Fifty Golden Years of IITM

D.R. Sikka

Indian Institute of Tropical Meteorology
Pune, India


INSTITUTE OF TROPICAL METEOROLOGY

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Former Directors

Prof. P.R. Pisharoty
(1962-67)

Prof. R. Ananthkrishnan
(1968-71)

Dr. K.R. Saha
(1974-76)

Dr. Bh. V. Ramana Murthy
(1978-85)

Shri. D.R. Sikka
(1986-92)

Prof. R.N. Keshavamurty
(1992-96)

Dr. G.B. Pant
(1997-2005)

Content

Foreword

I have been fortunate to be part of IITM's during the past five years in its journey towards the Golden Jubilee Year. During this period, there has been tremendous all round growth of the Institution and it has made a place in the world community as a Centre of Excellence. However, as an Institution of higher learning and training in weather and climate science, the journey of IITM during the past 50 years has not been without its share of highs and lows. At the momentous juncture of celebrating the Golden Jubilee of the Institute, it was felt that there were lessons to be learned in documenting the triumphs the Institute rejoiced and the trials it underwent in achieving the success it enjoys today. Therefore, it was decided to sponsor writing a monograph telling the story of 'Fifty Golden Years of IITM'. We are fortunate to have amongst us an ideal person for this job. He is a distinguished scientist who has been associated with IITM since its inception with a strong sense of bonding with the Institute. He is none other than our beloved Shri Devraj Sikka, (DRS) who was Director of the Institute during 1986-1992. As a true scholar, even at his advanced age, DRS not only keeps abreast of the global developments in the field but also engaged in research leading to publications in top journals. He has a unique historical perspective of scientific developments at IITM and also could effortlessly recount all major scientific results from IITM during the entire 50 years. I am extremely grateful to DRS for readily agreeing to my request to write this monograph. While he is passionate about IITM, he also provides a critical perspective. As can be seen, he has done an outstanding job of presenting a historical perspective of development of IITM during the five decades of its existence as well as narrating pioneering scientific contributions made by IITM during the

period. It is my proud privilege to present this Monograph to the IITM family as well as to the general public. A young group of scientists is currently taking the mantle of IITM and will have the responsibility of taking IITM to newer heights in the coming years. I believe, the story of IITM told by DRS will be inspiring to them.

In the monograph, DRS gives a lucid account of the journey of IITM from its establishment till present but intentionally leaves out the aspiration of the Institute for the future. As he desired, here I provide a brief perspective on the subject. In 2006, when I was given the responsibility to take the stewardship of IITM, I had a dream, a dream of making IITM a 'World Centre of Excellence in Basic Research required to improve predictions of Tropical Weather and Climate' (this is reflected in our current Vision Statement, please see our website). The dream was not just a wishful thinking as IITM has some inherent strength. It is the only Institution in the country that nurtured under the same roof critical masses of scientists capable of conducting world class field and laboratory experiments for understanding atmospheric processes together with a strong group of theoreticians and modelers. However, the road towards achieving the dream was not without many challenges. Apart from being the first Director coming from outside the Institution requiring to gain the trust of the IITM family (scientists as well as administration), I realized that the Institute was going through a kind of crisis. Sustained subcritical funding during the preceding couple of decades left the Institute with crumbling physical and highly inadequate scientific infrastructure, reflecting in unsatisfactory record of publication per scientist. After some introspection and brainstorming, it was recognized that if IITM had to leapfrog into limelight, serious thinking and action were needed in three fronts namely, (i) adequate funding for infrastructure, (ii) a focused science plan and (iii) a sustained long term plan for manpower development.

While IITM faced many challenges, the period of 2006-07 was also a period of opportunity. The 11th five year Plan was being formulated for the Institute. This was an opportunity when bold and appropriate formulation of the Science Plan could make a big difference in the way IITM would evolve in the coming years. With the help of our Research Advisory Council (RAC) and blessings from the Governing Council (GC), a strong and ambitious Science Plan was formulated and justified the need for funding on infrastructure. One qualitative change introduced was to bring the focus of the science plan back to the original mandate of IITM. While the original mandate of IITM was to carry out basic research required to improve skill of forecasts by the operational agency (namely the IMD), for various reasons, the link between IMD and IITM had weakened over the years and this focus of IITM research was lost. With the new focus, it was decided to concentrate on three major areas and build internationally competitive groups in these areas. They are (a) development and improvement of a dynamical forecast system for the seasonal mean monsoon and extended range prediction of the active and break spells, (b) science of global and regional climate change and (c) physics and dynamics of tropical clouds. As in India we did not have an end-to-end dynamical seasonal prediction system in

place and as NCMRWF is already helping IMD on development of short and medium range forecasting system, it was felt that IITM could complement by developing a seasonal prediction system and providing IMD with the necessary dynamical forecasts. It was also noted that for reliable projection of Indian monsoon to future, we need an Earth System Model (ESM) that simulates the present day monsoon with fidelity. Unfortunately, capacity to build such models in the country was also lacking. Hence, it was decided to build the capacity to develop an ESM for reliable attribution and projection of the Indian monsoon. We were aware that this is a challenging problem and dedicated mission mode work would be required to achieve this objective. As a result, a Centre for Climate Change Research (CCCR) has come up at IITM. It was also recognized that major errors in climate models required for (a) and (b) comes from our inability to formulate the tropical clouds correctly. Basic research on cloud-aerosol interaction and interaction between small scale clouds and large scale environment is required to improve parameterizations of clouds in climate models. Again, in the country, this expertise was also lacking. Therefore, it was decided to build a group at IITM and equip them with state-of-the-art instruments to come up with some breakthrough basic research in this area. The vision for the future of IITM is that it must play a leadership role not only nationally but also internationally in all these three areas.

The ambitious science plan would have remained just a 'plan' without the necessary funding to go with it. Fortunately for IITM, a second opportunity presented itself. I joined IITM in the exact opportune moment when the new Ministry of Earth Science (MoES) was born in later half of 2006. IITM is grateful to receive whole hearted support from the first Secretary of MoES, Dr. P. S. Goel which was continued with equally strong support from the next Secretary, Dr. Shailesh R. Nayak. This helped to overcome our financial woes and the Institute could concentrate on science. Several major scientific infrastructures have been established with support from MoES. One example is the setting up of a HPC at IITM with peak performance of 70 TF. This facility, second largest in the country, has put IITM in the world map and allowed us to carry out long ocean-atmosphere coupled climate model simulations as well as to make seasonal prediction of monsoon with high resolution coupled models and evaluate its retrospective forecast skills. The support from the Ministry has also helped IITM to take some other leadership initiatives such as the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) and the System of Air Pollution Forecasting and Research (SAFAR).

Even with generous support from MoES, the dream would have remained just that without trained manpower to deliver the objectives of the proposed ambitious programs. Without recruitment at higher levels in the past three decades, the aging scientific manpower at the Institute was not well equipped to face the modern challenges of the multi-disciplinary climate science. A long term manpower development program was, therefore, the need of the hour. With guidance from the RAC and GC, a three pronged approach was proposed to (i) sustain a one year Training Program for young scientists and

graduate students that not only provides a broad exposure to all aspects of climate science but also sensitizes students on the outstanding unresolved problems and cross cutting areas, (ii) vigorously recruit trained and established scientists at middle levels to provide the scientific leadership and (iii) excite the young scientists with short courses from eminent international scientists through a Distinguished Visiting Professor Program. Implementation of the second objective was faced with several challenges as it required sanctioned positions. Also until then recruitments whenever done was done only at the entry level (Scientist-B). However, with guidance from my GC and full support from the Ministry, these problems were overcome and we started recruitment of scientists earnestly from 2007. We also put in place the Training Program from August 2006. Looking at the evolution of The Training Program and its impact on the scientific productivity of the Institute, MoES suggested IITM to expand the scope of the Program to start a National Centre on Advanced Training on Earth System Science and Climate to cater to the need of not only IITM but also of the other Institutes under the Ministry. With this background, the Advanced Training Centre on Earth System Science and Climate (CAT-ESSC) has been started at IITM from 2011 with a job linked training program. This is another leadership initiative that IITM is undertaking.

In implementing these Programs, the support, encouragement and guidance from IITM Governing Council with the Chairmanship of eminent scientist Prof. U. R. Rao, has been invaluable without which the dream would have remained a dream. Over the past five years, about 40 scientists have been recruited mostly in Scientist-C, D, and E levels reducing the average age of scientist at IITM from 47.33 in 2006 to 44.89 in 2011. The average number of SCI publications per year during period between 1986 and 2006 was about 35 with average impact factor of less than 0.9 which increased to 95 in 2010 with average impact factor of 1.922. Also the publication per scientist of 0.3 during the previous two decades has increased to 0.9 in 2010.

I believe that IITM is in the right growth path towards fulfilling the aspiration of being counted as one of the world leaders in the three areas that I mentioned earlier. The challenge now is not only to maintain this scientific growth but also to provide impetus to accelerate it. During the journey over the past five years, I am indebted to my scientist colleagues and students who have not only embraced my vision, accepted me as part of IITM family, taken part in the Training Program enthusiastically but also put in hard work towards achieving the accelerated growth. I am also grateful to the IITM Administrative, Technical and other supporting staff without whose help timely execution of the major programs would have been impossible.

Happy reading the monograph!

Prof. B. N. Goswami
Director
Indian Institute of Tropical Meteorology
Pune

Preface

Rich history of civilization over the Indian continent is spread over thousands of years and has strong links with weather and climate over the region. It is, therefore, natural that study of weather and climate attracted Indian scholars from ancient times as evidenced by the hymns in the Rig Veda in praise of different deities which were then supposed to control the meteorological phenomena. Enquiries about the nature of these phenomena continued in the Uppanishadic times in Smiriti literature and in later classical Sanskrit literature between 3000 BC to 1000 AD. However, this knowledge was primarily based on human experience with speculations about the meteorological phenomena and it was transferred from generation to generation. Although some information about the changes in winds and rainfall distribution over India was then available but there were no precise measurements about them as well as other meteorological elements, for non-availability of measuring instruments. Basic weather instruments and the physical and chemical laws governing atmosphere were invented and discovered respectively during the period of scientific revolution in Europe between the 15th to 17th centuries. India had to wait for another two centuries for setting up of a system of meteorological observations on country wide scale which came into existence after the Government of India established the India Meteorological Department (IMD) in 1875. Between 1875 to 1950, IMD setup the basic observational recording, reporting and weather forecasting systems. Its officers also conducted important researches on the weather and climate of India and neighboring countries besides performing their operational responsibilities for efficient functioning of the above mentioned basic systems. Till the beginning of the Second World War, IMD at par with Europe and America not only in its operational functions but also in research. IMD has been also playing important role in international collaboration as a member of the International Meteorological Organisation (IMO) and its successor, World Meteorological Organisation which was set up in 1950 and became the special agency of the United Nations in 1951. During and soon after the war years, the situation was rapidly changing. IMD stretched its major resources to operational functions demanded by a democratic system. By the beginning of 1950s technological innovations and concentrated research effort in Centres of research in advanced countries had resulted in tremendous progress in meteorology. IMD also wanted to catch up with this progress and started thinking of setting up a research institute as its distinct part to pursue full-time research that would contribute to its operational functions besides advancing knowledge of the Tropical Meteorology. The Government of India approved their proposal in the Third Five Year and the UNDP Special Fund assisted in the establishment of the Institute of Tropical Meteorology (ITM) at Pune. I vividly remember 17 November, 1962 when Prof. P.R. Pisharoty, an eminent senior meteorologist in IMD, took over charge as the founder Director of the Institute. At that time Prof. Pisharoty was the lone member of ITM. His office happened to be next to the room where I had my table in the office of the Dy. Director General of Observatories

(Climatology and Geophysics) in the Meteorological Office, Pune. Soon the Institute was located in Ramdurg House, adjacent to Meteorological office, a building acquired by the IMD for temporarily housing the ITM. Later in 1964, I became a part of the ITM on being selected as a scientific officer.

IITM has now entered 50th year of its existence and the celebrations for its Golden Jubilee begin from 17 November 2011. It is a momentous occasion for the Institute and its past and present employees. Since 1962 the Institute has passed through different phases of evolution and witnessed good as well as not so good years. As India's economy began to grow fast since 2000, Institute also received enhanced funding. Under the Ministry of Earth Sciences (MoES), the Institute has considerably expanded its activities and research infrastructures. Over the years it has gained national and international repute as a centre of advanced research in atmospheric, oceanic and climate sciences. It has also taken up responsibility, on behalf of the MoES, to set up a National Centre for Climate Change Research and another Centre for Advanced Training for generating human resources in atmosphere-ocean sciences.

About a year back as the Golden Jubilee Year was approaching, in one of my discussions with Prof. B.N. Goswami, the present Director of the IITM, I had suggested to him that in the Golden Year an account of the evolution of the Institute be released. This book is a result of those discussions. It basically consists of two parts. The first part gives an account of the developments of various activities of the Institute since its inception. In the second part I have attempted a review of its past and current research programmes, highlighting the major scientific contributions made by its scientists. The Institute's research has received very good citations in the national and international journals which reflect the high standard of work done at the Institute. In the recent years the Institute, under the leadership of Prof. B.N. Goswami, has put considerable emphasis on modelling tropical climate variability, understanding of the coupled ocean-atmosphere-land Asian Monsoon System and even predicting its behavior on extended, inter-annual and climate scales.

I take this opportunity to congratulate the entire staff of the Institute on this occasion and wish that in the coming years, with their sincere and dedicated efforts, IITM will achieve higher glory. It is my pleasure to thank Prof. B.N. Goswami in giving me the opportunity to write this book. It has been a journey down the memory lane for me and I thoroughly enjoyed it. The views expressed in the book are my personal ones. I could do this work having been associated with the IITM since its very inception. Though I retired from the Institute on 29 February 1992 as its Director, in the last twenty years, the successive Directors have kept me involved with major occasions and activities in the Institute. I am much thankful to them for this kind gesture and admire them for their courtesy shown to me.

In writing this book, I was supported in several ways by Mrs. A.A. Shiralkar, the former Head of the LIP Division of IITM and the staff of LIP Division. I convey my sincere thanks to them for this invaluable support.

D.R. Sikka

1. Introduction

Special anniversaries in the life of Institutions like Silver Jubilee, Golden Jubilee, Centenary, etc. are special times to reflect on the past, present and future in terms of their performances. The Indian Institute of Tropical Meteorology (IITM), known at its inception as Institute of Tropical Meteorology (ITM), was established at Poona (now Pune) as a distinct unit of the India Meteorological Department (IMD) on 17 November 1962, when Prof. P.R. Pisharoty assumed charge of the position of Director of the Institute. The Institute now proudly celebrates its Golden Jubilee in 2011-12. This booklet represents the history

and scientific achievements of the Institute since its inception. Judged by any measures the IITM has been very successful and it looks forward to the future with great promise.

IMD had acquired Ramdurg House, a building adjoining their grand complex in Pune, to house the institute. IMD, later with Prof. Pisharoty's efforts also acquired a large tract of land adjoining the National Chemical Laboratory, Pune to ultimately build a permanent complex of the Institute. Part of IITM began to function in the present complex from 1982. The process of completely shifting the Institute in the present complex was completed in 1987-88. Since then, the Institute has added its Library complex in 1995 and the computing resource building also housing a Training Wing in 2010. An incubation centre of the Centre for Climate Change Research (CCCR) was established in the Library Building in 2009.

The Institute began with the setting up of a special temporary Division known as the International Meteorological Centre (IMC), Bombay (now Mumbai) in the campus of the Regional Meteorological Centre, Colaba, Mumbai with effect from 1 January 1963 for coordinating and supporting the Meteorology Programme of the International Indian Ocean Expedition (IIOE). The staff of the IMC was drawn from different offices of the IMD. Thus, the IITM's birth coincided with an international collaboration program to understand weather, climate and oceanography of the Indian Ocean in which many nations contributed. Data collected during the IIOE field programme led to several path making researches on the meteorology and oceanography of the Indian Ocean [1-12].

Ramdurg House

2. Background Leading to the Establishment of the Institute

Scientific studies on the weather and climate of India began when the European mariners entered the Indian Ocean toward the end of the 15th century. Data collected over the long and treacherous voyages were used by Edmond Halley in his illustrious work published in 1666 on the origin of monsoons. For nearly 200 years, till the middle of the 19th century, work on Indian meteorology had mostly prospered as the result of personal efforts of the officers of East India Company who were interested to understand the weather and climate of India on the recommendations of the Royal Society, Royal Asiatic

Society of Bengal, the Sanitary Commission in India and Chamber of Merchants in Calcutta (now Kolkata), made between 1860 to 1870. A major step was taken by the Government of India to establish the India Meteorological Department (IMD) in 1875 as an Imperial Central Agency for study of weather and climate of undivided India. Since then, the growth of meteorology in India got linked with the progress of IMD. The officers of the IMD, between its beginning in 1875 and India's freedom in 1947 and subsequently till the inception of ITM in 1962 for nearly 90 years, following the traditions set by pioneers like H.F. Blanford, John Eliot, Gilbert Walker, J.H. Field, C.W.B. Normand, S.K. Banerji, K.R. Ramanathan, B.N. Desai, S. Mall, and others had combined operational work with research pursuits on their own initiatives which produced outstanding research on weather and climate of the subcontinent. Among the scientific organizations set up during the British rule in India, IMD held a prominent position as it had impact on several societal issues. Its head (Director General of Observatories) served as Chairman or member of different advisory committees used to be set up by the Govt. of India on scientific matters. Beginning in 1945, a new wave of organizing scientific research began in India with the establishment of the Council of Scientific and Industrial Research (CSIR) which set up several research laboratories during 1952 – 1962. Also, other centres like the Tata Institute of Fundamental Research (TIFR), the Department of Atomic Energy and the Indian Institute of Technologies (IITs) were set up during 1945-1960. In this period, Organization of Agricultural Research also took place under the Indian Council of Agricultural Research (ICAR), earlier known as Imperial Council of Agricultural Research.

Soon after India's Independence the tempo of all round national developmental activities were enhanced with the launching of India's First Five Year Plan (1951-56). As Meteorology plays a crucial role in providing multifaceted services to the society, IMD in post-Independent India, also initiated its development activities in the First Five Year Plan, which were mostly focused on modernizing its activities to serve the expanding civil aviation. During the first two Five Year Plan periods (1951-61) the IMD had to stretch its meager financial and human resources to meet increasing service requirements at national and international levels. Meanwhile, after the end of the Second World War meteorological research at international level had begun to expand with introduction of weather radars, upper air sounding stations, electronic computers, etc. New disciplines in every branch of meteorology, particularly in Numerical Weather Prediction and Climate Dynamics, had begun to emerge between 1940s and 1960s. Post-World War developments were taking place at a phenomenal pace and side by side the service demands in the IMD had also risen manifold. Faced with this situation, from the mid-1950s and particularly during the International Geophysical Year (IGY) period (1957-58), IMD recognized that without proper long-time sustained effort, supported by adequate infrastructures, further significant advances in the physical and dynamical understanding of the atmospheric processes in the tropics were hard to be achieved. Without such an understanding the problems of weather prediction on short-, medium-,

and long-range scales could not be properly resolved. During the Second World War years, IMD had established a Training Centre at Pune, but it was more focused on training the technical and scientific staff to take care of operational demands and its courses lacked depth in basic physical and dynamical aspects of Atmosphere-Ocean Coupled System which was at the heart of research on Monsoon Meteorology and Tropical Cyclone. Higher education in Meteorology at the university level was in its infancy in India as with the help of the retired scientists of IMD only two universities viz., Banaras Hindu University and Andhra University had begun M.Sc. level courses in early 1950s in which meteorology formed as part of Geophysics, and Meteorology & Oceanography degree at the M.Sc. level.

During the Second Five Year Plan period (1956-61), the need for establishing an exclusive centre for meteorological and ocean research in the country was acutely felt in order to carry out the R&D requires to improve meteorological services provided by the IMD. The increasing recognition of the global nature of weather and climate events and the possibilities afforded by rapid technological advancements for monitoring and rapid exchange of weather and climate information were getting recognized by the World Meteorological Organization (WMO), a special agency of the United Nations successor to the erstwhile International Meteorological Organization (IMO). India had become founding member of the WMO and through the adoption of Resolution 22 (CG-III 1959), WMO took an important step to promote meteorological research recommending establishment of exclusive research centres in the countries situated in the tropical belt to tackle meteorological problems peculiar to the region.

It was in 1959 that the Director General of Observatories (DGO) as head of the IMD had initiated a proposal with the panel of scientists attached to the Planning Commission of India for establishing a 'National Institute of Meteorology'. The panel of scientists recommended establishment of an Institute for the purpose during the Third Five Year Plan. CSIR not only gave its support to IMD for an Institute in Meteorology but also proposed setting up a National Institute of Oceanography in the same period. The DGO submitted a scheme in June 1961 to the Government for the establishment of a research Institute in Meteorology, where scientists could devote themselves, exclusively, to important research goals, '*untrammeled by rising day to day demands of a modern developing weather service*'. By this time WMO had established a Special Fund Project of the United Nations Development Programme (UNDP) for planning research centres in developing countries. India approached the WMO for financial assistance in setting up the proposed research Institute under the UNDP. **Finally, Govt. of India approved the setting up of the Institute under the IMD, as an exclusive organization for which recruitment was to be made separately and the scientific and technical staff was to be permanently attached with the Institute.** The Institute was formally established on 17 November 1962 with the posting of a Director. Also, WMO agreed to provide financial and scientific support for the formative period of 5 years (1963-67) under the UNDP Special Fund Programme. WMO's support was used for purchasing some special

equipment like IBM 1620 Electronic Computer and some other equipment like microfilm camera, photocopier, etc., as well as training its scientists in USA and Japan under the UNDP Fellowships Program in addition to arranging extended visits of experts from advanced countries to ITM. The experts who visited India during 1963-67 included Professors Donald Jones, Ernest Hovmoller, Francis Ho, Ferdinand Baer, Takio Murakami and Hiroshima Ito. The first two regular divisions of the Institute began to function from 1963 when its specially recruited scientists joined. The other four Divisions viz. Physical Meteorology and Aerology (PM&A) and Instruments and Observational Techniques (I&OT), Training, and Library, Information & Publications (LIP) were added during 1965 - 1968. With the formation of the PM&A Division in 1966, the Centre for Rain and Cloud Physics Studies, which was functioning in New Delhi under the CSIR since 1955, was also transferred to ITM as a constituent unit of the PM&A Division.

