Prognostic aerosols in the Ensemble Prediction System and impacts at the monthly/sub-seasonal scales

Angela Benedetti

With contributions from:

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ECMWF

OUTLINE

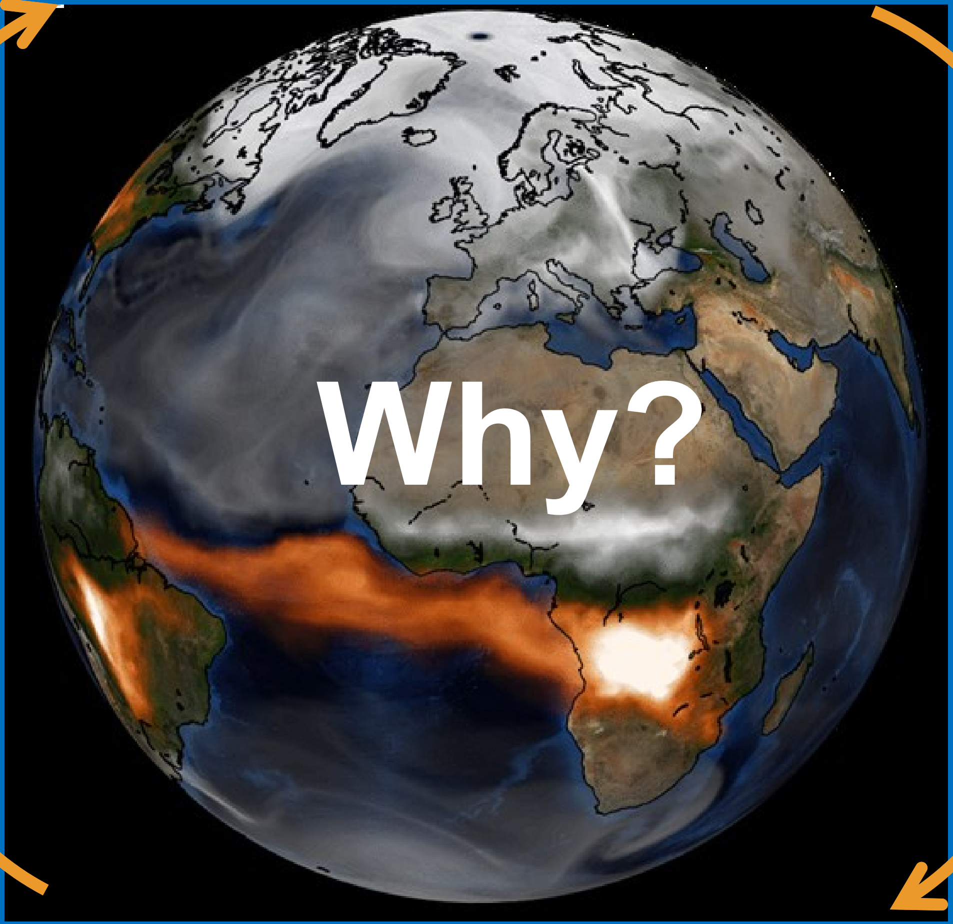
- General context: the Copernicus Atmosphere Monitoring System (CAMS)
- Scientific motivation
- Overview of modelling efforts with focus on aerosols
- Impact of aerosols on NWP (medium-range and sub-seasonal range)
- Summary and future perspectives

THE COPERNICUS ATMOSPHERE MONITORING SYSTEM (CAMS)

Atmospheric composition is a pivotal element between human activities and the Earth Environment

emissions

mitigation



aerosol

ozone

PM

greenhouse gases

NOx

air quality

climate change

ozone hole

numerical weather prediction

impacts

exposure

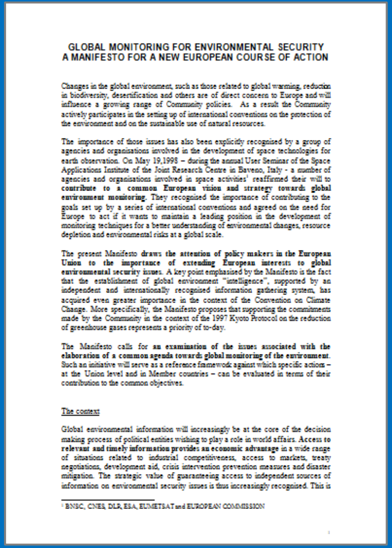
adaptation

Atmospheric composition and its changes affect our health and well-being

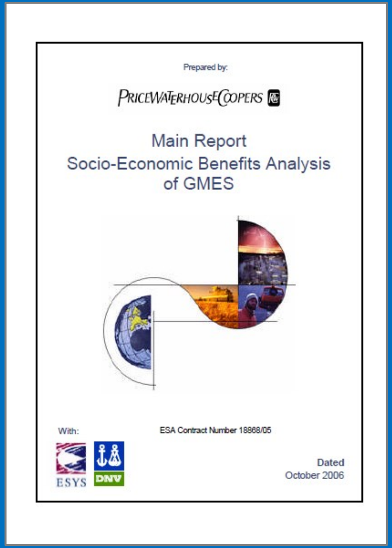
CAMS: A Significant Heritage

- A decade-long series of R&D projects and an internationally respected European achievement (GEMS, MACC, -II, -III)
- An equally long experience in engaging with users and potential users in Europe and across the world (PROMOTE, MACC, -II, -III)

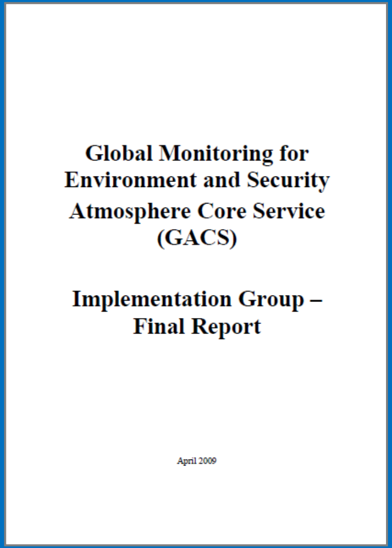
Strategy



Socio-economic impact



Experts

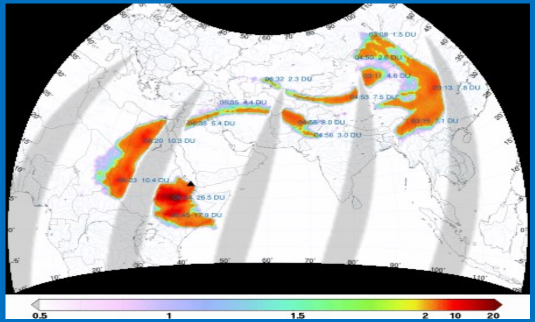


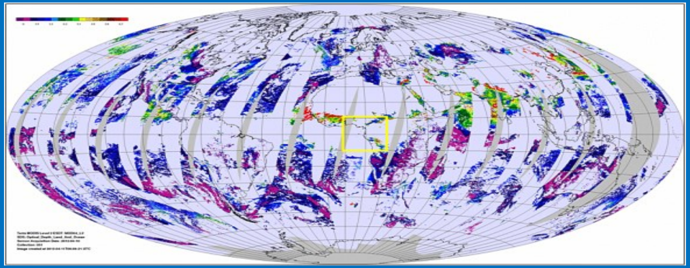
Users

copernicus

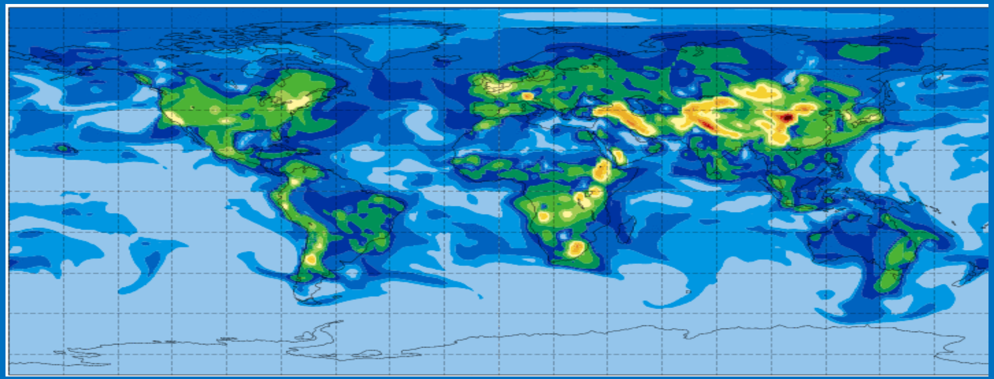
ECMWF

From Earth Observation to policy-quality products

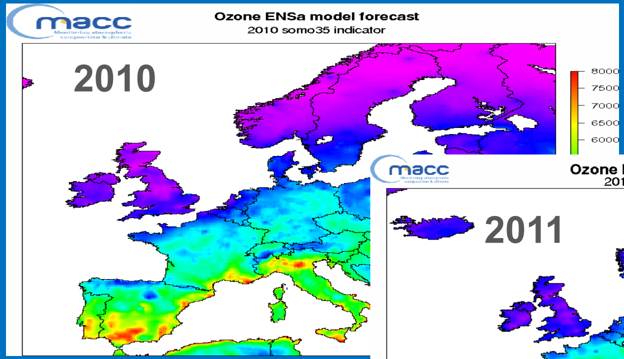


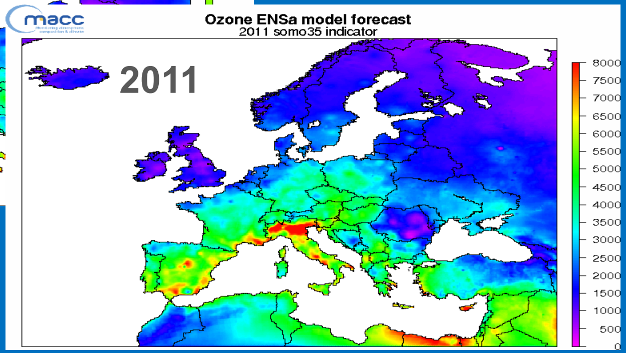


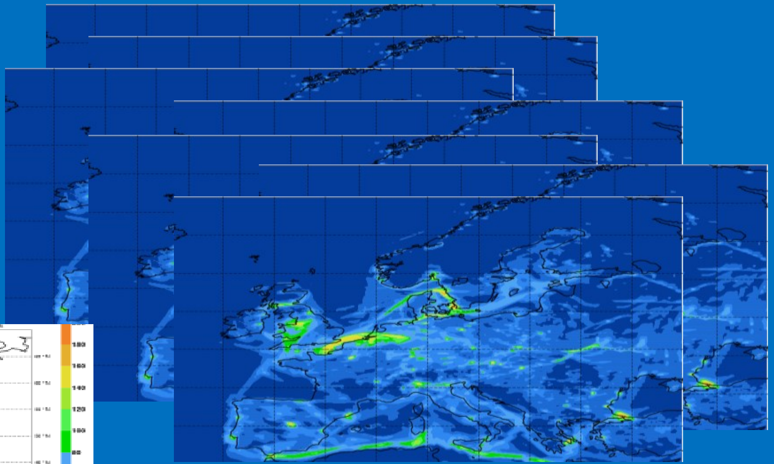
Over 70 EO instruments are assimilated in the global system



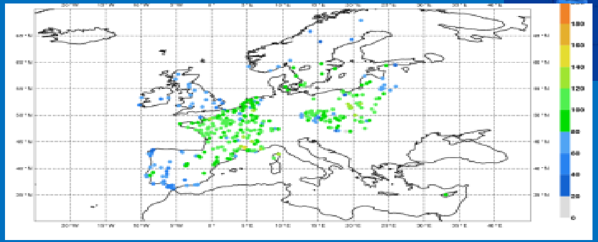
Boundary conditions feed an <u>ensemble</u> of high-resolution European AQ systems (in order to assess uncertainties)







More data are assimilated (in particular in situ) and used for extensive validation



Policy-relevant (here health indicator for ozone) products are delivered. They are “maps with no gaps”, which observations alone don’t provide and are essential to assess impacts.

CAMS Portfolio

AIR QUALITY AND ATMOSPHERIC COMPOSITION

European air quality analyses, forecasts and assessments in support of reporting and policy making, pollen forecasts, global transport of constituents/pollutants.

CLIMATE FORCING

Distributions of aerosol components and their radiative impacts, other radiative forcings.

OZONE LAYER AND UV

Monitoring and forecasting of the ozone layer / hole, UV index, UV radiation (crops, ecosystems).

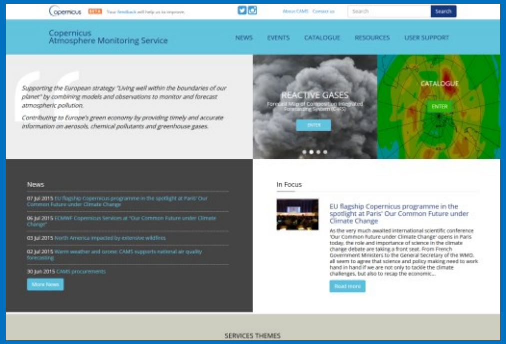
SOLAR RADIATION

Estimates of solar irradiance at surface, improved potential yield assessments for solar plants.

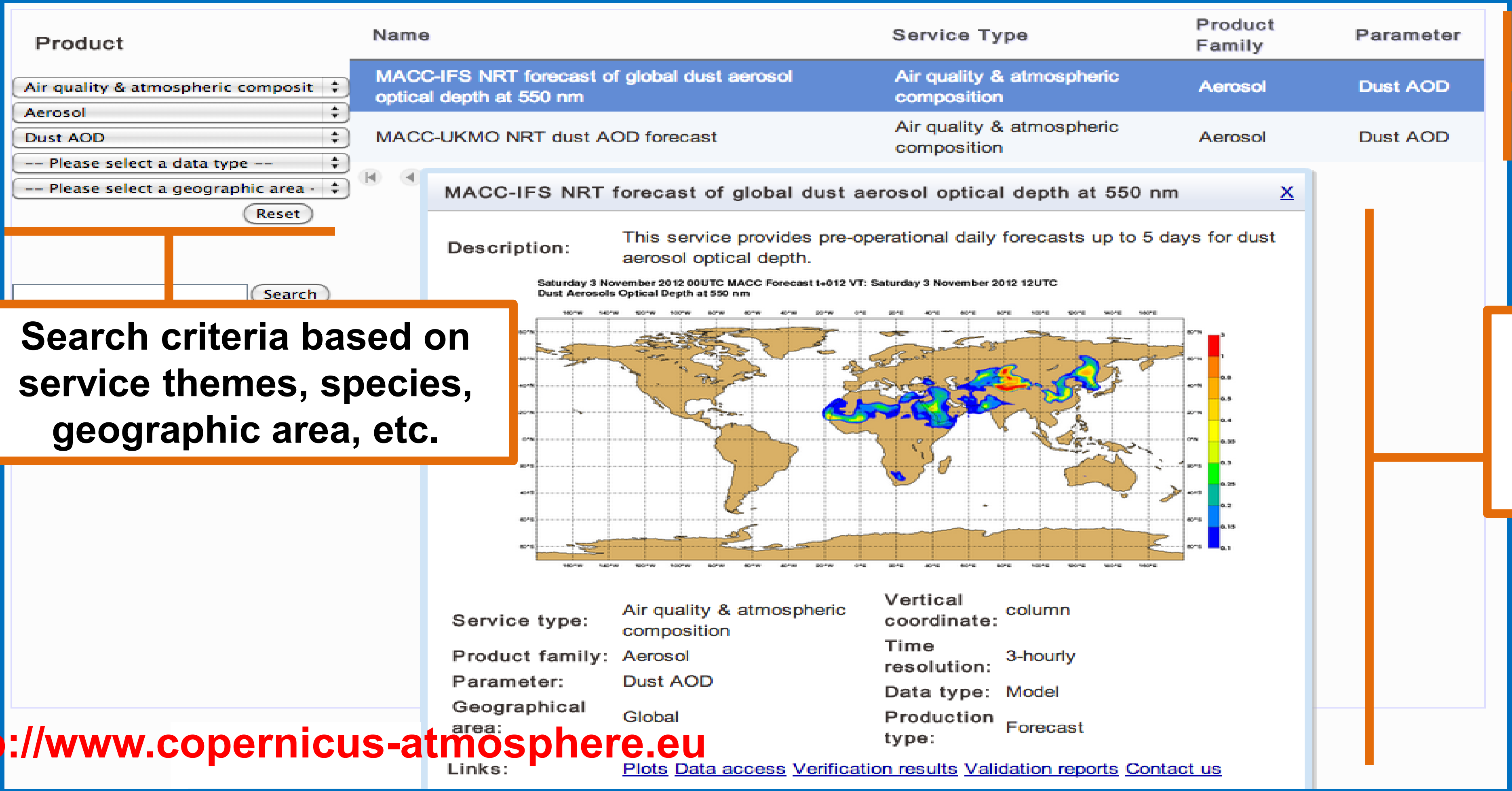
EMISSIONS AND SURFACE FLUXES

Estimates of human emissions globally and in Europe (high-resolution), emissions by wildfires, surface fluxes of CO_2, CH_4 and N_2O.

http://www.copernicus-atmosphere.eu



CAMS online catalogue search (open data policy)



Products found

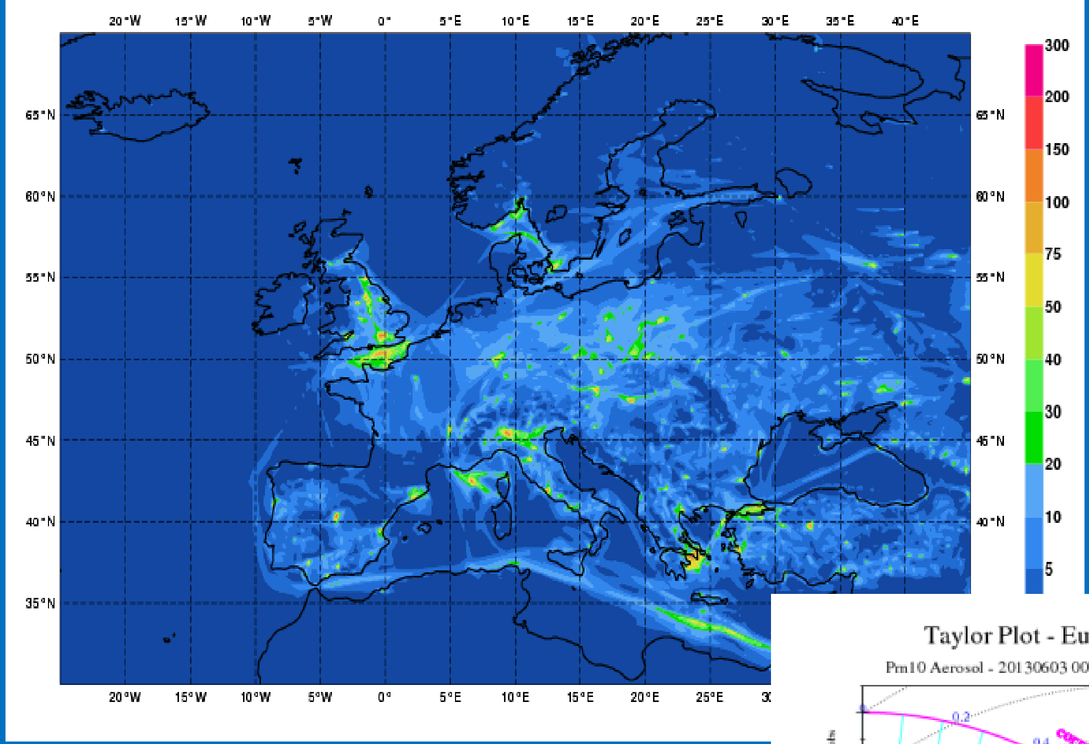
Search criteria based on service themes, species, geographic area, etc.

