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Executive Summary

The performances of the old and new versions of the Object-Oriented (OO) conceptual life cycle Model (OOM) in GANDOLF have been compared with those of a 2 km resolution Nimrod advection scheme and a Eulerian persistence forecast. Twelve precipitation events were used in the evaluation. These included examples of widespread rain associated with frontogenesis (two cases), and non-frontal showers associated with airmass convection in weak and strong synoptically forced settings (ten cases). A range of categorical and continuous quantitative statistics were computed for each model and event. These were presented as a function of forecast lead time and size of validation area.

In agreement with studies in the literature (Wilson *et al.*, 1998), the results show that linear extrapolation (the Nimrod advection scheme) is generally better than more sophisticated non-linear techniques (e.g. the old and new versions of the OOM), not only in cases of frontal precipitation where the superior performance of linear extrapolation is to be expected, but also in cases of non-frontal convection associated with strong synoptic scale forcing (e.g. showers developing around Atlantic depressions in polar maritime or polar maritime returning flows). In the latter scenario, showers tend to be relatively long lived and well organised when compared to those evolving in a weaker synoptic setting; thus, the Lagrangian persistence assumption is a good one, at least in the short range.

In the two cases where convective precipitation developed in conditions characterised by weak synoptic scale forcing in the boundary layer, the performance of the OOM (old and new versions) exceeded that of the Nimrod advection scheme only in the early stages of shower development. However, in neither of these cases, was the convection accompanied by significant vertical wind shear. Consequently, one of the principle advantages of the OOM – namely, its ability to model daughter cell initiation and growth – was not adequately tested. In earlier studies by Hand (1996), this aspect of the OO scheme has been shown to account for its improvement on the performance of FRONTIERS (the predecessor to Nimrod).

Evidence regarding the relative performance of the old and new versions of the OOM during the convective case studies examined in this report is ambiguous. Quantitative statistics averaged over the twelve case study events show the performance of the new OO scheme to have been superior to that of the old for lead times in the range T+5 to T+60 minutes. Conversely, evidence from two, key convective case studies suggests that the old version of the OOM is somewhat better than the new, although on the occasions in question it was noted that the new OO scheme had problems distinguishing precipitation from anaprop and residual clutter in the radar data. If these problems had been corrected for (as they should have been), it is likely that the difference between the models would have been less.

On the basis of the evidence presented here, and in other papers (Pierce & Hardaker, 1997), it is proposed that the new OOM replace the old OOM in the operational GANDOLF system. However, the implementation of the new model should only be undertaken when the clutter and anaprop removal schemes in the new OO analysis have been examined and improved. The most likely reason for the scheme's failure to removal spurious radar echoes is an error in the model code. Following successful, operational implementation of the new OOM, it is recommended that the first version of the integrated Nimrod-GANDOLF system combine the 2 km resolution Nimrod advection scheme with the new version of the OOM. The integration should be achieved in such a way that the OOM is only run when severe convection develops in the presence of strong vertical wind shear.

It is clear that further work is needed to improve existing algorithms for the deterministic nowcasting of precipitation. It is recommended that a more sophisticated conceptual model of shower evolution be developed that can be applied in both weak and strong synoptically forced environments. This scheme must consider the combined effects of cumulus scale, mesoscale and synoptic scale forcings on the initiation, life cycles and movement of convective cells. The need to improve the treatment of embedded mesoscale features within frontal precipitation bands has also been highlighted in this report. The development of a Rain Object Classifier capable of distinguishing rain "objects" on the basis of their synoptic context and predominant forcing is likely to provide a way forward.

Additionally, given the obvious complexities entailed in the prediction of precipitation at high spatial (2 km) and temporal (5 minutes) resolutions, and the limitations of deterministic approaches to precipitation nowcasting, it is also recommended that parallel R&D work on probabilistic rainfall forecasting be combined with the Nimrod–GANDOLF integration programme in the near future.

1. Introduction

As part of Stage 3 of the Nimrod-GANDOLF integration project, the performances of rainfall nowcasts produced by the old and new Object Oriented Models (OOMs) and a 2 km resolution Nimrod advection scheme have been assessed using case study material and a range of categorical and continuous, quantitative statistics. A variety of rainfall events have been included in the evaluation, encompassing cases of widespread frontal rain, and convective rain associated with both weak and strong synoptic scale forcing. The results will facilitate the design of an integrated nowcasting scheme combining the predictive capabilities of Nimrod and GANDOLF.

Although the OOM in GANDOLF was originally designed to improve the treatment of convective precipitation, and in cases studies investigated for the Environment Agency generally performed well when compared to Nimrod (5 km resolution) and the Local Forecast Model (LFM: 2 km resolution) of the Centre for Ecology and Hydrology (Pierce & Hardaker, 1997), a statistical comparison between the OOM and a 2 km resolution version of the Nimrod advection scheme has not been undertaken until now. This comparison is particularly pertinent, because it is widely accepted in the field of Quantitative Precipitation Forecasting (QPF) that few, if any rainfall nowcasting algorithms, have demonstrated unambiguously a predictive capability over and above that afforded by linear extrapolation schemes (see for example Wilson *et al.*, 1998).

This report serves several purposes. Firstly, it details the changes made in the new version of the OOM and, in so doing, addresses some of the points raised by the Environment Agency regarding deficiencies in the behaviour of the current operational version of the OOM (Pickles, 2000). Secondly, the report reviews the performance of the old and new versions of the OOM, relative to the 2 km resolution Nimrod advection scheme, and an Eulerian persistence nowcast. A number of case studies are presented to aid in the interpretation of the quantitative statistics summarised in Appendix A.

2. Overview of the old and new object-oriented models

2.1 The old OOM

The OOM, originally developed by Hand and Conway (1995), was based upon a conceptual model of a mid-latitude convective cell. This conceptual model was empirical in nature, it having been formulated from many thousands of rainfall radar observations of precipitating convective clouds in the UK. The forecast scheme was object-oriented in design. This allowed it to model individual convective cells independently of one another. Single site multiple beam radar data, Meteosat infra-red derived Cloud Top Temperatures (CTTs) and Mesoscale Model (MM) forecast wind fields were used to detect, classify and forecast precipitating convective cells on a ten minute cycle, at 2 km and 10 minute spatial and temporal resolutions respectively.

The aim of the scheme was to provide more reliable very-short range forecasts (T+0 to T+180 minutes) of heavy convective precipitation for the Environment Agency. These were to be used to make short-range predictions of river and stream flows in various flood-prone river catchments in the vicinity of London. The quantitative predictive skill demonstrated by the first version of the model was partly attributed to its ability to distinguish between cells in developing and dissipating phases of their life cycles. Given this capability it was then possible to predict, albeit crudely, the subsequent evolution of each cell and its associated rainfall.

Another key feature of the scheme shown to afford additional skill over and above that demonstrated by Lagrangrian persistence algorithms, was the capability to model daughter cell evolution – the process whereby existing mature convective cells with strong downdraughts can trigger the development of new cumulus clouds through the collision of near-surface gust fronts. On several occasions when severe convection was observed to develop in conditions characterised by large static instability and strong wind shear, Hand (1996) was able to demonstrate that this feature of the object-oriented scheme provided enhanced performance when compared with nowcast algorithms relying solely on advection of the observed precipitation field.

Despite these demonstrable advantages over Lagrangian persistence, the original version of the OOM had several fundamental weaknesses. These were the result of an over-simplified cell life cycle model whose characteristics were pre-determined by a combination of climatological observation and the recently observed life cycle history of existing convective cells. As a consequence, the object-oriented forecast scheme made predictions of convective cell evolution without any direct knowledge of the thermodynamic or dynamic properties of the troposphere, or of how these properties might vary in time and space over the duration of a forecast (3 hours). In addition, the scheme largely ignored the interactions between cells, and this led to situations in which more than one cell could occupy the same physical space in the model domain.

Recently, a formal validation of the performance of this original version of the OOM, conducted by the Environment Agency (Pickles, 2000), identified the following deficiencies in the scheme:

- a tendency for the model to over-predict rainfall area and intensity in the first hour of a forecast, and to under-predict them beyond one hour;
- a tendency for precipitation rates over large areas to pulse on a 30 minute cycle;
- a failure to decay severe storms;

- no demonstrable ability to predict the development of new convection in regions of clear air.

The first two of these deficiencies arose from a combination of two model features: a failure of the forecast scheme to predict the evolution of cells in their earliest developmental stages; and the synchronous evolution of cells of the same stage as a result of a fixed duration life cycle.

The tendency for the OOM to maintain the intensity of severe storms for the full duration of a forecast arose because the scheme had no knowledge of the tropospheric environment in which radar-observed convective cells were allowed to evolve. Cell life cycles were solely determined by the cell analysis scheme and could not be modified to account for changes in the state of the troposphere in space and time.

The OOM was primarily designed to predict the evolution of existing areas of convective precipitation. However, it was given a limited capability to develop new convection in areas where Mesoscale Model (MM) resolved wind field convergence was deemed to be sufficient to release static instability through forced ascent from the boundary layer. However, the reliance of this component of the forecast scheme on a single convergence threshold, and the absence of information on the stability of the lower atmosphere meant that this aspect of the scheme was unreliable.

2.2 The new OOM

The new version of the OOM has been designed to address the key deficiencies outlined above in Section 2.1. This has primarily involved the introduction of a more realistic cell life cycle model that can modify cell behaviour in space and time in accordance with predicted changes in the state of the troposphere, as forecast by the MM. In addition, a new version of the object-oriented analysis scheme has been developed to reduce the dependence of the cell classification on empirical relationships between cell surface rain rate and cell stage. A full but succinct description of the new model is provided in the sub-sections below.

Section 2.2.1 The new OOM analysis scheme

The starting point for a cell analysis is the generation of a 3-D rain analysis from all available multi-beam radar data in England and Wales. This rain analysis has a 2 km horizontal resolution. In the vertical it distinguishes four meteorologically significant tropospheric layers that together characterise the vertical distribution of rain rates between the ground and convective cloud tops. A 3-D version of Nimrod's 2-D rain object clustering algorithm is used to identify 3-D rain objects. The 2-D footprint of these objects is mapped onto outputs from the Neural Network Cloud Classifier (Pankiewicz, 1995; 1997). Those rain objects that are predominantly convective (> 50%

convective cloud pixels and associated with MM Convectively Available Potential Energy > 10 J Kg^{-1}) are used in the cell classification algorithms.

The new cell classification algorithms have been adapted from those used in the original version of the OOM. The latter relied heavily upon single rain rate thresholds at given heights within a convective cloud to distinguish cells by developmental stage. However, in Hand's original paper on the OOM (Hand, 1996) the author suggests that the overall vertical distribution of rates should be the primary basis for this cell stage classification. Consequently, the new version of the analysis scheme relies as much as possible on the relative magnitudes of the rain rates in the four point vertical profiles generated by the 3-D rain analysis.

A comparison of the outputs from the original and new cell analysis schemes has shown that the new scheme produces a similar distribution of cell stages to that found with the old scheme. However, overall the new scheme tends to identify more cells and these are evenly spread between the five stages. In common with the original version of the OOM, the new analysis also makes use of Cloud Top Temperatures (CTTs) to quality control the cell stages assigned using the 3-D rain analysis.

A range of new cell attributes are calculated in the new scheme and stored in a more comprehensive version of the cell object template devised by Hand (1996). These include:

- the age of a cell derived from its Cloud Top Temperature (CTT) and an estimate of the time taken for a dilute parcel to rise through the MM atmosphere to a height corresponding to this CTT;
- cell stage transition times – estimates of the times when a cell will reach specific evolutionary stages. For cells in the developing phase of their life cycle (stages 'd', 'm' or 'M'), transition times are derived from the estimated times for a dilute parcel to reach suitable CTTs corresponding to each stage. For dissipating cells (stages 'E' or 'D') transition times are computed from a combination of dilute parcel ascent times and the Lagrangian Decorrelation Time (L_T) estimated from Storm Relative Environmental Helicity (Pierce and Hardaker, 1997). In this way, cell life cycles are allowed to vary in form and duration, and have a more physical than climatological basis;
- cell peak convective gust. This is computed from MM 3-D fields using the energy conservation formulation proposed by Nakamura *et al*. (1996);
- hail size. This is an empirically based algorithm that was implemented for use in the Sydney version of GANDOLF. It uses a series of observed linear relationships between height of the freezing level and the maximum height of the 50 dBZ radar reflectivity above the freezing level to estimate hail size in centimetres.

Section 2.2.2 The new OOM forecast scheme

The new forecast scheme has been modified comprehensively, primarily in an effort to improve the physicality of the life cycle model. In the original version of the OOM, the life cycle characteristics of cells were determined during the object-oriented analysis. Cells were assigned a development potential – effectively a semi-quantitative, numeric representation of the vigour of convection associated with each cell. This development potential was based upon a 10 minute resolution time series of cell stage analyses for the period T-20 to T+0 minutes. Cells that were observed to be developing rapidly or maintaining a mature steady state during this interval were assigned a strong development potential, whereas those that were shown to be decaying were assigned weaker development potentials.

In the original version of the forecast scheme, these development potentials were used to determine which cells would initiate new convection through the process of daughter cell generation. Since these daughters inherited the attributes of their parent cells, the development potential assigned to a cell in the analysis scheme determined whether it's associated precipitation would dissipate in one life cycle (~60 minutes) or persist indefinitely through cycles of growth and decay, maintained by the daughter cell generation mechanism.

Case study evidence presented by Hand (1996) showed that, in those relatively rare cases of severe airmass convection where the daughter cell mechanism was known to be important, the OOM forecast scheme could perform better than a Lagrangian persistence forecast. However, the model's performance in the majority of non-severe cases of airmass convection was far less encouraging owing to inappropriate application of this same daughter cell initiation algorithm, and the model's failure to consider stability changes in the atmospheric environment, and the interactions between cells.

The new object-oriented scheme attempts to address these deficiencies. The concept of cell potential has been abandoned. The new analysis scheme classifies cells according to the size and composition of the 3-D rain objects they belong to, and the thermodynamic and dynamic states of the troposphere is which they reside. Three distinct cell types are recognised: *single cell*, *multi-cell* and *supercell*. A life cycle model is associated with each of these categories.

Cells classified as *single cell* will grow and decay in one life cycle. By contrast, *multi-cells* can generate daughters by the daughter cell initiation mechanism implemented by Hand (1996) in the original version of the OOM. Whether individual cells of type *multi-cell* initiate a daughter or not depends upon their position within the multi-cell storm envelope, and also on the strength of the downdraught they can produce (formulation after Nakamura *et al.*, 1996). In the new scheme, cells on the edge of a storm envelope are more likely to generate daughters than those embedded in the middle of the storm cluster.

Supercells, an extremely rare occurrence in the UK, are allowed to reach maturity and then persist in a steady state until the atmospheric conditions favour their dissipation, or transition from *supercell* to *multi-cell* or *single cell* types. Thus, one key feature of the new forecast scheme is its ability to modify cell type and therefore cell behaviour during the course of a forecast cycle. These cell type changes are allowed to occur in response to changes in the stability of the atmospheric environment as represented by the MM.

The basis for the three way cell type classification outlined above varies between the object-oriented analysis and forecast schemes. In the analysis, the classification is dependent solely upon attributes of the convective rain objects identified in the T+0, 3-D rain rate analysis. By contrast, in the forecast scheme (beyond T+30 minutes), the classification relies upon static and wind shear instability measures derived from MM outputs. This dichotomy of classification method is designed to preserve large or high intensity rain objects in the first hour of an object-oriented forecast. Thereafter, the OOM will tend only to preserve rain objects that occur in MM environments capable of supporting convection as a result of significant static instability and marked wind shear.

In the analysis scheme, convective rain objects larger than the size of a single dissipating cell (100 km^2) and / or with rain rates in excess of 10 mm hr^{-1} are deemed to contain *multi-cells* with the capability of generating daughters. Other rain objects are assumed to comprise of *single cells* only. At T+30 minutes and beyond, cell type and thus behaviour are considered to be a function of MM dilute parcel CAPE, and the vertical shear in the horizontal wind speed and direction. Three idealised wind shear and instability profiles are used to distinguish between MM environments that will support *single*, *multi-cell* or *supercell* storms (after Browning, 1984; Ludlam, 1980; Weisman & Klemp,1982).

The *single cell* environment is characterised by weak static instability (< 100 J kg^{-1}) and weak vertical shear in the horizontal wind speed and direction between the ground and the convective cloud top (< 15 m s^{-1} and < 45 degrees). Conversely, the *multi-cell* is characterised by moderate to large static instability (> 100 J kg^{-1}) and moderate or strong vertical shear in the horizontal wind (≥ 15 m s^{-1} and ≥ 45 degrees). Conditions that support the generation and maintenance of *supercell* convection are highly unlikely to be experienced in the UK (small modified Richardson number, very large static instability and strong wind shear, especially below 2 km), but have been catered for to allow for the running of the model in Sydney, Australia.

Other significant changes made to the OOM concern the assignment of surface rain rates to cells. In the original version of the object-oriented analysis, minimum, mean and maximum instantaneous rain rates were computed for each cell using a surface rain rate composite generated from the surface beam reflectivities of all available single site radars. In the forecast scheme, cells were ascribed the mean rain rates for their particular stage, and these changed over time in accordance with regular life cycle cell stage changes. As a consequence, the resultant forecast precipitation fields tended to be rather uniform in appearance and to lack detail.

In the new OOM, analysed cells preserve their individual rain rates. The mean rates for each stage are used to compute the average changes in rain rate between cell stages. In combination, these attributes are employed to estimate the cycle of precipitation growth and decay applied to each cell over the duration of a forecast. The resultant precipitation fields tend to preserve the spatial variations in intensity present in the object-oriented rain analysis. Furthermore, problems with unrealistic, synchronous changes in cell stage are less evident because each cell follows its own life cycle dictated by the cell stage transition times computed in the analysis scheme.

The new OOM forecast scheme has an improved algorithm for predicting initiation of cells in clear air. The old model had a very limited capability to trigger such new development. This was based upon a single, boundary layer convergence threshold, above which the resultant uplift was deemed sufficient to trigger new cumulus formation. However, since the algorithm did not consider the static stability of the lower atmosphere it was of limited value, and tended not to produce new areas of precipitation, except in cases of frontal or trough convergence when application of the OOM was questionable.

In the new OOM, the convergence and resultant uplift in the boundary layer is compared to the Convective INhibition (CIN) energy beneath the Level of Free Convection. In those MM grid boxes where the upward vertical velocity is sufficient to overcome the negative buoyancy force represented as a downward velocity with magnitude $(2*CAPE)^{0.5}$, a new cell is initiated. These new cells inherit the mean precipitation attributes for each cell stage, but cell transition times and a cell type computed from MM models fields in the relevant location.

