How important are aerosols for predicting the physical system (NWP, seasonal, climate) as distinct from predicting the aerosols themselves?

How important is atmospheric model quality for air quality forecasting?

Contribution of the Centres
compiled by S. Freitas

saulo.freitas@cptec.inpe.br

Japan Meteorological Agency

UPDATE OF AEROSOL CLIMATOLOGY OF OPERATIONAL GSM

Update of aerosol climatology of GSM

- Climatological aerosol is used in calculation of aerosol direct effect
- Seasonal variation of horizontal distribution is considered
  - Monthly averaged climatological distribution of vertically accumulated optical depth derived from satellite observation is used.

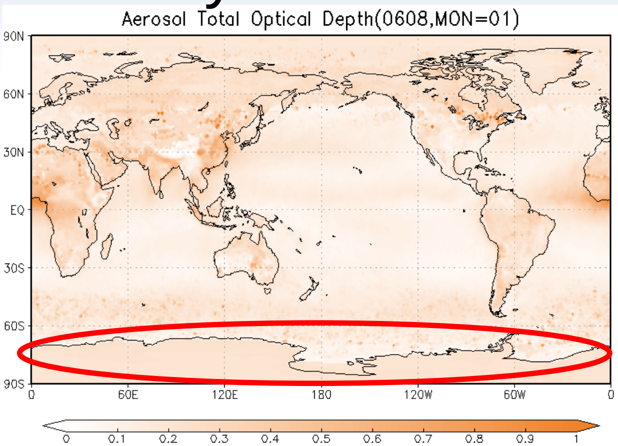
- JMA plans to update aerosol optical depth climatology
  - Use new satellite data, extend period for climatology calculation
  - New optical depth tends to be smaller over land (especially over the Antarctica and over desert) than current optical depth
  - Closer to observations by sun photometer.

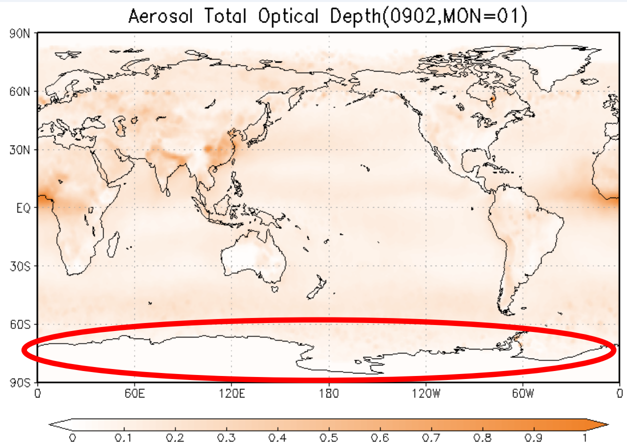
- Seasonal variation is not considered for vertical distribution (not updated)
  - Vertical distribution of optical properties climatology
  - Continental type and maritime type

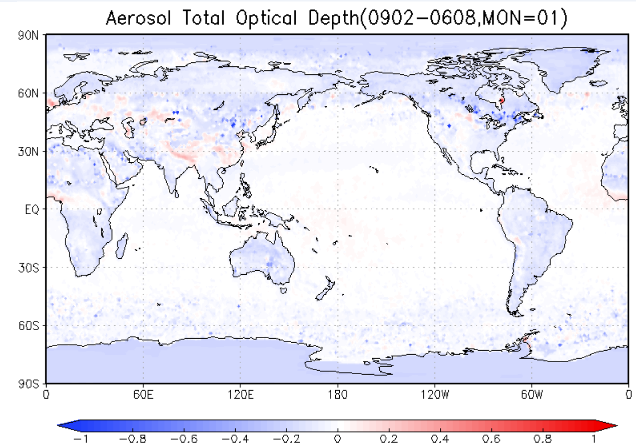
Difference between two optical depths

Current climatology | New climatology | (New)-(Current)

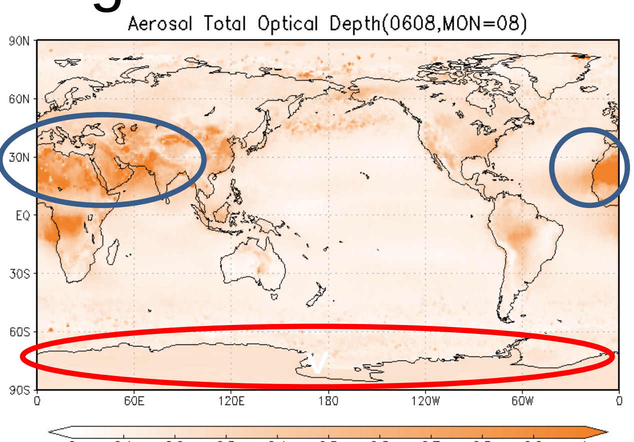
January

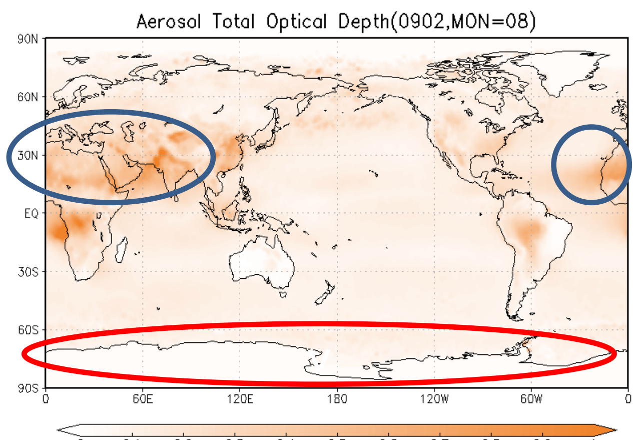


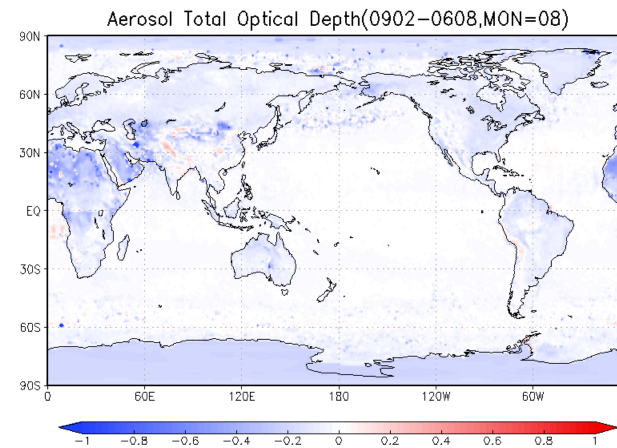




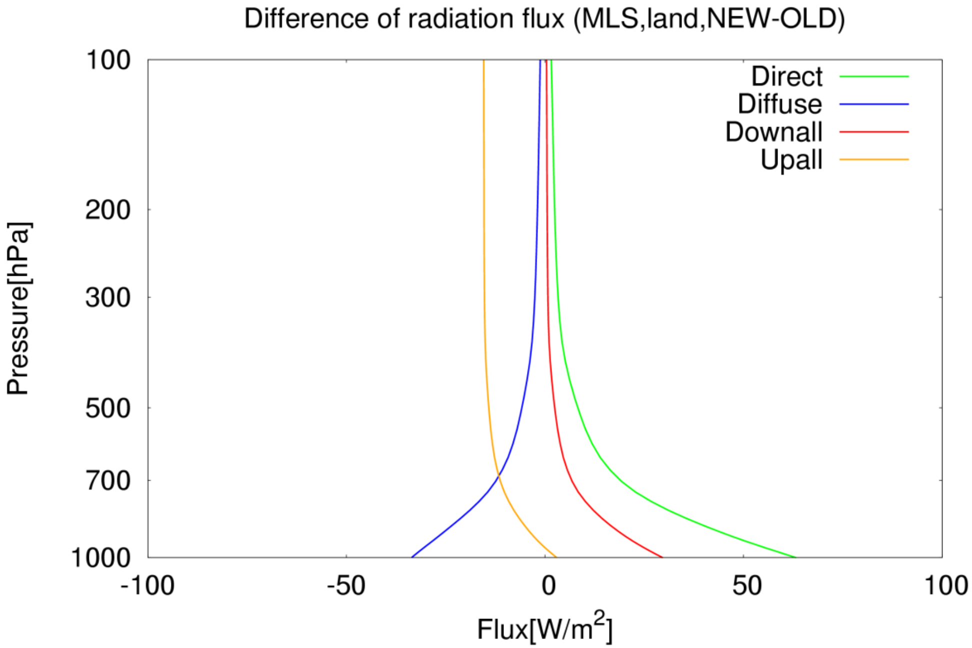
August



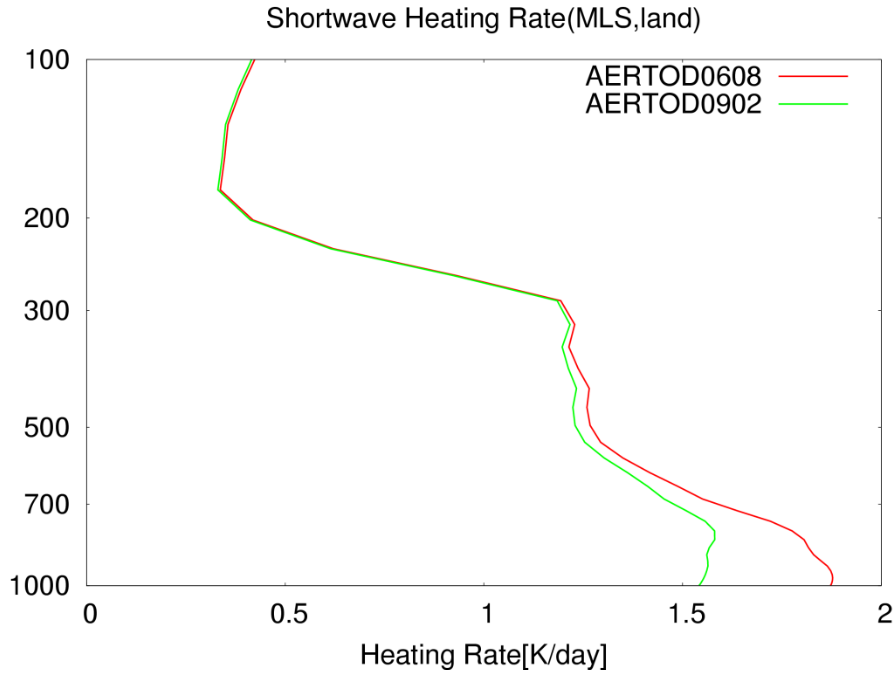




SCM experiment



Shortwave radiation flux
(new)-(current)



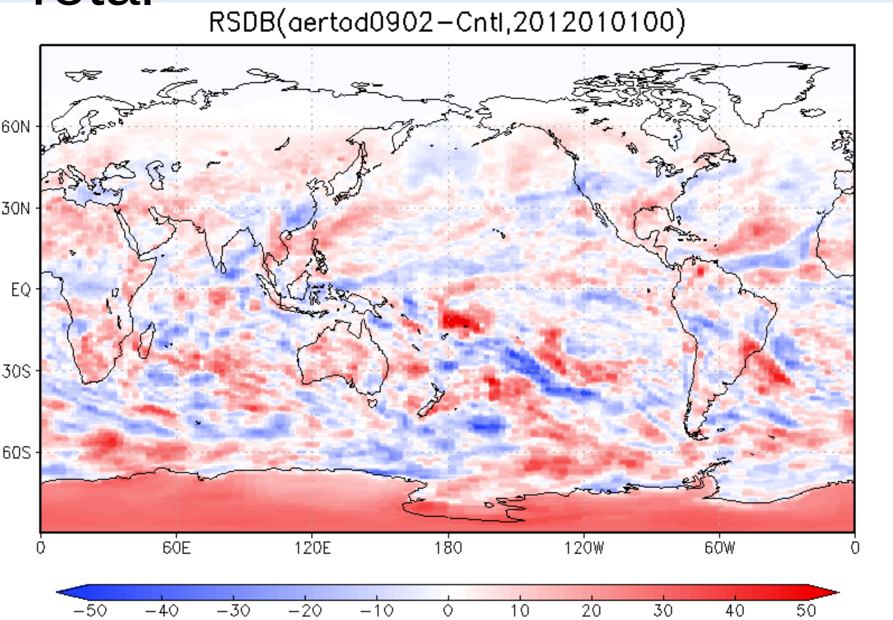
Heating rate by shortwave radiation
Red: current, green: new

Mid latitude summer standard atmosphere, clear sky, surface albedo: 0.1, solar zenith angle: 60°

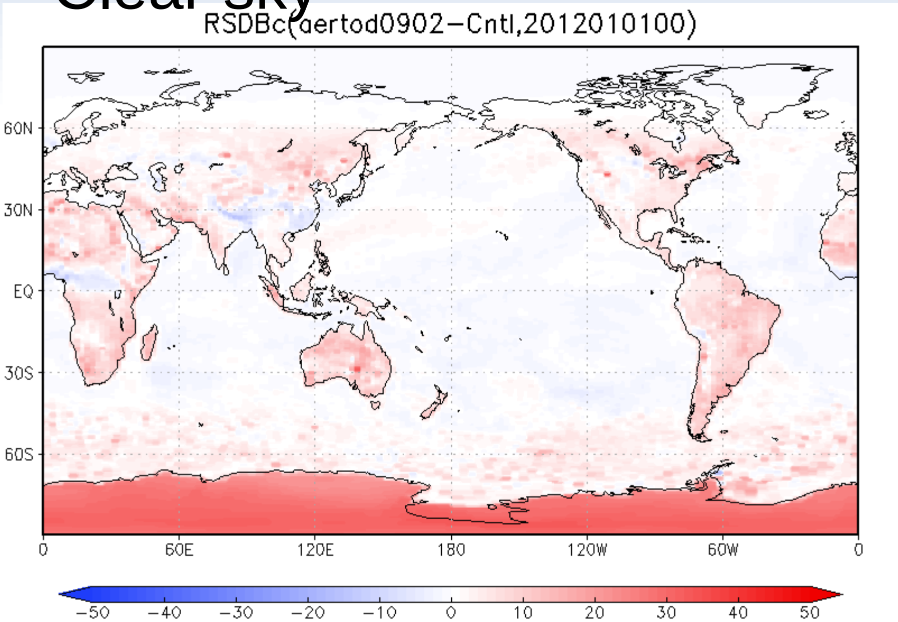
Smaller optical depth results in increase of shortwave radiation reaching surface and decrease of heating rate by shortwave radiation.

One-month average radiation flux (winter)

Total



Clear sky

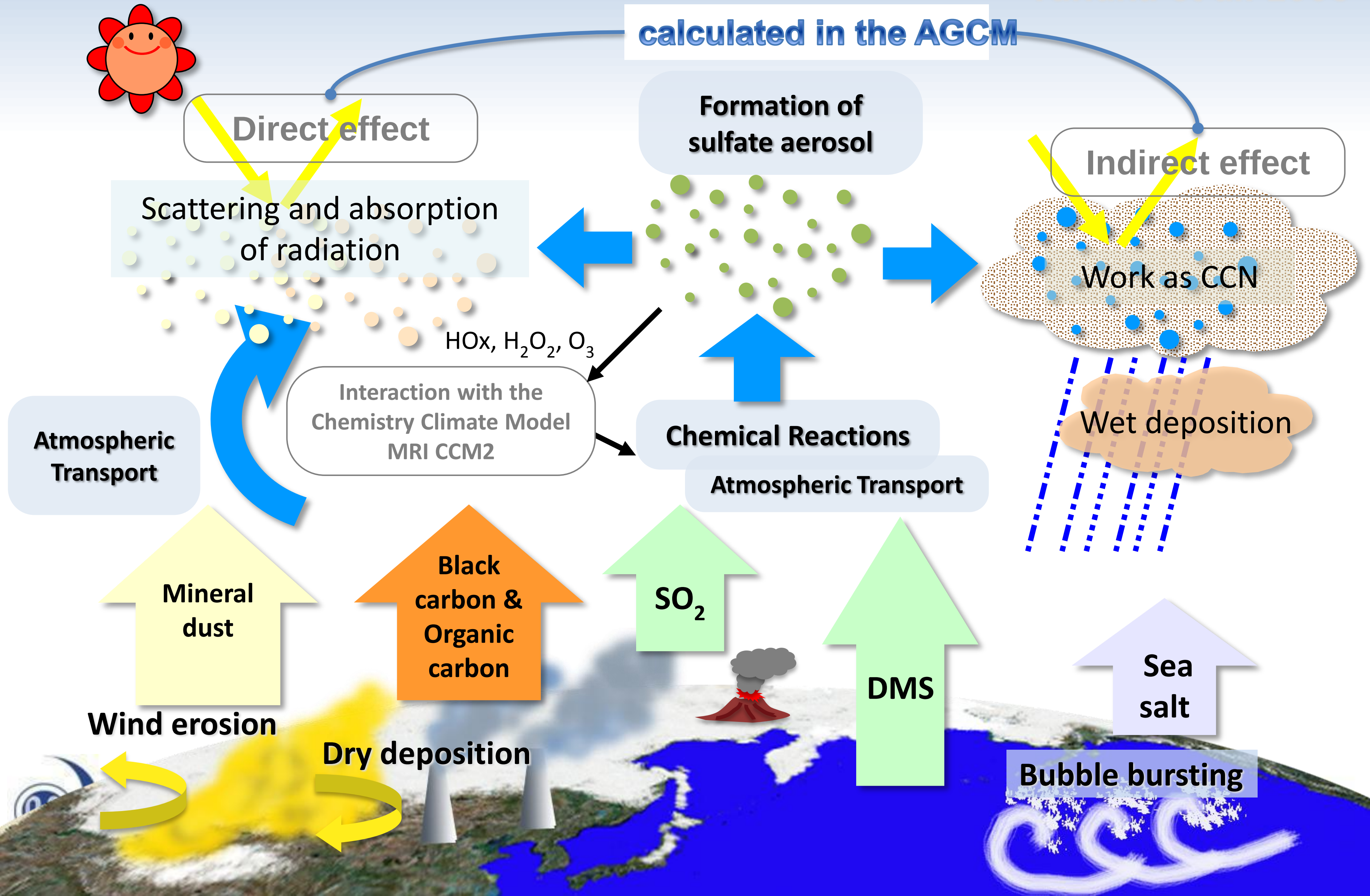


Downward shortwave radiation flux at surface (W/m^2)
(New)-(Current), 2012/01/01 00UTC init

DEVELOPMENT OF GLOBAL AEROSOL CHEMICAL TRANSPORT MODEL FOR CLIMATE CHANGE

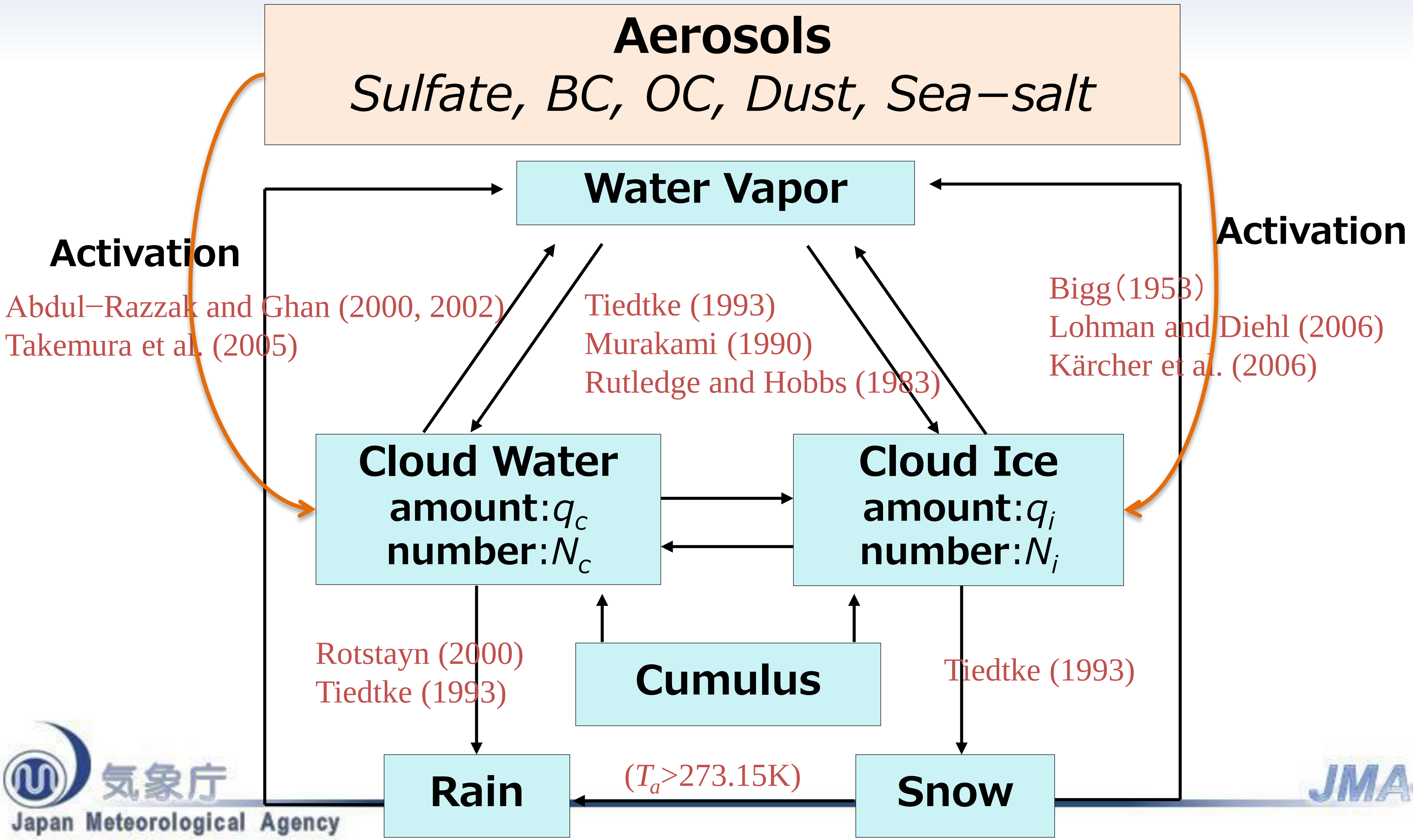
Processes in the Global Aerosol Chemical Transport model MASINGAR

