# Use of Short- and Long-term Meteorological Information in Flood Forecasting

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***Abstract***
*Floods are a disastrous phenomena causing considerable loss of life and property. In India, most floods occur in the northern sub-Himalayan region in the Gangetic-Brahmaputra basin during the south-west monsoon and are caused by excessive rainfall in the catchment area. The forecasting of meteorological conditions that will lead to excessive rainfall in these catchments is important since it can provide the information needed to issue flood forecast warnings with longer lead times. The National Center for Medium Range Weather Forecasting has been producing medium range (up to four days) weather forecasts for the past ten years by running global circulation models on supercomputers. These numerical models have full physics capabilities and can utilise both conventional and satellite data whether received from the regional telecommunication hub in New Delhi or downloaded from other sites. The global circulation model can predict several days in advance the meteorological conditions that produce flood conditions, these include the movement of lows and depressions, and monsoon troughs. A multi-institutional programme on mountain meteorology has been initiated to predict the severe weather conditions that can develop over complex mountain regions. To satisfy the requirements of this programme, two meso-scale models – one (MM5) from the National Centre for Atmospheric Research (NCAR) and the other (Eta) from the National Centre for Environmental Prediction (NCEP) – are run daily. The MM5 is run for three separate resolutions – 90 km, 30 km, and 10 km – and the eta model with a resolution of about 40 km. These higher resolution models are able to predict higher rain intensities that are closer to the observed ones and thus have an improved potential for increasing the lead time for flood forecasting. However, the validity of these models for predicting ground precipitation has not yet been tested for the Himalayan region and needs to be tested in cooperation with the relevant neighbouring countries. Furthermore, the utility of the inputs that these models can provide needs additional testing to assess their accuracy in forecasting run-off and stream-flow.*

## Introduction

Floods represent the most frequent and widespread of all the natural disasters and are responsible for the largest proportion of deaths (20%) and property damage (32%). In India over the last 20 years at least 18 mha have been affected by floods (as reported by the Central Water Commission). The floods, which begin as high streamflows in rivers and streams, are generally caused by excessive rainfall in the river catchments. The time lag between the occurrence of precipitation and increased river discharge depends on the basin characteristics; the size of the basin, the topography, the type of vegetation, the antecedents, and the soil-wetness, among others. The time lag observed in many rivers of the sub-Himalayan region, north Bihar, north-east India, and north-west India is short, around 12 hours in the case of flash floods. The occurrence of such floods cannot be predicted a few days in advance even theoretically. Attempts have been made to derive the streamflow from rainfall data measured at different locations in the mountainous region. The remoteness of many of these locations makes actual measurements problematic and often of limited usefulness since the lead-time is so short. It is thus desirable and advantageous to be able to predict meteorological conditions like atmospheric circulation that cause heavy precipitation a few days in advance in order to provide sufficient lead-time for forecasting the occurrence of floods. Such forecasting can help prevent loss of life and property, and can also be used as a guide to help regulate the waiting volume in reservoirs that are used for flood control and generating hydroelectric power. It is now possible to forecast synoptic scale atmospheric features and their associated precipitation using numerical models. The National Centre for Medium Range Weather Forecasting (NCMRWF) in New Delhi is developing global and regional weather prediction models for short and medium-range weather forecasting. The NCMRWF is the only organisation in India (and in the tropics) where real-time assimilation of global data is incorporated in the routine prediction of weather parameters using state-of-the-art global and meso-scale numerical models. The weather predictions are disseminated to the various user agencies including the India Meteorological Department (IMD), the Agro-Met field units, the Defence establishments, and several other economic sectors. The feedback from these agencies has been encouraging.

In the following, a brief description of the global data assimilation system and the global models used at NCMRWF is given, together with a few examples of significant weather events predicted by these models. Subsequent sections provide brief descriptions of the MM5 meso-scale model together with the results of few case studies; the Eta meso-scale model and the results it yields in some typical cases; the conditions that can cause flooding and the flood monitoring setup that is in place; and a brief outline of planned future work.

## Global Data Assimilation and Forecast System

At NCMRWF, global data assimilation and forecasts are carried out at two different resolutions. A forecast suite at T80 horizontal resolution (150x150 km grid) with 18 vertical layers has been operational since 1994. A new forecast suite at T170 (75x75 km grid) with 28 vertical layers has been developed and implemented recently at the Centre. The 6-hourly intermittent (0000 UTC {Coordinated Universal Time}, 0600 UTC, 1200 UTC, and 1800 UTC) global data assimilation system (GDAS) consists of three main components:

i. data processing and quality control;
ii. analysis based on spectral statistical interpolation (SSI); and
iii. a global atmospheric model for preparation of short range forecasts used as a background field.

Figure 1 shows a schematic diagram of the data assimilation system at NCMRWF. Although most of the conventional data used in GDAS are received through the Global Telecom. System (GTS), via the Regional Telecom Hub (RTH) New Delhi, a large amount of data are downloaded through file transfer protocol (ftp) from Special Sensor Microwave Imager (SSM/I), Advanced Tirros Operational Vertical Sounder (ATOVS), and QuickScat, among others.

