Karlsruhe Institute of Technology

ES1004 EuMetChem

Online coupled meteorology-chemistry modelling: Current status and case studies

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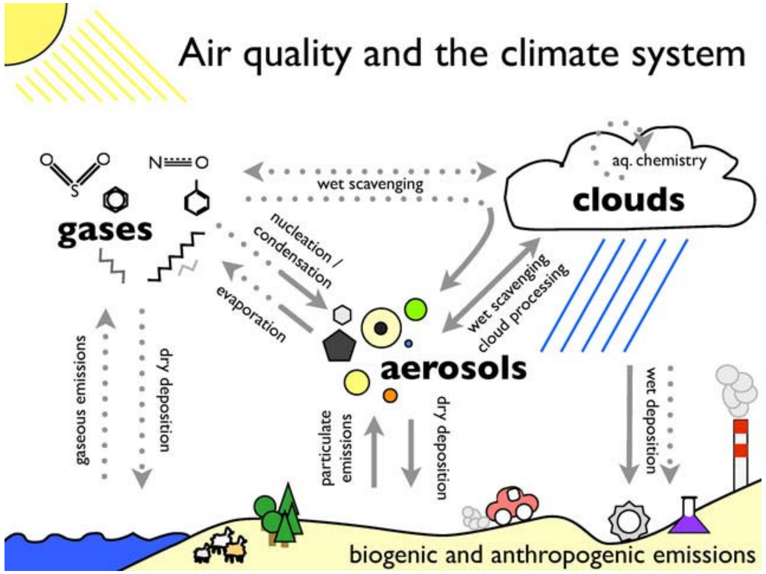
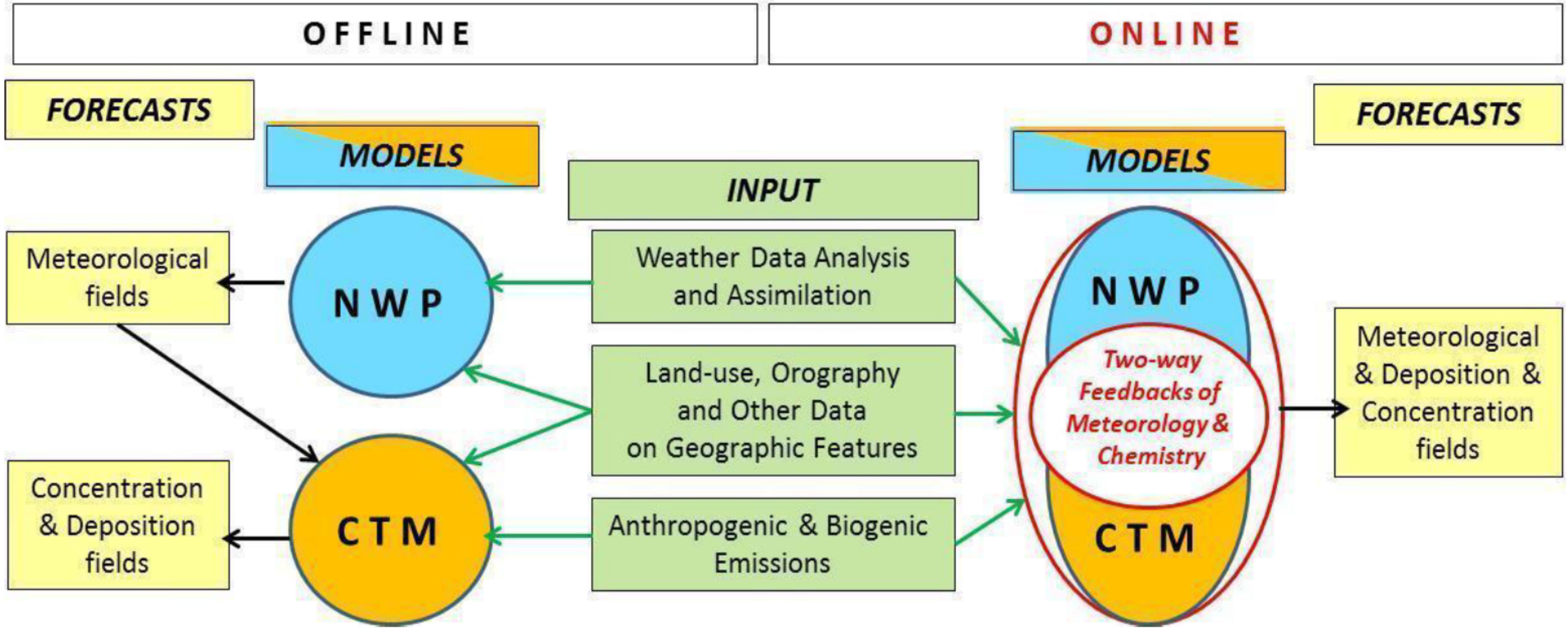
Outline

