The role of aerosols in the predictability at the S2S scale

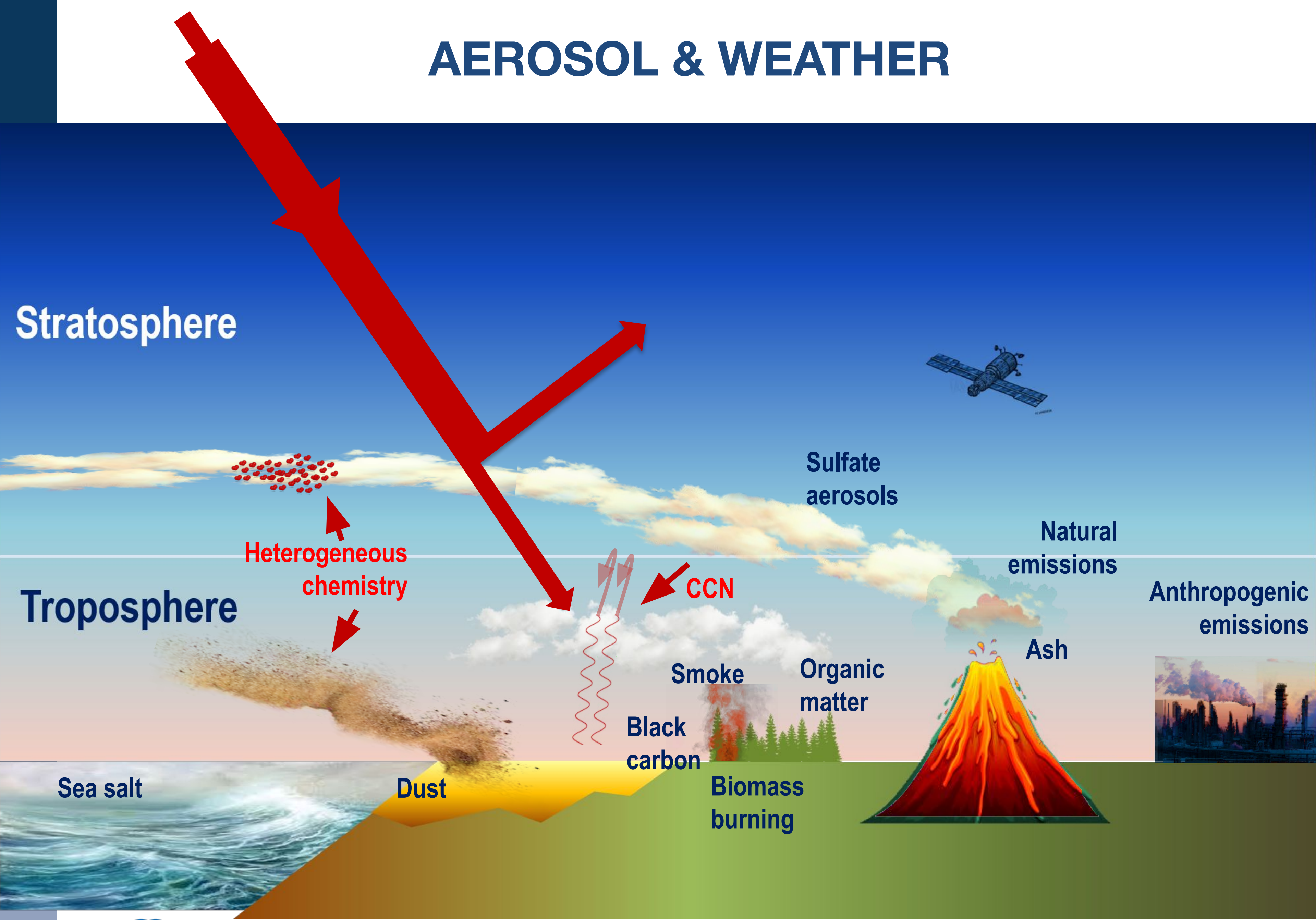
Angela Benedetti and Frédéric Vitart (ECMWF)

with many thanks to: the Copernicus Atmosphere Monitoring Service team and several other colleagues at ECMWF

OUTLINE

- General background
- How aerosols impact NWP
- Examples from the ECMWF's experience with focus on the Subseasona-to-Seasonal (S2S) scales
- Open questions

AEROSOL & WEATHER



Credits: Rossana Dragani

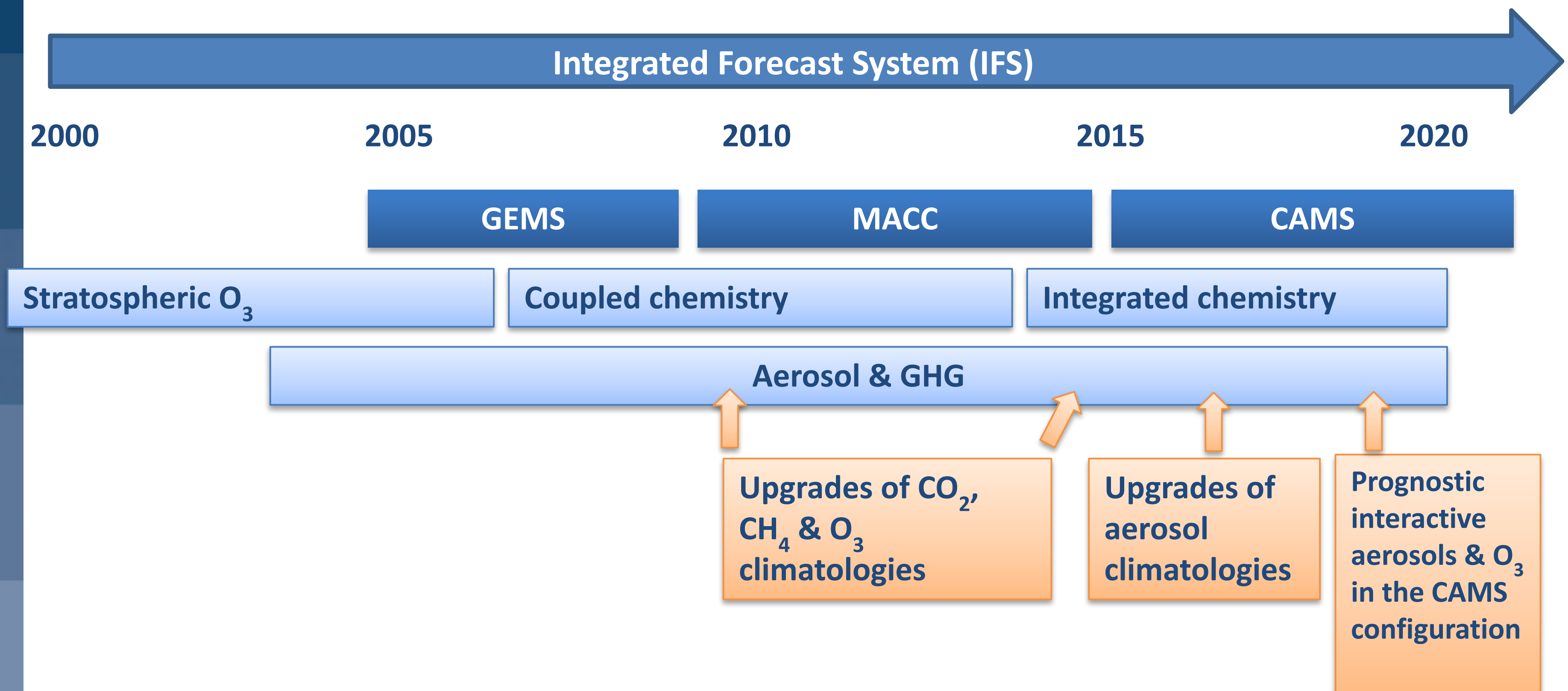
Aerosols affect NWP in several ways and across various scales