Tanaka et al. 2003



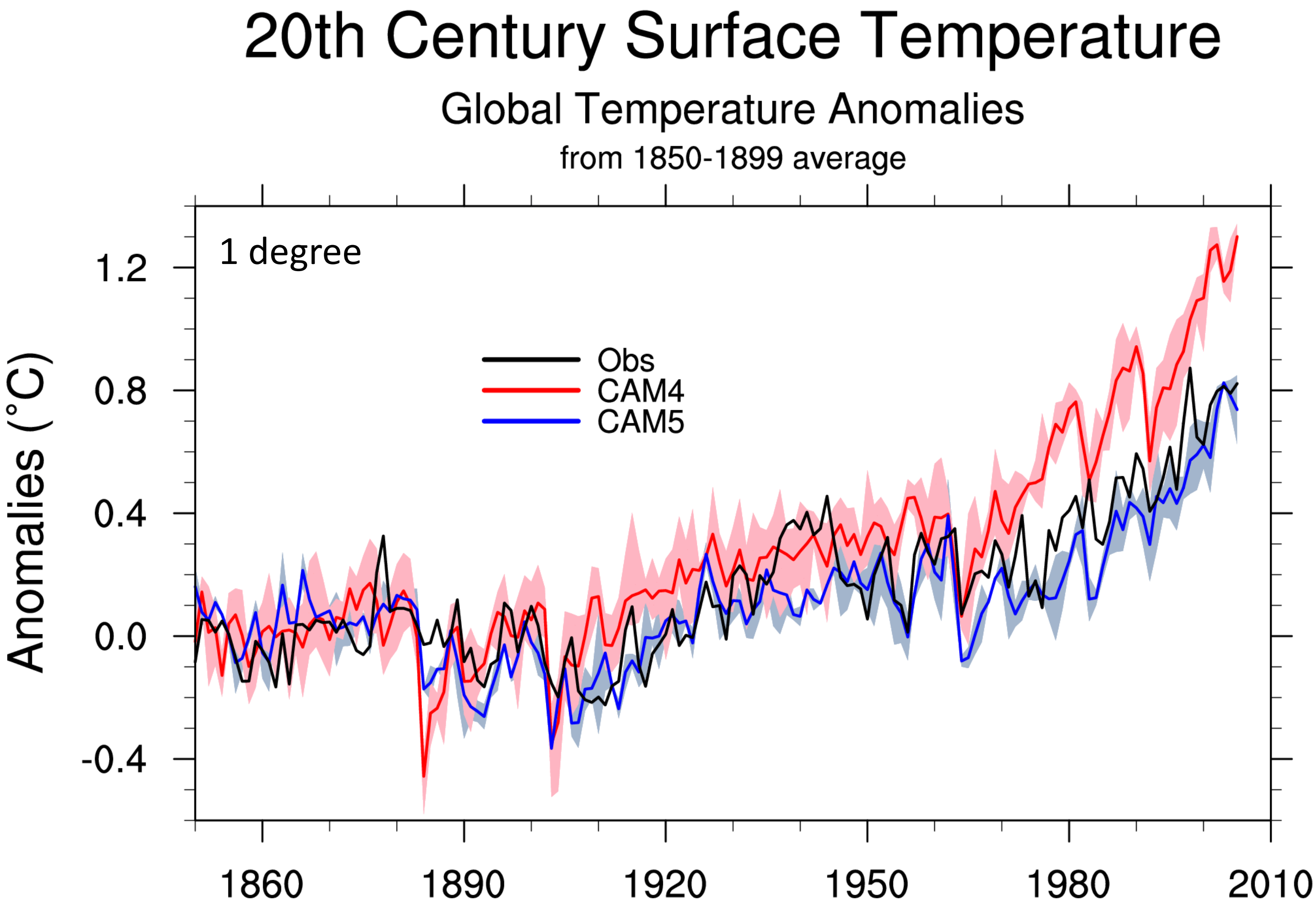
Cloud Model in MRI−AGCM3

Two-moment Bulk Cloud Model (Sakami 2009)



NCAR

CESM(CAM5.1) 20th Century



CAM4 – bulk aerosols, no indirect effect

CAM5 – multiple-moment aerosols with cloud microphysics/aerosol interaction

ECMWF

Interactions Atmospheric Composition & NWP (inputs: VH Peuch & JJ Morcrette)

Main objectives:

- Investigate “most promising” areas where improved representation of atmospheric composition can benefit NWP, long-range predictions and re-analysis
- Use atmospheric composition observations as an additional monitoring and diagnostics capability for winds/transport and physical processes
- Investigate new forecast capabilities (visibility, comprehensive land surface, surface albedo including aerosol deposition on snow…)

Main foci:

- Experiment direct (and indirect) aerosol effects
- Ozone assimilation
- Develop “affordable” composition representation in high res. IFS
- PBL diagnostics and atmospheric tracers
- Mass conservation/correction
- Handling of multiple grid in IFS

Challenges:

- Cost of atmospheric composition representation for operational forecasting

Preliminary findings

- Distribution of the various prognostic aerosols can be rather different from the climatology of aerosols presently used operationally.

- Given the present configuration of the MACC/ECMWF aerosol analysis, having the full interactions between aerosols and radiation/cloud processes within the analysis does not bring much to the subsequent FCs. The increased complexity and cost (~x2) does not justify its operational implementation

- When direct and indirect effects are considered, the first order response of the Dir/Ind FCs is roughly the sum of Dir+Ind.

- The impact of the aerosol-cloud-radiation interactions on traditional meteorological scores is negligible on geopotential, only noticeable on rms errors of T below 850 hPa

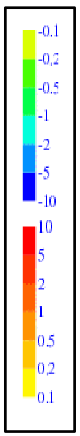
- Current research includes replacing old aerosol (1997) climatology with MACC climatology

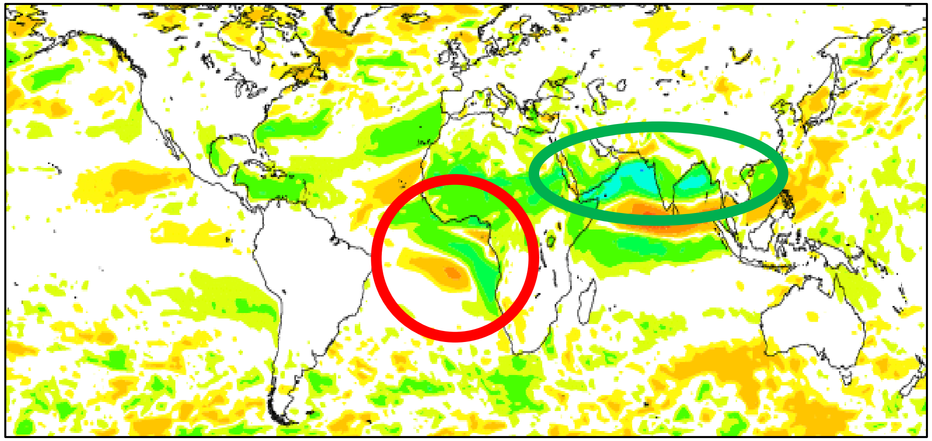
- Locally, it can have a significant impact (e.g 10 meter-winds- see next slide)

Aerosol direct effects: MACC / MACC clim / Oper clim

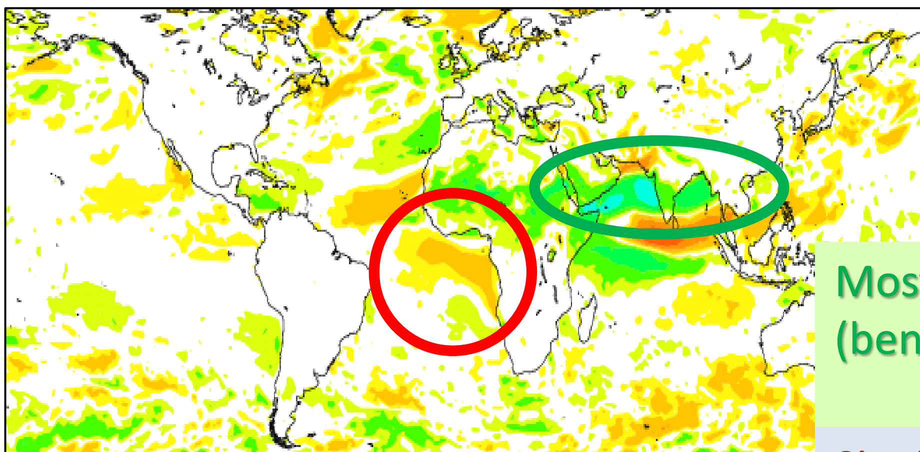
July 2011, 31 days average, TL255 L60 10-d forecasts

10m wind difference





{MACC aerosol – REF Oper clim}



{MACC $\text{clim}_{\text{July}}$ – REF Oper clim}

Most global patterns captured including (beneficial) deceleration of Somali jet

Significant differences in some aerosol hot spots with high variability

UK Met Office

Understanding aerosol impacts at NWP timescales

Conducted a set of NWP experiments covering June-July 2009 period using different aerosol representations:

Increase in Complexity

= Increase in Cost!

- Simple Cusack climatology (Cusack et al., 1998) (Control)
- Monthly mean aerosol climatologies derived from HadGEM-2 climate runs.
- Prognostic aerosol species modelled using the CLASSIC aerosol scheme (Bellouin et al, 2011)
- Initialized CLASSIC aerosol using GEMS assimilated aerosol forecasts

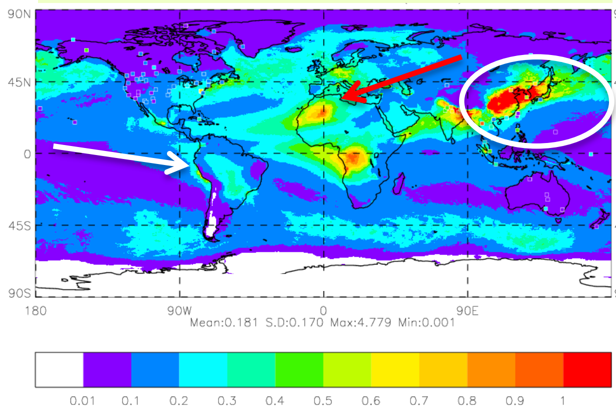
Evaluation of aerosol predictions and direct and indirect aerosol impacts (separately & combined) on model's radiation and meteorological fields carried out against a range of observations.

Assessment of different aerosol representations in global NWP model

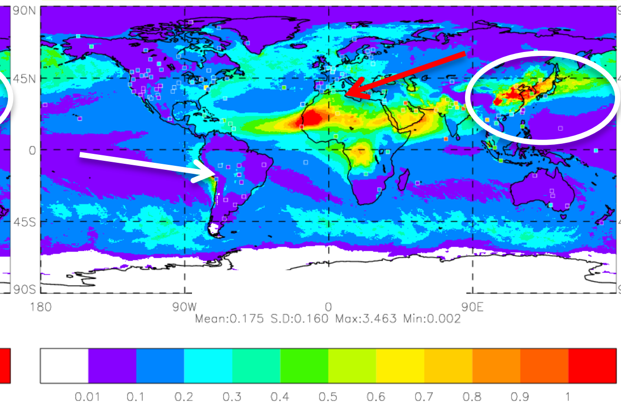
Met Office

Jun/Jul 2009 mean T+120 AOD (550nm)

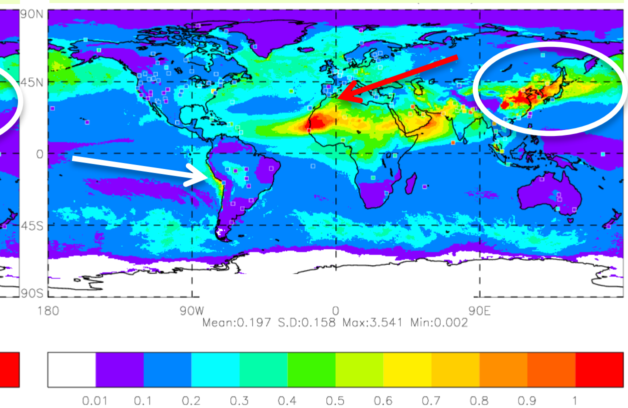
Monthly mean Climatologies



Prognostic CLASSIC aerosol scheme

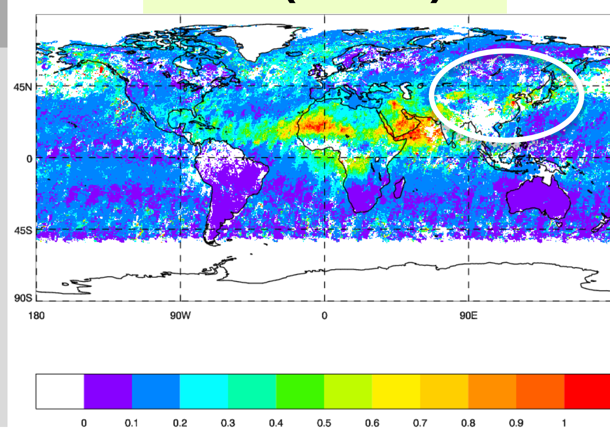


Initialised CLASSIC aerosol using GEMS assimilated aerosol

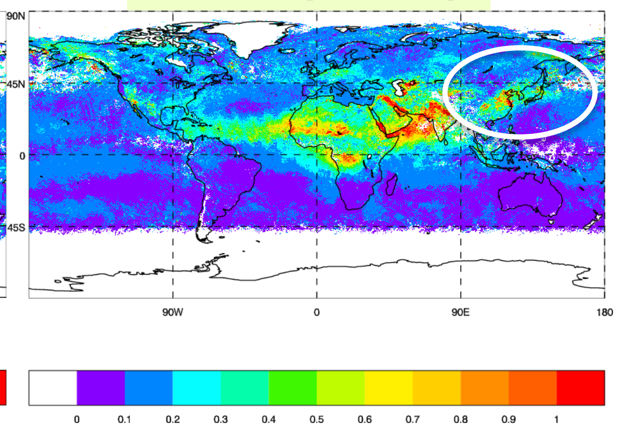


Global Mean AOD	
CLIM:	0.181
AER_DIR_DIR:	0.175
INIT_DIR_INDIR:	0.197
MISR:	0.189
MODIS:	0.186

MISR (555nm)



MODIS (550nm)



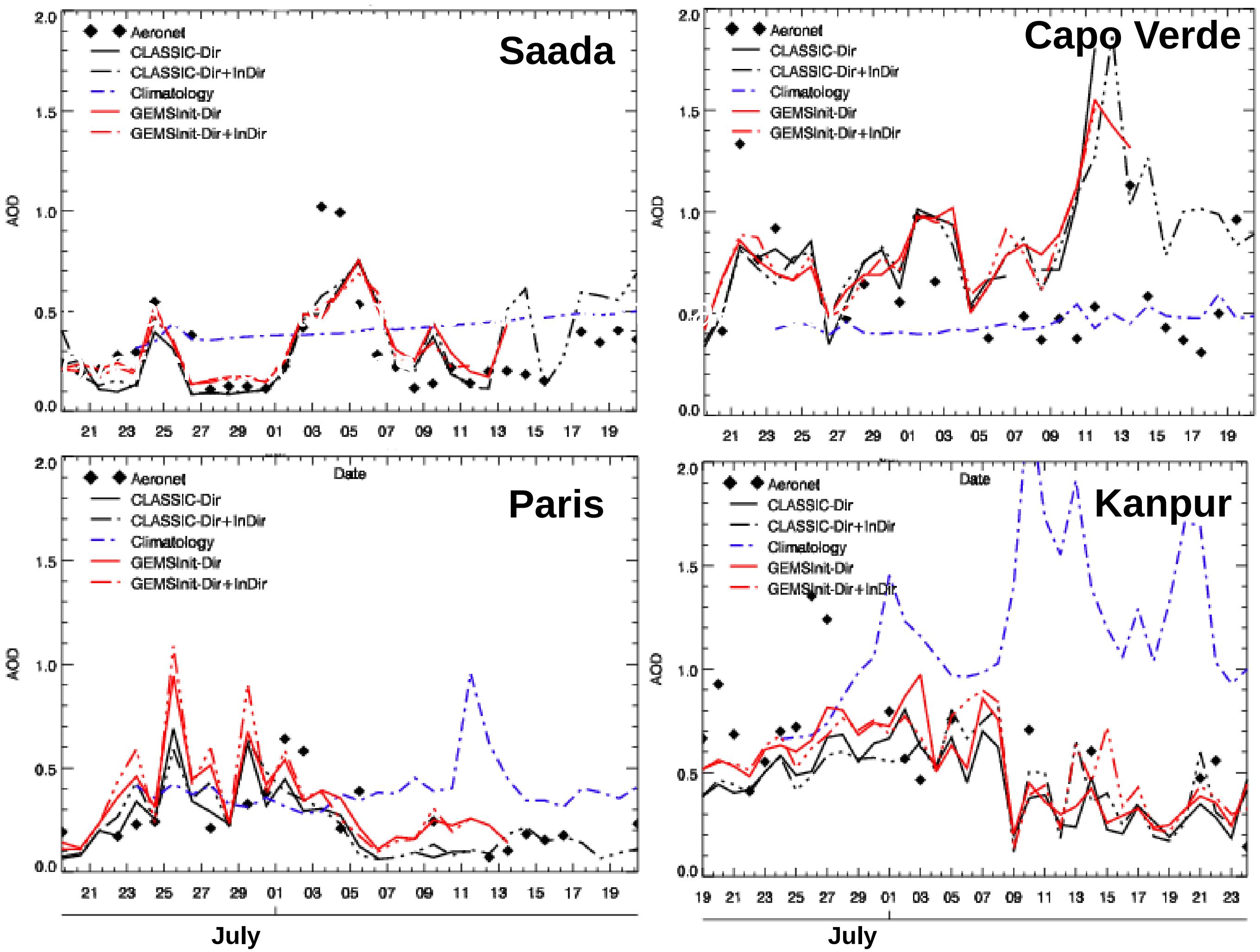
AERONET Comparisons: Jun/Jul 2009 AOD (440nm) T+120

Benefit of having the prognostic aerosols over climatologies:
better diurnal variability of AOD

Dust aerosol

diamonds = observations
Black = classic
Red = Initialised classic
Blue = climatology

