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Planning MONTBLEX – An overview

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Abstract. The multi-institutional experiment MONTBLEX aimed at sensing and studying the atmospheric boundary layer over the monsoon trough region of the northern plains of India during the summer monsoon of 1990. Four core facilities consisting of micro-meteorological towers and state-of-the-art instrumentation were created along the trough axis. This overview emphasizes the key features of project planning, management and execution, and provides details of all the experimental observation sites.

Keywords. MONTBLEX; monsoon trough; micrometeorological towers; atmospheric sensing.

1. Introduction

The Monsoon Trough Boundary Layer Experiment, acronymed MONTBLEX, was an intense multi-institutional effort sponsored by the Department of Science and Technology (DST), Government of India, intended to probe the atmospheric boundary layer (ABL) over the monsoon trough region of the Gangetic Plains. The project, initiated in March 1987, may be described as the largest meteorological field experiment originating from India and one among the largest atmospheric boundary layer projects carried out anywhere.

Atmospheric boundary layer processes affect cumulus convection, sub-cloud layer convergence, pollution dispersal, land-air and air-sea interaction etc. The monsoon trough (figure 1) is the seat of cyclonic vorticity in the lower troposphere, particularly along its eastern end over the north Bay of Bengal where organized moist convection prevails during the monsoon months. The disturbances move westwards and cause rain all over the Gangetic Plains. The western end of the monsoon trough is over west Rajasthan and adjoining Pakistan and is characterized by dry convection with shallow clouds. Very little information is available on the effects of boundary layer processes associated with the deep moist and the unsaturated, near-dry processes that respectively take place over the length of the monsoon trough as it extends inland, although understanding such processes is of primary importance for the investigation of monsoon dynamics.

A brief account of the genesis of the project appears in Sikka and Narasimha (1995). The project evolved from various discussions between different scientists, most notably R Narasimha, D R Sikka, A Prabhu and S Gadgil. Based on the recommendation of a scientists' meeting on implementation of the expert panel report on atmospheric sciences, held on 5th April 1984, DST constituted an expert group on atmospheric boundary layer studies chaired by R Narasimha, which after a number of meetings submitted a report on a co-ordinated study of the atmospheric boundary layer. This was

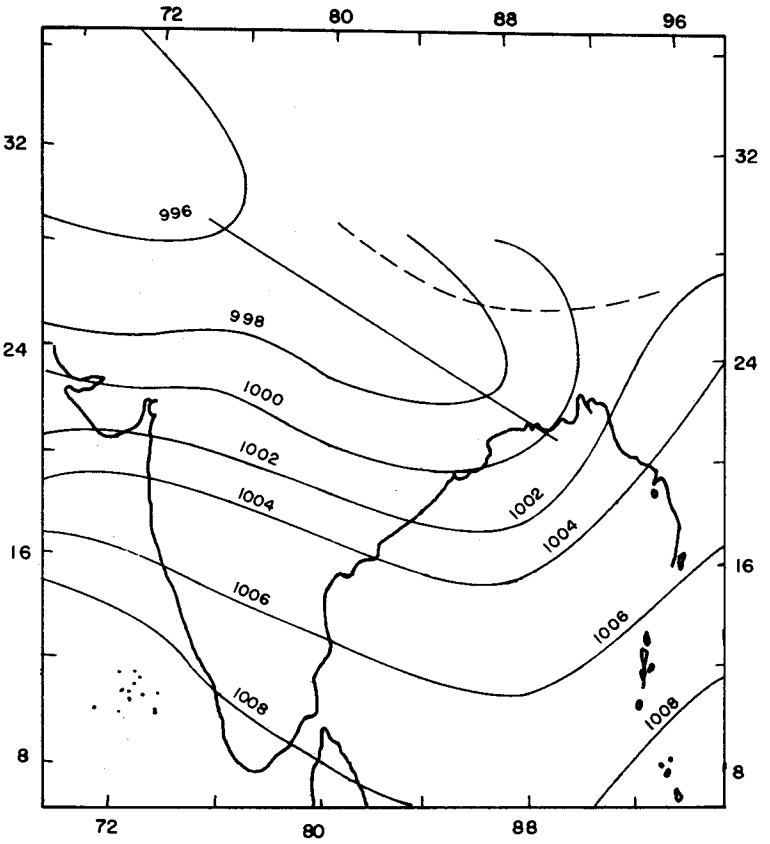

Figure 1. The position of the monsoon trough. The thick line indicates it's position during active monsoon periods and the dashed line shows its northward shift during 'breaks' in the monsoon.

reviewed by the Project Execution and Monitoring Committee of the DST under the chairmanship of R P Sarkar, the then Director General of the India Meteorological Department (IMD), and the concept of MONTBLEX was accepted in July 1987. Three projects under the auspices of the Indian Institute of Tropical Meteorology, Pune (IITM), Indian Institute of Science, Bangalore (IISc) and the Indian Institute of Technology, New Delhi (IITD) respectively were approved as parts of a co-ordinated project on boundary layer studies on 25th March 1988.

2. Objectives, scope of the project and the organizations involved

The objective of the experiment was to collect comprehensive data on both mean and fluctuating atmospheric parameters from stations along the location of the monsoon trough and selected adjoining areas including the Bay of Bengal during the period of the 1989 monsoon. These dates were later modified so that a pilot experiment could be conducted during the 1989 monsoon with the full-fledged main experiment slated for 1990.

