

SEVENTH INTERNATIONAL WORKSHOP ON TROPICAL CYCLONES

4.3 Operational Warning Strategies

Rapporteur: S.T. Chan
Hong Kong Observatory
134A Nathan Road, Kowloon, Hong Kong

Email: stchan@hko.gov.hk
Phone: +852 2926 8434

Working group: Daniel Brown, Philippe Caroff, Jeffrey Callaghan, Shuyi S. Chen, Chip Guard, Masashi Kunitsugu, H.P. Lam, C.H. Qian, O.P. Singh

4.3.1. Introduction

National Meteorological and Hydrometeorological Services (NMHSs) have a special role to play in the mitigation of natural disasters by issuing early warnings of hazardous weather to enable government, the private sector and individuals to take actions to minimize risks or to avoid danger. The weather warning service that will safeguard life and property depends on an end-to-end forecasting system that commences with meteorological observations, then data communication, analysis, forecast preparation, and finally warning generation and dissemination. As “natural disasters” arise from the interaction of natural phenomena and human societies, NMHSs must deal with both the scientific and human aspects, in order to ensure that their warning service is effective.

According to WMO (2006), below are the characteristics of an effective warning issued by NHMSs:

- (i) Accurate – on the onset and intensity of the weather hazard, and the geographic area likely to be affected. It is also important to include discussion of the uncertainties so that the warning recipients will understand how to deal with the warnings effectively.
- (ii) Clear and understandable – about the expected phenomenon and the risks to person, community and property. This allows the community to respond in commensurate with the risk involved as the weather situation develops.
- (iii) Available to all – the warning must be disseminated to all affected, including those unable to receive television, radio or the Internet.
- (iv) Reliable and timely – so as to develop trust in the warnings from the users, who would then be prepared to act when a warning is issued.
- (v) Authoritative – the media and partners participating in addressing the hazard must not create or broadcast conflicting information.
- (vi) Collaborative – through development of strong partnerships with all levels of decision-makers involved in disaster prevention and mitigation.

In this report, a review of the scientific and technical advancements and challenges since IWTC-VI of the warning service are provided in the next section. Discussion on items (ii)-(iv) above, essentially about warning presentation and dissemination, are given in Sections 4.3.3 and 4.3.4 respectively. Sections 4.3.5 and 4.3.6 on preparedness and response process, continual improvement and inter-agency collaboration are then followed covering issues relating to items (v) and (vi). A summary of recommendations are given in the last section.

4.3.2. Science and technical issues

4.3.2.1 Tropical cyclone track forecasting

Tropical cyclone (TC) track forecasts have greatly improved in the past several years. Benefiting from the advances of numerical weather prediction and the multi-model consensus technique, reduction in the track forecast errors has been impressive. RSMC La Reunion saw a big step forward in their operational performances in 2006, when a spectacular gain exceeding 30% for forecasts beyond 48 hours was attained. Since then, the track errors have stabilized with a slight downward trend (Fig. 1).

The improvement in the track forecasting has led to the extension of La Reunion’s official forecasts out to 5 days starting from February 2010. Day 3 track forecasts are now better than were the day 2 forecasts before 2006 and the forecasts for day 5 are also better than were the forecasts for day 3 compared with four years ago.

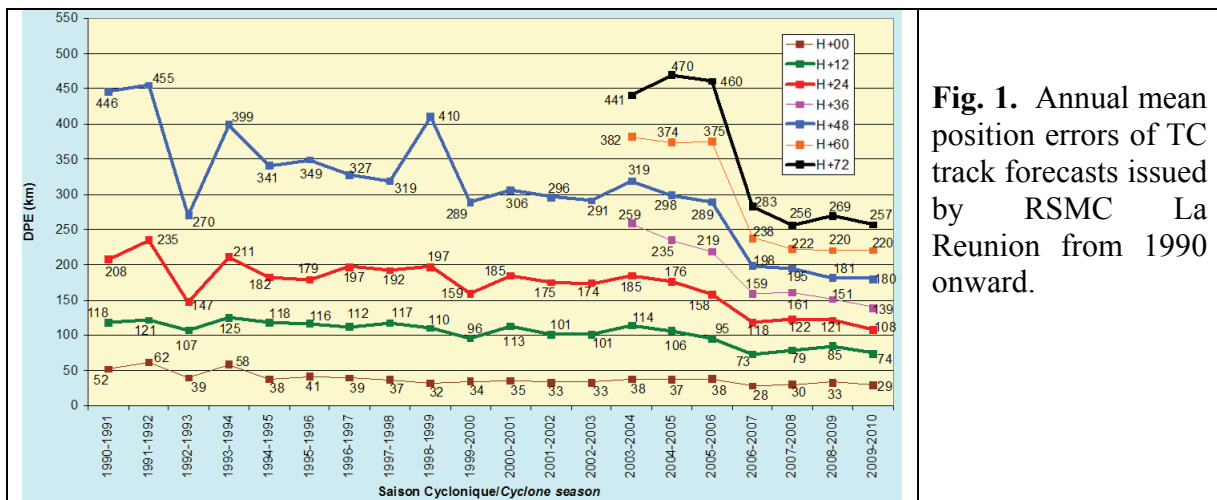


Fig. 1. Annual mean position errors of TC track forecasts issued by RSMC La Reunion from 1990 onward.

Similar enhancement was also implemented in other centres - RSMC Tokyo extended its TC track forecasts from 3 days to 5 days in April 2009. As a primary basis for TC track forecasting, JMA refers to the Global Spectral Model (GSM), the horizontal resolution of which was upgraded to approximately 20 km in November 2007, and also to the Typhoon Ensemble Prediction System (TEPS) which became operational in February 2008. The annual mean errors of 24-, 48-, 72-, 96-, and 120-hour forecasts of the TC centre position in 2009 were 122 km, 216 km, 312 km, 415 km and 528 km respectively.

China Meteorological Administration (CMA) also followed suit to extend its track forecast from 3 days to 5 days in 2010, based on one-year test in 2009. The annual mean errors of 24-, 48-, 72-, 96-, 120-h track forecast in 2009 were 119 km, 205 km, 299 km, 392 km and 514 km respectively.

Technological advancements over the past two decades have also enabled US National Weather Service (NWS) to make more accurate TC track forecasts, thus allowing the extension of watch and warning lead times. Due to the increasing time needed to evacuate many hurricane-prone coastal areas along the US Gulf Coast and Eastern Seaboard and requests from many emergency managers, the NWS has changed its Watch criterion from 36 hours to 48 hours and its Warning criterion from 24 hours to 36 hours starting from the hurricane season in 2010. These changes are effective for the areas of responsibility of the National Hurricane Center (NHC) in Miami and the Central Pacific Hurricane Center (CPHC) in Honolulu. The criteria for Watches and Warnings set by the Weather Forecast Office in Guam for the islands of Micronesia did not change, remaining at 24 hours for Warnings and 48 hours for Watches.

Despite the significant reduction in track forecast errors in recent years, we have not yet reached the point where this could result in a major change in the approach of decision making for emergency management and warning strategy. With the 24-h track forecast errors still above 100 km on average, the contingency of being hit or not hit by the core of a TC remains too uncertain to avoid taking preventive measures that may eventually turn out to be excessive or unnecessary. This is especially the case for small islands like La Reunion or the metropolitans like Hong Kong where the issue may amount to an “all or nothing” question when a midget TC passes nearby.

There still remain cases where large forecast errors sometimes occur, arising from, say almost likely alternative scenarios or from great uncertainty in the timing of sharp track change involving an interaction of the storm with a trough-ridge pair, with one of these centres of action finally winning the "steering contest". On some occasions, systematic biases are observed in all NWP models. For example, most models persistently predicted Typhoon Fengshen in 2008 would recurve early in its life cycle (Fig. 2). Yet very large right-of-track errors eventually developed which has led to PAGASA (the Philippine Atmospheric, Geophysical and Astronomical Services Administration) being sued over its forecasts by the owner of the MV Princess of Stars, which was capsized during the passage of Fengshen. The end-users of the warning really need to be educated on the predictability and informed of the uncertainty of a given situation.

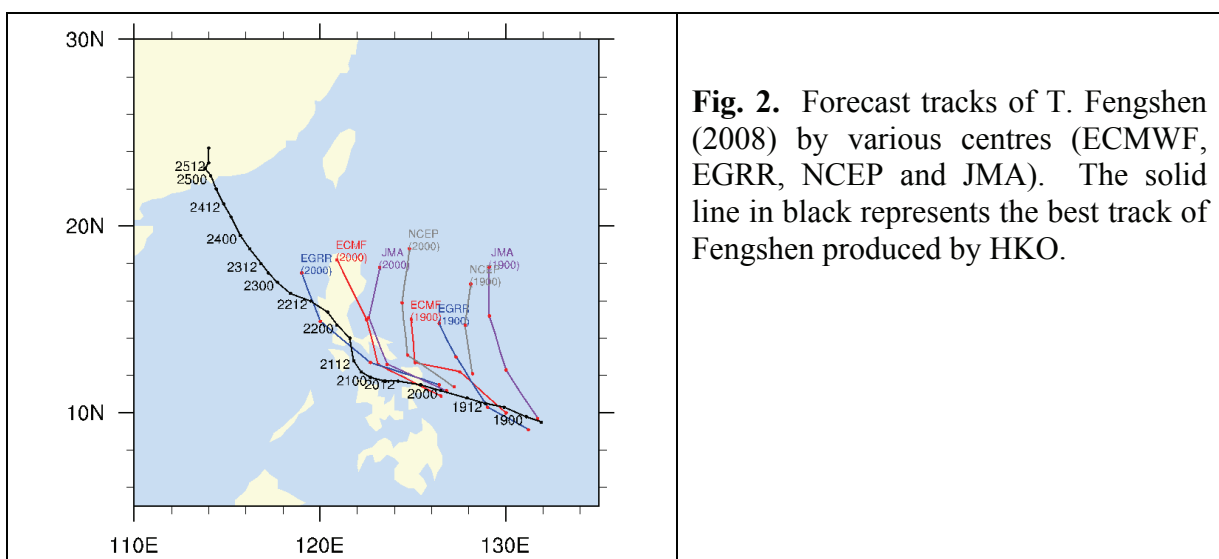
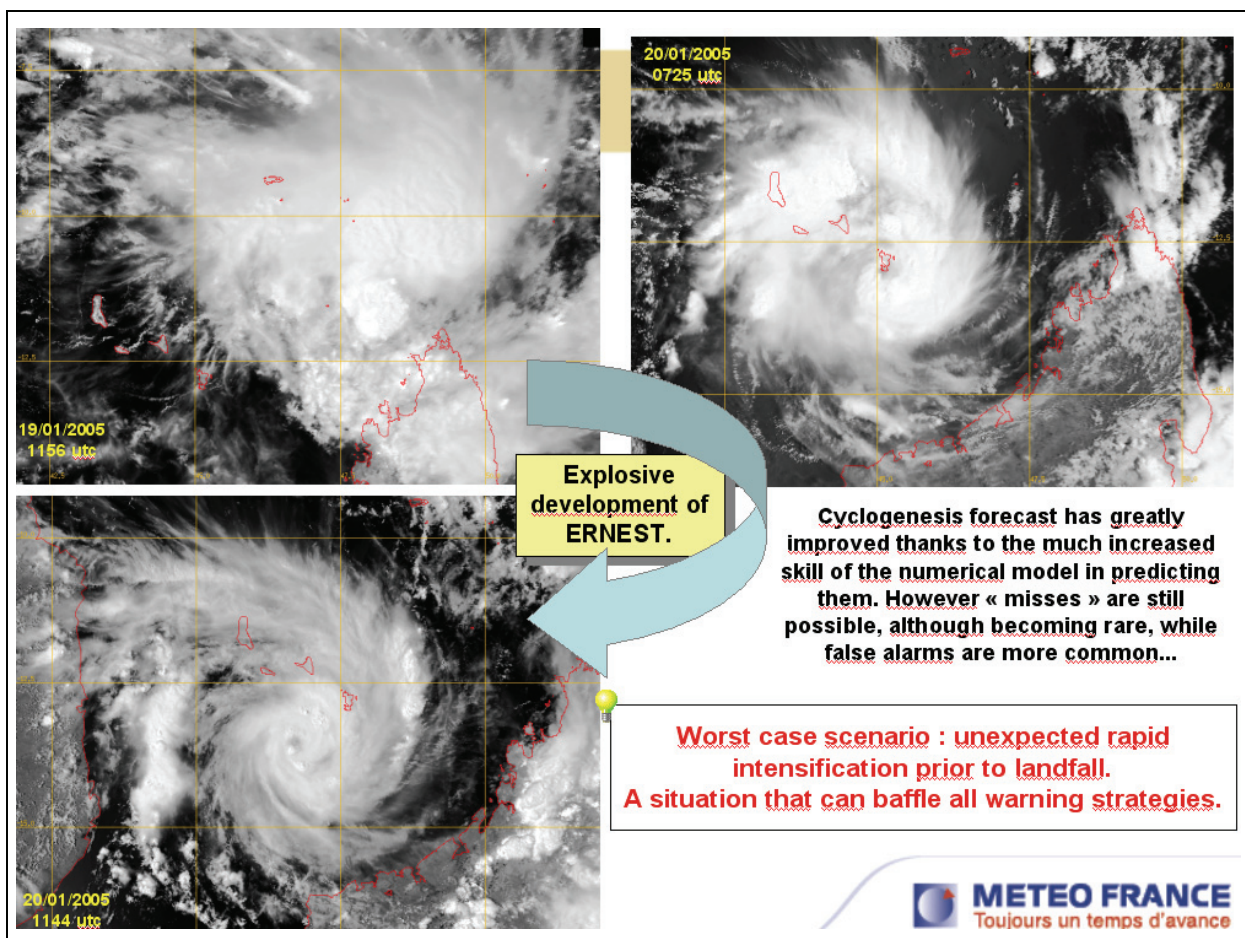


