

SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 5.1 : **Evaluating the Effectiveness of Warning Systems**

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Abstract

The warning process consists of two stages; forecasting and conveying information. Since IWTC-V, the guidance from ensemble prediction system and satellite observing system extensively used for the operational centers with the support of nowcasting tools for the landfalling tropical cyclones. The statistical and dynamical guidance yet need to be improved particularly for the weak cyclones, for the unusual track behaviors, and cyclones under extratropical transition.

The uncertain nature of forecasts and increasing vulnerability has been reflected in the probabilistic expression of forecasts and warnings. The multimedia channels are more widely used for dissemination, including Internet, mobile phones, and digital multimedia broadcasting. The intensity scales and instruction to protect against a tropical cyclone have been refined further to personalize the risk. The various outreach programs has been effectively conducted to promote public awareness. Increased investment is required in public awareness in cyclone forecasting through very large investment of fund and dedicated efforts of meteorologists and scientists on a worldwide scale.

There exist a technical gap among meteo-hydrological centers, and international cooperation need to be strengthened to share the information and analysis tools among the centers.

5.1.1 Introduction

5.1.1.1 The Team on Topic 5.1 on evaluating the Effectiveness of Warning System consists of 11 members. This draft is to summarize the major findings and recommendations on the topic based on the input from the members, and partially from the summary and recommendation at the workshop on effective tropical cyclone warning (Typhoon Research Coordination Group, 2005).

5.1.1.2 The effective measures for disaster preparedness is a well-functioning early warning system that delivers accurate and user-friendly information in a timely manner, considering the following aspects, as pointed out in the WMO Expert Meeting on Effective Early Warnings of Tropical Cyclones in Kobe, Japan on 17 and 18 January 2005, in association with the World Conference on Disaster Reduction (WCDR) (Kobe, 18 to 22 January 2005). The major elements are:

- (a) Adequate resources for disaster mitigation caused by tropical cyclones/severe weather hazards;
- (b) Improved accuracy in meteorological and hydrological forecasts for longer-ranges and quantification of uncertainty;
- (c) Qualified meteorological, hydrological and disaster prevention and preparedness personnel;
- (d) Sufficient attention to non-structural (public awareness, information sharing, etc.) mitigation

measures to cope with tropical cyclones/severe weather events;

(e) Adequate institutional and infrastructure practices for coordination and capacity-building at national, regional and international levels to cope with the negative impact of tropical cyclones/severe weather risks on economic growth and human progress;

(f) Adequacy of a National Disaster Management Policy that includes effective local dissemination of information to cope with the menace of meteorological and hydrological disasters;

(g) Community consciousness for all stakeholders involved in tropical cyclone/severe weather-related disaster mitigation process and measures.

5.1.1.3 This draft is focused on the technical progress on one hand, and on the disaster prevention and preparedness on another, considering the viewpoints in the said WMO meeting.

5.1.2: Accuracy of track and intensity forecasts

5.1.2.1 The basic concerns for the forecasting of a tropical cyclone are wind, precipitation, storm surge and high wave, which depend on the track and intensity. Both dynamical and statistical models are used for the preparation of forecast at the pre-warning stage.

5.1.2.2 The new CLIPER extends the forecasts from 3 to 5 days and exhibits smaller forecast biases than the previous CLIPER, although forecast errors are comparable (Aberson and Sampson, 2003). An e-folding time-scale of about 15 h was calculated for the northwest Pacific basin, compared to just under 15 h in the Australia basin, and near 15 h in the North Atlantic. With e-folding error growth on that scale, 5-day forecasts can be expected to show some skill. As a result, interest has increased in medium-range tropical cyclone track prediction in the northwest Pacific basin, and the current operational at the Joint Typhoon Warning Center CLIPER model provides a baseline by which the track prediction skill can be measured.

5.1.2.3 The minimum attainable forecast error from an optimum statistical model with "perfect" input data are 53, 107, and 145 nm (98, 198, 269km) at 24, 48, and 72 hours respectively (OFC, 1997).

5.1.2.4 The performance of tropical cyclone track forecasts by leading centers has been continuously improving in recent years.

(a) Operational track forecasts at RSMC Tokyo Typhoon Center for 19 tropical cyclones which attained TS intensity or higher in 2005 (as of 30 September) were verified against best track data of the Center. The annual mean position errors for this year are approximately 100 km (125 km in 2004) for 24-hour forecast, 174 km (243 km) for 48-hour forecast and 278 km (355 km) for 72-hour forecast. The annual mean position errors for 24-hour forecast in 2005 are smallest after each forecast started operationally. The annual mean ratios of EO (position errors of operational forecasts) to EP (position errors of PER-method forecasts) are 51 % (54 % in 2004) for 24-hour forecast, 37% (47 %) for 48-hour forecast and 37% (45%) for 72-hour forecast, which are also lowest after inauguration of each operational forecast. (RSMC Tokyo, 2005)

(b) The recent assessment of tropical cyclone track forecasts showed that the 72-hr forecast error in the prediction of the tropical cyclone center in the South -West Indian Ocean is about 250 km. > 3.6 (RAI Tropical Cyclone Committee, 2005).

(c) The global model at Korea meteorological Administration (KMA), the 72-hour model forecast error has decreased from roughly 500 km to roughly 400 km over the past 5 years.

5.1.2.5 Position forecast of a Tropical Depression is less reliable than that of a Tropical Storm.

5.1.2.6 Intensity is more difficult to forecast than position. Better understanding of the initiation and mechanisms of rapid deepening and of the timing and amount of intensity fluctuations caused by concentric eyewall cycles is essential to skillful intensity forecasts (OFC, 1997).

5.1.2.7 The potential forecast capabilities of STIPS model in terms of percent variance explained (R^2) and mean absolute error (MAE) can be estimated from the dependent data. MAE is shown to increase from a value of 5.6 kt at 12 h to a value of 21.8 kt at 120 h. The percent variance explained of DELV, a measure of intensity change from the initial forecast time, starts with a relatively large value of 40 % at 12 h and increases to only 67.8 % at 120 h, keeping in mind that most (increasing 19.6%) of the variance of this variable is explained during the 12-60 h forecast time versus the 72-120 h forecast time (increasing 8.2 %). In independent predictions, these statistics are expected to degrade due to the influences of artificial statistical skill and the errors associated with the perfect prog assumption – particularly when track deviations are larger than 200 km (Knaff et al., 2005).

5.1.2.8 The annual mean RMSEs of central pressure forecasts at RSMC Tokyo Typhoon Center were 12.2 hPa (11.4 hPa in 2004), 16.4 hPa (16.1 hPa), and 19.4 hPa (18.6 hPa) for 24-, 48- and 72-hours, respectively, while those of maximum wind speed forecasts for 24 hours were 5.5 m/s (5.1 m/s in 2004), 7.5 m/s (7.1 m/s) and 10.4 m/s (8.1 m/s), respectively. (RSMC Tokyo, 2005)

5.1.2.9 Mesoscale numerical prediction for local wind and precipitation has not been improved significantly. Only a limited number of models have attained resolutions where cyclone structure (including intensity) can be addressed. These models are displaying real skill with regard to motion prediction and have the potential to handle cyclone genesis. (RAI Tropical Cyclone Committee, 2005).

5.1.2.10 The Tropical Cyclone Program had engaged the services of Systems Engineering Australia Pty. Ltd. in July 2003 to undertake reviews and assessments that would lead to suitable conversion factors between the WMO 10-minute average wind and 1-minute, 2-minute and 3-minute sustained winds. (RAV Tropical Cyclone Committee, 2004).

5.1.2.11 There is no commonly accepted definition of extratropical transition (ET). A variety of factors are assessed by different forecast centers to decide whether or not a tropical cyclone is undergoing ET.