Pop-up window with product description and links to plots, data, and validation

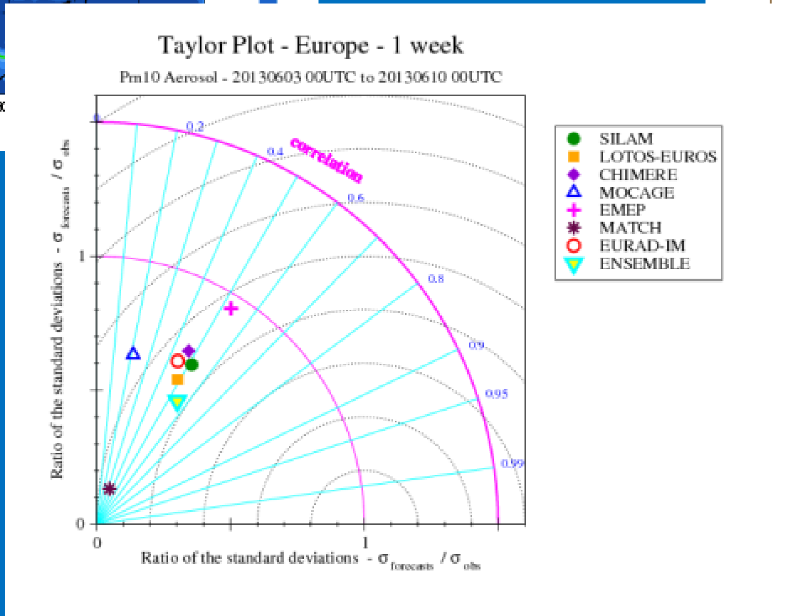
http://www.copernicus-atmosphere.eu

FORECAST PRODUCTS

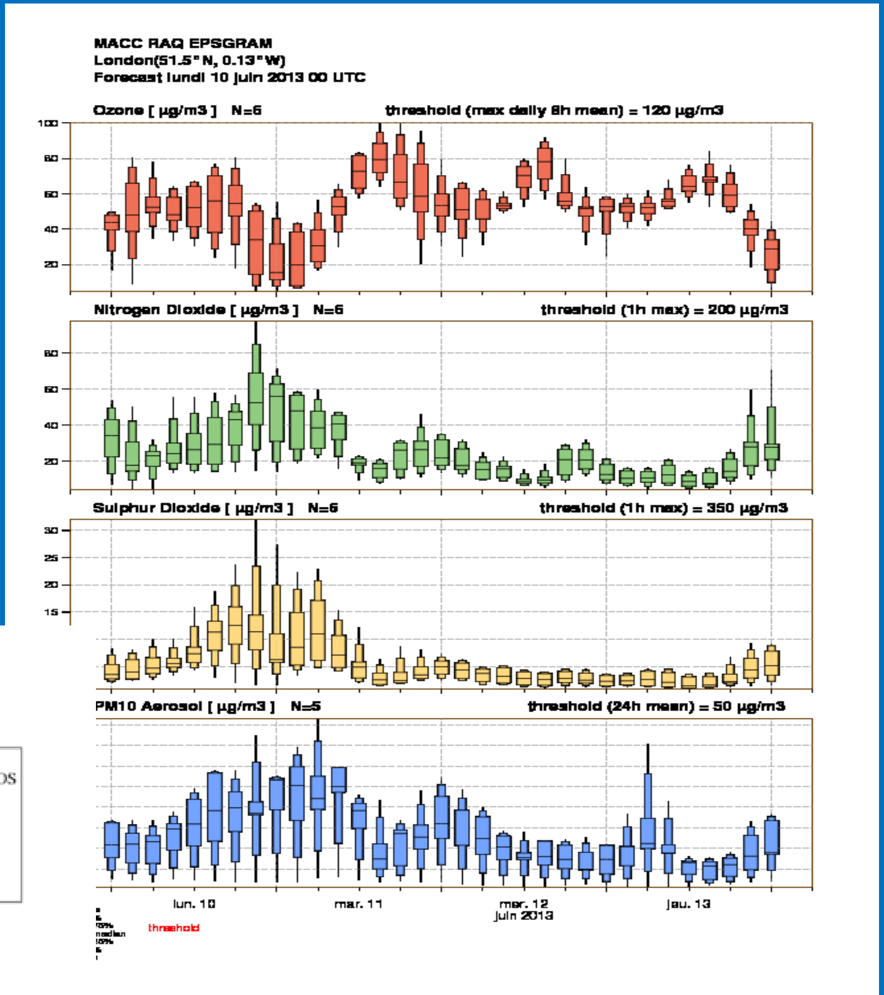
NO2, Europe-wide, ~15 km, hourly +96h



Global and European maps of major pollutants

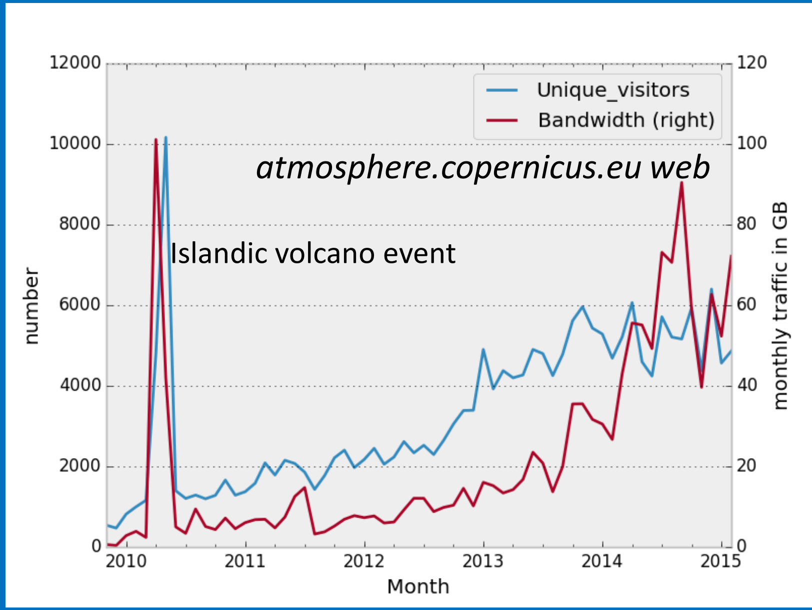


NRT / on-line evaluation

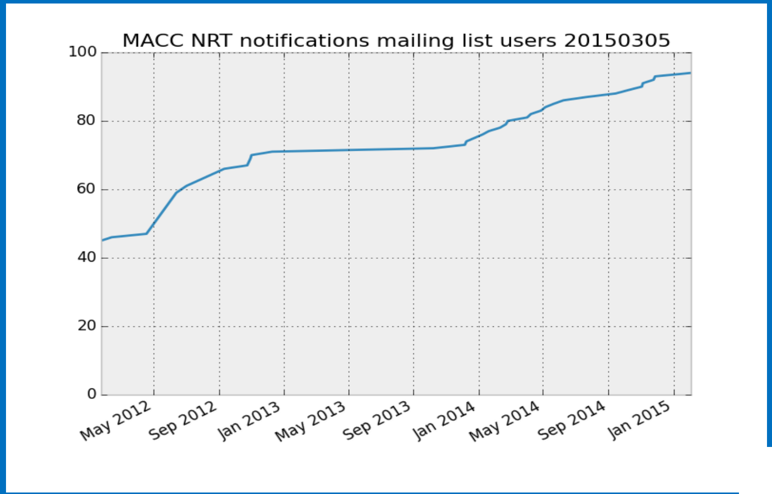


Multi-model spread as a measure of forecast uncertainty

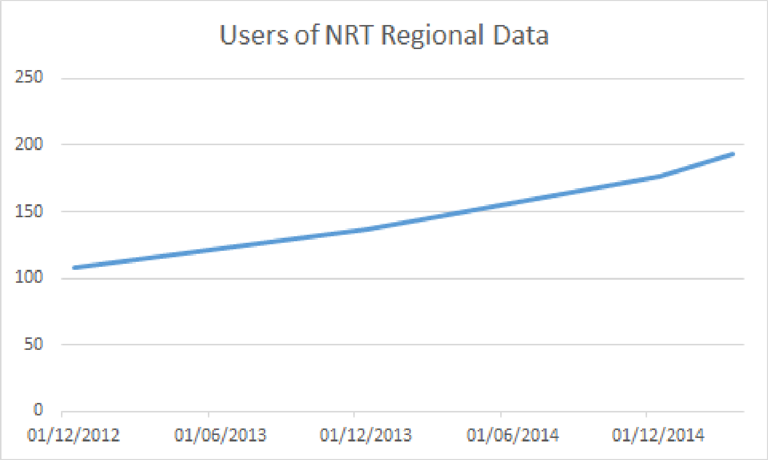
GROWING CAMS AUDIENCES (3000+ USERS)



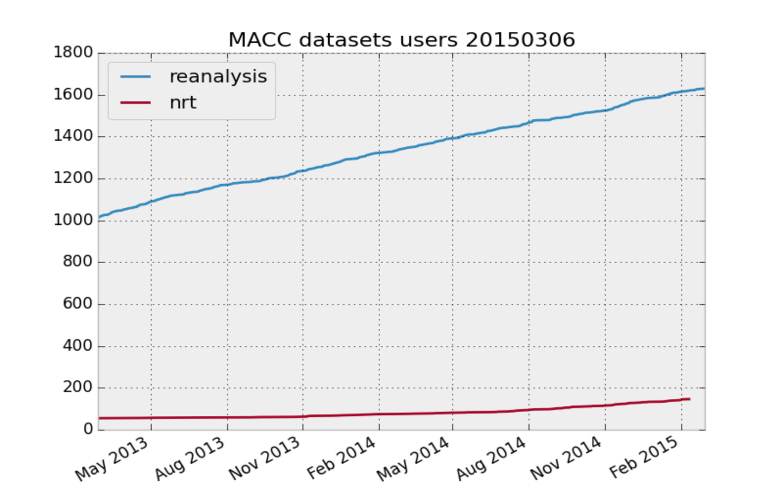
Daily time-critical users of Global Services



Daily time-critical users of Regional Services



Users of the global re-analysis



Service	Number of Users/ Requests for data
Global NRT Analyses & Forecasts	~225 users
Regional NRT Analyses & Forecasts	155 users
Global Reanalysis	1600 users
GHG flux inversions	40 users
Solar Radiation	~1000 requests/year
Global ftp	~ 40 users
Emissions, fire	1773 users (716 institutes)

EXTREME EVENTS: INDONESIAN FIRES(AUG-OCT 2015)

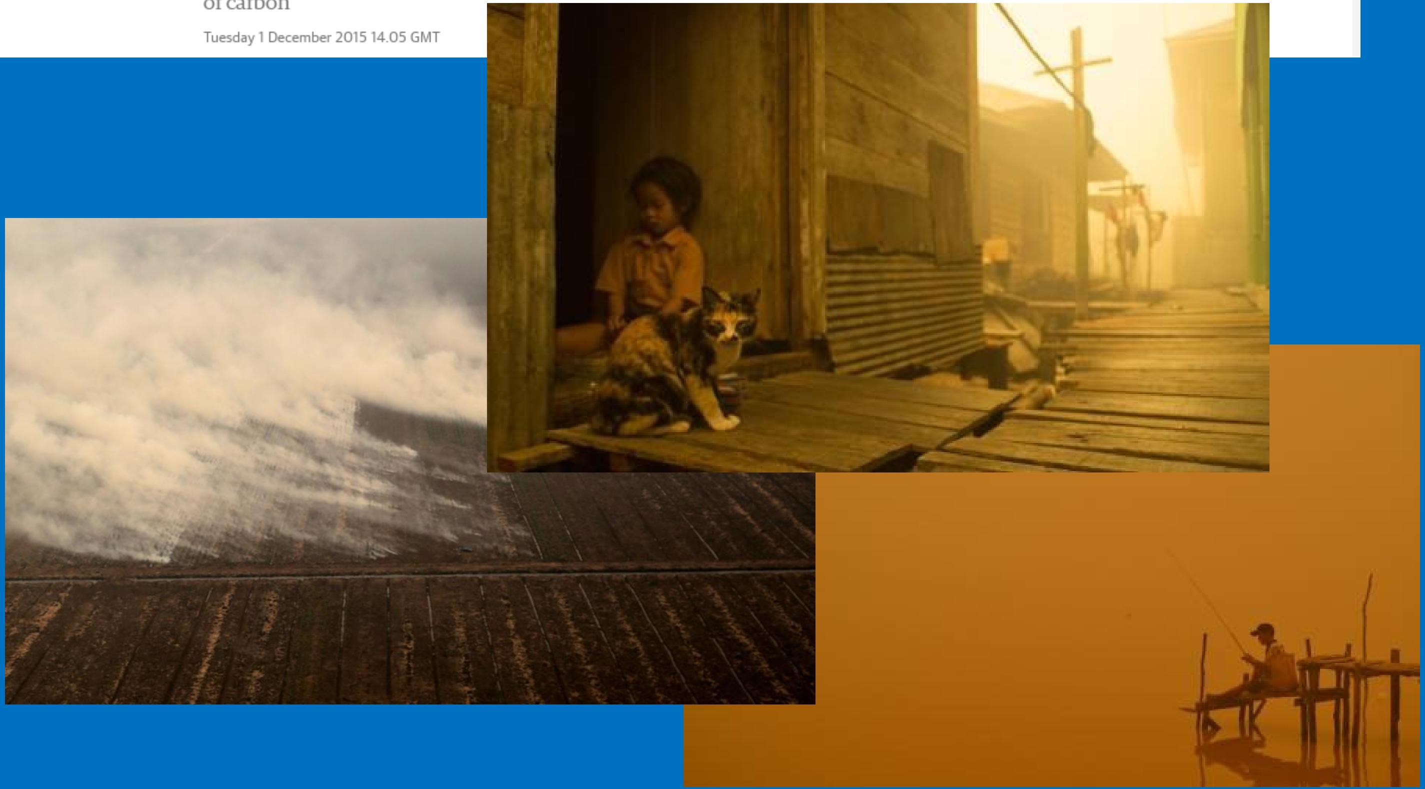
theguardian ≡ all

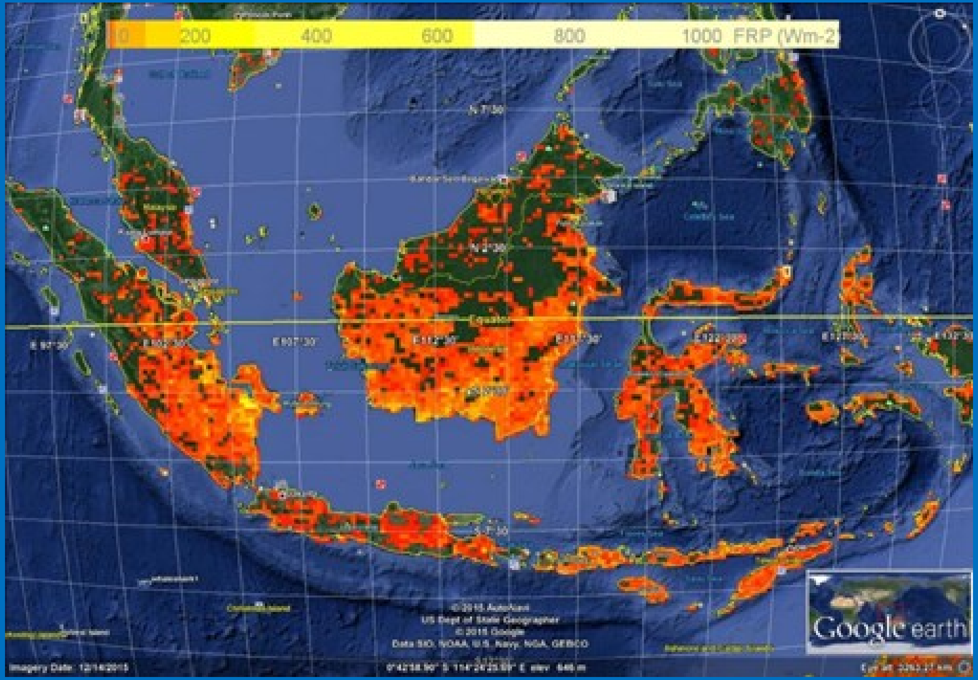
Deforestation

Indonesia forest fires: how the year's worst environmental disaster unfolded - interactive

As world leaders gather in Paris to discuss the global response to climate change, we assess the impact of the widespread forest fires in Indonesia. Set to clear land for paper and palm oil production, the fires have not only destroyed forest and peatland, but also severely affected public health and released massive amounts of carbon

Tuesday 1 December 2015 14.05 GMT



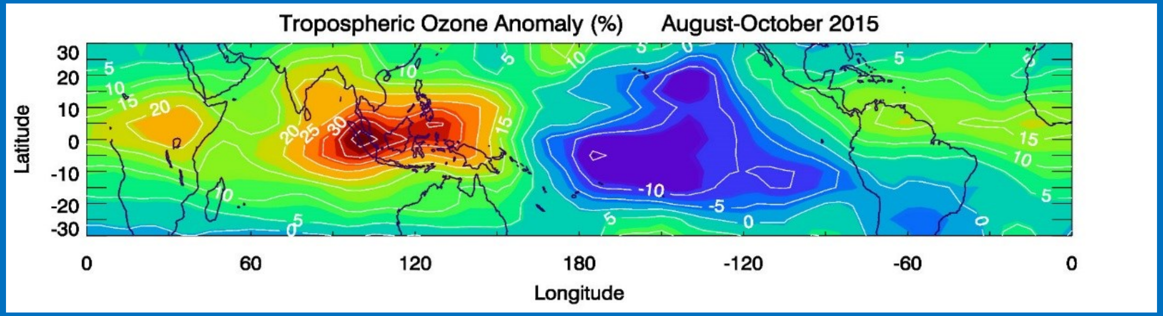


Fire Radiative Power (W/m2) accumulated over Indonesia during the 2015 fire season (Aug-Oct). Credits: Francesca Di Giuseppe

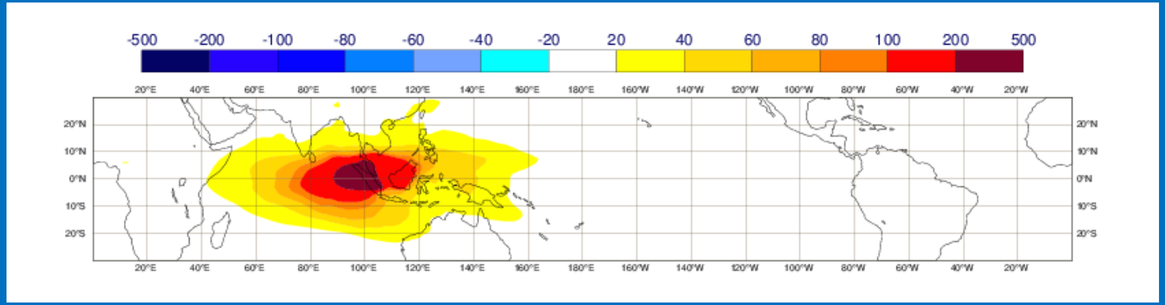
ECMWF

INDONESIAN FIRES
(AUG-OCT 2015)

