Department of Meteorology

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Evaluation of a Physically-Based Stochastic Boundary-Layer Perturbation Scheme using a Super-Ensemble

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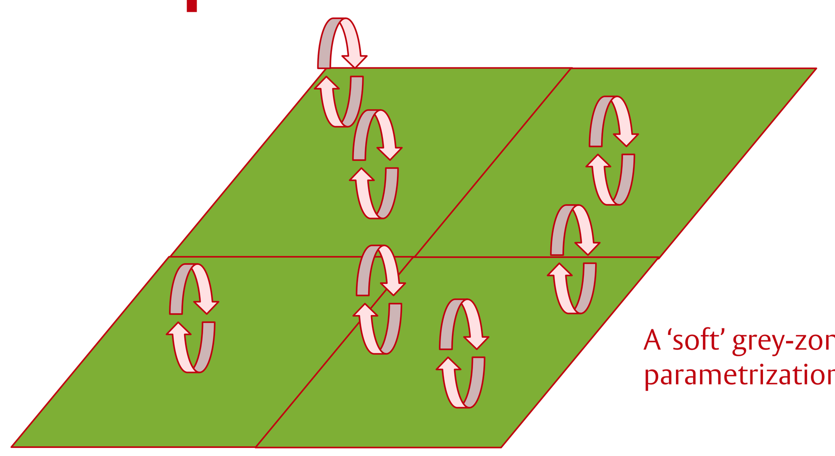
Introduction

Considerable research effort has gone into characterising the uncertainty in initial conditions in a numerical forecast, and, when applied to limited area models, this translates into uncertainty in boundary conditions through the generation of a host ensemble forecast. We call this Initial and Boundary Condition (IBC) uncertainty. On the other hand, while we recognise that forecasts are subject to uncertainty because of uncertainty in the treatment of diabatic processes, it is much more difficult to quantify this uncertainty.

Here we consider a simple but physically realistic representation of a fairly well-understood source of uncertainty, namely the inherent turbulent variability of the boundary layer, and develop methods to compare the stochastic boundary layer (SBL) uncertainty with IBC uncertainty.

The SBL perturbation scheme



The basic idea:

- The BL is modified by random, discrete events ('thermals').
- Thermals have scale $\sim h$=BL depth and are not spatially resolved.
- Hence only the number of 'thermals' occurring in a given area affects the variability.
- Temporal correlation occurs on eddy turnover timescale, τ_*.

Mathematical Framework:

- $\Delta\phi_{stochastic} = \Delta\phi_{average} + f_i \Delta\phi_{average}$
- $\Delta\phi$ is the increment in a timestep.
- $f_i = \mu f_{i-1} + (1-\mu)\left(\frac{n_i}{\lambda} - 1\right)$
- $\mu = \max\left(0, 1 - \frac{\delta t}{\tau_*}\right)$.
- n_i is number of thermals in timestep δt and area ΔA: Poisson distributed with mean $\lambda = \frac{\Delta A \delta t}{h^2 \tau_*}$.

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The 'Super-Ensemble' Framework

The Met Office's operation MOGREPS-UK ensemble prediction system formed the basis of this study, providing IBC perturbations in a 12-member 'convection-permitting' configuration with horizontal grid length 2.2 km, embedded in a 33 km grid length global ensemble.

Each member then generates a sub-ensemble using 11 different realisations of the SBL scheme plus a control member without the SBL scheme. Results are shown for an 8x8 grid box averaging area.

