Environment Agency | Met Office | NERC SCIENCE OF THE ENVIRONMENT

Royal Society, London | 27 November 2018

FLOODING FROM INTENSE RAINFALL (FFIR)

A five year NERC funded programme aiming to reduce the risk of damage and loss of life caused by surface water and flash floods

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Flooding From Intense Rainfall (FFIR) is a joint Natural Environment Research Council (NERC) and Met Office funded programme supported by the Environment Agency. The programme brings together researchers from universities, the Met Office and environmental consultancies.

Our research focusses on flooding associated with intense, localised rainfall events. These are typically thunderstorms that happen over just a few tens of square kilometres lasting 1 to 3 hours, making them difficult to predict. We have considered the prediction of surface water and flash floods from observations of the atmosphere; through weather and flood forecasts to the impacts on the ground. Our findings will improve forecasts and risk management associated with these type of events.

Organisations that have been funded by the programme include:

University of Reading

University of Exeter Centre for Water Systems

University of Hull

King's College London

Newcastle University

British Geological Survey Expert | Impartial | Innovative

JACOBS

University of Bristol

University of Surrey

JBA consulting

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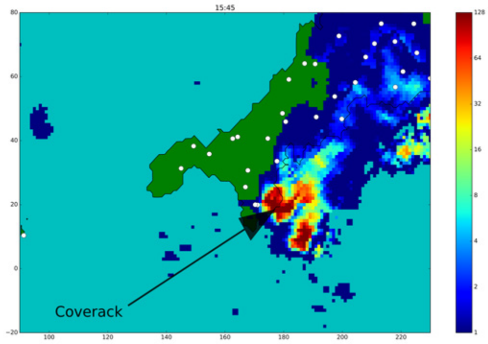
OBSERVING INTENSE RAINFALL WITH RADAR

Radars inform decision makers of observed rainfall over large areas. They provide real time observations in places where there are no rain gauges. They also provide information for use in weather forecasting models.

Radars work by sending out electromagnetic waves. These waves are reflected back by moisture in the atmosphere. This tells us where and how much it is currently raining. However the waves may also be reflected back by objects such as buildings and trees and can be affected by hail.

Accurate radar observations of rainfall are particularly important for FFIR events. The radar network in the UK has recently been upgraded, providing an opportunity to improve the performance of radar in intense rainfall events.



Radar observations of rainfall leading to the July 2017 event in Coverack. Raingauge locations are shown in white.

Key achievements

Working closely with the Met Office we have:

- Used the new data from the upgraded radars to improve radar processing to make better estimates of rainfall rates
- Investigated the impact of non-meteorological effects on the radar for example from buildings or trees
- Investigated new ways to use the radar to measure changes in moisture levels near the earth's surface that can drive the formation of clouds
- Studied how variations in raindrop size identified by the radar can affect rainfall rates
- Developed ways of using radar data to monitor change in performance over time indicating a need for maintenance

What impact will this work have?

Radar data is used directly by decision makers and as input into flood forecasting models. Much of the FFIR work is already being used operationally by the Met Office resulting in immediate improvements to radar rainfall for monitoring and forecasting. Being able to identify the need for maintenance from data will reduce the cost of un-necessary site visits.

Future challenges

The use of radar rainfall data is widespread among decision makers. Radar data is becoming more reliable in intense rainfall events but cannot identify all rainfall events accurately at all times. There remains a need to effectively communicate the limitations of radars to end users.

"The updated radar network increases the accuracy of rainfall forecasts "particularly in very intense events, allowing for more accurate and timely warnings, which will give emergency responders and the public better and earlier information to help protect lives, livelihoods and property."

Met Office (2018) Optimising the accuracy of radar products with dual polarisation

For more information about the Flooding from Intense Rainfall Programme please contact:
Professor Hannah Cloke or Professor Sarah Dance: **ffir@reading.ac.uk**

MAKING BETTER USE OF WEATHER OBSERVATIONS

To make accurate weather forecasts we first need to know the current conditions. Meteorologists use observations from instruments such as weather stations, radar and satellites for this purpose.

At the start of a new forecast run the observations are combined with previous model forecasts using the processes of data assimilation. To simplify the data assimilation procedure, conventionally only a few percent of the available observations are used at a coarse resolution. Intense rainfall events are known to be very localised and this resolution may not identify them. The FFIR programme has developed a method to more accurately represent intense rainfall events by using observations at higher resolutions.