Fig. 2. Forecast tracks of T. Fengshen (2008) by various centres (ECMWF, EGRR, NCEP and JMA). The solid line in black represents the best track of Fengshen produced by HKO.

4.3.2.2 TC intensity forecasting

While track forecasts have improved, the main roadblock of TC forecasting remains with the lack of significant improvement in TC intensity and structure change forecast. Limiting factors for TC intensity forecasting include the lack of understanding of rapid changes in storm structure and intensity, routinely available in situ observations, and high-resolution coupled air-sea-land models (Chen et al., 2007). Although forecasters have now integrated some harbinger signals on the microwave imageries (structure of the convection and low-level circulation as seen on 36 or 37 GHz – see example in Fig. 3 of the early stage of development of TC Ernest as seen on microwave imageries) that may help anticipate a rapid intensification (RI) to come, this may often be at a rather short notice. A situation of RI can become really annoying or even critical when it occurs close to a populated area with the landfall happening soon after, since the lead time may then become too short for the issue of a proper warning to the public.



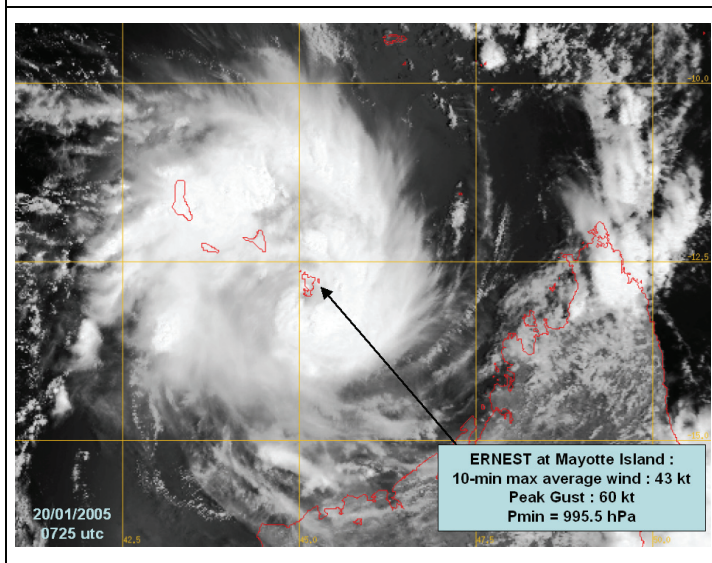
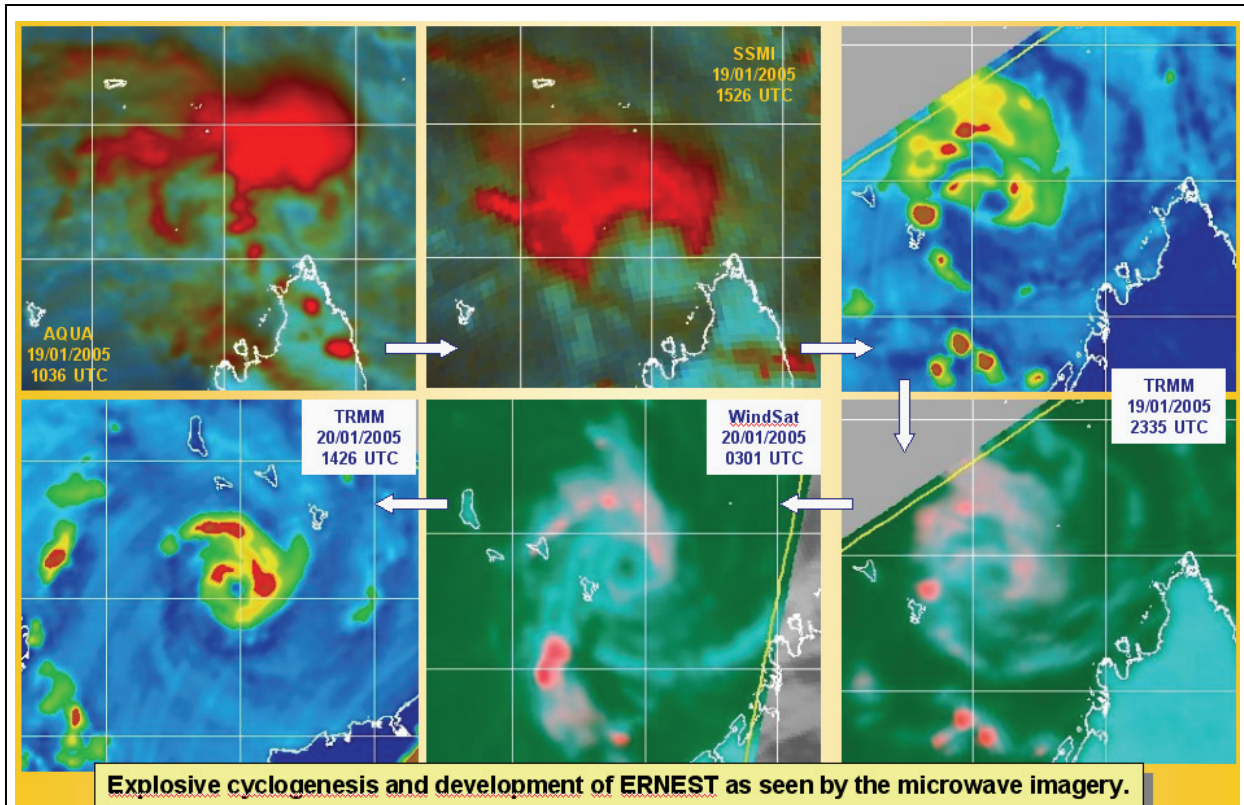


Fig.3. On 20 January 2005 Tropical Cyclone ERNEST developed very rapidly on the northern Mozambique Channel passing from 25 to 65 kt max 10-min average winds in 24 hours' time. This unexpected evolution (all numerical models had failed to predict this RI and even the genesis of this storm – some even hardly seeing a significant low) resulted in gale force winds affecting Mayotte Island (easternmost island of the Comoros Archipelago). As a result no warning had been issued for the island. But would have the island been situated 150 km to the southwest it would have been hit by a stronger storm and would have undergone gusts over 150 km/h by the end of the afternoon. In that situation the 1st warning would have been issued only 8 hours prior to the occurrence of such cyclonic conditions – too short for activating the warning process.

The shortcomings in intensity forecasting skill also result in a limitation to the gains that can be reaped from an excellent track forecast. For instance, if a tropical depression is heading towards La Reunion, the fact of having a great confidence in the track forecast would not really help if there is a great uncertainty in the intensity forecast, which will probably force RSMC La Reunion to overestimate the real threat for the island at 24- or 48-h range to avoid falling in the situation of having the population under-warned in the case of unexpected intensification during the final phase of the approach of the storm.

Similar problem occurred last year (2009) in Vietnam. The forecast issued by the Joint Typhoon Warning Center (JTWC) for Tropical Storm Parma at 0600UTC, 13 October 2009 suggested that the peak gusts were 45 knots. At 0730UTC on 13 October 2009, the station at

Bach Long Vi of Vietnam reported mean winds of 80 knots and gusts to 105 knots. Perhaps the best strategy here where there is so much uncertainty in how much the system will re-intensify on entering the Gulf of Tonkin would be to frame the warning so as to force fishing boats back to land immediately.

By the same token, TC genesis forecast still poses a big challenge to TC forecasters, especially in the South China Sea. CMA makes continual efforts to obtain objective forecasts for TC genesis based on the statistical and dynamical methods. In Vietnam, the forecasters especially concerns not only about significant TCs, but also tropical depression that formed near the coastline. According to the past records, tropical depressions could cause as much rainfall as significant TCs, even for a longer period of time.

4.3.2.2 TC analysis

The system as shown in Fig. 4 below was considered a tropical low below TC intensity until the observation of 65 knots sustained wind from Willis Island was received. It makes people wonder how many of these sheared type systems are more intense than they think. It illustrates the necessity of more frequent observation platforms like ASCAT and QuikSCAT rather than relying completely on Dvorak cloud top analyses.