The main component of the project was the construction of three micro-meteorological towers at Kharagpur, Varanasi and Jodhpur and augmenting an existing tower at the IIT, Delhi. These towers were equipped with state-of-the-art fast-response instrumentation and data acquisition systems for sensing and recording the mean and fluctuating wind speed, wind direction, temperature and humidity in the ABL and soil temperature (Rudrakumar *et al* 1995; Narahari Rao 1995).

Complementing the towers were extensive observations of the state of the atmosphere with an array of sensing systems including sodars, pilot balloons, tethersondes, radiometer flights, radar and ground observations from weather stations at the tower sites and the existing networks of IMD and the Indian Air Force (IAF). Simultaneous oceanographic and meteorological observations during cruises by ORV *Sagarkanya* of the Department of Ocean Development in the Bay of Bengal and aircraft flights by the IAF over the trough region were also conducted.

The responsibility for the tower stations, from design to collection and validation of data, was with A Prabhu and his group from the Centre for Atmospheric Sciences (CAS), IISc. The group from IITM led by K G Vernekar conducted sodar, tethersonde and pilot balloon experiments from Kharagpur and took part in the ship cruises. The IMD and the Met. Division of the IAF conducted ground and pilot balloon measurements. The IMD was also in charge of radiometer, radar, satellite and upper air observations while the IAF also conducted instrumented aircraft flights.

The National Institute of Oceanography (NIO) conducted the special MONTBLEX cruise of the ORV *Sagarkanya* during which measurements were made by scientists from IITM, IMD, the Naval Physical and Oceanographic Laboratory (NPOL) and NIO.

The National Physical Laboratory (NPL) installed a monostatic sodar and conducted measurements at Jodhpur while the Indian Statistical Institute (ISI) did so at Varanasi.

Goel and Srivastava (1989, 1990) have earlier discussed the limitations in the current knowledge of the monsoon system and the scope for additional observations that led to the concept and objectives of MONTBLEX, the design of the experiment and future data needs.

3. Project planning

The planning and execution of the project was carried out through various committees and groups, with the composition shown in Appendix 1. The progress of the project was continually reviewed by the MONTBLEX Monitoring Committee (MMC). A Science Advisory Group (SAG) assisted the MMC in scientific matters. A modelling group took care of advising the MMC on the specialized requirements of data for monsoon modelling, one of the primary objectives of MONTBLEX. Plan documents (see below for details) on operations and data management were prepared. A MONTBLEX Operations Control Centre (MOCC), set up in the offices of the IMD, New Delhi, identified periods for intensive observation and informed all data collecting platforms about the progress of the monsoon. A MONTBLEX Operations Director (MOD) performed the critical task of setting up and running the MOCC. On completion of the project a data centre was established where all data were collated and stored centrally. A data users meeting assessed data needs and archiving options from the point of view

of the users of MONTBLEX data. Various workshops were conducted on the basic physics of the atmospheric boundary layer, the science (and art) of its measurement and on the results of analysis of the data acquired. Reports were prepared on the various aspects of MONTBLEX including studies using data acquired from its different observation platforms. *MONTBLEX News*, a newsletter sponsored by DST, was published from IISc detailing the progress of the project. The DST earth and atmospheric sciences section was the primary administrative node for all the inter-institutional co-operative efforts.

3.1 *Monitoring MONTBLEX*

This was in the charge of MMC, which met five times from 1988 till 1992 at various places including IIT Kharagpur, IISc and DST Delhi, to monitor the health of the project and decide on the future course of action at each stage of the project. On 19th – 20th September 1988, MMC took various preparatory steps, including the establishment of a data management cell, the publication of a MONTBLEX bulletin, the organization of a winter school for participants and observers, and the constitution of the Scientific Advisory Group. On 19th May 1989, it was decided to conduct a pilot experiment during 1st to 7th July 1989 and in this connection to establish an operations centre at Calcutta. On 19th September 1989 the pilot experiment was reviewed, and it was decided to go ahead with the main experiment in 1990, including a ship observation plan. On 12th April 1990 the state of preparedness for the main experiment was reviewed.

On completion of the main experiment, the results were reviewed on 23rd January 1991 and it was decided that all data should, on completion of processing, be transferred to a MONTBLEX Data Centre to be set up at IITM.

3.2 *Scientific Advisory Group*

This group (SAG) prepared the observation strategy for MONTBLEX. It guided the project on positioning the ORV *Sagarkanya* over the head of the Bay of Bengal, the need for supplementary aircraft observations and the preparation of a detailed map of the observation system to study the monsoon circulation. The group also formulated the detailed observational programme to be implemented by IMD and other participating institutions, for an area of radius 400 km centred around the Kharagpur tower, with an area within a radius of 200 km being a core region.

On 3rd July 1991, upon the completion of the experiment, SAG suggested that the infrastructure created under MONTBLEX continue to be operational. A spin-off has been the formulation of a programme on Radio Acoustic Sounding System (RASS) for which a RASS core group has been constituted to suggest an action plan.

3.3 *The modelling group*

The MONTBLEX modelling group met at DST on 21st March 1990, reviewed the results of the pilot experiment and made recommendations on calibration of sensors and on collection of additional soil data.

3.4 *Plan documents*

As part of the planning process, two plan documents, on operations and data management respectively, were prepared and submitted to the monitoring committee.

