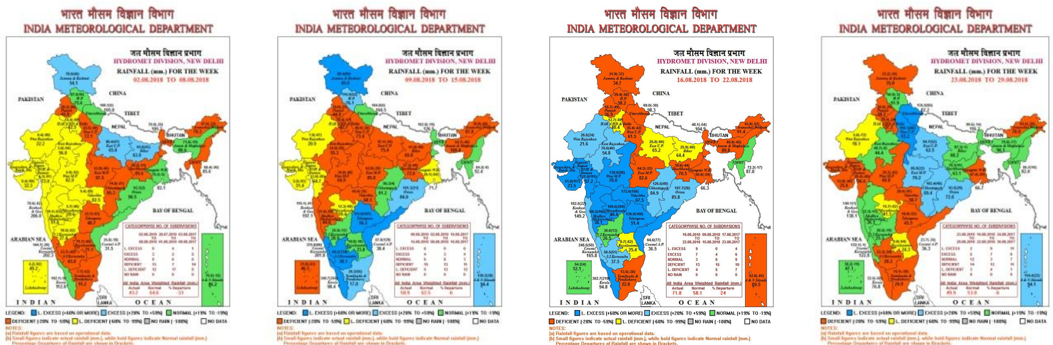
Bulletin of IMSP   BIMSP

September 2018

Vol. 17,2 2018



Subdivision wise rainfall distribution in the first (2-8 August), second (9-15 August), third (16-22 August) and fourth (23-29 August) week of August 2018 (Figures taken from IMD website).

Photograph of teachers, chief guest, guest of Honours, faculty of the teacher's training workshop held in IITM during 30, 31 August and 1 September 2018

India Meteorological Society

Pune Chapter 2018-2020

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1. Advancement of Meteorological and allied sciences in all their aspects
2. Dissemination of the knowledge of such sciences both among the scientific workers and among the public and
3. Promotion of application of Meteorology and allied sciences to various constructive human activities

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Bulletin of IMSP

September 2018, Vol 17, 2

Contents

Monsoon Activity during August 2018

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Abstract

The activity of the southwest monsoon during August 2018 is presented in this paper. In this month break like situation prevailed up to 7 August over many parts of the country. There were 4 low pressure systems (LPS) and 2 depressions in the month. The country as a whole, rainfall was 92.4 % of long period average which was close to long range forecast given on 31 May 2018. All India area weighted weekly rainfall departures in the four weeks were -33%, -6%, +24% and -6% respectively. The rainfall conditions over India and Maharashtra improved due to formation of LPS over the head Bay of Bengal (BoB), Odisha coast in the second and third weeks of August. The contribution to August month all India rainfall by LPS was 57.11% and by depressions 18.57%. Abnormally heavy rainfall occurred over Kerala during 13-20 August which resulted in to state wide floods in Kerala.

1) Rainfall distribution

1.1) Spatial distribution

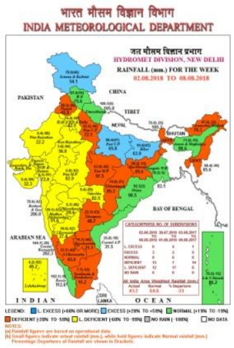
Table 1 shows spatial rainfall distribution over country as a whole and four homogeneous regions of India (Table is taken from IMD web site)

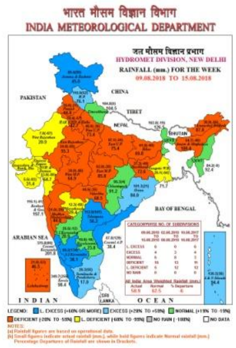
AUGUST-2018	1-Aug	TO	31-Aug
REGION	ACTUAL	NORMAL	% DEP
COUNTRY AS A WHOLE	241.4	261.3	-7.6
NORTHWEST INDIA	197.7	215.6	-8.3
EAST & NORTHEAST INDIA	279.2	355.1	-21.4
CENTRAL INDIA	273.8	305.0	-10.2
SOUTH PENINSULA	223.7	180.7	23.8

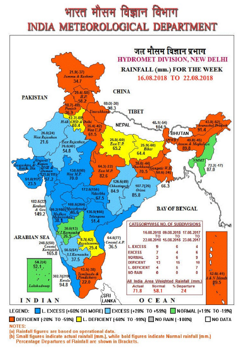
In this month, country as a whole, received rainfall 7.6% below the long term normal. As per the second stage forecast given on 31 May, by IMD, the country as a whole, rainfall during August was likely to be 94% with model error of ± 9%. Actual rainfall in this month was very close with that predicted. East and northeast India show maximum negative departure of – 21.4% whereas south peninsula shows maximum positive departure of 23.8% .

1.2) Weekly rainfall distribution over India

Figures 1- 4 show subdivision wise weekly rainfall distribution over the country in the month.







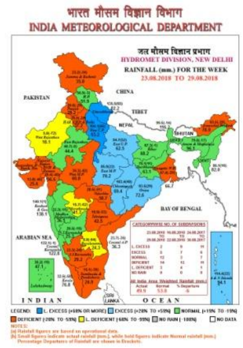


Figure 1 Figure 2 Figure 3 Figure 4

Figure 1,4; Subdivision wise rainfall distribution in the first (2-8 August), second (9-15 August), third (16-22 August) and fourth (23-29 August) week of August 2018 (Figures taken from IMD website).

In the first week (2- 8 August), all India rainfall departure was -33%. 24 subdivisions were in deficient or large deficient category. In the second week (9-15 August), the rainfall condition over the country improved. All India rainfall departure was -6%. 21 subdivisions were in the deficient or large deficient category. In the third week (16-22 August), the rainfall condition over the country improved still further. All India rainfall departure became +24%. 17 subdivisions were in deficient or large deficient category. In the fourth week all India rainfall was -6%. Number of deficient subdivisions remained same as 17.

1.3) Weekly rainfall distribution over Maharashtra

The state of Maharashtra has four meteorogical subdivisions. The weekly rainfall distribution over these subdivisions is given in Table 2.

Table 2: Weekly rainfall distribution over four subdivisions of Maharashtra in the month of August 2018.

Subdivision/ week (rainfall in % departure)->	Week 1	Week 2	Week 3	Week 4
Konkan	-62	-41	22	1
Marathwada	-86	-69	284	-62
Madhya Maharashtra	-63	-29	160	-11
Viderbha	-89	-35	156	-51

All the four subdivisions had rainfall below normal in the first two weeks. The rainfall condition improved in the third week having positive departures in all the four subdivisions. Again in the last week, the rainfall was below normal in three subdivisions.

2. Low pressure systems (LPS)

In the month, four low pressure systems (LPS) and two depressions formed. First LPS developed over north Bay of Bengal (BoB) on 6 August which intensified into depression on

8 August. Second LPS developed over the northwest BoB and West Bengal on 13 August, which intensified into depression over Odisha on 15 August. Third LPS formed on 19 August over northwest BoB, and travelled westward. The LPS lay over northwest MP on 22 August. Fourth LPS formed over West Bengal and north BoB on 25 August which had a short life. Improvements in rainfall conditions over India and Maharashtra in the second and third weeks of August were due to these 4 LPS and 2 depressions.

Figure 5 shows the track of these four LPS and depressions.

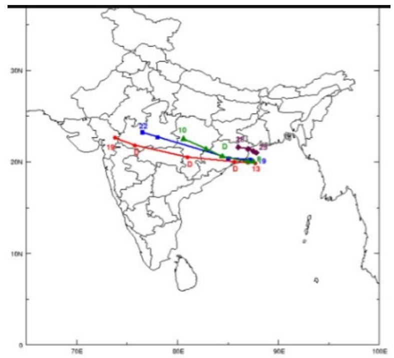


Figure 5: Tracks of lows and depressions in the month of August

Mooley and Shukla (1987) showed that number of LPS in the month of August is 3.6 with standard deviation of 1.1. This year's number of four LPS is close to climatological normal value of LPS. The monsoon rainfall increases during the presence of LPS. All India monsoon rainfall is well correlated with number of LPS, more with LPS days. The maximum correlation is with extent of westward travel of LPS. In this month, total LPS-days were 16 and 4 depression-days. The contribution to monthly rainfall by these LPS has been estimated by measuring the rainfall on the LPS days. It is seen that the contributions to August month all India rainfall are 57.11% and 18.51% by lows and depressions respectively.

