Volcanic eruptions and operational seasonal forecast systems

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Operational seasonal forecast systems

Reliable prediction of day-to-day fluctuations in weather is impossible beyond a few weeks, due to the chaotic nature of both tropical and mid-latitude weather systems. Slowly varying parts of the earth system give predictability over longer time-scales by perturbing these faster processes and changing the probabilities of different patterns of weather. Many timescales are involved. At the extended-range (10-30 days), the Madden-Julian Oscillation (MJO) in the tropics often dominates, but soil moisture is also important, as is stratospheric variability in the winter polar vortex. At seasonal timescales (months to seasons), El Nino is the biggest single source of variability, and SST variations in other parts of the tropics are also important. Stratospheric, land and sea-ice influences are also present, and variations in greenhouse gases and aerosols also play a role. It is because of this wide spectrum of drivers of seasonal climate and the many non-linearities involved that operational seasonal forecasts are based on comprehensive GCMs. Ensemble forecasts are used to estimate, for each starting date, the range of probable outcomes.

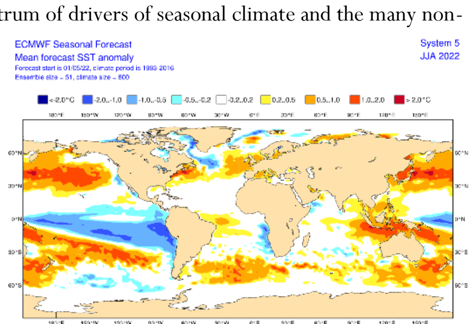


Figure 1: SST anomaly for JJA 2022, from ECMWF's operational system, SEAS5.

The basic elements of seasonal prediction (El Nino, the background of global warming) are handled relatively well by forecast models but getting the full range of processes right is extremely challenging, and accurate initialisation can also be hard. Often forecasts from multiple models are combined to average out some of errors.

Operational centres feed their forecasts into well-developed chains of downstream applications, through national Meteorological Services, NGOs and commercial customers. Public access to data and products is also possible, for example via the EU Copernicus Climate Change Service.

A major volcanic eruption will substantially perturb the climate system, and once the plume characteristics are established, the influence should be predictable. But how do we integrate the volcanic influence with everything else that may be happening? And how do we ensure the results are fed into the myriad of applications that exist around the world? The best way to do this is to ensure that the volcanic influence is represented in operational forecast systems.

Representation of volcanic aerosol

ECMWF operational seasonal forecasting systems have included a highly simplified representation of volcanic aerosol since 2011. So far the main impact has been on the re-forecasts created for calibrating each new system, which extend back to the 1980s and include El Chichon and Pinatubo.

- Vertically integrated visual optical depth based on GISS datasets
- Reduced to 3 numbers: NH, tropics, SH
- Evolved during forecast by damped persistence from initial state (value from previous month)
- Vertical distribution: constant mass-mixing ratio from tropopause to specified height
- Fixed optical properties

In the case of a large real-time eruption, estimates of optical depths (3 numbers) would be entered into the input file used in the real-time forecasts. Small real-time eruptions are ignored. We have monitored a few events, but so far we have never activated the real-time option.

This approach still allows a reasonable treatment of the impact on incoming solar radiation, allowing us to capture the global cooling response to an eruption. We also want to predict the dynamical response of the stratosphere, which depends on the structure of the heating. This is not so well represented at the moment, due to the high level of approximations made.

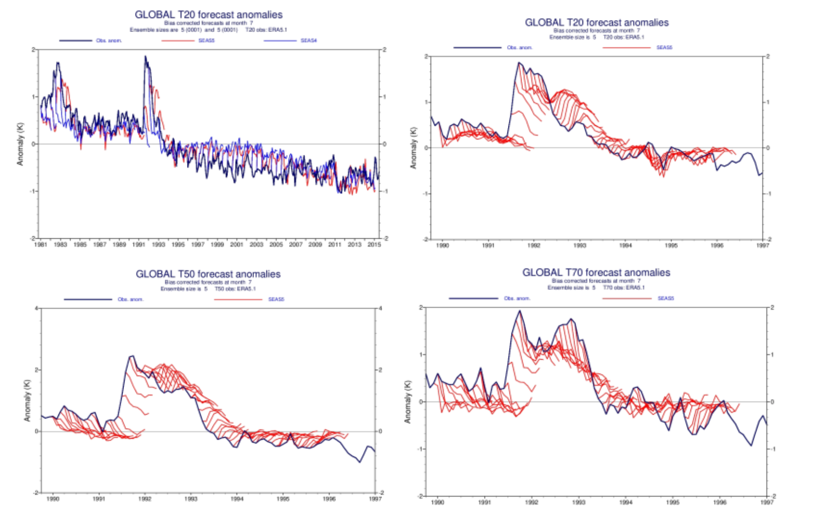
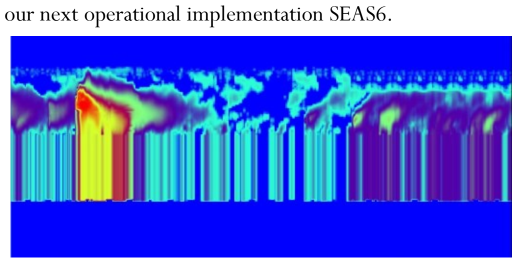


Figure 2: The evolution of global mean stratospheric temperature according to SEAS5 (red), the previous system (blue) and ERA5 reanalysis (black). The top left figure shows a multi-decadal period at 20 hPa; the other figures show more detail for the response to Pinatubo, at 20, 50 and 70 hPa.

Current developments

CONFESS is (partially) funding further development. A fully vertically resolved dataset for use in the IFS has been developed from the latest GLOSSACv2.1 data, with stratospheric background removed, and stratospheric volcanic aerosol extrapolated downwards for use in stratospheric intrusions. The EVA_H model (Aubry et al, 2020) will be implemented to approximate the full resolution data with an 8-box model, appropriate structure functions, and a time-evolution capability tuned on previous events. It is hoped that this can form the basis of our next operational implementation SEAS6.



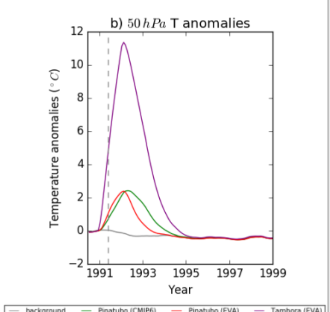


Figure 3: Time evolution of stratospheric volcanic aerosol 525nm optical extinction at equator from new full-resolution dataset (above), and previous results from EVA model in EC-EARTH experiments at BSC (right, from Martin et al in prep).

Challenges

Cost: operational systems use large ensembles of high-resolution models, with large reforecast calibration datasets (SEAS5: 11,500 years of 36 km resolution L137 model). Representation of volcanic aerosol must be low-cost.
Operational schedule: real-time forecasts within 24 hours on the first of every month
Initial conditions: Real-time specification of state of stratosphere, produced operationally.
Optical properties: still only have single fixed values. Best way forward?
Tropopause region (UTLS): modelling experience suggests that aerosol at the bottom of the stratosphere has largest dynamical impact on NH winter tropospheric circulation. How well can we measure volcanic aerosol in this region?
Uncertainty representation: How best to represent uncertainty in aerosol mass, distribution and optical properties in the ensemble?
Prioritization: Motivating investment and preparation *before* next major eruption.

Please contact me to discuss further: In person or tim.stockdale@ecmwf.int

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