

## SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

### Topic 0.4 : **Observations and forecasts of storm tides**

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#### 0.4.1 **Introduction**

The damage from land falling cyclones is mainly due to three factors: rain, strong winds, and storm tide. Storm tides associated with severe tropical cyclones are by far the most damaging. The storm tide is the combined water level associated with the simultaneous effects of the astronomical tide, storm surge and breaking wave set-up (refer Figure 0.4.1). Death and destruction arise directly from the intense winds that are characteristic of tropical cyclones blowing over a large surface of water, bounded by a shallow basin. These winds cause the sea water to pile up on the coast and leads to sudden inundation and flooding of coastal regions. About 90% of the damage is due to inundation of land by seawater. In addition, flooding of the river deltas occur from the combined effects of tides and surges from the sea penetrating into the rivers, because at the same time excess water in the rivers due to heavy rains from the cyclone is trying to flow through the rivers into the sea. On the other hand, small offshore islands in deepwater environments can be most affected by the breaking wave setup component (e.g. on fringing reefs such as TC Zoe at Tikopia in 2003 and TC Meena at Rarotonga in 2005) or wave run up (on unprotected steep deepwater coasts, e.g. the devastation caused by overtopping at Niue Island during TC Heta in 2004). Most of the world's greatest human disasters associated with the tropical cyclones have been directly attributed to storm surges. Thus, the real-time monitoring and warning of storm tide is of great concern. It is necessary that the problem of the storm tide be seriously addressed by the countries of the various regions through collective efforts and in an integrated way.

It may be noted that prediction of storm surge amplitude, peak wave heights and extent of coastal inundation depend critically on the prediction of track (landfall), intensity and the spatial structure (wind, pressure) of tropical cyclones. Progress has been made in cyclone forecasting and warning during the last two decades under regional projects on tropical cyclones. The same cannot be said about the procedure for storm tide forecasting and warning. It is still inadequate. Cyclone forecasting must be further improved, and applied to drive models for forecasting storm tides. There are several aspects of the cyclone and storm tide warning systems and the disaster mitigation that require considerable improvements so as to bring about better response and minimize the loss of life and property.

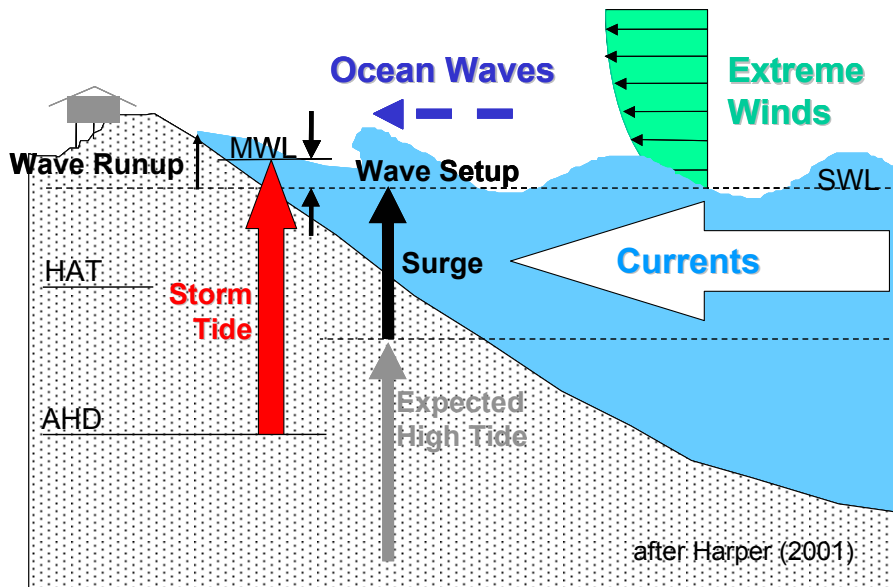


Fig. 0.4.1: Components of a storm tide

#### 0.4.2 Progress in Storm Tide Modelling and Forecasting

There has been little new formally published material on the subject of the modelling and forecasting of storm tide since the IWTC-V in 2002. The reason for this is possibly that:

- a) the hydrodynamics of storm tide generation and propagation is relatively well established;
- b) accuracy of predictions is largely limited by the meteorological inputs, and
- c) implementation of new regional models is limited by lack of resources and data.

The latter factor is critical in that many developing countries, typically with the greatest exposure to storm tide, lack the resources, data and funding to develop sophisticated warning systems, even though the science to do so is well established. In Australia, an upsurge in natural hazards risk assessment spending driven by the desire to understand enhanced Greenhouse threats has led to increased development of models and systems (e.g. HARPER 2001, 2005). These developments have additionally led to improvements in operational storm tide warning systems.

JENSEN ET.AL (2005, 2006) simulated extreme storm surge events in the German Bight and computed the probabilities of their occurrence. Bibliography at the end of the report attempts to partially list the publications on storm surge since ITWC-V in 2002.

### 0.4.3 Operational Storm Surge Prediction Models

Operational numerical storm surge prediction models have been developed and are being routinely used for several coastal regions of the world, such as North Sea, the Gulf of Mexico and Atlantic coasts, Hong Kong, China, etc.

