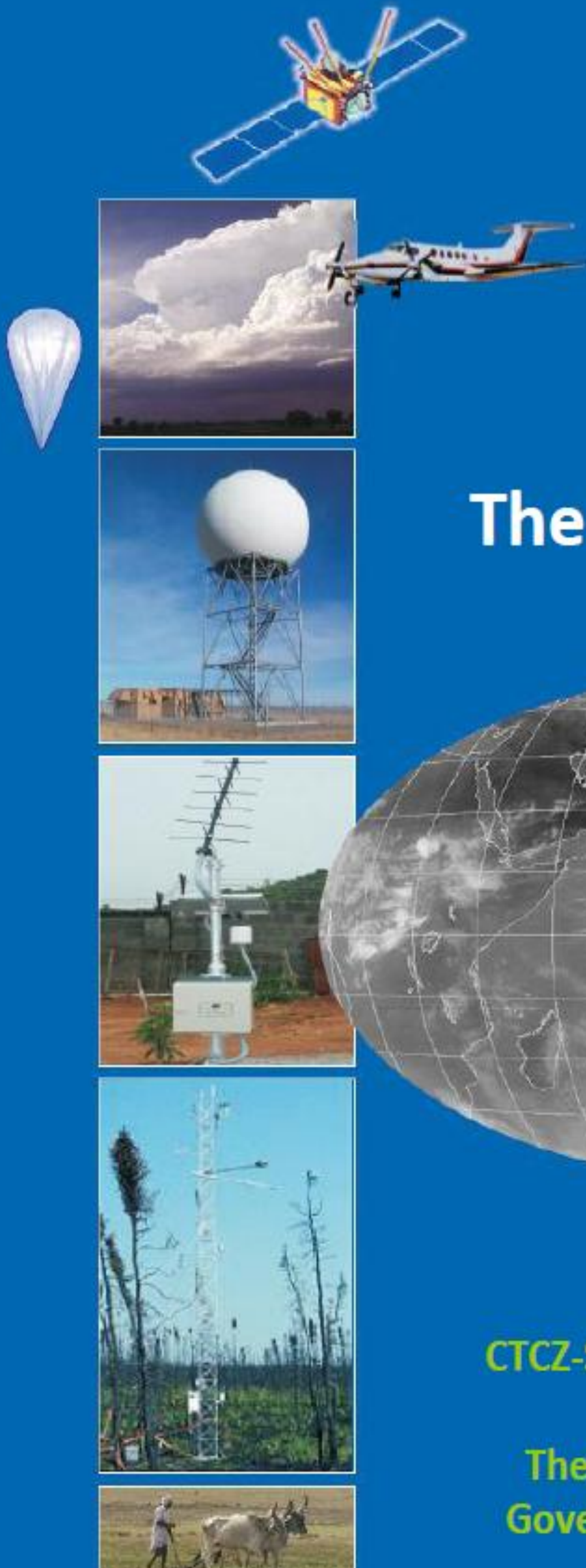
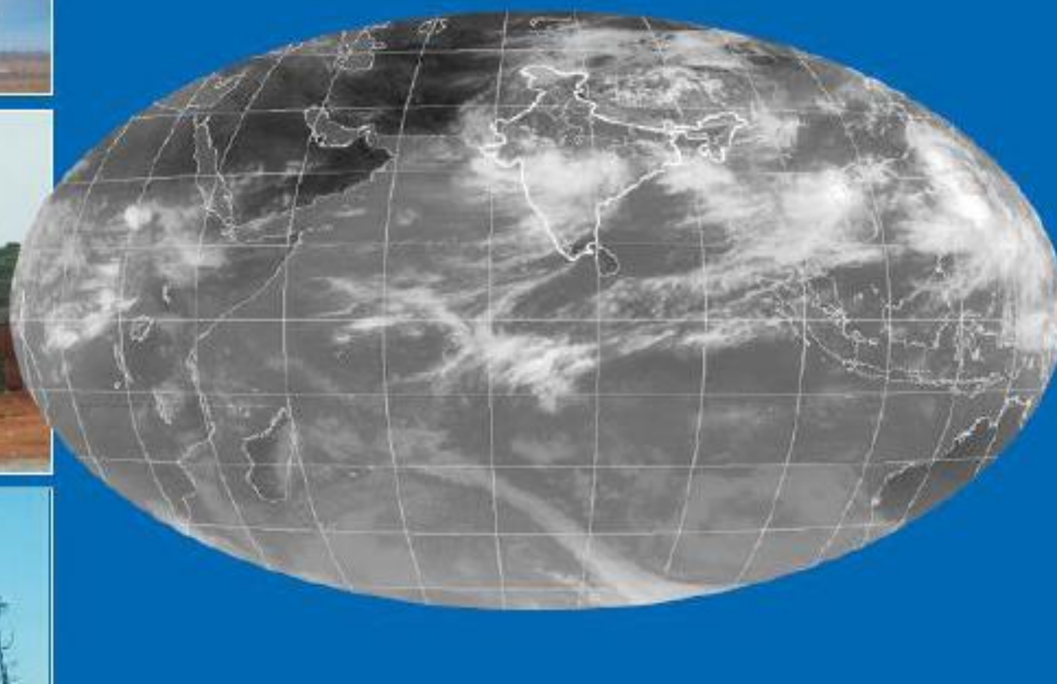


Proposal

for

The CTCZ Programme



Recommended by the
CTCZ-Scientific Steering Committee
to
The Ministry of Earth Sciences
Government of India, New Delhi

Proposal for

Continental Tropical Convergence Zone (CTCZ) programme

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January 2011

Continental Tropical Convergence Zone programme

1. Introduction

The Continental Tropical Convergence Zone (CTCZ) programme is the sequel to the successful Bay of Bengal Monsoon Experiment (BOBMEX) in 1999 and Arabian Sea Monsoon Experiment (ARMEX) in 2002 and 2003 under the Indian Climate Research Programme (ICRP), which was launched in 1996 as a coordinated effort to further our understanding of our climate and improve the prediction skill. The CTCZ programme will focus on understanding the variability of convection/rainfall over the Indian monsoon zone. A major objective of the CTCZ programme is understanding the variability of the large-scale monsoon rainfall associated with space-time variation of the CTCZ on subseasonal and interannual scales, its links with variation of the cloud systems over the oceans surrounding the Indian subcontinent, the role of land-surface-vegetation-atmosphere interactions and the contributions of the interactions between convective systems of cloud scale, meso-scale, and synoptic and planetary scales.

Under the CTCZ programme, special efforts will be made to elucidate the nature of the cloud systems over land and measure critical components of water and heat balance in selected basins/watersheds to understand the impact of land surface processes and gain insight into genesis of cloud systems and their propagations over land and water. As there are strong links between the variation in monsoon rainfall and convection over the surrounding oceans, it is very important to analyze the data from ocean-based platforms such as buoys, ARGO floats, etc. and also conduct special observations over the critical regions of the oceans. Thus, a multi-pronged approach involving field experiments, analysis of existing data from conventional platforms as well as satellites, buoys, and ARGO floats, and theoretical studies with process models, complex atmospheric general circulation models, as well as coupled ocean-atmosphere models has been adopted for attaining this challenging objective.

The CTCZ programme is envisaged as is a multi-institutional programme under the leadership of the Ministry of Earth Sciences with major contributions from the different institutions under the ministry such as IMD, IITM, INCOIS, NIOT, Department of Space (and the organizations/institutes under ISRO), the Indian Air Force (IAF), the Indian Navy, Department of Science and Technology as well as scientific institutions such as the National Institution of Oceanography under CSIR, Indian Institute of Science, Indian Institutes of Technology and various universities. The science and implementation plans have been prepared by the CTCZ-SSC. A proposal for the CTCZ programme under MoES for carrying out special observational and modeling studies during 2011-2013 to achieve the scientific objectives was prepared by the scientists interested in participating in the CTCZ programme, namely, the atmospheric and oceanic sciences community. After review by the members of the CTCZ-SSC and outside experts, the proposal was revised, taking into account the comments/suggestions received. The revised proposal was discussed at the meeting of the CTCZ-SSC and approved. The proposal recommended by the CTCZ-SSC for the CTCZ programme for support from MoES is presented here.

The next section comprises the proposal for the CTCZ programme as a whole. The proposal for the CTCZ programme as a whole is presented in the next section. The scientific background is discussed in section 2.1, the science foci and the main objective in section 2.2, the management structure in section 2.3, the financial requirements in 2.4 and the deliverables in section 2.5. The CTCZ programme involves addressing three major themes with observations and modeling studies viz., (i) land-surface processes, including hydrology and vegetation as well as land-atmosphere interaction and feedbacks, atmospheric boundary layer, clouds and aerosol, (ii) ocean processes, convection over the ocean and air-sea interaction, and (iii) the large-scale processes of the monsoon and the ocean. The objectives, implementation plan and budget for each of these themes are given in sections 3-5.

2. The CTCZ programme

2.1 Science background

The large-scale rainfall over the Indian region during the summer monsoon is associated with a continental tropical convergence zone (CTCZ), which appears as a prominent zonal cloud band in satellite imagery (e.g. Fig 1.1). The major phases of the CTCZ are (i) the spring to summer transition which occurs in the onset phase, and (ii) the peak monsoon months of July and August, when the CTCZ fluctuates primarily in the core monsoon zone (Fig 1.2). An important feature of the intraseasonal variation of the CTCZ is the fluctuation between active and weak spells (e.g. Fig. 1.3). The onset phase involves northward propagation of the TCZ from the equatorial Indian Ocean onto the Indian subcontinent. The advance of the monsoon over the northern plains also involves westward propagation of synoptic-scale systems from the Bay of Bengal. There is considerable variation from year to year in the dates of onset and advance of the monsoon. The timing, duration and intensity of the active and weak spells/breaks in July-August also vary from year to year. Revival from breaks occurs with propagation of cloud systems emanating from the Bay of Bengal or the equatorial Indian Ocean onto the core monsoon zone.

Seasonal evolution and spatial distribution of monsoon rainfall are influenced by land-atmosphere-ocean-biosphere interactions. The Indian monsoon zone is one of the major ‘hot spots’ where soil-moisture variations have a significant impact on the precipitation on the synoptic timescale. Detailed studies of the atmosphere-land-hydrosphere-biosphere feedbacks are needed with special observational sites located in regions considered critical for understanding these processes and events, such as break-active-break monsoon transitions, in which they are expected to play an important role. The observations on the heat and water balance in selected watersheds/river basins are to be used for testing a variety of land-vegetation-hydrology models employed in atmospheric general circulation models.

In the large-scale cloud band characterizing the CTCZ, cloud systems of synoptic and meso-scale are generally embedded. Such systems, with a life cycle of a few days, produce heavy rainfall over the Indian region. Various facets of the meso-scale and synoptic scale systems, such as the preferred location of formation and movement of synoptic scale systems, their intensification, propagation, interaction with the land surface, duration, diurnal variation, etc., need to be understood. The microphysical and dynamical characteristics of cloud clusters associated with these systems have not been studied. The fractional area covered by convective and stratiform clouds, estimation of the cumulus mass flux, and the mesoscale mass fluxes are essential to ascertain the deficiencies of the representation of cloud dynamics in numerical models.

The atmospheric boundary layer (ABL) is the lowest layer of the atmosphere (typically less than 2 km deep) and forms the interface between the surface (be it land or ocean) and the rest of the atmosphere. The ABL plays an important role in the variability of convection over land and ocean. Properties of the ABL determine convective cloud properties and are required for the representation of cloud processes in global atmospheric models, i.e., cloud parameterization schemes. Over land, evapotranspiration is an important component of the hydrological cycle and the land-atmosphere-vegetation interactions are critically dependent on the ABL. There is a large variation in the surface characteristics across the monsoon zone. The largest amplitude of diurnal cycle in the troposphere occurs within ABL and more specifically in the surface layer. Soil temperature and moisture, and vegetation parameters evolve with the progress of the monsoon. We expect ABL properties to respond to these changes and also to vary between active and break monsoon conditions. The CTCZ region is often a low-wind regime even within a monsoon season. Formulations in fluxes under low-wind-speed regimes under unstable and stable conditions need to be established and validated. Thus, determining the surface fluxes under the entire range of wind speeds that prevail during the monsoon, including the low-wind regime, is an outstanding problem that needs to be undertaken during the CTCZ programme.

Recent studies have shown that aerosols can cause substantial alteration in the energy balance of the lower atmosphere and at the earth's surface, thus modulating the hydrological cycle. Observations of the space-time variation of aerosols particularly over regions which are considered to be critical for impact on the monsoon, aerosol life cycles in clouds and impact of aerosols on atmospheric radiation, are needed. The CTCZ programme offers a unique opportunity to address several challenging scientific issues related to the interactions of the monsoon with the ABL, ocean-atmosphere coupling and land-surface/cloud/aerosol processes.

2.2 Science Foci and Main Objective

The variability of the monsoon associated with the variability with the CTCZ is a highly complex phenomenon where local, regional and global scale processes/phenomena interact. Land-atmosphere interactions, hydrological feedbacks and aerosols influence the seasonal transitions and intraseasonal variation during the summer monsoon. Most of the cloud systems in the CTCZ (synoptic scale in particular) are generated over the warm oceans around the subcontinent and propagate onto the Indian region. Therefore, it is important to investigate the links of monsoon variability with the oceanic conditions and convection over the surrounding oceans. Accordingly, the science foci of CTCZ comprise of both important phenomena and process studies as listed below.

Phenomena

(a) Seasonal transition and intraseasonal variation of the monsoon.

(b) Links of monsoon variability with the convection over the surrounding oceans.

Process studies

(i) Land-atmosphere interactions and hydrological feedbacks.

(ii) Role of aerosols in monsoon variability.

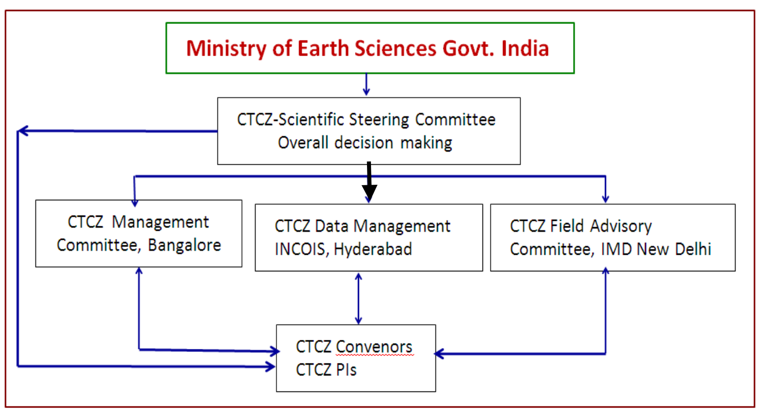
(iii) Scale interactions in convection ranging from the cumulus to the large scale.

The main objective of the CTCZ programme is to understand the mechanisms leading to the space-time variation of rainfall and the embedded monsoon disturbances during the summer monsoon.

1.3 CTCZ Management structure

CTCZ is a multi-institutional, inter-agency monsoon research programme under the MoES. A national programme of this nature needs a management structure with well-defined roles for effective implementation. The new CTCZ Scientific Steering Committee (CTCZ-SCC) to be set up by MoES based on the present proposal, will be responsible for facilitating the successful execution of the CTCZ main phase during the years 2011 and 2012, and encouraging research for the CTCZ programme. CTCZ-SCC will guide the programme and take major policy decisions related to CTCZ.

More than 25 organizations are expected to take part in CTCZ (Appendix A). Furthermore, the CTCZ programme comprises several components: (i) land-surface processes including hydrology and vegetation as well as land-atmosphere interaction and feedbacks, atmospheric boundary layer, clouds and aerosol; (ii) ocean processes, convection over the ocean and air-sea interaction; and (iii) the large scale processes of the monsoon and the ocean. Each component involves field campaigns, data analysis and modeling. This is to be accomplished by projects executed by different investigators from different institutions in the country and committed contributions from institutions under MoES and DOS. The broad-based SSC is responsible for generating proposals relevant to the CTCZ programme from the atmosphere and ocean science community, recommending sanction for those proposals on the basis of reviews about the relevance to the CTCZ programme, the proven competence of the investigators and feasibility of attaining the objectives. The overall scientific responsibility of ensuring deliverables also rests with the CTCZ-SSC. The proposed management structure of CTCZ is shown below.



CTCZ Management Structure

For effective management of the implementation of the programme, which also incorporates field programmes, important decisions have to be taken rather frequently. A group, of size much smaller than the SSC, which is capable of monitoring the programme and the individual projects and making decisions and directing change when required, has to be set up. It is proposed that a CTCZ management committee comprising the major scientists involved in formulation of the important components of the science and implementation plans and the heads of all the important institutions in MoES be set up.