3. Overview of the 2 km resolution Nimrod advection scheme

The 2 km resolution Nimrod advection scheme was designed to be as similar as possible to that implemented in the existing, operational 5 km forecast scheme (Golding, 1998). The nowcasting approach adopted in Nimrod involves the disaggregation of the radar observed precipitation field into distinct precipitation "objects". This is achieved by applying certain rules regarding the expected size of objects and the minimum separation distance between them. An optimal motion vector is determined for each identified object based upon its recently observed motion. Object position, size and assigned motion vector are stored in an "object details" file.

The 2 km resolution Nimrod advection scheme requires three initial inputs:

- the object details file from the previous hour's run (T-60 minutes);
- the precipitation analysis from the previous hour's run;
- the current precipitation analysis.

The Nimrod analysis identifies precipitation in the current rainfall radar composite and divides this into objects according to the predefined limits on object separation distance and the total number of objects allowed. The latter is limited to ensure efficient and timely running of the analysis and forecast schemes. If the number of objects exceeds the specified limit, the objects closest to each other are combined until the total number is equal to, or lower than the limit.

Precipitation analyses valid at T-1 hour and T+0 are compared. This allows objects in analyses valid at T-1 hour and T+0 to be matched, and associated *u* and *v* velocity vectors to be estimated. These vectors are used to determine whether a cross correlation vector or a MM wind vector will best predict object motion in the recent past. An object details file valid at the current time is created. This contains skill scores comparing the performance of forecasts produced using these two advection techniques. The most skilful method is used to forecast object motion. This may vary from object to object.

In the Nimrod advection forecast, each precipitation object is advected using its assigned, optimum motion vector. Forecasts of low and high intensity rainfall may be produced separately, and then merged. The distinction between high intensity and low intensity rain is designed to allow for the differential treatment of convective and stratiform rainfall. In the former case, Nimrod attempts to simulate the differential motion of individual cells and their associated storm envelope. In cases of stratiform rain, differential motion within in a precipitation object is generally assumed not to occur.

Outputs from the 2 km resolution Nimrod advection scheme include instantaneous rain rate and rainfall accumulation. These have a five minute temporal resolution and a range of three hours. The integration period for accumulation products is15 minutes.

4. Verification procedure

4.1 Overview

The verification of rainfall nowcasts produced by the old and new versions of the OOM and the 2 km Nimrod advection scheme has been conducted using a slightly modified version of the standard Nimrod verification software. Performance was assessed over square validation areas of varying dimensions: 360 km by 360 km, 180 km by 180 km, and so on, down to 10 km by 10 km. For all but the largest validation area, statistics were computed for each grid box and then averaged. In so doing, the aim was to demonstrate how performance varied with catchment size.

The old and new versions of the OOM and the Nimrod advection scheme were run over domains of varying size: the old OOM used single site radar data from the Chenies radar only; the new OOM received single site radar data from Chenies, Clee Hill and Cobbacombe; and the 2 km Nimrod advection scheme ran on a composite rain rate field generated from the surface beam data of all single site radars in England and Wales. Each model was validated against its own analyses.

The case studies chosen for the verification included cases of widespread rain accompanying frontogenesis, and non-frontal convection associated with both weak synoptic forcing (local, surfaced forced, "airmass" convection) and strong synoptic forcing (synoptically organised bands or clusters of showers). In all, twelve rainfall events were examined and a range of categorical and continuous performance statistics were generated for each model. Eulerian persistence statistics were computed to provide a bench mark against which the performance of Nimrod and the OOM could be assessed.

Tables A.1 to A.3 in Appendix A provide summary statistics for the three case study events described in Section 5. Similar statistics, averaged over the twelve precipitation events studied for this report, are presented at the end of Appendix A in the table set A.4.

4.2 Categorical statistics

The following categorical statistics were used to evaluate the spatial performance of the systems: Critical Success Index (CSI), Hit Rate (HR), and False Alarm Rate (FAR). They take no account of discrepancies between collocated forecast and observed rainfall rate. Analyses and forecasts are binarised (1 for rain and 0 for no rain) using a rain/no rain threshold of 0.125 mm h^{-1}. The formulae employed are given in Table 1.

Table 1. Formulae for the spatial performance statistics CSI, HR and FAR.

$CSI = \frac{A}{A+B+C}$	$FAR = \frac{C}{A+C}$	$HR = \frac{A}{A+B}$

Table 2. Contingency table expressing the meaning of the scenarios *A*, *B*, *C* & *D*.

		Forecast	
		Rain	No rain
Observed	Rain	A	B
	No rain	C	D

The quantities *A*, *B*, *C* and *D* were derived according to Table 2. Since both the Nimrod and OOM forecast schemes are mainly concerned with predicting the motion and/or evolution of radar observed precipitation, the ability to forecast the non-occurrence of rain is not assessed in any of the categorical statistics presented in Appendix A.

4.3 Continuous statistics

In addition to the spatial measures of performance described above, the accuracy of forecast rain rates was also assessed. The Root Mean Squared Factor (RMSF) and Root Mean Squared (RMS) error were computed for this purpose:

$$RMSF = \exp\left\{\frac{1}{N}\sum_{i=1}^{N}\ln\left(\frac{f_i}{o_i}\right)^2\right\}^{1/2} \quad (1),$$

$$RMS = \left\{\frac{1}{N}\sum_{i=1}^{N}(f_i - o_i)^2\right\}^{1/2} \quad (2).$$

Here, *f* and *o* are rain intensities measured in mm h^{-1}.

If either the forecast or observed rain intensity is zero, the RMSF is not defined. To account for this, two different RMSF values are calculated. Firstly, only collocated pixel pairs in which the forecast and observed rain rates are greater than or equal to a threshold level (0.125 mm h^{-1}) are counted, and the RMSF derived. Secondly, in cases where either the forecast or the actual rain rate (but not both) is below the threshold, a new threshold value is calculated equal to half the previous threshold value. The RMSF is then re-calculated with the new halved threshold. This version of the RMSF

(RMSF_OR in the tables in Appendix A) will include all data pairs which were originally counted, and additionally, all the pairs with one data point (but not both) below the first threshold. Data pairs that are both below the first threshold are ignored in both cases. An equivalent version of the RMS referred to as the RMS_OR is computed in a similar way.

Also computed were the mean error or bias (MEAN) and the mean factor error (MEANF) given by:

$$MEAN = \frac{1}{N}\sum_{i=1}^{N}(f_i - o_i) \quad (3),$$

$$MEANF = \exp^{\frac{1}{N}\sum_{i=1}^{N}\ln\left(\frac{f_i}{o_i}\right)} \quad (4).$$

5. Case Studies

5.1 Overview

Only three of the twelve case studies for which performance statistics were produced are examined here. These serve as representative examples of:

- widespread rain associated with frontogenesis (Section 5.2);
- widespread showers evolving in a strong synoptically forced environment (Section 5.3);
- scattered showers evolving in a weak synoptically forced environment (Section 5.4).

These cases are chosen to highlight the capabilities and deficiencies of the 2 km resolution Nimrod advection and object-oriented forecast schemes across a spectrum of precipitation events that encompasses synoptically forced, widespread rain at one extreme, and locally forced showers at the other extreme.

5.2 Widespread rain associated with frontogenesis – 3 April 2000

With a deep low pressure system in the Bay of Biscay, and high pressure to the north-west of Scotland, the UK lay under the influence of a strong surface pressure gradient oriented north-west to south-east (Figure 1). Aligned broadly with the surface isobar pattern were a series of quasi-stationary fronts. These were associated with a broad belt of rain aligned south-west to north-east across England and Wales. An upper air sounding from Herstmonceaux at 1200 GMT on 3 April 2000 showed moist air extending through the full depth of the troposphere, and a cooling rate with ascent somewhat less than saturated adiabatic.

A sequence of 2 km resolution Nimrod composite analyses from 3 April 2000 confirm the extent of the precipitation and also reveal some mesoscale structure to the band. For example, the composite analysis from 1030 GMT shows some relatively localised areas of heavy rain, some of which may be associated with embedded convection (see Figure 2). Surface observations from northern England and the Scottish borders indicate the presence of much cooler air to the north of the band with reports of sleet and snow on the northern edge of the precipitation belt. Sleet and snow progressed southwards during the course of the day as the precipitation belt slid very slowly south-eastward.

In this type of event the predominant forcing is synoptic scale frontogenesis. The accompanying precipitation is often extensive and relatively long lived, and the evolution of the field over time is slow when compared with that observed during outbreaks of non-frontal, upright convection. In these circumstances the assumption of pattern continuity in a frame of reference moving with the rain area is likely to be more accurate than a scheme that attempts to model both the movement and the complex and often subtle changes in the evolving field. Consequently, there is an expectation that the 2 km Nimrod advection algorithm will significantly out perform the OOM.

Figure 2 pictorially compares the performance of the old version of the OOM in GANDOLF with that of the Nimrod 2 km advection scheme. Shown are time synchronous half hourly rainfall forecasts based upon rain rate analyses validating at 1000 GMT. Output from the new version of the OOM is not included. Despite differences in the coverage of the two rain analyses – the old OOM used Chenies single site data only – it is quite apparent that inappropriate application of the OOM produces inferior results to that afforded by the Nimrod scheme.

Closer scrutiny of the Nimrod forecasts shown in Figure 2 indicates that the advection scheme failed to identify any significant movement in the precipitation field. As a result, the four half hourly forecasts are almost identical, since no attempt has been made to model changes in precipitation intensity. Comparison of this forecast sequence with the relevant rain analyses shows the Nimrod advection scheme to have been successful at capturing the lack of movement in the broad swathe of precipitation. However, its inability to model the subtle changes in the structure of the band probably limits the useful range of the forecasts to less than 90 minutes, at least for quantitative flood forecasting on the scale of small river catchments.

The quantitative performance statistics for 3 April 2000 can be found in Tables A.1 (pages 34–39) of Appendix A. These largely confirm the inferences drawn from Figure 2 regardless of the size of validation area used. It is no surprise that the categorical statistics (CSI, HR, FAR) show the 2 km Nimrod advection scheme to have significantly improved upon the OOM. This finding is confirmed by the continuous statistics. The values of the RMSF,

RMSF_OR and RMS_OR for the OOM are significantly larger than those of Nimrod.

5.3 Showers associated with a low pressure system – 17 April 2000

Several "wrap-around" occlusions, one of which lay over parts of southern and central England, accompanied a complex low with centres south-west of Eire and over north Wales (Figure 3). Associated with these features were several bands of showers over England and Wales. These moved in a cyclonic fashion, north-eastwards to the south of the depression centre and south-westwards to the north. An upper air sounding from Herstmonceaux at 1200 GMT on 17 April 2000 showed the troposphere to be moist through its entire depth with significant potential instability if lifted from the boundary layer. Little directional wind shear was apparent with height – a south-westerly direction was maintained between the surface and the tropopause indicating an absence of thermal advection at all levels. However, 20 knots of speed shear were apparent between the surface and 500 hPa.

Surface synoptic weather reports for 17 April 2000 indicate that the showers moving across southern England were accompanied by hail, thunder and gusty winds. The sequence of 2 km Nimrod composite rain analyses from the morning of 17 April showed the showers to be heavy, but quite widely separated by cloud free regions, as is often observed in "open-cell" convection at sea. Towards evening the convection weakened and most inland areas became dry after sunset.

In this type of precipitation event, none of the nowcast schemes on trial can be expected to perform especially well. Although showers evolving in strong synoptically forced settings such as this (e.g. in cold air around a depression) will undergo cycles of growth and decay, the characteristics of these life cycles are unlikely to be determined simply by local static instability and wind shear considerations, or by interactions with the environmental wind field such as those embodied by the daughter cell initiation mechanism in the OOM. The presence of large scale, dynamically driven upward motion may mean that individual convective cells are longer lived than those forming in a weak synoptic setting. In addition, showers are more likely to be organised in accordance with synoptic scale or mesoscale disturbances (e.g. troughs), than in response to cumulus scale wind field interactions.

The limitations of the life cycle conceptual model in GANDOLF imply that it may give misleading guidance during events such as occurred on 17 April 2000. The Lagrangian persistence assumption employed in the Nimrod advection scheme might be expected to perform rather better, since the showers on this occasion are associated with weak surface troughs. However, neither algorithm is likely to provide satisfactory guidance in the three hour time frame.

Figure 4 compares model runs from the old and new versions of the OOM with a 2 km resolution Nimrod advection forecast for the Data Time 0830 GMT. Four half hourly instantaneous forecasts are shown. Outputs from both the old and new versions of the OOM are noticeably different to each other and to those of the Nimrod scheme. Again, ignoring the differences imposed by the differing radar inputs to the models (the old OOM has been run on Chenies data alone; the new OOM on radar data from three radars: Chenies, Cobbacombe and Clee Hill), the Nimrod scheme generates rainfall fields that, in terms of their shape and structure, more closely match those observed by the radars. It also captures the cyclonic motion of the showers around the low centre reasonably well.

Although the motion of the showers over southern England is represented adequately by both old and new versions of the OOM, the evolution of their respective rainfall fields is quite different. The forecast sequence generated by the old version of the model highlights a key feature of the conceptual model as implemented by Hand (1996). Over time, this version of the scheme will maintain only those showers that have exhibited a steady mature state or growth in the twenty minutes prior to the model run. On this occasion, such an approach correctly maintains the bands of showery precipitation over south-east England and the Midlands. However, the structural detail in the fields is poor on two counts. The distribution of rain rates is different to that observed by the radar, and these rates are generally too high, leading to a significant positive bias in the forecast. The reasons for this behaviour have been previously documented in Pierce and Hardaker (1997), and the new version of the OOM has been modified explicitly to address these and other weaknesses in the original version of the conceptual model.

The new version of the OOM produces a better representation of the rain rate distribution than the old version. However, unlike Hand's original scheme, it is unable to maintain the showers for more than an hour. This is because it does not consider the impact of mesoscale and synoptic scale atmospheric dynamics on the initiation or maintenance of convection. The new formulation of the conceptual model can only preserve showers when the daughter cell generation mechanism is allowed to operate. This mechanism requires sufficient static instability and vertical wind shear to maintain separate, convective updraughts and downdraughts. On 17 April 2000, the lack of directional wind shear with height largely inhibited daughter cell initiation in the new OO forecast scheme. In the old scheme this was not the case. Given the synoptic setting, and the fact that showers appeared to move with the wind at around 700 hPa (they did not right or left move), the mechanism by which the old model maintained precipitation in the forecast sequence seems not to have been applicable.

In summary, the 2 km Nimrod advection scheme provided better guidance than either version of the OOM. In terms of predicting shower longevity, the performance of the old version of the OOM was superior to that of the new scheme. However, this was the result of inappropriate application of the daughter cell generation mechanism, and is therefore not indicative of any genuine improvement over the new scheme. In terms of the rain rate distribution, the new object-oriented scheme clearly improved upon the old. However, overall it is evident that linear extrapolation, for all is simplicity, was generally superior to the object oriented approach.

The quantitative performance statistics for 17 April 2000 can be found in Tables A.2 of Appendix A. Again, these largely confirm the inferences drawn from Figure 4 regardless of the size of validation area chosen. Notably, the 2 km Nimrod advection scheme out performed both versions of the OOM and Eulerian persistence. This finding is supported by the categorical and continuous statistics. Tables A.2 also show the performance of the new version of the OOM to have been an improvement on that of the old, at least in the first hour. Thereafter, the situation is reversed because the new scheme dissipated all observed showers.

5.4 Scattered intense showers and thunderstorms – 8th May 2000

The UK and much of mainland Europe lay under the influence of a slack surface pressure field with high pressure to the north and east of the UK and a thermal low and several troughs to the south-east, over southern England, the low countries, northern France and Germany (Figure 5). The surface flow over the UK was light and predominantly from the south-east. An upper air sounding from Herstmonceaux at 1200 GMT on 8 May 2000 showed the troposphere to be moist through its full depth and to have a temperature profile close to that of a saturated adiabat. The vertical gradient of wet-bulb potential temperature was markedly negative in the lowest 300 hPa implying that significant quantities of Convectively Available Potential Energy (CAPE) would be released with minimal lifting of air in the boundary layer. Winds were light, from the south-east between the surface and the tropopause suggesting that any showers or thunderstorms would be slow moving.

During the morning of 8 May 2000, heavy, thundery showers were reported around Bristol. Later in the day these became more widespread around the coasts of England and Wales. With little or no synoptic scale surface pressure gradient, sea breezes developed readily around the coasts, and these, in combination with preferential heating on some south facing slopes, were the triggers for the storms. Once initiated these storms tended to move very slowly inland with the sea breeze fronts. It is not clear precisely how important the daughter cell generation mechanism would have been, but it is apparent that there was minimal vertical wind shear. Scrutiny of a sequence of 2 km Nimrod composite radar analyses revealed that strong echoes were maintained along the leading edge of the sea breeze fronts, whilst those to the rear of the fronts decayed. Showers persisted until early evening when they weakened and dissipated.

A superficial appraisal of this event might lead one to assume that the object-oriented approach should be more applicable than linear advection for the purposes of short range forecasting. However, the lack of shear in the Herstmonceaux sounding suggests that the daughter cell generation mechanism may not have been effective as a trigger for new cell development, although outflows ahead of cells anchored to the sea breeze fronts may have interacted with local topography to generate sufficient lift. The fact that showers were relatively long lived might work in favour of the Nimrod advection scheme. Nonetheless, the OOM is likely to have had an advantage in the early stages of the event when growth processes predominated.

Comparison of the forecast sequences in Figure 6 with time synchronous, 2 km Nimrod rain rate analyses shows the Nimrod advection scheme to have performed well up to 30 minutes ahead. Thereafter it is evident that linear extrapolation fails to capture the motion of one of the precipitation areas over south-east England. This is because the apparent motion of the object is a product of both genuine movement and differential growth and decay. Despite this deficiency, the assumption of Lagrangian persistence seems to improve upon the life cycle modelling approaches (see Tables A.3).

The two versions of the OOM differ quite markedly in several respects, with the old version of the model producing forecasts that more closer resemble actuality in the south-east of England. In the new version both the spatial distribution and intensity of the storms are relatively poorly forecast. Furthermore, there are tendencies in the early and later stages of the sequence for the new model to develop spurious areas of convection. Closer scrutiny of the radar analyses and new OOM forecasts revealed that the new OO analysis scheme failed to remove residual clutter and anaprop echoes from the single site radar data. Had these been removed, forecasts from the new OOM would not have predicted the new shower development that was observed in the early stages of the forecast. In terms of shower longevity, both OOMs failed to predict the decay of the storms towards the end of the forecast period.

