The impact of aerosols on sub-seasonal prediction: a study using the ECMWF's coupled Ensemble Prediction System

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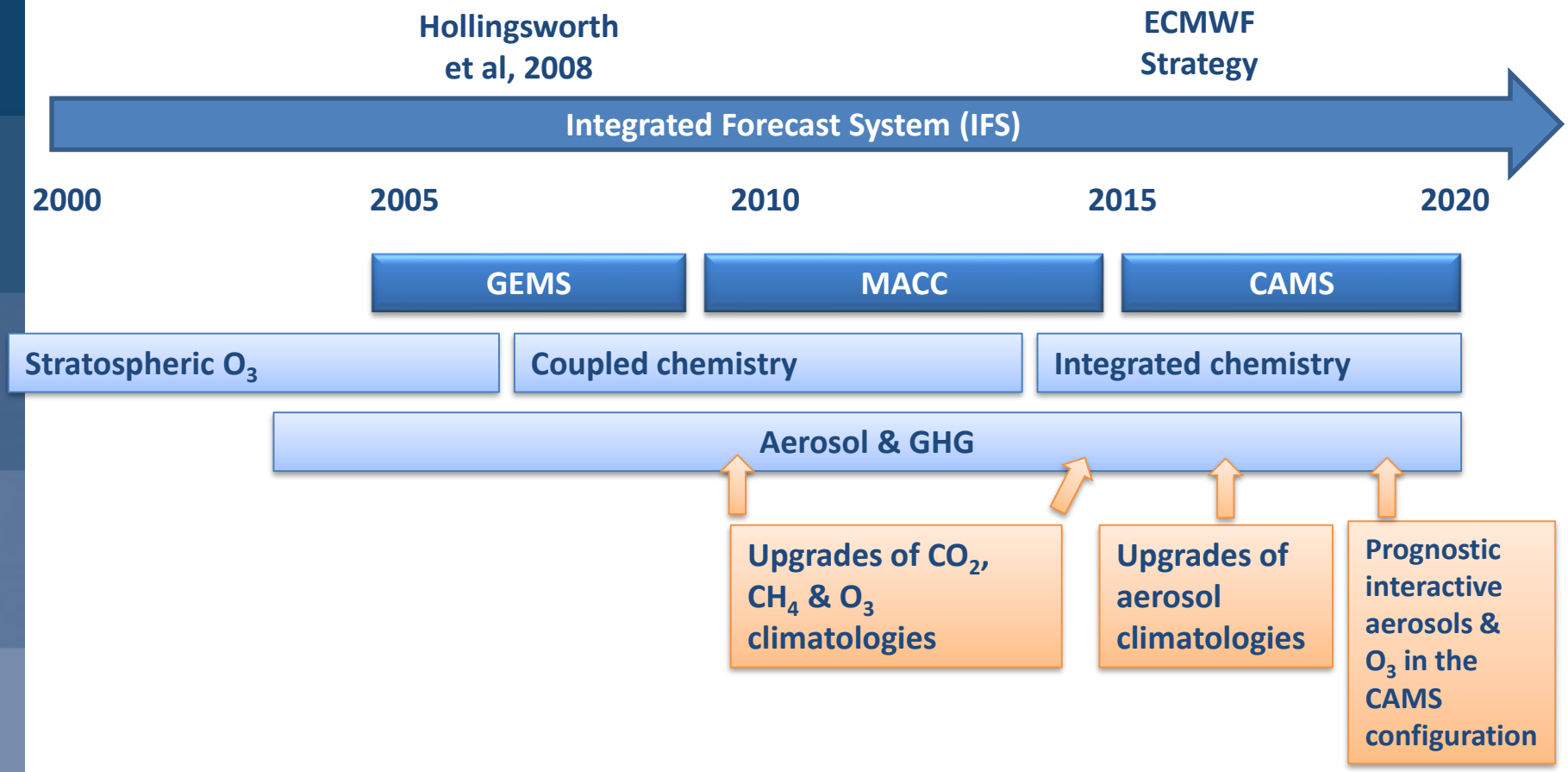
Motivation