- Online coupled models: Rationale and concept
- Current status and activities
- Examples, AQMEII 2 and EuMetChem case studies
  - Aerosol radiative effects
  - Aerosol cloud interactions
- Concluding remarks



Concept/definition

Offline: Subsequent runs of met. model and chemistry
Integrated or online coupled meteorology atmospheric chemistry models: 1 simulation for met. and chemistry



Why integrated online modelling of meteorology and air quality?

Meteorology has an impact on atmospheric chemistry

- Wind and temperature: Transport, vertical exchange, reaction rates, …
- Radiation: Photolysis, BVOC emissions, …
- Cloud processes: wet removal, aq. chemistry

These effects are included in offline and online models

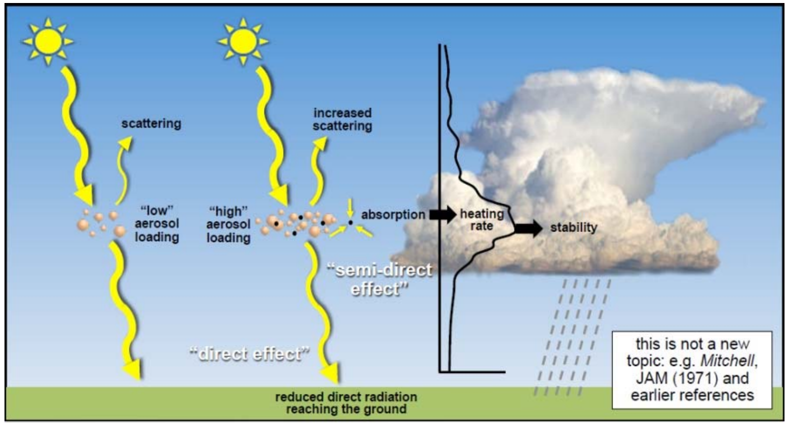
Description of gas phase and liquid phase chemistry and aerosol processes with different degrees of complexity in individual models

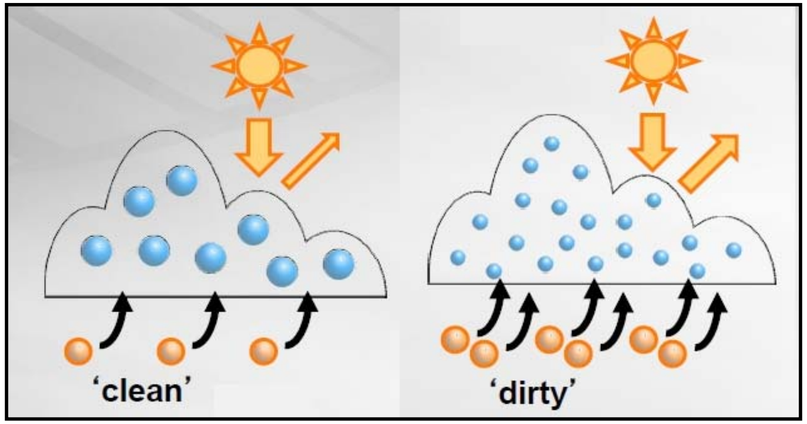
NOT the subject of this talk

Why integrated online modelling of meteorology and air quality?

