Perturbation Growth at the Convective Scale

G. Leoncini, R. S. Plant, S. L. Gray and P. A. Clark

Joint Centre for Mesoscale Meteorology, University of Reading

Introduction 1

Severe rainfall from convective events is the leading cause of floods and flash floods over the summer months in the UK. Improvements in computational power mean that operational weather prediction models can now be run at convection-permitting resolutions. Poor convective-scale predictability is most likely due to the significant nonlinearities of the atmosphere at small scales (processes such as microphysics, radiation and flow dynamics are strongly coupled). This makes ensemble prediction systems particularly valuable. However, the techniques applied for the well-established generation of synoptic-scale ensembles cannot necessarily be applied at the convective-scale.

The aims of this study are to identify the physical processes that lead to perturbation growth at the convective scale in response to model-state perturbations and to determine their sensitivity to the character of the perturbations.

Methodology 2

- The Met Office Unified Model was run for a case observed during Intensive Observing Period 18 (IOP18) of the convective storms initiation project (CSIP).
- Gridsize is 4 km with 38 vertical levels.
- A modified version of the Gregory and Rowntree (1990) convective parameterization scheme was used that avoids the accumulation of high values of CAPE at the gridscale (forcing the model to explicitly resolve most deep convection).
- Model-state perturbations were implemented as random potential temperature perturbations at ∼1300m height.
- The perturbation fields were constructed by convolving a random number field with a Gaussian kernel. The structure of the perturbation field and effect of applying it are shown in Fig. 1.
- We considered both sequential perturbations (applied every 30 min., no temporal correlation) and single perturbations made at a specific time.
- Different perturbation amplitudes (1, 0.1 and 0.01 K) and scale lengths (σ=24, 8 and 0 km) were considered.
- Diagnostics were carefully chosen to reveal both the direct effects (within one timestep) and indirect effects (during the entire simulation) of the perturbations.
- Diagnostics included root mean square precipitation: $\boldsymbol{RMSP} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\boldsymbol{p_i} - \boldsymbol{c_i})^2}$ where $\boldsymbol{p_i}$ and $\boldsymbol{c_i}$ are the hourly-accumulated precipitation in the perturbed and control simulations respectively and summation is over those $\boldsymbol{N}$ grid points where $\boldsymbol{p_i}$ or $\boldsymbol{c_i}$ is at least **1** mm.

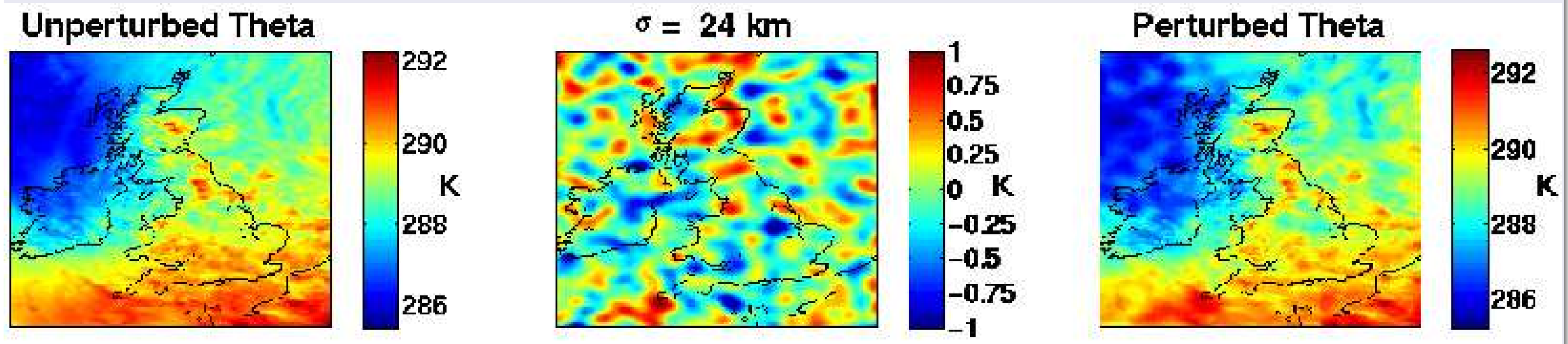

Figure: 1. Example structure of perturbation field (scale length 24 km, amplitude 1 K) and effect of applying it.

Case study: CSIP - IOP 18 3

- Strongly upper-level forced case (implying synoptic-scale predictability) but with detailed mesoscale/convective-scale evolution that was dependent on smaller-scale processes (such as secondary initiation).
- Southern England lay under a tropopause fold; widespread scattered convection and a day-time squall line were triggered (Fig. 2).
- Boundary-layer development was characterized by transition periods at sunrise and sunset (Fig. 3).

