SUMMARY OF MAJOR RECOMMENDATIONS FROM IWTC-VI

These high-priority recommendations are in no particular order of importance and are stratified in the same way as the entire set of recommendations: WMO-directed in red, Research-directed in blue and Operational-directed in green.

- IWTC-VI urges the WMO Space Program to convey to all consortiums and entities involved in the development of satellite programs the importance of maintaining and even increasing the level of remote sensing coverage, with specific attention given to instruments that provide data for monitoring and prediction of tropical cyclones (microwave data, scatterometer data, altimeter data, total precipitable water data, etc.).

- In particular, the issue of decreased scatterometer and altimeter data availability in the near-future is a matter of major concern to the tropical cyclone community.

- WMO should take action to ensure the operational, timely availability and dissemination of all satellite data of major interest to the tropical cyclone community. Please refer to actions proposed on page 2 of the recommendations for achieving this goal.

- The WMO should take all necessary action to:
  a) improve the communication between operational centres and facilitate the dissemination of all tropical cyclone-related NWP products, such as the deterministic and ensemble forecasts (including the full set of ensemble runs), and
  b) make them available to all RSMCs, TCWCs and researchers in real-time.

- NWP centres should verify their forecasts (including probabilistic forecasts) and document their performance in a common standard format. WMO/CAS could ask, in cooperation with WWRP, the Working Group on Forecast Verification to put in place a formal mechanism for this purpose, defining a common methodology and set of parameters appropriate to tropical cyclones to be verified.

- The re-analysis of past data using current understanding and new techniques was recognised by the IWTC-VI as a major necessity. IWTC-VI strongly encourages all forecast centres to continue revising their historical best-track data base at the highest possible temporal resolution.

- As a major initiative an international database should be developed to track the loss of human life and socio-economic impacts of tropical cyclones as well as the costs associated with tropical cyclone forecasting and disaster mitigation initiatives.
  A small multi-disciplinary task force should be formed to monitor the development of the database and to liaise with other groups with a similar goal.

- IWTC-VI strongly recommends that greater efforts be put into intensity and structure prediction of tropical cyclones. The development of dynamical models, including coupled ocean-atmosphere models, statistical-dynamical models and all methodologies aimed at improving the skill in intensity and size prediction (and resulting wind and rainfall fields) should be strongly encouraged.

- IWTC-VI considers that the tropical cyclone community should engage and cooperate with the THORPEX activities of relevance to the tropics, especially the THORPEX Pacific Asian Regional Campaign (T-PARC) and the Interactive Grand Global Ensemble/Global Interactive Forecast System, which aims in particular to develop generic probabilistic forecast products from a global archive of ensemble forecasts originating from a number of NWP centres.

IWTC-VI
Recommendations

By

Philippe Caroff (Météo-France, RSMC La Réunion), Elizabeth Ritchie (University of Arizona, USA), Jim Davidson (Bureau of Meteorology Brisbane TCWC, Australia), Chip Guard (National Weather Service Guam, USA)

The recommendations are categorised as WMO-directed (in red), Research-directed (in blue) and Operational-directed (in green). High-priority items are labelled as (HP) at the beginning of the recommendation.

1.0 DATA AVAILABILITY AND RELATED ISSUES

1.1 Observations

Atmospheric and oceanic observations are the fundamental basis for all research and operational activities in meteorology and this is particularly true for tropical cyclones, which develop, evolve, and interact with, the data-sparse oceans. Maintaining or increasing the amount and quality of observations of both the atmosphere and ocean is critical to improving the quality of services provided to users and populations by the National Meteorological and Hydrological Services (NMHS) in order to reduce community impacts (including the loss of life) during tropical cyclone events.

The minimum requirement from the tropical cyclone community is a two-dimensional surface wind based on observational data and accumulated precipitation data at adequately high temporal and spatial resolution.

1.1.1 Satellite data are the greatest source of observations of tropical cyclones and we strongly recommend the continued support of satellite-based remote sensing technologies (both existing and future) for the purpose of tropical cyclone detection and structure characterisation, nowcasting, forecasting, and post-analysis.

