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Application of Ensemble Typhoon Method to a Tropical Cyclone in the Bay of Bengal

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Synopsis

The method of ensemble Typhoon was applied to a strong tropical cyclone in the Bay of Bengal, Aila in 2009. An ensemble of 63 members was successfully generated which are used to assess the impact to the society along the Bay of Bengal. The precipitation output is used in a hydrological model to assess discharge at the lower reach of the Ganges,

Keywords: Tropical Cyclone, Bay of Bengal, WRF, Ensemble forecast

1. Introduction

Tropical Cyclones (TCs) are getting huge attention due to their large disaster potential and ability to threat billions of people. Because of its disastrous nature, accurate forecast of its track and intensity is highly required from the society. However, present forecasting skill remains unsatisfactory, and the accurate forecasting is still a very challenging job due to the uncertainty in initialization and complexity of physical processes involved.

Disaster management (mitigation) actions need to be started prior to the TC overpass. The maximum amount of damage caused by TC depends on societal factors such as population density, terrain structure, building construction and so on. Further, the relative location of TC track to these societal infrastructure is the key of reliable estimation of hazards. It is well known that strong winds blow on the starboard side of TC migration. This is also a favorable location of high storm surge. Mountainous regions collects huge amount of water vapor and land slide, flush flood and other variety of water related hazards take place in many area and these area particularly requires forecasted information well in advance in order to start evacuations earlier and to minimize loss of human life and damage to property as possible.

World's largest population density lives in Indo-Bangladesh region which is located between the northern coasts of the Bay of Bengal and the Himalayas. In metropolitan regions, the population density comes into 20-50 thousand people per square kilometer. Landfall of a super-cyclone on the northern coastal region of Bay of Bengal can cause large damage and great number of human loss both from the oceanic hazards and from heavy rain in mountains and the associated river discharge.

Recent record breaking disaster produced TC is Aila which landed on 25th May 2009 at this coastal region and proceeded up to the foothill region of the Himalayas. This cyclone put in life risk conditions of about hundred million people in the Indo-Bangladesh region. Damage caused by the cyclone is estimated as much as five hundred million USD or the more. In addition to the direct destroy by the storm, the life-risk diseases related to drinking water prevailed due to floods by the continuously heavy precipitation during this tropical cyclone.

In order to prepare for a variety of direct and indirect hazards caused by TCs, it is needed to consider various thereat of TCs to natural and social environment. The frequency of disastrous Cyclones in the Bay of Bengal is, however, limited to cover all possible aspects of disasters. An approach to meet the requirement is the use of ensemble TC method developed by Ishikawa et al. (2013). Though their first applied the technique in estimating the possible worst scenario of TC in global warming environment, Kobayashi et al. (2014) and Oku et al. (2014) applied it to existing typhoon cases.

In the present study, the ensemble TC technique is applied to Aila to assess the possible maximum hydrological impact of tropical cyclone Aila. Using this method various TC tracks and the associated meteorological fields are generated. The potential vorticity (PV) inversion technique is adopted in the present study. In this procedure, position of the tropical cyclone is shifted artificially at a certain time before landing. The relocated TC is further integrated with time, which produces different history of the TC. Over an ensemble of relocated cases possible worst scenario can be searched for various kind of disasters at target city. The precipitation pattern of the cyclonic system, for example, is further utilize as input to another hydrological model to study the river discharge over Indo-Gangetic Basin.

2. Methodology

The mesoscale meteorological model, the Weather Research and Forecasting (WRF) model version 3.1.1, was used to simulate TC Aila in 2009. The NCEP-FNL data of one degree resolution was used as input meteorological data. We first conducted a simple hind-cast simulation using NCEP-FNL data as the initial and the boundary conditions. The computational domain and the selection of physical parameterization are listed in Table. 1. The largest domain is of 30 km horizontal resolution covering a wide region from the eastern part of the Indian subcontinent including the coastal region of India-Bangladesh and the Himalayas. The smallest domain is of 3.3 km resolution where cumulus parameterization can be shut off. In vertical as many as 64 levels are employed and the model top was set as 10 hPa which is a little higher than the ordinary set up of the WRF simulation. This is required since the PVI method does not converged in some cases when the top is 50 hPa or the lower. We call this hind-cast simulation as the CTRL simulation, hereafter. In order to guide the simulated Aila to the proper position, spectral nudging is used for CNTL. This option was shut in producing ensemble.

The details of WRF parameters used in the experiments are given in Table 1. The model is initialized at 00:00 UTC, 23 May 2009 and is integrated for four days and 6 hours until 00:00 UTC, 27 May. The integration time steps are 60 s.

