Academy of Finland

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Name of responsible leader:

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Name of research project:

An integrated monitoring and modelling system for wildland fires - IS4FIRES

Participants:

1. Finnish Meteorological Institute (FMI), Helsinki
2. University of Helsinki (UH)

Collaborators (participate using their own resources):

1. Dr. Johann G. Goldammer, The Global Fire Monitoring Center (GFMC), Fire Ecology Research Group, Max Planck Institute for Chemistry, c/o Freiburg University, Hamburg, Germany
2. Dr. Philippe Bougeault, European Centre for Medium Range Weather Forecasting (ECMWF), Reading, U.K.
3. Dr. Tom Keenan, Bushfire, Cooperative Research Centre (BCRC), Melbourne, Australia
4. Dr. Alexander Baklanov, Danish Meteorological Institute, Copenhagen, Denmark
5. Dr. R.Vankevich, Russian State Hydrometeorological University, St. Petersburg, Russia

CONTENT:

1. Background and motivation

Wildland fires occur annually on every continent except Antarctica, but their quantitative description is scarce. Wildland fires take place every spring and summer in Europe, and they are especially common in Western Russia. Increasing trends in wildland fire activity have been reported, and their occurrence is expected to substantially increase (National Assessment Synthesis Team, 2002) in response to climate change. Land and forest fires (collectively referred to as wildland fires) have serious negative impacts on human safety, air quality and health, regional and global climate change and regional economies (e.g., tourism, transport, aircraft operations). Forest fires can substantially increase the regional scale emissions of greenhouse gases and particulate matter into the atmosphere, especially during spring and summer.

Fires produce a wide range of harmful or hazardous pollutants, including fine particles that can be transported all over Europe, where they can constitute a serious health risk for the population. According to the latest results of the CAFÉ (Clean Air for Europe) programme, pollution-originated fine particulate matter causes over 300 thousand excess deaths and a total loss over 3 million life-years in EU in 2000, in a population of approximately 450 million people (http://europa.eu.int/comm/environment/air/cafe/). However, there are currently no quantitative scientific assessments of the health effects caused by the wildland fires. E.g., the CAFÉ study did not address the health effects caused by wildland fires, as there were no reliable methods for evaluating the emissions and atmospheric dispersion for such cases.

Fire detection systems have been developed to provide early warning on the occurrence of wildland fires using various techniques, based on remote sensing systems using local observations with infrared cameras, or satellites providing fire maps on a global scale. The latter can detect both burning areas and pollutant plumes. At FMI, a prototype of an automatic forest fire detection system is already operational (Rauste, 1997), but it only provides qualitative information on the location of the burning area. For quantitative information of the effects of wildland fires, accurate estimates are needed (i) on the size of the burning area, (ii) the fire intensity and initial elevation of the plume, (iii) the emissions of particulate matter and gaseous pollutants, (iv) the transport and evolution of the resulting pollutant plume.

The web fire mapper provided by the University of Maryland and the NASA MODIS team (http://rapidfire.sci.gsfc.nasa.gov/subsets/) provides global wildland fire detection in near real time. Several algorithms have been developed for the estimation of fire radiative energy (FRE) (Dozier 1981, Kaufman and Justice 1998, Wooster et. al 2003). However, the derivation of other properties, such as e.g. the emission rates, assumes homogeneous fire background, with constant emissivity-temperature characteristics. This assumption is not valid in various boreal environments that consist of a mosaic of water surface, forests with various canopy characteristics. The effect of inhomogeneous terrain and vegetation therefore needs to be evaluated, and the algorithms need to be improved based on existing land-use data bases. Plume rise heights need to be evaluated using lidar measurements from space (CALIOP). The use of satellite data to determine the change in aerosol properties has been demonstrated by, e.g., Robles Gonzalez (2003).

This proposal integrates ground-based in situ measurements and satellite observations, an experimental database from the so-called TROICA expedition, results of a controlled forest burning experiment, fire propagation models and chemical transport models. In situ ground-based measurements provide detailed information on the chemical composition of the fire plumes, and on the chemical tracers of wood combustion, while satellite observations provide spatial distributions of fires and fire plumes over extensive areas. The TROICA observations in Russia provide direct measurements of the properties of fresh fire plumes, as this scientific train expedition actually passed through some of the fire areas. The forest burning experiment provides quantitative information regarding the emissions as function of carefully controlled burning and environmental parameters. Atmospheric dispersion modelling is needed in order to produce forecasts (and possibly advance warnings) of fire plumes, and the inverse dispersion modelling is needed in order to find out source areas.

Five most relevant publications:

1. Kelhä, V., Rauste, Y., Häme, T., Sephton, T., Buongiorno, A., Frauenberger, O., Soini, K., Venäläinen, A., San Miguel-Ayanz, J. and Vainio, T. (2003). Combining AVHRR and ATSR satellite sensor data for operational boreal forest fire detection, International Journal of Remote Sensing, Vol. 24, No. 8, p. 1691-1708.

2. O'Dowd, C.D., P.P. Aalto, K. Hämeri, M. Kulmala, T. Hoffmann, 2002, Aerosol formation: atmospheric particles from organic vapours. Nature, 416, 497-498.

3. Sillanpää M., Saarikoski S., Hillamo R., Pennanen A., Makkonen U., Spolnik Z., Van Grieken R., Koskentalo T. and Salonen R. (2005). Chemical composition, mass size distribution and source analysis of long-range transported wildfire smokes in Helsinki. Science of The Total Environment 350, 119-135.

