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- COST -

Secretariat

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COST 4188/10

MEMORANDUM OF UNDERSTANDING

Subject : Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1004: European framework for online integrated air quality and meteorology modelling

Delegations will find attached the Memorandum of Understanding for COST Action ES1004 as approved by the COST Committee of Senior Officials (CSO) at its 180th meeting on 1 December 2010.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action ES1004
EUROPEAN FRAMEWORK FOR ONLINE INTEGRATED AIR QUALITY AND METEOROLOGY MODELLING

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4159/10 “Rules and Procedures for Implementing COST Actions”, or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to set up a multi-disciplinary forum for online integrated air quality/meteorology modelling and elaboration of the European strategy for a new-generation integrated ACT/NWP-CLIM modelling capability/framework.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 60 million in 2010 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

The Action - European framework for online integrated air quality and meteorology modelling (EuMetChem) - will focus on a new generation of online integrated Atmospheric Chemical Transport (ACT) and Meteorology (Numerical Weather Prediction and Climate) modelling with two-way interactions between different atmospheric processes including chemistry (both gases and aerosols), clouds, radiation, boundary layer, emissions, meteorology and climate. At least, two application areas of the integrated modelling are aimed to be considered: (i) improved numerical weather prediction (NWP) and chemical weather forecasting (CWF) with short-term feedbacks of aerosols and chemistry on meteorological variables, and (ii) two-way interactions between atmospheric pollution/ composition and climate variability/change. The framework will consist of four Working Groups namely: 1) Strategy and framework for online integrated modelling; 2) Interactions, parameterisations and feedback mechanisms; 3) Chemical data assimilation in integrated models; and finally 4) Evaluation, validation, and applications. Establishment of such a European framework (involving also key American experts) will enable the EU to develop world class capabilities in integrated ACT/NWP-Climate modelling systems, including research, forecasting and education.

Keywords: online integrated meteorology - air quality modelling systems, chemistry-aerosols-clouds-radiation-climate feedbacks, numerical weather prediction, chemical weather forecasting, chemical data assimilation

B. BACKGROUND

B.1 General background

Although at present atmospheric chemical transport (ACT) models can be coupled to numerical weather prediction (NWP) models either offline or online, a scientific perspective of chemical weather forecasting (CWF) would argue for an eventual migration from offline modelling (where the ACT model is run after the NWP model is completed) to online modelling, allowing coupling and integration of the physical and chemical components of CWF systems. Specifically, better and more complete representations of physical and chemical processes and interactions in the models are needed. One of the key outcomes of the finalized COST-728 was to suggest a European strategy for integrated Atmospheric Chemical Transport / Numerical Weather Prediction and Climate (ACT/NWP-CLIM) modelling that would result in a European framework (see: http://www.cost728.org). Based on this and recent discussions with interested researchers at workshops held in Lecce, Copenhagen, Reading, Geneva and at ECMWF and WMO this new Action is suggested. The Action focus will be on the online coupled ACT/NWP-CLIM modelling with two-way feedbacks and development of a European framework for integrated modelling systems.

Historically Europe has not adopted a community approach to modelling and this has led to a large number of model development programmes, usually working independently. However, a strategic framework (within a COST Action) will help to provide a common goal and direction to European research in this field while having multiple models.

This COST Action seems to be the best approach to streamline, integrate and harmonize the interaction between atmospheric chemistry modellers, weather modellers and end users. It will lead to strongly integrated and unified tools for a wide community of researchers and users. Previously, air quality (AQ) and numerical weather prediction were developed separately. With more advanced NWP and AQ models it became easier to study urban-scale air pollution and therefore, allow the integration of NWP and AQ. The strategy of integrated modelling and online coupling of air quality and meteorology modelling has a good perspective in future, and therefore, this Action will help building widely useful information for the community based on the new generation of integrated 'environment - weather' forecasts.

The COST Action funds will be used only for networking and capacity-building activities, the main research developments will be funded by relevant collaborating EU FP7 research projects (e.g. MACC, MEGAPOLI, CityZen, PEGASOS, PBL-PMES, see more in Sec. B4) and by national programmes of the participating countries.

B.2 Current state of knowledge

The prediction and simulation of the coupled evolution of atmospheric transport and chemistry will remain one of the most challenging tasks in environmental modelling over the next decades. Many of the current environmental challenges in weather, climate, and air quality involve strongly coupled systems. It is well accepted that weather is of decisive importance for air quality, or for the aerial transport of hazardous materials. It is also recognized that chemical species will influence the weather by changing the atmospheric radiation budget as well as through cloud formation. Until recently however, because of the complexity and the lack of appropriate computing power, air quality and weather forecasts have been developed as separate disciplines, leading to the development of separate modelling systems that are only loosely coupled (offline). In NWP, the dramatic increase in computer power enables to use higher resolution to explicitly resolve fronts, convective systems, local wind systems, and clouds, or to increase the complexity of the numerical models. Additionally it is now possible to directly couple AQ forecast models with NWP models to produce a unified modelling system – online – that allows two-way interactions. While climate modelling centres have gone to an Earth System Modelling (ESM) approach that includes atmospheric chemistry and meteorology, land and oceans, NWP centres as well as entities responsible for AQ forecasting are only beginning to discuss whether an online approach is important enough to justify the extra cost. NWP and AQ forecasting centres may have to invest in additional computer power as well as additional man power, since additional expertise may be required. We are in favour of integrating weather and chemistry together, for both NWP and CWF. For NWP centres, an additional attractiveness of the online approach is its possible usefulness for meteorological data assimilation, where the retrieval of satellite data and direct assimilation could benefit from forecast concentrations of aerosols and radiatively active gases.

