Implementing Multi-Hazard Impact-based Forecast and Warning Services

A report on a Workshop organized by China Meteorological Administration – Shanghai Meteorological Service and the Global Facility for Disaster Reduction and Recovery

PART I Summary

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Preface

The workshop described here is part of a series of activities conducted by the World Meteorological Organization (WMO) and the Global Facility for Disaster Reduction and Recovery (GFDRR) to share concepts and practices on the implementation of impact-based forecast and warning services. The GFDRR organized events are focused on introducing these concepts in countries where the World Bank is making or planning to make investments to modernize National Meteorological and Hydrological Services (NMHSs) and disaster management organizations. GFDRR and the Shanghai Meteorological Service (SMS) of the China Meteorological administration (CMA) have a long-standing partnership, which started with the introduction of Multi-Hazard Early Warning Systems (MHEWS) to World Bank clients and to the World Bank staff in 2012 and 2013 and has evolved to include the newest ideas on impact-based forecasting and warning services.

The Workshop brought together practitioners from World Bank client countries, World Bank Task Team Leaders (TTLs) and experts from SMS and GFDRR to share best practices in transforming early warning systems into multi-hazard impact-based forecast and warning services. An impact-based forecast and warning service, at its simplest, is the translation of hazard jargon into clear information about the likely impact. Supplementing the forecast of "60 knot winds" with the likely impact on homes, for example, would raise awareness of the actual threat to life and property. More quantitative impact-based forecasts explicitly consider vulnerability specific locations – elevation and risk of flooding; quality of buildings and bridges to withstand wind, mudslides, flood water; the resilience of critical infrastructure, such as electrical power, water and sanitation; the resilience of hospitals, schools and other public services, as well as the capacity of government and people to respond. The timing and location of livelihood activities, such as farming and fishing, which expose people directly to hazards, such as winds, lightning and waves, need to be quantified so that impact-based forecasts are tailored to those at risk.

Implicit in this approach is the need to shift from deterministic to probabilistic forecasting techniques that highlight not only the most likely impact, but also reasonable worst case scenarios, which are often the cause of avoidable disasters. Also, there needs to be greater emphasis on coupling meteorological, hydrological, hydraulic and ocean models within decision-support systems that facilitate critical decision-making.

Successful implementation of impact-based forecast and warning services requires a significant change in working practices among meteorologists, hydrologists, disaster managers and those responsible for critical decision-making. Close operational cooperation is essential.

Summary

Forecasting impacts

Impact-based forecast and warning services have been identified as a high priority by WMO Members to increase the relevance and utility of their National Meteorological and Hydrological Services' (NMHSs) forecasts and warnings. Impact-forecasts emphasize what a hazard will *do* rather than what a hazard will *be*. Achieving this requires NMHSs to increase their emphasis on delivering risk-based[1] forecast and warning services. WMO, World Bank- and GFDRR- supported modernization efforts already emphasize service delivery. Moving beyond hazard forecasting is a significant step-up, requiring effective partnerships with many different government agencies, as well as volunteer organizations and non-Governmental organizations, which have access to relevant data. This is perhaps one of the most difficult things to achieve and where the World Bank Group (WBG) has a role through its convening power to bring together many of the actors and stakeholders to help NMHSs and disaster management agencies create the necessary partnerships and data sharing arrangements; and encouraging other development partners to support this approach.

Impact-based forecasting and warning services focus on translating meteorological and hydrological hazards into sector- and location- specific impacts, and the development of sectorial responses to mitigate those impacts. By focusing on impacts, it is expected that those exposed to a hazard will have a better understanding of the risk and will more likely take appropriate action.

Probabilistic predictions

Successful implementation depends on good working relations among all stakeholders and close cooperation between stakeholders and the NMHS. In turn, to generate risk-based meteorological and hydrological forecasts, the NMHS must have access to the best available *probabilistic* weather prediction guidance from numerical models. This is often the most challenging, but increasingly possible as higher resolution ensemble numerical weather predictions become available from the WMO global production centres and the WMO Regional Specialized Meteorological Centres (RSMCs), which are tasked to support NMHSs. This can be taken a step further nationally if the country has the capacity and capability to run very high resolution models (better than 2km resolution), which incorporate assimilation of local data from radar and other observing systems. If this is not possible reliance on the global and regional centres may be a sufficient meaningful first step.

Risk matrix

The level of risk relates the likelihood of a hazard happening and the anticipated level of impact. The likelihood of the hazard is an output of an ensemble prediction, while the expect impact is estimated based on time of day, time of year, past occurrences, expert knowledge and a wide range of societal and economic parameters related to the resilience of people and infrastructure. A climatology of risk can be built using historical data.

Visualizing warnings

While not essential for the successful implementation of impact-based forecast and warning services, it is highly desirable to develop map-based warning systems. One approach divides a country into a convenient grid and uses colours to represent warning levels within each of the grid boxes. This was originally developed by MétéoFrance and has been adopted Europe-wide through the MeteoAlarm portal. Other countries are following this example, which enables stakeholders to visualize at-a-glance the geographical extent and type of warning. Updated frequently, warnings evolve during an event and in response to actions taken to mitigate risks. This tool has been used to display traditional meteorological warnings and, more recently, sector-specific impact-warnings. It also highlights the importance of common colour-coding for specific levels of risk regardless of the hazard, impact or sector. This way a better "feeling" for risk is established across all sectors.

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[1] "Risk-based" considers the socio-economic impacts of a hazard integrating hazard uncertainty with vulnerability and exposure information. The terms "risk-based" and "impact-based" are often used interchangeably.

Transitioning warning services

WMO and the WBG are playing a key role in promulgating best practices from the leading practitioners of impact-based forecast and warning services to their Members and clients, respectively.

The workshop, hosted by the SMS with the support of the WBG, provided an opportunity for meteorologists, hydrologists and disaster managers from WBG client countries to share experiences and learn about new practices in the delivery of warning services. The curriculum was developed in partnership with the WMO Weather and Disaster Risk Reduction Services Department (WMO/WDS), SMS and GFDRR. It introduced participants to the Shanghai Multi Hazard Early Warning System (MHEWS) and best practices implemented by the City of Shanghai for the management and mitigation of multiple hazards through the combined efforts of the SMS, the Shanghai Water Affairs Bureau, and the Shanghai Emergency Management Office. Methods to implement impact-based forecast and warning services were shared with participants and exercises were conducted to demonstrate risk-based warning techniques.

Workshop Findings

- Participants agreed that there is a need for warnings to emphasize the impact of hazards by considering the vulnerability of people and assets.
- Impact-based forecast and warnings services need to be based on ensemble predictions to capture and exploit the uncertainty in the forecast to improve decision-making. A lot of effort is needed to explain the concept of uncertainty in weather and hydrological forecasts. The use of a risk-based warning matrix based on likelihood of occurrence and level of impact provides useful guidance.
- Risk-based warnings should consider the **impact**: time of day; time of year; the hazard; non-meteorological and non-hydrological factors; antecedent conditions; rural versus urban factors; and the **likelihood**: forecast uncertainty, most likely scenario; and reasonable worst case scenario.
- Emergency Managers agreed that the concept of *likely impact* and *reasonable worst case*, introduced by the UK Met Office, is a useful way of conveying information on low likelihood, but high impact events, and this approach could facilitate better decisions.
- Colour-coding the risk matrix and mapping improves communication of the warnings. The risk matrix should always accompany the warning because it provides additional information on the likelihood and severity of the impact. Warnings are generally issued only if the impact is likely to be medium or high.
- Good communication among meteorologists and hydrologists, disaster managers and other stakeholders is essential for proper actions in response to impact-based forecasts and warnings. Warning systems should be developed with the participation of all stakeholders.
- NMHSs need staff specialized in advising partners by providing the interface between the technical meteorological and hydrological forecasts and the interpretation of the impact-based warnings by emergency managers and other decision-makers. The human-to-human interaction is a critical component of effective warning services.
- The resilience of individuals, communities, infrastructure, etc. determines the level of impact and, therefore, the severity of risk. High resilience may occur within an otherwise vulnerable location because of preparedness, quality of infrastructure, access to shelters, etc. Two adjacent communities may, therefore, experience different levels of risk for the same hazard.
- Emphasizing impacts means that warnings tend to be more localized – geographically-specific or related to an activity.
- A flood forecast is a secondary hazard derived from meteorological conditions; a flood forecast, therefore, is not an impact-based forecast. River levels and warning thresholds on their own do not convey sufficient information about the impact of the flood, which must take into consideration vulnerability and exposure factors. The same approach to impact-based forecast and warning services applies equally to meteorological and hydrological hazards.
- Meteorological and hydrological models need to be coupled to ensure the hydrological forecast is updated as the meteorological situation evolves.
- Historical data on hazards and their impacts is needed to create a robust risk matrix.

Feedback

Based on feedback from the participants, the workshop was successful in sharing ideas on implementing impact-based forecast and warning services. Teams from countries and regions that included meteorologists, hydrologists, and disaster managers benefited the most from exercises. From the forecasters perspective, the participants highlighted that “what the weather will do is the fundamental question that all weather forecasters should be concerned about”.

Introduction

Each year the impacts of severe hydro-meteorological events around the world give rise to multiple casualties and significant damage to property and infrastructure, with adverse economic consequence for communities, which can persist for many years. All this happens despite good forecasts of many of these severe events, with accurate warning information disseminated in a timely fashion by the responsible NMHSs and disaster management agencies.

The reasons for this apparent disconnect lie in the gap between forecasts and warnings of hydro-meteorological events and an understanding of their potential impacts, by the NMHSs, by the authorities responsible for civil protection / emergency management, by the sectors impacted, and by the population at large. Put simply, while there is a realization of what the hazard might be, there is frequently a lack of understanding of what the hazard might do.

If this gap is to be closed, then an all-encompassing approach to observing, modelling and predicting severe hydro-meteorological events, and the consequent cascade of hazards through to impacts, is needed. Tackling this problem requires a multi-disciplinary approach to access the best possible science, and the optimum services, to manage multi-hazard events today, and to provide the best possible evidence base on which to make the costly decisions on infrastructure investments to protect the population in the future. This is a key component to achieving the goals of the Sendai framework for disaster risk reduction (United Nations 2015).

All countries should provide their citizens and economic sectors actionable information that wherever possible identifies the timing and anticipated impacts of specific hazards. An informed population that fully understands what a hazard will do is more likely to take the necessary actions that protect their lives and livelihoods.

Until now, most WBG projects for NMHSs have focused on institutional strengthening, improving observing and forecasting systems and the quality of warnings, which is a necessary but not sufficient step to mitigating the adverse consequences of hydrometeorological hazards. NMHSs must also work closely with emergency services, disaster reduction and civil protection agencies to share data and to interpret forecasts into a form that results in appropriate actions by everyone (Rogers and Tsirkunov 2013). This is a new area for many NMHSs, since it requires extensive knowledge of how meteorology and hydrology affects day-to-day activities, the vulnerability of infrastructure, and the likely behaviour of people during an emergency. None of which may be available within NMHSs in developing countries, some of which already struggle to produce basic meteorological and hydrological forecasts and services.

Impact-based forecasting, at its simplest, is the translation of hazard jargon into clear information about the likely impact. Supplementing the forecast of “60 knot winds” with the likely impact on homes, for example, would raise awareness of the actual threat to life and property. More quantitative impact-based forecasts explicitly take into consideration location-specific vulnerability – elevation and risk of inundation; quality of buildings and bridges to withstand wind, mudslides, flood water; the resilience of critical infrastructure, such as electrical power, water and sanitation; the resilience of hospitals, schools and other public services, as well as the capacity of government to respond. The timing and location of livelihood activities, such as farming and fishing, which expose people directly to hazards, such as floods, winds, lightning, and waves, need to be quantified so that impact-based forecasts are tailored to those at risk. In many countries, these data are more and more routinely acquired as a part of extensive risk mapping projects, often supported by development partners and the Global facility for Disaster Reduction and Recovery (GFDRR).

This has several implications for the future of NMHSs; the need to develop the kind of skills required to understand how the weather impacts society and the necessary tools to more effectively inform users. Some may argue that forecasting disaster risk and forecasting hydrometeorological impacts is beyond the remit of meteorologists and hydrologists; however, since the risks and impacts associated with extreme weather events are dynamic and significant, NMHSs are probably best equipped to predict their impact. And, in many countries, those affected are demanding more than statements of expected weather conditions from their NMHSs (WMO 2012). Impact-based forecast and warning services are being pioneered by NMHSs in collaboration with disaster management agencies. The techniques apply equally to weather, climate and hydrological hazards, as well as their consequential effects.

WMO has responded by developing guidelines for the staff of NMHSs on multi-hazard impact-based forecasting and warning services (WMO 2015). The workshop, reported here, builds on this work focusing on the steps needed to implement these services as a part of NMHSs modernization projects often supported by NMHSs' development partners.

Workshop Format

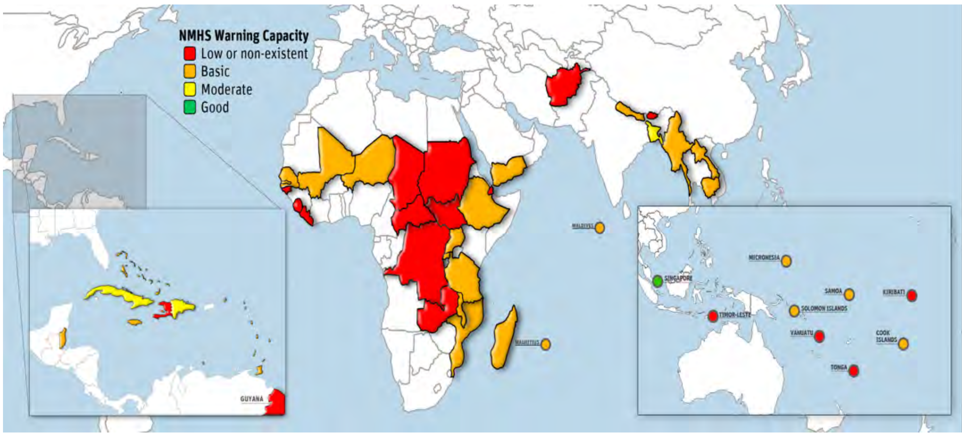
The workshop was organized by the Shanghai Meteorological Service (SMS) and GFDRR with the assistance of World Meteorological Organization's Weather and Disaster Risk Reduction Services (WMO/WDS) Department. The aim was to share new techniques and knowledge on implementing impact-based forecast and warning services with technical staff from WBG client countries' NMHSs and disaster management agencies and with WBG Task Team Leads responsible for modernization projects. The participants are listed in Annex 1. The workshop was also an opportunity for participants to share their national experiences and exchange ideas to improve forecast and warning services. The full agenda can be found in Annex 2. All of the presentations referred to here can be found in Part 2 of this report.

World Bank/GFDRR and Shanghai Meteorological Service Activities

Overview of the World Bank and GFDRR programs supporting modernization of Hydromet and early warning systems

The first session focused on introducing the participants, the objectives and expected outcomes of the workshop. Vladimir Tsirkunov and Makoto Suwa provided an overview of the WBG and GFDRR programs supporting the modernization of meteorological and hydrological services and early warning systems. Based on the capacity of hydrometeorological services, the status of early warning systems in small island developing states (SIDS) and least developed countries (LDCs) is of concern (Figure 1).

Figure 1 Early Warning Systems status in SIDS and LDCs (Source Tsirkunov and Suwa)

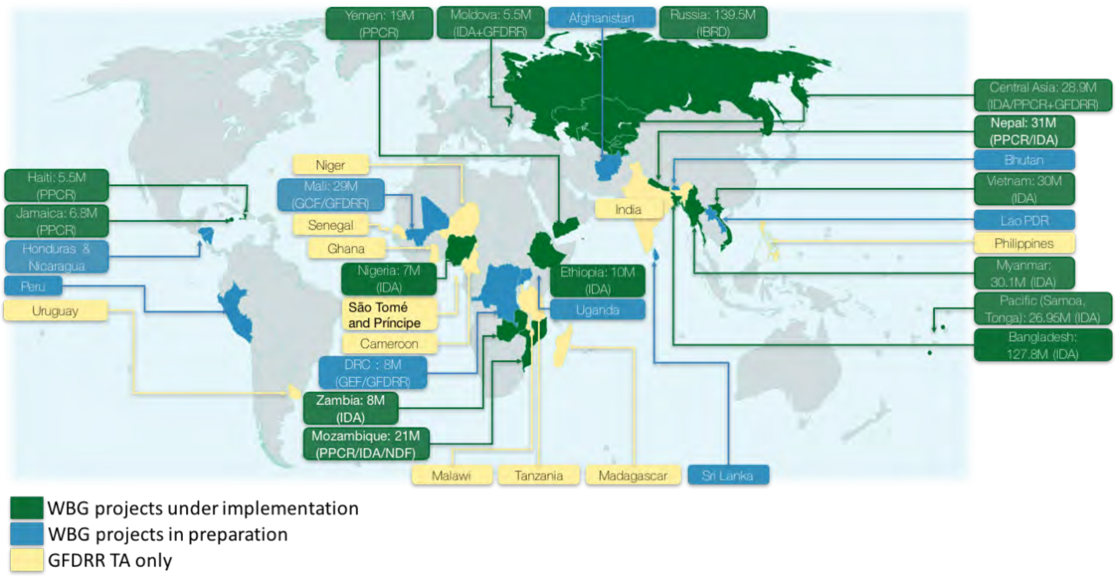


In LDCs and SIDS :

- About ¾ of countries have low or basic capacity to provide early warnings;
- Only 4-5 countries have good capacity to provide early warning

This is being addressed in a growing number of countries through investments in hydromet and early warning system modernization projects (Figure 2). These projects emphasize national capacity building and institutional strengthening; modernization of infrastructure; and service delivery. It is also recognized that strengthening relations between advanced and developing NMHSs through operational twining arrangements is an important step in rapidly improving weaker institutions.

Figure 2 Selected WBG/GFDRR Hydromet and early warning system projects (Source: Tsirkunov and Suwa)



Overview of Shanghai Multi-Hazard Early Warning System (MHEWS)

Chen Zhenlin, Director-General, of the Shanghai Meteorological Service, CMA described the Shanghai Multi-Hazard Early Warning System (MHEWS) and the practice of integrated urban weather and climate services. Shanghai is a show case for a multi-hazard warning system and weather and climate services because of its size (population exceeding 24 million), its importance in the Chinese economy as a financial, trade, transportation and shipping centre, and its vulnerability to weather events (Figure 3).

Figure 3 Severe weather disasters in Shanghai (Source: Chen Zhenlin)

The frequent disasters occurred in shanghai include **typhoon**, **rainstorm**, **lightning**, and **gale**.

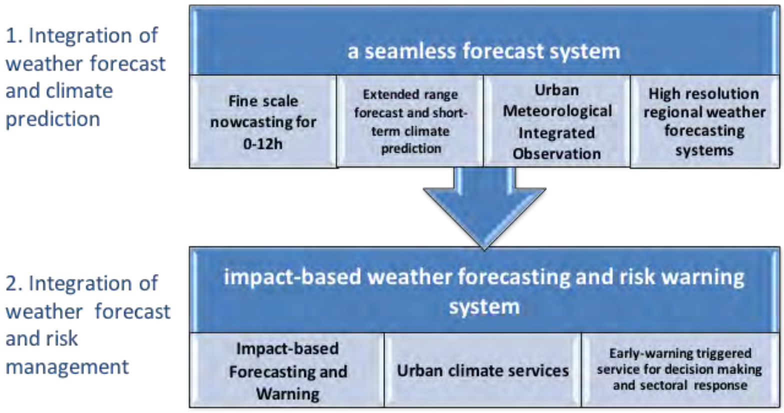
- Magnification Effect:
  Even slight weather events can trigger significant loss of life and property due to high population density and critical economic activities.
- Domino Effect:
  Natural hazards can lead to accidents, life and economic losses. Secondary and tertiary effects of weather induced disasters can have severe short and LONG TERM consequences.

Impacts of meteorological disasters on Shanghai during 1984-2009

Type of disasters	Number of deaths (people)	Number of injuries (people)	Collapsed building(houses)	Direct economic losses (million CNY)
Rainstorm/flood	28	56	788	237
Typhoon	54	394	26030	650
Thunderstorm	85	58	108	13
......				
Total	**312**	**1928**	**38290**	**1082**

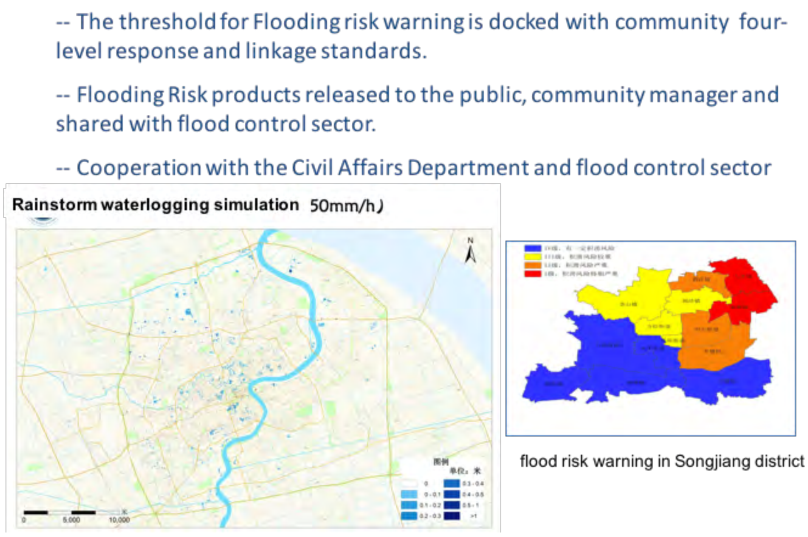
In response, Shanghai has developed an integrated urban weather and climate service that links a "seamless" weather and climate forecasting system from hours to weeks with an integrated impact-based forecast and risk warning system (Figure 4).

Figure 4 Shanghai Integrated Urban Weather and Climate: Two Integrations (Source: Chen Zhenlin)



This has been put into practise as part of the Shanghai urban flood impact forecast and warnings (Figure 5). Similar approaches are used for health, environment, rail and air transport.

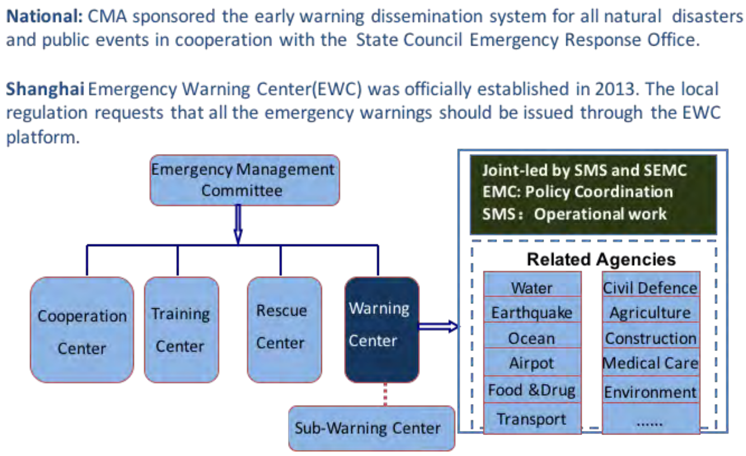
Figure 5 Impact-based forecasting and warning: Urban Flood (Source: Chen Zhenlin)



A feature of the Shanghai system is the decision by the government to use the SMS early warning system platform for the dissemination of all warnings. This ensures close cooperation between emergency management committee and the SMS, and all related agencies (Figure 6)

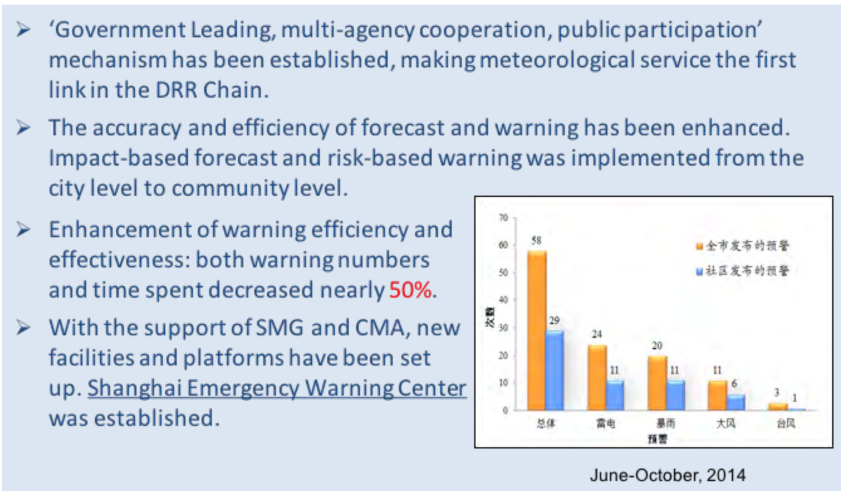
The benefit of this system is illustrated in Figure 7. By shifting to a risk based system, warning efficiency and effectiveness has improved with both number of warnings and time spent decreasing by nearly 50%. The structure has established the meteorological service as the first link in the Disaster Risk Reduction chain.

Figure 6 Mechanisms: Shanghai Emergency Warning Centre



Future plans include establishing a big data platform accessible by related departments, enterprises and social media; establishing an intelligent meteorological system, including digital tools to integrate simulations, observations and impact-based weather forecasts and risk warnings; and establishing the Shanghai e-weather service platform (E3 platform), including Early warning triggered service for decision-making; Enterprises tailored service for economic activity, and Everyone empowered service for the general public. A high resolution regional numerical modelling innovation centre will focus on impact-based forecasts and risk-informed warnings for urban flooding, aviation, marine navigation health and land transportation based on high resolution numerical weather forecasting products; transitioning from basic forecasts to impact-based forecasts using impact assessment models in cooperation with partners; and transitioning from warnings based on fixed meteorological thresholds to those based on users' risk matrices with the integration of user decision-making mechanisms. Other efforts will focus on building community resilience, and risk reduction and risk transfer through construction standards and insurance.

Figure 7 Benefit Assessment (Source: Chen Zhenlin)



Operations of the Meteorological Service, Hydrological Service and Disaster Management in Shanghai

A more detailed description of the Shanghai meteorological and hydrological services, and disaster management was presented by Kong Chunyan from SMS, Zhang Zhenyu, Shanghai Water Affairs Bureau and Yang Xiaodong, Shanghai Emergency Management Office[2]. Kong Chunyan described the public weather service in Shanghai. She highlighted the high frequency of meteorological hazards (Figure 8). The greatest economic losses typhoons are caused by typhoons, but lightning causes the most civilian casualties.

The city is highly sensitive to meteorological factors. For example, during the summer, a 1°C increase in temperature can result in a 610, 000 Kilowatt increase in the daily maximum power supply load and up to 58,000 cubic metres increase of water supply in the downtown (Figure 9).