4. Sofiev M, P. Siljamo, I. Valkama, M. Ilvonen and J. Kukkonen, 2006. A dispersion modelling system SILAM and its evaluation against ETEX data. Atmos. Environ. 40 (2006) 674–685.

5. Saarikoski, S., Sillanpää, M., Sofiev, M., Timonen, H., Saarnio, K., Teinilä, K., Karppinen, A., Kukkonen, J. and Hillamo, R., 2007. Major biomass burning episode in northern Europe in spring 2006: the chemical composition and atmospheric chemistry of aerosols. Atmos.Environ. (accepted).

2. Objectives

An overarching objective of the project is to develop an Integrated Monitoring and Modelling System (IS) for wildland fires and the resulting pollutant plumes. The system is designed (i) to detect major wildland fires and the pollutant plumes originating from fires, using a combination of satellite remote sensing and ground-based measurements, (ii) to model the spread of the fires in the terrain, (iii) to model the fire radiative energy, the emissions of particulate matter from the fires, and the atmospheric dispersion of the fire plumes in the atmosphere, and (v) to find out the most probable source areas using coupled ground-based air quality measurements and an inverse dispersion modelling system.

A crucial objective of the study is the critical evaluation of all the modelling tools against experimental data, and their scientific evaluation in terms of the model structure, taking into account the physical and chemical limitations of the methods. The emission and dispersion models are evaluated using the controlled fire experiment, the TROICA data, the data from existing ground-based air quality networks, and the satellite-based data. All used satellite retrieval algorithms will be verified using the fire experiment and the TROICA data, and whenever applicable, the ground-based air quality measurements. On the European scale, in situ data are available from various air quality networks (such as, e.g., WMO-GAW and EMEP).

The scientific objectives include (i) detailed measurement and modelling of the chemical and physical composition of the fire plumes, (ii) the development of models for the estimation of particulate matter and gaseous pollutant emissions from the fires, and (iii) refinement and evaluation of satellite-based measurement techniques, regarding the detection of temperatures, types of fires (e.g., smouldering), and the formation of the source terms from fires.

The IS can also be used for forecasting in time the concentrations of the pollutants, especially particulate matter, that are formed in wildland fires. Assimilation of both satellite remote sensing data and ground-based air pollution measurements into the dispersion model is essential for the identification and forecasting of the fire plumes. The IS intended to be developed in this project can be used both as a diagnostic modelling system and an air quality forecasting system.

3. Materials and methods

The research group has developed and compiled a semi-operational, nearly real-time assessment system for forest fires that contains the following information and tools (clearly, some parts that are listed below are available from third parties):

1. a pre-processing module that uses the forest fire observations of the MODIS satellite instrument (http://rapidfire.sci.gsfc.nasa.gov/subsets/),

2. modelling of the emissions and atmospheric dispersion of $PM_{2.5}$ from forest fires (http://silam.fmi.fi/),

3. the monitoring of the concentrations of $PM_{2.5}$ or PM_{10} at several air quality stations in Finland (http://www.fmi.fi/ilmanlaatu/ilatausta_20.html) and
4. the measurements of the chemical composition and specific wood burning tracer substances of particulate matter at one station.

This system is described in more detail by Saarikoski et al. (2007). The scientific challenges in order to improve this system were sketched in the introductory section.

3.1 Wildland fire and plume detection using satellite observation techniques

The existing FMI fire detection system using Modis algorithms will be the starting point of this work. The sensitivity of the Modis algorithm to sub-pixel fires (less than 1 km^2) needs to be improved (Wooster et al., 2003). The resolution can be improved especially applying the BIRD satellite data. However, these algorithms are validated only in homogeneous areas. The fire radiative energy (FRE) algorithm, based on previous work (Dozier, 1981, Kaufman and Justice, 1998, Wooster et al., 2003), will be improved based on the land use and biomass information provided by Corine land cover from European areas and TerraNorte (Russian Academy of Sciences' Space Research Institute IKI) for Russia. Datasets from the projects GEOLAND, GEIA and other international projects will also be used.

In order to estimate the emissions, there are two main methods that have been applied up to date. Emissions have been estimated by the use of models, which require information, among others, on the burned area, biomass density and the emission factor. The second approach is to estimate the emissions more directly from the satellite-measured FRE (Ichoku and Kaufman, 2005). Our goal is to refine the latter approach.

In addition to emissions, the initial plume rise is an important parameter for dispersion modeling. This is estimated by the BUOYANT model (Kukkonen et al., 2000, Nikmo et al., 1999), which solves the three-dimensional flow equations associated to a strongly buoyant source, and predicts the plume dispersion on local and regional scales. The model uses as input the MODIS measured thermal anomalies and the meteorological data from weather prediction models. The model has preliminarily been evaluated against the wildland case study of Trentmann *et al*. (2002) and showed good agreement with other models and observations made during this controlled burning experiment. The CALIPSO satellite (launched in 2006) is equipped with a lidar, and therefore provides unique vertically resolved information on aerosols and clouds. The CALIOP measurements will be used to evaluate the performance of the BUOYANT model.

As low-orbiting satellites provide only one (or sometimes a few) glance(s) at each specific region per day, their information cannot reproduce the temporal evolution of fires and can easily be obstructed by clouds. On the other hand, geostationary satellites have less good characteristics in the northern regions. Therefore, the evolution of fire in-between the observation periods will be modelled via fire propagation models, such as (Viegas, 1998 and Séro-Guillaume & Margerit, 2002).

