Evaluating Aerosols Impacts on Numerical Weather Prediction: a WGNE/WMO initiative

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With inputs from: Mauricio Zarzur, Arlindo Silva, Angela Benedetti, Georg Grell, Oriol Jorba, Morad Mokhtari, Samuel Remy and WGNE Members Participants

Working Group on Numerical Experimentation (WGNE)
https://www.wmo.int/pages/about/sec/rescrosscut/resdept_wgne.html

Goals of the Exercise

- This project aims to improve our understanding about the following questions:
- 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?
- What are the current capabilities of NWP models to simulate aerosol impacts on weather prediction?

The general approach of the proposed work is:

- Select strong or persistent events of aerosol pollution worldwide that could be fairly represented in the current NWP model allowing the evaluation of aerosol impacts on weather prediction.
- Perform model runs both including and not the feedback from the aerosol interaction with radiation and clouds.
- Evaluate aerosol simulation
  - AOD or related parameter
  - Verification: AERONET, MODIS, MISR
- Evaluate aerosol impact on meteorology:
  - 2-meter temperature, 2-m dew point temperature, 10-meter wind
  - rainfall, surface energy budget, etc.

Protocol: Experiments

Experiment	Direct Effect	Indirect Effect	No aerosol Interaction
1	X		
2		X	
3	X	X	
4			X

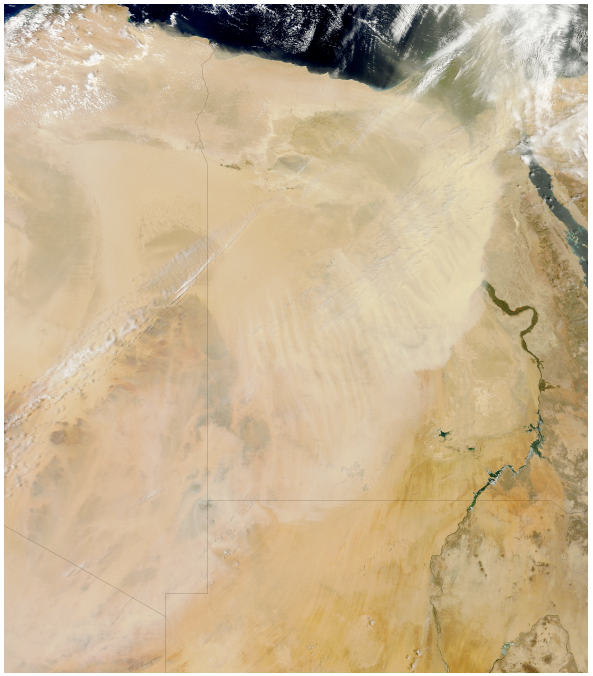
Protocol: Variables

- Variables to compare:

Variable name on 3 hours interval	Dimensio-nality	units	obs
2m-Temperature	x,y	K	
10m-wind direction and magnitude	x,y	Degree m/s	
Aerosol optical depth at 550 nm	x,y	-	
total aerosol mass column integrated	x,y	Kg/m^2	
Precipitation (from convective parameterization)	x,y	mm	
Precipitation (from cloud microphysics at grid scale)	x,y	mm	
shortwave and longwave downwelling radiative flux at the surface.	x,y	W/m^2	
temperature tendency associated to the total radiative flux divergence.	x,y,z	K/s (or dy)	
Temperature	x,y,z	K	
Relative Humidity	x,y,z	-	
Cloud drop number concentration	x,y,z	cm^{-3}	

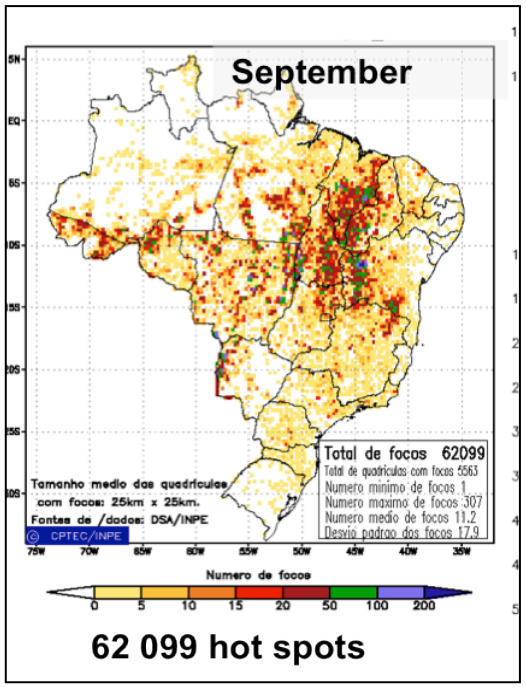
- Output should be using a lat-lon rectangular grid. The preferred format is NETCDF.

Case Studies



1) Dust over Egypt: 4/2012

2) Urban Pollution in China: 1/2013



3) Smoke in Brazil: 9/2012

Participants (8 centers)

Participants	Case 1	Case 2	Case 3	Type of model	**Complexity level**	**People Involved**
CPTEC/Brazil			**X**	**R**	aerosol direct effect only	Saulo Freitas,Karla Longo, Mauricio Zarzur,
JMA/Japan	**X**	**X**	**X**	**G**	ind, dir, ind+dir, no-aer	Taichu Tanaka, Chiasi Muroi
ECMWF/ Europe	**X**	**X**	**X**	**G**	(aerosol direct effect only	Angela Benedetti, Samuel Remy, Jean-Noel Thepaut
Météo-France/Met. Serv. Algeria	**X**			**R**	aerosol direct effect only	Morad Mokhtari, Bouyssel Francois
ESRL/NOAA/ USA		**X**	**X**	**R**	aerosol direct and indirect effect	Georg Grell
NASA/ Goddard/USA	**X**	**X**	**X**	**G**	direct effect only	Arlindo da Silva
NCEP/USA	**X**	**X**	**X**	**G**	direct effect only	Sarah Lu, Yu-Tai Hou, S.Moorthi, and F. Yang
Barcelona Super. Ctr. Spain	**X**			**R**	aerosol direct effect only	Oriol Jorba Casellas

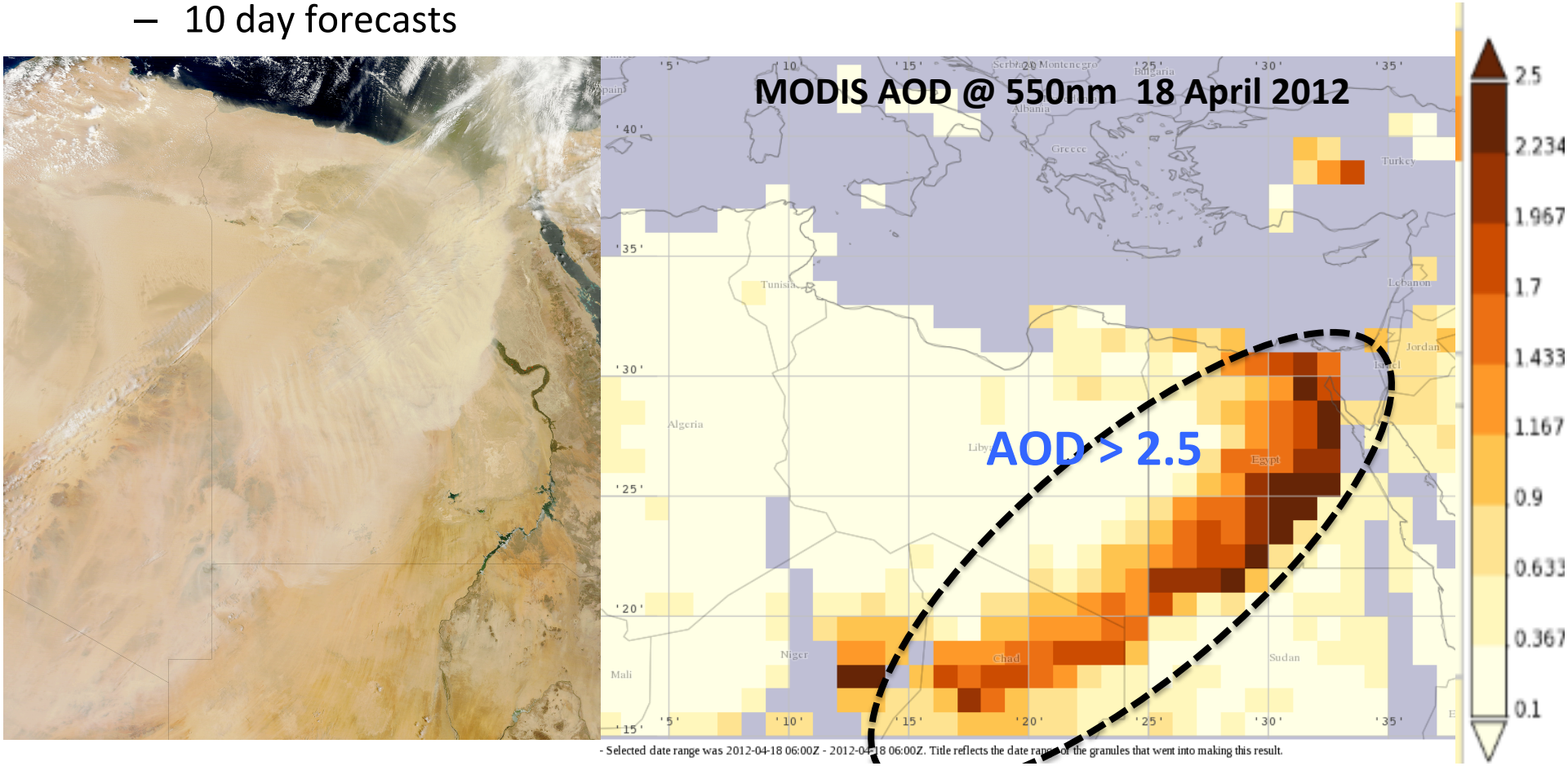
Participating Models

Institution Model	Domain Resolution	Aerosol Species	A & BB Emissions	Aerosol Physics	Cloud Physics	Aerosol Assimilation
CPTEC BRAMS LAM+CCAT	Regional 10 km	BC, Sea-Salt, OC, SO4	EDGAR 4. 3BEM	bulk	2-mom	no
JMA MASINGAR	Global TL319L40	Dust, Sea-Salt, BC, OC, SO4	MACCity GFAS 1.0	2-mom	2-mom	no
ECMWF Global	Global T511L60			Bulk	Bulk	yes
Météo-France ALADIN + ORILAM	Regional 7.5 km	Dust	DEAD model	3-mom lognormal	Bulk	no
ESRL/NOAA WRF-Chem	Regional cloud res.	(many)	EDGAR 4. 3BEM	Bulk and Modal	2-mom	no
NASA/GSFC GEOS-5+GOCART	Global 25 km	Dust, Sea-Salt, BC, OC, SO4	EDGAR 4.1 QFED 2.4	Bulk	Bulk or 2-mom MG	yes
NCEP NGAC+GOCART	Global T126	Dust, Sea-Salt, BC, OC, SO4	Climatological Aerosols	Bulk	Bulk	no
Barcelona SC	regional	dust	BSC-dust model	8 dust size bins	Same as in WRF	no

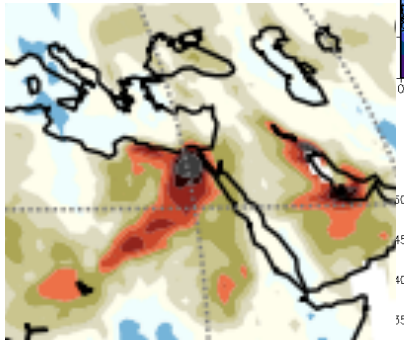
Case 1: Dust Plume over Egypt

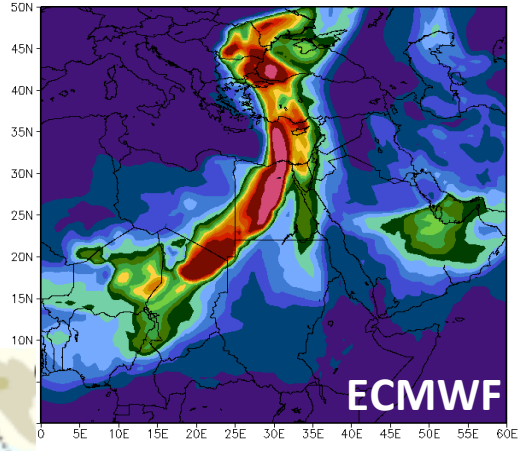
- Forecasts
  - April 13-23 2012
  - From 0 or 12 UTC
  - 10 day forecasts

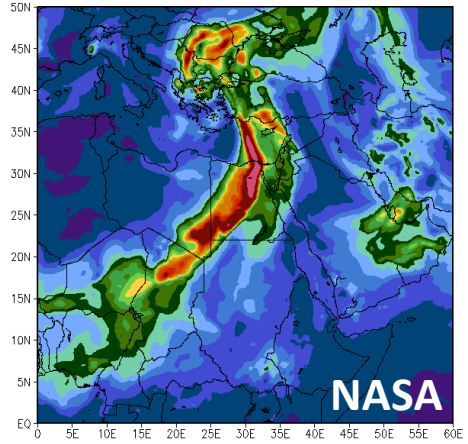
Model configuration : same as for NWP
Direct effects only

