University of Reading

Recent Flooding Events in the United Kingdom

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Executive Summary

In recent years, the UK has been subject to a number of flash floods that have caused widespread devastation. Flooding can be caused by the inability of natural water courses to cope with excessive persistent rainfall, the inability of urban drainage to cope with excessive rainfall, or direct runoff over land causing rapid flooding. Flash floods are caused by extremely intense rainfall over a small spatial scale, with rapid catchment response leading to flooding. Despite flash floods being highly localised events, flood damage can be significant over large areas. The source of most flooding has a meteorological origin or dependence and this shall be considered rather than the hydrological processes operating.

There are two main sources of extreme rainfall, with average rainfall of up to 250 mm in 24 hours. The first is convective instability, which is the biggest cause of summer floods and the most difficult to model given the very intense rainfall and short time scale as well as the highly localised nature of some of these events (Boscastle, 2004 and Helmsley, 2005). The second is orographic enhancement of frontal precipitation through the seeder-feeder mechanism. This is well understood, but generally poorly reflected in models whose resolution has been too coarse to capture the details of the local topography (Carlisle, 2005).

We start with an assessment of current extreme rainfall forecasting capabilities, including the development of higher resolution models, the use of radar-based nowcasts, and the importance of ensemble methods. We then examine the main government bodies that legislate and coordinate regional and local agencies that respond in the case of extreme weather emergency. Special attention is given to the collaboration between the Met Office and the Environment Agency and the alert services they provide to the local authorities and public in general. Finally we review how this works in practice in a set of recent flood events which we believe are representative, with a particular focus on the Boscastle flood of August 2004.

Convection activity forecasting has improved and is a subject of ongoing research and development, with grid length of 1.5 km being tested. Emergency response to weather events in the UK is well-coordinated and benefits from prior warning. There is much mutual cooperation between the forecasting and operational agencies.

Charles Boschetto

1. The Need for Accurate Forecasts of Extreme Rainfall

(Alison Cobb)

Flash floods are associated with very heavy rainfall and rapid occurrence, able to cause landslides, mud flows, bridge collapses, damage to buildings and people, and are exacerbated by accumulation of debris (Collier, 2007). The Lynmouth flood in 1952 was a summer thunderstorm that had catastrophic results after the build-up of water behind debris, which subsequently burst (Hand et al, 2004), causing 34 deaths (Golding, 2009). Therefore accurate forecasts of these events are vital to prevent such devastation, and major developments have taken place in flood forecasting and warning in the UK over the last decade (Ryder, 2009).

1.1. Causes of Extreme Rainfall

Flashy catchments are those where flash floods are likely to occur, and are typically small and have features that cause rapid surface runoff. Providing flood forecasts in flashy catchments poses significant challenges and this is particularly the case when the prediction of high intensity rainfall at small spatial scales is difficult (Werner & Cranston, 2009). Extreme rainfall events generally occur in the summer and early autumn in the UK in the form of major convective storms. An extreme rainfall event is likely to produce serious flooding, particularly if it occurs over a sensitive catchment or steep orography or when the ground is very wet from previous rainfalls (Collier & Fox, 2003). In the case of a single intense event, information about the exact location, intensity, surface runoff and response of the catchment will be vital (Hand et al, 2004), so accurate warning systems depend on the accurate real-time provision of rainfall information, on the use of accurate hydrological models and on surface run-off features in the catchment. Of 50 cases of rainfall events that could cause flash floods in the UK investigated by Hand et al (2004), 30 were predominantly convective and a number of the frontal cases had a significant convective element, usually characterised by embedded thunderstorms.

The topography of the UK has a large influence on the initiation of convection; however this initial development of convective cells remains one of the least understood aspects of convection (Collier, 2007).

1.2. Forecasting of Extreme Rainfall

Flash floods are caused primarily by high intensity rainfall, so accurate precipitation forecasts are vital to increase the lead times beyond the natural lead times of the catchment, so that warnings can be issued before the intense rainfall causes a flood situation. Even for the short term, this poses significant challenges (Werner & Cranston, 2009) and Numerical Weather Prediction (NWP) models are becoming increasingly skilful at high resolution predictions for short lead times, even in complex topographical areas (Zappa et al, 2008), however there is still significant progress to be made.

Real-time measurement of rainfall is vital to forecasting flash floods, using networks of rain-gauges, weather radar, or satellite systems (Collier, 2007).

1.2.1. Rain-gauge Measurements

Robbins and Collier (2005) found that rain-gauge inputs gave smaller errors than rainfall inputs from radar for uniform rain, but as the rain became more variable, this ceased to be the case (Collier, 2009c). During an event, remote sensing such as radar and satellite, and high-resolution Numerical Weather Prediction (NWP) models are more useful than rain-gauges. The strong spatial variability of intense rainfall causing flash floods reduces the accuracy of point measurements from rain-gauges extrapolated up to area rainfall, especially where network density is very low.

1.2.2. Satellites

Due to the short time-scale associated with flash floods, polar orbiting satellites are not suitable and only geostationary platforms are appropriate for monitoring these events. Cold, deep cloud produces more precipitation at its base and satellite data is calibrated with rain-gauge measurements to produce a forecast of precipitation.

1.2.3. Weather Radar

The Met Office operates a network of 15 operational weather radars generating high resolution (down to 1km) radar data which is fed into a range of models to give a detailed assessment of the impacts of rainfall and other severe weather events (metoffice.gov.uk).

Radar measurements are shown to give relatively good results, though several issues remain, including the use of radar in mountainous areas and the under-prediction of rainfall amounts for extreme events (Werner & Cranston, 2009). Both observed and forecasted radar rainfall are obtained operationally through the Nimrod system, which is an automatic radar analysis and forecasting system operated by the UK Met Office. It allows the processing of radar reflectivity images through to quantitative rainfall estimates, including several corrections for bright band and orographic enhancement, and ground-truthing based on radar-gauge comparisons (Werner et al, 2008).

Radar data are likely to have bias errors which will vary with time and in space, and which propagate through hydrological models in different ways depending upon the model structure (Collier, 2009c), therefore calibration is needed in almost real time. When carefully adjusted by the use of rain-gauge data, areal rainfall estimates from radar are as accurate as those from a very dense rain-gauge network (Collier, 2007). In a region with no radars nearby, horizontal resolution will be limited and also the radar scans are too high to see low-level precipitation resulting in significant underestimation of the rainfall when there is orographic enhancement through the seeder-feeder mechanism (Roberts et al, 2008) (Section 4), therefore the radar estimate includes an allowance for orographic enhancement.

Werner & Cranston (2009) found that the capability of the radar to estimate rainfall amounts varies significantly from event to event and that the proximity of the catchment to the radar station is of little importance, as long as the catchment falls within the 50km radius for which 1km resolution data are available.

Radar has fine spatial resolution, down to 1km, and high temporal resolution, approximately 5 minutes. For longer lead times, the nowcasting predictions tend to under-estimate the rainfall amounts, partly due to the blending of the radar forecasts with NWP forecasts available at too coarse a resolution to represent high intensity rainfall in such small catchments properly (Werner & Cranston, 2009).

1.2.4. Nowcasting

Alongside providing estimates of the observed radar rainfall data, the Nimrod system also generates radar-based nowcasts with a lead time of 6 hours, at hourly intervals. (Werner &

Cranston, 2009; metoffice.gov.uk). This is very short-range forecasting that maps the current weather and uses an estimate of its speed and direction of movement to forecast the weather for a short period ahead, assuming the weather will move without significant changes (metoffice.gov.uk). A Probability Distributed Model (PDM) for rainfall-runoff modelling and forecasting is incorporated into MOSES (Met Office Surface Exchange Scheme) for use in the Nimrod nowcasting system. (Roberts et al, 2009).

In the UK, rainfall nowcasts can be useful up the three or four hours ahead in widespread rain bands in winter, but only one to two hours ahead for thunderstorms (metoffice.gov.uk). To extend the period of predictability, nowcasts can be combined with output from NWP models (metoffice.gov.uk). The nowcast model applies corrections to deal with orographic enhancements and effects of wind speed, forecasts of which are derived from the Met Office mesoscale NWP model. A blending procedure is also applied at the start of the forecasts with the radar observations, and NWP forecast precipitation amounts being increasingly added towards the end (Werner & Cranston, 2009; Golding, 2000).

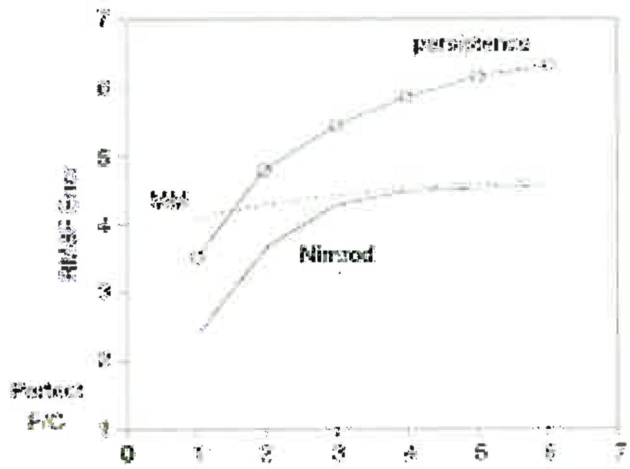

Fig 1.1: Level of performance achieved by Nimrod as a function of lead time (hours). MM is the mesoscale model and RMSF is the root mean square factor (Golding, 1998). Adapted from Collier (2007)

It is clear *(figure 1.1)* that Nimrod outperforms the mesoscale model at short lead time (1-4 hours). Thereafter, the skill of the mesoscale model matches that of Nimrod, and it has been shown that for lead times beyond a few hours, the mesoscale NWP precipitation output provides the most reliable forecasts, which also include the development of new rain areas

(Collier, 2007). The first two hours of the mesoscale model forecast are shown to be less accurate than persistence as the model had to 'spin up' from coarser resolution information.

A major limitation of the Met Office Nimrod system is the way it handles convective initiation and development. To improve the representation of convective storms, Gandolf was developed (Collier, 2007). Gandolf is the best available very short-range forecast of rainfall intensity at 2km resolution, drawing on techniques developed for Nimrod, a specialised thunderstorm model, and a project diagnosing convection (metoffice.gov.uk).

The Met Office also runs STEPS (Short Term Ensemble Prediction System), a rainfall nowcasting system in which the rainfall distribution is separated into different sizes of rainfall feature, so large rainfall events (more predictable) can be nowcast for longer, and small events are only nowcast for a very short time (metoffice.gov.uk), enabling the location of extreme rainfall to be pinpointed several hours before it occurs. Beyond this predictability limit, information is used from the NWP model. This ensemble approach has a 2km resolution and provides probabilitics of rainfall propagation up to a 6 hour lead time.

Nowcasts contribute positively to the skill of the forecasts, despite the uncertainties they contain (Werner & Cranston, 2009). Radar rainfall nowcasts such as those provided by the Met Office Nimrod system provide short range predictions at these spatial scales and can be used as an input to hydrological models for the prediction of flood flows (Werner & Cranston, 2009). Such forecasts are considerably uncertain and this influences the reliability of hydrological forecasts used in flood warning and forecasting (Werner & Cranston, 2009).

1.2.5. Numerical Weather Prediction

Radar-based forecasts of intense rainfall for short lead times (an hour or so) are very useful, however for longer lead times, NWP models are more effective. The Met Office runs its short range (1-2 days) model over the UK with a 4km grid length. Much of the UK's most damaging weather involves convective clouds, and the model falls short of representing the spatial variability of precipitation produced by these features (Collier, 2007; Wetterhall et al, 2009). Parameterization deals with convective clouds, however it is possible that some convective clouds may be resolved, leading to an over-sizing of these phenomena. As computer power increases, it is possible to reduce the grid box size, and the Met Office is experimenting with models which take a major jump in resolution towards a 'convective-scale NWP' (metoffice.gov.uk) of 1.5km grid length (Collier, 2009b). This model is routinely run in preparation to become the operational model. A series of projects have demonstrated the ability of a 1-2km grid length NWP model to reproduce realistically the structure of convective storms and to forecast them accurately when other conditions such as windspeed and humidity are adequately represented (Golding, 2009; Roberts et al, 2008; Lean et al, 2008). A 2km grid length is the coarsest that can represent a typical UK thunderstorm of ~10km diameter (Golding, 2009). In higher resolution models, it has been shown that there are improvements in the correct simulation of orographic enhancement and seeder-feeder mechanisms (Werner et al, 2009) (e.g. Boscastle 2004, Section 3), as lower resolution NWP models may have insufficient resolution to represent local orographic effects (Roberts et al 2009).

1.2.6. Ensemble Forecasts

Deterministic forecasts of flood-producing rainfall are limited to a few hours ahead by the chaotic nature of the atmosphere. Developments in probabilistic forecasting over the past decade offer the possibility of useful information at more extended forecast ranges (Golding, 2009). Ensemble forecasts can be used to distinguish and forecast an extreme event, enabling warnings to be issued with an understood level of confidence (Golding, 2009). It is possible to define threshold probabilities for prescribed events at which specific actions should be initiated, and in some cases this can be as low as 20% in extreme circumstances (*section 2.3.)*, when the result of not mitigating may be extremely costly or politically unacceptable (Golding, 2009).