3.2 Atmospheric dispersion, data assimilation and source apportionment modelling

After the forest fire has been identified, the dispersion of gaseous and aerosol pollutants emitted by the fire will be forecasted using a dispersion model. We will use the SILAM model (e.g., Sofiev et al, 2006a, Sofiev & Siljamo, 2003, http://silam.fmi.fi). The system contains both an Eulerian model and a Lagrangian Monte-Carlo random walk advection-diffusion scheme; it is capable of both forward and inverse problem solutions. The latter is often also called a source apportionment problem.

The SILAM physico-chemical modules can treat the following species: sulphur oxides, various types of aerosols (including those originated from wildland fires), radioactive species, sea salt, probability (regarding source apportionment). The treatment of aerosol is based on a modal representation of the aerosol size spectrum and state-of-the-art parameterizations of the dry and wet deposition processes. The model has been evaluated in several international projects and successfully used for solving the source apportionment problem within the ETEX experiment (Sofiev & Atlaskin, 2004), and Chernobyl accident

(Sofiev *et al*, 2006b). In those studies, the modified variational data assimilation 4D-VAR was applied as the technique for the inverse problem solving. The system has been able to forecast the fire-induced episodes during summer 2006 (Saarikoski et al., 2007); the results are comparable with the FLEXPART model results of Stohl *et al* (2007), who analysed the further transport of the same plume towards Spitsbergen.

The fire propagation models include, e.g., that presented by Clark *et al*. (2000), or the Prometheus model (http://www.firegrowthmodel.com). The model comparison with observations will utilise the Model and Measurement Analysis Software (MMAS: http://www.fmi.fi/research_air/air_49.html) developed at the FMI. This tool has recently also been tested and used internationally more widely as a basic model evaluation tool in the EU-funded project FUMAPEX.

3.3 Ground-based measurements of fire plumes at various air quality stations

Quantitative information on the transportation of particulate pollution originating from Russian forest fires to Finland is obtained from real-time, surface-based air quality measurements. They are conducted at eleven measurement stations indicated in the map of Figure 1 in Annex A. Three of the stations are situated in the immediate vicinity of the Russian border.

The detection of the fire plumes and contribution of biomass combustion in particulate matter can be partly based on the chemical composition, partly on the size distribution and mass concentrations of particular matter. The research team has previous experience on the application of such methods in Helsinki and in five other European cities (e.g., Sillanpää *et al*., 2005a, Sillanpää et al., 2005b and Saarikoski et al., 2007). During the wild fire cases observed in Helsinki in autumn 2002 and spring 2006, the $PM_{2.5}$ mass concentration increased significantly. In both cases, examination of the relatively large chemical dataset together with the backward air mass trajectories showed that biomass combustion had a strong impact on the $PM_{2.5}$ mass when the air masses came over the Baltic countries, Belarus and the European part of Russia. The concentration of biomass signatures (levoglucosan, water-soluble potassium and oxalate) in accumulation mode fine particles (diameter 0.1-1 μm) were clearly increased during these episodes. Levoglucosan was regarded as the best tracer of long-range transported wildfire smokes, as it is exclusively formed from the combustion of cellulose (Sillanpää *et al*., 2005).

The stations listed in Annex A are equipped with a variety of real-time monitors for the concentration of particulate mass (PM_{10} and $PM_{2.5}$), concentration of particulate black carbon (BC), particle number concentration, particle size distribution, aerosol scattering coefficient and aerosol optical depth. Taken together, the real-time measurements from these stations provide comprehensive information on the type of particulate pollution arriving in Finland, on the geographical extent of this pollution, and facilitate the differentiation of wildland fire episodes from other categories of air pollution episodes (classified by Kukkonen et al., 2005). In addition, several other parameters, such as aerosol inorganic chemistry (e.g. sulphate), major gaseous pollutants (e.g., sulphur dioxide), meteorological conditions, and aerosol and gas fluxes are monitored.

3.4 Case study: TROICA-9 expedition

TROICA-9 expedition (Trans-Siberian Observations Into the Chemistry of the Atmosphere) was conducted along the Trans-Siberian railway between Moscow and Vladivostok (9200 km) in October 2005 (http://www.troica-environmental.com/Overview.html). During the expedition, measurements of aerosol chemical and physical properties were carried out by the FMI and by the UH. Measurements were made from a mobile laboratory based on a railway carriage. The obtained dataset includes several episodes when the train passed the plumes of forest fires. Based on this data set, it is possible to detect several plumes from an individual forest fires or from larger forest fire areas.

For instance, the concentration of levoglucosan, a tracer of biomass burning, was at its highest in the area at distances from 5926 to 7064 km from Moscow. In the same area, online measurements showed temporarily high concentration levels of oxalate, potassium and black carbon. The observations made for chemical composition of particulate matter fit well with the wildfire map based on the observations of the

MODIS instrument. This data set also provides an unprecedented opportunity to evaluate the dispersion modelling system.

3.5 Case study: a controlled forest burning measurement campaign

The objective of this experiment is to produce a set of high-quality field data of meteorological conditions, gas concentrations, aerosol particle chemical composition, and aerosol particle and air ion concentrations and size distributions before, during and after the forest-fire. This dataset can be used in order to develop emission models for forest fires, in terms of meteorological and fire conditions, and also for the evaluation of dispersion models and satellite retrieval algorithms (using part of the data in model development, and part in model evaluation). We will also archive and use the corresponding satellite information, as well as the relevant meteorological data during the selected burning period.