The analysis scheme operational at NCMRWF is an adaptation of NCEP's early version of the global 3-D variation analysis scheme, the SSI scheme (Parrish and Derber 1992). In SSI, observation residuals are analysed in spectral space on sigma surfaces. The objective function minimised in SSI is defined in terms of the deviations of the

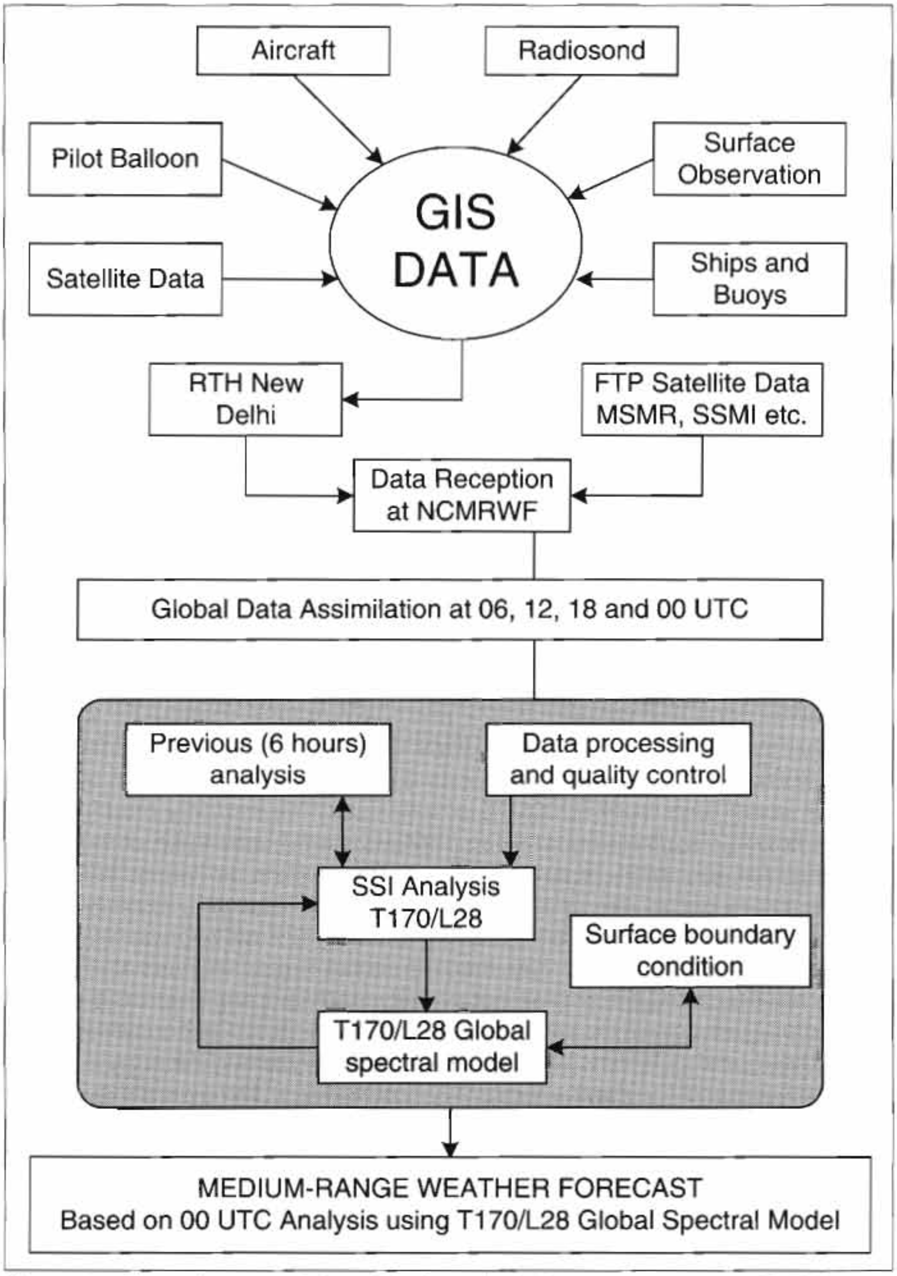


Figure 1: Flow diagram of the global analysis forecast system at T170/L28 Resolution

desired analysis from the first guess field (which is taken as the six hour forecast of the operational T80-Global spectral model) and observations are weighted by the inverse of the forecast and the observational error variances respectively.

