the HYMN gases.
- To identify atmospheric loss of CH<sub>4</sub> and H<sub>2</sub> and the impact of changing anthropogenic and natural (climate-induced) emissions on regional OH trends and on current and future global CH<sub>4</sub> and H<sub>2</sub> levels
- To quantify how the possible future change to a *hydrogen economy* will affect the H<sub>2</sub> distribution and the distribution of CH<sub>4</sub> and O<sub>3</sub> through changes in emissions of H<sub>2</sub> and pollutants (NO<sub>x</sub>, CO, VOCs).
- To evaluate the simulations with a novel coupled atmospheric chemistry-biosphere model for CH<sub>4</sub>, N<sub>2</sub>O and H<sub>2</sub> by comparison with ground based and satellite observations on a global and regional scale
- To make new estimates of the sources and sinks of CH<sub>4</sub> and H<sub>2</sub> including their temporal and spatial variability

HYMN will make use of several basic methods to improve knowledge on global and regional natural sources and sinks of atmospheric gases: up-scaling of local (flux) measurements, process-based land-biosphere modelling and top-down inverse modelling using atmospheric concentration variabilities. HYMN will use these three methods in their optimal combination and confront the obtained results with satellite and surface-based observations.

The direct coupling of land-biosphere processes to anthropogenic emission distribution patterns, atmospheric chemistry and long-range transport models will allow to quantify important feedback mechanisms related to wetlands, permafrost, wildfires, soil moisture and temperature, and vegetation changes.

Using the newly developed modelling and inversion tools HYMN will be able to provide advice on future emission reduction strategies based on improved knowledge on the budgets, biogeochemical cycles and spatio-temporal distributions of sources and sinks of the HYMN gases.

Given the possible transition to a hydrogen economy, HYMN will be able to answer the questions on the potential environmental impact of increased H<sub>2</sub> on the atmosphere, also in combination with an associated decrease in NO<sub>x</sub> emissions (Schulz et al., 2003) and taking into account interactions with the biosphere. Thus HYMN will also be able to give advice on future emission controls.

### B1.2 State of the art

The concentrations of long-lived greenhouse gases in the atmosphere are increasing rapidly as a consequence of human activities. The atmospheric concentration of the most important long-lived greenhouse gas, carbon dioxide (CO<sub>2</sub>), has been steadily rising by about 100 ppm since pre-industrial times to about 380 ppm presently. Other major greenhouse gases with significantly increased concentrations since pre-industrial time include methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), tropospheric ozone (O<sub>3</sub>) and a group of fully man-made gases, including the industrial Kyoto Protocol gases and halocarbons regulated in the Montreal Protocol.

Methane, the second most important long-lived greenhouse gas, is about 20 times more efficient than carbon dioxide in heating the atmosphere and has risen rapidly from about 750 ppb in 1800 to about 1775 ppb presently. However, the annual growth rate of methane is much more variable than that of carbon dioxide. While methane was increasing by more than 1% per year in the 1970s and 1980s, there have recently been years with zero or even negative growth rates (Dlugokencky et al., 2003; Simpson et al., 2002). The reasons for the strong fluctuations in the growth rate and its overall slowdown are badly understood. Suggested causes include changes in wetland emissions, biomass burning and fluctuations in OH, the main sink for

methane (a.o., Bousquet et al., 2005; Chen and Prinn, 2005; Wang et al., 2004; Dentener et al., 2003a,b; Warwick et al., 2002; Karlsdóttir and Isaksen, 2000).

Nitrous oxide has increased from about 270 ppb to about 319 ppb presently. It has a lifetime of about 120 years and its main sink is photolytic formation of NO in the upper stratosphere. The increase in concentration is ascribed to an imbalance with its sources that can be attributed in particular to the intensification of agricultural practices. The annual average growth rate is about 1 ppb per year.

Carbon monoxide is not a greenhouse gas itself but it is a precursor of CO<sub>2</sub> in the atmosphere, as well as a product of methane oxidation. About half of the CO in the atmosphere is a product from oxidation, the other half being related to CO emissions. Changes in the emissions and concentration of CO have a large impact on the methane budget and lifetime because of the competition between the reaction of OH with CO and CH<sub>4</sub>. Since pre-industrial time CO concentrations have risen significantly, although with large regional variations because of its relatively short life time of 1-2 months comparable to tropospheric ozone.

### *Methane budget*

The individual sources and sinks of methane are highly uncertain, even though the global budget is rather well constrained. Wetlands constitute the largest source of methane, contributing 25-40 % to the total annual source, likely with significant interannual variability. The actual emissions probably cover only a small part of the wetland area, because biogenic methanogenesis is highly dependent on the availability of substrate, soil temperature and the water level. As a consequence wetland emissions are strongly affected by variations in meteorological parameters such as precipitation and temperature (Walter and Heimann, 2000).

The emissions of methane from fossil fuel production and consumption is relatively well known from energy statistics and contributes about 15 % to the total annual source. Biomass burning is another rather variable source that can possibly contribute up to 10-20 % in certain years. Ruminants, rice agriculture and waste treatment contribute 10-20% each. Other, smaller, sources include termites and the oceans.

By far the most important sink (about 85 %) of atmospheric methane is its oxidation by the hydroxyl radical, OH, the remaining being lost in the stratosphere and consumed by terrestrial ecosystems. The reaction of OH with methane is together with the reaction of OH with CO, which is also a by-product of CH<sub>4</sub> oxidation, the major loss mechanism for OH. This leads to a strong positive feedback of methane changes on methane itself. An increase in methane sources is estimated to lead to about a factor 1.4 larger increase in the methane concentration due to the associated decrease in OH and increase in methane lifetime (Karlsdóttir and Isaksen, 2000; IPCC, 2001). Methane oxidation in the stratosphere constitutes an important source of stratospheric water vapour, which constitutes a radiative forcing and has implications for the ozone layer.

Estimates for the global annual methane source vary by about 20 % (IPCC, 2001). Recent studies on the geographical distribution of the CH<sub>4</sub> sources suggest a stronger contribution from tropical areas than previously thought (Frankenberg et al., 2005; Mikaloff Fletcher et al., 2004b). Interannual variability in the sources is thought to be the cause of the recent strong fluctuations in the annual growth rate of methane (Mikaloff Fletcher et al., 2004a) and long-term changes in the sources might be responsible for the slowing down of the methane growth rate on time scales of decades (Dentener et al., 2003a; Gupta et al., 1998). However, also changes in OH (and CO) could explain part of the variability and long-term trend (Dentener et al., 2003a; Warwick et al, 2002; Karlsdottir et al, 2000). Recent model studies indicate that the trend in OH over the last two decades might be small, although there are also large interannual fluctuations (Bousquet et al., 2005; Dentener et al., 2003b; Krol and Lelieveld, 2003; Prinn et al., 2001).

### ***Molecular Hydrogen budget***

The oxidation of methane in the atmosphere produces formaldehyde which through subsequent photolysis produces hydrogen and which presently constitutes the most important source of hydrogen to the atmosphere. Only rather recently a few model studies (Hauglustaine and Ehhalt, 2002; Sanderson et al., 2003; Schultz et al, 2003) have addressed the budget and life cycle of hydrogen in the atmosphere. Apart from methane oxidation they find as important hydrogen sources the oxidation of NMHCs, and fossil fuel and biomass burning. Minor sources include ocean release and nitrogen fixation in soils. The most important sink is deposition with destruction by micro-organisms which until now has been modelled rather crudely, and to a much less extent oxidation by OH.

Possible future increases of hydrogen emissions themselves are expected to affect OH and tropospheric O<sub>3</sub>, although the estimates are highly uncertain and depend on the global amounts of hydrogen that are required to fuel future energy systems. More importantly, the introduction of hydrogen technology is expected to lead to a reduction in the emission of NO<sub>x</sub> by the transport sector. Resulting changes in OH, methane lifetime and tropospheric O<sub>3</sub> have been investigated in only one study (Schultz et al., 2003) and need to be confirmed by further studies. Because the lifetime of molecular hydrogen with respect to OH oxidation is 9-10 years, stratospheric H<sub>2</sub> concentrations will increase as well. This constitutes an extra chemical source of stratospheric water vapour next to methane oxidation with uncertain effects on climate and the ozone layer.

### ***Nitrous Oxide budget***

The global sources of nitrous oxide are primarily related to soils under natural vegetation and agricultural practices. Industrial processes would contribute at most a few percent. The global current natural and agricultural soil emissions are estimated to be about equal in size, with large regional differences mainly depending on land use. The long life time of nitrous oxide in the atmosphere against photochemical breakdown, the increased concentrations extend into the stratosphere. There nitrous oxide constitutes an important source of nitrogen oxides which are estimated to play an increasingly important role in stratospheric ozone depletion as the halogens concentrations get reduced in compliance with the Montreal Protocol.

### ***Atmosphere-Biosphere modelling***

Atmospheric Chemistry Models (ACMs), including Chemistry-Transport Models (CTMs) and Chemistry-Climate Models (CCMs), have progressively included more chemical and physical processes in the past decade. European models such as the CTMs CTM-2 and TM5 and the CCM LMDz-INCA have been extensively applied and evaluated with respect to ozone chemistry in recent EU projects. All three ACMs have been applied for studies of the variability in methane and OH trends (e.g. Karlsdottir and Isaksen, 2000; Krol and Lelieveld, 2003; Bousquet et al., 2005). A full investigation of the relations between the cycles of methane, nitrous oxide and hydrogen, including OH changes, however, requires inclusion in such models of multiple couplings to the terrestrial biosphere. Descriptions of the emissions from wetlands and of the frequency, intensity and burnt area of fires are crucial for a good model representation of methane and carbon monoxide. Other important elements include the soil uptake of CH<sub>4</sub>, the emission fluxes of NO<sub>x</sub> and N<sub>2</sub>O from soils, and the deposition of NO<sub>x</sub> to vegetation. Finally, the emissions and deposition of H<sub>2</sub> need to be parameterised.

A comprehensive model taking into account all these couplings is presently not available but can be constructed on the basis of land-biosphere models presently available in Europe. The well-established Lund-Potsdam-Jena (LPJ) model is one of the most advanced dynamic global vegetation models available in Europe. In HYMN the LPJ model will be coupled to the above mentioned ACMs in order to construct a comprehensive coupled model that contains all biosphere-chemistry feedbacks required for studies of the life cycles of the HYMN gases.



### Satellite observations

Use will be made of three satellite instruments performing CH<sub>4</sub> column measurements: SCIAMACHY, IMG and IASI:

The SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) on board the European Space Agency (ESA) environmental research satellite ENVISAT records the intensity of solar radiation, reflected from the Earth surface or the atmosphere, in more than 8000 spectral channels between 240 and 2390 nm. The near-infrared spectrometers are used for global measurement of total columns of CH<sub>4</sub> and CO. ENVISAT has been launched in 2002 and operates in a nearly polar, sun-synchronous orbit at an altitude of 800 km, crossing the equator at 10:00 a.m. local time. SCIAMACHY offers a variety of measurement geometries. For the column retrievals we use the nadir mode in which the instrument points down almost perpendicular to the earth's surface detecting reflected sunlight. The spatial extent of the ground pixels is 60 km (east-west) by 30 km (north-south). Global coverage is achieved every 6 days.

The Interferometric Monitor for Greenhouse gases (IMG) is a Fourier-Transform spectrometer that flew on board the Adeos-1 platform June 1996- August 1997. IMG obtained high resolution spectra of thermal infrared radiation from the earth's surface and the atmosphere that include absorption and emission signatures of atmosphere gases, including CH<sub>4</sub> and CO. The available data set consists of 4 days-periods of data available every 10 days. This makes the IMG data most useful to test retrievals and validation exercises, while its monitoring contribution should be considered marginal, also because of its limited period of functioning.

The Infrared Atmospheric Sounding Interferometer (IASI) is a nadir-viewing remote sensor due for launch on board the European Metop satellites the coming 15 years. The first satellite METOP 1 is scheduled for launch in June 2006. After the commissioning phase (6 months), the data will be available in near-real time to HYMN, which is guaranteed because IASI is on the METOP meteorological payload with operational commitments. The measurements will be performed two times per day, at every location on the globe.

Satellite Instrument \ Years	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
IMG													
SCIAMACHY													
IASI													

**Table 2:** CH<sub>4</sub> satellite remote sensing data available in HYMN. IMG flew on Adeos-1 performing measurements until the failure of the platform from June 1996 – August 1997. SCIAMACHY is onboard Envisat launched in 2002 and CH<sub>4</sub> data is available from 1 January 2003 onwards. IASI will be launched on the operational meteorological satellite MetOp in 2006 and first CH<sub>4</sub> data will be available to HYMN.

### Inverse modelling and 4D-var Data Assimilation

Inverse modelling refers to techniques to improve upon estimates of sources and sinks by using observations of trace gas concentrations. As such, inverse modelling can be contrasted to forward modelling of trace gas distributions based on emission inventories. Different approaches to the inverse problem can be applied. In a very recent inverse model study using ground based observations Bergamaschi et al.(2005) showed that emission estimates of individual European countries can be determined from high frequency observations at several European and global stations. Satellite observations of trace gases in the atmosphere can offer further constraints on emissions for global verification and improvement of global emission inventories. Because accurate satellite CH<sub>4</sub> observations are only available very recently, the

inverse modelling using satellite CH<sub>4</sub> observations is a new field with is just starting to develop. At present accurate satellite observations of N<sub>2</sub>O or H<sub>2</sub> do not exist.