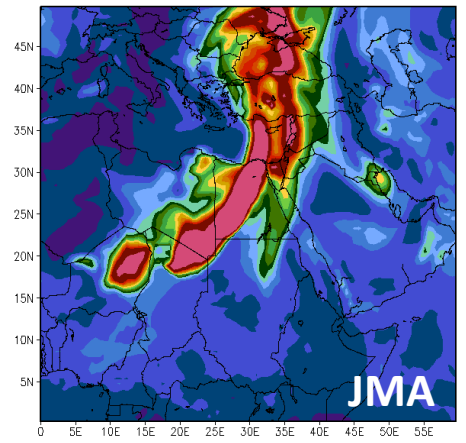


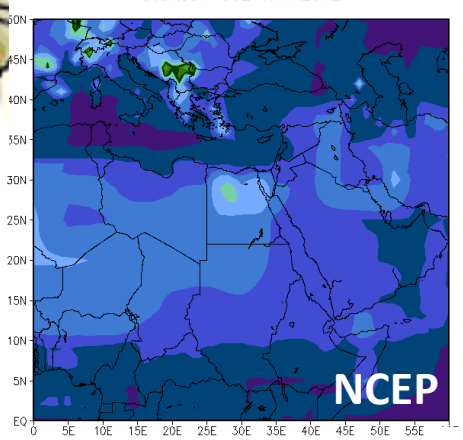
AOD at 550nm: Forecast 09UTC18apr2012 (33h fct)
Init: 00UTC17apr2012

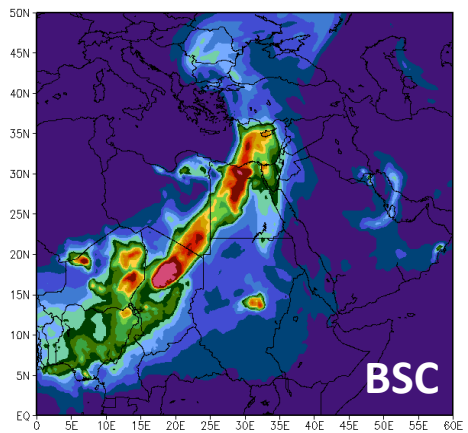


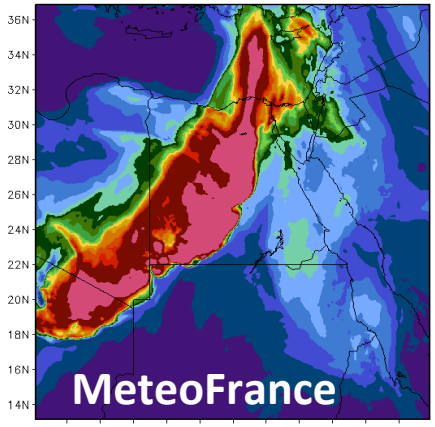


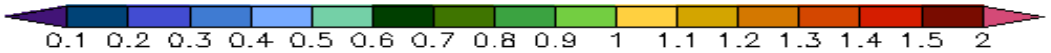












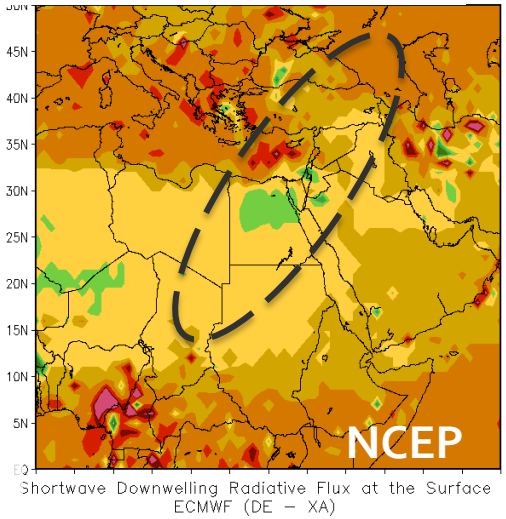
- NCEP : climatology aerosol field does not capture this transient/strong event (as expected).
- The other centers have similar pattern in terms of spatial distribution.
- AOD values : MF > JMA ~ ECMWF > NASA ~ BSC

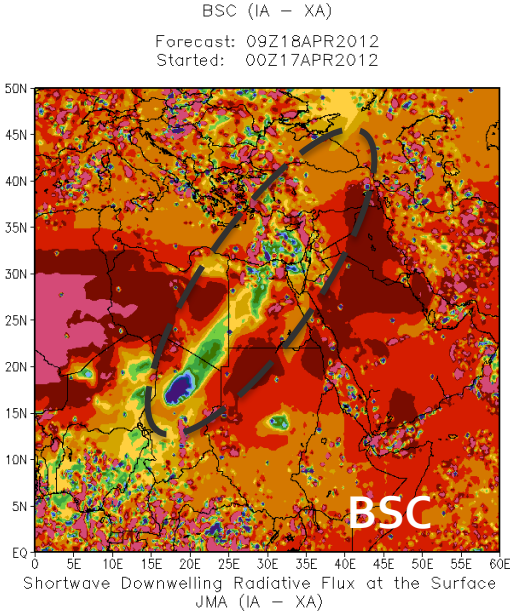
Impacts on weather forecasting

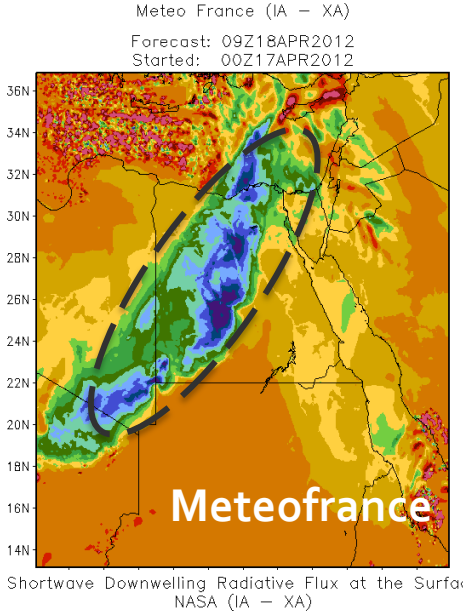
- Radiative short/longwave downwelling flux at surface
- Air temperature at 2m

AER-NOAER: Shortwave Rad @ Sfc 09UTC 18APR2012

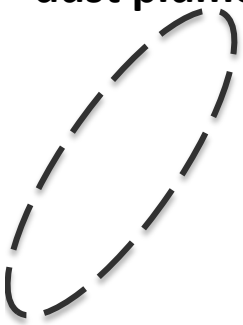
" Climatological" aer Δ > -75 Wm^{-2}

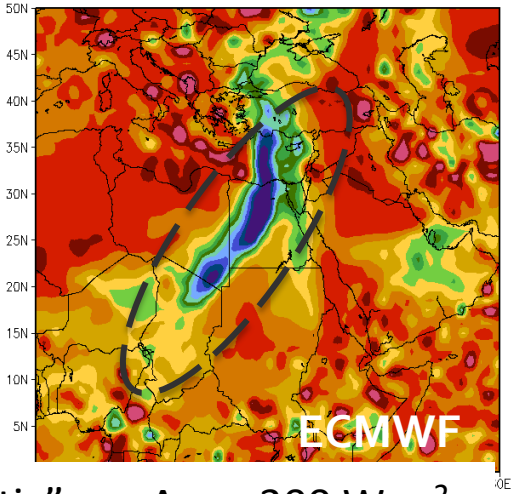


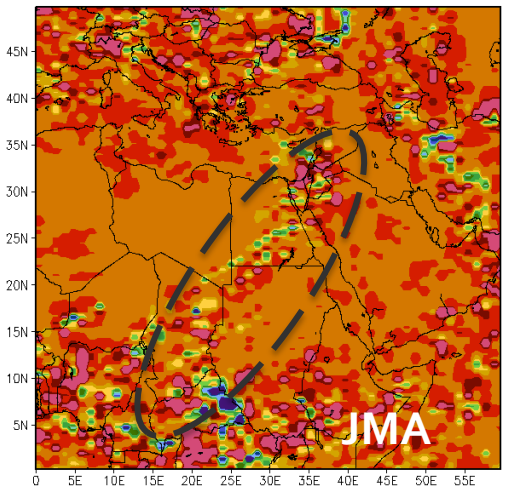


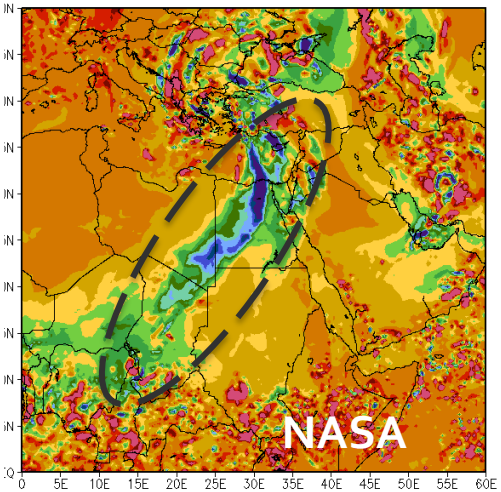


Location of the dust plume

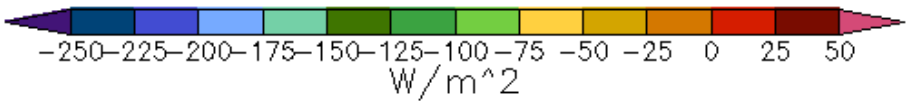






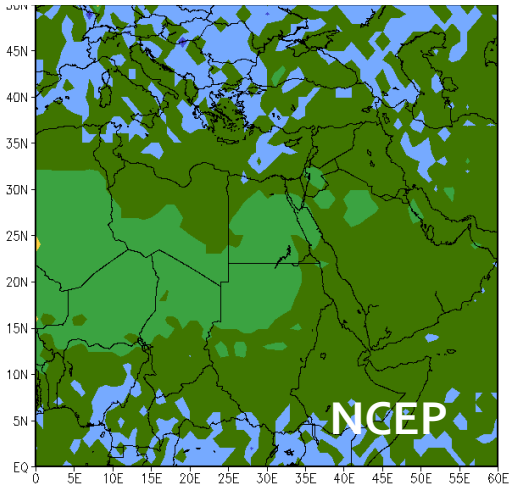


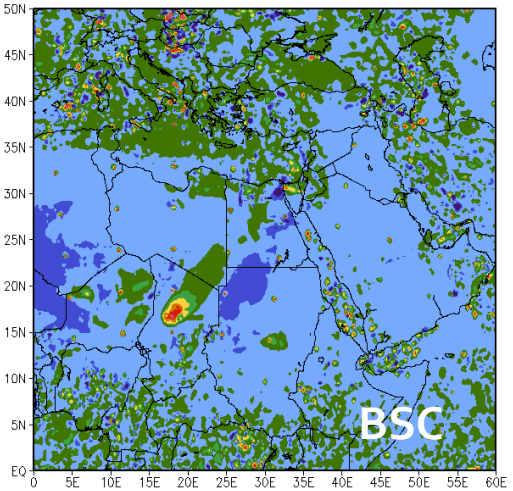
" prognostic" aer Δ > -300 Wm^{-2}

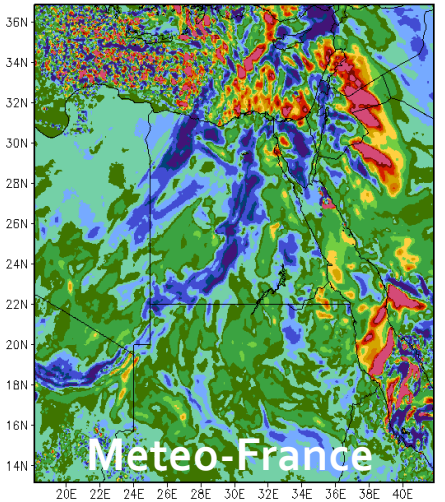


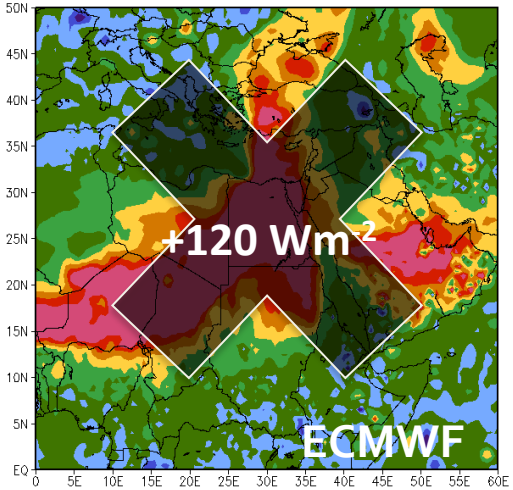
AER-NOAER : Longwave Rad @ sfc 09UTC 18APR2012