The Institute at its formation was known as the Institute of Tropical Meteorology (ITM). It was modeled on the lines of the Meteorological Research Institute (MRI), Japan under the Japanese Meteorological Agency (JMA). Shri P.R. Krishna Rao, Deputy Director General of Meteorology, who later functioned as the DGO during 1959-65, was deputed by the IMD in 1958 to Japan to study the functioning of the MRI under the JMA. The Institute effectively began to function from 6 April 1963, when Forecasting Research Division and the Climatology and Hydrometeorology Division were formed with some basic staff. Like the MRI, research activities of the ITM were to be organized under separate but mutually interacting Divisions which were constituted as follows:

Division	Year in which established
Forecasting Research (FR)	April 1963
Climatology and Hydrometeorology (C&H)	April 1963
Physical Meteorology and Aerology (PM&A)	September 1965
Instruments and Observational Techniques (I&OT)	December 1965
Training in Advanced Studies	February 1968
Library, Information and Publication (LIP)	February 1968

At the time of the formation of first two Divisions in 1963 the Institute had 15 scientific officers and 44 scientific assistants, most of them came from IMD. Subsequently, with the establishment of the remaining Scientific Divisions, and Technical and Administrative Divisions the Institute received approval of total 217 sanctioned posts. The recruitment process, initiated in the middle of 1964 with the appointment of two Assistant Directors, was continued further. At the time of the Institute's transformation in to an autonomous organization it had total 188 persons in position. Due to lack of adequate physical facilities such as office space, laboratories, workshop and library the remaining 13% of the posts had remained unfilled for about seven years.

Prof. P.R. Pisharoty
Founder Director

3. Formative Years of the Institute (1963-1971)

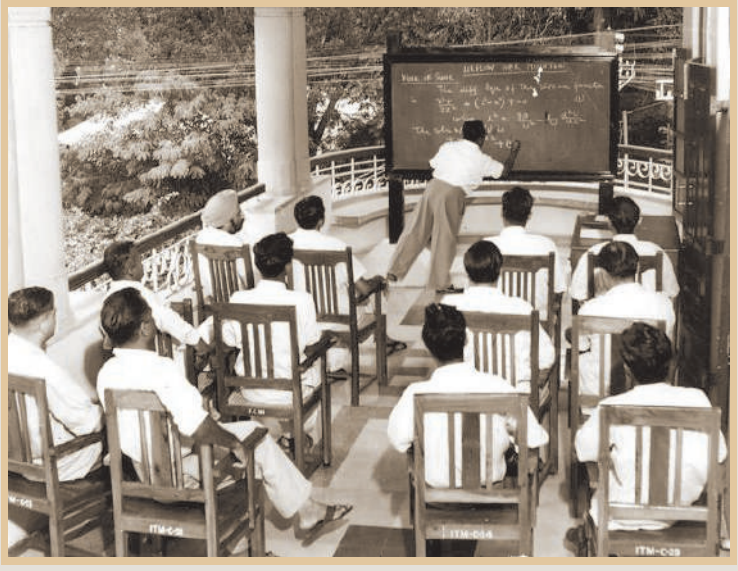
Between November 1962 and June 1964, Dr. P.R. Pisharoty was the only scientist and its head which was exclusively recruited for the Institute. Thus, in this period IMD deputed some of its senior scientists and technical staff to function at ITM. A good number of technical staff at the medium-range forecast project of the IMD was transferred to ITM. There were also some well experienced scientists of IMD like Dr. E.V. Chellam, Dr. S. Rangarajan, Dr. K.V. Rao and others, who had volunteered to work at the ITM, were shifted to it from the Meteorological Office, Pune. Also, Prof. P.R. Pisharoty, a well known

meteorologist of international repute, who had done his doctorate at the University of California, Los Angeles (UCLA) under Prof. J. Berkenes in a record time and had participated in the General Circulation Project in USA, took up the inspiring challenge of realizing the IMD's vision. He was devoted to the idea that meteorological research would immensely benefit India's development agenda by providing tools to understand and predict weather and climate events for the good of the society. Though work of several scientists at the Institute and the collaboration of other centres of atmospheric-ocean research in India and abroad have contributed to the growth of ITM, it can be said that much of the characters of the Institute emerged from the devotion and vision of its founding father, Prof. Pisharoty.

The International Meteorological Centre (IMC), Mumbai, set up for the IIOE period, remained attached to the Institute as a Special Division from January 1963 to Mid-1966 in which scientists from the IMD and a few scientists recruited specially for the Institute in 1964 continued to work. Several new young scientists like J. Shukla, U.S. De, R.P. Sarker, R.R. Kelkar, D.A. Mooley, O.N. Dhar, R. C. Srivastava, A.S.R. Murty, D.R. Sikka, R. Suryanarayana, Y. Ramanathan, H. S. Bedi, R.N. Keshavamurty and others joined different Divisions of the Institute during 1964 to 1968. Some of them made their career in the Institute while others left by 1974 to return to the IMD or migrated to USA.

So long as Prof. P.R. Krishna Rao remained as DGO, the Institute had a smooth period between November 1962 and July 1965. He, being the founding father, devoted special care to the Institute. With judicious guidance and oversight support of Prof. Krishna Rao, the Institute was firmly set to make long-term progress. In fact during his retirement party held at Mumbai in July 1965, Prof. Krishna Rao admitted to the criticism that he was partial to the Institute by saying "Yes, I was partial to ITM just like a parent is when a new baby joins the family and the parent sacrifices so that the baby grows". Such lofty sentiments come only from great leaders. However, most of the higher echelons of the IMD had become jealous of the ITM as they unnecessarily thought that research contributions in IMD would be undermined with the establishment of the ITM. So, they raised the well meaning campaign within IMD to 'publish or perish'. Some top officers of the IMD were openly critical of Prof. P.R. Pisharoty. On the retirement of Prof. P.R. Krishna Rao in July 1965, Prof. Pisharoty, who was working vigorously for growth of the Institute, took the personal criticism of his colleagues in IMD to his heart. However, with the help of his deputies like Dr. K.R. Saha and Dr. P. Jagannathan, Heads of the FRD and C&H Division respectively, continued to give his guidance, particularly to young scientists who had joined the Institute in its formative years. Prof. Pisharoty was very keen that modern forecasting techniques, based on Numerical Weather Prediction (NWP), be developed. He had correspondence with experts in Germany, U.K., Japan and USA seeking their suggestions on the development of NWP in India. As high speed computing was needed for the purpose and the TIFR, Mumbai had acquired CDC 3600 Computer by 1964, he sought the help of Prof. Homi J. Bhabha, Director of TIFR and Head of Atomic Energy Department, to obtain approval for the special use of TIFR computer for NWP effort at ITM. Several young scientists of the ITM were deputed under the UNDP Fellowships for advanced training in

NWP, Satellite Meteorology, Climatological Research, Hydrometeorology, Medium- Range Forecasting, Atmospheric Boundary Layer, Cloud Physics and Instrumentation. Also, weekly seminars on important subjects were given on regular basis. There was no seminar hall and yet the desire was so strong that a verandah facing the Director's office could serve as 'seminar verandah' by erecting a black board at its one end. Many visiting scientists from India and abroad gave special seminars at this make-shift hall. The Institute would remember the visit of Noble Laureate Prof. C.V. Raman. Prof. Pisharoty and Prof. R. Ananthakrishnan, the first two Directors of the Institute and several illustrious scientists of the IMD had begun their formative scientific research at the Raman Research Institute at Bangalore during 1930s to 1950s.



Seminar in verandah at Ramdurg House

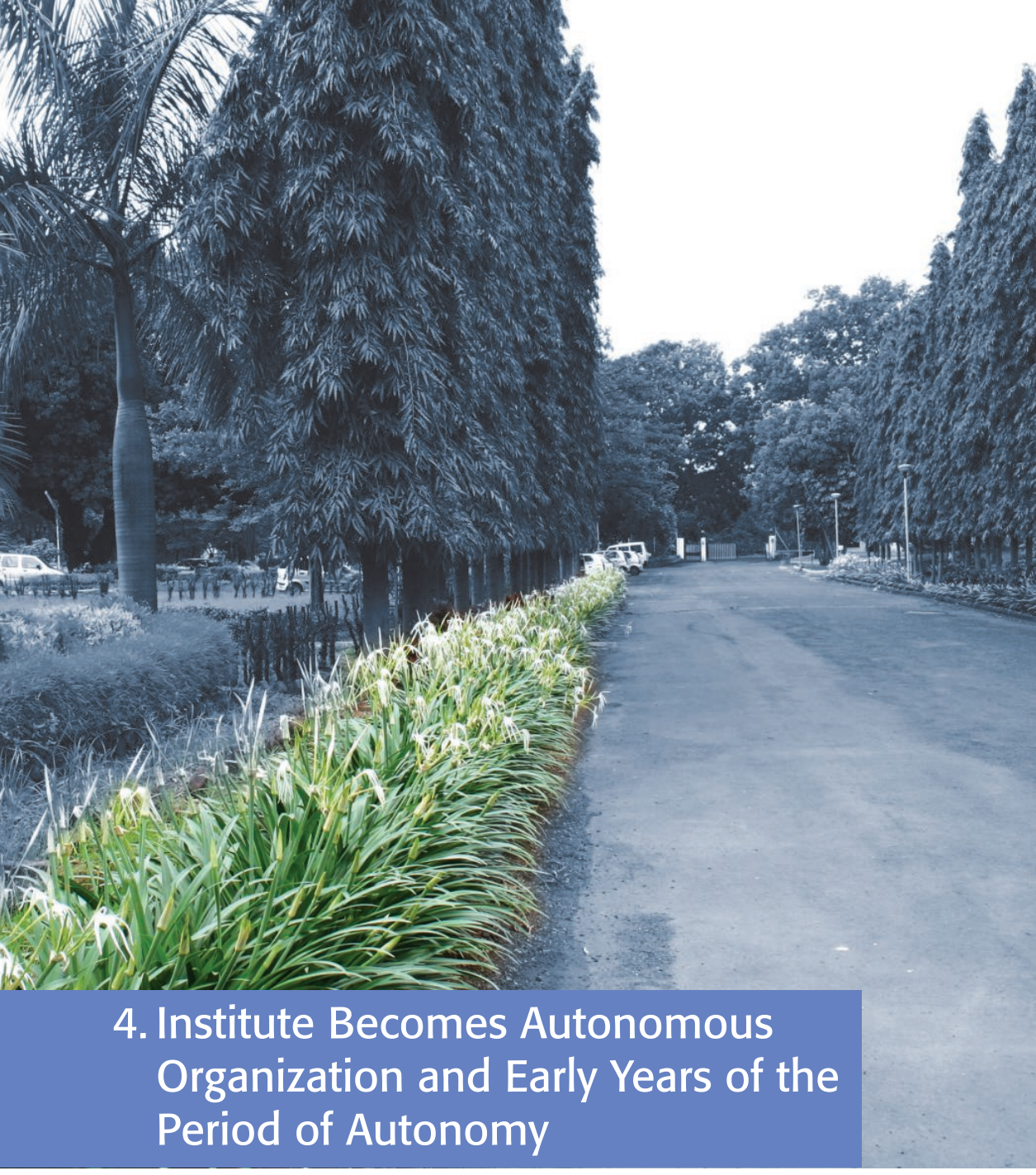
At the end of the International Symposium on Scientific Results of the IIOE, held in July 1965 at TIFR, all the foreign scientists who had participated in the Symposium visited the Institute. Some of them like Prof. T.N. Krishnamurti established a life - long attachment with the Institute. The ITM set on a path where post-graduate research was pursued at ITM. Air India also provided support for two Air India Scholarships for pursuing doctorate work at ITM. Soon R.P. Sarker, R.R. Kelkar, Brahmanand Rao, D.A. Mooley, O.N. Dhar, D. Sreeramamurthy (S. Daggupaty), B.M. Mishra and others registered for Ph.D. degrees. Prof. T. Murakami, WMO Expert with ITM during 1966-68, helped young Air India Scholar D. Sreeramamurthy (S. Daggupaty) to pursue Ph.D. in application of Quasi-geostrophic Instability Theory to the Monsoon Flow and also formed a team consisting of Ramesh Godbole and R.R. Kelkar, with himself as the leader to simulate monsoon on computer. Since the computing power for such a venture was not available, they simulated the monsoon in Y-Z plane along 80°E in 1970 and showed the role played by the ocean and the Himalayan orography in monsoon processes [13- 16]. This was much before the simulation of monsoon with and without mountains simulated by the famous work of

Hahn and Manabe in USA at the Geophysical Fluid Dynamics Laboratory in USA in 1975 ***(Hahn D.G., Manabe S., 1975, Role of mountains in the South Asian Monsoon circulation, Journal of the Atmospheric Sciences, 32, 1515-1541).***

Prof. Pisharoty had initiated two major projects in Forecasting Research Division (FRD) on categorization of weather charts for the monsoon season and medium- range weather forecasting on statistical basis. Prof. G.C. Asnani, who had joined the Institute in the FRD, initiated work in 1966 on constructing a barotropic model (with geopotential as input) of the atmosphere. He later continued it in the Training Division which he headed in 1968. In spite of great efforts of the Institute, its Training Division could not thrive as IMD had its own Training Centre at Pune which was recognized by the WMO as the Regional Training Centre. Hence, with great regret, the Training Division of the ITM was converted into Theoretical Studies Division in 1971. Prof. Asnani had begun the practice of reviewing and discussing some chosen land-mark papers published in prestigious scientific journals on atmospheric dynamics. This provided a means for the young scientists to study those papers deeply and present it before the participating scientists of the Institute. This introduced a self training mechanism for researchers and also helped young scientists to form a habit of reading current scientific literature.

While serving as Member of the WMO/ICSU Joint Planning Committee for Global Atmospheric Research Programme (GARP), Prof. Pisharoty had proposed that the objectives of GARP's First Global GARP Experiment (FGGE), to be carried out for a year long period, should include special emphasis on study of monsoons. This took shape in the form of the Monsoon Experiment (MONEX-1979) for the study of the South Asian Monsoon in which IITM played a major role in implementation of its field phases at Mumbai and Kolkata for the Arabian Sea and the Bay of Bengal components in May-June and July-August 1979, respectively.

Visit of Noble Laureate Prof. C.V. Raman



4. Institute Becomes Autonomous Organization and Early Years of the Period of Autonomy

All the Divisions of the Institute, conceived in its Planning document, were formally established by 1968. The Govt. of India constituted a Committee for Organization of Scientific Research (COSR) in 1969, under the Chairmanship of Prof. S. Bhagvantam. Prof. P.R. Pisharoty, who by then had retired from the Institute in 1966 and joined the Physical Research Laboratory (PRL), Ahmedabad as a member of this Committee. COSR first of all undertook scientific review of the IMD, a scientific organization of long standing.

Following the recommendations of the Committee, three organizations under the IMD, under Government umbrella viz., Institute of Tropical Meteorology, Pune, Astrophysical Laboratory, Kodaikanal and Geomagnetism Observatory, Colaba, were given the status of autonomous research institutes with effect from 1 April 1971 and were renamed as Indian Institute of Tropical Meteorology (IITM), Indian Institute of Astrophysics (IIA) and Indian Institute of Geomagnetism (IIG) respectively. Thus, IITM was set up as an autonomous organization with DGO being the ex-officio Chairman of its Governing Council. The first meeting of the Governing Council decided to convert the Training Division into Theoretical Studies Division.

Soon after the autonomy, the Institute chalked out well-oriented projects in each Division for long-term research goals and till about 2006 the concept of Divisions and projects within the Divisions were followed as given below:

Research Area within Different Divisions of IITM (1972-2006)

	Area	Division
i.	Numerical Weather Prediction	Forecasting Research
ii.	Extended Range Prediction	
iii.	MONEX Studies	
iv.	Short-range Prediction	
v.	Climate and Climate Change	Climatology and Hydrometeorology
vi.	Hydrometeorological Studies	
vii.	Cloud Physics and Weather Modification	Physical Meteorology and Aerology
viii.	Environmental Physics	
ix.	Aerosol and Climate	
x.	Development of Meteorological Payloads for Rockets and Satellite	Instruments and Observational Techniques
xi.	Development of Instruments for Boundary Layer Studies and Studies on Atmospheric Boundary Layers	
xii	Instruments for Cloud Physics and Weather Modification Studies	
xiii	Studies on Dynamic Instability	Theoretical Studies
xiv	Studies of Monsoon and Tropical Circulation Systems	

Some changes were introduced in the areas within Instruments and Observational Technique during 1987-1992 as the area on rocket and satellite payloads was dropped and in its place the areas of Atmospheric Boundary Layer and Atmospheric Electricity were

added. Similarly, Theoretical Studies Division embraced the work on ocean dynamics and modeling from 1987 onward.

The Institute, which was under the umbrella of the Ministry of Tourism and Civil Aviation, was transferred to the Department of Science and Technology (DST) toward the beginning of 1985 under which it functioned for nearly two decades and ultimately was transferred to a new Ministry, formed in 2006 as the Ministry of Earth Sciences (MoES), while retaining its autonomous character. Both these changes facilitated the Institute in its functioning and organizing the research on new horizons with adequate financial support which has helped it to achieve national and international recognition. Meanwhile in 1990, DST, while recognizing the evergrowing importance of climate modeling and following the recommendation of a Committee set up under the Chairmanship of Prof. Pisharoty, set up another Division of Climate and Global Modelling in 1993. Over the last 50 years Institute has built up scientific connections with all major research organizations, universities and IITs dealing with atmosphere-ocean studies in India. It has also established relationships with international centres of advanced research in the area of its interest and also as part of the government to government collaborative research programmes with several countries in the world like USA, UK, France, Russia, Japan, etc.

Beginning 2007 and recognizing the importance of inter-divisional collaboration, the Divisions, though existing, now no longer remain as watertight compartments. A concept of 'Programs' instead of Divisions has been introduced. Based on the new science focus of the Institute, the following 'Programs' were formulated:

- Centre for Climate Change Research (CCCR)
- Development of System for Dynamical Seasonal Prediction of Monsoon
- Development of System for Dynamical Prediction of Active/Break Spells
- Cloud Aerosol Interaction and Precipitation Enhanced Experiment (CAIPEEX)
- High Performance Computing
- Climate variability and Predictability
- Thunderstorm Dynamics and Prediction
- Aerosol and Climate Studies
- Chemical Transport Models and Middle Atmosphere Dynamics

This has lead to organization of projects and field campaigns on multi-divisions basis, drawing scientists from different divisions to work in collaboration. This has resulted in more cohesive range of projects and in their smooth implementation.

Shri S.M.L. Bhatnagar
Secretary, Ministry of Tourism and Civil Aviation
laying the foundation stone of IITM

5. Build-up of Infrastructural Facilities

Infrastructural facilities of the Institute have grown enormously over the years. Institute had started functioning from Ramdurg House in 1962 at its inception. As it grew, it rented two buildings viz., Gharpure Building and Vohra Building. Prof. Pisharoty, as a visionary, had acquired a large piece of land (over 80 acres) in Pune for its laboratories in the neighbourhood of the National Chemical Laboratory and the Defence Research Complex. Part of the land was transferred to IMD and they have built a Research and Training complex of their own on this land opposite to the IITM complex. IITM, with meager grants

at that time, could begin construction work of its complex in 1979 and the work was completed in three stages between 1982 and 1989. All the Scientific Divisions and the Administrational structure were shifted to the Pashan Complex by 1989 when the Second Phase of the building construction was over. The Library Building was constructed by 1995. The Conference complex came in by 2005. IITM complex has now the two main buildings housing laboratories and offices, an exclusive library building with conference facilities, a computation and training complex and a modern guest house. The front building of the Institute was designed giving it a slight curvature so that the building could merge with the curve of the surrounding hills behind the Institute in a harmonious manner, representing a concept of functioning in tune with nature. Construction of a separate building for the Centre for Climate Change Research (CCCR) has been started in 2011. It will be completed within a period of one year. This building is planned to be a green building.

Pisharoty Conference Hall

Varahamihir Seminar Hall

Aryabhatta Conference Hall

Hostel

Residential Complex

Guest House

Community and Recreation Hall

IITM New Delhi branch

The Institute had acquired an IBM 1620 computer in 1964 under the Special Fund Project. The computer was installed at the International Meteorological Centre (IMC), Mumbai to mainly perform data processing for the IIOE program and also used for computations for research. At the end of the IIOE program, the computer was shifted to the Ramdurg House complex of the Institute at Pune and became the main tool for performing computations for research. A computer Section was established in 1967 to support the research. The Computer Section did a marvelous job to train Institute's scientists as well as scientists from IMD, Central Water and Power Research Station (CWPRS) at Pune and other organizations in computer programming and successful implementation of the programmes written by researchers. Even the Director, Prof. Ananthakrishnan, acquired proficiency in programming which was a source of inspiration to young scientists as he used to stand in queue for punching / modification of program cards. As the work of NWP needed faster and better machine, the Institute used to send the scientists engaged in NWP to Mumbai for using TIFR CDC 3600. Later by 1975 a messenger used to go daily to Mumbai by train with program cards and bring the output of the programs run on the previous day at TIFR, Mumbai. This system served the needs of researchers well in the intervening years till 1987 when the Institute acquired its own mainframe. It is difficult to imagine, in the present days of in-house availability of enormous computing power, the trouble undergone by the scientists of the Institute to meet their computing needs for nearly first 25 years (1962-1987) of the Institute.

HPC Machine

The IBM 1620 Computer served the needs of the Institute for over 20 years supplemented by the use of CDC 3600. Funds were not easy in those days and hence only in 1987-88 the Institute could acquire another computer ND 560/CX System and subsequently, a High-end Workstations viz, RISC based HP-9000/735 and Silicon Graphics Incorporation's (SGI) Power Challenge were added in 1992-93 and 1997-1998 respectively. While computational facilities in similar research laboratories abroad the world leapfrogged from eighties to early 2k, it remained at a low level at IITM due to unavailability of funds. This seriously restricted the type of weather prediction and climate

modelling research that could be carried out. Recognizing the need the MoES decided to set up High Performance Computer (HPC) facility at IITM, IMD and NCMRWF (National Centre for Medium Range Weather Forecasting) and INCOIS (Indian National Centre for Ocean Information Service). Under this project a 7.2 teraflop machine was commissioned at IITM in 2009. To meet the rising requirements of climate modeling, the Institute has enhanced its computational power to 70 teraflop in 2010. The Institute has built a modern building in 2009 to house the HPC keeping provision of future expansion.

HPC Building

The Institute also gave a thrust to acquiring sophisticated instrumentation such as LIDARS for atmospheric aerosol studies, Spectrophotometers for atmospheric chemistry work, aircraft instrumentation for cloud physics and other instruments for boundary layer and atmospheric electricity studies. Several of the instruments like LIDARS, spectrometers and electric field mills were assembled or built by its own scientists. Weather radars, wind profilers, GPS radiosondes and other equipments for carrying out field research programmes have also been added recently and a few more are being acquired. A laboratory for green house gases has also been established. A modern, fully computerized library supports the research needs of the Institute's scientists as well as goes all out to meet the needs of scientists working in the Universities and other Institutions. The library has built a comprehensive collection of national and international publications and has built connections to acquire special publications which are not available on the internet.

There was a period between 1968-1980, when the Institute passed through a difficult period during the early years of its autonomy. First the concept of autonomy was unknown to the staff that was drawn mostly from the IMD being controlled by the rules and regulations of the Government. They were uncertain about their future as the governing rules of the autonomous Institute were yet to be formulated. However, the government provided options to the then serving staff of the Institute to opt for retirement benefits under the government or be governed by the Institute's Byelaws. By April 1974 majority of the existing staff of the IITM gave their final options and the period of unrest was over.