CTCZ Management Committee

The CTCZ Management Committee with following membership is to be set up.

1.	Prof. G. S. Bhat, IISc	Chairman
2.	DGM, IMD	Member
3.	Director, IITM	Member
4.	Director, INCOIS	Member
5.	Director, NIOT	Member
6.	Director, NCAOR	Member
7.	Dr. V K Dadhwal, NRSC	Member
8.	Dr. K Krishnamoorthy, SPL, VSSC	Member
9.	Dr. D. Shankar, NIO	Member
10.	CTCZ Programme Manager	Member Secretary

For facilitating implementation of the CTCZ programme, it is necessary to establish a project office for CTCZ. It is proposed that such an office be set up at IISc, Bangalore.

CTCZ Programme Office (CTCZ-PO)

The programme office (CTCZ-PO), which will work under the CTCZ Management Committee, will facilitate coordination between the participating scientists, the management committee, and the CTCZ-SSC, and, when required, with other committees of MoES, DOS, etc. The annual report for the CTCZ programme as a whole will be prepared by the CTCZ Programme office. The CTCZ Programme office will receive the annual scientific reports and utilization certificates for each of the projects funded under CTCZ, which after examination by the CTCZ Management Committee, will be forwarded to the ministry for release of further installations. The CTCZ-PO will also be responsible for publication of posters, newsletters, etc., help in organizing meetings, workshops, etc.

The Program Office will have a Program Manager (to be hired on contractual basis), who will be responsible for coordination among various components, and follow ups with progress made by each component and institute. He will serve as the member secretary of the CTCZ management committee.

The Programme Manager will be assisted by 4 JRFs (of whom 2 will be placed at IMD New Delhi for supporting activities of the CTCZ-AO), and secretarial support.

CTCZ Field Advisory and Monitoring Office (CTCZ-AO), IMD New Delhi

It would be essential, like in previous programmes, to set up a Field Operation Centre for the CTCZ. This Field Operation Centre would be responsible for conducting thrice-a-week meeting to assess the developing monsoon situation and send special messages to all their field observatories and other observing components of CTCZ. For this purpose, a CTCZ-AO committee is set up with following membership.

1. DGM, IMD	Chairman
2. Sri D.R. Sikka	Co-Chair
3. Representative, NCMRWF	Member
4. Representative, Indian Navy	Member
5. Representative, IAF	Member
6. Representative, IIT Delhi	Member
7. Rep IMD	Member
8. Rep, IMD	Member (Member Secretary)

CTCZ-AO will be in touch with CTCZ-PO at IISc, convenors of the CTCZ components, INCOIS, NRSC, NCAOR, NIOT, etc. Two JRFs will be deputed from CTCZ-PO to CTCZ-AO to assist in arranging the meetings, communication and data management.

Data Management

A huge amount of routine and special observational data is planned to be collected; these data would be supplemented by model-based products on large and meso-scales. These data are complex and interdisciplinary in nature. Hence, management of CTCZ data set (collection, quality control, distribution to scientific community and exchange with other national and international programs) would require a data management system and data centre.

The data centre should be accessible even years after the field phase is over. Therefore, it should be located/associated with an established institute/organization already familiar with data management. INCOIS has been archiving ocean data since several years, and its efforts are well appreciated. INCOIS has the infrastructure and other resources to manage a data centre. Director, INCOIS has kindly agreed to host CTCZ data centre for both atmospheric and oceanic components. This may be mirrored at IMD Pune.

2.4 Deliverables

The major aim of the CTCZ programme is to improve the understanding of the variability of the CTCZ/monsoon on the intraseasonal scale and in seasonal transitions and get deeper insight into the role of land-atmosphere-vegetation feedbacks, links to convection over the oceans, aerosols and interaction between the meso-scale, synoptic-scale and large-scale convection. Experience of the other dominant phenomenon in the tropics, viz. ENSO has clearly shown that understanding the physics of the critical processes is essential for progress in prediction. We expect the CTCZ programme to contribute to the improvement of the skill of prediction of rainfall over the Indian Region. On the short and medium scales, predictions are generally based on the expected propagations of the cloud systems observed over the surrounding oceans. At present, the skill of the atmospheric general circulation models in predicting the major features of intraseasonal variation, i.e., active-break fluctuations and revival from breaks with northward propagations of the large scale cloud band from the equatorial Indian Ocean, is far from satisfactory. Understanding the underlying mechanism is essential for improving the models to generate reliable predictions. Hypotheses have been proposed (in studies in India as well as abroad) about the mechanisms responsible for these features. These hypotheses have to be tested using good quality data on critical facets like the vertical profiles of temperature, water vapour and heat sources and moisture sinks. Such data are expected to become available from conventional and satellite data since the main phase of the CTCZ programme overlaps with INSAT 3D and Megha-Tropiques satellites. For improving the short-term predictions of tracks of synoptic-scale systems on land, it is necessary to incorporate the feedbacks between the land-surface hydrology, vegetation and the atmosphere. A major aim of the CTCZ programme is to make such measurements and also assess the ability of the current models at simulating them. Deeper understanding of the links of monsoon variability on intraseasonal and interannual scales to the variability of convection over the equatorial and northern Indian Ocean is expected to lead to improvements in Indian monsoon prediction for these timescales, and hence for societal benefit. The additional data collected during the multi-year campaigns would contribute to providing better initial conditions by assimilation of the data into the prediction system. Improved understanding and data would also lead to guidance for setting up priorities for operational work and help develop the observing system for monsoon monitoring and research under the CTCZ programme.

It is important to note that the CTCZ programme is the first observational programme treating the monsoon as a coupled land-ocean-biosphere-atmosphere system. Also for the first time, simultaneous *in situ* cloud microphysics and dynamics observations will be made. During the field phase, extensive data will be collected using conventional and special field programmes. Data from different sources flowing to the data centre will be made freely available to researchers in the country. This should attract a large scientific community to monsoon research (including student theses). Such data sets will go a long way in promoting basic monsoon research. Therefore, while the special observations in the CTCZ programme are, at this point, planned for only two monsoon seasons (2011, 2012), the work involving data analysis, interpretation and modeling will continue for several years as happened in the case of the international observational programmes, GATE and TOGA-COARE. Thus, we expect that the CTCZ programme will have a long-term impact on monsoon research.

2.5 Financial requirements

CTCZ involves field observations, data analysis and modeling. Field observations are essential to provide the required data. For this purpose, new equipment/sensor and manpower are needed, and facilities set up and/or upgraded. For both data analysis and modeling, computational and human resources are required, especially at academic institutes. A Programme Office also needs to be set up to coordinate the activities. Further, it is planned to organize a series of workshops to go into depth in important themes such as land-surface processes, cloud modeling, etc. to promote interactions between working scientists and expose the younger scientists to challenging problems.

Letters seeking project proposals under CTCZ were sent to all major organizations working in atmospheric and oceanic sciences in the country. In all, 27 proposals have been received so far for the CTCZ programme. These proposals have been reviewed. The CTCZ-SSC will discuss the proposals and reviews on 29th January 2011 and recommend appropriate funding for the approved projects. The budget estimate below is based on the fund requirements for the proposals (whose objectives meet CTCZ programme requirements) including expenses for instruments on board ships, equipment for special field experiments on land as well as ocean, manpower for observational and modeling studies in project mode as well as the requirements for the CTCZ-PO. It is also planned to organize several theme and CTCZ programme based workshops to discuss the scientific results. MoES support is needed for this purpose as well as for the Programme Office. Expected overall **fund requirement for the CTCZ programme for three years** under different headings are given in table 2.1 below, and the yearly budget in table 2.2.

Table 2.1 Estimated fund requirements of the CTCZ Programme for 3 years.

Item		**Budget (in lakhs)**
Equipment	:	332
Consumables	:	210
Travel	:	74
Man power	:	419
Meetings, workshops, etc.	:	55
Overheads, etc.	:	207
Total:		**1297**

Table 2.2. Yearly budget requirements for the CTCZ programme. (Rs. in lakhs)

Item	Year 1	Year 2	Year 3	Total
Component 1	400	135	125	660
Component 2	195	80	55	330
Component 3	121	104	82	307
	716	319	262	1297

The proposals received under the three components of CTCZ are given in Tables PC1, PC2 and PC3 (after section 5). It may be remarked here that the scientific issues in the three components are not independent and have some overlap. In fact, work proposed in some proposals deal with more than one component, and these proposals are assigned a component where the relevance/quantum of proposed work is more. The approved proposals in prescribed format and the recommendation by CTCZ-SSC will be forwarded to the ministry for funding separately.

It should be noted that there will be considerable expenditure by IMD, IITM, NRSC, NIO, NCAOR, NIOT, INCOIS, etc. for observations during the field phase of the CTCZ; this expenditure will be borne by these organizations and is not budgeted for here.

3. CTCZ Component 1: Land-surface processes, atmospheric boundary layer, clouds, aerosols

Convenors:

V. K. Dadhwal (NRSC),

G. S. Bhat (IISc)

K. Krishnamoorthy (SPL)

Co-Convenor

B. Mukhopadhyay (IMD)

There are several themes in this section, each somewhat independent but also connected to each other. Objectives, implementation, and deliverables for these themes are separately given below.

3.1 Land-Atmosphere-Hydrology & Vegetation: observations and modeling

Pronounced changes in land-surface vegetation cover and soil moisture take place between May and September. Variation of the land surface characteristics leads to a variation in the fluxes of heat and water vapour to the atmosphere which, in turn, can lead to changes in the circulation and precipitation. The sensitivity of the atmosphere to variations in these characteristics varies in space and time. Indian monsoon zone is one of the major 'hot spots' where a significant impact of soil moisture variation on the precipitation on the synoptic timescale has been observed in numerical models. Land-surface processes and inhomogeneities can generate mesoscale circulations, giving rise to preferred areas of formation and dissipation of convective systems. Soil moisture and nature of the vegetation are important. Therefore, it is necessary to understand how land-surface and hydrological processes modulate the monsoon rainfall patterns and surface hydrology under the CTCZ programme using observed land-surface data as boundary conditions in models. This understanding can be achieved through a combination of observations, modeling, and analysis at a range of spatial and temporal scales. Accordingly, following are the main objectives of the hydrological component of CTCZ.

3.1.1 Approach and Objectives

The overall objective of this component of the CTCZ programme is developing a better understanding of land-vegetation-atmosphere interactions over the CTCZ region. The approach will involve (i) elucidation of the observed variation of critical attributes such as vegetation cover and soil moisture by combining satellite data with ground truth from special field observation, (ii) observations collected in special field experiments for selected catchments and river basins, and (iii) studies with a hierarchy of models ranging from simple hydrological models to complex GCMs, which can be validated by observations (such as of inflow into reservoirs or runoff to the sea in the case of river basin). The sources of spatial variability in the basin-wide hydrological components of the CTCZ region at event, intraseasonal, and inter annual timescales and their impact on land-surface and monsoon characteristics have to be determined. The specific objectives are the following.

(i) Elucidation of Vegetation and Land Cover Characteristics by generating high resolution 'Land Surface Data sets' required in the modeling studies, and study and documentation of land cover/vegetation during monsoon with special attention being paid to intraseasonal variation in monsoon and vegetation characteristics.

(ii) Basin-scale hydrological modeling for two river basins in the CTCZ area.

3.1.2 Implementation

For addressing the first objective, the following land-surface data sets will be generated by NRSC.

(a) A high-spatial-resolution (1 km) land use, land cover (LULC) map will be generated by NRSC for the pre-monsoon and monsoon seasons on the basis of multi-temporal satellite observations, ground truth and land use and crop statistics from state agricultural departments. USGS-compatible 2009-10 data will be given before the 2011 campaign starts (one data set for the season as a whole, in 25 classes). Similar products will be generated for 2011 and 2012 as well, within 9 months from the end of the monsoon season.

(b) In-season land-cover change data, incorporating water spread and water-logged areas, will be generated using radarsat data for each of the flood events on monthly basis. The radarsat data, to be procured from a Canadian agency, is expensive and depends on the total area considered. For CTCZ purpose, the area considered for radarsat data is 75^o-85^o E, 20^o-25^oN, for 2011 and 2012 June-September period.

(c) Information will be provided on vegetation phenology at high resolution vis-à-vis intraseasonal monsoon variability with a retrospective, multi-year analysis (2010-12).

(d) Vegetation index will be prepared on a fortnightly basis during kharif season by the end of each monsoon season (lead time ~2 months).

(e) Mapping of soil moisture integrating satellite (AMSRE) and field observations (in-situ field-scale soil-moisture measurement will be carried out at IMD sites and at AWS/ boundary layer tower sites). If IMD soil moisture data (past and those to be measured in 2011-12) is given to NRSC, it will be examined along with satellite-based drought project and WARIS. The data set generated on land-surface characteristics, vegetation and soil moisture would be very useful for modeling studies (for the CTCZ programme this data set is required for the period 2011 – 2012).

(f) Energy-water balance measurements will be done using flux tower data. The ongoing projects for this purpose include (1) Ranchi site operated by BIT, Mesra, (2) tower at IIT (Kharagpur), (3) agrometeorology towers operated at various locations by SAC, Ahmedabad, and (4) Carbon flux towers planned under National Carbon Project of ISRO-GBP at Haldwani (Forest Plantation), Meerut (Indo-Gangetic Plain, mini mobile EC system for crops /grasslands), Barkot (Dehradun, Sal forest), and Betul (MP, mixed vegetation) by IIRS.

Flux tower instruments to be operated are (some more details can be found in the ABL section that follows)*:*

- Fast response sensors (≥20 Hz) for wind, water vapour, CO2 and temperature
- Radiation (four components) instruments, Line quantum PAR sensors (2)
- Soil moisture & soil temperature probes (4-6 levels), Heat flux plate
- One/multi level met parameters using slow response sensors (humidity, air temperature, pressure, rain, wind speed, etc.).

For addressing the second objective, one river basin considered is that of Mahanadi (Brahmini or Vaitirini) located at the eastern end of CTCZ. The second one is Luni river in Sabarmati basin, which covers the western end of CTCZ. Some work is already in progress for the Haldwani river, and this is also a potential water shed for CTCZ studies. These basins offer good contrast in rainfall and LULC. The main objective is to characterize temporal variability of soil-moisture storage and evapotranspiration at the basin scale as a function of active and break period of monsoon. Mahanadi also offers an opportunity to investigate response of ocean parameters to surface runoff. Both lumped and distributed hydrological models will be used. The soil moisture and evapotranspiration over large regions will form a cross-validation data set for atmospheric models. While a number of studies have been carried out at the basin scale earlier, the challenge remains to account for surface storage as well as irrigation at intraseasonal scale at the level of the basin. Thus, choice of model and integration of collateral data on these parameters is important. Remote sensing data to a limited extent will provide supplementary information.

The approach comprises the following.

(a) Observations **:** Field observation of surface meteorological parameters, soil moisture measurements, soil hydrological properties and discharge.

(b) Spatial data sets : Land cover/use, soil maps and spatial forcing field generation.

(c) Model selection : Lumped and distributed hydrological models such as SWAT, VIC, etc.

(d) Model calibration : Calibration of the existing spatial distributed hydrological model for the basin, considering the dominating hydrological processes.

(e) Model validation : Validation of the model with available observations of surface runoff and soil moisture.

(f) Model Analysis: Model runs for CTCZ period will be investigated for intraseasonal variability in major water balance components, especially as it relates to active and break period of monsoon.

NRSC will provide high-resolution topography and data on soil characteristics for use in modeling 3 watershed studies (Mahanadi, Haldwani and one site in Gujarat) in collaboration with the WARIS project under NRSC. Detailed watershed level observations (stream runoff at few locations, rainfall/precipitation, evapotranspiration, rain gauges to capture rainfall spatial variations) are needed. Where not adequate, new observations are to be made at least at a few critical locations. In addition, soil moisture data along with all the data for calculating water balance will also be available from the special observations in the identified 2/3 river basins and watersheds (see Table 3.1). The NRSC group also contributes to hydrological/river basin modeling.

Hydrology and NWP divisions of IMD will also contribute to hydrological modeling,

Table 3.1 For modeling activities, following data will be made available by NRSC.

