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

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European Centre for Medium-Range Weather Forecasts

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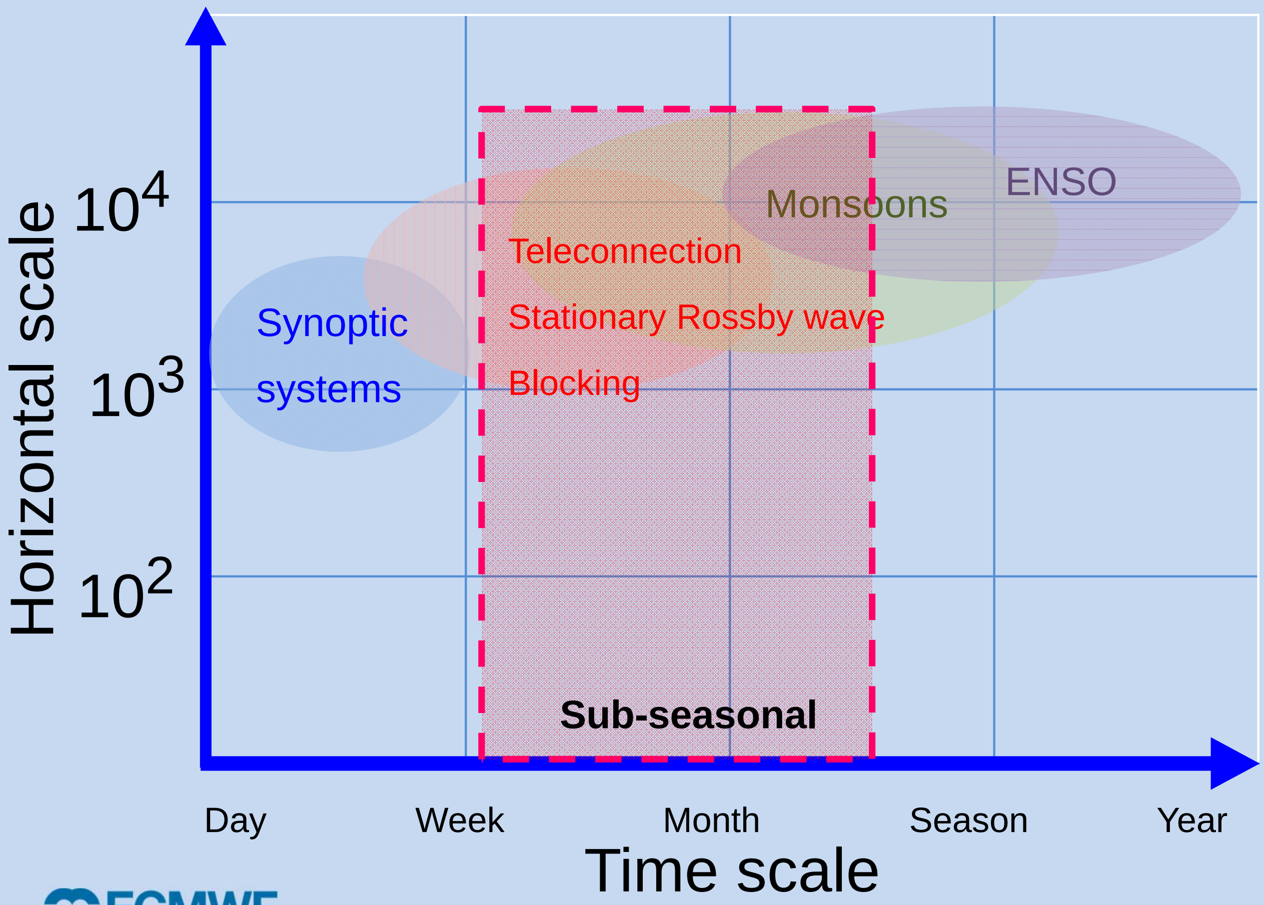
Sub-seasonal time range



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Sub-seasonal prediction

- Bridges the gap between weather and climate forecasting.
- First attempts of sub-seasonal forecasting started in the 1980s (Miyakoda, Molteni..)
- A particularly difficult time range:

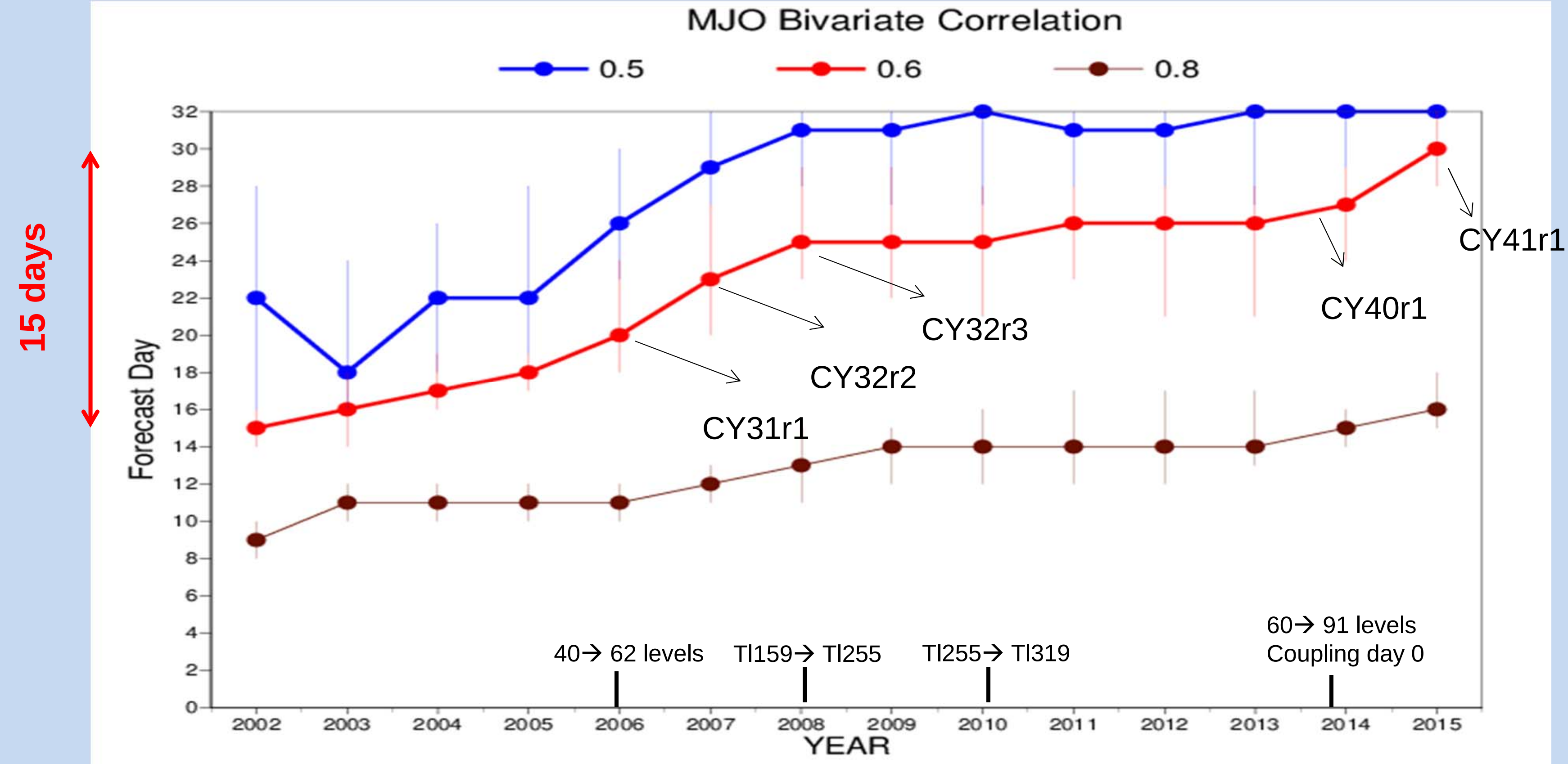
Is it an **atmospheric initial condition problem** as medium-range forecasting or is it a **boundary condition problem** as seasonal forecasting? Is it a “Predictability Desert” ?

Sources of sub-seasonal predictability

- Madden-Julian Oscillation
- Extra-tropical modes (weather regimes: blockings, NAO, PNA, SAM..)
- Sudden Stratospheric Warming
- Quasi-Biennal Oscillation
- ENSO
- Slowing varying processes: Soil moisture/vegetation, snow, sea ice, ocean SSTs/heat content
- Chemistry: Ozone, aerosols…
- Others?

Sub-seasonal skill is strongly flow-dependent

Madden Julian Oscillation prediction at ECMWF



CY31R1: Parameterisation of ice supersaturation
CY32R2: McRAD (radiation scheme)
CY32R3: Changes in convective scheme (Bechtold at al. 2008)
CY40R1: Improved diurnal cycle of precipitation
CY41R1: revised organized convective detrainment and the revised convective momentum transport. …

Wheeler and Hendon (2003) Index

Improvements in MJO Prediction mostly due to changes in convective parameterization

Does adding complexity improves sub-seasonal skill scores?

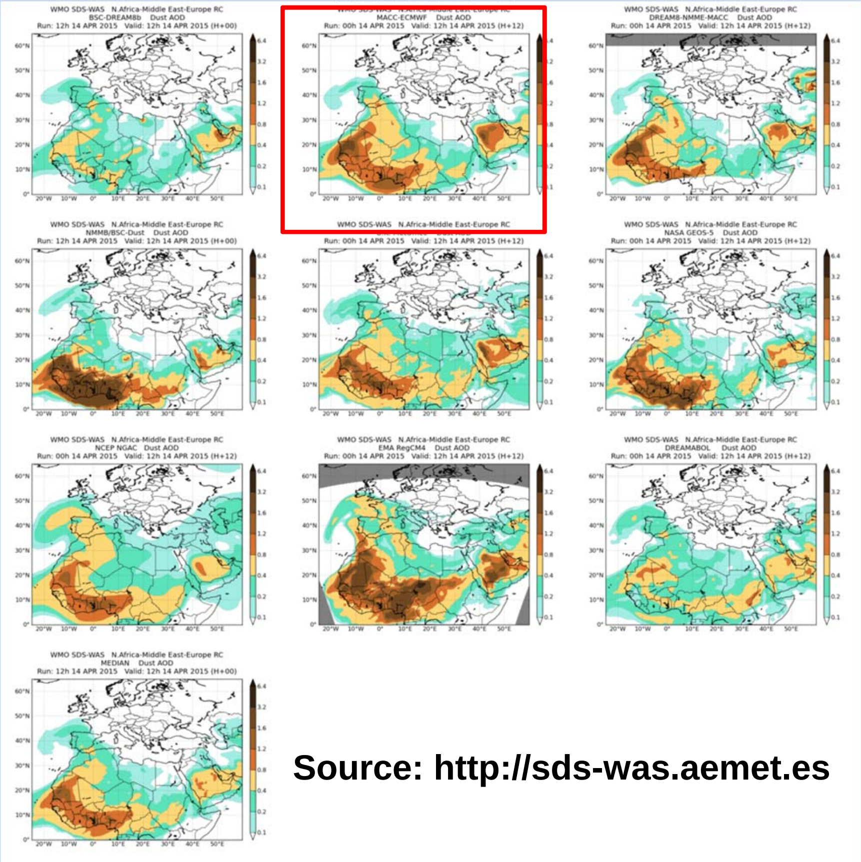
- Could add new sources of predictability