3. Important meteorological feature of the month

Kerala state witnessed large scale floods during the period 13-15 August. Heavy to very rainfalls occurred during 7-13 August in Kerala. The rainfalls in 6 out of 14 districts were more than 10 times the normal. Idukki district rainfall broke the record of 111 year of the highest rainfall. It received 1419 mm rainfall in August; its previous highest was 1387 mm in 1907.

Acknowledgement

All the material is for this paper is taken from IMD site: www.imd.gov.in. Author acknowledges the same. Author thanks Mrs. Ravdekar for help in the preparation of the paper.

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The history of Cloud Seeding in India

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1) Origin and science of cloud seeding

Water is one of the most basic needs for sustaining human life. It is essential for human consumption, agricultural purposes and power generation. It is the fact that traditional sources and supplies of water (ground water, rivers and reservoirs) are either inadequate or under threat from ever increasing water demands due to growing populations and changes in land use. The ultimate source of fresh water is precipitation. In some areas where the rainfall is marginal, the agricultural productivity can be substantially boosted and the region transformed even by the small proportional increases in the rainfall through a systematic programme of human intervention in the precipitation forming processes. The art of artificial intervention of influencing the weather has attracted men from ancient times. The earliest attempts consisted of prayers and sacrifices to placate the deities. In the late 1940s, Langmuir and his colleagues at the General Electric Research laboratory discovered that dry ice, when dropped into a supercooled cloud deck from an airplane, caused a rapid conversion of water to ice, leading quickly the production of snowflakes and dissipation of cloud in the seeded region. Soon they discovered that silver iodide had same nucleating property. Another method for stimulating the precipitation has been found by injecting salt particles near the base of the cloud to provide centers for droplet formations. After this numerous attempts were made in Australia, USA and Israel where convincing and significant increases in precipitation were noted.

The sizes, types and concentration of nuclei present in the atmosphere play an important role in determining the efficiency with which a cloud system forms and ultimately produce precipitation. The type of cloud seeding depends on the vertical extent of the cloud and is of two types. (1) Warm Cloud Seeding is done in warm clouds (vertical extent up to the freezing level) by injecting salt particles/hygroscopic giant size nuclei near the base of the cloud to provide centers for droplet formations. This stimulates the growth of raindrops by the collision-coalescence mechanism. (2) Cold Cloud (or dynamic) Seeding (reaching above freezing level and having supercooled water) is done by introducing artificial ice nuclei (silver iodide) to produce ice crystal at the cloud top. The conversion of supercooled liquid water to ice releases heat which, in turn, increases cloud buoyancy. This increased buoyancy invigorates the cloud and prolongs its life time.

2) Experiments in India

In India for the first time attempts were made by Tata firms in 1951 to seed clouds in the Western Ghats region using ground-based silver iodide generators (Banerji and Mukherji 1955). Then attempts were made by Dr. S.K. Banerji at Calcutta in 1952 by dispersing seeding agents like salt and silver iodide by means of hydrogen filled balloons released from the ground to reach the clouds. In 1953, the Committee on the Atmospheric Research of the

CSIR recommended that a research Unit called Rain and Cloud Physics Research (RCPR) be set up for undertaking extensive scientific studies on Cloud Physics and Rainmaking. Thus RCPR was set up in 1955 at the National Physical Laboratory, New Delhi. This was subsequently transferred in 1967 to the Institute of Tropical Meteorology, Pune. The RCPR unit conducted long term randomized warm cloud modification experiments through salt seeding using ground-based generators during 1957-1966 in north India. The results of the rainfall analysis showed statistically significant increase by ~20% on seeded days (Ramana Murty and Biswas 1968). Limited salt seeding experiments using aircraft were also conducted in the Delhi region in the monsoon season of 1962 but no significant results were obtained.

Randomized salt seeding experiments with a fixed control-target design were conducted using ground-based generators at Tiruvallur (Madras) during the southwest and northeast monsoon of 1973, 1975-1977. The results of these experiments suggested that the rainfall on seeded days showed an increase of 32% during southwest monsoon season and a decrease of 17% during the northeast monsoon season. The results are not statistically significant. As the experiment could not be conducted systematically it was discontinued. Also few clouds were seeded using aircraft with 50 km off the Mumbai coast during monsoon seasons of 1973 and 1974. During these experiments radar and in-cloud electrical, microphysical and dynamical observations were made (Chatterjee et al. 1978). The radar observations indicated increases in areal echo coverage, vertical extent and echo intensity following the release of salt particles into the clouds. The variations noticed in the electrical, microphysical and dynamical conditions of cloud following seeding are consistent with the warm cloud modification hypothesis.

3) Experiments in IITM

Then the Indian Institute of Tropical Meteorology, Pune launched a Warm Cloud Modification Experiment using aircraft in 1973 in the semi-arid region located to the east of Pune on the lee-ward side of the Western Ghats. A randomized double area cross-over design, with a buffer area, was used for these experiments. The three sectors have been designated as North (N), South (S) and Buffer (B) sectors. The area of each sector was 1600 km^2. In the experimental area 90 standard type meteorological rain gauges were installed. The DC-3 aircraft was used for releasing the seeding material containing the mixture of salt and soapstone in the ratio 10:1. The following physical observations were made using the instrumented aircraft during 1973-74, 1976, 1979-1986: cloud droplet size distribution, cloud liquid water content, electric field, cloud droplet charge, temperature of the cloud and cloud-free air, cloud condensation nuclei, giant size condensation nuclei, cloud photography and cloud size, chemistry of the rain water collected during the experimental regions. The results showed 24% increase in the rainfall (Murty et al. 2000). The review of the Indian cloud seeding studies can be found in Kulkarni et al. (2008).

During 1973 and 1974, IITM carried out cloud seeding operations over Rihand catchment in the state of Uttar Pradesh (Kapoor et al. 1976). In 1975, operational programme of cloud seeding was conducted over Linganamakki catchment area in the state of Karnataka. These programmes were operational; hence their effect in increase in rainfall could not be assessed. Apart from these some operational seeding were conducted by State Governments for augmentation of precipitation: (i) Tiruchirapalli, south India (1962-64 and 1966-67), (ii) Bhiwani and Hissar in Haryana (1973), (iii) Godhra, Gujarat (1972-74 and 1975) and (iv) Tamil Nadu (1975), (V) State Governments of Karnataka (2003-2005, 2012, 2017), Andhra Pradesh (2005-2007) and Maharashtra (2004, 2009, 2015).

This has prompted atmospheric scientists to explore the possibility of augmenting water supplies by means of cloud seeding as one possible mitigation strategy among multitude that could be considered (WMO 1999, Bruintjes 1999).

During the later part of the decade 1980-1990, the scientific activity of cloud seeding remained subdued mainly because of lack of new findings. In the early decade of 1990-2000, witnessed many advances in the airborne instrumentation, radars, flares and softwares. The South African cloud seeding experiment was carried out during 1991-1995 with new technology. The results showed statistical increase in rainfall in all types of clouds (small to large). This gave impetus to cloud seeding research in different parts of the globe. Some of the important programmes carried out and in the process are: Mexican Experiment: 1996-1998; United Arab Emirates Experiment: 2001-2004; Italy Experiment: 2004-2005; Indonesian Experiment: 2005; Wyoming Experiment: 2005-2010; Southeast Queensland Cloud seeding Experiment: 2008-2010.

4) National CAIPEEX program

Latest using the modern airborne instruments, radar, flares and software the cloud seeding experiments were conducted by IITM as nodal institution from 2009-2011, and still continuing in 2018. This is called Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) (Kulkarni et al. 2012). This is multi-institutional national research experiment. CAIPEEX has two components (i) Cloud Aerosol interaction and (ii) precipitation Enhancement. Many new things emerged through the aircraft and radar observations carried out in CAIPEEX. The experiment was conducted in different phases. Phase I (background aerosol and cloud microphysical observations in 2009), Phase II (Randomized cloud seeding experiment 2010 and 2011), The prominent outcomes from CAIPEEX are: (1) Mechanism of rainfall over the west coast of India (Maheskumar et al. 2014), (2) mixing of dry air and impact on the cloud microphysical parameters (Morwal et al. 2015) (3) Gray Ocean clouds over peninsular India (Padmakumari et al. 2018) (4) spatio-temporal variability of convection over rain-shadow region of peninsular India (Morwal et al. 2016; 2018). The results showed that the convective clouds over peninsular India are suitable for hygroscopic and glaciogenic seeding. The protocol for seeding has been prepared for operational cloud seeding programs in India. The program is being conducted to get sufficient number of randomized cases in the year 2018.

