Chapter Eight

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8. Operational Strategy

8.1 Introduction

The aim of this chapter is to suggest an operational strategy to optimise the efficiency and effectiveness of a Tropical Cyclone Warning Centre (TCWC)[1]. The efficiency and effectiveness of TCWC operations is affected by such diverse factors as for example the physical layout of the office, the training of staff, the design and documentation of forecast processes, and business continuity planning. In short it is concerned with all the non-meteorological aspects of delivering a cyclone warning service. In the period since the last edition of the Global Guide to Tropical Cyclone Forecasting (hereafter Global Guide) a number of factors have greatly influenced the TCWC systems and processes.

Tropical cyclone track forecasting skill has improved steadily over the last two decades, aided by improved numerical weather prediction (NWP) and widespread adoption of consensus track forecasting methods that optimise the skill of the available forecast aids. However the increase in forecast skill has lead to an increase in service expectations. Tropical Cyclone Warning Centres (TCWCs) are now typically providing longer lead time forecasts, with an expanded range of products - particularly in graphical formats.

Demands on TCWC forecasters have also grown through an increase in the volume of data to be assimilated during each forecast cycle. Observational data has increased, predominantly as a consequence of a greater number of low earth orbit satellites providing passive and active microwave satellite data that requires additional skills and time to be properly incorporated into the analysis process. The increased number of NWP models available to the forecaster has also imposed a burden on the forecaster to be familiar with the characteristics of a wide range of models and to find the time to diagnose the model forecasts in order to determine where NWP failure may occur and, where different models predict significantly different tracks/intensities, to ascertain what the significant differences are in the model fields.

The rapid advancement of computer technology has offered efficiency dividends to TCWCs, and has helped TCWCs cope with the increased data flows, but it has also raised training overheads for staff, who must now be proficient users of technology in order to meet the demands placed on them.

Operational strategy is important because if TCWC processes are inefficient forecasters find themselves spending the majority of time preparing products and dealing with technological issues and are be unable to devote adequate time to understanding the meteorology of the situation. Operational strategy offers a means by which service improvements can be delivered independent of improvements in forecast accuracy.

Throughout this chapter we will examine how the changes broadly outlined above have affected TCWCs. With the contemporary TCWC in mind we will identify ways in which the available human and technological resources can best be harnessed, and how TCWC processes can be optimally designed to ensure the efficiency and effectiveness of warning operations.

There is considerable diversity in the structure, client focus and funding levels of TCWCs across the globe. Some TCWCs average very few tropical cyclones per season, indeed there are TCWCs that average less than one cyclone per season , whereas others deal with significant numbers (eg. an average of between nineteen and twenty tropical cyclones occur in the Philippines (PAGASA) area of responsibility each season). To ensure that a broad range of perspectives were considered the following TCWCs kindly provided detailed input on current operational strategy: Australian Bureau of Meteorology TCWCs (Brisbane, Darwin and Perth), the Hong Kong Observatory (HKO), Jakarta TCWC, JTWC, RSMC La Reunion, RSMC Tokyo, and the Vietnam National Centre for Hydrometeorological Forecasting (NCHMF).

Given the organisational diversity of TCWCs we cannot take a prescriptive approach to operational strategy, but we can examine the issues which affect operational efficiency and recommend sound strategies for dealing with those issues.

1In referring to TCWCs we include specialised centres (e.g., Regional Specialised Meteorological Centre (RSMC) La Reunion, the US National Hurricane Center (NHC) and the US Department of Defence Joint Typhoon Warning Center (JTWC)) that employ tropical cyclone specialists as well as National Meteorological and Hydrological Services (NMHSs) that generally do not employ specialist tropical cyclone forecasters and which have diverse levels of funding, staffing and training.

8.2 Infrastructure and systems

8.2.1 Physical design of the forecast/warning office

When considering the effectiveness and efficiency of a TCWC some attention should be given to the physical layout of the forecast office. Layout will largely be a function of the available space, and the equipment and people to be accommodated - parameters that will vary considerably between forecast offices - however some general principles can be suggested as guidance.

The TCWC should be located so that outside distractions are minimised. During the forecast cycle there will be times when the TCWC staff are under pressure to make critical warning decisions while meeting tight deadlines. Unnecessary distractions can hamper efficiency.

Sufficient space should be allocated to ensure that during periods of peak work load staff have adequate room and are able to easily move about the area to access equipment and interact with each other.

The layout of equipment should reduce the need for forecasters to move around to access data. The data should be channelled toward the forecaster so that the most commonly accessed data is closest to hand. In the last two decades the use of computer workstations has become ubiquitous and nowadays most data is accessed in this manner. Indeed it is now common for forecasters to use multiple workstations to access additional computing power and “screen real estate” allowing for dedicated radar or satellite displays. Multiple workstations also allow for the use of software with specific operating system requirements. The office layout should ensure that the forecaster can operate frequently used workstations with minimal movement. If a single workstation (perhaps a dedicated radar display for example) is to be shared by a number of forecasters it should be placed closest to the forecasters who need to access it the most as the frequency with which forecasters will refer to data can be influenced by the ease of access.

Ergonomic furniture including adjustable chairs and desks should be stipulated to avoid health problems that can arise from continual use of monitors and keyboards.

Good lighting is also essential, especially in areas used for analysing synoptic charts and other hard copy data. Areas of strong reflection or glare should be minimised as they invariably cause problems with ease of reading computer screens, leading to eye strain.

Noise from equipment such as computers, printers and fax machines should be minimised by the use of sound-absorbent materials, "silent" printers and by placing unavoidably noisy equipment in more unobtrusive places in the office.

Some TCWCs disseminate warnings via a recorded message service and if this is the case some thought should be given to establishing an area separate to the main forecasting area where forecasters can record warning messages without interruption or background noise. A separate area for conducting media interviews is also desirable for some TCWCs and this concept will be considered in more detail later in this chapter.

Manual analysis of hard copy charts is still common and they need to be in an area that is accessible to all forecasters without causing "traffic jams". Although there has been a proliferation of electronic equipment in the forecasting office over the last few decades we have not seen the advent of the "paperless office" and it is still common for many resources to be accessed via hardcopy. The nature of these is varied (standard operating procedures, checklists, Dvorak flowcharts, lists of phone numbers) but invariably the number of such documents grows to be quite large, and it is important that these resources are stored in a logical fashion that facilitates quick retrieval. It is handy to have a fair amount of free wall space for hanging maps and storing these resources. Constructing folders of forecast aids and other resources that are organised in a logical fashion can help ensure efficient retrieval of information under pressure, but this can also be done electronically and this will be covered in greater detail later in thie chapter.

There are generally three different styles of TCWC accommodation:

1. TCWC incorporated into the main forecasting area: When the TCWC function occurs in an area of the main forecasting operations regular liaison between the two functions is encouraged, however care should be taken to ensure that the two functions do not disrupt each other. An area within the forecast office should be clearly designated as the TCWC (even if it is only on a temporary basis as the need arises) and should contain the equipment necessary to carry out the cyclone forecasting task. Shared facilities should be carefully located to ensure they are easily accessible to both operations.

2. TCWC adjacent to main forecasting area: A TCWC that is separate from the main forecasting area but located adjacent to it offers forecasting staff in both areas greater insulation from the distractions caused by the other operations while still encouraging liaison to maintain consistency between forecast products. Ideally the TCWC will be equipped to run independently of the main forecasting area, however if some facilities need to be shared they should be located close to both operations.

3. Dedicated TCWC: In the case of an office dedicated to the tropical cyclone forecasting function there is generally greater scope to ensure the office design supports the forecast process. The design should channel the information to the forecaster, usually by placing key workstations at the forecasters' fingertips and ensuring synoptic charts are close at hand. The relationship of the shift supervisor to support staff needs to be considered and some thought may need to be given to facilitating the briefing of senior management by the shift supervisor without disrupting support staff.

8.2.2 Technology and data access

A key technological requirement of an efficient TCWC is high speed access to satellite and NWP data through robust information technology (IT) infrastructure. The bandwidth requirements of TCWCs have increased significantly over the last two decades as the variety and resolution of satellite imagery and NWP products has increased. Because of the time constraints in the forecast cycle, forecasters require rapid access to key data sources. Information that may be of value to the decision making process, but which takes time to access, is at high risk of being overlooked by time-poor forecasters. A significant proportion of the TCWCs surveyed reported that the speed of internet connections or of Local/Wide Area Networks (LAN/WAN) occasionally limited data access during operations.