B.3 Reasons for the Action

The focus on integrated systems is timely, since recent studies have shown that meteorology/climate and chemistry feedbacks are important in the context of many research areas and applications, including NWP, climate modelling, air quality forecasting, climate change, and ESM. Potential impacts of aerosol feedbacks include:

- the direct effect - a reduction of downward solar radiation;
- the semi-direct effect - changes in surface temperature, wind speed, relative humidity, and atmospheric stability;
- the first indirect effect - a decrease in cloud drop size and an increase in drop number by serving as cloud condensation nuclei;
- the second indirect effect - an increase in liquid water content, cloud cover, and lifetime of low level clouds, and suppression or enhancement of precipitation.

Traditionally, aerosol feedbacks have been neglected in NWP and AQ modelling mostly due to a historical separation between the meteorological and air quality communities as well as limited understanding of the underlying interaction mechanisms. Such mechanisms may, however, be important on a wide range of temporal and spatial scales, from days to decades and from global to local. Field experiments and satellite measurements have shown that chemistry-atmosphere feedbacks exist among the Earth systems including the atmosphere.

Current overviews showed that there exist a number of online coupled ACT/NWP-CLIM modelling systems in Europe. However, many of such models were not built for local to regional scales, but they are global-scale systems including only relatively simplified chemistry components (e.g., MESSy). Some meso/regional-scale online integrated modelling systems are developing today (WRF-Chem, Enviro-HIRLAM, RegCM-Chem, etc.) which consider feedbacks with direct and indirect effects of aerosols and radiatively active gases. However, more research remain to be done to develop and evaluate advanced integrated coupled models covering the full range of spatial and temporal scales and applications from weather and air pollution to climate change simulation.

The Action plans to build a network of European and non-European groups involved in the development of coupled ACT/NWP-CLIM models, ranging from global to regional and local, and from meteorology to climate time scales. Such a network would facilitate the further improvement and intercomparison of models, collection of observations suitable to evaluate the models and sharing of knowledge on chemistry-meteorology/climate feedbacks.

B.4 Complementarity with other research programmes

This COST Action will be closely linked with, and complementary to many ongoing and planned research EU FP7 projects: MACC, MEGAPOLI, CityZen, PEGASOS, PBL-PMES, TRANSPHORM; International programmes: WMO GAW GURME, IGBP/IGAC, GEMES, COSMOS, AQMEII initiative; COST Action ES0602 on Chemical Weather, etc. All the European NWP communities: the ALADIN, COSMO, HIRLAM and UK UM are actively participating in this COST Action.

Most of the active participants of the COST Action are already deeply involved in the integrated modelling activities, e.g., in the scope of ongoing mentioned EU FP7 research projects, EU TEMPUS educational projects COMBAT METEO and QUALIMET, Nordic Network project MUSCATEN, and a number of national research projects. The importance of integrated systems and such COST Action is fully understood and supported by the research community. The COST Action is not duplicating the aims of above mentioned research projects, but focusing on the European framework, networking and capacity-building activities.

C. OBJECTIVES AND BENEFITS

C.1 Main/primary objectives

An overall objective of the Action is to set up a multi-disciplinary forum for online integrated air quality/meteorology modelling and elaboration of the European strategy for a new-generation integrated ACT/NWP-CLIM modelling capability/framework. The main topics are: 1. Online versus offline modelling: advantages and disadvantages, 2. Analysis of priorities focusing on interaction/feedback mechanisms, 3. Chemical data assimilation in integrated models, 4. European strategy/framework/centre for online integrated modelling, 5. Evaluation and validation framework of online ACT/NWP-CLIM models, 6. Collection of suitable datasets for model development, testing and evaluation.

C.2 Secondary objectives

Specific objectives addressing the key components of the overall goal are:

• Comprehensive review of existing online coupled integrated modelling systems in Europe and worldwide;
• Identification of critical gaps in current knowledge;
• Better coordination between different on-going research efforts;
• Establishment of networking between groups focusing on parameterizations of feedbacks and interactions;
• Development of a detailed strategy and specific action plan for improving the scientific knowledge and converting the findings into integrated modelling systems;
• Establishing a two-way dialog with end-users;
• Agreeing on input data formats for easy application in multiple models;
• Recommendations for a software bank with agreed coding standards (i.e., making easier an interchange and coupling various parts/blocks of modelling systems).

C.3 How will the objectives be achieved?

The Action participants represent most of the European teams developing online integrated modelling systems, key American experts in this field, and collectively have world-leading expertise and research track record in the online integrated modelling. So, all the European integrated ACT-NWP/Chem models will be involved in the COST Action analyses, intercomparisons and recommendations. The Action members, invited experts and external partners from the collaborating projects have access to a wide range of methods, parameterisations, datasets and the latest NWP and ACT models to undertake the simulations and analyses and achieve the objectives.

Considered in the Action models, modules, parameterisations and datasets (subject of an agreement with the developer) will also be shared with other projects collaborating with the COST Action. Methodologies, model inventories, case studies and validation protocols and datasets will be adapted from previous and current projects and COST Actions (e.g., the model inventory and evaluation protocols – from COST 728; specific case studies, emission inventories and scenarios, ensemble tools, model setups and parameterisations – from COST ES0602, FP7 projects MEGAPOLI, MACC, PEGASOS, TRANSPHORM; modelling systems and computer facilities of participating research organisations, NWP centres and communities, e.g., the Chemical branch of the HIRLAM consortium, etc.

C.4 Benefits of the Action

The Action will constitute an important element in cross-discipline coordination of research and application studies related to integrated air quality and weather/climate modelling. The comprehensive reviews of achievements and existing gaps, advantages and shortcomings (both within each research area and across their inter-connections) will lead to a better understanding of a variety of processes determining and influencing numerical weather forecasting and chemical weather and climate, as well as their interactions.

