8.13 THE PERFORMANCE OF THE GANDOLF NOWCASTING SYSTEM DURING THE SYDNEY 2000 FORECAST DEMONSTRATION PROJECT

M.W. Sleigh[1*], N.I. Fox[1], C.G. Collier[1], and C.E. Pierce[2]
[1]University of Salford, UK and [2]Meteorological Office, UK

1. INTRODUCTION

During the Sydney 2000 Olympic Games a number of nowcasting systems were tested and demonstrated as part of the World Weather Research Programme’s Sydney 2000 Forecast Demonstration Project (Keenan *et al*, 2001). One of the systems was GANDOLF, the UK Met. Office’s semi-operational automated convection nowcasting system. GANDOLF relies on a conceptual model of the life cycle of a convective cell to produce surface precipitation forecasts out to 3h ahead. The University of Salford is using the data collected during the FDP as part of a research project to improve conceptual model-based forecasts of severe weather.

2. THE GANDOLF SYSTEM

GANDOLF was developed in the mid-nineties as a response to requests from the UK Environment Agency (whose remit includes disseminating flood warnings) for improved quantitative precipitation forecasts during convective events. The original work, by Hand and Conway (1995) and Hand (1996), was based around an idealised convective cell life cycle with 5 stages of development. GANDOLF determined the stage of development of analysed cells by comparing their vertical radar reflectivity profiles with idealised profiles for each stage. Cells were then advected by the mesoscale model wind using a simple steering level model propounded in Bennett *et al* (1986) – the steering level is deemed to be at a height equal to the cloud base height plus of the cloud’s depth. Growth and decay were predicted by assigning cells with a development potential, which determined how the cell would progress through the sequence of development stages. This method was removed after extensive testing in Sydney, since forecasts were being made without any direct knowledge of the dynamic or thermodynamic structure of the troposphere. Furthermore precipitation rates were seen to pulse cyclically, since the cells tended to advance into the next stage of development simultaneously – a consequence of cell stages having fixed durations which were multiples of ten minutes. To remedy this, a scheme was introduced which allowed the duration of growing cell stages to be determined from theoretical parcel ascent times to levels corresponding to each stage, and for decaying cell stages to be determined using an empirical relationship between Lagrangian decorrelation time and storm-relative helicity (Pierce *et al*, 2000).

3. SYSTEM PERFORMANCE

Performance statistics, such as POD, FAR and CSI were calculated for a number of storm events during the project using the method described in Sleigh *et al* (2000). In particular a supercell occurred on 3 November 2000 which was associated with cricket ball-sized hail and at least three confirmed tornadoes. POD, CSI and FAR are plotted against leadtime in Fig. 1, averaged over all forecasts made during the event.

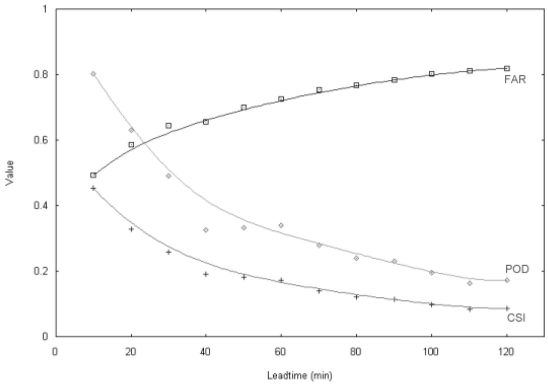

Fig 1 Performance statistics for 03/11/2000

GANDOLF forecasts made during the project show a marked improvement over those made during testing (Sleigh *et al*, 2000), due to the improvements in the way the cell life cycle is handled by the model. However, subjective analysis during the project indicated that GANDOLF dissipated storms much too quickly, and often when the storm was clearly growing. This is due to the fact that the stability profile obtained from the mesoscale model was rarely unstable enough to maintain storms alone. Storms were enhanced by large-scale forcing, orographic enhancement and local-scale convergence, none of which is accounted for in the model. Explicitly accounting for large-scale forcing is beyond the scope of current work, but it is believed that some improvement would be made should the cell stage identification scheme rely on the historical and dynamic properties, rather than the static properties, of a cell at a given moment in time. Doswell (1996) states that “…important events that are created by the

---

[*] *Corresponding author address:* Michael Sleigh, TIES, D12, Peel Building, University of Salford, M5 4WT, UK

same physical processes characterizing the members of some class of events may not always meet the criteria to belong to that class.” Thus a key aim of this work was to develop alternative enhancements to the life cycle model that will allow identification and evolution to be more skilfully handled.