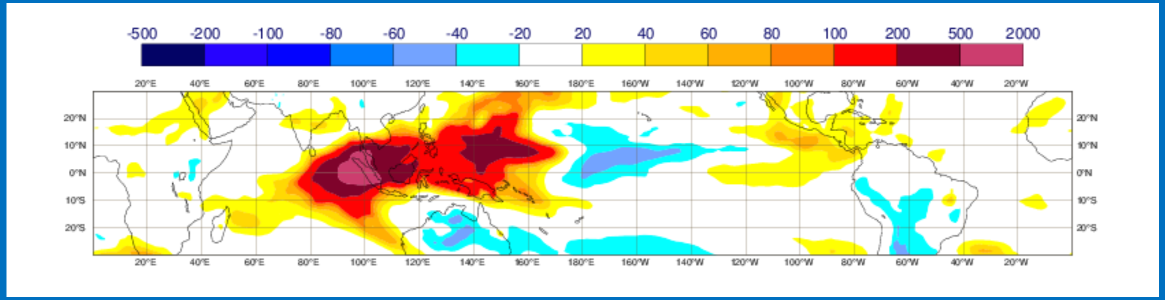
O3 anomaly: 30-40 %

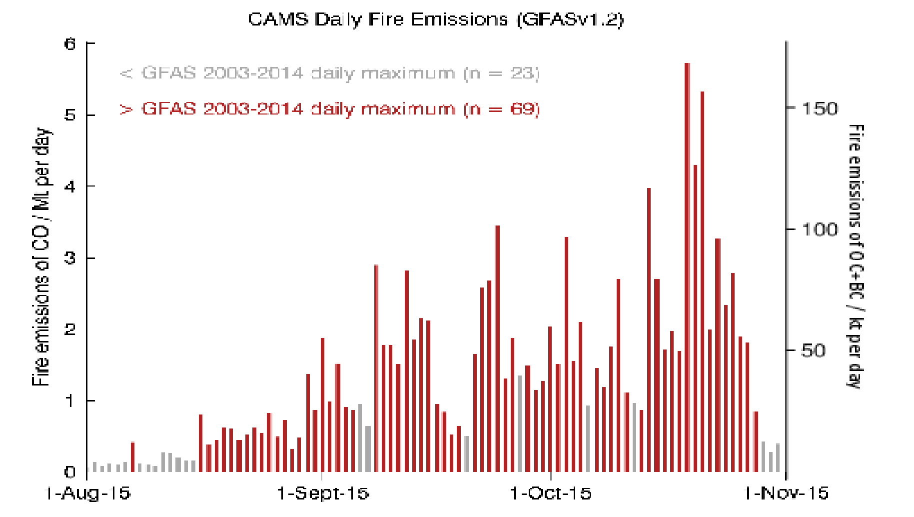


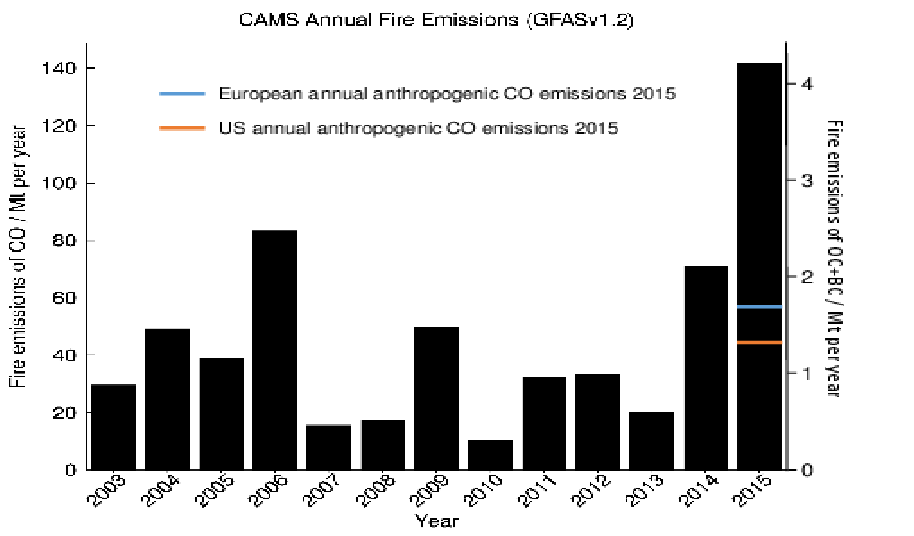
CO anomaly: up to 500%



Biomass burning AOD anomaly: up to 2000%







Benedetti et al, 2016, in "State of Climate 2015", BAMS.
Credits: Antje Inness, Mark Parrington (ECMWF), Gerry Ziemke (NASA)

EXTREME EVENTS:
CHILEAN FIRES(JAN 2017)


theguardian
website of the year
UK world politics sport football opinion culture business lifestyle fashion environment tech all sections
home › world › americas asia australia africa middle east cities development europe US

Wildfires

Chile battles devastating wildfires: 'We have never seen anything on this scale'

The world's largest firefighting aircraft has flown in from the US, alongside help from France, Peru and Mexico, as fires continue to ravage Chilean lands

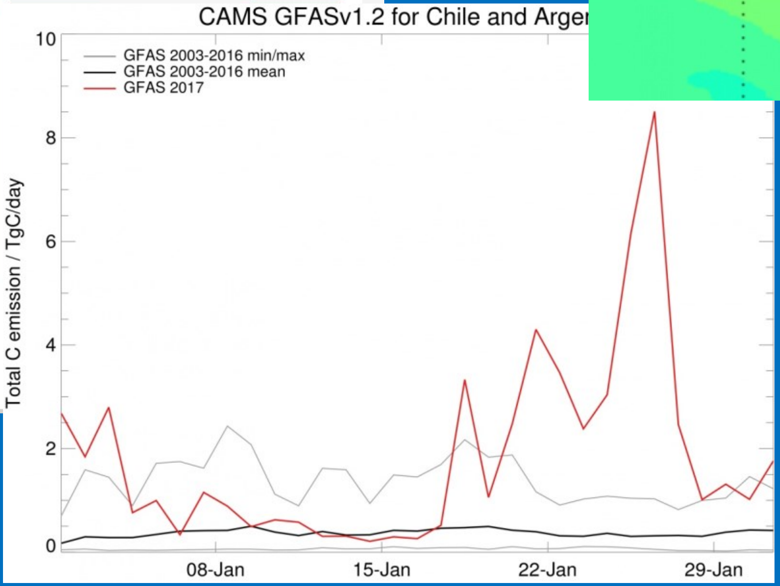
22k

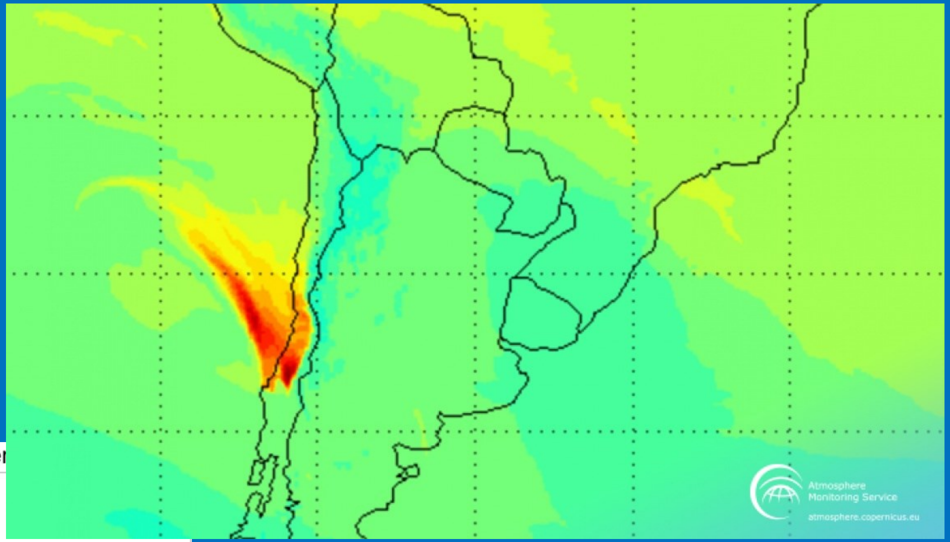
Jonathan Watts, Latin America correspondent

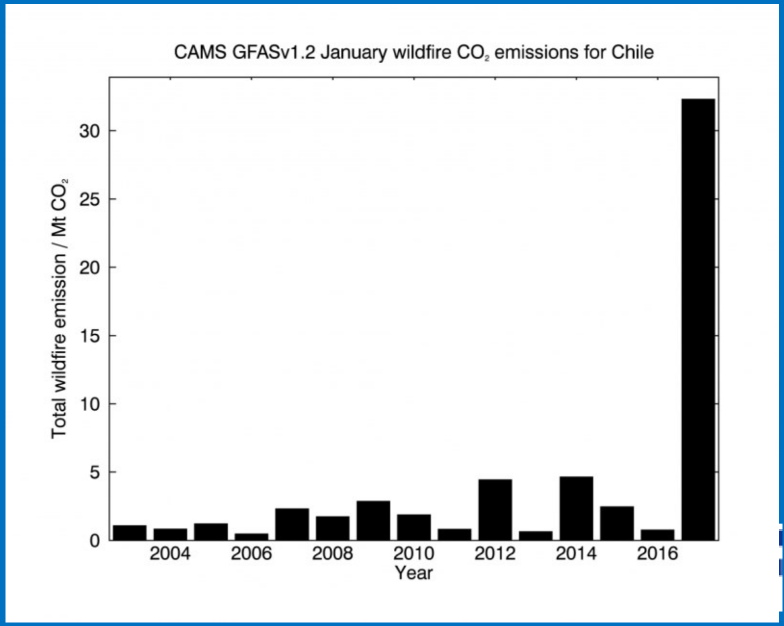
Wednesday 25 January 2017 23.06 GMT

Advertisement

View of a forest fire in Chile in 2015. Photograph: STR/AFP/Getty Images







Credits: Mark Parrington (ECMWF)

AEROSOL MODELLING

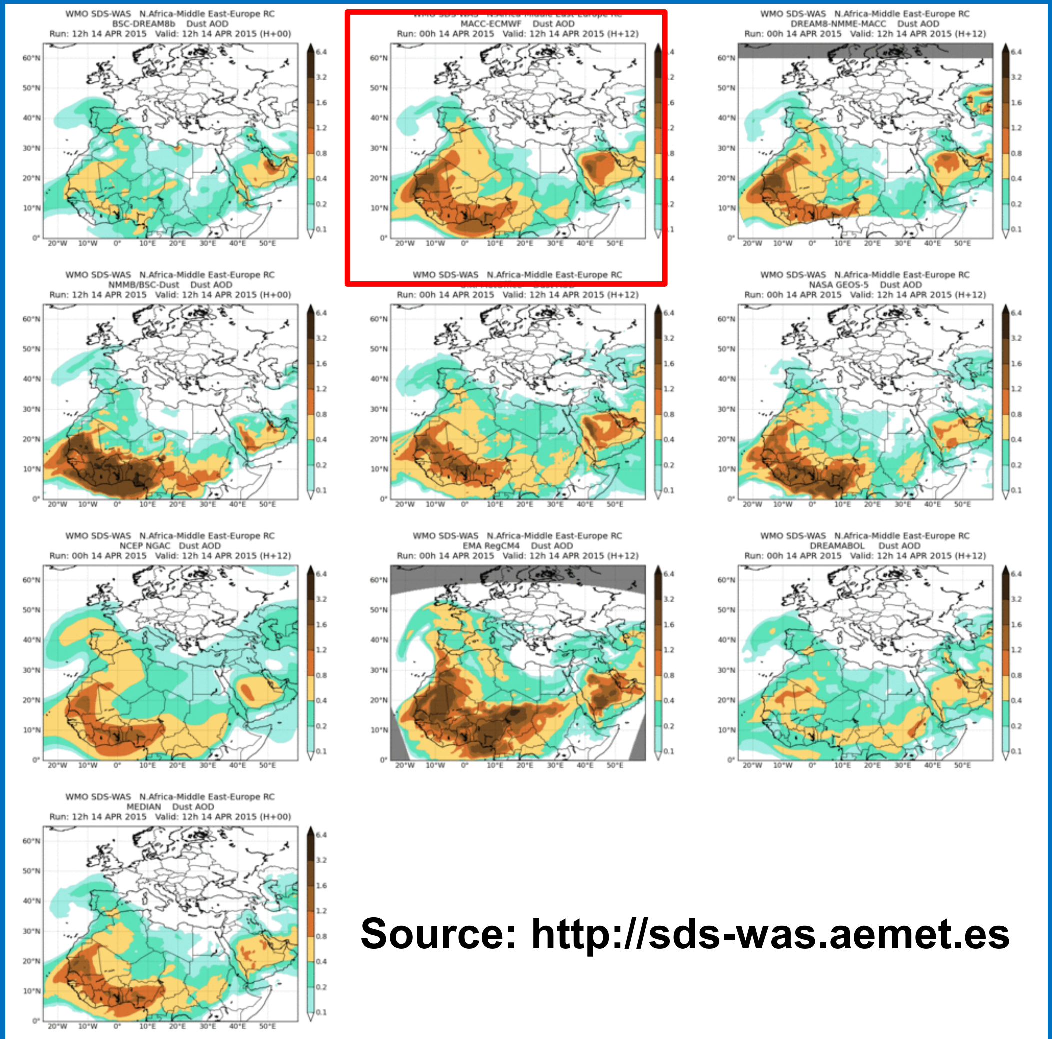
CAMS aerosol forecasts

- Built on the ECMWF NWP system with additional prognostic aerosol variables (sea salt, desert dust, organic matter, black carbon, sulphates)
- Aerosol data used as input in the aerosol analysis:

  - NASA/MODIS Terra and Aqua Aerosol Optical Depth at 550 nm

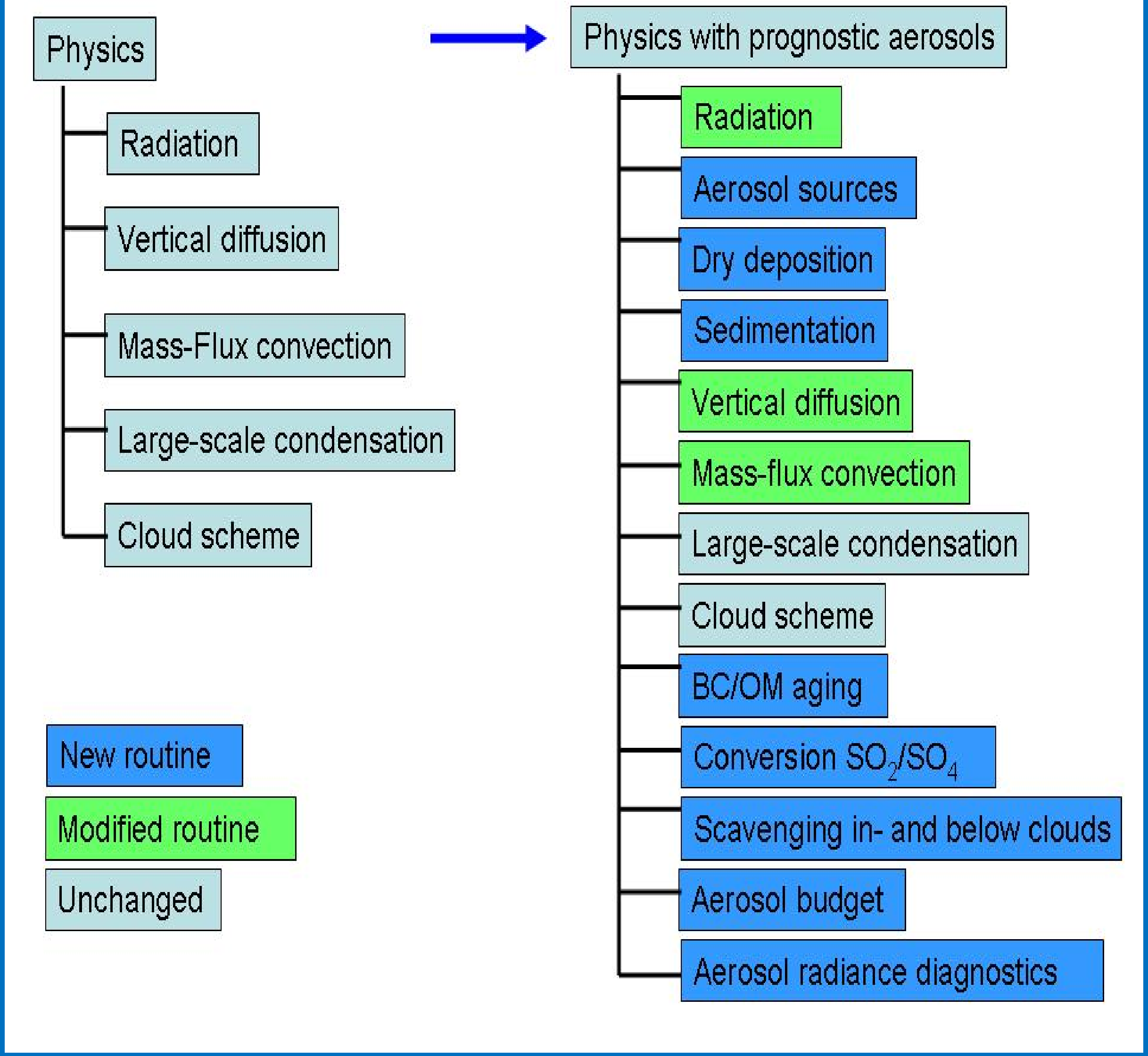
  - NASA/CALIOP CALIPSO Aerosol Backscatter (experimental)

  - AATSR, PMAP, SEVIRI, VIIRS (experimental)
- Verification based on AERONET Aerosol Optical Depth (and now also Angstrom exponent)
- Part of multi-model ensemble efforts such as the International Cooperative for Aerosol Prediction (ICAP) and the WMO Sand and Dust Storm Warning and Assessment System (SDS-WAS) North-African-Middle-East-Europe and Asian nodes.



