

SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Special Theme

Topic 0: **Quantitative Forecasts of Tropical Cyclone Landfall in relation to an Effective Warning System**

Topic Chair: Jim Davidson, (Australian) Bureau of Meteorology

- 0.1 Track Forecasts
- 0.2 Observations and Forecasts of Wind Distribution
- 0.3 Observations and Forecasts of Rainfall Distribution
- 0.4 Observations and Forecasts of Storm Surges
- 0.5 Observations and Forecasts of Hydrology-related Issues

Abstract

This Workshop report summarises developments in the 4 years since IWTC-V in providing quantitative forecasts of tropical cyclone landfall in relation to an effective warning system. Here the landfall phase is defined as that period of a cyclone's lifecycle bounded by the immediate approach of the cyclone to the coast through to the early part of its transition over land.

The five rapporteurs have reported on monitoring, scientific, and modelling advances since 2002 and all have highlighted the established fact that landfall parameter prediction is highly dependent on the cyclone's track. At a particular location, even small deviations in track can result in vastly different impacts from wind, storm tide, precipitation and flooding. Most deaths in cyclones continue to be caused by flooding and landslides. With the steady growth in coastal population and infrastructure, we are witnessing what amounts to a quantum leap in vulnerability (and therefore risk) in many cyclone prone areas, irrespective of trends in cyclone numbers and intensities. Evacuation times have increased accordingly.

More focus is directed in recent years to gaining a better understanding of the smaller scale wind features in land-falling cyclones as now regularly evidenced by prominent streaks in the surveyed damage pattern. Also attracting global attention are the apparent anomalies in the operational application of the Dvorak technique for estimating cyclone intensity. In accord with an IWTC-V recommendation, the wind conversion factors appearing in the Global Guide on Tropical Cyclone Forecasting are being updated. Any one or possibly all of these developments could ultimately have a bearing on the forecasting of a cyclone's landfall parameters and category scales.

Prospects for further improvements in quantitative forecasts of cyclone landfall appear to rest on greater availability of consensus/ensemble forecasts of not only track and intensity but also precipitation. A multi-global model approach is preferred. Significant forecasting gains can also be realised through the continuing development and distribution of parametric models for a range of landfall parameters. As resources allow, these initiatives should be underpinned by field experiments, demonstration projects and various capacity building activities. Remote sensing data, especially from satellites, will remain critical to the forecast process.

(A) Effective Warning System

To set the scene, what does constitute an “Effective Warning System”?

Extract from WMO PWS-13 “Guidelines on Integrating Severe Weather Warnings into Disaster Risk Management” – Jim Davidson and M. C. Wong – 2005:

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

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

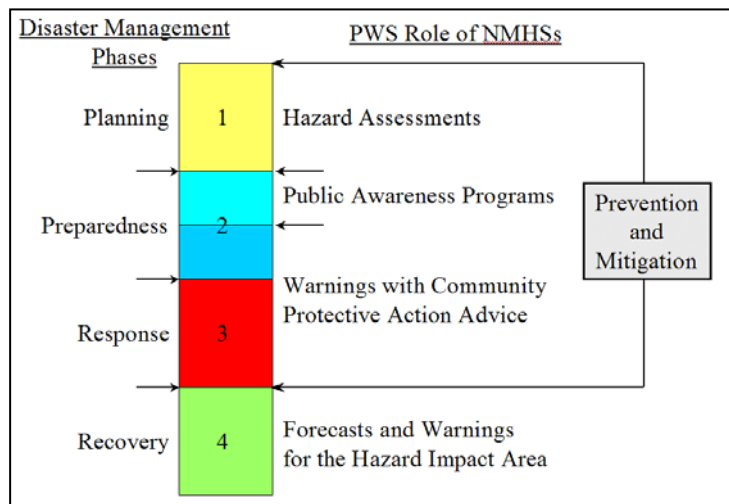
Greater focus towards disaster mitigation also means:

- Further increasing the emphasis on extending the lead time of warnings,
- Improving the accuracy of warnings at varying lead times,
- Presenting warnings in different formats (including graphical products),
- Satisfying greater demand for probabilistic forecasts,
- Better communication and dissemination of warnings,
- Using new technologies to alert the public, and
- Better targeting of the warning services to relevant and specific users (that is, the right information to the right people at the right time at the right place).