- Could impact sources of predictability and/or their teleconnections

Aerosols impacts on the sub-seasonal prediction

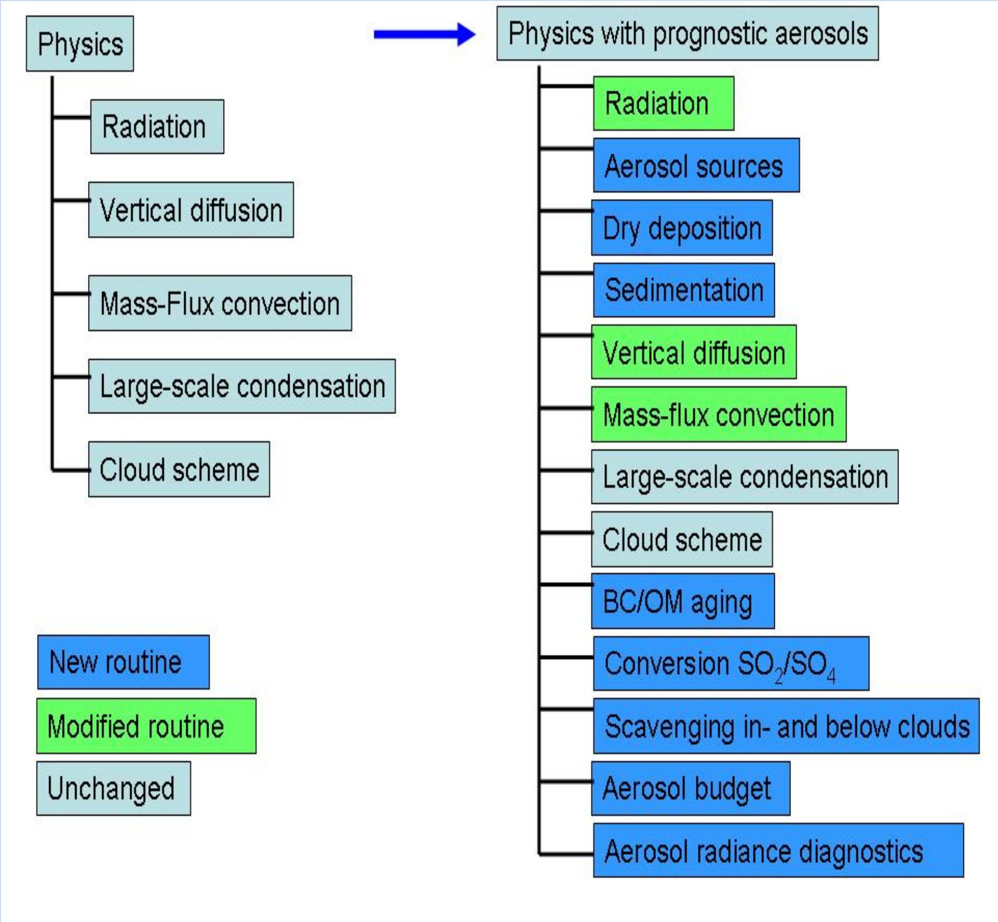
CAMS aerosol forecasts

- 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, now also PMAP AOD at 550nm
  - 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



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

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

More species to come (i.e. nitrates) and revisited parameterizations (Remy et al, 2017, in preparation)

Physical processes include:

• emission sources (some of which updated in NRT, i.e. fire emissions),
• 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)

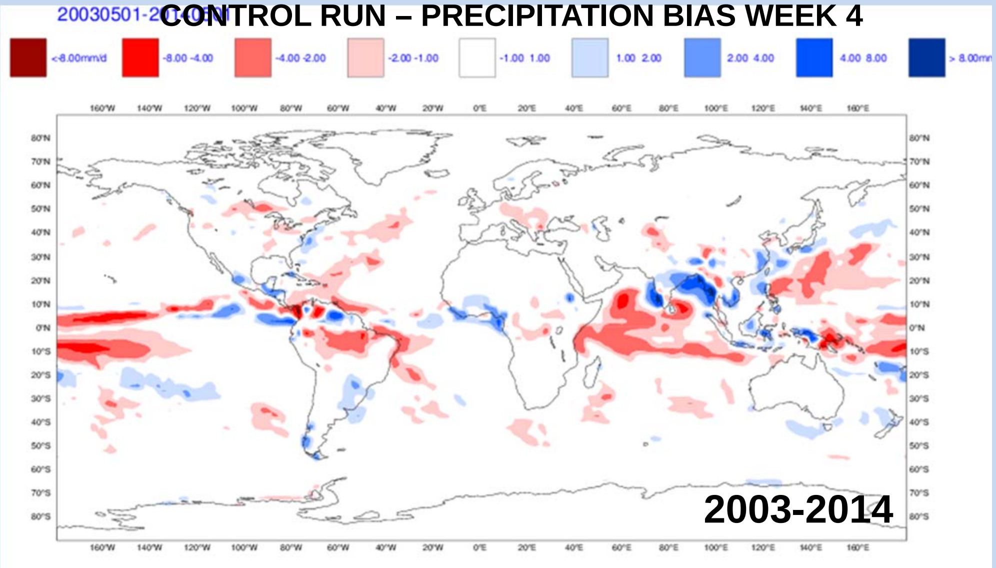
Monthly EPS coupled runs with interactive aerosols

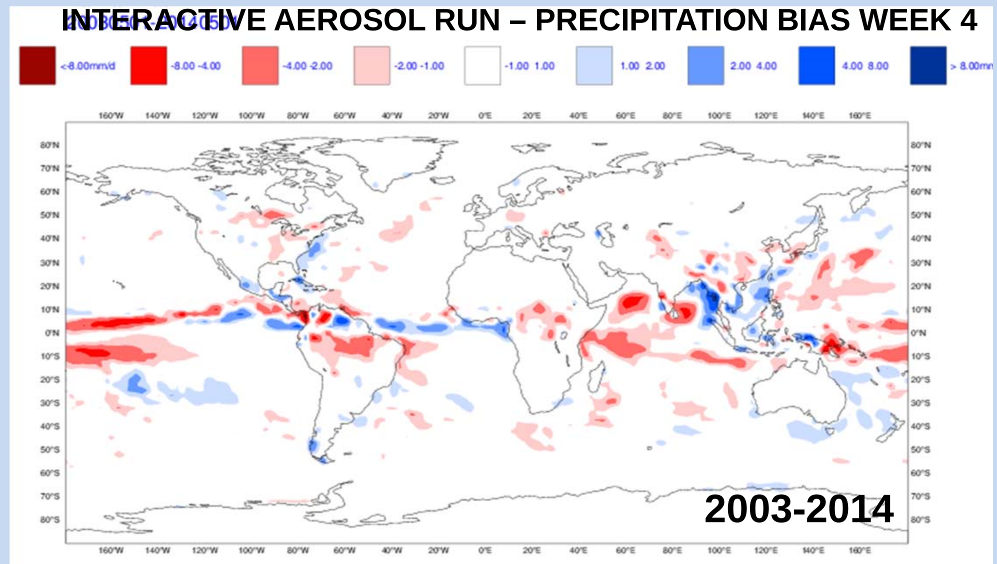
- Control run for the period 2003-2015 uses standard Tegen et al 1997 climatology
- Interactive aerosol run covers the same period and uses fully prognostic aerosols in the radiation scheme – only aerosol direct effect
- Free-running aerosols with updated emission for biomass burnin
- Ensemble size is 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

ECMWF

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

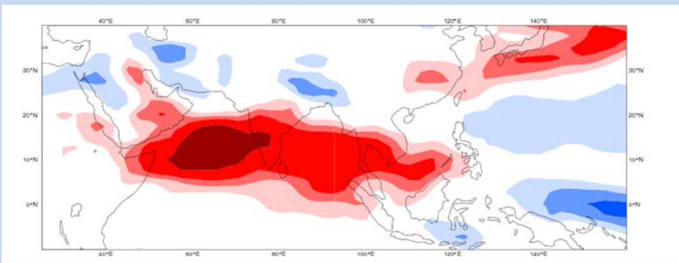




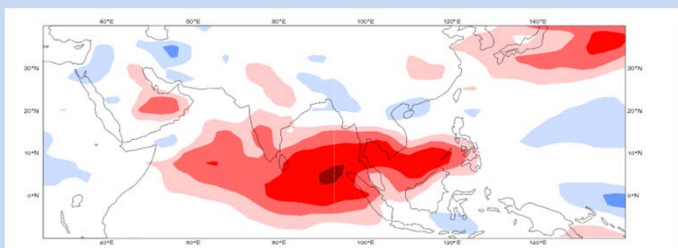
ECMWF

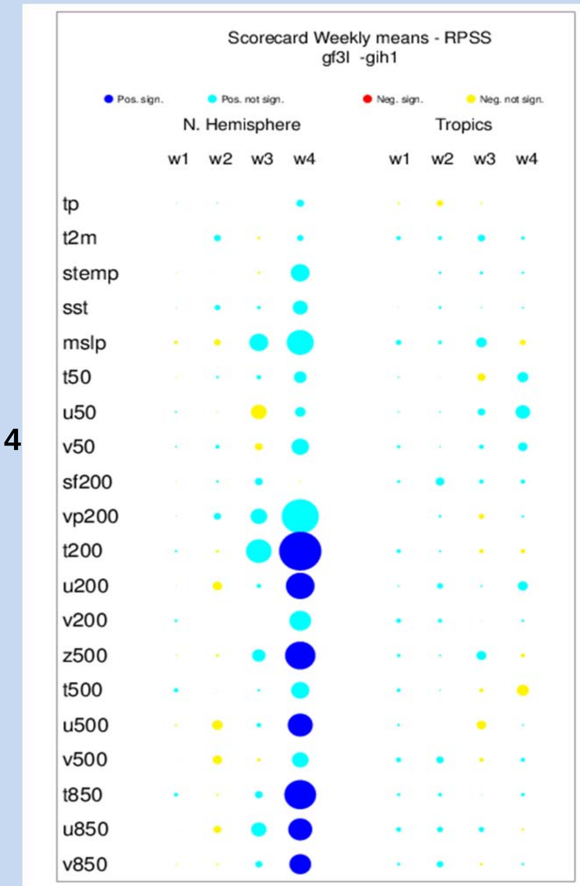
Aerosol impacts on monthly forecasts (summer)

