MAUSAM, **66**, 3 (July 2015), 579-584

551.509.5 : 551.553.2 : 551.577.23 (540)

Skill of operational forecast of heavy rainfall events during southwest monsoon season over India

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सार – प्रचंड मौसम का सटीक पूर्वानुमान करना प्रचालनात्मक पूर्वानुमानकर्ता के लिए चुनौती पूर्ण कार्य है। प्रेक्षणात्मक संजाल में हाल ही में हुई वृद्धि और नए पूर्वानुमान उपकरणों और तकनीकों के विकास से मौसम को समझने में सहायता मिली है, जिससे पूर्वानुमानकर्ता बेहतर पूर्वानुमान की सेवाएं उपलब्ध करा रहे है। भारत में, वार्षिक वर्षा की लगभग 80 प्रतिशत वर्षा मॉनसून ऋतु (जून से सितम्बर) में होती है जिसमें प्राय: प्रत्येक मॉनसून ऋतु में देश के विभिन्न भागों में भारी वर्षा (HR) से अलग-अलग प्रकार की प्रलयकारी बाढ़ की स्थितियां बनती हैं। अतः मॉनसून ऋतु में HR की घटनाओं का, पूर्वानुमान और सत्यापन करने से सामाजिक और आर्थिक प्रभाव के कारण उनका महत्व बहुत अधिक बढ़ जाता है। यह अध्ययन पिछले 12 वर्षों (2002-2013) के आँकड़ों का उपयोग करते हुए मॉनसून ऋतु (जून से सितम्बर) में भारत में प्रचालनात्मक HR के पूर्वानुमान के सत्यापन पर केंद्रित है। भारत में 24 घंटों के HR की घटनाओं के पूर्वानुमान के लिए गत वर्षों के स्किल स्कोरों में उल्लेखनीय रूप से वृद्धि देखी गई है। विभिन्न स्किल स्कोरों विशेषकर क्रिटीकल सक्सेस इंडेक्स (CSI), फॉल्स अलॉर्म दर (F) और हईदके स्किल स्कोर (HSS) से पूर्वानुमान की सटीकता में सुधार देखा गया है, जिसमें वर्ष 2002 से क्रमशः 42 प्रतिशत, 52 प्रतिशत और 43 प्रतिशत सुधार हुआ है।

ABSTRACT. To predict extreme weather correctly has always been a challenge for operational forecaster. Recent enhancement in observational network and development of new forecasting tools & techniques has helped in increasing the understanding of weather, eventually enabling the forecaster to provide better forecast services. In India, about 80% of its annual rainfall occurs during monsoon season (June to September) in which heavy rainfall (HR) events give major contribution in causing flood situations of varying severity in different parts of the country in almost every monsoon season. Therefore, the forecast and verification of HR events during monsoon season is of great importance due to their social & economic impact. The present study focuses on verification of operational HR forecast over India during monsoon season (June to September) using data of recent 12 years (2002 – 2013). A significant improvement in skill scores in recent years is observed for 24 hours HR events forecast over India. The improvement in the accuracy of the forecast is seen from various skill scores particularly critical success index (CSI), False Alarm Rate (F) and Heidke Skill Score (HSS), which has improved by 42%, 52% and 43% respectively since 2002.

Key words – Forecast, Heavy rainfall, Monsoon, Skill and verification.

1. Introduction

Study of extreme events and their forecast is of great importance for economic and disaster point of view on Indian subcontinent. Recently in monsoon 2013, extremely heavy rainfall over Uttarakhand and Gujarat states caused extreme damages in economy and huge loss of life. In India, HR events and their impact exhibit a lot of temporal & spatial variability. Normally, they occur more frequently & with more severity over orographic dominated area like Western Ghats, Assam & Meghalaya etc. In addition, East and central India receives HR events mainly due to oscillation of seasonal Inter Tropical Convergence Zone (ITCZ) and embedded low pressure systems. Foothills of Himalayas receive rainfall due to shift of ITCZ close to the foothills of Himalayas and orographic condensation. Western Himalayan region in particular receives HR events due to shifting of ITCZ along the foothills of Himalayas and its interaction with mid-latitude westerly systems as was the case during disaster at Uttarakhand in 2013. In literature, there are many studies related to HR events over Indian sub-continents. Rakhecha and Pisharoty (1996) found large spatial and temporal variability in intensity of heavy rainfall in India by studying the daily rainfall records of about 500 stations during monsoon seasons. Sinha Ray and Srivastava (2000) studied the heavy rainfall during southwest monsoon over various locations and found increasing trends in heavy rainfall. Goswami *et al*. (2006) studied the extreme rain events over central India during the monsoon seasons and observed significant rising trends in its frequency and magnitude.