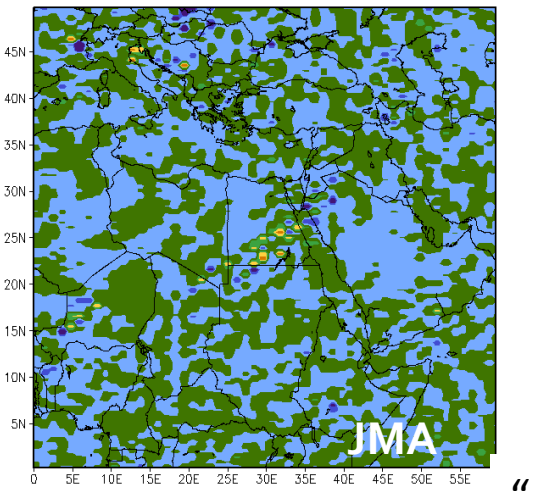
" Climatological" aer Δ < 20 Wm^{-2}

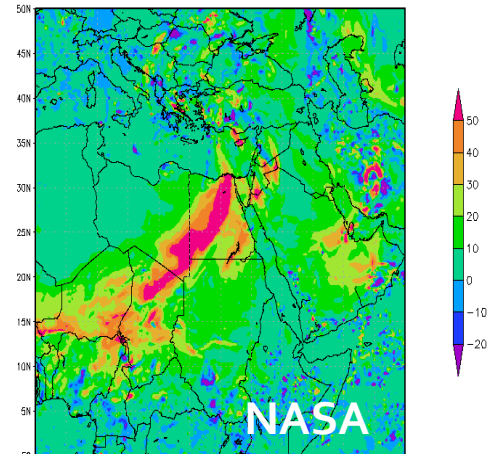




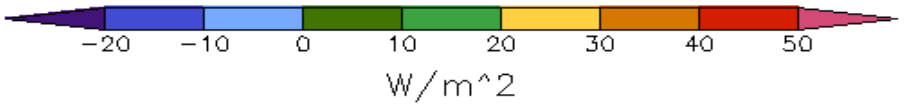








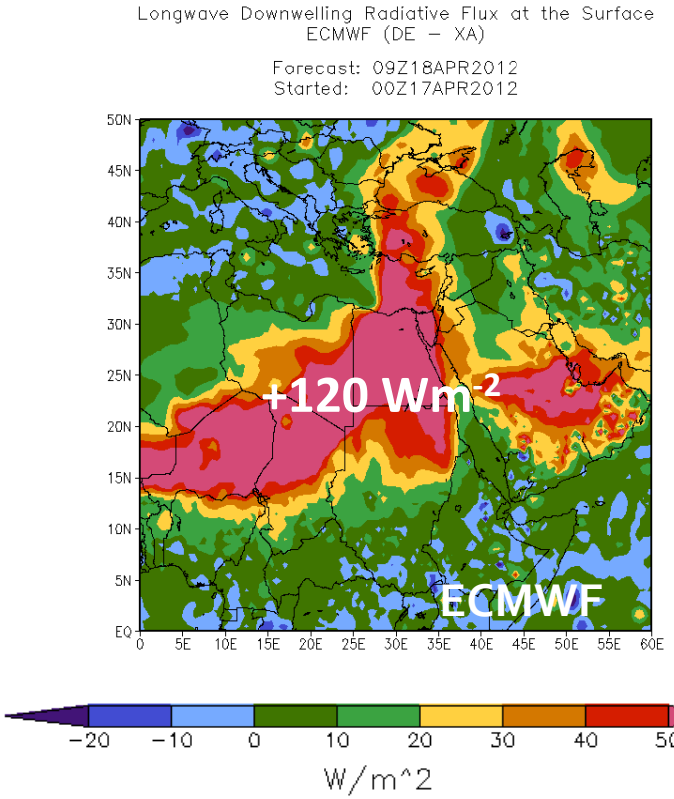
" prognostic" aer Δ < 60 Wm^{-2}



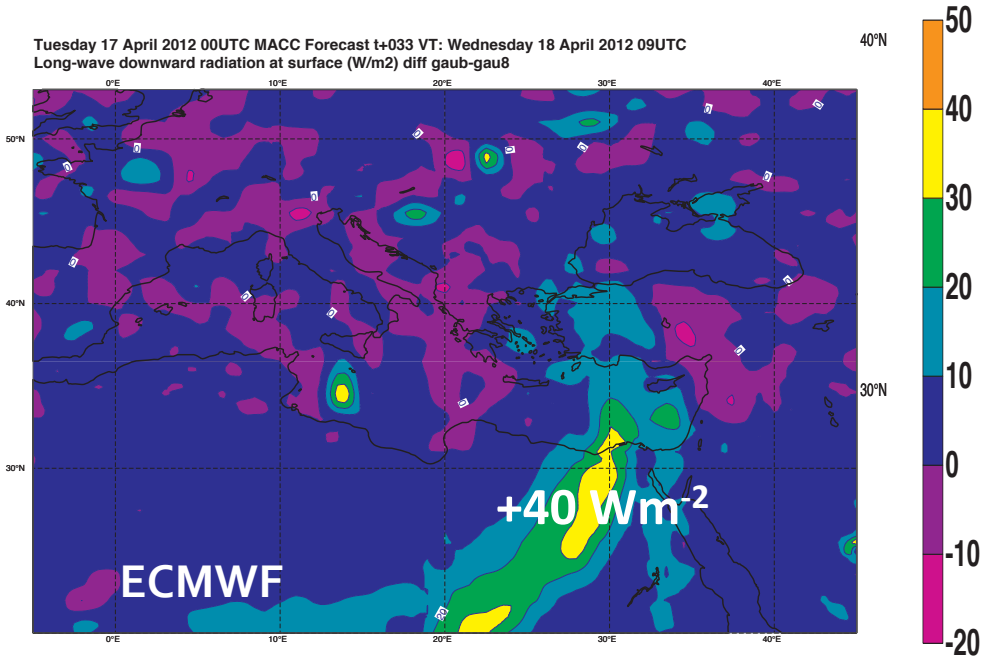
DIFF of LW downward radiation at surface
AER-NOAER

18APR2012 09 UTC (morning)

Before



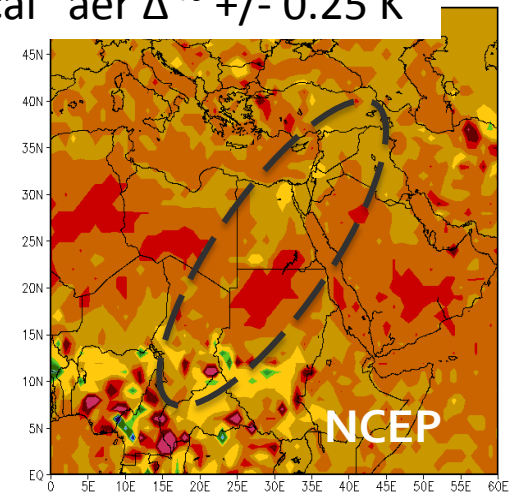
After bug fix

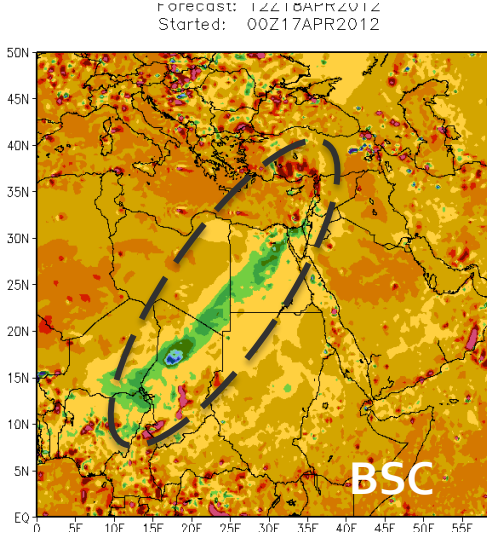


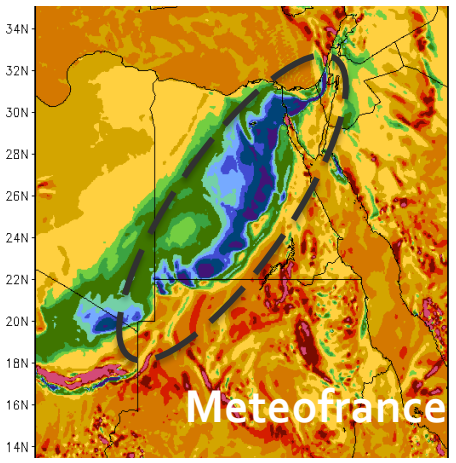
AER-NOAER : 2m Temp 12UTC 18APR2012

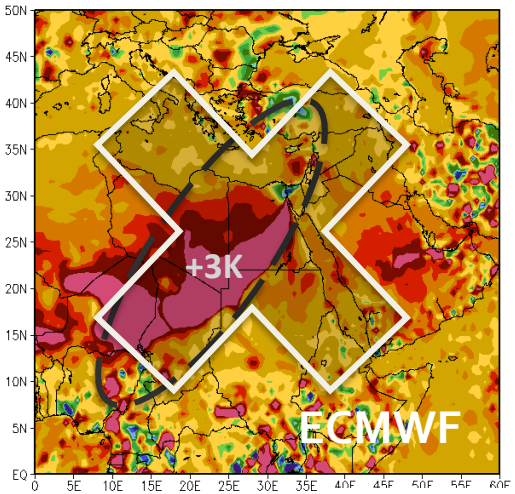
" Climatological" aer Δ ~ +/- 0.25 K

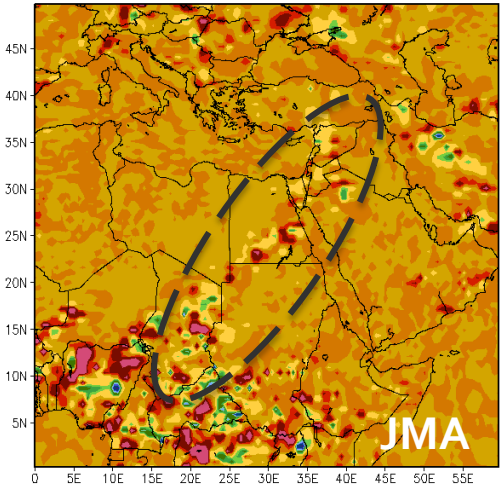
" prognostic" aer Δ > - 3 K

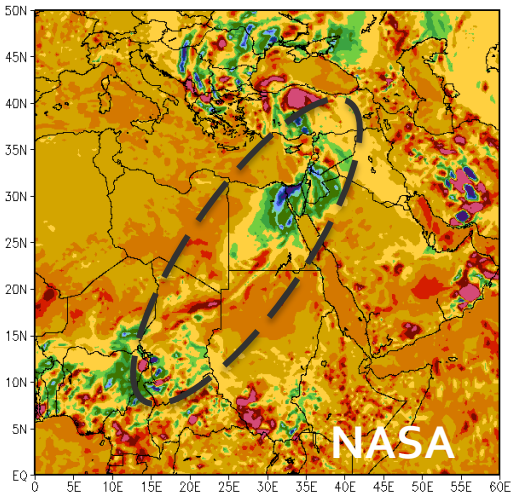


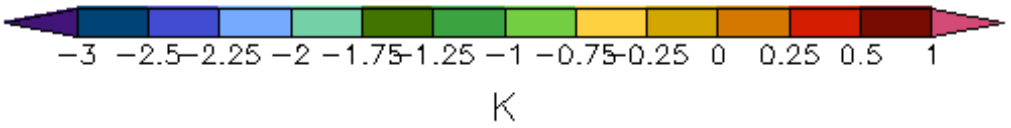










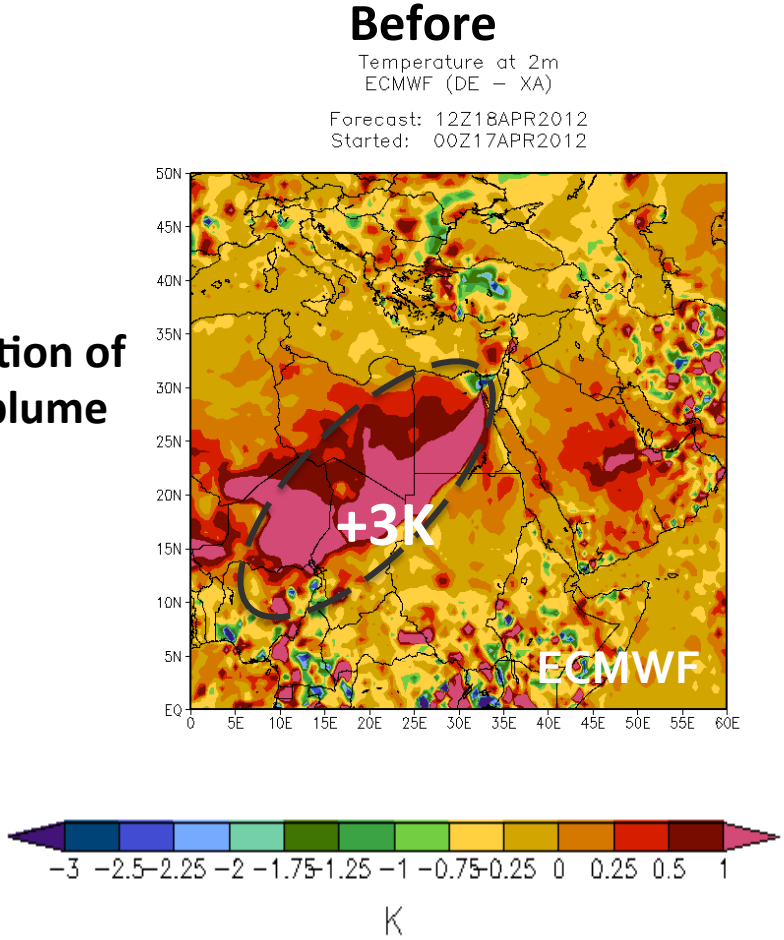


DIFF of Temp @ 2-m
AER-NOAER

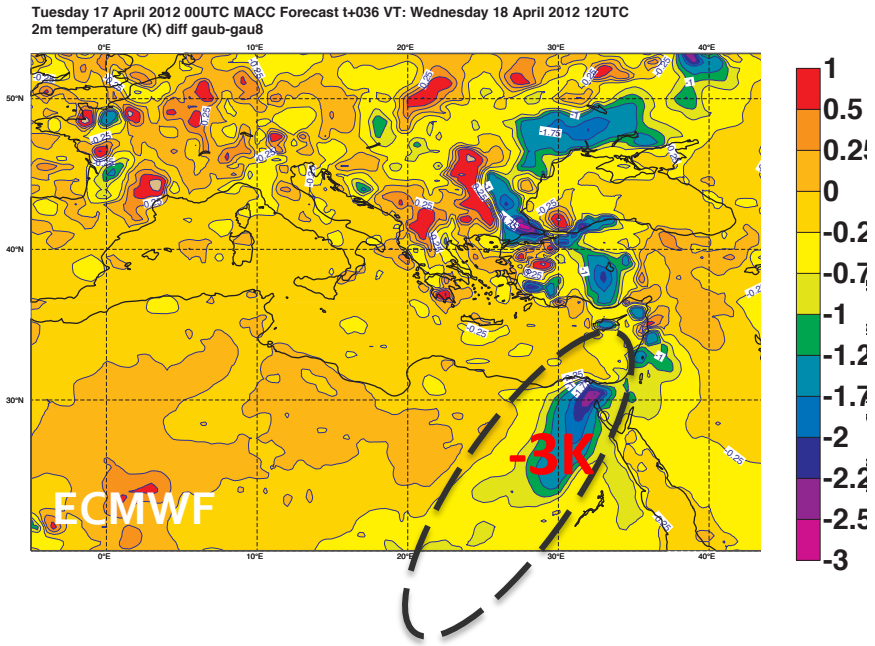
12 UTC (morning)

