Aerosol forcings, cloud feedbacks and temperature trends: a seasonal forecast perspective

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Climate forcings in seasonal forecast systems

Operational seasonal forecast systems predict temperatures and weather patterns for the coming seasons, and their real-time forecasts need to be referenced in some way to previous years. To do this well, the forecast systems need to reproduce the observed low-frequency changes in the climate system. This is partly done through the influence of the initial conditions but is also sensitive to climate forcings. The SEAS5 operational forecasts show a strong warming trend, largely driven by the CMIP6-specified greenhouse gases. However, only sulphate tropospheric aerosols are specified as time-varying, with other types fixed. As part of the CONFESS project, and to support the development of the next-generation ECMWF SEAS6, substantial work has been done to improve the representation of time-varying tropospheric aerosols.

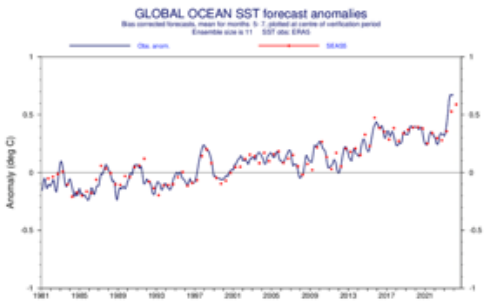


Figure 1:Global mean SST anomalies from 1981 to present, from ERA5 (blue) and from SEAS5 forecasts for months 5-7 (red dots).

Development of a new time-varying aerosol climatology

ECMWF presently uses three different configurations for aerosol in the IFS. The CAMS configuration, used for air quality and chemistry forecasts, has fully interactive aerosol. NWP configurations use a climatology with 11 aerosol types, derived from a much earlier version of CAMS by Bozzo et al. (2020). ERA5 reanalysis and SEAS5 seasonal forecasts use a CMIP6 time-varying sulphate aerosol climatology, with the other 10 aerosols using the same climatology as the NWP system. The out-of-date nature of the NWP climatology and the lack of compatibility led us to develop a new, time-varying climatology. The methodology is conceptually simple – we use the latest version of CAMS aerosol and chemistry modelling (with 16 aerosols and 123 chemical species), specified emissions from the latest version of CEDS and CMIP6 biomass burning, and winds and meteorology constrained by ERA5 reanalyses, to produce a pseudo-reanalysis of aerosol from 1951 onwards. From this, a time-varying climatology can be derived - dust and sea-salt have a fixed seasonal cycle, but for other aerosols an approximate 10-year running mean is applied to the seasonal cycle. The resulting climatology, with a small additional background term, performs well in NWP tests and representing the recent climate mean state.

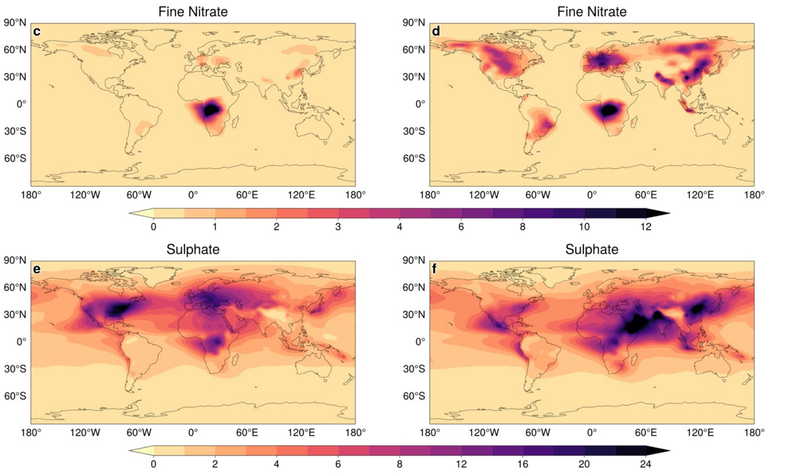


Figure 2: Vertically integrated mass (in mg/m2) of JJA aerosol climatology for fine nitrate (top) and sulphate (bottom), for the epochs centred on 1975 (left) and 2015 (right), showing the different regional evolution of these two example species between these periods.

Aerosol validation

No additional in-situ validation was done as part of this development, but the CAMS aerosol model and analyses are continually monitored and validated (see for example https://global-evaluation.atmosphere.copernicus.eu/aerosol). The free-running aerosol model which we rely on to generate our climatology slightly underestimates total AOD against AERONET ground-based data, but the latest version performs well across a wide range of metrics.

