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International Federation of Red Cross and Red Crescent Societies

The Netherlands Red Cross

FORECAST-BASED ACTION

In late April 2015, the Uganda Red Cross Society conducted a drill rehearsing the distribution of water purification tablets according to standard operating procedures for a forecast-based financing project. Pictured is Deborah Amujal, URCS focal person for the climate change adaptation project, explaining the session to residents. (Photo: Eddie Jjemba / Climate Centre)

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EXECUTIVE SUMMARY

Skilful forecasts of an imminent disaster can allow the prevention of disaster effects and preparation for the impacts of disaster for many of the world's most vulnerable groups and individuals. However, while forecasts are becoming increasingly available, humanitarians regularly fail to implement such Forecast-based Action. This report demonstrates the interdisciplinary challenges in moving towards robust frameworks for Forecast-based Action (FbA) for different humanitarian actors. This is a particularly critical strategy in light of changing risks worldwide, and research investments are needed to provide information, methods, and guidance for the successful establishment of such systems.

The Red Cross Red Crescent Climate Centre (RCCC) is developing a novel framework for Forecast-based Action, called Forecast-based Financing (FbF). This framework is addressing the interdisciplinary challenges by developing Standard Operating Procedures (SOPs) to be defined in advance of a forecast, and activated when a forecast exceeding a pre-specified risk level is issued. This FbF system has been initiated in Pilot Studies for flood risk in Uganda and Togo, and their initial success has led to the development of further Pilot Studies in Mozambique, Peru, Ethiopia and Bangladesh.

The aim of this report was to establish research priorities for informing the development of frameworks for Forecast-based Action, basing these on the considerations, successes, and challenges faced in the FbF pilot studies. While the FbF concept is applicable to any predictable hazards where loss-avoiding action is possible, this report focusses primarily on floods, mirroring the focus of the FbF pilot studies and acknowledging that floods are the most common natural disaster, accounting for 43% of all recorded events and affecting nearly 2.5 billion people between 1994 and 2013 (CRED, 2015). Given the disproportionate impact of natural hazards in lower-income countries (CRED, 2015), and the reported success of flood early warning systems elsewhere (Stephens and Cloke, 2014), improving the capacity of communities, nations and humanitarian organisations to utilise skilful flood early warnings systems can have considerable impact.

The FbF pilot studies were examined based on seven components that need to be considered when defining standard operating procedures: probability, magnitude, hazard, action, cost, effect and organisation. These components would need to be addressed when implementing FbA for any natural hazard; therefore they could be used as guidelines for setting up FbF or FbA for different hazards. The research priorities for FbF are detailed within the report, and are categorised under the following headings:

The wider context: Where does forecast-based financing sit within forecast-based action frameworks and within the wider remit of disaster risk reduction and humanitarian response?

- Disaster information: What disaster data are necessary to develop an FbF system?
- Forecasting Science: What developments are needed in forecasting science to support FbF?
- Evaluation: How can we gauge the success of a framework for forecast-based action?
- Scaling up: What are critical methodologies and opportunities to bring FbF to scale?

The research roadmap reflects the interdisciplinary research priorities and acknowledges the many different actors with an extremely broad variety of expertise that need to be brought together and managed in a coherent way. It can serve as a guide to the opportunities, gaps, and future priorities for the development of new research and programmatic agendas that support DFID's resilience framework and the Sendai Framework on Disaster Risk Reduction.

CONTENTS

1. INTRODUCTION

Operational forecasting systems provide information on when there is a heightened chance of a natural hazard occurring in the coming days or weeks, as opposed to risk assessment or mapping, which provides an indication of the long-term chance of that hazard occurring (e.g. on average once in every 20 years). Skilful forecasts of an imminent extreme event can allow people to prevent or reduce negative consequences, prepare for the impacts of unavoidable disasters, and sometimes even take advantage of the information to leverage opportunities presented by climate variability. However, even though forecasts are becoming increasingly available, humanitarians regularly fail to implement such Forecast-based Action (FbA) so there is a clear need to create a framework to enable actions from uncertain forecasts.

There are a number of barriers to effective use of forecasts. Firstly, forecasts of hydrometeorological variables, such as river flow or level, need to be translated into a probability of impact, which is the information that is necessary for deciding what action to take (e.g. Pagano et al. 2002). Secondly, there are also institutional and political barriers to using uncertain forecast information (e.g. Rayner et al. 2005, Demeritt et al. 2010, Demeritt et al. 2013), particularly given the perceived high consequences of 'acting in vain' (Coughlan de Perez, 2015b). In addition, humanitarian organisations and at-risk stakeholders do not have a clear mandate for action based on probabilistic signals of likely losses, and when a forecast is made that indicates a heightened probability of a disaster, are not confident in determining what action is "worth" taking (e.g. Hillbruner & Moloney 2012). Lastly, funding sources for forecast-based early action are few; the bulk of funding is available only post-disaster, or through long-term project agreements (See: Kellett & Caravani 2013, Jahre & Heigh 2008).

These obstacles are interlinked, for example, an action that needs to be taken two days in advance of a flood would be worth taking if there is confidence in the forecast system out to two days. Therefore determining what actions are worth taking will be in some part related to how far in advance of a disaster the forecast has skill. As a consequence, there are interdisciplinary challenges to moving towards robust frameworks for Forecast-based Action (FbA) for different humanitarian actors.

Frameworks for Forecast-based Action (FbA) can be considered within the social-science theory of *anticipation*. Anticipation is increasingly central to urgent contemporary debates, from climate change to the global economic crisis, with anticipatory practices coming to the forefront of political, organisational, and citizens' society. For example, DFID's 2011 policy: *Saving lives, preventing suffering and building resilience: The UK Government's Humanitarian Policy,* lists as its first policy goal to "Strengthen anticipation and early action".

Research into anticipation is deeply fragmented yet anticipatory practices to address individual, social, and global challenges are relevant to building resilience (Boyd et al., 2015a). The development of skilful weather and hydrological forecasting systems can be thought of as an emerging technology, particularly within the humanitarian sector. In contrast to existing narrowly framed problem-focused assessment for emerging technologies, anticipatory governance adopts a broader and interventionist approach that recognises the social construction of technology design and innovation. Anticipatory governance can be defined as "a new approach to manage the uncertainties embedded on an innovation trajectory with participatory foresight" (Ozdemir et al., 2011).

The Red Cross Red Crescent Climate Centre (RCCC) is developing a framework for FbA, called Forecast-based Financing (FbF). This framework is addressing the interdisciplinary challenges by developing Standard Operating Procedures (SOPs) to be defined in advance of a forecast, and carried out when a forecast exceeding pre-specified risk level is issued. The SOPs specify what action should be taken at what probability/magnitude of forecast, and by whom; for example, "when a 60% chance of a river flow of 400m^3/s over the next 48 hours ..." The goal of FbF is to reduce losses and suffering by accelerating delivery of disaster response services and, whenever possible, prevent the losses and suffering from happening in the first place or even take advantage of opportunities offered by unusual conditions.

These SOPs are accompanied by funding mechanisms that predictably disburse the required amount of funding when a forecast is issued. Such a structure is similar to that adopted for the specification of operational rules for water resources management (e.g. Gong et al., 2010; Schwanenberg et al. 2015), though is novel when applied to the emergency response or humanitarian context.

The structure of such a forecast-based financing system has evolved through the development of the pilot studies and can be distilled from Coughlan de Perez et al. (2015b) as follows:

> "When forecast states that an agreed-upon *probability* threshold is exceeded for a *hazard* of a designated *magnitude*, then an *action* with an associated *cost* must be taken that has a desired *effect* and is carried out by a designated *organisation*."

Though the creation of SOPs may be specific to the FbF framework, the components underlined in the previous sentence represent challenges generic to any such FbA framework. This report will address each of the underlined components individually, to distil structure from a complex concept.

This report builds on the foundations laid out by the United Nations Sendai Framework on Risk Reduction (2015-2030), that reiterates the commitment of States to disaster risk reduction and resilience to disasters. In particular, Priority 4 of the framework calls for "enhancing disaster preparedness for effective response" as well as stating that it is important to "invest in, develop, maintain and strengthen people-centred multi-hazard, multisectoral forecasting and early warning systems" (33b). This report more broadly addresses the challenge (stated in Paragraph 14) of "strengthening disaster risk governance and coordination of relevant institutions and sectors" by considering the expertise and actors involved in taking Forecast-based Action. The focus of the FbF pilots is on flood disasters, as is reflected within this report, therefore also aligns with Paragraph 34(e) that specifically mentions the implementation of global mechanisms on hydrometeorological issues.

Lastly, disaster risks are constantly evolving, and future risks will be substantially different from the present due to processes such as urbanisation, environmental degradation, and climate change. Forecasts offer an opportunity to anticipate these risks as they are changing, and an FbF system therefore affords stakeholders a method to adapt to changing risks as they happen by integrating forecasts for increasingly predictable hazards with advances in knowledge on dynamic patterns of differential vulnerability.