5.1.2.12 Operational forecasting centers may continue to use the name assigned to the tropical cyclone during ET so that the general public does not underestimate the hazards associated with an ET event (e.g., in Canada an ET system is referred to as “post tropical cyclone”). (Jones et al., 2003) Another extreme is to keep naming tropical cyclone while the ET cyclone is weakened sufficiently.

5.1.2.13 A presentation from Pat Harr and Sarah Jones at IWET2 in Halifax in 2003 indicated that the greatest model errors, globally, came from ET events. An ET event can substantially reduce the skill of the medium-range forecasts downstream of the tropical cyclone and, thus, can have an impact on Europe and western North America. Extratropical transition poses an especially challenging quantitative precipitation forecasting (QPF) problem. Successful QPF requires an accurate prediction of the track, intensity, and structural changes of storms undergoing ET. The timing of the precipitation shift relative to the storm track described above is very sensitive to physical mechanisms that govern the ET process (e.g., the dynamical and thermodynamic structure of the upstream trough). (Jones et al., 2003).

5.1.2.14 The rapid change in translation speed decreases the warning time for small fishing and recreational vessels that frequent the marine areas in summer and autumn. If the timing of the increase in translation speed is misjudged, track errors of hundreds of kilometers can occur. (Jones et al., 2003)

5.1.2.15 Use of the Cyclone Phase Space (CPS, Hart and Evans) diagrams as a diagnostic tool has proven invaluable in interpreting ET in various dynamical models (Hart, 2003). The Canadian Hurricane Centre has been successfully using this tool operationally since 2001. It is also an excellent tool for assessing tropical cyclone genesis within models.

Summary

5.1.2.16 The track forecasting based on both statistical and dynamical models have been improved steadily for the range up to 72 hours, but with further investigation on its performance in the range between 72-120 hours. The position forecast for a tropical depression is less reliable than that of a tropical storm.

5.1.2.17 The intensity forecast is a challenging subject in the operational center. The model guidance has a limited value, and supplemented by the conceptual models and or statistical models.

5.1.2.18 The rapid change in the translation speed, structure, and distribution of precipitation and wind during the ET can substantially reduce the skill of medium range forecast of sensible weather in the downstream of a tropical cyclone. From the public standpoint, the naming of ET may cause underestimation of the hazards ahead.

Recommendation

5.1.2.19 Develop an integrated network for sharing of enhanced observations (GEOSS), model forecasts and products at the regional and global levels;

5.1.2.20 Use of more observational data improves short range forecast. Making the most of observational data and output of NWP model is necessary. Meteorological data such as raingauge data and radar data observed by organizations other than NMHSs should be obtained and utilized in order to monitor weather more effectively and to improve weather forecast. Raingauge data by volunteers could also be useful. Increased effort should be made to incorporate new and emerging data sources into dynamical model runs (data such as: dropsondes; satellite data such as QuikScat, AMSU, etc.)

5.1.2.21 Availability of these products based on the statistical and dynamical models, though, does not guarantee accuracy. The final warning may depend on the skills and experiences of duty forecasters. Hence familiarity of the forecasters with the performance of such tools will affect the decision making process of which product or combination of products will be the final basis of the warning

5.1.2.22 Continued interaction through workshops and advanced forecaster training sessions should be encouraged to develop national TC forecasting capability.

5.1.2.23 Greater awareness of the CPS diagrams should be generated and encouraged where dynamical models are used to assist forecasters.

5.1.2.24 Public understanding has to be enhanced to realize the hazards associated with Et cyclones as dangerous as s tropical cyclone

5.1.3 Interaction with other systems

5.1.3.1 Tropical cyclones often interact with other circulation systems such as monsoon, midlatitude troughs, and topography, etc.. Heavy rainfall and flooding is often associated with the remnants of tropical cyclones interacting with monsoon circulation in Philippines, Vietnam, and Laos. Recently, heavy rainfall of 300~500mm occurred on the stationary front intensifying with the input stream of moistures from the remnants of tropical cyclones, BILIS and KAEMI, at Korea. The two tropical cyclones made landfall at China before the heavy rainfall over Korea.

5.1.3.2 Large uncertainty in rainfall prediction is associated with track errors, interactions with other weather systems, and topography. The local dams or levee failure, debris in channels and streams, and

debris backup behind bridges may increase the possibility and scale of flash flooding.

5.1.3.3 Hydrologists need forecasts of the positions of tropical cyclones and the associated precipitation for various purposes. The required horizontal resolution, temporal resolution and lead time of the precipitation forecast depend on the specific purpose as well as the scale of the river. The precipitation forecast in the time scale of 1 day with the lead time of 3 days is required for the purpose of water resources management, drought relief and flood control for large basins. On the other hand, rainfall forecasts with intervals of 6 hours or less are required for flash floods, landslides, sediment disasters, and other hydrological requirements.

5.1.3.4 U.S. Geological Survey (USGS) and NOAA scientists use a variety of sophisticated operational hydrologic models for flood prediction, which could be adapted for use in data-poor settings, such as the island of Hispaniola. Hydrologic models will take the model- or satellite-estimated precipitation to create maps of flooding, a process now underway in the USGS Mekong River Project (Negri et al., 2005).

5.1.3.5 The current generation of landslide and debris-flow models is probabilistic because the scale of the phenomenon is small compared to the resolution of the currently available rainfall estimates. Nonetheless, simple solutions, such as the intensity-versus-duration plots, offer discrimination of landslide versus nonlandslide rainfall conditions for Puerto Rico (Negri et al., 2005). The soil water index developed at JMA, based on a tank model, is effective in operational use as an indicator for the prediction of landslides.

Summary

5.1.3.6 Large uncertainty exists in the forecasting of flooding, storm surge, and landslides, as a tropical cyclone makes landfall.

5.1.3.7 Various tools are available, however, the communication need to be enhanced among scientists in the various disciplines including meteorology, hydrology, oceanography, and other geosciences.

Recommendation

5.1.3.8 Direct communications between Meteorological Service and Hydrological Service should be engaged in real time for hydrologists to understand the probability of TC forecasts and for meteorologists to understand the requirements of hydrological issues.

5.1.3.9 Improve flash flood forecasting for ungauged basins and rainfall forecasts.

5.1.3.10 Improve coordination among meteorologists, hydrologists, DPPs, and other stakeholders for flash flood forecasting.

5.1.3.11 Considerable sophistication has been gained in storm surge forecasting. This gain should be reflected in providing more specific information regarding surge height and location warnings to permit effective evacuation.

5.1.3.12 Flash flood vulnerability indicators such as hazard mapping should be developed considering the urbanization and extension of megacities.

5.1.4 Application of ensemble prediction system (EPS)

5.1.4.1 TC forecasting and the associated decision making process involves high uncertainty. Ensemble Prediction Systems (EPS) provides extreme scenarios on severe weather phenomena, and

they serve as pre-alerts to forecasters well ahead of time, and inputs to other models such as storm surge and wave model, flood forecasting model, etc.

5.1.4.2 Krishnamurti et al. (1999) and Kumar et al. (2003) proposed that, by applying a simple multiple regression procedure that regresses different model forecasts against observations, a statistical prediction (a “superensemble”) can be obtained to give a better prediction than any of the model forecasts. Results from both tests indicated that the superensemble was able to produce an average 72-h TC track forecast error of ~210 km in the Atlantic (versus a consensus forecast error of ~300 km) and an intensity error of 20 kt (versus an ensemble average of five models of ~25 kt).

5.1.4.3 EPS has been operated in many NWP centers in recent years. Several meteorological centers provide their EPS products on the Internet. For instance, ECMWF open probability strike map on the web for WMO Members. Since the horizontal resolution of the global NWP models used in the EPS is relatively low, the models cannot always represent TC. Therefore, a calibration method to reduce underestimation of TC intensity should be developed.