Figure 8 High Frequency of meteorological Hazards (Source: Kong Chunyan)

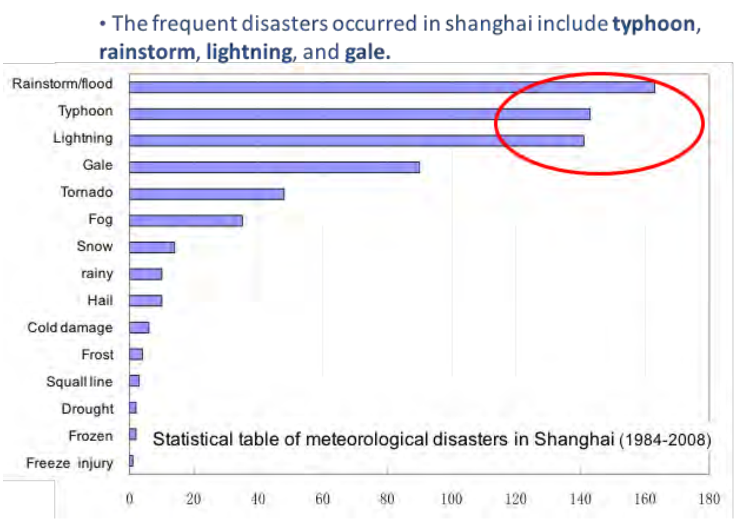
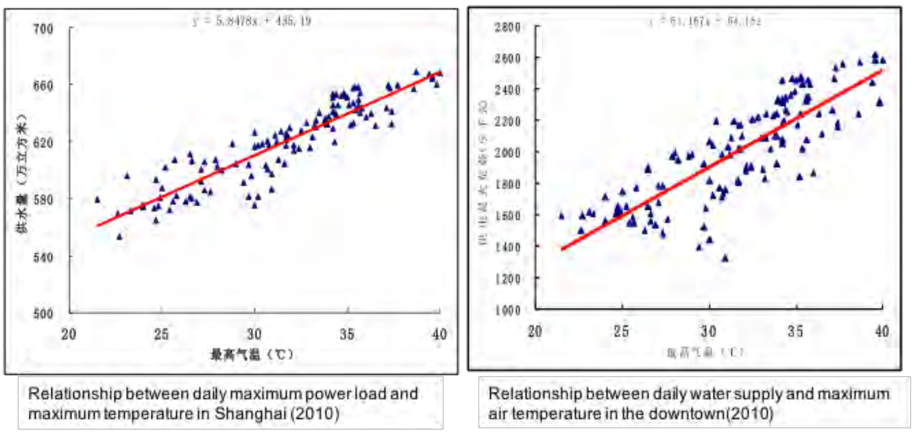


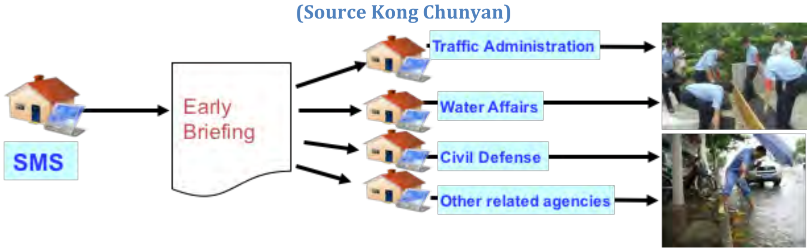
Figure 9 Sensitivity of Shanghai to meteorological factors (Source Kong Chunyan)



The public weather service of the SMS has built differentiated services for its government, public and economic sector stakeholders. The government service focuses on guaranteeing the safe operation of the city through a command support system to provide data and technology for policy makers to deal with emergencies. This includes the development of the emergency warning platform described earlier. An important aspect of the service for government decision-makers is the concept of "early briefing", which has proved effective in reducing the impacts of disastrous weather events. Early briefings are given to special users and agencies well in advance of releasing public warnings so that the agencies have enough time to react and prepare (Figure 10).

[2] Two of the presentations were in Chinese only and are not included in this summary.

Figure 10 Early briefing of government agencies in advance of public warnings (Source Kong Chunyan)



The service for production sectors focuses on boosting the economy of the city. SMS provides tailored weather services to customers based on data fusion and impact-based weather products to reduce production loss and increase benefits. Customers include traffic, power, agriculture and travel. For the public, the goal of the service is to improve quality of life. SMS cooperates with social media and uses multi-dissemination channels to provide comprehensive services to the public. Short messages for the whole city can be sent to all mobile phones, and new-generation multiplex broadcasting technology has been developed to disseminate information via all public media outlets. The services to the pubic also promote social participation interaction and public innovation. For example, SMS is cooperating with social media to run an “atmosphere perception program”. Using a portable mobile sensor, basic meteorological data is shared via a public interaction platform (Figure 11).

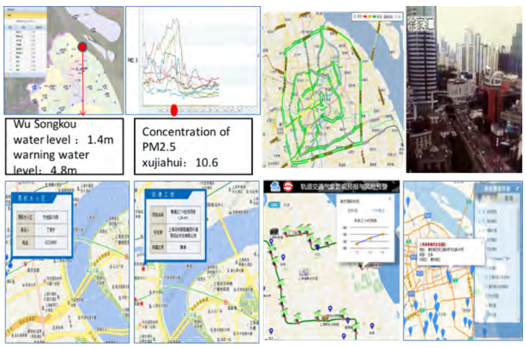
Figure 11 SMS Atmosphere Perception Program (Source: Kong Chunyan)

Figure 12 illustrates how the public weather services serves all sectors during a typhoon

Information is collected from various sources – weather, water levels, air quality, traffic, waterlogging, etc. These data are pooled and analysed to understand the impact of changes in the weather conditions. This enables impact-based forecasts and risk warnings about waterlogging, health, air pollution, aviation, metro, the expressway, etc. (Figure 13).

Figure 12 Public Weather Service in action (Source: Kong Chunyan)

Figure 13 Integrated urban weather and climate service based on risk management



Impact-Based Forecast and Warning Services

What is an Impact-based Forecast and Warning service?

David Rogers, GFDRR, introduced the necessary steps to implement impact-based forecast and warning services. Unlike objective weather, climate and hydrological forecasts, which can be developed with one or two disciplines, impact-based forecasts require access to a wide-range of new data including crowdsourced, behavioural and livelihood information, and the resilience of infrastructure systems and services. Thus, there are many more actors, including communities, which play a role through their response to impact-based forecasts and provide feedback to the forecasters. In effect "last-mile" connectivity between the communities affected and information providers becomes much stronger. Information users drive the requirements for information and therefore receive it in a form they are expecting and understand.

Scaling up the introduction of multi-hazard impact-based forecast and warning services should be viewed as a central part of the effort to modernize NMHSs. This requires a significant change in NMHSs' operations, responsibilities, training and partnerships with other national and international actors. The expected benefit would be a significant increase in the capacity of communities to take appropriate action to protect their families, livelihoods and property and therefore a reduction in disasters. It would reach far beyond the technical improvement in services to strengthen resilience within communities.

In many places, meteorological and hydrological hazards are likely to become more dangerous due to climate change. Existing community experience and knowledge alone will not be sufficient to handle these new threats. However, the capacity to cope can be improved if the public are consulted and engaged in the development of warning services that are adapted to their needs.

The WMO guidelines define three forecasting paradigms – Weather forecasts and warnings, which include information about the hazard only; impact-based forecasts and warning, which include information about the hazard and vulnerability to that hazard; and impact forecast and warnings, which include information about the hazard, vulnerability and exposure.

Vulnerability and exposure may be defined in several ways – for the present purposes and in the context of meteorological and hydrological hazards, by vulnerability, we mean the susceptibility of exposed elements, such as people, their livelihoods and property, to suffer adversely when affected by a hazard. Vulnerability is related to predisposition, sensitivities, fragilities, weaknesses, deficiencies, or lack of capacities that favour adverse effects on the exposed elements. Vulnerability is situation specific, interacting with the hazard to generate disaster risk. By exposure, we mean who and what may be affected in an area in which hazardous events may occur. If the population and its economic resources were not located in (exposed to) potentially dangerous setting, no risk would exist.

Exposure is a necessary, but not sufficient determinant of risk. It is possible to be exposed but not vulnerable, for example, by living on a floodplain but having the means to modifying building structures and behaviour to mitigate potential loss. However, to be vulnerable it is necessary to be exposed.

Knowledge of individuals' exposure to a hazard is limited at present. We make decisions based on general knowledge and experience, rather than on knowing the specific circumstances of everyone at risk. Hence even impact related warnings remain quite generic with the onus on the individual to assess their exposure and vulnerability to the hazard or on civil protection to act on behalf of those at risk.

Soon, we can expect communication tools and social media to advance to a point where personalized warnings will be the norm in developed and developing countries alike, and direct feedback from people will be possible as they act to reduce their exposure. In addition, we can expect these tools to be available in developing countries as well as developed. But for now, we focus primarily on developing impact-based forecast and warning services, which only consider the hazard and vulnerability to the hazard with more generic assumptions about exposure.

The evolution of weather forecasts to impact forecasts is summarized in Table 1, which is adapted from the WMO guidelines for the specific case of a tropical cyclone.

Table 1 Evolving Warning Paradigm using a tropical cyclone as an example

Type of Forecast and warning	Description of forecast or warning	Factors incorporated
General Forecast	In the next 24 hours, the tropical cyclone is likely to impact or has already had an impact on the target area.	Hazard
Warnings with fixed thresholds	In the next 24 hours, the tropical cyclone is likely to impact the target area. Average wind speeds of 118-133 km/h on- and off-shore or gusts of 150-166 km/h; this condition is to continue	Hazard
Warnings with user defined thresholds	Rainfall accumulations of 200 to 300 mm expected, with a high probability of the overflow of drainage system in District A *(This warning would be issued by a municipal authority only)*	Hazard, Vulnerability
Warnings with spatial and/or temporal variations in thresholds	Spatial differences: Tropical cyclone warning, gusts of 150 km/h generally, with local gusts in District B expected to exceed 180 km/h Temporal differences: Tropical cyclone warning – rainfall accumulations of 200 to 300 mm expected tomorrow afternoon during the peak rush hour	Hazard, Vulnerability
Impact-based warning	Rainfall accumulations more than 200 mm are expected tomorrow, expect road closures and rerouting of traffic to avoid flood prone areas. *(Here the impact is road closures)*	Hazard, Vulnerability
Impact warning	Based on the risk of flooding along your normal commute from workplace to home tomorrow, follow the alternative route… flexible time will be implemented – Based on your usual work schedule, leave work at least 1 hour earlier than normal to avoid significant delays. *(Here the information is intended to reduce exposure, while still permitting productive activity)*	Hazard, Vulnerability, exposure

The importance of this shift from weather forecasts and warnings to impact-based forecast and warning services is illustrated in the following case from Uttarakhand, India (Box 1).

Box 1 The case for impact-based warnings: Uttarakhand Floods 2013, India

In the Indian State of Uttarakhand, the monsoon in June 2013 arrived almost two weeks earlier than expected. From June 15 to 17, 2013, heavy rainfall, 375 percent above the rainfall that the State would normally receive during the monsoon, hit several parts of the higher reaches of the Himalayas. This resulted in a rapid increase in water levels that gave rise to flash floods in the Mandakini, Alakananda, Bhagirathi and other river basins, causing extensive landslides. Continuous rains caused Chorabari Lake to rise and the lake's weak moraine barrier gave way causing a huge volume of water along with large boulders came down the channel to the east, devastating the towns of Kedarnath, Rambara, Gaurikund and others in its wake.

The floods were well forecast by the Indian Meteorological Department (IMD) and timely warnings of extremely heavy rainfall were issued. However, lack of understanding of how to interpret the information led to an inadequate response and significant loss of life. The published reponse from the Vice Chair of the National Disaster Management Authority typifies the problem "We get a copy of the IMD bulletin but action has to be taken by state government only. They put out bulletin (this time) and said "very heavy rain". What does "heavy rain" mean? "Very heavy rain" means very heavy rain. But it doesn't mean that in such a short time so much rain""[1]

According to official sources, over 900,000 people were affected by the event in Uttarakhand with official estimates of fatalities in excess of 5700, the majority of them tourists on pilgrimage to the State's Sikh and Hindu holy sites.

[1]Interview by Rediff.com with M. Shashidhar Reddy, Vice Chair of NDMA, immediately following the Uttarakhand flood (see complete transcript here - http://www.rediff.com/news/slide-show/slide-show-1-uttarakhand-more-than-4000-deaths-are-expected/20130705.htm#1)

The case of Uttarakhand demonstrates that unless warnings are issued with adequate knowledge of the impact of the hazard, the desired response from the public or disaster managers will not happen. This means that more effort is needed to use impact-based forecasts and analyses to build scenarios, and to use these to train and educate the public, communities and sectors on what actions must be taken to avoid disasters. In Tonga, following the devastation caused by Tropical Cyclone Ian in January 2014, the Meteorological Service surveyed the areas worst affected by the event. They found that people evacuated only when their homes were destroyed putting themselves at great risk of injury, which highlighted their lack of understanding of the severity of the weather warning. Since then Tonga has made some simple first steps by asking communities what information would help them make the right decisions to protect their lives, livelihoods and property. Warnings need to relate to familiar elements of their communities – the effect of wind on banana trees and coconut trees, for example, is more readily understood than wind speed.

Tang et al. (2012) highlighted the importance and effectiveness of a multi hazard approach to reducing disasters by understanding how a meteorological or hydrological hazard can produce a series of social consequences, which are also public hazards. The emphasis on impacts, therefore, also implies the warnings should be related to multiple hazards since the initial event can cause a series of cascading threats or consequential effects – public health, accidents, infrastructure damage, civil unrest, food insecurity, etc. Ideally, each of these should also be considered and the means to predict their likelihood developed. Obviously, these are not necessarily the responsibility of NMHSs; however, an inclusive approach to coping with multiple hazards would be more effective. This highlights not only the technical requirements, but also the need for an effective operational partnership among stakeholders. It also highlights the need to distinguish between forecasting an event, such as a tropical cyclone, from the numerous hazards resulting from that event – flash floods, riverine floods, storm surges, high winds and wind gusts. It is to the latter that we want to relate to impact-based forecasts and warnings (Table 2).

Table 2 Examples of multiple hazards resulting from meteorological events

Event	Primary hazard	Secondary hazard	Tertiary hazard
Tropical Cyclones	• Strong winds • Lightning • Heavy rainfall • Tornados	• Riverine and coastal flooding • Surface water flooding • Flash flooding • Land instability • Storm surge	• Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Infectious diseases • Water insecurity • Widespread economic losses
Monsoons	• Strong winds • Heavy Rainfall • Thunderstorms	• Riverine and coastal flooding • Surface water flooding • Flash flooding • Land instability	• Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Infectious diseases • Widespread economic losses
Convective rainstorms	• Strong winds • Tornados • Lightning • Heavy rainfall	• Riverine flooding • Surface water flooding • Flash flooding • Land instability	• Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Infectious diseases • Local economic losses
Prolonged period of hot weather	• Heat	• Thunderstorms (and their associated hazard phenomena) • Drought • Dust/smog/haze	• Land instability • Non-infectious diseases • Algal blooms • Food insecurity/nutrition • Water insecurity • Widespread economic losses
Prolonged period of dry weather	• Reduced rainfall	• Dust/smog/haze/fog • Reduced ground water flow • Deteriorating water quality • Drought	• Loss of infrastructure systems and services (energy supply) • Non-infectious diseases • Infectious diseases • Food insecurity/nutrition • Water insecurity • Subsidence • Widespread economic losses
Excessive cold with frost	• Cold • Frost	• Wind chill	• Loss of infrastructure systems and services (energy supply) • Non-infectious diseases

Table 2 illustrates that the cascade of hazards, which transform from purely meteorological and hydrological into hazards related to infrastructure systems and services, human health and economic disruption.

Understanding sectorial interdependencies (Table 3) is also necessary to determine vulnerabilities and therefore in developing the appropriate impact-based forecasts and warnings. Addressing these vulnerabilities is a way to increase resilience and reduce the risk of disaster stemming from a failure to cope adequately with the primary and secondary meteorological and hydrological hazards (Rogers et al. 2016).

Table 3 Examples of sectorial interdependencies for 7 sectors (source Rogers et al. 2016)

Sector	Dependencies on Infrastructure	Impacts on other sectors
Food	• Water for irrigation • Transport infrastructure for agricultural activities and food supply • Energy for storage and agricultural activities	• Domestic is dependent on food supply
Energy	• Water for cooling in power stations, fuel refining and energy production • Transport for fuel supply and workforce • ICT for control and management systems of electricity	• Transport is dependent on energy • Food production is dependent on energy • Water is dependent on energy for pumping, treatment and supply • Domestic is dependent on energy for heating and cooling and many other functions
Social and Domestic	• Food, Water ICT, Transport, Energy for all aspects of life and livelihoods • Emergency services providing continuity to operate while recovering from an event	• All sectors dependent on workers and efficient domestic consumption of sectorial resources • Health is dependent on general well-being of population to avoid overwhelming sector • Water depends on well-managed sanitation systems to avoid contamination of water supply • Emergency services infrastructure depends on people for effective response
ICT	• Energy for all services • Transport for maintenance workers	• All sectors dependent on ICT
Transport	• Domestic infrastructure for travel to and from work, school, etc. • Energy infrastructure for fuel and electricity • Drainage infrastructure to prevent flooding • Internal dependencies with and across modes (road, rail, sea, and air)	• All sectors depend on transport
Water	• Energy for treating, pumping and processing • ICT for control systems • Transport for workers and supplies for processing	• All workplaces and domestic homes require water for people and sanitation • Cooling water for some energy infrastructure • Energy infrastructure may depend on water for generation • Food production requires water
Emergency Services	• Transport (all modes) for safe and rapid evacuation, and emergency supplies • Energy to manage emergency pumps to relieve flooding and operate flood controls • Health infrastructure to respond to emergency situations • Water infrastructure to extinguish fires • ICT to respond effectively to emergency situations • Domestic infrastructure to provide security for population	• All sectors depend on emergency services for safety and security during emergency situations • Health infrastructure for emergency response

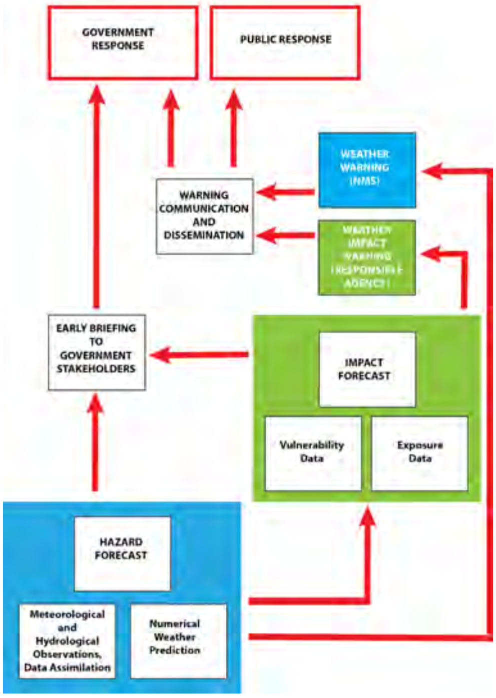
By understanding the vulnerability of the infrastructure system and services to the primary and secondary hazards, it is possible to provide more accurate and timely warnings that would protect a population from existing weaknesses in infrastructure that compound the threat of mortality and morbidity posed by the initial hazards. Collapse of buildings, bridges, and roadways, loss of ICT, electricity, transportation and sanitation frequently contribute to creating the circumstances of subsequent disasters.

The structure of a warning system, incorporating impact-based forecasts, is shown in Figure 14. The meteorological or hydrological hazard forecast depends on global, regional and local observations, assimilation of these data in numerical models operated locally, regionally or globally and climate records, especially the climatology of extreme events, which provide guidance to the forecasters. In a traditional system based on weather warnings only, early briefings can be given to government stakeholders, which enables adequate preparation ahead of public warnings (Tang et al. 2012). The weather warning system may also include some assessment of the consequences of the hazard, which can be used to develop the early briefing.

Impact forecasts are tailored to the needs of different stakeholders; for example, emergency responders, highways authorities, water resources agencies, municipal authorities and domestic and industrial energy suppliers, as well as the public at risk. Early briefings, based on impact forecasts, are used to assess the likely effect of the hazard over time at specific geographical locations, highlighting when and where the impacts may be dangerous or disruptive to society. Early briefing enables government agencies to prepare for contingencies to protect the public and critical infrastructure. Public warnings follow early briefings per standard operating procedures (Tang et al. 2012).

In summary, effective impact-based forecast and warning services should inform about the cascading threats caused by meteorological and hydrological events to prevent the hazards from becoming human disasters. This requires the capacity to predict the onset of specific meteorological and hydrological hazards and the subsequent impact based on the vulnerability of a society to those hazards, the ability to communicate and inform, and for society to understand the threats and be able take appropriate mitigating actions.

Figure 11 Schematic of information flows from basic meteorological and hydrological hazard forecasting to impact forecasting to early briefing and warning to action. The figure highlights the importance of early briefing to key stakeholders prior to issuing public warnings to ensure an effective response from public agencies. The standard meteorological process is shown in blue; the additional impact-based forecasts and warnings are shown in green.



The NMHS may or may not be responsible for issuing the impact-based warning. In some countries, this may be the purview of the disaster management agency or other designated authority. In all cases, however, there should be very close and continuous cooperation among the responsible agencies including the NMHS. This is particularly important where the hazardous situation may evolve rapidly escalating the threat and the need to update warning information frequently.

Implementing Impact-based Forecast and Warning Services

Based on the practical experience of the World Bank and the Global Facility for Disaster reduction and recovery (GFDRR), Rogers and Tsirkunov (2013) recommend that design and implementation of modernization projects for NMHSs have three basic components – Institutional strengthening, capacity building and implementation support; modernization of observing infrastructure and forecasting; and enhancement of the service delivery system.

Fundamental to the introduction of impact-based forecast and warning services is ability to provide timely and accurate forecasts of meteorological and hydrological hazards. Thus, there is no short cut to the transformation from the forecasting of "what the hazard will be to what the hazard will do". It requires a rethink of the structure of the organization and the way it operates, an expansion of training to strengthen capacity both within the NMHSs and with partner organizations and users, and new operational partnerships.

It requires investment in observing networks, including rehabilitation and reequipping meteorological, hydrological and other networks as required, introducing ground-based remote sensing systems for nowcasting and very-short range forecasting, upper air measurements, quality control and calibration facilities. It requires the modernization of communication and ICT systems, which meet WMO information system standards, archiving, data management and digitizing, and in the more advanced NMHSs it may include capacity for limited area numerical weather prediction. However, it is recommended to encourage greater reliance on regional specialized centres for routine NWP support, which also entails the willingness to share national data to provide more precise and accurate model products. The forecasting system requires computer and visualization systems to process observations and model products that provide the forecaster with guidance. Climatology-based regional and/or seasonal specific thresholds can provide a valuable starting point of discussions for the forecaster in estimating the severity and the impact of an event.

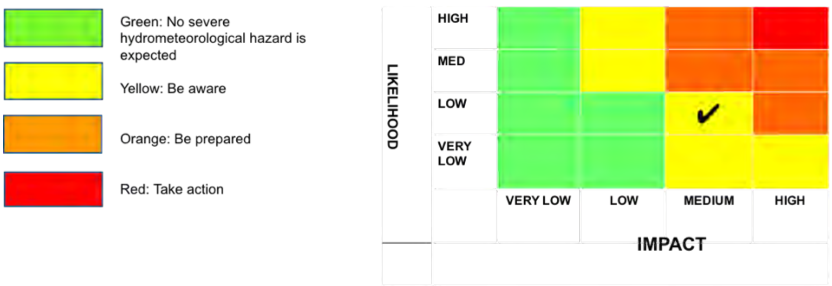
Enhancing service delivery starts with strengthening the public weather service function, particularly support for disaster management, the public, and the main economic sectors. It is within this component that weather, climate and hydrological forecasts would be transformed into impact-based forecasts and warnings, distributed and communicated with stakeholders. It is also the primary means to obtain feedback on the effectiveness of the forecasts and warnings and the actual situation in disaster affected areas, and the means to update information on vulnerability and exposure. The relationship between the NMHSs service delivery system and emergency/disaster management should be as close as possible, ideally with joint responsibility for issuing impact-based warnings (Rogers and Tsirkunov 2013). It is essential that this relationship is based on trust and mutual understanding of respective roles and responsibilities of each partner agency. Similarly, close working relations should be established with other sectors based on the development of shared standard operating procedures (SOPs).

The following is a step-by-step guide to help NMHSs and development partners in setting up an impact-based warning system.

Step 1: Develop the Risk Matrix

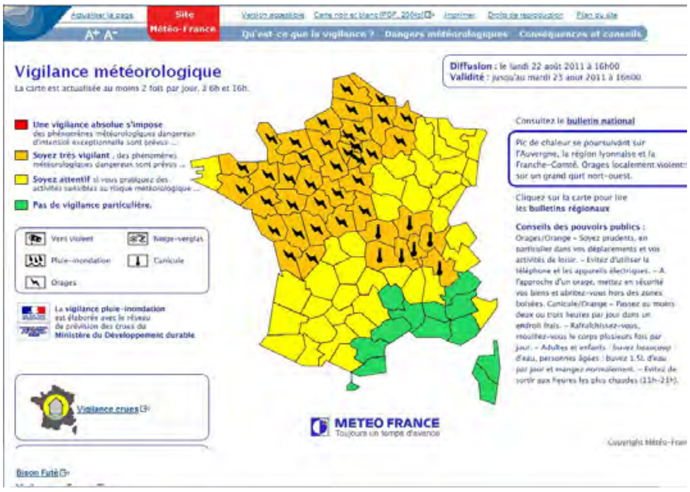
The basic tool of an impact-based warning system is the *Risk Matrix* (Figure 15). The matrix relates the expected impact of a hazard to the likelihood of occurrence of the hazard. The likelihood is best determined from a probabilistic forecast using ensemble techniques. The level of the impact is determined from knowledge of vulnerability and exposure. Together, these determine the severity of the warning using a four-colour system – green, yellow, orange, red.

Figure 15 The risk matrix (source: Met Office)



The arrangement of colours in the matrix is based on the experience of the UK Met Office, and should be fixed. It is recommended that warnings should only be issued when the impact is expected to be *Medium* or *High*. The impact of a hazard may increase without altering the likelihood of the hazard: this occurs when there is a forecast change in timing of the hazard; for example, a shift from night time to the morning "rush hour". It is therefore important for decision-makers to have access to the risk matrix as well as the colour-coded level of the warning. A red warning is limited to high likelihood, high impact only. Therefore, we should expect this to be a relatively rare occurrence. Warnings for different hazards should be consistent; it is recommended, therefore, to avoid creating alternative classifications for warnings since we want to minimize the risk of confusion among those at risk.