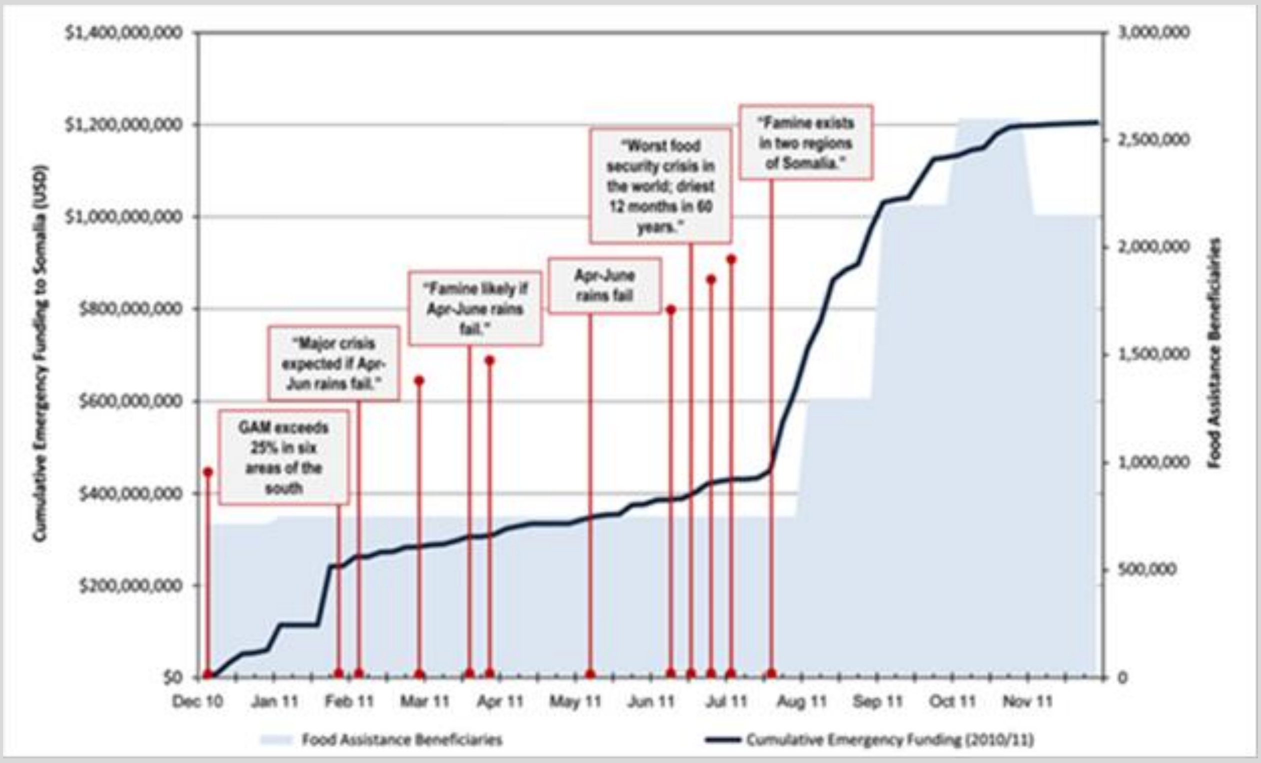
Spotlight on Somalia: Can we learn from failure?

In Somalia in 2011, a famine was declared that, along with the complexity of the conflict situation, was responsible for thousands of deaths. At its peak, almost 4 in every 10 children in Southern Somalia were acutely malnourished, and 4 million people were estimated to be without basic food.

The horror of this tragedy has since haunted the international community, who received 11 months of early warnings before a famine was declared. Beginning with La Nina forecasts almost one year in advance, FEWS-NET and others provided briefing notes and warning information to humanitarian actors in the region. Several months later, these alerts explained that rainy seasons had already failed, and that major impacts were extremely likely (Hillbruner and Moloney 2012).

There has been a great deal of analysis of this event, in which several conclusions have come to light. One is that funding needs to be more readily available based on forecasted information (Lautze et al. 2012). The below graph (Hillbruner and Moloney 2012) demonstrates how large-scale funding was mobilized in the aftermath of the famine declaration, and was ultimately available after the most vulnerable had died.

Secondly, the humanitarian community needs to clearly take responsibility for acting in advance of a disaster, even in complex cases like the Somali context. At the moment, such organizations are not held accountable for failure to act on early warning, as disaster response is considered business-as-usual. Shouldering the responsibility to act in this critical moment between a warning and a disaster could avoid such impacts in the future (Lautze et al. 2012).



1.1. Aim and Objectives

The aim of this report is to establish research priorities for informing the development of a disaster risk reduction framework which uses forecasts to take pre-emptive action.

> Objective 1: to use the achievements and challenges of the FbF pilot studies for flood disasters to identify interdisciplinary future research needs.
>
> Objective 2: to elucidate research priorities for supporting and scaling-up such pilot studies, highlighting both the programme of research needed, and also the expertise required to successfully undertake it.
>
> Objective 3: to briefly discuss how research priorities differ between hazards.

This report focusses primarily on floods, mirroring the focus of the FbF pilot studies and acknowledging that floods are the most common natural disaster, accounting for 43% of all recorded events and affecting nearly 2.5 billion people between 1994 and 2013 (CRED, 2015). While there is uncertainty over the impact of climate change on flood hazard (IPCC, 2012), flood risk will increase due to population growth and land use change. Given the disproportionate impact of natural hazards in lower-income countries (CRED, 2015), and the reported success of flood early warning systems elsewhere (Stephens and Cloke, 2014), improving the capacity of communities, nations and humanitarian organisations to utilise skilful flood early warnings systems can have considerable impact.

2. THE FORECAST-BASED FINANCING PILOTS

In 2013, the German Federal Ministry for Economic Cooperation and Development (BMZ) funded two Integrated Climate Change Adaptation Programmes, implemented by the Uganda Red Cross Society and the Togolese Red Cross and supported by the German Red Cross and the Red Cross Red Crescent Climate Centre. These 6-year pilot projects included an innovative new element termed "Forecast-based Financing", and project objectives included the development of Standard Operating Procedures to specify when a forecast is "worth" acting on, and what action should be taken when such a forecast is issued.

The German Red Cross provided funding in a special Preparedness Fund for each country that would be available to finance the actions designated in the SOP when a triggering forecast was issued. In both countries, the Red Cross identified floods as a major hazard in the project areas, which are also hazards that can be forecasted with enough lead time to allow for a variety of actions. The team worked with communities and national stakeholders to define the actions that could be taken prior to a flooding disaster, and investigated what forecasts are available to trigger such actions. In Togo, forecasts of unusual water flows passing through a hydropower dam will be used to trigger action downstream, whereas in Uganda, global flooding forecasts from the Global Flood Awareness System (GloFAS) will be used. Further details on these pilot studies can be found in Coughlan de Perez (2015b).

The RCCC is also working with the Ethiopian Red in the Somali Region together with the Netherlands Red Cross in a project supported by the Netherlands Government. The idea being developed is to merge together the concepts of climate triggered, *Early Actions* with the financing mechanisms of FbF. Standard Operating Procedures are being developed to guide individuals how to avoid and manage risks related to flood; small livestock keepers when and how to sell animals in advance of potential drought conditions; small-scale commercial farmers to avoid crop losses due to drought and how parents can help their children to avoid or at least manage wet season illness. These actions draw on local expertise - government and businesses. They are triggered by climatic events. They also include provision for the Red Cross Branch to scale up their support commensurate with evidence of increasing likelihood of an extreme weather event, and include provision for a Red Cross Branch response where those events result in crisis.

Though the pilot studies represent an innovative new way of working, they do not aim to address every barrier related to forecast use. The pilot studies do not focus on improving forecasting science, but rather on evaluating and utilising the potential of existing systems. They were established in partnership with two Red Cross National Societies who were engaged with the concept and had project support. While the projects will finish in 2017, the implementing teams began the project with the goal to encourage further research and seek out collaborations that are required to maintain them into the future and support their scale-up.

The number of pilots in place by the Red Cross movement is increasing, with forecast-based financing systems proposed or beginning in Ethiopia, Peru, Bangladesh, and Mozambique. The two original pilots for flood hazard have needed to address the other six components introduced in this report, which we will analyse in further depth here. The importance of each component is demonstrated by highlighting what needs to be considered and how the challenges have been addressed within the initial FbF pilot studies. Challenges that still need to be resolved, particularly for continuation and scale-up of the pilot studies, are also outlined.

2.1. Probability

Introduction to ensemble flood forecasting

Often a cascade of preparedness actions are taken at different lead-times in advance of a flood, and the choice of flood forecasting system may differ for each, depending on how far in advance each decision needs to be taken and also the legal / institutional framework. In many cases the choice will also be limited by the lack of data for detailed modelling, or computing power. Where the lead time required for decisions is shorter than the catchment concentration time (the time taken for a catchment to respond to a particular rainfall event) (Cloke and Pappenberger, 2009) modelling systems can take observations of rainfall or river flow to determine future river flow conditions (e.g. Bell and Moore, 1998). However, where observations of rainfall or flow are limited (e.g. due to lack of gauges or rainfall radar data) or where decisions need to be made at timescales longer than the catchment concentration time, operational forecasts of floods usually require the use of ensemble numerical weather prediction models.

Ensemble techniques have been prevalent in operational weather forecasting since the early nineties in recognition that "forecasts are stochastic not deterministic in nature" (Tracton and Kalnay, 1993, p379). Ensemble prediction systems are now used operationally by many different flood forecasting centres (http://hepex.irstea.fr/operational-heps-systems-around-the-globe/), representing the state of the art in forecasting science (Cloke and Pappenberger, 2009). Ensemble techniques take account of the uncertainties associated with modelling a nonlinear and complex chaotic system. Multiple runs of the operational weather and hydrological forecasting systems (ensemble members) are carried out using small changes in the initial conditions and model parameters to produce an ensemble prediction of future weather. At a simple level, the percentage of ensemble members that exceed a threshold (such as a temperature of 40 degrees Celsius) is assumed to give the probability of that particular event occurring.

Are forecasts accurate enough?

It is not possible to make overarching statements that forecasts are "accurate enough" to take action; in fact, skill needs to be assessed related to the decision that could be taken. The answer to the question of whether a forecasting system is skilful enough for FbA to be successful is dependent on a number of factors, and ultimately much related to the action itself.

The type of hazard, and particularly its onset is one such factor. For example, on large rivers observations of upstream flow can enable accurate forecasting of slow-onset downstream flooding in a specific location days or even weeks in advance. However, forecasts of fast-onset flooding on small rivers, or surface-water flooding in urban locations requires the development and operationalisation of convection-permitting forecasting systems over Africa.

Whether a forecast system has enough skill for FbA also depends on the lead-time needed for the mitigating action; planting drought-resistant crops requires skilful seasonal forecasts, but sourcing and distributing water purification tablets can be done in a matter of days. The requirements in terms of forecast skill are also influenced by the spatial scale of the action; tropical cyclones are relatively well predictable days in advance, but there may be uncertainty over the precise location of the greatest impact; in this case the uncertainty may not prohibit successful preparedness actions over a large spatial scale but it might limit the effectiveness of community-level actions.

A priority in the near-term is to carry out research in collaboration with practitioners to provide a first-brush identification of where FbA could be successful for each specific hazard and action. This would need to take into account not only the forecast skill but also the availability and access to different forecasting systems and observational data. Following this first-brush assessment, in-depth studies of forecast-skill would need to be carried out during project set-up.

