Development of a monthly prediction system for aerosol/ozone

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ECMWF, Shinfield Park, Reading, UK

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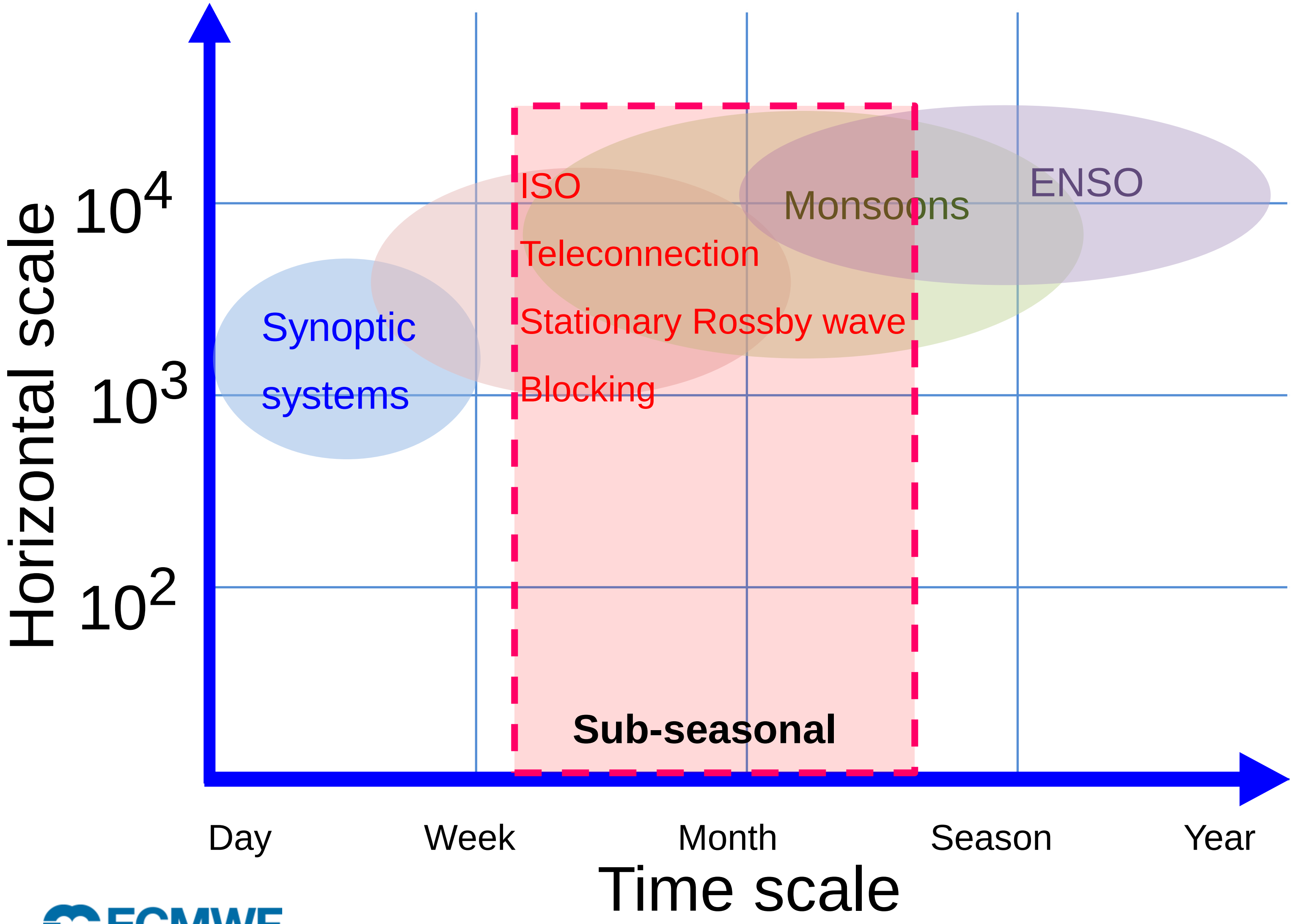
Sub-seasonal time range



ECMWF

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

ECMWF monthly forecasts

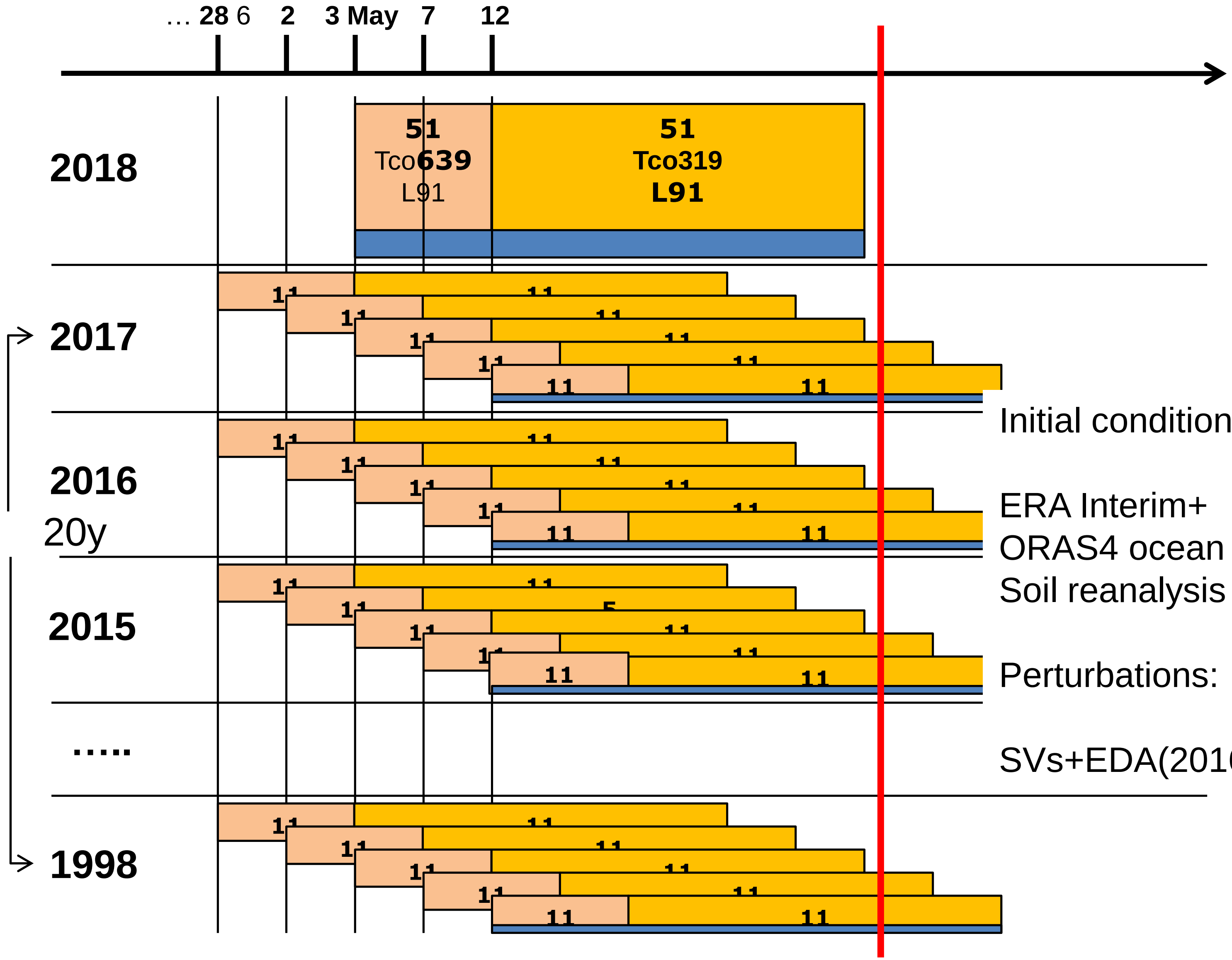
- A 51-member ensemble is integrated for 46 days twice a week (Mondays and Thursdays at 00Z)

- Atmospheric component: IFS with the latest operational cycle and with a Tco639L91 resolution up to day 15 and Tco319L91 after day 15.

- Ocean-atmosphere coupling from day 0 to NEMO (about 1/4 degree) every hour.

ECMWF

The ENS re-forecast suite to estimate the M-climate



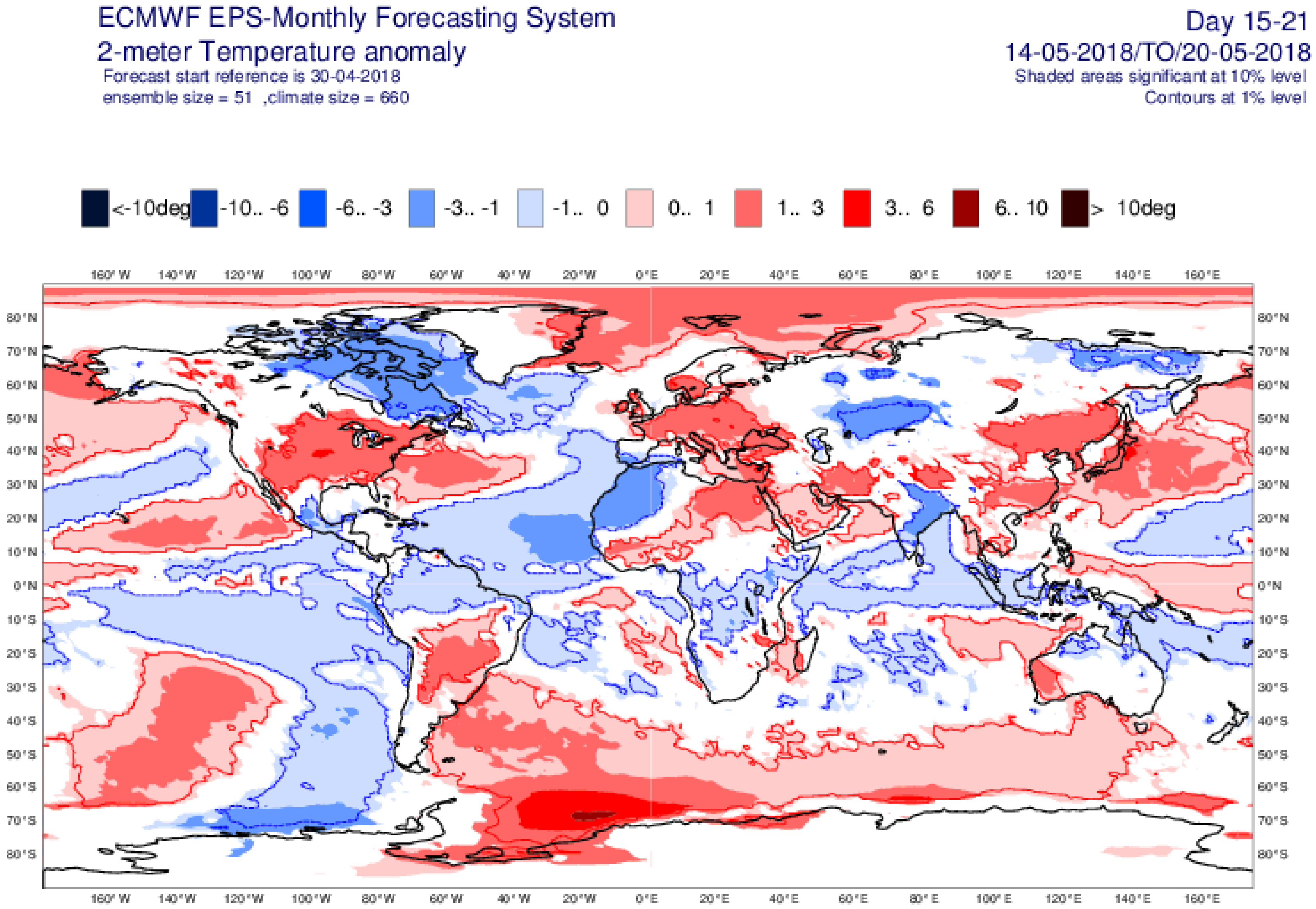
Initial conditions:

ERA Interim+
ORAS4 ocean Ics+
Soil reanalysis

Perturbations:

SVs+EDA(2016)+SPPT+SKEB

The ECMWF monthly forecasts

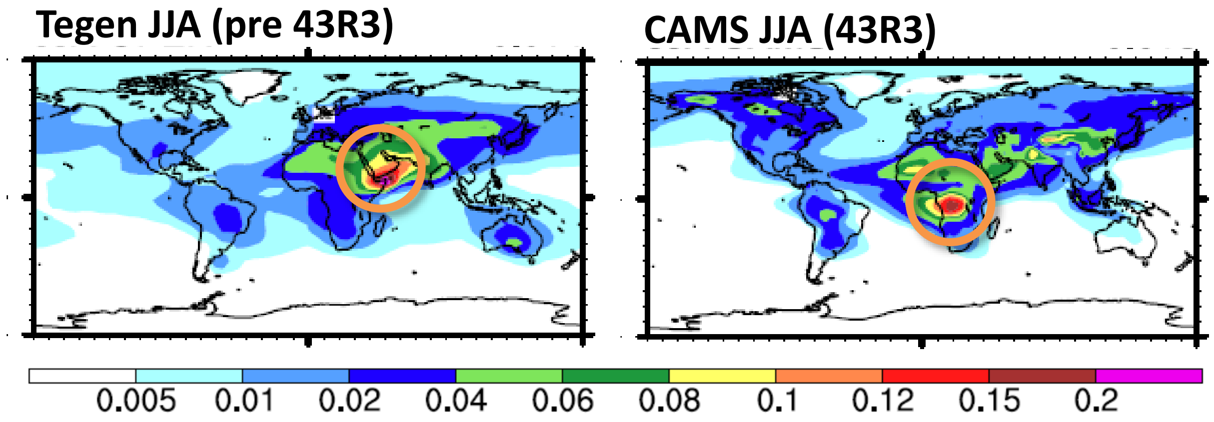


Anomalies (temperature, precipitation..)