Anthropogenic aerosol



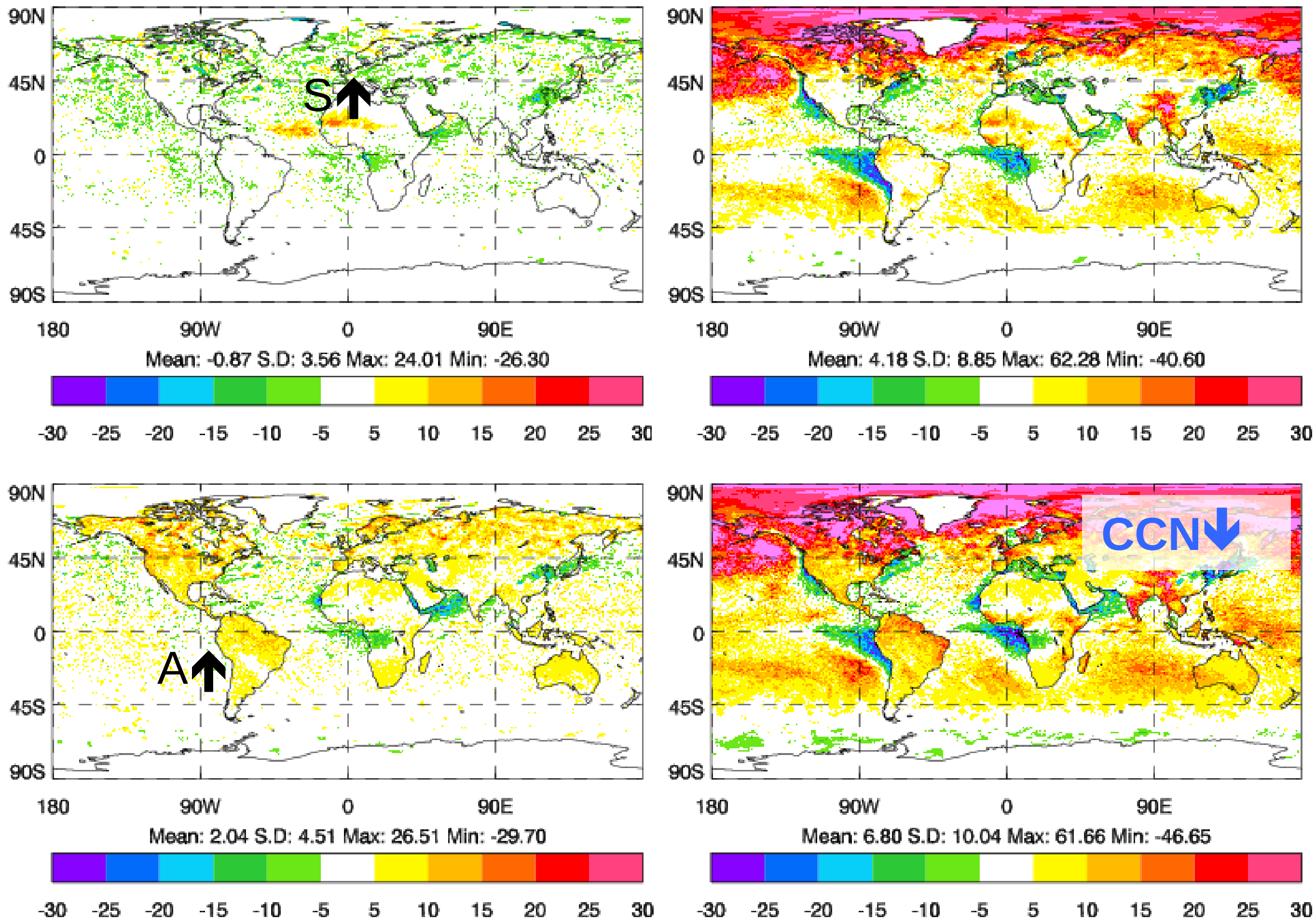
Impacts on net radiation T+120

{CLASSIC} – {CLIMATOLOGY}

Direct Effect | **Direct & Indirect Effect**

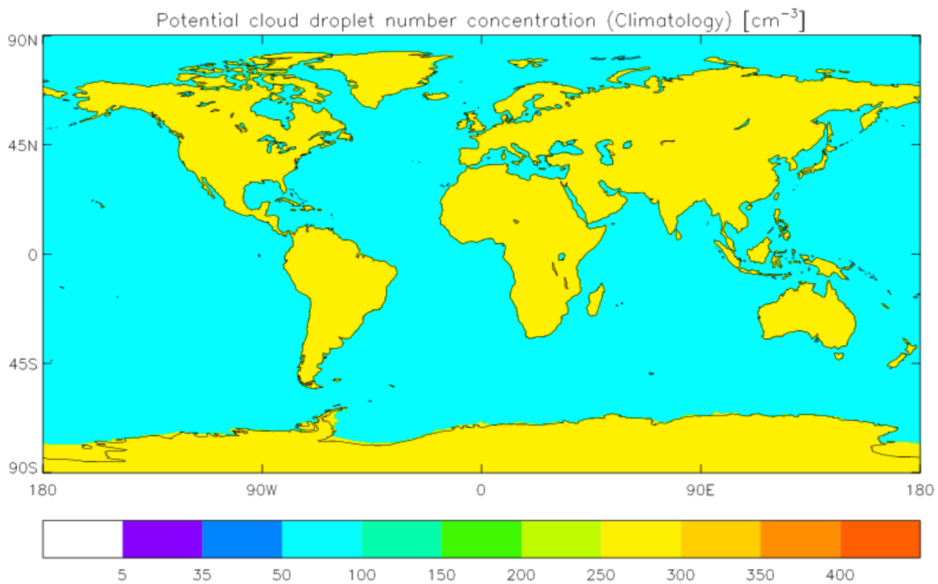
Top of Atmosphere Net Radiation

Surface Net Radiation

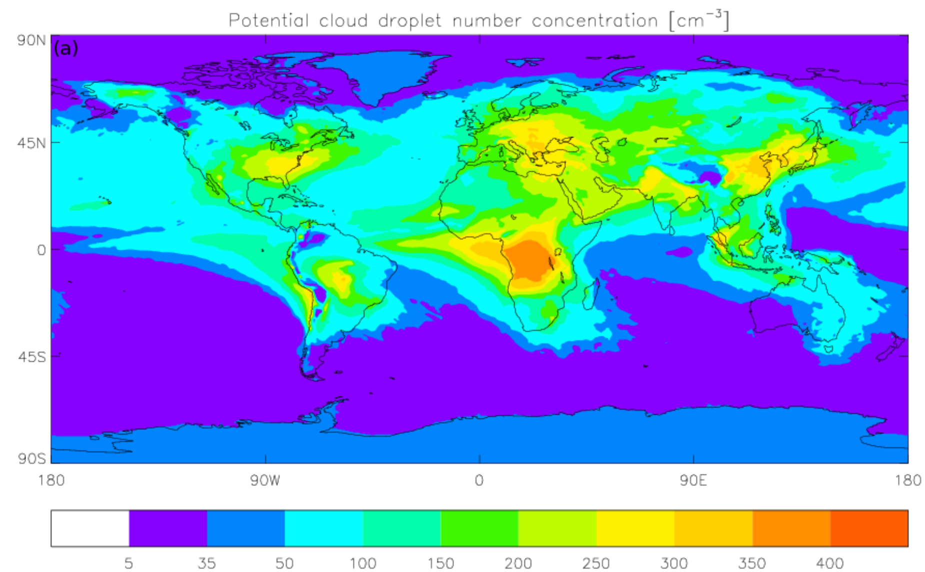


Cloud droplet number conc.

Large sensitivities in remote clean air regions to more “realistic” CDNC



Control

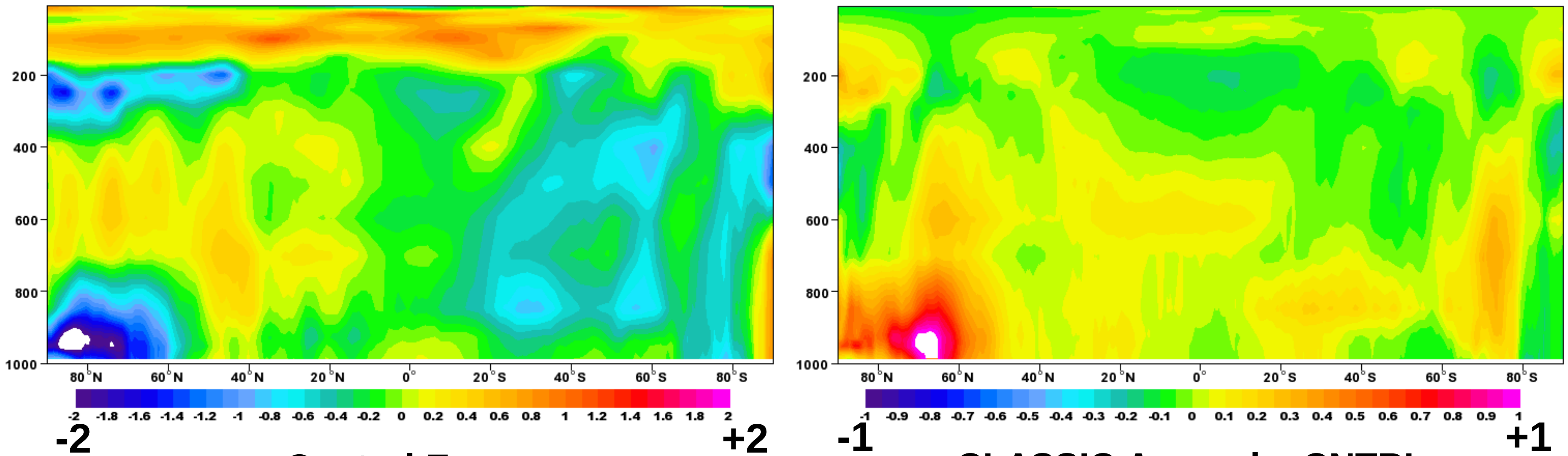


Aerosol Direct & Indirect (AER_Dir_Indir)

Zonal Temperature T+120

Jun/Jul 2009

Inclusion of the indirect effect leads to an improvement in NH cold bias and in some regions of SH

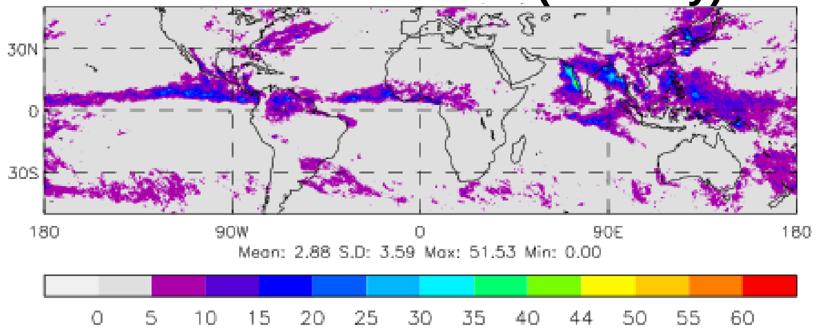


Control Error **CLASSIC Aerosol – CNTRL**

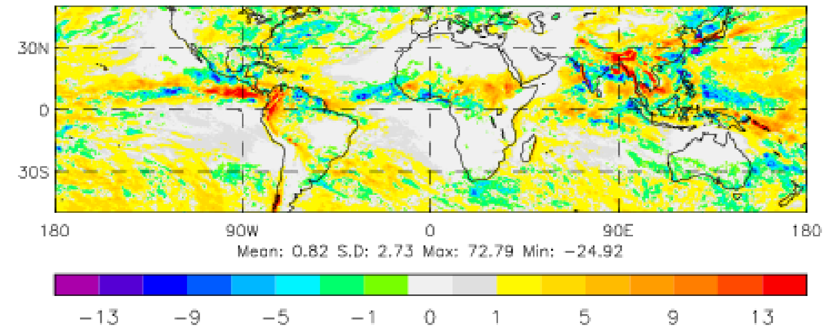
Precipitation Error T+120

Jun/Jul 2009

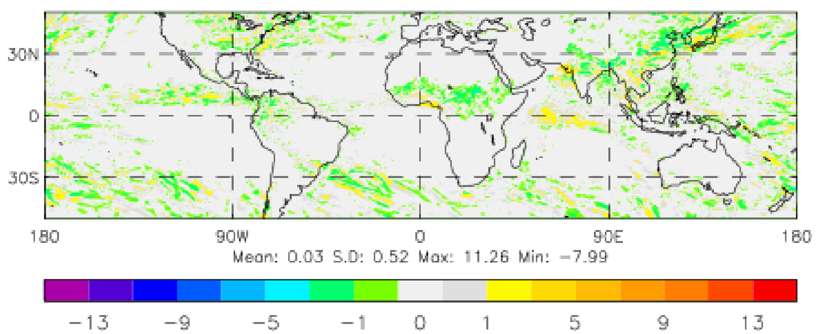
TRMM Observations (mm/day)



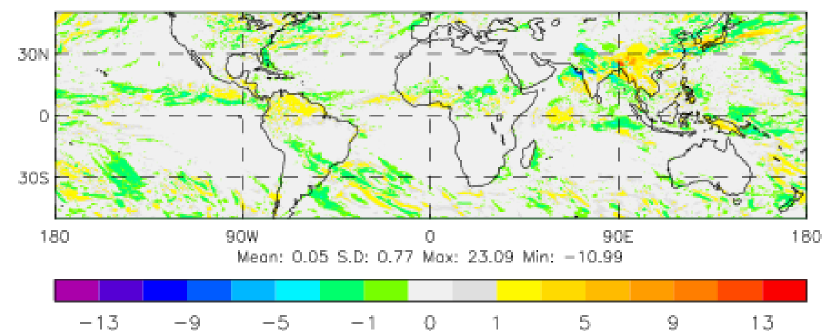
Control Error



Direct Effect - Control



Direct+Indirect Effect - Control

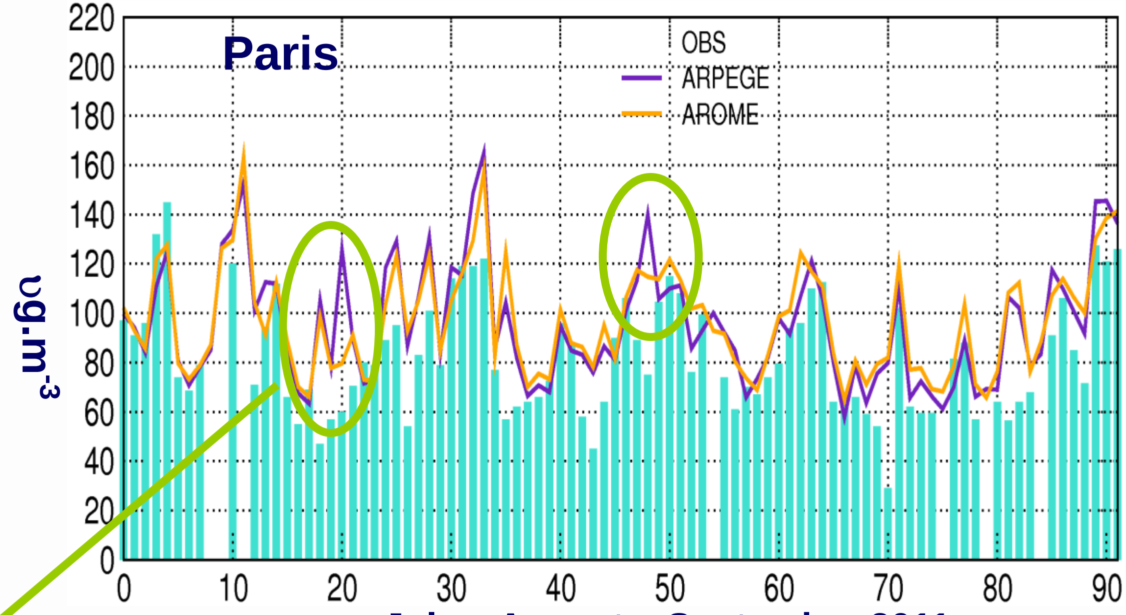


The impacts are small, but they improve the errors.

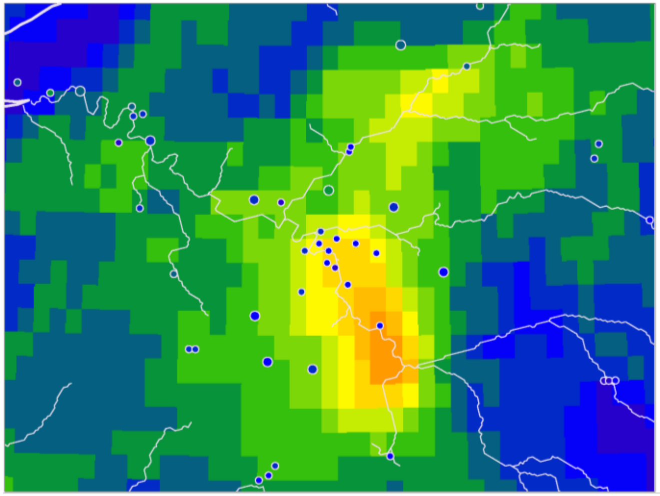
MeteoFrance

Forecasts of ozone maxima with MOCAGE chemistry transport model

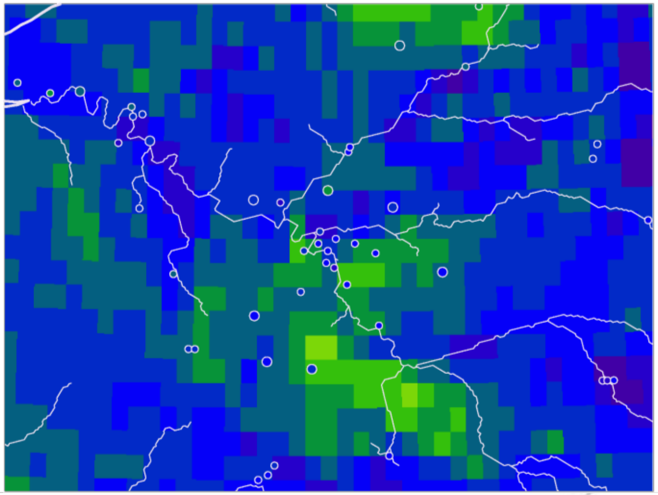
With the same horizontal resolution (0.1°), meteorological forcings from AROME (2.5km) give better results for Paris than from ARPEGE (10km).

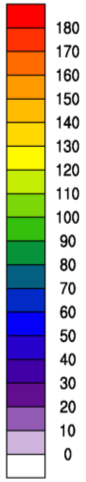


Forcings from ARPEGE



Forcings from AROME



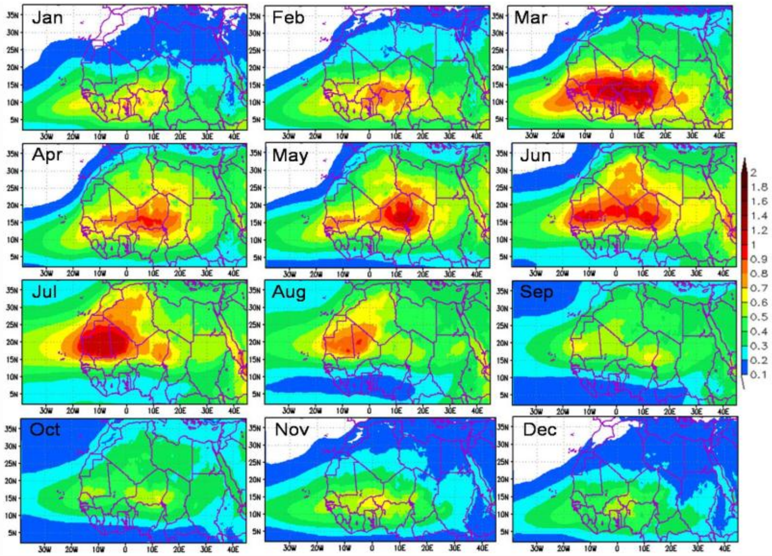


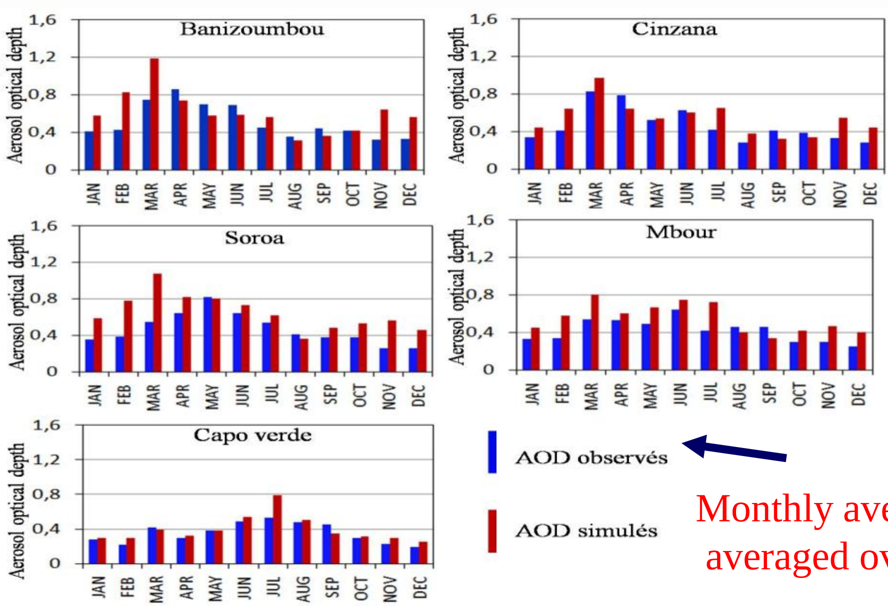
Surface ozone concentrations ($\upsilon g.m^{-3}$) from observations and forecasts on 21/07/11 at 15h.