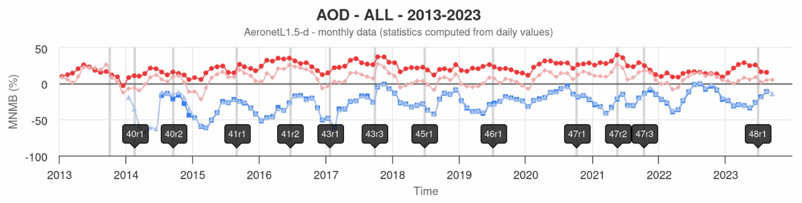
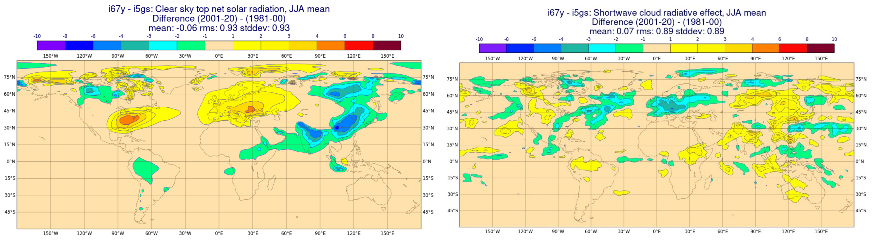


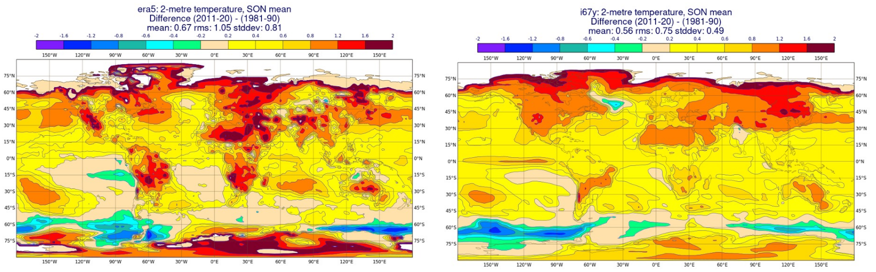
Figure 3: Evolution of mean relative bias of CAMS operational analysis (red) and no-data-assimilation control run (blue) against AERONET data. From CAMS validation report, Period June-August 2023.

Clear-sky radiative forcing and cloud feedbacks



Comparing seasonal reforecasts with the new time-varying tropospheric aerosol climatology with other reforecasts using fixed aerosols shows the impact of aerosol time-variation on trends in the forecasts. These plots show the difference in trend (defined as the difference between 2001-2020 and 1981-2000) in JJA forecasts from the 1st May. The impact on top-of-atmosphere (TOA) net clear-sky solar radiation (left) is easily understood and is likely to be reasonably accurate. However, cloud changes are less certain. The change in cloud radiative effect on TOA solar (right) in the IFS shows that the reduction in aerosol over Europe and the US has gone together with a **reduction** in cloud reflectance, which is wrong. The reason is that the IFS cloud microphysics do not see the changing aerosol and do not include indirect effects such as the brightening of clouds by sulphate aerosols. The only way in which the changing aerosols change the cloud is the semi-direct effect – as the air over Europe becomes cleaner, there is less absorption of heat by aerosol, and the cooler atmosphere become cloudier. The (incorrect) cloud feedback roughly cancels the clear-sky effect over northern Europe, meaning the aerosol changes have almost no impact on T2m. Other, less cloudy, regions are less affected, and here the time-varying aerosol improves the accuracy of the T2m trends. In all cases the time-varying aerosol modifies much larger trends present due to increasing greenhouse gas and warmer ocean initial conditions.

Thirty-year trends



The total trend in T2m, shown here for SON from ERA5 (left) and from 1st May forecasts using the new time-varying aerosol (right), shows that our latest seasonal forecast system captures the overall global mean warming well, but still gets some details wrong. Europe and the Amazon are two regions where observed warming has been stronger, in the case of Europe at least this is likely to be due to incorrect cloud feedbacks. Note also the discrepancy in trends in the Eastern Pacific. Other trend discrepancies (not shown) are in 200 hPa winds over the tropical Atlantic, relevant for hurricane numbers. Time-varying aerosol reduces the discrepancy but does not remove it.

Conclusions

An accurate representation of climate forcings and the resulting temperature **trends are critically important** for operational seasonal forecasts. Indeed, the climate change signal dominates seasonal temperature forecasts. Trend errors have limited impact on skill estimates, since years in the middle of the calibration period are little affected, but real-time forecasts can be badly exposed if trends are wrong. Uncertainty in our process modelling directly impacts both our forecasts, and the confidence we can have in them.

Aerosols and their optical properties are important for air quality forecasting and NWP, and operational models have been improving rapidly, driven by validation with in-situ and satellite data. Cloud-aerosol interactions in ECMWF NWP systems are less well developed, but are now receiving attention.

Seasonal forecast systems can be effective in diagnosing errors in temperature trends, because their initialisation eliminates a substantial part of the natural variability in the climate system.

Convergence and collaboration between climate change earth system models and operational NWP and seasonal prediction systems can offer benefits all round. This matters, because the scientific challenge of understanding clouds and aerosol in a changing climate is both difficult and critically important.

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