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| **Institution:** University of Reading | | |
| **Unit of Assessment:** 7 - Earth and Environmental Sciences | | |
| **Title of case study:** Strengthening the quality and use of flood forecasts to maximise effectiveness of humanitarian aid | | |
| **Period when the underpinning research was undertaken:** Between 2014 and 2020 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** | **Role(s) (e.g. job title):** | **Period(s) employed by submitting HEI:** |
| Liz Stephens | Associate Professor | 2013 to Present |
| Hannah Cloke | Professor | 2012 to Present |
| **Period when the claimed impact occurred:** Between 2014 and 31 December 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** No | | |

## 1. Summary of the impact

Humanitarian agencies, including the Red Cross Red Crescent movement (RCRC), recognise that flood and drought forecasts can revolutionise support of people affected by disasters. Forecast-based Action (FbA) before disasters strike can maximise the effective distribution of aid and ultimately reduce suffering. Previously, RCRC used seasonal rainfall forecasts for flood preparedness. Evidence from Reading research proved that seasonal forecasts do not have the skill to inform flood preparedness decisions and demonstrated how extended-range forecasts (out to 14 days) are more appropriate. Furthermore, Reading research made a significant contribution to the development of a new and improved tool for forecasting floods globally, the Global Flood Awareness System (GloFAS). Reading research supported the implementation of these forecasts within decision-making frameworks of RCRC and UN Agencies and others, across 60 countries. Its success led to a dedicated funding mechanism within the RCRC for FbA and inspired USD145M of dedicated funds from other international organisations. In 2020 alone, over GBP5M was released based on a trigger from GloFAS to protect hundreds of thousands of people in Bangladesh. Local ownership was ensured by working closely with local stakeholders; for example, GloFAS is now used by national agencies in Bangladesh, Uganda, Kenya, Nepal and Peru.

## 2. Underpinning research

Humanitarian agencies recognise that flood forecasts can be used to trigger the release of aid to vulnerable communities before a disaster strikes. In flood-forecasting systems, rainfall observations or meteorological forecasts are used as input to statistical or physics-based models, along with upstream flow observations, to predict when a river will flood. Prior to this research, humanitarian agencies did not have the confidence to trigger monetary disbursements based on these complex systems which use an ensemble approach to estimate the probability of flooding.

Since 2014, Stephens has worked in collaboration with the Red Cross Red Crescent Climate Centre (RCCC) to support the use of flood forecasts within the Red Cross Red Crescent movement (RCRC) - which includes 192 national societies, the International Federation of Red Cross/Red Crescent Societies, and the International Committee of the Red Cross. Stephens worked to understand the decisions that would be made as part of the initial stages of development of Forecast-based Action (FbA), a humanitarian system which releases funding for early action before a disaster and is based on a forecast trigger and a pre-agreed plan of action. Through this early work, Stephens expressed concern that seasonal rainfall forecasts had previously been used incorrectly to inform flood preparedness activities, because non-linearity between rainfall totals and river flow meant that a signal of 'above normal' rainfall is not likely to be strongly correlated with flood events. Humanitarian preparedness decisions were being made across regions rather than river catchments, but there was no metric to capture when flood incidence in those regions was unusual.

To tackle this challenge, Stephens et al. [R1] developed a metric called 'floodiness' - a measure of the incidence of flooding across a whole region based on the percentage of the river network exceeding a specified flood threshold. Using bias-corrected reanalysis datasets of precipitation, driven through the Global Flood Awareness System (GloFAS – which Reading

co-developed, and detailed below) to generate river flow, this work compared regional precipitation totals with floodiness to provide the evidence that the two were not well correlated. Taking this work further, Coughlan de Perez et al. [R2] applied the floodiness metric at seasonal timescales in decision-relevant regions within sub-Saharan Africa. This work showed that even if a forecast could skilfully predict that seasonal rainfall totals would definitely fall within the 'above normal' tercile of the climatology, it should not be used for flood preparedness, because of the poor correlation with floodiness.

These research conclusions motivated the shift away from a focus on the use of seasonal forecasts for FbA. To support this shift, research was conducted in collaboration with RCCC to demonstrate how short-to-medium-range (up to 40 days) flood forecasts could be applied for decision-making. This work applied freely available forecasts produced by GloFAS to a Ugandan case study, demonstrating how forecast verification could take into account the parameters of each action (such as the action lifetime; for example, the shelf life of water purification tablets) to determine appropriate forecast triggers for use by the Uganda Red Cross Society [R3]. This approach has inspired applications of GloFAS around the world as the FbA initiative has been scaled up (see Section 4).

