World Meteorological Organization

GUIDELINES ON EARLY WARNING SYSTEMS AND APPLICATION OF NOWCASTING AND WARNING OPERATIONS

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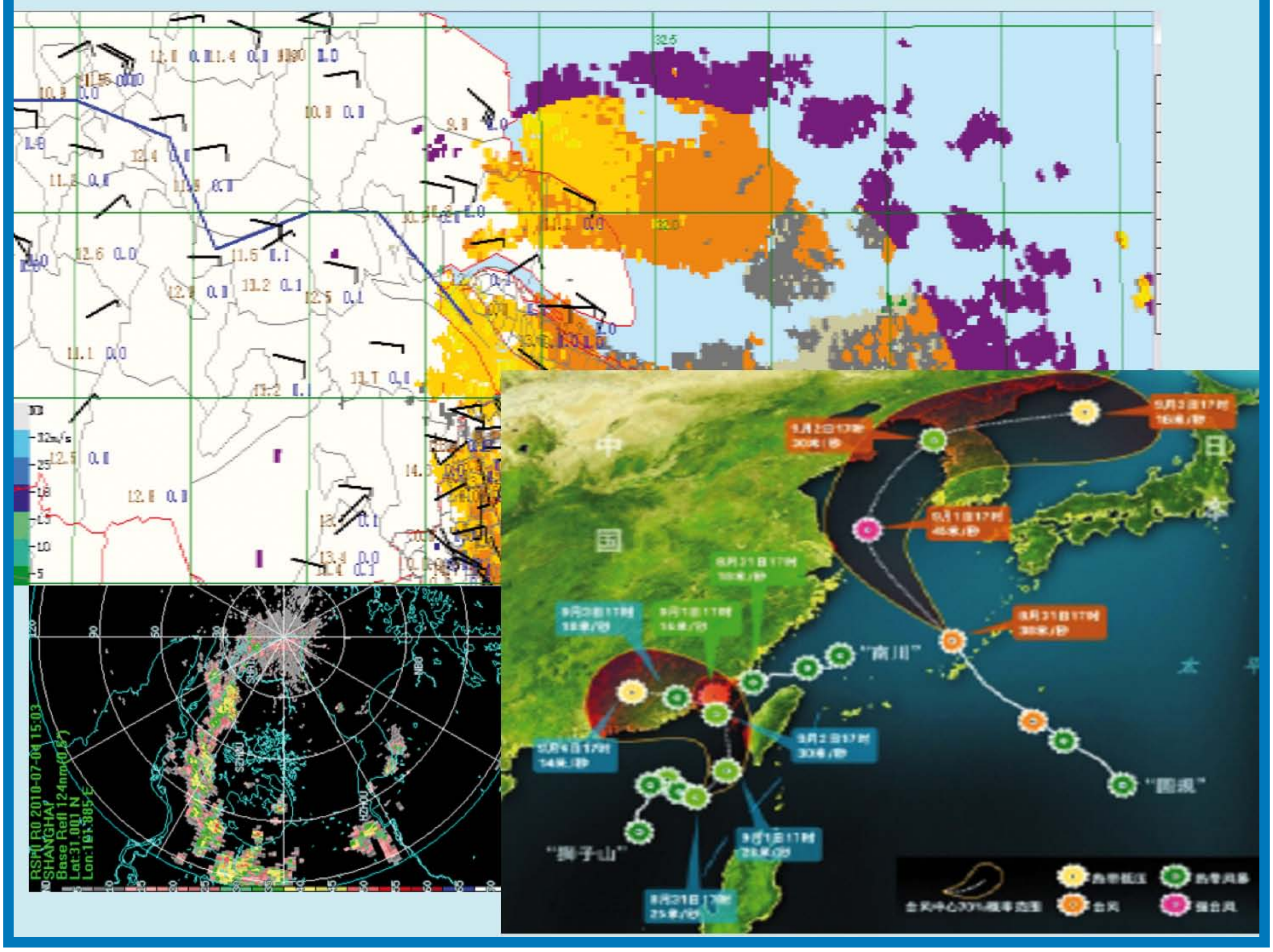

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Chapter 1:
INTRODUCTION

From 1991 to 2005, floods, wind storms, droughts, and landslides worldwide killed over 422,000 and affected over 3 billion people (International Strategy for Disaster Reduction 2006). In 2008, Cyclone Nargis devastated Myanmar, killing over 100,000 and displacing many others. Tropical cyclones during the 2000s, including Nargis, caused thousands of casualties, inflicted enormous economic losses, and caused considerable human suffering. Exposure to tropical cyclones has increased as more people have moved to vulnerable coastal locations than ever before.

Likewise, vulnerability to wildfires has increased. In 2009, a series of large, rapidly-moving bushfires devastated populated areas near Melbourne, Australia. Massive firefronts moved with incredible speed and ferocity, taking 173 lives and destroying thousands of homes.

In 2010, a historic heat wave and numerous wildfires impacted Moscow and surrounding areas in the Russian Federation. At the same time, catastrophic flooding from unusually heavy monsoon rains was ongoing in Pakistan. Both events led to many fatalities and considerable human suffering. As climate change due to anthropogenic forcing continues, extreme weather events such as these are likely to become more common (IPCC 2007), further increasing the need for preparedness and early warning systems.

The need for robust early warning systems goes beyond purely natural disasters and extends to include response to man-made disasters. In 2010, a catastrophic oil spill in the Gulf of Mexico devastated the ecosystem, and severely impacted the local fishing and tourism industries. In such a disaster, meteorologists must be prepared to work with emergency response officials and experts in other disciplines to mitigate the effects of the disaster through effective decision support services.

The dramatic impact of natural disasters and the subsequent response activities often attract much international interest. Attention is being increasingly focused upon natural disasters inflicting tremendous economic losses (in addition to human suffering and casualties) and the efforts expended on the mitigation and reduction of such disasters. Disaster prevention and mitigation is now a recognized international priority. WMO cooperates within many other organizations and international programs, particularly the International Strategy for Disaster Reduction (ISDR), in its efforts to improve natural disaster prevention and mitigation. In September 2006, Mr Kofi A. Annan, then the UN Secretary-General, said in the Forward to *The Global Survey of Early Warning Systems*, "Natural Hazards will always challenge us, but people-centered early warning systems can be a potent weapon in ensuring that natural hazards do not turn into unmanageable disasters."

Increasingly, it is recognized that disasters are linked. The impacts of many types of natural disasters do not happen in isolation, but recognition of such cause and effect on a global and regional scale is leading to the creation of early warning systems that can accommodate multiple hazards and cross-boundary impacts. At the same time, governments are becoming aware that a paradigm shift from crisis management to risk management is necessary if the finite resources available are spent in the most efficient way to assist the populations at risk to prevent or mitigate disasters.

The World Conference on Disaster Reduction, which was held at Hyogo, Japan in 2005, identified five (5) priority areas in the Framework of Action it adopted for 2005-2015. The second item on the list is "Identify, assess and monitor risks and enhance early warning." Natural hazards turn into disasters if the affected people cannot cope with them. A community without early warnings will be unprepared and suffer from the full-blown damages inflicted by the hazard.

At its Fourteenth Session, the WMO Commission for Basic Systems (CBS, CBS-XIV, Dubrovnik, Croatia, 2009) requested the WMO Public Weather Services Programme (PWSP) to continue its focus on assisting Members to improve their national Public Weather Service programmes by providing guidance on the application of new technology and scientific research in data acquisition and use, especially for nowcasting and multi-hazard warnings. These guidelines are prepared with focus on the role of NMHSs in reducing the impact of disasters. The development of early warning systems is seen as part of the operational responsibility of NMHSs. The essential elements of such systems and in particular, forecasting, formatting, presenting and communicating of warnings of severe weather, and the accompanying public education and capacity building of NMHSs are given special attention in these guidelines. The application of nowcasting in warning operations and examples of nowcasting systems used by various NMHSs complete the document.

Chapter 2:
THE ROLE OF NMHSS IN DISASTER RISK MANAGEMENT

In the context of the current guidelines, a natural hazard is a weather or flood-related situation with potential to inflict loss or damage to the community or environment. A natural disaster is a catastrophic event caused by a natural hazard that severely disrupts the fabric of a community and usually requires the intervention of government to return the community to normality. While hazards may induce a crisis, they do not necessarily lead to disasters. Though many natural hazards may be inevitable, natural disasters are not totally unavoidable. A disaster will depend on the characteristics, probability, and intensity of the hazard, as well as the susceptibility of the exposed community based on physical, social, economic, and environmental conditions.

In some instances, natural disasters cannot be prevented from occurring. However, their overall impact can be significantly reduced through disaster prevention and mitigation. Disaster mitigation is the process of managing the "risks" associated with potential natural disasters so that loss may be minimized or even eliminated. This includes the disaster response which are actions taken in anticipation of, during, and immediately after, a natural disaster to ensure that its effects are minimized, and that people affected are given immediate relief and support. A systematic approach should be taken to manage the risk of natural disasters. This process of disaster risk management should consider the likely effects of natural hazards and the measures by which they can be minimized. A disaster risk management system should incorporate response actions that are appropriate to the social and economic conditions of the community under threat.

The concept of disaster risk is used to describe the likelihood of harmful consequences arising from the interaction of natural hazards and the community. Two elements are essential in the formulation of disaster risk: the probability of occurrence of a hazard, and the vulnerability of the community to that hazard.

Risk = Hazard Probability x Vulnerability

A closer look at the nature of hazards and the notions of vulnerability allows for a better and more comprehensive understanding of the challenges posed by disaster mitigation:

i. Nature of hazard - By seeking to understand hazards of the past, monitoring of the present, and prediction of the future, a community or public authority is poised to minimize the risk of a disaster. The NMHSs play a key role in this aspect of risk management of weather-related natural disasters; and,

ii. Notions of Vulnerability - The community vulnerability is the susceptibility and resilience of the community and environment to natural hazards. Different population segments can be exposed to greater relative risks because of their socio-economic conditions of vulnerability. Reducing disaster vulnerability requires increasing knowledge about the likelihood, consequences, imminence and presence of natural hazards, and empowering individuals, communities and public authorities with that knowledge to lower the risk before severe weather events, and to respond effectively immediately afterwards.