CONTROL RUN – 850 hPa U WIND BIAS WEEK 4



INTERACTIVE AEROSOL RUN – U WIND BIAS WEEK 4

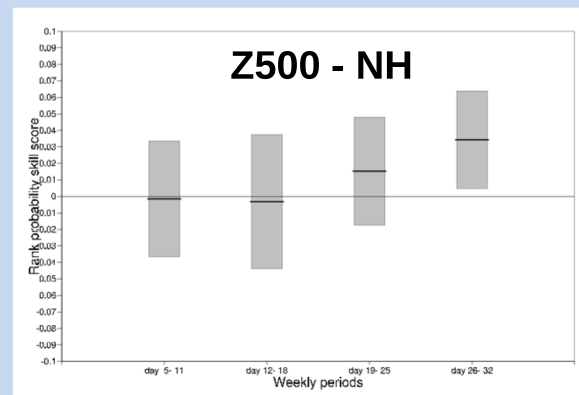




Scorecards measures

- 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

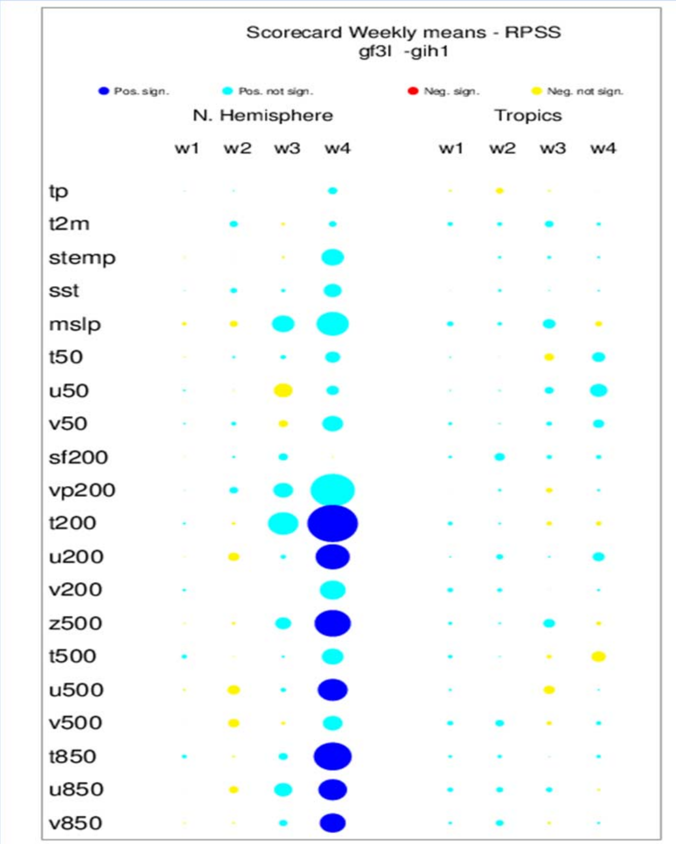
(Scores are applied to bias corrected fields)



- **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**

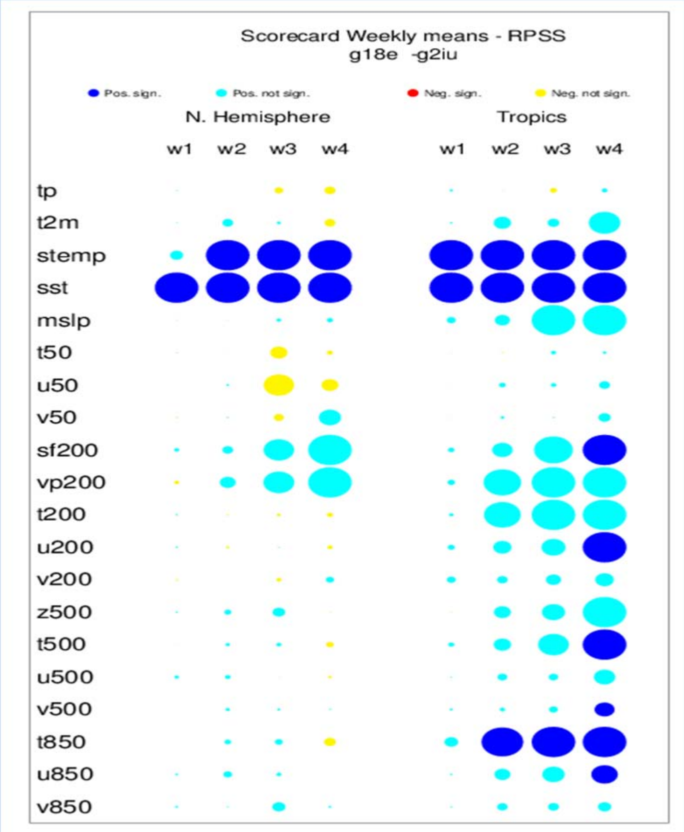
Improvements to sub-seasonal skill scores

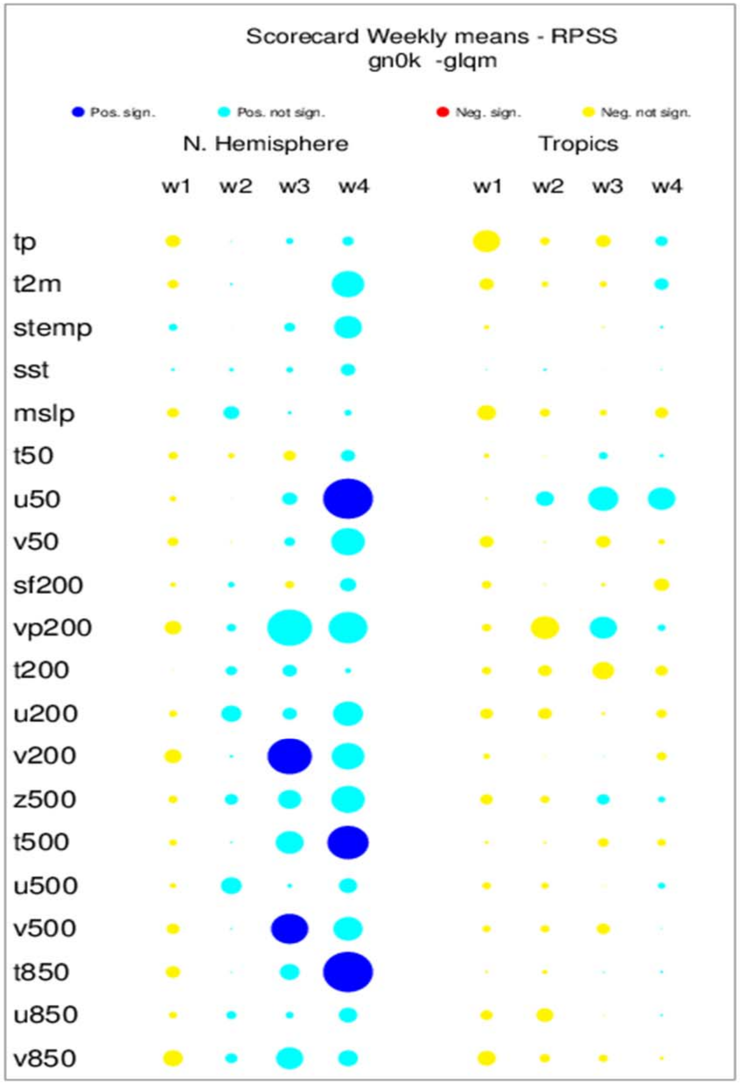
Active aerosols



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

Coupled vs pers SST




Scorecard Weekly means - RPSS
gn0k -glqm
Pos. sign.
Pos. not sign.
Neg. sign.
Neg. not sign.
N. Hemisphere
Tropics
w1 w2 w3 w4 w1 w2 w3 w4
tp
t2m
stemp
sst
mslp
t50
u50
v50
sf200
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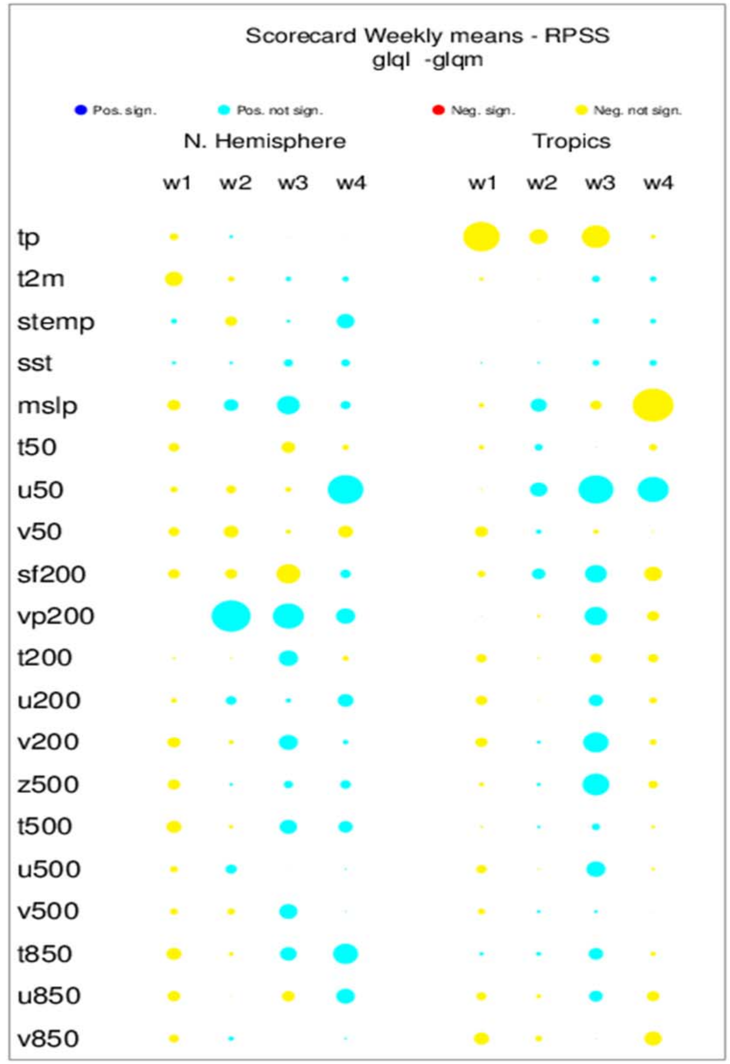
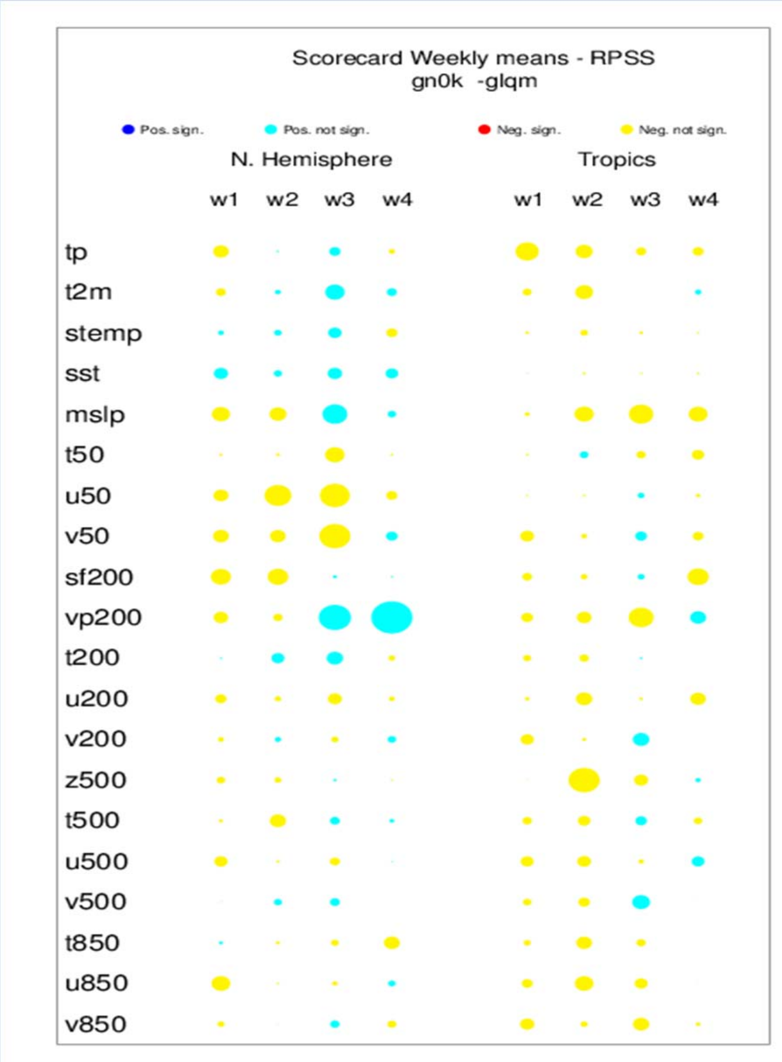
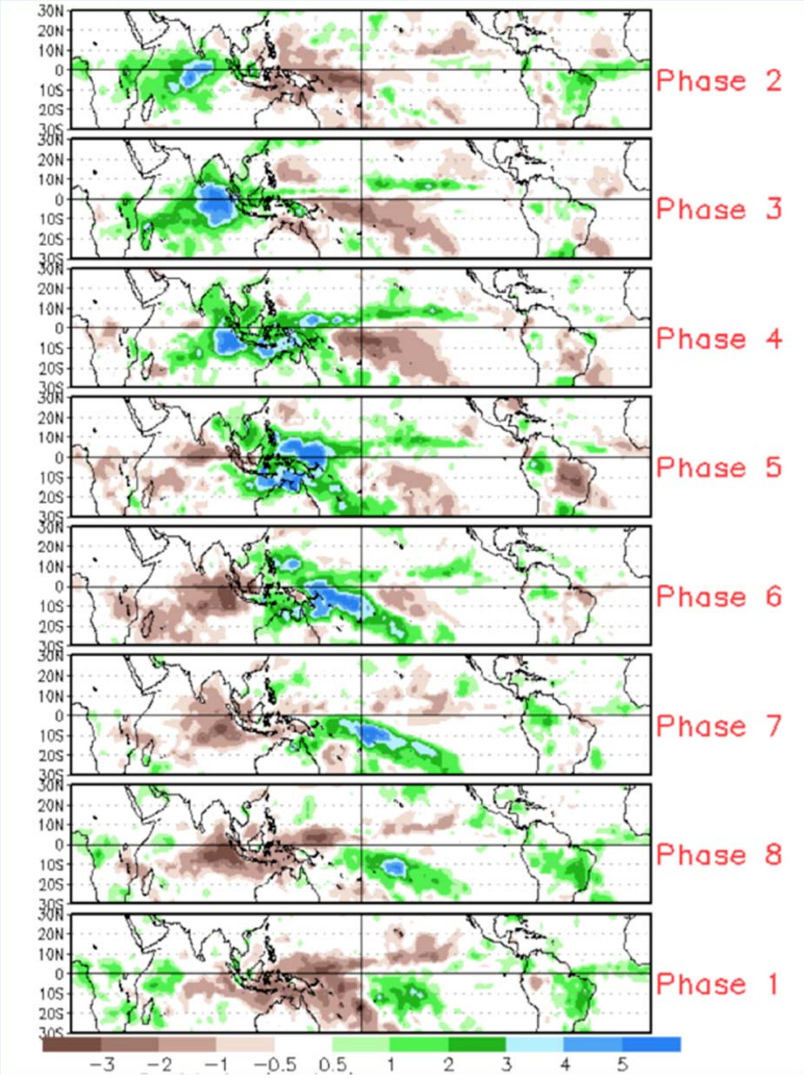
v500
t850
u850
v850