ECMWF

Aerosols climatology in CY43R3

- Atmospheric forcing depends on *absorption* optical depth:

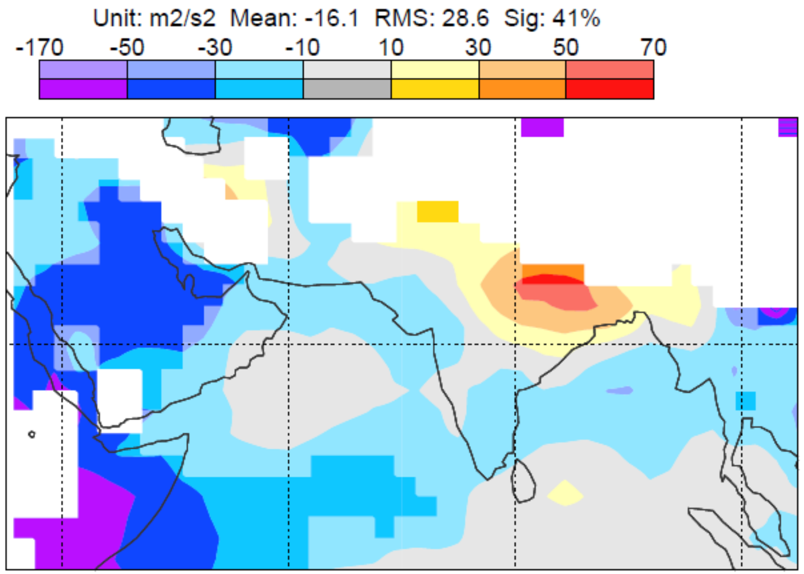


- Reduced absorption over Arabia in new CAMS climatology weakens the overactive Indian Summer Monsoon, halving the overestimate in monsoon rainfall

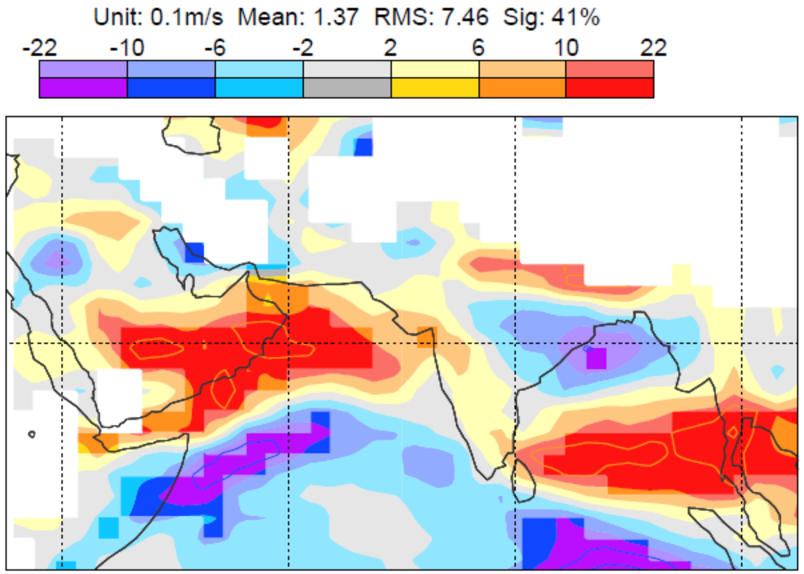
- Increased absorption over Africa degraded 850-hPa temperature, traced to excessive biomass burning in CAMS

- *We can measure the impact of aerosols on the tropical atmosphere more easily than the absorption optical depth itself! Use to provide information on aerosol errors?*

(b) CAMS climatology: geopotential *bias*



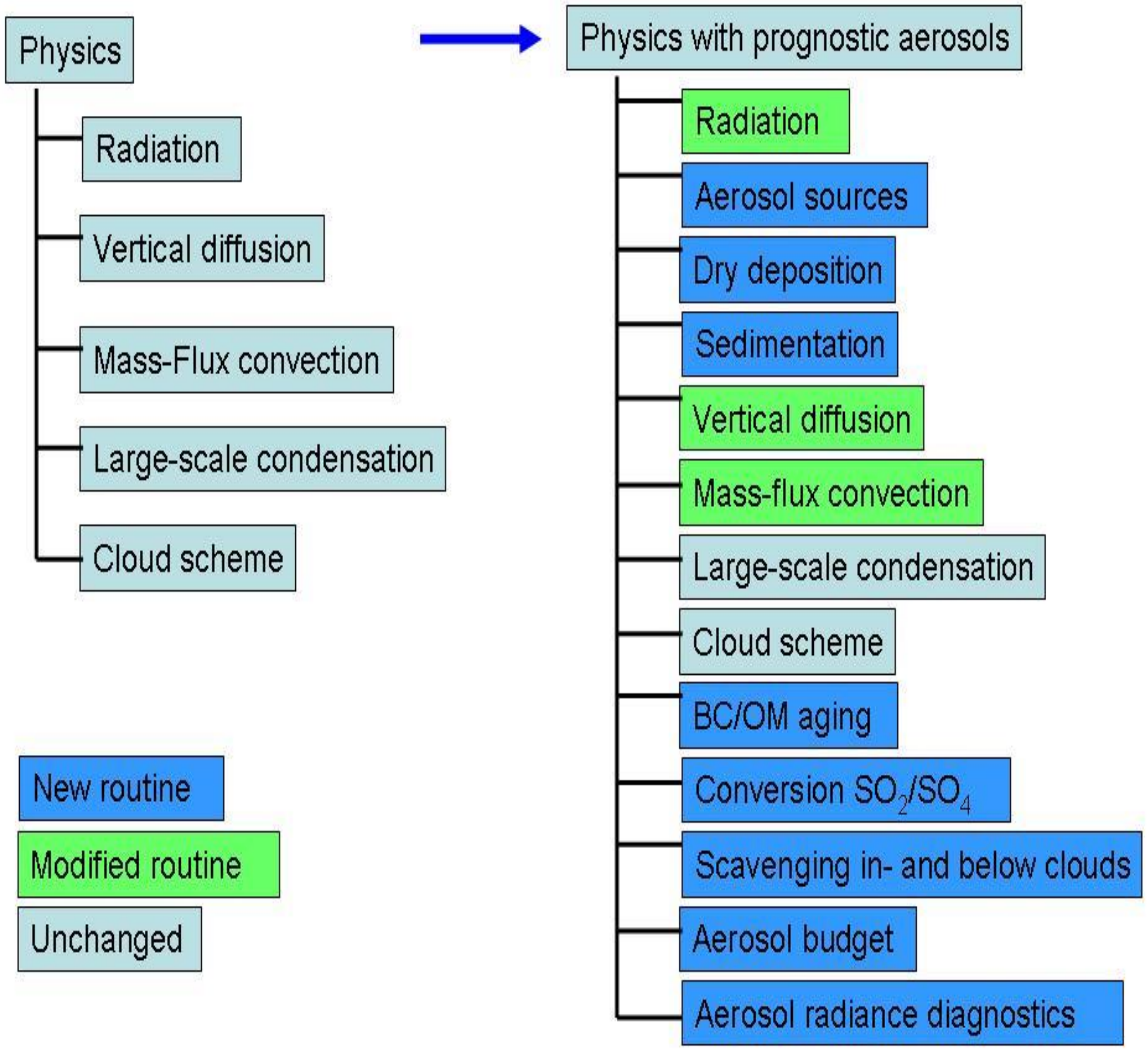
(d) CAMS climatology: zonal wind *bias*



Bozzo et al, TM 801, 2017

Aerosols impacts on the sub-seasonal prediction

Aerosols in the ECMWF 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

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)

ECMWF

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

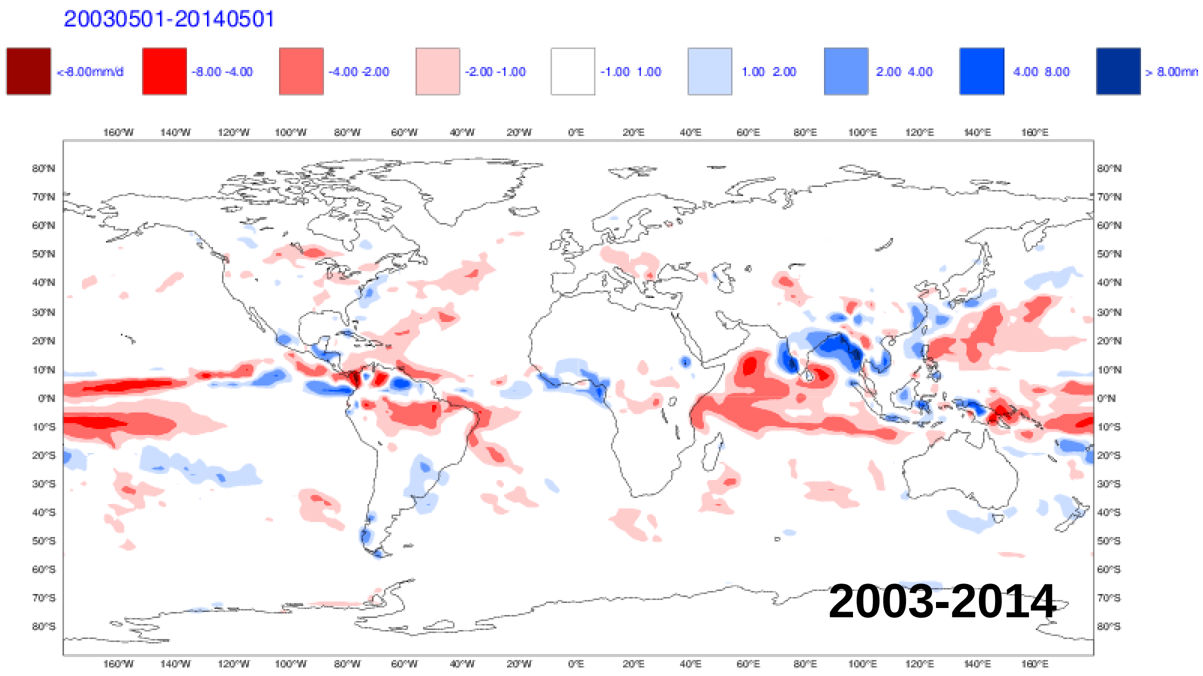
Monthly EPS coupled runs with interactive aerosols Cycle 41R1

- 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 burning
- 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

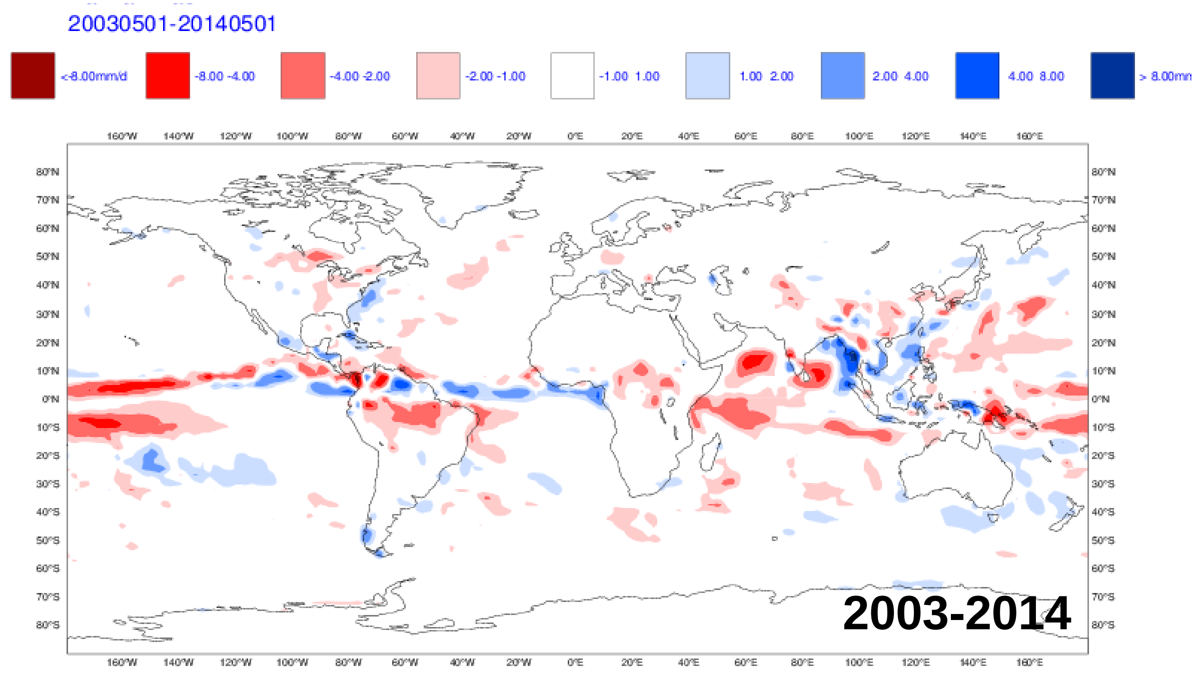
Aerosol impacts on monthly forecasts (summer)

- 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

CONTROL RUN – PRECIPITATION BIAS WEEK 4

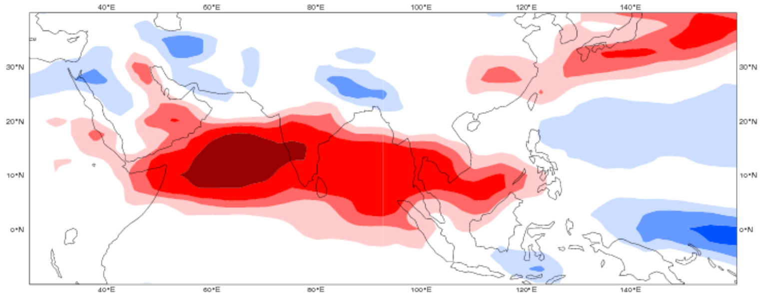


INTERACTIVE AEROSOL RUN – PRECIPITATION BIAS WEEK 4

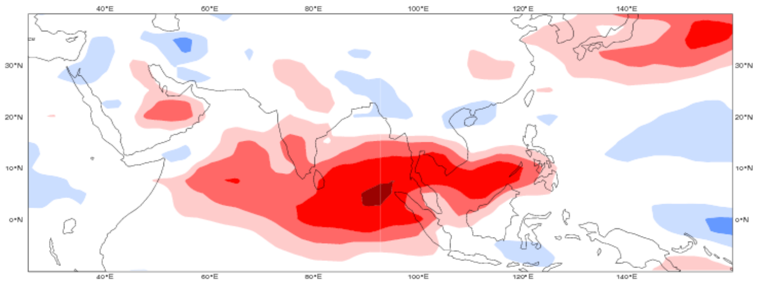


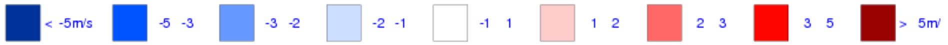
Aerosol impacts on monthly forecasts (summer)

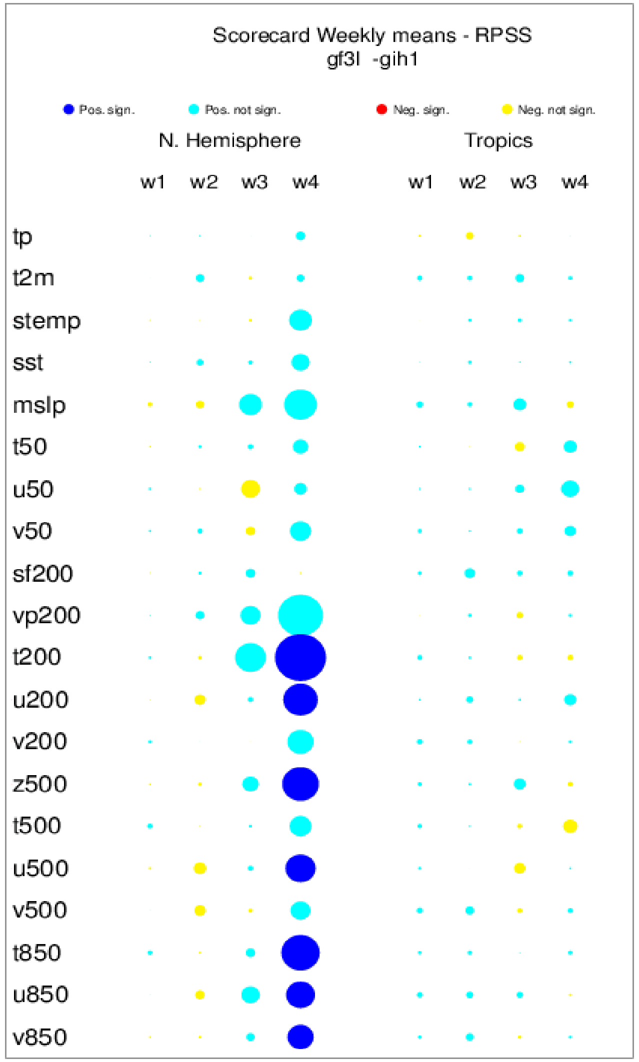
CONTROL RUN – 850 hPa U WIND BIAS WEEK 4