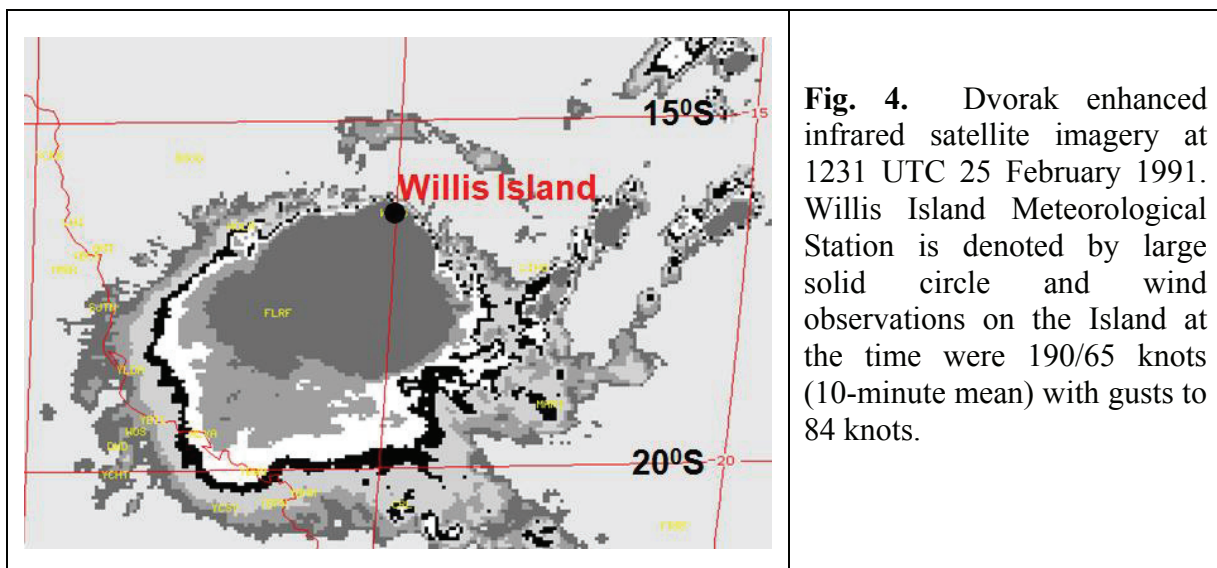
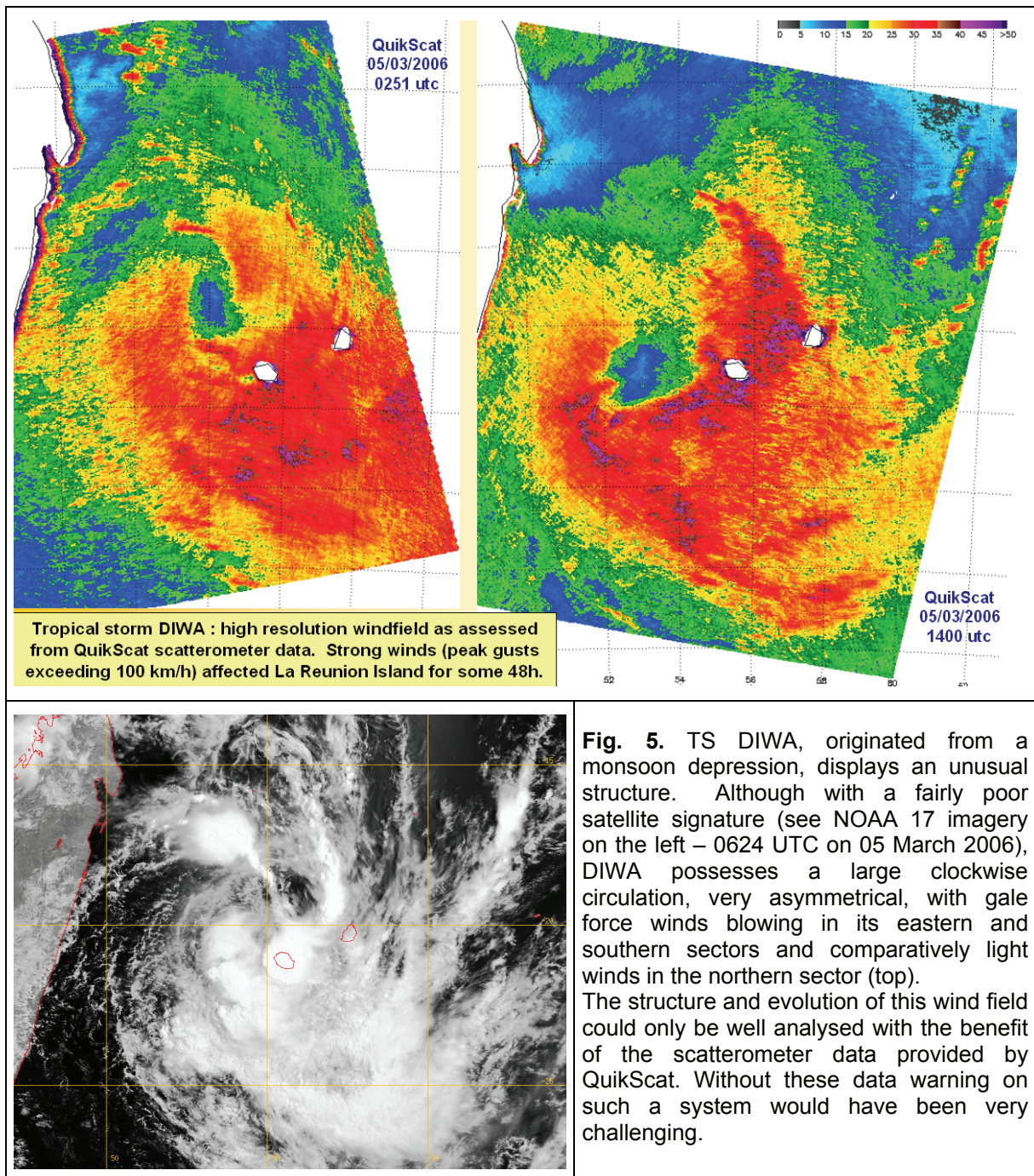


Fig. 4. Dvorak enhanced infrared satellite imagery at 1231 UTC 25 February 1991. Willis Island Meteorological Station is denoted by large solid circle and wind observations on the Island at the time were 190/65 knots (10-minute mean) with gusts to 84 knots.

There were active discussions on the Tropical Storms Group (<http://www.tstorms.org/tropical-storms/>) about the satellite intensity estimates for Tropical Cyclone Phet in the Northern Indian Ocean in June 2010. In particular, at one moment an interesting spread in the operational and objective satellite estimates for Phet with the maximum wind varying from 85 knots to 127 knots was noted. Along with this widespread uncertainty in the use of the Dvorak method, some particular cyclones do not lend themselves to accurate intensity estimates from the method. Validation studies on various satellite estimates would definitely help the forecasters in the region to make better use of the tools in operation.

While the common belief is that NWP will continue to improve and so will the TC forecasts, it is questionable whether the observations critical for the analysis and indirectly for the NWP through assimilation would keep on increasing in terms of quantity as well as quality. Some indeed do fear that the satellite "golden era" has ended and that due to budget constraints the future satellite coverage may not be as rich as it has been in 2008 or 2009.

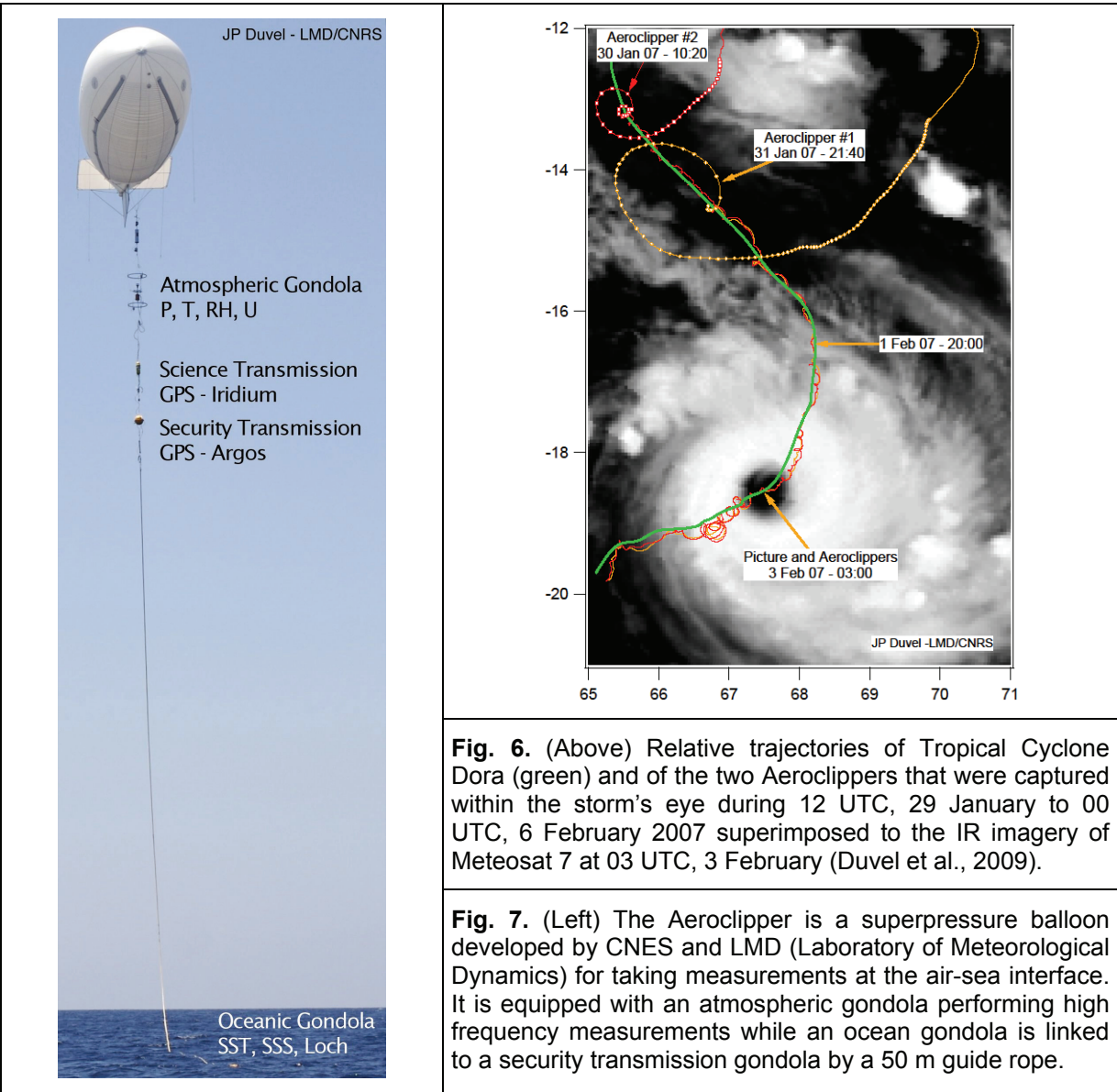
In recent years the TC community had to make a very active lobbying to "save" the TRMM satellite from deorbitation and we have already seen the loss of the scatterometer QuikScat data in late 2009 resulting in the degradation in the quality of the assessment of the TC wind field. There is a case in the South-West Indian Ocean (SWIO) region of a monsoon depression which developed into Tropical Storm Diwa in March 2006. The structure of the wind field of Diwa was so atypical that without the crucial assistance of QuikScat it would have virtually been impossible to make a correct assessment and consequently to make a good forecast of the gales that affected La Reunion Island for several days.



It is our belief that observations remain the key to effective TC analysis and warnings and that the ability to maintain a perennial satellite coverage of high quality is the greatest challenge for the coming years. Meteo-France has made a lot of lobbying to ensure that the microwave data from the Megha-Tropiques satellite, due to be launched in early 2011, will be

available in near-real time to the operational TC community (prospects look good with advanced contacts between CNES – the French spatial agency – and EUMESAT but still not completely guaranteed yet).

Meanwhile, new sensors and technologies are emerging which will increase our observing capabilities. While the deployment of unmanned vehicles to make air reconnaissance is still to be realized, a new promising device called Aeroclipper fortuitously revealed as a serious candidate to become the first tool being able to continuously conduct in situ monitoring of the intensity of a TC. The Aeroclipper is a streamlined balloon maintained in the surface layer by a guide rope dragging on the ocean surface. During the VASCO (Validation of the Aeroclipper System under Convective Occurrences) experiments operated in the SWIO in January and February 2007, eight Aeroclipper prototypes were launched from Mahé Island, Seychelles. Two of them were accidentally captured by the circulation of Tropical Cyclone Dora and drifted towards the centre of the storm, and survived the hurricane force winds when crossing the eyewall. The two Aeroclippers stayed within Dora’s eye for more than a week and thereafter near the low centre following the transition of the storm into an extratropical depression (Duvel et al., 2009).