Inverse modelling using observations from ground networks such as, e.g., applied for CH<sub>4</sub> by Bergamaschi et al.(2005) and for CO<sub>2</sub> by Peylin et al.(2005) is necessarily limited to relatively large regions because the constraints by the sparse observations are rather weak, certainly on a global scale. Another approach to improve upon emission estimates is based on four-dimensional variational (4D-var) data assimilation. 4D-Var is an efficient method to deal with large amounts of satellite data and to retrieve emissions at high resolution. This method has been applied to, e.g, satellite ozone observations (Eskes et al, 1999) and synthetic measurements of CH<sub>4</sub> (Meirink et al., 2005). In this approach emissions and initial concentrations are optimised simultaneously, thus allowing inversions to be carried out on time scales of weeks to months, short compared with the lifetime of methane. Observing System Simulation Experiments (OSSEs) have demonstrated the feasibility of the method and the utility of SCIAMACHY CH<sub>4</sub> observations for source estimation (Meirink et al., 2005). This study suggests that CH<sub>4</sub> sources/sinks estimates can be derived with a spatial resolution of 500-1000 km.

### **B1.3 How will HYMN advance the state of the art?**

HYMN will advance the state-of-the-art by

- Improving the methodology to derive multi-annual global time-series of CH<sub>4</sub> observations by SCIAMACHY onboard ENVISAT and IASI onboard MetOp
- Improving the methodology for continuous monitoring of CH<sub>4</sub> and N<sub>2</sub>O by a ground-based remote sensing network of FTIR-instruments located mainly in Europe, but also at some selected sites elsewhere, such as the tropics, where sources have considerable uncertainty.
- Deriving better error estimates for the above observational time series.
- Improving insight in the influence of the biosphere on sources, sinks and trends in H<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O by constructing a new comprehensive coupled biosphere-atmospheric chemistry model and confronting it with observations.
- Quantification of the impact of future emission changes on H<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O, the possible interactions, and the feedbacks on climate through changes in the oxidising capacity and the stratosphere. This will take into account the relevant couplings with the terrestrial biosphere, including wetlands and fires.
- Improving estimates on the regional sources and sinks of H<sub>2</sub> and CH<sub>4</sub> by application of advanced inverse modelling and 4D-Var data assimilation techniques.

## B.2 Relevance to the objectives of the Global Change and Ecosystems Sub-Priority

HYMN is a research and technology proposal in response to a thematic call in the area “Global Change and Ecosystems”, a sub-priority of the FP6 Framework Program (FP6-2005-Global-4). In the work programme to this sub-priority seven areas are distinguished. The call is part of Area I on the ‘Impact and mechanisms of greenhouse gas emissions and atmospheric pollutants on climate, ozone depletion and carbon sinks’ (SUSTDEV-3.1). The objective for this area is *to detect and describe global change processes, associated with greenhouse gas emissions and atmospheric pollutants from all sources, including those resulting from energy supplies, transport and agriculture, to improve prediction and assessment of their global and regional impacts, evaluate mitigation options and improve the access of European researchers to facilities and platforms for global change research*. The set-up of HYMN is chosen to reflect all of these general objectives.

Research in the thematic area is divided into different topics. The topic relevant for this call is on “Atmospheric pollutants and their regional impacts” and research activities for this topic should focus on:

- (i) The chemistry of atmospheric pollutants and greenhouse gases and their impact on regional air quality and climate
- (ii) The quantification and prediction of the emissions and long range transport of atmospheric constituents, and
- (iii) Atmospheric chemistry-climate interactions, including their links with land and ocean processes at regional and global scale

The research activities proposed in HYMN covers the three focal points (i), (ii), and (iii) of this topic by a combination of monitoring activities from satellite platforms as well as using a ground-based network and the application of global integrated biosphere-atmosphere models that are adequate for climate impact assessments and the study of long-range transport and still have sufficient spatial resolution to study regional air quality and chemistry-climate interactions at the regional scale. The regional aspect is further emphasized by the process-based approach for the description of the biosphere-atmosphere interactions.

The five specific scientific objectives for this call which are relevant for the atmospheric composition change of methane, nitrous oxide and molecular hydrogen include:

1. Provide a better understanding of the global cycles of the HYMN gases ( $H_2$ ,  $CH_4$ , and  $N_2O$ )
2. Quantify sinks and sources of the HYMN gas, including the regional scale
3. Contribute to the monitoring of the HYMN gases
4. Quantify current  $H_2$  levels, variability and trends, and
5. Investigate the role of  $H_2$  in the global atmosphere on the budgets of  $OH$ ,  $CH_4$ , and  $O_3$

Each of the five scientific objectives, quoted from the FP6 workprogramme to the sub-priority, is covered by the research activities proposed in HYMN. For aspects 1 and 5, on global cycles, chemical budgets and better understanding, mainly modelling tools will be used including global atmospheric chemistry models and process-based biosphere-atmosphere models. Satellite observations as well as the observations from ground networks (FTIR, CMDL, and GAW) cover the required monitoring contribution (aspects 3 and 4), and the combination of observations, integrated atmosphere-biosphere models and inverse modelling and advanced data assimilation techniques will be used to address the quantification of sources and sinks on a regional scale (aspect 2). Regionalisation of source and sink estimates is refined by using a nested domain modelling approach (zooming in into Europe).

The research undertaken under “Global change and Ecosystems” has to be considered as a major support to the European Union (EU) Strategy for Sustainable Development which has been emphasized at the Göteborg European Council in 2001 and enlarged to an international

scale in the Johannesburg Summit on Sustainable Development in 2002. HYMN will strengthen the necessary scientific basis, including socio-economic assessments and tools and management practices, for the future orientation and implementation of abatement strategies for climate and air quality, as well as for the assessment of the potential effects of conversion to a hydrogen economy. HYMN will give important input to current and future policies on the most effective emission controls on greenhouse gas emissions in order to limit global warming. HYMN will also supply fundamental information to support the post-Kyoto negotiations.

Research undertaken under this priority should strengthen the scientific and technological capacities needed for Europe to understand and control global change. HYMN will contribute by an integrated approach to biosphere-atmosphere interactions and their role in the budgets of greenhouse gases, as well as on the possible future role of molecular hydrogen in the Earth system. In particular the tools developed in this project can and will be applied to yield top-down estimates of emissions derived from atmospheric observations. This provides a baseline, against which bottom-up emission numbers provided by EU-member states as well as countries outside the EU, or from independently constructed emission inventories, can be compared.

HYMN will encourage international cooperation to achieve common strategies to respond to global change issues. In the context of the Group-on-Earth-Observations (GEO) initiative, and the European contribution to GEO, Global Monitoring for Environment and Security (GMES), HYMN will contribute to the long-term monitoring programs, both from the surface and from space, and provide scientific input for the further development of a system of earth observation systems.

## B.3 Potential impact

### B.3.1 Strategic impact

The HYMN project will yield precise top-down regional estimates of greenhouse gas sources and sinks for Europe and elsewhere. It will therefore make a direct contribution to EU policies with respect to the Kyoto Protocol and global compliance to it.

It will also make a direct contribution to the EU policies for the post-Kyoto era. Improved emission estimates and better understanding of the atmospheric cycles of these gases this improves the knowledge base for developing post-Kyoto policies. The inversion methodology also offers an interesting perspective on present country-based bottom-up emission reports which may strengthen the European position in international negotiations.

The project will provide information relating various economic activities (energy use, agriculture, etc.) to climate change. The impact of land use (e.g. wetlands, land fills) on greenhouse gas emissions will be detailed. As such HYMN supports implementation of climate targets in various policy fields, such as energy, transport, agriculture, and nature protection (wetlands). Dissemination and use of the project results will thus help the development of policies for sustainable growth.

The HYMN project results also contribute to the GMES goals in the sense that our deliverables constitute an implementation of future GMES services (greenhouse gas monitoring and emission inversions).

### B.3.2 Innovation-related activities

In the project for the first time a comprehensive integrated biosphere-atmosphere model will be applied for studying the coupled budgets of H<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O and their relationship to changes in the major atmospheric cleansing agent, OH. The capability for determining sources and sinks of these greenhouse gases through inversions will also be greatly increased by applying improved modeling and retrieval techniques to new global observations from satellite instruments. Finally, a new common standard for monitoring of CH<sub>4</sub> and N<sub>2</sub>O by FTIR will be developed and implemented in the existing network of FTIR.

### B.3.3 Dissemination plan

The plans, progress and results of the project will be presented publicly through the external project web site. An advisory committee including key players from sectors producing the emissions will not only provide technical information to the project but also allow preliminary dissemination of the project results to the sectors.

In month 12 a brochure explaining the objectives, approach and expected outcomes of the project will be produced. At the end of the project a brochure explaining the results will be made and distributed.

An open conference will be organised at the end of the project. The conference will deal with both scientific and policy subjects in the field. The organising committee will consist of representatives active in science, policy making, and economic actors such as industry and agriculture.

The scientific results from the project will be published in peer-reviewed international journals and presented at international conferences. The results will also provide direct input to the next (5th) assessment report of the IPCC.

The developed emission inversion and data assimilation products will be integrated in the ESA PROMOTE / TEMIS web service at the end of the project, which will open the possibility to continue their operation after the HYMN project itself has finished.

The developed methodology for greenhouse gas monitoring by FTIR will be proposed as a standard for the global NDSC FTIR network.

### B.3.4 Added-value of the European level

The HYMN project establishes a consortium of world leading institutes in various disciplines, bringing together expertise in the fields of greenhouse gas monitoring, satellite observations, biosphere and atmospheric chemistry modelling and emission inversions. Such a consortium cannot be formed at the national level of any of the participating countries. The HYMN cooperation will increase the European capability in assessing the anthropogenic impacts on the chemical composition of the atmosphere and on climate, in particular with respect to the role of the biosphere for the HYMN gases. The integration of biosphere modelling and atmosphere modelling is a large effort and requires an multi-angle approach, such as proposed in HYMN. HYMN will increase the cohesion between European research institutes in an interdisciplinary way.

Monitoring by a ground network requires international coordination and harmonization of measurement practices, calibration, and data processing. These common practices are also essential for the validation of global satellite measurements. The monitoring activities proposed in HYMN are in accordance with the recommendations made in recent strategy reports on long-term monitoring, including the report of the EU GMES-GATO project (EC, 2004), and the IGOS theme report on atmospheric chemistry Integrated Global Atmospheric Chemistry Observations (WMO, 2005).

### B.3.5 Relation to other research activities

HYMN will make use of the existing and planned monitoring capacities in Europe and elsewhere.

- Greenhouse gas measurements from surface stations are collected by GAW and available through the World Data Centre for Greenhouse Gases. The NOAA CMDL baseline observations are part of GAW, but we also have direct and access to NOAA CMDL through an existing cooperation that includes application of the TM5 model for greenhouse gas inversions. CMDL is probably the only laboratory that can provide globally distributed H<sub>2</sub> observations.
- The EU project Evergreen has set up European capacity for greenhouse gas retrievals and inversions from satellite observations. KNMI led and UHEI-IUP was partner in Evergreen. The present proposal builds on retrieval and inversion algorithms constructed during Evergreen.
- UiO leads the model evaluation activity in the EU ACCENT network. The models involved in this project all take part in the model benchmarks executed in this activity, allowing an assessment of implemented model improvements and identification of potential model flaws.
- The EU project UFTIR project is built around the European part of the NDSC FTIR community. Within the project a common strategy has been established for the retrieval of vertical profiles of several gases from FTIR ground-based measurements. Available spectral data have been re-analysed and revised consistent time series of vertical profiles and total columns have been provided for N<sub>2</sub>O, HCFC-22, CO, C<sub>2</sub>H<sub>6</sub> and O<sub>3</sub>. The retrieval strategy for CH<sub>4</sub> has been investigated but more work needs to be done for making it optimal.
- Within the EU project STAR a Pilot Study was conducted in order to assess the feasibility of operating an FTIR instrument at the inner-tropical station at Paramaribo (Suriname). Three campaigns have been conducted at Paramaribo and the spectra are available for the retrieval of CH<sub>4</sub> and N<sub>2</sub>O.
- The EU project SCOUT focuses on the upper troposphere/lower stratosphere region and provides some support to FTIR-measurements on board the research vessel Polarstern and at the Ile de La Réunion. These measurements will be also available for CH<sub>4</sub> and N<sub>2</sub>O retrieval within HYMN.

- GEOMON is a proposal for an integrated project enhancing the European monitoring capabilities. Through its coordinator IPSL, HYMN will have direct access to its results. A cooperation agreement will be established whence both projects have been approved.
- KNMI has experience in coupling different earth system model components with the model coupling system developed in the EU PRISM project, presently for instance being applied in the EU GEMS project. As much as possible use will be made of the existing PRISM concepts and facilities for coupling the atmosphere and biosphere models involved in HYMN.

### **B.3.6 Contributions to standards/ policies/ regulations**

HYMN will contribute to the regulations, emission ceilings and policies related to the implementation of the Kyoto protocol by better quantifying the impact of anthropogenic activities on the CH<sub>4</sub> and N<sub>2</sub>O budgets as well as the role of the biosphere. For the EU the targeted emission reductions for CH<sub>4</sub> and N<sub>2</sub>O are substantial and amount to about 32% and 12%, respectively. For the post-Kyoto era new regulations will be required. There will be several mitigation options. Finding the optimal strategy is complex, and HYMN will provide the information that is needed for several of the trade-offs that can be made.

With respect to the emission trading system it is required to know what is the impact of reductions of one component on the concentration of other components. These interactions will be better quantified within HYMN in relation to the climate gases as well as with regard to regulated pollutant emissions, including the emissions of NO<sub>x</sub>, CO and VOCs. In this respect HYMN will also contribute to the European policies on Air Quality.

Given the possible future change to a *hydrogen economy* HYMN will quantify how this will affect the H<sub>2</sub> distribution and the distribution of CH<sub>4</sub> and O<sub>3</sub> through changes in the emissions of H<sub>2</sub> and pollutants such as NO<sub>x</sub>.