V. Marécal

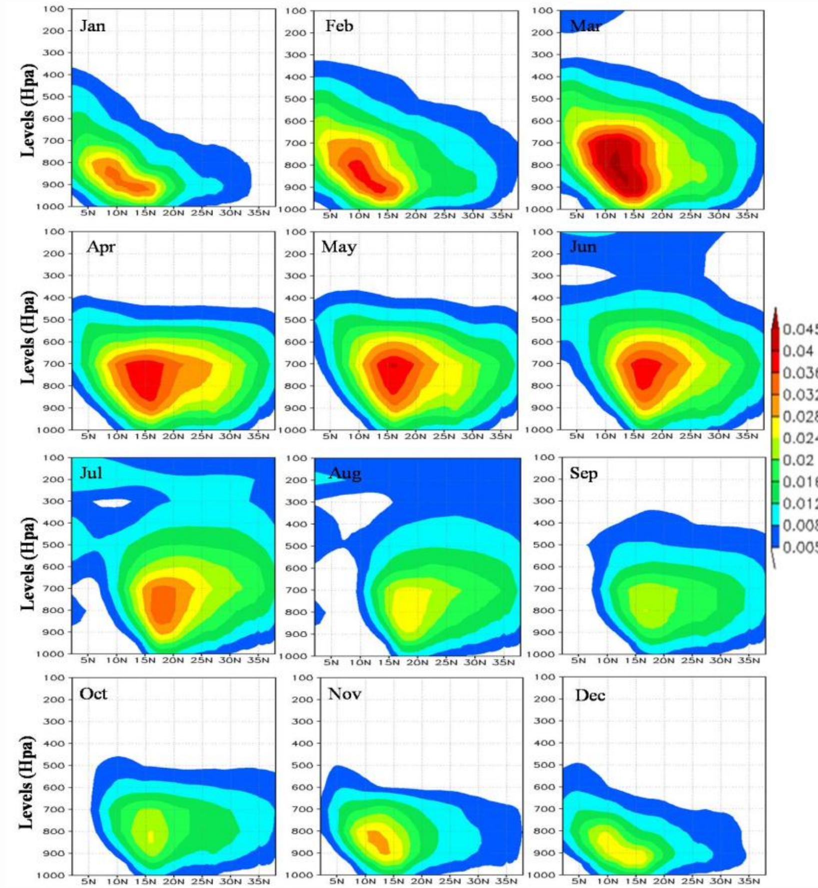
Climatology of desert dust simulated by the ALADIN model

AOD simulated by ALADIN, averaged over **2006-2010**





Vertical cross-sections (30°O – 40°E)
of extinction coefficients (km $^{-1}$) simulated by ALADIN
Averaged over 2006-2010 over North Africa

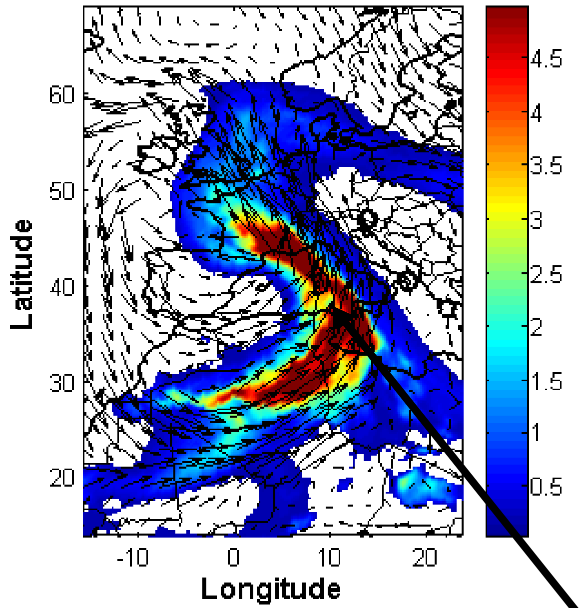


Monthly averages of oberved (blue) and simulated (red) optical depths averaged over 2006-2010

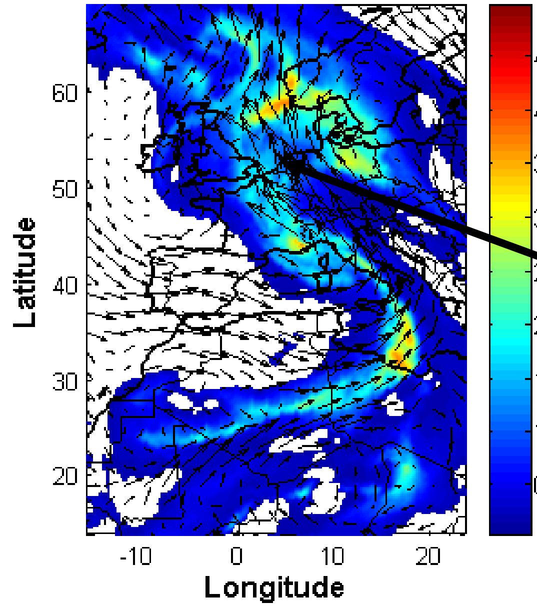
J-P Lafore

MesoNH modelling of desert dust outflow over Europe (EUCAARI)

AOT 28 May, 12 UTC

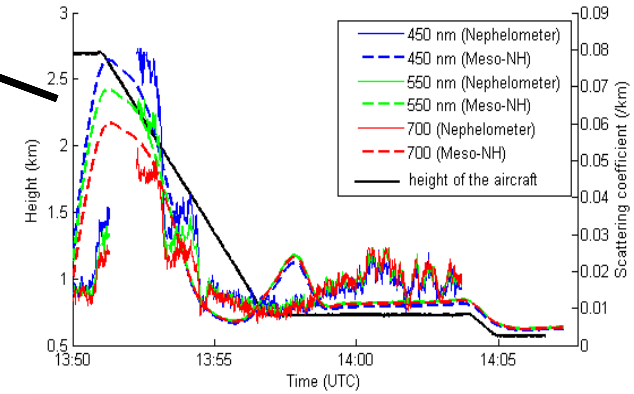


AOT 30 May, 12 UTC



Begue et al., 2012, jgr

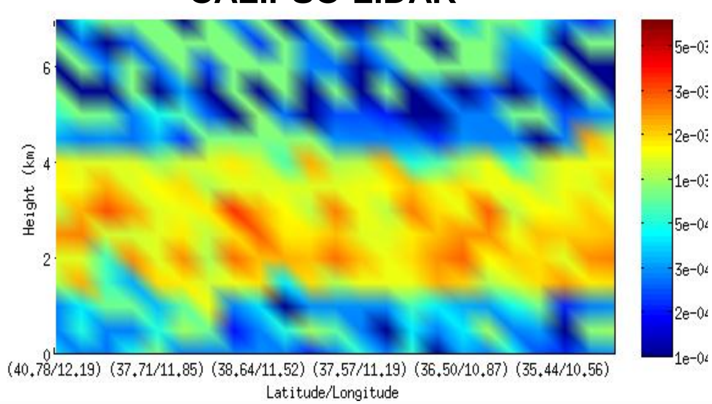
Comparison Diffusion Coeff (λ)
MesoNH – ATR 42 (aircraft instrument)
30 May 2008. EUCAARI field campaign



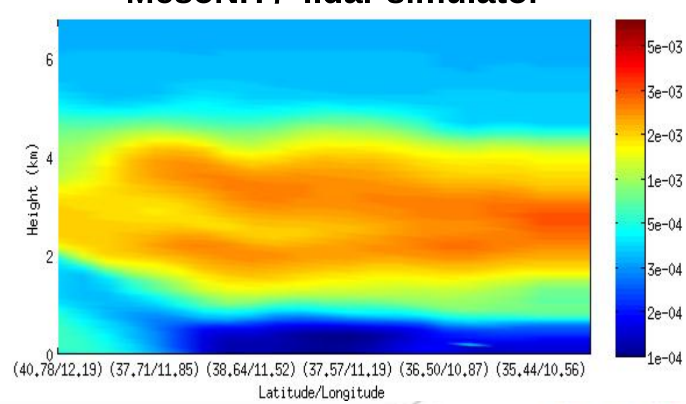
Wavelength dependency: wet deposition by convection over Corsica

Comparison of backscattered signal
28 My 2008. EUCAARI field campaign

CALIPSO LIDAR

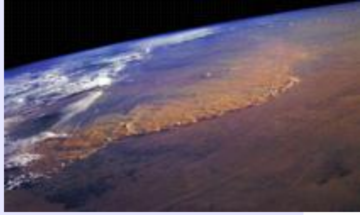


MesoNH / lidar simulator



Bègue, N.
and P. Tulet
(LACy)

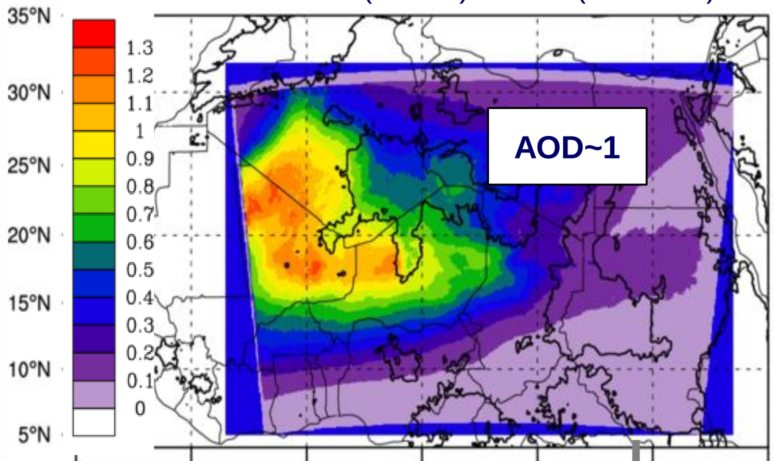
Impact of desert dust on high resolution numerical modelling: AROME coupled to a desert dust module



Real time simulations: 5km / 41 levels / West Africa : 850x550pts [*Grini et al.* 2006, *Tulet et al*. 2005]
Realistic modelling of on-line lift-off, transport and radiative impact of desert dust

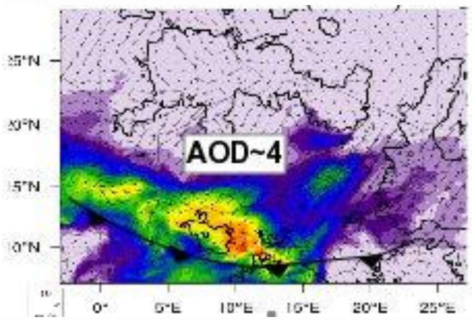
Monthly means

June 2006 (AMMA) + 2011 (FENNEC)

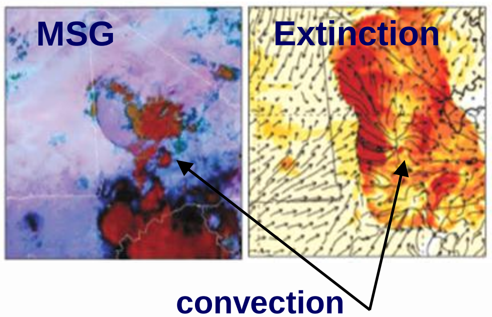


synoptic case study

Storm caused by a cold surge
6-14 mars 2006 (AMMA)



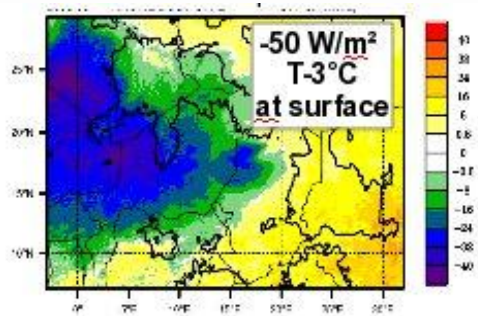
Density Courants
23 June 2011 0000utc (t+30h)
(FENNEC)



IMPACTS :

Dust absorb and diffuse solar radiation:
→ Heating in the dust layer (de-stabilisation)
→ Cooling above (stabilisation)

Difference in radiative forcing with and without dust



→impact on monsoon

-100 W/m² , T-8°C à la surface

Taking into account the radiative impact of dust improves prediction of the storm over W Africa.
C. Kocha

Environment Canada

Canadian AQ Forecasting System

- Primary messaging tool is the Air Quality Health Index (AQHI)
- Main target is urban areas > 100,000 population
- On-line forecast model GEM-MACH provides guidance on AQHI component values (NO_2, O_3, $PM_{2.5}$) and meteorological fields out to 48 hours

GEM-MACH

- GEM-MACH is a multi-scale chemical weather forecast model composed of dynamics and physics (GEM) and *on-line* chemistry modules

- Operational configuration of GEM-MACH includes
  - limited-area-model (LAM) grid configuration for North America
  - **10**-km horizontal grid spacing, **80** vertical levels to 0.1 hPa
  - 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10 μm) with 9 chemical components
  - forecast species include O_3, NO_2, and $PM_{2.5}$ needed for AQHI

Plans for the future:

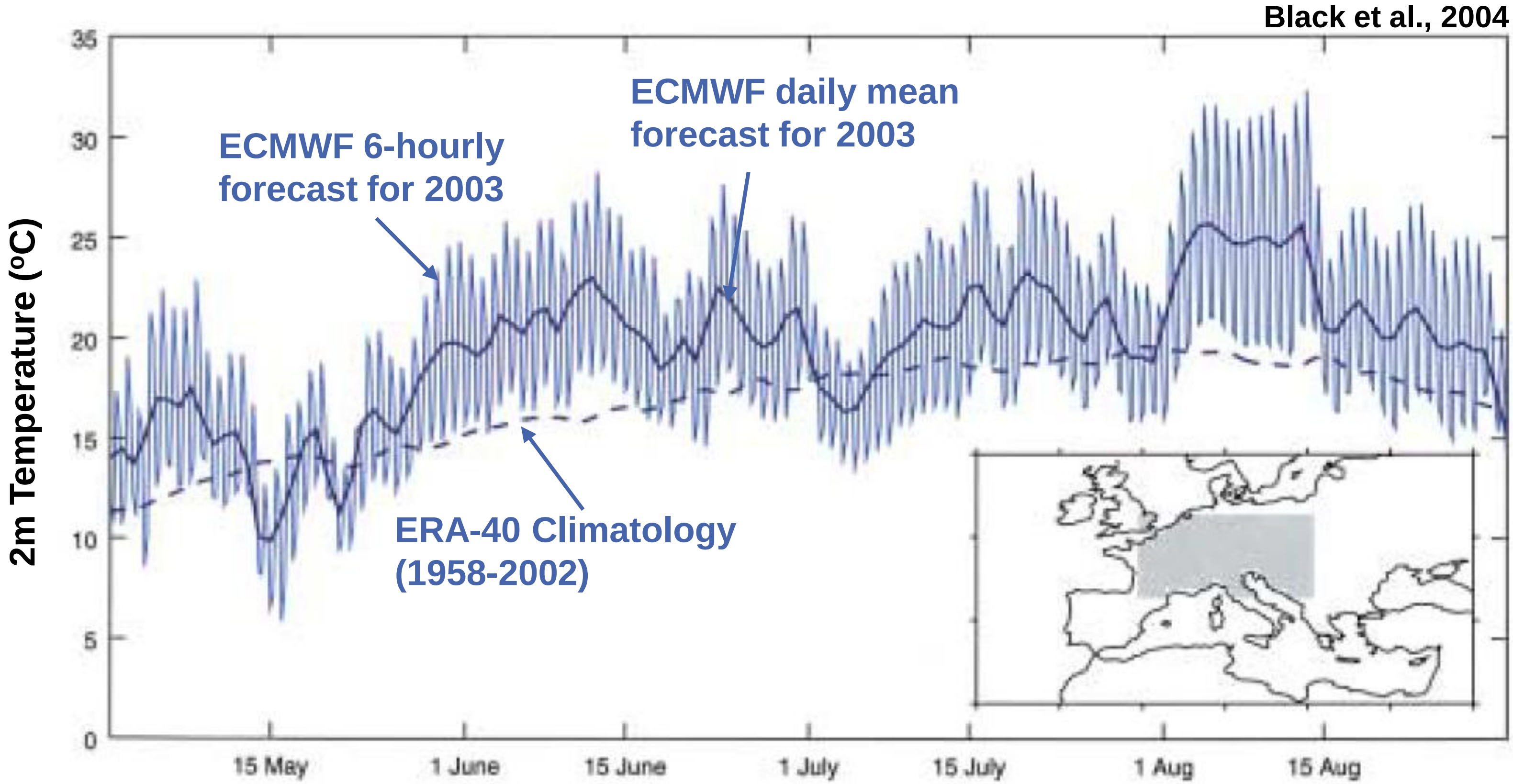
The Canadian model (**GEM-MACH**) currently used for air-quality forecasts is not a fully interactive model.

For **phase 2 of AQMEII** (Air Quality Modelling Evaluation International Initiative): a new version of GEM-MACH -- allowing full interaction among the various atmospheric and chemical (gas and aerosol) processes such as clouds, radiation, boundary layer, etc. -- will be developed in 2013.

DWD

COSMO – ART (Aerosol and Reactive Tracers)