Spatial resolution of ensembles typically lags deterministic forecasts (Golding, 2009). In recent years, the Met Office has developed a regional ensemble MOGREPS (Met Office Global and Regional Ensemble Prediction System) which has recently been reduced from 25km to 16km grid length. This ensemble system produces uncertainty information for short-range forecasts up to two days ahead, giving earlier and more reliable warnings of extreme events, such as rapid storm development. Ideally the ensemble approach should be applied to convective forecasting; however, there are currently computer power limitations. The Met Office has the aim of having this capability by 2012 (Golding 2009).

1.3. Hydrological Modelling

River hydrograph forecasts are dependent upon the rainfall data being very accurate at a specific time (Collier, 2007). The added value of using radar rainfall measurements and nowcasts has been recognised by the hydrological forecasting community (Werner & Cranston, 2009). A vision for the future is that automated end-to-end systems that feed high-resolution NWP rainfall forecasts into hydrological models will become a standard part of the flood warning procedure (Roberts et al, 2009).

1.4. Climate Change

The enhanced greenhouse effect is likely to lead to a more active hydrological cycle and an increase in the frequency of heavy rainfall events (Collier, 2009; Collier, 2007; Senior et al, 2002), leading to a reduced return period (i.e. more frequent occurrences) of extreme precipitation in many locations (Senior et al, 2002). The resolution of climate models is unable to represent extreme events and local impact (Ryder, 2009); however, trends are evident on a broad scale.

1.5. From Forecasts to Warnings

The Met Office, Environment Agency and other organisations issue warnings in response to extreme weather forecasts (Section 2). The Met Office and Environment Agency has created the Extreme Rainfall Alert launched in July 2008, to alert emergency responders to the probability of rainfall sufficiently heavy to cause flooding somewhere (Golding, 2009; Werner et al, 2009). The forecasters who issue the alerts use evidence from the 4km UK model and the 2km STEPS nowcast, and for the advisory warnings they also use the 25km MOGREPS ensemble (Golding 2009). Even though nowcasting provides accurate forecasts up to a 6 hour lead time, which is sufficient for the general public, there is a requirement for longer lead time warnings for emergency responders and infrastructure operators (Golding, 2009).

1.6. Conclusions

The hydrological response time of these flashy catchments is so short that the forecast uncertainty is determined primarily by the forecast rainfall (Werner & Cranston, 2009). Precipitation forecasts can be made using rain-gauge measurements, radar, satellite and NWP data. With increased model resolution in the future, convective processes should be resolved and more accurate forecasts of intense precipitation can be produced. The use of ensembles at high resolution and more frequent hourly updates to the early parts of the forecasts should improve the forecast of extreme rainfall events that may cause flooding. Nowcasting is vital to observe changes during the event, using calibrated radar data and predicting the flow up to a 6 hour lead time. In the future with this increased resolution and use of ensembles at higher resolutions, early warnings will be possible and will hopefully reduce the amount of damage caused by extreme rainfall propagating flash floods.

2. Government Bodies and Public Responses to Extreme Weather
(Maria Helena L.R. Serrano)

The aim of this part of the report is to provide the readers with an overview of the government bodies, local authorities and other entities that work closely together in the prevention and management of the worst effects of extreme weather events. The emphasis however will be given to floods, as it is the main theme of the group project. The reference to the entities will start at higher level of decision and regulation and will end at the public level.

2.1. Cabinet Office UK Resilience

The Government Cabinet Office UK Resilience provides resource for civil protection practitioners, supporting the work which goes on across the United Kingdom to improve emergency preparedness. The *Civil Contingencies Act (CCA) (figure 2.1)* delivers a single framework for civil protection.

CIVIL CONTINGENCIES

ACT 2004

Fig 2.1: the Government Cabinet Office UK resilience: Civil Contingencies Act 2004

The Act is separated into two substantive parts: local arrangements for civil protection which establish a clear set of roles and responsibilities for those involved in emergency preparation, and response at the local level and emergency powers (table 2.1.).

Organizations	Responsibilities
Category 1: *Local Authorities* (county and district council) *Emergency Services* *Health* (NHS bodies) *Environment Agencies*	o Assess the risk of emergencies occurring and use this to inform contingency planning; o Put in place emergency plans; o Put in place Business Continuity Management arrangements; o Put in place arrangements to make information available to the public about civil protection matters and maintain arrangements to warn, inform and advise the public in the event of an emergency; o Share information with other local responders to enhance co-ordination; o Co-operate with other local responders to enhance co-ordination and efficiency; o Provide advice and assistance to businesses and voluntary organisations about business continuity management (Local Authorities only).
Category 2: *Utilities* *Transport* *Health and Safety*	Less likely to be involved in the heart of planning work but will be co-operating and sharing relevant information with other Category 1 and 2 responders.

Table 2.1: The CCA 2004 divides the responders into two categories with different set of duties

2.2. Environment Agency and Scottish Environment Protection Agency

The Environment Agency is the lead agency for dealing with flooding and drought in England and Wales, together with the Scottish Environment Protection Agency (SEPA). The Environment Agency (EA) was established by the Environment Act 1995 and is a Non-Departmental Public Body of the Department for Environment Food and Rural Affairs (Defra) responsible for flood and coastal erosion risk management (*figure 2.2)*.

Fig 2.2: Environment Agencies

The EA is empowered under the Water Resources Act 1991 to manage flood risk arising from designated "main" rivers and the sea. It supervises all matters relating to flood defence including building and maintaining defences and other management measures on designated Main Rivers. It is also responsible for flood forecasting and warning and for, improving public awareness of flood risk. Both the EA and SEPA work closely with the Met Office to produce the floods warnings. Descriptions of the warning codes used are in *table 2.2*.

Flood Watch	Flooding of low lying land and roads is expected. Be aware, be prepared, and watch out.	-Monitor local news and weather forecasts. -Be aware of water levels near you. -Be prepared to act on your flood plan. -Check on the safety of pets and livestock. -Charge your mobile phone.
Flood Warning	Flooding of homes and businesses is expected. Act now!	-Move cars, pets, food, valuables and important documents to safety. -Get flood protection equipment in place. -Turn off gas, electricity and water supplies if safe to do so. -Be prepared to evacuate your home. Protect yourself, your family and help others. -Act on your flood plan.
Severe Flood Warning	Severe flooding is expected. There is extreme danger to life and property. Act now!	-Collect things you need for evacuation. -Turn off gas, electricity and water supplies if safe to do so. -Stay in a high place with a means of escape. -Avoid electricity sources. -Avoid walking or driving through flood water. -In danger call 999 immediately. -Listen to emergency services. -Act on your flood plan.
All Clear	Flood watches or warnings are no longer in force for this area.	-Keep listening to weather reports. -Only return to evacuated buildings if you are told it is safe. -Beware sharp objects and pollution in flood water. -If your property or belongings are damaged, contact your insurance company. -Ask their advice before starting to clean up.

Table 2.2: EA flood warning codes (source: www.environment-agency.gov.uk)

The Flood Risk Management (Scotland) Act 2009 received royal assent on 16 June 2009 and sets out new duties with respect to flood risk management for SEPA, local authorities, Scottish Water and other responsible authorities. T*able 2.3* for SEPA lays out the transitional steps for the integration of flood risk information.

Step	Date	SEPA Information Basis for Flood Risk Advice
1	26 November 2009-22 December 2011	Indicative River & Coastal Flood Map (Scotland)
2	Post 22 December 2011	Outcomes of the preliminary flood risk assessment
3	Post 22 December 2013	flood hazard and flood risk maps
4	Post December 2015	Production of (district) flood risk management plan
5	Post-2016	Production of (local) flood risk management plan

Table 2.3: SEPA Transitional steps for the integration of flood risk information (Source: SEPA briefing note, Flood Risk Management (Scotland) Act 2009)

2.3. The Met Office

The Met Office (*figure 2.3)* is a Trading Fund (UK government department) within the Ministry of Defence (MoD) and is the official source of meteorological information in the UK.

Fig2.3: Met Office

Legislation supporting the Civil Contingencies Act 2004 states that Category 1 responders must have regard to the Met Office's duty to warn the public, and provide information and advice, if an emergency is likely to occur or has taken place

Other than the latest forecast and weather observations that are automatically updated on their website, the Met Office has a number of services that help authorities prepare and respond to emergencies.

The *National Severe Weather Warning Service (NSWWS)* provides warnings of severe or hazardous weather which could cause problems, ranging from widespread disruption of communications to conditions resulting in transport difficulties. Weather warnings for specified severe weather events are sent to responders using fax, e-mail, FTP and SMS text message formats.

This service was improved in 2008 in order for emergency planners better be able to forward plan and increase (or decrease) mitigation actions through time as an event nears. The aim for the new system are to provide

- Fewer warnings
- Severe and extreme events are highlighted in advance during normal hours at all times
- Differentiation between severe and extreme events *(figure 2.4)*
- Earlier indications of severe or extreme weather *(figure 2.5)*

No severe weather
Be aware
Be prepared
Take action

As a quick guide to the colours, they should be interpreted as:
'Be aware' means: Remain alert and ensure you access the latest weather forecast.
'Be prepared' means: Remain vigilant and ensure you access the latest weather forecast. Take precautions where possible.
'Take action' means: Remain extra vigilant and ensure you access the latest weather forecast. Follow orders and any advice given by the authorities under all circumstances and be prepared for extraordinary measures

Table 1: Colour matrix used to denote confidence levels in both severe and extreme forecast weather events

Risk/confidence	Very low < 20%	Low ≥ 20 < 40%	Moderate ≥ 40 < 60%	High ≥ 60 < 80%	Very high ≥ 80% Including flash messages
Severe event	Green	Green	Yellow	Amber	Amber
Extreme event 'unusual weather'	Green	Yellow	Amber	Red	Red

Fig 2.4: Colour matrix used to denote confidence levels in severe and extreme forecast weather events

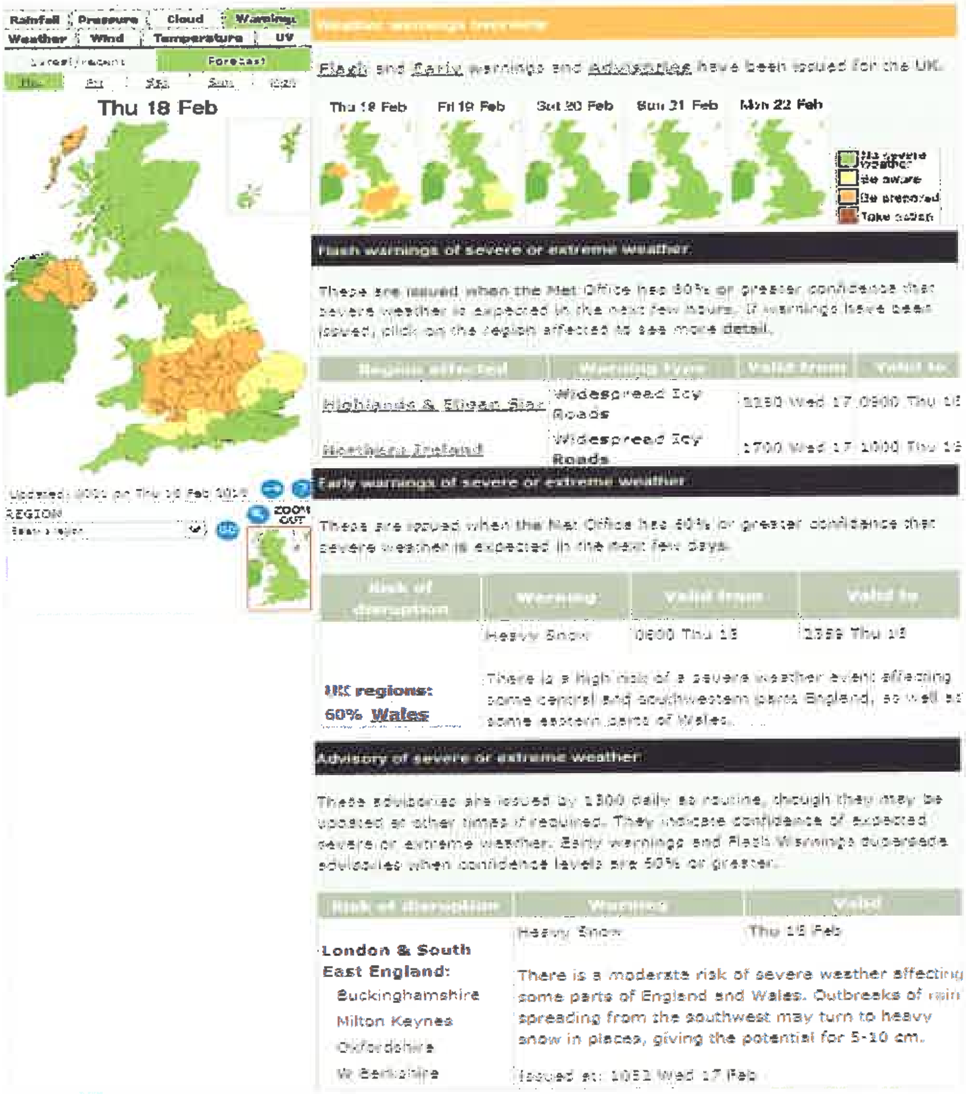

Fig 2.5: An example from the Met Office NSWWS website for 18th February 2010

2.4. Co-operation between Met Office and Environment Agency

The Met Office works closely with the Environment Agency (EA) in England and Wales and the Scottish Environment Protection Agency (SEPA) to forecast areas where floods are likely. The Environment Agency, SEPA and local authorities share responsibility for providing advice and information to the public during flood emergencies.