Advent of powerful personal computers has set up a trend to run storm surge models in real-time on PC-based workstations in an operational office. In fact, a PC-based work station (the Automated Tropical Cyclone Forecasting System, ATCF) has already been operation at the Joint Typhoon Warning Centre, Hawaii for years. The Australian Bureau of Meteorology Research Centre, together with their Bureau Severe Weather Programme Office, has also developed an Australian workstation for storm surge forecasting. This has been augmented recently by the adoption of rapid assessment parametric storm tide models in Queensland (e.g. derived from HARPER,2001) and by a probabilistic forecast model for the Northern Australian coastline (SEA 2005ab). In India, DUBE ET AL (1994) developed a real-time storm surge prediction system for the coastal regions of India. Real-time storm surge prediction systems have also been developed for Bangladesh, Myanmar, Oman, Pakistan, Sri Lanka and Thailand.

The National Meteorological and National Hydrological Services of many countries have achieved some success in provision of storm surge warnings and for implementing improved models through co-operative and co-ordinated sharing of responsibilities within the framework and overall guidance and supervision of the Tropical Cyclone Programme (TCP) of the World Meteorological Organization (WMO). The TCP of WMO supported technology transfer to Bangladesh, Myanmar, Oman, Pakistan, Sri Lanka and Thailand from the Indian Institute of Technology-Delhi/Kharagpur. However, there are still several nations that still do not have expertise and resources to run an operational storm tide model.

General forecasting authority of the Federal Government of Germany attached to the Federal Maritime and Hydrographic Agency forecasts the daily tide level and storm surge. In case of storm surge they warn for the whole North Sea coast and give a prognosis for Hamburg.

### 0.4.4 Probabilistic storm tide forecasting (Ensemble methods in storm tide modeling)

While preparing meteorological fields for storm tide forecasting, it is important to consider the error of tropical cyclone track forecast and its influence on storm tide forecasting. Although the performance of tropical cyclone forecast has been advancing steadily, the mean position error in track forecast today is still around 100km for 24-hour forecast and 300km for 72-hour forecast as shown in Figure 0.4.2 (JMA, 2005). This implies that there is probably a large spread of possible forecast values of surface winds and atmospheric pressure at a certain location and the spread, which makes accurate storm surge prediction difficult even for 24-hour forecast.

Figure 0.4.3 demonstrates how the difference in the path of a typhoon changes storm surge occurrence. If a typhoon takes a path left of the forecast track, a storm surge may occur in the western bay in the area shown in the figure (Figure 0.4.3(b)), while a surge may occur in the eastern bay in the figure if the typhoon takes a right path (Figure 0.4.3(c)).

To take into account the influence of tropical cyclone track on the occurrence of storm surge, some National Meteorological Services utilize ensemble or probabilistic methods in storm tide forecast.

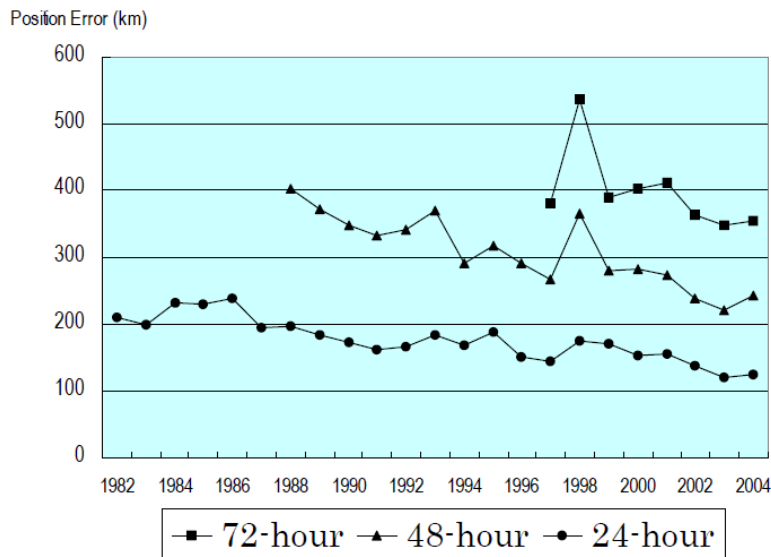


Fig. 0.4.2: Annual mean position errors of 24-, 48- and 72-hour operational typhoon track forecasts (From JMA, 2005)

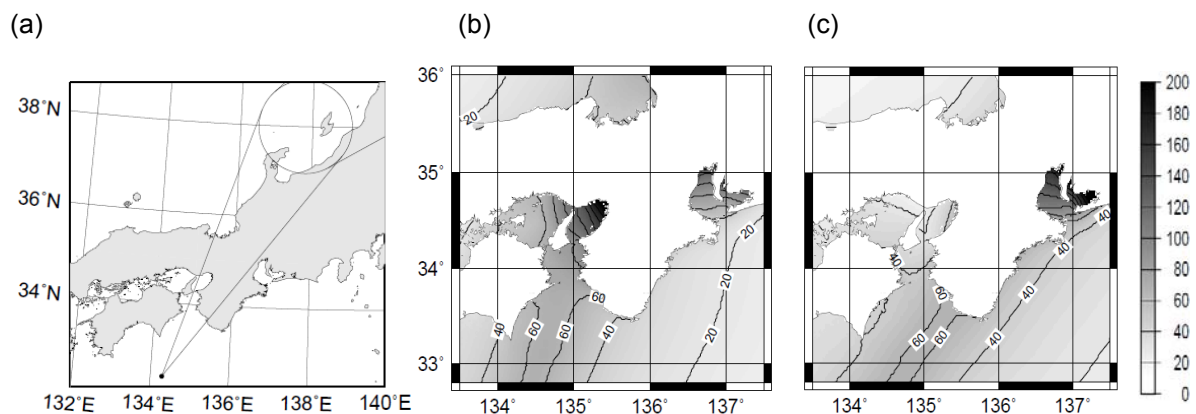


Fig. 0.4.3: Maximum surge envelopes simulated with different typhoon tracks. (unit: cm) (a) Typhoon track used in the simulations. (b) The case in which a typhoon takes the westernmost path. (c) The same as (b) but for the easternmost path.