Summer 2003: Exceptionally warm and dry



Model setup

Karlsruhe Institute of Technology

dx = 14 km

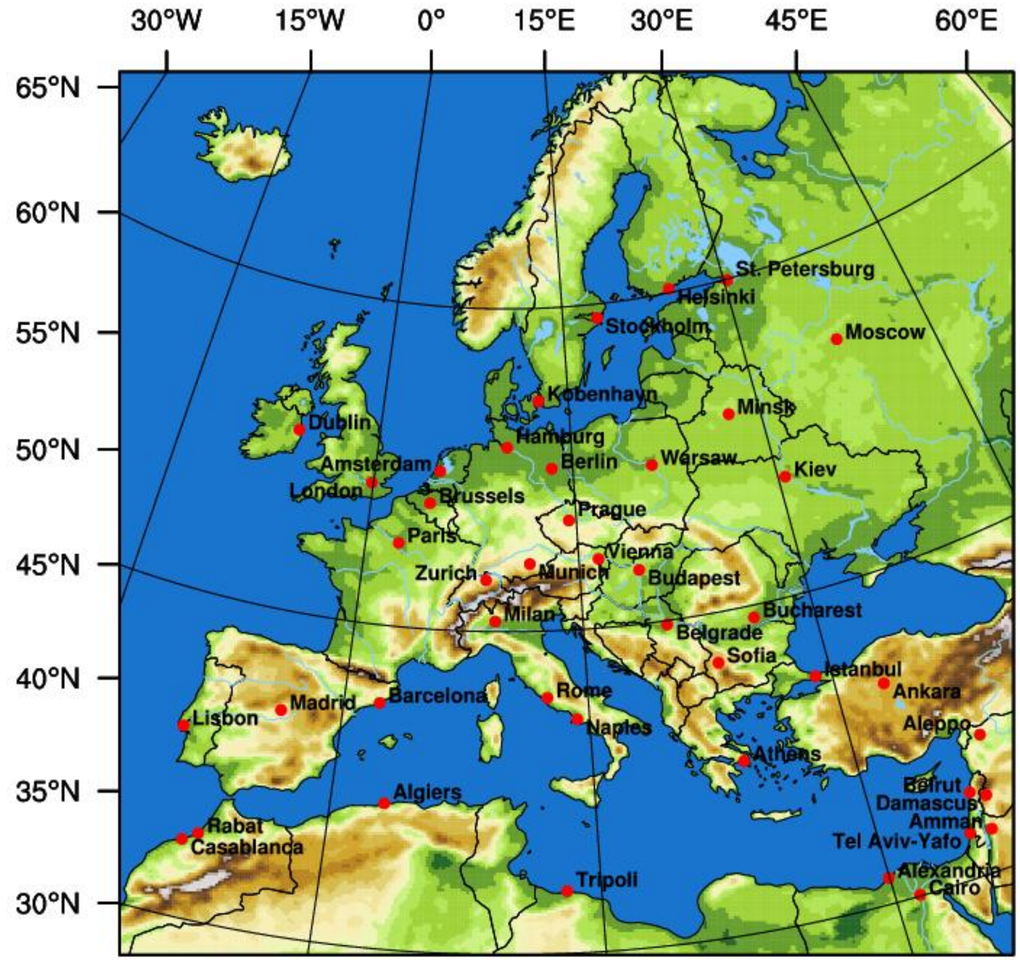
dt = 40 s

Forcing: ERA-interim

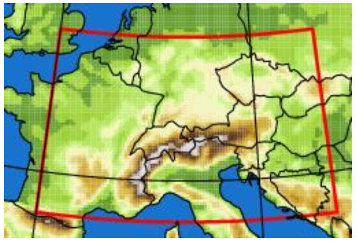
15th June to 20th August 2003

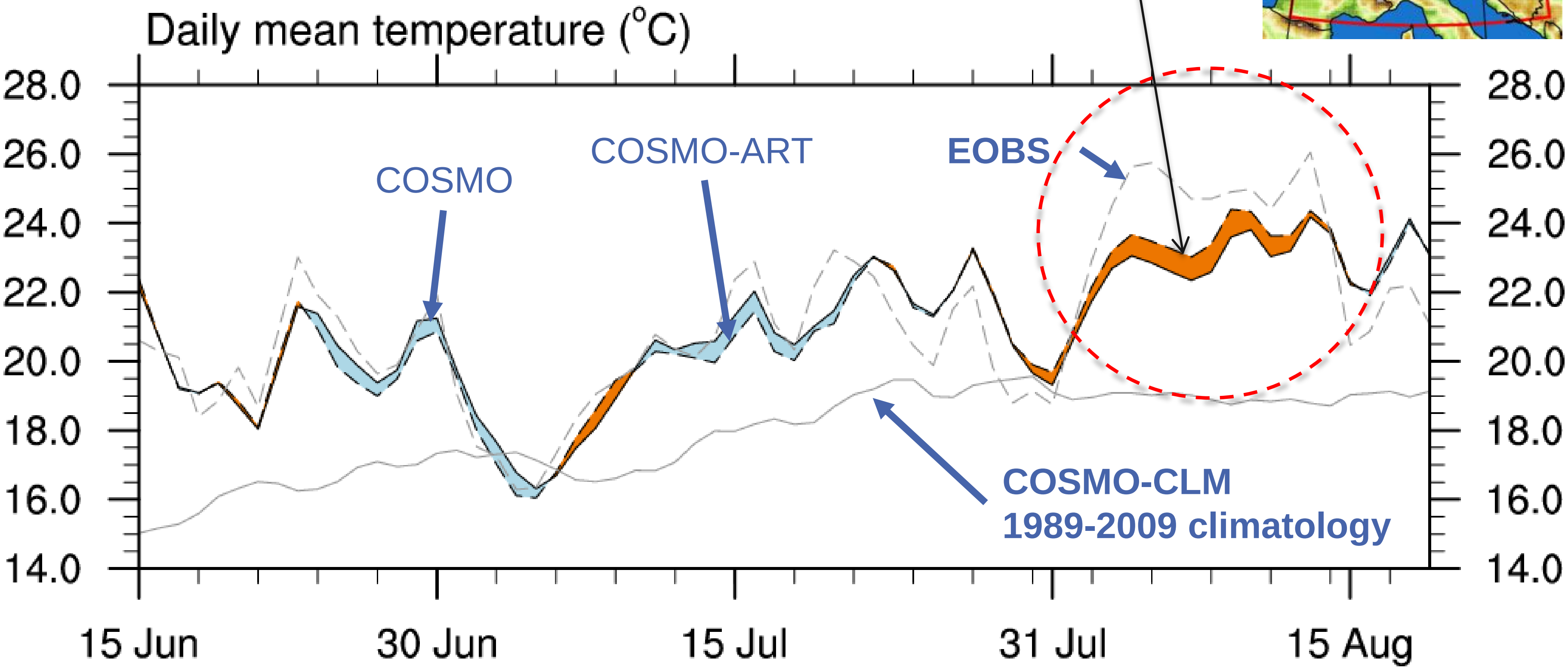
COSMO spin-up since 1st January 2002

Anthropogenic emission data from TNO



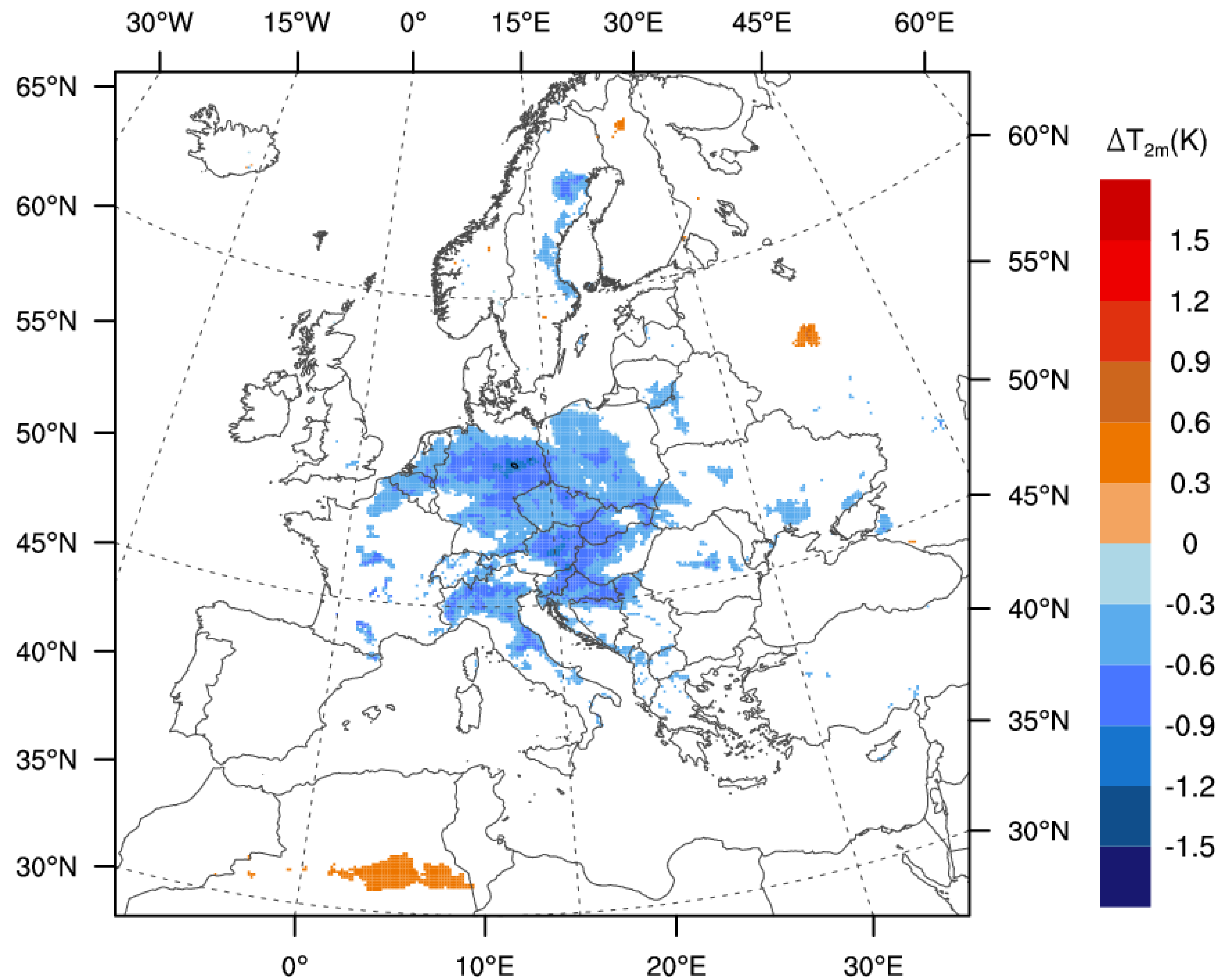
Impact on 2 m temperature





Impact on 2 m temperature

Statistical significant



NCEP

NEMS GFS Aerosol Component (NGAC)
NCEP's global interactive atmosphere-aerosol forecast system

Model Configuration:

- Forecast model: Global Forecast System (GFS) based on NOAA Environmental Modeling System (NEMS), NEMS-GFS
- Aerosol model: NASA Goddard Chemistry Aerosol Radiation and Transport Model, GOCART

Phased Implementation:

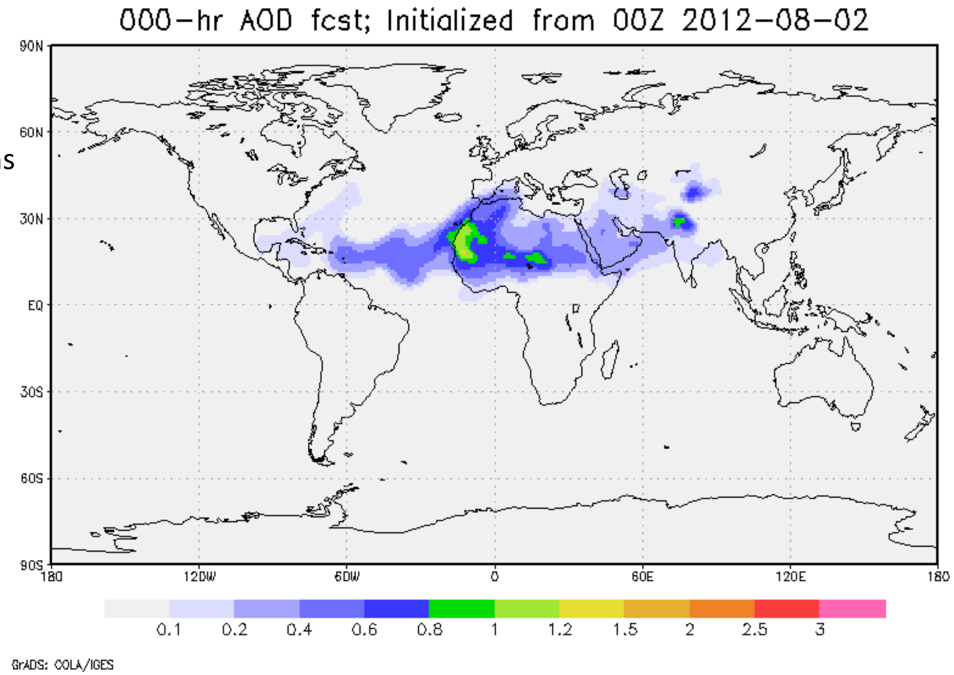
- Dust-only guidance is established in Q4FY12
- Full-package aerosol forecast after real-time global smoke emissions are available and tested (JSCDA project)

NRT Dust Forecasts

- 5-day dust forecast once per day (at 00Z), output every 3 hour, at T126 L64 resolution
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- Operational since Sept 2012

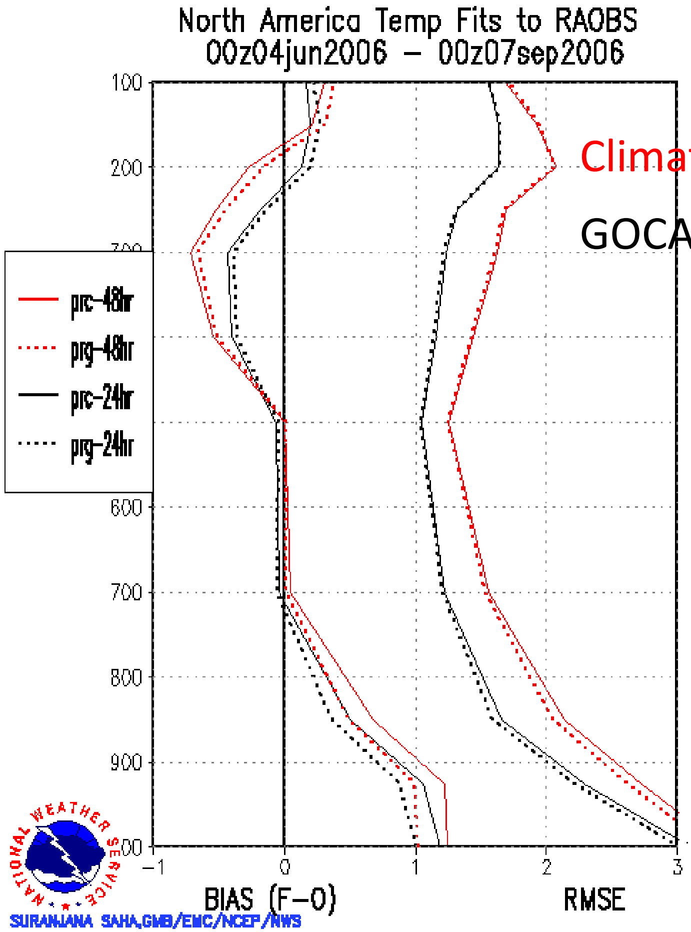
Future operational Benefits

- Enables future operational global short-range (e.g., 5-day) aerosol prediction
- Allows aerosol impacts on medium range weather forecasts (GFS/GSI) to be considered
- Provides global aerosol information required for various applications (e.g., satellite radiance data assimilation, satellite retrievals, SST analysis, UV-index forecasts)
- Provides a first step toward an operational aerosol data assimilation capability at NCEP
- Allows NCEP to explore aerosol-chemistry-climate interaction in the operational Climate Forecast System (CFS)
- Provides lateral aerosol boundary conditions for regional aerosol forecast system



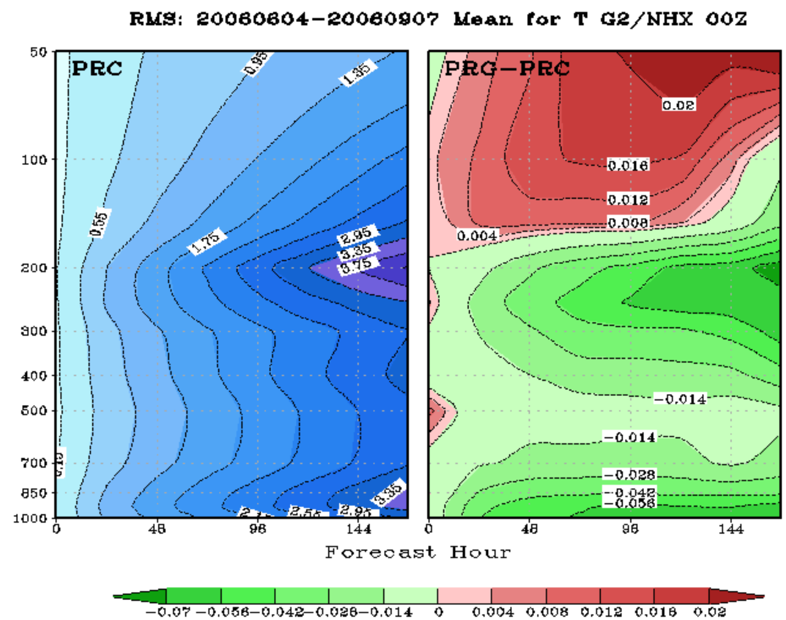
Acknowledge: Development and operational implementation of NGAC represents a successful "research to operations" project sponsored by NASA Applied Science Program, Joint Center for Satellite Data Assimilation and National Weather Services

Aerosol-radiation feedback:
Impact of aerosols on weather forecasts



Climatology aer

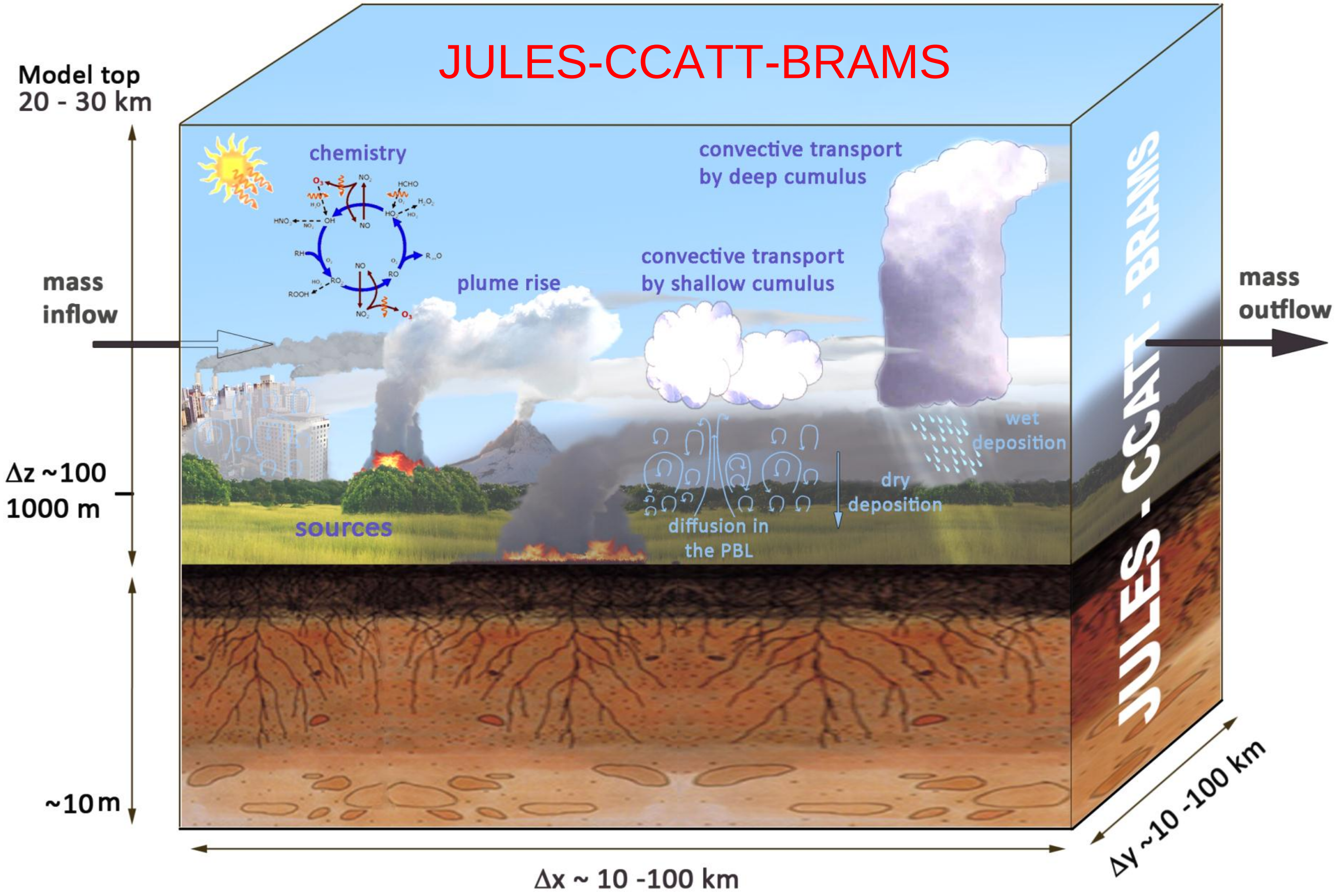
GOCART aer 6/6h



Verification against analyses and observations indicates a neutral-to-positive impact in temperature forecasts due to realistic time-varying treatment of aerosols.

- T126 L64 GFS/GSI experiments for the 2006 summer period
- PRC uses the OPAC climatology (as in the operational applications)
- PRG uses the in-line GEOS4-GOCART dataset (updated every 6 hr)

Brazil - CPTEC



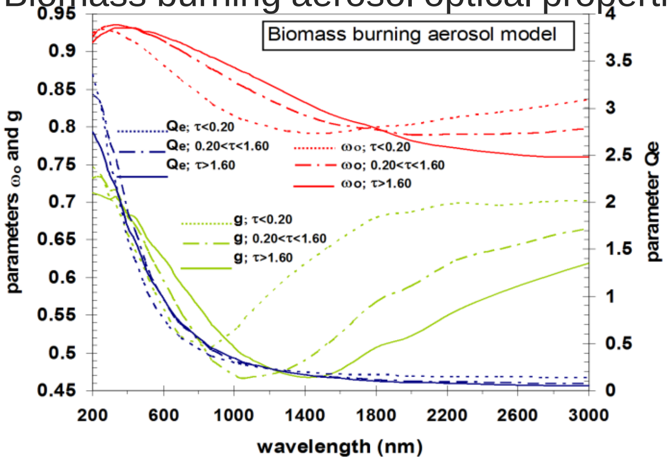
With contributions of K. Longo, N. Rosário, D. Moreira

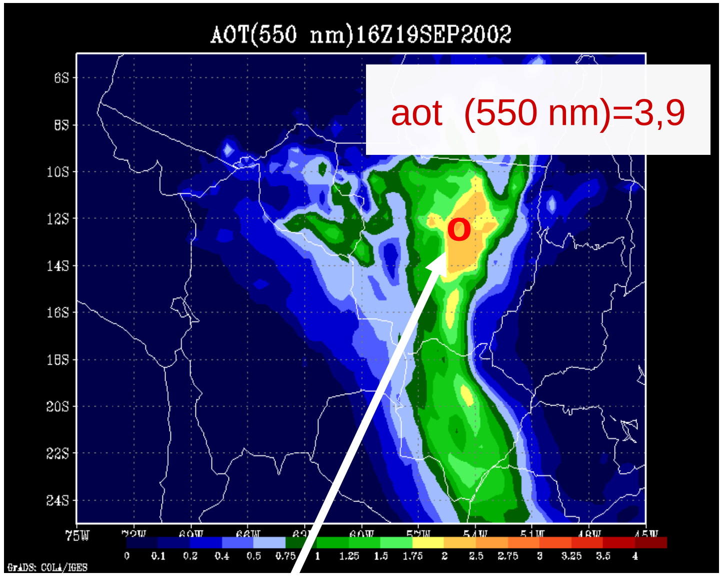
Coupled Chemistry-Aerosol-Tracer Transport model to the Brazilian developments on the RAMS:

CCATT-BRAMS	FORMULATION
Dynamics	Non-hydrostatic / time-split compressible (RAMS/CSU)
Advection	Monotonic, low numerical difusion (Walcek 2000, Freitas et al. 2011)
Sub-grid scale convective transport/ wet deposition	Coupled to Grell and Deveny (2002) cumulus scheme – (deep / shallow), now also with G3d.
PBL Turbulence	Several, normally M&Y 2.5, also Nakanishi and Nino (200x)
Dry deposition	Resistance approach coupled with surface scheme/PBL
Emissions	MEGAN, EDGAR, RETRO, 3BEM, GFED, GOCART, Volcanoes. Urban regional update for SA (Alonso et al 2010).
Plume rise – Veg. Fires	1-D in-line cloud model forced by heat flux / fire size and thermodynamic profile simulated by the host model (Freitas et al., 2007/2010)
Gas-Phase Chemistry	SPACK pre-processor (RACM, RELACS, CB07; Longo et al., 2011)
Photolysis	LUT, FAST-JX, FAST-TUV(in-line, aerosol and clouds effects)
Boundary condition	MOCAGE global chemistry model
Aerosol with direct effect on radiation	Simple mono-disperse for biomass burning/urban (Longo et al 2006, Rosário et al., 2011). The aerosol model "MATRIX" (Bauer et al., 2008) is under implementation.
Indirect effect	Cloud microphysics and cumulus parameterization (under evaluation)

