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

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Alexander Baklanov,
WMO Atmospheric Environment Research Division
E-mail: abaklanov@wmo.int

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

WMO OMM
World Meteorological Organization
Organisation météorologique mondiale

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

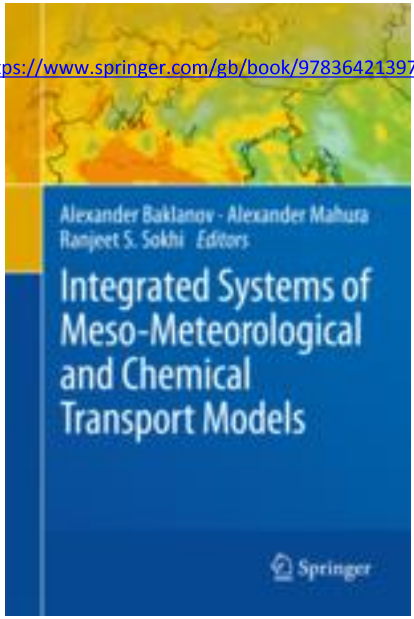
1st International Workshop on CCMM, Copenhagen, 2007

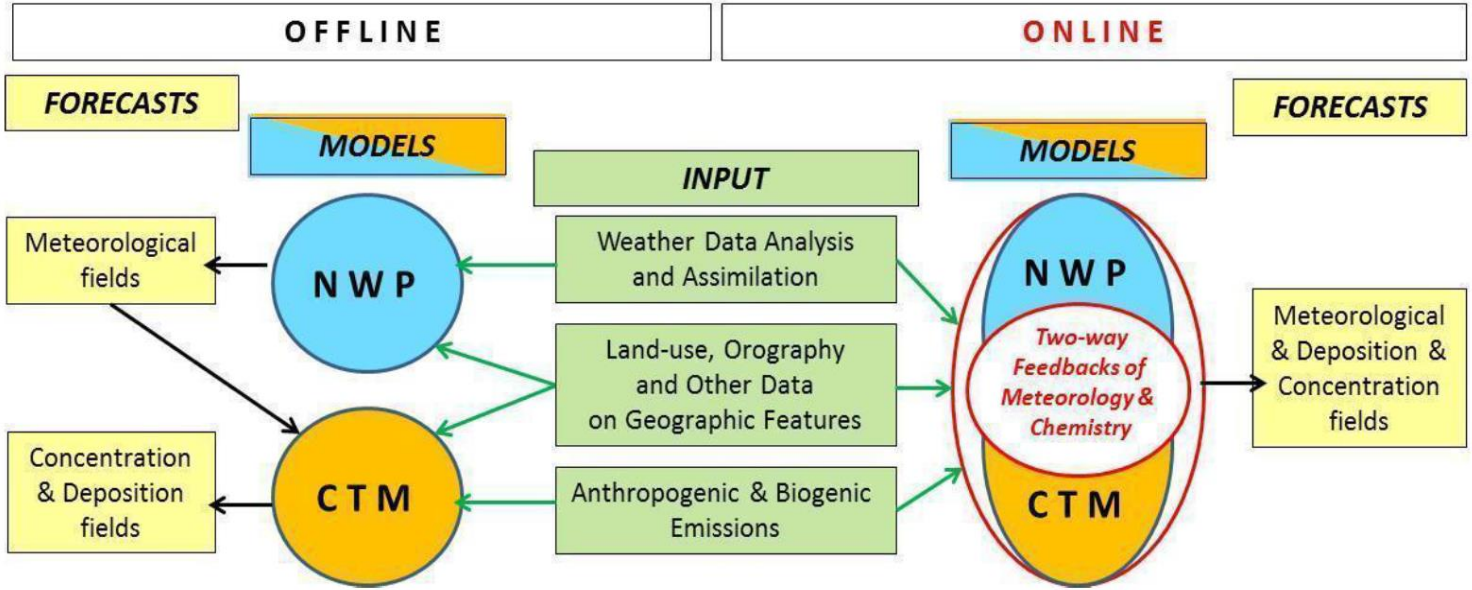
Motivation: A new concept for Coupled Chemistry-Meteorology Modelling

- 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 !

https://www.springer.com/gb/book/9783642139796





European Cooperation in the field of Scientific and Technical Research

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, PT, RS, SE, SI, TR

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: Deniz Karaca, Deniz.Karaca@cost.eu





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 Elbern),

WG4 Evaluation, validation, and applications (coordinated by Dominic Brunner and

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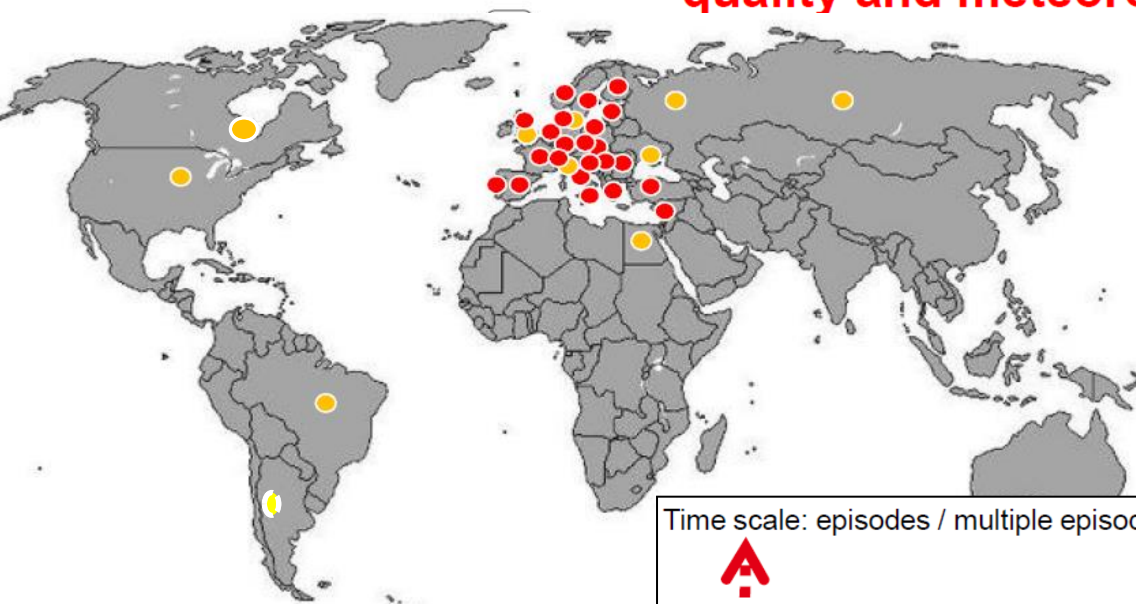
Action COST ES1004

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



Base map: © 2004-2009 sc

- **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. Seigneur, H. Elbern, G. Carmichael).
- **Evaluation, validation, and applications**
  - 33 experts (D. Brunner, K.H. Schlünzen, S. Galmarini, S.T. Rao).

(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 =>

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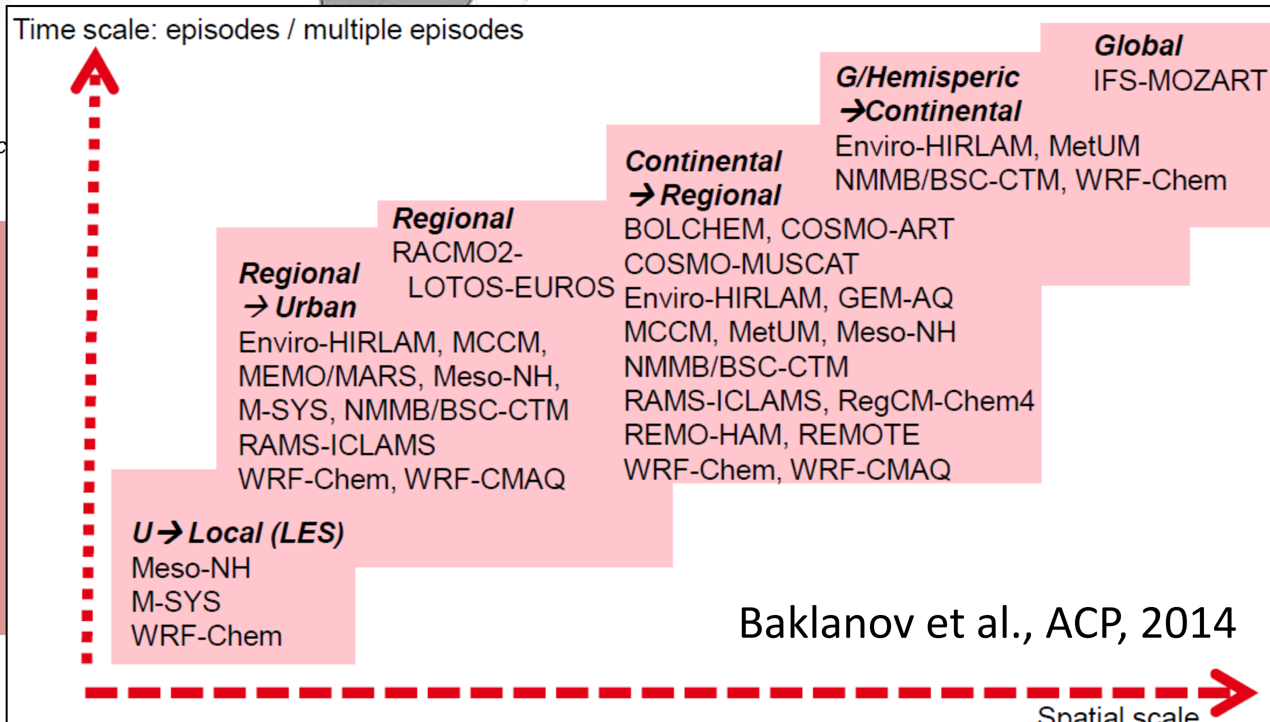

Baklanov et al., ACP, 2014

Overview of European progress in AQF and CCMM

Atmos. Chem. Phys., 12, 1–87, 2012
www.atmos-chem-phys.net/12/1/2012/
doi:10.5194/acp-12-1-2012

Atmospheric Chemistry and Physics

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

J. Kukkonen[1], T. Olsson[1,2], D. M. Schultz[1,2,3], A. Baklanov[4], T. Klein[5], A. I. Miranda[6], A. Monteiro[6], M. Hirtl[7], V. Tarvainen[1], M. Boy[2], V.-H. Peuch[8,9], A. Poupkou[10], I. Kioutsioukis[10], S. Finardi[11], M. Sofiev[1], R. Sokhi[12], K. E. J. Lehtinen[13,14], K. Karatzas[15], R. San José[16], M. Astitha[16], G. Kallos[18], M. Schaap[19], E. Reimer[20], H. Jakobs[21], and K. Eben[22]

Atmos. Chem. Phys., 14, 317–398, 2014
www.atmos-chem-phys.net/14/317/2014/
doi:10.5194/acp-14-317-2014

Atmospheric Chemistry and Physics
Open Access

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

A. Baklanov[1], K. .Schlünzen[2], P. Suppan[3], J. Baldasano[4], D. Brunner[5], S. Aksoyoglu[6], G. Carmichael[7], J. Douros[8], J. Flemming[9], R. Forkel[3], S. Galmarini[10], M. Gauss[11], G. Grell[12], M. Hirtl[13], S. Joffre[14], O. Jorba[4], E. Kaas[15], M. Kaasik[16], G. Kallos[17], X. Kong[18], U. Korsholm[1], A. Kurganskiy[19], J. Kushta[17], U. Lohmann[20], A. Mahura[1], A. Manders-Groot[21], A. Maurizi[22], N. Moussiopoulos[8], S. T. Rao[23], N. Savage[24], C. Seigneur[25], R. S. Sokhi[18], E. Solazzo[10], S. Solomos[17], B. Sørensen[15], G. Tsegas[8], E. Vignati[10], B. Vogel[26], and Y. Zhang[27]

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

usually decreasing complexity of chemistry

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

Chemical parameter	Effect on . . .	Model variables
aerosols (direct effect)	radiation (SW scattering/absorption, LW absorption)	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_4^{2-}, NO_3^-, NH_4^+, Na, Cl, H_2O dust, metals, base cations
aerosols (direct effect)	visibility, haze	aerosol absorption & scattering coefficients, RH, aerosol water content
aerosols (indirect effect)	cloud droplet or crystal number and hence cloud optical depth	interstitial/activated fraction, CCN number, IN number, cloud droplet size/number, cloud liquid and ice water content
aerosols (indirect effect)	cloud lifetime	cloud cover
aerosols (indirect effect)	precipitation (initiation, intensity)	precipitation (grid scale and convective)
aerosols (semi-direct effect)	ABL meteorology	AOD, ABL height, surface fluxes (sensible and latent heat, radiation)
O_3	UV radiation	O_3, SW radiation < 320 nm
O_3	thermal IR radiation, temperature	O_3, LW radiation
NO_2, CO, VOCs	precursors of O_3, hence indirect contributions to O_3 radiative effects	NO_2, CO, total OH reactivity of VOCs
SO_2, HNO_3, NH_3, VOCS	precursors of secondary inorganic and organic aerosols, hence indirect contributors to aerosol direct and indirect effects	SO_2, HNO_3, NH_3, VOC components (e.g. terpenes, aromatics, isoprene)
soot deposition on ice	surface albedo change	snow albedo

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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:

