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Ex-hurricane Ophelia and air quality impacts over Europe in CAMS forecast systems

Dimitris Akritidis[1], Eleni Katragkou[1], Aristeidis K. Georgoulias[1], Prodromos Zanis[1], Stergios Kartsios[1], Johannes Flemming[2], Antje Inness[2], and Henk Eskes[3]

[1] DEPARTMENT OF METEOROLOGY AND CLIMATOLOGY, SCHOOL OF GEOLOGY, ARISTOTLE UNIVERSITY OF THESSALONIKI, THESSALONIKI, GREECE

[2] EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS (ECMWF), READING, UK

[3] ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE (KNMI), DE BILT, THE NETHERLANDS

e-mail: dakritid@geo.auth.gr

CAMS and observational data

The **Copernicus Atmosphere Monitoring Service (CAMS)**[1] is one of the six services that **Copernicus** provides, using a comprehensive global assimilation and forecasting system to **assess the state and composition of the atmosphere** on a daily basis.

CAMS global system

- Based on the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS).
- Horizontal resolution of about 40 km and 60 vertical levels reaching up to 0.1 hPa.
- Assimilation of aerosol, ozone, nitrogen dioxide, carbon monoxide, and sulfur dioxide using the 4D-VAR data assimilation system (Inness et al., 2015, 2019)
- An extended version of the Carbon Bond 2005 (CB05) chemical mechanism is used (Flemming et al., 2015) and the Morcrette et al. (2009) aerosol parameterization.

CAMS regional system

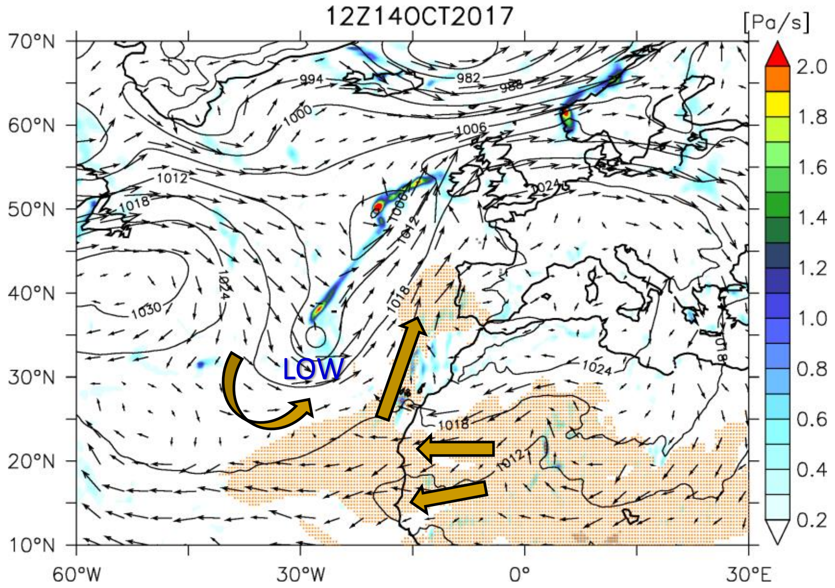
- The CAMS regional forecast system provides the ensemble median (RegEns) and members of the European-scale air quality forecasts up to 4 days in advance.
- The products have a 0.1° horizontal resolution and are based on state-of-the-art numerical air quality models developed in Europe: CHIMERE, EMEP, EURAD-IM, LOTOS-EUROS, MATCH, MOCAGE and SILAM.
- CAMS regional models assimilate PM_{10} and $PM_{2.5}$ surface observations but not satellite aerosol products.