Within ACT/NWP-CLIM the challenge will be in predicting the incredibly complex atmospheric system that contains nonlinear hydrodynamic, thermodynamic, radiative, chemical, and physical interactions. It will also highlight the existing gaps in knowledge and help identify the most important areas for future developments towards advanced integrated forecasting and simulation systems for chemistry and meteorology/climate.

Two-way coupling of chemistry and atmosphere components will be used for application to CWF, decadal predictions and long-term climate change simulations. The primary aim of the Action will be to improve our understanding of chemistry-atmosphere feedbacks at scales ranging from global to regional/local. This will entail the participation of modelling groups working on different scales, which will improve the dialog and interactions across these communities. The design of benchmark experiments and observational datasets will enable different groups to evaluate their models and simulated feedback processes within a coordinated effort including a variety of modelling systems. European integrated modelling framework and strategy will be elaborated in this Action. Different feedback mechanisms for modelling in air quality, weather and climate will be analysed.

Direct outcomes from the Action will include benefits for:

(i) meteorological weather forecasting (e.g., in urban areas, severe weather events, fog and visibility, UV-radiation and solar energy, etc.),

(ii) chemical weather/air quality and bio-meteorology forecasting,

(iii) seasonal and decadal air quality/climate prediction,

(v) global and regional projections of the climate/earth system.

Outcome from the Action will also include benefits for scientific community via

1. Better integration of researches across different areas of Earth sciences,
2. Linking developments aiming at mutual enrichment and cross-validation,
3. Identifying important areas for future research,
4. Providing a flexible forum for planning future activities.

Specific scientific impacts of the Action will include,

1. A list of strengths and weaknesses of the existing knowledge-base,
2. Established/strengthened communications between different research fields involved,
3. Established/strengthened connections with end users and beneficiaries of physical and chemical weather integrated assessment and forecasting systems,
4. A mid-to-long-term common research agenda for the future.

Besides, benefits for society will include the following:

1. Contribute to better forecasting of severe weather events and their consequences (forest fires, dust storms, flooding, volcano eruption, etc.),
2. Contribute to reduction of detrimental combined health effects,
3. Contribute to better prediction of climate change and to climate change adaptation strategy,
4. Cost-effective measures to manage transport and energy production,
5. Improved management and protection of terrestrial, coastal, and marine ecosystems,
6. Enhanced quality of life, especially in urban areas,
7. Decreased overlap and redundancy of national, regional or local activities and arrangements,
8. Better possibilities to relate the AQ, meteo/climate factors with human health and impacts on ecosystems.

C.5 Target groups/end users

The target group and potential end-users are:

• Scientific institutes and laboratories working in the related areas and organizations coordinating European, international and national research programmes;

• European, national, and regional authorities, whom are responsible for the strategy to provide comfortable living conditions for population;

• National authorities, meteorological services, environmental research institutes, which are developing the strategy to improve the quality of forecasting weather, climate and air quality changes;

• National and municipal authorities maintaining control over the quality of weather and air pollution forecasts;

• National Ministries of Education and Universities responsible for educational programmes in meteorology, climate change and environmental protection;

• European Environment Agency, WHO, EUMetNet, ECMWF and other organisations that participate in the formulation and application of research policies, like the European Commission and the associated DGs;

• WMO and its units responsible for international monitoring programmes, research and education in meteorology, climate change and environmental protection;
• Organisations responsible for preventive measures against weather–related hazards and emergencies;
• Organisations, providing preventive measures against emergencies related to elevated levels of air pollution concentrations.
See also the Section H: Dissemination plan

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The scientific programme of the Action will be organised in 4 work packages (WP) / Working Groups (WG) with the following specific objectives:
WG 1: Strategy and framework for online integrated modelling,
WG 2: Interactions, parameterisations and feedback mechanisms,
WG 3: Chemical data assimilation in integrated models,
WG 4: Evaluation, validation, and applications.
At the current time we support the scientific hypothesis that feedback mechanisms are important for multi-scale modelling and for quantifying the direct and indirect effects of aerosols. However, the following key scientific questions still await answers and require further research:
• What are the effects of climate/meteorology on the abundance and properties (chemical, microphysical, and radiative) of aerosols on urban/regional scales?
• What are the effects of aerosols on urban/regional climate/meteorology and their relative importance (e.g., anthropogenic vs. natural)?
• How important are the two-way feedbacks and chains of feedbacks among meteorology, climate, and air quality in the estimated effects?
• What is the relative importance of aerosol direct and indirect effects as well as of gas-aerosol interactions in the estimates on different spatial and temporal scales?
• What are the key uncertainties associated with model predictions of mentioned effects?
• How to realize chemical data assimilation in integrated models for improving NWP and CWF?
• How the simulated feedbacks can be verified with available observations/datasets?

D.2 Scientific work plan methods and means

WG1: Strategy and framework for online integrated modelling

The overall objectives of WG1 will be to develop model frameworks and effective code implementation and management strategies for online-coupled meteorology and chemistry models and to identify the model development priorities and milestones.
Models up- and down-scaling: To assess the climate change impact on future air quality at urban and regional scales the three approaches may be used: (i) to downscale from a General Circulation Model (GCM) to a regional NWP model and similarly to downscale from a global ACT model to a regional ACT model; (ii) to expand the model treatments in GCMs/ Global ACT models for mesoscale processes; (iii) to globalize the existing urban/regional coupled meteorology and chemistry models, such as WRF/Chem or Enviro-HIRLAM for long-term climate-air quality modelling at all scales. These mentioned approaches will be compared; and the 3rd approach will be applied to develop a unified model framework for consistent physical, dynamical, and chemical treatments from global to urban scale in the online-coupled climate/meteorology and chemistry modelling.