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Importance of the Satellite Data in Meteorology

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1. Dawn of the Satellite Era in Meteorology

With the launch of an artificial satellite of the earth- the Sputnik-1 by the Soviet Union on 4th October 1957, marked the beginning of the satellite technology in the field of space science. Then the USA also undertook the major space program launching the Explorer-Ion 31st January 1958 and subsequently the first satellite with the equipment for the meteorological observations- TIROS-1 (Television Infrared Observational Satellite)on 1st April 1960. This was the dawn of the satellite era in meteorology.

USA continued this space campaign with the orbiting of the several satellites by NASA (National Aeronautics and Space Administration) and NOAA (National Oceanic and Atmospheric Administration). Afterwards, some other countries or the agencies like European Space Agency (ESA), Japan, China and India also joined this space club during the next few years and a lot of progress is witnessed in this field over the period ofpast six decades.

2. Indian Scenario

Indian Space Organization (ISRO) was established in 1969 to fulfil the dream of Dr. Vikram Sarabhai to utilize the space technology in India for the national development. He was closely associated with an eminent Meteorologist and the founder Director of IITM, Dr. P.R. Pisharoty who is also considered as the father of Indian remote sensing. It may be mentioned that Dr. Pisharoty joined this new discipline of the science after his retirement from IITM. He was instrumental in putting the instruments (sensors) onboard the Indian satellites for the meteorological parameters. Thus, we owe much to these two stalwarts for their role in providing the satellite derived meteorological data for this discipline.

India's launched the first satellite- Aryabhata in 1975 followed by Bhaskara in 1978. Later on, ISRO continued to undertake several successful missions over the period of past forty years with the specific themes.

Dr. Vikram Sarabhai Dr. P.R. Pisharoty

Physicist *Meteorologist*

The father of Indian Space Science *Father of Indian Remote sensing*

3. **Types of the satellite**

In general, there are two types of the satellite used for the Meteorological purpose -the geostationary and other one the low earth orbit as described below.

Geostationary or **GEO** satellite is placed over the equator at a specific longitude at the height of about 35800 km from the surface of the earth. It revolves around the earth with the same velocity as that of the earth's rotation around its axis. Therefore, the satellite is stationary with respect to the earth. Hence, it has the advantage that it can view the same region continuously over the earth under its coverage. However, it cannot see the polar regions.

The examples of GEO satellite are the Indian National Satellite (INSAT) series, Geostationary Operational Environmental Satellite (GOES) of the USA, the METEOSAT of the ESA and Himawari of Japan.

Low earth orbit or the LEO satellite on the other hand is placed at the height between 350 and 2000 km above the earth surface. It does not continuously see the same location, but scans entire globe daily depending upon its orbit specifications. The polar orbiting satellite passes over the location near the north and south poles. The sun-synchronous orbit of the polar satellite covers its scan area with the same solar illumination for each orbit. The advantage of the polar LEO satellite is that it provides the observations over the polar regions which is not possible for the GEO satellite as mentioned earlier. Moreover, the resolution of LEO is better as compared to the GEO because of its lower altitude above the surface of the earth. Its orbital period is about 90 -120 minutes.

The examples of polar orbiters are the NOAA series of the satellites of the USA and the Oceansat of India. There are some LEO satellites designed with specific purpose and they are not the polar orbiters, but scan the earth with different scan angles (inclination).

4. Principles of the satellite remote sensing

The payloads (sensors) on the satellite are designed with appropriate bands of the electromagnetic spectrum to collect the radiation emanating (reflected, emitted or scattered) from the constituents of the earth-atmosphere system in visible, infrared (IR) and microwave (MW) channels. Then, several meteorological parameters are derived by application of different techniques. The imager on the satellite gives the parameters at certain levels and the sounders probe the atmosphere to determine the vertical profiles of the variables like the temperature and moisture.

Visible channel provides information during day time only while in IR, the observations can be collected during night also. MW channels on the other hand, are useful for viewing all the time weather as they can penetrate the clouds to see further below, but with lower resolution.

5.Present GEO and LEO satellites over the Indian region

ISRO launched a geostationary satellite INSAT-3Din 2013 with the meteorological payloads and placed at Long. 82^o E. It carries 6 channel imager and 19 channel sounder. For more details one can refer to the link- http://satellite.imd.gov.in/dynamic/INSAT3D_Catalog.pdf). Some specifications INSAT-3D Imager are shown in Table.

Table - Some specifications of INSAT-3D Imager

Spectral Band	Wave length (micrometer)	Ground resolution (km)
Visible	0.55 – 0.75	1
Shortwave infrared	1.55 – 1.70	1
Middle infrared	3.80 – 4.00	4
Water vapour	6.50 –7.10	8
Thermal infrared-1	10.3 – 11.3	4
Thermal infrared-2	11.5 – 12.5	4

The GEO satellites- INSAT-3DR (at 74^o E) and METEOSAT-8 (at 41.5^{o}E)also coverdata of the Indian ocean region.

For the LEO, the NOAA series (NOAA: *http://eoedu.belspo.be/en/satellites/noaa.htm)* and some other satellites also provide useful data over this region.

5. Satellite Derived parameters

During last 2-3 decades, the wealth of meteorological data are made available by the satellites. Especially, the satellite data over the vast oceanic region are very valuable as these observations are not available at regular time and space intervals by other means. Some of the satellite derived parameters are given below-

Cloud cover, their types and temperatures of the top level, sea surface temperature and winds, vertical temperature and humidity profiles, cloud motion and water vapour derived upper level winds, rainfall estimates, outgoing long wave radiation, snow cover, fog, aerosol, ozone, intensity and the tracks of the tropical cyclones and so on.

Extracting data from the satellites and applying it in meteorology has become indispensable part of this field in the recent years. Now, the Satellite Meteorology is a specialized branch where a number of scientists are engaged world over to utilize this data for many applications in the field. Some of them are briefly discussed in the following section.

6. Use of the satellite data in meteorology

Satellite data has applications in various disciplines right from weather forecasting to the climate change issues as described below.

6.1. **Weather forecasting**

Weather forecasting is done adopting following methods or techniques with applications of the satellite data.

(a) Synoptic method

For day-to-day weather forecasting, synoptic method is used which is based on the analysis of the synoptic charts. The satellite derived parameters like the information of the clouds, OLR (convective activity), winds, humidity are also considered along with the conventional observations. This gives better insight of the current weather situation to the meteorologist to forecast the future state of the atmosphere over the region.

(b) Numerical weather prediction (NWP)

NWP is a technique where the physical laws governing the atmospheric processes are applied to predict the weather using a powerful computer. The mathematical equations involved in this process are very complex and sensitive to the accuracy of the initial data. Therefore, the small errors in the meteorological parameters at the beginning get amplified rapidly and vitiate the forecast in the course of time. In order to predict the weather for more than 4-5 days, the data of the entire globe is necessary. We know that more than 70 % of the earth is covered with the oceans and certain land regions are also data sparse. Therefore, only the chain of the satellites which observe the earth and its atmosphere for 24 hours can supplement the conventional observation sfor the NWP models. During last couple of decades, the quality and the quantity of the satellite data have improved considerably .As a result, the present NWP models give better forecast because of the assimilation of good quality satellite data, availability of the high speed computers and the improvement in the model characteristics.

(c) Seasonal and monthly weather forecasting

All India summer monsoon (June-September) rainfall (AISMR) is important from the economic and social points of the country. Therefore, its forecasting is useful for planning the activities dependent on the rainfall. This is an example of the seasonal forecasting.

The statistical models are often used for this purpose. These models are based on the identification of certain antecedent (of the earlier period) regional or the global parameters (predictors) which can be linked to the parameter to be forecast (predictand). For the development of the statistical model for the monsoon forecast, the correlation coefficients (CC) between the AISMR and some other parameters as mentioned above are computed using the past data. Then, applying some statistical techniques the regression equation is developed choosing appropriate predictors. This equation is used for forecasting the ensuing AISMR.