5.1.4.4 The typhoon forecasts of nine Numerical Weather Prediction (NWP) centres are now posted in Web site at JMA and that they would shortly provide the ensemble mean of these forecasts. (RAV Tropical Cyclone Committee, 2004)

5.1.4.4 Ensemble techniques and probabilistic forecasts, either in the form of NWP EPS or multi-model ensembles, are probably most useful at the pre-warning stage. Under a cooperative research project between the Hong Kong Observatory and Japan Meteorological Agency (JMA) on the utilization and verification of JMA’s Ensemble Prediction System (EPS) tropical cyclone track data, a suite of new techniques including simple ensemble mean, track clustering, cluster means, conditioned strike probability and intensity calibration was developed. For divergent EPS track scenarios, conditioned strike probability using actual TC positions (i.e. positions observed between the last model run and the latest fix) a posteriori and adopting a clustering approach were found to have potential operation benefits.

5.1.4.5 The application extracts DMO (Direct Model Output) TC intensity information, categorizes the TC in terms of TD, TS, STS and T in a probabilistic sense and generates estimates of minimum MSLP and maximum winds at the centre of the TC. Using the TC category probabilities as weights, a probabilistic estimate of overall minimum MSLP and maximum can be derived. The technique as applied to JMA GSM has been completed. Extending the technique to other models will continue and eventually, combined estimates based on a multi-model approach are also feasible.

5.1.4.6 TC warning signals are issued based on the wind strength experienced or expected over Hong Kong. A methodology using a combination of statistical and NWP techniques has been developed to predict the probability of strong or gale force winds in Hong Kong. Occurrence probabilities are extracted based on climatological data from historical cases in 1968-2001 with respect to the TC’s position relative to Hong Kong and stratified by TC intensity (i.e. TD, TS, STS and T). The uncertainties in TC positions forecast by HKO’s operational warning track, which is very much guided by the multi-model ensemble forecasts, are estimated by: (i) past statistical position error distribution; or (ii) spread of individual model forecasts from the model ensemble mean compiled from ECMWF, JMA, NCEP and UKMO global models. A total of 25 member tracks are then constructed within 85% of the bivariate Gaussian distribution fitted to the perturbation fields. The probability of strong or gale force winds computed at hourly intervals is taken to be the weighted mean of probabilities for the 25 member tracks

5.1.4.7 The emergence of model ensemble techniques (for tropical cyclone prediction in the order of days) and nowcasting (for impact of inclement weather associated with tropical cyclones in the order of hours) are offering possibilities for forecasters to assess objectively the merits of various pre-warning and warning strategies. It is reasonable to assume that improved pre-warning and warning

procedures would be reflected in the long term assessment of benefits and gains as mentioned above. For tangible cost-benefit analysis, reduction in economic losses can then be evaluated against the cost of, say, maintaining 5 separate models or running the same model 50 times with different perturbations (to generate the model ensemble forecast), or the cost of operating a radar or local AWS network in support of various nowcasting systems.

Summary

5.1.4.8 EPS is increasingly used in both track and intensity forecasting of tropical cyclone, particularly for the pre-alert of severe weather in the medium-range.

5.1.4.9 Many EPS products are available on the Web, and forecasters need to get information and knowledge on how to access, to interpret, and to estimate the uncertainty associated with the EPS guidance.

Recommendations:

5.1.4.10 Outputs of EPS operated by NWP centers should be made available to NMHSs for TC forecasting.

5.1.4.11 Techniques to make EPSs applicable to TC forecasting should be developed. Methods for calibration of TC intensity, utilization of an ensemble of EPSs, interpretation techniques of probabilistic forecasts for decision makers, and downscaling techniques should be developed.

5.1.4.12 The potential benefits of EPS have to be realized through collaboration among meteorologists and various users.

5.1.4.13 The ongoing projects under Asian THORPEX and WMO demonstration projects have to be accelerated through regional cooperation

5.1.4.14 Once EPS is shown to be operationally useful, seminars and workshops for the training of forecasters to be acquainted with EPS should be held. Further recommendations are that at least two demonstration projects be held for the application of EPS in storm surge, landslide, wave model, and flood forecasting.

5.1.4.15 Hydrologists should explore the use of ensemble model outputs in flood forecasting.

5.1.5 Application of satellite observations and nowcasting tools

5.1.5.1 The fix of TC, and determination of the radius and deepness, based on the satellite observation and/or other in situ observation. is the very first step for the analysis of TC, and for the initialization of dynamical models.

5.1.5.2 Tropical cyclone fix has uncertainty especially in the early stages. In many cases of tropical cyclone formations over remote ocean areas, Quikscat gives the first evidence of the surface-wind circulation centre, and this sometimes results in major relocations of the centre. The Quikscat surface wind distributions have also improved the analysis of the outer vortex structure (e.g. 35 kt wind radius), which is useful for estimating ocean-surface wave generation, and wind-structure changes during extra-tropical transition of a tropical cyclone. A variety of opinions have been expressed as to the maximum wind speeds in a tropical cyclone that can be reliably measured by Quikscat. (Elsberry and Velden, 2003).

5.1.5.3 An Advanced ODT (AODT) and a multivariate linear regression technique that are being

developed by UW-CIMSS were presented in a special focus session at the IWTC-V. The AODT is being tested at the US National Hurricane Center and Joint Typhoon Warning Center and provides, specifically, intensity estimates for the tropical storm and tropical depression stages. If the AODT and regression technique do well in pre-operational testing, they would complement the manual Dvorak-type intensity estimates that nearly all warning centres use. Even small warning centres with PC-type computers could apply these two techniques. (Elsberry and Velden, 2003) Similar technique has been adopted at KMA as a test basis, which show positive impact during this season.

5.1.5.4 The microwave imagery is also useful for precipitation estimation, although only a few warning centres have taken advantage of this aspect. Whereas 21 of 31 centres indicate they had access, eight centres indicated that the microwave information was not used. Lack of training was cited as a primary reason why it was not used. Questions also arise as to how to interpret the rain-flagged wind estimates and the various wind-direction ambiguity solutions. (Elsberry and Velden, 2003)

5.1.5.5 Tropical cyclone gale radii are routinely assessed by QuikScat, although its use for storm centre quantification is still problematic.

5.1.5.6 In the North Pacific basin, the definition of tropical storm is not consistent from center to center. For instance the RSMC-Tokyo and JTWC have different criteria for the discrimination of tropical storm from tropical depression, and for the definition of tropical depression. These may be of confusion for the definition of tropical depression itself.

5.1.5.7 A major advance in the past four years has been the availability on Internet Websites of real-time satellite imagery and digital data geo-referenced to the tropical cyclone position. Two of the best-known USA Websites are at the UW-CIMSS and the Naval Research Laboratory-Monterey (NRL). It has become evident that these Websites are being routinely accessed by many tropical cyclone warning centres. (Elsberry and Velden, 2003)

5.1.5.8 Nowcasting techniques as applied to the close approach and landfall of tropical cyclones are most relevant in shaping the warning strategies at the warning stage. The applications used at the Hong Kong Observatory for TC-related weather in terms of wind and rain is TC-LAPS and SWIRLS:

5.1.5.9 TC-LAPS is an application adapted for the nowcast of tropical cyclone winds from the Local Analysis and Prediction System (LAPS) of NOAA Forecast Systems Laboratory. Through a combination of successive correction and 3-D variational techniques, the system ingests conventional data as well as observations from less conventional sources such as AMDAR, QuikScat, Doppler winds, TREC winds (from SWIRLS, see below), profilers and AWS networks in an attempt to re-construct a 3-D wind fields for TCs approaching Hong Kong. The horizontal resolution is down to 1 km and the analyses are updated hourly. The nowcast is achieved by extrapolation along a given forecast track to generate time series of wind speed, wind direction and mean-sea-level pressure at specific locations in Hong Kong

5.1.5.10 SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) is a radar-based QPF system designed for the nowcast of rainstorms in the next three hours and updated every six minutes. Radar-rain intensity is dynamically calibrated in real time based on ground truth from a dense network of raingauges. The extrapolation is achieved by the use of TREC (Tracking Radar Echoes by Correlation) winds. Results have shown that SWIRLS QPF is particularly effective from rain associated with TCs due to the dominant advective factor and relatively small fluctuations in rain intensity during the nowcast period.