Several sensitivity studies have been carried out to improve data analysis, especially using various satellite data over the data sparse regions. Various experimental analyses were carried out at T80 resolution to examine the impact of wind speeds and total precipitable water content (TPWC). Data from the Tropical Rainfall Measuring Mission (TRMM) microwave imager, SSM/I, and the Indian remote sensing satellite IRS-P4 multi-scanning microwave radiometer (MSMR) were analysed and used to predict the Indian summer monsoon. In a study of the Orissa super cyclone of October 1999, Kar et al. (2003) found that the best analysis was obtained using the TMI data. The National Environmental Satellite, Data, and Information Service (NESIDS) derived temperature and moisture information from ATOVS that is now obtained through GTS and an ftp server at 120 km resolution. Several experiments have been conducted to study the impact of these data sets on NCMRWF's analysis and forecasting system for the summer monsoon season. Since these data have correctly defined the initial state of the atmosphere, they have been included in the operational system. The result has been that this data has improved the calculation of wind field characteristics over the northern Indian Ocean and the results are considerably more accurate when compared to those produced by other major centres (Goswami and Rajagopal 2003).

The first guess for the analysis cycle (four 6-hour cycles in a day) is provided from a 6-hour forecast produced by the global spectral models (Kar 2002). The physical processes in the model include the non-local closure planetary boundary layer scheme (Basu et al. 2002), the National Atmosphere and Space Administration (NASA) radiation scheme (John and Begum 1997), and the Kuo-type scheme for cumulus convection, shallow convection, mountain wave drag, and land surface schemes as in Kanamitsu (1989). Medium range predictions are prepared by NCMRWF by integrating the models for seven days from 0000UTC of each day. The monthly mean rainfall patterns from the T170L28 model and the T80L18 model have been compared with the observed rainfall for July 2001. A comparison of the models indicates that the higher resolution one shows better rainfall distribution over the mountainous regions (figure not shown). Figure 2 shows how the model performed for a recent case of heavy rain and snowfall in northern India and over the Himalayan region in February. The model in its 3-day forecast predicted the movement of the westerly trough over the region and predicted precipitation forecasts as shown in the Figure. Tests performed thus far indicate that the model performs well in predicting heavy precipitation events both during the monsoon and during the winter season and that the time range of useful prediction is longer for the winter season.

## Prediction Using the MM5 Model

The MM5 model is the 5th generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (limited area). This model is non-hydrostatic, the terrain follows sigma coordinates and is designed to simulate or predict mesoscale and regional scale atmospheric circulation. It can be configured to run from global scale to cloud scale in one model. It has multiple nesting capabilities and can be run in both 2-way and 1-way nesting mode. It has options for a wide variety of advanced physical parameterisation schemes. The model can be run using routine observations and has provision for 4-dimensional data assimilation.

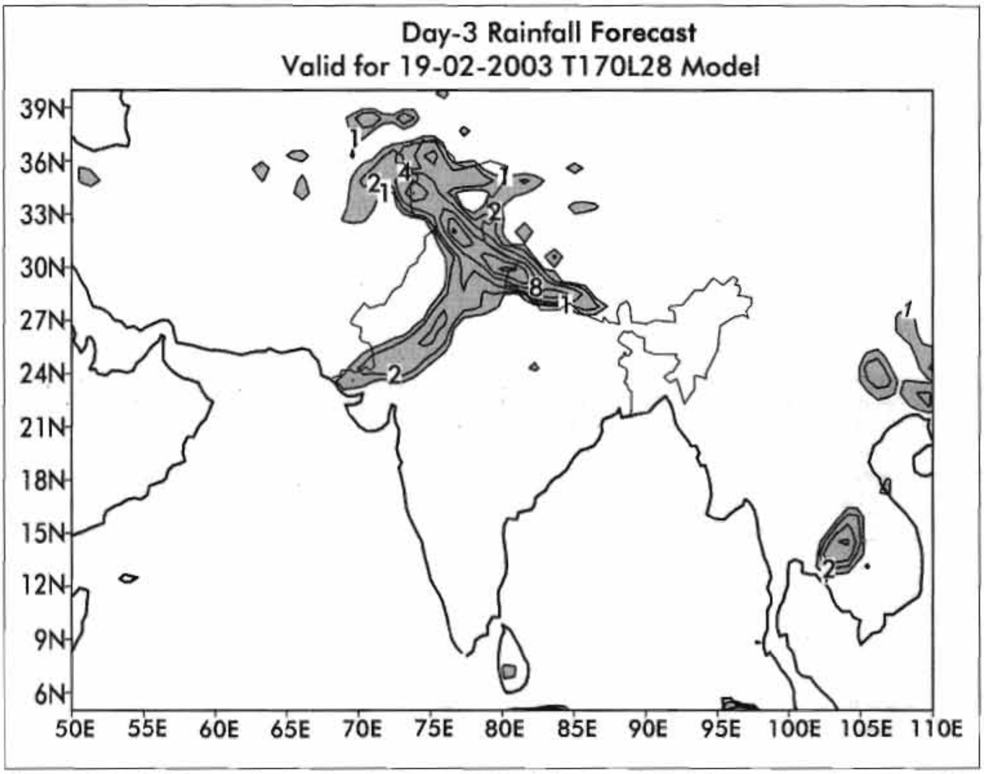


Figure 2: Rainfall prediction by the T170/L28 global model 72 hours in advance valid for 19 February 2003, when a large amount of precipitation was observed over Northern India due to a western disturbance