Scorecard Weekly means - RPSS
glql -glqm
Pos. sign.
Pos. not sign.
Neg. sign.
Neg. not sign.
N. Hemisphere
Tropics
w1 w2 w3 w4 w1 w2 w3 w4
tp
t2m
stemp
sst
mslp
t50
u50
v50
sf200
vp200
t200
u200
v200
z500
t500
u500
v500
t850
u850
v850

Scorecard Oct-Nov cases



MJO phases

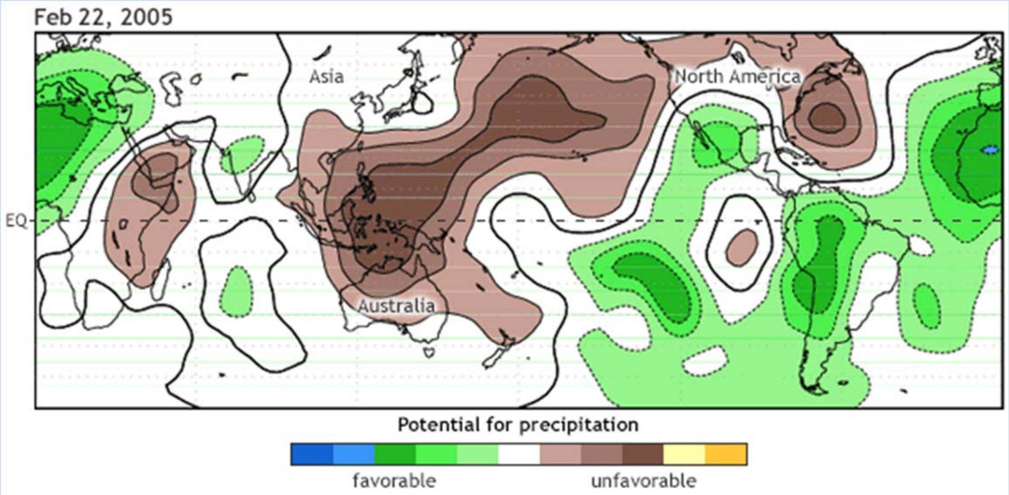


Average rainfall for all MJO events from 1979 to 2012 for the period November-March

Green/blue shading represents areas of enhanced convection

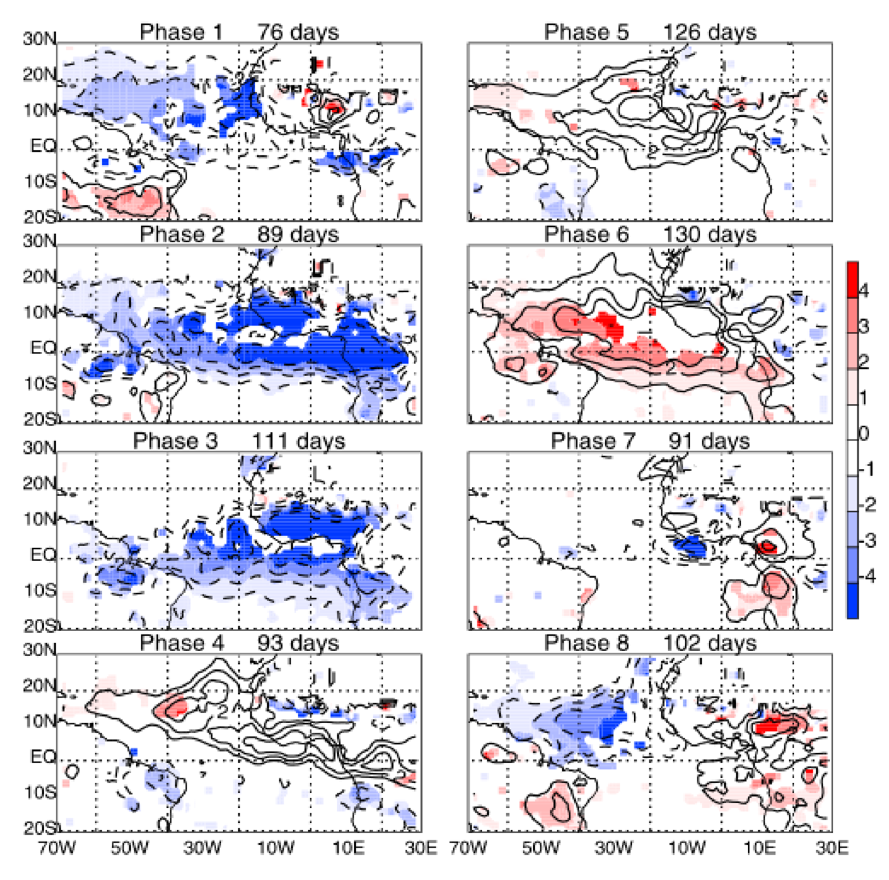
Brown shading represents areas of suppressed convection

Note the eastward shift of the dipole with the successive phases

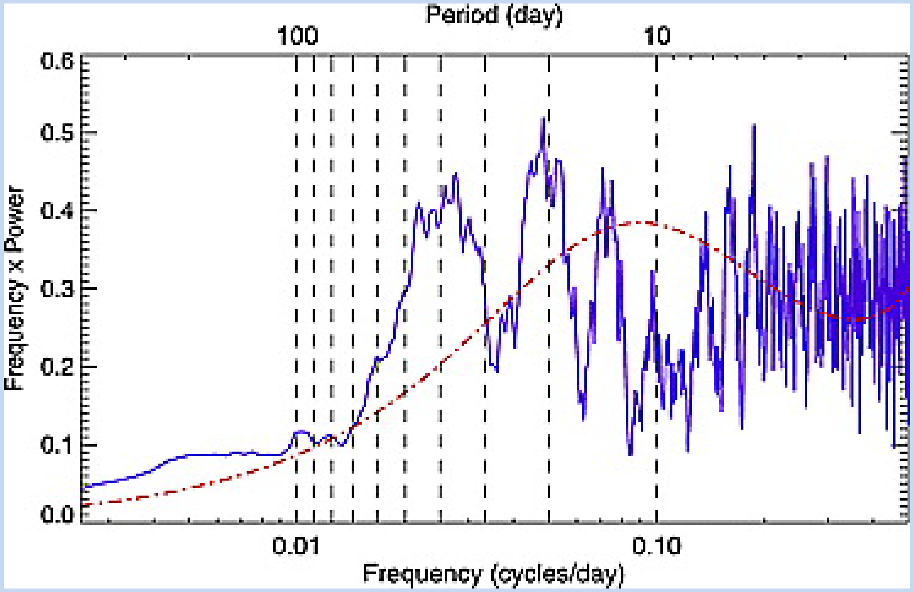


Source: NOAA

Sub-seasonal variability of aerosols



Time series spectrum of unfiltered MODIS AOT anomalies over the Atlantic

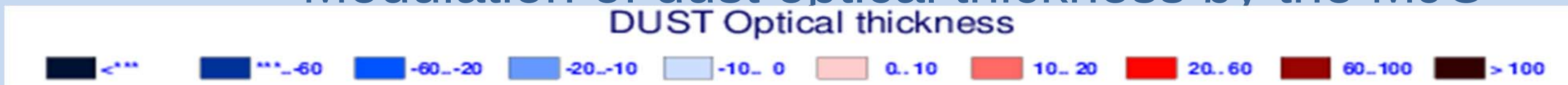


B. Tian et al, 2011

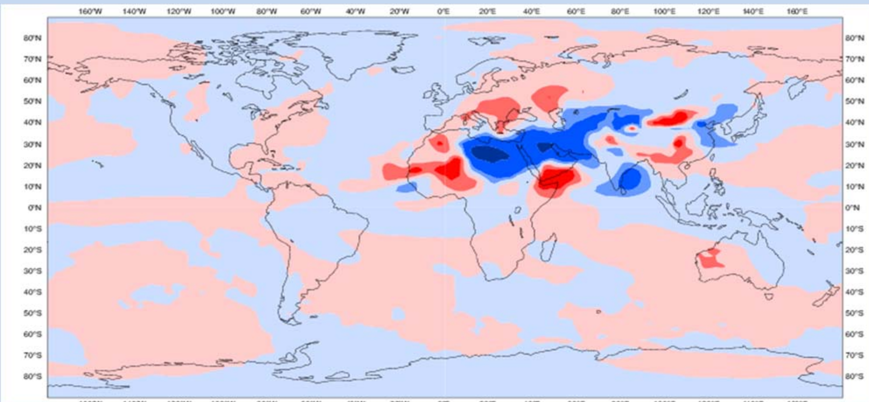
Intra-seasonal variance of AOT= ¼ of total variance of AOT

