A Proposal for

Centre for Earth Systems and Climate Change Research

Indian Institute of Technology Kanpur (IITK)

August, 2009

1.0 Preamble

In recent years, the emphasis on understanding the exogenic and endogenic processes operating on Earth have moved towards adopting a more holistic view of the Earth as a 'system' comprising of lithosphere, biosphere, hydrosphere and atmosphere. The most important example of this '**integrated'** system is the Earth's climate system, which requires the understanding of atmosphere, ocean and land systems and their interactions within and with societies and technologies. In India, our research priorities have not responded to these changes. As a result, the climate research in India is highly unidirectional and we have failed to respond to the multi-dimensionality of the problem. Climate change is no longer a 'myth' and it needs an **interdisciplinary approach** to understand the impacts and to develop mitigation strategy.

The issue of global climate change and its impact on socio-economic and natural resources has become a major concern in all parts of the world. Although there is some scientific consensus on the triggering factors and enormity of the impacts of climate change but these factors must be spatially variable. Similarly, the impact of climate change in different parts of the world would also be different, primarily a function of socio-economic conditions and existing regional climatic regime. Several international collaborations in the earth and environmental sciences have been facilitated by inter-governmental organizations and international professional societies to advance the science of climate change and to assess the impacts. Economic and policy aspects of climate change have become central to foreign policy and international relations of several countries. A critical need remains for coordination and collaboration amongst various disciplines of science, engineering and technology directed to climate change mitigation and adaptation strategies. Technological innovation and major shifts in energy generation and use are essential to mitigation of climate change impacts. The combined global resources of science and engineering disciplines in research and training must be effectively and rapidly mobilized to meet these rapid challenges. We must discover, develop and broadly apply physical and institutional solutions for collective survival.

In order to understand the recent climate changes and to accurately predict the climate variability in future, it is essential to study the natural variability in climatic past in millennium, century, and decadal scale. Understanding climate variability within the recent past is extremely important to determine the magnitude, frequency and rate of past climate changes, so that the General Circulation Model (GCM) or regional climate models can realistically simulate and predict future climate change. Some of the outstanding questions which remain unanswered till date are:

- How did the Natural and anthropogenic climate forcing factors vary in the past?
- How sensitive was (and is) the climate system to these forcings, and in particular to the anthropogenic forcing in recent past?
- What caused the natural greenhouse gas and aerosol variations? What is the rate at which these are added to the atmosphere?

- To what extent can palaeodata constrain climate sensitivity and the carbon cycle-climate feedback?
- In what precise sequence and over what timescales did changes in forcings occur and how long did it induce changes in the climate and ecological systems?
- How do we assess the impact of climate change on natural resources e.g. water resources and on ecological systems?
- How do we develop socio-economic strategies to adapt to changing climate – technological solutions, social engineering, public participation?

These questions demand a multi-disciplinary approach and a coordinated effort to find answers and to move forward. It is important that the combined resources of science and engineering at our Institute are effectively and rapidly mobilized to take up the challenges of climate research and to find ways to mitigate the impacts of climate change for our collective survival.

Climate research has been a top priority in developed countries like USA and European countries for several decades in order to develop strategies to minimize the impact of climate change. This is also an integral part of the strategic planning of top universities and research institutions in the world. India, being a fast developing nation, is emerging as a major player in climate research in recent times. IITK, an institution of excellence and prominence made of diverse group of researchers, should offer its expertise and make a collective effort to actively pursue climate change scenarios in India for the survival of a nation whose economic growth and huge population is inducing irreversible climate changes day-by-day.

2.0 Goals and Objectives

It is proposed to set up a 'Centre for Earth Systems and Climate Change Research' at IIT Kanpur. The primary goal of this Centre would be to develop infrastructure facilities for climate research and a coherent, multi-disciplinary research group and manpower to take up large projects of national and social relevance.

The specific objectives of the proposed Centre are envisaged as under:

- To generate new data and knowledge on the climate variability (spatial and temporal variations and forcing functions) of the Indian sub-continent and its bearing on global scale
- To impart training for capacity building and manpower development in Earth systems and climate studies.
- To develop infrastructural facilities for climate change research related to observational, experimental, analytical and modelling studies.
- To facilitate information, literature and data collection and dissemination related to climate change scenarios in India.
- To make policy makers aware of the key issues related to climate change.