Source: http://sds-was.aemet.es

Aerosols in the ECMWF IFS (C-IFS)



12 aerosol-related prognostic variables:

* 3 bins of sea-salt (0.03 – 0.5 – 0.9 – 20 μm)
* 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
* Black carbon (hydrophilic and –phobic)
* Organic carbon (hydrophilic and –phobic)
* SO_2 -> SO_4

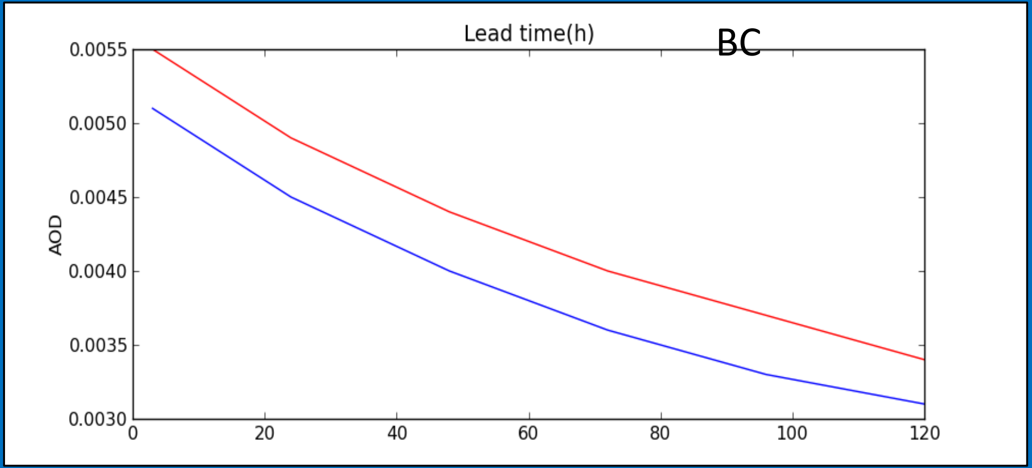
Physical processes include:

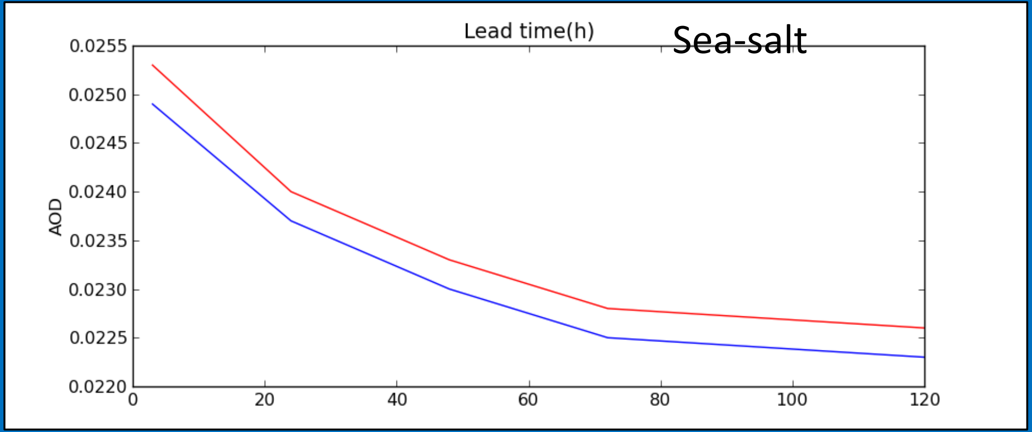
• emission sources (some of which updated in NRT, i.e.fires),
• horizontal and vertical advection by dynamics
• vertical advection by vertical diffusion and convection
• aerosol specific parameterizations for dry deposition, sedimentation, wet deposition by large-scale and convective precipitation, and hygroscopicity (SS, OM, BC, SU)

Morcrette et al. 2009, *JGR*, **114**, doi:10.1029/2008JD011235

Recent developments: Use of a mass fixer for aerosol species in CIFS

- For aerosol species as for chemical species, the Semi Lagrangian Advection (SLA) scheme is not mass conservative.
- With the hybrid sigma-pressure system, the vertical discretization changes with surface pressure and orography.
- The GRG project already studied the impact of this phenomenon (Flemming and Huijnen, 2013, Diamantakis and Flemming, 2014) on chemical species.
- Tests with the same mass fixer as used by GRG : additive mass fixer
- Impact important on OM and BC (-10% AOD), significant on Sulfates (+3% AOD), small on total AOD (-1%)
- **It was the missing term to balance aerosol species' budgets!**





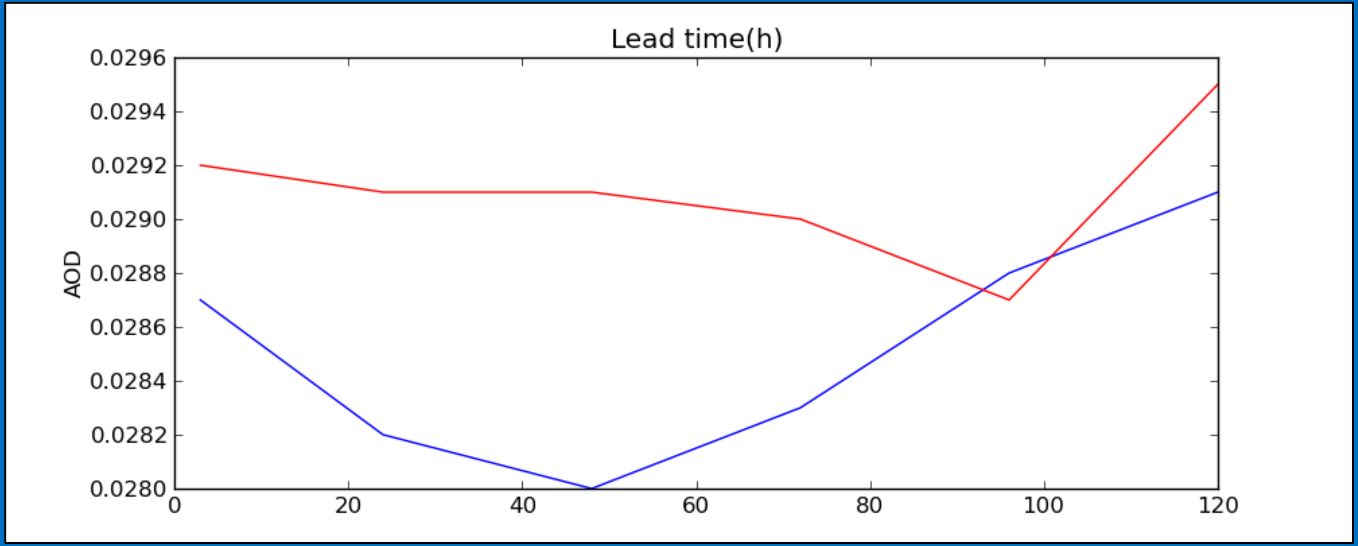
Mean global AOD for May 2014 for BC (top) and sea-salt (bottom), reference in red, with mass fixer in blue

Credits: Samuel Rémy (LMD), Johannes Flemming (ECMWF)

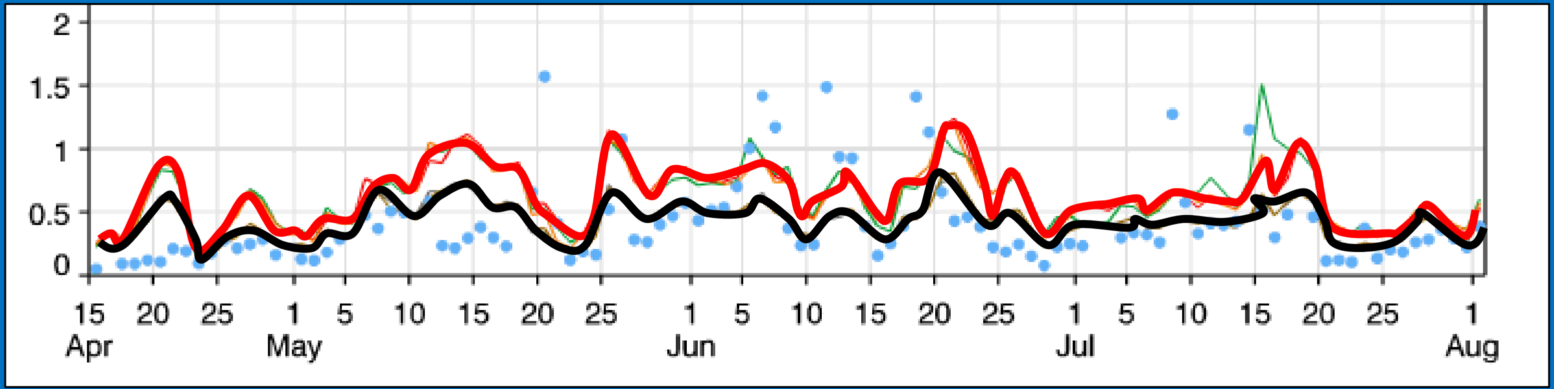
ECMWF

Recent developments: Dust emissions

- Overestimation of dust AOD : the **aerocom average is 0.023**
- Compared to the literature and other models, the amount of larger particles in dust emissions is too low.
- => decrease of the amount of small particles in the emissions, increase the amount of larger particles



Global dust AOD for May 2014 as a function of lead time, with (red) and without (blue) data assimilation



AOD at the AERONET station of Tamanrasset (Algeria), from 15/4/2014 to 1/8/2014. Observations (blue), old emissions (red) and new emissions (black)

- Better balance between the model and observations after the introduction of new emissions

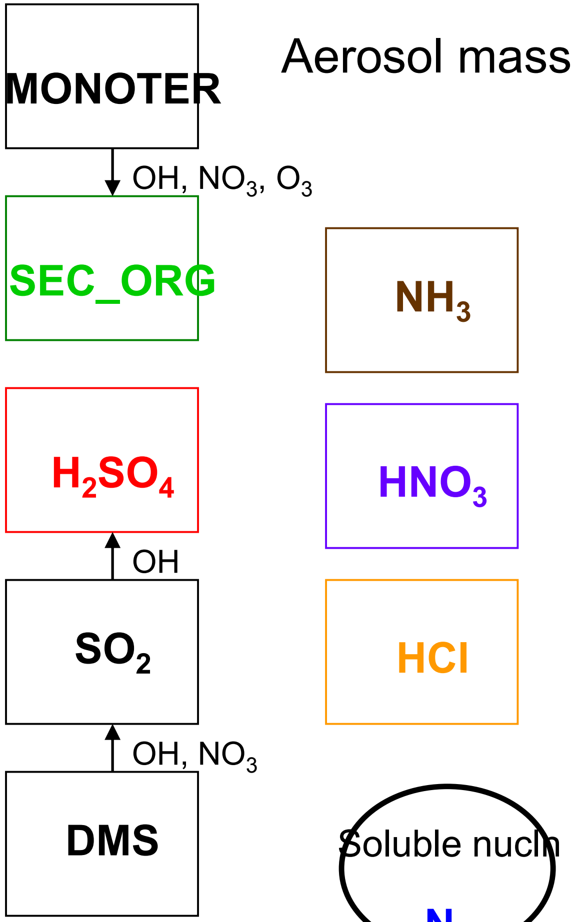
Credits: Samuel Rémy

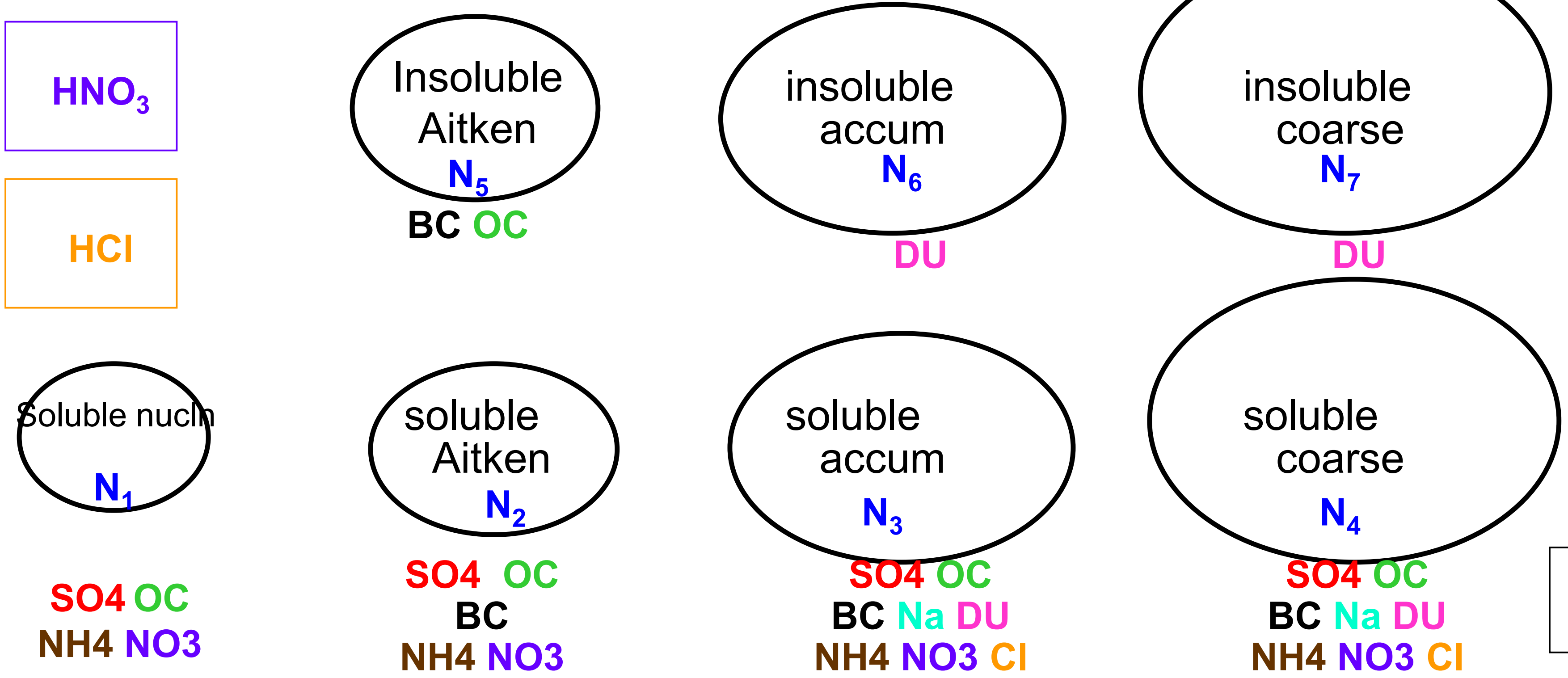
Future: GLOMAP aerosol in C-IFS

Aerosol mass as "components" in internally mixed modes

Sulphate, sodium, black carbon, organic carbon, dust
Ammonium, nitrate, chloride

Also emit sea-spray as sodium chloride & sodium sulphate.
Account for sea-salt-SO4 as well as usual nss-SO4.





component mass conc.

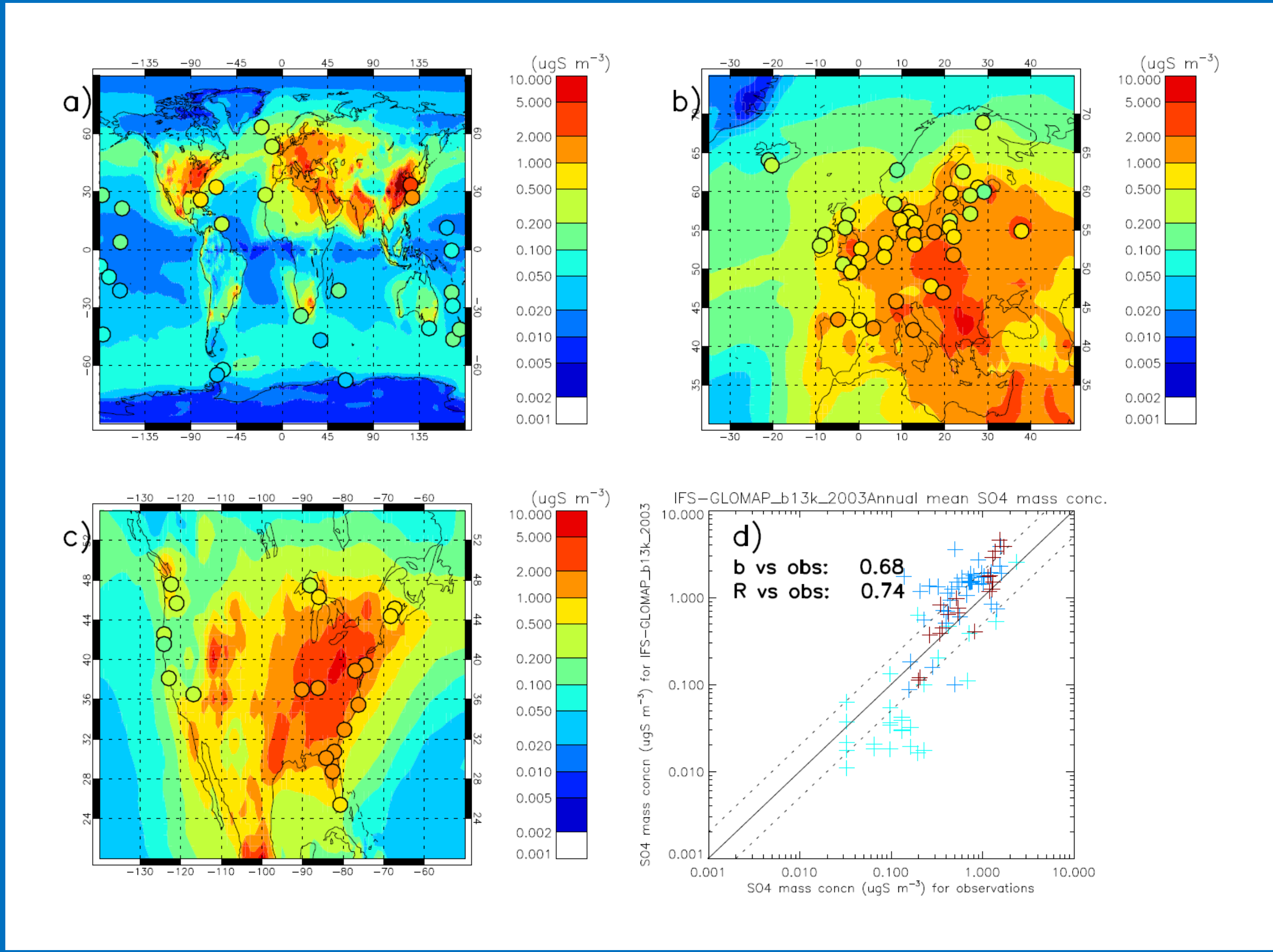
29 mass
7 number

Transported tracers=36

Credits: Graham Mann (University of Leeds)

ECMWF

Evaluation suite for assessing IFS- GLOMAP (also in UM, TOMCAT)



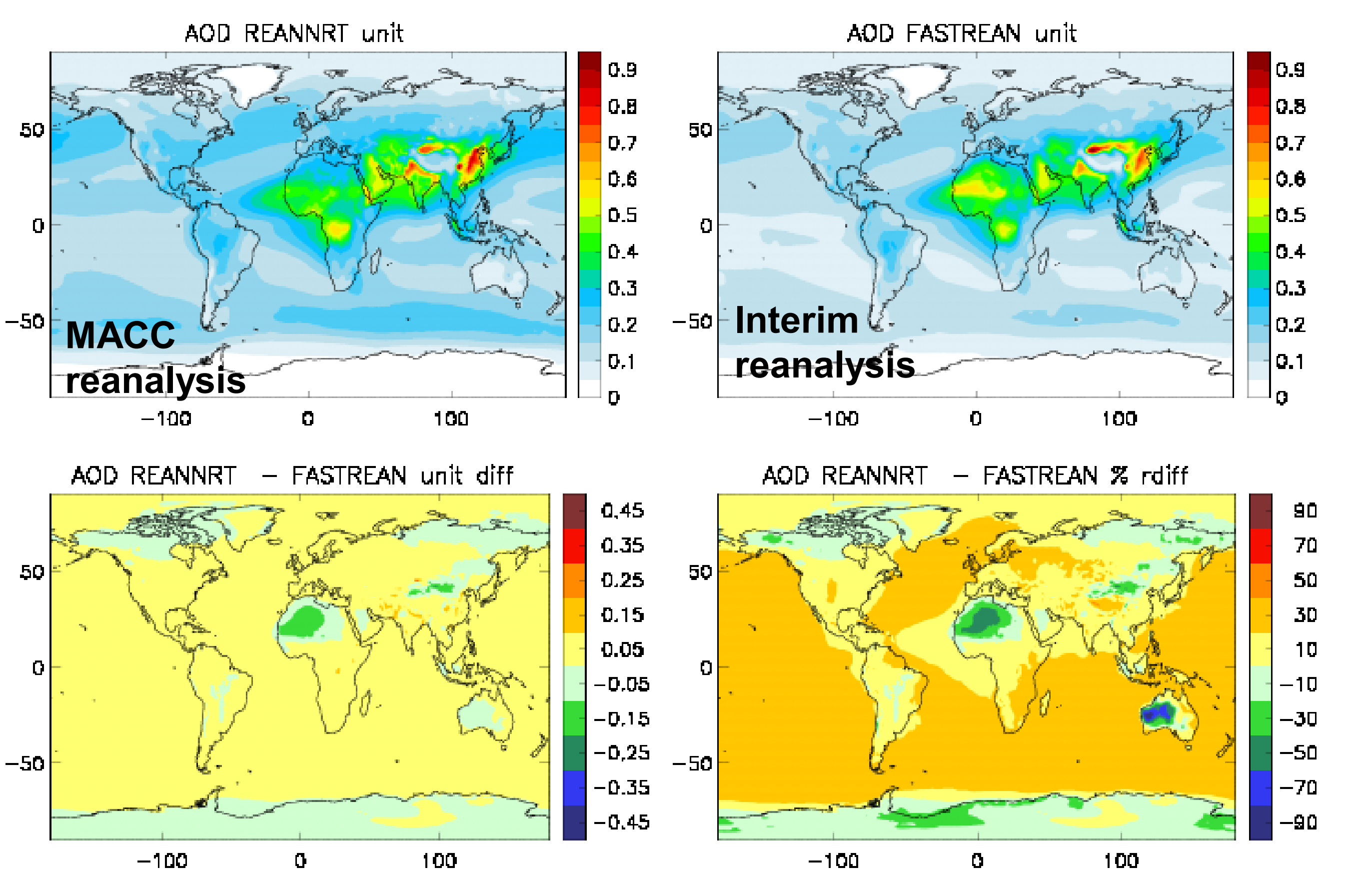
Credits: Graham Mann, Sandip Dhomse (Uni Leeds)

Sulphate mass evaluation against EMEP, IMPROVE, U. Miami obs datasets for reference IFS-GLOMAP run

- GLOMAP evaluation strategy involves assessing a range of aerosol metric against observations. As well as aerosol optical depth speciated mass, size-resolved number concentrations are used.

