Lessons from EuMetChem for Aerosol Prediction and WMO GAW Strategy for Seamless CCMM

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International Cooperative for Aerosol Prediction (ICAP)
10th working group meeting: Seamless model development:
Aerosol modelling across timescales
6-8 June 2018, MetOffice, Exeter, UK
Outline

• Coupled Chemistry-Meteorology/Climate Modelling
• Online CCMM for CWF in Europe
• EuMetChem COST Action ES1004
• CCMM Symposium and its Recommendations
• WMO Seamless Approach for Prediction
• Aerosols as a Research Priority of WMO Commission for Atmospheric Science (CAS)
• Global Atmosphere Watch (GAW) Research Program
• WWRP, WCRP & GAW WGNE TT on Aerosols for NWP
• SDS-WAS Program and Dust forecasting
• GAW APP SAG and Chemical Weather Forecasting
• From Research to Services: Global Data-processing & Forecasting System (GDPFS)
• Cooperation with ICAP: Suggestions
Motivation: A new concept for Coupled Chemistry-Meteorology Modelling

- Physical and Chemical Weather: dependence of meteorological processes on atmospheric composition (especially aerosols).
- Meteorological data assimilation (in particular assimilation of radiative properties) also depends on chemical composition.
- Air quality forecasts loose accuracy when CTMs are run offline.
- Climate modeling: large uncertainty of SLCFs, water vapor feedbacks, etc.

=> Need for a new generation of seamless integrated meteorology and chemistry modelling systems for predicting atmospheric composition, meteorology and climate evolution!
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 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 and Jose M. Baldasano),
- WG2 Interactions, parameterisations and feedback mechanisms (coordinated by Michael Gauss and Alberto Maurizi),
- WG3 Chemical data assimilation in integrated models (coordinated by Christian Seigneur and Hendrik Elbenn),
- WG4 Evaluation, validation, and applications (coordinated by Dominic Brunner and Xiubin Liu).
Action COST ES1004
European framework for online integrated air quality and meteorology modelling (EuMetChem)

- Strategy and framework for online integrated modelling
  - 17 experts (P. Suppan, J.M. Baltasano, G. Grell).
- Interactions, parameterisations and feedback mechanisms
  - 22 experts (M. Gauss, A. Maurizi, Y. Zhang).
- Chemical data assimilation in integrated models
  - 13 experts (Ch. Seigneure, H. Elbern, G. Carmichael).
- Evaluation, validation, and applications

(Duration: 02.2011 ... 02.2015)

Chair: A. Baklanov,
Co-chairs: S. Joffre, H. Schluenzen

23 COST countries
4 COST neighbour countries
3+2 COST partner countries
3 EU institutions
18 online models analysed => Baklanov et al., ACP, 2014
Overview of European progress in AQF and CCMM

A review of operational, regional-scale, chemical weather forecasting models in Europe

J. Kukkonen¹, T. Olsson¹,², D. M. Schultz¹,²,³, A. Baklanov⁴, T. Klein⁵, A. I. Miranda⁶, A. Monteiro⁶, M. Hirtl⁷, V. Tarvainen¹, M. Boy², V.-H. Peuch⁸,⁹, A. Poupkou¹⁰, I. Kioutsioukis¹⁰, S. Finardi¹¹, M. Sofiev¹, R. Sokhi¹², K. E. J. Lehtinen¹³,¹⁴, K. Karatzas¹⁵, R. San José¹⁶, M. Astitha¹⁶, G. Kallos¹⁸, M. Schaap¹⁹, E. Reimer²⁰, H. Jakobs²¹, and K. Eben²²

Online coupled regional meteorology chemistry models in Europe: current status and prospects

CCMM Application Areas

**Air pollution modeling**
- from urban to continental scale
- air quality forecasts (few days) or assessment of past/current/future AQ
- sensitivity studies: emission reduction scenarios
- modeling of hazardous plumes
- aerosol studies: natural (dust, sea salt), BB, SOA, SIA, EC/OC

**Numerical weather prediction**
- potentially improved weather forecast by considering aerosol feedbacks
- natural aerosols: dust, sea salt
- biomass burning impacts
- anthropogenic aerosols, e.g. China, India; what about Europe?