But: Chemistry has also an impact on meteorology

- Aerosol radiative effects (direct aerosol effect)
- Aerosol cloud interactions (CCN numbers) and resulting effect on radiation (indirect aerosol effect)
- Radiative effect of gases





Figures from A. Hodzic, 2013

Features/advantages/challenges

- Update of meteorological input at each time step (mostly hourly for offline models)
- Exchange of information between meteorology and atmospheric chemistry in both directions
  ➡ Online coupled meteorology-chemistry models can account for feedback effects to meteorology (temperature, cloud lifetime, precipitation, ...)
- More realistic meteo for aerosol extreme events (homogeneous aerosol or climatology for offline)
- Need more computational resources
- More complex, in particular when feedback effects are considered

Status

- Originally two separate NWP and AQ communities
- Increasing number online coupled mesoscale meteorology-atmospheric chemistry models
- Currently about 18 applied in Europe: BOLCHEM, COSMO-ART, COSMO-MUSCAT, Enviro-HIRLAM, GEM-AQ, IFS-MOZART, MCCM, MEMO/MARS, Meso-NH, MetUM, M-SYS, NMMB/MSC-CTM, LOTOS-EUROS, RAMS/ICLAMS, RegCM-Chem4, REMOTE, WRF-Chem, WRF-CMAQ
- Almost all include direct aerosol effect, about half of them include aerosol-cloud interactions

Review paper: Baklanov et al. 2014, *Atmospheric Chemistry and Physics* 14, doi:10.5194/acp-14-317-2014

Key scientific questions

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- 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 is our current understanding of cloud-aerosol interactions and how well are radiative feedbacks represented in NWP/climate models?
- 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?