While probabilistic forecasting of track has become more widespread in many agencies through the use of ensemble NWP tracks, the extension to wind probabilities and especially storm tide forecasting is yet to be widely adopted. While trivial in concept, (i.e. multiple storm surge, wave and/or other associated modelling for a forecast event) the practical implementation in a forecasting environment can be difficult and the computational burden can be significant. Nevertheless, given that the accuracy of storm surge and wave modelling is largely dependent upon the accuracy of the meteorological inputs, it is clear that stochastic simulation of storm tide is an important component for an effective warning system. Besides the dependency of peak storm surge on landfall position and local bathymetry, a macro tidal environment is especially sensitive to the relative timing of the tide and the landfall. Changes in track, speed and intensity can therefore all significantly change the forecast impact. In the past this variability has been accommodated by the use of databases of precomputed MEOWs

(Maximum Envelope of Waters) and also the Maximums of the Maximums (MOM)s technique (e.g. FEMA 1999). While the MEOW/MOMS approach is typically conservative it does not necessarily provide the best information to emergency managers and it is difficult to apply directly in a macro tidal environment.

The Darwin Tropical Cyclone Warning Centre (TCWC) has recently adopted the SEAtide probabilistic model (SEA 2005ab), which uses a parametric storm tide subsystem to enable a rapid Monte Carlo simulation of a user-specified range of storm parameters. The system includes astronomical tide and waves, with allowance for some non-linear interactions. Figure 0.4.4 shows an example of the SEAtide model applied to Townsville in North Queensland, where the 10% non-exceedance storm tide is demonstrated, the prediction being based on a sample of 20 possible forecast scenarios (100 or more scenarios can be rapidly simulated). These concepts can be readily extended to full numerical solutions if the computational power is available, or the parametric forecasts can be further verified by a deterministic storm surge.

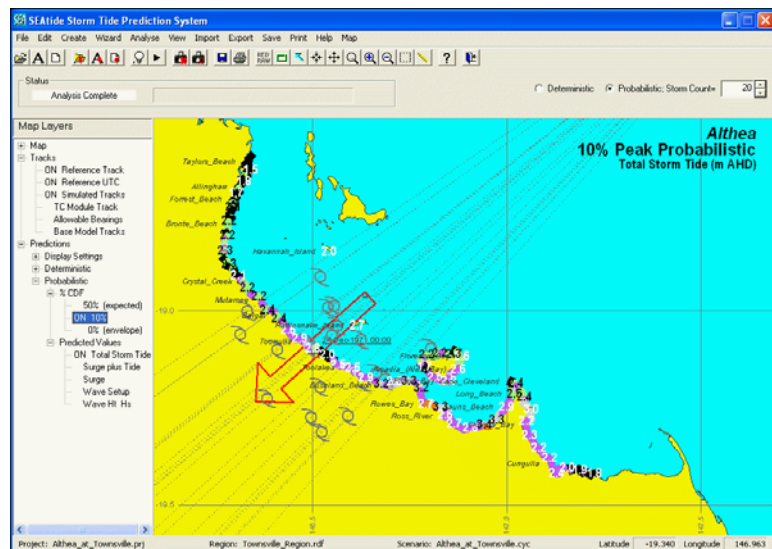


Fig. 0.4.4: An example of the SEAtide model probabilistic storm tide output

Importantly, the system provides the emergency manager with a comprehensive assessment of all threatened localities and the timing and relative impact of possible storm tide flooding.

The advantage of probabilistic storm tide forecasting would be that the full range of viable possibilities is explored (track, speed, intensity, scale, tide, timing etc) and the forecaster can focus on which specific meteorological parameters are the least well known and/or will have the greatest effect on a specific storm tide forecast in a specific area of coast.

Japan Meteorological Agency (JMA) conducts five runs of the storm surge model with five possible typhoon tracks in its storm surge prediction system. These five typhoon tracks are prescribed at the center and at four points on the forecast circle within which a typhoon is forecasted to exist with a probability of 70%, and used to make meteorological fields with the empirical typhoon model.

Having a sufficient number of ensemble members, the ensemble will provide probabilistic information on storm surges. For example, NOAA, U.S.A. starts the provision of "The experimental Probabilistic Hurricane Storm Surge product" on their web page since the beginning of this hurricane season. The product consists of two graphics for the Gulf of Mexico and the Eastern Atlantic coastal areas (Figure 0.4.5). One shows probabilities, in percent, of storm surge exceeding 5 feet. The other indicates there

is a 10 percent chance of the displayed storm surge heights being exceeded. These storm surge graphics are based upon an ensemble of Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model runs using the National Hurricane Center (NHC) official advisory and accounts for track, size, and intensity errors based on historical errors.

