Medium-Range Prediction of Winter Precipitation over India Using a Global Circulation Model

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Abstract

The winter precipitation over north-west India and the Himalayas realised under the influence of western disturbances is vital for replenishment of water resources. Although the amounts and frequency of rainfall in the plains of North India are less than those during the monsoon, these spells of light-to-moderate precipitation are of immense use for *rabi1* crops. A critical evaluation of the performance of the Global Circulation Model, viz., T-80 /L-18, operational at the National Centre for Medium Range Weather Forecasting, New Delhi, in predicting the occurrence and passage of extratropical systems in the westerlies over India, has been carried out with a view to assessing the overall efficiency of the model so that its product can be utilised for location-specific medium-range weather forecasting (MRWF) over the region. Typical characteristics of the winter synoptic systems affecting the Indian subcontinent from December 1994 to February 1995 have been examined in detail. During the winter season (Dec. - Feb.) of 1994-95 there were ten epochs of precipitation over north-west India, of which six were of moderate-to-active intensity. Day-to-day circulation features in the model analysis, and 72-hour forecasts and associated precipitation, were studied. The performance of the model in prognosticating the beginning of the western disturbances (both qualitatively and quantitatively) in terms of events, trends, patterns, and the intensity of precipitation over north-west India was examined. It has been observed that the model possesses a reasonably good capacity to predict the movement of the majority of winter disturbances at least three days in advance. The average root mean square errors in the position of the low pressure areas and troughs at 850hPa in the analysis and 72-hour forecast were in the order of 1.8° latitude and 3.4° longitude. Although the distribution and the upward or downward trend of precipitation are well captured in the model's forecast, the heavy-to-very heavy amounts of precipitation were generally underpredicted.

Introduction

The Indian economy is mainly based on agriculture. Only 30 per cent of our total cropped area is irrigated, the rest being totally under rainfed cultivation. Therefore, rainfall is of utmost importance for food production in India. In order to achieve the maximum benefit from rainfall events for agriculturally-based operations, there is a need to study future trends, patterns, and amounts of precipitation both

1 Rabi - refer to

qualitatively and quantitatively over space and time. As far as the seasonal variation of rainfall is concerned, most of the annual precipitation occurs during the monsoon period, but the precipitation during winter over north-west India also plays a very important role in building and replenishing water resources in the western Himalayas. The weather systems responsible for ushering in winter rainfall over these areas are popularly known as western disturbances (WD). The WDs, as their name suggests, approach the Indian sub-continent from the west in the form of a trough in the upper and middle tropospheric westerlies (Pisharoty and Desai 1956). These moving troughs give rise to the formation of closed cyclonic circulations in the lower tropospheric level and often at the sea level chart over Iran, western Pakistan, and North India. It is generally believed that the westerly troughs and associated lower level cyclonic systems originate in the Mediterranean or western Atlantic, with secondary depressions developing over the Persian Gulf, either directly or as a result of the arrival of low pressure systems from south-western Arabia. It is well known that the western disturbances occasionally deepen when they come over the Indo-Pakistani area, particularly over Rajasthan and Punjab (Rao and Srinivasan 1969). One of the reasons assigned to this intensification is the cooperative feed of relatively moist air from the Arabian Sea or from the Bay of Bengal and the central parts of India. However, another school of thought holds that dynamic effects and not the advection of air masses of different temperature and density are responsible for fall in pressure at any locality.

Severe winter storms are considered major natural disasters in some countries of the higher latitudes. The biting cold winds, snowfall, and blowing snow associated with such systems can cause havoc over large areas. These extratropical systems travel in the form of waves in the upper tropospheric westerlies. The magnitude of these waves is in the order of 20-30 degrees of latitude.

The Global Spectral Model T-80, operational at the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi, provides global analysis and five-day forecasts for different meteorological fields. This paper presents a detailed evaluation of the model's performance during the winter of 1994-95.