In accordance with one of the key objectives of the FP5 'Global Change and Ecosystems' Sub-Priority HYMN will significantly advance the state-of-the-art with respect to greenhouse gas emissions and atmospheric pollutants to improve upon the prediction and assessment of their global and regional impacts and to evaluate mitigation options.

## B.4 The consortium and project resources

### B4.1 The consortium and the respective roles of the participants

The consortium was constructed to cover in an efficient way the different expertise and tools required for answering the questions posed in the call.

The modelling includes world leading expertise in the fields of biosphere modelling (UBRIS), atmospheric chemistry modelling (UiO, KNMI), and chemistry-climate modelling (IPSL) in order to construct innovative coupled biosphere-chemistry models needed for obtaining accurate estimates of sources and sinks of the HYMN gases.

The observations include the new and promising technique of monitoring greenhouse gases from space with SCIAMACHY and IMG/IASI, which will be applied and improved by UHEI-IUP, IPSL, and KNMI. UHEI-IUP and KNMI have collaborated on CH<sub>4</sub> satellite measurements in the past within the European project EVERGREEN. Ground based observations are needed as independent truth against which the satellite observations and model simulations can be evaluated, and vice versa. All six European partners of the FTIR network are in the project (though with modest budgets; partners 6-11) in order to ensure full homogenisation of procedures and data quality over the network. Through NDSC coordinated activities the FTIR-partners are experienced in handling data quality issues and have participated in a number of instruments and algorithm intercomparisons. They also have collaborated in the past in European projects like the successive ESMOS projects, COSE and UFTIR.

The models and observations are combined in emission inversions and data assimilation by IPSL and KNMI in order to quantify regional sources and sinks. UiO will lead a comprehensive comparison of observations and models as well as scenario studies of the impact of a future hydrogen economy.

The paragraphs below list the respective descriptions of the participants and their specific skills:

#### ***Royal Netherlands Meteorological Institute (KNMI);1***

KNMI is the national meteorological service of the Netherlands. Its department of Atmospheric Composition Research has as task to investigate the changes in atmospheric composition in relation to climate change through modelling and satellite observations. KNMI is the co-PI of the SCIAMACHY instrument and PI of the OMI-instrument, and has a wide spectrum of satellite activities including operations, calibration, retrieval, chemical data assimilation and inverse emission modelling. KNMI has co-developed the global atmospheric chemistry transport model TM, which has been applied to perform chemical reanalyses, evaluate future emission scenarios and perform chemical data assimilation and emission inversions in multiple national and European projects. Version 5 of the TM model, TM5, has several levels of nested domains allowing zooming in into regions of interest such as Europe with a resolution of 1x1 degree. KNMI has extensive experience in administrating and managing European and other research projects.

KNMI will coordinate this project (WP 1) and couple its atmospheric chemistry model TM5 to the biosphere model developed by UBRIS. The resulting coupled biosphere-chemistry model will be evaluated against ground-based and satellite observations, and applied to determine the budgets and trends of CH<sub>4</sub> and N<sub>2</sub>O including consequent changes in the oxidising capacity (WP5). Regional sources and sinks of CH<sub>4</sub> will be determined by inverse modelling of the SCIAMACHY satellite observations with TM5 (WP6).

**Dr. Peter van Velthoven** leads the working group of Atmospheric Composition Modelling at KNMI and directs the further development of the TM model. He has almost 15 years experience in atmospheric chemistry modelling. He has more than 70 peer-reviewed publications and has been participant in more than 10 European projects, presently in the FP5 project RETRO and FP6 QUANTIFY IP and ACCENT NE.

**Dr. Michiel van Weele** got his PhD in 1996 on photo-dissociation processes in the atmosphere. As a Post-Doc at KNMI since 1997 he is participating in diverse international research projects. His key expertises include global atmospheric chemistry-transport modeling with focus on CH<sub>4</sub> and the oxidizing capacity, radiative transfer, and satellite remote sensing of the atmospheric composition. Last years he has been involved in different ESA projects and the FP5 project EVERGREEN. He is co-author of a recent paper in Science on the interpretation of CH<sub>4</sub> measurements from SCIAMACHY.

**Dr. Henk Eskes** joined KNMI in 1996 and is an expert in 4D-var and statistical interpolation data assimilation schemes for GOME/SCIAMACHY/OMI type of satellite observations. He has coordinated the EU project GOA (GOME assimilated and validated O<sub>3</sub> and NO<sub>2</sub> fields for scientific users and model validation) and is currently involved in the EU ASSET and GEMS projects, the ESA GSE project PROMOTE, and the OMI project. He has participated in the EU project EVERGREEN for the development of 4D-Var emission estimation and data assimilation software for CH<sub>4</sub> measured by SCIAMACHY.

### *University of Bristol (UBris);2*

The University of Bristol is continuing to make major investments in biogeochemistry and Earth System Science, building on the strengths of its Department of Earth Sciences and Schools of Geographical Sciences and Chemistry, which work together within the framework of the Bristol Biogeochemistry Research Centre on a vast range of process studies and modelling activities. Earth Sciences also houses the core team of the new Natural Environment Research Council programme QUEST (Quantifying and Understanding the Earth System), which is led by Professor Colin Prentice. QUEST has a major ambition to develop integrated models of the Earth System incorporating biological and chemical as well as physical components. Prof. Prentice is also the original developer of LPJ, a very intensively tested and widely applied modelling framework for terrestrial biosphere dynamics, and he is the co-chair of the new IGBP project AIMES (Analysis, Integration and Modelling of the Earth System). Geographical Sciences houses the BRIDGE initiative which has a strong focus on modelling and understanding present and past climates. BRIDGE is led by Professor Paul Valdes, who has carried out pioneering work on the role of changing biospheric emissions on atmospheric chemistry on palaeo time scales, and includes Dr Sandy Harrison, who is a leading expert on the reconstruction and modelling of past climates and environments as well as a prominent member of international panels dealing with land-atmosphere interactions (iLEAPS) and global terrestrial observations relating to climate (TOPC).

The continuing development of LPJ as a comprehensive model of biosphere dynamics and function, in partnership with co-developers at Lund University and the Potsdam Institute for Climate Change Research, is a major goal for Bristol, including a strategy for model development and evaluation which draws on a wide range of approaches and time scales. Bristol also participates in the GREENCYCLES EU research and training network which aims to contribute to the development of the next generation of Earth System models and modellers. The present proposal builds on a growing cross-departmental team of young scientists including Dr Kirsten Thonicke, who has pioneered global fire dynamics and trace gas emissions modelling in the LPJ framework, and research students working on modelling the climate control of methane emissions from wetlands and dust emissions from drylands in LPJ. The role of Bristol in the present proposal thus corresponds to a natural extension of ongoing model development, taking advantage of the close interaction of the model developers with experimental biogeochemists in Chemistry and Earth Sciences.

### *University of Oslo (UiO);3*

The Department of Geophysics at the University of Oslo (UIO) has a long experience in studies related to tropospheric chemistry, ozone depletion and climate processes. The studies focus on modeling of distributions and long-term changes in pollutants and chemically active greenhouse components and their forcing due to human activity. The leader of the group, Prof. I.S.A. Isaksen, has co-ordinated several EU projects where the focus has been on the impact of air traffic on radiatively active gases (AEROCHEM, AEROCHEM II, TRADEOFF) and is

currently participating in several EU projects in the field of tropospheric chemistry (SCOUT-O3, RETRO, QUANTIFY). He also leads the Atmospheric Modeling Activity of the Network of Excellence ACCENT. He has participated as author in many international assessment reports on climate and ozone (IPCC climate assessments, WMO/UNEP ozone assessment, IPCC and EU assessments on atmospheric aircraft emissions). UIO will apply their CTM2 model to investigate the coupling between the HYMN gases and the related changes in atmospheric OH and evaluate it against the satellite and ground-based observations.

***University of Heidelberg (UHEI-IUP);4***

IUP is the Institute of Environmental physics at the University of Heidelberg in Germany. The “Atmosphere and remote sensing” department deals mainly with the chemical composition of the Earth’s atmosphere. Key expertise is in differential optical absorption spectroscopy (DOAS) in general, including instrument design, algorithm development and application of the DOAS technique using instruments on various platforms (ground based, airborne, multi-axis, tomographic approaches, satellite based). The satelliteborne remote sensing of the Earth’s atmosphere at the University of Heidelberg started in 1996 with the retrieval of atmospheric trace gases, namely NO<sub>2</sub> and BrO. Today, a wide variety of trace gases, aerosols, and cloud parameters from different satellite instruments are investigated at the IUP (<http://satellite.iup.uni-heidelberg.de>). As regard to HYMN, there is a renowned and long-term expertise in satellite based retrievals from GOME and SCIAMACHY. In addition to key target species in the UV/Vis spectral regions, retrievals of CO, CH<sub>4</sub> and CO<sub>2</sub> are now feasible using the near-infrared channels featured by SCIAMACHY. A modified DOAS algorithm for an optimized retrieval of trace gases in the near infrared spectral region has been developed at IUP and led to the discovery of underestimated tropical methane sources. IUP has extensive experience with national and European research projects such as ACCENT, SCIAMACHY validation, NOXTRAM, STAR, FORMAT or EVERGREEN.

**Prof. Dr. U. Platt** leads the Atmosphere and Remote Sensing group at IUP. He established the DOAS method and is internationally renowned as expert in the field of atmospheric chemistry.

**Dr. Christian Frankenberg** is working at IUP since 2002 and established a modified DOAS algorithm for trace gas retrievals in the near infrared. He is involved in the EVERGREEN and ACCENT project and lead author of a recent paper in Science about first precise global methane measurements from SCIAMACHY.

**Dr. Thomas Wagner** leads the satellite (sub)group at IUP and has long-term and renowned experience with trace gas retrievals from GOME and SCIAMACHY (lead author of a Nature article about BrO measurements from GOME).

***Insitut Pierre Simon Laplace (IPSL);5***

IPSL (Institut Pierre Simon Laplace) is a federation of six research laboratories in the Paris area. The objectives of this federation are three-fold: fundamental research in sciences of the global environment and planetology, observations of the Earth System, together with education in Earth System science. Research activities focus on process studies (chemistry and dynamics of the atmosphere, energy exchanges at interfaces, etc.) and on modelling of coupled ocean-atmosphere-biosphere-cryosphere systems. IPSL acts as a leading institution in chemistry and climate research, has co-ordinated several European projects, has been involved in international programmes as co-ordinators or members of steering committees and contributed to European and international scientific assessments.

**Frédéric Chevallier** (Dr), was appointed permanent research scientist at LSCE in December 2003, after a PhD at Laboratoire de Météorologie Dynamique (LMD, Palaiseau, France) and a six-year stay at the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, UK). His involvement in data assimilation has been increasing over the years, in particular to initiate the assimilation of cloud-affected and rain-affected satellite radiances at ECMWF and to develop a 4D-Var system at LSCE. He is a co-investigator in three EU-funded projects about the carbon cycle (CARBOEUROPE, GEOLAND and GEMS of FP6).

**D. Hauglustaine** (Chargé de recherche au CNRS) has 15 years research experience in atmospheric sciences. He graduated from the University of Liège (Belgium) in 1987 and got

his PhD in Physics in 1992. He entered CNRS in 1993 and spent 4 years as a post-doctoral fellow at the National Center for Atmospheric Research (NCAR), Boulder, CO (1994-1998). He has developed 1-D, 2-D, and 3-D atmospheric models and has been involved in the simulation of the distribution and budget of tropospheric ozone and its precursors on various geographical and time scales. He has been involved in the simulation of the evolution of atmospheric composition under anthropogenic activities and calculation of ozone radiative forcing on the climate system. D. Hauglustaine has been involved in the development of the chemical-transport-model MOZART widely used in the scientific community and is currently leading the development of an interactive chemistry model (INCA) coupled to a general circulation model (LMDz) in order to investigate in more details the coupling between atmospheric chemistry, aerosols and climate. D. Hauglustaine has published a first global modelling study H<sub>2</sub> budget in the troposphere. He is co-I of several EU projects dealing with climate-chemistry interactions or the impact of aircraft on atmospheric composition. D. Hauglustaine has also participated to the several WG1 IPCC reports as a lead authors.

**Dr. Cathy Clerbaux** obtained her PhD in Physics in 1993 from the Université Libre de Bruxelles. She moved to Service d'Aéronomie in Paris where she became a CNRS research scientist in 1995. She is currently involved in the study of atmospheric constituents using measurements provided by infrared remote sensors, which includes development of trace gases retrieval algorithms, validation, and analysis of the observations using chemistry-transport atmospheric models and data assimilation tools. She has been involved in the analysis of satellite data for several missions, including MOPITT/TERRA, IMG/ADEOS and ACE. As a member (PI) of the IASI Sounding Science Working Group (ISSWG), she is in charge of the development of the operational retrieval algorithm for the trace gases inversion from the IASI data. She is also a remote sensing expert for Eumetsat and contributes to the definition of the Meteosat Third Generation satellite.

**Dr. Philippe Bousquet** got his PhD in inversion of CO<sub>2</sub> measurements to infer surface fluxes in 1997. He joined LSCE/IPSL and university of Versailles as an assistant professor in 1998. He is now part of the assimilation team of LSCE/IPSL. His research focuses on estimates of greenhouse gases sources and sinks using inverse modelling of atmospheric transport and chemistry. He more precisely worked on estimation of sources and sinks of CO<sub>2</sub>, CH<sub>3</sub>CCl<sub>3</sub> and recently of CH<sub>4</sub> and H<sub>2</sub>. He has strong links with other European institutes (MPI-Iena-Germany, ECN-Netherlands) and international institutes (NOAA-CMDL, CSIRO-Australia) and developed an expertise on assimilating greenhouse gas measurements that suits HUMN project.