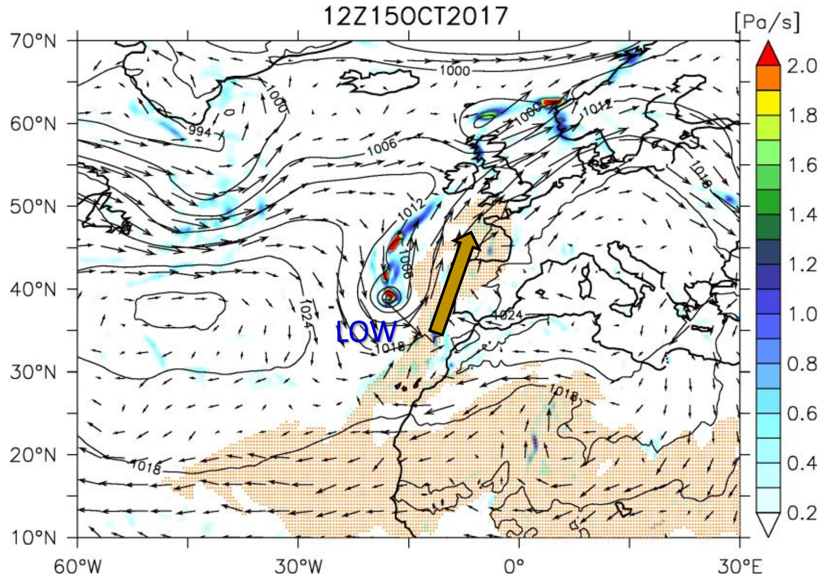
Data

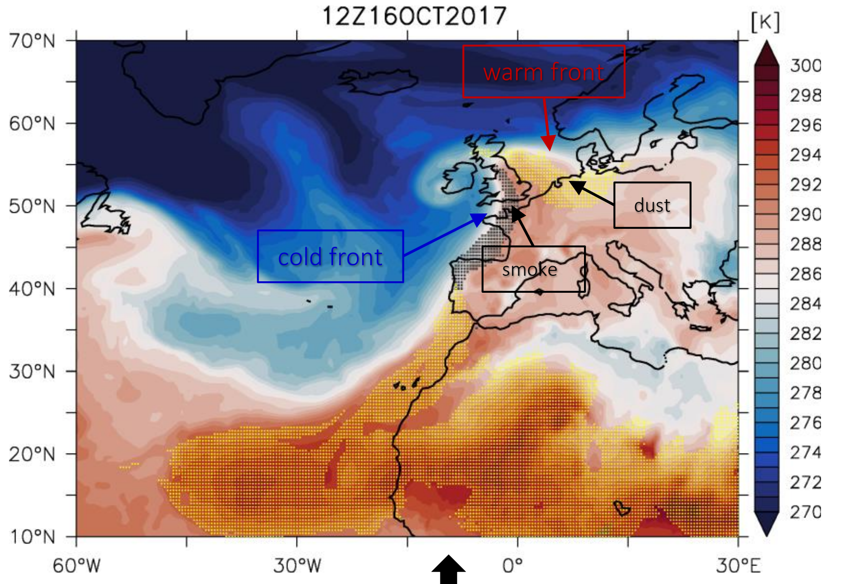
- We use CAMS-global (IFS) and CAMS-regional (RegEns) day-1 forecast data.
- AOD_{550} data from the two MODIS sensors aboard EOS Terra (equator crossing time 10:30 LT) and Aqua (equator crossing time 13:30 LT) satellites are used (Levy et al., 2013; Sayer et al., 2015).
- Also used are aerosol subtype data from CALIOP/CALIPSO (equator crossing time 13:30 LT) (Kim et al., 2018).
- Ground-based observations of PM_{10} and $PM_{2.5}$ surface concentrations are used from rural background stations, obtained from the European Monitoring and Evaluation Programme (EMEP) (Tørseth et al., 2012).