Hydrology

S.No.	Parameter	Existing data acquisition	Additional Requirement
1	Discharge	Existing gauge and discharge sites in several river basins (CWC and state govt. departments)	To be identified based on existing network in gap areas
2	Soil moisture	At existing meteorological stations by state govt. and agriculture departments	To be identified based on existing network in gap areas
3	Ground water level	At existing ground water level observation wells maintained by CGWB and state ground water departments	To be identified based on existing network in gap areas

Vegetation and Soil Parameters

S.No.	Parameter	Approach & Location	Equipments/measurement required
1	Soil Texture, OC, BD	Soil map from soil survey/lab analysis	Soil sampling in soil-scape units within CTCZ
2	Soil infiltration, hydraulic &Thermal Conductivity,	Field measurements in dominant soil categories in CTCZ	-thermal probe -double ring infiltrometer
3	Surface roughness, plant height	Statistical (Z_0 and RS derived canopy structure (LAI /canopy height)	LAI /canopy height measurements at tower sites/ (Plant canopy analyzer)
4	Albedo	MODIS data	Portable albedometer
5	Leaf photosynthesis Canopy resistance/leaf conductance	Measurements at tower sites	Leaf photosynthesis system Automatic porometer
6	Rooting depth	Root morphology & root length measurements	DeltaT-scan

3.2 Atmospheric Boundary Layer (ABL)

ABL is the lowest layer of the atmosphere (typically less than 2 km deep) that forms the interface between the surface (be it land or ocean) and the rest of the atmosphere. Its properties are basically related to the surface characteristics and synoptic conditions. Properties of ABL (also called sub-cloud layer) determine convective cloud properties and are required for the representation of cloud processes in global atmospheric models, i.e., cloud parameterization schemes. Interactions of the ABL with the surface layer of the ocean are a key element of the ocean-atmosphere component of the CTCZ programme. Over land, evapotranspiration is an important component of the hydrological cycle and the land-atmosphere-vegetation interactions take place in the ABL. Flow in ABL is normally turbulent. Turbulence in ABL and the nature of the surface determine the properties of aerosols and CCN. Thus, ABL has links with several components of the CTCZ programme.

The CTCZ programme offers a unique opportunity to address several scientific issues related to ABL. The eastern end is marine in nature whereas the western part is semi-arid. The largest amplitude of diurnal cycle in the troposphere occurs in the ABL. Soil temperature and moisture, and vegetation evolve with the progress of the monsoon. Also, we expect ABL properties to vary between active and break monsoon conditions. These changes are to be documented during the CTCZ programme. The CTCZ region is often a low-wind regime even within a monsoon season. Formulations for fluxes under low wind-speed regimes under unstable and stable conditions need to be established and validated. Thus, determining the surface fluxes under the entire range of wind speeds that prevail during the monsoon, including the low-wind regime, is an outstanding problem. The data required to address this will be collected during CTCZ.

3.2.1 Objectives

The scientific objectives of the ABL component under CTCZ are as follows.

(i) Measuring surface fluxes under different wind speed and thermal stability conditions for surfaces representative of the CTCZ region.

(ii) Formulation and validation of fluxes under different wind-speed regimes over land and ocean.

(iii) Interactions between ABL and cloud updraft & downdraft.

(iv) Role of north-south SST gradient on ABL properties over Bay of Bengal.

(v) Surface heat balance and SST evolution over the Bay.

3.2.3 Work Plan and Methodology

The work plan and approach involved in implementing the ABL component over land and ocean are different. Therefore, we consider them separately.

3.2.3a. Over Land

ABL consists of several layers including the surface layer, mixed layer and the interface layer. Exchange of fluxes between land surface and atmosphere takes place in the surface layer. For meeting the first objective above, instrumented towers are needed. Under DST's STORM programme and the IGBP/National Carbon Project of ISRO, boundary layer towers have been established at few places within the CTCZ domain covering different climatic conditions. Available tower facilities are as follows.

(1) Flux tower at IIT Kharagpur

A 50-meter micro-meteorological tower is set up at IIT Kharagpur under the STORM programme. The available sensors include temperature, moisture and wind measurement at six levels, fast-response (sonic) anemometer, net radiometer (NRLITE), raingauge and soil temperature and moisture measurements at 2 depths (Table 3.2).

The existing tower lacks the fast-response humidity sensor, which is needed to get the latent heat flux from eddy covariance method. The observational facility is to be augmented with infrared (fast response) hygrometer (20 Hz or better), net radiometer, soil-temperature and moisture sensors at additional four depths, one data-logger (CR3000) (for the additional sensors) and data retrieval & storage devices.

(2) Flux tower at BIT Ranchi

The BIT Ranchi campus has a 32-m micro-meteorological tower with slow-response sensors for temperature, humidity, wind speed/direction at 6 levels (1, 2, 4, 8, 18 and 32 meter heights). A 10 Hz sonic anemometer is the fast-response sensor installed. Four components of radiation, pressure, soil moisture, soil temperature (at different depths), soil heat flux, evapotranspiration, rainfall, albedo are also being measured. BIT is also having the following instruments.

1. Sky Radiometer to study aerosol and ozone depth with the help of IITM Pune.
2. ARFI station to monitor aerosol and black carbon for eastern India using Athalometer (Aerosol Optical Depth, Black Carbon, etc.) and Sun Photometer (AOD & AOT) with the financial support of SPL, VSSC (ISRO) Trivandrum.
3. Plan to start upper air observations using ISRO's Pisharoty GPS-Sonde System under SPL's ABLN&C programme & under ISRO's PRWONAM scheme. VSSC and ISRO HQ have provided their GPS RS/RW system and expected to be operational by January 2011.
4. RASS and SODAR facility for the study of lower boundary layer by January 2011 with the support of Space Physics Laboratory, VSSC Trivandrum.

5. Will install MWR Radiometer by the end of December 2010 with the help of Space Physics Laboratory, VSSC Trivandrum (ISRO).
6. Will install Metek Sonic anemometer by February 2011.

BIT tower is about 3 year old and needs maintenance (including replacement of some sensors) and additional instruments. The list of additional sensors is shown in Table 3.3.

Table 3.2. Existing sensor arrangement and augmentation required at IIT Kharagpur.

Sr. No.	Instrument / Sensor	Parameter measured	Level	Present Status
1.	RM YOUNG Wind Monitor	Wind speed and direction	6 levels: 2, 4. 8, 16. 32 and 50 m	Working
2.	Air Temperature & Humidity Sensor	Relative Humidity and Air Temperature speed	6 levels: 2, 4. 8, 16. 32 and 50 m	Working
3.	RM YOUNG Barometric Pressure Sensor	Surface Pressure (hPa)	1 meter (Approx.)	Working
4.	Tipping Bucket Raingauge	Rainfall (mm)	Surface	Working
5.	NR LITE radiometer	Net radiation (W m^{-2})	2.50 m	Working
6.	RM YOUNG Sonic Anemometer	Turbulent measurement of wind components and temperature (ms^{-1} & ^{o}C)	10 m	Working
7.	Soil Temperature Probe	Soil temperature (^{o}C)	10, 20 & 50 cm Depth	First 2 levels are working, ***the third level is not working***
8.	Water Content Reflectometer	Volumetric moisture content (%)	10, 20 & 50 cm Depth	First 2 levels are working, ***the third***

Additional sensor/instrument requirements at IIT Kharagpur

Sr. No.	Instrument / Sensor	Parameter measured	Level
1.	Infrared Hygrometer	Moisture and CO_2 flux	10 m
2.	Net radiometer CNR4	Four components of Radiation	2.5 m
3.	Soil Temperature Probe	Soil temperature (ºC)	Surface, 30 cm, 50 cm, 100 cm
4.	Water Content Reflectometer	Volumetric moisture content (%)	Surface, 30 cm, 50 cm, 100 cm
5.	Data logger	Data archival	

Table 3.3. Additional sensors/materials/services needed at BIT Ranchi.

No	Sensor/Equipment	No required
1	Fast response IR Hygrometer	1
2	Slow Humidity/Temperature sensors	3
3	Soil moisture sensor	3
4	Computer, accessories	1 set
5	AMC Charges for existing equipments	for 2 years
6	Observatory instruments Radiosonde, balloons, gas, etc.	200 per year

(3) Flux towers built under IGBP & National Carbon Project

Carbon flux towers have been set up under National Carbon Project of ISRO-GBP at NRSC/IIRS has set up flux towers at Betul (in a teak forest, 50 m high, 8-level instrumentation) and at Haldwani (in a sal forest, 30 m high), Meerut (Indo-Gangetic Plain, mini mobile EC system for crops /grasslands) and Barkot (Dehradun, Sal forest).

(4) IMD New Delhi flux tower along with microwave radiometer will measure the detailed time evolution of ABL at New Delhi.

Data analysis & flux algorithms

The above towers cover different land-surface conditions in the CTCZ domain, namely, humid, sub-humid mixed vegetation, semi-arid crop lands, semi-arid forested and semi-arid land. Data is to be collected continuously from pre-monsoon to September end for the years 2011 and 2012. Using the fast-response sensor data, fluxes of momentum, sensible and latent heats can be calculated using the eddy covariance method, which defines the reference flux values. Multi-level slow sensor data can be used for flux estimations from bulk method, which models use. Combining these, appropriate algorithms valid for different surface and weather conditions will be derived.

Microwave Radiometer (MWR)

For addressing the third objective, a microwave radiometer will be deployed, in the CTCZ domain, preferably in the Mahanadi basin in collaboration with the Megha-Tropiques validation programme. MWR continuously measures temperature and humidity profiles in the atmosphere up to 10 km height and at 39 levels. In the lowest 2 km, it gives data at 25 levels when scanned in the boundary layer mode, thus providing a very high resolution in the ABL. A profile is available every 5 to 15 minute interval depending on the scan strategy. This will enable the study of the diurnal evolution of ABL, changes in the boundary layer as a convective system builds up, matures and decays. In order to verify the profiles measured by

MWR and fine tune the retrieval algorithm, GPS radiosondes will be released at least once a day in collaboration with IITM.

At present, models use thresholds of convective indices such as CAPE and CINE to initiate deep convection, but there is no solid observational basis. MWR and GPS radiosonde data together will enable the computations of CAPE and CINE on a continuous basis as the diurnal cycle evolves or a synoptic system develops or passes over the site. Such data will provide the basis for setting the right convection thresholds in models. The temporal changes in the vertical profiles will also help in understanding the ABL and cloud interactions.

3.2.3b. Over ocean

Over the ocean, surface fluxes and vertical profiles of the atmosphere are to be measured. For this purpose, request for ship time has been made for ORV Sagar Kanya and RV Sagar Nidhi. In the year 2011, observations will be for one month duration (1-30 June) to capture the monsoon onset and break/active conditions. Detailed cruise tracks are discussed in the ocean component in section 8 (see Figure 5.1).

Upper air observations

IMD will provide the GPS radiosonde receivers for upper air observations for both the ships. Normal frequency of launch is 2 per day and during IOPs increased to 4 day^{-1}. The number of radiosondes required is 70 for each ship for 2011, and 120 for each ship in 2011. Thus the total number required is 380 for 2 years.

Surface met and flux measurements

Complete surface meteorological data including temperature, humidity, wind speed and direction (all these at one level), four components of radiation or net radiation, pressure, rainfall, SST and ship navigation data will be measured from both the ships. INCOIS has installed AWSs (I-RAWS system) on both the ships, and most of the above variables are measured and archived at every one minute interval. The AWS is fixed on a mast on the forecastle deck on board both the ships. During time-series observations, dynamic positioning system is used for keeping the ship in one place. This system works best when the ship is so positioned that wind blows from behind the ship. In this orientation, the ship structure blocks the wind blowing towards the AWS; thus, there could be a large error in wind data at such times. To overcome this problem, INCOIS has been requested to install an additional AWS at the other end of the ship also.

For verifying the bulk flux algorithms, sensible and latent heat fluxes are to be calculated using the eddy correlation method. For this purpose, fast response sensors are required along with full ship motion information (acceleration and tilt). Fast-response wind, temperature and humidity sensors were used during BOBMEX and ARMEX. Fluxes have been calculated using eddy correlation and inertial dissipation methods (so called direct methods). Comparison of direct and bulk fluxes showed reasonable agreement in the mean but with considerable scatter. Further, while the agreement in the mean fluxes look reasonable, when one examines the scales of wind, temperature and specific humidity from the two approaches, there is a large difference and bias. Also, indirect estimation of flow distortion near the ship has been made. It was noted that values measured on the boom at 10 m height (above sea level) was that of air between 2 and 8 m levels in the (undistorted) free atmosphere depending on wind direction and speed relative to ship. This introduces error in the mean wind field and comparing fluxes from direct and bulk methods. Flow distortion correction requires detailed 3D simulations, which has not been done so far for Indian research ships. Another limitation was that the best frequency response for the met sensors was 10 Hz (in 1998-99), which is not adequate for capturing energetic frequencies in a turbulent flow field in ABL (now sensors with 20-100 Hz sampling rate are available).

For the CTCZ cruises, it is proposed to use fast-response sensors with a sampling frequency of 20 Hz or more. Sensors for wind, temperature and water vapour will be mounted on a boom (along with ship motion sensors to correct for ship motion including rolling & pitching). In order to collect data over a longer time interval than the one-month-long CTCZ cruise, the flux sensors will be operated till the end of September.

IISc will make flux measurements on one ship. Numerical simulation of flow around the ship will also be carried out for this ship to correct for flow distortion effects on the estimated fluxes. NIO Goa will measure fluxes from the second ship. (This could be NIO's ship Sindu Sankalp.)

ABL Modeling

ABL modeling studies will enable extending measurement results to models. Different parameterization or turbulence closure schemes will be tested. Since accurately capturing diurnal cycle is critical for predicting the time of occurrence of convection, ability of the models in correctly getting the phase and amplitude of the diurnal variations should be examined closely. Also, the CTCZ area is a low-wind regime. Efforts are required for developing flux schemes under low-wind conditions covering different stability regimes. In BOBMEX and ARMEX, ABL modeling work was done at IIT Delhi, NCMRWF and IITM Pune. Now, IIT Kharagpur and BIT Ranchi have also formulated proposals for such studies under the CTCZ programme. IMD has a numerical modeling group and it will involve in incorporating CTCZ ABL data in the forecast model.

Link with other components

As stated earlier, the ABL forms the interface between the atmosphere and the underlying land/ocean surface. The ABL measurement plan needs to be discussed with hydrology, synoptic, cloud systems and aerosol groups. Link between modelers and observational groups is essential for developing/testing parameterization schemes.

Participating Organizations

NRSC Hyderabad/ IIRS Dehradun, IISc Bangalore, IITM Pune, IIT Delhi, BIT Ranchi, IIT Kharagpur, NIO Goa, IMD, SAC Ahmedabad, University of Pune, IIST Trivandrum.

3.2.4. Committee for instruments and calibration

Flux tower measurement involves different groups. In order that data collected is to the best ability of the sensors/instruments used and useful for developing new flux algorithms, it is essential that sensors are well calibrated and intercomparisons carried out where possible. Following team will look into flux tower instruments, measurement strategies and calibration issues.

a. Prof. G S Bhat, IISc
b. Dr. V. K. Dadhwal NRSC
c. Dr. C. S. Jha NRSC
d. Dr. V. V. Rao NRSC
e. Prof. U C Mohanty, IIT Delhi
f. Sri Krishnaiah, DDGM (SI) IMD
g. Dr. M. Mondal, IIT Kharagpur
h. Dr. Manoj Kumar, BIT Ranchi

The team will also recommend data collection and archiving protocols, and flux analysis methods.

3.3 Clouds and Cloud Systems

Cloud is inherently a multi-scale phenomenon, with interactions taking place on scales starting from sub-micron (CCN) to synoptic scale (supply of moisture). To cover physical processes occurring over this vast range in the scales, it is convenient to consider cloud microphysical, convective cloud and mesoscale separately.

3.3.1 Objectives

(i) Cloud microphysical properties in the CTCZ area.

(ii) Updraft & downdraft structure in monsoon cloud systems and interaction with the boundary layer.

(iii) Monsoon precipitation characteristics.

(iv) Size distribution and chemical compositions of CCN.

(v) Life cycle of MCSs: Preferred location of formation, intensification/development, and propagation during active and break monsoon.

(vi) Local feedbacks, life duration, diurnal variation, etc.

3.3.2 Work Plan

Addressing the first objective calls for *in situ* cloud observations. Rain is an end product of a complex chain of processes occurring over a wide range of scales, and clouds are central to this chain. Formation of cloud droplets and a few of them growing to precipitation size is an important process. Although several monsoon experiments have been carried out so far, no data on CCN, cloud microphysics and precipitation mechanism were available in the CTCZ region till the CAIPEEX observations carried out in 2009. CTCZ will be the first among monsoon experiments to address cloud microphysics and dynamics.