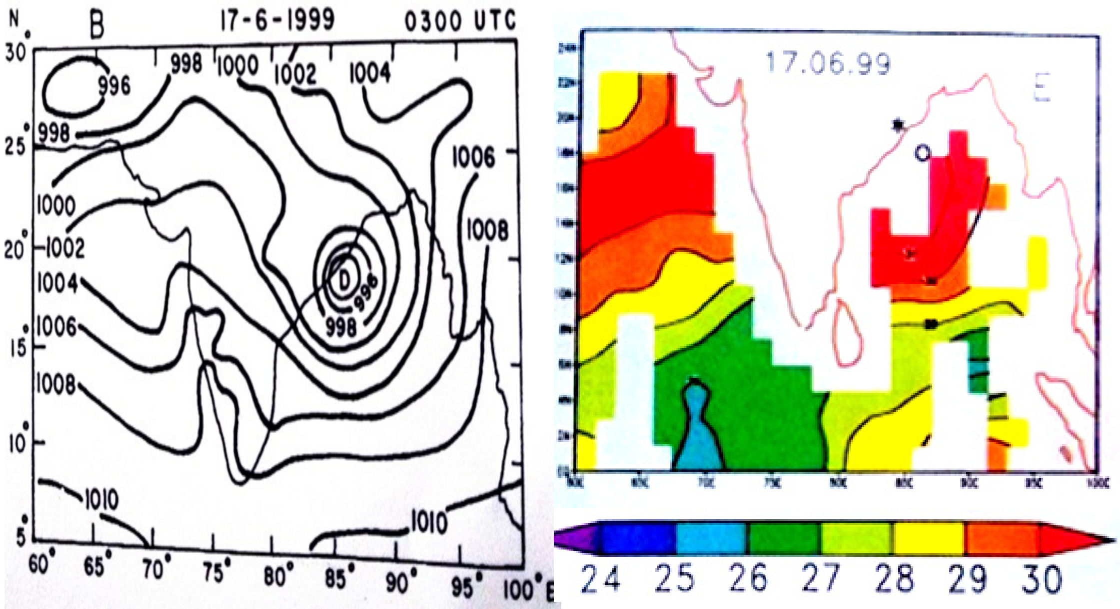
Some of the predictors in these equations may be the snow cover over the mountain ranges, the sea surface temperatures of the particular oceans or the ice accumulated over the polar regions averaged during the certain period of the earlier months. Such data is derived from the satellites and the conventional observations. Therefore, the satellite data are important for the seasonal weather forecasting.

Statistical models can also be developed for the regional as well as the monthly scales weather forecasting.

6.2. **Diagnostic studies – Application of the MW data**

Under certain favourable conditions, some weather systems form over the Indian region in different seasons. In order to study the life cycle of any system, the information during its formation, intensification or dissipation is useful for carrying out the diagnostic studies to anticipate its effects. One of the applications of the satellite microwave remote sensing is demonstrated here for a case of monsoon depression (MD).MD is an important low pressure system that normally forms over the North Bay of Bengal and produces widespread rainfall over the large area of its influence during the summer monsoon season. A diagnostic study of a MD formed in June 1999 was carried out using the MW channels. ISRO launched a satellite Oceansat-1 (IRS-P4) in 1999 with the capability of providing some meteorological parameters over the ocean. Although, full life cycle of this MD was studied with the satellite data for four parameters, only a case of one parameter namely-the sea surface temperature (SST)is presented here for one day. Figure 1-A shows the position of the monsoon depression marked with 'D' on 17 June 1999 in the Bay of Bengal as per India Meteorological Department (IMD) analysis. Its central pressure was 996 hPa increasing outwards as seen from the isobar pattern. The signs o and * indicate the locations of the depression at 3 and 12 hours UTC respectively.

As the Oceansat-1 was a LEO satellite, its observations were recorded during its passes over the scan width (swath) of 1360 km - both over the Arabian sea and the Bay of Bengal. The corresponding SST field retrieved from Oceansat-1 is depicted in figure 1 (B). The SST values are shown in different colours for identification of its variation in space and time. The red colour indicates SST =30^{o}C. With such data we can study the day to day changes in the meteorological parameters associated with the different stages of the weather system. It may be mentioned that the sea surface observations are possible even below the cloudy region because of the MW channels (6.6, 10.65, 18 and 21 GHz) of this satellite payload. These parameters can be used as the input to the NWP models with proper validation studies. As such, this is the advantage of the MW satellite remote sensing.



(A) (B)

Fig. 1 : Satellite observed SST during monsoon depression as on 17 June 1999.

[**Reference**- Oceansat-1 derived met-ocean parameters --------- east coast of India. Published *in Indian Journal of Marine Sciences (2004)* by RM Khaladkar, PNMahajan, SG Narkhedkar, Sathy Nair, PK Pal and PC Joshi]

6.3. **Tropical cyclone Monitoring**

The tropical cyclones are very disastrous weather systems forming over the ocean and causing vast damage to the life and property when they hit the coast. Sometimes, India is affected by the tropical cyclones mostly during pre and post monsoon seasons. INSAT keeps continuous watch over the cyclones right from their genesis to the dissipation. The intensity of the cyclone is assessed by applying Dworak's technique which is primarily based on the satellite observed features. Accordingly, the cyclone stages are classified with the 'T' numbers which increase with the strength. As per the classification followed in IMD, T1.5 indicates a depression stage (wind speed 31-49 km/h) while T6.5 is a super cyclone stage which is most severe cyclone (wind speed exceeding 222km/hr). Such information is very important for giving guidance to the public as well as to the government authorities to take appropriate measures to reduce the damage. INSAT also carries one special equipment- Satellite Aided Search and Rescue (SAS and R) for issuing necessary warning about the disaster for the rescue operations.

In the recent years, although some part of India was badly hit by the cyclones, the death casualties have been reduced to the minimal as compared to the thousands during the pre-satellite era. This is because of the role of the satellites in the cyclone predictionskill andthe better transport facilities available at present. During past 2-3 decades not a single cyclone over the globe has escaped from the satellite surveillance. Apart from issuing warning about their disastrous effects, their information is also important from some other aspects like the study of the transport of heat and moisture in the atmosphere.

As an example of the satellite monitoring of the cyclone, a case of a cyclone which affected India in 2017 is illustrated here.

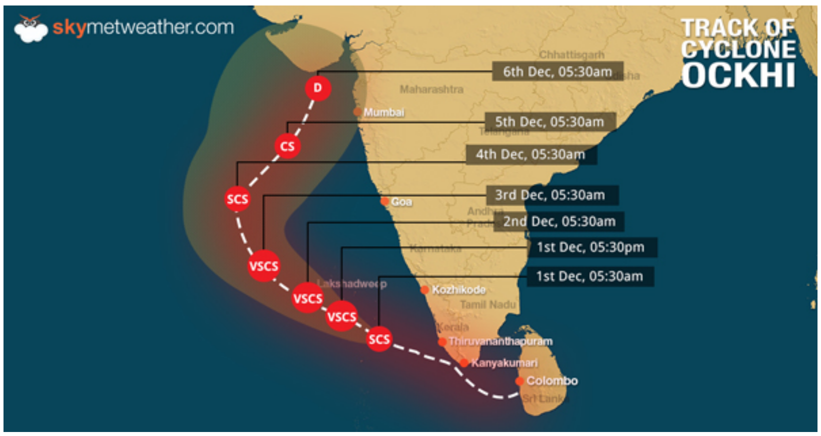


Fig. 2 : Track and the stages of Ockhi cyclone during Nov-Dec. 2017.

(Signs - e.g. VSCS – very severe cyclonic storm stage, D- depression stage)

Some parts of Sri Lanka and the peninsular India experienced large scale damage due to a very severe tropical cyclone -Ockhi that passed over the Arabian sea during 29 November to 6 December 2017. Its track and different stages of the severity as depicted by the Skymet weather service is shown in the Figure 2. This cyclone was very well monitored by the satellites and hence helped to reduce the damage considerably.

6.4. **Mapping of the disaster events - An example of heavy rainfall**

During the third week of August 2018, Kerala state experienced unprecedented amount of rainfall. More than 300 persons lost their lives and caused vast damage to the property estimated to be around Rs. 2000 crore.

This event of very heavy rainfall was caught by the NASA satellite (Figure 3). The figure shows the rainfall of order about 30 cm on 17th August 28, 2018 over the state. Very heavy rainfall over some part of north India is also noticed in this figure.