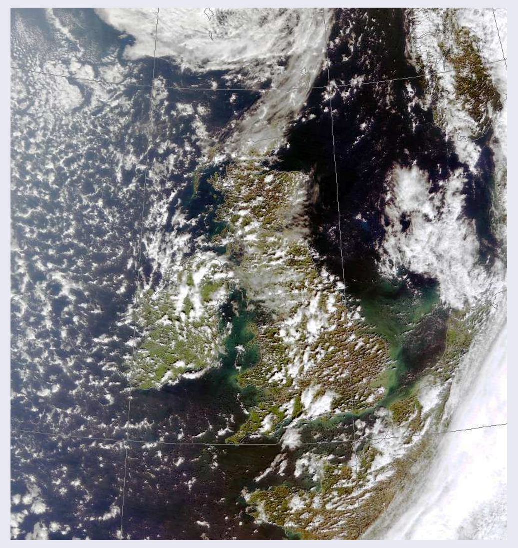

Figure: 2. Terra visible image at 1126 UTC August 25th 2006 - Dundee satellite receiving station.

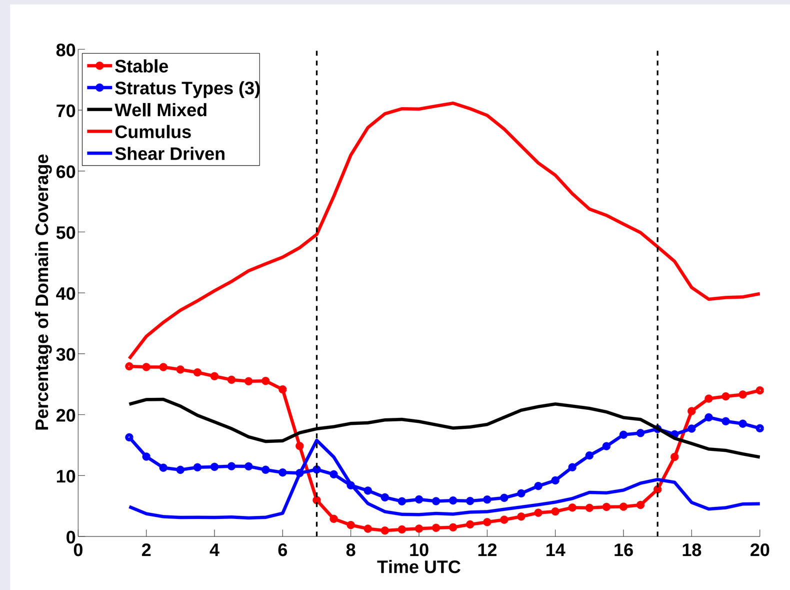

Figure: 3. Evolution of boundary layer types during the day.

Direct effects 4

The direct effects of the perturbations were

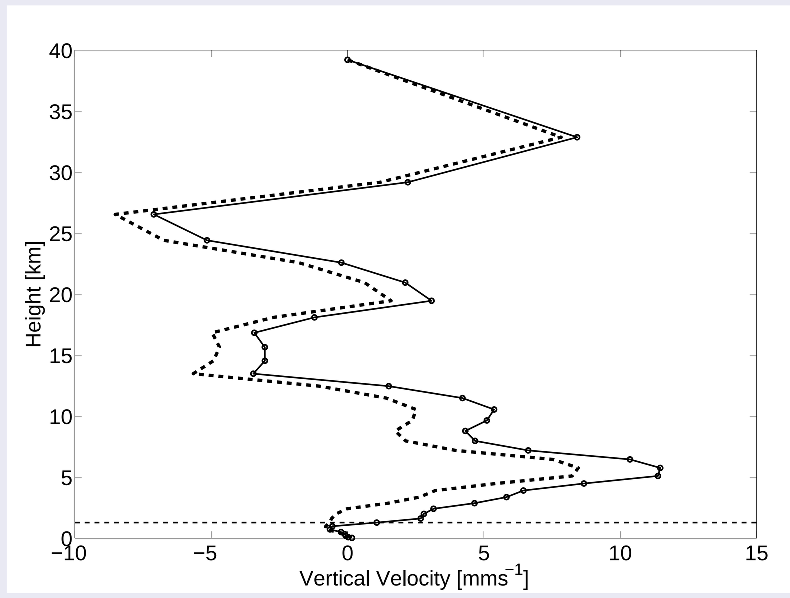

Figure: 4. Vertical velocity in the control run (dashed line) and run with 1 K amplitude perturbations applied at 0700 UTC (solid line) one timestep after the perturbation application averaged only over the grid points where the perturbation was positive in the perturbation run.