**Regional climate modeling**
- potentially improved regional climate simulations by considering aerosol feedbacks
- additional interactions with land surface and ocean/sea
- from seasonal climate to multi-year climate simulations
Key scientific questions:

• What are the advantages of integrating meteorological and chemical/aerosol processes in coupled models?
• How important are the two-way feedbacks and chains of feedbacks for meteorology, climate, and air quality simulations?
• What are the effects of climate/meteorology on the abundance and properties (chemical, microphysical, and radiative) of aerosols on urban/regional/global scales?
• What is our current understanding of cloud-aerosol interactions and how well are radiative feedbacks represented in NWP/climate models?
• What is the relative importance of the direct and indirect aerosol effects as well as of gas-aerosol interactions for different applications (e.g., for NWP, air quality, climate)?
• What are the key uncertainties associated with model predictions of feedback effects?
• How to realize chemical data assimilation in integrated models for improving NWP and air quality simulations?
• How the simulated feedbacks can be verified with available observations/datasets? What are the requirements for observations from the three modelling communities?
# Effects of Chemistry on Meteorology

<table>
<thead>
<tr>
<th>Chemical parameter</th>
<th>Effect on . . .</th>
<th>Model variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>aerosols (direct effect)</td>
<td>radiation (SW scattering/absorption, LW absorption)</td>
<td>AOD, aerosol extinction, single scattering albedo, SW radiation at ground (up- and downward), aerosol mass and number size distributions, aerosol composition: EC (fresh soot, coated), OC, SO$<em>{4}^{2-}$, NO$</em>{3}^{-}$, NH$_{4}^{+}$, Na, Cl, H$_2$O dust, metals, base cations</td>
</tr>
<tr>
<td>aerosols (direct effect)</td>
<td>visibility, haze</td>
<td>aerosol absorption &amp; scattering coefficients, RH, aerosol water content</td>
</tr>
<tr>
<td>aerosols (indirect effect)</td>
<td>cloud droplet or crystal number and hence cloud optical depth</td>
<td>interstitial/activated fraction, CCN number, IN number, cloud droplet size/number, cloud liquid and ice water content</td>
</tr>
<tr>
<td>aerosols (indirect effect)</td>
<td>cloud lifetime</td>
<td>cloud cover</td>
</tr>
<tr>
<td>aerosols (indirect effect)</td>
<td>precipitation (initiation, intensity)</td>
<td>precipitation (grid scale and convective)</td>
</tr>
<tr>
<td>aerosols (semi-direct effect)</td>
<td>ABL meteorology</td>
<td>AOD, ABL height, surface fluxes (sensible and latent heat, radiation)</td>
</tr>
<tr>
<td>O$_3$</td>
<td>UV radiation</td>
<td>O$_3$, SW radiation &lt; 320 nm</td>
</tr>
<tr>
<td>O$_3$</td>
<td>thermal IR radiation, temperature</td>
<td>O$_3$, LW radiation</td>
</tr>
<tr>
<td>NO$_2$, CO, VOCs</td>
<td>precursors of O$_3$, hence indirect contributions to O$_3$ radiative effects</td>
<td>NO$_2$, CO, total OH reactivity of VOCs</td>
</tr>
<tr>
<td>SO$_2$, HNO$_3$, NH$_3$, VOCs</td>
<td>precursors of secondary inorganic and organic aerosols, hence indirect contributors to aerosol direct and indirect effects</td>
<td>SO$_2$, HNO$_3$, NH$_3$, VOC components (e.g. terpenes, aromatics, isoprene)</td>
</tr>
<tr>
<td>soot deposition on ice</td>
<td>surface albedo change</td>
<td>snow albedo</td>
</tr>
</tbody>
</table>

Baklanov et al., ACP, 2014
Coupled chemistry-meteorology models

Advantages as compared to offline models

- meteorological fields accessible at every time step
- single executable, single simulation, single parallelization strategy
- consistent treatment of processes acting on chemical and meteorological variables, computed only once in one code
- possibility to consider interactions between chemistry and meteorology
- data assimilation affects at same time chemical and meteorological variables
- no meteo preprocessing, no need for reading meteo from disk

Challenges

- chemistry to be solved at same (high) resolution as meteorology
- meteorology changes when feedbacks are activated
- significant investment to ensure consistent treatment of processes (e.g. radiation, transport)
- development of chemistry and meteorology parts not separated; therefore strong co-ordination needed

After Grell and Baklanov, AE, 2011
Key scientific questions:

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Importance and Representation of Aerosol-chemistry-meteorology interactions for NWP, CWF and Climate models

Table 1 List of meteorology-chemistry interactions

1. Temperature $\rightarrow$ reaction rates
2. Radiation $\rightarrow$ reaction rates
3. Temperature $\rightarrow$ biogenic emissions
4. Radiation $\rightarrow$ photosynthesis $\rightarrow$ biogenic emission
5. Temperature $\rightarrow$ volatility of species
6. Temperature $\rightarrow$ aerosol dynamics
7. Liquid water $\rightarrow$ wet scavenging, concentrations
8. Temperature & humidity $\rightarrow$ gas/particle partition
9. Precipitation (frequency/intensity) $\rightarrow$ concentration
10. Soil moisture $\rightarrow$ dust emissions
11. Soil moisture $\rightarrow$ dry deposition (biosphere and soil)
12. Wind speed $\rightarrow$ dust & sea salt emissions
13. Temperature vertical gradients $\rightarrow$ vertical diffusion
14. Lighting $\rightarrow$ NO$_x$ emissions
15. Water vapour $\rightarrow$ OH radicals $\rightarrow$ ozone
16. Aerosols $\rightarrow$ SW scattering/absorption, LW absorp
17. Radiatively active gases $\rightarrow$ radiation
18. Aerosol $\rightarrow$ haze
19. Soot deposition $\rightarrow$ ice albedo
20. Aerosol $\rightarrow$ cloud droplet/crystals $\rightarrow$ cloud O.D.
21. Aerosol $\rightarrow$ cloud morphology (e.g., reflectance)
22. Aerosol $\rightarrow$ precipitation (initiation, intensity)
23. Climate change $\rightarrow$ forest fire emissions
24. Changes in land surface $\rightarrow$ BVOC emissions