Fig. 1. Meteorological sub-divisions and homogeneous regions of India

Kishtawal *et al*. (2009) observed significant increasing trend in HR frequency during monsoon season over urban areas of India.

Verification of its forecasts is an important activity of any national meteorological service. It not only helps to monitor & improve the forecast quality but also helps in comparing the quality of different forecast systems. Therefore, an attempt has been made to conduct systematic verification of forecast of HR events as per World Meteorological Organization guidelines. According to Murphy (1993), there are three types of goodness of forecast verification:

(*i*) Consistency - Forecasts agree with forecaster's true belief about the future weather.

(*ii*) Quality - Correspondence between observations & forecasts

(*iii*) Value - Incremental benefits of forecasts to users

In present study, forecast verification of 24 hours HR forecast issued by National Weather Forecasting Centre (NWFC) of India Meteorological Department (IMD) for the 36 meteorological subdivisions of India has been carried out by using a 2 × 2 contingency table (Wilks, 1995) during monsoon season using the data of recent 12 years (2002-2013).

2. Data and methodology

NWFC, IMD is issuing weather forecast and heavy rainfall warning valid up to next 72 hours for the 36 meteorological sub-divisions of India (Fig. 1). As per the criterion of IMD, HR event is said to be occurred over a station, if it reported 6.5 cm or more rainfall in past 24 hours, recorded at 0830 hours IST. Therefore, we are dealing with categorical dichotomous forecast (Mariani and Casaioli, 2008), *i.e*., yes/no statement. In the present study, a "heavy rain day" is counted in a meteorological subdivision, if HR event is reported in atleast over one station in the meteorological sub-division. To calculate annual performance over a monsoon season, forecast-observation pairs are pooled in space and time from June to September of a particular year. This would provide a large overall sample size of events for each year, which would lead to only small uncertainty in the values of the annual scores.

Thus, verification of HR events is carried out by using the following 2 × 2 contingency table (Wilks, 1995):

Forecast	Observed		
	Yes	No	Total
Yes	Hits	False alarms	Forecast yes
No	misses	Correct negatives	Forecast no
Total	Observed yes	Observed no	Total

Forecast	Observed		
	Yes	No	Total
Yes	a	b	a + b
No	c	d	c + d
Total	a + c	b + d	n = a + b + c + d

Using above 2 × 2 contingency table and following Mohapatra *et al*. (2009), given below measures have been calculated:

(a) Frequency Bias Index,

$$FBI = \frac{(a+b)}{(a+c)}, \text{ Range: 0 to } \infty \text{, Perfect score = 1}$$

(b) Probability of Detection,

$$PoD = \frac{a}{(a+c)}, \text{ Range: 0 to 1, Perfect score = 1}$$

(c) False Alarm Ratio,

$$FAR = \frac{b}{(a+b)}, \text{ Range: 0 to 1, Perfect score = 0}$$

(d) Miss Rate,

$$MR = \frac{c}{(a+c)}, \text{ Range: 0 to 1, Perfect score = 0}$$

(e) Percentage Correct,

$$PC = \frac{(a+d)}{n}, \text{ Range: 0 to 1, Perfect score = 1}$$

(f) False Alarm Rate,

$$F = \frac{b}{(b+d)}, \text{ Range: 0 to 1, Perfect score = 0}$$

(g) Critical Success Index,

$$CSI = \frac{a}{(a+b+c)}, \text{ Range: 0 to 1, Perfect score = 1}$$

(h) Heidke Skill Score,

$$HSS = \frac{2(ad-bc)}{[(a+c)(c+d)+(a+b)(b+d)]},$$

Range: $-\infty$ to 1, Perfect score = 1

3. Results and discussion

3.1. *Average number of heavy rainfall events in monsoon 2013*

The total numbers of HR days in different sub-divisions of India during monsoon 2013 are shown in Fig. 2. In monsoon 2013, there was on average 53 HR days during monsoon season in each sub-division of India with highest HR events over Assam & Meghalaya (90) and lowest in Lakshadweep (14). In region wise distribution, central India received HR on 65, east India on 63, east India on 63, northeast India on 62, south India on 47 and northwest India on 45 days. Subdivisions namely Assam & Meghalaya, Sub Himalayan West Bengal & Sikkim, Orissa, West Madhya Pradesh and West coast received HR in more than 70 days. However, sub-divisions namely Marathawada, Rayalaseema and Lakshadweep received HR for less than 20 days.