Impact on NWP	Mechanism
Dynamics , thermodynamics	Radiative interaction
Precipitation and clouds	Cloud Condensation Nuclei and radiative effects
Winds	4D-Var tracer mechanism
Radiance assimilation (Temp,WV)	Observation operator for radiative transfer

Adapted from: Rossana Dragani

THE ECMWF EXPERIENCE: GENERAL BACKGROUND

Development of atmospheric composition in the Integrated Forecast System



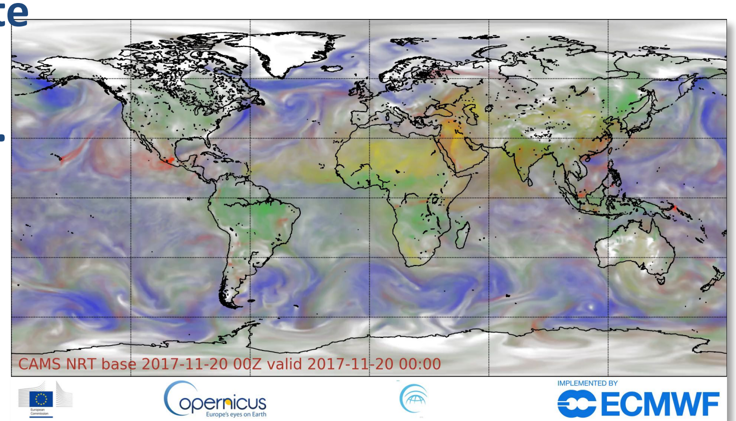
GEMS = Global and regional Earth-system (atmosphere) Monitoring using Satellite and in-situ data
MACC = Monitoring Atmospheric Composition and Climate
CAMS = Copernicus Atmosphere Monitoring Service

Credits: Richard Engelen

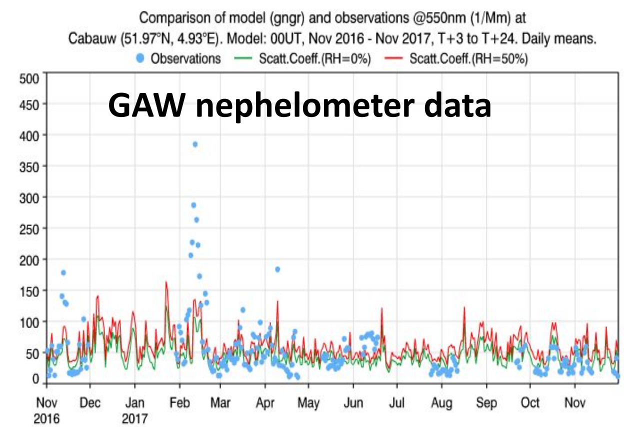
Copernicus Atmosphere Monitoring Service

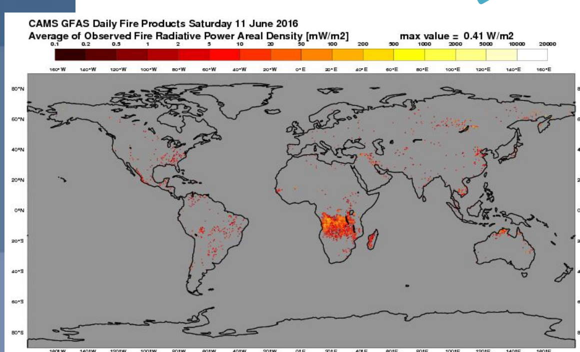
https://atmosphere.copernicus.eu/

Transforming satellite observations into user-driven services.

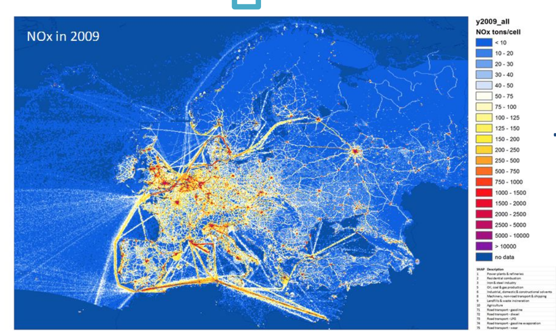


Using ground-based observations to verify the model prediction





Fire emissions



Anthropogenic emissions

The CAMS/ECMWF model is based on:

- ECMWF 4D-var and meteorology
- Integrated chemistry and aerosol representation
- Integrated natural biosphere model

Richard Engelen, Vincent-Henri Peuch, ECMWF

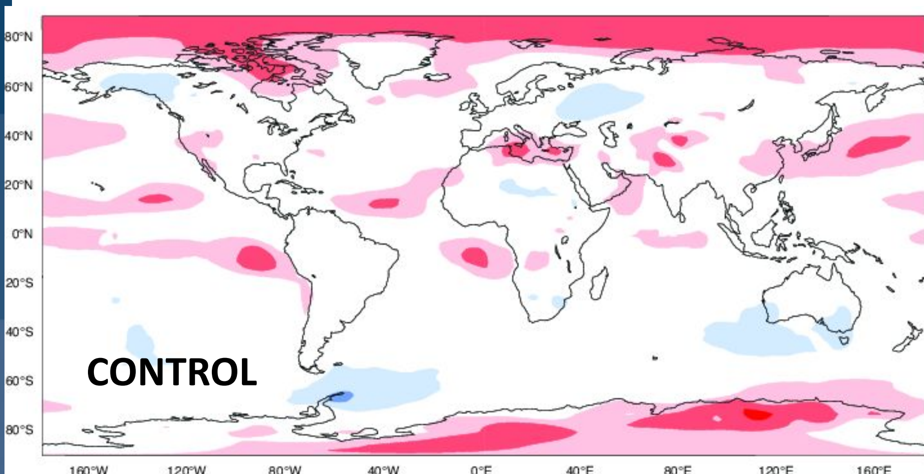
THE ECMWF EXPERIENCE: AEROSOL IMPACTS AT THE S2S SCALES

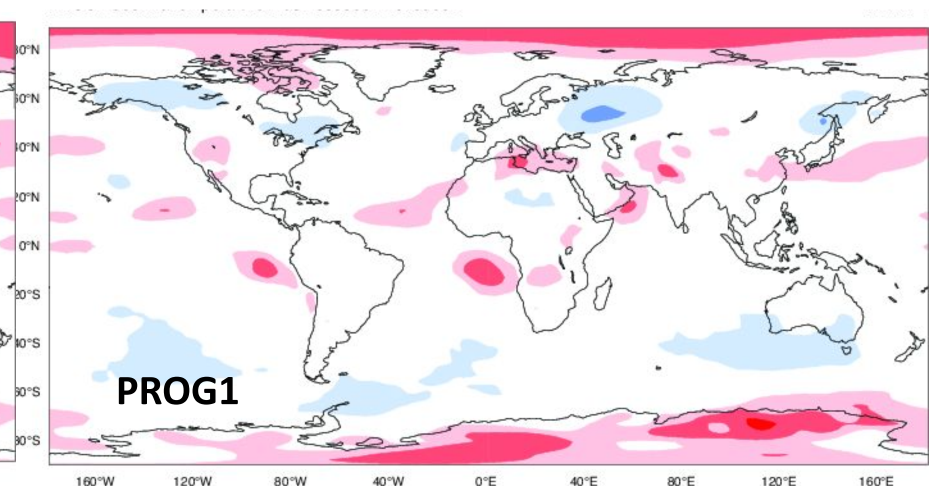
Aerosol impacts at the S2S scales

- 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
- Period 2003-2015
- Results summarized in **Benedetti and Vitart, MWR, 2018**