Aircraft to be hired for CAIPEEX in 2011 and 2012 is to be deployed for CTCZ cloud studies as well. IITM will provide 50 hours of flying time on the CAIPEEX cloud physics aircraft. The measurements available on this aircraft are shown in Table 3.4. Bhubaneswar is a good location for aircraft operations for the CTCZ region if local logistic support is available.

Disdrometer measures rain rate and drop size distribution at the ground level. It is strongly recommended that disdrometers are available at each DWR station in the CTCZ area. It is also proposed to make disdrometer measurements on board the ship as well to understand rain characteristics over the Bay. This will enable characterizing the nature of precipitation (convective versus stratiform) during CTCZ field phase.

Instrumented air craft will also measure velocity field inside and around clouds. DWR gives some information on the velocity field inside precipitating clouds. When such data are combined with radiosonde and tower data, we get information to address objective (ii) above.

Table 3.4: Proposed Instrument list for the Research Aircraft during the CAIPEEX Phase-II Second year operations – 2011

Variable	Instrument	Range	Quantity required
Air Data Probe	Aircraft Integrated Meteorological Measurement System (AIMMS-20, ADP, IMU, WAAS DGPS, CPM)		1
Air temperature	Rosemount temperature	-50°C to +50°C	1
Dew point temperature	Chilled mirror aircraft hygrometer	-40°C to +60°C	
Logging, telemetry & event markers from aircraft to base of operations	ESD DTS (GPS)		1 airborne unit and 1 ground based unit
Cloud droplet size distribution	DMT CDP or equivalent	3 to 47 µm	1
Cloud particle imaging and size distribution	DMT CIP or equivalent	25 to 1550 µm	1
Stereo cloud particle imaging and spectra		10 to 1280 µm	1
Precipitation imaging and size distribution		100 to 6000 µm	1
Liquid water content	Hotwire Liquid Water Content (LWC)	0 to 3 g/m^3	2
Isokinetic aerosol inlet	Diffuser inlet installed in laminar flow outside of the aircraft boundary layer	> 20 lpm	1
Nucleation mode aerosol spectrometer	High flow Differential Mobility Analyzer (DMA)	0.01 to 0.5 µm	1
Accumulation and coarse mode aerosol spectrometer		0.1 to 3 µm	1
Cloud and aerosol spectrometer		0.5 to 50 µm	1
Cloud residuals	Counter flow Virtual Impactor (CVI) inlet	variable cloud droplet cut size 5 -20 µm	1
Cloud condensation		0.1 to 1.2 % SS	1

nuclei (switch between aerosol inlet and downstream of CVI)			
Fine mode aerosol size distribution (downstream of CVI)		0.055 – 1 µm	1
Coarse mode aerosol size distribution (downstream of CVI)		(0.5 – 5+ µm)	1
Total aerosol concentration (downstream of CVI)		> 10nm	1
Particle chemistry (downstream of CVI)	Cascade impactor based instrument for different sizes. Particle into Liquid Sampler (PILS)		1 1
Short-wave irradiance, up & downwelling		285-2800 nm	1
Long-wave irradiance, up & downwelling		4-50 µm	1
Data acquisition system			1

3.3.3 Clouds: cloud systems

Active monsoon systems have deep clouds organized on synoptic and mesoscale. The environmental conditions in the CTCZ are special with the presence of both horizontal and vertical wind shears, eastward moving upper air westerly trough and westward moving low along the monsoon trough. Such systems produce heavy rainfall over the Indo-Gangetic plains and their life cycle may be about few days. The microphysical and dynamical characteristics of cloud clusters associated with these systems have not been studied. The fractional area covered by stratiform clouds, estimation of the cumulus mass flux, and the mesoscale mass flux are essential to ascertain the deficiencies of the representation of cloud dynamics in numerical models.

Data requirement

The data required include vertical soundings from the entire Indian region and surrounding areas, where available, and rainfall, radar reflectivity and velocity profiles, surface met from AWSs and manual observations, soil moisture and vegetation, and model reanalysis products, all relevant satellite data, including pixel level data from INSAT satellites (visible, IR and soundings from INSAT-3D). Satellite data should cover as wide an area as possible to see the link with synoptic and planetary scale systems (see next section). Cloud data from MEGHA-TROPIQUES, TRMM and other polar orbiting satellites are also to be archived and made available.

In order to capture the initiation, evolution and propagation of MCSs, geostationary satellite data at hourly intervals and DWR and AWS data at finer temporal resolutions are required. Normal 2 radiosondes a day frequency is adequate in general and during IOPs, the radiosonde launch frequency can be 4 to 6. If microwave profilers are available, then data should be collected in the continuous scanning mode. Rain water will be collected for isotope and water source identification purposes.

For understanding the dynamics of convective systems and precipitation processes, radar data is essential. Enhanced Radar network of the IMD is to be fully utilized. Hourly INSAT pictures and TRMM and other US/European satellite information are to be collected through the IMD /ISRO. These frequent time interval data will be useful for the analysis of high impact rainfall events as well as to understand diurnal variability in convection which impacts on mesoscale and synoptic scale variability, specially enhanced networks of surface and upper air observations are necessary.

Data for pre-monsoon and monsoon months are to be archived in the CTCZ data center and made available.

Observing strategy

Clouds are propagating systems. Therefore, we need to follow the monsoon system from the Bay and over land as it moves over the CTCZ area and sample the convective and stratiform clouds at different altitudes at different stages of development. To capture the precipitation mechanism in monsoon clouds, clouds in their initial stages of development are to be targeted. For this purpose, availability of a radar in the region is essential. Radar will provide information on the convective cloud growth and stratiform regions in the cloud system and aircraft can probe these regions repeatedly.

Vertical profiles are needed within and outside the clouds, and will be collected using constant-level flights at cloud base, freezing level and top of the convective clouds. The horizontal traverses will be of 500-1000 km. Vertical profiles will be maximum allowable flight level for the hired aircraft. Observations are needed during different times of the day for understanding diurnal variations. Bhubaneswar is a good ground base for air craft operations. Then it will be possible to cover areas over the Bay and main monsoon zone.

Data Analysis

This component of CTCZ is ideal for academic research. Research scholars and faculty from universities can take up the data analysis work. It is important to make the data available to interested users through the CTCZ website.

Modeling

We expect to have high-density AWS and rain-gauge network data, special upper air observations, DWR and satellite data. This data set will give a large number of cases to test the ability of regional models to simulate monsoon cloud systems. Modeling exercises are also needed to produce high-spatial-resolution reanalysis for the CTCZ region. Modeling is also needed to improve both ABL and cumulus parameterization schemes.

Modeling work can be carried out at research and academic institutes and universities. The initial conditions are to be made available through CTCZ data center. Several proposals have been received on modeling clouds.

Under the modeling component, simulation of individual intense rainfall events as well as the propagation of monsoon lows and depression are to be carried out. It is also important to simulate (prolonged) monsoon break conditions. This will also highlight the importance of the land surface and boundary layer processes, cloud microphysics and dynamics, and synoptic forcing. Role of CAPE and CINE in triggering organized convection will also be investigated.

Participants

IMD, ISRO, NCMRWF, IITM, Indian Air Force, Indian Navy will provide their data. Universities, academic and research institutes will be involved in data analysis. Most organizations/groups indicated in Appendix A can be involved in this activity.

Logistics

Requirements include research aircraft, aircraft base and hanger, and DWR. IITM will hire instrumented aircraft for the CAIPEEX programme. 50 hours time will be made available for investigating clouds in the CTCZ area.

Organizations, core groups & members

This component of CTCZ requires collaboration with the CAIPEEX Programme being carried out by IITM Pune. Therefore, IITM has the major role. Other organizations involved are IIT Kanpur, ISRO (NRSC, SAC), Pune University and IISc Bangalore (Appendix A). Modeling groups from different organizations will join as evident from the proposals received.

3.4 Aerosols

Aerosols influence the monsoon precipitation through cloud microphysics (CCN) and altering atmospheric stability through interaction with radiation. When the CCN have significant amounts of BC or dust coated with BC, the cloud microphysics and precipitation pattern could be perturbed significantly. Terrestrial ecosystems modulate aerosols including biogenic particles. Aerosols, particularly the anthropogenic component, which contributes most of the accumulation mode fraction, are potential health hazards, have the potential to perturb the regional and global radiation balance and therefore to perturb climate. Over the Indian region, there is a large concentration of aerosols during April to June. Absorbing aerosols such as dust and black carbon heat the atmosphere by absorbing solar radiation. In contrast, non-absorbing aerosols, such as sulphate, scatter solar radiation and have relatively weak atmospheric heating effect. Both absorbing and non-absorbing aerosols reduce the solar radiation reaching the surface, referred to as the ‘‘solar dimming’’ effect. The dimming effect is global, even though sources of aerosols are local, because of long-range transport of aerosols. In the Asian monsoon regions, the dimming effect is especially large due to heavy local pollution, and frequent occurrence of dust storms. Recent atmospheric GCM experiments have demonstrated significant impacts of aerosols on the Asian monsoon. *However, there is no consensus yet on the sign of the impact on the Indian monsoon***.** It has been suggested that absorbing aerosols (dust and black carbon), may intensify the Indian monsoon through the so called ‘‘Elevated-Heat-Pump’’ (EHP) effect. These studies indicate plausible scenarios of aerosol impacts, and suggest that aerosol effects on monsoon water cycle dynamics are extremely complex, and dependent on aerosol characteristics, vertical distribution, as well as on spatial and temporal scales.

The region-specific nature of the aerosol characteristics and the large spatial and temporal variations make the problem more complex. Mineral dust, transported by winds and convective motion over vast arid regions and deserts of western Asia and Eastern Africa, constitutes one of the major natural aerosol species over the CTCZ region during spring and summer. These particles contribute significantly to the coarse mode concentration of aerosols and thereby to the longwave radiative forcing. If BC gets deposited on dust particles, it makes them absorbing in nature. This process leads to higher absorbing efficiency for dust over Indian regions than over African regions.

3.4.1 Objectives

The overall objectives of the aerosol component of the CTCZ programme are the following.

1. Elucidation of the space-time variation of aerosols particularly over regions that are considered to be critical for impact on the monsoon, and elucidation of aerosol sources and sinks and of the impact of aerosols on the atmosphere.
2. Studies of the impact of the observed aerosols on the monsoon in models.

Detailed aerosol characteristics have been documented under winter and pre-monsoon conditions, i.e., under dry, clear sky conditions. Such characterization of the aerosols during the monsoon period is yet to be taken up. There are several outstanding issues of which the following will be addressed under the CTCZ programme.

1. Role of changing aerosol levels (both natural and anthropogenic) on cloud microphysics (including droplet activation/growth processes, chemistry and dynamics).
2. Variation of CCN and CN in the CTCZ zone, cloud liquid water content, identification of aerosol sources and sinks, aerosol life cycles in clouds, aerosol characteristics over continent and ocean (using ship and aircraft-based platforms).
3. Characterizing the absorbing efficiency of dust over the CTCZ zone during pre-monsoon and monsoon seasons.
4. Modeling and simulation studies incorporating HYSPLIT and aerosol chemical transport model (MATCH-MPIC). Examine the impact of interannual and intraseasonal variability on aerosol on CTCZ activity and vice-versa using global GCM. The new observations shall be included in the models to explore the changes/improvement on forecast performance during May to September (Action: NCMRWF).
5. Aerosol-cloud-precipitation-climate interactions and effect on monsoon rainfall.
6. Influence of aerosols and clouds (including cirrus) on atmospheric radiation, environmental pollution and hydrological cycle.

3.4.2 Observation strategy

The properties of aerosols that are important from the perspective of CTCZ are listed in Table 3.5. Over land, regular aerosol measurements will be made at the ARFI network of aerosol observatories (figure 3.1) established under the ISRO-GBP by the Space Physics Laboratory (SPL) with inter-institutional collaboration. Of the ARFI network, stations at Kullu, Nainital, Dehradun, Patiala, Varanasi, Jaiselmir, Udaipur, Bhubaneswar,

Table – 3.5. Aerosol related measurements relevant to CTCZ

Columnar	Ambient	Spatial	
		Horizontal	Vertical
Spectral AOD	TSP, PM2.5	Domain: India Centered	BC
Columnar water vapour (W)	Mass size distribution (MSD)	Special focus: 18 – 30 N; 65 – 92E	NSD of fine particles
Columnar size distribution (CSD)	Number size distribution (NSD)		Extinction Profile (Ex(h))
Columnar SSA	BC concentration(BC)		Scattering Coefficients
	Chemical Speciation (CSp)		

Visakhapatnam, Port Blair, Shillong and Dibrugarh would fall in and around the CTCZ core region. Basically, AOD and BC data will be available on a programmatically sharing basis during the CTCZ campaign period of 2011-12. IMD has the largest network over the country having very good infrastructure and manpower. As a part of modernisation of IMD's network, several new observation systems are being added. The data from these would be a great boom to CTCZ, at least in the years 2011-12.

Aerosol measurements will also be made over the Bay of Bengal. For 2011, experiments on two ships are planned in June, one in the northern bay and the other in the southern bay. Sun-photometer and lidar measurements have highly limited scope during this season and would be a gamble. Surface measurements onboard the cruise would be useful to quantify the change in the aerosol type (physically and chemically) with monsoon progress.

Aircraft Measurements

1. In spite of the high probability of extensive cloudiness, aircraft measurements are the key for vertical profiling during this season. The largest aircraft experiment during the years 2011-12 would be the CAIPEEX sorties for 50 hrs covering the areas of interest with high-resolution profiling and mission sorties.

2. Under ISRO-GBP a focused field experiment, Aerosol Radiative Forcing over India_Regional Aerosol Warming Experiment (ARFI_RAWEX), is planned during 2009-12, with SPL as the implementing agency (a project document is available with ISRO GBP program office) and the entire ARFI team being the participant. As the focus of this experiment is the meridional gradient in aerosol heating of lower atmosphere (an outcome of the ICARB), intense measurements will be a part of it. An aircraft sortie of short duration will be a part of ARFI_RAWEX during the pre-monsoon season. The data and information from this experiment would also be available for the scientific community.

3.4.3 Collaboration with CAIPEEX

Under CAIPEEX, implemented through IITM, measurements of altitude profiles of several parameters will be measured during 2009-11 monsoon period. Out of the numerous parameters, most of which have relevance to CTCZ the parameters pertinent to aerosols and aerosol cloud interactions are listed in Table 6.4.

3.4.4 Participating Institutions

There are several institutions, with necessary infrastructure and expertise, which have shown interest in contributing to the aerosol measurements during CTCZ. The major ones are (in alphabetical order): IISc, IIT (Kanpur and Delhi), IITM, IMD, NARL, NRSC, NPL, PRL, SK University, SPL and University of Pune.

3.5 Budget

Note that major contributions to this component are from NRSC for observations and modeling of the land-surface processes, aerosol programmes under DOS and from the CAIPEEX programme of IITM. None of these are budgeted for in this proposal. Thus, the budget reflects only the support to different institutions in the project mode. A number of project proposals have been received from different institutions (IISc, IARI, IIT (Delhi), IIT (Kharagpur), BIT (Ranchi), IIST (Trivandrum), Pune Univ., IITM and NIO) addressing the objectives of this component on. The proposed studies under this component are shown in Table PC1.

The total budget for the proposals received under this sub-component is Rs. 660 lakhs. The break up is as follows.

Head	Budget (Rs. Lakhs)
Equipment	225
Man power	200
Travel	30
Consumables/ contingencies	95
TOTAL (including 20% overheads)	**660**

4. CTCZ Component 2: Ocean Processes, convection over the ocean and air sea interaction

Convenor:

D. Shankar, NIO Goa

4.1 Ocean Processes

The role of the low-salinity surface layer in the northern bay and its potential role in the genesis of disturbances (low-pressure systems) has been mentioned in the CTCZ Science Plan. The potential of this low-salinity surface layer in air-sea interaction is obvious: it keeps the mixed layer shallow, allowing rapid recovery from the cooling associated with an active phase. The low-salinity layer is due to in situ rainfall, which has its peak in the northeastern bay adjoining the Arakan coast of Myanmar, and the freshwater discharge from the Ganga and Brahmaputra, which empty into the northern bay. This region was surveyed during BOBMEX, but it is evident that the hydrography needs to be mapped more intensively. For example, Argo floats were not available during BOBMEX.