3.0 Available Expertise at IIT Kanpur and Knowledge Partners

IIT Kanpur has been involved in earth systems and climate research for the last several decades. The Department of Civil Engineering (CE) at IIT Kanpur is the only department in the country, which integrates Engineering Geosciences (EG), Environmental Engineering (EE), Geoinformatics (GI), and Hydraulics and Water Resource (HWRE) and therefore a multi-disciplinary expertise needed for promoting earth systems and climate studies already exists. Several faculty members of the department are involved in climate related research for more than a decade and have been collaborating with experts across the globe. Moreover, several other departments such as Aeronautical Engineering (AE), Chemical engineering (CHE), Computer Science and Engineering (CSE), Humanities and Social Sciences (HSS), Industrial Management and Engineering (IME), Mechanical Engineering (ME), and Physics (PHY) can contribute in taking up various activities related to climate research and applications. A research centre on this theme at IIT Kanpur will greatly facilitate a coordinated activity in this area and would provide the necessary impetus for climate research in India.

3.1 Participants from IIT Kanpur and their expertise

Participants/Departments	Specialized areas of research
1. Rajiv Sinha, CE	Earth systems, river response to climate change, paleoclimatic reconstruction
2. S.N. Tripathi, CE	Aerosol Radiative Effects, Aerosol-Cloud-Hydrological Cycle Interactions, Aerosols in Planetary Atmosphere, Laboratory Simulation of Fog
3. D. Paul, CE	Earth systems, isotope geochemistry, Paleoclimate reconstruction
4. Rajesh Srivastava, CE	Hydrology and water resource development
5. Ashu Jain, CE	Hydrological modelling
6. P.K. Mohapatra, CE	Hydrological and numerical modeling
7. Tarun Gupta, CE	Instrumentation for aerosol measurement, physico-chemical characterization of atmospheric pollutants, formation of secondary organic aerosol, formation and control of engine exhaust emissions and health risk assessment.
8. Harish Verma, Phy	Nanocrystalline Magnetic Materials and Alloys Systems, meteorites and extinction boundaries
9. Sanjay Mittal, AE	Computational Fluid Dynamics, Finite Element Methods, Parallel Computing, Flow-induced oscillations
10. Mahendra Verma, Phy	Turbulence theory and simulations, High performance computing.
11. Pankaj Jain, Phy	Physics of the Universe, Atmospheric Physics

12. P.M. Prasad, HSS	Microeconimcs, Law and Economics, Environmental Economics, Development Banking
13. Praveen Kulshreshtha, HSS	Microeconomics, Industrial Economics, Governance and Ethics
14. Sarani Saha, HSS	Environmental economics, public economics, applied microeconomics
15. Anoop Singh, IME	Infrastructure and Regulatory Issues, Energy and Environment, Microeconomics
16. Ishan Sharma, Mech	Mechanics, Granular media, Planetary science, modeling.
17. T.V. Prabhakar, CSE	Software Architecture, Knowledge Engineering, Web 2.0,
18. Rajat Moona, CSE	Computer Hardware and Architecture, Embedded Systems
19. R. Gurunath, Chem	Environmental Biodegradation, Biochemistry and microbiology.

3.2 Knowledge partners

Institutions	Participating scientists
National	
• Physical Research Laboratory, Ahemedabad	Shyam Lal, M. M. Sarin, Sunil Singh,
• National Institute of Oceanography, Goa	Rajiv Nigam
• National Centre for Ocean and Antarctic Research (NCOAR), Goa	Rasik Ravindra
• University of Delhi, Delhi	Vikrant Jain, S.K. Tandon
• School of Environmental Sciences, JNU	Jayant Tripathi, V. Rajamani
• Indian Institute of Technology Roorkee	U.C. Kothiyari
• Dibrugarh University, Assam	J.N. Sarma
• Indian Institute of Technology Kharagpur	Anindya Sarkar, P. Sanyal
• Indian Institute of Technology Mumbai	C. Vekataraman, Malay Mukul
• Birbal Sahni Inst of Paleobotany, Lucknow	N.C. Mehrotra, Vandana Prasad
• World Wide Fund for Nature (WWF), India	Suresh Rohilla
• National Institute of Hydrology, Roorkee	Bhishm Kumar
• Indian Institute of Technology Delhi	Om P. Sharma
• Vishwabharti University	Sheena Panja
International	
• Columbia University, New York, USA	Upamanu Lall
• CH2M HILL, Oakland, CA 94612	Uday P. Singh
• CBFS ESSIC-UMD, MD 20740, USA	Raghu Murtugudde
• University of Cambridge, UK	David Hodell, C.A. Petrie
• Imperial College, London	Sanjeev Gupta
• University of Durham, UK	Alexander Densmore
• George Mason University, U.S.A.	J.P. Shukla
• NASA Goddard Space Flight Center	B. Holben, J. Welton, C. Randles