Two-way feedbacks: The importance of feedback mechanisms for multi-scale modelling will be emphasised. However, many key questions still require further research. In particular, there is a need to quantify different interaction mechanisms on different spatial and temporal scales. This activity will identify the processes which are most important for simulating direct and indirect effects of aerosols that need to be included in the aimed unified model framework.
Computer architecture and code implementation: Computational resources for intense numerical studies with integrated systems will be reassessed. The code implementation and management strategies will be developed. An overarching guidance on model development and evaluation for the Action will be provided.

Open online integrated modelling framework: Based on outcomes from the above activities, guidelines for a joint European platform/framework for online coupled integrated modelling systems, open for implementation of different national NWP/CLIM or ACT models, will be elaborated. Development and implementation strategies may include parameterizations of detailed process treatments for long-term simulations, the use of two-way nesting and dynamic grids, meteorological pre-processing, and the use of numerical methods to enhance scalability across scales and improve model accuracy. Code management strategies may include the creation of a software bank (SB) with strict coding standards for community code interchange, the regular release of the codes with user's guide and testbeds, and development of a standard testbed and model evaluation protocol for the module improvement and addition into the unified model system by research community. Training of graduate/post-doctoral young researchers via courses/summer schools will be arranged.

The following tasks are proposed:

(1) conduct a comprehensive literature survey on existing online coupled models and Earth System Models to identify the best model framework for the online coupled model to be developed;

(2) Identify the most important processes for simulating aerosol direct and indirect effects that need to be included in the unified model framework under this Action to set the priorities for model development and improvement;

(3) Identifying requirements for an integrated modelling framework including tools and capability; building of guidelines for the online coupling system including the requirements for unification and integration.

(4) Develop code implementation and management strategies and milestones and provide an overarching guidance on model framework development and evaluation for the whole Action.

The modelling strategies would also address the formulation of requirements of the ACT/NWP-CLIM framework as a whole since it may be more critical for achieving accurate forecasts in complex modelling systems. Within the strategy of this Action more attention should be also be given to interactions and dialogue between the meteorological and air pollution communities.
WG1 Deliverables:

- Overview of the current state-of-the-science of online coupled modelling systems;
- Recommendations for module implementation priorities and strategies;
- Recommendations for code management and sharing;
- Guidelines for an open framework for online coupled integrated modelling systems.

WG2: Interactions, parameterizations and feedback mechanisms

The overall objectives of WG2 will be to establish the current state-of-the-science in the meteorology-chemistry interactions and to provide a framework for the development of accurate yet efficient techniques for the coupling of numerical weather prediction and atmosphere via process-oriented parameterizations and feedback algorithms, which will improve the NWP and CWF.
The phrase "Chemical Weather" invokes the temporal and spatial variability and complexity of atmospheric physical and chemical processes. Chemical/Weather and Climate represented as an integrated framework within an online coupled system offers the advantage of a more general applicability, in particular under climate change conditions, compared to conventional air quality, chemical transport, numerical weather prediction and climate models where meteorological processes and air quality are considered separately. In particular, the formation of tropospheric ozone and aerosols from precursors originating from various anthropogenic and biogenic processes has a potentially important consequence for radiative forcing and climate feedback. Overall, the integrated framework of the atmospheric modelling system will be able to handle the following major processes and interactions:

- The radiative effects of chemical species such as ozone and aerosols in the atmosphere via absorption and scattering (direct effects);
- The effects of aerosols and clouds on photolysis rates via modifying actinic fluxes and temperature (semi-direct effects);

- The effect of aerosols on boundary layer meteorology via changing meteorological variables and atmospheric stability (semi-direct effects);
- The effect of aerosols on cloud formation, albedo, and lifetime via aerosol activation and droplet nucleation, autoconversion, and collection (first and second indirect effects);
- The effect of aerosols on precipitation by affecting clouds and water vapour (indirect effects).

These processes and interactions are essential to study air quality and climate jointly. For example, a recent study showed that aerosols can reduce incoming solar radiation by up to 16%, near surface temperatures by up to 0.37 °C, and planetary boundary layer (PBL) height by up to 24% under summer conditions over continental U.S., indicating a more stable atmospheric stability that can further exacerbate air pollution over areas where air pollution is already severe. They are also important to correctly forecast air quality and weather. For example, neglecting the radiative effects of aerosols on air quality may lead to large errors in estimating the number of situations when ozone critical values are exceeded.

There are various ways to treat these interactions because of the complexity of the processes involved and different levels of details may be used in an integrated model. For example, the activation of aerosol particles is a function of the chemical composition and size, as well as the updraft velocity and maximum supersaturation. The radiative effects of aerosols are not only a function of their size distribution and bulk chemical composition but also depend on the treatment of particles as internal or external mixtures. Therefore, the treatment of a size- and chemically-distributed aerosol population in the integrated model is a key component of the meteorology/chemistry interactions. The formulation of the radiative transfer in the model is important because it directly affects the heat budget and the chemistry via photolytic reactions. Other important aspects that have to be considered for coupling of meteorology and chemistry are subgrid variability of aerosol plumes and clouds, because many aerosol/cloud interactions occur at spatial scales smaller than the grid resolution. Thus, aerosol microphysics and cloud resolution should be improved within the new integrated framework.

An integrated system will also allow a more detailed consideration of the impact of semi-direct aerosol effects on biosphere-atmosphere interactions. For example, the radiative effect of aerosols can affect evapotranspiration as well as the emission of biogenic VOC by plants, which will – depending on the emitted VOCs - contribute to the formation of ozone and secondary aerosol (which additionally contributes to the radiative aerosol effect).

The following tasks will be conducted:

(1) Development of the state-of-the-science for the treatment of meteorology/chemistry interactions. For the 1st task the mentioned review work will provide the foundation, and an up-to-date assessment of currently available models and algorithms. Using this review as a starting point a comprehensive literature review of current status and challenges in simulating meteorology/chemistry interactions will be conducted.