This kind of products is expected to provide users with information, which enhances their ability to make preparedness decisions specific to their own situations.

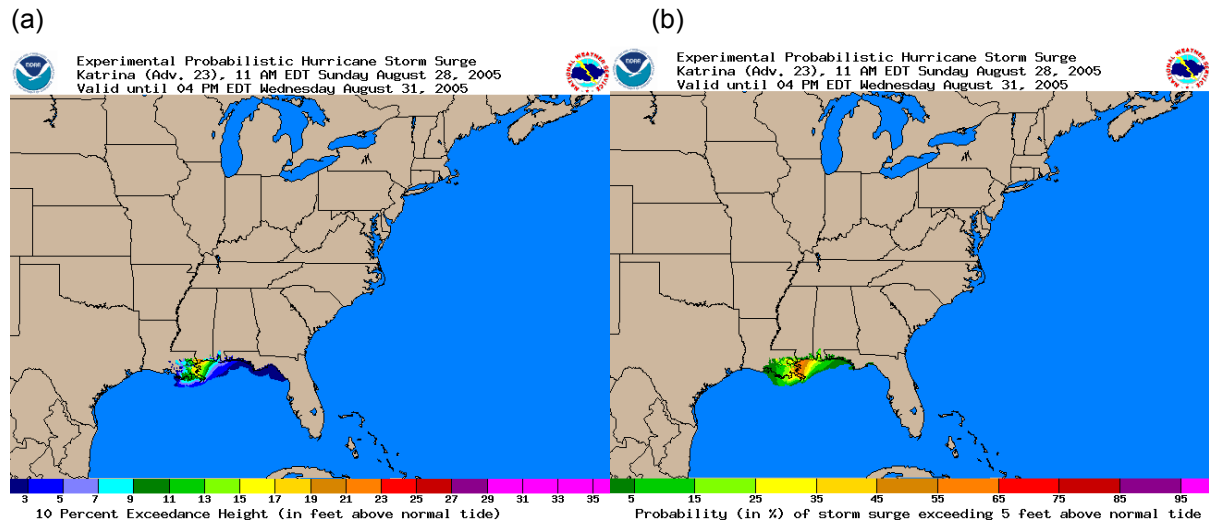


Fig. 0.4.5: Examples of “The experimental Probabilistic Hurricane Storm Surge products” (From NOAA web site, <http://www.weather.gov/mdl/psurge/>) (a) 10 Percent exceedance height, (b) Probability of storm surge exceeding 5 feet above normal tide

#### 0.4.5 Improvements in specifying wind and pressure fields

As Meteorological fields, particularly wind fields, have the biggest impact on the performance of storm tide modeling, it is of great importance to improve the accuracy of wind and pressure fields.

Typically, numerical storm tide modelling systems incorporate simplified (analytical, parametric) descriptions of the wind and pressure fields of tropical cyclones (e.g. HOLLAND, 1980). While such representations are consistent with the level of storm details currently provided by, for example, the worldwide use of the Dvorak technique, increasing knowledge of storm structure and behaviour leads to a desire to improve such models. More sophisticated models have become available in recent years (KEPERT 2001, Willoughby et al. 2005) that have the capacity to improve the representation of wind and pressure fields and these should be considered for future model developments. In all cases, calibration remains an essential tool when considering the relative merits of different wind and pressure models.

In recent years, non-hydrostatic mesoscale NWP models with high horizontal resolution, say, 5-10km, such as NHM of JMA (SAITO ET AL., 2006) have been put into operation at several National Meteorological Services in order to improve short-range weather forecast. Because they are having a capability to represent the structure of a tropical cyclone, applying the meteorological fields derived from these NWP models is likely to improve the performance of tropical storm surge forecasting dramatically, especially for short-range surge forecast. It should be noted that those NWP models could provide sufficient wind fields for storm surge modeling only when given an initial condition that reflects the observed tropical cyclone structure correctly. The initialization can be accomplished by a so-called “bogusing” scheme and sophisticated data assimilation method like 4D-VAR.

Considering the current progress of NWP model technology, the feasibility of applying mesoscale NWP model results to storm tide modeling should be further investigated.

While there may be advantages to some agencies in developing more complex coupled ocean and atmospheric models for improving storm intensity forecasting, the advantages in specifically extending this to include storm tide are likely to be less critical, especially if coastal data is of poor quality. The use of simplified analytical wind and pressure models continues to show good performance for storm tide modelling and, provided uncertainty in parameter estimation is addressed, many nations could continue to significantly improve their storm tide forecasting capabilities without resorting to the additional expense of developing complex coupled models. Importantly, complex models should not prevent the forecaster from adequately considering the uncertainty in the meteorological parameters.

One major benefit of coupled models however could be in the area of improving surface wave estimates due to a potentially better representation of wave fetch. The relative import of this would be site specific but likely to improve wave setup forecasts for offshore islands, where water level and peak spectral wave period can become critically important. A powerful yet simpler technique is to incorporate more sophisticated parametric wind models, such as that by HARDY ET AL. (2003).

#### 0.4.6 Potential impacts of possible enhanced Greenhouse climate change

While the potential for sea level rise under a changed climate will add to any predicted storm tide level in a direct way, the likely impacts on the meteorological parameters are still subject to intense debate. More subtle effects however may eventuate due to nonlinearities of interactions in some specific regions and situations. These possibilities should be explored within the mitigation-planning framework through the systematic consideration of possible climate change effects (e.g. HARPER, 2001; 2004). Detailed numerical modelling should then provide adequate allowance for these effects and forecast models can be readily adapted to meet this challenge.