Reading has a role as the only University partner in the development of GloFAS, alongside the Joint Research Centre (JRC) of the European Commission and the European Centre for Medium-Range Weather Forecasts (ECMWF). Stephens has been the bridge between the humanitarian agencies and GloFAS developers, not only supporting their use of the forecasts, but also feeding humanitarian priorities and needs back into the forecast development. The use of global-scale models, such as GloFAS for local decision-making requires an approach that assumes that forecasts of, for example, a 20-year return period flow within the 'model world' can be linked to 20-year return period flows and water levels in the real world, rather than being able to forecast precise water levels directly. As such, it is extremely important that the techniques for representing and identifying those extreme events are well developed. The existing method for flood threshold definition used reanalysis datasets (reconstructions of past conditions) using a single threshold across all forecast lead times. As part of a joint Reading/ECMWF PhD studentship, Ervin Zsoter's research [R4] demonstrated benefit in using reforecasts (the current forecast model re-run for the past) rather than the reanalysis to generate the return period thresholds. By using reforecast-based thresholds that vary with forecast lead time, there is a more robust identification of floods within the forecast model, which can reduce the incidence of false alarms.

In addition, Reading researchers, led by PhD student Rebecca Emerton [R5], also worked closely with ECMWF to lead the development of the first ever global seasonal hydrometeorological forecasting system, as an addition to the GloFAS model. This approach of coupling meteorological and hydrological models is a significant improvement over simply using seasonal rainfall forecasts as a proxy for flooding. It has been shown in many parts of the world to provide more skilful forecasts than the use of El Nino/La Nina events as predictors [R6].

## 3. References to the research

Research Quality Statement: All references were published in the peer-reviewed literature and meet or exceed the two-star quality criteria ("provides useful knowledge and influences the field"; "involves incremental advances"). Evidence of influence is indicated by Web of Science Citations in square brackets, as at December 2020.

**[R1]** **Stephens, E.**, Day, J. J., Pappenberger, F., & Cloke, H. (2015). 'Precipitation and floodiness'. *Geophysical Research Letters*, **42**(23), 10-316. DOI: 10.1002/2015GL066779 [27]

**[R2]** Coughlan de Perez, E., **Stephens, E**., Bischiniotis, K., Van Aalst, M., Van Den Hurk, B., Mason, S., & Pappenberger, F. (2017). 'Should seasonal rainfall forecasts be used for flood preparedness?'. *Hydrology and Earth System Sciences*. **21**(9), 4517-4524. DOI: 10.5194/hess-21-4517-2017 [16]

**[R3]** Coughlan de Perez, E. C., van den Hurk, B., van Aalst, M. K., Amuron, I., Bamanya, D., Hauser, T., Jongman, B., Lopez, A., Mason, S., Mendler de Suarez, J., Pappenberger, F., Rueth, A., **Stephens, E**; Suarez, P., Wagemaker, J., & Zsoter, E. (2016). 'Action-based flood forecasting for triggering humanitarian action'. *Hydrol. Earth Syst. Sci*. **20**, 3549-3560. DOI: 10.5194/hess-20-3549-2016 [21]

**[R4]** Zsoter, E., Prudhomme, C., **Stephens, E.,** Pappenberger, F., & Cloke, H. (2020). 'Using ensemble reforecasts to generate flood thresholds for improved global flood forecasting'. *Journal of Flood Risk Management*. **13** (4), e12658. DOI: 10.1111/jfr3.12658 [0]

**[R5]** Emerton, R., Zsoter, E., Arnal, L., Cloke, H. L., Muraro, D., Prudhomme, C., **Stephens, E. M.,** Salamon, P & Pappenberger, F. (2018). 'Developing a global operational seasonal hydro-meteorological forecasting system: GloFAS-Seasonal v1.0'. *Geoscientific Model Development*, **11**, 3327-3346. DOI: 10.5194/gmd-11-3327-2018 [25]

**[R6]** Emerton, R. E., **Stephens, E. M.**, & Cloke, H. L. (2019). 'What is the most useful approach for forecasting hydrological extremes during El Niño?'. *Environmental Research Communications*, **1**(3), 031002. DOI: 10.1088/2515-7620/ab114e [5]

## 4. Details of the impact

Reading's research provided support for forecast-verification and estimating uncertainty, and in doing so, provided evidence to support humanitarian agencies in moving away from using seasonal forecasts for their flood preparedness activities. Furthermore, the research has led to expert advice to country-based RCRC teams on how to interpret forecasts and triage between different sources of information to define appropriate forecast thresholds for triggering humanitarian action. Together with RCCC, Reading led a report on the research priorities for FbA, which informed the research direction in this area. Using this experience, Reading fed the needs and priorities of humanitarians back to forecast developers at ECMWF and collaborated with humanitarian agencies on research that focused on aspects of the forecast most related to their decision-making; for example, how extreme events were defined. Reading has also co-developed GloFAS, a global flood awareness system which has benefited the lives and livelihoods of hundreds of thousands of people across the globe.