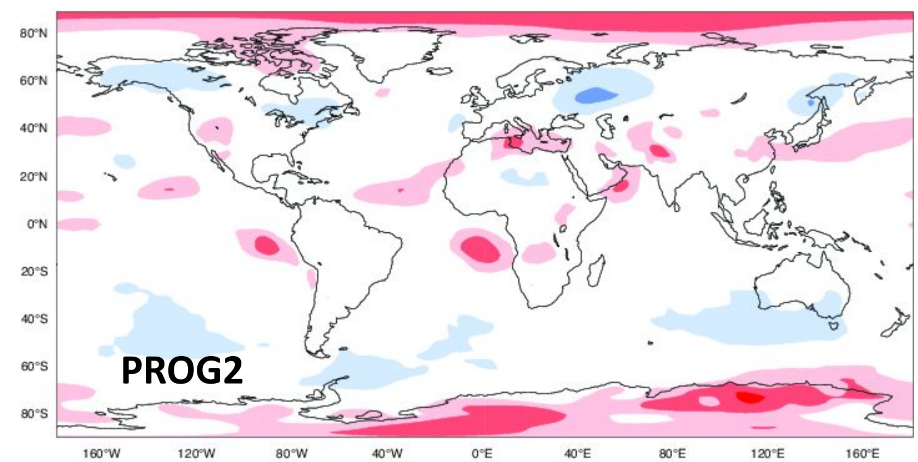
CONTROL1	Tegen et al (1997) climatology in the radiation
CONTROL2	Bozzo et al (2017) climatology in the radiation
PROG1	Interactive aerosols initialized from the CAMS Interim Reanalysis (Flemming et al 2017)
PROG2	Interactive aerosols initialized from a free-running aerosol simulation

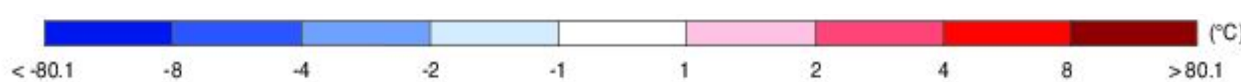
Aerosol impacts on the monthly forecasts: temperature bias week 4



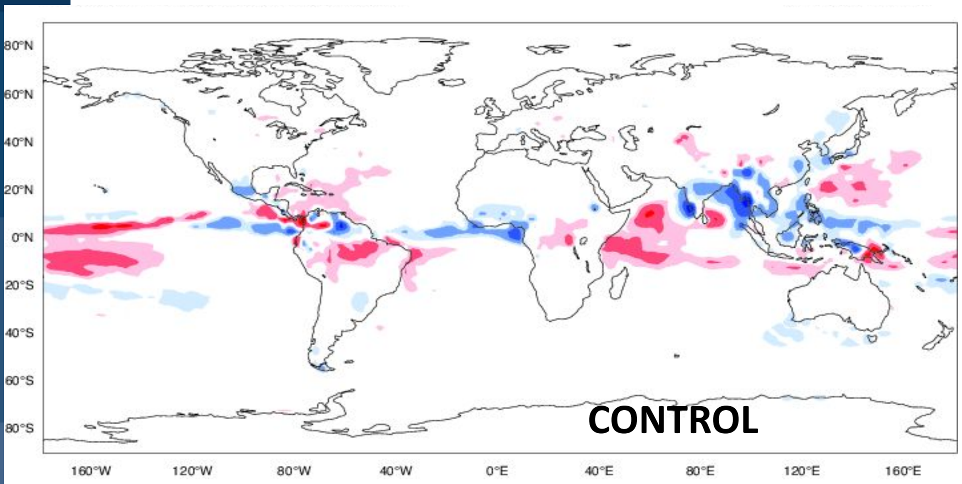


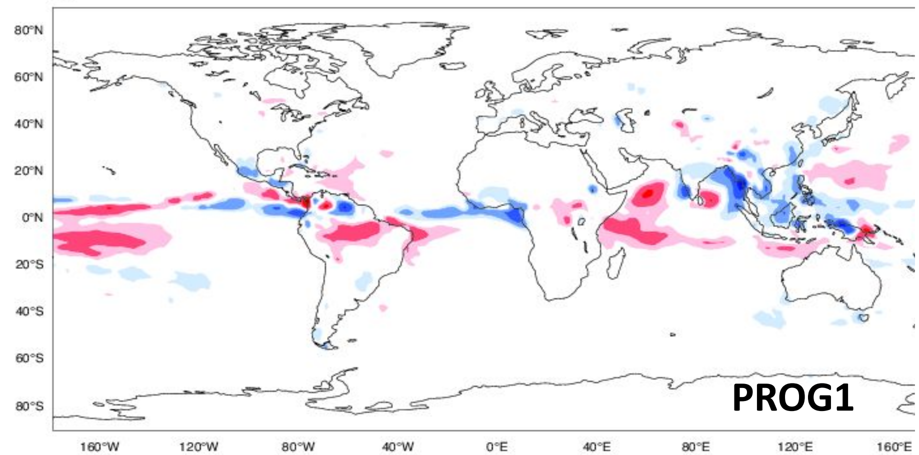
- Areas impacted: **Mediterranean basin, the Asian dust belt in the Northern Pacific Ocean and the North Atlantic dust belt**.
- In some areas the temperature bias is reduced between -**0.5 and 2.0 degrees**



