Modelling convective precipitation unresolved by NWP using an ensemble-based approach within the Short Term Ensemble Prediction System (STEPS)

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1. Introduction

Recent Met Office R&D has focused on the development of STEPS (Short Term Ensemble Prediction System), a stochastic precipitation nowcast scheme capable of quantifying nowcast errors and conveying these to the customer. STEPS blends an extrapolation nowcast (derived using radar inferred analyses of rain rate) with deterministic, mesoscale NWP model forecasts of rain rate and stochastic noise. The noise component has spatio-temporal statistical properties inferred from the radar data. The evolution of the predicted field of rain rate is modelled in a scale-dependent way using a cascade model framework (Lovejoy *et al.* ,1996; Venugopal *et al.*,1999). Sources of error considered include uncertainties in the advection and Lagrangian evolution of the extrapolation nowcast, NWP forecast displacement/timing errors and bias.

STEPS makes no attempt to model the uncertainty arising from the failure of the NWP model to predict showers triggered by unresolved, sub-grid scale forcings. At the Met Office, the CDP (Convection Diagnosis Programme – Hand, 2002) was implemented in conjunction with the Mesoscale Model (~12 km grid length configuration of the Unified Model) for this purpose. The CDP post processes Mesoscale Model model output to estimate the probability of occurrence of showers. Use is made of sub-grid scale forcing data and NWP model error statistic climatologies for pertinent variables. These data are used to increment to the Mesoscale Model's level 1 temperature, moisture and wind fields by amounts that correspond to predefined probabilities of convective initiation. Here, we describe a modified version of the CDP, designed to generate an ensemble of CDP convective precipitation forecasts for integration with a STEPS ensemble.

2. STEPS description

- STEPS blends extrapolation and high resolution (~4 km grid length) NWP forecasts of precipitation with stochastic noise. Blending is performed in a scale-dependent way using a cascade modelling framework (Lovejoy *et al.* ,1996; Venugopal *et al.*,1999). This framework allows the scheme to capture the scale-dependent loss of predictive skill in the extrapolation forecast with advancing lead time (Venugopal *et al.*, 1999; Germann and Zawadzki, 2002) and the scale dependence of the skill of the NWP model forecast.
- The evolution of the extrapolation forecast is modelled separately on each level in the cascade using a hierarchy of second order Auto-Regressive (AR-2) models (Seed, 2003)

$$Y^e_{k,i,j}(t+t_l)=\phi_{k,1}(t)\cdot Y^e_{k,i,j}(t+t_l-\Delta t)+\phi_{k,2}(t)\cdot Y^e_{k,i,j}(t+t_l-2\Delta t)$$

where $Y^e_{k,i,j}(t+t_l)$ is the predicted extrapolation cascade valid at lead time, t_l, based upon similar cascades valid at the two previous lead times. The AR-2 parameters, $\phi_{k,1}(t)$ and $\phi_{k,2}(t)$, control the rate of evolution at each scale and are determined from a sequence of three rain analyses.

- The temporal evolution of the noise is controlled by the same AR-2 parameters

$$Y^n_{k,i,j}(t+t_l)=\phi_{k,1}(t)\cdot Y^n_{k,i,j}(t+t_l-\Delta t)+\phi_{k,2}(t)\cdot Y^n_{k,i,j}(t+t_l-2\Delta t)+\phi_{k,0}(t)\cdot \varepsilon_{k,i,j}(t+t_l)$$

where $Y^n_{k,i,j}(t+t_l)$ is the predicted noise cascade valid at lead time, t_l, and $\varepsilon_{k,l,j}(t)$ is a temporally independent but spatially correlated noise cascade generated for each time step.

- A forecast is produced by blending the extrapolation, noise and NWP cascades

$$Y_{k,i,j}(t+t_l)=w^e_k(t+t_l)Y^e_{k,i,j}(t+t_l)+w^m_k(t+t_l)Y^m_{k,i,j}(t+t_l)+w^n_k(t+t_l)Y^n_{k,i,j}(t+t_l)$$

where w^e_k, w^m_k and w^n_k are the weights applied to the extrapolation, NWP and noise cascades respectively. The weights applied to the extrapolation component are derived from the AR-2 auto-correlation coefficients. Those ascribed to the NWP forecast are based upon its skill, estimated by cross correlation with a recent rain analysis.

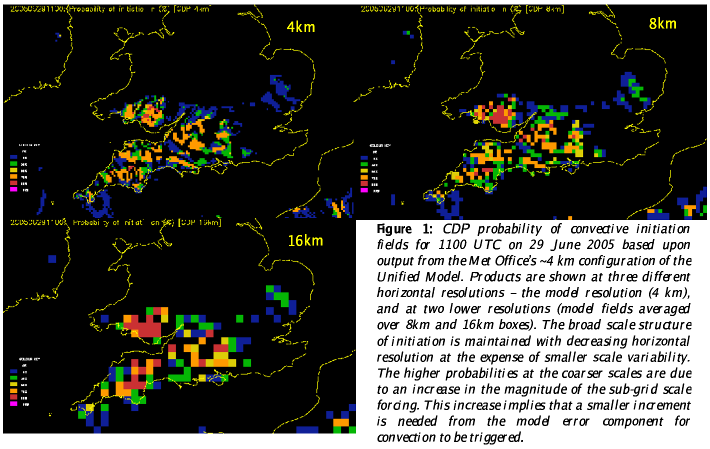

Figure 1: *CDP probability of convective initiation fields for 1100 UTC on 29 June 2005 based upon output from the Met Office's ~4 km configuration of the Unified Model. Products are shown at three different horizontal resolutions – the model resolution (4 km), and at two lower resolutions (model fields averaged over 8km and 16km boxes). The broad scale structure of initiation is maintained with decreasing horizontal resolution at the expense of smaller scale variability. The higher probabilities at the coarser scales are due to an increase in the magnitude of the sub-grid scale forcing. This increase implies that a smaller increment is needed from the model error component for convection to be triggered.*