Though it is known that both river discharge and in-situ rainfall over the Bay of Bengal contribute to the low-salinity surface mixed layer, it is only a few modelling studies that have attempted to trace the pathways of these freshwater sources. As noted in the Science Plan (Section 2.6), the rainfall over the bay is stronger towards the northeast while the river discharge into the northern bay is more in the north (Ganga and Brahmaputra) and northeast (Mahanadi). Is it possible to use isotopic studies to delineate the pathways of the freshwater from river discharge and from rainfall? If yes, then such a study would provide, in observations, a pathway for the changes in the surface salinity field in the northern bay. NIO Goa and PRL Ahmedabad may jointly plan Isotope studies and prepare teams for collection of data and analysis.

The CTCZ Science Plan spells out the important role of the ocean in the northward propagation of the TCZ over the Bay of Bengal. This northward propagation was one of the foci of the BOBMEX programme, but it is now clear [from the recent studies on the relatively cold pool that forms in the southern bay due to the Summer Monsoon Current (SMC)] that the southern time-series location (TSL) at 13°N was too far north. Hence, a more useful location of the TSL for understanding the northward propagations would be within the cold pool in the regime of the SMC. The cooling in this part of the Bay of Bengal is driven more by the seasonal cycle of ocean circulation rather than by air-sea fluxes. The salinity is also higher here than in the northern bay, implying a different heat budget for this part of the bay.

What is needed during the CTCZ programme is a focused ocean observational programme to map the hydrography of the northern and southern bay: we need CTD sections that map the spatial variability of the hydrography of the region. We also need underwater radiation and chlorophyll measurements that are crucially required to close the heat budget.

For the pilot phase in July–August 2009, MoES provided two ships during July-August. ORV Sagar Kanya was deployed in the northern bay and TDV Sagar Nidhi in the southern bay. Given the instrumentation available on board the ships and the instruments proposed for the pilot phase in 2009, the following objectives of the ocean-atmosphere component of the CTCZ Science Plan were realistic targets.

1. Mapping the hydrography of the northern and southern Bay of Bengal.
2. Understanding the role of ocean dynamics in the mixed-layer physics of the northern bay.
3. Quantifying the impact of biology (chlorophyll) on the sea surface temperature in the bay.

Of these objectives, the first was exclusively observational. The other two objectives primarily involved modelling, but the data collected during the cruises were essential for assembling a successful modelling strategy. The sampling strategy for these cruises was designed accordingly. Analysis of the data is still in progress and the research results should tell how much of the objectives have been met.

Data requirements

In 2011, the following data will be obtained using the ships. Oceanic data include temperature and salinity profiles (restricted to the top 1000 m), sea surface temperature and sea surface salinity, current measurements using ship-borne ADCPs, and underwater radiation profiles. Atmospheric data include complete surface met data including temperature, humidity, wind speed and direction (all these at one level), four components of radiation, pressure, rainfall, SST and ship navigation data. It is also necessary to have vertical profiles of temperature, water vapour and wind at high temporal and vertical resolution as well as aerosols.

Apart from data from in situ platforms, data from satellite-based sensors are critical and will have to be sourced from different sites in order to complete the assembly of data relevant for CTCZ. Specifically, satellite data on rainfall, sea surface temperature, surface (10 m) winds, clouds and outgoing longwave radiation (OLR) will be required. Data from satellites will form a critical component of the analysis and modelling. Hence, it is important that data from satellites be available to PIs.

Model reanalysis, whether from AGCMs or OGCMs or CGCMs, now form an important element in our analysis of any phenomenon. Such reanalysis products are practically considered an alternative to synoptic data over the oceans and their importance in the context of a multi-dimensional programme like CTCZ cannot be overemphasized. As with satellite data, it would be useful to have such data products available to PIs.

Platforms

The CTCZ programme requires at least two research ships, which are the main platforms for observations at sea. As for the pilot phase in 2009, ORV Sagar Kanya and RV Sagar Nidhi are available in 2011 too. Sagar Nidhi now has an AWS, but it is important to enable launching of radiosondes; provision will have to be made for storing the hydrogen cylinders.

Other oceanic platforms include ARGO floats, moored buoys from the NDBP and RAMA programmes, and moored sub-surface buoys with upward looking ADCPs deployed by NIO. XBTs and XCTDs will also be launched on the Chennai-Port-Blair-Kolkata line.

Instruments

Oceanic instruments on board the two ships include a portable CTD (in addition to the SeaBird or Idronaut CTDs available on board), ship-borne ADCP, hyperspectral radiometers, and, if available, thermosalinograph. The portable CTDs will include chlorophyll sensors. In situ chlorophyll measurements will also be made in order to calibrate the chlorophyll sensors.

Observing strategy

Moorings and floats

The moored instruments and floats are expected to be in place before the ship-borne observations begin during the summer monsoon of 2011. They are expected to yield a time series of the oceanic or atmospheric (or coupled) variable through the duration of the CTCZ programme. Hence, with respect to the moored instruments, it is desirable that they be serviced (and re-deployed after downloading data if they do not transmit via satellite) at least by May. The position of the floats has to be checked in the first quarter of the year and additional floats should be deployed, if required, to maintain the float array during the summer monsoon.

The moored buoys are of three types.

NDBP surface buoys The current status of the moored buoys deployed by NIOT under the NDBP is shown in Figure 4.1.

RAMA buoys These buoys are of two types: flux reference sites (FRS) and surface meteorological sites (SM). The FRS in the Bay of Bengal is at 90E/15N; SM are located at several places. Figure 4.1 shows the location of the RAMA buoys. The existence of these buoys implies that the ship-based observations can be planned to exploit the long-term data from these moorings.

Sub-surface buoys NIO is deploying sub-surface ADCP moorings off the Indian west and east coasts. Along the west coast, two buoys, one each on the continental shelf and slope, have been deployed off Mormugao (Goa) and Kollam (Kerala); one buoy on the continental slope has been deployed off Mumbai and Kanyakumari. On the east coast, similar mooring pairs have been deployed off Cuddalore, Kakinada, and Gopalpur; the location of these moorings was chosen to match that of the HF radars deployed by NIOT in these three regions. One additional ADCP has been deployed at the CTCZ time-series location in the northern bay (89E/19N). These direct current measurements, even if they cannot yield a time series of surface currents, would be off immense help in analysing the data collected from other platforms and in modelling studies. Till now, no such direct current measurements have been made in the northern bay. These sub-surface current data will be supplemented by the HF radar data on surface currents. The location of these ADCP moorings is shown in Figure 4.1.

Floats

The floats include Argo floats, drifting buoys, and gliders. The current location of Argo floats is shown in Figure 4.1.

Since the CTCZ programme has to cover a large area, most of which cannot be sampled adequately by the available ships, the only way to obtain temperature and salinity profiles over the region of interest is through Argo floats. In order to minimize the drift of the floats (which can lead to large regions going unobserved), INCOIS is considering using Iridium as the means of communication rather than ARGOS, and has placed an order for 10 such buoys for the Bay of Bengal. If they are available, they will be deployed during the CTCZ cruises at the following locations.

Since the RAMA3 mooring (FRS) at 90E/15N provides data on air-sea fluxes, surface and sub-surface currents, and sub-surface temperature and salinity, it is possible to use this mooring to estimate a heat budget if Argo floats are deployed a short distance, say 25 km, to the north, south, east, and west of the RAMA3 mooring. To provide a perspective for the time-series observations made during the cruises, it would be good to deploy Argo floats at the TSLs when the ships leave following the time series.

The RAMA moorings provide a north-south transect. To complement it with an east-west transect in the northern and southern bay, it would be good to deploy Argo floats along the 8N transect to be covered by Sagar Nidhi. (The southern TSL, as in 2009, will be located at 85E/8N and the zonal section at 8N can extend from 85E to 93E.)

Drifting buoys are being deployed under the Ocean Observing System programme of MoES and some of them will be available in the bay during the CTCZ experiment. These buoys provide data on currents (Lagrangian), SST, and sea-level pressure. These drifters also give an estimate of surface currents, but not at a location: the current is estimated from the drift. These drifters can also be equipped with a salinity sensor, but the salinity sensor is much more expensive than the temperature and pressure sensors; it is also more susceptible to fouling, implying that data are unreliable after a couple of months. Equipping some drifter with salinity sensors can help to map the salinity field in the northern Bay of Bengal, where the salinity gradients are large, but have not been mapped satisfactorily. It is evident that deployment of drifters in the northern bay will yield data only for a few months because the drifters are likely to hit land sooner than drifters deployed in the open ocean. Hence, such drifter deployments are rarely done. The CTCZ programme presents an opportunity to use a set of drifting buoys to map the salinity field because it is a programme that needs information on salinity. It would be good to deploy a set of buoys in 2011, with a few of them equipped with a salinity sensor, and to see how useful the data are. If the data are useful, a larger salinity-measurement programme using drifters can be funded for 2012, the main phase of the CTCZ experiment.

Though gliders have not yet been deployed by Indian scientists, the CTCZ programme presents an opportunity to exploit this new technology. The logistics of deployment will have to be decided based on the glider available for this programme.

Ship-borne observations

Apart from the deployment of moored and floating platforms, the CTCZ observational programme over the oceans will comprise XBT observations and also involve cruises on board at least two research ships.

XBT observations XBT observations are being made every month on the Chennai-Port-Blair-Kolkata XBT line. These observations, initially funded by DST, are now supported by MoES under its ocean observing system programme. It is important to ensure that the XBT line is operational during the ship-observation phase of CTCZ. If possible, it would be good to deploy XCTDs at least once during the ship-observations phase. This XBT line, cutting across the central bay and mapping a section from the east-central bay to northwestern bay, covers a key region of the bay that is otherwise going to be mapped only by Argo floats. The additional funds required for this are being sought from INCOIS.

Cruises The ship-borne observations are to include a 15-day time series and sections. As discussed in the Science Plan, it is important to map the variability simultaneously in both northern and southern Bay of Bengal. One ship will cover the northern Bay of Bengal and the other ship the southern Bay of Bengal. It is important to ensure that the same set of measurements can be made from both ships. Equally crucial is the need to ensure that the instruments available are in good working condition and have been calibrated. In particular, if there are doubts concerning the CTDs on board the available ships, then two portable CTDs will be needed on board each ship to ensure that the planned observations can be carried out. Ship cruises will be jointly planned by the NIO Group and the IISc Group.

The detailed plan of ship-borne observations during 2011 is given below.

Ship-borne observations: 2011

MoES has committed to making available two ships, ORV Sagar Kanya and TDV Sagar Nidhi, for the 2011 experiment. As in 2009, owing to its higher speed and the longer distances to be covered in the southern bay, Sagar Nidhi will be deployed in the southern bay and Sagar Kanya in the northern bay. Both cruises will last for about 30 days.

The ship-borne observations will include a 15-day time series and sections. As discussed in the Science Plan, it is important to map the variability simultaneously in both northern and southern Bay of Bengal. The time series will be covered during the second half of the cruise, which will be in June.

The data collection strategy for the atmospheric measurements is as over land, except that the data are one-minute averages. This shorter averaging period is needed to correct the wind field for ship motion. The additional radiosonde ascents during IOPs add to the information on ABL.

The detailed cruise tracks and stations are given in Figure 4.2.

Time series The northern TSL is proposed at 89E/19N. This TSL is located within the Indian EEZ and the water column here is between 1000 and 2000 m deep. The southern TSL is proposed at 85E/8N. This TSL is located in international waters, to the east of the Sri Lankan EEZ, and the water column here is between 3000 and 4000 m deep. To ensure that oceanic tides can be resolved, the time series has to be 15 days long. Resolution of the tides also demands that the CTD measurements be made at an interval of two hours, as was done during ARMEX.

The time series essentially involves a CTD cast to 250 m every two hours. The total cast time is about 15 minutes, leaving plenty of time for restoring position. This restoration of position is usually done at a slow speed because the drift is not much, but the vessel should sail in a straight line for at least 20 minutes at least 2-3 knots. These two constraints are due to the ship ADCP. At a station, when the ship drifts, the ADCP currents are not good. So, during the time series, it is likely that the ADCP data will be usable only during this position-restoration period. For a stable current average, the sailing time has to be at least 20 minutes. The ship speed should also not be too low or too high: so 2-3 knots is the minimum speed.

Another requirement from the time series is a consequence of having only one ship and the need to ensure that it makes all the measurements needed to estimate the advective component. The ship ADCP will provide the data on currents, but the temperature (and salinity) gradients have to be measured. Since these additional measurements have to be made using the same ship, it has to move away from the TSL for some CTD casts. We call this "Operation Advection" (OA for short). During the CTCZ pilot in 2009, the ship did CTD casts to the north, south, east, and west of the TSL every day during the night.

The OA plan is as follows. Do CTD casts for about 12 hours at the TSL during the day. Then move 3.5 miles north to do a CTD cast to 250 m; this cast will take about 30 minutes. Then return to TSL and do a cast to 250 m. Then move 3.5 miles south and do a CTD cast to 250 m. Return to TSL and do a CTD cast to 250 m. Repeat for locations east and west of the TSL. (During the 2009 pilot, the CTD casts at TSL were done to 1000 m depth, but the experience suggests that it is not possible to make every CTD cast during the time series to a depth of 1000 m. Hence, except for the cast around noon, which will be to 1000 m, the other casts during the time series are proposed to be restricted to the top 250 m. This restriction in depth implies a time saving of about 25 minutes.)

Since the CTD cast at the TSL is done every 2.5-3 hours even during OA, then we can easily interpolate the TSL values to the time of the CTD casts at the N/S/E/W locations.

If the interval between the TSL casts is of the order of, say, 6 hours, then this interpolation is not possible.

Hence, it is important to ensure that the gap between the TSL casts does not exceed 3 hours. The ships will have to carry out Operation Advection well after sunset so that the diurnal cycle to avoid the diurnal cycle in the top few metres. Hence, starting OA after, say, 8 pm, will permit OA to be completed easily before the sun rises and the ocean surface layer starts warming again.

Sections Both ships will map sections in addition to the time series. See the map in Figure 4.2 for the section tracks. In the northern bay, one EW section is proposed at 19N, the latitude of the TSL. Sagar Kanya will also cover a NS section at 90E, the longitude of most of the RAMA moorings, from the Indian coast (~ 22N) to 12N and three cross-shore sections from the TSL to the coast. The sections will be repeated after the time series. In the southern bay, one EW section is proposed at 8N, the latitude of the TSL. In addition, Sagar Nidhi will do two NS sections, one at 90E, the longitude of most of the RAMA moorings, and the other at 85E, the longitude of the southern TSL. Both NS sections will be from 6N to 12N.Along the NS and EW sections in the south, the CTD measurements are proposed every degree lat / long. In the north, CTD measurements are proposed every degree lat for the NS section, every half degree long for the EW section, and at finer intervals on the shelf for the cross-shore sections.

The two ships will meet at 90E/12N, the location of a RAMA mooring, for sensor inter-calibration.

The responsibility for operating the research ships would be with the group leading ocean component of CTCZ. Floats and the NDBP moored buoys would be operated by INCOIS and satellite data would come from SAC Ahmedabad. The ADCP moorings will be operated by NIO. The coordination of the entire ocean component will rest between the ocean component group and the CTCZ Program office.

The experience of the 2009 pilot shows that it is useful for both ships to be equipped with XCTD launchers and XCTDs to ensure continuity of the time series when it proves difficult to operate the winch owing to bad weather.

4.2 Atmospheric Component

A majority of the monsoon systems form/develop over the bay and then move into the CTCZ. It is important to understand why head bay promotes the frequent genesis of monsoon systems, and the mechanism of propagation. Measurements made during BOBMEX enabled documentation of the conditions that prevail over the head bay during one case each of active and break transitions. Surface heat budget and SST evolution were studied. It is observed that low salinity does play a major role in the rapid recovery of SST after a convective event. However, what is equally important is the large variation in the net heat flux between active and break conditions. During active monsoon conditions, wind speed increases to more than 10 m/s, whereas during the break, wind speed drastically decreases below 3 m/s. Clear sky conditions and low windspeed together make the net heat flux into the north bay nearly double the amount observed over other tropical ocean, e.g., the western Pacific warm pool. This is an equally important process in the SST variation over the head bay. Owing to lack of upper air data from the second ship (southern bay), theories on the propagation of cloud systems could not be tested.

Monsoon onset conditions have not been observed over the bay earlier. Therefore, in CTCZ, ship observations are planned during June in 2011 as well as 2012. In 2012, observations are also proposed during July-August. The main objectives of the atmospheric component over the ocean are the following:

(i) Testing the theories on the propagation of monsoon systems.

(ii) Role of north-south SST gradient on ABL properties.

(iii) Surface fluxes and SST evolution.

(iv) LHF and SHF after accounting for flow distortion from ship structure. (Without this, it is not possible to accurately derive fluxes from the fast response measurements.)