Extract from Final WMO Report on Meeting of Expert Team on Public Weather Services in Support of Disaster Prevention and Mitigation – June 2006:

“The scope of disaster prevention and mitigation extends beyond the Planning phase to also include relevant NMHS actions and responsibilities during the Preparedness and Response phases of Disaster Management. In partnership with emergency services authorities, prevention and mitigation by NMHSs during the 3 phases are broadly defined in Figure 1 as being:

- Undertaking hazard assessments utilising severe weather databases during the **Planning** phase;
- Conducting public awareness programs explaining the hazard risk during the **Preparedness** phase; and
- Operationally including community protective action advice in warnings during the **Response** phase.”



(B) Developments since IWTC-V in 2002

Extract from IWTC-V Final Report - Tropical Cyclone Landfall Processes

“The major loss of life in recent decades has been from inland rainfall and its’ associated flooding, land slips and mud slides.”

The GOOD report card in 2002: “The available observing systems and techniques have reached the level of sophistication to enable detailed analysis and research into the related processes and effects on the cyclone structure and associated impacts. We have seen an enormous increase in relevant data from the USA field programs and increasing operational use of remote sensing systems, both satellite and land-based, which provide a wealth of information for research activities. Numerical models with higher resolution allow direct calculation of mesoscale (and even microscale) processes, and lead to improved parameterizations, and thus provide a capacity for both improved research and future operational forecasts. Innovative basic research approaches are improving our understanding and capacity to analyze important features of the boundary layer wind field. In addition, the impacts/response and meteorological communities have moved closer together in improving the warning message and its communication.”

The NOT SO GOOD report card in 2002: “We have very little real skill in forecasting the intensity and structure of tropical cyclones as they approach land, especially when rapid intensity changes occur (up or down), and no skill in predicting any details of the rapid structural changes that occur at landfall. No real skill exists in forecasting tropical cyclone rainfall, and in many cases such forecasts are little more than a general indication of rainfall conditions. This deficiency is the major limitation to hydrological modelling of the run-off and flooding that ensues. Whereas the storm surge modelling is relatively sophisticated, the high dependence on the tropical cyclone track and the wind structure and the poorly modelled interactions with river flooding, are critical limitations.”

The criticality of TRACK forecasts in 2002 (and TODAY): “Overlaying all of these aspects is the great dependence on track forecasts, where even relatively small track errors can result in substantially different rainfall, storm surge, precipitation, and localized wind-field changes.”

Summarising in 2006: In a very general sense, not a great deal has changed since IWTC-V in regards to marked improvement in the “quantitative forecasts of tropical cyclone landfall”. There is little doubt however that the much greater range/quality of information today, especially from weather satellites, has enabled forecasters to better monitor the cyclone track, intensity and structure. The following forecasting strengths and weaknesses still remain, as well demonstrated in the Rapporteur Reports.

Relative Strengths in forecasting landfalling tropical cyclones

- Track forecasting (but note however that small deviations do matter)
- Hydrological and Storm Surge modelling (but still dependent on inputs)

Relative Weaknesses in forecasting landfalling tropical cyclones

- Forecasting cyclone intensity, structure, and structural change
- Forecasting spatial and temporal rainfall patterns
- Modelling wave action (including wave set-up and wave run-up)
- Modelling the combination of riverine flooding, storm tide and waves

Of relevance to this Session are the major outcomes of an International Workshop on Tropical Cyclone Landfall Processes held in Macau, China in March 2005. To quote directly from the Workshop Summary Report:

“The participants gave the following ranking of priorities in regards to improving tropical cyclone landfall forecasts:

- (1) Further improvements in track landfall forecasts;
- (2) Improved predictions of tropical cyclone-related precipitation following landfall;
- (3) Advances in understanding and predictions of structure and intensity during and following landfall, and from tropical storm stages to extra-tropical transition; and
- (4) Further applications of storm surge models, including improved specification of the meteorological forcing.”

Also very worth noting are the key findings of the Workshop Working Group for Tropical Cyclone Landfall Impacts. A series of questions and the associated unedited responses are summarised below.

(1) What have been the chief advances in understanding and forecasting the various impacts of a TC landfall?

- Track forecasting
- Numerical modelling
- Remote sensing data especially satellite
- Availability of radar data on the Internet and TV weather channels has improved chances of people responding appropriately
- Greater knowledge of TC structure eg concentric eye walls, rain bands mainly through better observations
- More graphical products have benefited the community
- More risk/vulnerability studies
- Better communication between NMHSs, media and disaster managers
- Inclusion of “protective action advice” in warnings
- Better understanding of wave action and its components

(2) What are the prioritised requirements related to the impacts of TC landfall?