INTERACTIVE AEROSOL RUN – U WIND BIAS WEEK 4



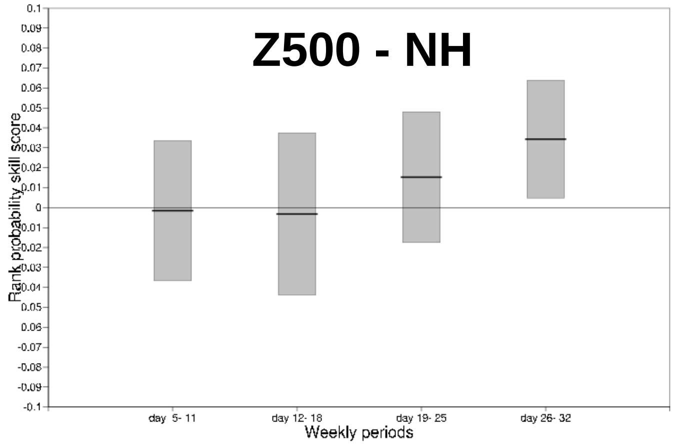




Scorecards measures

- 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)

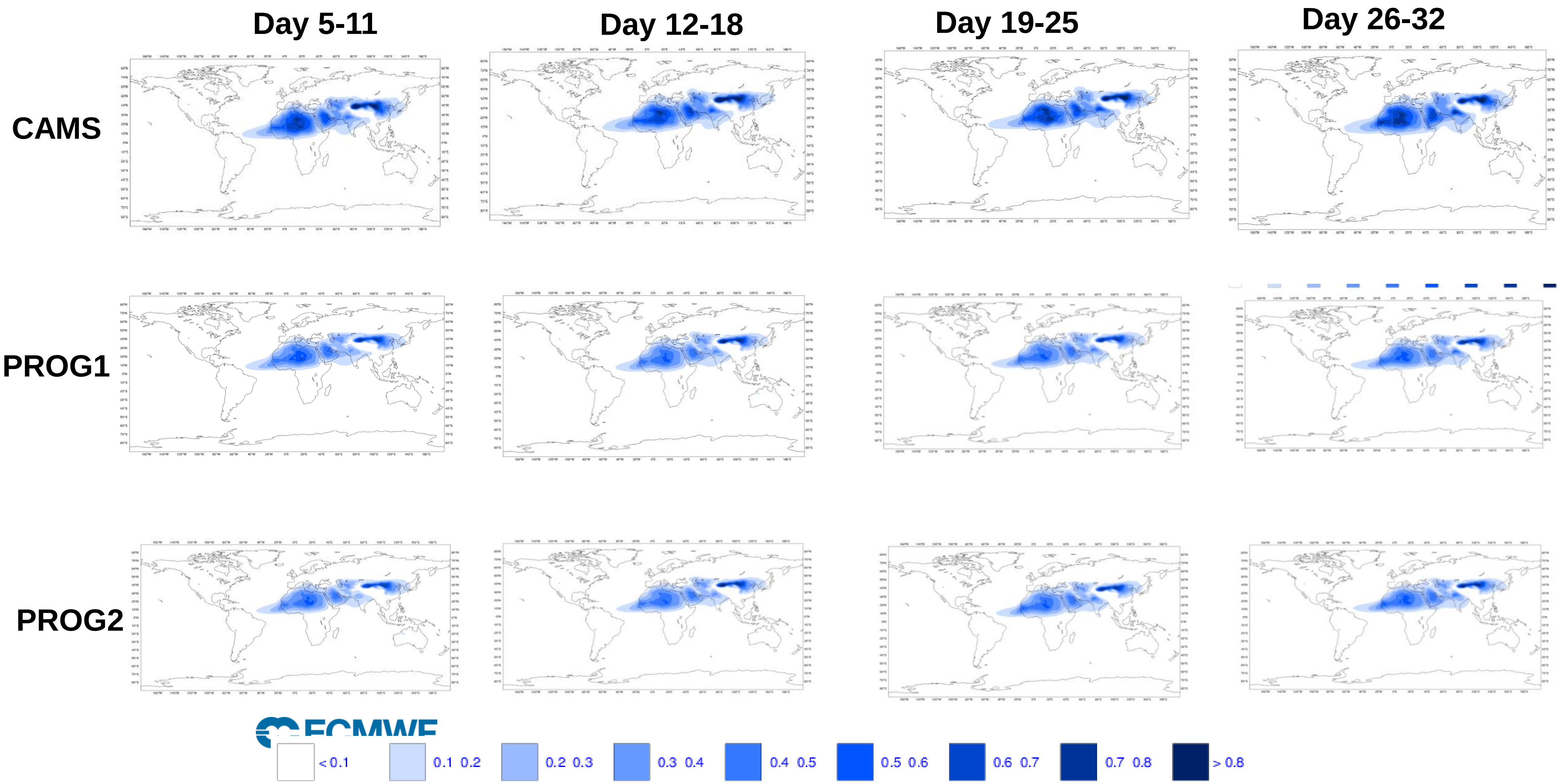


- **Similar impacts are observed with the new ECMWF/CAMS climatology**
- **Need to understand the relative importance of the meteorological feedback on the daily variability of aerosols**

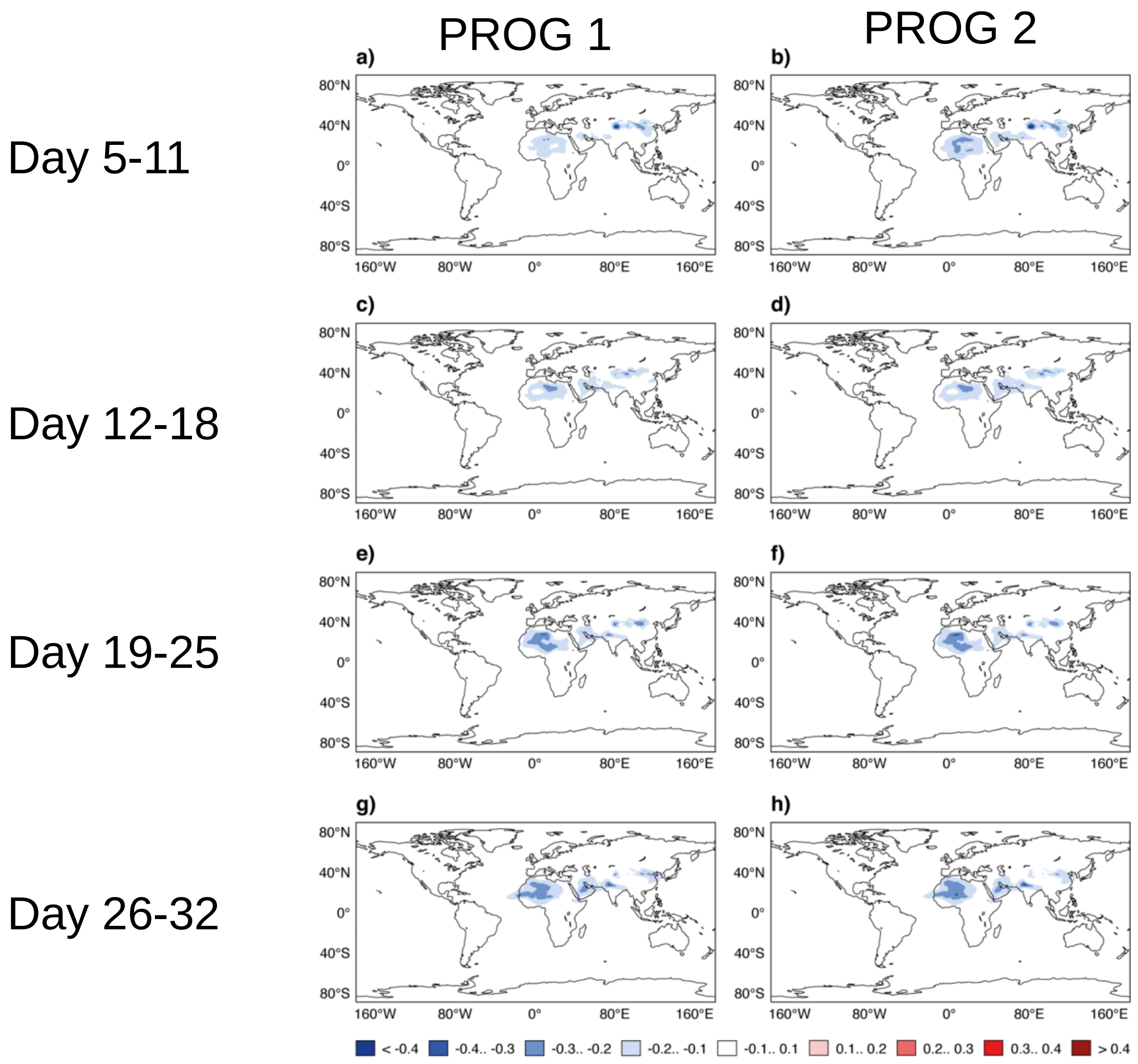
Experiment Setup (CY43r1)

- Two control runs for the period 2003-2015 were used: one with the Tegen et al 1997 climatology (CONTROL1) and one with the Bozzo et al 2017 climatology (CONTROL2)
- Interactive aerosol simulations cover the same period and use fully prognostic aerosols in the radiation scheme – only aerosol direct effect are included
- Two initializations used for the experiments: one using the CAMS Interim Reanalysis (PROG1) and another using an average aerosol state from a free-running model simulation (PROG2).
- Free-running aerosols with observed emissions for biomass burning
- Ensemble size is 11 members, T255 resolution, 91 levels
- 5 different start dates around May 1 (55 cases in total)
- The experiments were let to run for 6 months

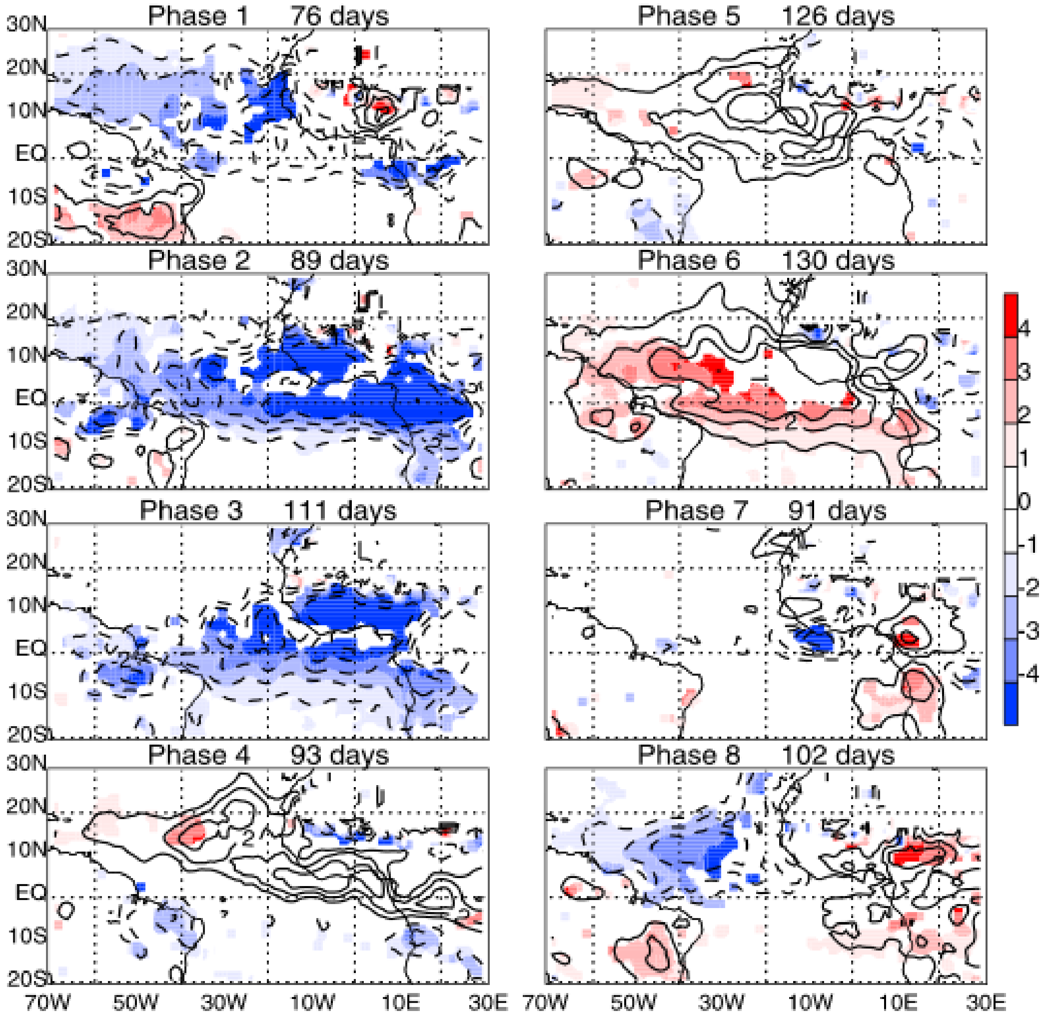
Climatology – DUST - start dates: 20 April 2003-2015



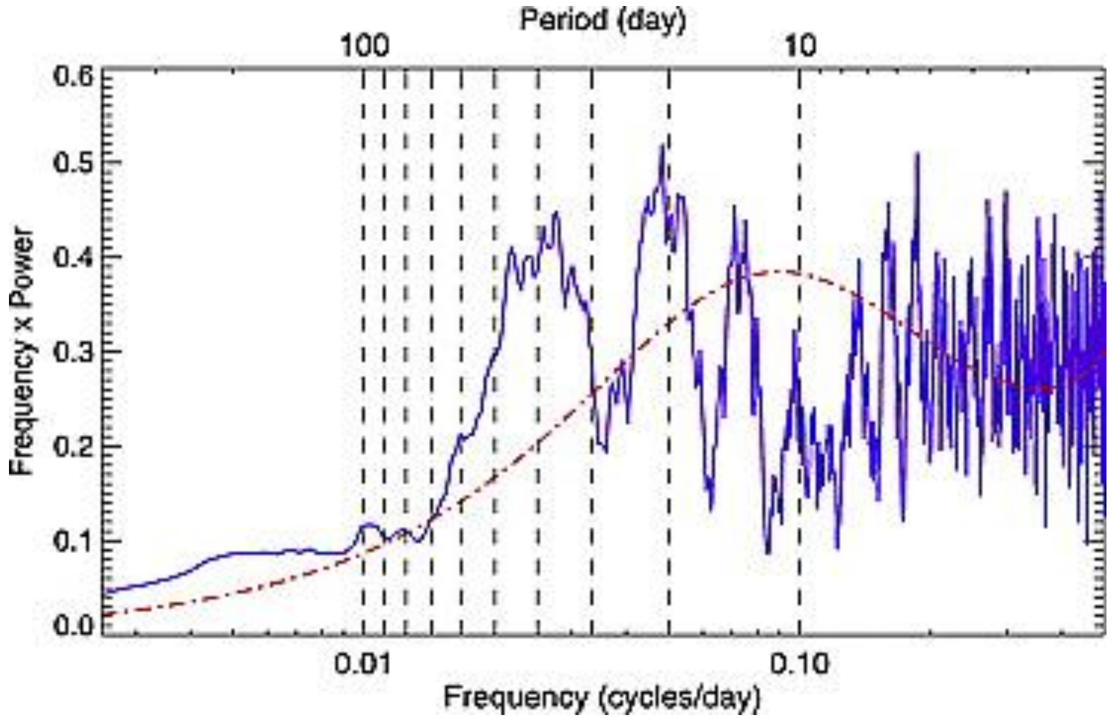
Aerosol Biases (relative to CAMSira) – DUST



Sub-seasonal variability of aerosols (Observations)