- In recent years the impact of aerosols in numerical weather prediction has received more attention at operational centres
- Thanks to developments funded by the European Commission, ECMWF has been in a unique position to test the impact of aerosols in its complex **Earth-System model**
- Recent efforts have been aimed at investigating the aerosol impacts in the coupled Ensemble Prediction System (EPS) at the sub-seasonal (S2S) time scales.
- Results show a substantial impact of the aerosols at week 3-4, **due to the interaction of the Madden-Julian oscillation with the aerosol fields**
- There is also potential to predict large aerosol events associated to wild-fires with strong seasonality – this could be the next frontier in the field, provided that a dynamical fire emission model is developed

Development of atmospheric composition in the ECMWF's Integrated Forecast System



GEMS = Global and regional Earth-system (atmosphere) Monitoring using Satellite and in-situ data
MACC = Monitoring Atmospheric Composition and Climate
CAMS = Copernicus Atmosphere Monitoring System

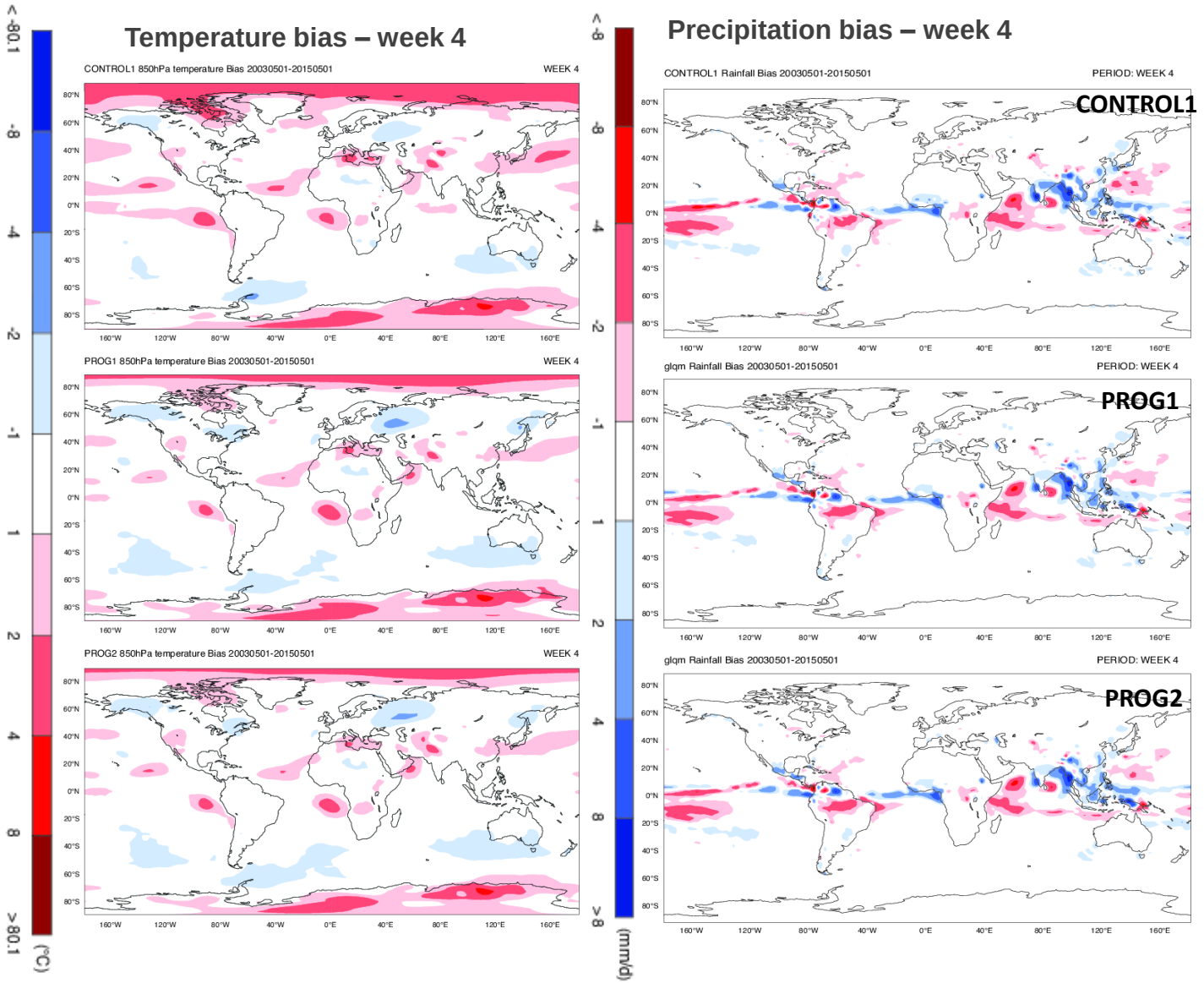
Experiment set-up

- Period 2003-2015