- 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?
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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 → reaction rates
2	Radiation → reaction rates
3	Temperature → biogenic emissions
4	Radiation → photosynthesis → biogenic emissior
5	Temperature → volatility of species
6	Temperature → aerosol dynamics
7	Liquid water → wet scavenging, concentrations
8	Temperature & humidity → gas/particle partition
9	Precipitation (frequency/intensity) → concentrati
10	Soil moisture → dust emissions
11	Soil moisture → dry deposition (biosphere and so
12	Wind speed → dust & sea salt emissions
13	Temperature vertical gradients → vertical diffusi
14	Lighting → NO_x emissions
15	Water vapour → OH radicals → ozone
16	Aerosols→SW scattering/absorption, LW absorpt
17	Radiatively active gases → radiation
18	Aerosol → haze
19	Soot deposition → ice albedo
20	Aerosol → cloud droplet/crystals → cloud O.D.
21	Aerosol → cloud morphology (e.g., reflectance)
22	Aerosol → precipitation (initiation, intensity)
23	Climate change → forest fire emissions
24	Changes in land surface → BVOC emissions

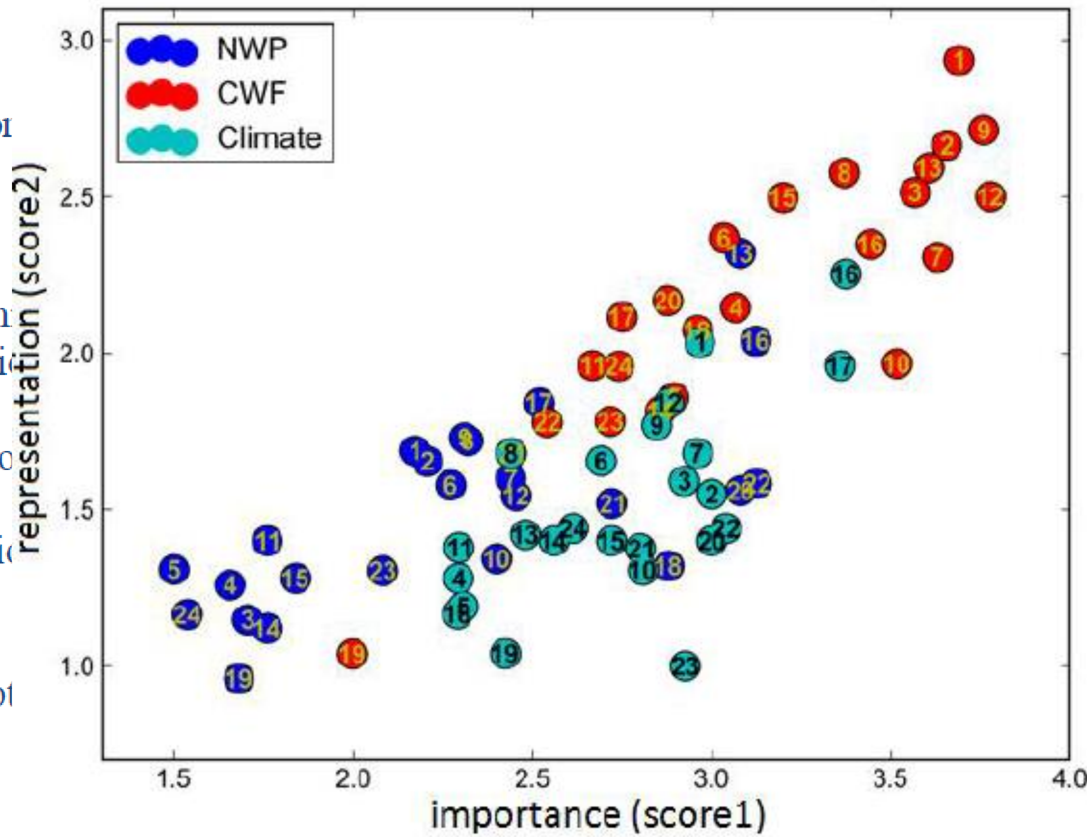


Figure 1 COST ES1004 expert survey results

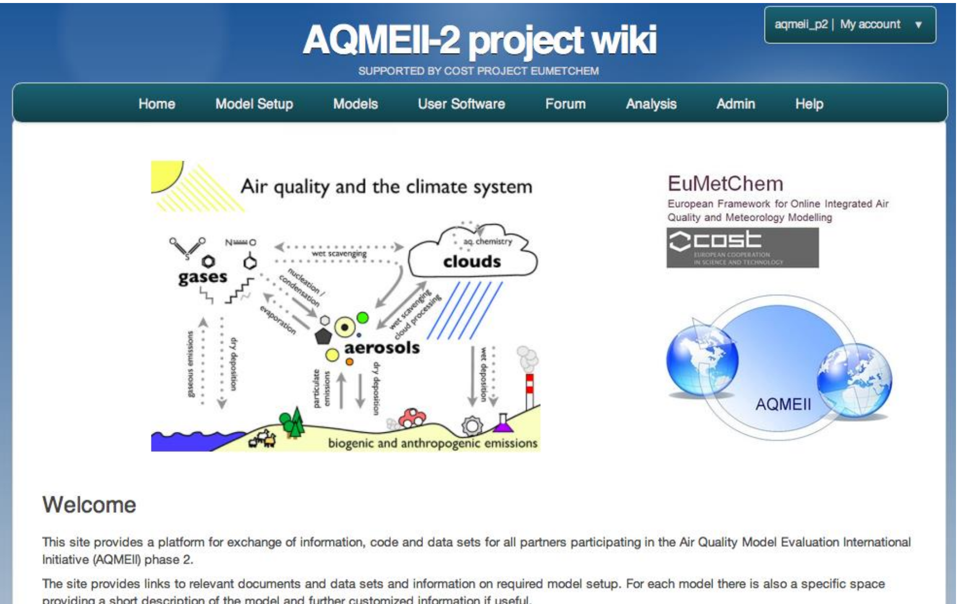
Baklanov et al., ACP, 2014
Kong et al., AQC, 2014

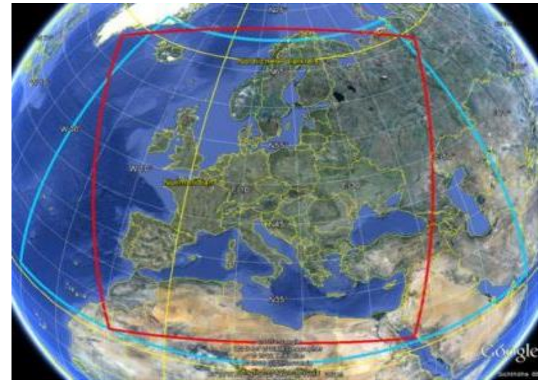
Survey Results –Top Six Ranked Important Interactions

Top six ranked Meteorology and chemistry interactions Changes in … affect (->) …	Score1	Score2
(A) Numerical Weather Prediction (NWP)		
aerosol -> precipitation (initiation and intensity of precipitation)	3.1	1.3
aerosols -> radiation (shortwave scattering/absorption and longwave absorption)	3.1	1.9
temperature vertical gradients -> vertical diffusion	3.1	2.2
aerosol -> cloud droplet or crystal number density and hence cloud optical depth	3.1	1.3
aerosol -> haze (relationship between the hygroscopic growth of aerosols and humidity)	2.9	1.0
aerosol -> cloud morphology (e.g., reflectance)	2.7	1.2
(B) Chemical Weather Forecast (CWF)		
wind speed -> dust and sea salt emissions	3.8	2.5
precipitation (frequency/intensity) -> atmospheric composition	3.8	2.7
temperature -> chemical reaction rates and photolysis	3.7	2.9
radiation -> chemical reaction rates and photolysis	3.7	2.7
liquid water -> wet scavenging and atmospheric composition	3.6	2.3
temperature vertical gradients -> vertical diffusion	3.6	2.6
(C) Climate modelling		
aerosols -> radiation (shortwave scattering/absorption and longwave absorption)	3.4	2.3
radiatively active gases (e.g., water vapour, CO_2, O_3, CH_4, NO and CFC) -> radiation	3.4	2.0
aerosol -> precipitation (initiation and intensity of precipitation)	3.0	1.4
radiation -> chemical reaction rates and photolysis	3.0	1.5
aerosol -> cloud droplet or crystal number density and hence cloud optical depth	3.0	1.4
temperature -> chemical reaction rates and photolysis	3.0	2.0

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





European domain

Year 2010

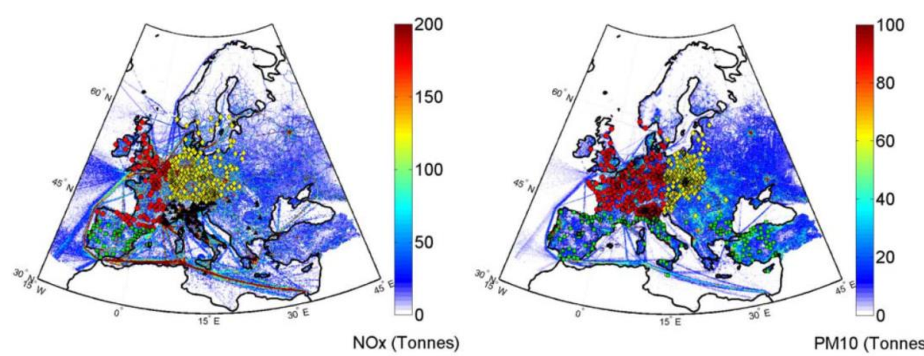
	Groups	Domain	Met Model	CTM	Resolution	Biogenic Model	Gas Phase	Reference
M1	NL2	EU	RACMO	LOTOS-EUROS	0.5?×0.25?	Guenther et al., 1991	CB-IV	Segers A., 2013
M2	BG1	EU	WRF	CMAQ	25 km	BEIS	CB-IV	Byun and Schere, 2006
M3	SI1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M4	IT2	EU	WRF	CHEM	23 km	MEGAN	RACM	Grell et al., 2005
M5	DE4	EU	WRF	CHEM	[illegible] km	MEGAN	RADM2	Grell et al., 2005
M6	IT1	[illegible]	WRF	[illegible]	[illegible] km	MEGAN	CBMZ	[illegible] et al., 2005
M7	CH1	EU	COSMO	COSMO-ART	0.22°		RADM2K	Vogel et al., 2009
M8	UK5	EU	WRF	CMAQ	[illegible]	MEGAN	[illegible]	[illegible] et al., 2012
M9	UK4	EU	MetUM	UCKA RAQ	0.22 °		UCKA RAQ	Savage et al., 2013
M10	ES1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M11	ES2a	EU	NMM	BSC-CTM	0.20 °	MEGAN	CB-V	Jorba et al., 2012
M12	DE3	EU	COSMO	MUSCAT	0.25°	Gunther et al., 1993	RACM-MIM2	Renner and Wolke, 2010
M13	AT1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M14	ES3	EU	WRF	CHEM	23 km	MEGAN	CBMZ	Grell et al., 2005
M15	ES1	NA	WRF	CHEM	36 km	MEGAN	RADM2	Grell et al., 2005
M16	US6	NA	WRF	CMAQ	12 km	BEIS3.14	CB-V-TU	Wong et al., 2012
M17	CA2	NA	GEM	MACH	15 km	BEIS	ADOM-II	???
M18	US7	NA	WRF	CHEM	36 km	MEGAN	MOZART	Grell et al., 2005
M19	US8	NA	WRF	CHEM	36 km	MEGAN	CB05	Grell et al., 2005
M20	ES3	NA	WRF	CHEM	36 km	MEGAN	CBMZ	Grell et al., 2005

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

Selected case studies for aerosol feedbacks:

1. Russian forest fires, summer 2010
2. Sahara dust episode over Europe
3. MEGAPOLI Paris measurement campaign

Collective analysis by JRC



NO_x 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

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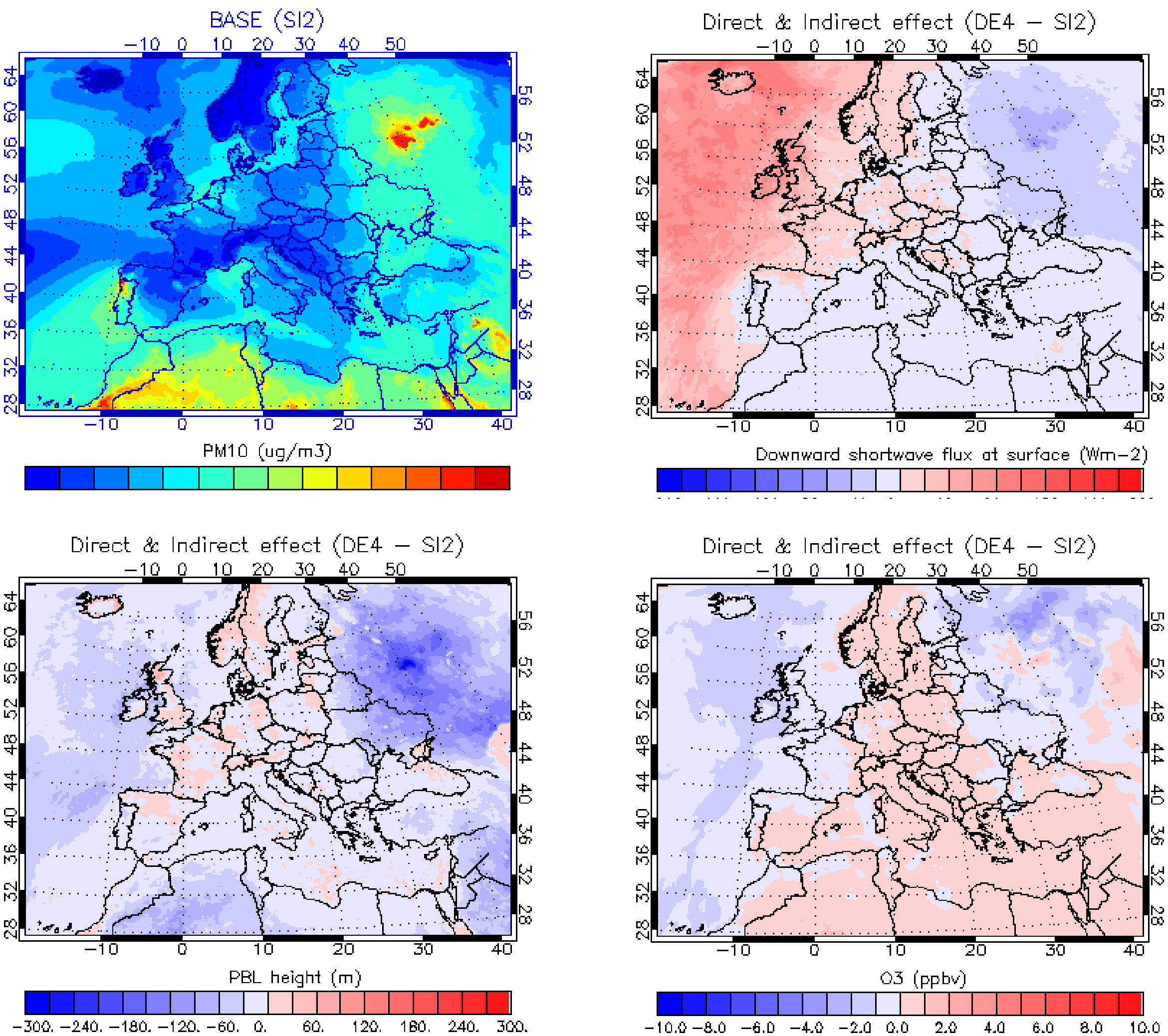
Materials Science & Technology

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.

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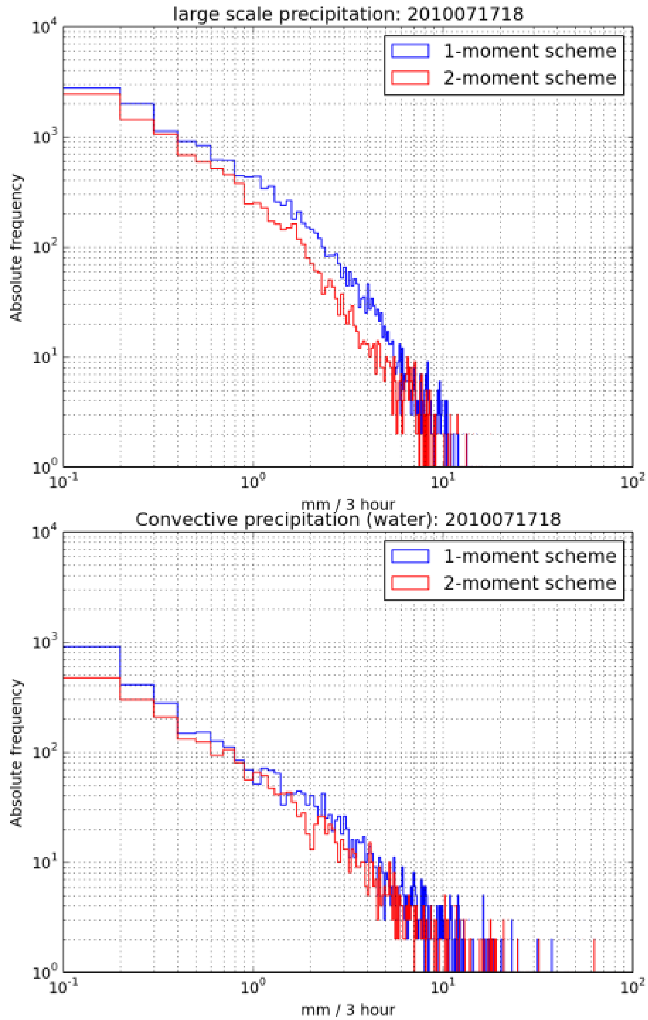
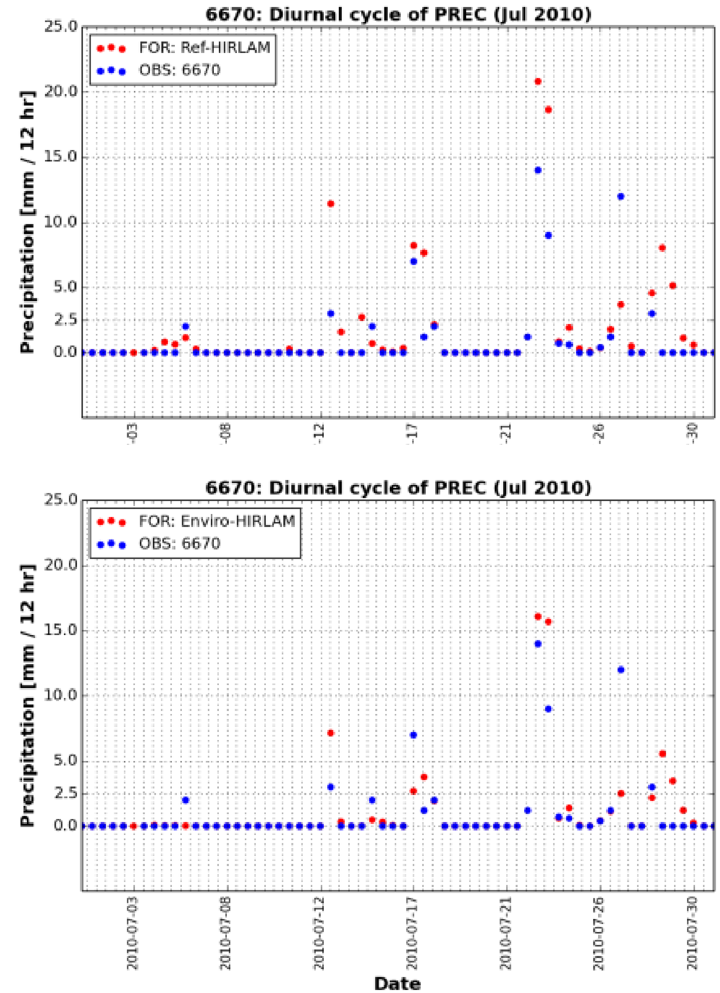
Kong et al, AE, 2015

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 SO_2 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

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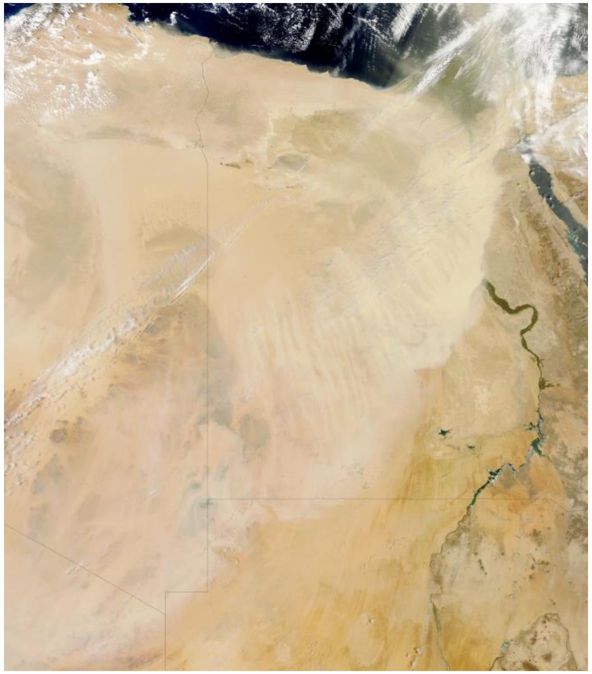
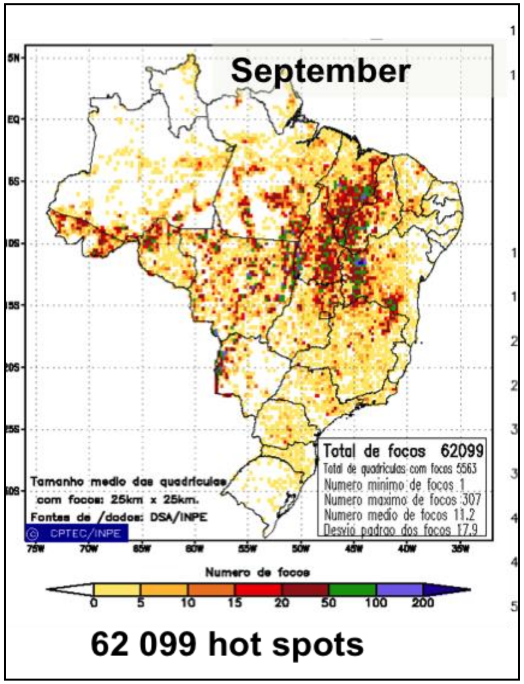
Case Studies



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

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Freitas et al., 2015

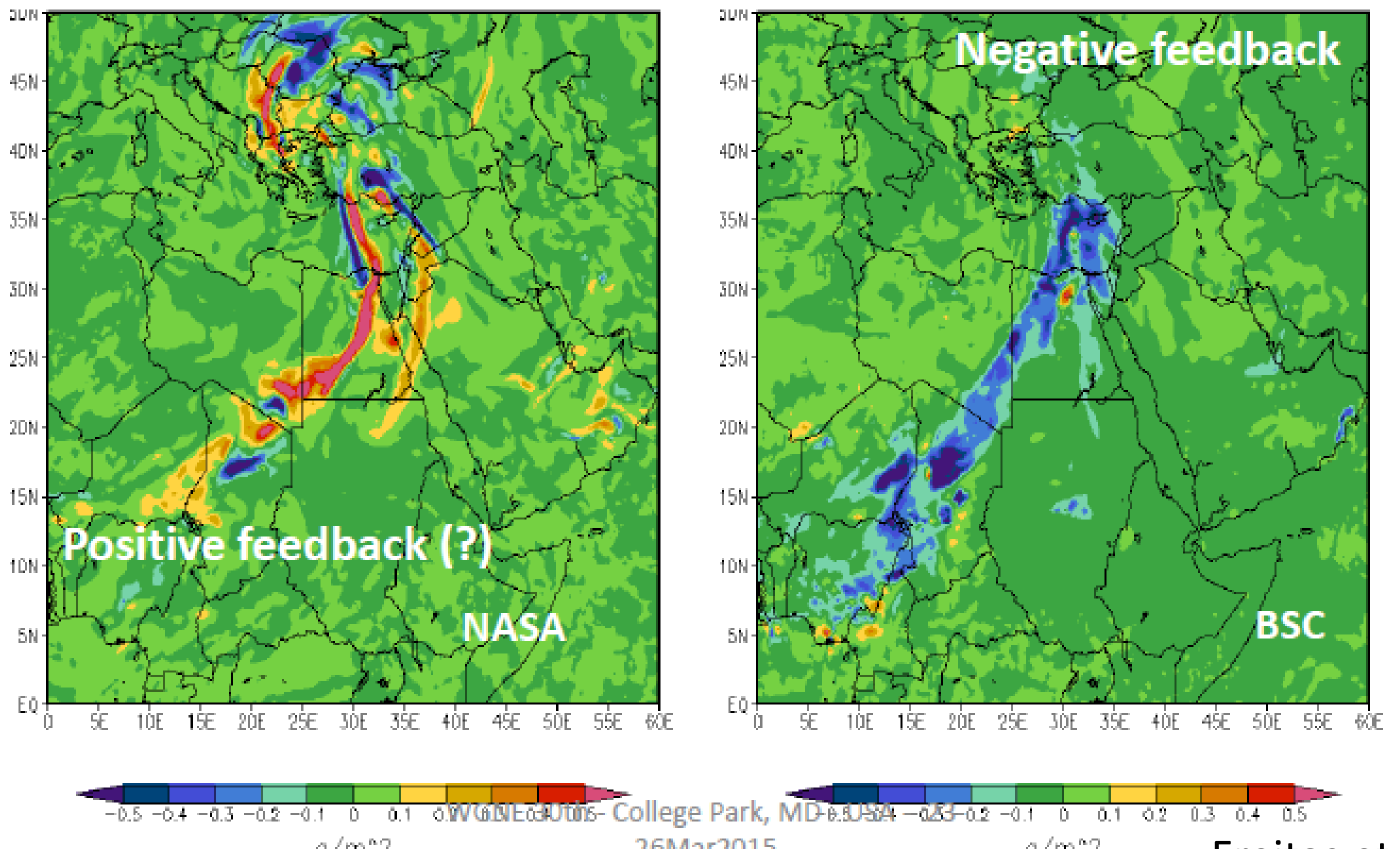
Case 1: Sahara Dust Episode

How much interactive aerosol dust changes dust concentration itself?