5.1.5.11 By the time a TC hits Hong Kong, it is invariably near the point of landfall and hence subject to drastic intensity and structural changes as a result of interaction with land mass. The resultant development (or non-development) of rainbands and their attendant squalls also has a knock-on effect on the perception of "gustiness" or "storminess". Both TC LAPS and SWIRLS are tools that rely

heavily upon short-term extrapolation techniques and as such do not have the capacity or capability to allow for such significant intensity-related changes both spatially and temporally. The lack of reliable objective guidance can sometimes make decision-making at the stage of warning cancellation rather tricky. The challenge remains to: (a) develop better NWP models in the simulation of landfalling TCs; and (b) incorporate such numerical information into the nowcasting or other expert systems for critical decision-making processes in the operation of warnings.

5.1.5.12 The automatic weather station(AWS) network, updated every minute, is very efficient to fix the center position of tropical cyclone moving over the land after landfall, while the radar and satellite image provide only very limited information on its structure. The position and intensity of Tropical cyclone EWINIAR (0603) is determined by the wind circulation and pressure measured at surrounding AWSs at KMA. The Forecast Analysis System (FAS), visualization tools based on interactive workstation at KMA, provides information on the movement of radar echoes along with the synoptic wind circulation overlaid with satellite images and spots of lightening. The System of Convection Analysis and Nowcasting (SCAN), adopted from U.S.A. on workstations at KMA, give guidance on realtime movement vector and intensity of storm cells associated with spiral band of tropical cyclone or rainband interacting with remnants of a tropical cyclone.

Summary

5.1.5.13 Satellite observations are major source for the determination of position, radius, deepness of a tropical cyclone. Automatic Dvorak techniques are tested in many operational centers, and microwave channel data are increasingly used.

5.1.5.14 Many centers may use nowcasting tools for the warning of heavy precipitation and strong wind for landfalling tropical cyclone, for instance, Hong Kong observatory effectively use the tools on operational basis.

5.1.5.15 Various diagnostics and satellite observations are available through Internet, and more training and education is requested for forecasters to apply them.

Recommendation

5.1.5.16 NMHSs should enhance their forecasting capabilities by utilizing current and emerging satellite data.

5.1.5.17 Dvorak-type tropical cyclone intensity estimates need to be validated by special *in situ* observation field campaigns in all basins that lack routine reconnaissance programmes. (Elsberry and Velden, 2003)

5.1.5.18 Training seminars and workshops are required to demonstrate on the application of AODT and other interpretation techniques of satellite observations.

5.1.5.19 It is desired to make a survey on the nowcasting tools of heavy rain and gust wind for the landfalling tropical cyclones to share them among forecasters

5.1.6 Warning presentation

5.1.6.1 The accuracy of the forecast as well as landfall still remain worrisome on the part of disaster response community as well as the ultimate user, the affected common people. In united States, the warning zones have historically averaged about 300 nm (556km) in length. This distance has evolved as a trade-off between the desire to provide maximum lead time and the necessity for keeping the size of the warning area within reasonable limits. In as much as a typical damage swath from a hurricane is

100 nm or less, approximately two-third of the residents within the coastal warning zone are over warned. One reason the length of the hurricane warning zone has not shrunk more is that the large increase in coastal population and property valuation has dramatically increased the vulnerability of the area and, thus, the consequences of a bad forecast. (OFC, 1997)

5.1.6.2 A major problem of issuing severe weather warnings is that the probability of the most extreme weather events occurring is very low; this means that warnings of severe weather that could cause the most damage are not always taken as seriously as they should be because they appear to be very unlikely. Therefore decision-making for events of this severity should be related not just to the probability of occurrence but also to the impact of the event. A simple example is to ask the question: if there was a 5% chance of rain would you play golf? Whereas if there was a 5% chance that the flight you had booked would crash, would you board the flight? The impact clearly is important to the decision

5.1.6.3 Information on the uncertainties in tropical cyclone forecast and intensity were conveyed to the public on the tropical cyclone forecast track map and other methods so as to manage their expectation on the forecast accuracy.

5.1.6.4 In Malaysia since Tropical Storm Greg, the TC warning has been revised to include direct TC impact.

5.1.6.5 The set of precautionary announcements and advisories based on pre-agreed courses of actions with the parties concerned were selected at the time to reflect prevailing circumstances to give maximum protection to the public.

5.1.6.6 In the USA, studies following hurricanes Camille and Eloise revealed that people who knew the difference between a “watch” and a “warning” were no more or less likely than others to evacuate. What does matter is that people are told explicitly what actions they need to take to protect themselves and why (WMO, 2002).

5.1.6.7 The S-S Scale and STiCKs - In general, tropical cyclone disaster scales serve two purposes: 1) to allow people to relate a specific intensity (wind speed) value to particular levels of damage or destruction so that they can make appropriate decisions; and 2) to help assess tropical cyclone intensity at locations where wind measuring devices have failed or been destroyed, or where they were non-existent. Here we discuss two similar Scales that were developed for different areas: the Saffir-Simpson Hurricane Scale (SSHs) (Saffir 1972, Simpson 1974) and the Saffir-Simpson Tropical Cyclone Scale (STiCKs) (Guard and Lander 1999). Sheifer and Ellis (1986) presented a formalized methodology for tropical cyclone damage assessment, which was incorporated into the latter Scale. In recognition of the utility and success of STiCKs, the French countries of the Southwest Pacific and the Southeast Indian oceans requested that the WMO translate the Scale into French, and in 2005, a French translation was produced (N. Lomarda, personal communication). While the original northern hemisphere version is being used in most of the southern hemisphere tropical islands, it is desirable to produce a southern hemisphere version in the near future. Other Scales have been developed in Australia and the Philippines (Amadore 1985). There are likely others. In operational practice, emergency managers should not use these Scales for real-time decisions, but instead should use the products provided by the National Meteorological Center or Tropical Cyclone Warning Center. However, the data in these Scales provide a good first guess for planning and response when better data are not available.

5.1.6.8 Perhaps it is time to conduct a survey and assessment of the existing Scales. The major strength of these scales is their simplicity and ease of understanding, especially with less sophisticated users. The scales can also be fine-tuned for a specific area or location. The major weakness with these scales is with the storm surge values. Storm surge can vary greatly depending on the storm size, speed of motion, prior intensity, and several other factors. Thus, the storm surge values can sometimes be one Category in error (B. Harper, personal communication).

