Modelling frontal and convective rainfall distributions over North Wales

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Introduction

Hydrology research is being carried out at the University of Wales, Bangor, to investigate flooding in the mountainous northern region of Wales. It is necessary to obtain accurate rainfall distribution data over an extended period as an input to a groundwater model, in order to simulate the antecedent conditions leading to saturation-excess flood events. Continuous short interval rainfall distributions during individual storms are also needed in order to model hillslope runoff and the extent of surface water encroachment onto floodplains.

North Wales has a complex topography, with mountain ranges either cross-cutting or sub-parallel to the tracks of prevailing westerly weather systems, leading to a complex relationship between rainfall patterns and altitude. A problem for modelling has been a lack of raingauge data, so the MM5 modelling system is being evaluated as a means of synthetic rainfall pattern generation which can be linked directly to hydrological models. An array of 26 raingauges has been established in one catchment as a check on the accuracy of MM5 results. Two documented storm events, both leading to serious flooding, are discussed in this paper.

3-4 February 2004

A stationary cold front across North Wales during the period 3-4 February 2004 led to prolonged heavy rainfall from moist low-level air. Rainfall intensity was exceptional, with hourly means of over 12 mm. The railway line in the Conwy valley was severely damaged and put out of action for several months (Sibley, 2005).

For the February 2004 event, MM5 was run with a 0.5km grid on the inner domain, using no cumulus parameterisation. Rainfall distribution (Fig 1) and intensity correspond accurately with the recorded raingauge data. Rainfall is relatively low over the coastal mountain range of the Rhinogs (719m), and concentrated instead further inland over the Arenigs (853m).

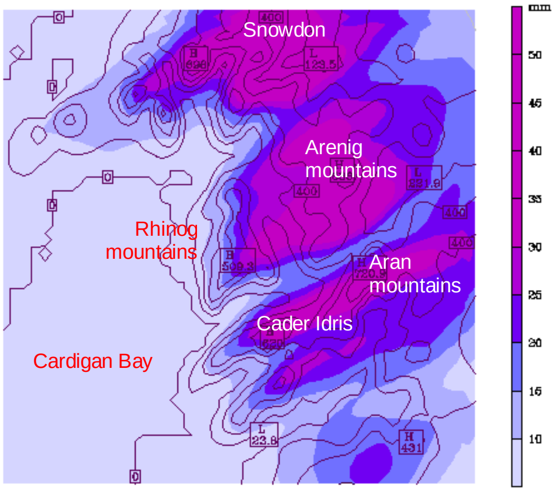

Fig 1: Rainfall totals for the 6 hour period 0600 –1200, 3 February 2004

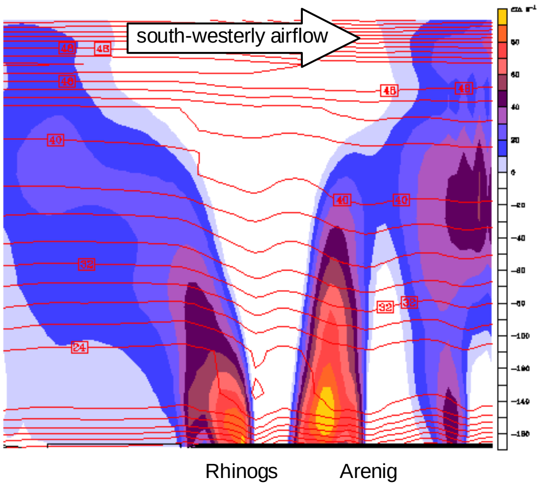

Fig 2: Vertical section from Cardigan Bay to the Arenig mountains. Shading indicates vertical air velocity. Contours indicate horizontal velocities. The profile is consistent with the presence of a jet of 85knots at 750mb identified in a radiosonde ascent for 0600 on 3 February from Aberporth (Sibley, 2005)

The mechanism of orographic enhancement of rainfall inland suggested by Sibley (2005) is a seeder-feeder process by which raindrops fall from higher seeder clouds through saturated feeder cloud. Barry (1992) discusses the generation of cloud by mountain-induced gravity waves. Chen and Lin (2003) identify a situation in which high wind speed over a mountain, combined with low convective available potential energy, leads to a downstream propagating cloud system. These mechanisms are illustrated by the MM5 model of the storm event:

Fig 3 shows gravity waves induced by the mountain ranges. Fig 4 identifies zones of saturation at low cloud height which are consistent with the observed pattern of rainfall enhancement inland. Isosurfaces in Fig 5 illustrate the stratiform nature of cloud generation and the possibility of a seeder-feeder mechanism operating.