ECMWF

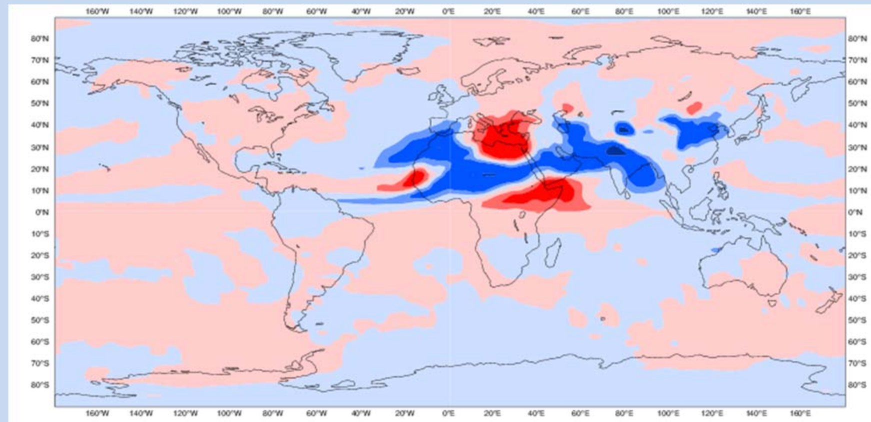
Modulation of dust optical thickness by the MJO