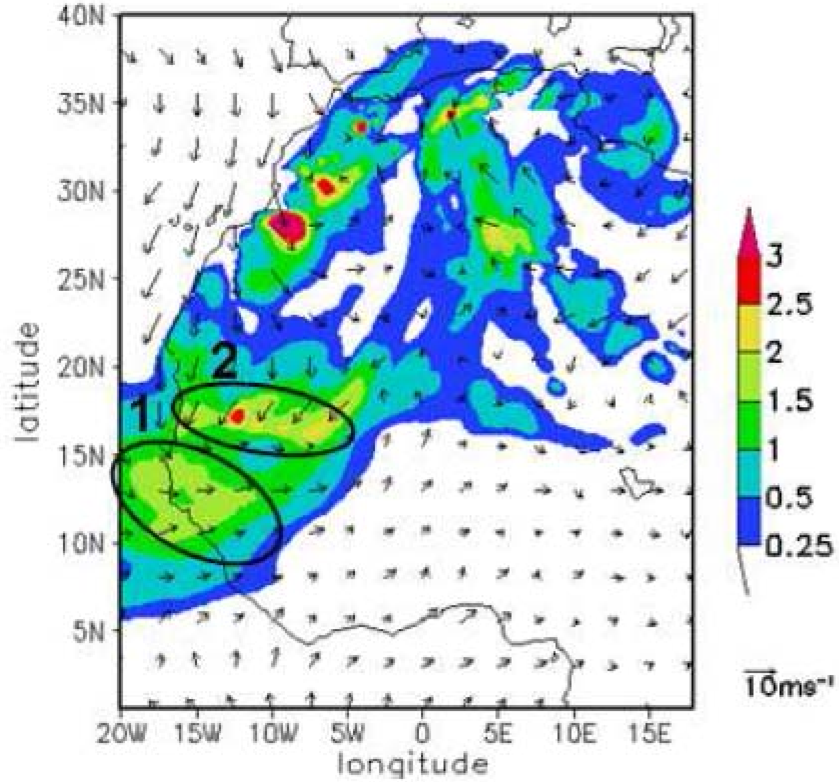
Recent & current research initiatives

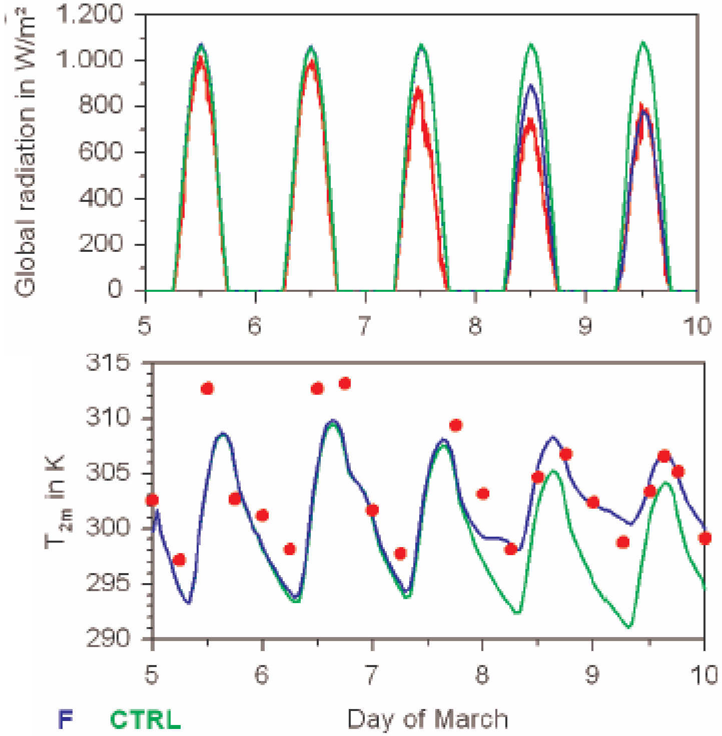
- COST Action ES1004 EuMetChem: European Framework for Online Integrated Air Quality and Meteorology Modelling
- WMO WGNE study Aerosol effects on NWP, GURME: GAW Urban Research Meteorology and Environment , SDS-WAS: Sand and Dust Strom Warning Advisory and Assessment System
- AQMEII: Air Quality Model Evaluation International Initiative
- and many national climate, AQ and NWP forecast programs, complemented by research studies

AQMEII: Atmospheric Environment Special Issue, Aug 2015

COST Action EuMetChem: ACP/GMD special issue

Examples: Direct aerosol effect

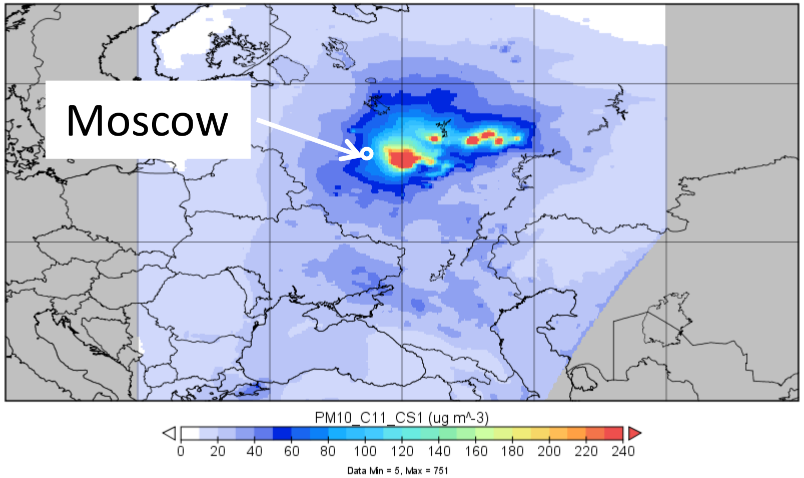




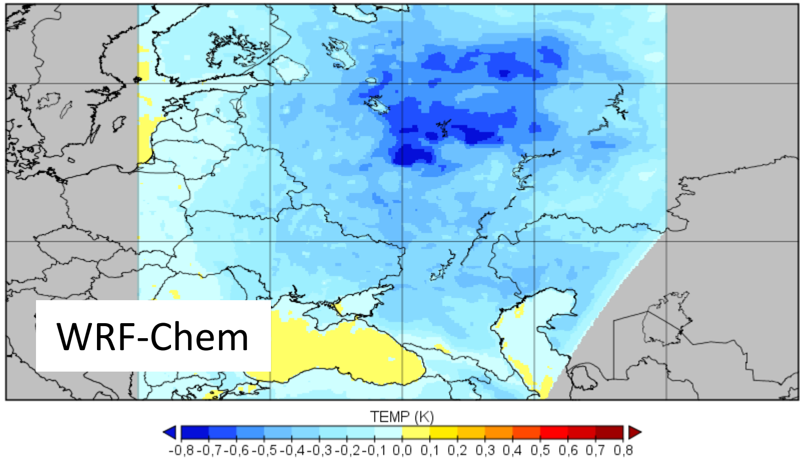
- Saharan dust event, improved radiation and T with direct effect (COSMO-ART, Stanelle et al. 2010)
- Other applications: fires, volcanic ash, urban, pollen