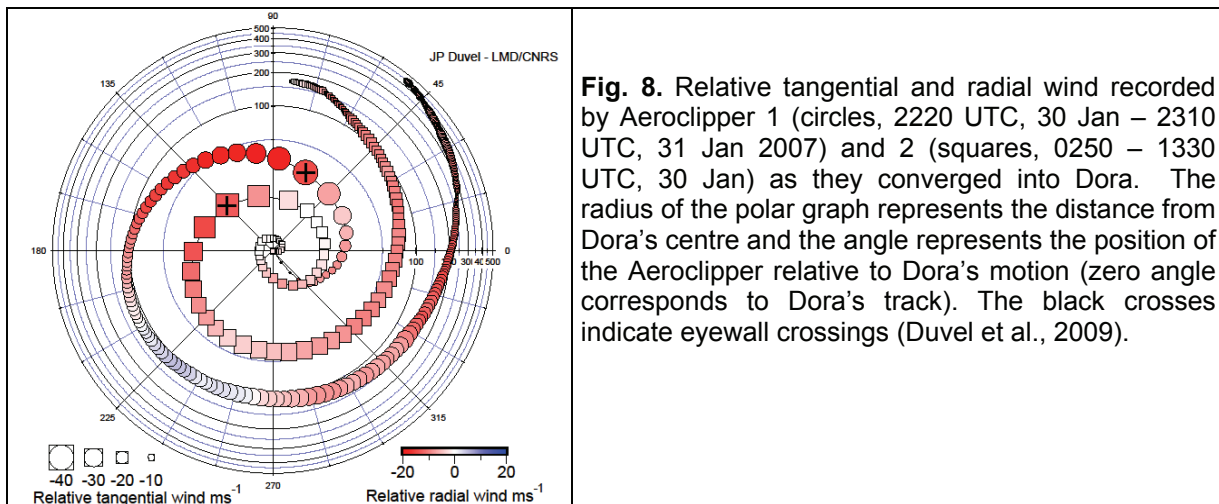


Fig. 8. Relative tangential and radial wind recorded by Aeroclipper 1 (circles, 2220 UTC, 30 Jan – 2310 UTC, 31 Jan 2007) and 2 (squares, 0250 – 1330 UTC, 30 Jan) as they converged into Dora. The radius of the polar graph represents the distance from Dora's centre and the angle represents the position of the Aeroclipper relative to Dora's motion (zero angle corresponds to Dora's track). The black crosses indicate eyewall crossings (Duvel et al., 2009).

4.3.3. Warning presentation

4.3.3.1 Forms of presentation

In transforming weather forecasts into warnings, it is essential that the warning messages should be clear and understandable, so that the warning recipients know how to incorporate the information into their decision-making process, and most importantly, be prepared to take appropriate actions. The warning messages should be developed best suited to the strength of the dissemination channels and the level of target warning recipients to enable effective communication of the warnings.

The broadband capacity of the Internet allows detailed information such as real-time observation data, radar and satellite imageries, predicted TC tracks, etc. to be made available to the public. This would enable the sophisticated users to assess for themselves the risk associated with their particular circumstances and to devise response actions accordingly.

A lot of work has recently been done by RSMC La Reunion to design a new specialized website in order to provide the best access to the Centre's products (both real-time and archives) and to relevant information such as satellite imageries and NWP outputs by the users. This bilingual (French and English) site, which includes GIS-related facilities for "dynamical" visualization of maps of tracks and related data such as wind radii, has been opened in April 2010.

The NHC issues TC watches and warnings in both textual and graphical advisory products. TC watches and warnings for the United States are issued in a coded text product called the Tropical Cyclone Watch Warning Product (TCV). This product summarizes all new, continued, and cancelled TC watches and warnings for the United States in a coded format that is used by computer plotting programs. Areas under a TC watch or warning in the United States are defined using a list of well-known, recognizable geographical locations along the coast. The NHC also provides a summary of all coastal TC watches and warnings in effect in the TC Public Advisory and Forecast/Advisory. These are text products that include TC forecast information. The NHC also graphically depicts the watch and warning areas for the United States and foreign countries on the TC Track Forecast Cone and Watch/Warning Graphic (Fig. 9) and the Initial Wind Field Graphic. Besides, NHC provides watch/warning information in GIS format with each forecast advisory.

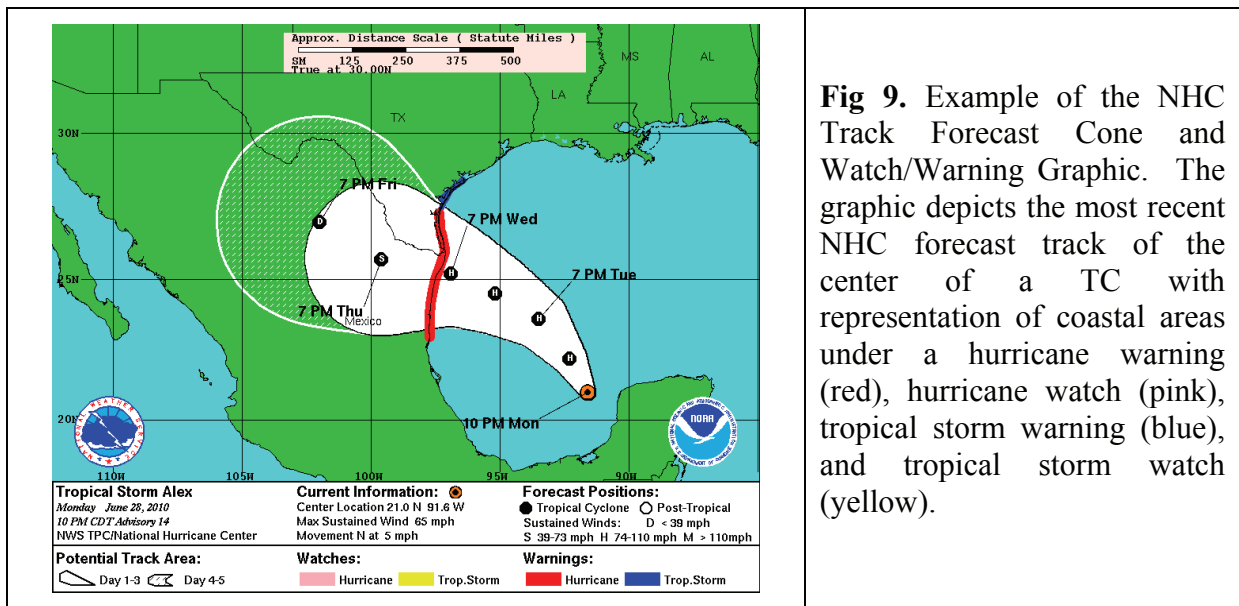


Fig 9. Example of the NHC Track Forecast Cone and Watch/Warning Graphic. The graphic depicts the most recent NHC forecast track of the center of a TC with representation of coastal areas under a hurricane warning (red), hurricane watch (pink), tropical storm warning (blue), and tropical storm watch (yellow).

CMA labels 24-h and 48-h warning zones within its responsible area. Normally CMA issues TC track forecast 4 times a day at 00, 06, 12, 18 UTC. When TC enters the 48-h warning zone, CMA provides additional 4 times forecast at 03, 09, 15, 21 UTC. With TC further approaching the mainland and entering the 24-h warning zone, CMA issues TC position and intensity every hour to the meteorological communities and public in a variety of ways.

Bulletins of TC advisories are issued by RSMC Tokyo in text and CREX, the table driven codes introduced by WMO to replace the various alphanumeric codes. Those in Extensible Markup Language (XML) format, an Internet-based language format which facilitates the exchange of data between incompatible systems and applications, will be disseminated to domestic users in 2011.

4.3.3.2 Communicating forecast uncertainties

As weather forecasting involves an element of probability, it is important that the forecast information provided to emergency services and government decision makers includes discussion of any uncertainties, so that they will understand how to deal with them effectively.

With increased skill and confidence in the forecast tracks of TC there are now situations where we can make the “economy” of a warning, e.g. a warning not be issued while it would have been issued a few years ago. Having now a much better objective idea of the degree of uncertainty of the forecast also helps a lot to take decisions and to convey the degree of confidence of the forecast to the users and decision makers.

In 2007, based on the past 5-year mean track forecast errors, CMA introduced 70% probability circle in their official TC track forecasts. In Hong Kong, uncertainty circles are also presented, the radii of which represent the historical errors of the respective forecast range.

Instead of referring to simple climatological uncertainties, RSMC La Reunion is working on a dynamical approach to convey track forecast uncertainty based on the outputs of the ensemble prediction systems (EPS). The tests using ECMWF EPS data have revealed that the uncertainty of the spread of the ensemble (with 50 members) contains skilful information

on the uncertainty in the track forecast at least up to the 72-h range. Plan is underway at La Reunion to produce the EPS-based dynamical cones of uncertainty with radii of the 75% probability circles and include them in the operational products on the centre's website by the end of 2010.

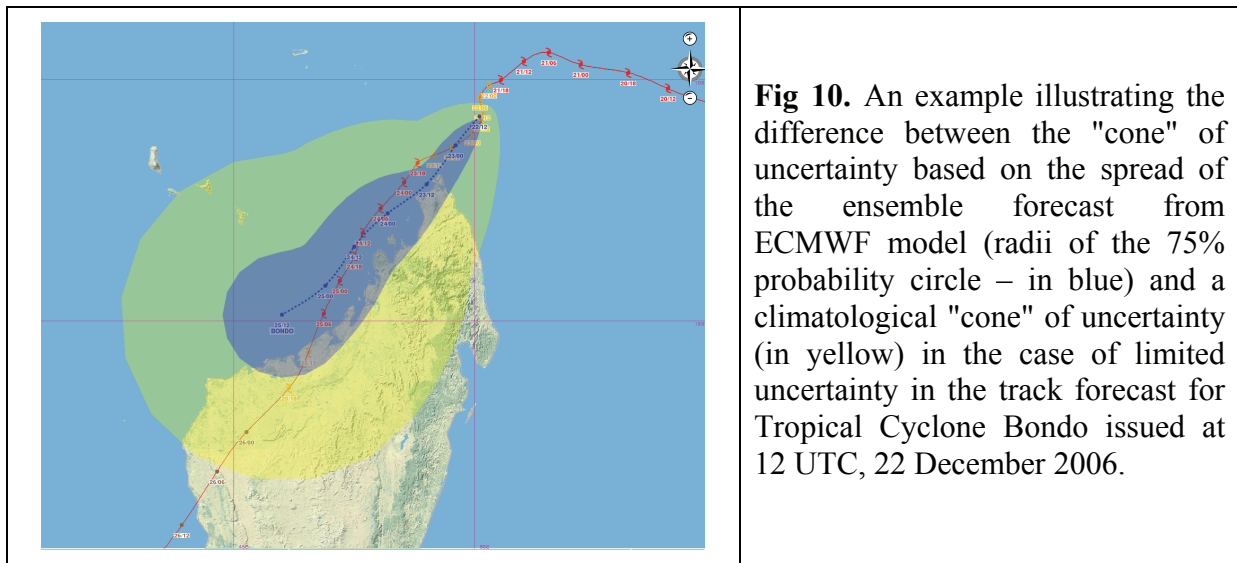


Fig 10. An example illustrating the difference between the "cone" of uncertainty based on the spread of the ensemble forecast from ECMWF model (radii of the 75% probability circle – in blue) and a climatological "cone" of uncertainty (in yellow) in the case of limited uncertainty in the track forecast for Tropical Cyclone Bondo issued at 12 UTC, 22 December 2006.