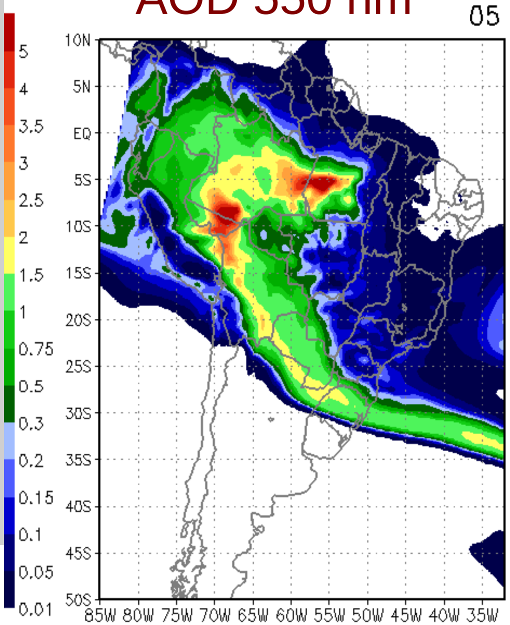
Biomass Burning Aerosols

Biomass burning aerosol optical properties

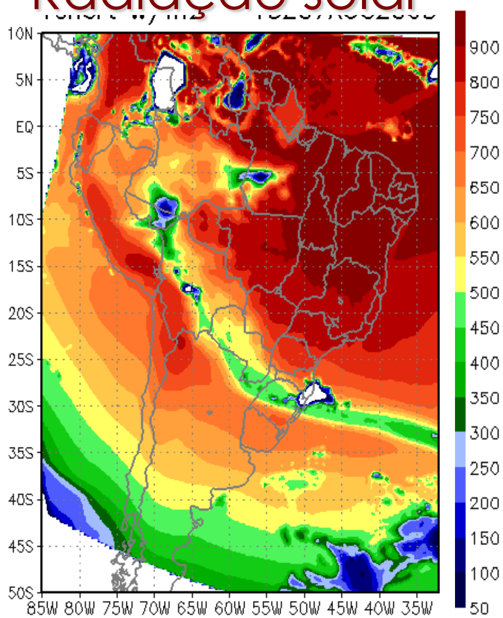


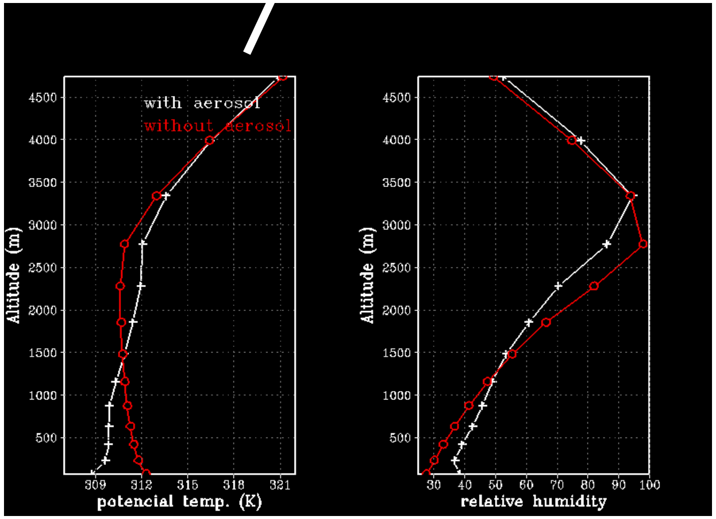


AOD 550 nm



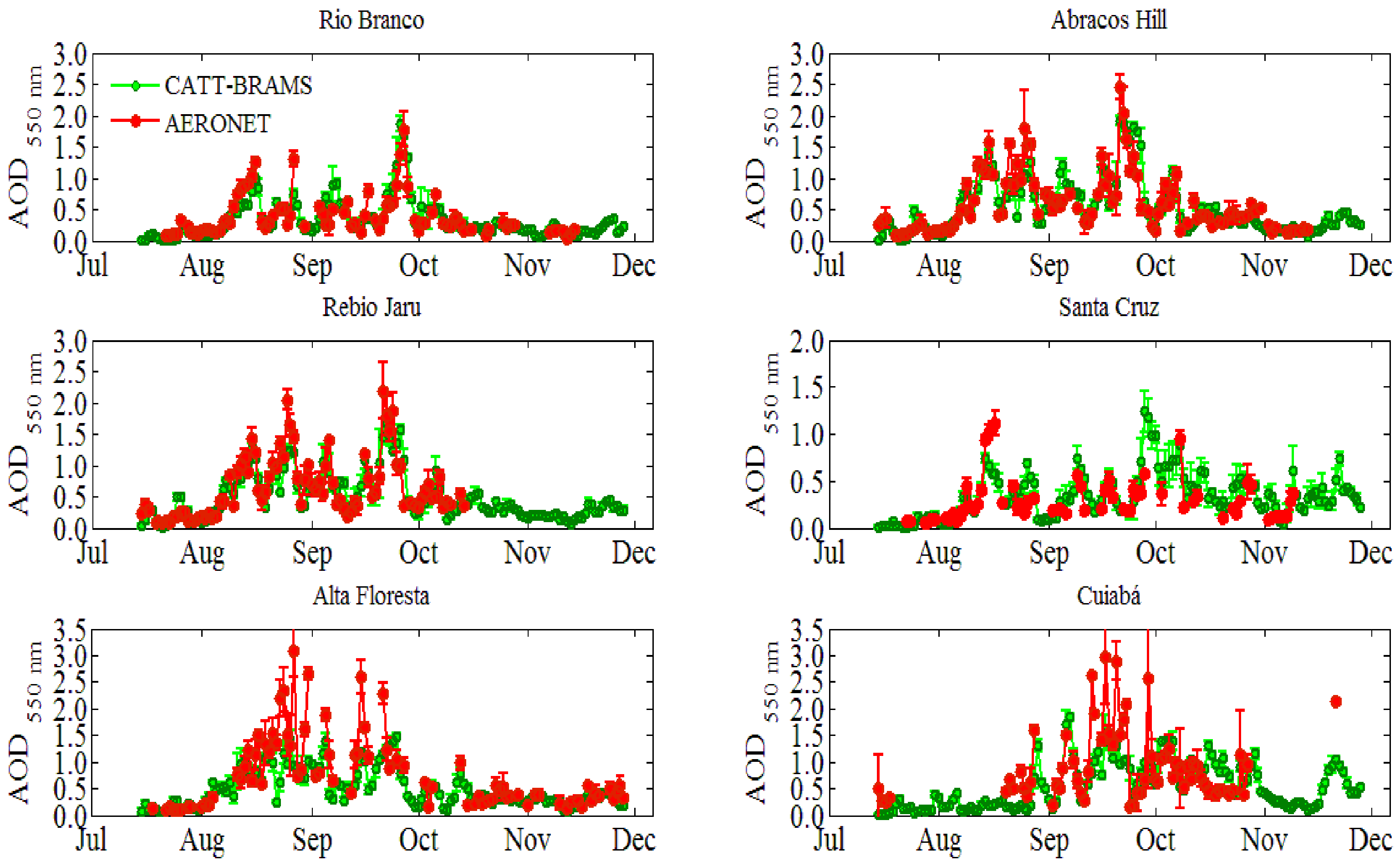
Radiação solar





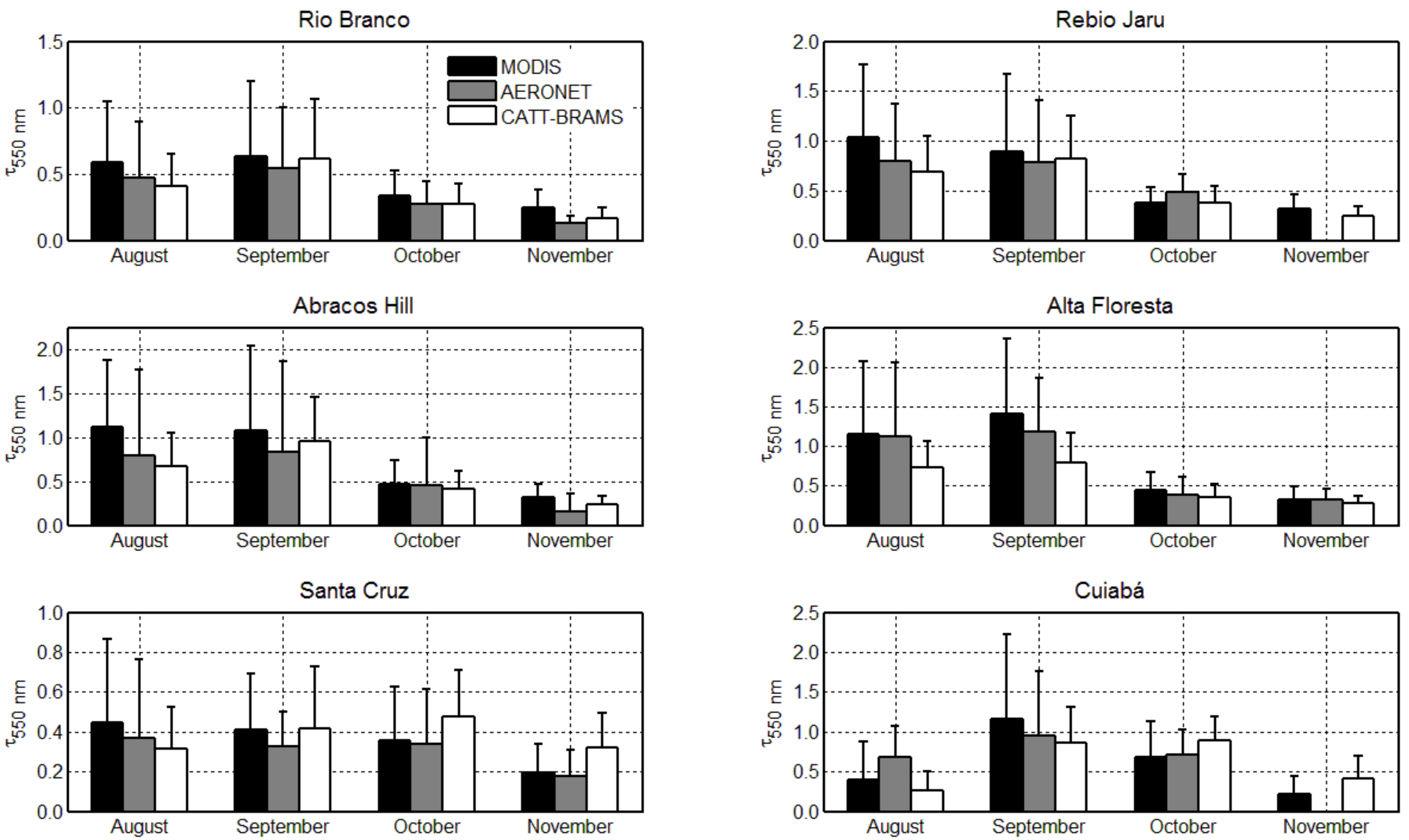
Longo et al., 2006

AOD (550 nm) – biomass burning South America
CATT-BRAMS versus AERONET



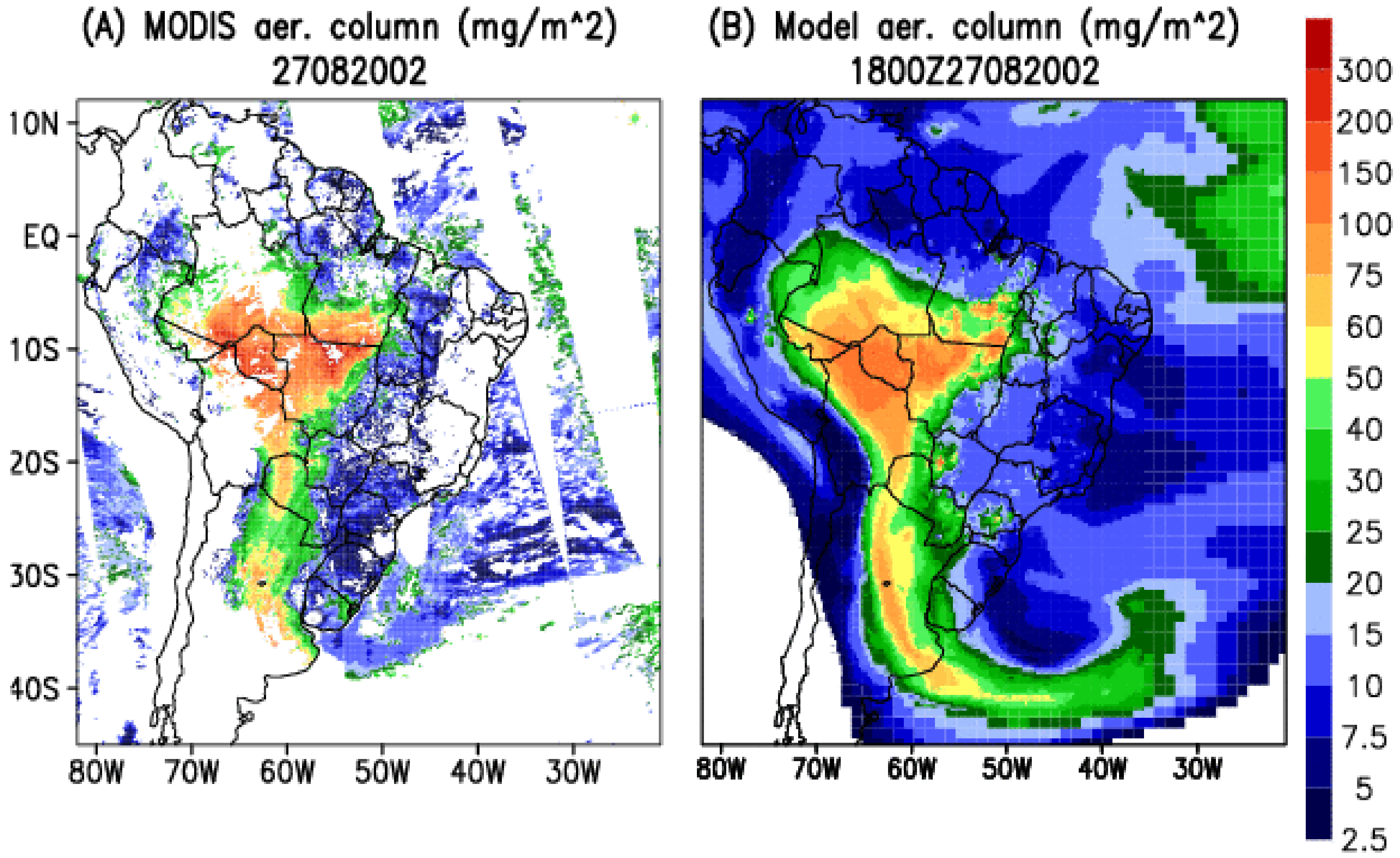
Rosário et al., 2012

AOD (550 nm) – biomass burning South America CATT-BRAMS versus AERONET and MODIS



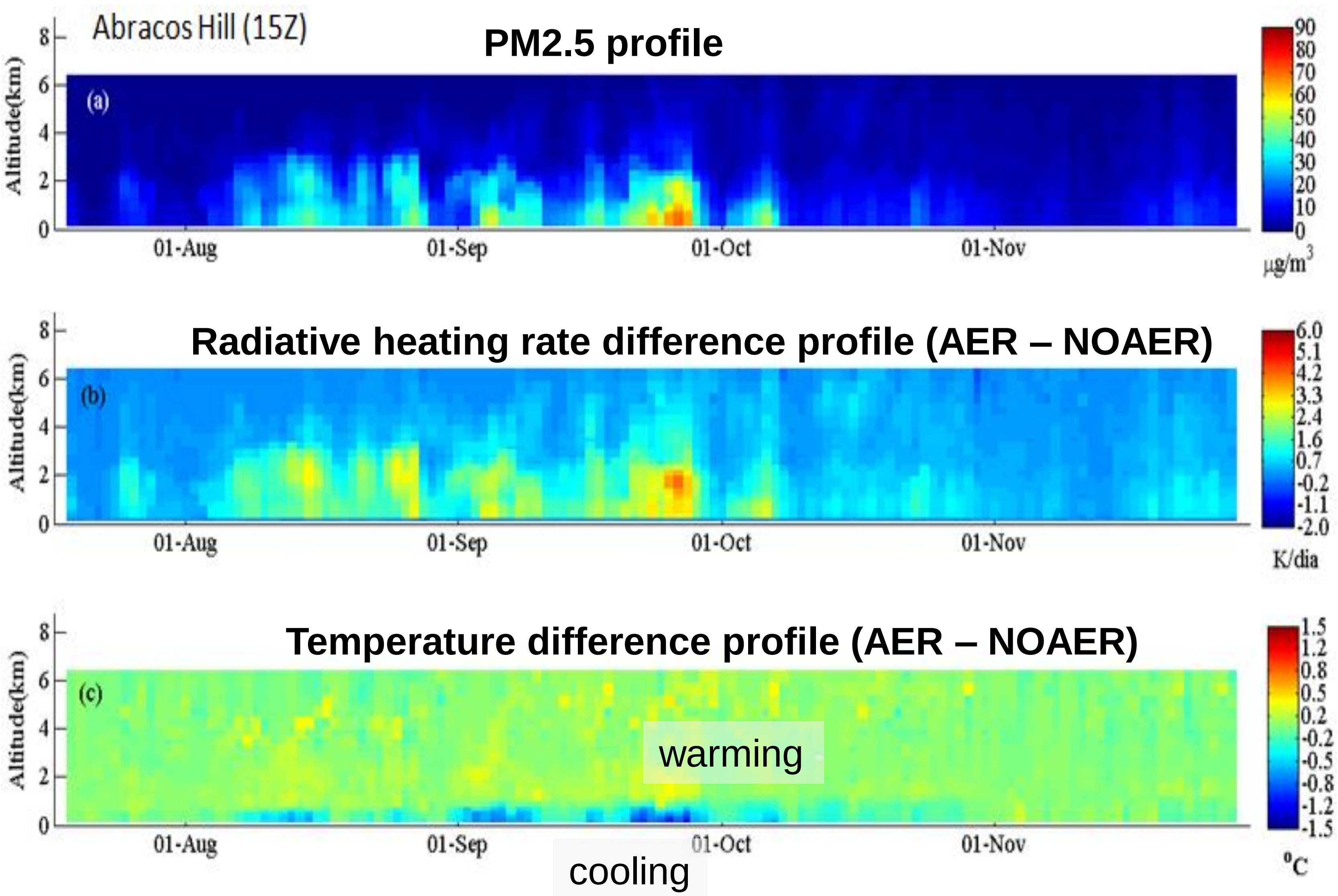
Rosário et al., 2012

Mass Aerosol Column (PM2.5)
MODIS x CATT-BRAMS model



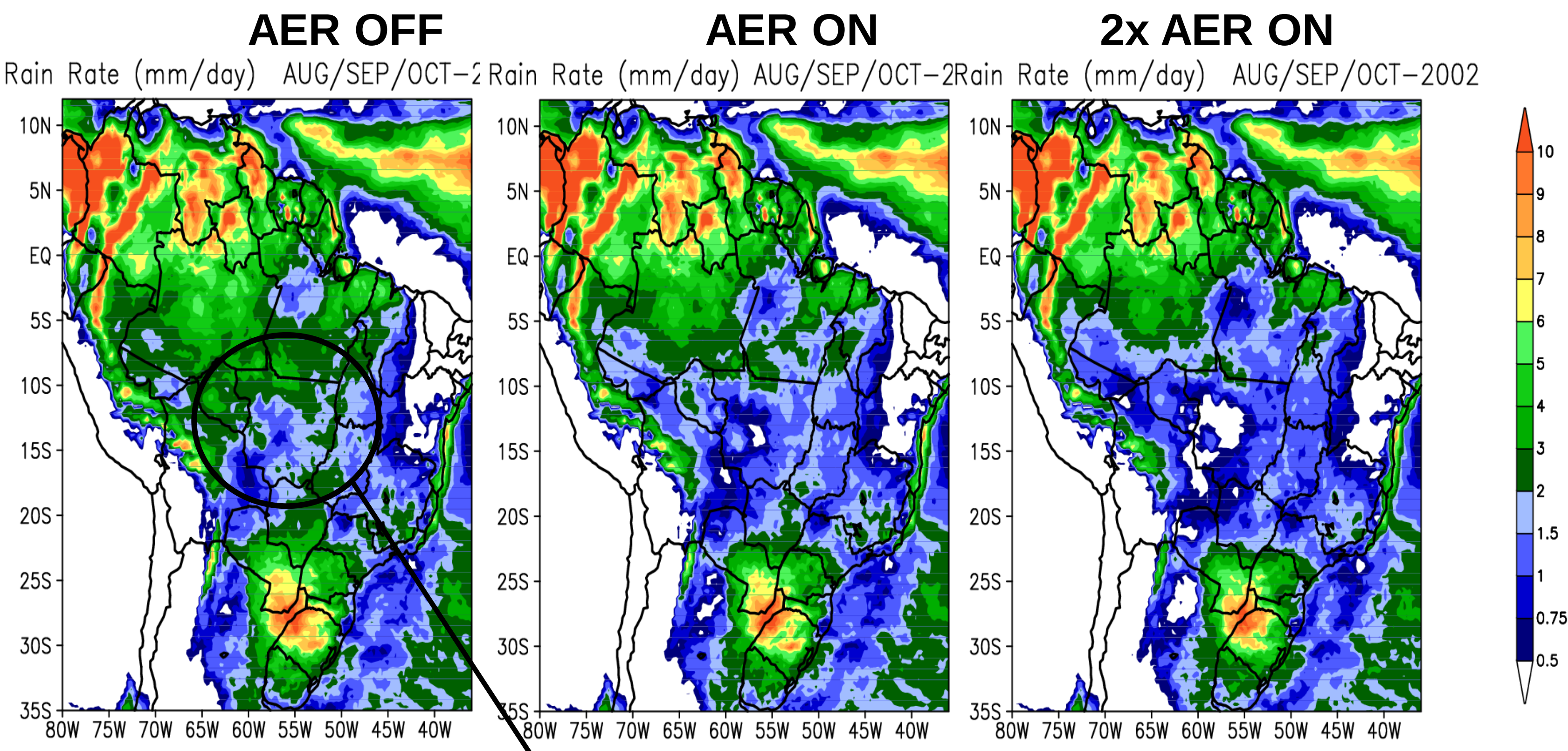
Freitas et al., 2009

Aerosol Direct Radiative Effect:
PM2.5 profile x temperature profile



Rosário et al., 2012

Modeling Impacts of Biomass Burning Aerosols on Rainfall



Climatology (ASO): ~ 1 mm/day

(only the direct effect is included)

Tuning the surface scheme LEAF to work better for tropical/sub-tropical biomes

floresta, pastagem e cerrado.