Examples: Direct aerosol effect

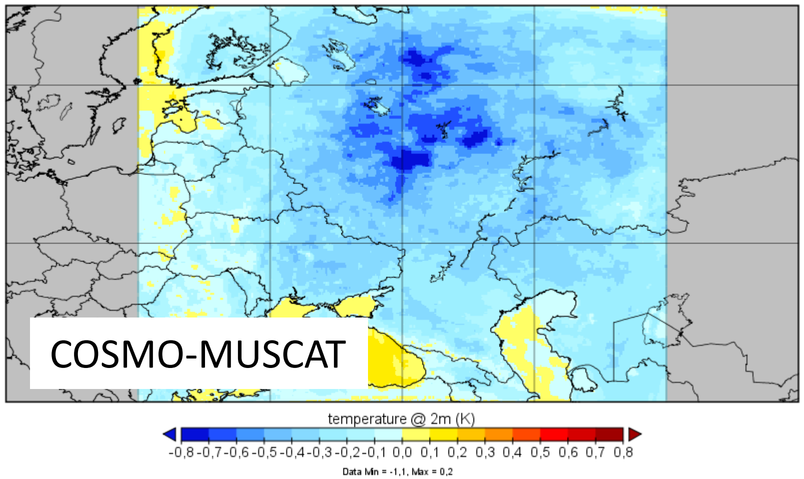
PM10



ΔT Direct - Base



ΔT Direct - Base

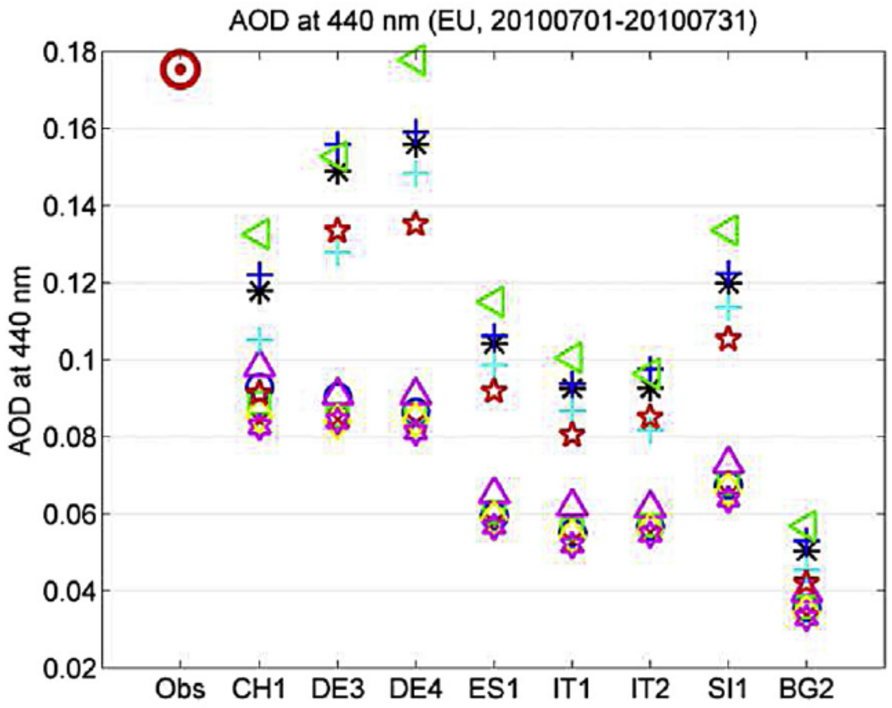


EuMetChem case studies on Russian forest fires 2010:

- Different models may show different response
- Closer to obs. with direct effect

Examples: Direct aerosol effect

- Though well established, calculation of aerosol optical properties can vary strongly among models