4. MODEL ENHANCEMENTS

Work is currently underway at the University of Salford to work around two major obstacles to GANDOLF’s ability to forecast with skill – the lack of Doppler radar data capability, and its reliance on relatively low-resolution mesoscale model output. Operational weather radars in the UK do not measure radial velocities, thus GANDOLF requires mesoscale model wind fields to determine wind shear and to advect storms. Crude horizontal wind vectors, however, can be obtained by cross-correlating subsequent analysis fields at multiple heights. The 3D continuity equation can then be applied to determine vertical velocities, giving a full 3D wind field at high resolution. This will be subject to errors derived from the fact that no account will be taken of the contribution of buoyancy or latent heat release to the vertical velocities – density is assumed constant. It is intended to remedy this at a later date, should time allow.

There are three ways in which high-resolution 3D wind data could be used: to extrapolate storm motion, thus reducing reliance on mesoscale model wind fields; to determine wind shear values at each pixel, which can be fed back into the model to help evaluate storm severity and longevity; and to evaluate the tipping term of the vorticity equation for each cell, which can be used as a measure of ‘three-dimensionality’ of storms. This latter is the most interesting prospect, since it may provide a method of reinforcing the cell stage identification scheme using the dynamic properties of cells. The tipping term, given in Eqn. 1, is the contribution to the absolute vorticity caused by the tipping of vorticity about a horizontal axis, where this tipping results from horizontal gradients in vertical velocities (see for example Hess, 1959, for a more detailed explanation).

$$\mathrm{T} = -\left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z} \right) \qquad [1]$$

This will be small in the absence of a storm, where vertical velocities may be considered constant over horizontal scales of the order of storm size. However, as a convective updraught develops over time, the tipping term can be expected to increase, peak as the storm does, then decay correspondingly. It may be that a vorticity-informed description of the 3D wind field could be utilised in the cell identification scheme.

5. METHODOLOGY

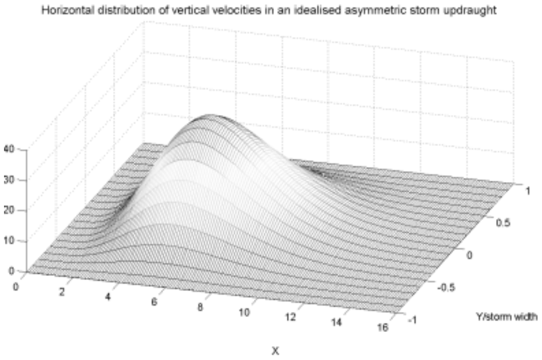

Fig 2 Horizontal distribution of vertical velocities of an idealised storm at its peak. Max vertical velocity is $30\mathrm{m.s}^{-1}$

In order to examine the behaviour of the tipping term under convective conditions, an idealised storm updraught was created using the product of a gamma function in one dimension and a sinusoidal function in the orthogonal direction (Eqn. 2):

$$w(x,y) = e^{-\frac{kx}{X_s}} \left(\frac{kx}{X_s} \right)^{n-1} . \sin^2 \left(\frac{\pi y}{Y_s} \right) \qquad [2]$$

Here X_s and Y_s are the maximum x- and y-dimensions of the storm, and 0 □ x □ 1 and 0 □ y □ 1. For $n = 2\pi$, $k = 20$ constrains the function to the desired range. This function provides a ‘snapshot’ of the updraught at its peak. To simulate a storm that grows and decays with time, the function is allowed to vary sinusoidally from 0 to its maximum value (Eqn. 2) then back to 0 (Eqn. 3):

$$w(x,y,t) = w(x,y).\sin^2 \left(\frac{\pi t}{T_s} \right) \qquad [3]$$

Here, T_s is the duration of the storm and 0 □ t □ 1. The shape of the storm is shown in Fig. 2.

Calculation of the tipping term requires a value for the wind shear du/dz and dv/dz. These were set as hyperbolic functions after Weisman and Klemp (1982).

$$u = u_s \tanh \left(\frac{z}{z_s} \right) \qquad [4]$$

As in Weisman and Klemp (1982), z_s was kept constant at 3km and u_s was varied between 0 and $45\mathrm{ms}^{-1}$. A identical equation was used to determine v, although v_s was not necessarily equal to u_s. This allowed the calculation of the tipping term field at horizontal slices through the storm. The equivalent using real data would involve calculating the term at each pixel in the volumetric radar scan. Initial examination of some idealised fields, derived using the functions above, show no indication of proving useful in the conceptual model at this early stage. It remains to determine a suitable method of averaging these values to obtain a single representative number for each cell, which can then be plotted against time.