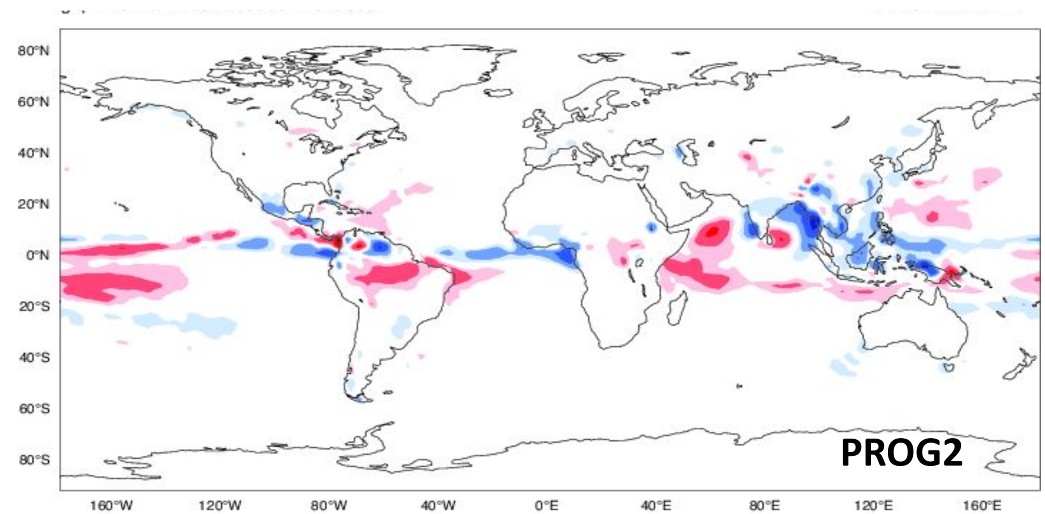


Aerosol impacts on the monthly forecasts: precipitation bias week 4



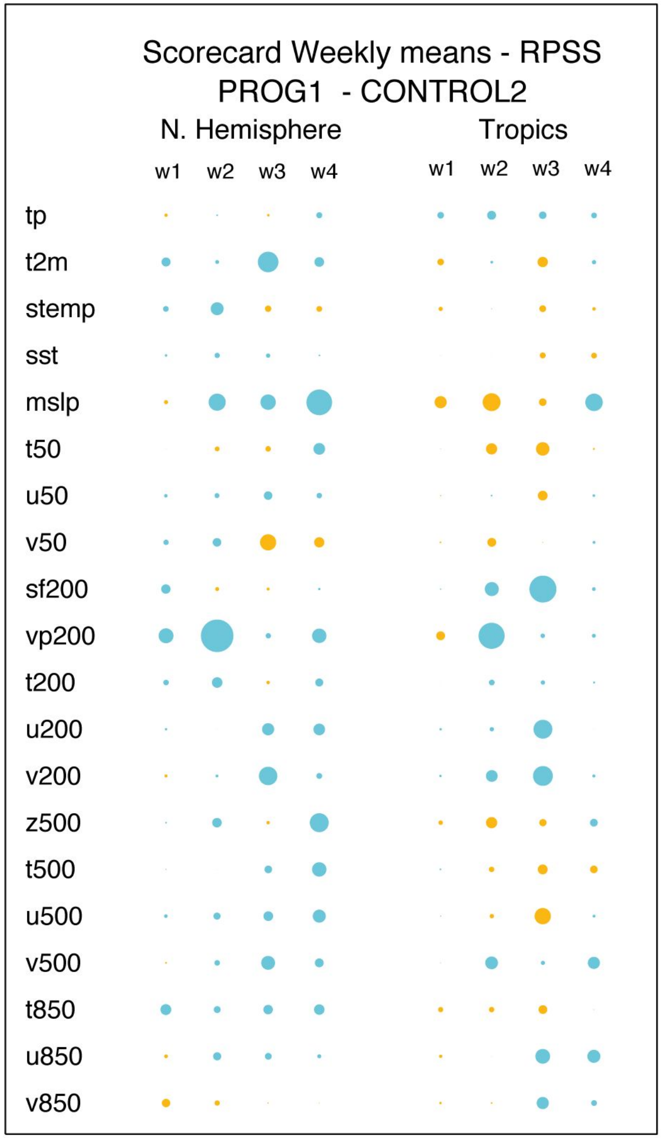


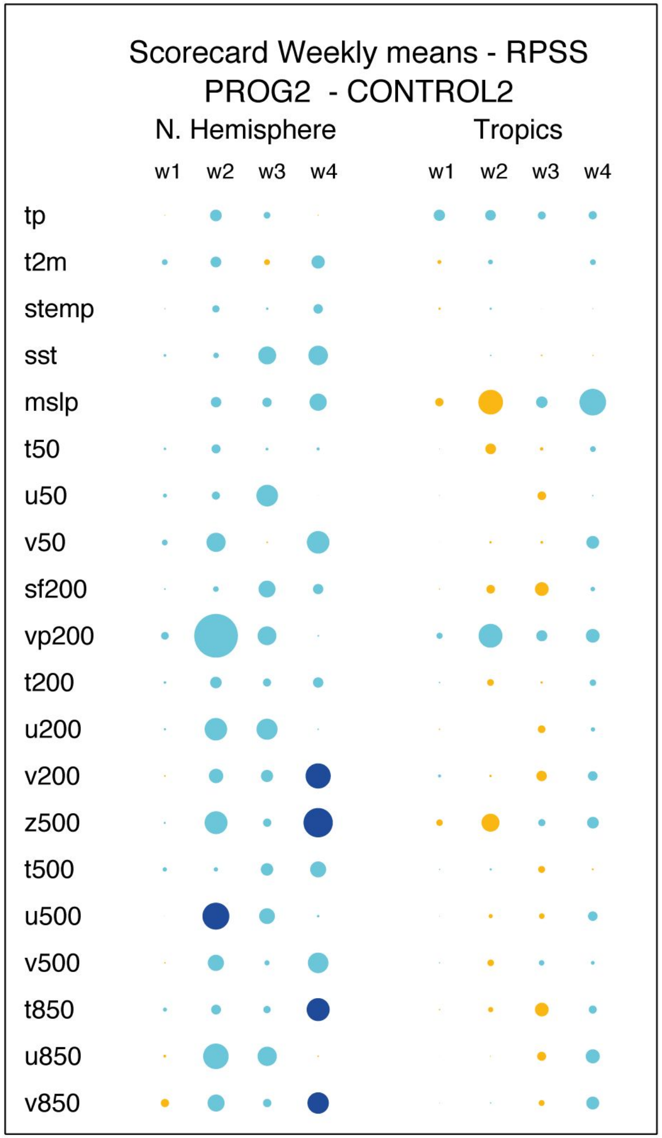
- Precipitation biases are also reduced over several **tropical regions**
- Precipitation bias reduction in East Asia amounts **to 0.5-1 mm/day.**



Aerosol impacts on the monthly forecasts: Rank probability skill scores

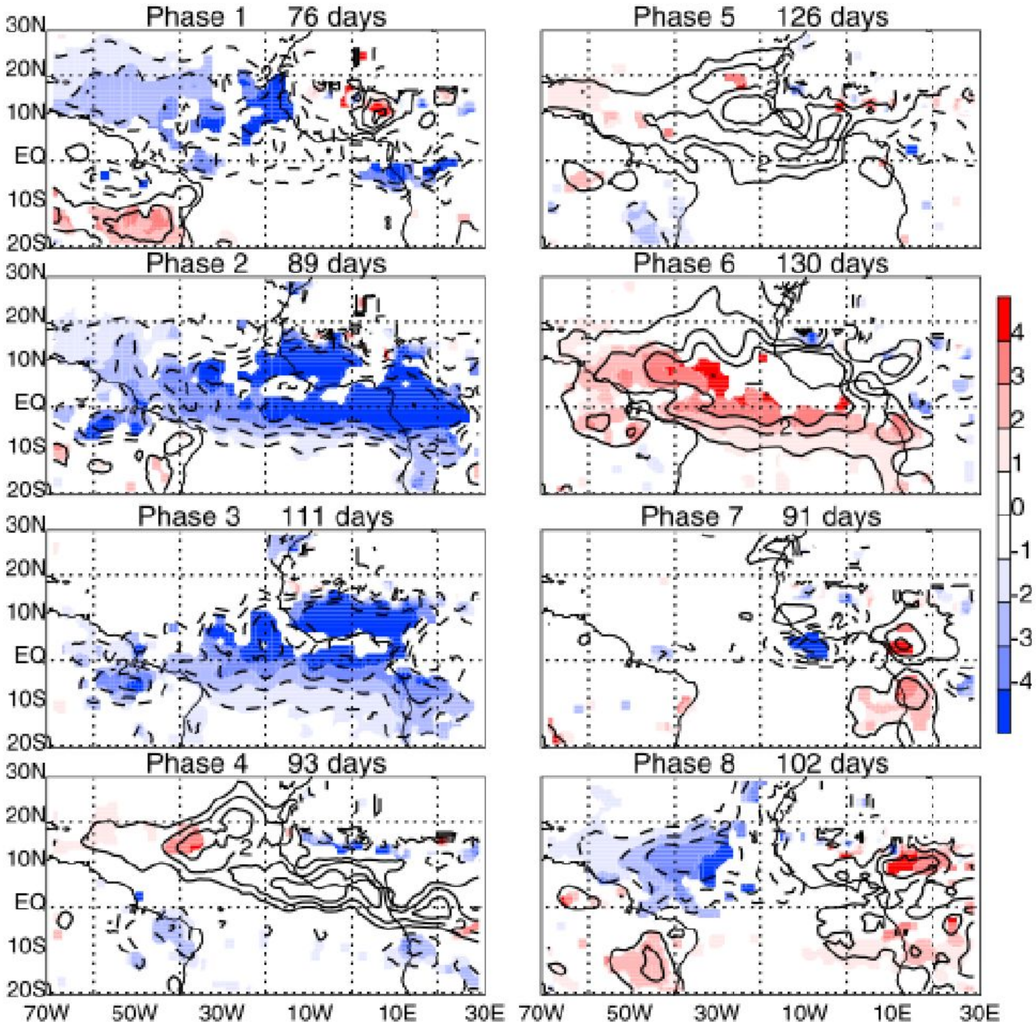
Aerosol impacts on the monthly forecasts: Rank probability skill scores