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

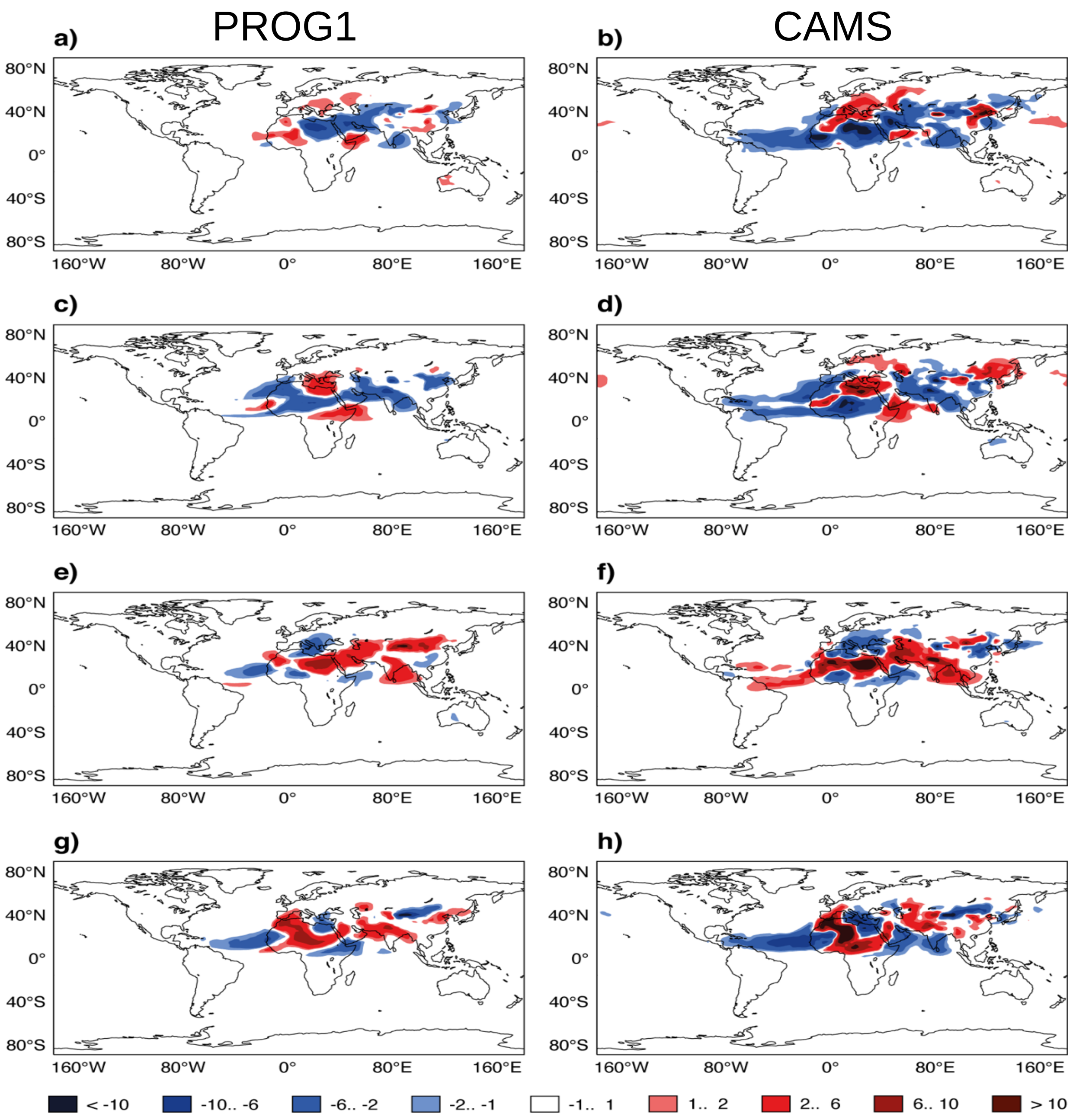
Impact of MJO on Dust optical depth anomalies

Phase 2-3

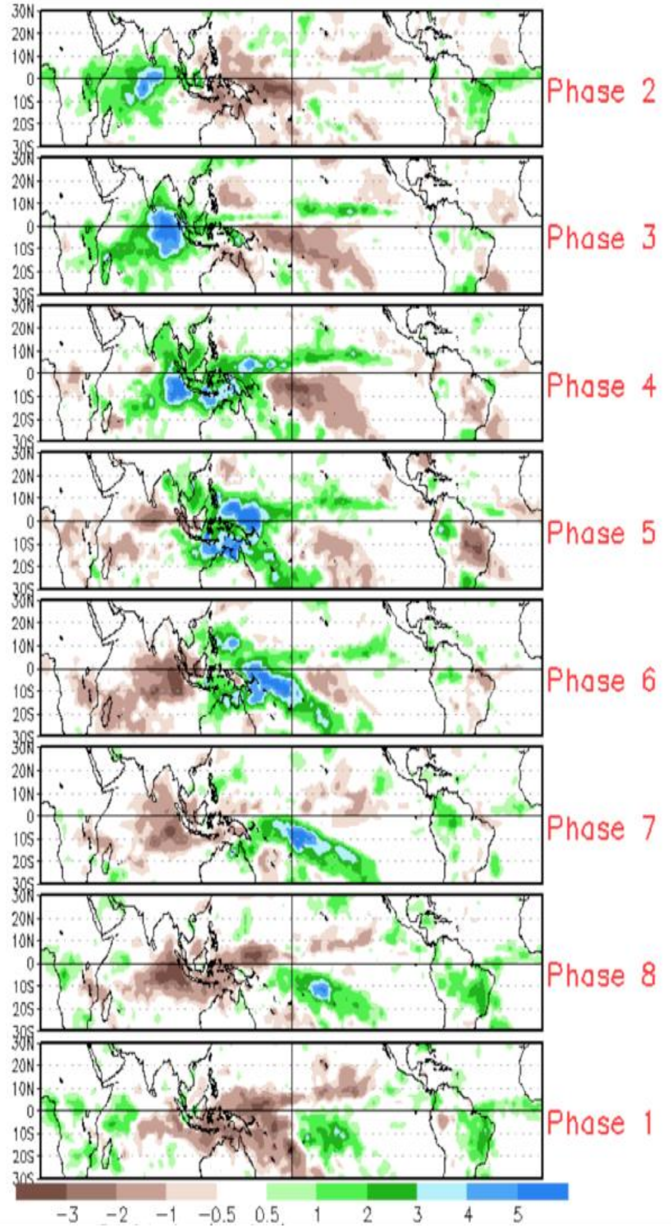
Phase 4-5

Phase 6-7

Phase 8-1



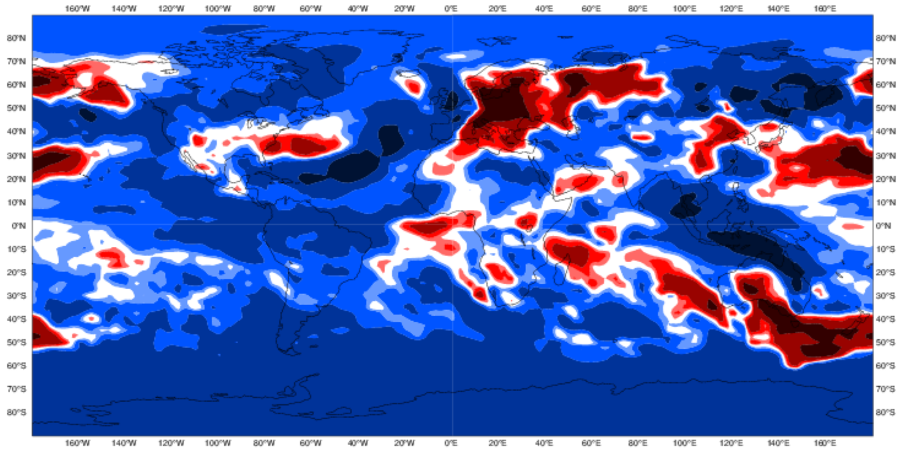
MJO Phases



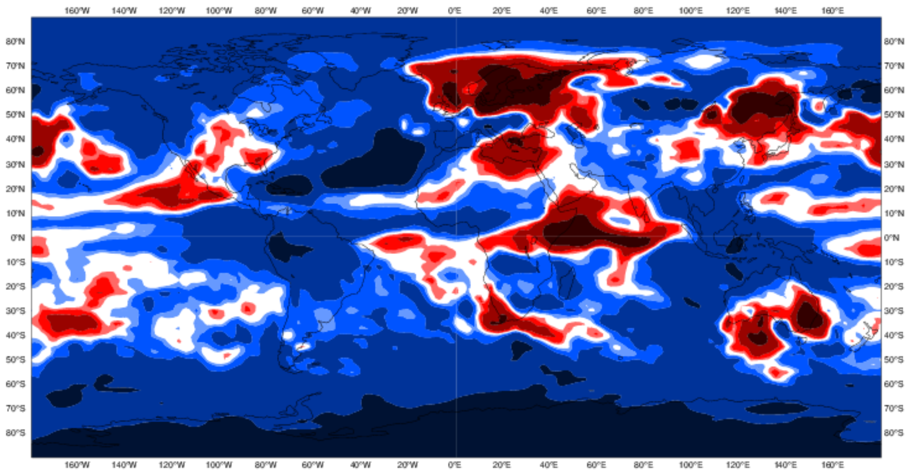
Modulation Of dust optical depth by the MJO (%) – CAMS Analysis