The importance given to socio-economic vulnerability as a rapidly increasing factor of risk in most of today’s societies underlines the need to encourage the participation of a wide spectrum of stakeholders in hazard and risk reduction activities. Stakeholders are those people or organizations who may affect, be affected by, or perceive themselves to be affected by, a decision or activity. In developing a disaster risk management system, no single agency can provide a fully comprehensive solution. It is essential that agencies work together and with stakeholders to narrow knowledge gaps and to develop disaster risk management plans using a coordinated approach.

2.1 FRAMEWORK OF RISK MANAGEMENT

Wilhite et al. (2000) have taken the commonly-accepted cycle of disaster management and redefined it in terms of crisis management and risk management. Crisis management emphasizes post disaster impact assessment, response, recovery, and reconstruction; whereas risk management emphasizes protection through mitigation, preparedness, prediction, and early warning.

Traditionally, the focus of disaster management has almost been exclusively on actions taken immediately before, during, and shortly after a disaster. The Hyogo Framework for Action 2005 – 2015 (HFA) (International Strategy for Disaster Reduction, 2005) provides the framework for a new paradigm in disaster risk management with a strong focus on prevention and preparedness strategies based on identification and quantification of potential risks. It encompasses risk identification, risk reduction and risk transfer. Figure 1 provides a simplified schematic of a comprehensive national strategy for disaster risk management derived from HFA.

Figure 1: Schematic showing the inter-relationship of the elements of the Hyogo Framework for Action.

There is no doubt that the role of relief assistance during a crisis will remain important and need to be enhanced at all levels. However, a paradigm shift is occurring with a move away from purely reactive response and recovery to a much more proactive and holistic concern about preparedness and prevention. Proactive mechanisms are sought to reduce the economic costs and impacts of hazards, improve response capacity, decrease vulnerability, and enhance communities' resilience to disasters.

The NMHSs role within each element of this framework would involve:

i. In risk identification element: Systematic observation and monitoring of hydrometeorological parameters; provision of quality-assured archived and real-time data; hazard analysis and mapping; as well as forecasts of hazards and their changing patterns;

ii. In risk reduction element: Provision of hazard forecasts and early warnings to support emergency preparedness and response; climate data and forecasts (probabilistic information on hazards and their changing patterns) to support medium and long-term sectoral planning; and,

iii. In risk transfer element: Provision of historical and real-time hazard data and analysis to support catastrophe insurance, bonds and weather-indexed risk transfer mechanisms.

An effective early warning system is critical to disaster risk reduction. Responses to warnings about natural hazards generally involve making decisions based on calculated risks and uncertainty. Although safety assurance of life and property is a common ideal underlying all warnings, one has to have to accept that risks can never be totally eliminated. Thus risk management generally involves the challenging task of minimizing threats to life, property and the general environment, yet at the same time without imposing excessive constraints on the daily life of the communities likely to be affected by natural hazards.

2.2 PARTNERSHIPS

The design and operation of severe weather warning systems, and on a larger scale, the risk management plan, must be based on a commitment to cooperation and information exchange and the concept of partnership in the overall public interest. The benefits of such partnerships include:

i. drawing expertise from a wide range of disciplines, such as social science, community planning, engineering, etc.;

ii. accomplishing tasks that cannot be managed by a single agency or organization;

iii. demonstrating to government budget planners a commitment to work together towards a common goal and making better use of scarce financial resources;

iv. leveraging resources for research, awareness, preparedness, etc.;

v. sharing costs, knowledge, and lessons learned;

vi. ensuring a consistent message (the warning bulletins and other outreach material) from multiple credible sources; and,

vii. yielding wider distribution of the message through multiple outlets and receiving feedbacks from a whole range of users.

To identify and evaluate the weather information needs of the users, NMHSs need to build relationships and work in partnership with users in both the public and private sectors. NMHSs partners include:

i. other government agencies with missions involving the protection of life and property, such as the National Hydrological Services (NHSs) where they are separate agencies from NMHSs, national, regional or local emergency management agencies, first responders, and infrastructure managers (dams, highway departments, bridges);

ii. the media;

iii. Non-Government Organizations (NGOs);

iv. emergency relief and humanitarian organizations, such as the International Red Cross and Red Crescent Society (IFRC);

v. academic institutions and schools;

vi. trained volunteers associated with NMHSs, such as cooperative observers, storm spotters, and amateur radio operators;

vii. meteorological societies and other professional associations in risk management disciplines;

viii. private sector weather companies, and,

ix. utility services, telecommunication operators and other operation-critical or weather-sensitive businesses.

A typical partnership would involve disaster, warning, and risk management experts from government, business, academia, non-government relief organizations such as the Red Cross and Red Crescent Society, and emergency management officials, to agree on warning standards, procedures, and systems.

Sustained partnerships must also be formed with the social science community. An interdisciplinary group of practitioners, researchers, and stakeholders is best suited to address challenges in reaching out to vulnerable populations and turning warnings into effective action. In addition to stakeholders and partners, a range of experts in various fields such as economics, sociology, and human factors should be consulted throughout the planning and implementation of any new severe weather services.

The NMHSs must also understand the tactical decision making process being made by emergency managers and have a thorough knowledge of how these processes may be affected by weather. This will allow the development of decision support services tailored to these stakeholders. While these processes and the associated NMHSs services must be identified and trained on in advance, NMHSs must also be adaptable enough to address unforeseen needs that may arise with little or no advance warning in an operational setting.

Effective decision support services involve efficient and timely synthesis and elucidation of weather data and its effects on the incident's operations and objectives. These needs may vary widely from stakeholder to stakeholder for the same weather event. An excellent way for NMHSs to prepare and refine their decision support service is to be an active participant in tabletop, functional and full-scale exercises by local emergency managers.

2.3 STAKEHOLDER INVOLVEMENT

Effective inclusion of the severe weather warning system in a risk management plan relies on NMHSs to appreciate the needs of a multi-cultural, economically stratified and often mobile community, and the understanding by the community of the hazard, its vulnerability and the most suited protective action to take.

Stakeholders need to be consulted as partners in the design and refinement of severe weather warning systems, and on the larger scale, the risk management plan. Stakeholders include the public, other national government agencies, emergency management agencies, local authorities, NGOs, the media, social scientists, national and regional infrastructure authorities, academia, etc.

Involving stakeholders in developing and enhancing the end-to-end-to-end severe weather warning system has many benefits, such as:

i. improved presentation, structure, and wording of the warnings themselves;

ii. more effective communication of the risks and actions to take in response to severe weather;

iii. better understanding of how, and how often, stakeholders want to receive warnings; and,

iv. increased sense of ownership, and therefore, credibility in the warning system.

More discussion on the concept of risk management and the formulation of risk management action plan may be found in the PWS Guidelines on Integrating Severe Weather Warnings into Disaster Risk Management. PWS-13, WMO/TD No. 1292. The remaining chapters of these Guidelines focus on the operational role of NMHSs in early warning systems.

Chapter 3:
EFFECTIVE EARLY WARNINGS

The primary objective of a warning system is to empower individuals and communities to respond timely and appropriately to the hazards in order to reduce the risk of death, injury, property loss and damage. Warnings need to get the message across and stimulate those at risk to take action.

Disaster mitigation decision makers require increasingly-precise warnings to ensure effective measures may be formulated. Generally, demands for improvement in severe weather warnings take on the following form (Gunasekera 2004):

i. extending the lead time of warnings;

ii. improving the accuracy of warnings;

iii. greater demand for probabilistic forecasts;

iv. better communication and dissemination of warnings;

v. using new technologies to alert the public;

vi. targeting of the warning services to relevant and specific users (right information to right people at right time at the right place); and,

vii. warning messages are understood and the appropriate action taken in response.

It should be noted that longer warning lead times should be considered together with the need to reduce the false alarm ratio and a balance should be achieved between the two whereby decisions can be based on optimum lead times for warnings.

As described at the 3rd International Conference on Early Warning (EWC III, Bonn, Germany, 2006), effective early warning systems must be people-centered and must integrate four key elements:

i. knowledge of the risks faced;

ii. technical monitoring and warning service;

iii. dissemination of meaningful warnings to those at risk; and,

iv. public awareness and preparedness to act.

The EWC III produced a document "Developing Early Warning Systems: A Checklist", available at the following link: http://www.ewc3.org/upload/downloads/checklist.final_pdf.pdf, which is used here as a framework for discussing the steps to be taken by NMHS in developing effective early warning systems.

3.1 THE PEOPLE CENTERED APPROACH

The goal of early warning systems for natural hazards is to reduce damage inflicted by hazards on people who may be affected. To be effective, warnings must have not only a sound scientific and technical basis, but also a strong focus on the people exposed to risk. In the case of meteorological hazards, NMHSs are the experts and are therefore are critical players in the development of countries' risk management plans.

NMHSs must be credible authorities for information on severe weather warnings and have a reputation for accuracy, reliability, and timeliness. It is also increasingly recognized that NMHSs need to develop a corporate culture of being caring and people-centered, in addition to the more traditional culture of being professional and science-centered. Developing working relationships with partners such as emergency managers and the media and involving stakeholders in the development and review of the warning system is essential.

People-centered early warnings need to be:

i. clearly understood by the people;

ii. easily and readily accessible to people;

iii. timely; and

iv. tied to response actions to be taken by the people in advance of, during, and after the event.

3.2 RISK KNOWLEDGE

As noted in the last chapter, risks arise from the combination of hazards and vulnerabilities. Assessments of risk require systematic collection and analysis of data and should consider the dynamic nature of hazards and vulnerabilities that arise from socio-economical conditions and changing environment. The hazard and vulnerability information is central to almost every aspect and every stage of natural disaster risk management. This information is essential for assessing risk and potential vulnerability in the earliest stages of community planning for construction of new facilities (such as dams, bridges and population centers) or for individuals planning to move to new locations (such as beaches, flood plains and mountain sides). Such information is also crucial when natural hazards threaten and when communities prepare to withstand the potential onset of disaster; and can be even more essential in the critical post-disaster recovery phase when affected communities are shattered and confused, when fear of the unexpected is greatly heightened, and when relief authorities need to know everything that is going on to enable them to manage the complex mix of issues involved in restoring essential facilities and in meeting the physical or social needs of devastated communities.

NMHSs therefore need to develop a knowledge base for the effective provision of severe weather warnings. Examples of initiatives to build such a knowledge base include:

i. applied research regarding the severe weather hazards of the country;

ii. development of historical database of past severe weather events;

iii. production of hazard risk assessments; and,

iv. development of a national risk management plan for regional and local applications.