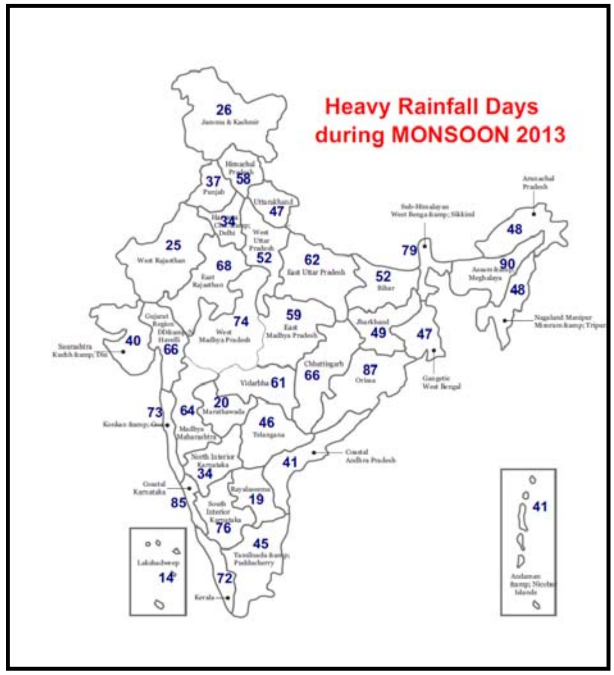

Fig. 2. Meteorological Sub-divisions wise HR events of monsoon 2013

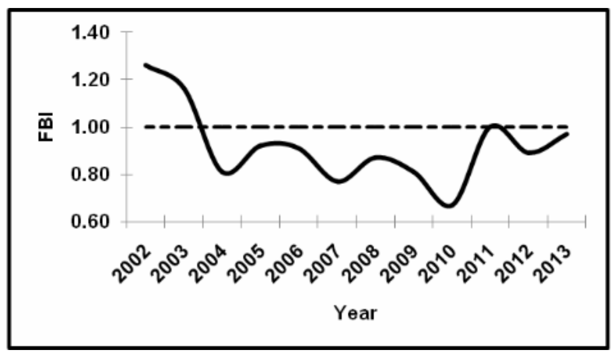

Fig. 3. FBI trend of HR events from 2002 to 2013

3.2. *FBI of HR events*

FBI = 1 means that forecast is unbiased that HR forecasts and HR observed have the same frequency. FBI > 1 is considered to be over warning and less than 1 is considered to be under warning. FBI trend for India as a whole between 2002 and 2013 is shown in Fig. 3. HR forecasts were over warning in 2002 & 2003 and unbiased in 2011, and under warning the remainder of the time.

In monsoon 2013, FBI was 0.97 which means nearly an unbiased HR forecast. Region-wise, forecast of HR was nearly unbiased (0.98) over central India and was highly biased over south India (1.52). Highly biased (over warning) are observed generally over Himalayan region and Indian Islands areas.

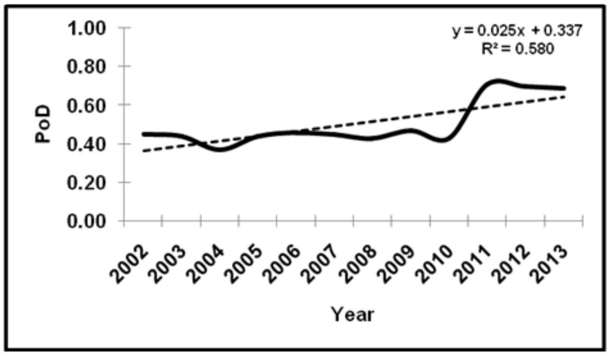

Fig. 4. PoD trend of HR events from 2002 to 2013

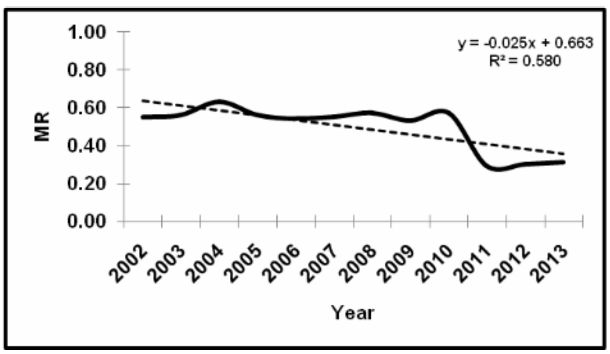

Fig. 5. MR trend of HR events from 2002 to 2013

3.3. *PoD of HR events*

PoD is sensitive to hits and ignores false alarms. Generally, PoD scores are high in case of low frequency of HR events. PoD trend of HR events of India as a whole from 2002 to 2013 is shown in Fig. 4.