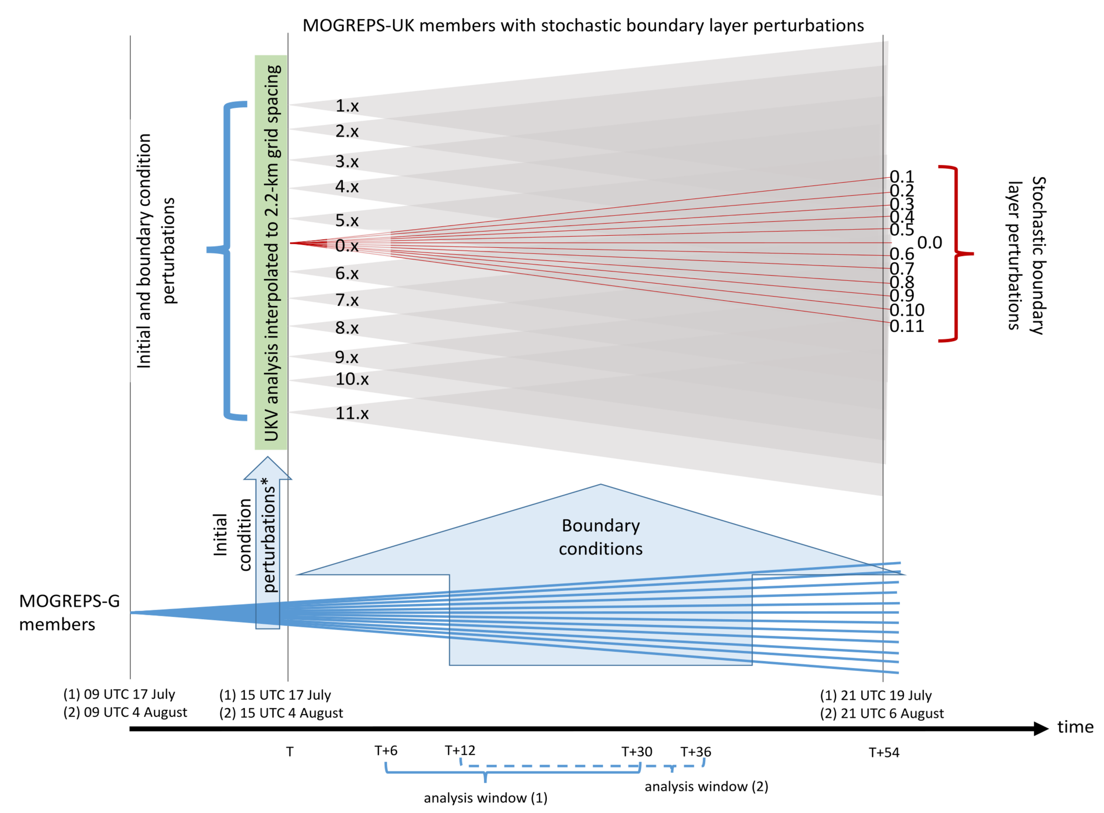

Figure 1. Illustration of the 'super-ensemble' configuration.

Cases Studied

We have studied two cases of severe convection over the UK but only the 'Coverack' case is shown here. This case is highlighted by a flash flood that swept through the village of Coverack in southern Cornwall. The convective event formed off the coast of Brittany at approximately 1200 UTC on 18/07/2017 and progressed northward, reaching Coverack at around 1400 UTC. The second case produced very similar conclusions; see Clark et al , (2021) and Flack et al (2021) for full descriptions of both.

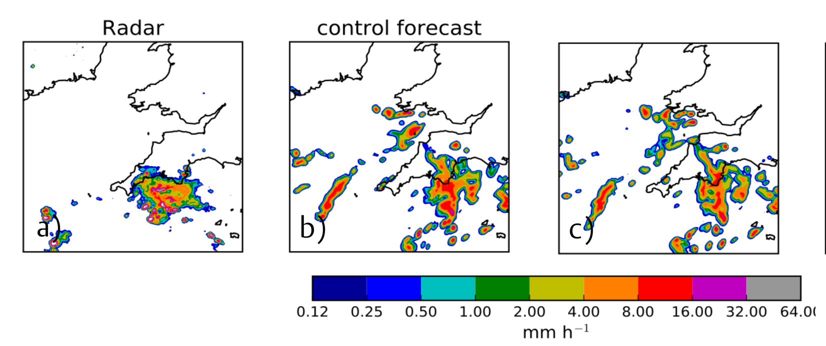

Figure 2. Snapshots of surface rainfall rate at 1400 UTC on 18/07/2017. a) Met Office Radarnet, b) control ensemble member, c) and d) two super-ensemble members.