Effective risk management of, and preparedness for, natural hazards require free and unlimited access to relevant risk information to facilitate monitoring, assessment and prediction. NMHSs and other agencies involved in risk management planning should establish collaborative methods for effective exchange of information among relevant hazard databases to facilitate monitoring, assessment, and prediction.

3.2.1 Risk data

The scientific basis of good early warning systems is data on the hazards and the vulnerability of the community to be protected. Information that is most vital in the design of an early warning system consists of the full suite of climatological data and products, including model studies of extreme events, that will enable the potential natural hazard to be accurately characterized (e.g., through hazard maps), and the necessary decisions on siting, construction, protection and precaution to be taken on a fully informed basis. Communities and civic authorities need to know the nature, severity, and likely return periods of all kinds of potential hazards. This information has to come from the careful analysis of records of what has happened in the past. In this regard, meteorological databases (including warnings and climate databases) contain information relating to natural hazards of a meteorological origin.

Disaster data, including damage and loss due to past events, characterize the impact of hazard and the vulnerability of the community. Local knowledge, community "memory", and relevant experience during past events is essential in the assessment of vulnerability of the community to the hazards identified. Geographical distribution of the hazards also enables identification of the vulnerable community and region.

3.2.2 Risk Assessment

Risk is the outcome of the interaction between a hazard phenomenon and the elements at risk within the community (e.g. people, buildings and infrastructure) that are vulnerable to such an impact. Disaster data contain information largely driven by economic and financial considerations such as insured or un-insured losses. To effectively assess the vulnerability and risks involved, analysis has to be done by integrating or cross-referencing such data and information with the hazard data.

Each hazard likely to impact upon a community should be systematically analyzed in this fashion. The vast majority of information, relationships and processes involved in understanding risk are spatial in nature. For example, people in the coastal zone are more vulnerable to storm surge flood and people on slope are more vulnerable to land slide. Graphical Information Systems (GISs) are especially useful for this purpose.

In risk assessment, one has to consider the probabilities of hazardous events affecting the community and the consequent harm to the community. Probability is a concept and skill that most people have problems understanding, as many cannot handle statistical concepts or effectively factor probabilities into their decision-making. More discussion on the presentation of forecast uncertainty and probabilistic forecast may be found in the *"PWS Guidelines on Communicating Forecast Uncertainty" (PWS-18), WMO/TD No. 1422.*

3.3 MONITORING AND WARNING SERVICE

3.3.1 Forecast and Nowcast

The prerequisite to effective warnings and response is timely, accurate forecasts and "nowcasts" (a forecast for the very near term, generally zero to six hours). These forecasts generally are based on four components: Observational Data and Monitoring Systems; Numerical Weather Prediction; Conceptual Models; and, and Situational Awareness.

Observational Data and Monitoring Systems

A critical requirement for an effective forecast system is adequate observational data at both the surface and aloft. This includes the reliable availability of temperature, humidity, pressure, and wind data. In general, higher temporal and spatial resolution of these data will lead to better weather diagnosis and prognosis.

Parameters to be measured for each type of hazard should be monitored constantly and processed on a real-time or near real-time basis. Measurement networks with adequate coverage for vulnerable regions need to be set up and maintained to ensure high data availability and accuracy. The output data quality and coverage of the network should be kept under continuous review to ensure that the operational requirements of warning operations are met. Besides *in situ* data collected by ground based stations, remote sensing data from weather radar and meteorological satellites are essential in the monitoring high-impact weather such as tropical cyclones, heavy rain, thunderstorms and tornadoes. Relevant data, analysis from regional networks and adjacent territories and international sources should be acquired. To support the development of knowledge of hazards, data have to be archived routinely for subsequent study and research.

Numerical Weather Prediction

Dependable, accurate observational data serve as inputs into Numerical Weather Prediction (NWP) models. Acquiring and maintaining the computers needed to create useful NWP guidance can be expensive, time-consuming, and labor-intensive, but result in major benefits by facilitating the anticipation of hazardous weather events. Those NMHSs without NWP models are able to access via the Internet freely available numerical guidance generated by a number of reputable global models.

Conceptual Models

Conceptual models can serve to synthesize observational data and guidance from NWP models to provide decision support for current and future weather hazards. For example, the identification of conditions favorable for damaging ice accumulation at the surface from freezing rain requires observational data, NWP guidance, and the correct application of a conceptual model. A meteorologist may notice as heavy rain approaches that observed surface wet bulb temperatures are slightly below freezing, which is lower than the previous forecast, indicating that conditions are becoming more favorable for dangerous ice accumulation.

Successful combination of observational and NWP model data with human conceptual models requires ongoing investment in training, as well as infusion of the knowledge gained through experience. Thus, continual education and training of the meteorologist is a critical component to NMHSs severe weather warning programmes.

Situational Awareness

While meteorologists may have considerable observational and NWP information at their disposal to form a conceptual model of existing and future weather hazards, they must also have a variety of means to assess how the forecast is verifying in real-time. In the freezing rain example, the forecaster used one skill associated with conceptual models (pattern recognition) combined with situational awareness (approaching precipitation and observed wet bulb temperatures lower than earlier expected) to identify the potential weather disaster before the first reports of significant ice accumulation were received.

In addition to the traditional meteorological observations, reports from people in the field, remote cameras, news media, emergency management and law enforcement officials can help increase situational awareness. The meteorologist must be trained to recognize quickly when the forecast is not verifying as expected, and must be able to critically re-evaluate the old conceptual model, form a new conceptual model based on the new observational evidence, and act decisively to correct the forecasts and warnings.

3.3.2 Institutional and operational arrangement

A robust early warning system is central to a disaster risk management plan. It is essential that prior agreements between NMHSs and disaster responding agencies be reached to establish the protocol of warning system operation – who issues what warnings for what hazards and using which dissemination pathways. Language used in the warnings should be consistent. A hazard response plan should be drawn up to specify actions to be taken by different parties before, during, and after a hazardous event. Legal provisions should be set up as appropriate.

Early warning centers should be set up to monitor for hazards around the clock and issue warnings to initiate disaster response actions. A national disaster risk management body should be in place to coordinate various processes. Such a body should be linked to the early warning systems for the timely and reliable reception of the warnings. Effective communication between national disaster risk management bodies and NMHSs is also necessary to ensure the warnings meet the requirements of the people. To ensure preparedness, the warning systems should be tested frequently.

Operational systems at the warning centers should be robust with backup, continuity of operations plans, redundant equipment, and support to ensure high service availability.

3.3.3 Forecasting and warning system

Effective warnings are at the core of early warning systems. They should be based on analysis of observational data and NWP guidance using scientific methodology. International standards on data quality and warning products should be adopted where possible. NWP guidance and nowcasting techniques are becoming increasing accessible and should be used in forecasting and warning operations.

NMHSs should undertake research activities in the fields of meteorology, climatology, hydrology, oceanography, and even the social sciences to enhance their understanding of hazards and the ability to forecast them. Storing and updating the results of such research activities is a fundamental requirement for any scientific base of early warning systems.

Technical capacity in forecasting and warning is built through staff training and research. Capacity building activities and research collaboration are regularly offered under various WMO programmes. International collaboration in research activities, through networking of institutions or individual scientists is a solution to muster technical resources for the understanding of physical processes in the atmosphere. Such understanding often requires full scale field experiments to gather data and information, but these experiments are usually out of the reach of individual scientists or individual NMHSs. Many of these collaborative research projects aim to improve capability in warning for meteorological hazards.

3.3.4 Research

The Observing System Research and Predictability Experiment (THORPEX) under the WMO World Weather Research Programme (WWRP) is one prominent example of a collaborative effort which aims at improving the accuracy of one-day to two-week forecasts of high impact weather (http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html).

With particular emphasis on nowcasting applications, the Beijing 2008 Olympics Forecast Demonstration Project (B08FDP) and the Shanghai World EXPO 2010 Nowcasting Service (WENS) Demonstration Project take the opportunities offered by the Beijing Olympic 2008 and Shanghai EXPO 2010 to demonstrate how nowcasting applications enhance short range forecasts of high-impact weather warning services.

NMHSs will increase their capacity to fulfill their role in early warning when the results of such research activities in other specialized fields are integrated into their own knowledge base. Participation in multi-disciplinary seminars or colloquia dealing with natural hazards is necessary, but not sufficient. In building a real knowledge base, the mere exchange of results among meteorologists, hydrologists, sociologists, psychologists, and media specialists is a good start but will probably still fall short of providing an overall approach and understanding of hazards in the context of attendant societal or economical problems. Solutions have to be worked out through working together and cross-discipline research. This point was well illustrated by Glantz (2003) who noted, "With regard to geological or hydrometeorological hazards, the physical processes are either well understood or are under close scrutiny by scientific researchers. With regard to socio-economic and political processes, there is a heightened need to understand their roles in the conversion of a potential hazard into an actual disaster."

3.4 DISSEMINATION AND COMMUNICATION

Effective early warnings have to be communicated and disseminated to people to ensure communities are warned in advance of impending hazardous events and to facilitate national and regional coordination and information exchange.

3.4.1 Organizational issues

The role of NMHSs in issuing warnings of meteorological hazards must be made known to people and risk management authorities. The dissemination chain and responsibilities of parties concerned should be specified in the national disaster risk response plan. Where possible, arrangements for cross border exchange of warnings also should be defined.

NMHSs should identify and designate appropriate sources of issuing warnings and information from within NMHSs structures for different types of risks occurring at different locations. For local hazards, the community is more likely to trust information from someone with a local knowledge of the area, rather than someone from a distant office who may not be as sensitive to the local needs.

3.4.2 Warning presentation

Warnings may be prepared for presentation in several different formats – text, graphics, color-coded categories, audio – and should include specific actions for people to take to respond to the event. Different formats also make it easier for people with disabilities to receive and act on the warnings. All formats, however, must present the information accurately and consistently.

3.4.3 Effectiveness of communication

Dissemination is delivery of the warning messages, but communication is accomplished only after the information is received and understood. So the foundation of warning communication rests on the format and wording of the warnings, dissemination methods, education and preparedness of stakeholders, and their understanding of the risks they face.