The TC ensemble technique utilizes PVI method (Davis and Emmanuel, 1991). This is one of the so called bogus technique. Since a TC is non-linearly balanced in environmental meteorological field, it is difficult to pick up TC only. However, when Potential Vorticity is computed, the TC related PV is well separated with environmental PV. Thus, we can pick up the TC derived PV distribution and put it at the other place in environment. The whole meteorological field can be inversely recovered from new PV fields with several assumptions. A new initial and boundary condition was computed for each of the cyclone relocations, and further numerical integration of WRF yielded different typhoon cases. It is to be noted that spectral nudging was not applied during the integration after the relocation so as to avoid artificial forcing on the simulated physical processes. Though the PVI method is only quasi-nonlinear, but not fully nonlinear, it reduces the physical imbalance of meteorological variables, as compared to other bogus techniques.

In order to produce an ensemble of perturbed typhoon members, the typhoon was relocated to different locations at 00:00 UTC on 24 May. At this instance, the potential vorticity was computed from the output meteorological variables of the CTRL

Table 1 Details of WRF Parameterization

Nesting	Triply nested
Hor. Resolution	30 km > 10 km > 3.3 km
Ver. Resolution	64 levels up to 10 hPa
Radiation	RRTM
Cumulus	Kain-Fritsch scheme
Microphysics	WDM6
PBL	Mellor-Yamada-Janjic 2.5
Land surface	5-layer thermal diffusion
Nudging	Spectral nudging for CNTL

simulation, and the TC relocation was applied. The cyclone position at the time was relocated within a range of ±8grids of domain 1 in both east-west and north-south direction, which is equivalent to 1760 km2 over the Bay of Bengal. The total 63 cases of such relation cyclones have been studies which are further investigated for the variation of river discharge of India's one of the major river, Ganga using a distributed hydrological model due to changes of spatial distribution of precipitation by the such modification of cyclonic tracks.

A distributed hydrological model, 1k-dhm-event model (Version 1.3.5), is prepared for the water discharge peak investigation. This is an object-oriented hydrologic modelling system developed in Kyoto University. 1K-FRM-event is a distributed flow routing model based on kinematic wave theory. The input topography data is generated using HydroSHED 30 second digital elevation model and flow direction data. Forcing data to drive 1K-FRM-event such as runoff generation or precipitation is supposed to be hourly gridded data. At first, a method to develop topography data for 1K-FRM-event is described. Then, by using the developed data, an example of rainfall-runoff simulation using 1K-FRM-event is demonstrated.

3. Results and Discussions

A suit of 63 different typhoon cases was produced as shown in Figures 1 to 3. In each figure 63 different tracks are shown. The tracks are colored by the central pressure (Fig. 1), the maximum wind speed (Fig.2) and maximum rainfall (Fig. 3). Among the deviated cases, no track followed the reference or control runs. This is not considered curious because spectral nudging was not employed in the TC relocation cases and is considered acceptable for the present application of searching for the severest case. The well-known feature of typhoon decay was clearly evident after landing. For the tracks deviated to the west, the vortex initially tend to move eastward toward the original track then migrate northward. These are relatively weaker. Conversely, cases shifted to the east maintained strong intensity.

Fig.4 shows the distribution of the maximum hourly precipitation during the passage of the deviated case that brought the worst case for the Kolkata metropolitan area in terms of hourly precipitation. It is obvious that strong hourly precipitation was linked to the passage of several convective cells from the southeast to northwest that originated in the coastal Bay of Bengal.

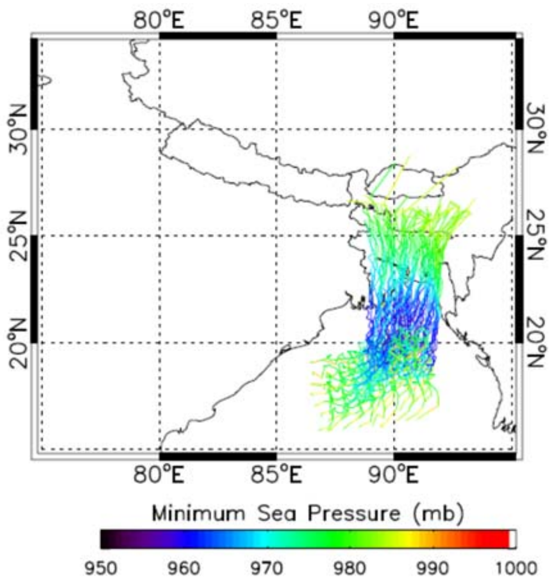

Fig. 1 All 63 tracks in the ensemble. The track is colored with the central pressure of the cyclone.