Suitability of forecasting systems

In assessing the suitability of a forecasting system for a specific hazard in a given location, it is important to understand the cause of that hazard. Each sub-hazard is driven by a set of geophysical factors that may very well overlap, but can differ significantly in the context of temporal and spatial distribution (Barredo 2007) as well as predictability. For example, 'flood' is a broad term, used to represent any occasion where water temporarily inundates the land. When choosing a suitable forecasting system the cause (e.g. flash, fluvial, surface-water, lake, storm-surge or glacial lake outburst flooding) needs to be disaggregated, since a system designed to predict a particular flood sub-hazard may not be suitable for predicting another. Flooding is an in interesting example in that sense, since riverine floods can occur with little or no rainfall at the location of the flood, while flash floods will almost only occur if heavy and/or persistent local rainfall has been experienced (Jonkman 2005).

Establishing forecast skill

In the forecast-based financing pilots, the humanitarian actors needed to know how likely it is that the anticipated disaster will occur. Based on this, they can estimate how often they are going to "act in vain" (or the "false alarm ratio") if they take action based on a forecast (Suarez & Tall 2010). Because this component is so central to decision-making, a key to establishing trust in a forecasting system and enable confidence in its use for decision making is robust validation of model predictions.

There are many methods of evaluating probabilistic forecasting systems (Wilks, 2011), which provide valuable information for model development, but it is important to ensure that the science is reported with respect to decision-relevant parameters (Coughlan de Perez, 2014). One of the main challenges is the collation of the observational data required to perform the necessary validation to give confidence in decision making. This is particularly pertinent for probabilistic forecasting where data from multiple events are needed to perform a robust evaluation. For example, to assess forecast reliability, enough observations are needed to evaluate that a forecast of a 10% chance of a flood will lead to a flood occurring on average 1 in every 10 occasions.

For a perfectly reliable forecast, a 10% chance of an event equates to action "in vain" 90% of the time. In many cases, forecast-based actions lead to more than ten times better results when the one-in-ten occasions when the extreme event materialises. From the humanitarian actor's perspective, the chance of acting "in vain" is critical to the decision of whether or not to act (see Simmons & Sutter 2009, Coughlan de Perez et al. 2015a). Based on this, the skill score of greatest interest is the False Alarm Ratio (FAR), which indicates, even for a non-reliable forecast, the likelihood of acting in vain given a specific forecast probability.

For the Uganda FbF pilot, located in the north eastern part of the country, local flood forecasting systems do not exist. Therefore, the project team assessed the Global Flood Awareness System (GloFAS, www.globalfloods.eu) (described by Alfieri et al. 2013) for its ability to forecast floods in the villages of interest. Using hindcasts of the GloFAS model (archived at the European Centre for Medium-Range Weather Forecasts, ECMWF) the team calculated the FAR for each forecast probability, identifying the likelihood of acting in vain if any of those probabilities were used as a trigger for action. One of the major challenges in an operational context is the paucity of data available to calculate such statistics, a challenge particularly in Africa where in situ observations are limited (Alfieri et al. 2013). Records of disaster, should they exist, can also support in determining the FAR, and in this case, disaster records as well as the forecasting skill at a river gauge on a neighbouring catchment was used to help estimate forecasting skill at the pilot location.

As such, the real FAR for a region in Uganda could be any one of a large range of values, for example, anywhere between a 25% and 50% chance of acting in vain. Therefore the humanitarian actors need to ensure they are comfortable with any of the possible outcomes in terms of number of instances of acting "in vain". Given the sensitivity of the humanitarian community to acting in vain, it is important that further development of the forecasting systems focusses on ensuring that uncertainties are represented accurately. This requires investment in the assimilation of satellite and in situ data for post processing as well as the integration of local-scale disaster records to enable forecast evaluation at decision-relevant spatial scales.

The value in GloFAS is its 'reference climatology' approach to forecasting, whereby hindcast runs of the system are carried out to enable comparisons between the forecasts and estimated return periods for the same model. This approach ties the predictions and verification to a particular model version, therefore close communication and collaboration between forecaster and decision-maker is required to communicate when changes to the model system are made and to share the latest dataset - data that can be many terabytes in size. In operational NWP rigorous procedures exist for notifying users of changes to the system, but the relationship between GloFAS (which is largely an unfunded Joint Research Centre of the European Commission / ECMWF initiative run off the back of the European Flood Awareness System) and RCCC is currently informal. GloFAS runs at 0.1° horizontal resolution (~10 km), and given the coarse resolution of the model and from initial estimates of system performance it is recommended that the model is used for river sections with a minimum of 10000 km^2 upstream area (Alfieri et al. 2013). Ideally, information on forecast skill should be used to inform the location of future pilot studies, therefore further research is needed to map what FARs can be expected in which locations, to give an indication of the type of actions that can be triggered and where.

Choosing a probability threshold

For the FbF pilot study the choice of probability threshold is made during the creation of the Standard Operating Procedures, thus removing the pressure on a decision-maker to interpret complex probabilities in real time. We need simple decision-based forecasts, and smart forecast-based decisions (Suarez 2009). The questions of communicating information and importance of probabilities and uncertainty are addressed at the outset, during the consultative discussions with RC staff held in Uganda and Togo to establish the SOPs. A sense of ownership over the SOPs is necessary to establish a decision-making system that is automated in real-time, understanding the challenges of linking actions with forecasts that have an appropriate degree of uncertainty.

As part of the consultative process, the project team engaged in interactive activities to discuss their willingness to take specific actions "in vain", and came to group consensus on the conclusions. To model complex systems and interact with probabilistic information, stakeholders played games designed specifically for this purpose (see http://www.climatecentre.org/resources-games/paying-for-predictions). Once threshold-action pairs were proposed, the team also modelled what this would have looked like over the past few years, and discussed the combinations of hypothetical success and action in vain.

Communication and understanding of uncertainty

One of the main challenges found during the initial stages of the FbF programme was addressing the perception of acting in vain. Workshops and games were designed to help participants to understand that, if the return on investments is high enough, it may be the 'right' decision to act when there is a 40% chance of an event occurring, even if this meant that they would be 'acting in vain' on 6 in every 10 occasions. Calculating the probability on which to take action requires understanding the costs of not acting and acting in vain, but these costs are difficult to quantify given that the effect of false alarms on future behaviour is not well known. Will one event where the action has been taken in vain lead to a negative impact on future action? Or will it be two, five, or ten consecutive events?

Behavioural economics experiments have shown that students are able to make better decisions when provided with information on forecast uncertainty (Joslyn et al. 2012), but high false alarm rates can affect decision-making (LeClerc and Joslyn, 2015). However this 'cry wolf' effect is more complex in reality; and there is some evidence to suggest (in the natural hazards context at least) that with the associated media attention and discussion false alarms are not detrimental and can even offer the opportunity to learn appropriate emergency responses (see Barnes et al. 2007). Further research is needed to limit the impact of false alarms in FbA, also considering differences and variations between different society and institutional cultures.

2.2. Magnitude

One of the most important choices for taking pre-emptive action from forecasts is deciding which magnitude of hydrometeorological event is the appropriate level of "disaster" to trigger each specific action. Risk perception will vary across different actors, and for that reason there may be varying opinions on what the trigger event magnitude should be, and would likely be different for different actors. For example, a humanitarian organisation might set a higher event magnitude than a resident community. In the context of specific user-groups of climate information, it is quite possible that risk perception can exist across a gradient within a community, potentially varying based on socioeconomic and demographic factors such as gender (Miceli et al. 2008), income (Kahn 2005) and education (Messner and Meyer, 2006). Risk perception is a key factor that needs to be considered when determining a disaster magnitude threshold.

The relevance of impact-based forecasting for FbA

'Impact-based forecasting' (IbF) is a popular concept amongst organisations such as the World Meteorological Organisation (WMO) (see Fleming, 2014; Soares, 2014) and also adopted by the UK Met Office for Severe Weather Warnings. IbF is a recognition that weather forecasts constitute just one part of the decision-making process, so IbF increases the relevance to decision-makers by reflecting their needs. One example put forward in the citations above is the 2013 Typhoon Haiyan in the Philippines, where the meteorological variables were well forecasted but the impacts were not; the implication being that if the impacts were well forecasted then measures could be taken to prevent them.

IbF reflects that the actual impact of a disaster with a particular hazard threshold can be highly variable, based on the vulnerability of the local population at the time. An example of how an impact-based threshold had more flexibility than a hazard-based one comes from flood forecasting in the UK - a flood was due to hit the highly populated South East of England during the Christmas holiday period in 2013. People were in locations where they were unfamiliar with flood risk, homes were vacant over the holiday period and many public services were running with skeletal staff. This meant that emergency responders and public servants needed to make response preparations before the holiday, public messaging needed to highlight the risk and the vulnerability of the population and properties was higher due to the number of people travelling and not in their normal location during the holiday period. Raising awareness and entering into dialogue early about the potential impacts, even when the confidence was low, helped enable better preparations, mitigating actions and response (pers. comms., Joint Flood Forecasting Centre employee).

A WMO report on IbF has no mention of specific actions, only that impact forecasts enable 'appropriate' or 'effective' action, and effective partnerships with disaster reduction and civil protection agencies can help to evaluate vulnerabilities, impacts and mitigating actions (WMO, 2015). The approach taken in the FbF pilot studies reflects that linking forecasts to impact is only one of the many barriers to the effective use of forecasts by the humanitarian community. FbF provides a clear mandate and funding mechanism for taking action, listing what action is 'worth' taking at a given lead time, taking into account the effect of acting in vain; in that sense what FbF undertakes is 'Action-based Forecasting' rather than 'Impact-based Forecasting'. Action-based Forecasting is one step beyond IbF, enabling mitigating actions to be taken.

The current approach to FbF links forecasted magnitude with an associated impact in a static way, but more complex representations of impact could be built into the Standard Operating Procedures, for example by designating different thresholds during different times of day or year, e.g. a flood with lower magnitude might instigate actions during the harvest season but not otherwise. As a first step towards assessing the robustness of FbF SOPs further research could be undertaken to determine whether actions become more or less effective when certain vulnerability indicators (food security, political instability, failure of transportation infrastructure) occur.

Spotlight on Peru: Forecasts of extreme events

Examples of forecasts that do not trigger action are common. In Peru, the National Service of Meteorology and Hydrology (SENAMHI) issue warnings on an ongoing basis for different types of extreme events in the country.