Effective warning messages are short, concise, understandable, and actionable, answering the questions of "what?", "where?", "when?", "why?", and "how to respond?". They should also be consistent over time. Alert messages should be tailored to the specific need of intended users. The use of plain language in simple, short sentences or phrases enhances the user’s understanding of the warning. In addition, the most important information in the warning should be presented first, followed by supporting information. They should also include detailed information about the threat with recognizable or localized geographical references.

Effective communication about risks and warnings requires knowledge about the recipients. In most countries, the public is very diverse, with different backgrounds, experiences, perceptions, circumstances and priorities. Any attempts to communicate with the public must reflect this diversity. Concerns of the affected community have to be identified such that actions to protect their interest may be included in the warning messages (e.g., instructions for safeguarding livestock).

There should be provisions for informing the users when the threat of hazards is over and emergency measures may be stepped down.

3.4.4 Communication means

Communication means to meet the needs of individual communities must be put in place covering the entire affected population. These may include a variety of formats (text, graphics, audio) and a wide range of media as available (radio, telephone, Internet, pagers, sirens, visual warnings and even messenger runners for some remote locations). Warnings should be disseminated over multiple channels to ensure minimum delay in delivery to the end users. Furthermore, communication is also significantly enhanced when consistent warning information is received from multiple credible sources. Media broadcasts from the weather office and / or radio and television interviews with one or more authoritative figures can be effective in triggering response from people. These authoritative figures may be from NMHSs (such as a forecasters or managers at local weather offices) or a community leader (such as the governor or emergency manager).

Warning communication channels should be made known to all recipients and should preferably be consistent across different types of warnings to minimize confusion or misunderstanding among users. The transmission of warning should be reliable and reception by intended users should be acknowledged.

The ability to quickly adapt to emerging communication technology is becoming a key requirement of NMHSs. People expect to be notified about dangerous conditions on a variety of new platforms (smart phones, tablet mobile computers, etc.) via social networks, as well as older platforms (TV and radio). The popularity of platforms and social networks can change quickly, so NMHSs must be equally flexible in order to successfully reach as many people as possible.

3.5 WARNING RESPONSE

In order that early warning systems reduce disaster risk, the ability of the community to respond to natural disasters must be strengthened. Public education and awareness, stakeholder involvement, warning presentation, and warning communication all contribute to an appropriate response to the warning.

3.5.1 Public perception

The warning message by itself does not stimulate an immediate response from individuals. Individuals receiving the warning will first assess their own personal sense of risk and seek a secondary source of confirmation. The additional information required before they take action depends on the content and clarity of the initial warning and the credibility of the issuing organization. Respect of the warning by the public is essential to ensure prompt and effective response. Measures to foster trust among the public in the warnings and to ensure prompt responses include:

i. warning messages issued before a particular event are updated frequently;

ii. warnings are disseminated by respected organizations or leaders;

iii. difference between forecasts and warnings are highlighted;

iv. false warnings are minimized and improvements in performance are promulgated;

v. warnings are delivered by multiple credible sources;

vi. warning messages are consistent over time; and,

vii. warnings are scientifically based.

3.5.2 Response plan

A disaster emergency and response plan should be established addressing the risk of the vulnerable communities. The plan should be prepared in collaboration with the parties who have emergency responsibilities or are required to take actions upon the issuance of warnings. Regular tests and drills should be undertaken to ascertain the readiness of the warning systems and response mechanisms. Lessons learned in operations should be analyzed and the plan should be improved to rectify any weakness identified.

3.5.3 Public education

Preparedness of the community to respond to natural hazards is enhanced through public education. The people should be familiarized with the danger of the hazards, the dissemination channels, and meaning of the warnings and actions to reduce losses and damages. This should be accomplished well before the hazardous conditions are developing. The potential for individuals to respond appropriately is dramatically increased if they are informed of their personal risk and what life- or property-saving actions to take in the event of a weather emergency. Awareness of natural hazards should be covered in school curricula at all levels. Mass media and the Internet should be used to spread the information. Special publicity and education campaigns may be needed to cater for special community groups as necessary. The WMO PWS document *"Guide on Improving Public Understanding of and Response to Warnings"*, *PWS-8, WMO/TD No. 1139* includes more discussions on warning presentation and dissemination, public education and awareness initiatives.

3.6 MONITORING AND REVIEW

The effectiveness of the dissemination and communication systems during both drills and actual events should be studied and faults must be addressed to ensure preparedness of the systems.

Verification and assessment of the warning services after a severe weather event are essential to measure performance, identify and correct deficiencies, and capture best practices, which can be shared with other parts of the Service or with risk management partners. In addition to quantitative measurement, objective assessment is also valuable. Interviews or surveys conducted with partners and stakeholders can yield significant insight into how products and services were received, interpreted, and what actions were taken as a result of the warning. This feedback can then be used to make adjustments for future warning events.

Weaknesses in monitoring and forecasting the hazards should be identified and research should be conducted to strengthen the technical capability.

Publishing verification scores and post-event assessments can add to the credibility of NMHSs and, for stakeholders and partners, reinforce the perception of NMHSs as being user-oriented and dedicated to the cause.

3.7 CAPACITY-BUILDING

In support of an effective severe weather warning system, NMHSs should ensure that capacity-building of their severe weather warning specialists is high on the national agenda. NMHSs should secure the necessary financial and personnel resources for:

i. ongoing maintenance and improvement of the national meteorological observation infrastructure;

ii. development and improvement of technical, operational and dissemination capabilities;

iii. pure and applied research – both meteorological and in the social sciences and other disciplines associated with risk management (most likely through partnerships and collaboration);

iv. ongoing training for NMHSs staff, partners, and stakeholders; and,

v. public education and awareness

Training should not be limited to NMHSs staff, but must also include partner agencies as well as communities at risk. For example, in the United States, the National Weather Service (NWS) works with the Federal Emergency Management Agency (FEMA) to teach emergency managers how to use NWS product and services, using resident and distance-learning components on the following:

i. Hazard Weather and Flood Preparedness;

ii. Warning Coordination;

iii. Partnerships for Creating and Maintaining Spotter Groups; and,

iv. Hurricane Planning.

CHAPTER 4:
EXAMPLES OF SUCCESSFUL EARLY WARNING SYSTEMS

The examples in this chapter provide practical applications of some of the principles summarized in these guidelines.

4.1 EXAMPLES FROM HONG KONG, CHINA

Hong Kong is a metropolis with over seven (7) million people and is frequented by tropical cyclones and heavy rain. Tropical cyclones may bring gales or even hurricane force winds as well as torrential rain to the city. It is not uncommon to register more than 100 mm of rain a day in tropical cyclone or monsoon trough situations, causing landslides and flooding. The following examples illustrate how the Hong Kong Observatory (HKO), the National Meteorological Service in Hong Kong, China, mitigates the impacts of these and other natural hazards.

Tropical Cyclone Warning Signal System as a Triggering Mechanism for *Protective Actions against Hazardous Weather*

On average, six tropical cyclones affect Hong Kong each year. To mitigate the impact of tropical cyclones, Hong Kong operates a graded Tropical Cyclone Warning Signal System to warn the public of the threat of winds associated with a tropical cyclone. The System consists of five numbers representing increasing levels of wind strength. The Tropical Cyclone Signal No. 1 is issued whenever a tropical cyclone is within 800 km of Hong Kong and may affect the territory later. Signals No. 3 and No. 8 warn the public of strong and gale/storm force winds in the territory respectively. Signal No. 9 signifies increasing gale or storm force winds, while No. 10 warns of hurricane force winds.

In view of the stringent building codes in Hong Kong, homes are generally considered the safest place for people to take refuge from a tropical cyclone. When Signal No. 8 is issued, HKO advises the public to stay home or return home. Practically all activities in the city are shut down. All schools, government offices, banks, the stock market, and courts are closed. Most public transport services will start to cease operation. When Signal No. 9 is sent, trains may stop operation. With Signal No. 10, the city grinds to a complete halt to prepare for the onslaught of a full-fledged typhoon.

However, the issuance of Signal No. 8 itself has the potential of causing chaos as millions of people try to go home all at once. To facilitate an orderly shutdown, a special announcement to the public (the Pre-8 Announcement) about the impending No. 8 is issued two hours before the actual issuance of the Signal. This enables transport operators to take measures to cope with the surge in demand for public transport and to allow the public to go home in a safe and orderly manner before the cyclone hits.

The tropical cyclone warning signal system has been in use for many years and the public are familiar with it. Together with the well-coordinated response actions taken by relief agencies, the system has proved very effective in reducing the loss of life and property due to tropical cyclones.

Linking Rainstorm Signals to School Operation

Hong Kong is affected by severe local rainstorms, typically between April and September. The rainstorms can develop explosively with very intense rainfall, with instantaneous rates sometimes exceeding 300 mm/hr. In such a densely-populated city, the heavy rain and resulting landslides and flooding can lead to chaos if not properly managed, particularly during rush hours.

Since 1992, HKO has operated a color-coded rainstorm warning system which consists of 3 levels, namely: Amber, Red, and Black. The Amber signal is issued to give alert on potential heavy rain which may develop into Red/Black rainstorms. The Red and Black signals are issued to warn the public about the occurrence of heavy rain (50 and 70 mm/hr respectively) which can be hazardous and may result in major disruptions.

By the time the Red signal situation is reached, road conditions are considered unsuitable for students to commute between home and school. The issuance of the Red signal will trigger a series of response measures in relation to school operation. Prior instructions are given to school administrators, school-bus operators and parents on the actions to take. Students are advised to stay home if they have not left for school. For those on the way to or already at school, the schools will be open and have sufficient staff to take care of the students until conditions are safe for them to return home. Classes already in session will not be affected by the issuance of the signals and students will only be released when the threat subsides. Forecasters will collaborate closely with the education authority when heavy rain is expected and the Red signal is imminent. Such close coordination has been in operation for over ten years and there is practically no death or injury of students as a result of such inclement weather conditions.

Very Hot and Cold Weather Warnings and Temporary Relief Centers for the Needy

In the subtropical climate of Hong Kong, extreme temperatures are rare, seldom exceeding 36°C and never falling below 0°C. Nonetheless, social consequences and health impacts can still be felt whenever temperatures rise above or drop below certain "comfort" levels during heat waves or prolonged cold spells that may affect Hong Kong several times each year. The elderly and patients with chronic illnesses are particularly at risk. Hypothermia and heat stroke could lead to death for people who are over-exposed to the elements or engaged in outdoor activities.