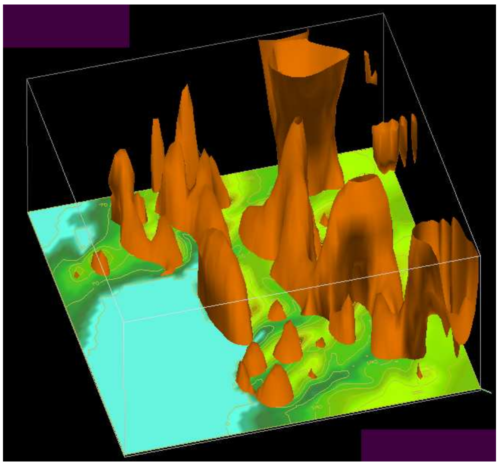

Figure 3: Isosurface for 40cm s^{-1} vertical velocity component. 0600, 3 February 2004.

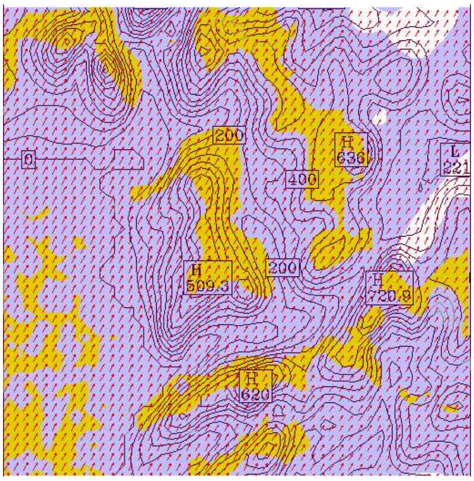

Figure 4: Zones of 100% relative humidity (yellow) at 950mb. 0600, 3 February 2004.

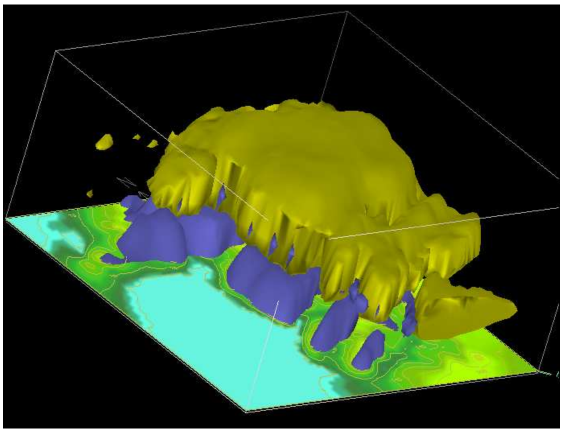

Figure 5: Isosurfaces for cloud mixing ratio=0.4 (blue) and precipitation mixing ratio=0.4(yellow). 0600, 3 February 2004.

3 July 2001

On 3 July 2001, an approximately 300-year maximal flood event occurred in the Mawddach catchment around the Arenig and Aran mountains, causing extensive damage to bridges and roads. Over a year's construction work was required to fully restore the transport infrastructure of this rural area.

The storms across Wales on 3 July 2001 were the result of intense convective thunderstorm activity along a squall line (Mason, 2002). Raingauge data from Caer'r Defaid on the southern margin of the Arenig mountain block includes three successive hourly totals of 20mm, 35mm and 26mm as the storms passed overhead (Barton, 2002).

The convective nature of the July 2001 event has provided an opportunity to compare the convective parameterisation schemes provided within the MM5 modelling system. The results for two schemes, Anthes-Kuo and Grell are discussed below:

Anthes-Kuo cumulus parameterisation

A rainfall distribution map using Anthes-Kuo parameterisation is given in Fig 6. This shows a close correspondence to observed rainfall patterns. The north-south orientation of the squall line is clearly defined, with several thunderstorm cells in observed locations over the mountain region. The only deficiency of the model is that the zone of intense rainfall (>25mm/hour) should extend some 5-10km further northwards along the squall line to account for extensive flood damage in the Arenig area.