Library Building

Library Inner View

However, a small number of scientists had opted to return to the IMD as they had their permanent positions in IMD. Thus, after passing through the difficult period beginning in 1968, the Institute could stabilize by 1974. The recruitment and promotions in the Institute had remained almost blocked for a decade (1968-78). Prof. R. Ananthakrishnan, who was the Director when autonomous status was granted, retired in early April 1971 and the Institute was placed under the charge of Dr. K.R. Saha who was the senior most scientist in the Institute. Dr. Saha, being a person of independent views, could not easily follow the views of the DGO for running the autonomous IITM. The DGO had important role to play in the development of the Institute being the ex-officio Chairman of its Governing Council. However, Dr. Saha could steer the Institute well but he could become the regular Director of the Institute in 1974 only as he remained officiating Director for five years. Dr. Saha retired on 31 December 1976. It was only in 1978-85 that the Institute began to chalk out its independent course under the stewardship of Dr. Bh. V. Ramanamurty and celebrated its two decades in 1982. To commemorate this distinct landmark in its history, the Institute organized a Symposium on 'Current Trends in Tropical Meteorology' on 29 June 1984 followed by the Third Annual Convention of the

Association of Hydrologists of India. Shri D.R. Sikka was appointed as Director in October 1986. The Silver Jubilee of the Institute was celebrated in 1987-88 with great enthusiasm and hope for future progress.

The Byelaws of the Institute were modulated particularly in relation to the promotion policy, with effect from 1988 and in 1998. Dr. G.B. Pant, the then Director, succeeded in making them more flexible as the scientists could be upgraded to a higher position every 5-years till they reach the grade of the Director. Also, from 1988 onward the rules for taking up invitations from foreign research institutions for research were relaxed. These measures brought new enthusiasm among the Institute scientists. The recruitment for vacant and new positions had re-started from 1976 onward and several young scientists entered the Institute. This process has been accelerated by the present Director Prof. B.N. Goswami and several scientists have been inducted by direct recruitment to even senior scientists positions (Scientist E) in the last three years. Several scientists of the Institute have the honour of serving at prestigious international and national bodies such as Joint Scientific Committee (JSC) of ICSU/WMO, WMO's Commissions, Working Groups and Scientific Steering Committees for planning of International Field Programmes such as the Tropical Ocean Global Atmosphere Program (TOGA), GAME, AMY and others **(Appendix-I)**. Institute took a lead role in 1994 to chalk out the scientific plan of multi-agency Indian Climate Research Programme (ICRP) under the stewardship of the DST, which continued till 2009 and now is under implementation of the MoES.

Beginning 1970s, the work of several young scientists of the Institute has been rewarded by recognitions like Fellowships of the Scientific Academies in India and the WMO Young Scientist Award, Hari Om Award Ashram Prerit Dr. Vikram Sarabhai Research Award **(Appendix-II)**. To mark its Silver Jubilee, the Institute also began giving yearly reward to scientist (s) of a research paper published in peer reviewed journal judged as the best paper in the previous year **(Appendix-III)**. Also, the Institute started to invite a leading scientist from abroad for lecturing at the Institute as a Visiting Scientist **(Appendix-IV)**.

6. Field Observational and Research Programmes

Mystery of the Atmosphere had influenced Prof. Pisharoty over his career. He recognized that unfolding these mysteries needed special field studies. So, one of the important features of the Institute's programmes, right from its inception till the present, has been the organization of and participation in national and international programs aimed for the purpose of the field data for diagnosing process – oriented atmospheric studies. Over the years the Institute has kept the tradition of active participation in several international and national field programmes. Through these efforts the Institute scientists

not only gained rich experience in management of field programmes but also acquired leadership qualities and familiarity in working with arrays of advanced research facilities at the ground, over the high seas and in the air. Although the Institute might have been formed for basic research work, participation of IITM scientists in the field programmes has been beneficial for the research efforts of the Institute. As already mentioned, the Institute's Special Division at IMC, Mumbai was the centre of international activity on the weather and climate of the vast Indian Ocean region. This provided an important opportunity for the young scientists, posted at the IMC, Mumbai, to work in an international research environment in which U.S. scientists, led by Prof. C.S. Ramage, worked in close contact with them. Also, visiting scientists and research ships participating in the IIOE paid visits to IMC and delivered special lectures. A team of scientists from USA and the personnel of Research Flight Facility of NCAR were stationed in Mumbai during May to June 1963 to conduct research aircraft flights. The Indian scientists took part in these flights which was a unique experience. The research aircrafts were taken to New Delhi and even the Prime Minister, Shri Jawaharlal Nehru, came to see the research aircraft.

During his professional career as an operational weather forecaster during the Second World War, Prof. Pisharoty was intrigued by the thunderstorms of Peninsular India as these were hazards to civil and military operations. He, therefore, conceived a field programme on meso-meteorology around Pune, in 1963, soon after the Institute was set up, Prof. Pisharoty, recognizing the importance of specialized field data for process-oriented studies in tropical meteorology, organized a meso-meteorology experiment around Pune during May to July 1963 to probe pre-monsoon thunderstorms and heavy monsoon spells which occasionally occur around Pune in the summer monsoon season. Prof. T. Murakami, when he learnt about the reduction of rainfall downstream of the Palghat Gap in Kerala during the summer monsoon season, encouraged the Institute's scientists to launch a field programme in 1966 to study the dynamical aspects of the Palghat Gap on Monsoon wind and rainfall over the Palghat gap region. Other field programmes which were organized by the Institute during 1970 to 1985 were:

- Boundary layer experiment in and around Pune in 1977 and 1980.
- Air pollution monitoring around several thermal power plants in the country on request from plant authorities (1978, 1981, 1982).
- Atmosphere's response to total solar eclipse at Raichur and Pune (February 1980).
- Measurements on atmospheric electricity and cloud microphysical properties and atmospheric aerosols and chemistry during summer monsoon at a high altitude complex of the Western Ghats around Mahabaleshwar, Khandala and Sinhagad (1969, 1970, 1971, 1972, 1973, 1975, 1977, and 1983).
- Total ozone measurements as part of the Indo-Soviet experiment on ozone measurements (March 1983).
- Study of marine boundary layer around the Indian coast (May 1983).
- Atmospheric aerosol measurements at Thumba (February 1984).
- Indian Middle Atmosphere Program during 1985-88.

By participating in the International field experiments on the summer monsoon viz., Indo-Soviet Monsoon Experiment (ISMEX 73), Monsoon-77 and Summer MONEX-79 which was part of the Global Atmospheric Research Programme the Institute's scientists played vital roles. Participation in Summer MONEX-79 gave the Institute's scientists experience and confidence to plan, organize and implement major multi-agency field programmes. Since 1988 they began to implement several field programmes in collaboration with the Indian atmosphere-ocean science community which have resulted in the following field campaigns:

- Monsoon Trough Boundary Layer Experiment (MONTBLEX) - 1989-1990.
- Land Surface Processes Experiment (LASPEX) - 1995-1996.
- Bay of Bengal Monsoon Experiment (BoBMEX) - 1998-1999.
- Arabian Sea Monsoon Experiment (ARMEX) - 2002, 2003 and 2005.
- Indian Ocean Experiment (INDOEX) - 1999.
- Severe Thunderstorm-Observations and Regional Modelling (STORM) - 2006 - 2011
- Continental Trough Convergence Zone (CTCZ) - 2009, to be continued up to 2012

The above field programmes were aimed to study special complex processes in the interactive atmosphere-land-ocean-vegetation system of the Indian Summer Monsoon.

A multi-year field programme conducted by IITM during 1973 to 1985, which deserves special mention, is the Weather Modification of Warm Clouds using aerial cloud

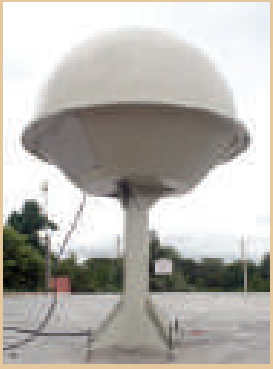
Participation in
Antarctica and Arctic Expeditions

Participation in MONTBLEX Expedition

seeding and randomized seeding technique around Pune region. The objective was to assess the seedability criteria and possibility of rain enhancement under deficient rainfall situations. Since weather modification offers an alternative to fill dams for irrigation and hydroelectric generation, several state governments approached the Institute to conduct rain enhancement in specific river catchments. The Institute yielded to conduct such operational experiments to meet societal demands, but without undertaking rigid scientific validation. The 12 years long (1973-1985) warm rainfall enhancement experiment undertaken by the Institute did not yield conclusive results for seeding the clouds with hygroscopic finely powdered common salt. However, it resulted in identifying seedability criteria. The demand for such experiments by the State Government has persisted since that time with a view to relieve stress on water resources due to repeated droughts since 1985. Between 1985 and 2009, the science and technology of cloud seeding has undergone considerable change and now sodium chloride flares are even available commercially. Therefore, the Institute decided in 2007-2008 to revisit cloud modification techniques and launch a special field campaign under the name Cloud-Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX). For this purpose, a fully instrumented research aircraft was hired and the experiment was conducted in 2009, 2010 and 2011 under much improved scientific strategy than that used in previous 12-year period experiments. Instrumented aircraft flights, inputs from dynamical mesoscale model forecast, continuous weather satellite watch, weather radars as well as use of sodium chloride and silver iodide flares have been employed in CAIPEEX. The experiment conducted in 2009 was to survey the atmosphere aerosols-cloud interactions over different regions of India on cloud-aerosol interactions under different weather conditions over different parts of India. Such a background study of cloud-aerosol interactions was of great importance. For the 2010 campaign the experimental seeding in Peninsular India was conducted. Several interesting papers have already resulted from the 2009 experiment. The experiments which began in 2009 are likely to continue for another 3-5 years.

CAIPEEX - Phase I- 2009 Flag Off

CAIPEEX - Phase II
1st year (2010) & 2nd year (2011)



GPS Upper Air System

7. National and International Conferences

Importance of participation and conducting national and international conferences cannot be overemphasized as such conferences bring in established and young scientists on the same platform to share scientific knowledge. Institute has actively promoted conducting such conferences at its campus as well as deputing its scientists to participate in conferences conducted in India and abroad. This was the key activity which helped the Institute to enhance research and scientific human resources by keeping its scientists glued together. Also, it immensely helped the scientists to join forces with advanced countries in tackling some of the most complex processes relating to weather and climate.

At the termination of the IIOE, the Institute organized an 'International Symposium on the Scientific Results of the IIOE' in July 1965. In September 1976, the Institute organized an 'International Conference on Tropical Monsoons'. Again in November 1988 an 'International Symposium on Monsoon Understanding and Prediction' was organized to commemorate the Silver Jubilee of the IITM, IIOE and a decade of the MONEX which was a sub-programme of the Global Weather Experiment (GWE). Several outstanding scientists of international repute from USA, Europe and Japan participated in this symposium. This gave visibility to the Institute in the scientific community. Since then holding of international and national conferences, seminars, symposia, workshops, meetings, etc. have been an ongoing activity in IITM. Following are some of the international conferences seminars, symposia, workshops, meetings, etc. hosted and organized by the IITM:

- Meeting on Indo-US Collaborative Climatic Research Programme under the Indo-US Subcommission of the Atmospheric Sciences, November 1989
- Indo-US Seminar on Parameterization of Sub-Grid Processes, August 1990 (Papers presented at this Seminar were brought out in the form of a book entitled, "Physical Processes in Atmospheric Models" edited by D.R. Sikka and S.S. Singh)
- Third WMO/IMD Regional Workshop on Asian/African Monsoon Emphasizing Training Aspects, February 1991
- An Interagency Meeting of the Monsoon Sections (MONSEC) under the Indo-Soviet Collaborative Programme (ILTP), September 1991
- Indo-Brazilian Joint Workshop on Climate Research, December 1996
- Meeting of the International Scientific Steering Committee of PAGES Core Project of IGBP and PAGES Workshop on South Asian Palaeoenvironments, February 2000
- Workshop on Seasonal Climate and Crop Forecasting Methods for South Indian Rainfed Agriculture Jointly with the International Research Institute for Climate Prediction (IRI), USA, May 2003
- Session of the CLIVAR Asian - Australian Monsoon Panel (AAMP) and CLIVAR/IOC Indian Ocean Panel (IOP) followed by an International Workshop on Role of Indian Ocean in Climate Variability (INDOCLIM), February 2004
- WMO/GCOS International Workshop on Enhancing South and Central Asian Climate Change Monitoring and Indices, February 2005
- UK - India Workshop on Regional Climate Change, Variability and Impacts: Scientific Perspectives, January 2006,
- One - day IGBP (International Geosphere Biosphere Program) Workshop on Global Change followed by Annual Meeting of the Scientific Steering Committee of the IGBP (SC-IGBP), Annual Meeting of the Joint Scientific Committee (JSC) of the World

Climate Research Program (JSC - WCRP), and Joint Session of the SC-IGBP and JSC-WCRP Meeting, March 2006

- Indo - US Workshop on Integrating Weather and Climate Information in Water Management, July 2006
- Indo- UK Workshop on Modeling the Land Surface and Climate Change in India, March 2008
- GURME (GAW-Global Atmosphere Watch) Urban research Meteorology and Environment Program) International Workshop on Air Quality Forecasting (GURME-2008), December 2008
- Asia Pacific Network (APN) Conference focusing on Asia Pacific Network (APN) initiatives on South Asia Proposal Development Training Workshop (PDTW) and South Asia Sub-Regional Co-operation (SA-SRC) Meeting followed by Workshop on Downscaling of South Asian Climate Projection, November 2010
- Under WMO's auspices the First and Second Sessions of the South Asian Climate Outlook Forum (SASCOF), April 2010 and 2011
- The 18th SPARC - (Stratospheric Processes and their Role in Climate - A core project of the World Climate Research Programme) Scientific Steering Group Meeting, February 2011

IITM had an honour to host a Meeting of the WMO/ICSU, the IGBP Workshop on Global Change, and the Joint Sessions of the JSC of IGBP and Steering Committee (SC) of WCRP for the first time anywhere in Asia. JSC is the highest scientific body to promote research in climate at the international level.

Institute has routinely held important national workshops and seminars/symposia in subjects forming the core of its scientific activities. Numerous national conferences to plan and organize national field programmes and discuss their scientific results have also been conducted at the Institute's premises since 1988, on regular basis. For training of young scientists and research scholars the Institute organized DST–sponsored SERC Schools on different topics of Atmospheric Sciences such as four out of five year cycle of SERC Schools on 'Advanced Geophysical Fluid Dynamics' in 1994, 1995, 1996 and 1997 respectively, a series of two SERC Schools on Cloud Physics and Atmospheric Electricity in 2000 and 2001 and on 'Global Warming and Climate Change' in December 2010.

First International Symposium held at IITM

Participants of the First International Symposium held at IITM


MONSOON-UNDERSTANDING AND PREDICTION


INDO-US SEMINAR ON
SUB-GRID SCALE PROCESSES


INTERNATIONAL WORKSHOP


South Asian Climate Outlook Forum


WHO INTER-REGIONAL
CLIMATE INFORMATION AND PREDICTION SERVICES (CLIPS)
TRAINING WORKSHOP
ON
URBAN CLIMATOLOGY


SPARC Local Workshop and
18th Session of SPARC-SSG Meeting


FIRST ANNUAL CONFERENCE OF IASTA
AEROSOL SCIENCE - A PERSPECTIVE ON
RESEARCH AND DEVELOPMENT IN INDIA
INDIAN AEROSOL SCIENCE AND TECHNOLOGY ASSOCIATION
& INDIAN INSTITUTE OF TROPICAL METEOROLOGY
MARCH 23-24, 1990


विश्व मौसम विज्ञान संगठन/भारत मौसम विज्ञान
विभाग की एशियाई/अफ्रीकी मानसून पर प्रशिक्षण
अभिमुखता के महत्व पर तीसरी क्षेत्रीय कार्यशाला.
THIRD WMO/IMD REGIONAL WORKSHOP ON ASIAN/AFRICAN MONSO
EMPHASIZING TRAINING ASPECT

8. Academic Programmes

The Institute, right from its inception, has promoted academic excellence by helping its scientists to register for Ph.D. degrees of different Universities. S. Rangarajan (1966), S. Ramachandran (1966), R.P. Sarker (1968), D. Sreeramamurthy (1968), V. Brahmanand Rao (1969), Mary Selvam (1970), J. Shukla (1971) and R.R. Kelkar (1971), were among the first who received their Ph.D. degree while working at the Institute in its infancy years, 1963-1971. As the Institute's research Divisions got fully established, award of Ph.D. degrees to Institute scientists became an every year affair and

several scientists of the Institute viz., D.A. Mooley (1972), R.N. Keshavamurty (1972), Ramesh V. Godbole (1972), D. Subramanyam (1973), A.S.R. Murty (1974), B.M. Mishra (1974), O.N. Dhar (1975), H.S. Bedi (1978), K. Krishna (1978), S. Rajamani (1978), S.T. Awade (1980), B.K. Mukherjee (1982), R.S. Reddy (1983), P.E. Raj (1983), B. Parthasarthy (1985), S.K. Mishra (1983), S.S. Singh (1978), S.V. Singh (1984), H.N. Bhalme (1984), P.S. Salvekar (1985), S.N. Bavadekar (1985), L.T. Khemani (1985), J.M. Pathan (1985), P.R. Rakhecha (1989), S.S. Parasnis (1989), K. Indira (1990), Poonam Sikka (Mehra) (1991), acquired Ph.D. degrees during 1972 - 1991 while working at the Institute. There was also some junior scientific staff at the Institute, inducted during 1963 - 1975, who had entered the Institute with a B.Sc. qualification. The Institute, in 1978, approached the University of Poona to recognize it as a research centre so that scientists with M.Sc. could register for Ph.D. and those with B.Sc. can acquire M.Sc. degree by research in Physics Faculty. Thus, almost all the junior staff could acquire M.Sc. and subsequently Ph.D. degree by 2000. This has enhanced the scientific image of the institute and emphasized scientific excellence in the working of the Institute. At the beginning of the Institute most of research and scientific staff joined with M.Sc. or B.Sc. degrees. However, since 1985 the regular staff of the Institute began to enter with M.Sc. and/or Ph.D. degrees. This is a major change, following similar change in other research organizations in India. About 20 scientists/academicians of other Institutions/Universities have also acquired Ph.D. under the guidance of Institute's scientists.

Air India initiated two fellowships for research in tropical meteorology at the Institute in early 1960s. Institute also established its own Research Fellowship starting with two and later on enhancing it to four. Considering the acute need of the manpower development in the field of meteorology and atmospheric sciences the Institute's Research Scholarships/Fellowships Programme has been enhanced since 2000 and at present about 30 such Fellows are working at the Institute under different research programmes. These Fellows have now become the backbone of the high quality research. A few CSIR Research Fellows are also posted for carrying out research in meteorology and atmospheric sciences leading to Ph. D. under the guidance of the Institute scientists. With all these efforts 44 Research Fellows have acquired Ph.D. since inception of the Institute. A few Research Fellows received regular scientific position in the Institute and acquired their Ph.D. degree while working in the Institute. A few scientists and students from other organizations and Universities have carried out research and obtained Ph.D. under the guidance of Institute's scientists.

At the inception of the Institute, there were only 3 Ph.D.s in research staff of the IMD. This figure became 46 in 1991 and now up to 2011 it has reached to about 150. This could happen because the Institute promoted organization of higher degrees by its research and scientific staff, and in the process, a generation of Ph.D. guides helped their colleagues in following the Ph.D. programme.

Appendix V gives the list of names of scientists and Research Fellows who have acquired Ph.D. degree since the inception of the Institute.

Since 1978, Institute scientists also deliver courses in the Training School of the IMD at Pune. IITM has been involved in scientific collaboration with universities and research organizations, both at the national and international levels. IITM has been recognized by several Indian Universities for carrying out research work leading to the award of M.Sc. and Ph.D. degrees in Atmospheric Sciences. These are University of Kerala, University of Pune, Banaras Hindu University, M.S. University, Andhra University, Mysore University, Punjab University, Nagpur University, Bangalore University, Agra University, Bombay University and Bharati Vidyapeeth (Deemed University).

The University Grants Commission (UGC) had selected the Department of Physics of the University of Pune as one of the five National Centers for starting the post-M.Sc. M.Tech. (Atmospheric Physics) programme in 1988. Since then the IITM has been collaborating with the University of Pune in running its M.Tech. (Atmospheric Physics) course. UGC funded this programme for eleven years. In collaboration with the IITM the UGC organized a 'Summer School in the Atmospheric Science' during 4 May - 12 June 1987 at the University of Pune with a view to promote post M.Sc. courses in Atmospheric Sciences in Indian Universities. After the UGC's funding was over a Memorandum of Understanding (MoU) between the University of Pune and the IITM was signed on 26 May 1999 to run the M.Tech. programme jointly. To attract the students towards research in Atmospheric Sciences IITM started a scholarship, initially only for the meritorious students and now for all the students of this M.Tech. course. The scientists of the Institute contribute to the academic programmes of universities and other institutions by providing their expertise through lectures, guidance, and working as examiners, paper setters and members of Board of Studies.

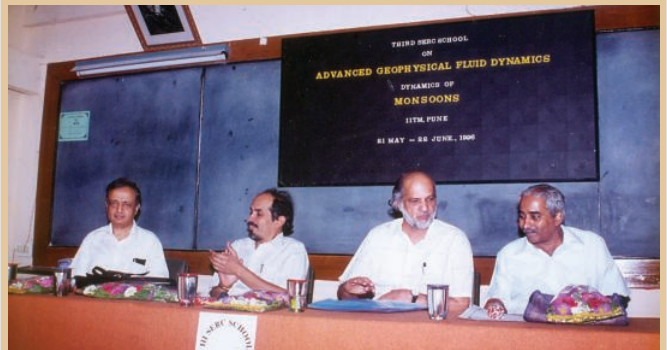
Training Programmes for Research Scholars have also received active attention of the Institute since 1990s. As the Institute started taking up research projects from DST and other government departments, research scholars/research associates were also

MoU between IITM and University of Pune

inducted along with the projects. The Institute conducted prolonged training programmes under the SERC Schools of the DST on different topics of Atmospheric Sciences.

Recognising the fact that the Research Fellows come from various different backgrounds and the need for a broad exposure of the Research Fellows to the basic concepts of climate science and challenging outstanding problems, Prof. B.N. Goswami introduced a regular two semester Pre-Ph.D. course work since 2007. In order to orient the Research Fellows to modern atmosphere-ocean research, Prof. Goswami has himself taken the lead to deliver courses on modern topics for the Research Fellows and young scientists. This is yielding great benefit in promoting the temper and culture of research in the Institute. As training of researchers in atmosphere-ocean problems is very prolonged and in a specialized discipline, there is an urgent need for human resources development in India.

Several Training Programmes in Palaeoclimatology, Climate Modelling and related fields have been organized in the Institute for the benefit of students and young scientists from India, South Asian Regions and other countries.