Figure 1 COST ES1004 expert survey results

Baklanov et al., ACP, 2014
Kong et al., AQC, 2014
## Survey Results – Top Six Ranked Important Interactions

<table>
<thead>
<tr>
<th>Top six ranked Meteorology and chemistry interactions</th>
<th>Score1</th>
<th>Score2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(A) Numerical Weather Prediction (NWP)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosol -&gt; precipitation (initiation and intensity of</td>
<td>3.1</td>
<td>1.3</td>
</tr>
<tr>
<td>precipitation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosols -&gt; radiation (shortwave scattering/absorption</td>
<td>3.1</td>
<td>1.9</td>
</tr>
<tr>
<td>and longwave absorption)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature vertical gradients -&gt; vertical diffusion</td>
<td>3.1</td>
<td>2.2</td>
</tr>
<tr>
<td>aerosol -&gt; cloud droplet or crystal number density</td>
<td>3.1</td>
<td>1.3</td>
</tr>
<tr>
<td>and hence cloud optical depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosol -&gt; haze (relationship between the hygroscopic</td>
<td>2.9</td>
<td>1.0</td>
</tr>
<tr>
<td>growth of aerosols and humidity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosol -&gt; cloud morphology (e.g., reflectance)</td>
<td>2.7</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>(B) Chemical Weather Forecast (CWF)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wind speed -&gt; dust and sea salt emissions</td>
<td>3.8</td>
<td>2.5</td>
</tr>
<tr>
<td>precipitation (frequency/intensity) -&gt; atmospheric</td>
<td>3.8</td>
<td>2.7</td>
</tr>
<tr>
<td>composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature -&gt; chemical reaction rates and photolysis</td>
<td>3.7</td>
<td>2.9</td>
</tr>
<tr>
<td>radiation -&gt; chemical reaction rates and photolysis</td>
<td>3.7</td>
<td>2.7</td>
</tr>
<tr>
<td>liquid water -&gt; wet scavenging and atmospheric</td>
<td>3.6</td>
<td>2.3</td>
</tr>
<tr>
<td>composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature vertical gradients -&gt; vertical diffusion</td>
<td>3.6</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>(C) Climate modelling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerosols -&gt; radiation (shortwave scattering/absorption</td>
<td>3.4</td>
<td>2.3</td>
</tr>
<tr>
<td>and longwave absorption)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>radiatively active gases (e.g., water vapour, CO₂,</td>
<td>3.4</td>
<td>2.0</td>
</tr>
<tr>
<td>O₃, CH₄, NO and CFC) -&gt; radiation</td>
<td></td>
<td></td>
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<td>aerosol -&gt; precipitation (initiation and intensity of</td>
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<td>2.0</td>
</tr>
</tbody>
</table>

*Primary attention needs to be given to the interactions with high ‘score1’ (importance of the interaction for models) together with low ‘score2’ (adequacy of the representation of the interaction in models)*
EuMetChem in AQMEII online models evaluation exercise

Selected case studies for aerosol feedbacks:
1. Russian forest fires, summer 2010
2. Sahara dust episode over Europe
3. MEGAPOLI Paris measurement campaign

14 models for EU domain (but only 7 individual models)

NOx and PM10 measurement stations overlaid over corresponding emission maps. Symbols colored according to evaluation subdomain.
CCMM Evaluation – AQMEII-2 results

*Atmospheric Environment* Special Issue, Eds Galmarini et al, Aug 2015

**Operational evaluation**
- *Im et al. 2015a,b*
  - PM and ozone, AQ monitoring sites, $O_3$ profiles, AERONET
- *Brunner et al. 2015*
  - Meteorology: surface T, wind, radiation, precipitation, profiles
- *Giordano et al. 2015*
  - MACC reanalysis and its influence as BC for regional models
- *Badia et al. 2014*
  - Evaluation of NMMB-BSC
- *Yahya et al. 2015*
  - Evaluation of WRF-Chem