- Interactive aerosol simulations use fully prognostic aerosols in the radiation scheme – **only aerosol direct effects are included**
- Free-running aerosols with observed emissions for biomass burning
- Ensemble size is 11 members, T255 (about 60km) resolution, 91 levels
- 5 different start dates around May 1, 55 cases in total
- 6 months simulations

CONTROL1	Tegen et al (1997) climatology in the radiation
CONTROL2	Bozzo et al (2017) climatology in the radiation
PROG1	Interactive aerosols initialized from the CAMS Interim Reanalysis (Flemming et al 2017)
PROG2	Interactive aerosols initialized from a free-running aerosol simulation

Aerosol impacts on the monthly forecasts: bias

- Areas impacted: **Mediterranean basin, the Asian dust belt in the Northern Pacific Ocean and the North Atlantic dust belt**.
- In some areas the temperature bias is reduced between **-0.5 and 2.0 degrees**
- Precipitation biases are also reduced over several **tropical regions**
- Precipitation bias reduction in East Asia amounts **to 0.5-1 mm/day.**



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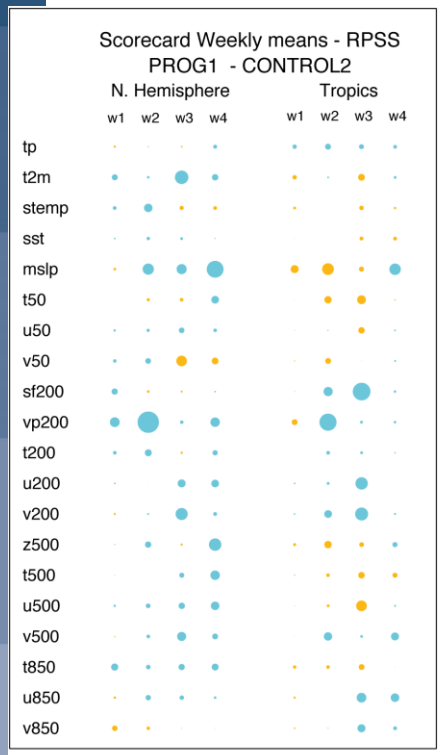
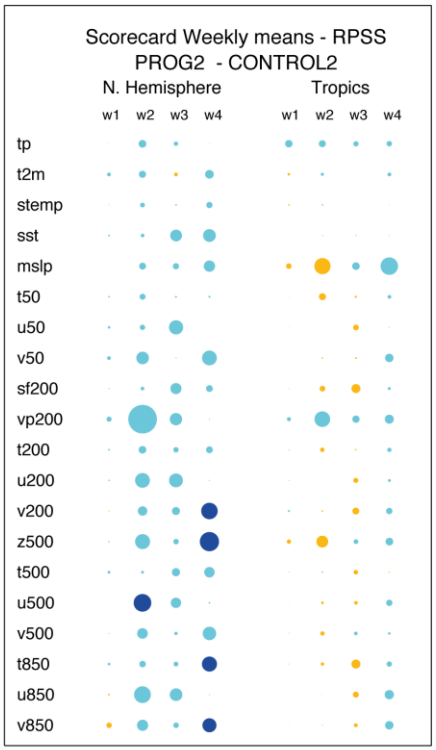
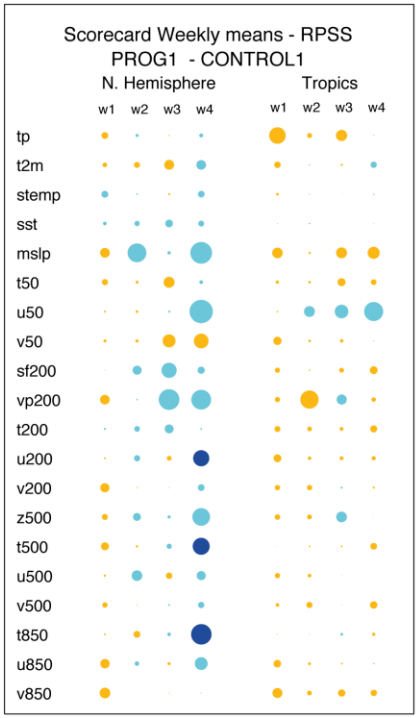
Aerosol impacts on the monthly forecasts: Rank probability skill scores

