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<b>1 A. Title:</b>	
<b>Integrated observations and modelling of Greenhouse Gas budgets at the national level in the Netherlands</b>	
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**2. History and Background of the Research Proposal; Problem Definition:**

In Kyoto countries agreed to reduce their anthropogenic greenhouse gas (GHG) emissions by 8% in 2008-2012, relative to (for most GHG's) the 1990 emissions. The Netherlands committed itself to reductions of 6%. For the period after that the required emission reductions will more likely be on the order of 30% or more, on which the negotiations will start soon. Such reductions require wide spread measures in all economic sectors with often only small incremental contributions. The achieved reductions will be reported following standard IPCC Guidelines. Basically this is a bottom-up summation over various (anthropogenic) activities of the products of the volume of that activity and an emission factor. As reductions become more and more challenging to achieve, and as penalties for non-compliance may become more serious, the need for independent verification mechanisms -at country level at first, later perhaps at smaller administrative units- will increase.

Eventually, emission reductions should have observable effects on atmospheric concentrations of GHGs. These concentrations should be the basis of an independent, top-down approach to verify the emission reductions. Inverse methods provide such an approach. Atmospheric concentrations of GHGs are determined by the net flux in and out of the atmosphere. For the three primary GHGs, CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O, the magnitude of natural fluxes are of similar orders of magnitude as anthropogenic emissions (others like SF<sub>6</sub>, HFCs, etc. are of almost exclusively anthropogenic origin). So an important pre-requisite for any verification methodology is that it should be able to separate the two, natural vs anthropogenic, contributions.

Inverse methods use actually measured time series of a particular greenhouse gas mixing ratio at one or more sites, together with transport and diffusion information from an atmospheric model to improve the source/sink distributions of that greenhouse gas in time and space. An *a-priori* source/sink distribution must be provided to the inverse computation scheme that will be improved towards values more in agreement with the observed concentration fields. The method sofar has been used mostly at larger, continental to global scales (e.g. Bousquet et al. 1999a,b), but in principle can be used at smaller scales too, (Hensen et al., 1999; Dolman et al., 2004). Thus it can provide a tool to verify the emissions at roughly national and perhaps sub-national levels.

However, the challenges of developing a verification tool at these relative small scales are large and in part of a different nature than those developed for continental to global scales. These have to do with the very large variability of fluxes in landscapes exhibiting e.g. cities and forests, covariance of fluxes and atmospheric PBL dynamics and the resulting problems of representativity and aggregation of data. Therefore, at these scales it is imperative to make use of all of the constraints provided/imposed by different data streams, and by process knowledge of ecosystem behaviour (natural and man made) and of atmospheric dynamics as embodied in state-of-the-art models.

Based on the above situation sketch, the overall objective of the current research proposal is:

*To develop an advanced GHG information system - consisting of a comprehensive set of monitoring systems, combined with a complementary suite of 3D models – that is able to quantify the magnitude, trends and associated uncertainties of the biogenic and antropogenic greenhouse gas budgets high spatial an temporal resolutions. While doing so we will develop a protocol to provide an independent reference estimate for the verification of national emissions reported by the parties in the UNFCCC and Kyoto framework.*

A lot of research addressing the above issues at the regional scale is of relative recent origin, and large efforts are currently being made by US and European consortia. Dutch participation, by partners also contributing to the present proposal, in European frameworks has been and still is highly significant and visible. The present proposal aims to continue this situation by providing on one hand the individual partners the possibility to continue playing this role in their respective niches, while -by providing an integrated framework and end-target- on the other hand we will enable the consortium as a whole to make definite steps towards actually reaching GHG budget closure at regional scales.

The latter objective, of high international scientific and political relevance, can never be realised from individual grants alone, and as such only the BSIK grant may provide a sufficient level of thrust to achieve the ambitious goals of this proposal.

### 3. Objectives:

The objectives of the proposed research activities are:

- To develop the elements of an advanced GHG information system, - consisting of on one hand a complementary set of surface, tower based, airborne and remote sensing monitoring systems, and on the other hand a complementary suite of forward and inverse, lagrangian and eulerian 3D models .
- To quantify the magnitude, trends and associated uncertainties of the biogenic and antropogenic greenhouse gas emissions and atmospheric budgets at spatial resolutions of roughly 50km (implying grid sizes of 10km and less) for a domain of 400x400km, and at temporal resolutions of 1 month for at least a single full year (model time steps are much shorter of course), making use of all constraints imposed by the respective elements of the GHG information system.
- To develop a protocol to provide an independent reference estimate for the verification of national emissions, that allows determination of the accuracy and some of the uncertainties of the emissions reported by the parties in the UNFCCC and Kyoto framework, through critical evaluation of all elements making up the information system and of all necessary steps involved in reaching GHG estimates.

Therefore a research plan is proposed consisting of five complementary work packages, the objectives of which comprise the following:

- To develop for this particular spatial scale a cost-efficient observation network and sampling protocol to quantify, continuously in time and space, the sources and sinks of GHG's and aerosols. Use will be made of
  - Continuous ground based remote sensing measurements of atmospheric column properties [wp1]
  - An observation network monitoring PBL height dynamics and its primary driver (sensible heat flux) combining ceilometers and scintillometers [wp1]
  - satellite based GHG mapping [wp2]
  - Continuous tall-tower atmospheric concentration monitoring [wp2]
  - Repetitive airborne flux measurements [wp3]
- To produce unique datasets needed for development of the above, consisting of
  - Continuous time series of PBL height at multiple sites in the Netherlands [wp1]
  - Continuous, high precision time series of GHG concentrations and supplementary tracers at multiple levels and at two sites in the Netherlands [wp2]
  - Daily estimates of source area for tower observations, based on back-trajectories
  - Systematic airborne flux and concentration transects, sampling the full seasonal cycle and major landscapes in the Netherlands [wp3]
  - Flux maps, continuous in space and time, for *a-priori* inversion estimates [wp3]
  - Problem oriented datasets for PBL studies, for specific areas and for specific seasonal phases [wp1, 2, 3]
- To further the development of 3D transport models, improved with respect to
  - Vertical mixing through implementation of state-of-the-art PBL parameterisations, including entrainment and if needed GHG-specific flux/profile relations [wp4, 1]
  - GHG nudging algorithms i.e. offline coupling between complementary models [wp4]
  - Improved bottom-boundary conditions (LSMs, otherwise prescribed fluxes) [wp4, 3]
  - Additional GHG species transport: CH<sub>4</sub>, N<sub>2</sub>O, isotopes, CO [wp4]
- To develop inversion algorithms, based on eulerian and lagrangian concepts, improved with respect to
  - Input flexibility: allowing the use of concentration flux data that are (relatively) irregularly distributed in space and time [wp4]
  - An assessment of uncertainties as can be attributed to a) variation between transport models and b) variation between inversion algorithms. [wp4]
  - The use of high-frequency variation in the concentration time series (increased resolution in time and space)

- To make a first attempt ever at independently verifying Dutch national emissions, as reported in the UNFCCC-NIR, for one particular year [wp5]
- To outline a verification protocol based on the experiences in these. [wp5]

#### **4 A. Research Questions and scientific relevance (maximum 2 pages):**

The atmosphere is a fast but incomplete mixer and integrator of spatially and temporally varying surface fluxes of GHGs. Through inverse modelling the distribution and temporal evolution of CO<sub>2</sub> and other GHGs in the atmosphere can be used to quantify surface fluxes, using numerical models of atmospheric transport. To make progress in the objectives described in the previous two sections a number of problems must be overcome, as large-scale inversion-based sink/source estimates of GHGs suffer from a number of errors (see e.g. Gerbig et al., 2003, for a discussion with respect to CO<sub>2</sub> but largely valid also for other GHGs):

- Solving for continental fluxes is an ill-constrained inverse problem given uneven distributed and sparse stations under continental influence.
- There is a large variability in both atmospheric transport and surface fluxes over vegetated areas, which yields a peak in the CO<sub>2</sub> variance near the ground, so that the signal of mean continental fluxes is difficult to characterize from the noise (variability) when only discrete (flask) sampling is available.
- Vertical mixing and biogenic surface fluxes (e.g. NEE) - but also anthropogenic fluxes (e.g. traffic) - vary together on diurnal and seasonal scales to yield rectification gradients in mixing ratios that are especially difficult to capture in large scale transport models (Denning et al., 1996).
- Diurnal and seasonal atmospheric transport processes (e.g. boundary layer mixing and ventilation, orographic effects, frontal uplift of tracers etc.) are usually poorly represented in large-scale transport models.
- Given the flux heterogeneity, measurements from a single location are not immediately representative of larger regions or grid cells thus causing representation errors, and preventing the information obtained at these sites to be simply aggregated up to the scale of a region.
- Solving for aggregate fluxes that do not evenly influence the overall mixing ratio may cause aggregation errors (Kaminski et al., 2001)

These errors can be substantially reduced when at the regional level a good link between the measurements obtained at the surface flux stations and those from continental scale inversions can be established. To achieve this, a region needs to be monitored equally well in spatial and temporal terms, while the precision and representativeness of the measurements should match that of the involved major source and sink processes. Therefore, continuous monitoring of GHG concentrations in the PBL, of PBL dynamics and its drivers, and of temporal and spatial variability of surface fluxes are one side of that link. Using atmospheric transport models of high resolution, with good parameterizations of PBL processes, of surface fluxes of heat and GHGs and resolving mesoscale transport (e.g. see breezes, orographic flows, convection) are the other side of this link. Combining the two, inversions then provide objective uncertainties of the estimated net surface fluxes. Using various combinations of atmospheric observations, the inverse modelling framework also permits studies of optimal sampling strategies for adding new stations to the network and for filtering the concentration "signal" representative of regional sources and sinks, from the "noise" induced by local fluxes and transport patterns.

Gerbig et al. (2003) indicate that a significant fraction of the information present in the signature of GHG concentrations observed within the atmospheric boundary layer is contained in relatively small spatial and temporal scales. This suggests that to be able to use the variance in these the observations, analysis with grid cells of less than 30 km is required. This requires experimental sampling and model development to resolve the diurnal timescale and to make them appropriate at such small spatial scales. To achieve this, the daytime, convective boundary layer (CBL) can be used as a natural integrator of the surface fluxes at the regional scale (Lloyd et al., 1996; Raupach 1992). However, a problem associated with the CBL budgeting technique is that the spatial footprint of the so-retrieved fluxes is not explicitly known unless advection is quantified or a Lagrangian approach is chosen (Lloyd et al. 2001; Schmitgen et al. 2003). Further, entrainment with air from the free troposphere by CBL growth and large scale vertical fluxes influence the rate of change of CO<sub>2</sub> as well as surface fluxes, and those terms are also poorly quantified.

In order to produce a best estimate of carbon dioxide uptake and its uncertainty, we need to make use of all of the constraints provided/imposed by the different data streams, as well as the physiological and ecological constraints embodied in behaviour of the land surface and the process-based Terrestrial Ecosystem Models (TEMs). Thus, we need to simultaneously use the observations to constrain the internal parameters of the TEMs, whilst using the TEMs to interpolate the plot scale observations to produce useful large-scale estimates of the carbon sink and its causes. In the frame work of the EU-FP5 funded RECAB project (Hutjes, et al. 2003) a first attempt has been made to quantify CO<sub>2</sub> emissions at regional scales. With analyses still continuing (e.g. under the EU-FP6 CarboEuropeIP

Regional component) a number of (tentative) lessons can be drawn from that project, and others addressing similar scales (e.g. CHIOTTO). Airborne flux measurements can provide estimates of regional fluxes that are directly comparable to tower based flux estimates (Gioli et al. 2004) and that can be used to validate fluxes simulated by distributed land surface models. Continuous, tall-tower based concentration measurements exhibit large signals (relaxing the need for sensor accuracy somewhat), that provide valuable information on diurnal flux dynamics representative of areas of  $\sim 10^4$  km<sup>2</sup>, provided that also the dynamics of PBL growth are well known. The footprint of such observations may be known through inverse lagrangian approaches, e.g back trajectories, etc. CBL budgetting approaches are sometimes succesful, but basically are limited in their application by the same factors: general lack of information on important parameters in PBL dynamics (e.g. entrainment, advection) and imprecise knowledge of the footprint. On the modelling side it has been demonstrated that both forward and inverse approaches can be 'downscaled' to resolutions of a few kilometers and may work in principle. But, where ecosystem fluxes are relatively well known for small space (plot) and time (diurnal) scales, anthropogenic fluxes are generally known only at national and annual levels respectively (from census data), requiring development of proper downscaling techniques.