[1] https://atmosphere.copernicus.eu/

Ophelia & transport pathways







Black contours: mslp (hPa)
Black vectors: wind arrows at 850 hPa
Color shaded: negative of omega vertical velocity (Pa/s) at 850 hPa
Orange shaded: dust mass mixing ratio > 80 ug/kg at 850 hPa
Grey shaded: CO mixing ratio > 200 ppb at 850 hPa

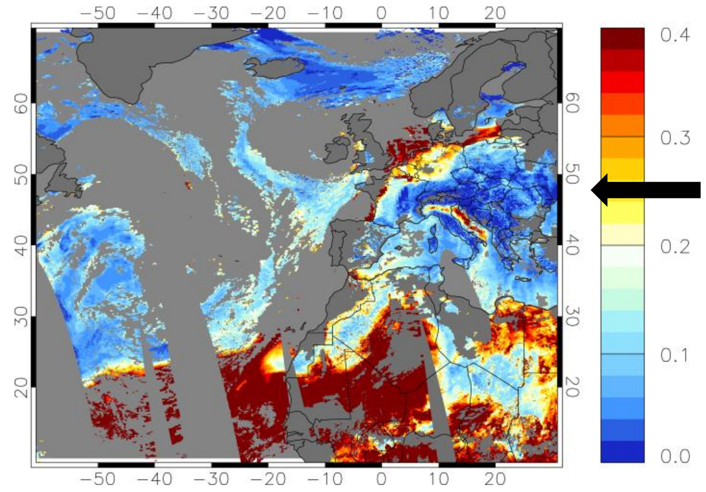
Color shaded: temperature (K) at 850 hPa
Orange shaded: dust mass mixing ratio > 80 ug/kg at 850 hPa
Grey shaded: CO mixing ratio > 200 ppb at 850 hPa

Saharan dust being transported through the trade winds over the west coast of Africa, is exposed to the southerlies on the east side of Ophelia system, setting up a dust outbreak that gradually moves to the north.

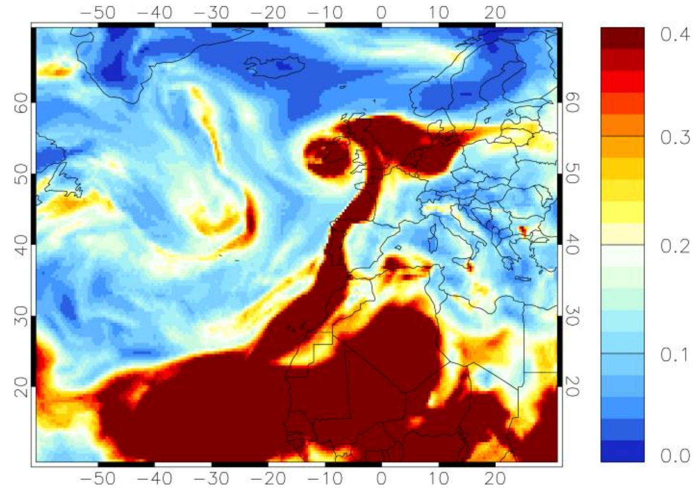
On 00Z of October 16th the Ophelia storm merges with the frontal system, while smoke from wildfires that have been burning across Portugal is evident at 850 hPa, as high CO concentrations (> 200 ppb) (not shown). From this moment and until 18Z of October 16th, dust and smoke particles gather on the warm and cold front of Ophelia's warm sector, respectively, transported over Western Europe through the frontal system.