The IWTC-VI has been advised of a likely reduction in meteorological satellite data, including microwave data that are critical for forecasting and research on tropical cyclones.

- **(HP)** IWTC-VI urges the WMO Space Program to convey to all consortiums and entities involved in the development of satellite programs the importance of maintaining and even increasing the level of remote sensing coverage, with specific attention given to instruments that provide data for monitoring and prediction of tropical cyclones (microwave data, scatterometer data, altimeter data, total precipitable water data, etc…).
- **(HP)** In particular the issue of decreased scatterometer data availability in the near-future is a matter of major concern to the tropical cyclone community.
- Given the escalating importance of global ocean heat content on hurricane intensity and ENSO activity, the WMO should strongly emphasize the importance of satellite radar altimeter measurements from multiple platforms.
- IWTC-VI recommends that the WMO Space Program strongly endorse the specific recommendations of the US National Oceanic and Atmospheric Administration Operational Satellite Ocean Surface Wind Vector Winds Requirements Workshop Report (workshop convened at the US Tropical Prediction Center/National Hurricane Center on June 5-7, 2006).
- The WMO Space Program should also encourage NASA (National Aeronautics and Space Administration, USA) to continue with its plans to launch the Global Precipitation Mission platform.

• The WMO Space Program should actively promote a better global cooperation between all agencies in the fields of oceanographic and meteorological remote sensing to guarantee the most cost-effective satellite coverage that will ensure short-, mid- and long-term availability of data.

• New satellite observing systems for tropical cyclones should be encouraged. In particular, WMO should promote the design and launch of geostationary active/passive sensors. There is a specific need for developing active microwave (Doppler radar) observing platforms enabling a permanent space-based global coverage.

This would help monitor the 3-dimensional structure of tropical cyclones and contribute to improved assimilation of related mesoscale data into cloud-resolving tropical cyclone prediction models.

For this purpose, it is of extreme importance that these new technologies (both atmospheric and oceanic) be calibrated against in situ surface data.

The other **major concern** about remote sensing data deals with their dissemination. Many of the satellite data most useful for tropical cyclone monitoring and prediction, especially track forecasting, are available on web servers that are not continuously maintained (e.g., NRL, CIMSS, CIRA).

• **(HP)** WMO should therefore take action to ensure the operational, timely availability and dissemination of all satellite data of major interest to the tropical cyclone community.

• Whenever possible, dissemination in a digital manner through the GTS and through an operational website should be sought.

• The solution of establishing a WMO-sponsored operational "Satellite Observing Data Centre" should be explored.

This central repository centre would serve (through real-time and archive access) all relevant tropical cyclone-related satellite data and products (including microwave data, scatterometer data – with wind ambiguities –, driftwinds-derived products, etc…).

• The IWTC-VI recommends that improved scatterometer wind ambiguity selection techniques that account for the tight flow curvature in tropical cyclones and initialised by analysed cyclone centre positions, be developed and implemented by the scatterometer data centres. These analyses should be placed in a gridded format and made available to all weather forecast centres.

1.1.2 Rawinsonde Data

The IWTC-VI expressed **concern** about a diminution of rawinsonde observations.

• WMO should explore all possible means to maintain, restore, and even expand, the existing upper-air network, especially in developing countries. Targeted observation strategies could be used to optimize the implementation of rawinsonde stations.

1.1.3 Radar data and conventional data are of major interest for the tropical cyclone community so that:

• the timely dissemination of radar data, ship observations, rawinsondes and other conventional data, and fixes of all relevant specific observations not already routinely disseminated on the GTS by the NMHSs should be converted to operational routine procedures.

1.1.4 Targeted observations – Experiments conducted in the environment of tropical cyclones in recent years have demonstrated value in significantly reducing track forecast errors when ingested in the data assimilation systems of Numerical Weather Prediction (NWP) models.

IWTC-VI recognizes that adaptive observations are a very promising way to improve tropical cyclone track prediction and therefore recommends that:

• WMO encourage expansion of aircraft targeting capabilities in various tropical cyclone basins.

• Research on targeted data should be extended to other observing systems and data (e.g. satellite-derived soundings, ocean data, and rawinsondes). Application of new concepts in predictability and data assimilation should be tested.