The responsiveness of software used for in the TCWC is also important to operational efficiency. When selecting software for TCWC operations there is often a focus on the functionality and cost, however speed of response should be also be considered a key criterion.

It is also important that the responsiveness of software is tested under operational conditions as response times may increase significantly under the heavy loads that can arise in operations.

The free availability of operationally focused web pages such as:

- the Naval Research Laboratory (NRL) Monterey Marine Meteorology Division Tropical Cyclone Page (http://www.nrlmry.navy.mil/tc_pages/tc_home.html),
- the Fleet Numerical Meteorological and Oceanographic Centre Satellite Data Tropical Cyclone Page (https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi),
- the Cooperative Institute for Meteorological Satellite Studies Tropical Cyclone page (http://cimss.ssec.wisc.edu/tropic2/), and
- the National Environmental Satellite, Data, and Information Service (NESDIS) / Cooperative Institute for Research in the Atmosphere (CIRA) / Regional and Mesoscale Meteorology Branch (RAMMB) Real-Time Tropical Cyclone Products web page (http://rammb.cira.colostate.edu/products/tc_realtime/index.asp)

allows TCWCs sufficient access to satellite data, in a convenient format, without maintenance overheads. Through the provision of resources such as these research centres make significant contributions to the effectiveness and efficiency of tropical cyclone warning centres in a manner that ensures global equity of access.

The Sixth WMO International Workshop on Tropical Cyclones (IWTC-VI) recommended that all tropical cyclone-related Numerical Weather Prediction (NWP) products be made available to all operational centres in real-time. It is hoped that development of GIFS-TIGGE, the Global Interactive Forecast System THORPEX[2] Interactive Grand Global Ensemble will provide the vehicle through which this is achieved. This would mark a similar advance in ensuring equitable global access to NWP products as the above research centres have done for satellite data.

[2] THORPEX is The Observation System Research and Predictability Experiment, a project of the World Meteorological Organisation's World Weather Research Program (WMO/WWRP).

The technological advances described above improve the efficiency and effectiveness of TCWCs through improved data access. Operational strategy also needs to consider the role of technology in streamlining and supporting the forecast process and dissemination of products. Using software in the forecast process can lead to significant improvements in efficiency through automation or partial-automation of tasks; and can lead to improvements in effectiveness through reduction in errors, including errors of logic and transcription. It is not surprising that all the TCWCs surveyed for this chapter use some level of technological support and in many TCWCs the majority of tasks are now either automated, or where subjective judgement is required or desirable (e.g., subjective Dvorak analysis) interactive software is used. The range of technological enhancements being considered here ranges from software specifically designed to support the forecast process (such as the Automated Tropical Cyclone Forecasting System (ATCF) (Miller et al. 1990) or the Australian Bureau of Meteorology Tropical Cyclone Module (TC Module)), to simple technological enhancements, such as the use of a specially designed spreadsheet to record subjective Dvorak estimates in place of hardcopy recording. (Click here to download an MS Excel spreadsheet for recording Dvorak estimates.)

When considering the incorporation of technology into the operational process the following factors should be considered:

- robustness,
- fitness for purpose,
- future obsolescence,
- maintenance, and
- training requirements

Tropical cyclone warnings services are generally regarded as a critical function for national meteorological services and it is vital that any technology that is relied upon to deliver those services is robust. This applies whether it is hardware or software under consideration. It is important that testing is done under loads as large as might be experienced in operations. For example, when testing operational software on TCWC workstations it is not sufficient to test a software package in isolation. The stability and response times of the software need to be tested when the workstation is running the full complement of operational software, and with the local area network under a load similar to that which will result during significant events - when it is likely that every available workstation will be in use.

Fitness for purpose is another important consideration for TCWC technology infrastructure. Short Message Service (SMS) text messaging is the most widely used data application in the world however its fitness for purpose for the transmission of critical messages to important clients, such as emergency services managers, can be called into question. As a result of its design as a "best effort" service[3] delivery is not guaranteed and there are occasional long delivery times. Hence it cannot be relied upon in situations where a rapid response from the recipient may be vital. Similarly the timeliness of delivery via email cannot be guaranteed so care needs to be taken to explain to recipients the possible risks involved in this method of delivery.

When incorporating new technologies into operations future obsolescence should be considered. In contemporary times it is not uncommon for new technologies to become superseded or functionally obsolete within five to ten years. If it is unlikely that funding will be available to replace the technology within this time frame then its incorporation into the TCWC may cause future problems.

The level of maintenance required to keep the technology operational and prevent obsolescence should also be considered. For example, software designed to incorporate NWP data may require frequent modification to allow for the rapid evolution of NWP models. In this case it will be necessary to ensure that there will be continued access to the expertise required to maintain the software software’s functionality.

Finally, the amount of training needed to ensure efficient and effective use is an important consideration when evaluating technology for incorporation into a TCWC. A software package that is designed for "power users" may provide good support to well trained forecasters familiar with its operation while leading to a reduction in efficiency amongst forecasters who are only occasional users of the software. Maintaining the skills of infrequent users at the required level may prove overly burdensome, especially if there is a high level of turnover amongst operational forecasters in the TCWC.

[3] See http://en.wikipedia.org/wiki/Best_effort_delivery for a description of best effort delivery.

8.3 People

8.3.1 Staffing

Due to budgetary constraints, forecast offices are often staffed for "average" weather conditions, with "average" usually meaning "fine" weather conditions. Consequently the extra workload associated with a tropical cyclone often means there are not enough staff to cope with both the routine obligations and the workload specifically related to the tropical cyclone. In many jurisdictions this problem is exacerbated because the workload associated with the routine forecasts (e.g., Terminal Area Forecasts) increases at the same time as the new range of products specifically relating to the tropical cyclone become required. Hence the staff members involved in general forecasting are under increased pressure at the same time that weather service managers are looking to free up staff resources to cope with the extra workload involved in producing tropical cyclone warning services.

It is important that weather service managers give careful consideration to the numbers of staff required to carry out tropical cyclone duties effectively, and the following points need to be considered.

- A TCWC should be manned 24 hours a day once a tropical cyclone poses a significant threat to communities. Ideally the TCWC would be manned 24 hours a day for any tropical cyclone in its area of responsibility, but this is often not possible, particularly if there is the likelihood that the TCWC will be active for a prolonged period causing a strain on available staff resources.
- The level of staffing should increase as the threat level increases. For example, when a cyclone is in the area of responsibility but does not pose a significant threat to communities it may be sufficient to have two 9 or 10-hour shifts with just one person per shift. As the threat to communities increases the staffing should increase to 24-hour coverage; which may require three shifts per day to conform to occupational health and safety guidelines for rostering (see below). It will also likely be necessary to increase the number of staff on each shift as the threat increases.
- The detrimental effects of fatigue on decision making are well documented (eg. Castellan 1993) and it is important that rosters are designed to minimise fatigue. TCWC

managers are urged to consult the available literature when designing shift rosters. Key points to note include:

- The longer the shift length the less consecutive shifts should be worked.
- No shift should exceed 12 hours duration.
- No more than 2 consecutive night shifts should be worked.
- Split shifts should be avoided.

All staff should be assigned clearly defined duties so that there is a minimum of confusion within the office routine during a tropical cyclone event. Care should be taken to limit the other responsibilities of staff assigned to tropical cyclone duties. In high stress situations people tend to focus on the tasks that they are most familiar and comfortable with. Hence if tropical cyclone forecasters are expected to continue to carry out routine tasks not associated with the tropical cyclone, and which they are more familiar with, there is a risk that they will fail to give priority to the TCWC duties.

There are large benefits in having tropical cyclone (or, in general, severe weather) specialist positions established within a TCWC. As well as being able to bolster forecasting staff numbers in cyclone events, cyclone specialists can fulfil a number of other roles which are central to the overall efficient running of a TCWC, including:

- training other forecasters,
- maintaining procedural documentation,
- providing a focal point for tropical cyclone matters throughout the year, and leadership in the TCWC during events,
- conducting applied research and techniques development work for the benefit of the TCWC,
- undertaking seasonal verification work,
- conducting public education campaigns,
- establishing close links with emergency management groups, and
- generally maintaining the TCWC at a high level of efficiency.

8.3.2 Training

The meteorology of tropical cyclones is a specialist area. Consequently the forecasting of tropical cyclones requires specific techniques and skills (e.g., Dvorak analysis) which are not required, or not as heavily relied upon (e.g., analysis of passive microwave data) in general forecasting. It is important that all staff be trained in both the science of tropical cyclone meteorology and in efficient TCWC procedures. The more proficient staff members are in TCWC procedures the more time they will be able to devote to considering the meteorology of the event.