Aerosol atmospheric composition

MODIS AOD_{550} at 16/10/2017



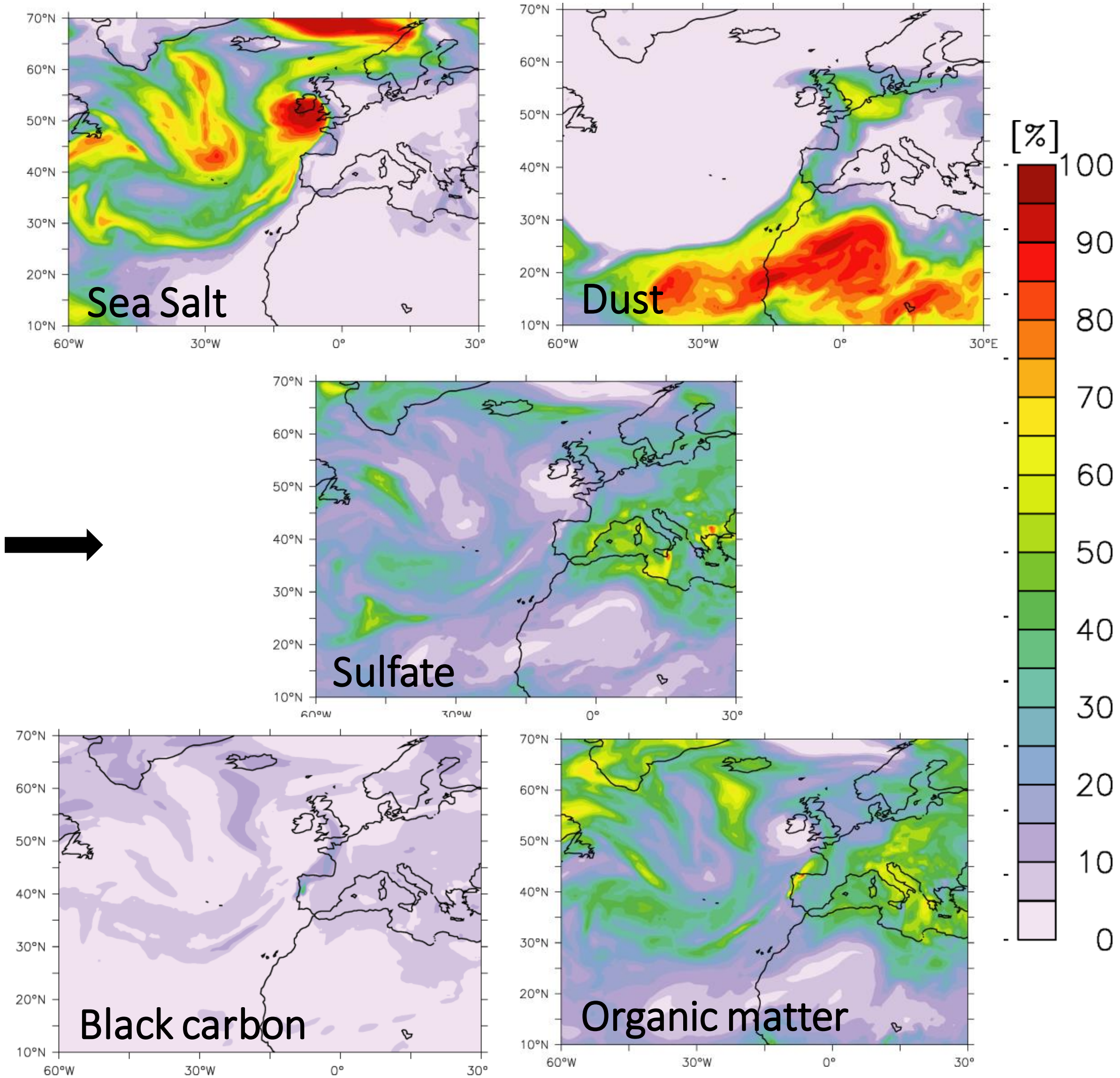
IFS AOD_{550} at 12Z 16/10/2017



- On October 16th, **high AOD_{550} values are observed** over North and Baltic Sea, France, Belgium, the Netherlands and Germany.