**Diagnostic evaluation**
- *Knote et al. 2015*
  - Gas-phase chemistry schemes
- *Curci et al. 2015*
  - Uncertainties in aerosol optical properties
- *Balzarini et al. 2015*
  - Chemical mechanisms in WRF-Chem
- *Baro et al. 2015*
  - Microphysics schemes in WRF-Chem on indirect effects
- *Forkel et al. 2015*
  - Radiative feedbacks in WRF-Chem
- *Makar et al. 2015a,b*
  - Feedback effects on weather and on chemistry
- *Kong et al. 2015*
  - Meteo–chemistry interactions during air pollution episodes

**Dynamic evaluation**
- *Hogrefe et al. 2015*
  - Evaluation of WRF-CMAQ and response to emission changes
- *Wang et al. 2015*
  - Column variables evaluated vs. satellites for 2006 and 2010
- *Campbell et al. 2015*
  - $O_3$ & PM2.5 response to emission changes 2006-2010
WRF-Chem Sensitivity Runs on 2010 Russian Fire Case Study: Chains of aerosol direct & indirect effects on meteorology

• Significant aerosol direct effects on meteorology (and loop back on chemistry).
• Reduced downward short wave radiation and surface temperature, and also reduced PBL height. It in turn reduced photolysis rate for O3
• The normalized mean biases are significantly reduced by 10-20% for PM10 when including aerosol direct effects.
• Indirect effects are less pronounced for this case and more uncertain.

Kong et al, AE, 2015
Enviro-HIRLAM: aerosol–cloud interactions

Frequency distribution in [mm/3 hour] of stratiform precipitation (top) and convective precipitation (down). Comparison of 1-moment (Reference HIRLAM) and 2-moment (Enviro-HIRLAM with aerosol–cloud interactions) cloud microphysics STRACO schemes.

Precipitation amount (12 hrs accumulated) of reference HIRLAM (top) and Enviro-HIRLAM with aerosol–cloud interactions (down) vs. surface synoptic observations at WMO station 6670 at Zurich, Switzerland during July 2010.

*Nuterman et al., 2014; Baklanov et al., 2017*
Conclusions & recommendations

EuMetChem & AQMEII-2 specific:

- Inter-model differences in simulated chemical and meteo variables often larger than aerosol direct and indirect effects.
- Regional CCMMs are still young, deficiencies have been identified for several models, further improvements needed
- Large differences found for aerosol mass and composition. Additionally evaluate (a) sulphate aerosols and contribution of different SO₂ oxidation pathways (b) parameterizations of naturally emitted aerosols (dust, sea salt) (c) secondary organic aerosol formation
- Chemical fields from global model used as BC have significant impact on regional models. Better harmonization between regional and global models desirable, including (a) better harmonization of the emission inventories (b) a better harmonization of chemistry & aerosol schemes
- SW & LW radiation measurements at surface are important for analysing aerosol direct and indirect effects but hardly available
- Satellite observations have high potential for evaluating regional CCMMs, especially with respect to direct and indirect effects
Case Studies

1) Dust over Egypt: 4/2012
2) Pollution in China: 1/2013
3) Smoke in Brazil: 9/2012

WMO WGNE Aerosol Task Leader Saulo Freitas, INPE/NASA

Freitas et al., 2015
Case 1: Sahara Dust Episode

How much interactive aerosol dust changes dust concentration itself?

Mass of dust column integrated (AER-NOAER)
forecast 09UTC18APR2012
Init.:00UTC17APR2012

Positive feedback (?)

Negative feedback

NASA

BSC

Freitas et al., 2015
DIFF of Temp @ 2-m
AER-NOAER

- 12 UTC (morning)
- Large discrepancies among centers

Opposite signal

Location of the plume

Freitas et al., 2015
SW Rad @ Sfc Intercomparison

- 9 UTC (morning)
- Large discrepancies among centers

Location of the plume

Freitas et al., 2015
Case 2: Beijing episode

JMA – Rad shortwave at sfc (W m\(^{-2}\))

Init 00UTC12JAN FCT: 03UTC14JAN

DIR effect:
-25 to -100 W m\(^{-2}\)

INDIR effect:
-100 to -300 (or less) W m\(^{-2}\)

INDIR effect has more pronounced effect on sfc rsw extinction

Freitas et al., 2015
Case 3: Brasil, the SAMBBA experiment

BIAS: 2-m Temperature

Consistent bias reduction with increasing aerosol treatment complexity during the day, with a slight increase during the night.

Consistent bias reduction

Bias decreases during the day, but increases at night

Slight decrease of bias during 12-18 UTC

Freitas et al., 2015
100 participants from all continents
46 oral talks, 36 posters,
All presentations are available on: http://eumetchem.info/
7 topics brain-storm teams to conclude
WMO Report to be published
ACP & GMD Journal CCMM Special Issue
Outcomes provided for 17th WMO Congress

Symposium on Coupled Chemistry-Meteorology/Climate Modelling
Status and Relevance for Numerical Weather Prediction, Air Quality and Climate Research
WMO Headquarters, Geneva, Switzerland
23-25 February 2015

Topics
- Coupled chemistry-meteorology (weather and climate) modelling (CCMM): approaches and requirements;
- Key processes of chemistry-meteorology interactions and their descriptions;
- Aerosol effects on meteorological processes and NWP;
- CCMM for air quality and atmospheric composition;
- CCMM for regional and global climate modelling;
- Model validation and evaluation;
- Data requirements, use of observations and data assimilation;
- Outlook and future challenges.

