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SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 0.5 : **Observations And Forecasts Of Hydrology-Related Disasters**

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Abstract:

When a tropical cyclone moves over land, it generates (i) storm surges and heavy rain that result in severe flooding, landslides and debris flow; (ii) strong winds that uproot trees and damage vehicles, buildings etc and (iii) tornadoes activities that cause tremendous damages. The severity and extents of the hydrological related disasters, particularly flooding, landslides and debris flow, caused by tropical cyclone appear to increase in recent years. Thus an early warning system for hydrological related hazards is very crucial to ensure that timely and appropriate preventive and mitigation actions can be taken to reduce loss of lives and socio-economic damages. This report will summarize the operational forecasting tools and models for flooding, landslides and debris flows used in a number of countries.

0.5.1 **Introduction**

The hydrological related disasters caused by tropical cyclone are influenced by many natural phenomena and human activities. Among them, rainfall is a major triggering factor. The main problems encountered in the early warning systems for tropical cyclone induced hydrological hazards are forecasting the pattern and rate of rainfall produced by the storm and the storm's track. The other problem is the understanding of the interaction between the rainfall patterns with topography and environmental flow features.

Practically all nations affected by hydrological related disasters, whether caused by tropical cyclone or not, have an early warning system in place. Most nations maintain at least a minimum essential observation station network, including automatic weather stations, upper air and radar stations, meteorological satellites data receiving and processing facilities to monitor the weather development and river and tidal gauges to monitor water levels and tides and wave conditions. But it is more critical and essential to enhance hydrological related disaster early warning systems by identifying effective decision-support tools and best practices. Some of the essential components of early warning systems for hydrological related disasters are flood, landslide and debris flow hazard mappings, flash flood and sediment disaster forecasting and warning, flood forecasting model evaluation and reservoir operations for flood management.

Tropical cyclones take away many lives, damage properties and severely disrupt the socio-economic activities of many countries whenever they make landfall. Realizing the catastrophic impacts of tropical cyclone on socio-economic activities of a nation, the World Meteorological Organization (WMO) helped many nations to enhance their capabilities in related disaster management, including flood forecasting and warning. WMO through its six Regional Specialized Meteorological Centres (RSMCs) with specialization in tropical cyclones, also issues forecasts and advisories around the clock on the occurrences of tropical cyclones.

0.5.2 **Forecasting Tools and Models For Floods**

For operational flood forecasting, China uses various mathematical hydrological models, such as watershed hydrological models used in Xinanjing and Shaanbei (runoff yield under excess infiltration), API model, Sacramento model, Synthesized Constrained Linear System, channel routing models which used either Maskingum routing method or Lag/K routing method or Linear Diffusion Wave Routing method or Dynamic Wave routing method, Empirical methods such as P+Pa~R and relation curve of water level between upstream and downstream, and commercial model package such as MIKE 11. Some of the application of GIS and DEM in hydrological forecasting includes, delineating basin boundary and estimating basin area, generating Thiessen polygons of rain-gage network, calculating areal-mean rainfall, computing watershed parameters like land slope and river. China also planned to use the radar rainfall products in real time flood forecasting.

The Bureau of Meteorology (BOM), Australia does not run hydraulic model, but the results of the hydraulic model are nevertheless used to refine the operational flood hydrological model, that is a distributed network storage routing model (named URBS). A typical configuration for the tropical cyclone-affected river systems along the Queensland coast has various models or routines that generates and simulates parameters or products such as (i) temporal and spatial variability of rainfall and runoff; rainfall-sub-catchment routing; dam storage routing and stream routing; (ii) non-linear storage-discharge relationship for sub-catchment routing with sub-areas typically resolved to about 50 to 100 km^2; (iii) Muskingum routing of channel flows; (iv) dynamic calculation of each sub-area rainfall using the observed rainfall inputs from available (serviceable) stations; (v) simple rainfall loss (initial loss, continuing loss or proportional runoff, loss recovery and saturation); (vi) optional real-time forcing of observed internal hydrographs and downstream boundary conditions; (vii) multiple forecast locations within each river basin (with output of both discharge and height hydrographs); (viii) forecast rainfall with several options for spatial and temporal distribution; and (ix) observed and forecast downstream boundary condition, including astronomical tide and storm surge/tide prediction.