Location of the plume

Before



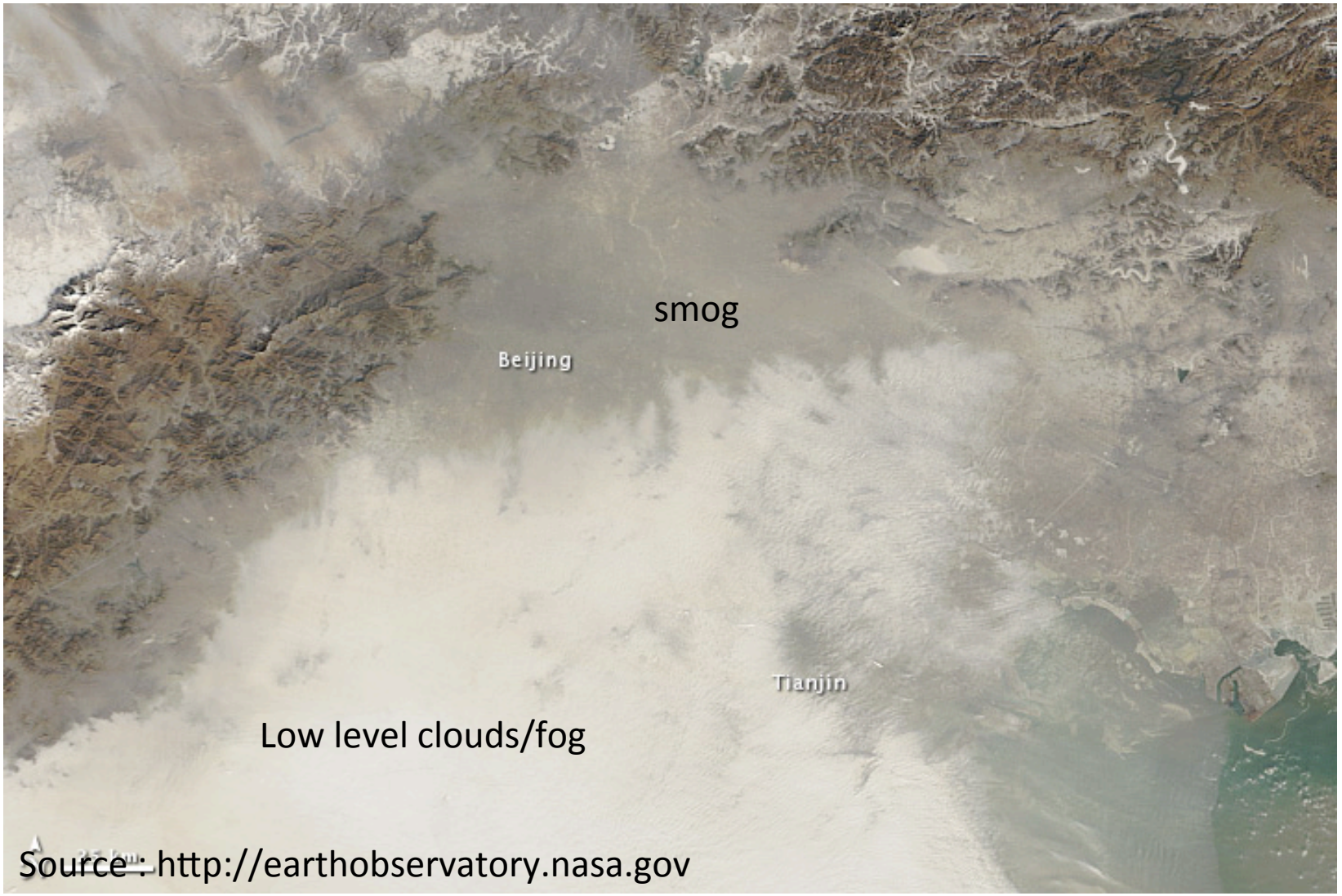
After bug fix



Case 2
Extreme Urban Pollution in Beijing

- January 2013
- Forecasts
  - January 7-21 2013
  - From 0 or 12 UTC
  - 10 day forecasts
- Center of domain
  - 116E, 40N
- Model configuration
  - Same as for NWP
- Direct & Indirect effects

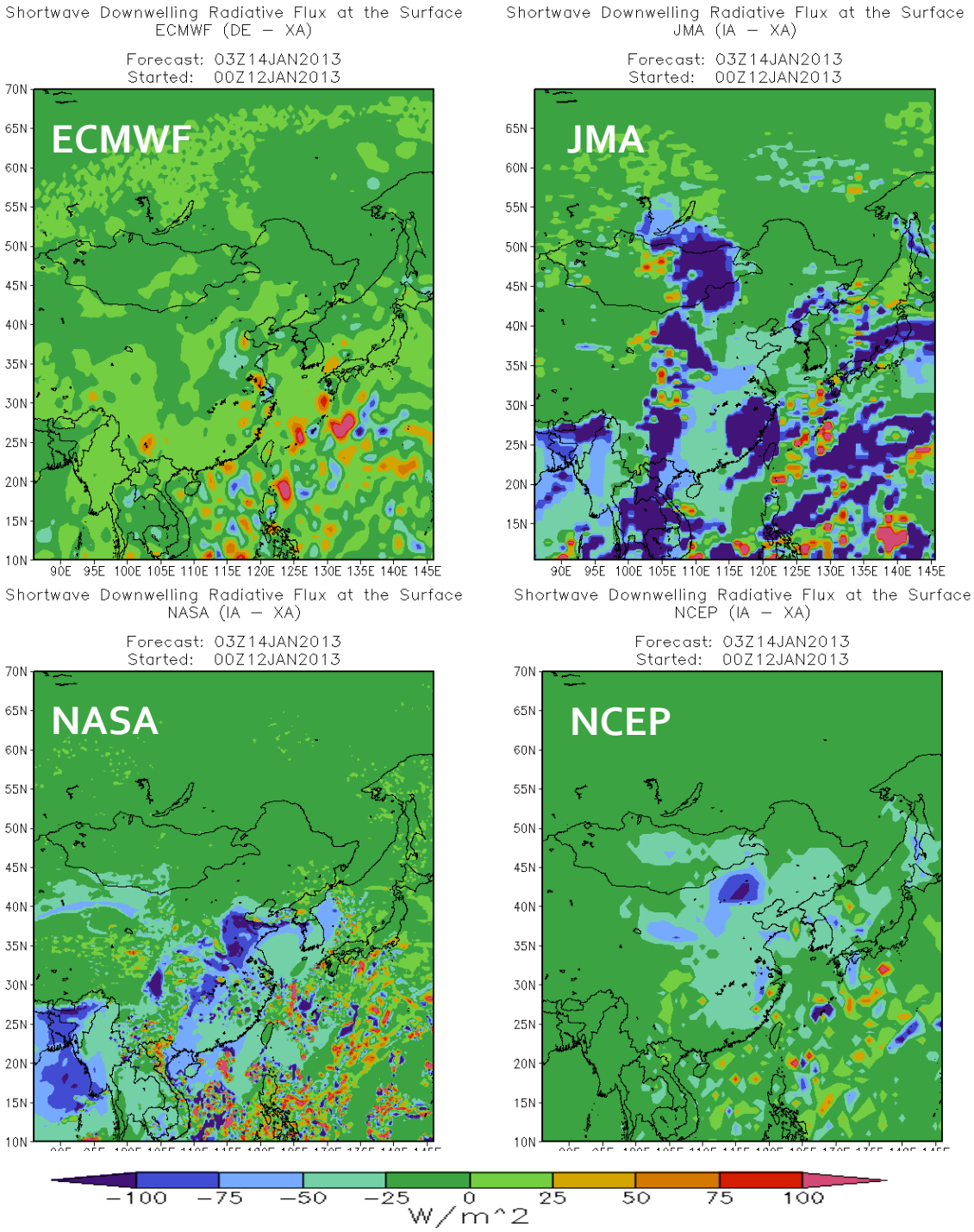
Case 2 – Urban Pollution



Source : http://earthobservatory.nasa.gov

SW Radiation @ Surface Impact (AER-NOAER) 14 Jan 2013

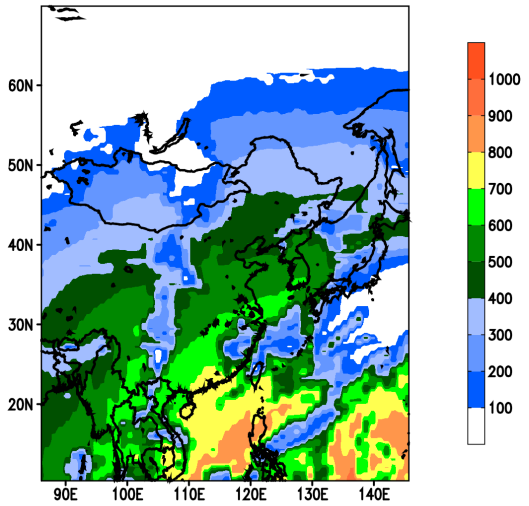
- 3 UTC (day time)



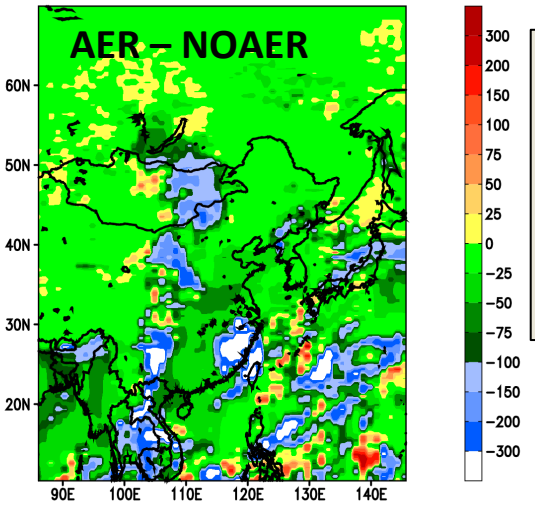
JMA – Rad shortwave at sfc (W m^{-2})

Init 00UTC12JAN FCT: 03UTC14JAN

RShortWave(aer)

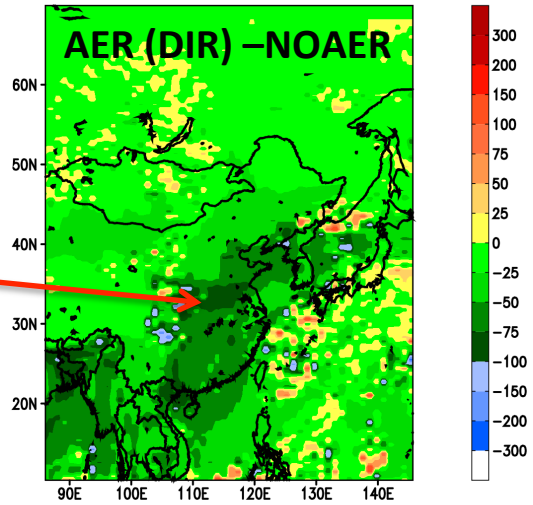


RShortWave(aer)−RShortWave(no−aer)



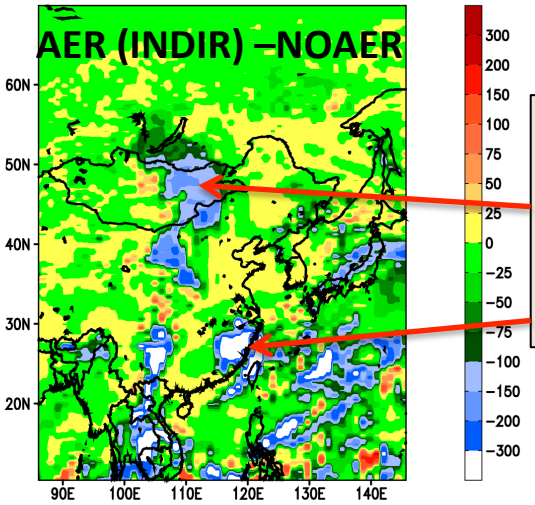
INDIR effect has more pronounced effect on sfc rsw extinction

RShortWave(direct)−RShortWave(no−aer)



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

RShortWave(indirect)−RShortWave(no−aer)