Mass of dust column integrated (AER-NOAER)

forecast 09UTC18APR2012

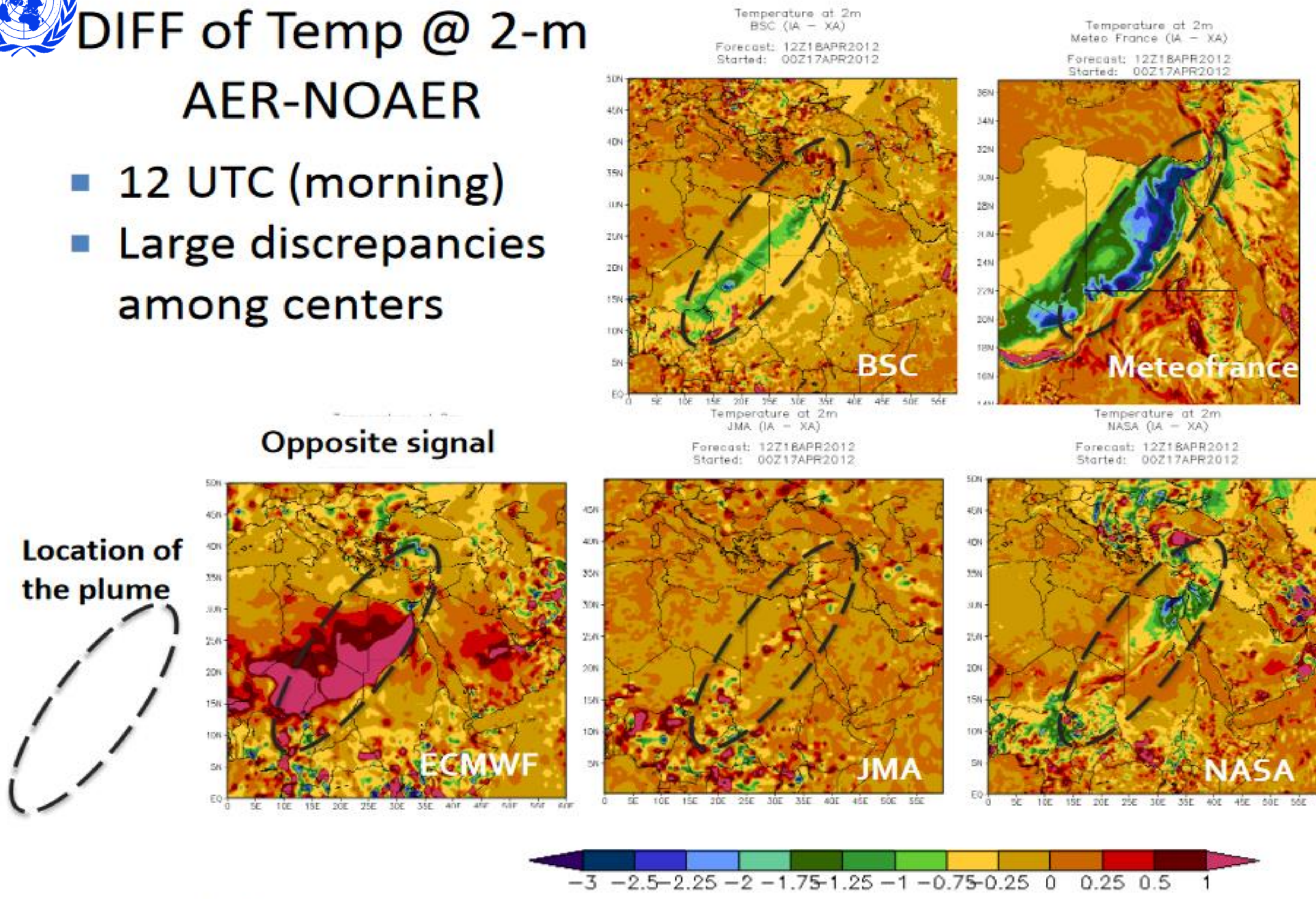
Init.:00UTC17APR2012



Freitas et al., 2015

DIFF of Temp @ 2-m AER-NOAER

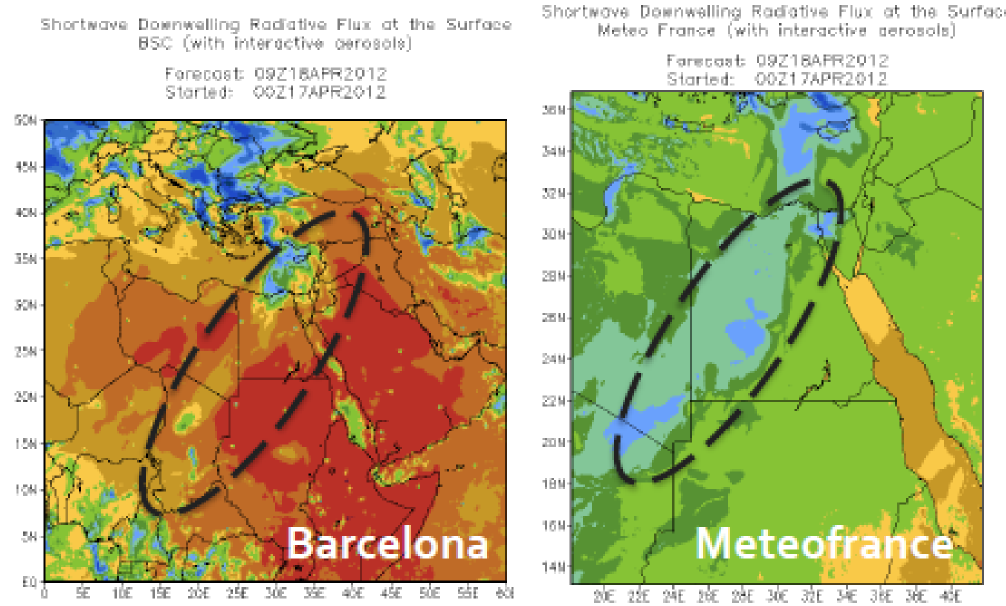
- 12 UTC (morning)
- Large discrepancies among centers



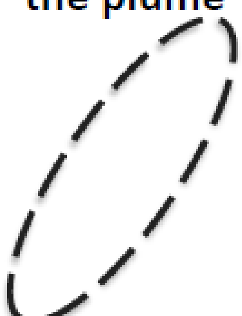
Freitas et al., 2015

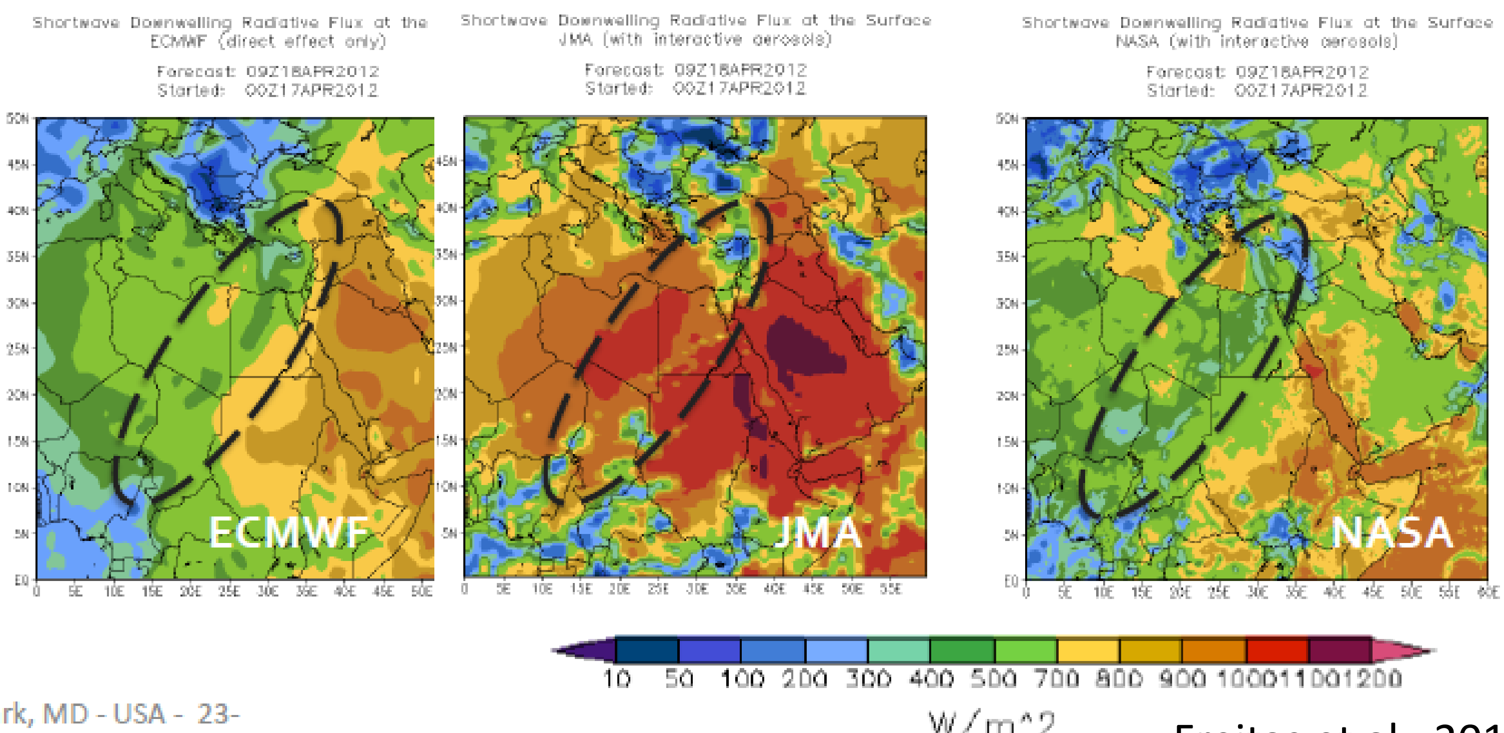
SW Rad @ Sfc Intercomparison

- 9 UTC (morning)
- Large discrepancies among centers



Location of the plume



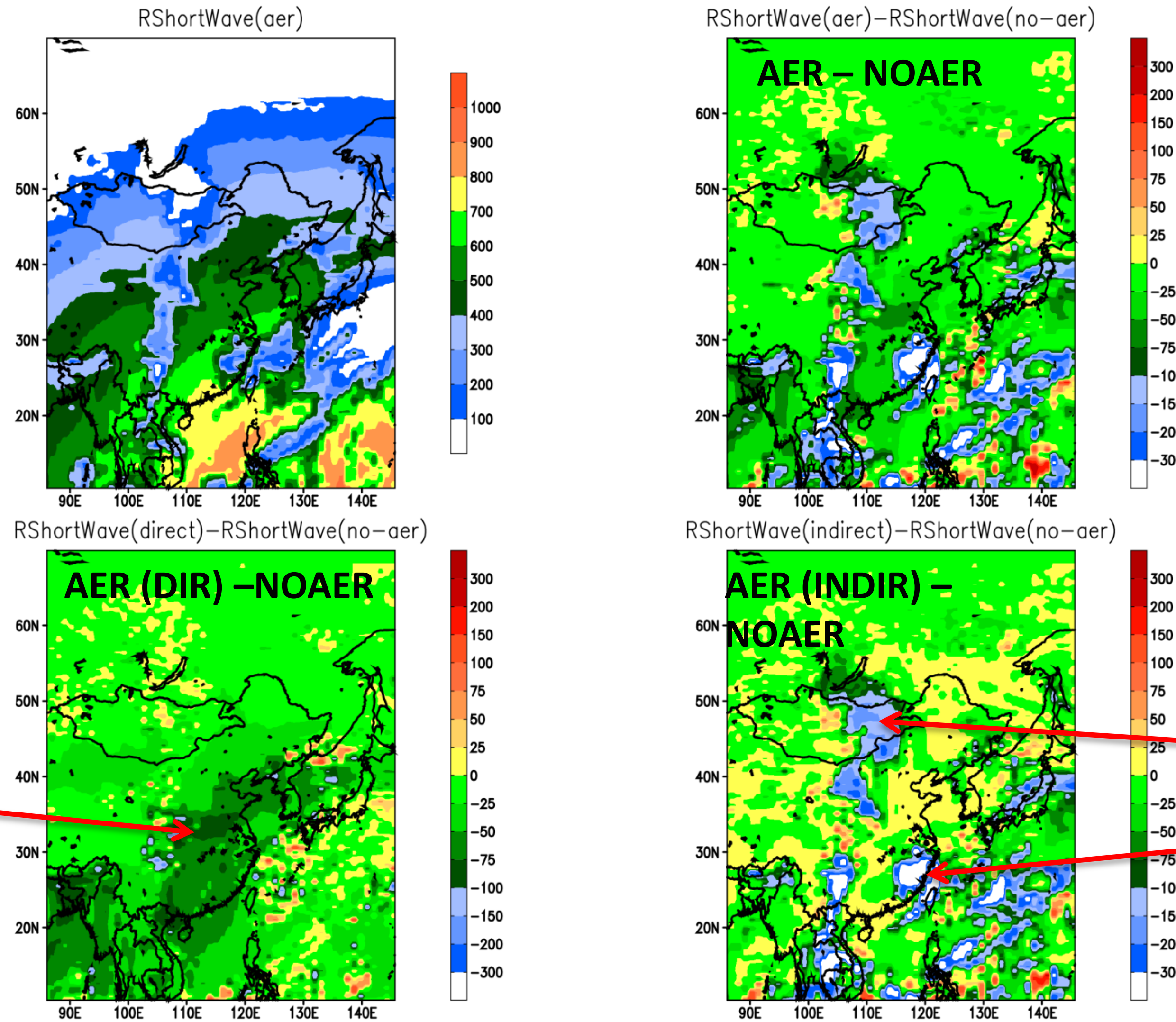


Freitas et al., 2015

Case 2: Beijing episode

JMA – Rad shortwave at sfc (W m^{-2})