<-50 | -50..-20 | -20..-10 | -10..-5 | -5..5 | 5..10 | 10..20 | 20..50 | > 50

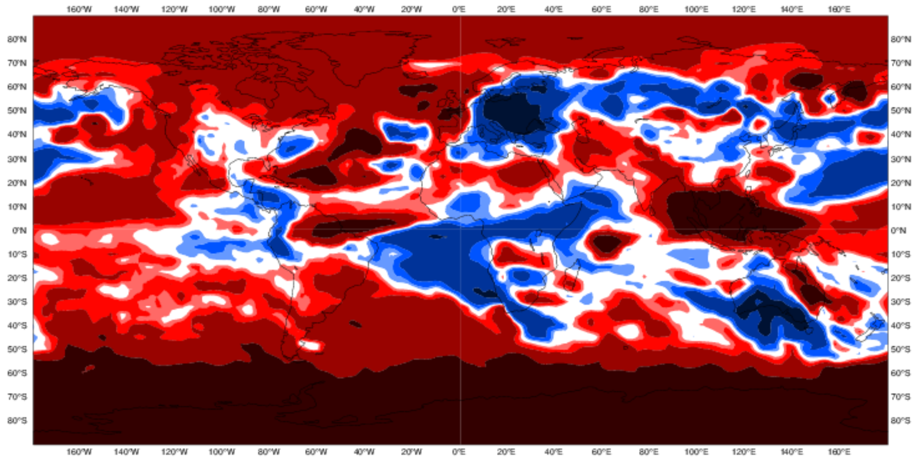
MJO Phase 23



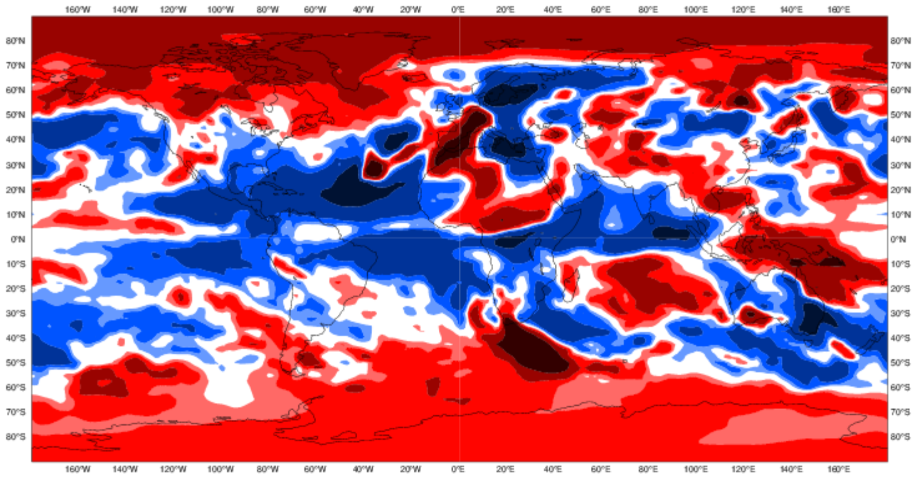
MJO Phase 45



MJO Phase 67



MJO Phase 81



Impact of MJO on Biomass Burning optical depth anomalies

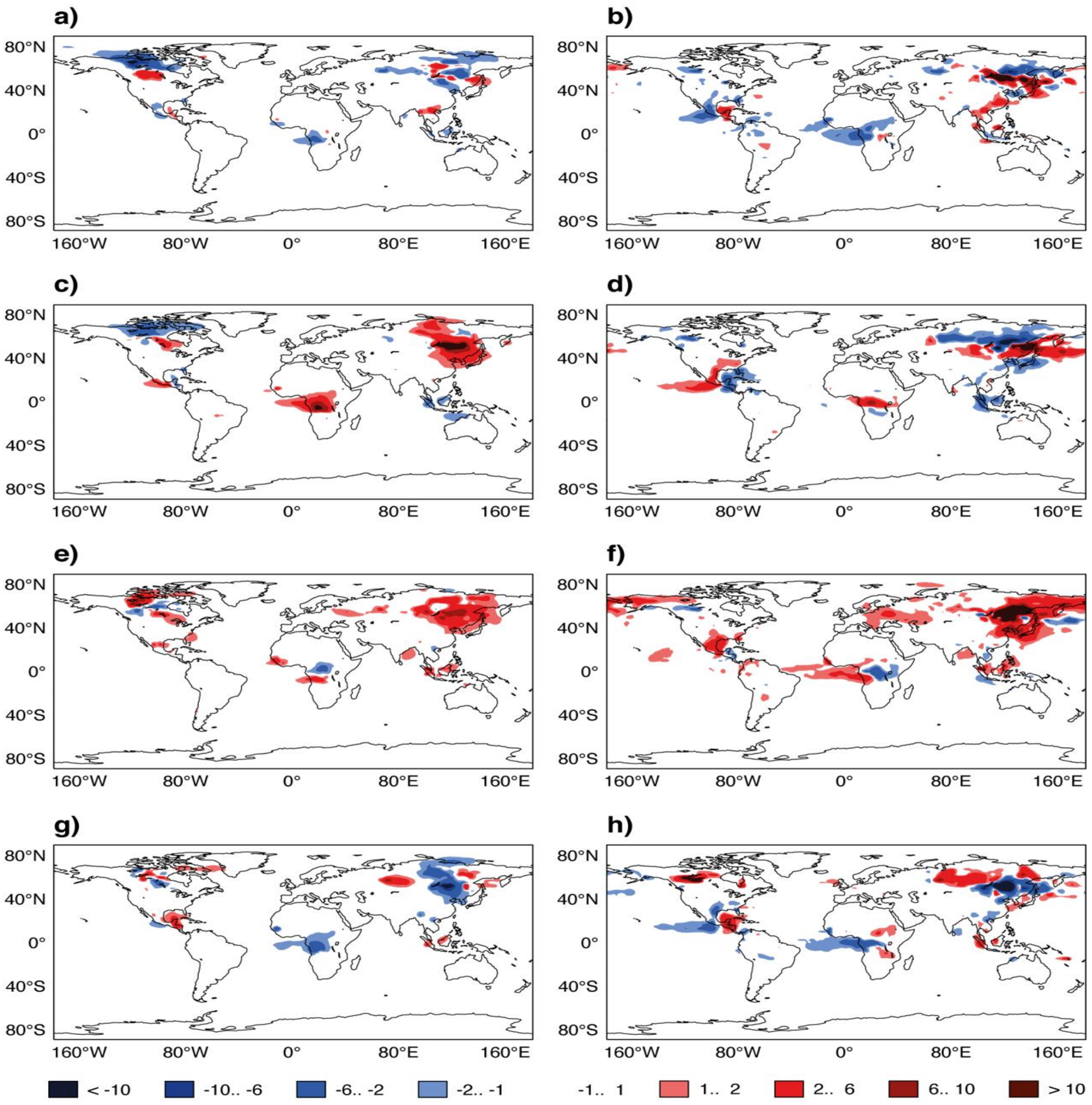
PROG1 | PROG2 | MJO Phases

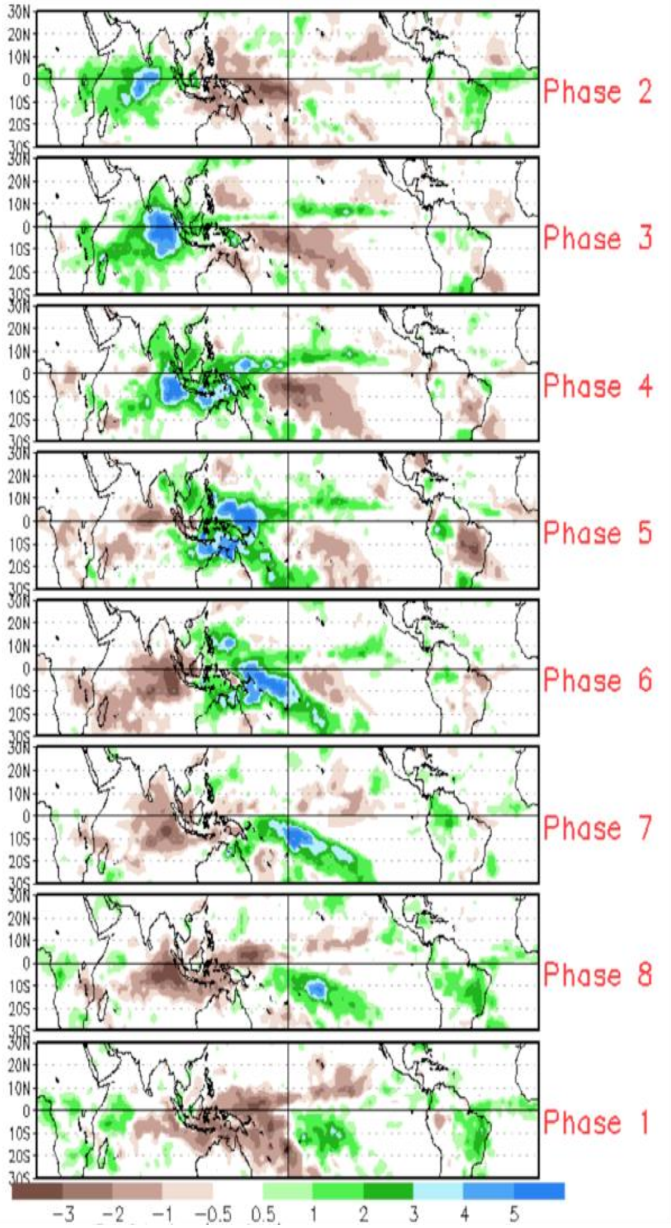
Phase 2-3

Phase 4-5

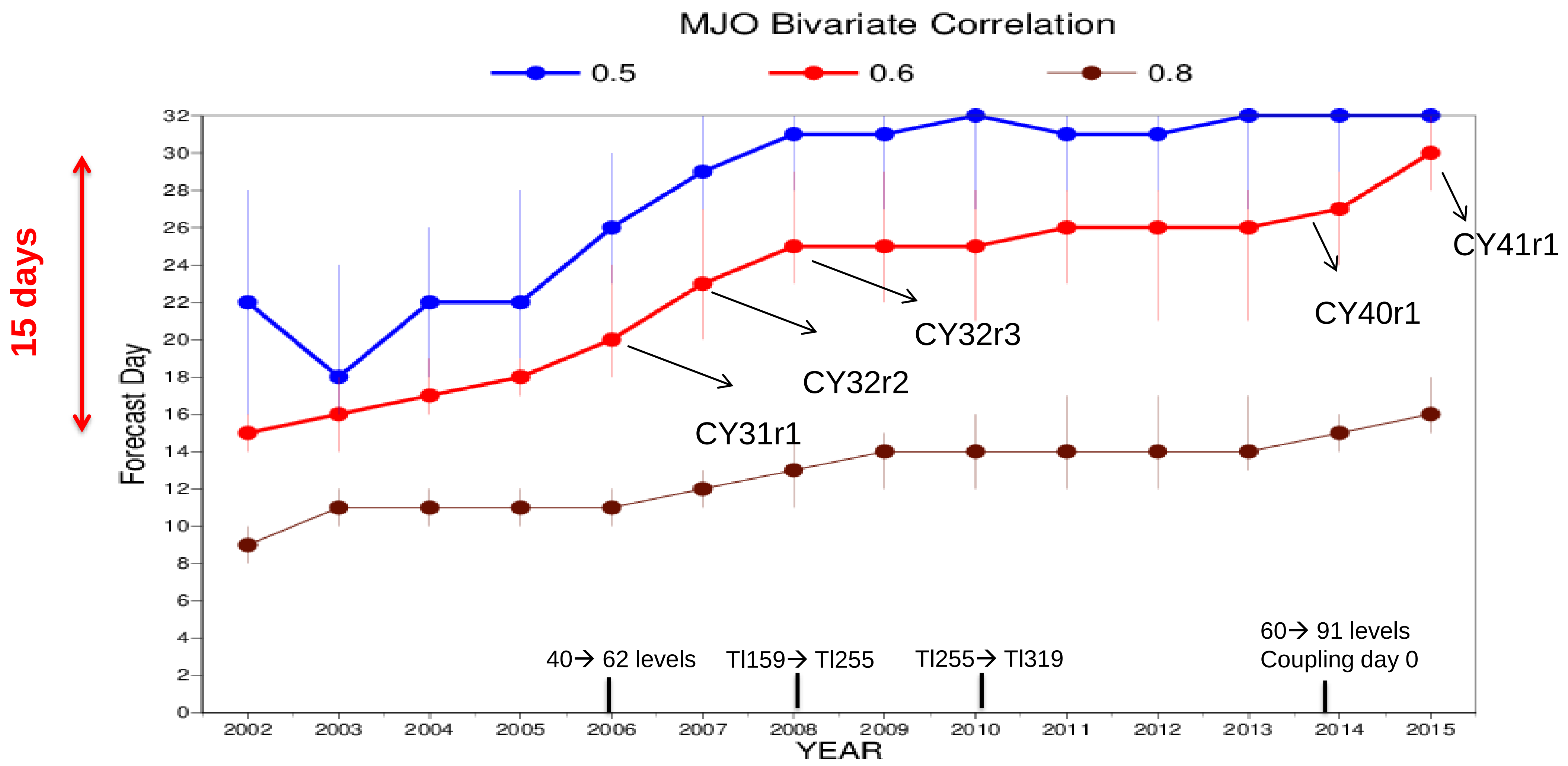
Phase 6-7

Phase 8-1





Madden Julian Oscillation prediction at ECMWF

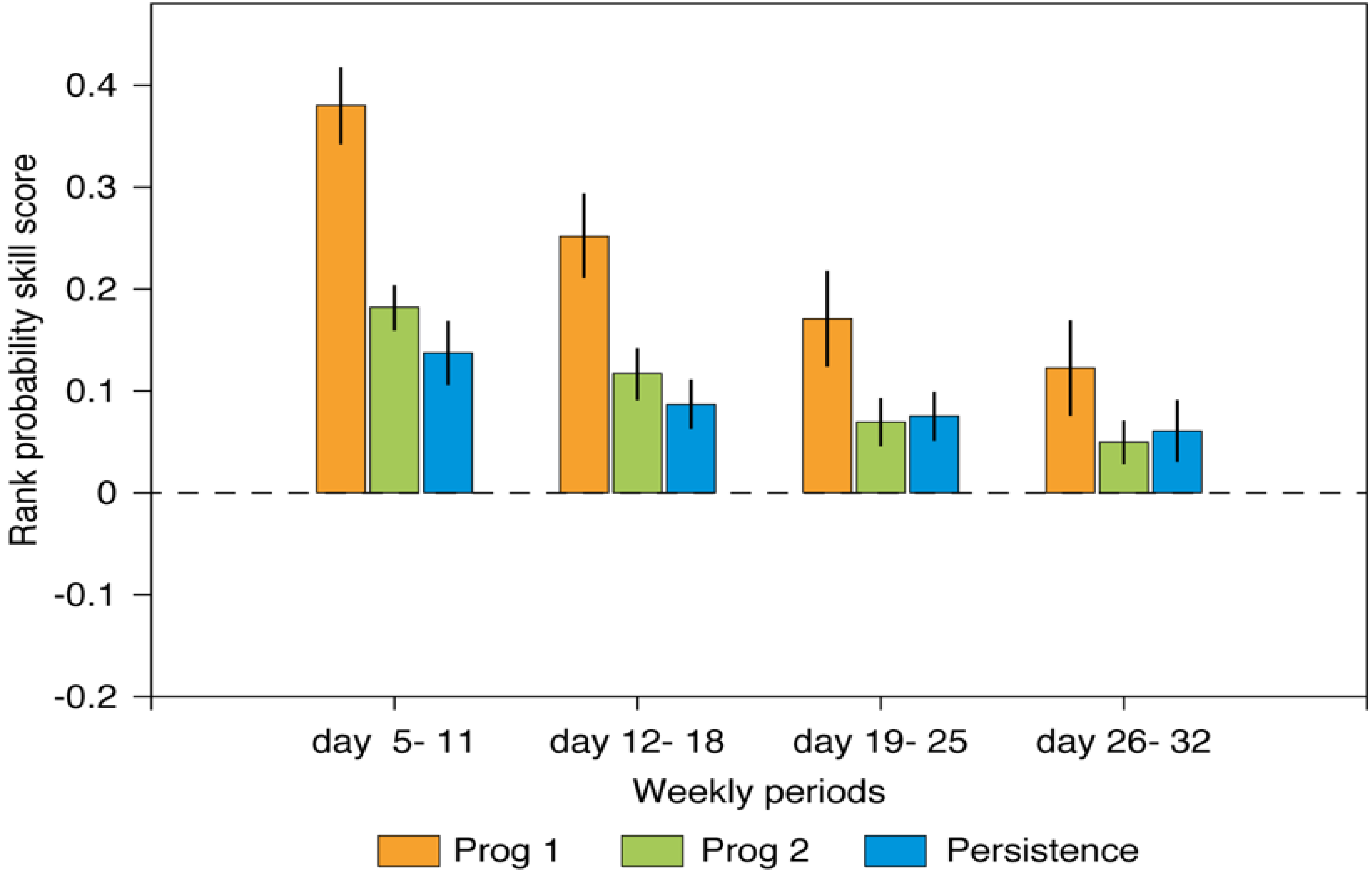


CY31R1: Parameterisation of ice supersaturation
CY32R2: McRAD (radiation scheme)
CY32R3: Changes in convective scheme (Bechtold at al. 2008)
CY40R1: Improved diurnal cycle of precipitation
CY41R1: revised organized convective detrainment and the revised convective momentum transport. …

Wheeler and Hendon (2003) Index

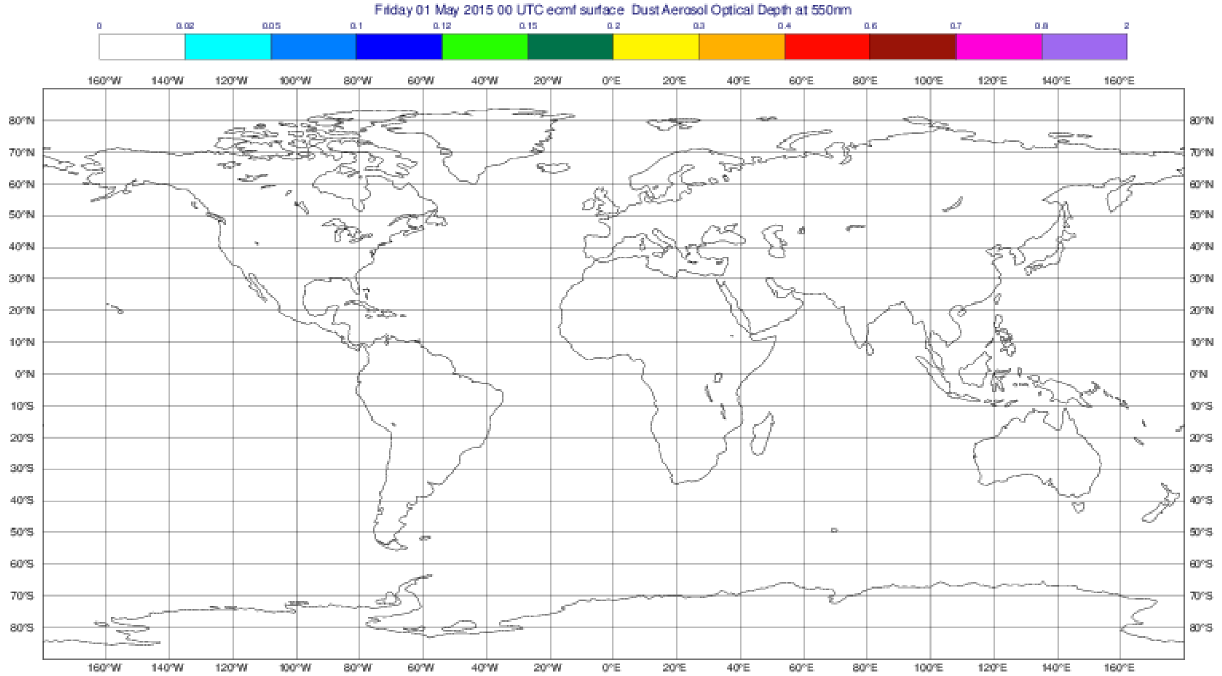
Improvements in MJO Prediction mostly due to changes in convective parameterization

Skill in the monthly prediction of aerosols (RPSS) - Tropics

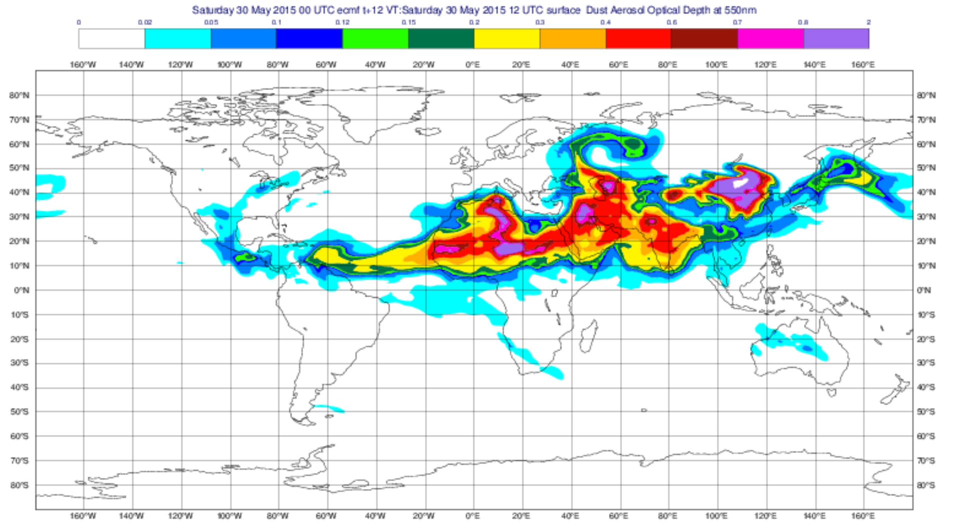


By-product: monthly dust forecast (May 2015)