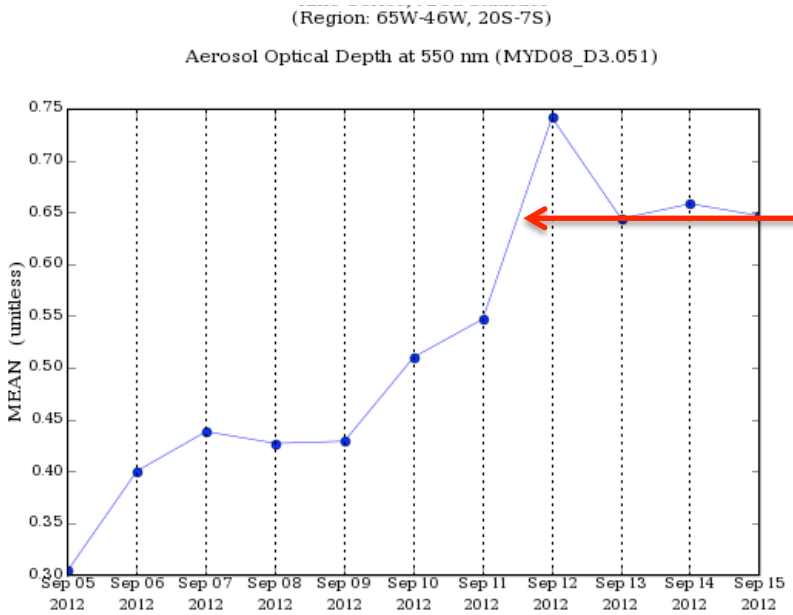
INDIR effect: -100 to -300 (or less) W m^{-2}

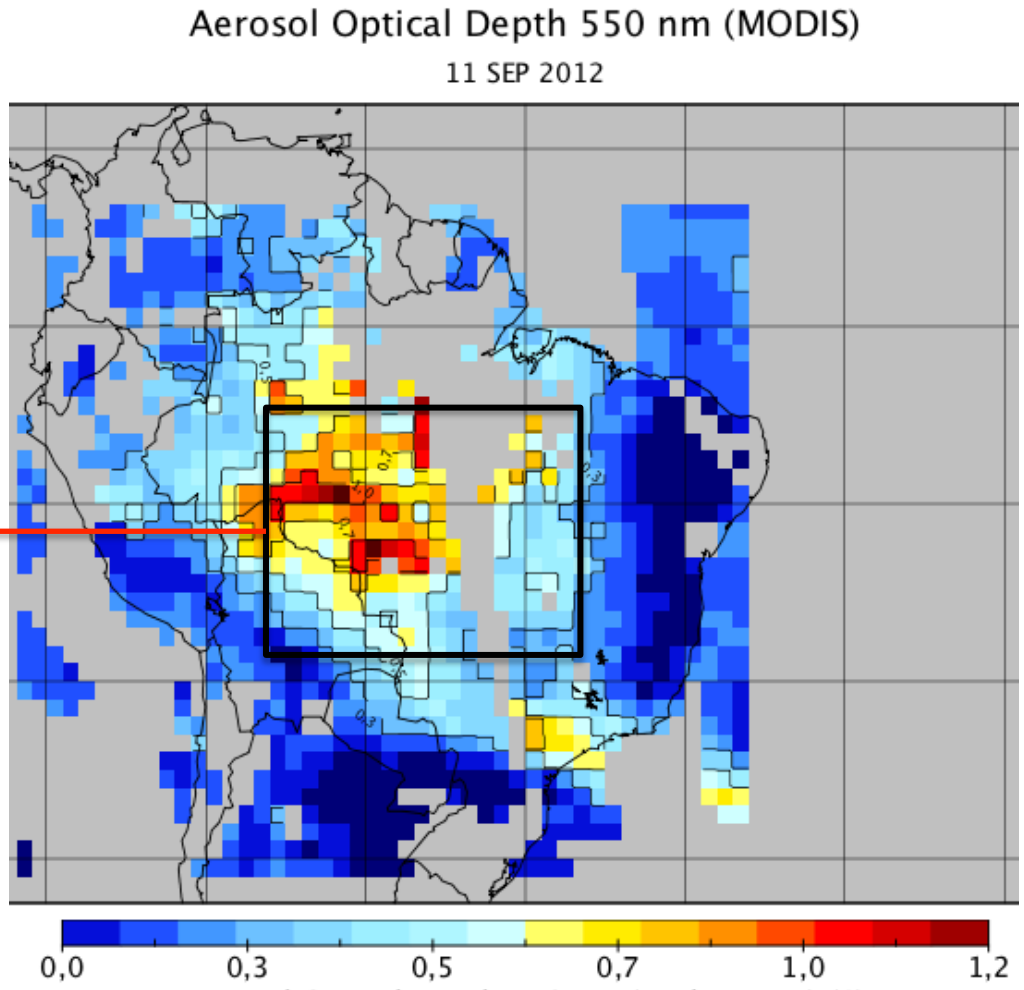
Case 3- Persistent Smoke in Brazil - SEP 2012

Forecasts
- September 5-15, 2012
- From 0 or 12 UTC
- 10 day forecasts

Model configuration: same as for NWP

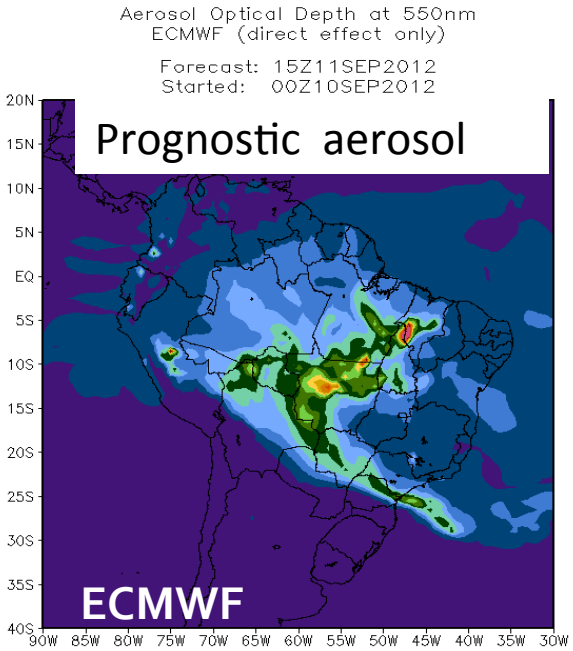
Direct & Indirect effects

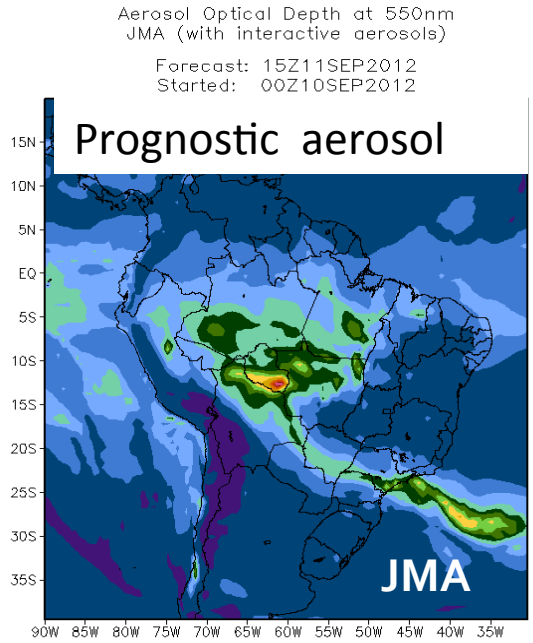


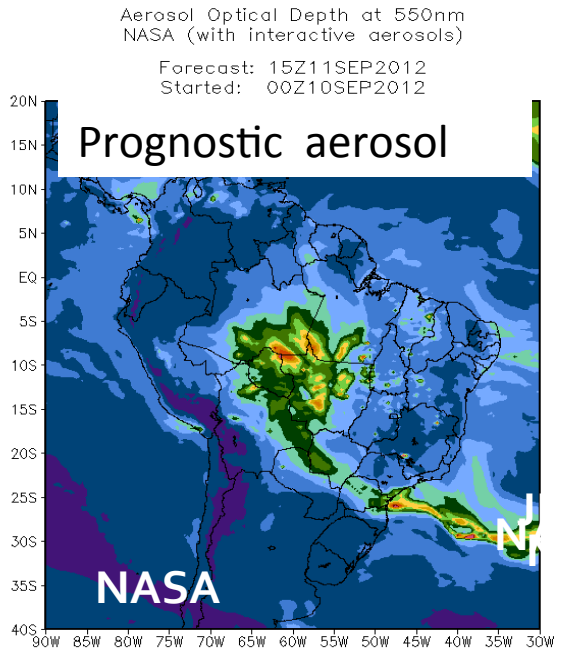


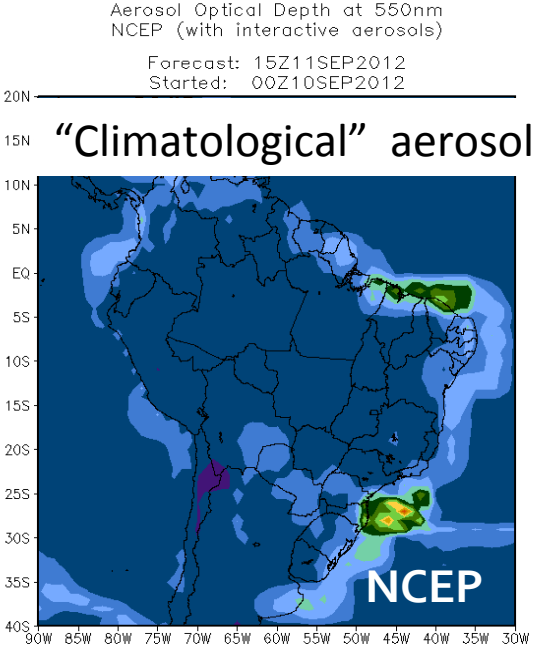
AOD at 550 nm
Fct.: 15UTC11SEP
Init.: 00UTC10SEP

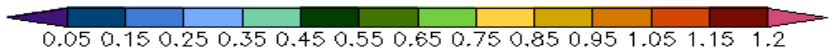
- **Similar prognostic aerosol distribution and AOD field.**
- **Climatological aerosol provides a completely unrealistic AOD field.**