Init 00UTC12JAN FCT: 03UTC14JAN



INDIR effect has more pronounced effect on sfc rsw extinction

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

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

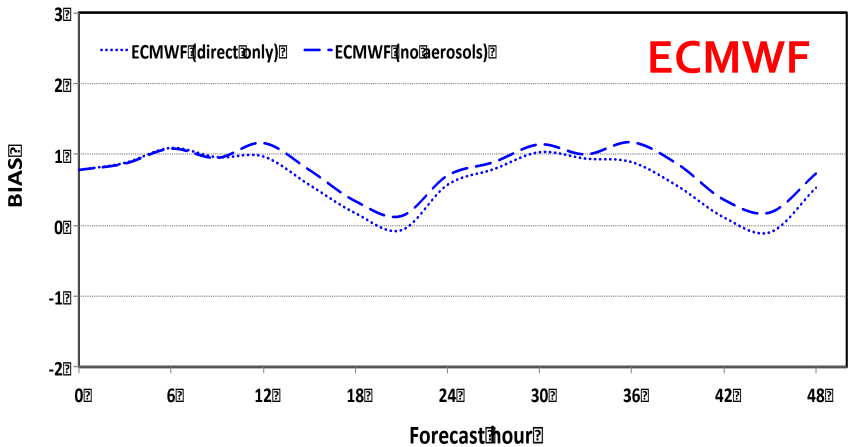
WMO OMM

Freitas et al., 2015

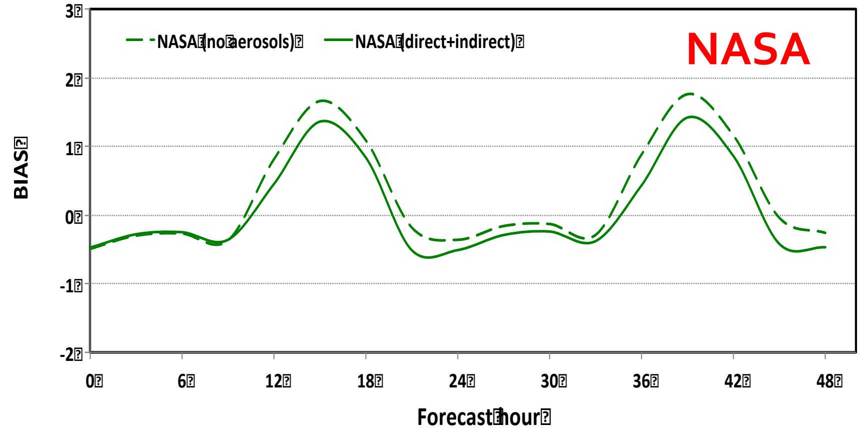
Case 3: Brasil, the SAMBBA experiment

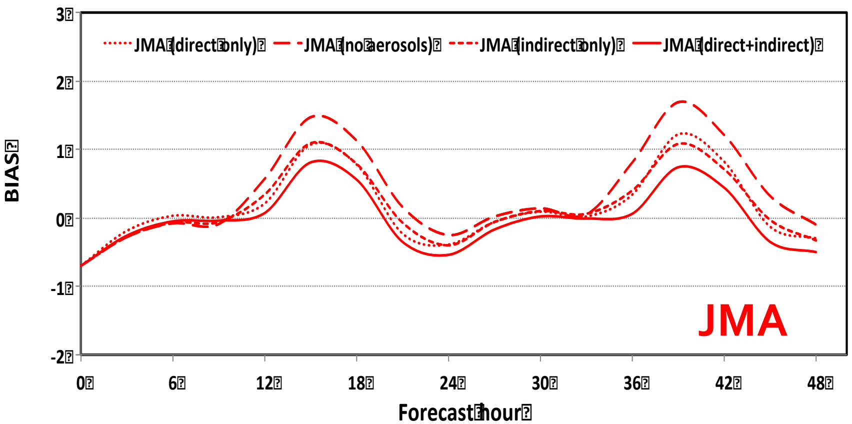
BIAS: 2-m Temperature

Consistent bias reduction

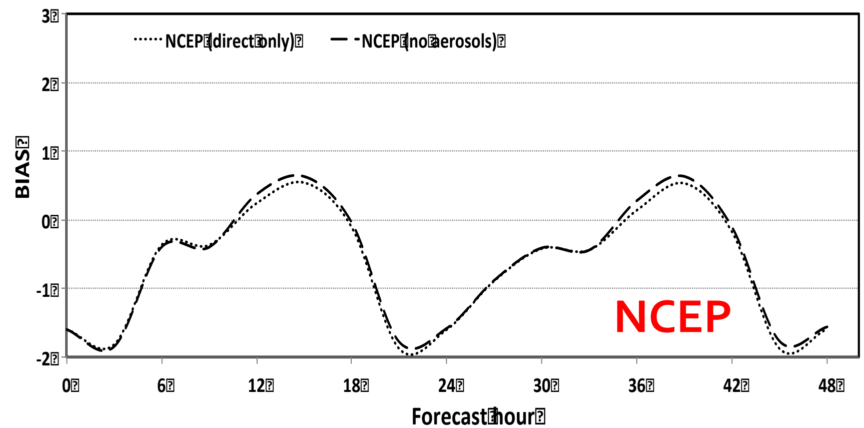


Bias decreases during the day, but increases at night



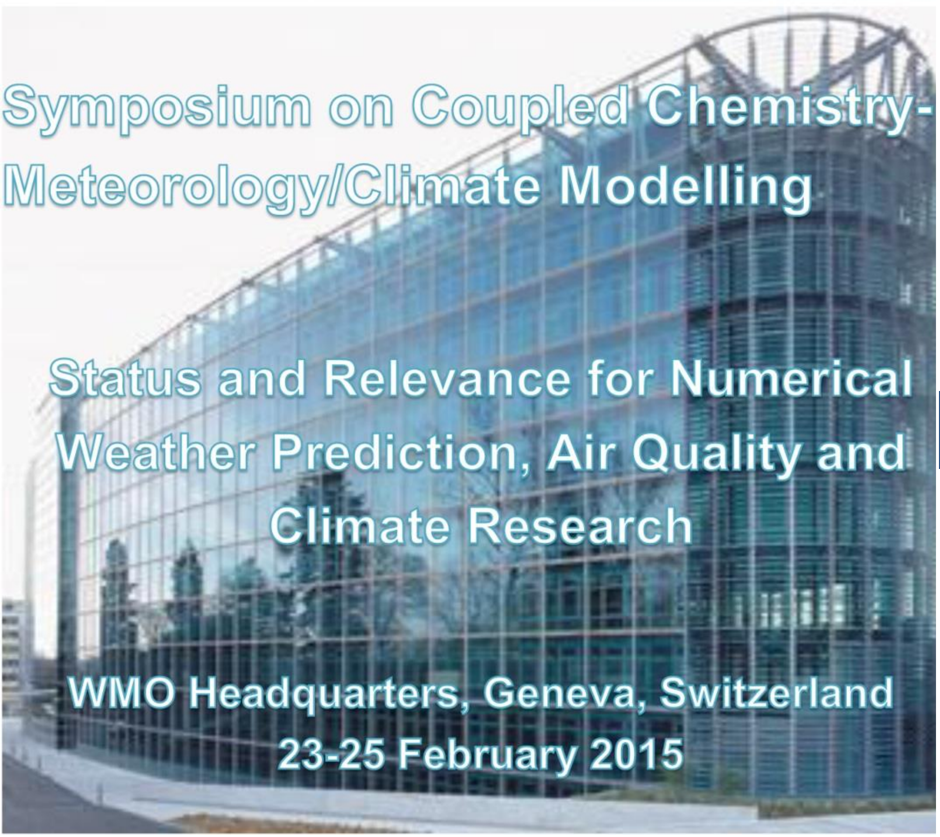


Consistent bias reduction with increasing aerosol treatment complexity during the day, with a slight increase during the night.



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 17^{th} WMO Congress

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.

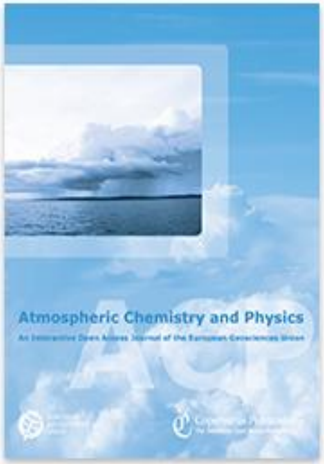
CCMM Applications Areas

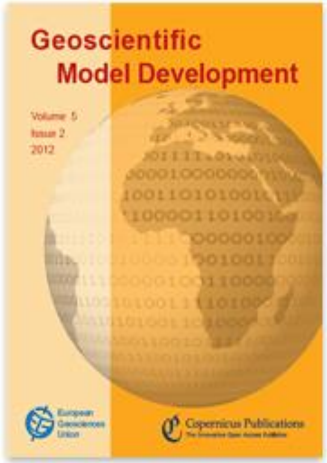
Air pollution modeling
- from urban to continental scale
- air quality forecasts (few days) or assessment of past/current/future AQ
- sensitivity studies: emission reduction scenarios
- modeling of hazardous plumes
- aerosol studies: natural (dust, sea salt), BB, SOA, SIA, EC/OC

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

Main Outcomes





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

http://www.atmos-chem-phys.net/special_issue370.html

BAMS IN BOX INSIGHTS and INNOVATIONS

Key Issues for Seamless Integrated Chemistry–Meteorology Modeling

Alexander Baklanov, Dominik Brunner, Gregory Carmichael, Johannes Flemming, Saulo Freitas, Michael Gauss, Øystein Hov, Rohit Mathur, K. Heinke Schlünzen, Christian Seigneur, and Bernhard Vogel

Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-42
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 27 February 2018

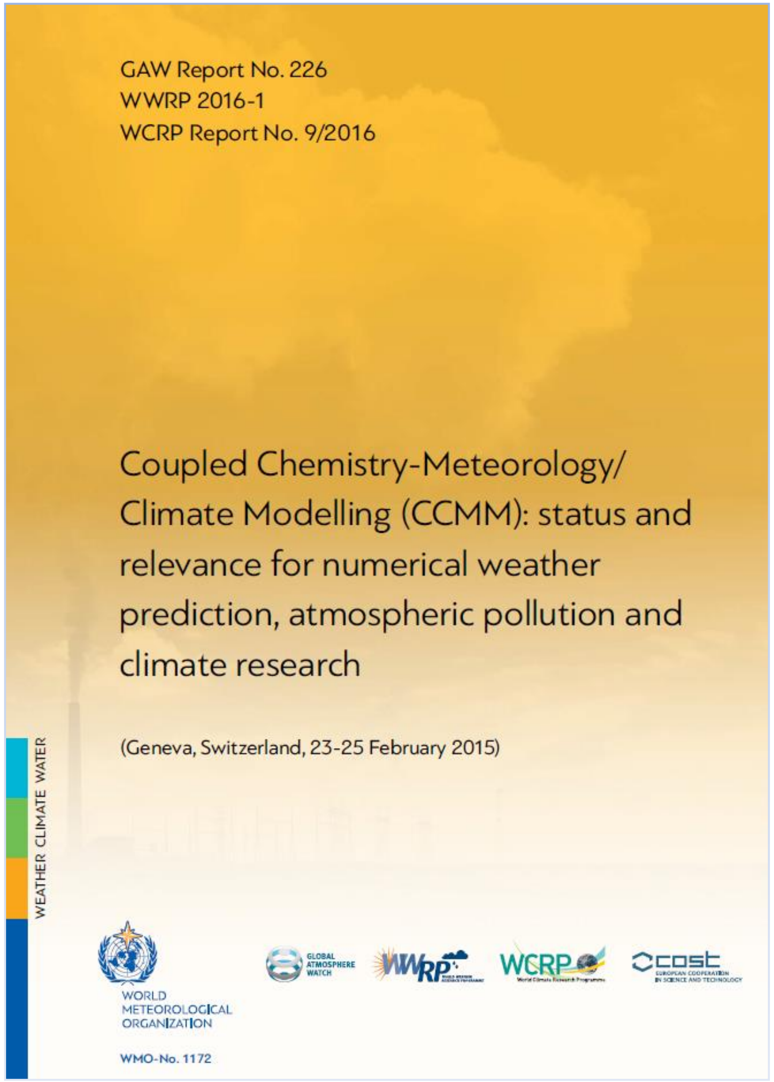
Atmospheric Chemistry and Physics Discussions Open Access EGU

Aerosol SAG overview paper:

Status and future of Numerical Atmospheric Aerosol Prediction with a focus on data requirements

Angela Benedetti[1], Jeffrey S. Reid[2], Alexander Baklanov[3], Sara Basart[4], Olivier Boucher[5], Ian M. Brooks[6], Malcolm Brooks[7], Peter R. Colarco[8], Emilio Cuevas[9], Arlindo da Silva[8], Francesca Di Giuseppe[1], Jeronimo Escribano[5], Johannes Flemming[1], Nicolas Huneeus[10,11], Oriol Jorba[4], Stelios Kazadzis[12,13], Stefan Kinne[14], Peter Knippertz[15], Paolo Laj[16], John H. Marsham[6,17], Laurent Menut[18], Lucia Mona[19], Thomas Popp[20], Patricia K. Quinn[24], Samuel Rémy[5], Thomas T. Sekiyama[21], Taichu Tanaka[21], Enric Terradellas[22], and Alfred Wiedensohler[23]