(v) Nature of precipitation (convective vs. stratiform) over the bay.

Observations/measurements

Complete surface meteorological data are required. This includes temperature, humidity, wind speed and direction (all these at one level), four components of radiation, pressure, rainfall, SST and ship navigation data. It is also necessary to have vertical profiles of temperature, water vapour and wind at high vertical resolution.

Sensors include propeller anemometer, temperature and humidity sensors, barometer, raingauge, solar and long wave radiation instruments (4 components individually or net radiation), sea surface temperature and salinity and ship navigation data. Data are to be archived every minute. Data logger with capacity to store data every minute interval for a period of at least a week is needed. INCOIS has installed AWSs on ships involved in the CTCZ cruises. IISc Bangalore will set up direct flux measurement arrangement on one ship and NIO Goa on a second ship.

Upper air data using high resolution GPS sonde are required from both ships. IMD will provide the required facilities for radiosonde observation from ships.

4.3 Participants

NIO Goa, IISc Bangalore, INCOIS Hyderabad, IMD, NIOT Chennai, NCAOR Goa, IITM Pune, SPL Trivandrum, IIST Trivandrum, PRL Ahmedabad.

4.4 Budget

Proposals have been received from scientists at NIO, IISc, INCOIS and Jadavpur university for studies relevant to the ocean component of the CTCZ. The list of proposals is shown in Table PC2. The expected budget for research relevant to the ocean component is as follows.

The total budget for the proposals received under this sub-component so far is Rs. 330 lakhs. The break up is as follows.

Head	Budget (Rs. Lakhs)
Equipment	93
Man power	90
Travel	20
Consumables/ contingencies	72
TOTAL (including 20% overheads)	**330**

5. CTCZ Component 3:   Large scale component

Convenors:

AVM Ajit Tyagi

D. R. Sikka

5.1 Objectives

The large scale component of the CTCZ programme addresses primarily the phenomena identified as foci, viz.

(i) spring to summer transition, and intraseasonal variation of the monsoon, and

(ii) links to convection over the surrounding ocean.

5.2 Approach

Study of the slow and fast build-up processes of the seasonal transition in April-May and subseasonal variation of the monsoon system within the season requires monitoring of the diurnal, synoptic and intraseasonal fluctuations during the pre-monsoon and the summer monsoon seasons for the years of 2011-2012 with the operational observing systems (Fig 5.1) and over the large-scale region between 30ºS to 50ºN and 40ºE to 140ºE. The aim is to monitor the African monsoon system near Indian side, the West Pacific monsoon system, the East Asian monsoon system and the South China monsoon system and investigate their links with the variability of the Indian summer monsoon. For this purpose collection of data routinely received from different observational systems at NCMRWF and operational analysis from the global models (for all levels) on grid point basis and 1-5 days forecast, is the first major requirement. Upper air soundings at all Indian stations may cover up to 50 hPa and the ascent is to be repeated in case it does not reach 100 hPa. For this purpose IMD may acquire special balloons / instruments. Relevant satellite data (from INSAT, QuickScat, TRMM, Megha-Tropiques and METEOSAT) and data from the buoys and Argo floats from INCOIS, NIO and NIOT have to be archived at the CTCZ Data Centre. Observational data (surface and upper air) collected by Indian Navy, Indian Air Force and ISRO AWSs are also required for making a complete quality-controlled data set. Additionally, IMD is to providequality-controlled data from their operational network. IMD is also to provide additional observations during Intensive Observational Periods (IOPs). For this purpose a Committee will be set up to decide upon IOPs and also, if possible, coordinate IOPs with the AMY International Project Office in relation to IOPs over AMY region. IOPs are required for each of the important phases of the summer monsoon as given later in this section.

A major event is the monsoon onset over Kerala which is now defined by IMD on the basis of rainfall over Kerala, depth of westerlies in the box equator to 10^0N and 55^0E to 80^0E (which should be maintained up to 600 hPa), the zonal wind speed over the area bounded by lat 5^0-10^0N, Long 70^0-80^0E (which should be of the order of 15-20 knots at 925 hPa) and INSAT-derived OLR in the box defined by 5^0-10^0N and 70^0-75^0E (which should be below 200 Wm^{-2}). These features of circulation and OLR will have to be monitored and an IOP declared when onset is imminent or as soon as it occurs. The key elements in the onset and advance of the monsoon are the northward and westward propagations of synoptic and larger scale convective systems generated over the equatorial and central Bay of Bengal (BoB) and the eastern Arabian Sea. For identification of the factors/processes that lead to the genesis and propagations of synoptic and larger scale systems, it is very important to have special observational experiments over the Indian seas in this phase. An IOP is required in the final phase of the advance, which involves westward propagation across the core monsoon zone.

The active/weak spells can be operationally identified on the basis of the rainfall over the core monsoon zone as demonstrated by IMD during the monsoon season of 2008 (Monsoon 2008, IMD report). Monitoring the rainfall over this region will make it possible to have an IOP which comprises a transition from active phase to a break phase, the established break phase as well as the revival from the break phase to an active phase, The final IOP should be during the withdrawal of the monsoon.

Thus for the CTCZ Programme extended IOPs (over periods of 7-15 days) approximately around the periods mentioned below can be planned under the large-scale component of CTCZ program.

(i) During the onset phase of Monsoon over Kerala and its advance along the West Coast (end of May to mid-June).

(ii) Advance of Monsoon along Gangetic plain and into NW India (3^{rd} week of June to 2^{nd} week of July).

(iii) Mid-season break and revival of Monsoon (3^{rd} week of July to mid-August).

(iv) Withdrawal of monsoon (mid-September to end-September).

At this stage these periods are based on climatological knowledge. They could be somewhat modulated in each yearly campaign by the Programme Office and all participating organizations will be informed 3-days in advance of each phase. These IOPs are mentioned in regard to monitoring major episodes in monsoon evolution and the exact periods and duration of IOPs will be determined by a special team which would function at CTCZ field operation centre at IMD, New Delhi.

The large-scale component of the CTCZ would provide vital data for the study of other subcomponents like

i. land-atmosphere-hydrology-vegetation modeling,

ii. data assimilation and regional re-analysis, and

iii. validating global and high-resolution model being run at IMD/NCMRWF and other research centres.

It is expected that the modeling centres would make different experiments on the data assimilation with operational data and delayed mode data separately to bring out the importance of the additional observations for the prediction of the monsoon on short to medium range scales. In such experiments, the special data collected on other components such as atmospheric boundary layer, land-surface processes etc would be separately examined by specialized groups. The observational system in the marine environment would include research ships, met-ocean buoys, moorings, Argo floats and satellites.

5.3 Functional responsibilities of the IMD for the large scale component of CTCZ

IMD's responsibilities would chiefly consist of the following.

i) Optimum maintenance and operations of the presently existing and planned observational network by May 2011. For this purpose it would be preferred if its AWS and ARG network is enhanced in Chhattisgarh and Rajasthan areas, which are respectively near the eastern and western ends of the CTCZ., by June 2011.

ii) Implementation of planed radar network along Gangetic plains consisting of Mohan bari, Agartala, Patna, Lucknow, Patiala and over central India at Nagpur, Mumbai and Bhuj. These stations should follow a uniform scan strategy such that a radar mosaic can be prepared by including new stations along with existing stations as (Kolkata, Vishakhapatnam, Machhilipatnam, Chennai, Delhi and Hyderabad). These stations will also keep their radar data in the archives.

iii) During the field phase of the CTCZ experiment, all the upper air stations will take two observations per day (00 and 12Z). Each ascent will go at least 100 hPa level. For this purpose supply of the instruments, balloons and gas has to be ensured by May 2011. The requirement for two regular ascents for 39 stations would be around 8000. Over and above these regular ascents there could be additional ascents during IOPs which are estimated to be about 1200. Also IMD may provide balloons gas and instruments for the two ships (Sagar Kanya and Sagar Nidhi) and the ground receivers for the ships. IMD may make budgetary provisions for these additional ascents as part of their CTCZ proposal to SSC-CTCZ. The requirement for the ship based ascent based on 25 regular ascents and for 2 additional during IOPs could be around 150.

iv) ISRO has given some mobile GPS stations (Pisharoty sonde) to IMD. These will be utilized for the CTCZ. IMD may take up with ISRO requirement of Pisharoty Sonde and also plan for the supply of gas.

v) Mirror data centre can be at IMD, Pune/IITM, for which a suitable proposal can be submitted to SSC-CTCZ.

Contributions to Research

IMD, being the lead agency for the large-scale programme, shall contribute largely to the phenomenological and modeling research for understanding large scale component of the CTCZ such as onset of the monsoon, intraseasonal variation involving fluctuations between active and weak spells/breaks, synoptic structure and dynamical diagnostics studies, etc. This could also be done in collaboration with scientists from other institutions and research funding for research relevant to CTCZ can be provided.

5.4 Modeling studies and prediction

Studies of the sensitivity of the simulation of major features of the intraseasonal variation as well as the interannual variation of the seasonal rainfall simulated by different general circulation models in the country (atmospheric as well as coupled), to the land-surface processes and aerosols have to be taken up using the high-resolution data on land surface and vegetation generated for 2011-2012. In the intraseasonal variation over the Indian region, in addition to the 30-50 day mode, the 10-15 day mode is important during the summer monsoon. The transition to active phase is associated with northward or westward propagations of cloud systems generated to the south and east of the Indian monsoon zone. However, models have difficulty in getting the propagation over the land mass, especially in the CTCZ domain. The skill of the general circulation models in simulating propagation features under realistic land-surface boundary conditions which will be generated under the CTCZ programme needs to be examined.

Several groups in the country, including those under MoES (NCMRWF, IMD, IITM) IISc, IIT Delhi, NRSC, SAC Ahmedabad, are involved in modeling of relevant facets, and some have already formulated projects under CTCZ for participating in modeling related phenomena.

5.5 Data assimilation and reanalysis

The high resolution data generated from routine observations and satellites on land surface and vegetation, on clouds, along with the data collected in special field experiments on land and ocean, have to be assimilated in the models.

Two ongoing programmes at NCMRWF, in collaboration with NCEP (South Asian Regional Reanalysis, SARR) and UKMET Office are very relevant to CTCZ. The UKMET Office global and regional model with 4D-var assimilation scheme will be implemented at NCMRWF by March 2011. Spatial resolutions of UKMET model are: for the global model 25 km horizontal with 70 vertical levels, and for the regional model ~ 8 km (Domain is entire Indian landmass + surrounding seas + beyond Himalayas). Observations that can be assimilated include those from AWS (temperature, RH, pressure, wind field), radiosonde and satellite radiance. NCMRWF can generate the regional reanalysis products within 9 months from the CTCZ campaigns for each of the 3 years programme (2010-12) using the SARR framework which is based on WRF model and its associated a 3D-Var data assimilation scheme. Assimilation of DWR (reflectivity and radial component of velocity) in regional reanalysis would also be attempted. NCMRWF will archive its model analysis and medium range forecast data for the monsoon seasons of 2011 and 2012.

IIT Delhi also has expertise in WRF model and its 3D-Var assimilation scheme. IIT Delhi will also run the WRF model (with a different physics option) and bring out its reanalysis products for some select cases during the CTCZ campaign. These products will help in the study of various scale interactions in the CTCZ region and also enable the comparison of different assimilation schemes.

Impact of better data of soil temperature, net radiation, vegetation fraction, land use and land cover (LULC from NRSC) could also be examined within the CTCZ reanalysis.

5.6 Budget

Major contribution to this component comes from IMD. Some proposals have been received for relevant research from organizations such as IIT (Delhi) in collaboration with NCMRWF and IMD on high resolution data assimilation and simulation of intense convective systems associated with CTCZ including role of land surface processes. Table PC3 shows proposals relevant to the large scale component. The estimated budget is shown in the table below.

The total budget for the proposals received under this sub-component so far is Rs. 307 lakhs. The break up is as follows.

Head	Budget (Rs. Lakhs)
Equipment	12
Man power	135
Travel	24
Consumables/ contingencies	94
TOTAL (including overheads)	**307**

Appendix A. Participating organizations/institutes/groups and their contribution

The expected contributions of the different organizations are listed in Table 1 below. A majority of these organizations have already made commitments along these lines, and commitments from others is expected by the time the field phase begins.

Table 2. Participating organizations and their contributions.

S. No.	Participating Organization/Group	Contribution/Responsibility
1.	MoES, New Delhi [Ministry of Earth Science]	**Constituting** Scientific Steering Committee of the CTCZ program, Inter-Ministerial Board and various committees for CTCZ implementation. **Getting** help and cooperation from different ministries **Facilitating** the full participation of organizations under MoES **Funding** of different projects recommended by the CTCZ -SSC **Support** to the Program Office
2.	IMD, New Delhi [Ministry of Earth Sciences]	**Facilitating** Field Phase Program Office **Participation** of all of their observing systems (including lightening detection, soil moisture, aerosols) and carrying out advisories during IOPs. **Facilitating** meetings of the Large Scale Operational office at New Delhi and Pune. **Provision** of final quality control data from their observing systems to the Data Management Group (AWS, ARG, DWR, upper air, satellite, model forecasts). **Facilitating the collection** of upper air data from 2 MoES ships **Contributions** to research and modelling components
3.	Indian Institute of Tropical Meteorology, Pune [Ministry of Earth Sciences]	**Coordination** of CAIPEEX activities with CTCZ and provide CAIPEEX cloud physics aircraft for CTCZ investigation. Its upper air and radar data also useful for CTCZ. **Providing** radiosondes for observations at two land stations (IIT Kharagpur & Mahanadi basin/BIT) **Observations of** CCN during the field phase **Modeling** and data assimilation research **Contribution** to ABL and aerosol components **Participation** of their Scientists in different sub-programs of CTCZ by taking intensive observations from Pune & Delhi.
4.	NCMRWF, Noida [Ministry of Earth Sciences]	**Providing** 5-day advance forecast **Data** assimilation and reanalysis products using UMMET Office global and regional models. Also

		generating reanalysis from SARR model. **Land**-Surface & data assimilation modeling studies.
5.	INCOIS, Hyderabad [Ministry of Earth Sciences]	**Coordination** of Ocean observing systems (including Indian buoys, RAMA arrays, ARGO floats, etc.) and ocean data collection. **Housing** and managing CTCZ data centre **Deployment** of gliders and remote sensing data. **Installing** and maintaining AWS on research ships **Participation** in research and modeling. **Facilitate** links with INDOMOD projects
6.	NCAOR, Goa [Ministry of Earth Sciences]	**Providing** Research vessel ORV Sagar Kanya along with operation of onboard instruments for Ocean observations**.** **Logistics** support at ports **Participation** in cruises and research**.**
7.	NIOT Chennai [Ministry of Earth Sciences]	**To provide** R V Sagar Nidhi for ocean measurements **Maintain** Met-ocean Buoys**.** **Logistics** support at ports
8.	NRSC, Hyderabad [Department of Space]	**Implementation** of land surface component (Hydrology, vegetation etc.) of the CTCZ program with observations, data analysis and modeling. **Providing** various satellite derived products for the land surface including LULC data for the Indian region, radarsat water logged areas, soil moisture, land vegetation cover. **Flux** towers data in CTCZ area. **Observing** and modeling 2 water sheds (Mahanadi/ Vaitarani/ Brahmini)
9.	SPL, Thiruvananthapuram [Department of Space]	**Management** of Aerosol component of CTCZ **Strengthening** the network by new stations at Gorakhpur, Agra, Patna, Kharagpur**.** **Participation/**contributing to in aircraft mission for aerosol in collaboration with CAIPEEX **Shipboard** measurements of aerosols and related black carbon parameters**.**
10.	SAC, Ahmedabad [Department of Space]	**Provision** of US / European satellite data on ocean-atmospheric parameters like SST, SSM/I, TRMM rainfall, CALIPSO data**.** **Participation** in modeling and diagnostic research **Participation** in CTCZ cruises and Meghatropique, OCEANSAT-2 data validation
11.	NARL, Gadanki [Department of Space]	**To provide** data from their in situ observational systems at Gadanki**.** **Take part** in Aerosol campaign.
12.	PRL, Ahmedabad [Autonomous, Department of Space]	**To provide** observations from their Lidars on aerosol and ozone profiles**.** **Surface** ozone, radiation and other trace gas measurement at Ahmedabad and Mount Abu. **Aerosol** optical depths, shortwave and longwave fluxes, aerosol mass, black carbon mass, aerosol scattering coefficients and ultrafine particles using condensation particle counter composition data**.**