3.4.1 *The MONTBLEX operations plan*: This document (Kusuma Rao and Prabhu 1988) summarized the scientific objectives, specific tasks and data requirements to be fulfilled by MONTBLEX, listed the participating agencies and identified the MONTBLEX area of operations. Based on these proposals, the plan identified the operations schedule at the different experimental sites and components for 1989 and 1990.

The observational programme was divided into a core programme and a supplementary programme. The core programme included measurements of surface turbulent fluxes at the four tower locations representative of various distinct physical processes that take place in the region of the monsoon trough; and radiosonde, radiometer, sodar, tethersonde, radiation, radar, ship and satellite information which are to be collected from identified stations along with standard synoptic data. A supplementary programme was to have included tower observations at NIO, Goa and INCOR, Visakhapatnam but this unfortunately had to be abandoned. A work plan showing the responsibilities of each participating group was described in considerable detail. The specifications of the measuring sensors were also set out in the plan.

The concept of the MONTBLEX operations centre (later to become the MOCC) was introduced and its role identified. This centre was planned to consist of operational forecasting, scientific planning, operations control, administrative services and data management. Key components of the MOC were a forecast centre located at IMD Delhi, a support centre housing the data management group at Bangalore, and an intensive operations period advisory group.

At the suggestion of the MMC, a design and operation plan for MONTBLEX-90 was prepared by D K Rakshit. The plan highlighted the objectives and goals of the experiment, identified 18 institutions and agencies to be involved in the data collection, analysis and modelling, listed observational requirements and allocated specific tasks.

3.4.2 *Data management plan*: This plan (Kailas and Prabhu 1988) considered various aspects of data collection, quality control and archiving of all the data recorded during the operational periods of the different segments of the MONTBLEX data acquisition system. In particular, the plan included the following: summary of all data acquisition platforms including the instrumentation; data expected to be available from the above and the responsibility of data collection and transmission to the data centre; periodic checking of data for quality control and feed-back to the collecting agency; quick dissemination of data while events are fresh in the minds of MONTBLEX participants and other user groups; ensuring a centralized and well-documented archive of all data under the MONTBLEX data centre, and preparation of a catalogue of the MONTBLEX data base called the MONTBLEX data book.

A time table was also formulated to help the investigators plan the various stages of the experiment well in advance, and to bring out the data book.

3.4.3 *Ship observation plan*: Following various earlier discussions, the ship observation plan was finalized on 18th August 1989. It was decided that the ORV *Sagarkanya*

would be on a MONTBLEX cruise between 10th June and 31st July 1990 in the north Bay of Bengal during different monsoon conditions coinciding with the major observational phase of MONTBLEX. The period was later changed to 10th August to 30th September 1990 based on the availability of the ship. Scientists from IMD, IITM, NIO and NPOL Cochin, participated in the cruise. It was decided to acquire surface meteorological observations every hour, radiosonde observations twice a day as routine and four times a day during the intensive observation periods, along with XBT and thermistor chain data and omegasonde readings.

3.5 *The MONTBLEX operations control centre*

This centre, with its own operations director, was set up to co-ordinate all operations and advise on the intensive observation periods during the MONTBLEX main experiment, viz., 15th May to 30th September 1990. The centre was established as an extension of one of the field units of IITM Pune, at the office of the Director General of Meteorology, New Delhi, utilizing the extended weather charts and other facilities for monitoring the evolution of the monsoon systems available there. MOCC was under the overall guidance of the MMC. M G Gupta, the Director of MOCC, received support from IMD scientists at the Northern Hemisphere Analysis Centre (NHAC), New Delhi, scientists of the MONTBLEX modelling group and representatives of the Indian Air Force in discharging his operational responsibilities. The day-to-day progress of the monsoon was critically reviewed in periodic discussions (normally tri-weekly). Extended weather charts, cloud pictures recorded by INSAT, rainfall summary prepared by NHAC and other relevant information were used in these discussions to assess the prevailing weather systems relevant to the monsoon and their likely behaviour during the next 2–3 days. Based on these, advisories were finalized for the observation programme with the specific intent to identify Intensive Observation Periods (IOPs) and aircraft tracks.

The IOPs identified during MONTBLEX 1990 are listed by Srivastav (1995). The withdrawal of the monsoon did not commence till 14th September 1990 when MOCC discontinued issue of operational messages.

3.6 *Data users meeting*

Immediately after the successful completion of the main experiment, the following five groups were formed by data users to co-ordinate data processing, with IISc handling the surface and tower data; IITM, Pune the sodar data; IITM, Delhi the IAF data; and NIO the ORV *Sagarkanya* observations. Also a data archiving and distribution centre was established at IITM. A data catalogue based on the WMO format with INSAT pictures included in the synoptic report was prepared by the MOCC.

3.7 *The data centre*

This centre has been set up at IITM, and is described separately by Vernekar (1995).

3.8 *Training programmes*

A training-cum-orientation workshop for MONTBLEX participants was organized by the Department of Physics and Meteorology at IIT Kharagpur from 3rd to 7th April 1989. Using the first MONTBLEX tower as it was getting ready, various scientific groups, particularly the observational and experimental teams, were trained on various data-collecting methods and procedures used in the project. An intensive course on the atmospheric boundary layer and turbulence was conducted at IISc from 25th April to 4th May 1990. Over thirty participants were introduced to MONTBLEX tower instrumentation and related hardware and software, for which purpose a small micro-meteorological tower was erected.