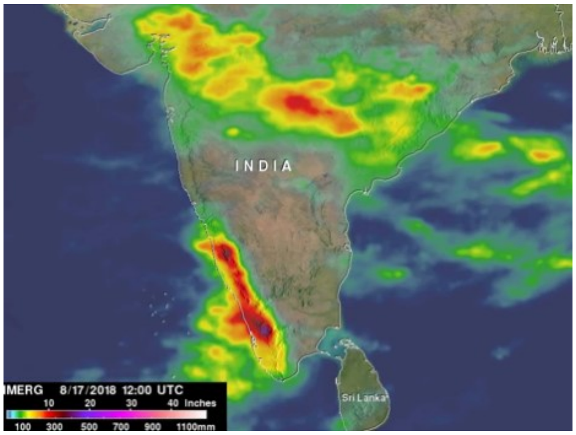


Fig. 3 : Satellite derived very heavy rainfall event over Kerala

6.5.**Climatological studies**

Day to day weather that we experience is due to the interaction between the earth atmosphere system and the solar radiation. The average weather for some particular months or the season is the climatology. The knowledge of the climatology is necessary for the agricultural operations, preparedness for the likely natural calamities, day-to-day life of the citizens, tourism and some other activities over the region.

The events like the El Nino and La Nina (warming and cooling phases of the sea surface over the east equatorial and central Pacific Ocean respectively) take place with the periodicity of about 3-5 years. They affect large scale circulation features over different parts of the globe.

The satellite derived OLR data are useful to identify the convective areas. The low OLR(less than 240 W/m^2) values imply the deep convective clouds indicating the high rainfall activity. This type of information is important for understanding the radiation balance of the earth.

Good quality data sets of about 1^o x 1^oLat./Long. Resolution are required for the study of the diurnal, inter-annual and the decadal variability of various meteorological parameters.

Many satellites of the world have been providing good information for the climatological aspects some of which are mentioned above.

Tropical rainfall measuring mission (TRMM)- a joint mission of NASA and USA as well as the Megha-Tropiques: an Indo-French collaborative program are the examples of the projects undertaken for the climatic studies. Both are the LEO satellites with low inclination covering the tropical regions. Similarly, the data of the satellites like the Defence Meteorological Research Program (DMSP), Quik SCAT (for measuring the sea surface winds) of the USA are also useful in this respect. Further, the International satellite cloud climatology project (ISCCP)is also dedicated for the climate studies.

6.6.**Climate change issues**

For the last few decades, there is worldwide debate on the global warming and some other issues of the climate change.

One of the effects of the global warming will be the melting of the polar ice caps resulting in the sea level rise. This will be dangerous for some islands and the coastal stations. Secondly, there may be the change in the global circulation and the climate patterns affecting the agriculture production and some other activities on the earth.

Similarly, it is noticed that the stratospheric ozone which protects the life on the earth from the harmful ultraviolet radiation of the sun, has reduced in the recent years. This is the so called ozone hole.

If such a situation is taking place, then the question also arises about the contribution of the human caused (anthropogenic) activities leading to the increase in the green house gases or the pollutants in the atmosphere.

In the event of the global warming, the changes in the polar ice coverage or reduction in their thickness as mentioned above can be confirmed from the continuous availability of the satellite data.

In this respect, the long term data of the satellites like TERRA and ACQUA and Orbiting carbon observatory-2 (OCO-2) of the NASA are important to document the status of the climate change and human contribution in it.

The Intergovernmental panel on climate change (IPCC) is working to address various aspects of the climate change.

7. Concluding remarks

This article is written to give general idea about the importance of the tremendous potential of the satellite data for various disciplines of meteorology. Alot of work is carried out in India and abroad on the applications of the satellite data in several studies. In the coming years, more and more satellites will be launched by many agencies in the world providing continuous flow of enormous amount of meteorological data which was not available here before. Hence, there is a need of enough strength of the man power to exploit this opportunity to utilize such precious data for many weather related studies and their applications in the numerical and the statistical models to improve the skill of the weather forecasting as much as possible.

It is hoped that this valuable satellite data will also enhance our ability to understand the issue of the climate change and control the interference of the human activities to save our earth from the disastrous situation in the future.

Acknowledgments

Author is happy to contribute this article for the Bulletin of Indian Meteorological Society, Pune Chapter. Thanks are due to Dr. J. R. Kulkarni, Chairman, IMSP for his suggestion to write it.

Long term variation in southwest monsoon rainfall over Maharashtra during : 1871-2016

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Abstract

The distribution of southwest monsoon rainfall in space and time is very important for country's agriculture production, industries and generation of hydroelectric power. Timely and spatially well distributed rainfall gives good amount of food grain production, whereas erratic behaviour has adverse effect on the food grain production. Keeping this view, in the present study, characteristics of rainfall of four subdivisions i.e. Konkan & Goa (KOG), Madhya Maharashtra (MAM), Marathwada (MAR) and Vidharbha (VID) of Maharashtra have been studied.

The summer monsoon rainfall series of KOG MAM, MAR and VID have been used to examine the rainfall variation in two periods i.e. entire period 1871-2016 and recent period 1981-2016. The long term mean monsoon rainfall of KOG, MAM, MAR and VID for the period 1871-2016 are 2424.5, 582.5, 689.5 and 944.3 mm respectively, whereas, for the period 1981-2016, are 2594.6, 589.2, 689.7 and 915.3 mm. The mean monsoon rainfall of recent period (1981-2016) of KOG has significantly increased from the entire period mean rainfall. During the period 1871-2016, KOG, MAM, MAR and VID experienced the 24, 23, 23, 21 excess years and 15, 22, 21, 25 deficient years, respectively. The probability of occurrence of deficient rainfall over KOG is less (10 %) and highest over VID (17 %).

The long term trend in monsoon season rainfall of KOG MAM, MAR and VID have also been examined for recent as well as entire periods. Monsoon rainfall of KOG, MAM and VID show statistical no significant increasing trend of 6.26, 1.69 and 1.78 mm/year respectively while MAR rainfall shows statistical no significant decreasing trend of -2.05 mm /year for the period 1981-2016.

Key words Trend, Excess year, deficient year

1 Introduction

The state of Maharashtra is located on the western side of the Indian peninsula between latitude 15°35’ to 22°02’ N and longitude 72°36’ E to 80°54’ E. Maharashtra state receives nearly 75 % of annual rainfall during the summer monsoon (June to September) season and maximum rainfall occurs during the months July and August. On the basis of climate variability and topographical features, the Maharashtra state is divided in to four meteorological subdivisions namely Konkan & Goa, Madhya Maharashtra, Marathwada and Vidarbha. Konkan and Goa is spread north south along the extreme western part of west coast, coastline stretching nearly 720 kilo meters along the Arabian Sea of India and Vidarbha subdivision is the extreme eastern parts of the state. The Sahyadri mountain ranges provide physical backbone to the state on the west which help for good amount of rainfall over Konkan & Goa and some parts of the Madhya Maharashtra subdivision. Madhya Maharashtra and Marathwada subdivisions lie between Konkan & Goa and Vidarbha subdivisions. Vidarbha receives less rainfall than Konkan & Goa but higher than the Madhya Maharashtra and Marathwada. Marathwada is having slightly higher rainfall than the Madhya Maharashtra, however , there is high spatial rainfall variability over Madhya Maharashtra. Mukherjee and Singh (1978) reported that there was an increase in the rainfall during the period 1910 to 1955 and then a decrease till 1974 over west coast. Variability of rainfall is very high in Madhya Maharashtra during the chief monsoon months, i. e. July and August (Mukharjee et al. 1979). Alvi and Koteswaram (1985) observed increasing trend in the rainfall over the west coast stations north of Trivandrum. Guhathakurata et al. (2011) and Sinharay & Srivastava (2000) noticed increasing trends in heavy rainfall events and also in total rainfall over Madhya Maharashtra and Konkan & Goa. Ratna (2012) reported that the rainfall is highly variable over all of Maharashtra with the coefficient of variability of the daily rainfall varying between 100 and 300%.

