European framework for online integrated air quality and meteorology modelling – *EuMetChem*
COST Action ES1004 (03.2011 – 02.2015)

A. Baklanov (1), S. Joffre (2), H. Schlünzen (3), P. Suppan (4), M. Gauss (5), Ch. Seigneur (6), D. Brunner (7)

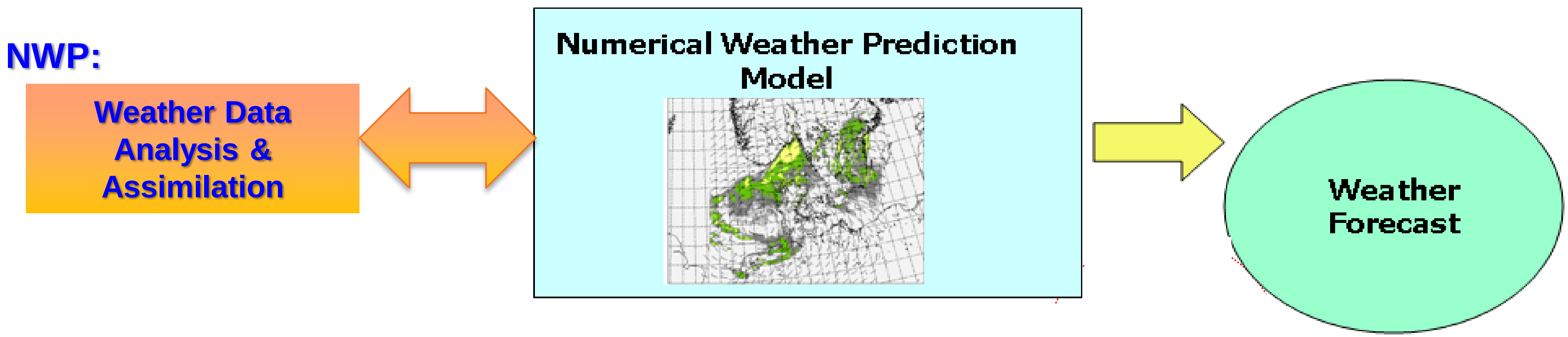
(1) Danish Meteorological Institute, Meteorological Research, Copenhagen, Denmark
(2) Finnish Meteorological Institute
(3) Meteorologisches Institut, KlimaCampus, Universität Hamburg
(4) Karlsruhe Institute of Technology (KIT), Institute for Meteorology and Climate Research
(5) Norwegian Meteorological Institute
(6) CEREA, École des Ponts ParisTech
(7) EMPA, Swiss Federal Laboratories for Materials Science and Technology

and the COST ES1004 team:

Aksoyoglu S., Baldasano J.M., Douros J., Flemming J., Forkel R., Galmarini S.,Grell G.,Hirtl M.,Kaas E., Kaasik M., Kallos G. Korsholm U., Lohmann U., Manders A., Maurizi A., Moussiopoulos N., Orba O.,Savage N., Sørensen B., Vignati E., Vogel B., Zakey A., Zhang Y.

Motivation:
Physical and Chemical Weather → Off-line coupling

- Meteorological (Numerical Weather Prediction – NWP) and Air Quality Modeling – two independent problems and research communities
- Chemical weather forecasting (CWF) - is a new, quickly developing and growing area of atmospheric modeling
- Simplified concept of CWF includes only operational air quality forecast for the main pollutants by using numerical atmospheric chemical transport (ACT) models driven by NWP



Motivation:
Physical and Chemical Weather Forecast → New concept

- Experimental studies and simulations show that atmospheric processes
  → meteorological weather, incl. precipitation, thunderstorms, radiation, clouds, fog, visibility and PBL structure)
  depend on concentrations of chemical components (especially aerosols) in the atmosphere
- Meteorological data assimilation (in particular assimilation of radiative properties) depends on the chemical composition
- Studies also show that air quality forecasts loose accuracy when ACT's are run offline

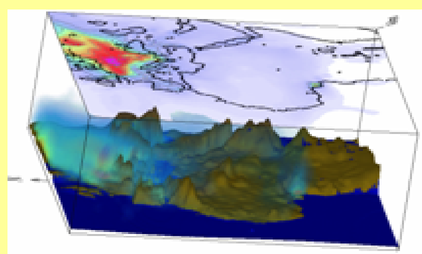
New generation of online integrated meteorology and chemistry modeling systems for predicting atmospheric composition, meteorology and climate change is a vital necessity

Meteorological and Chemical data Analysis & Assimilation & Emissions

↔

Integrated numerical weather and chemistry forecasting model

Full interaction of Chemistry, Aerosols and Meteorology: radiation, clouds, etc.