It is beneficial for trainers to themselves be given training in how to most effectively deliver training, but they must also be respected for their knowledge of the science and have operational experience. Specialist training positions staffed by persons with scientific skills, operational experience and a background in educational theory is an optimal goal that is out of reach of most centres. In the absence of that level of staff resource, the task of delivering training most often falls to the most skilled and experienced forecaster.

Where software is introduced to support the forecasting function forecasters need to be properly trained in its efficient use. The degree to which software can enhance the efficiency of a TCWC is partly a function of its design. It can be extremely beneficial for the programmers writing or updating the software to have an understanding of the forecast processes in the TCWC. If possible they should be encouraged to witness the TCWC in operation and closely examine the workflow in order to be able to design the software to support the process, rather than simply providing a toolbox that includes the necessary functions. Within the Australian Bureau of Meteorology, the occasional deployment of programmers to the TCWC during operations has been recognised as having facilitated a much greater degree of support for the forecast process within the specialist software used in Australian TCWCs (TC Module). This has helped to re-establish sufficient time for meteorological analysis despite an increase in the number of products being issued and in the amount of data being assimilated. Where software is used as a decision support tool it is particularly important that software engineers have an in depth understanding of the forecast decision process.

8.3.3 Roles

Training needs of staff members is best considered in relation to the roles they will fill in the warning centre. The operational functions within the TCWC can be separated into various roles such as:

(a) *scientific officer*: responsible for all meteorological aspects of operations;
(b) *incident manager*: akin to shift supervisor, in charge of overall operations including warning policy decisions, and also acting as primary contact for emergency management;

(c) *logistics officer*: responsible for providing technical and logistical support to the TCWC (for example organising extra observations, maintaining records and checking products prior to dissemination) and

(d) *media/information officer*: primary responsibility for conducting media interviews.

It is very common for one staff member to perform multiple roles in a low-key situation, but as the threat to communities escalates there is generally a need to increase the staff resource in the TCWC and assign one or more staff members to the separate roles. Once the processes and procedures of the TCWC are designed and documented the TCWC supervisor needs to identify which staff members will fill the different roles. Some staff members may need to be trained in all roles, but some will only be brought into the TCWC to fill a specific role. If there is a clear demarcation of roles and the training program is oriented around those roles the efficiency and effectiveness of the TCWC team can be greatly enhanced during the hectic periods of heightened TCWC activity when communities are under threat.

The TCWC environment can be a high stress and/or high work load environment in which there is little time for explicit coordination strategies. To ensure the cohesion of the TCWC team it is important that the team members not only have clearly defined roles but that they share a common mental model of the operational strategy of the warning centre. One of the goals of training should therefore be to establish a shared mental model of TCWC operational strategy. Providing people with knowledge of the meteorology of tropical cyclones and the principles of good warning strategy is not sufficient to ensure effective performance, either of the individual or of the overall team. Training needs to establish a degree of commonality of understanding of how the TCWC functions, from the application of the science to the resolution of warning policy issues and the communication to clients.

The sharing of a common mental model of operational strategy is also important because the forecast and warning process within a TCWC is a continuous process that extends over many days. The cohesion of the TCWC team needs to extend across the rotation of shifts. If clients perceive that the message being broadcast is regularly changing with the shift changeover it can significantly erode their confidence in the reliability of the forecasts. This is particularly true of emergency services personnel who are in close contact with the forecast centre and are attuned to any sudden changes in forecast policy. On the other hand one of the benefits of the rotation of personnel through the warning centre is the fresh perspective that is brought to bear. Having gone through a complex decision making process, assimilating a myriad of observational and NWP data in order to arrive at a conceptual picture of the meteorology of the tropical cyclone and determine the optimum warning strategy, there is a natural resistance to abandon that model in the light of new information. Instead there is a very human tendency to assimilate new information in the light of the existing conceptual model. The change of shift therefore brings the opportunity for a fresh appraisal. A degree of commonality in the mental model of how the forecast and warning process operates does not prevent the reassessment of operational strategy and in fact this fresh appraisal at the changeover, and the strategies for managing how abrupt changes in forecast policy are managed should all form a part of the shared understanding of operational strategy. A common understanding of the processes by which operational decisions are made can mitigate against fatigue by enabling team members to develop methods of interaction that improve their effectiveness, even when fatigued (Foushee et al. 1986, cited in Canon-Bowers et al. 1993).

8.4 TCWC process and procedures

In this section we will examine a very important component of operational strategy: TCWC process and procedures. The two terms are related and before we proceed some explanation of how we will use them is warranted. In this chapter we will use "process" to denote the higher level sequence involved in transforming a set of inputs (e.g., observations, NWP products, etc.) into outputs (e.g., warning products). We use "procedure" to denote the steps involved in accomplishing a specific task (e.g., performing subjective Dvorak analysis).

8.4.1 A cyclical view of TCWC process

The tropical cyclone warning process can be thought of as comprising the following:

- Gathering meteorological observations and forecast guidance (predominantly Numerical Weather Prediction (NWP) products),
- Presenting the observations and forecast guidance to the forecaster,
- Analysing the observations, diagnosing the forecast guidance and constructing a forecast policy,
- Preparing forecast products
- Disseminating forecast products.

The dissemination of forecast products needs to adhere to a rigid time schedule and hence time management is critical in TCWC operations. TCWC operations typically occur on a six hour cycle where forecast products are updated at a minimum of every six hours (in synchronisation with common NWP cycles), with some products being issued more frequently. Products issued at intermediate intervals typically involve an update to analysis information without a complete reformulation of forecast policy. To simplify the discussion we will consider a forecast

8.4.2 Documenting procedures

The procedures associated with the forecast process need to be documented, and the documentation needs to be: complete, easy to access and up-to-date. Some operational centres use printed reference materials such as a folder of standard operating procedures standard, some use electronic media such as a Wiki page. Many forecasters find a mixture of hard copy and electronic resources most suitable, with hard-copy checklists used in conjunction with electronic reference material. Electronic media generally have the advantage that they can be multi-levelled, outlining a concise high level guide while presenting hyperlinks to more detailed procedural information. A generalised example of this style of process is presented in Appendix 8.1. A procedural checklist can be developed from this list. In an electronic version each section would hyperlink to other web or Wiki pages providing more detailed instructions on how to perform each procedure and links to relevant resources. In this way it can be made as extensive a reference as requirements and resources dictate.

8.4.3 The critical time window

Within the typical six-hourly forecast cycle there is a critical time window between the time of the last observation (the analysis or "fix" time quoted in warning products) and the time the products are issued. This window of time can be expressed as follows:

I – O = L + A + P,

where:

I = warning (I)ssue time
O = time of latest (O)bservation (analysis/fix time)
L = observation (L)atency, the time taken to obtain, process and display the observational data to forecasters
A = time available for (A)nalysis, assessment and incorporation into the forecast policy
P = time taken for message (P)reparation.

The product issue times are fixed, and warning effectiveness is enhanced if the analysis information is recent, so there is an imperative to keep the amount of time between analysis time and issue time **(I – O)** to a minimum. This time window may vary according to product requirements but it is often of the order of 30 to 90 minutes. This is the most hectic time in the TCWC forecast cycle and careful consideration must be given to maximising the efficiency of TCWC processes that impact on this aspect of operations. Every effort should also be made to perform tasks outside this window where possible.

To optimise the accuracy and effectiveness of warnings we need to have **A** (the time devoted to analysis, assessment and the formulation of forecast policy) as large as possible. To achieve this we need to minimise **L** and **P**.

L is the observation latency: the period between the time of an observation and the time that the observation becomes available to the forecaster in a form that they can assess and analyse. Some of the factors affecting data latency are technological and can be addressed at an organisational level by adopting appropriate infrastructure. In the case of satellite data for example, the location of satellite receiving stations and the means of reception by the forecasting office will impact on the time taken for the satellite imagery to arrive at the TCWC. There has been a general trend toward decreased data latency as technological infrastructure has developed. Machine plotting of observations onto synoptic charts is now universal and this has reduced data latency in relation to synoptic observations. The use of computer workstations to process and observations in both tabular and spatial formats further reduces the time taken to make synoptic observations available to forecasters but does not facilitate the manual analysis still valued in most TCWCs.

