Chemical Weather Forecasting: A New Concept and Methodology

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CITES-2009, Jul 2009, Krasnoyarsk, Russia
Chemical weather forecasting (CWF) - is a new quickly developing and growing area of atmospheric modelling.

Possible due to quick growing supercomputer capability and operationally available NWP data as a driver for atmospheric chemical transport models (ACTMs).

The most common simplified concept includes only operational air quality forecast for the main pollutants significant for health effects and uses numerical ACTMs with operational NWP data as a driver.

Such a way is very limited due to the off-line way of coupling the ACTMs with NWP models (which are running completely independently and NWP does not get any benefits from the ACTM) and not considering the feedback mechanisms.
Many experimental studies and research simulations show that atmospheric processes (meteorological weather, including the precipitation, thunderstorms, radiation budget, cloud processes and PBL structure) depend on concentrations of chemical components (especially aerosols) in the atmosphere.

Therefore, ACTMs have to be run together at the same time steps using on-line coupling and considering two-way interaction between the meteorological processes and chemical transformation and aerosol dynamics.

New concept and methodology considering the chemical weather as two-way interacted meteorological weather and chemical composition of the atmosphere.

CWF should include not only health-effecting pollutants (air quality components) but also GHGs and aerosols affecting climate, meteorological processes, etc.

Strategy of new generation on-line integrated meteorology and ACT modelling systems for predicting atmospheric composition, meteorology and climate change (as a part of and a step to Earth Modelling Systems, EMS).
Mesoscale Meteorological Modelling Capabilities for Air Pollution and Dispersion Applications (I)

**COST Action 728:**

**Working Group 2:**
Integrated systems of MetM and ACTM – strategy, interfaces and module unification

**Aim:**
• to identify requirements for unification of MetM and ACTM/ADM modules, and
• to propose recommendations for European strategy for integrated mesoscale modelling capability.

**NWP Communities Involved:**
• HIRLAM, COSMO, ALADIN/AROME, UM communities;
• MM5/ WRF/ RAMS users/developers.

**Main Tasks / Sub-groups:**
• Off-line models and interfaces;
• On-line coupled modeling systems and feedbacks;
• Model down-scaling/ nesting and data assimilation;
• Models unification and harmonization.
Mesoscale Meteorological Modelling Capabilities for Air Pollution and Dispersion Applications (II)

2008 - Overview of Existing Integrated (off- and on-line) Mesoscale Systems in Europe

2009 - Meteorological and Air Quality Models for Urban Areas
Baklanov, Grimmond, Mahura, Athanassiadou (Eds),

2009 - Integrated Systems of Meso-Meteorological and Chemical Transport Models
Baklanov, Mahura, Sokhi (Eds),
Springer, 186p. – Uncorrected Proofs.

2008 – Young Scientists Summer School and Workshop – 1st YSSS+W
Integrated Modelling of Meteorological and Chemical Transport Processes / Impact of Chemical Weather on Numerical Weather Prediction and Climate Modeling
Zelenogorsk (near St.Petersburg) Russia, 7-15 Jul 2008
see details at http://netfam.fmi.fi/YSSS08/

2010 – 2nd YSSS+W
Univ of Tartu / Vilnus (Baltic States), Summer 2010

Outcome → to COST Action ES0602: Chemical Weather Forecasting (2008-2012)
**One-way:**
- NWP meteo-fields as a driver for ACTM (off-line);
- ACTM chemical composition fields as a driver for R/GCM (or NWP).

**Two-way:**
- Driver + partly feedback NWP (data exchange via an interface with a limited time period: off-line or on-line access coupling, with or without second iteration with corrected fields);
- Full feedbacks included on each time step (on-line coupling).
Definitions of Integrated / Coupled Models

**Off-Line Models:**

- separate ACTMs driven by meteorological input data from meteo-pre-processors, measurements or diagnostic models,
- separate ACTMs driven by analysed or forecasted meteodata from NWP archives or datasets,
- separate ACTMs reading output-files from operational NWP models or specific MetMs with a limited periods of time (e.g. 1, 3, 6 hours).