The Model

At NCMRWF, an adapted version of the NMC T-80, 18-layer Global Spectral Model is being run as an operational model to obtain weather forecasts of up to five days for various weather elements. The initial surface boundary fields and cloud parameters being used are surface temperatures, soil moisture, albedo, snow, roughness length, plant resistance, soil temperature, and convective clouds.

The Medium Range Analysis Forecast System (MAFS) of the NCMRWF (Fig. 1) consists of (i) data processing and quality control, (ii) utilisation of non-conventional data, (iii) data assimilation, (iv) model integration, (v) post-processing and diagnostics, and (vi) preparation of location-specific forecasts for agrometeorological advisories. The system involves reception of meteorological data from all over the globe through the Global Telecommunication System (GTS), decoding and quality checking, and data assimilation and analysis to generate forecasts by means of the Numerical Weather Prediction (NWP) Model. The GTS

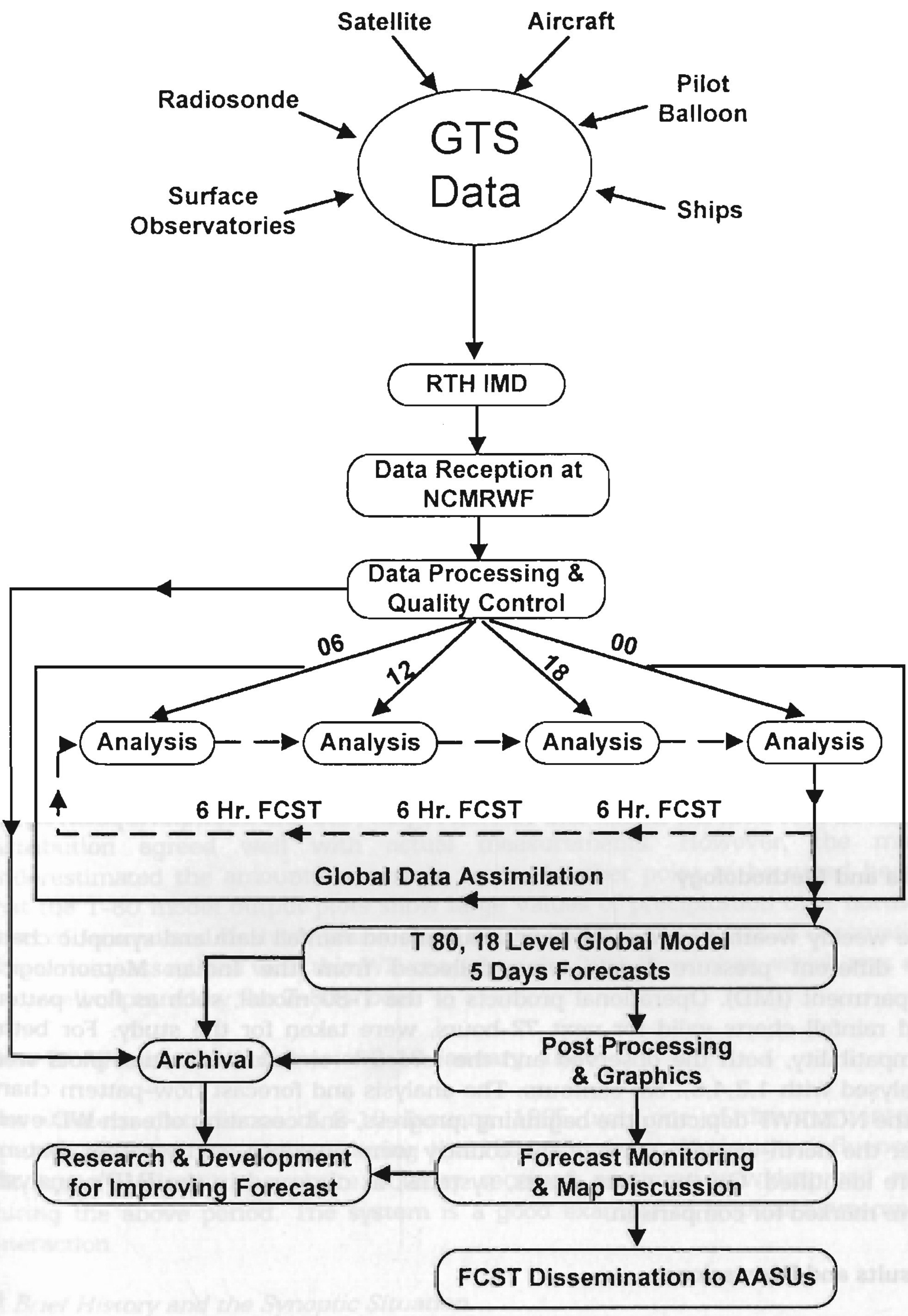

Figure 1: NCMRWF's Global Data Assimilation and Forecast System

data on Synoptic Observations (SYNOP), Radiosonde Observations (TEMP) and TEMP ship reports, Pilot Balloon Observations (PILOT) and PILOT Balloon Observations from ship reports, synop-ship, cloud motion vectors, aircraft winds, and temperature and satellite temperature profiles are received and passed through rigorous quality control checks. The data processed have been observed within three hours of analysis, as received over GTS. After the quality control, these data are utilised in a six-hour assimilation cycle. The main function of the data assimilation system is to assemble meteorological observations taken all over the globe and eventually prepare a picture of the atmospheric state consistent with the forecast model, which uses all current and past information. The analysis system used at the NCMRWF is known as the Spectral Statistical Interpolation (SSI). The data observed within three hours of the main synoptic hours (00, 06, 12, and 18 UTC) are initially treated as observed at synoptic hours. This scheme produces the analysis output, which provides initial conditions in the forecast model. At present, the assimilation system is run four times a day and takes into account all synoptic and asynoptic observations collected throughout a 24-hour period and is thus referred to as a 4-D intermittent data assimilation system. To meet the computational requirements of the MAFS, a cray super computer with VAX-gateway and VAX-based front-end processors was commissioned at NCMRWF in January 1989.