On all-India scale, Kothawale and Rajeevan (2017) have prepared monthly, seasonal and annual rainfall series for all-India, 5 homogeneous regions and 30 meteorological subdivisions for the period 1871-2016. They reported that all-India monsoon rainfall shows very weak decreasing trend of -0.18 mm and -0.17 mm per year for the period 1871-2016 and 1981-2016 respectively. On the sub-divisional scale, East Rajasthan and Saurashtra, Kutch & Diu show significant increasing trend at 10 and 5% significant level respectively, whereas, there are 3 subdivisions namely East Uttar Pradesh, Assam & Meghalaya and Sub-Himalayan West Bengal show significant decreasing trend at 1 %, 10% and 10% significance level during the period 1981-2016. Farming in Maharashtra is heavily dependent on the temporal and spatial monsoon rainfall distribution. The present study focuses on occurrence of excess, deficient years as well as trend in the rainfall series over entire as well as recent periods.

2 Data and Methodology

The present study, we used the monthly and seasonal area weighted rainfall series of four meteorological sub-divisions of Maharashtra namely Konkan & Goa, Madhya Maharashtra, Marathawada and Vidharbha for the period 1871-2016. The data sets are taken from Indian Institute of Tropical Meteorology (IITM) Pune (http://www.tropmet.resin) and IITM Research Report RR-138. Kothawale and Rajeevan (2017) derived the area weighted rainfall time series of all-India, 5 homogeneous regions and 30 meteorological subdivisions for the period 1871-2016. The details of the preparation of time series and quality of the data is given in the IITM Research Report RR-138. Monthly rainfall time series of Konkan & Goa, Madhya Maharashtra, Marathawada and Vidharbha are constructed by considering the rainfall data of 5, 9, 5 and 8 districts respectively. The district rainfalls are obtained from India Meteorological Department Pune.

Long term changes in the seasonal rainfall for the periods 1871-2016 and 1981-2016 of 4 sub-divisions of Maharashtra have been evaluated by the linear trend. The statistical significance of the trend is assessed by means of Mann Kendall rank statistics. Frequency of excess and deficient monsoon rainfall years during the period 1871-2016 have been examined for all the above sub-divisions. The following criteria is used to identify excess and deficit monsoon rainfall years.

Excess Rainfall : R > or = M+SD

Deficit Rainfall : R< or = M-SD

Normal Rainfall : M-SD < R<M+SD

Where M and SD are Mean and Standard Deviation of monsoon seasonal rainfall time series, and R is seasonal rainfall. The criteria used in this study is taken from Parthasarathy et al. (1992b). The change between mean monsoon rainfall based on the period 1871-1980 and 1981-2016 for the 4 sub-divisions have been examined by using student **'t'** test.

3 Discussions

Variability in monsoon season rainfall

In this section, the trends in monsoon season rainfall of 4 sub-divisions of Maharashtra have been examined for the periods 1871-2016 and 1981-2016. The statistical characteristics of monsoon rainfall series have also been computed.

3.1 Monsoon rainfall of Konkan & Goa

Mean, SD and Coefficient of Variations (CV) monsoon season rainfall of Konkan & Goa are 2424.5 mm , 472.6 mm and 19.4% respectively (Table 1). These statistical characteristics are based on the period 1871-2016. The monsoon rainfall showed the significant increasing trend of 2.96 mm/year for the entire period, however during the recent period 1981-2016 trend was increasing but not statistical significant. This is due to decadal variability in monsoon rainfall (Figure 1). During the recent years, rainfall was above mean in many years but year to year variation is less. Mean monsoon rainfall based on the period 1981-2016 is increased significantly (significance at 5 % level) from the mean based on the period 1871-1980 (Table 2).

3.2 Monsoon rainfall of Madhya Maharashtra

Madhya Maharashtra receives less rainfall than the rest of the sub-divisions**.** Mean, SD and Coefficient of Variations (CV) monsoon season rainfall are 582.5 mm , 125.2 mm and 21.5 % respectively. The monsoon rainfall showed very little increasing trend during the period 1871-2016, however during the recent period 1981-2016, pronounced increasing but not statistical significant trend (1.69mm/year) was observed. It is due to rainfall variation after 2000, rainfall is above normal in 9 years and below normal in four years (Figure 2) . Out 9 years, there are 5 excess years (2004, 2005, 2006, 2007 and 2010) and one year rainfall (2010) is just reaching to the excess rainfall. Mean monsoon rainfall based on the period 1981-2016 is just higher than mean based on the period 1871-1980 (Table 2).

3.3 Monsoon rainfall of Marathawada.

Marathawada receives nearly 84 % of annual rainfall during the monsoon season and highest rainfall during the month of September (24 % of annual rainfall, Kothawale and Rajeevan 2017). Variability of monsoon season rainfall is highest over this subdivision. The coefficient of variation and SD is 189.5 mm 27.4 % respectively. The mean monsoon rainfall is 689.5 mm. Monsoon rainfall show very little trend of -0.19 mm/year during the period the 1871-2016, however during the recent period 1981-2016, it shows negative tend of -2.05 mm/year but trend is not statistical significant (Figure 3). Because of, during the recent period, most of the years, monsoon season rainfall is below normal than the above normal and some years rainfalls are also deficit.

Mean monsoon rainfall based on the period 1981-2016 is equal to mean based on the period 1871-1980 (Table 2).

Table 1 Statistical characteristics of monsoon rainfall of 4 sub-divisions of Maharashtra (based on period (1871-2016) (** Trend significant at 1 % level)

	Sub-division	Mean Rainfall (mm)	SD (mm)	CV (%)	Trend (mm/year)	
					1871-2016	1981-2016
1	Konkan & Goa	2424.5	472.6	19.4	2.96**	6.26
2	Madhya Maharashtra	582.5	125.2	21.5	0.07	1.69
3	Marathawada	689.5	189.5	27.4	-0.19	-2.05
4	Vidharbha	944.3	182.8	19.3	-0.35	1.78

Table 2 : Comparison between subdivisional mean summer monsoon rainfall of different period (** difference significant at 5% level)

Sr. No.	Sub-division	Mean base on period 1871-1980 (mm)	Mean base on period 1981-2016 (mm)	Difference between two means (1981-2016) - (1871-1980)
1	Konkan & Goa	2368.96	2594.59	225.63**
2	Madhya Maharashtra	580.34	589.2	8.86
3	Marathawada	689.53	689.69	0.16
4	Vidharbha	953.87	915.29	-38.58

3.4 Monsoon rainfall of Vidharbha.

Vidharbha sub-division falls under monsoon depression and low pressure track, hence it receives substantial amount of rainfall during the monsoon season. The mean of monsoon rainfall is 944.3 mm and SD and CV is 182.8 mm and 19.3 % respectively. Monsoon rainfall show very little trend of -0.35 mm/year during the period the 1871-2016, and during the recent period, trend is 1.78 mm/year (Figure 4). During the entire period rainfalls are excess in 21 years and deficit in 25 years. Mean monsoon rainfall based on the period 1981-2016 is slightly less than the mean based on the period 1871-1980 (Table 2)

4. Conclusions

1) The monsoon rainfall of only Konkan & Goa compare to the rest of the sub-divisions showed the significant increasing trend of 2.96 mm/year for the entire period, however during the recent period 1981-206 trend was increasing but not statistical significant. The mean monsoon rainfall based on the period 1981-2016 is increased significantly (significance at 5 % level) from the mean based on the period 1871-1980 .

2) Madhya Maharashtra, Marathawada and Vidhrabha monsoon rainfalls do not show any significant increasing/ decreasing trend in both periods 1871-2016 and 1981-2016. As well as there is no significant change between mean monsoon rainfall based on the period 1981-2016 and the mean based on the period 1871-1980.

Acknowledgement

The authors are thankful to Director, Indian Institute of Tropical Meteorology (IITM), Pune and Dr. J.R. Kulkarni Chairman of India Meteorological Society Pune Chapter. The authors are also grateful to India Met. Department Pune for providing rainfall data.