[1]European Centre for Medium-Range Weather Forecasts, Reading, UK
[2]Naval Research Laboratory, Monterey, CA, USA
[3]World Meteorological Organisation, Switzerland
[4]Barcelona Supercomputing Center, BSC, Barcelona, Spain



http://www.wmo.int/pages/prog/arep/gaw/documents/Final_GAW_226_10_May.pdf

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"* O_3.
- *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:

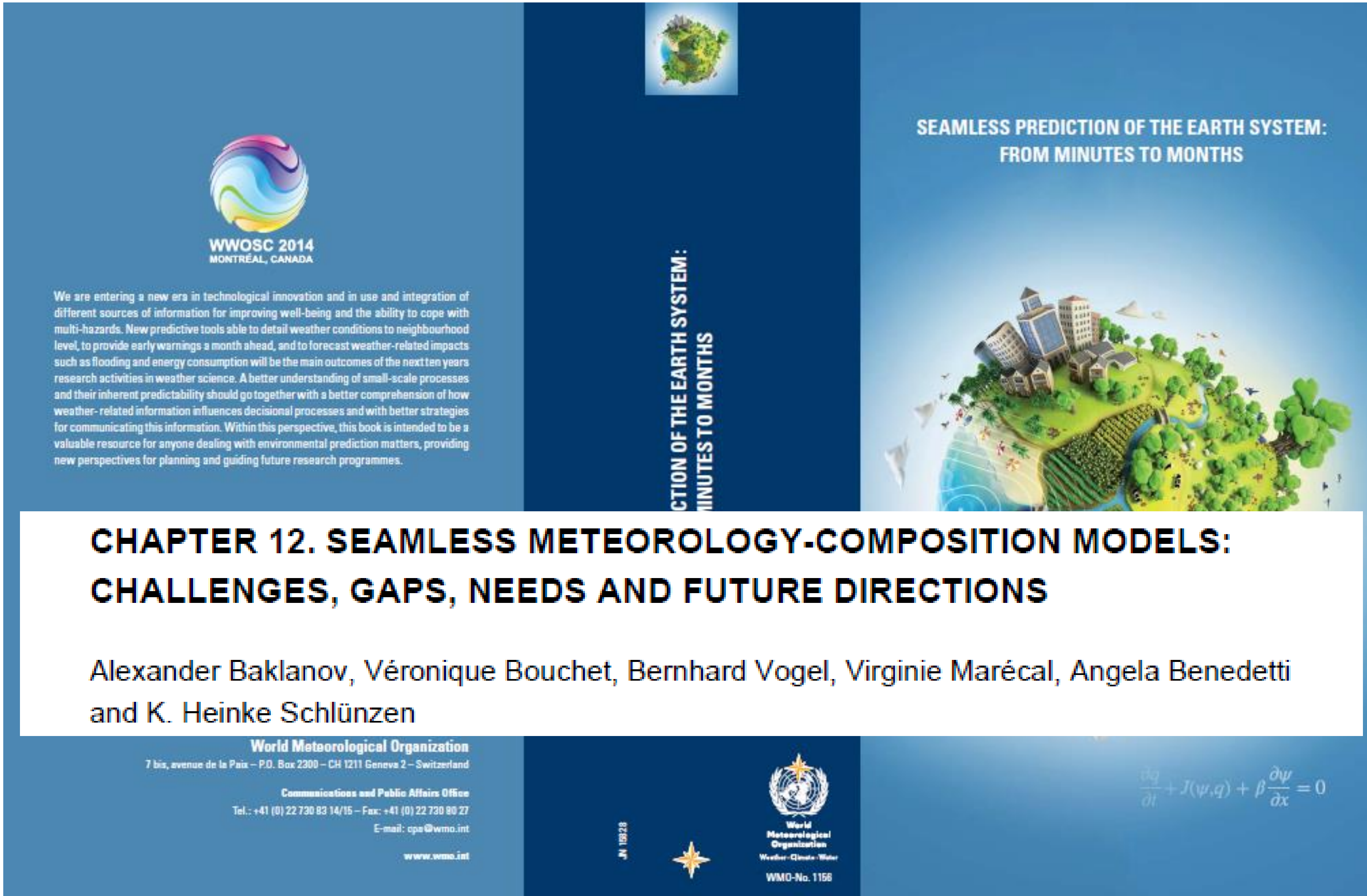
- Improve our understanding of indirect effects (e.g. BC on clouds).
- Develop CCMs with prognostic aerosol to asses what is the tradeoff between a more complex aerosol representation on the one side and model resolution, or the atmosphere-ocean coupling, on the other side?
- Test model performance in 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).

WMO OMM

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).

Seamless Prediction



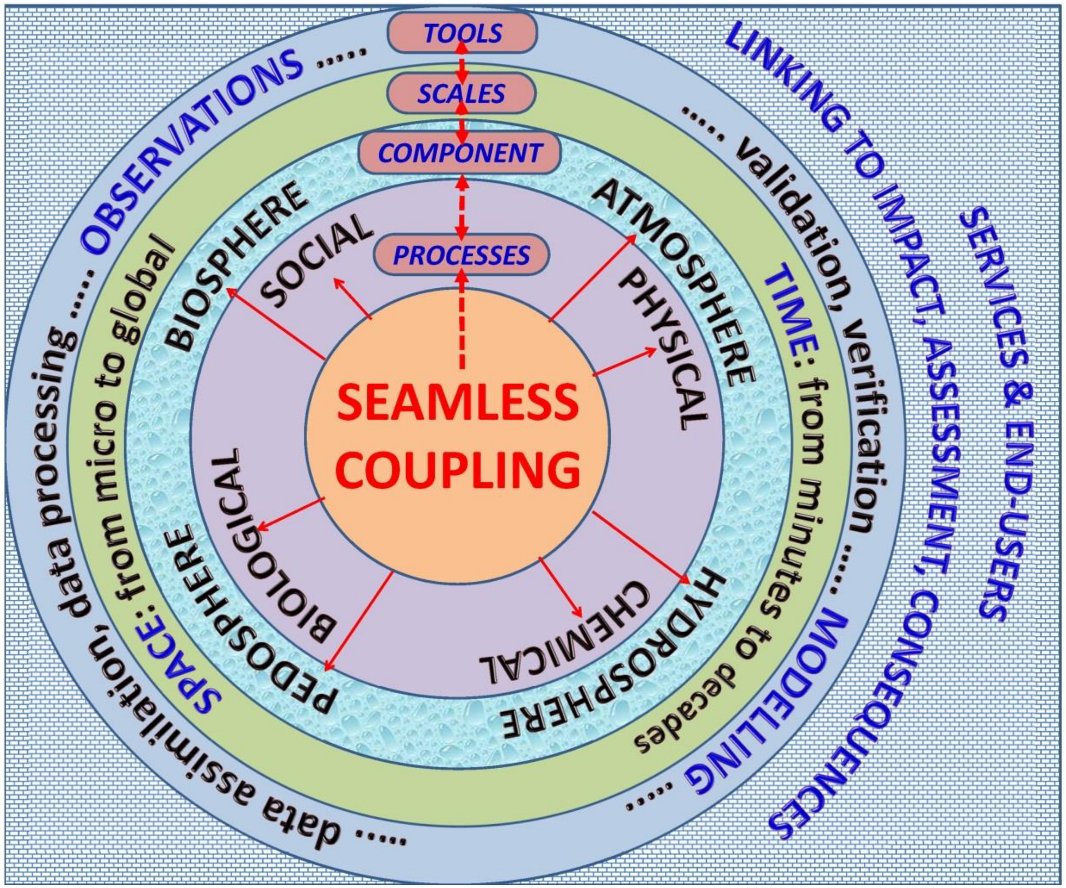
CHAPTER 12. SEAMLESS METEOROLOGY-COMPOSITION MODELS: CHALLENGES, GAPS, NEEDS AND FUTURE DIRECTIONS

Alexander Baklanov, Véronique Bouchet, Bernhard Vogel, Virginie Marécal, Angela Benedetti and K. Heinke Schlünzen

WMO WWOSC 'Seamless Earth System Modelling' Book:

http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

The seamless approach considers several dimensions of the coupling:



=> New generation of seamless models integrated with observations

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**.

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WMO Commission for Atmospheric Science (CAS)

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.

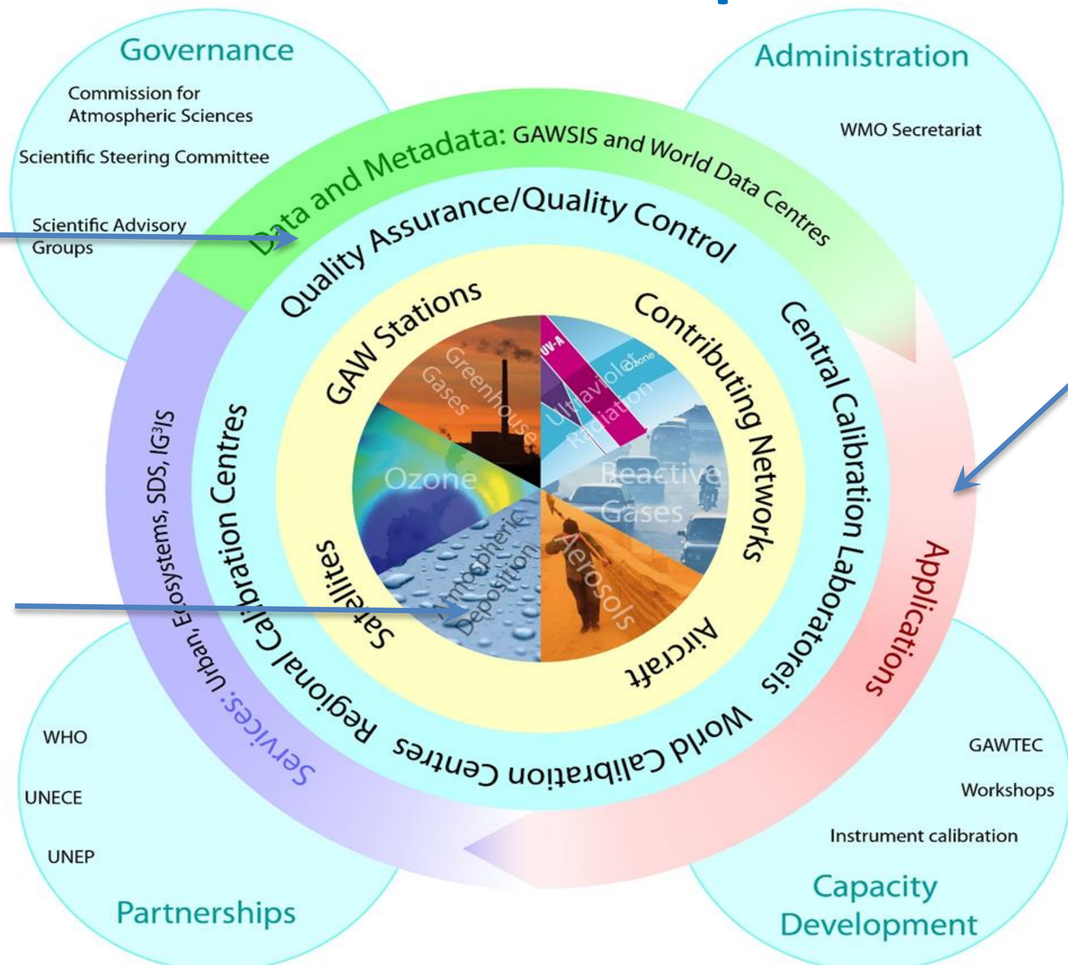
CAS stressed the need to plan for an **integrated global aerosols observation system**.

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***

WMO OMM

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

GAW
WORLD METEOROLOGICAL ORGANIZATION

(1) Assessment activities

- Health, climate change, ecosystems

(2) Improving emissions

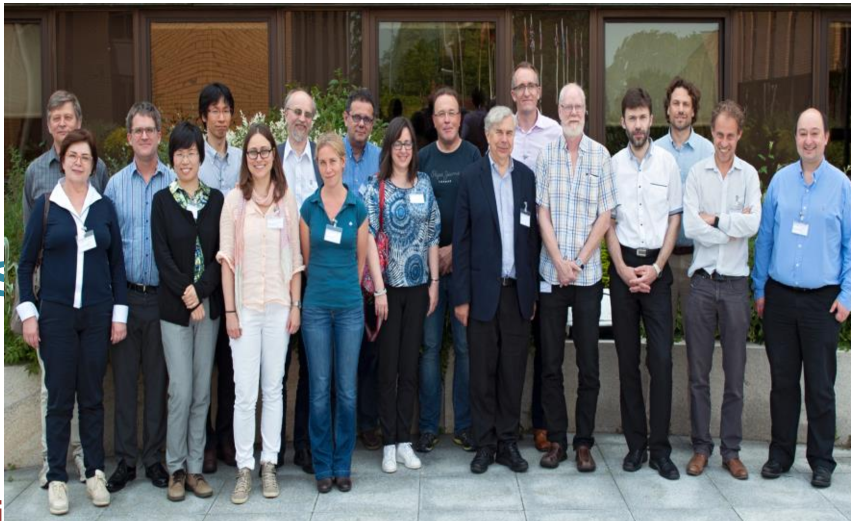
- Up-to-Date, weather- (or proxy) dependent
- Inverse modelling

(3) Developments of NRT systems

- Ensembles, help set-up applications worldwi
- MAP-AQ as a key project

(4) Data aspects

- Identify gaps (limb sounding…), common ski
System



co-chairs: F. Dentener (JRC) & V.-H. Peuch (ECMWF)

(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?