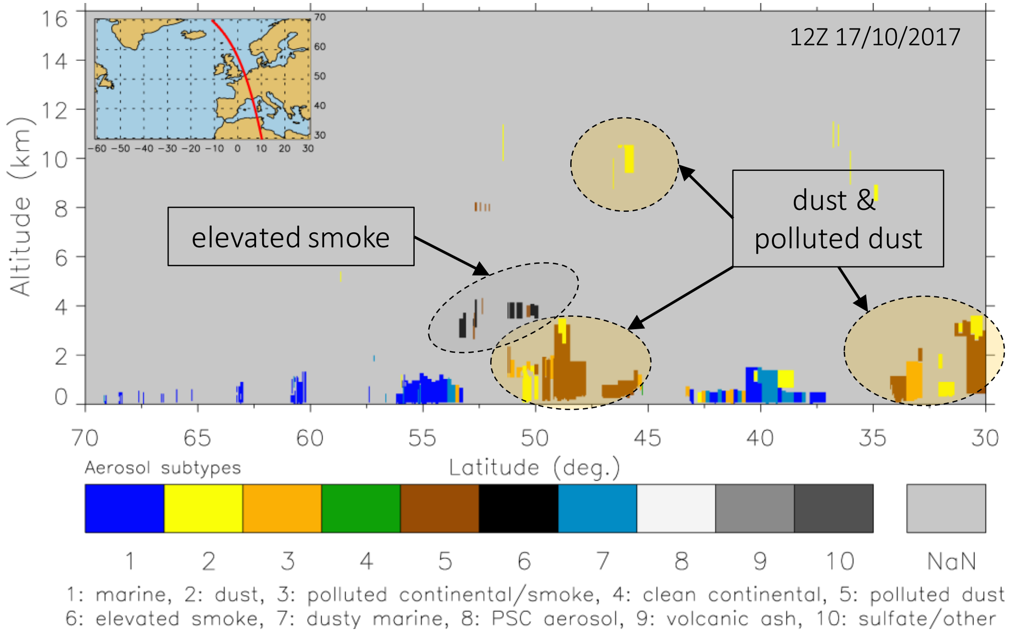
- The dust AOD contribution over Great Britain (GB) ranges with a percentage between 20-35%, while over the North Sea and the Netherlands it reaches values up to 65%.
- The biomass burning emission trails originating from Portugal are also a significant input for AOD, with black carbon and organic matter aerosols contributing up to 20% and 40%, respectively, over GB.