A forest area of 3.8 hectars will be burned that is located about 550 meters south-east of the SMEAR II station in Hyytiälä. In this area, the dominating species is 75-95 years old Scots pine with stem volume about 300 m^3 per hectar. The controlled burning will be performed in the summer of 2007 or 2008.

Estimated duration of the controlled burning will be about three hours. The objective is to perform the burning in clear sky conditions, in order to optimise the use of satellites for detecting the fire and the resulting pollutant plume. We will utilize all the data from the continuous measurements (e.g., aerosol particle and air ion concentrations and size distributions, gas concentrations, fluxes and meteorological measurements) performed at the SMEAR II station (described in Annex A). During this campaign, volatile organic compounds (VOC's) will be measured from the gas phase using a fast response on-line trace gas analyzer, proton transfer reaction - mass-spectrometer (PTR-MS, Ionicon GmbH, Innsbruck, Austria). With the PTR-MS we will be able to measure VOC concentrations and fluxes and see their changes in the time scale of a few minutes.

Besides straight emissions, forest fires have a marked effect on soil nutrient cycling and they may influence greatly fluxes of greenhouse gases from the soil. Information on the effect of forest fires on the fluxes of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the boreal region is scarce and needs more attention. Soil emissions of CO_2, CH_4 and N_2O will be measured before and after the burning by chamber technique and by measuring the gas concentrations in the soil profile. Adjacent to the gas flux measurements, soil biological, chemical and physical parameters that affect gas exchange processes will be studied.

This data set will also be utilized in International Polar Year 2007-08 project POLARCAT (zardoz.nilu.no/~andreas/POLARCAT/), which evaluates the effects of forest fires on Arctic ecosystems.

4. Ethical questions and data protection issues

Utilisation of the above data sets and models does not cause any ethical problems. All datasets will be used in agreement with the producers of the data. We also have the required permissions to use all the mathematical models presented above.

5. Work plan and expected results

An overview illustration of monitoring, models and model evaluation of this study is presented on the cover page of this application.

5.1. The project work packages

WP 1. The detection of wildland fires and smoke plumes by satellite observation techniques, coordinated by Prof. Jarkko Koskinen, FMI.

The objectives are to develop methods that use satellite data i) to detect and map burning area and biomass, ii) to estimate fire intensity and iii) to track smoke plumes and aerosols.

Task 1. Detection of wildland fire and mapping of burning area. Satellite sensors (EOS-Modis, Envisat-Meris) will be used to detect fires and map burning area. NASA hot spot algorithm will be further developed to be better suitable for complex boreal environments. The algorithm will be validated in case studies (analysis of selected wildland fire episodes) and in the measurement campaign organized in WP4. We will also adopt novel satellite sensors (Bird, ESA sentinel 3) that are dedicated to wild land fire detection.

Task 2. Estimation of Fire Radiative Energy (FRE). FRE is estimated using the measurements obtained by thermal R bands of the satellite sensors. Several algorithms presented in the literature (Dozier, 1981, Kaufman and Justice 1998, Wooster et al., 200) introduce methods to derive FRE from satellite observations. However, none of these is validated for such heterogeneous environments as those in boreal areas. Within this task, these algorithms will be validated and further developed to optimally estimate the FRE in a boreal environment and connect it with the main parameters of the fires. FRE values are inserted as input values to the BUOYANT model, these will be subsequently utilised for computing the released thermal energy for the plume rise modelling. This procedure will be evaluated in case studies and in the measurement campaign organized in WP4.

Task 3. Estimation of emissions from satellite measurements of FRE. Approach similar to Ichoku and Kaufman (2005) will be adapted for absolute emission rates and verified and adapted to a boreal environment. Regarding the plume elevation, Ichoku and Kaufman (2005) assumed a plume height of about 1.5 km. However, as they showed, while in many cases the actual height does not cause significant differences in the emission coefficients, in the regions of major influence on Finland and Scandinavia, the sensitivity to the height is more obvious. FRE values will be used as one of input values to the BUOYANT model for computing the released thermal energy for the plume rise modelling. A full-scale algorithm will incorporate the meteorological information and necessary local data on vegetation, etc. as the FRE carries insufficient information. This development work will be particularly based on the actual profile information available from CALIOP measurements and the WP4 case study.

Task 4. Evaluation of initial plume rise predicted by the BUOYANT model. The BUOYANT model estimates the initial plume rise based on FRE as the main pre-cursor information. The CALIOP measurements of aerosol vertical profiles will be used to evaluate the performance of the the BUOYANT model. This methodology will also be evaluated against known case studies, such as Trentmann *et al.* (2002), and in the measurement campaign organized in WP4.

Task 5. Detection and tracking of smoke plumes arising from the burning area. A series of satellite images are used to detect and track the transport of smoke plumes. A mapping algorithm is developed to classify the transport of smoke plumes and aerosol clouds. The classified data is used in WP2 for assimilation in the SILAM model in order to improve the accuracy of the model predictions and allow for an inverse problem solution in case of insufficient or inaccurate information about fires. The algorithm will be validated in case studies and in the measurement campaign organized in WP4.