Key Achievements

- We have improved understanding of uncertainty from observations and the forecasting model
- We have demonstrated a method that increases the percentage of radar data used in weather forecasting models by reducing the distance between observations to a few kilometres. This allows us to capture the small scale features which lead to intense rainfall
- We have shown that it is possible to improve the forecast quality for intense rainfall events without having a negative impact on the quality of the forecast for other types of weather events

What impact will this work have?

- We have increased the value for money of investments in weather radar by making better use of all available data
- In the long term the new method will help improve the rainfall data available for flood forecasting
- The new techniques developed in the FFIR programme are adaptable for other applications to make better use of all available data for example other weather observations or soil moisture observations from satellites

Future challenges

The use of data assimilation methods are complicated. Changes to the underlying numerical weather prediction models can affect the data assimilation process. Therefore any changes in the model code require re-checking of the data assimilation methods. This work is already informing new Met Office science. The next challenge is to implement the work in the operational forecasting model and then extend the methodology to make better use of all surface observations of weather.

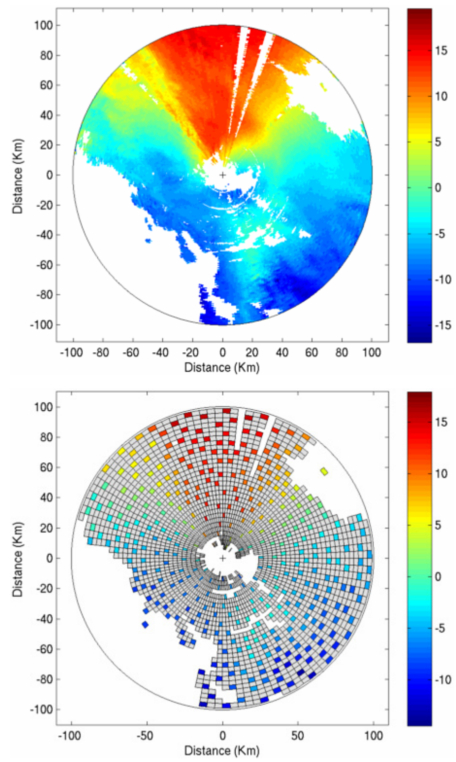


Illustration of the limited number of observations used in convectional radar data processing. The top image shows all available observations. The bottom image shows the observations that are currently used

"The UK spends a lot of money on radar observations. There are millions of data points available every hour but the current assimilation method only uses a small number of these. Increasing the percentage of observations used increases the value for money from observations"

Jo Waller, University of Reading and David Simonin, Met Office

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MAKING BETTER USE OF HISTORICAL DATA

Flood events are rare. Even in places where there has been one in living memory people forget or don't realise they are at risk. Understanding what type of rainfall events could lead to flooding in different areas is difficult. Especially as there are limited long and reliable rainfall and flow records. By making better use of the data that is available from newspaper archives and other sources, we have improved understanding of flash flood events in the UK.

Key achievements

- We have analysed large scale weather patterns to understand the atmospheric conditions that might lead to intense rainfall in the UK. This will help to alert forecasters to potential events in advance
- We have produced a chronology of past flash flood events from the 1700s across the most vulnerable parts of England from newspaper archives and other sources. We have used this data to understand more about flash flood frequency in the UK
- We have produced a quality controlled data set of hourly rainfall. Using this data we have carried out detailed analysis of intense rainfall events

What impact will this work have?

- The flood chronologies provide a powerful data set to develop storylines around flood histories which can be used to engage local communities
- The availability of quality controlled sub-daily rainfall data will have wide reaching impacts on improved modelling of FFIR. For example it will contribute to long term improvements in representing intense rainfall in climate change models
- The rainfall quality control methods could also be used to improve the reliability of real time rainfall data

Future challenges

In the UK we often use case studies of individual flood events in our research. To understand more about FFIR we need to change our practice from looking at events in isolation to looking at the geography of flash flooding across the UK. To do this we need long term funding to update and maintain the valuable datasets produced by the FFIR programme.