The *Flood Forecasting Centre (FFC)* is a partnership between the Environment Agency and the Met Office, combines meteorology and hydrology expertise to forecast for river, tidal and coastal flooding as well as extreme rainfall which may lead to surface water flooding. The new service will complement existing public flood warning arrangements from the

Environment Agency and public weather warnings from the Met Office. This new collaboration is a response to Pitt's Review into the summer 2007 floods.

Working together the warnings produced are clearer, consistent and targeted, giving Category 1 and 2 partners longer lead times so that, in turn, they can be better prepared for flooding events. The FFC developed also the *Extreme Rainfall Alert Service*. This service, issued at county level, complements the flood warning because extreme rainfall can provoke floods before water enters a river or watercourse, or where none exists. This is especially true when the level of rainfall is more than drains can handle. These services are issued via email, auto-voicemail, SMS or fax to the category 1 responders.

Key	Very low risk	Low risk	Medium risk	High risk
RIVER & COASTAL FLOODING Probability >100 properties will flood, or extreme danger to life, from rivers or the sea	<20%	≥20% to <40%	≥40% to <60%	≥60%
EXTREME RAINFALL Probability that ERA thresholds will be met, leading to possible surface water flooding • 30mm per hour • 40mm in three hours • 50mm in six hours	<10%	≥10% to <20%	≥20% to <60%	≥60%

Figure 2.6: Levels of risk of a major flood event happening for each day of a five day period. (Source: www.metoffice.gov.uk)

Risk levels *(figure 2.6)* are agreed on a daily basis with each Environment Agency region via Forecasting Duty Officers (for river and coastal flooding) and with the chief forecaster at the Met Office (for probabilities of extreme rainfall). In order to identify and assign the risk level and assess of the probability of a severe or extreme weather event occur the FFC has to take into account the following (Flood Guidance Statement User Guide, Met Office):

- Recent weather conditions (is it shortly after an earlier period of prolonged rain or other high impact weather event?)
- Actual information of catchments within the areas at risk (how saturated are the catchments, how high are the rivers?)
- Spatial/temporal extent of the event (is it short and localised or large and over several hours?)
- Timing of the event (does it coincide with a major outdoor activity or national holiday?)
- Impact of fluvial (river) flow and spring tides

The Met Office has also *Public Weather Service Advisers* that work closely at local level with responder agencies to ensure that the emergency services have access to up-to-date and timely advice on the warnings released. They typically interact with Gold Command officers for actual incident management (*table 2.4).*

Gold, Silver and Bronze Command

Agreed national framework for managing the local multi-agency response to emergencies.

Bronze – the operational level

- Immediate "hands-on" work
- Assessment of nature and extent of the problem.
- In most instances, coordinated by the Police.
- Implementation of silver commander's tactical plan when applicable

Silver – the tactical level

- Coordination of Bronze level by most senior officers
- Usually located nearby or directly adjacent to the scene.
- Decision of if and when to invoke the gold level of management

Gold – the strategic level

- aka Strategic Co-ordinating Group (SCG) and "gold command"
- brings together gold commanders from relevant organisations
- Chaired by the police, which usually transfers responsibility to local authority at recovery phase
- Primary interface with regional or central government

Table 2.4: Gold Silver and Bronze Event Command Structure. (Northumberland Local Resilience Forum – Multi Agency Debrief – Sept 2008)

2.5. Other Authorities and Their Responsibilities

2.5.1. Local Authority

Local authorities have the responsibility for local flood risk management – surface water, groundwater, ordinary water courses. They prepare development plans and determine planning applications in line with planning policy. Local authorities also coordinate local resilience and emergency planning in their area, including response to and recovery from major flood emergencies.

2.5.2. Police and Fire Services

The police initially assess the emergency. Among other responsibilities, they assure the security of the incident site, traffic diversions, control and co-ordination of media. The fire services assist in the mitigation of the damage and are involved in the evacuation process.

2.5.3. Water Authority

The water authority works in partnership with the local authority and emergency services to alleviate any flooding of foul sewers and the impact of this flooding. Some of its responsibilities are to maintain water supply and to manage the storage and release of flood water supply reservoirs.

2.4.5. Voluntary agencies

Volunteers play a key role in helping flood victims (e.g. the Red Cross, and the Royal Society for the Prevention of Cruelty to Animals).

2.6. Major Reports and Projects

Several significant reports about past floods have been produced by the Environment Agency, providing a clear understanding of the meteorological reasons that led to each flood and how the emergency plans were put in to practice. They provide important lessons learned to carry out future improvements in the plans. Other major reports are mentioned below.

2.6.1. The Foresight Future Flooding Project

This report tries to answer how climate change will affect us in 30 to 100 years time, how the risks of flooding and coastal erosion change in the UK might be met and what the best options are for government and the private sector to respond to these challenges. Under every scenario considered, flooding would increase substantially by the 2080s, however the flood risk will vary across the UK. Coastal erosion will increase substantially in all scenarios. In the future many drivers like climate change, socioeconomic factors, governance issues such as stakeholder behaviour and environmental regulation will influence flood risk.

2.6.2. The Pitt Review - Learning Lessons from the 2007 Floods

On 8 August 2007 Sir Michael Pitt was appointed by the Secretary of State for the Environment, Food and Rural Affairs to chair an independent review into the floods which affected parts of the United Kingdom in the summer of 2007. His interim report was published on 17 December 2007 and contains 92 proposals which are to be implemented if communities are to be better protected.

2.6.3. Exercise Triton 04 Report

The 1st UK National Flood Exercise was taken in June and July 2004. The Environment Agency and individuals from over 60 organisations were presented with a scenario that depicted massive storms and widespread flooding of the coasts of England and Wales, under potential impacts of climate change. The exercise aim was to refine and develop emergency plans in the line of the lessons learned in the exercise. Some of the lessons learned during this exercise were the need to improve knowledge of roles, responsibilities between control posts, and to improve forecasting of the timing, extent of tidal flooding, as well as the need to improve the ability of all organisations to assimilate information quickly enough to make decisions. (Exercise Triton 04, Overview report of lessons identified).

2.7. Conclusion

In general, it is noted that the organizations have been adapting themselves to the challenges of a flooding event. The publications of reports that assess the effectiveness of the emergency plans for major flood events bring to the authorities the clear need and suggestions for improvement. Therefore, it is very important professional leadership within the organizations for effective changes to be produced.

The creation of the partnership between the Met office and the Environment Agency in the new Flood Forecasting Centre is one good example of response to the lessons learned in the Pitts Review Report 2007.

Overall, there is evidence that the UK is looking for better ways to improve the flood emergency plans, and is implementing gradual changes in the organizations in order to improve co-ordination.

In the following sections of the report we look at case studies of recent flood events in the UK to get an overview of how effectively they were predicted and how efficient was the emergency response from the authorities.

3. Extreme Flooding Event at Boscastle, Cornwall, on 16th August 2004

(Simon Rowell)

This small Cornish village was inundated by a flash flood on 16th August 2004. The topography of the area, the meteorological situation prior to and during the incident and the forecasting of and response to the emergency is examined.

3.1. Location and Topography of Boscastle and the Surrounding Area

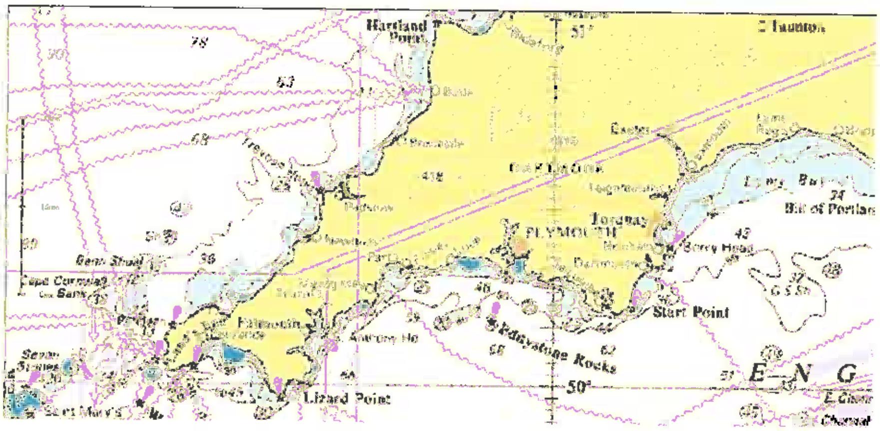

Fig 3.1: the Cornish peninsula. UK Hydrographic Office, 2009

Boscastle lies on the north coast of Cornwall *(figure 3.1)* and is close to the high ground of Bodmin Moor (notice the 418m elevation on *figure 3.1* just south east of Boscastle). The village itself is a typical Cornish fishing village and is built in the valley of the Valency River *(figure 3.2)*.

Fig 3.2: Ordnance Survey map of Boscastle. Environment Agency, 2010

The valley is typical of rocky river valleys in north Cornwall and Devon, in that it collects rain fall efficiently from its catchment area and immediately adds it to the existing river flow, which then flows directly to the sea. A post-flood geological survey (British Geological Survey, August 25th 2004) found that the superficial materials covering the valley sides had little depth or coherence, meaning that rainfall went almost immediately down to the watercourse, rather than soaking into subsoil (Mason, 2004).

3.2. Meteorological Conditions Prior to August 16th 2004

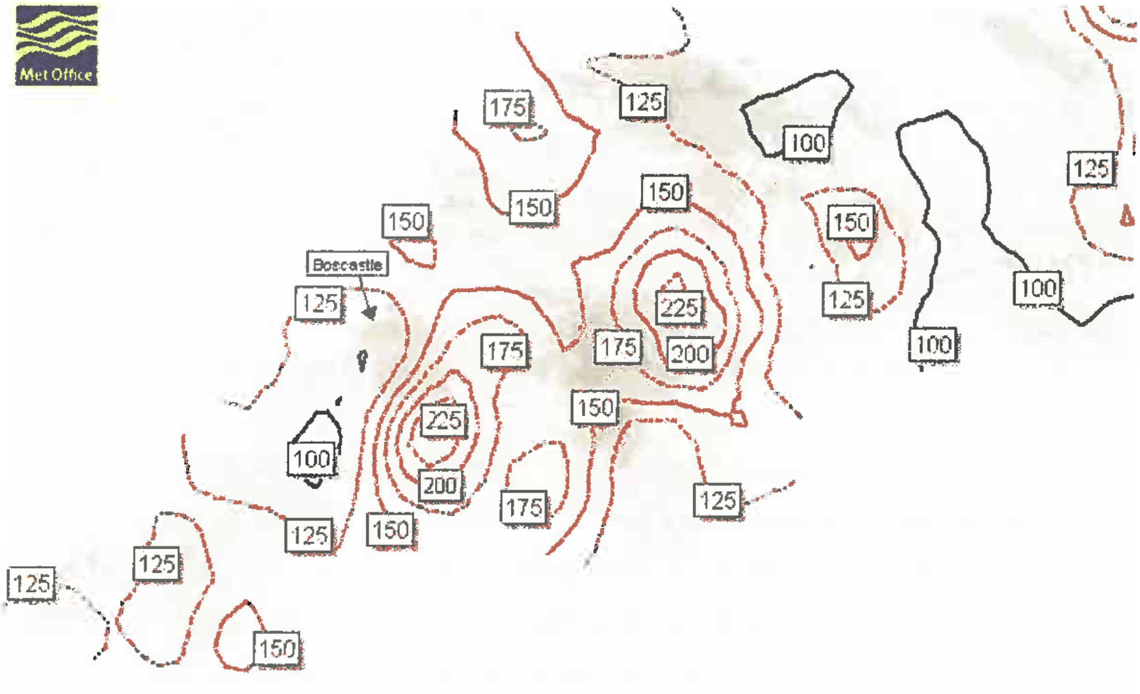

Fig 3.3: Precipitation anomaly map for south-west England, 1–15 August 2004, relative to 1961–90 averages (Golding et al, 2005)

The 2004 summer had been wetter than average, with the UK for August as a whole receiving 89% more than the 1971-2000 average (the Met Office). Boscastle and the surrounding area had received about 25% more than the mean for the first half of the month *(figure 3.3)*, so there had not been a massive build up of ground water in the surrounding area.