RSMC Tokyo also issues radii of the 70% probability circles of four and five-day track forecasts determined using the degree of forecast uncertainty derived from the ensemble spread of the JMA's TEPS.

In US, when issuing TC watches and warnings, the NHC forecasters take into account the uncertainties in the track, size, and intensity forecasts. Typically, the NHC forecasters determine the watch or warning area by adding the 5-year mean track forecast error to the deterministic forecast track, after accounting for the forecast size of the wind field. Uncertainties of the timing of the arrival of tropical-storm-force winds, and size and intensity of the TC are also considered when determining the type of watch or warning (tropical storm vs. hurricane) and the area to be placed under a TC watch or warning. Figure 11 illustrates how track uncertainty is incorporated when determining coastal watch and warning areas.

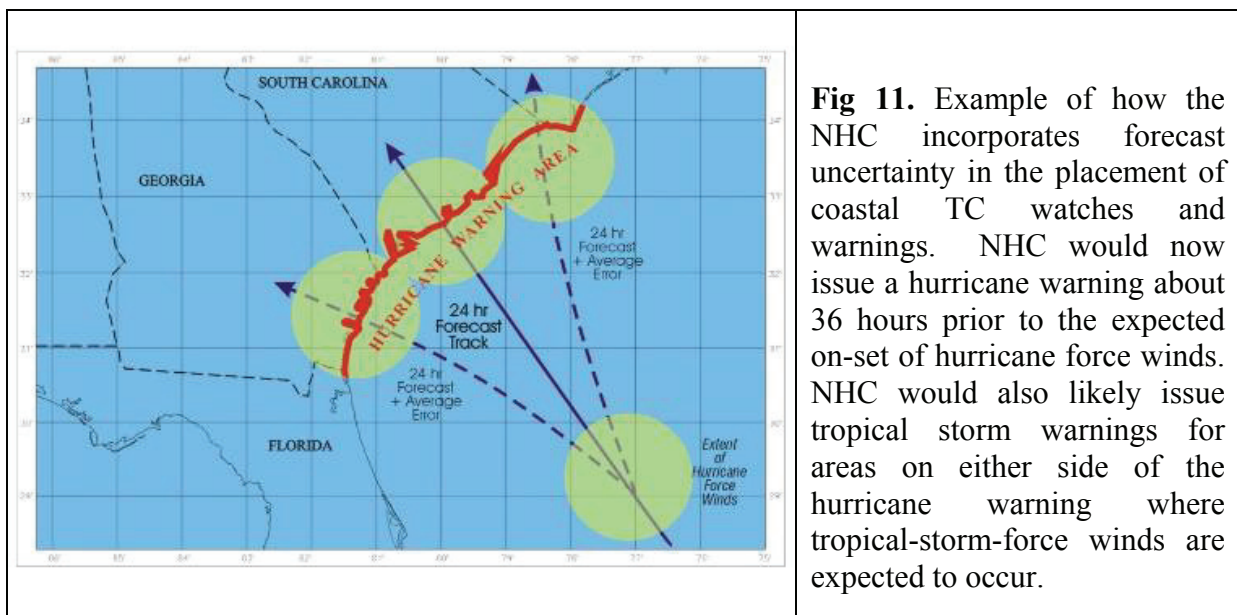


Fig 11. Example of how the NHC incorporates forecast uncertainty in the placement of coastal TC watches and warnings. NHC would now issue a hurricane warning about 36 hours prior to the expected on-set of hurricane force winds. NHC would also likely issue tropical storm warnings for areas on either side of the hurricane warning where tropical-storm-force winds are expected to occur.

NHC also communicates forecast uncertainty by issuing text and graphic wind speed probability products. These products show the chance of 34-, 50-, and 64-kt or greater winds occurring at individual locations during the 5-day forecast period (Fig. 12). The probabilities are calculated using a set of 1000 realizations, or alternate tracks and intensities, that vary around the official forecast based on a Monte Carlo sampling of the previous 5-year errors in NHC track and intensity forecasts (DeMaria et al., 2009). Figure 12 shows an example of the hurricane-force-wind probabilities when a hurricane warning was issued for south Texas and northeastern Mexico for Tropical Storm Alex in June 2010. As indicated by the product, the highest probability of hurricane-force-winds at any individual location within the warning area was about 18% (at Brownsville, Texas, located near the Mexico-U.S. border). This example illustrates how emergency planners often deal with small probabilities of hurricane force winds when making evacuation decisions.

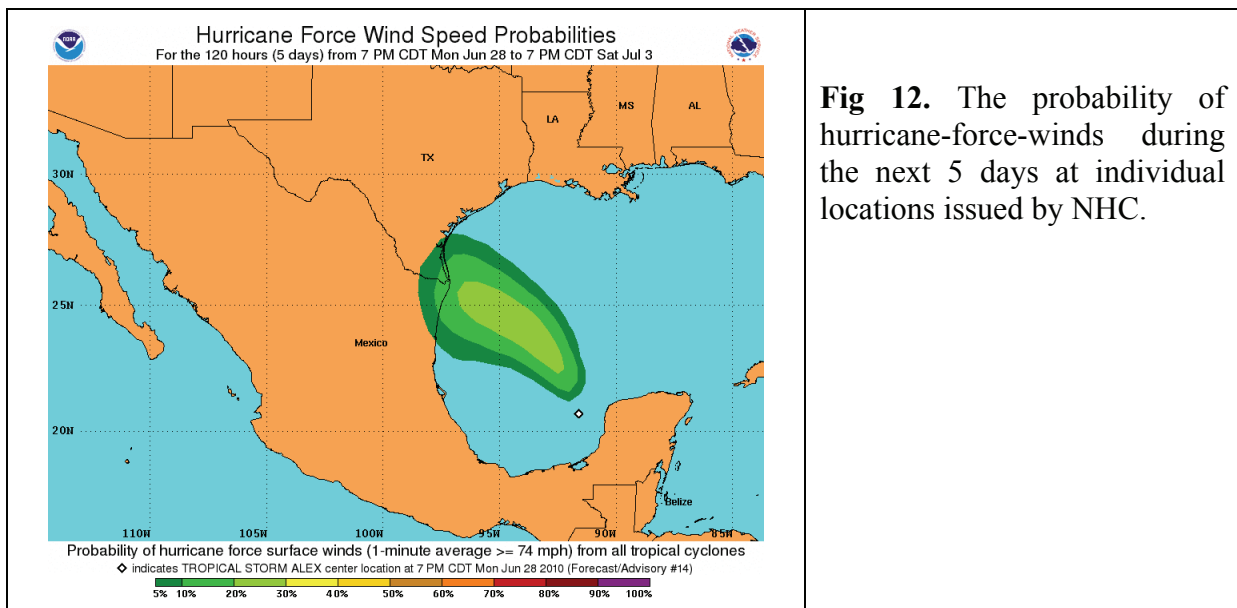


Fig 12. The probability of hurricane-force-winds during the next 5 days at individual locations issued by NHC.

4.3.3.3 From weather prediction to weather impacts prediction (National Research Council, 2010)

The atmospheric community has been spending a lot of efforts to improve the accuracy and resolution of the atmospheric quantities predicted by NWP models, such as temperature, wind and precipitation. Users have largely taken these weather predictions and used them in their own decision support and risk management process. However, this approach has not always produced the desired outcome, especially when complex weather forecasts are difficult to understand and yet require public action in response to the forecast. For instance, probabilistic forecasts of a landfalling hurricane’s track and intensity, without specific impact information such as timing and location of storm surge, extent of flooding, extreme winds, and power outages, are insufficient for effective responses from emergency managers.

A new paradigm is for both the scientists and the end-users to work together to provide explicit weather impact forecasts and warnings. This transition from simple weather prediction to weather impacts prediction demands a full integration of the physical sciences with the socioeconomic sciences. One key component of the prediction of impacts is to more fully exploit the capabilities of ensemble modelling to produce probabilistic forecasts of

atmospheric quantities, and for these to then be used to generate probabilistic forecasts of the weather impacts, thereby enabled improved decision making.

Fig. 13 shows an example comparing traditional portrayals of weather forecasting, and the potential for impacts forecasting. The weather services should place priority on providing not only improved weather forecasts but also explicit impact forecasts.

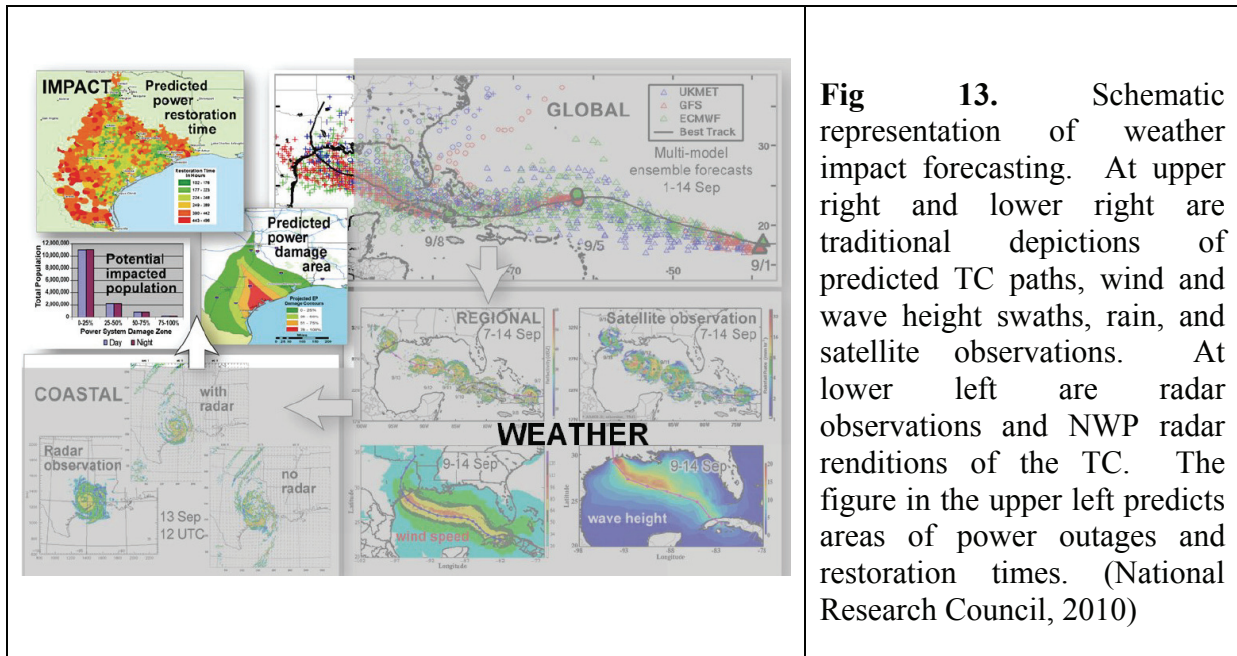


Fig 13. Schematic representation of weather impact forecasting. At upper right and lower right are traditional depictions of predicted TC paths, wind and wave height swaths, rain, and satellite observations. At lower left are radar observations and NWP radar renditions of the TC. The figure in the upper left predicts areas of power outages and restoration times. (National Research Council, 2010)

4.3.4. Warning dissemination

4.3.4.1 Various modes of warning dissemination

Timely delivery of warnings to the public is essential for disaster preparedness and mitigation. In India and Vietnam, like most other countries, the TC warnings are disseminated to users through telephone, fax, email and GTS. These warnings/advisories are also put on the website of the Hydro-Meteorological Service of Vietnam (VHMS, www.nchmf.gov.vn) and the Indian Meteorological Department (IMD, www.imd.gov.in). Another means to transmit warning is through the Voice of Vietnam (VOV) channel. During TCs, VHMS staff will attend live interviews on VOV to explain to the public the latest weather situation. This kind of warning dissemination is one of the fastest and most direct ways to reach the public. At IMD, one other effective mode of warning transmission is via IVRS (Interactive Voice Response system). The requests for weather information and forecasts from the general public are automatically answered by this system. Besides, high speed data terminals (HSDT), installed across the whole country, are capable of sending short warning messages as SMS and the whole warning message as email.