The aftermath of flooding in Lynmouth in 1952 (top) and associated press headlines (bottom, from Delderfield, 1953)

> "Flood history provides the potential for improving flood risk assessment even in locations subject to pluvial flooding and within small ungauged catchments"
>
> **Archer et al (2017) *Hydrology Research 1, 48 (1)*: p1–16**

> "Before this programme we had limited historical sub-daily data. Now we have quality controlled hourly rainfall data for almost 2000 gauges."
>
> **Stephen Blenkinsop, Newcastle University**

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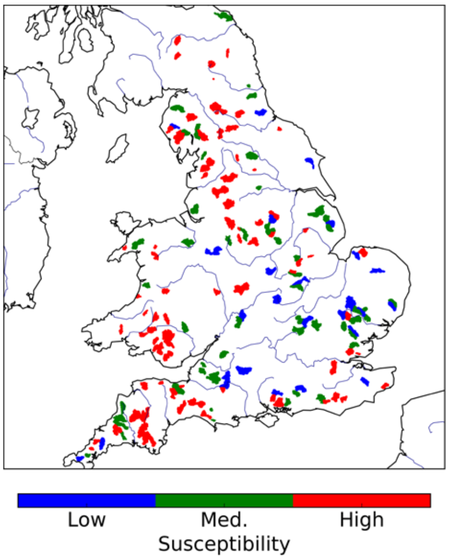
SUSCEPTIBILITY TO FLASH FLOODING

There are many local communities in small predominately rural catchments that are susceptible to flooding from intense rainfall. Some places are more susceptible to flash flooding than others, for example rivers and streams in steep sided catchments rise quickly after heavy rainfall.

Many of these communities do not have flood warning systems. By combining data from past flood events with data describing the climate and geography of catchments, we have developed a scoring system that can be used by flood risk managers to assess catchment susceptibility.



Location of catchments identified as susceptible to flash flooding

Key achievements

- We have created an inventory of past flood events and the associated hourly rainfall for 550 catchments
- We have the identified catchments in the UK which are most susceptible to FFIR based on how fast rivers and streams respond to rainfall
- Using this knowledge, we have developed a scoring method using catchment characteristics. This method can be used to identify locations without river gauges that are susceptible to flash flooding
- Other research has identified two primary groups of Chalk groundwater floods. Faster responding but shorter-lived floods occur in the catchments without clayey superficial geology

What impact will this work have?

- Improved knowledge of catchment susceptibility will help decision makers identify locations at risk of flooding based on forecasts
- We are developing rainfall thresholds so this work can be used in real time for catchments not covered by existing flood warning systems

Future challenges

This work provides a useful approach to identifying susceptibility to flash flooding in ungauged catchments. However there is a limit to how much detail this type of approach can provide. Natural variability in rainfall and catchment characteristics will limit our ability to differentiate between the causes of susceptibility.

"This research gives us a greater understanding of how rare events are. We can then ask questions like 'should I be worried?' 'Have we seen an event like this before?'"

Greg O'Donnell, Newcastle University

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COLLECTING DATA DURING FFIR EVENTS

Flash flood events often occur in upstream catchments or urban areas. There are limited gauges in these locations making collecting observations difficult. Where traditional river gauges do exist floods can often flow around the gauge or sometimes destroy the gauge.

By using novel sources of data, including community sourced data and video footage, we have built up a better picture of what happens during floods. This data can be used to improve flood models and to inform decision makers.

Drone footage of flooding in Perthshire from the Alyth Burn, July 2015 (Image source Angus Forbes Photography)

Key achievements

- We have observed flood processes and collected data from flood events around the UK including Glenridding in 2015
- We have developed new methods for observing floods using video footage from unmanned aerial vehicles (UAVs, drones) and CCTV cameras. This can be used to calculate flow across the flooded area including out of bank flows
- We have worked with communities in the North East to explore how to use community sourced data such as mobile phone footage and community weather observations to improve flood modelling

What impact will this work have?

- This work opens up an additional data source where previously there has been nothing
- Setting up the cameras has helped foster community engagement. By immediately combining live footage with their own observations local communities have become more flood aware
- The video data is robust event during extreme floods. It can provide an independent check of real time flood forecasting models. This can alert flood forecasters to otherwise unknown problems such as if the river is blocked by debris or there has been a major erosion event
- These techniques have already been shown to be useful in other countries. One example is in Chile where river channels are very mobile and traditional gauging is not possible

Future challenges

Incorporating new data sources into existing systems is difficult. Challenges remain to establish the best way of working with new techniques. To do this more studies comparing multiple data sources for flood events are required.