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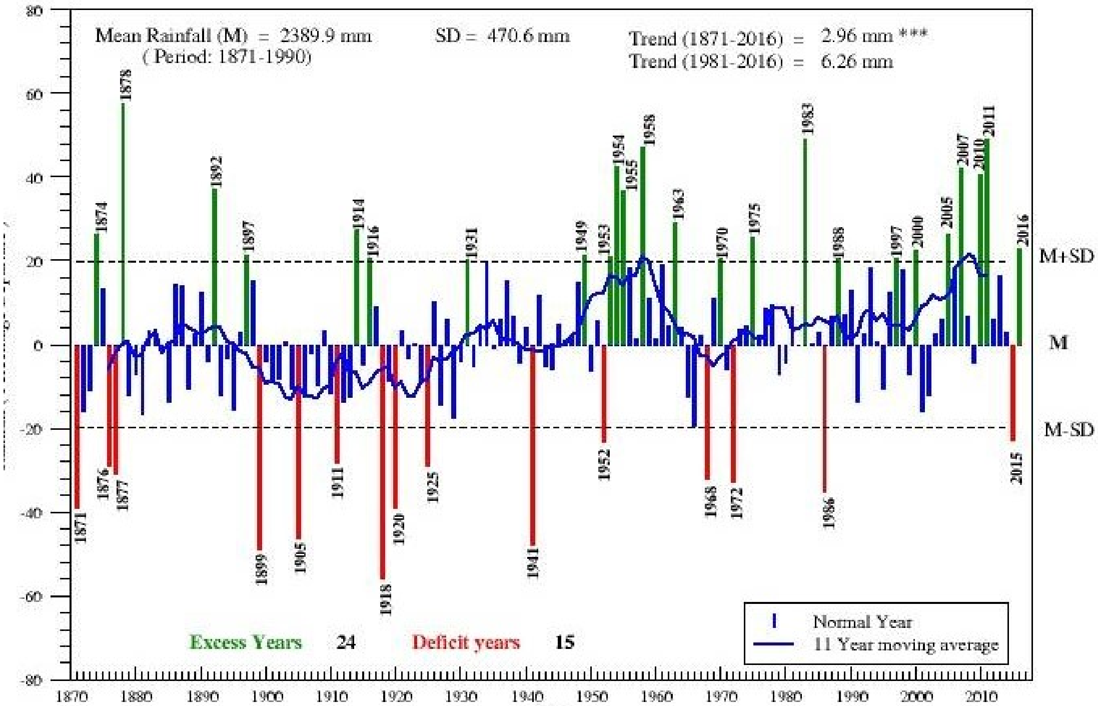
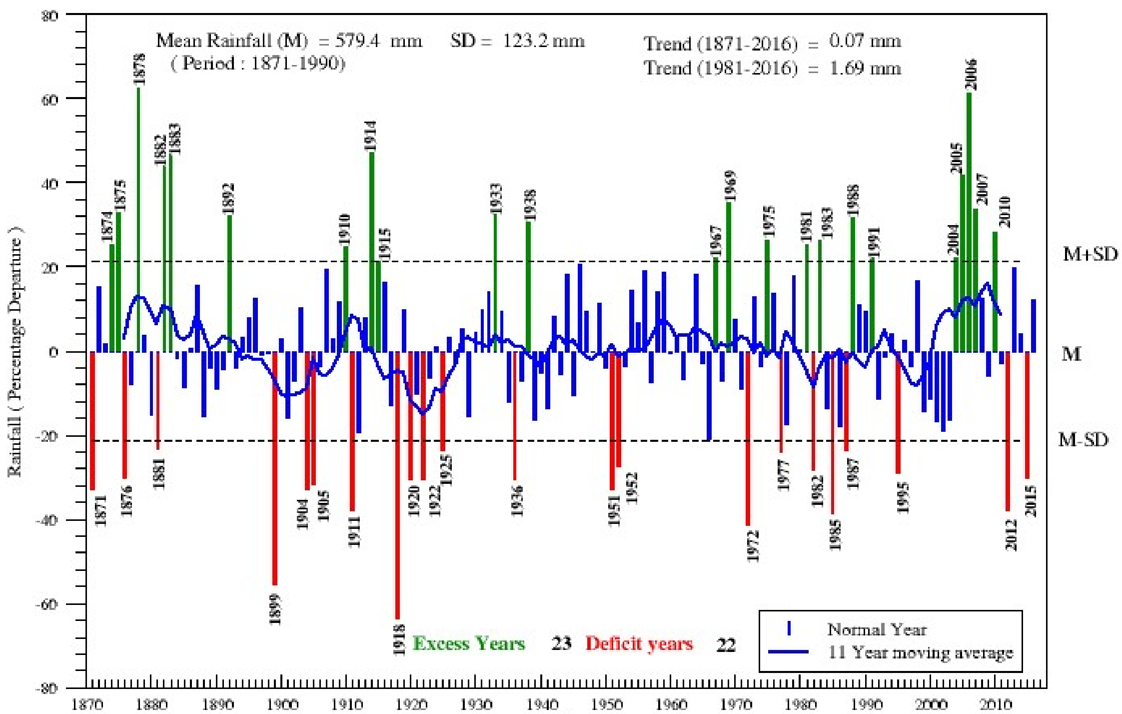


Figure 1: Konkan and Goa subdivision summer monsoon (JJAS) rainfall (mm) :1871-2016
(Trend - mm/year, *, ** and *** significance at 10%, 5 % and 1% level, rainfall data for the period 1871-2014 based on 306 and 2015-2016 based on IMD subdivisional rainfall)



Fingure 2: Madhya Maharashtra subdivision summer monsoon (JJAS) rainfall (mm) :1871-2016
(Trend - mm/year, *, ** and *** significance at 10%, 5% and 1% level, rainfall data for the period 1871-2014 based on 306 stations and 2015-2016 based on IMD subdivisional rainfall)

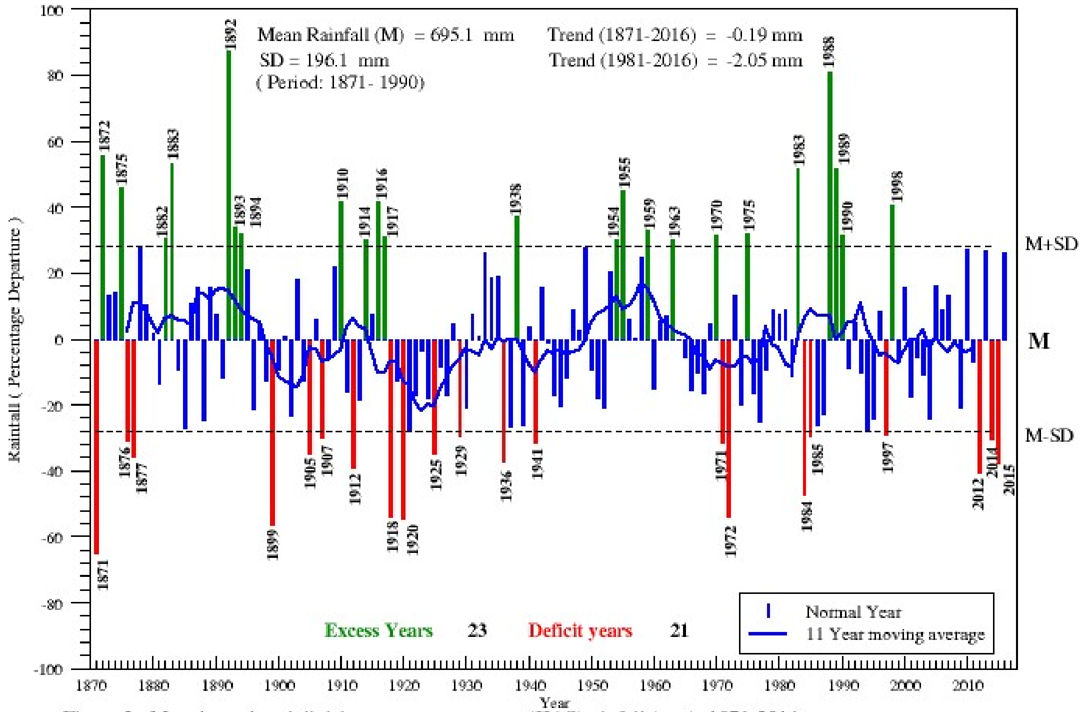


Figure 3 : Marathawada subdivision summer monsoon (JJAS)rainfall (mm) :1871-2016

(Trend - mm/year, *, ** and *** significance at 10%, 5% and 1% level, rainfall data for the period 1871-2014 based on 306 stations and 2015-2016 based on IMD subdivisional rainfall)