The present proposal will build on this heritage from REcab and others, while closely collaborating with ongoing initiatives (CarboEuropeIP, ..) to advance on the development of both observational and modelling components that together will constitute an information system that will eventually be able to quantify - with known uncertainties - magnitudes and trends of CO<sub>2</sub> and other GHG emissions at scales of 10<sup>3</sup> -10<sup>5</sup> km<sup>2</sup>. Most partners involved in the present project maintain active research lines well embedded in the mentioned past and present international frameworks. Proper embedding, close collaboration, and sharing of data and tools will provide essential input for the proposed project to achieve its ambitious goals, and minimise the risk of failure by provision of a certain level of redundancy of tasks to be completed in both this project and its European equivalent.

We propose a project structured around five work packages, as outlined in section 5. The aim is to establish an intensive observational programme both at the ground and in the atmosphere, in order to quantify with the highest possible accuracy the balance of the most important greenhouse for the Netherlands **for at least a full year**. Improved, high resolution atmospheric transport models -forward and inverse- will help interpret and analyse the data. Multiple components will be measured and modelled as together they may constrain the atmospheric budgets better than. E.g. the use of <sup>222</sup>Rn to test the model behaviour for continental influence on the air masses. The forward modelled concentrations of components in the order of growing source complexity (<sup>222</sup>Rn, SF<sub>6</sub>, HFC, N<sub>2</sub>O, CH<sub>4</sub>, CO<sub>2</sub>) will help to evaluate and compare the performance of the different models. The emission budget of the other most important greenhouse gases will be quantified using the same models and inverse methods as for CO<sub>2</sub>

For socio economic relevance we refer to section 12.

#### **4 B. Relevant Publications (max. 10):**

- I. Dolman, A.J. Schulze, E-D. Valentini, R., 2003. Analyzing Carbon Flux Measurements. *Science*, 301: 916-917.
- II. Janssens, I.A., Annette Freibauer, Philippe Ciais, Pete Smith, Gert-Jan Nabuurs, Gerd Folberth, Bernhard Schlamadinger, Ronald W. A. Hutjes, Reinhart Ceulemans, E.-Detlef Schulze, Riccardo Valentini, and A. Johannes Dolman, 2003. Europe's Terrestrial Biosphere Absorbs 7 to 12% of European Anthropogenic CO<sub>2</sub> Emissions *Science* 300: 1538-1542; Published online May 22, 2003; 10.1126/science.1083592
- III. Vilà-Guerau de Arellano, J., B. Gioli, F. Miglietta, H.J.J. Jonker, H. Klein Baltink, R.W.A. Hutjes and A.A.M. Holtslag (accepted june 2004) The entrainment process of carbon dioxide in the atmospheric boundary layer. *JGR Atmospheres*.
- IV. A.J. Dolman, R. Ronda, F. Miglietta and P. Ciais (2004) Regional measurement and modeling of carbon balances Chapter in: H. Griffiths & P.J. Jarvis (Eds), *The Carbon Balance of Forest Biomes*
- V. S. Houweling, I. Aben, F.-M. Breon, M. Gloor, C. Rödenbeck, and P. Ciais, Inverse modeling of sources and sinks of CO<sub>2</sub> and scale dependent benefits of measurements from different satellite instruments, *Atmos. Chem. Phys.*, 4, 523-548, (2004).
- VI. B. Gioli, F. Miglietta, B. De Martino, R.W.A. Hutjes, A.J. Dolman, A. Lindroth, J. Lloyd, M.J. Sanz, R. Valentini and E. Dumas (accepted) Comparison between tower and aircraft-based eddy correlation fluxes in five regions of Europe. *Agric. Forest Meteorology*.
- VII. Bergamaschi P, Krol M, Dentener F, Vermeulen A, Ciais P & Graul R, 2004. Inverse modelling of national and European CH<sub>4</sub> sources using the atmospheric zoom model TM5. Submitted to *Atm Chemistry and Physics Discussions*
- VIII. Ramonet M., P. Ciais, Nepomniachii I., Sidorov K., Neubert R., Picard D., Kazan V., Biraud S., Gusti M., Kolle, Schulze E.-D. and Lloyd J., 2002. Three years of aircraft based trace gas measurements over the Fyodoroskoye southern taiga forest, 300 km North-West of Moscow. *Tellus B*, Volume 54-5: 713-734

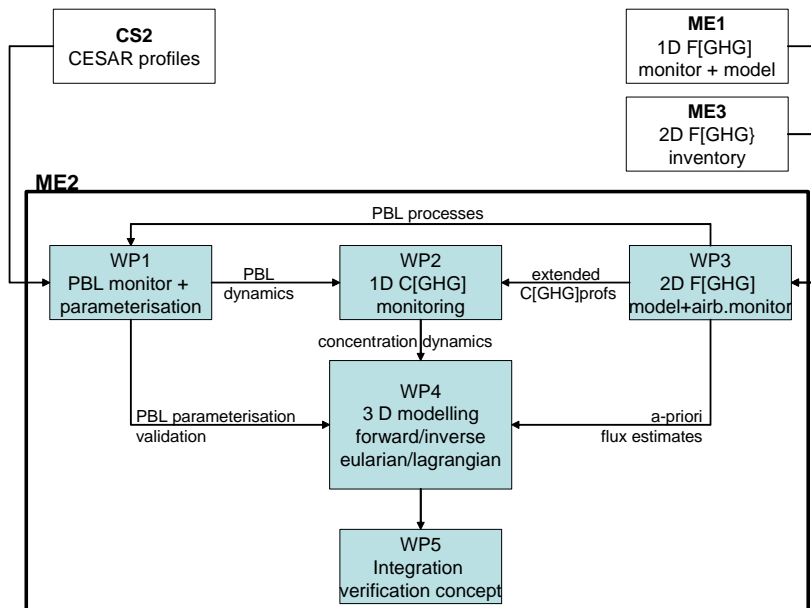
- IX. Gerbig, C.; Lin, J. C.; Wofsy, S. C.; Daube, B. C.; Andrews, A. E.; Stephens, B. B.; Bakwin, P. S.; Grainger, C. 2003b A. Toward constraining regional&hyphen;scale fluxes of CO<sub>2</sub> with atmospheric observations over a continent: 1. Observed spatial variability from airborne platform. *J. Geophys. Res.*108-D24, doi:10.1029/2002JD003018
- X. Apituley, A., A.v. Lammeren, and H. Russchenberg, High time resolution cloud measurements with lidar during CLARA, *Phys. Chem. Ear.*, 25 (2), 107-113, 2000

### 5. Description of the project; approach, methodologies and implementation plan:

The proposed project will be structured along 5 workpackages:

- WP 1. will address the influence of PBL dynamics and mixing processes on GHG concentrations observed within that same PBL. It will monitor continuous time series of PBL height and its driving variables at a number of locations in the NL. It will perform specific experiments addressing those aspects of PBL currently most limiting the progress in modeling and understanding. It will develop improved parameterizations for mesoscale models reflecting existing and new understanding.
- WP 2. will monitor, continuously and with high precision concentrations of GHGs (CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O, SF<sub>6</sub>, CO, HFC and Rn) at two sites and at several levels using tall towers. It will provide daily assessments (maps) of the source area for the measurements through backward trajectories. It will further develop a method to identify trends in long time series of observations using advanced filter techniques to separate the contributions from global scale regional and local scale.
- WP 3. will provide *a-priori* flux fields as input to the inversion models based on airborne flux observations, spatially explicit land surface models and input from inventory based methods. Airborne sampling strategies covering major Dutch landscapes and full seasonal cycles will be developed, as well as novel ways to scale these data and use them to calibrate the 2D LSMs.
- WP 4. will further develop the necessary forward (3D atmospheric) models providing the transport terms and source-receptor matrices for the inverse methods. It will further develop inversion algorithms allowing ingestion of the full suite of measurements made in WP2 and 3. Both eulerian and lagrangian approaches will be used.
- WP 5. will integrate the information from the other WPs directed at producing an annual, nation wide GHG budget constrained by atmospheric observations, and while doing so develop a protocol to provide an independent reference estimate for the verification of national emissions, that allows to determine the accuracy and credibility of the UNFCCC and Kyoto reports.

The five WPs, their mutual relations and relations to other BSIK projects are given in the following figure



## WP1 Novel Observations and Improved Parameterizations of the Atmospheric Boundary Layer

Partner	WUR-METAQ	KNMI	TUD	RIVM	Alterra	Total
Man months	70	34	26	10	3	143

Surface fluxes and the dynamics of the atmospheric boundary (ABL) have a major impact on the regional and global cycles of heat, water (vapor), greenhouse gasses and aerosols, and on the resulting concentrations of these. Given the poor quality of the current representations of the surface heat fluxes and the ABL in atmospheric models, there is an urgent need for improvement and evaluation on the scale of the model grid box (order of 5 to 50 kilometers). Evaluation of atmospheric flows simulated by meso-scale models (i.e. MM5, RAMS) has shown that the results are strongly dependent on the atmospheric boundary (ABL) layer scheme used. During daytime the ABL typically is too shallow as compared with observations (e.g., Holtslag, et al 1995; Vila et al, 2004). Consequently, the modeled boundary layer is characterized by lower values of the (potential) temperature and higher values of the specific humidity and mixing ratios of GHGs. Under nocturnal conditions, the model results show the difficulty to predict the minimum temperature and peak GHG concentrations close to the surface as a result of too much mixing (e.g., Vogelesang and Holtslag, 1996).

Therefore WP1 has the following objectives, and related tasks:

- 1a. To make an assessment of the performance of the boundary layer and surface flux schemes against detailed single column observations (both existing and novel) at Cabauw, NL
- 1b. To monitor and parameterize the spatial variation in ABL dynamics over the Netherlands in relation to the variation in its drivers
- 1c. To evaluate and to improve ABL parameterizations in 3D meso-scale atmospheric models.

Task 1a focuses on boundary layer budgets and profiles at Cabauw. The existing database will be expanded with data from new instruments providing much more detailed information than currently available. Surface sensible heat fluxes on scales up to 10 kilometers will be monitored using *scintillometry* (Meijninger et al, 2002; see appendix 2). A novel *lidar* will provide detailed profiles of water vapor and high resolution estimates of ABL height (Van Pul et al., 1994; Turner, 2002); a novel *radar* will provide profiles of mixing intensity ( $\sigma_w$ ) (both in collaboration with project CS2). See appendix 2. With WP3 we will add aircraft data of flux profiles for specific cases. Thus, a virtually *continuous* record of ABL dynamics will be built against which we assess the performance of the boundary layer schemes (mostly in column mode), thereby focusing not only on specific (ideal) case studies, but also on ‘average’ performance under a wide variety of synoptic conditions.

Task 1b addresses the spatial variation of the ABL and its dynamics. The variation will be monitored through a new operational network of optical scintillometers over different types of terrain (providing sensible heat fluxes), in combination with ceilometer data from a number of operational stations of KNMI (providing ABL height). For the latter a procedure for deriving boundary layer depths from ceilometer data will be developed and validated against high-resolution lidar measurements at Cabauw (with task 1a and project CS2) and subsequently applied to the network data. The results are compared with results of a 3D mesoscale model with high resolution. As such the model system creates the possibility to calibrate and evaluate the surface fluxes and the dynamics of boundary layer profiles on regional scales.

Task 1c will focus on evaluation and improvement of the representation of the surface fluxes and especially of the atmospheric boundary layer. Two broad categories of ABL schemes exist: non-local K scheme (Holtslag and Boville, 1993; MRF scheme by Hong and Pan, 1996) and local K scheme (ETA, Burk and Thompson, 1989). The comparison between model results and observations have shown that non-local K schemes are more suitable to reproduce the main features of the diurnal boundary layer whereas local K schemes performed better under stable stratification situations. Note that most of the recently published ABL parameterization improvements are not yet implemented in e.g. RAMS, MM5 and RACMO, which hampers the quality of these models for practical applications and scenario studies. Therefore, a fast track approach will be followed in which state of the art insights and parameterizations (e.g. Cuijpers and Holtslag, 1998; Van der Wiel et al, 2002; Lenderink and Holtslag, 2004; Vila et al, 2004) will be implemented in a mesoscale model and evaluated under various atmospheric conditions (with help of the data of task 1a). Subsequently, the performance on the regional scale will be evaluated in meso-scale models using the observations of task 1b and project CS2.