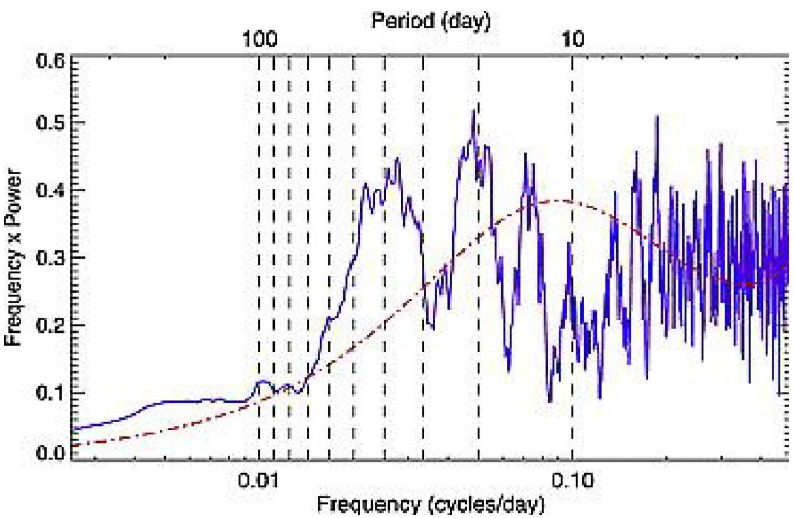


Pos. sign. Pos. not sign. Neg. sign. Neg. not sign.

Subseasonal aerosol variability



Time series spectrum of MODIS AOD anomalies over the Atlantic

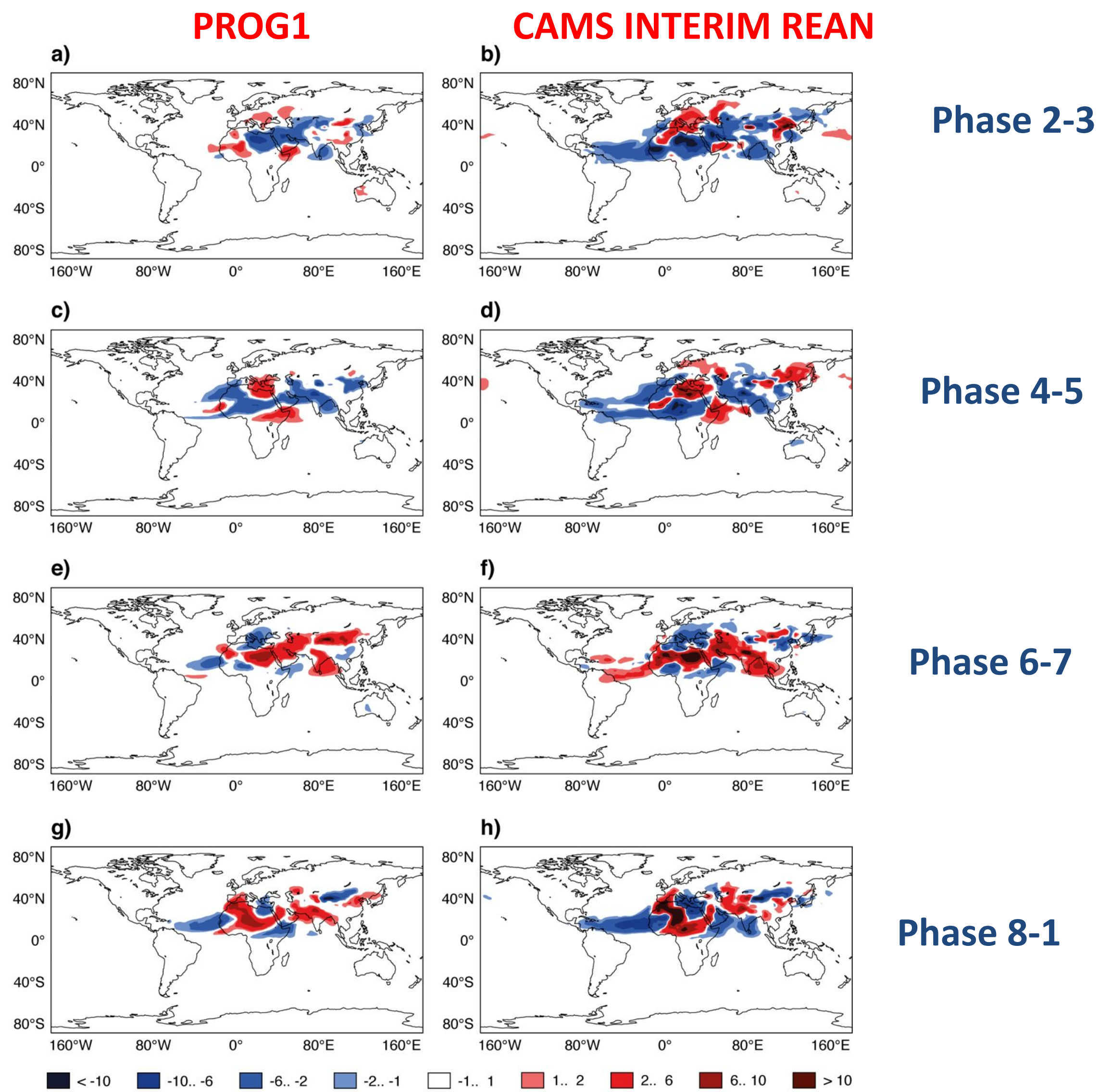


Tian et al, 2011

Intra-seasonal variance of AOD = ¼ total AOD variance

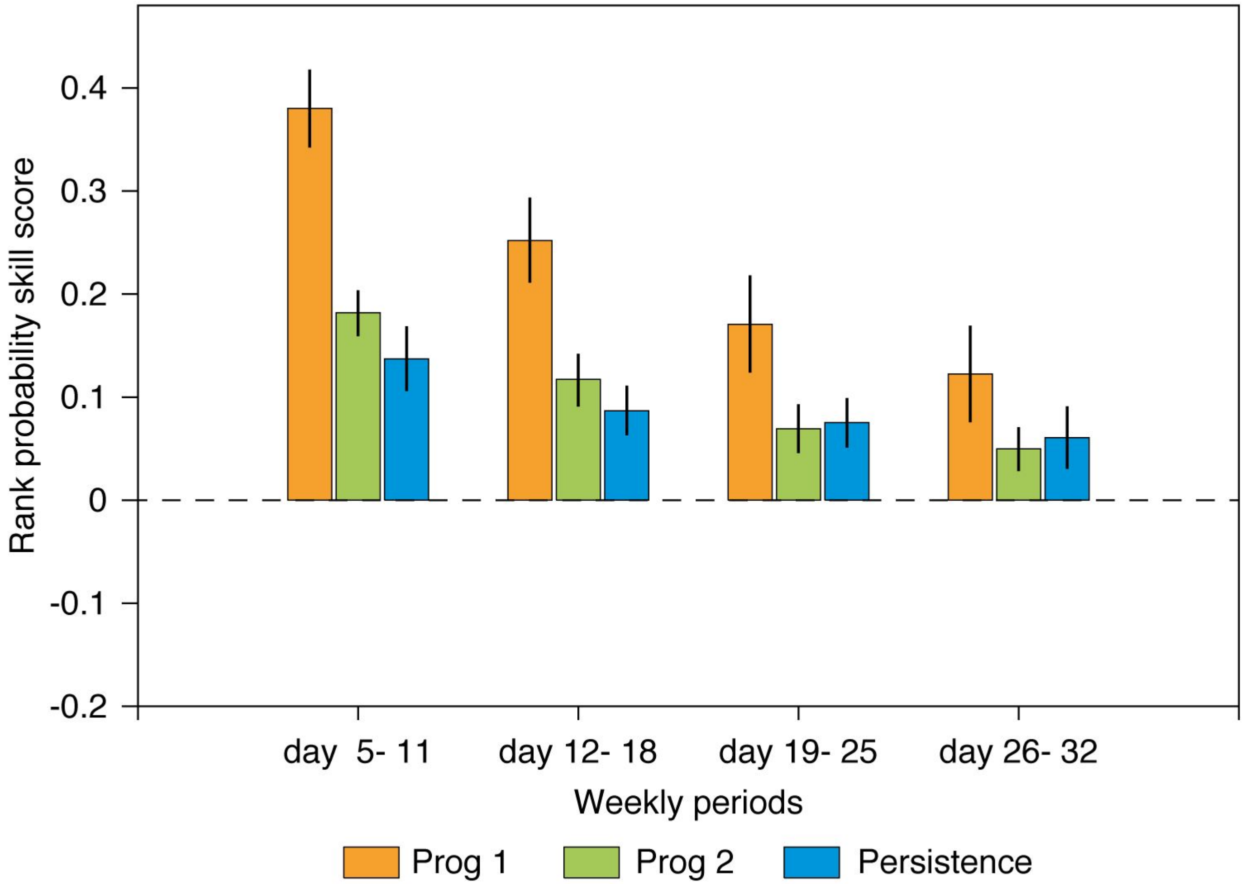
Aerosol modulation by the MJO:
Dust Aerosol Optical Depth anomalies