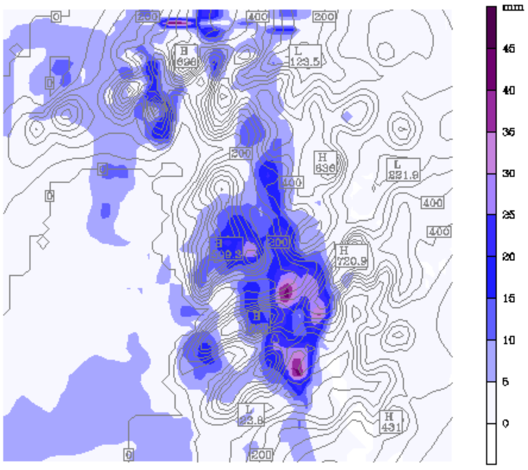

Figure 6: One hour rainfall total. 1800-1900, 3 July 2001. Anthes-Kuo model.

Examination of the MM5 model results shows the intense convective activity associated with the squall line (Figures 7–9).

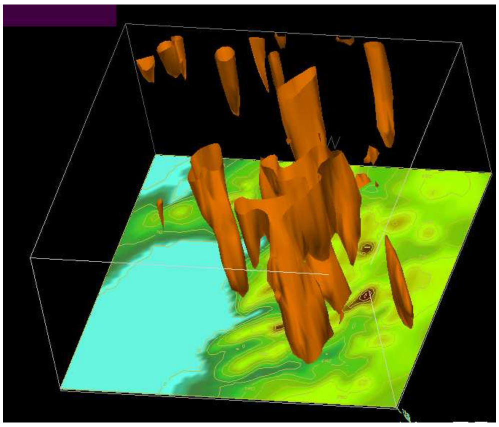

Figure 7: Isosurface for 40cm s^{-1} vertical velocity component. 1800, 3 July 2001. Anthes-Kuo model.

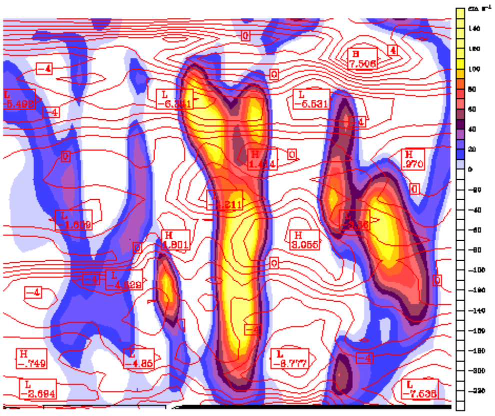

Fig8: Vertical section from Cardigan Bay to the Arenig mountains. Shading indicates vertical air velocity. Contours indicate horizontal velocities. 1800, 3 July 2001. Anthes-Kuo model.

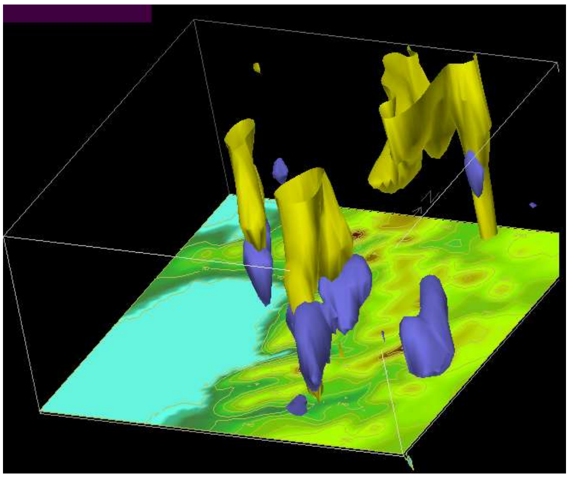

Figure 9: Isosurfaces for cloud mixing ratio=0.4 (blue) and precipitation mixing ratio=0.4(yellow). 1800, 3 July 2001. Anthes-Kuo model.

Grell cumulus parameterisation

Results from the MM5 run using Grell cumulus parameterisation (Fig 10) are very different from those of the Anthes-Kuo model, and bear little resemblance to observed rainfall patterns during the storm event. Rainfall is modelled as occurring mainly over the sea, and is about half of the true intensity.