The T-80 Model uses climatological boundary conditions for several parameters. Snow depth is one of the features which goes as an estimate into the model. The mean snow depth values for the months of January and February over the Himalayas and Tibetan plateau are presented in Table 1. In January, the maximum values are found over the western parts of the Himalayas, ranging from 80 to 173mm compared to 80-105 and 6,099 for the central and eastern parts respectively. During February, a significant increase in the snow depth values is observed over both the Indian and Tibetan region (492 and 222mm respectively).

Data and Methodology

The weekly weather report, 24-hour accumulated rainfall data and synoptic charts for different pressure levels were collected from the Indian Meteorological Department (IMD). Operational products of the T-80 model, such as flow pattern and rainfall charts valid for next 72-hours, were taken for the study. For better compatibility, both the observed and the forecast rainfall distribution plots were analysed with 1,2,4,6,. cm contours. The analysis and forecast flow-pattern charts of the NCMRWF depicting the beginning ,progress, and cessation of each WD event over the north-western parts of the country were analysed, and weather systems were identified. On the same charts, systems, as observed in the IMD's analysis, were marked for comparison.

Results and Discussions

The winter season of 1994-95 (Dec. '94 - Feb. '95) witnessed above-normal rainfall activity over the entire Indian north-west. There were as many as ten significant events of winter precipitation over the country (Table 2). Two of these were largely confined to tropical latitudes and produced post-monsoon rains. Out of the remaining eight, five caused widespread precipitation over the northern parts of the country, including the region of the western Himalayas. In order to illustrate the performance of the model in predicting these systems, each epoch of a WD event is discussed separately. The WD events 8 to 10 in January 1995, being the strongest amongst all, have been discussed in greater detail.