Other runs of the OOMs examined on this occasion (not shown) indicated that the object-oriented schemes improved upon the performance of the Nimrod advection scheme during the early stages of the event (the first 10 minutes). This improvement is attributable to the life cycle model which is capable of identifying shower clouds before they produce surface precipitation, and of estimating their subsequent growth.

Tables A.3 in Appendix A summarise the quantitative performance statistics for the Nimrod and OOM schemes on 8 May 2000. These confirm the conclusions drawn from Figure 6. Notably, the 2 km Nimrod advection scheme performs better than the new and old versions of the OOM and also Eulerian persistence. However, none of the models do particularly well. This is partly because the rain was of limited spatial extent, but also because they failed to capture the observed pattern of growth and decay. Tables A.3 also show the performance of the new version of the OOM to have been inferior to that of the old version. This is apparent in Figure 6 and was largely due to the presence of spurious echoes in the new OO rain analysis.

6. Review of the quantitative performance statistics

Tables A.1 to A.3 in Appendix A summarise the performance of the 2 km Nimrod advection scheme, and the old and new versions of the OOM as a function of event (3/4/2000, 17/4/2000, 8/5/2000), catchment size and forecast lead time. Tables A.4 summarise the performance of the models over all twelve events examined for this report (additionally 23/3/2000, 24/3/2000, 27/3/2000, 18/4/2000, 10/5/2000, 15/5/2000, 16/5/2000, 18/5/2000, 9/6/2000). In each table are presented the categorical scores A,B,C and D as described in Table 2, the Hit Rate (HR), False Alarm Rate (FAR), Critical Success Index (CSI), Root Mean Squared Factor (RMSF RMSF_OR), Root Mean Squared error (RMS_OR), the bias (MEAN) and Mean Factor Error (MEANF).

The trends apparent in tables A.1 to A.4 are summarised below.

- The forecast accuracy of all models, whether measured in spatial terms only (as given by the categorical statistics, HR, FAR and CSI), or, additionally, in terms of rain intensity (as given by the continuous statistics, RMSF, RMSF_OR, RMS_OR, MEAN and MEANF), tends to decrease with increasing lead time and decreasing catchment size.
- For a given catchment size and given lead time, the forecast accuracy of all models varies as a function of the total precipitation area and its distribution. Accuracy is highest in widespread rain events, when there are few, large precipitation objects, and decreases as total precipitation area and object size decrease. Thus, the performance of the models varies with the type of precipitation event. Forecasts tend to be relatively skilful in widespread frontal rain events and less skilful in cases of scattered convection. Essentially, this is because advection errors have greater impact on forecast accuracy when the size of the precipitation object is small relative to the size of the validation area.
- During events characterised by frontal rain bands or widespread showers, the performance of the 2 km resolution Nimrod advection scheme is generally superior to that of the new and old versions of the OOM at all lead times. The Nimrod advection scheme is also generally superior to Eulerian persistence, except on occasions when the precipitation is extensive and/ or slow moving.
- In cases of scattered, intense convection with little or no significant vertical wind shear, the performance of the 2 km Nimrod advection scheme may be superior to that of the OOMs, if showers are long lived. However, the performance of both new and old OOMs is generally superior to that of Nimrod in the early stages of such events when growth processes predominate. (This is not apparent from the tabulated statistics

since these represent an average performance over all model runs during a precipitation event.)

- In cases of scattered, intense convection with little or no significant vertical wind shear, the performance of the new OOM has been shown to be inferior to that of the old model. The relatively poor performance of the new model on these occasions appears to have been due mainly to an error in the new OO analysis scheme. This resulted in a failure to remove residual clutter and anaprop echoes from single site radar data.
- When the relative performance of the new and old OOMs is considered over all twelve precipitation events, the new model is shown to be superior to the old model. However, none of the twelve cases examined for this report were believed to be ideal candidates for application of the conceptual life cycle model since significant vertical wind shear was not present in representative upper air soundings.

7. Summary

As detailed in the relevant Stage Plan, the aims of Stage 3 of the Nimrod–GANDOLF integration project were three fold:

- to develop a 2 km resolution Nimrod advection forecast (no NWP merging) with temporal resolution and domain equivalent to those of the improved Object-Oriented (OO) life cycle model;
- to develop an improved version of the Object-Oriented life cycle Model (OOM) run by GANDOLF;
- to compare 2 km resolution precipitation forecasts produced by the Nimrod advection scheme with those generated by the OOM (both operational and new versions).

Cooper (2000) describes the R&D work undertaken in fulfilling the first of these aims. Work undertaken to achieve the remaining two objectives has been summarised in this report.

Sections 2 and 3 briefly described the 2 km Nimrod advection scheme (described in detail in Cooper, 2000), the current, operational Object-Oriented Model (also referred to as the old OOM or old OO scheme) and its intended replacement (also referred to as the new OOM or new OO scheme). The new OOM has been designed to address well documented deficiencies in the old scheme (see Pierce and Hardaker, 1997; Pickles, 2000). These deficiencies are primarily attributable to limitations in the formulation of the conceptual life cycle model.

For example, the current, operational OO forecast scheme employs a life cycle model of fixed duration. As a result, forecasts may exhibit synchronised life cycle changes that are accompanied by an unrealistic, cyclical pulsing of rain intensity. Furthermore, it has been noted that the old OOM employs the recent life cycle history of a convective cell to determine whether or not it can initiate a daughter cell. This representation fails to recognise the importance of instability and vertical wind shear in daughter cell initiation. Recent verification studies suggest that the old OOM often applies this generative mechanism incorrectly (Pierce and Hardaker, 1997).

In the new OO forecast scheme, comprehensive modifications have been made to the life cycle model to allow for a more explicit and physically-based representation of the processes which control convective cell behaviour. Thus, rather than employing a single life cycle model of fixed duration, the new scheme incorporates three such models that reflect the evolutionary characteristics of single cell, multi-cell and super cell convection. In addition, life cycle duration is allowed to vary with Storm Relative Environment Helicity (SREH) in a way that is consistent with the findings of a recent report on the relationship between wind shear and cell longevity in the UK (Rippon, 1995).

Section 4 reviewed the statistical techniques employed to assess the relative performance of the 2 km resolution Nimrod advection scheme and the old and new versions of the OOM. The importance of distinguishing between a model's ability to forecast rainfall extent, and its ability to predict the quantitative distribution of rain was recognised in the computation of both categorical and continuous statistics. These included the Critical Success Index (CSI), Hit Rate (HR), False Alarm Rate (FAR), Root Mean Squared error (RMS_OR), Root Mean Squared Factor (RMSF, RMSF_OR), the bias (MEAN) and Mean Factor Error (MEANF). The verification software was adapted from code used to verify the operational Nimrod system. This allowed model performance to be expressed as a function of rainfall event, catchment size (the size of validation area), and forecast lead time.

Tables A.1 to A.4 in Appendix A present performance statistics for Nimrod, and the old and new versions of the OOM for each of three case studies, and as an average performance over a total of twelve precipitation events. Statistics are categorised by lead time and catchment size. They give a number of important insights in to the benefits and failings of the models. First and foremost, the results demonstrate the performance of the 2 km resolution Nimrod advection scheme to be superior to that of the OOMs during cases of frontal precipitation and widespread showers. Quantitative Precipitation Forecasting (QPF) studies described in the literature (Wilson *et al.*, 1998) support this finding since they generally agree that linear extrapolation techniques are superior, or at least as good as, more sophisticated, non-linear modelling techniques in very short range precipitation forecasting (up to one hour ahead).

When showers are scattered and weakly forced at the synoptic scale, both versions of the OOM exhibit some additional skill over linear advection. However, this is not apparent in the tabulated performance statistics in Tables A.1 to A.4 because the OOM's superiority is generally limited to the early stages of a convective event when the precipitation field is growing rapidly. Here it must be noted that none of the twelve case studies examined for this report involved the evolution of showers in the presence of strong vertical wind shear. It is this sort of event for which the OOM was designed. In such cases, Hand (1996) has clearly shown that modelling daughter cell initiation effectively, gives the OOM an advantage over forecast schemes that rely upon linear extrapolation.

Both old and new versions of the OOM incorporate the same daughter cell initiation algorithm, although in the new model this is applied only when vigorous convection is accompanied by strong vertical wind shear (as predicted by the Mesoscale Model). In the old model, the daughter cell algorithm is applied to all young mature and mature convective cells (cumulonimbi) that have exhibited a steady mature state or growth during the past 20 minutes. In earlier studies (Pierce and Hardaker, 1997) it has been shown that this method of applying the daughter cell initiation algorithm can produce spurious, persistent areas of heavy rain. Another point in favour of the new OOM concerns the representation of precipitation rate. In the old scheme there is often a large positive bias in forecast rain rate. In the new scheme this has been much reduced.

8. Conclusions

The conclusions reached in this study are summarised below.

- Both old and new versions of the OOM will tend to perform better than the 2 km resolution Nimrod advection scheme during:
  - the early stages (first 10 minutes or so) of shower evolution when the precipitation field is growing rapidly;
  - episodes of severe multi-cell convection in which the multi-cell storm envelope propagates to the right or left of cell steering level flow, in response to marked vertical wind shear (Hand, 1996).
- The performance of the 2 km resolution Nimrod advection scheme will generally be superior to old and new versions of the OOM in the zero to three hour time frame during:
  - widespread frontal precipitation when the evolution of the precipitation field is relatively gradual;
  - episodes of showers that are well organised at the synoptic scale or mesoscale.
- Due to a dearth of appropriate case studies, the evidence presented in this report concerning the relative performance of the old and new versions of the OOM is of limited value. Despite some failings in the new OO analysis scheme with respect to the removal of spurious echoes, it has several advantages over the old version:

- the new model applies the daughter cell initiation algorithm in a more sparing and physically realistic manner;
- the new model produces better estimates of surface precipitation rate.

9. Recommendations for further work under the Nimrod–GANDOLF integration project.

The following recommendations are made on the basis of the findings presented in this report and in earlier reports and papers on QPF (e.g. Pierce and Hardaker, 1997; Hand, 1996; Wilson *et al.*, 1998).

- There appears to be a problem with the removal of spurious radar echoes in the new OO analysis scheme. This needs to be examined and corrected for.
- Further quantitative assessment of the performance of the new OOM is required, with an emphasis on cases of severe airmass convection in which the daughter cell generation mechanism is known to be important.
- The first version of the integrated Nimrod-GANDOLF system should combine outputs from the 2 km resolution Nimrod advection scheme and the new version of the OOM. Problems with the new OO analysis scheme should be resolved before this integration is undertaken.
- In the integrated Nimrod-GANDOLF system, the Nimrod 2 km advection scheme should be run in preference to the new OOM, except in cases of severe convection accompanied by marked vertical wind shear.
- Further R&D work is needed to improve the prediction of showers, their organisation and longevity, particularly in strong synoptically forced environments. The development of a new conceptual life cycle model of a shower that takes account of synoptic scale and mesoscale forcings may provide a way forward. This should make use of NWP-based diagnostics recently developed in NMC by Tim Hewson.
- Further R&D work is required to improve the prediction of mesoscale precipitation features embedded within frontal rain bands. This should draw upon the experience gained by the Bureau of Meteorology (BoM) in the development of the Spectral Prognosis (S-PROG) rainfall nowcasting system.
- A parallel R&D programme should explore ways of representing uncertainty in precipitation nowcasts with a view to the generation of stochastic short-range precipitation forecasts in a later version of the integrated Nimrod-GANDOLF system. This work should exploit the techniques developed at JCHMR to improve very short range precipitation probability forecasts (CIF project 38 in FY 00/01 entitled "Improved very short range precipitation probability"), and those proposed by Dr. Dan Cornford in the Mathematics and Computing department at the University of Aston.

- The development of an enhanced version of the Neural Network Cloud Classifier (Pankiewicz, 1995; 1997) capable of distinguishing rain objects (a Rain Object Classifier) on the basis of their synoptic setting and predominant forcing is likely to be beneficial to the R&D work in the above mentioned areas.

10. References

Browning, K. A. 1984. "Morphology and Classification of Mid-Latitude Thunderstorms" in *Thunderstorm Morphology & Dynamics*, Ed. E. Kessler, University of Oklahoma, USA.

Cooper, A. 2000. Development and preliminary appraisal of a 2 km resolution Nimrod advection forecast, Unpublished Tech. Report, Met Office, UK, April 2000.

Golding, B. 1998. Nimrod: a system for generating automatic very short-range forecasts. *Met. Apps.*, 5, 1–16.

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

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

Ludlam, F. H. 1980. Clouds and Storms. The behaviour and effect of water in the atmosphere. Pennsylvania State University, USA.

Nakamura, K., Kershaw, R. and Gait, N. (1996). Generation of near surface gusts by deep convection. *Met. Apps.*, 3, 157–168.

Pankiewicz, G. S. 1995. Pattern recognition techniques for the identification of cloud and cloud systems. *Met Apps.*, 2, 257–271.

Pankiewicz, G. S. 1997. Neural network classification of convective airmasses for a flood forecasting system. *Int. J. Remote Sensing*, 18, 887–898.

Pickles, A. 2000. "An assessment of the performance of GANDOLF - a convective activity warning system - for the period May to November 1999", Flood Warning Group, Environment Agency, Thames Region, July 2000.

Pierce, C. E. and Hardaker, P. J. 1997. GANDOLF Thunderstorm Warning Project, final R&D Technical Report W103, Environment Agency.

Rippon, J. 1995. Estimating limits of forecast lead-times in an operational flood forecast system. MSc Thesis, Dept. of Geog., Univ. of Birmingham, Sept., 84pp.

Weisman, M. L. & Klemp, J. B. 1982. The dependence of storm structure on vertical wind shear and buoyancy. *Monthly Weather Review*, 110, 504–520.

Wilson, J. W., Crook, N. A., Mueller, C. K., Sun, J. and Dixon, M., 1998: Nowcasting Thunderstorms: A status report. *Bull. Am. Met. Soc.*, 79, 2079-2099.