As a result of the overriding influence of technological infrastructure, reducing data latency often involves decisions at an organisational level. However forecasters can often contribute to reducing data latency by being aware of multiple delivery channels and knowing which channel is likely to provide the earliest access to the observation. For example a forecaster may have a preferred site for viewing scatterometer data but be aware that an alternative site often provides access several minutes earlier. The forecaster will then be sure to check the alternative site during the critical window of time prior to issue if it is expected that a satellite pass will soon become available. This kind of detailed information on data sources needs to be shared amongst forecasters to ensure optimum efficiency, and the best way to do this is to ensure that procedures are thoroughly documented and regularly updated.

We want **A**, the time for analysis and forecasting, to be as large as possible but we must also keep in mind that much of the information that a forecaster must assimilate can be assessed outside of this critical window of time, in the remainder of the six-hourly cycle. For instance, since the NWP models are most commonly run at six to twelve-hourly intervals the diagnosis of NWP fields is best performed outside this window of time. Forecasters should record notes of their synoptic reasoning and NWP diagnosis at the time they perform these tasks. This enables proper documentation of the reasoning behind specific forecast decisions and also makes the construction of comments in technical bulletins more efficient. It is also more effective and efficient to draft the prose elements of public warnings during less pressured parts of the forecast cycle rather than waiting until the high pressure period before issue to perfect the wording of the warning. So for example, it may have become apparent through feedback from others in the forecast office that a particular phrasing in the warning is ambiguous or fails to highlight the greatest risk. It is better to redraft the wording immediately, even if an immediate update is not warranted, rather than leave it to the last minute to try and improve the wording to achieve better communication. When the forecast products are being prepared it is then a simple matter of copying and pasting the prepared prose into the relevant product parts. Efforts such as these can greatly improve the efficiency of product preparation, thus reducing **P**, the time taken for message preparation.

The public's trust in the warning message can be significantly degraded if there are errors within products or inconsistencies between products. It is therefore essential that products are checked before issue, and this can be considered part of the preparation time. When the issue time is imminent it may be tempting to shortcut this step. However the potential damage to the effectiveness of the warnings should not be underestimated and hence this is an important component of operational strategy. Where different products within the product suite are crafted separately and do not share data, the workload associated with this step can be significant. The number of errors in disseminated products and the time taken to check products prior to issue can both be greatly reduced using appropriate software. The Australian Bureau of Meteorology achieved a significant reduction in product errors and inconsistencies through the development of TC Module. TC Module supports product preparation by allowing the forecaster to enter all the components of the forecast policy (including prose components of public warnings) into a database and then feeding the data into products in a structured manner. Because the forecast policy components are error checked and automatically fed from a single source the potential for typographic errors and inconsistencies between products is virtually eradicated. The person asked to check the products prior to dissemination can then concentrate on ensuring that the written communication in the public warnings is of the highest standard. It should be noted that wherever possible products should be checked by people who were not involved in writing them, as a fresh perspective can catch errors of phrasing that are not readily apparent to those involved in the drafting of the product.

8.4.4 Coping with the extraordinary

Every tropical cyclone basin will carry cases of systems that have not satisfied the definition of a tropical cyclone but have still caused flash flooding, landslip, wave damage or local wind damage with the aftermath criticism of the adequacy of the warning system. When writing procedures for tropical cyclone operations it is necessary to discuss what to do with systems that do not make it through the tropical cyclone threshold and definition but which can nevertheless be quite troublesome from a forecasting and warning sense and sometimes, quite lethal. Operational strategy needs to remain flexible enough to enable forecasters to respond effectively in these atypical situations. The documentation may simply instruct forecasters to consult senior management; however even if this is the case the documentation needs to give a clear indication of the circumstances under which the forecaster should cease to exercise their own discretion and is obliged to consult management.

8.5 Delivering the message

8.5.1 Forecast dissemination

An accurate forecast is of no benefit if it is not received, understood and acted upon in a timely manner. Once the warning is prepared, rapid dissemination is essential. The method of delivery of warnings is a function of the communications infrastructure of individual countries. However rapid change in communications technology has been universal and it is clear that this will continue, so it is important for warning agencies to stay abreast of emerging trends. Dissemination via facsimile (fax) machines is on the decline in many countries while email, social media and social networking has undergone explosive growth. Later in this section we consider the importance of these new communication channels from the viewpoint of operational strategy, but first we examine the forecaster's role in the dissemination process.

Operationally, a forecaster's job does not end when the warning is issued. Forecasters need to be involved in some aspects of the dissemination process; however for the sake of the overall efficiency of the TCWC, the general rule should be that the less human intervention in the sending processes the better. Warnings prepared on a workstation can be interfaced with the office's communications system for direct transmission. However warnings need to be disseminated using multiple channels and some of these will involve forecaster input, such as media interviews on television and radio or perhaps input into social media forums.

The optimum methods of delivery are likely to vary according to the type of hazard and the immediacy of the threat. Television has strong visual impact and is a good channel for disseminating warnings about slowly developing events (Mileti and Sorenson, 1990). Television typically reaches a large number of people in the evening hours and has the advantage that graphic information such as maps or diagrams can be incorporated into the message.

Radio is also a major channel for disseminating warnings during non-sleeping hours because it can quickly reach a large number of people. Radio tends to be able to respond more quickly and is therefore generally a more valuable medium than television in a rapidly changing scenario. Radio also has the advantage that it is inexpensive to buy some sortof radio receiver, and battery powered radios allow people to stay informed even if their normal power supply has failed.

Networking of both television and radio stations can make it more difficult to break into programming to deliver emergency messages to the public in areas at risk. Program content may be being broadcast across a very large area that includes many people not at risk. Establishing memorandums of understanding (MOUs) with broadcasters can ensure that warning messages are broadcast in a timely fashion, preferably at agreed times. Scheduled broadcasts enable people to know when they can tune in to obtain updates. In Australia, for example, communities in cyclone-prone areas know that warnings are broadcast at set times (in most cases, 15 minutes past the hour) by regional radio stations. The broadcast is preceded by a distinctive alerting sound which draws people's attention to the fact that cyclone information is about to be transmitted. MOUs can also ensure that warning messages are read out word-for-word by the broadcaster.

8.5.2 Interaction with the media

Good tropical cyclone forecasters have a sound scientific knowledge of meteorology combined with experience, but "complete" tropical cyclone forecasters are also excellent communicators. People will react to a warning only if they believe that the information they are hearing is true and is relevant to them. A good communicator will give the cyclone warning this credibility and relevance. There are two major benefits of forecasters interacting directly with the media. Firstly this helps to curtail misinterpretations of a warning message. Secondly, it establishes a direct link between the forecaster and the affected community.

All TCWCs rely on senior management and/or operational forecasters to meet the needs of the media in high impact events. Rather than leave good communication to chance, all staff members who interact with the media should be trained in media presentation. The media do not want a sterile scientific portrayal of the hazard. They want to engage with vibrant personalities who can communicate in plain language the excitement and tension of the tropical cyclone hazard. If forecasters cannot meet the needs of media they will tend to look elsewhere in order to find the "talent" they need. It is in the best interests of warning agencies to ensure they have people who are skilled presenters on both radio and television in order to ensure the organisation maintains a high profile.

There are no hard and fast rules for any particular office about how to interact with the media. It will always be a matter of the circumstances surrounding each cyclone event and the traditions and backgrounds of each individual country. The degree of interaction is very much a function of the sophistication of the media itself. TCWCs should try to develop a protocol which minimises media intrusion on staff already under stress from dealing with the tropical cyclone, but still shows the TCWC as a dynamic, credible organisation. If a separate area can be allocated in the layout of a TCWC specifically for media interviews, then disruption to the office routine can be minimised. However, this should done in consultation with the media - it would be plainly wasting resources to set up a facility that the media would not be happy to use, and media who have traditionally enjoyed free access to a TCWC may not see any benefit from this at all.

Television (TV) is a visual medium and reporters will want to capture vision of the TCWC as a dynamic and animated place. Even if it is possible to conduct all media interviews in other areas it may be necessary to allow some intrusion into the operational area by TV cameras, despite the annoyance this can cause to staff that are already under pressure from the task at hand.

The U.S. National Hurricane Center has adopted a policy which allows the media to have open access during a hurricane event with free access to the forecasting area and to all staff, particularly senior decision makers. This gives the NHC a high public profile during a hurricane event and creates a path for effective, direct communication. The trade-off for this is a corresponding level of disruption for staff involved in the forecasting process.

In contrast the Hong Kong Observatory uses a specially designed TV studio for conducting all briefings and media are not invited into the operational forecasting centre. However they cater to media needs through the provision of graphics presentations of the typhoon event.
In some Australian TCWCs specially designed media briefing rooms have been built adjacent to operational areas, with glass walls allowing the media to film the operational areas without intruding on operational staff. The media are allowed into the operational areas only with permission of the senior forecaster (usually outside the critical window of time leading up to issue of forecasts).