Case I : Western Disturbance of 27-30 December, 1994

This was the first snowfall spell of the 1994-95 winter. On 27 December, the main flow was governed by a low pressure area at 850hPa centred over western Pakistan, Jammu and Kashmir, and adjoining areas. An associated trough was seen at 500hPa. The system at 850hPa moved over Jammu and Kashmir and neighbouring territory on the 28 December. While at 500mb, the trough strengthened and moved eastward. It was lying around 70^0 E. The location, extent, and movement of the system were predicted well by the T-80 model, 72 hours. in advance.

It may be emphasised that rain and snow commenced on the 27th and ceased on the 30th December. The commencement and cessation of precipitation were linked with the development and movement of the disturbance across the northern parts of the country. A significant amount of precipitation, 12cm, was observed in an area characterised by pronounced convection lying over Jammu and Kashmir on 28 December. The rainfall amounts in Jammu and Kashmir, HP, and Punjab were in the order of 6-10cm, 4-5cm and 3-4cm respectively (Figs 2a and b). However, the 72-hour forecast based on the IC of 25 December shows that the precipitation belt as predicted by the model extends from Pakistan to Himachal Pradesh, covering Jammu and Kashmir and parts of Punjab in north-western India. The maximum amount of precipitation predicted by the model was 5.1cm, which is quite comparable with the observed amounts. The trend and pattern of the rainfall distribution agreed well with actual measurements. However, the model underestimated the amounts in certain areas. Another point to be noted here is that the T-80 model output plots show large values of precipitation over northern parts of Jammu and Kashmir which could not be verified due to lack of observation. The activity associated with this WD ceased on the 30th December, which was also very well captured by the T-80 model.

Case II : Western Disturbance of 8-10 January, 1995

The western disturbance of 8-10 January, 1995, was one of the most intense systems affecting the country during the 1994-95 winter. Under the influence of the system, almost the entire country received scattered-to-widespread rains during the above period. The system is a good example of tropical-extratropical interaction.

A Brief History and the Synoptic Situation

At 00 UTC on 5 January, a feeble trough in the westerlies at 500hPa lay along 72^0E, extending up to 15^0 N. By 200hPa, the trough was more pronounced.

However, the jet of strong winds in excess of 70kt was situated around 25°N. At 850hPa, the remnants of an earlier system lay over north-western India and

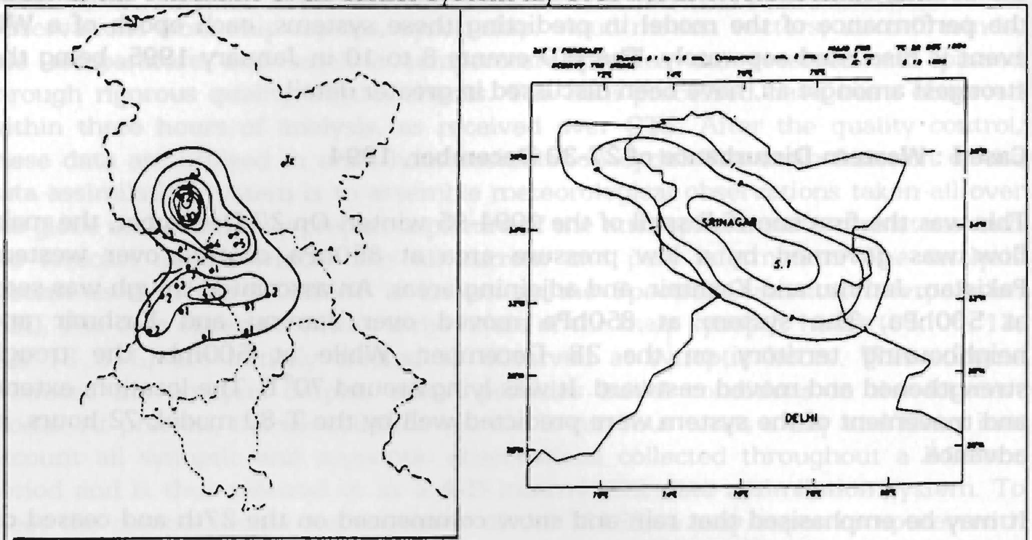

Figure 2: Twenty-four Hour Accumulated Precipitation Valid for 0300 UTC of 28.12.94 (a) Observed (b) Seventy-two Hour Prediction

adjoining North Pakistan as feeble low pressure areas. In the tropical latitudes, however, a low pressure area embedded in the easterlies lay off the west coast around 13^0N/72^0E at 850hPa.