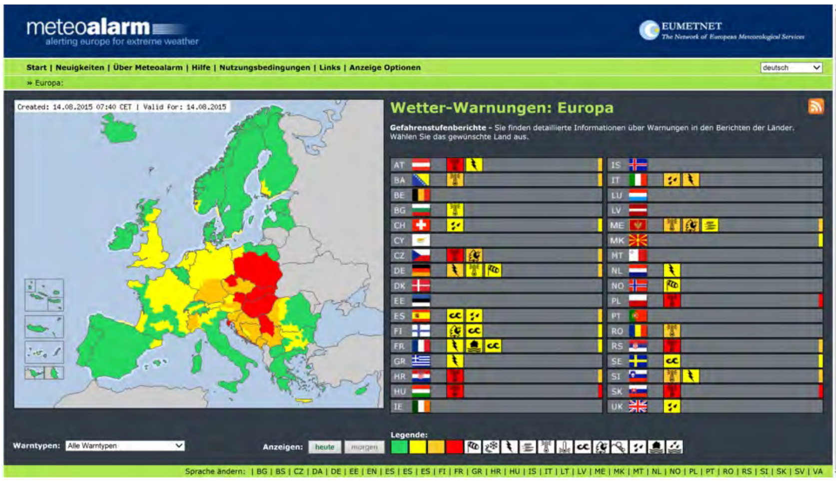
Figure 16 Example of the vigilance map used by MétéoFrance to display warnings of meteorological hazards and associated advice



In the case of a warning affecting a region, it is useful to map the warning. One approach to visualizing meteorological warnings is the "Vigilance météorologique" system developed by MétéoFrance (Figure 16) and utilized as the framework for the European MeteoAlarm (Figure 17). The vigilance system utilizes a gridded map based on administrative boundaries – 100 French Departments. Alternatively, geographical divisions could be used. The advantage of matching administrative boundaries is the presence of public officials in each of the "grid cells", which have responsibility for the first response to a warning. Colours – green, yellow, orange and red – are used to represent the severity of the warning, while symbols for each of the meteorological hazards – wind, rain, lightning/thunderstorms, heat and snow/ice are displayed to show the type of hazard. This has mostly been used for hazard warnings, but may be adapted to impact-based warnings.

Each grid cell may have its own granular structure depicting a much finer mesh and more detailed warning information. This is particularly important where there are terrain features, which may influence the meteorology or vulnerable infrastructure, requiring very high-resolution forecasts. This finer scale will be determined largely by the resolution and accuracy of the available numerical weather prediction guidance – ideally 1km or better in areas of critical infrastructure.

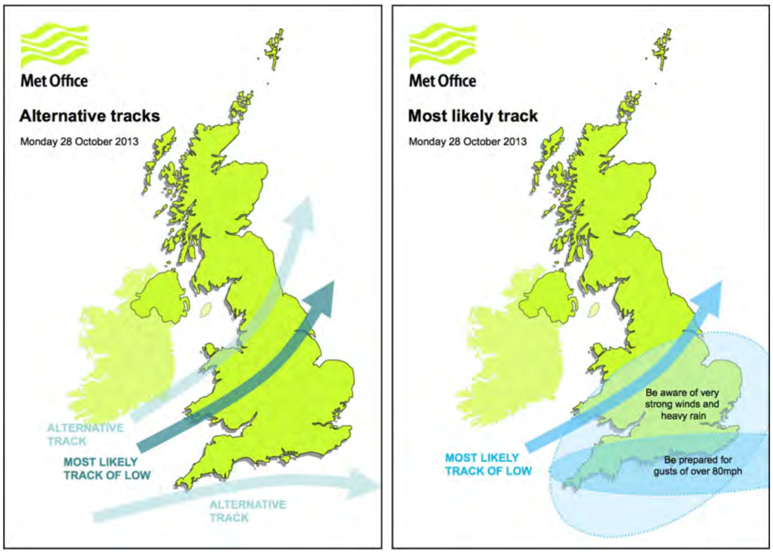
Figure 17 Example of the graphical output from the MeteoAlarm portal. The colour coding is consistent across all participating European countries.



A potential limitation of this approach is that it is not easy to represent alternative scenarios – the reasonable worst case versus the most likely scenario. In which case, additional information may be needed (see for example, Figure 18).

Establishing a uniform colour-coding system across different countries is not easy, particularly if a country has established different warning systems for different threats, which may have their own unique combination of colours, symbols and numbers.

Figure 18 Displaying most likely and alternative tracks of a storm system (Source: Met Office). Areas impacted could be shown for each scenario. This type of information is most useful for sectors, which are highly sensitive to impacts and required to act even if the likelihood is low or very low.



In the MeteoAlarm Programme of EUMETNET, led by ZAMG, this was overcome by focusing not on meteorological parameters, but on the priority of the impact of extreme weather and the necessary actions to be taken by emergency responders and people concerned. This gave a clear guideline for meteorological thresholds, which must differ very much per the climatology of the different regions, vulnerability and exposure of endangered people and goods.

The level red is therefore primarily defined by the success criteria on the advice: "follow the order of authorities under all circumstances and be prepared for extraordinary measures" and in this way, result orientated, instead of being focused on meteorology.

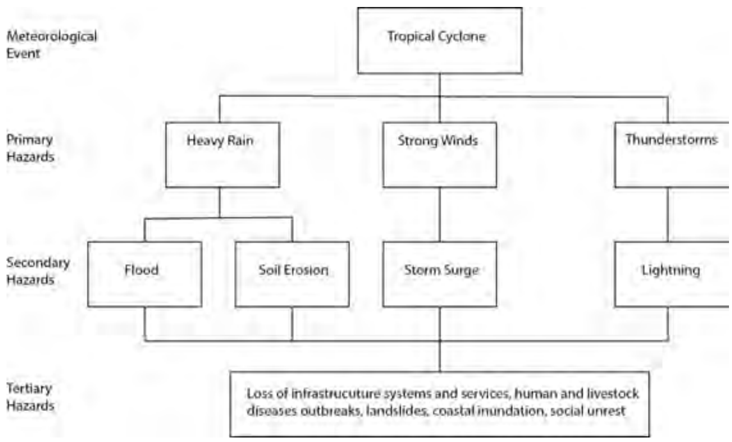
The homogenization of the MeteoAlarm system process took several years and required close cooperation and exchange of knowhow with Civil Protection and first responders. Within the participating Met Services, collaborative decision-making was a way to involve forecasters, climatologists, civil protection and media experts both in the planning and the actual decision making process.

As European cross country investments, exchange of work force and tourist movements increased significantly during the last 15 years, a homogenized warning system of well-coordinated National Weather Services provides the best available information for any user outside his own country. The output of the MeteoAlarm system is presently reused by more than 1000 information providers across the globe. A second important user emerged during the last 3 years with the ERCC (Emergency Respond and Coordination Centre) of the European Commission, who used the MeteoAlarm system is primary input for a European overview and funded several of additional features.

Step 2: Identify Events and Hazards

The identification of all events impacting the territory of the country, and the primary, secondary and tertiary hazards (Table 4) is required. The primary hazards are caused directly by the event and cannot be mitigated to any significant extent (e.g., rain will fall). The secondary hazards are related to the primary hazard and can often be partially mitigated (e.g., structural works can reduce the possibility of a surface flood in an urban area). The tertiary hazards, which are generally non-meteorological or hydrological, are caused by the primary and secondary phenomena or may be a consequence of human failure. The latter have the greatest scope for mitigation by either structural measures to reduce vulnerability or exposure or both. An example of a cascade hazards and the impact is a warning of illness (risk of impact), which could occur in the population vulnerable and exposed to an infectious disease (tertiary hazard) caused by contaminated floodwater (secondary hazard) resulting from a flood caused by monsoon (event) rains (primary hazard). Based on this information, sector-by-sector hazard matrices can be developed (Figure 19). The distinction between an event and a hazard is important because a single event may include multiple hazards. A tropical cyclone is often mistakenly referred to as a hazard; it is the high wind, rainfall, floods and storm surge within the cyclone that causes the damage. The intensity of these hazards is highly variable in time and space requiring precise location-specific forecasts. The use of the various scales to estimate tropical cyclone intensity is at best only indicative of the strength of the winds, it does not say anything about the specific impact of the meteorological and hydrological hazards. This can be misleading. Hurricane Sandy in the United States illustrates the problem: in this case, responders and communities lowered their guard interpreting the meteorological downgrading of the storm from a hurricane to an extratropical cyclone by the National Weather Service as a weakening of the intensity of the overall system. In fact, the winds remained strong resulting in extensive damage that might have been averted had the communities and responders remained more vigilant.

Figure 19 Example of a hazard matrix hierarchy. This illustrates the cascading nature of hazards where there is a causal relationship among primary, secondary and tertiary hazards. The distinction between a tertiary hazard and impact is subtle. Tertiary hazards have wide ranging social and economic impacts. For example, we consider a disease is a tertiary hazard – a resulting illness is an impact because it is a consequence of exposure and vulnerability to that disease.



Identifying each hazard with a unique symbol can help establish its importance. Table 4 shows the hazards identified by stakeholders in Myanmar during a workshop in 2015.

Table 4 Multiple hazards resulting from meteorological events defined by stakeholders at a workshop led by the Department of Meteorology and Hydrology, Myanmar

Event	Primary hazards	Secondary hazards	Tertiary hazards
Cyclone	• Strong wind • Lightning • Heavy rainfall • Tornado	• River flood • Surface water flooding • Flash flood • Landslides • Storm surge • Water level rise in reservoirs • River bank erosion • Muddle	• Damage in Dams and appurtenant structures, embankment, irrigation and drainage facilities, pumping facilities • Submerging paddy fields • Migration • Food shortage • Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Waterborne diseases • Environmental degradation • Snake bite • High sediment transport into reservoirs
Monsoon	• Strong wind • Heavy Rainfall • Lightning • Monsoon break	• River flood • Coastal flood • Flash flood • Landslides • Less rainfall amount	• Damage in Dams and appurtenant structures, embankment, irrigation and drainage facilities, pumping facilities • Submerging paddy fields • Insect and pest problems • Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Infectious diseases • Waterborne diseases • High sediment transport into reservoirs • Snake bite • Sand and silt deposition
Heat wave	• Extreme temperature • Heat related complications in livestock and animals	• Heat stroke • Widespread Fire • Urban Fire • Biological Hazards • Stress on vegetation • Water insecurity	• Socio-economic impacts • Hydro power shortage • Changes in ground water level • Water borne diseases (eg. Conjunctivitis) • Food shortage
Drought	• High temperature • Heat wave • Less rainfall amount	• Water scarcity • Low flow (low river flow) • Lesser inflow • Forest fire and surface fire • Damage to crops	• High evaporation loss in reservoirs • Shortage of storage water in Reservoirs • Insufficient diversion in weirs • Salt affected soil • Food Shortage • Energy Shortage • Pumping System Difficulties • Air pollution/haze • Smog/Dust • Sand dunes
Earthquake	• Shake • Shifting Geological Formation	• Landslides • Tsunami • Fire	• Damage in Dams and appurtenant structures, embankment, irrigation and drainage facilities, Pumping Facilities, • Loss of Infrastructure System and Services (shelter, transportation, schools, hospitals, energy supply, communication) • Coastal Flood • Changes in Ground water formation • Psychological problems

Step 3 Assess Vulnerabilities Related to the Identified Hazards

Various tools exist to carry out vulnerability assessments. They should be infrastructure system and service specific. For example, the vulnerability of bridges and roads to inundation or destruction due to flooding should be estimated. Understanding the interdependencies of the infrastructure systems and services is essential – for example, the vulnerability of transportation networks to flooding and to the destruction of bridges, roads, rail should be assessed (Rogers et al. 2015). A good reference, among many examples, is the data base created for the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) (World Bank 2012, 2013). GFDRR supports the development of risk assessments in several ways, including conducting risk assessment studies, developing guidelines for risk assessment methodologies, supporting the development and distribution of spatial risk datasets and setting up platforms as risk analysis and communication tools for decision-makers.

However, to date, these data have been used primarily for planning and infrastructure investment, but have not been used routinely to improve forecasts and warnings. The GFDRR Innovation Lab can provide additional guidance on this. A useful approach is the Open Data for Resilience Initiative (OpenDRI), which provides a guide to the collection of the appropriate disaster risk management data and the use of InaSAFE to visualize potential impacts of hazards on specific infrastructure. In its simplest form, InaSAFE can be used to establish geographical specific thresholds for impact-based warnings. A more advanced form would use the vulnerability data within a time dependent model to forecast the evolving situation, which would have the potential to target the generally limited civil protection resources to maximum effect. Given the request by many NMHSs to access digital forecast data, this model approach may be the most appropriate. However, at its simplest, vulnerability information can be based on expert knowledge, which can be used to develop qualitative statements about impacts.

Step 4 Develop Impact Tables

An impact table needs to be developed for each hazard and for each sector. It requires knowledge of the hazard and expert knowledge of the likely impact on a specific sector. This may or may not be informed by a formal vulnerability assessment. At its most basic it would rely on expert knowledge rather than quantitative data. In the case of flood risk, this may involve water resource managers, irrigation experts, dam operators as well as disaster managers. An example developed for the UK by the Met Office is shown in Table 5. In this case the information is still general, but can be more geographically specific and targeted to specific groups at risk.

Table 5 Example of a flood impacts table for the public (Source: Met Office)

Flood Impacts Table for the public			
Very Low	**Low**	**Medium**	**High**
• Generally, no impact expected • Isolated and minor flooding of low lying land and roads • Isolated instances of spray/wave overtopping on coastal defences • Little or no disruption to travel although wet road surfaces or waterlogging could lead to difficult conditions • Isolated damage to vegetation due to wind	• Localized flooding of land and roads • Localized flooding could affect individual properties • Individual properties in coastal locations affected by spray and/or wave overtopping • Localized disruption to key infrastructure identified in flood plans (e.g. rail and utilities) • Local disruption to travel • Localized damage to properties due to wind	• Flooding affecting properties and parts of communities • Damage to buildings/infrastructure is possible • Possible danger to life due to fast flowing/deep water/wave and storm surge overtopping/wave inundation, landslides and wind • Disruption to key infrastructure services identified in flood plans (e.g. rail, utilities and hospitals) • Disruption to travel is expected. Several roads are likely to be closed • Outbreaks of illnesses caused by water-borne diseases possible • Isolated food shortages • Localized water contamination	• Widespread flooding affecting significant numbers of properties and whole communities • Collapse of buildings/infrastructure is likely • Danger to life due to fast flowing water/ deep water/ wave, storm surge overtopping and wave inundation, landslides and wind • Widespread disruption caused by loss of infrastructure identified in flood plans • Large scale evacuation of properties may be required • Severe disruption to travel. Risk of motorists becoming stranded. • Large scale evacuation of people may be required • Severe disruption to travel. • Outbreaks of illnesses caused by water-borne diseases expected

Step 5 Develop Advisory Tables

A final component of the warning system is to provide advice on what actions to take. These messages will be tailored to specific needs of each stakeholder. Typically, this will involve disaster management and other key stakeholders. Examples of alerts and warning advisories and actions are shown in Table 6.

Table 6 Advisory Table for the public, which relates warnings and actions to the probability of an impact based on an impact risk matrix. The levels reflect the colour coding of the risk matrix (Adapted from Met Office)

Advisory Table			
Very low risk	**Low risk**	**Medium risk**	**High risk**
1. Example of flood risk for the public associated with a Tropical Cyclone event			
ALERT: Unlikely the Tropical Cyclone (Event) will affect the designated region **ACTION:** Keep an eye on the weather and flood forecasts	**ALERT:** Likely the tropical cyclone will cause some limited flooding and wind damage in the designated region **ACTION:** Remain alert and ensure you access the latest weather forecast for up to date information. Prepare to act to protect life, livelihood and property in the designated region.	**WARNING:** Likely the tropical cyclone will cause widespread flooding and wind damage in the designated region **ACTION:** Secure property and livelihood assets. Be prepared to evacuate. Be aware of the potential risk of landslides and flash floods in your area. Follow civil protection orders. Maintain radio/media watch for latest updates.	**WARNING:** Certain tropical cyclone will cause widespread flood and wind damage in the designated region **ACTION:** Evacuate if ordered to do so by civil protection Be prepared for extraordinary measures to protect life and property

An advisory table for a specific sector would include more detailed information (Table 7)

Table 7 Advisory table for dam operations, which relates warnings and actions to the probability of an impact based on an impact risk matrix.

Advisory Table			
Very low risk	**Low risk**	**Medium risk**	**High risk**
1. Example of flood risk for dam operations associated with a Tropical Cyclone event			
ALERT: Unlikely the Tropical Cyclone (Event) will affect the designated region **ACTION:** Keep an eye on the weather and flood forecasts	**WARNING:** Likely the tropical cyclone will cause some limited flooding and wind damage in the designated region **ACTION:** Expected inundation levels do not require any action, but beware of the potential for the risk to increase	**WARNING:** Likely the tropical cyclone will cause widespread flooding and wind damage in the designated region **ACTION:** Activate standard operating procedures associated with an orange alert to mitigate the risk of damage to the dam and appurtenant structures and mitigate the risk of exacerbating flooding downstream of the dam SOPs will include all measures to warning others potentially impacted by the dam operations	**WARNING:** Certain tropical cyclone will cause widespread flood and wind damage in the designated region **ACTION:** Activate standard operating procedures associated with a red alert to mitigate the risk of damage to the dam and appurtenant structures and mitigate the risk of exacerbating flooding downstream of the dam. SOPs will include all measures to warning others potentially impacted by the dam operations

Effective standard operating procedures are a critical component of the successful management of risk. This is discussed in more detail below. Key elements are good communication among the relevant stakeholders and timely action.

Key elements of an Impact-based Forecast and warning Service

Partnerships

A successful impact-based forecasting service will require close operational cooperation with the agencies responsible for meteorology, climatology, hydrology, disaster management, and first-responders as well as other sectors with access to, and ownership of, data on infrastructure systems and services (e.g., energy, transportation, health, water resources). This would require a high-level agreement that describes the commitment of the agencies to work closely together to share data, information, expertise and responsibility. The sectors with information on their own vulnerability will also be the ones that would benefit the most from impact-based forecast and warning services.

There should be flexibility to expand this partnership as required to achieve the objective. The partnership would benefit from the inclusion of media, NGOs and others responsible for direct interaction with communities. The partnership may also include WMO regional centres and representatives of other NMHSs and flood forecasting agencies. The details need to be developed during initial definition of the partnership within a country.

Given the importance of reducing the impact of meteorological and hydrological hazards on societies, the partners may expect to have high visibility nationally and internationally. The partners will have access to technologies and training to enable them to communicate the results of the project effectively.

Joint Development of Information and Services

The partnership is a perquisite for the joint development of services. This would include using 24/7 operational forecasting capabilities of the NMHS, joint development of flood forecasting, and joint operations combining the expertise of meteorologists, hydrologists, disaster managers. The implementation of a joint operations centre should be considered.

Developing capacity of NMHSs' and disaster management staff, partners and users

Frequent training is essential to increase and maintain the skills of an NMHS's staff in different areas of their work. Such training should be viewed as a continuous process, in which all staff members are involved in a long-term program to improve their skills. As part of the twinning arrangements, study tours and familiarization visits should be organized to expose senior management and forecasters to specific advanced technologies that could be implemented to improve forecast production and delivery. Priorities for technical training should focus on modern forecasting methods and application of technologies that are fit for purpose for the level of capacities that exist in individual NMHSs. For example, in the absence of radar which would allow more reliable and accurate forecast of rainfall due to convective activities, other technologies or techniques could be employed by the forecasters to help them with this kind of prediction.

However, in the case of impact-based forecasting and warning services, forecasting skills alone are not sufficient. A very important part of such training should be on relationship building and developing skills in collaboration and communication with staff from other organizations. For the NMHS, this could be accomplished by designating staff as warning advisors with counterparts, sometimes referred to as lead resilience advisors located in emergency management or emergency operations.

Building trust among all involved in impact-based forecasting is a key to ensure that all participating agencies and individuals realize the crucial role that each play towards maximizing public safety in the face of severe events. Sharing of information and data is a specific aspect of such a relationship building. In the case of many countries special authorization needs to be granted by higher levels of government for different organizations to share their data. In country training on impact-based forecasting techniques should be conducted for all members of the operational team, which would include designated staff from the NMHS and emergency management. Ideally, DRM specialists and hydrological specialists would be temporarily assigned to work within the forecast office of the NMHS. These specialists would have the responsibility for the development of the impact-based forecasts and warnings, based on the meteorological and hydrological information provided by the NMHS. Alternative approaches should also be explored to determine the optimum arrangements. The initial training would focus on the qualitative translation of weather forecasts to impact-based forecasts and warnings.

Twinning with one or more advanced NMHSs, which have already developed impact-based forecast and warning services would also be desirable. The pairing arrangement would provide operational backup for the forecasters, enabling them to receive guidance on complex weather situations, and with public weather service divisions to assist in the translation of meteorological and hydrological information into impact-based forecasts and warnings. The twining arrangements would also enable the NMHS to focus more attention on impacts and service delivery and less on the details of the production of the weather forecast.

Validation

Validation and verification are important components of any forecasting system. However, impact-based forecasting and warning systems need different methods to those applied to objective forecasts. Here the emphasis is on the *utility* of the forecast, not just the *accuracy* of the underlying meteorological or hydrological prediction. This requires agreement among stakeholders and partners on what constitutes utility and cooperation to analyse and evaluate events to improve the warning system.

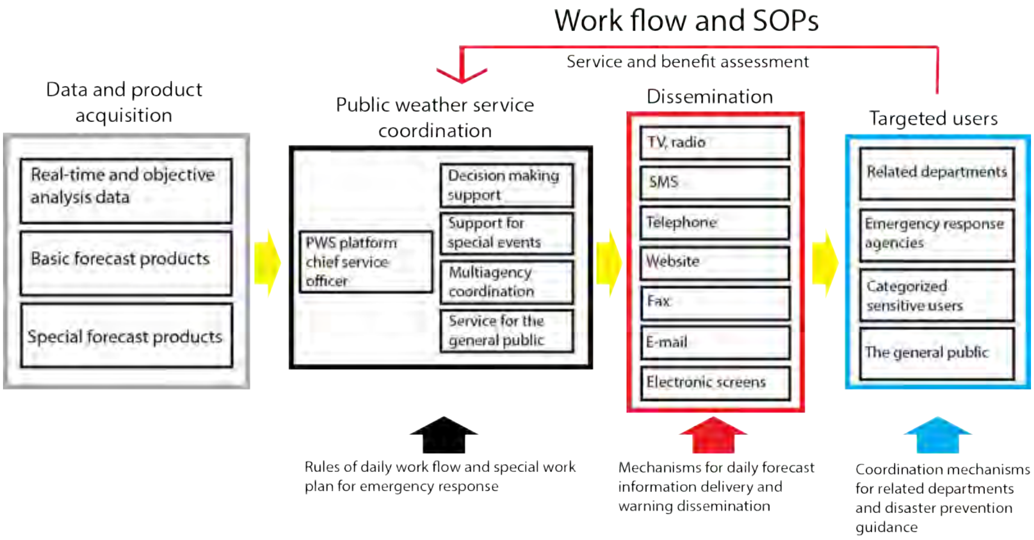
Public Weather Service and Standard Operating Procedures

The framework for the provision of services is usually a separately defined group within the NMHS, which is referred to as the Public Weather Service (PWS) (WMO 2012). Weather forecast production is the purview of forecasters. The PWS function translates those forecasts into actionable information. In the case of impact-based forecasts this is done by combining the weather forecast with vulnerability information stored in a database. The database platform consists of historical and real-time data supplied by all agencies and sectors. The number of agencies involved is likely to be large. In the case of Shanghai, for example, more than 17 departments support this database. In the UK, more than 11 agencies provide data essential to produce impact-based forecasts.

Key components of effective impact-based warning services are Standard Operating Procedures (SOPs), which codify the roles and responsibilities of all stakeholders and actors in all possible scenarios. In Shanghai, there are at least 36 joint-response mechanisms among 25 government departments. An example of the public weather services workflow developed by the Shanghai Meteorological Service is shown in Fig. 10 (Rogers and Tsirkunov 2013). Early briefing (see Fig. 4) prepares the departments to act ahead of joint-response mechanisms and prior to issuing public warnings.

Another important element, highlighted by Rogers and Tsirkunov (2013), is the inclusion of the warning system within the public weather service operations. The person in charge of the public weather service is responsible for disseminating routine weather information and impact-based forecasts and warnings. It should be noted that the final dissemination of warnings to the public may be governed by the governmental structures and practice which determine the flow of the information. For example, while in some countries the NMHS is responsible for and authorized to disseminate the warnings directly to public, in some others, the warnings are disseminated through the disaster management organizations. While the structures and legal mechanisms in each country should be respected, the most important point is that procedures should not introduce delays and hinder the dissemination of highly perishable information (e.g., warnings of a flash flood expected to impact a city at rush hour), hence putting the public and responders in unnecessary danger.

Figure 20 Public Weather Service Workflow (from Rogers and Tsirkunov 2013)



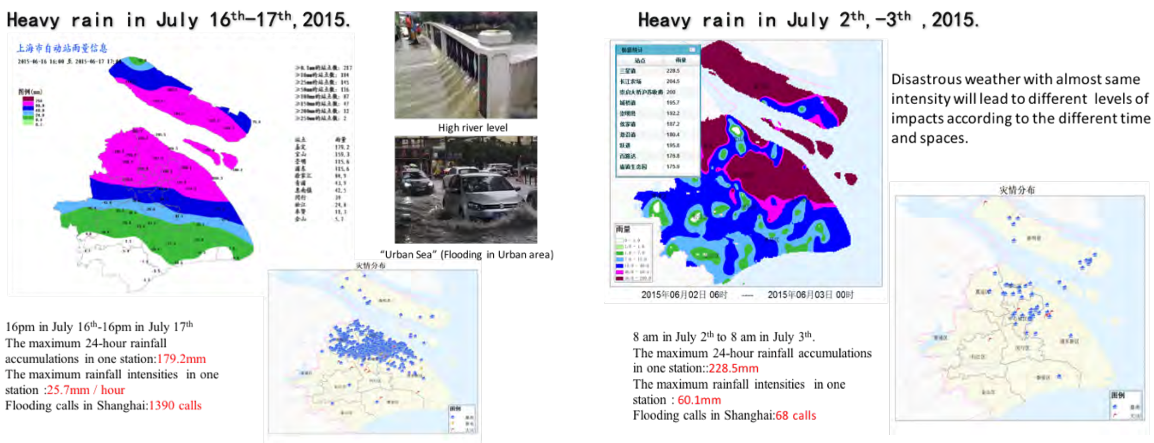
The Practice of Impact-based Forecast and Risk-based Warning Services in Shanghai

The Case of Urban Flooding

Wang Qiang described the evolution of forecasting services in Shanghai. The impetus for the focus on impact-based forecasting and warnings is related to the need to strengthen urban flood forecasting. The following highlights the issue (Figure 21).

Heavy rainfall can lead to quite different impacts depending on the specific time and location of the events. In the first instance (Figure 21a), rainfall accumulations of up 179 mm and maximum intensity of 25.7 mm/h resulted in 1390 flood related calls to the operations centre. In contrast, an apparently more intense system with rainfall accumulations exceeding 228 mm and maximum intensity of 60.1 mm/h resulted in on 68 emergency calls to the operations centre (Figure 21b).