• Further research should be undertaken to define the best way to optimise targeted observations.

Furthermore, the following topics should be addressed: sampling strategies, sensitivity analysis of the different techniques and of the data assimilation schemes, definition of the most sensitive regions to be targeted for optimal and cost-effective efficiency and what subsets of data are the most effective in data assimilation for tropical cyclone prediction.

• More work is encouraged to develop methods adequate to assess the impact of any changes on the current observing network and in making optimal use of the related data. In particular, targeted observation methodologies should be utilized to identify cost-effective strategies for maintaining and expanding the current rawinsonde upper-air observing network.

• Observing Systems Experiments should be conducted to assess the observing system impacts.

The IWTC-VI further recommends that:

• both field and community surveys regarding impact, response and preparedness should be conducted in the aftermath of landfalling tropical cyclones.

• A comprehensive post-event report of all the wind, pressure and rain data collected during the tropical cyclone event, as well as its societal impact, should be documented, published, and made available via an appropriate (password-protected) WMO web site.

1.2 Numerical Weather Prediction Products

In light of the benefits yielded by the multi-model consensus approach, the ***sharing*** of all ***ensemble and deterministic forecasts*** issued by the different Numerical Weather Prediction (NWP) centres has been recognised by the IWTC-VI as a **top priority**.

• **(HP)** The WMO should take all necessary action to: 1) improve the communication between operational centres and facilitate the dissemination of all tropical cyclone-related NWP products, such as the deterministic and ensemble forecasts (including the full set of ensemble runs); and 2) make them available to all RSMCs, TCWCs and researchers in real-time.

WMO should investigate the most appropriate ways to achieve this goal:

• coordinate with the NWP and major operational centres (RSMCs and TCWCs) in order to define a set of resolvable tropical cyclone characteristics to be provided and timely disseminated by the NWP centres through the GTS (e.g. centre location, minimum sea level pressure, max wind, wind radii by quadrants, etc…) and define the appropriate standardised format.

• and/or find a WMO-sponsored dedicated reference centre (similarly to what has been done with the Severe Weather Information Centre for the dissemination of the analysis and forecast products issued by the main operational centres) able to host and maintain a single global data base of the tropical cyclone forecasts originating from the different NWP centres.

The data should be made available through a timely and convenient access (password-protected platform or website – like the one hosted by the Japan Meteorological Agency – recommended). Posting of a significant subset of fields, including a suitable number of upper-level fields, from the NWP centres would provide great added value. Interaction with the TIGGE initiative could be considered (see TIGGE item thereafter).

• NWP centres and major operational centres should also coordinate to develop a common standardised vortex tracker to apply to their global and regional models.

• It is further recommended that NWP centres flag model outputs when a synthetic tropical cyclone procedure has been used during initialisation of the model forecast with

some agreed upon common flag. It is important that information regarding the bogussing procedure be made readily available to forecasters and researchers.

- **(HP)** NWP centres should verify their forecasts (including probabilistic forecasts) using tropical-cyclone related metrics and document their performance in a common standard format (information on biases and variance of errors should be included).
- WMO/CAS could ask, in cooperation with WWRP, the Working Group on Forecast Verification to put in place a formal mechanism for this purpose, defining a common methodology and set of parameters appropriate to tropical cyclones to be verified (e.g. genesis, tropical cyclone tracks – including provision of along track and cross track error statistics –, intensities or intensity changes, size – wind radii –, rainfall prediction, etc…).

- IWTC-VI considers that the tropical cyclone community should engage and cooperate on a long-term basis with the THORPEX Interactive Grand Global Ensemble/Global Interactive Forecast System (TIGGE)/(GIFS), which aims in particular to develop generic probabilistic forecast products from a global archive of ensemble forecasts originating from a number of NWP centres. This would enable integration of single- and multi-model consensus approaches.
- IWTC-VI requests that the TIGGE archived data include a set of tropical cyclone-related parameters (e.g. centre location, minimum sea level pressure, max wind, wind radii by quadrants, etc…). Tropical cyclone-related probabilistic product-generation tools should be included in the TIGGE phase-2 and also made available to operational centres in real time.
- As one of the most important users, the tropical cyclone community should also be involved in the design of the future operational GIFS system.
- WMO is asked to report these IWTC-VI recommendations to the upcoming meeting of the International Core Steering Committee (ICSC) for THORPEX in April 2007.