On 6 January 00 UTC, the trough at 500hPa was still at the same longitude but had become pronounced and now extended up to 10°N. The jet stream at 200hPa and higher levels had come down to a lower latitude (20°N). At 850hPa, an interesting situation was observed. While a north-south trough embedded in the tropical easterlies was running from Gujarat to the central Arabian Sea, a low pressure area embedded in the extratropical westerlies lay over the Persian Gulf and adjoining Iran.

At 00 UTC of 7 January, the trough in the westerlies at 500hPa remained stationary but became much more marked, with an induced low pressure area forming around 25°N/68°E over Pakistan and adjoining Rajasthan. The axis of the core of strong winds in the order of 50 knots and more was running from Gujarat to the north-eastern states at 500hPa. At 200hPa, the sub-tropical westerly jet stream lay around 18^0N over the Indian region. The situation at 850hPa showed this low pressure area over Gujarat and the adjoining Arabian Sea forming in the easterlies, as a result of an intensification of the north-south trough on the previous day and another one over Pakistan originating as a consequence of the intensification of the trough in the westerlies. Around this, a number of stations in north-western India and eastern parts of Pakistan were showing a tendency towards rapid fall in surface pressure. The $P_{24}P_{24}$s over some stations in Gujarat and adjoining areas of Rajasthan were in the order of 4-6hPa.

By 00 UTC on 8 January, both these low pressure areas had become merged with each other and formed a well-marked low pressure area at 850hPa over Gujarat and neighbouring territory, with the trough extending right up to Jammu and Kashmir (Figs. 3a and b). It is interesting to note that while the system remained embedded in the easterlies in the lower levels, with the vertical extent of the system, it was the westerlies which were dominant above 850hPa, having virtually taken the system into its grip. This is a very favourable situation for the system to be intensified and maintained through the supply of adequate moisture from the Arabian Sea and Bay of Bengal, while the middle and upper troposphere cooling and necessary thermal gradient are provided by the westerlies of extratropical origin. The system provided copious amounts of rainfall over different parts of the country, as discussed in the next section. The 24-hour pressure changes became negative over the entire country, except for the eastern parts. The maximum value of the change was in the order of 6-8hPa in Gujarat and Himachal Pradesh.

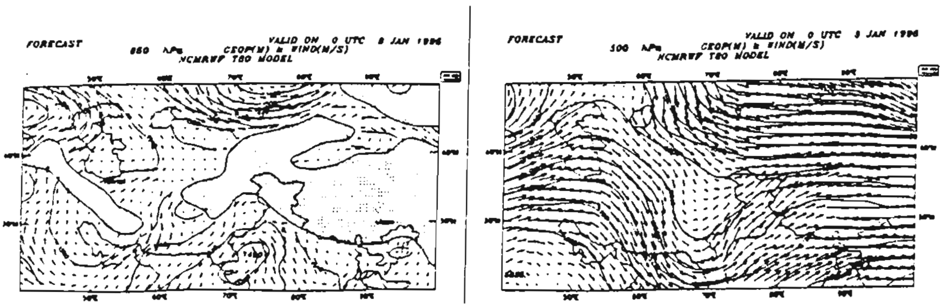

Figure 3: Seventy-two Hour Forecast of Wind Flow Pattern Valid for 00 UTC of 08.01.95 at (a) 850 hPa and (b) 500 hPa

Subsequently, on the 9th January, the system moved north-north-eastward and lay centred over Punjab and the adjoining areas. The troughs at 500hPa and 200hPa moved slightly eastward and come to lie along 76°E . However, the significant change which occurred from the previous day was that the system at 850hPa was now embedded in the westerlies instead of the easterlies (Figs. 4a and b). The rainfall over central and western parts of India decreased significantly. As the troughs in the middle and upper troposphere became less pronounced and the low pressure area weakened and moved eastward, the rainfall belt showed a more eastward extent. The system became unimportant after 10^{th} January (Figs. 5a and b).