		Aerosol chemistry (rain water sampling from land and ship) **Participation** in ship cruises, aerosols and chemistry
13.	Indian Institute of Remote Sensing, Dehradun [Department of Space]	**Hydrology** observations and modeling
14.	IISc, Bangalore [Ministry of HRD]	**Hosting** CTCZ Programme Office **Coordinating** the CTCZ activities **Organization** of cloud system sub-program **Managing** atmospheric observations from one research ship in Bay of Bengal. **Diagnostic** and prognostic research **Ocean** – atmosphere, land-atmosphere-hydrosphere and cloud system modeling, etc. **Organizing** boundary layer studies on land and over ocean **CTCZ** ABL data analysis, flux algorithms and modeling **Flow** distortion corrected flux data from ship
15.	IIT, Delhi [Ministry of HRD]	**Mesoscale** modeling and data assimilation **Diagnostic** observational research on large scale component **Modeling** and research on ABL processes **Cloud-**aerosol modeling
16.	IIT, Kharagpur [Ministry of HRD]	**Operation** of ABL tower and AWS network **Operation** of Vaisala R S system during IOPs in collaboration with IITM. **Diagnostic** and prognostic research. **Surface** flux algorithms & modeling studies
17.	IIT, Kanpur [Ministry of HRD]	**Observations** of aerosols and CCN **Ground** based observations of aerosols columnar and vertical properties at IIT Kanpur **Modeling** of cloud-aerosol interactions **Parameterization** of cloud microphysical processes **Computation** of aerosol’s radiative effects using aircraft and ground based data
18.	NIO, Goa [Council of Scientific and Industrial Research]	**Management** of ocean program and one research ship for the same. **Managing** Field operation centre for ocean component. **Modeling** and diagnostic research on ocean atmospheric interaction.
19.	NPL, New Delhi [Council of Scientific and Industrial Research]	**To provide** observations from the Lidar, surface ozone and aerosol network. **Take part** in aerosol – cloud interactions studies.
20.	BIT, Ranchi [Deemed University]	**Boundary** layer measurements using 30 m high tower. **Launching** Pisharoty radiosondes **Research** on surface fluxes and ABL

21.	University of Pune, Pune	**Ice Nuclei** Measurements (Condensation-Freezing and Deposition) daily surface observations at Pune. **Aircraft** observation as a part of CAIPEEX program, **Measurements**/data analysis related to boundary layer tower data (fast and slow). **Cloud** system studies
22.	Jadhavpur University, Kolkatta	**Analysis** & modeling small scale processes in land-atmosphere-ocean interactions
23.	Bangalore University	**Atmospheric** electricity
24.	Indian Air Force Met Branch [Ministry of Defence]	**Participation** in various committees **Provision** of final quality control data from their observing systems to the Data Management Centre.
25.	DNOM, Indian Navy, new Delhi [Ministry of Defence]	**Organisation** of RS/RW, AWS data from their coastal and on-board naval ships. **Participation** in large scale and ocean component research **Participation** in Field Operation Office at IMD Delhi.
26.	Anand Agricultural University, Anand [State Agricultural University]	**Maintenance** of ABL tower and participation in ABL sub-program, Research on ABL **Aerosol** and trace gas measurements in crop environment.
27.	Central Water Commission, New Delhi [Ministry of Water Resources]	**Coordination** with respect to Hydrological measurements in selected river basins.
28.	National Institute of Hydrology, Roorkee [Ministry of Water Resources]	To participate in Hydrology component being coordinated by Dr. Dadhwal, Dehradun.
29.	ARIES, Nainital [Ministry of Science & Technology]	To participate in aerosol and atmospheric chemistry measurements
30.	Universities (Andhra, BHU, Cochin, Calcutta,)	CTCZ research, deputation of research scholars for participation in Field Phase and Training etc.

Fig. 1.1: Cloud band delineating the TCZ on 7 August 2007; note that the TCZ extends from the CTCZ over the Indian region to the oceanic TCZ over the west Pacific.

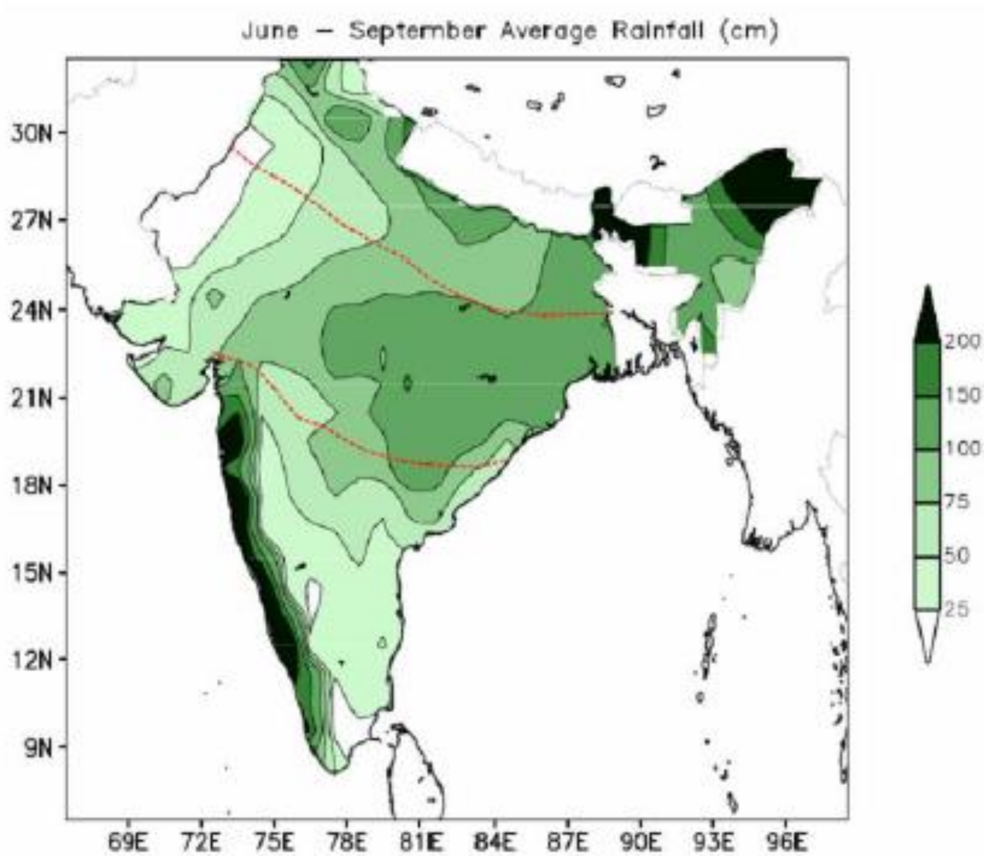


Fig 1.2 : Mean June-September rainfall over the Indian region (cm); approximate limits of the core monsoon zone indicated by red dashed lines

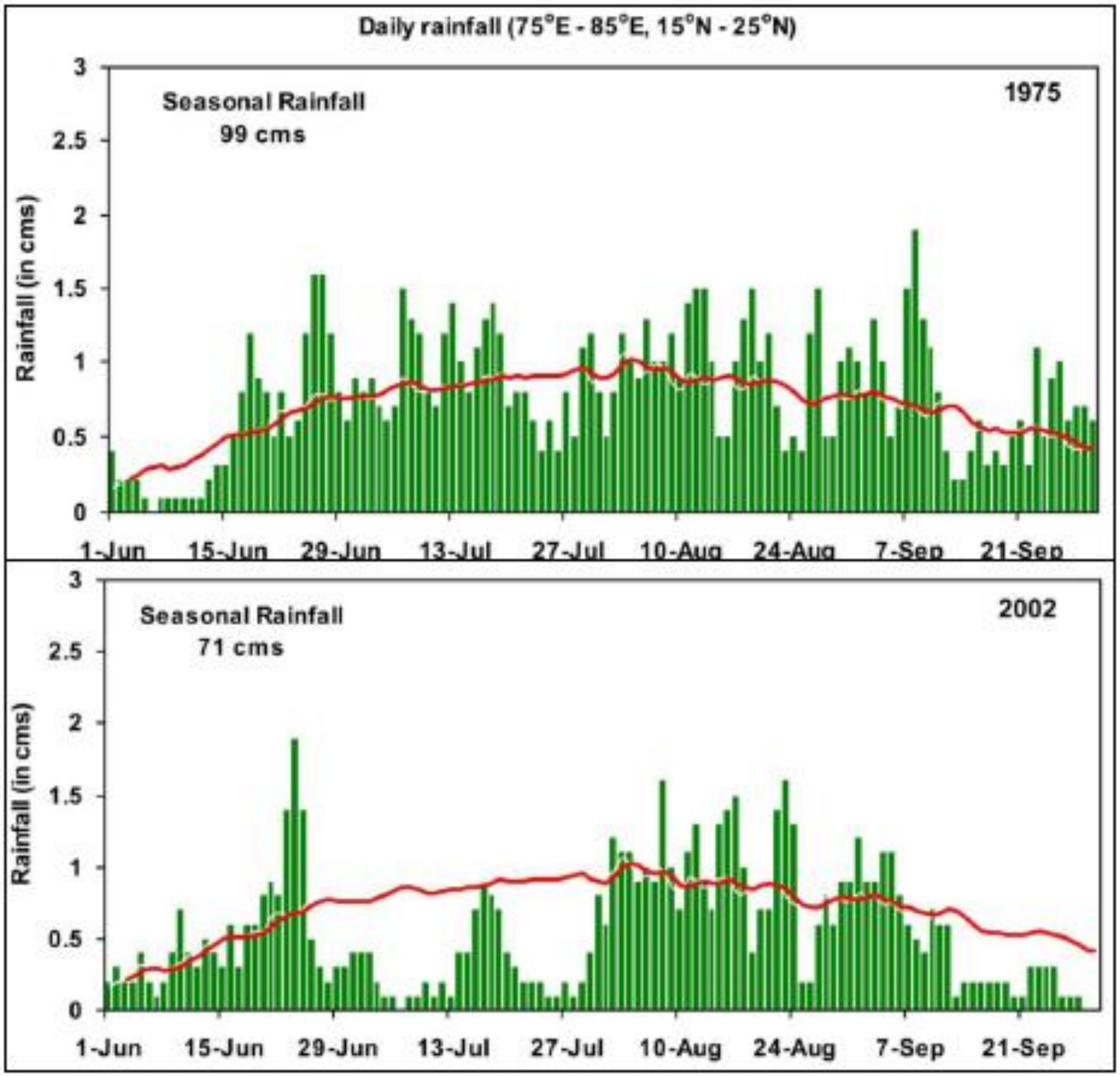


Fig. 1.3: Variation of the daily rainfall over central India during June – Sept. 1975, 2002

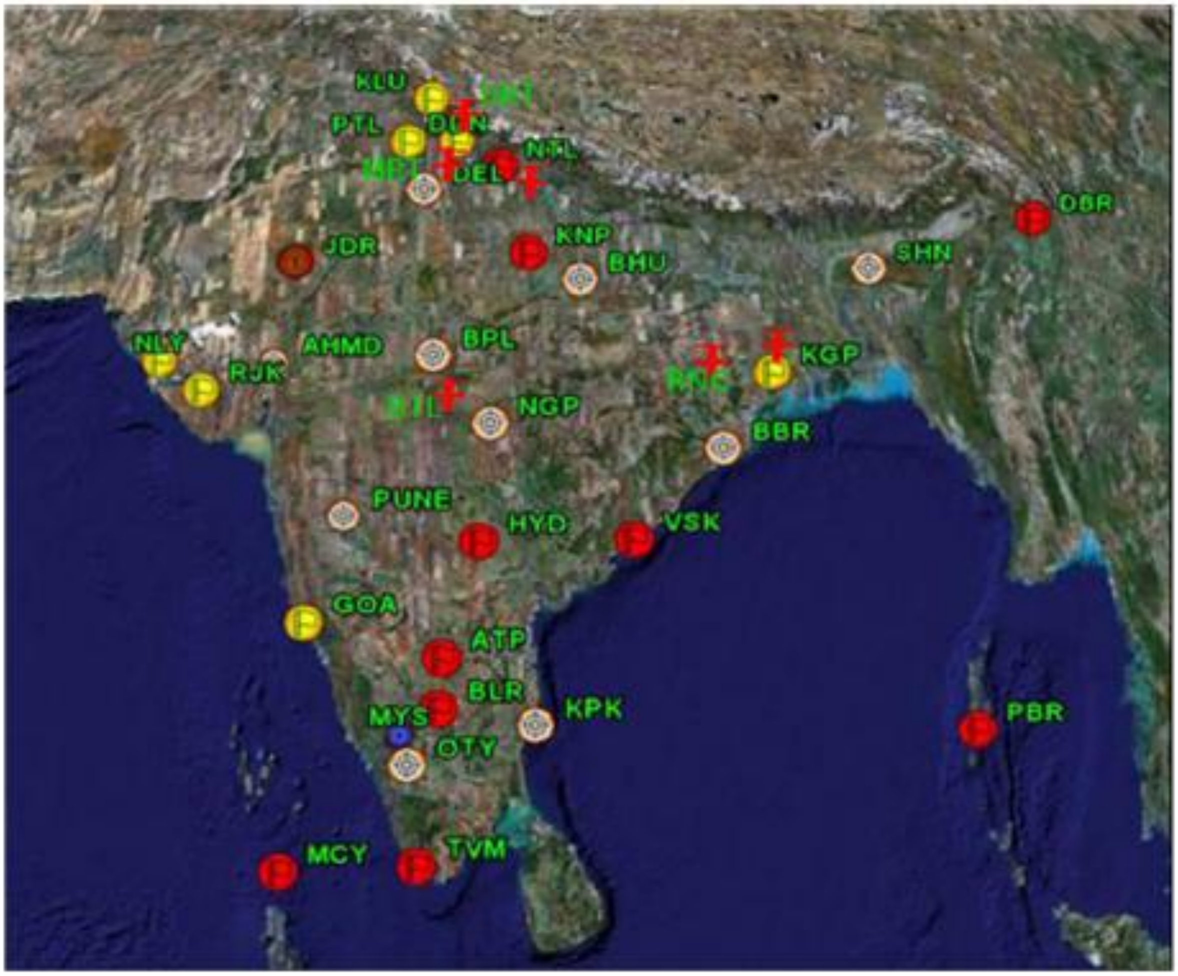


Figure:6.1 Spatial distribution of ARFI network observatories under ISRO-GBP. The red and yellow symbols represent observatories that are currently operational and expected to be functioning through the CTCZ period. The orange symbols circumscribing the blue wheel represent stations that are in the pipeline and expected to be ready by early 2009. While stations coloured yellow will have basic AOD measurements with BC at some of the locations, while stations coloured red will have parameters. The dotted circle approximately represents the study region, including the core monsoon zone and the foothills of Himalayas. Vertical bar with two cross lines shows the approximate location of boundary layer towers.