Perturbation Growth

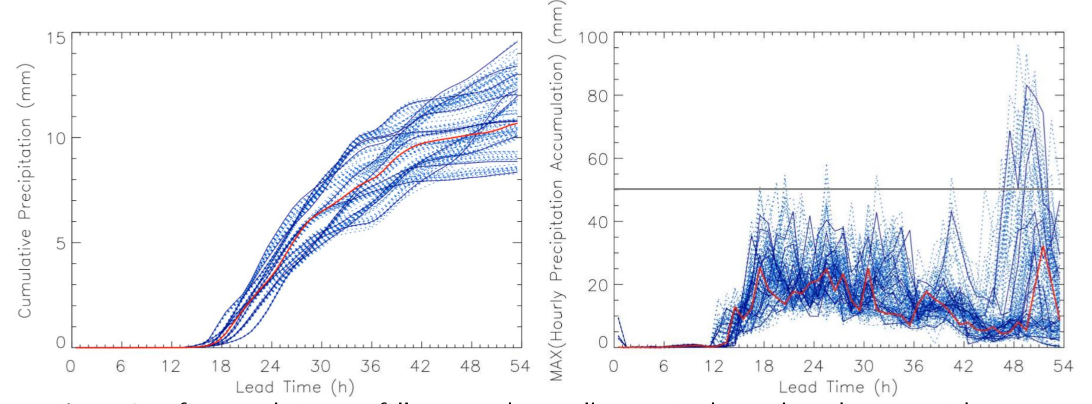

Figure 3. Left : cumulative rainfall averaged over all points in the analysis domain . Right: maximum hourly accumulation of any grid point within the analysis domain across the forecast .The solid lines represent the control sub-ensemble members (a.0), the red line is the control forecast of the SE (0.0), and the dashed lines are the stochastic ensemble members (a.x). The gray horizontal line in the right panel indicates 50 mm.

- The SBL perturbations are small but accumulate and grow 'fill in the gaps' between MOGREPS-UK members. to produce significant variation between members after 12 h 'spin-up'.
- They produce little change in the overall accumulated rain (controlled by forcing) but have an impact on both the magnitude and locations of peak accumulations.

Scale-dependent Evaluation

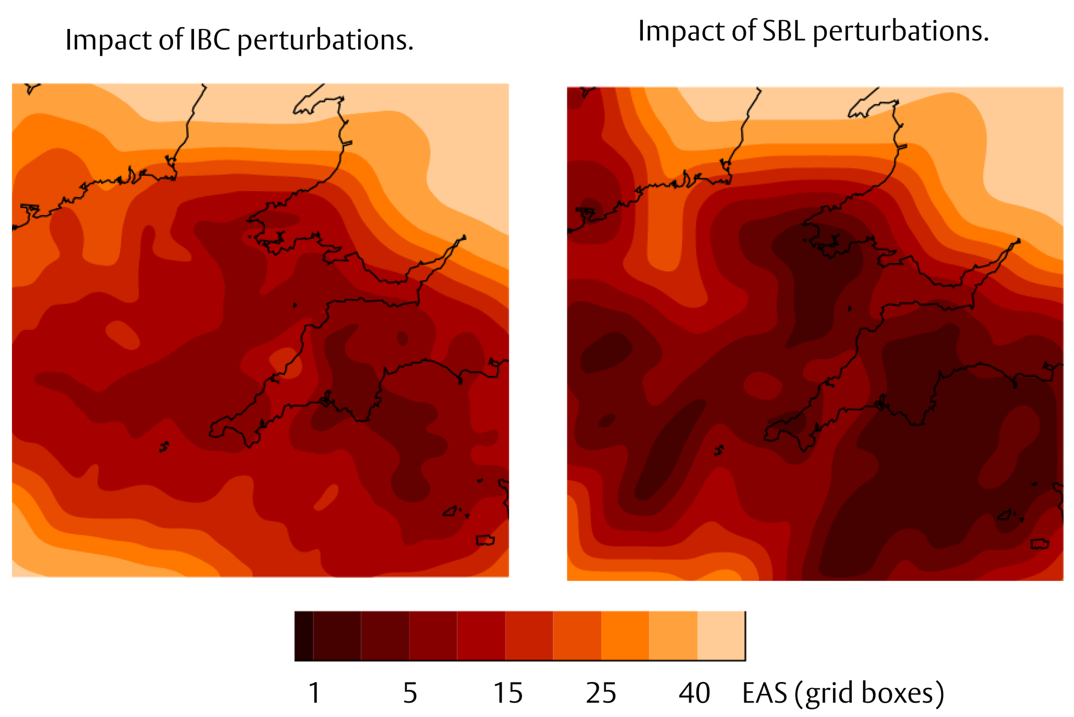

Figure 4. The ensemble agreement scale (EAS, in grid boxes) for the control IBC ensemble and the control SBL ensemble for the Coverack case at 1500 UTC.