Figure 1 Surface synoptic analysis valid at 1200 GMT on 3rd April 2000

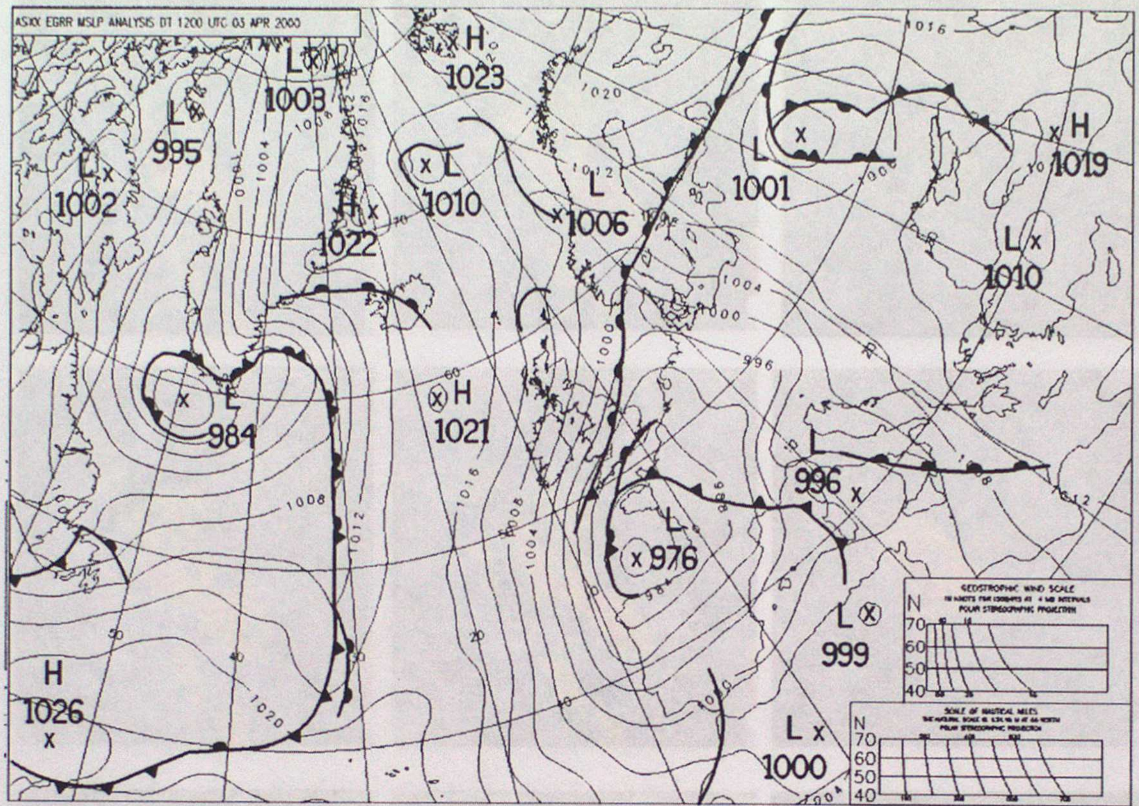


Figure 2 Widespread frontal rain - 3rd April 2000

Old OOM | Nimrod 2 km Forecast | 2km Radar Composite

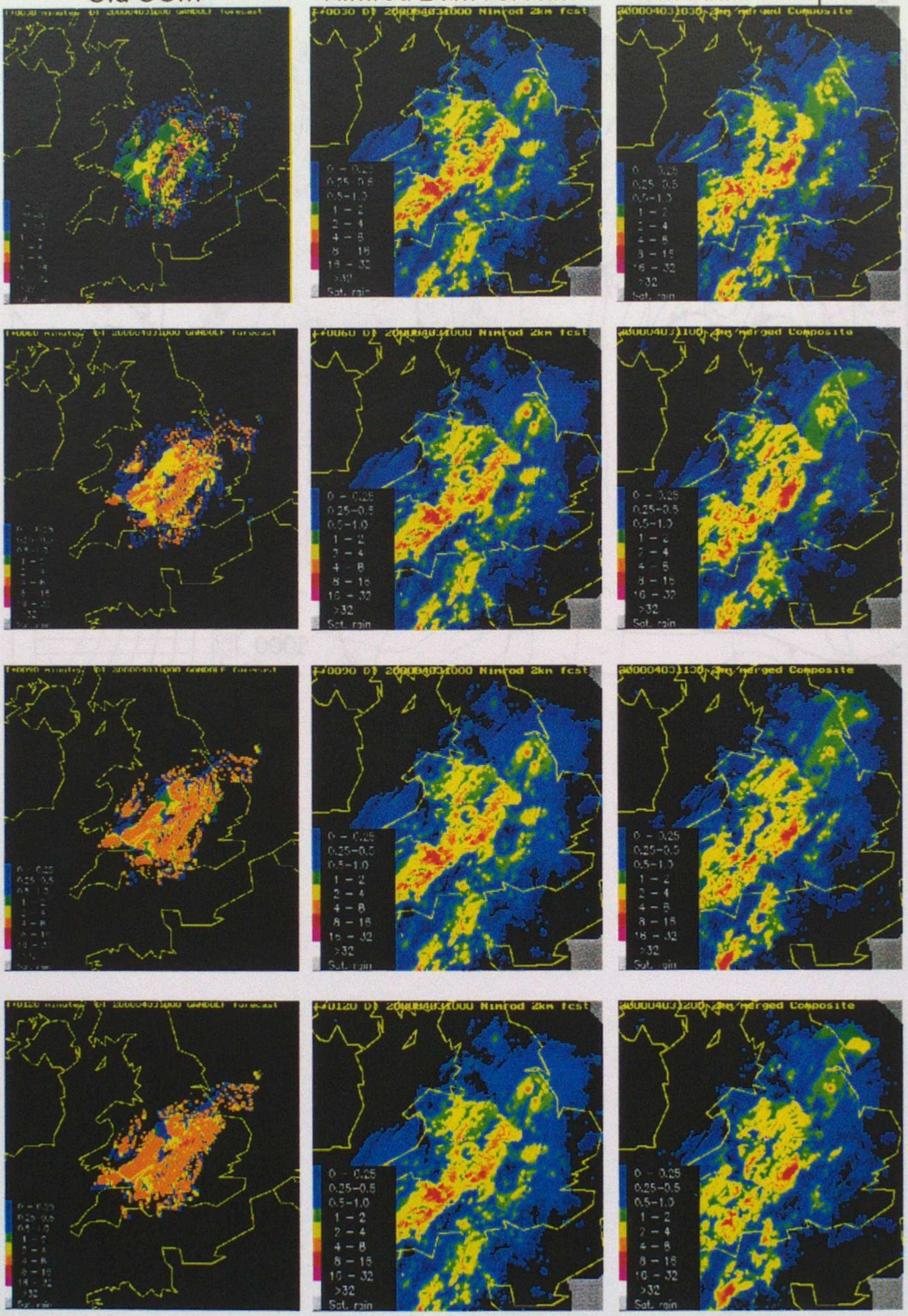


Figure 3 Surface synoptic analysis valid at 1200 GMT on 17th April 2000

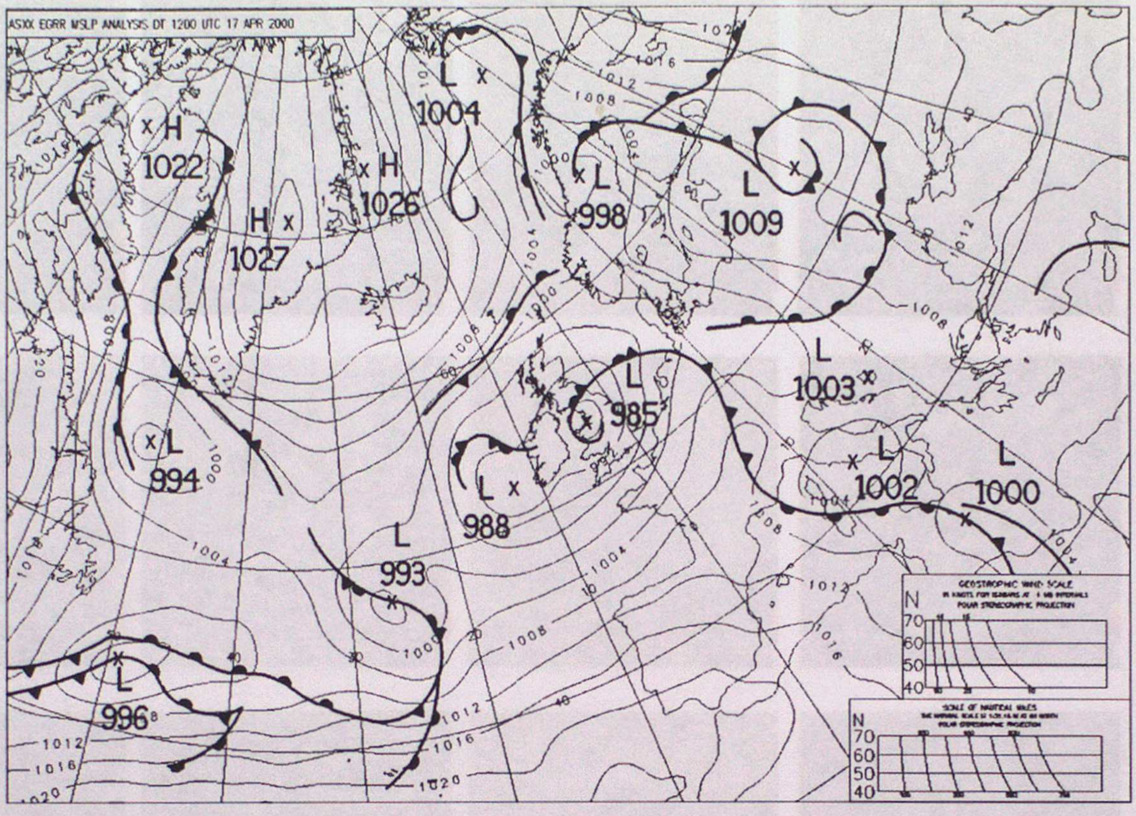


Figure 4 Bands of showers around a low pressure system – 17th April 2000

Old OOM	New OOM	Nimrod 2 km Forecast	2km Radar Composite

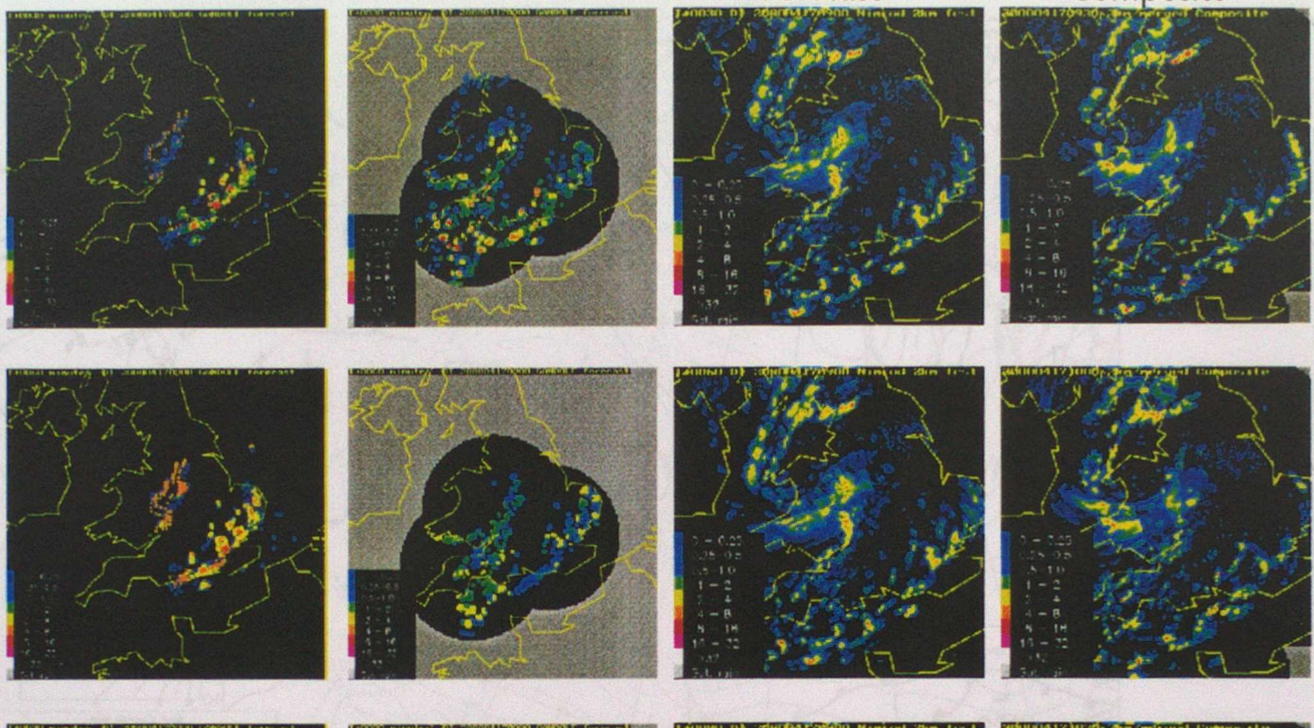


Figure 5 Surface synoptic analysis valid at 1200 GMT on 8th May 2000

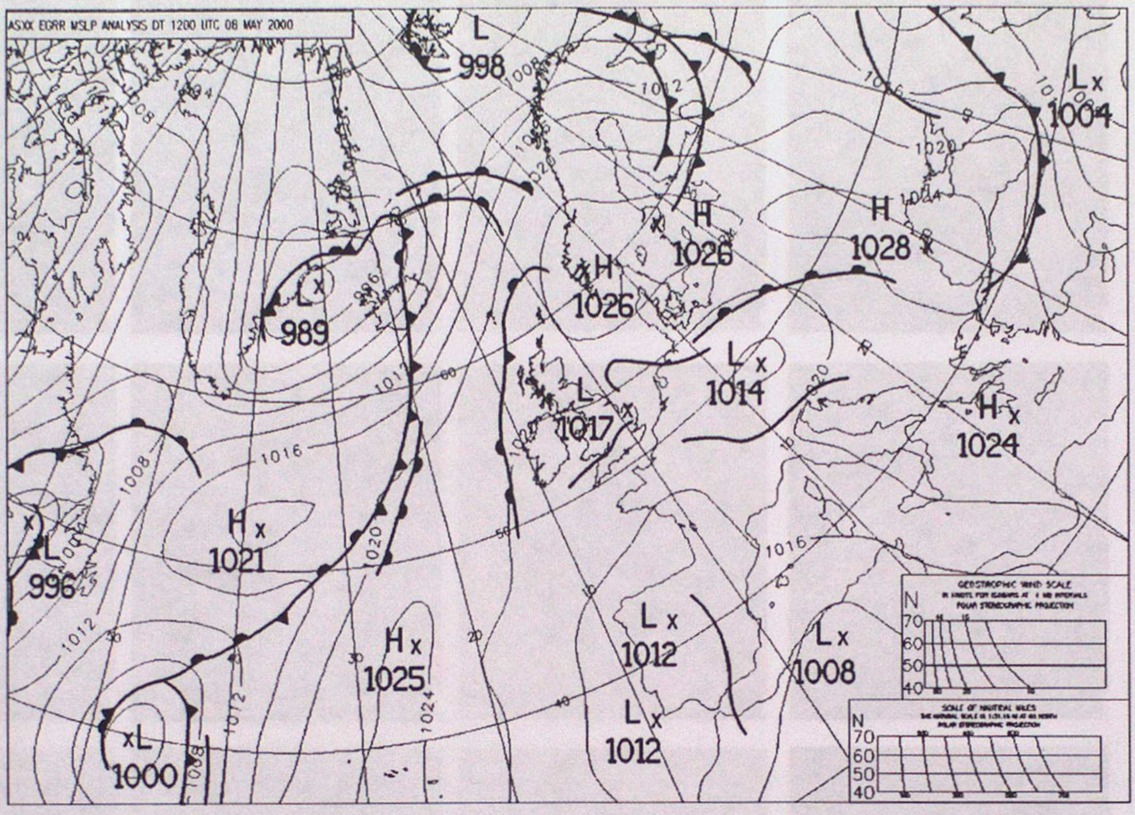
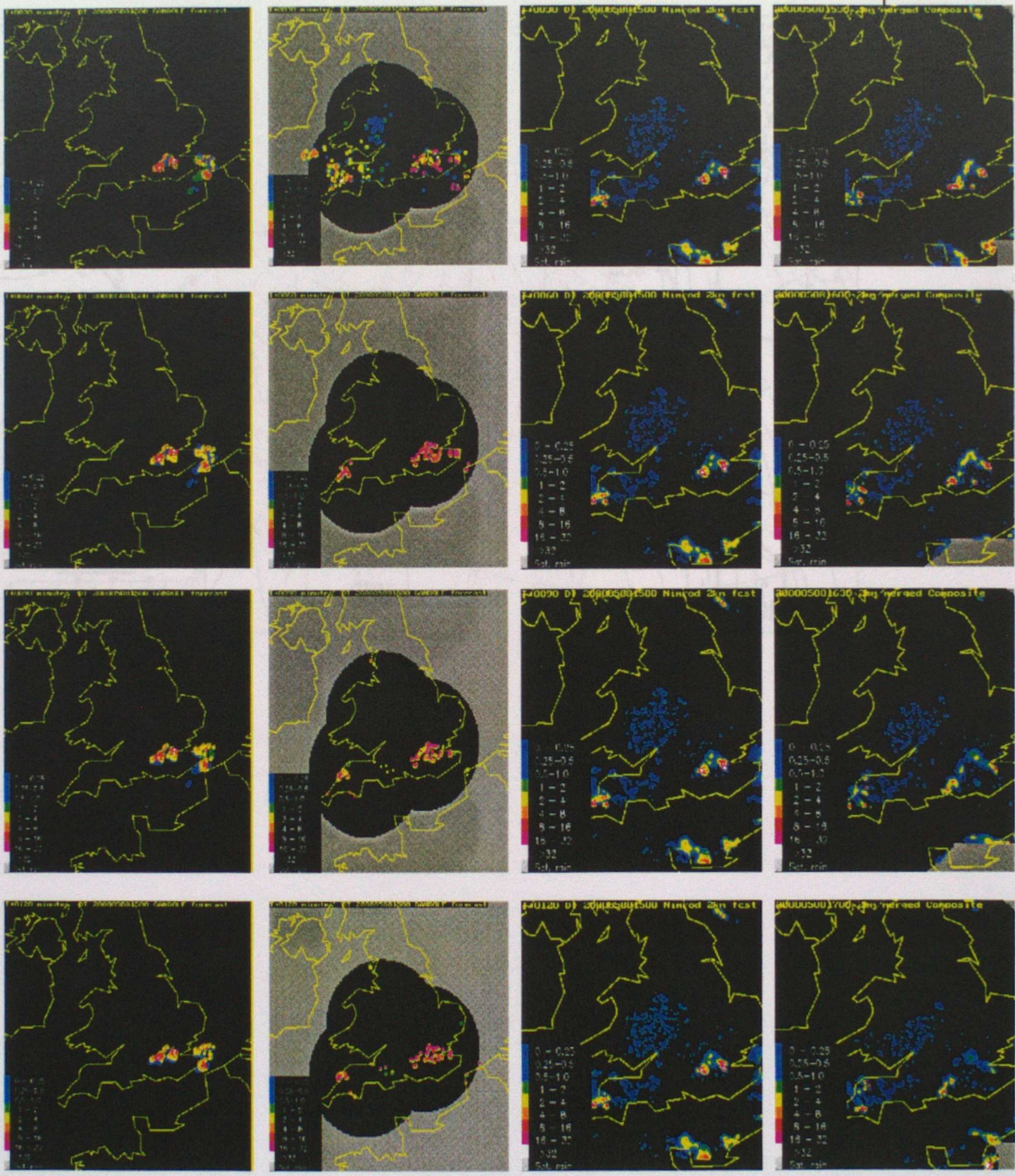


Figure 6 Scattered outbreaks of showers and thunderstorms – 8 May 2000

Old OOM | New OOM | Nimrod 2 km Forecast | 2km Radar Composite



Appendix A Tabulated quantitative verification statistics

Table sets A.1 to A.4 compare the performance of the 2 km resolution Nimrod advection scheme (ADV) and the OOM (the old version only in one case; both old and new versions in the other cases) in GANDOLF (GAN) with an Eulerian persistence forecast (PER). Table sets A.1 to A.3 summarise the performance of the models during three specific precipitation events (3/4/2000, 17/4/2000, 8/5/2000). Table set A.4 presents similar quantitative performance statistics averaged over twelve precipitation events (additionally 23/3/2000, 24/3/2000, 27/3/2000, 18/4/2000, 10/5/2000, 15/5/2000, 16/5/2000, 18/5/2000, 9/6/2000).

In each set of tables (A.1 to A.4) performance statistics are presented as a function of catchment area (320 km by 320 km, 160 km by 160 km, .., 10 km by 10 km) and forecast lead time (LT: T+30, T+60,..,T+180 minutes). The following categorical and continuous statistics are included in each table: the categorical scores A,B,C and D as described in Table 2, the Hit Rate (HR), False Alarm Rate (FAR), Critical Success Index (CSI), the Root Mean Squared Factor (RMSF, RMSF_OR), the Root Mean Squared error (RMS_OR), the mean error or bias (MEAN: in units of 32^{nd} mm h^{-1}) and the mean factor error (MEANF). The columns headed NVS and NVS_OR refer to the Number of Valid Samples upon which computations of the RMSF (NVS), RMSF_OR and RMS_OR (NVS_OR) are based.