GÖNNERT, (2002) computed maximum storm surge curve for North Sea (Figure 0.4.6) due to the global warming in the 20<sup>th</sup> century with an increase of the temperature of 0.6 to 0.9° C. The numerical modelling considers the projected global warming from the Intergovernmental Panel of Climate Change (IPCC, 2001; GROSSMANN, et.al. 2007).

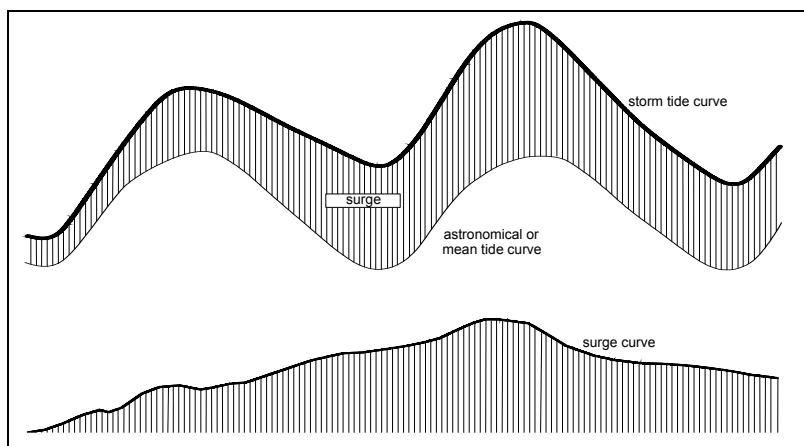


Fig. 0.4.6: Storm Tide and Storm Surge Curve in the North Sea (GÖNNERT, 2002)

Recently there have been some studies (WOTH, 2005; WOTH, K. and STORCH, H. VON, 2006; WOTH ET AL., 2006) to look into the possible changes in North Sea storm-related water heights due to increasing greenhouse gases.

#### **0.4.7 Workshops and Hands-on Forecast Training Laboratories Storm Surge and Wave Forecasting (WMO/JCOMM Initiatives)**

JCOMM/TCP took initiatives, under the leadership of Dr Johannes Guddal, to organize series of Workshops on storm surge and ocean waves and hands on training for the countries of South China Sea and also Indian Ocean. The overall aim of the workshop was to enable these countries, through technological and scientific progress and mutual cooperation, to establish and/or to improve their systems of marine forecasting, in particular with regards to coastal storm surges connected with tropical cyclones. Except the first workshop subsequent workshops were structured as a hands-on training laboratory for ocean forecasting (Ocean waves and storm surges) At the end of the workshops forecasting models were transferred to the participants to enable trainees to run operational wave and storm surge forecasting in their respective home countries. Workshops and hands-on training have been great success. The detailed reports of the workshops can be found out at <http://www.wmo.int/web/www/TCP/TCP-home.html>.

*List of the workshops organized is given below:*

1. JCOMM/TCP Workshop on South China Sea Storm Surge, Wave and Ocean Circulation Forecasting (Hanoi, Viet Nam 21 – 24 January 2002).
2. The Second Workshop on South China Sea Storm Surges, Waves and Ocean Circulation Forecasting “A Hands-on Ocean Forecast Training Laboratory for the South China Sea Region” Kuantan, Malaysia, 15 – 19 September 2003.
3. Third Regional Workshop on Storm Surge and Wave Forecasting – A Hands-on Forecast Training Laboratory (Beijing, China, 25 to 29 July 2005).
4. Fourth Regional Workshop on Storm Surge and Wave Forecasting - A Hands-on Forecast Training Laboratory (Manila, 11 to 15 September 2006).

#### **0.4.8 Recommendations**

- a) Storm surge forecasting and warning systems are not adequate in many nations. Particular attention is urgently needed to develop models for different coastal zones.
- b) Storm surge predictions are readily affected by the error in tropical cyclone predictions in terms both of their tracks and of intensities. Taking into account this, ensemble (-like) and probabilistic methods and outputs should be considered to use in operational storm surge forecast.
- c) As mesoscale NWP models with high resolution are having ability to solve tropical cyclone fields, the use of the results of these NWP models in tropical storm surge modeling should be investigated.
- d) The most important need is the development of robust and reliable operational technique for prediction of storm surge – based on sound hydrodynamics in numerical models. Particular

attention needs to be given to the coastal regions taking into account the complex coastal orientation and estuaries, and this includes their massive freshwater discharge.

