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SATELLITE INFORMATION REQUIREMENTS FOR COASTAL INUNDATION FORECASTING AND WARNING

In support of the Coastal Inundation Forecasting Demonstration Project (CIFDP)

The Coastal Inundation Forecasting Demonstration Project (CIFDP) was initiated jointly by the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the WMO Commission for Hydrology (CHy), aiming to provide an example of cooperative work as a strategy for building improved operational forecast and warning capability for coastal inundation from combined extreme waves, surges and river flooding events, that can be sustained by the responsible national agencies. The fist sub-project of CIFDP is being launched in Bangladesh where the most destructive coastal inundation regularly occurs due to storm surges and associated flooding.

Satellite observations have clearly demonstrated the potential to provide information to improve coastal inundation monitoring, forecasting and warnings; yet the quality and usability of these observations are still to be improved. This paper introduces the currently identified requirements for satellite information in support of the associated coastal applications, and proposes actions for CGMS Satellite Operators to participate in and contribute to the CIFDP implementation.

Actions/Recommendations proposed:

- CGMS Satellite Operators are invited to consider the requirements of satellite information for coastal applications that are described in this paper, and provide comments to WMO (Dr Boram Lee, blee@wmo.int);

- CGMS members are encouraged to identify opportunities to develop and share improved products / services;

- CGMS members are invited to consider participating in and contributing to CIFDP and relevant R&D activities such as *eSurge*, and to identify ways to coordinate related activities.

- CGMS members are encouraged to liaise with WMO/JCOMM (contact to Dr Boram Lee, blee@wmo.int) to coordinate training activities on forecasting and warning for storm surges and coastal inundation.

Requirements of Satellite Information for Coastal Inundation Forecasting and Warning

1 INTRODUCTION

Coastal regions around the world are often heavily populated and their economic productivity and importance is significant. Of the 33 world cities predicted to have at least 8 million people by 2015, at least 21 are coastal, including 8 of the 10 largest, and highly vulnerable to coastal hazards. In the meantime, a large number of natural hazards occurring particularly in coastal zones are weather–related events. A total of 950 natural catastrophes were recorded in 2010, nine-tenths of which were weather-related events like storms and floods (*Munich Re, Annual Statistics 2010)*.

These events and their impact on coastal areas are not from a sole reason: various factors – such as sea-level rise, increased storminess, inundation – combine and cause greater damage to low-lying coastal regions. To improve the predictability of coastal hazards, those various factors should be considered altogether. As mean sea levels rise by 20-90 cm towards the end of this century, storm surge issues for both real-time warning systems and risk assessment will become even more important.

The Scientific and Technical Symposium on Storm Surges held during 2-6 October 2007 at Seoul, Korea Republic (SSS: http://surgesymposium.org), organized by the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), initiated renewed awareness of the need to improve storm surge forecasting systems that make full use of modern techniques and observations. The SSS made a number of wide-ranging recommendations on future requirements for development of two key activities: (1) real-time operational storm surge forecasting as a contribution to multi-hazard marine warning systems and (2) improved risk assessment. Underpinning those requirements is the need for enhanced observational data for a number of parameters on a range of temporal and spatial scales.

Both WMO and IOC governing bodies endorsed the recommendations of the Symposium, and encouraged Members/Members States to actively contribute to these activities in support of improved global forecasting of storm surges and risk assessment. JCOMM, the technical body of experts in this area is responsible for the implementation and coordination.

2 ONGOING ACTIVITIES: COASTAL INUNDATION FORECASTING DEMONSTRATION PROJECT (CIFDP)

Discussions at the SSS have recently realized in the advisory Workshop on enhancing forecasting capabilities for North Indian Ocean storm surges under the framework of the UNESCO project on “Enhancing regional capabilities for coastal hazards forecasting in North Indian Ocean” (http://www.jcomm.info/SSIndia2), and the *eSurge* project by the European Space Agency (http://www.storm-surge.info/) to look at how storm surge forecasting systems and applications can be improved through the innovative use of ocean, land and atmospheric satellite observations. One common goal from all of these coordinated activities will be to comprehensively define a set of data requirements, both in-situ and remotely sensed. Broad support for these important initiatives is essential to improve our understanding and prediction of the most destructive phenomenon in the marine environment.