The model has been installed at NCMRWF on the supercomputers CRAY-SV1 and PARAM-10000 as well as on the workstations SGI-Origin and Dec-Alpha. The model has been tested with double and triple nested domains at 90, 30, and 10 km resolutions over the Indian region. The innermost domain at 10 km resolution has been placed over the Jammu and Kashmir regions. The model is run using the Grell scheme for cumulus parameterisation and, the non-local closure scheme for boundary layer parameterisations. Explicit treatments of cloudwater, rainwater, snow, and ice are performed using a simple ice scheme. Cloud radiation interaction is allowed between explicit cloud and clear air. The initial and lateral boundary conditions are obtained from the operational global T80 model of NCMRWF.

The model has been producing real-time forecasts since the 1st of January 2002. Several case studies of western disturbances, active monsoon conditions, heavy rainfall events, and cyclones over the Bay of Bengal have been studied using this model. Results show considerable improvements in the forecasts compared to the global T80 model. The model has also been studied at cloud resolving scale (1 km resolution) for a specific case study of a heavy rainfall episode over Delhi. In another application, the model has been applied to mountain weather forecasting over the Himalayas. The results indicate that the model can be used for mesoscale weather forecasting over the Indian region with reasonable accuracy.

A sample forecast of a western disturbance that passed over the Himalayan region during 14-17 January 2002 is presented here. The western disturbance extended up to 4.5 km above sea level and moved over Jammu and Kashmir and surrounding areas on the 14th of January 2002. The system propagated eastward during the next three days depositing considerable precipitation and snowfall on its way over the high mountain regions. Cold wave conditions prevailed in most parts of north-west India. The rainfall reported at some of the stations in this period is shown in Table1. Snowfall ranging from 15 to 50 cm was reported at many places in Jammu and Kashmir and Himachal Pradesh. Figure 3 shows the rainfall forecasts for 16-17 January over the central Himalayas. The model was able to forecast the rainfall distributions over different parts of the Himalayas reasonably well as compared to the actual observations.

**Table 1: Observed Rainfall (January 2002)**

| Station (Western Himalayas) | Rainfall (mm) 16th Jan | Station (Central Himalayas)* | Rainfall (mm) 16th Jan | Rainfall (mm) 17th Jan | Station (Eastern Himalayas) | Rainfall (mm) 17th Jan |
|---|---|---|---|---|---|---|
| Delhi (Saf., Pal.) | 15, 10 | Dadeldhura | 30.3 | - | Guwahati | 12 |
| Chandigarh | 5 | Dipayal | 30.8 | - | Shillong | 3 |
| Bhuntar | 24 | Dhangadhi | 28.5 | - | | |
| Shimla | 7 | Surkhe | 35.4 | - | | |
| Srinagar | 10 | Nepalgunj | 27.2 | - | | |
| Patiala | 1 | Jumla | 38.5 | - | | |
| Jaipur | 5 | Dang | 13.4 | T | | |
| Lucknow | 8 | Pokhara | 30.6 | 1.6 | | |
| Dehradun | 8 | Bhairawa | 17.6 | 1.6 | | |
| | | Kathmandu | 10.2 | 10.2 | | |
| | | Okhaldhunga | 3.6 | 6.6 | | |
| | | Taplejung | 5.4 | 19.2 | | |
| | | Dhankuta | 1.6 | 10.8 | | |
| | | Nagarkot | 16.0 | 13.5 | | |
| | | Jiri | 12.2 | 11.2 | | |
| | | Bharatpur | 16.5 | 2.5 | | |