- Better topographic and bathymetric data for modelling
- Better modelling of the combined effects of storm tide, wave action and riverine flooding
- Better modelling/monitoring/validation of inland flooding from storm tide (as water kills)
- Better modelling of wave action especially for vulnerable islands
- Better historical records for both mitigation and warning
- Better surface observational platforms
- Better information on TC impacts through developing and maintaining databases
- More risk assessments of low probability high impact TC events
- Greater use of TC forecast graphics

(3) What are the meteorological requirements for improved storm surge, hydrology and wind decay forecasting?

- Good return period (or exceedance probability) TC hazard maps
- More surface observations (land and ocean) available in real-time
- Better temporal and spatial rainfall forecasts
- Better description of the TC wind profile
- Greater resource focus on the dangerous/destructive elements
- Wind decay rate is important and is often influenced by neighbouring weather systems
- Greater use of GIS in mapping the TC hazards

- Influence of tidal cycle on storm tide prediction so better timing of landfall is critical – keeping in mind that there’s both a directional and timing element to a TC track forecast
- TC speed after landfall is also critical as this could well have a bearing on both rainfall amounts and wind damage eg a slow moving TC will often produce relatively high rainfalls and greater wind damage

(4) What are the gaps in observations, models etc that must be filled to make progress?

- More aircraft observations eg dropsondes, doppler radar
- Need to ingest radar data into numerical models
- Greater sharing of data/techniques between nations especially in the same region
- The question was then asked – how many global numerical models does the international meteorological community really need?
- More radars – both doppler and conventional
- More use of high resolution coupled (in every way) numerical models
- Greater availability of ensemble prediction systems, consensus forecasts, TC strike forecasts and probability forecasts
- Development of a suite of parametric models for all or most TC hazards
- More attention to developing techniques for estimating the interaction between storm tide, wave action and riverine flooding

(5) What are the opportunities for working with societal impacts experts to improve warnings and responses to warnings of TC landfall?

- Establish an inventory of “where we are now” with the involvement of social scientists
- Many social scientists out there working in the field of natural disasters but very few aligned with NMHSs
- Employ social scientists (in collaboration with emergency managers and maybe the media) to construct the “protective action advice” statements in warnings
- Social scientists would arguably improve the communication, perception, understanding, and response to warnings
- Economists could work out the costs/benefits of disaster mitigation measures, estimate avoidable losses etc
- More international collaboration is needed between “TC hazard” social scientists
- Social scientists could assist in mitigating the overconfidence which is sometimes exhibited by emergency managers
- Important to continue to include “TC Impact” session(s) at IWTCs

(6) If there is to be an international or multi-nation program, what aspects of TC landfall impacts should be the central foci?

- Simulator model – a significant TC event in one part of the world could be transposed to another region or country to test those components of the total warning system from warning to response
- This has the advantage of being more realistic than the standard table-top exercise with a synthetic TC
- Actual evacuations could be factored into the exercise
- The weakest link in the total warning system is more likely to be in the response area than with the warning
- The simulator model aside, field and community surveys should be included in any TC landfall impact program/exercise
- The SW Pacific and the Caribbean were singled out as the parts of the world (where TCs are experienced) that could benefit most from programs/exercises

(C) Rapporteur Report Summaries
0.1 Track Forecasts (Lixion Avila)

The rapporteur noted the steady improvement that has been realised in tropical cyclone track forecasts over the past 10 to 20 years. The reduction in track error could be attributed to various factors, including the improved quantity and quality of observations from a suite of observational platforms ranging from satellites to dropsondes, the use of improved data assimilation techniques (particularly for unconventional satellite observations), and significant advances in the resolution and physics of NWP models. This improvement has been generally reflected in both a reduction in the average length of coastline placed under cyclone warning and an increase in warning lead-time.

Centres issuing tropical cyclone warnings must carefully balance the need to minimize the negative impacts of over-warning against the need to safeguard lives and property. In many cyclone prone areas, the continual increase in coastal population and infrastructure without significant expansion of evacuation routes has resulted in the need for increased evacuation lead-times. This largely explains why greater attention is being placed on translating forecast improvements into increasing the lead-time of warnings as opposed to reducing the warning area.

A number of centres are now providing a pictorial “cone of uncertainty” to display the uncertainties in a track forecast, using either historical forecast track errors or single or multi-model consensus/ensemble output. RSMC Miami has also begun to use “wind speed probabilities” graphics to even better convey the uncertainty in track, intensity and size forecasts.