Coastal TC watches and warnings issued by the NHC are officially disseminated via the NOAA Weather Wire. Watch/warning information is also available on the NHC Internet website and email. While email is not the official NHC mechanism for warning dissemination, this delivery option has become quite effective for NHC users. External partners such as the media and emergency managers play a critical role in the dissemination process by relaying watch/warning information to the general public. During hurricane

threats, NHC typically makes spokesperson, usually the NHC Director, Deputy Director, Hurricane Specialist Unit Branch Chief, or one of the Hurricane Specialists, available to the media. When hurricane watches or warnings are in effect for the United States, NHC activates a media pool, which allows local and national media to schedule short windows of time to interview the spokesperson. NHC also activates a Hurricane Liaison Team (HLT) to assist in the communication of information with federal and state emergency responders. The HLT is led by the U.S. Federal Emergency Management Agency and is staffed by emergency managers and meteorologists from outside the affected region. Informational briefings, typically led by the NHC Director or Deputy Director, are provided to federal and state emergency managers through the HLT when it is activated.

The channels through which the warnings are relayed to the public have indeed, undergone evolution, in response to user needs and taking advantage of the advancement of communication technology. The trend of utilization of various channels in the past decade, as revealed by user surveys conducted by HKO, whereby members of the public obtain weather information, is given in Fig. 14. Television and radio remain the most popular means. This is followed by the HKO web site.

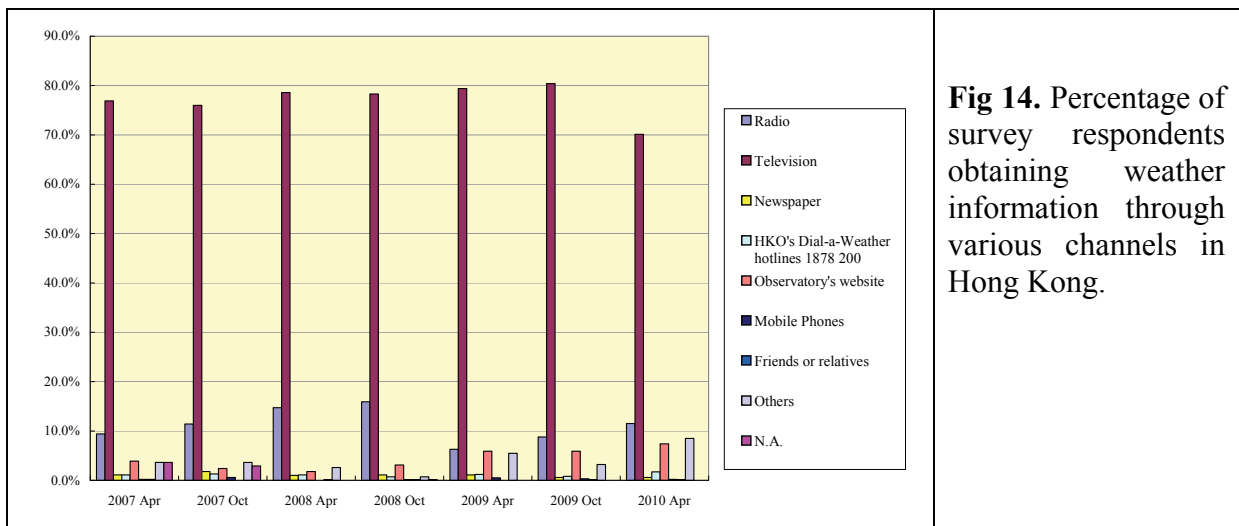


Fig 14. Percentage of survey respondents obtaining weather information through various channels in Hong Kong.

The warning recipients span a wide spectrum, ranging from the little-educated and the under-privileged to sophisticated users capable of assimilating large amount of information themselves. As shown in Fig. 15, the rapid rise in internet usage has not diminished the use of telephone calls to get weather information. It illustrates very well the persistent needs of a sector of the community which still relies on simple, cheap technology to access weather information or warnings. While adding advanced technology into their operation, NMHSs should not forget the former category of recipients, otherwise, the most vulnerable sector of the community would be left out in the disaster mitigation effort.

In addition to a ‘pull’, the Internet also allows an information ‘push’ to the user. It also makes individual alerting and customization possible. A case in point is the provision of lightning location information by HKO on the Internet. Here a user may pick his/her location of interest and choose the alert range circles for receiving distinct audio and/or visual alarms when lightning occurs within a particular alert range. Coupled with geographic information, user-specific alerts thus set up provide fast and very relevant information, which is conducive to prompt and effective response actions.

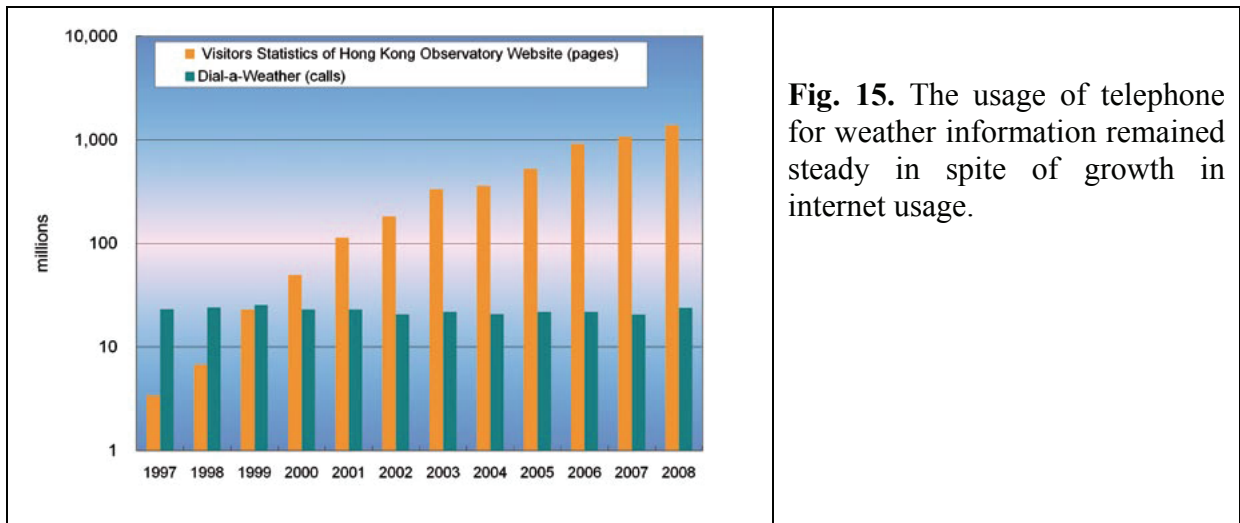


Fig. 15. The usage of telephone for weather information remained steady in spite of growth in internet usage.

In order to make available severe weather warnings to members of the local community as well as to any interested individuals anywhere on the globe, the HKO has developed a web-based weather wizard program. This program is available on the HKO web site for download by users. The program will enable a weather warning to be displayed automatically on the ‘Taskbar’ at the bottom of the user computer, whenever a warning is issued. A dialogue box will pop up with audio alarm to alert the user when there is any change in warning status. The same methodology is being applied in SWidget (<http://severe.worldweather.wmo.int/swidget/swidget.html>) hosted on the Severe Weather Information Centre (see Section 4.3.6 for more details about SWIC) web site for dissemination of warnings by participating Typhoon Committee members. SWidget is a widget which allows users to choose and obtain readily near real-time local severe weather warnings in different regions issued by official weather services. Users can select region/city/warning according to their preference. A dialog box will pop up with an audio alarm on the user's personal computer when there is a change of warning status issued by the selected official weather services. At present, warnings from three regions, namely, Hong Kong, China; Macao, China and Guam, U.S.A, are available in the beta version. Other official weather services will be invited to participate and provide their local severe weather warnings.

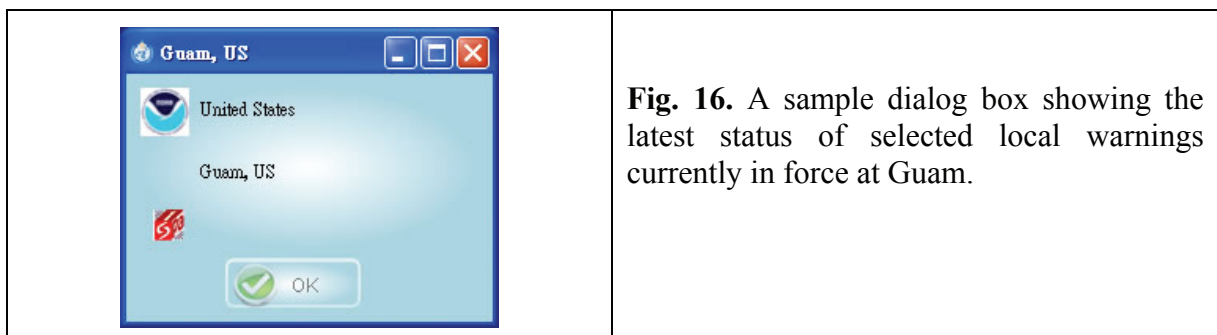


Fig. 16. A sample dialog box showing the latest status of selected local warnings currently in force at Guam.

Mobile technology in the past decade has been used for timely delivery of weather warnings and information to people on the move. A number of official weather services are now using short message service (SMS) to deliver weather warnings to special users. The messages are

particularly suited for warning of rapidly developing hazards such as thunderstorms and flash floods.

The HKO recently has also started exploring social networking services for warning dissemination. The Twitter service in both PC and mobile setup (Fig. 17) is being tried out. Weather warning, in the form of a ‘Tweet’, will be published on the Observatory’s Twitter profile and spread to all users. Tweets are text-based messages of up to 140 characters, which are suitable for conveying simple warning messages, in a one-way broadcast mode. The advantage of using Twitter is that it is relatively inexpensive to implement and maintain. The drawback is that the dissemination relies on the proper functioning of the Twitter service. At present, many international and national weather organizations are using Twitter for information dissemination. Examples are: WMO (<http://twitter.com/WMOnews>), ICAO (<http://twitter.com/icaoqh>), UK Met Office (<http://twitter.com/metoffice>) and NOAA (<http://twitter.com/usnoaagov>).



Fig. 17. Warning message issued via Twitter.

4.3.4.2 Warnings to the last mile

The warning messages must be disseminated to all affected persons and groups, including those unable to receive television, radio or the Internet. This entails the operation of a robust warning dissemination system which could withstand the furious onslaught of TCs and deliver the warning messages through to the ‘last mile’.