South Korea implements the Unified Flood Forecasting System(UFFS) that integrates the existing five regional flood forecasting systems of the country. The hydrological models used in the system include the Storage-Function method, init hydrograph method, kinematic method, and a hydraulic model, DWOPER (Fread, 1987), developed by US NWS. An integrated operation system of reservoirs and rivers for flood control, including rainfall-runoff model, hydrological channel model, optimal joint operation model for reservoir system, simulation model for reservoir system and hydraulic channel routing model was also developed.

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In Japan, it is compulsory for authorities responsible for areas with medium- and small-sized rivers to designate anticipated inundation area for which flood hazard maps have to be prepared by municipalities concerned. Whereas for authorities responsible for areas with large rivers to provide warnings of expected inundation areas and water levels during flooding.

In the United States of America, National Weather Service River Forecast System (NWSRFS) uses either hydrologic or hydraulic models to forecast the water levels for America’s rivers and streams at about 4,000 locations. If the watershed involved in the flood forecast is located near the coast, the dynamic routing techniques and hydraulic models are used to address the effects of tides and storm surge. The use of estuarine models that include the coupling between meteorological-hydrological-hydraulic-estuarine-tide models is also becoming a part of the forecast during normal and stressed conditions. These prototypes would include the forecasting of storm surge during hurricane conditions. In USA the depiction of the inundation area, is also provided to the end user and emergency personnel though a simpler technique, called Simplified Hydraulic Routing Technique (SHRT) is being proposed. A simplistic hydrological models, based either in antecedent precipitation indexes (API) or initial Soil Moisture conditions, are developed to forecast flash flood events for basins and catchments with short lead times.

The U.S. Geologic Survey (USGS) has also developed a hydrological model, Precipitation-Runoff Modeling System (PRMS) that can be run under daily time steps as well as under storm events for temporal resolution of less than one hour. The model is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on stream flow, sediment yields, and general basin hydrology.

0.5.2.1. **Limitations, Challenges and Issues**

Forecasting of flood caused by land falling tropical cyclone still contains much uncertainty due to a number of constraints. Many times the adequacy of the model is determined but the developing hydrologic and/or hydraulic data and precipitation network are non-existent or poor to ensure good calibration of the model. The forecaster must also be experience to use the appropriate model, under the circumstances he/she is facing. The important issue is that he/she recognizes that he/she must address differently coastal, slow responding areas to flashy, steep, fast responding basin.

Some of pertinent observations and issues, all associated with the limitations of quantitative precipitation forecasting, of the meteorological inputs to the hydrologic modeling process that need to be further enhanced are (i) flood-producing potential of approaching tropical cyclone; (ii) forecast or actual landfall location; (iii) quantitative precipitation forecast (QPF) which is the most important input, possibly by at least an order of magnitude; (iv) radar rainfall estimation and (v) storm tide prediction. The spatial resolution of gauges and radar, plus the incorporation of the dense networks is also critical. This will help in the calibration of radars and also in the determination of precipitation estimates based on gauges only.

0.5.2.2 **Future Direction**

There is a need to continue in improving operational hydrologic and hydraulic flood modeling, and this includes consideration of a tighter coupling with meteorological, hydrological/hydraulic, and tidal modeling outputs where useful. We need to have a better definition of the track and intensity forecast of tropical cyclone path and quantitative precipitation forecast (QPF) associated to tropical models. The use of ensemble forecast and short term QPF should be considered.

Some other works that need to be considered include;- (i) implementation of continuous soil moisture accounting models; (ii) revision of current rainfall inputs to hydrologic models to allow for gridded rainfall inputs from improved operational rainfall spatial analysis and forecast rainfall grids from NWP models; (iii) digital representation of hydrologic model sub-areas to enable improved spatial rainfall inputs (iv) use of radar-rainfall estimation, and forecasting for short lead times, for flash flood situations, (v) hydraulic flood plain modeling for continued refinement of hydrologic models, and for possible operational use in defined areas, (vi) review the methodology to generate inundation maps and the data needed for a product to accurate depict what the user needs, in terms of resolution and (vii) Increase the observation network, frequency, type, etc. and to obtain bathymetry at better spatial resolution and flows and stages at smaller time steps.