## WP 2 Greenhouse gas concentration measurements and satellite retrieval

Partner	ECN	RUG CIO	TNO-MEP	SRON-IMAU	WUR METAQ	total
Man months	24	67	19	12	8	130

Inverse model verification of emissions forms a challenging task, for which the correct combination at all relevant scales in time and space of observational data and models, and the ability of the model(s) to describe the factors that influence the concentrations, is of utmost importance. Budget limitations budget constrain number of species and frequency of the observational and model data based on cost-effectiveness and judgement of fit-for-purpose. In this WP we will monitor concentrations of the most important greenhouse gases at two tall towers in The Netherlands with high precision and high time resolution. Several studies have shown that tall towers receive source information in the concentration signal from an area round the tower extending several hundreds of kilometers. Therefore two towers will most likely give enough information on the emissions of the study area. More than 50% of the CH<sub>4</sub> concentration signal at Cabauw on top of the global background can be assigned to the area of the BeNeLux countries (Vermeulen et al., 2001; Bergamaschi et al., 2004). The data from the additional tower at Lutfjewad will further constrain the emission fluxes of the land surface of the Netherlands, as well as from coastal seas to the north. Also column total concentrations of GHGs will be derived on the basis of remote sensing. One of the main innovative features of the project is the multi-scale, multi-component approach.

WP2 has the following objectives, and related tasks:

- 2a. To derive long term observational data on GHG concentrations for CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O, SF<sub>6</sub>, CO, HFC's and <sup>222</sup>Rn at representative locations at several vertical levels using tall towers and using a satellite retrieval system for selected tracers
- 2b. To give insight in the source areas for the tall tower measurements through backward trajectories on a day to day basis
- 2c. To identify trends in long time series of observations using advanced filter techniques to separate the contributions from global, regional and local scale.

Task 2a.1 Monitor, continuously and with high precision, concentrations of GHGs (CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O, SF<sub>6</sub> and <sup>222</sup>Rn) at the sites Lutfjewad & Cabauw (Cabauw also CO+HFC's) and at several vertical levels using two tall towers. The temporal resolution of the observations will fit with time scale of concentration change in the atmosphere as determined by mixing and transport and source/sink terms: this time scale is 1 hour or less. Continuous records over several years allow for detection of long term trends and allow for better quality inversions, due to better statistics. We will expand existing records (CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O, CO) and add new species (HFC, <sup>222</sup>Rn). A high precision of the concentration data is required for the data to be successfully inverted using models also fed and/or based on background observational data (NOAA CMDL, ALE/GAGE etc.), in order to avoid systematic errors in the mean fluxes due to small absolute errors in the mean concentrations levels. Therefore, continuous careful calibration of the instruments and comparison with the worldwide observational networks is required, and will be provided within EU FP6 project CarboEurope IP, next to constant quality control of the measurements. The multi component measurements will allow for not only determining emissions of several of the most important greenhouse gases at the same time, but will also allow for testing model performance by using the information supplied by <sup>222</sup>Rn levels and that of sources with lower complexity in spatial/temporal patterns of the emissions (SF<sub>6</sub>, HFCs). Observations of CO and <sup>14</sup>C levels allow for determination in the measured signals of the relative importance of sources of fossil origin versus other sources (for experimental setup see Appendix 2).

Task 2a.2 Within this task we will investigate the use of satellite measurements in the form of Sciamachy retrieved total columns of CO<sub>2</sub>. This product is expected to be most useful over remote continental regions at large distances of operational surface monitoring sites, which is true for most of the tropics. In addition, however, we will evaluate to potential of the available measurements over the European continent. CO<sub>2</sub> retrieval will be carried out in framework of this task, with emphasis on regions and times that are relevant to the other measurement and modeling activities.

Task 2b provide daily assessments (maps) of the source area for the measurements through backward trajectories. This will also allow selecting periods that provide useful information for the inverse modeling exercises (WP4) and help at evaluating periods with airplane observations (WP3). The resulting ABL parameterizations of WP1 will be applied to the measured vertical concentration gradients at both tall towers to estimate on a daily basis the local surface exchange fluxes along the footprint area of the towers.

Task 2c Develop a method to identify trends in long time series of observations using advanced filter techniques to separate the contributions from global scale regional and local scale. This part of the project proposes a method to identify trends in long time series of observations. In Roemer et al. (2003) and Roemer and Tarasova (2002) filter techniques were developed to separate the global scale from the regional and from the local scale. In this task the filter techniques to separate the regional from the local scale will be improved. This will be done by simulating the long time series developed in this project of CH<sub>4</sub> and some of the other gases with the LOTOS model system. The contributions of different scales can be marked and identified in the time series. This will enable the development of a more refined filter. Secondly, the meteorological variables in the LOTOS model will be used to quantify more precisely the influence of the meteorological variability. This will enable to improve the regression model and to more precisely quantify the emission part in the trends of CH<sub>4</sub> and CO<sub>2</sub> at the measurement locations This method will be applicable also on other time series.

**WP3 Spatially explicit quantification of GHG fluxes through measurements and modelling.**

Partner	Alterra	VUA	WUR METAQ		total
Man months	61	6	5	0	72

Inversion techniques need *a-priori* estimates of GHG fluxes at the surface. At present these are generally derived from one or a combination of the following: distributed ecosystem models (calibrated using fluxtower data), remote sensing based ecosystem models, neural network interpolated flux tower data, and inventory based emission data, downscaled in space and time to relevant resolutions. This work package will provide *a-priori* estimates of natural GHG fluxes based on distributed ecosystem models (calibrated using flux tower data from project ME1), improved and verified through airborne flux measurements. For anthropogenic fluxes we will build on inventory based products developed in project ME3.

Airborne eddy correlation is proven tool to measure energy and carbon dioxide exchange at the “regional scale” (Stull, 1989, Culf et al., 1997, Millan et al., 1996, Lloyd et al., 1996) and may give results no less accurate than from a careful flux-tower operation: the primary difference is in how the data must be interpreted (Mahrt, 1997). Recently, an extensive comparison between airborne and ground-based flux data has been concluded for seven flux measurement sites in Europe, based on the same airborne (mobile) flux platform (MFP) as proposed in this project (Gioli et al. accepted). Friction velocity ( $u^*$ ) and latent heat flux ( $\lambda E$ ) estimates made by airborne and tower data were comparable at all sites and under whatever condition, but for CO<sub>2</sub> and sensible heat fluxes differences between the two were found that could be attributed to flux divergence with height.

The objectives and tasks of WP3 are:

- 3a. To make operational in the Netherlands an airborne facility for measurement of turbulent fluxes of heat momentum and CO<sub>2</sub> and develop an airborne observational strategy for dedicated campaigns, execute and analyse
- 3b. Develop an observational strategy for full year MFP sampling of major Dutch landscapes, execute and analyse producing regional flux maps
- 3c. Produce flux maps, continuous in space and time, for *a-priori* inversion estimates, combining 3b data and distributed ecosystem maps and inventory data,

Task 3a will acquire a SkyArrow650ERA equipped with dedicated turbulence and slow response instruments (see Appendix 2) and make it operational .We will develop an airborne observational strategy for dedicated campaigns, execute and analyse falling in two generic classes: *PBL campaigns*: generally vertically stacked short transects from surface to above PBL top, near Cabauw or otherwise intense PBL probing sites, (input to WP1). *Specific landscape* campaigns: e.g. urban, inland & coastal waters, campaigns (coordinated with ME1); generally a single landscape in dedicated short campaign (input to task 2 & 3). Campaigns of these types are foreseen for year 1 and 2 and if needed year 4. Post-processing software tool development, GIS integration, will be further developed in collaboration with international partners employing an identical aircraft.

Task 3b will develop an observational strategy for full year MFP sampling of major Dutch landscapes, execute and analyse. In preparation we will use strategic 2D modeling using the same distributed ecosystem models as employed in the next task to develop a sampling stratification in space (major Dutch landscapes) and time (critical phases in seasonal cycle), in conjunction with flight pattern development. The sampling concept will be developed and tested in conjunction with the CarboEuropeIP Regional campaign, foreseen in 2006. In 2007 we will execute for at least 1 year systematic and repeated sampling in the Netherlands itself, process the data and build a database. In parallel we will develop a scaling technique translating transect-based MFP data to regional maps (e.g. based on land cover class specific light response curve).

Task 3c will develop accompanying techniques to exploit these data, using their full information content, to calibrate/validate distributed land-atmosphere exchange models, aka TEMs (either coupled to RAMS as used in WP4, or stand-alone). A combination of short-term SVAT models will be used such as SWAPS-C and ANIMO, to parameterize and calibrate daily and seasonal GHG fluxes and longer-term models such as CENTURY and FORSPACE, to calibrate the longer-term effects of growth and SOM dynamics. Normally these models have been validated/calibrated against tower data for at best a limited number of selected sites, deemed representative for their particular land cover class (as will be done in project ME1 !). The aircraft flux data provide information on spatial variations within these classes and direct estimates of aggregate fluxes integrated over more than one land cover class, and thus, in principle, providing additional constraints for model parameters. This requires the development of novel quantitative multi-variate optimization techniques to calibrate model parameters against measurements, and as a first step involves an assessment of the essential functional parameters needed in multi-gas SVAT models, and of the required precision in these to usefully contribute to *constraining regional* fluxes. The improved distributed models, in combination with downscaled anthropogenic emission inventory data (from ME3), will then provide the flux maps, continuous in space and time, for *a-priori* inversion estimates in WP4.

#### **WP 4 Regional scale forward and inverse modeling of sources and sinks of CO<sub>2</sub> and CH<sub>4</sub>**

Partner	VUA	Alterra	TNO-MEP	SRON- IMAU	WUR- METAQ	ECN	total
Man months	64	36	19	36	18	24	197

With the inverse modelling concept, the distribution and temporal evolution of CO<sub>2</sub> in the atmosphere can be used to quantify surface fluxes, using numerical models of atmospheric transport. Errors inherent in large-scale inversions-based sink/source estimates of CO<sub>2</sub>, can be substantially reduced when at the regional level a good link between the measurements obtained at the surface flux stations and those from continental scale inversions can be established. Gerbig et al. (2003) indicate that a significant fraction of the information contained in the signature of boundary layer CO<sub>2</sub> is contained in relatively small spatial and temporal scales. This suggests that to be able to use the variance of the observations, analysis with grid cells of less than 30 km is required. This requires experimental sampling and model development to resolve the diurnal timescale and to be appropriate at such small spatial scales.

In order to produce a best estimate of GHG emission and carbon uptake and its uncertainty, we need to make use of all of the constraints implied by the different data streams, as well as the atmospheric, physiological and ecological process-related constraints embodied in behaviour of the land surface and Terrestrial Ecosystem Models (TEMs). Thus, we need to simultaneously use the observations to constrain the internal parameters of the models, whilst using the models to interpolate the observations to produce useful large-scale estimates of the carbon sink and its causes. This requires a combination of forward and inverse models.

The methodology proposed here will produce aggregated regional estimates of ground based data that can be meaningfully compared to those from the smallest downscaled information of atmospheric measurements which can currently be expected from a continental scale inversion models (of order 50 km). Recently, a number of studies have demonstrated the feasibility of this method and confirmed that the concept is promising (Gurney et al., 2002). These studies address large scales only, regional scales are less well investigated yet – most likely – more complex and challenging. See Appendix 1 for a short description of the models used.

WP4 has the following objectives and related tasks:

- 4a. to provide a quantitative assessment of the performance of a set of transport models and inversion algorithms
- 4b. to develop and apply a nested modeling framework for the estimation of sources and sinks of CH<sub>4</sub>, N<sub>2</sub>O and CO<sub>2</sub>
- 4c. to apply Lagrangian Dispersion models to estimate regional sources and sinks
- 4d. to provide a modeling framework that can be used as a prototype verification system for regional emissions.

Task 4a Inverse models suffer from errors that are caused by poor simulation of transport and by errors introduced by the inverse algorithm, choice of a priori values, parameters etc (Gurney et al., 2002). We will set up a systematic intercomparison of the performance of the models used in our project, by trying to separate the transport error from the inversion error, by comparing transport performance separately against Radon and SF<sub>6</sub> measurements, and by separately comparing the performance of algorithms with single imposed transport for

specific cases. This allow us to better quantify the uncertainty involved in our approach and feeds back immediately in activity 4.

**Task 4b** Two nested models are used in this project: TM5 and LOTOS (TM3 based). We propose to develop an inverse modeling system for the quantification of sources and sinks of CO<sub>2</sub> and CH<sub>4</sub> over the European continent. For this purpose we will use the atmospheric chemistry and transport model TM5 and we will explore the combined use of tower and satellite data. The obtained source and sink estimates are expected to reduce the uncertainties of the currently available greenhouse gas emission inventories, and will provide useful boundary conditions for smaller scale analyses, aiming, for example, on the Netherlands. In a grid model the transport within a few grid cells around a source is poorly described. Improvement is expected when the very local transport is described by means of a plume model. It is proposed to incorporate a plume model into LOTOS zoom as a first step in improvement. A second step is made by using meteorological fields that take into account local features. It is expected that both steps will lead to a better forward simulation of GHG and other components, thereby leading to more reliable emission estimates by inverse modelling.