#### ***University of Bremen (Uni-HB);6***

The Institute of Environmental Physics (IUP) at the University of Bremen (Uni-HB) focusses on the investigation of the atmosphere, the cryosphere, and the oceans of the earth. More than 100 scientists are working at the IUP. Remote sensing of the atmosphere from ground- and space-based platforms is one of the fields of expertise of the institute. Relevant to HYMN are the solar and lunar absorption measurements by FTIR-spectrometry which are performed at the NDSC-sites in NyÅlesund (Spitsbergen), Bremen (Germany) and on board the research vessel Polarstern as well as during several campaigns e.g. in Paramaribo (Suriname). The instruments at NyÅlesund, on Polarstern and the campaign instrument are operated in cooperation with the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven. In HYMN, Uni-HB will contribute to the delivery and characterization of vertical profile and total column data of N<sub>2</sub>O and CH<sub>4</sub>, from FTIR observations performed at Ny-Ålesund (Spitsbergen), Bremen (Germany), Paramaribo (Suriname) and during ship cruises on the Atlantic. The measurements at Ny-Ålesund and Bremen will be continued for the duration of the project.

**Prof. Dr. Justus Notholt** graduated in Solid State Physics at the University of Kassel in 1985 and received his PhD degree in Physical Chemistry at the same University in 1989. During a two years stay as postdoctoral fellow at the Joint Research Centre of the EC, Environment Institute, Ispra (Italy), he initialised DOAS observations applied to trace gas and aerosol measurements in the free atmosphere and to laboratory investigations. Since September 1990,

he has been associated with the Alfred-Wegener-Institute for Polar and Marine Research. He began atmospheric trace gas measurements by FTIR-spectrometry at the NDSC station Ny-Ålesund in February 1992 and developed measurement and analysis techniques for IR observations during the polar night. In 1994 he started the IR observations during ship cruises and in 2000 he performed a measurement campaign in Antarctica. In April 2002 he obtained a professorship at the university of Bremen. The FTIR-activities in the high Arctic, during the ship cruises and in the tropics are conducted in close cooperation with AWI. In addition to the FTIR-activities he is responsible for the trace gases observations at several stations by the Microwave radiometers.

**Dr. Thorsten Warneke** graduated in physics from the University of Heidelberg in 1998 and received his PhD degree in terrestrial environmental physics at the Southampton Oceanography Centre in 2002. Since August 2002 he is doing postdoctoral research at the Institute of Environmental Physics of the University of Bremen. He has participated in diverse national and international research projects involving FTIR spectroscopy. Currently he focusses on solar absorption measurements in the tropics.

#### ***Belgian Institute for Space Aeronomy (BIRA-IASB);7***

The Belgian Institute for Space Aeronomy (BIRA-IASB) has a strong expertise in atmospheric physics and chemistry research, including UV-VIS DOAS and FTIR remote-sensing observations from space and ground (algorithm developments, data retrieval and analysis), as well as tropospheric and stratospheric modelling, including inverse source modelling and 4D var data assimilation. It also performs laboratory spectroscopy experiments for atmospheric applications. It has a strong involvement in the satellite experiments GOME, ENVISAT, and ACE as well as in OMI, GOME-2 and IASI. BIRA-IASB has been involved in many EU projects, often as coordinator, e.g., the past ESMOS and COSE projects and the current UFTIR project. At present, it is partner in the EU projects Evergreen, STAR, SCOUT-O3 and GEMS, and in the ESA GSE project PROMOTE. BIRA-IASB plays an important role in the NDSC, being co-chair of the infrared, UV-Vis and satellite working groups (WG).

In HYMN, BIRA-IASB will contribute to the delivery and characterization (incl. evaluation of error budgets) of vertical profile and total column data of N<sub>2</sub>O and CH<sub>4</sub>, from campaign observations at Ile de La Réunion in 2002, 2004 and during a campaign to be performed in the course of the project. If planning is kept nominal, the FTIR measurements at Ile de La Réunion will become continuous (and automatic) in 2008. BIRA-IASB will coordinate the validation of the satellite data for CH<sub>4</sub> using the FTIR data available in HYMN. Key personnel involved:

**M. De Mazière**, Dr. Sciences, Head of Section at BIRA-IASB since 1994. Special expertise in atmospheric remote-sensing with FTIR spectrometry (operations, algorithm development, data retrieval and analysis). Responsible for the FTIR observations at Ile de La Reunion and for the development of a system for automatic operation of the FTIR instrument, in collaboration with Dr. E. Neefs (engineer). Collaboration with ULg for the FTIR observations at the Jungfraujoch. Coordinator of the EU projects COSE and UFTIR and of several national projects for atmospheric chemistry research; co-chair of the NDSC IRWG (2006). Involved with satellite validation using ground-based FTIR data, for ACE, SCIAMACHY, MIPAS and IASI (future) through projects funded by ESA, EU (Evergreen) and Belgian Science Policy. M. De Mazière is (co-)author of many scientific papers, and of the recent EU reports GMES-GATO and AIRES III.

**C. Vigouroux**, Dr. Sciences. Expertise in retrieval of ground-based FTIR data. She is working on the projects UFTIR and STAR.

**B. Dils**, Dr. Sciences. Expertise in the interpretation of FTIR ground-based data and their use for satellite validation. He is working on the project Evergreen.

#### ***University of Liege (UL);8***

The GIRPAS group (Groupe Infra-Rouge de Physique Atmosphérique et Solaire) of the University of Liège (ULg) has been involved in atmospheric research activities since the mid-1970s, using state-of-the-art instrumentation to monitor the Earth atmosphere from the ground

and from stratospheric balloon- and space-based platforms. In particular and within this framework, the group has built, installed and operated on a regular basis high-resolution infrared instruments at the Jungfraujoch station. This has resulted in gaining instrumentation expertise and in the gathering of a unique observational database presently spanning three decades. In 1989, the GIRPAS became affiliated to the NDSC network. Since then, two FTIRs have been operated intensively at the Jungfraujoch to record solar absorption spectra under clear sky conditions, with on average 110 days of observations per year. Consistent spectrometric analysis of these observations with NDSC-recommended algorithms has allowed to monitor about two-dozen atmospheric species of key relevance to the Montreal and/or the Kyoto Protocols. The group has also regularly supported atmosphere-dedicated European campaigns (EASOE, SESAME, and THESEO); it has also contributed to the data validation of numerous space missions (ATMOS, HALOE, CLAES, MAPS, CRISTA), it is currently involved in the MOPITT and ENVISAT validations and is prepared to do so for ACE, AURA and IASI. These various and complementary activities have essentially been carried out within the frame of national and EU projects (the GIRPAS has been active partner of four EU projects over the last five years). Within the specific frame of HYMN, ULg will participate to the definition of optimum retrieval strategies for CH<sub>4</sub> and N<sub>2</sub>O, assess their error budgets, perform the retrievals of both species from the Jungfraujoch observations and further validate satellite measurements of CH<sub>4</sub> total columns. All these activities are part of WP4.

**Pierre Duchatelet** is a physicist who joined the GIRPAS group at the end of 2000. He is deeply involved in data analysis with the SFIT-2 algorithm of species of relevance to the HYMN project. He also participates to observational missions at the Jungfraujoch.

**Dr Emmanuel Mahieu** has been with GIRPAS since 1991. His expertise is in IR remote sensing data analysis of space- and ground-based high-resolution observations. He is further involved in data interpretation and validation, in algorithm intercomparisons and in the archiving of the geophysical databases derived from the Jungfraujoch observations. He has been involved in several EU and national research projects since 1992. Together with Philippe Demoulin, also with GIRPAS, he is the PI of the Jungfraujoch NDSC-affiliated FTIRs.

#### ***Chalmers University of Technology (ChUT);9***

Chalmers University of Technology is one of the leading Technical Universities in Sweden, located in Gothenburg on the west coast of southern Sweden. The optical remote sensing group at the Radio and Space department has more than 20 years experience in optical remote sensing of the atmosphere. In 1994, a site for ground-based high resolution solar FTIR spectroscopy was established at 60°N 11°E at Harestua in Southern Norway. In 1996 the activity was approved as a complimentary FTIR site within NDSC (Network for the Detection of Stratospheric Change).

The group has participated in several EU projects (SESAME, COSE and UFTIR) and measurement campaigns: SESAME, ESMOS-Arctic and THESEO/SOLVE. In addition has the group contributed to the validation of the satellite instruments CRISTA II, SCHIMACHY, MIPAS and MOPITT. The measurements at the Harestua site were originally focused on winter/spring stratospheric chemistry related to vortex and vortex edge phenomena but more recently there has been considerable focus on measurements of tropospheric species such as CO, ethane and N<sub>2</sub>O in the EU project UFTIR. The work has involved development and assessment of algorithms for retrieval of vertical concentration profiles from high resolution FTIR spectra. The role of Chalmers in the project will be to work with the following: measurements, measurement strategy, retrieval strategy for CH<sub>4</sub>, error budget, satellite validation and homogenization of column and profile data.

The key personnel involved will be:

**Dr. Johan Mellqvist** received a M.S.c. in Engineering Physic 1990 a Licenciate of Engineering in 1995, and a PhD in experimental physics in Feb 1999, all at the Chalmers University of Technology. He is presently an associate professor at the Radio and Space department at the Chalmers University of Technology, responsible for developing and applying remote sensing measurements for flux and atmospheric composition measurements. Between 1990 and 1999 he was employed by the Swedish Environmental Research Institute in

Göteborg as a research scientist in applied spectroscopy and remote sensing techniques. Such techniques involve DOAS (Differential optical Absorption Spectroscopy) and FTIR (Fourier Transform InfraRed) applied for remote sensing of atmospheric pollutants both in the troposphere and stratosphere. He is PI for the NDSC measurements at a Norwegian site and has more than 10 years of experience with high resolution FTIR for atmospheric composition measurements.

**Dr. Bo Galle** received a MS.c in Engineering Physics in 1976 and a PhD in Environmental Science in 1999, both at Chalmers University of Technology in Gothenburg and is associate professor and group leader of the ORS group. During 1979 – 1999 he was employed at Swedish Environmental Research Institute as research scientist responsible for applied spectroscopy and remote sensing techniques. This work comprised development and application of various optical techniques; LIDAR, correlation spectroscopy, DOAS and Long Path FTIR.

***Institut für Meteorologie und Klimaforschung, Atmospheric Environmental Research (IMK-IFU);10***

FZK/IMK-IFU located at Garmisch-Partenkirchen, Germany is a partial institute of Forschungszentrum Karlsruhe, which again is part of the Germany Helmholtz Society of Research Centers. About 60 employees and about 20 PhD-students are working at the Garmisch institute which is studying the impact of man's activities on the chemical composition of the atmosphere and determining the subsequent consequences of a changing atmosphere on the environment. Major activities are studying the atmosphere-biosphere exchanges and the chemistry of the troposphere, determining the distribution of trace constituents in the troposphere and stratosphere, modeling the transport processes as well as developing measurement techniques for special research tasks. The institute's activities in remote sensing are covering FTIR solar absorption spectrometry, lidars for aerosol, O<sub>3</sub>, and H<sub>2</sub>O, and UV spectro-radiometry; three of the systems (FTIR, aerosol lidar, and UV-B) are part of the NDSC Primary Alpine Station. Based upon this remote-sounding instrumentation a focus of the institute's current research program is the built up and operation of a Permanent Ground-Truthing Facility at Zugspitze, Garmisch, Germany. Experience in satellite validation covers a variety of activities related, e.g. to MAPS, SAGE, EOS-Aqua/AIRS, EOS-Aura, ENVISAT, EPS.

In HYMN, FZK/IMK-IFU will deliver and characterize vertical profiles and total columns of N<sub>2</sub>O and CH<sub>4</sub> from the continuous FTIR measurements at Zugspitze/Garmisch, which started in 1995 in a fully operational mode with approximately 2 measurement days per week on average since then. FZK/IMK-IFU will put its focus on optimizing the FTIR retrieval strategy for N<sub>2</sub>O and CH<sub>4</sub> and on performing problem oriented validation studies for the satellite measurements of CH<sub>4</sub>. The key personnel involved will be:

**Dr. Ralf Sussmann** is head of the FTIR NDSC Primary Station at the mountain Zugspitze, Germany and working group leader for Sounding of the Atmosphere at FZK/IMK-IFU. He obtained his PhD in laboratory spectroscopy in 1994 and built up the FTIR observatory at the Zugspitze summit in 1995 as well as the Garmisch FTIR observatory in 2003. His research experience includes lidar remote sensing of contrails, and he is first author of more than 20 peer reviewed papers in spectroscopy and atmospheric sciences journals. He has contributed to a number of national and international research and satellite validation projects and campaigns. Recently, he has been PI of a German project for SCIAMACHY validation by FTIR, and he currently is PI of a EUMETSAT project on EPS/MetOp validation. He is first author of three 2005 ACP papers on ENVISAT validation by FTIR for the species CO, CH<sub>4</sub>, and NO<sub>2</sub>.

**Dipl.-Phys. W. Stremme** and **Dipl.-Inf. T. Borsdorff** will contribute to this project with their expertise obtained during their ongoing PhD theses dealing with the optimized retrieval from the Zugspitze long-time measurement series of N<sub>2</sub>O, CH<sub>4</sub>, and CO.

***Institut für Meteorologie und Klimaforschung, Karlsruhe (Univ K-IMK);11***

The stratospheric ozone depletion, especially in the middle and high latitudes of the northern hemisphere, is one of the main research areas of the IMK. Moreover, exchange processes between the stratosphere and troposphere as well as the distribution of tropospheric and stratospheric trace constituents are investigated. All these atmospheric processes are studied by means of extended field measurement campaigns and by numerical modelling of the middle atmosphere. Several Fourier Transform infrared (FTIR) spectrometers of the MIPAS type have been developed and successfully employed during national and international campaigns. IMK has strongly been involved in the design and the data analysis of the space-borne MIPAS instrument aboard ENVISAT.