To alert the public of such risks, HKO disseminates Very Hot and Cold Weather Warnings. Taking into account the combined effects of wind and humidity, the reference urban temperature criteria for operating the warnings are usually around 33°C and above for the Very Hot Weather Warning, or around 12°C and below for the Cold Weather Warning. The warnings are broadcast on radio and TV, with advisories on actions to take. Upon the issuance of such warnings, temporary relief shelters operated by the Home Affairs Department, where accommodation is provided with air conditioning in very hot weather and blankets as well as hot food in cold weather, are opened to help the needy through the difficult time.

4.2 EXAMPLE FROM FRANCE

Significant Events in the Past Decade and Their Impact on “Vigilance”

In the last decade, metropolitan France has experienced several large-scale natural disasters with significant impact in terms of loss of life and / or property damage, each of which has led to the improvement of the relevant part of the early warning system.

I. 2003 Heat Wave

Between June and August 2003, Europe was hit by an unprecedented hot spell. Both the duration of this heat wave as well as the temperature records set during the first half of August were particularly significant in France. Although the corresponding medium-range meteorological forecasts proved accurate, the human impact of this natural disaster was especially severe, with an abnormally high death rate estimated at nearly 15,000 persons during the month of August, primarily among the elderly. Consequently, there was a great deal of criticism concerning the delay in implementing an emergency plan. The overhaul of the disaster prevention and warning services as well as the relief and emergency services that was set up following this disaster led, in particular, to the inclusion of heat wave risk in the Vigilance system. The development was also attributed to the introduction of coordination arrangements between the Ministry of Health, INVS (Health Monitoring Institute), the National Health and Medical Research Institute, and Météo-France.

II. 2005 Floods

The flooding that occurred in the departments of Gard and Hérault between 5 and 9 September 2005 claimed two lives and caused property damage in 242 communes. These were not the worst floods to hit this part of France in recent years. The respective tolls for the floods in 1999, 2002, and 2003 were worse still. Nevertheless, the events of 2005 are worthy of note because they resulted in improved coordination between the hydrological and weather services in the provision of early warnings. Previously, Météo-France’s Vigilance system, of a purely meteorological nature, focused on the phenomenon of heavy precipitation and did not address the impact of “flooding”. Following the 2005 floods, a decision was made to replace the parameter “heavy precipitation” with the parameter “rains-flooding”, based on a consolidated procedure involving cooperation and coordination between Météo-France’s weather forecasting services and the flood prediction network.

Recent Events Where the Operational “Vigilance” System Has Proved Effective

III. 2006 Heat Wave

From 30 June to 1 August 2006, much of France was affected by a hot spell, giving rise to three successive Vigilance “heat wave” orange warnings during which 66 departments were placed on orange level at some point. A study of the meteorological characteristics of the summer of 2006 revealed that the heat wave was one of the most severe observed in France since the 1950s, after the one in 2003. By way of comparison, the 2006 episode lasted longer but was less intense and less widespread than in 2003. The heat wave was expected to bring about 6400 deaths, based on the temperature – mortality correlation. With the new prevention and mitigation system, including the Vigilance early warnings issued to the public, which was put in place following the 2003 disaster, the number of extra deaths was reduced to about 2000.

IV. The “Klaus” Storm of 24 January 2009

An exceptionally strong storm swept over southwestern France on 24 January 2009. Winds reached speeds comparable to those recorded in December 1999, with gusts peaking at 190 km/h on the Mediterranean coast. During this episode, Météo-France placed nine departments on red alert, the maximum danger level, marking the first time since the introduction of the Vigilance system that a red alert was triggered for a storm. With confirmation of the model results on each run and observations from satellite imagery which showed the storm forming and developing over the Atlantic, the shift to a red alert was activated more than 12 hours in advance. Crisis centers were set up, extra staff were laid on for each service, and emergency resource deployment and traffic restriction measures were activated. Even though the storm affected a smaller area than in 1999, the impact of this storm was horrendous, with eight deaths directly due to the storm and four deaths from carbon monoxide poisoning (caused by back-up generators or heating facilities in areas hit by power cuts). Apart from the massive impact on the forests, there was no comparison with the fatality inflicted by the 1999 storm, during which nearly 90 people lost their lives.

4.3 EXAMPLE FROM THE UNITED STATES OF AMERICA

The Incident *Meteorologist Program*

In the United States (US), The NWS supports the wildland fire agencies, and other emergency management agencies, with specially trained Incident Meteorologists (IMETs). IMETs are volunteer forecasters in numerous weather forecast offices from across the nation and are specially trained to work in the emergency management support role. Their mission is to provide short and long-term weather forecasts, weather data interpretation and a real-time meteorological watch to provide for the safety of the responders for the incident as well as provide weather data pertinent to the tactical decisions made on the incident. IMETs are on 24-hour notice and can be anywhere in the US within 24 hours of being requested, providing on-site weather support.

The NWS IMET program, at the time actually part of the US Department of Agriculture, began in 1916 with on-site weather support to the US Forest Service in wildland fire suppression. Through the years the wildland fire agencies mission has changed from a pure fire suppression role to more of a wildland fire management role, sometimes suppressing fire, but also sometimes utilizing fire, much as nature had in the past, to manage fuel loading in the national forests. The IMET program grew along with it, and today the program has around 80 fully trained meteorologists in the program.

The IMET trainee takes numerous incident command and fire weather training courses. Total classroom time for each trainee is approximately 250 hours. The IMET trainee is then assigned a taskbook and works under the tutelage of a certified IMET to complete various skill requirements within the taskbook. This normally takes another 80 to 160 hours of in the field training on fire weather forecasting and incident command system. Once the taskbook and the courses are completed, the trainee is certified as an IMET. In order to retain their certification, they must take a refresher workshop every spring, which includes items such as incident safety procedures, as well as serve as an IMET on an incident the year prior.

The IMET's equipment, called the All-hazards Meteorological Response System (AMRS), consists of a laptop, communications devices for remote internet and voice communications, printer, and upper-air observing (radiosonde) system. As long as the IMET has a power supply source, which may even include using a generator or the battery power from an automobile, the IMET can setup a mobile field office within 15 minutes and begin producing forecasts within 30 minutes. The IMET is self-sustaining for the first 72 hours, including camping gear and food.

In the last 30 years, the IMET's role has expanded to provide support to not only wildland fire, but also all hazards support. Special training is provided on HAZMAT, marine forecasting and oil spill response. Some recent examples of incidents supported by on-site IMETs include the space shuttle Columbia recovery effort, Emergency Operations Center support for the national conventions of the two major political parties within the US, and support for emergency responders in the Gulf of Mexico with both Hurricane Katrina in 2005 and the Deepwater Horizon oil spill of 2010. The IMET program has also expanded to provide help and expertise internationally, by participating in a fire weather forecaster exchange program with Australia's Bureau of Meteorology (BoM) where IMETs from the US augment BoM staff during their fire season from November to March and BoM staff augment NWS staff during the US fire season from May through September, working not only in the forecast offices, but also in the wildland fire emergency operations centers, providing weather forecasts and briefings.

4.4 THE EUROPEAN EXAMPLE OF EMMA

Most European countries are relatively small in comparison with the scale of typical synoptic meteorological phenomena. Many important weather events, including windstorms, heavy rains, coastal surges or cold spells can affect large geographical areas containing several countries simultaneously; and these can occur within a very short timescale. There are also numerous seas with shorelines in multiple countries such as the Baltic Sea, English Channel, the Mediterranean and the North Sea. This means that the need for effective exchange of warnings has existed in various European countries, and such exchanges have been developed for some time.

The European Multi-Purpose Meteorological Awareness (EMMA) Programme

The EMMA Programme is based on the concept of meteorological awareness and its general objective is to develop a graphical information system accessible by the general public for the provision of expected meteorological hazard information within at least the next 24 hours.

The system is intended to complement the existing national warning systems by providing a simple and efficient way of making users aware of possible meteorological risks. It also allows an efficient method of exchanging meteorological information related to high-impact weather events between European forecasters.

The main characteristics of the system are as follows:

i. colour-coded regions related to the meteorological awareness level for the severe weather phenomena covered by the system;

ii. a core of severe weather phenomena to be addressed across Europe and to be displayed through a homogeneous set of pictograms, to be augmented, as necessary, by some "national" phenomena;

iii. interactive access to additional levels of information, such as risk qualification for the identified phenomena to develop awareness;

iv. flexible updating procedures designed to account for individual NMHS modus operandi, geographical areas and time zones;

v. availability of textual information in several languages, at least for the higher levels of access; and,

vi. implementation of the system using internet technologies.

The"Meteoalarm" Website

The specifications laid down by EMMA Programmes have now been developed into a "Meteoalarm" website, http://www.meteoalarm.eu, which allows inclusion of internal links and all available technology for flexible access. These include provision of hyperlinked access to the information, zooming in from a map of Europe to the national detailed alerts or warnings, and, for many countries, access to textual components at least in the national language and in English.

Meteoalarm provides both a synchronous view of the awareness status in the different participating countries or "regions" and the capability to select a working language among 28 different choices. Hyperlinks lead to explanation of the pictograms ("captions"), background information, terms and conditions, and links to other relevant sites and information.

A zoom-in capability is provided region by region. The zoom-in feature helps to elucidate the situations where different types of risks co-exist locally, each shown with the appropriate colour. A link attached to the national second level allows access to current regional warning bulletins in the national language and, in many cases, also in English..

CROATIAN EXAMPLE

In Croatia, the roles and responsibilities of agencies involved in different aspects of the Early Warning System (EWS) and disaster management are defined in national plans and supported by legislation, with collaboration and coordination mechanisms that are defined through standard operational procedures.

The leading partners in the EWS program are the Meteorological and Hydrological Service (DHMZ) and the National Protection and Rescue Directorate (DUZS). The cooperation between DHMZ and DUZS is based on a considerable history of joint work and previous mutual contacts in both routine and extraordinary situations.

In routine situations, the DUZS is supplied all observational data and daily weather forecasts by DHMZ. The DUZS then disseminates the weather information through its communication network to its County Centres.