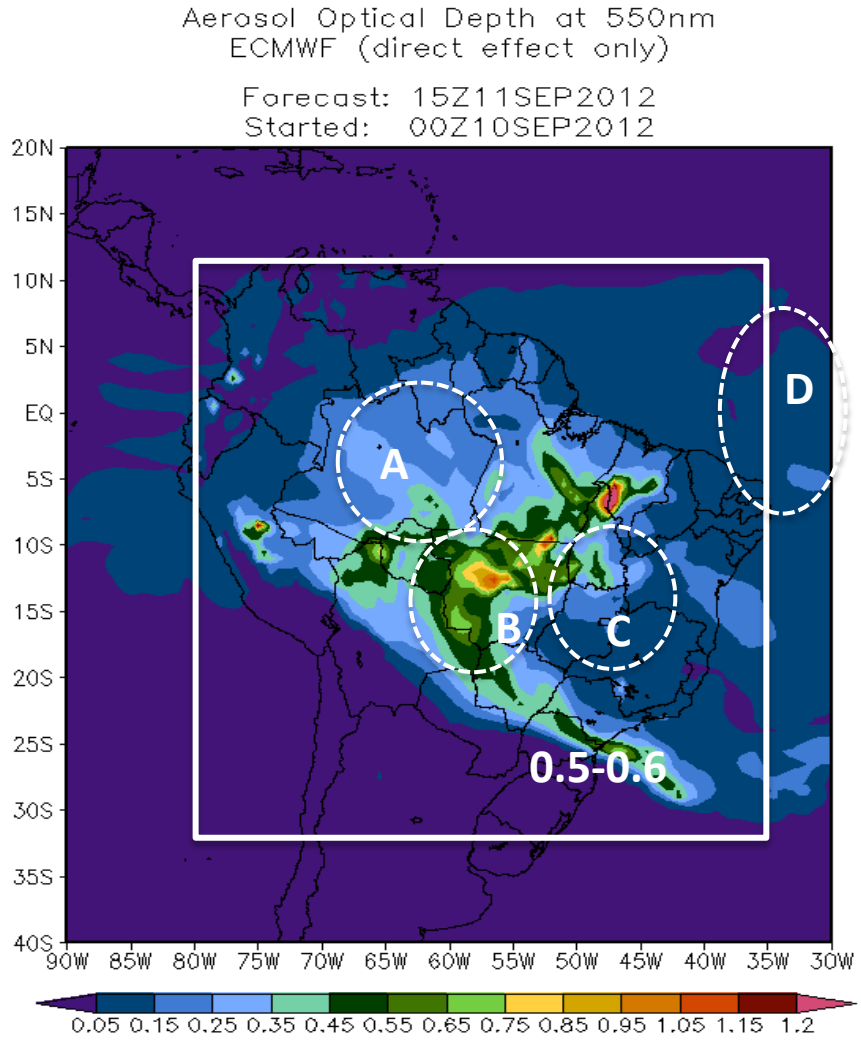


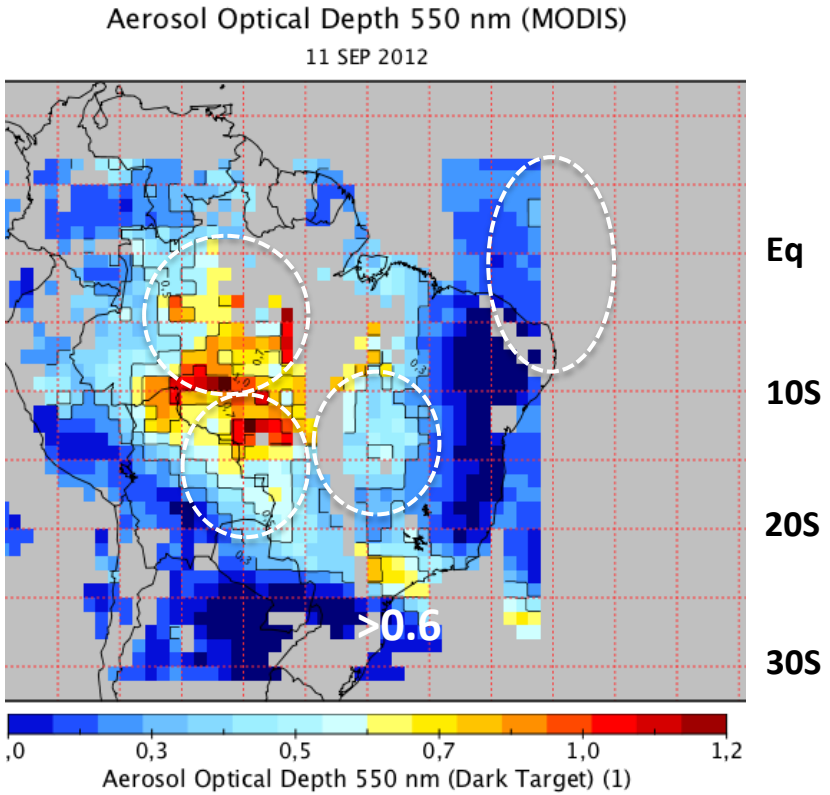




ECMWF : AOD at 550 nm

Forecast for 15UTC11SEP - Init.: 00UTC10SEP

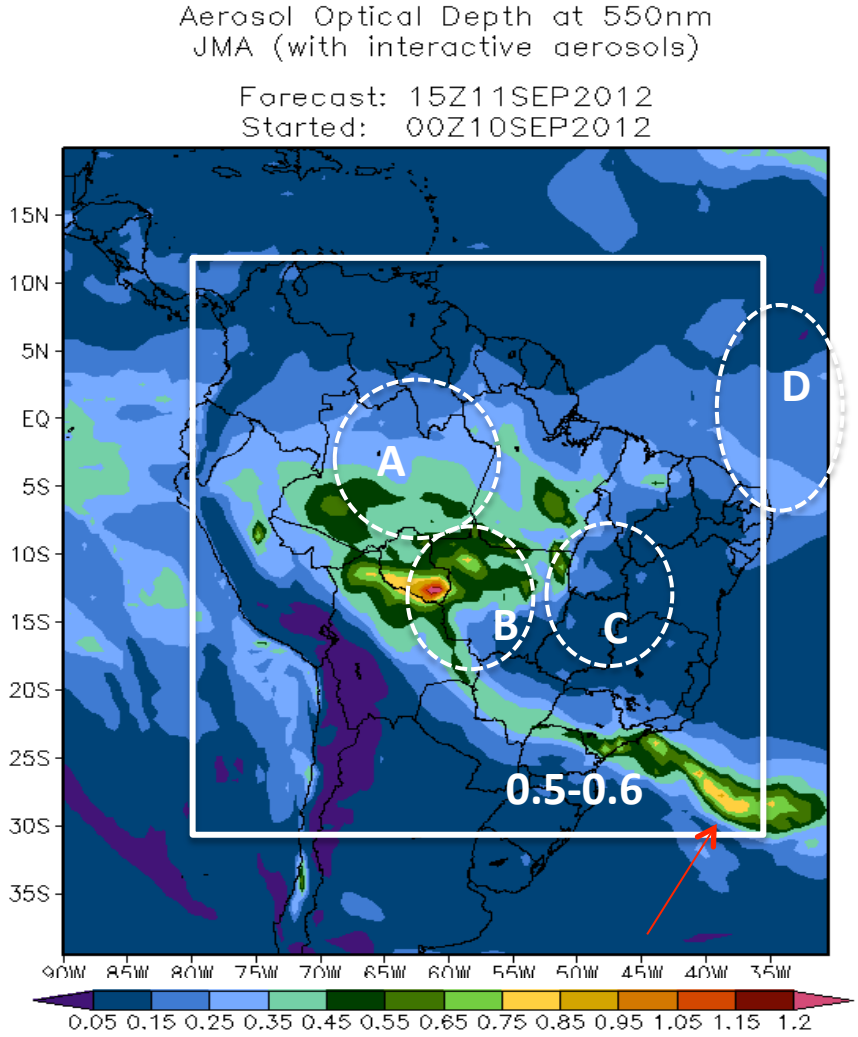


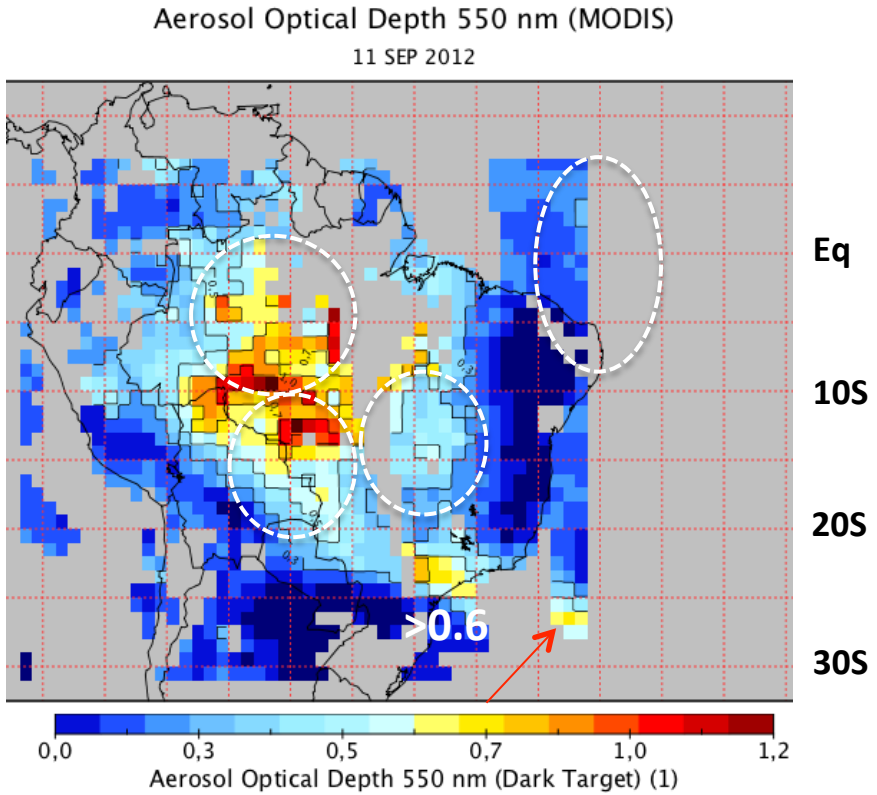


A: AOD is underestimated in the interior of the Amazon basin (underwood fires?)
B: gradient from NW-SE is well represented, but with lower AOD
C: AOD is also underestimated (might be related to missing fires, savanna area)
D: Smoke inflow from African fires looks also underestimated
E: SE outflow looks fine (mag and location)

JMA : AOD at 550 nm

Forecast for 15UTC11SEP - Init.: 00UTC10SEP

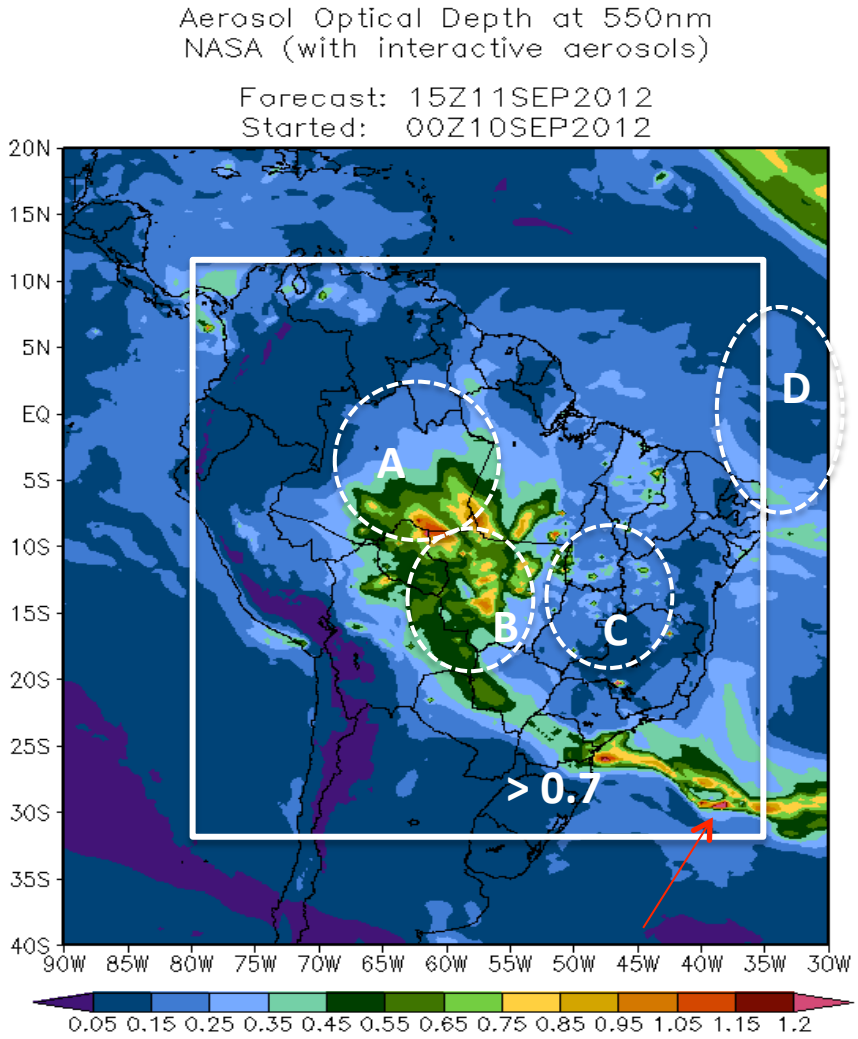


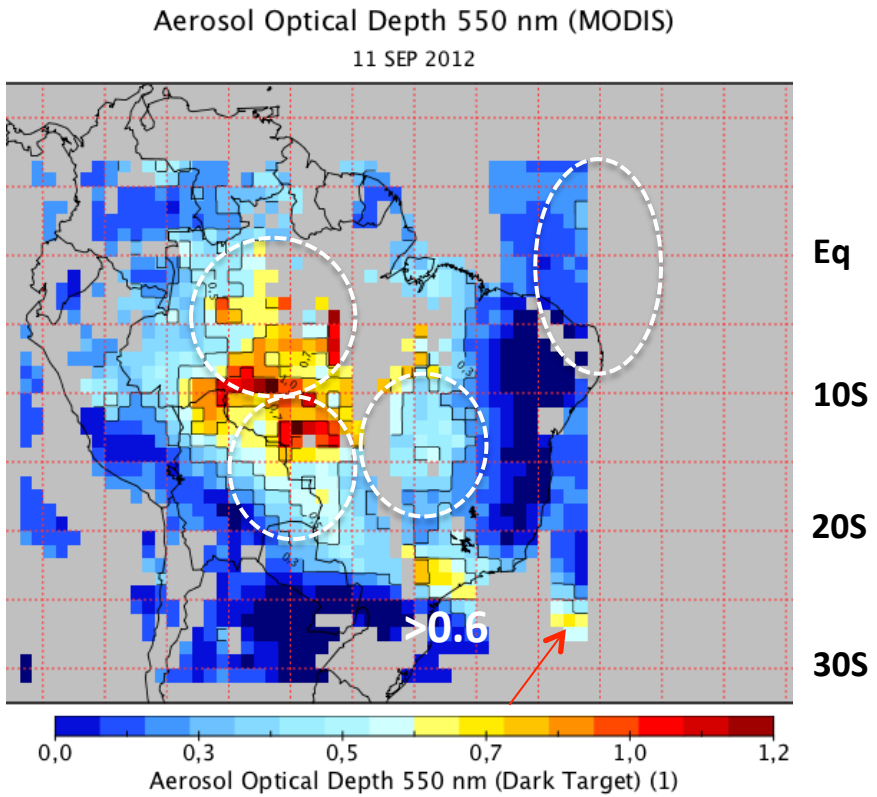


A: AOD is underestimated in the interior of the Amazon basin (underwood fires?)
B: gradient from NW-SE is well represented, but with lower AOD
C: AOD has the larger underestimation
D: Smoke inflow from African fires looks fine
E: SE outflow looks fine (mag and location)