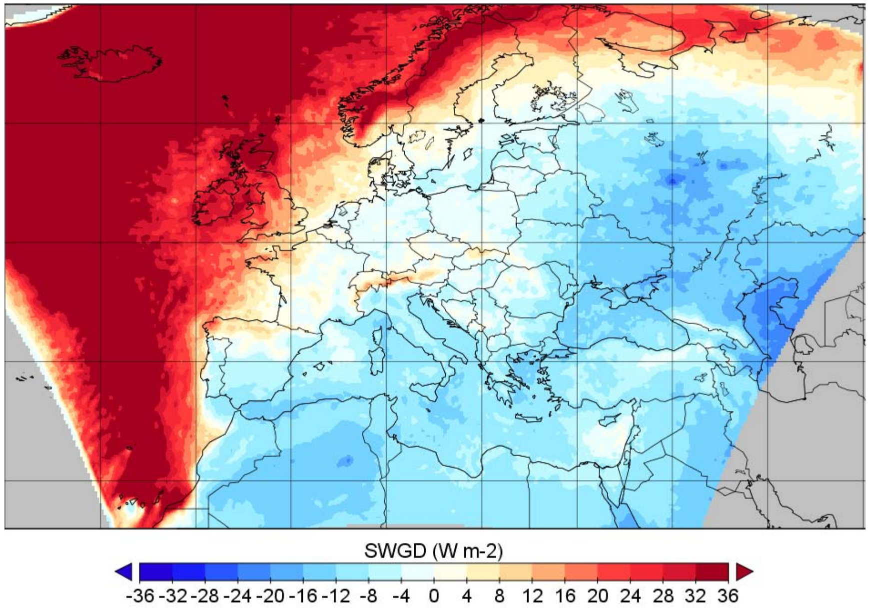
Current 3-d mesoscale models always include simplifications and assumptions.
Effect of aerosol mixing state, hygroscopicity, core representation, …

Curci et al., 2015: Atmos. Environment 115

AQMEII international model intercomparison initiative, phase 2: Atmospheric Environment 115, page 340 - 755

Examples: Aerosol cloud interactions

Summer 2010 difference in solar radiation:
With aerosol-cloud interact. - baseline



North Atlantic and Northern Europe: Cloudy, low aerosol → less droplets than climatology → higher solar radiation

AQMEII intercomparison: WRF-Chem simulation
Forkel et al., 2015, Atmos. Environment 115

- Changed droplet numbers affect radiation
- Closer to observations for clean and cloudy areas
- Different models will show different response

Examples: Aerosol cloud interactions

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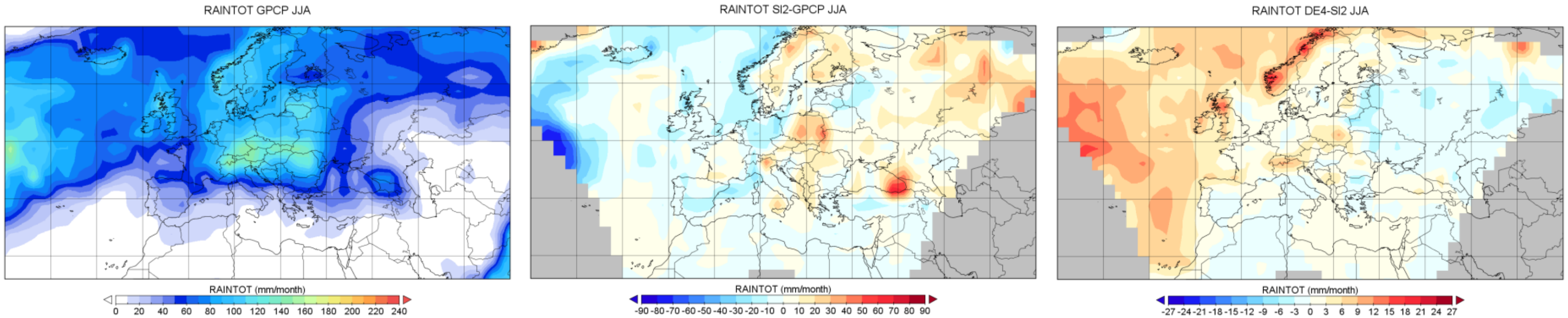
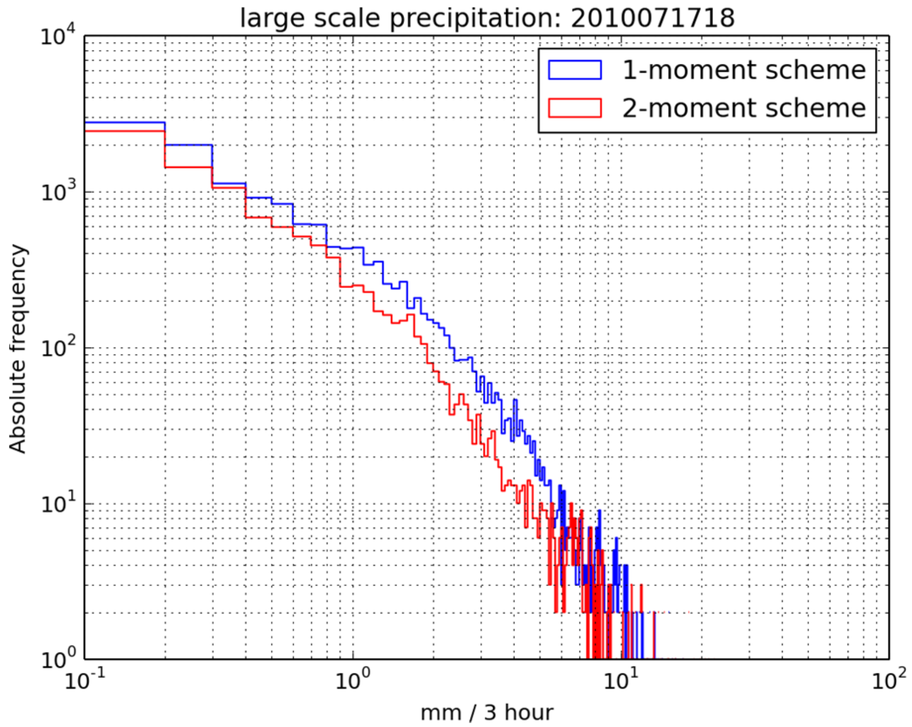
Precipitation: WRF-Chem case studies within AQMEII 2