WP 2. Development of atmospheric dispersion modelling, data assimilation and source apportionment methods, coordinated by Prof. Jaakko Kukkonen, FMI

The objectives are to refine the modelling methods, integrate these to the IS, and evaluate the models agains experimental data.

Task 1. Development and coupling the SILAM and BUOYANT modelling systems. Wild land fires are highly buoyant and can cover wide areas; it is therefore crucial to evaluate properly the initial dispersion and plume rise. This will be modelled by integrating the SILAM dispersion model with the plume-rise model BUOYANT. The task relies on WP1 where the BUOYANT model will be connected with the fire detection and estimation part of the IS; the evaluation will be part of the WP4.

Task 2. Description of the fire evolution for the needs of the atmospheric dispersion modelling will follow the principles of Jenkins *et al.* (2002). Since the atmospheric models have much lower resolution than the size of a typical boreal fire, very complex models, such as the Prometheus model, will not be used. However, we will address in detail the connection between the diurnal variation of the meteorological parameters and the fire emission rates. The corresponding parameterization will be developed using the available fire propagation models.

Task 3. The data assimilation capabilities of SILAM will be extended to include the satellite measurements of various species observed in the vicinity of the fires, as well as in-situ data. The basic methodology will be 4D-VAR, while the list of assimilated parameters will include the aerosol optical depth mainly obtained from satellites retrievals, such as MODIS, OMI, etc. Ground-based observations will provide larger set of species, including NOx and organic matter, important for refining the emission composition of the fires. Their assimilation will require finalising the tangent linear model and creating an adjoint chemical scheme to SILAM. This work will be done in synergy with EU-GEMS and ESA-PROMOTE projects (see "Cooperation" section).

Task 4. The integration of the combined SILAM/BUOYANT model into the IS. The updated dispersion modelling system will be integrated with other parts of the IS – satellite fire detection and retrieved particulate matter concentrations, ground-based air quality observations, etc. The approach will partly follow the PRISM standards for the inter-operable systems. The final product will be an updated modelling system that is adapted to the specific input and output information of the IS.

WP 3. Detection and quantification of particulate matter formed in fires at surface measurement stations, and the related modelling, coordinated by prof. Risto Hillamo, FMI

The objectives are (i) to reliably detect and quantify particulate matter from wild land fire episodes based on ground-based air quality measurements, (ii) to evaluate the temporal and spatial evolution of the fire plumes based on ground-based air quality measurements, and (iii) to model the emissions and atmospheric dispersion for the selected wind land fire episodes.

Task 1: Identification of long-range transported pollution episodes caused by forest fire emissions. This will be achieved by detailed, continuous measurements of both the physical and chemical aerosol properties specific for fire emissions at high temporal resolution at the SMEAR III station in Kumpula, Helsinki. Typically 2-3 forest fire episodes, lasting from a few days up to weeks, will be detected annually.

Task 2: Quantification of the geographical extent and temporal evolution of forest fire episodes. Once identified, the spatial coverage and temporal evolution of the long-range transported forest fire episodes will be quantified based on the data from multiple surface measurement sites. Two networks will be used: 1) sites measuring particle number size distributions at 10-minute resolution (Virolahti, Kuopio, Hyytiälä, Värriö and Pallas stations in Finland, and two stations in Sweden, if needed), and 2) sites measuring continuously PM_{10} and/or $PM_{2.5}$ (Utö, Virolahti, Pallas, Sevettijärvi and Raja-Jooseppi), black carbon (Pallas and Virolahti) and bulk inorganic particulate matter at 24-hour resolution (Utö, Virolahti and Pallas). Both networks are supported by the continuous aerosol optical depth measurements at Jokioinen and Sodankylä. The station of Kumpula has instruments to detect fire tracer substances with 15 min time resolution.

Task 3. Application of the SILAM/BUOYANT modelling system for re-analysis of the past fire episodes, in which the observations of the fires are available from ground-based observations and from satellites. These applications will include data assimilation for source apportionment and for further evaluation of the air quality impact using the concentration information as the main initialization field for the dispersion models. This also yields quantitative evaluation of the accuracy and reliability of the combined fire detection, analysis of fire intensity and dispersion modelling system.

WP 4. Organisation of a forest fire dispersion measurement campaign in the vicinity of the SMEAR2 station, and the related modelling, coordinated by Prof. Gerrit de Leeuw, HU.

The main objectives are (i) to study the emissions of a forest fire, and (ii) model the local scale dispersion of the fire plume, and (iii) evaluate the models against the new dataset.

Task 1. Quantification of emissions from forest burning and their effect on air quality, on composition and size distribution of aerosol particles and on soil carbon and nutrient cycling, through measurements of gas concentrations, air ion concentrations and aerosol size distributions and chemical composition before, during and after the controlled forest burning in Hyytiälä near the SMEAR II measurement station.

Task 2. The initial shaping of the plume computed by the BUOYANT model will be evaluated against the actually observed cloud. All key parameters needed for BUOYANT will be directly measured during the experiment and subsequently evaluated from the “standard” IS-based procedure that will derive them from the satellite retrievals (FRE), meteorological models, and other input data.

Task 3. Application of satellite observation techniques and the dispersion modelling for analysis of the results of the measurement campaign. The satellite retrievals of the plume from the burning experiment will be compared with meso-to-regional scale dispersion simulations of SILAM. The SILAM runs will use the best-available information about the initial plume shape and elevation (Task 2), as well as the Task-1 emission data. The retrievals of aerosol optical depth will allow at least a simplified regional inverse modelling exercise, which results will be compared with the outcome of Task 1.