- e) Total storm tide water level is the combined effect of storm surge, wave set-up and high tide, and so accurate prediction of wind waves and tidal height together with their non-linear interaction with the storm surge in the model is essential, but prediction methods for wave setup are not well established yet. Therefore, further studies of wave setup prediction method are needed.
- f) While accurate prediction of surge is important, it is also necessary to have an estimate of the coastal stretch likely to be inundated for effective evacuations. To achieve this effort, to develop real-time ocean-river coupled models are required for the regions where they do not exist. For the Bay of Bengal region, this aspect is very important as one of the world's largest river systems (Ganga-Brahmaputra-Meghana) joins the head Bay of Bengal (DUBE et al. 1986; DUBE ETAL. 2005). The Southeast River Forecast Center in the USA is working with the University of Central Florida to use tide forecast and ultimately storm surge forecasts, in conjunction with the National Weather Service River Forecast System. A dynamic routing model is proposed to be applied and the river-level forecast is expected to improve under normal tides and storm surge conditions.
- g) Another area that requires attention is the impact of climate change and a possible sea-level rise and changes in the frequency and intensity of storms. These factors may change flooding risks from storm surges, especially in the low-lying regions of the world such as Bangladesh and Maldives.
- h) Detailed time histories and data dossiers of individual storm surges should be prepared by the concerned countries, which will enable calibration of storm surge models and improvement of prediction techniques. These data are also helpful to assess the potential and susceptibility of the coastlines. Estimates of storm surge potential from historic records are also valuable for efficient administration of cyclone mitigation plans to determine the safety and economics of coastal construction and installations.
- i) It also would also be appropriate to store all the pertinent data when a given storm affects an area, i.e., inundation maps, high-water marks, etc. It is also important to mention that now GIS (Geographical Information System) work is a common tool for most researchers, the design and creation of a GIS that contains precipitation, stream flow, and hurricane track data would be very valuable.
- j) The response of the public and disaster preparedness agencies must be strengthened through better scientific understanding of cyclones and storm surges, and their warnings and related information. This is the area that requires great attention. In spite of some improvement in warning systems, adequate attention has not been given in the development of mechanisms for public response and disaster preparedness organizations. Reliable forecasts lead to public confidence and positive responses to warnings. To get a better response from the public, it is necessary to disseminate this information in a language and wordings that the public can understand, so threats can be properly conveyed to them. Effort is also needed to strengthen communication systems together with warning systems in the regions.
- k) Capacity building and development of human resources in all facets of the storm surge problem is the most important area, which should be given great attention to achieve self-sufficiency by the nations, which lack expertise. Short-term orientation courses for operational forecasters, plus regular workshops and seminars should be organized in the regions.

#### 0.4.9 Summary

This report includes progress and improvements of the storm surge models (including inland inundation). Developments are proposed in effective operational numerical storm surge prediction facility for forecasting the total water level by including non-linear interaction of wind waves and astronomical tides. A key component of the recommendation is capacity building and human resources development in the region of the vulnerable nations through training, provision of transfer of technology, and workshops / seminars.

#### Bibliography

- BAERENS, C. (2003): Die Wasserstände an der Ostseeküste: Entwicklung, Sturmfluten, Klimawandel.
- BARDOSSY, A., PAKOSCH, S. (2005): Wahrscheinlichkeiten extremer Hochwasser unter sich ändernde Klimaverhältnissen. Wasserwirtschaft, Heft 7-8, Wiesbaden.
- BÄRRING, L., H. VON STORCH (2004): Northern European Storminess since about 1800. Geophysics. Res. Letters 31.
- BOON, JOHN D. (2004): Secrets of the tide: tide and tidal current analysis and applications, storm surges and sea level trends. Chichester, U.K
- CHITTIBABU, P., S. K. DUBE, P. C. SINHA, A. D. RAO, AND T. S. MURTY, (2002). Numerical simulation of extreme sea levels for the Tamilnadu (India) and Sri Lanka coasts. Marine Geodesy 25, 235-244.
- CHITTIBABU, P, S. K. DUBE, J. B. MACNABB, T. S. MURTY, A. D. RAO, U. C. MOHANTY AND P. C. SINHA, (2004). Mitigation of flooding and cyclone hazard in Orissa, India. Natural Hazards 31 (2004) 455-485
- DUBE, S.K., P.C. SINHA, AND G.D. ROY, (1986). Numerical simulation of storm surges in Bangladesh using a River - Bay coupled model. Coastal Engineering, 10, 85-101.
- DUBE, S.K., A.D. RAO, P.C. SINHA, AND P. CHITTIBABU, (1994). A real-time storm surge prediction system: An application to east coast of India. Proc. Indian Natn. Sci. Acad. 60, 157-170.
- DUBE S. K., P. CHITTIBABU, P. C. SINHA, A. D. RAO AND T. S. MURTY, (2004). Numerical modeling of storm surges in the head Bay of Bengal using location specific model. Natural Hazards 31 (2004), 437-453
- DUBE, S. K., GÖNNERT, G., MUNROE, A., MURTY, T. S., PADALA, C., RAO A.D., SINHA, P. C. (2004): Storm Surges from Extra-Tropical Cyclones. In: Rao, A. D., Gönnert, G. (Ed.): Storm surges, sedimentation and coastal erosion, Natural Hazards, (32) 2, Special Issue.
- DUBE, S. K., P. C. SINHA, A. D. RAO, INDU JAIN AND NEETU AGNIHOTRI, (2005). Effect of the Mahanadi river on the development of storm surge along the Orissa coast of India: A numerical study. Pure appl. Geophys. 162 (2005) 1673-1688.
- EMANUEL K. (2003): A Similarity Hypothesis for Air Area Exchange at Extreme Winds Speeds. Journal of Atmospheric Sciences, 60.
- FEMA (1999) Northwest Florida hurricane evacuation study. Prep by FEMA, NOAA, State of Florida and US Army Corps of Engineers, July.
- FISCHER-BRUNS, I., H. VON STORCH, F. GONZÁLEZ-ROUCO AND E. ZORITA. (2005): Modelling the variability of multitude storm activity on decadal to century time scales, Geesthacht.