*Source: HMGN Dept. of Hydrology and Meteorology

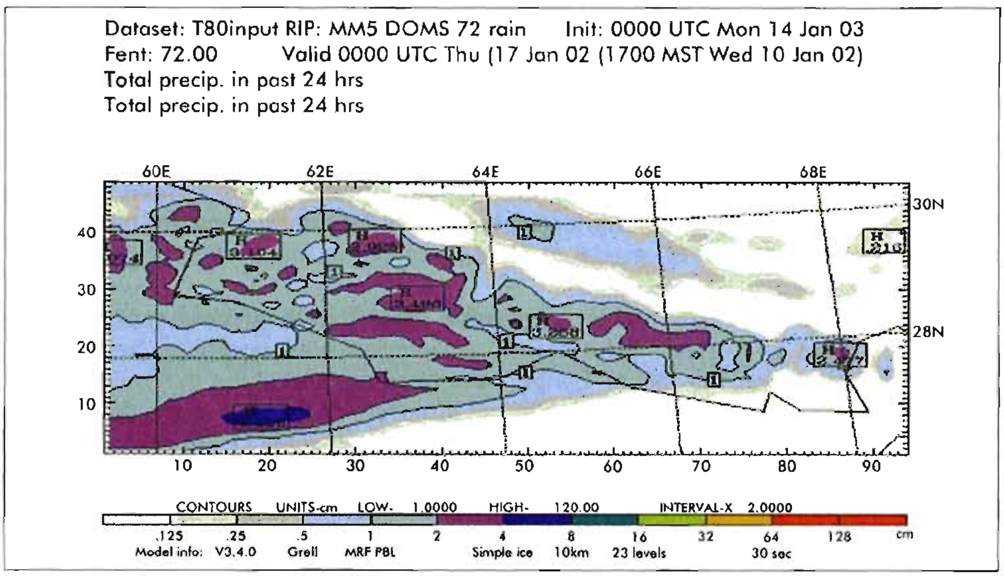

Figure 3: Rainfall forecast (72 hrs) over the central Himalayas valid on 17 January, 2002

## Prediction Using the Eta Model

The NCEP in the USA, developed a step-mountain eta ($\eta$) coordinate model generally known as the Eta model which was made operational in 1993 (Black 1994). A workstation version of the Eta model (Version 0.2) released in March 2000 has recently been installed on an SGI-Origin 200 workstation at NCMRWF. The model has been run operationally since 1 January 2002, and the forecasts displayed on the NCMRWF website (www.ncmrwf.gov.in).

The Eta model is a hydrostatic mesoscale weather forecast model which accurately treats complex topography using eta vertical coordinates and step-like mountains, eliminating errors present in the sigma coordinate in the computation of pressure gradient forces over steeply sloped terrain (Mesinger and Black 1992). The model employs a semi-staggered Arakawa E-grid in which wind points are adjacent to the mass points configured in rotated spherical coordinates. The mesoscale Eta model is run operationally with a horizontal grid spacing of 48 km and 38 vertical levels, with layer depths that range from 20m in the planetary boundary layer to 2 km at 50 mb. The model top is at 25 hPa. Split explicit time differencing is used with a time step of 120 seconds. Spatial differencing is done with a conserving Arakawa type scheme and the model's step mountains are derived using the official United States Geological Survey (USGS) topographical data.

The physics of the model as described by Janjic (1994) includes a modified Betts-Miller scheme for deep and shallow convection and the prediction of cloudwater/ice. The GFDL scheme is used to calculate radiation. Free atmospheric turbulent exchange above the lowest model layer is computed using a Mellor-Yamada level 2.5 closure and the surface layer similarity functions are derived from Mellor-Yamada level 2.0 closure. A viscous sub-layer is used over water surfaces. The land surface scheme is a version of the OSU scheme modified by Chen et al. (1997).

NCMRWF global (T80/L18) analysis and 6 hourly global model forecasts are used for initial and lateral boundary conditions. Wind, temperature, relative humidity, and geo-potential height are interpolated to 26 pressure levels and a 1° x 1° global resolution is used. Daily NCEP 1° global sea surface temperature (SST) analysis, and 23 km daily NESDIS snow cover downloaded from <ftp.ncep.noaa.gov> are used. Soil moisture at 2 layers (surface and root zone), soil temperatures at 3 layers, and global sea-land-ice mask are extracted/generated from the surface analysis of the NCMRWF global analysis-forecast system.

A new version of the Eta model, which has nesting capability, has been installed on a Linux PC to produce higher resolution forecasts. This version uses the NCMRWF's operational Eta model outputs as initial and lateral boundary conditions. This methodology would be very useful for sharing with other interested neighbouring countries. A sample plot of rainfall forecasts for a recent case from the 2 model runs is shown in Figures 4 and 5.

## The Flood Situation in India

India is a vast country with a large variety of weather systems; the extent to which each system affects a given region gives that region its distinct seasonal character. Though floods occur in the southern parts during the north-east monsoon and in coastal areas