WP 5. Evaluation, analysis and modelling of the aerosol data measured during the TROICA campaign, coordinated by Prof. Veli-Matti Kerminen, FMI

The objectives are (i) to detect and analyse wild land fire episodes in Russia based on TROICA data and corresponding satellite retrievals, and (ii) to model these cases and evaluate the system accuracy.

Task 1. Identification of the episodes, collection of the related satellite retrievals, analysis of the observational data, especially including the evaluation of forest fire episodes detected at different transport distances. The measurements made during TROICA-9 provide us with a unique data set to characterize forest fire episodes and to evaluate the aerosol processes (dilution, aerosol ageing etc.) that modify particulate matter during its transport in the atmosphere.

Task 2. Application of the atmospheric dispersion modelling system in case of the episodes detected in TROICA. The BUOYANT-SILAM system will be applied for the TROICA observations of plumes from the forest fires, combined with appropriate satellite retrievals of wildfire hot spots in Siberia. The model results will be compared with both TROICA observations of the plume composition and PM content, as well as with the satellite retrievals of the aerosol total column. In case of sufficient data, the inverse modelling problem will be solved to refine the emission term for the fires and to provide the uncertainty range for the IS accuracy.

For the project duration of 2008 – 2010, the timetable planned is the following.

WP	Abbreviated title	2008	2009	2010
WP1		**********	***	
WP2		*******	********	
WP3			**********	**
WP4			*****	**********
WP5			***	**********

5.2. Publication and dissemination of the research results

The main research results will be published in international peer-reviewed papers, throughout the duration of the project. The final stage of the project (late summer and autumn of 2009) is specifically devoted to writing such papers and a final technical report. Fairly short review-type papers will be published nationally in Finnish. A www site will be created for the dissemination of information, and also to act as a working platform, within the first three months of the project.

Dissemination of the results will include the following:

1. The scientific results are disseminated within the European atmospheric pollution and aerosol science research communities mainly via presentations in conferences and publications in peer-reviewed scientific journals.
2. The methods developed and the numerical results will be made available for the CAFÉ (Clean Air for Europe), EEA (European Environmental Agency), and the CLEAR cluster of European EU-funded research projects, as well as for the Ministries of Interior and the Environment and Transport and Communications in Finland.

5.3. Project innovation and benefits

An Integrated Monitoring and Modelling System (IS) including the whole chain of processes - from retrieval of fire parameters, observations of the fire plumes, evaluation of their evolution, assimilation of all information into the dispersion models with subsequent air quality simulations and ground-based monitoring - has not been developed previously anywhere. The IS to be developed here contains several new innovations that have not been previously presented, such as (i) the integration of satellite-based detection of fire intensity with the subsequent plume buoyancy computations for wild land fires, and (ii) data assimilation for the source apportionment of the fire location, using both the satellite and the in-situ data.

The project is also designed to facilitate re-analysis of selected historical major wild land fires; such analyses conducted systematically using both earth observation (EO) and ground-based data, and related modelling, have been scarce. The novel TROICA observations provide a unique opportunity for studying major wild land fires in the Russian territory. Finally, the controlled forest fire experiment in the immediate vicinity of the SMEAR II supersite provides an unprecedented chance in order to study the pollutants, especially particulate matter that are formed in a major forest fire.

6. Performers of the research and resources

The FMI research team is responsible for the coordination of the project and coordination of WP's 1-3 and 5-6. It has extensive expertise on urban, regional and continental air pollution research. Atmospheric dispersion models and air quality measurements have been developed and applied at FMI since the early 1970's.

The main researchers participating in the study are the following:

Finnish Meteorological Institute:

Prof. Jarkko Koskinen, Research Professor, Head of Earth Observation
Prof. Jaakko Kukkonen, Research Professor, Head of Air Quality Research
Prof. Risto Hillamo, Manager of research team "Aerosol Research"
Adjunct prof. (doc.) Ari Karppinen, Manager of research team "Atmospheric Dispersion Modelling"
Dr. Antti Arola, senior research scientist responsible for aerosol observations from satellites
Dr. Mia Pohjola, particulate matter dispersion modelling.
Dr. Markus Sillanpää, Chemical and source characterisation of urban particulate matter.
Ph.D. student M.Sc. Otto Hyvärinen, Monitoring of wild land fires using earth observation techniques, Ph.D scheduled in 2009.
Ph.D. student M.Sc. Ms. Pilvi Siljamo, SILAM model applications, Ph.D scheduled in 2009.
Ph.D. student M.Sc. Ms. Minna Rantamäki, the combined use of dispersion models and numerical weather prediction models, PhD scheduled in 2009.
Ph.D. student Lic. Ms. Leena Partanen, data analysis and dispersion modelling, Ph.D scheduled in 2010.
Ph.D. student M. Sc. Karri Saarnio, contribution of biomass combustion in particulate matter, PhD scheduled in 2009.
Ph.D. student M.Sc. Ms. Sanna Saarikoski, Sampling and analysis of organic aerosol, Ph.D scheduled in 2007.

MSc student Milla Lanne, Monitoring of wild land fires using EO techniques.