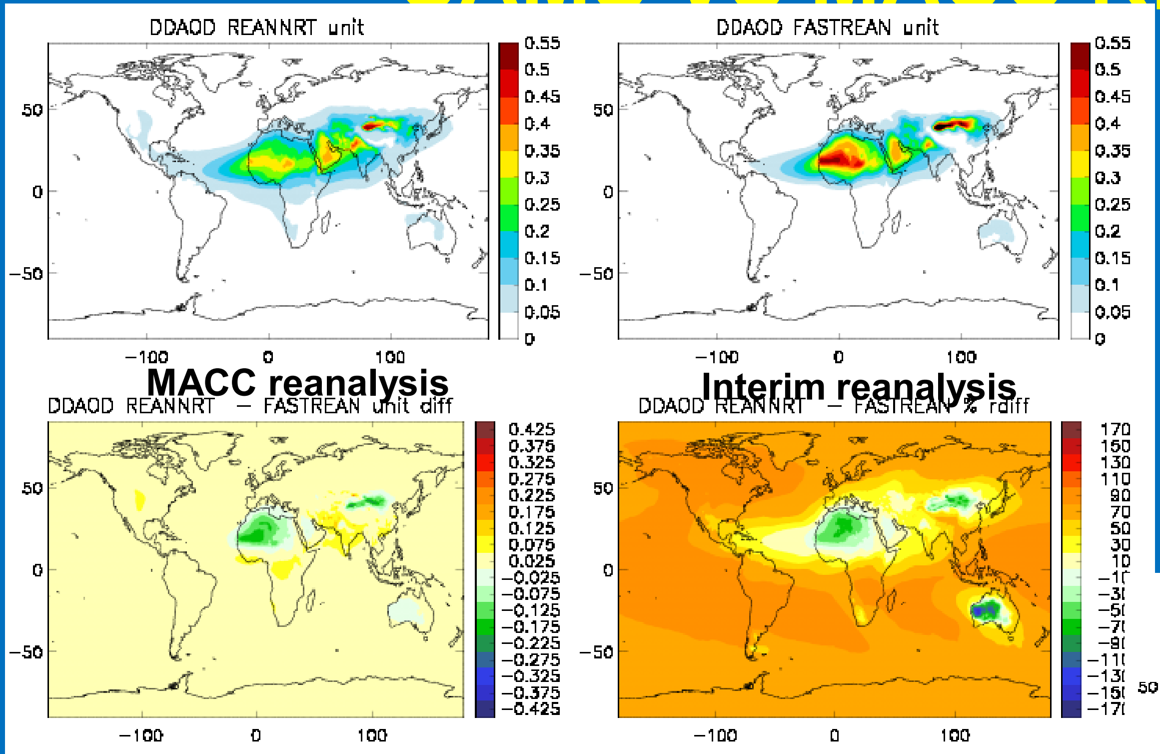
CAMS REANALYSIS RUNS

- "Interim" reanalysis from 2003-2016 has been produced (Flemming et al 2017, ACP)
- Limited number of archived fields & reduced number of meteorological datasets
- Overall good performance
- Used for contribution to the State of Climate (BAMS) publication (2015 and 2016 contributions)
- New CAMS reanalysis in preparation

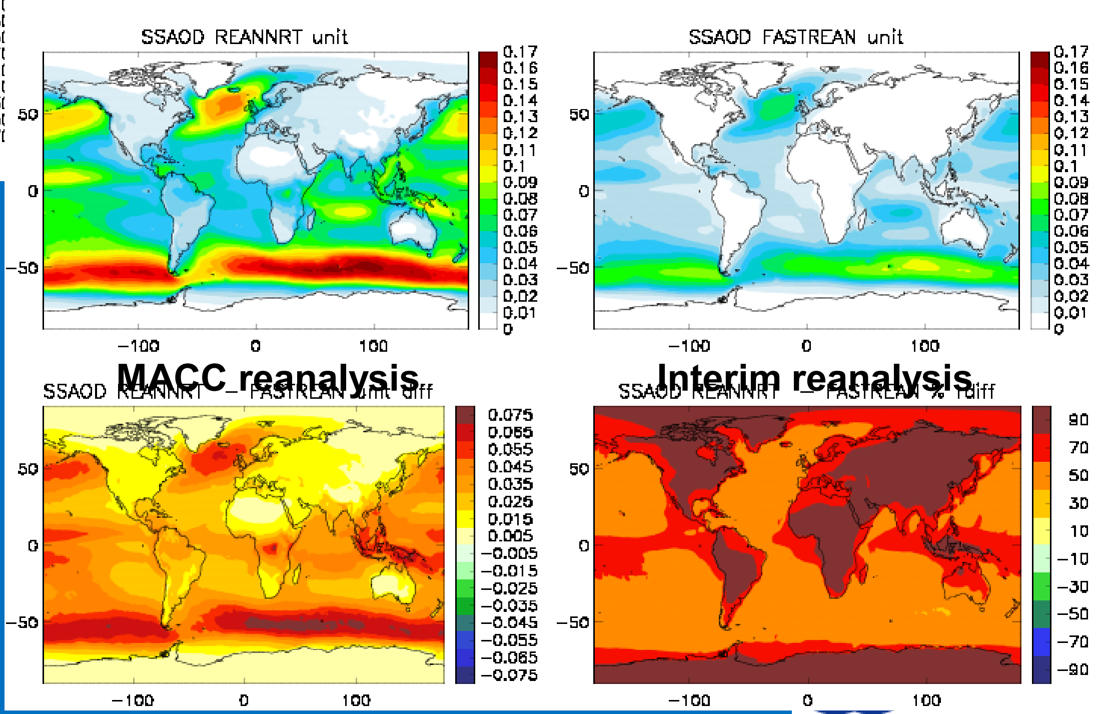


In collaboration with: Johannes Flemming and Antje Inness

CAMS VS MACC REANALYSIS RUNS



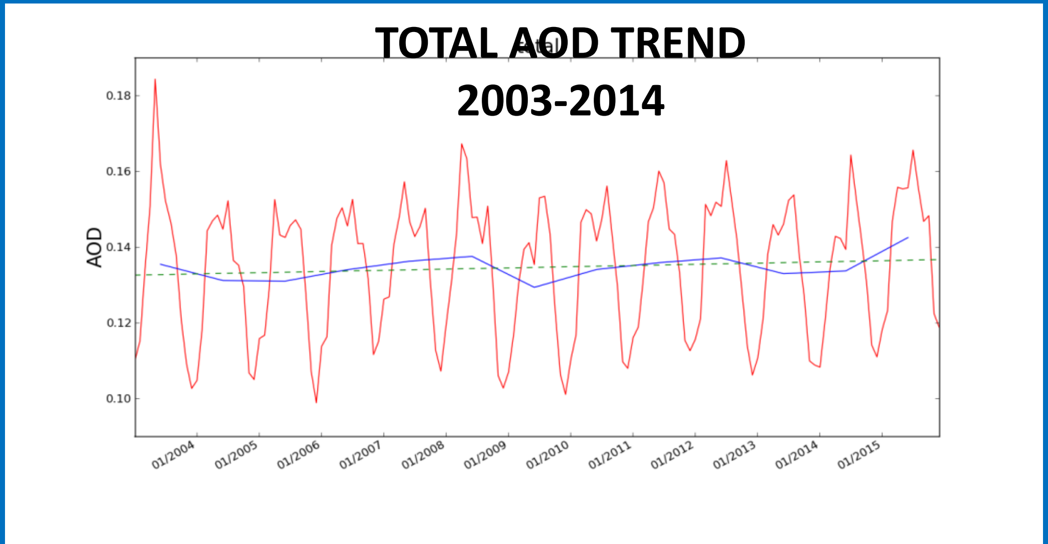
- Main differences in AOD are down to model changes since the CAMS “Interim” reanalysis uses MODIS Dark Target as the MACC reanalysis
- Increase in dust (particularly close to the source areas)
- Perhaps now too much dust but this is being corrected for the next reanalysis

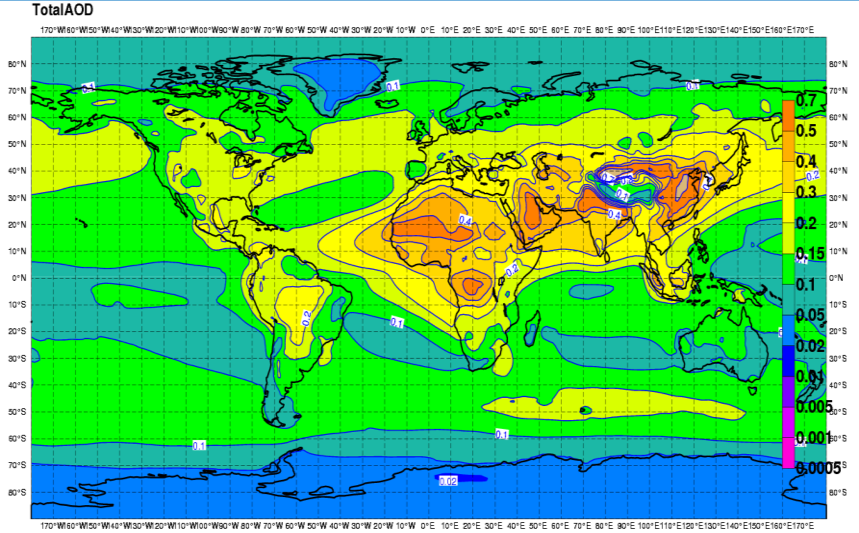


- Striking differences in sea salt are attributable to model changes (big impact)
- Bias correction for MODIS data includes also surface wind speed as predictor (smaller impact)

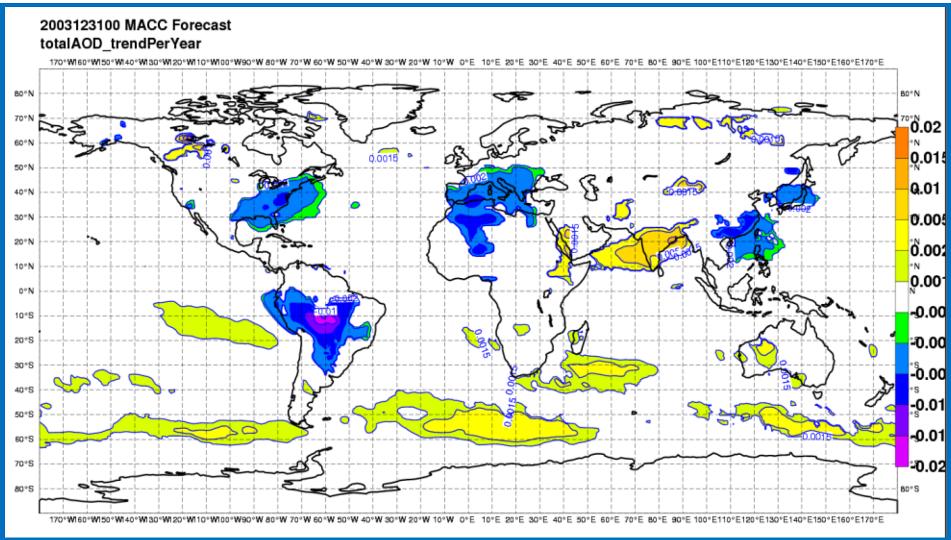
In collaboration with: Johannes Flemming and Antje Inness

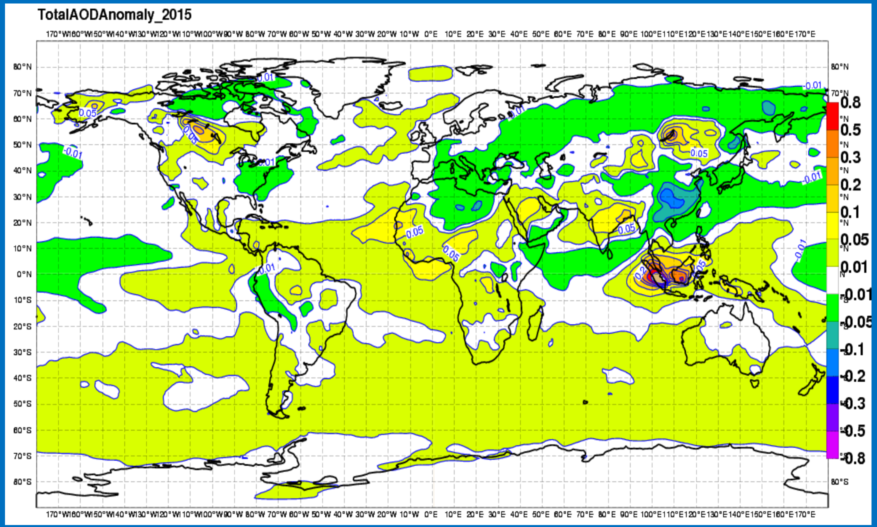
REANALYSIS RUNS: BAMS STATE OF CLIMATE 2015





TOTAL AOD 2003-2014





AOD ANOMALY 2015

Rémy et al, 2016: [Global climate] Aerosols [in "State of the Climate in 2015"].

2016 contribution is in preparation!

ECMWF

Summary so far…

- CAMS offers many services related to atmospheric composition from daily forecasts to reanalysis runs both at the global and at the regional (European) level

- Model developments related to aerosols have been carried out for the past 12 years during precursors projects. These are now part of the ECMWF's Integrated Forecast System (IFS)

- Several datasets related to atmospheric composition are routinely assimilated and more are in the pipeline (Copernicus Sentinel satellites)

AEROSOL IMPACTS ON NUMERICAL WEATHER PREDICTION

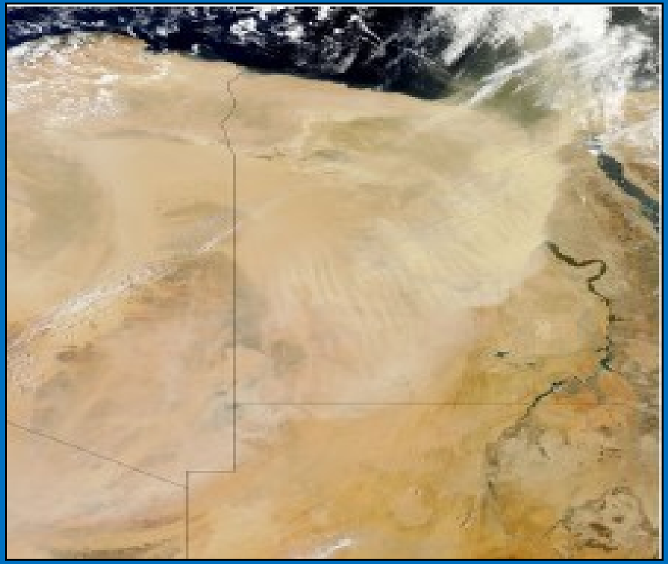
WMO Working Group on Numerical Experimentation (WGNE)

This inter-comparison aims to evaluate the impact of aerosols on Numerical Weather Prediction

Three situations were proposed :

- Dust storm over Egypt on 18th of April 2012
- Extreme pollution over Beijing, 12-16th of January 2013
- Extreme biomass burning over Brazil in September 2012 during the SAMBBA field campaign

Participants : Météo-France, Met-Office, JMA, ECMWF, NOAA, NASA, CPTEC (Brazil)



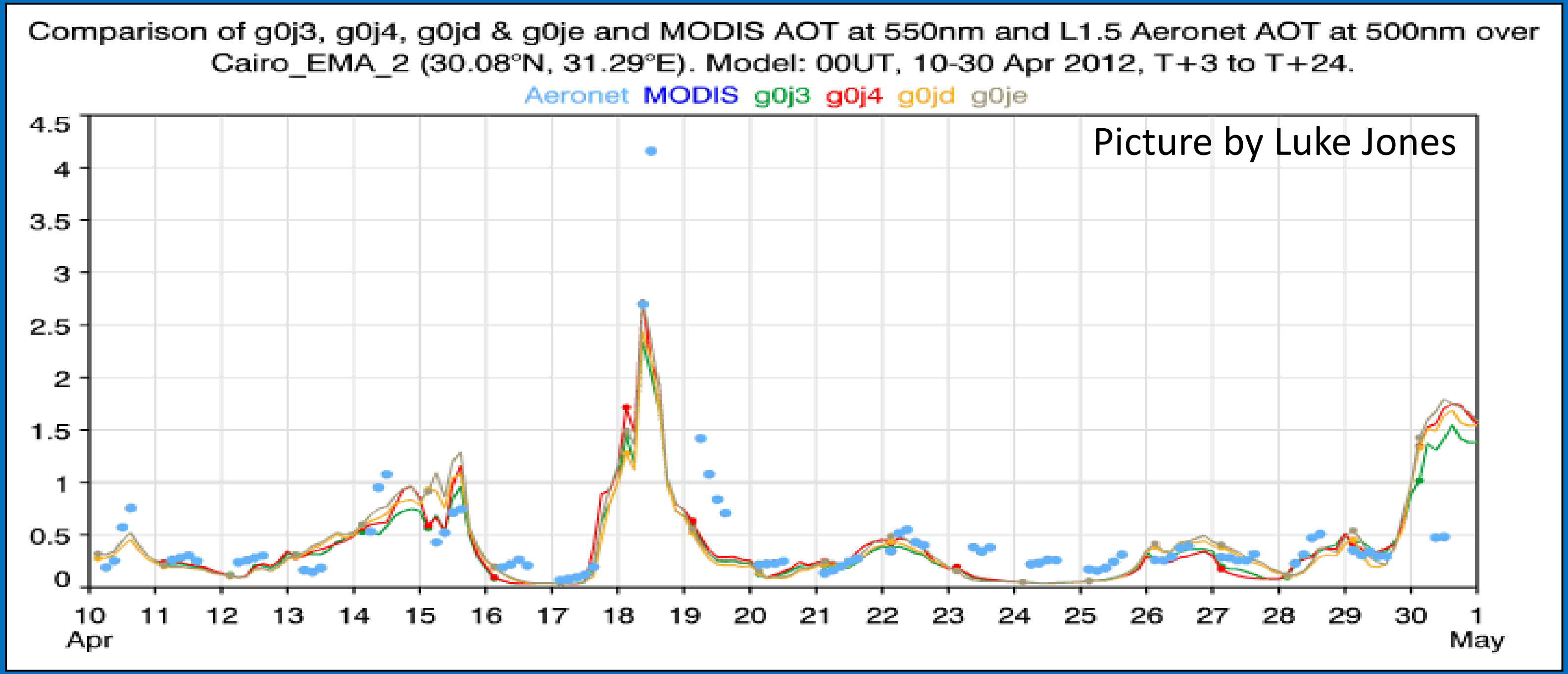
MODIS imagery, 18/4/2012

Beijing , 14/1/2013

ECMWF

Dust case of April 2012 – AOD forecasts

- Cycling forecast with the MACC global system, with aerosol direct effect from climatology or prognostic aerosols at T511, L60
- Dust bins : 0.03 – 0.55 – 0.9 – 20 µm
- AOD peak of 18th of April well timed but underestimated
- End of the event forecast too soon



Rémy et al, 2015, ACP, doi:10.5194/acp-15-12909-2015

ECMWF

Dust case of April 2012 – Impact on temperature, winds and dust production

Table 2. 2m temperature, RMSE of REF_ASSIM and TOTAL_ASSIM for forecast times 0, 12, 24, 36 and 48h, average for the period of 10th to 25th of April 2012. Stations considered are Hurguada, Luxor, Kosseir, Siwa, Wadi el Natroon, Cairo, Port Said and Ras Sedr in Egypt, and Ben Gurion airport close to Tel Aviv in Israel.