When weather hazards and potential or actual disasters occur, the Standard Operative Procedure (SOP) for the Use of Weather Forecasts of the DHMZ regulates the content of forecasts and warnings, the time of delivery, and dissemination of specific warnings, additional data, interpretations and explanations. The required activities depend on the type of hazard:

For Type I (meteorological hazards), the DHMZ has the sole mandate for issuing public warnings (e.g., strong winds, severe thunderstorms, heavy snow, etc.). Generally, there are two modes of warnings - public warnings and user-defined special forecasts and warnings.

Public warnings are specially prepared for media (radio, TV, Internet). Usually, forecasters on duty are involved in TV and radio broadcasting of warnings. In Croatia, that form of communicating DHMZ forecasts and warnings to the public is a long tradition (for radio since 1950 and for TV since 1956) and all forecasters in DHMZ are especially-trained for effective warning communication.

User-defined special forecasts and warnings are tailored for specific needs and directed by specific criteria suggested by users (e.g., DUZS). Furthermore, the Meteoalarm information for Croatia has been found beneficial for DUZS activities and as a valuable supplement to regular coordination. As a result, Croatia has been operationally contributing to the Meteoalarm warning system since 2009.

For Type II (non-meteorological hazards), the DUZS has the sole mandate for the development of the warning for the specific hazard. The DHMZ plays a support role to responding agencies by providing special weather forecasts and warnings along with interpretations as necessary before, during, and after the event.

Chapter 5:
NOWCASTING SYSTEMS

Nowcasting generally refers to weather forecasting for the following few hours via the analysis and extrapolation of the weather systems as observed on radar, satellites, and other observational data, and via the application of short-range numerical weather prediction. The technique is often applied to the near-term forecasting of small-scale weather systems such as thunderstorms which cause tornadoes, flash floods, lightning strikes, and destructive winds. It is a powerful tool in warning the public of hazardous, high-impact weather.

Extrapolation of storm cells and deep convection in radar and satellite imagery is an old technique that has been around since weather forecasters have access to these remote sensing observation data. What has been developed in the last two decades is the ability to digitalize and merge these data with *in situ* observational data such as rain gage data, and with NWP forecasts. Radar data provides the size, shape, intensity, speed and direction of movement of individual storms on a practically continuous basis. The intensity and movement of a particular storm or group of storms can be estimated. The ability to forecast the precipitation amount or probability of hazardous weather like lightning strikes and squalls at a given location in a given time is, in particular, useful for the development of early warnings for mesoscale systems. Information about built-up space, drainage and land-use in general can be used to produce warnings of floods with higher accuracy.

Despite the usefulness of these techniques, nowcasting is still a science being actively researched. Many NMHSs have developed nowcasting systems and operate them to support weather warning services for high-impact weather. More information on nowcasting research may be found on the WMO WWRP Website at the following weblink: http://www.wmo.int/pages/prog/arep/wwrp/new/nowcasting_research.html.

5.1 NOWCASTING SYSTEMS

The following sections describe nowcasting systems of some NMHSs which participated in the Beijing 2008 Olympics Forecast Demonstration Project (B08FDP) as discussed by Wang, et al. (2009).

5.1.1 Beijing Auto-Nowcaster and NCAR VDRAS

The Beijing Auto-Nowcaster (BJANC) is a 0-1 hour thunderstorm nowcasting system provided by the Beijing Meteorological Bureau. It grew out of a technology transfer activity of the U.S. National Center for Atmospheric Research (NCAR) and was based on the NCAR Auto-Nowcaster. The BJANC ingests multiple data sets including radar, satellite, surface stations, radiosondes and numerical model outputs. From these data sets, a variety of forecast parameters are derived and combined using fuzzy logic to generate convective nowcasts. Some of the algorithms and forecast rules were modified from those used for the Sydney Olympic WWRP Forecast Demonstration Project (FDP). These modifications include: a.) algorithms for real-time Quantitative Precipitation Estimation (QPE) and Quantitative Precipitation Forecasting (QPF); b.) an optimal Z-R relationship for the Beijing region; c.) irregular polygon fitting for the single-cell tracking algorithm; and, d.) tuning and optimization of algorithm parameters based on storm climatology research, case studies and forecast experiments.

BJANC produced 30 and 60 minute forecasts of radar reflectivity and precipitation rate with an update rate of six (6) minutes. The system showed skill in nowcasting convective storm initiation, growth and dissipation. Also, based on human-entered convergence lines, it provided extrapolation forecasts of their future position.

Also tested was the NCAR Variational Radar Data Assimilation System (VDRAS), an advanced 4-dimensional data assimilation system for high-resolution (1-3 km) and rapid updated (12 min.) wind analysis ingesting data radar radial velocity, reflectivity, and high-frequency surface observation data.

5.1.2 Canadian Radar Decision System

The Canadian Radar Decision System (CARDS) is the operational radar processing system in Environment Canada. It is designed to process volume scan data for a variety of purposes including: general weather surveillance; severe weather detection and warning guidance; quantitative precipitation estimation; and, radar-based precipitation nowcasting. The client provides interactive capabilities including: product display; animations; pan-zoom; interactive cross-section; and "drill down" capability from mosaics to the thunderstorm cell level. Forecasters can display plan views and vertical slices through the data. For severe weather application, CARDS identifies cells, their properties (such as area and intensity), the presence of mesocyclone and downbursts, and forecast tracks. A key diagnostic tool is the ability to shift from the synoptic-mesoscale mosaic products used for surveillance immediately down to the multitude of thunderstorm scale products needed for warning decision making. For QPE, the system relies on quality controlled data and the appropriate Z-R relationship. For precipitation nowcasting, persistence and cross-correlation area tracking on the planar products are used to determine areal motion and nowcasting 90 minutes into the future. In Canada, the standard product is a point forecast presented as a meteogram.

5.1.3 GRAPES-based Severe Weather Integrated Forecasting Tools

The Global/Regional Assimilation PrEdiction System (GRAPES)-based Severe Weather Integrated Forecast Tools (GRAPES-SWIFT) was initially developed in 2005 by the Guangdong Provincial Meteorological Bureau in collaboration with the Chinese Academy of Meteorological Sciences (CAMS). The system is designed to provide an operational platform for strong convective weather nowcasting, incorporating data from China's new-generation Doppler radar, Automated Weather Stations (AWSs), satellite and mesoscale NWP model outputs. The platform features convective weather monitoring, analyzing, forecasting and warning functions and GIS-based product displays.

The GRAPES-SWIFT includes two components. The first component is a non-hydrodynamic mesoscale model called GRAPES with horizontal resolution of 3 km and 31 vertical layers, which provides 3-houly analyses and 6-hourly forecasts. The second is comprised of a nowcasting module, SWIFT, that produces nowcasts using radar data extrapolation techniques and statistical methods. The convective algorithm in GRAPES-SWIFT generates a 2-D radar reflectivity mosaic, quantitative precipitation estimates, 0-3 hour QPF, convective weather potential and single-cell storm identification, tracking and forecasts.

5.1.4 McGill Algorithm for Precipitation Nowcasting by Lagrangian Extrapolation

The McGill Algorithm for Precipitation Nowcasting Using Lagrangian Extrapolation (MAPLE), developed at McGill University in Montreal, Canada, uses statistical techniques on past radar images to predict the future location and intensity of reflectivity and future quantitative precipitation. Prior to MAPLE processing, radar data were quality controlled and combined into a 3-D mosaic using software developed at the National Severe Storms Laboratory (NSSL). Two output files from the NSSL mosaic software are the composite reflectivity and a "lowest-level" terrain following reflectivity field from which the QPF is derived.

5.1.5 Niwot

Niwot is a nowcasting system that was developed by NCAR to perform 1-6 hour forecasts of convective precipitation. The forecasts are based on the merging and blending of precipitation forecasts from the extrapolation of radar echoes with precipitation forecasts from NWP. The forecast-analysis system assimilates upper air data, wind profiles, ground-based GPS water vapour and mesoscale surface data. Niwot uses a limited set of heuristic rules to perform the blending.

The primary assumption for blending is that the location of the precipitation is best forecast by radar echo extrapolation and the numerical model provides skill at forecasting changes in the extent of the precipitation. Therefore, if radar echoes greater than 35 dBZ are present at the forecast issue time, the forecast is based on the extrapolated radar echo and the area of the extrapolated echo is increased or decreased based on the fractional change in model forecast area. If no radar echo exceeding 35 dBZ is present at the forecast issue time and NWP predicts the initiation of convection, then the NWP output is used as the forecast. In addition, Niwot allows a manual modification of the automated blend forecast. The forecaster can select any location and modify the forecast as desired.

Niwot products include hourly radar reflectivity forecasts for 1-6 hours with a horizontal resolution of 1 km. Forecasts are available hourly from radar echo extrapolation, model precipitation converted to reflectivity, blended forecast, and human-modified blended forecast.

5.1.6 Short-Term Ensemble Prediction System

The Short Term Ensemble Prediction System (STEPS) is a quantitative radar precipitation estimating and forecasting system based on results of the Sydney FDP, and was jointly developed by BoM and UK Met Office. STEPS uses an advanced echo tracking algorithm and an ensemble precipitation forecasting component. The radar QPE system includes algorithms that account for partial beam blocking by the topography, removal of clutter due to anomalous propagation, sea and ground returns, correction for the vertical profile of reflectivity, separate Z-R relations for widespread and convective rainfall, and real-time bias adjustment using rain gages as ground truth. The STEPS system uses a statistical model to generate ensembles of spatial and temporal precipitation patterns in the forecast period. The ensemble forecasts are used to derive the probability of exceeding a number of rainfall thresholds in the next 60 minutes.

Major STEPS products include hourly accumulated quantitative precipitation analysis (QPE), precipitation forecasts in next 30, 60 and 90 minutes, and the probability exceeding 1, 2, 5, 10, 20 and 50 mm precipitation in the next hour.

5.1.7 Short-range Warning of Intense Rainstorms in Localized Systems

The HKO nowcasting system, SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems), has been in operation since 1999. Its second-generation version (referred to as SWIRLS-2) has been under development and real-time testing in Hong Kong since 2007. The original SWIRLS focused primarily on rainstorm and storm track predictions. The much enhanced SWIRLS-2 comprises a family of sub-systems for ingestion of conventional and remote-sensing observation data, execution of nowcasting algorithms, as well as generation, dissemination and visualization of products via different channels. It embraces new nowcasting techniques, including blending and combined use of radar-based nowcast and high-resolution NWP model analyses and forecasts, detection and nowcasting of high-impact weather including lightning, severe squalls and hail based on conceptual models, a grid-based, multi-scale storm-tracking method, and probabilistic representation of nowcast uncertainties arising from storm tracking, growth and decay.