NASA : AOD at 550 nm

Forecast for 15UTC11SEP - Init.: 00UTC10SEP



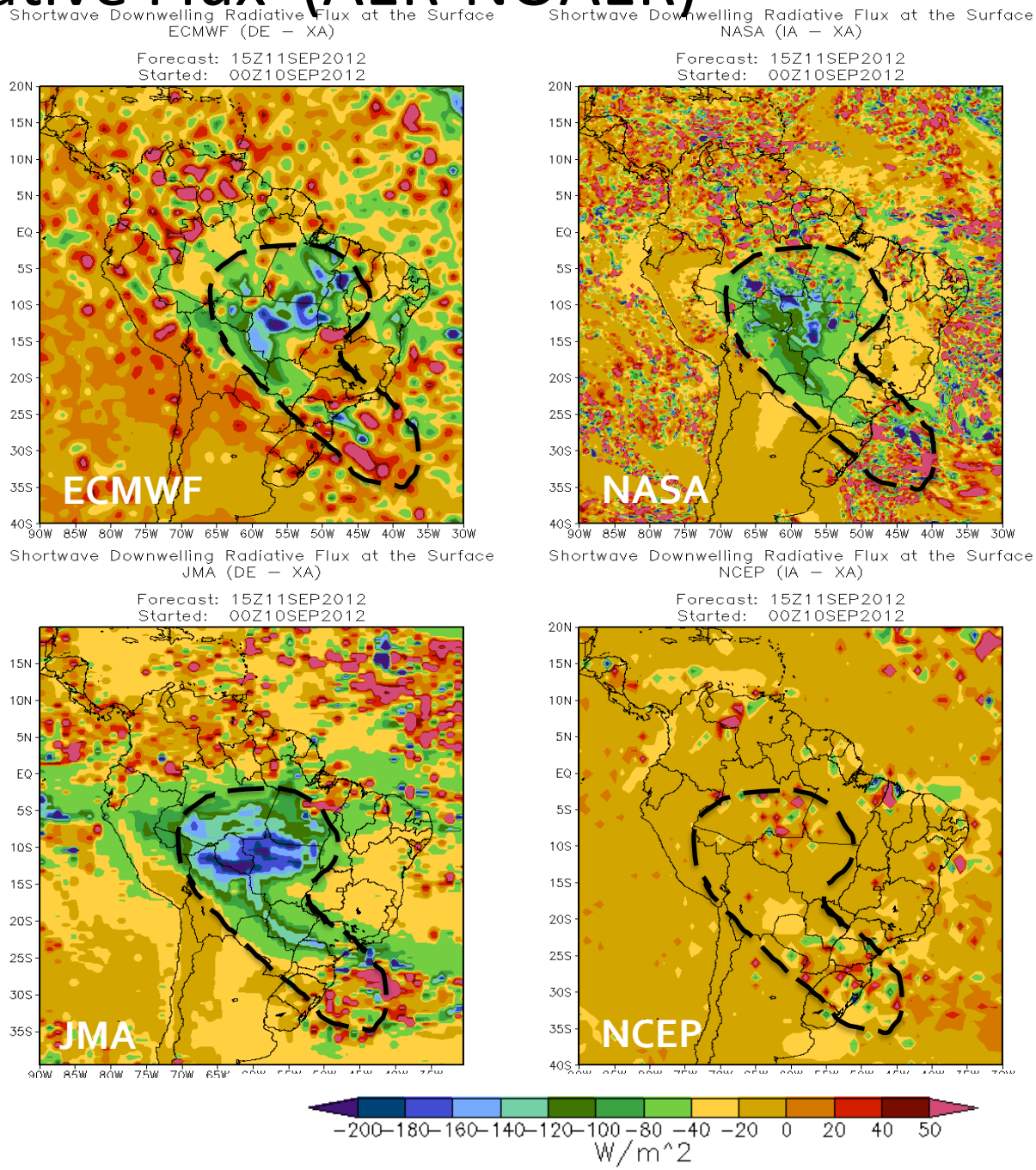


A: AOD is better represented in the interior of Amazon basin
B: gradient from NW-SE is well represented, but with lower AOD
C: AOD is also underestimated (might be related to missing fires, savanna area)
D: Smoke inflow from African fires looks better represented
E: SE outflow looks fine (mag and location)

SW Radiative Flux (AER-NOAER)

FCT.: 15UTC11SEP
Init.: 00UTC10SEP

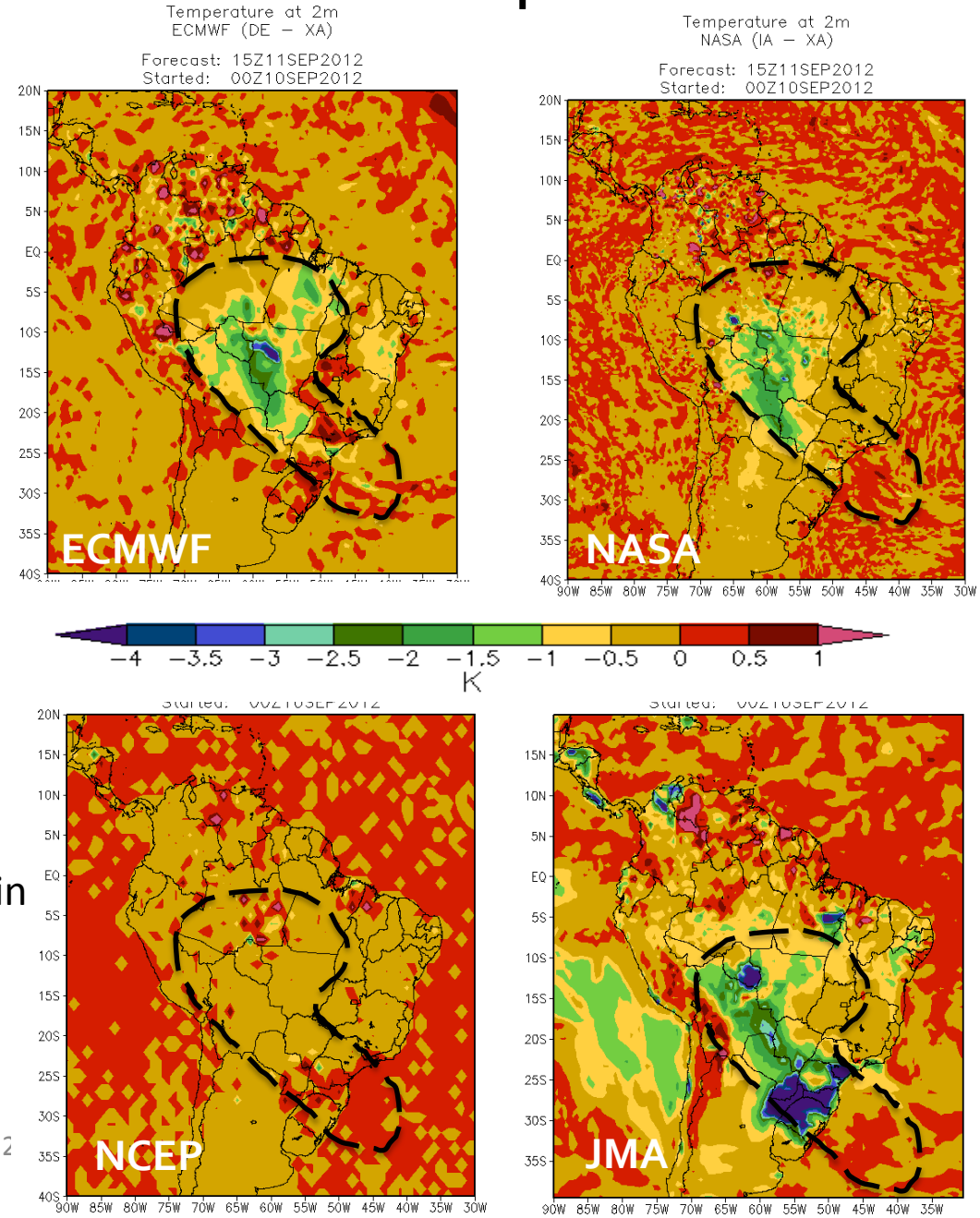
- Direct effect can produce a reduction of up to ~ 200 W/m^2 when applying prognostic aerosols.
- The use of climatological aerosols implies on much lower impact.



AER-NOAER : 2m Temperature

FCT.: 15UTC11SEP
Init.: 00UTC10SEP

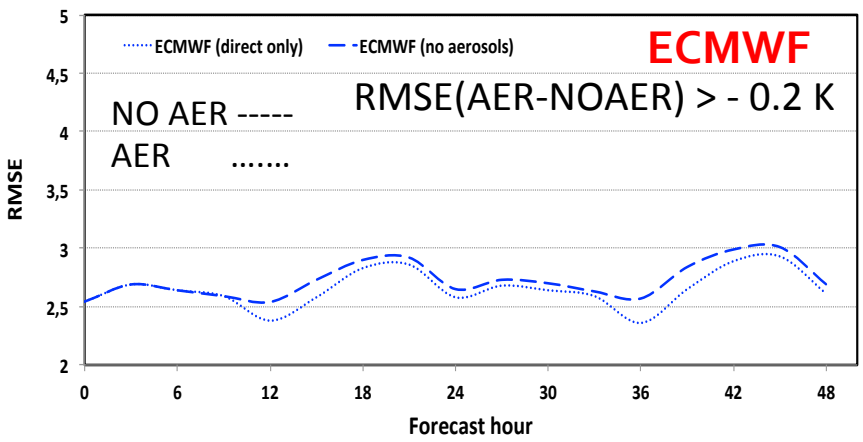
- Direct effect can produce cooling of up to ~ 3.5 K when using prognostic aerosols
- Indirect effect can even produce larger reduction on T2m
- Use of climatological data implies in negligible impact.

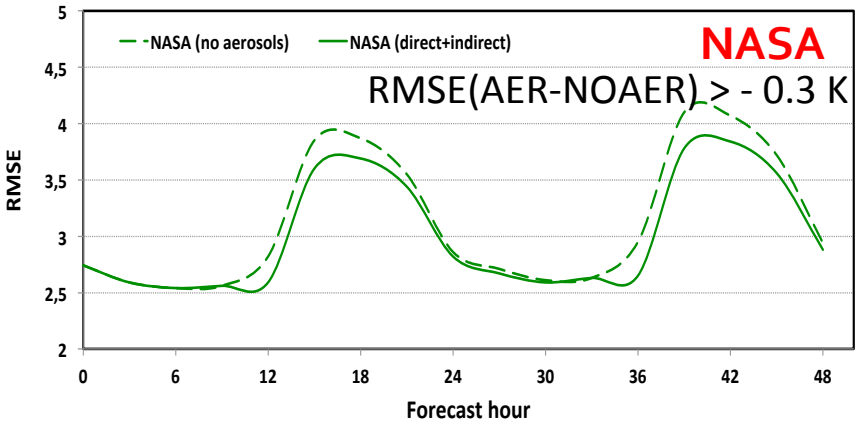


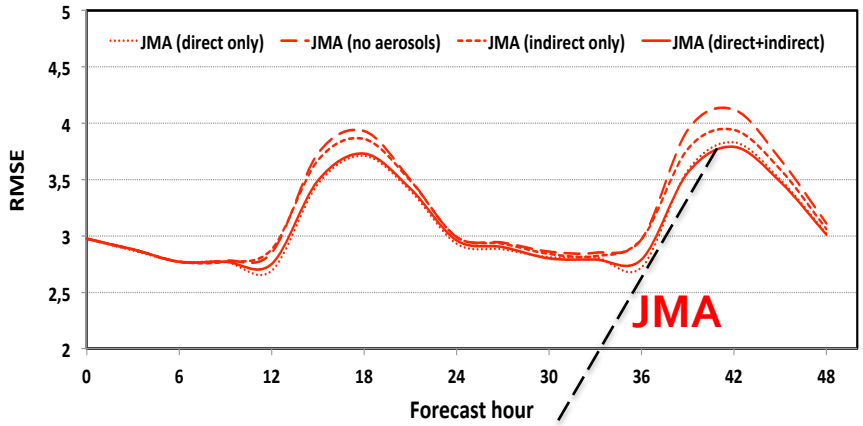
Preliminary quantitative evaluation for the SAMBBA case

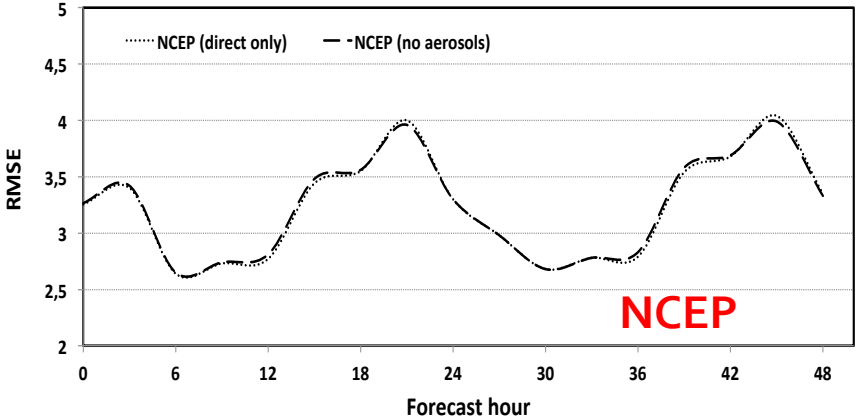
- Parameter: 2-meter temperature.
- Observational data: up to 1200 meteo. surface stations over S. America.
- Interpolation method: nearest neighbored.
- Time period: 5 – 14 SEP, up to 48 hours forecast.