On the 20th of August 2013, SENAMHI issued a cold wave advisory for the Puno region, and the extreme weather began 4 days later. However, it was not until 4 additional days after people were impacted that help arrived to the mountainous region, consisting of vaccines, blankets, and food for the affected population. Had this response been mobilized based on the advisory, many of the impacts could have been avoided.

Similarly for flooding, SENAMHI informed Peru on the 12th of March 2012 that the Amazon River was likely to overtop its banks. In the third week of March, the river did indeed overflow into a nearby city, where 80,000 people were affected. It was on the 6th of April that the president arrived as part of the response effort.

Defining the threshold

Drought has multiple definitions (meteorological, hydrological, agricultural) (Lloyd-Hughes, 2014), and there are also multiple definitions of a flood. The standard hydrological definition is when a river goes out-of-bank, however, from a human perspective a flood can be defined more broadly as when water temporarily inundates the land causing a negative impact. This is very difficult to estimate in advance: in the UK detailed mapping of flood inundation extents and urban areas enables a strong link between a given river flow and the number of people and properties at risk. Even then, there is considerable uncertainty in the impact given that some properties have floor levels raised above ground levels and the link between depth and damage is quite uncertain. The question that needs to be answered, is when is a forecasted flood large enough to issue a warning or take some kind of action? At the Global Floods Partnership meeting in Boulder we heard from the Nigerian Disaster and Emergency Management Agency that if even one person was to die in a flood then that would count as a flood disaster, whereas the World Food Programme have a 5000 persons affected threshold (UNHRC, accessed: July 3rd 2015). Clearly the magnitude of flood hazard that constitutes an impact worth preparing for will depend on who the forecast is for; there will be no one-size-fits-all solution.

The choice of threshold decision will also need to be relevant to the information that the forecasting system can provide; for example operational global scale flood forecasting systems provide awareness of extremes in river flow, but not of inundation itself, or the number of people that might be affected. The current FbF SOPs predetermine a hazard threshold based on an understanding of the associated impact, this enables a threshold to be included as part of an automated decision making process. This is an obstacle for users such as the World Food Programme, with their 5000 person threshold. The impact of an event is dynamic, and as has been seen in the UK context, often requires expert negotiation on when to act (see Haines and Stephens (In Review)).

In addition, the vulnerability of the population is dynamic (related perhaps to conflict, famine, etc.) and therefore global-scale vulnerability layers are unlikely to provide the depth of information needed for a forecast to integrate them fully into a global-scale impact-based forecasting system. In practice the assessment of impact needs to be carried out at the local level, and understanding how to incorporate [dynamic] local information, the type that is perhaps currently unrecorded in centralised databases, into large-scale forecasting systems is a grand challenge. Conceivably, future FbF standard operating procedures could incorporate vulnerability as well as hazard assessments; for example if food security situation is x and forecasting is y; but care needs to be taken when incorporating subjective assessments, since they can be a barrier to effective decision-making under uncertainty and could potentially leave the system at risk of corruption.

Choosing the thresholds for the FbF pilots

In the Uganda and Togo pilots, the project teams examined the historical record of disasters, including local memories of events and recorded documents and impact databases. An interactive game called "Memory Strings" was designed to encourage discussion of historical events (see Appendix A), and rolled out in project areas to capture historical timelines. The team also compiled available disaster datasets from the Red Cross National Society and online records such as Desinventar and the IFRC DREF database. It is critical to consult many information sources to gather a timeline of past events, as perceptions of impact can vary. Based on this initial pilot, it was clear that people living in one location can agree on the dates of the largest historical disasters, but differ substantially in their recollection of smaller disasters. We recommend consulting the local population about what events they can remember, but also asking them to provide more information about the events that are documented in databases or newspapers to validate and verify those sources.

From this, the team corroborated modelling efforts to identify the magnitude of historical extreme events that were likely to have caused disaster at that time. However, the limited historical record of disasters adds uncertainty to the analysis of model performance, and as a consequence, the FbF framework itself. This means that there is remaining uncertainty in the likelihood of acting "in vain", because we do not have a very long record to show how many times that would have happened in the past. Such experiences and historical analyses are helpful to give context to the system, for decision-makers to consider how this system would have functioned. With better information, the teams can select more precise thresholds, and perhaps include higher-regret actions that require more certainty in the likelihood of acting in vain. Further research in this area could build approaches for incorporating the potential impact of limited disaster records within the SOPs.

2.3. Action

During the development of the actions, it is imperative to acknowledge national, sub-national, district level and informal disaster risk reduction practices currently in place to reduce the risk of duplication, increase probability of post-pilot persistence and increase the likelihood of involvement of government and other stakeholders. In particular it is important to scope how these practices vary across different forecast lead times (daily, sub-seasonal, seasonal) as well as how the message is propagated from forecaster onto the community to distil where the opportunities for FbA lie. Furthermore, the mandates and remits authorising FbA in a particular country context need to be taken into account. For example, the remit to develop and disseminate an early warning message may be different from country to country and may differ on the hazard and even sub-hazard level. For example, In Malawi, the remit to develop and disseminate flood early warning information is split across 2 ministries; The Ministry of Irrigation and Water handles riverine floods and the Department of Climate Change and Meteorological Services (DCCMS), which resides within the Ministry of Natural Resources, Energy and Mining, is responsible for flash floods. As frameworks for hazard information dissemination can vary country-by-country, it is important to explore the current systems in place and include this information within the development of an FbA programme.

The relationship between forecaster and end-user

Given the above parameters, the actor developing SOPs needs to determine which actions can be taken before a disaster. These actions will depend on (and iteratively select) the magnitude of the forecast used in the SOP, and the probability at which each action will be triggered. To manage reputational risk and the 'cry wolf' effect, the action should be able to withstand a certain level of acting "in vain", which should accord with the FAR of the forecast selected.

Because the action and the forecast magnitude/probability are linked, it is central to the SOPs to 'counter the loading-dock approach' (Cash et al. 2006) by creating close contact between forecast provider and end-user (Demeritt et al. 2010). A co-creation process (see Vogel and O'Brien 2006, Lang et al. 2012, Cornell et al. 2013), in which the actor specifies disaster "magnitudes" of interest and ability to act "in vain", is necessary to iteratively design appropriate thresholds. The forecasting agency can offer forecasts and skill scores that represent the best available science, and together, the two can determine what matches between forecasts and actions create the ideal SOPs.

FbF Actions

In the Uganda and Togo pilots, implementing teams divided actions into two phases: the "preparation phase" and the "activation phase". In the former, all necessary preparations are put in place ahead of time to enable the activation phase to happen quickly when a forecast is issued. For example, in Uganda, water treatment tablets are procured at the beginning of the rainy season (preparation phase), which can require more than one week to obtain. When a flood forecast is issued above the pre-determined threshold, the team is left with only 3 days to dispense the tablets (activation phase), which is feasible because the preparatory actions were already completed. There is a minimal cost of failure here: the leading brand of tablets has a shelf life of 5 years.

It was clear during the consultations on the ground in Uganda and Togo that when discussing the actions that can be taken during a forecast, at-risk communities and businesses do not only see this as an opportunity to avoid loss, but also an opportunity to take advantage and benefit from the forecast knowledge. Consequently FbA frameworks can include both actions that reduce the expected loss and suffering or benefit from the variability (see Table 1 and Appendix B for further examples). However, many of the actions that can be taken in the FbF context are also applicable as DRR actions at other timescales, or as response actions post-disaster. Further research, carried out in partnership with emergency response, DRR and public health experts, is needed to explore which actions are most effective when implemented under each of these frameworks, particularly in the developing world.

SECTOR	TYPE OF WARNING	LEAD TIME	ACTION	COST/ BENEFIT
Government (State government of New York City) (Tollefson 2013)	Flood and droughts, based on threshold levels of rainfall.	Seaso nal and short term	Adjust reservoir levels	Cost of alternatives, are $ 200-500 million for a new intake system at one reservoir or increasing the size of a second reservoir. A new filtration system could run up to $10 billion. Cost of forecast-based system = $8 million.
UK government (Colne Barrier) (Dale et al. 2013).	Tidal Flooding. Threshold = forecasted level of 3.1 meters.	10 days	Close the barrier at Wivenhoe	Cost of £4000 per closure, costs of flooding are thought to be much higher an example of a forecast benefit of £101, 144 in 2011 given. Can act as a reference figure though this represents only one instance and will vary for different forecasts.
AT&T (AT&T 2012)	Hurricane forecasts	Not given	Topping up fuel at generator cell sites, installing and testing high capacity backup batteries at cell sites, installing quick connector generator plugs, distributing portable generators, adding capacity to the wireless network, preposition of resources.	Not given.
Oil and Gas Producers in the gulf of Mexico (Considine et al. 2004)	Hurricane forecasts	48 hours	Evacuation of offshore drilling rigs and ceasing production	Value of forecast estimated at 8 million per year during the 1990s.
UK Flood Forecasting Centre (Stephens and Cloke, 2014)	Storm-surge forecast	Up to a week	Advanced warning to the emergency response community, management of human resources, checking of condition of flood defences	Cost / benefit not quantified, but enables a better coordination of emergency response activities.
Netherlands Rail Network (Haines and Stephens, In Review)	Snow forecasts	48 hours and 24 hours	48 hours in advance forecasters are sent to work within the Rail Network's offices, 24 hours in advance the Timetable is changed to minimise impact on the network	Cost is not given, benefit is largely seen in terms of not having the consequences of negative publicity

Table 1: Selected developed-world case studies of forecast-based actions

2.4. Effect of preparedness actions

When designing an FbA framework it is important for actors to come together to decide on the intended effect of that framework. For example, is it for emergency managers to respond to early warnings; for communities to take preparedness actions in anticipation of a disaster; or for humanitarian organisations to improve response times to disaster?

The benefits of actions could be in terms of saving lives, reducing the risk to health or reducing the impact on livelihoods. Table 1 provides examples of forecast-based actions and their benefits outside of the development / humanitarian context. Advanced humanitarian action could have the advantage of not only reducing the risk to local communities, but in a better management of resources it allows them to have a wider reach and demonstrate a better use of donor funds. As discussed during the FbF pilots, local actions in advance of a flood could not only limit the impact of the disaster, but also enable a positive benefit to be gained from it.

In the FbF pilots, it was clear that some forecast-based actions benefited certain groups of people and not others; for example, in some areas, migrating cattle based on a forecast is only relevant to men, as women do not own livestock. Such intra-community diversity in terms of the potential benefits of forecast-based action must be explicitly examined and accounted for if an FbF system aims to benefit the most vulnerable members of community.