3.3. The Meteorology Behind the Extreme Precipitation

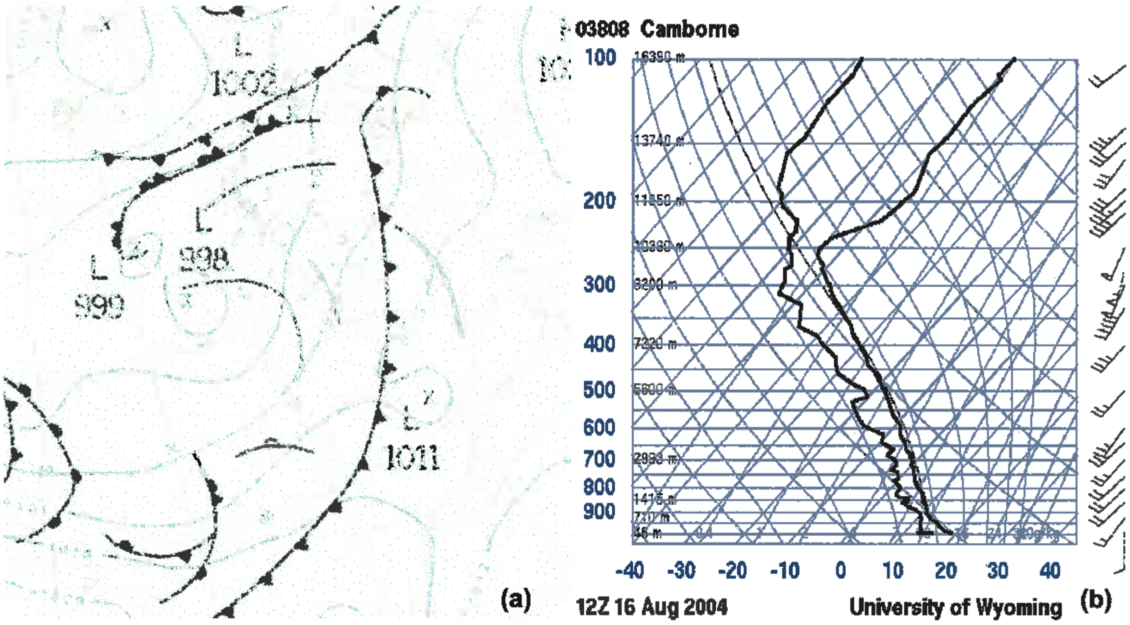

Fig 3.4: (a) synoptic analysis at 1200Z, 16th August 2004 (the Met Office), (b) upper air sounding from Camborne at 1200Z, 16th August 2004 (University of Wyoming)

The weather over the UK was dominated by a complex slow moving low to the west of Ireland *(figure 3.4(a))*, bringing generally moist south westerly flow over Cornwall and the south west in general. The 1200 UTC sounding for Camborne, approximately 70 km to the south west and directly in line of the air flow *(figure 3.4(b))*, shows that the air was moist all the way up to the tropopause starting from a cloud base at about 900m. This meant that the area was ripe for convection to start, and the available CAPE was 170 Jkg^{-1} (Golding et al, 2005).

The sounding data *(figure 3.4(b))* shows that the surface wind is backed by friction to SSW, as compared to the general SW flow. This caused convergence along the north Cornish coast, bringing both air and moisture together. This was combined with general orographic lifting (the Lookout Station just south of Boscastle Harbour entrance is at 97m *(figure 3.2)*, giving an indication of the sharp elevation rise in this coastal region). These two lifting processes overcame the convective inhibition, and started the process of convective cell formation. This was assisted by the large scale synoptic situation – the region was to the left of a jet exit *(figure 3.5)*, a source of upper level divergence and therefore a help to surface convergence. As the convecting air rose, the air entrained into it was itself moist, and so there was no snuffing out of the development of the convective cells. The vertical wind records *(figure 3.4(b))* show a weak unidirectional shear, which meant that the downdrafts were separate from the rising convection.

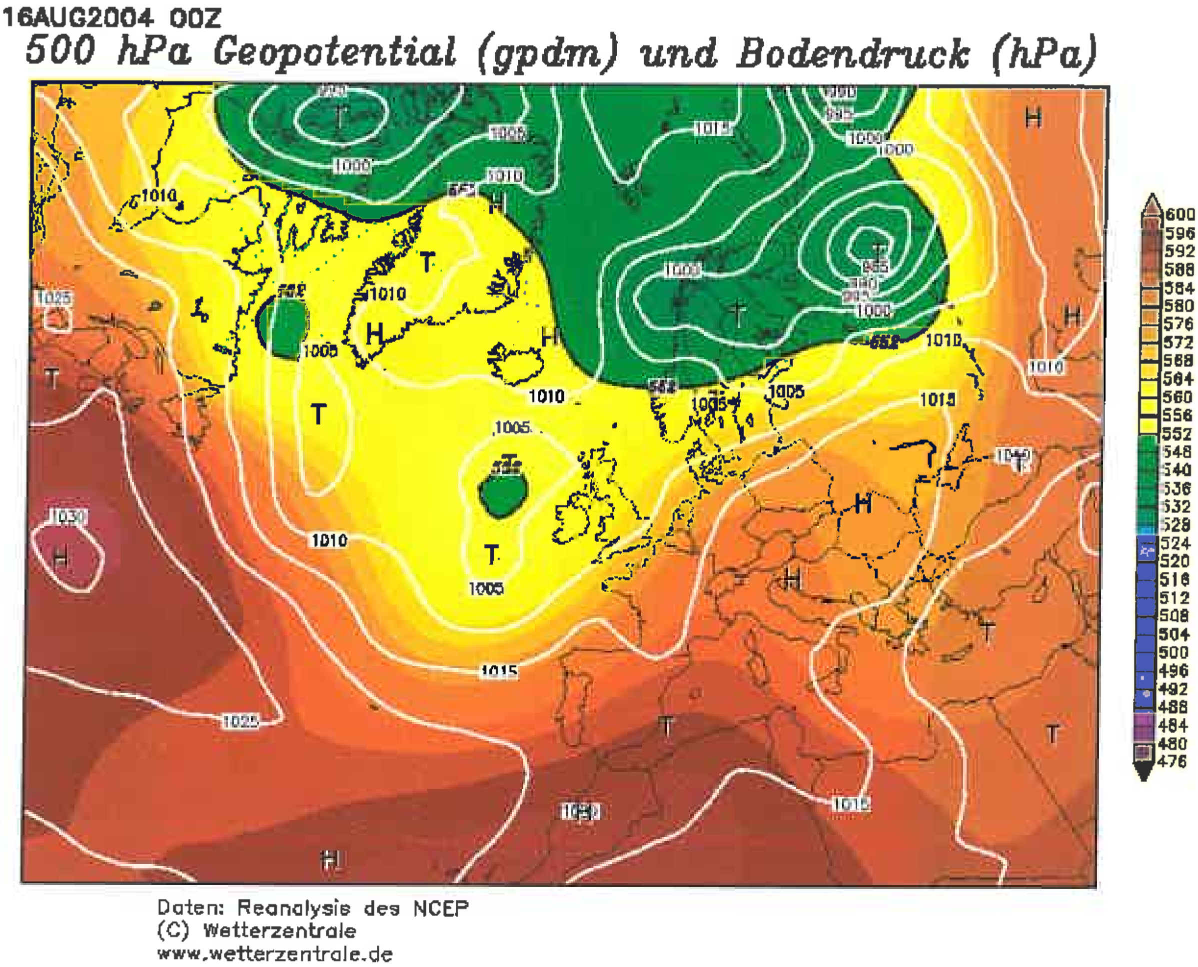

Fig 3.5: 500hPa geopotential and mean surface level pressure, 16th August 2004, 0000 UTC. Copyright Wetterzentrale, www.wetterzentrale.de

3.4. The Precipitation Events

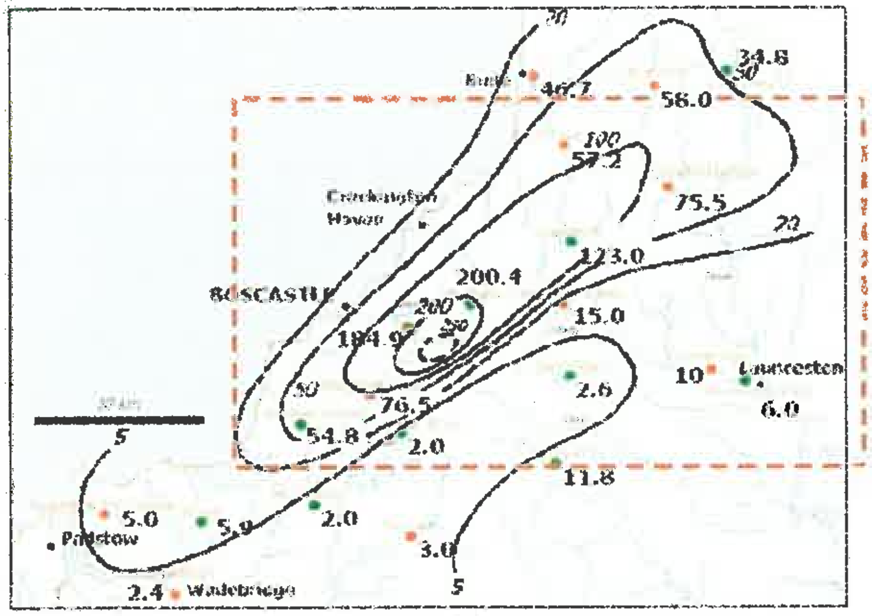

Fig 3.6: Approximate distribution of rainfall for the rainfall day of 16 August 2004. Units are millimetres: isohyets are at 5, 20, 50, 100 and 200mm. The area covered by the dashed rectangle corresponds to the outline box in *Fig 3.7.* (Burt, 2005)

The overall rainfall distribution *(figure 3.6)* shows a corridor of rainfall starting at the initial convective cell generation point just east of Padstow, with a peak of over 250 mm just near Lesnewth (south-east of Boscastle), falling off after that. consistent with convective cells starting and then moving downwind. As they moved, the convection would build, with peak precipitation occurring as shown.

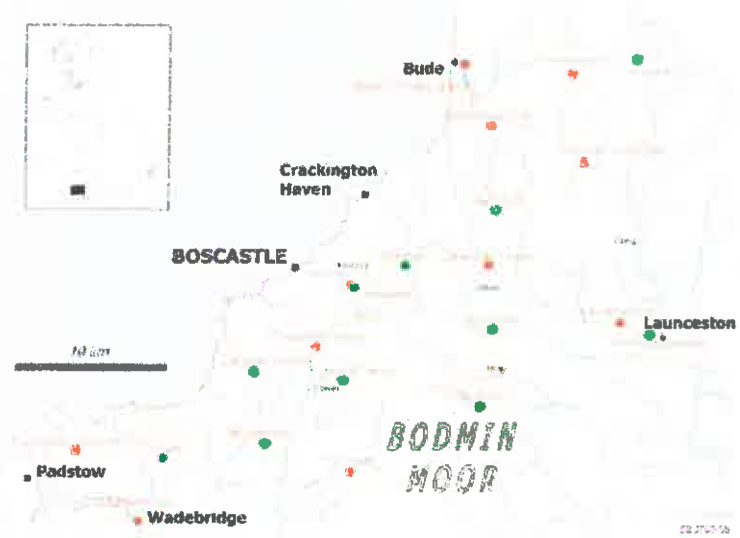

Fig 3.7: Locations referred to in the text; inset shows location of detailed map *(Figure 3.6)*. Standard daily-read raingauges are shown by green circles, recording gauges by red circles (Burt, 2005)

The sequence of events (refer to *figure 3.7)* was:

1115 UTC: first cell originated just south west of Padstow. This then moved north east and produced5.5mm in 30 minutes at Slaughterbridge, and then 18mm in 30 minutes at Lesnewth.

1215 UTC: a major cell formed near Delabole, followed by a series of 10km wide convective cells, which eventually went all the way north east to the Bristol Channel.

1300 UTC: This series of cells formed the source of very heavy precipitation over Lesnewth.

1430 UTC: Delabole was again the source of another intense cell, which developed very rapidly as it moved north east, with its heaviest precipitation occurring at Lesnewth again.

1440 UTC: this was the start of the heaviest and most prolonged precipitation at Lesnewth, building to a peak at 1535 UTC and ending at 1619 UTC (from the recording tipping gauge).

1446 UTC: first notification of events to the emergency services, in this case the Marine Rescue Coordination Centre (MRCC) at Falmouth, who scrambled two Search and Rescue helicopters to the scene.

1536 UTC: the MRCC declared a "major incident" and all available emergency services were deployed.

1615 UTC: the rainfall changed from a series of extremely heavy cells to a much wider, much less intense conglomeration of convective cells.

The radar images *(figure 3.8)* show this development of convective cells almost anchored to the same starting point, only spreading out and easing after 4 hours.