3.9 *News about MONTBLEX*

A news letter on MONTBLEX provided a useful record of the activities of the many different groups, institutions and data platforms, and acted as a forum for exchange of information and messages. Five issues of the news letter were issued from May 1989 to January 1992. Articles in scientific journals (Goel and Srivastava 1989, 1990) presented the details and scope of MONTBLEX to a wider audience.

4. Experiments conducted

4.1 *The pilot experiment*

In July 1988, the IISc team along with the IITM instrumentation group and IIT Kharagpur scientists set up the first of the 30 m MONTBLEX towers in the farmland near the southeastern boundary of IIT Kharagpur. The tower site enjoys an uninterrupted fetch of over 500 m towards the south, the region of the prevailing monsoonal winds. The tower (set up in two weeks) had instruments to measure slow winds (1 Hz), humidity, temperature and direction at 6 levels: 1, 2, 4, 8, 15 and 30 m. In addition, fast response (around 8 Hz), wind speed and temperature sensors were installed at 4 and 15 m. At 15 m a hot wire anemometer was also installed. A PCM telemetry system transferred the data signals conditioned by translators housed at the foot of the tower to a PC kept in a room some 200 m away. For details on the instrumentation see Rudra Kumar *et al* (1995).

The instruments withstood the vagaries of the tempestuous weather at the site in 1989, and the team had an opportunity to learn about possible problems when the data acquisition system failed due to lightning, power failure or theft of a section of the linking cable. Some of the data were analysed by the Bangalore group and presented at a project monitoring committee meeting at Kharagpur in September 1989.

With this tower ready and operational, the pilot experiment was conducted during 1st–7th July 1989. The objectives of the experiment were to test all the tower instruments and the data acquisition system, initiate an operations centre at IMD Calcutta, activate the communications network for data transfer, and gear up the data management centre for large scale data processing and replication; in other words, to

test if the system worked well as an integrated whole. The observation platforms included for this experiment were the tower at IIT, Kharagpur, the 20 m tower at IIT, Delhi and the IMD network over the trough region.

The IISc group reached Kharagpur on 1st July and, after calibrating and checking out the whole system, began data acquisition on 2nd July 1989. Three-minute averages of slow tower data were recorded on cassettes, and fast data on the hard disk of a PC-XT. The IITM group installed a Lyman-alpha humidity meter and launched minisondes. There were many improvements incorporated, notable among them being the complete automation of the data acquisition making it possible to record data automatically for a specified period at specified intervals. For details on the tower, sensors and on the data availability see Prabhu *et al* (1990).

4.2 *The main experiment*

4.2.1 *The 1990 monsoon*: A brief discussion of the progress of the 1990 monsoon over India appears in Srivastav (1995). It is seen that the monsoon advanced into the south Andaman Sea and adjoining southeast Bay of Bengal on 19th May, one day ahead of the normal date. It set in over Kerala on 28th May four days ahead of the normal date, and reached Bombay ten days ahead of the normal date.

The progress in the East was only slightly slower, setting in over Calcutta and most of the northeast on 6th June, close to the normal date. Further advance came with the depression of 14th–15th June and its westward movement. Subsequent lows that developed in the monsoon trough region and moved west-northwest, maintained the progress of the monsoon into northwest India. Delhi witnessed its arrival on the normal date of 29th June. The pace then quickened and the entire country was covered by 1st July, two weeks in advance of the normal date. In short, the progress of the onset of the monsoon from Kerala to northwest India took 35 days, less than the normal 45 days. It arrived 7–10 days ahead of normal onset over most of the country, and two weeks ahead in many places in northwest India.

During most of July, the monsoon trough was fairly active and a number of embedded lows were formed. These travelled as usual in a west-northwest direction and were generally associated with an upper air circulation extending to mid-tropospheric levels. The few western disturbances of that year also moved across the northern part of the country causing a temporary 2–3 day northward shift of the monsoon trough. Interestingly, break conditions in the monsoon, when the entire trough axis shifts to the Himalayan foothills, did not develop in the July–August period.

August was remarkable for the strong variations in the synoptic conditions. The upper troposphere in the northern extratropical regions of the country was affected by the meridional flow displacing the sub-tropical high northward. This led to weak surface pressure gradients, so much so that the monsoon trough was not discernible for a few days till a depression developed in the west central Bay of Bengal and travelled across central India. A few days later another depression with a life span of 5 days formed in the north Bay. The passage of the remnant of Typhoon Becky into the northeast Bay across the Arakan Coast towards the end of August and its progress west-northwest helped in the continuance of the mid-monsoon phase, which was 3–4 weeks longer then normal over many parts of NW India, probably being the cause of the above-normal rainfall.

Normally the June–September monsoon season is punctuated by 9–10 depressions (1–2 in June, 2–3 each in the following months). The 1990 monsoon saw only 4 depressions – one each in June and September and two in August (see table 3 in Srivastav 1995).

The early onset along with the absence of break conditions and the late withdrawal provided a longer than normal mid-monsoon phase. Rainfall was fairly well distributed in time and space with no report of severe flood conditions anywhere in the country. The country thus experienced good rainfall (6% above normal, among the best three of the decade, the other two being 1983 and 1988) during the southwest monsoon season of 1990. An overall review of the season is presented by Srivastav (1995).