5.1.6.9 The Australian scale - while also 5 category levels - is quite different to the US S-S scale. The scale is based on maximum wind gusts (3sec) using the theory and evidence that these strong gusts that are responsible for the most significant damage during an event. It is recognized that other factors will have a significant effect on the amount of damage - for example the length of exposure to these cyclonic conditions can have a significant effect on impact - particularly with strong cyclones where damage debris can accumulate - escalating the damage. The Australian scale covers tropical cyclones (T.Storms) and severe tropical cyclones (Hurricanes/Typhoons), whereas the S S scale is only for Hurricanes

http://www.bom.gov.au/catalogue/warnings/WarningsInformation_TC_Ed.shtml

5.1.6.10 The Philippines scale - there are four public storm signals for purpose of categorizing the impacts of tropical cyclones. Delineating the areas under each warning signal depends on the forecast wind strength. Values within the range may be easily decided on, but values near the boundaries of each range may prove to be difficult and could result to over warning or under warning as the case maybe, which can result to post warning criticisms – from the media and the public at large- at the very least or productivity losses for over warning cases and damages and casualties in the under warning cases. Based on damages information, most impacts were caused by tropical depressions and severe tropical storms and at times, their interaction with the monsoon systems. From experience also, typhoons with high winds were mostly fast moving; since the Philippines are archipelagos, it only takes short time for typhoons to move across the land. It is the slow moving depressions and storms laden with lots of rainfall, which cause so much troubles for the country.

5.1.6.11 The distorted common perception of cyclone as a wind related phenomena is a barrier to understanding the danger related to storm surge and flooding. This also deters timely evacuation of people from critical areas. In many a case, the warning has maritime bias. The example of Bangladesh may be cited here. In Bangladesh, the cyclone warning issued by Bangladesh Department of Meteorology (BMD). The BMD issues cyclone warnings based on sea ports and river ports, which are in turn used for disaster preparedness. As can be seen from the contents of the warnings, in the existing warning system most of the signals depend on the cyclone track relative to a port. The numbering of the signals is confusing. The understanding is that higher is the number of signal the more is the intensity of the cyclone. But that is not true, in the existing system higher number of signals do not necessarily indicate stronger cyclone. For example, there is no difference among the danger signals (e.g. signal no. 5, 6 and 7) from the point of view of the intensity of cyclone. Signal 5 is hoisted when the cyclone is expected to cross the coast to the north of the port, whereas signal 7 is issued when it is expected to cross near or over the port. Signal no. 8, 9 and 10 (great danger signals) are issued when it is expected that port will experience severe weather from a storm of great intensity (normally which is 90 km/hour or more). But there remains a confusing point regarding maximum limit or the signals of great danger.

5.1.6.12 While several Members use TC warnings, several Members use separate warnings concurrently to warn the public of heavy rain, strong wind, storm surge, and high wave associated with tropical cyclones or their remnants as well as rain-induced disasters such as floods and landslides.

5.1.6.13 During the passage of tropical cyclones, presentations of tropical cyclone warning information and advisories in caring wording with a human touch by experts from NMHSs through live broadcasts on radio and TV will be effective in capturing public attention and relaying the latest critical weather information and advice. The media are interested in personalities.

5.1.6.14 Presentation and content are important, but there is no guarantee that people will heed even “perfect” warnings. Despite very accurate forecasts and warnings and round-the-clock television coverage for Hurricane Katrina, nearly 1300 people perished. A Special Report on the aftermath of Katrina summed up the challenge as: “The meteorological community once again needs to determine how to get better results out of its best efforts to fight the unthinkable” (Rosenfeld, 2005). How do we

battle human nature? We must better understand what motivates people to heed or ignore warnings. We must figure out how to convey probabilistic information in an easily understood manner.

5.1.6.15 Getting the science right is only ½ the equation. Hurricane *Katrina* has clearly demonstrated that good science is not enough to avert a disaster. There is a need to ensure that forecasters are trained in speaking to the media and that they develop credibility in vulnerable communities so that their message will be clearly heard, understood, and acted upon. In Australia, this is achieved through media skills training, on-going media exposure in at-risk communities and a policy of having the tropical cyclone forecaster do all radio interviews/broadcasts to affected communities (RAI Tropical Cyclone Committee, 2005).

5.1.6.16 Following the landfall of Hurricane Juan (2003) as SS2 storm in Nova Scotia, Canada, the Canadian Hurricane Centre (CHC) instituted the use of tropical storm and hurricane watches and warnings. These are issued by the CHC and are independent of elemental watches and warnings issued by the various Canadian Storm Prediction Centres and Forecast Offices. They are not just coastal bulletins, as in the United States, but extend inland through forecast areas.

Summary

5.1.6.17 The uncertainty of tropical cyclone track and intensity is conveyed to the users in terms of probabilistic expression. It depends on the accuracy of forecasts and on the vulnerability of the target area.

5.1.6.18 The warning has to be interpreted in terms of action words to allow the users to respond on. The various scales on intensity have been developed, depending on the socio- economic conditions.

Recommendation

5.1.6.19 Issue probabilistic forecasts of tropical cyclone/severe weather conditions up to 5 days ahead in all regions, to allow appropriate response. A better way is needed to communicate with the public so as to improve their understanding of probabilistic prediction. One solution for more understandable probabilistic prediction might be to translate it into a more illuminative language, for different stakeholders. Assistance from social scientists may be necessary in the translation process;

5.1.6.20 Conduct research to find out what people understand and do not understand, then evaluate through demonstration projects.

5.1.6.21 The warning message should contain information on what is to be done to minimize loss of lives and properties by the individuals and community. Such information will provide outlet for positive action on the face of cyclone threat.

5.1.6.22 good tropical cyclone warning system should be simple, easy to understand, and able to trigger organized responses of the government and orderly collective responses of the public to minimize loss of lives and damage to property.

5.1.6.23 Tropical cyclone warning symbols/categories should be considered as an efficient way of conveying tropical cyclone warning message to the public and facilitates the public triggering of a timely collective response, hence promoting effectiveness of the tropical cyclone warning.

5.1.6.24 Different forms of presentation of tropical cyclone messages should be developed and fitted to the strength of the dissemination channels and the level of the intended audience to enable effective communication of the warning to different sectors of the community.

5.1.6.25 Warning signals in the form of flags or similar symbols culturally acceptable to the community

should be adopted for easy dissemination of warning signals in societies with low literacy level and with limited communication infra-structure.

5.1.7 Warning dissemination

5.1.7.1 NMHSs need to be aware that the warning message may change in the transmission process and the recipients may not understand the warning and know how to respond in their own best interests.

5.1.7.2 In beach areas of south-east Florida during hurricane Andrew in 1992, 30 per cent of the residents said they did not hear from officials that they needed to evacuate their homes for safety. The influence of hearing vs. not hearing evacuation notices is greatest not in beach areas but in mainland locations that would flood dangerously only in strong storms (WMO, 2002).

5.1.7.3 To facilitate broadcast of the change in the tropical cyclone warning status by radio and TV stations simultaneously at the scheduled time and to avoid possible confusion by the public, the warning can be issued to the station 5 to 10 minutes earlier with an embargo on its release prior to the scheduled time.

5.1.7.4 In tourist cities, tourists and visitors will get to know tropical cyclone warning information from hotels and other sources.

5.1.7.5 Today, a majority of people appears to receive most of their warning information by television or radio, as has been documented by survey research with the public in Australia, Bangladesh and the USA. A great deal of hurricane information is accessible via the Internet but, as yet, fewer than 10 per cent of US households say they rely a great deal on that source for information about a threatening storm. (WMO, 2002).