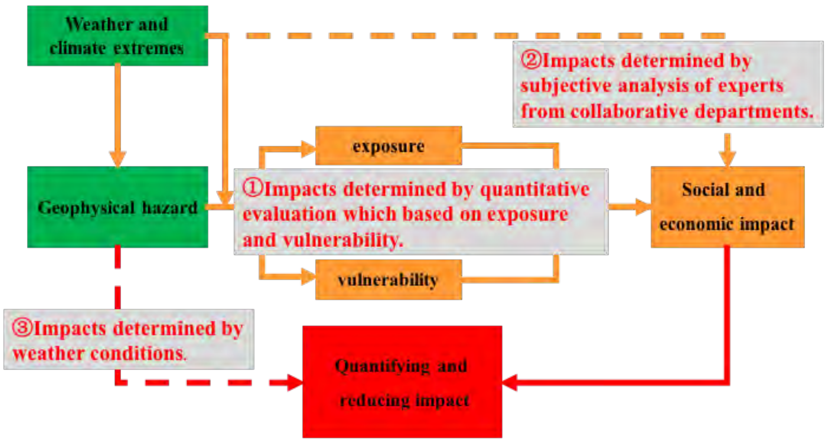
Figure 21 Comparison of two heavy rainfall events in Shanghai: a) July 16-17, 2015 & b) July 2-3, 2015 (Source: Wang Qiang)



Exposure and Vulnerability

Figure 22 illustrates three approaches to impact-based forecasting based on access to vulnerability and exposure data: 1) the ideal approach where impacts are quantitatively determined based on exposure and vulnerability data; 2) impacts are determined subjectively; and 3) impacts are determined by weather conditions alone. With the capacity to acquire extensive vulnerability and exposure data, Shanghai has developed an urban flood impact-based forecast and risk based warning system based on quantitative evaluation of exposure and vulnerability.

Figure 22 Urban flood impact-based forecast and risk-based warning should be based on quantitative evaluation of exposure and vulnerability (Source: Wang Qiang)

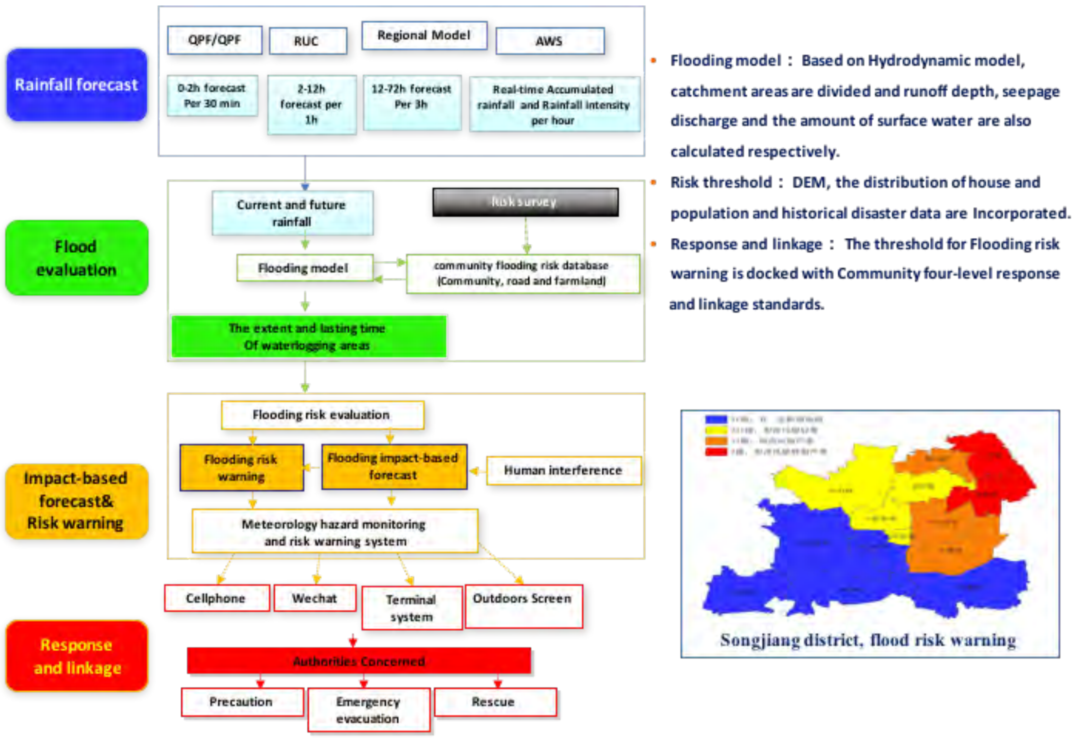


WMO《THE WMO GUIDELINES ON MULTI-HAZARD IMPACT-BASED FORECAST AND WARNING SERVICES》（CBS TT-IMPACT， WMO-No. 1150）

Urban Flood impact-based forecast and risk-based warning system

The resulting forecast system flow chart is shown in Figure 23. It is comprised a rainfall forecast; flood evaluation; impact-based forecast and risk warning; and response. The rainfall forecast is based on a combination of rainfall observations, data assimilation and quantitative precipitation forecasts, which drive a hydrodynamic flood model. With access to digital elevations, data on assets, etc., risk thresholds, which underpin the warning system, are calculated. These outputs feed into the meteorological hazard monitoring and risk warning system, which enables distribution of alerts and warnings via mobile phones, WeChat, public terminals, outdoor screens, etc. with standard procedures for an effective response to the situation.

Figure 23 Impact-based forecast and risk-based warnings service flow chart for urban flooding



The system combines rainfall forecast products, supported by high resolution regional models (Figure 24) with data on potential high risk points, such as roads and living quarters and important sites, such as primary and secondary schools (Figure 25).

Figure 24 Rainfall forecast products: support from high resolution models (Source Wang Qiang)

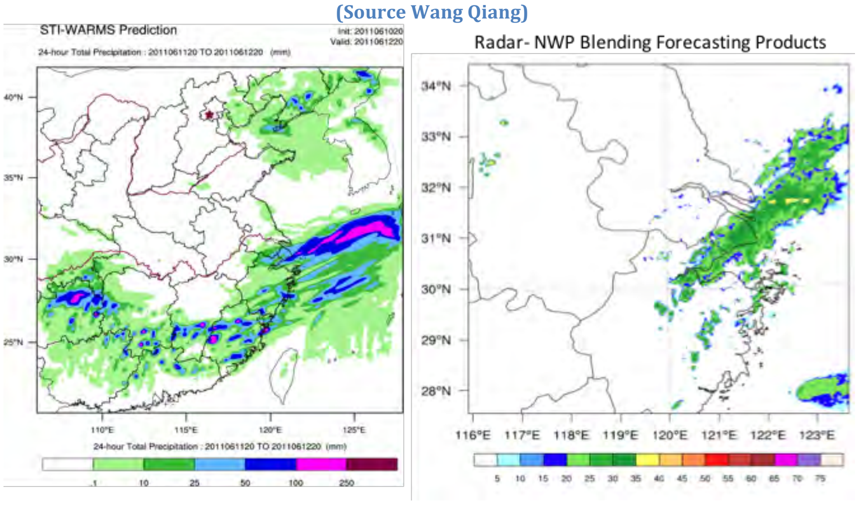
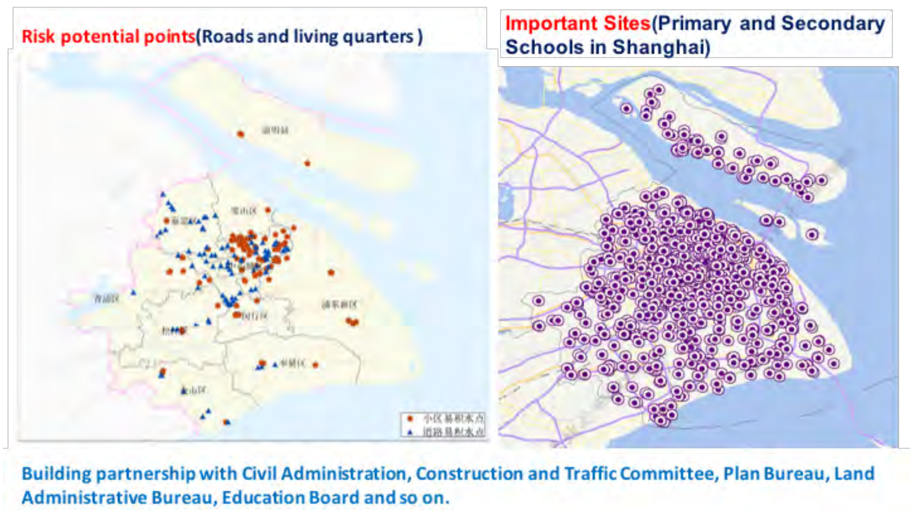


Figure 25 Building data sharing mechanism for long-term data sharing and regular updating (source: Wang Xiang)



Data from authoritative and crowd sources are combined in the emergency centre providing real-time monitoring of an emergency (Figure 26).

Figure 26 Building data sharing mechanism for real time information (source Wang Qiang)

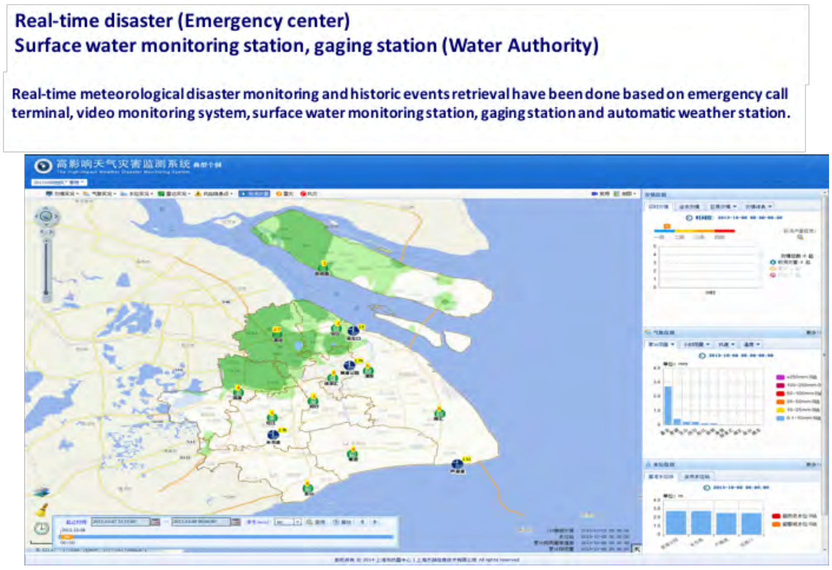
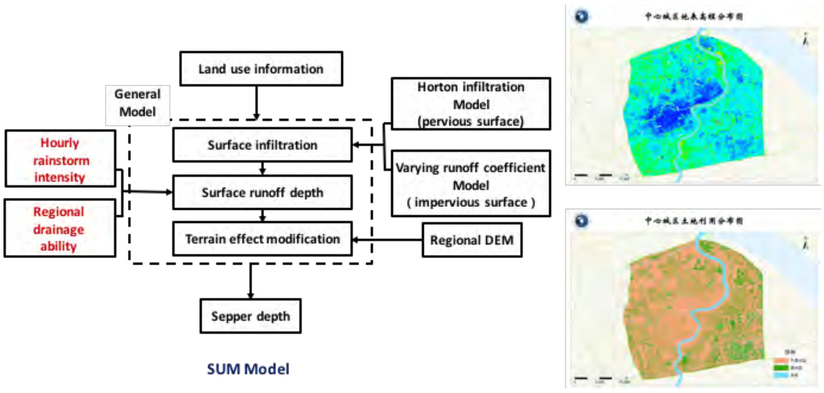


Figure 27 Urban Flooding Assessment model (Source: Wang Qiang)



Urban Flooding Assessment Model

The Shanghai Urban flooding assessment model (SUM) simulates rainfall runoff processes within the city and calculates surface water depth and water distribution based on digital elevation, etc. (Figure 27).

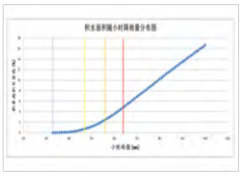
Verification

Verification of assessment results are carried out by 8 teams, which conduct field surveys of disaster areas immediately after a hazardous event (Figure 28).

Figure 28 Verification of assessment results (Source: Wang Qiang)

Figure 29 urban flood impact levels and hazard thresholds (Source: Wang Qiang)

	Low	Medium	High	Very High
Urban flooding Impact level	Houses inundated and surface water appeared in the low areas and etc.	Houses inundated , some roads inundated and etc.	Houses inundated badly, some roads inundated and etc.	Houses inundated badly, roads inundated badly and etc.
Surface water area ratio and water depth	(0,1.25%)	[1.25%,2.5%) or deepest depth >15cm	[2.5%,5%) or deepest depth >35cm	[5%, +∞) or deepest depth >50cm



Determining urban flooding impact levels and relevant hazard thresholds

Figure 29 illustrates the urban flood impact levels and surface water area ratio and water depth used to determine the level of impact.

Warning Icons

An important aspect of impact-based warnings is the evolution of signals from warnings based on meteorological thresholds to warnings based on impacts (Figure 30). Icons are a very useful way to convey the level of risk.

Figure 30 Comparison of a) meteorological and b) impact-based warnings (Source: Wang Qiang)

a) Warnings based on fixed meteorological thresholds

Warning Icon	Explanation
暴雨 RAIN STORM	Rainfall accumulations of 50mm in 12 hours
暴雨 RAIN STORM	Rainfall accumulations of 50mm in 6 hours
暴雨 RAIN STORM	Rainfall accumulations of 50mm in 3 hours
暴雨 红 RAIN STORM	Rainfall accumulations of 100mm in 3 hours

b) Urban flooding impact-based warnings

Warning Icon	Explanation
	Low risk. Relevant preparation work for pumping must be done.
	Medium risk. Monitoring work must be continue and relevant preparation work for pumping must be done.
	High risk. Real-time monitoring and rescue are needed ASAP.
	Very High risk. Real-time monitoring, rescue and proper aid for victims are needed ASAP.

Service interfaces

SMS has developed several new service interfaces to communicate differentiated warning information to stakeholders. The community meteorological risk warning service system, which is based on a 3-d realisation of the city, is used by the Community Grid Management Centre to manage flood risks. The system displays the meteorological disaster risk analysis, real-time meteorological information and tailored warning information (Figure 31).

Figure 31 Urban flood forecasting displays in the Community Grid Management Centre (source: Wang Qiang)

Urban flooding risk assessment

The system has been using by the community gird management center

New tools using "smart media" are also available to the public through "My weather station" app, which provides warnings, real-time data, 5-day forecasts and typhoon track forecasts. Meteorological services are also embedded in a smart TV information system (Figure 32). Smart Songjiang information platform has currently about 300,000 cable TV users, broadband users and mobile phone users.

Figure 32 Smart Songjiang Platform (Source: Wang Qiang)

Home page of Smart Songjiang information issuing platform

Secondary page of community meteological services

In summary for Shanghai, compared with the traditional weather forecast, the impact-based forecast and risk-based warning is more practical as they meet the needs of users, while they also require close cooperation with users. In different areas and periods of impact-based forecasting and risk-based warning, different methods should be adopted to collect, estimate and use exposure and vulnerability data. The uncertainty of the weather forecast and flooding evaluation affects the accuracy of impact-based forecasts and risk-based warnings. Thus, ensemble forecasts and probability forecasts should be used. New communication techniques and tools are used to promote the understanding and use of impact-based forecasts and risk-based warnings.

China National Perspective

Chan Xiao from the National Climate Centre, CMA provided a national perspective on meteorological disaster and disaster risk management. China is prone to frequent disasters caused by meteorological hazards – drought; heat waves; heavy rain; strong winds; floods; typhoons; thunderstorms; and dust storms (Figure 33).

Figure 33 Main meteorological hazards impacting China (Source: Chan Xiao)

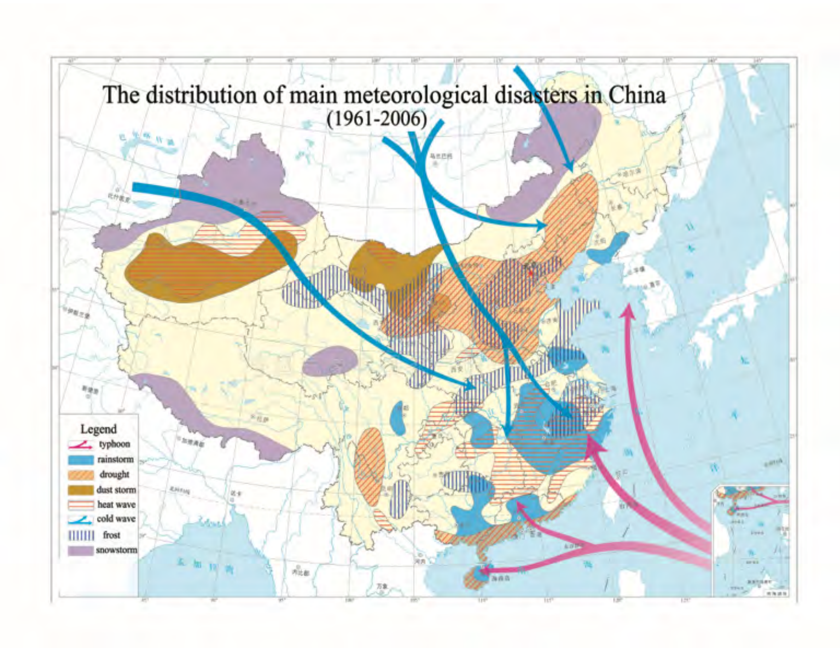
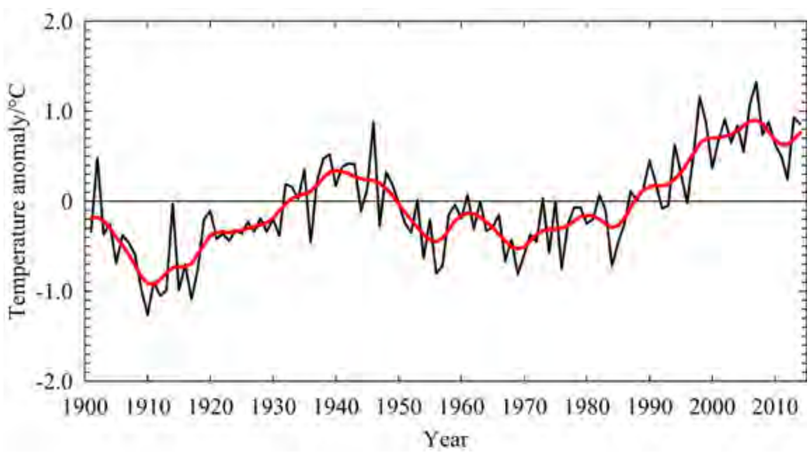


Figure 34 Annual mean temperature anomalies in China during 1901-2014 (relative to 1971-2000) (Source: Chan Xiao)



China has experienced a warming of the land averaging 1.09°C between 1901 and 2014 (Figure 34).

Figure 35 shows the annual losses in China due to meteorologically-related disasters. The annual number of casualties is about 3600; the direct economic losses are about 230 billion RMB, which corresponds to 71% of the entire economic losses from natural disasters.

Figure 35 Losses due to meteorologically-related disasters (Source: Chan Xiao)

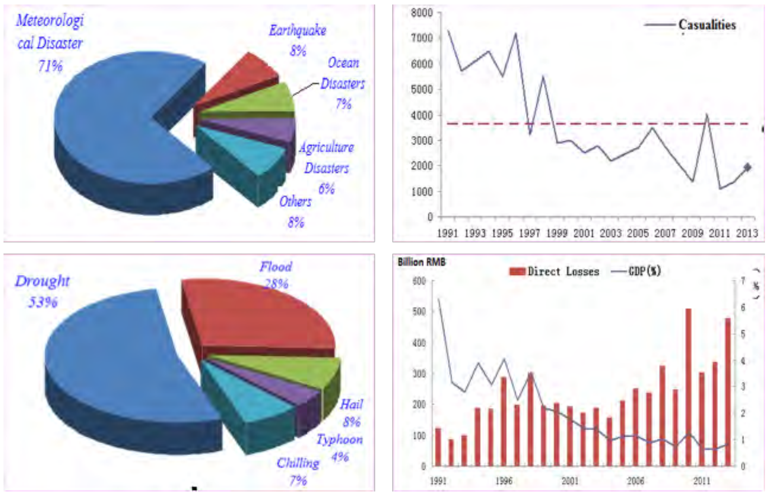
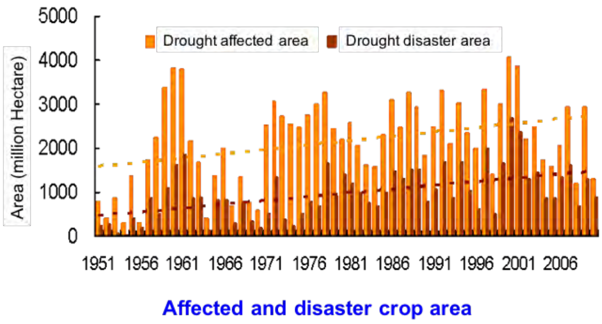


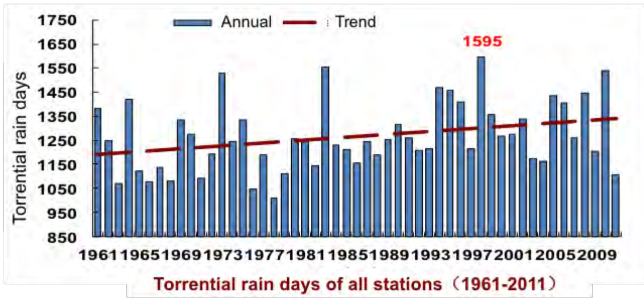
Figure 36 Drought events and area exposed are increasing (Source: Chan Xiao)



Drought is one of the major causes of disasters facing the agricultural sector. Every year grain losses total between 25 and 30 billion kg. Since 1961, the frequency of droughts has increased along with the area affected (Figure 36).

Figure 37 Torrential rain days have increased significantly (Source: Chan Xiao)

The frequency of heavy rain events has also increased since 1961 with floods affecting 40% of the population, 35% of arable land and 50% of industrial and agricultural output value (Figure 37).



Trend of Torrential rain days in Seven largest river basin

	Pearl	Yangtze	Huai	Yellow	Hai	Liao	Songhua
Trend	↑	↑	↑	↓	↓	—	—

Cold waves are generally decreasing in China; however, anomalous cold periods in the south cause significant impacts to people and the economy. In contrast heat waves are increasing with prolonged periods above 35°C.

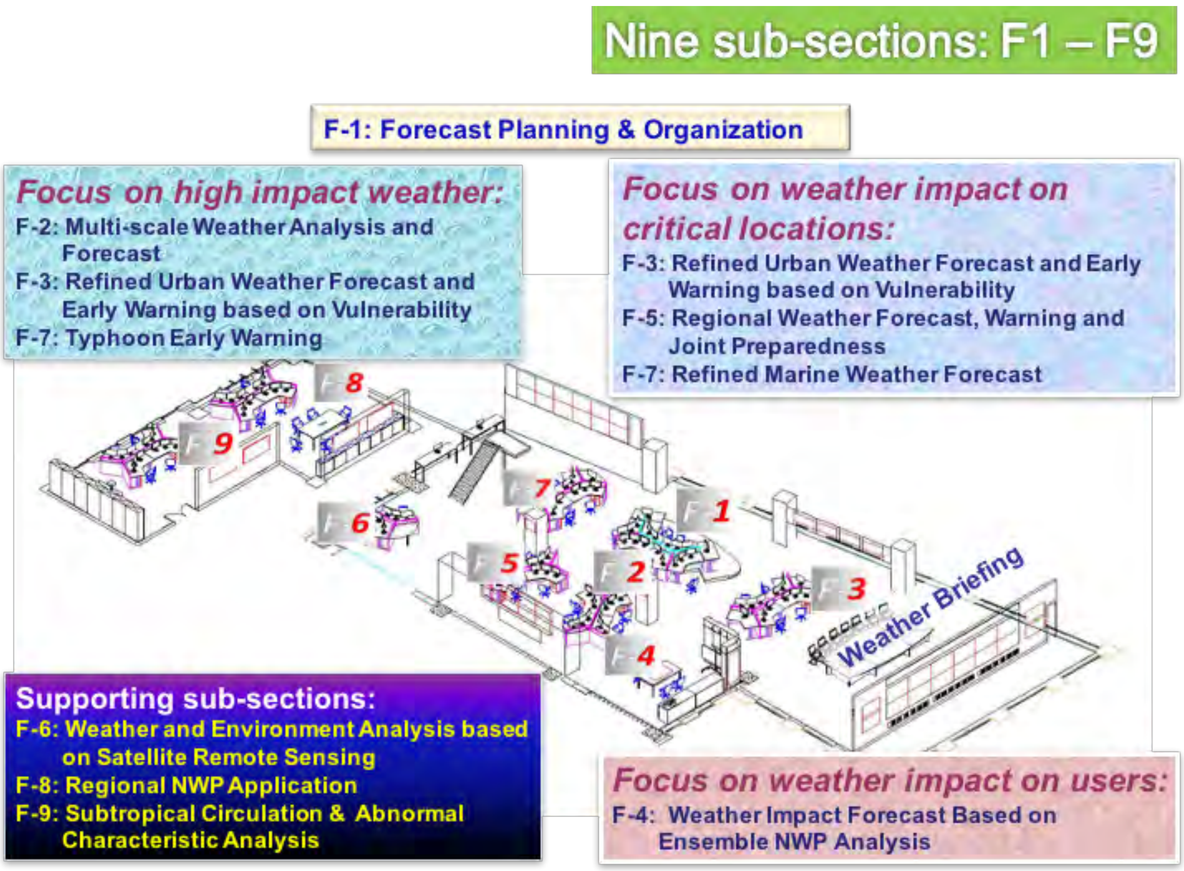
Because of these increasing threats, there is a new demand for disaster risk reduction. While China can predict severe weather with sufficient accuracy, there is a need to determine the impact of severe weather. This has led to the development of impact-based forecasting and risk-based warning systems throughout China. A key element of China's effort to reduce the impact of disasters is adherence to laws, regulations and policies designed to enhance meteorological disaster risk reduction; these include the meteorological law of the People's Republic of China, the Flood Control Law of the People's Republic of China, the Regulations on Prevention of and Preparedness for Meteorological Disasters, and the Drought Control Regulation of the People's Republic of China.

Overall monitoring and forecasting systems have improved significantly. Warning information services are continuously expanding and the overall reach through all media exceeds one billion people daily. Progress has been made in building multi-agency synergy for the prevention and preparedness for meteorological disasters and public awareness of disaster prevention and emergency self-rescue capacity has increased.