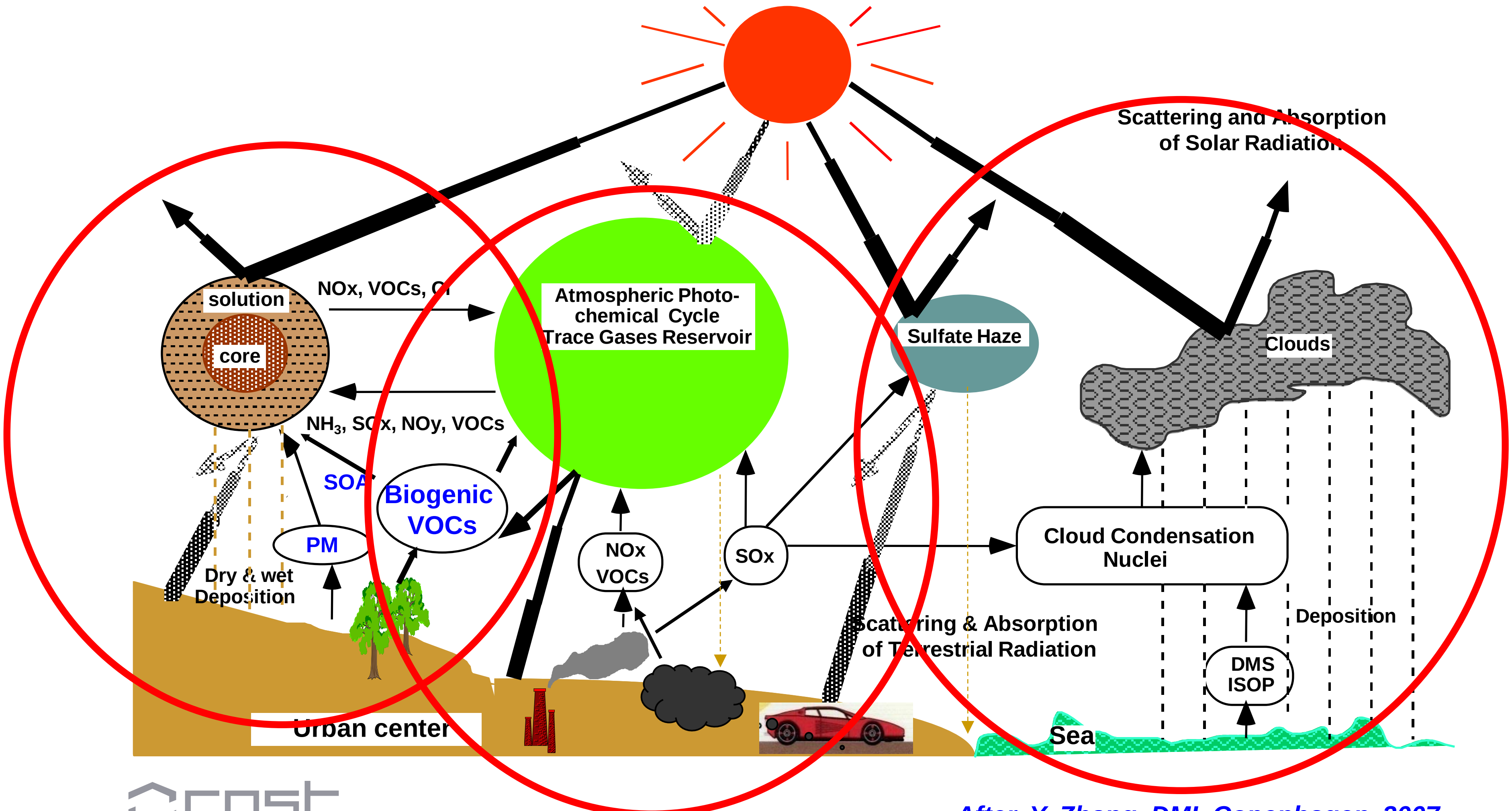


→

Meteorological, chemical and biological forecast

EUROPEAN COOPERATION IN

Atmosphere Interactions: Gases, Aerosols, Chemistry, Transport, Radiation, Climate



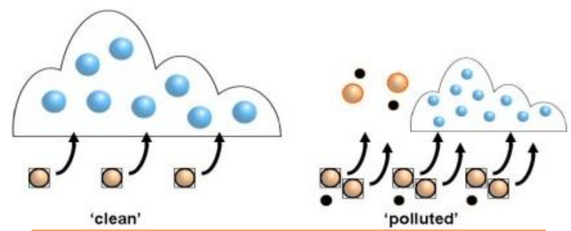
After Y. Zhang, DMI, Copenhagen, 2007

Motivation:
Aerosol Effects on Atmospheric Processes

Direct effect → decrease solar/ thermal-IR radiation and visibility;
warming: GHGs, BC, OC, Fe, Al, polycyclic/nitrated aromatic compounds
cooling: water, sulfate, nitrate, most OC
(scattering, absorption, refraction, etc.)

Semi-direct effects → affect planetary boundary layer (PBL), meteorology and photochemistry;

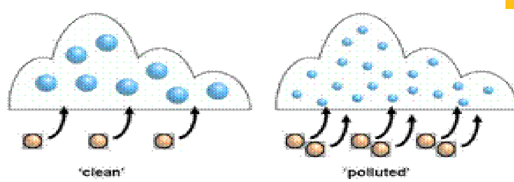
Semi-Direct Effect



Influence of aerosol absorption of sunlight on formation and evaporation of clouds

First indirect effect → affect cloud, drop size, number, reflectivity, and optical depth via CCN;

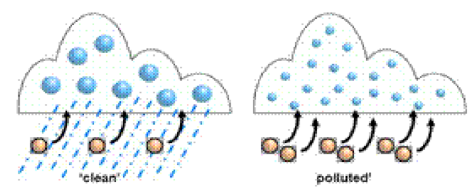
First Indirect Effect



Influence of cloud optical depth through impact on effective radius, with no change in water content of cloud

Second indirect effect → affect cloud, liquid water content, lifetime, and precipitation;