Precipitation

Inclement weather started over India as early as 7 January, even though the associated system was far to the west. On 8 January, rainfall of up to one centimetre was observed over north-western parts of the country, whereas the T-80 model was predicting amounts of less than one cm over the same sector. The observed distribution of precipitation reported as a result of the passage of these disturbances is shown in Figure 6a. The movement of the trough towards the east was responsible for accentuating the surface system on the 9th of January and led to a lot of rainfall, ranging from two to 12cm, over north-western parts. The maximum rainfall predicted by the 72-hour forecast was four cm. The areal extent of the precipitation matches very well (Fig 6b).

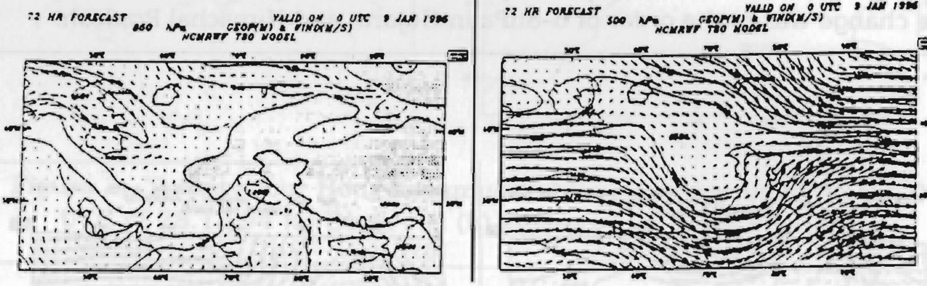

Figure 4: Seventy-two Hour Forecast of Wind Flow Pattern Valid for 00 UTC of 09.01.95 at (a) 850 hPa and (b) 500 hPa

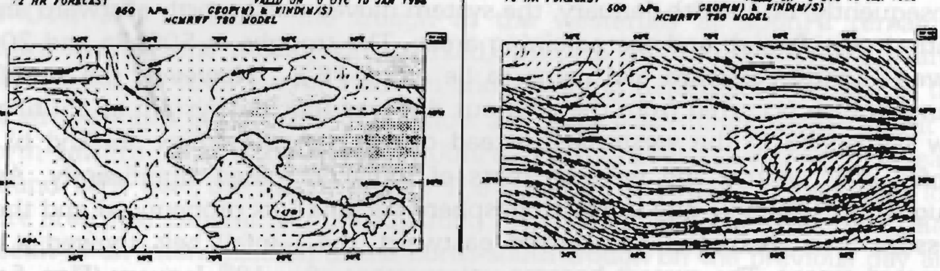

Figure 5: Seventy-two Hour Forecast of Wind Flow Pattern Valid for 00 UTC of 10.01.95 at (a) 850 hPa and (b) 500 hPa

By 10 January, the system was weakening and moving further eastwards, producing one to two centimetres of rainfall over Jammu and Kashmir, H.P., and Punjab, and around two centimetre over M.P. and north-eastern parts. Exactly the same pattern had been depicted by the T-80 model 72 hours in advance. The movement of the precipitation belt towards the north-west was also in good agreement. On 11 January, with the passage of the system over India, almost clear weather was observed, as predicted by the model well in advance.