CCMM Applications Areas

**Air pollution modeling**
- from urban to continental scale
- air quality forecasts (few days) or assessment of past/current/future AQ
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**Numerical weather prediction**
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Main Outcomes

CCMM Special issue 370: 42 papers
http://www.atmos-chem-phys.net/special_issue370.html

Aerosol SAG overview paper:
Online coupling for (i) NWP and MetM, (ii) AQ and CWF, (iii) Climate and Earth System modelling

- Relative importance of online integration and level of details necessary for representing different processes and feedbacks can greatly vary for these related communities.

- **NWP** might not depend on detailed chemical processes but considering the cloud and radiative effects of aerosols can be important for fog, visibility and precipitation forecasting, surface T, etc.

- For **climate modelling**, feedbacks from GHGs and aerosols become extremely important. However in some cases (e.g., for long-lived GHGs on global scale), fully online integration of full-scale chemistry is not critically needed. Still too expensive, so models need to be optimized and simplified.

- For **chemical weather forecasting and prediction of atmospheric composition**, the online integration definitely improves AQ and chemical atmospheric composition projections.

- **Main gaps:**
  - Understanding of several processes: aerosol-cloud interactions are poorly represented;
  - data assimilation in online models is still to be developed;
  - model evaluation for online models needs more (process) data and long-term measurements – and a test-bed.
What are the advantages of integrating meteorological and chemical/aerosol processes in coupled models for NWP?

- Advantages for episodes in relation to
  - health effects
  - aviation forecasts (icing, volcanic ash)
  - Radiation & surface temperature
  - Plume rise
- Cloud properties – probably.
- Precipitation - not yet clear.
- Benefits under ‘normal’ conditions not clear.
- Improving satellite retrieval of CO2 concentrations (and others?)
How important are the two-way feedbacks and chains of feedbacks for NWP?

- strong evidence for the importance of some of the model chains:
  - increased AOD -> lower surface T -> shallower PBL-> increasing primary pollutant concentrations
  - increased AOD -> lower surface T higher T above -> stronger stability- > convection inhibition
- Importance varies strongly with location (indirect effect more important in tropics?) and time (episodes) and with the model applied.
- For weather prediction the 3D real-time aerosol would most probably be important in specific cases of high aerosol concentrations.
CCMM for air quality and atmospheric composition
Main Challenges and Gaps

- **Urban/stable boundary layer**: interactions between atmospheric chemistry and dynamics
- **Finer scale model applications** require frequent coupling between the dynamical and chemical
- Changes in **stratosphere-troposphere exchange and impacts on “background” O₃**.
- **Integrating emerging satellite observations** with CCMMs
- **Pollution scavenging and deposition** – inclusion of aerosol-cloud interaction
- **Need to evolve the way we compare grid based models with point observations**
Recommendations for future research (CCMM, 2017): For climate research:

- Improve our understanding of indirect effects (e.g. BC on clouds).
- Develop CCMs with prognostic aerosol to assess what is the tradeoff between a more complex aerosol representation on the one side and model resolution, or the atmosphere-ocean coupling, on the other side?
- Test model performance in terms of relevant physical, chemical, and radiative processes and mechanisms (in contrast to just testing mean performance).
- Test model performance in terms of tropospheric dynamics/meteorology and their effect on composition (and vice-versa).
Future Needs

- Continue intercomparisons both at global and regional scale for AQ, NWP and climate; should consider also intercomparison that are cutting across all 3 fields.

- Need some specifically defined experiment that looks at chemistry-cloud-microphysics at different scales.

- Need for (field experimental) data to evaluate online coupled models.

- Improving the numerical and computational efficiency of the models as the complexity of applications grows (e.g., scales).
CHAPTER 12. SEAMLESS METEOROLOGY-COMPOSITION MODELS: CHALLENGES, GAPS, NEEDS AND FUTURE DIRECTIONS

Alexander Baklanov, Véronique Bouchet, Bernhard Vogel, Virginie Marécal, Angela Benedetti and K. Heinke Schlünzen
The seamless approach considers several dimensions of the coupling:

i) **Time scales** (from minutes and nowcasting till decades and climate time-scale);

ii) **Spatial scales** (from street till global scales with downscaling and upscaling methods);

iii) **Processes**: physical, chemical, biological, and social;

iv) **Earth system components**: atmosphere, hydrosphere, pedosphere, ecosystems/biosphere;

v) Different types of **observations** and modelling tools: data processing and **data assimilation**, validation and verification of modelling results; and

vi) **User-oriented** integrated systems and **impact based forecasts and services**.

