Comparing model-state and model-physics ensembles for high-resolution NWP simulation of the Boscastle flood

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1. Outline

Severe rainfall from convective events is the main cause of summertime flash floods in the UK. The Met Office Unified Model is now run operationally at convective-scale resolution. Nonetheless, forecasting remains a challenge as the uncertainties are not well understood with significant nonlinearities at small scales. Appropriate ensemble techniques need to be developed. Here we investigate predictability of the Boscastle flood of 16th August 2004, comparing model-state and model-physics perturbation strategies.

2. The Event

Figure 1 Radar rain accumulations (mm in 5h).

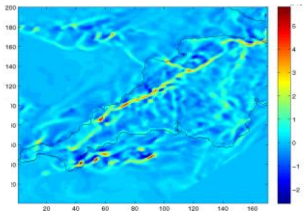


Figure 2 Divergence in 10m wind field. Control run at 11UTC, when the first cells initiate ($\times 10^{-3} s^{-1}$).

- Flash flooding at Boscastle, on northern coast of Cornwall, with rain gauge accumulations of up to 200mm in 5h.
- Warm moist air at low levels from WSW large-scale flow.
- Mesoscale uplift under the left-hand exit of an upper-level jet streak.
- Convergence line due to land/sea roughness and thermal contrast, modulated by topography.
- Cells repeatedly initiate and propagate along coast producing a line of rainfall less than 10km wide.
- Cells strong enough to rain heavily over very small catchment, but downdrafts did not distort the convergence line, which persisted throughout the day.

3. Model ensembles

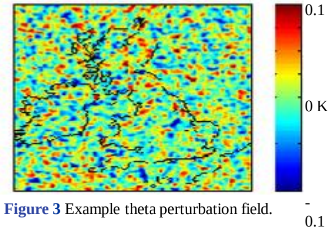


Figure 3 Example theta perturbation field.

- Met Office Unified Model with 1km grid spacing.
- Model-state perturbations provide a simple treatment of boundary-layer representivity error. A random potential temperature field is applied every 30 min with no temporal correlations. The field is constructed by convolving a random number field (maximum amplitude 0.1K) with a 2D Gaussian kernel (8km standard deviation).
- Ensembles of 8+1 members generated from 8 realizations of model-state perturbations + base run with no such perturbations.
- Each ensemble has given physics: standard set-up or various perturbations to physics parameters and/or methods. We perturb autoconversion threshold, aerosol concentrations, temperature of heterogeneous ice nucleation, soil moisture contents and roughness length for grass.
- Also consider ensemble of base runs: physics perturbations with no model-state perturbations.

4. Results

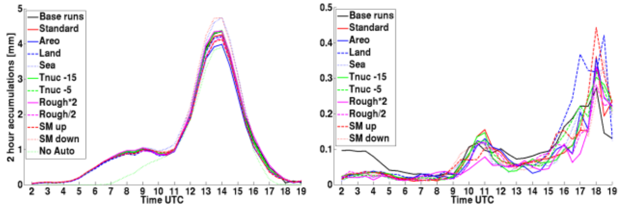
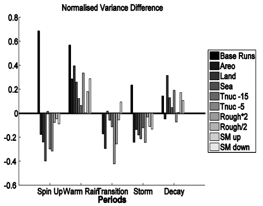


Figure 4 Left: ensemble-mean 2h accumulations within circle of 60km diameter around Boscastle. **Right**: ratio of standard deviation to ensemble mean.

- Resampling of a large test ensemble implies 8 members sufficient for sampling errors of less than 10% in ensemble-mean rain accumulations for circle of 60km diameter around Boscastle.
- Fractional skill score analysis (Roberts and Lean 2008) shows useful model skill for the storm on scales of 20km and larger.
- Ensemble means in close agreement (except when autoconversion disabled).
- Variability largest during development and decay of the storm.

NVD is calculated as $(\sigma^2-\sigma^2_{ref})/(\sigma^2+\sigma^2 r_{ef})$ and compares variance with that from the reference ensemble using model-state perturbations and standard physics. An ensemble of physics changes (labelled base) has larger variance for all periods other than the transition to the main storm, when triggering due to boundary-layer variability is the main uncertainty. Changing the physics generally tends to reduce somewhat the sensitivity to model-state perturbations, except during the warm-rain period.

Figure 5 NVD plot to show differences between ensembles with different physics. The time periods are 1-5UTC (spin-up), 5-9UTC (warm rain), 9-12UTC (transition phase), 12-15UTC (storm) and 15-18UTC (decay).



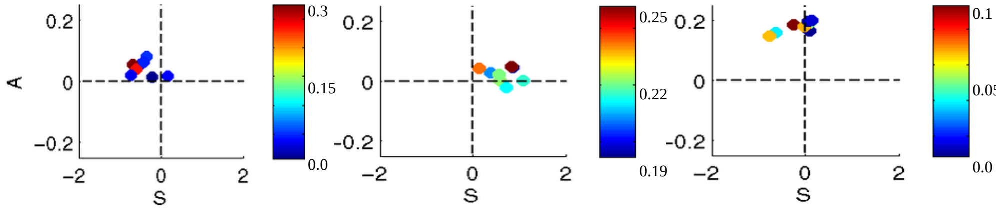


Figure 6 SAL differences for model-state ensemble members relative to their base run. **Left**: standard physics. **Centre**: increased aerosol over sea. **Right**: reduced roughness length over land.

- A SAL analysis (Wernli et al 2008) gives scores for Structure, Amplitude and Location errors for comparing simulated and observed accumulations.
- Here, we use the method to compare characteristics of the simulated convective cells between ensemble members with model-state perturbations and their corresponding base run.
- With standard model physics, model-state perturbations produce cells that are smaller and more peaked (S<0).
- With increased aerosol over the sea, model-state perturbations produce cells that are broader and flatter (S>0) and somewhat displaced (L).
- With reduced roughness over land, model-state perturbations produce cells that precipitate more strongly (A>0)

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5. Conclusions

- The Boscastle flood had strong predictability (given a convective-scale NWP model)
- For accumulated rainfall close to Boscastle, spread from model-state perturbations similar to spread from model-physics uncertainty
- For this case, a suitable ensemble could be generated with a very simple method, without needing to understand the detailed physics of the case
- But the spread may be achieved somewhat differently, different physics changing cell characteristics and exhibiting different sensitivities to model-state perturbations

6. References

Roberts, N. M. and Lean, H. W. Scale-selective verification of rainfall accumulations from high-resolution forecasts of convective events. Mon. Wea. Rev. 136:78-97, 2008.

Wernli, H., Paulat, M., Hagen, M. And Frei, C. SAL – a novel quality measure for the verification of quantitative precipitation forecasts. Mon. Wea. Rev. 136:4470-4487, 2008.

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