Within the framework of the NDSC (Network for Detection of Stratospheric Change) ground-based FTIR measurements are performed at Kiruna (Sweden, since 1996) and at Izaña, Tenerife Island (since 1999). At the IMK radiative transfer models and least squares fit retrieval techniques have been developed and applied since many years. In particular, the retrieval software PROFFIT (PROFile FIT) to derive profiles from ground-based spectra has been developed at the IMK. The accurate knowledge of the instrumental line shape (ILS) is essential for a good profile retrieval. Therefore, the ILS is determined routinely by low pressure gas cell measurements analyzed with the LINEFIT software. The LINEFIT software has been developed at the IMK, and the NDSC-FTIR community has been provided with this software. Key personnel:

**Dr. Thomas Blumenstock** is leader of the group 'groundbased FTIR measurements'. He has more than 10 years of experience in ground-based FTIR spectroscopy, in operating high-resolution FTIR instruments as well as in retrieving atmospheric parameters and their interpretation. He has participated in several international campaigns like CHEOPS-III, EASOE, ESMOS, SESAME, THESEO-2000, VINTERSOL, ENVISAT and ILAS validation experiments. He is PI of an ENVISAT-AO validation project.

**Dr. Frank Hase**, has investigated and improved the instrumental line shape of the instruments. He developed the software for LINEFIT and for profile retrieval (PROFFIT) from ground-based FTIR measurements. He is an expert in applied spectroscopy and profile retrieval theory.

**Dr. Matthias Schneider** is in charge of the FTIR measurements at Izaña Observatory. He is performing FTIR measurements and analyzing spectra. He has several years of experience in operating optical instruments and analyzing spectra.

**B4.2 Project resources (human and material) and overall financial plan*****Personnel costs***

The manpower allocation for the various partners is in alignment with the tasks attributed in the project (see B4.3). The coordinator (KNMI, partner 1) has been attributed some more man power in order to facilitate project and data management. Relatively much man power is attributed to UBRIS to support the major task of including new biosphere processes in the biosphere model and to couple it to the ACMs and evaluate the coupled model against observations. Total man power costs and man months are indicated below. Note that the Project management costs are 100 % re-imbursable through the coordinator, while other costs for FC and FCF partners can be maximally re-imbursed for 50% by the EU.

The HYMN budget for manpower requested for the European FTIR groups will be used:

- to guarantee at least 1 meas/week at the European NDSC stations (Table 1)
- to support the data analysis, characterisation and homogenisation, and
- to support the satellite validation.

Participant N°	1	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Participant name	KNMI-management	KNMI	UBRIS	UiO	UHEI-IUP	IPSL	Uni-HB	BIRA	Ulg	ChUT	FZK-IMK-IFU	UKarl-IMK-ASF	
Participant Role	CO	CO	CR	CR	CR	CR	AC	CR	CR	CR	CR	CR	
Cost basis	FC	FC	AC	AC	AC	FCF	AC	AC	AC	AC	AC	AC	
Personnel costs	46.315	613.000	282.800	218.000	184.200	254.836	76.180	87.000	85.680	80.100	86.184	84.400	<b>2.098.695</b>
Person months	3	51	60	36	36	56	24	18	17	15	24	20	<b>360</b>

Table 3. *Personnel costs*

**Travel costs**

Each group has travel costs to the 4 planned project meetings and the Open Science and Policy workshop. Besides this, there are 2 additional meetings of the Steering Committee. The Advisory Committee will gather three times in conjunction with Project meetings. Their traveling costs will be reimbursed through the Coordinator. The kick-off and final project meetings will be at a central location in Europe, likely at KNMI. The other project meetings will be in the countries of the different partners. These different needs as well as different geographical locations are reflected in the different travel budgets for the different partners as outlined in Table 4. Travel for the campaign in Reunion is funded elsewhere (national funding).

<b>Partner</b>	<b>Cost (Euro)</b>	<b>Justification</b>
1. KNMI	24.000	3 project meetings x 3 persons, 2 SC meetings, 2 visits to EU, 2 related EU project meetings, 6 conference presentations
1. Advisory Committee (KNMI)	18.000	3 AC meetings x 6 persons
2. UBRIS	13000	2.5 persons x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentations
3. UiO	12.000	~2 persons x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentations
4. UHEI-IUP	10.000	~2 persons x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentations
5. IPSL	16.000	3 persons x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentations
6. Uni-HB	9.000	1.5 person x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentations ; 2 trips to Spitsbergen
7. BIRA	2.000	1 person x 4 project meetings, 2 SC meetings, HYMN open workshop, conference presentation
8. ULg	4.320	1 person x 4 project meetings, 2 SC meetings, HYMN open workshop
9. ChUT	6.900	1 person x 4 project meetings, 2 SC meetings, HYMN open workshop; 7 site trips
10. FZK-IMK-IFU	2.000	1 person x 4 project meetings, 2 SC meetings, HYMN open workshop
11. Ukarl-IMK-ASF	5.600	1 person x 4 project meetings, 2 SC meetings, HYMN open workshop; 1 trip Kiruna, 1 trip Izana
<b>Total</b>	<b>122.820</b>	

Table 4. *Travel costs*

**Consumables costs**

Some of the partners have (modest) computing costs related to running their models and processing and visualizing the output.

All the measurement groups (partner 6-11) already have a high resolution state-of-the-art FTIR instrument that is operational. Occasionally replacements of minor optical components are needed. Spectrometers also require liquid nitrogen for their operation. To be able to fully exploit the vertical profiling capabilities of ground-based FTIR measurements it is necessary to routinely measure the instrument line shape of the individual instruments. Several groups have already low pressure cell systems suitable for ILS measurements. Additional reference gases and optics are required for these measurements. The partners also dispose of the necessary computing infrastructure to carry out the data analyses. Nevertheless upgrading the computing power is required regularly, as well as the renewal/upgrading of particular scientific software licenses.

<b>Consumables</b>			
<b>Partner</b>	<b>WP</b>	<b>Cost (Euro)</b>	<b>Justification</b>
1. KNMI	6	6.000	computing
2. UBRIS	2	4.200	computing
3. UiO		0	
4. UHEI-IUP		0	
5. IPSL	6	11.000	computing
6. Uni-HB		4820	Upgrade of PC computing power, accessories, licenses, minor optical and chemical equipment, datastorage media
7. BIRA		1000	Upgrade of PC computing power
8. ULg		0	
9. ChUT		3000	Liquid nitrogen, computing, replacement of minor optics
10. FZK-IMK-IFU		1816	Audit costs
11. Ukarl-IMK-ASF		0	
<b>Total</b>		<b>31.836</b>	

Table 5. *Consumables costs*

## B4.3 STREP Project Effort Form

## STREP Project Effort Form

## Full duration of project

(person-months for activities in which participants are involved)

Project acronym - HYMN

	KNMI (1)	UBris (2)	UiO (3)	UHEL- IUP (4)	IPSL (5)	Uni-HB (6)	BIRA (7)	ULg (8)	ChUT (9)	FZK- IMK-IFU (10)	UKarl- IMK-ASF (11)	TOTAL PARTICIPANTS
Research/innovation activities												
WP2	2	45	1		1							49
WP3				36	10							46
WP4						24	18	17	15	24	20	118
WP5	15	15	35		12							77
WP6	34				33							67
<b>Total research/innovation</b>	<b>51</b>	<b>60</b>	<b>36</b>	<b>36</b>	<b>56</b>	<b>24</b>	<b>18</b>	<b>17</b>	<b>15</b>	<b>24</b>	<b>20</b>	<b>357</b>
Consortium management activities												
WP1	3											
<b>Total consortium management</b>	<b>3</b>											<b>3</b>
<b>TOTAL ACTIVITIES</b>	<b>54</b>	<b>60</b>	<b>36</b>	<b>36</b>	<b>56</b>	<b>24</b>	<b>18</b>	<b>17</b>	<b>15</b>	<b>24</b>	<b>20</b>	<b>360</b>

## B.5 Project management

### *Work management*

The HYMN project is broken down in individual work packages with clear responsibilities defined. Deliverables and milestones have been identified per work package. The organisation of the work packages and the interactions between the work packages is most clearly illustrated in the Pert diagram in Section B6. The diagram also shows the output flows of the HYMN project in terms of trends, assessments, knowledge on sources and sinks, and monitoring data sets.

Each work package has a WP co-ordinator, which is of most relevance for the work packages in which more partners are involved. Each WP co-ordinator will assemble reports from involved WP partners and produce a collective report for the work package. The coordinator will collect all reports and assemble collective reports. This includes three annual reports and three more concise intermediate reports. These progress reports will be prepared according to a strict time schedule and be ready 2 weeks in advance of meetings of the Steering Committee (see below), so that they can be used for monitoring of the progress and the identification of problem areas by the Steering Committee and coordinator, as well as the EU. The project coordinator will monitor the work progress on a regular basis and ensure flow of information and (intermediate) results within the consortium.

Plenary progress meetings with all consortium partners will be held twice each year, logically timed with respect to the subsequent deliverables and milestones that have been specified. The main purpose of the bi-annual meetings is the exchange of results and experience, reporting of progress, discussion of (intermediate) results and implications to the project objectives and preparation of reports.

Further communication amongst consortium partners will be through e-mail, telephone (conferences), fax, etc. A project mailing list shall be set up by KNMI. Flow of data and files will be organised through a password-protected central ftp-site at KNMI with full archiving facilities (after the project has been ended this will be opened to a wider audience). The web-services based on satellite data will at the end of the project be integrated in the ESA TEMIS website at KNMI. More general information about the project and its progress will be made available on the public project web-site.

Contacts with the EU will be taken care of by the coordinator.

### *Decision making*

A Steering Committee (SC) consisting of one representative for each participating institute will be formed that will make decisions regarding the project on the basis of a majority of votes. It will convene in conjunction with bi-annual project meetings and be presided by the coordinator.

The SC will be advised by an Advisory Committee (AC) that consists of key players from sectors producing the emissions as well as scientific experts in the fields of greenhouse gas modelling, observations and emissions. The AC will convene once a year. A representative from the EU will be invited for the meetings of SC and AC. Representatives from related projects can be invited to the bi-annual project meetings in order to ensure potentially useful information flow between projects.

### *Intellectual property rights*

The project partners will respect their individual Intellectual Property Rights. In the event of an invention being the work of a single party of the project and solely the result of this intrinsic skills rather than shared knowledge, this party will be the exclusive owner of the results, subject to granting access rights to the other participants where necessary for their work in the project. The conditions will be fixed in a Consortium Agreement.

If, in the course of carrying out work on the project, a joint invention, design or work is made - and more than one Party is contributor to it - and if the features of such joint invention design or work are such that it is not possible to separate them for the purpose of applying for, obtaining and/or maintaining the relevant patent protection or any other Intellectual Property Right, the Parties concerned agree that they may jointly apply to obtain and/or maintain the relevant rights.

Access-rights to software which is knowledge or pre-existing know-how, needed for the execution of the project shall be granted on the basis of royalty free limited source code access upon written request, specifying the scope and duration of the application particularly with respect to software which is pre-existing know-how.

## B.6 Workplan

### B6.1 Introduction

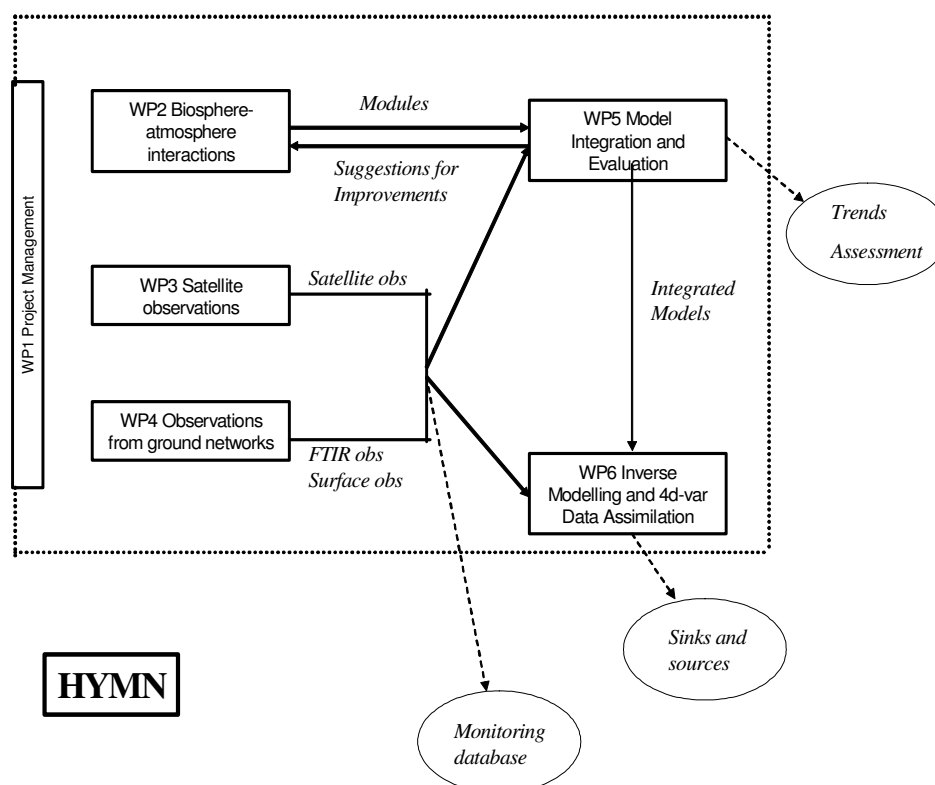
No demonstration activities are planned in HYMN. The management activities are combined in WP1 and include among others overall project management, progress monitoring and reporting, organisation of meetings, dissemination activities and external relations.