=> New generation of seamless models integrated with observations
AEROSOLS - One of six CAS PRIORITIES

Aerosols: Impacts on air quality, weather and climate

- The monitoring and modelling of aerosols is a significant challenge – many stations needed to measure a wide variety of variables.

CAS stressed the need to plan for an integrated global aerosols observation system.
Global Atmosphere Watch (GAW) Programme

New IP for 2016-2023 on concept “science for services”

New GAW Data Management strategy

New focal area – total deposition

New Scientific Advisory Group on Applications, lead by V.-H. Peuch, CAMS & F. Dentener, JRC

GAW has >800 stations in >100 countries and works with >100 variables!

Overarching goal of GAW research is a better understanding of atmospheric processes with underpins science based products and services
GAW – enhancing modeling

The broad “atmospheric chemistry” application area was substituted with more specific application areas:

- “atmospheric composition forecasting”,
- “atmospheric composition analysis and monitoring”
- “urban services”.

Expand GAW’s role in enhancing predictive capabilities (atmospheric composition and its uses)

- urban air quality forecasting capabilities through GURME,
- new Modelling Applications SAG (“Apps”) – usefulness exchanging chemical observational data in NRT
- expanding collaborations with WWRP/WCRP/WGNE and others
GAW SAG-APPs Work Streams

(1) Assessment activities
   - Health, climate change, ecosystems

(2) Improving emissions
   - Up-to-Date, weather- (or proxy) dependent
   - Inverse modelling

(3) Developments of NRT systems
   - Ensembles, help set-up applications worldwide
   - MAP-AQ as a key project

(4) Data aspects
   - Identify gaps (limb sounding…), common skill scores

(5) Developing scientific activities
   - interactive chemistry/radiation for improving NWP forecasts (up to seasonal),
   identify gaps in knowledge

(6) Outreach
   - Summer schools, webinars, “Year of Air Quality” initiative?

co-chairs: F. Dentener (JRC) & V.-H. Peuch (ECMWF)
Applications in GAW to supports Members

Observations and reanalysis: direct support of conventions (LRTAP, Montreal Protocol)

Specific service oriented applications:

• **Support of climate negotiations:** IG³IS
• **Ecosystem services:** Analysis of total deposition, nitrogen cycle, deposition to the oceans/marine geoengineering
• **Health:** Regional (MAP-AQ) and Urban air quality (GURME)
• **Sand and Dust Storm Warning Advisory and Assessment System** (SDS-WAS)
• **Vegetation Fire and Smoke Pollution Warning and Advisory System** (VFSP-WAS)
• **Food security:** Atmospheric composition and agriculture
• **Transport security:** Volcanic ash forecasting
• **Weather forecasting:** aerosol effects on NWP, high impact weather
GAW DATA USED FOR CAMS VERIFICATION
(GLOBAL, NRT)

http://atmosphere.copernicus.eu/user-support/validation/verification-global-services
WMO Global Atmosphere Watch (GAW)

Integrated Global Aerosol Observing System

Global Products

1. Data Uses/Applications
2. Air Quality Warnings
3. WMO SDS-WAS Assessments
4. WMO SDS-WAS Warnings
5. Aerosol Bulletins
6. Surface and air transport
7. Improved Weather Forecasts
8. Improved Climate Prediction

Air/Surface Exchange & Emissions

Data Assimilation By Forecast Models
(e.g. MACC; SDS-WAS etc.)

Observation Optimization

Real-Time Data Delivery

Data Archival and/or Access Facilities
(e.g. WDCA; WDC-RSAT)

Satellites:
MODIS, CALIPSO, MISRMSG

Aircraft: IAGOS

Surface-based:
Remote sensing: AOD
Remote Sensing: GALION
In situ: PM, optical, etc
In situ: chemistry

RI for Calibration & Quality Assurance
Sand & Dust Storm Warning Advisory & Assessment System (SDS-WAS)

- 3 Regional Nodes, 15 organizations providing forecast
- WMO WWRP/GAW Global Coordination: Steering Committee and Trust Fund
- Regional coordination through regional activity nodes
- SDS-WAS Science & Implementation Plan approved:

WMO SDS-WAS Web-Site:
http://www.wmo.int/pages/prog/arep/wWRP/new/Sand_and_Dust_Storm.html
### Numerical models contributing to WMO SDS-WAS (2017)