Principais parâmetros/processos modificados:

- LAI (NDVI – MODIS)
- albedo
- condutância estomática máxima
- rugosidade (z_0)
- plano de deslocamento (d)
- capacidade térmica do solo e da biomassa
- porosidade, ponto de murcha do solo, condutividade hidráulica
- esquema de raízes de Arora e Boer (2003)
- umidade do solo estimada (Gevaerd e Freitas, 2006)
- vegetação atualizada com dados do PROVEG

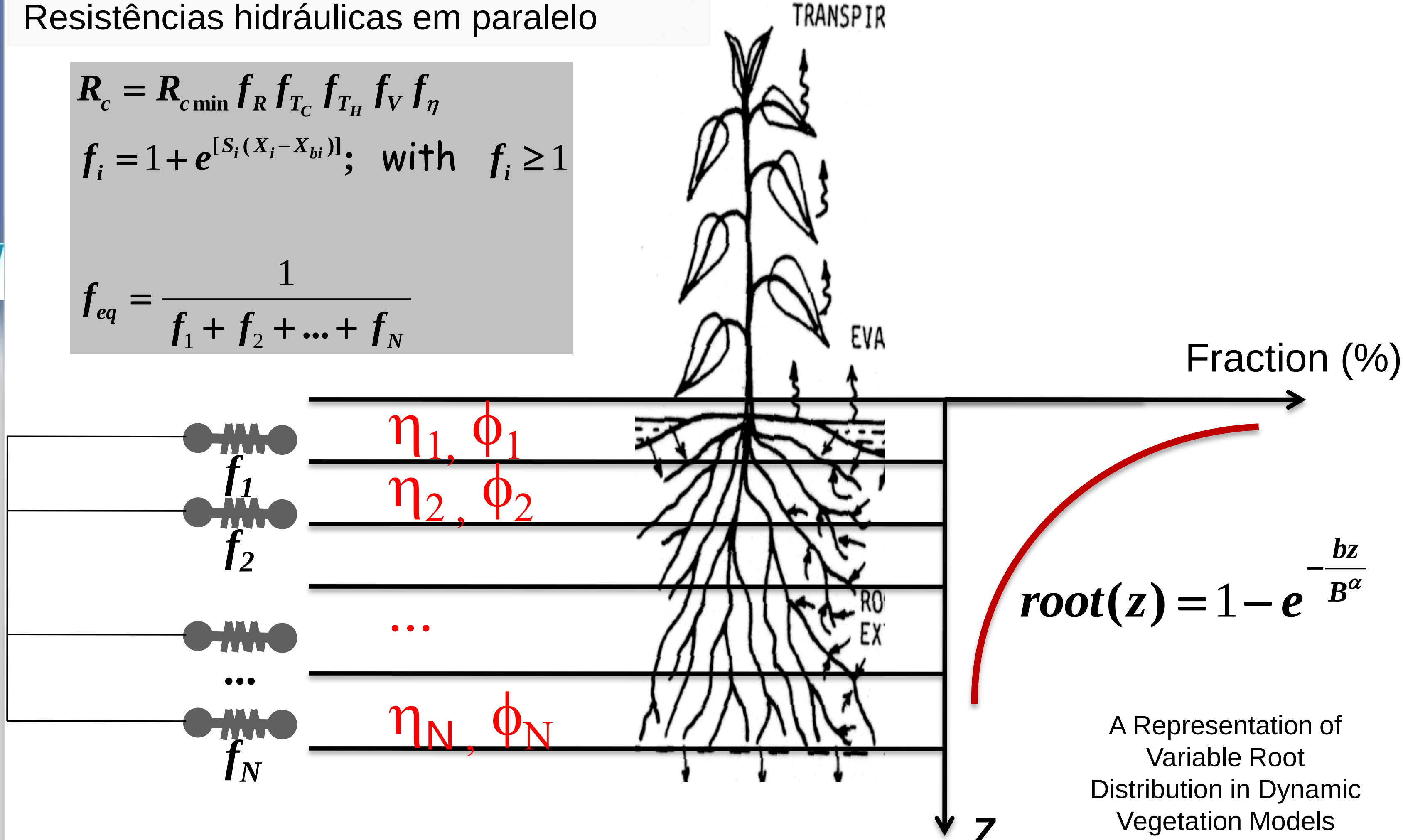
New root profile in LEAF-3

Resistências hidráulicas em paralelo

$$R_c = R_{c\,\min} f_R f_{T_C} f_{T_H} f_V f_\eta$$

$$f_i = 1 + e^{[S_i(X_i - X_{bi})]};\quad \text{with}\quad f_i \geq 1$$

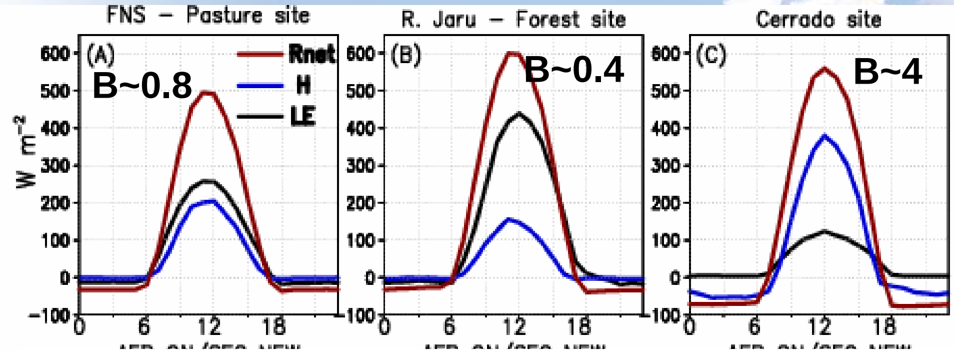
$$f_{eq} = \frac{1}{f_1 + f_2 + \dots + f_N}$$



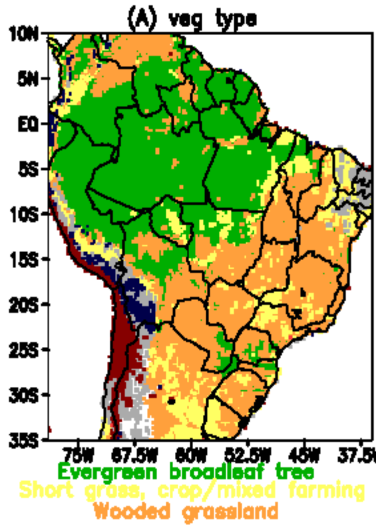
A Representation of Variable Root Distribution in Dynamic Vegetation Models (Arora & Boer, 2003)

LE, H, Rnet observations

von Randow et al., 2004
Miranda et al., 1997

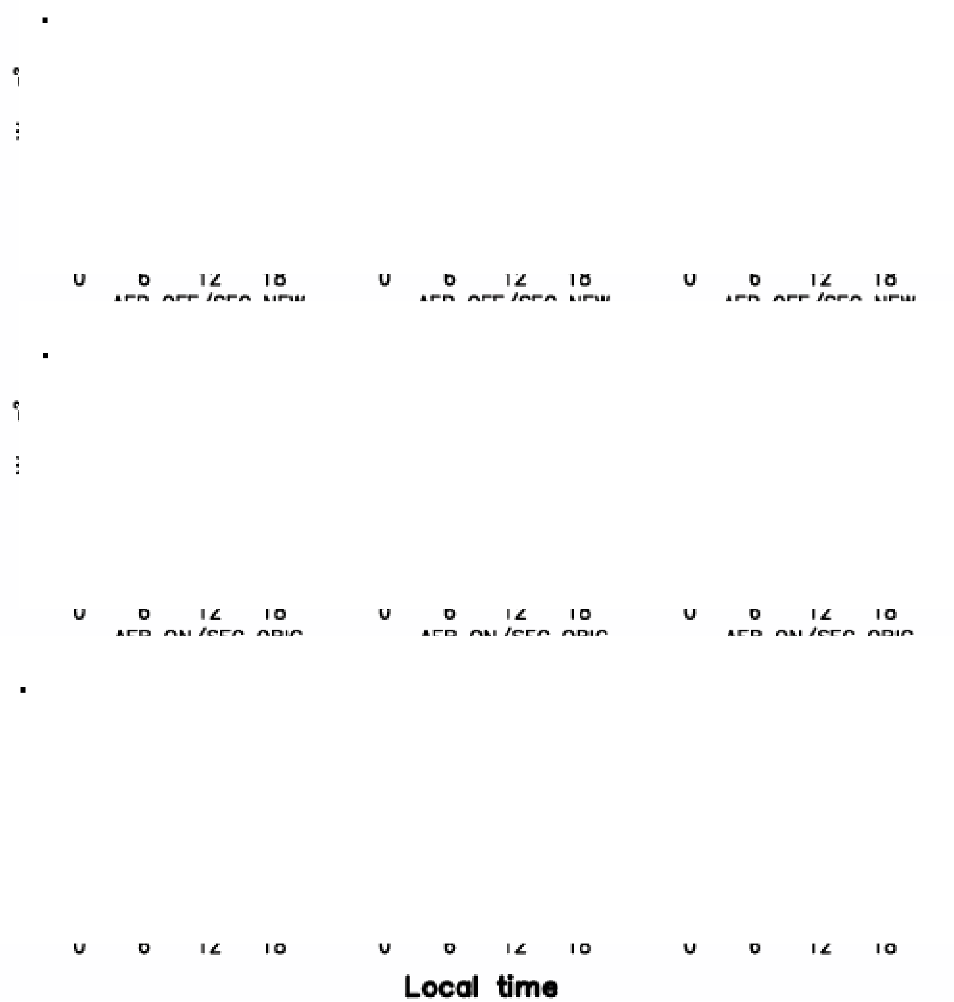


Improved sfc
aerosol ON

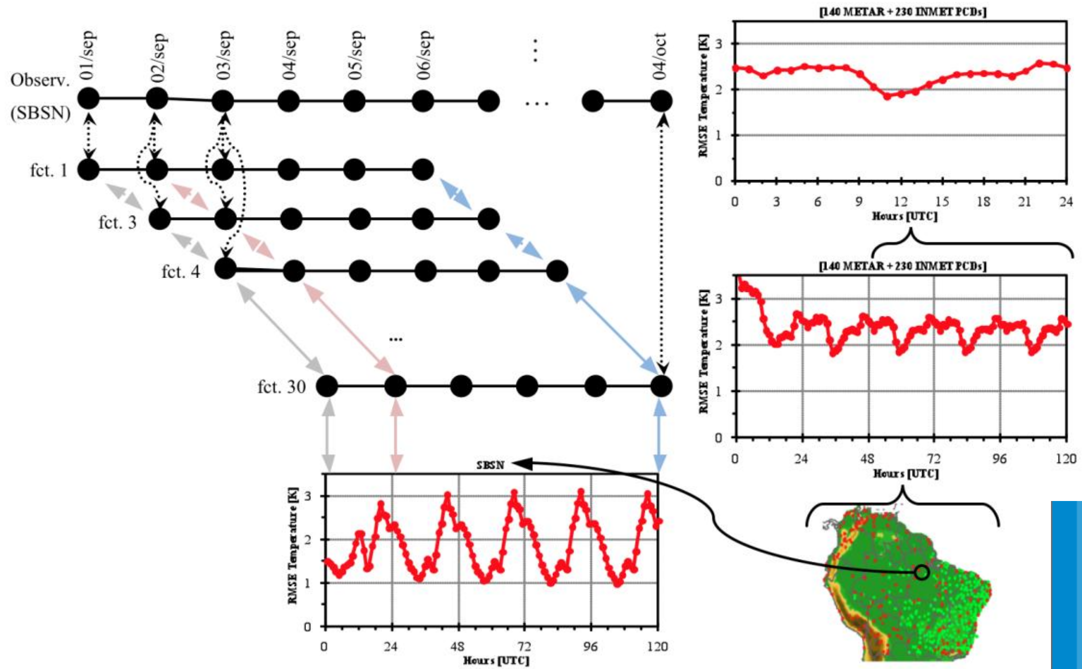


Improved sfc
aerosol OFF

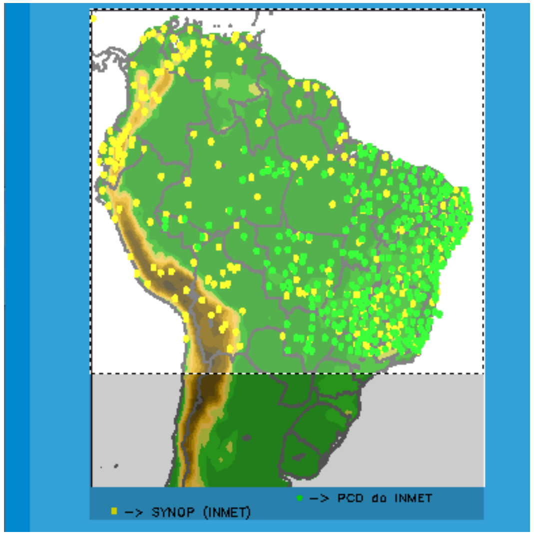
Original sfc
aerosol ON



BRAMS Weather Forecast Evaluation with JULES
Including the Aerosol Direct Effect



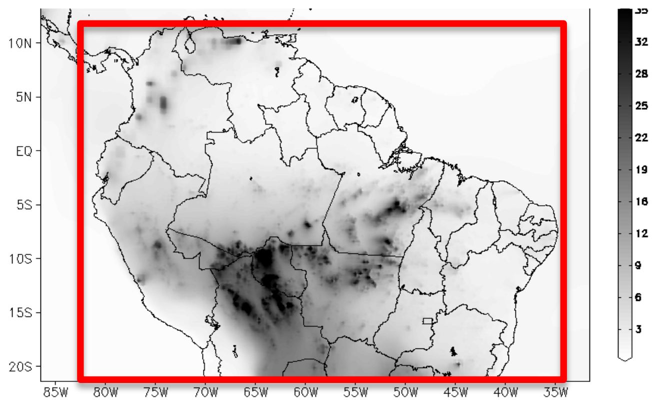
Evaluation for September (peak of the fire season) 2010 :
1 month runs with 5 days forecast each day (150 forecasts)

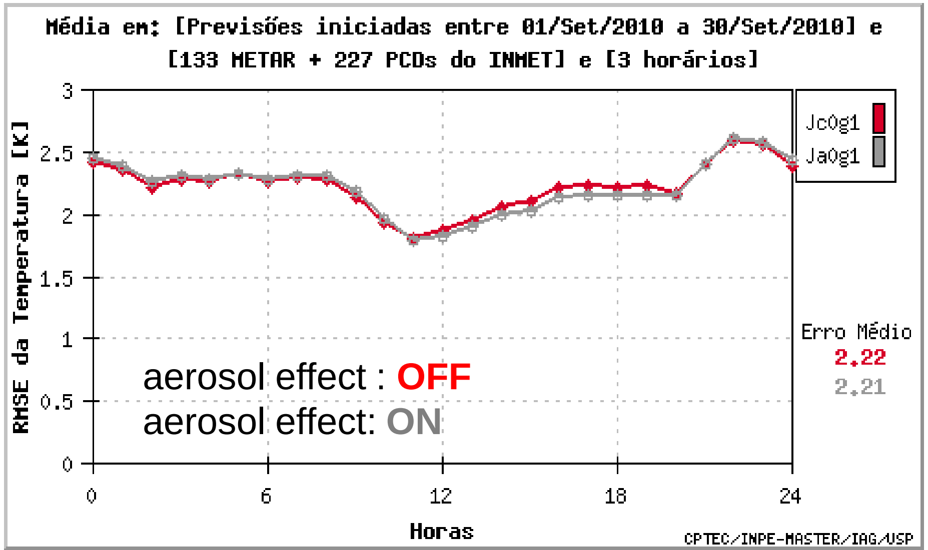


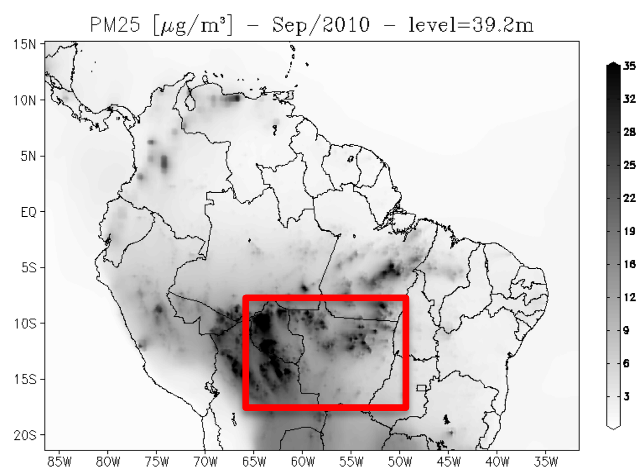
~ 300 stations

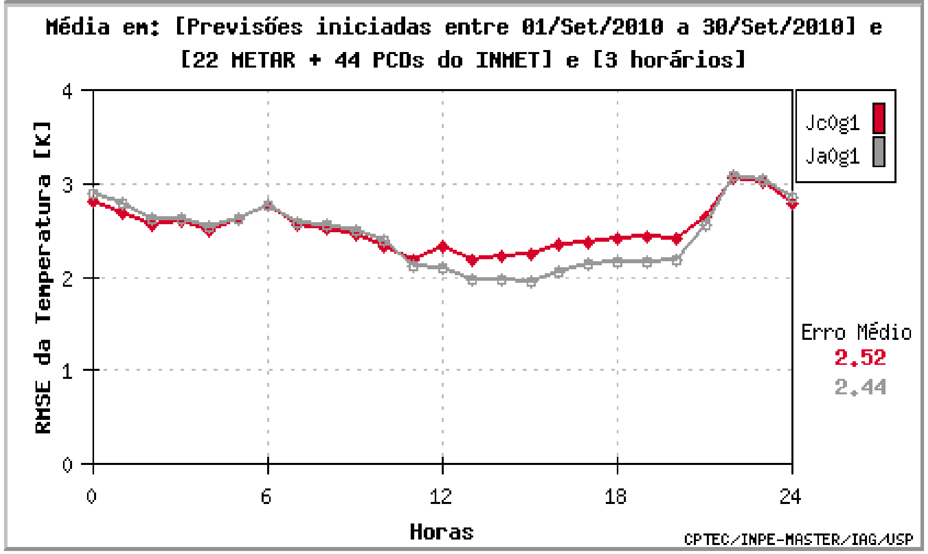
Biomass burning aerosol impact on 2m-temperature (RMSE)

PM2.5 – monthly average (sep2010)



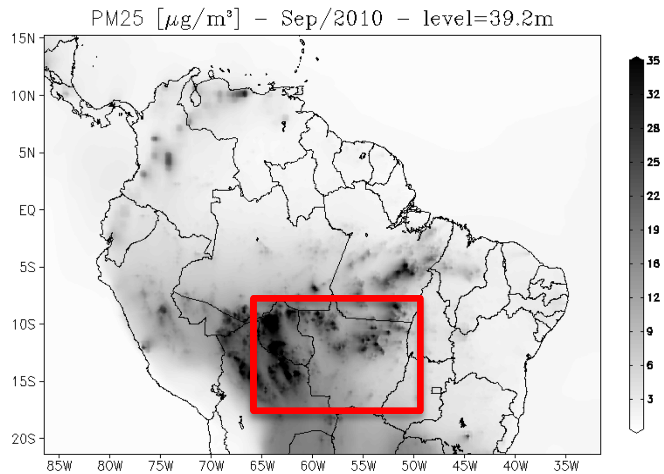


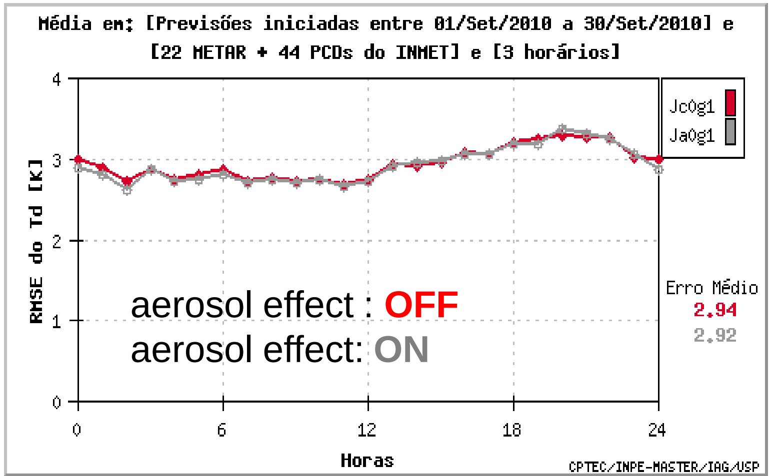


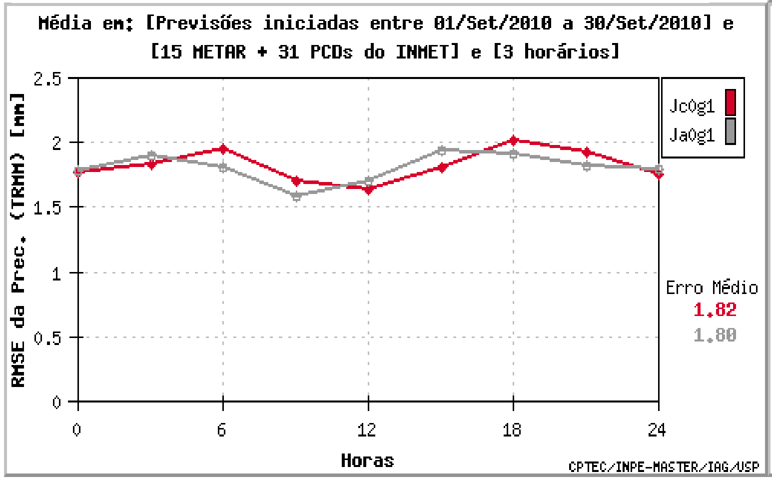


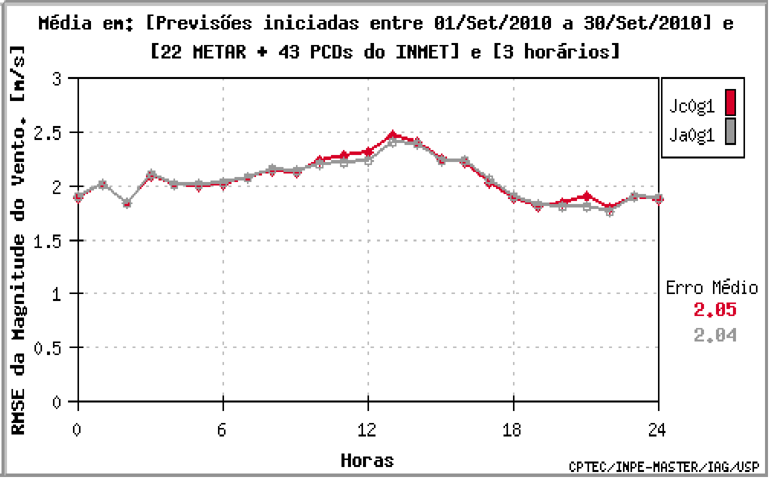
Moreira et al (in prep.)