- GISZAS, H. (2004): Sturmflutschutz: Herausforderung und Sicherheitskonzepte. Hansa, 141. Jahrgang Nr. 2, Februar 2004, Hamburg.
- GÖNNERT, G. (2002): Risk assessment by calculating a maximum storm surge curve in Hamburg due to global climate change during the 20th century. In: Deutsches IHP-OHP - Nationalkomitee (Ed.): Low-Lying Coastal Areas - Hydrology and Integrated Coastal Zone Management, Koblenz, 2002, S. 73-78.
- GÖNNERT, G. (2004): Sturmfluten und Windstau in der Deutschen Bucht. Charakter, Veränderungen und Maximalwerte im 20. Jahrhundert. In: Die Küste, 67.
- GÖNNERT, G., (2004): Maximum storm surge curve due to the global warming during the 20<sup>th</sup> in the European North Sea Region (German Bight). In: Rao, A. D., Gönnert, G. (Ed.): Storm surges, sedimentation and coastal erosion, 2004, Special Issue. Natural Hazards, (32) 2, Special Issue S. 211-218.
- GÖNNERT, G. (2004) : Coastal Protection in Hamburg. In: Schernewski, G., Dolch, T.: Geographie der Meere und Küsten. Coastline Reports des EUCC 2004-1.
- GÖNNERT, G. (2004): Sturmfluten und Windstau in der Deutschen Bucht. Charakter, Veränderungen und Maximalwerte im 20. Jahrhundert. In: Die Küste, 67, 2004
- GÖNNERT, G., GIESE, H., PLÜß, (2004), A.: Charakterisierung der Tidekurve. In: Die Küste, 68.
- GÖNNERT, G., GRABL, H., KUNZ, H., KELLETAT, D., VON STORCH, H., SÜNDELMANN, J. (2004): *Klimaänderung und Küstenschutz. Proceedings zur Tagung vom 29. und 30.11.2004, Hamburg.*
- GÖNNERT, G., GÜNTHER, H., BEHRENDT, M. (2005): Sturmflutsicherheit in Hamburg angesichts eingetretener sehr hoher Oberwasser vor dem Hintergrund des Augusthochwassers im Jahre 2002. In: Tagungsband der Konferenz der Hafenbautechnischen Gesellschaft 2005. Hamburg.
- GROSSMANN, I., K. WOTH AND H. VON STORCH. (2006): Localization of global climate change: Storm surge scenarios for Hamburg in 2030 and 2085.
- HANS KUNZ. (2005): Statements zu Küstenschutz und Risikobewältigung: Sprechtag zum Thema "Klimaänderung und Küstenschutz". Hansa, Bd. 142.
- HARPER B.A., (2004) Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering – 2004 Update. Engineers Australia, National Committee on Coastal and Ocean Engineering, EA Books, 76pp. [see also <http://www.engineersaustralia.org.au/nccoe/publicat.htm>]
- HARPER B.A., (2005) Recent advances in storm tide modelling in Australia, WMO International Workshop on Tropical Cyclone Landfall Processes, p17-21, Macau, China, March.
- HAGEN, S.C., O. HORSTMAN, AND R.J. BENNETT, (2002). " An Unstructured Mesh Generation Algorithm for Shallow Water Modeling." The International Journal of Computational Fluid Dynamics", 16, 83-91.
- HARDY, T.A., MCCONOCHIE, J.D. AND MASON, L.B., (2003) Modelling tropical cyclone wave population of the Great Barrier Reef. J. Waterway, Port, Coastal and Ocean Engineering, ASCE, 129 (3), 101-113.
- HOFSTEDE, J. (2005): Comrisk: common strategies to reduce the risk of storm floods in coastal lowlands. The Coast, Bd. 70.
- HUPFER, P. (2003): Die Wasserstände an der Ostseeküste: Entwicklung - Sturmfluten – Klimawandel. Cuxhaven: Kuratorium für Forschung im Küsteningenieurwesen
- ISERT, K., GÖNNERT, G., GIESE, H. (2003): Analyse der Tidekurve. In: Daschkeit, A./ Sterr, H., 2003: Aktuelle Ergebnisse der Küstenforschung. 20. AMK Tagung Kiel. Berichte, Forschungs- und Technologiezentrum Westküste d. Univ. Kiel, 28. Kiel.

JAPAN METEOROLOGICAL AGENCY (2005): Annual Report on Activities of the RSMC Tokyo –Typhoon Center,  
<http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/AnnualReport/2004/Text/Text2004.pdf>

JENSEN, J. (2003): Neue Verfahren zur Abschätzung von seltenen Sturmflutwasserständen. Hansa, Bd. 140.

JENSEN, J. (2005): Abschlussbericht: Modellgestützte Untersuchungen zu Sturmfluten mit sehr geringen Eintrittswahrscheinlichkeiten an der Deutschen Nordseeküste (MUSE). Siegen.

JENSEN, J., FRANK, T. (2003): Abschätzung von Sturmflutwasserständen mit sehr kleinen Überschreitungswahrscheinlichkeiten. In: Die Küste, Heft 67.