Second Indirect Effect



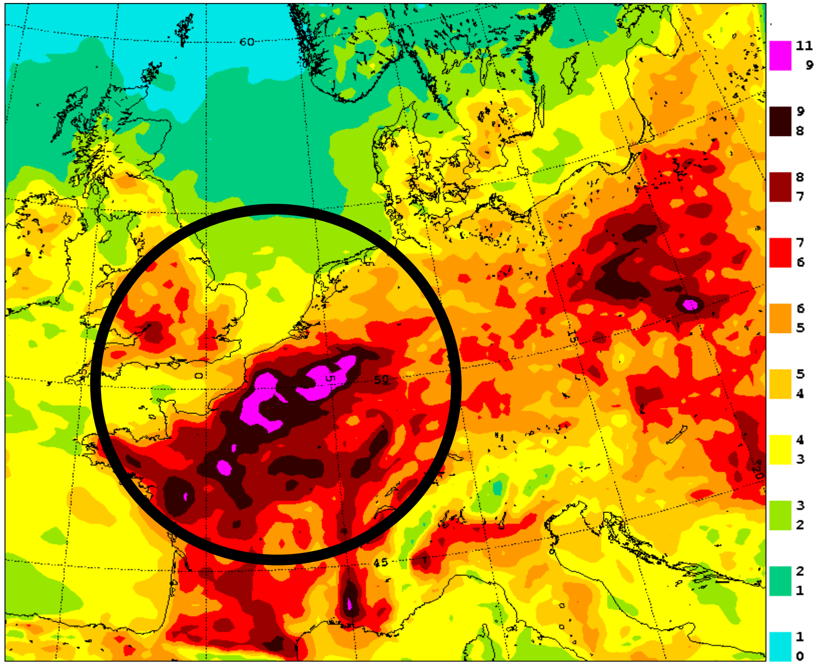
Influence of cloud optical depth through influence of droplet number on mean droplet size and hence initiation of precipitation

Chain of all aerosol effects → **strong nonlinear interaction**

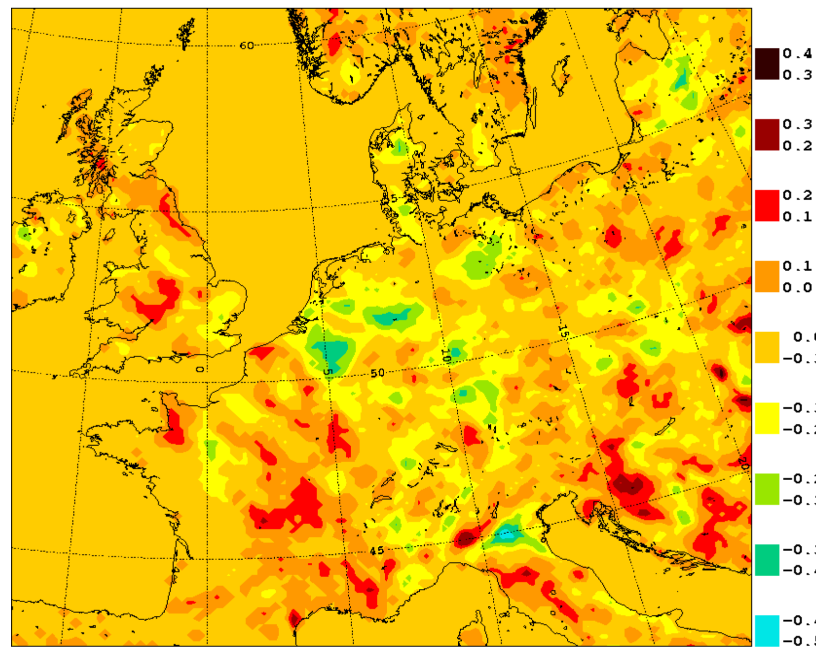
➡ **High-resolution on-line models with a detailed description of the PBL structure are necessary to simulate such effects**

➡ **On-line integrated models are necessary to simulate (exact as possible) effects which considers secondary feedbacks**

MEGAPOLI study: Comparing simulations with and without aerosol indirect effects for June 2009



Monthly averaged CCN number concentration (x107 m-3) at 850 hPa

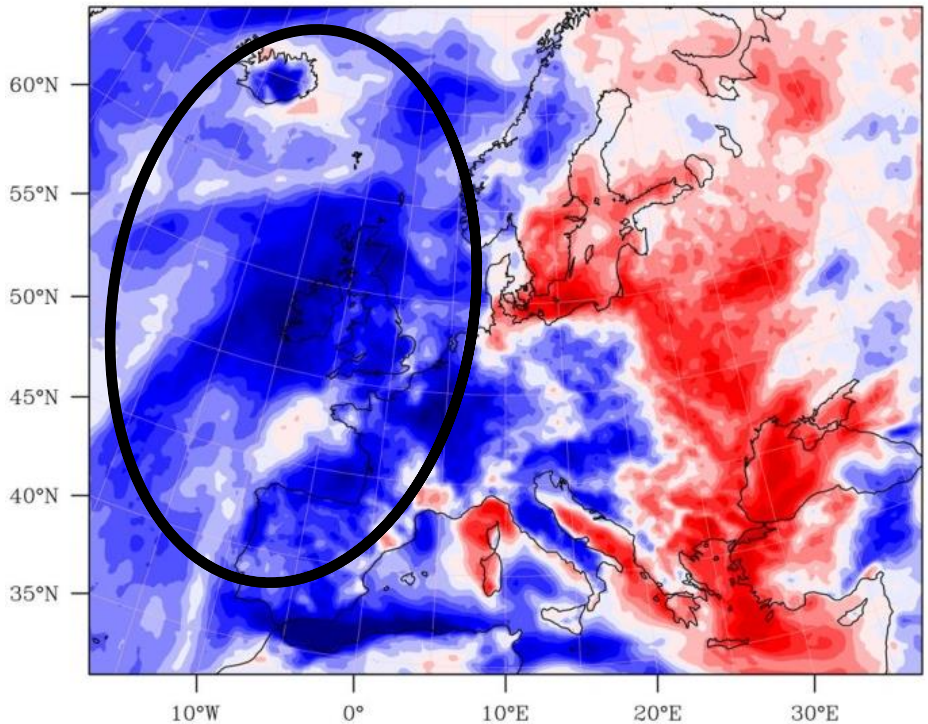


Monthly averaged difference in Ts (°C) (RUN - BASELINE)