• Georgia Institute of Technology	Mike Bergin
• Center for Climate System Modeling	Terry Nakajima
• University of Reading, UK	R. Giles Harrison
• Oxford University	R. G. Grainger
• CRPG-CNRS, Nancy	Christian France-Lanord
• IPGP, Paris	Francois Metivier

4.0 Proposed structure and research activities

The proposed structure of the Centre is shown in a flow chart. Five focal areas of activities are proposed as follows:

Focus I: Earth's climate system and processes

Focus II: Hydrological cycle and water resources

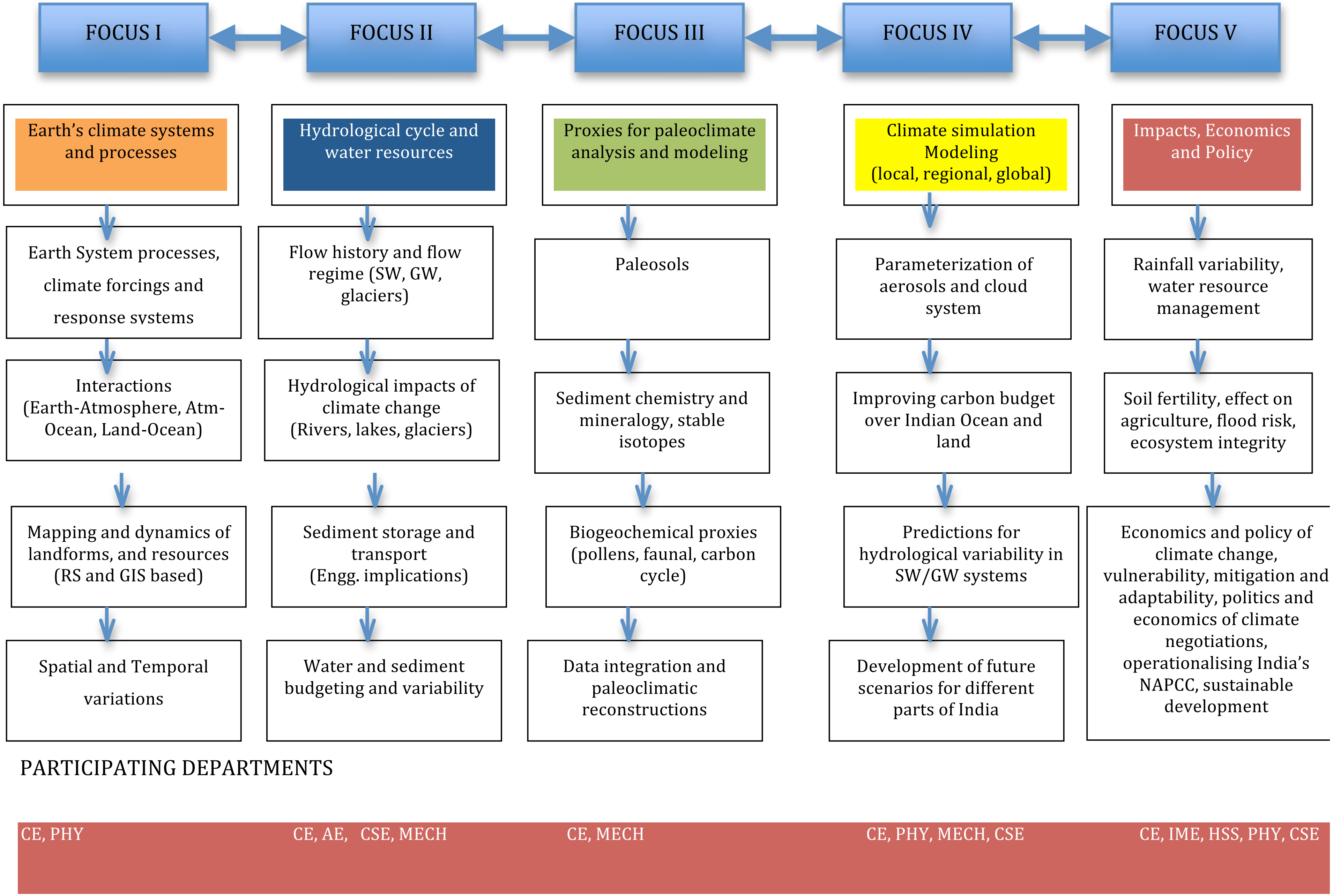
Focus III: Proxies for paleoclimate reconstruction

