JP3.1 STATISTICAL METHODS FOR NOWCASTING THUNDERSTORM RAINFALL

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1. INTRODUCTION

For many hydrological applications, especially flash flood warning and urban drainage management a good short period forecast of heavy rainfall is required. However, the deterministic nowcasting of thunderstorm motion and development has proved a difficult problem in meteorology due to the short spatial and temporal continuity of convective systems. For the effective hydrological use of intense precipitation nowcasts a deterministic method can be misleading. As all forecasts have an inherent error, any attempt to use a deterministic forecast of precipitation in a hydrological application, without reference to the range of outcomes and their impact on the hydrological situation, will inevitably result in poor hydrological forecasts. Methodologies that use simple extrapolation techniques (e.g. TITAN: Dixon and Weiner1993; SCIT: Johnson et al. 1993) cannot provide information that can be applied for such hydrological applications in a robust manner. These methods lack the ability to show development of systems and fail to provide a measure of error associated with the nowcast. Systems that attempt to model storm development (e.g. GANDOLF: Pierce et al. 2000) have been demonstrated to be very sensitive to the data used to parametrise the convective model (Sleigh 2002) and, again, do not provide error characteristics. In this paper we demonstrate the use of a statistical method of nowcasting.

The methodology presented herein utilizes an approach that efficiently parameterizes spatio-temporal dynamic models in a hierarchical framework. Furthermore, this approach can easily incorporate additional information to aid in the nowcast. Finally, we note that the approach accounts for the uncertainty in the prediction and provides relevant distributional information concerning the nowcast. Case studies are presented that show the effectiveness of the technique and its potential for hydrological use.

The authors present a new method based on Bayesian statistical methods that aims to produce a deterministic nowcast of convective storm location and intensity bracketed by knowledge of the probability of error. The methodology also deals on a pixel-by-pixel basis which allows for greater flexibility in forecasting structural changes in storms compared with cell or object oriented schemes.

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2. METHODOLOGY

Consider the stochastic integro-difference equation (IDE) for an underlying spatio-temporal process $y_t(s)$ which in general is assumed to be continuous in space and discrete in time:

$$y_{t+1}(s) = \gamma \int k_s(r;\theta_s) y_t(r) dr + \tilde{\eta}_{t+1}(s) \qquad \textbf{(1)}$$

where s and r are spatial locations in the domain of interest, $k_s(r;\theta_s)$ is a redistribution kernel that describes how the process at time t is redistributed in space at time t+1, μs are parameters of the redistribution kernel (that may be spatially varying), ˜´ is a spatially-colored noise process that is independent across time, and ° is a growth/stationarity parameter. Note that there is a substantial literature on deterministic integro-difference equations in the mathematical ecology literature related to the dispersal of ecological processes over time (e.g., Kot et. al 1996). Stochastic versions of the IDE model have been considered by Wikle and Cressie (1999), Brown et al. (2000), and Brown et al. (2001), and Wikle (2001, 2002).

It is well-recognized in the ecology literature that the deterministic IDE framework can accommodate diffusive dynamics, and that the behavior of the dynamics is determined from the kernel specification (e.g., Kot et al. 1996). Wikle (2001,2002) showed that the IDE representation is significantly more powerful in that it can model more complicated dynamical behavior, including the propagation of spatial features through time. For illustration, consider the one-dimensional Gaussian spatial kernel,

$$k_s(r,\theta_1,\theta_2) = \frac{1}{\theta_2\sqrt{2\pi}} \exp\left\{\frac{-.5(r-\theta_1-s)^2}{\theta_2}\right\} \textbf{(2)}$$

where the kernel is centered at $\theta_1 + s$ and thus is shifted by θ_1 spatial units relative to location s, and θ_2 is the scale parameter. We refer to θ_1 as the translation parameter and θ_2 as the dilation parameter. In the IDE kernel context, these parameters influence the dynamical evolution of the y process. Specifically, the dilation parameter controls the diffusion, such that wider kernels imply greater diffusion. The translation parameter controls the propagation. If the kernel is shifted to the left (right) of the center, propagation is to the right (left). In the two-dimensional spatial setting, the Gaussian kernel is elliptical and controlled by two shift parameters, two dilation parameters, and an orientation parameter (corresponding to the mean, variances and correlation parameters of a 2-dimensional normal distribution, respectively). Again, the diffusion properties are largely controlled by the dilation parameters, and the propagation is controlled by the shift parameters; the propagation is essentially in the opposite direction to the kernel shift, relative to location *s*.