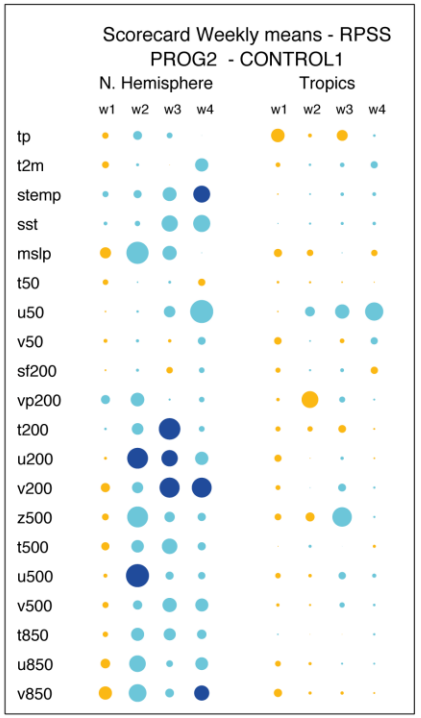
- Scorecard measures the performance of interactive aerosol experiment with respect to a control run **for several meteorological parameters.**

- Overall the experiments with prognostic aerosols **perform better** if compared with the CONTROL1 and CONTROL2









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Better

Pos. sign. Pos. not sign. Neg. sign. Neg. not sign.

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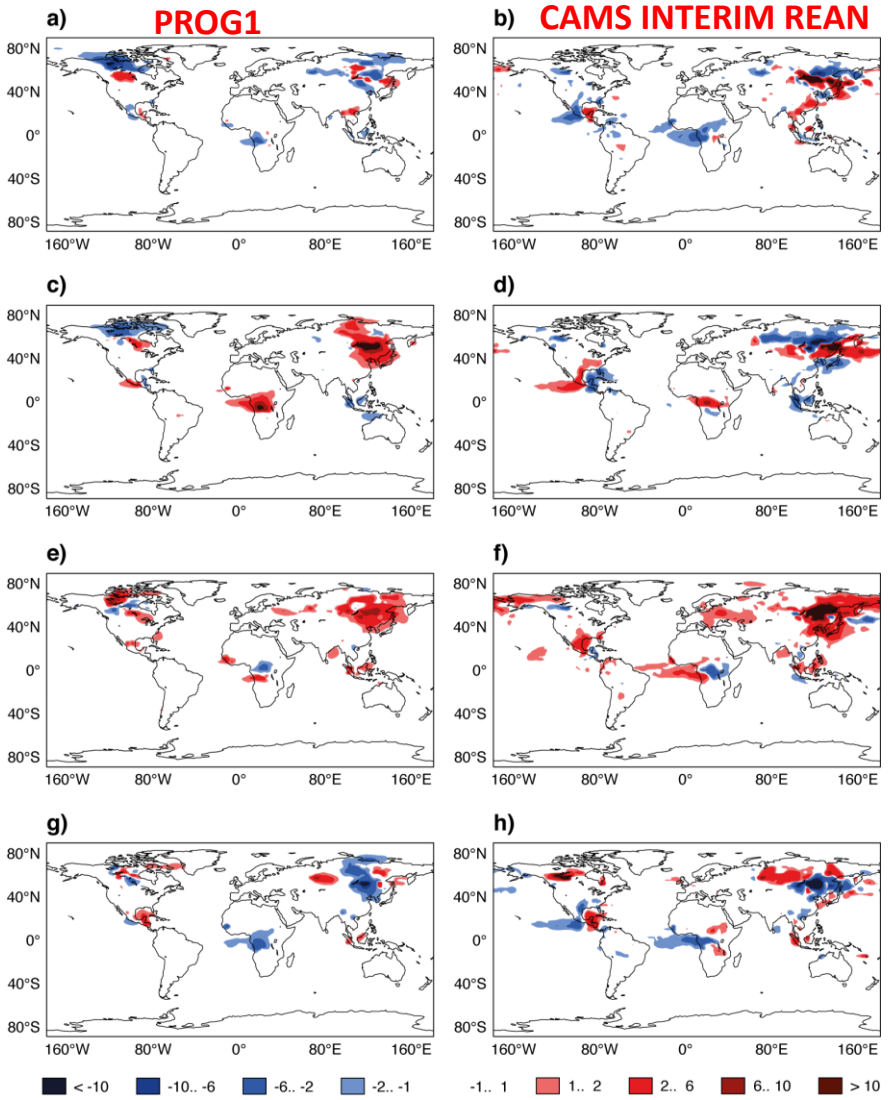
Aerosol modulation by the MJO