- **Composites of dust aerosol 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.**



ECMWF EURC

Predicting dust aerosols a month ahead

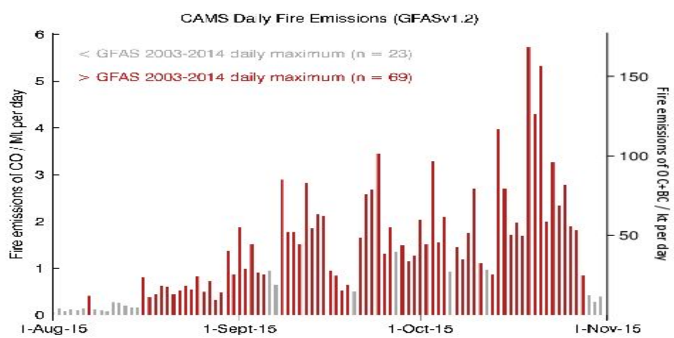


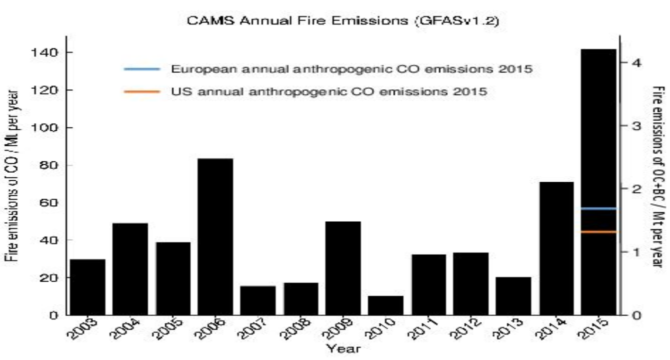
- RPSS for dust AOD from the experiments with interactive prognostic aerosols is higher than persistence as compared with the CAMS Interim Reanalysis

Extreme events: the Indonesian Fires of 2015

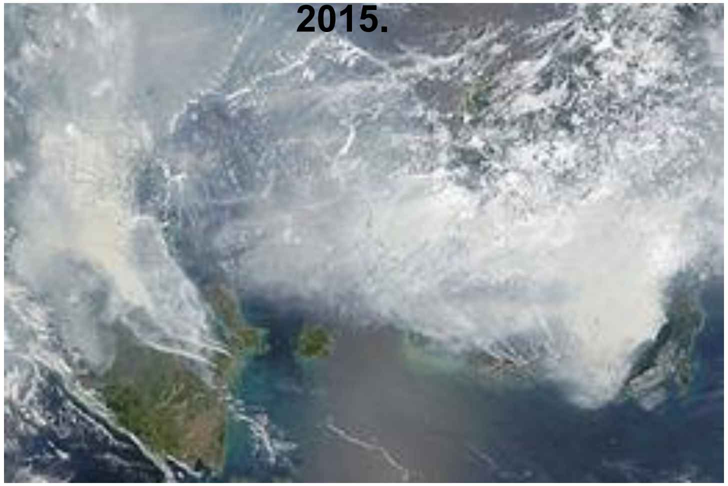
- **2015 was a record-breaking year for Indonesia.**
- During the burning season of August-October, wildfires spread widely across the region creating a humanitarian crisis due to the high levels of air pollution induced by the smoke.
- **Around 600 million tonnes of greenhouse gases were emitted,** an amount described as 'roughly equivalent to Germany's entire annual output'.

CAMS daily Fire emissions

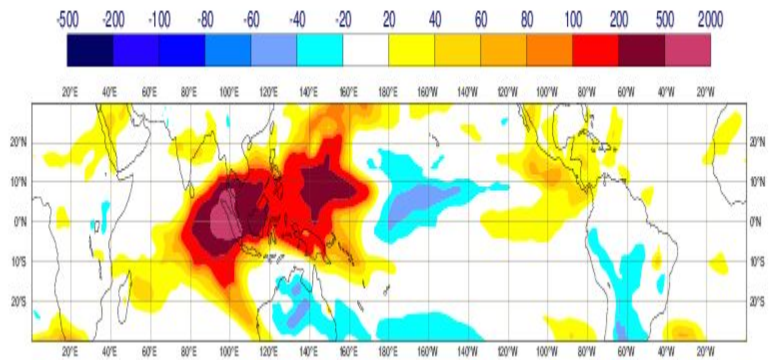




A NASA satellite image showing the extent of the haze on 24 September 2015.



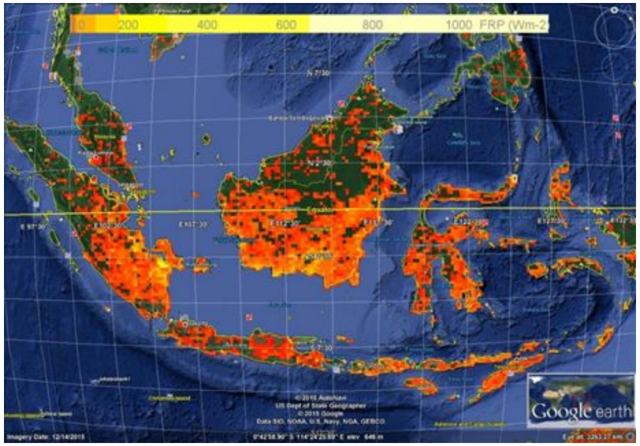
Biomass burning AOD anomaly



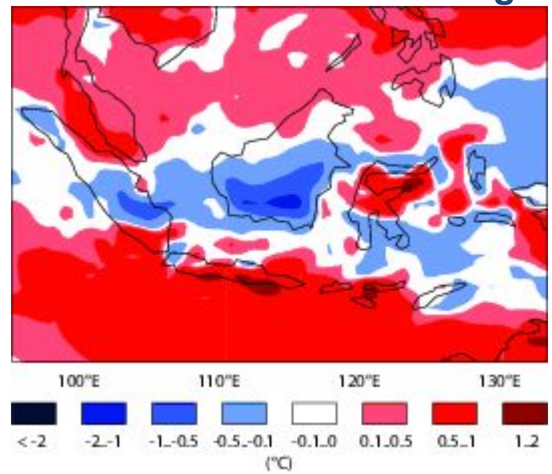
Benedetti *et al*, in State of Climate 2016, BAMS.