(2) Identification of priorities for improving the representation of interaction processes in integrated models with a focus on the development of operational tools for air quality forecasting and climate assessment as well as application of such tools for policy analysis. In the 2nd task both the practical aspects of online coupling of meteorology and chemistry and the research needs that are essential for the future developments of effective techniques and accurate treatments for various interactions and feedback mechanisms will be addressed. Inputs to the activity of WG2 will be information available in the peer-reviewed scientific literature, information from modelling results obtained by participants, as well as information provided by the major organisations active in this area.

WG2 Deliverables:

- Overview of the current state-of-the-science on interactions, parameterizations and feedback mechanisms for integrated modelling;
- Recommendations for short-term operational developments of process-oriented modules;
- Recommendations for research and development needs to improve online coupling of meteorology and chemistry in integrated models;
- Recommendations for laboratory and field experiments for evaluation of simulated aerosol direct, semi-direct, and indirect effects.

WG3: Chemical data assimilation in integrated models

The overall objective of WG3 will be to establish the current state-of-the-science in this area and to provide a framework for the development of efficient techniques for chemical data assimilation (CDA) in integrated models.

Data assimilation has been conducted for a long time in meteorological modelling and is now performed routinely for weather forecasting. On the other hand, data assimilation in air quality modelling is more recent; the field is rapidly evolving and operational applications are still limited at this point. Clearly, air quality forecasting can improve significantly if CDA was conducted routinely in an effective fashion. It is, therefore, timely to address this complex and challenging issue for integrated models, which combine both meteorology and chemical transport modelling. Briefly, CDA aims to improve model performance by modifying one or several components of the model (initial conditions, model inputs such as emissions, boundary conditions or some model parameters). Various mathematical techniques are used to assimilate the chemical observations and modify the model components, including variational techniques, ensemble or reduced-rank Kalman filters and other optimization techniques.

The modification of the chemical initial conditions is a natural extension of data assimilation as it is used in meteorology, where the chaotic nature of the primitive equations makes the system very sensitive to its initial conditions. However, modifying the initial chemical concentration field typically has an effect that lasts only a few hours, because the air quality system is characterized by exponential decay type terms, which implies that it tends to be governed by its input functions rather than by its initial conditions. These input functions are primarily the emission field, for some pollutants, the boundary conditions, and, for offline models, the meteorological fields (wind, vertical turbulent diffusion). Thus, the chemical transport component of an integrated model differs significantly from the meteorological model and, consequently, requires a different approach for data assimilation.

Recent efforts for CDA have focused mostly on chemical transport models, and to date only limited work has been conducted for integrated models. CDA for chemical transport models has included optimization of the initial chemical concentrations, boundary concentrations, emission rates and chemical reaction kinetic parameters. However, CDA in air quality forecasting, using either chemical transport models or integrated models, tends to be currently limited to modification of the chemical initial conditions. As mentioned above, greater improvements in model performance can be expected if the CDA can be extended operationally to other components of the model (i.e., emission fields, boundary conditions and selected key model parameters). Clearly, CDA for air quality forecasting is still in its infancy, in particular for integrated models.

An additional attractiveness of the online approach is its possible usefulness for meteorological data assimilation, where the retrieval of satellite data and direct assimilation of radiances will likely improve – assuming that the modelling system can beat climatology when forecasting concentrations of aerosols and radiatively active gases.

The following tasks will be conducted:

(1) Review the approaches currently used in chemical data assimilation, both in chemical transport models and integrated models. For the 1st task the various aspects of CDA will be considered, i.e., the model components being optimized (initial conditions, boundary conditions, emissions, model parameters) and the mathematical/numerical techniques available (4D-Var, ensemble Kalman filters, optimal interpolation, etc.). An important addressed aspect will be multi-species CDA for species that have chemical interactions. The pros and cons of various sources of chemical data (ground monitoring network, satellites, lidars, etc.) will be discussed.

(2) Identify priorities for the implementation of chemical data assimilation techniques for the short-term (less than 5 years), mid-term (5 to 10 years) and long-term (more than10 years) with a focus on the development of operational tools for air quality forecasting. In the 2nd task both the practical aspects of CDA and the research needs that are essential for the mid- and long-term developments of effective techniques will be addressed.

WG3 Deliverables:

- Overview of the current state-of-the-science on chemical data assimilation;
- Recommendations of short-term operational developments;
- Recommendations for improving chemical data assimilation in integrated models for mid- and long-term applications.

WG4: Evaluation, validation and applications

The overall objective of WG4 will be to develop tools and methodologies that can be applied to validate and evaluate integrated meteorology-chemistry models, as well as recommendations on applications of online integrated modelling systems.

Evaluation of the integrated meteorology-atmospheric chemistry model is necessary since only the evaluation enables to assess model strengths/limitations and improve model physics and chemistry. A critical assessment of model performance will help to build confidence in the use of models for research, forecasting and policy-making. A key outstanding question in addressing the modelling uncertainty is how well current models represent the regional and temporal variability of aerosol radiative forcing for current and past conditions? The confidence can be added to the estimates of the projected impacts arising from changes in both anthropogenic forcing and climate change. In particular, it can be done through carrying out a comprehensive assessment of the various processes influencing aerosol distributions, their optical properties, and consequently their radiative effects and verification of the simulated effects for retrospective time periods relative to the air quality observations. The study aims at addressing this issue through a systematic investigation of the changes in the anthropogenic emissions of SO_2 and NO_x over Europe, their impacts on anthropogenic aerosol loading over Europe, and subsequent impacts on regional radiation budgets.