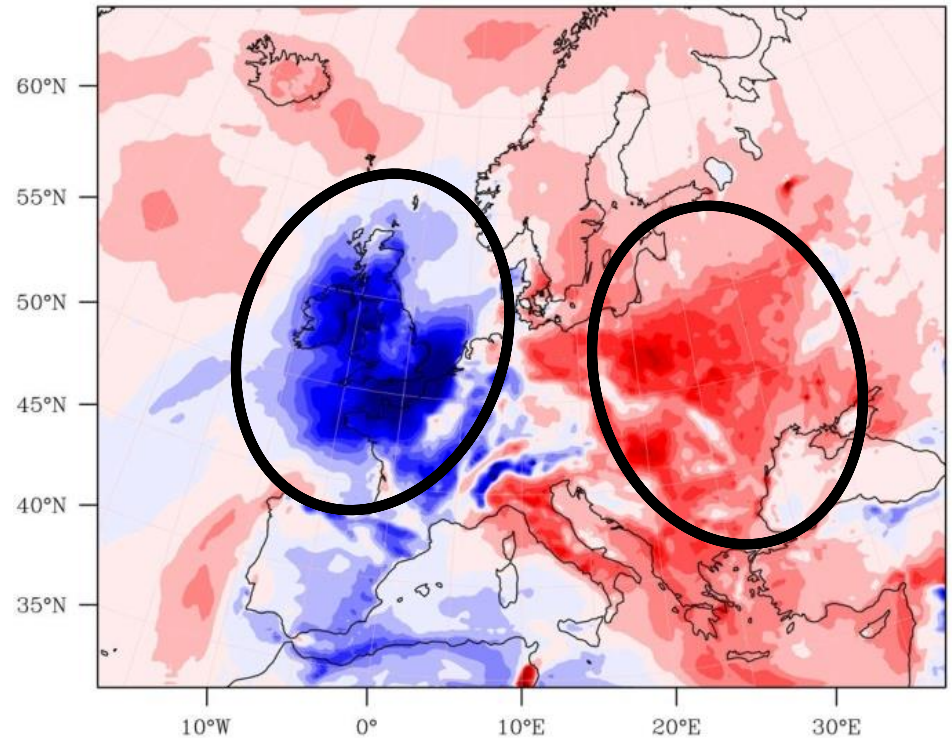
Korsholm et al., 2009

WRF/Chem: Aerosol Effects on Meteorology and Chemical Composition

RFBC- BASE



RFBC- BASE



Differences in ozone (left) and PM10 (right) concentrations in July 2006 between two WRF/CHEM simulations. Simulation BASE does not consider interactions between aerosols and meteorology. Simulation RFBC considers both direct and indirect effects (RFBC).

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Forkel et al. (Atmos. Environ. 2012)

Motivation: Needed European actions

No European community approach on modelling → large number of model development programmes

Besides Air Quality and Meteorological (Numerical Weather Prediction) communities worked independently

- **Strategic framework** is needed to provide a common goal and direction to European research → multiple models.
- **On-line coupling** between meteorology and chemistry will be a strong research area → 5-10 years.
- **Require enhanced dialogue** and knowledge from several scientific areas → mathematics, physics, chemistry, computer programming, etc.
- Best approach **to integrate, streamline and harmonize** the interaction between atmospheric chemistry modellers, weather modellers and end users → COST Action

COST Action ES1004
Scientific context and objectives

Action aims on a new generation of online models, using integrated Atmospheric Chemical Transport *(ACT)* and Meteorology *(Numerical Weather Prediction (NWP) and Climate)* modelling with two-way interactions

Overall objective

- multi-disciplinary forum for online integrated air quality/meteorology modeling
- elaboration of the European strategy for a new generation integrated ACT/NWP-CLIM modeling capability/framework

Main application areas of the integrated modeling

- improved NWP and CWF with short-term feedbacks of aerosols and chemistry on meteorological variables, and
- two-way interactions between atmospheric pollution/composition and climate variability/change.

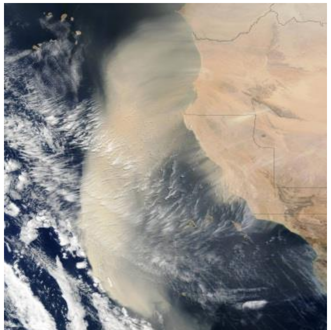
COST Action ES1004
Key Scientific Questions

- 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/chain feedbacks** among meteorology, climate, and air quality in the estimated effects?
- 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 can simulated **feedbacks** be **verified** with available observations/datasets?

COST Action ES1004
Benefits for Society

- Contribute to **better forecasting of severe weather events** and their consequences (forest fires, dust storms, flooding, volcano eruption, etc.)
- Contribute to **reduction of adverse health effects**
- Contribute to **better predict climate change**
- **Cost-effective measures** to manage transport and energy production
- Improved **management and protection** of terrestrial, coastal, and marine ecosystems
- Enhanced **quality of life** especially in urban areas,
- **Decreased overlap and redundanc**y of national, regional or local activities and arrangements




Cost Action ES1004 Working Groups

- **WG1:** Strategy and framework for online integrated modeling
  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
- **WG2:** Interactions, parameterizations and feedback mechanisms
  to establish the state of the science in meteorology-chemistry interactions and to provide a framework for the development of efficient techniques for the coupling of NWP and CTM via process-oriented parameterizations and feedback algorithms
- **WG3:** Chemical data assimilation in integrated models
  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 in integrated models
- **WG4:** Evaluation, validation and applications
  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 modeling system