In each of these cases special technological infrastructure has been put into place to make it easier for media to do direct broadcasts from the forecast office. Media interaction should be integrated into the office routine as a planned, deliberate task rather than left as an ad hoc exercise. With prior coordination it is usually possible to minimise the intrusion into critical periods in the forecast cycle.

8.5.3 Social media

It is important for tropical cyclone warning agencies to acknowledge and incorporate emerging communication trends into common place work practice to facilitate stronger linkages with the community. While radio and television continue to be major communication channels, in the last two decades there has been explosive growth in social media and social networks, collectively referred to as Web 2.0[4]. The uptake of social media and involvement in social networks is particularly high amongst young people.

Email, Short Message Service (SMS) texts, instant messaging, Facebook® and Twitter® have become ubiquitous. When the Global Guide to Tropical Cyclone Forecasting was last published in 1993 commercial deployment of SMS was just beginning. It is now the most widely used data application in the world with particularly high rates of usage in Asian countries (Motlik, 2008). Facebook was only launched in 2004 but has already reached over 400 million active users (Website-Monitoring.com, 2010). Twitter and Facebook are largely becoming functions that users place on mobile devises and receive "tweets" and messages as they would an SMS. This capability allows people to receive, read, update and pass on information anywhere at anytime. Facebook and Twitter allow people to receive links to warning information in real time. This is particularly relevant for Twitter as the short summary messages of 140 characters or less, allows users to quickly scan information and links of interest.

Many meteorological agencies worldwide are utilising social media and social networks to help achieve their organisational responsibilities. Some of these agencies include NOAA, UK Met Office and the NZ Met Service. Web 2.0 technologies may also be useful as a means of maintaining operational liaison with emergency services, allowing graphical briefings during operations for example.

4 **Web 2.0** is a term describing the broad shift towards online communication platforms and environments characterised by interaction, collaboration and user-generated content. Web 2.0 encompasses social media technologies and social networks.

Social media are built on technological foundations which use highly accessible and scalable publishing techniques that collectively facilitate communication. Types of social media include internet forums, blogs, wikis, podcasts, pictures and picture-sharing, video, music and music-sharing, rating and bookmarking, instant messaging and email.

Social networks are services which build online communities of people who share interests, information and/or activities. Facebook and Twitter are examples of social network services which are widely used globally and provide the platform for individuals, groups and organisations to engage.

8.5.4 Interaction with Emergency Management agencies

Coordination with emergency management agencies is critical to the overall effectiveness of the tropical cyclone warning efforts. Emergency managers make critical decisions during tropical cyclone events based largely on meteorological advice. Forecasters have responsibility for ensuring that emergency managers have the best possible information on which to make decisions and possess a clear understanding of the probabilities and risks associated with the full range of forecast scenarios.

Poor communication can result in poor decision making that will directly affect many in the community. It is advantageous for forecasters to have a basic understanding of the emergency management arrangements in their jurisdiction. There may be multiple levels of operational emergency management during a large scale event. In order to provide relevant and appropriately targeted briefings forecasters need to understand the role of the group they are briefing within the overall emergency response structure. The effectiveness and efficiency of communication is further improved if the forecasters have developed relationships with key emergency managers. The investment in "relationship maintenance" outside the peak of the season can be of great benefit during operations.

8.6 Outreach and public education

A warning service is only effective if it stimulates appropriate action and for this to happen recipients of the warning must understand what is being said. It is essential therefore to embark on a campaign of public education to help overcome ignorance of tropical cyclone hazards. Storm surge is a clear example of an area where many people are unaware of the nature and scale of the risk. Deficiencies in understanding make it much harder to effectively communicate during operations and can be the root cause of criticism after the threat has passed. Put another way, a weather service can achieve a marked increase in its value to the community — even though its actual forecasting skill has remained unchanged, by undertaking to raise awareness of tropical cyclones.

Public education is usually more effective if it is done in collaboration with the country's counter disaster organisations. Senior personnel, and particularly those personnel who will be conducting media interviews during operations, should be closely involved in the public education programme. A cyclone education campaign is valuable in the following ways:

- It presents a face for the public to associate with and to focus on so that the weather service is not seen as just an anonymous organisation from which impersonal information issues;
- It lets weather service people tell the public the risks involved with tropical cyclones, what a cyclone is, how a cyclone forms, how it can behave, and the problems involved in forecasting tropical cyclones;
- It can acquaint people with how a TCWC operates; how it detects and tracks cyclones and how it puts a warning together;
- It can try to curtail complacency, particularly in areas that have not been seriously affected for some time or where there is a transient population;
- Through a strong bias towards local counter-disaster groups it can ensure that key people involved in emergency response at the local level are well informed about cyclones and TCWC operations.

8.7 Continuous improvement

Components of the tropical cyclone warning system are continuously evolving. Consequently it is important to routinely review operational strategy to ensure that the TCWC continues to operate in the most effective and efficient manner.

8.7.1 Immediate post impact assessment

Post impact assessments are important to understanding the effectiveness of tropical cyclone warning systems and hence should be considered as part of the operational strategy.

They can also yield important information regarding track and intensity in areas where observations are sparse. For example, in areas where there are limited numbers of tide gauges it is often possible to estimate storm tide heights through a field survey. Damage to vegetation or to simple structures such as road signs can also be used to estimate wind speeds.

Assessment of social aspects of the warning system are equally important and is best done while people have recent memories of how they received the warnings, how they understood the messages and the actions they took. Post impact surveys are also a way of building the relationship with the community and can affect the response of the community to subsequent threats.

A wide range of skills is needed to conduct a multi-faceted post impact assessment and they are best conducted by multi-disciplinary teams sourced from relevant agencies. It is necessary to build strong relationships between the agencies in order to be able to organise a post impact assessment in a timely manner following a cyclone impact. To keep the organisation of the field trip to a manageable level, and to prevent unnecessary disruption to communities in recovery, teams should be kept as small as possible. Separating the physical and social aspects can assist in this regard.

8.7.2 Formal review/verification

Continuous improvement is not possible without routine performance review. It is strongly recommended that each weather service should carry out a rigorous evaluation of its forecast ability. A routine validation programme can assess any tangible improvements in forecast skill, and may even be able to suggest where resources could be most economically directed to effect forecast improvements.

The bare minimum of any weather service's validation programme should be an assessment of its forecasts of track position and intensity; at least at 12, 24 and 48 h. Ideally however, an office should validate all of the parameters that it uses in its warnings. Eventually parameters should include position, intensity, size, wind speed and direction (for site specific warnings and/or for islands), rainfall, storm surge, area of land under warning and timing of onset of gales.

Performance validation can be a time consuming process, involving many hours of staff time, which some countries may struggle to afford. However workstations allow the validation process to be automated. With a database management system running in the background of normal operational tasks, forecast data can be efficiently stored, and then used by the verification program to produce the desired results very efficiently and with a minimum of human resources. It is further recommended that weather services also verify the effectiveness of any forecast guidance material that they use to produce their warnings. An analysis of such data will assist in determining the relative usefulness of individual forecast techniques and products.

Debrief meetings following significant impacts can help to establish where existing systems and procedures need improvement. They enable the shiftwork team to gather as one to discuss operational strategy. It is often through meetings such as these that more efficient procedures identified by one team member are discussed, documented and adopted by other members of the team.

8.7.3 Preseason readiness

As part of a TCWC's operational strategy, it is absolutely necessary that there be planning for the coming cyclone season. Forecasters in particular must be ready and waiting for the first active episode in the season rather than merely reacting to events as they unfold. Managers should be aware of issues such as systems preparedness, staff preparedness and public education, prior to the start of the season.

Systems preparedness

It is important that every piece of equipment that is needed to make a TCWC functional works. This will require a systematic checking and monitoring programme which should also be carefully costed and incorporated into the weather service's annual budget. The following points are noteworthy in a TCWC pre-season schedule:

1. There is an operational plan that is both effective and current. If any deficiencies are identified in the cyclone warning system, then the plan should be amended to correct these;
2. Data acquisition systems are operative, e.g., radars tested, remote AWS serviced, observation sites checked (barometers, hydrometers, anemometers etc), and satellite equipment serviceable;
3. All computer systems are operative, e.g., chart plotters, workstations, etc;
4. Warning proformae are up to date
5. Office equipment is serviceable and in adequate supply;
6. All communications are tested, e.g., data in, communication lines out (fax, SSB radio, etc.), and trial warning messages sent to ensure the recipients of the warnings are ready and that address lists for warnings are current;
7. Contingency plans should be in place. There needs to be fallback positions in case of major failure of equipment so that some level of service can still be maintained. It helps to ask the question "What if this fails?" for every piece of equipment in the TCWC. Ideally a business continuity plan will be drawn up that allows for a full range of contingencies including the building being uninhabitable (due to fire for example);
8. The cyclone season programme must be adequately funded so that it can work properly, e.g., extra funds allowed for supplementary observations and payment for staff callouts (if applicable).