A positive improvement in PoD is observed over India as a whole in recent years. In percentage wise, it is about 27% improvement since 2002. During Monsoon 2013, PoD was 0.69 for India as a whole. The jump in the PoD in the last few years may be mainly attributed to the availability & use of latest forecasting tools & techniques including numerical weather prediction (NWP) Models and satellite information.

Region-wise, PoD was highest over west India (0.77), which was mainly due to high scores of sub-divisions namely Marathawada (0.88) and Konkan & Goa (0.85). It was lowest over northwest India (0.62) mainly due to Punjab (0.32) sub-division. In general, it was observed that PoD was more than 0.80 over the sub-divisions, where the frequency of HR events was less like, Jammu & Kashmir, Marathawada and Lakshadweep.

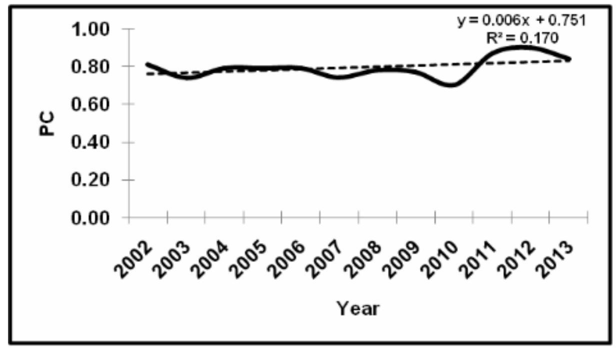

Fig. 6. PC trend of HR events from 2002 to 2013

3.4. *FAR of HR events*

FAR is sensitive to false alarms and ignores misses. FAR during 2013 was 0.29. It was 0.36, 0.29 and 0.22 during 2010, 2011 and 2012 respectively.

Region-wise, FAR was lowest over east India (0.17), which was mainly contributed by low score of sub-division namely Jharkhand (0.11). It was highest over northeast India (0.49), which was mainly due to high score of sub-division Nagaland, Manipur, Mizoram and Tripura (0.67).

3.5. *MR of HR events*

MR is sensitive to misses and ignores false alarms. Like PoD, MR is less in case of rare events. MR trend of HR events for India as a whole between 2002 and 2013 is given in Fig. 5. MR has also shown positive reduction in recent years; it has reduced by 28% since 2002.

MR of India as a whole during 2013 was 0.31 with lowest MR over west India (0.23) and highest over northwest India (0.38). The lowest MR over west India was mainly due to lowest missing rates over the sub-divisions namely Marathawada (0.13) and Konkan & Goa (0.15). Highest MR over northwest India was mainly due to missed events over the Punjab sub-division (0.68).

3.6. *PC of HR events*

It is the probability of occurrence of the observed event and is heavily influenced by the "no event" category. So, it gives high value of PC over the sub-divisions, where the frequency of HR events is less. Thus, it does have direct relevance to assessment of forecasting skill, because forecasting system has no control over the rate of occurrence of HR event (Jolliffe and Stephenson, 2003). The trend of PC for the period between 2002 and 2013 is given in Fig. 6.