Extreme events: Indonesian Fires of 2015

Fire radiative power Aug-Oct 2015



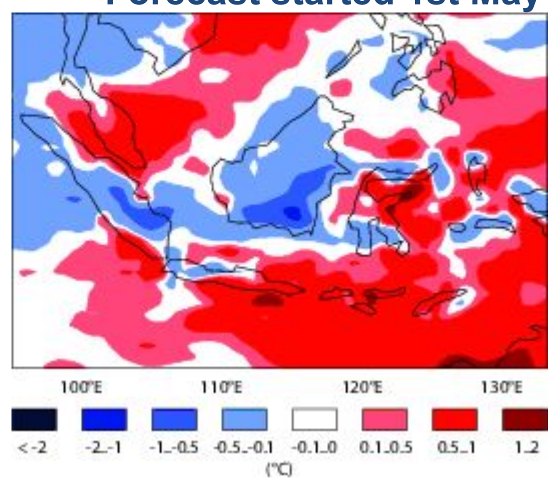
2m Temp anomaly Oct 2015 - Forecast started 1st Aug



Cooling due to smoke aerosols predicted **3 months ahead**

- The EPS system re-forecasts with interactive aerosols predicted 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)
- Need for a **predictive fire dynamical model**

2m Temp anomaly Oct 2015 - Forecast started 1st May



Cooling due to smoke aerosols predicted **6 months ahead**

Benedetti, Vitart and Di Giuseppe, in preparation

Evaluating aerosols impacts on Numerical Medium-Range and Subseasonal Prediction –the WGNE-S2S-GAW Aerosol project

Ariane Frassoni (CPTEC, Brazil) and **François Engelbrecth** (WITS, S. Africa) for WGNE

Frederic Vitart and **Angela Benedetti** (ECMWF) for S2S

Paul Makar (ECCC, Canada) and **George Grell** (NOAA, USA) for GAW SAG APP

WGNE = Working Group on Numerical Experimentation
S2S = Subseasonal-to-Seasonal project
GAW = Global Atmosphere Watch
SAG APP = Scientific Advisory Group on Applications

The Second Phase of the WGNE-S2S-GAW Aerosol Project

Medium-range experiments

- Higher resolution regional/global configurations in order to address the importance of interactive aerosols on medium-range predictability
- Longer periods to test different situations (not case-based)

S2S experiments

- Subseasonal re-forecasts experiments based on ensemble approach in a global scale in order to address the importance of interactive aerosols on subseasonal predictability

Goals of the Project

This project aims to improve our understanding about the following questions:

How important are aerosols for predicting the physical system (at short-range, medium range and S2S time scales) as distinct from predicting the aerosols themselves?

What are the current capabilities of NWP models to simulate aerosol impacts on medium-range and subseasonal prediction?

How important is forecast skill for air quality forecasting?

Are the S2S air quality forecasts useful for impacts purposes?

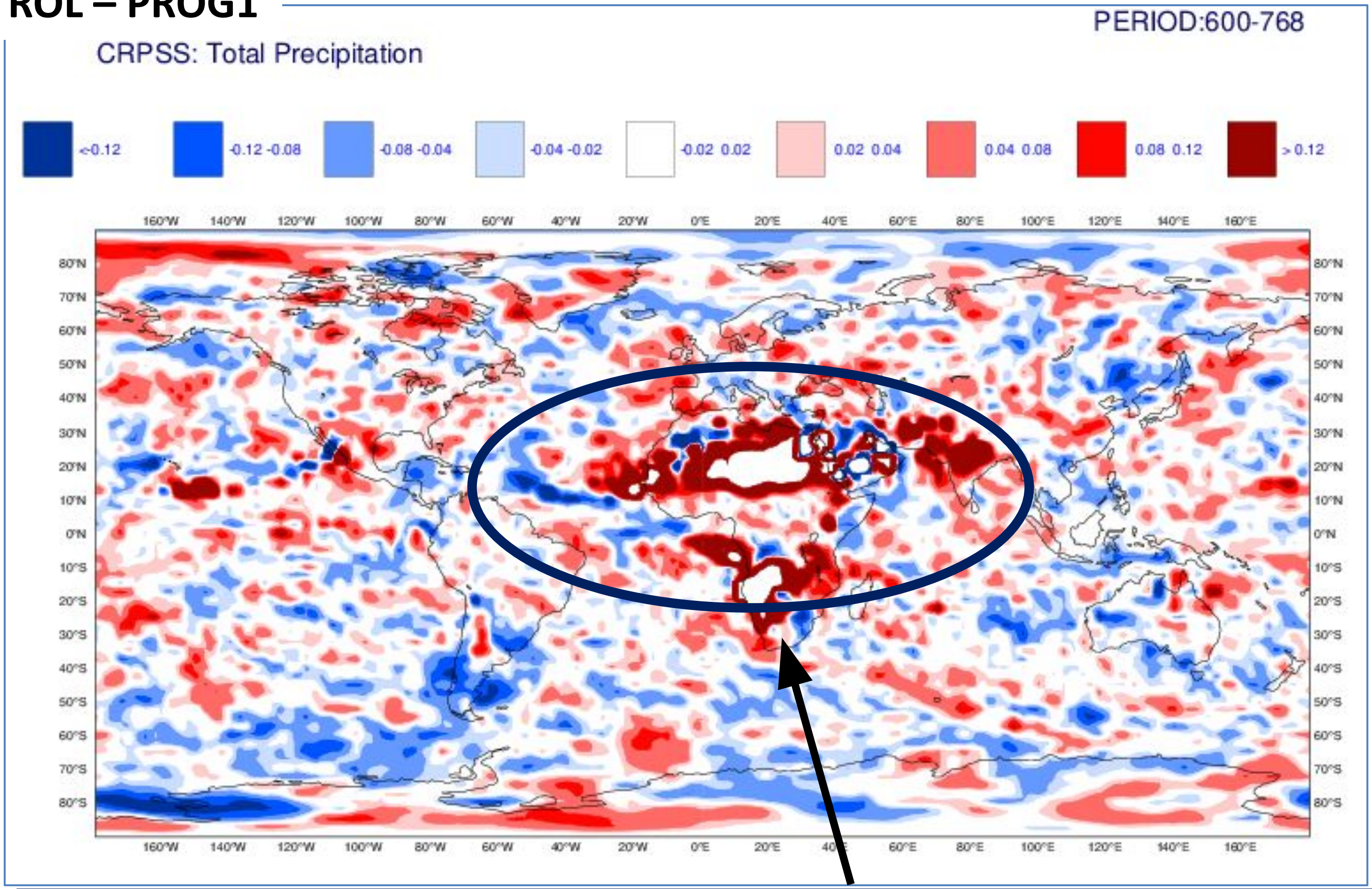
S2S coordinated experiments at ECMWF

- 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, 137 levels, CY47R1
- 5 different start dates around May 1, and September 1, 55 cases in total
- 1 month simulations
- Period 2003-2019

CONTROL	Bozzo et al (2020, GMD) climatology in the radiation
PROG1	Interactive aerosols initialized from the CAMS Reanalysis (Inness et al 2019)
PROG2	Interactive aerosols initialized from a fixed year (2010)

Aerosol S2S impacts (May 1 start date)