Meteorological Operations at Shanghai Meteorological Service

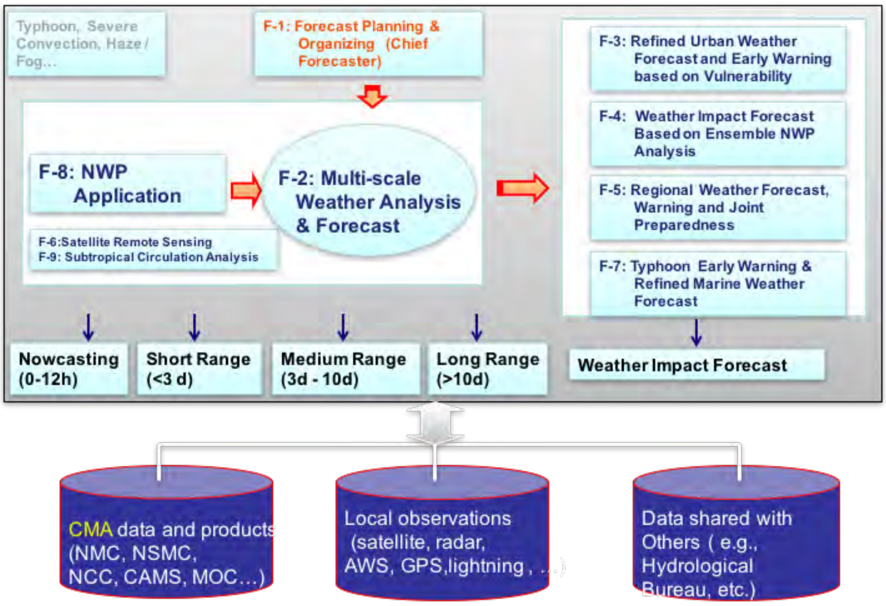
The workshop participants visited the SMS operations centre. All description of the SMS operations can be found in Part 2 of this report. The integrated platform for meteorological operations consists of three areas: the weather forecast area, IT support and data services, and the public weather service area. A schematic of the weather forecast area is shown in Figure 38. The forecast area is divided into nine subsections.

Figure 38 Schematic of the weather forecast area of the Shanghai Met Service



The operational organization and workflow is shown in Figure 39.

Figure 39 Operational Organization



The complete presentation can be found in Part 2 of this report.

Participant Case Studies

In preparation for the workshop, participants were asked to describe how forecasts and warnings are used in their countries by describing a meteorological or hydrological event. How well was it forecast? How were warnings created and communicated? How did the public and other sectors respond? What was the impact of the hazard? What did you learn from the event? What could be done better?

The participants were asked to describe the event from the perspective of a forecaster and from the perspective of disaster management/emergency response.

How did the hazard impact the public and how did they respond?

What worked and what didn't.

While few of the participants followed the template closely, their presentations offer insight into the issues affecting each country. Brief summaries of their case studies follow and the full case studies are included in Part 2 on this report.

Bangladesh

(**Aziz Mazharul**, Department of Agriculture Extension, Ministry of Agriculture)

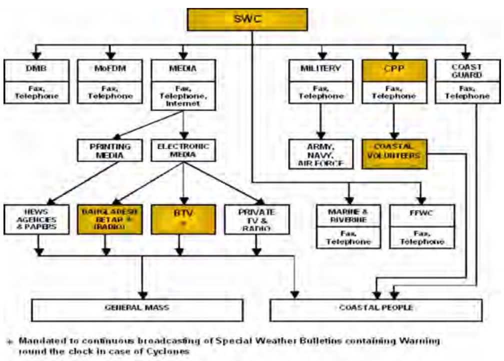
An overview of Bangladesh is shown in Figure 40. The country is affected by multiple hazards including cyclones and storm surges, thunderstorms, tornadoes and hailstorms, floods, droughts, heavy rain and landslides, heat waves, cold waves and dense fog, and earthquakes and tsunamis.

Figure 40 Brief overview of Bangladesh

Given the frequency of the impact of tropical cyclones and storm surges, early warning allows the population to take effective measures and evacuate and shelter (Figure 41).

Figure 41 Emergency warning and evacuation I Bangladesh

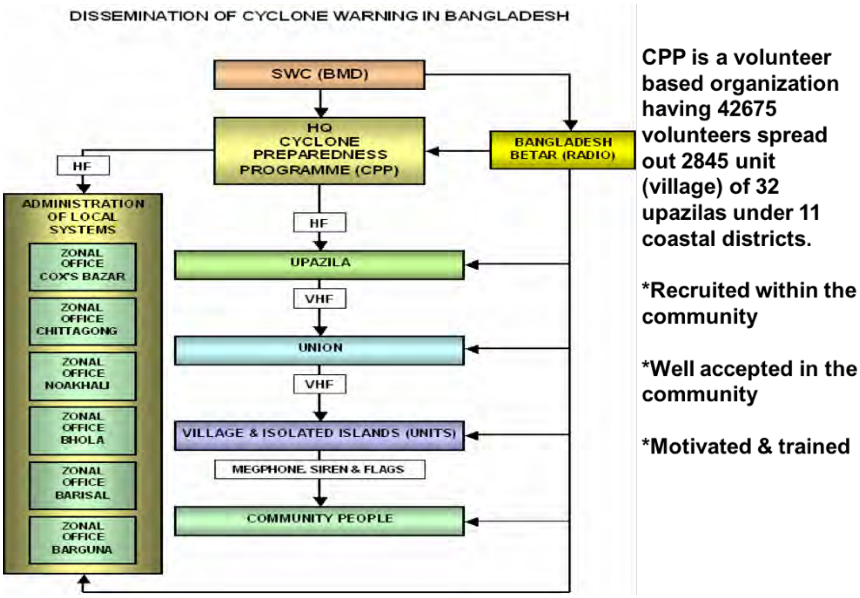
Figure 42 Warning Dissemination mechanisms



The Storm Warning Centre (SWC) is the principal means by which warnings related to typhoons are issued (Figure 42). However, unlike Shanghai, which has a single warning centre for all hazard warnings; the SWC is only responsible for tropical cyclones.

Typhoon warnings are disseminated by the Cyclone Preparedness Programme (CPP), which is a volunteer organizing comprising 42,675 members recruited from within local communities (Figure 43). This system is very effective. Similar translation and dissemination mechanisms are needed for other hazards and sectors; e.g., farming community.

Figure 43 Dissemination of typhoon warnings by CPP



The following are identified as needs:

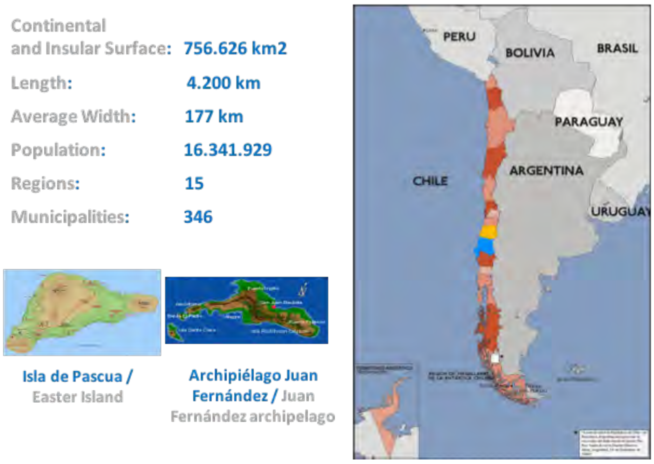
- There is a need to develop better decision support services and build capacity to translate forecasts so that they can be readily used from web-based platforms.
- Innovation in the use of ICT tools and techniques is needed to collect, analyse and translate disaster-related information; i.e., simplify multi-hazard data collection and develop effective feedback mechanisms.
- Develop multi-timescale longer range hazard information and translate these products for different sectors.
- Build on and scale up existing advisory system
- Make use of Union Information Service Centres (UISCs) for early warning dissemination and communication at the local level
- Push and pull SMS service should be introduced for hazard early warning messages
- Community radios should be used as another channel for dissemination and distance learning
- Subscription services could be introduced for emails and mobile SMS

Chile

(**Natalia Silva Bustos** & **Felipe Riquelme Vasquez**, National Emergency Office of Ministry of Interior and Public Security (ONEMI), Chile)

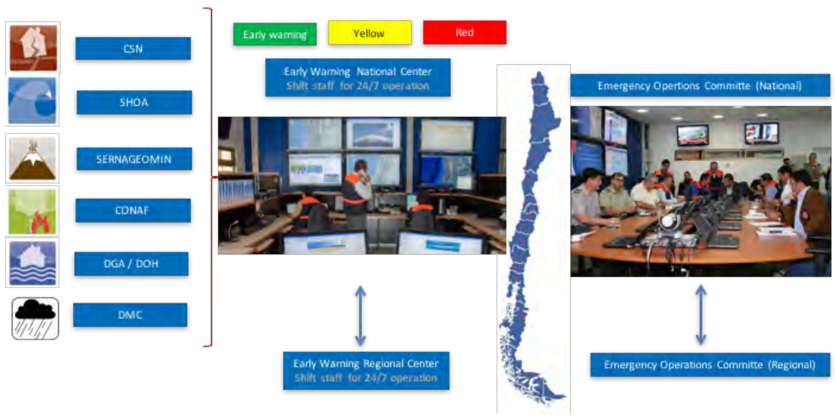
A general overview of Chile is shown in Figure 44. Chile is impacted by volcanic eruptions, forest fires, storms surges and tsunamis, earthquakes, floods and droughts. There are more than 500 active volcanoes, 90 of these are high risk. There are more than 200 seismic events per day. 46% of Earth's seismic energy released during the 20th Century focused on Chile.

Figure 44 Brief Overview of Chile



ONEMI is the state's technical organization, which leads the national civil protection system and coordinates the actions of public, private. Scientific-technical, NGOs, civil society, UN system, among others related to disaster risk management. The structure and flow of information from technical agencies to the early warning centres and emergency operations committees is shown in Figure 45.

Figure 45 Monitoring and Warning System



A case study of rainfall, floods, mudflows and landslides on March 25, 2015 illustrates the strengths and weakness of the system. An extreme hydrometeorological event – unseasonal heavy rains due to a cold front – occurred in the north of Chile. The event caused mudflows and flash floods. 27,413 people were affected, 5,585 were sought shelter, 31 people died due the mudflows and 16 remain officially missing. 28,000 homes were affected including 2,071 destroyed and 6,253 severely damaged. There were impacts on health, mining, connectivity, critical infrastructure, etc. Waste materials from mining contributed to a public health crisis.

The meteorological situation was well forecast at least 4 days in advance, and both the authorities and public were alerted. The normal rainfall is 4-5 mm per year. At its most intense, 8.2 mm of rain fell in 15 minutes. This was the worst rain in the past 80 years. In 3 hours, rainfall exceeded the 30-year average.

There are several factors that contributed this emergency becoming a disaster:

- Low spatial distribution of meteorological stations
- Hydrological and meteorological models are not coupled
- Lack of similar historical cases
- No experience in this kind of hazard
- Lack of scientific and technical knowledge about this phenomenon
- Inadequate capacity to translate rainfall into landslides or mudflows
- Impact information is disaggregated in different sectors
- Lack of evacuation plans and established safety zones

In response, Chile is:

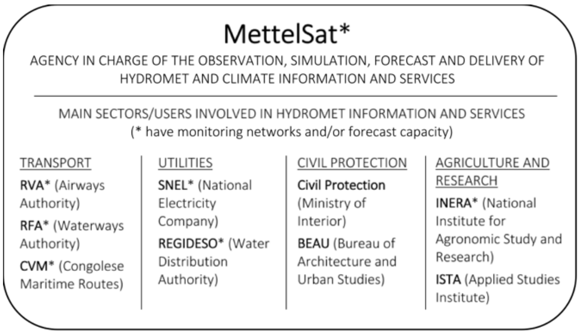
- Investing in a project to integrate different hydrological and meteorological stations through a public-private partnership
- Supporting drills about landslides in high risk areas
- Working with different technical organizations and researchers to develop a multi-hazard approach to warnings and response.
- Strengthening the national governance to create the capabilities to assess risk and determine potential impacts.

Democratic Republic of Congo

(**Donatien Barthelemy Kamunga Musungayi**, MettelSat; **Jean K'Onganga Kitambala**, Protection Civile; **Placide Munsai Masena**, Hydrographie et Balisage)

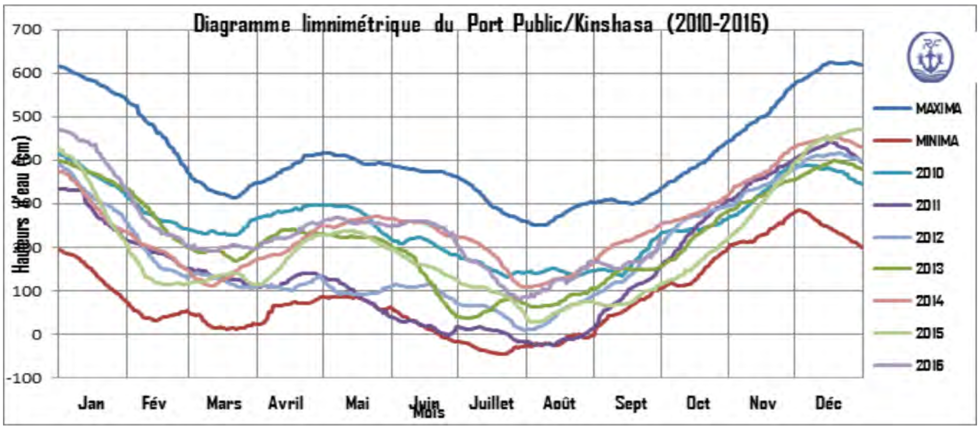
The institutional landscape of agencies involved in Hydromet information services is shown in Figure 45.

Figure 45 Institutional landscape



A case study of extreme low water levels in the Congo River in 2011 highlights some of the issues facing DRC. From a hydrological viewpoint, the low water levels in the Congo River experienced in June and July 2011 were not forecast with the sharp drop in water levels surprising all technicians and users. Meteorological observations revealed below normal rainfall before the dry season. MettelSat had access to these observations from DRC and Zambia, but they did not share this information with the river navigation authority (RVF). No warnings were issued. On the collaboration between the RVF and MettelSat, data exchange should be more systematic and based on better data management tools. On the warning development process, the low runoff observed since May could have been better interpolated. Figure 46 shows that the low water levels were close to the minimum for the river.

Figure 46 Description of event in terms of monthly water levels



The impact of the event is shown Figure 47. After on large ship was wrecked and many had run aground, ship owners reduced their loads to navigate in lower water levels within the 400 km of the navigable reach. The RVF updated signage in the river to improve navigation safety. The Electricity company (SNEL) dredged the channel to ensure continuity of hydro-electricity generation, and the drinking water supply authorities (REGIDESO) moved its pumping infrastructure. The overall impact was reduced water and electricity consumption by the public; and reduced river transport, hydropower generation and driving water production.

The event confirmed the need for:

- Capacity building for staff in forecasting and predictive modelling
- Automatic observation and communication of rainfall and hydrological observations
- Updated rating curves, which are presently only available in Kinshasa
- Improved collaboration between meteo, hydro, transportation, energy and civil protection

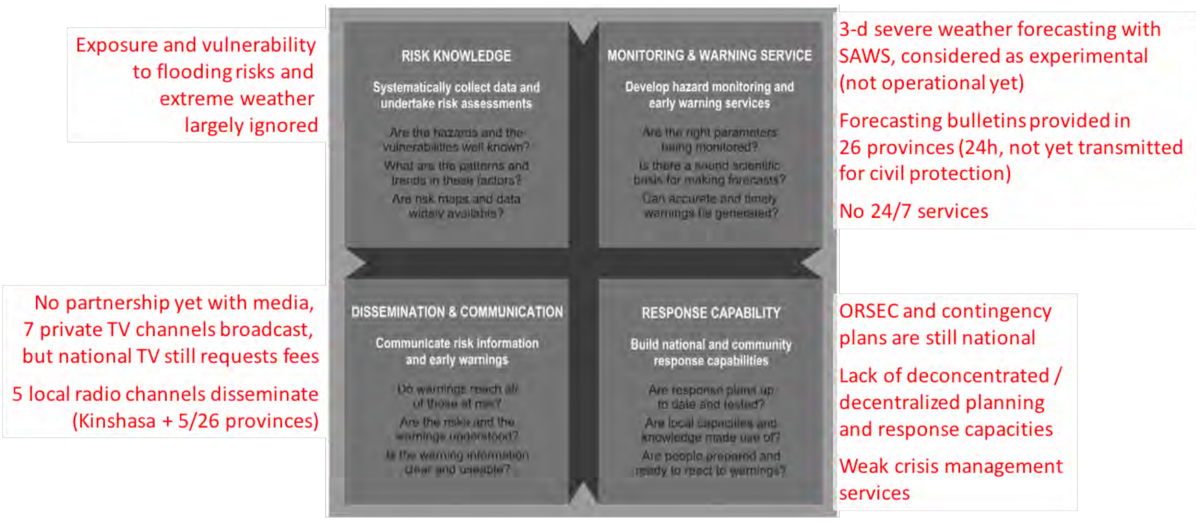
Figure 47 Impact of the low river levels

From the perspective of emergency response, the following highlights some of the issues and solutions:

- No forecasts were received. Civil protection was invited to a workshop to improve stakeholder coordination in the management of the emergency
- Civil protection had the responsibility to communicate warnings, but no forecast, alert or warning was received from the technical agencies. Civil protection is responsible for following up on the stakeholder workshop recommendations
- Civil protection has communicated the recommendations from the workshop to decision-makers and ensure follow-up on their implementation
- Life jackets are now mandatory on all ships. Civil protection has improved collaboration with forecasters to anticipate impacts from hydrometeorological events and act early

A project to strengthen the capacity of the Hydromet and early warning services is underway. Priorities for strengthening early warning are shown in Figure 48

Figure 48 Priorities for strengthening early warning



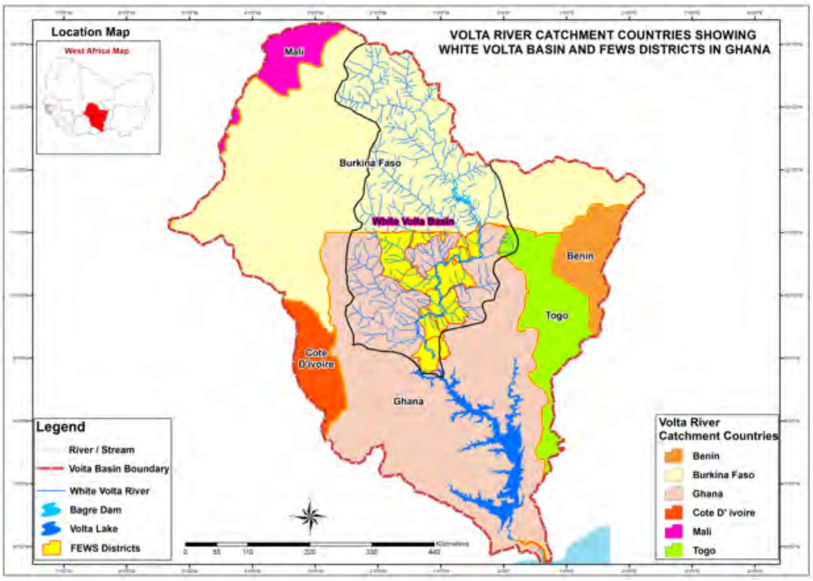
Source: 2006 Global Survey of EWS

Ghana

(**Miawuli Lumor**, Water Resources Commission; **Gavivinia Yao Tamakloe**, National Disaster Management Organization; **Sylvester Darko**, Hydrological Services Department; **James Barrone Dusu**, Ghana Meteorological Agency)

Ghana is vulnerable to flooding and following major floods in 2007 and 2010 has embarked on strengthening flood management (Figure 49).

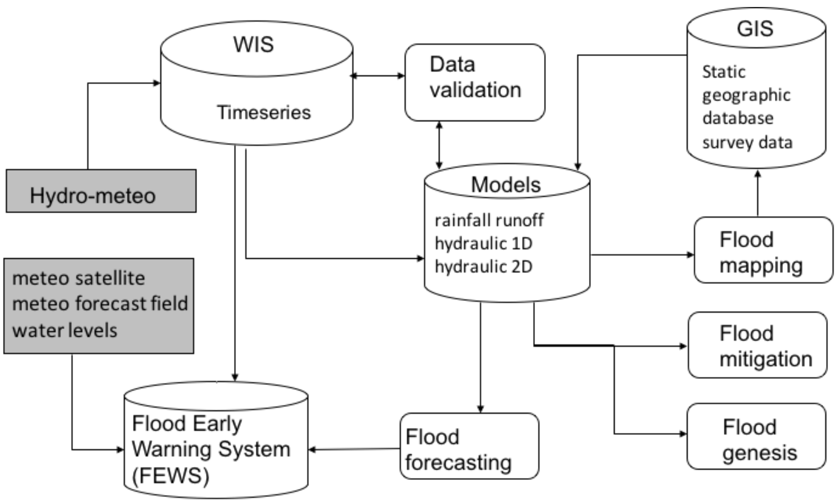
Figure 49 Overview of Ghana



Disaster risk management involves the key agencies: Ghana Meteorological Agency (GMet) for meteorological forecasts and warnings; Water Resources Commission (WRC) for transboundary basin management and the coordinating agency on water resources related issues; Hydrological Services Department (HSD) for hydrological monitoring and flood early warning system; and the National Disaster Management Office (NADMO), which is responsible for the management of disasters and related emergencies. NAMDO depends on GMet and HSD to obtain early warnings of floods and drought. It is coordinates activities of all actors in disaster management and is responsible for emergency operations and engaging the community in improving resilience.

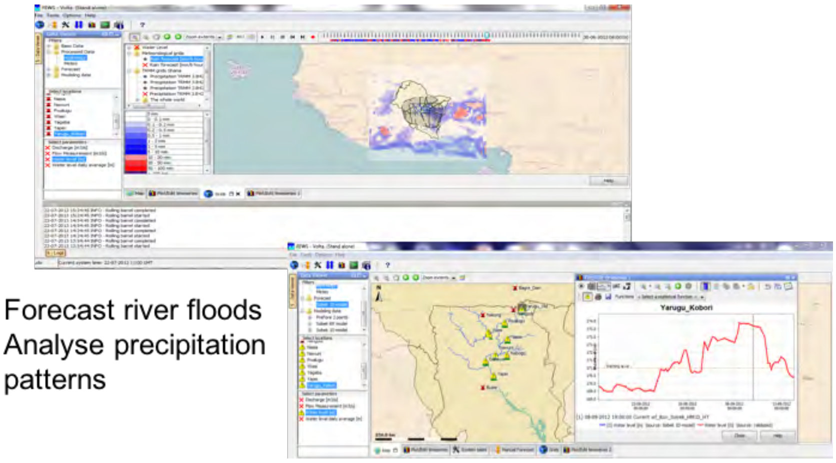
A flood forecasting system is in development, which will provide flood early warning and assessment (Figure 50).

Figure 50 Flood forecast and warning system



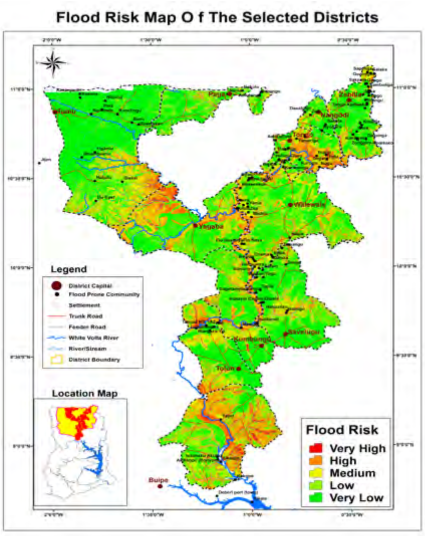
An example of the flood early warning system for White Volta is shown in Figure 51.

Figure 51 Flood early warning system White Volta



This is enabling the validation and incorporation of flood risk maps in planning and flood management, which is shared with communities to encourage alternative land use in high risk areas Figure 52).

Figure 52 Flood risk map for selected districts and alternative land use options for flood prone districts



Alternative land use options in the flood prone districts

No.	Municipal/District	Before floods (May-July)	After floods (Nov-January)
1	West Mamprusi	Cultivation of millet and maize	Cultivation of water melon and vegetables
2	Mamprugu Moanduri	Cultivation of maize and millet	Cultivation of vegetables
3	Savelugu-Nanton	Cultivation of millet and maize	Cultivation of water melon and vegetables
4	Bawku West	Cultivation of maize, millet and soghum	Cultivation of water melon, Tobacco and vegetables
5	Nabdam	Cultivation of maize and soghum	Cultivation of water melon, Tobacco and vegetables

Some of the achievement since 2011 include:

- Increased capacity of the national hydro-meteorological services:
  - Water Information System established and operational;
  - HSD systematically collects, stores and calibrates hydrological information;
  - Real-time tele-transmission of 8 gauging stations
  - 20 Ghanaians were trained in flood hazard assessment and forecasting.

- Informed decision making for effective flood prevention in Northern Ghana:
  - The genesis of the floods in Northern Ghana is understood;
  - Effectiveness of flood prevention measures is assessed;
  - Flood hazard maps for the White Volta and tributaries are available.

- Strengthened emergency preparedness in Northern Ghana:
  - Flood forecasting system with 3-day lead time for the White Volta is operational;
  - Flood propagation time and hazard maps are available for preparedness planning.

- Fostered institutional collaboration on flood management:
  - Agreement on institutional responsibility for forecasting are reached;

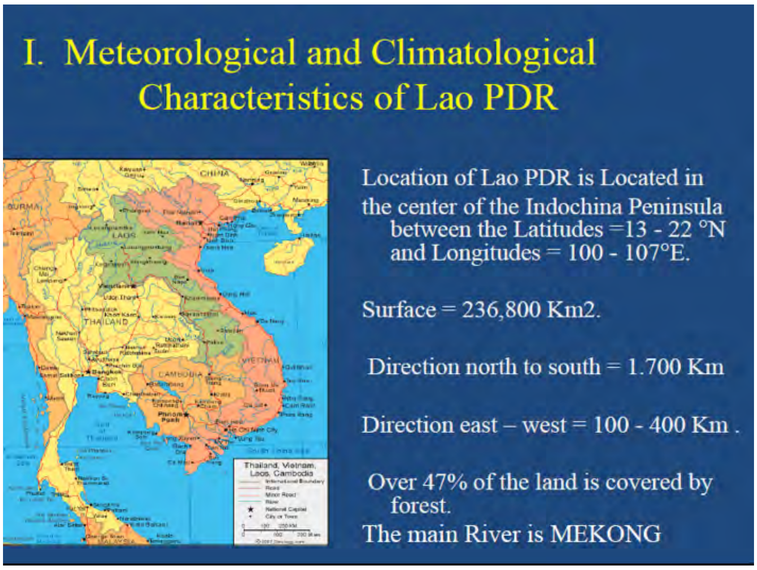
Remaining challenges include:

- Coupling the FEWS model with climate data from GMet
- Building "last mile connections"
    - Ensuring that information effectively reaches flood affected communities
    - Supporting district assemblies mainstreaming information in district planning
- Sustaining the capacity of national agencies for flood forecasting
    - Continuing training of hydrologists and meteorologists in forecasting
    - Repairing, maintaining, operating and upgrading critical hydro-met stations in the White Volta Basin
- Increasing accuracy of flood forecasting
- Fostering effective collaboration among national agencies in flood forecasting
- Understanding the social and economic impacts of flooding in the White Volta Basin
- Extending flood forecasting to all parts of the country
- Increasing the number of emergency operations centres at the local authority level – most districts are not covered
- Target audience still do not understand their responsibilities in disaster management chain
- Volunteerism is very low

Lao Peoples Democratic Republic

(**Outhone Phetluangsy**, Department of Meteorology and Hydrology)

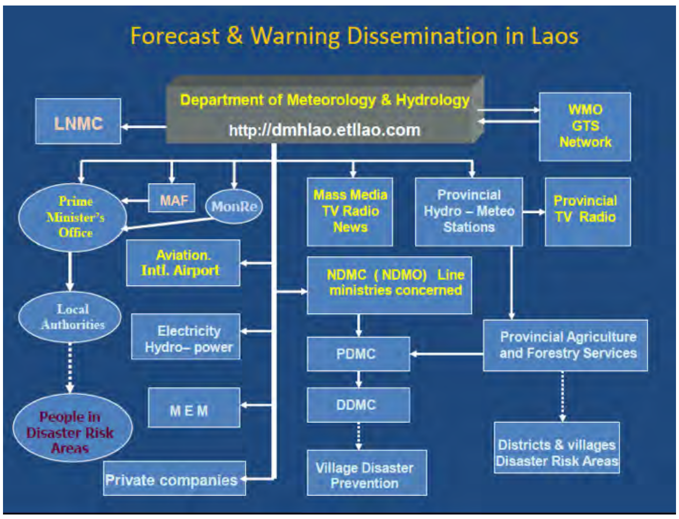
Figure 53 Overview of Lao PDR



An overview of Lao PDR is shown in Figure 53. Lao PDR has a tropical monsoon climate with a wet season and a dry season. The dry season is from mid-October to mid-May, which is the period of the Northeast monsoon. The wet season is from mid-May to mid-October, which is the period of the Southwest monsoon and is associated with tropical cyclones over the Northwest Pacific. 85-95% of floods occur between June and October.