University of Helsinki

Prof. Gerrit de Leeuw, expertise on satellite observation techniques.
Prof. David Schultz, expertise on meso-scale meteorology
Ph.D. student M.Sc. Ms. Tiia Grönholm, dynamics of atmospheric aerosol particles in boreal boundary layer, PhD scheduled in 2008.
Ph.D. student M.Sc. Ms. Taina Ruuskanen, the influence of trace gases on aerosol particle formation, PhD scheduled in 2008.

Collaborators (participating with own resources), contributions to the project:

1. Dr. Johann G. Goldammer, The Global Fire Monitoring Center (GFMC) / Fire Ecology Research Group, Max Planck Institute for Chemistry, c/o Freiburg University, Hamburg, Germany
2. Dr. Philippe Bougeault, European Centre for Medium Range Weather Forecasting (ECMWF), Reading, U.K.
3. Dr. Tom Keenan Bushfire, Cooperative Research Centre (BCRC), Melbourne, Australia

The collaboration between FMI, Max Planck Institute BCRC and ECMWF is organized through a joint co-operation project named "Global Early Warning System for Wildland Fire". The collaboration focuses on following issues: to develop a global early warning system for wildland fire based on existing and demonstrated science and technologies, to develop an information network to quickly disseminate early warning of wildland fire danger that reaches global to local communities, to develop an historical record of global fire danger information for early warning product enhancement, validation and strategic planning purposes, and to design and implement a technology transfer program to provide training for global, regional, national, and local community applications in the above mentioned areas.

Dr. Alexander Baklanov, Danish Meteorological Institute, Copenhagen, Denmark

He will participate in development of the meteorological part of the forecasting system, data assimilation and estimation of source term based on monitoring data (e.g., Penenko and Baklanov, 2001, Penenko et al., 2002).

4. Dr. R.Vankevich, Russian State Hydrometeorological University, St.Petersburg, Russia

Following the cooperational agreement between FMI and RSHU, the group of R.Vankevich will concentrate on evaluation and quantification of the forest fires in Russia and provide the high-resolution mapping for the local vegetation type and state, as well as the methodology linking it with the local fires.

5. Academy Prof. Markku Kulmala, Head of the Division of Atmospheric Sciences of Department of Physical Sciences, HU, Prof. Veli-Matti Kerminen, Research Professor, Expertise on aerosol science and the TROICA campaign, FMI.

7. National and international co-operation, connections to other projects

A strong link is envisaged with the EU-GEMS Integrated Project, where FMI (M.Sofiev) is a leader of the emission work package, and also responsible for the wild land fire assimilation system in the Global Aerosol sub-project.

There has been continuous co-operation of both FMI and UH with EMEP (European Monitoring and Evaluation Programme) MSC-W (Meteorological Synthesizing Centre –West). There is also a previously established co-operation between the FMI and UN-ECE Convention on Long-Range Transboundary Air Pollution and the European Monitoring and Evaluation Programme EMEP, regarding the modelling of atmospheric dispersion of aerosols.

Regarding the model development, model evaluation and applications, the proposed project is closely related the previous EU-funded project "Source apportionment of urban airborne particles and polycyclic aromatic hydrocarbons in Europe – SAPPHIRE" (2002 – 2006).

Cooperation with the EU-GEMS project will be based on FMI participation in Global Aerosol and Regional Air Quality sub-projects, where it is responsible for the evaluation og emissions, including the wildland fire sources, and regional air quality forecasting over Europe. The latter topic is also a priority within the scope of the ESA-PROMOTE 2 project.

8. Research training provided in connection with the project

The project emphasizes post-graduate studies for PhD-degrees, post-doctoral training and training of graduate students. The research group has active connection to two graduate schools: the Graduate School in Remote Sensing and the Graduate School ”The physics, chemistry, biology and meteorology of atmospheric composition and climate change”. The research groups at both UH and FMI have long and successful experience on research training. Also postgraduate courses and seminars are available for students. The laboratory of aerosol and environmental physics (UH) offers more than 25 credit postgraduate studies. Supervision of studies is organized by Professors de Leeuw and Schultz.

The project will contribute to the studies of eight PhD students: Ms. L. Partanen, Ms. M. Rantamäki, Mr. Otto Hyvärinen, Ms. S. Saarikoski, Mr. K. Saarnio and Ms. P. Siljamo (all of these at FMI), Ms. T. Grönholm and Ms. Taina Ruuskanen (both at HU). Dr. M. Pohjola (UH) and Dr. Markus Sillanpää will conduct post-doctoral studies within the project. The managers of the participating research teams at UH and FMI have leading roles in the guidance and supervision of these students. Professors de Leeuw and Schultz (UH) participate actively in the guiding of PhD students; J. Kukkonen, V.-M. Kerminen, R. Hillamo and A. Karppinen are also working part-time as docents at the University of Helsinki (UH); J. Kukkonen is also working part-time (including guiding of Ph.D. students) as a Visiting Professor in Atmospheric Sciences at the University of Hertfordshire (U.K.). This project is expected to produce eight doctoral dissertations.

9. Project financial plan

The requested funding from Academy of Finland is 322 000 € for a period of three years, 2008-2010. Most of this funding will be spent to salaries of young and promising pre- or post-doctoral scientists: Ms. L. Partanen (20 person-months), Mr. Otto Hyvärinen (31 person-months) and Ms. S. Saarikoski (15 person-months; all of these at FMI), and Ms. T. Grönholm (31 person-months, HU). Most of the overhead costs, computing etc. will be covered from the budgets of the participating institutes. FMI will also provide a funding contribution mainly spent to salaries of J. Kukkonen, V.-M. Kerminen, R. Hillamo and A. Karppinen, totally approximately 230 000 €, UHEL for the salaries of G. de Leeuw and D. Schultz, totally 45 000 €.