Staff preparedness

All staff should be completely aware of their individual roles in a cyclone event. Pre-season briefing sessions are an effective means of doing this, although it can present problems when staff are operational shift workers and cannot all make meetings at the same time. Every endeavour should be made to overcome these sorts of problems. The task of ensuring staff preparedness is an important role and emphasises the fact that there should be a designated specialist within the TCWC to accommodate this.

Forecasters should be aware of the office procedures, particularly any new procedures or techniques that have been introduced. Established techniques should be revised (e.g., Dvorak, formation checklists, motion techniques, storm surge calculation, etc.). The normal or expected performance of the TCWC should be pointed out to forecasters (e.g., previous seasons' forecast errors) as well as general climatological trends, and tips/rules from the more experienced staff on features that should be watched for in the coming season.

Procedural checklists should also be in place so that TCWC duties are clear and can be worked through systematically in a cyclone event (refer Appendix 8.1). This can minimise instances where tasks may be forgotten under pressure.

An invaluable means of preparation is the use of training modules and educational videos from experts in various fields. This can be an effective method of overcoming the problems of rotational shift working staff becoming familiar with procedures and techniques.

Support staff must also be aware of their duties in a cyclone event. Check lists should be prepared for all staff so that the performance of peripheral tasks is not neglected or forgotten, to the detriment of overall operations.

8.8 A forecaster's operational strategy

The previous sections have outlined areas where efficiencies could be made in an operational environment. These involved office layout and staffing, observing systems, the use of workstations, warning dissemination systems, validation of forecasts and the need for public education programs. Something that has not been adequately addressed in the chapter so far is what forecasters actually do during a cyclone episode. Much of the rest of this chapter takes the perspective of management responsible for designing the systems and processes of a TCWC. In this section we take a look at operational strategy from the perspective of a forecaster. The following points are intended to serve as general guidance — a checklist of how to prepare and what to do.

8.8.1 Know your operational plan

Your government may be able to justify an inaccurate forecast made with the best intentions and based on all available information a lot easier than trying to justify an inaccurate forecast resulting from a lapse in procedures or indecision that could point to some degree of incompetence. Forecasters should be fully aware of the operational plan and adhere to it.

8.8.2 Know your duties

Have available a checklist of duties on a time schedule. You can then manage your available time more effectively. There is nothing worse than not being able to make a warning deadline, particularly if the delay was avoidable.

8.8.3 Know your equipment

Once upon a time tropical cyclone forecasters required no more technological skill than the ability to keep a pencil sharp. Advances in technology have changed all that and a forecaster must be very familiar with the intricacies of all operational equipment, especially computer based workstations. Although these systems are designed with robustness in mind, one can never eliminate the possibility of "crashing" a system, and this is most likely to occur in a pressure situation. A forecaster will need to be able to quickly restore a system in such an event (assuming the problem is not hardware related). Pre-season familiarisation with equipment is essential.

8.8.4 Try to anticipate cyclogenesis

Refer to Chapter 4 of this manual for techniques to use in assessing cyclone formation. If the suspect area has the potential to produce gales within 24 h[5], act. If the system does not develop, then the warning can be readily cancelled, but as long as there is a recognised potential for cyclone formation, there should be appropriate alerts to users. It is easier and often a lot less painful to cancel a warning for a system that did not develop than to issue a reduced lead time warning for a developing system.

5The trigger points may be longer for some products. Trigger points will be documented in standard operating procedures.

8.8.5 Locate the system centre as effectively as possible

Make sure each position fix is consistent with previous fixes. It may be necessary to revise past locations in the light of more recent data. Always have a consistent track. Know the location errors associated with each technique used (refer to Section 3.2 for position analysis). Make sure you have processed all available information.

8.8.6 Use all available prediction techniques

Refer to Chapter 4 of this Global Guide on intensity change techniques and Chapter 3 on track prediction techniques. Be aware of the techniques and objective aids and of their shortcomings. Forecasters need to know which techniques to favour in certain circumstances. This ability may be acquired after years of working in a TCWC and it may be called "experience", but if it can be documented, this useful knowledge can be passed on to others.

8.8.7 Keep a log

If time permits, keeping a log or diary (for example, of reasons for adopting certain policies, or reasons for discounting a certain track prediction technique or for positioning the centre in a particular location) can be of significant benefit. By documenting everyone's reasoning, someone (your cyclone specialist, for example) can post-analyse why things went right or maybe astray. Forecasters may be squandering vast amounts of experience and knowledge by not documenting their actions.

8.8.8 Issue "now-time" warnings

In a warning message, always give the cyclone position corresponding to the warning issue time or at the most, 1 h before. For example, the last firm cyclone fix may have been at 2100 UTC, prior to the next warning issue time of 2400 UTC. That warning should carry an extrapolated cyclone position for either 2300 UTC or 2400 UTC. The error in the extrapolation will be small overall, but it will have the effect of enhancing the timeliness and the credibility of the whole warning message. Users do not respond well to apparently "hours old" information. Also, make sure the warning carries the time of the next warning issue, so that users will be in no doubt when the next information update will be (and adhere rigorously to that schedule). Warning proformae should help ensure warning fix times are current and the time of the next warning is included, so be familiar with your proformae.

8.8.9 Know the danger zones for possible cyclone impact

Forecasters should be aware of when a cyclone is starting to pose a threat to a community. Local research into the location of cyclones 24 h prior to impacting a community can lead to the identification of "danger zones" to alert forecasters as to what may be occurring. Continually ask yourself: "When might the gale/storm/hurricane force winds reach the coast if the system moves (i) at the most likely speed (your motion forecast)? (ii) at the fastest speed indicated as possible by the available guidance?" Don't fall into the trap of thinking only about when the system centre will cross the coast, conditions may have become dangerous many hours before that time depending on the structure and size of the system.

8.8.10 Keep your message clear

Tell people what you know when you know it, and don't get caught up with your "gut feeling". Be as specific as you can in the information you provide but remember that there will always be uncertainty in forecasting. The trick is in how you convey your knowledge of the forecast so that the community understands the scenario they are faced with. When briefing emergency services and the media always try to focus on the likely time when gale force or stronger winds will commence on the coast, rather than when the system centre will cross the coast. If there is uncertainty about when the strong winds will commence indicate both the range of uncertainty and why there is uncertainty. For example, rather than saying, "Strong winds are expected to commence some time during Wednesday", it is better to say, "The system is moving very slowly now but is expected to accelerate toward the coast overnight. Depending on just when it begins to move we may see gales commence as early as around sunrise. It's most likely gales will commence around lunchtime but everyone should be prepared before retiring for the evening."

8.8.11 "Double check" warning information

It is easy to make mistakes when working under the stress of a tropical cyclone event — simple mistakes such as putting in the wrong issue time, or the wrong date, or an incorrect position coordinate, or even leaving out an important piece of information about the cyclone. Simple, avoidable errors and omissions like these can have the effect of eroding credibility amongst users. Make it a policy to double check every warning before releasing it. If possible get another staff member to check the warning text, as a fresh eye will usually pick up an error much more effectively. Time taken at this stage for one final check will pay dividends, so make allowances for this step when you reach the critical time window prior to the scheduled issue time.

8.8.12 Be responsive

If there is a major change likely to the forecast (for example, a cyclone changing direction, a significant relocation of centre position or sudden intensification), know the key outside people who need to be contacted and pre-empt the issue of the next warning by informing them of the changes as soon as possible. Time saved at this stage can be invaluable. However don't delay issuing products beyond the scheduled transmission time to incorporate insignificant changes in the analysis position that may have come to light as you were preparing the products.

8.9 Summary

The theme of this chapter is building systems — putting together all the knowledge and techniques presented in the other chapters and moulding it into an effective tropical cyclone warning service. If the system is not effective, or if it is deficient in any one aspect of tropical cyclones, then the price in life and property could be intolerably high.