Tables A.1 Widespread frontal rain – 3rd April 2000

20000403															
Catchment area: 320 by 320 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	46087	3534	4519	48260	0.93	0.09	0.85	1.744	46553	2.161	25.531	53995	0.387	1.043
ADV	30	44876	3556	4546	49421	0.93	0.09	0.85	1.753	45367	2.169	34.429	52814	0.693	1.044
GAN	30	4741	1097	9510	87052	0.75	0.68	0.30	10.331	7373	15.312	38.906	17888	13.481	2.916
PER	60	44915	4085	6214	47186	0.92	0.12	0.81	2.029	45375	2.675	32.365	55075	0.760	1.094
ADV	60	43824	4169	6149	48259	0.91	0.12	0.81	2.053	44277	2.707	38.909	53965	1.205	1.087
GAN	60	4703	912	11136	85650	0.78	0.71	0.27	10.257	7019	19.923	62.283	19252	38.103	4.910
PER	90	44052	4381	7537	46430	0.91	0.15	0.79	2.235	44480	3.074	36.939	55856	1.105	1.137
ADV	90	43079	4560	7356	47405	0.90	0.15	0.78	2.278	43506	3.128	42.911	54820	1.688	1.124
GAN	90	3966	1432	10266	86736	0.68	0.73	0.25	10.188	5978	26.324	77.890	18368	54.822	6.419
PER	120	43331	4662	8736	45672	0.90	0.17	0.76	2.404	43759	3.412	39.512	56621	1.601	1.177
ADV	120	42402	4902	8460	46637	0.89	0.17	0.76	2.468	42850	3.493	45.725	55601	2.523	1.169
GAN	120	3718	1492	11238	85952	0.65	0.76	0.22	8.708	5504	30.537	76.813	19320	55.427	7.058
PER	150	42895	4745	9677	45083	0.90	0.19	0.75	2.537	43307	3.672	41.639	57229	1.857	1.217
ADV	150	41815	5051	9445	46088	0.89	0.19	0.74	2.609	42260	3.797	47.336	56182	3.114	1.213
GAN	150	3498	1501	12281	85120	0.63	0.78	0.20	9.435	5138	31.294	74.524	20185	54.176	7.305
PER	180	42381	4923	10704	44392	0.90	0.20	0.73	2.618	42758	3.902	42.562	57954	2.332	1.260
ADV	180	41188	5263	10497	45452	0.88	0.20	0.72	2.653	41549	4.051	48.240	56868	3.537	1.253
GAN	180	3295	1440	12819	84846	0.61	0.81	0.18	10.452	4836	36.246	71.582	20593	53.355	7.649

Tables A.1 Widespread frontal rain – 3rd April 2000

Catchment area: 160 by 160 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	13081	1482	2293	34344	0.89	0.14	0.78	1.731	6404	2.248	19.839	8128	0.835	1.100
ADV	30	12034	1506	2272	35389	0.88	0.15	0.76	1.750	5880	2.281	20.882	7597	0.940	1.105
GAN	30	3379	690	4857	42274	0.68	0.78	0.20	10.326	2594	38.532	33.439	4905	12.311	4.259
PER	60	12430	1634	3312	33824	0.88	0.19	0.73	1.999	6085	2.775	24.934	8381	1.616	1.224
ADV	60	11375	1695	3260	34871	0.87	0.20	0.71	2.035	5555	2.843	25.793	7842	1.856	1.234
GAN	60	3154	743	5209	42095	0.71	0.79	0.19	9.728	2387	47.550	57.392	4955	34.356	7.431
PER	90	11917	1623	4249	33411	0.87	0.23	0.69	2.189	5821	3.165	28.282	8593	2.686	1.381
ADV	90	10959	1764	4077	34400	0.86	0.24	0.68	2.247	5340	3.256	28.949	8076	2.959	1.374
GAN	90	2466	1275	4417	43042	0.66	0.78	0.18	9.360	1925	58.035	71.581	4533	48.541	10.936
PER	120	11462	1607	5181	32950	0.87	0.27	0.66	2.316	5601	3.487	29.905	8821	3.853	1.560
ADV	120	10663	1793	4805	33940	0.85	0.26	0.65	2.388	5204	3.552	30.424	8301	4.015	1.520
GAN	120	2304	1327	4558	43012	0.58	0.78	0.17	7.578	1757	65.559	68.313	4599	45.958	10.720
PER	150	11130	1593	6013	32464	0.87	0.30	0.63	2.433	5429	3.781	31.159	9068	4.856	1.735
ADV	150	10406	1824	5501	33469	0.85	0.30	0.62	2.524	5070	3.883	32.451	8549	4.678	1.665
GAN	150	2192	1305	4656	43046	0.50	0.78	0.17	8.165	1642	74.933	65.275	4600	43.672	10.785
PER	180	10866	1589	6871	31874	0.87	0.33	0.60	2.533	5283	4.053	32.044	9376	5.875	1.901
ADV	180	10193	1809	6341	32857	0.85	0.31	0.60	2.580	4944	4.168	32.845	8870	5.669	1.833
GAN	180	2084	1192	4693	43232	0.59	0.78	0.16	8.638	1572	90.223	62.728	4549	42.992	11.259

Tables A.1 Widespread frontal rain – 3rd April 2000

Catchment area: 80 by 80 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	9112	673	877	14937	0.57	0.39	0.49	1.734	2206	2.562	15.732	2541	-0.275	1.072
ADV	30	8870	678	917	15136	0.55	0.41	0.48	1.752	2149	2.572	16.041	2493	-0.447	1.074
GAN	30	2530	297	2893	19880	0.64	0.75	0.22	16.444	908	37.830	85.416	1485	1.326	3.730
PER	60	8936	744	1139	14780	0.55	0.43	0.47	1.838	2166	2.904	19.261	2575	-0.605	1.146
ADV	60	8682	777	1196	14946	0.52	0.43	0.44	1.870	2106	2.939	18.944	2533	-0.960	1.113
GAN	60	2480	269	3288	19564	0.61	0.74	0.21	10.101	882	45.377	120.288	1548	18.457	6.164
PER	90	8840	708	1364	14688	0.53	0.45	0.45	2.034	2141	3.050	21.384	2598	-0.634	1.202
ADV	90	8599	780	1437	14784	0.53	0.47	0.44	2.027	2086	3.070	20.812	2570	-0.649	1.124
GAN	90	2198	467	3163	19772	0.57	0.77	0.16	7.850	817	55.380	161.187	1523	40.360	9.362
PER	120	8801	658	1526	14615	0.53	0.42	0.44	2.048	2135	3.134	22.152	2614	-0.471	1.219
ADV	120	8576	735	1607	14682	0.52	0.42	0.44	2.105	2081	3.161	21.810	2594	-0.345	1.126
GAN	120	2127	458	3299	19717	0.53	0.78	0.16	7.018	777	63.566	198.352	1563	38.770	9.296
PER	150	8725	654	1685	14536	0.54	0.44	0.43	2.220	2116	3.269	23.432	2633	-0.303	1.296
ADV	150	8442	733	1810	14614	0.52	0.47	0.42	2.277	2049	3.392	23.832	2611	-0.525	1.222
GAN	150	2084	379	3449	19688	0.49	0.78	0.17	6.520	751	75.292	59.349	1573	38.904	9.752
PER	180	8628	683	1853	14436	0.51	0.42	0.42	2.226	2091	3.475	24.511	2658	-0.139	1.326
ADV	180	8298	735	1967	14601	0.51	0.39	0.41	2.280	2008	3.661	24.838	2616	-0.678	1.260
GAN	180	2010	308	3538	19744	0.65	0.78	0.18	8.677	727	91.800	60.118	1561	42.496	11.024

Tables A.1 Widespread frontal rain – 3rd April 2000

Catchment area: 40 by 40 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	4291	278	397	7834	0.67	0.32	0.57	1.636	491	2.529	16.861	560	0.172	1.237
ADV	30	4195	280	401	7924	0.67	0.33	0.57	1.641	480	2.430	17.240	549	0.232	1.220
GAN	30	1333	134	1616	9717	0.77	0.68	0.29	7.270	215	7.537	36.519	377	12.235	3.990
PER	60	4238	289	507	7766	0.67	0.34	0.56	1.834	485	2.800	20.695	568	-0.003	1.369
ADV	60	4133	307	522	7838	0.66	0.33	0.55	1.873	473	2.714	20.497	559	0.263	1.255
GAN	60	1291	126	1949	9434	0.78	0.69	0.27	4.746	208	11.719	64.150	407	39.541	6.570
PER	90	4182	294	628	7697	0.68	0.36	0.55	2.031	478	2.948	24.065	576	0.090	1.463
ADV	90	4072	328	666	7733	0.66	0.37	0.54	1.993	466	2.866	23.167	570	1.155	1.297
GAN	90	1136	231	1911	9521	0.72	0.71	0.22	6.346	187	17.809	89.373	405	56.692	10.424
PER	120	4145	295	712	7648	0.68	0.34	0.55	1.987	474	3.017	24.791	581	0.185	1.509
ADV	120	4049	318	745	7689	0.67	0.34	0.54	1.937	463	2.914	23.827	576	1.768	1.376
GAN	120	1091	223	2014	9473	0.66	0.71	0.22	6.750	175	20.291	96.184	416	62.388	12.058
PER	150	4112	289	753	7647	0.70	0.35	0.54	2.055	470	3.109	25.793	581	0.183	1.556
ADV	150	3984	296	799	7721	0.67	0.38	0.52	2.038	454	3.071	25.447	573	1.805	1.478
GAN	150	1002	192	2040	9566	0.69	0.72	0.22	6.522	158	20.923	97.219	411	58.979	12.189
PER	180	4051	316	825	7609	0.67	0.34	0.52	2.086	462	3.266	26.535	587	0.704	1.651
ADV	180	3844	305	933	7718	0.67	0.34	0.50	2.069	436	3.301	25.767	574	2.662	1.650
GAN	180	872	194	2066	9668	0.77	0.73	0.21	8.836	135	22.579	108.507	399	60.491	13.545

Tables A.1 Widespread frontal rain – 3rd April 2000

Catchment area: 20 by 20 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	2239	117	173	3872	0.81	0.19	0.74	1.632	115	2.038	17.387	128	-0.008	1.133
ADV	30	2179	114	180	3927	0.78	0.22	0.70	1.632	113	2.102	18.271	125	0.078	1.160
GAN	30	661	69	848	4822	0.85	0.64	0.33	8.051	46	12.532	41.052	89	7.473	5.041
PER	60	2212	114	234	3841	0.80	0.22	0.71	1.861	114	2.359	21.814	130	0.075	1.277
ADV	60	2147	124	246	3884	0.78	0.23	0.68	1.885	111	2.425	21.759	128	0.559	1.289
GAN	60	622	76	1052	4650	0.83	0.66	0.30	6.435	44	15.685	84.726	95	38.724	11.831
PER	90	2190	103	305	3803	0.80	0.24	0.68	2.043	113	2.630	25.224	132	2.031	1.458
ADV	90	2122	121	333	3823	0.77	0.27	0.66	1.988	110	2.677	24.387	130	3.643	1.468
GAN	90	517	144	1040	4699	0.72	0.72	0.22	9.013	37	24.302	91.976	93	57.049	18.588
PER	120	2169	102	366	3764	0.79	0.24	0.67	2.103	112	2.816	26.459	134	3.036	1.558
ADV	120	2088	115	421	3777	0.78	0.27	0.64	2.014	108	2.875	24.556	133	3.298	1.630
GAN	120	483	136	1016	4766	0.68	0.73	0.20	8.682	33	24.361	119.451	90	57.438	18.333
PER	150	2157	87	391	3765	0.82	0.23	0.67	2.206	111	2.912	27.200	134	3.854	1.662
ADV	150	2052	86	465	3797	0.82	0.29	0.63	2.210	106	3.054	26.007	132	3.695	1.811
GAN	150	443	103	1020	4833	0.74	0.74	0.18	8.831	29	24.852	129.300	88	57.397	17.706
PER	180	2103	101	449	3748	0.80	0.24	0.64	2.157	108	3.099	27.373	135	3.173	1.809
ADV	180	1977	86	541	3797	0.80	0.28	0.60	2.110	101	3.352	26.418	132	5.717	2.085
GAN	180	412	63	1086	4838	0.76	0.78	0.17	10.709	27	26.333	148.982	89	62.289	19.421

Tables A.1 Widespread frontal rain – 3rd April 2000

Catchment area: 10 by 10 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	1126	53	84	1937	0.87	0.15	0.78	1.629	23	1.988	19.355	25	0.694	1.218
ADV	30	1094	53	89	1964	0.85	0.17	0.76	1.644	22	2.030	20.543	25	1.067	1.228
GAN	30	320	41	425	2414	0.83	0.65	0.32	8.217	9	9.473	46.994	17	13.967	6.594
PER	60	1110	56	117	1918	0.86	0.18	0.74	1.875	23	2.362	23.652	26	0.994	1.414
ADV	60	1072	63	128	1936	0.83	0.20	0.72	1.891	22	2.420	23.709	25	2.000	1.447
GAN	60	297	47	506	2350	0.84	0.69	0.28	6.751	9	16.066	68.957	18	44.059	13.527
PER	90	1099	48	154	1899	0.86	0.20	0.73	2.054	22	2.657	27.268	26	2.852	1.675
ADV	90	1059	60	173	1908	0.84	0.23	0.70	2.097	22	2.769	27.513	26	5.328	1.752
GAN	90	253	75	512	2360	0.75	0.70	0.23	7.943	7	25.590	95.373	18	71.405	22.286
PER	120	1090	45	182	1882	0.86	0.21	0.72	2.119	22	2.833	27.977	27	4.390	1.869
ADV	120	1048	50	210	1892	0.86	0.23	0.69	2.129	22	3.005	27.788	26	6.431	2.035
GAN	120	241	63	526	2371	0.78	0.72	0.23	8.112	7	27.028	96.816	18	69.136	23.612
PER	150	1085	34	199	1882	0.88	0.22	0.72	2.204	22	2.945	28.508	27	6.883	2.021
ADV	150	1028	37	238	1897	0.87	0.27	0.67	2.347	21	3.293	30.421	26	7.350	2.255
GAN	150	220	50	543	2387	0.82	0.73	0.22	8.511	6	27.509	99.753	18	69.661	23.895
PER	180	1062	36	226	1876	0.87	0.24	0.69	2.204	22	3.151	28.961	27	8.813	2.239
ADV	180	996	37	277	1890	0.86	0.28	0.64	2.244	21	3.554	30.678	27	9.672	2.606
GAN	180	198	37	554	2411	0.83	0.78	0.19	11.054	5	29.325	104.975	18	76.712	26.107

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

20000417															
Catchment area: 320 by 320 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	10455	8808	9160	73977	0.54	0.47	0.37	2.750	11735	6.667	39.204	30529	0.339	1.034
ADV	30	12968	6142	7042	76248	0.67	0.36	0.49	2.545	14765	4.252	31.965	27349	-0.103	1.030
GAN	30	1009	654	4865	95871	0.67	0.82	0.16	16.575	2228	53.648	81.825	9285	27.396	4.208
GAN_NEW	30	3975	5081	5943	87401	0.36	0.6	0.25	3.172	6277	8.797	91.23	17761	-8.56	2.764
PER	60	9084	10179	10840	72297	0.47	0.55	0.30	2.957	10129	7.609	41.044	32452	0.628	1.062
ADV	60	10339	8673	9457	73931	0.54	0.48	0.36	3.049	11820	6.084	37.943	30022	-0.352	1.021
GAN	60	760	972	5449	95219	0.48	0.88	0.11	19.337	1692	87.788	83.572	10561	33.481	4.244
GAN_NEW	60	2816	5667	6527	87390	0.25	0.7	0.16	3.385	4223	9.265	93.157	17754	-15.218	2.434
PER	90	8265	10845	11858	71432	0.43	0.59	0.26	3.142	9173	8.086	41.554	33460	1.001	1.095
ADV	90	8656	10350	10766	72628	0.45	0.56	0.29	3.211	9930	7.148	39.608	31594	-0.954	0.991
GAN	90	476	1334	4958	95631	0.28	0.92	0.07	26.554	1227	120.980	72.420	11321	28.826	3.364
GAN_NEW	90	109	7715	481	60761	0.01	0.8	0.01	4.333	166	12.546	201.432	10117	-42.983	1.513
PER	120	7673	11339	12659	70728	0.40	0.62	0.24	3.265	8540	8.410	42.049	34211	1.414	1.128
ADV	120	7571	11469	11425	71935	0.39	0.61	0.24	3.306	8704	7.796	40.335	32479	-1.490	0.962
GAN	120	339	1609	4849	95602	0.18	0.94	0.05	28.615	971	150.510	64.108	12076	22.969	2.394
GAN_NEW	120	5	7091	72	52375	0	0.79	0	1.196	12	14.902	283.579	8826	-34.995	1.874
PER	150	7003	12003	13502	69892	0.37	0.66	0.21	3.309	7755	8.835	42.615	35181	1.690	1.149
ADV	150	6747	12328	11748	71577	0.35	0.64	0.22	3.360	7774	8.209	40.887	33000	-1.886	0.931
GAN	150	307	1595	4950	95548	0.17	0.95	0.04	22.441	835	134.729	81.633	11387	24.905	2.510
GAN_NEW	150	2	8291	65	63273	0	0.73	0	0.312	5	15.302	265.145	10283	-43.668	1.391
PER	180	6455	12584	14176	69184	0.34	0.69	0.19	3.364	7125	9.172	42.954	35987	1.886	1.164
ADV	180	6081	13018	11882	71419	0.31	0.67	0.19	3.374	7009	8.437	40.963	33321	-2.360	0.902
GAN	180	233	1869	4697	88458	0.12	0.95	0.03	18.905	686	149.709	90.641	11695	22.404	2.254
GAN_NEW	180	0	7946	80	63605	0	0.69	0	0.178	1	14.385	276.383	9886	-46.91	0.939

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

Catchment area: 160 by 160 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	5834	3998	4342	37027	0.54	0.48	0.38	2.883	3182	6.514	35.302	7385	0.962	1.082
ADV	30	6694	2959	3684	37863	0.67	0.37	0.48	2.497	3706	4.228	28.774	6803	1.115	1.122
GAN	30	803	386	3167	46844	0.66	0.84	0.14	15.852	886	70.189	75.346	2926	25.266	5.410
GAN_NEW	30	1715	2007	2744	44734	0.31	0.64	0.2	2.853	1371	7.705	55.315	3759	-5.208	2.635
PER	60	5129	4703	5339	36029	0.48	0.55	0.31	3.097	2794	7.375	38.803	7925	1.730	1.157
ADV	60	5414	4121	4941	36724	0.54	0.50	0.36	3.004	3009	6.045	35.004	7453	1.458	1.169
GAN	60	577	595	3255	46773	0.45	0.87	0.11	18.935	637	107.310	79.742	3049	26.430	5.411
GAN_NEW	60	1410	2083	3106	44601	0.24	0.69	0.14	3.175	1044	8.178	49.022	3807	-9.096	2.51
PER	90	4554	5099	6102	35444	0.43	0.61	0.26	3.237	2473	7.982	40.372	8250	2.569	1.240
ADV	90	4480	4989	5647	36084	0.45	0.58	0.28	3.188	2510	7.130	37.421	7831	0.942	1.152
GAN	90	351	821	2694	47334	0.27	0.90	0.07	26.983	454	147.958	68.728	3076	19.430	4.033
GAN_NEW	90	74	3192	252	47681	0.01	0.75	0.01	4.375	53	10.393	50.028	2115	-22.674	1.643
PER	120	4142	5393	6704	34961	0.40	0.64	0.24	3.304	2251	8.445	41.681	8504	3.250	1.316
ADV	120	3736	5709	5973	35782	0.38	0.63	0.23	3.244	2110	7.786	37.471	8036	-0.419	1.084
GAN	120	225	996	2258	47721	0.16	0.92	0.05	33.792	322	181.947	56.774	3076	13.589	2.538
GAN_NEW	120	1	3033	19	48147	0	0.55	0	0.316	1	11.007	47.965	1862	-17.128	2.713
PER	150	3766	5703	7258	34472	0.37	0.68	0.21	3.253	2037	8.868	42.353	8777	3.867	1.393
ADV	150	3178	6265	6144	35613	0.31	0.67	0.19	3.288	1815	8.175	37.285	8167	-1.480	1.021
GAN	150	181	1013	1767	48239	0.13	0.91	0.05	24.542	248	151.385	72.536	2608	7.423	2.462
GAN_NEW	150	0	3582	18	47601	0	0.69	0	0	0	12.03	56.41	2196	-25.215	1.964
PER	180	3474	5972	7708	34047	0.35	0.71	0.19	3.341	1871	9.245	43.152	9011	4.492	1.460
ADV	180	2755	6697	6101	35646	0.27	0.71	0.16	3.288	1589	8.448	37.486	8196	-2.397	0.958
GAN	180	116	1196	1223	48666	0.08	0.91	0.04	20.658	170	164.189	85.783	2522	-10.103	1.461
GAN_NEW	180	0	3456	29	47716	0	0.69	0	0.178	0	11.813	59.038	2131	-27.467	1.528