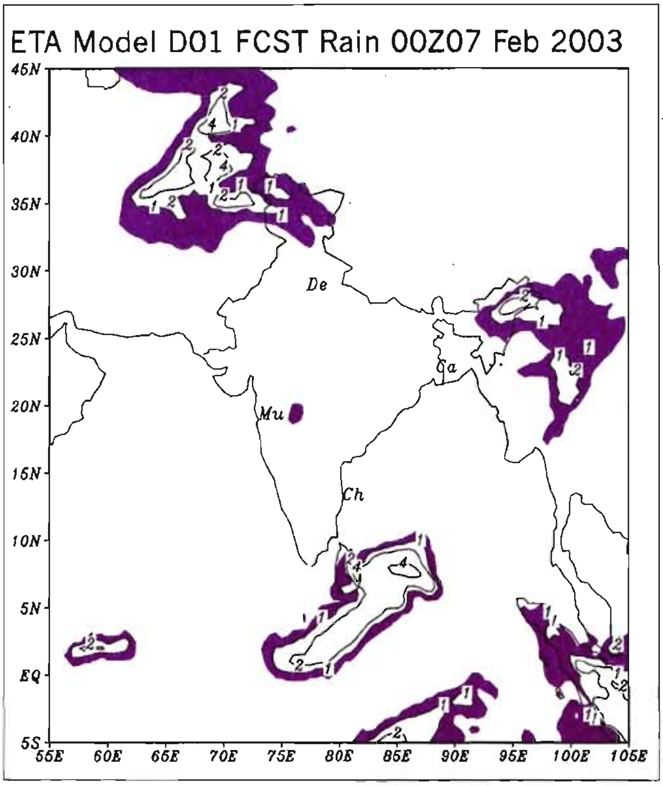


Figure 4: Day 1 rainfall forecast from 48 km Eta model valid for 00z 07 February, 2003

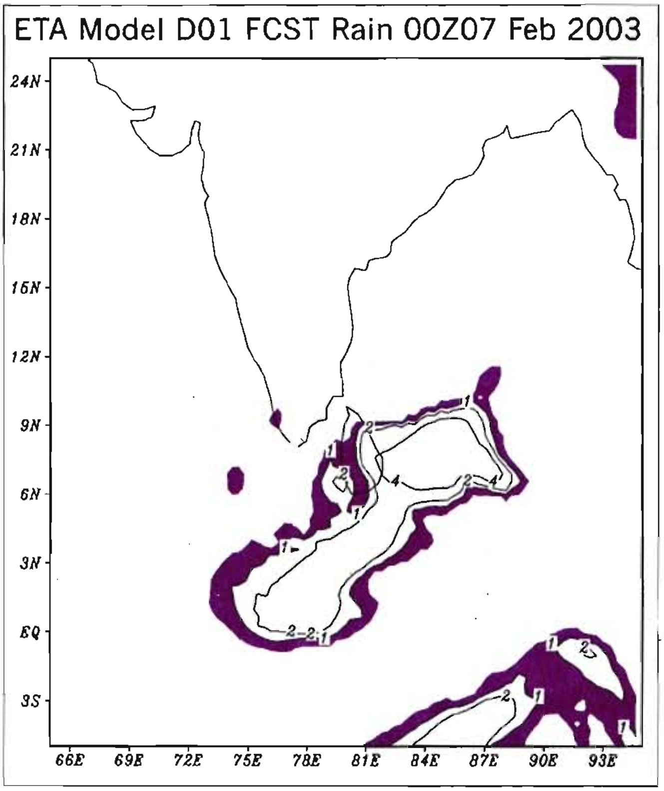


Figure 5: Day 1 rainfall forecast from 32 km Eta model valid for 00z 07 February, 2003

as part of tropical cyclones experienced in the pre and post monsoon seasons, most floods occur during the summer monsoon, which is responsible for 78% of the annual rainfall in the country. Floods commonly occur in the Indo-Gangetic plains in north India, the Narmada and Tapi river valleys in central India, the Krishna, Kaveri, and Godavari valleys in peninsular India, and the Brahmaputra-Barak river basin in north-east India. The most frequent floods occur in the sub Himalayan region from the Ganges-Brahmaputra river systems, and the Indian part of the Indus river system. East Uttar Pradesh and Bihar are the most flood prone states in India. This region contains over 18% of the flood-affected area and nearly 30% of the flood affected population of the country. Some statistics on flood damage are shown in Figure 6.

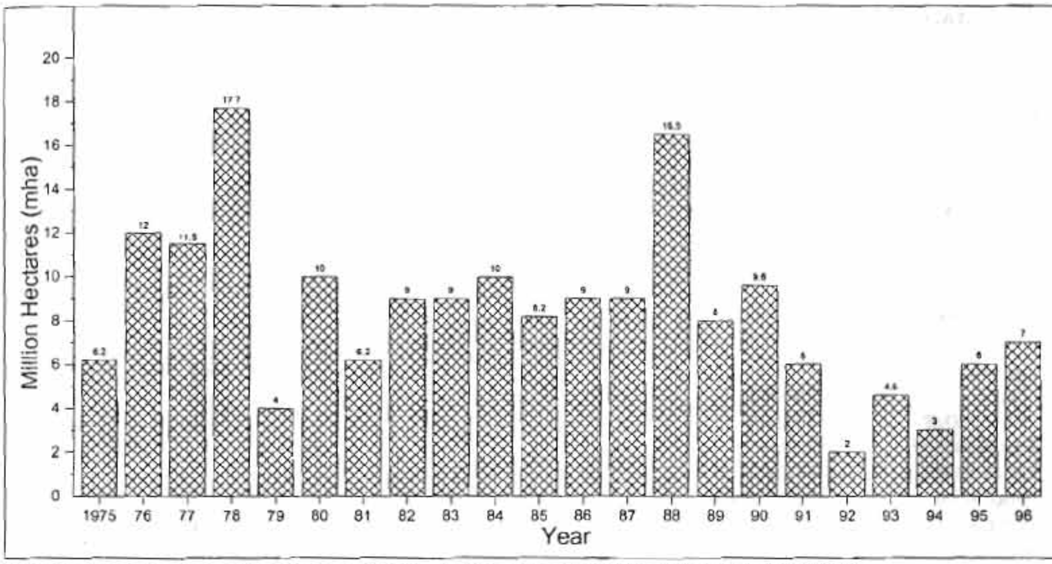


Figure 6: Inter-annual variability of flood damage in India (after CWC 1998)