**Task 4c** Lagrangian particle transport models are based upon the assumption that turbulent diffusion can be modeled as a Markov chain. Their main advantage that no choices have to be made on beforehand of model grid sizes, inherent numerical diffusion that causes Eulerian models to have effective spatial resolutions of 2-3 times the grid size and too large vertical diffusion is also absent. The calculation times scale linearly with the number of particles modeled. Another advantage of the lagrangian approach is that processes like entrainment are modeled through particle movements quite naturally without required strong parameterizations to force them in a vertical grid structure. We will use FLEXPART [(Stohl, 2002) and LPD (Lagrangian Particle Dispersion) or perhaps its advanced version STILT (Lin et al., 2003) in the current project. For background conditions we will be using background concentration data from the TM5 model for the borders of the modeled domain. (activity 2) A relatively simple trajectory model (COMET) will be extended to more gases and improved in order to be used to (inverse) model long timeseries for several stations. Special attention in COMET will be payed to the description of the Boundary Layer height based on the improved schemes developed in WP1.

**Task 4d** Ideally, the inverse modelling framework should be able to determine fluxes at a spatial resolution of at least 10 km, compatible with the coarse end of the continental scale resolution and the influence region of the CBL, with temporal resolution of at least a week. These Inversions provide objective uncertainties of the estimated net surface emissions. Using various combinations of atmospheric observations, the inverse modelling framework also permits studies of optimal sampling strategies for adding new stations to the network. We will implement a strategy to develop such an inversion system based on results from WP1 to WP3, that not only quantifies the emissions at small spatial scale, but also generates the associated uncertainties. Here, the high resolution forward models RAMS and MM5 will be used to produce the source-receptor matrices, forced at the lateral boundaries by fields generated in task 4.b.

#### **WP 5 Integration to annual, nation wide GHG budget and verification-protocol development**

Partner	Alterra	VUA	WURMETAQ	ECN	RUG-CIO	IMAU/SRON
Man months	12	12	6	12	3	8
Partner	TNO-MEP	KNMI	TUD	RIVM		total
Man months	2	3	2	1		61

For the Dutch NIR (Olivier, et al.2002) uncertainties in GHG emissions are reported as 3%CO<sub>2</sub>, 25%CH<sub>4</sub>, 50% N<sub>2</sub>O (or together in CO<sub>2</sub>eq 5%) and uncertainties in trends as 3%, 7%, 12% respectively (CO<sub>2</sub>eq 3%). The observed emission trends between 1990-2000 are reported as +9%, -24%, +3% respectively (CO<sub>2</sub> eq +3%). Uncertainties of top-down inversion estimates are typically much larger (easily >100%). Nevertheless, we believe that top-down inversion estimates may eventually provide a useful check on the magnitude and trends of bottom-up derived emission estimates, especially when emission reductions as targeted for Kyoto at -6% in 2010, become much more severe after Kyoto (-30%).

The objectives of this work package are:

- 5a. To make a first attempt ever at independently verifying Dutch national emissions, as reported in the UNFCCC-NIR, for one particular year
- 5b. To outline a verification protocol based on the experiences in these.
- 5c. Communicate the value, limitations and perceived future prospects of inversion based verification methods to policy makers

Task 5a will guarantee that the execution of the respective work packages are properly coordinated with respect to each other, that data, model components and algorithms are shared and become available at appropriate phases, and last but not least that all partners work together to producing an annual nation wide GHG budget (for management structure see section 7 of this proposal. In terms of *planning* we see the first two years as a development and testing phase for the separate elements which together should constitute a verification methodology. During that phase e.g. model parameterizations will be improved; data processing chains will be developed and tested; inversion algorithms improved; etc. Year three (2007) will be the year for which we aim to close atmospheric budgets. The observational network and strategy should be in place producing a continuous and precise as possible dataset of GHG concentration time series, airborne flux measurements and PBL dynamics. Year four will be devoted to further processing and analyzing the data from the previous year; to run forward models for the full year and target domain and to apply the inversion algorithms to full year data. coordinated efforts are required to arrive at a tested verification protocol. 80% of the time scheduled for this WP is allocated to the latter tasks.

Task5b will perform a critical evaluation of the observational and modeling activities in year 3 and 4 that will then form the basis for compiling a protocol for emission verification. The evaluation will be in terms of a) relevance, coverage and accuracy of input data; b) relevance, performance and practicality (e.g. computational constraints) of modeling tools and algorithms; c) possibly missing observations or limiting model components; d) implications of the above for resulting uncertainties in output (i.e. annual flux estimates).

Task5c Stakeholder interactions (see item 10 of this proposal), concentrated in early and late phases of the project. The first stage interaction should discuss the possible future status of verification and the implications that might have for the verification tools. This involves confrontation of uncertainties of both bottom-up and top-down methods, their meaning and potential use. Towards the end of the project we will come back to issues and discuss progress resulting in an assessment of the value, limitations and perceived future prospects of inversion based verification methods to policy makers.

**6 A. Output and/or Products:**

See Gantt chart

**6 B. Milestones Knowledge Transfer and Dissemination (maximum 1 page):**

See Gantt chart

**6 C. Milestones Translation into Application (maximum 1 page):**

See Gantt chart



**WP3 Spatial quantification of GHG fluxes**

**Task 3.a Campaign mode airborne flux studies**

M3.a.1 SkyArrow650ERA operational

M3.a.2 PBL and Landscape campaigns

D3.1 Campaign wise QA'd datasets

D3.2 Report/papers on 1) PBL studies; 2) specific landscape studies

**Task 3.b Operational airborne flux mapping**

M3.b.1 Stratification/sampling strategy ready

M3.b.2 Scaling technique based on airborne flux measurements

M3.b.2 Operational sampling SW France completed

M3.b.3 Operational sampling Netherlands completed

D3.3 QA'd data set on regional fluxes SW France

D3.4 QA'd dataset on regional fluxes Netherlands

D3.5 Report/papers on 1) sampling strategy; 2) French dataset 3) Dutch datasets

**Task 3.c A-priori flux maps for inversion studies**

M3.c.1 1) TEM parameters from ME1; 2) Anthropogenic fluxes from ME3

M3.c.2 TEM optimisation technique using airborne data

M3.c.3 Synthetic a priori flux datasets (3 monthly QA'd delivery)

D3.6 Synthetic a priori flux datasets

D3.7 Report/paper on 1) TEM optimisation; 2) a-priori flux datasets

**WP4 Regional scale forward and inverse modelling**

**Task 4.a Assessment of inverse model performance distinguishing transport and inversion errors**

M4.a.1 Intercomparison protocol ready

M4.a.2 Intercomparison analysis ready

D4.1 Report/paper on Assessment

**Task 4.b Continental scale (nested) modelling**

M4.b.1 TM5 inversion method ready

M4.b.2 LOTOS subgrid plume model implemented

M4.b.3 LOTOS local meteo improvement ready

D4.2 Improved model versions of TM5/LOTOS

D4.3 lateral boundary forcing dataset for hi-res modelling

D4.4 Report/papers on 1) TM Inversions and 2) LOTOS improvements

**Task 4.c Lagrangian modelling**

M4.c.1 STILT model implemented for EU/NL

M4.c.2 STILT analysis 'golden year'

M4.c.3 FLEXPART analysis 'golden year'

D4.5 Lagrangian emission estimates NL

D4.6 Report/paper lagrangian emission estimation

**Task 4.d National scale (nested) modelling**

M4.d.1 National scale forward model implemented

M4.d.2 national scale inversion algorithms implemented

D4.7 'Operational' modelling chain ready

D4.8 Report/paper on national scale modelling

**WP 5 Integrated GHG assessment and verification-protocol development**

**Task 5.a Integrated GHG emission assessment for 'golden year'**

M5.a.1 Forward model analysis of 'golden year' (3 monthly delivery)

M5.a.2 Inverse analysis of 'golden year' (3 monthly delivery)

D5.1 Annual, national GHG emission estimate

D5.2 Report/paper on national GHG emission estimate

**Task 5.b Verification protocol development**

M5.b.1 Evaluation of data needs ready

M5.b.2 Evaluation of modelling tools ready

M5.b.3 Evaluation of error propagation

D5.3 Verification protocol

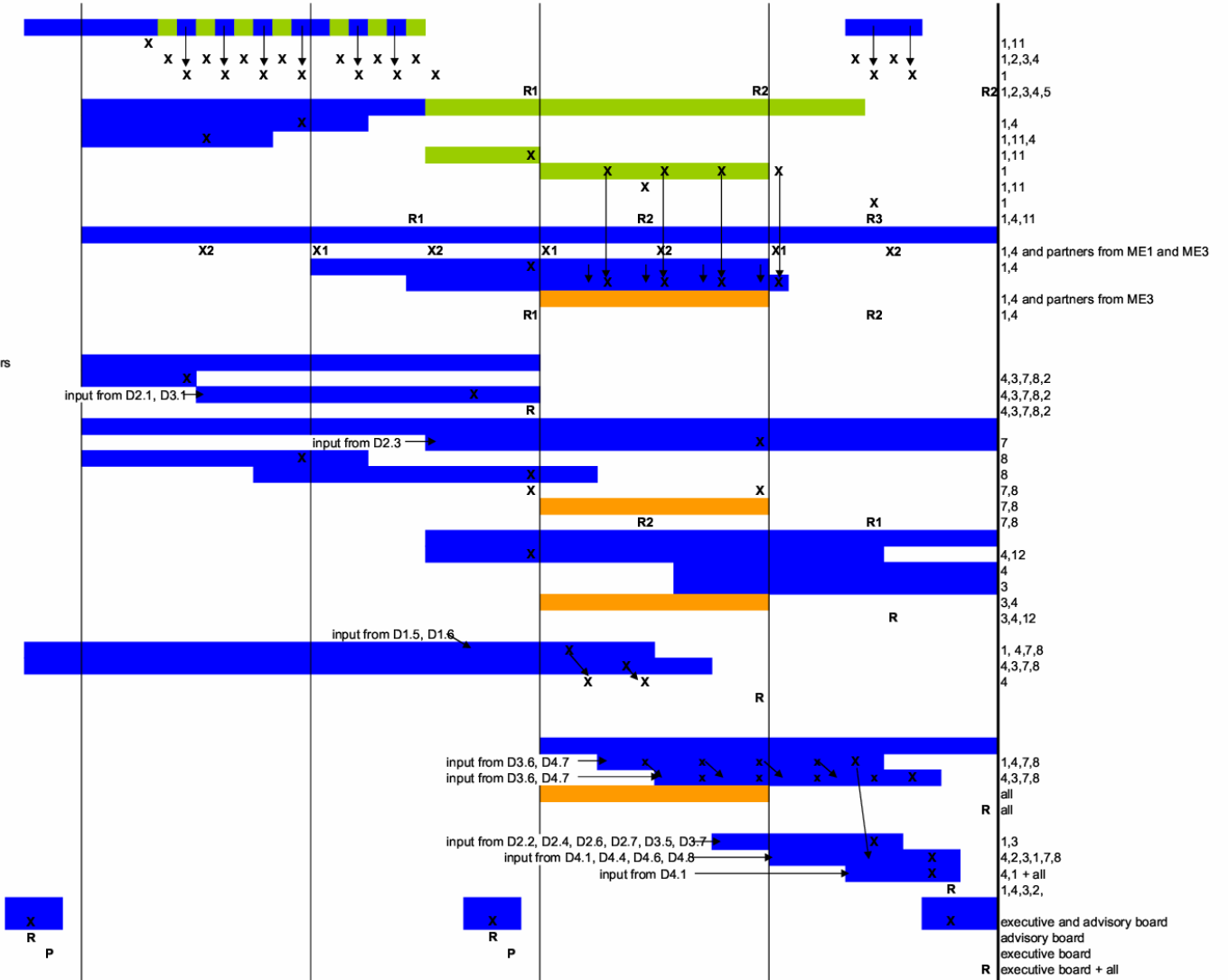
**Task 5.c Stakeholder interactions**

M5.c.1 Stakeholder workshops

D5.4 Project evaluation report

D5.5 Revised project plan

D5.6 Policy paper on verification potential



<b>7 Consortium</b>			
<b>7 A. What are the involved Core-partners (science, public, private)? Please, give name institute and name contactperson.</b>			
	<b>Name</b>	<b>Contact person</b>	<b>Science/ Public/ Private</b>
<b>Coordinating Institute/ Partner 1</b>	Alterra	Ronald Hutjes	Science
<b>Partner 2</b>	Wageningen University, dept Meteorology and Airquality	Bert Holtslag	Science
<b>Partner 3</b>	Energy Centre Netherlands	Alex Vermeulen	Science
<b>Partner 4</b>	Free University Amsterdam, dept Earth and Life sciences	Han Dolman	Science
<b>Partner 5</b>	KNMI	Fred Bosveld	Science
<b>Partner 6</b>	Groningen University, Centre for Isotopic Research	Rolf Neubert	Science
<b>Partner 7</b>	National Institute for Space Research (SRON), Utrecht University - Institute for Marine and Atmospheric Research	Sander Houweling	Science
<b>Partner 8</b>	TNO Environment, Energy and Process Innovation	Michiel Roemer	Science
<b>Partner 9</b>	Technical University Delft, International Research Centre for Telecom - Transmission and Radar	Herman Russchenberg	Science
<b>Partner 10</b>	RIVM, Laboratory for Environmental Monitoring	Arnoud Apituley	Science
<b>Partner 11</b>	IBIMET, Florence, Italy	Franco Miglietta	Science
<b>Partner 12</b>	MPI-BGC, Jena, Germany	Martin Heimann	Science