<table>
<thead>
<tr>
<th>Model</th>
<th>Institution</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSC-DREAM8b_v2</td>
<td>Barcelona Supercomputing Center, Spain</td>
<td>Regional</td>
</tr>
<tr>
<td>CAMS</td>
<td>European center for Medium-Range Weather Forecast, U. K.</td>
<td>Global</td>
</tr>
<tr>
<td>DREAM-NMME-MACC</td>
<td>South east European Climate Change Center, Serbia</td>
<td>Regional</td>
</tr>
<tr>
<td>NMMB/BSC-Dust</td>
<td>Barcelona Supercomputing Center, Spain</td>
<td>Regional</td>
</tr>
<tr>
<td>MetUM</td>
<td>Met Office, U. K.</td>
<td>Global</td>
</tr>
<tr>
<td>GEOS-5</td>
<td>National Aeronautics and space Administration, U. S.</td>
<td>Global</td>
</tr>
<tr>
<td>NGAC</td>
<td>National Centers for Environmental Prediction, U. S.</td>
<td>Global</td>
</tr>
<tr>
<td>EMA REG CM4</td>
<td>Egyptian Meteorological Authority, Egypt</td>
<td>Regional</td>
</tr>
<tr>
<td>DREAMABOL</td>
<td>National Research Council, Italy</td>
<td>Regional</td>
</tr>
<tr>
<td>WRF-CHEM</td>
<td>National Observatory of Athens, Greece</td>
<td>Regional</td>
</tr>
<tr>
<td>SILAM</td>
<td>Finnish Meteorological Institute, Finland</td>
<td>Regional</td>
</tr>
<tr>
<td>CUACE/Dust</td>
<td>China Meteorological administration, China</td>
<td>Regional</td>
</tr>
<tr>
<td>MASINGAR</td>
<td>Japan Meteorological Agency, Japan</td>
<td>Global</td>
</tr>
<tr>
<td>ADAM</td>
<td>Korea Meteorological Administration, Korea</td>
<td>Regional</td>
</tr>
</tbody>
</table>

- **7 global models**
- **11 regional models**
- **15 organizations**
- **3 regional nodes** *(NAMEE, Asia, Americas)*
- **2 regional centers**
MAP-AQ - a Key GAW AQF Project

International System for Monitoring, Analysis, and Prediction of Air Quality

Monitoring
(In situ and space observations of weather and atmospheric composition)

Prediction
(Multi-scale short-term weather and air quality predictions to protect public health)

Management
(Translate technical details into actionable information and disseminate to public)

Scenario Analysis
(Design permanent air pollution control strategies to protect public health in long-term)

Capacity building
(Train local students, scientists and public in developing countries)
Using Global AQ Forecasts (CAMS and others) for Regional and Urban Downscaling in Africa

Suggestions for cooperation with ICAP:

- GAW observations for evaluation and assimilation
- ICAP global ensemble for members: research and operational
- Contribution for SDS-WAS and GAW APP with global dust and atmospheric composition forecasts
- Host a global center for SDS-WAS and CWF
- Other GAW application areas for 200 Member countries and in support of Conventions
- Other suggestions from ICAP?
Thank you!

ICAP is welcome contributing to WMO GAW
Some References

Modelling recommendations for simulation of meteorological, chemical, biological variables

<table>
<thead>
<tr>
<th>Modelling recommendations</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol/chemistry transport and interactions to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Identify shortcomings in transport schemes,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Improve assimilation of meteorological satellite data (better</td>
<td></td>
<td></td>
</tr>
<tr>
<td>through a better representation of gases, aerosols, radiative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>transfer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Extend forecasts to AQ in weather time scale</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Meteorology impacts acting online to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Reduce interpolation efforts and increase accuracy</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Improve meteorology-dependent processes</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Improve cloud-connected processes.</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

EuMetChem: Baklanov, Schlünzen et al.
## Recommendations for model evaluation of coupled meteorology, chemistry, biology models

<table>
<thead>
<tr>
<th>Recommendations for evaluating models</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>International test-bed for model evaluation of urban- and mesoscale models (AQMEII...)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>To be additionally evaluated:</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Shortwave and longwave radiation,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Photolytic rate of NO$_2$,</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• AOD, COT, CCN</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Cloud droplet number concentration</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• Precipitation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Additional measurements needed for evaluations:</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Radiative forcing,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• PBL height or vertical mixing,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Photolytic rates of NO$_2$,</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• AOD, COT, CCN</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• Long-term measurement data sets (incl. met. variables, aerosol and cloud properties, biol. variables)</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

EuMetChem: Baklanov, Schlünzen et al.
## Relevance of better knowledge on specific processes to improve simulation of meteorological, chemical, biological variables

<table>
<thead>
<tr>
<th>Processes (clouds, aerosols)</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cloud processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Microphysics, dynamics,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• In-cloud and below-cloud scavenging,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Aqueous-phase chemistry</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Aerosol processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Chemistry</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>• Thermodynamics</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Dynamics</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td><strong>Representation of aerosol–radiation–cloud–chemistry interactions (improve indirect estimates of aerosol effect)</strong></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

EuMetChem: Baklanov, Schlünzen et al.
Relevance of better knowledge on properties to improve simulation of meteorological, chemical, biological variables