0.2 Observations and Forecasts of Wind Distribution (Sai-Tick Chan)

The rapporteur noted the inability of NWP models to be run at a resolution high enough to adequately resolve the cyclone structure, especially in an operational mode. Only a limited number of objective guidance techniques have been specifically designed for the task and statistical methodologies continue to be the mainstay in defining/forecasting the wind distribution.

Research is continuing into the structural and wind distribution changes arising from land-sea contrasts, in particular the influence of land-induced asymmetric friction on the boundary layer winds, and the effects of the moist processes in introducing asymmetries in structure at landfall. In recent years due to an increased number of phenomena reports, more research is focussing on the damaging fine-scale surface wind features such as boundary-layer rolls, small-scale spiral bands and vortices, wind streaks, and terrain-induced wind accelerations (both up-slope and down-slope).

The GPS dropsonde has led to a greater understanding of cyclone structure, including eyewall replacement cycles in the more intense systems. Extreme gusts have been reported in both horizontal and vertical wind components. Such events contribute greatly to the extensive wind damage that can result from a landfalling cyclone that cannot be adequately represented by the Saffir Simpson Scale and similar broad-based cyclone category systems.

The justification for using basin-specific wind-pressure relationships was challenged, and it was argued that the variability in wind-pressure balance within and between individual cyclones is likely to be much greater than any regional “average”. Therefore it is considered important to incorporate storm spatial scale and profile shape to allow for the expected natural variability in the wind-pressure balance. The Holland B parameter is a widely applied indicator of the wind-pressure relationship. One of the more recent studies provides a basis for utilising the readily available operational parameters of size, latitude and environmental pressure to enable forecasters to adopt specific wind-pressure pairings on a case-by-case basis.

Notwithstanding the increasing availability of remotely sensed data (e.g. scatterometer) for estimating

surface wind speeds, there remains a critical need to maintain and expand surface wind measurement networks in all areas prone to tropical cyclone impacts. Verification of forecast/modelled winds must remain a priority if real improvements in techniques and procedures are to be realized. Standardisation of wind sampling is also essential.

“Wind Speed Averaging Guidelines” are currently being reviewed in a study sponsored by WMO-TCP, with the goal of updating the relevant mean wind-gust factor table in the Global Guide for Tropical Cyclone Forecasting. It is expected that the results of that study will be presented at IWTC-VI.

Parametric wind field modelling is not generally available to cyclone forecasters. In the absence of aerial reconnaissance, Dvorak is often seen as the only practical operational technique for estimating intensity. Parametric modelling does rely on having at least one or two nearby surface wind and/or pressure observations but can be readily applied within a simplified modelling context to add significant value to satellite-only intensity estimates. The practical utility of parametric models has been boosted in recent times by the emergence of scatterometer data.

SHIPS (Statistical Hurricane Intensity Prediction Scheme) is a relatively successful statistical-dynamical model used in some centres for intensity forecasting, and several recent modifications have improved the technique.

The rapporteur made a number of recommendations that included (1) more research into structural changes at landfall and extreme localised wind gusts, (2) greater operational use of parametric wind field models, (3) improved verification of forecast/modelled winds, (4) expanded network of wind/pressure observations in cyclone prone areas, and (5) standardisation of wind measurement and reporting.

0.3 Observations and Forecasts of Rainfall Distribution (Lianshou Chen)

The rapporteur noted that remotely sensed observations are important in estimating tropical cyclone rainfall QPE. Included here are TRMM, SSM/I, AMSU and IR/VIS satellite data as well as (conventional and Doppler) radar reflectivities. A dense network of rain gauges is also very desirable for rainfall calibration of the remote sensors. Not to be overlooked is that the basic ingredient of tropical cyclone rainfall is moisture supply, best estimated from radiosondes, satellite images and/or radar reflectivities.

A range of QPF techniques have been employed with landfalling tropical cyclones. These include limited area or mesoscale models, with remotely sensed data assimilation improving initialization of the model and the rainfall forecast accuracy. Single and/or multi-model ensemble rainfall forecasts are available in a small number of centres, and showing good potential. Statistical, combined statistical-dynamical and empirical approaches are still commonly used.

A significant advance in recent times is the Very Short Range Forecast (VSRF) that provides 6-hour quantitative precipitation forecasts updated every 30 minutes. The VSRF is based on extrapolation of the latest observed precipitation for the first 3 hours and then model results are combined with extrapolation for the second half of the period.