Cost Action ES1004
First Results

- **Review paper (draft version; anticipated submission next weeks)**
  Online Coupled Regional Meteorology-Chemistry Models in Europe
- **Survey on existing online coupled models (~ 19 models)**

Model/Country/References	Gas phase chemistry and aerosol component	Feedback of pollutants to meteorology	Applications	Scale
BOLCHEM, Italy **http://bolchem.isac.cnr.it/**	SAPRC90 gas phase chemistry, AERO3 aerosol module	Direct aerosol effect on radiation	CWF; climate; Episodes	Continental to regional
COSMO-ART, Germany **Vogel et al., 2009;** **Stanelle et al., 2009,** **Bangert et al., 2011a,** **Bangert et al., 2011b**	Extended RADM gas phase chemistry, modal aerosol, soot, pollen, mineral dust, volcanic ash?	Direct aerosol effect on radiation, indirekt effects	Episodes, Climate mode	Continental to regional
COSMO-LM-MUSCAT, Germany	RACM gas phase chemistry, 2-modal	Direct aerosol effect	Episodes	Continental

- **Participation on "Air Quality Model Evaluation International Initiative (AQMEII)"**

Advancing approaches to the evaluation of regional scale photochemical air quality modeling systems (Phase II)

→ *Ensemble modeling exercise for European and North-American modeling communities*

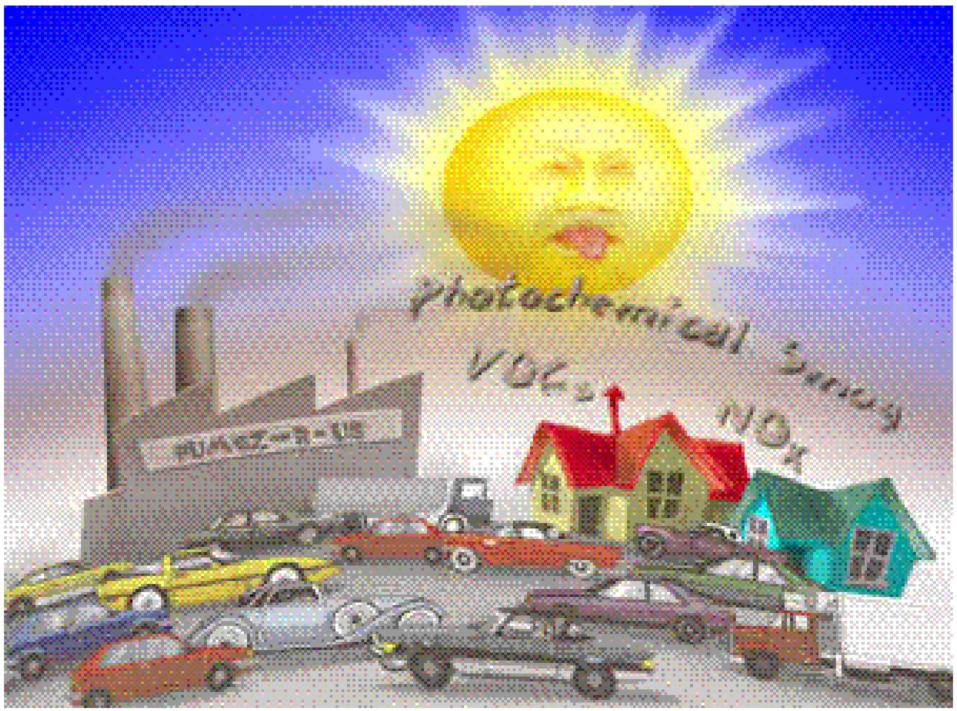
Conclusion

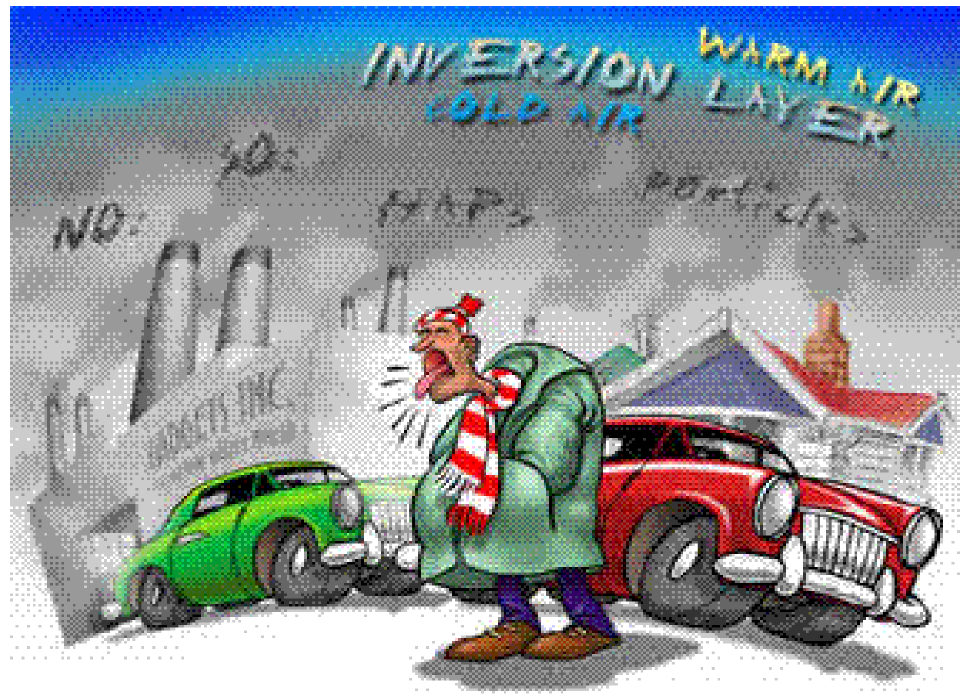
- **On-line integration** of NWP and ACTMs enables:
  - *utilisation of all meteorological 3D fields in ACTMs at each time step;*
  - *consideration of feedbacks of air pollution on meteo-processes & climate forcing.*
- **New generation** of integrated models
- Main **advantages** of on-line coupling:
  - *only one grid for NWP and ACTM, no interpolation in space and time;*
  - *physical parameterizations are the same, no inconsistencies;*
  - *all 3D meteorological variables are available at each time step;*
  - *no restriction in variability of meteorological fields;*
  - *possibility to consider two-way feedback mechanisms;*
- **Feedback mechanisms** - important in CWF modeling and quantifying direct and indirect effects of aerosols (and probably GHGs); full chain is needed, strong non-linearity