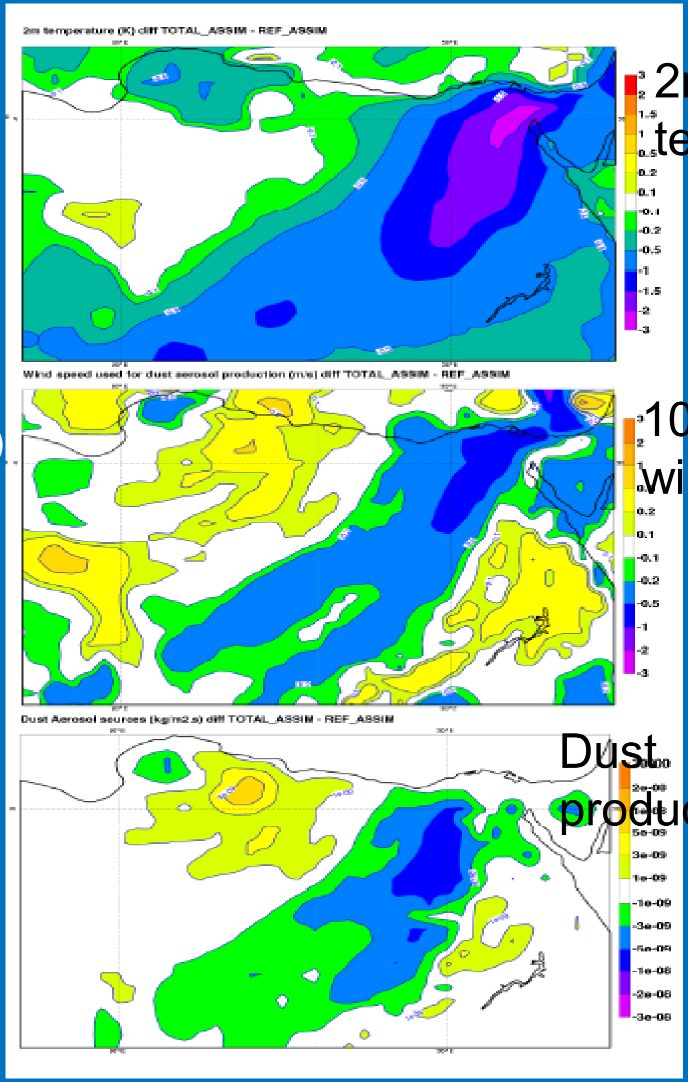
Forecast time	0h	12h	24h	36h	48h
REF_ASSIM	1.46	1.48	1.5	1.62	1.53
TOTAL_ASSIM	1.32	1.49	1.43	1.6	1.58

Table 3. 2m temperature, bias of REF_ASSIM and TOTAL_ASSIM for forecast times 0, 12, 24, 36 and 48h, average for the period of 10th to 25th of April 2012 over the same selection of weather stations as table 2.

Forecast time	0h	12h	24h	36h	48h
REF_ASSIM	-0.87	-0.05	-0.73	0.48	-0.47
TOTAL_ASSIM	-0.65	-0.18	-0.58	0.2	0.26

Difference between run with interactive aerosols (TOTAL_ASSIM) and reference run (REF_ASSIM) 36 hour forecast (valid on April 18th at 12UTC)

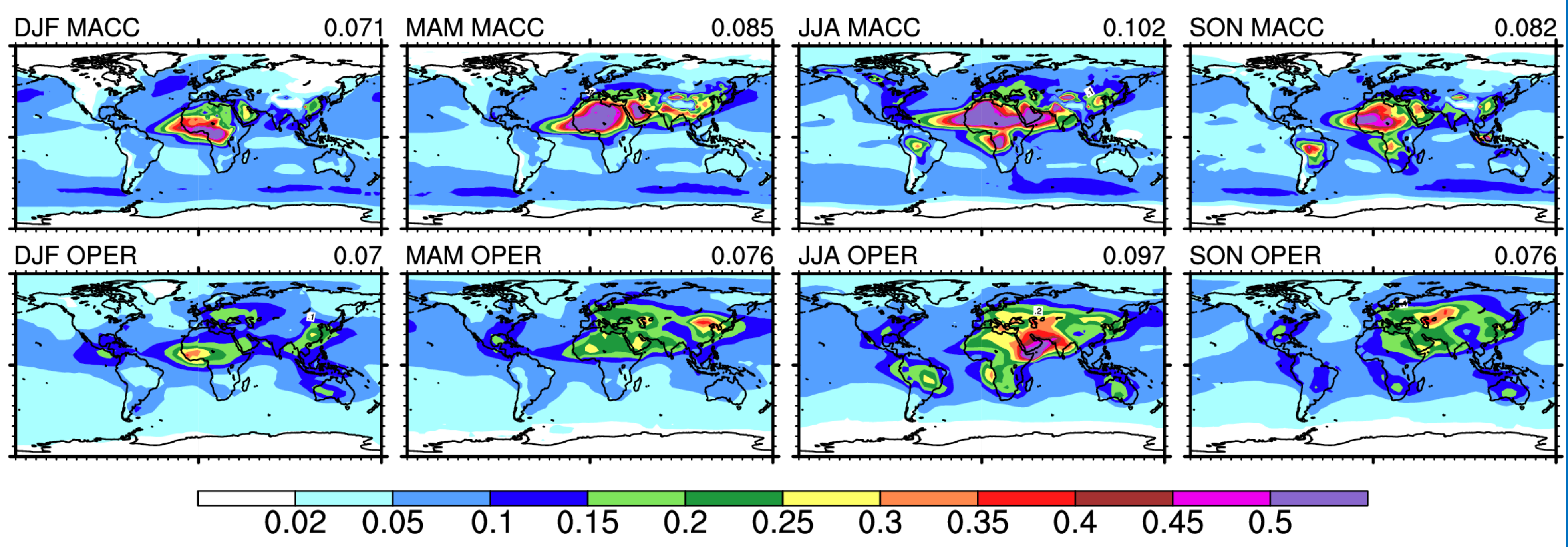
- Reduced 2m temperature
- Increased surface winds
- Increased dust production



Rémy et al, 2015, ACP, doi:10.5194/acp-15-12909-2015

Climatological AOD 550nm distribution MACC vs Tegen et al 1997 (OPER)

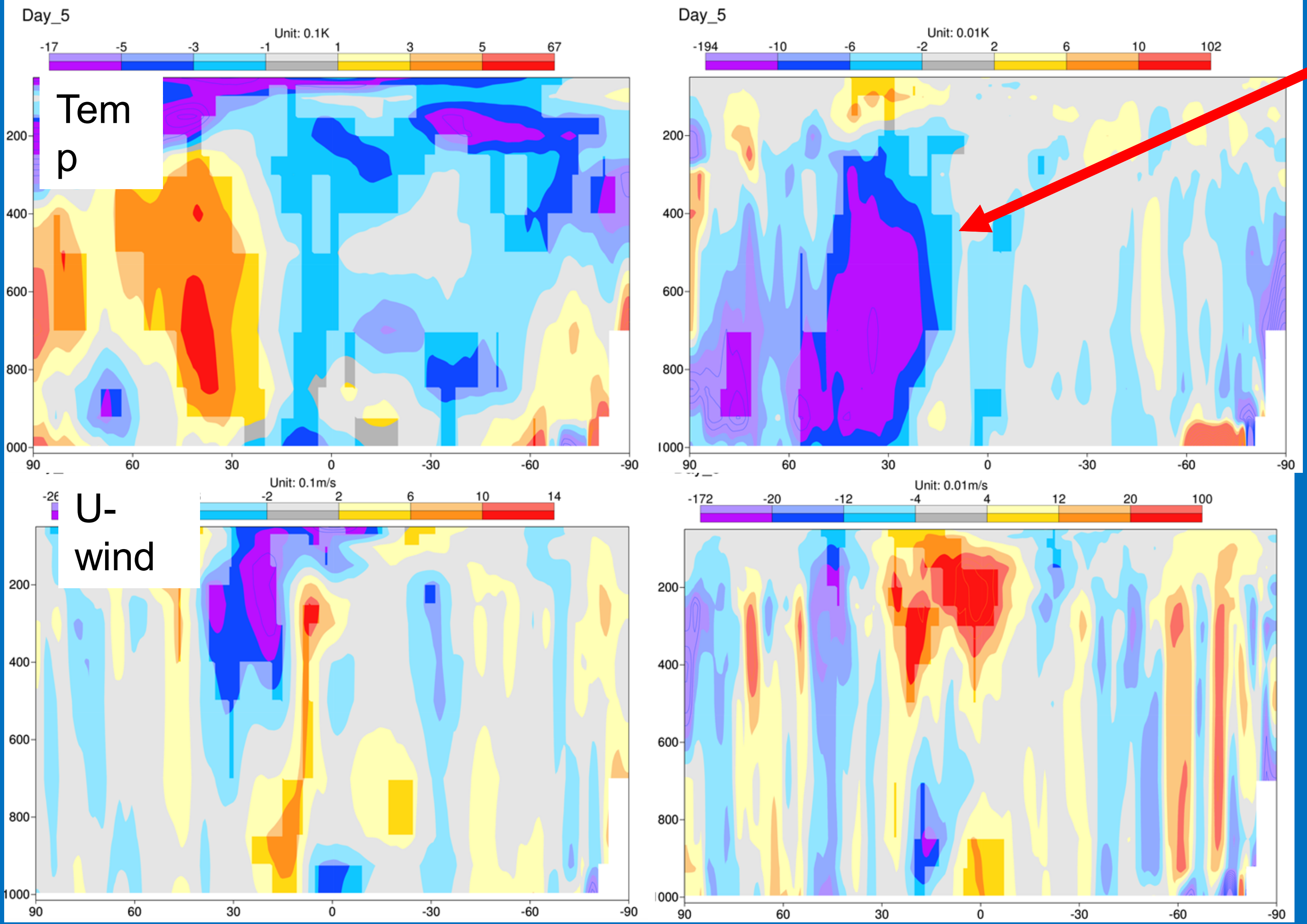
Credits: Alessio Bozzo



- MACC run (2003-2012): sources of biomass burning from GFAS, sulphate aerosol precursor from EDGAR 4.1, prognostic for sea salt and dust, revised dust model
- Optical properties recomputed for RRTM spectral bands and for each aerosol type/size bin. Mass mixing ratio as input to radiation
- Vertical distribution following an exponential decay with scale height derived from the MACC model for each aerosol type. Monthly varying for dust.

ECMWF

Impacts on forecast errors



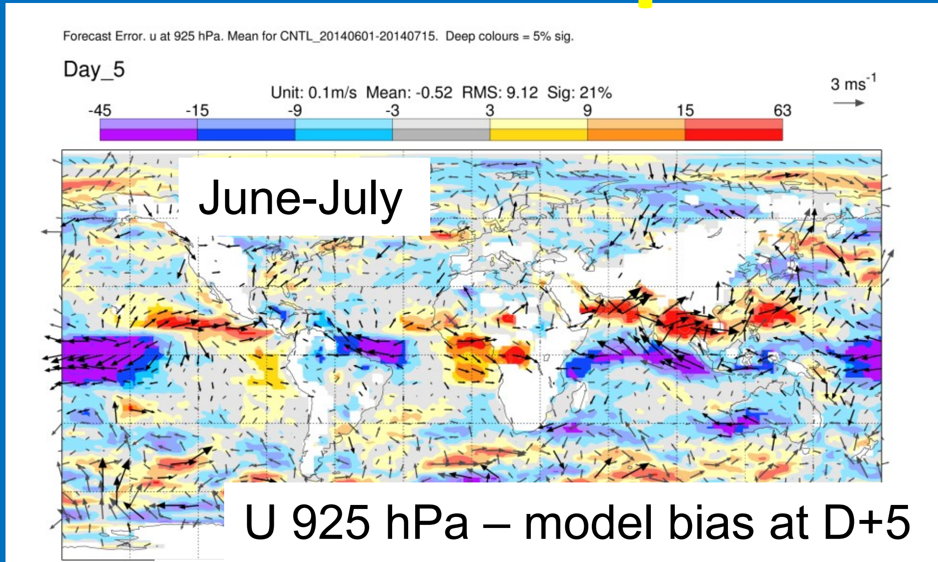
June-July
Model FC error d+5

June-July
Change in FC error d+5

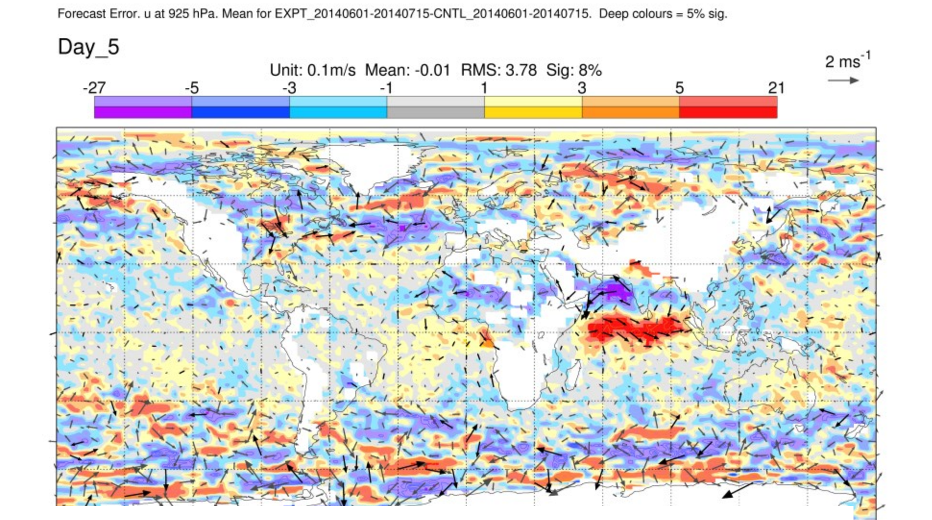
- Change in mass distribution and optical properties -> reduction in SW absorption -> reduction in temperature (positive)
- This is of the order of 0.1K for a bias of the order of 0.3K – it explains at least ~30% of the temperature error.
- Similar for winds at upper levels