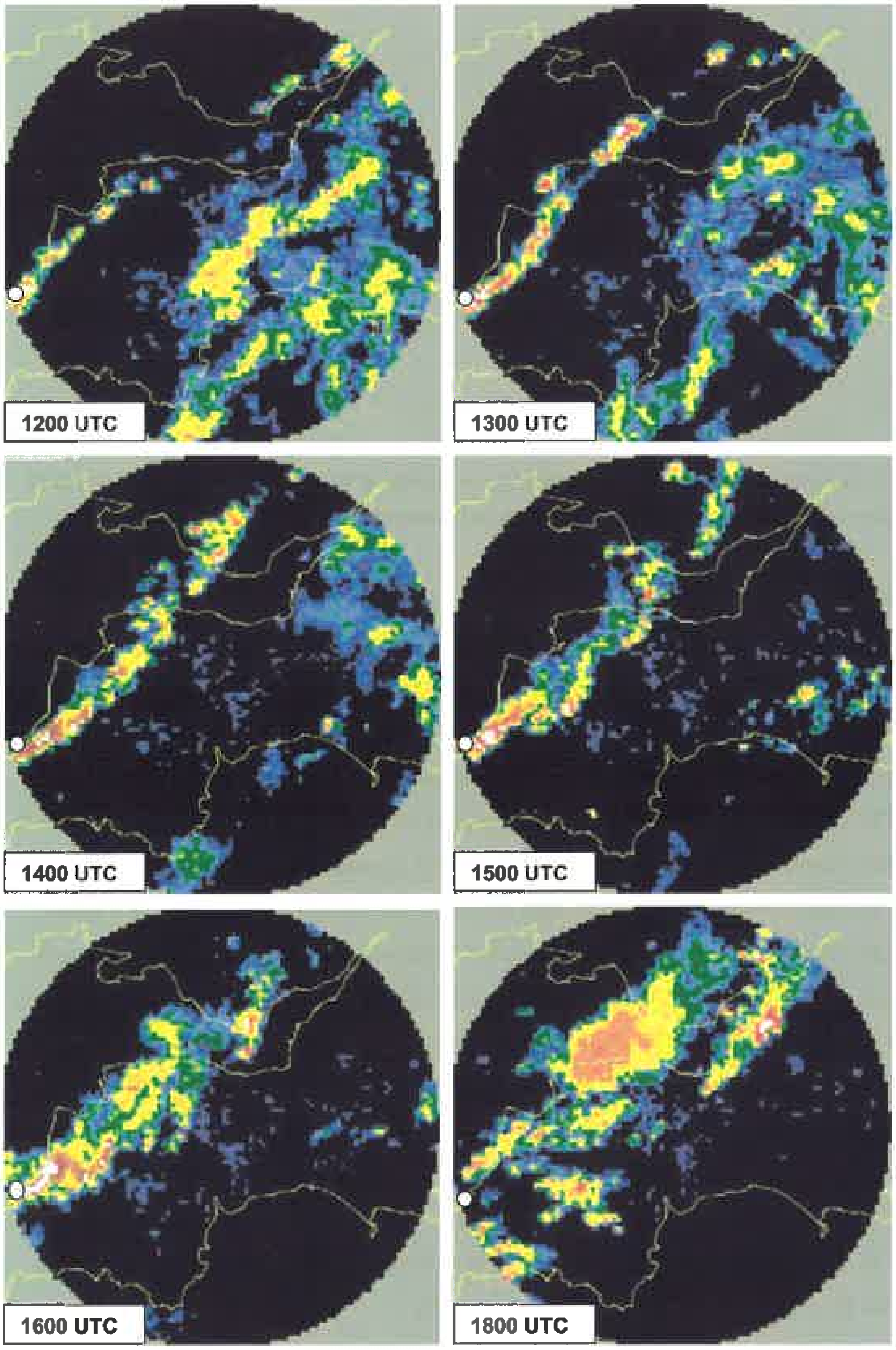

Fig 3.8: High-resolution (2×2 km) radar rainfall data from Cobbacombe Cross at intervals from 1200 to 1800 UTC on 16 August 2004. Boscastle is marked as a white dot (Burt, 2005)

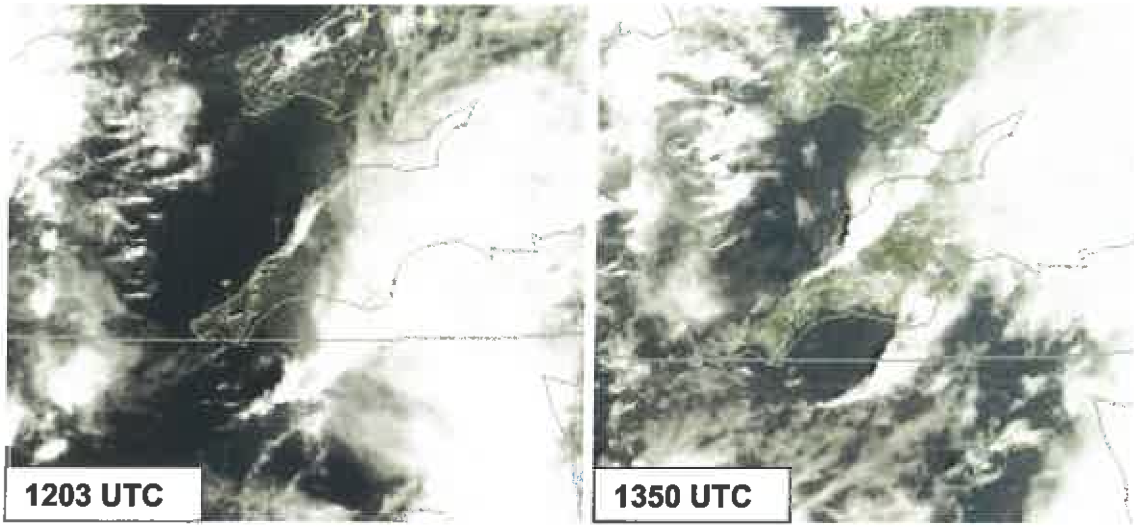

Fig 3.9: MODIS composite images, August 16th 2004 (www.sat.dundee.ac.uk)

The convection activity can clearly be seen developing on satellite images (*Figure 3.9,* with the stream of convection cells in a tight line following the convergence line up the coast, starting at the same point in both images. A wider streak of similar convective activity can be seen on the north Brittany coast.

3.5. The Amount and Location of the Heaviest Precipitation

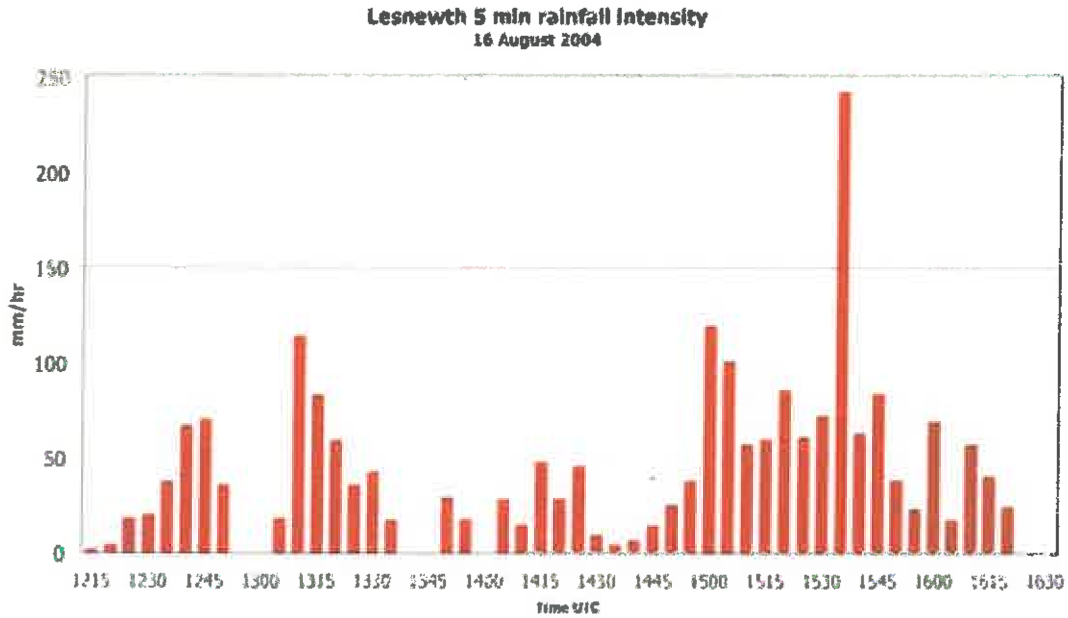

Fig 3.10: Rainfall intensity (in millimetres per hour) at Lesnewth over 5 minute periods from 1215 to 1630 UTC on 16 August 2004 (Burt, 2005)

The telemetering gauge at Lesnewth is a tipping bucket gauge with a 0.2mm tipping bucket. This worked throughout the event, and has a standard daily-read gauge just next to it (*figure 3.7*) for cross-referencing. This allowed rainfall rate data of high resolution to be obtained (*figure 3.10*). The significant problem with tipping gauge rainfall data at high precipitation rates (above about 50 to 100 $mmhr^{-1}$) is that the tip time reduces the actual recorded amount. Also, at extremely high rates the downflow may swamp the tipping bucket, causing operation to cease completely. The data shown (*figure 3.10*) has been corrected for this (Burt, 2005).

The four distinct rainfall events (referred to at 1115 UTC, 1215 UTC, 1300 UTC and 1440 UTC above) can clearly be seen on the rainfall rate record, and in the peak ending at 1535 UTC there was a 20s period where the rainfall rate approached and possibly exceeded 500 $mmhr^{-1}$. In the main and last burst, 109 mm fell from 1440 UTC to 1610 UTC, and the last tip was recorded at 1619 UTC; the total 24 hour (0900 UTC on the 16th to 0900 UTC on the 17th of August) rainfall for Lesnewth was 184.9mm.

This was not the highest record for the day – Otterham, just 4km to the north east of Lesnewth, recorded 200.4mm for the same period, and at Hendraburnick Down (2.5 km south south east of Lesnewth, marked HD) the estimated rainfall was 250mm ±20% (*figure 3.7)*.

This spread of the highest rainfall was responsible for lessening the flood impact. The Valency River was not the only one that flooded that day, though the impact in its case was by far the most severe. The Inny, Ottery and Camel rivers also received significant runoff (*figure 3.11),* and it can be seen that the area of highest precipitation lies virtually in between these four headwaters. Had the peak area been directly over Lesnewth, then far more runoff would have gone down the Valency River, which would have greatly amplified an already major incident. There was also very little time lag between the precipitation and the flood – the heaviest rain occurred at 1535 UTC, and by this time the event had already been classified as a "major incident".

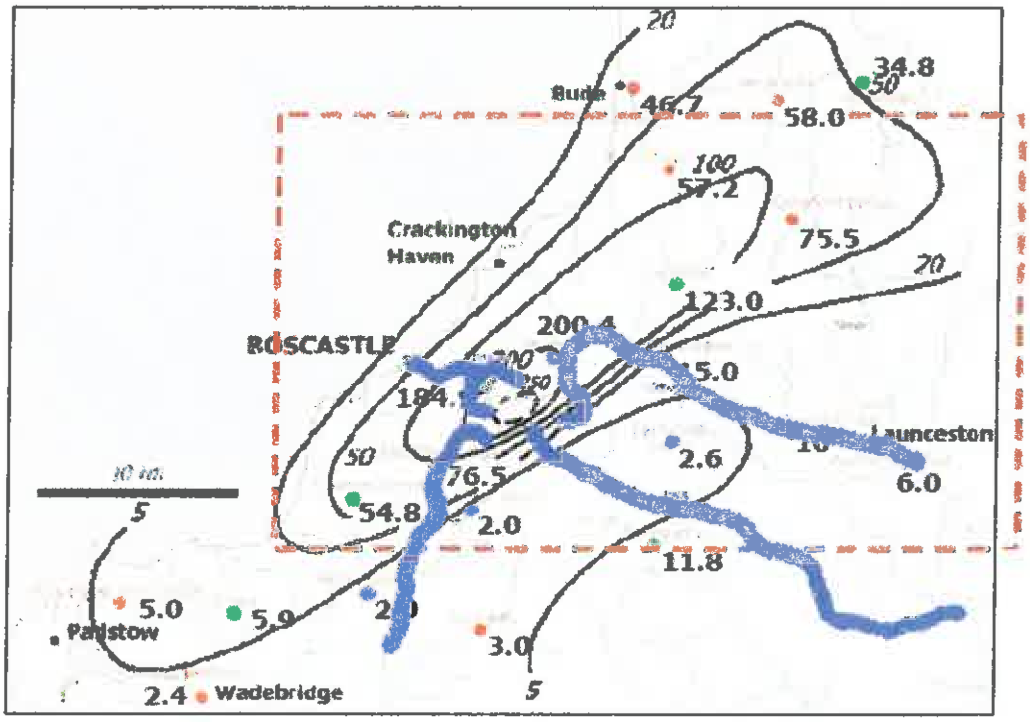

Fig 3.11: Approximate distribution of rainfall for the rainfall day of 16 August 2004, showing the courses of the rivers Valency, Ottery, Inny and Camel, starting in the north west quadrant and going clockwise. (Image taken from Burt 2005 and modified)

3.6. Meteorological Forecast

The Met office forecast for that day, using the 12km grid model run at the time, did not forecast the extreme precipitation. The 4 km grid model used from 2005 onwards has been tested for this event and does a far better job. It can be compared to the radar returns for the period *(figure 3.12)*. Extreme convective activity at this small spatial scale is difficult for an NWP model to forecast – with a 12km grid box, the smallest convection event that can be resolved by the model is 60km across.