CONTROL – PROG1

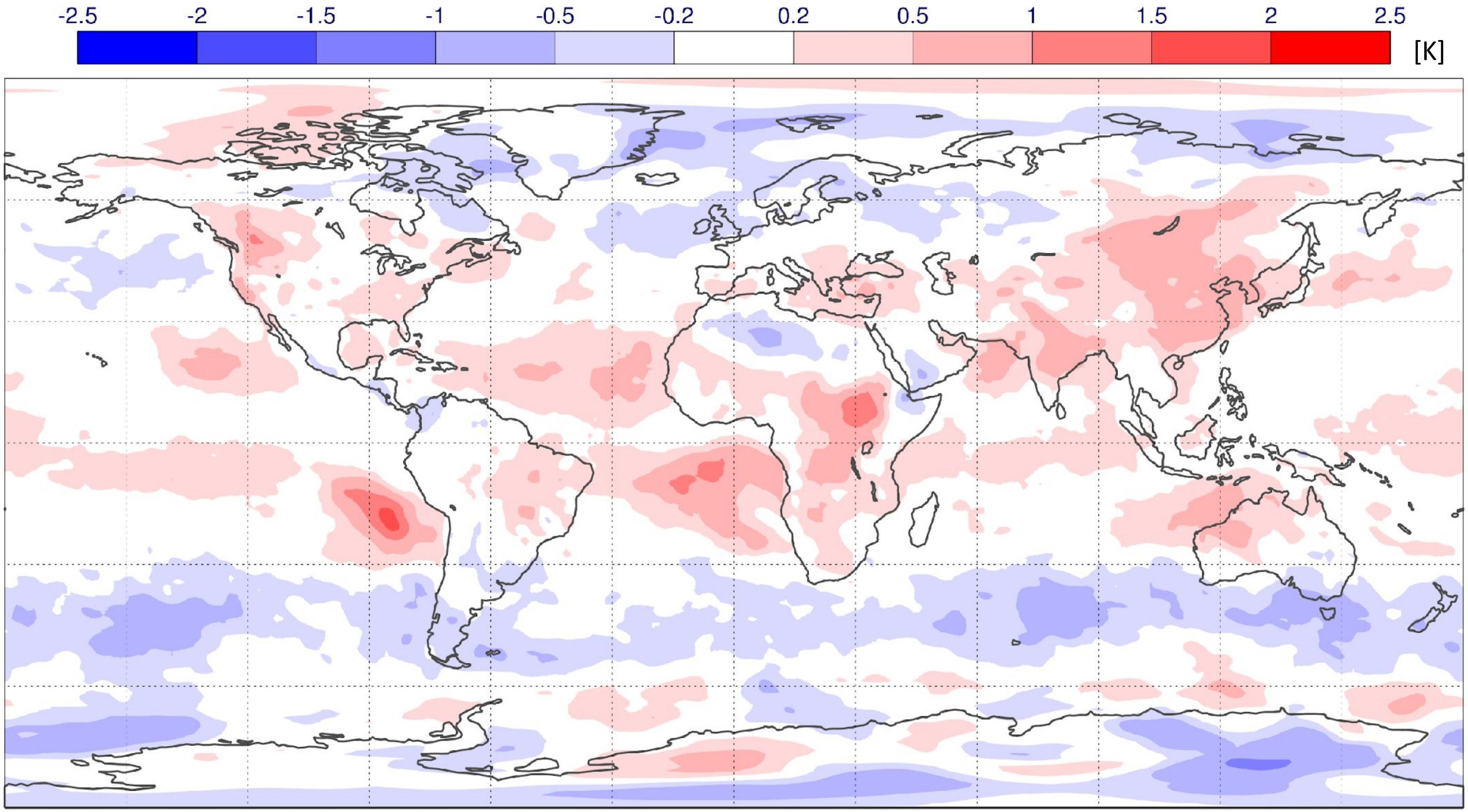


- Skill degradation in experiments with interactive aerosols connected with dust and biomass burning aerosols in total precipitation
- Not going in the hoped direction, but still showing high sensitivity to aerosols.

Aerosol impacts at the medium-range

T850 Mean Error: HRES (~9km, climatological aerosols)

Period: 202104-202201
Run: 00 UTC
Step: 120 h



Verification against own analysis

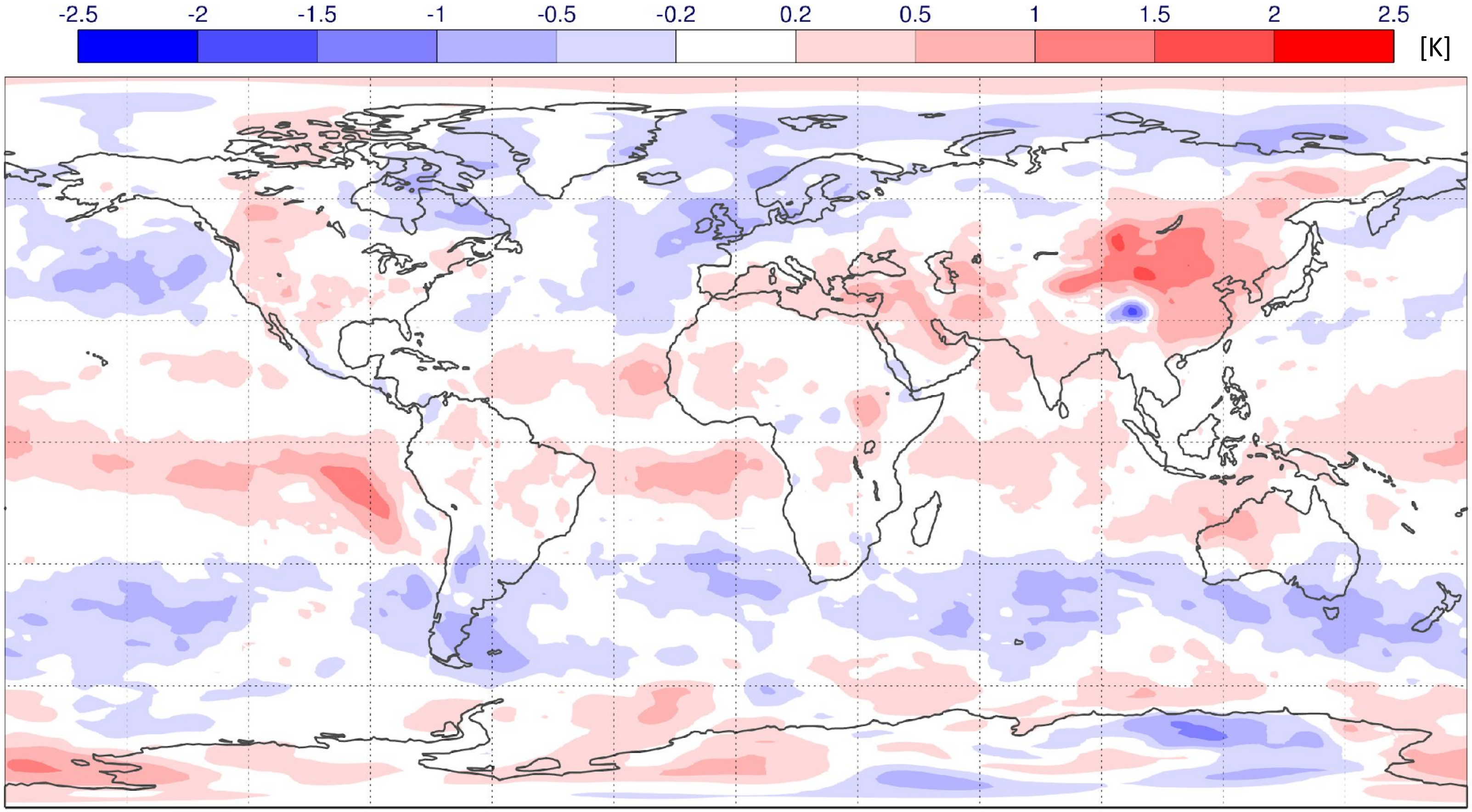
Credits: Thomas Haiden, ECMWF

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Aerosol impacts at the medium-range

T850 Mean Error: CAMS (~40km, interactive aerosols)

Period: 202104-202201
Run: 00 UTC
Step: 120 h



Verification against own analysis

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ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Summary

- **Aerosols are an integral part on the Earth system**
- **An accurate numerical weather prediction** (NWP) model with physical and chemical processes and realistic emissions **offers the perfect framework to model aerosols**
- In return, aerosols **can improve the weather forecasts** at various temporal scales, including the S2S, via different interaction mechanisms
- The **degree of complexity** of aerosols needed in NWP **depends on the specific application** and there might need to be a compromise with computational cost
- Potential for **S2S prediction of aerosols fields, particularly dust,** could open new avenues

Thanks for your attention!
Any questions?

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