1.3 Databases

All major operational centres (Regional Specialised Meteorological Centres (RSMC) and Tropical Cyclone Warning Centres (TCWC)) should maintain a comprehensive historical tropical cyclone database of best-track (post-storm analyses) in their respective basins.

- **(HP)** The re-analysis of past data using current understanding and new techniques was recognised by the IWTC-VI as a **major necessity.**
- **(HP)** IWTC-VI strongly encourages all forecast centres to continue revising their historical best-track database at the highest possible temporal resolution (e.g., fixes are made more frequently than the archived 6 hours).
- Where multiple "best tracks" exist for a specific basin, these need to be incorporated into a unified, re-analysed tropical cyclone database.

Such re-analysis efforts will by nature generally create a heterogeneous time series because of differing available observations; however, it is also crucial that homogeneous tropical cyclone climate databases be developed.

- For this purpose the WMO format for best track databases should be modified in order to include metadata relating to basic observational quantities and intensity estimate procedures. All derived quantities such as pressure-wind relationships should be appropriately flagged.
- Furthermore, uncertainty in the historical tropical cyclone databases should be determined and recorded.
- In addition, there is a need to identify a set of useful ocean metrics to be either maintained in the tropical cyclone best track database or kept in a separate oceanic tropical cyclone database. A careful re-analysis of past oceanic data should be undertaken as a part of the database development.
- WMO/CAS/TMRP, should provide support for these activities where needed and encourage all efforts to assemble long-term, written, historical records (like the China 500-y record of landfalling typhoons, the Japanese records, and the Cuba records) and other relevant data coming other historical studies (e.g. paleotempestology work).

• WMO should facilitate a working group of experts (operational and research) who maintain or work with these databases to produce a common set of standards on archiving these data and establish a standard procedure for the re-analysis of these best track data. A goal of this group should be to create a single, uniform global best track data base.

1.4 Field Experiments

Sustained efforts to conduct field programs and experiments should be encouraged.

• They should not only focus on synoptic surveillance missions but inner core missions should also be planned, especially in cyclone basins that have not been yet investigated.

• Researchers from all countries and applicable forecast centres are encouraged to support and participate in the tropical and extratropical components of the THORPEX-Pacific Asian Regional Campaign (T-PARC) field experiment in the western North Pacific during 2008.

• Existing datasets from previous field experiments should be made available to all interested groups within the operational and research community, preferably in one central location.

2.0 TRACK FORECASTS

The IWTC-VI affirms that although substantial improvements have been achieved in the past decade, ***track forecasting*** **still remains a high priority.** It is recommended that efforts should continue to further reduce track forecast errors. All potential sources of track errors (model physics, initial conditions, etc.) should be examined, but special emphasis should be given to the following issues:

• investigate the causes of large forecast errors and try to remedy them through comprehensive examination of all relevant potentially linked elements: observations, data assimilation and vortex specification techniques for initial conditions, model resolution and physical processes representations, etc. Systematic review of major failures in track prediction should be undertaken with case studies and inter-comparison exercises. Synoptic patterns likely to be associated with large forecast errors should be documented including identification of model biases and weaknesses.

• while the dissemination of extended long-range forecasts by all operational centres should be encouraged, consideration should also be given to improve short-range forecasts (6 to 24h), which is of critical impact for landfalling tropical cyclones.

• development of high-resolution models should be encouraged. Because they in particular resolve orography, they may be of great help to improve track and structure prediction of tropical cyclones near landfall (including wind and rainfall distribution). Serious consideration should therefore be given by operational centres benefiting from such high-resolution models to test the skill of these models and eventually put them into operations.

3.0 INTENSITY and STRUCTURE PREDICTION

The IWTC-VI acknowledges that intensity changes and structure prediction of tropical cyclones remain a challenge and that past improvements on these aspects have been inadequate.