**Evidence to support humanitarian use of forecasts for early action:** Without the evidence provided by Reading's research, seasonal rainfall forecasts, which do not provide enough lead time or location-specific information to prepare an adequate humanitarian response, would likely have continued to be used to anticipate floods. Research by Stephens et al has provided evidence against their use and instead has supported the use of short to medium-range forecasts for preparing for floods, enabling allocation of humanitarian resources to the worst hit areas and helping those people most in need. Through their 2015 development of the 'floodiness' measure of the incidence of flooding across a whole region [R1], the Reading researchers have steered the RCRC Movement towards areas where forecasts have skill. For example, they have moved away from repeating the use of seasonal rainfall forecasts for flood preparedness (something that RCRC had previously used to invest almost CHF300,000 in West Africa in 2008) on more occasions and across more locations. Working in collaboration with RCCC, Stephens advised on how the operational flood forecasts from GloFAS could be applied and evaluated in Uganda [R3]. Even during a pilot phase in 2015, 370 households were given support before floods occurred [S1]. Before the 2015/16 El Nino event impacted Peru, Stephens provided expert advice for RCCC to support the development of FbA protocols for pilot projects in the northern regions of Piura and Lambayeque. This helped to significantly reduce the expected damage to housing for 2,000 families that were supported by the pilot [S2]. RCCC has stated that "*because these first Red Cross pilots were the first to test this FbF approach worldwide, the learning from these pilots and the University of Reading collaboration has been immensely instrumental in shaping how FbF has evolved in all of these 60 countries*" [S3]. (Here, FbF or Forecast-based Financing is used synonymously for FbA.)

This initial work [R3] inspired the use of GloFAS as part of humanitarian Early Warning Protocols in countries including Bangladesh, Uganda and Zambia during the REF2021 impact

period [S3]. Reading researchers joined the fortnightly Technical Advisory group for developing Early Action Protocols for flood in Uganda, which specify who should receive aid and which action should be taken, releasing funds when a specific forecast trigger is met. The GloFAS was also incorporated into Early Action Protocols for flooding in Bangladesh, thanks to the Reading team's collaboration with RCCC and the Bangladesh Flood Forecasting and Warning Centre (FFWC). This work *"has played a central role in an enormous multi-agency intervention before flood events in Bangladesh in 2020, reaching a very vulnerable population during the COVID-19 pandemic"* [S3]. On 4 July 2020, on the basis of the GloFAS forecast, over USD5.2m [S4] was released from the UN's Central Emergency Response Fund and CHF230,000 [S5] from the Red Cross's FbA by the Disaster Relief Emergency Fund. Once the FFWC short-range forecast confirmed the imminent flooding, the agencies executed pre-agreed actions. This early action before the flooding struck protected 16,500 people (Red Cross, [S5]), 100,000 people (World Food Programme, [S4]), 15,000 people (UNFPA, [S4]) and 15,000 families (Food and Agricultural Organization, [S4]). The success of these partnerships has led to the Foreign, Commonwealth and Development Office to commission Reading and other partners to produce flood forecast bulletins when high-impact events are forecasted. These have been used in Central America to support the humanitarian effort [S6].

**Inspiring USD145M dedicated funding per year for forecast-based action:** The successful implementation of the early pilot projects, through the expert advice from Reading, led to the development of systematic funds for financing forecast-based action. Stephens leads the Natural Environment Research Council (NERC) / Department for International Development-funded Forecasts for Anticipatory Humanitarian Action (FATHUM) project (2016-2021). This "*has enabled FbF* (FbA) *to take off and grow rapidly,*" [S3] inspiring the design and development of the International Federation of Red Cross Red Crescent Societies (IFRC). Forecast-based Action by the Disaster Relief Emergency Fund *"is capitalized at more than CHF5m* (million)" [S3]. This Red Cross initiative itself has motivated *"the equivalent fund for UN agencies"* which *"has made up to $140 million* (USD) *available for piloting this anticipatory approach"* [S3]. These UN agencies collaborated with the Red Cross team to jointly use the GloFAS triggers in Bangladesh. Reading researchers have also informed the choice of appropriate forecasting systems within the 'FbF Manual' guidance given for developing Early Action Protocols [S3]. Through a secondment to the RCCC starting in November 2020, Stephens evaluated "*Early Action Proposals that have been submitted to the fund"* and led *"Technical Reviews following extreme events such as Super Typhoon Goni (November 2020) in the Philippines, as well as provided advice on how to estimate how frequently the release of funds will be triggered to support the financial management of the fund*" [S3].