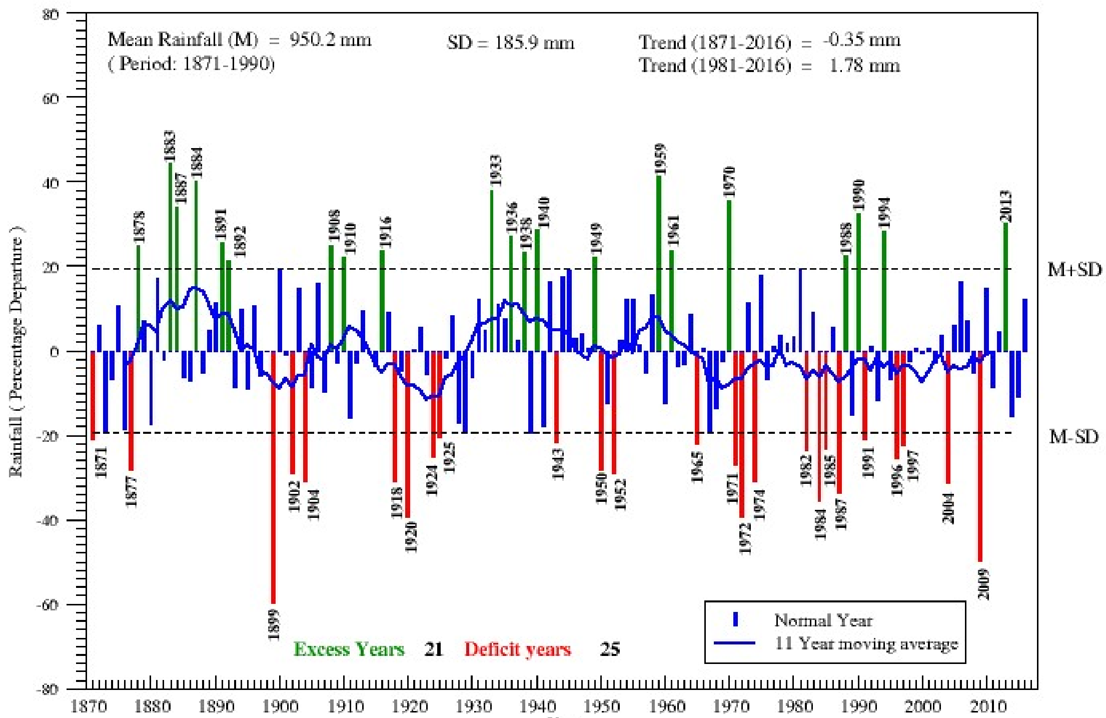


Figure 4 : Vidharbha subdivision summer monsoon (JJAS) rainfall (mm) :1871-2016

(Trend - mm/year, *, ** and *** significance at 10%, 5% and 1% level, rainfall data for the period 1871-2014 based on 306 stations and 2015-2016 based on IMD subdivisional rainfall)

IMSP NEWS:

Science and Geography Teacher's Training workshop

IMSPune chapter organised 3-days teachers' training program during 30th, 31stAugust and 1st September 2018 at IITM Pune. The first two days' program was sponsored by MoES/ IMS National Council Delhi and the program on 1st September was sponsored by Director, IITM, Pune.

The Opening ceremony was held on 30 August at 9-30 am in the Meghdoot hall of IITM. Prof.Ravi Nanjundiah, Director IITM was the Chief guest of the function and Dr.AjitTyagi, Ex DG IMD & Ex. IMS President NC,was the Guest of Honour.Dr. G. Pandithurai (Co-Chairman IMSP & IITM Scientist) welcomed the Chief Guest, the Guest of Honour, dignitaries, workshop faculty, participating teachers from different schools and Junior colleges(of Pune & other parts of Maharashtra and beyond Maharashtra), and other imminent people who attended the inaugural function.While speaking on the occasion, Dr. A.K. Sahai (Head, CR&S, IMD, Pune and Vice President, National Council of IMS) highlighted the importance of the workshop in familiarizing teachers about the advances in weather and climate sciences. He emphasized on the role of teachers in spreading meteorological knowledge among students and the public. He was happy to learn that many outstation teachers were also attending the workshop, in addition to the teachers from Pune.

Dr .Ajit Tyagi explained the background of teacher's workshop. The subject of meteorology is the in syllabus of school curriculum. This workshop aims to provide more information of these subjects by the experts in the field to the teachers, in turn the teachers will explain to students. Therefore such programs are very important. These programs are run in four IMS chapters in India and Pune IMS chapter is one of those.

Prof. Ravi Nanjundiah, Director IITM, delivered the inaugural address. He welcomed the teachers, who have come to attend the workshop. He reiterated the objectives of IMS to popularize meteorology in different sections of society. IMS tries to build up an association between the meteorologist and the common people. Weather plays an important role in our all aspects of life. Hence knowledge of weather becomes essential to us. IITM has always supported IMSP activities and will continue to do in future.

On this occasion, the Bulletin of IMSP (BIMSP) was released at the hands of the dignitaries.

Dr. J.R. Kulkarni (Chairman, IMSP, Ex-Scientist of IITM and Ex-WMO Expert) delivered an introductory lecture on the fundamentals of atmosphere and other basic concepts in meteorology. Dr. Kulkarni also spoke about the future activities of IMSP like visits to meteorologically important sites, regular discussions on important weather phenomena, workshops for farmers and journalists, etc.

Ms.Latha Sridhar (EC Member, IMSP) anchored the inauguration function in pure Hindi language.

Mr.Somnath Mahapatra, Secretary, IMSP presented the vote of thanks. He sincerely thanked Director, IITM for generously providing financial and logistic support (including IITM guest-house & office facilities at the venue)He thanked Dr.Ajit Tyagi for kindly gracing the occasion and kindly agreeing to address the gathering. He thanked Dr.A. K. Sahai for his kind guidance and support towards organization of the event, including guest house facility to the teachers during the workshop and overall support from IMD Pune. He thanked IMS National Council, IITM, IMD, CDAC and other sponsors for their financial support. He thanked the faculty for kindly agreeing to deliver lectures and coordinators for arrangement for laboratory visits. He thanked IITM & IMD administration for all logistic support and the participating teachers for their interest in the workshop. Finally he thanked IMSP organizers, especially Mr .S. M. Jamadar (Member, NEC), Dr .Devendraa Siingh (Joint Secretary, IMSP) & Mr. Jose (Treasurer, IMSP), EC members of IMSP and all volunteers from IITM and IMD.

Total 42 teachers participated in the workshop. 31 were from Pune and 11 were from outside Pune.

Following scientists delivered lectures in the workshop.

Prof. Sulochana Gadgil (Retd Scientist IISC), Dr. A. K. Sahai (Vice President IMS), Mr. R. R. Mali, Dr. A. K. Srivastav (IMD), Mr. S. M. Jamadar (IMD), Dr. D. M. Rase (IMD), Dr. Divya Surendran (IMD), Ms. Latha Sridhar (IMD), Dr. J. R. Kulkarni (Chairman IMSP), Dr. G. Pandithurai (IITM), Dr. S. D. Pawar (IITM), Dr. T.P. Sabin (IITM), Dr. B.S. Murthy (IITM). Mr. S. Mahapatra (IITM), Dr. S. Kulkarni (C-DAC).

On the third day of the workshop, in the afternoon, after the feedback session, valedictory function was conducted. Dr. G. B. Pant, Ex Director IITM was the chief guest of the function. Shri. R. R. Mali, Ex-chairman of IMSP also graced the occasion. Shri. R. R. Mali told that, IMD in the past supported schools for setting up meteorological observations and will continue to do in future.

Dr. J. R. Kulkarni Chairman, IMSP, told that this workshop is a starting point of long term collaboration in the future. He assured the teachers that all of our faculty members will be free to interact with students in future whenever there is requirement. For the benefit of a large number of students, the scientists in IITM and IMD will visit to schools and give talks on the current meteorological topics. He further told that a student chapter of IMSP will be started soon, in which the school and college students can become member. A special student conference can be held in Pune in future. In order to popularise meteorology, activities like trips to meteorological important places will be organized, in which students along with their parents can join. The first such one day trip is planned on 6th October 2018 to Wind mill at Supe, 90 km north of Pune.

The Chief Guest, Dr. G. B. Pant gave away the Participation certificates to all participants.

Dr .G. B. Pant, in his speech, told the importance of meteorology in the life of common man. Teachers are links between meteorologists and students. The branch of atmospheric sciences and meteorology needs man power in future as topics such as climate change are facing problems to the world. Teachers can explain the meteorological phenomenon to students in such a way to develop interest in the subject.


इंडियन मिटियोरोलॉजिकल सोसायटी, पुणे शाखा
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