Concerning the research and technology activities, the HYMN project objectives will be achieved by a combination of bottom-up and top-down modelling of sources and sinks, employing a comprehensive biosphere model, coupled to state-of-the-art atmospheric chemistry models, both evaluated using global satellite observations and time series from monitoring networks, as well as advanced inverse modelling and 4D-Var data assimilation techniques to improve on sources and sinks estimates.

The work plan is structured as follows:

- WP1 Project Management
- WP2 Biosphere-Atmosphere Interactions
- WP3 Satellite Observations
- WP4 Observations from Ground Networks
- WP5 Model Integration and Evaluation
- WP6 Inverse Modelling and 4D-Var Data Assimilation

The relations between the WPs are illustrated by the Pert diagram below. The timing of the WPs a Ghant chart is added as well. In the next section the five main workpackages (WP2-WP6) are described, showing their rationale and overall methodology to produce the deliverables and meet the verifiable objectives. WP1 has been described in Section B5.



**Figure 1.** Pert diagram showing the interdependencies between the workpackages and the main deliverables

	month 0-6	month 7-12	month 13-18	month 19-24	month 25-30	month 31-36
WP1						
WP2						
WP3						
WP4						
WP5						
WP6						

Draft products



End products



**Figure 2.** Gantt chart showing the timing of the different WPs and their components

## B6.2 Overall methodology

### *Biosphere-Atmosphere interactions (WP2)*

A new comprehensive, climate-driven global land-biosphere model will be developed for the exchanges of key reactive trace gas species between the atmosphere and the terrestrial biosphere. The model will be built on the existing well-established dynamic global vegetation modelling framework (LPJ, Sitch et al, 2003; Thonicke et al., 2005). The extensions to this framework will include dedicated modules (which are already under active development) on wetland dynamics and permafrost and associated emissions of CH<sub>4</sub>, as well as frequency, intensity and area burned by fires, allowing emission factors to be used to estimate sources of multiple trace gases including CH<sub>4</sub>, CO and H<sub>2</sub>. Other important elements that will be integrated in the land-biosphere model include the soil uptake of CH<sub>4</sub>, the emission fluxes of NO<sub>x</sub> and N<sub>2</sub>O from soils, and the deposition of NO<sub>x</sub> to vegetation. Finally, the emissions and deposition of H<sub>2</sub> will be embedded in the model. A modular setup will be used to allow for process-based evaluation with observations (WP3/WP4) and to interface with the ACMs (WP5/WP6).

### *Satellite observations (WP3)*

Global CH<sub>4</sub> column measurements from SCIAMACHY onboard ENVISAT recently have become possible with adequate precisions to distinguish methane source regions (Frankenberg et al., 2005a,b). At the same time CO column measurements from SCIAMACHY are becoming available from 2003 onwards (Frankenberg et al, 2005c). The combination of CH<sub>4</sub> and CO satellite measurements will be used to better constrain the models on the methane lifetime which also depend on the CO distribution. ENVISAT operates in a near polar, sun-synchronous orbit at an altitude of 800km with a local equator crossing time of approximately 10:00 am. The instrument alternates between limb and nadir modes of measurement. In the latter mode, a swath of 960 km gives full global coverage every six days (14 orbits everyday) with ground pixel size of 30 km (along track, i.e. approx. north-south) times 60 (across track, i.e. approx. east-west). Following Frankenberg et al. [2005a,b], we only used spectra from channel 6 for the CH<sub>4</sub> retrievals. The data sets will be homogenised to cover the time period from January 2003 onwards.

For earlier years mainly CH<sub>4</sub> satellite observations of IMG are available (Clerbaux et al., 2003). Simultaneous with the SCIAMACHY observations are the CH<sub>4</sub> infrared observations

from IASI onboard MetOp to be launched in 2006. It will be investigated to what extent combined retrievals of CH<sub>4</sub> from SCIAMACHY and IASI will help to better separate the boundary layer column from the total column. Simultaneous with the SCIAMACHY observations are the CH<sub>4</sub> infrared observations from IASI onboard MetOp, to be launched in June 2006 (Turquety et al. 2004). After the commissioning phase (6 months), the data will be available in near-real time as IASI is on the METOP meteorological payload with operational commitments. The measurements will be performed 2 times per day, at every location on the globe, and the time period should be for 15 years from 2006 onwards as there will be 3 METOP platforms.

It will be investigated to what extent combined retrievals of CH<sub>4</sub> from SCIAMACHY and IASI will help to better separate the boundary layer column from the total column. Also the observations of the ground network (WP4) will be used for this purpose. More detailed information on the vertical profile of CH<sub>4</sub> will help to better constrain the source inversions based on satellite observations (WP6).

#### *Observations from ground networks (WP4)*

Through NDSC coordinated activities all FTIR-partners (partners 6-11) are experienced in handling data quality issues and have participated in a number of instruments and algorithm intercomparisons. They also have collaborated in the past in European projects like the successive ESMOS projects, COSE and UFTIR.

FTIR observations are needed in HYMN for satellite validation, model evaluation and emission inversions. Raw FTIR observations are available for several years, but require homogenisation with regard to retrieval and calibration before they can be used for HYMN. In the UFTIR project the retrieval strategy for several gases was partially optimised and homogenised for the European NDSC stations. In case of N<sub>2</sub>O this has been accomplished to a large extent but for CH<sub>4</sub> much more work is needed to optimise and homogenise the measurements. Furthermore, HYMN will detail the error budget of the FTIR-data to allow application for satellite validation and a-priori error estimates for emission inversions. In addition to the European NDSC stations, also FTIR observations from outside Europe are needed, especially from tropical regions because of the present-day emission uncertainties in this region. The retrieval has to be adapted for tropical measurements.

In HYMN a consistent set of total column densities and vertical profiles of CH<sub>4</sub> and N<sub>2</sub>O will be made available for the different FTIR instruments in Europe and elsewhere, covering up to more than 10 years of data. The possible addition of the earliest data of Jungfraujoch back to 1989 will be evaluated after careful investigation and characterization of the retrieved products.

For the evaluation of model simulated H<sub>2</sub> and inversions of the H<sub>2</sub> sources and sinks use will be made of the CMDL surface measurements available at about 20 sites since 1989. Regular observations of European GAW stations of CH<sub>4</sub> and N<sub>2</sub>O will be collected.

#### *Model integration and evaluation (WP5)*

The sources and sinks of CH<sub>4</sub>, N<sub>2</sub>O and H<sub>2</sub> are strongly affected by interactions with the biosphere. In this project two atmospheric chemistry models will be coupled with the detailed biosphere model developed in WP2. Apart from the biosphere, the atmospheric distribution of CH<sub>4</sub> and H<sub>2</sub> is in addition to emission from natural and anthropogenic sources controlled by oxidation with OH. OH varies significantly in time and space, its future trend, necessary to understand future trends in CH<sub>4</sub>, H<sub>2</sub> and also O<sub>3</sub> is expected to vary significantly from region to region depending on changes in precursor emissions (NO<sub>x</sub>, CO, VOCs) and on changes in climate. It is therefore essential to have good knowledge about the variation in space and time of the chemical oxidation process and how it changes with changing atmospheric conditions.

With the HYMN models we will calculate the atmospheric chemical distribution and changes due to human impact (emissions, climate change) for CH<sub>4</sub>, H<sub>2</sub> and N<sub>2</sub>O. The HYMN models

all have extensive chemistry modules that take into account the chemical interactions in the ozone-methane chemistry and have sufficient spatial resolution to study regional differences (up to  $1^\circ \times 1^\circ$  horizontal resolution).

The models will be evaluated with the observations from the ground networks (WP4) and the satellite observations (WP3). The three atmospheric-chemistry models (ACMs) applied in this study are the CTM2 and TM5 chemistry-transport models (Krol et al., 2005) and the LMDz-INCA chemistry-climate model (relaxed towards ECMWF meteorology). Three different ACMs are applied in order to assess the dependency of the results on model formulation. Taking into account sensitivity on model formulation is particularly important in case of emission inversions (WP6). Detailed investigations are undertaken on the impact of emission changes for  $H_2$ ,  $CH_4$  and  $N_2O$  and the possible interactions and feedbacks in the response. The TM5 global model will be used in zoom mode to regionalise the forward simulations.

*Top-down emission inversions and 4D-Var data assimilation (WP6)*

The ACMs will be used in conjunction with satellite and ground based observations to improve the estimates in sources and sinks of atmospheric  $CH_4$ ,  $H_2$ , and  $N_2O$ . Forward modelling with the new coupled model versions and systematic evaluation against satellite data ( $CH_4$ ) and observations from ground networks ( $CH_4$ ,  $N_2O$ ,  $H_2$ ) will already provide information on errors in the applied sources and sinks, as in Frankenberg et al. (2005a,b). However, in the HYMN project we will go one step further by performing regional inversions and 4D-var assimilation. The forward runs and their evaluation (WP5) are used to derive error estimates and biases in the model results that are needed for the inversions.

Inverse modelling of surface emissions and sink by OH oxidation of  $CH_4$  will be performed using the LMDz-INCA model as well as inverse modelling of surface emissions, atmospheric photochemical production, destruction by OH and surface uptake of  $H_2$ . These inversions will be performed on a regional basis. For TM5 use is made of the existing 4D-var assimilation scheme for  $CH_4$  source and sink estimations (Meirink et al., 2005), extending on the work performed over the last three years in the 5<sup>th</sup> FP project EVERGREEN (EnVisat for Environmental Regulation of GREENhouse gases, Feb 2003 – Jan 2006). For LMDz-INCA a 4D-var assimilation system for  $CH_4$  observations will be developed. Both schemes will be applied to derive global distributions of optimized sources and sinks of  $CH_4$  through variational assimilation of  $CH_4$  satellite data (WP3) and observations from ground networks (WP4). The variational optimizations will allow to derive information on the applied model resolution. Currently, the TM5 model can be applied in zoom mode down to a resolution of  $1^\circ \times 1^\circ$ , which will be improved to  $0.5^\circ \times 0.5^\circ$  during the course of the project.

**B6.3 Workpackage list and workpackage descriptions**

Work-package No	Workpackage title	Lead contract or No	Person-months	Start month	End month	Deliverable No
1	Project Management	1	3	0	36	D1.1 – D1.15
2	Biosphere-Atmosphere Interactions	2	49	0	36	D2.1 – D2.3
3	Satellite Observations	4	46	0	36	D3.1 – D3.6
4	Observations from Ground Networks	6	118	0	36	D4.1 – D4.8
5	Model Integration and Evaluation	3	77	0	36	D5.1 – D5.5
6	Inverse Modelling and 4D-Var Data Assimilation	5	67	0	36	D6.1 – D6.3
	<b>TOTAL</b>		360			

## Workpackage 1

Workpackage number	1		Start date or starting event:							0	
Workpackage title : <b>PROJECT MANAGEMENT</b>											
Participant id	1	2	3	4	5	6	7	8	9	10	11
Person-months per participant:	3										
<b>Objectives</b> <ul style="list-style-type: none"> <li>▪ Financial management of the project</li> <li>▪ Coordinating the work flow (project, SC and AC meetings, reporting, monitoring progress)</li> <li>▪ Providing internal communication tools (external and internal website, ftp-site, mailing list, etc.)</li> <li>▪ External communication (EU, other EU projects, dissemination and consultation of external parties, open conference, project leaflets)</li> </ul>											
<b>Description of work</b> <p>The coordinator will coordinate financial reporting by the partners and take care of the distribution of funding according to the EU rules and guidelines.</p> <p>The coordinator will organise regular Project meetings, where possible connected with bi-annual meetings of the Steering Committee (SC) as well as three meetings of the Advisory Committee (AC).</p> <p>The coordinator will set up an internal and external project web site, as well as an ftp-site for data exchange and a mailing list including mailing addresses of all persons involved in the project.</p> <p>The coordinator will coordinate the writing of bi-annual progress reports and submit all deliverables to the EU.</p> <p>The coordinator will monitor the project progress, identify problems and risks, and report and resolve them if possible.</p> <p>The coordinator will coordinate the organisation of an open science and policy workshop at the end of the project.</p> <p>The coordinator will take care of external contacts of importance to the project</p> <p>The coordinator will prepare a leaflet about project goals and a leaflet with project results.</p>											
<b>Deliverables</b> <p><b>D1.1</b> Mailing list (<i>month 1, partner 1</i>)</p> <p><b>D1.2</b> Internal website and ftp-site (<i>month 3, partner 1</i>)</p> <p><b>D1.3</b> External and external website and ftp-site (<i>month 3, partner 1</i>)</p> <p><b>D1.4</b> First bi-annual financial and progress report (<i>month 7, partner 1</i>)</p> <p><b>D1.5</b> Information leaflet about project (<i>month 12, partner 1</i>)</p> <p><b>D1.6</b> Second bi-annual financial and progress report (<i>month 13, partner 1</i>)</p> <p><b>D1.7</b> Third bi-annual financial and progress report (<i>month 19, partner 1</i>)</p> <p><b>D1.8</b> Fourth bi-annual financial and progress report (<i>month 25, partner 1</i>)</p> <p><b>D1.9</b> Fifth bi-annual financial and progress report (<i>month 31, partner 1</i>)</p> <p><b>D1.10</b> Information leaflet about project results (<i>month 36, partner 1</i>)</p> <p><b>D1.11</b> Final financial report (<i>month 37, partner 1</i>)</p> <p><b>D1.12</b> Final project report (<i>month 37, partner 1</i>)</p>											
<b>Milestones and expected result</b>											