(HP) IWTC-VI strongly recommends that greater efforts being put into these aspects and encourages the development of dynamical models, including coupled ocean-atmosphere models, statistical-dynamical models and all methodologies aiming to improve the skill in intensity and size prediction (and resulting wind and rainfall fields).

• More research is encouraged to improve our understanding of intensification, size changes, and weakening processes. Special interest should be put on addressing Potential Intensity theories.

• WMO should encourage and facilitate the transfer of research and technique developments, for example intensity guidance such as SHIPS, from the Atlantic and western North Pacific to other basins.

• WMO should organise a model inter-comparison study for evaluating the existing model capabilities on predicting tropical cyclone structure change including identification of metrics for structure and structure change validation (as in Macau Workshop).

• Research on multi-model consensus and single-model ensemble approaches, which show promise for intensity prediction, should be encouraged.

• More research (numerical and statistical) is also needed to improve tropical cyclone initialisation (e.g. bogussing), via data assimilation, parameterisation, and inclusive of the inner core and outer core regions.

• Main operational NWP centres should explore ways of making suitable shear products available to users such as RSMCs and TCWCs. There is also a recommendation for the development of an interpretative measure of vertical wind shear in layers of varying depth. The effects of various types of shear need to be better understood.

• The IWTC-VI recognised that more research and case studies should be conducted to understand the influences and interactions of the upper-level environment on the intensity and size changes of tropical cyclones.

Key aspects of this "good trough" vs. "bad trough" issue may include finding objective ways to quantify upper-level forcing in NWP fields and its influence on tropical cyclone outflow.

• Research is needed to assess coupled model performance with respect to air-sea interaction parameterisations, ocean model initialisations, and vertical mixing schemes used in the coupled models.

A key aspect here is to understand how uncertainties in the parameterisations propagate through the coupled models.

• Centres performing ocean data assimilation should be encouraged to provide ocean heat content products for all tropical cyclone basins. These products should be evaluated and validated using common metrics. The inclusion of a global ocean heat content product to the WMO tropical cyclone website should be considered.

4.0 ENSEMBLE and CONSENSUS

IWTC-VI was presented evidence of the tremendous positive impact the recently developed ***consensus techniques*** have had for tropical cyclone track prediction since being implemented in the major operational centres.

• The development and utilisation of ensemble-based probabilistic guidance should be generalised and extended to prediction of all other tropical cyclone parameters (e.g., genesis, intensity, storm tide, waves, rain and flood forecasting). However, more studies are needed in order to develop a more systematic and optimised approach for the best use of ensemble-based products in operations.

• Forecast uncertainty information should be provided by operational NWP centres to operational forecasters. NWP centres should perform verification of tropical-cyclone related probabilities produced by ensemble prediction systems. The possibility of improving the representation of uncertainty by exploiting the information contained in the spread of the models and of their ensemble should be explored in order to generate a true envelope of uncertainty in tropical cyclone forecasts. Tools to best display ensemble products and also high-resolution models should be developed.

• Further research is also needed to refine the single-model ensemble techniques. The impact of ensemble data assimilation techniques should be in particular explored and tested against variational assimilation techniques.

Multi-model (consensus) forecasts should be closely evaluated in collaboration with WGNE to identify:

(a) the minimum number and optimal combination of forecast members that adds value to the forecast process;
(b) scenarios that yield small errors; and
(c) strategies to deal with situations when the uncertainty associated with the consensus forecast is large (e.g. bifurcation scenario when members are in two different track types)

5.0 EXTRATROPICAL TRANSITION AND GENESIS

- NMHSs are requested to add a flag in their best-track data that indicates the period of extratropical transition (from onset to end). Furthermore, it is recommended that a common definition for the labeling of "ET" in the best tracks of all operational centres should be used for consistency.
- A systematic study is encouraged of NWP model predictability for tropical cyclone genesis and extratropical transition, including identification of conditions of model forecast failure.
- It is recommended that conceptual models of the physics of extratropical transition be developed that will assist forecasters in forecasting ET, particularly when landfall is expected. It is further recommended that improved quantitative precipitation estimates (QPF), particularly at landfall, be a high priority for ET verification programs.
- An ET ensemble forecast methodology to characterise the uncertainties in the forecast should be developed.