<table>
<thead>
<tr>
<th>Properties (clouds, aerosols)</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Droplet number concentrations, size distribution,</td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>• Cloud fraction,</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>• Liquid water content, optical depths</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Aerosol properties</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>• Number, aerosol mass, size distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Composition, phase, hygroscopicity, mixing state,</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>• Optical depths</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

EuMetChem: Baklanov, Schlünzen et al.
Relevance of better process descriptions to improve simulation of meteorological, chemical, biological variables

<table>
<thead>
<tr>
<th>Process (emissions)</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorology-dependent emission processes to be described more accurately:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Biogenic</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Sea spray</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Windblown dust</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>• Lightning</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>Anthropogenic emission data in urgent need for improvement:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Wild fires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Volcanic eruptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat fluxes sources needing better knowledge:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Wild fires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Volcanic eruptions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Model formulation and implementation aspects to improve simulations of meteorological, chemical, biological variables

<table>
<thead>
<tr>
<th>Model formulation and implementation</th>
<th>For variables in</th>
<th>For applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of coupling between meteorology and chemistry models needs to be high enough to (at least) properly consider effects of mesoscale events (land-sea breeze, etc.).</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Data assimilation methodology for meteorological <strong>and</strong> chemical data that avoids antagonistic effects and over-specification due to interactions between meteorological and chemical variables</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Consistency in processes ensures one single atmosphere is simulated (to achieve by improving collaboration of communities)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Online access modelling to be transferred to online integration of met., chem., biol., to avoid double work</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
WHAT IS OUR CURRENT UNDERSTANDING OF AEROSOL–CLOUD INTERACTIONS AND HOW WELL ARE RADIATIVE FEEDBACKS REPRESENTED IN NWP/CLIMATE MODELS?

• Shortwave radiation in CCMMs is the best represented radiative feedback process, while longwave radiation is less well represented and cloud–aerosol interactions are poorly described.

• The indirect effects seem to be very sensitive to the sophistication of the chosen parameterizations and to the detail of the implementation. The models (e.g. AQMEII, WGNE) had very different results. Idealized model sensitivity studies on isolated clouds show a clear aerosol effect, while in more realistic simulations the atmospheric feedback is more complex, including chains of interactions with many other processes and with compensating effects. The large scatter in plots of laboratory data of particles’ capability to act as ice nuclei shows that this is a topic for more research.

• In NWP: to develop diagnostics and validation methodologies to more explicitly separate the different effects of the intertwined feedback processes.

• Climate modeling: cloud–aerosol interactions are also not yet fully understood, in particular for ice clouds and mixed-phase clouds including midlevel and Arctic clouds.

• Experiments are needed that are specifically defined to look at chemistry–cloud microphysics at different scales. And the numerical and computational efficiency of the models will need to improve as the complexity of applications grows (e.g., scales).

• Climate community will need to develop CCMs with prognostic aerosol, which means the level of sophistication of such modules needs to be defined. For example, what is the trade-off between a more complex aerosol representation on the one side and model resolution, or the atmosphere–ocean coupling, on the other side? In addition, the consistency between resolution and parameterizations needs to be assessed.
Enviro-HIRLAM online integrated meteorology–chemistry modelling system: strategy, methodology, developments and applications (v7.2)

Alexander Baklanov¹,a, Ulrik Smith Korsholm¹, Roman Nuterman², Alexander Mahura¹,b, Kristian Pagh Nielsen¹, Bent Hansen Sass¹, Alix Rasmussen¹, Ashraf Zakey¹,c, Eigel Kaas², Alexander Kurganskiy²,³, Brian Sørensen², and Iratxe González-Aparicio⁴

¹Danish Meteorological Institute (DMI), Copenhagen, Denmark
²Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
³Russian State Hydrometeorological University, St. Petersburg, Russia
⁴European Commission, DG – Joint Research Centre, Institute for Energy and Transport, Petten, the Netherlands

a now at: World Meteorological Organization (WMO), Geneva, Switzerland
b now at: University of Helsinki, Helsinki, Finland
Role of mineral dust in cloud formation: modelling aspects

S. Nickovic\textsuperscript{1,2}, B. Cvetkovic\textsuperscript{1}, L, Ilic\textsuperscript{2}, G. Pejanovic\textsuperscript{1}, S. Petkovic\textsuperscript{1}, F. Madonna\textsuperscript{3}, M. Rosoldi\textsuperscript{3}, D. Weber\textsuperscript{4} and H. Bingemer\textsuperscript{4}, J. Nikolic \textsuperscript{1}

\textsuperscript{1}Republic Hydrometeorological Service of Serbia (RHMSS), Belgrade, Serbia
\textsuperscript{2}Institute of Physics Belgrade, Serbia
\textsuperscript{3}Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l’Analisi Ambientale, Potenza, Italy
\textsuperscript{4}Institut für Atmosphäre und Umwelt, Goethe-Universität, Frankfurt/M., Germany

9th International Workshop on Sand/Duststorms and Associated Dustfall, 22-24 May 2018, Tenerife, Spain