- M1.1** Project mailing list (*month 1*)
- M1.2** Kick-off Project, SC and AC meetings (*month 1-2*)
- M1.3** Internal and external project website and ftp-site (*month 3*)
- M1.4** SC meeting (*month 6*)
- M1.5** Financial and progress report (*month 7*)
- M1.6** Project and SC meeting (*month 12*)
- M1.7** Information leaflet about project (*month 12*)
- M1.8** Financial and progress report (*month 13*)
- M1.9** SC and AC meeting (*month 18*)
- M1.10** Financial and progress report (*month 19*)
- M1.11** Project, SC meeting (*month 24*)
- M1.12** Financial and progress report (*month 25*)
- M1.13** Project and SC meeting (*month 30*)
- M1.14** Financial and progress report (*month 31*)
- M1.15** Open science and policy workshop, SC and AC meeting (*month 36*)
- M1.16** Information leaflet about project results (*month 36*)
- M1.17** Final financial and project report (*month 37*)

## Workpackage 2

Workpackage number	2		Start date or starting event:				0				
Workpackage title : <b>BIOSPHERE-ATMOSPHERE INTERACTIONS</b>											
Participant id	1	2	3	4	5	6	7	8	9	10	11
Person-months per participant:	2	45	1		1						
<p><b>Objectives</b></p> <p>A comprehensive, climate-driven global model will be developed for the exchanges of key reactive trace gas species between the atmosphere and the terrestrial biosphere. The model will build on the well-established Lund-Potsdam-Jena (LPJ) dynamic global vegetation modelling framework with the modules added for wetland dynamics, permafrost and associated CH<sub>4</sub> emissions; frequency, intensity and area burned by fires, and associated emissions of CH<sub>4</sub>, CO, H<sub>2</sub>, and NO<sub>x</sub> as well as new components on the aerobic soil uptake of CH<sub>4</sub>, the emission fluxes of NO<sub>x</sub>, H<sub>2</sub>, and N<sub>2</sub>O from soils and the deposition of NO<sub>x</sub> to vegetation, and the various biospheric sources and sinks of H<sub>2</sub> and major NMHCs. The modules will be set up so that standard runs of the model can be compared with the observational data sets (WP3/4) and interfaced with the atmospheric chemistry-transport models (WP5/6).</p>											
<p><b>Description of work</b></p> <ol style="list-style-type: none"> <li>1. Complete a process-based global model of CH<sub>4</sub> emissions from wetlands, including representation of permafrost dynamics interacting with vegetation and soil properties, based on the LPJ modelling framework.</li> <li>2. Derive CH<sub>4</sub>, CO, NO<sub>x</sub> and H<sub>2</sub> emissions from fires (natural and human-set) by applying emission factors to results of a process-based fire module coupled to LPJ</li> <li>3. Derive N<sub>2</sub>O and NO<sub>x</sub> soil fluxes, using a semi-empirical approach with emissions tied to the rate of microbial N transformations in the soil</li> <li>4. Derive H<sub>2</sub> fluxes associated with N-fixation and wetland biogeochemistry and plant emissions of major VOCs (isoprenes, monoterpenes), using a semi-empirical approach</li> <li>5. Produce outputs from standard model runs in the form of trace gas fluxes for comparison with observations</li> <li>6. Set up the global model for interfacing with the atmospheric chemistry-transport model</li> </ol>											
<p><b>Deliverables</b></p> <p><b>D2.1</b> A structurally complete, initial version of a comprehensive, climate-driven global model for the exchanges of key reactive trace gas species between the atmosphere and the terrestrial biosphere, built on the LPJ dynamic global vegetation modelling framework ready for coupling to the atmospheric chemistry-transport models (<i>month 18, partner 2</i>).</p> <p><b>D2.2</b> Report on the evaluation of the model's ability to simulated observed trace gas fluxes from observations in different regions (<i>month 26, partner 4</i>).</p> <p><b>D2.3.</b> A comprehensive, climate-driven global model fully set up to interface with the atmospheric chemistry-transport models (<i>month 28, partner 4</i>).</p>											
<p><b>Milestones and expected result</b></p> <p><b>M2.1</b> A structurally complete model, evaluated in a preliminary sense and ready for coupling to the atmospheric chemistry-transport models (<i>month 18</i>).</p> <p><b>M2.3</b> Final evaluation of the model's ability (<i>month 26</i>)</p> <p><b>M2.3</b> Final model version (<i>month 28</i>).</p>											

## Workpackage 3

Workpackage number	3		Start date or starting event:				0				
Workpackage title : <b>SATELLITE OBSERVATIONS</b>											
Participant id	1	2	3	4	5	6	7	8	9	10	11
Person-months per participant:				36	10						
<p><b>Objectives</b></p> <ul style="list-style-type: none"> <li>▪ Compilation of a consistent dataset of CH<sub>4</sub> and CO retrievals from SCIAMACHY onboard ENVISAT from the year 2003 onwards, accompanied by a detailed error analysis of the retrievals.</li> <li>▪ Compilation of CH<sub>4</sub> infrared retrievals from IMG onboard Adeos-1 and IASI onboard MetOp (when available).</li> <li>▪ Evaluate the possibility of combined retrievals using SCIAMACHY and IASI satellite measurements of CH<sub>4</sub></li> </ul>											
<p><b>Description of work</b></p> <p>The retrieval of methane and carbon monoxide will be performed using the IMPA-DOAS algorithm developed at IUP Heidelberg. As to carbon monoxide, several instrumental effects have to be analysed in detail to ensure a bias-free retrieval.</p> <p>The error analysis will include statistical errors due to instrumental noise and possible systematic biases due to partial cloud cover, aerosol loadings and high-frequency changes in surface and/or cloud albedo. Sophisticated radiative transfer models will be used to simulate and quantify the factors that might introduce these systematic errors.</p> <p>The Infrared Atmospheric Sounding Interferometer (IASI) is a nadir-viewing remote sensor due for launch on board the European Metop satellites (METOP 1 is scheduled for June 2006). Atmospheric concentrations are retrieved at IPSL/CNRS-SA from the high resolution radiance spectra recorded in the thermal infrared spectral range, along with error budget and information content. The efficiency of the retrieval algorithm was demonstrated on the atmospheric measurements provided by the Interferometric Monitor for Greenhouse Gases (IMG)/ADEOS, allowing to obtain the first remote-sensing simultaneous distributions of ozone and its two precursors, CO and CH<sub>4</sub>.</p>											
<p><b>Deliverables</b></p> <p><b>D3.1</b> First report on estimates of possible statistical and systematic errors for retrievals from SCIAMACHY (<i>month 15, partner 4</i>)</p> <p><b>D3.2</b> First set of total columns CH<sub>4</sub> and CO from the year 2003 onwards, retrieved from SCIAMACHY (<i>month 18, partner 4</i>).</p> <p><b>D3.3.</b> First set of total CH<sub>4</sub> columns retrieved from IMG/IASI including error estimates (<i>month 18, partner 5</i>)</p> <p><b>D3.4</b> Complete final set of total columns CH<sub>4</sub> and CO from the year 2003 onwards, retrieved from SCIAMACHY (<i>month 33, partner 4</i>)</p> <p><b>D3.5</b> Complete set of total CH<sub>4</sub> columns retrieved from IMG//IASI (<i>month 33, partner 5</i>)</p> <p><b>D3.6</b> Final report on estimates of possible statistical and systematic errors for retrievals from SCIAMACHY (<i>month 36, partner 4</i>)</p>											
<p><b>Milestones and expected result</b></p> <p><b>M3.1</b> Optimised the IMAP algorithm setup for the retrieval of CH<sub>4</sub> and CO from 2003 onwards (<i>month 15</i>)</p>											

**M3.2** First consistent methane and carbon monoxide datasets from SCIAMACHY and IMG with preliminary error budget in database (*month 18*)

**M3.3** Completion of the data set for recent years and full quantification of all possible error sources influencing the SCIAMACHY CH<sub>4</sub> and CO retrievals, including possible revisions (*month 33*)

**M3.4** Final reporting on retrievals (*month 36*)

## Workpackage 4

Workpackage number	4				Start date or starting event:				0			
Workpackage title : <b>OBSERVATIONS FROM GROUND NETWORKS</b>												
Participant id	1	2	3	4	5	6	7	8	9	10	11	
Person-months per participant:						24	18	17	15	24	20	
<p><b>Objectives</b></p> <ul style="list-style-type: none"> <li>▪ To perform solar absorption measurements in the mid-infrared spectral region at the 7 European NDSC stations spanning latitudes from 28°N to 80°N, throughout the duration of the project, at a minimal frequency of about 1 meas./week.</li> <li>▪ To perform solar absorption measurements at Ile de La Réunion (France) in the tropics during a 3-months campaign.</li> <li>▪ To optimise the retrieval of CH<sub>4</sub> in the mid-infrared spectral region.</li> <li>▪ To evaluate the error budget of CH<sub>4</sub> and N<sub>2</sub>O vertical profile data.</li> <li>▪ To provide a consistent set of total column densities and vertical profiles of CH<sub>4</sub> and N<sub>2</sub>O for model evaluation and satellite validation.</li> <li>▪ To validate and calibrate the SCIAMACHY and infrared satellite measurements.</li> </ul>												
<p><b>Description of work</b></p> <ol style="list-style-type: none"> <li>1. The FTIR measurements at the 7 European NDSC stations will be continued at all sites for the duration of the project at a minimal frequency of 1 measurement per week on average.</li> <li>2. A three months measurement campaign will be performed at Ile de La Réunion (France)</li> <li>3. Optimize the retrieval strategy for CH<sub>4</sub> in terms of precision and consistency among the measurement stations. Extend the optimized retrieval strategy for N<sub>2</sub>O, developed for the European NDSC within the EU project UFTIR, to the tropical stations. Among the most important retrieval parameters are: the selection of spectral microwindow(s) and associated spectroscopic parameters, the instrument line shape function, a priori profiles and parameters and associated error covariance matrices, choice of ancillary data (p, T, a priori profiles of interfering species), fitting options, etc.</li> <li>4. At all stations, the retrieval strategy developed will be applied to retrieve CH<sub>4</sub> and N<sub>2</sub>O from the spectra. This includes all available time series of FTIR spectral measurements.</li> <li>5. Perform a detailed error analysis.</li> <li>6. Determine a common strategy to validate CH<sub>4</sub> total columns of SCIAMACHY as well as the infrared satellite instruments</li> <li>7. Validate the satellite measurements of CH<sub>4</sub> total columns</li> </ol>												
<p><b>Deliverables</b></p> <p><b>D4.1</b> Report on common measurement strategy (<i>month 8, partner 6</i>)</p> <p><b>D4.2</b> For all FTIR stations: preliminary historical time series of total column abundances and vertical profiles for CH<sub>4</sub> and N<sub>2</sub>O (for model evaluation and satellite validation) (<i>month 12, partners 6-11</i>)</p> <p><b>D4.3</b> Assessment report of associated retrieval error budget (<i>month 20, coordinated by partner 6</i>)</p> <p><b>D4.4</b> Report on optimized retrieval strategy (<i>month 20, coordinated by partner 10</i>)</p> <p><b>D4.5</b> For all FTIR stations: revised historical time series of total column abundances and vertical profiles for CH<sub>4</sub> and N<sub>2</sub>O (for model evaluation and satellite validation) (<i>month 24, partners 6-11</i>)</p> <p><b>D4.6</b> Preliminary results on the validation of the satellite data with FTIR observations from all sites. At all sites solar absorption measurements extent back several years, hence the validation can be done for the lifetime of SCIAMACHY, IMG and first years of IASI. (<i>month 24, coordinated by partner 7</i>)</p> <p><b>D4.7</b> For all FTIR stations: time series of total column abundances and vertical profiles for CH<sub>4</sub> and N<sub>2</sub>O, extending to the last year of the project (<i>month 36, partners 6-11</i>)</p>												

**D4.8.** Final results on the validation of the satellite data with FTIR observations from all sites.  
(*month 36, coordinated by partner 7*)

**Milestones and expected result**

**M4.1** A common measurement strategy will be determined and implemented (*month 3*).

**M4.2** Historical time series column abundances and vertical profiles for CH<sub>4</sub> and N<sub>2</sub>O in database  
(*month 12*)

**M4.3** Optimised retrieval parameters and associated retrieval error budget determined (*month 20*).

**M4.4** Revised (new retrieval) historical observations time series of total column abundances and vertical profiles for CH<sub>4</sub> and N<sub>2</sub>O in database (*month 20*)