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

Catchment area: 80 by 80 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	3612	2097	2283	17608	0.47	0.53	0.33	2.751	934	6.927	30.964	1991	0.002	1.267
ADV	30	3928	1725	2054	17892	0.57	0.46	0.40	2.504	1039	4.777	25.955	1886	0.403	1.306
GAN	30	346	182	1463	23609	0.62	0.88	0.11	25.522	186	53.082	46.478	658	18.413	4.974
GAN_NEW	30	917	1284	1536	21864	0.31	0.64	0.18	2.884	355	7.625	43.448	1047	-1.239	3.011
PER	60	3273	2436	2793	17098	0.42	0.60	0.27	2.904	846	7.712	34.176	2123	0.060	1.500
ADV	60	3247	2385	2663	17304	0.46	0.56	0.30	2.932	859	6.483	31.347	2050	0.284	1.534
GAN	60	214	313	1327	23747	0.38	0.90	0.08	25.068	115	93.767	58.106	651	21.141	5.576
GAN_NEW	60	740	1298	1677	21885	0.22	0.75	0.1	2.968	266	7.844	38.248	1046	-5.436	2.808
PER	90	3014	2640	3170	16777	0.40	0.62	0.24	3.010	775	7.967	36.096	2211	0.410	1.726
ADV	90	2780	2880	2974	16966	0.38	0.61	0.25	2.981	739	7.445	34.066	2147	-1.148	1.503
GAN	90	107	430	932	24131	0.21	0.92	0.05	18.662	68	151.702	103.777	637	12.773	4.146
GAN_NEW	90	54	1850	151	23544	0.01	0.62	0.01	3.648	20	9.561	42.423	592	-18.133	1.909
PER	120	2737	2895	3545	16423	0.38	0.66	0.21	3.296	702	8.739	38.026	2304	0.994	1.904
ADV	120	2387	3301	3134	16778	0.32	0.66	0.20	3.286	642	8.290	35.690	2206	-3.086	1.485
GAN	120	44	536	640	24380	0.06	0.94	0.02	18.124	36	204.367	95.246	634	-1.873	1.922
GAN_NEW	120	1	1818	6	23775	0	0.45	0	0.316	1	10.556	44.474	536	-16.149	2.715
PER	150	2515	3145	3837	16103	0.34	0.69	0.19	2.998	641	9.389	39.963	2393	1.391	2.052
ADV	150	2095	3660	3173	16672	0.27	0.70	0.17	3.115	573	8.836	36.699	2243	-5.454	1.464
GAN	150	27	581	351	24641	0.03	0.91	0.02	12.431	21	170.919	55.346	524	-11.376	1.369
GAN_NEW	150	0	2289	10	23300	0	0.62	0	0	0	10.792	47.815	676	-21.144	1.897
PER	180	2307	3382	4083	15828	0.32	0.71	0.17	3.110	586	10.063	41.841	2465	1.761	2.238
ADV	180	1839	4006	3067	16689	0.23	0.71	0.15	3.183	508	8.927	36.294	2250	-8.075	1.161
GAN	180	5	683	112	24800	0.01	0.74	0.00	5.938	5	199.479	67.675	514	-28.703	0.107
GAN_NEW	180	0	2257	17	23327	0	0.69	0	0.178	0	11.217	49.58	669	-19.989	2.385

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

Catchment area: 40 by 40 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	1929	991	1116	8764	0.53	0.50	0.34	2.480	236	5.719	23.918	471	1.224	1.698
ADV	30	2031	848	1147	8774	0.55	0.51	0.36	2.501	253	4.708	22.577	464	3.309	1.813
GAN	30	183	91	762	11764	0.64	0.87	0.12	23.084	46	55.210	119.799	159	13.035	4.165
GAN_NEW	30	499	709	819	10772	0.29	0.68	0.17	2.734	92	7.163	36.435	270	2.241	2.841
PER	60	1761	1159	1407	8473	0.47	0.57	0.29	2.668	217	6.575	27.000	506	1.932	1.969
ADV	60	1704	1131	1446	8519	0.45	0.60	0.27	2.879	211	6.305	27.597	498	4.223	2.312
GAN	60	115	147	733	11805	0.40	0.89	0.08	31.664	29	75.033	94.579	160	12.470	4.977
GAN_NEW	60	387	726	823	10865	0.2	0.75	0.1	2.805	64	7.484	30.486	260	-2.654	2.816
PER	90	1629	1250	1623	8298	0.45	0.59	0.26	2.913	200	7.123	28.685	529	2.448	2.335
ADV	90	1450	1346	1596	8407	0.39	0.65	0.22	3.071	181	6.896	28.686	513	2.375	2.260
GAN	90	52	207	486	12055	0.21	0.91	0.04	21.971	14	130.736	115.416	150	8.558	3.961
GAN_NEW	90	11	1036	28	11724	0.01	0.42	0	1.247	2	7.818	30.371	148	-16.837	0.926
PER	120	1525	1311	1797	8168	0.45	0.62	0.24	3.060	187	7.525	29.617	546	3.529	2.508
ADV	120	1252	1497	1669	8382	0.33	0.67	0.18	3.181	158	7.358	29.437	518	-0.188	1.952
GAN	120	16	257	267	12260	0.06	0.94	0.02	14.183	6	190.737	78.464	140	-8.533	1.229
GAN_NEW	120	1	988	1	11811	0	0.09	0	0.261	0	7.121	28.792	138	-16.694	0.556
PER	150	1418	1379	1954	8050	0.41	0.64	0.21	2.831	172	8.052	30.881	562	3.684	2.679
ADV	150	1112	1618	1768	8302	0.30	0.70	0.16	3.165	143	7.409	28.327	531	-1.551	1.863
GAN	150	4	263	84	12449	0.01	0.76	0.00	12.495	2	151.513	55.815	103	-26.964	0.134
GAN_NEW	150	0	1150	2	11648	0	0.23	0	0	0	8.559	33.72	160	-17.587	0.788
PER	180	1289	1460	2116	7935	0.39	0.66	0.19	3.093	156	8.524	31.931	577	4.036	2.845
ADV	180	968	1747	1792	8294	0.27	0.71	0.14	3.115	126	7.672	28.166	535	-1.898	1.914
GAN	180	0	305	11	12484	0.00	0.41	0.00	0.552	0	143.083	64.248	103	-30.660	0.075
GAN_NEW	180	0	1080	5	11714	0	0.31	0	0.141	0	8.523	34.699	150	-17.728	0.821

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

Catchment area: 20 by 20 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	1013	509	578	4300	0.53	0.50	0.34	2.540	55	5.172	21.407	109	1.206	1.759
ADV	30	1066	425	628	4281	0.54	0.54	0.34	2.455	59	4.351	19.928	109	3.313	1.916
GAN	30	98	45	434	5823	0.66	0.86	0.13	23.900	11	33.536	109.985	39	17.603	4.594
GAN_NEW	30	249	373	432	5347	0.3	0.7	0.16	2.899	20	7.494	33.986	62	4.602	3.441
PER	60	937	585	728	4151	0.49	0.57	0.28	2.870	51	5.988	24.461	117	2.432	2.223
ADV	60	903	565	759	4173	0.45	0.61	0.25	3.001	49	5.774	23.775	116	3.221	2.392
GAN	60	71	68	425	5835	0.43	0.88	0.09	44.637	8	78.711	143.702	39	26.873	6.947
GAN_NEW	60	218	357	453	5372	0.24	0.77	0.11	2.645	16	7.76	30.926	62	-1.997	3.284
PER	90	870	621	839	4069	0.49	0.58	0.26	3.136	47	6.531	26.719	122	3.404	2.613
ADV	90	771	679	820	4129	0.40	0.65	0.21	3.243	42	6.338	24.808	118	1.789	2.587
GAN	90	34	101	278	5987	0.25	0.90	0.05	26.029	4	117.354	114.806	35	25.419	6.204
GAN_NEW	90	5	529	13	5852	0.01	0.35	0	1.048	1	8.122	29.452	33	-15.23	0.665
PER	120	789	679	962	3969	0.46	0.62	0.22	3.306	43	7.196	27.497	128	4.009	2.991
ADV	120	651	770	838	4141	0.37	0.65	0.18	3.370	35	6.783	24.804	118	0.653	2.540
GAN	120	7	138	132	6122	0.06	0.88	0.02	13.860	1	124.852	109.830	31	8.792	3.000
GAN_NEW	120	1	512	0	5887	0	0.02	0	0.261	0	7.065	25.747	31	-14.634	0.082
PER	150	727	723	1060	3890	0.43	0.64	0.20	3.218	39	7.721	28.543	132	4.944	3.316
ADV	150	600	809	889	4102	0.34	0.67	0.17	3.049	34	6.745	23.995	121	-0.207	2.497
GAN	150	1	146	22	6231	0.00	0.65	0.00	10.941	0	123.043	84.552	22	-29.408	0.167
GAN_NEW	150	0	592	1	5807	0	0.08	0	0	0	7.763	27.846	36	-15.452	0.224
PER	180	653	767	1149	3831	0.43	0.66	0.18	3.450	35	8.278	29.338	136	5.679	3.669
ADV	180	520	879	940	4060	0.31	0.69	0.14	3.092	30	7.051	23.818	124	-0.560	2.530
GAN	180	0	166	1	6234	0.00	0.07	0.00	0.000	0	109.009	64.550	23	-34.846	0.071
GAN_NEW	180	0	560	2	5838	0	0.15	0	0.141	0	7.7	28.167	34	-15.558	0.178

Tables A.2 Bands of showers around a low pressure system – 17th April 2000

Catchment area: 10 by 10 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	499	257	291	2153	0.55	0.47	0.35	2.498	11	4.897	18.942	21	1.498	2.120
ADV	30	516	225	337	2123	0.51	0.57	0.31	2.664	11	4.383	17.574	22	2.879	2.298
GAN	30	49	22	209	2921	0.63	0.84	0.13	27.018	2	43.238	48.992	7	21.346	5.244
GAN_NEW	30	132	180	218	2670	0.3	0.68	0.16	2.964	4	8.127	32.871	13	7.443	4.653
PER	60	457	299	370	2074	0.52	0.54	0.29	2.970	10	5.746	21.795	23	2.944	2.642
ADV	60	444	287	400	2070	0.44	0.60	0.24	3.446	10	5.726	20.811	23	3.015	2.933
GAN	60	35	33	221	2911	0.44	0.89	0.08	13.566	2	69.585	68.726	8	32.807	8.240
GAN_NEW	60	110	178	247	2664	0.26	0.76	0.11	2.928	3	8.446	30.844	13	2.842	4.043
PER	90	424	316	424	2036	0.52	0.55	0.27	3.342	9	6.325	23.621	24	4.624	3.117
ADV	90	378	343	428	2052	0.39	0.65	0.19	3.498	8	6.188	21.495	24	2.398	3.030
GAN	90	16	48	152	2984	0.24	0.91	0.04	18.161	1	91.893	91.451	7	31.229	8.568
GAN_NEW	90	2	261	5	2932	0.01	0.18	0.01	1.314	0	8.277	26.959	7	-14.887	0.368
PER	120	379	351	488	1981	0.50	0.59	0.23	3.697	8	6.990	24.507	25	5.196	3.548
ADV	120	318	385	442	2055	0.36	0.65	0.17	3.320	7	6.569	21.282	24	1.551	3.017
GAN	120	2	67	65	3066	0.04	0.88	0.01	8.976	0	136.164	59.289	6	7.181	4.845
GAN_NEW	120	1	249	0	2950	0	0.02	0	0.238	0	6.938	22.251	6	-12.725	0.098
PER	150	348	372	537	1943	0.49	0.61	0.21	3.737	7	7.529	25.062	26	5.687	3.932
ADV	150	302	394	466	2037	0.35	0.68	0.16	3.052	7	6.616	20.608	24	1.330	3.273
GAN	150	0	71	15	3114	0.00	0.50	0.00	0.479	0	120.261	72.321	5	-19.198	1.569
GAN_NEW	150	0	290	1	2909	0	0.08	0	0	0	8.254	25.204	7	-13.075	0.206
PER	180	306	397	587	1910	0.48	0.65	0.19	4.143	6	8.202	25.982	27	6.642	4.482
ADV	180	260	432	487	2021	0.30	0.69	0.14	2.955	6	6.931	20.639	25	1.065	3.270
GAN	180	0	79	1	3121	0.00	0.07	0.00	0.000	0	128.337	63.420	4	-30.159	0.230
GAN_NEW	180	0	274	0	2926	0	0.08	0	0	0	8.247	25.56	7	-13.318	0.169

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8th May 2000

20000508															
Catchment area: 320 by 320 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	1571	1365	1447	98017	0.54	0.47	0.36	3.537	1758	6.619	94.980	4494	0.028	1.036
ADV	30	1676	1235	1372	98117	0.58	0.45	0.39	3.307	1891	6.200	97.880	4369	0.322	1.063
GAN	30	364	112	941	983	0.76	0.72	0.26	4.866	663	12.126	249.628	1861	14.527	4.570
GAN_NEW	30	879	1719	1254	86048	0.33	0.57	0.22	5.081	1390	10.172	202.376	4592	-31.072	1.138
PER	60	1066	1870	2049	97415	0.36	0.65	0.22	4.404	1201	10.042	112.434	5180	0.650	1.099
ADV	60	1184	1718	1901	97596	0.41	0.61	0.25	4.285	1345	9.533	115.949	4961	-0.083	1.077
GAN	60	328	162	1210	700	0.66	0.79	0.19	6.799	570	17.456	281.488	2154	20.891	4.692
GAN_NEW	60	515	2083	805	85664	0.19	0.61	0.14	6.428	749	13.801	224.412	3971	-30.681	0.592
PER	90	766	2145	2395	97094	0.27	0.75	0.15	4.638	847	11.854	116.250	5570	0.705	1.128
ADV	90	834	2042	2277	97247	0.29	0.73	0.16	4.800	946	11.839	119.226	5368	0.228	1.099
GAN	90	256	244	1208	693	0.49	0.82	0.15	7.516	450	23.093	295.889	2179	21.538	4.205
GAN_NEW	90	298	2284	819	84714	0.11	0.74	0.08	5.266	445	15.485	225.949	4084	-11.408	0.688
PER	120	599	2304	2619	96879	0.21	0.81	0.11	4.717	655	12.663	118.448	5824	1.641	1.159
ADV	120	584	2260	2580	96976	0.20	0.82	0.11	4.668	662	13.122	120.913	5676	1.428	1.146
GAN	120	194	320	1203	8375	0.35	0.85	0.12	7.330	343	27.657	301.159	2230	24.696	3.955
GAN_NEW	120	212	2353	1101	98733	0.08	0.8	0.06	6.366	328	17.649	223.161	4530	-8.649	1.074
PER	150	512	2364	2772	96752	0.18	0.84	0.09	4.986	557	13.119	120.617	5976	2.969	1.220
ADV	150	446	2348	2768	96839	0.16	0.86	0.08	4.720	501	13.650	121.392	5849	2.899	1.214
GAN	150	134	390	1301	8909	0.23	0.90	0.08	8.455	245	30.142	292.776	2397	40.123	4.058
GAN_NEW	150	159	2361	1140	98741	0.06	0.84	0.04	7.728	252	18.298	218.986	4579	-5.923	1.34
PER	180	475	2369	2875	96681	0.17	0.86	0.08	4.749	516	13.351	119.292	6057	2.797	1.270
ADV	180	382	2325	2886	96807	0.14	0.88	0.07	4.915	417	13.869	117.138	5895	3.210	1.287
GAN	180	86	432	1326	555	0.15	0.93	0.05	7.910	164	32.776	274.889	2458	40.898	4.439
GAN_NEW	180	125	2326	1373	98576	0.04	0.88	0.03	7.728	213	19.478	206.093	4868	-1.904	1.767

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8th May 2000

Catchment area: 160 by 160 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	983	758	688	48771	0.47	0.50	0.31	3.191	545	5.435	65.079	1237	-0.405	1.413
ADV	30	1086	709	681	48723	0.48	0.49	0.32	3.054	612	4.866	64.752	1259	-1.071	1.137
GAN	30	362	111	801	49926	0.76	0.69	0.28	4.834	331	11.758	260.370	818	7.255	4.140
GAN_NEW	30	357	716	599	49528	0.22	0.69	0.11	5.206	299	9.651	132.98	1024	0.685	2.53
PER	60	622	1119	999	48460	0.37	0.61	0.22	3.962	350	8.253	81.390	1410	1.029	1.861
ADV	60	743	1102	991	48365	0.39	0.58	0.24	3.883	426	7.010	75.328	1460	-2.561	1.063
GAN	60	327	161	1027	49685	0.66	0.78	0.20	6.786	284	16.347	261.553	936	20.608	4.193
GAN_NEW	60	280	819	432	49669	0.12	0.76	0.08	5.275	205	12.082	153.473	906	0.431	1.881
PER	90	436	1359	1155	48250	0.29	0.72	0.15	4.289	240	10.564	90.227	1539	-0.320	1.989
ADV	90	486	1399	1200	48115	0.26	0.72	0.14	4.686	280	9.657	83.672	1608	-3.800	1.090
GAN	90	256	242	1049	49653	0.49	0.81	0.16	7.516	225	22.630	287.051	964	19.087	3.974
GAN_NEW	90	196	925	600	49480	0.09	0.88	0.05	4.965	153	14.285	146.308	1051	11.864	4.588
PER	120	333	1511	1235	48121	0.28	0.73	0.14	4.279	184	10.520	86.930	1609	0.749	2.068
ADV	120	308	1612	1350	47930	0.21	0.76	0.11	4.434	181	9.786	77.646	1712	-2.253	1.189
GAN	120	194	320	1024	49662	0.35	0.83	0.12	7.330	171	28.047	301.667	979	36.307	4.657
GAN_NEW	120	153	988	834	49225	0.07	0.9	0.04	6.669	121	14.59	136.143	1250	14.732	4.073
PER	150	288	1597	1267	48048	0.25	0.78	0.11	4.784	156	11.095	88.629	1655	1.444	2.262
ADV	150	231	1709	1397	47863	0.16	0.84	0.08	4.769	132	10.300	77.625	1761	-2.007	1.286
GAN	150	134	390	1092	49585	0.23	0.87	0.08	8.455	122	31.053	296.625	1044	37.448	5.135
GAN_NEW	150	120	1038	923	49120	0.05	0.92	0.03	7.754	98	16.31	136.771	1339	17.264	5.623
PER	180	242	1678	1311	47969	0.24	0.80	0.10	4.928	133	11.142	88.701	1694	1.920	2.389
ADV	180	179	1754	1443	47824	0.15	0.86	0.07	5.611	99	10.253	74.306	1787	-1.307	1.313
GAN	180	86	432	1091	49591	0.15	0.91	0.05	7.910	82	32.584	251.295	1052	49.602	6.713
GAN_NEW	180	96	1064	1114	48927	0.04	0.93	0.02	7.943	84	17.864	130.314	1485	27.44	6.442