Ways and means were discussed in which to optimise efficiency and enhance effectiveness within a TCWC, reasoning that real advances made in the organisation of a forecasting office can compensate to some extent for the relatively slow rate of improvement of forecasting performance.

Modification to the general layout of the forecast office should be considered by weather service managers when any deficiencies are found to exist in this area. If information can be channelled into the forecaster rather than the forecaster having to physically search it out, then economies of time could be made which may then translate into improvements in the warning itself. Occupational health and safety issues also need to be dealt with when planning the layout of a TCWC. Aspects such as the reduction of background noise and the use of appropriate lighting were seen to be important areas for consideration.

Adequate staffing should be made available to cope with a cyclone event. Advantages were seen in the appointment of specialist positions that were capable of concentrating on tropical cyclone issues on a year round basis.

Communications are an integral part of the effective functioning of a TCWC and this was discussed both for incoming data and outgoing warning information. The principle data types were examined and the most effective methods of assimilating these into a TCWC were discussed. The most efficient methods of ingesting data involved the use of workstation technology for most data types. Rapid ingestion of data into a readily accessible form will allow the forecaster more available time to assess the situation. The less rushed a forecaster is, the more likely it is that the forecasting decisions that are made will be better reasoned and the warnings issued will be error-free.

Personal computer-based workstations are rapidly becoming more accessible and more affordable, and will eventually become essential to effective operations. The development of software applications specifically for tropical cyclone forecasting will most likely be at the forefront of any future major advances in TCWC operations. Warning dissemination is an important issue if a TCWC is to be effective. Dissemination systems should be developed so that warnings are issued in a timely manner and reach the user as quickly as possible. This usually means a minimum of human intervention (the fewer links in the warning chain the better). The main methods of sending warnings were identified and discussed. An issue here was the need for forecasters to become involved directly with the media. Good media skills will pay off through an increase in the credibility of a warning and a better reaction to the warning information by the general public.

A TCWC must be prepared well before the cyclone season begins. For a warning system to work, it must be well understood by everybody involved, including forecasters themselves, counter disaster groups and the general community. Forecasters' briefing sessions should be encouraged within the TCWC. Close liaison should be nurtured with disaster management groups, and the participation by weather service personnel in public education programs is essential. Also, equipment and systems should be fully tested prior to the commencement of the tropical cyclone season.

The importance of routinely verifying tropical cyclone warnings was emphasised. Although it was recognised that manual verification techniques are tedious, the advent of a verification package on a tropical cyclone workstation and running off a database management system made the prospect of routine verification highly realisable.

Finally, an attempt was made to list (generally, and without being region specific) the sort of strategy which should be adhered to by an operational tropical cyclone forecaster. The underlying message was to be systematic in one's personal approach to forecasting and be involved to ensure that the overall warning system is as efficient as possible. The stakes are much too high to be anything else.

8.10 References

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Appendix

Appendix 8.1 TCWC forecast process time line

This example is intended to be illustrative only, but could be used to build a time line checklist for a specific TCWC scenario.)

At start of each shift:

1. Handover, situational awareness.
2. Review existing products.
3. Assess the broad scale environment (e.g., oceanic heat content, long loops of WV and IR, isobaric and streamline analyses over the entire basin).

Each six-hourly cycle:

1. Analyse synoptic environment. Build a conceptual picture of the dominant synoptic influences on the system. Look for changes in intensity/structure/motion, and changes in the environment (e.g., factors that may affect vertical shear). Take notes to document your synoptic reasoning and for use in technical products.
2. Review current location, intensity and structure (subjective Dvorak, ADT, AMSU intensity estimates, scatterometer data).
3. Review major NWP guidance. Determine consistency with current analyses, consistency between models, variations in timing, amplitude and location of synoptic features, differences in environmental vertical shear. Build a physically consistent conceptual picture of the likely evolution of the system and the spread of possible outcomes arising from different forecast scenarios. Take notes to document your synoptic reasoning and for use in technical products.
4. Check for additional NWP data and ingest/construct NWP guidance forecasts.
5. Locate the system centre. Use all available data and interpreted using the conceptual framework you have built up during your synoptic analysis.
6. Perform Dvorak analysis.
7. Compare against all available intensity guidance (ADT, AMSU estimates, etc.) and assign final estimate of intensity.
8. Assess structure (radius to gales/storm/hurricane winds, eye diameter, radius outer closed isobar, environmental pressure).
9. Create consensus and official forecast tracks. Note the spread of model tracks. Only exclude models if you have a clear rationale for doing so. Check short term forecast speed and direction against recent movement.
10. Determine all forecast parameters (intensity and structure) to the required forecast period (e.g., +120 hrs).
11. Consider warning policy. (Do any communities need their alert status changed?) Determine likely gale/storm onset times at key locations.

12. Determine rainfall forecasts. (Consider eTRAP, NWP forecasts, ensemble products, possible totals under different development scenarios, etc.)
13. Storm surge forecasts (work through probable and worst case scenarios…)
14. Pre-issue liaison with internal stakeholders and emergency management if required.
15. Review latest observational data and update analysis/forecast if significant change implied.
16. Prepare and issue product suite, taking account of priorities and deadlines.
17. Once products issued, check for successful delivery (on publicly available web sites for example).
18. Conduct internal briefings/emergency management briefings/media interviews.
19. Ensure logs (operational diary/Wiki, etc.) are up to date.

Return to beginning of six-hour cycle.

Appendix 8.2 Tropical Cyclone Information Processing System (TIPS) at the Hong Kong Observatory

A decision-support tool named Tropical Cyclone Information Processing System (TIPS) was developed by the Hong Kong Observatory, Hong Kong, China to facilitate decision making in forecasting and warning operations during tropical cyclone (TC) situations. TIPS serves four main functions: (i) integrate all TC related information and data, including satellite/radar fixes and imageries, forecast tracks from warning centres and those derived from NWP models for display; (ii) assimilate track data for computation of an ensemble track for operational forecasting; (iii) compute key parameters for evaluating local impact to facilitate warning decisions; and (iv) generate and dispatch forecast and warning products to the local public and other weather centres. The system has been in operation since 2001 and forecasters at the Hong Kong Observatory find TIPS to be user-friendly and indispensable in TC forecast and warning operations.

A paper which describes the design and features of TIPS is available from the HKO: http://severe.worldweather.org/tcc/document/other/TIPS-final.doc

Appendix 8.3 Some capabilities at the RSMC - Tropical Cyclone Centre New Delhi

Technical capability

Regional Specialized Meteorological Centre (RSMC)-Tropical Cyclones, New Delhi, which is co-located with Cyclone Warning Division of the India Meteorological Department (IMD), has the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the World Meteorological Organization (WMO) / Economic and Social Cooperation for Asia and the Pacific (ESCAP) Panel region bordering the Bay of Bengal and the

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Arabian Sea, namely Bangladesh, Pakistan, Maldives, Myanmar, Sultanate of Oman, Sri Lanka and Thailand. It has also the responsibilities to issue Tropical Cyclone Advisories to the designated international airports as per the requirements of the International Civil Aviation Organization (ICAO).

Observational system

Surface observatories

IMD has a network of 559 surface observatories. The data from these stations are used on real time basis for operational forecasting. Recently a number of moored ocean buoys including meteorological buoy (MB), shallow water (SW), deep sea (DS) and ocean thermal (OT) buoys have been deployed over the Bay of Bengal and Arabian Sea. A number of automated weather stations (AWS) are also in operation along the Indian coast and provide surface observations on hourly basis which are utilized in cyclone monitoring and forecasting.

Upper air observatories

IMD's upper air network includes 62 pilot balloon observatories, 39 radiosonde / radiowind observatories and 1 radiosonde observatory.

Cyclone detection radars

There are 11 S-band radars for cyclone detection located at Kolkata, Chennai, Visakhapatnam, Machilipatnam, Sriharikota, Paradip, Karakikal, Kochi, Goa, Mumbai and Bhuj, which provide vital information for forecasting cyclone landfall point and intensity. IMD has plans to augment its network of AWS and cyclone detection radars.