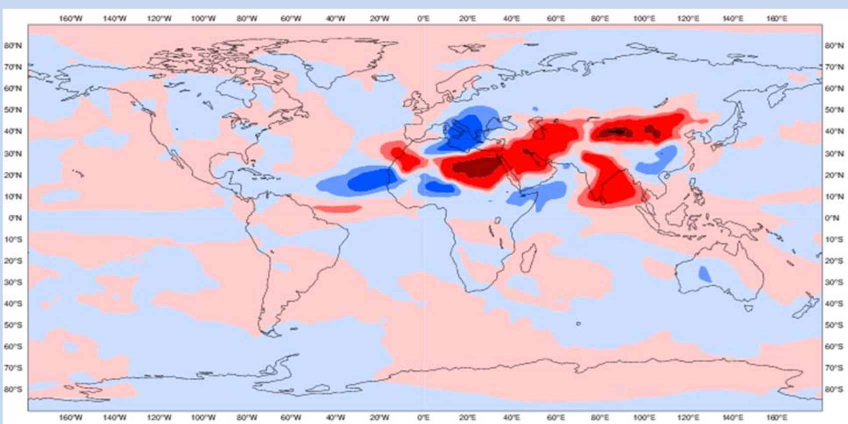
MJO Phase 23



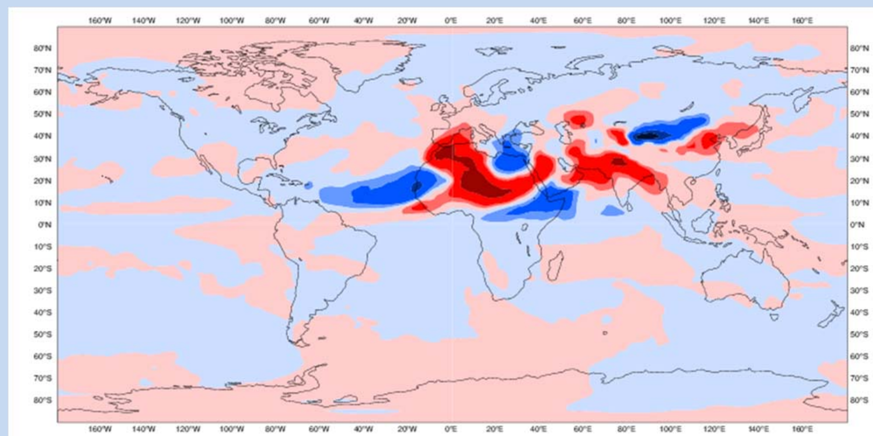
MJO Phase 45



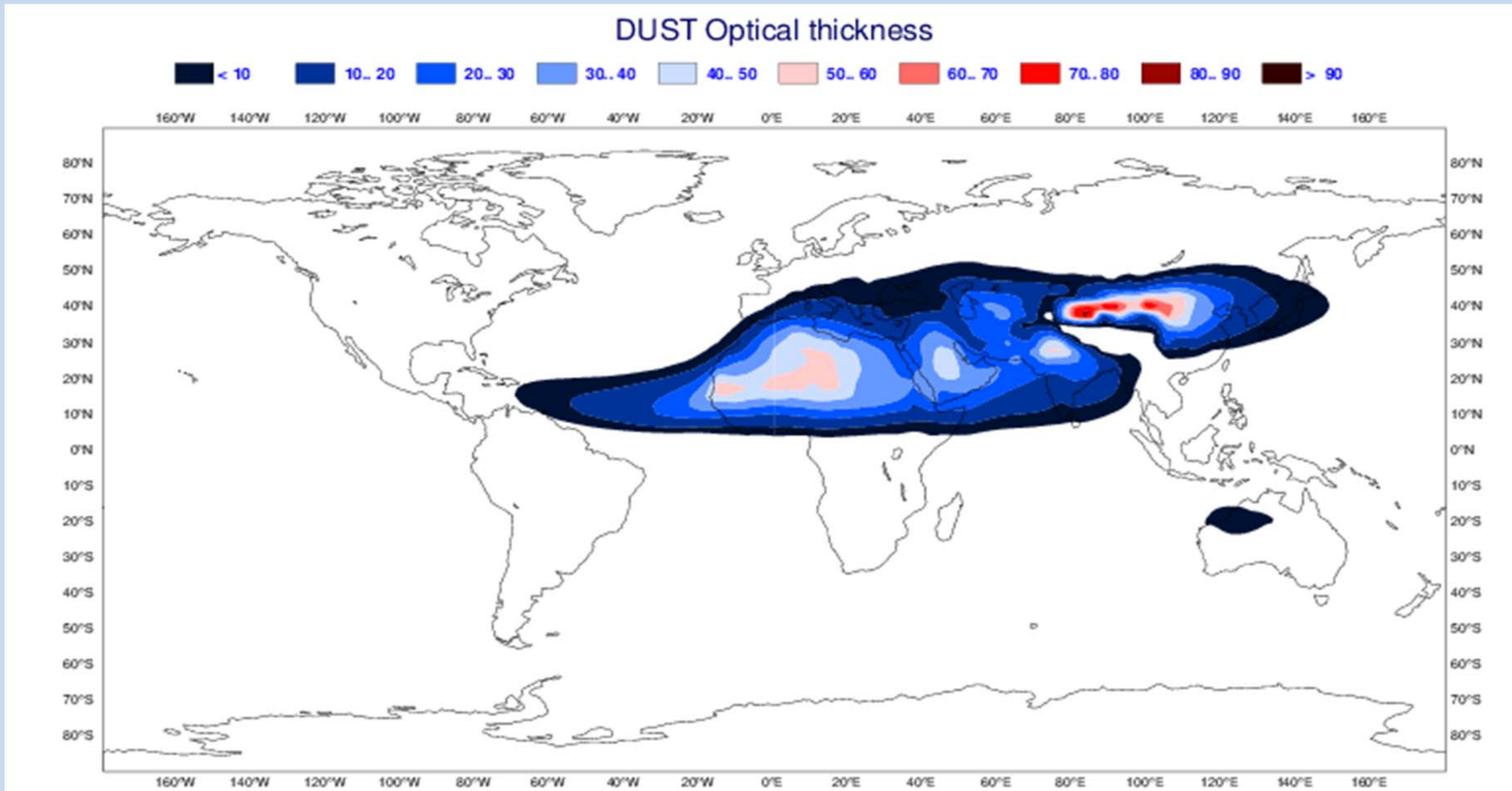
MJO Phase 67



MJO Phase 81

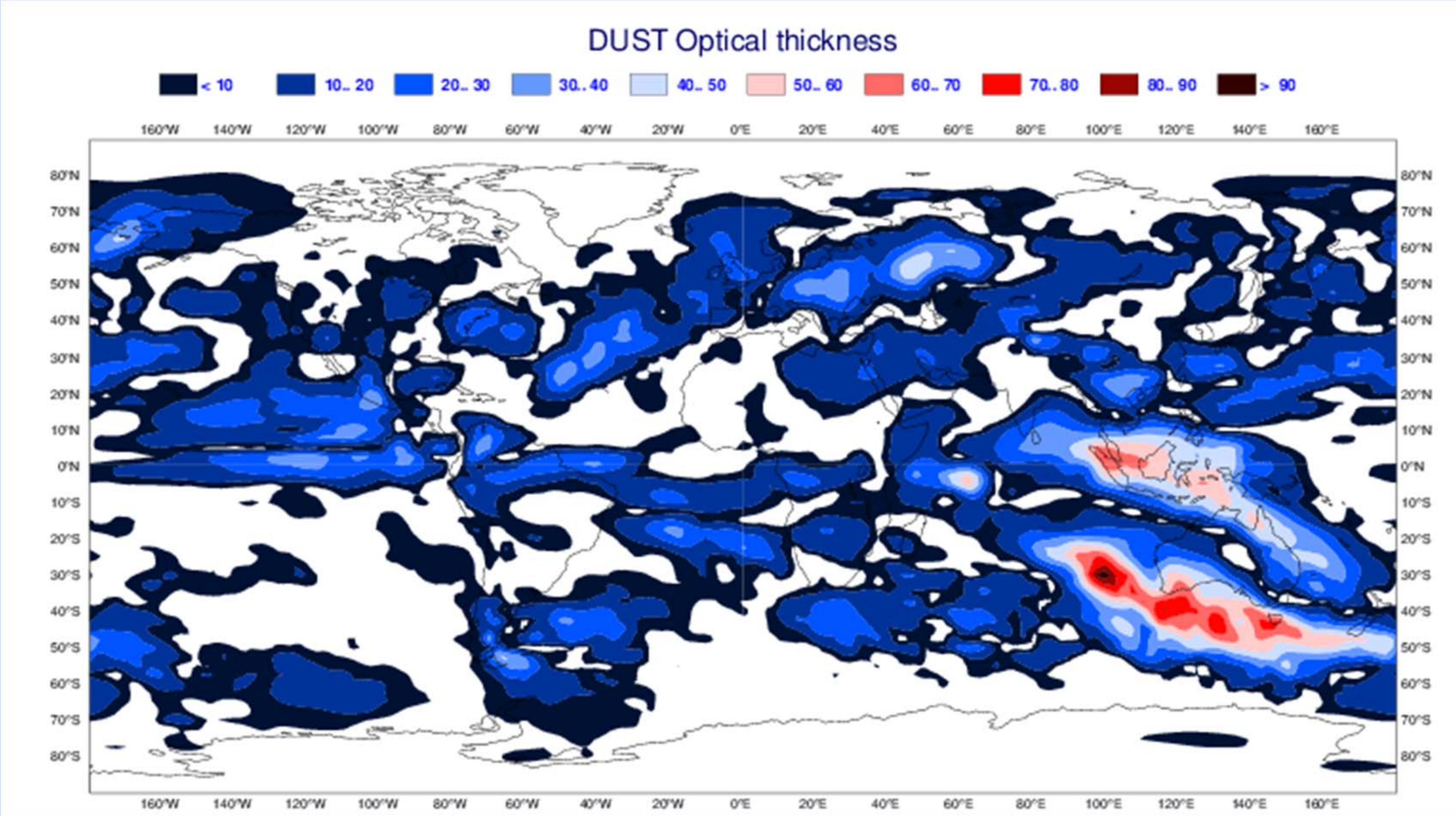


Climatology of Dust optical Thickness (x100)
May-June – Month 1



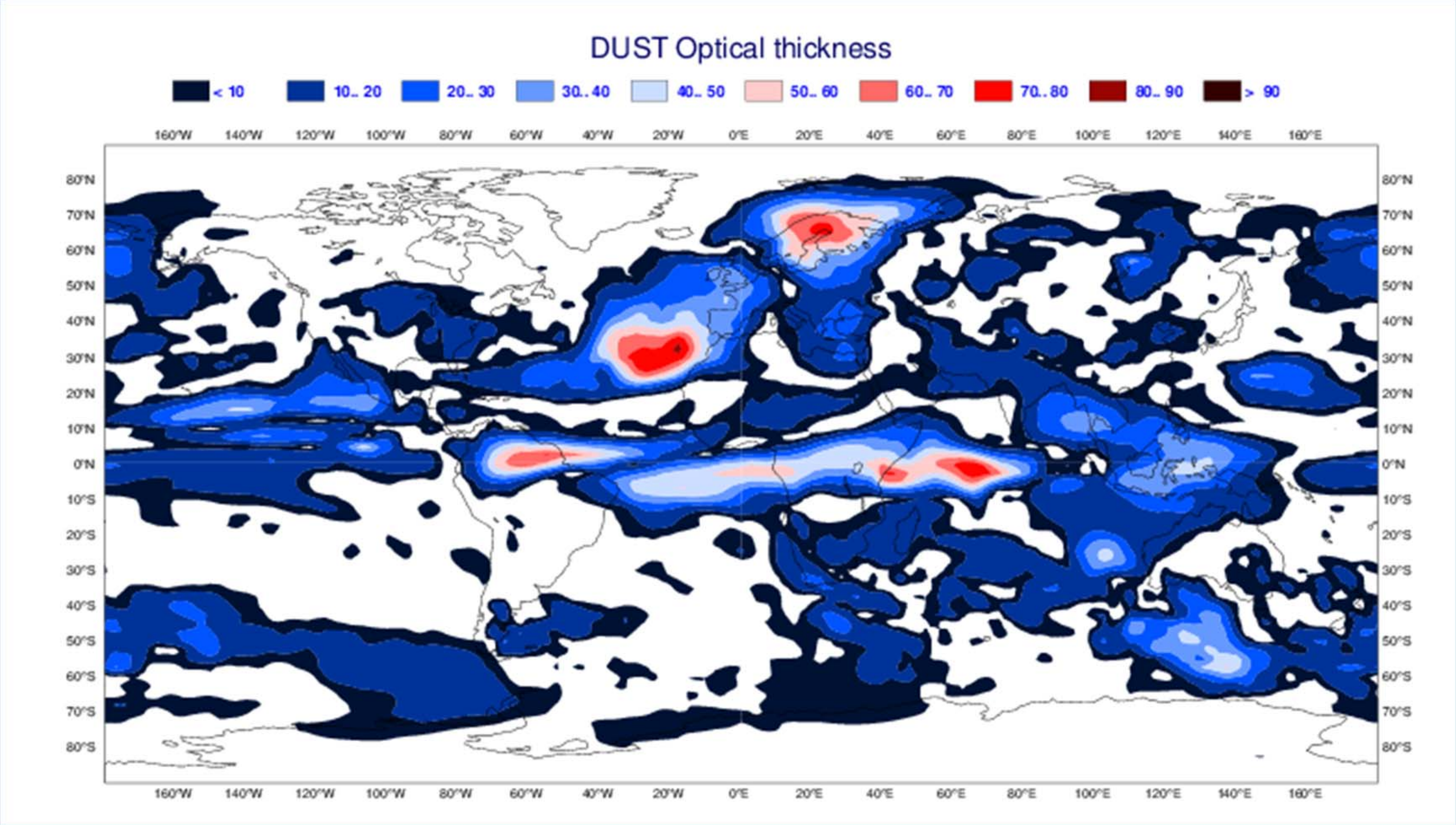
ECMWF

Fraction of change in Dust optical thickness in MJO Phase 23 relative to climatology



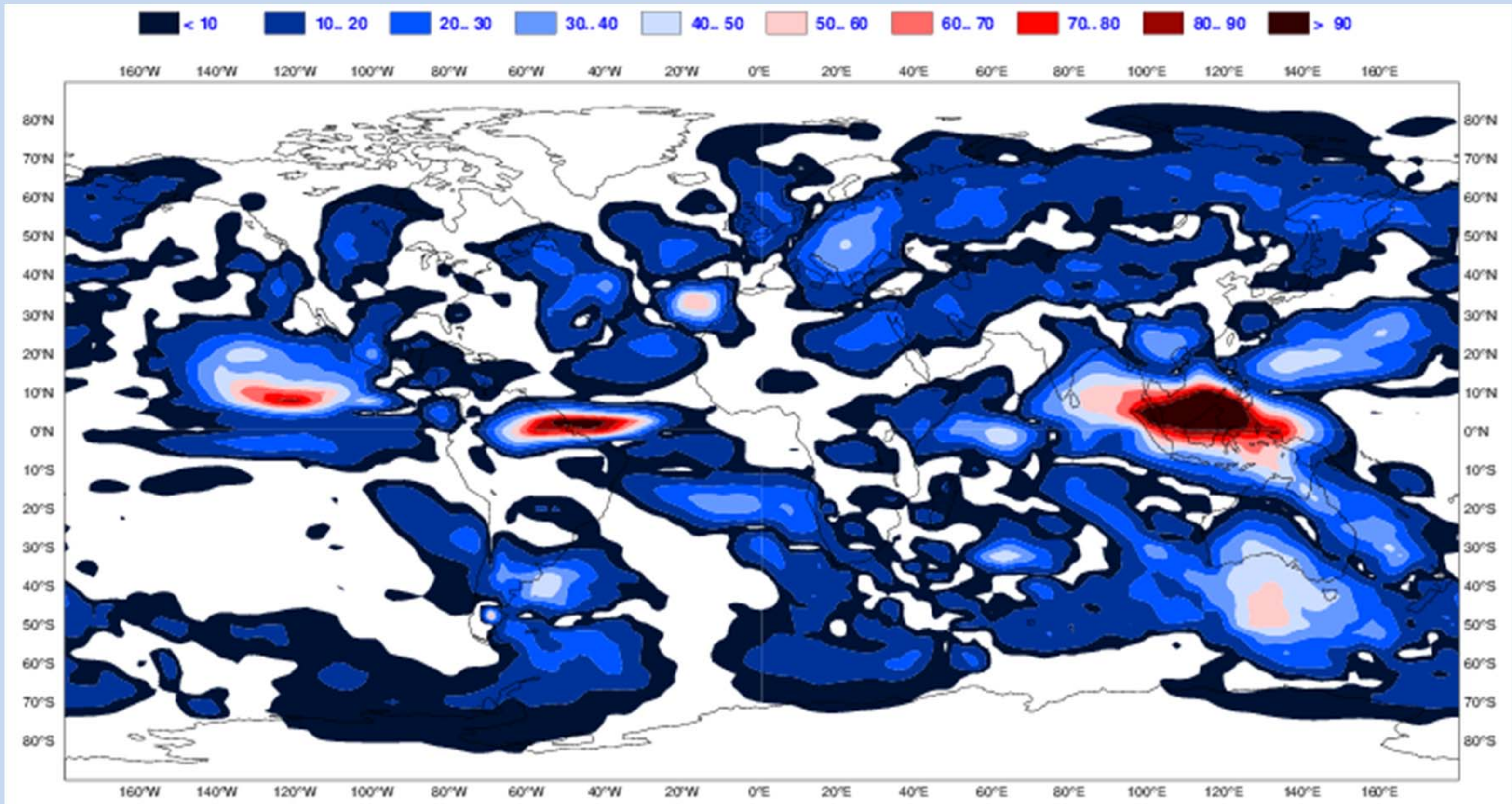
ECMWF

Fraction of change in Dust optical thickness in MJO Phase 45 relative to climatology