The tributaries of the Ganges that originate in the Nepal Himalayas (Mahakali, Karnali, Adhawara, Gandaki, Kosi, Luri, Rapti, Kamla, Bhagmati, Mahananda) and join the Ganges in Uttar Pradesh, Bihar, and West Bengal are particularly susceptible to floods due to the geomorphology of the region. Antecedent rains moisten and saturate the subsoil hindering further percolation. The resultant runoff quickly joins the streamflow leading to severe flooding in the affected areas. Similar conditions apply for the Brahmaputra-Meghna-Barak basin. This region receives heavy downpours daily during the monsoon onset (sometimes exceeding 20 cm a day) due to the release of convective instability, and the region can witness multiple floods in the same monsoon season.

### Heavy Precipitation Events

Floods are generally preceded by heavy monsoon rainfall, which is highly convective in nature. Nearly 80% of the seasonal rainfall is produced by only 10% to 20% of the rainfall events lasting for 1-3 days. The four main areas that receive exceedingly heavy rainfall are the west coast of India, north-east India, the foothills of the central and western Himalayas, and central India. The first three of these are associated with large-scale vertical motion related to synoptic and mesoscale disturbances and orographic lifting, where it is common to experience up to 40 to 50 cm of rain per day. Cherrapunji, a hill station in Meghalaya in north-east India (which holds several world records), has recorded the highest rainfall accumulations of 104 cm, 165 cm, and 224 cm in 1, 2, and 3 days respectively. The highest rainfall in a plains station – 99 cm, 126 cm, and 145 cm in 1, 2 and 3 days – occurred over Dharampur in Gujarat. Table 2 shows some of the highest 1, 2 and 3 day rainfalls recorded (after Rakhecha and Pisharoty 1996). About 15-50% of daily rainfall can occur during a 1-hour session and rainfall of 6 cm in 1 hour is not uncommon. Such intense precipitation often leads to flash floods particularly in mountainous regions.

**Table 2: Highest recorded 1,2 & 3-day rainfall values between 1875 & 1982**

| Station | State | Height (m) | 1-Day (cm) | 2-Day (cm) | 3-Day (cm) | Date |
|---|---|---|---|---|---|---|
| Mawsynarm | Meghalaya | 1401 | 99 | 143 | 201 | Jul-1952 |
| Cherrapunji | Meghalaya | 1313 | 104 | 165 | 224 | Jun-1876 |
| Bhagamandala | Karnataka | 876 | 84 | 136 | 136 | Jul-1924 |
| Ponnampet | Karnataka | 857 | 52 | 61 | 67 | Jul-1965 |
| Agumbe | Karnataka | 659 | 62 | 93 | 95 | Jul-1963 |
| Satna | Madhya Pradesh | 549 | 54 | 58 | 61 | Jun-1882 |
| Khandala | Maharashtra | 539 | 52 | 67 | 73 | Jul-1958 |
| Bassi | Rajastan | 351 | 56 | 84 | 85 | Jul-1981 |
| Rewa | Madhya Pradesh | 286 | 77 | 77 | 82 | Jun-1982 |
| Dhampur | Uttar Pradesh | 258 | 77 | 99 | 99 | Sep-1880 |
| Bamanwas | Rajastan | 252 | 51 | 76 | 103 | Jul-1981 |
| Nagina | Uttar Pradesh | 250 | 82 | 104 | 104 | Sep-1880 |
| Najibad | Uttar Pradesh | 240 | 72 | 98 | 98 | Sep-1880 |
| Karjat | Maharashtra | 107 | 61 | 67 | 73 | Jul-1958 |
| Dharampur | Gujarat | 38 | 99 | 126 | 145 | Jul-1941 |
| Gopalpur | Orissa | 17 | 51 | 65 | 70 | Oct-1954 |
| Porbandar | Gujarat | 12 | 51 | 62 | 66 | Sep-1977 |
| Cuddalore | Tamil Nadu | 12 | 57 | 82 | 95 | May-1943 |
| Bombay | Maharashtra | 11 | 57 | 80 | 88 | Jul-1974 |
| Vegurla | Maharashtra | 9 | 53 | 82 | 88 | Jun-1958 |
| Kakinada | Andhra Pradesh | 8 | 50 | 53 | 57 | Jun-1941 |
| Quilandi | Kerala | 8 | 91 | 109 | 113 | May-1961 |

## Meteorological Conditions Responsible for Floods

The intense rainfall that leads to floods occurs in association with sub synoptic and mesoscale circulation embedded in synoptic scale disturbances. The size, speed, and intensity of these disturbances may determine the magnitude and distribution of rainfall during the passage of a weather system. The location of river catchments with respect to the weather disturbance and the topography of a region may ultimately decide the runoff. The meteorological conditions generally associated with monsoon floods are as follow.