Thank You !

COST ES1004 EuMetChem: http://eumetchem.info

Alexander Baklanov (alb@dmi.dk)
Peter Suppan (peter.suppan@kit.edu)

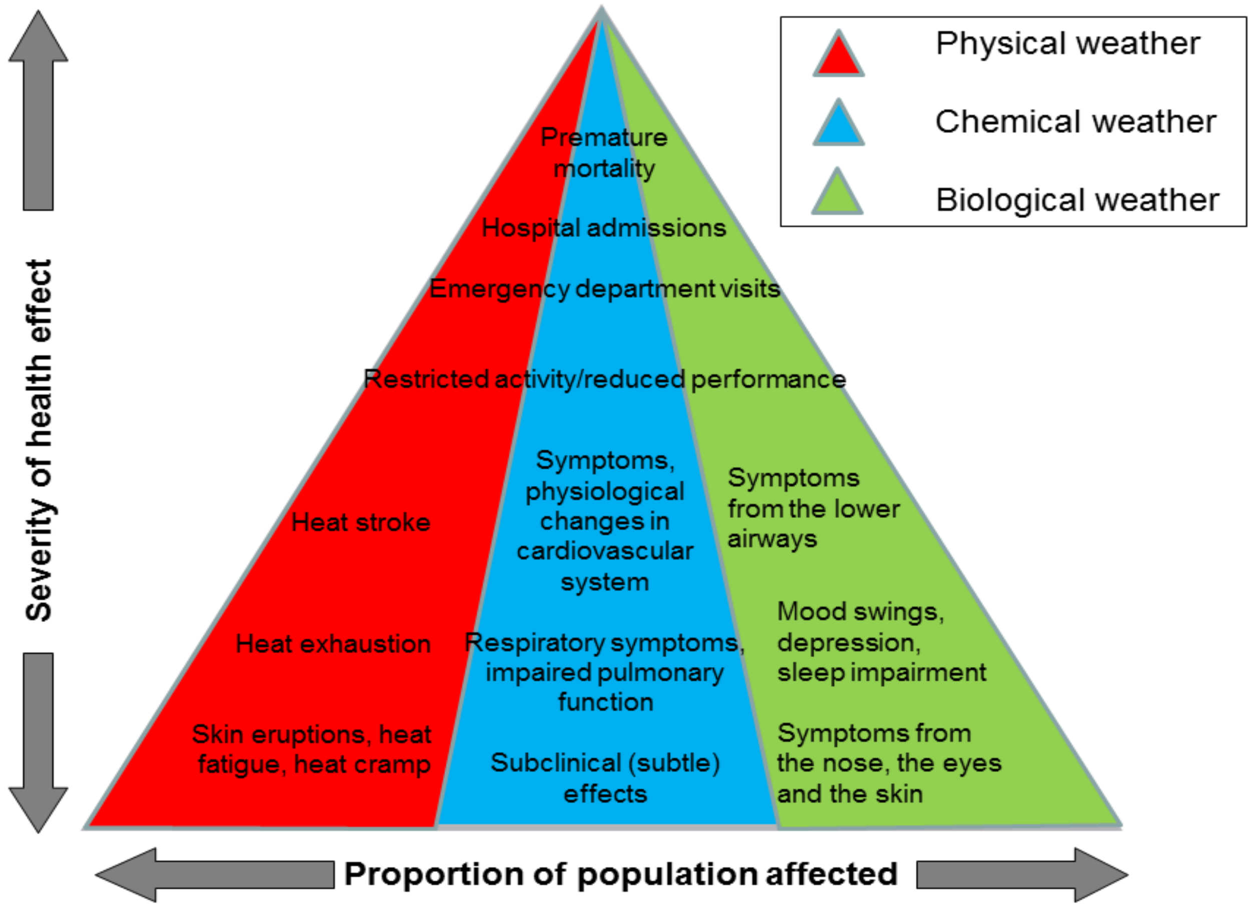




Interactions of physical, chemical and biological weather calling for an integrated approach
(Collaboration with COST ES0602 and ES0603)