FOURTH SERC SCHOOL
ON
ADVANCED GEOPHYSICAL FLUID DYNAMICS
DYNAMICS OF CLIMATE & CLIMATE VARIABILITY
IITM, PUNE 8


मेघ भौतिकविज्ञान और वायुमण्डलीय विद्युत पर सर्क स्कूल -मूल सिद्धान्त
SERC SCHOOL ON CLOUD PHYSICS & ATMOSPHERIC ELECTRICITY-FUNDAMENTALS
JUNE 13 - JULY 14, 2000
SPONSORED BY DST AND ORGANISED BY IITM, PUNE AND
PUNE UNIVERSITY AT
INDIAN INSTITUTE OF TROPICAL METEOROLOGY, PUNE


मेघ भौतिकविज्ञान और वायुमण्डलीय विद्युत पर सर्क स्कूल - परिसीमाएं
SERC SCHOOL ON CLOUD PHYSICS & ATMOSPHERIC ELECTRICITY-FRONTIERS
JUNE 7 - JULY 5 2001
SPONSORED BY DST AND ORGANISED BY IITM, PUNE AND
PUNE UNIVERSITY AT
INDIAN INSTITUTE OF TROPICAL METEOROLOGY, PUNE


एस इ आर सी प्रभाग, विज्ञान एवं प्रौद्योगिकी विभाग, भारत सरकार
जलवायु परिवर्तन एवं ग्लोबल वार्मिंग पर एस ई आर सी स्कूल
दिसंबर 1 - 21, 2010
जलवायु परिवर्तन अनुसंधान केंद्र
भारतीय उष्णदेशीय मौसम विज्ञान संस्थान, पुणे
SERC Division, Department of Science and Technology, Govt. of India
SERC School on Global Warming and Climate Change
December 1 - 21, 2010
Centre for Climate Change Research
Indian Institute of Tropical Meteorology
DR. S. CHAKRABORTY
DR. M.K. KULKAR

With strong recommendations and initiatives of the Ministry of Earth Sciences, Govt. of India the Centre for Advanced Training in Earth System Sciences and Climate (CAT- ESSC) has been launched in IITM. The CAT-ESSC has been set up under the leadership of IITM, as a national capacity building facility to address the problem of paucity of skilled scientific manpower required for improving the quality of weather and climate forecasts in the country with particular focus on the Indian monsoon. This would be the world-class state-of-the-art Training Centre. The Centre will run the job linked integrated training programme leading to M.Tech and/or Ph.D. Degrees. A large pool of trained and dedicated climate and earth system modelers is proposed to be created through the training programme. Meritorious students with master in science or bachelor in engineering degree will be eligible for this training programme. The programme will go beyond the conventional training on individual systems and address weather and climate as processes arising from interactions between the component systems. In depth hands-on expertise building on individual physical processes of the land, ocean, atmosphere, biosphere and cryosphere is envisaged. The selected trainees would receive consolidated monthly pay of Rs. 25,000/- on entry and, on successful completion of the programme, will be placed in any one of the institutions of MoES viz. IITM, IMD, INCOIS, NIOT, NCAOR, NCMRWF, ICMAM and CMLRE or other leading research centres at appropriate scientific positions. First batch of the training started in August 2011. This is a much needed facility. The Institute would do its best to rise to the occasion to provide modern training facilities within the scope of its exclusive training centre. Thus, the clock has turned full circle and the need for Training Division, which was felt at the inception of the Institute 50 years ago, is now fully recognized.

Thus by a variety of ways Institute's capabilities are being increasingly used in training of human resources in atmospheric sciences in the country.

Inauguration of CAT-ESSC

CAT-ESSC Training

9. Research Highlights in Different Areas

We now provide some highlights of research conducted at the Institute, in different areas of Tropical Meteorology, during the last 50 years. As the work is enormous, it would not be possible to give details of different research contributions and refer to them individually. As such a broad survey of the research highlights is provided. The research contributions to various areas came from individual divisions as well as through collaborations of scientists working in each division and across the divisions.

9.1 Numerical Weather Prediction

By the time the Institute was established, considerable strides had already been made in Numerical Weather Prediction (NWP) at advanced research centres in USA, Japan, and European countries like Germany, USSR, France and United Kingdom. Noting the great potential offered by the NWP and its relevance to day to day forecasting of tropical weather systems, the Institute took little time for organizing research in this important area. In 1964 Prof. G.C. Asnani began working on development of a geostrophic barotropic model for the Indian region. Advantage was taken of the UNDP fellowship and a few scientists were deputed to USA and Japan to acquire knowledge in the developing field of NWP and its applications in the tropics. Shri R. Suryanarayana worked at the NOAA's operational National Meteorological Centre (NMC) at Washington D.C. Shri J. Shukla also visited NMC at Washington D.C. for a short time and spent a few months at the National Hurricane Research Centre, Miami. On returning to India he spent some time at Japan's MRI with Prof. Gambo. Shri Y. Ramanathan and Shri S.K. Mishra also went through formal courses at the Florida State University. While at the NOAA's NMC at Washington D.C. Shri Suryanarayana, Shri Shukla and Shri Sikka got introduced to Dr. Takahasi of Japan who was visiting NMC. Dr. Takahasi took interest in them and used to lecture on NMP methods in the evening hours which really excited the young scientists. Also, these scientists used to attend seminars being held from time to time at the NOAA's Geophysical Fluid Dynamics Laboratory, which was being headed by Dr. Joseph Smagorinsky. IITM's young scientists had the opportunity of meeting Dr. Manabe and Dr. Miyakoda, who were working on developing atmospheric general circulation models for simulation of the Earth's climate.

On return of these scientists to India in 1967, and thereafter, the Institute vigorously organized work on NWP under the leadership of Dr. K. R. Saha, Head of the FRD. Initial efforts were directed toward the development of simple and idealized models for predicting synoptic scale disturbances over Indian region. This was essential to gain experience and confidence in pursuing this line of research. Shri Shukla concentrated on experimenting with non-divergent barotropic model with wind as input. Shri Sikka and Shri Ramanathan focused their efforts on experimenting with different schemes on objective analysis of the wind field and application of Reverse Balance Equation for deriving geopotential field from wind field and for diagnostic studies, along with Shri C.M. Dixit. Shri Ramanathan also successfully worked for development of a primitive equation (PE) barotropic model during 1970-73 and Shri Sikka tested a multi-level quasi-geostrophic model with wind as input. Also, Shri H.S. Bedi worked on the global PE barotropic model. Shukla, Ramanathan and Bedi acquired Ph.D. degrees for their work. Shukla left the Institute for higher studies in USA in 1971. Ramanathan and Bedi got selected as Meteorologist in IMD in 1973 and were attached to IMD's Delhi Unit where they implemented a multi-level quasi-geostrophic model and a multi-level PE model, respectively, for operational use.

The NWP efforts continued in IITM with young researchers like S.S. Singh, S. Rajamani, S. Sinha, A. Bandyopadhyay, P.L. Kulkarni, etc. who had joined the Institute in early 1970s

and their efforts led to the development of three versions of P.E. barotropic model, with wind as input. By 1983, S.S. Singh was successful in implementing a multi level P.E. Model in x, y, p, t coordinate system with inclusion of parameterized physics and dynamic initialization scheme. Several experiments on NWP system were conducted during 1979-1988 using Summer MONEX data [17-25].

By 1988, DST had set up the National Centre for Medium Range Weather Forecasting (NCMRWF) at Delhi with a super computer facility. NCMRWF adopted dynamic weather prediction methodology for 3 -10 day scale using a global model. As a result, efforts within the NWP community of IITM were directed to adopting high resolution meso-scale models for predicting high impact weather and evaluating them for prediction of severe thunderstorms and for monsoon prediction. Due to non-availability of good computing facility during the period starting from mid eighties NWP research at IITM remained at a low key.

9.2 Development of Empirical Forecasting Techniques

Along with the development of NWP techniques for short-range weather forecasting, considerable efforts were also devoted to development of empirical techniques based on synoptic-climatological method as well as statistics-based objective methods for forecasting of weather developments over India on short- to medium- range scales. These techniques broadly covered the following aspects:

- **Analogue forecasting for 24-hr to 48-hr validity, based on 25 years of categorization of surface weather charts during the monsoon season.** The method was found to have skill in rainfall forecasting, particularly when associated with transient monsoon disturbances and fluctuations of the monsoon trough [26-29].
- **Objective method for forecasting tracks of tropical cyclones up to 48-hr, based on computerized version of half persistence and climatology.** Probability ellipses for the track prediction were also developed. The method was applied on real-time basis and finally passed on to IMD. This served the purpose till mid-1980s and was abandoned when dynamical methods were introduced for operational work [23, 30-33].
- **Concurrent relationships were found between (i) 700 hPa geo-potential anomaly over a region and the latitudinal position of the monsoon trough axis and (ii) 700 hPa geopotential anomaly and rainfall distribution over the country.** Significant relationships of the pentad anomaly with the rainfall in the next pentad were used to prepare probability forecasts [28, 34-50].
- Significant **concurrent relationships were found between the 700 hPa circulation and satellite-observed cloudiness on pentad basis.** Also, concurrent and lag correlations have been found between daily rainfall and surface and 700 hPa circulation features in daily, 5-day, 10-day, monthly and seasonal scales [51, 52].
- **Multiple screening regression equations** were developed to predict 5-day and 10-day rainfall over meteorological sub-divisions from 700 hPa geopotential field [53-57].

- **EOF analysis** was performed on mean monthly 700 hPa geopotential and rainfall of India. The first three functions were found to account for 70 to 90% of the variance. Lag correlations were found to be related to EOFs for skillful forecasting of rainfall all over India. Some of the results from the above studies were later used during 1990-95 in NCMRWF for developing model-based rainfall forecasting [28, 58].

Forecasting of rainfall over different parts of India exceeding 3 days in duration is one of the most challenging problems to meet the requirement for agricultural and other societal applications. Prior to ITM, this work was being carried out in IMD by using empirical techniques. The Institute, in 1965, organized the work to develop objective techniques for such forecast, based chiefly on statistical and synoptic climatological techniques [34, 37, 44, 59]. This was carried out by S.V. Singh, R.H. Kripalani and K.D. Prasad and their colleagues till 1990. For this purpose daily weather charts for 21 years were analyzed at surface, 700 and 500 hPa levels. This was a massive effort and yielded a valuable data bank for further research. A technique for using surface weather analogues for short-range forecasting was developed based on the data bank and transferred it to IMD. Tropical storm prediction based on computerized persistence climatology was also developed and used operationally. Empirical models based on concurrent relationships between circulation patterns and rainfall over different parts of India were also built using 700 hPa and 500 hPa levels data [60 - 62]. Besides showing usable skills of the techniques the work also provided an insight into fluctuations of the monsoon rainfall on sub-seasonal scale. The data were also used to develop models by applying multi-screening regression technique and for preparing climatology of large scale circulation parameters and their association with subseasonal monsoon rainfall [50, 53 – 57, 63].

The Institute also contributed to the work on the long – range forecasting of seasonal monsoon rainfall [64 - 66]. This work was done on the following lines:

- Identification of conditions which led to the monsoon droughts of 1972 and 1987 [67 - 82].
- Linkages of monsoon with El Nino Southern Oscillation (ENSO) phenomenon [73, 83 - 111].
- Modulation of seasonal monsoon rainfall over India by warming in the Indian Ocean [73, 89, 94, 111 - 113].
- Study of Monsoon-Himalayan snow cover, Monsoon- Eurasian snow cover and snow depth data over USSR and Tibet [114 - 118].
- North Atlantic Oscillation (NAO) and Indian summer monsoon rainfall [119 - 126].
- Relationship between monsoon rainfall and surface temperature over the Northern Hemisphere and monsoon rainfall and Sea Surface Temperatures (SSTs) over different sectors of global oceans [7, 9, 96, 102, 109, 127 - 138].
- Indian Ocean Dipole and Interannual Variability (IAV) of monsoon rains over India [139-152].

- Pre-monsoon characterization of global circulation features and monsoon performance [153-156].

Some of the above relationships were quantified in terms of regression equations to predict the seasonal monsoon rainfall. Following the major drought of 1987, DST under the leadership of its then Secretary Dr. Vasant Gowariker, organized a special multi-agency effort to formulate new models for Long-Range Forecasting (LRF) of monsoon. In this effort IITM was also actively involved and it resulted in multi-parametric empirical and power regression models of the monsoon during 1988-90 [157, 158]. These models worked satisfactorily for a decade or so but the performance deteriorated with time as was the case with earlier statistical models in IMD.

Beginning 2005 the work on extended-range and long-range forecasting of monsoon has taken a new shape. The effort on forecasting the extended range scale has been focused on prediction of active and break spells as well as transition from one type of spell to the other. For this purpose two approaches have been used. One is based on using analogues of satellite observed outgoing long wave radiation data set and projecting the analogue for future sequence [159]. This approach has shown skill and is being applied operationally since 2008 by the combined efforts of IMD and IITM. The other method is also an analogue method but uses a nonlinear pattern recognition technique called Self Organizing Map (SOM) to identify analogues of nonlinear phases of the monsoon ISO [29]. The technique also showed good skill in predicting active and break phase, about 20 days ahead and has been providing experimental forecasts during 2009 and 2011.

9.3 Monsoon Diagnostics

A large number of studies on dynamical aspects of monsoon circulations have been undertaken with special emphasis to understand (i) theory of maintenance of mean monsoon circulation, (ii) vertical motion field in active/break phases of monsoon and in excess/drought seasons, (iii) energetics of monsoon depressions, iv) energetics of global circulations in wave number domain in the troposphere during extreme monsoon seasons on the basis of daily and monthly data to understand the role of transient and stationary eddies in the long waves on monsoonal oscillations, (iv) modeling the IAV of monsoon, v) role of triad kinetic energy interactions during summer monsoon and non-linear kinetic energy interactions and their contributions during summer monsoon season, and (vi) mechanism of ISOs of monsoon and its application for the prediction of monsoon rainfall on extended range scale.

9.3.1 Long term monsoon rainfall and monsoon variability on seasonal and longer time scale

Several important investigations have been done on the traditional problem of climatological aspects of the Indian summer monsoon rainfall. Towards this, two important long-term rainfall series have originated from the Institute. The first series in the monthly mean, seasonal mean and annual mean rainfall of India as a whole, rainfall of 4 homogeneous regions and sub-divisional rainfall for the years

1871 to 1994 which has been updated annually. This series was based on the identical 306 raingauge stations over India and has become the bases of Indian rainfall used in many studies done in India and abroad [75, 77, 80, 81, 160 - 177]. The second series used the longest rainfall records from 1800 onward based on increasing number of rain gauges from a few to over 300 stations [178-190]. This work showed that there is a very high correlation of the Indian rainfall from a few fairly scattered raingauge networks to fairly dense networks. These data were used to produce a massive atlas covering seasonal aspects of such regional rainfall on state-wise, sub-division wise and even river basin wise bases. The data set was also used to produce climatology of the moisture regime over India and its fluctuations on inter-annual basis, identifying eastward/westward shift of the moisture regime between monsoon excess seasons to monsoon drought seasons. The rainfall series were used to understand secular variation and decadal variability of rainfall which showed that although there are epochal fluctuations in the rainfall but the all India rainfall has been quite stable on long-term and multi–decadal basis [168, 191-193]. Two series of flood and drought indices for the Indian summer monsoon based on sub-divisional rainfall were also prepared, based on long period data. During a monsoon drought (excess) season, the area of India under drought (excess) was found to be 40% (35%) or more. Years of floods and droughts were related to double sun-spot cycle. Several other variations of monsoon rainfall on all India and sub-regional basis have been done. Also, detailed study of the monsoon depressions and low-pressure systems has been done to understand their role in fluctuations in the monsoon rainfall.

The two Indian rainfall series were examined in relation to the rainfall series from neighbouring countries like Bangladesh, Nepal, Thailand and even northern China. Several other studies on Indian rainfall were based on these two series such as the variability of rainfall on arid, semi-arid and moist regimes over India.

9.3.2 Teleconnections of seasonal monsoon rainfall

One of the most important areas in monsoon meteorology has been the identification of teleconnections over different regions for fluctuations in the monsoon seasonal rainfall. This work was extensively carried out in the Institute during 1970 to 2010 which resulted in the determination of three teleconnections. These are El Nino Southern Oscillation (ENSO) and monsoon, North Atlantic Oscillation (NAO) and monsoon, and the Indian Ocean dipole and monsoon. Many studies have been carried out in the last four decades to understand Indian monsoon rainfall and fluctuation in relation to these three patterns. Monsoon droughts have been linked to warm phase of ENSO pattern and the secular variations in this link as well as its weakening in last three decades have been examined [73, 83 – 111, 119 – 126, 139 – 151, 194 - 198].

Relationship of winter and spring season snow cover over Eurasian region and Tibetan region were examined and even the climatology of Soviet snow cover data

and satellite observed snow depth data were examined in relation to seasonal monsoon rainfall data which re-established the traditional snow-monsoon relationship for Indian summer monsoon rainfall [114-118]. Similarly, the emerging field of Monsoon-Aerosols interaction has also been examined on present and futuristic basis.

Fluctuations in monsoon rainfall have also been studied in relation to food grain production in the country as well as in relation to socio-economic factors [199 - 210]. To sum up climatological rainfall studies in relation to incidence of droughts and excess rainfall seasons, their impacts on society and finding relationships with regional circulation and important modes and ocean-atmosphere cryospheric and land surface features have been examined in varied contexts in the last 50 years at the Institute. Even empirical base for predicting the seasonal rainfall based on three teleconnections, Eurasian, snow coverage, global surface temperatures, global SSTs, etc. were examined in several studies [7, 9, 95, 102, 109, 114 – 118, 127 - 138]. However, success has been limited on operational forecasting of seasonal monsoon rainfall. The dynamical basis of such prediction efforts have started in the Institute since 1990's and this would be discussed as a separate discipline under climate modeling.

9.3.3 Diurnal variability, extreme events, onset of monsoon, intraseasonal variability, effect of orography on rainfall, etc.

Diurnal variability of the rainfall and pentad-wise rainfall etc. were also examined. It was found that three different regimes of diurnal rainfall fluctuations exist over India viz. with maximum in the afternoon, late morning hours, and late night – early morning hours. Pentad rainfall analysis showed an important singularity of minimum rainfall in the season which was found to occur in pentad 45 (mid-August) rainfall climatologically. This singularity could be linked to the preponderance of epochs of break monsoon and north-south oscillation of monsoon trough, now known as 'August Climatological Break'.

In another new finding recently, it was determined that since 1950s there has been increase in the incidence of heavy rainfall events over central India accompanied by decrease in the incidence of low rainfall events [211- 213, 311, 346]. Climatology of the monsoon depressions, cyclonic and severe cyclonic storms in the north Indian Ocean was examined for trends. The Poisson probability model was found to fit the cyclonic storm series and a quasi-biennial oscillation was observed in monsoon depressions. During the last decade climatology of the low pressure systems (LPS) (low pressure area and depressions) in the monsoon system has been examined in different ways. It is found that though depressions have shown significant decrease in the last 3 decades but there is no reduction in the frequencies of LPS. Possible reasons for the decrease in monsoon depressions have been sought in the decrease in monsoon zonal flow and decrease of meridional SST gradients over the Bay of Bengal.

Another area of importance, studied from climatological aspect, has been the onset of monsoon over Kerala, stagnation in the advance of monsoon and possibility of determining monsoon onset using not only the rainfall but mid-upper tropospheric meridional temperature gradients over the country. It was also noted that the winter to summer transition is a slow process starting from February onward in the upper troposphere and near the surface. As the pre-monsoon season advances, the upper tropospheric transition and near-surface transition descend and ascend respectively and by the time of monsoon onset, the two types of changes meet at the middle troposphere.

Examination of data for the normal monsoon year of 1967 using several atmospheric parameters, in collaboration with Prof T.N. Krishnamurti's group at Florida State University, showed the prevalence of quasi-bi-weekly oscillation in the different components of the regional summer monsoon system ***(Krishnamurti T.N., Bhalme H.N., Oscillations of a monsoon system Part I Observational aspects, Journal of Atmospheric Science, 33, 1976, 1937-1954).*** Since then, research on this quasi-bi-weekly oscillation of the monsoon system has been continued at the Institute using observations and modeling technique.

Institute also played a key role in establishing the spatio-temporal scale of the northward propagating monsoon intraseasonal oscillations (MISO) facilitating development of theories of MISO subsequently [48].

It has been well known that orographic features influence rainfall. Theoretical studies were performed to form a model of the orographic effect of Western Ghats on the rainfall. Also, mountain wave over NE India in winter and Western Ghats in summer monsoon season were examined theoretically as well as through the study of satellite observations on the mountain waves. Another feature examined was the forcing of the lee trough over Peninsular India in the lower troposphere. It was shown that this quasi-stationary trough was forced by the Western Ghats and a numerical modeling study confirmed it.

9.4 Dendroclimatology

A new discipline of palaeoclimatology was added in the Institute in 1970s. To begin with, efforts were focused to study dendroclimatology of western Himalayan tree species to extend the instrumental records of rainfall backward with the help of study of tree rings of certain species (Deodar). Several teams led by Dr. G.B. Pant, visited difficult areas of western Himalayas to obtain specimens of tree cores. A specialized laboratory for dendroclimatological studies was set up at the Institute. Calibration of tree rings data was done with past instrumental records and with the proxy data based on tree ring record was created. Later, such work was extended to central and eastern Himalayas and recently for the tree species (teak) of Peninsular India. The dendroclimatological activities at IITM have

recently been enhanced. A Tree-ring density measurement system has been acquired which includes Dendro-2003 Workstation, Dendro X-Ray and Dendro-cut machines for measuring the earlywood, latewood density and maximum-minimum density along with tree-ring width parameters for dendroclimatic reconstructions. A Stable Isotope Ratio Mass Spectrometer laboratory has also been established for determining the isotopic ratios of a variety of natural archives such as tree rings, corals, speleothems, varves etc. to understand the past climatic processes and environmental changes in different time scales [214-247].

Dendroclimatology Lab

Tree-ring Density Measurement Systems

Samples for Tree-ring studies

Gas Chromatography Lab

Stable Isotope Ratio Mass Spectrometer

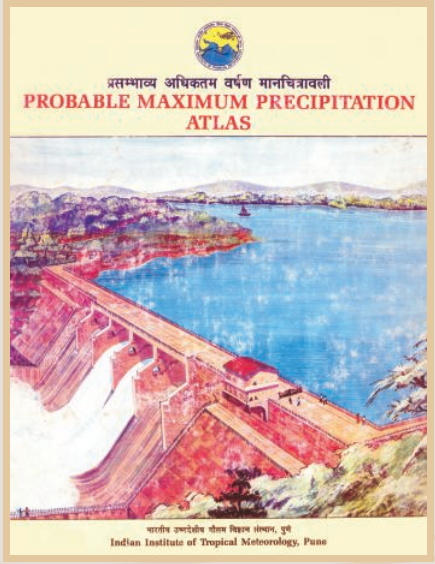
Sample Processing Lab

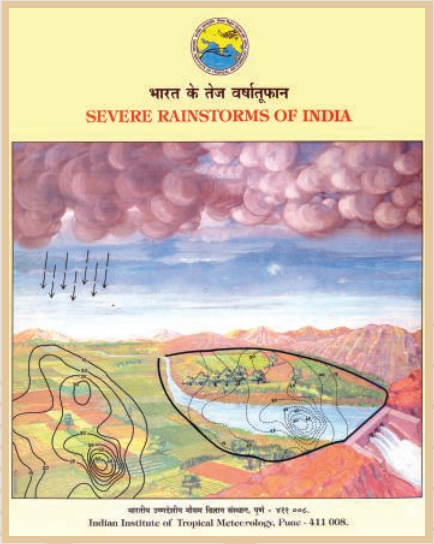
Field Campaign for Tree-ring Sample Collection

9.5 Hydrometeorological Studies

A significant amount of work has been done at the Institute on Hydrometeorology of India based on daily rainfall data such as epochs of heavy and exceptionally heavy rainfall, probable maximum precipitation (PMP) for 1-,2-, and 3- day basis, rainstorm intensity - area relationship for different river basins, design storms for dams constructions, rainfall associated with transient disturbances resulting in three favourable tracks of heavy rainfall over the country, rainfall distribution patterns in contrasting monsoon seasons, sub-regional rainfall studies, rainfall potential of monsoon transients, sub-Himalayan and Himalayan rainfall, frequency of monsoon floods, optimization of rain gauge network and several other aspects of the hydrometeorology [248 – 292]. This work has direct relevance to utilization of the water resources of India and for the engineering community in the country working on building dams, canals, culverts, bridges, etc. Since extreme rainstorms in different river catchments and the PMP information are frequently needed by water resources engineers, the Institute has published two atlases viz. Probable Maximum Precipitation Atlas and Extreme Rainstorms over River Basins of India.