There has been a significant progress on regional scale model evaluation and a number of statistical approaches have been identified. Regional scale model evaluations have been conducted over the years independently in North America, Europe and Asia from science and policy perspectives. The research to be accomplished here builds on the ongoing major international collaborative project known as AQMEII. AQMEII is aimed at providing a permanent forum to constantly monitor the state of advancement in regional scale air quality model evaluation methodologies (http://aqmeii.jrc.ec.europa.eu/). It would enable us to utilize infrastructure of AQMEII. This is achieved through the organization of periodic workshops, involving scientists from Europe and North America, for considering/testing different aspects of model performance evaluation.
This study will apply the four components of model evaluation and will follow the four main tasks listed below.

1. Operational Model Evaluation involves the direct comparison of model output with analogous observations in an overall sense. It utilizes routine observations of ambient pollutant concentrations, emissions, meteorology, and other relevant variables.
2. Diagnostic Model Evaluation examines the ability of a model to predict pollutant concentrations by correctly capturing physical and chemical processes, and their relative importance as incorporated in the model. This type of model evaluation generally requires detailed atmospheric measurements that are not routinely available.
3. Dynamic Model Evaluation focuses on model's ability to predict changes in air quality levels in response to changes in either source emissions or meteorological conditions. This exercise requires historical case studies where known emission changes or meteorological changes occurred that could be confidently estimated.
4. Probabilistic Model Evaluation attempts to capture statistical properties, including uncertainty or level of confidence in the model results for air quality management or forecasting applications; this approach is based on knowledge of uncertainty imbedded in both model predictions and observations.

The research approaches on model evaluation presented in WG4 and the ACT/NWP-CLIM model development (which will be tested within the developed frameworks) are important for validation and verification of online integrated modelling systems used in this Action. Moreover, the documentation of online coupled modelling system from the web-based model inventory (created in COST728/COST732 model inventory; http://www.mi.uni-hamburg.de/costmodinv) will be extended with a focus on coupling methods and feedbacks.

WG4 Deliverables:

- Evaluation summary of online modelling systems performance through validation for selected specific case studies and episodes;
- Evaluation summary on verification of online modelling systems for the long-term periods/ studies;
- Recommendations/guidelines for the validation methodology/protocol for online integrated modelling systems;
- Recommendations on applications of online integrated modelling systems.

E. ORGANISATION

E.1 Coordination and organisation

The team involves more than 40 experts from 30 organizations from 18 COST member countries and several external experts from USA, Canada, Russia and from international organisations. The Action is well linked with existing international programmes and organisations (JRC, WMO, ECMWF, EEA, EUMETNET), EU and national projects (CityZen, MEGAPOLI, MACC, PEGASUS, Risc Habitat Megacity, MUSCATEN, etc.).

Given the historical diversity of the model development trail in Europe, a single system approach will not be a viable option but a common framework which can eventually develop into an open system platform for partners to add modules/blocks with harmonized interfaces and parameters could be considered. This will still require strengthen and improved communication and cooperation between European partners.

A common modelling framework would facilitate and enhance information exchange between models (including datasets, scenarios definition and design). Thus, it would lead to closer collaboration between member states. At the same time by preserving individuality and diversity of models it will foster growth of individual/ national research capabilities that provide expertise to local/individual/national authorities by addressing specific air quality/environmental concerns. Furthermore, it would provide a platform for better understanding and appreciation of environmental issues in different regions of Europe.

The Management Committee (MC) and WGs will meet twice a year, usually in conjunction with each other. A Rapporteur from the MC will be appointed to monitor the activities and outputs. WG and expert meetings may be organised on different occasions, according to specific aims. Each WG will be coordinated by a Chair who will report to the MC. A leader will also be allocated for each task of the WGs. When required, external experts will be invited to MC and WGs meetings to seek advice and/or enlarge the application basis of the Action.

The MC will supervise the overall progress of work against the listed objectives, tasks and deliverables. It will link and coordinate WG activities so that the knowledge, needs and results of each WG will serve as input to the others, and will ensure wide dissemination of the results obtained. The MC Chair, Vice-Chair and the four WG Chairs will constitute the leading structure of the Action.

A public website will be created within the first six months of the Action. It will be updated in a timely and continuous manner to serve as an information management and working tool, act as a focus for information exchange and as a medium for disseminating the results of the Action.
Care will be given to involving all key actors in the field including the international networks listed in the background section. Their representatives will be either involved as invited experts or national delegates from the hosting countries (see the list of interested scientists).

Necessary technical and organizational support will be given to the problem of data exchange. These will include, for example, the dedicated protected data exchange services at the Action website, encouraging the information exchange via Short-Term Scientific Missions (STSM) or other mechanisms, and involvement of the data producers and owners into the Action work and publications. The MC will pay special attention to the issue and form, if this appears necessary, a Task Force for the data exchange involving all data producers and owners to elaborate the mechanism of making the state-of-the-science data available for the Action and, to the largest possible extent, to the wider community.

WGs will include a wide spectrum of experts with the main aim to produce a comprehensive review of existing information and foreseen studies, as well as to prepare guidance for future developments. By its nature, such work requires flexible and dynamic consortium, which can easily incorporate new participants with their specific contributions developed elsewhere. The most appropriate form is then a concerted Action with strong networking capabilities, such as the COST Action.

All organizations and scientific groups involved in the Action have their own funding for their activities coordinated by the current Action and thus, do not count on this Action for supporting the actual developments.

The scientists involved in the current Action will specify their contribution and goals in a form of Expression of Commitment. This will ensure the efficient kick-start of the Action, speed-up the formation of the Working Groups, and then largely simplify monitoring of the progress by the WG leaders and the Chair of the Management Committee against the contributions. This mechanism will also ensure involvement of all Action participants to work in corresponding WGs.