The IDE representation is even more powerful if one considers a spatially-varying kernel, in which the parameters are allowed to vary with space. Such spatially-varying (heterogeneous) kernels can capture more complicated dynamics than homogeneous kernels in that the speed and direction of propagation can vary throughout the spatial domain of interest. The difficulty with allowing the kernel parameters to vary with space is the large number of parameters that must be estimated. However, as discussed in Wikle (2002), we are able to proceed by utilizing an equivalent spectral representation of the stochastic IDE as well as modeling the parameters as spatial random fields in a hierarchical Bayesian framework.

In the context of the radar nowcasting problem, the past radar images inform the kernel orientations for the current time, which in turn, controls the propagation of disturbances in the forecast. Specifically, the disturbance is propagated in a pixel-by-pixel fashion, in such a way that all of the pixels that make up a disturbance do not necessarily move in the same fashion - they may move into regions that have different kernel orientations than their neighbors. However, we note that the model inherently "blurs" or smooths the disturbances by the averaging nature of the kernel (e.g., Brown et al. 2000). In addition, this approach does not allow one to predict (i.e., generate) new disturbances that are not suggested by past data. Modifications to the methodology, in which other weather parameters are used to suggest new development, could be implemented in principle.

The Bayesian method produces a full predictive distribution of forecasts in addition to the average forecast. Although it is not presented in this paper one can access the full realization of the nowcast or estimates of predictive error.

3. CASE STUDY

Studies have been made using data collected during the World Weather Research Programme Sydney 2000 Forecast Demonstration Project (Fox et al. 2001, Keenan et al. 2002). Four cases were selected to examine; three of these involved convective storms and the fourth a frontal stratiform rainfall event. In this paper we present preliminary results from one of these cases, that of 3 November 2000. On this day several convective cells developed in the Sydney region. One of the cells developed into a supercell, spawning at least three tornados. The meteorology of this case has been examined by Sills et al (2002). The development and propagation of the convective cells on this day was particularly complex with a strong sea breeze front and a large number of boundaries generated by outflows from the various cells.

Figure 2 shows a sample forecast. In this instance, radar data was available at 10 minute intervals and 1.5km CAPPI data were used. Six scans were used to train the model, with the forecast run out to T+40, again at 10 minute steps. The model appears to capture the non-linear motion of the cell and retain some of the intensity features, although these are not accurately forecast.

4. DISCUSSION

The work presented here is at any early stage. The results presented show promise that the statistical method can capture cell motion and development. As mentioned above there is potential to incorporate other meteorological parameters into the model to constrain the motion and development of the systems. The authors intend to pursue this avenue starting with windfield data. This approach should allow a more realistic nowcast to be produced. We will also examine further cases and develop more efficient programs so that longer nowcast periods can be examined and the model run more quickly.

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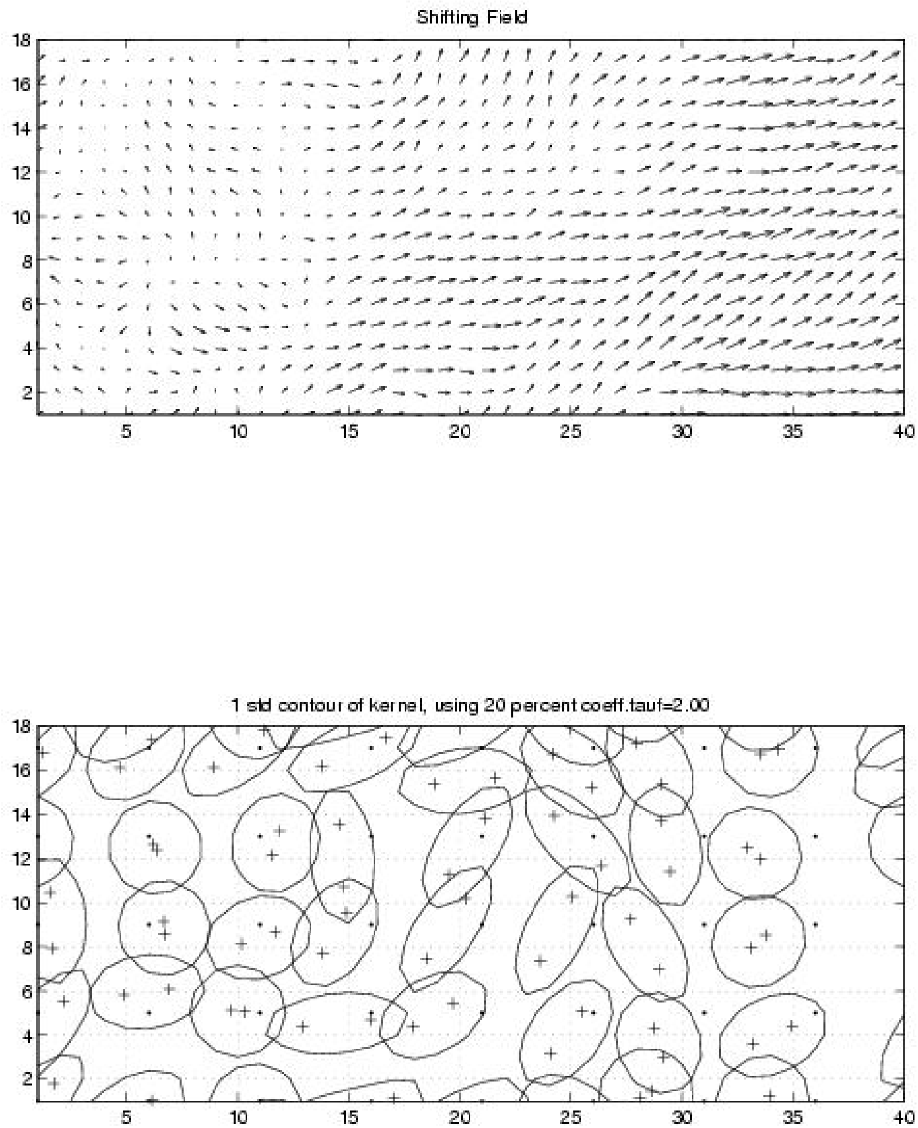