Enormous amount of utility-oriented work done as part of the hydrometeorological studies have found favour with the Central Water Commission of India, Ministry of Water Resources, water resources agencies of state governments in their own work as well as work undertaken under the World Bank funded Hydrometeorology Project in India.





9.6 Climate Change

Anthropogenic climate change has become a hot topic of climate research since 1980s. As data on Indian temperature and rainfall extend to late 19th century, past observations were analysed to isolate any signature of climate change in these two parameters. Earlier studies on rainfall series during 1920s to 1960s had found that it would require several decades of data to determine climate change in rainfall. Since rainfall data were available from 1870 onward its analysis did not show any definite trend or change in the rainfall series but multi-decadal fluctuations were found. The annual temperature series, examined for the first time at the Institute in 1980, showed a definite warming trend over most of India which has now reached about a 0.6°C to 0.8°C per century for the whole of India [161, 212, 293 - 315]. Several studies on the analysis of data on seasonal basis and for the minimum and maximum surface temperatures have been carried out which find mention in the IPCC reports.

Studies on climate prediction and climate change over India, using climate models (stands above atmospheric general circulation models and coupled ocean-atmosphere models) have become central to the present and future research foci of the Institute. The Climate and Global Modelling Division (CGMD), and the Centre for Climate Change Research (CCCR) of the Institute have launched a massive initiative to address the problems connected with climate modeling and climate change. Adequate computing resource is now made available with the installation of High Performance Computer and the next decade would show important results.

Modeling climate system for monsoon studies

Earth's climate system is governed by complex interactions between the atmosphere with its chemical composition and ocean, cyrosphere and the land surface (vegetation/biosphere). It remains in a stable state around its mean on centennial scale but changes in climate can occur due to natural and human induced activity. Climate has its variability due to natural causes on millennial, centennial, decadal and inter-annual scales as a result of complex interactions between the components of the climate system. Humanity at the present stage is confronted with the possibility of climate change due to increasing human activity as a result of enormous energy consumption drawn from fossil fuel burning as well as degradation of land surface (deforestation, desertification, land-use change, etc.). Thus, since 1980s, enormous amount of research has been undertaken, globally, firstly to simulate the global climate, using fast computers, on annual, seasonal and monthly scales and secondly to understand its sensitivity to various processes in the interacting climate system. IITM also began to investigate the monsoon climate system within the scope of the global climate system. For this purpose, two approaches have been followed since 1990s. First approach is based on analyzing the results of global atmosphere and coupled ocean-atmosphere models, run in advanced countries of the world with respect to monsoon simulation, and its sensitivity to various surface boundary conditions (SSTs and snow cover) as well as doubling of CO_2 etc. In the second approach, global models have been adopted and used for climate simulation and determining the efficacy of models for diagnosing as well forecasting of inter-annual variability of the regional monsoon system. Some highlights of the research done on these aspects is summarized for (i) simulation of Indian Ocean circulation and diagnosing the source of its phenomenological aspects, (ii) adoption of a few atmospheric general circulation models (AGCMs) for monsoon climate simulation and using them for studying IAV of monsoon and for long range forecasting of monsoon seasonal rainfall over the country, (iii) adoption of coupled ocean-atmosphere models for the same purpose as stated above for CGCMs (iv) analyzing century scale runs of coupled models with double the CO_2 of the present state for diagnosing climate change, and (v) using regional high resolution atmospheric models with boundary values drawn from a coarse resolution CGCMs to investigate impact of human induced climate change on the monsoon rainfall. A large number of research papers from the Institute have appeared on the above topics and only brief account is presented in the following paragraphs [7,9,53,109,134,144,145,148,159,316-389].

9.7. Application of Atmospheric General Circulation Models (AGCMs) for Monsoon Diagnosis and Long-Range Forecasting of Summer Monsoon

With the setting up of the Global Modeling Division of IITM in 1993, efforts were directed to use AGCMs for monsoon understanding and long-range dynamical forecasting of monsoon. For this purpose a suite of AGCMs were ported and at first, their capability for simulation monsoon circulation and rainfall was systematically examined. A few of the

models were integrated for 20 years to prepare their climatology for monsoon simulation. Within the scope of a model, its behaviour for simulating the transient disturbances of the monsoon season and their structure was also examined [29, 373, 390, 391].

After satisfying that the models could efficiently simulate large scale features of the monsoon circulation, the models have been applied for long range forecasting (LRF) of seasonal rainfall by observed forecast SST conditions and the forecast supplied to IMD for the last 5 years or so. The Institute also participated in a national campaign, known as Seasonal Prediction of Indian Monsoon (SPIM), launched in 2004, in which AGCMs available with different organizations were intercompared for the LRF of monsoon. The model of the Institute was found to perform well in the SPIM intercomparison ***(Gadgil Sulochana and Srinivasan J., 2011, Seasonal prediction of the Indian monsoon, Current Science, 100, 343-353).*** The results of the SPIM for dynamical LRF by using AGCMs were mixed and hence, the Institute has recently decided to apply coupled ocean atmosphere modelling approach for LRF of monsoon within the scope of the Monsoon Mission established by the MoES for this purpose. Latest version of the NCEP/NOAA coupled system forecast model has been installed at IITM and its use for LRF of monsoon will be evaluated. It is now recognized that LRF of the Indian Summer Monsoon rainfall is a very complex problem and progress is likely to proceed on slow trajectory. Computational power is now available with the Institute to work systematically to tackle this problem. Institute also intends to apply statistical post processing, downscaling and bias corrections for each grid point and even make a super ensemble based on different models run in India and other world centres to make dynamical LRF of monsoon more skillful. It is hoped that concerted research on the complex field of seasonal monsoon prediction may lead to more skillful prediction for predicting performance of extreme seasonal monsoon rainfall over the country.

9.8 Major Results from Field Programs on Summer Monsoon

Institute scientists took active part in all the field programmes, national as well as international, organized for better understanding and prediction of the regional monsoon system. They also extensively analyzed the data sets. Major findings of the Institute scientists from the analysis of field data are summarized below [2, 6, 10, 11, 20, 48, 51, 52, 76, 77, 392 – 411]:

- Most of the moisture flux entering west coast of India, during the monsoon season, results from the evaporation over the Arabian Sea. Some other researchers also showed that the cross-equatorial water vapour transport also contributes substantially to the moisture flux entering India across the West Coast. Also, water vapour flux during an active spell of monsoon was worked out
- Detailed dynamical structure of a new synoptic entity, now known as mid-tropospheric cyclone, which produces very heavy rainfall for 3-5 days over Konkan and Gujarat coasts, was diagnosed from IIOE aircraft probe data.
- Mean monthly wind charts for the Indian Ocean region for standard vertical levels in the troposphere were prepared. The charts showed the existence of double equatorial trough on either side of the equator in the lower troposphere. This entity plays a vital

role in monsoon processes. Later studies with satellite data have shown the existence of a marked band of the near-equatorial cloudiness between 5°N-5°S and 70-100°E which fluctuates in opposite sense to the major summer monsoon cloud band along 20-25°N. The dipole-like structure of organized convection is now regarded to play important role in monsoon active-break cycle on intra-seasonal (IS) scale as well as on drought-excess monsoon oscillation on inter-annual (IA) scale.

- Satellite observed cloudiness data were examined for several years in relation to near-equatorial cloudiness. Spectral analysis of satellite cloudiness showed the existence of 4-6 days and 10-15 day oscillation. A detailed day to day analysis of monsoon cloudiness revealed existence of a prominent low frequency 30-50 day oscillation in monsoon in which a near-equatorial cloud band progresses northward to 20-25°N to activate the monsoon trough clouding after a break spell in the monsoon. This was a major new finding which has attracted the attention of researchers world-wide in the last 30 years [48]. Many modeling and diagnostic studies have appeared in the literature about this IS variability (ISV) of the monsoon and the subject still attracts attention of monsoon researchers and dynamical modelers. The sea-saw in monsoon cloudiness between 20-25°N and 5°N-5°S over the Indian Ocean appears to be the key factor in ISV of the monsoon and is still a challenge for the dynamical prediction models.
- Individual droughts of 1972, 1979, 1987, 2002 and 2009 have been studied in detail and the role of regional and planetary scales anomalies in the coupled ocean-atmosphere system were diagnosed for the occurrence of droughts.
- Mean heat and moisture budgets of the monsoon trough were quantitatively examined and their role in the sub-seasonal oscillation of the monsoon was examined based on MONEX-79 data as well as for some other years.
- A series of investigations involving ocean-atmosphere interactions on the global and regional scales have been undertaken using the data of field experiments obtained from 1963 to 2009.
- FGGE GARP Summer MONEX-79 data sets were extensively used to characterize the following aspects:
- Linkages of monsoon events over India with circulation features of the south Indian Ocean.
- ITCZ over the north Indian Ocean and northern West Pacific and interaction between the two regimes.
- Contrasting features in tropospheric circulation during the years of good and bad monsoon.
- MONEX data were used to indentify relationship between moisture convergence and convective activity over India. Also, detailed diagnosis of heat sources and moisture sink produced new insight in to active break cycle of monsoon.

- Detailed diagnostics of the structure of monsoon depressions, vertical motion field and energetics were preformed in several studies.
- In another diagnostic study, it was shown that the multi-layered clouds are the main modulators of IR flux in the troposphere and the differential radiative cooling rates, existing between cloudy and cloud-free regions in the vicinity of a synoptic scale disturbance could play important role in the dynamics of the monsoon disturbances.
- Several sensitivity experiments were performed with available dynamical prediction models to identify the role in which crucial extra observations play in the dynamical prediction of monsoon transients [109, 347, 352, 377, 384].

9.9 Studies with Recent Field Programs

MONTBLEX data were used for study of ocean-atmosphere interactions. Also, the interactions between the usually moist eastern end of the monsoon trough and its usually dry western end were examined as a transient monsoon disturbance moves across the monsoon trough region. Similarly, LASPEX data were analyzed to identify the role of transients in moisture convergence and boundary layer processes over the western India. Boundary layer processes over the Bay of Bengal – east coast of India, eastern Arabian Sea and west coast of India were examined with BOBMEX and ARMEX data sets.

9.10 Atmospheric Physics

Studies on atmospheric physics at the Institute broadly covered the areas of cloud physics, weather modifications, atmospheric aerosols and atmospheric electricity. Research on these areas has produced large number of good publications in national and international journals. Only the highlights of the research efforts in this discipline are summarized.

Cloud physics

Research on cloud physics began in India in 1955 with the establishment of Rain and Cloud Physics Research (RCPR) unit at the CSIR, New Delhi. With the formation of the ITM, the CSIR transferred this unit to ITM in 1967. The Institute launched a well organized research programme in 1967 consisting of laboratory studies and field studies aimed at understanding the microphysics of clouds and precipitation mechanism in tropical monsoons. It also undertook the study of warm cloud modification for enhancement of rain. Laboratory experiments were carried out in a special cold chamber to study ice nucleation processes under controlled conditions. Freezing of water drop under supercooling conditions and a dynamic effect of evaporation on supercooling were examined which could partially explain the phenomenon of multiplication in supercooled clouds. Also, a variety of seeding materials were identified. The efficiency of seeding materials for the collision-coalescence of water drops under the influence of electric field was also examined in the laboratory. The role of electric field in precipitation formation was discussed based on the results of laboratory experiments [412-424].

Cloud seeding experiments

The Institute carried out Cold Cloud Seeding Experiment during winter seasons of 1968 - 1975 using Silver Iodide as seeding agent and radar observations of aerial echo-coverage and echo-height of clouds within 50 km around Delhi. Analysis of echo-coverage indicated positive result in four seasons and negative in three seasons. The analysis based on echo-height indicated 11% increase in rainfall as cumulative result. The result was statistically significant in both the cases. The Institute organized another field experiment at Thirunallar (near Chennai) during the SW and NE monsoon seasons between 1973 and 1977 using ground based generators, but the results were not found to be significant for rain enhancement. Aerial experiment for warm cloud seeding were organized in 1973 around Pune and carried out for a long period of 11 years till 1985. The seeding was done under randomized process using sodium chloride powder as the seeding agent. The experiments yielded a large number (over 120) of pairs of days but statistical analysis did not yield categorical results with regard to the efficiency of warm cloud seeding for rain enhancement. However, seedability criteria for isolated and organized areal cloud systems were determined. Potential for enhancing rain was found to be higher for areal cloud seeding system. Dynamic cloud seeding effect was found in massively seeded clouds in the form of rise in cloud-air temperature by 1-2°C, increase in liquid water content up to 200% before the onset of rain and increase in vertical thickness of clouds from about 1.5 km before seeding to 2.5 km after seeding. The cloud microphysics parameters and atmosphere electric parameters, monitored before and after the seeding operations, also showed dynamic effect of sodium chloride seeding. Assistance was provided to various state governments for their operational cloud seeding experiments.. As the experiments were not done on highly scientific bases, the results were not evaluated. The Institute also carried out work in 1970s and 1980s on numerical simulation of weather modification experiments and numerical modeling of monsoon clouds. These experiments resulted in several research papers. The results of numerical modeling of warm clouds showed sensitivity to cloud electric activity, cloud-drop spectra, variance of in-cloud temperature and humidity. These features showed that monsoon clouds cannot be explained by a simple entraining cloud model. However, the predicted rain-drop size spectrum closely followed the Marshall Palmer distribution law. Past weather radar data obtained from the RCPR Delhi was examined from different perspectives such as growth and decay rates of clouds and the statistics on the depth of convective clouds at Delhi [425-434].

Currently, since 2009, Institute has launched a massive field programme under the Cloud-Aerosol Interactions for Precipitation Enhancement Experiment (CAIPEEX) to advance research on the role of cloud and aerosols and cloud-radiation feedback on the physics of rainfall and microphysics of clouds. The Experiment uses instrumented aircraft for collection of data. In the next few years, the results are expected to enlighten scientific community about the central problem undertaken under the CAIPEEX over

monsoon tropics. CAIPEEX-2009 data sets over different parts of India have been used in several important studies to document the role of cloud condensation nuclei (CCN) in cloud formation, importance of effective cloud radius for rain formation and role of aerosols with CCN in cloud processes under dry and wet monsoon conditions.

9.11 Atmospheric Electricity

An Atmospheric Electricity Laboratory was established at the Institute in 1980. Measurements of space charge were carried out at three different heights close to ground during the Solar Eclipse of 16th February 1980 [435–438]. Diurnal variability in space charge was found and the changes in polarity were found to be abrupt. Instruments to measure the electric charge were indigenously fabricated at the Institute. Field mills to measure gradient of electric potential at ground surface were fabricated at the Institute. These field mills have been used in the field experiments on thunderstorms under different environments in India. Other prominent studies on atmospheric electricity were related to:

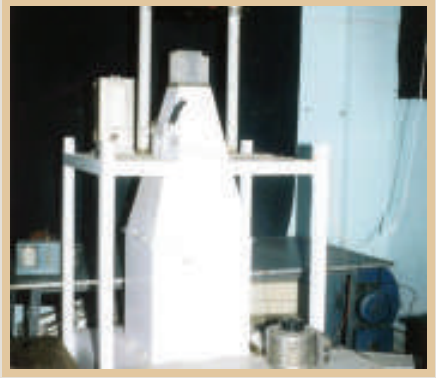
- Determination of cloud electrification and precipitation mechanism [439-443].
- Electric atomization of water drops [444,445].
- Cloud electrification and microphysical characteristics of clouds [446-450].
- Thunderstorm electrification around Pune in the pre- and post- monsoon season [451-455].
- Diurnal variation in the electric field associated with ionospheric processes and vertical coupling of electric field and solar influence on atmospheric electric fields [456-466].

Thunderstorm incidence over India in different seasons formed another important area of research and resulted in a number of papers. Recent studies in the area have been chiefly carried out on the following aspects:

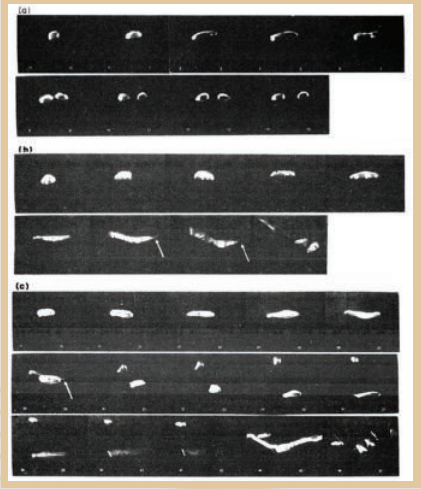
- Lightning strokes and intensity of thunderstorm and rainfall at Pune and in its vicinity [451,452,460,467-474].
- Scavenging of atmospheric ions by drifting snow at Antarctica, diurnal variation of electric field conductivity at Antarctica and physical properties of aerosols at Antarctica [475–482].
- Effect of coagulation on the asymmetric charging of aerosols [483-485].
- Scavenging of aerosol [478,486-489].
- Atmospheric conductivity and background aerosol concentrations [456,458,490-493].
- Survey of atmospheric electricity parameters in seas around India [455,492,494-509].
- Time conductive and frequency distribution of point discharge current over Pune and similar other studies [472, 510- 513]. The Institute is now planning to establish a rather high latitude laboratory for the study of cloud physics of monsoon clouds at a hill station (Mahabaleshwar)) near Pune at an altitude of about 2 km.

Laboratory experiments with vertical wind tunnel

Wind tunnel consists of a blower which sucks the air, a divergent section, a reservoir, a section having a honeycomb and three wire-mesh screens, a contraction section having a cross-wired screen at its downstream-end and a test-section. Honeycomb and screens minimize the turbulence in the flow. To maintain the desired airflow pattern and velocity well above the crossed-wired screen and to exert a back pressure on the airstream, a back-pressure plate is placed about 22 cm above the test-section. A water drop of millimeter size could be suspended above the test-section for many minutes. The measurements of turbulence level in the airstream in test-section are done with a hot-wire anemometer. Water drops of required size formed from the triply distilled water are introduced with a calibrated pipette, in the test-section of tunnel where the turbulence level in the air stream is less than 0.8%. Since the size of a water drop continuously changes due to its evaporation while being suspended, the flow of the air stream in the wind tunnel is continuously controlled with a variac so the drop remains suspended above the test-section of the tunnel at its terminal velocity. The wind tunnel is located inside an air-conditioned room and the temperature and relative humidity of the airstream is controlled between 28 and 31^{0}C, and 30 and 40%, respectively. The atmospheric pressure of the air in the laboratory is about 950 hPa. In order to electrically charge the water drops one end of a wire connected to a power supply is dipped in water in the pipette. The voltage to which the wire should be raised to get a positive charge of 10^{-10}C is calibrated for different drop sizes. The wind tunnel helped to study how vertical and horizontal electric field lead to distortion and break up of rain drops having implication in determining the observed drop size distribution of raindrops in thunderstorms [514-517].



Wind Tunnel



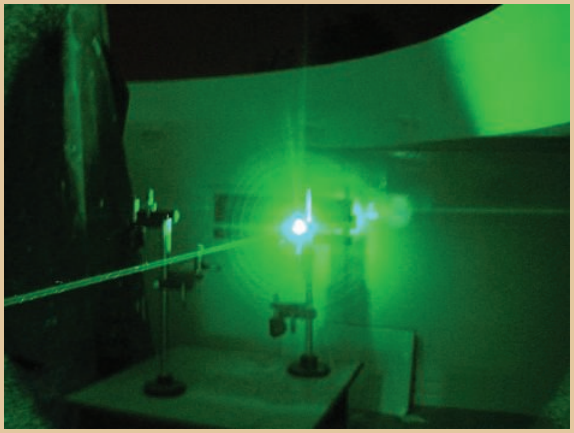
Electrified Water Drops

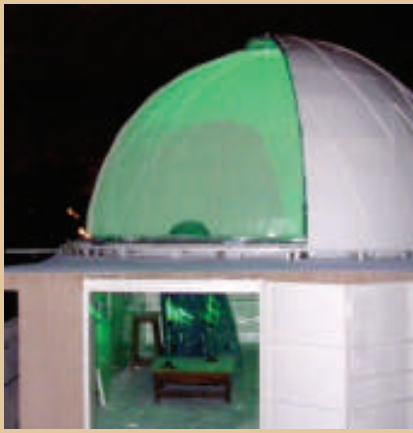
9.12 Atmospheric Aerosols

The Institute initiated work in 1980s on the study of atmospheric aerosols in relation to pollution and study of air chemistry. Toward the end of the decade of 1980s, this work was organized at Pune for the purpose of long term monitoring of aerosols with their possible effect on local scale rain processes. The atmospheric aerosol laboratory now houses a variety of aerosol LIDARS. A long term series of Aerosol Optical Depths (AOD) at Pune since 1988 shows gradual increase in AOD caused by urbanization [518 - 521]. Various physical properties of the aerosols have been determined and source apportioning studies have been carried out [522 - 524]. Aerosol effect on UV B radiative has been examined. Increasing aerosol load has been found to have dimming effect on incoming solar radiation [525].

The Institute played important role in the atmospheric aerosol field campaigns at national and international levels undertaken in India. A large amount of scientific studies relating to physical properties of aerosols over India, role of aerosols in cloud processes and in monsoon fluctuations and similar several other aspects, have resulted from the Institute scientists. The study is being further enhanced through the recently undertaken a major field campaign of the CAIPEEX deploying instrumented aircrafts.