4.2.2 *The tower sites*: The instrumentation group at CAS, IISc set up the two towers at Banaras Hindu University (BHU), Varanasi and Central Arid Zone Research Institute (CAZRI), Jodhpur in January 1990. At Jodhpur, the whole system was also tested and all links checked out in January; this early operationalization was beneficial, for it took just three days to reactivate it for the main experiment (which began only some months later). The system worked uninterruptedly except when severe floods in late June forced a shut-down for a few days. Though the Varanasi tower could not be made operational till early June due to various local problems, once these were sorted out, the system ran satisfactorily though not as spectacularly. The Jodhpur tower over-looked a large 400 m swath of desert flats while the Varanasi tower overlooked nearly 300 m of flat (and at that time fallow) farmland with trees in the distance.

The fast-response sensors, complementary signal conditioning electronics and data acquisition software, all developed for the experiment, worked satisfactorily. All the towers had Lyman-alpha fast-response humidity sensors developed in-house at CAS, IISc with the collaboration of IITM. A fast-response infra-red humidity meter was also developed but could not be made operational for MONTBLEX due to difficulty in procuring certain critical imported sensors. As the dates for the main experiment neared, the group had upgraded the 32-channel PCM transmitter-receiver system to handle 64 channels and vastly improved its electronics and reliability. The instrumentation at each tower is discussed by Rudra Kumar *et al* (1995).

The Kharagpur tower was made operational for the main experiment on 25th May 1990 by the IISc team. The slow data from 32 channels of the tower sensors were continuously recorded on cassette tape of a Campbell data logger as three-minute averages. Fifteen minutes of fast data from 32 channels were recorded on the hard disk of a PC-XT every three hours (0530, 0830, 1130, 1430, 1730, 2030, 2330 hrs UTC) and transferred on to a cartridge tape.

At Varanasi, the slow data acquisition system was tested (after drawing a temporary cable over a distance of nearly 400 m) at the time of setting up the tower in January 1990. After the team returned to Varanasi on 26th May, a temporary shed housed the data acquisition computer, and data acquisition was begun on 8th June after considerable teething trouble. Because of the lack of time for a thorough running-in of the system and the extreme heat, less data could be acquired than at the other sites. The system was otherwise identical to that at Kharagpur.

At Jodhpur the tower was installed in late December 1989. Most of the instruments were mounted and both the slow and fast data acquisition were checked out in early January itself. All the systems were rechecked in April.

The whole system was quickly made operational in June. The configuration of the system was the same as at Kharagpur and Varanasi. The system broke down due to unprecedented floods (the worst in a 100 years) in Rajasthan, with Jodhpur being among the worst hit. Despite the incessant rain and water-logging the system was reactivated in near entirety within a few days. The early operationalization of the tower is reflected in the fact that this tower provided the cleanest and largest amount of data.

The Delhi tower, identical to the other towers, was made operational in May 1990 with data being acquired from early June.

The tower data have been discussed by Rudra Kumar *et al* (1995). A series of eight checks were made on both profile and turbulence data. These consist of:

- time traces from various sensors;
- comparative plots of data from sensors measuring the same variable;
- wind and temperature profile plots;
- calculation of roughness lengths;
- statistical parameters;
- stability parameters and their diurnal variation;
- probability density plots; and
- energy spectra.

The data analysed were selected randomly from sonic, hotwire and Gill anemometers, slow and fast platinum temperature sensors, humicaps and windvanes. Plots of time series helped eliminate data that is too spiky or having signal drop-outs or having poor correlation between different levels. Comparison of traces of different sensors measuring the same physical variable helped in the data reliability assessment and faulty sensors are listed. If the number of spikes are few it is reported as 'spiky' or the actual number of spikes are listed in an appendix that is attached to the data report (Rudra Kumar *et al* 1991). If the data is very bad, either due to too many spikes or because the sensor was not working for a major part of the time, that data set is not stored.

Traces of horizontal velocity from the sonic and Gill anemometers were compared to that of the cups and mismatches reported.

Comparison was made of fast temperature from the platinum thermometer and the sonic anemometer. Only Lyman-alpha data which matched data from the nearest humicap sensor were stored.

Profile plots of averages helped indicate offset errors in different sensors which would show up as kinks in the otherwise smooth profile. Statistical parameters like standard deviations, fluxes and correlation coefficients were determined and checked for expected values as quoted in the literature. Diurnal variation of the gradient Richardson number, the flux Richardson number, the Monin-Obukhov length, fluxes, eddy coefficients etc. were computed and checked for expected trends. Probability distributions were checked for deviation from the standard Gaussian. The spectra of the velocity components from the different fast sensors, and of the temperature and humidity, were plotted and checked for the existence of the Kolmogorov drop-off in the inertial sub-range.

The data are checked for invalid values (e.g., negative values when the sensor is off), and wrong entries by the collecting personnel. It is finally organized into files containing all available data of *one variable* from one station along with useful notes and comments on the various data sets available.

Table 1. Special IMD stations for radiosonde/radiowind observations for MONTBLEX-90.

Station	No. of RS/RW ascents	No. of low level soundings	Total
Calcutta	261	70	331
Bhubaneswar	170	70	240
Ranchi	214	57	271
New Delhi	262	46	308
Jodhpur	249	46	295

Table 2. Special IMD stations for pilot balloon ascents.