Quantifying the benefits of preparedness actions

One challenge of moving towards a wider adoption of FbA measures is providing quantitative estimates of the effect of such frameworks, since the benefits of preventative action are complex given that it is difficult to assess both tangible losses (e.g. assets) and intangible losses (e.g. lives). Direct and indirect benefits can be convoluted, and require in-depth research and statistical economic analyses (see Kull et al. 2013). Table 1 provides developed-world case studies with information on costs and benefits of each.

Spotlight on West Africa: Benefits of early response

Based on a forecast indicating an augmented probability of above-normal rainfall in West Africa in 2008, the regional office of the International Federation of Red Cross and Red Crescent Societies purchased relief supplies in advance of the rainy season. Because supplies can take weeks to arrive from the logistics unit in Dubai, this can cause normal disaster response to delay substantially if procurement only begins when people are affected.

In this case, supplies were pre-positioned in regional warehouses in West Africa, allowing them to reach beneficiaries within 24-48 hours. Supplies such as blankets, cholera kits, soap, tents, and sanitation kits did indeed reach countries within days of flood reports, which was a marked improvement over the 40 days necessary to reach beneficiaries during flooding in the previous year (Braman et al. 2013).

A Boston Consulting Group study on Return of Investment in Emergency Preparedness (BCG, 2015) demonstrated a Return of Investment rate of 2:1 for preparedness interventions in Chad, Pakistan and Madagascar in 2014. A total of $5.6 million was invested with savings in future emergency-response related costs of $12.0 million. This report demonstrated that humanitarian preparedness is complex and must be tailored to context since an action with ROI in one country may not produce the same benefits in the next. For example, it was found that the largest ROI could be achieved where a country is more dependent on external goods and services, but for countries with higher coping capacity then the larger ROIs were from training or increasing organisational capacity.

In the context of the Uganda and Togo pilots, project teams assessed benefits of each action qualitatively, and articulated a theory of change for each of the preventative actions in several group settings, where participants were able to vet and corroborate the anticipated benefit to society. The theory of change has been used to develop monitoring and evaluation protocols for each of the actions, and the effect of these actions can then be assessed and documented both qualitatively and quantitatively.

2.5. Cost

What are the cost of such actions? For whom?

It is widely accepted that effective preparedness or preventative actions have lower costs than responding to disaster; prepositioning humanitarian supplies by truck prior to a disaster is an order of magnitude less costly than airlifting it in during the event. In this way, a forecast-based financing system can be an efficient use of resources, making effective use of limited funding. Many actions can also have long-term benefits, regardless of whether the flood happens at all. For example, first aid training can be beneficial for road accidents, and therefore would have add-on benefits if there was never a flood in the location.

There are several types of costs, depending on the result of the forecast and anticipated disaster event (see Table 2 for possible outcomes). In the case of "Worthy Action", there is a certain cost to taking an action in advance. For some actions, there is a mismatch between the "lifetime" of the action and the timescale of the warning. For example, if a household digs drainage trenches based on a 3-day storm forecast, these trenches might remain useful for one year. If that particular storm did not materialise, the action might still be considered "worthwhile" during its lifetime, if a storm later happened while the trenches were still in place.

In the case where there is no extreme event during the lifetime of the forecast - the "Act in Vain" scenario - there are additional costs (and benefits) that might accrue. For example, there is a reputational cost to acting in vain for the person/organisation who did so or there may be a 'cry wolf' effect that discourages action on the basis for a future forecast. However, there might also be some costs that can be recuperated, such as selling of items that were purchased to prepare for a flood.

	EXTREME EVENT	NO EXTREME EVENT
ACTION	"Worthy Action" Action cost	"Act in Vain" Action cost + additional costs/benefits
INACTION	"Fail to Act" Response cost	"Worthy Inaction" No cost

Table 2: Illustration of possible outcomes of forecast-based action, adapted from Suarez and Tall (2010)

The costs of taking preventative action are not widely researched, and in the case of the Uganda/Togo pilots, each country team carried out an economic analysis to assess the cost of each of the preventative actions. In Uganda, a research study looked specifically at these costs, noting that disaster prevention-type actions that avoided losses altogether were significantly less costly than actions that prepared for response. For example, digging trenches or supplying flood-proof crops is 50 times cheaper than preparing an evacuation in this area (Jongman et al., in prep).

2.6. Organisation

The human factor is central to supporting effective action from forecasting systems. For these systems to reach their potential, socioeconomic aspects such as the generation, provision, communication and interpretation of forecast information need to be considered alongside the scientific and technological aspects (Morss et al. 2008). Preparedness actions for floods can require coordination across organisations as diverse as emergency services, police, fire departments, government agencies, water management, meteorological services, land use/agricultural organisations, and local government.

For example, in response to challenges of delivering information across many actors during the 2005 floods, the municipality of Mumbai recognised the need for more coordinated planning and effective early warning systems (Boyd et al. 2015b). In another example, the Malawi Department of Climate Change and Meteorological Services monitored rainfall forecasts prior to a flooding event, and issued a 'heavy rainfall warning'. However, it was a separate government body, The Ministry of Irrigation and Water, who had the mandate to issue flood warnings and recommend actions. Mapping out the communication and dissemination pathways of climate information on various timescales is critical to understand which actions can be taken, who has the authority to suggest such actions and how a forecast-based financing system can integrate actions and forecasts (see Appendix C for more examples and considerations).

Convening the critical stakeholders and establishing a multi-stakeholder organisational structure of collaboration is an important step in an FbF system. Resources are therefore required not only for the anticipatory actions themselves, but also for additional aspects such as investment in human capacity, technological and scientific capacity, infrastructure, communications and information management, and equipment.

Governance of the financial mechanism itself is critical to the timely and adequate disbursement of forecast-based financing, and roles and responsibilities need to be carefully managed for a successful FbA framework. There may also be critical or dissenting voices or competing needs, such as balancing the commercial focus of water management for hydroelectric supply, managing international collaboration for transboundary rivers, or considering the opinions of religious leaders.

Roles and responsibilities

Organisations can be thought of as collectives that have capacity to enable institutions to mediate actions (Pelling et al. 2008). From an organisational perspective, a framework for Forecast-based Action will need to detail who is responsible for:

1. Leading the development of the framework or standard operating procedures; requiring both expertise in forecasting science and an ability to engage with and understand the requirements of the local community. Resource-wise, this may involve extensive travel as well as access to computing resources for data analysis.
2. Convening all needed stakeholders to discuss governance, co-innovations, roles, and responsibilities.
3. Developing and running the forecasting system; operational weather and hydrological forecasting systems require 24/7 support to ensure that forecasts are issued regularly and on time.
4. Disseminating the forecast; this requires reliably sending the forecast information in an actionable format.
5. Releasing funds; the framework will need to specify who has the responsibility of holding the funds and making them available once the forecast threshold has been reached.

6. Receiving funds, paying for equipment, supplies and staff once a threshold has been reached, and taking the actions.
7. Evaluating the progress of the pilots and ensuring that there is a robust exit strategy so that any successes of the pilot studies can be maintained into the future.

In the case of the forecast-based financing pilots, SOPs have been co-produced by the Red Cross National Society, local stakeholders, the RCCC, and German Red Cross. The development and running of the GloFAS is carried out through an informal arrangement with the ECMWF, and dissemination will be automated through email alerts. Funds will be released by the German Red Cross following the forecast threshold being reached, and these funds will be disbursed to the Red Cross National Society. Actions will be taken by local Red Cross branches and volunteers. The monitoring and evaluation framework is developed jointly between the RCCC, the German Red Cross, and the National Society, and carried out by the National Society.

3. EMERGING PRIORITIES FOR FBF

3.1. Lessons learned from pilot studies

The approach piloted in these case studies has been received with interest in the international and national arenas. Humanitarian and development actors recognise the link between their two spheres, and appreciate the practicality of setting SOPs in advance of a forecasted disaster. This recognition has led to growing interest in replicating the Uganda and Togo pilot studies; international donors are considering making funding more readily available in this category. The German Federal Foreign Office released an action plan in 2015 to combat climate change (Rüth, 2015), this plan centres on the implementation of forecast-based financing in six new countries. The implementing teams will include the World Food Programme (WFP) in addition to the Red Cross Red Crescent. At the same time, WFP is piloting a new mechanism called the Food Security Climate Resilience (FoodSECuRE) Facility, which will enable the release of funding based on climate forecasts. Ethiopia Red Cross is also beginning a forecast-based financing pilot, with support from the Netherlands Red Cross and RCCC and funding from the Netherlands Ministry of Foreign Affairs.

An overview of the research roadmap

The following research roadmap reflects the interdisciplinary research priorities and acknowledges the many different actors with an extremely broad variety of expertise that need to be brought together and managed in a coherent way.

It highlights research that can tackle several challenges encountered in the pilot projects. For example, humanitarian priorities focus on the most vulnerable areas, which are often those most under-served by skilful forecasts. Evaluation of FbF is also a critical challenge. Ideally, there should be a holistic evaluation that takes into account whether the forecasting system chosen was adequate, the probability and magnitude thresholds were the right ones, and if both the local and humanitarian community view the pilot as a success. This can be affected by the number of false alarms that happen in the short period of time of a project, and therefore an evaluation that also considers the long-term usefulness of the project is crucial.

Questions of sustainability and scale-up of a forecast-based financing system also have critical research gaps. The pilot studies include intense analysis at the local scale, something which may act as a barrier to scaling up over larger areas. Scaling-up of the FbF pilots will require an understanding of what parts of the analysis are a key requirement and what parts can be excluded or carried out in a different way that is perhaps more efficient at country or regional levels. Further work at the local level will need to address social barriers such as caste (Jones and Boyd, 2011) to further understand how cultural perspectives can shed light on forecast-based action constraints (Cannon et al., 2014; Krüger et al. 2015). Risk perceptions and religion, in particular, can play a role in explaining how and why those who are exposed to disasters may disagree with external actors responsible for forecasts and preparedness (e.g. Schipper, 2010).