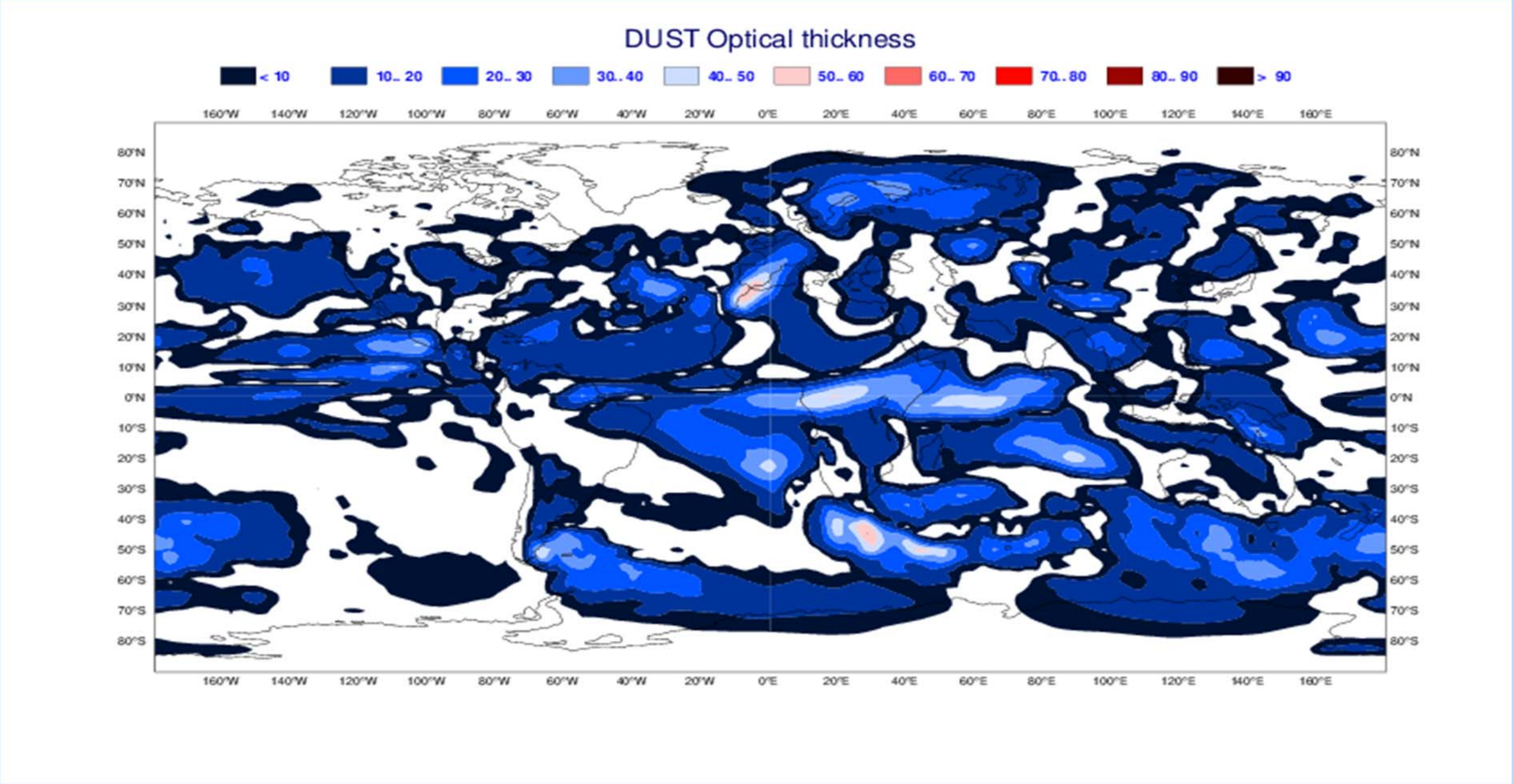
ECMWF

Fraction of change in Dust optical thickness in MJO Phase 67 relative to climatology



ECMWF

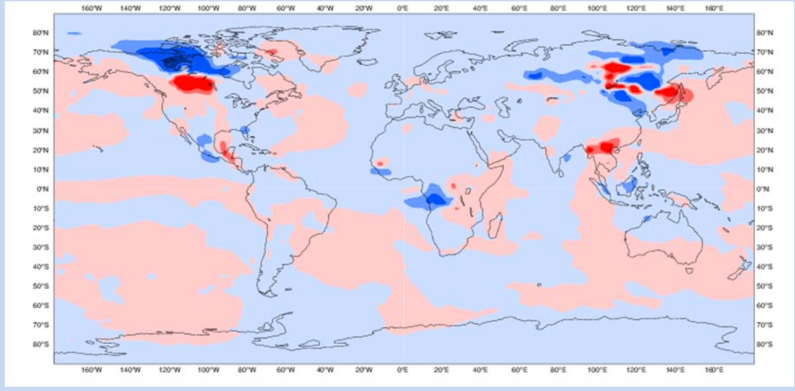
Fraction of change in Dust optical thickness in MJO Phase 81 relative to climatology



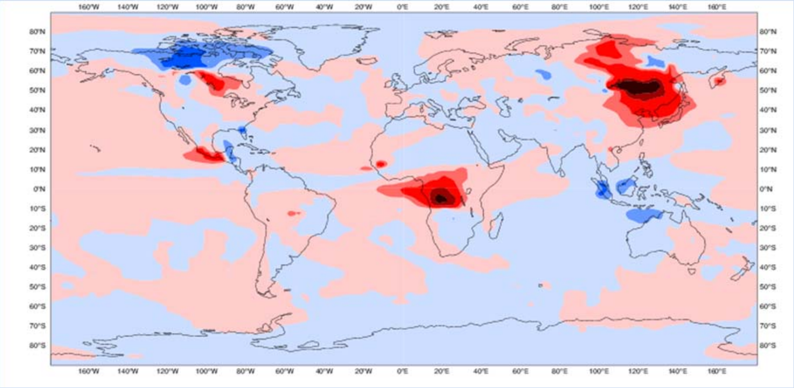
ECMWF

Modulation Of Organic Matter at 550 nm Optical Depth by the MJO

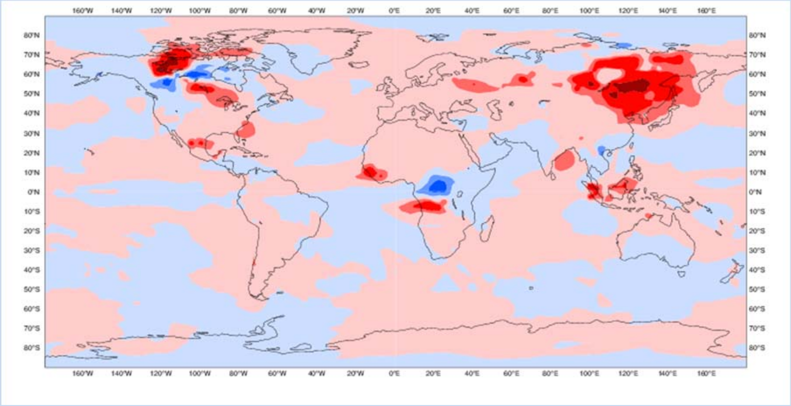
MJO Phase 23



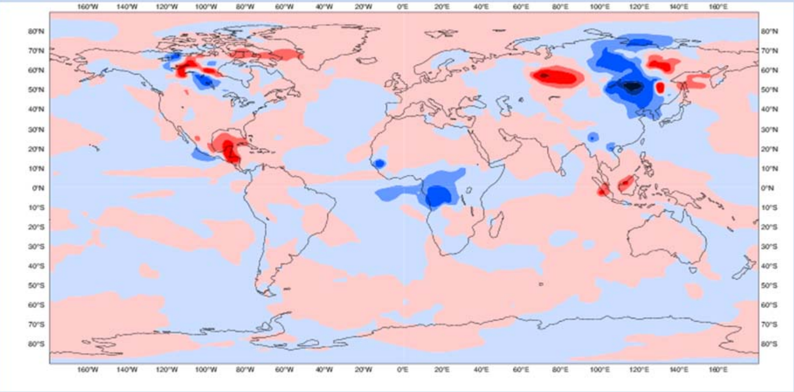
MJO Phase 45

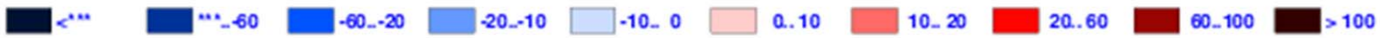


MJO Phase 67

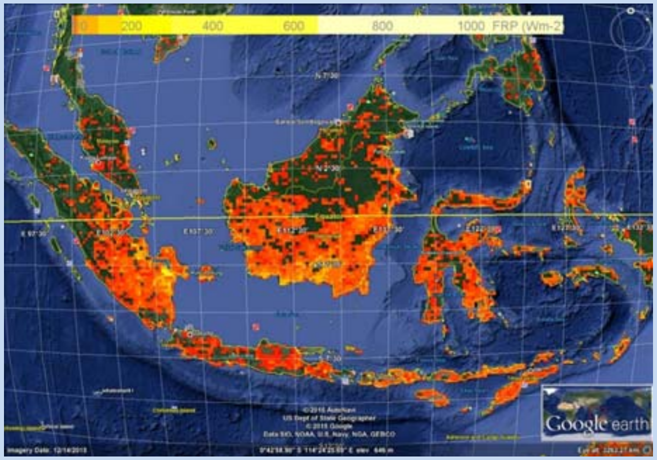


MJO Phase 81



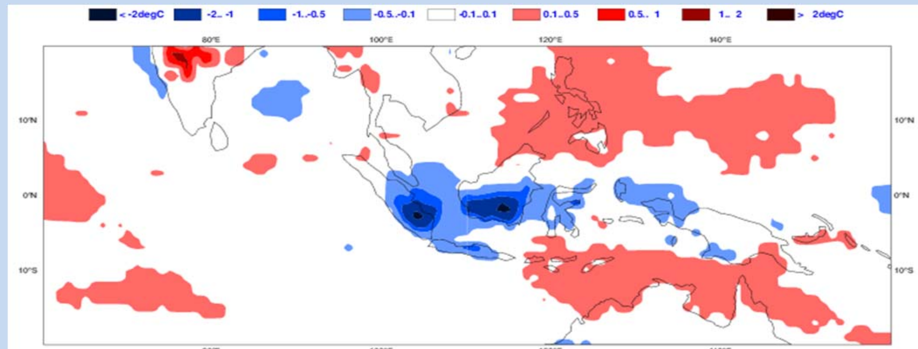


A striking case: Indonesian fires (Aug-Oct 2015)