5.1.7.6 Recent time has seen revolution in telecommunication technology. Now cyclone warning services have access to mobile telephones, satellite phone, satellite based warning broadcast system in addition to landline telephone networks. As emphasized earlier, public telephone network (landline/cellular) are effective before the disaster strikes. Once the disaster has struck, these networks are prone to failure/outages due to heavy traffic congestion, power breakdown etc. As such, these are not effective in dissemination of updated information to Disaster managers, broadcasters, affected communities etc. The role of electronic media (radio/TV) in informing the communities becomes limited because the broadcaster may not get latest warnings from warning service due to communication failure and the target audience may not be able to operate radio/TV due to power breakdown. In such situations, satellite based communications systems like satellite phone, VSAT terminal, Digital data/voice broadcast system, are much more effective in warning dissemination, as these are less prone to failure during adverse weather conditions. A satellite based voice broadcast systems known as "Cyclone Warning Dissemination System (CWDS)" has been functioning at several cyclone prone locations on the east and west coast of India, for the last several years and has proved quite effective in cyclone warning dissemination directly to people at risk. The system is owned and operated by India Meteorological Department(IMD). Cyclone Warning Centre prepares customized warning messages for each receiving location in local language and sends to specific location through satellite uplink. At the receiving end, when system is activated by Cyclone Warning Centre, the receiver sets off a loud siren to alert staff attached to receiver so that he can arrange to receive the warning message. The siren is followed by voice message containing details of adverse weather conditions likely to affect that area in local language. The message is noted by the staff and disseminated to local communities at risk.

5.1.7.7 KMA recently disseminates warning messages to digital multimedia broadcasting (DMB), and to the Internet portal sites.

5.1.7.8 In some countries like Cambodia, the GTS communication network is not available and the only means of communication with foreign countries is the Internet.

5.1.7.9 In developing societies, where most death occurs due to cyclone disaster, warning dissemination to the target population is challenging in view of poor infrastructure, limited access of population to mass media, remote location and the like factors. In such societies, a combination of modern and traditional media is to be used for warning dissemination. Community organizations and volunteers can be useful in disseminating warning in most developing countries. Throughout the warning phase of a cyclone, the CPP volunteers caution the people through megaphone and house-to-house contact as well as shift the endangered people to safe places and cyclone shelters. The headquarters of CPP maintained round the clock contact with the coastal region through 56 field wireless stations before, during and after the disaster.

5.1.7.10 Baker reports that the public is most effectively informed when authorities go door-to-door notifying residents of the need to evacuate or drive through neighborhoods announcing the evacuation over loudspeakers. (Schmidlin, 2006)

5.1.7.11 In some of the more developed countries for those who can afford it, the private sector has moved in to fill the shortfalls of the NMHSs. They specially tailor products and services for specific customers or sectors, but for a price. In some developed countries, the NMHSs themselves provide this service for a fee.

5.1.7.12 Automatic telephone inquiry system (telephone recorders and poll faxes) provides a direct and simple way for the public, especially the underprivileged who will have to rely on the phone, for acquiring the latest weather forecast and warning information.

5.1.7.13 Radio offers an extremely effective and widely adopted means of disseminating weather information and will continue to be one of the most common and critical components of the dissemination system of warning messages.

5.1.7.14 The effectiveness of the tropical cyclone warning system can be further enhanced by harnessing the power of the Internet.

5.1.7.15 The WMO websites for Severe Weather Information Centre (SWIC) and World Weather Information Service (WWIS) containing official weather forecasts and tropical cyclone warnings in different regions of the world demonstrated the synergetic effect of contributing NMHSs, maximizing the effectiveness of warnings at the global level.

5.1.7.16 Tropical cyclone products and information are disseminated through multiple channels in most Member countries such as amateur radio, HF radio, GTS, fax, US NWS network, Internet, IRC chat and voice, military communication circuits in JTWC, EMWIN, and RANET. Emergency Management Weather Information Network (EMWIN) and the RANET digital satellite radio broadcast are inexpensive ways to send communications to small, rural areas.

5.1.7.17 In Canada many media outlets have a reduced capacity on weekends, and in the case of some commercial radio stations, they may even be fully automated. In such cases, contacting media personnel to notify them of tropical warnings has proven problematic and emergency preparedness organizations have been engaged to aid in this process.

Summary

5.1.7.18 The communication channels for the dissemination of warnings continue to expand to DMB, Internet portal sites, mobile phones, satellite broadcasting, along with conventional means.

5.1.7.19 However, the door to door notification is yet the efficient way of communication to personalize the risk.

Recommendation

5.1.7.20 Ensure dependable and effective dissemination of nowcasts, forecasts, advisories, watches and warnings in real-time to decision-makers including emergency managers, media, general public and other stakeholders in most countries and regions.

5.1.7.21 NMHSs should if possible disseminate warnings through multiple and diverse channels with varieties of high and low technology with backup capabilities to facilitate users to respond to the warning in a timely manner.

5.1.7.22 Members may consider adopting the use of colored or numbered codes/categories in a tropical cyclone warning system as an effective way in conveying tropical cyclone warning status to the public.

5.1.7.23 NMHSs should take advantage of the advances in communication means such as wireless broadband access, GPS, and GIS technologies to enhance the relevance and effectiveness of warning.

5.1.7.24 Warnings should be disseminated through as many ways as possible such as :

- (a) Text warning messages could be disseminated proactively to users via emails.
- (b) Dedicated web pages with audio warning alerts can be developed to provide tailor-made weather services to special clients.
- (c) Web pages in a variety of formats, viz. graphics, text-only, audio, Wireless Application Protocol (WAP) and Personal Digital Assistant (PDA), extensible Markup Language (XML) versions can satisfy the needs of diverse users.

5.1.7.25 Attempt should be made to develop volunteers at the community level under appropriate organizational arrangement as vehicle for tropical cyclone warning message dissemination on a door to door basis in a cost-effective manner. Such organization could also work on preparedness and response with community involvement. The Cyclone Preparedness Program (CPP) in Bangladesh can serve as an useful model of grassroots level organization for cyclone mitigation.

5.1.8 Education, promotion, and nonstructural means

5.1.8.1 More accurate and timely forecasts are also important for decrease of natural disasters, however, improvements in warning systems and in disaster management remain critical to mitigating the loss of lives and, to some extent, the damage over the world. Political and administrative decision makers are responsible for natural causes. They have to take these realities into account, not just in developing a vigilant disaster management system, but also in land-use planning, development of coastal districts, and insurance measures (Reason and Keibel, 2004).

5.1.8.2 One of the biggest obstacles to vulnerability reduction is the lack of public awareness of the threat and basic mitigation and preparedness measures.

5.1.8.3 Even when information is made public, it does not always reach the target audience. Surveys conducted by researchers at James Cook University in Australia following cyclones Justin and Gillian found that the majority of respondents had been unaware of cyclone safety information in their telephone directories. But general knowledge about tropical cyclones and associated safety rules is not sufficient in many cases. In the USA, people who could name hurricane safety rules, knew the definition of "low-lying area" and knew the difference between hurricane "watches and warnings" were no more

likely than others to evacuate in Camille and Eloise (WMO, 2002).

5.1.8.4 Interviews were conducted with residents of two communities in Bangladesh following the 1991 cyclone that killed 139 000 people. Most people said they did not believe the warnings or they were afraid of looting if they left their home unattended. The expression “it won’t happen here” is related to the failure to believe warnings. Haque indicated that warnings were not believed partly due to past false alarms. The notion “it won’t happen here” stemmed from the fact that the area had not been struck by a major storm since 1960. (WMO, 2002)

5.1.8.5 A great deal of research has been conducted in the USA to explain why some people evacuate and others do not. The examples of hearing evacuation notices, perception of vulnerability, and housing type have already been mentioned. In fact, those variables, plus the actual physical vulnerability of a person’s location (e.g. living on the beach susceptible to wave action and inundation even in weak storms vs. living on the mainland in areas only flooded by strong storms) account for the great majority of the variation in whether people evacuate in the USA. (WMO, 2002)

5.1.8.6 Familiarity of the tropical cyclone warning system by the public is essential for an effective and orderly implementation of response actions.