E.2 Working Groups

A structure with four Working Groups is the following: (1) Strategy and framework for online integrated modelling, (2) Interactions, parameterisations and feedback mechanisms, (3) Chemical data assimilation in integrated models, (4) Evaluation, validation, and applications.

A three-phase schedule of the Action with dedicated milestones for the WGs activities is envisaged: Phase I: Planning, operational arrangements, establishment of WGs and model inventories (year 1); Phase II: Main assessments, benchmarking and design work to be conducted by all WGs (years 2-3); Phase III: Final conclusions and recommendations; reports and final publications (year 4).

A preparatory phase will be implemented during the first year and will help building an initial inventory of existing activities in various European countries and outside Europe. Much of the compilation work will be conducted using participants' networks and national arrangements. These preliminary inventory results will be assessed to establish the detailed work programme, activities and the membership of WGs. To support this, the opinions of the wider community will be sought through the first Action's Workshop.

During the main phase II, interactions between the WGs will be firmly established and maintained, so that they will work in synergy, eventually coming together in the final phase (last year) during which the results will be completed, integrated, reviewed and published. Aspects of the activity will be also presented at workshops, meetings, etc., and published at national and international level during the intermediate period.

During the final phase, joint recommendations of the WGs will be compiled in the final report for wide dissemination. Attention will be paid to the dissemination of results towards end users via technical and practical publications and workshops (see the Dissemination section).

E.3 Liaison and interaction with other research programmes

Preliminary discussions have already taken place with key EC FP7 projects, including MACC, MEGAPOLI, PBL-PMES, PEGASOS and TRANSPHORM, international programmes (e.g. WMO GURME, WCRP), AQMEII: Air Quality Model Evaluation International Initiative and several national programs (e.g. Danish CEEH, German 'Risc Habitat Megacity', etc.) on how to establish joint activities such as model runs, exchange of data, model parameterizations and other achievements. Many key members of partner projects are already involved into the COST Action, other will be invited as experts to relevant Action meetings. Another area where joint work will be beneficial in the area of developing databases and websites, producing joint newsletters, special issues, organization of joint seminars, workshops, conference special sections and young scientist summer schools.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas. Moreover, the Action will try to follow of 50% balance of female experts in the leadership of WGs.

It is foreseen that the Action will involve the active participation of female scientists, about 21% of the list of potential participants are women. According to our preliminary survey, nearly all participating teams actively involve many young researchers (not listed as experts) both female and male, who will be further supported by the Action via STSMs and other mechanisms (e.g., publication or meeting/school attendance support).

The STSM will be used to maximise the exchange of experience among the participants. Young scientists and female participants will be particularly encouraged to use the STSM mechanism for their broader networking and advancing their career. Training courses and young scientist summer schools on integrated modelling will be organised by the Action in collaboration with other programs and partners. For example, the 1st ACT-NWP Integrated Modelling School (held in July 2008, Zelenogorsk, Russia) attended 50% of the female young scientists/ students.

F. TIMETABLE

The overall duration of the COST Action is 4 years. The work will be arranged in three main phases. The main Working Groups are: WG1 - Strategy and framework for online integrated modelling; WG2 - Interactions, parameterizations and feedback mechanisms; WG3 - Chemical data assimilation in integrated models; and WG4 - Evaluation, validation, and applications. Annual workshops and young scientists' schools (year 1, 4) with invited experts and lecturers will be organized during the Action. The final workshop for wrapping up conclusions and recommendations for the final report will be held during the 4th year with invited external experts and scientists and broad presentation and discussion of the Action results.

Tasks of the Phase I (year 1) “Inventory”:

MC:

- Establish WGs membership and working plans, contacts with existing and identify new potential end-users and major stakeholders;

All WGs:

- Joint determination of horizontal links and cross-group information flows;
- Report to the MC every 6 months on progress of work;
- 1st Workshop and School preparation.

At the end of Phase I, preliminary inventories of the knowledge and user communities as well as a paper with a comprehensive review of existing online integrated models are expected. Phase II starts from preparation on their basis of the detailed work plan until the end of the Action.

Tasks of the Phase II (years 2-3) “Development, Assessment, Applications”:

MC:

- Finalising the WGs and preparing the detailed work programme based on outcomes of Phase I (first 6 months of Phase II);
- Planning and executing STSMs as appropriate;
- Monitoring WGs activities and advances outside the Action;
- Dissemination of results through publications and participation in international conferences, workshops, schools as well as in the Action events;
- Preliminary definition of the final report structure (year 3).

All WGs:

- Regular WG meetings for planning, implementing, reviewing and synthesising the work;
- Report to the MC every 6 months on progress of work;
- Supporting and extending the cross-WG links ensuring the horizontal integration of the information;
- Joint analysis of the Action stakeholders' needs and their satisfaction by the integrated system framework;
- 2nd and 3rd Workshops preparation (year 2, 3).

Tasks of the Phase III (year 4) "Synthesis and Dissemination of Action results":

MC:

- Final Workshop with the Action conclusions, especially to end-users;
- Completion of the final report;
- Dissemination of results through reporting and participation in international workshops/ events and committees.

All WGs:

- Finalisation of the expected outputs;
- 2nd School and final workshop preparation (year 4);
- Contributions to the Action final report.

Year	1				2				3				4			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Phases	I				II								III			
MC-meetings		x		x		x		x		x		x		x		x
WG-meetings				x		x		x		x		x		x		x
Workshops/ Schools			W/S				W				W			S		W
WG reports/ papers				P		R		P		R		P		R		P
Reports to TC				R				R				R				R
Final report																R
WWW-info update		x		x		x		x		x		x		x		x

x – event; W – workshop, S – school, P – publication, R – report

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: DE, DK, EE, EL, ES, FI, FR, IL, IT, LT, NL, NO, PL, SE, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 60 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.
USA, Russia, Canada, EUMETNET, WMO, EEA and ECMWF have also expressed their interest to participate to the Action.