Credits: Alessio Bozzo

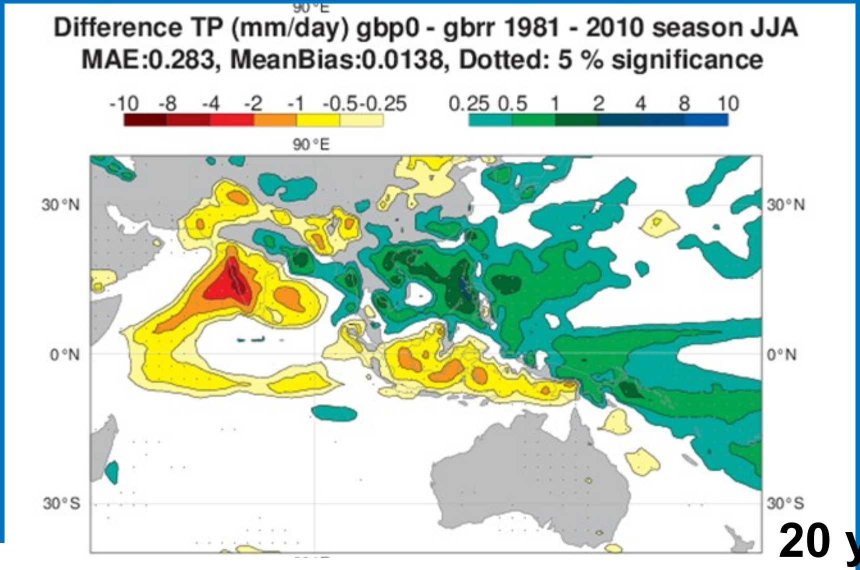
Impacts on FC errors



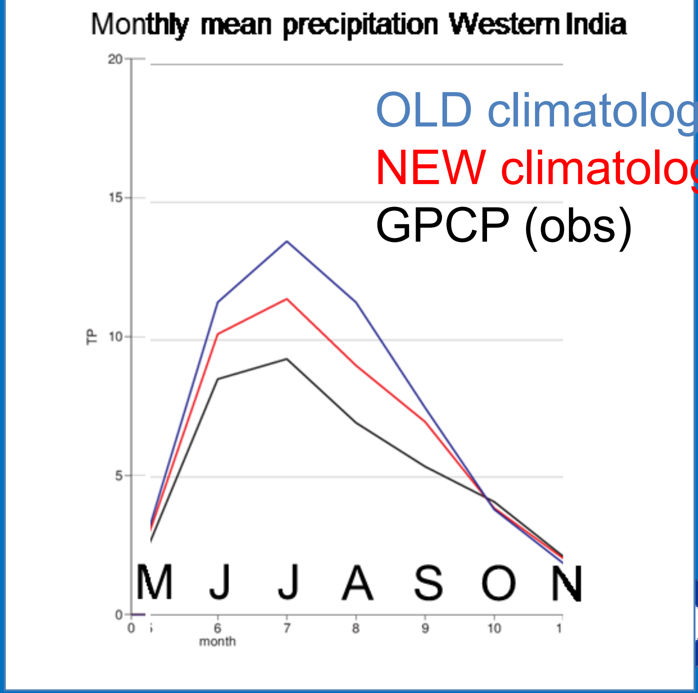
U 925 hPa – model bias at D+5



U 925 hPa – change in model bias

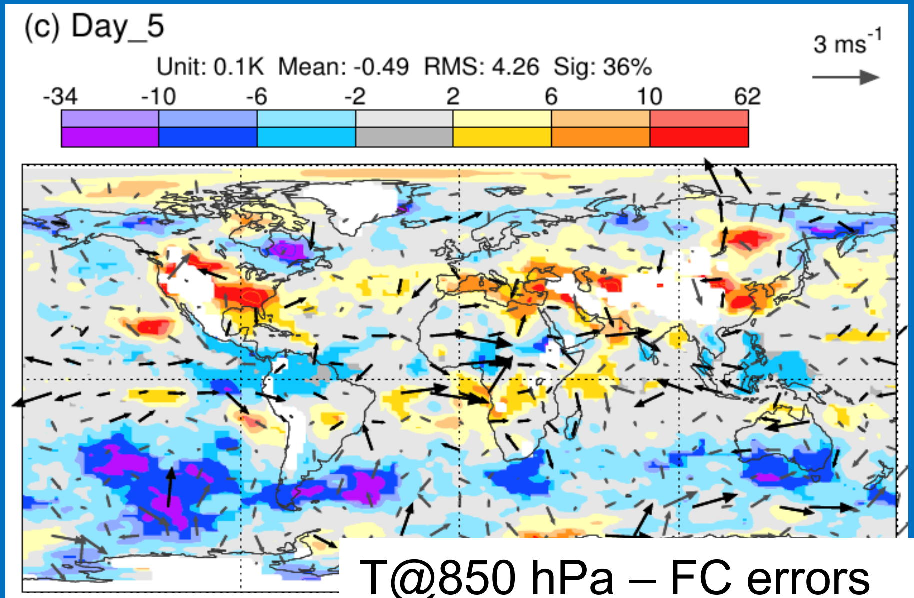


20 year run

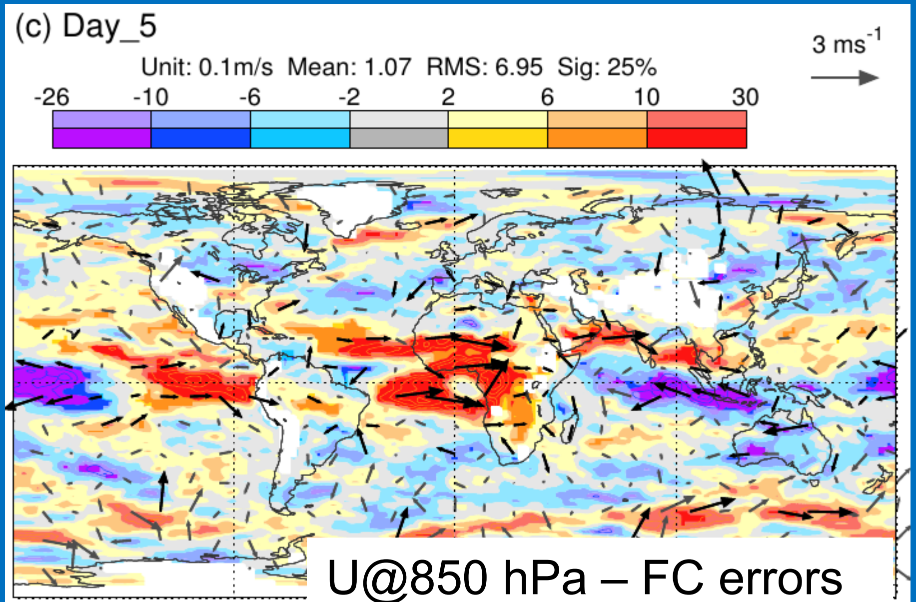


Credits: Alessio Bozzo, Linus Magnusson

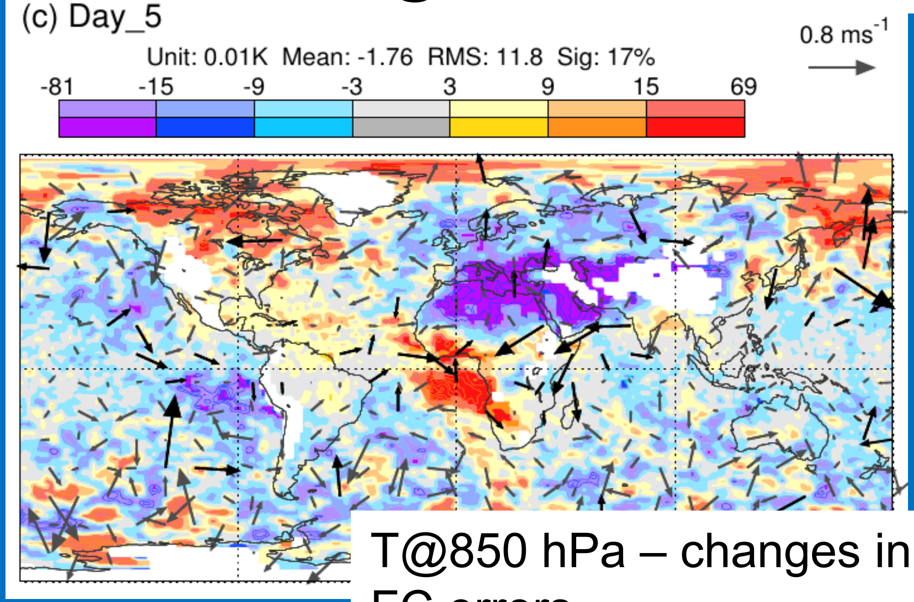
Impacts on FC errors



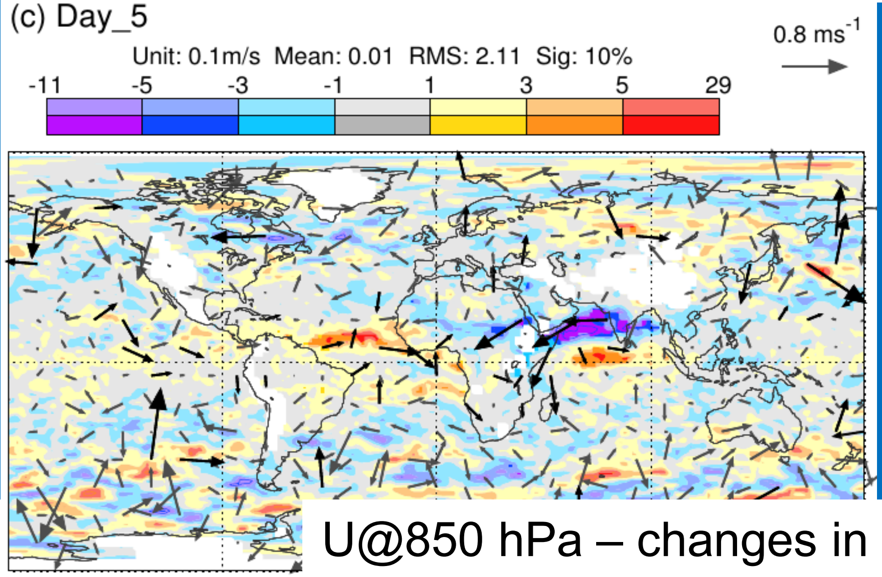
T@850 hPa – FC errors



U@850 hPa – FC errors

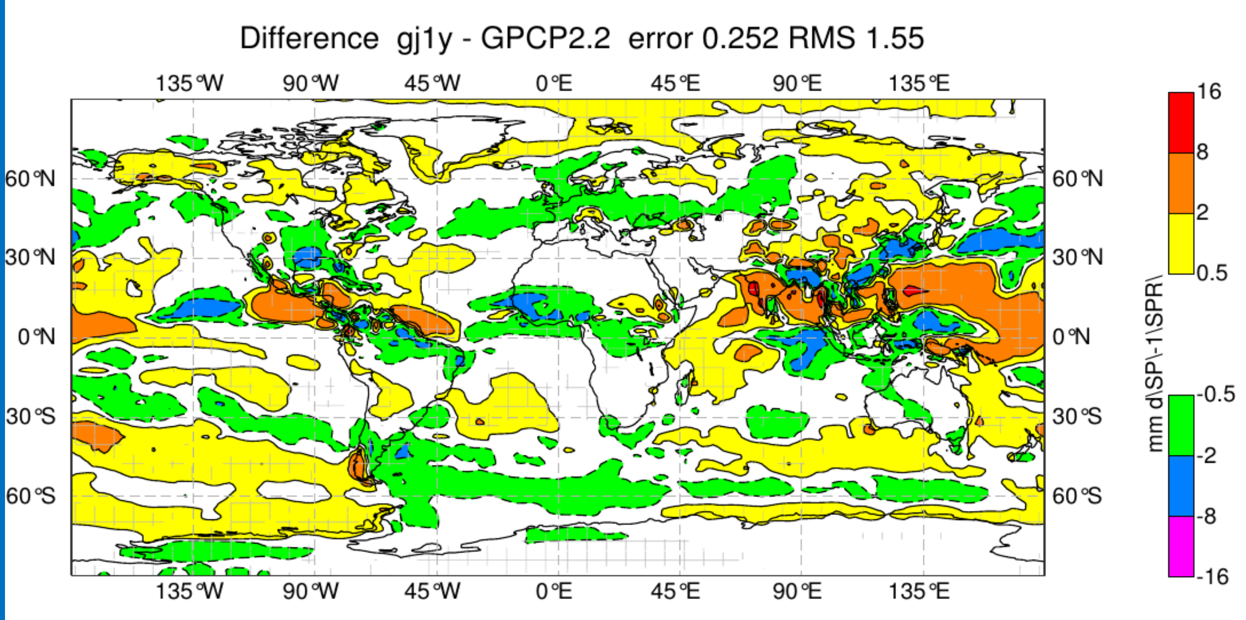


T@850 hPa – changes in FC errors

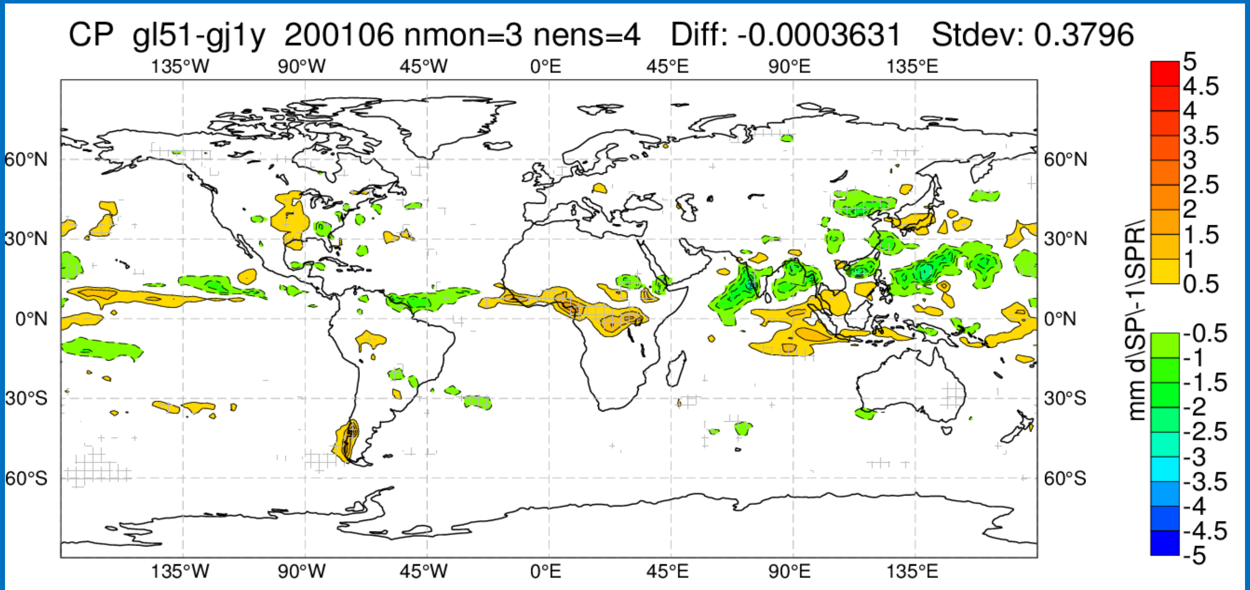


U@850 hPa – changes in FC errors

Impacts on precipitation patterns - JJA



Model error against GPCP2.2



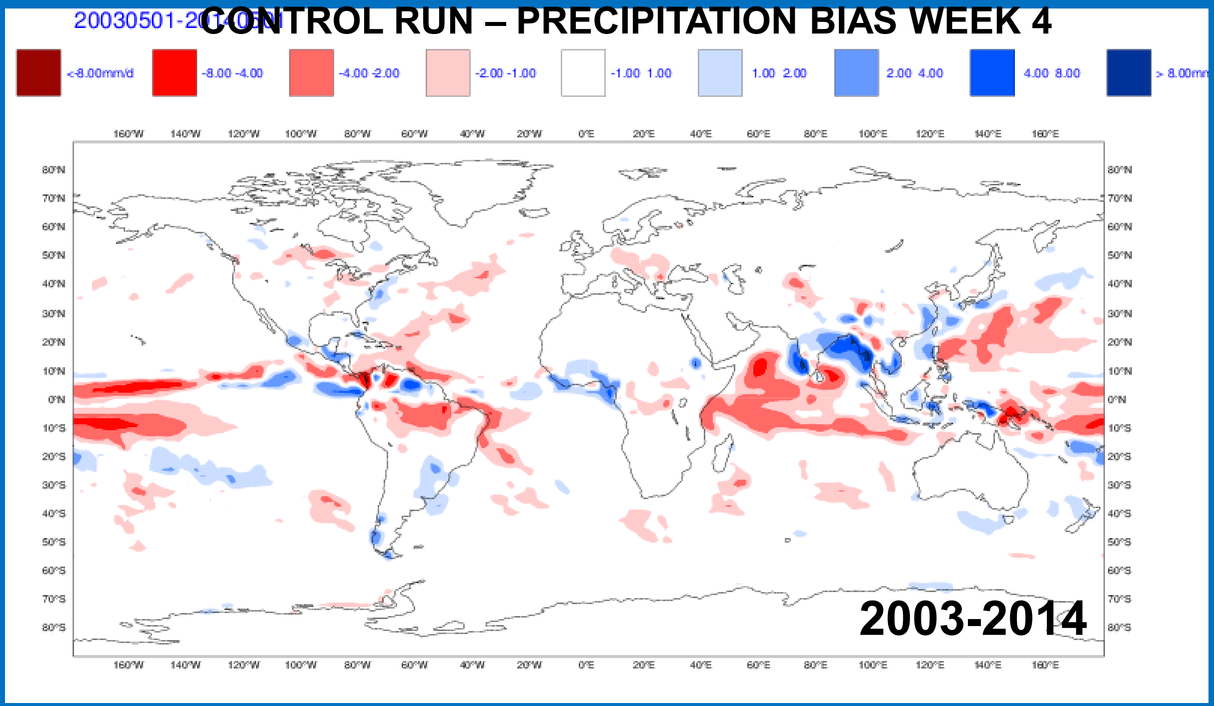
ECMWF

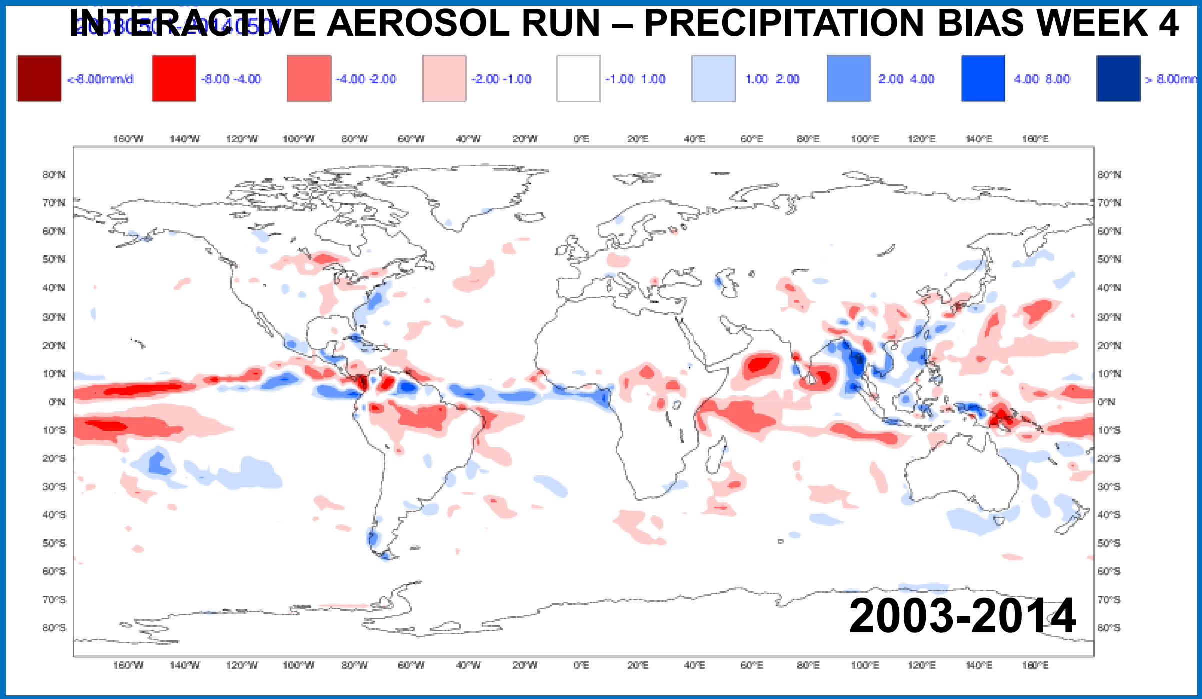
Monthly EPS coupled runs with interactive aerosols

- Control run for the period 2003-2015 uses standard Tegen et al 1997 climatology
- Interactive aerosol run covers the same period and uses fully prognostic aerosols in the radiation scheme – only aerosol direct effect
- Free-running aerosols with updated emission for biomass burnin
- Ensemble size is 11 members, T255 resolution, 91 levels
- 5 different start dates around May 1 (55 cases in total) – summer runs (focus of this talk)
- 3 different start dates around November 1 (33 cases in total)- winter runs

Aerosol impacts on monthly forecasts (summer)

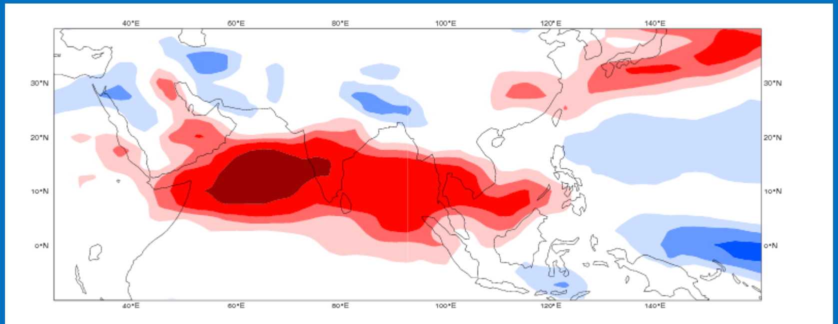
- Preliminary results show a positive impact (reduction in bias) of the interactive aerosols on meteorological fields (winds and precipitation) as observed in studies using a more up-to-date aerosol climatology
- More prominent (positive) impact over the Indian Ocean and to a lesser extent in other areas which is also consistent with new climatology results for the same model release



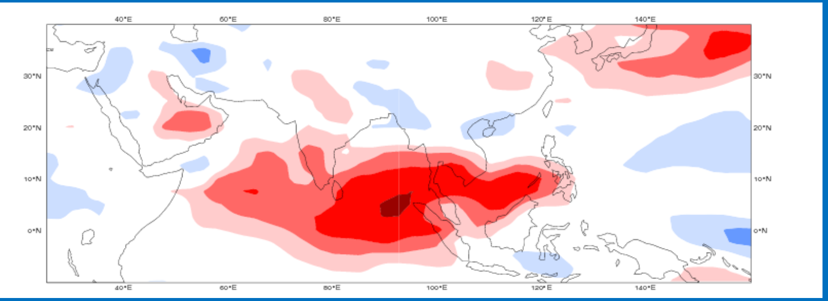


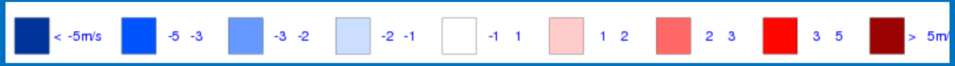
Aerosol impacts on monthly forecasts (summer)

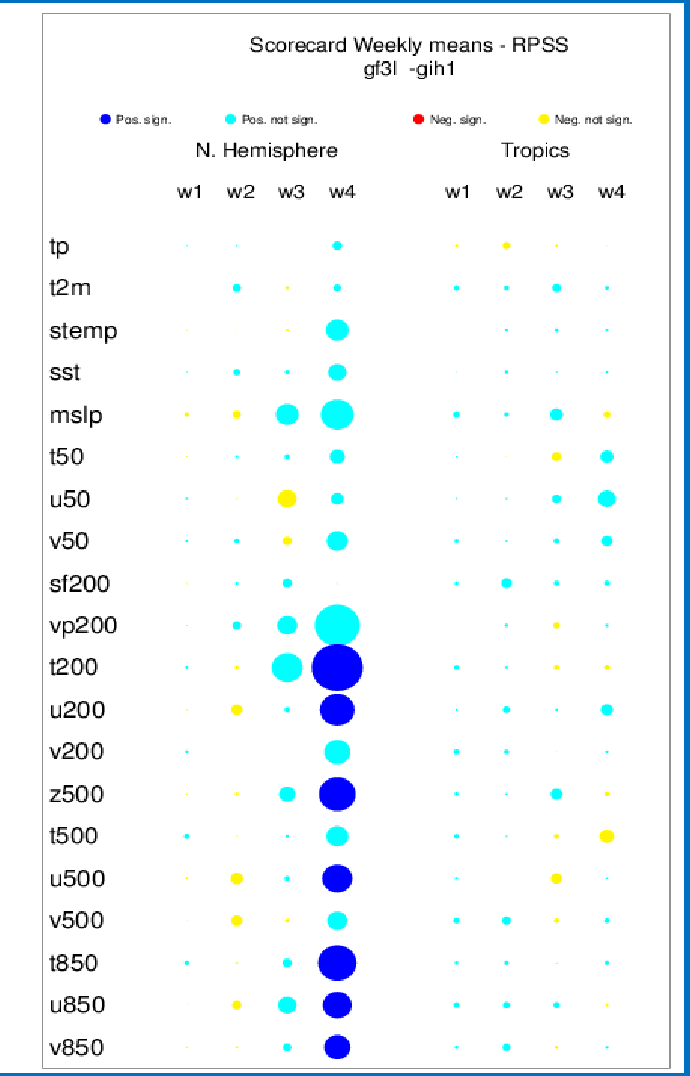
CONTROL RUN – 850 hPa U WIND BIAS WEEK 4



