Extremely Heavy Rainfall (EHR) over Mumbai during 2019: Observations and Model Forecasts

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Abstract:

Mumbai, The commercial and financial capital of India, experiences continuous annual rain episodes with very active spells during monsoon season which leads to increasing vulnerability to flooding. After the infamous episode of 2005 Mumbai flood, the government and public of Mumbai needs a good forecast to avoid the severe vulnerability. In 2019, Mumbai recorded as many as 5 Extremely Heavy Rainfall (EHR) days with more than 200mm of rainfall in 24hrs during its monsoon season. This downpour lashed the city disrupted daily life. An attempt has been made to verify the skill of NCUM (global and regional) model in predicting these 5 EHR events. The results are depicting that these events are due to the presence of mid-tropospheric cyclonic circulations presented at 600hPa and the winds turning in anticyclonic circulation with height from 850hpa to 400hPa. The NCUM-G model is not able to predict the intensity of the rainfall in all 5 EHR events whereas NCUM-R is comparatively better in terms of magnitude.

1 Introduction

During monsoon season (June, July, August and September (JJAS)), especially in the active period of the monsoon, many places along the west coast of India will receive heavy rainfall. The interaction of strong westerlies with topography causing heavy precipitation over these regions (Sahany et al., 2010). These winds are rich in moisture since they are coming from Arabian Sea. The other factors for this intense heavy rainfall is mid-tropospheric cyclones (Krishnamurti and Hawkins 1970). In a study by Singh et al., (2017) mentioned that Mumbai got 5th place out of 20 coastal cities around the world as most vulnerable to losses due to flooding. Mumbai experiences severe flood almost every year during JJAS. In 2005, Santacruz, a station in Mumbai experienced unprecedented rainfall of 944 mm in 24hrs with an all-time record over the city (Janamani, et al., 2006). Mumbai received 5 EHR events with more than 200mm rainfall during the summer monsoon season of 2019. Most rains received over Mumbai in this year were either very heavy rain or extremely heavy rain category.

The change in the wind direction with height detects the possibility of EHR events. The overall trend in the last decades shows an increase in extreme rainfall events (Sagar et al., 2017). Therefore the forecasting of these events well in advance is very essential.

Being an operational forecasting center, National Center for Medium Range Weather Forecasting (NCMRWF) runs NCUM-G and NCUM-R twice a daily and integrated up to 10days (regional model, 3days). The assessment of NCMRWF models (global, Regional) skill in predicting the EHR events over Mumbai has been studied.

2 Data and Methodology

The observed and rainfall data over India used in this study are briefly described in this section.

2.1 Observed Rainfall Data

The IMD gauge data The IMD-NCMRWF daily high resolution (0.25° x 0.25°), satellite and gauge merged rainfall analysis is used. The merged analysis at 0.25° is appropriate for capturing the large scale rain features associated with the monsoon.

Global Precipitation Measurement (GPM) satellite (IMERGE) 30 min rainfall data sets with 0.1° x 0.1° grid resolution is also used.

2.2 ERA-5 Reanalysis

The latest ERA-5 reanalysis data sets with 0.25° x 0.25° grid resolution is used to study the zonal and meridional wind anomalies.

2.2 NCUM Model Forecast Rainfall Data

The NCUM has 12 km horizontal grid resolution with 70 vertical levels. The model is integrated to produce forecasts up to 10 days. Additional details can be found at Kumar et al., 2018. The model forecasts are gridded to the 0.25° x 0.25° observed rainfall grids over Indian regions

The NCUM-R has 4km horizontal resolution with 70 vertical levels. The regional models is integrated up to 75 hrs and the domain is 650 E -1020 E and 50 - 400 N.

2.3 Cases of Extremely Heavy Rainfall (EHR)

The five cases of EHR are tabulated in Table 1which are the 24h accumulated rainfall in Santacruz. The rainfall activity in each of these events is associated with well defines synoptic condition involving the mid-tropospheric cyclonic systems (MTC). The observations and forecasts clearly show well defined MTC. The model accurately captures the development and westward movement of the MTC over the central India.

Table 1. Five cases of Extremely Heavy Rainfall (EHR) over Mumbai during JJAS 2019.

	Date	Rainfall
1	29th June 2019	23 cm/day
2	02nd July 2019	37 cm/day
3	27th July 2019	22 cm/day
4	04th Aug 2019	20 cm/day
5	05th Sep 2019	**24 m/day**

3. Figures and Tables

The assessment of 5 EHR events has been carried out in this study. The model forecasts are compared with IMD gridded gauge, IMD-NCMRWF merged and GPM IMERGE data sets. Fig.1 shows a case study on 29JUN2019. The day-1, day-3 and day-5 forecasts from NCUM-G and day-1, day-2 and day-3 from NCUM-R are shown in the middle and lower panels of Fig.1. NCUM-G

model is not able to predict the intensity of the rainfall during the EHR events of all 5 cases whereas NCUM-R model performs better in predicting higher peak intensity. For the case of 02Jul2019, NCUM-R model forecasts of day-2 and 3 are very realistic on the other hand day-1 and 2 are very close to the observation in the case of 27JUL2019. However, NCUM-G model is under predicted the high intensity rainfall in all 5 cases.