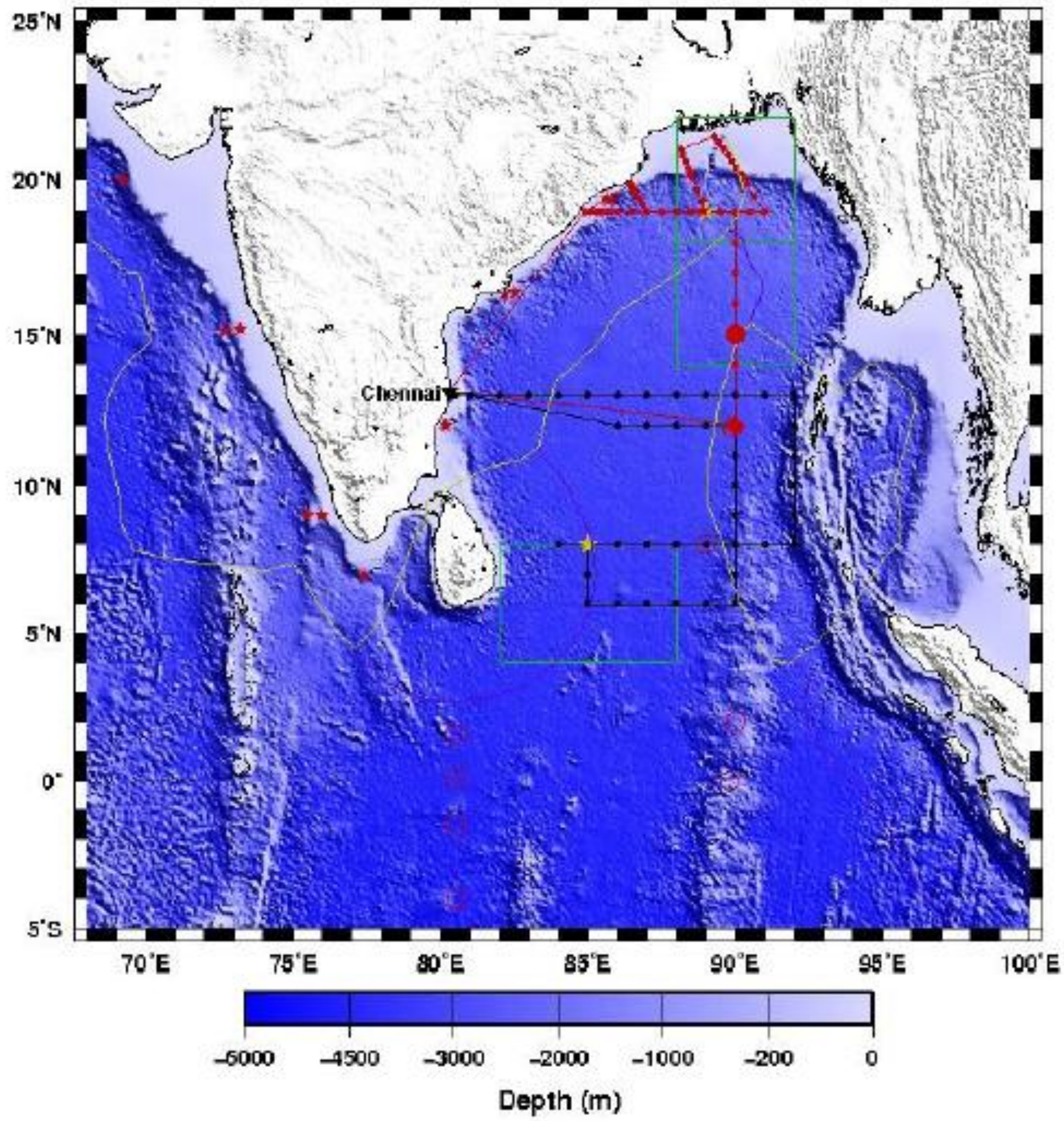


Figure 7.1. Cruise tracks for Sagar Kanya (green lines) and Sagar Nidhi (black lines). Chennai has been assumed to be the port of embarkation and disembarkation. CTD stations along the sections are shown by solid circles. The yellow asterisks mark the time-series locations in the northern (89E/19N) and southern (86E/6N) bay. The inter-comparison location (89E/11N) is shown by the red diamond. The red pluses mark the proposed locations of ARGO floats communicating via the Iridium satellite; 10 such floats are to be deployed by INCOIS. The red asterisks mark the locations of NIO's ADCP buoys; the buoys on the east coast are to be deployed in April 2009.

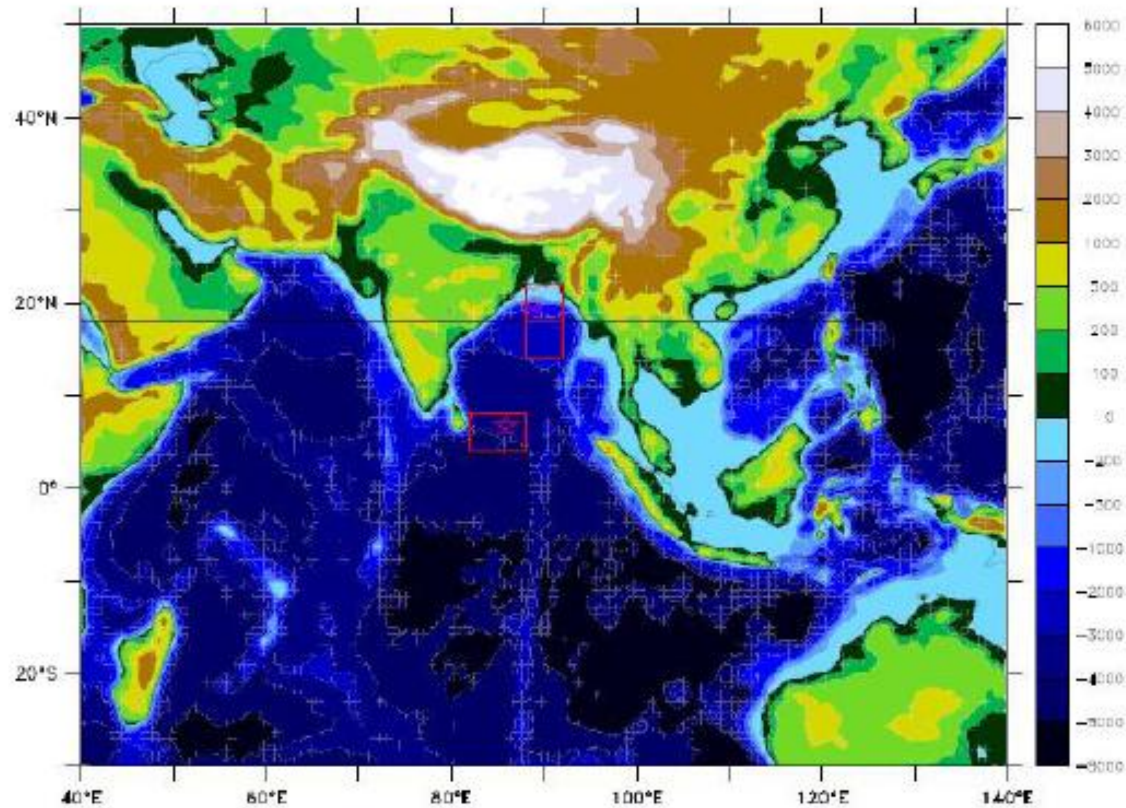
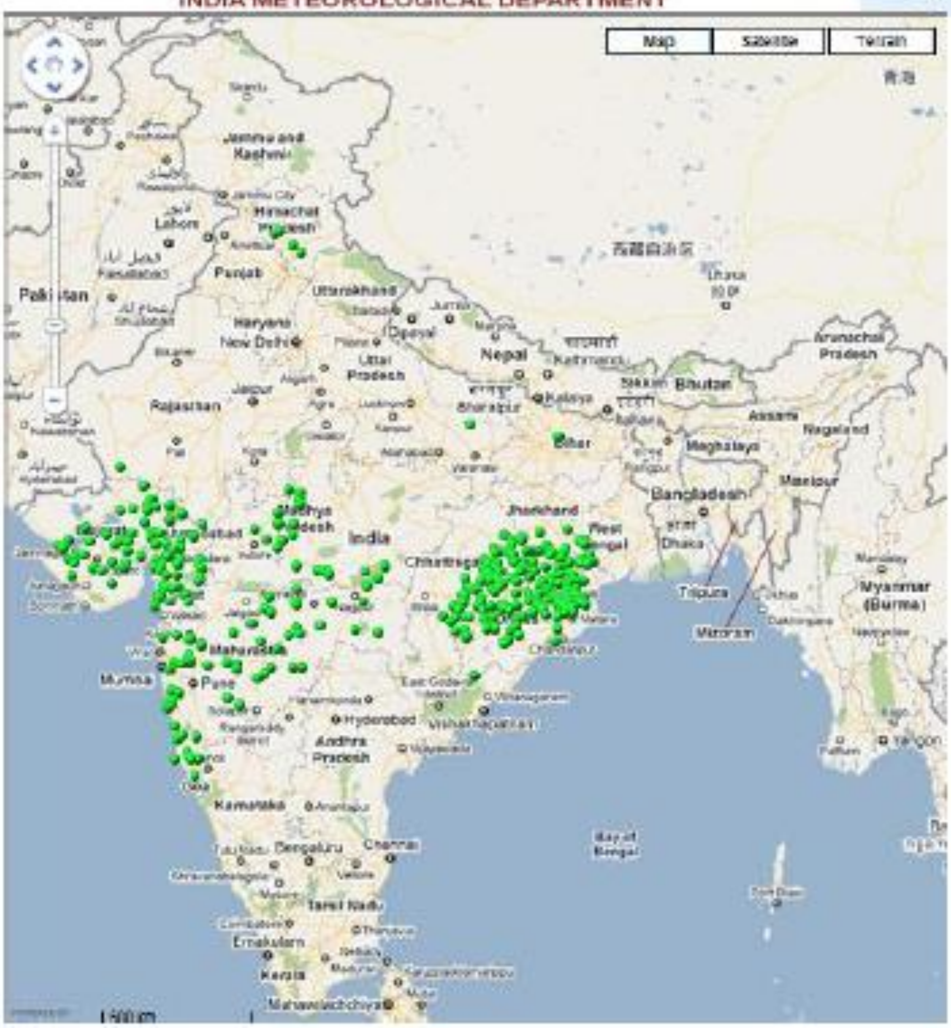


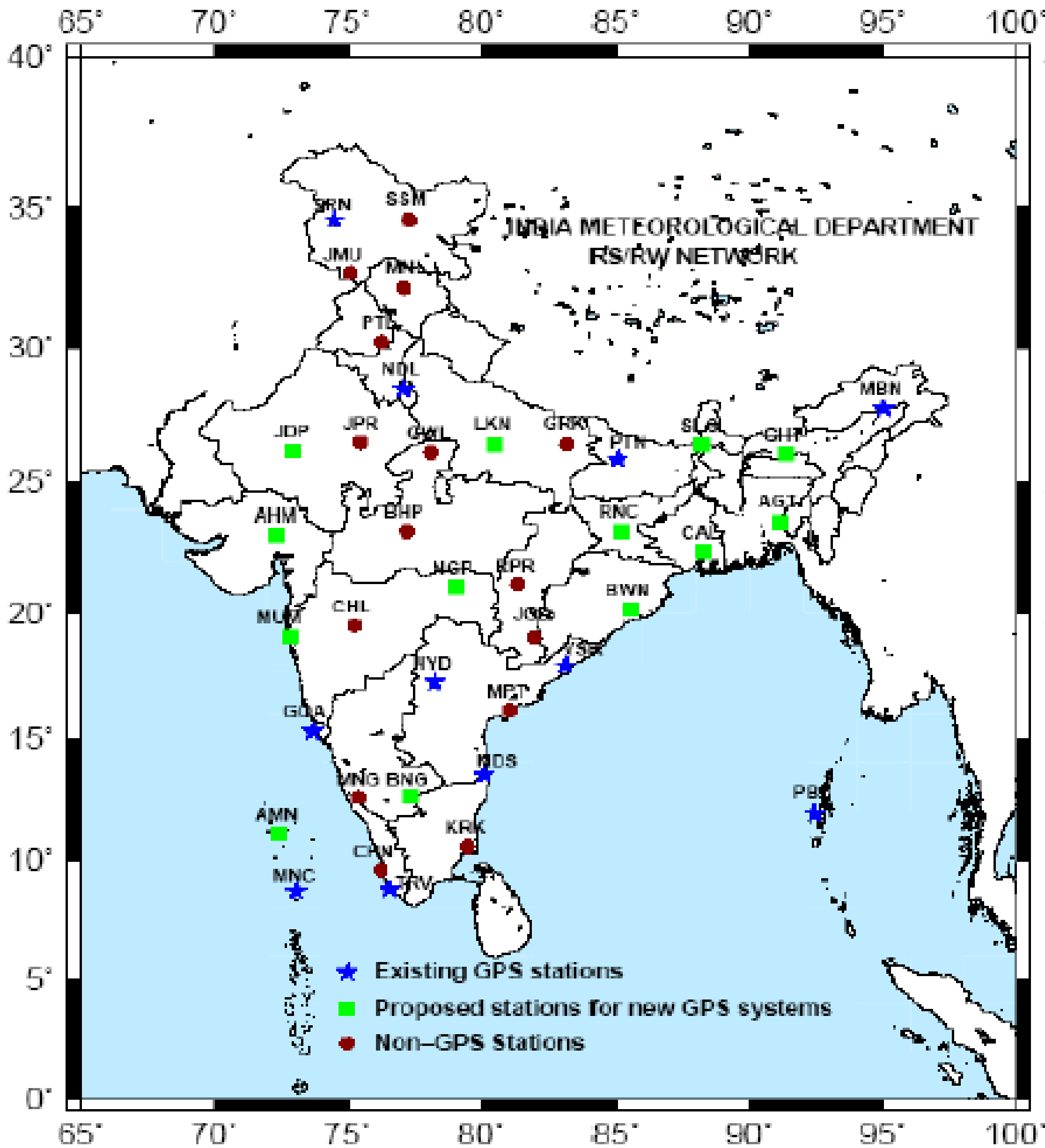
Fig 8.1: Large scale region for monitoring and the study area over the Indian land region . The black line corresponds to 18^0N. The region for intensive observations and special observational experiments on the land area under the CTCZ programme is the Indian land region north of 18^0N.

AWS STATIONS of IMD 494 as on 26 Nov 2010

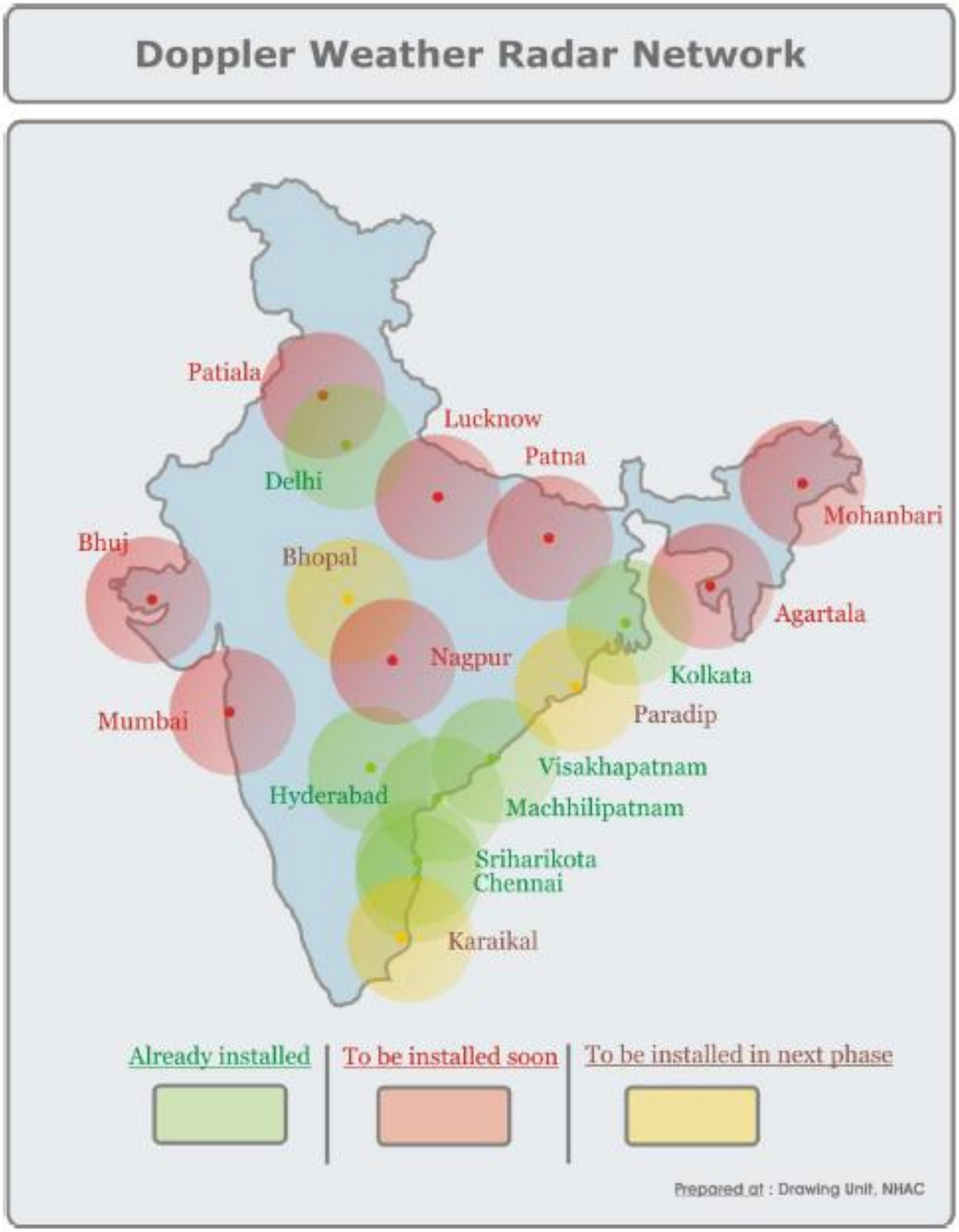
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT



ARG STATIONS of IMD 334 as on 26 Nov 2010



Upper air stations of IMD.



IMD's DWR network