For many storm surge warning and coastal management applications the Total Water Level Envelope (TWLE) at a given location and time is extremely useful. TWLE is the combined effect of residual surge, high tide, wave setup, wave run-up, and for some regions, precipitation and river flow. In the meantime, there exists limitation of operational technologies to precisely predict TWLE. Building on the past and ongoing efforts to improve operational capabilities for storm surge forecasting, JCOMM and WMO Commission for Hydrology (CHy) jointly initiated a demonstration project with the objective of building improved operational forecasts and warnings capability for coastal inundation from combined extreme waves, surges and river flooding events. The main focus is to facilitate the development of efficient warning systems for coastal inundation based on clearly identified national/regional requirements. Therefore the Coastal Inundation Forecasting Demonstration Project (CIFDP) should:

- Support informed decision-making on warning issuance and dissemination (that includes information on land-use and planning);
- Transfer and translate science and technology to communities (technology development and transfer);
- Facilitate the development of a comprehensive Storm Surge Watch Scheme (SSWS) in basins subject to tropical cyclones and storm surges;
- Facilitate the development and implementation of warning services;
- Provide improved science to forecasters;
- Support risk assessment and mapping;
- Provide a framework for Coastal Flood Management; and
- Identify and support end-user needs.

In the context of cross-cutting capacities, the project aims to establish collaboration and regular communication between scientists, forecasters, national meteorological/hydrological services and institutional end-users, to meet users' requirements and enhance response to coastal inundation risks.

3 SATELLITE DATA REQUIREMENTS FOR FORECASTING AND WARNING OF STORM SURGE AND ASSOCIATED COASTAL INUNDATION, IN SUPPORT OF CIFDP

The TWLE and associated data are required from a number of well-documented surge episodes from a region for calibration and validation of numerical predictive models, analysis of historical events and real-time forecasting and verification of storm surges and associated inundation. A considerable range of meteorological, oceanographic, bathymetric, topographic, hydrological and orographic data is required to underpin a reliable TWLE forecasting and analysis for a given area.

Numerical models of atmosphere and ocean play a critical role in forecasting storm surges and associated coastal inundation, since the resolution required in marine meteorological and oceanographic (‘metocean’) forcing and evolution of the surge as it approaches the coast is considerably higher than that provided by most observational systems. Nevertheless, it is the observation-model combination that provides the best results. In recent years with the advent of additional data types, and the increased sophistication of storm surge models, the possibilities and requirements for additional data have evolved. A schematic of the storm surge prediction process is shown in Figure 1.

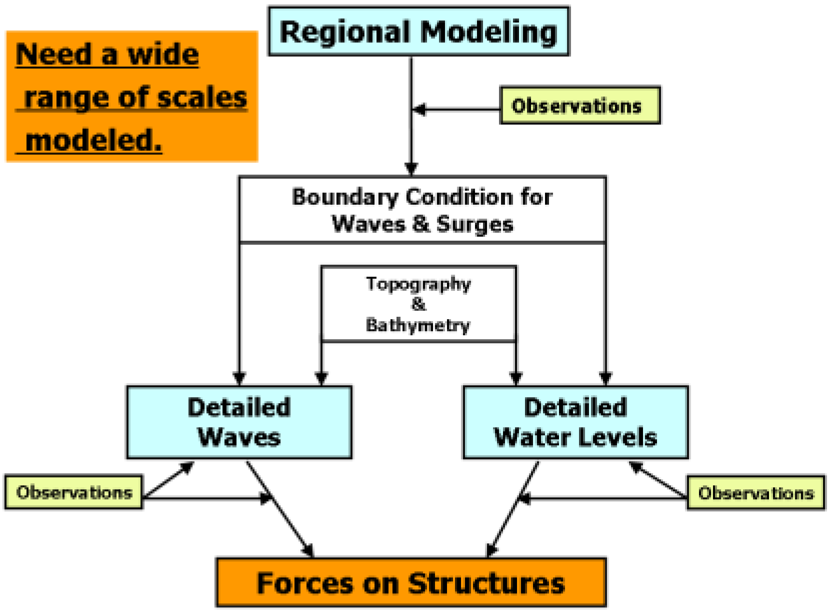

Figure 1. Schematic of data requirements for total water level predictions.