Major SWIRLS products include rainfall accumulation forecasts out to six (6) hours, probability forecasts for precipitation and lightning, radar-echo motion vectors, storm-cell track analysis and forecasts, threat forecasts for rainstorm, cloud-to-ground lightning initiation, severe downbursts, hail, and severe squalls. Additionally, SWIRLS also features various interactive Graphical User Interfaces (GUIs), including a Tephigram viewer, an echo-motion field viewer, a thunderstorm and severe weather viewer, an integrated alerting panel, Keyhole Markup Language (KML) products displayable on GIS software and virtual globes, and web pages for the display of NWP charts and satellite imagery.

5.2 NOWCASTING SERVICES

Based on the output of nowcast systems, useful products and services may be developed to enable the public and users undertaking weather sensitive operations, to take mitigation measures to reduce risk of damage and loss caused by approaching high-impact weather. With Internet technology, quantitative nowcast products may now be presented to the users in graphical 3-D (x, y and time) format.

The following sections describe examples of nowcasting services provided in Hong Kong, China for the 2010 Shanghai World EXPO, and in Australia.

5.2.1 Rainfall Nowcast for the Pearl River Delta Region (China)

The Pearl River Delta is an area around the estuary of the Pearl River in southern China covering an area of 40,000 square kilometres with a population of 48 million. Convection associated with monsoon and tropical cyclones is not uncommon in the area during summer months. A radar-based nowcast product for the area, developed by HKO, is a forecast map of rainfall distribution for the following two hours (with respect to radar scan time). The aerial coverage of the product is about 120 kilometres around Hong Kong. It provides the public with quantified and graphical rainfall forecast information.

The product employs Open GIS standard KML. Users may zoom into a small area of interest and animate the rainfall nowcast. This enables the users to visualize the spatial coverage and the movement trends of the rain areas, as well as the amount of rainfall that can be expected.

The rainfall forecasts are generated by the HKO's SWIRLS nowcasting system. The main inputs of SWIRLS include radar reflectivities (the reflected radar signals from raindrops) collected by the Observatory's weather radars, as well as the rainfall recorded at local rain gages. Four main steps are involved in rainfall nowcasting, namely:

i. tracking of the radar echoes;

ii. real-time calibration and conversion of radar echoes into rainfall rate;

iii. extrapolation in time of the radar-derived rainfall (assuming that both the rainfall rate and movement of echoes remain unchanged); and,

iv. computation of the accumulated rainfall amount at the surface grid.

The horizontal resolution of the grid used to generate the rainfall forecast product is 2 kilometres. The nowcast product is updated once every 30 minutes, following the completion of the radar scans starting at the 00th and 30th minute of every hour. Figure 2 is a sample nowcast showing the passage of a squall line over the Pearl River Delta.

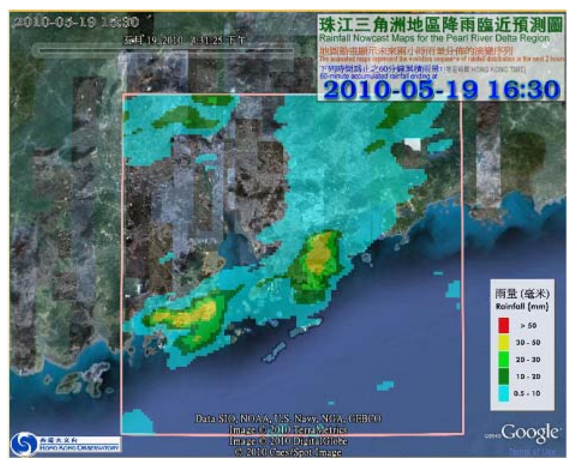

Figure 2: T+2 hour nowcast of hourly rainfall over the Pearl River Delta during the passage of a squall line.

5.2.2 World EXPO Nowcasting Service (China)

During the Shanghai World EXPO 2010, precipitation and thunderstorms occurred frequently, together with some high-impact weather that included heavy rain, squalls, hail, lightning, and tropical cyclones. Nowcasting of high-impact weather was required to support planning and coordination of the EXPO activities, to ensure the safe and smooth operation of the exhibition pavilions, and to safeguard people and property during the occurrence of high-impact weather.

The Shanghai Meteorological Bureau (SMB) of the China Meteorological Administration (CMA) was the provider of the EXPO weather services. In case of thunderstorms or other severe weather being forecast, severe weather outlooks (0-12 hour) were issued at 6-hour intervals for the EXPO site, and special early warning information was issued through the Dissemination Platform of the Shanghai Multi-Hazards Early Warning System (M-HEWS).

World EXPO Nowcasting Service (WENS) was conducted by CMA and international participating groups with active support from WMO. The following systems were used to generate the nowcast products:

i. Beijing Auto-NowCaster (BJANC) – Beijing Meteorological Bureau;

ii. NowCAsting and Warning System (NoCAWS) – Shanghai Meteorological Bureau;

iii. Short-Term Ensemble Prediction System (STEPS) – Bureau of Meteorological, Australia;

iv. Severe Weather Automatic Nowcast system (SWAN) – China Meteorological Administration;

v. Shanghai Typhoon Institute WRF ADAS-3dvar Rapid Refresh (STI-WARR) – Shanghai Typhoon Institute; and

vi. Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS) – Hong Kong Observatory.

The users of the WENS products included:

i. weather forecasters;

ii. World EXPO 2010 organizers and participants;

iii. relevant government departments, especially the emergency response agencies;

iv. special users, particularly those in the transport and energy sectors; and,

v. the public (including visitors to the World EXPO).

Typical WENS nowcast products included:

i. Last 0-1 h QPE;

ii. 0-6h QPF (10-15 min interval);

iii. 0-6h Radar reflectivity (1 hour interval);

iv. Lightning;

v. Squalls; and,

vi. Hail

Figures 3 - 7 show some examples of WENS products.

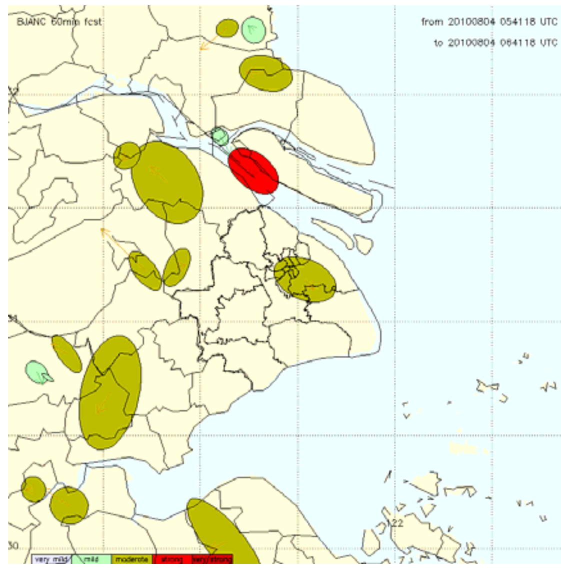

Figure 3: T+60 minute thunderstorm nowcasting generated by BJANC

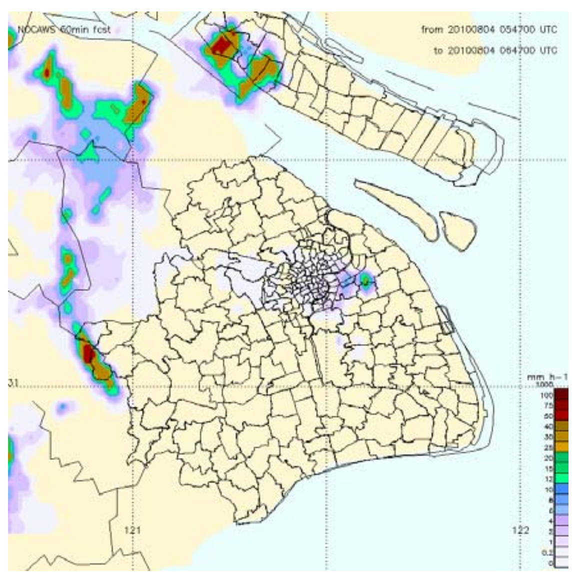

Figure 4: T+60 minute hourly rainfall nowcast generated by NoCAWS

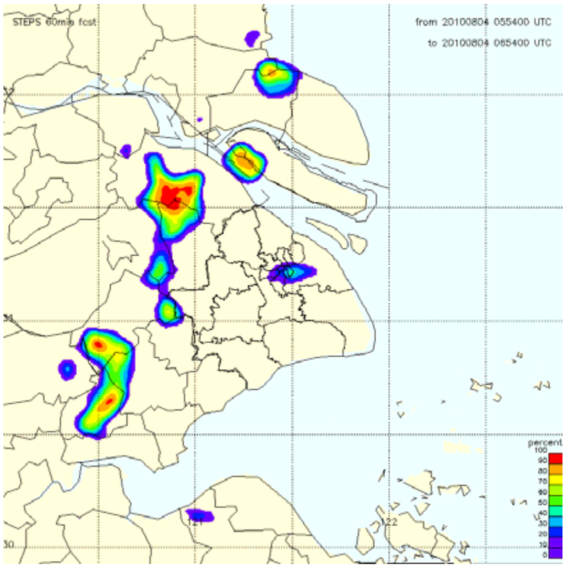

Figure 5: Probability of nowcast hourly rainfall over 10 mm in the following hour generated by STEPS