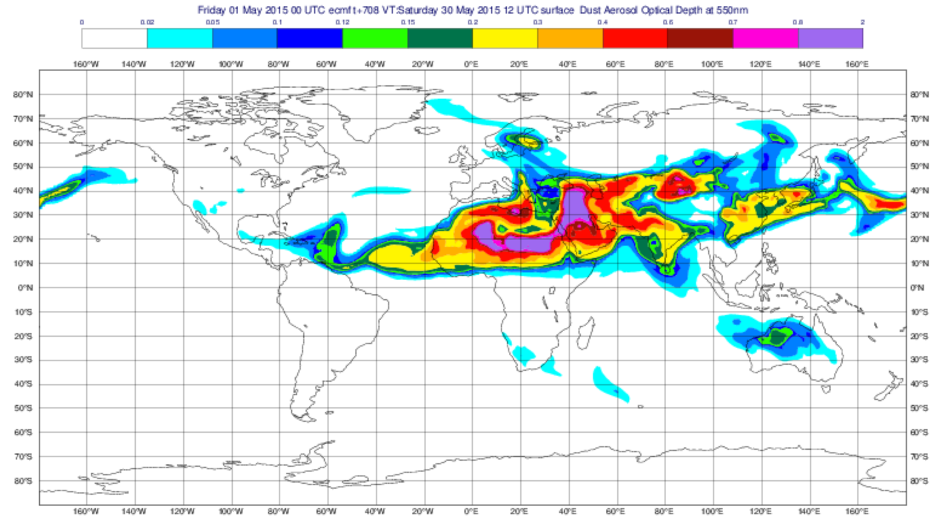
DUST AEROSOL OPTICAL DEPTH @ 550nm



CAMS ANALYSIS – 30 May 2015 @ 1200UTC



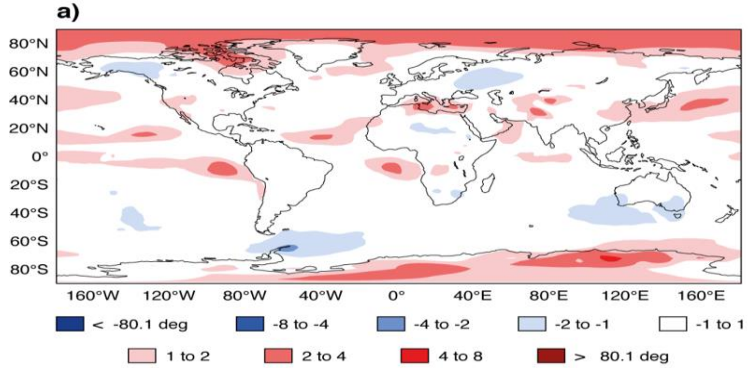
MONTHLY FORECAST valid for 30 May 2015 @ 1200UTC



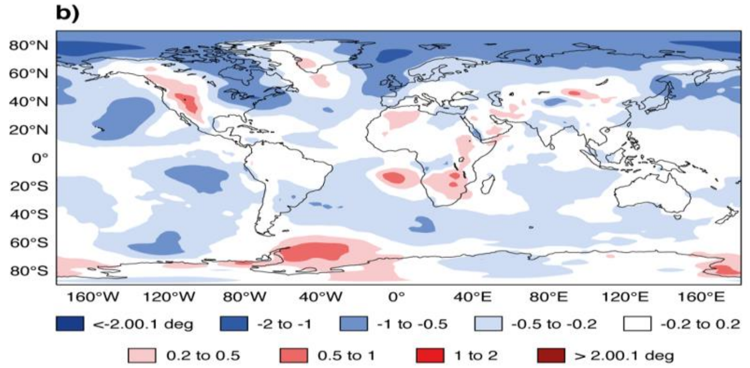
ECMWF

Aerosol impacts on monthly forecast biases – Temperature at 850 hPa

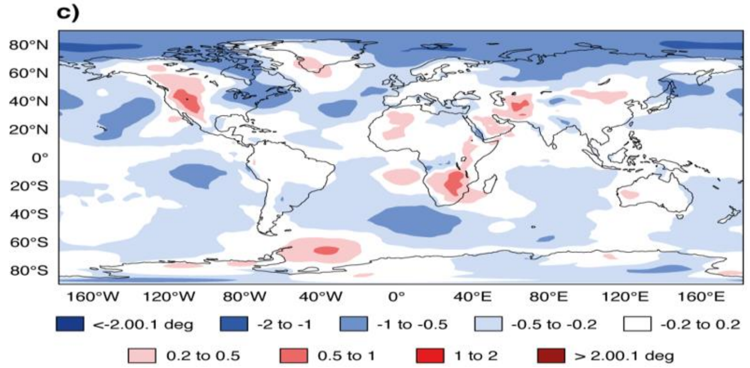
Control1 – ERA Interim



PROG1 – Control1

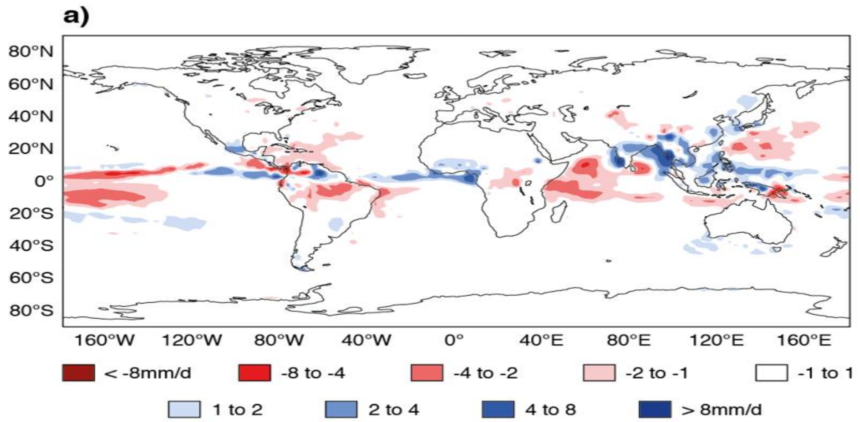


PROG2 – Control1

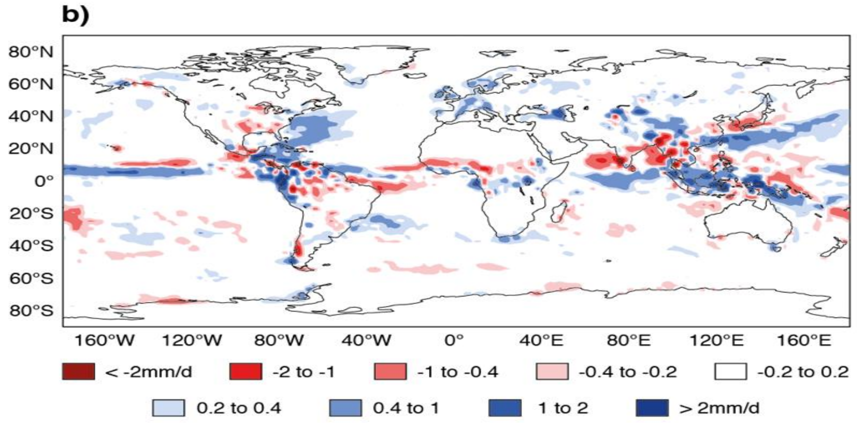


Aerosol impacts on monthly forecast biases – Precipitation

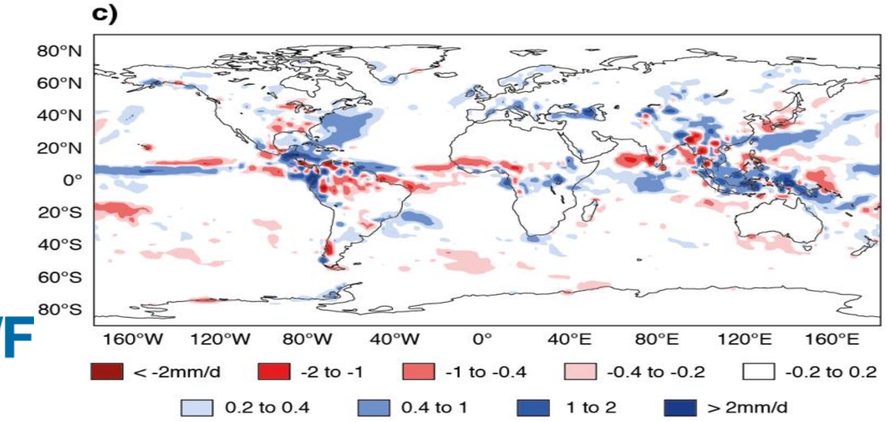
Control1 – ERA Interim



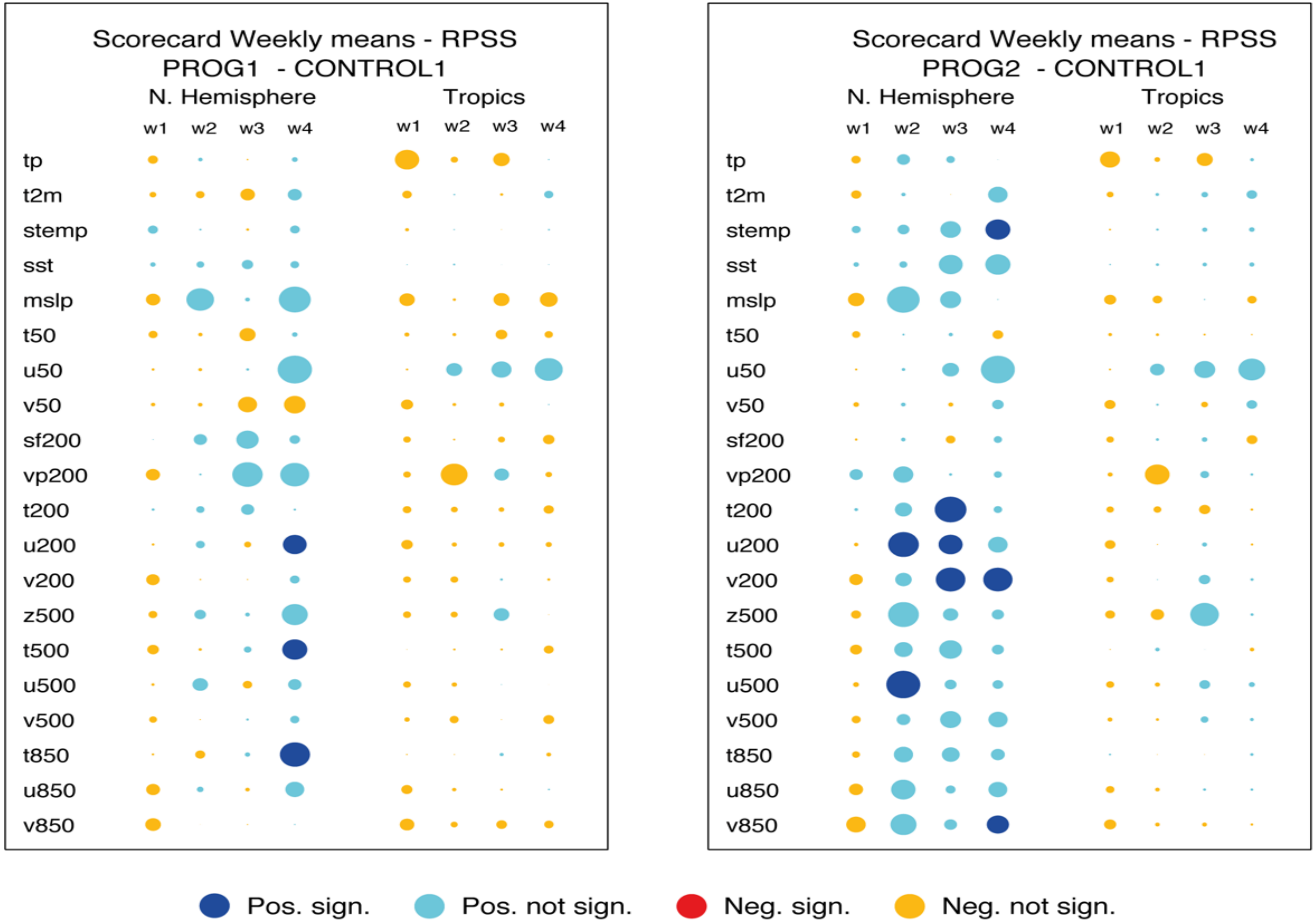
PROG1 – Control1



PROG2 – Control1

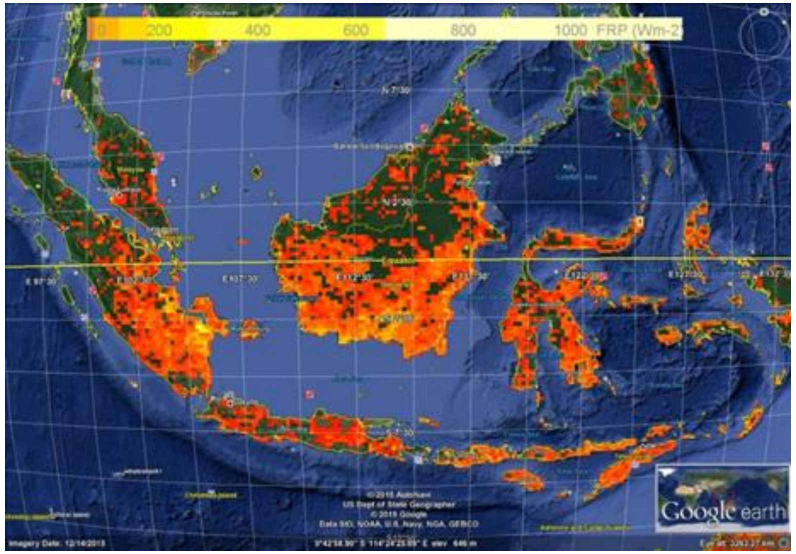


Impact on monthly prediction skill scores



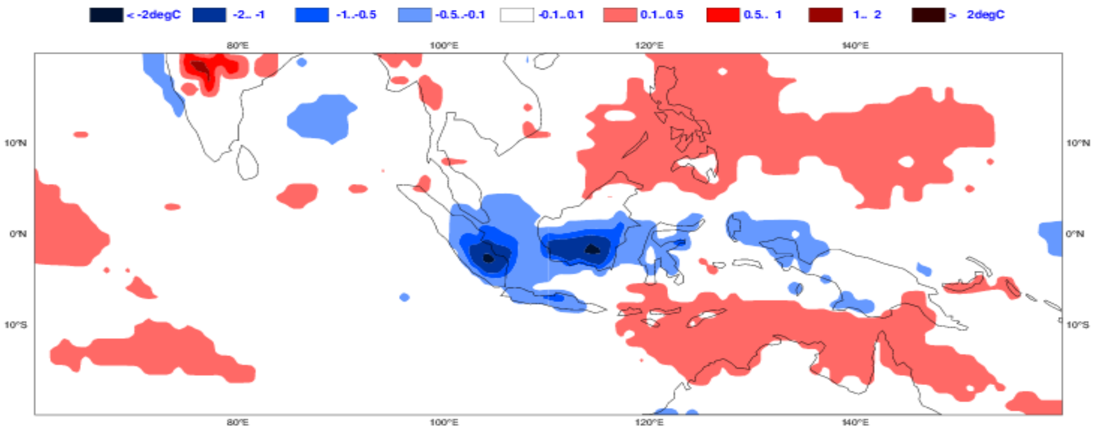
Impact on monthly prediction skill scores

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

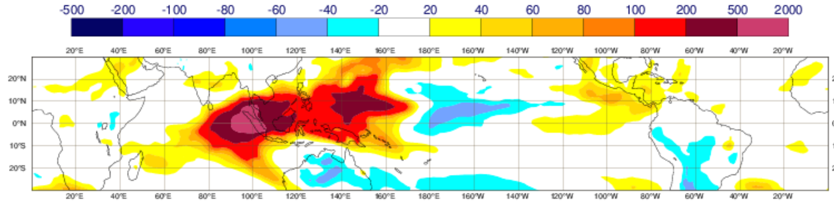


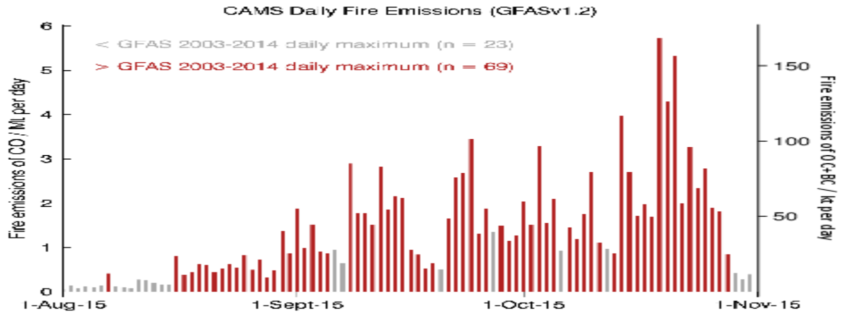
Fire radiative power Aug-Oct 2015

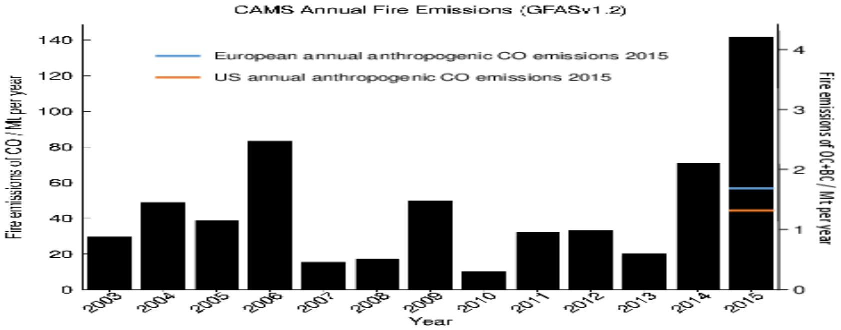
2m-tm anomaly Oct 2015 - Forecast starting 1st May



Biomass burning AOD anomaly: up to 2000%







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

Prediction of fire emissions is needed (under development)

Copernicus
Europe's eyes on Earth

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

- Strong modulation of aerosols by MJO, which is generally well simulated by the ECMWF S2S forecasts.