- **Composites of carbonaceous optical depth anomalies**, relative to the model climatology, have been **produced in the different phases of the MJO**
- Close similarity of patterns in the PROG1 experiment and in the CAMS Interim Reanalysis
- **Opposite phases of the MJO** (for instance phase 2-3 and phase 6-7) **have opposite impacts on the aerosol variability** suggesting that the **MJO modulation is a robust signal.**

Anomaly of carbonaceous aerosol optical depth



Phase 2-3

Phase 4-5

Phase 6-7

Phase 8-1

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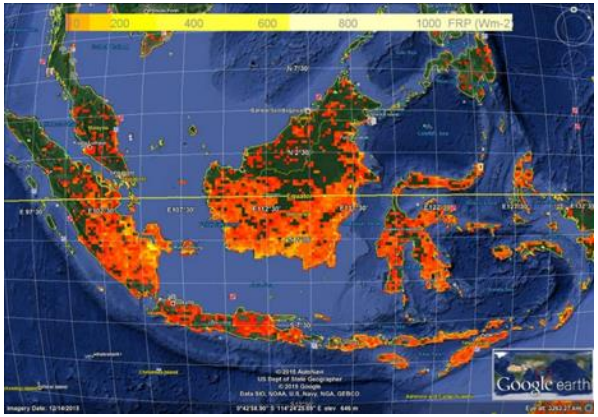
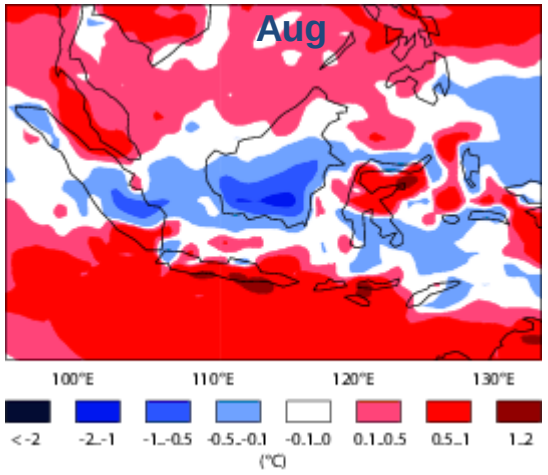
Indonesian Fires of 2015