- The movement of monsoon disturbances like depressions and low-pressure areas from the Bay of Bengal and the Arabian sea (as well as similar systems generated over the landmass of India) cause heavy rainfall along their tracks, especially in their south-west sectors. The flood situation is aggravated if the monsoon disturbances impact the same areas in succession within a 3-5 day period.
- Formation of a mid-tropospheric cyclone (MTC) along the Goa-Konkan-Gujarat coast causes very heavy rainfall over western India.
- Interactions between the monsoon systems and the baroclinic disturbances (westerly troughs) moving from west to east across northern India.

- 'Active' monsoon conditions for several days and associated orographic ascent.
- 'Break' monsoon conditions over India, which result in heavy rainfall along the foothills that lie in the path of several major rivers and streams across Himachal Pradesh, Punjab, Haryana, West UP, Bihar, West Bengal, and the states of north-east India.
- The occurrence of meso-scale vortices located off the coast of India.

In north-east India severe flooding is experienced during the advance phase of the summer monsoon and later due to the northward movement of the monsoon trough in mid-season. The latter situation is associated with a break in the monsoon activity over central India. Occasionally, monsoon depressions may also move northwards after formation over the head bay or adjoining land regions. The individual flood events are not necessarily associated with the all India scale performance of the monsoon season. For example, extreme flood events occurred in the Brahmaputra area in the deficient monsoon years of 1972, 1984, and 1987, as well as in the excess monsoon years of 1973, 1976, 1983, and 1988. Likewise, the severe rainstorm in Dharampur mentioned earlier occurred in 1941, a year in which the monsoon rainfall was 14.4% below average. Floods in the western Himalayas may result from recurring monsoon depressions after interaction with a trough in the westerlies or movement of the western end of the monsoon trough to the Himalayas. Floods in May and June may also occur as a result of rapid melting of the winter snow.

### The Flood Forecasting System

The India Meteorological Department issues warning of heavy rainfall on the basis of the prevailing meteorological conditions, taking into account both the climatology and the intensity and persistence of the ongoing rain producing weather phenomena such as troughs, depressions, and cyclones. For this purpose, it has established 10 Flood Meteorological Offices (FMO) which report on the various catchments in the country (Table 3). The CWC has a network of 157 flood forecasting stations located all over India. Flood forecasts are issued daily from May through October, with an average of about 6,000 flood forecasts per year.

**Table 3: Flood Meteorological Offices in India**

| Name | River catchments |
|---|---|
| Agra | Lower Yamuna, Chambal & Betwa |
| Ahmedabad | Narmada, Tapi, Mahi, Sabarmati, Banas & Daman Ganga |
| Asansol | Ajay, Mayurakshi & Kangsabati |
| Bhubaneswar | Mahanadi, Brahmani, Baiterini, Bruhabalang, Subernarekha, Rushkulya & Vansdhara |
| Guwahati | Brahmaputra & Barak |
| Hyderabad | Godavari & Krishna |
| Jalpaiguri | Teesta |
| Lucknow | Ganga, Ramganga, Gomti, Sai, Rapti, Ghagra & Sarada |
| New Delhi | Upper Yamuna, Lower Yamuna & Sahibi |
| Patna | Kosi, Mahananda, Baghmati, Kamala, Gandak and Buri Gandak, North Koel & Kanhar & PunPun Upper Sone |

## Future Work

The precipitation predictions produced by the different numerical models have now achieved a good level of credibility; the next step will be to systematically validate their outputs by testing them in applied flood forecasting situations. The traditional concept of quantitative precipitation forecasting (QPF), pursued until a few years ago, is no longer used. The forecasts may be more accurate for the sub-Himalayan region, which lies near 30°N latitude, but the steep topography and paucity of data in the adjoining Tibetan Plateau region may impede the improvement of forecasts. The forecasts need to be validated against high-density gauge or satellite data. The gauge data may be used along with the satellite derived rain data to initialise the models, leading to improved forecasts. Data from radar may also be used to initialise the mesoscale systems. The availability of faster computers will enable the use of higher resolution, non-hydrostatic or cloud resolving models. NCAR is in the process of amalgamating the MM5 and Eta models. The new model, known as WRF, will have a hybrid coordinate system, which will include potential temperature as a vertical coordinate to treat the orography appropriately. The multi-model mesoscale predictions may be tested to give a probabilistic estimate of weather prediction as was previously done for the large-scale and tropical cyclone predictions. The cooperation by the neighbouring countries will be key for the testing and development of these new models.

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