Data requirements for forecasting and risk assessment of storm surges and associated inundation fall into three main categories, and encompass several different variables and observational methods:

(1) Data we need **in advance** of an event, which need to be updated on longer time scales. This includes shoreline geometry, bathymetry and coastal elevation. These data are a common requirement with the tsunami forecasting and inundation activities.

- Bathymetry on continental shelf areas should be available on a horizontal resolution of 100 m, with a vertical resolution of 1 m, and be updated every 5 years, with more frequent updates in sensitive river mouth areas such as Bangladesh.
- Digital elevation data for coastal areas should be available with a horizontal resolution of 5 m, a vertical resolution of 0.5 m, and be updated on a decadal time scale.

(2) Data we need **after** the event for model and forecast validation and calibration. This is comprised of post-event surveys of inundation extent, depth and duration. This should include crest gauges or ribbon networks (specially treated ribbons which indicate exposure to flood water, deployed in advance of a storm), satellite photos of inundated regions, and manual surveys of inundated areas, with in-person interviews. This information should be collected over periods ranging from a few hours after the storm to several days depending on the rate of retreat of the water. The required horizontal resolution for this information is 25 m; satellite images may be able to provide information at 10 m resolution. This is also a common requirement with the tsunami community for extent of tsunami inundation.

(3) Data we need **during** the event, over the period of a few days preceding landfall of a storm (tropical or extratropical), updated in real time. This can generally be characterized as metocean data, including the meteorological forcing and the water level response. These data would include:

- storm track and intensity,
- nearshore wind fields,
- wave heights,
- surface water levels (at least 1-minute average values),
- surface pressure fields, at least pressure drop
- surface currents,
- sea surface temperature, vertical temperature profiles, sea surface height anomalies.

These data may be provided from a range of observational systems (ground-based, buoys, aircraft, satellites). Table 1 describes sources of required metocean data for forecasting storm surges and associated coastal inundation, as documented by the JCOMM Services and Forecasting System Programme Area (SFSPA).

Table 1. Sources of Metocean data
(excerpt from JCOMM SFSPA Observations User Requirement Document)

Parameter	Field data sources	Satellite data sources	Numerical model and analysis data sources
Sea state	Wave buoys. Ship observations. Oil platforms. Coastal HF radar.	Satellite altimetry (wave height data). Synthetic Aperture Radar data.	Wave model analysis and forecast systems
Surface wind	Moored buoys. Drifting buoys. Ship observations. Oil platforms.	Scatterometer data. Satellite altimetry.	NWP analysis and forecast systems.
Precipitation	Ship observations. Coastal stations. Oil platforms. Weather radar.		NWP analysis and forecast systems.
Sea surface temperature	Argo floats. Ship observations. Moored buoys. Drifting buoys.	Infrared satellite data. Microwave satellite data.	SST analysis systems. Ocean analysis and forecast systems.
Bathymetry / shoreline	Aerial photographs.	Satellite imagery.	Bathymetric chart data. Gridded bathymetric datasets.

The data identified in paragraph (3) above are the ones most relevant to an operational metocean ocean observing program. They are also common to many other programs, so there is a large degree of commonality in terms of the data requirements and accuracy.

Requirements for accuracy of the metocean parameters needed are basically as given by WMO (e.g. Rolling Review of Requirements), although the spatial resolutions required for storm surge forecasting will be of higher resolution, at least in the shelf areas.