- Small perturbations in CAPE (except where the strongest perturbations set or removed a convective lid).
- Localised effects on cloud condensate.
- Boundary-layer-type changes at up to 2% of points.
- Generation of Lamb and acoustic waves (acoustic waves demonstrated in Fig. 4) that rapidly modified the environmental profile throughout the domain.

Indirect effects 5

The indirect effects of the perturbations were changes in the intensity and location of convection and cloud size distribution.

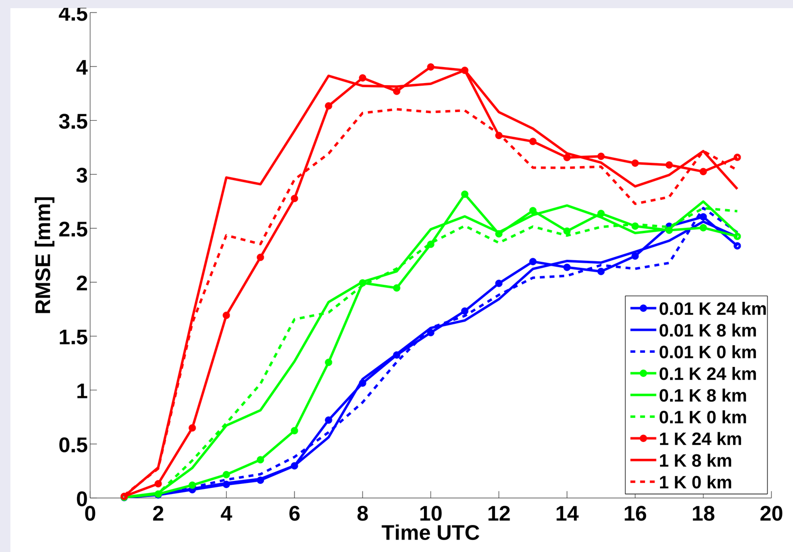

Figure: 5. Evolution of RMSP for nine sequential perturbation simulations with different perturbation amplitudes and scale lengths.

- RMSP most strongly controlled by the perturbation amplitude (Fig. 5).
- Similar RMSP values attained at the end of all perturbation runs (Fig. 5).
- Small amplitude perturbations had little effect on the precipitation until after sunrise (Fig. 5).
- The spread of random ensemble members increased with perturbation amplitude and is similar to the spread for different scale lengths (Fig. 6).
- The effect of perturbations was to change both the location (Fig. 7) and intensity of storms.

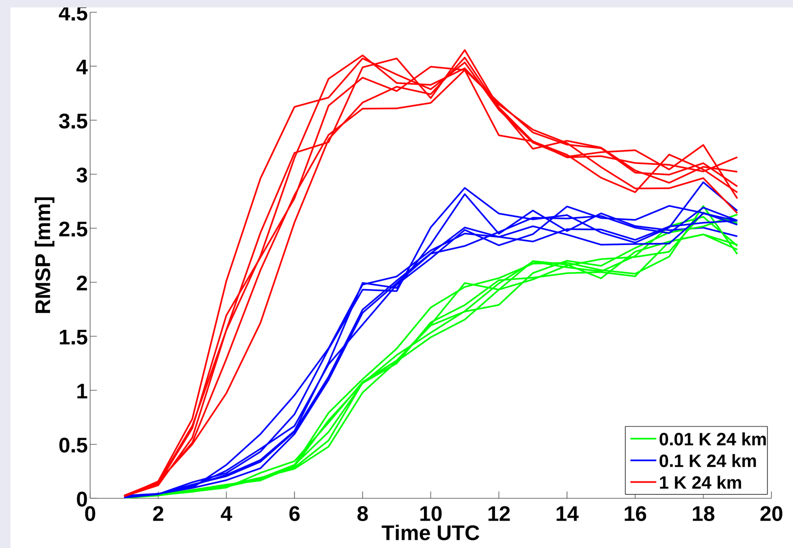

Figure: 6. Evolution of RMSP for three random ensembles (generated using different random number seeds) with different perturbation amplitudes.