**On-Line Models:**

- on-line access models, when meteodata are available at each time-step (it could be via a model interface as well),
- on-line integration of ACTM into MetM, when ACTM is called on each time-step inside MetM and feedbacks are available (will use this definition as on-line coupled modelling).
## Advantages of On-Line & Off-Line Modeling

### On-Line Coupling
- Only one grid;
- No interpolation in space
- No time interpolation
- Physical parameterizations are the same; No inconsistencies
- Harmonised advection schemes for all variables (meteo and chemical)
- Possibility to consider aerosol forcing mechanisms
- All 3D met. variables are available at the right time (each time step); No restriction in variability of met. fields
- Possibility of feedbacks from meteorology to emission and chemical composition
- Does not need meteo- pre/post-processors

### Off-Line
- Possibility of independent parameterizations;
- Low computational cost (if NWP data are already available and no need to run meteorological model);
- More suitable for ensembles and operational activities;
- Easier to use for the inverse modelling and adjoint problem;
- Independence of atmospheric pollution model runs on meteorological model computations;
- More flexible grid construction and generation for ACT models,
- Suitable for emission scenarios analysis and air quality management.
Aerosol Effects to be Considered

- Direct effect → decrease solar/ thermal-IR radiation and visibility;
- Semi-direct effect → affect PBL meteorology and photochemistry;
- First indirect effect → affect cloud drop size, number, reflectivity, and optical depth via CCN;
- Second indirect effect → affect cloud liquid water content, lifetime, and precipitation;
- All aerosol effects

⇒ 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 correctly the effects involved 2nd feedbacks
Atmospheric Chemical Transport Modeling (DMI)

**Aerosol Module**

**Approaches:**
- Normal distribution, Bin approach

**Physics:**
- Condensation
- Evaporation
- Emission
- Nucleation
- Deposition
- Coagulation

**Chemical Solvers**

1. Gas Phase
2. Aqueous phase
3. Chemical equil.
4. Climate Modeling

**Met. Models**

- ECMWF
- DMI-HIRLAM

**Tropo. Trans. Models**

- Eulerian transport 0.2-0.05 lat-lon, 25-40 vert. layer, 3-D regional scale
- Stochastic Lagrangian transport, 3-D regional scale

**Micro-Scale Obstacle Resolved CFD-type Model M2UE (TSU)**

**Off-Line Chemical Aerosol Trans. CAC**
- Regional (European) to city scale air pollution: smog and ozone.

**On-Line Chemical Aerosol Trans. Enviro-HI RLAM**
- Regional (European) to city scale air pollution: smog and ozone.

**Emergency Preparedness & Risk Assessment. DERMA**
- Nuclear, veterinary and chemical.
Types of Integrated Urban Air Quality Modeling (from FP6 FUMAPEX Experience)

- Off-line integrated urbanised UAQIFS in FUMAPEX
- On-line integrated new generation system with feedbacks – starting Enviro-HIRLAM

- There is a number of on-line coupled MMM and ACTM model systems in Europe.
- However, many of them were not built for the meso-meteorological scale, most of them do not consider feedback mechanisms or include only direct effects of aerosols on meteorological processes.
- Only two meso-scale on-line integrated modelling systems (WRF-Chem and Enviro-HIRLAM) consider feedbacks with indirect effects of aerosols.
Integrated (On-line Coupled) Modeling System for Predicting Atmospheric Composition

Enviro-HIRLAM: Environment – HIgh Resolution Limited Area Model

Started by DMI Environmental Meteorology Team
+ joined by countries of the HIRLAM Consortium → HIRLAM Chemical Branch
+ joined: Russian State HydroMet Univ, Univ Tartu, Univ Vilnus, Odessa State Envir Univ
Enviro-HIRLAM: On-Line vs. Off-Line Comparison