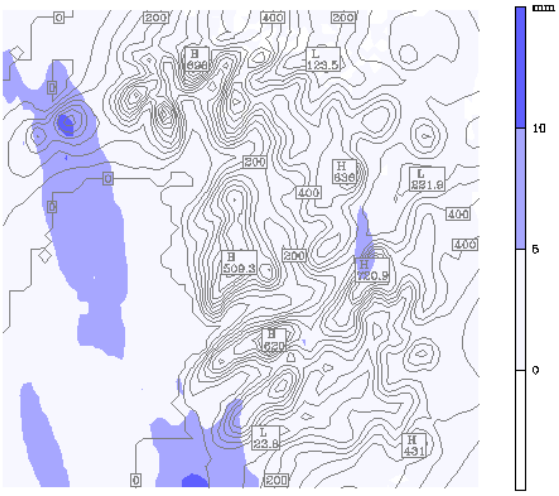

Figure 10: One hour rainfall total. 1800-1900, 3 July 2001. Grell model.

Patterns of vertical air motion produced by the Grell model (Fig 11) indicate a number of small convective cells distributed over a broad belt, in contrast to the few very large cells of the Anthes-Kuo model. Little rainfall is shown as being generated by the convective system.

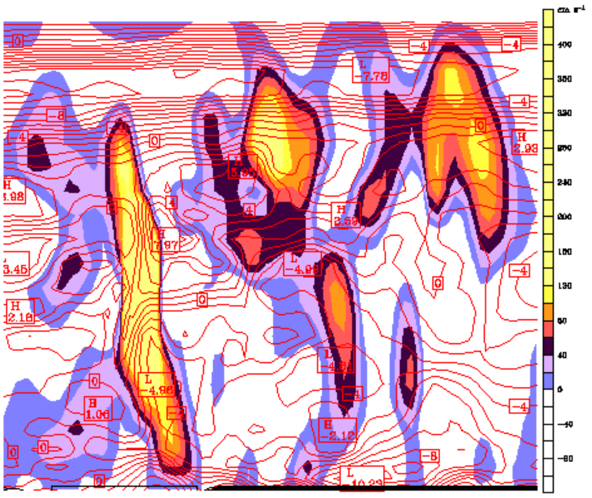

Fig 11: Vertical section from Cardigan Bay to the Arenig mountains. Shading indicates vertical air velocity. Contours indicate horizontal velocities.
1800, 3 July 2001. Grell model.

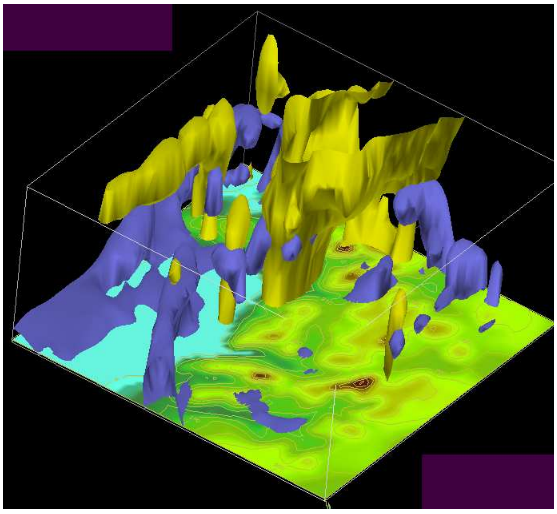

Figure 12: Isosurfaces for cloud mixing ratio=0.4 (blue) and precipitation mixing ratio=0.4(yellow). 1800, 3 July 2001. Grell model.

Discussion

Tests carried out with MM5 show that rainfall patterns associated with frontal systems are accurately simulated for the instrumented catchment. Analysis of RIP and VIS-5D plots is giving useful insight into the atmospheric processes controlling rainfall distribution. We have confidence in accepting frontal rainfall patterns generated by MM5 for the larger region.

The July 2001 flood event was different in nature, resulting from intense convective thunderstorm activity along a squall line. Simulation of this event with MM5 has produced varied results with different cumulus parameterisations. The Anthes-Kuo scheme corresponds well to the sparse rain gauge data available, and gives a rainfall distribution which is largely consistent with field observations of flood damage and maximum river levels. The Grell and Kain-Fritsch schemes considerably underestimated rainfall volumes. Provided care is taken in selecting the most appropriate model for a particular event, an accurate regional rainfall distribution pattern for convective storms can be obtained from MM5.

Tests are now being carried out with the WRF modelling system to simulate both the frontal and squall line storm events.

It is hoped to integrate MM5/WRF output directly into groundwater and surface water models in order to identify temporal and spatial areas where antecedent conditions indicate a high flood risk, and to generate runoff simulations during storm events.

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