Stations	Number of ascents
Jamshedpur	350
Raipur	399
Gopalpur	399
Balasore	425
Jharsuguda	277
Gaya	474

The tower team consisted of A Prabhu, S V Kailas, S Ameenulla, S Rudra Kumar, H P Srinivasan, S Vasudev, B Madhu, Chikke Gowda, H Raja and K Shiva Shankar from IISc and A Chandrashekar, Badrinath and Rajkumar from IIT, Kharagpur took part.

4.2.3 *The IMD component*: The IMD conducted extensive observations from 15th May to 22nd September. These included upper air, pilot balloon (PB), surface and radar observations (see Srivastav 1995).

In addition to the routine observations carried out by the upper air network, additional observations were required from various network stations. Hence besides the usual 0 and 12UTC radiosonde/radiowind observations, five stations (Calcutta, Bhubaneswar, Ranchi, New Delhi and Jodhpur) were earmarked to take special observations at 6 and 18UTC using low level sondes and these are listed in table 1. Similarly, in addition to routine observations from a number of PB stations in the area of interest, the six stations at Jamshedpur. Raipur, Gopalpur, Balasore, Jharsuguda and Gaya carried out additional PB observations all of which are listed in table 2.

The Calcutta centre conducted one radiometersonde ascent per week during the IOPs, whereas Bhubaneswar and Jodhpur conducted routine fortnightly ascents. In all, 10 ascents were made at Calcutta and 6 each at Jodhpur and Bhubaneswar.

Weather radar observations, three-hourly or more frequent, were taken from the X-band radars at Calcutta and Ranchi. The Calcutta radar made 1503 observations while the one at Ranchi made 289.

The IMD scientists on board ORV *Sagarkanya* on the MONTBLEX cruise (11th August – 23rd September 1990) carried out three-hourly surface observations in

addition to one daily radiosonde (00 UTC) and low level ascent. In all 275 surface observations, 33 radiosonde and 30 low level soundings were taken during the cruise.

All the stations which conducted PB ascents also recorded three-hourly surface observations.

The participants from IMD are too numerous to be listed here but the contributions of the teams led by S K Srivastav and others have been extensive.

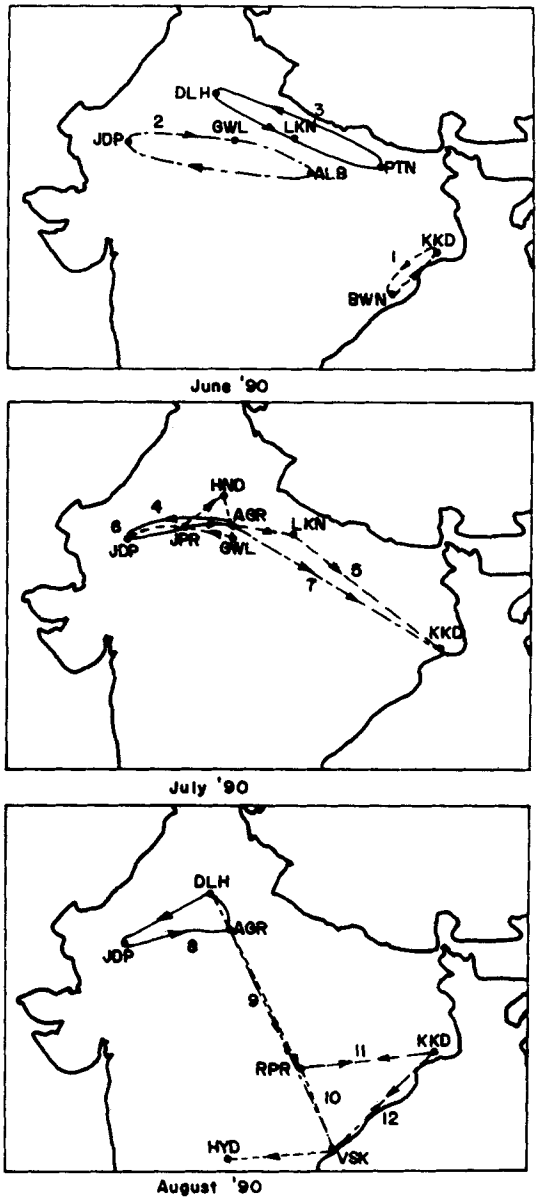

Figure 2. The paths of the aircraft flights. In all, 12 flights were made over the monsoon trough region and sometimes beyond.

4.2.4 *The IAF contribution*: The Indian Air Force collected surface and pilot balloon data along the monsoon trough from their in-house observatories besides undertaking rather extensive aircraft flights for MONTBLEX.

Twelve IAF met. sections, viz., Kalaikunda, Allahabad, Kanpur, Lucknow, Gorakhpur, Hindon, Agra, Jodhpur, Gwalior, Bareilly, Suratgarh and Bhatinda took surface observations from 1st May to 15th September 1990. Surface observations were recorded at three hourly intervals at the synoptic hours. During IOPs, surface observations were recorded by the hour UTC.

Pilot balloon observations were recorded at four stations, Kalaikunda, Agra, Suratgarh and Bhatinda at 00 and 12UTC, with 06UTC recorded additionally during IOPs.

Cloud ceiling readings were recorded at Kalaikunda, Gwalior, Agra and Jodhpur using laser ceilometers and ceilographs.

Twelve An-32 sorties (42 hours in all) were flown by IAF from Allahabad, Hindon, Agra, Kalaikunda and Jodhpur (with one Met. Officer on board on all the flights). In-flight observations of wind direction, wind speed and air temperature were taken every 10 minutes. All the sorties were arranged with a notice of 48 hrs. The sorties covered the areas of meteorological interest determined by MOCC. Figure 2 shows the tracks of these flights.