Atmospheric Aerosol Lab





Newtonian Telescope

Mobile Doppler LIDAR Profiler

Mobile X Band Radar

Raman LIDAR

Microwave Radiometer Profiler

Micro-rain Radar

Laser Ceilometer

Sky Radiometer

Distrometer

9.13 Rain Water and Atmospheric Chemistry

Rain water chemistry

Special equipments like atomic absorption spectrometer was installed at the Institute in early 1980s for chemical analysis of rainwater samples collected at Pune and other environments in India. Research on rain water chemistry has yielded vital information on (i) the chemical constituents of rain water for the first fraction as well subsequent fractions, (ii) the role of soil dust for maintaining alkaline nature (non-acidic nature) of rainfall over India, (iii) role of industrial and agricultural practices in modulating the rainfall chemistry around important cities, and (iv) role of industrialization / urbanization in changing the pH value of rainfall. Observations on gaseous and particulate pollutants were made during special field experiments on land mass of India and neighbouring seas.

Special Field Experiments

Rain Water Chemistry Lab

Atmospheric Chemistry

Several trace gases such as ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide are measured at the Institute. This work was recently extended to Delhi metropolitan Area during the 2010 Common Wealth Games. Trends in total ozone and surface ozone data have been examined and they gave insight into ozone depletion and role of air pollutants in enhancing surface ozone. Also, an inventory of pollutant gases has been prepared for India. Trends in ionic composition of troposphere to lower thermosphere under the influences of global change have been determined. Stratospheric chemical processes have received special attention and recently, a global model for atmospheric chemistry has been installed. Impact of geo-engineering on ionic composition of stratosphere has also been analyzed.

UV Spectrometers for measuring trace gases in the atmosphere were fabricated and used for studying vertical distribution of trace gases. The Institute now serves as a permanent Centre of Environmental Information System (ENVIS) of the Ministry of Environment and Forests (MoEF) and regularly publishes the ENVIS Newsletter. Atmospheric chemistry research has been further intensified recently by the establishment of a laboratory for the analysis of green house gases. It is hoped that bottle samples from different environments of India will be collected for analysis under highly standardized conditions.

9.14 Dynamics of the Middle Atmosphere

Middle atmospheric studies have been carried out at the Institute since 1970s. In the initial period, analysis of Soviet M-100 rocket-sonde data, for the first time revealed the presence of sudden warming in equatorial region resulting in strong flow of easterly winds in the tropical stratosphere. Linkages of summer-season low-latitude warming with summer monsoon activity over India were found which showed the contrasting features of stratosphere-mesosphere in contrasting monsoon seasons (1972 for drought and 1973 for good monsoon) over three stations at Thumba, Ascension Island and Kwajalein [302-305]. Summer time warming of middle atmosphere was associated to vertical propagation of Rossby-gravity waves under suitable wind conditions. A quasi-periodicity in temperature at 55-65 km altitude was found by the examination of rocket-sonde data for Thumba, suggesting some interaction between stratosphere major warming at high latitudes and mesospheric warming at low latitudes. Geomagnetic storms activity was related to variability in NE monsoon rainfall [526 - 527]. Recently middle atmospheric processes relating to global change induced ionic changes at troposphere to lower thermosphere, solar response of temperature over equatorial middle atmosphere, long-term changes of solar irradiance on stratosphere-ionosphere system, have also been examined [528 - 533].

9.15 Atmospheric Boundary Layer Studies

Research on atmospheric boundary layer (ABL) began at the Institute in the middle of 1960s in the Palghat gap experiment in September-October 1966. The observations showed fanning out effect of near surface winds (difference and divergence) at the exit of the gap region with strong divergence (50×10^{-5} sec^{-1}) in afternoon hours. A conceptual model of ABL in the gap region was proposed [306, 534 - 537].

Later, ABL was examined as part of the support to the weather modification studies over the Deccan Plateau. The ABL over the Deccan plateau was classified under four categories depending upon thickness of the mixed layer and potential temperature gradient within the ABL. During the summer MONEX Experiment in 1979, high resolution aircraft probes were made in a 30 km flight path at 14 vertical levels over the Arabian Sea. Analysis of these data showed detailed structure of the ABL off the west coast of India with dry adiabatic and stable layers alternating with each other. The slope of the dry bulb temperature spectra was found to be less than - 5/3 and wet bulb spectra was found to be higher. It was also found that the wind flow in the ABL is often organized in helical secondary circulation, aligned parallel to the mean flow in the form of vortex rolls or large eddies.

Several instruments were designed and acquired for ABL studies during 1970s to 1980s such as temperature profile indicator, Layman hygrometer, eddy correlator etc. to measure seminal heat fluxes. Also, an instrument to measure Bowen's ratio, a Kytoon payload to measure temperature up to 1000 meter height, Doppler SODAR, etc. were also deployed to understand ABL processes. These instruments were used in several field campaigns. The Institute initiated a rigorous programme for the monsoon ABL studies

toward the end of 1980s which was followed up to 1990s. A national field experiment under the name Monsoon Trough Boundary Layer Experiment (MONTBLEX) campaign was launched in 1989-90 with the Institute as the nodal agency, for studying the role of ABL processes as the monsoon evolves into different phases over the eastern moist end of the monsoon trough. Both the unstable and stable characteristics of the monsoon trough ABL and the fluctuations in the soil heat flux, sensible heat flux and latent heat flux were examined in contrasting synoptic situations. Latent heat flux (sensible heat flux) was found to be much higher (lower) in unstable (stable) atmospheric conditions. Another field experiment known as Land Surface Processes Experiment (LASPEX) was undertaken for two years during 1995 and 1996 over western part of India in which five instrumented surface layer towers were used (four in a quadrilateral form and the fifth at the centre of the quadrilateral). ABL fluctuations on season basis and in contrasting wet and dry conditions were examined from the heat flux measurements as well as from Doppler SODAR data. ABL structures on bare soil versus vegetated soil were also diagnosed. Observations were also used to understand the reversals in mixing ratio in marine boundary layer and mixing processes in the monsoon convective boundary layer along with the thermodynamics of downdrafts in the monsoon convections. Conserved variable analysis of convective boundary layer characteristics were examined over different environments of India based on radiosonde data. Based on the radiosonde data of research ship transits in the Bay of Bengal, Arabian Seas and equatorial Indian Ocean, characteristics of ABL were identified in different experiments. Also, the character of ABL fluctuations in the monsoon experiments, e.g. MONTBLEX and ARMEX during 1998-99 and 2002-2004 were examined with the ship and coastal radiosonde ascents. For ARMEX, a special boundary layer experimental site was established on coastal Goa in the premises of the National Centre for Antarctic and Ocean Research (NCAOR), Goa. Currently, ABL is being studied as a part of the CAIPEEX studies to understand the role it plays in convective processes which ultimately may influence the cloud aerosol interactions.

Instrumented Towers

9.16 Studies of Dynamical Instability of the Monsoon Region

Studies on applying methods based on dynamic instability of the atmosphere for the growth of monsoon disturbances began in the early years of the ITM [541]. Since then and up to 1980s, different theoretical approaches viz. baroclinic, barotropic and combined barotropic - baroclinic - CISK (Conditional Instability of the Second Kind) instability approaches, have been applied by the different scientists of the Institute to understand monsoon cyclogenesis. The first study in 1967 was related to apply the linear quasi-geostrophic baroclinic instability theory with two layers in the vertical. The results did not support the instability of the large scale monsoon flow under dry state. Subsequently, barotropic instability theory was applied which supported a small growth in the disturbances in the zonal flow. Later, in 1980, it was shown that the observed strong low level westerlies and the strong upper level easterlies could satisfy the necessary conditions for baroclinic instability. Thus, high resolution 20-layer linear quasi-geostrophic stability analysis was performed in the highly resolved boundary layer in the lower troposphere. This study indicated the preferred growth of the initial disturbances on the zonal flow such that the computed structure of the amplifying disturbance was found in close agreement with the observed scale of monsoon depression. Further, in two observational studies, performed in 1981 and 1983, of a monsoon depression in the Bay of Bengal on 3 July 1979, showed that both barotropic and baroclinic processes contributed to its intensification. The result also showed that the transport of kinetic energy from upper layer to lower layer was the source of energy for the lower layer. However, there was deficiency as the observed monsoon disturbance moved westward whereas the theoretically simulated disturbance moved eastward. This difference between observations and theory was explained through analytic solution of Omega equation for vertical motion [551]. Orography was found to be an important factor for inducing westward motion in the lower troposphere. Existence of vertical transport of cyclonic vorticity from boundary layer to the upper layer was found to be necessary, which was earlier diagnosed by another scientist of the Institute by using balance Omega equation, taking place through cumulus convection [545]. Again the role of Ekman boundary layer processes in monsoon cyclogenesis was determined numerically in another study with a quasi-geostrophic model [550].

A primitive equation barotropic stability analysis of 700 hPa zonal flow was performed in a monsoon onset vortex flow with MONEX data of 10-14 June 1979 [404, 539, 540, 547, 552]. The study revealed many observed features of simulated disturbance to agree with observations. Barotropic instability theory was applied to the upper troposphere easterly flow of the Indian summer monsoon, and the flow was found to promote growth of disturbance at a horizontal wavelength range of 5000-7000 km which moved westward with an average speed of 10^{-12} ms^{-1} [538, 548, 549]. Also, relatively small deviations of the core of the Tropical Easterly Jet in the summer monsoon upper troposphere have been explained theoretically.

A simple quasi-geostrophic thermally forced model forced by annual diabatic heating in the presence of Ekman Boundary Layer friction was applied to simulate the annual cycle of the monsoon with annual mean zonal flow as initial conditions. The model was able to simulate the observed structure of the summer monsoon flow over Asia. Also, a computationally efficient spectral technique was applied to develop a P.E. barotropic model in spectral space [543]. Besides these theoretical studies, several observational studies

were also done under this area with regard occurrence of two Meridional Cells on either side of the equator and with a cell at the equator separating the two Hadley Cells[322, 323]. Also, interaction between the regional Meridional Cell and the Walker Cell in the Indian summer monsoon system was investigated [1, 543]. Similarly, the maintenance of the monsoon trough against friction was examined observationally and it was found that work done by the pressure force is the contributory factor in this process [542].

9.17 Modelling Indian Ocean Circulation and Phenomenological Studies

Theoretical Studies Division of the Institute began working on this problem from 1990 onward as a result of the collaboration between Institute's and Soviet scientists under the Integrated Long Term Programme (ILTP) of the DST. At the beginning of 1990, the Institute adopted a simple barotropic model for simulating the ocean circulation of north Indian Ocean, performed sensitivity studies and for understanding IAV of the ocean circulation and investigated response of the Bay of Bengal to changes in the mixed layer induced by tropical cyclones. IAV of the SST of the tropical Indian Ocean was also investigated [327, 553- 557]. An attempt was also made to numerically simulate the state of the north Indian Ocean prior to the onset of summer monsoon.

The Indian Ocean was influenced remarkably by the Indian Ocean Dipole (IOD) phenomenon in May-November 1994 (a very strong positive IOD event), this aspect was also examined to relate it to unusual ocean-atmosphere condition. Other phenomenological studies for understanding processes in Indian Ocean circulation related to (i) Seasonal heat transport in the north Indian Ocean during contrasting monsoon seasons, (ii) Evolution of IOD events in a simple mixed layer ocean model as well as impact of Biennial Rossby waves on circulation of IOD and IAV of Rossby waves in tropical Indian Ocean in relation to IOD and ENSO, (iii) IAV of upper ocean heat contents in the Indian Ocean, (iv) Response of the Arabian Sea to the local forcing during pre-monsoon heating phase for the season of 2003, (v) Water mass properties and transport in the Arabian Sea from Argo observations, (vi) Simulation of SST in the equatorial Indian Ocean, (vii) Understating of IAV of the atmospheric and oceanic processes in the Arabian Sea in contrasting monsoon seasons, (viii) Seasonal variations of synoptic features over north Indian Ocean during IOD years, (ix) Changing trends in tropical Indian Ocean SST during La Nina years, (x) Variability of mini-cold pool in the southern tip of India from a thermodynamic upper ocean model. Formation of barrier layer near the ocean surface along Bay of Bengal, SE Arabian Sea and tropical southwest Indian Ocean and its impact on local SSTs has been extensively examined through observational and modeling studies in collaborative research within the Institute as well as with other organizations in India [132, 133, 137 - 152].

9.18 Dynamical Approach for Monsoon Climate Change: AGCMs and CGCMs Results

Institute had pioneered observational research in mid-1980s to analyze signatures, if any, for anthropogenic climate change over India. In 1990s, its scientists used the AGCM results of advanced centres in USA for analyzing the climate change over the Indian sector. Recently, Institute scientists could acquire the data of over two dozen CGCM runs under the AR-4 model integration of CO_2 on the monsoon seasonal rainfall over India. It was

found that based on the climatology of the models and their IAV, only 4 models would qualify as good for using their rainfall output with regard to diagnosing climate change in monsoon rainfall by the end of the present century. The study revealed that there is likelihood of the monsoon rainfall to increase by about 5% with little change in IAV by the end of the 21st century [390, 558].

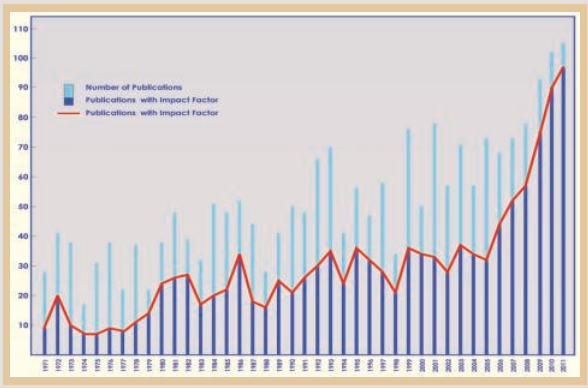
The Institute also did an important piece of work in collaboration with U.K. Met. Office with regard to adopting a regional climate model for South Asia which was being forced at the horizontal boundaries by the output of the global Hadley Centre Atmospheric Model. This modeling research, which formed the basis of India's National Communication at international level, also showed that Indian monsoon seasonal rainfall would show 5 to 10% increase accompanied with more intense rainfall events and decrease of low intensity rainfall events [313, 559]. The model results have been used by other agencies for evaluating the impact of model produced monsoon rainfall climate change for assessing impact on agriculture, water resources, forestry, etc. Further, work for the second National Communication has progressed since 2008.

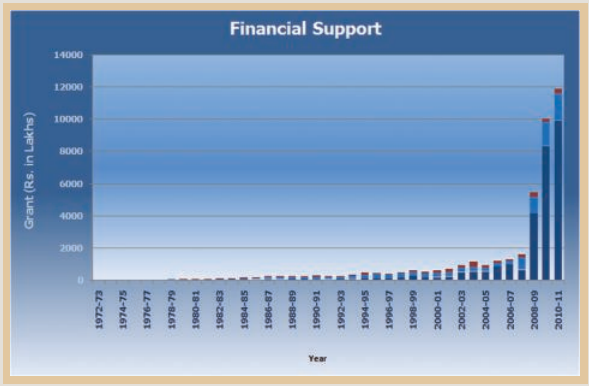
Human-induced climate change of monsoon is of strategic importance for several sectors of Indian economy. It has policy implications too. The Government of India is concerned on the possible emerging impacts of climate change on India's development efforts and fighting poverty reduction. Sustainable development of India on the large scale and development at sub-regional level (state-level) is likely to depend on climate change scenarios. These scenarios have to be understood with regard to building resilience of the development effort to climate change. Vulnerability analyses to the climate change in different states have to be made in order to assess the resilience of the states to monsoon climate change. Also, meeting the monsoon climate change requires preparing the society and economy to bear climate shocks and formulating measures to reduce the ill-impacts. The Institute has recently established a Centre for Climate Change Research (CCCR) under its umbrella which is funded by the MoES. The Institute has plans to give thrust to understanding monsoon climate change, build different scenarios for the country and participate in research along with other specialized centres in the country for study of impact of monsoon climate change on different sectors of economy as well as for risk management, adaptation to climate change and mitigation of ill effects of climate change. For these purposes, understanding monsoon climate change and deciding upon the reliability of various scenarios, based on in-house research and research done in advanced countries is very crucial. Determining uncertainty in regional climate change projections is a crucial area of research. The work at the Institute would hopefully contribute to the Indian Climate Mission Program under the discipline of "Strategic Knowledge for Climate Change".

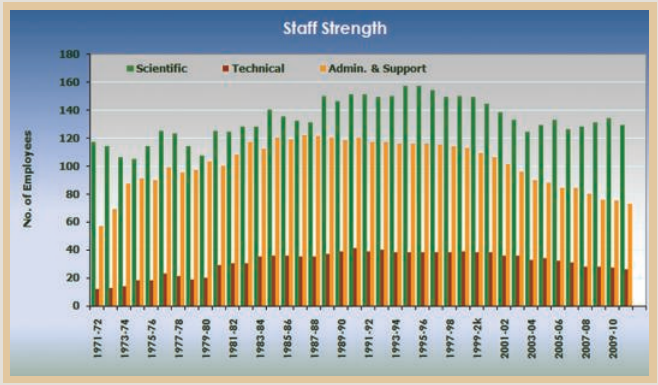
The Institute has brought in a well calibrated change in its research pursuits and priorities. Understanding and prediction of monsoon using dynamical modeling strategy, climate change modeling and prediction, understanding monsoon-aerosol interactions for precipitation enhancement, studies in atmospheric aerosols and atmospheric chemistry and climate variability and factors responsible for it on interannual and decadal scales, are receiving greater attention using observations, modeling and theoretical approaches. Institute is determined to intensively pursue these studies in the forthcoming years to address the societal needs of rapidly developing India.

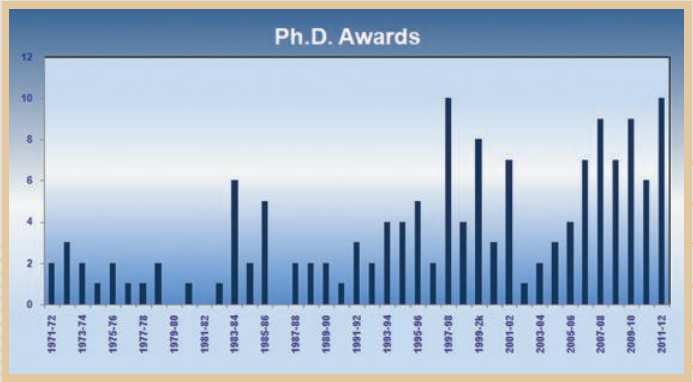
10. Progress in Research Publications

Right from its inception, Institute scientists have strived hard to project their research through publications in national and international journals. Graph given below shows the trend in publications in peer- reviewed scientific journals. The research output depended on the number of scientists engaged for research, number of research Scholars working at the Institute, availability of research infrastructure and facilities for training and international collaborations. The research output increased in the first two decades, remained more or less steady between 1980s to 2000 and has steadily grown in the last decade. For the year 2010, over 100 publications came from the Institute scientists and over 90% of them were published in high impact factor foreign journals. Publications in prestigious foreign journals had started from the very early years of the Institute and this output fluctuated between 30 to 50 percent of total publications in a year up to 2005. However, the Institute has shown a dramatic change where research published in prestigious foreign journal has made a jump in the last five years. The higher visibility of Institute's publications in foreign journals reflects the rising of aspirations of the Institute, which deserves appreciation.


Number of Publications
Publications with Impact Factor
Publications with Impact Factor

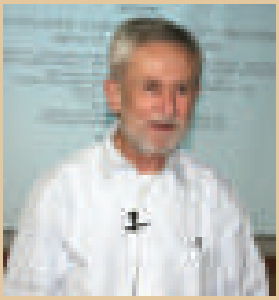

Financial Support
Grant (Rs. in Lakhs)
Year


Staff Strength
Scientific
Technical
Admin. & Support
No. of Employees


Ph.D. Awards

Distinguished Visiting Professors

Dr. Kamal Puri



Prof. John Michael Wallace

Prof. Jagdish Shukla

Prof. Robert Houze

Prof. T.N. Krishnamurti

Prof. Ruby Krishnamurti

Prof. Raghu Murtugudde

Dr. Duane Waliser

Visit of Ministers and Eminent Personalities

Dr. Karan Singh,
Minister of Tourism & Civil Aviation

Shri. Raj Bahadur
Minister of Tourism & Civil Aviation

Shri. P.L. Kaushik
Minister of Tourism & Civil Aviation

Shri. Kapil Sibbal
Minister of Science & Technology

Shri. Rana Jagjitsinh Patil
Minister of State for Agriculture
Govt. of Maharashtra

Shri. Prithviraj Chauhan
Minister of Science & Technology

Prof. G.O.P. Obasi
Secretary General, WMO

Dr. A.P.J. Abdul Kalam

Dr. A.K. Kamra
receiving WMO Young Scientist Award

Dr. S.K. Mishra
receiving Second SAARC Award

Dr. G. Beig
receiving Shanti Swarup Bhatnagar Award

Dr. G. Beig
receiving Norbert Gerbier-MUMM
International Award

Dr. K. Krishna Kumar
receiving Norbert Gerbier-MUMM
International Award

Science Popularisation Activities

International Programmes

- Indo - UK Programme on Impact of Climate Change on Water Resources
- INDO - US (DST - NSF) Projects on Aerosol Studies
- Indo - France Programme for the Study of Sensitivity of the Indian Summer Monsoon to Anthropogenic Climate Change
- UK - India Education and Research Initiative (UKIERI)
- Asia - Pacific Network (APN) for Global Change Research
- Indo - Bulgarian Programme of Cooperation in Science and Technology
- Indo - Swedish Collaborative Programme on Composition of Asian Deposition (CAD)
- Indo -Korean Programme on Seasonal Prediction and Climate Change
- Indo Australian Programme on Monsoon in a warming World
- Indo German Programme on Modern and past Climate Himalayas
- Indo Brazil South Africa (IBSA) Earth System Modelling

National Programmes

- Indian Climate Research Programme (ICRP) of the Department of Science and Technology, (DST), Govt. of India
- Indian Ocean Modelling (INDOMOD) of the Department of Ocean Development (DoD), Govt. of India
- IRSP4 Applications Programme of the Indian Space Research Organization (ISRO), Govt. Of India
- Environmental Information System (ENVIS) of Ministry of Environment and Forests (MoEF), Govt. Of India
- Climate Change Projects of The Energy Resources Institute (TERI)

Collaborative Research

- World Climate Research Programme (WCRP)
- Climate and Variability (CLIVAR)
- International Geosphere Biosphere Programme (IGBP)
- Intergovernmental Panel of Climate Change (IPCC)
- United Nations Framework Convention on Climate (UNFCCC)

Institutional Membership

- American Meteorological Society, USA
- Royal Meteorological Society, UK
- Indian Meteorological Society, New Delhi
- Current Science Association, Indian Academy of Sciences, Bangalore
- Indian Association of Hydrology, Roorkee
- National Association of Geographers India, New Delhi
- Indian Science Congress, Kolkata
- Deccan Geographical Society, Pune
- Computer Society of India, Mumbai
- Indian Maritime Foundation, Pune
- Indian Association of Special Libraries and Information Centres, Kolkata