No restrictions should be placed on the availability of water level and related data; complete documentation of a storm surge may require extensive cooperation between neighbouring countries. One of the most challenging areas is to ensure national access to, or development of, high resolution, near shore, bathymetric data sets

Need for Improved Information / Products from Satellites

Surface wind data from satellite, especially scatterometer, plays an important role in defining the forcing for storm surge generation, from both tropical and extra-tropical storms. Research requirements for remotely sensed winds (and waves) include calibration issues in the most extreme conditions, and rain attenuation effects, which will be critical in tropical cyclones. Satellite SAR (Synthetic Aperture Radar) can measure speeds, both in the coastal zone and in the open ocean where no in-situ measurements are possible.

Visible and infrared satellite images can be used to track the progress of storms and estimate their landfall location. They can also be used to assess the degree of inundation after an event, both to support recovery efforts and to assess the performance of the models used. Combined with SAR, such images can help estimating the coastal stretch likely to be inundated.

An important potential data set for forecasting storm surges and associated inundation would be from satellite altimeter, particularly in the areas near the coast. In many areas with limited infrastructure, this is the only feasible way to consistently measure this parameter. Cipollini et al (2010) discussed the possibilities of extending the capabilities of current and future altimeters as close as possible to the coast, with the ultimate aim to integrate the altimeter-derived measurements of sea level, wind speed and significant wave height into coastal ocean observing systems: They note that “the quintessential, most immediate application of coastal altimetry is to look at the coastal sea level, including short term sea level variations (leading to monitoring of surges)”. Several parameters derived from altimetry can contribute to forecasts of tropical cyclone paths, including wind speed and wave height, meso-scale circulation and the tropical cyclone heat potential, as well as improvement of tide knowledge by direct assimilation of the data into hydrodynamic models.

Most satellite altimetry techniques, however, have been developed to measure Sea Surface Height (SSH) in the open ocean, and some work still needs to be done for extending these measurements to the coast. The recently launched *eSurge* project, funded by the European Space Agency (ESA), aims to address this issue within the context of the project.

This application of satellite information includes assimilation into numerical models, including global and regional offshore wave models and storm surge models. Altimeter wave height observations provide the most straightforward data set to use, and would generally be used alongside associated wind speed observations. SAR derived wave spectra can also be used, but present more technical challenges.

Whilst the satellite instruments clearly have the potential to provide observations with synoptic global coverage, the quality and usability of these observations is dependent upon good calibration of the satellite sensors. This can only be achieved through use of a sufficiently dense network of accurate in situ measurements. Point data are required for validation of altimeter wave measurements, whilst spectral data are required for use with SAR derived wave spectra.

Table 2 suggests a subset of satellite observations to meet the currently identified requirements, as documented by the JCOMM Services and Forecasting System Programme Area (SFSPA).

Table 2. Implications for Satellite observing system
(excerpt from the JCOMM Services Requirements)

Platform	Required network	Comments
Satellite altimeter	Minimum 20km resolution required for use in regional models. Along track spacing is likely to be adequate to meet this requirement; cross-track spacing is not. Multiple altimeters are therefore required to provide adequate cross track sampling. Fast delivery (within 6 hours at most) required with accuracy of 10% / 25cm for wave height, and 1 second for wave period. Long-term, stable time series of repeat observations required for climate applications.	Primary requirements arise from data assimilation. Secondary requirement for use in validation. Swath data would be advantageous. Precise specification of wave period products is required.
Synthetic aperture radar / Real aperture radar	100km resolution required for use in regional models, with fast delivery required (within 6 hours)	Primary requirements arise from data assimilation. Secondary requirement for use in validation. Real aperture radar capability expected to be available within 5 years.

4 PROPOSED ACTIONS AND RECOMMENDATIONS

CGMS Satellite Operators are invited to consider the requirements of satellite information for coastal applications that are described in this paper, and provide comments to WMO (Dr Boram Lee, blee@wmo.int). Sharing data, information and products is the key to improve and maintain the high quality prediction; therefore CGMS members are encouraged to identify opportunities to develop and share improved products / services.