Floods, flash floods, landslides, earthquakes and drought are major hazards. The ministry of Water Resources and Environment Administration is responsible for the operation of hydro-meteorological forecast dissemination. Daily forecasts are issued through radio, television, newspaper, provincial offices of DMH, the National Disaster Management Office and line agencies (Figure 54). All warnings are based on meteorological and hydrological thresholds with tropical storm warnings focused on the location of the system relative to Lao PDR.

Figure 54 Forecast and warning dissemination



Challenges include the need to:

- Focus more attention on inundation through heavy rainfall flood forecasting and warning
- Increase the frequency of forecasts and warnings through mass

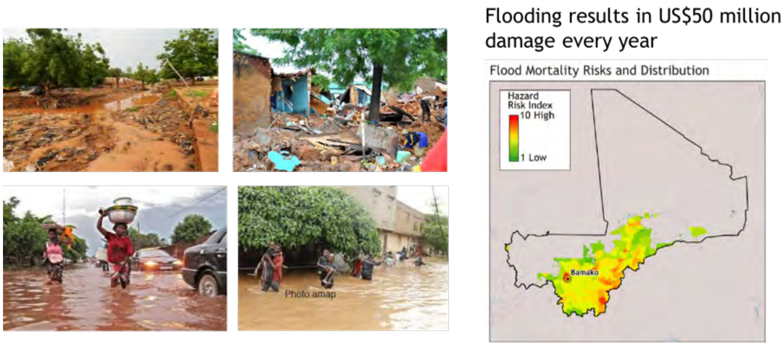
media to the public and directly to concerned end-users
- Enhance awareness and preparation of people and have a plan to respond before a flood
- Improve forecast verification.

Mali

(**Moussa Toure**, Mali-Meteo; **Cheick Fanta Mady Kone**, Protection Civile)

Mali is frequently affected by floods (Figure 55). In the case of flooding in Bamako on 28 August 2013, intense precipitation was forecast 8 h ahead of the impact. Radio messages were issued; however, no information on amount of precipitation or its impact was provided. Partly because of this, no actions were taken ahead of the event. 2000 households were flooded and temporarily evacuated, 240 houses collapses, and 56 people died. Most of the casualties were caused by electrocution or in the case of children, drowning.

Figure 55 Overview of flooding in Mali



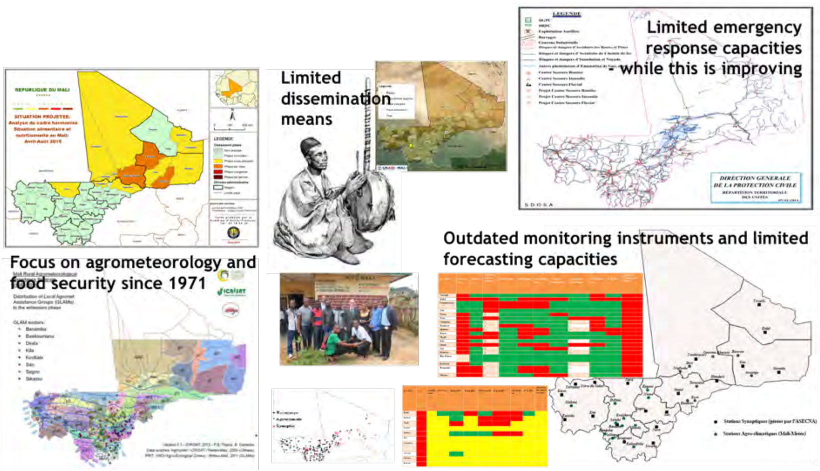
From the perspective of the civil protection directorate, there was a lack of understanding of the impacts. It is the responsibility of civil protection to covert forecasts into warnings, to disseminate the warnings, anticipate and reduce damage, manage the response, learn lessons from the event, and enhance preparedness for future events. As soon as the flood occurred, civil protection strengthened the response teams with volunteers, evacuated household, and coordinated humanitarian assistance.

The following needs were identified:

- forecast precipitation amounts and anticipate impacts per historical events (deterministic based upon return period) and modelling (probabilistic);
- trigger emergency plans before the impacts to mobilize more staff and volunteers and reduce damages;
- enhance dissemination (radio) in local languages
- develop warning and activate response plans through joint process with met service, civil protection and municipalities
- enhance awareness-raising activities and simulations to ensure better preparedness

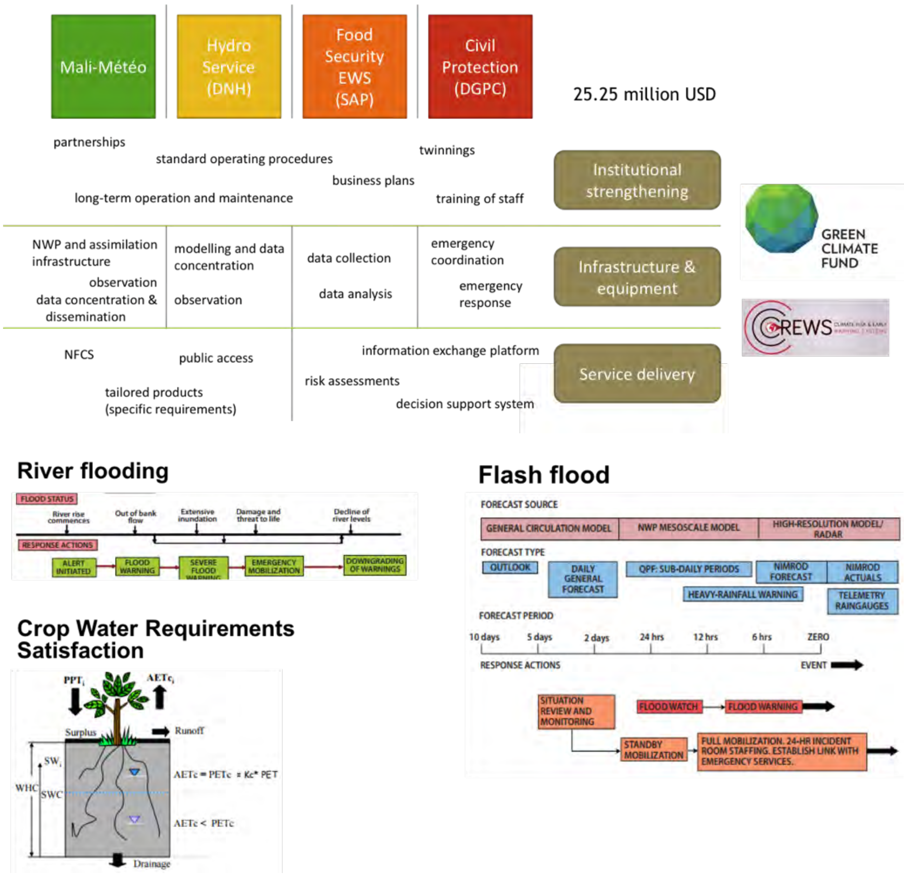
Some of the limiting factors in early warning are summarized in Figure 56.

Figure 56 Early warning limiting factors



Some of the planned improvements are summarized in Figure 57.

Figure 57 Future improvements

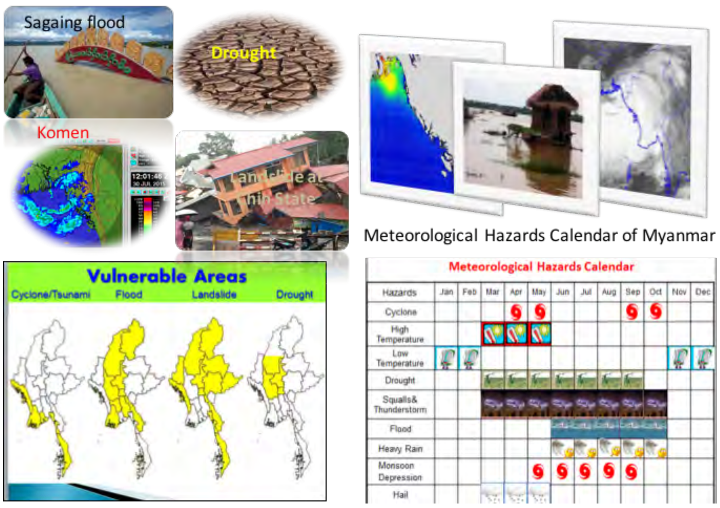


Myanmar

(**Win Maw**, DMH; **Tin Mar Htay**, DMH; and **Su Sandar Win**, Relief and Resettlement Department)

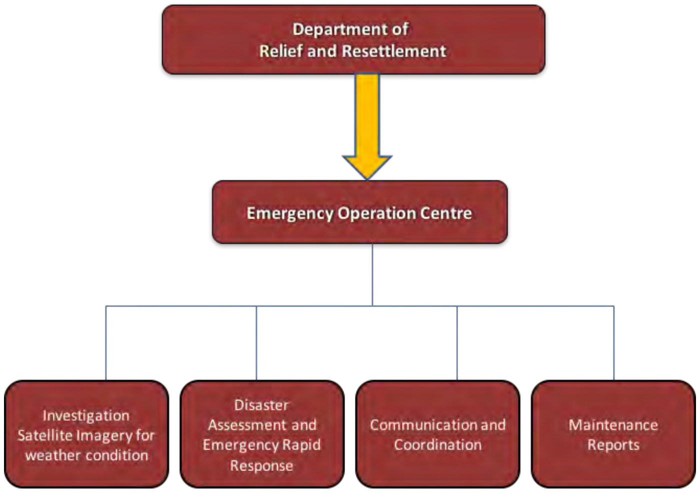
Figure 58 summarizes some of the major hazards affecting Myanmar. These include cyclones, heavy rainfall, storm surge extreme temperature, scanty rainfall, river flood, flash flood and coastal flood. Recent extremes include 47.2 °C in Myinmu in 2010; 29.10 inches of rainfall in 12 hours in Taungkok in 2011 resulting in flooding, and 8.03 inches of rainfall in Chin State in 2015 resulting in landslides.

Figure 58 Hazards in Myanmar



The Department of Meteorology and Hydrology is responsible for forecasting and warning and communication of meteorological and hydrological hazards to agencies responsible for action to the Ministry of Social Welfare, Relief and Resettlement (MSWRR), Red Cross, Ministry of Interior and General Administration Department (GAD). The Department of Relief and Resettlement is responsible for emergency operations (Figure 59).

Figure 59 Structure of Emergency of Operations



Key activities of the Emergency Operations Centre are

- In normal conditions:
    - Investigating and monitoring the weather condition
    - Information sharing to related government organizations and NGO, INGO organizations (such as, MRCS, WFP, UNOCHA, etc.)
    - Implementing for disaster preparedness, information management and coordination for disaster risk reduction.
- In an emergency:
    - Supporting for emergency management, response and logistics through information sharing on network and quick decision making.
    - Providing the comprehensive solution to the decision makers by collecting necessary data and information for effective response.
    - Cooperation with related organizations for making plans to give assistance the needs of disaster affected people in disaster affected area.

The DMH and Emergency Operations Centre share responsibility for coordination and decision-making. There is good communication with formal data sharing arrangements. At present DMH does not develop impact-based forecasts and warning, only warnings based on meteorological and hydrological thresholds are issued. Vulnerability and exposure data are collected by several government agencies/departments including MSWRR, GAD, Ministry of Agriculture and Irrigation, Myanmar Information Management Unit, Ministry of Home Affairs, and Ministry of Commerce.

The strengths and weaknesses include:

- Strengths
    - Strong will of staff
    - Relatively high academic background
    - Staffs' passion and willingness to improve DMH
    - Consecutive budget increases
- Weaknesses
    - Outdated infrastructure
    - Shortage of budget
    - Shortage of manpower
    - Insufficient overall facilities

Nepal

The location, topography and river systems of Nepal are shown in Figure 60.

The Department of Hydrology and Meteorology (DHM) is responsible for all hydrological and meteorological activities and services in Nepal. The hydrology division has sections for the river network; flood forecasting; data; snow, water quality and environment; and technical. A major objective of DHM is flood forecasting and early warning. Hazard-related losses for 1990-2015 are shown in Figure 61.

Figure 60 Location, topography and river systems

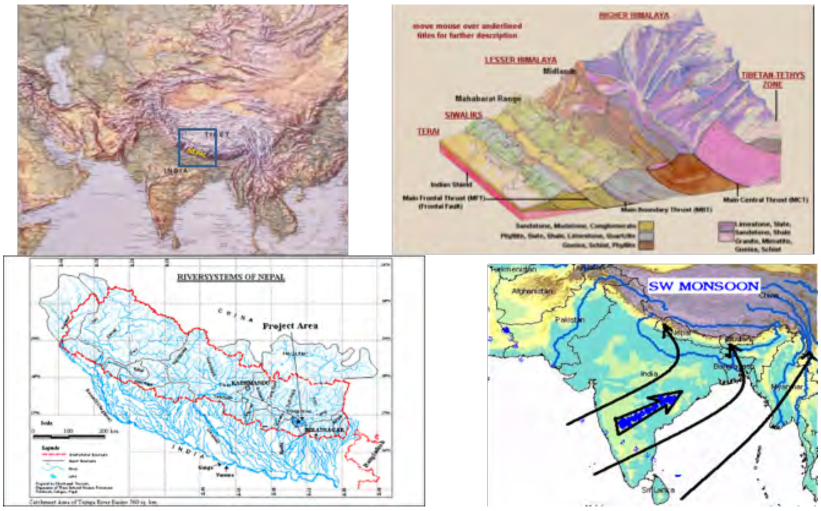
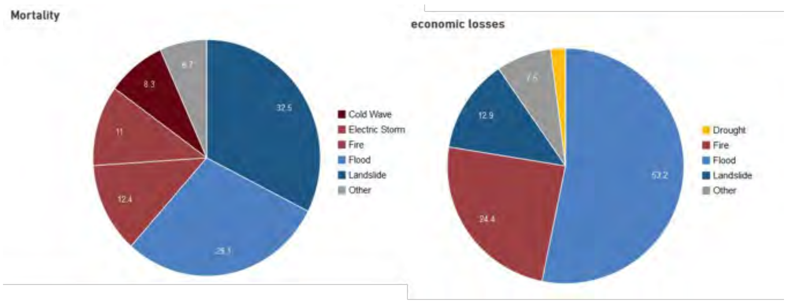


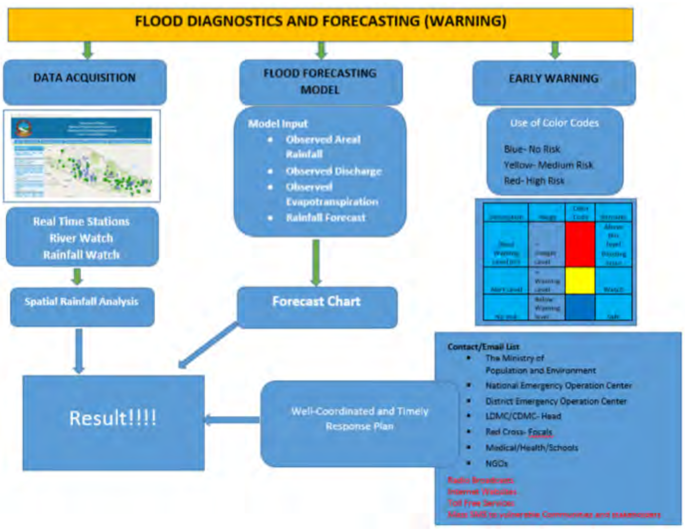
Figure 61 hazard related losses 1990-2015



Source: MoHA, 2015

A significant investment is underway to modernization DHM. A schematic of the flood forecasting and warning system is shown in Figure 62

Figure 62 Flood diagnostics and forecasting (warning)

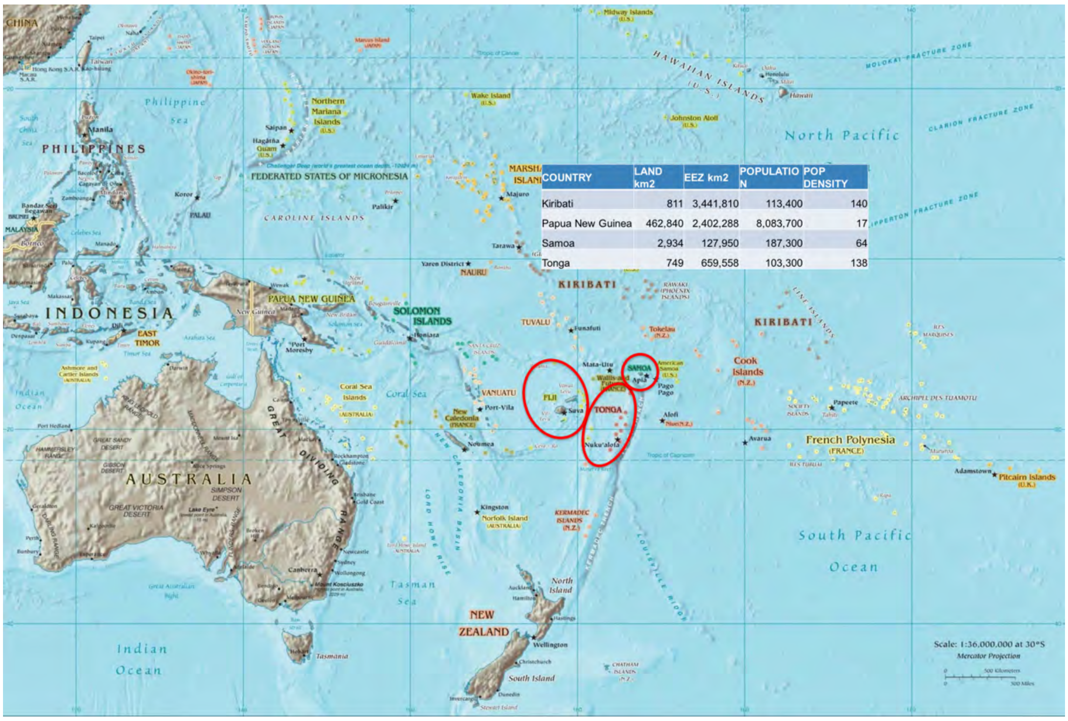


Pacific – Fiji, Samoa and Tonga

(**Litea Biukoto** and **Cyprien Bosserelle**, Pacific Community; **Titimanu Simi**, MNRE-DMO, Samoa; **Lameko Asora**, MNRE-WRD, Samoa; **Luteru Agaalii Tauvele**, Samoa Met Service; **Moleni Tu'uholoaki** and **Laitia Fifita**, Tonga Meteorological Services)

The locations of Fiji, Samoa and Tonga are shown in Figure 63. These islands are frequently impacted by Tropical Cyclones, which cause strong winds, storm surges, and flooding. They are also vulnerable to earthquakes and tsunamis.

Figure 63 Islands of Fiji, Samoa and Tonga



COUNTRY	LAND km2	EEZ km2	POPULATION	POP DENSITY
Kiribati	811	3,441,810	113,400	140
Papua New Guinea	462,840	2,402,288	8,083,700	17
Samoa	2,934	127,950	187,300	64
Tonga	749	659,558	103,300	138

Tonga

Tropical Cyclone Ian, which struck Tonga on January 11, 2014 illustrates challenges. TC Ian was well forecast and continuous briefings were given to Tonga's National Emergency Management Office and operations centre. The Prime Minister's office was informed that TC Ian would rapidly intensified into a category 5 system; a state of emergency declared at 8 am on January 11. TC Ian's eye passed over the Ha'apai Islands at 1430 local time. Communication with Ha'apai was lost at 1300 local time. The cyclone caused extensive damage (Figure 64)

Figure 64 Impact of Tropical Cyclone Ian on Ha'apai

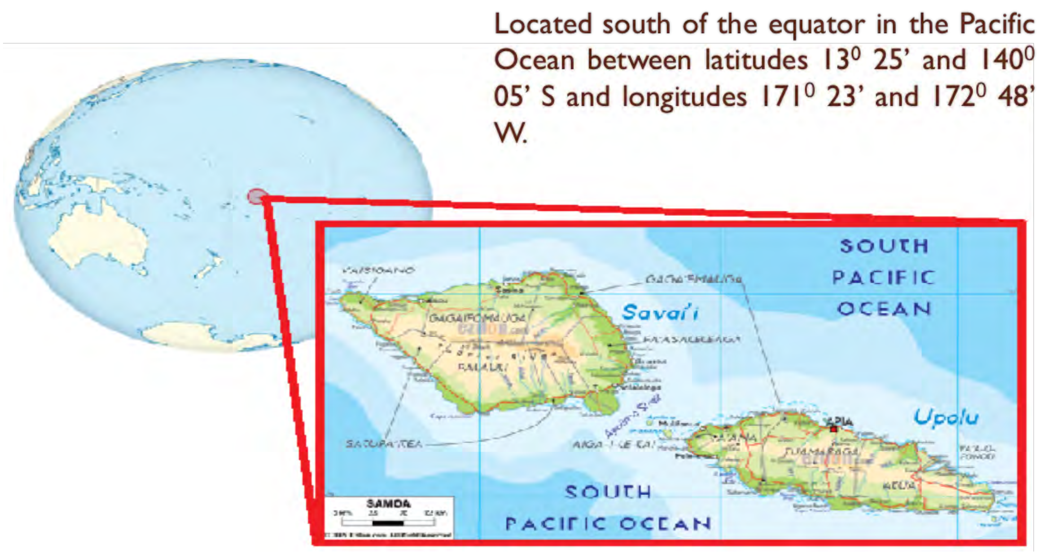
Some of the lessons learned and challenges include:

- Timely Delivery of Warnings to the people of what would happen just before, during and after eye past (TC Ian).
- Some people just evacuated during or near the height of the storm
  - Understanding forecast?
- Technical wordings of forecast and warnings
  - difficult to understand?
- NDMO giving free credits to public to help them with reporting directly for emergency responses
  - Misuse of funds
- Local shipping Agencies continuing operations given warnings are IN FORCE
- Lack of effective information on Disaster impacts
  - Historical reference/records of past impacts of certain Hazards
- Poor communication coverage for warnings
  - Needs automatic dissemination systems
- Lack of observation networks within our area of responsibility and in the ocean
- Lack of operational resources to implement impact-based forecast and warnings services
  - Human capacity development
  - Equipment
- Implementing preparedness & Awareness Strategies

Samoa

The country profile of Samoa is shown in Figure 65. Samoa is highly vulnerable to tropical cyclones and tsunamis. It is located 160 km north of the earthquake generating Tongan Trench and at the heart of the South Pacific cyclone belt. Three cyclones and one Tsunami resulted in losses of nearly US$1 billion

Figure 65 Country Profile of Samoa



Samoa's early warning system is shown in Figure 66. There are standard operating procedures in the case of a category 3-5 tropical cyclone:

Step 01: Continue Discussion with Neighbour National Weather Services

Step 02: Issued SWB every 3 hours

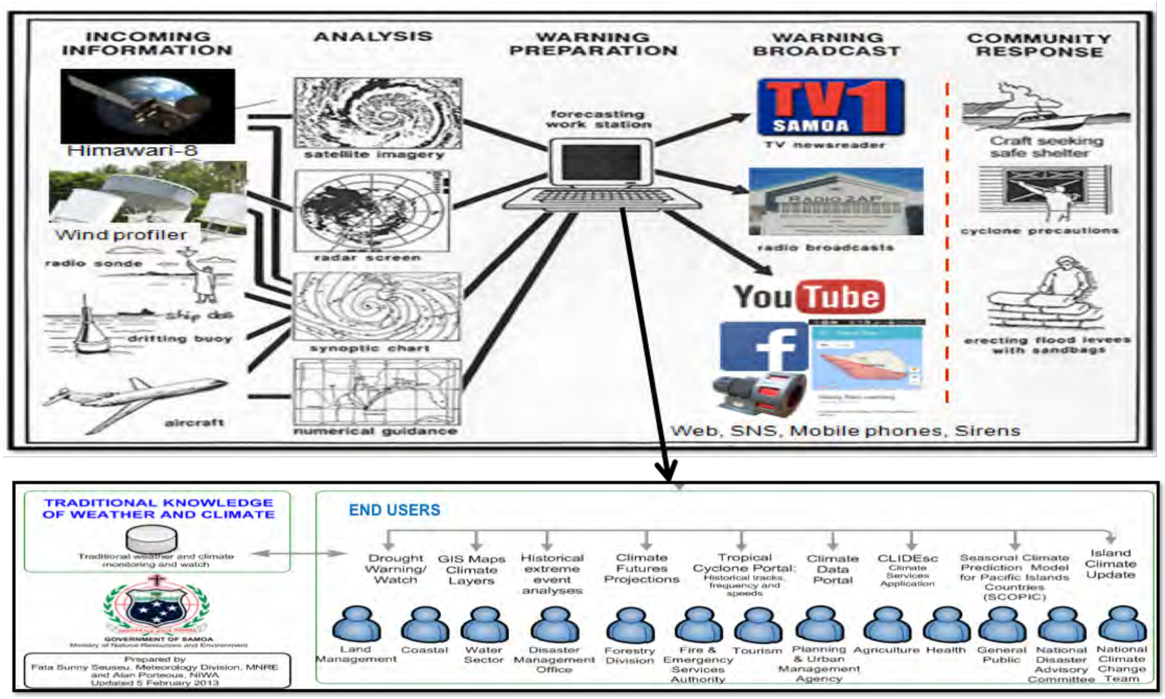
Step 03: Director Met/Acting Director Met brief CEO every 3 hours after every issue

Step 04: CEO/Acting CEO MNRE brief NDC

Step 05: Director Met/Acting Director Met brief DMO every 3 hours after every issue

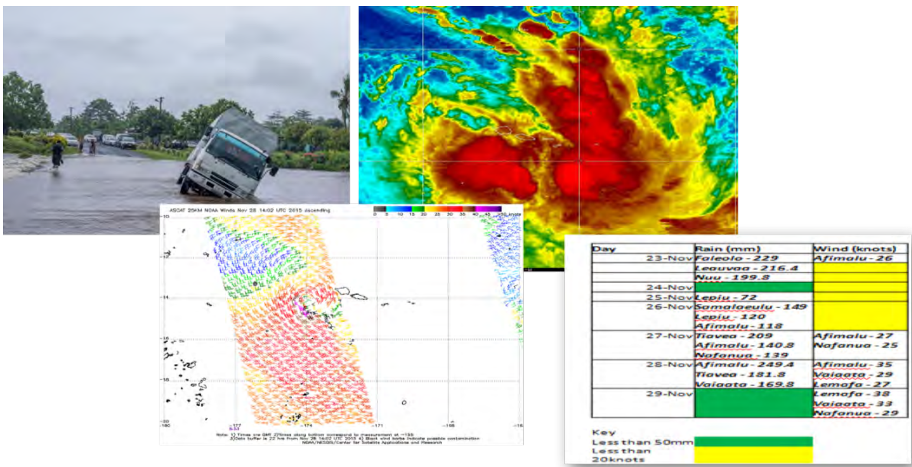
Step 06: Director/Acting Director Met follow-up Media interview every 6 hours

Figure 66 Samoa Early Warning System



The case of Tropical Cyclone Tuni, which was a Category 1 event in November 2015 is shown in Figure 67. The first Special Weather Bulletin was issued at 262100 UTC or 11 am SLT on Friday 27 following the activation of the STCWC on 262000 UTC or 10 am SLT the same day, 33 hours before the system was named by the RSMC Nadi. This was done due to the threat that the developing Depression has a high chance to develop into a Tropical Cyclone while moving south easterly passing the south of the Samoan islands.