Appendix I

Membership of Committees

Scientist	Membership of the National & International Committees
Shri D. R. Sikka	International Radiation Commission of the IAMAP (IUGG)
	Organizing Committee of the World Climate Research Programme (WCRP) of the JSC/CCCO Scientific Steering Group for the International Tropical Ocean Global Atmosphere (TOGA) Programme, a Project under the WCRP Scientific Steering Committee TOGA, WMO, Geneva
	WMO-CAS Working Group on Tropical Mid-Latitude Interaction, WMO, Geneva
	Expert, WMO/UNEP Inter-Governmental Panel on Climatic Change (IPCC)
	Expert, Bureau of Inter Governmental Panel on Climate Change (IPCC) in the areas of Climate Modeling, Climatology and Hydrometeorology.
	Inter Governmental Panel on Climate Change (IPCC), UNEP, Bangkok, Thailand
Prof. R.N. Keshavamurty	National Committee on Science and Technology in Developing Countries (CODATA),Indian National Science Academy (INSA)
	National Committee on World Climate Research Program (WCRP), Indian National Science Academy (INSA)
Dr. G. B. Pant	CLIMAT SAT (Climatological Satellite) Programme Definition Group, Indian Space Research Organization
	Project Advisory and Monitoring Committee, Monsoon and Tropical Climate (MONTCLIM), Department of Science and Technology
	Action Plan Committee for the Indian Climate Research Programme (ICRP), Department of Science and Technology
	National Committee on Science and Technology in Developing Countries (CODATA),Indian National Science Academy (INSA)
	Scientific Steering Committee of the past Global Changes (PAGES), a Core Project of IGBP

	Steering Committee of START - SASCOM, a South Asian Regional Programme of START (a project of WCRR, IGBP, HDP)
	Joint Scientific Committee of the World Climate Research Programme (WCRP) (WMO/ ICSU/ IOC)
	WMO Commission for Atmospheric Sciences working on Tropical Meteorology Research
	Expert, Bureau of Inter Governmental Panel on Climate Change (IPCC) in the areas of Climate Modeling, Climatology and Hydrometeorology
	Expert, Committee on Palaeo-climate and Environmental Research
	National Committee of the Indian National Science Academy (INSA) on the World Climate Research Programme
	Project Advisory Committee on the Theoretical and Applied Mechanics under the ILTP with Russia sponsored by Department of Science and Technology (DST), Govt. of India
	Panel on Ocean Environment appointed by the Naval Research Board, Ministry of Defence
	Core Group on Global Warming/Climate Change Constituted by the Planning Commission, Government of India
	Member, Committee National Natural Resource Management System, Planning Commission, Government of India
	First Board of Governors of Government College of Engineering (Pune Institute of Engineering and Technology), Pune
Prof. B. N. Goswami	Scientific Steering Group (SSG) of the International Climate Variability and Predictability (CLIVAR) Programme of the World Meteorological Organization (WMO)
	Joint Scientific Committee (JSC) of WCRP/IOC/ICSU of World Meteorological Organization (WMO)
	Associate, International Centre for Science and High Technology of ICTP, Trieste, Italy
	CLIVAR Monsoon Panel of the International CLIVAR Project of World Climate Research Programme (WCRP)
	CLIVAR Scientific Steering Group (WCRP)
	Editorial Board of International Journal of Climatology

	Science Education Panel of the Indian Academy of Science, Bangalore
	Earth Commission, Ministry of Earth Sciences, Govt. of India
	Expert Committee set up by Prime Minister on Impacts of Climate Change
	Standing Committee on Ocean Resources & Meteorology (SC-OM)
	Steering Committee - National Disaster Management Authority
	SERC (Science & Engineering Research Council), Department of Science & Technology, Govt. of India
	S & T Cooperation - China - as nodal scientist - Climate Change & Forecasting, Department of Science & Technology, Govt. of India
	India UK S & T Cooperation (Joint Evaluation Panel) Weather Science and Climate Change, Department of Science & Technology, Govt. of India
	Committee on Definition of Monsoon Season, Ministry of Earth Science, Govt. of India
	Advisory Committee to evaluate DST FIST Proposals on Earth Sciences
	Program Advisory Council, Earth Science, Department of Science & Technology, Govt. of India
	Research Advisory Committee, National Centre for Antarctica and Ocean Research (NCAOR), Goa
	Advisory Committee for the Shanti Swarup Bhatnagar Award in Earth Sciences
	Research Advisory Committee (RAC), Indian National Centre for Ocean Information Services (INCOIS), Hyderabad
Dr. A. K. Kamra	WMO Commission for Atmospheric Sciences, Geneva, Switzerland
	Programme Advisory Committee, Science and Engineering Research Council (SERC), Department of Science and Technology Govt. of India
	Physical Sciences Research Committee of the Council for Scientific and Industrial Research (CSIR)
	Scientific Steering Committee for the Continental Tropical Convergence Zone (CTCZ) Field Campaign under the Indian

	Climate Research Programme (ICRP), Department of Science and Technology (DST), Govt. of India
	Programme Implementation Committee (PIC) of Severe Thunderstorm - Observational and Regional Modeling (STORM), Department of Science and Technology (DST), Govt. of India
Dr. P. C. S. Devara	Executive Committee of the International Commission on Cloud Physics (ICCP)
	Chairman, Asian Young Aerosol Scientist Award (AYASA) Committee constituted by the Asian Aerosol Research Assembly (AARA)
	Stratospheric Process and their Role in Climate (SPARC) Scientific Steering Group (SSG) of World Climate Research Programme (WCRP)
	International Aerosol Research Assembly (IARA)
	New York Academy of Sciences, USA
	National Committee on Aerosol and Radiation Budget Studies (ARBS) constituted by the ISRO, Bangalore
	Governing Council, Instrument Society of India (ISOI), Bangalore
	Project Advisory Committee (PAC), International Program on Environment, Earth and Atmospheric Sciences, Department of Science and Technology (DST), Government of India, New Delhi
	Scientific Advisory Committee, Space physics Laboratory (SPL), Thiruvanathapuram, Department of Space (DOS), Indian Space Research Organization (ISRO)
Dr. G. Beig	Scientific Committee of the Working Group 4.4, on Ionosphere and Upper-Atmosphere Variability
	Scientific Steering Committee, International Commission for the Middle Atmosphere (ICMA)
	Executive Committee and Information Officer of the Scientific Working Group (WG) Long Term Trends in the Mesosphere, Thermosphere and Ionosphere Constituted jointly under SCOSTEP (Scientific Commission on Solar Terrestrial Physics), ICMA (International Commission for the Middle Atmosphere) and IAGA (International Association of Geomagnetism Aeronomy)

	Chairman, MTTA (Mesospheric Temperature Trend Assessment) Panel constituted jointly under the auspices of IAGA, ICMA, and SCOSTEP (PS-MOS) Working Group on Trends
	International Committee of Young Scientists of International Association of Geomagnetism and Aeronomy (IAGA) on Future of Association and its Scientific Priorities over the Following 20 years Called 'IAGA 2020 Vision'
	Scientific Steering Committee (SSC) of the International Global Atmospheric Chemistry (IGAC) Project of the International Geosphere-Biosphere Programme (IGBP) and International Commission for Atmospheric Chemistry and Global Pollution (CACGP)
	Associate, Committee for Space Research, Paris, France
	New York Academy of Sciences, New York
	Scientific Advisory Group (SAG), Global Atmospheric Watch (GAW) Urban Research Meteorology and Environment (GURME) Project of World Meteorological Organization (WMO)
Dr. A. K. Sahai	CCL Task Team on CLIPS Evolution of World Meteorological Organization (WMO)
Dr. P.S.P. Rao	Scientific Steering Committee, International Body on Composition of Asian Deposition (CAD)
	Scientific Advisory Group (SAG) on Precipitation Chemistry under the Global Atmospheric Watch (GAW) Programme of World Meteorological Organization (WMO)
Dr. K. Ashok	APEC (Asia Pacific Economic Cooperation Climate) Centre's Climate (APCC) Outlook Committee, Korea
Dr. H.P. Borgaonkar	Working Group (WG) viz. Asia-2k (Asian Climate during the Last Two Millennia) of Focus 2: Regional Climate Dynamics of PAGES Science Activity
Shri S. D. Pawar	Committee set up by the Department of Revenue and Forest, Govt. of Maharashtra to study the losses due to lightning.
	Working Group on Megha-Tropiques Science and Applications (WG-3)
Dr. (Smt) Thara Prabhakaran	Steering Committee of Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers (VAPOR)

Dr. Devendraa Siingh	Climate and Weather of the Siingh Sun-Earth System (CAWSES), Boston University, Boston, USA
	Expert Researcher European Fleet for Air Borne Research, Romania
Shri M. Mahakur	Working Group on Megha-Tropiques Science and Applications (WG-3)
Dr. K. Rupa Kumar	Australian- Asian Monsoon Panel of the International Research Programme, CLIVAR
	Co-Chair of Asian-Australian Monsoon Panel (AAMP) (2005-2008) of the Scientific Steering Group for the Climate Variability and Predictability (CLIVAR) project of the World Climate Research Programme (WCRP)
Dr. A.S.R. Murty	International Commission on Cloud physics (ICCP) of the International Association of Meteorological and Atmospheric physics (IAMAP)
	Member, WMO/CAS Working Group/Executive Panel of Experts on Physics and Chemistry of Clouds and Weather Modification Research
Dr. S. S. Singh	National Committee on GAME (GEWEX Asian Monsoon Experiment)
Shri K. G. Vernekar	Committee on Anthropogenic and natural factors in environmental degradation due to atmospheric pollution and climate variability constituted by the ISRO in ISRO-SCHENE collaboration in the field of meteorology and upper atmospheric research
Dr. S. K. Mishra	Tropical Ocean Global Atmosphere (TOGA) Modeling Group
Dr. H. N. Bhalme	World Meteorological Organisation (WMO) Commission on Climatology
	Expert, Bureau of Inter Governmental Panel on Climate Change (IPCC) in the areas of Climate Modeling, Climatology and Hydrometeorology
Dr. P.R. Rakhecha	Expert, WMO/UNEP Inter-Governmental Panel on Climatic Change (IPCC)
	Expert, Bureau of Inter Governmental Panel on Climate Change (IPCC) in the areas of Climate Modeling, Climatology and Hydrometeorology

Appendix II

Honours (Fellowships, Memberships)

Royal Meteorological Society, U.K.	Dr. P.C.S. Devara
Indian National Science Academy, New Delhi	Dr. S. K. Mishra Prof. B.N. Goswami Dr. A.K. Kamra
Indian Academy of Sciences, Bangalore	Shri D.R. Sikka Prof. B.N. Goswami Dr. A.K. Kamra Dr. K. Krishna Kumar Dr. G. Beig
Indian Meteorological Society	Prof. P.R. Pisharoty Dr. K.R. Saha Prof. R. Ananthakrishnan Prof. R.N. Keshavamurty Prof. G.C. Asnani Shri D.R. Sikka Dr. S.K. Mishra Dr. D.A. Mooley Dr. A.K. Kamra Dr. O.N. Dhar Dr. G.B. Pant Prof. B.N. Goswami
Institution of Electronics and Telecommunication Engineers (IETE), New Delhi	Dr. P.C.S. Devara
Maharashtra Academy of Sciences	Dr. G.B. Pant Dr. P.C.S. Devara
TWAS, The Academy of Sciences for the Developing World, Italy	Prof. B.N. Goswami
Andhra Pradesh Academi of Sciences	Dr. P.C.S. Devara

Awards

Award and Year	Award Winning Scientist(s)	Award Winning Paper
Dr. B.N. Desai Award, Indian Meteorological Society, 1968	R.N. Keshavamurty	On the maintenance of the mean zonal motion in the Indian summer monsoon, Monthly Weather Review, 96, 1968, 23-31
Indian Journal of Meteorology and Geophysics Award, 1969	R.V. Godbole and R.R. Kelkar	Net terrestrial radiative heat fluxes over India during monsoon, Indian Journal of Meteorology and Geophysics, 20, 1969,1-8
WMO Research Award for Encouragement of Young Scientists, 1973	B.M. Mishra	Time series analysis of the global atmospheric pressure, Indian Journal of Meteorology and Geophysics, 24, 1973, 251-256
WMO Research Award for Encouragement of Young Scientists, 1975	A.K. Kamra	Role of electrical forces in charge separation by falling precipitation in thunderclouds, Journal of the Atmospheric Sciences, 32, 1975, 143-157
Shri Hari Om Ashram Prerit Dr. Vikram Sarabhai Research Award, 1976	A.S.R. Murty	---
Third Prize (Students' Technical Session), The Institution of Engineers (India), 1977	S.K. Sharma	Field-testing of two cloud-droplet samplers, The Student Journal, 13, pt, S4, 1980, 110-112
Second Prize (Students' Technical Session), The Institution of Engineers (India), 1977	S.K. Sharma	Multi-side coating gadget for measurement of cloud-droplets, Journal of the Institution of Engineers (India), Vol. II, Part ST, No. S I, 1977, 27-29
Young Scientist Award by the Andhra Pradesh Academy of Sciences, Hyderabad, 1980	P.C.S. Devara	---

WMO Research Award for encouragement of Young Scientists, 1980	S.K. Mishra and P.S. Salvekar	Role of baroclinic instability in the development of monsoon disturbances, Journal of the Atmospheric Sciences, 37, 1980, 383-394
Dr. B.N. Desai Award, Indian Meteorological Society, 1978	D.R. Sikka and Sulochana Gadgil	Large-scale rainfall over India during the summer monsoon and its relation to the lower and upper tropospheric vorticity, Indian Journal of Meteorology and Geophysics, 29, 1978, 219 - 231
Prof. P. T. Rao Shastiabadhipoorty Prize in Physics, Andhra University, Waltair, 1983	P.E. Raj	---
B.P. Kapadia Memorial Prize, Eighth All India Students Seminar, The Institution of Engineers (India), 1984	S.K. Sharma	---
13th Mausam Award, 1984 -1985	S. Rajamani	(i) Energetics of the monsoon circulation over south Asia : I-Diabatic heating and the generation of available potential energy, Mausam, Vol. 36, 1, 1985, 7-12
		(ii) Energetics of the monsoon circulation over south Asia : II-Energy terms and energy transformation terms, Mausam, 36, 1985, 405-412
2nd SAARC Award, 1985	S.K. Mishra, M.D. Patwardhan and L. George	Primitive equation barotropic instability study of the monsoon onset vortex, 1979, Quarterly Journal of Royal Meteorological Society, 111, 1985, 427- 444
14th Mausam Award, 1986-1987	P.S. Salvekar and S.K. Mishra	Effect of Ekman boundary layer friction on the baroclinic growth of monsoon depression, Mausam, Vol. 37, 1987, 147-152

Best Paper Award of NSSS-87, Ahmedabad, 1987	R.K. Verma	---
Young Scientist Award for Best Presentation of Paper, 1990	K. Indira	Changes in dynamical parameters of the middle atmosphere associated with the storm activity over Bay of Bengal, Seminar on Geophysics in National Development, Banaras Hindu University, Varanasi,29-31 August 1990
J. Das Gupta Award, Indian Meteorological Society, 1987-1988	K.G. Vernekar, S. Sivaramakrishnan, Brij Mohan and S. Saxena	Estimation of fluxes from wind and temperature profiles in the marine atmospheric surface boundary layer, Mausam, 38, 1987,157-162
6th SAARC Award, 1987	S.V. Singh and R.H. Kripalani	Application of extended empirical orthogonal function analysis to inter-relationships and sequential evolution of monsoon fields, Monthly Weather Review, 114, 1986, 1603-1610,
7th SAARC Award, 1988	M.K. Tandon	Robert's recursive frequency filter: a reexamination, Meteorology and Atmospheric Physics, 37, 1987, 48-59
Dr. B.N. Desai Award, Indian Meteorological Society, 1989	S. Rajamani	Some dynamical characteristics and thermal structure of monsoon depression over the Bay of Bengal, Tellus, 41A, 1989, 255-269
10th SAARC Award, 1992	M.K. Soman and K. Krishna Kumar	Some aspects of daily rainfall distribution over India during the South-West monsoon season, International Journal of Climatology, 10, 1990, 299-311
Best Research Paper Award, 1996	R.V. Kharul, S.S. Parasnis and M.G. Takwale	Numerical simulation of wind pattern for wind energy generator, Award at the 9th National Space Science Symposium (NSSS-96), Hyderabad, 6-10 February1996

13th SAARC Award, 1993-1994	N. Singh	Optimizing a network of rain-gauges over India to monitor summer monsoon rainfall variations, International Journal of Climatology, 14, 1994, 61-70
J. Das Gupta Award, Indian Meteorological Society, 1995-1996	P.C.S. Devara, P.E. Raj, G. Pandithurai and S. Sharma	High spectral resolution radiometer for atmospheric monitoring, Journal of Instrumentation Society of India, 25, 1996, 142-154
Bose-Nandi Award of Calcutta Statistical Association, 1999	N.R. Deshpande and A.P. Gore	On computation of probable maximum precipitation, Journal of Calcutta Statistical Association Bulletin, 49, 1999, 193-194
National Young Scientist Award in the Physical Sciences for 1999-2000 by Muslim Association for Advancement in Science and Centre for Studies on Science, 1999	G. Beig	---
Dr. Vikram Sarabhai Memorial Lecture and Cash Award by the Indian Remote Sensing Society, 2001	G.B. Pant	---
Nobert-Gerbier Mumm International Award of WMO, 2003	G. Beig, S.S. Fadnavis et.al	Review of mesospheric temperature trends, Reviews of Geophysics, 41, 2003, doi:10.1029/2002RG000121
Best Paper Award, 2004	A.M. Grimm, A.K. Sahai and C.F. Ropelewski	Long-term variations in the performance of climate models, 13th Brazilian Symposium of Atmospheric Modellling in the 13th Brazilian Congress of Meteorology, Fortaleza, Ceara, Brazil, 30 August - 3 September 2004

Best Paper Award, 2004	R. Bhawar	Ground-based radiometric measurements of aerosols and pre-cursor gases over Pune and their comparison with TOMS and MODIS satellite data, IASTA Meeting and International Conference on Aerosols, Clouds and Indian Monsoon, Indian Institute of Technology, Kanpur, 15-17 November 2004
Dr. B.N. Desai Award, Indian Meteorological Society, 2006	O.P. Singh, K. Rupa Kumar, P.K. Mishra, K. Krishna Kumar and S.K. Patwardhan	Simulation of characteristic features of Asian summer monsoon using a regional climate model, Mausam, 57, 2006, 221-230
Shanti Swarup Bhatnagar (SSB) Award of Council of Scientific and Industrial Research (CSIR) for young Scientists, 2006	G. Beig	---
Maharana Udai Singh National Award-2007 by the Maharana Mewar Foundation, 2007	G. Beig	---
Certificate of Merit Award by Ministry of Earth Sciences, 2007	K. Krishna Kumar	---
Prof. A.D. Vernekar Award, Indian Meteorological Society, 2003-2004	R. Krishnan, M.S. Mujumdar, V. Vaidya, K.V. Ramesh and V. Satyan	Abnormal Indian summer monsoon of 2000, Journal of Climate, 16, 2003, 1177-1194
Admirable Contributors of the Nobel Peace Prize to the IPCC, 2007	G.B. Pant, K. Rupa Kumar and K. Krishna Kumar	---
The Kalpathi Ramakrishna Ramanathan Medal by Indian National Science Academy, 2008	B.N. Goswami	---

Certificate of Merit Award by Ministry of Earth Sciences, 2008	G. Beig	---
Kamal Kumari National Award for Science and Technology by The Kamal Kumari Foundation, 2008	B.N. Goswami	---
Norbert Gerbier-MUMM International Award of WMO, 2009	K. Krishna Kumar, et.al.	Unraveling the mystery of Indian monsoon Failure during El Nino, Krishna Kumar K., Rajagopalan B., Hoerling M., Bates G. and Canes M., Science, 314, 2006,115-118
Certificate of Merit Award by Ministry of Earth Sciences, 2009	A.K. Sahai	---
Certificate of Merit Award by Ministry of Earth Sciences, 2010	A. Suryachandra Rao	---
Significant Contribution Award, Computer Society of India (CSI), 2010	M.K. Tandon	---
Young Scientist Award along with Certificate of Merit Award by Ministry of Earth Sciences, 2011	C. Gnanaseelan	---

Appendix III

IITM Silver Jubilee Award

Award	Award Winning Scientist(s)	Award Winning Paper
1st Award, 1988	K. D. Prasad and S.V. Singh	Large-scale features of the Indian summer monsoon rainfall and their association with some oceanic and atmospheric variables, Advances in Atmospheric Sciences, 5, 1988, 499-513
2nd Award, 1989	A.K. Kamra and D.V. Ahire	Wind-tunnel studies of the shape of charged and uncharged water drops in the absence or presence of an electric field, Atmospheric Research, 23,1989, 117-134
3rd Award, 1990	S.S. Parasnis and S.B. Morwal (S.S. Goyal)	Thermodynamic features of the atmospheric boundary layer during the summer monsoon, Atmospheric Environment, 24A, 1990, 743-352
4th Award,1991	P.N. Mahajan and S.P. Ghanekar	Assessment of satellite-observed HRC data for rainfall estimates over the tropical Indian Ocean, Mausam, 42, 1991, 347-352
5th Award, 1992	S.S. Dhanorkar and A.K. Kamra	Relationship between electrical conductivity and small ions in the pressure of intermediate and large ions in the lower atmosphere, Journal of Geophysical Research, 97, 1992, 20345-20360
6th Award, 1993	P.E. Raj, S. Sharma, P.C.S. Devara and G. Pandithurai	Study of Laser Scintillation in different atmospheric conditions, Journal of Applied Meteorology, 32, 1993, 1161-2167

7th Award, 1994	S. Sharma, P.C.S. Devara, P.E. Raj and G. Pandithurai	An optical scintillometer for simultaneous measurements of atmospheric C2n and winds, Journal of the Institution of Electronic and Telecommunication Engineers, 40, 1994, 101-104
8th Award, 1995	A.M. Selvam and R.R. Joshi	Universal spectrum for interannual variability in COADS global air and sea-surface temperatures, International Journal of Climatology, 15, 1995, 613-623
9th Award, 1996	H.P. Borgaonkar, G.B. Pant and K. Rupa Kumar	Ring-width variations in Cedrus deodara and its climatic response over the western Himalaya, International Journal of Climatology, 16, 1996, 1409-1422
10th Award, 1997	R.H. Kripalani and A.A. Kulkarni	Rainfall variability over south-east Asia-connections with Indian monsoon and ENSO extremes: New perspectives, International Journal of Climatology, 17, 1997,1155-1168
11th Award, 1998	R. Krishnan, C. Venkatesan and R.N. Keshavamurthy	Dynamics of upper tropospheric stationary wave anomalies induced by ENSO during the northern summer: A GCM study, Proc. Indian Academy of Sciences (Earth and Planetary Sciences), 107, 1998, 65-90
12th Award, 1999	G.K. Manohar, S.S. Kandalgaonkar and M.I.R Tinmaker	Thunderstorm activity over India and the Indian southwest monsoon, Geophysical Research Letters, 104, 1999, 4169- 4188
13th Award, 2000	G. Beig	Relative importance of Solar Activity and Anthropogenic Influences on the Ion Composition, Temperature and Associated Neutrals of the Middle Atmosphere, Journal of Geophysical Research, 105, 19, 2000, 841-856