JENSEN, J., MUDERSBACH, CH. (2003): Untersuchungen zur Wasserstandsentwicklung an der dt. Nord- und Ostseeküste bis 2001. Bericht im Auftrag des BfG.

JENSEN, J, MUDERSBACH, CHR. (2006): Personal Communication, Hamburg

KATZ, R.W., PARLANGE, M.B. UND NAVEAU, P. (2002): Statistics of extremes in hydrology, Advances in water resources 25. Elsevier.

KEPERT, J. (2001) The dynamics of boundary layer jets within the tropical cyclone core - part I: linear theory. Jnl Atmospheric Sciences, 58, Sept, 2469-2484.

KRAUS E. B., EBEL U. (2003): Risiko Wetter. Die Entstehung von Stürmen und anderen atmosphärischen Gefahren.

KUNZ, H. (2004): Sturmflutschutz und Küstenmanagement. HTG-Kongress 2003, Hansa 141. Jahrgang, Nr.2, Hamburg.

LASSEN, H., SIEFERT, W., GÖNNERT, G. (2002): Windstauentwicklung in dem Tiefwasserbereich der Südöstlichen Nordsee bei Sturmflutwetterlage. In: Die Küste, 64.

LOEWE P. (2005): Nordseezustand 2003. Report of Federal Maritime and Hydrographic Agency, Nr. 38.

MÜLLER-NAVARRA. (2006): Sturmflutvorhersagen für die Nordsee. Sturmfluten sind durch meteorologische Einflüsse verstärkte Fluten.[www.dwd.de/de/Zusatzmenues/Presse/Mitteilungen/20060215e.htm](http://www.dwd.de/de/Zusatzmenues/Presse/Mitteilungen/20060215e.htm) - 8k –

MÜLLER-NAVARRA, S. H., LANGE, W., DICK, S., SOETJE, K. C. (2003): Über die Verfahren der Wasserstands- und Sturmflutvorhersage: Hydrodynamisch-numerische Modelle der Nord- und Ostsee und ein empirisch-statistisches Verfahren für die Deutsche Bucht. Promet, 29.

PLÜß, A. (2003): Das Nordseemodell der BAW zur Simulation der Tide in der Deutschen Bucht. In: die Küste, Heft 67.

PUGH, DAVID T. (2004): Changing sea levels: effects of tides, weather and climate. Cambridge University Press, Printout

REESE, STEFAN (2003): Die Vulnerabilität des schleswig-holsteinischen Küstenraumes durch Sturmfluten: Fallstudien von der Nord- und Ostseeküste. Forschungs- u. Technologiezentrum Westküste, Büsum.

SAITO, K., T. FUJITA, Y. YAMADA, J. ISHIDA, Y. KUMAGAI, K. ARANAMI, S. OHMORI, R. NAGASAWA, S. KUMAGAI, C. MUROI, T. KATO, H. EITO AND Y. YAMAZAKI (2006): The Operational JMA Nonhydrostatic Mesoscale Model. Monthly Weather Review, 134, 1266–1298.

SCHWENN, VERENA (2005): Zur Gefährdung der Nord- und Ostseeküsten sowie der Schifffahrt durch große Sturmfluten. Diploma Thesis Sommersemester 2005.

SEA (2005a) Darwin TCWC Northern Region Storm Tide Prediction System – System Development Technical Report, Prep by Systems Engineering Australia Pty Ltd for the Bureau of Meteorology, Darwin, 208pp, Dec.

SEA (2005b) SEAtide V1.1 Users Guide. Systems Engineering Australia Pty Ltd, 46pp, Dec.

SZTOBRYN, M. (2005): Sturmfluten in der südlichen Ostsee (westlicher und mittlerer Teil). Maritime and Hydrographic Agency, Hamburg.

TRIEBNER, J., GÖNNERT, G. (2004): Besonderheiten des Sturmflutschutzes in urbanen Ästuargebieten am Beispiel Hamburgs. In: Gönnert, G., Graßl, H., Kunz, H., Kelletat, D., Von Storch, H., Sündermann, J. (Ed.): Klimaänderung und Küstenschutz. Proceedings zur Tagung vom 29. und 30.11.2004, Hamburg.

WEISSE, RALF (2005): Marine Climate Change: Ocean Waves, Storms and Surges in the Perspective of Climate Change.

WEISSE, R. PLÜß, A. (2005): Storm related sea level variations along the North Sea Coast as simulated by a high-resolution model. Ocean Dyn. 1958-2002.

WEISSE, R., VON STORCH, H. AND FESER, F. (2005): Northeast Atlantic and North Sea storminess as simulated by a regional climate model 1958-2001 and comparison with observations. J. Climate 18.

Willoughby, H.E., Darling, R.W.R. and Rahn, M.E., (2005) Parametric representations of the primary hurricane vortex. Part II: A new family of sectionally continuous profiles. Mon. Wea. Rev., 134, (4), 1102-1120.

WOTH, K. (2005): Projections of North Sea storm surge extremes in a warmer climate: How important are the RCM driving GCM and the chosen scenario? Geophysics. Res. Let., vol32.

WOHT, K. (2006) :Ppersonal Communication.

WOTH, K., STORCH, H. VON. (2007): Personal Communication, Hamburg.

WOTH, K., WEISSE, R. AND VON STORCH, H. (2006): Dynamical modelling of North Sea storm surge extremes under climate change conditions. An ensemble study. Ocean Dynamics, Vol56.