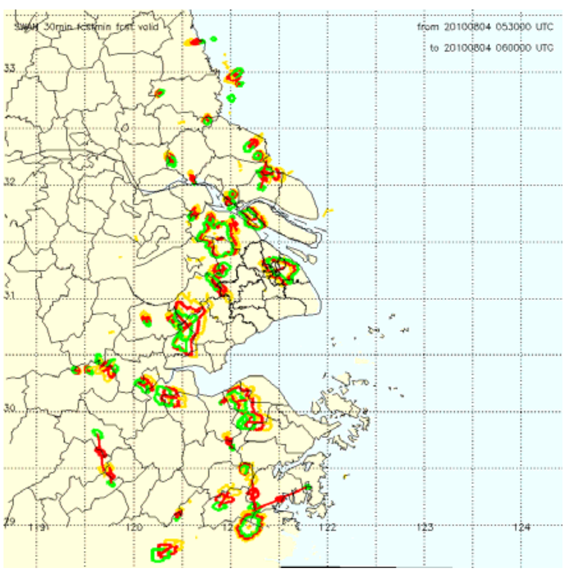

Figure 6: Storm track nowcast for the following 30 minutes generated by SWAN

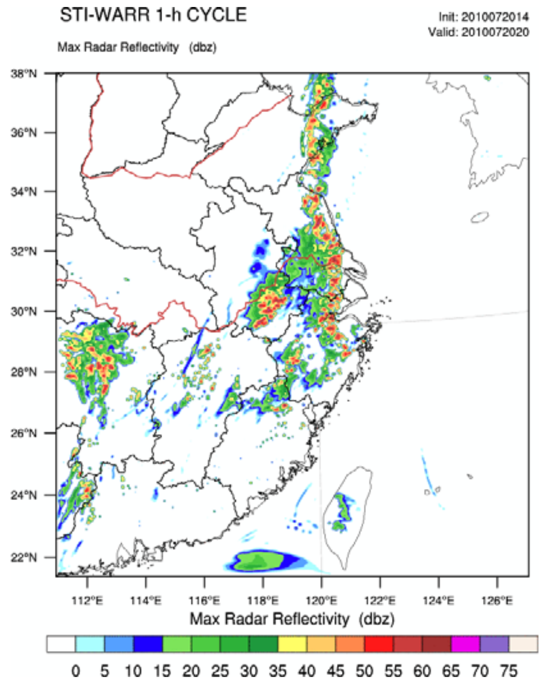

Figure 7: Radar reflectivity nowcast for the following 60 minutes generated by STI-WARR

5.2.3 Severe Thunderstorm Warnings (Australia)

In Australia, the Severe Thunderstorm Warning is a highly-detailed alert issued to the public, emergency services, and other organizations. For this warning to be issued, a severe thunderstorm is expected to produce one or more of the following:

i. A tornado;

ii. Hail of diameter 2cm or greater;

iii. Wind gusts of 90 km/h or greater;

iv. Very heavy rain leading to flash flooding.

These Warnings depict and describe individual severe thunderstorms and therefore rely heavily on a detailed analysis of radar data. In addition, data from AWSs, measurements of upper air conditions from weather balloons, atmospheric profilers, specially instrumented aircraft, and NWP products are also used.

In graphical depictions of the warning available on the Internet (Figure 9), the location of each severe thunderstorm is indicated by a red ellipse. The ellipses show the position of the thunderstorm at the "valid time" stamped on the image. This will generally be a few minutes before the Warning was issued. The thunderstorm positions shown are derived from radar data. The graphic shows a simplified representation of the situation, which may be very complex. In particular, only severe thunderstorms (or thunderstorms imminently expected to become severe) are depicted.

SAMPLE

IDQ20038
Bureau of Meteorology
Queensland Regional Office
The Standard Emergency Warning Signal should NOT be used with this message.

TOP PRIORITY FOR IMMEDIATE BROADCAST
SEVERE THUNDERSTORM WARNING - SOUTHEAST QUEENSLAND
for DAMAGING WIND
For people in parts of the GYMPIE, MORETON BAY, SUNSHINE COAST, SOMERSET, SOUTH BURNETT and TOOWOOMBA Council Areas.

Issued at 3:33 pm Thursday, 21 August 2008.

The Bureau of Meteorology warns that, at 3:35 pm, severe thunderstorms were detected on weather radar near Haden. These thunderstorms are moving towards the northeast. They are forecast to affect Crows Nest, Toogoolawah, Moore, the area west of Toogoolawah and the area between Crows Nest and Cooyar by 4:05 pm and Kilcoy, the area west of Kilcoy, Conondale, Montville, Mapleton and Kenilworth by 4:35 pm.

Damaging winds are likely.

The Emergency Management Queensland advises that people should:
* Move your car under cover or away from trees.
* Secure loose outdoor items.
* Seek shelter, preferably indoors and never under trees.
* Avoid using the telephone during a thunderstorm.
* Beware of fallen trees and powerlines.
* For emergency assistance contact the SES on 132 500.

The next warning is due to be issued by 4:35 pm.

A more general severe thunderstorm warning is also current for the Wide Bay and Burnett, Darling Downs and Granite Belt, Southeast Coast and parts of the Central Highlands and Coalfields and Maranoa and Warrego districts.

Warnings are also available through TV and Radio broadcasts, the Bureau's website at www.bom.gov.au or call 1300 659 219. The Bureau and Emergency Management Queensland would appreciate warnings being broadcast regularly.

Figure 8: Example of Severe Thunderstorm Warning

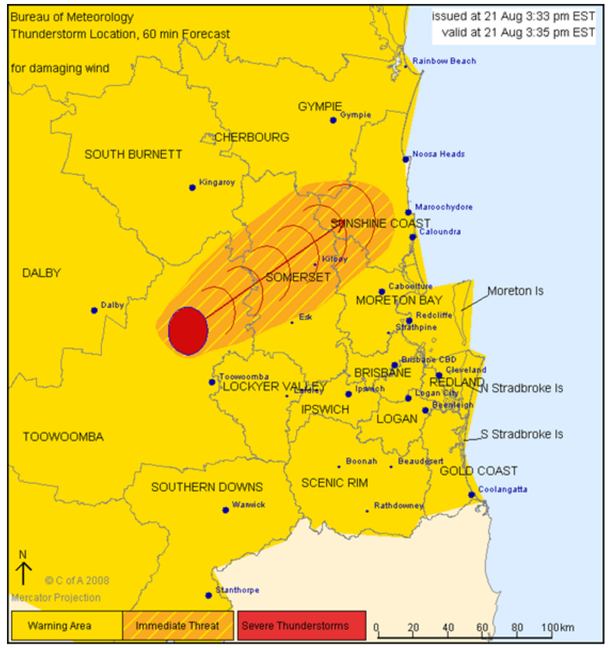

Figure 9: Sample severe thunderstorm nowcast for southeast Queensland, Australia

An arrow indicates the forecast direction of movement of each thunderstorm. This is the direction towards which the thunderstorm is moving. Arcs are used to show the forecast positions of the front edge of the thunderstorm at 10 minute intervals (Figure 9).

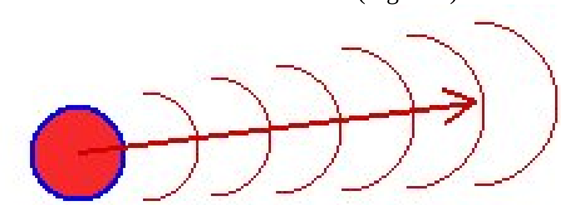

Figure 10: Graphical depiction of thunderstorm movement

The number of ten-minute forecast positions shown will depend on the current behaviour of the thunderstorms. Usually six arcs will be shown, giving forecast positions for the front edge of the thunderstorm at ten (10) minute intervals out to 60 minutes from the valid time. Sometimes, for more long-lived thunderstorms, forecast positions will be extended out to 90 minutes. On other occasions, individual severe thunderstorms may be expected to last only for a short period and tracks will be shown only for the next 30 minutes.

Occasionally, severe thunderstorms and their associated severe weather can be especially short-lived. Individual thunderstorm locations and forecast tracks would then be of little use because the thunderstorms would likely dissipate before the Warning reached the public. In these situations, the broad area under threat from severe thunderstorms will be shown but individual cells will not be depicted.

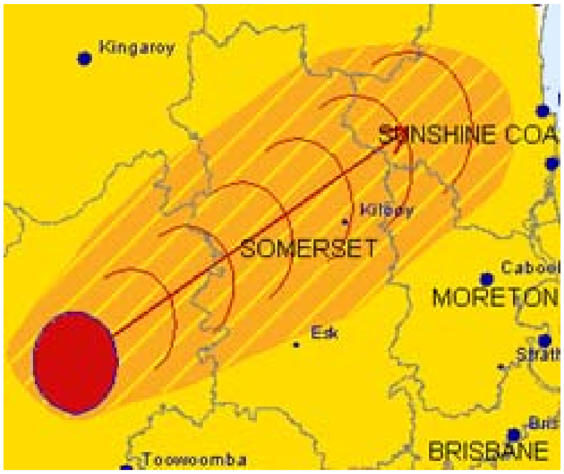

Figure 11: Thunderstorm threat area in nowcast product

The shaded area in the graphical warning depiction indicates the area the forecasters consider under immediate threat from severe thunderstorms during the warning period (Figure 11). It will often be larger than the area under the forecast tracks of the severe thunderstorms shown on the graphic to account for the possibility that thunderstorms might deviate from the forecast tracks, and allow for the development of new severe thunderstorms or the intensification of thunderstorms not yet meeting severe thunderstorm criteria.

The issue time is the local time at which the Warning was transmitted by BoM. The valid time is the time of validity of the initial severe thunderstorm locations shown by red ellipses on the chart. Warnings are valid for up to 90 minutes but will be updated every 30 to 60 minutes as a weather situation evolves.

Only thunderstorms that are identified as severe, or expected to become severe (according to the definition above), are depicted and described in a Warning. Other thunderstorms not showing the radar characteristics usually associated with severe thunderstorms are not included.

Another tailored graphical product is provided to disaster response agencies but not to the general public. This graphic not only shows the area under immediate threat of a severe thunderstorm but also the area which has recently experienced a severe thunderstorm. Such information is particularly useful to disaster response agencies in quickly deploying their personnel to areas where assistance is most likely required.

Chapter 6:
REFERENCES AND FURTHER READING

I. REFERENCES AND FURTHER READING

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II. USEFUL WEBSITES

Billion Dollar U.S. Weather Disasters, since 1980 http://www.ncdc.noaa.gov/oa/reports/billionz.html

International Strategy for Disaster Reduction (ISDR) http://www.unisdr.org

UN/ISDR Platform for the Promotion of Early Warning http://www.unisdr.org/ppew/ppew-index.htm

3rd International Conference on Early Warning: http://www.ewc3.org

WMO World Weather Research Programme (WWRP) nowcasting research Website: http://www.wmo.int/pages/prog/arep/wwrp/new/nowcasting_research.html

[United States] Federal Emergency Management Agency National Response Framework: http://www.fema.gov/emergency/nrf/

[United States] Natural Hazards Center: http://www.colorado.edu/hazards

Meteoalarm: http://www.meteoalarm.eu