Biomass burning aerosol impact on 2m-Td, Precip, wind magnitude (RMSE)









Moreira et al (in prep.)

Aerosol Indirect Effect included in the G3d convective parametrization.

- Implementing scale dependence
  - The finer the resolution the less strong are the parameterized tendencies.
  - Clouds get shallower as resolution increases (for dx < 5km), solution converges more and more towards cloud resolving model.

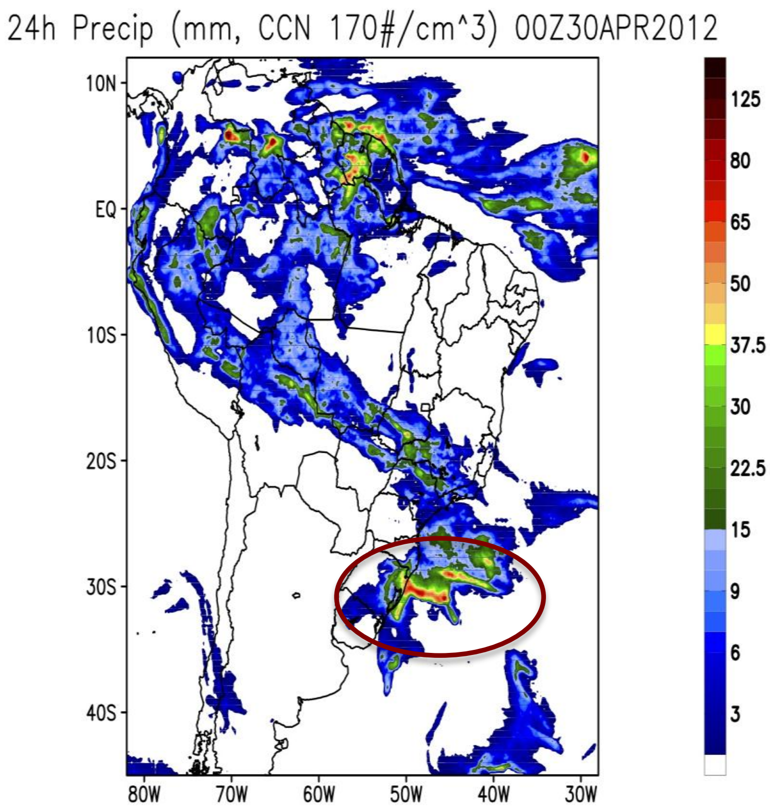
- Implementing aerosol feedback (CCN derived from AOD, or directly from aerosol model if available).
  - Variable autoconversion (Berry formulation) for conversion of cloud water to rainwater (Berry 1968),
  - Variable precipitation efficiency; more efficient evaporation of smaller droplets (polluted air) causing stronger downdrafts (Jiang et al., 2010).

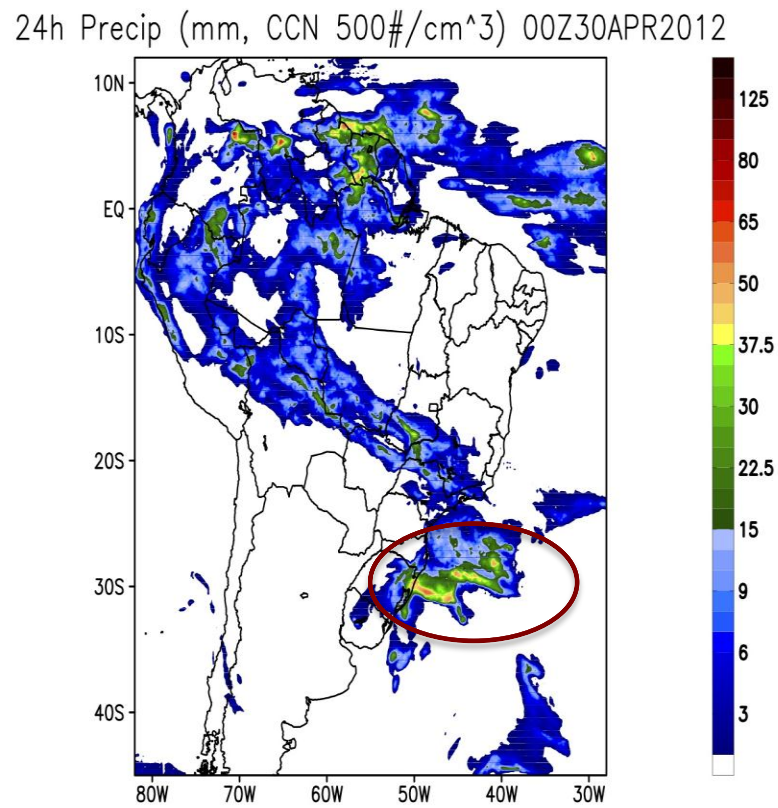
Grell and Freitas (in preparation)

Aerosol Indirect Effect included in the G3d convective parametrization.

Sensitivity simulation - 24 h accumulated precipitation for 2 scenarios

Clean atmosphere	Semi-polluted
CCN = 170 m^{-3}	CCN = 5m^{-3}



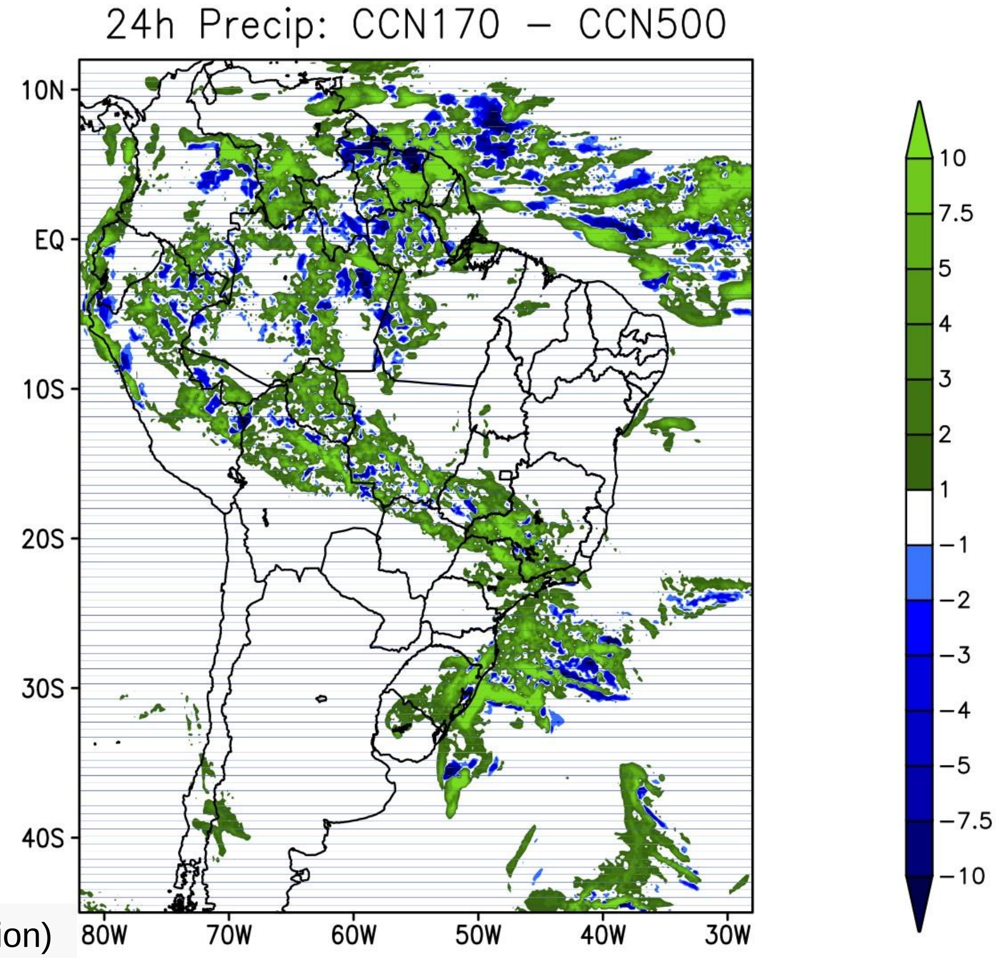


Grell and Freitas (in preparation)

Aerosol Indirect Effect included in the G3d convective parameterization.

Sensitivity simulation - 24 h accumulated difference on precip

Precip {CCN = 170 m^{-3}} – Precip(CCN = 500m^{-3})



Grell and Freitas (in preparation)

Regional Climate Impact of Biomass Burning Aerosols on Amazon Basin

Emission Scenarios of biomass burning aerosol (2007-2030)

- Mapa de uso da terra
- Total de emissão de carbono equivalente

- Hipótese: 85% do CO2 gerado por combustão

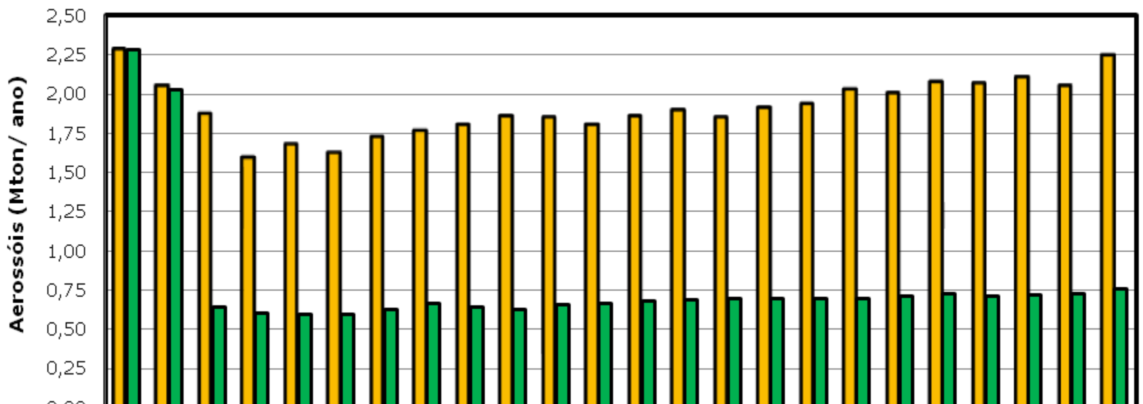
$$ET_{aer}=(EF_{aer}/EF_{CO2}).ET_{CO2}$$

Brazil low carbon study - World Bank

Modelo econômico
Brazil Land Use Modeling (BLUM)
Demanda e oferta produtos agrícolas e pecuária (Ícone-embrapa)

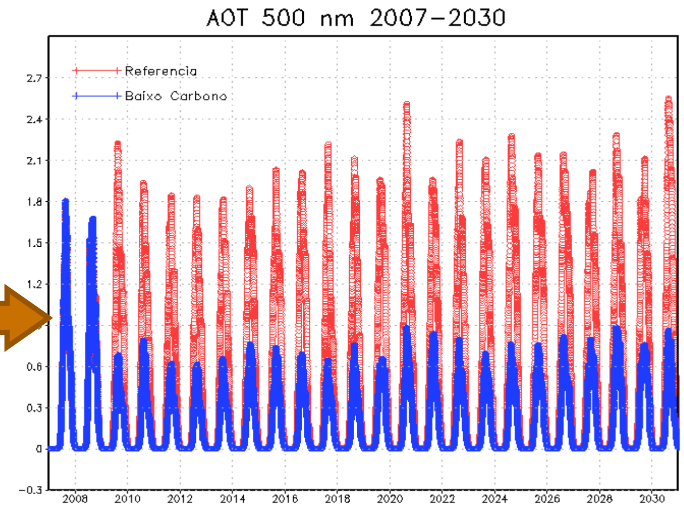
Espacialização georeferenciada
Simulate Brazil (SIM BRAZIL)
Alocação das áreas modificadas no Brasil (2007 – 2030) (UFMG)

Estimativa de emissão total de aerossóis no Brasil



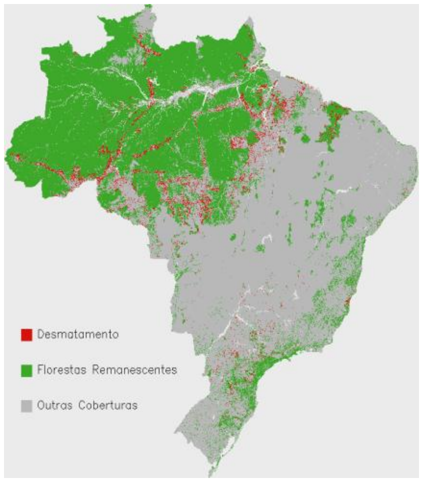
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Referência	2,28	2,05	1,87	1,59	1,67	1,62	1,72	1,76	1,80	1,85	1,84	1,80	1,85	1,89	1,85	1,91	1,93	2,02	2,00	2,07	2,06	2,10	2,05	2,24
Baixo Carbono	2,29	2,03	0,64	0,60	0,60	0,59	0,62	0,67	0,64	0,63	0,65	0,67	0,68	0,69	0,70	0,70	0,70	0,69	0,71	0,72	0,71	0,72	0,73	0,76

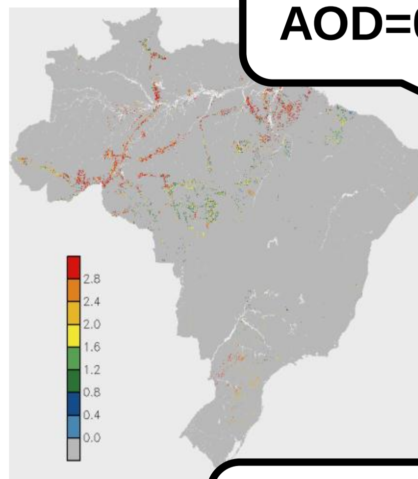
AOT na Amazônia - CCATT-BRAMS



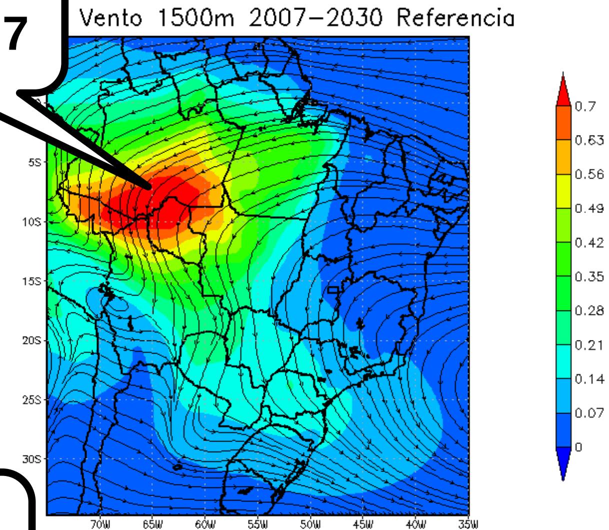
Spatial Emission Distribution and the associated simulated AOD @ 500 nm

Control Scenario

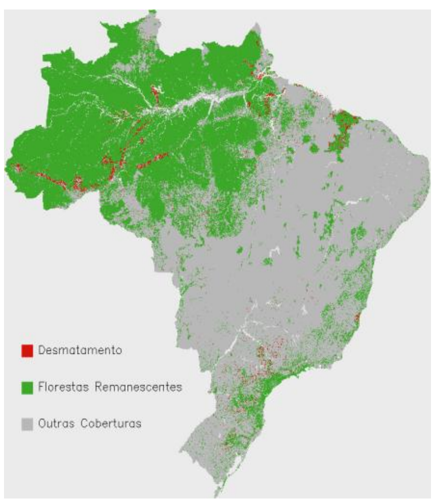


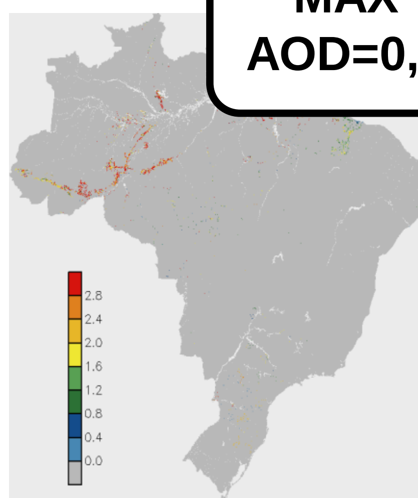


MAX AOD=0,7

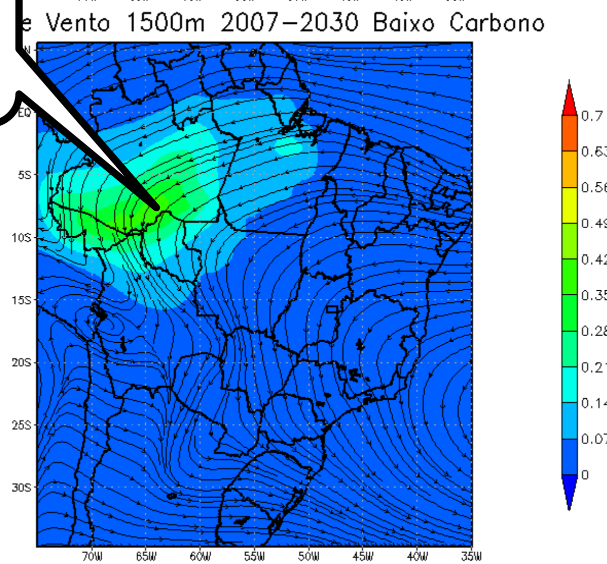


Low Carbon Scenario





MAX AOD=0,4



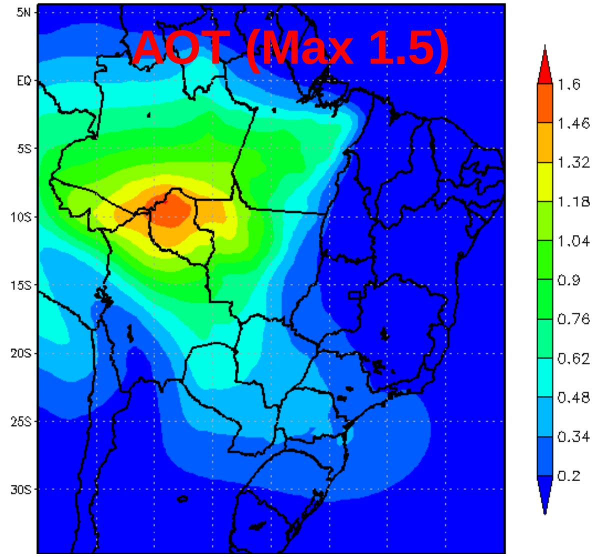
Deforestation

2007-2030

Emission [ton/(hec year)]
2007-2030

Impacts : reference x low carbon scenarios (Months: AUG-SEP-OCT)

Diferenca AOT 500 nm AGO-SET-OUT 2007-2030



Difere

Thanks for your attention !