5.1.8.7 The best way to accomplish this is to incorporate the information into the curriculum of primary and secondary education systems. The Weather Forecast Office at Guam worked with middle school science teachers to develop a curriculum that addressed the natural hazards that affect and influences the lives of the people of the region. Some 45 hours of instruction and a multitude of materials were provided to the teachers. They developed the curriculum within 6 months, but it has yet to be reviewed and accepted by the public school system. There is tremendous competition for the hours that will be needed for the lessons to be taught and tremendous inertia to change.

5.1.8.8 Outreach can be an effective method to get specific information to a targeted audience. However, outreach requires a large investment of time for what is usually a relatively small audience. Thus, the payoff should be high. As an example, each year, the Weather Forecast Office in Guam conducts 20 workshops, makes 20 school presentations, entertains 25 school visits, addresses 15 civic groups, and talks to 220 different individuals about specific aspects of weather support. This amounts to about 2500 contacts per year for 300 events that last an average of 120 minutes. At the same time, the Office conducts an average of 50, 10-minute radio and television interviews per year, with an audience of 5000 people per interview. Which is best? It depends on the purpose. Outreach provides a lot of information to a small audience over several hours, while media passes a little information to a lot of people over a few minutes. Cottrell (2004) demonstrated the value of the local knowledge and local survival strategies, specifically of women in Northern Australia, in increasing the effectiveness of mitigation planning.

5.1.8.9 NMHSs have to be aware that warnings and hazard awareness need to be internalized by the society through time, cyclone warnings have to be recognized in time and space ahead of or alongside the hazard. Warnings and responses are at the opposite ends of a chain of processes. Failure of links between and among players in the warning process will reduce effectiveness. The players may include meteorologists/ hydrologists, government decision makers, emergency management disaster planners, media, local government units, community action and response teams as well as individuals.

5.1.8.10 In the Philippines, establishment of a community-based early warning system for floods, landslides and flashflood is being set-up in various communities around the major river basins in the country. The idea here is to empower local government units and community volunteers to develop localized indicators that will relate flashfloods for example, to rainfall observations. The success of such community-based early warning system relies heavily on the design of the flow of communications from the observation sites to the decision-maker and the timing of the warning to reach the affected community for them to evacuate to safe areas at the shortest time possible. Also, the sense of

ownership of the community for the early warning system contributes its effectiveness. The major role of the national hydrometeorological service is to be able to transfer the “technical know how” to volunteers in a pragmatic way. Both the NHMS and the community are expected to give their commitment, cooperation and support to make the system sustainable. This effort requires a lot of coordination with local government units, public information drive and genuine interest and faith in the success of the system.

5.1.8.11 Community-based approach is one of the social instruments being used to involve stakeholders in the decision-making process particularly the most disadvantaged or affected groups. It is part of a larger participatory process. In many developing countries including the Philippines, this approach is being employed mostly in environmental concerns. Four years ago, we included community-based flood early warning system (CBFEWS) in one of the activities in the Typhoon Committee. This is a response of TC to involve the three disciplines of meteorology, hydrology and disaster prevention in one activity. Malaysia, Thailand and the Philippines participated in a pre-workshop on this activity.

5.1.8.12 The Hong Kong Observatory and other local government departments jointly organized a year-long public education campaign in 2005 to promote public awareness and understanding of natural hazards. The campaign involved the active participation of the public (“Safer Living-Reducing Natural Disasters” campaign and the “Tropical Cyclone Name Nomination Contest”). The public supported this initiative.

5.1.8.13 Media liaison officers in NMHS are important in developing close connections among various stakeholders in the warning and response process. People have different types of attitudes and perceptions towards risk, warning and disaster preparedness education. It is important to promote the appropriate disaster preparedness education and school curriculum packages having in mind the intended audience.

5.1.8.14 In many countries, public awareness activities, whatever may be the scale, is mostly confined to tropical cyclone seasons. This should give way to year round public awareness activities on a sustained basis to create public understanding and consequent preparedness and mitigational behavior at the level of the community.

5.1.8.15 In most developing societies, coastal inhabitants are reluctant to evacuate or to move to cyclone shelters due to attachment to their worldly possessions including that of livestock and poultry. The impact study of Bangladesh May 1994 cyclone by Helen Keller International indicated that most residents in the affected area waited until the wind flow started to seek shelter or did not move until their home collapsed. In the event that the cyclone had been more severe,

5.1.8.16 A further challenge of ET for the forecaster is communicating with emergency management personnel and the public, particularly since there is much less public awareness of the hazards associated with ET than of those due to a tropical cyclone. (Jones et al., 2003)

5.1.8.17 In Canada, Hurricane Juan (2003) was a stark reminder of the realistic threats of hurricanes when, in spite of solid forecast guidance from the CHC, the public were found to be generally unprepared. A post-event assessment of failing points yielded a variety of reasons for the poor response:

- a) A significant over-reaction of the media to Tropical Storm Isabel (9 days earlier) left the media feeling timid about repeating the false alarm. Accordingly, it was extremely difficult to engage them to the fullest extent required.
- b) Since it had been more than 100 years since the city of Halifax had experienced a hurricane of that magnitude there was no corporate memory for people to draw from – they were essentially unschooled in the threats of a category 2 hurricane. Accordingly, most people didn’t know how to react.

- c) Many had a false sense of security based on their experience with SS1 Hurricane Hortense (1996) . . . a storm which resulted in some (but minimal) impacts to Halifax since it made landfall east of the city. The public felt that that they knew what a hurricane could do and were unprepared for a stronger hurricane making landfall just west of the city.
- d) Many/most residents of Nova Scotia believed that they were not seriously threatened by hurricanes, or that impacts, if any, would be insignificant (Hanson, 2003).
- e) Of the few that did believe that hurricanes could strike Nova Scotia, most felt that the cold water surrounding the province would mitigate the effects by weakening the storm. At the time of Juan, however, SSTs were running 3-5 degrees C warmer than normal . . . a fact that resulted in Juan remaining at category 2 strength (Fogarty et al., 2006).
- f) Much of the general public had a poor sense of vulnerability.
- g) Many believed that since they had been impacted by Hortense in 1996 that Juan would NOT strike because hurricanes do not occur with that frequency.
- h) Of the few that paid attention to the track forecasts (disseminated through the internet and the media), a great percentage placed too great an emphasis on the track-line and gave too little credence to the worded statements that talked about impacts extending a significant distance from the track line.
- i) Many felt that although the CHC statements were accurate and factual, they lacked the necessary dire-nature to engage the public at the highest level.

5.1.8.18 Even in the presence of structural means, there is a necessity for comprehension of flood disaster prevention and mitigation through inclusion of nonstructural means including:

- (a) Legal framework, coordination among stakeholders
- (b) Land use (spatial) management
- (c) flood monitoring, forecasting & early warning systems
- (d) Preparedness –hazard mapping, improving communication, education to raise awareness
- (e) Insurance and mutual aid

Summary

5.1.8.19 The public does not always respond to protect from the danger of tropical cyclone even when the warning itself is accurate and disseminated in time. Numerous factors influence the behavior of users including the false alarms, rare occurrence, belief “it won’t happen here”, and so on.

5.1.8.20 Various activities are on-going to enhance public awareness on the risk of tropical cyclone through outreach programs, primary and secondary education, and cooperation among decision makers, emergency managers, media, stake holders at community level.

Recommendation

5.1.8.21 Increase investment in awareness programmes related to the risks and consequences of natural hazards for decision-makers, emergency managers, media, NGOs, public and other stakeholders for prompt and effective response at the national to community levels;

5.1.8.22 Educate stakeholders annually on proper interpretation of forecasts, advisories, warnings and other meteorological and hydrological information. The goal is to conduct at least one session for each stakeholder; and

5.1.8.23 NMHSs should collaborate with scientists and researchers to develop TC disaster scenarios and visualize hazards in the form of hazard map, risk map or disaster management map, designating evacuation sites, and displaying warning/evacuation signs etc. All stakeholders including national and local governments, non-government organizations, private sectors and individuals should develop disaster management plans stipulating the roles of different stakeholders. The plans should be updated constantly to reflect the current situation. Drills of disaster management plans and test of

communication links involving all stakeholders should be organized by local government.