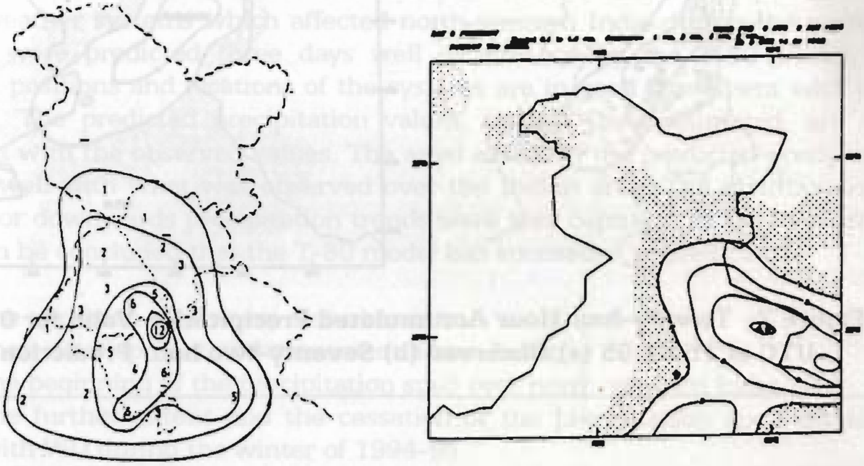

Figure 6: Seventy-two Hour Accumulated Precipitation Valid for 0300 UTC of 09.01.95 (a) Observed (b) Seventy-two Hour Prediction

Case III : Western Disturbance of 15-17 January, 1995

The third case of moderate precipitation during the winter of 1995 was during 15-17 January, 1995. In fact this was a most disastrous event, causing lots of landslides in Jammu and Kashmir and H.P. Though the amounts of precipitation associated with this event were not very heavy, a large amount of snow accumulation from previous events may have led to this disaster. A strong circulation was seen over Pakistan, Jammu and Kashmir, Punjab, H.P., and Rajasthan at 850hPa in the analysis of 15 January, while in the 72-hour forecast a strong circulation was expected with an associated trough extending up to western U.P. This circulation with the associated trough can be seen in the upper level at 500hPa in the 72-hour forecast.

On the 16 January analysis at 850hPa, the system intensified and moved towards India. In the 72-hour forecast based on the IC of 13 January, the same pattern was observed.

The observed amounts of precipitation over Jammu and Kashmir, H.P., and Punjab were in the ranges of 1-7, 1-4, and up to 4cm respectively. In the 72-hour forecast plot valid for the same day, the precipitation belt extended from Jammu and

Kashmir to H.P., covering parts of Punjab with a maximum amount of two centimetres as against an observed rainfall of seven centimetres (Figs 7a and b).

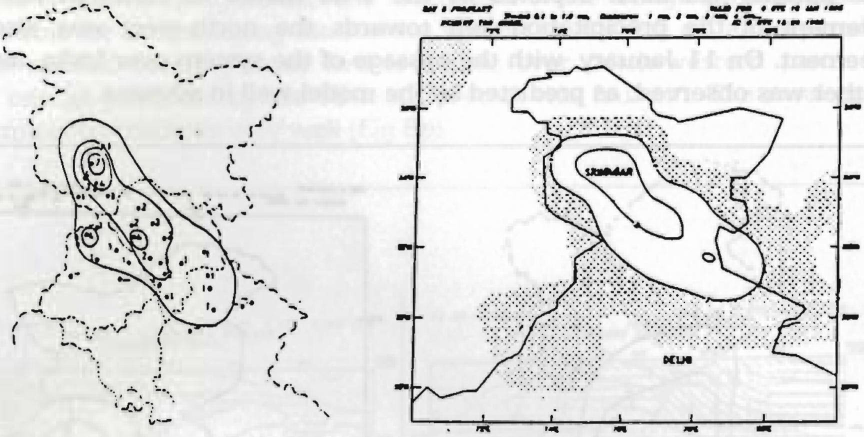

Figure 7: Twenty-four Hour Accumulated Precipitation Valid for 0300 UTC of 16.01.95 (a) Observed (b) Seventy-two hour Prediction