Satellite monitoring

At present IMD is receiving and processing meteorological data from two Indian satellites, namely Kalpana-1 and INSAT-3A. Kalpana-1 was launched on 12th September, 2002 and is located at 74.0°E. INSAT-3A was launched on 10 April, 2003 and is located at 93.50°E. Kalpana-1 and INSAT-3A both have three channel Very High Resolution Radiometer (VHRR) for imaging the Earth in visible (0.55-0.75 μm), infrared (10.5-12.5 μm) and water vapour (5.7-7.1 μm) channels having resolution of 2x2 km in visible, and 8x8 km in water vapour (WV) and infrared (IR) channels. In addition the INSAT-3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62-0.69 μm), near IR (0.77-0.86 μm) and shortwave IR (1.55-1.77 μm) bands of the spectrum. The resolution of the CCD payload in all the three channels is 1km x 1km. At present about 48 satellite images are taken daily from Kalpana-1 which is the main operational satellite and 9 images are taken from INSAT-3A. Imaging from CCD is done 5 times during daytime only. All the received data from the satellite are processed and archived in National Satellite Data Centre (NSDC), New Delhi.

The Indian Meteorological Data Processing System (IMDPS) is processing meteorological data from INSAT VHRR and CCD data and supports all operational activities of the Satellite Meteorology Division on a round the clock basis.

Under INSAT-3D programme, a new geostationary meteorological satellite, INSAT-3D, is being designed by ISRO. It will have an advanced imager with six imagery channels (VIS, SWIR, MIR, TIR-1, TIR-2, & WV) and a nineteen channel sounder (18 IR and 1 visible) for derivation of atmospheric temperature and moisture profiles. It will provide 1 km resolution imagery in the visible band, 4 km resolution in IR bands, and 8 km in the water vapour channel. This new satellite was launched in July 2013 and should provide much improved capabilities to the meteorological community and users.

Analysis and Prediction

Cloud imageries from geostationary meteorological satellites INSAT-3A and METSAT (Kalpana-1) are the main sources of information for the analysis of tropical cyclones over the data-sparse region of the north Indian Ocean. Data from ocean buoys also provide vital information. Ship observations are also used critically during the cyclonic disturbance period.

The analysis of synoptic observations is performed four times daily at 00, 06, 12, and 18 UTC. During cyclonic disturbance (depression and above intensity), synoptic charts are prepared and analysed every three hours to monitor the tropical cyclones over the north Indian Ocean.

The direction and speed of the movement of a tropical cyclone are determined primarily from the three hourly displacement vectors of the centre of the system and by analyzing satellite imagery. When the system comes closer to the coastline, the system location and intensity are determined based on hourly observations from CDR and DWR stations as well as coastal observatories. The AWS stations along coast are also very useful as they provide hourly observations on real time basis. The WV and CMV, in addition to the conventional wind vectors observed by radio wind (RW) instruments, are very useful for monitoring and prediction of cyclonic disturbance, especially over the Sea region.

A new weather analysis and forecasting system has been installed at IMD, New Delhi, which has the capability to plot and analyse different weather parameters, INSAT and radar imagery and NWP products using pc software known as Synergie, procured from Météo-France International (MFI). It has a tropical cyclone model, to deal with various aspects of cyclonic disturbances. The experimental run in the system commenced at the end of 2009.

Prediction models in operational use

Quasi-Lagrangian Model (QLM)

The QLM, a multilevel fine-mesh primitive equation model with a horizontal resolution of 40 km and 16 sigma levels in the vertical, is being used for tropical cyclone track prediction in IMD. The integration domain consists of 111x111 grid points centred over the initial position of the cyclone. The model includes parameterization of basic physical and dynamical processes associated with the development and movement of a tropical cyclone. The two special attributes of the QLM are: (i) merging of an idealized vortex into the initial analysis to represent a storm in the QLM initial state, and (ii) imposition of a steering current over the vortex area with the use of a dipole. The initial fields and lateral boundary conditions are derived based on global model (T-80 and T254) forecasts obtained online from the National Centre for Medium Range Weather Forecasting (NCMRWF), India. The model is run twice a day based on 00 UTC and 12 UTC initial conditions to provide 6 hourly track forecasts valid up to 72 hours. The track forecast products are disseminated as a World Weather Watch (WWW) activity of RSMC, New Delhi.

Limited Area Model (LAM)

The operational forecasting system known as Limited Area Forecast System (LAFS) is a complete system consisting of data decoding and quality control procedures, 3-D multivariate optimum interpolation scheme for objective analysis and a semi-implicit semi-Lagrangian multi-layer primitive equation model. The model is run twice a day based on 00 UTC and 12 UTC observations. The horizontal resolution of the model is 0.75° x 0.75° with 16 sigma levels in the vertical. First guess and boundary conditions for running the LAFS are obtained online from the global forecast model being operated by the NCMRWF. During a cyclone situation, the model is run by including the Holland vortex scheme. The forecast products are disseminated as a WWW activity of RSMC, New Delhi.

Non-hydrostatic Meso-scale Model MM5 (Version 3.6)

The non-hydrostatic model MM5 is being run on operational basis daily once based on 00 UTC initial conditions for the forecast upto 72 hours. The horizontal resolution of the model is 45 km with 23 sigma levels in the vertical. The domain of integration covers the area between latitude 25°S to 45°N and longitude 30°E to 120°E. National Centre for Environmental Prediction (NCEP) analyses and six hourly forecasts are used as initial and boundary conditions to run the model. During cyclone situations, the model is run by including the Holland vortex scheme. The forecast products are disseminated as a WWW activity of RSMC, New Delhi.

Non-hydrostatic mesoscale model WRF

The Weather Research and Forecast (WRF) model has been implemented based on 00 UTC initial and boundary conditions from NCEP model outputs for the forecast up to 72 hours. The model is run with a single forecast domain covering the Indian subcontinent at a horizontal resolution of 27 km. The performance of the model is found to be reasonably skillful for cyclone genesis and track prediction.

Multi-model ensemble (MME) technique

The multi model ensemble (MME) technique is based on a statistical linear regression approach. The predictors selected for the ensemble technique are forecast latitude and longitude positions at 12-hour interval up to 72-hour of five operational NWP models. In the MME method, forecast latitude and longitude position of the member models are linearly regressed against the observed (track) latitude and longitude position for each forecast time at 12-hour intervals for the forecast up to 72 hours. The model outputs at 12 hourly forecast intervals are first post-processed using the GRIB decoder. The 12 hourly predicted cyclone tracks are then determined from the respective mean sea level pressure fields using a cyclone tracking software. Multiple linear regression technique is used to generate weights (regression coefficients) for each model for each forecast hour (12hr, 24hr, 36 hr, 48hr, 60hr, 72hr) based on the past data. These coefficients are then used as weights for the ensemble forecasts.

Forecast Demonstration Project (FDP) on Landfalling Tropical Cyclones over the Indian Ocean

A Forecast Demonstration Project (FDP) on landfalling tropical cyclones over the Bay of Bengal has been taken up. It will help us in minimizing the error in prediction of tropical cyclone track and intensity forecasts. The programme was divided into three phases:

(i) Pre-pilot phase: Oct-Nov. 2008, 2009
(ii) Pilot phase: Oct-Nov. 2010, 2011
(iii) Final phase: Oct-Nov 2012

Cyclone Warning Dissemination

Cyclone warnings are disseminated to various users through telephone, fax, email, GTS. These warnings/advisories are also put in the website www.imd.gov.in of IMD. Another means to transmit warning is IVRS (Interactive Voice Response system). The requests for weather information and forecasts from general public are automatically answered by this system. For this purpose, the person has to dial a toll free number, "1 800 180 1717" from anywhere in the country. This system has been installed at 26 Meteorological Centres/ Regional Meteorological Centres. High Speed data terminals (HSDT) are installed almost at almost all MCs and RMCs. HSDTs are capable of sending short warning message as SMS and the whole warning message as email. Local weather warnings are put in IMD website for common people. GMDSS message is also put in IMD website as well as transmitted through GTS. Fax is also used extensively for weather warning dissemination.

In addition to the above network, 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 the broadcast capacity of the INSAT satellite. This is a direct broadcast service of cyclone warning 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 IMD's Area Cyclone Warning Centres (ACWCs) at Chennai, Mumbai, and Kolkata and Cyclone Warning Centres (CWCs) at Bhubaneswar, Visakhapatnam, and Ahmedabad are responsible for originating and disseminating the cyclone warnings through CWDS. The bulletins are generated and transmitted every hour. The cyclone warning bulletin is up-linked to the INSAT in C band. For this service, the frequency of transmission from ground to satellite (uplink) is 5859.225 MHz and downlink is at 2559.225 MHz. The warning is selective and will be received only by the affected or likely to be affected stations. The service is unique in the world and helps the public in general and the administration, in particular, during the cyclone season. It is a very useful system and has saved millions of lives and enormous amount of property from the fury of cyclones. The digital CWDSs have shown good results and working satisfactorily.

References

These references are provided for further reading related to the material in this appendix

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