There is a clear priority to better understand how these initiatives such as FbF can be governed, expanded, and sustained over time. One important issue deserving investigation is the feasibility of creating a Forecast-based Financing Facility, i.e. a global mechanism to address technologies, methods, financial instruments and educational approaches that can accelerate the removal of barriers to designing, implementing and scaling up this innovative approach, particularly among the most vulnerable. Such mechanism could address local, national and regional scales, in order to:

- Support the development of forecast-based financing pilots
- Provide technical assistance to design and implement the required policy and institutional infrastructure to enable FbF instruments

- Foster knowledge creation and capacity building, including assessing and disseminating useful developments, tools and institutional arrangements
- Form working partnerships or collaborating relationships with key institutions
- Create enabling environments and tools for learning and dialogue, including the development of criteria and instruments for monitoring and evaluating FbF
- Pool local, national and regional risks, linking sources of funding with stakeholders who can hold and rapidly disburse funding, with organizations that can trigger action based on pre-defined forecast thresholds

In terms of collecting, holding and disbursing funds, this facility could substantially reduce costs and increase efficacy of the needed financial instruments, especially by pooling capital and expertise. While the initial support for FbF originates from solidarity instruments (e.g., humanitarian and development assistance), the mandate and scope of this global mechanism could also be expanded to integrate other FbF-relevant risk financing approaches such as pooling and transfer instruments (e.g., insurance and alternative risk instruments like catastrophe bonds), informal risk sharing (e.g., remittances), inter-temporal risk spreading (e.g., micro-savings; emergency liquidity funds for micro-credit institutions).

If the creation of such a global mechanism for FbF is deemed desirable, the next steps would include carrying out an analytically rigorous feasibility study, with proper consideration of inter-institutional complexities as well as a transparent, participatory consultation process (see Linnerooth Bayer et al 2010 for potential methodology). If feasible, next steps would involve developing a business plan, securing financial resources, carrying out negotiations with key partners within and outside the humanitarian sector, and developing detailed criteria for evaluating progress.

3.2. Research Roadmap for FbF

Research Priority: The wider context

Where does forecast-based financing sit within FbA frameworks and within the wider remit of disaster risk reduction and humanitarian response?

- What disaster effects are most efficiently mitigated by disaster risk reduction vs. forecast-based financing, and which disaster effects are not efficient to mitigate?

- How much funding should be directed towards risk reduction, forecast-based financing, and disaster response? What sources of funding are best suited for forecast-based action, and what mechanisms would need to exist for its timely and transparent disbursal?

- What incentives are created by investments in forecast-based financing, and how can this avoid creating unnecessary disincentives for investments in risk reduction and disaster response? Are there disaster response protocols that create disincentives for forecast-based financing?

- How does organisational culture and aims influence the governance approach for forecast-based financing?

What would an international mechanism for FbF look like?

Research Priority: Disaster information

What disaster data are necessary to develop an FbF system?

- What datasets exist (including new Big Data analysis approaches) to develop a timeline of historical disasters in a location?

- What methodologies can combine disaster records and limited observational networks to estimate the reliability of a forecast and the likelihood of "acting in vain"?

- What approaches exist to define the critical threshold of impact, and what minimum resources are needed to carry out this research in a location that would like to develop an FbF system?

- How can [dynamic] local information be incorporated within large-scale forecasting systems?

- How can risk perception be taken into account when determining a disaster-magnitude threshold, and when evaluating the willingness or behavioural response to acting "in vain" (of an individual or an organisation)?

Research Priority: Evaluation

How can we gauge the success of a framework for forecast-based action?

- What criteria should(n't) be used to update SOPs, and how can this information be absorbed on an ongoing basis?

- What evaluation criteria should be considered, and whose perspective should be consulted, to evaluate the impact of a preventative action triggered by forecast-based financing?

- What evaluation metrics are most appropriate for forecasts at different timescales?

FORECAST-BASED FINANCING SYSTEM

Research Priority: Scaling-up

What are critical methodologies and opportunities to bring FbF to scale?

- Which activities that constituted a resource-burden during the pilot studies can be streamlined when establishing an FbF system in new locations? Which must be repeated?

- How can FbF transition from small pilot studies to a systemic way of working in the humanitarian and development sectors? What represents a robust exit strategy for FbF projects?

- Can FbF be successful in a region with political fragility and little in situ data? In a data poor region, what are the priorities for data production?

- How can traditional and indigenous forecasts relate to FbF systems?

Research Priority: Forecasting Science

What developments are needed in the forecasting science to support FbF?

- What improvements in forecast capacity will enable the greatest impact from FbF systems?

- How does the scale and resolution of the forecasting system affect how it can be used?

- How should the skill of (potential) forecasting systems be estimated, communicated and used to inform where the FbA might be successful?

- What value does more accurate or longer observational records (e.g. gauged river flows, disaster records) add to the specification of FbA frameworks?

- What are the incentives and funding structures to encourage forecasters to generate hazard magnitudes of relevance, and calculate reliable probabilities (or skill scores)?

4. FBF IN THE WIDER CONTEXT OF FBA

4.1. Other forecast-based action systems

There are many successful cases outside of the FbF pilots of when forecasts have been linked to action. Critical characteristics of these efforts include a well-functioning governance framework that includes formal institutions supported by centralised governance structures, national policy and legislation frameworks that incorporate risk reduction and crisis management (Menne and Murray, 2013).

This section provides examples of Forecast-based action projects. In all of these examples, it is notable that the projects aim to reduce disaster impacts on the livelihoods and communities of the most vulnerable. In most of the projects, networks of actors work collaboratively, and finance mechanisms and international funds are often enabled through a network of partners. However, there is little detailed information published on the range of finance mechanisms. The forecast systems used are quite diverse, and range in size.

Little information is available on the types of efforts to scale-up or how to exit from the projects/ programmes. In the case of Practical Action, it is clear that they have plans to scale up through frameworks, methods and partnership building from the bottom up. In contrast, others operate closely with government agencies developing tools and technical systems that will be embedded within national policy and planning systems. The Red Cross is embedding its work through voluntary networks of people.

FoodSECuRE: the Food Security Climate Resilience Facility

The UN World Food Programme is actively developing a corporate facility for forecast based action. The Food Security Climate Resilience Facility (FoodSECuRE) is a new institutional mechanism ('facility') that will financially and programmatically support community-centered action to reinforce and build climate resilience, addressing increasing loss and damage from climate disasters and improving resilience building in post-disaster recovery (WFP 2014). FoodSECuRE will 1) Trigger early action based on climate forecasts – using forecast-based financing to enable community resilience building and preparedness before climatic shocks occur, and 2) Support post-disaster resilience building – providing predictable multi-year funding for resilience interventions following a climate disaster.

As of August 2015, FoodSECuRE is in its final design phase. The development of a seasonal forecasting and trigger mechanism will start by the second half of 2015 and is expected to be ready for field test by the end of 2015. Pilot testing of the initiative is planned initially in five countries (Guatemala, Niger, Philippines, Sudan and Zimbabwe) (personal communication with WFP).

Additional information can be gained from the WFP's FoodSECure website.

Early-warning systems in Bangladesh

Bangladesh's Comprehensive Disaster Management Programme includes efforts to increase the timeliness and effectiveness of warnings to enable both the government and its citizens to prepare for flooding (Luxbacher, 2011). The creation of effective warning systems, public awareness campaigns and evacuation systems along with investment in typhoon shelters following the devastating 1991 cyclone in Bangladesh contributed to an order of magnitude reduction in the number of deaths (Luxbacher, 2011) during 2007 Cyclone Sidr: 3406 compared to an estimated 140,000 (Paul, 2009).

Community-based early warning systems in Nepal

Practical Action have worked with communities in Nepal to establish community-based early warning systems. A low-tech observation tower and siren enables a purely local-led observation and warning system that is managed by the community and therefore independent of outside support: something that provides sustainability in a country with a variable security situation. The use of local resources cuts costs and creates a greater sense of ownership, with community members actively gathering information rather than passively receiving warnings. The system has reduced the risk to both lives and livelihoods by enabling evacuation and movements of livestock and tools. (Practical Action, 2008)

4.2. Applicability to other hazards

While the research roadmap for FbF presented in this report has been developed from the priorities for research elucidated during the FbF pilot studies for flood disasters, the components of the standard operating procedures would need to be addressed when implementing FbA for any natural hazard, or even any other non-natural threat that can be anticipated with some level of skill. Therefore these components could be used as guidelines for setting up FbF or FbA for different hazards.

However, different hazards have differing rates of onset and differing impacts, as well as different challenges faced in their forecasting. The development of the FbF pilot studies has underlined that the actions and the skill of the forecast are intrinsically linked. This clear link suggests that research programmes to strengthen FbA capabilities need to reflect the in-depth interdisciplinary rigour needed to address often very specific SOPs, and therefore may not realistically be able to also reflect the high-level 'multi-hazard' agenda. Despite this, any FbA research should consider what FbA systems for other hazards exist for the actor, community, region or nation of interest. The following subsections outline some of the challenges of FbA for different hazards; most of the examples are simple early warning systems, though some systems are linked to mechanisms for financing and implementing preparedness actions.

Heat waves

Heat-health action plans have pioneered some of the best examples of operational forecast-based action systems. Anchored by a set of Standard Operating Procedures triggered by a forecast of extreme heat, heat-health action plans, sometimes referred to as Heat wave Early Warning Systems (HEWS), are automatically executed and financed based on a pre-determined threshold.

As in the case of floods, further research on the appropriate actions to trigger is necessary in the case of extreme heat. While some studies have gauged the benefits of preparedness interventions (e.g. Ebi et al. 2004, Fouillet 2008), there is still discussion about whether some of the commonly-recommended actions are in fact reducing the potential heat effects (Hajat et al. 2010).

There has been extensive research on magnitudes of heat that cause disaster in the developed world, particularly for areas that have experienced heat waves in the past (e.g. Fouillet 2006). However, little has been researched on magnitudes of heat that cause excess deaths in the developing world; South Asia's first heat-health action plan was implemented in 2013 (Knowlton et al. 2014). Further, research has shown that there are difficulties in assessing the effectiveness of interventions due to challenges in evaluating the effectiveness of actions actually taken rather than the perceived effectiveness of recommendations (Lowe et al. 2011).

Storms

(In this context, tropical storms and extratropical storms are regarded as the same hazard)

There are a number of public and private SOPs that exist to trigger action based on storm forecasts (see examples in section B). Unlike the case of non-storm flooding, there is a substantial literature base in the humanitarian logistics community that optimises actions based on storm warnings (e.g. Lodree 2011). However, this literature tends to treat storm forecasts as deterministic; further research is necessary to incorporate longer-range probabilistic storm forecasts into such planning given the benefits of probabilistic storm-surge modelling outlined in Stephens and Cloke (2014).