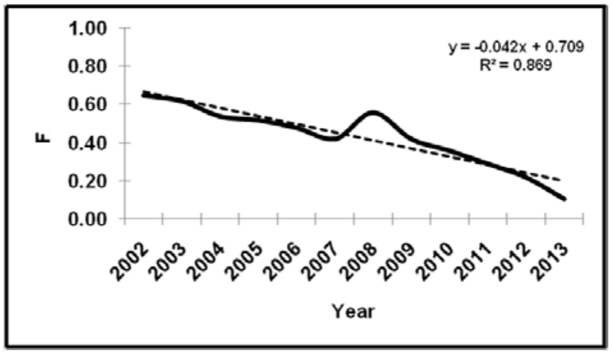

Fig. 7. F trend of HR events from 2002 to 2013

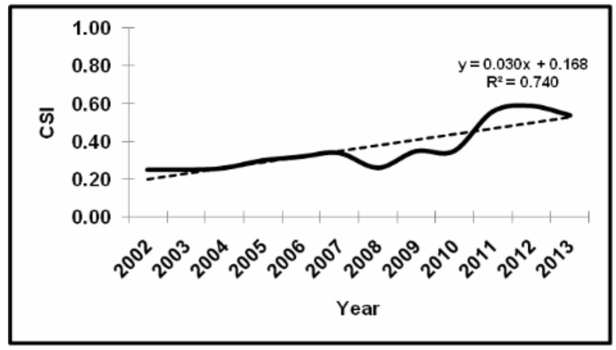

Fig. 8. CSI trend of HR events from 2002 to 2013

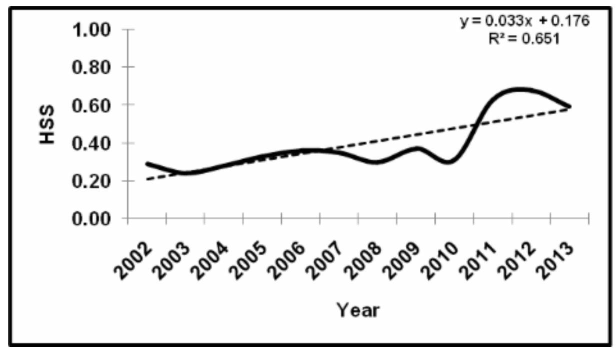

Fig. 9. HSS trend of HR events from 2002 to 2013

During monsoon season 2013, PC for India as a whole was 84%. Region-wise PC is maximum over West India (87%) and lowest over northeast India (76%). The highest score over west India is mainly attributed to sub-divisions namely Saurashtra & Kutch and Marathawada. Further, subdivision-wise analysis indicate that PC was generally high over the sub-divisions with less frequency of HR events and low over the sub-divisions with more frequency of HR events.

3.7. *F of HR events*

This score is highly sensitive to false alarms and ignore misses. It is highly dependent on the frequency of HR events. Generally, its score is good with more frequency of events. F trend of all India rainfall between 2002 and 2013 is given in Fig. 7. A positive reduction in F by 52% is observed since 2002. The remarkable improvement may be due to standardization in the forecast practices and higher confidence of the operational forecasters in the use of NWP & Satellite products.

In monsoon 2013, F was 0.11. Region-wise, F was lowest over northwest India (0.07) and highest over northeast India (0.22). High scores of F over northeast India were mainly due to high scores of Arunachal Pradesh (0.25) and Assam & Meghalaya (0.25). ‘F’ was nearly zero over Punjab, Haryana and west Rajasthan.

3.8. *CSI of HR events*

CSI are mostly used for forecasts of rare events like HR as a performance measure because it is calculated without using the correct no events (Jolliffe and Stephenson, 2003). So CSI is only concerned with the forecast and not with the non-occurrence of events. CSI is sensitive to hits and penalized to false alarm and miss rate. CSI trend between 2002 and 2013 are given in Fig. 8.

There is positive improvement in CSI in recent years; it has increased by 42% since 2002. In monsoon 2013, CSI for India as a whole is 0.54. Region-wise, Central India has highest CSI (0.63) and northeast & south India has lowest score (0.41). Good CSI score over Central India was mainly due to west Madhya Pradesh sub-division (0.80).

3.9. *HSS of HR events*

It is the measure of fractional improvement over random chance. HSS of HR events for India as a whole from 2002 to 2013 is given in Fig. 9. It shows a positive improvement in HSS by 43% since 2002. In monsoon 2013, HSS value was 0.59 with highest value of 0.64 in Central, west & east India and lowest value of 0.38 in northeast India.

4. Conclusions

The following conclusions can be drawn from this study:

(*i*) There is positive improvement in the accuracy and skill in the forecast of HR events over India during southwest monsoon season in the recent past. The noticeable improvement in the last few years may be mainly attributed due to enhancement in observing systems, improvement in the skill of NWP models, use of latest forecasting tools & techniques and trained human resource.

(*ii*) The skill scores particularly CSI, HSS and PoD has improved by 42%, 43% & 27% respectively since 2002.

(*iii*) There is a large reduction in F and MR is observed in recent years. F & MR are reduced by 52% & 28% respectively since 2002. The remarkable improvement in F may be due to adoption of standard forecast practices and higher confidence of the operational forecasters in NWP & Satellite products.

(*iv*) Analysis shows that skill scores like PoD, PC, CSI and HSS are generally better over high rainfall regions like west, central and east India.

(*v*) Also, it was observed that MR is highest and F is lowest over northwest India as compared to other regions, which may possibly be due to less frequency of HR events.

Acknowledgement

Authors are very thankful to Dr. Elizabeth Ebert of Centre for Australian Weather and Climate Research for her helpful comments.

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