(Korsholm et al., 2008)

False peak due to off-line coupling

ETEX: concentration at DK02 station for different coupling intervals: 10-360 min

ETEX: concentration after 36 h for different coupling intervals
Enviro-HIRLAM: Aerosols Feedbacks

Case Study: 28 Jun – 3 Jul 2005

(Korsholm et al., 2009)

445 km

665 km

Difference (reference - perturbation)

Temp 2 m, deg C

Wind 10 m, m/s

Changes in:
• temperature – up to 2-3 deg C,
• wind speed – up to 2-4 m/s,
• urban boundary layer height – up to 200 m,
• dry and wet deposition – up to 7%.
Enviro-HIRLAM: Birch Pollen Forecasting

(Mahura et al., 2008)

Phenological model output

Emission rate & fractions of birch trees

Normalized concentrations
24 hours forecast                   48 hours forecast

Copenhagen, Denmark

Collaboration –
Danish Asthma Allergy Association,
Finish Meteorological Institute

Enviro-HIRLAM model output

Normalized concentrations
24 hours forecast                   48 hours forecast

Copenhagen, Denmark

Source: silam.fmi.fi
Enviro-HIRLAM: Road Forecasting

(Mahura et al., 2009)

Add line source traffic emissions
(daily and weekly variability)

16637 stretches for 296 roads
(at distances of 1 km)

781 road stretches
in Ribe Amt region

Collaboration –
Danish Road Directorate
Conclusions

• Concept: the chemical weather as two-way interacted meteorological weather and chemical composition of the atmosphere.
• On-line integration of MesoMetMs and ACTMs enables the utilisation of all meteorological 3D fields in ACTMs at each time step and the consideration of the feedbacks of air pollution on meteorological processes and climate forcing.
• New generation of integrated models => not only for the chemical weather forecasting, but also for climate change modelling, weather forecasting (e.g., in urban areas, severe events, etc.), air quality analysis and mitigations, long-term assessment chemical composition, etc.
• Main advantages:
  – Only one grid for MMM 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;
  – Does not need meteo- pre/post-processors.
• Conclude - feedback mechanisms are important in CWF modelling and quantifying direct and indirect effects of aerosols, and it is supported by simulation results.
Publications:

Aerosol Effects to be Considered

- **Direct effect** - Decrease solar/thermal-IR radiation and visibility
  - Processes needed: radiation (scattering, absorption, refraction, etc.)
  - Key variables: refractive indices, ext. coeff., SSA, asymmetry factor, AOD, visual range
  - Key species: cooling: water, sulfate, nitrate, most OC  
    warming: BC, OC, Fe, Al, polycyclic/nitrated aromatic compounds

- **Semi-direct effect** - Affect PBL meteorology and photochemistry
  - Processes needed: PBL/LS, photolysis, met-dependent processes
  - Key variables: T, P, cloud frac, stability, PBL height, photolysis rates, emission rates of met-dependent primary species (dust, sea-salt, biogenic)

- **First indirect effect** – Affect cloud drop size, number, reflectivity, and optical depth via CCN
  - Processes needed: aero. activation/resuspension, cld. microphysics, hydrometeor dynamics
  - Key variables: int./act. frac, CCN size/comp., cld drop size/number/LWC, COD, updraft vel.

- **Second indirect effect** - Affect cloud LWC, lifetime, and precipitation
  - Processes needed: in-/below-cloud scavenging, droplet sedimentation
  - Key variables: scavenging efficiency, precip. rate, sedimentation rate

- **All aerosol effects**
  - Processes needed: aero. thermodynamics/dynamics, aq. chem., precursor emi., water uptake
  - Key variables: aerosol mass, number, size, comp., hygroscopicity, mixing state

⇒ High-resolution on-line models with a detailed description of the PBL structure are necessary to simulate such effects
⇒ Online integrated models are necessary to simulate correctly the effects involved 2nd feedbacks