<b>7 B. Which other organisations are involved in the project?</b>
<p><b>Privat Partners (enterprises, consultancy)</b></p> <p>Aircraft operations will be outsourced to a private enterprise (probably a Small or Medium sized Enterprise - SME) that will be responsible for aircraft maintenance and operations. Aircraft flying time will be hired at an hourly rate comprising fuel and maintenance costs, pilot hire, insurance, etc. The company is yet to be identified and conditions negotiated.</p> <p>Two international partners will collaborate in the project, both from the CarboEurope IP consortium : IBIMET, Firenze, Italy; PI Dr Franco Miglietta will collaborate in WP3 assembling the instrumentation on the aircraft, sharing post processing software, and collaborating in flight planning and data analysis in both the current proposed Dutch monitoring activities as well as in CarboEurope campaigns. Collaboration will be intense through a planned ‘Scholarship for visiting scientist’ (separately funded) enabling IBIMET scientist to work at Alterra for at least 6 months. MPI-BGC, Jena, Germany; PI Prof Martin Heimann will collaborate in WP4 in developing inverse methods to derive fluxes at regional scales.</p> <p><b>Public Partners (NGO’s, interest groups)</b></p> <p>Selected public and governmental partners will be represented in the Advisory Board see sections 7C and 10A</p> <p><b>Governmental Partners (national, local, regional, water boards)</b></p> <p>Selected public and governmental partners will be represented in the Advisory Board see sections 7C and 10A</p>
<p><b>7 C. What is the organisation/management structure and how is participation with non-consortium partners arranged?</b></p> <p>The proposed consortium consists of leading Dutch research groups for their respective fields of expertise. The partnership is largely complementary in terms of specific expertise, with little overlap in observational of theoretical skills, but all share a strong track record in areas of GHG emissions and atmospheric transport. The Alterra group has a long tradition in measuring and modeling land surface atmosphere interactions, especially long term monitoring of ecosystem exchange of carbon and its modeling, initiating and coordinating regional studies on the carbon balance (RECAB) and exploring the use of high resolution 3D atmospheric models in this context. The WUR METAQ group has a long track record of ABL studies and land surface exchanges at both plot and regional scales, and both observational and modeling. The ECN group for many years already monitors</p>

GHG concentrations (and other air quality parameters) in the Netherlands, and analyses the data using inverse models, also in the emission verification context (for CH<sub>4</sub>). The VUA group is experienced in carbon cycling in general and recently explored the potential of inverse modeling at high spatial resolutions. The KNMI group, RIVM and TUD groups have a long term involvement in measurements (a.o. by remote sensing) of atmospheric dynamics and composition and their interpretation at Cabauw. The IMAU/SRON group has a long standing research line in 3D modeling (also inverse) of atmospheric chemistry in relation to emissions and transport at large scales, as well as in exploring the use of satellite retrieval of GHG concentrations. The TNO-MEP group is highly experienced in monitoring air-quality parameters and its (trend) analysis through 3D and regression type of models.

Together, we believe this group to harbor all the necessary expertise to maximize the chances of success of reaching proposed project goals. It is a combination of groups that have solid international reputation, proven ability to contribute significantly to complex research projects and complementary skills in estimating and observing and modeling regional emissions of GHGs.

The project is structured along 5 work packages. For each a responsible PI will be appointed. These WP leaders have been chosen for scientific track record in the respective research areas and their proven management skills in related (international) projects:

- WP1 leader (prof Holtslag) has a strong reputation in ABL studies and currently chairs the WCRP *GEWEX Atmospheric Boundary Layer Study (GABLS)*.
- WP2 leader (dr Vermeulen) has a strong reputation in GHG monitoring and inverse lagrangian modeling and currently chairs the CarboEurope project *Continuous High precision tall tower observations of greenhouse gases (CHIOTTO)*
- WP3 and 5 leader (dr Hutjes) has a strong reputation in mesoscale modeling of GHGs and carbon cycling and until recently chaired the CarboEurope project *Regional assessment monitoring of the carbon balance in Europe (RE CAB)*
- WP4 leader (prof Dolman) has a very strong reputation in carbon cycling studies at regional and plot scales; until recently he chaired the CarboEurope cluster of projects and currently chairs the CarboEuropeIP component on Regional Carbon budgets

These WP leaders and coordinator together will constitute the *project executive board* responsible for day to day operations, meeting 4 times a year or more often as required, otherwise interacting by phone/email. Regular meetings at project and work package level involving all relevant partners are foreseen. At project level at least on a yearly interval, at work package level on a 6 month basis or more often as needed.

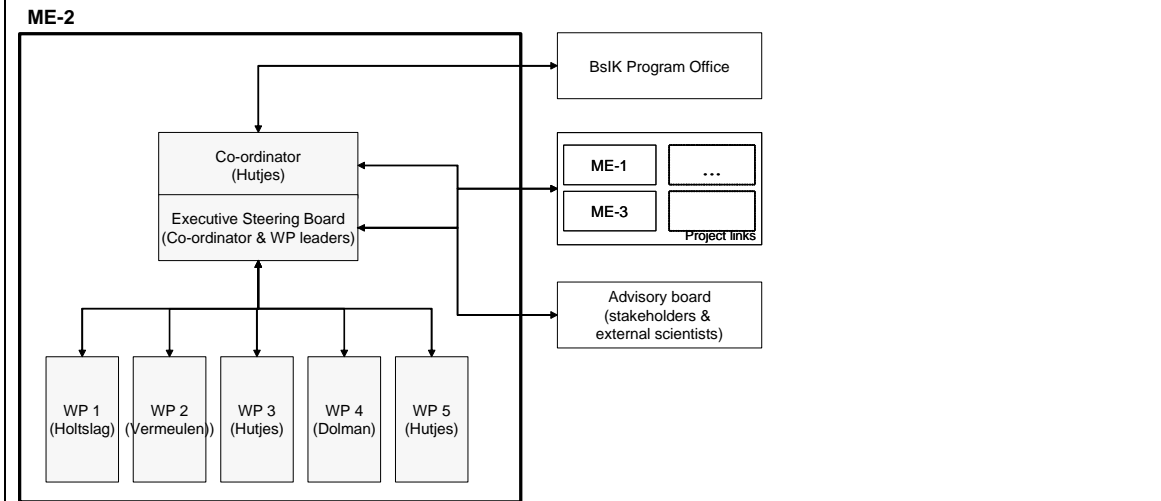
The coordinator is responsible for communication between the project and the BSIK programme office particularly regarding the conformance with contractual provisions and the implementation of contingency plans where needed. He will ensure appropriate and timely financial and scientific reporting.

The *project executive board* is responsible for the effectiveness of the "internal" communication and decision making between the co-ordinator, work package leaders, individual PIs and PhD supervisors. It is also responsible for project communication with stakeholders (anticipation of outcomes and possible end-users interests, contact preparation and follow-up), project self-assessment through benchmarking activities, and possible conflicts of interest regarding data policy, intellectual property and commercialization of project research output.

Strong interactions are foreseen with the ME1 and ME3 projects also proposed in this BSIK programme. This is informally facilitated by considerable overlap between ME1 and ME2 in the groups and PIs involved. More formally, we will occasionally organize joint steering board and even joint project meetings. The latter will be held at project start, mid-term and towards project conclusion. The joint executive/steering board meetings will meet additionally in-between the joint project meetings.

The *project executive board* will also be the primary point of interaction with the stakeholders represented in an *Advisory board*. The advisory board will advise on overall project goals and their translation in tasks, and in response to requests of the of this group the executive board will provide policy-relevant syntheses of project results, but also respond quickly on ad hoc requests in order to produce a harmonized, consolidated response from the consortium. See section 10 for more.

The following figure outlines the described management structure:



**8 A. Team-members Project Team who will carry out the research**

See ME2 TEAM COST.xls

**8 B. Please attach CV or other documents of all involved researchers to illustrate scientific excellence. (Please use CV template)**

See Appendix 4

**9. Time schedule, including delivery of products, responsibilities/tasks by partner**

See gantt chart

**10 A. Knowledge: distribution and transfer (maximum 3 pages)**

Communication activities will be developed in close collaboration with the BslK dissemination strategy through the National Communication Centre on Climate Change, NCCC, as part of project IC1. The coordinator will have responsibility to act as liaison between NCCC and the current project.

**Scientific dissemination**

Scientific knowledge will be disseminated in publications in peer-reviewed journals, also as special issues and books if appropriate, on conferences held together with annual project meetings, external conferences and internal and open workshops in specific project activities and for specific questions integrating several activities and components such as the harmonisation of measurement protocols and data – model intercomparison. Web and ftp-based activities will be the central tool for project internal communication but will also provide a user-friendly interface for policy makers and the broad public served with up-to-date information. We will aim to set up within the BslK overall database activities a web based data base that allows retrieval of GHG concentration and flux measurements, as well as consolidate products in the form of aggregate emission estimates at (sub)national levels.

Data will become available to project members as soon as possible, i.e. unchecked data no later than about a month after acquisition; data gone through some minimum level of post calibration and quality assurance no later than 6 months after acquisition. After that, improved and more consolidated data versions will become available depending on research progress. We envision an open data policy, meaning that internally published data generally will also be available to scientists and others outside the project, in return requesting joint analysis and co-authorship of resulting publications.

We will co-ordinate efforts in modelling (future projections, assimilation methods, and analysis of past changes) integration, interpretation, and future data acquisition strategies. We will contribute to the development of common assessment methods and state-of-the-art reports within the context of international projects like CarboEurope IP and the Joint Carbon Project and the Global Land project of IGBP/WCRP.

We intend to organise (in collaboration with others, and separately funded) international summer schools to disseminate the methodological and theoretical knowledge gained during the field campaigns and modelling studies to PhD students and interested staff. In these summer schools time will also be devoted to the translation

of research findings to policy aspects, building on the one hand on the experiences obtained in the former National Research Programme on Global Air Pollution and Climate Change and on the other on more recent policy research." Five PhD positions are included in the current proposal. For them we will seek linkage with the research schools 'SENSE' and 'Buys-Ballot' directed on research and education on fundamental processes in the climate system. They will also participate in PhD seminars together with PhD from projects ME1 and ME3.

### **Stakeholder dissemination**

The stakeholders of the current project will be represented in an *Advisory board*, together with a number of international scientist external to the project. The *advisory board* will advise on overall project goals and their translation in tasks, and in response to requests of the of this group the *project executive board* will provide policy-relevant syntheses of project results, but also respond quickly on ad hoc requests in order to produce a harmonised, consolidated response from the consortium.

At least three moments of interaction between *advisory board* and *project executive board* are foreseen. At the start of the project, for a more precise definition of products and as far as possible mapping of project goals onto current and future policy developments. A mid term review is foreseen involving external reviewers and stakeholders to assess the quality and scope of the work in relation to its objectives, which in principle could lead to a reallocation of resources over the various sub-themes and partners. Near project conclusion this review will be repeated and policy-relevant syntheses of project results will be compiled. Other interactions will occur as needs arise on either side.