RMSE: 2-m Temperature







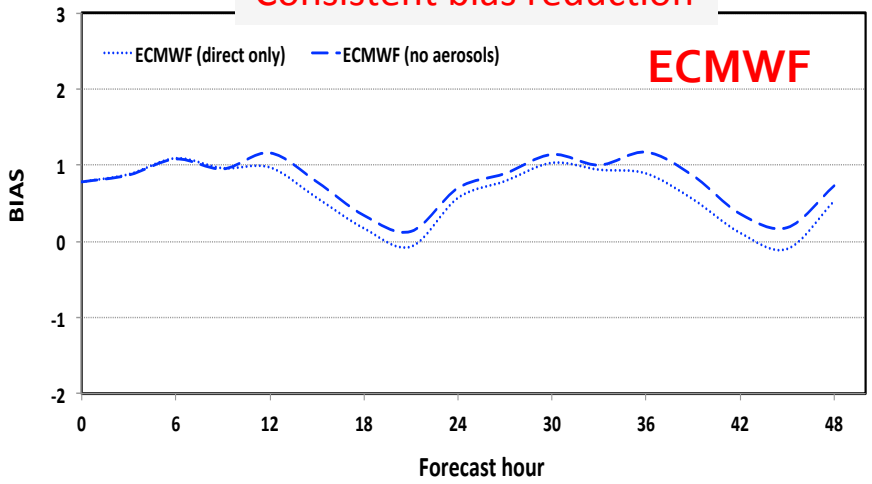


4.12 – no interaction
3.94 – indirect only
3.83 – direct only
3.79 – IND + DIR

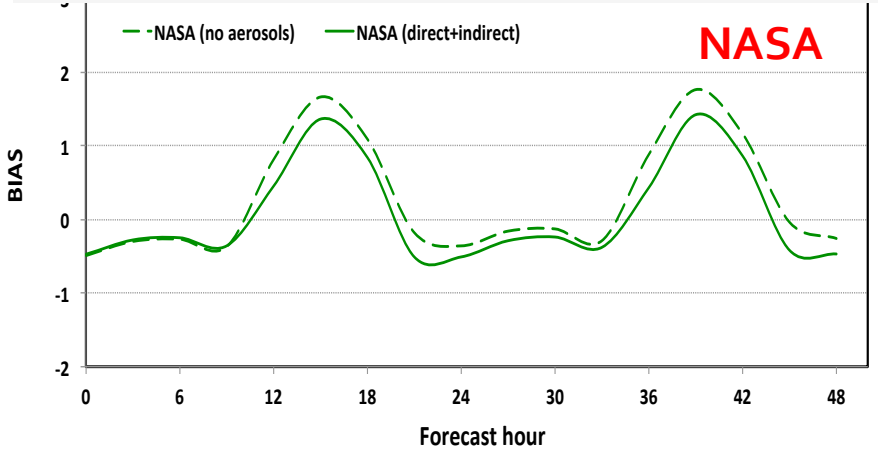
- ECMWF, NASA, JMA: Consistent and significative RMSE reduction
- NCEP : negligible change
- JMA : RMSE reduction increases with the aerosol treatment complexity

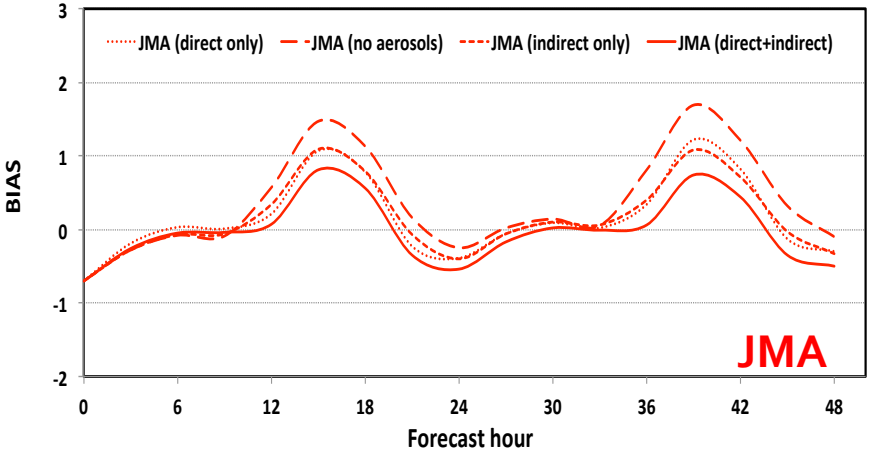
BIAS: 2m Temperature

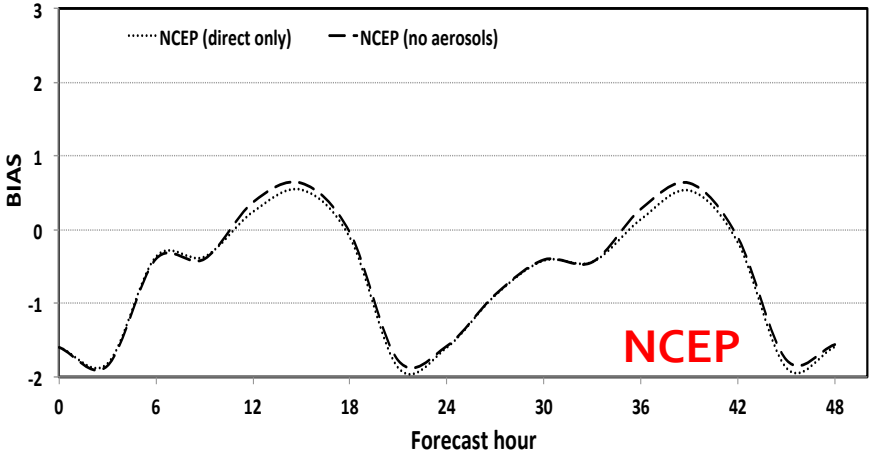
Consistent bias reduction



Bias decreases during the day, but increases* at night





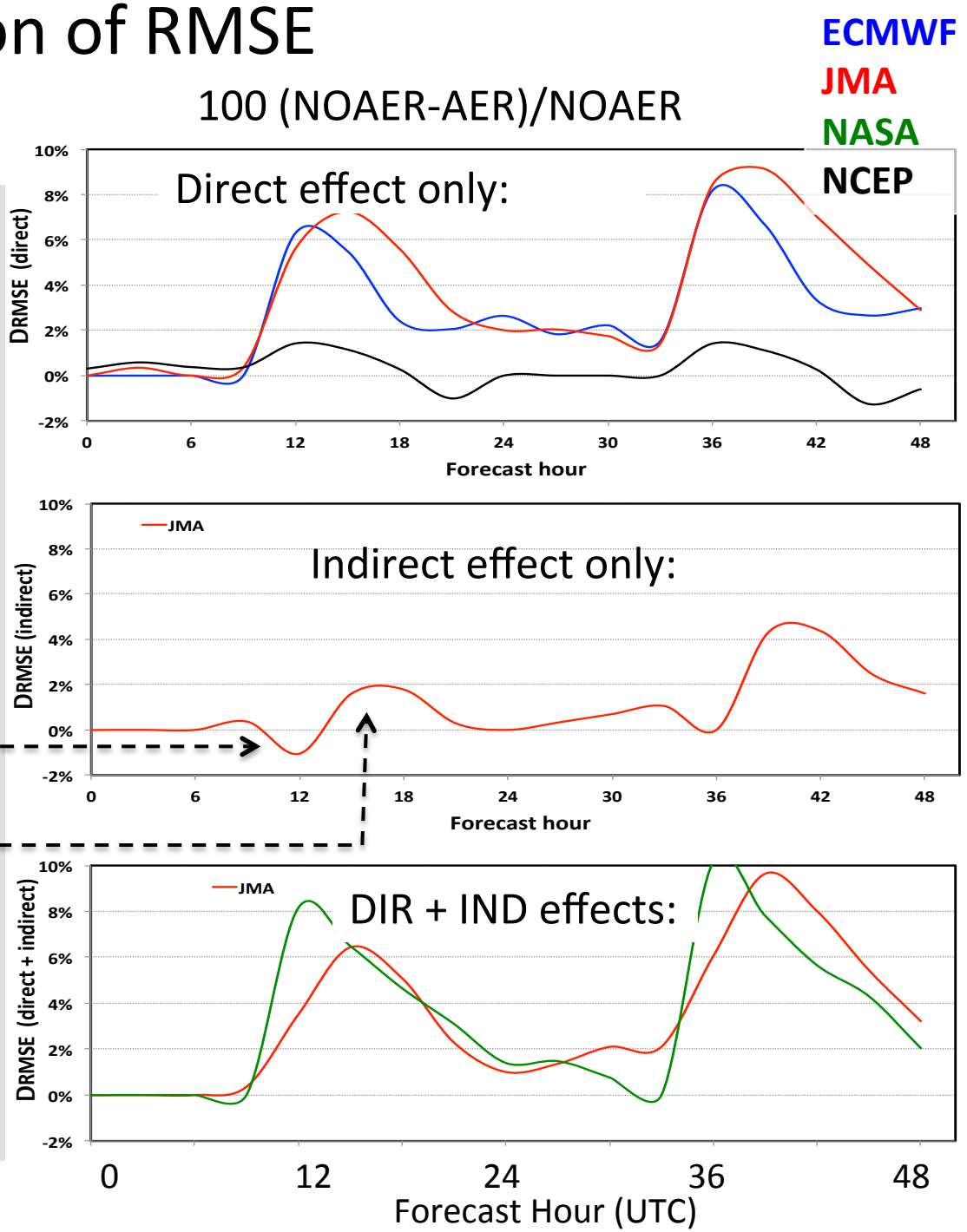


Consistent bias reduction with increasing aerosol treatment complexity during the day, with a slight increase* during the night.
(*) Absolute value

Slight decrease of bias during 12-18 UTC

Relative Variation of RMSE

- prognostic/interactive aerosol can improve RMSE up to 10%.
- For this case (dry season), direct effect has the larger impact on the improvement.
- Indirect effect imposes an initial deleterious RMSE increase in morning
- but further improvement on afternoon.
- Perhaps, this indicates a misrepresentation of the diurnal cycle of convection?



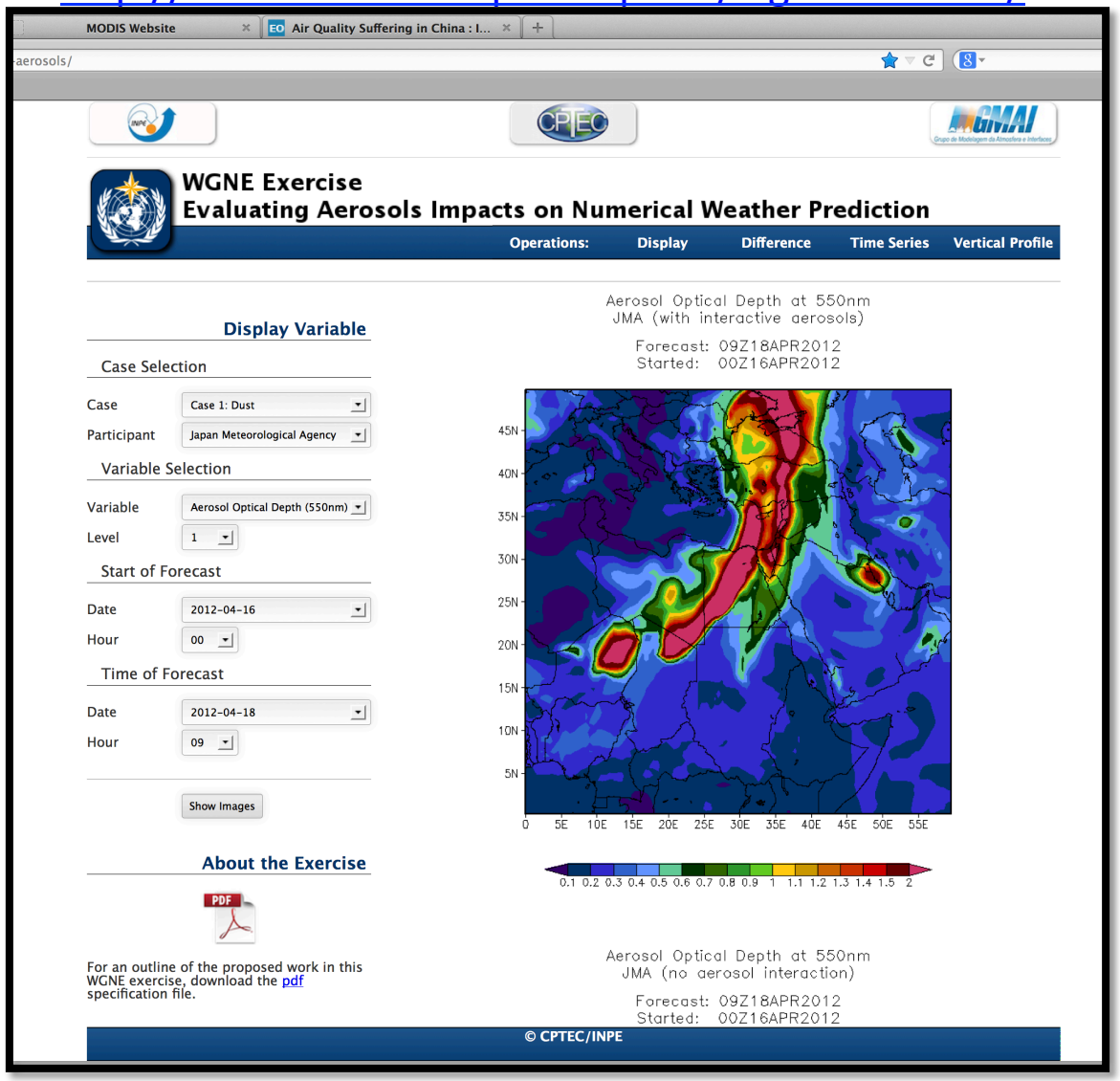
Next Steps

- Perform data evaluation using
  - Atmospheric observational data from CPTEC/Brazil, CMA/China, ECMWF.
  - Retrieved/Analyzed/Observed AOD data from NASA/Goddard provided by A. Silva and from AERONET.
  - TRMM/meteo station rainfall data.
- Produce a report.
- Propose a second phase:
  - Revised runs and datasets (if needed).
  - Constrain initial and boundary conditions using a unified data/procedure by data assimilation.
  - Improves the diagnostic approach of indirect effect (e.g. clear definition of the physical process(es) being represented, more detailed information about the representation of aerosols (e.g. speciation, extinction coefficients, etc.)

Analyzing the data with GrADS Online

Webpage hosted by CPTEC/Brazil for data analyzing and visualization

http://meioambiente.cptec.inpe.br/wgne-aerosols/



Developed by M. Zarzur

- We are open to new participants.
- Contact : saulo.freitas@cptec.inpe.br.

- Thanks for your attention!
- Questions ?