The 'Ensemble Agreement Scale' (EAS) determines the spatial variation in spatial agreement between members.

- By comparing ensemble members, we can determine the scales at which they agree or differ.
- The SBL perturbations have an impact at smaller scales than the IBC perturbations.
- The spatial scale is not uniform in space or time but depends on the prevailing meteorology.
- The EAS from the IBC ensemble can provide suitable scales from which we can generate synthetic ensemble members using neighbourhood processing.

Neighbourhood Processing

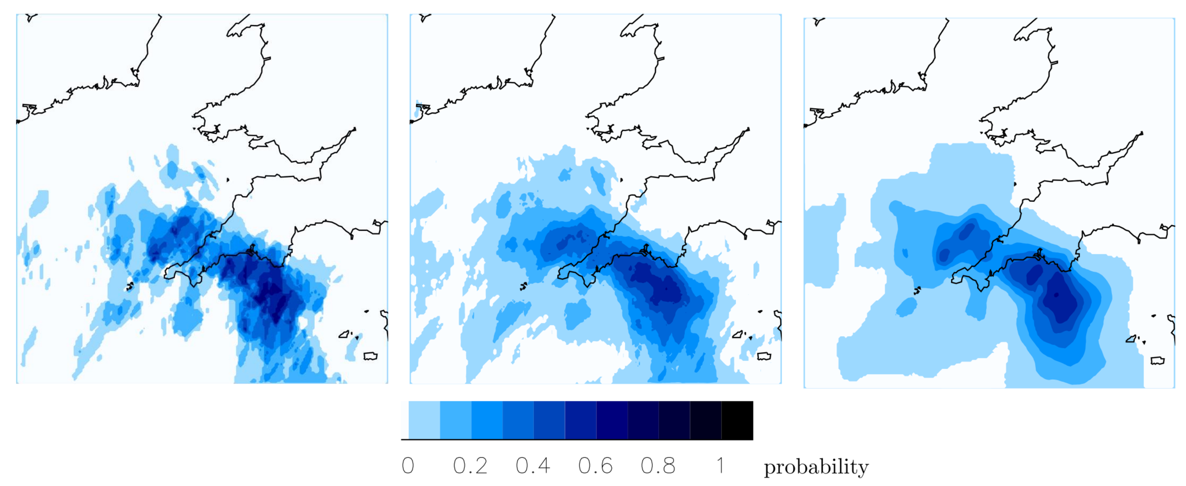

Figure 5. Probability for exceeding an hourly accumulation of 4mm for the Coverack case at 1500. Left: The probabilities from the IBCs (control sub-ensemble; a.0), centre: the full SE. Right: the control sub-ensemble (a.0) postprocessed to the neighbourhood size equal to the EAS at each grid point calculated from the control sub-ensemble.

- Convection-permitting ensemble members have considerable variability at cloud scale.
- A large ensemble would be needed to represent the true probabilities accurately.
- We take the distribution of precipitation rate on scales below EAS for the IBC ensemble as representative of those scales.
- This provides a 'dressing' for the IBC ensemble that smooths the predicted probabilities.
- The result is very similar to the probabilities derived from the super-ensemble.

Conclusions

- The SBL scheme, on its own, produces significant uncertainty compared with IBC uncertainty.
- On forecast timescales roughly 12-36 h typical of residence times in the domain, the SBL uncertainty is on a smaller scale than the IBC uncertainty but is sufficient to change the location of convective cells and hence location of extreme accumulations.
- The scale of predictability provided by the IBC uncertainty justifies treating smaller scales as providing a pdf without small scale spatial skill.
- Hence, for the cases studied, a neighbourhood post-processing technique to generate synthetic ensemble members produces similar results to the super-ensemble of IBC and SBL perturbations.

References

1. Clark et al.(2021). A Physically Based Stochastic Boundary Layer Perturbation Scheme. Part I: Formulation and Evaluation in a Convection-Permitting Model, JAS, **78**(3), 727-746.
2. Flack, et al. (2021). A Physically Based Stochastic Boundary Layer Perturbation Scheme. Part II: Perturbation Growth within a Superensemble Framework, JAS, **78**(3), 747-761.

Acknowledgements

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