AVM. N Natarajan, Air Cmde. K C Varma and Gp. Capt. O P Madan, besides many observers from the different centres, took part in this effort.

4.2.5 *The ocean observations*: Cruise 56 of the ORV *Sagarkanya* sailed from Marmugao at 12UTC on 11th August 1990 for MONTBLEX observations in the north Bay of Bengal. Surface meteorological observations were started from 15UTC on 11th

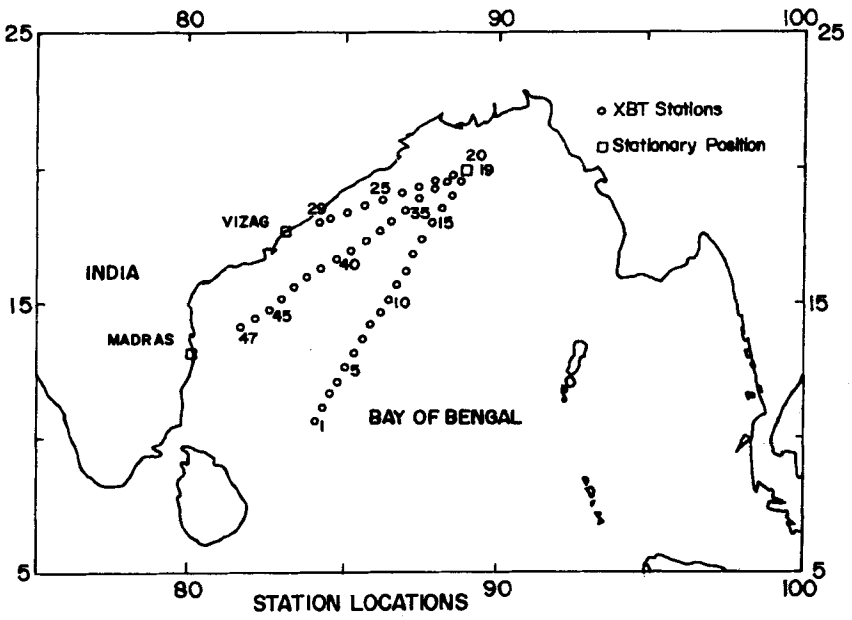

Figure 3. The path of the ORV *Sagarkanya* during its MONTBLEX cruise showing XBT stations.

Table 3. Observations made on ORV *Sagarkanya.*

Parameter	No. of observations
CTD	251
STD	210
Upper air ascents	73
XBT	48

August and were repeated at 3-hour intervals. Upper air ascents were begun from 15th August when the vessel entered the Bay of Bengal, and were repeated at the synoptic hours. The vessel reached the stationary position 20°N/89°E at 2230UTC on 17th August, at which time observations on oceanographic and meteorological parameters were started; they continued till 2330UTC on 1st September. The vessel reoccupied the same position from 1640UTC on 8th September till 2330UTC on 19th September after a trip to Visakhapatnam for provisions and bunkers. Figure 3 shows the track of the ORV *Sagarkanya.*

The observations made at the synoptic hours consisted of CTD up to 100 m, STD up to 300m, surface and micrometeorological observations (with sensors fixed on a 5 m long boom projecting into the sea from the bow of the vessel), upper air ascents at 00 and 12UTC, continuous measurements of atmospheric electricity and precipitation current measurements when rain occurred. XBT launches were made at 3-hourly intervals when the vessel was cruising from 10, 34·2°N/84, 02·2°E up to 20°N/89°E during 15th–17th August, from 20°N/089°E up to Visakhapatnam during 1st–3rd September and from 20°N/089°E up to Madras during 19th–22nd September. Table 3 lists the number of observations made at the synoptic hours. Three additional radiosonde ascents were made at 06UTC during 23rd–25th August.

During the cruise the vessel experienced four low pressure systems of which two were weak. The observations were completed on 19th September at 2330UTC and the cruise concluded at 08UTC on 22nd September when the vessel reached Madras.

The cruise participants were D P Rao with Y V B Sarma, G Nampoothiri, A M Michael, R Vaithiyanathan and P Chodankar (all from the Physical Oceanography Division of NIO), Y E A Raj, P P Butala, P Sridharan, Kuldip Wali, P M Jagmohan Rao and S V Lambat (from IMD), P Seetharamaiah and C G Deshpande (from IITM), K V Sanil Kumar, N Mohankumar and M X Joseph (from NPOL) and 7 graduate trainees.

4.2.6 *Studies by IITM*: The instrumentation group at the Indian Institute of Tropical Meteorology, Pune operated a Doppler sodar, a Kytoon and minisondes at the Kharagpur core station during MONTBLEX.

The Doppler sodar was made operational on 15th May 1990 and collected data up to 8th September 1990, operating continuously during IOPs, but was restricted to day time observations during other periods, except during 1200–1500 h UTC and during power failures.

Data on the three wind components and their standard deviations, echo intensity, reliability of data etc. were recorded and are available on IBM compatible floppies recorded in ASCII or as facsimile records of the return echo.

The tethersonde system was operated at Kharagpur from 22nd May to 28th June. The number of flights had to be restricted due to high wind, rain, lightning and other constraints. In all 28 flights were recorded. Data are available as a computer printout for wind speed and direction, dry and wet bulb temperatures and pressure. Other derived parameters like relative humidity, mixing ratio, potential temperature, dew point etc. are also available.