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8th May 2000

Catchment area: 80 by 80 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	585	467	393	24154	0.45	0.53	0.28	3.363	161	6.435	62.244	366	-3.459	1.464
ADV	30	631	451	381	24136	0.45	0.52	0.30	3.157	176	5.939	64.051	369	-4.134	1.197
GAN	30	153	56	395	24996	0.64	0.76	0.20	4.679	74	13.023	150.028	194	19.037	5.071
GAN_NEW	30	169	382	313	24736	0.19	0.71	0.1	4.358	66	9.298	81.472	255	-1.211	2.513
PER	60	364	688	561	23986	0.32	0.68	0.17	4.033	102	9.741	74.100	413	-2.336	2.005
ADV	60	422	699	503	23975	0.34	0.62	0.20	3.762	119	8.985	77.830	414	-3.579	1.280
GAN	60	118	93	452	24937	0.46	0.83	0.12	7.387	56	17.389	165.195	208	21.819	5.548
GAN_NEW	60	76	481	183	24860	0.06	0.79	0.04	4.585	30	10.941	88.219	216	-11.894	1.416
PER	90	256	826	610	23908	0.25	0.75	0.12	4.533	70	11.972	81.365	439	-7.131	2.128
ADV	90	277	895	550	23878	0.23	0.74	0.12	3.952	77	11.994	88.222	444	-5.235	1.504
GAN	90	80	138	415	24968	0.30	0.86	0.07	7.119	39	23.840	181.540	202	18.466	6.425
GAN_NEW	90	61	508	252	24780	0.05	0.87	0.03	3.954	25	11.991	95.106	246	-6.765	2.344
PER	120	205	916	601	23877	0.23	0.76	0.11	4.700	57	12.164	81.358	447	-6.635	2.445
ADV	120	158	1070	574	23798	0.18	0.79	0.08	4.134	45	12.565	86.234	467	-10.476	1.766
GAN	120	48	184	366	25001	0.16	0.85	0.05	5.030	25	30.670	222.577	199	18.403	6.550
GAN_NEW	120	43	544	368	24645	0.04	0.92	0.02	6.688	18	14.995	109.189	295	1.389	3.548
PER	150	196	975	561	23868	0.22	0.74	0.10	4.923	53	12.535	86.531	452	-5.866	2.670
ADV	150	120	1168	521	23791	0.13	0.84	0.06	2.920	33	13.359	93.513	471	-11.329	1.950
GAN	150	23	227	347	25003	0.10	0.91	0.02	3.201	12	32.754	219.333	205	15.588	7.169
GAN_NEW	150	31	580	407	24582	0.03	0.94	0.02	10.322	14	15.113	110.201	324	3.113	4.451
PER	180	164	1064	554	23818	0.21	0.74	0.09	3.613	46	12.438	86.555	463	-6.573	2.894
ADV	180	99	1252	462	23787	0.13	0.85	0.06	3.008	26	13.714	93.222	471	-9.032	2.073
GAN	180	6	262	322	25010	0.01	0.98	0.01	1.232	3	33.816	233.275	206	28.622	7.576
GAN_NEW	180	24	617	497	24462	0.02	0.94	0.01	11.891	12	16.959	123.887	368	5.674	5.203

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8th May 2000

Catchment area: 40 by 40 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	333	208	188	12071	0.44	0.53	0.29	2.964	41	5.336	37.811	86	-2.904	1.483
ADV	30	338	204	184	12073	0.42	0.55	0.27	2.948	42	5.820	40.928	84	-6.058	1.159
GAN	30	145	44	327	12285	0.71	0.72	0.23	4.508	34	15.202	197.673	78	17.478	5.086
GAN_NEW	30	143	278	200	12180	0.18	0.71	0.1	4.21	28	8.379	81.406	86	-0.459	2.3
PER	60	225	317	288	11970	0.33	0.62	0.20	3.537	28	8.096	44.942	100	-2.573	2.082
ADV	60	234	314	260	11992	0.31	0.62	0.18	4.174	29	9.134	47.849	96	-7.441	1.284
GAN	60	115	75	362	12248	0.52	0.79	0.15	7.505	26	24.363	238.875	82	25.994	6.688
GAN_NEW	60	68	354	104	12274	0.06	0.68	0.04	3.63	13	10.457	93.444	72	-12.07	1.175
PER	90	152	391	341	11916	0.26	0.70	0.14	3.059	17	10.145	50.352	108	-5.063	2.285
ADV	90	157	407	318	11918	0.23	0.67	0.13	3.375	19	11.445	54.749	106	-8.164	1.546
GAN	90	78	116	322	12285	0.35	0.82	0.09	7.131	19	31.947	247.917	77	25.628	8.320
GAN_NEW	90	53	376	105	12266	0.05	0.78	0.03	3.823	11	11.357	93.067	75	-10.653	1.786
PER	120	113	435	362	11890	0.24	0.73	0.13	2.716	13	10.915	52.466	111	-5.259	2.520
ADV	120	98	488	347	11867	0.20	0.72	0.10	3.686	12	12.720	58.487	112	-7.482	1.721
GAN	120	48	159	276	12317	0.17	0.84	0.06	4.903	12	35.663	256.843	76	28.636	8.405
GAN_NEW	120	36	408	148	12209	0.04	0.81	0.02	6.519	8	13.086	102.325	85	-6.469	2.391
PER	150	94	470	363	11874	0.23	0.75	0.11	1.990	10	12.166	57.845	114	-6.110	2.836
ADV	150	84	538	315	11862	0.16	0.75	0.08	2.733	9	13.734	63.097	114	-8.485	1.991
GAN	150	23	201	210	12366	0.10	0.91	0.03	3.133	6	36.022	241.140	72	23.009	8.349
GAN_NEW	150	25	444	142	12189	0.07	0.78	0.02	10.182	5	13.782	112.764	92	-6.785	2.982
PER	180	63	523	364	11850	0.23	0.78	0.08	2.648	6	13.123	61.567	117	-8.657	2.889
ADV	180	82	585	271	11862	0.17	0.79	0.08	2.359	9	14.381	66.431	113	-8.528	2.163
GAN	180	6	236	127	12431	0.02	0.97	0.01	1.469	2	33.153	222.449	65	17.065	7.109
GAN_NEW	180	17	487	176	12120	0.03	0.83	0.01	12.146	4	15.221	119.856	101	-1.078	4.087

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8th May 2000

Catchment area: 20 by 20 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	180	93	72	6054	0.45	0.56	0.26	3.302	10	5.826	32.485	18	-0.613	1.652
ADV	30	181	100	77	6041	0.43	0.59	0.24	3.073	10	6.968	35.255	19	-2.793	1.432
GAN	30	70	25	158	6147	0.69	0.72	0.17	5.025	7	29.866	94.592	17	23.064	7.530
GAN_NEW	30	56	148	111	6085	0.2	0.57	0.09	6.196	5	12.14	69.795	19	8.201	3.33
PER	60	129	144	105	6022	0.34	0.65	0.18	7.621	7	8.118	37.446	20	-1.888	2.257
ADV	60	131	158	104	6008	0.30	0.69	0.15	7.320	7	10.678	42.820	20	-1.278	2.020
GAN	60	54	42	182	6122	0.47	0.74	0.08	8.233	5	49.848	148.752	18	35.110	8.657
GAN_NEW	60	21	188	50	6141	0.08	0.62	0.04	4.962	2	19.825	106.224	16	12.462	3.128
PER	90	95	187	120	5998	0.25	0.70	0.12	9.208	5	10.202	40.782	21	-2.267	3.290
ADV	90	98	198	138	5966	0.25	0.72	0.11	5.643	6	12.267	46.229	23	-4.001	3.126
GAN	90	36	63	158	6143	0.33	0.67	0.06	9.919	4	55.617	174.854	17	42.889	9.832
GAN_NEW	90	15	195	44	6146	0.04	0.71	0.02	3.255	1	20.104	85.156	16	-2.35	2.369
PER	120	69	220	126	5985	0.22	0.71	0.11	2.468	4	11.594	43.149	22	-5.811	3.353
ADV	120	71	233	151	5945	0.21	0.73	0.08	3.393	4	13.486	48.248	24	-3.266	3.278
GAN	120	17	88	145	6150	0.11	0.79	0.02	2.566	2	54.680	200.031	18	44.480	9.718
GAN_NEW	120	14	197	65	6123	0.06	0.78	0.03	5.626	1	17.314	79.102	18	0.378	3.209
PER	150	47	249	131	5973	0.18	0.75	0.08	1.892	2	12.828	45.735	23	-5.064	3.471
ADV	150	63	258	146	5933	0.16	0.76	0.06	3.077	4	15.446	54.033	25	-3.218	3.572
GAN	150	9	105	125	6162	0.05	0.87	0.01	3.228	1	46.945	151.825	18	43.918	9.735
GAN_NEW	150	8	212	73	6108	0.07	0.76	0.02	8.832	1	21.115	106.446	19	4.207	4.252
PER	180	31	273	134	5962	0.19	0.77	0.07	2.266	2	14.255	49.991	23	-4.538	3.595
ADV	180	60	283	135	5923	0.17	0.83	0.06	2.054	3	15.809	55.170	25	-2.457	3.601
GAN	180	0	123	91	6186	0.00	0.91	0.00	0.000	0	40.961	129.172	16	28.713	7.782
GAN_NEW	180	5	230	87	6078	0.03	0.82	0.02	5.612	1	22.851	100.38	21	5.702	4.535

Tables A.3 Scattered outbreaks of showers and thunderstorms – 8^{th} May 2000

Catchment area: 10 by 10 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	106	43	33	3018	0.53	0.45	0.34	2.574	2	6.615	40.369	4	3.531	1.657
ADV	30	105	47	36	3012	0.54	0.46	0.34	2.463	2	8.021	44.886	4	2.269	1.867
GAN	30	40	14	74	3072	0.55	0.65	0.17	3.903	2	30.846	148.993	3	38.976	8.178
GAN_NEW	30	32	77	48	3043	0.17	0.51	0.09	5.527	1	13.88	39.349	4	0.367	2.53
PER	60	79	70	52	2999	0.48	0.53	0.27	7.182	2	10.486	44.927	4	3.313	2.588
ADV	60	78	78	54	2990	0.42	0.56	0.25	7.057	2	13.358	50.807	4	6.234	2.842
GAN	60	30	25	83	3063	0.42	0.65	0.09	7.182	1	55.275	142.024	3	46.410	10.505
GAN_NEW	60	12	100	24	3065	0.06	0.56	0.03	7.03	0	25.805	64.399	3	-1.124	1.562
PER	90	58	94	63	2986	0.42	0.59	0.21	8.298	1	12.833	45.104	4	2.374	4.021
ADV	90	59	101	69	2970	0.38	0.62	0.19	4.776	1	18.966	67.096	5	5.419	4.361
GAN	90	20	36	66	3078	0.27	0.65	0.06	4.635	1	57.515	131.295	3	17.664	7.150
GAN_NEW	90	9	105	23	3063	0.04	0.63	0.02	1.374	0	27.779	59.862	3	-0.974	2.546
PER	120	40	116	70	2974	0.40	0.60	0.19	1.410	1	14.208	50.308	5	0.662	4.162
ADV	120	37	128	79	2956	0.29	0.71	0.12	2.203	1	17.496	58.814	5	5.118	4.629
GAN	120	9	50	52	3088	0.08	0.76	0.03	2.794	0	55.255	109.692	3	23.779	10.120
GAN_NEW	120	7	108	35	3051	0.05	0.7	0.01	5.221	0	22.166	61.365	4	1.146	3.752
PER	150	27	133	72	2968	0.36	0.64	0.16	0.924	1	15.537	50.155	5	1.989	4.421
ADV	150	32	143	74	2951	0.23	0.76	0.08	2.780	1	18.394	59.602	5	4.018	4.737
GAN	150	5	59	43	3093	0.02	0.62	0.01	1.944	0	57.556	110.305	3	18.687	8.187
GAN_NEW	150	4	115	39	3041	0.05	0.8	0.02	10.555	0	23.312	84.105	4	5.721	4.659
PER	180	16	149	73	2962	0.35	0.68	0.13	0.541	0	17.258	52.385	5	0.167	4.335
ADV	180	30	160	65	2945	0.23	0.81	0.08	1.986	1	22.227	68.850	5	2.044	4.307
GAN	180	0	70	38	3092	0.00	0.55	0.00	0.000	0	47.360	110.265	3	11.977	5.727
GAN_NEW	180	5	124	45	3026	0.03	0.64	0.02	5.468	0	27.766	68.769	5	1.136	3.715

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 320 by 320 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	12079.00	5305.25	5362.42	76434.17	0.57	0.43	0.43	2.876	12625.42	5.843	44.312	23474.67	-0.152	1.036
ADV	30	12982.75	4290.58	4290.67	77463.00	0.65	0.35	0.51	2.551	13757.83	4.443	41.350	21952.08	-0.731	1.008
GAN	30	1485.25	475.42	4142.75	55614.08	0.60	0.73	0.18	6.404	2597.00	22.209	114.785	7369.83	14.782	3.268
GAN_NEW	30	3462.75	5450.75	3546.00	83243.50	0.33	0.54	0.24	3.954	5334.00	9.401	116.677	14284.75	-23.378	1.346
PER	60	11050.42	6294.33	6471.67	75870.42	0.49	0.51	0.36	3.136	11498.67	7.091	48.522	24637.67	-0.215	1.055
ADV	60	11572.42	5756.92	5398.83	77232.75	0.54	0.44	0.40	3.038	12224.67	6.044	47.854	23262.25	-1.591	0.970
GAN	60	1379.75	602.42	4613.67	55195.67	0.49	0.76	0.14	8.576	2312.67	35.208	135.918	7935.17	23.251	3.811
GAN_NEW	60	2961.50	5996.50	3484.75	82777.75	0.23	0.59	0.17	4.696	4075.75	11.050	125.385	14144.75	-29.061	1.004
PER	90	10308.67	7003.08	7179.33	75924.92	0.44	0.55	0.31	3.274	10692.67	7.794	49.950	25377.17	-0.398	1.068
ADV	90	10536.08	6790.25	5955.83	76826.42	0.46	0.50	0.34	3.263	11098.25	7.071	50.095	23919.67	-2.372	0.939
GAN	90	1020.58	976.42	3774.25	53672.50	0.34	0.77	0.11	8.930	1754.92	48.328	142.196	7419.58	23.715	3.933
GAN_NEW	90	167.25	8819.00	430.75	76911.50	0.04	0.68	0.03	4.522	244.00	16.303	178.107	10918.75	-33.483	0.637
PER	120	9791.08	7550.67	7705.42	75117.25	0.41	0.58	0.29	3.348	10150.25	8.231	50.864	25959.75	-0.560	1.074
ADV	120	9713.33	7592.83	6273.17	76470.50	0.41	0.55	0.30	3.345	10221.50	7.721	51.051	24286.25	-2.945	0.915
GAN	120	816.42	1205.75	3700.17	53004.58	0.25	0.79	0.09	8.709	1396.42	56.966	144.011	7549.83	21.792	4.035
GAN_NEW	120	58.50	8945.25	313.00	80096.00	0.02	0.64	0.02	2.704	91.25	18.093	179.609	10872.50	-28.846	0.828
PER	150	9302.58	8046.92	8201.50	74765.67	0.38	0.61	0.26	3.452	9621.83	8.603	51.745	26507.33	-0.608	1.092
ADV	150	9034.08	8242.83	6455.17	75817.17	0.37	0.58	0.27	3.408	9494.17	8.152	51.632	24496.17	-3.420	0.897
GAN	150	707.75	1326.33	3859.75	51885.00	0.21	0.80	0.07	8.313	1193.83	55.498	142.498	7723.67	20.911	4.115
GAN_NEW	150	41.25	9425.50	310.75	82430.75	0.02	0.57	0.01	2.249	65.75	18.177	173.247	11440.00	-30.119	0.721
PER	180	8878.25	8472.25	8638.00	74702.25	0.36	0.63	0.24	3.504	9175.17	8.844	51.987	26966.75	-0.736	1.112
ADV	180	8412.75	8835.50	6581.67	76543.25	0.33	0.60	0.24	3.456	8826.75	8.464	51.590	24641.17	-4.017	0.881
GAN	180	599.42	1458.83	3778.83	49591.92	0.17	0.79	0.05	11.936	999.75	61.197	143.579	7781.83	18.937	4.022
GAN_NEW	180	31.25	9504.25	370.00	82024.25	0.01	0.56	0.01	2.035	53.75	18.394	173.959	11614.50	-29.729	0.713