Figure 67 Tropical Cyclone Tuni Cat 1, November 2015



A total of 10 SWBs including a Cancellation bulletin (SWB 10) were issued every 6 hours for this event. The bulletin includes the warnings and advisories for the potential hazards associated with the storm, the latest position of the storm and its expected location in the next 6-12 hours, the expected effects and the potential impacts.

Apart from preparing and sending the warnings, the Weather and Forecasting section was also responsible for briefing the local and international media as well as the Disaster Advisory Council and all relevant agencies.

Continuous discussions with the regional partners including the Fiji Meteorological Services and Neighbouring Meteorological Services.

Some of the challenges are:

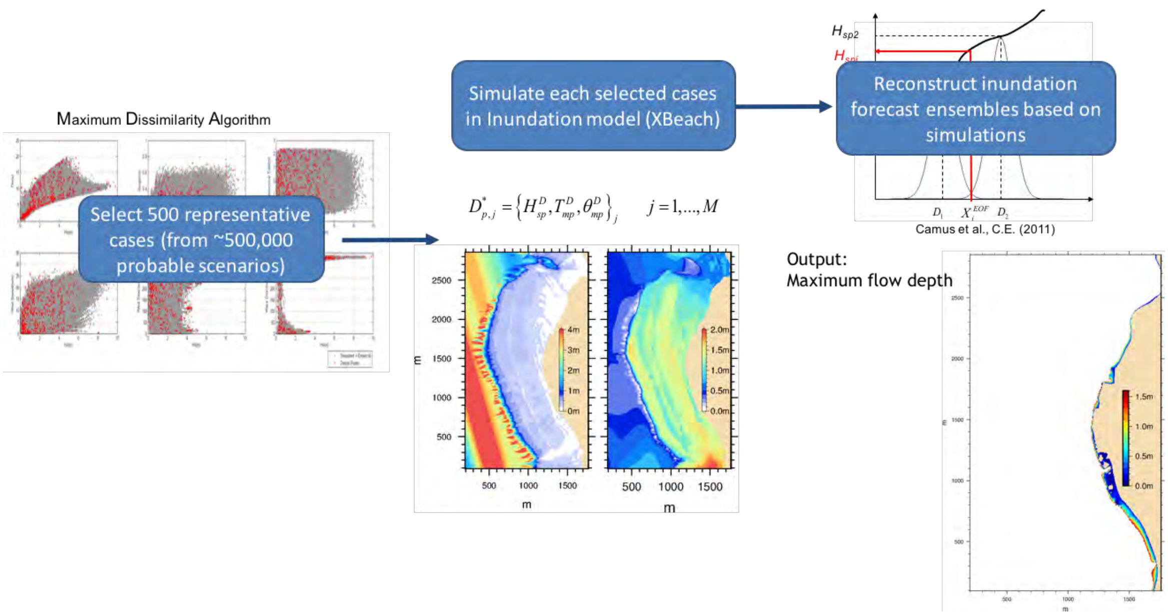
- Lack of awareness of available Information Providers and available data
- Lack of capacity to utilize and apply data in an effective and efficient way
- Lack of resources (radars) and expertise to guide and implement the use and application of space-based technologies
- Lack of information dissemination

Some actions Samoa expects to take include:

- Increase awareness of information providers and data available
- Build local capacity to enable the effective and efficient utilization of available services and data
- Promote and encourage collaboration and communication amongst regional member countries and organizations
- To seek funding and training opportunities to increase the self-sufficiency of local programmes and officials
- Encourage and increase information dissemination to relevant actors and the public to improve Disaster Management across the board
- Development of more user friendly ways of information dissemination (mobile apps)

Efforts are also underway to improve forecasts of coastal inundation. Since real-time run-up models are very slow, the preferred approach is to create a data base of 500,000 probable scenarios and select 500 representative case from which an ensemble forecast can be made (Figure 68).

Figure 68 Met-models for operational probabilistic inundation simulations



Sri Lanka

(**Kehelella Sarath Premalal**, Department of Meteorology; **Sulaima Lebbe Mohamed Aliyar**, Irrigation Department)

Sri Lanka is an island in the tropics with two major seasonal monsoonal regimes – Southwest from May to September and Northeast from December to February. In addition, there are two inter-monsoon seasons namely first inter-monsoon (March-April) and second inter-monsoon (October – November).

The monthly and average rainfall and some of the important impacts are shown schematically in Figure 69.

Estimates of cyclone related damage in 2000 and 2003 are shown in Figure 70.

Figure 69 Monthly and average (1961-1990) rainfall in Sri Lanka

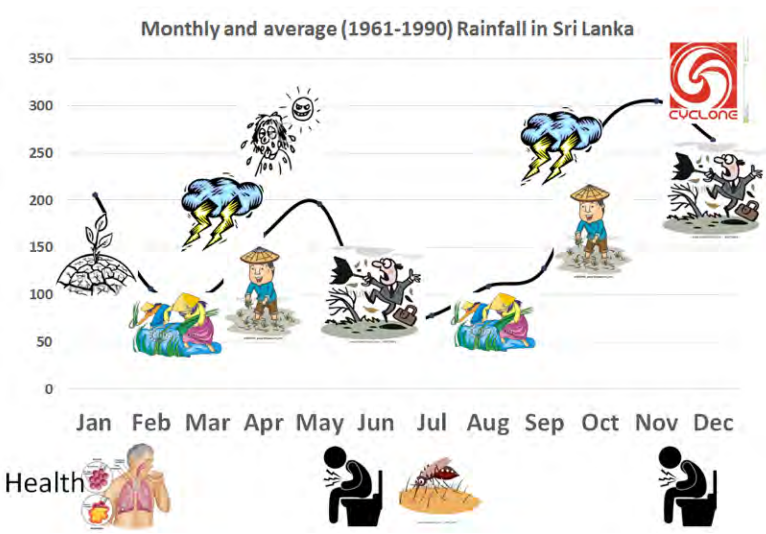
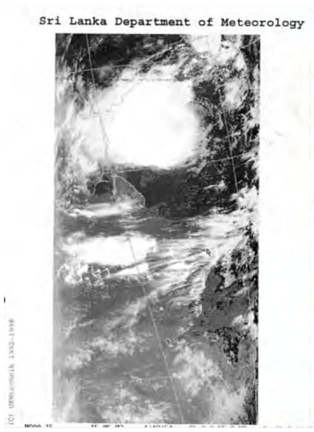
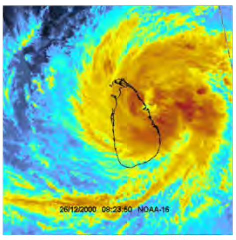


Figure 70 Estimates of cyclone related damage in 2000 and 2003



	2000 December	2003 May
Families Affected	170,149	138973
House Completely damaged	57,273	9,294
House Partly Damaged	20,860	302,260
Human death toll	11(16)	236
The damage of the National economy (Million Rs)	1500	2700



In 2003, some area received nearly 700 mm /24 hour

The case of Cyclone Roanu, which developed in the Bay of Bengal, 14-20 May 2016, highlights some of the problems facing Sri Lanka. The cyclone originated as a low-pressure area to the south-east of Sri Lanka on 14 May. It slowly moved north west very close the east coast of Sri Lanka becoming a depression on 17 May and a Cyclonic Storm on 19 May. The forecasts underestimated the rainfall and were not precise about the location of the heaviest rains. The forecasts were also not customized and were not impact-based. The forecast for 15 May and the actual rainfall for 15-18 May are shown in Figure 71.

Figure 71 Forecast for 15 May and actual rainfall.

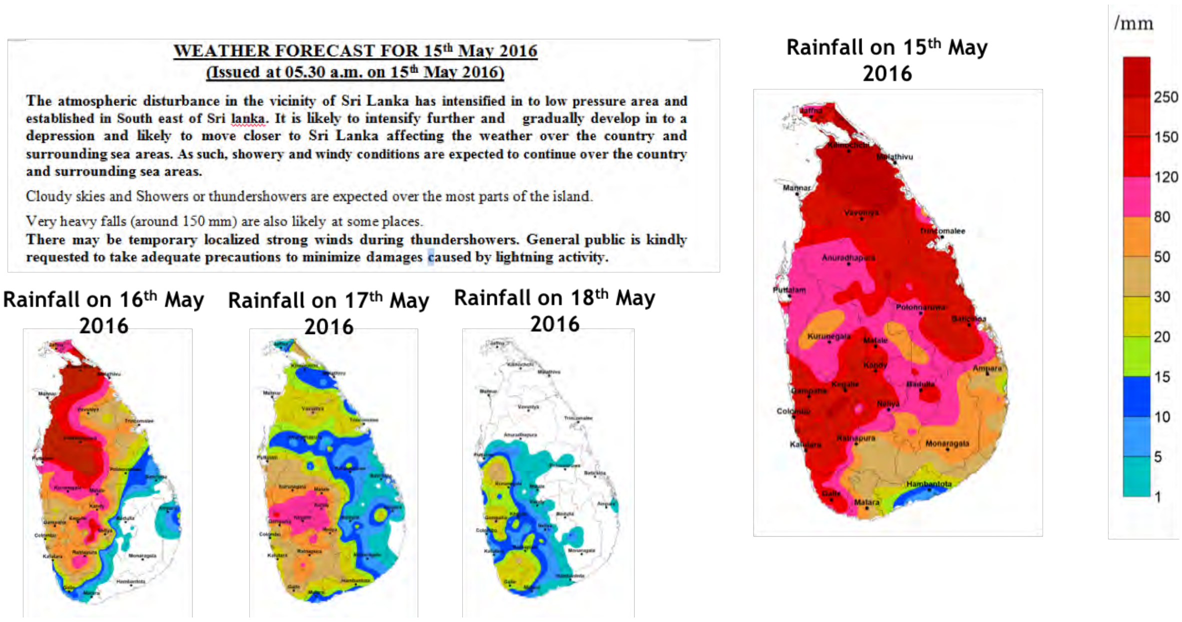
WEATHER FORECAST FOR 15th May 2016
(Issued at 05.30 a.m. on 15th May 2016)

The atmospheric disturbance in the vicinity of Sri Lanka has intensified in to low pressure area and established in South east of Sri lanka. It is likely to intensify further and gradually develop in to a depression and likely to move closer to Sri Lanka affecting the weather over the country and surrounding sea areas. As such, showery and windy conditions are expected to continue over the country and surrounding sea areas.

Cloudy skies and Showers or thundershowers are expected over the most parts of the island.

Very heavy falls (around 150 mm) are also likely at some places.

There may be temporary localized strong winds during thundershowers. General public is kindly requested to take adequate precautions to minimize damages caused by lightning activity.



The impacts included:

- Situation was the worst floods in last 25 years
- According Disaster Management Centre, 301,602 people have been affected by the floods and landslides and estimated 21,484 people displaced. 104 people are known to have died and 99 people are missing.

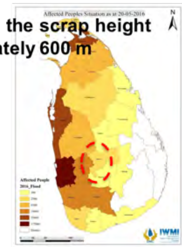
Figure 72 landslide in Aranayake, Kegalle District

Aranayake sudden landslide situation on 17th May 2016 at around 4.30-5.00 in the evening

The width of the crown of the landslide is about 345 -350 m and the scrap height is about 50-75 m. The widest part of the landslide is approximately 600 m

A debris flow about 75-100 m wide and 2.3 km long

landslide in Aranayake, Kegalle District	
Recovered Bodies	48
Missing Persons	96



- Estimated 623 houses have been destroyed and 4,414 have been damaged
- 25,000 to 30,000 businesses have been impacted by the disaster
- 171 schools in North Western, Sabaragamuwa and Western provinces were damaged
- It is estimated that 70,000 of school going children are affected by the disaster

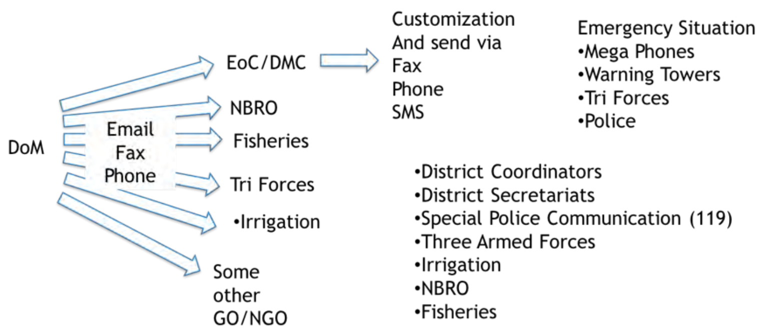
In Kegalle district, a landslide caused extensive loss of life and property (Figure 72)

The means of communicating warnings are shown in Figure 73.

Some of the lesson learned following the May 2016 disaster include:

- Warnings were not received by the people affected.
- Lead time was not sufficient even though warnings received.
- No proper assessment on what is happening outside the river.

Figure 73 Method of Communicating Warnings



- Flood hazard maps, inundation data were not shared and the public was unware of their vulnerability
- Misinterpretation of warning messages
- Lack of customization of the forecast
- No impact forecast
    - Forecasters lack knowledge about impacts from meteorological and hydrological hazards
    - Lack of knowledge of river floods
- People in the Colombo City had little experience of flash floods
- The increased vulnerability of the population due to major land use changes were not taken into consideration

Based on these findings, there is a need to

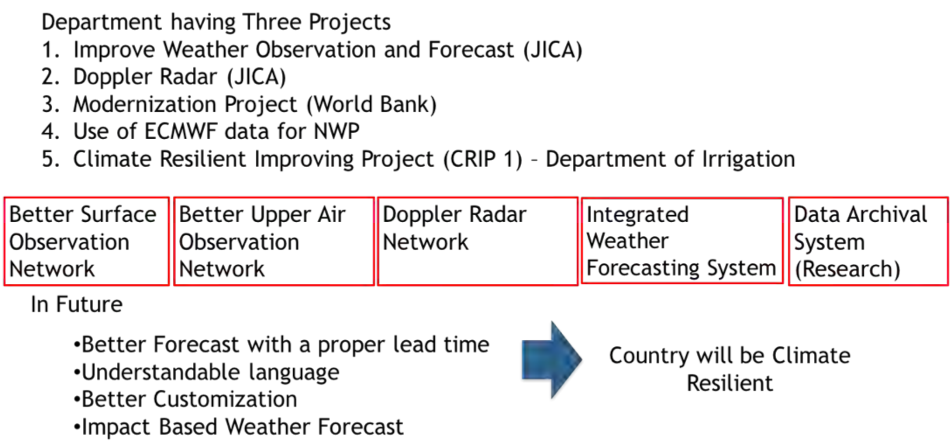
- Strengthen DoM capacity in QPE
- Close stakeholder coordination
- Better communication and customization of Forecast and warning
- Regular discussion / Awareness creation
- Change the present language of weather Forecast (understandable Language)
- Establish a video conferencing system among DoM, DMC, NBRO, DOI and media

The following activities are planned:

- Improve the accuracy of forecasts
- Timely dissemination
- Regular discussions with stakeholders
- Advance the leas time of forecasts and warnings
- Improve the method of dissemination and contents of meteorological and hydrological information
- Impact-based warnings

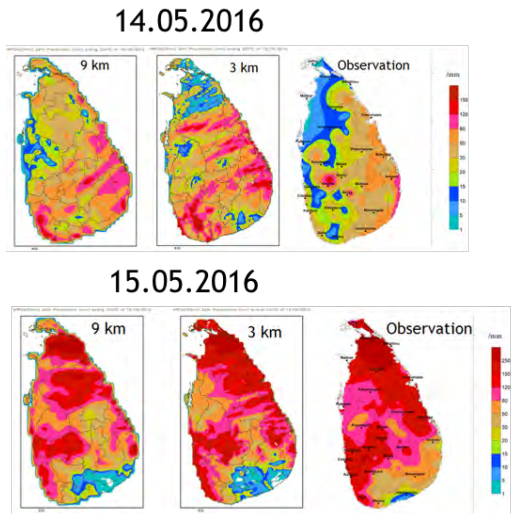
Figure 74 shows how impact-based forecasting may be improved.

Figure 74 Future aim for impact-based warnings

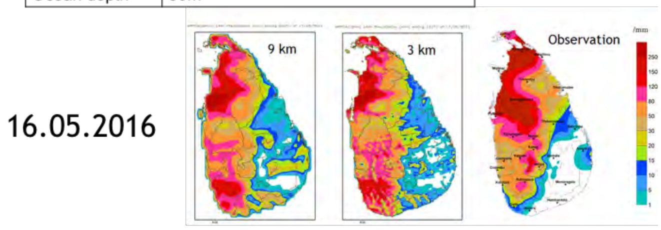


An example of improved forecasts for the May 2016 event is shown in Figure 75.

Figure 75 model simulation of extreme rainfall situation with WRFDA (NCEP)



Model Physics	
Micro physics	14 - WRF double moment, 5-class scheme
Long wave	1 - rrtm scheme
Shortwave	1 - Dudhia scheme
Surface layer	1 - Revised MM5 Monin-Obukhov scheme
Surface physics	2 - unified Noah land-surface model
Pbl physics	1 - YSU scheme
Cu physics	1 - Kain-Fritsch scheme
Ocean physics	1 - 1D ocean mixed layer
Ocean depth	50m



Impact-Based Forecasting Exercises

Exercise 1

The purpose of this exercise is to look at warnings from the perspective of two groups: Forecasters (meteorologists and hydrologists) and disaster managers. Each group is asked the following questions:

- Who are the audience for weather and hydrological warnings?
- What do they need to know?
- When do they need to know?
- How should we tell them?

The underlying benefit is to get the participants talking to each other and sharing their own experiences.

Exercise 2

Developing impact tables (Table 4 above). The purpose of this exercise is to show how useful vulnerability information can be created from expert knowledge. Here the participation of disaster managers is very useful because they are often more knowledgeable about impacts of specific hazards based on emergency response. In operational practice input from many different stakeholders is needed and this can lead to a more complex table based on impacts tailored to specific sectors (See annex 3).

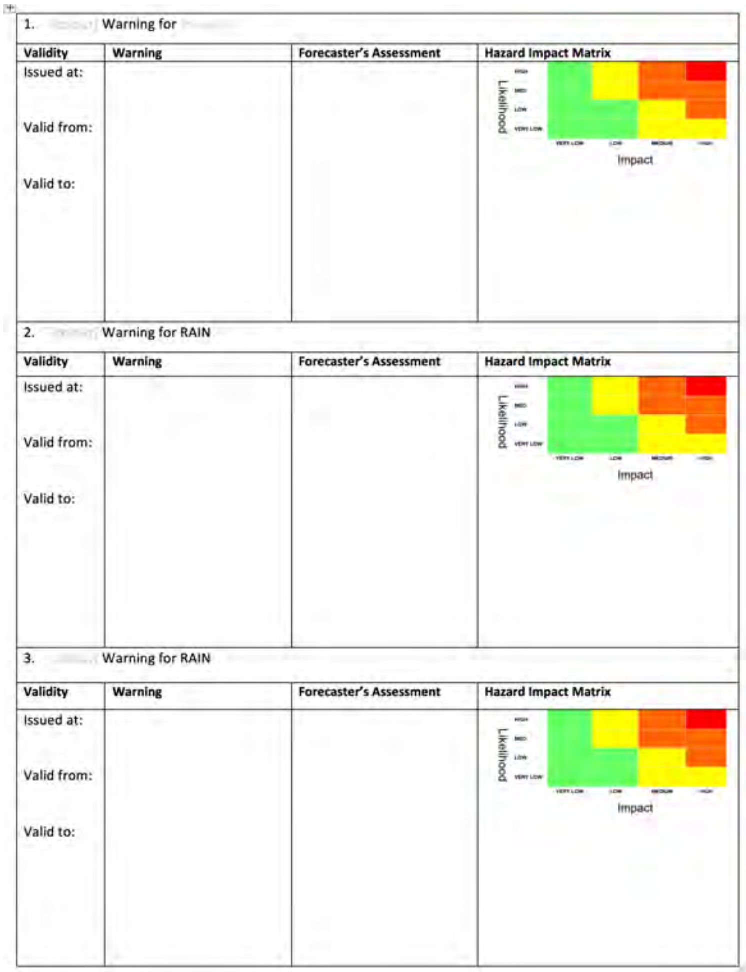
Exercise 3

This exercise introduces the idea of the impact matrix. A detailed explanation accompanies Figure 15.

Exercise 4

Each of the forecasters is given a weather and/or hydrological situation, which they must forecast. In the first part of the exercise, they will provide the meteorological and/or hydrological guidance. In the second part of the exercise, the forecasters will work with emergency managers to develop impact tables for the specific hazard and applicable sectors. Based on the likelihood of the event and other factors, such as time of time, existing conditions, etc., the team (forecasters and emergency managers) will select a box in the matrix and issue a warning according the colour of the box and likely impact (Figure 76 and Annex 4)

Figure 76 Impact Forecast and Warning Template



1.	Warning for		
Validity	Warning	Forecaster's Assessment	Hazard Impact Matrix
Issued at: Valid from: Valid to:			Likelihood Impact

2.	Warning for RAIN		
Validity	Warning	Forecaster's Assessment	Hazard Impact Matrix
Issued at: Valid from: Valid to:			Likelihood Impact

3.	Warning for RAIN		
Validity	Warning	Forecaster's Assessment	Hazard Impact Matrix
Issued at: Valid from: Valid to:			Likelihood Impact

The purpose of this exercise is work through the translation of a weather or hydrological forecast into an impact forecast and assign a warning level. The exercise can be adapted to a specific event, which evolves with time or to different geographical areas, which may have different levels of alert or warning.

The basic simplicity of the process is emphasized to encourage easy adoption in operational services.

Conclusions

The ability to understand and respond effectively to warnings is central to a resilient population. By avoiding physical harm, recovery from a hazard is likely to be faster and more complete (Rogers et al. 2016). Impact-based forecast and warning services complement the traditional role of meteorological and hydrological forecasting services by translating technical knowledge into information of direct relevance to those affected. Advances in our understanding of the atmosphere-ocean-land system coupled with advances in numerical prediction and observation of this system means that we can make timely and accurate forecasts of hazards. The use of ensemble prediction techniques gives us insight into the likelihood of a hazard and we can use this knowledge, coupled with information about what and who is likely to be affected, to provide more actionable warnings.

The experience of those WMO Members, which have developed and used these techniques, is invaluable in helping others. Further guidance is available through WMO programmes and together, WMO and World Bank/GFDRR are working to ensure that the efforts to modernization NMHSs can strengthen their capabilities to deliver more relevant forecast and warning services.

In a relatively short training course, it is difficult to get across all the concepts that will enable the operational implementation of impact-based forecasts and warnings. Feedback from the participants highlight the importance of the topic and the need to learn more about how to implement it within the specific constraints of a country (See Annex 5). Sharing the experiences of countries trying to cope with the impact of hydrometeorological hazards is integral to adapting the tools to their specific needs. Bring together meteorologists, hydrologists and disaster managers to work on operational scenarios was a high point of the workshop.

References

Rogers, David P., and Vladimir V. Tsirkunov. 2013. Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services. Directions in Development. Washington, DC: World Bank.

Rogers, D.P. H. Kootval and V.V. Tsirkunov. 2016: Early Warning, Resilience and Risk transfer. Submitted for publication.

Tang Xu, Lei Feng, Yongjie Zou, and Haishen Mu. 2012. "The Shanghai Multi-hazard Warning System: Addressing the Challenge of Disaster Risk Reduction in an Urban Megalopolis." In *Institutional Partnerships in Multi-Hazard Early Warning Systems*, edited by Maryam Golnaraghi, 159-79. Heidelberg, Germany. Springer.

United Nations. 2015. Sendai Framework for Disaster Risk Reduction 2015-2013. United Nations, New York.

World Bank. 2012. World Bank Disaster Risk Financing and Insurance (DRFI) Program. http://www.gfdrr.org/gfdrr/DRFI.

———. 2013. Pacific Catastrophe Risk Assessment and Financing Initiative. Risk Assessment – Summary Report. Washington, DC: World Bank.

World Meteorological Organization. 2012. "The WMO Strategy for Service Delivery." WMO, Geneva. http://www.wmo.int/pages/prog/amp/pwsp/documents/SDS.pdf.

———, 2015: WMO guidelines on multi-hazard impact-based forecast and warning services. WMO TD no. 1150.