In fact, the day in Boscastle started off bright and sunny, a typical tourist season Cornish day, to the extent that a local bed-and-breakfast owner had looked at the forecast and had planned to use the day to install a water feature in his garden (Lusher, 2008).

A flood watch *(table 2.2)* had been issued for parts of North Cornwall at 1530 BST the previous day, but was not upgraded due to the lack of a severe weather warning from the Met Office.

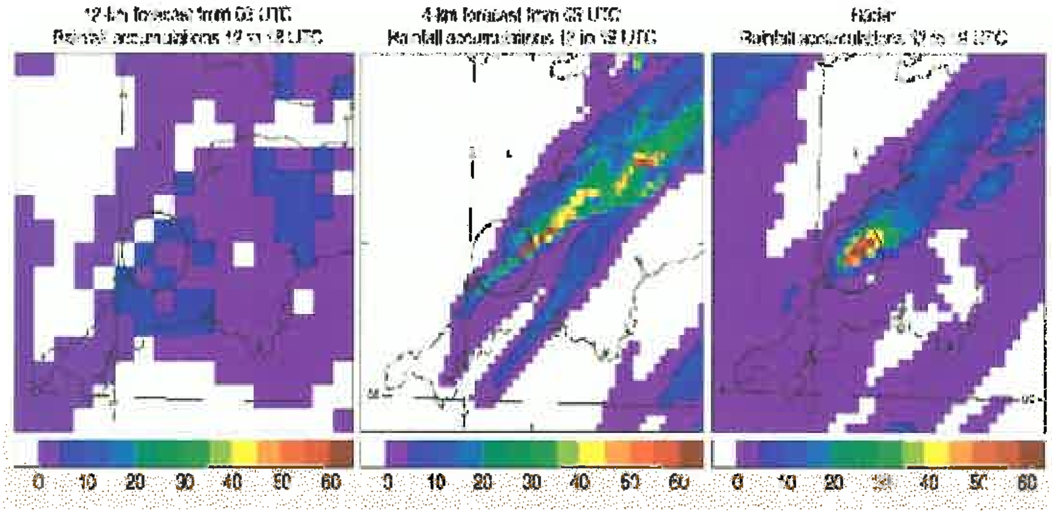

Fig 3.12: (a) actual 12km grid forecast precipitation, (b) 4km grid forecast with more recent software, (c) radar rainfall accumulations for the period (Lean et al., 2005)

3.7. Return Period

This is determined by the risk of an event happening – for example a 1 in a hundred year event has a 1% chance of occurring in any particular year. As with all statistical indicators, getting the context right is crucial. There are several approaches.

Recent Events: the nearby Lynmouth flood of August 1952 had similar rainfall amounts (229.5mm in 24 hours), and was equally devastating. This would imply a 1 in 50 year event.

Flood Estimation Handbook method: this 5 volume publication by the Centre for Ecology and Hydrology gives a probability of a similar rainfall amount at any time of year as a 1 in 200 year event (Doe, 2004)

Flood Risk Analysis: the Environment Agency gives an annual probability for flooding of 1.3%, i.e. a 1 in 75 year event. This is the figure used by insurance companies (Barham 2004).

3.8. Response to the Event

The emergency services response to this event was successful, in that there was no loss of life or serious injury. H.M. Coastguard initially co-ordinated the incident air-lifting 97 people to safety, including a baby in a rucksack. The fire services, police, RNLI, the ambulance service, the National Trust and other agencies were heavily involved, as were several volunteer organisations such as the Royal Society for the Prevention of Cruelty to Animals.

The Multi-Agency Report (South West Regional Resilience Forum, 6th April 2006) has one major point for hindrances to the operation, and that was communications. Cornish coastal villages in general suffer from poor communications by mobile telephone and hand-held VHF radios. These devices require line of sight coverage by masts or transmitters, which in the steep coastal valleys often is not there. The first few hours of the event were much hampered by this, and it was only when satellite radio equipment was brought in that the problem was solved.

Among the aspects praised by the report were multi-agency interaction, helped greatly by joint exercises (Triton 2004, *section 2.6.3.*), and that each agency's emergency plan worked. Also, there were many significant personal contributions by emergency service personnel and volunteers. This was crucial, especially in the first few hours before effective communications were established.

3.9. Since the Event – the Aftermath and Rebuilding

Insurance estimates were initially for approximately £4.5 million of damage, with up to another £10 million in business impact costs (Barham, 2004). The work included deepening and widening the Valency River, and through the village itself it was widened by about 3m and deepened by 1m, doubling the available volume. The car park upstream of the village *(figure 3.2)* which had most of its parked vehicles washed through the village out to sea in 2004 was moved back 10m from the riverbank and raised nearly 1m (Lusher, 2008).

On June 21st 2007 about 100mm of rain fell in 4 hours, and while there was some flood damage (several houses had between 0.6 and 0.9m flooding), the flood defences held and no major damage was done (Savill and Condron, 2007).

3.10. Conclusions

The Boscastle floods were caused by low level convergence in a very moist air mass being lifted orographically. This formed a series of intense convection cells, which led to extreme precipitation over a concentrated area, with 250 mm falling in just over 4 hours (Burt, 2005). A significant proportion of this water flowed down the steep-sided Valency River through Boscastle, causing severe flooding with associated damage to the village. The multi-agency emergency response was good, hampered initially by communication difficulties, with 97 people airlifted to safety, no fatalities and only minor injuries. The physical damage was repaired (£4.5 million of direct damage) with flood defences installed, which have since been seen to be effective during the floods of summer 2007. The event was not forecast, mainly due to the 12 km grid size in use at the time in the NWP, but subsequent tests (Lean et al, 2005) have shown that a 4km grid would have given a significantly better forecast.

4. Other Recent Representative Flash Flood Events in the UK

(Charles Boschetto)

We chose here to focus on two events *(figure 4.1)* illustrating other types of weather phenomena which can lead to flash floods, as well as the range of outcomes in precipitation but also damages and government responses to such events depending on the circumstances. We contrast and compare those to the events at Boscastle.

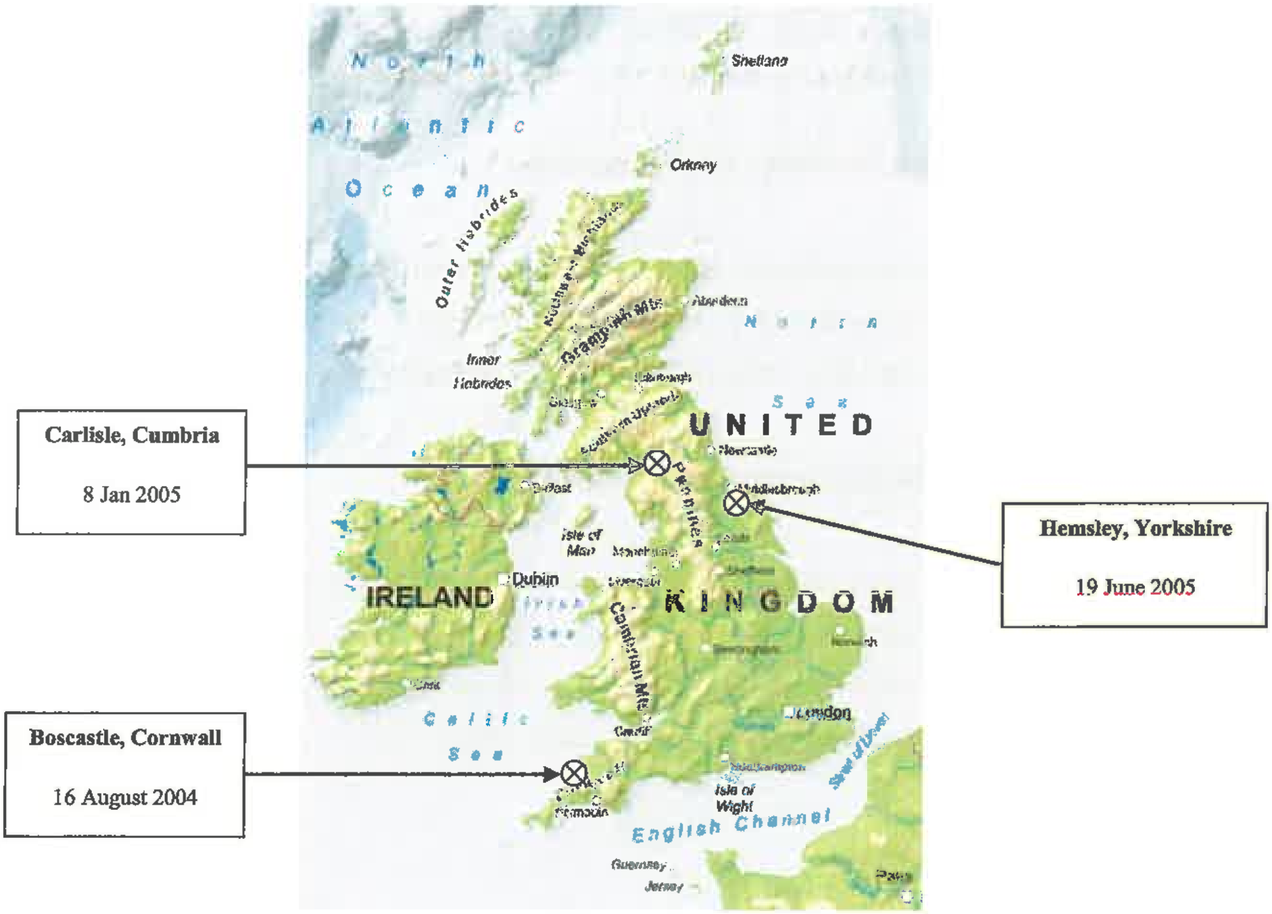

Fig 4.1: event locations around the UK

4.1. Carlisle, Cumbria, 8 January 2005

Fig 4.2: (a) Carlisle's topographical location, (b) Carlisle Flooding, January 2005: © Prestwood

4.1.1. Antecedents and Conditions Prior to the Event

The city, which lies at the confluence of the Rivers Eden, Petteril and Caldew *(figure 4.2(a))*, is notoriously subject to floods with events recorded as far back as the 1700's. In recent years there have been floods in 1963, 1968, 1979, 1980, 1984 and 2005 *(figure 4.2 (b))*.

4.1.2. Meteorology Behind the Extreme Precipitation

On the 7th a warm, moist south westerly airstream affected the UK with a near stationary weather front across northern England and southern Scotland. A wave formed on the cold front situated at the time over Northern Scotland which prevented it from moving south. On the 8th very elongated cold front passed over Cumbria *(figure 4.3)*.

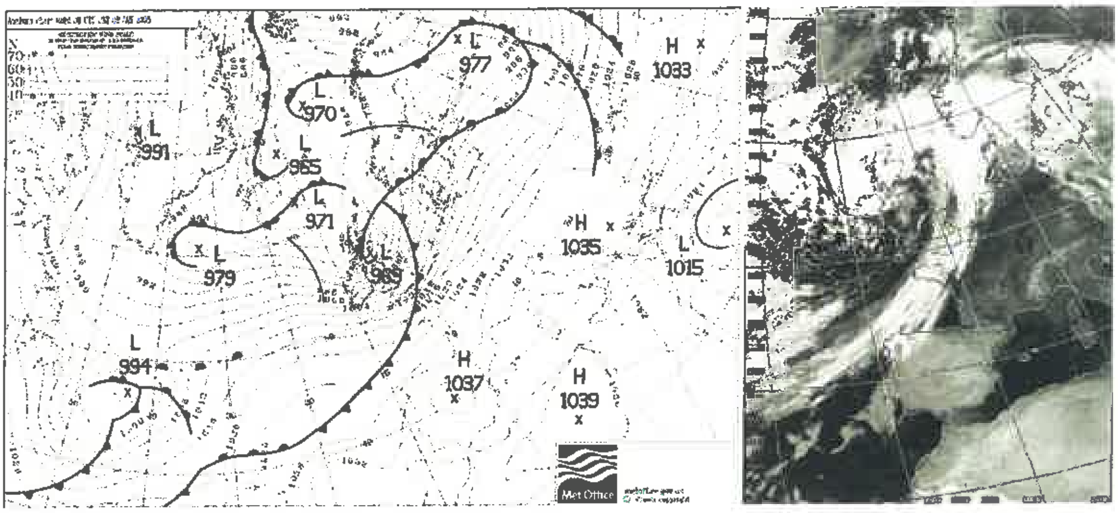

Fig 4.3: (a) surface analysis 06 UTC 8 Jan 2005, (b) IFR 0600 UTC 8 January 2005

(http://www.wetterzentrale.de/topkarten/tkfaxbraar.htm and http://www.sat.dundee.ac.uk/)

Frontal rain was reinforced as it fell through lower level clouds produced by orographic lifting of warm, moist air over the Cumbrian mountains, with the associated so called "seeder–feeder" mechanism (Roberts, Cole, Forbes, Moore, & Boswell, 2009). As wind pushes air against a mountain range, air is lifted and saturates, leading to cloud formation. Although "feeder" clouds (typically stratus, in the warm sector, at the edge of the cold front) created that way are not deep enough to produce precipitation themselves, they act as a catalyst and reinforcement by coalescence of rain drops coming from "seeder" clouds above *(figure 4.4)*.