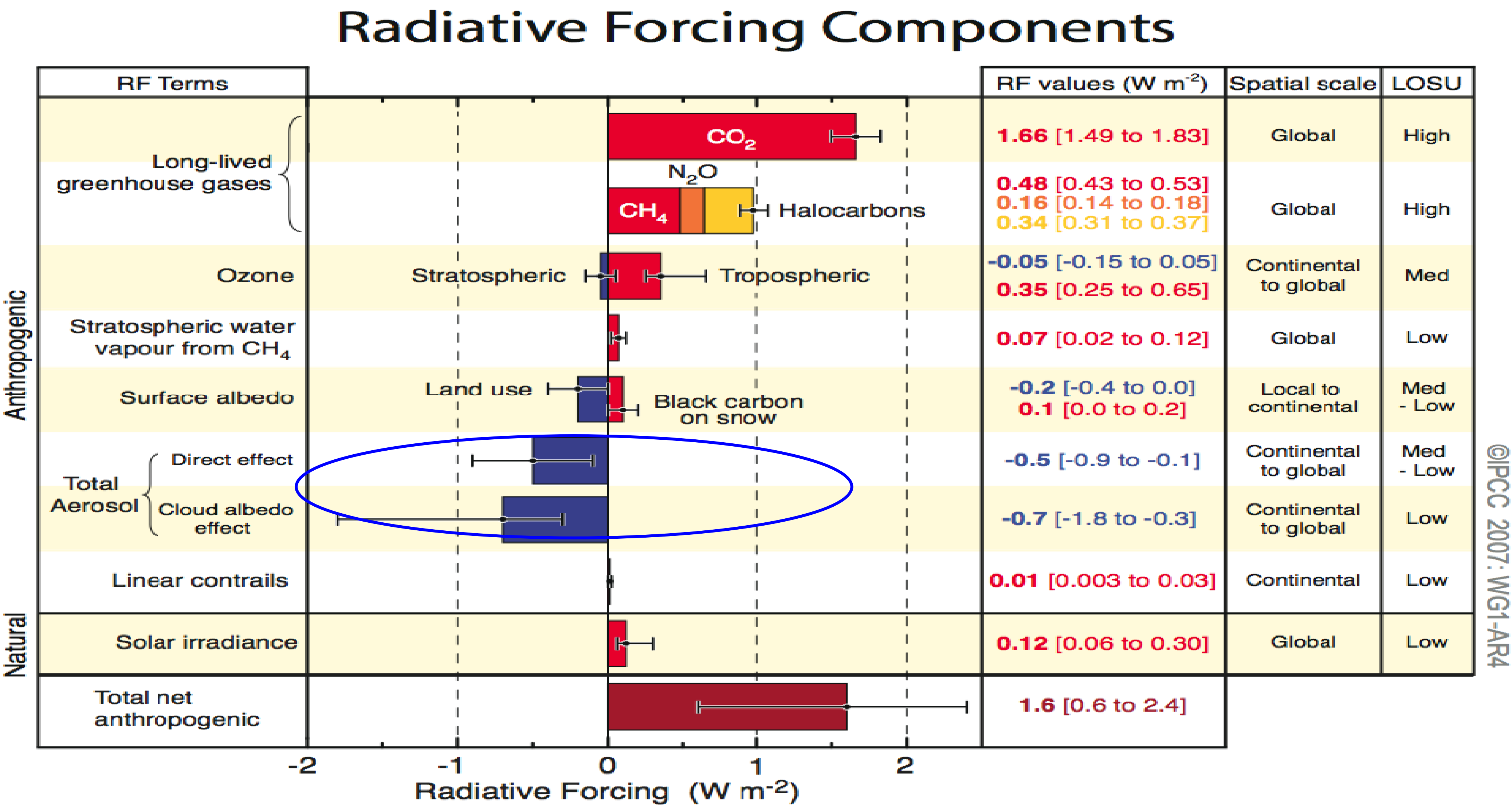
- **Physical weather** is defined as the short term atmospheric state and variation, characterized by physical atmospheric variables, such as solar radiation, temperature, humidity, pressure and wind speed and direction.
- **Chemical weather** is defined as the short term (less than two weeks) state and variation of the atmospheric chemical composition.
- By analogy, the short-term state and variation of concentrations of bioaerosols such as allergenic pollen and fungal spores, can be defined as the **biological weather**.

→ **Towards Integrated Services**



Klein, Kukkonen, Dahl, Bossioli, Baklanov, Vik, Agnew, Karatzas, Sofiev, AMBIO, 2012

2007 IPCC Estimate of Gas and Aerosol Radiative Effects



Online coupled or online access Atmospheric Chemistry-Meteorology models developed or applied in Europe (1)

Model/Country/References	Online coupled gas phase chemistry and aerosol	Feedback of pollutants to meteorology	Applications	Scale
BOLCHEM, Italy http://bolchem.isac.cnr.it/	SAPRC90 gas phase chemistry, AERO3 aerosol module	Direct aerosol effect on radiation	CWF; climate; Episodes	Continental to regional
COSMO-ART, Germany Vogel et al., 2009	Extended RADM gas phase chemistry, modal aerosol, soot, pollen, mineral dust	Direct aerosol effect on radiation	Episodes	Continental to regional
COSMO-LM-MUSCAT, Germany Wolke et al., 2004; Heinold et al., 2007	RACM gas phase chemistry, 2 modal aerosol models, mineral dust module	Direct aerosol effect on radiation for mineral dust	Episodes	Continental to regional
ECHAM5/6-HAMMOZ, Germany Pozzoli et al., 2008	MOZART gas phase chemistry, HAM aerosol scheme	Direct aerosol effect, indirect aerosol effect	Episodes, long term	Global
ENVIRO-HIRLAM, Denmark and HIRLAM countries Baklanov et al, 2008; Korsholm et al., 2008	NWP gas phase chemistry, modal and sectional aerosol modules, liquid phase chemistry	Direct and indirect aerosol effects	Episodes, chemical weather forecast	Hemispheric to regional and urban
IFS-MOZART (MACC/ECMWF) Flemming et al., 2009, Kinnison et al., 2007, http://www.gmes-atmosphere.eu	MOZART gas phase chemistry with updates to JPL-06, MACC aerosol scheme	Direct aerosol effect, indirect aerosol effect	Forecasts, Re-analysis, Episodes	Global
MC2-AQ, Canada (used in Polen) Kaminski et al., 2007	ADOM gas phase chemistry	none, but possible	Episodes	Regional to urban
Meso-NH, France http://mesonh.aero.obs-mip.fr/mesonh/	RACM or ReLACS gas phase chemistry, modal aerosol module	Direct aerosol effect	Episodes	Continental to regional
MESSy(-ECHAM5) , Germany Jöckel et al., 2005; http://www.messy-interface.org/	Various gas phase chemistry modules, modal aerosol module	Direct aerosol effect, indirect aerosol effect	Episodes, long term	Global