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

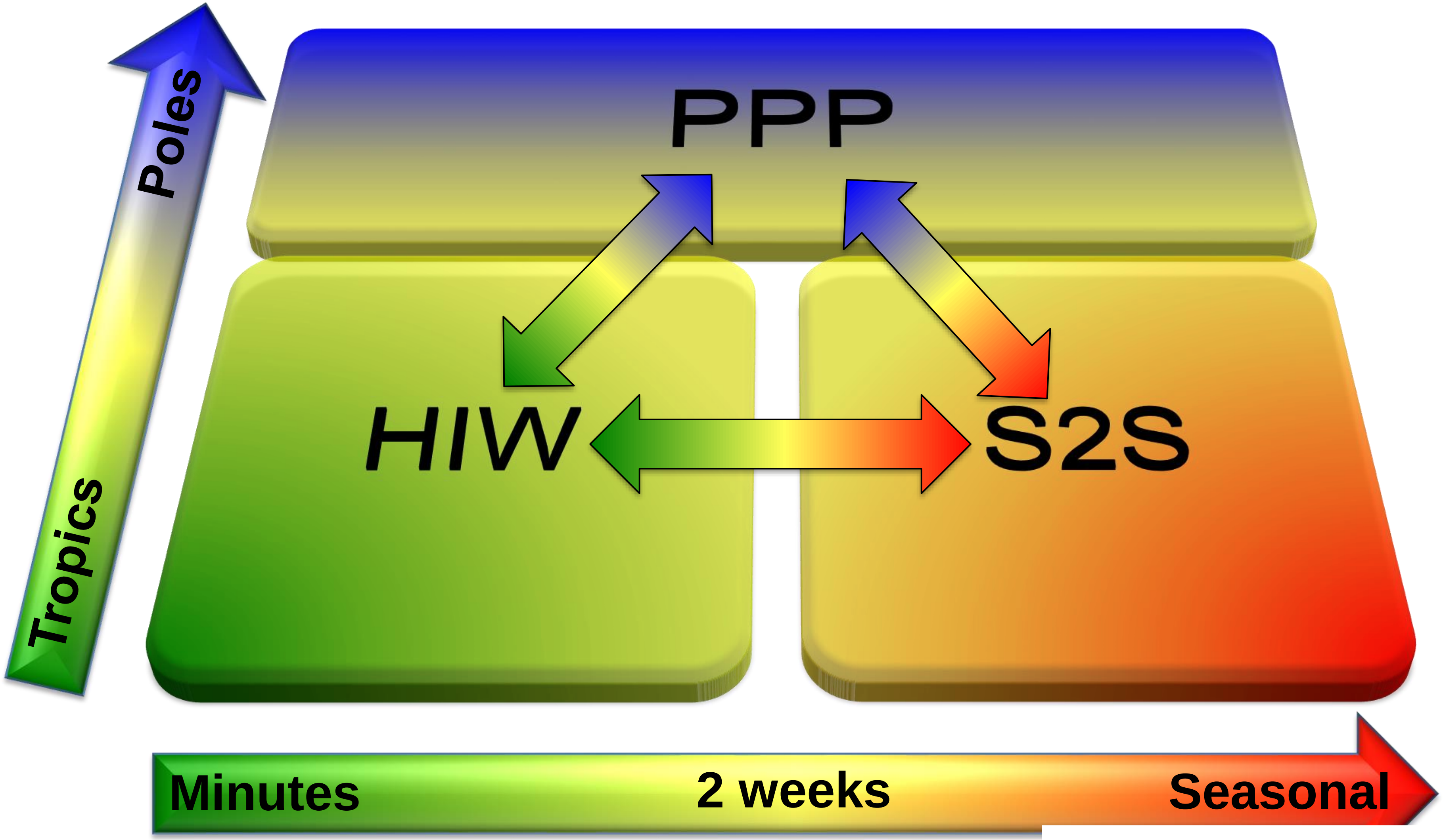
- Results show a strong dependence on the initialization (reanalysis are important!!!!)

- 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

- 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.

WWRP/WCRP S2S project

WMO/WWRP International Legacy Projects



From S. Majumdar

Mission Statement

- To improve forecast skill and understanding on the sub-seasonal to seasonal timescale with special emphasis on high-impact weather events”

- “To promote the initiative’s uptake by operational centres and exploitation by the applications community”

- “To capitalize on the expertise of the weather and climate research communities to address issues of importance to the Global Framework for Climate Services”

ECMWF

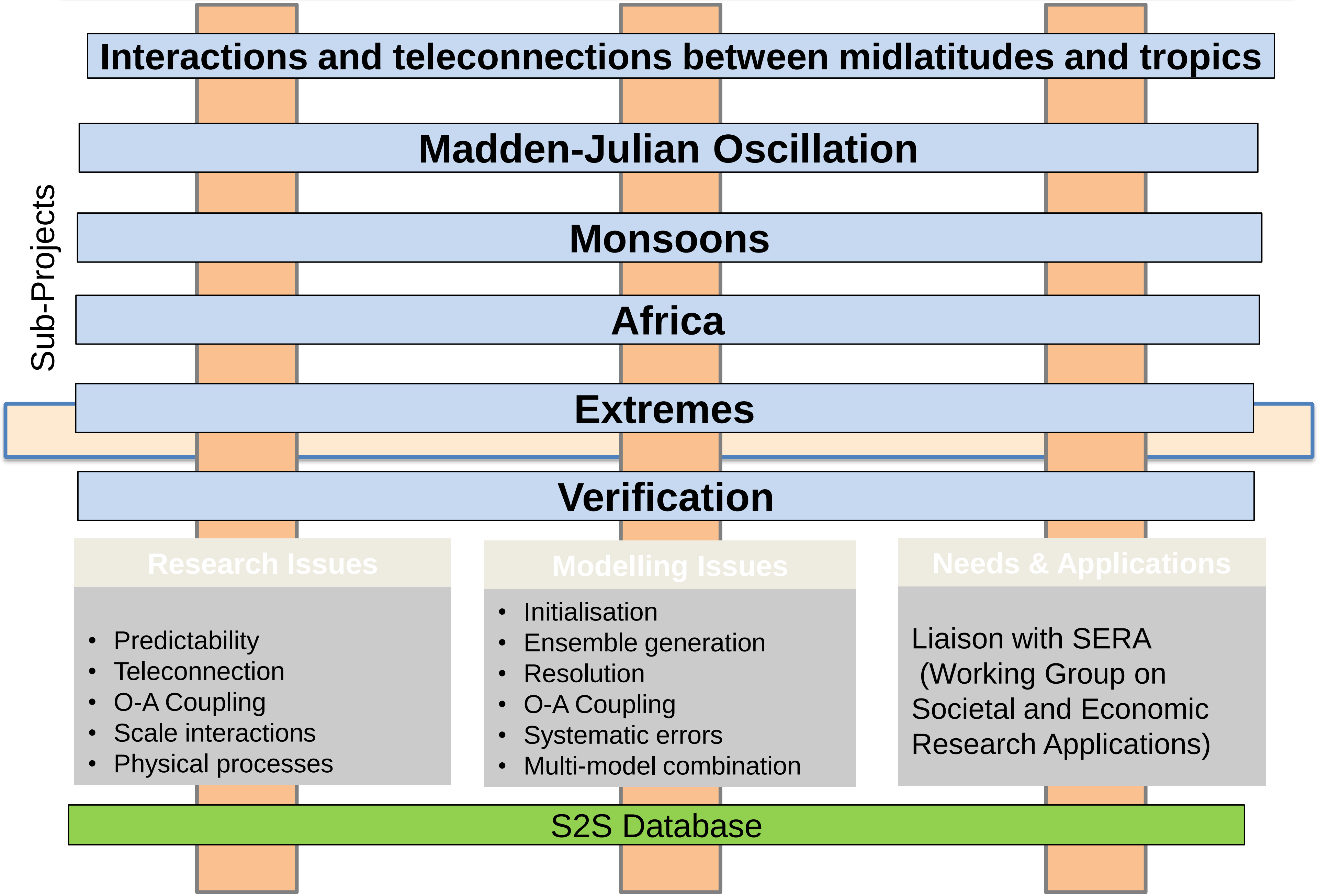
S2S project

- 5-year project, started in Nov 2013 – Possibility of Phase 2 for the period 2019-2023.

- Project office: KMA/NIMR hosts the project office in Jeju island.

- Trust Fund: Contributions from Australia, Canada and

Sub-seasonal to Seasonal (S2S) Prediction Project



S2S database

	Time-range	Resol.	Ens. Size	Freq.	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	D 0-46	Tco639/319L91	51	2/week	On the fly	Past 20y	2/weekly	11
UKMO	D 0-60	N216L85	4	daily	On the fly	1993-2015	4/month	7
NCEP	D 0-44	N126L64	4	4/daily	Fix	1999-2010	4/daily	1
EC	D 0-32	0.6x0.6L40	21	weekly	On the fly	1995-2014	weekly	4
CAWCR	D 0-60	T47L17	33	weekly	Fix	1981-2013	6/month	33
JMA	D 0-33	Tl479/Tl319L100	50	weekly	Fix	1981-2010	3/month	5
KMA	D 0-60	N216L85	4	daily	On the fly	1996-2009	4/month	3
CMA	D 0-45	T106L40	4	daily	Fix	1886-2014	daily	4
CNRM	D 0-32	T255L91	51	Weekly	Fix	1993-2014	2/monthly	15
CNR-ISAC	D 0-31	0.75x0.56 L54	40	weekly	Fix	1981-2010	6/month	1
HMCR	D 0-63	1.1x1.4 L28	20	weekly	Fix	1981-2010	weekly	10

S2S Phase 2 (2019-2023) Proposal

Research activities (sub-projects)

- MJO Prediction and teleconnections
- Ocean and sea ice initialization and configuration
- Land Initialization and configuration
- **Aerosols**
- Ensemble generation

Aerosols Sub-project

Main questions to be addressed:

1. What is the impact of prognostic (vs climatologically specified) aerosol loading in the atmosphere on S2S forecasts via its effects on radiation?

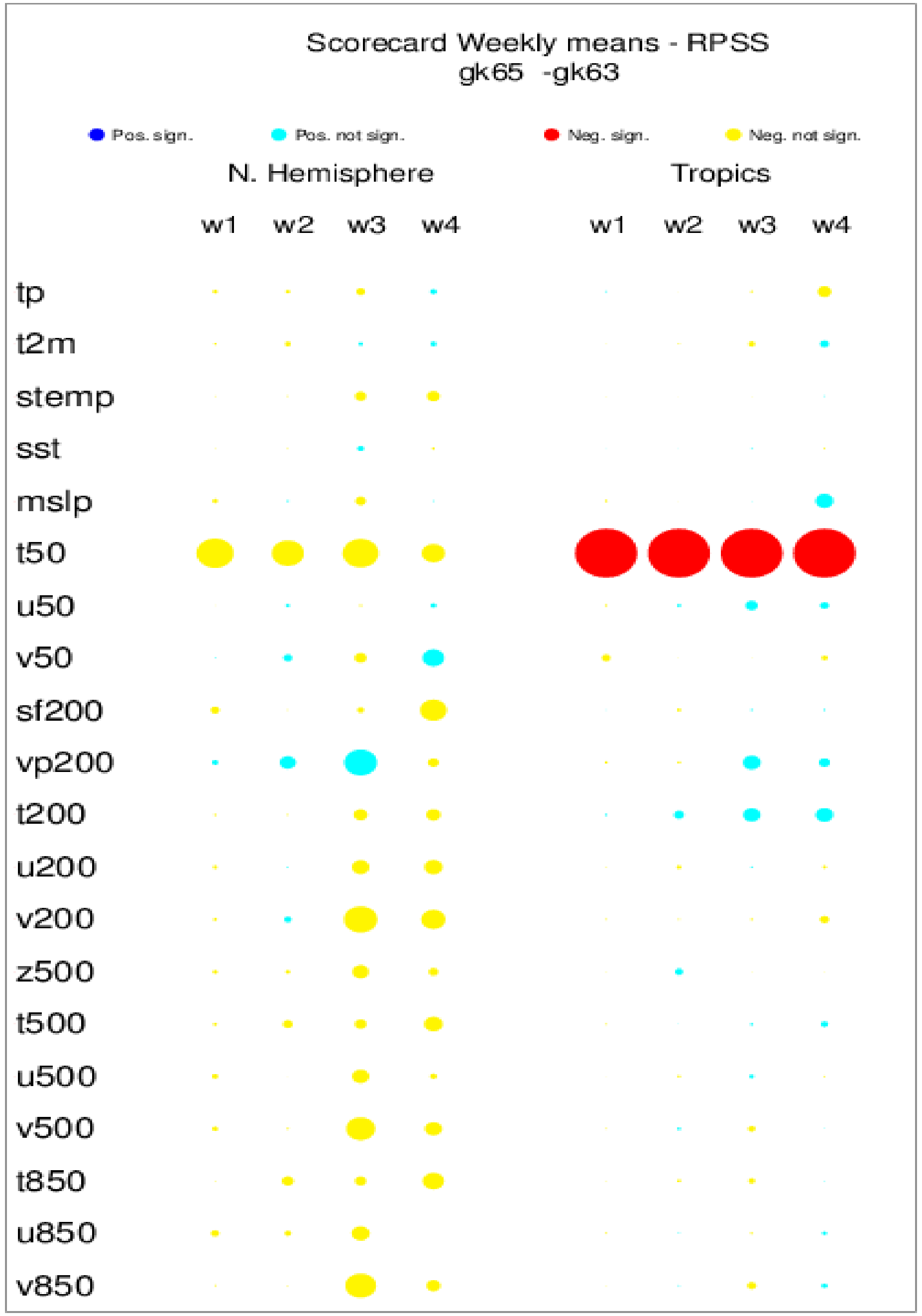
2. What level of complexity is needed?