CaseVI : Western Disturbance of 12-15 February, 1995

This system was of moderate intensity, spreading fairly widespread rain and snow over Jammu and Kashmir, HP, Punjab, Haryana, the hills of western UP, Bihar, West Bengal, Assam, and Meghalaya. The system was initially seen on 12 and 13 February as a low pressure area over North Pakistan and the neighbouring territory, extending up to the middle troposphere. Subsequently it moved eastwards across the Himalayan ranges and weakened on the 16th. Figures 8a and b are respectively the observed conditions and the 72-hour prediction of precipitation valid for 03 UTC on the 14th February. It may be seen that while the maximum predicted amount (2.3cm) was slightly less than what was observed (7.0cm), the areal extent of the precipitation was well captured by the model.

Case V: Western Disturbance of the 27th-28th February, 1995

This was a feeble low pressure system which moved across the northern parts of the country. The system brought fairly widespread rain to Jammu and Kashmir, Punjab, HP, Haryana, and the hills of western UP during the above period. Figures 9a and b depict the observed conditions and the 72-hour prediction of precipitation valid for 0300 UTC on 28 February.

The average root mean square errors of positions of the weather systems (Table 3) in the NCMRWF analysis and the 72-hour forecast compared to the observed analysis of the IMD are range from 1.1° to 1.8° and 1.9° to 3.4° longitude at 850hPa, whereas the variations at 500hPa are in the order of 1.2° to 1.9° and 3.1°

to 3.9° longitude. The minimum root mean square error values are observed for ridges in the T-80 analysis as well as in the forecast and range from 1.1° to 1.9° latitude and 1.2° to 3.1° longitude at 850hPa, while the maximum values, in the order of 1.8° to 3.4° latitude and 1.9° to 3.2° longitude, are found in the case of low pressure areas.

Conclusions

All the weather systems which affected north-western India during the winter of 1994-95 were predicted three days well in advance by the T-80 model. The predicted positions and locations of the systems are in good agreement with those observed. The predicted precipitation values, though underestimated, are quite consistent with the observed values. The areal extent of the predicted precipitation matches well with what was observed over the Indian area. The distribution and upwards or downwards precipitation trends were well captured in the forecast (Fig 10). It can be concluded that the T-80 model has succeeded in predicting:

i) the approach of western disturbances,
ii) their development and movement across India,
iii) the beginning of the precipitation spell over north-western India, and
iv) the further extent and the cessation of the precipitation spell associated with WD during the winter of 1994-95.

The heavy-to-very-heavy amounts of precipitation predicted by the model were, however, less than the observed amounts, and this can be attributed to the fact that due to coarse resolution of the model (nearly 1.5° lat./long.), the isolated heavy amounts are averaged out at the grid points.

At the NCMRWF, efforts are going on to evaluate and utilise forecast products in all seasons for the benefit of the farming community. At present, the centre is providing agricultural advisory services to farmers on the scale of agroclimatic zones based on location-specific, medium-range weather forecasts of the Department of Science Technology (DST 1990). These weather-based advisories provide guidelines to minimise the losses which may be incurred due to adverse weather and further suggest management practices for tactical decision-making. Plans are afoot at the NCMRWF to implement and operationalise a high resolution (50km) Regional Spectral Model, embedded within the existing global model, in the near future to improve the synoptic-scale skills of medium-range prediction in the Indian region.

This study has demonstrated the capability of the T-80 model to provide better support for analysing and forecasting the western disturbances that bring winter precipitation to north-western India. By knowing the intensity and the areal extent of precipitation associated with winter systems 72 hours in advance, planners can suggest the adequate management measures to be taken for the storage and optimal utilisation of water resources available for irrigation.

An important aspect revealed by this study is that the systems moving across the extreme northern parts of the country are not captured well by the model. One of the reasons assigned to this deficiency is the lack of an adequate observational network over the entire Himalayan region in general and the western Himalayas in particular to validate the predictions. It is high time that the necessity of setting up a close network of meteorological and hydrological observatories be thought over seriously. The conference may serve as an important platform to address these issues boldly and to make suitable recommendations.

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