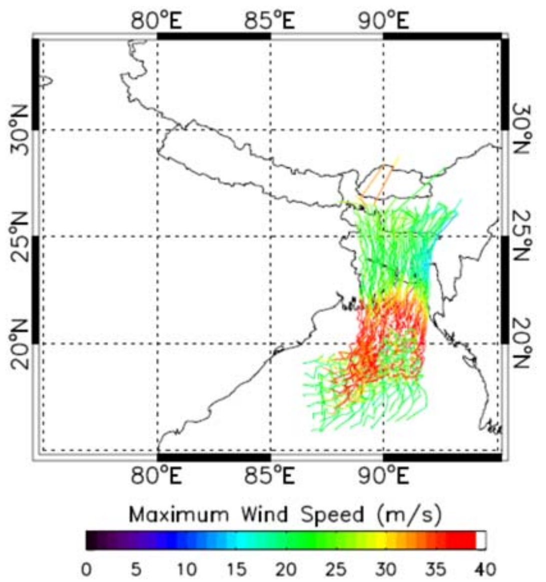

Fig. 2 Same as Fig. 1, but the color is for maximum wind speed

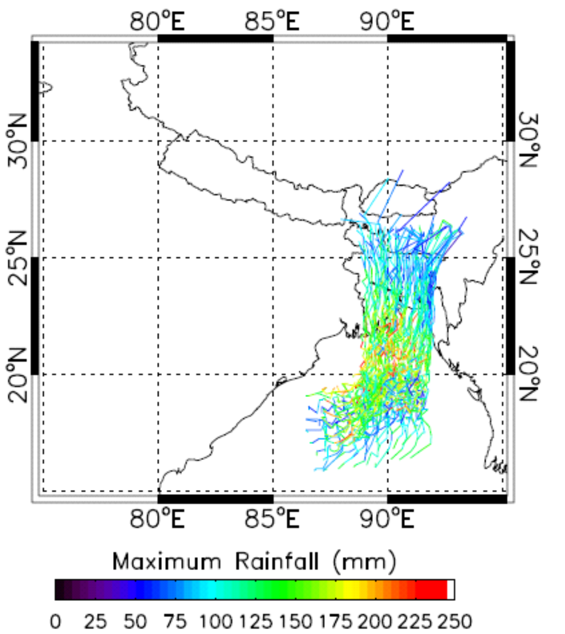

Fig. 3 Same as Fig. 1, but the color is for maximum Rainfall.

The possible maximum flood region in the Ganga River basin can be estimated using the precipitation output from the artificially shifted typhoon cases. Each ensemble member of different tracks produces different precipitation amounts with differing spatial and temporal patterns in the target basin. An example is shown in Fig. 4.

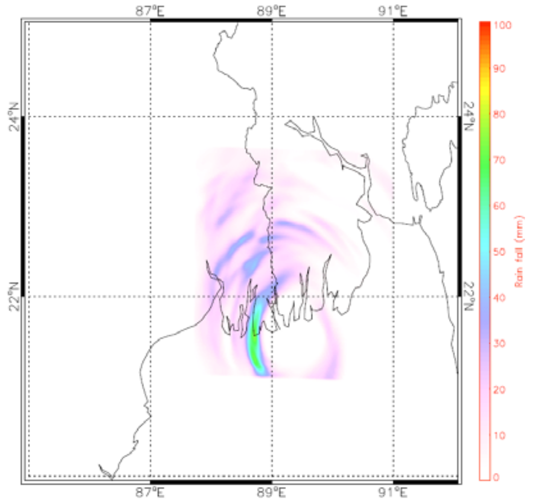

Fig.4 The distribution of the maximum hourly precipitation during the passage of the deviated case that brought the worst case for the Kolkata metropolitan area in terms of hourly precipitation.

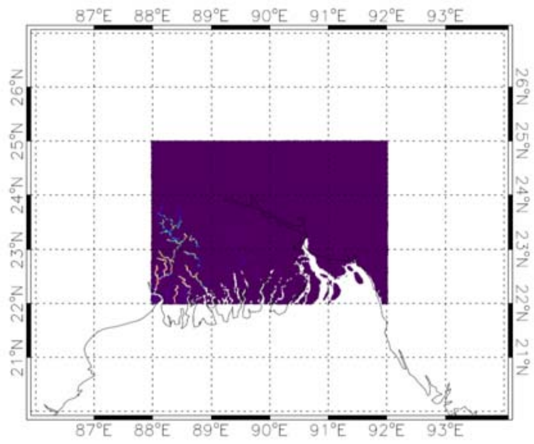

Fig.5 A trial simulation of river discharge with 1K-DHM model.

A distributed hydrologic model built on very fine geographic information was prepared to simulate river discharge considering the spatially and temporally variant precipitation patterns. The precipitation input from the various cyclone tracks were provided in hourly interval with 3.3 km spatial resolution. Evaporation and transpiration amounts were ignored in this trial study because the amount is negligible on rainy days especially when there is a large amount of precipitation due to the cyclone. The duration of hydrological computation was from midnight of 24 to 27 May 2009. The hourly discharge of river water flow rate during the landfall period of Aila Cyclone at the estuary region of Indo-Gangetic Basin. The simulation study shows the high water flow nearby region of Kolkata and alert for the flood.

4. Remarks

This is the first application of the TC ensemble method with Potential Vorticity Inversion to a basin other than western north-Pacific. The current study is a first step toward the preparation of extreme cyclone in global warming era at the urban region in India where the highest population. We are also interested in the aerosols effects on precipitation and cloud microphysical properties in this region.

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