The plan is to install **one** *Advisory board* for the three GHG monitoring projects (ME1, ME2, ME3) together because of the large commonality in end goals of the three projects: a better understanding and quantification of GHG emissions, biogene and anthropogene in the Netherlands. Possible members of the *Advisory Board* will be on one hand stakeholders, representatives of:

- Werkgroep Emissie monitoring Broeikasgassen (WEB) subgroup on carbon-sinks, responsible for developing protocols to report carbon sinks and stocks in the UNFCCC National Inventory Report
- Nederlandse Emissie Autoriteit (NEa), responsible for legal and policy aspects of trading in CO<sub>2</sub> (and NO<sub>x</sub>) emission rights
- Ministry of Agriculture, Nature and Food quality (LNV), responsible for developing monitoring systems enabling to report carbon sinks and stocks in the UNFCCC National Inventory Report, and for policies on manure related emissions (CH<sub>4</sub>, N<sub>2</sub>O), and for UNFCCC negotiations around C-sinks
- Ministry of Spatial planning, Housing and Environment, first responsible for climate policies and negotiations, for emission inventories, etc
- other relevant stakeholders at EU level, like EU Monitoring Mechanism Working Groups 1 and 2, European Commission, European Climate Change Programme (DG Environment, DG Agriculture, working groups on sinks), European Environment Agency,
- Non governmental groups like regional and national forest administration, private forest owners, and SMEs involved in certification and auditing of Kyoto-related projects.

And on the other hand a limited number of international scientist external to the project but involved in

- CarboEuropeIP, North American Carbon Programme, FLUXNET, EuroTrac, etc.

The *Advisory board* will aim to line up our efforts with those of CarboEurope-IP to streamline the flow of information.

Analyses and consultation will cover issues such as to analyse, in light of the research results from the activities, key policy-relevant issues, such as:

- the separation of carbon sequestration by terrestrial ecosystems among direct human induced, indirect and natural effects,
- suitability of the developed methods for monitoring and verification of GHG emissions and removals under UNFCCC and the Kyoto Protocol, and how these could be applied on a European-wide basis,
- technical possibilities for "full carbon accounting",
- effects of land management and land use change on the overall balance of GHG,
- To suggest possible implementation of updated and new rules for LULUCF under Kyoto Protocol rules in the second commitment period that would be consistent with the scientifically sound measurement and observation methods such as those developed and applied in this project

The staffing of the *Advisory board* will be coordinated in collaboration with the programme level communication project (IC1) and its resources for activities/product compilation may also be supported by IC1, and the stakeholder dialogue process methodologically supported by project IC8, both as needed/appropriate.

## 10 B. Potential risks and solutions

We hope to anticipate the risk that partners do not produce what they promised to produce by request six-monthly to yearly progress reports. Our *project executive board* will deal with problems arising out of badly-performing partners and settle disputes that may arise out of this. In cases where overall project goals are threatened, this may lead to re-allocation of resources to partners (if need be international) that are capable of taking over the required task. Similarly risks related to the functioning of links with other BSIK projects and partners will be dealt with here. The current proposal depends on other BSIK projects for some crucial inputs (notably ME1, ME3 and CS2). In case one of these projects will not be granted, or the if relevant components in these fail to deliver alternatives must be found. In some cases we might be able to fall back to similar products, expertise generated by international partners we are already collaborating with in e.g. CarboEuropeIP. In other cases reallocation of project resources might be needed to produce the most essential input. If needed, advice and mediation in all such case might be sought with the *Advisory Board* and/or the BSIK Programme Office.

We expect the risk related to failure of the communication strategy with the stakeholders to be small. Most of our PI's have strong existing involvement with (inter)national policy communities or NGO's. We expect that our *advisory board* and the involvement/support from communication and stakeholder-dialogue projects (IC1 and IC8) and BSIK management will further reduce that risk.

Finally, the "normal" scientific risk, that hypothesis cannot be proven, the method chosen does not function, unforeseen instrumental catastrophes etc. We expect to deal with these when they arise. The track record of the PI's is such that we expect that the more routine failures can be remedied. In the budgets some allocation is made for spare parts to cover unforeseen breakdown. In case of more major instrument catastrophes (eg airplane crash) we might be able to use instruments of international colleagues on a loan or hire basis, to generate the most needed, but necessarily more restricted datasets. This applies to that category of data that are crucial to Netherlands-specific emission estimates. For more general method development, model testing and validation in some cases we might fall back on existing datasets not specific to the Netherlands and generated elsewhere (e.g. in the CarboEurope Regional experiment).

When more severe problems arise our scientific steering committee will adjudicate. We believe to have chosen a good set of well-proven and more innovative technologies and models, such that the risk of failure of innovative technologies is well balanced by the low risk of the proven ones or by some form of redundancy in the international community that might be accessed.

## 11. What are the links and how are these capitalized upon:

### 11 A. With other themes / projects within the Climate changes Spatial Planning programme?

#### Input from/output to:

Project nr	Project title	Details (description, timing, etc.)
ME1	Integrated observations and modelling of greenhouse gas budgets at the ecosystem level in The Netherlands	a) ME1→ME2: 1-D ecosystem models will be parameterised for major dutch ecosystems in ME1 providing the basis for 2D modelling and scaling up to nation wide coverage b) ME2 →ME1 airborne flux measurements will help to assess spatial representativity of site level studies in ME1 - interacts mostly with WP3 - interactions almost continuously - need joint identification of ecosystems / landcover classes to be addressed in experiments and models - need joint identification of minimum set of model parameters to be quantified
ME2	Inventory based soil-carbon budget and greenhouse gas emission statistics	a) ME3→ME2: spatially explicit and temporally disaggregated inventory data will serve as a-priori anthropogenic flux estimates and will facilitate scaling up of 1D ecosystem models to national scales b) ME2→ME3: ultimately ME2 will deliver a methodology to verify inventory based annual, national emission estimates improved in ME3 - interacts mostly with WP3 - need for joint determination of spatial and temporal resolution of inventories - need for fast track product from ME3 in year 1, improved products

		towards end of year 3 - verification methodology available towards end of ME2
<b>CS2</b>	Monitoring and profiling with the Cabauw Experimental Site for Atmospheric Research	CS2→ME2: the CESAR facility of CS2 will provide detailed atmospheric column information at Cabauw, relevant for PBL parameterisation development and monitoring in ME2-WP1, as well as serving as background information for the analysis of GHG concentration dynamics in WP2 - need for short period data-rich sets in year 1, 2, 4 based on existing and new CESAR infrastructure - need for continuous (gap filled) datasets of PBL height and few other parameters throughout the project, but especially in year 3
<b>CS4</b>	Regional distribution of aerosols	ME2→CS4 inversion techniques developed in ME2 will also be of use for inferring source strength and distributions of aerosols;
<b>CS6</b>	Climate scenarios of wind and precipitation around The Netherlands	ME2→CS6 we will produce improved parameterisations of especially PBL dynamics for implementation in the CS6 regional climate model
<b>A6</b>	Adaptations in the Netherlands Continental Shelf	joint coordinated measurements of CO2 fluxes to/from coastal seas and large inland water bodies ME2→A6: airborne CO2 flux measurements over water A6→ME2: dpCO2 observations in surface waters and model/RS based interpolation

**11 B. With other BSIK programmes (including so-called bridge-projects)?**

not applicable

**11 C. With international programmes (e.g. FP6, etc)?**

The project is strongly embedded in the EU-FP6 CarboEurope Integrated Project as well as a number of still ongoing FP5 projects (CHIOTTO, CAMELS). Of the CarboEurope-IP in particular the 'Regional component' is relevant and many of the tasks foreseen in the current proposal will be executed and products developed in close cooperation with international partners in that 'Regional component'. Other relevant programmes are the IGBP-WCRP-IHDP Joint Carbon Project, IGBP-iLEAPS, and the international programs WCRP, GEWEX, GABLS, GLASS, FLUXNET.

**11 D. How is tuning and/or co-operation arranged?**

*Within BSIK Climate changes Spatial Planning*

Strong interactions are foreseen with the ME1 and ME3 projects also proposed in this BSIK programme. This is informally facilitated by considerable overlap between ME1 and ME2 in the groups and PIs involved. More formally, we will occasionally organize joint steering board and even joint project meetings. The latter will be held at project start, mid-term and towards project conclusion. The joint executive/steering board meetings will meet additionally in-between the joint project meetings.

*Internationally*

Many project PI participate also in at least one component of these CarboEurope projects. Expertise and data sharing will be facilitated through participation in (sub)project meetings, CarboEurope-wide plenary workshops and other scientific conferences.

Two PI's (Dolman, Vermeulen) currently are represented at coordination levels (Steering committee) in CarboEurope thereby guaranteeing overall embedding and mutual beneficiary planning of tasks. Similarly PIs have coordinating roles in GABLS (Holtslag) and many more are active at some level in the other programmes mentioned.

**12. How is this project contributing to (maximum 2 pages):**

**12 A. New (Inter)national policies in relation to climate and spatial planning, sustainability and environment?**

The proposed project addresses policies related to the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. The proposed research addresses several aspects of climate change, the land carbon balance, and GHG emissions in line with National and European political interests, integrating Dutch and European expertise in all relevant disciplines. The scientific methods, understanding, validation and monitoring tools resulting from the project will have great relevance to a number of international treaties and conventions, to which the Netherlands and the EU are signatories, in particular:

1. The UNFCCC. Among other obligations, Parties of the UNFCCC have committed themselves to develop, periodically update, publish and make available to the Conference of the Parties (CoP), national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the

Montreal Protocol. CarboEurope-IP will develop an integrated methodology based on observations and innovative modelling and best estimates of the land carbon sink to complement national estimates and to enable the European Union to fulfil this commitment, and to provide a scientifically independent verification of reports of land carbon uptake from other Parties of the UNFCCC.

2. The **Kyoto Protocol**, especially the paragraphs that relate to biospheric sinks and sources (3.3.; 3.4.) and to the reporting and verifiability issues of the Protocol. The lack of an adequate terminology and methodology for the attribution of the land carbon sink to human-induced and other factors, and the lack of scientific confidence about the magnitude of the land carbon sink, were among the most important reasons for the failure of the The Hague negotiations (CoP6) on implementation of the Kyoto Protocol. With present knowledge, human-induced contributions to the land carbon sink can be separated from indirect and natural effects by means of models only. Such models, however, based on a carbon data assimilation scheme, have not yet been developed and applied to Europe. The proposed project will fill this gap by attributing and quantifying the human-induced land carbon sink in Europe and elsewhere.
3. The **European Commission Communications COM(97)481, COM(98) 353** and in particular "Preparing for Implementation of the Kyoto Protocol" (**COM(99)230**) and the related **Council Decisions Dec93/389** - Council decision of 24 June 1993 for a monitoring mechanism of Community CO<sub>2</sub> and other greenhouse gas emissions and **99/296/EC**. Our results will strengthen the Dutch Government's ability to monitor and verify the land GHG balance, and facilitate the development of a common strategy for monitoring greenhouse gas exchange between land and atmosphere. It will help to fill gaps in national reports of carbon fluxes related to land use, land use change and forestry recently identified in the first progress report under 99/296/EC. The science/policy interface of our project will directly support and advise the **Werkgroep Emissie monitoring Broeikasgas (WEB)** that report to the the EU Monitoring Mechanism, as well as the **National Emission Authority** dealing with emission monitoring and emission trading by industry.
4. We have critical links with the **CarboEurope-IP** that arguably is the single most important research project addressing the carbon balance of Europe. With newly proposed projects on the nitrogen cycle and existing national programmes within the EU we aim to contribute to a better scientific understanding and better use of scientific data in reporting to the UNFCCC and Kyoto protocol.
5. The current project will provide critical methodologies and results for the international negotiations, in the **Second and later Commitment Periods** under the Kyoto Protocol, on carbon sinks, on the potential for 'total carbon accounting' and on the potential for independent verification of reported emissions
6. The **Evaluatie Nota Klimaat beleid** (28-240) evaluated the climate policies of the Dutch Government (Uitvoeringsnota Klimaat, I and II). These government documents focus largely on the industrial emissions. Key issues as the linkage with the biogenic emissions and the link with air pollution issues are poorly adressed. We aim to contribute to strengthening this linkage substantially.

### **12 B. Innovations?**

Innovative aspects of the proposal centre around the issue of using inverse methods at the resolution and scale foreseen, and to make a first ever attempt to independently verify GHG emissions using top-down methods at the national scale. This requires a level of integration of monitoring activities with model development and model based interpretation (forward and inverse) that has not been attempted before in the Netherlands, and which is just emerging internationally.