Once the ideal behaviour of the averaged term, under conditions of varying storm size, shape, intensity, lifetime, and environmental wind shear, has been investigated, real data can be used in place of the simulated storm, and the deviation from expected behaviour can be accounted for. It then remains to determine how the average tipping term, or more likely its gradient with respect to time, can be related to the cell development stage, and whether a relationship exists which can be employed to more accurately identify what stage of development a storm is in, when it is analysed by radar.

6. DISCUSSION

There are a number of potential problems with the approach described, both due to data quality and to flaws in the theory. The first will be a consequence of the resolution of the radar data. The horizontal resolution is 2km, which is adequate, but there are only four points in the vertical. This is a consequence of the way GANDOLF was designed to work in the UK, and would be easily remedied using radar data from another source.

The second will arise from the necessary crudeness of the cross-correlation scheme. Time will not allow for a scheme to be implemented which reflects the current state-of-the-art in this field, but again, this would be easily remedied – a number of advanced algorithms exist which have shown good results. Furthermore, Doppler radar data - which were not available to the designers of GANDOLF, thus have not been integrated into the scheme despite being available during Sydney 2000 - could be used along with cross-correlation to provide a much improved horizontal wind vector field.

Thirdly, the use of the 3D continuity equation to obtain a 3D wind field from 2D wind fields at multiple heights, will introduce errors, since no account will be taken, initially at least, of contributions to vertical velocity by surface heating or latent heat release.

Fourthly, to obtain the tipping term with respect to height rather than to pressure required the substitution of the equation of hydrostatic equilibrium. This is invalid under conditions of cumulus convection, and presents a more serious flaw. It is yet to be seen how the tipping term behaves with real data, and thus the extent of this problem is not yet known.

Finally, the presence of the downdraught is currently ignored, and this will certainly have serious consequences for the behaviour of the tipping term.

Despite these flaws, it is believed that the tipping term, or a similar quantity which describes the way the updraught velocity changes with time, could be beneficial in the conceptual model. The horizontal gradients of vertical velocity in developing storms are likely to be greater and also more rapidly changing than in dissipating storms. If this property can be adequately represented in the conceptual model, the cell stage identification scheme may be made more robust.

7. ACKNOWLEDGEMENTS

The authors would like to thank the staff of the Bureau of Meteorology, New South Wales Regional Office, Sydney, and the Bureau of Meteorology Research Centre, Melbourne; especially Andrew Treloar and Geoff Freeman. Also, the members of the Hydrometeorology and Environmental Remote Sensing Research Group at the University of Salford, especially Kevin Sandiford.

8. REFERENCES

Bennetts, D.A., McCallum, E., and J.R. Grant, 1986: Cumulonimbus clouds: an introductory review. *Meteor. Mag.*, **115**, 242-256.

Doswell III, C.A., Brooks, H.E. and R.A. Maddox, 1996: Flash flood forecasting: an ingredients-based methodology. *Wea. Forecasting*, **11**, 560-581.

Hand, W.H., 1996: An object-oriented technique for nowcasting heavy showers and thunderstorms. *Met. Apps.*, **3**, 31-41.

Hand, W.H. and B.J. Conway, 1995: An object-oriented approach to nowcasting showers. *Wea. Forecasting*, **10**, 327-341.

Hess, S.L., 1959. An Introduction to Theoretical Meteorology. Constable and Co., London, 362pp.

Keenan, T.D. and coauthors, 2001: The World Weather Research Programme (WWRP) Sydney 2000 Forecast Demonstration Project: Overview. Preprints, 30th Conf. Radar Meteor., Munich, AMS.

Pierce, C.E., Hardaker, P.J., Collier, C.G. and C.M. Haggett, 2000: GANDOLF: a system for generating automated nowcasts of convective precipitation. *Met. Apps.*, **7**, 341-360.

Sleigh, M.W., Fox, N.I., Collier, C.G., and C.E. Pierce, 2000: On the performance of a conceptual model of convection during preparations for the World Weather Research Project nowcasting intercomparison during the Olympic Games in Sydney, Australia. *Phys. Chem. Earth (B)*, **25**, 1299-1304.

Weisman, M.L. and J.B Klemp, 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. *Monthly Wea. Rev.*, **110**, 504-520.