- Bias of precipitation improved for summer with aerosol cloud interactions included
- No improvement for other seasons (ice phase?)
- Closer to obs. for extreme aerosol concentrations
- Besides aerosol composition, response depends also on model, season, baseline assumptions

Forkel et al., 2015, Atmos. Environment 115

Examples: Aerosol cloud interactions



Effect on rain intensity: Decrease except for the highest intensities

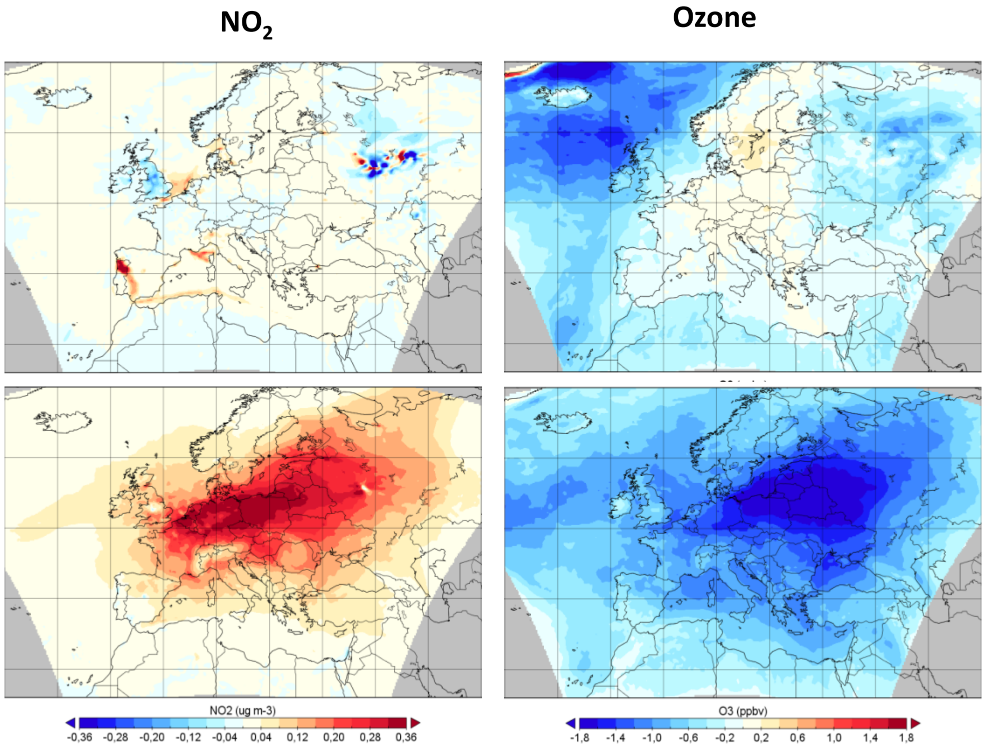
Enviro-HIRLAM (Korsholm et al. 2008)

Frequency distribution [mm/ 3 hour] of stratiform precipitation: Comparison of simulated precipitation without (1-moment) and with (2-moment) aerosol–cloud interactions.