H. DISSEMINATION PLAN

H.1 Who?

The results of the Action are of specific interest for various actors involved in atmospheric environment issues on the scientific, meteorological and environmental applications sides. The direct users of the Action deliverables are: (i) scientific institutes and laboratories working in the related areas, (ii) organizations coordinating European, international, and national research programmes, (iii) meteorological services, environmental research institutes and companies, environment protection and public health authorities at various levels. In addition, the result of the Action are of main interest for Universities and Higher Education institutes, that provide with study programmes in the fields of meteorology, atmospheric environment, environmental engineering, environmental management, etc. It is essential to educate a new generation of scientists to use modern state-of-the-science methods and tools. The Action will also promote such activities by supporting young researcher’s summer schools, seminars, and STSMs.

H.2 What?

The results of the Action will be disseminated through a range of methods. These will include a dedicated public website, COST reports, conference presentations and peer-reviewed publications. Particular attention will be paid to informing end-users and policy makers and to transmit results to different modellers’ communities.

Several partners of this Action have national or regional NWP and AQ forecasting duties. They also have mandates to inform the public on the developments in these areas. The Action will utilise this channel to disseminate the results and explain the benefits to the widest possible audience. It is also expected that improved quality of the meteorology and air quality information due to synthesising work of the Action will provide additional benefits to the public.

Moreover, the Action will seek the collaboration with bodies like the EEA, WMO, WHO, EURASAP and EUMetNet as well as with organisations that participate in the formulation and application of research policies, like the European Commission and the associated DGs.

The Action will prepare a dissemination and sustainable operation plan that will be updated throughout its duration, including:

- Main goals and dissemination methods used to achieve/ support operation plan;
- Methods and tools for the sustainable operation of the Action, as well as for its follow-up and parallel activities;
- A record of decisions taken from the scientific, policy-making, and other bodies, that are supported from or interacted with the Action;
- Education related activities supported by the Action, research plans for STSM, etc.

H.3 How?

The results achieved will be disseminated through the following:

- COST Action web-site continuously updated (including newsletters and reports on the progress of the Action and selected results). This will actually be a portal with functionalities supporting scientific collaboration and information exchange, like a wiki. Moreover, a twitter channel is foreseen for a rapid dissemination of information. In addition, an information aggregation service will be developed, in order to automatically search and harvest information related to the scientific activities of interest, from various web portals worldwide, and then provide this information via a Really Simple Syndication (RSS) feed. For the latter, the Action's portal will make use of the RSS feeds already produced by organisations like the EEA.
- Scientific papers in peer-reviewed journals, textbooks and reports;
- Scientific and application meetings, conferences, schools and workshops organised, co-sponsored or otherwise supported at various levels by the Action (see the list below);
- Information provided to relevant international organisations concerning the process, solutions and outreach in order to achieve a broader impact, e.g.: EEA, EUMetNet, EU JRC and WMO;
- Existing participating or collaborating meteorological and air quality networks and their channels of information dissemination (e.g., by the ALADIN, COSMO, HIRLAM and UKMO communities).

Special efforts will be deployed to have contacts with as many key players and stake-holders as possible. Links will be established with the EC (DG-Environment), relevant European networks and bodies, and also with WMO and UN Economic Commission for Europe (UN-ECE). Links will also be established with international societies interested in problems of meteorology, air quality and climate change. During the meeting of the MC and WGs, international agencies involved in the fields of this COST Action, and representatives of the users, will be invited for exchange of information, coordination, and developing synergies and collaborations.

At least two online coupled models, Enviro-HIRLAM, developed by the Action participants, and WRF-Chem, developed by a large consortium of US organisations and European users, are public-domain systems freely available, which will further strengthen the dissemination outreach and provide wider opportunities for building the joint European models framework and promoting the COST and specifically the Action work around the global communities.

Organised workshops, courses and schools will be also used for disseminating the results especially among potential users and for promoting COST activities in Europe and worldwide. Wherever it is possible the Action will host workshops jointly with other international meetings. These will include:

- The International Young Scientists Summer School on ACT-NWP Integrated Modelling (Odessa, Ukraine, summer 2011);
- The International Workshop and School on Regional Climate and Chemistry (Trieste, Italy, summer 2012);
- The Annual Meetings of the European Meteorological Society (EMS) in session on “Environmental Meteorology” (EU, autumn, 2011-2015);
- The Annual General Assemblies of the European Geosciences Union (EGU) in session on “Integrated physical and chemical weather forecasting with two-way interactions” (EU, spring, 2011-2015);
- The NATO International Technical Meetings on “Air Pollution Modelling and its Application” (2013);
- The 8th International Conference on “Air Quality – Science and Application” (2012).

Special attention will be paid in the dissemination of Action results for the benefit of public. For this purpose, the Action will create a portfolio of analysed cases and user scenarios of online integrated meteorological and air quality modelling results. Emphasis will be given to the development of quality of life information services. These services will demonstrate the advantages of the approach in addressing the daily lives of people and may have a positive impact in reducing environmental burdens and health risks.

An additional aspect of information dissemination will be the usage of the infrastructure and technology of the European Chemical Weather Forecasting (initially developed within the COST Action ES0602; http://www.chemicalweather.eu/Domains), for the dissemination of integrated modelling results. Services for the harmonisation, comparison and combination of NWP and ACT model results, as well as for the comparison of models with air quality observations on near real time basis, are aimed to be investigated and developed on a pilot basis, so that all Action members as well as interested parties will be able to seamlessly access model results. Moreover, user tailored product examples are going to be built, targeted at the demonstration of the practical impacts of ACT/NWP-CLIM modelling to the public and interested users.