There exists a wide range of activities under way that pursue common goals to the CIFDP and related WMO activities, as coastal disaster management is one of the key issues in many operational agencies. CGMS members are invited to consider participating in and contributing to CIFDP and relevant R&D activities such as eSurge, and to identify ways to coordinate related activities.

Capacity Development and technology transfer is a critical aspect for the coastal hazard forecasting and warning. At JCOMM-III (2009), Members / Member States emphasized that consideration should be given to workshops on marine services including links to public weather services and disaster risk reduction aspects, with a focus on regions of specific concern, such as coastal inundation in vulnerable low-lying areas. CGMS members are encouraged to liaise with WMO/JCOMM (contact to Dr Boram Lee, blee@wmo.int) to coordinate training activities on forecasting and warning for storm surges and coastal inundation.

It was proposed that space agencies investigate feasibilities to provide high resolution bathymetric and coastal zone topographic data for better storm surge and coastal inundation forecasts. CGMS Members are invited to discuss on this issue considering both technical and operational aspects, and provide feedback to WMO/JCOMM (blee@wmo.int).

5 REFERENCES

Bourassa, M. & Co-Authors (2010). Remotely sensed winds and wind stresses for marine forecasting and ocean modeling. In these proceedings (Vol.2).

Cipollini, P. & Co-Authors (2010). The Role of Altimetry in Coastal Observing Systems. In these proceedings (Vol.2).

Dube, S. K., Chittibabu, P., Sinha, P. C., Rao, A. D. and Murty, T. S. (2004). Numerical modeling of storm surges in the head Bay of Bengal using location specific model. Natural Hazards 31, 437-453.

Dube, S. K., Sinha, P. C., Rao, A. D., Jain, I. and Agnihotri, N. (2005). Effect of Mahanadi River on the development of storm surge along the Orissa coast of India: A numerical study. Pure and appl. geophys 162, 1673-1688.

ESA (2011), eSurge Project website: http://www.storm-surge.info

Horsburgh, K. J., and Flowerdew, J. (2009). Real time coastal flood forecasting. In: Applied uncertainty analysis for flood risk management. Editors K. Beven and J. Hall. World Scientific Press. (in press).

IPCC (2007). *Climate Change 2007*: *Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp

JCOMM (2008). Proceedings of the 1st JCOMM Scientific and Technical Symposium on Storm Surges, Seoul, Republic of Korea, 2-6 October 2007. *JCOMM Technical Report No. 44, WMO/TD-No. 1442*. Geneva, Switzerland. (http://www.surgesymposium.org)

Lee, B. and Dube, S. (2009). Advisory Workshop on enhancing forecasting capabilities for North Indian Ocean Storm Surges, 14-17 July 2009. IOC Workshop Report No. 223, Paris, UNESCO, 37pp.

McInnes, K. L., Macadam, I., Hubbert, G.D. and O'Grady, J.G. (2009). A Modelling Approach for Estimating the Frequency of Sea Level Extremes and the Impact of Climate Change in Southeast Australia. Numerical modelling of Storm Surges--- the latest developments. Natural Hazards Special Issue (Val Swail, Shishir Dube, Paula Etala, Kevin Horsburgh, eds.) 51 (1), 115-137.

Resio, D.T. and Westerink, J.J. (2008). Modeling the physics of storm surges. Physics Today. September 2008, 33-38.

Thompson, K. R., Bernier, N. and Chan, P. (2009). Extreme Sea Levels, Coastal Flooding and Climate Change With a Focus on Atlantic Canada. Numerical modelling of Storm Surges--- the latest developments. Natural Hazards Special Issue (Val Swail, Shishir Dube, Paula Etala, Kevin Horsburgh, eds.) 51 (1), 139-150.

V. Swail, B. Lee, A. Soares, D. Resio, K. Horsburgh, T. Murty, S. Dube, M. Entel, and J. Flowerdew (2009), Storm Surge, OceanObs'09 Community White Paper

World Meteorological Organization, Rolling Review of Requirements and Statements of Guidance, in (http://www.wmo.int/pages/prog/sat/rrr_en.php).