**M4.5** A strategy for the validation of the satellite measurements has been determined (*month 20*).

**M4.6** First full validation of available satellite measurements (*month 24*)

**M4.7** Observations made during the project included in the database (*month 36*)

**M4.8** Completed validation of all satellite measurements (*month 36*)

## Workpackage 5

Workpackage number	1		Start date or starting event:								0
Workpackage title : <b>MODEL INTEGRATION AND EVALUATION</b>											
Participant id	1	2	3	4	5	6	7	8	9	10	11
Person-months per participant:	15	15	35		12						
<p><b>Objectives</b></p> <ul style="list-style-type: none"> <li>▪ Evaluation of the coupled global model results for CH<sub>4</sub>, H<sub>2</sub>, and N<sub>2</sub>O by comparison satellite observations and observations from ground networks.</li> <li>▪ Identify atmospheric loss of methane and hydrogen and the impact of changing anthropogenic and natural (climate induced) emissions on the regional OH trends and on current and future global methane and hydrogen.</li> <li>▪ Quantify how the transfer to a future hydrogen economy affect hydrogen distribution and the distribution of methane and ozone and their impact on the environment through changes in emission of hydrogen and pollutants (NO<sub>x</sub>, CO, VOCs).</li> </ul>											
<p><b>Description of work</b></p> <p>Three global atmospheric chemistry models are used to calculate the atmospheric chemical distribution and changes due to human impact (emissions, climate change). The models also calculate stratospheric distributions where CH<sub>4</sub> and H<sub>2</sub> are partly converted to water vapour. The model calculations will be performed by coupling to the land-biosphere modules from WP2. The observations from WP3 and WP4 will be used for model evaluation. The following modelling studies will be performed:</p> <ol style="list-style-type: none"> <li>1. Sensitivity/model performance runs to quantify current sinks and their regional differences. Improvement of models for distribution and trend studies through the use of improved land-biosphere modules from WP2 and observational data from WP3 and WP4 for model validation. Improvement of model performance through participation in ACCENT model intercomparison and evaluation studies (models of all 3 partners).</li> <li>2. Decadal runs (~10-20 year) for a better understanding of recent variability in trends of CH<sub>4</sub> and H<sub>2</sub>, possibly related to interactions with the biosphere, and feedbacks due to CH<sub>4</sub>, H<sub>2</sub> and N<sub>2</sub>O trends, such as on the oxidizing capacity and the stratosphere (three models).</li> <li>3. Model runs of future changes to explore the impact of future emission changes of pollutants and climate on hydrogen and methane through changes in OH oxidation. (with CTM2 only)</li> <li>4. Scenario runs to quantify the effect of transformation to a H<sub>2</sub> economy on the CH<sub>4</sub> and ozone budgets and estimates of the climate impact (with CTM2 only).</li> </ol>											
<p><b>Deliverables</b></p> <p><b>D5.1</b> Output from sensitivity runs (in database, <i>month 18, partners 1, 3 and 5</i>)</p> <p><b>D5.2</b> Report on the influence of the biosphere on trends and variability in CH<sub>4</sub>, H<sub>2</sub> and N<sub>2</sub>O (<i>month 24, coordinated by partner 5</i>)</p> <p><b>D5.3</b> Output from decadal runs (in database, <i>month 24, partners 1, 3 and 5</i>)</p> <p><b>D5.4</b> Report on variability in the trends of CH<sub>4</sub>, H<sub>2</sub> and N<sub>2</sub>O and associated feedbacks (month partner <i>month 28, partner 3</i>)</p> <p><b>D5.5</b> Assessment report on the possible future effects on methane and ozone and on climate and pollution levels of the transformation to a hydrogen economy (<i>month 36, partner 3</i>).</p>											
<p><b>Milestones and expected result</b></p> <p><b>M5.1</b> Sensitivity runs ready (<i>month 17</i>)</p> <p><b>M5.2</b> Improved model tools for studies of the interaction of methane and hydrogen with atmospheric chemistry (<i>month 24</i>).</p>											

**M5.3** Decadal runs ready (*month 23*)

**M5.4** Model study of CH<sub>4</sub>-H<sub>2</sub>-OH coupling ready (*month 24*)

**M5.5** Estimated future changes in OH, methane, hydrogen and ozone under changing atmospheric conditions (*month 28*).

**M5.6** Scenario runs ready (*month 33*)

**M5.7** Estimated changes in OH, methane, hydrogen and ozone and the environmental impact of such changes due to the transformation to a hydrogen economy (*month 36*).

## Workpackage 6

Workpackage number	6		Start date or starting event:								0
Workpackage title : <b>INVERSE MODELLING AND 4D-VAR DATA ASSIMILATION</b>											
Participant id	1	2	3	4	5	6	7	8	9	10	11
Person-months per participant:	34				33						
<p><b>Objectives</b></p> <ul style="list-style-type: none"> <li>▪ Estimate the surface emissions of CH<sub>4</sub> and H<sub>2</sub> on a regional basis based on inverse modeling and their evolution over the period 1980-2000.</li> <li>▪ Estimate the evolution of global and hemispheric OH in the atmosphere over the period 1980-2000 through inverse modeling.</li> <li>▪ Derive the global optimized distributions of CH<sub>4</sub> and H<sub>2</sub> sources and sinks on a pixel by pixel basis based on 4D variational data assimilation.</li> </ul>											
<p><b>Description of work</b></p> <p>Global chemistry-transport models will be used in conjunction with satellite and ground based observations to improve the estimates in sources and sinks of atmospheric CH<sub>4</sub>, H<sub>2</sub>, and N<sub>2</sub>O.</p> <p><b>1.</b> Global forward modeling of CH<sub>4</sub>, N<sub>2</sub>O, and H<sub>2</sub> and systematic evaluation against satellite data (CH<sub>4</sub>) and ground based measurements (CH<sub>4</sub>, N<sub>2</sub>O, H<sub>2</sub>). Derive error estimates and biases in model results.</p> <p><b>2.1</b> Inverse modeling of surface emissions and sink by OH oxidation of CH<sub>4</sub>.</p> <p><b>2.2</b> Inverse modeling of surface emissions, atmospheric photochemical production, destruction by OH and surface uptake of H<sub>2</sub>. This work will be done based on available surface measurements and satellite observations of CH<sub>4</sub>. These inversions will be performed on a regional basis.</p> <p><b>3.</b> Derive global distributions of optimized sources and sinks of CH<sub>4</sub> and H<sub>2</sub> through variational assimilation of methane satellite data and surface measurements. These optimizations will be performed on a pixel basis.</p>											
<p><b>Deliverables</b></p> <p><b>D6.1</b> Report on model performances in terms of forward simulations of CH<sub>4</sub>, H<sub>2</sub>, and N<sub>2</sub>O using a-priori distribution of emissions and atmospheric sinks and derived error and biases against model results and observations (<i>month 24, coordinated by partner 5</i>).</p> <p><b>D6.2</b> Report on emissions of CH<sub>4</sub> and H<sub>2</sub> over the 1980-2000 period derived from inverse modeling of available satellite and ground-based observations on a regional basis. Comparison with a priori emissions (<i>month 36, partner 5</i>).</p> <p><b>D6.3</b> Report on fully optimized distributions of emissions, production, and sinks for CH<sub>4</sub> and H<sub>2</sub> obtained through 4D var data assimilation on a pixel by pixel basis (<i>month 36, partner 1</i>).</p>											
<p><b>Milestones and expected result</b></p> <p><b>M6.1</b> Forward simulations of H<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O using a priori emissions and comparison with available observations (<i>month 12</i>).</p> <p><b>M6.2</b> Inversion of CH<sub>4</sub> surface emissions and atmospheric OH over the 1980-2000 period and comparison with a priori emissions (<i>month 33</i>).</p> <p><b>M6.3</b> Inversion of H<sub>2</sub> surface emission and soil uptake and photochemical production over the period 1980-2000 period (<i>month 33</i>).</p> <p><b>M6.4</b> Fully optimized distribution of sources and sinks of CH<sub>4</sub> and H<sub>2</sub> through variational data assimilation (<i>month 35</i>).</p>											

## B6.3 Deliverables list

Deliverable No <sup>1</sup>	Deliverable title	Delivery date <sup>2</sup>	Nature <sup>3</sup>	Dissemination level <sup>4</sup>
D1.1	Mailing list	1	O	Pu
D1.2	Internal website and ftp-site	3	O	PP
D1.3	External website	3	O	Pu
D1.4	First bi-annual financial and progress report	7	R	PP
D4.1	Report on common measurement strategy	8	R	Pu
D1.5	Information leaflet about project	12	O	Pu
D4.2	For all FTIR stations: preliminary historical time series of total column abundances and vertical profiles for CH <sub>4</sub> and N <sub>2</sub> O (for model evaluation and satellite validation)	12	O	PP/Pu <sup>4*</sup>
D1.6	Second bi-annual financial and progress report	13	R	PP
D3.1	First report on estimates of possible statistical and systematic errors for retrievals from SCIAMACHY	15	R	Pu
D2.1	A structurally complete, initial version of a comprehensive, climate-driven global model for the exchanges of key reactive trace gas species between the atmosphere and the terrestrial biosphere, built on the LPJ dynamic global vegetation modelling framework ready for coupling to the atmospheric chemistry-transport model	18	P	PP
D3.2	First set of total columns CH <sub>4</sub> and CO from the year 2003 onwards, retrieved from SCIAMACHY	18	O	PP/Pu <sup>4*</sup>
D3.3	First set of total CH <sub>4</sub> columns retrieved from IMG/IASI including error estimates	18	O	PP/Pu <sup>4*</sup>
D5.1	Output from sensitivity runs (in database)	18	O	PP/Pu <sup>4*</sup>
D1.7	Third bi-annual financial and progress report	19	R	PP
D4.3	Assessment report of associated retrieval error budget	20	R	Pu
D4.4	Report on optimized retrieval strategy	20	R	Pu

<sup>1</sup> Deliverable numbers in order of delivery dates: D1 – Dn

<sup>2</sup> Month in which the deliverables will be available. Month 0 marking the start of the project, and all delivery dates being relative to this start date.

<sup>3</sup> Please indicate the nature of the deliverable using one of the following codes:

**R** = Report

**P** = Prototype

**D** = Demonstrator

**O** = Other

<sup>4</sup> Please indicate the dissemination level using one of the following codes:

**PU** = Public

**PP** = Restricted to other programme participants (including the Commission Services).

**RE** = Restricted to a group specified by the consortium (including the Commission Services).

**CO** = Confidential, only for members of the consortium (including the Commission Services).

<sup>4\*</sup> All observational data sets and model output will only be open to the programme participants initially, so that the results can be published in scientific literature by them. 1 year after delivery of the data sets they will become public.

D4.5	For all FTIR stations: revised historical time series of total column abundances and vertical profiles for CH <sub>4</sub> and N <sub>2</sub> O (for model evaluation and satellite validation)	24	O	PP/Pu <sup>4*</sup>
D4.6	Preliminary results on the validation of the satellite data with FTIR observations from all sites. At all sites solar absorption measurements extent back several years, hence the validation can be done for the lifetime of SCIAMACHY, IMG and first years of IASI.	24	R	Pu
D5.2	Report on the influence of the biosphere on trends and variability in CH <sub>4</sub> , H <sub>2</sub> and N <sub>2</sub> O	24	R	Pu
D5.3	Output from decadal runs (in database)	24	O	PP/Pu <sup>4*</sup>
D6.1	Report on model performances in terms of forward simulations of CH <sub>4</sub> , H <sub>2</sub> , and N <sub>2</sub> O using a-priori distribution of emissions and atmospheric sinks and derived error and biases against model results and observations	24	R	Pu
D1.8	Fourth bi-annual financial and progress report	25	R	PP
D2.2	Report on the evaluation of the model's ability to simulated observed trace gas fluxes from observations in different regions	26	R	Pu
D2.3	A comprehensive, climate-driven global model fully set up to interface with the atmospheric chemistry-transport models	28	P	PP
D5.4	Report on variability in the trends of CH <sub>4</sub> , H <sub>2</sub> and N <sub>2</sub> O and associated feedbacks	28	R	Pu
D1.9	Fifth bi-annual financial and progress report	31	R	PP
D3.4	Complete final set of total columns CH <sub>4</sub> and CO from the year 2003 onwards, retrieved from SCIAMACHY	33	O	PP/Pu <sup>4*</sup>
D3.5	Complete set of total CH <sub>4</sub> columns retrieved from IMG//IASI	33	O	PP/Pu <sup>4*</sup>
D3.6	Final report on estimates of possible statistical and systematic errors for retrievals from SCIAMACHY	36	R	Pu
D4.7	For all FTIR stations: time series of total column abundances and vertical profiles for CH <sub>4</sub> and N <sub>2</sub> O, extending to the last year of the project	36	O	PP/Pu <sup>4*</sup>
D4.8	Final results on the validation of the satellite data with FTIR observations from all sites	36	R	Pu
D5.5	Assessment report on the possible future effects on methane and ozone and on climate and pollution levels of the transformation to a hydrogen economy	36	R	Pu
D6.2	Report on emissions of CH <sub>4</sub> and H <sub>2</sub> over the 1980-2000 period derived from inverse modeling of available satellite and ground-based observations on a regional basis. Comparison with <i>a priori</i> emissions	36	R	Pu
D6.3	Report on fully optimized distributions of emissions, production, and sinks for CH <sub>4</sub> and H <sub>2</sub> obtained through 4D var data assimilation on a pixel by pixel basis	36	R	Pu
D1.10	Information leaflet about project results	36	O	Pu
D1.11	Final financial report	37	R	PP
D1.12	Final project report	37	R	Pu

**B.7 Other issues****B.7.1 Ethical issues****Table A.**

Does your proposed research raise sensitive ethical questions related to:	YES	NO
Human beings		X
Human biological samples		X
Personal data (whether identified by name or not)		X
Genetic information		X
Animals		X

**Table B.**

Research activity aimed at human cloning for reproductive purposes
Research activity intended to modify the genetic heritage of human beings which could make such changes heritable
Research activity intended to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer.

	YES	NO
<b>Confirmation : the proposed research involves none of the issues listed in Table B</b>	X	

**B.7.2 Gender issues:**

The project will promote and facilitate the participation of women in science and technology, e.g. when positions in the framework of the project are opened. Meetings will be scheduled such that unnecessary weekend travelling is avoided as much as possible. A female representative of one of the participating institutes will monitor the implementation of this objective. Each project report to the EU will contain a section on gender issues.

**B.7.3 Policy issues:**

The results of the project will benefit the second European Climate Change Program (ECCP II) or its follow-up in the sense that it will provide the tools independent (top-down) monitoring of emissions of EU regions, and also of other parts of the world. These tools will also help in establishing a firmer basis for post-Kyoto EU policies and strategies targeting stronger reductions in response to the call of IPCC and other international organisations to limit greenhouse gas concentrations at a level that prevent dangerous anthropogenic interference with the climate system.

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