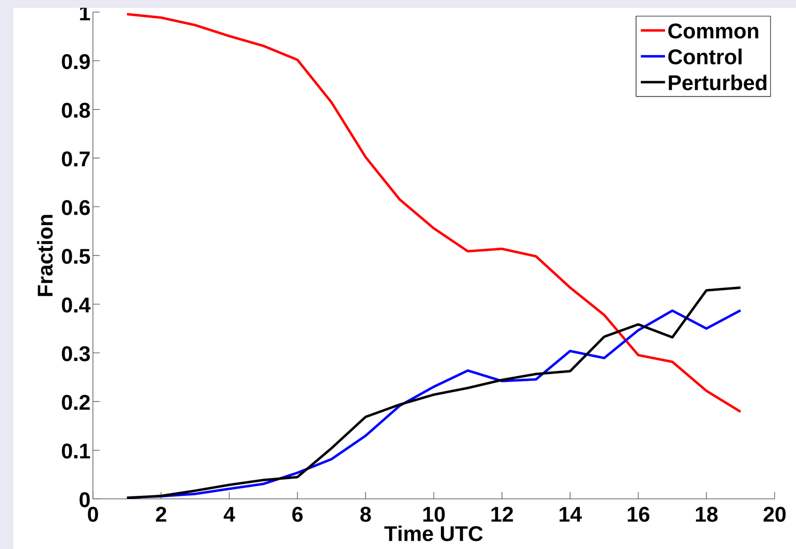

Figure: 7. Evolution of fraction of rainy gridpoints that are common to control and perturbation runs or found solely in perturbation or control run for perturbation run with amplitude 0.1 K and scale length 8 km

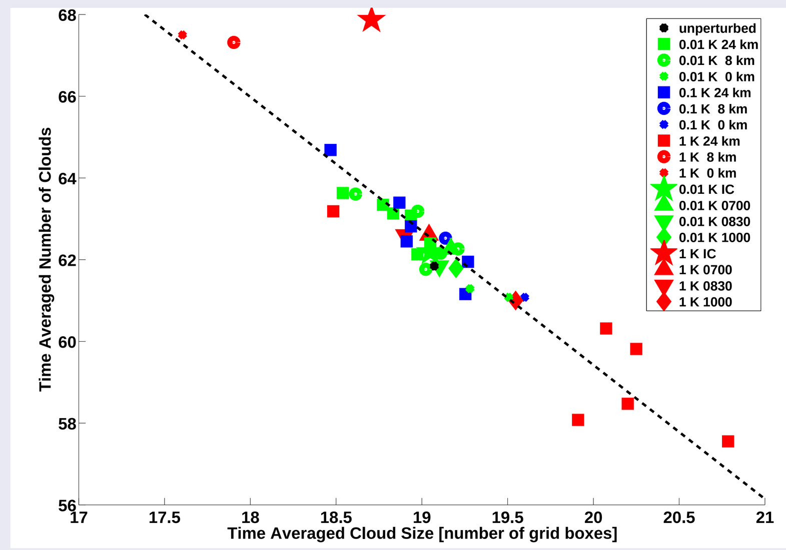

Figure: 8. Time averaged number of clouds against mean cloud size for precipitating clouds (rates exceeding 1 mmh^{-1}).

- Mean size of clouds is smaller if there are more of them (Fig. 8).
- Significant deviation from control (black circle) for runs with 1 K perturbations (Fig. 8).
- Outlier (red star) is run where perturbations were applied to initial conditions only (Fig. 8).

Conclusions 6

- The processes leading to the growth of convective-scale model-state perturbations and the sensitivity of the perturbation growth to the perturbation characteristics have been investigated for a CSIP case study.
- Spatially coherent but temporally incoherent potential temperature perturbations were applied every 30 min. (or just once) during simulations.
- The direct effects of the perturbations were to generate propagating Lamb and acoustic waves and produce generally small changes in cloud parameters and convective instability. Exceptionally, switching of the diagnosed boundary-layer type or discontinuous changes in convective instability occurred.
- The indirect effects were changes in the intensity and location of precipitation and in the cloud size distribution.
- Qualitatively different behaviour was found for strong (1 K amplitude) and weak (0.01 K amplitude) perturbations with sensitivity to the time of day found only for the weaker perturbations.
- But, the overall perturbation growth reached similar values at saturation, regardless of the perturbation characterisation.

References, acknowledgements and contact information

References:

Gregory D, Rowntree PR. 1990. A mass flux convection scheme with representation of cloud ensemble characteristics and stability-dependent closure. *Mon. Wea. Rev.* **118**: 1483–1506.

Acknowledgements: This project is NERC funded through the Flood Risks from Extreme Events (FREE) programme. We thank the Met Office for making the MetUM available and NCAS (National Centre for Atmospheric Science) CMS (Computational Modelling Services) for providing computational and technical assistance.

Contact info.: Giovanni Leoncini, Department of Meteorology, University of Reading, Earley Gate, PO Box 243, Reading, RG6 6BB, UK. email: g.leoncini@reading.ac.uk.