Figure 1. The top panel shows the estimated propagation orientation as suggested by the spatially-varying kernels shown in the bottom panel. These estimates are based on the 3 November 2000 storms in Sydney, shown in Figure 2.

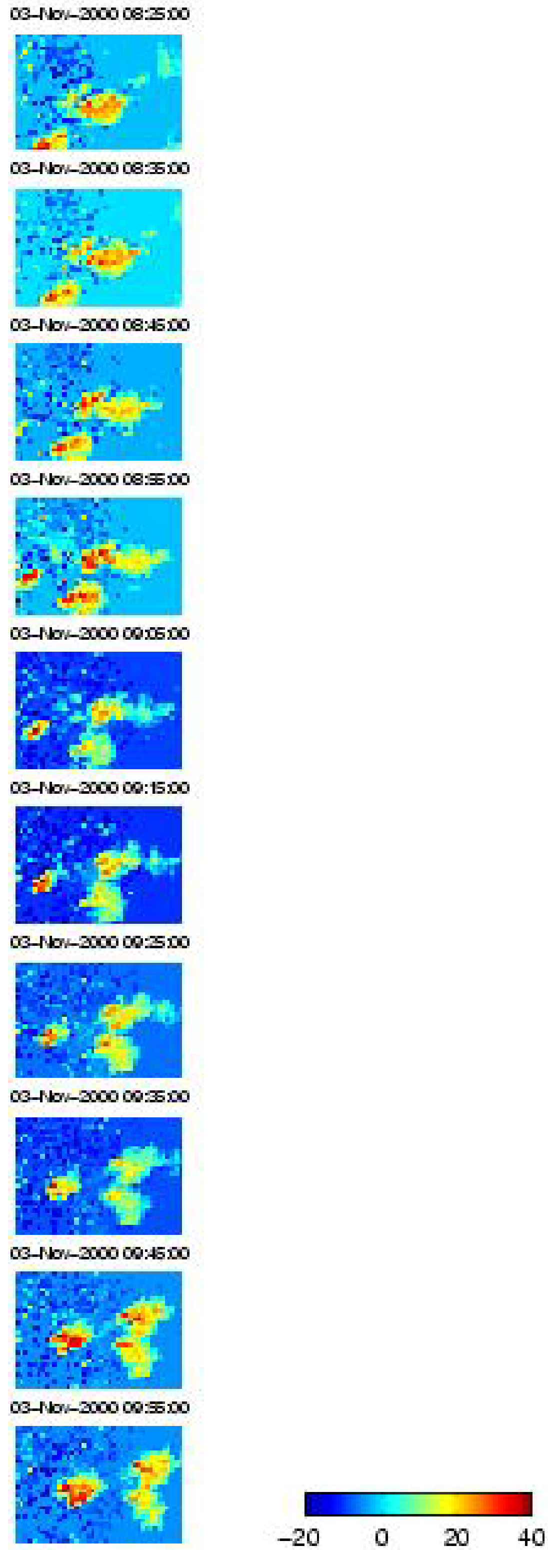

Figure 2. Estimation and nowcast of storms in Sydney on 3 November, 2000. The left panel shows consecutive 10 minute returns, with the right panel showing the model estimates for the first 6 time periods (i.e., the model training period) and forecasts out to 9:55 based on data through 9:15.