Percentage contribution to the IFS AOD_{550} at 12Z 16/10/2017

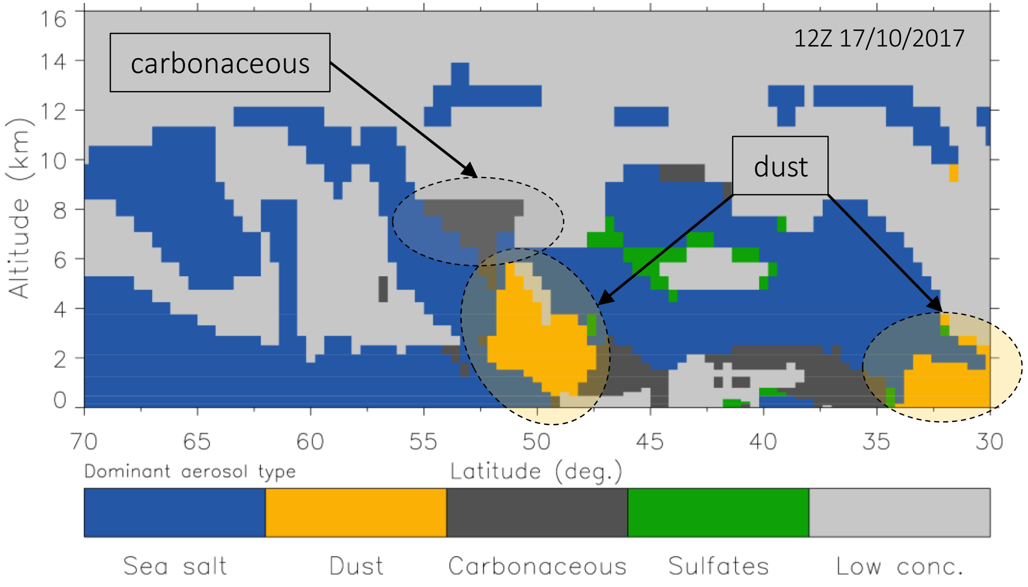


Aerosol atmospheric composition

CALIOP/CALIPSO AEROSOL SUBTYPES



IFS DOMINANT AEROSOL TYPE

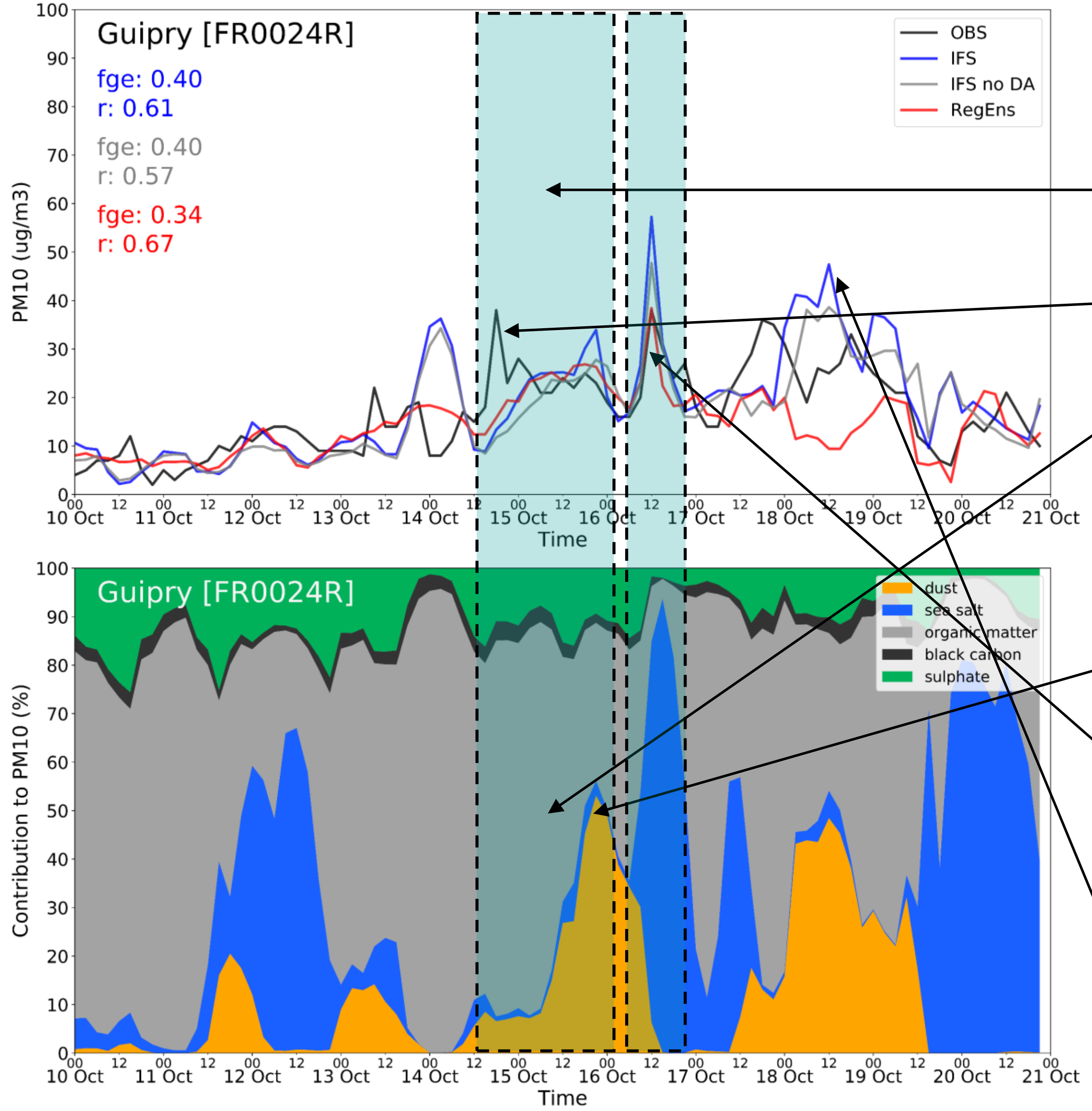


Vertical cross-sections of CALIOP/CALIPSO aerosol subtypes and IFS dominant aerosol type on 12Z of October 17th 2017. The embedded map depicts the respective CALIOP/CALIPSO track.

- Dust and polluted dust are detected at 45°N-50°N and 30°N-35°N up to 3 km.
- Dust is also observed in the upper troposphere (10 km) over France.
- Elevated smoke is identified over the North Sea at 4 km.