Currently, three satellite-based data broadcast systems, namely PCVSAT, DVB-S, FENGYUNCast are operated by CMA for distribution of meteorological data as well as weather warnings. FENGYUNCast uses AsiaSat-4’s C-band transponder to cover Asia and part of the western South Pacific region. PCVSAT and DVB-S uses AsiaSat-5’s Ku-band transponder to cover China and the surrounding areas. FENGYUNCast is also the regional GEONETCast Network Centre (GNC) of Asia. At the end of 2010, CMA will combine the 3 systems into one, known as CMACast, and conduct data transmission based on DVB-S2 (second-generation Digital Video Broadcast) technology using a C-band transponder on AsiaSat-4. The advantages of C-band transmission are its bigger footprint, high bandwidth, and less likely to be affected by severe weather.

For quick dissemination of warning against impending disaster from approaching cyclones, IMD has installed specially designed receivers within the vulnerable coastal areas for transmission of warnings to the concerned officials and people using broadcast capacity of INSAT satellite. This is a direct broadcast service of cyclone warnings in the regional languages meant for the areas affected or likely to be affected by the cyclone. There are 352 Cyclone Warning Dissemination System (CWDS) stations along the Indian coast; out of these 101 digital CWDS are located along Andhra coast. The warning bulletins are generated and transmitted every hour via the INSAT in C-band. The warning distribution is selective and will be received only by the affected or likely to be affected stations. It is a very useful system which has saved millions of lives and enormous amount of property from the fury of cyclones.



EMWIN (Emergency Managers Weather Information Network) and RANET (Radio InterNET) are two communications programs that have had a great impact on advancing the warning capabilities and strategies of many developing countries, especially in the Pacific basin. EMWIN has been discussed at many WMO conferences and workshops, and RANET was discussed in some detail at the International Workshop on Tropical Cyclones (IWTC)-VI in San Jose, Costa Rica by Anderson-Berry (WMO, 2007). Since IWTC-VI, several new capabilities have come on-line or are being tested.

EMWIN has been in use for nearly two decades in the US and for over a decade in the Pacific basin as a low-cost method for passing weather and warning information to emergency managers, weather service offices, and other critical locations such as hospitals and college campuses (<http://www.nws.noaa.gov/emwin/>). In some cases, EMWIN has been used as a backup system, but for many developing island nations, it has been the primary or only source of reliable weather information. GOES satellites that no longer provide meteorological data but that still have communications capability are sometimes repositioned near the International Date Line to support EMWIN and another US communications program called the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) (<http://www.peacesat.hawaii.edu/>). This program transmits, via satellite from the University of Hawaii and via satellite and HF Radio from the University of Guam, important distance education programs and critical storm and warning information to many isolated islands in the Pacific basin. The program also coordinates search and rescue in the Micronesian islands and passes daily weather information to the remote islands. Occasionally, the operator at the PEACESAT terminal at the University of Guam will call forecasters at the Weather Forecast Office on Guam (WFO Guam) and request them to provide a live, real-time assessment of upcoming weather. In the US, EMWIN has been using the digital Low Rate Information Transmission (LRIT) standard in areas covered by GOES-East and GOES-West. LRIT and EMWIN are now being made available in other parts of the Pacific not in the footprint of the operational GOES-West satellite (<http://noaasis.noaa.gov/LRIT/>). A High Rate Information Transmission (HRIT) capability is being developed for US users in the future (http://www.goes-r.gov/hrif_emwin/index.html). This capability will combine the current LRIT broadcast services with the EMWIN broadcast services and transmit both at a significantly higher data transfer rate.

The purpose of RANET (<http://beetle.ranet.mobi/>) (Clarke et al, 2010) is to get important information about TCs and other hazards down to the community level. Over the years, RANET has taken on many forms, especially in terms of the types of hardware and communications methods used. In the western Pacific, two new uses of RANET are highlighted. The first is the installation of FM radio stations in some island weather facilities,

allowing them to pass critical weather and warning information from the weather service office directly to the community level. The second is the development of the “Chatty Beetle” (<http://beetle.ranet.mobi/>), a durable, low-power, easy-to-maintain, two-way communications device designed to get emergency warning information down to the most isolated locations, such as remote atolls and islets. Both of these systems have proved to be very useful, and could be used in many other locations.

In July and August 2008, Mr. Bruce Best of the University of Guam and his team installed an 80-foot FM radio transmitting tower and an FM transmission and recording console at the Weather Service Office (WSO) in Chuuk State, Federated States of Micronesia (FSM) (Best and Marquez, 2008). There was no reliable radio station in Chuuk State, and the island State is very vulnerable to numerous natural hazards such as typhoons, flash floods, mudslides, droughts and high surf events. An FM Radio solution was ascertained as the most economical way to pass critical weather information and warnings to the 40,000+ residents living on islands in the Chuuk Lagoon. Special radios, such as the VHF radios that are required with the US NOAA Weather Radio program, are not needed. In fact, simple transistor radios, car radios and “boom boxes” can be used by residents to get the weather and warning information. A repeater was later installed to extend the range and coverage of the signal to more locations in the lagoon. In 2009, a similar FM radio station was installed in Majuro, Republic of the Marshall Islands (RMI). Since there is reliable radio service there, the FM station is used in times of emergency rather than routinely. A repeater is planned to push the signal to the neighbouring atoll of Arno in the RMI. This FM radio concept is an inexpensive, highly reliable, and relatively simple method to pass critical and routine weather information to the public. It could be considered as a potential solution for developing countries with communications challenges, especially those oceanic nations with small islands in close proximity or inside lagoons.

	<p>Fig. 18(a). Wantok FM radio Station similar to the one installed at the Weather Service Office in Chuuk Lagoon.</p>
	<p>Fig. 18(b). The “Chatty Beetle”.</p>

On 29 May 2010, a submarine volcano erupted in the Commonwealth of the Northern Mariana Islands (CNMI) about 90 miles north of Saipan and a few miles south of Sarigan Island. Scientists on Pagan Island (about 80 miles north of the eruption) could not be reached

by HF radio. A “Chatty Beetle” was on Pagan as part of a program to test the equipment and concept. The Emergency Management Office (EMO) in Saipan sent a message setting off a loud alarm on the “Chatty Beetle” and instructing the scientists on Pagan Island to call the EMO on Saipan via their HF radio. Silencing the alarm automatically acknowledged receipt of the message. Communications with the “Chatty Beetle” are conducted via Iridium satellites, and batteries are charged via solar panels. The volcanic incident was a great proof of concept, and the equipment worked flawlessly. Donors are being arranged to fund the purchase of the “Chatty Beetles” and the monthly Iridium satellite usage charges.

Other new, robust warning dissemination channels are also emerging. The Bureau of Standards, Metrology & Inspection of Taiwan and local telecom operator (Chunghwa Telecom) developed a natural disaster alert system along with their provision of the time services. The alert system distributes warning messages to the timepieces with low-frequency radio time signals. Chunghwa Telecom has set up base stations in Namasia Township, Kaohsiung County, which suffered a lot from the flash floods and landslides brought by Typhoon Morakot in 2009. The network began to operate in June 2010. With this new service, people can receive the warnings about natural disasters including tropical cyclone passages via the ordinary timepieces. Low-frequency has the advantage that it is not affected by landforms, inclement weather conditions, or power failure. The warning signals from the weather authority can be delivered to the public via the watches or clocks instantly. The required equipment is cheap, and its power-consumption is very little – it can run for a long time on batteries (Merit Times on 27 June 2010 and CAN News on 26 June 2010: http://stn.nsc.gov.tw/en/view_detail.asp?doc_uid=0990628001).

4.3.5. Preparedness and response process, continual improvement

4.3.5.1 Education and awareness

Tropical Cyclone Nargis (2008), which resulted in one of the deadliest known storm surges any where, struck Myanmar – a country rarely affected by these events (Fig. 19). According to the official statistics, Nargis has killed at least 138,000 people across the country (http://en.wikipedia.org/wiki/Cyclone_Nargis). Education without alarming people is a positive way of dealing with this problem. In the Nargis case the forecasts were good where numerical models indicated a strong chance that a severe TC would strike Myanmar, though some reports indicated that the storm surge effects were not addressed in the warnings. Obviously such areas extremely vulnerable to storm surge like the Ayeyarwady Delta must be identified in the regions which are rarely affected by TCs. Efficient early warning systems have to be implemented in these locations with the population concerned fully informed and educated in order to reduce death toll.

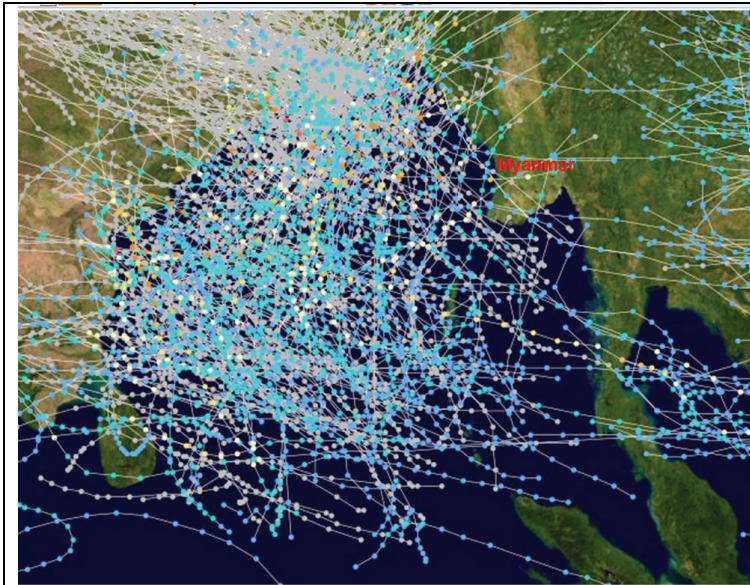


Fig 19. Past TC tracks showing that few hit Myanmar (source: discussions on Tropical Storms Group at

<http://www.tstorms.org/tropical-storms>).

The warning process involves three main components: the meteorological component, the emergency management and the transmission and communication component (including the essential role of the media). A failure of any of these will affect the efficiency of the whole warning process.

One of the problems that La Reunion encounters is a high turnover rate of the emergency managers and authorities of the Civil Defence. They change frequently and the new staffs who come from European France generally have little knowledge of the TC phenomenon and of the related issues and pitfalls to avoid. It is a permanent challenge to work with new faces and with such people as partners – who have the legal authority for deciding of the activation of the different stages of alert but are almost completely inexperienced and novice in the TC business. Briefing sessions were arranged by the weather office to give them some minimum knowledge and background in order to avoid the problems observed in the past, but there is still no absolute guarantee that they will react properly. In these circumstances, it appears that drills have to be conducted regularly to test out the effectiveness of the contingency plans in place and at the same time to ensure everyone involved in the warning process would react properly. Adequate resources and high priority should be allocated for this purpose.

Concerning education and training, the COMET® Program (<http://www.comet.ucar.edu/>) provides valuable resources that are available on the Internet. The Program, established by the University Corporation for Atmospheric Research (UCAR) and the National Weather Service (NWS), addresses education and training needs in the atmospheric and related sciences through three main activities: distance education, residence courses, and outreach. The distance education is available to meteorologists and hydrologists around the world, usually at no-cost through the MetEd program website. The Program is sponsored by NWS, with additional funding provided by the Air Force Weather Agency, the Australian Bureau of Meteorology, the Meteorological Service of Canada, the National Environmental Education Foundation, National Polar-orbiting Operational Environmental Satellite System, NOAA National Environmental Satellite, Data and Information Service, and the Naval Meteorology and Oceanography Command. While most of the modules are in English, several have been translated into Spanish and French.