"When you are working in small catchments you need local gauges near areas of vulnerability"

Andy Russell, Newcastle University

The potential for using drones "to provide valuable information about the hydraulic conditions present during dynamic, high-energy flash floods has until now not been explored."

Perks et al (2016) *Hydrol. Earth Syst. Sci.*, 20, p4005–4015

MODELLING CONVECTION

To reduce the risks of damage and loss of life caused by surface water and flash floods we need to know where to expect rainfall in advance. This is challenging as the location, timing and severity of intense rainfall events are hard to predict.

Ensembles have increasingly been used to improve our ability to forecast intense rainfall accurately. In a rainfall ensemble forecast the forecast model is run multiple times to produce a range of equally likely scenarios which help inform decision making. By increasing our understanding of how convective events form, the FFIR programme has developed efficient techniques to make better use of rainfall ensembles.

Key achievements

- We have learnt more about how uncertainties develop in weather forecasting models for different types of weather conditions
- We have added value to forecasts for intense rainfall by being able to identify the type of conditions where we expect the ensemble forecast to perform well and where we expect there will be more uncertainty around the location, timing or intensity of the event
- Running multiple forecasts to produce larger ensembles takes more time and uses more computational resource. We have contributed to ongoing work to investigate how existing ensemble data can be used to improve decision making without having to run additional forecasts

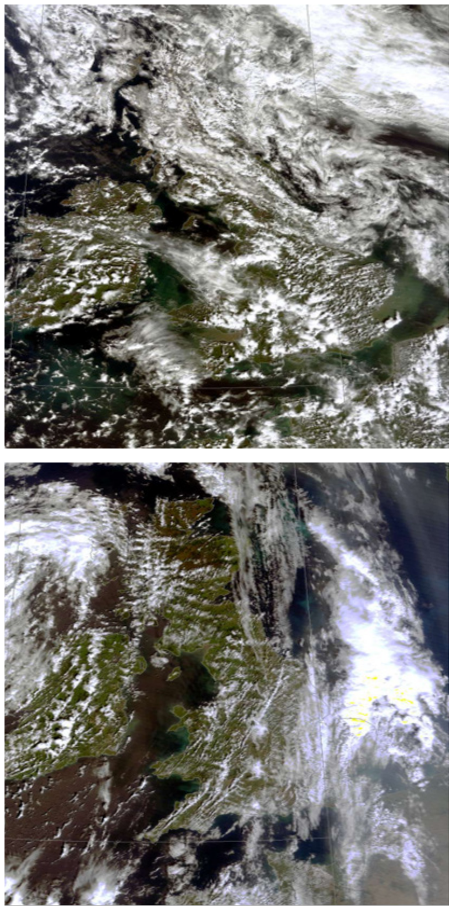
What impact will this work have?

- Knowing more about how convective events form, and the challenges of modelling them, will help us to understand how uncertainty in rainfall forecasts affects flood models and decision making
- The FFIR work on designing ensemble forecasting for intense rainfall events has been well received by the international group of scientists working on improving the Met Office forecast ensembles

Future challenges

As ensemble rainfall forecasting improves, questions remain around how to best use the data to improve flood modelling and decision making. Addressing this challenge would be easier if data was more easily accessible for case study events.

Ensemble forecasts can be hard to understand. There is an ongoing need for improved communication and education to support meteorologists, hydrologists and decision makers to make effective use of ensemble forecasts.



Satellite imagery showing two different types of convective event

"Our ability to forecast convective events is case dependent and linked to the larger scale weather situation."

David Flack, University of Reading

MODELLING FLOODS

By improving computer models of intense rainfall we have increased our ability to forecast these events. The next step is to predict where the water will go once it hits the ground.

Traditionally flood models were designed for long duration rainfall events across large areas. By looking in detail at how rainfall and runoff is represented we have shown how existing models could be modified to better represent FFIR. As it is difficult to forecast heavy rainfall events more than a few hours ahead, we have developed efficient flood models for urban areas which give quick and accurate predictions of where will be flooded based on forecast rainfall.