- The latitudinal bands of IFS dust aerosol dominance are consistent with CALIPSO, yet, fire-originated aerosols (carbonaceous aerosols) are found over the North Sea higher (above 5 km) compared to CALIPSO. This might be due to sea salt aerosol overestimation that prevents carbonaceous aerosols to appear as the dominant type below 5 km.

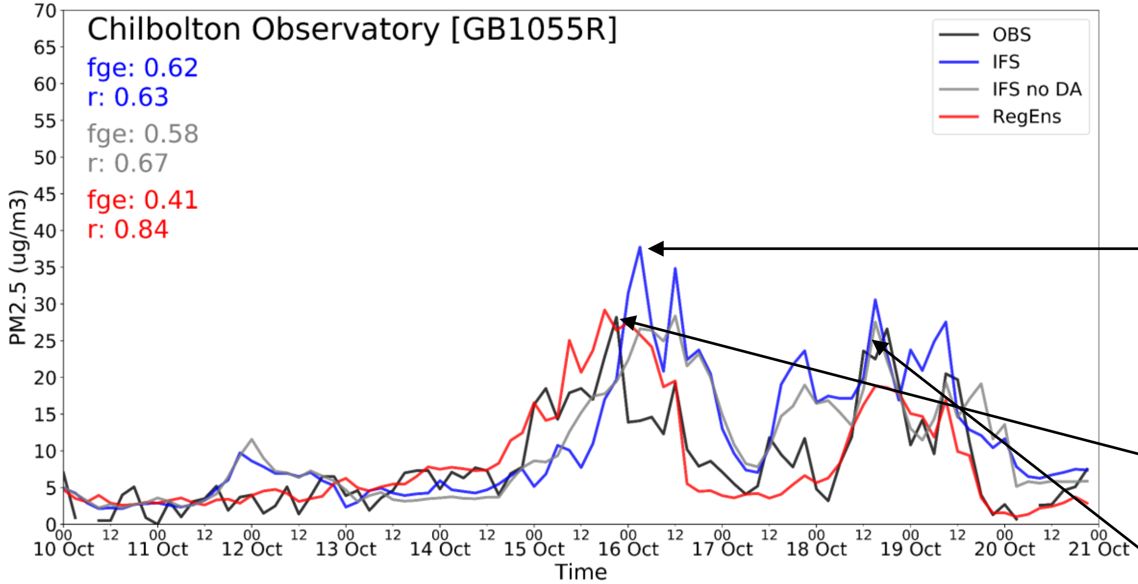
Impacts on air-quality (PM_{10})