Intense rainstorms brought about by tropical cyclones often caused severe landslides and debris flows, which have claimed many lives and properties. It is imperative that the flood forecasting agencies do research into and develop forecasting models for landslides and debris flows. Currently this is an area where the USGS and NWS are partners to develop such forecasting.

0.5.3 Forecasting Tools and Models For Geological Disasters (GDs)

In Japan, one of the methods used to forecast sediment disaster is The simplified critical line setting method. Japan is revising its sediment-related Disaster Prevention Law to make it compulsory for authorities to provide sediment-related disaster hazard maps and information with risk predictions.

Korea uses an algorithm called SINMAP to predict possible landslide sites. The effects and proper ranges of three calibration parameters of SINMAP, i.e. soil friction angle, cohesion and T/R could be used as an effective screening tool for landslide hazard mapping especially for mountain areas with fairly steep slopes and relatively thin soil layers.

Landslides and debris flows induced by local storms or persistent rainfall are the most frequent geological disasters (GDs) all over China. In China, the basic simple approach of geological disasters (GDs), landslides and debris flows, forecast is to investigate the statistical relation between historical GD occurrences and rainfall observations so as to determine the criteria for rainfall that can trigger GDs. Five (5) rainfall-related factors (i.e. the same day rainfall, the previous day's rainfall, the accumulative previous days' rainfall, the previous wet days and the effective rainfall) are selected to build the GD occurrences model. For each factor, a set of thresholds and their corresponding probabilities of GD occurrences are determined. The overall probability of GD occurrence at a site is the weighted sum of these individual probabilities. A GD occurrence model was built for many sub-areas according to the geology and the climate of China and a national map for the spatial distribution of GD probabilities was produced. Finally, probabilities of 10%, 25%, 50%, 75% and 95% are selected to divide the results into 5 levels, from I to V with increasing susceptibility to GDs. The final forecast product is a national GD risk map distinguished by 5 levels. The GD forecast would be published through mass media if a level IV appears in an area (at least covering three weather stations), while a GD warning will be made when a level V is forecast.

China is also developing an advanced GD occurrences model using Logistic regression In brief, if we denote by $p_{s,t}$ the probability of GD at site *s* and on the day *t* in the data set, conditional on a predictor vector $x_{s,t}$, then the model is given by

$$\ln (p_{s,t} / (1 - p_{s,t})) = X'_{s,t}\beta$$

for some coefficient vector β.

A wide range of elements has been selected as predictors. GD occurrences data and daily rain observations can be regarded as the dynamic part of the model. The relatively 'static' part, including topographical, geological and land use information was remotely sensed and constitutes the background of GD occurrences. This model has showed satisfactory performance in practice and will soon be replacing the current basic simple approach model.

0.5.3.1 Limitations, Challenges and Issues

Landslides and debris flows are local disasters in mountainous areas with horizontal scale generally less than 1 km. These small-scale GD phenomena pose a very serious challenge for their prediction and prevention. Thus the difference of spatial scales between GDs and meteorological variables should be considered carefully when predicting GDs using precipitation information. In addition, accurate GD forecast requires real-time observations of extensive geological conditions and accurate predictions of rainfall. It is difficult to accurately predict the occurrences of GDs at a high spatial resolution under current circumstances. Currently available GD forecast models are only for probability predictions at low spatial-temporal resolutions.

0.5.3.2 **Future Direction**

There are several issues to be considered to build an effective forecast and warning system for landslides and debris flow hazards especially for country with diverse natural conditions as big as China. There is a need to have a denser nationwide GD observational network. A closer joint researches and regularized collaborations on study of GDs, including tropical-induced GDs, by scientists from different disciplines and among different governmental agencies also should be in placed.

0.5.4 **Summary**

Though some of the existing models in use in operational hydrological related disasters forecasting are highly simplified conceptual representation of rainfall-flood and rainfall-geological disaster response and fail to model the complexities of the land-based water cycle, it was found that the simplified models provide reasonably good results. It is very difficult to forecast the hydrological related disasters and forecaster should rely on personal experience in many parts of forecasting. There is an urgent need to improve the capacity of meteorological and hydrological services so as to jointly deliver timely and more accurate forecast and warning for disaster managers.

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