5.1.8.24 DPP should gear towards the prediction of extreme weather events. Studies on the climate variability and change impacts on extreme weather events should be carried out to enhance disaster preparedness.

5.1.8.25 The tropical cyclone warning criteria and protective measures must be publicized through as many channels as possible such as websites, publications for teaching materials, guidelines, demonstration of past achievements on the assessment of vulnerability and risk management distributed at schools, district offices, entry ports, resource centers, short advertisement broadcast by radio and TV.

5.1.8.26 Promote public education and conduct outreach activities such as talks, exhibitions, school visits, TV documentary series, education and publicity campaigns to raise awareness and people's preparedness for possible tropical cyclone related disasters, community empowerment and awareness.

5.1.8.27 Include materials on tropical cyclone warning system, tropical cyclone related hazards and corresponding disaster preparedness in the school curriculum and educational resources to promote public education to students and teachers.

5.1.8.28 NMHSs must formulate strategies on disaster risk management. These include

- (a) establishing a legal frame that will allow coordination mechanisms and protocols;
- (b) integrating disaster reduction concepts into land use planning;
- (c) improving information sharing and management;
- (d) promoting education and public awareness for example by integrating disaster education into the curriculum;
- (a) developing multi-stakeholder partnerships and public participation.

5.1.8.29 Knowledge, Attitude and Practice (KAP) survey on cyclone warning should be initiated on systematic basis in every tropical cyclone prone country on periodic basis and after every major cyclone to establish benchmarks and monitor progress in public understanding and internalization of cyclone warnings in the life style of individuals and communities inhabiting the coastal belts. Such survey findings would be very useful pointer to policy makers for investment decisions and NMHSs to assess preparedness of the communities at risk of losing invaluable lives. KAP survey on cyclone warning should be also conducted on other stakeholders viz political decision makers, disaster preparedness personnel, non-government organizations and others involved in DPP activities to identify the need for training and orientation type of activities to ensure provider preparedness.

5.1.8.30 Social impact study of tropical cyclone should be conducted on periodic basis with joint team of meteorologists, hydrologists and social scientists in every cyclone prone society in line with the recommendation of IWTC-V. A compilation of such studies should be published to promote the '*culture of promotion*' as advocated by WMO

5.1.8.31 The accuracy of warning can be directly evaluated through a post event verification scheme, comparing the forecasts included in the warning against the observed. Field surveys and damage assessment may also help establish the degree of correctness of the delineation of areas under a certain warning category.

5.1.8.32 In societies with dense population, the pressure on land plus attraction of coastal land fertility attracts people to settle in fringe land or islands in the coast. Regulatory framework on land use in the coastal areas should be developed and enforced to reduce vulnerability.

5.1.9 International cooperation

5.1.9.1 Larger warning centers may use specially designed computer systems that manage and co-register numerous sources of data and computer model output, and allow the forecaster to formulate the forecast into pre-formatted bulletins and products. These products may be sent over a wide variety of dissemination systems. Other NMHSs may have to develop the warnings from a limited amount of data and computer model guidance from a few disjointed sources, and then manually produce the warning on a simple word processing system. These products may be sent to a very limited number of dissemination systems.

5.1.9.2 Almost under-developing countries do not have numerical weather prediction (NWP) capacity, and the challenges and potential solutions for improved tropical cyclone forecasting for these regions are required. In order to improve of NWP over these countries, international cooperation is indispensable. Moreover, national forecasters must at least be in a state of heightened alert of tropical cyclones, in advance by sharing the information through world wide network. The international training programs for typhoon forecasts are able to contribute advance to other countries (Raghavan and Rajesh, 2002).

5.1.9.3 Various EPS products are available on the Web, and will increase in the future through international projects under THORPEX Interactive Gland Global Ensemble (TIGGE).

5.1.9.4 The EPS model products were increasingly becoming useful for tropical cyclone forecasting. It was, however, noted that most countries of the SWIO were not yet familiar with the use of these products for tropical cyclone forecasting. (RAI Tropical Cyclone Committee, 2005)

5.1.9.5 A request was made to the JMA that real-time track forecasts for tropical cyclones be provided for the Southern Hemisphere, particularly the South Pacific Ocean. This would be a valuable addition to the limited suite of NWP-based TC track products available to the SW Pacific Nations that can be used for more effective ensemble-type forecasting techniques. (RAV Tropical Cyclone Committee, 2004)

5.1.9.6 The effectiveness of tropical cyclone warning can be enhanced by inter-agency partnerships and cooperation. In the process, effective communication and interaction through capacity building, governance, community empowerment, and disaster preparedness program are critical.

5.1.9.7 Cambodia, Vietnam, the Philippines, DPR Korea, and Lao PDR expressed the need for additional rain gauges to monitor rainfall for improving flood forecasts.

Summary

5.1.9.8 The resource and information is limited in the developing countries to provide warning service for a tropical cyclone

Recommendation

5.1.9.9 NMHSs should foster closer regional coordination and collaboration in the application of model and other forecasting guidance in tropical cyclone prediction and enhancement of telecommunications capability. Local NMHS can then adjust the service to cater for local characteristics.

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Acronym

AMSU	Advanced Microwave Sounding Unit
AODT	Advanced Objective Dvorak Technique
AWS	Automatic Weather Station
BMD	Bangladesh Department of Meteorology
CBFEWS	Community-based Flood Early Warning System
CHC	Canadian Hurricane Centre
CIMSS	Cooperative Institute for Meteorological satellite Studies
CLIPER	CLImatology and PERsistence
CPP	Cyclone Preparedness Program
CPS	Cyclone Phase Space
CWDS	Cyclone Warning Dissemination System
DMB	Digital Multimedia Broadcasting
DMO	Direct Model Output
EMWIN	Emergency Management Weather Information Network
ET	Extratropical Transition
FAS	Forecast Analysis System
GEOSS	Global Earth Observing System of Systems
GTS	Global Telecommunication Network
HKO	Hong Kong Observatory
IMD	India Meteorological Department
JMA	Japan Meteorological Agency
JTWC	Joint Typhoon Warning Center
KAP	Knowledge Attitude and Practice
KMA	Korea Meteorological Administration
LAPS	Local Analysis and Prediction System
MAE	Mean Absolute Error
NCEP	National Center for Environmental Prediction
NMHS	national Meteorological and Hydrological Service
NRL	Naval Research Laboratory
NWP	Numerical Weather Prediction
OFC	Office of the Federal Coordinator
PDA	Personal Digital Assistant
QPF	Quantitative Precipitation Forecasting
QuikScat	Quick Scatterometer
RANET	RAdio and interNET
RSMC	Regional Specialized Meteorological Center
SCAN	System of Convection Analysis and Nowcasting
SSHS	Saffir-Simpson Hurricane Scale
StiCKs	Saffir-Simpson Tropical Cyclone Scale
SWIC	Severe Weather Information Centre
SWIRLS	Short-range Warning of Intense Rainstorms in Localized Systems
TC	Tropical Cyclone
THORPEX	The Hemispheric Observing system and Predictability EXperiment
TIGGE	THORPEX Interactive Gland Global Ensemble
UKMO	United Kingdom Meteorological Office
USGS	U.S. Geological Survey
WMO	World Meteorological Organization
WWIS	World Weather Information Service
XML	Extensible Markup Language