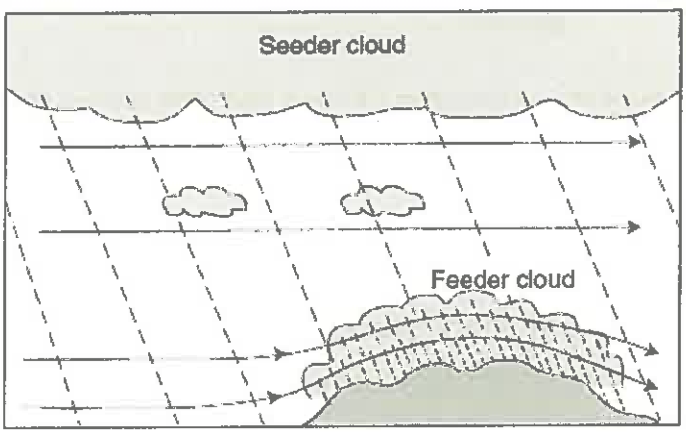

Figure 4.4 Schematic of Seeder-Feeder mechanism as adapted from the Forecasters' Reference Book (Met Office, 1997) by (Roberts, Cole, Forbes, Moore, & Boswell, 2009)

This differs from the Boscastle case, where topography acted as a blocking factor in the context of land/sea interaction.

4.1.3. Precipitation Events

Very high rainfall persisted for more than 36 hours. Honister received the highest recorded total of 213 mm in the 48 h ending at 1200 GMT on the 8th January, of which 112.6 mm fell in the 12 h period between 1200 GMT on the 7th and 0000 GMT on the 8th (*figure 4.5*). The River Eden flowed at 1520 $m^3.s^{-1}$, with a return period of 175 to 200 years (0.5%). The 1822 watermark was exceeded by 1m, leading to direct flooding of 1934 properties, up to second floor for some. The entire city bus fleet (80 buses) was annihilated. Total damages amounted to £450m.

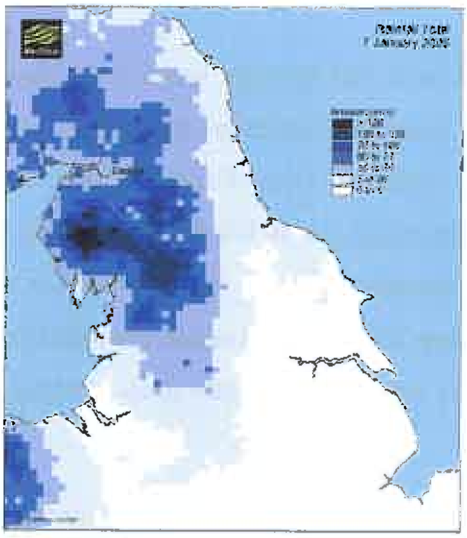

Fig 4.5: Distribution of rainfall on 7 January 2005 (0900 on 7th to 0900 on 8th) (http://www.metoffice.gov.uk/climate/uk/interesting/jan2005floods/)

4.1.4. Forecasting accuracy

The Met Office Unified Model, with a 12km resolution at the time (4km today, 1km targeted for 2010), produced around 30–50% too little rain over the highest areas (*figure 4.5*) as it did not model in enough detail the topography and associated seeder–feeder mechanism. The location of highest rainfall was also too far south west as this is where the steepest altitude gradient was modelled, contrary to actual topography (Lean 2008).

Radar also underestimated precipitation associated with the seeder-feeder mechanism. The resolution of the radar network in Cumbria being limited to 5 km squares, radar scans had to be aimed high enough to cover the area *(figure 4.6)* but as a result could not see low-level precipitation. (Roberts, Cole, Forbes, Moore, & Boswell, 2009)

The Skill of advection 'nowcasting' methods was affected by the fact that the Nimrod model used the same 12km resolution as thw NWP Model at the time.

Fig. 4.6: Great Gable in Partial Shadow
Passing clouds give the fell a mottled look when viewed from just below Sca Fell Pike summit

4.1.5. Government response

The government response was excellent. The first Flood Watch was issued by the Environment Agency at 1600 on 6 January and the first Flood Warning at 1310 on 7 January, 30 hours and 10 hours respectively before the first flooding was reported. The vast majority of those registered for the Environment Agency Automatic Voice Messaging (AVM) service were sent warnings before they were affected by the flooding.

The Cumbria County Council Emergency Control Centre was activated, with its own standby generator, at 2330 on 7 January. Following complete failure of the electricity, mobile and landline networks (hence no 999 calls possible) from 8 November, Mountain Rescue Radio Operators placed in vehicles were located at all public call boxes. A base station was established in the County Council Control Centre to receive emergency calls that could then be passed to the emergency services. This limited the number of casualties to 2.

On 13 January, management of the situation was transferred to the Carlisle city council. (Carlisle Storms and Associated Flooding - Full Multi-Agency Debrief Report, 2005).

4.2. Helmsley, Yorkshire 19 June 2005

Fig 4.7: (a) location and (b) overhead image of Helmsley showing water course

4.2.1. Antecedents and Conditions Prior to the Event

High pressure over the UK and south-easterly winds coming off a very warm continent brought a very hot summer spell. Temperatures peaked at 33.1°C in central London on the 19th, the hottest day anywhere in the UK since 11 August 2003 when 34.7°C was recorded at Gravesend (Kent). The preceding November-June period was the driest for England and Wales since 1948/49, resulting in parched surfaces which promoted run off. The area is not normally subject to floods.

4.2.2. Meteorology Behind the Extreme Precipitation

Similarly to Boscastle, this flooding event was linked to a highly convective situation, but of a different nature. Blight (Blight 2005) attributes the June 2005 storms to so plumes of warm, moist tropical maritime air came from Southern Europe at high altitude (above 850 hPa) over the UK, also known as "Spanish Plumes" because they originate from Iberia.

As successive pulses of cold air overran them from the south-west, they became convectively unstable. This led to a situation with small Convective Inhibition and a large Convective Available Potential Energy released upon a marginal temperature increase, and overshooting up to 45,000 feet. (CSIP 2005 Field Catalogue n.d.). *Figure 4.8* shows two very clear convective "bombs" in bright white above Yorkshire. *Figure 4.9* illustrates the strong convergence at the surface. *Figure 4.10* shows the warm, moist air with wet bulb of about 19°C, small CIN, and large CAPE (Blight 2005).

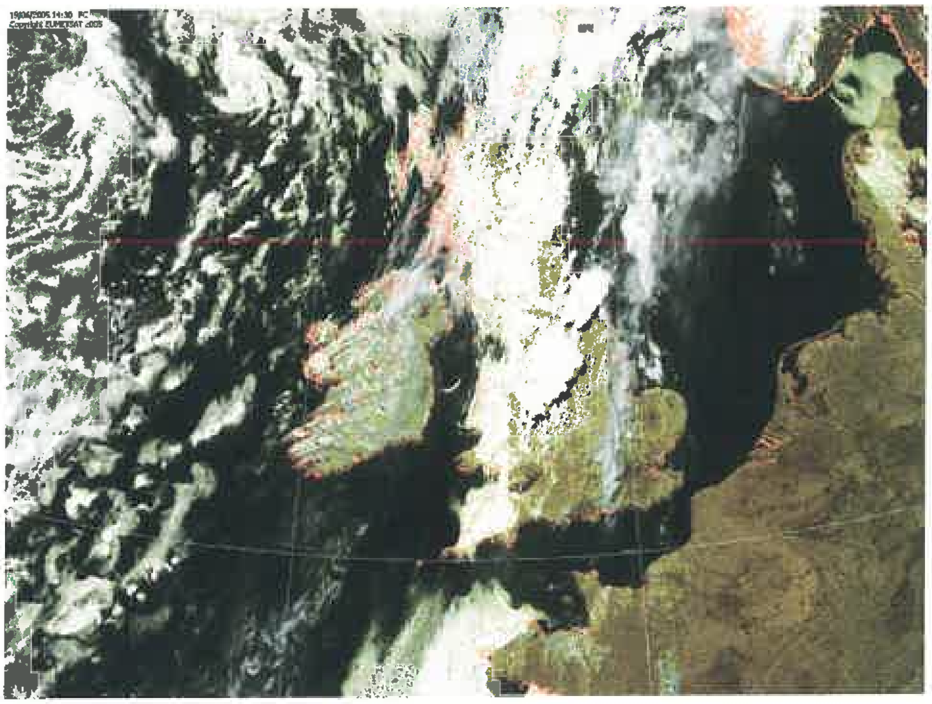

Fig 4.8: HRV image 19 June 1200 (http://www.wiseweather.co.uk/id100.html)

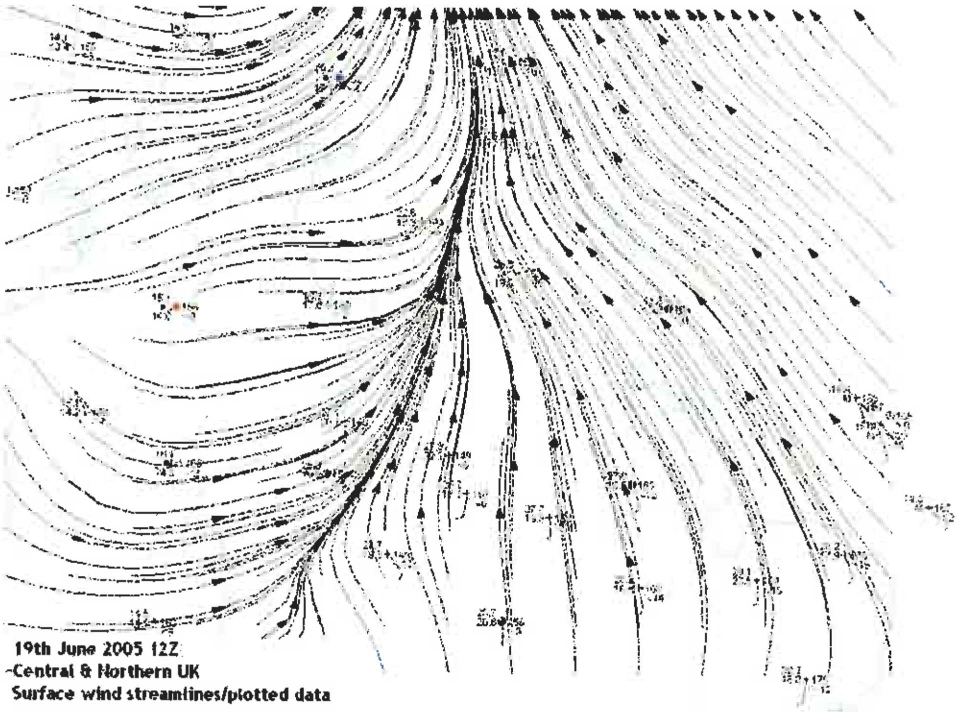

Fig 4.9: 10m Streamline plot, 1200 UTC 19 June 2005

(from http://www.wiseweather.co.uk/id100.html)

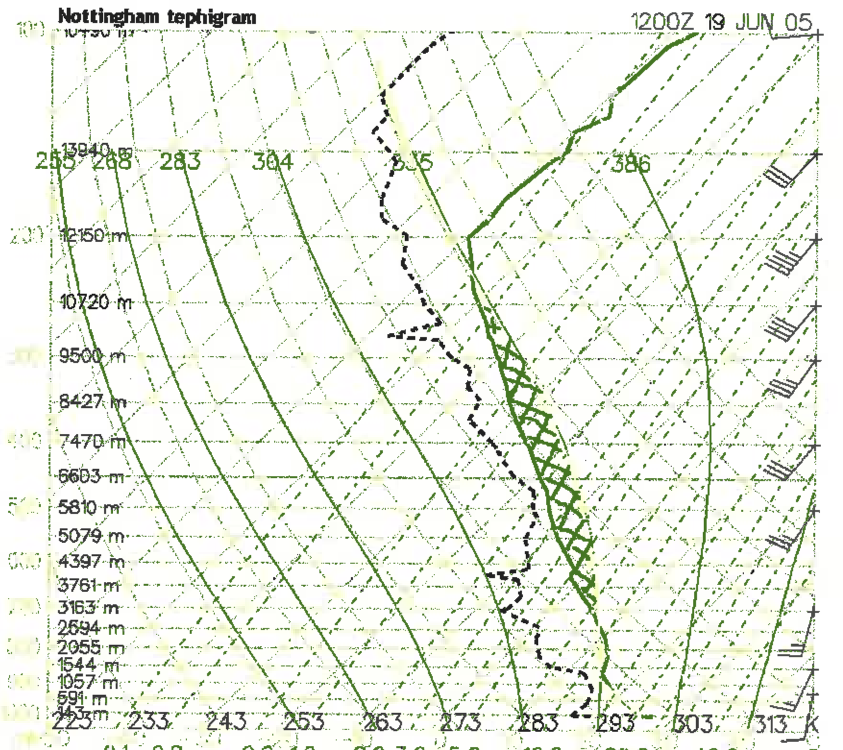

Fig 4.10: Tephigram Nottingham, 1200 UTC 19 June 2005

(http://www.wiseweather.co.uk/id100.html)

Van Delden (van Delden 2001), who analysed thunderstorm frequency over more than 200 stations in Western Europe, mentions the "Spanish Plume" as a typical triggering mechanism. The process starts when a trough approaches the Bay of Biscay and pushes the high (1,000m, 700hPa to 800 hPa) very warm air of the Iberian plateau north. This is illustrated here with the case of 20 July 1992. At 850 hPa, we see a zone of warm air advection: the "Spanish plume" stretching from Iberia over the Bay of Biscay and western France *(figure 4.11)*.