The Philippines Government has made available a Quick Response Fund for Local Government Units, which is comprised of up to 30% of their Local Disaster Risk Reduction and Management Fund (Brower et al. 2014). The Quick Response Fund is now available to be triggered based on a forecasted calamity, and further research is needed to learn from the governance and financial allocations in this national FbF system.

Drought

In contrast to other events, droughts are almost always slow onset, yet commonly characterised by a sudden exponential increase in impact when various climatic, environmental and socioeconomic thresholds are reached. The gradient of vulnerability across a relatively long temporal extent of a single drought event can lead to significant variation in risk perception, willingness to suggest action at the government level and ability to assess the effectiveness of intervention (Botterill 2012).

While drought forecasts are widely available (e.g. Ross 2009), very few Standard Operating Procedures are available to react to such information. In the case of Somalia in 2011, prolonged discussions about the appropriate action to take culminated in a famine (Hillbruner and Moloney 2012), and review of the event concluded that "Famine early warning systems have a good track record of predicting food crises but a poor track record of triggering early action" (Bailey 2013).

While there has been substantial research into the communication of drought warnings, further research is needed into the appropriate actions that could be triggered. In particular, research is needed into actions that can establish an enabling environment for at-risk people to take action based on such a warning.

Landslides

Being complex geomorphological phenomena triggered by natural drivers, anthropogenic forces, or a combination of both, the ability to forecast landslides is hindered by unique challenges (Horbitz et al. 2006). However, the predictive capacity for an early warning system has been explored by isolating specific causes of landslides, for example, rainfall induced (Kirschbaum et al. 2012), seismic induced (Gasparini et al. 2007) and those caused by a multitude of factors (Zan et al. 2002 & Hong and Adler 2007). Furthermore, ongoing research to produce a global landslide catalogue will afford the ability to analyse the spatiotemporal properties of landslides (Kirschbaum et al. 2015). Using globally available remotely sensed data, this catalogue can be used to explore the relationship between various remotely sensed climatic and environmental variables and landslides. With this increase in understanding of how the changes in those variables, on different timescales, can impact the occurrence of a landslide, the *forecasts* for the changes in climatic and environmental variables can potentially be used to trigger a shift in risk for a certain type of landslide to occur.

With a number of landslide early warning systems in various stages of development, the opportunity exists to prioritise linking FbA with climatic, environmental and geomorphological driven thresholds. Further, as the risk for landslide related hazards can vary greatly across timescales, a global EWS addressing all landslides may not be most useful in the context of informing the development of a framework for FbA. Future research would also need to address what kinds of actions could be implemented based on a heightened risk across a region, rather than at community-level.

Other threats

The Forecast-based Financing mechanism could lend itself for other hazards that offer sufficient lead time between the science-based signal of enhanced risk and the materialization of that risk - allowing for actions that can reduce or avoid losses and suffering. Examples can range from man-made threats (such as enhanced risk of industrial accidents or meltdown in nuclear power plants) to unusual but predictable threats on a longer-term timescale, e.g. fairly predictable climate anomalies will be triggered by certain 'explosive' volcanic eruptions (which have happened every 30 to 100 years): when large amounts of sulphur reach the upper atmosphere, an umbrella of sulphuric acid droplets blocks sunlight and changes rainfall and temperature patterns around the world for up to a couple of years - allowing to anticipate unusually cold, dry and other extreme conditions likely to manifest several months after the eruption. The humanitarian consequences could be catastrophic unless action is triggered after the eruption but before the full manifestation of the extreme anomalies (Robock 2013).

5. CONCLUSIONS

Skilful forecasts of an imminent disaster can allow the prevention of disaster effects and preparation for the impacts of disaster for many of the world's most vulnerable groups and individuals. However, while forecasts are becoming increasingly available, humanitarians regularly fail to implement such Forecast-based Action. This report demonstrates the interdisciplinary challenges in moving towards robust frameworks for Forecast-based Action (FbA) for different humanitarian actors. This is a particularly critical strategy in light of changing risks worldwide, and research investments are needed to provide information, methods, guidance and institutional mechanisms for the successful establishment of such systems.

The Red Cross Red Crescent Movement has developed Standard Operating Procedures in Uganda and Togo to trigger action when a forecast exceeding pre-specified risk level is issued. These pilots are expanding to several new countries, but FbF has yet to become a systematic way of working in the humanitarian and development sectors. In particular, there are unanswered questions regarding how this financing technique can best complement long-term disaster risk reduction investments and post-disaster response efforts.

The aim of this report was to establish research priorities for informing the development of frameworks for Forecast-based Action, basing these on the considerations, successes, and challenges of the FbF pilot studies. These pilot studies were examined based on the seven components that need to be considered when setting up standard operating procedures: probability, magnitude, hazard, action, cost, effect and organisation. These components would need to be addressed when implementing FbA for any natural hazard, therefore they could be used as guidelines for setting up FbF or FbA for different hazards.

The research roadmap reflects the research priorities and acknowledges the many different actors with an extremely broad variety of expertise that need to be brought together and managed in a coherent way. Given the need for interdisciplinary collaboration, the key to a successful research agenda will be co-produced research that works towards the central goal of supporting successful Forecast-based Action, and not isolated projects that address the priorities individually.

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APPENDIX A: MEMORY STRING GAME

by Erin Coughlan de Perez and Pablo Suarez

I. INTRODUCTION

This participatory activity aims to support experiential learning and dialogue on past disaster events in a community. Players recall historical events, and then compare their recollection with other groups to win prizes. Similar to a historical profile, participants build a picture of past events in their location, and can see patterns over time. Incentives to compare between groups helps the participants focus on generating accurate information that is representative of what other community members have also experienced, and triangulation of data between teams generates robust results. Results can then be compared to external data, such as rainfall records, to learn more about the effect of larger-scale events in the community. The game is freely available for not-for-profit use.

II. GAME MATERIALS (4-20 PLAYERS)

4 pieces of string, each 5 meters long: two of one colour, two of another colour

10 index cards of one colour (ie: yellow): cut into 4 equal pieces

80 index cards of another colour (ie: blue): 10 are cut into 4 equal pieces, 20 are cut in half, and 50 remain whole, so there are 40 cards of three different sizes: small, medium, and large

4 tape dispensers

12 pens

Worksheets for the notetaker

III. GAME SETUP

- Facilitator determines the start date and end date of the time period that will be discussed in the game (ie: 1980-2013).
- Facilitator writes the start date (1980) on four small yellow notecards, and attaches one to the end of each of the strings with tape.
- Facilitator writes the end date (2013) on four small yellow notecards, and attaches them to the other end of each of the strings.
- Facilitator writes several of the in-between dates on 4 notecards, and attaches them to each string at the appropriate place between the start and end date. It is recommended to leave more space for the most recent years. The facilitator should then have four identical timelines.

IV. RULES OF PLAY & FACILITATOR GUIDANCE

- Facilitator asks two volunteers to hold the ends of the timelines (all four are held together) and stretch them across the room in front of the other players.
- The facilitator asks participants to name important events, or "moments of change" that have happened over the course of the timeline. When a participant names an event, the facilitator asks the person to stand next to the location on the timeline that represents when their event happened. The notetaker should record all events in sheet 1.
- Once many people are standing and have mentioned a variety of events, the facilitator explains to participants that they will now focus on disasters (ie: floods).
- Women will represent the first team. The facilitator asks all the women to stand next to the place on the timeline that represents when they moved to the community or when they

were born there. Then, the women count off from 1-2 starting at the most recent year, to create two half-teams of women with diverse ages.

- This is repeated with the men. (Note: in communities where it is acceptable for men and women to discuss together, this can be eliminated and mixed gender groups can be created at once by having everyone count off by 4.)
- Each half-team of women is given one timeline of the same colour. The two half-teams of men are given timelines of the other colour.
- The Facilitator explains that there will be two rounds of this game, and for each round, team-members will receive a prize according to the number of answers that match between half-teams. However, there is no communication allowed between half-teams!

V. ROUND ONE

1. Each half-team is given 12 blue cards of each size, 3 pens, and a tape dispenser. The large notecard size represents a large flood, the medium size a medium flood, and the small size a small flood.

2. The Facilitator asks each half-team to discuss when floods happened in the past, and their magnitude. For every flood they discuss, they should tape a notecard of the corresponding size to the timeline in the place when the flood happened. If players are literate, they can indicate the year and season on the notecard.

3. After about 20 minutes of discussion, teams come together. For the first team, the Facilitator places their two timelines of the same colour next to each other, and the other colour team is asked to judge how many matching events are on the two timelines. The notetaker should record all events in sheet 2. The team then switches roles, and the first team becomes the judge of the matching events of the second team.

4. Prizes are awarded to all team members according to how many events matched in date and magnitude.

VI. ROUND TWO

1. Each half-team is given 1 blue cards of each size, and 3 pens. The large notecard size represents a large flood, the medium size a medium flood, and the small size a small flood.

2. The Facilitator asks each half-team to discuss what happens during a small flood, a medium flood, and a large flood.

3. After about 10 minutes of discussion, the Facilitator asks each half-team to draw what they have discussed on each of the notecards, to represent flood effects for each of the three magnitudes of floods.

4. After 2 minutes teams come together. The first team begins by comparing the drawings of their two half-teams to represent small floods, and the other team judges whether they are the same. This is repeated for medium and large floods, and then the two teams switch roles. The notetaker should record all information in sheet 3.

5. Prizes are awarded to all team members according to how many drawings were the same between half-teams.

VI. NOTES ON POST-GAMEPLAY DEBRIEF

Memories of past events are revealed in a fun and playful manner during the game. During post-game debrief, the facilitator should elicit feedback and opinions on several topics. What were the perceived differences across the “memory strings”? Why did some people label a flood as “big”, others “small”, and others not even mention it? Is there a difference between the teams of women and men, or a difference according to age/livelihood? How do people see trends in the disaster events, and how does this relate to some of the "moments of change" that were identified at the beginning?

Then, the facilitator can turn the game debrief to a discussion of the disaster effects that were drawn during round two, and how these can be prevented in the future. What losses are avoidable? What can be done before the disaster to prevent these losses? Refer back to the drawings at this point.