References

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Lovejoy, S., Duncan, M. R., and Schertzer, D., 1996: Scalar multi-fractal radar observer's problem. *J. Geophys. Res.*, **101(D21),** 26479-26491.

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3. CDP description

The operational version of the CDP run at the Met Office post processes output from the Mesoscale Model (~12 km configuration of the Unified Model), and generates a range of probabilistic precipitation forecast products for predefined probabilities of convective initiation. The ensemble version of the CDP, developed for integration with STEPS, post processes output from the ~4 km configuration of the Unified Model, and produces a range of convective rainfall scenarios by the addition of random increments to the level 1 temperature, moisture and wind fields.

a) Components of both the operational and ensemble versions of the CDP

- Increments are added to the Unified Model level 1 temperature, moisture and wind fields and passed to the convection scheme. Increments are a combination of a sub-grid scale forcing component and NWP model errors derived from operational verification statistics.
- Sub-grid scale forcings considered are: elevated heating and forced ascent due to sub-grid scale orography, variations in temperature and humidity due to land-use type inhomogeneities, and general background variations in temperature and humidity.
- Grid mean rain rates and convection diagnostics taken from the Unified Model convection scheme are passed to a lifecycle model. This predicts the temporal evolution of individual convective cells.

b) Operational version

- The response of a parcel at level 1 to increments in temperature, moisture and wind speed corresponding to prescribed probabilities of occurrence (10%, 30%, 50%, 70%, 90%) is tested using the convection scheme until the smallest increment that results in convective rain is found.
- The forcing mechanism with the highest probability of initiation is assumed to generate the shower.

c) Ensemble version

- Random increments of temperature, moisture and wind are sampled from *pdf*s based upon expected error distributions and added to the level 1 model variables.
- The forcing mechanism that results in the highest convective rain rate is assumed to be responsible for shower initiation.

d) Scale considerations

- The ensemble version of the CDP post processes output from the ~4km configuration of the Unified Model. Tests have shown that the computational expense of running the CDP at this grid length is prohibitive, so upscaling of model fields is required. **Figure 1** shows that increasing the grid length leads to some loss in small scale variability in the probability of initiation field but the broad structure of the field is maintained.

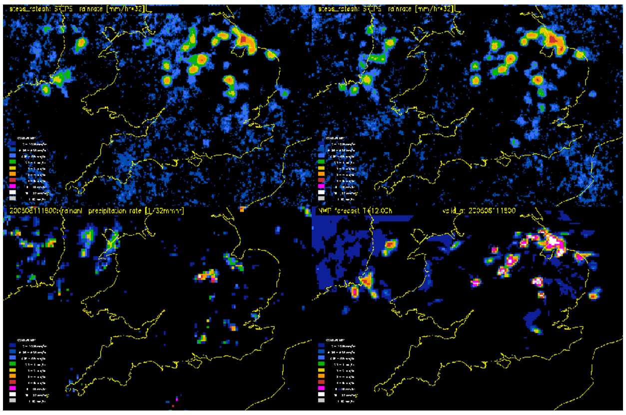

Figure 2: *Two members of a STEPS ensemble forecast of rain rate valid at 1800 UTC on 11 August 2005 (T+2hrs) incorporating CDP convective rain within the NWP forecast component (top row). The verifying radar composite rain rate is shown bottom-left, and the unmodified ~4km Unified Model forecast rain rate bottom-right. The shower observed to the north of the Isle of Wight was not forecast by the Unified Model, but when CDP output is added both STEPS members forecast a shower in the vicinity. This shower is more intense in the ensemble member on the right.*

4. Combining the CDP with STEPS

a) Add CDP rain to the NWP component (see **Figure 2**)

- Generate an ensemble of CDP forecasts.
- Use the CDP lifecycle model to control the temporal evolution of convective cells. This approach only allows single cell showers to develop.
- Add the grid mean rain rate from the CDP lifecycle model to the NWP forecast where no rain exists in the NWP forecast.
- Perform cascade decomposition on NWP forecast field with CDP rain added.
- The weight assigned to the CDP modified NWP forecast is that given to the NWP forecast without the CDP added.
- Stochastic noise adds small scale structure to the CDP and NWP rain.

b) Use CDP probability of initiation to condition the noise component of STEPS

- Run the operational version of the CDP.
- The probability of initiation field defines neighbourhoods where initiation is possible.
- At locations where there is a finite probability of initiation, the relevant cascade level variances and/or means of the temporally independent component of the noise, $\varepsilon_{k,l,j}(t+t_l)$, are enhanced in an appropriate number of ensemble members.
- The noise is used to model the precipitation structure of the showers. This allows multi-cell showers to develop.
- Temporal evolution of the showers is controlled by the AR-2 models.

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