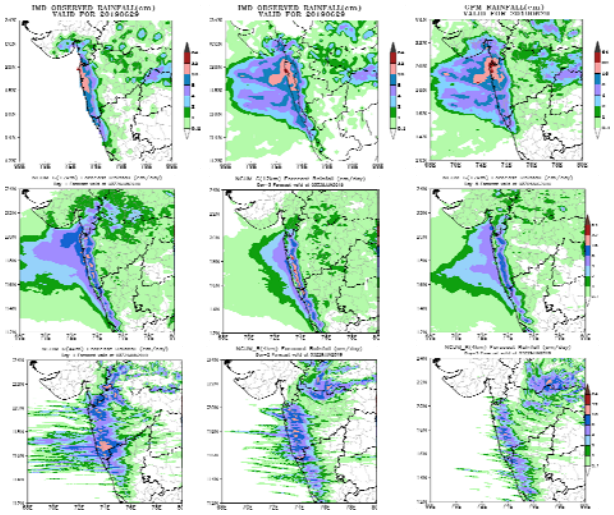

Fig.1. EHR Case on 29JUN2019.

The assessment of diurnal variation of rainfall during all 5 cases has been carried out. The results (ex.Fig.2) depict that the peak intensity of the rainfall in all cases is noticed during 05-10 hrs IST and 15-20 IST hrs. The NCUM-G model is not able to capture the diurnal variation of rainfall. Whereas, NCUM-R is able to predict the peak hours.

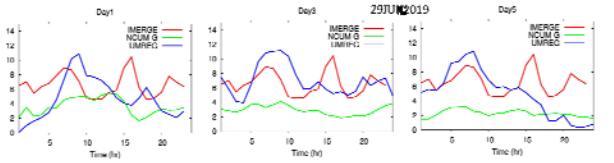

Fig.2. Diurnal variation of rainfall on 29JUN2019.

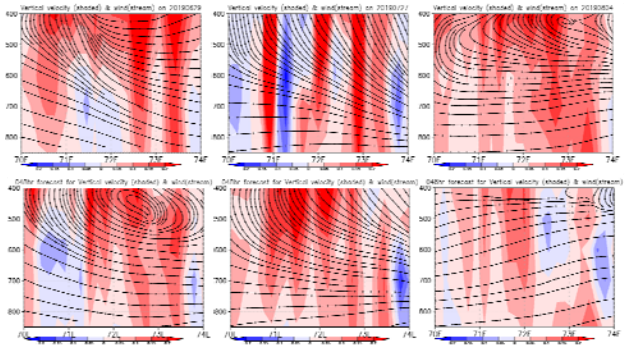

Fig.3. Vertical profile of winds (stream line) and vertical velocity (shaded)

The synoptic analysis of wind at various pressure levels reveals that the presence of mid-tropospheric cyclone from 700hPa to 500hPa. The presence of mid-tropospheric cyclone at all these levels is well predicted by both global (up to day-5) and regional (up to day-3) models.

Further the vertical cross section of the winds during all 5 cases have been studied and a case (29JUN2019) is presented in Fig.3. The wind circulation are represented in streamlines and the vertical velocities are represented as shaded. Geographically Mumbai is extends between 18.00°–19.20°N and 72.00°–73.00°E covering a total area of 437.79 km^2. The winds and vertical velocities are averaged from 18-19.2°N. During all the EHR cases, the change in the wind direction in anti-cyclonic sense from 850hPa to 500hPa is noticed over Mumbai location. As mentioned previously, the presence of mid-tropospheric cyclone at 600hPa and the wind turning in anti-cyclonic sense may lead to heavy rain over Mumbai region.

The very strong positive vertical velocity over Mumbai suggests the strong upward motion of air parcel. This suggests the favourable condition for strong convection over Mumbai region.

The wind anomalies at various levels has been computed for these 5 cases. To compute the anomalies, ERA-5 reanalysis monthly dataset with 0.25°×0.25° grid resolution is used. The model forecasts are re-gridded to ERA-5 in order to calculate anomalies. The significant positive anomalies are noticed before and during the EHR event occurred.

4. Summary

The Mumbai received 5 EHR events during JJAS of 2019. The presence of strong mid-tropospheric cyclone at 700, 600 and 500 hPa levels, and the turning of winds in anticyclonic direction with height leads to produce heavy rainfall over Mumbai. The verification of NCUM-G and UMREG has been conducted. The NCUM-G model is not able to predict the intensity of these 5 heavy rainfall cases where as UMREG is able to predict. The diurnal variation of Rainfall over Mumbai region depicts the unpredictability of NCUM-G model. However, the presence of trough at mid tropospheric levels and anticyclonic circulation of winds with height is well predicted by the global model. The vertical structure of the U and V wind components also suggest there is a sudden change in their direction over Mumbai region in the mid-tropospheric levels.

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