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 160 by 160 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	6118.92	2882.83	2926.75	39271.50	0.52	0.48	0.38	2.876	3154.17	5.769	37.590	6043.50	-0.043	1.117
ADV	30	6517.50	2414.17	2338.00	39930.33	0.58	0.41	0.44	2.567	3409.75	4.447	33.495	5636.25	-0.795	1.058
GAN	30	1085.75	318.17	2519.00	47277.17	0.58	0.76	0.14	6.217	945.42	23.240	97.192	2292.42	12.067	3.810
GAN_NEW	30	1571.75	2439.25	1611.50	45577.50	0.28	0.62	0.18	3.903	1216.50	8.541	72.647	3171.50	-6.510	1.991
PER	60	5524.83	3443.50	3550.92	38680.67	0.45	0.54	0.32	3.102	2837.92	6.909	41.808	6355.17	0.042	1.220
ADV	60	5671.33	3281.92	2929.50	39317.58	0.48	0.50	0.35	3.038	2959.50	5.946	39.316	5978.75	-1.634	1.063
GAN	60	976.58	429.42	2574.17	47219.67	0.48	0.75	0.12	8.637	821.17	34.111	114.901	2320.75	16.841	4.338
GAN_NEW	60	1416.00	2649.50	1514.50	45620.50	0.20	0.64	0.14	4.062	971.50	9.463	76.891	3112.50	-12.492	1.471
PER	90	5111.00	3835.50	3963.33	38290.33	0.41	0.59	0.28	3.221	2616.00	7.625	43.778	6566.42	-0.065	1.306
ADV	90	5059.42	3897.33	3200.08	39042.92	0.41	0.56	0.29	3.248	2633.50	6.935	41.788	6141.92	-2.232	1.080
GAN	90	681.58	728.58	1924.42	47865.42	0.34	0.74	0.10	8.955	593.25	46.493	132.118	2094.83	17.410	5.221
GAN_NEW	90	93.50	4028.50	242.50	46835.50	0.03	0.61	0.02	4.136	68.00	12.984	78.350	2517.25	-20.749	1.697
PER	120	4826.25	4122.83	4269.42	37981.58	0.38	0.61	0.25	3.244	2469.25	7.969	44.431	6725.83	-0.097	1.380
ADV	120	4551.08	4413.08	3315.58	38920.42	0.36	0.59	0.25	3.343	2367.42	7.440	41.751	6223.58	-2.932	1.088
GAN	120	515.75	908.83	1660.58	48115.17	0.24	0.73	0.07	9.098	444.08	54.718	133.487	2029.25	15.947	5.480
GAN_NEW	120	39.25	4146.75	215.75	46798.00	0.02	0.42	0.01	2.209	31.00	13.589	76.573	2564.50	-19.495	1.863
PER	150	4573.50	4388.75	4541.25	37696.67	0.36	0.63	0.23	3.307	2334.33	8.287	45.330	6878.50	-0.030	1.459
ADV	150	4134.67	4839.50	3322.33	38903.67	0.32	0.62	0.23	3.565	2147.33	7.816	42.360	6249.33	-3.705	1.080
GAN	150	419.75	1009.25	1495.17	48275.92	0.18	0.72	0.06	7.898	352.42	53.273	127.713	1951.67	9.442	5.042
GAN_NEW	150	30.00	4404.25	236.00	46530.00	0.01	0.44	0.01	1.969	24.50	14.330	79.128	2730.75	-21.585	1.949
PER	180	4363.17	4623.25	4782.58	37431.25	0.35	0.65	0.22	3.384	2224.67	8.517	46.049	7016.83	0.009	1.532
ADV	180	3758.25	5229.00	3293.08	38919.58	0.29	0.64	0.20	3.531	1948.67	8.102	42.577	6253.17	-4.648	1.070
GAN	180	335.67	1097.33	1258.58	48508.58	0.15	0.68	0.05	13.149	276.33	59.614	120.495	1866.25	3.350	4.583
GAN_NEW	180	24.00	4479.00	286.00	46411.25	0.01	0.45	0.01	2.030	21.00	14.836	78.870	2806.75	-20.063	2.041

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 80 by 80 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	3559.00	1496.42	1474.42	19070.25	0.46	0.52	0.33	2.817	887.92	5.618	31.728	1606.08	-0.679	1.195
ADV	30	3756.50	1288.17	1226.67	19328.92	0.50	0.48	0.37	2.548	951.50	4.553	29.006	1523.58	-1.103	1.146
GAN	30	693.25	160.00	1425.33	23321.58	0.53	0.75	0.12	8.227	280.83	23.875	68.404	631.42	9.928	3.991
GAN_NEW	30	961.75	1526.50	945.75	22166.50	0.27	0.62	0.17	3.729	361.00	8.330	54.397	931.75	-6.121	2.036
PER	60	3265.50	1785.33	1756.08	18793.00	0.40	0.58	0.27	2.977	811.33	6.747	35.118	1677.33	-0.750	1.385
ADV	60	3343.08	1746.17	1459.33	19051.42	0.40	0.56	0.28	2.949	843.42	6.055	34.339	1600.00	-1.924	1.219
GAN	60	632.75	220.00	1423.33	23324.17	0.38	0.72	0.10	9.033	248.42	37.370	85.886	630.75	11.732	4.333
GAN_NEW	60	962.75	1556.75	908.50	22171.75	0.16	0.66	0.10	3.799	319.25	9.046	55.353	919.50	-14.709	1.378
PER	90	3041.83	2012.17	1945.08	18600.83	0.36	0.62	0.24	3.099	752.67	7.394	37.033	1728.17	-1.402	1.509
ADV	90	3048.25	2080.92	1521.58	18949.08	0.34	0.60	0.24	3.119	767.50	6.967	36.664	1630.83	-3.115	1.232
GAN	90	454.58	401.42	1070.58	23673.50	0.22	0.68	0.06	7.503	185.08	52.216	108.260	574.50	10.529	5.086
GAN_NEW	90	51.25	2504.50	125.25	22918.75	0.02	0.56	0.02	3.211	18.00	12.068	60.398	742.00	-20.446	1.203
PER	120	2901.42	2187.58	2071.83	18439.08	0.34	0.62	0.22	3.158	716.58	7.762	37.996	1769.92	-1.507	1.641
ADV	120	2791.00	2374.75	1532.42	18902.25	0.30	0.63	0.21	3.224	702.33	7.504	37.316	1647.50	-4.742	1.262
GAN	120	358.92	506.08	888.58	23846.33	0.15	0.62	0.04	5.958	143.83	62.052	117.565	551.42	6.701	4.953
GAN_NEW	120	11.25	2601.50	95.00	22892.25	0.01	0.38	0.01	1.786	4.75	13.397	65.344	757.00	-18.491	1.724
PER	150	2781.42	2351.08	2167.17	18300.42	0.33	0.63	0.20	3.226	684.92	8.057	39.258	1806.42	-1.586	1.746
ADV	150	2570.33	2636.83	1480.08	18912.67	0.26	0.65	0.18	3.108	646.58	7.852	38.422	1649.67	-6.198	1.240
GAN	150	311.92	557.50	795.42	23935.17	0.12	0.60	0.04	6.767	121.08	62.322	100.708	530.83	2.872	4.642
GAN_NEW	150	7.75	2801.75	104.50	22685.75	0.01	0.41	0.01	2.581	3.50	13.536	66.660	819.25	-19.720	1.646
PER	180	2661.58	2516.17	2259.17	18163.42	0.31	0.64	0.19	3.208	654.08	8.337	40.197	1841.33	-1.739	1.843
ADV	180	2366.25	2888.00	1413.83	18932.25	0.24	0.65	0.17	3.188	594.00	8.204	39.327	1579.91	-5.611	1.199
GAN	180	269.75	604.58	676.83	24048.83	0.12	0.58	0.03	3.905	101.50	67.594	101.966	510.50	0.796	4.339
GAN_NEW	180	6.00	2874.00	128.75	22591.50	0.01	0.42	0.00	3.017	3.00	14.224	70.860	847.75	-18.845	1.953

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 40 by 40 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	1786.67	720.92	720.17	9572.17	0.48	0.52	0.33	2.793	210.25	5.188	25.580	374.58	-0.115	1.418
ADV	30	1881.92	618.50	620.33	9679.17	0.48	0.51	0.34	2.556	225.00	4.587	23.855	357.08	-0.692	1.326
GAN	30	390.33	85.58	770.25	11553.75	0.50	0.70	0.13	6.475	73.25	15.758	67.606	163.17	9.119	3.701
GAN_NEW	30	538.75	799.25	529.25	10932.75	0.27	0.62	0.17	3.429	96.00	7.554	49.246	241.75	-3.490	1.983
PER	60	1650.58	855.83	856.33	9437.25	0.42	0.57	0.28	3.012	193.50	6.325	28.871	391.25	-0.161	1.734
ADV	60	1702.83	810.33	734.17	9552.67	0.40	0.58	0.27	2.889	203.00	5.933	27.915	374.00	-1.452	1.516
GAN	60	348.17	121.50	782.75	11547.50	0.38	0.68	0.10	9.150	63.75	22.855	79.514	163.50	12.489	4.358
GAN_NEW	60	513.50	838.75	501.50	10946.50	0.18	0.58	0.12	3.182	80.50	8.193	50.845	236.00	-11.918	1.366
PER	90	1531.33	976.17	961.83	9330.58	0.38	0.60	0.24	2.914	178.58	6.964	30.410	404.58	-0.571	1.938
ADV	90	1550.92	975.08	770.00	9503.92	0.34	0.60	0.23	2.934	184.83	6.638	29.731	380.92	-2.774	1.550
GAN	90	247.33	223.42	587.25	11742.08	0.25	0.60	0.07	7.605	46.33	33.397	90.791	148.42	11.070	4.746
GAN_NEW	90	25.75	1349.75	46.50	11377.75	0.02	0.40	0.01	2.180	4.50	11.266	54.027	187.75	-20.545	0.825
PER	120	1456.17	1062.83	1035.25	9245.75	0.37	0.61	0.22	2.963	169.50	7.360	31.361	414.92	-0.700	2.073
ADV	120	1420.00	1123.75	783.08	9473.50	0.30	0.62	0.20	3.036	169.08	7.129	30.767	386.00	-3.682	1.544
GAN	120	193.33	281.33	470.92	11854.42	0.17	0.57	0.05	6.161	35.42	41.216	93.123	140.25	10.028	4.751
GAN_NEW	120	9.50	1400.00	38.25	11352.75	0.01	0.25	0.01	1.724	2.00	11.921	57.309	192.50	-20.269	0.900
PER	150	1392.00	1141.67	1090.58	9176.17	0.36	0.62	0.21	2.976	161.50	7.732	32.504	423.42	-0.916	2.191
ADV	150	1314.08	1260.25	756.67	9468.92	0.27	0.64	0.19	3.008	156.58	7.527	31.649	388.08	-4.969	1.513
GAN	150	164.00	308.00	402.67	11925.17	0.14	0.55	0.04	7.295	29.00	40.271	89.417	131.67	4.466	4.304
GAN_NEW	150	6.25	1492.75	36.00	11265.00	0.02	0.25	0.01	2.546	1.25	12.505	60.994	205.50	-20.939	1.005
PER	180	1329.42	1223.67	1138.25	9108.67	0.34	0.62	0.20	3.104	153.83	8.087	33.632	431.83	-1.414	2.291
ADV	180	1206.00	1392.92	727.83	9473.42	0.25	0.64	0.17	3.064	143.42	7.908	32.573	387.92	-6.022	1.504
GAN	180	135.92	335.83	334.75	11993.75	0.13	0.46	0.04	2.858	23.08	38.800	94.529	125.33	0.568	3.961
GAN_NEW	180	4.25	1530.50	45.25	11219.75	0.01	0.29	0.00	3.072	1.00	13.103	63.859	211.00	-20.016	1.285

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 20 by 20 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	921.42	366.50	365.17	4747.08	0.49	0.51	0.34	2.713	48.33	4.957	22.189	85.83	0.073	1.645
ADV	30	968.33	314.08	310.50	4807.17	0.49	0.51	0.35	2.386	51.67	4.236	20.157	81.67	-0.473	1.444
GAN	30	204.50	45.08	398.50	5752.00	0.49	0.67	0.14	5.418	16.92	15.977	54.700	38.25	10.113	3.921
GAN_NEW	30	279.75	410.25	277.50	5433.00	0.28	0.59	0.17	3.942	22.25	8.407	44.070	55.75	-0.166	2.550
PER	60	854.58	432.08	431.58	4682.08	0.44	0.55	0.29	3.254	44.67	5.914	24.743	89.50	-0.046	2.075
ADV	60	878.33	409.17	367.08	4745.50	0.41	0.55	0.28	3.076	46.75	5.535	23.896	85.50	-0.845	1.746
GAN	60	176.17	69.08	404.50	5750.50	0.37	0.62	0.10	10.858	14.25	29.250	71.093	38.08	14.023	4.893
GAN_NEW	60	246.50	451.75	249.75	5452.00	0.20	0.56	0.12	3.512	17.50	10.787	52.484	54.50	-5.677	2.021
PER	90	795.00	491.50	484.08	4629.33	0.41	0.57	0.26	3.405	41.25	6.599	26.139	92.25	-0.189	2.411
ADV	90	800.25	488.92	385.33	4725.67	0.37	0.58	0.24	3.076	42.75	6.193	25.332	86.67	-1.896	1.923
GAN	90	120.08	124.42	303.08	5852.33	0.25	0.57	0.07	7.846	10.08	39.469	76.214	34.33	13.935	5.668
GAN_NEW	90	10.75	696.25	20.50	5672.00	0.02	0.34	0.01	2.042	1.00	13.807	49.733	43.00	-17.580	0.908
PER	120	754.83	535.33	526.75	4582.92	0.39	0.59	0.24	2.919	39.25	7.081	27.129	94.83	-0.480	2.570
ADV	120	727.42	566.67	390.75	4715.25	0.33	0.60	0.21	2.984	38.58	6.659	25.776	87.50	-2.963	1.907
GAN	120	91.00	155.08	243.17	5910.75	0.17	0.54	0.05	6.231	7.42	44.575	83.285	32.42	12.280	5.717
GAN_NEW	120	3.75	720.75	17.25	5658.00	0.02	0.22	0.01	1.472	0.25	13.248	48.458	44.00	-17.426	0.989
PER	150	722.75	572.50	555.92	4548.75	0.38	0.59	0.22	2.941	37.42	7.397	27.744	96.58	-0.608	2.659
ADV	150	679.08	628.42	386.08	4706.50	0.30	0.61	0.20	2.856	36.33	7.142	26.805	88.33	-4.171	1.883
GAN	150	79.42	164.83	209.33	5946.50	0.14	0.51	0.04	7.665	6.08	44.427	77.892	30.33	6.464	4.951
GAN_NEW	150	2.00	765.50	18.50	5614.25	0.02	0.21	0.01	2.208	0.25	14.328	54.801	47.00	-16.988	1.186
PER	180	687.42	612.75	581.58	4518.25	0.37	0.60	0.21	3.111	35.50	7.710	28.511	98.33	-0.871	2.736
ADV	180	626.08	694.33	370.08	4709.33	0.27	0.62	0.18	2.803	33.42	7.456	27.343	88.25	-5.125	1.848
GAN	180	66.25	177.50	175.17	5981.17	0.12	0.37	0.03	2.648	4.92	42.418	77.533	29.08	1.255	4.364
GAN_NEW	180	1.25	786.50	22.25	5590.00	0.01	0.24	0.01	1.438	0.25	15.067	54.445	48.25	-17.284	1.240

Tables A.4 Averaged statistics over all 12 precipitation events

Catchment area: 10 by 10 km															
fc	LT	smA	smB	smC	smD	smHR	smFAR	smCSI	RMSF	NVS	RMSF_OR	RMS_OR	NVS_OR	MEAN	MEANF
PER	30	456.58	180.75	181.50	2381.25	0.52	0.46	0.36	2.794	9.50	5.006	21.465	16.75	0.755	2.031
ADV	30	481.42	152.75	156.33	2409.42	0.51	0.48	0.36	2.361	10.17	4.130	19.353	16.00	0.210	1.688
GAN	30	101.83	22.50	200.00	2875.67	0.45	0.64	0.13	5.935	3.33	15.029	48.880	7.33	13.716	4.472
GAN_NEW	30	143.75	205.25	134.00	2717.00	0.27	0.56	0.16	3.844	4.50	8.970	34.510	11.25	-0.601	2.824
PER	60	423.92	213.00	215.67	2347.58	0.49	0.50	0.31	3.254	8.75	6.047	23.611	17.67	0.862	2.479
ADV	60	438.08	197.42	188.00	2376.58	0.44	0.52	0.30	3.197	9.33	5.572	22.551	16.58	0.293	2.144
GAN	60	87.42	34.50	200.00	2878.08	0.37	0.59	0.10	6.173	2.92	24.905	55.660	8.00	18.462	5.657
GAN_NEW	60	119.50	233.25	129.00	2718.50	0.20	0.53	0.11	4.273	3.25	12.599	40.409	11.00	-6.419	1.952
PER	90	394.17	242.42	240.92	2322.50	0.46	0.53	0.29	3.446	8.00	6.800	24.607	18.25	0.677	2.849
ADV	90	398.25	237.17	196.83	2367.83	0.40	0.55	0.26	3.173	8.42	6.633	25.320	17.17	-0.125	2.339
GAN	90	58.83	62.67	150.42	2928.00	0.24	0.54	0.07	6.315	1.92	33.599	63.804	7.09	16.159	6.393
GAN_NEW	90	5.00	350.75	10.50	2833.75	0.02	0.27	0.01	1.247	0.00	16.130	40.760	8.75	-15.840	0.898
PER	120	373.67	263.50	264.25	2298.75	0.45	0.54	0.26	3.071	7.75	7.275	25.717	18.58	0.798	3.044
ADV	120	362.58	274.25	198.92	2364.42	0.36	0.57	0.23	2.936	7.67	7.004	25.091	17.08	-1.336	2.389
GAN	120	45.67	76.67	124.00	2953.67	0.17	0.53	0.05	6.051	1.42	41.839	61.944	6.91	13.885	6.755
GAN_NEW	120	2.00	360.50	9.75	2828.00	0.01	0.20	0.00	1.365	0.00	14.791	40.896	8.75	-15.233	1.142
PER	150	356.50	281.83	280.08	2281.50	0.43	0.55	0.25	3.070	7.33	7.694	26.144	18.92	0.985	3.219
ADV	150	338.83	303.92	199.42	2357.67	0.33	0.59	0.21	2.915	7.17	7.431	25.837	17.33	-2.056	2.483
GAN	150	39.08	82.67	106.67	2971.58	0.15	0.44	0.04	2.174	1.17	41.212	63.499	6.45	7.744	5.651
GAN_NEW	150	1.00	383.25	10.00	2805.50	0.01	0.22	0.01	2.639	0.00	15.468	46.460	9.50	-14.674	1.295
PER	180	338.08	301.83	294.33	2265.92	0.41	0.57	0.23	3.226	6.92	8.183	27.066	19.33	0.977	3.356
ADV	180	311.42	338.75	188.75	2361.25	0.30	0.60	0.20	2.862	6.67	8.081	27.043	17.42	-3.475	2.307
GAN	180	32.83	88.83	87.83	2990.50	0.13	0.31	0.04	3.444	0.92	44.215	63.915	5.75	1.692	5.477
GAN_NEW	180	1.25	394.75	11.25	2792.75	0.01	0.18	0.01	1.367	0.00	16.941	43.709	10.00	-16.471	1.043