Data of temperature versus height from 42 minisondes with an ascent rate of 100 m/min during the IOP in July were recorded as graphs and tables.

The IITM team included K G Vernekar, S Sivaramakrishnan, L K Sadani, Brij Mohan, S B Debaje, S Pillai, B S Murthy, M N Patil, Subrato Sinha, Seethramayya and S S Parasnis.

4.2.7 *The NPL sodar experiments*: The MONTBLEX core station of Jodhpur, representative of the dry convection in the desert region in the west, was equipped with a monostatic sodar which was designed and set up by the acoustics section of the National Physical Laboratory, New Delhi.

The instrument worked automatically and almost continuously (70% of the time) from 30th May to mid-September 1990, needing very little personal attention and recording the thermal structure of the ABL up to a height of 700 m.

Shear echoes from nocturnal inversions with flat tops and tall spiky tops of the undulating kind have been seen. Day time thermal echoes showing the formation of thermal plumes due to solar heating of the earth's surface were also observed. The erosion of the nocturnal stable layer structure soon after sunrise has also been recorded. The height of the structures can be measured and the changes in the structures due to various weather phenomena can be studied (Singal *et al* 1993).

S P Singal, B S Gera and V K Ojha from NPL took part in the experiments.

4.2.8 *The ISI monostatic sodar*: The Indian Statistical Institute (ISI), Calcutta set up a monostatic sodar at Varanasi from 28th May 1990 to 3rd September 1990. Inversion heights, types of inversions and thermals were recorded as hardcopies. J Das took part in the experiment.

4.2.9 *Studies by NPOL*: Three scientists (see section 5.2.5) from the Naval Physical and Oceanographic Laboratory, Cochin took part in the MONTBLEX cruise of ORV *Sagarkanya*. Time series of vertical profiles of temperature and salinity were measured to understand the heat and salt budgets of the mixed layer.

5. The post-MONTBLEX workshops

After the completion of MONTBLEX, results of the analyses of the data were presented at two workshops. The first, titled 'Workshop on preliminary scientific results of the MONTBLEX programme', was held on 16th–17th January 1992 at IISc, while the next titled 'The second monitoring workshop on the MONTBLEX research results' was held on 26th–27th March 1993 at IITM. Proceedings of these workshops were brought out and are available at DST and IITM respectively. A report on the second workshop appeared in Goel (1993). These workshops were occasions for all those who had used MONTBLEX data to share their results and experiences from the analysis of the data,

Table 4. Consolidated picture of data acquired during MONTBLEX 1990.

Slow response tower data	on all days with few interruptions
Fast response tower data	70%
Soil temperature	90%
Doppler sodar (Kharagpur)	worked very well
Monostatic sodars (Jodhpur, Calcutta)	good
IMD radiosonde	500 ascents
IMD radar	2 stations
IMD radiometeorology data	90%
Kytoon flights (Kharagpur)	28
Miniradiosonde flights (Kharagpur)	42
XBT profiles (Bay of Bengal)	47
IAF upper air observations	12 stations

e.g., an intercomparison experiment for validating the methodology for computation of surface fluxes was conducted and the results presented in the second workshop.

6. Conclusions

MONTBLEX collected a vast amount of data, a consolidated picture of which is listed in table 4.

The set of extensive, simultaneous data collected over a vast region will probably continue to be analysed for a long time, hopefully revealing various facets of the Indian monsoon hitherto unknown to us.

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APPENDIX 1

The execution of the project was carried out through the following working groups and committees.

■ **MONTBLEX Monitoring Committee**: S K Dube (IITD), M Goel (DST, Convenor), R N Keshavamurthy (PRL), R Narasimha (IISc, Chairman), D K Rakshit (Delhi, Co-ordinator), Y Ramanathan (IITK), S N Sengupta (IMD), D R Sikka (IITM), D K Sinha (Calcutta Univ.), S K Srivastav (IMD).

■ **Science Advisory Group**: S Gadgil (IISc), Malti Goel (DST, Convenor), D K Rakshit (IIT Kh), Y Ramanathan (IITK), D P Rao (NIO), S N Sengupta (IMD), D R Sikka (IITM, Chairman).

■ **Data Users Groups**: R K Datta (NCMRWF), S K Dube (IITD), Malti Goel (DST, Convenor), Harsh Gupta (DST), M G Gupta (IMD), U C Mohanty (IIT), A Prabhu (IISc), D K Rakshit (DST/IIT Kh), Y Ramanathan (IITK, Chairman), D P Rao (NIO), D R Sikka (IITM), S P Singal (NPL), S K Srivastav (IMD), Doyil T Vengayil (DST), K G Vernekar (IITM).

■ **MONTBLEX Modelling Group**: Malti Goel (DST, Convenor), U C Mohanty (IIT), Y Ramanathan (IITK, Chairman), K J Ramesh (IIT), M Shankar Rao (IISc), D R Sikka (IITM), D K Sinha (Calcutta Univ.), S K Srivastav (IMD).

■ **MONTBLEX Operations Control Centre**: M G Gupta (IMD, Director), Gp. Capt. O P Madan (IAF), G S Mandal (IMD), U C Mohanty (IIT).

■ **Editorial Board of MONTBLEX News**: Sudarsh V Kailas (IISc, Editor), R Narasimha (IISc, Advisor).

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