Key achievements

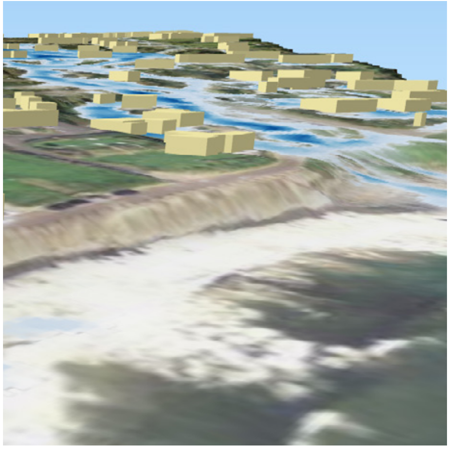
- We have shown that the way existing land surface models are set up poorly represents the hydrology of intense rainfall events and recommended improvements
- The forecasting of river flows has been improved using soil moisture measured by high resolution satellites
- We have explored the importance of incorporating erosion and deposition processes from flash flood events in hydrological models. We have shown that this is important for both long and short term risk assessments
- We have developed new approaches to represent sewers and shallow flood water in urban areas. This has helped us build faster, more efficient flood models
- By running our flood models on GPUs (Graphical Processing Units similar to those used for computer games) we have demonstrated the use of physically based catchment and city scale inundation modelling in real time

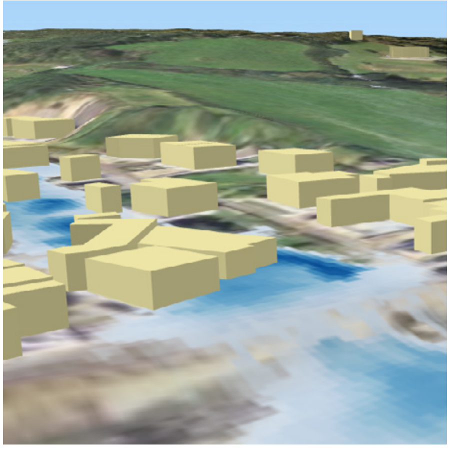
What impact will this work have?

- Being able to predict the inundation area for a forecast flood event in real time will enable better decision making and communication
- By integrating inundation modelling within the end-to-end forecasting chain we have shown the importance of understanding how uncertainties from rainfall observations, forecasts and hydrological models affect flood models

Future challenges

The inclusion of real time inundation modelling in the FFIR programme has been possible by using new computational technology. We must continue to make the best use of new technology to help us meet the challenge of modelling flash flood events. Flood modellers need to work closely with decision makers to improve the operational use of inundation models. We need to work together to answer fundamental questions such as 'how much information is needed to make an effective decision about flood risk?'





3D visualisation of modelled flash flooding in Coverack for the event in July 2017

Our new flood models are "able to support high-resolution simulations at a large scale and hence provide a new-generation of modelling tools for understanding the highly transient hydrological processes induced by intense rainfall."

Liang et al (2016) *Procedia Engineering*, 154, p975-981

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IMPROVING END-TO-END FORECASTING FOR FFIR

End-to-end flood forecasting is an integrated chain incorporating data collection, weather forecasting, hydrological modelling, flood modelling, decision making and communication of flood warnings.

The UK currently has an end-to-end flood forecasting system operated through the Flood Forecasting Centre and the Scottish Flood Forecasting Service. This system was designed around flooding from rivers and the sea. FFIR events are not well represented in the existing system.