**GloFAS – Better, earlier flood warning for national forecasting agencies to save more lives:** To strengthen the quality of flood forecasting systems, Reading is one of five partners in the development of the GloFAS system together with the JRC, ECMWF, RCCC and RIMES (the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia) [S7]. These forecasts are part of the European Commission's Copernicus Emergency Management Service. This partnership improved the short to medium range component of GloFAS and developed a new seasonal hydrometeorological forecasting component to these freely-available forecasts. Reading research fed the priorities and needs of the humanitarian community and their in-country partners back to forecast developers, which has led to the calibration of GloFAS forecasts in priority countries [S3] and an improved definition of return period thresholds [R4] enabling their use at longer lead times. Working together with RCCC, Stephens et al. worked closely with local stakeholders to collaborate on science and ensure local ownership of the process and results.

To support the implementation of the Sendai Framework for Disaster Risk Reduction, the Reading researchers have taken the philosophy that national hydrological and meteorological forecasting services should be used where available, and through working together with RCCC they have strengthened national capacity for forecasting and providing early warnings of floods in five countries. In Mali, Peru, Uganda and Zambia this has meant providing support

to use GloFAS where it is the only system available for the river systems of interest; and in Bangladesh, this means supplementing the existing forecasting system with the extended lead time and ensemble techniques that GloFAS offers. The Reading team has worked to engage with all of these national forecasting agencies, bringing them into the 'GloFAS Community' through trainings, placements, and supervising higher education of forecasting staff members which has supported them to evaluate forecasts and provide valuable feedback [S8] for the development of the operational GloFAS system. For example, in Uganda, the Ministry for Water and Environment "*had no established source of flood forecasting information*," but as a result of the collaboration, GloFAS has been used informally during the 2020 floods of Lake Victoria and the River Nile. The Principal Hydrologist has regularly referred to GloFAS and thought it to be "*very useful*" [S8]. GloFAS has now been adopted within Early Action Protocols produced by the Uganda Red Cross Society, and ongoing research is determining whether to formally list GloFAS forecasts within the Ministry's operational procedures [S8]. In Bangladesh, the collaborative research between Reading and FFWC led to FFWC using GloFAS alongside their own forecasts to *"successfully predict severe flood timing and duration during the 2019 and 2020 monsoon seasons*" [S9]. These flood characteristics drive the impact of floods on livelihoods in Bangladesh. In July 2020, GloFAS forecasts provided an early indication of the floods, enabling local administrations to prepare the communities and then immediately evacuate those 23,595 people once the later FFWC forecast confirmed the imminent flooding [S9].

**Summary:** Prior to this research, humanitarian agencies did not have the confidence to trigger monetary disbursements based on complex probabilistic forecasting systems but could see the potential that forecast-based humanitarian action had to revolutionise the way that the humanitarian system works, and therefore reduce suffering and improve cost-effectiveness. Reading's research contributed significantly to the development of both new and improved tools for forecasting floods globally. What is more, it has provided evidence on how these tools can be applied to support the implementation of forecasts within decision-making frameworks within the Red Cross Red Crescent movement, UN Agencies, and others like the Start Network of Non-Governmental Organisations. This has led to multi-million-pound investments that have already had a significant benefit on the lives and livelihoods of hundreds of thousands of people, as well as supporting national forecasting capacity to develop the effectiveness of government early warning systems.

**5. Sources to corroborate the impact**

**[S1]** RCCC website news story, 15 November 2015: https://www.climatecentre.org/news/657/a-humanitarian-historya-made-as-uganda-red-cross-launches-forecast-based-financing-for-real

**[S2]** Aguirre, J., Ugarte, D. D. L. T., Bazo, J., Quequezana, P., & Collado, M. (2019). 'Evaluation of Early Action Mechanisms in Peru Regarding Preparedness for El Nino'. *International Journal of Disaster Risk Science*, **10**(4), 493-510. DOI: https://doi.org/10.1007/s13753-019-00245-x

**[S3]** Letter from Erin Coughlan de Perez, Manager of Climate Science Team, Red Cross Red Crescent Climate Centre, 25 January 2021

**[S4]** Reliefweb press release, 15 July 2020 'UN helps monsoon-affected river communities in Bangladesh before peak flooding,' recent release of USD5.2m million

**[S5]** IFRC press release, 30 June 2020, stating that CHF230,000 released and 16,500 people protected in Bangladesh in advance of severe flooding

**[S6]** Tweet by Wendy Morton MP, referring to University of Reading press release, both from 25 November 2020: World-leading science is taking the UK's response to disasters to the next level. Here's how@UniOfReading & others are using advance weather forecasting in the wake of Hurricanes #Eta & #Iota to help us pinpoint those most in need of aid.

**[S7]** Letter from ECMWF Director of Forecasts, 21 January 2021

**[S8]** Letter from Uganda Ministry for Water and Environment, 17 November 2020

**[S9]** Letter from Bangladesh Flood Forecasting and Warning Centre, 15 November 2020