Annex 1 Workshop Participants

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47.	Xiao Chan	China	China Meteorological Administration	

Annex 2 Workshop Agenda

Monday, 12 December, 2016		
Start	**End**	
08:30		**Registration** *(participants will be meet in the lobby of Jian Guo Hotel at 08:30 to walk to Shanghai Met Service)*
09:00	10:00	**Introduction ofparticipants, objectives and expected outcomes of the meeting**
		Session 1: This session will introduce the World Bank GFDRR HydroMet program and multi-hazard early warning systems (MHEWS) in China. Presenters will describe how the GFDRR program is supporting new World Bank investments in meteorological and hydrological services; the importance of MHEWS; and introduce the audience to the concept of MHEWS as implemented by CMA in Shanghai. *(Session Chair:* **David Rogers**, *GFDRR)*
10:00	10:30	**Overview of WB and GFDRR programs supporting modernization of HydroMet and Early Warning Systems** **Vladimir Tsirkunov** *World Bank/GFDRR*
10:30	11:00	Coffee Break and Group Photo
11:00	12:00	**Welcome from Director General of Shanghai Meteorological Service** **Chen Zhenlin**, *SMS* **Concept of multi-hazard early warning in China and Overview of Shanghai Multi-Hazard Early Warning System (MHEWS)** **Chen Zhenlin**, *SMS*
12:00	14:00	Lunch
		Session 2: Operations of the Meteorological Service, Hydrological Service and Disaster Management in Shanghai. *(Session Chair:* **Chen Baode**, *SMS)*
14:00	14:45	**Meteorological Services** **Kong Chunya**, *SMS*
14:45	15:30	**Hydrological Services** **Zhang Zhenyu** *Shanghai Water Affairs Bureau*
15:30	16:00	Coffee Break
16:00	16:45	**Disaster Management** **Yang Xiaodong** *Shanghai Emergency Management Office of Shanghai Municipal Government*
16:45	17:30	**Discussion**

Tuesday, 13 December, 2016		
Start	End	
		Session 3: This session will introduce the concept of Impact-Based Forecast and Warning Services; how they can be implemented in NMHSs and Disaster Management organizations; and how impact-based warning services are being implemented in Shanghai. (Session Chair: TBD)
08:30	10:30	**Implementing Impact-Based Forecast and Warning Services** **(including exercise 1: effective warnings)** **David Rogers**, *GFDRR and* **Chen Baode**, *SMS* *Discussion*
10:30	11:00	Coffee Break
11:00	12:30	**Implementation of Impact-Based Forecasting in Shanghai** **Wang Qiang**, *SMS* *Discussion*
12:30	14:00	Lunch
		Session 4: China national perspective – In this session CMA will discuss how they support disaster risk reduction nationally
14:00	15:00	**CMA Meteorological Centre and Services for Disaster Risk Reduction** **Chan Xiao** *Meteorological Disaster Risk Management Division of National Climate Center Discussion*
15:00	15:30	Coffee Break
		Session 5: During this session, the participants will have a guided tour of the SMS operations centre
15:30	17:30	**SMS Operations Centre: brief presentations of each of the operational platforms** *(TBD)*

Wednesday, 14 December 2016		
Start	End	
		Session 5: In this session, participants will present several forecast and warning case studies, which highlight the issues we face in improving the public and sectorial response to hazardous meteorological and hydrological conditions. This will be an opportunity for all participants to share their experiences with the aim of identifying solutions, which may have universal application. *(Chair:* **David Rogers**, *GFDRR)*
08:30	10:30	**Participant Case Studies**
10:30	11:00	Break
11:00	12:30	**Exercise 2a: Impact Matrix**
12:30	14:00	Lunch
14:00	15:30	**Participant Case Studies**
15:30	16:00	Break
16:00	17:30	**Exercise 2b: Vulnerability Assessment**

Thursday, 15 December, 2018		
Start	End	
		Session 6: In this session, participants will be assigned to small groups to conduct an impact-based forecast and warning exercise using the ideas discussed during the earlier sessions and building on their own operational experiences and case studies *(Chair:* **David Rogers***, GFDRR and* **Chen Baode***, SMS)*
08:30	10:30	**Exercise 3: Impact-Based Forecast and Warning**
10:30	11:00	Break
11:30	12:30	**Exercise 3: Impact-Based Forecast and Warning Exercise**
12:30	14:00	Lunch
14:00	16:30	**Presentations by each group on findings and recommendations,** **Discussion, Reflections and Wrap Up**

Annex 3 Examples of Impact Matrices for Myanmar, Mozambique and Mauritius

Wind Impact matrices based on discussions with stakeholders in Myanmar.

Wind Impacts Matrix for the public (impacts that have a primary effect on the public – emergency response and public security)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Damages to billboards • Health & disease problems	• Electrocution • Electric shock • Falling lamp posts • Minor disruption to travel • Malaria • Psychological problems • Some injuries • Temporary stoppage of health services • Isolated loss of telecommunication and electrical power • Damage to roofing	• Localized loss of communication and electricity supply due to gusty wind damaging power lines • Localized business disruption (industrial zone, urban areas) • Localized disruption of schools • Population displacement • Diversion of aircraft • Danger to life from flying objects – injuries (physical trauma) • Air and sea search and rescue disrupted • Localized disruption to ground transport	• Widespread damage to weak structures – houses and commercial buildings collapsing • Trees falling down • Electric power lines falling down • Wind-driven waves damage coastal structures causing injury • Widespread delays to public transportation (Air, Road, Rail, Ship, Ferry). • Danger to vehicles on roads • Death • High risk to aircraft • Widespread loss of fishing boats, and other shipping • Search and rescue impacted on a large scale

Wind Impacts Matrix for the water sector (impacts that have a primary effect on the dams and irrigation)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
•	• Isolated loss of telecommunication and electrical power may affect operations	• Localized disruption to communication & electric supply affecting operations	• Control systems of dam breaking

Wind Impacts Matrix for the agricultural and fisheries sector (impacts that have a primary effect on farmers and/or fishers)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
•	• Isolated damage to crops • Soil erosion • High waves disrupt fisheries	• Loss of crops • Loss of livestock • Financial losses • Loss of fishing gear and boats, loss of life	• Widespread Loss of fishing boats and gear, loss of life • Crops, loss yield & Cultivation • Soil erosion • Financial losses to farmers and fishers

Wind Impacts Matrix for transportation sector (impacts that have a primary effect on transportation network)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Minor disruption to travel	• Disruption to Transportation (rail, road, inland water, airlines)	• Widespread disruption to transport networks (road, rail, air, sea)

Wind Impacts Matrix for energy and communication sectors (impacts that have a primary effect on energy supply and communication networks)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Temporary loss of telecommunication and electrical power may affect operations and supply	• Short break of hydro power generation • Minor disruption to Communication & Electric supply may affect supply •	• Widespread damage to communication and energy supply infrastructure

Wind Impacts Matrix for health sector (impacts that have a primary effect on health services)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Increase in presentation of injuries in emergency centers • Spread of malaria	• Injuries • Temporary stoppage of health services • Psychological impact • Population displacement due to loss of homes	• Loss of life, traumatic injuries (severity and duration, area extent) • Damage to Health care facilities

Wind Impacts Matrix for national planning (impacts that have a primary effect on central government)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**

•	•	• Population displacement • Widespread economic loss • Increased cost of rescue and rehabilitation. • Minor disruption to Communication & Electric supply	• Widespread damage to infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication)

Extreme temperature Impact matrices based on discussions with stakeholders in Myanmar.

Extreme temperature Impacts Matrix for the public (impacts that have a primary effect on the public – emergency response, and public security)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Health & disease problems	• Excessive sweating • Minor disruption to travel • Water related problems • Psychological problems • Vector-borne Diseases • Heat Exhaustion/ Heat Stroke • Hypothermia • Isolated shortage of food	• Heat stroke • Interruption of school hour • Snake bite • Decreasing food production • Localized shortage of food • Localized forest fire • Migration	• Death • Heat stroke • Decreasing crop production • Widespread forest fires destroy homes and businesses • Widespread displacement of population
Extreme temperature Impacts Matrix for the water sector (impacts that have a primary effect on the dams and irrigation)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
•	• Temporary loss of telecommunication and electrical power may affect operations	• Minor disruption to Communication & Electric supply affecting operations	• Not enough water in the water sources to supply irrigation water • River water level at lowest point
Extreme temperature Impacts Matrix for the agricultural, forestry and environmental sectors (impacts that have a primary effect on farmers and forestry)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
•	• Isolated damage to crops • Soil erosion •	• Loss of crops • Loss of livestock • Financial losses • Localized forest fire timber losses and environmental degradation	• Crops, loss yield & Cultivation • Financial losses to farmers and forestry • Widespread forest fires and environmental degradation
Extreme temperature Impacts Matrix for transportation sector (impacts that have a primary effect on transportation network)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Minor disruption to travel	• Disruption to Transportation infrastructure (rail, road, inland water, airlines)	• Widespread disruption to Transportation infrastructure (rail, road, inland water, airlines)
Extreme temperature Impacts Matrix for energy and communication sectors (impacts that have a primary effect on energy supply and communication networks)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Temporary loss of telecommunication and electrical power may affect operations and supply	• Short break of hydro power generation • Minor disruption to Communication & Electric supply may affect supply •	• Widespread disruption to communication and energy supply infrastructure
Extreme temperature Impacts Matrix for health sector (impacts that have a primary effect on health services)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Heat stroke case load increase • Snake bite case load increase • Vector-borne disease case load increase	• High Heat stroke case load • Loss of life among certain population groups	• Widespread loss of life among all population • Very high heat stroke case load
Extreme temperature Impacts Matrix for national planning (impacts that have a primary effect on central government)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
•	•	• Limited migration from affected areas	• Widespread migration

Flood Impact matrices developed by Stakeholders in Mozambique. The matrices were developed based on their primary impact on a sector; however, the effects may be cumulative. Impacts on water sector and agriculture sector, and local government responsible for services, for example, will likely impact the public and emergency responders.

Flood Impacts Matrix for the public (impacts that have a primary effect on the public, emergency response and public security)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Water in roads but people can still drive through • Some water around houses	• Some minor roads not passable. Major roads affected but can be used • Houses close to the river inundated but people can evacuate themselves • Some villages cut off for a short period of time, people are safe • Possible increase in water-borne diseases (malaria, cholera, etc.	• Major roads un-passable and damaged. Disruption to electricity and communication networks • Houses and streets inundated; schools, hospitals and other public services disrupted • Loss of life and large damages • Farms inundated. Issues of local food security	• Large scale damage to major and minor roads • Electricity and communication disrupted across large areas • Major towns and cities affected; public service disruption across a wide area • Large scale damage and loss of life • Agricultural grounds inundated across large areas with significant threat to food security

Flood Impacts Matrix for the water sector (impacts that have a primary effect on the dams and irrigation)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Roads not passable by small vehicles, traffic problems • Isolated low lying land flooding near river	• Roads and bridges flooded but passable, traffic affected • Localised flooding in rural populated areas • Localised flooding in low lying areas	• Roads, railways and bridges not passable at all • Dykes start overtopping • Widespread flooding in populated rural areas • Localised flooding of urban areas • Risk to lives of people • Risk to lives of animals	• Roads not passable by small vehicles, traffic problems • Isolated low lying land flooding • Roads and bridges flooded but passable, traffic affected • Localised flooding in rural populated areas • Localised flooding in low lying areas near river

Flood Impacts Matrix for the agriculture (impacts that have a primary effect on farmers, forestry, and environment)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
• Minor flooding to low land and crop areas • Isolated damage to vegetation	• Loss of crops at river margins. • Interruption of some small systems (irrigation). • Elevation of water levels in dams and other places (25-50%)* **Big difference from drought . The production of crops can increase after floods (higher soil fertility, more especially in high zones).*	• Crops and animals affected (50-75%) • Some infrastructure and irrigation systems	• Total destruction of crops. • Total or partial destruction of infrastructure. • Migration of people and animals. • Different diseases. • More costs after floods due to destruction of infrastructure

Wind Impact matrices based on discussions with stakeholders in Mozambique.

Wind Impacts Matrix for the public (impacts that have a primary effect on the public – emergency response and public security)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Trees blown over • Small scale damage to crops	• Roofs of houses damaged • More trees blown over in larger areas that block roads • More damage to agriculture • Small boats affected that are used for transport and fishing. Engine boats can still operate • Some electricity poles damaged, causing minor outages	• More vulnerable houses collapse • Significant damage to roofs of many houses. More trees fall down • Electricity poles fall down, electricity network disrupted on larger scale • Ferries cannot operate, also small to medium engine boats grounded • Primary schools cannot be used because of safety. Secondary schools can still be used. • Hospitals still operational, but possibly electricity problems	• Loss of life of both people and animals • Big trees fall down. • Many houses collapse or are severely damaged • Electricity network severely disrupted on large scale • No more boats can operate, even big ships grounded • Schools, hospitals and many public services, damaged and some cannot be used.
Wind Impacts Matrix for the water sector (impacts that have a primary effect on the dams and irrigation)			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
			• Loss of measurement equipment
Wind Impacts Matrix for the agricultural sector (impacts that have a primary effect on farmers and/or fishers)			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
	• Evapotranspiration (20% below normal)	• Loss of crops • Loss of livestock • Financial losses • Loss of fishing gear and boats, loss of life	• Widespread Loss of fishing boats and gear, loss of life • Crops, loss yield & Cultivation • Soil erosion • Financial losses to farmers and fishers

Flash flood Impact matrices developed by Stakeholders in Mauritius.

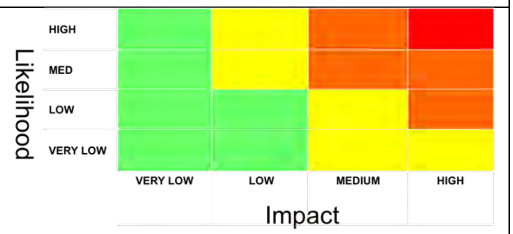
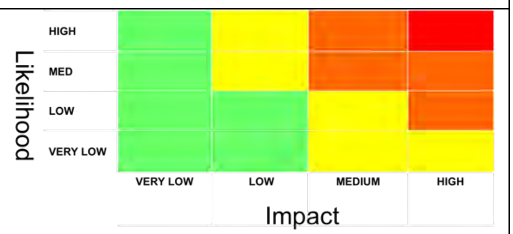
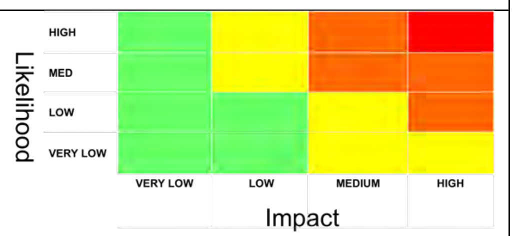
Flash Flood Impacts Matrix for First Responders			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• 1cm Surface water on road • Low visibility • Slow traffic • Very short duration	• 3-5 cm surface water on road • Traffic jam • Sporadic accumulation of water (compounds) • Disrupt outdoor activities • Small area affected • Short duration (15 min)	• 30cm surface water • Accidents • Heavy traffic jam • Disrupt socioeconomic activities (schools, transport, business) • Increased exposure • Stranded students/workers • Flooding in basements/ underground parking, • Larger area affected • Longer time duration (30 min) • Accumulation of debris (branches, rocks, silt) • Blocked drains and other water courses • Affect certain essential services (communication, waste water/sewage overflow) • Reduced sea activities • Small area of vegetation/agriculture affected • Cancelled public and outdoor events • Minor damage to infrastructures (road/ bridges/ buildings	• Up-to and above 1m • Casualties • Vehicles washed away • Drowning • Inundation of larger areas • Plied vehicles along water courses • Major damage to all infrastructure • Overflooded basement and underground parking • Trapped persons • Major Disruptions of essential services (public transport, communication, power supply, access to hospitals, etc) • Delayed access emergency responders • Contaminated potable water • Significant accumulation of debris • Larger area of vegetation/agriculture affected •

Flash Flood Impacts Matrix for Public			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Traffic jam and public stranded • Power supply disruption	• Soil erosion • Crop damage	• Panic behaviour • Debris flow • Socio-economic activities disruption • Mass casualty • Dam failure • Water Disruption	• Flooding (Commercial & Residential) • Drowning • Deaths • Animal deaths • Property damage (Commercial & Residential) • People and cars trapped in underground parking • Communication disruption
Flash Flood Impacts Matrix for WATER			
Minimal impacts	**Minor Impacts**	**Significant impacts**	**Severe impacts**
• Excessive spills from dams causing high peak flows	• Damage and loss of equipment • Reduce workforce • Telecommunication damage • Health impact • Electricity supply cut	• Disruption of water supply, electricity, transport • Siltation and blockage of water intake • Water contamination & proliferation of diseases • Damage of pipeline • Disruption of air traffic services, road traffic • Damage water resources infrastructure (feeder canals, dams, boreholes, etc.) • Socio-economical activities	• Immediate casualties • Disruption • Sedimentation of lagoons (death of aquaculture organisms) • Overflow of feeder canals, dams, rivers, etc. • Agriculture loss

Drought impacts matrix based on discussions with stakeholders in Mauritius

Drought Impacts Matrix for Water Sector			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
• Unpleasant environment	• Health impact • Social unrest • Disruption of work • Reduced hydro-electrical activities	• Socio-economic disruption • Imbalance of ecosystem & biodiversity • Spread of diseases • Poor sanitary conditions	• Excessive agriculture loss • Disruption of potable water supply • Wildfire
Drought Impacts Matrix for First Responders			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
• Occasional Small Fire in vegetation field	• Frequent small Fire outbreaks • Reduced water level in reservoirs • Reduced supply of water for irrigation • Reduced water level in river • Localised crop failures	• Frequent large Fire outbreaks • Water shortage • Public health problem • Limited agricultural products • Reduced supply of livestock • Disrupt economic activities • Reduce irrigation	• Major fire outbreaks • Acute Water shortage • Major Public health problem • Shortage of vegetables • Major sanitation issues • Reduced power supply • Stop operation of certain industry • Affected livelihood • Dam/Reservoirs drying up • • Stop irrigation
Drought Impacts Matrix for Public			
Minimal impacts	**Minor impacts**	**Significant impacts**	**Severe impacts**
• Wild fires • Hydro-electric generation	•	• Sanitation • Spike in vegetables prices	• Agriculture sector (crops & livestock) • Domestic water supply • Social unrest

Annex 4 Impact Forecast and Warning Template

1. [colour] Warning for {hazard}			
Validity	**Warning**	**Forecaster's Assess-ment**	**Hazard Impact Matrix**
Issued at: Valid from: Valid to:			
2. [colour] Warning for {hazard}			
Validity	**Warning**	**Forecaster's Assess-ment**	**Hazard Impact Matrix**
Issued at: Valid from: Valid to:			
3. [colour] Warning for {hazard}			
Validity	**Warning**	**Forecaster's Assess-ment**	**Hazard Impact Matrix**
Issued at: Valid from: Valid to:			

ACTIONS

Annex 5 Participant Feedback

Q1, Q3, Q4: 5 = excellent; 4 = very good; 3 = good; 2 = average; 1 = poor

Q2: 5 = exceeded expectations; 4 = met my expectations; 3 = nearly met my expectations; 2 = did not meet my expectations; 1 = Below my expectations

	Question	Rating
1	How would you rate the overall useful of this event?	3.9
2	To what extent did the workshop meet your expectations?	3.6
3	To what extent did the workshop help you learn good practices in multi-hazard impact-based early warning systems?	3.5
4	To what extend did the workshop provide networking opportunities	3.5

		Comments
5	What aspects of early warning systems /impact-based warning are you most interested to learn from Shanghai Meteorological Service?	• How they've made impact forecasting operational, Sharing of data/information and expertise. • River flooding, urban flooding • Guided tour for weather forecasting centre and Disaster management in Shanghai • Institutional collaboration for anticipation of impacts; Best approach to engage vulnerable communities in monitoring of impacts and updating impact thresholds • Dissemination systems for forecast information and early warning. The fact that the forecasts/warnings must be impact-based • Work station, forecasting area • I am most interested to learn about how instrumentation and communication was developed and how interactions between events are considered • Instrument, network, telecommunication system among others, technology, capacities, research sector relationship with SNS, how is the collaboration with other agencies (other hazards and other regions) • Estimation of reconstruct amounts and possible impacts on populations. • Impact of early warning system. • Rainfall estimate forecasting; and tools and methods of forecasting for areas of thunderstorm developments • Establishment of the brief agencies coordinating before its out to the public; Color coding and actions follow; and establishment of the Shanghai Emergency Warning Center. • Public Weather Service; swell forecasting; and introduction to their meteorological and forecasting system organization and setup. • Warning dissemination • I am interested in not only impact based warning and forecast but also real time monitoring system from Shanghai Meteorological Service. • I am more interested in dissemination system about early warning system/ impact based warning to their communities. • Model based EWS, dissemination of warnings • Technology • The responses from disaster manager, after warning based to met forecast • Communication network, coordination among stakeholders, meteorological radars • Stakeholders coordination before and during disasters, and their infrastructure and human resources • Flash flood forecasting; and Joint warning operations • Numerical weather prediction and coupling of climate and hydrological models. Will also like to learn about issuing warning using color coding. • Impact based early warning system of SMS; NWP system of SMS; AWS and observation system of SMS, marine; and Forecast of SMS are the most interested to learn for me • Forecasting sectoral impacts of different hazards - quantifying the size and nature of actual impacts • How they integrate impact and probability of occurrence when issuing warnings • Impact based forecast approach developed; and working groups thematics • During this workshop, we were impressed by how the Shanghai Meteorological Service manages meteorological and hydrological data. We are aware of their technological advances in meteorology and hydrology.

		• Interagency coordination, precision in data transmission.
6	What did you like best about this workshop?	• Sharing of experience between countries • There is no exercise to know how the flood models are forecasting (…..). (…….) the type of models are (…..) forecasting • Practical exercise met the expectation, for some extent. It is to be practice by ourselves to improve the knowledge. The lecture delivered by DG/SMS opened eye for the ability of impact based warning. The knowledge was enhanced by the related presentations provided by other presenters • Ability to understand countries share similar requirements and have very different solutions; Visit of the forecasting center; Experience of the organizers both on meteorology and emergency response / decision making • Group work and discussion. Best practices exchanges. • To know about SMS developed its system and how it is managing alerts. • Learn about other experiences, I recognized very different scopes and realities, I realize about the importance about integrating hydro-met knowledge • The fact that enough time was allocated to group works which allowed for individual participation was excellent. • Implementing impact-based forecast and warning services and including all the exercise. • Practical work and group interaction • As a forecaster, what the weather will do it the fundamental question all weather forecasters should concern about. Exercises on how to develop matrix for each scenario are the way forward for developing SOPs and actions to be performed for impact based forecast. • The interactive sessions on the last day on impact matrix exercises. Recommend more time allocated in to these types of sessions in the future; More effective group exercises. • The idea of impact-based warnings. The different case studies were eye opening. • I like one of the topic is exercise-3 impact based forecast and warning exercise. • I am really into doing the last day activities - impact based forecast warning exercise using respective country maps. • International participation; and sharing of ideas and processes of MHEWS • Facilities • I like the practice, because we get easily the liability to work; and to make warning impact after forecast do warning • Impact based warning, weather impact matrix, multi-hazard early warning system, good practices of SMS. • have clear idea of impact-based forecasting and risk based warning • Last day activity on impact forecasting • Presentations from various countries helped me learn about the various challenges and successes of the various countries. Presented me with new ideas on how to improve our system. • Practical exercise for impact based forecast/warning. Last day lecture/group work. • Interaction with regional countries and sharing experiences • Discussions and exercises around impact matrices • Assistance from WBG's staff; Understanding about impact based forecast; Organization has been good • Thanks to the organizers, I really appreciated the geographical diversity of the participants from around the world, and the opportunity to exchange the experience of data management in hydro-meteorology, to learn more about how data are obtained and processed. • The exchange of experience between countries and different types of forecast modelling.
7	What did you like least about this workshop?	• Long presentations (Some too exhaustive and theoretical) • Time constraints/limitations • language that was used • I think that interactions between hydrometeorological events and other, for instance, geological event was poor. • I expected more information about multi-hazard approach; and to know how to work with other sectors. I can see the relation about impacts, but not during the emergencies are evolving (cascade effects) • Difficult to indicate - probably my inability to look around Shanghai City. A tour of the city would have ever enhanced my knowledge better. • Time management of the workshop; Presentation times should be kept to 10 minutes. • It was a little intense. • All the topics are very interesting for my colleague, because my colleagues try to improve impact-based forecast process. No least about this workshop. • There are nothing dislike activities and events • No field based application was observed. • The materials of the workshop • The training about wind speed forecast. this is important for the population security.

		• There was no field visit • Had no common case study to discuss among the countries • Powerpoints in Chinese language. • Less time to learn about each other individually and also to explore the city of Shanghai • internet system • Communication barriers and inconsistent time and opportunities allocated to participants to share and contribute. • Too many presentations from SMS in day 1 and 2. • Workshop duration has been very short • The time lost for the interpretation did not allow us to go deeper and explain better the subject. Despite the interpretation, the language barrier made it difficult to comprehend the lecturers. • The program was very packed and they should have account for jetlag and change of time-zones.
8	Please share any other comments with us	• Opportunity to work on an operational scenario for the region. Bring together forecasters, hydrologists, DM practitioner to work on messaging. Exchange with other countries show met and DRM valuable. • Presentation may be any language with translation but the Powerpoint slides to be in English preferably; Please try to include some exercise (practical) works in (…….) programme; and Name board to be organized with country. • It is much important to include English Version of presentation, even if conduct with other language. * Time allocated for practicals was more or less enough; It is much helpful if you provide some literature about impact based warning • I recommend more examples of how institutions collaborate in Shanghai through practical cases and how capacities have evolved over time through return of experience. The country presentations through case studies was a very nice approach to show what happens in reality; most countries have not followed the template and this results in long presentations. • The issue of adequate time for the exchanges, discussions and exercises should be looked at; The workshop has been very informative and interactive for me, but for the time constraints, I would have wished that we continue. • more time used for translating. Not expected in this kind of workshop from participants. Participants should speak English to same time which is sometimes ("ANNOYING") • I think that the public was not chosen correctly. WB could have suggested previously the set couple to participate in the workshop. I believe that experiences from developed countries will be useful for us (Chile) not only one segment of economies (for instance, to share and know how USA; Germany; Japan; others) works in this issues... I hope that share with us all presentations and materials • The opportunity to meet all the participants from around the world created a very good platform for me (not only to learn from their experience here at the workshop, but also to create a platform for partner discussions which we care back in our countries) • This workshop was very useful for me, because we can share the experience between all the participants. We can have a better understanding of the value of multi-hazard impact based warning. • Meteorologists mush be given more time interaction duration and information about forecasting techniques • Sharing lessons learnt was absolutely helpful for the development of impact-based forecast for my country; The present of a disaster manager from my country would have been useful; Impact-based forecast demands more responses for delivery of a new service, hence for it to success, we need financial support from all levels. • Please require English fluency for participants; Very good organization of workshop; Please note here that the information packages given to us was out of date especially transportation advices/guidance. Please provide updated information to participant; please focus more interactive sessions dedicated to the Pacific perspective and needs. • Very good workshop. I would like to coordinate more exercise for impact-based warning, because we are trying to issue impact-based warning. If you have other training or workshop on this subject, please invite my colleagues. • We have to save our people and world as much as we can although we don't change the climate situations. • My expectations: hands on learning of new technology, softwares, procedures etc that I can take back and implement or advise country on a way forward. Too much time spent on country presentations. There are all of hydrological models with meteorological models that would have provided better understanding to improve our impact forecast + assessment. • The well coming. the organization on time, But the material is very poor, no time to visit Shanghai city. The duration is too short. The Shanghai meteorologist hire the visitors himself. • It was nice to know about forecasting and early warning systems of different countries in the globe, including Africa, Pacific Islands and South America; Thank you WBG, GFDRR and

		SMS • If there was a field visit of some community where the EWS is good implemented, was able to give more idea how they have been doing, would provide more knowledge on the system's effectiveness. • For the Chinese presentations, it would have been good if their slides are in English! • Will be good to have hands-on training on some few applications or more demonstrations on how the early warning systems works. • We need more information for impact based forecast/warning with color code. More practical exercise for specific impact. We need to know how to consider base data for color code impact based forecast/warning. • More informational materials could be prepared for participants. • We live on the same planet where no one is safe from the evil effects of the climate change. This workshop should be reproduced in different continents. • I'd like to thank the organizers for the workshop. It is of important to multiply the thoughts, the activities that we carry out before, during and after the projects (???). It's also important to foresee the translation and more or less the languages and issue the certificates of participation.