The travel costs (14 000 €) are scheduled to trips mainly to the project workshops and meetings of the above pre- and post-doctoral researchers. The workshop meetings and seminars will be organised in Finland (Helsinki and Kuopio) or related to international conferences in this area. The item “other costs” (11 000 €) covers mainly publication costs.

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Annex A. The ground-based measurement stations

Pallas (67°58'N, 24°07'E) is in subarctic region at the northernmost limit of the northern boreal forest zone (Hatakka et al., 2003). Particle number concentration is measured with a differential mobility particle sizer (DMPS) and a condensation nucleus counter (CNC), PM_{10} with a beta attenuation monitor, aerosol scattering coefficient with a nephelometer, and the airborne black carbon with an aethalometer. Daily aerosol samples are collected for inorganic analysis (e.g., sulphate), and flask samples are collected twice a week for the analysis of volatile organic compounds. Arctic Research Centre of FMI at Sodankylä (67°22'N, 26°38'E) is in a pine forest in central Lapland. The station is located 179 m a.s.l. Aerosol optical depth is measured with a sun photometer and carbon dioxide flux with the eddy covariance method. Värriö (67°45'N, 29°37'E) is in a nature reserve in eastern Lapland. The SMEAR I station is on a fjeld 400 m a.s.l. and it is surrounded by a forest consisting mainly of pines, spruces and birches. University of Helsinki (UH) measures aerosol particle number concentration with a DMPS and a CNC. FMI collects aerosol samples for inorganic analysis. Oulanka (66°19'N, 29°24'E) is located close to the Oulanka national park about 10 km west of the Russian border. The station is situated in a forest consisting mainly of pines, spruces and birches 310 m a.s.l. Weekly aerosol samples are collected for the analysis of inorganic components. Sulphur dioxide is measured continuously with a chemiluminescence monitor.

The measurement site in the city of Kuopio (62°54'N, 27°38'E) is located on top of the Puijo viewing tower, 200 m above the surrounding area, and 2 km west of the city centre. Aerosol particle size distribution is measured with a DMPS, black carbon with an aethalometer, and PM_{10} and $PM_{2.5}$ with a laser scattering instrument. Ähtäri (62°35'N, 24°12'E) is located in a young forest consisting mainly of pines, spruces and birches at an altitude of 180 m a.s.l. Weekly aerosol samples are collected for the analysis of inorganic components, e.g. sulphate. Sulphur dioxide is measured continuously with a chemiluminescence monitor. The SMEAR II station (61°51'N, 24°17'E) is located in a homogenous Scots pine stand (Pinus sylvestris L.) next to the Hyytiälä forestry station of the UH in southern Finland 181 m a.s.l.; (61º51'N, 24º17'E, denoted as 'Hyytiälä' in Figure 1). Scots pine is the dominating species in more than a half of the forest area in southern Finland. At the SMEAR II station UH measures continuously gas (H_2O, NO_x, O_3, CO_2, CO) concentrations, aerosol particle total number concentration, aerosol particle number size distribution (3-500 nm in diameter), aerosol particle mass fractions (PM_{10}, $PM_{2.5}$, PM_1), air ion number size distributions (0.46–40 nm in diameter), fluxes of H_2O, CO_2, O_3 and aerosol particles, and meteorological variables, such as temperature, pressure, radiation, humidity and wind speed and direction. FMI collects aerosol samples for inorganic analysis.

Figure 1. The locations of the air quality measurement stations selected for this study. A description of the detailed measurement programmes and the representativity of the stations is presented in Annex A.

Jokioinen (60°48'N, 23°30'E) is located in southwestern Finland, close to the Oulanka national park about 10 km west of the Russian border. The station is surrounded by open fields and forests consisting mainly of pines, spruces and birches. Aerosol optical depth is measured with a sun photometer. Virolahti (60°32'N, 27°41'E) is in a rural region close to the point where the border between Finland and Russia meets the coast of the Baltic sea. The station is surrounded by open fields and a forest consisting mainly of pines, spruces and birches. At the station aerosol particle size distribution is measured with a DMPS, black carbon with an aethalometer, and PM_{10} and $PM_{2.5}$ with beta attenuation monitors. Daily aerosol samples are collected for the analysis of inorganic components, e.g. sulphate. Sulphur dioxide is measured continuously with a chemiluminescence monitor and total gaseous mercury with a cold vapour atomic fluorescence analyser. Kumpula (60°12'N, 24°58'E) is in Helsinki about 5 km NE of the city centre in the vicinity of the FMI's premises. The station is surrounded by a park and the university campus; a major road passes the station within a distance of 100 m. Aerosol particle number concentration is measured with a DMPS and a CNC. Black carbon is measured with an aethalometer. CO is measured with a continuously operating IR analyser. Utö (59°47'N, 21°22'E) is located on a small island (about 1 km2) 60 km southwest of the coast of southwestern Finland. The vegetation on the island is sparse consisting mainly of grass, twigs and bushes. At the station aerosol particle size distribution is measured with a DMPS, black carbon with an aethalometer, and $PM_{2.5}$ with a beta attenuation monitor. Daily aerosol samples are collected for the analysis of inorganic components, e.g. sulphate. Sulphur dioxide is measured continuously with a chemiluminescence monitor.