On a more specific level we believe the following elements of the proposal to be most innovative:

- The continuous high precision monitoring of GHG concentrations *at multiple levels* builds provides a dataset unique in the world. Also the continuous monitoring of HFCs occurs at very few places in the world only, despite its foreseen relative increase in importance compared to the other GHGs
- Operational use of the SkyArrow650ERA; currently only a limited number of these observing facilities exist worldwide, and though the basic technology has been well validated, its operational use will be developed within the proposed project
- The diurnal operation of a multi-wavelength *Raman lidar*. To date, the achievement of this goal has been demonstrated for a single instrument worldwide (CARL: ARM Raman lidar). A feasibility study has already been completed.
- The use of an operational network of ceilometers and scintillometers to continuously map the spatial variation of ABL dynamics, requiring novel algorithm and product development.
- The development of inversion algorithms optimised for the scale of interest and the variety of constraining data available; not only 'fixed' point concentration measurements from towers will be ingested but also airborne fluxes and concentrations along varying flight tracks.

Eventually, patents may evolve from the activities dealing with software development, data assimilation techniques and observation technologies, sampling strategies, measurement and calibration protocols suitable for benchmarking and high-precision analyses.

## **12 C. Economy?**

The (socio-) economic impact of expected results depends a lot on how the political environment for emission reduction possibilities (e.g. using carbon sinks), for reporting scope and requirements (e.g. full carbon accounting) and for verification under the Kyoto Protocol evolves in the future.

Interactions with the Dutch national and international UNFCCC negotiation teams and scientific advisors (IPCC) is envisaged, especially in issues concerning the 2nd and later Commitment Periods under the Kyoto Protocol. Special attention and collaboration will be sought with those responsible for land use based emissions (and their reductions) of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in the Netherlands: the WEB-Sinks work group and representatives of the Dutch ministry of Agriculture, Nature and Food Quality (LNV), and at European levels with e.g. the European Climate Change Panel - Working Group Sinks related to Agricultural Soils.

In the proposed project we concentrate our resources on the natural science aspects of the GHG exchange between land and atmosphere in general (with special attention to carbon exchange between the terrestrial biosphere and the atmosphere) in the best possible trans-disciplinary way. We believe that this focus allows to achieve the ambitious goals rather than to broaden the coverage further, e.g. by including socio- economic aspects of e.g. energy production and or land use developments. Issues such as these will be dealt with in separate projects (e.g. in the Integration sub-programme where mitigation policies will be evaluated in their socioeconomic context).

Having noted all that, we believe that the proposed research will secure an internationally leading position of the partners involved with respect to scientific and practical knowledge on emission verification. This expertise will definitely increase their competitive power on the international market of verification, should it develop, and promote their market prospects for consultancy and involvement in monitoring activities related to the setup of advanced GHG information systems and verification protocols abroad. This applies to partners individually but perhaps even more so collectively.

## **13. Budget**

### **13 A. Specification of total project budget**

see excel sheet TEAM\_COST-ME2.xls

### **13 B. Motivation of budget items (personnel, equipment, consumables, travel, fieldwork, other)**

A detailed budget can be found in the spread sheet (see item 13 A). The overall project budget is 5.556 million euros of which is requested from BsIK 2.670million euros. For personnel 78% of the budget is used, the remaining is used for equipment 14% and consumables 4%, for coordination and dissemination activities 4% (incl programme office contribution). The distribution of effort (man months) over the work-packages is as follows: WP1 24%, WP2 22%, WP3 12%, WP4 33%, WP5 10%. This reflects the central position of (inverse) 3D modelling in our project, as well as our perceived importance of improved ABL representation in regional scale models, and for interpreting any measurements made within that ABL. The distribution of hardware investments and related consumables over the work-packages is as follows: WP1 48%, WP2 17%, WP3 32%, WP4 3%, WP5 0%, clearly reflecting the importance of observations in WP 1-3. The equipment in WP1 consists of contributions to the hardware at the Cabauw facility (3Ghz radar and Raman lidar, eddy correlation system), scintillometer network, ceilometer network adaptation and maintenance, and flying hours for ABL profiles. The equipment in WP2 consists of monitoring equipment (various gas chromatographs and peripherals) for the measurement of GHG concentrations (for CFC, HFC and Rn at Cabauw; for CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and SF<sub>6</sub> at Lutjewad) concentrations and some flying hours for ABL concentration profiles. The equipment in WP3 consists of the flux measuring aircraft and costs of flying hours.

These percentages reflect the overall budget, including matching.

### **13 C. Specification of matching**

The budget of the project is highly complementary to CarboEurope-IP, as are a number of the scientific tasks. The following partners use significant matching from EU sources: Alterra, ECN, VUA. Other sources of co-funding are from NWO, WUR-METAQ, and all other matching funds are from various sources of core-funding. For the consortium as a whole 13% is matched through EU-FP5/6 funds, 3% through NWO, 71% from institutional core funding and 13% from other sources.

## **Appendix 1 Models used**

### **LOTOS**

The LOTOS model system consists of three scale models: TM3 for the global scale, and feeding boundary conditions into LOTOS (European scale). LOTOS is a 3-D full chemical model (3-4 layers in the PBL) and a resolution of approximately 30x30 km (Blom and Roemer, 1997). LOTOS feeds (on an hourly basis) into LOTOS-zoom which has a model resolution of 3.8x3.8 km (finest resolution currently available). LOTOS-zoom describes the Netherlands and the nearest parts of neighbouring countries, but it can be used in other parts of Europe as well. LOTOS-zoom is refined compared to LOTOS with respect to emissions and land-use, but not with respect to meteorology (interpolated fields are used).

### **TM5**

This global model (Krol et al, 2004) has a zoom feature which allows two way nested zooming in on a particular region of interest (up to 0.5x0.5 degree). The high resolution within the zoom region allows high frequency measurements from tall towers to be taken into account in the inversion, while at the same time contributions from large scale transport are simulated realistically by the coarse resolution global domain (typically at 6x4 degree).

### **COMET**

COMET has been able to reproduce the night-time accumulation of CH<sub>4</sub> in the stable boundary layer, the concentrations in the well developed convective boundary layer during mid-day and the synoptic variations in concentrations for both CH<sub>4</sub> and CO<sub>2</sub>. We will extend both models to model the components N<sub>2</sub>O, SF<sub>6</sub> and HFC's. For the biogenic fluxes a simple TURC scheme will be used based on NDVI data. The COMET model allows to run (forward and inverse) simulations for several receptor stations and hourly observations with long time series (several years) with limited computed resources. The use of long time series allows for detection of trends in emissions in the inverse calculations; possible systematic errors will for a large part be ruled out in this method.

### **FLEXPART**

The FLEXPART model allows for more flexibility in the modeling and higher precision to the expense of increased computational demands. The precision of FLEXPART calculation is claimed to be equal or even better than far more demanding Large Eddy Simulation calculations [Stohl, 2002]. Together with the project partners we will work on improvements of the Boundary Layer and Convection schemes.

### **LPD / STILT**

LPD simulates upstream influences on the observation location (receptor) by following the evolution of a particle ensemble backward in time. The RAMS meteorological fields can be used as input for LPD (Uliasz, 1994) to run a variety of passive tracer simulations in both source- and receptor-oriented modes (Uliasz et al., 1996). The model simulates transport by following the time-evolution of a particle ensemble, interpolating meteorological fields to the sub-grid scale location of each particle. We have agreement with one of the investigators (Prof. S. Denning CSU, USA) to apply LPD model in our project. Alternatively, we may try to use the Stochastic Time-Inverted Lagrangian Transport model (STILT, Lin et al., 2003). Turbulent motions are represented by a Markov chain process. Significant computational savings are realized, because the influence of upstream emissions at different times are modelled using a single particle simulation backward in time, starting at the receptor and sampling only the portion of the domain that influences the observations.

### **RAMS**

Two partners in the project will be using the RAMS meso scale modelling system (both by partner 1 and 3). An extensive description of the model can be found in Pielke et al. (1992) and Walko et al. (2000). It is a non-hydrostatic model, together with its nesting options allowing it to be used in high resolution modes. Its land surface scheme uses the tile-approach for treating sub-grid variability in vegetation and soils. In its standard form, the version used (4.3) does not include CO<sub>2</sub> as a tracer nor any related surface fluxes.

Alterra therefore coupled RAMS to SWAPS-C, a two layer land surface scheme including CO<sub>2</sub> fluxes from assimilation and respiration. The standalone version of SWAPS-C allows easy calibration of its parameters on measured flux datasets.

The RAMS code allows passive atmospheric transport of any number of scalars. Alterra implemented this for CO<sub>2</sub>, and is planning to do this also for other relevant scalars such as CO, Rn and perhaps isotopes. CO<sub>2</sub> surface

fluxes come from either of three sources: i) Terrestrial biospheric fluxes simulated by SWAPS-C, ii) Marine biospheric fluxes computed from large scale observed partial CO<sub>2</sub> pressures in the marine surface layer, iii) Anthropogenic CO<sub>2</sub> emissions. Like for the other scalars, temperature and water vapour, also atmospheric CO<sub>2</sub> fields a nudging scheme is under development to use large scale analysis.

VUA uses a RAMS version coupled to GEMTM (Eastman et al., 2001). The general energy and mass transport model (GEMTM) is an ecophysiological process-based model, that can be used to simulate the dynamic interactions between the atmosphere and the growing canopy (Chen and Coughenour, 1994). It comprises plant and root submodels, and a detailed canopy radiation transfer. Also isotopic fractionation is accounted for, and the carbon isotopes are distinguished also in the atmosphere.

## **MM5**

The PSU/NCAR mesoscale model (<http://box.mmm.ucar.edu/mm5/>) is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. It has been developed at Penn State and NCAR as a community mesoscale model and is continuously being improved by contributions from users at several universities and government laboratories throughout the world.

WUR-METAQ has ample experience with the use of MM5. This experience entails both the use of the model for case-studies, and the validation and improvement of the parameterizations of the processes in the boundary-layer and at the land-surface.

## **Appendix 2 Equipment used**

### **Airborne flux monitoring platform**

The aerial platform (that was developed in EU-FP5 RECAB project) is based on the certified aircraft Sky Arrow 650 ERA (Environmental Research Aircraft), equipped with sensors to measure three dimensional wind and turbulence together with gas concentrations and other atmospheric parameters at high frequency. The aircraft engine is mounted in a pusher configuration and has a cruise flight speed of 85 knots with an endurance of 3.5 h, allowing it to cover flight distances of up to 400 km. Operating altitudes can range from 10 m above ground level to more than 3500 m above sea level. Atmospheric turbulence measurements are made with the “Best Aircraft Turbulence” (BAT) probe, developed by NOAA-ATDD and ARA Australia. In brief, the BAT probe measures the velocity of air with respect to aircraft using a hemispheric 9-hole pressure sphere that records static and dynamic pressures by means of four differential pressure transducers (Crawford and Dobosy, 1992). The Sky Arrow, allowing the BAT probe to be installed directly on the aircraft’s nose, thus minimizing airflow contamination due to upwash and sidewash generated by the wing (Crawford et al. 1996). The actual wind components (horizontal U, V and vertical W) relative to the ground are calculated introducing corrections for three-dimensional velocity, pitch, roll and heading of the aircraft. Those corrections are made using a combination of GPS velocity measurements and data from two sets of three orthogonal accelerometers mounted at the center of gravity of the aircraft and in the centre of the hemisphere. The GPS and accelerometer signals are blended to obtain attitude and velocity data at frequencies up to 50 Hz. Accordingly, *atmospheric turbulence* is actually measured at a frequency of 50 Hz and since the aircraft can fly at relatively slow speed ( $35\text{ m s}^{-1}$ ), a horizontal spacing of 0.7 m between 50 Hz measurements in no-wind conditions can be achieved. In this way, eddies of wavelengths larger than 1.4 m can be detected. The probe is equipped with a microbead temperature sensing element to measure air temperature with a response time of 0.02 s. A platinum resistance thermometer is used for a mean air temperature reference. A net radiometer (Q\*7, REBS USA) and upward and downward looking PAR radiometers (200s, LiCor USA) are mounted on the aircraft’s horizontal stabilizer. Low frequency air moisture measurements are made using a chilled mirror dew point sensor (EdgeTech, USA). Surface temperature is also measured at 1 Hz, using an infra red thermometer (4000.4GH, Everest USA). Atmospheric densities of carbon dioxide and water vapour are recorded at 50 Hz by a LiCor 7500 (LiCor, Lincoln, Nebraska) open path infrared gas analyzer installed on the aircraft nose (Fig. 1). All the digitally converted signals from the BAT Probe and the sensors are stored on a PC located on-board. Additional details of underlying theory and the technical implementation of flux aircrafts can be found in Crawford and Dobosy (1992) and Crawford and Hacker (2001), Brooks et al. (2001), Dumas et al. (2001).