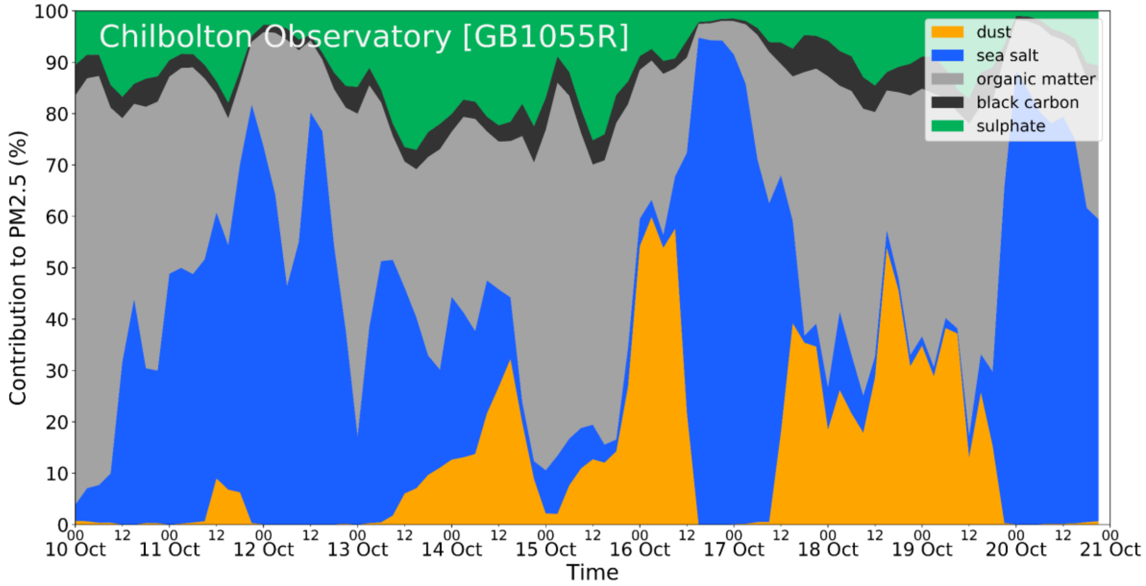


Observed (black), IFS (blue), IFS no DA (no Data Assimilation) (grey) and RegEns (red) 3-hourly timeseries of PM_{10} surface concentrations (ug/m^3) (top), and percentage (%) contribution of aerosol type to IFS PM_{10} surface concentrations (bottom) at Guipry (FR0024R), France.

- From 12Z of October 14th and up to October 16th an **increase in PM_{10} surface concentrations is observed**, also seen in IFS and RegEns.
- However, **the early peak in observations is not captured by CAMS** forecast systems.
- The percentage contribution of each IFS aerosol type to IFS PM_{10} concentrations indicates that the enhancement in PM_{10} surface levels is initially (00Z on 15 October) **due to organic matter aerosols (75%)**, probably related to transported smoke from fires burning over the Iberian Peninsula, while afterwards (21Z on 15 October) the **transport of dust induces a significant contribution from dust aerosols (53%)** as well.
- On 12Z of October 16th **a sharp peak is depicted in observed PM_{10} concentrations** reproduced from both IFS and RegEns, yet overestimated from IFS, which seems to result from **sea salt transport from the west** and on the south of Ophelia.
- IFS exhibits an increase of PM_{10} levels on 12Z of October 18th due to dust and organic matter aerosols which is not seen in RegEns and observations.

Impacts on air-quality ($PM_{2.5}$)





Observed (black), IFS (blue), IFS no DA (no Data Assimilation) (grey) and RegEns (red) 3-hourly timeseries of $PM_{2.5}$ surface concentrations (ug/m^3) (top), and percentage (%) contribution of aerosol type to IFS $PM_{2.5}$ surface concentrations (bottom) at Chilbolton Observatory, GB.

- After 15Z of October 15th the **observed $PM_{2.5}$ surface concentrations increase up to 28 ug/m^3**, with IFS peaking with a 6 hours delay.
- A second wave of dust and biomass burning transport is affecting $PM_{2.5}$ surface concentrations over the site on 15Z of October 18th as revealed from IFS, which is in agreement with observations, but not so profound in RegEns.

Take Home Messages

- African dust was transported towards northwestern Europe on the east side of Storm Ophelia forming an extended dust plume reaching the Baltic States. On it's passage, Ophelia lifted and drifted smoke aerosols from fires burning over the Iberian Peninsula carrying them over several European regions, such as France, Great Britain and the Netherlands.
- After 00Z of October 16th, dust and smoke aerosols are found on the warm and cold front of Ophelia, being transported within it's warm sector.
- The decomposition of IFS AOD_{550} fields indicates that African dust, organic matter from biomass burning over the Iberian Peninsula and sea salt aerosols sprayed in the vicinity of Ophelia, are the major contributors to the plumes of high AOD_{550}.
- The CALIOP/CALIPSO and the spatially and temporally collocated IFS cross sections of dominant aerosol types, reveal a good qualitative performance of IFS, as it generally manages to reproduce the type and location of aerosols during the passage of Ophelia.
- In terms of air quality, comparison with ground-based measurements from EMEP stations reveals that both IFS and RegEns are in general able to reproduce the observed signal of increase in PM_{10} and $PM_{2.5}$ surface concentrations, yet exhibiting some inconsistencies on the quantitative and temporal representation of the observed peaks.

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