We encourage the continued development of cyclone phase space and the evolution towards inclusion of satellite soundings in that development.

- For the next IWTC it is recommended to have a section on ET forecasting. The inclusion of a section on subtropical and hybrid systems and on tropical transition should also be considered.

- The far-field effects of tropical cyclones should be investigated via probabilistic forecasts with a view to determining and conveying how future predictability changes in response to the presence of a tropical cyclone in the model fields.
- More research is required to improve our understanding of the structural changes in tropical cyclones, including genesis, size changes, intensity, and extratropical transition processes. In particular, there is little understanding of the role of the upper ocean in all these processes (beyond the climatological factors). It is recommended that research be undertaken to understand the role of the upper ocean thermal structure on all tropical cyclone processes in the various basins. It is further recommended that the spatial resolution of ocean data that is required to detect effects on cyclogenesis be determined and efforts made to attain that level of detail. It is believed that this can be achieved through more observations of the atmosphere and ocean as well as through atmospheric and coupled models that include upper-ocean and air-sea interface effects.

- To better understand and forecast how genesis does occur in the different basins, further research into the different modes of genesis is needed. Such studies should address the role of the upper ocean in genesis (beyond the climatological factors). Furthermore, stochastic processes should also be investigated. It is further recommended that the spatial resolution of ocean data that is required to detect effects on cyclogenesis be determined and efforts made to attain that level of detail.
- The utility of statistical-based techniques for forecasting genesis should be investigated.
- We encourage research to improve understanding of the relationships between tropical cyclone genesis and the scales of circulation that can be forecast by climate models. Furthermore, we encourage research into establishing what those predictable scales of circulation are.

6.0 SEASONAL FORECASTS

Seasonal forecasts of tropical cyclone activity, some of them including prognosis on landfall probabilities, are issued by different agencies or operational centres in some cyclone basins. There is a need to better communicate and verify these forecasts.

- All seasonal predictions of tropical cyclone activity should be validated in a manner appropriate to their form of output and reported on a central website hosted by WMO.
- Furthermore, we suggest that WMO form a working group of experts to develop a common set of metrics for evaluating the skill of seasonal forecasts of tropical cyclone activity.
- In addition, we encourage that group of experts, under the auspices of WMO, document the purpose and goals of seasonal forecasting and the uncertainties in these forecasts.
- Finally, once a common metric is developed, WMO should coordinate the post-season verification of these forecasts and report them on the website.

6.1 Intra-seasonal and Inter-annual

Many research issues need to be addressed in order to improve the skill in seasonal forecasting. In particular, more work is needed on intra-seasonal and inter-annual variations and controls of tropical cyclone locations, including genesis and track.

- Research to determine the accuracy and limitations of numerical forecasts of tropical cyclone genesis and activity on seasonal and climate time scales should be undertaken.
- The capability for forecasting intra-seasonal variability of MJO- and other tropical wave-forecasting-based techniques should be verified.

We also encourage:

- Research into the large-scale steering mechanisms in individual basins that control tropical cyclone track and genesis locations on inter-annual time scales (e.g., ENSO);
- Research in collaboration with the oceanographic community into the role of intra-seasonal, inter-annual, and multi-decadal ocean heat content variability in tropical cyclone activity on similar scales;
- Research and observations into the El Nino Southern Oscillation (ENSO), to better understand its role in modulating tropical cyclone activity, and research into the forecasting and predictability of ENSO as this is a major roadblock limiting seasonal forecast skill.

It is recognized that there are significant interactions among ENSO, the MJO, and other global-scale circulations such as the Quasi-Biennial Oscillation (QBO) that are not well understood or forecast.

- We encourage research into a more unified theory of how various modes of variability and various scales of tropical waves interact to affect tropical cyclone activity and seasonal predictability.
- We suggest that WMO should facilitate a meeting between the interested operational and research experts to encourage interaction and collaborative research in this field.

6.2 Decadal Variability and Climate Change

Given the importance of this topic to humankind, including developing nations and island nations, it is recommended that WMO through the Tropical Meteorology Research Programme take steps to facilitate and encourage further research on climate effects (natural and human-induced) on tropical cyclones.