WMO OMM

Applications in GAW to supports Members

GAW

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

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GAW DATA USED FOR CAMS VERIFICATION

(GLOBAL, NRT)

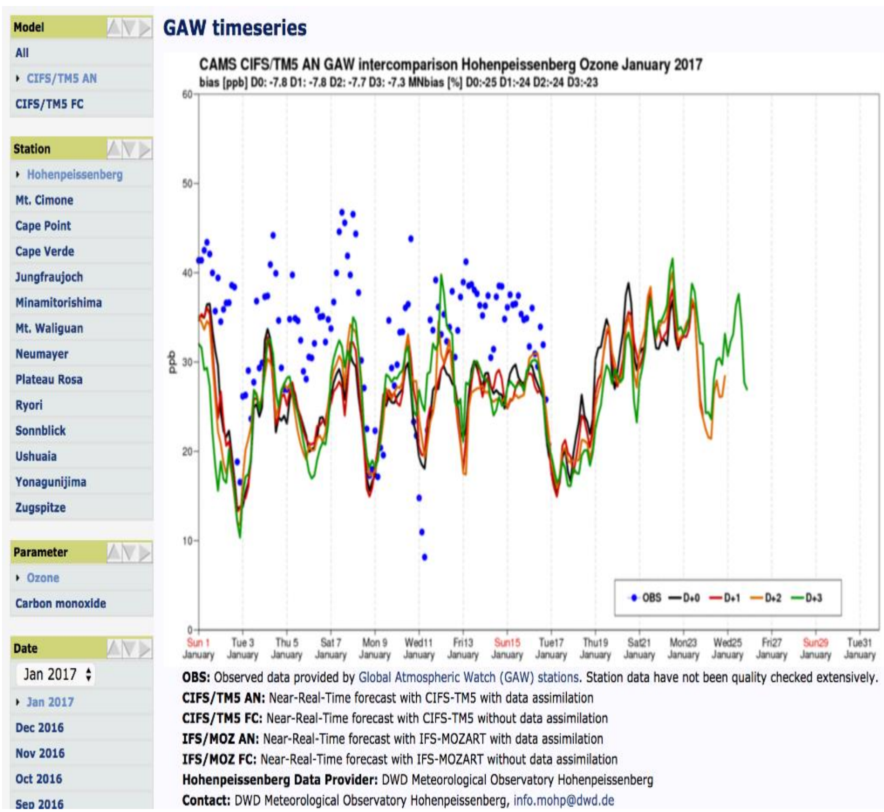
http://atmosphere.copernicus.eu/user-support/validation/verification-global-services

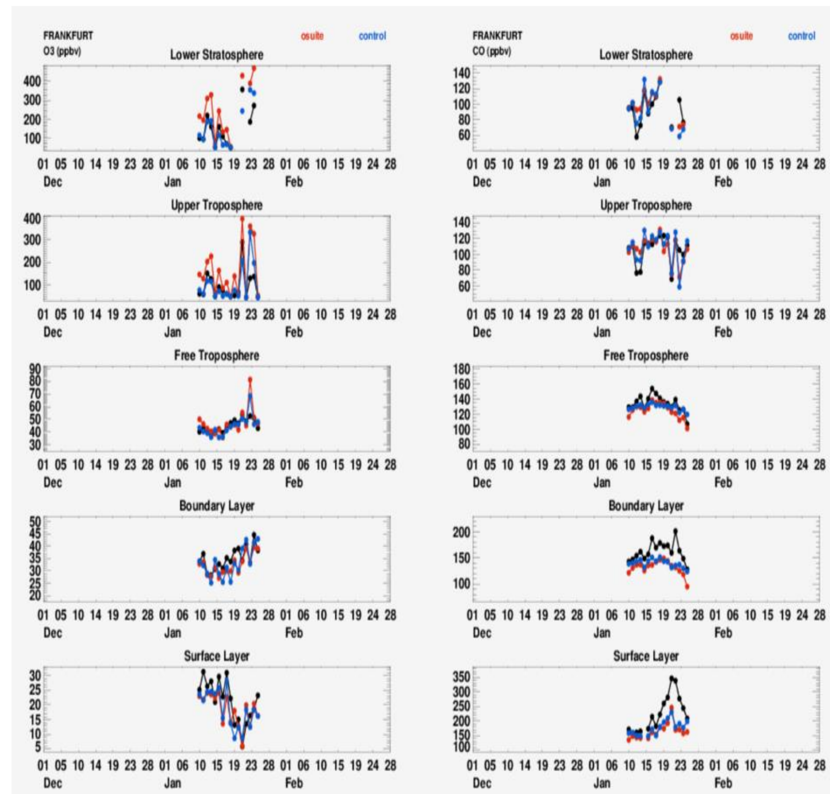
opernicus Europe's eyes on Earth

Atmosphere Monitoring Service

GLOBAL ATMOSPHERE WATCH

IAGOS





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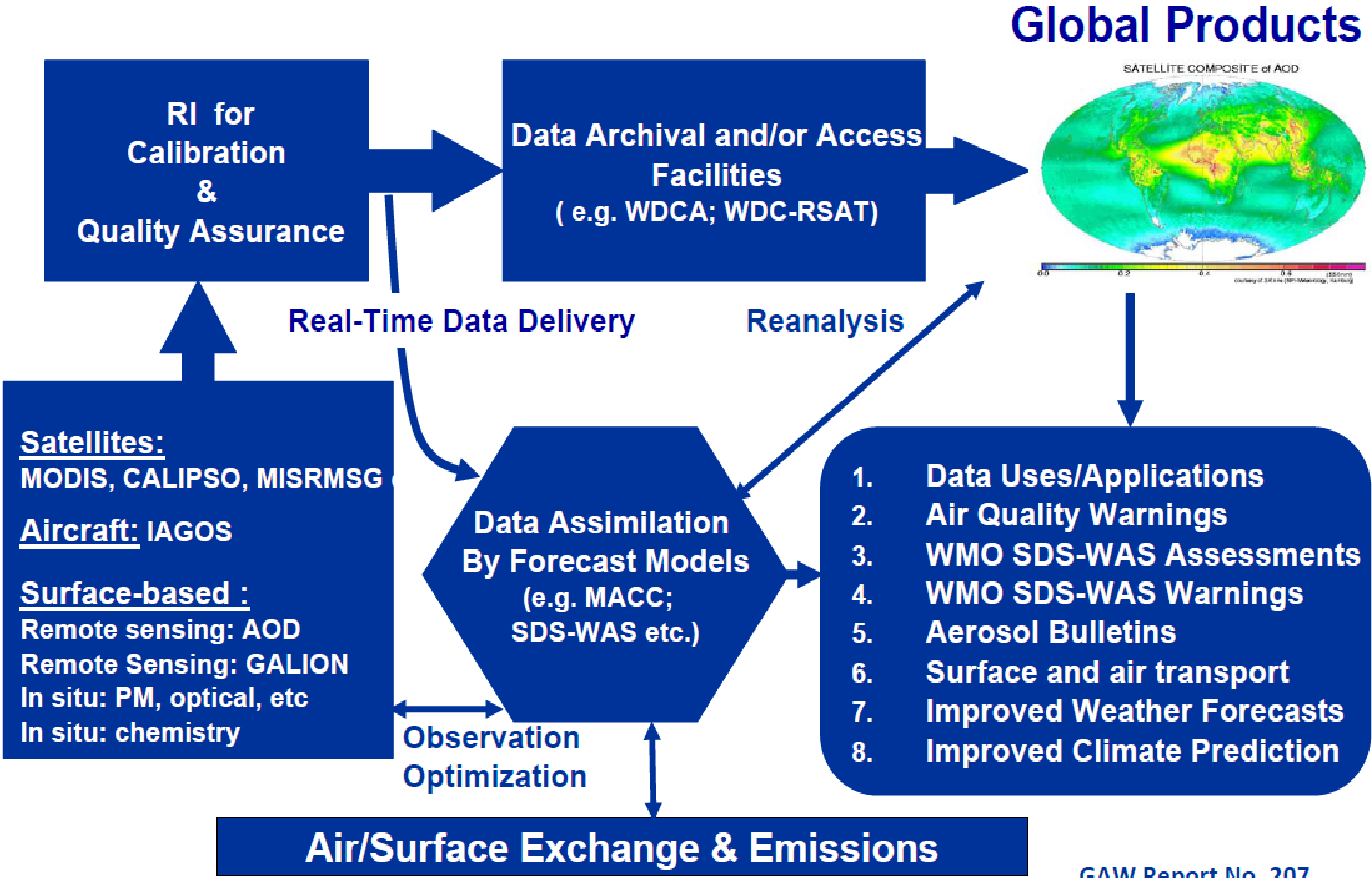
WMO Global Atmosphere Watch (GAW)

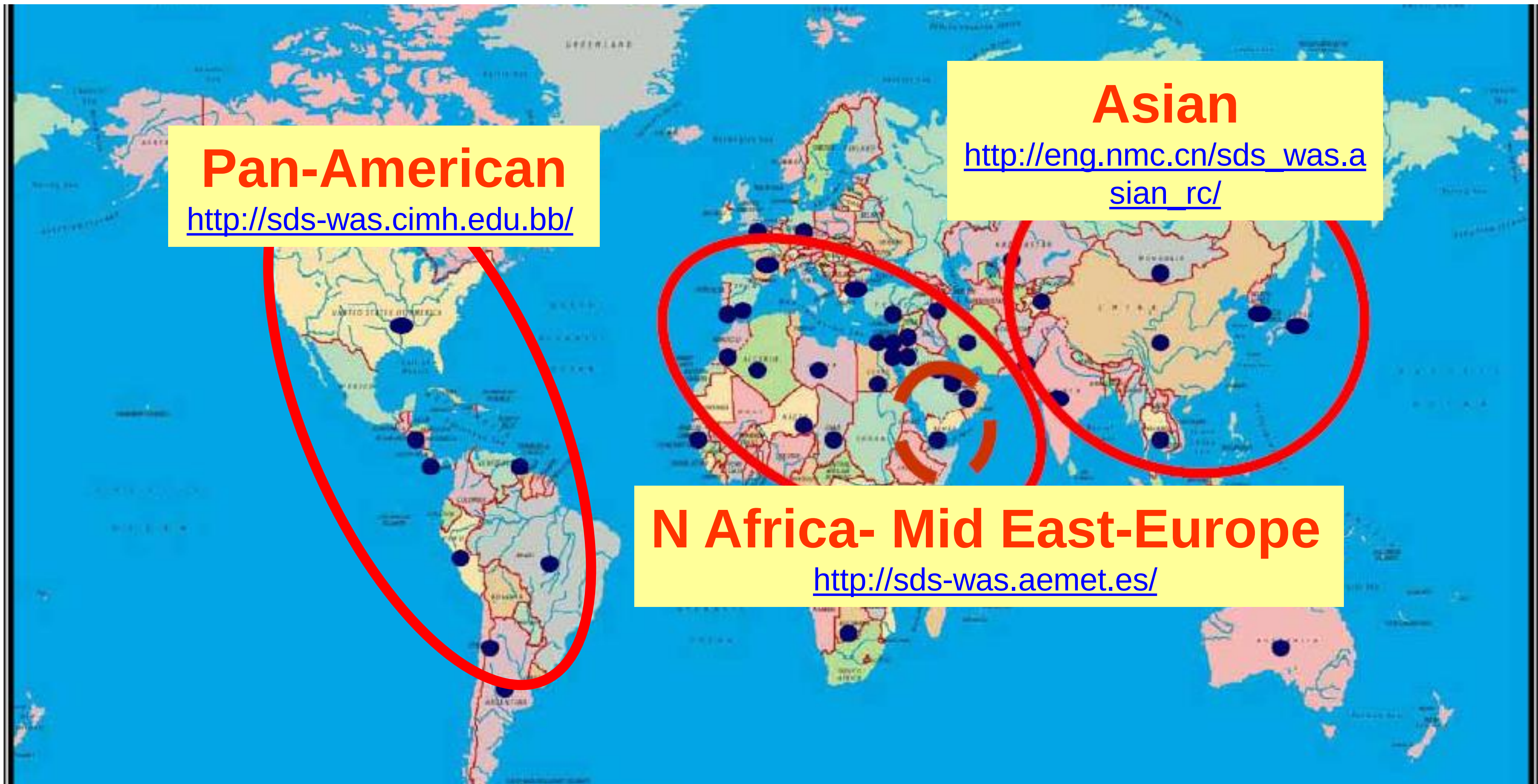
Integrated Global Aerosol Observing System



GAW Report No. 207

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 OMM

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)