14th Award, 2001	R.G. Ashrit, K. Rupa Kumar and K. Krishna Kumar	ENSO-monsoon relationships in a green house warming scenario, Geophysical Research Letters, 28, 2001,1727-1730
15th Award, 2002	J. Sanjay, P. Mukhopadhyay and S.S. Singh	Impact of nonlocal boundary-layer diffusion scheme on forecasts over Indian region, Meteorology and Atmospheric Science, 80, 2002, 207-216
16th Award, 2003	A.K. Sahai, A.M. Grimm, V. Satyan and G.B. Pant	Long lead predictions of Indian summer monsoon rainfall from global SST evolution, Climate Dynamics, 20, 2003, 855-863
17th Award, 2004	C.G. Deshpande and A.K. Kamra	Atmospheric electric conductivity and aerosol measurements during fog over the Indian Ocean, Atmospheric Research, 70, 2004, 77-87
18th Award, 2005	R. Krishnan and K.V. Ramesh	Coupling of mixed layer processes and thermocline variations in the Arabian Sea, Journal of Geophysical Research, 110, 2005, doi:10.1029/ 2004JC002515
20th Award, 2007	R.V. Bhalwankar and A.K. Kamra	Wind tunnel investigation of the deformation of water drops in the vertical and horizontal electric fields, Journal of Geophysical Research, 112, 2007, D10215,1-9
21st Award, 2008	A. K. Sahai	Objective identification of Nonlinear Convectively coupled phases of monsoon intraseasonal oscillation: Implications for Prediction, Journal of Atmospheric Sciences, 65, 2008, 1549-1569
22nd Award, 2009	R. Krishnan	Internal Feedbacks from Monsoon-Midlatitude Interactions during Droughts in the Indian Summer Monsoon, Journal of Atmospheric Sciences, 66, 2009, 553-578

Best Student Paper Award of IITM

The Institute has established an Annual Award of cash prize from the year 2008 as the Best Student Papers Award in order to encourage its Research Fellows (Ph.D. Students) to publish their research work. Outstanding papers of the Research Fellows (as the first author) published in the peer reviewed journals of good Impact Factor of previous year are selected for the Award. The Awards are presented on the occasion of the Institute's Foundation Day Celebration of the next year. Following papers have received the Best Student Papers Awards for the respective year from 2007:

Award Year	Award Winning Student	Award Winning Paper
2007	V. Pant	Measurements of positive ions and air-earth current density at Maitri Antarctica, Journal of Geophysical Research, Pant V., Siingh D. and Kamra A.K., Vol.112, 2007, D13212, 1-9
	S. M. Deshpande	Comparative study of structure of vertical motions in the lower troposphere over Pune, a tropical Indian station in March 2004 and 2005 using wind profiler data, Deshpande S. M. and Raj P.E., Annales Geophysicae, Vol.25, 2007, 2103-2111
2008	R. Chattopadhyay	Objective Identification of Nonlinear Convectively Coupled Phases of Monsoon Intraseasonal Oscillation: Implications for Prediction, Chattopadhyay R., Sahai A.K. and Goswami B.N., Journal of Atmospheric Sciences, Vol. 65, 2008, 1549-1569
2009	J.S. Chowdary	Westward propagation of barrier layer formation in the 2006-07 Rossby wave event over the tropical southwest Indian Ocean, Chowdary J.S., Gnanaseelan C. and Xie S.P. Geophysical Research Letters, 36, February 2009, L04607, doi:10.1029/2008GL036642, 1- 4
	S. Joseph	Eastward propagating MJO during boreal summer and Indian monsoon droughts, Joseph S., Sahai A.K. and Goswami B.N., Climate Dynamics, 32, June 2009, 1139-1153
	N.J. Mani and E. Suhas	Can global warming make Indian monsoon weather less predictable?, Mani N.J., Suhas E. and Goswami B.N. Geophysical Research Letters, 36, April 2009, L08811, doi:10.1029/2009GL037989,1-5

Appendix IV

Visiting Scientists invited to deliver series of specialized lectures

Visiting Professor	Period of Visit	Topics of the Series of Lectures delivered
Dr. Kamal Puri Bureau of Meteorology, Research Centre, Melbourne, Australia	5 - 21 December 1988	• Review of current status of tropical NWP • GCM type studies using Global Spectral Model • Spectral modelling and initialization
Prof. (Mrs.) Ruby Krishnamurti Florida State University, Tallahassee, USA	5 - 18 December 1993	• Turbulent convection • Geophysical fluid dynamics
Prof. T.N. Krishnamurti Florida State University, Tallahassee, USA	5 - 18 December 1993	• Monsoon • Physical initialization • Tropical cyclones • Cloud modelling • GEWEX
Dr. D.B. Rao, National Meteorological Center, Washington, DC, USA	13 - 24 February 1995	• Basic Geophysical Fluid Dynamics
Dr. Anandu Vernekar, Professor Emeritus, Department of Atmospheric and Oceanic Sciences and Earth System Sciences Interdisciplinary Center (ESSIC), University of Maryland, USA	26 September - 10 October 2006	• Monsoon variability
Prof. Raghu Murtugudde, Atmospheric and Oceanic Sciences, University of Maryland, USA	12-20 March 2008	• Ocean modelling
Prof. (Mrs.) Ruby Krishnamurti Florida State University, Tallahassee, USA	8 - 19 December 2008	• Laboratory experiments for weather and climate studies

Prof. T.N. Krishnamurti Florida State University, Tallahassee, USA	8 - 19 December 2008	• Modelling work for improving the forecasts
Dr. Duane Waliser, Jet Propulsion Laboratory, California, USA	4 - 11 February 2009	• US CLIVAR MJO Working Group: Efforts to Establish and Improve MJO Predictions, 5 February 2009 • Exploring the Biological and Chemical Reach of the MJO: Chl 03 & Aerosols, 6 February 2009 • Cloud Ice : A Climate Model Challenge With Signs & Expectations of Progress, 10 February 2009 • Year of Tropical Convection (YOTC): A WCRP/WWRP/ THORPEX activity addressing the challenge of organized convection" 11 February 2009
Prof. John Michael (Mike) Wallace, University of Washington, USA	20 - 24 February 2010	Patterns of Climate Variability
Prof. Jagdish Shukla, George Mason University, USA & President, Institute of Global Environment and Society, USA	20 - 24 February 2010	Predictability of Weather and Climate
Prof. Robert Houze, Department of Atmospheric Sciences, University of Washington, and an authority in Cloud Physics and Dynamics, USA	2-17 August 2010	Cloud Physics and Dynamics
Prof. Raghu Murtugudde, Atmospheric and Oceanic Sciences, University of Maryland, USA	17 February - 25 May 2011	Earth System Science

Appendix V

Ph.D.s produced by IITM

ITM/IITM Employees

1. S. Rangarajan (1966)
2. S. Ramachandran (1966)
3. R.P. Sarker (1968)
4. V.B. Rao (1969)
5. Mary Selvam (1970)
6. J. Shukla (1971)
7. R.R. Kelkar (1971)
8. D.A. Mooley (1972)
9. R.N. Keshavamurty (1972)
10. Ramesh V. Godbole (1972)
11. D. Subramanyam (1973)
12. A.S.R. Murty (1974)
13. B.M. Mishra (1974)
14. O.N. Dhar (1975)
15. H.S. Bedi (1978)
16. K. Krishna (1978)
17. S. Rajamani (1978)
18. S.S. Singh (1978)
19. S.T. Awade (1980)
20. B.K. Mukherjee (1982)
21. R.S. Reddy (1983)
22. P.E. Raj (1983)
23. S.K. Mishra (1983)
24. S.V. Singh (1984)
25. H.N. Bhalme (1984)
26. B. Parthasarthy (1985)
27. S.N. Bavadekar (1985)
28. L.T. Khemani (1985)
29. J.M. Pathan (1985)
30. P.R. Rakhecha (1989)
31. S.S. Parasnis (1989)
32. Poonam Sikka (Mehra) (1991)
33. A.K. Kulkarni (1992)
34. R.H. Kripalani (1992)
35. K.D. Prasad (1992)
36. G.K. Manohar (1993)
37. Dr. S. K. Sinha (1994)
38. S.S. Dhanorkar (1994)
39. N. Singh (1994)
40. M.K. Soman (1995)
41. P.N. Mahajan (1996)
42. S.S. Nandargi (1996)
43. P.L. Kulkarni (1997)
44. K. Krishna Kumar (1997)
45. N.A. Sontakke (1997)
46. H.P. Borgaonkar (1997)
47. P.S.P. Rao (1997)
48. R. Vijayakumar (1997)
49. K. Ashok (1997)
50. S.B. Morwal (1998)
51. S. Sivaramakrishnan (1998)
52. G. Pandithurai (1998)
53. S.K. Behera (1998)
54. Y. Jaya Rao (1998)

55. R.R. Joshi (1999)
56. A.L. Londhe (1999)
57. S.S. Kandalgaonkar (1999)
58. A.A. Munot (1999)
59. S.B. Debaje (1999)
60. J.S. Pethkar (1999)
61. M. Ravichandran (1999)
62. P.D. Safai (2000)
63. D.K. Singh (2000)
64. C.G. Deshpande (2000)
65. M.S. Naik (2001)
66. B.S. Murthy (2001)
67. M.N. Patil (2001)
68. B.D. Kulkarni (2001)
69. Kausar Ali (2001)
70. M. Mujumdar (2002)
71. S.G. Nagar (2003)
72. S.M. Bawiskar (2003)
73. D.R. Kothawale (2005)
74. P. Mukhopadhyay (2005)
75. B. Padmakumari (2005)
76. G.S. Meena (2006)
77. S.G. Narkhedkar (2006)
78. D.M. Chate (2006)
79. J.R. Kulkarni (2006)
80. A.A. Deo (2007)
81. J. Sanjay (2007)
82. S.D. Pawar (2008)
83. S.S. Fadnavis (2008)
84. N.R. Deshpande (2010)
85. J.V. Revadekar (2010)
86. S.K. Mandke (2010)

Employees / Students of other organizations

1. Rao Ramanuja K. (Gujarat University, 1966)
2. Narayanan V. (University of Pune, 1973)
3. Mokashi R.Y. (University of Pune, 1975)
4. P.V. Joseph (IMD, 1983)
5. G. Appa Rao (IMD, 1983)
6. Ishwar Datta (CWPRS, 1987)
7. C.K. Rajan (Cochin University, 1988)
8. J.K. Sahu (Air Force, 1998)
9. D.N. Nighut (Univ. of Pune, 1998)
10. T. Priscilla Pilli (Spicer College, Pune, 2003)
11. P.R. Patil (Karad, 2003)
12. M.K.R.V. Raja (Univ. of Pune, 2000)
13. Albert Owino (Univ. of Pune)
14. D.R. Jadhav (Univ. of Pune, 2005)
15. L.P. Devkota (Kathmandu, 2005)
16. Pankaj Kumar (IMD, 2007)
17. R.K. Yadav (IMD, 2007)
18. A.B. Kakade (Univ. of Pune, 2010)
19. Subhash D. Pawar (Univ. of Pune, 2011)
20. Khalid Ahmed Al Najar (2011)

Air India Research Fellows, CSIR Research Fellows and IITM Research Fellows

1. D. Sreeramamurthy (Daggupaty S.M.) (1968)
2. B.M. Mishra (1974)
3. M.V.H. Nair (1983)
4. P.S. Salvekar (1985)
5. D.V. Ahire (1988)
6. K. Indira (1990)
7. E.N. Rajagopal (1991)
8. S. Bose (1993)
9. K.K. Singh (1994)
10. S. Sharma (1995)
11. T.N. Pranesha (1996)
12. J.V. Ratnam (1998)
13. C. Venkatesan (1998)
14. R.S. Maheskumar (1999)
21. D.R. Pattnaik (IMD, 2001)
15. R. G. Ashrit (2001)
16. Nitu Saraf (2004)
17. P.R.C. Reddy (2004)
18. K.V. Ramesh (2005)
19. B. Thompson (2007)
20. Narendra Singh (2007)
21. J.S. Chowdary (2007)
22. R.L. Bhawar (2008)
23. A.K. Srivastava (2008)
24. Vinay Kumar (2008)
25. S.S. Gunthe (2008)
26. A.K. Mishra (2008)
27. B.H. Vaid (2008)
28. Vimlesh Pant (2009)
29. U.K. Singh (2008)
30. Suchitra Sundaram (2009)
31. K. Kamala (2009)
32. S.M. Deshpande (2009)
33. P.S. Praveen (2009)
34. R. Deepa (2009)
35. S.H. Kulkarni (2009)
36. M.K. Biswas (2010)
37. R. Chattopadhyay (2010)
38. A.S. Panicker (2010)
39. Medha Deshpande (2010)
40. S.K. Sahu (2010)
41. Susmitha Joseph (2011)
42. B.K. Samala (2011)
43. Saurav Taraphdar (2011)
44. P. Ramesh Kumar (2011)

References

International Indian Ocean Expedition (IIOE)

1. Keshavamurty R.N., Awade S.T., **1974,** Dynamical abnormalities associated with drought in the Asiatic summer monsoon, Indian Journal of Meteorology and Geophysics, 25, 257-266.
2. Miller F.R., Keshavamurty R.N., **1967,** Structure of an Arabian Sea summer monsoon system, IIOE Monograph No. 1, Hawai, 94 pp.
3. Pisharoty P.R., **1965,** Evaporation from the Arabian Sea and the Indian southwest monsoon, Proc. Symposium on Meteorological Results of the IIOE, 22-26 July 1965, 43 - 54.
4. Raman C.R.V., **1965,** Cyclonic vortices on either side of the equator and their implications, Proc. of Symposium on Meteorological Results of the IIOE, 22-26 July 1965, 155-163.
5. Raman C.R.V., Dixit C.M., **1964,** Analyses of monthly mean resultant winds for standard pressure levels over the Indian Ocean and adjoining continental areas, India Meteorological Department, International Meteorological Centre, Bombay.
6. Saha K.R., **1970,** Air and water vapour transport across the equator in western Indian Ocean during northern summer, Tellus, 22, 681-687.
7. Saha K.R., **1970,** Effects of ocean temperatures on atmospheric circulation and cloudiness in tropics, Science and Culture, 36, 498-500.
8. Saha K.R., **1970,** Inter-hemispheric drift of radioactive debris and tropical circulation, Tellus, 22, 688-698.
9. Saha K.R., **1970,** Zonal anomaly of sea surface temperature in equatorial Indian Ocean and its possible effect upon monsoon circulation, Tellus, 22, 403-405.
10. Saha K.R., Bavadekar S.N., **1973,** Water vapour budget and precipitation over the Arabian Sea during the northern summer, Quarterly Journal of Royal Meteorological Society, 99, 273-278.
11. Sikka D.R., Mathur M.B., **1965,** Transport of water vapour over Arabian Sea and adjoining Indian region during an active monsoon situation, Proc. Symposium on Meteorological Results of the IIOE, 22-26 July 1965, 55-67.
12. Suryanarayana R., Sikka D.R., **1973,** Evaporation over the Indian Ocean during IIOE period, Indian Journal of Meteorology and Geophysics, 24, 27-30.

Simulation of Monsoon

13. Godbole R.V., **1973,** Numerical simulation of the Indian summer monsoon, Indian Journal of Meteorology and Geophysics, 24, 1-14.

14. Godbole R.V., Kelkar R.R., **1971,** Influence of various physical factors upon the radiative equilibrium of the atmosphere, Indian Journal of Meteorology and Geophysics, 22, 161-168.

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Numerical Weather Prediction (NWP)

17. Rajamani S., Talwalkar D.R., Upasani P.U., Sikka D.R., **1982,** Impact of Monex-79 data on the objective analysis of the wind field over the Indian region, Pure and Applied Geophysics, 120, 422-436.

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24. Singh S.S., Sugi M., **1986,** Prediction of a monsoon depression with a regional primitive equation model, Mausam, 37, 17-26.

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Development of Empirical Forecasting Techniques

Analogue forecasting

26. Kulkarni A.A., Singh S.V., **1995,** Skills in prediction of 5-day monsoon rainfall by using self- analogues, Mausam, 46, 35-40.

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Objective method for forecasting tracks of tropical cyclones

30. Sikka D.R., **1975,** Forecasting the movement of tropical cyclones in the Indian seas by non-divergent barotropic model, Indian Journal of Meteorology and Geophysics, 26, 323-325.

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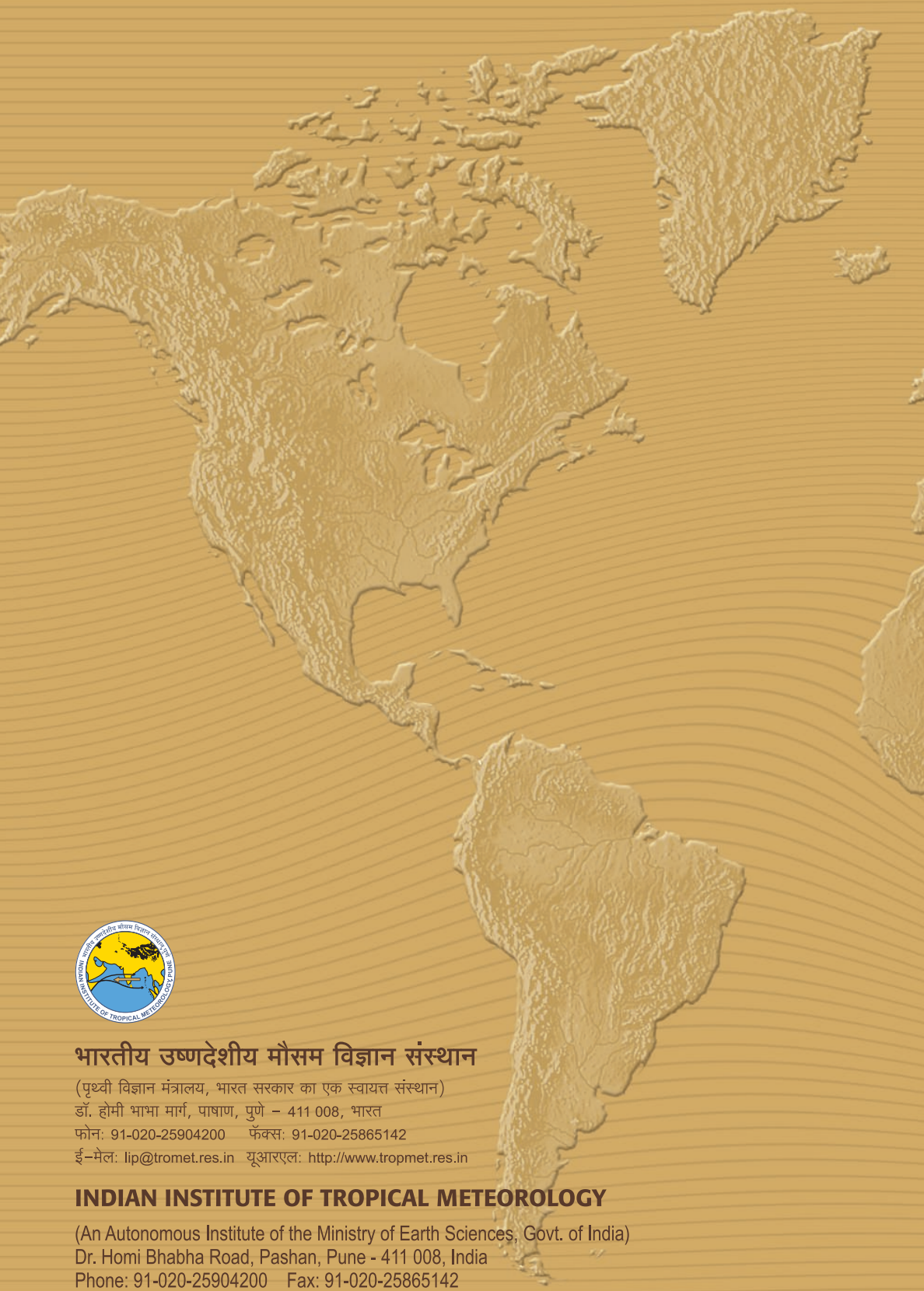
Shri Dev Raj Sikka was born on 01 March 1932 in Jhang Maghiana in pre-partition India (now in Panjab, Pakistan). He came over to India in Panipat on 30 August 1947, where he passed his high school examination. He did his M.Sc. in Physical Chemistry from Agra University with first rank in 1954. Within a few months after his post graduation, he was selected in the India Meteorological Department (IMD) and was posted to the Regional Meteorological Centre (RMC), Nagpur after completing the initial training in Meteorology in Pune. At RMC Nagpur Shri Sikka joined the Radiosonde-Radiowind Unit of the First Class Surface Observatory and Pilot Balloon Station. Nearly after eight years of his service in Operational Meteorology in Nagpur and Pune, Shri Sikka joined the International Meteorological Centre (IMC). The IMC was a specially formed centre in Bombay for coordinating and supporting the Meteorology Programme of the International Indian Ocean Expedition (IIOE) during 1963-1966. Shri Sikka joined the Institute of Tropical Meteorology (ITM), Pune as a Senior Scientific Officer in May 1964 and continued his service in the same Institute even after its transformation into an autonomous organization on 01 April 1971 and renamed as the Indian Institute of Tropical Meteorology (IITM), Pune. He was Head, Forecasting Research Division at IITM during 1981-1984. He played a leading role in operational phase of Indo-Soviet Monsoon-1973, International Monsoon-1977, MONEX-1979 and other International field programmes. On invitation, Shri Sikka worked for the Tropical Ocean Global Atmosphere (TOGA) Programme at the International TOGA Project Office in USA during 1984-1986. On being selected as Director, IITM, he returned to India and took up the position in October 1986. During his tenure as Director, Shri Sikka initiated several new scientific activities at IITM including multi-institutional observational programmes. He enhanced the academic programmes at IITM and improved collaboration with the Indian Universities for manpower development in Meteorology in India. He established strong linkages with scientists and institutions engaged in research and academic activities in Meteorology and allied subjects, both from India and abroad. He served as member of several national and international committees such as Radiation Committee of IUGG, TOGA Scientific Steering Committee, WMO Commission for Atmospheric Science, etc. He is a fellow of the Indian Academy of Sciences and the Indian Meteorological Society. He has been on the Editorial Boards of some prestigious scientific journals and has been associated with several national and international academic and research institutions. On superannuation, Shri Sikka formally retired from IITM on 29 February 1992 as Director, IITM. Even after the retirement, he is very active in research and is also playing a key role in several new national programmes. He has published about 200 research papers on different aspects of Meteorology in peer reviewed journals and reports of international repute. Many of his papers are highly cited by the research community. A relationship between the El Nino events over eastern equatorial Pacific Ocean and monsoon failure over India was first suggested by Shri Sikka in his paper published in 1980 in the Proceedings of Indian Academy of Sciences (Earth and Planetary Sciences). His another paper with Prof. Sulochana Gadgil on North/North West movement of the convective cloud bands published in 1980 in Monthly Weather Review was proved to be a pioneering one and is being cited even after three decades of its publication. During the last two decades, Shri Sikka has contributed immensely to the formulation and monitoring of new schemes and new field observational programmes in the country required for in-depth study of meteorological phenomena leading to better understanding of Indian Monsoon and improvement in its prediction.



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