• Research on multi-decadal variability and anthropogenic forcing effects on tropical cyclone activity in all basins, to more fully delineate the roles of natural variability and anthropogenic forcing. Physical relationships should be established, not just correlation statistics.

• More generally, we encourage development and research into greater understanding of the role of tropical cyclones in the general circulations of the atmosphere and ocean.

• There is a very large inconsistency between global warming modeling/theory (which suggests small changes in intensity several decades from now) versus some observational studies (which suggest that large changes have already occurred). Further global warming modeling/theory studies are needed to better understand the sensitivity to greenhouse forcing.

• To improve databases for the assessment of climate change and the development of improved tropical cyclone monitoring techniques, the IWTC-VI recommends that consortiums of nations develop the capability for continuous aircraft reconnaissance or as a minimum the validation of satellite-based intensity techniques in all tropical cyclone basins. We recommend that WMO take a lead role in facilitating such a program.

7.0 WINDS

• The IWTC-VI strongly endorsed the need to develop a unified enhanced Dvorak-like technique that will incorporate storm structure changes (including wind-pressure profile variations). Development of systems such as the Advanced Dvorak Technique that can incorporate multiple sources of information such as microwave should be encouraged.

• The IWTC-VI recommends that a public domain parametric wind field model that includes asymmetries be developed and fully tested, documented and verified by peer review. This model could then be used in conjunction with scatterometer data and the Dvorak technique to determine a cyclone's wind and intensity profile.

• The RSMCs and TCWCs are encouraged to work with a multi-disciplinary research community to develop graphic and text products that portray the tropical cyclone size and structure and the combined forecasted uncertainties in the track, intensity and size (e.g., wind probability tool) for public use.

• The IWTC-VI supports the requirement to improve understanding of the effects of variability of surface land roughness and topography on forecast wind speed. The IWTC-VI encourages research on land-surface variability impacts on the surface wind field.

• IWTC-VI reconfirms the requirement for a standard chart that enables users to convert between different wind-averaging periods and gust factors. The WMO should also help facilitate the standardisation of the wind reference amongst global tropical cyclone warning centres.

It is recommended that the various tropical cyclone wind scales in use globally be identified and a summary of their features published for reference by WMO/RSMCs/TCWCs.

• IWTC VI endorses the need to review tropical cyclone Category Scales, with the particular objective of better defining the impacts hazard to improve public understanding of the level of threat. Designing new tropical cyclone Hazard/Risk/Threat Scales that would integrate other hazards like storm tide and rain fall should be considered as it is recognized that, in particular, storm tide is a site-specific sensitivity.

• It was recognised that there is a significant need for further studies into the asymmetry in tropical cyclone structure, upon landfall primarily, including developing a greater understanding of fine-scale and transient features such as mesovortices, boundary layer wind streaks and roll vortices.

8.0 STORM TIDE AND HYDROLOGIC FORECASTS

Flooding is one of the main impacts due to tropical cyclones. The forecasting of floods is tied to meteorological (mainly rainfall forecast) inputs and in many cases to the tidal forecast as well. However, in order to effectively initialise hydrologic and hydraulic models, some improvements are needed.

The IWTC-VI emphasises the need for improved ***rainfall forecasts***. The IWTC-VI recommends that rainfall forecasting techniques for Quantitative Precipitation Forecast (QPF), at a greater spatial and temporal resolution, should be investigated.

- A parametric precipitation model associated with landfalling tropical cyclones should be developed and evaluated. This model would combine a short-range track and intensity forecast with the rainfall rates derived from satellite and radar imagery calibrated from a rain gauge network.
- The availability of short-range rainfall forecasting techniques would greatly assist in forecasting floods and flash flooding. In addition, it would help in forecasting other rainfall induced hazardous situations with short lead times, such as landslips, mudslides and debris flows. Increased research efforts on developing forecasting models dealing with these phenomena are also recommended.