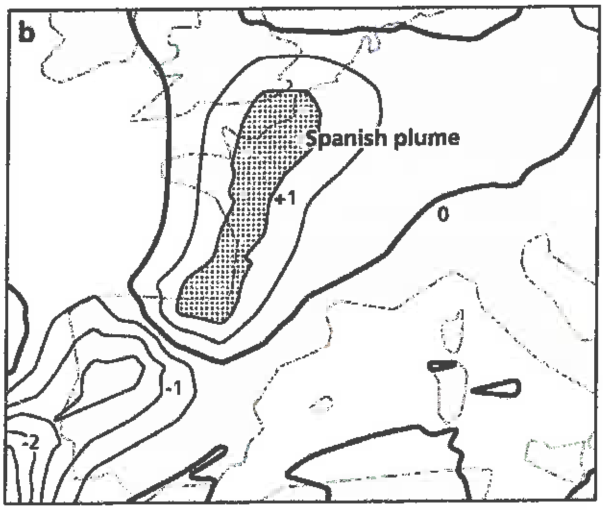

Figure 4.11 horizontal temperature advection, labelled in units of $10^{-4}K.s^{-1}$ at 850 hPa on 20 July 1992, 1200 UTC (van Delden 2001)

The term "Spanish Plume" was first used by Morris in 1986 (Morris 1986) in an article entitled "The Spanish Plume - testing the forecaster's nerve"! American literature refers to the high levels of potential static instability created in this situation as as a "loaded gun".

4.2.3. Precipitation Events

Thunderstorms contributed an unusually high proportion of the June rainfall in many parts of southern Britain. The sheer volume of water had little time to sink into the ground as the deluge fell on the parched surfaces, which lead to a very fast runoff.

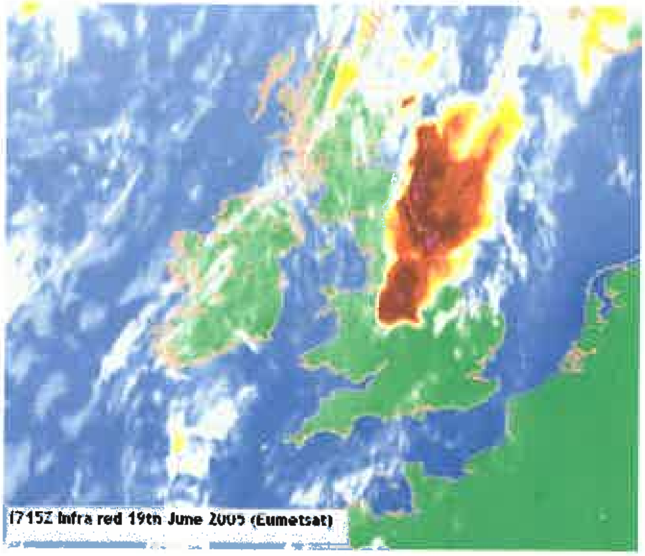

Fig 4.10: TIR image, 1715 UTC, 19th June 2005
(from http://www.wiseweather.co.uk/id100.html)

Hawnby (north-west of Helmsley) reported the most intense rainfall (*table 4.1*).

June 192005 rainfall

Station	Hour ending in GMT					
	15	16	17	18	19	Total rainfall
Hawnby (*)	-	5.8	59.8	3.8	-	69.4 (3 hr)
Church Houses (*)	-	0.6	27.0	16.1	0.4	44.1 (4 hr)
Topcliffe	0.2	7.4	29.2	3.6	0.0	40.4 (4 hr)
Westerdale (*)	-	[illegible]	27.2	[illegible]	-	[illegible] (3 hr)
[illegible] (*)	[illegible]	13.5	0.4	-	-	33.2 (3 hr)
Dishforth Airfield	0.0	6.0	16.4	3.0	0.0	25.4 (3 hr)
Osmotherley (*)	-	12.0	9.2	1.0	-	22.2 (3 hr)
[illegible] (*)	-	1.0	15.8	4.8	-	[illegible] (3 hr)
Hawarden (N Wales)	30.0	10.8	1.2	0.0	0.0	42.5 (3 hr)

Table 4.1: rainfall data, 19th June 2005
(from http://www.metoffice.gov.uk/climate/uk/interesting/19jun2005.html)

Based on data provided to them by the Environment Agency, the Met Office were able to plot precipitation in 5-minute intervals, showing just over 50 mm in a 30-minute period between 1630 and 1700 *(figure 4.11)*.

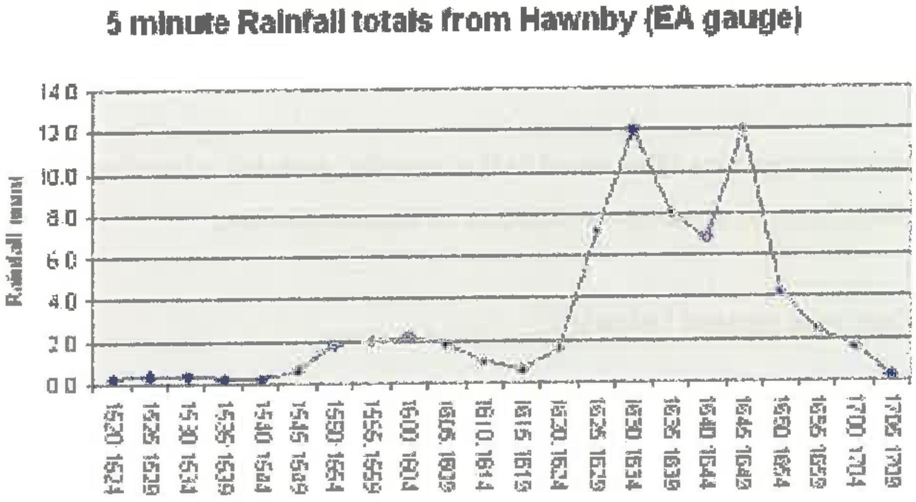

Fig 4.11: 5 minute rainfall totals from Hawnby
(http://www.metoffice.gov.uk/climate/uk/interesting/19jun2005.html)

The UK record for a 30-minute period is 80 mm at Eskdalemuir, Dumfries and Galloway, 26 June 1953. But more-intense rainfalls were recorded in Yorkshire. A total of 49.1 mm in 15 minutes, 45.9 mm in 10 minutes, 41.3 mm in 8 minutes, 30.0 mm in 5 minutes and 27 mm in 30 minutes was reported during the 19 June 2005 event. (Met Office).

4.2.4. Forecasting accuracy

The Environment Agency did not manage to post a warning until 6:09am on 20 June, four and a half hours after the flood waters peaked. The Times reported the spokeswoman for the Environment Agency to have said "It did come out of the blue," and that "causes of the flooding are still being looked at." (Sudden rain brings flash floods to North Yorkshire, 2005).

Numerical Weather Prediction of convective systems is still the focus of ongoing research. The 12-km resolution mesoscale model used at the time forecast that the front would clear and thunderstorms would then be initiated from within the Boundary Layer. This did not match the actual phenomenon of thunderstorms generated by high altitude plumes (CSIP 2005 Field Catalogue n.d.). Subsequent studies (Lean 2008) showed that the 12-km model has too much light rain, but not enough heavy rain, as the convection scheme is being averaged out over large grid boxes.

4.2.5. Government response

No multi-agency report could be found in this instance, probably a function of the size of the village affected as well as the new occurrence of flood in this area.

No casualties were reported Helmsley.

However the weekend's heat wave claimed 4 lives in drowning incidents as people tried to cool off in the sea, in lakes and in rivers.

4.3. Conclusion on Case Studies

In the two summer cases considered (Boscastle and Helmsley), warm, moist air advected by south westerly winds was the common character, whether over the ocean, or after a passage on land in the case of "Spanish Plumes". This resulted in potential instability which tested "forecasters' nerves".

Topographic features, leading to either blocking or orographic lifting, were an important factor at Boscastle and a determining one in Carlisle *(Table 4.2)*. They were not, at the time, well handled by either models or nowcasting, which did not reflect the actual intensity and location of precipitation experienced.

In all cases, the cooperation between the Met Office and the Environment Agency, as well as the preparedness of emergency teams, was tested. Setting up alternative communication networks was perhaps the most critical success factor in both Boscastle and Carlisle.

	BOSCASTLE	CARLISLE	HELMSLEY
History of floods	Yes	Yes	No
Time of year	Summer	Winter	Summer
Type	Potential Instability +Topography	Orographic lifting Seeder-Feeder	Potential Instability
Forecasting accuracy	Poor	Poor	Very Poor
Average rainfall intensity	250 mm in 24h	213 mm in 48h	69 mm in 3h
Top Rainfall intensity	500 $mmhr^{-1}$ for 20 seconds	110 mm in 12h	100 $mmhr^{-1}$ for 30 min
Casualties	None	2	None
Damages	£4.5M	£450M	32 homes
Gvnt Response	Goo	Excellent	Poor

Table 4.2: Overview of Selected Flash Floods Events in the UK

Conclusion

Having examined a number of recent flash flood cases in the UK, it is apparent that the extreme rainfall that causes flash floods can be caused by different forcings and that there is scale interaction between large scale and small scale systems. The comparison of the Carlisle and Yorkshire floods to that in Boscastle illustrates the different topographic and large scale features, which together with convection can cause intense rainfall.

The floods investigated have caused significant damage, and so the need for accurate forecasts of heavy precipitation which lead to these events is evident. Extreme localised rainfall is difficult to forecast, mainly due to insufficient resolution of NWP models to pick up convective events and the low predictability of such events occurring. The use of an ensemble approach is necessary to forecast the probability of an extreme rainfall event, and in the future it is hoped that ensembles will be run at resolutions approaching that of the newly developed convective-scale NWP, however at present, computing power is a major constraint.

The Boscastle case study provides evidence of the vast improvement in forecast ability when using the 4km model instead of the 12km model, and with the Met Office currently preparing a 1.5km gridlength 'convective-scale' NWP model, even smaller phenomena such as individual deep convective cells will be able to be resolved.

The Carlisle case study highlights the insufficiencies of radar data in an area with degraded radar coverage and significant topographic features which results in low-level precipitation being underestimated. However radar is becoming increasingly useful in the short-term prediction (up to 6 hours) of extreme rainfall in the form of nowcasts, with ongoing research into using it to obtain low-level wind fields that may provide an indication of where convection might break out.

Looking at the reports from these particular flood events, there is reasonable evidence that areas without recent history of extreme flooding have more difficulty in responding effectively. The flash flood in Yorkshire was unusual and in an area not usually subject to floods, and a late warning by the Environment Agency resulted in a poor response. However, locations with long histories of floods are in general better prepared and respond effectively to the challenge. Boscastle has a history of floods as its topography dictates fast runoff from precipitation. There was a good response to this event, even though it was not forecast. The Carlisle event was a well forecast event in an area notoriously subject to flood, and so warnings and emergency response to the event was excellent.

With the prediction of a more active hydrological cycle due to the enhanced greenhouse effect, it is likely that there will be increased frequency of heavy rainfall events. Research has shown that this may cause a significant increase in flood risk, and there are suggested schemes, notably land use planning, to help to reduce the damaging effect that this may have.

A positive note to take from this report is that evident effort is taken by the authorities to improve the situation. From every major flood event, reports with lessons learned are published. Reflection is indeed an essential step to improvement, allowing better planning and better response in the future.

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