The rapporteur made a number of recommendations that included (1) both a field experiment and a demonstration project on landfalling cyclones, (2) a global NWP rainfall comparison project, (3) roving seminars, special workshops and symposia on rainfall forecasting, and (4) greater operational availability of satellite data used in forecasting rainfall. A greater research effort also needs to be targeted at calibrating satellite data.

0.4 Observations and Forecasts of Storm Surges (Shishir Dube)

The rapporteur noted that the prediction of storm tide and the extent of coastal inundation depend critically on the prediction of track, intensity and the spatial structure (wind, pressure) of tropical cyclones. There has been little new published material on the subject of the modelling and forecasting of storm tide since IWTC-V. This may be due to a number of factors including (1) the hydrodynamics of storm tide generation and propagation is relatively well established, (2) the accuracy of storm tide predictions is largely limited by the meteorological inputs, and (3) the implementation of new regional models is limited by scarcity of resources.

The advent of powerful PC-based workstations has established a trend to run storm surge models operationally in real-time. This has been recently augmented by the adoption of rapid assessment parametric storm tide forecast models and probabilistic storm tide forecast models in at least a couple of centres. While the probabilistic forecasting of cyclone track has become more widespread through the combination of ensemble NWP tracks, the extension to wind probabilities and especially storm tide forecasting is yet to be widely adopted. The advantage of probabilistic storm tide forecasting is that the full range of parameter possibilities can be explored (track, velocity, intensity, scale, tide, timing etc) and the forecaster can focus on those specific meteorological parameters that will have the greatest effect on the storm tide forecast in a defined coastal zone.

Typically, numerical storm tide modelling systems incorporate simplified (analytical, parametric) descriptions of the wind and pressure fields of tropical cyclones. While such representations are consistent with the level of detail currently provided by the Dvorak technique for example, more sophisticated models have become available in recent years that have the capacity to improve the representation of wind and pressure fields. Considering the steady advancement of NWP models, the feasibility of applying mesoscale NWP model results to storm tide modelling should be pursued, as an improvement in storm tide forecasts is likely. Some "bogussing" of the initial conditions in the NWP model would be desirable.

While there may be advantages in developing or using more complex coupled ocean and atmospheric models for improving cyclone intensity forecasting, they can be costly and the advantages to storm tide forecasting are likely to be less critical, especially if coastal bathymetric data is of poor quality. Simplified analytical wind and pressure models continue to perform satisfactorily provided uncertainty in parameter estimation is considered. Wave set-up is technically a component of storm tide and therefore access to a suitable wave model is also required or a parametric approach adopted.

The rapporteur made a number of recommendations including (1) ensemble and probabilistic methods considered for operational use, (2) high resolution mesoscale NWP models to provide meteorological input investigated, (3) robust and reliable operational storm tide techniques developed, (4) further studies undertaken in estimating wave set-up, (5) coupled ocean-river models developed where applicable, (6) archiving of actual storm tide observations/reports for model calibration, (7) improved response through storm tide education of disaster managers, and (8) capacity building through workshops/seminars.

0.5 Observations and Forecasts of Hydrology-related Issues (Kang Shong)

The rapporteur noted that the severity and extent of hydrological related tropical cyclone disasters, particularly flooding, landslides and debris flow appears to have increased in recent years. Thus an early warning system for hydrological related hazards is becoming more critical. The main challenge here is forecasting the spatial and temporal rainfall pattern.

Some of the essential components of early warning systems for hydrological related disasters are flood, landslide and debris flow hazard mappings, flash flood and sediment disaster forecasting and warning, and flood forecasting model evaluation. Hydraulic models are usually not run operationally, but

nevertheless the hydraulic model results are used in refining the flood hydrological models.

Forecasting of floods produced by land falling cyclones still has a high degree of uncertainty due to a number of factors. Often the model is adequate but the hydrologic and/or hydraulic data and the precipitation network are either non-existent or poor so calibration of the model is difficult. Determining the flood producing potential (QPF) of an approaching cyclone is a related limitation. There is a need to also continue in improving hydraulic and hydrological flood modelling, and this necessarily includes consideration of a tighter coupling with tidal and meteorological modelling outputs.

Both ensemble rainfall forecasts and (very) short term QPF are desired by forecasters and hydrologists alike. Allowance should be made for gridded rainfall inputs to hydrological models to take advantage of improved spatial and temporal rainfall analyses from NWP models. Hydrological model domains could then be digitised to enable gridded rainfall inputs.

Intense rainstorms produced by tropical cyclones often cause severe landslides and debris flows, which have claimed many lives and properties. It is imperative that landslide and debris flow high resolution forecast models are developed, and for that purpose dense rainfall networks and strategically placed radars are essential.