Several new COMET® training modules have become available since IWTC-VI that can ultimately help better mold and improve warning strategies. Some of them fit into several TC-related topic areas, which include: coastal weather, environment and society, hydrology and flooding, tropical and hurricanes, and marine meteorology and oceans. Recent new modules that more directly target warning strategies are: “Community Hurricane Preparedness, 2nd Edition”, “Hurricanes Canadian Style: Extratropical Transition”, “Weather and the Built Environment”, “Understanding Marine Customers”, “Landfalling Cyclones”, “A Social Science Perspective on Flood Events”, “Anticipating Hazardous Weather and Community Response”, and “Hurricane Strike” - a module on hurricane science and safety for kids. Five new “Introduction to Tropical Meteorology” chapters or modules have been produced, as have several modules on ocean waves and tides, hydrology and rainfall, TC and ocean remote sensing, and conveying uncertainty.

Over the last few years, the NWS has also developed Advanced Warning Operations Courses (AWOC) and a Distance Learning Operations Course (DLOC) that integrates efficient use of the WSR-88D Doppler Weather Radar with operational meteorology and warning strategies. While DLOC is recommended for the AWOC Core study track, which is suitable for non-meteorologists/hydrologists who desire to better understand the NWS warning process, it is not required (<http://wdtb.noaa.gov/courses/awoc/>). Some of the more relevant AWOC courses are: “Situation Awareness and Decision Making in a Warning Environment”, “Expertise and Effective Office Warning Strategies”, “Conveying Warning and Public Response”, “Threat Assessment”, “The EF-scale (Enhanced Fujita-scale)”, other modules on tornado warning guidance and strategies, and several modules on precipitation forecasting and flash flood warning.

The online education resources introduced above are useful not only to the forecasters, but also to the emergency managers, decision makers, media, or even the public who are all stakeholders in the weather warning services. Greater understanding of the behaviour, characteristics, and hazards associated with TCs will allow the production of more relevant and effective warnings by the forecasters and the proper response taken by the users.

4.3.5.2 Continual improvement

Over time, the NMHSs must work with the users of its warning services to develop trust in the warnings and must deliver these services when and as often as needed. To this end, good connections with users should be established such that their requirements would be better understood and matched by proper products and delivery modes. Relevant initiatives include regular surveys on service performance, liaison or consultative groups for different user sectors, user visits to meteorological facilities to appreciate the strengths and limitations of the warning operation, etc.

A survey has been recently conducted from April-June 2010 by RSMC La Reunion to collect the opinions and expectations of the 14 NMHSs in the Southwest Indian Ocean region and member states of the RA I Tropical Cyclone Committee on the products and services provided by the RSMC. The results would help the RSMC to improve the design and content of their products for the coming years.

Annual survey on the use of weather information, including newly disseminated five-day TC track forecasts, was conducted in 2009 by RSMC Tokyo to monitor the satisfaction level of the public and their requirements. The results revealed that the accuracy of TC track and intensity forecasts should be further improved.

To meet the evolving needs of users, the warning systems and services should be suitably adjusted on a continual basis. The changes may not take place simply because of the emergence of new technology available to the NMHS. Instead, it could arise from regular interactions with the stakeholders. They all have different concerns and, for a warning service to work and meet people's needs, these concerns have to be addressed during the consultation process.

4.3.6. Inter-agency Collaboration

The effectiveness of TC warning services can be enhanced by inter-agency partnerships and cooperation. Since IWTC-VI, new initiatives have come out and substantial progress has been made in this aspect.

The Severe Weather Information Centre (SWIC) website is an excellent example of how exchange of technology and cooperation between NMHSs can benefit the international community. SWIC is a WMO website (<http://severe.worldweather.wmo.int/>) that integrates and enhances regional activities within an international framework for the reduction of loss of lives and damage. The web site provides a portal for TC information by the RSMCs and Tropical Cyclone Warning Centres (TCWCs) on basic information of the current TCs, and official warnings issued by NMHSs for their respective countries or regions. This web site currently covers TCs in virtually all basins. Up to 2010, a total of 21 WMO Members are participating in this operation. There are over 16 million page visits in 2008 and the results also show an increasing trend of global clientele. SWIC has established itself as a centralized source of authoritative and reliable weather information.

It was recommended in IWTC-VI that all TC-related NWP products, including the full set of ensemble forecasts, be made available to all operational and research users in real-time. In response to this, a pilot project has been established by the THORPEX Interactive Grand Global Ensemble (TIGGE) Working Group to test the real-time exchange of ensemble TC track forecasts from different NWP centres. The data in the TIGGE archive are processed in a common format (cyclone XML, CXML format) with a limited set of analysis and display tools. The project presents an opportunity for developing new products and techniques for TC forecasts. Since 2009, real-time ensemble forecasts have been available in CXML format from CMC (Canadian Meteorological Centre), CMA, ECMWF, JMA, KMA, UKMO and NCEP.

The Meteorological Research Institute of JMA further promotes the use of CXML under the WWRP-RDP project "North Western Pacific Tropical Cyclone (TC) Ensemble Forecast (NWP-TCEFP) Project" and set up a password-protected web site at <http://tparc.mri-jma.go.jp/cyclone/> in July 2010. It is a five-year project which commenced in 2009 and its objectives are to improve TC track forecast skill over the western North Pacific. More details are given under the Special Focus Session 2a on THORPEX/TIGGE applications to TC motion and forecasting.

At RSMC La Reunion, bulletins and TC advisories are issued in formats of text and BUFR. But it now uses extensively the CXML format for internal communication to exchange data between our different softwares, in particular between the Synergie Cyclone software used by the cyclone forecaster to display analysis and forecast information on his workstation and the Meteo-Factory software under construction that will replace (by 2011) the current software used to generate advisories and graphical products.

WMO designed and conducted the Severe Weather Forecasting Demonstration Project (SWFDP) with a view to closing the gap of the developing countries in application of advanced NWP technology in early warnings of severe weather. The first SWFDP was chosen to be initiated in Southeast Africa in 2007, for which Météo-France is highly involved through RSMC La Reunion. A more complete password protected extranet site with extensive access to NWP products and TC-related products is currently under construction. The site will facilitate the easy access by the National Meteorological Services of the Southwest Indian Ocean. The contribution of Météo-France to the SWFDP also includes the provision of NWP fields from its Limited Area Model ALADIN Réunion, which is a high-resolution model (8 km horizontally) specially dedicated to TC forecasting with specific treatments including a TC bogus).

Following the success of the SWFDP conducted in other regions, a SWFDP is being developed in Southeast Asia in RAI to start the field phase in May 2011. NMHSs such as Cambodia, Lao PDR, Thailand and Vietnam will participate in the project. One of the most important focuses is TC track, intensity, structure change, landfall process and heavy rainfall. RSMC Tokyo will contribute the project with its products as one of the Regional Centres.

RSMC Tokyo has been operating the Numerical Typhoon Prediction (NTP) website for registered users since October 2004. This service is provided as part of the activities of the ESCAP/WMO Typhoon Committee to facilitate better TC forecasting and warning operations by its Members. The site provides predictions of TC tracks performed by models of nine major NWP centers, i.e. BoM (Australia), CMC (Canada), CMA (China), DWD (Germany), ECMWF, KMA (Republic of Korea), NCEP (USA), UKMO (UK) and JMA to assist the NMHSs of the ESCAP/WMO Typhoon Committee Members in improving TC forecasting and warning services. In June 2009, RSMC Tokyo newly added a “Satellite Analysis” page to the NTP website which provides operational TC analysis such as Dvorak T-numbers as well as analysis of TCs in the early developing stage (early stage Dvorak analysis: EDA, Kishimoto, 2008). Another new initiative of the Typhoon Committee is the development of a web-based typhoon forum for its Members. The forum, developed and managed by CMA, was opened in 2009. The purpose of this website is to provide a platform for Typhoon Committee Members to exchange information in real-time, to ask questions, to get answers or help from other TC Members.

4.3.7. Summary

A list of recommendations based on the material and discussions presented in the preceding sections are given below.

1. Large systematic biases in forecast position sometimes occur across most NWP models such as in the case of Fengshen (2008). Full investigation into the cause is needed. The warning recipients need to be educated on the predictability and informed of the uncertainty of a given situation.
2. TC genesis near land and intensity change (in particular rapid intensification) remain two big issues which would baffle the warning strategies. High priority should be placed on related researches and development in coming years.
3. While Dvorak technique continues to be a key method and widely deployed for determining the intensity of a TC, some TCs do not lend themselves to accurate intensity estimates from this method. More and frequent observation platforms like ASCAT and

QuikSCAT are considered essential for conducting TC analysis and formulating the warning strategies. Comprehensive validation studies on various satellite estimates (including the Dvorak technique) would help the forecasters to make the better use of the tools in operation.

4. New sensors and technologies are emerging which will increase our TC observing capabilities. In particular, the Aeroclipper is a new approach for collecting continuous in-situ observations on the intensity of the TC. More field experiments are encouraged to study the potential operational value of this new equipment.
5. Communicating forecast uncertainties to end-users will help them make better decisions according to their own circumstances. Inclusion of relevant discussion in the TC warnings is highly recommended. Currently, estimation of the forecast uncertainty based on historical errors is widely used. Dynamical approach to the problem, e.g. by referring to the ensemble prediction systems, would hopefully reduce the degree of uncertainty of the forecasts.
6. An expansion in emphasis from weather prediction alone to the prediction of weather and related impacts is recommended in order to attract the proper response that minimizes and mitigates the impacts of hazardous weather associated with TCs. In this regard, NMHSs have to work together with the social scientists as well as professionals from user groups for the transition.
7. As a means for warning dissemination, Internet saw an exponential growth in terms of usage in the past decade and innovative modes of warning dissemination (e.g. through social networking services) are also coming into place. It allows more personalized and location-specific warning services to reach the users any time anywhere, contributing to effective safeguarding of people's life and property.
8. Many people still rely on simple and cheap technology such as telephone to access weather information and warnings. While adding advanced technology into the operation, NMHSs should not forget this group of people, otherwise the most vulnerable sector of the community would be left out in the disaster mitigation effort.
9. FM radio is an inexpensive, highly reliable, and relatively simple method to pass critical and routine weather information to the public. It could be considered as a potential solution for developing countries with communications challenges, especially those oceanic nations. To improve rural and remote community access to warning information, deployment of durable and low-power equipment similar to "Chatty Beetle" could be considered.
10. Warning message incorporated in the low-frequency radio time signals is an innovative way of warning dissemination that could survive the most severe weather conditions. Its application in the warning operation should be explored.
11. Certain areas (e.g. Ayeyarwady Delta), though not so frequently affected by TCs, are indeed extremely vulnerable to the destructive effects of TCs. Effective early warning systems should be implemented in these locations as a matter of high priority.
12. Drills need to be conducted regularly to test out the effectiveness of the contingency plans in place and at the same time to ensure everyone involved in the warning process would

react properly. This is particularly important when new decision makers, who are not familiar with the warning operation, keep arriving and leaving frequently.

13. NMHSs can make good use of the COMET® Program which presents a convenient and valuable resource to address the education and training needs of NMHSs for their staff members as well as emergency managers, decision makers, media or even the public.
14. Continual improvement of the warning services in consultation with other stakeholders is crucial in meeting the evolving needs of the users.
15. SWIC, exchange of CXML under TIGGE/THORPEX, SWFDP, NTP website and Typhoon Forum under Typhoon Committee are all important projects which have significantly benefited NMHSs in the operation of their TC warning systems. Increased international or inter-regional cooperation should be highly encouraged.

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