- The IWTC-VI recommends that in areas where operational hydrological and hydraulic models need to be coupled to tidal models, these should be implemented in an operational environment. The integration of meteorological, hydrologic, hydraulic, and tidal models should be evaluated and skill and uncertainties assessed.
- The IWTC-VI recognises that storm tide is a major tropical cyclone-related hazard, which requires specific attention. Operational storm tide forecasting techniques therefore need to be provided to tropical cyclone warning centres that currently do not have this capability. The IWTC-VI recommends that WMO conducts a review of available storm-tide prediction methodologies with the purpose of advising warning centres on the most appropriate options according to their regional characteristics. In particular, the review should consider the individual storm tide components (tide, surge, breaking wave setup, and wave runup). The review should include model validation, ease of use, computational requirements, and training needs.
- The IWTC-VI recommends that more focus be placed at the next IWTC on water-related issues including oceanic, coastal, and inland-flooding processes.

9.0 HAZARD ASSESMENT and MITIGATION

- The IWTC recommends that the WMO assists least-developed and developing countries so as to engage in hazard assessment, risk mapping, and tropical cyclone simulation exercises, to be conducted especially in highly vulnerable coastal and inland areas. Information derived could then be used by NMHSs disaster managers, local governments and communities to better manage and strengthen national disaster and mitigation plans.
- More prominence should be given at the next IWTC to the fields of disaster mitigation and societal impacts. This might be achieved by interweaving those topics into the main program or promoting those sessions to the start of proceedings. Consideration should also be given to inviting representatives of a wider range of related disciplines to the Workshop.
- Regional workshops should be conducted for practitioners every 4 years (2 years out of phase with IWTCs) for the purpose of advancing the Total Warning System concept and the sharing of tropical cyclone societal impact and disaster mitigation experiences.

(HP) As a major initiative an international database should be developed to track the loss of human life and socio-economic impacts of tropical cyclones as well as the costs associated with tropical cyclone forecasting and disaster mitigation initiatives. A small multi-disciplinary task force should be formed to monitor the development of the database and to liaise with other groups with a similar goal.

10.0 TRAINING/EDUCATION/OUTREACH/COMMUNICATION

There is a strong need to provide training to the forecasters to make best use of the new observing techniques (like those dealing with microwave and scatterometer data) and of new products from advanced NWP and operational centres.
IWTC-VI asks WMO to continue to support all initiatives aimed at that purpose: sponsoring of small focus thematic workshops, training courses, attachment of forecasters at the main operational centres (RSMCs and TCWCs), development of Computer Assisted Learning, etc.
Specific training focussed on the following topics should be promoted:

- Ensemble and consensus approaches and related forecasting and probability forecast interpretation
- Training on tropical cyclone rainfall and storm tide forecasting
- Identify effective methods and tools to better communicate the forecasts, warnings and the realistic threats to emergency managers, media and the public.
- The IWTC-VI also recommends that WMO hosts a dedicated tropical cyclone web page including tutorials, training modules, frequently-asked-questions and links to useful related sites.

- Regarding the preceding recommendation, the IWTC-VI recommends that a group of experts including forecasters, and communications experts identify effective communication tools.
- The IWTC-VI also recommends the use of education and outreach to aid in the process of communicating forecasts and warnings.

The IWTC-VI reiterates the urgent need to issue a revised and updated version of the Global Guide to Tropical Cyclone Forecasting and endorses the content of the major WMO recommendation already made on this topic at the previous IWTC-V meeting (refer to the related Proceedings), except that the chapter “The Total Warning System” should be expanded into “Effective Warning System and societal impacts”. A small multidisciplinary task force should be formed to prepare the new section.

IWTC-VI also asks WMO to rapidly initiate the process towards a follow on publication of an updated version of the Global Perspectives on Tropical Cyclones.
The IWTC-VI recognises that there should be inclusion in a coming WMO bulletin of a few articles coming from the IWTC-VI group.

11.0 DEFINITIONS

IWTC VI recommends that WMO be requested to provide agreed upon common definitions of:

1) tropical cyclone coastal crossing;
2) tropical cyclone landfall and tropical cyclone landfall phase (for islands and continuous coastlines);
3) tropical cyclone strike;
4) tropical cyclone Impact;
5) tropical cyclogenesis;
6) extratropical transition (ET);
7) tropical transition (TT);
8) hybrid cyclone; and
9) subtropical cyclone.