3. What is the predictability of aerosols (e.g. dust) at the S2S time-scale, and what would be the value of these forecasts

Numerical experiments could be coordinated in association with WGNE. Case studies or large set of re-forecasts? Issue: few centres have the capability of producing sub-seasonal forecasts with active aerosols.

Ozone

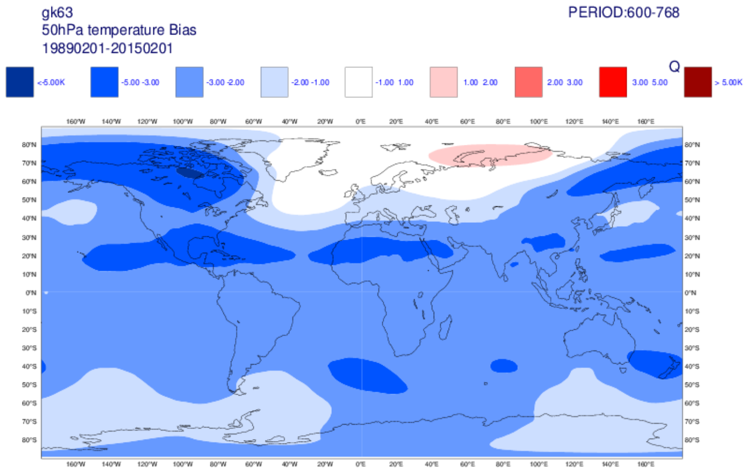
Impact of interactive ozone vs inactive ozone



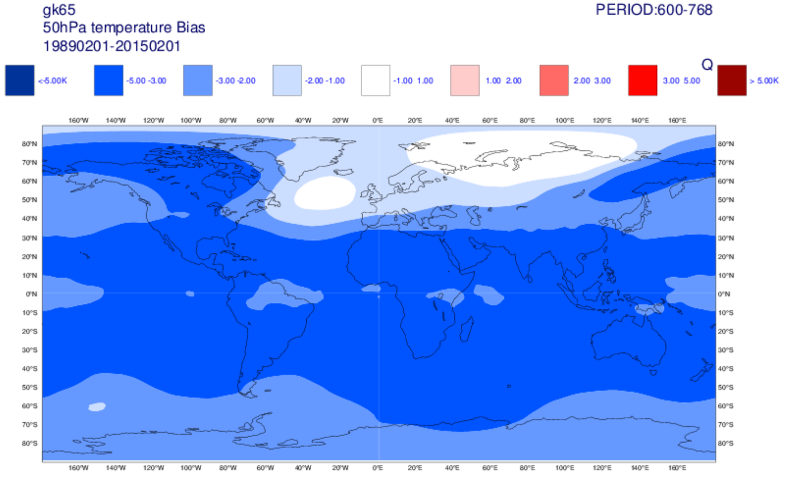
Impact on T50 Biases – W4

February start dates

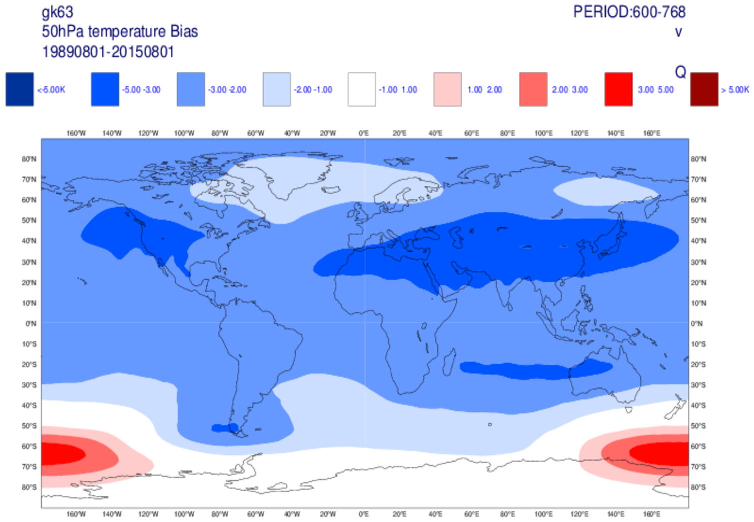
Control

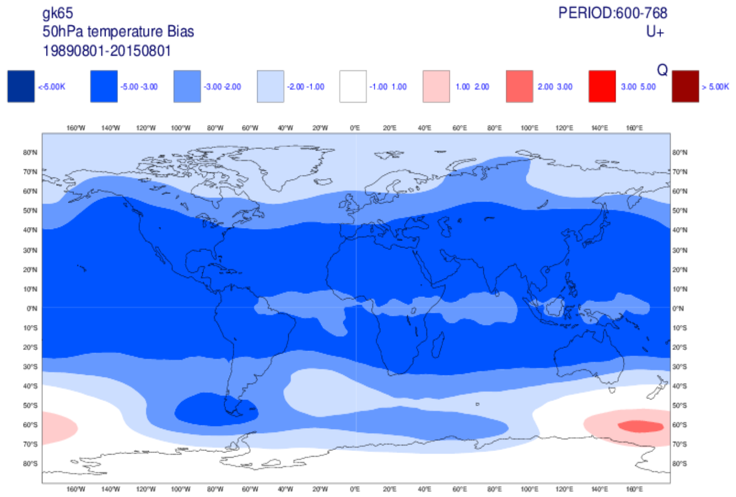


Interactive ozone

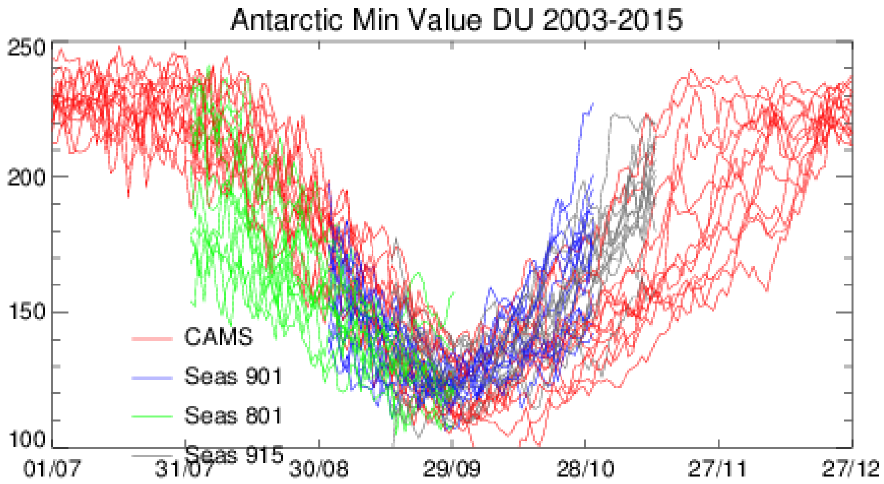


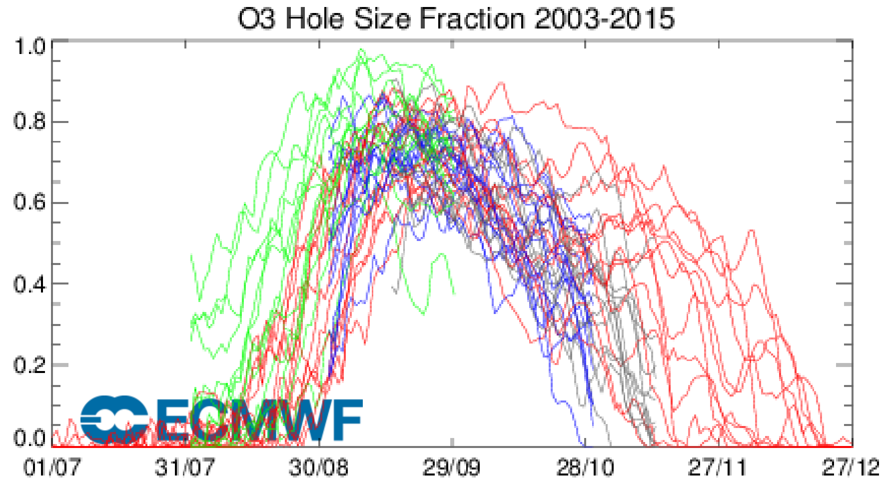
August start dates





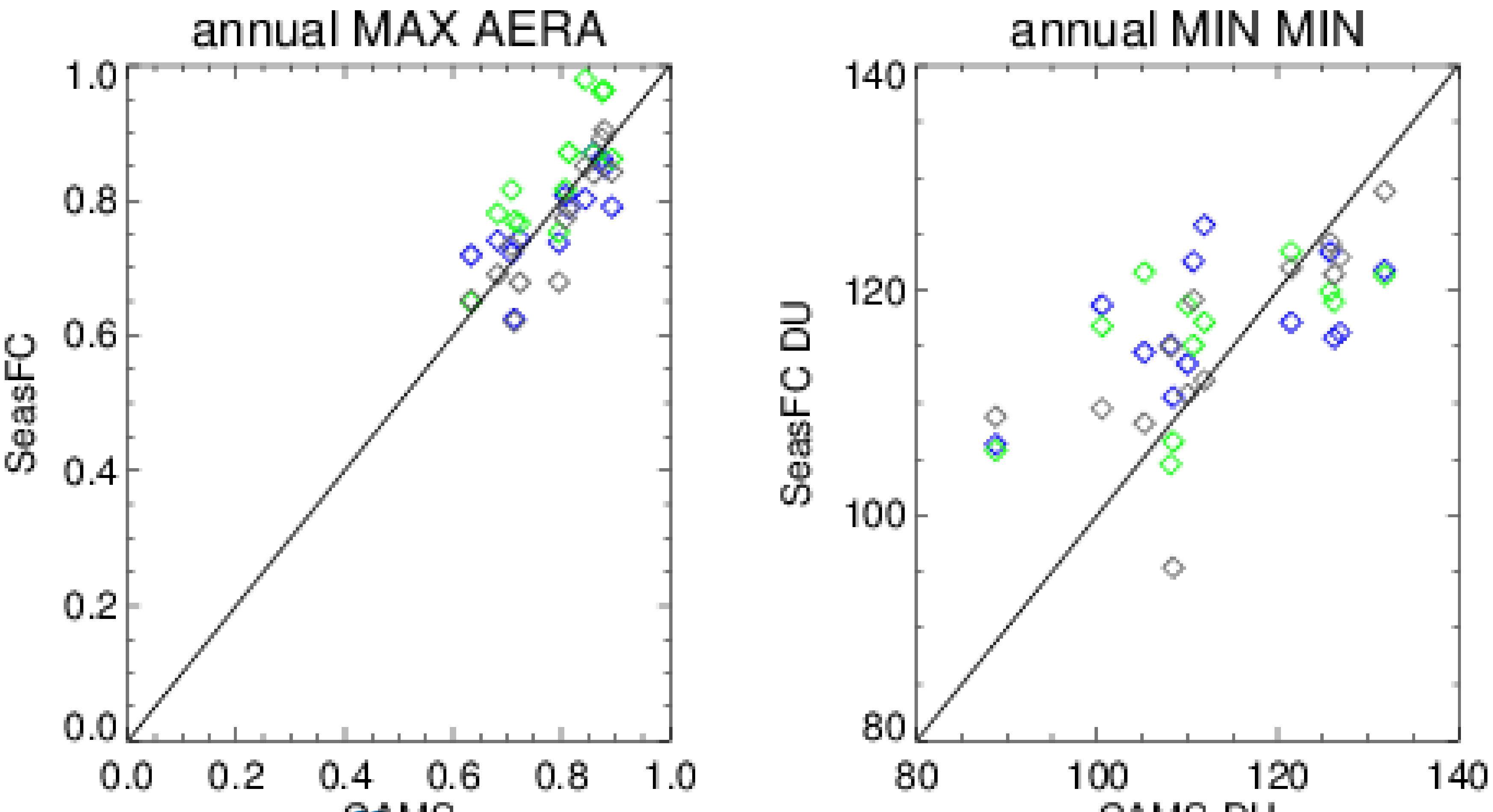
Ozone Hole (J. Flemming diagostics)





The simulated ozone hole starts too early and does not last long enough.

Scatter plots of the annual maximum area and minimum depth.



Some skill in predicting the year-to-year variability of the ozone-hole size and depth

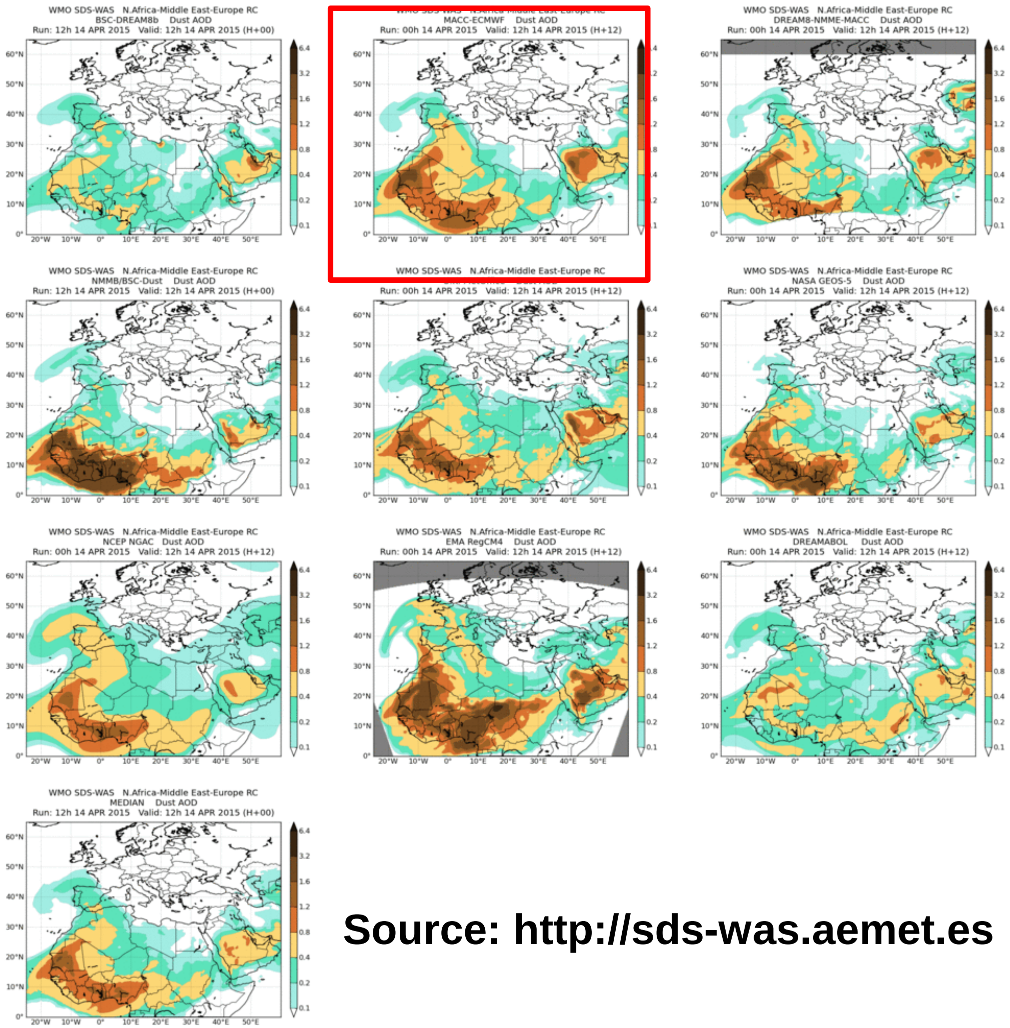
CAMS aerosol forecasts

- 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