Examples: Aerosol cloud interactions

Effect of modified COD on regional air quality

- Summer: Dominant effect of changed solar radiation
- Winter: Dominant effect of changed cloud opt. depth on infrared radiation affects nocturnal PBL



Case study with WRF-Chem

Forkel et al., 2015, Atmos. Environment 115

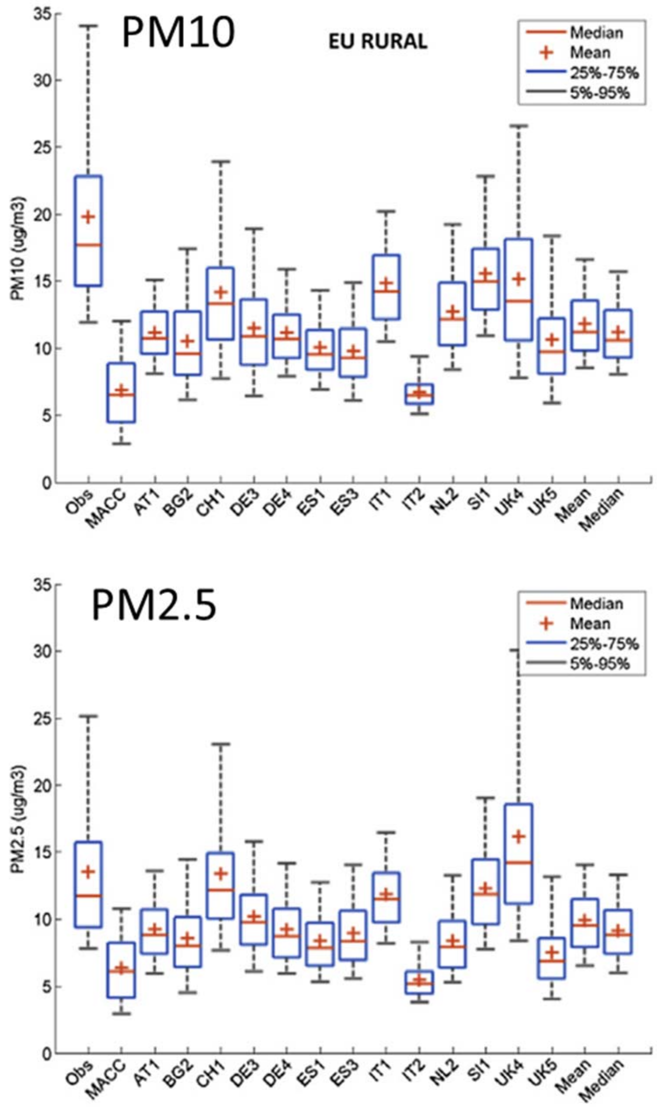
Examples: Model evaluation

AQMEII 2, Europe

Evaluation of mesoscale models with and without aerosol-meteorology interactions.
On the average dominant effect of model chemistry, aerosol representation etc.

Improvement when aerosol-meteorology interactions are included only for extreme situations.

Im et al., 2015, Atmos. Environment 115



Open issues

Better representation of

- ice phase in aerosol-cloud interactions
- aerosol-cloud interactions in convective subgrid scale clouds (so far only in Enviro-HIRLAM and rudimentary in WRF-Chem, nowhere else)
- aerosol mixing state (internal or external) for optical properties and aerosol cloud interactions
- SOA production
- Data assimilation

Inter-model differences in simulated chemical and meteo variables often larger than aerosol direct and indirect effects.

Concluding remarks

- Online modelling approach is a prospective way for future single-atmosphere modelling systems with advantages for applications at all time scales of NWP, AQ and climate models.
- There is no ‘best’ setup, particularly for precipitation feedback results sometimes in improvement, sometimes not
- Differences depend on current aerosol concentration and composition, meteorological conditions and on the parameters of the ‘base case’
- Not necessarily one integrated online modelling approach/system is best for all communities.

Acknowledgments:

- All groups who contributed to AQMEII phase 2
- All members of the COST action ES1004 EuMetChem
- All contributors to EuMetChem case studies

Thank you for your attention

(Sorry that chemistry was only hidden between the lines)

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