Online coupled or online access Atmospheric Chemistry-Meteorology models developed or applied in Europe (2)

Model/Country/References	**Online coupled gas phase chemistry and aerosol**	**Feedback of pollutants to meteorology**	**Applications**	**Scale**
MCCM, Germany Grell et al., 2000; Forkel & Knoche, 2006	RADM, RACM or RACM-MIM with modal aerosol module	Direct aerosol effect	Episodes, climate-chemistry	Regional
MetUM (Met Office Unified Model), UK Morgernstern et al, 2009; O' Connor et al 2010	2 tropospheric chemistry schemes, 1 stratospheric chemistry scheme. 2 alternative aerosol schemes.	Direct and indirect effects of aerosols, radiative impacts of N_2O, O_3, CH_4	Episodes, CWF, climate-chem. studies, long-range transport	Regional to Global
M-SYS (online version), Germany von Salzen and Schlünzen, 1999	RADM Gas phase chemistry, sectional aerosol module	none, but possible	Episodes	Regional to local
RegCM-Chem, Italy Zakey et al., 2006, Solmon et al., 2006	Updated GEOS-CHEM RACM, CBMZ, unimodal aerosol, sectional mineral dust, sulfur chemistry	Direct aerosol effect	Climate-chemistry	Continental to regional
RAMS/ICLAMS, USA/Greece http://forecast.uoa.gr/ICLAMS/index.php, Kallos et al. 2009, Solomos et al. 2010	Online photolysis rates. Coupled SAPRC99 gas phase, modal aerosol, ISORROPIA equilibrium and SOA, cloud chemistry.	Direct and indirect aerosol effect	Episodes, CWF, meteo-chemistry interactions	Continental to urban
WRF/Chem, US (used in UK, Spain, etc.) Grell et al., 2005; Fast et al., 2006, further references see Zhang, 2008	RADM, RACM, RACM-MIM with modal aerosol module or CBM-Z with sectional aerosol module, liquid phase chemistry	Direct aerosol effect, indirect aerosol effect	Episodes, chemical weather forecast, climate-chemistry	Continental to regional
WRF-CMAQ Coupled System, USA (used in UK) Pleim et al., 2008; Mathur et al., 2010	Gas-phase mechanisms: CB05, SAPRC-99; Modal aerosols based on the AERO5 CMAQ module	Direct aerosol effects on radiation and photolysis, indirect effect under development	Episodes to annual	Urban to Hemispheric

Courtesy of COST Action ES1004

European Cooperation in the field of Scientific and Technical Research

COST

www.cost.esf.org

Action COST ES1004

European framework for online integrated air quality and meteorology modelling (EuMetChem)

ESSEM

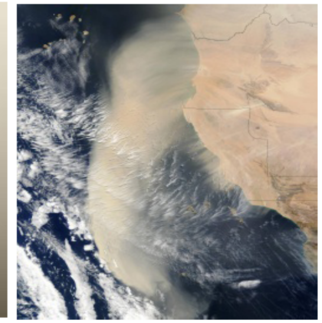
www.eumetchem.info

COST countries: AT, BG, CH, DE, DK, EE, ES, FI, FR, GB, GR, HU, IL, IT, MT, NL, NO, PL, SE

Chair of the Action: Alexander Baklanov, DMI, Denmark, alb@dmi.dk

Co-Chairs: Sylvain Joffre, FMI, Finland; **Heinke Schluenzen**, Uni Hamburg, Germany

COST Science Officer: Stefan Stueckrad, sstueckrad@cost.esf.org



The overall objective is to set up a multi-disciplinary forum for online integrated air quality/meteorology modelling and to elaborate an European strategy for an integrated ACT/NWP-CLIM modelling capability/framework.

Benefits for the Society

This European action (involving also key American experts) will enable the EU to develop world class capabilities in integrated ACT/NWP-RCM modelling systems, including research, education and forecasting. More than 40 teams from 19 European COST countries, as well as ECMWF, JRC, WMO, US EPA, NOAA, etc. are already involved in the Action. In detail the action will contribute to

- a better forecasting of severe weather events and their consequences (forest fires, dust storms, flooding, volcano eruption, etc.)
- the reduction of detrimental combined health

The Action aims towards a new generation of online integrated Atmospheric Chemical Transport (ACT) and Meteorology modelling systems (NWP and RCM) using two-way interactions between different atmospheric processes including chemistry, clouds, radiation, boundary layer, emissions, meteorology and climate (Fig. 1). The Action intends to consider at least two application areas of integrated modelling:

i.improved numerical weather prediction (NWP) and chemical weather forecasting (CWF) with short-term feedbacks of aerosols and chemistry on meteorological variables,

ii.two-way interactions between atmospheric pollutions / composition and climate variability / change.

The action covers four working groups:

WG1 Strategy and framework for online integrated modelling (coordinated by Peter Suppan, Jose Baldasano),

WG2 Interactions, parameterisations and feedback mechanisms (coordinated by Michael Gauss),

WG3 Chemical data assimilation in integrated models (coordinated by Christian Seigneur),

WG4 Evaluation, validation, and applications (coordinated by Heinke Schluenzen, Dominic Brunner, Pavlos Kassomenos).