VII. FLEXIBLE GAME DESIGN: CREATING NEW, MODIFIED VERSIONS

In communities where participants are illiterate, a few modifications to this game structure are suggested. Firstly, strings need not be prepared ahead of time with years attached; instead, the facilitator should ask participants to just estimate years when they stand along the timeline. Start and end dates should still be specified. Secondly, instead of drawing disaster effects on the three different size notecards, participants can be asked to identify symbols from the local environment to represent the disaster effects they have discussed (ie: rocks to represent houses). Each team will then present their symbols instead of their drawings.

This game can be played with many more than 20 participants. If there are more than 20 people, the facilitator should create additional teams and prepare two additional strings per team; the two strings should be one colour that is different from the other colours already used. In this case, the facilitator could introduce another level of competition, in which bonus prizes are given for pairs of teams with matching timelines or matching information on disaster effects.

APPENDIX B: FBF ACTION EXAMPLES

Here, we give a few examples flood preparation actions, and we categorise the examples in six categories. The first five derive from Arun Agrawal's "five classes of adaptation practices", and the sixth deals with technical/infrastructure investments.

Note that we do not classify "passing information" as an action in this table, although it is certainly a prerequisite to many of these actions being taken by the correct people. However, communication is not the end goal of a forecast-based financing system; an appropriate communication system needs to be set in place to trigger one of the following action examples when a pre-determined forecast is reached.

	HUMANITARIAN-STYLE ACTION Avoiding loss from extreme event	DEVELOPMENT-STYLE ACTION Take advantage of extreme event
Mobility	Evacuate people, animals Move valuables/assets to higher ground Relocate meetings, places of work	Plant crops (graze animals) in areas forecasted to receive rain/floods
Storage	Preposition relief supplies Create spaces / buildings for safe storage of food supplies during a flood	Store commodities to anticipate optimal market value based on forecast
Diversification	Split herds to reduce risk of loss of whole herd Diversify income with short-term wage labour contracts	Plant additional crops specialised for forecast scenario
Communal Pooling	Pool land to construct drainage canals	Pool labor to take advantage of opportunity for investment
Market Exchange	Harvest and sell crops prematurely Purchase (or distribute) water treatment tablets, plastic bags	Sell hoarded water/food/supplies
Technical and infrastructure investments	Dig trenches Build river barriers/reinforcements (sandbags, inflatable barriers, flood walls) Train citizens in first aid Recruit volunteers	Build storage facilities (or dams) to retain floodwater for later use in irrigation

Table A1: Local Level Action Examples

APPENDIX C: EARLY WARNING SYSTEMS

In analyzing the early warning system of a country it is important to assess the efficacy of a climate information pathway (including associated early warning systems), specifying various timescales, amongst the various nodes of communication. See Figure 1A for a description of an early warning system in Bangladesh.

In addition to exploring the nodes at which the message is at risk of super-propagation, and even where it may undergo significant modification, it may also be worth noting the variation in communication pathways across nearby communities. Understanding where authoritative actions are currently operational and are passed down by trusted sources (presumed) may aid in the development of a multi-hazard, multi-timescale FbA framework.

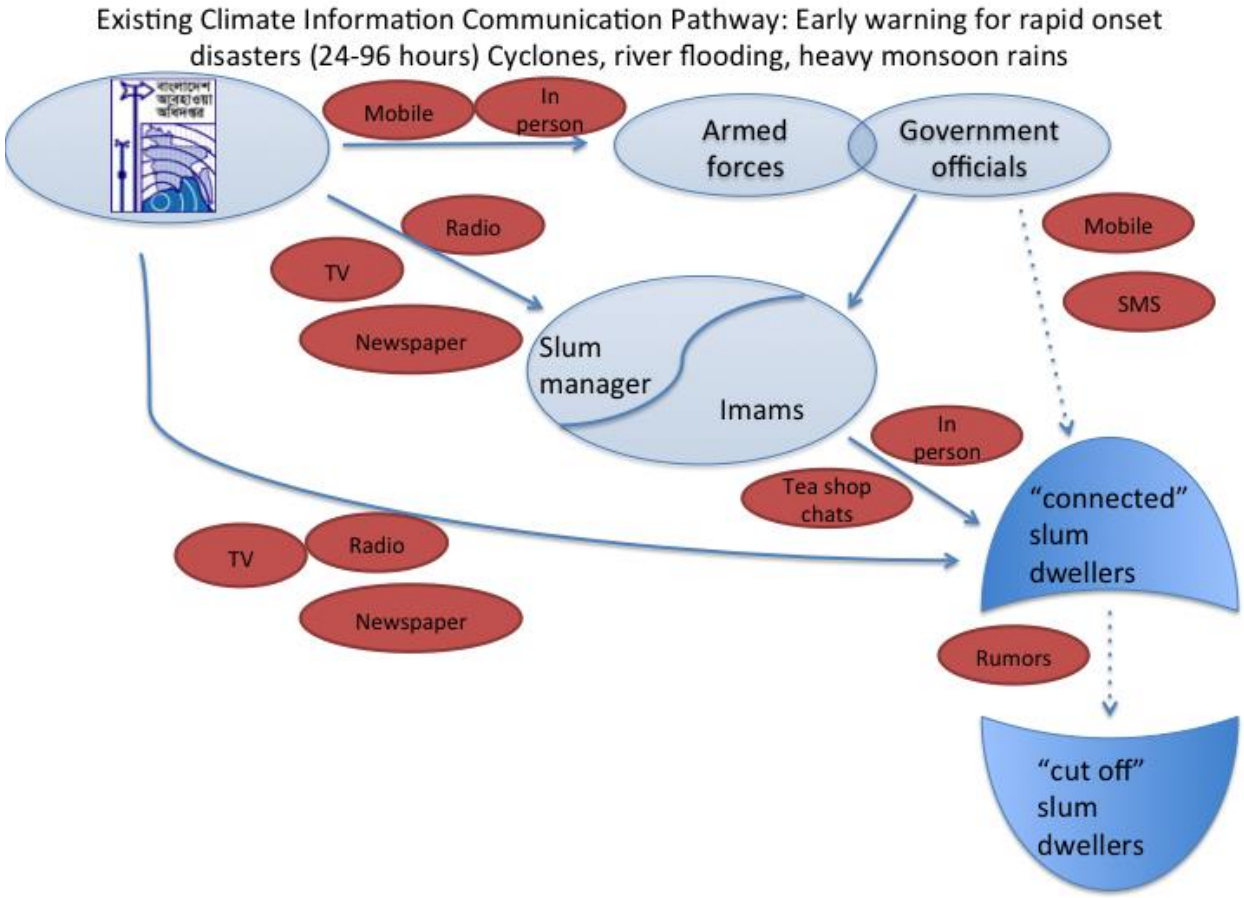

Figure A1: Early warning system for cyclones, from 24-96 hours lead time, targeting slum dwellers in Korail, Dhaka (Personal communication with Korail slum managers and BMD).

In the case of the Global Framework for Climate Services project in Kiteto province in Tanzania, a seasonal forecast message can be modified significantly by systematic downscaling using local knowledge of microclimate behavior, while short term warnings, also open to modification, may be downscaled in a different way, closer to the ultimate recipient.

APPENDIX D: FbA FACT SHEET

(1) What in the simplest terms is 'forecast-based action'?

Forecast-based action (FbA) –is when people are able to limit the consequences of disasters in response to forecasts before an actual event. Forecasts provide information on the chances of a natural hazard occurring in the next few days or weeks, as opposed to longer-term risk mapping. But even though such forecasts are increasingly available, business-as-usual humanitarianism often fails to respond to them; there is clear need for an FbA framework to change this.

(2) Where could forecast-based action have saved lives?

The international community started to receive drought warnings nearly a year before famine was declared in Somalia in 2011, for example, and it has been haunted by this ever since. One conclusion from later analysis was that funding needs to be more readily available based on forecast information.

In Peru, the national met service issues warnings for different extreme events, such as the 2013 advisory of a cold-wave in the mountainous Puno region. But that year it was not until four days after people began to be affected that vaccines, blankets and food arrived; had the response been mobilized immediately after the advisory, many impacts could have been avoided.

(3) Are forecasts good enough?

Whether a forecasting system is accurate enough for FbA to be successful depends on factors like the type of action you would take. For example, 'lead time' is an issue that narrows down the possible actions that could be taken: planting drought-resistant crops requires good seasonal forecasts, but distributing water-purification tablets is a short-term action so forecasts need only be skillful out to a few days.

A key is to establish trust in a forecasting system and change the humanitarian culture to make decisions based on the probability of an event occurring. In terms of the cost and benefit it may be the correct decision to take action when there is only a 40% chance of an event occurring; there needs to be an understanding that it is often justifiable to 'act in vain' on 6 times out of every 10.

(4) What types of actions are taken?

On the humanitarian level, people, animals and assets can be evacuated to higher ground, relief supplies pre-positioned, herds split up to reduce losses, land pooled for the construction of drainage canals, crops sold protectively, flood defences built, relief supplies distributed, and volunteers recruited. On the developmental level, crops can be planted in areas forecast to receive rain, commodities stored to anticipate higher prices, labour pooled to maximize returns on investment, and floodwater harvested for later use.

(5) Who is already doing this?

Pilot projects supported by the German government and Red Cross and implemented by the National Societies of Togo and Uganda started in 2013, and will include standard operating procedures to specify when a forecast is worth acting on and – using a preparedness fund – what action should be taken. Similar pilots are proposed with the World Food Programme in 7 new countries, and WFP has recently implemented FoodSECURE, which pilots in FbF in 5 additional countries.

(6) What are the prospects of scaling up this approach?

There are research gaps on the sustainability and limits forecast-based financing. Current pilots include full analysis only at the local level, and scaling up FbF will require extended analysis at country and regional levels. One important issue is the feasibility of a global FbF facility to remove barriers.

(7) What are the remaining challenges?

Forecasts of hydrometeorological variables need to be translated into a probability of impact. There are also institutional and political barriers to using uncertain forecast information, particularly given the consequences of acting in vain. Humanitarian organizations do not have a clear mandate for action based on probabilistic forecasts, and are not sure what action is worth taking. Lastly, funding sources for forecast-based early action are few; the bulk of funding is available only after disasters occur or from long-term agreements.