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

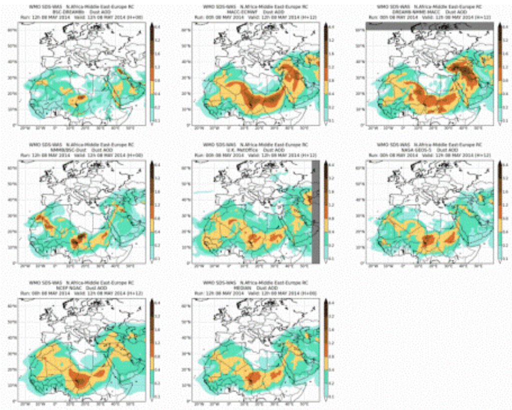
7 global models

11 regional models

15 organizations

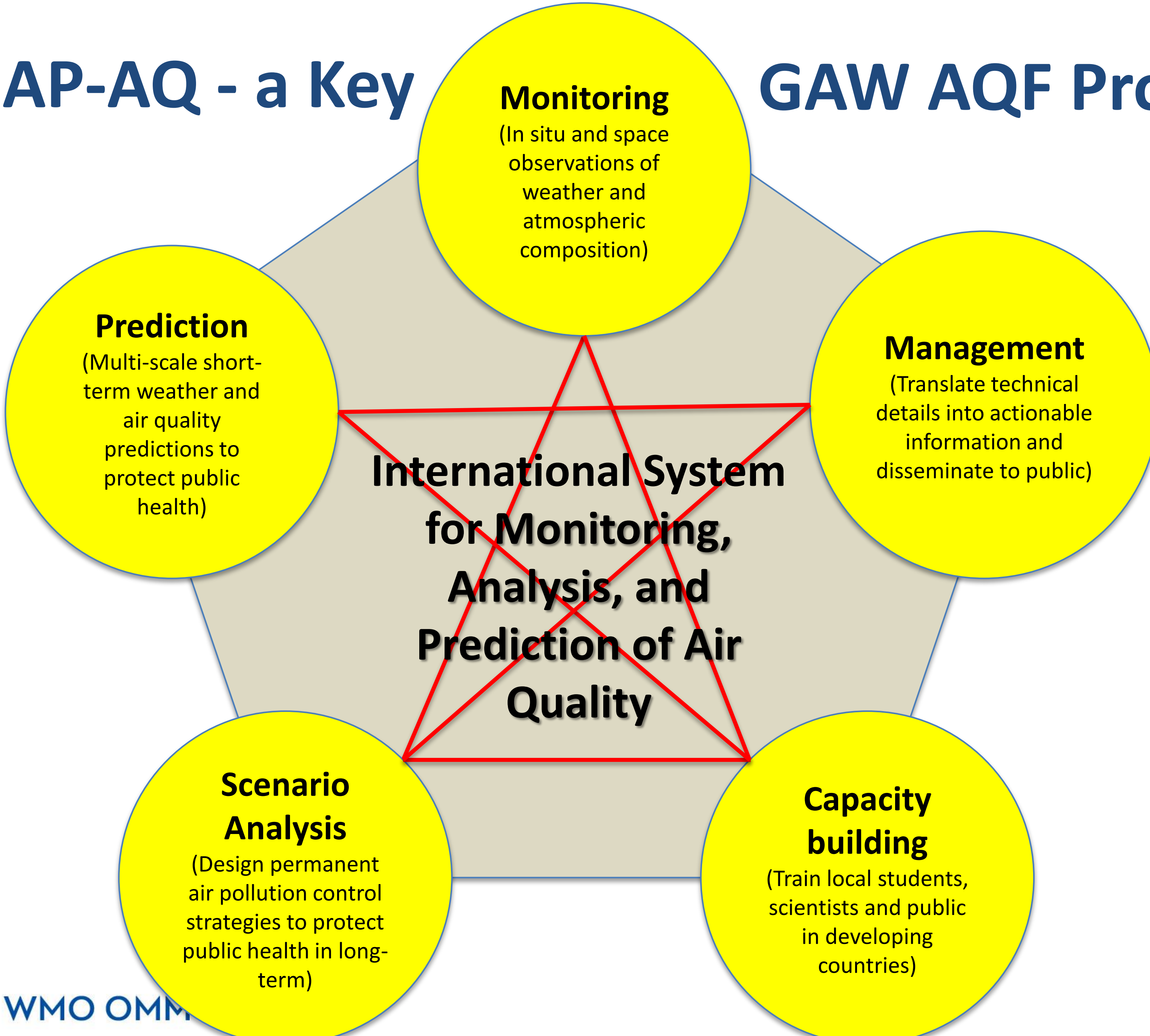
3 regional nodes (*NAMEE, Asia, Americas*)

2 regional centers



Weather • Climate • Water

MAP-AQ - a Key GAW AQF Project



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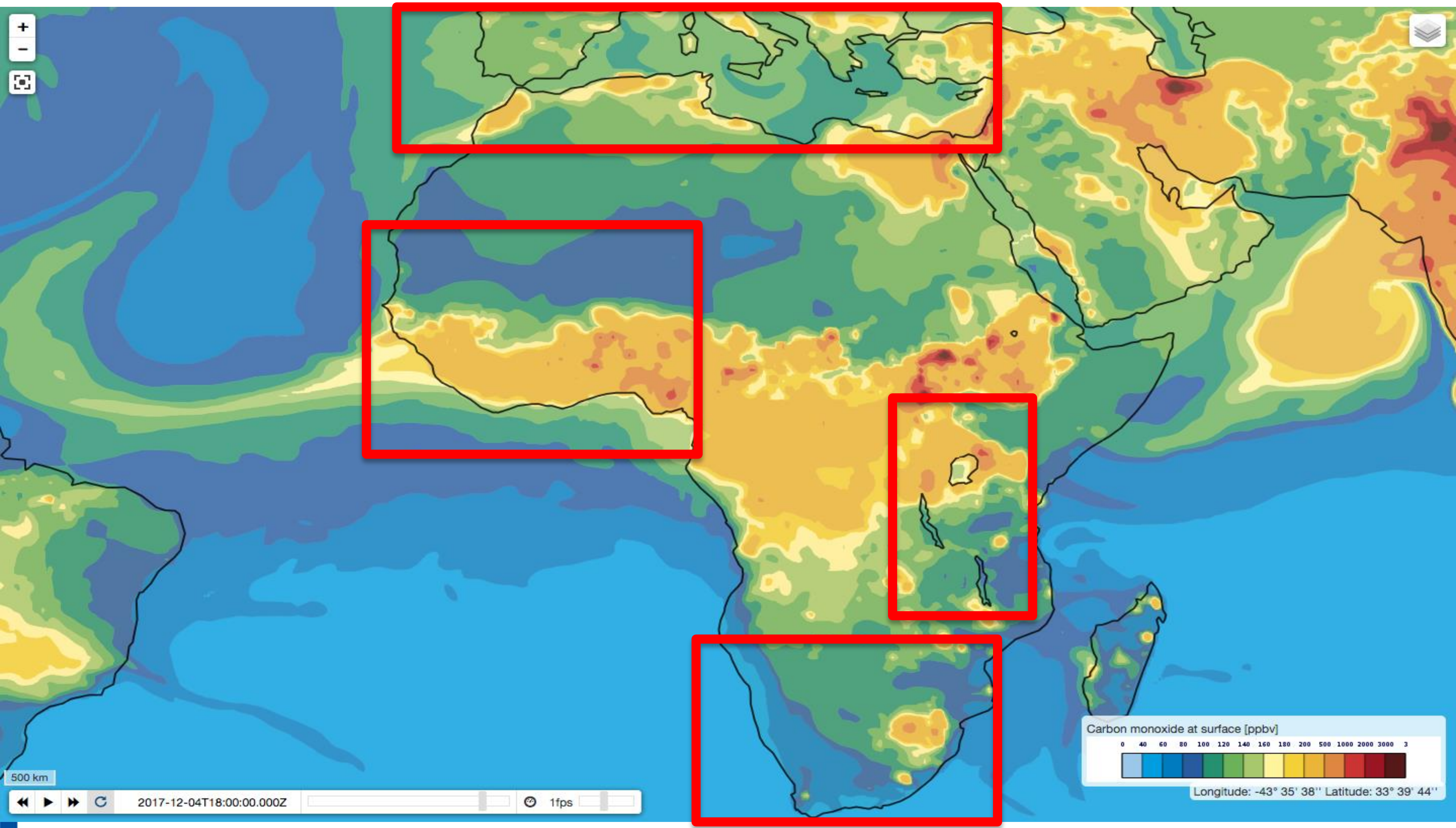
Using Global AQ Forecasts (CAMS and others) for Regional and Urban Downscaling in Africa

See: http://www.wmo.int/pages/prog/arep/gaw/WorkshoponSeamlessPredictionofAirPollutionforAfrica.html



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

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

GLOBAL ATMOSPHERE WATCH

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WMO OMM

Modelling recommendations for simulation of meteorological, chemical, biological variables

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

EuMetChem: Baklanov, Schlünzen et al.

Recommendations for model evaluation of coupled meteorology, chemistry, biology models

Recommendations for evaluating models	For variables in			For applications		
	Met.	Chem.	Biol.	NWP	AQ	Clim.
International test-bed for model evaluation of urban- and mesoscale models (AQMEII...+)	X	X	X	X	X	
To be additionally evaluated:						
•Shortwave and longwave radiation,	X	X	X	X	X	
•Photolytic rate of NO_2,		X			X	
•AOD, COT, CCN		X			X	
•Cloud droplet number concentration	X			X	x	
•Precipitation	X		X	X	X	
Additional measurements needed for evaluations:						
•Radiative forcing,	X	X	X	X	X	
•PBL height or vertical mixing,	X	X	X	X	X	
• Photolytic rates of NO_2,		X			X	
• AOD, COT, CCN		X			X	
•Long-term measurement data sets (incl. met. variables, aerosol and cloud properties, biol. variables)	X	X	X	X	X	X

EuMetChem: Baklanov, Schlünzen et al.

Relevance of better knowledge on specific processes to improve simulation of meteorological, chemical, biological variables

Processes (clouds, aerosols)	For variables in			For applications		
	Met.	Chem.	Biol.	NWP	AQ	Clim.
Cloud processes						
•Microphysics, dynamics,	X	X	X	X	X	X
•In-cloud and below-cloud scavenging,		X	X		X	X
•Aqueous-phase chemistry		X	X		X	X
Aerosol processes						
•Chemistry		X			X	X
•Thermodynamics	(X)	X		(X)	X	X
•Dynamics		X		(X)	X	X
Representation of aerosol–radiation–cloud–chemistry interactions (improve indirect estimates of aerosol effect)	**X**	**X**	**X**	**X**	**X**	**X**

EuMetChem: Baklanov, Schlünzen et al.

WMO OMM

Relevance of better knowledge on properties to improve simulation of meteorological, chemical, biological variables

Properties (clouds, aerosols)	For variables in			For applications		
	Met.	Chem.	Biol.	NWP	AQ	Clim.
Cloud properties						
•Droplet number concentrations, size distribution,	X	(X)		X	X	X
•Cloud fraction,	**X**	**X**	**X**	**(X)**	**X**	**X**
•Liquid water content, optical depths	**X**	**X**	**X**	**X**	**X**	**X**
Aerosol properties						
•Number, aerosol mass, size distribution		X	X		X	X
•Composition, phase, hygroscopicity, mixing state,	(X)	X	X		X	X
•Optical depths	X			X	X	X

EuMetChem: Baklanov, Schlünzen et al.

WMO OMM

Relevance of better process descriptions to improve simulation of meteorological, chemical, biological variables

Process (emissions)	For variables in			For applications		
	Met.	Chem.	Biol.	NWP	AQ	Clim.
Meteorology-dependent emission processes to be described more accurately:						
•Biogenic		X	X		X	X
•Sea spray		X			X	X
•Windblown dust	(X)	X		(X)	X	X
•Lightning		X			X	X
Anthropogenic emission data in urgent need for improvement:						
•Ships		X			X	X
•Wild fires		X			X	X
•Volcanic eruptions	X	X		X		X
Heat fluxes sources needing better knowledge:						
•Wild fires	X	X		X	X	X
•Volcanic eruptions	X	X		X	X	X

WMO OMM

EuMetChem: Baklanov, Schlünzen et al.

Model formulation and implementation aspects to improve simulations of meteorological, chemical, biological variables

Model formulation and implementation	For variables in			For applications		
	Met.	Chem.	Biol.	NWP	AQ	Clim.
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.).		X		(X)	X	(X)
Data assimilation methodology for meteorological **and** chemical data that avoids antagonistic effects and over-specification due to interactions between meteorological and chemical variables	X	X	X	X	X	X
Consistency in processes ensures one single atmosphere is simulated (to achieve by improving collaboration of communities)	X	X	X	(X)	X	X
Online access modelling to be transferred to online integration of met., chem., biol., to avoid double work	X	X	X	(X)	X	X

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EuMetChem: Baklanov, Schlünzen et al.

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.

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Geoscientific Model Development
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Enviro-HIRLAM online integrated meteorology–chemistry modelling system: strategy, methodology, developments and applications (v7.2)

Alexander Baklanov[1,a], Ulrik Smith Korsholm[1], Roman Nuterman[2], Alexander Mahura[1,b], Kristian Pagh Nielsen[1], Bent Hansen Sass[1], Alix Rasmussen[1], Ashraf Zakey[1,c], Eigil Kaas[2], Alexander Kurganskiy[2,3], Brian Sørensen[2], and Iratxe González-Aparicio[4]

[1]Danish Meteorological Institute (DMI), Copenhagen, Denmark
[2]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[3]Russian State Hydrometeorological University, St. Petersburg, Russia
[4]European 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

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Republic Hydrometeorological Service of Serbia (establishted 1888, WMO member since 1947)

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Role of mineral dust in cloud formation: modelling aspects

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

[1]Republic Hydrometeorological Service of Serbia (RHMSS), Belgrade, Serbia

[2]Institute of Physics Belgrade, Serbia

[3]Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l'AnalisiAmbientale, Potenza, Italy

[4]Institut für Atmosphäre und Umwelt, Goethe-Universität,Frankfurt/M., Germany

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