The rapporteur concluded that although some of the existing hydrological models are simplified conceptual representations of rainfall-flood response and fail to model the complexities of the land-based water cycle, the simplified models do provide reasonably good operational forecasts.

Experience in flood forecasting was considered important with an urgent need to improve the capacity of meteorological and hydrological services to jointly deliver timely and more accurate warnings.

APPENDIX: Relevant Recommendations from IWTC-V in 2002

- **Storm surge and wave height forecasting is still a significant problem in many tropical cyclone-affected countries.** WMO should endorse and encourage the establishment of storm surge techniques and models, including river flooding and wave action (especially for small islands), for regions that do not have this capability – and furthermore – one of the main impacts of tropical cyclones is the inundation of coastal areas. To address this problem, it is recommended that techniques for forecasting inundation areas be considered and applied, including the use of inundation maps with the combined effects of river floods and storm surge.
- **Although scatterometer data were not specifically developed for tropical cyclone applications, IWTC-V recognises the valuable contribution these data have provided to both the operational and research communities.** The meeting recommends that WMO encourage the development of future plans for deployment of scatterometer sensors, and other satellite surface wind vector retrievals within the tropical cyclone.
- **Tropical cyclone intensity should not be defined solely by a single parameter such as central pressure or maximum wind.** A more detailed structural analysis is required. The WMO should encourage forecast centres to report within the current WMO format structural information such as quadrant gale radii, eye size, and radius of outer closed isobar in international exchanges of both real-time and best track data. In addition, the time of occurrence and the value of the minimum pressure, and an indication of the occurrence of an eye passage should be added to the synoptic code. This information is needed to determine the maximum wind-minimum central pressure relationship associated with tropical cyclones.
- **The meeting endorses the increasing use and application of ensemble prediction systems (EPS) in forecasting tropical cyclones** – and furthermore - it is recognised that ensemble forecasting techniques may provide an important opportunity to improve tropical cyclone track predictions – and furthermore – the meeting recommends that the research community explore the use of ensemble forecasting techniques for tropical cyclone forecasting including track, intensity, Quantitative Precipitation Forecasts (QPF), storm surge, wind waves and flood forecasting.
- **The meeting considers small focus workshops to be a useful means to organise research-operational-hydrological interaction on topics of particular interest to the operational community.** The meeting endorses the increasing use and application of ensemble prediction systems (EPS) in forecasting tropical cyclones. WMO should organise a series of thematic workshops on (e.g.,)
 - flood forecasting models
 - forecasting of regional and local flooding due to TCs
 - storm surge forecasting
 - extratropical transition of tropical cyclones
 - ensemble models for QPF of tropical cyclone landfall
- **A parametric model of precipitation associated with a landfalling storm should be developed** combining short-range track and intensity forecasts and rainfall rates derived from satellite and radar imagery – calibrated from a rain gauge network.
- **Parametric wind models form a basis for a range of forecast and diagnostic applications.** Yet many such models are kept confidential or have not been adequately tested. The meeting recommends that a public domain parametric wind field model, fully tested and verified by peer review, be developed to provide the standard for comparison purposes.

- **The lack of observational data has caused difficulties with the calibration of the Dvorak intensity analysis technique.** It is recommended that calibration or re-calibration of the Dvorak technique, and all pressure-wind relationships, be undertaken in all basins.
- **Consensus forecasting techniques have been demonstrated to improve track forecasts provided an adequate number of skilful forecasts is available.** It is recommended that all major NWP centres make available track and intensity forecasts, and radius of gale/storm force winds out to 120 hours or beyond. Consensus forecasts should be closely evaluated to identify the minimum number and optimal combination of forecast members that adds value to the forecast process.
- **There is a need for a standard conversion chart that enables users to convert between different wind-averaging periods and gust factors.** The meeting endorses the RSMC recommendation for updating the conversion chart in the Global Guide on Tropical Cyclone Forecasting and requests that the updated values be distributed to TCWCs as soon as they become available.
- **The meeting recommends continued development of statistical-dynamical, ensemble strategies/techniques, dynamical and conceptual models for use in research and real-time operational forecasting of tropical cyclone structure and intensity change** over the ocean, during and following landfall – and furthermore – multidisciplinary co-operation is encouraged to address prediction of rainfall associated with tropical cyclones over land at high spatial and temporal resolution and the associated and subsequent effects of flooding, mudslides, and debris flows.