Fire radiative power Aug-Oct 2015



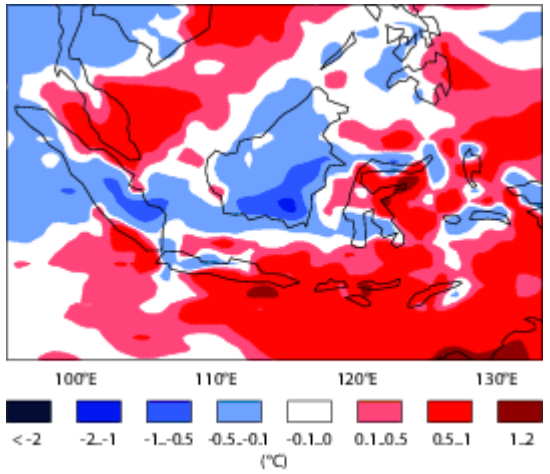
2m Temp anomaly Oct 2015 - Forecast started 1st



Cooling due to smoke aerosols predicted 3 months ahead

- The EPS system re-forecasts with interactive aerosols was able to simulate the temperature anomalies corresponding to the fire-affected area up to **6 months ahead**
- Prescribed **observed fire emissions** derived from Fire Radiative Power were used
- **Inherent high predictability** of these events connected to El-Nino (and agricultural practices in the area)
- If a **dynamical fire emission model** were developed, it would be possible to predict these extreme episodes a season in advance

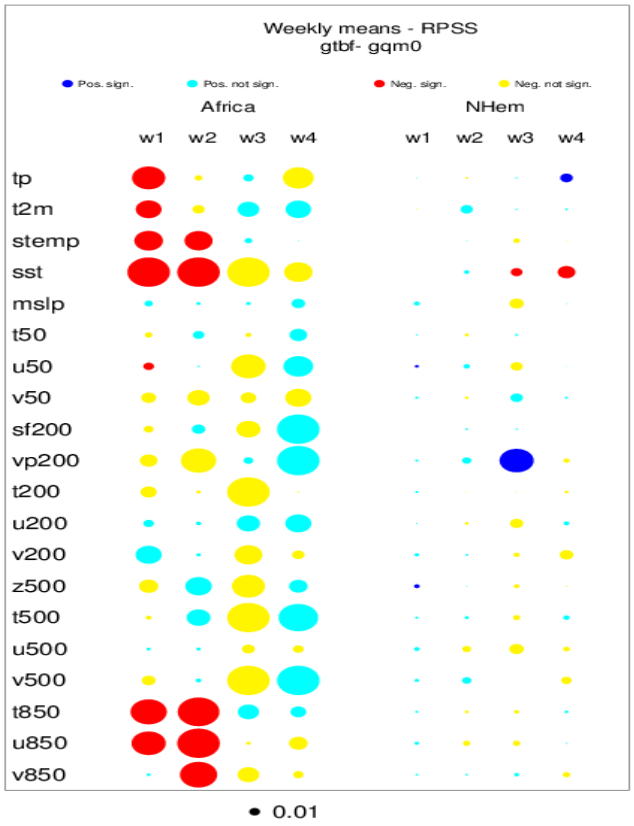
2m Temp anomaly Oct 2015 - Forecast started 1st



Cooling due to smoke aerosols predicted 6 months ahead

Sensitivity to biomass burning aerosols

- A further experiment with the coupled EPS system was designed **to understand the role of (interactive prognostic) biomass burning**
- Same set-up as previous runs using interactive prognostic aerosols with start date of May 1
- Control run with Tegen at al (1997) climatology
- **All emissions from wildfires were set to zero**



Scores for West Africa (15N 0S 10W 10E)

- **Some key variables** such as SST, surface temperature, total precipitation and lower-level winds are **significantly degraded** when biomass burning aerosols are not included in the system
- The global impact is less severe due to the spatial distribution of the biomass burning

Positive significant

Negative Non significant

Positive Non significant

Negative significant

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Summary and perspectives

- Using prognostic aerosols interactively in the radiation results in **increased model skill at the sub-seasonal range** for various meteorological parameter, the extent of the improvement being dependent on the aerosol model initialization.

- **MJO modulation of aerosol fields** seems the most likely mechanism through which this aerosol impact is delivered as it explains most of the aerosol variance at the monthly scale.

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

- Sensitivity to biomass burning aerosols is **regionally very large**

Acknowledgements: this research was partly funded under the DACCIWA project, funded from the European Union 7th Framework Programme (FP7/2007-2013) under Grant Agreement no. 603502