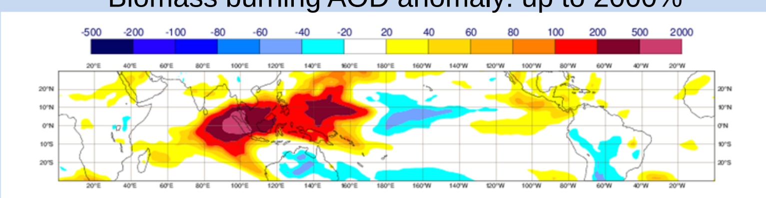


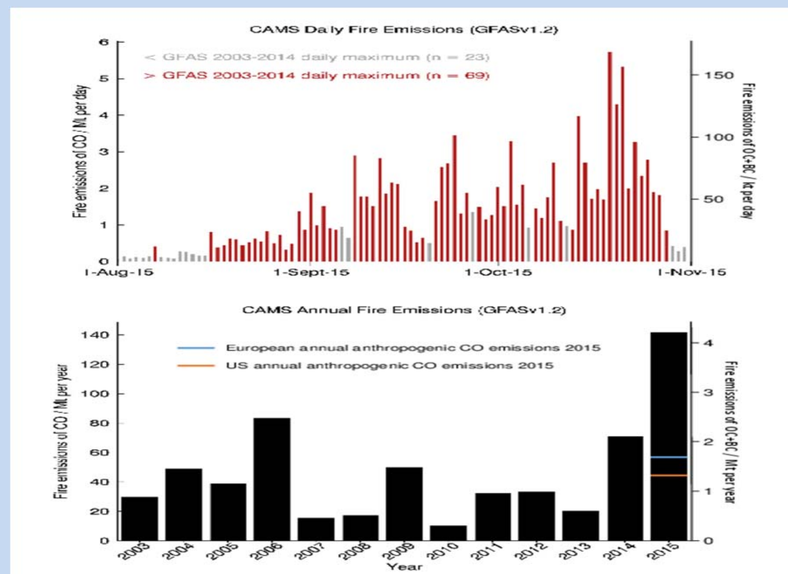
Fire radiative power Aug-Oct 2015

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



Biomass burning AOD anomaly: up to 2000%





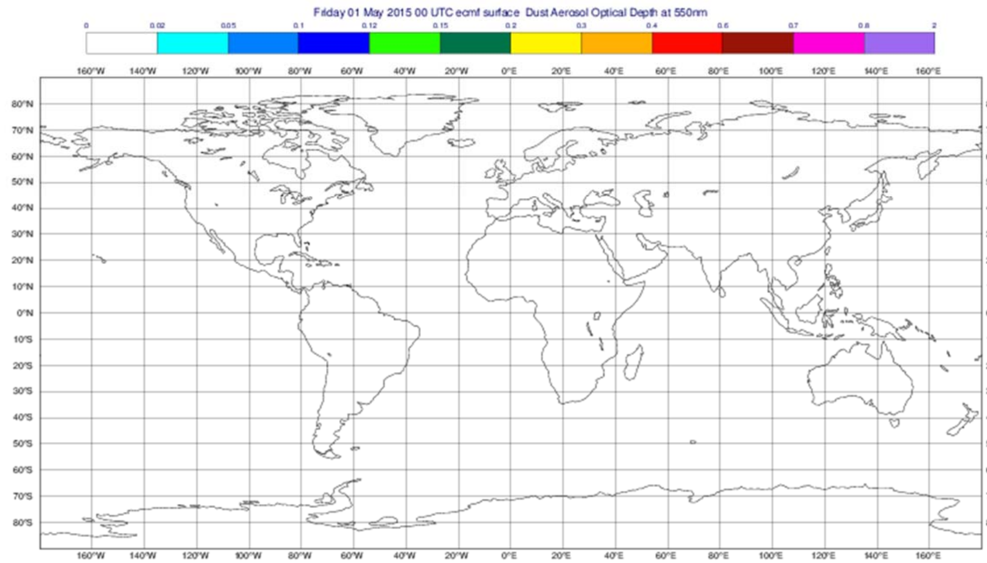
Benedetti et al, State of Climate 2016, BAMS.

- **Prediction of fire emissions is needed (under development, subject to funding)**

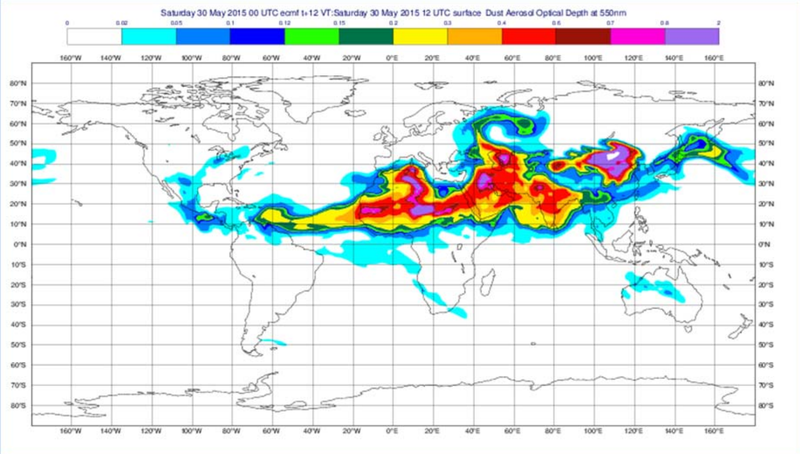
opernicus
Europe's eyes on Earth

By-product: monthly dust forecast (May 2015)

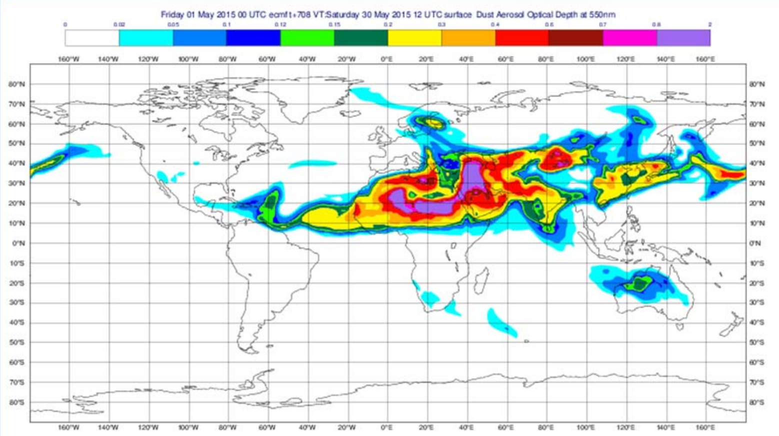
DUST AEROSOL OPTICAL DEPTH @ 550nm



CAMS ANALYSIS – 30 May 2015 @ 1200UTC



MONTHLY FORECAST valid for 30 May 2015 @ 1200UTC



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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 ongoing with the latest model release: control run with Tegen et al (1997) climatology, run with new ECMWF/CAMS climatology (see Sam's talk), runs with fully interactive prognostic aerosols

- Preliminary results show similar impacts as well as a strong dependence on the initialization (reanalysis are important!!!!)

ECMWF

Thank you for your attention!

More complexity for sub-seasonal forecasting?

Pros:

- Can improve skill scores (ocean, sea-ice, aerosols..)
- Can lead to new products:
    - **Active aerosols:** prediction of dust storm useful for Meningitis prediction
    - **Sea-ice model:** Extended-range sea-ice forecasts for ship routing in the Arctic in Summer.

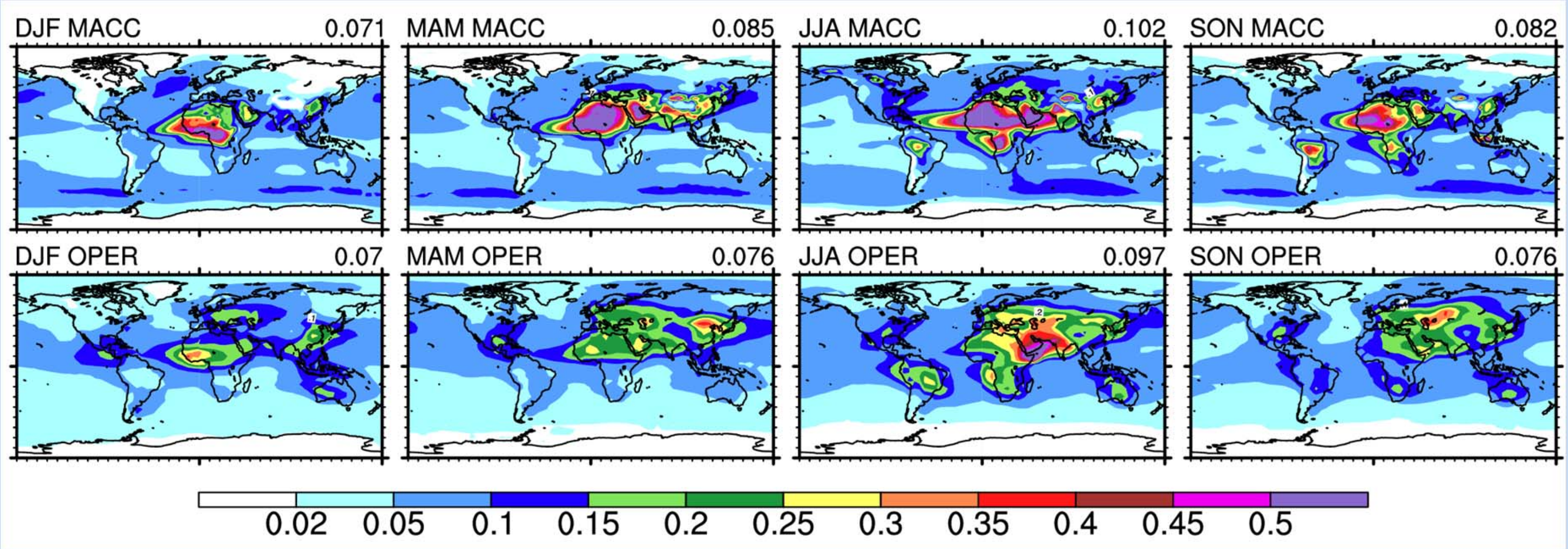
Cons:

- Can be very expensive (e.g. active aerosols = 50% increase in cost)

Resources could be allocated to improve tropospheric models, through, for instance, increased resolution, more frequent call to radiative transfer, increased ensemble size, more frequent forecasts (daily instead of twice weekly)

- Makes system more complex to understand and maintain
- **Can increase systematic errors particularly in short/medium-range forecasts and possibly affect teleconnections**

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



- 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.

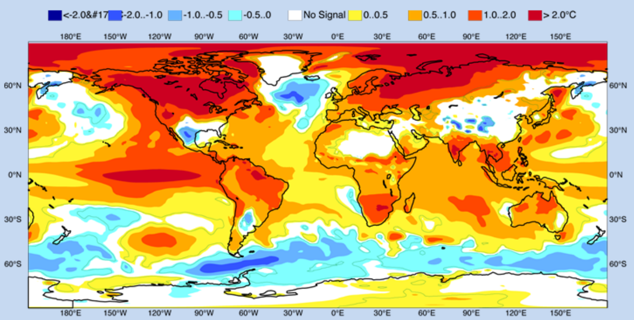
ECMWF

Credits: Alessio Bozzo

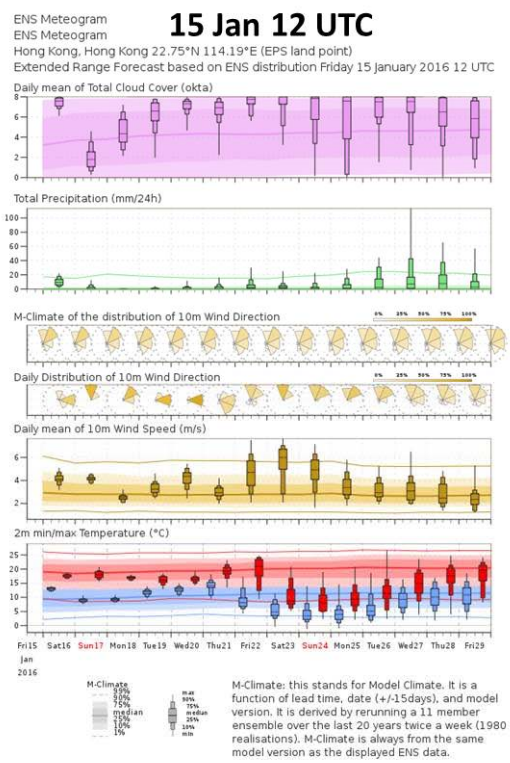
From medium-range to seasonal to extended range

Seasonal Forecast

DJF 2015/16



Medium-range



Extended-range