INTERACTIVE AEROSOL RUN – U WIND BIAS WEEK 4



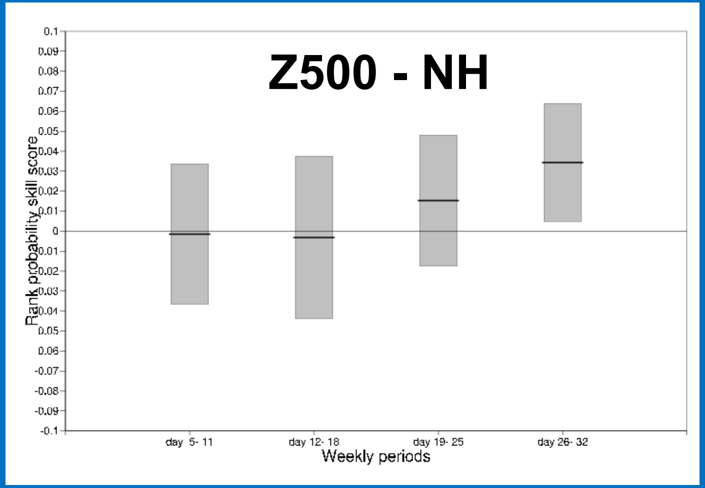




Scorecards measures

- Performance of interactive aerosol experiment with respect to a control run for several parameters.
- Blue circles indicate positive impact
- Dark blue circles indicate significant impact

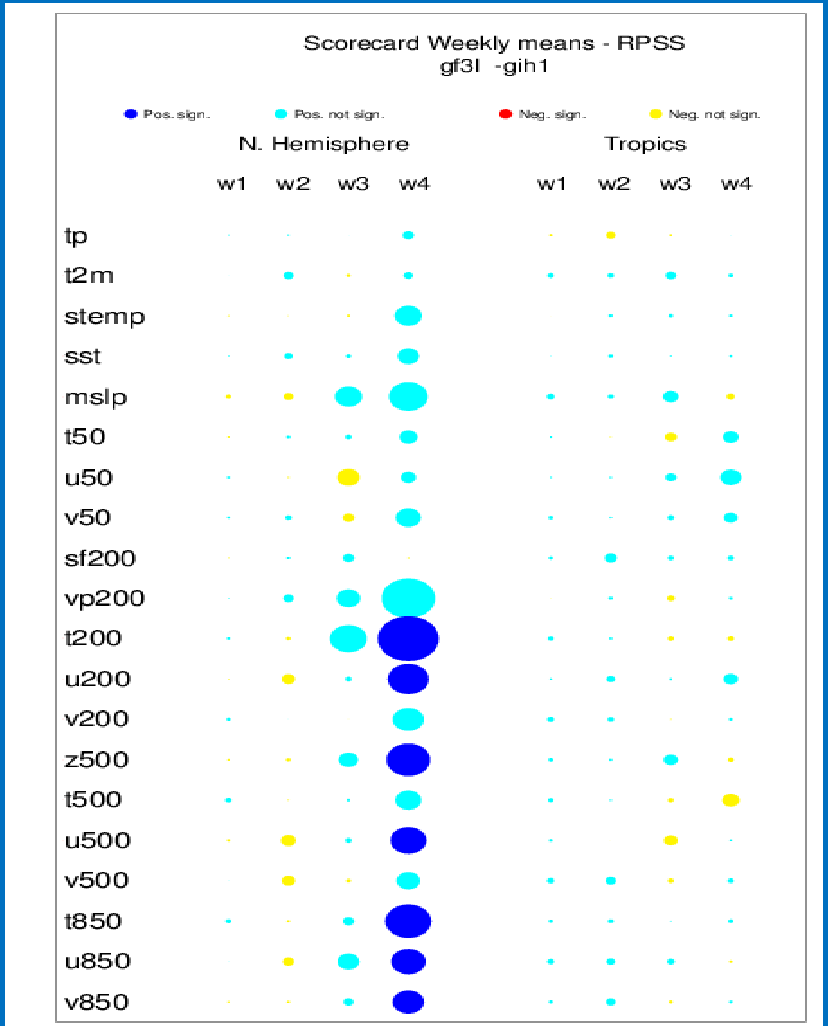
(Scores are applied to bias corrected fields)



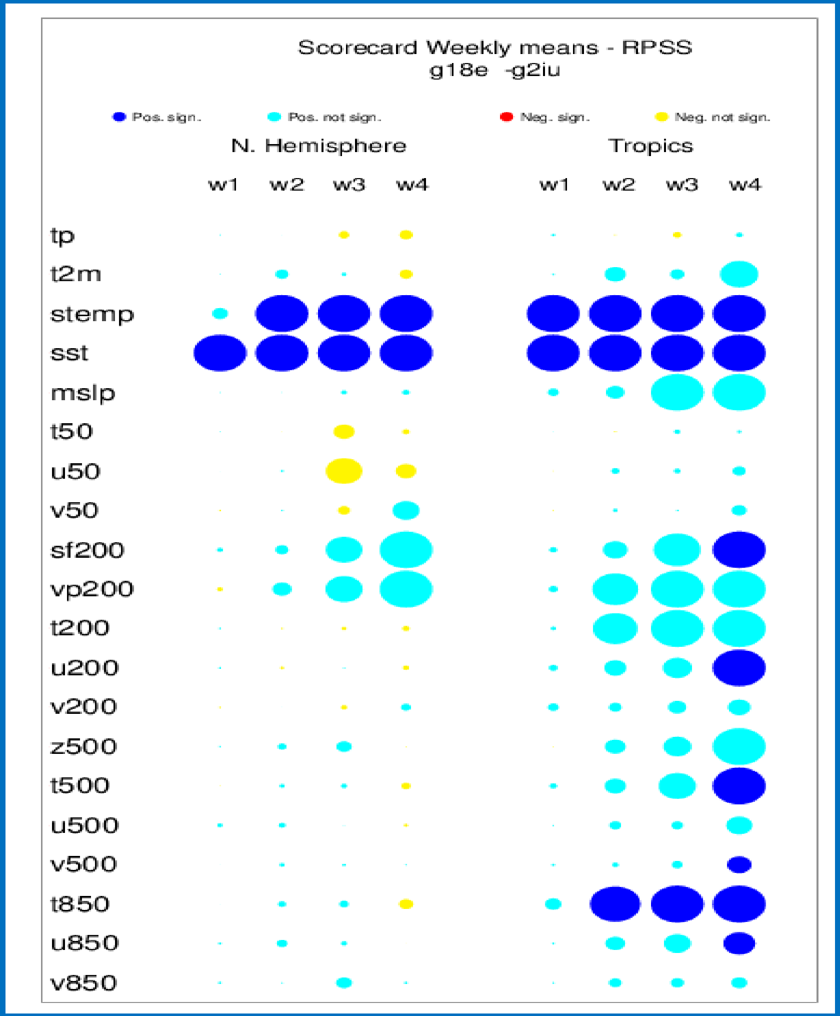
- **Similar impacts are observed with the new ECMWF/CAMS climatology**
- **Need to understand the relative importance of the meteorological feedback on the daily variability of aerosols**

Improvements to sub-seasonal skill scores

Active aerosols



Coupled vs pers SST

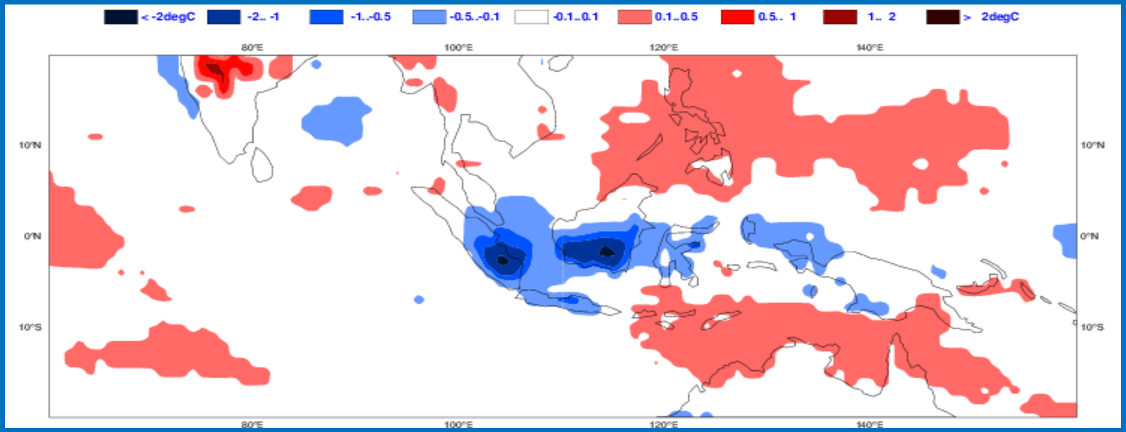


May start dates only (summer runs)
2003-2015 period
Observed (prescribed) Fire emission

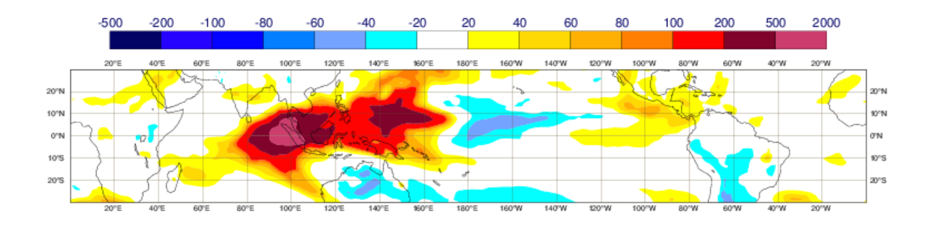
Indonesian fires (Aug-Oct 2015)

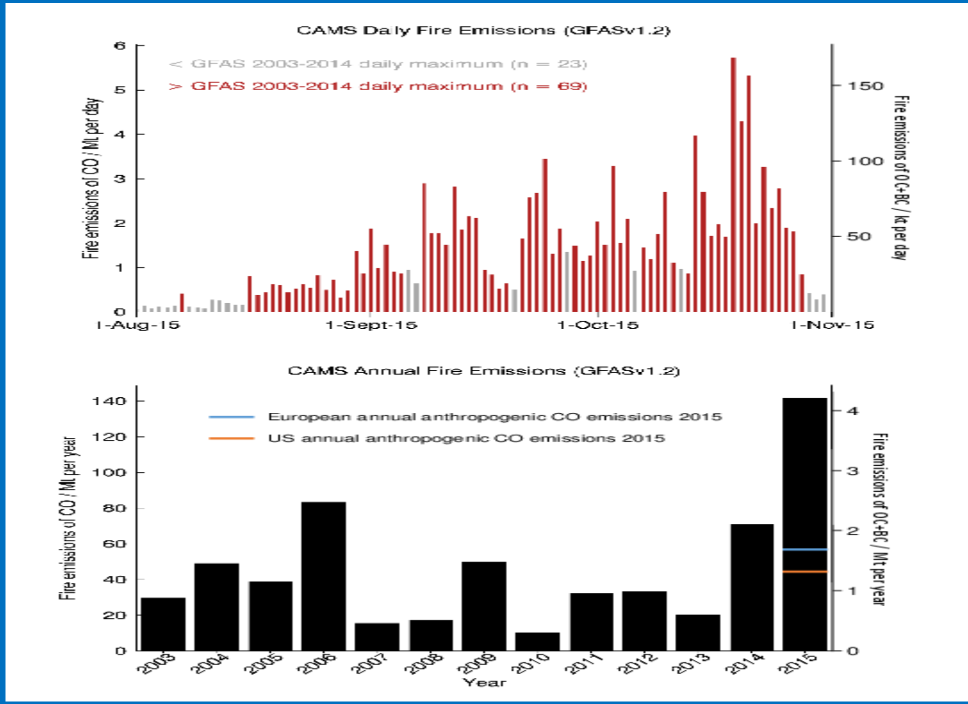
Fire radiative power Aug-Oct 2015

2m-tm anomaly Oct 2015 - Forecast starting 1st May



Biomass burning AOD anomaly: up to 2000%





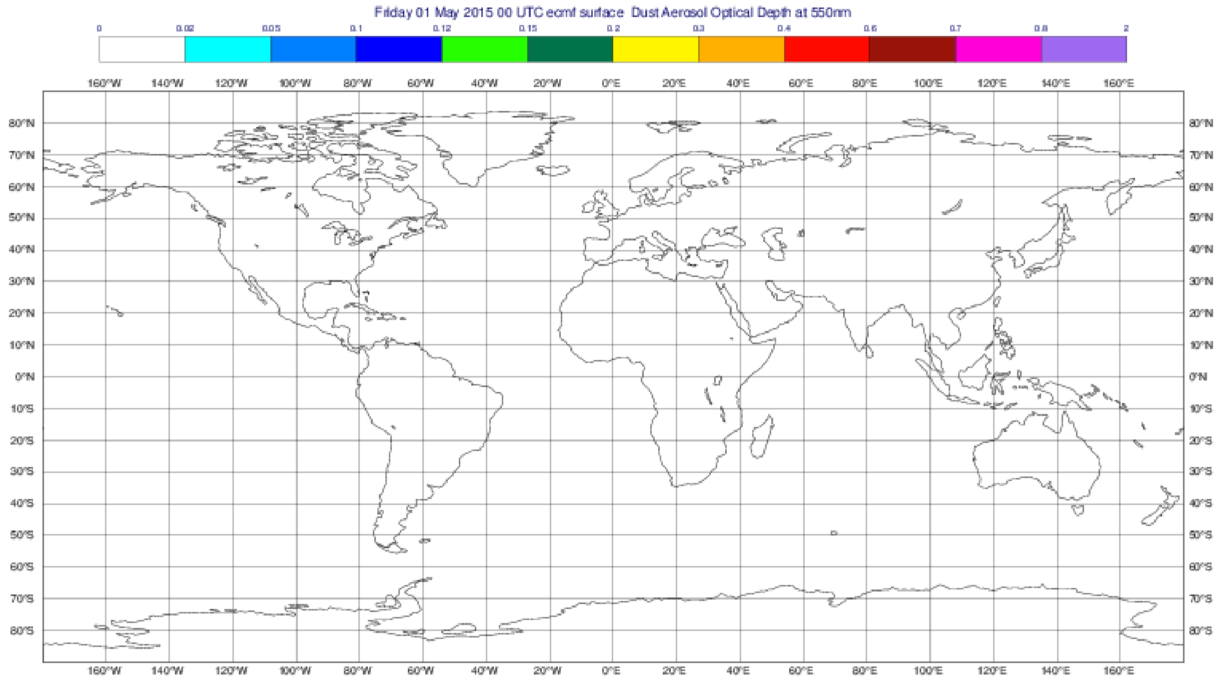
Benedetti et al, to appear in State of Climate 2016, BAMS.
Credits: Antje Inness, Mark Parrington (ECMWF), Gerry Ziemke (NASA)

Prediction of fire emissions is needed (under development)

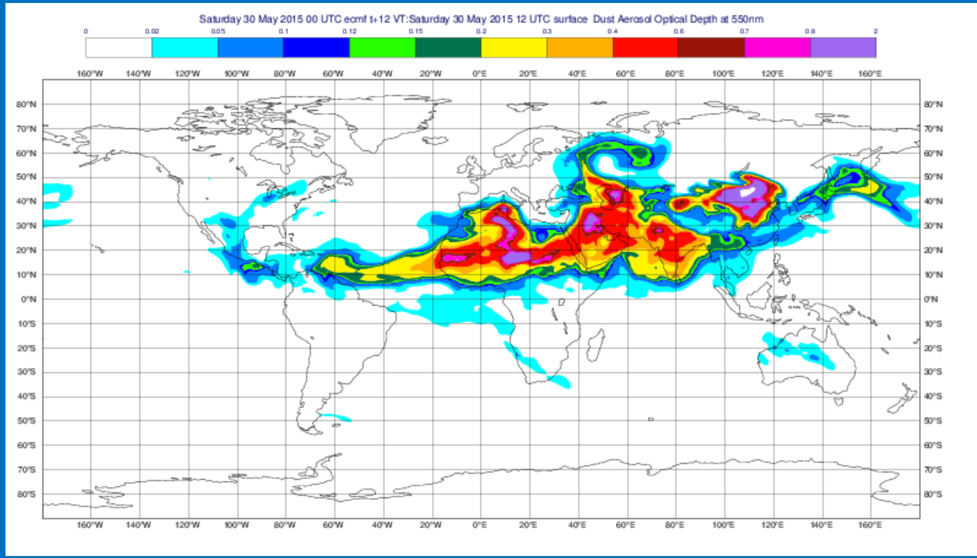
CMWF

By-product: monthly dust forecast (May 2015)

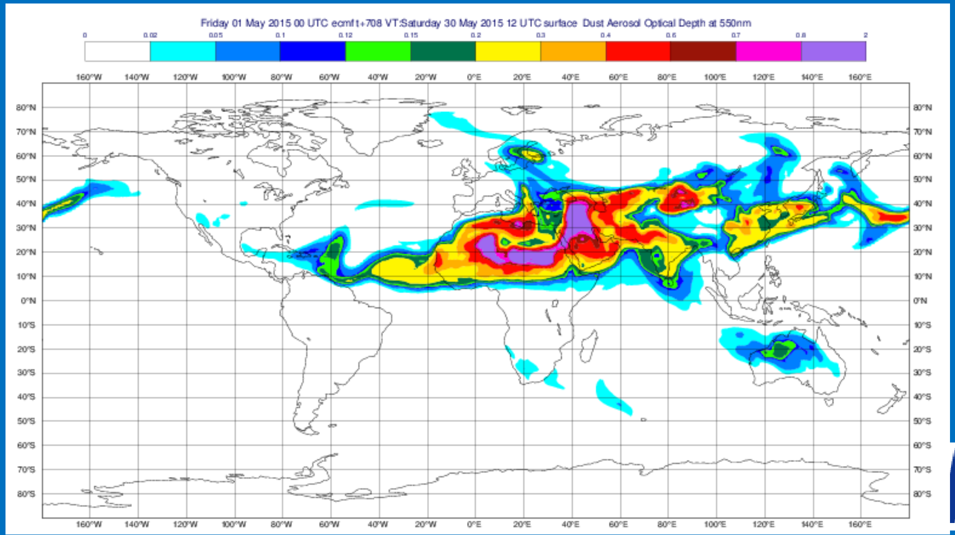
DUST AEROSOL OPTICAL DEPTH @ 550nm



CAMS ANALYSIS – 30 May 2015 @ 1200UTC



MONTHLY FORECAST valid for 30 May 2015 @ 1200UTC



Summary and Future Perspectives

- Using prognostic aerosols interactively in the radiation seems to be beneficial to model skill at the sub-seasonal range

- Similar positive results were obtained with an improved aerosol climatology

- More investigation is needed to understand if positive impact comes from resolved time and spatial variability or from a better representation of the aerosol fields which could be also delivered by an up-to-date accurate climatology

- Extreme events like the Indonesian fires of 2015 could only be captured with prognostic aerosols (and prognostic fire emissions) – these events are connected to El Nino and have a high degree of predictability at the seasonal scale

- By-products of using interactive aerosols is the sub-seasonal aerosol prediction per se

- More systematic experimentation is needed to understand benefits vs costs. In the current configuration the additional cost in the monthly EPS is 40-50%. HIGH RES runs are possibly prohibitive and perhaps benefits in the medium-range are smaller – an aerosol climatology would remain the most viable option.

- Experiments planned with the latest model release: control run with Tegen et al (1997) climatology, run with new ECMWF/CAMS climatology, runs with fully interactive prognostic aerosols

Thank you!

ECMWF