The subsequent calculation of carbon dioxide, water vapour, sensible and latent heat and momentum fluxes are made using conventional eddy correlation technique taking into account all the necessary corrections for open-path gas analyzers, frequency response loss, and stationarity corrections. The complete computation procedure is written in MatLab v6.0 (Mathworks, USA). The main difference between airborne and ground-based eddy covariance is in the averaging technique. Turbulent fluctuations (wind and associated scalars) are calculated using averages calculated over space (per meter) rather than over time (per second). The definition of a proper averaging length is critical to ensure that all significant flux-carrying wavelengths are taken into account. Such a length depends on the flying altitude, on the surface roughness, and on atmospheric stability. Using such an approach, proper averaging lengths ranging from 3500m to 4500m have been found in the different conditions encountered in the campaigns and have been used to calculate fluxes.

The fluxes thus measured have been widely validated against a number of tower flux sites across Europe and in different seasons (Gioli et al. 2004). It has also been used to study CO<sub>2</sub> flux divergence and entrainment in the ABL (Vilá Gerau et al. 2004).

### **Gas concentration measurements**

#### *Existing equipment Cabauw*

CO<sub>2</sub> is monitored continuously at *Cabauw* by (ECN). Summer 2004 new equipment will be installed in the frame work of the EU-FP5 CHIOTTO project. It consists of a Agilent 6890N GC system equipped with FID and  $\mu$ ECD detectors and a catalytic converter to convert CO in CH<sub>4</sub>. With this GC system 5 minute samples can be analysed for CH<sub>4</sub>, CO, N<sub>2</sub>O and SF<sub>6</sub> at very high accuracies. The GC system is a close copy of the WMO standard system (Worthy at al, 2003). In Table 1 the target precisions of the CHIOTTO project are shown. CO<sub>2</sub> is measured using a LiCor 7000 NDIR monitor that is maintained at a stable temperature ( $30 \pm 0.1$  °C) and <0.01 mbar pressure difference between span gas and sample gas, in order to reach the required stability of <0.1 ppm. Air is sampled through inlet filters and permature dryers through 1/4” high density gas tight polyethylene

tubing from the heights of 200, 120, 60 and 20 meter above the surface at a flow of 20 l/min. In the basement of the Cabauw tower building all equipment is placed and there 200 ml/min of the sampled air is taken consecutively from each high at a frequency of five minutes. All four sample streams are further reduced in water content by passing through a cryo-cooler system at minus 55°C. The sample air or calibration gas is then lead to the GC and the Licor monitor. A separate line runs from 200 meter samples height and through the cryocooler system to the automatic flask sampling system built by CIO-RUG.

The complete sampling system is run by a central PC that checked all equipments, flows and temperatures, Data is sent online to ECN at Petten.

#### *New equipment Cabauw*

In the current proposal this system will be extended to also monitor concentrations of HFC and CFC through a high precision GC-MS combo that is fed by an automated pre-concentration unit using automatic cuvettes and a cryocooler gas trapping system. Also added is a Rn monitor from Ansto (refs) that will sample air from 200 m ASL through a 3 m<sup>3</sup> sample vessel where the 222Rn concentration is directly determined by a radioactive decay counter (see under *New equipment Lutjewad*)

Precision and accuracy goals for CHIOTTO and CarboEurope (6th Framework):		
Gas species	Intra-laboratory instrumental precision	Inter-laboratory calibration scale accuracy
CO <sub>2</sub>	0.05 ppm	0.10 ppm *
CH <sub>4</sub>	2.0 ppb	3.0 ppb
CO	1.0 ppb	3.0 ppb
N <sub>2</sub> O	0.1 ppb	0.2 ppb
SF <sub>6</sub>	0.1 ppt	0.2 ppt
O <sub>2</sub> /N <sub>2</sub>	5 per meg	10 per meg
Rn	0.2 Bq m <sup>-3</sup> or 10% **	10% **
□ <sup>13</sup> C-CO <sub>2</sub>	0.007 ‰	0.01 ‰ *
□ <sup>18</sup> O-CO <sub>2</sub>	0.03 ‰	0.05 ‰ *

\* These values are the WMO/GAW goals for global network accuracy among different laboratories in the northern hemisphere. (In the case of the other species, no official WMO/GAW goals exist at this time).  
 \*\* For Radon, these values are the detection limit goal.

The (inter)calibration is performed by using secondary standards provided by NOAA-CMDL and daily calibration against working standards, monthly calibration using archive standards and 3-monthly travelling standards using the extensive CHIOTTO calibration protocol that was presented and was well received at the 2003 WMO expert meeting . Every half hour two target standards are measured to detect and correct for possible drift in the sensors.

#### *Existing equipment Lutjewad*

CIO-RUG is running its own atmospheric research and monitoring station *Lutjewad* close to Hornhuizen in the province of Groningen, directly on the Waddensea coast, since the end of 2000. The surroundings on the land side are agriculturally used and sparsely populated. The station is equipped with a 60 m tower. Air intakes are installed at 7 m, 40 m and 60 m above ground. Meteorological information (temperature, humidity, wind speed) is available at the same three heights, and in addition the atmospheric pressure, wind direction and precipitation are measured at one height. High volume CO<sub>2</sub> sampling for conventional <sup>14</sup>CO<sub>2</sub> analysis is done in threefold: there is one continuous sampling line and two lines sampling the north and south sectors respectively, yielding information about the continental fossil-fuel CO<sub>2</sub> contributions. Due to instrumental problems, the CO<sub>2</sub> and CH<sub>4</sub> data record from the in-situ quasi-continuous analysis by GC-FID (from 2002 on) has severe gaps. Flask samples are taken weekly semi-automatically and analysed in the CIO-RUG laboratory for their O<sub>2</sub>/N<sub>2</sub> ratio by a dedicated isotope ratio mass spectrometer (IRMS), for their CO<sub>2</sub>, CH<sub>4</sub> and CO concentrations by gas chromatography (GC-FID), and finally from the remaining air sample CO<sub>2</sub> can be extracted quantitatively for stable isotope ratio analysis by IRMS (δ<sup>13</sup>C and δ<sup>18</sup>O of CO<sub>2</sub>) and <sup>14</sup>CO<sub>2</sub>-analysis by accelerator mass spectrometry (AMS). From the combination of these analyzes a very detailed fingerprint of an air-mass can be deduced, including the separation of biogenic and fossil-fuel derived CO<sub>2</sub> contributions above the regional background.

#### *New equipment Lutjewad*

Within the current proposal, CIO-RUG will install a new gaschromatographic measurement system at Lutjewad for CO<sub>2</sub> and CH<sub>4</sub> (GC-FID) and also N<sub>2</sub>O and SF<sub>6</sub> (GC-ECD), according to the quality standards of the WMO

experts groups (WMO, 2001). Beyond being more reliable than the actual system, it will work with a higher precision as well for CO<sub>2</sub> and CH<sub>4</sub>. The working standards will be calibrated using CIO-RUG's NOAA-CMDL-derived secondary or tertiary standards. The system is based upon a Hewlett Packard GC 6890 instrument with dedicated auxiliary installations as elaborated by different laboratories. The old system will be kept working as long as possible to give a higher time and vertical resolution.

Radon measurements will be made at Cabauw and Lutfjewad applying ANSTO Radon monitors (Whittlestone and Zahorowski, 1998; E. -G. Brunke, C. Labuschagne, B. Parkera, D. van der Spuya and S.

Whittlestone (2002). ANSTO is world-wide the only semi-commercial supplier of Radon monitors to be used in high towers. The monitors are specified for atmospheric background concentration measurements, where all commercial instruments are made for measurements of enhanced concentrations in e.g. basements of buildings or other indoor or ground-related use. The second requirement is that no heavy installation and no service-intensive parts are needed in the tower, as would be the case with Radon-daughter monitors following the filter principle, where the filter and monitor have to be at the air inlet height. The ANSTO monitor is measuring Radon decays and thus has no problems with a longer air flow path between inlet and detector. ANSTO is supplying the monitors on a semi-commercial scientific cooperation basis which means that the newest developments will be implemented (at slightly lower rates).

### **RAMAN LIDAR**

Lidar (Light Detection And Ranging) is a widely used technique for vertical profiling of the atmosphere for a range of species. The Raman lidar proposed here is designed to simultaneously measure water vapor mixing ratio profiles, aerosol backscatter and extinction profiles and cloud properties, and includes a depolarisation channel for cloud phase determination. All parameters can be observed at nighttime throughout the troposphere and for water vapor up to at least 7 km. A single high-power Nd:YAG laser is used, emitting at 1064 nm, 532 nm and 355 nm. Elastic signals are detected at these same wavelengths, depolarisation detection is sufficient at a single wavelength. Raman scattered signals are detected at 387 nm (N<sub>2</sub> Raman shift from 355 nm), 607 nm (N<sub>2</sub> Raman shift from 532 nm) and 407 nm (H<sub>2</sub>O Raman shift from 355 nm). Multiple wavelengths are used so that aerosol backscatter and extinction can be obtained at two wavelengths. This ability will become increasingly important as advanced retrieval techniques emerge to estimate aerosol single scattering albedo and aerosol effective particle size from Raman lidar data. These new techniques require a minimum set of data that can be obtained from the instrument configuration proposed here (Müller, 2003, Veselovskii, 2004). A specific requirement is the daytime observation of water vapor profiles throughout the boundary layer for which, rejection of out of band background light from the sky is a major task. This will be accomplished by using narrow optical wavelength bands in the lidar detection and tight geometrical overlap between the emitted laser beam and the field of view of the receivers. Precision and accuracy are expected to be very similar to those published by Turner et al. (Turner, 2002).

Of great advantage of the Raman lidar is, one instrument is used that provides water vapor, aerosol and cloud measurements *simultaneously* and in *exactly* the same atmospheric volume – something that can never be realised to with different instruments, since these will always sample different volumes. This feature will become increasingly important as measurement schemes and retrieval techniques are developed to gain knowledge on the mechanisms of cloud formation where these quantities all act together in space and time (aerosol indirect effect) (Feingold, 2003).

Further advantages for the utility of the database of atmospheric parameters from the Raman lidar will be the diurnal operation of the system. The automation of a high power Raman lidar that is required for this has been demonstrated (Goldsmith, 1998) and this system has provided a wealth of information to the scientific community since it has become operational in 1996 (Ferrare, 2003). In order to operationalise the Raman lidar at the CESAR remote sensing site in Cabauw, the entire system will be enclosed in a weather proof 20 ft. seastainer. The enclosure will be equipped with proper laser safety installations and will be fully self-supporting, requiring only electrical power and a network communications link.

### **3 GHz Radar**

The Transportable Atmospheric Research TARA is a Doppler-polarimetric FM-CW radar, operating at 3 GHz. At this wavelength, radar reflections in the boundary layer are the result of coherent Bragg scatter; measurement of the Doppler shift then enables the observation of wind and turbulence. The system is equipped with the facility to switch electronically between between three antenna beams, separated by 15 degrees, which enables 3D measurements. The FM-CW principle enables a large sensitivity in combination with a high spatial resolution: values of 3 meter are easily achieved. TARA is one of the most sensitive and advanced systems worldwide (Russchenberg and Boers, 2003).

### **Scintillometry**

The sensible heat flux is the main driver of boundary layer growth. Scintillometry provides a very robust method to measure  $H$  at a wide range of scales. For a recent overview see the special issue of *Boundary Layer Meteorology* (BLM 105 (2002)) edited by the WUR-METAQ group. Here we propose to use Extra Large Aperture Scintillometry (XLAS). The XLAS is a very large aperture scintillometer, especially designed for use over large distances, up to 10 km. Its design is basically that of the Large Aperture Scintillometer (LAS) developed by the Department of Meteorology and Air Quality of the Wageningen University. The difference is that 32 cm diameter Fresnel lenses are used instead of 15 cm mirrors. Fresnel lenses have the advantage that they weigh less and are cheaper. The trade-off is that they are optically less perfect, compromising optical signal strength. An important consequence of a very large aperture is that the scintillation is reduced. The useful maximum range of a scintillometer is often determined by saturation of the scintillation phenomenon, a situation where the variance of the received light intensity becomes rather insensitive to the fluctuations of the refractive index. By having a large aperture the useful upper range of application is extended. The XLAS was successfully tested between the TV tower at IJsselstein and the KNMI meteo tower at Cabauw, covering a distance of 9.8 km (Koshiek et al. 2002). Also under much more heterogeneous surface conditions it performed well (Meijninger et al. 2002).

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**Appendix 4: CVs of all personnel involved**