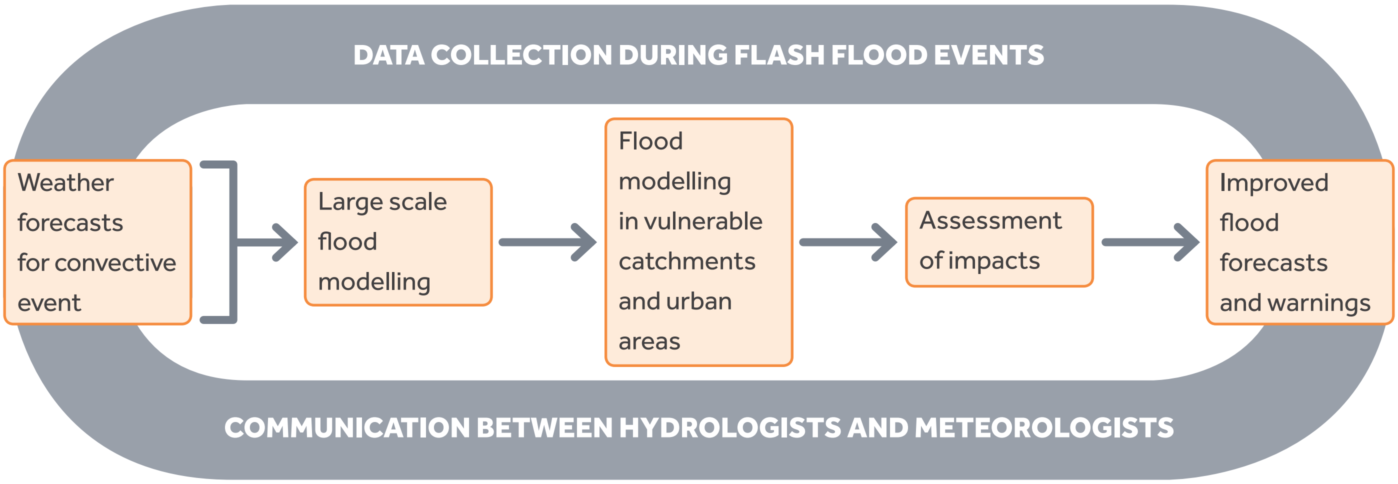
Recent flash flood events, and projected increases in intense summer rainfall in the UK from climate change, highlight the need for a fully integrated end-to-end system. Our new methodologies, and integrated ways of working, demonstrate a framework which will be integral to reducing the risk of damage and loss of life caused by surface water and flash floods.

Integrated end to end forecasting has a number of benefits. It helps:

"Put weather forecasts in the context of decision makers"
Ken Mylne Met Office

"Promote better understating and accessibility by exploring explicit links between parts of the chain "
Rob Lamb JBA Consulting

"Reduce wasted research effort as you only make improvements to things that are beneficial to those further down the chain"
Nigel Roberts Met Office



The end to end forecasting framework used in the FFIR programme

Key achievements

- We have supported improvements in end-to-end forecasting by working on each of the elements of chain and the links between them
- We have demonstrated the value of integrating hydrologists, meteorologists, researchers and practitioners in a joint programme and built strong foundations for future work

"Where meteorologists and hydrologists have worked together on the FFIR programme they have started to close the gaps in understanding between disciplines"
Rob Thompson, University of Reading

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Professor Hannah Cloke or Professor Sarah Dance: **ffir@reading.ac.uk**

KNOWLEDGE SHARING

Good communication between meteorologists and hydrologists is essential to help everyone understand the forecast, to develop useful tools and to deliver a consistent message to decision makers.

The FFIR programme has helped foster relationships and develop resources that can be used to share knowledge about flooding from intense rainfall with the public and professional partners.

Engaging with the public

- We developed the Flash Flood! simulation which uses virtual reality to place the user inside a river as it floods. Built using data from a real river and flood event, it shows the destructive geomorphic impact of flash flooding first-hand. The simulation is in its second iteration and has been demonstrated to thousands of people across the country at events, science festivals, museums, and in schools
- Our scientists have been on local and national TV explaining extreme weather events

Informing other projects

The opportunities for collaboration within FFIR between meteorologists, hydrologists, researchers, consultancies and decision makers were highly valued and will pave the way for future improvements in flood forecasting

Available resources

The data sets and methodologies developed in the FFIR programme are available for use by professional partners and in future projects:

FlashFlood! Simulator	Experience a flood event from the storm building to a flood rushing down the river valley. **https://seriousgeo.games/games**
Flood chronologies	Chronologies of historical flood events from newspaper archives and other sources for nine regions in England dating back to the 1800s. **http://ceg-fepsys.ncl.ac.uk/fc**
Rain gauge and river flow data	Products derived from the quality controlled hourly rainfall data.Rates of rise for rivers in south west England and linked rainfall and river flow data for 550 UK gauging stations. **http://ceg-fepsys.ncl.ac.uk/outputs**
Newcastle Flood Observatory	Description of new methods and data from non-contact flood monitoring sites. **https://flood-obs.com**

Top: Experiencing FlashFlood! at the NERC Into The Blue event (Image source: NERC Science)

Bottom: Attendees at the FFIR annual science meeting in 2017

"We valued the opportunity through the FFIR programme to test ideas with different people and organisations, with whom we might not otherwise have had so much contact"

Rob Lamb JBA Consulting

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Collecting data during flash flood events

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FLOODING FROM INTENSE RAINFALL (FFIR)

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