Focus IV: Climate Simulation modeling

Focus V: Impact, economics and policy of climate change

Research activities to be carried out by individual groups are interactive in nature in a way that data generated by each group can help not only to fine-tune the results of other groups, but also to correctly interpret respective data sets. For example, data generated by participants in Focus I, II and II should correlate each other because temperature and precipitation fluctuations affect various components of the hydrological cycle thereby inducing changes in distribution of water resources, which in turn affects the surface processes (such as weathering erosion and soil formation, sediment load of rivers, river morphology etc.). Data generated by the first three Focus and Focus III in particular, can be taken into account in climate simulation modelling efforts by Focus IV so that the regional climate model can reproduce the observed past fluctuations. Then only can such models accurately project climate fluctuations in near future. These future projections (along with data from other themes) will help Focus V to assess impending impacts of climate change on the society and national economy and suggest corrective measures that will help policy makers to take appropriate steps to minimize such impacts.

The following paragraphs enlist rationale and background information related to each. Some of the activities listed under are already being pursued at IIT Kanpur in collaboration with other institutions and several new activities are being proposed.


FOCUS I
FOCUS II
FOCUS III
FOCUS IV
FOCUS V
Earth's climate systems and processes
Earth System processes, climate forcings and response systems
Interactions (Earth-Atmosphere, Atm-Ocean, Land-Ocean)
Mapping and dynamics of landforms, and resources (RS and GIS based)
Spatial and Temporal variations
Hydrological cycle and water resources
Flow history and flow regime (SW, GW, glaciers)
Hydrological impacts of climate change (Rivers, lakes, glaciers)
Sediment storage and transport (Engg. implications)
Water and sediment budgeting and variability
Proxies for paleoclimate analysis and modeling
Paleosols
Sediment chemistry and mineralogy, stable isotopes
Biogeochemical proxies (pollens, faunal, carbon cycle)
Data integration and paleoclimatic reconstructions
Climate simulation Modeling (local, regional, global)
Parameterization of aerosols and cloud system
Improving carbon budget over Indian Ocean and land
Predictions for hydrological variability in SW/GW systems
Development of future scenarios for different parts of India
Impacts, Economics and Policy
Rainfall variability, water resource management
Soil fertility, effect on agriculture, flood risk, ecosystem integrity
Economics and policy of climate change, vulnerability, mitigation and adaptability, politics and economics of climate negotiations, operationalising India's NAPCC, sustainable development
PARTICIPATING DEPARTMENTS
CE, PHY
CE, AE, CSE, MECH
CE, MECH
CE, PHY, MECH, CSE
CE, IME, HSS, PHY, CSE

4.1 Focus I: Earth's climate system and processes

The Earth's climate system is a manifestation of several processes operating on earth and a thorough understanding of these processes and their interactions is crucial to understand and investigate the long-term as well short-term climate change. The Indian climate system is primarily governed by monsoonal circulation, the genesis of which is intricately related to the formation of the Himalayan ranges. A seasonally reversing wind which characterizes the Indian monsoon brings moisture from the Arabian Sea and the Bay of Bengal during June to September and causes rain in most parts of the Indian subcontinent. On the other hand, air blows from land during winter season resulting in dry winter monsoon. It has been suggested that the monsoon system was initiated about 20 Ma ago due to uplift of the Himalaya beyond a critical height. During summer, heating of Tibetan plateau creates low pressure which acts as a powerful pump for moist air from oceans resulting in heavy rain. Reverse circulation of wind occurs during winter; the radiative cooling of Tibetan Plateau causes flow of cold dry continental air towards the Indian Ocean. Experiments with atmospheric general circulation models have shown that changes in elevation of Himalaya-Tibet have large effects on the intensity of monsoon. Simulation with no mountains or reduced elevation has resulted in significantly weaker or even no monsoonal circulation. Monsoon intensity could also be affected by changes in surface boundary conditions, such as the albedo of Africa-Asia landmass, the extent of snow cover over Tibet, the sea surface temperature of the Indian Ocean and the concentration of atmospheric CO_2. A new perspective has also been that climate changes whether driven by uplift or otherwise, can alter the atmospheric and oceanic circulation in such a way that it changes rates and styles of erosion in high mountain terrain. Increased erosion also causes rebound of underlying layers (isostatic uplift). The interplay of climate and tectonics in landform evolution is often difficult to separate and significant attempts have been made across the globe on methods to decouple the effects.

The impact of climate change on natural systems such as rivers, oceans and atmosphere also requires an understanding of the processes operating within each of these, the interactions within and among the different parts of the system. Apart from hydrological impacts of climate change on river systems (discussed in the next section), it is also expected that catchment-scale and reach-scale processes will be affected keeping in view the 'geomorphic connectivity' of the system. Climate change not only significantly changes the water discharge in a river system but also significantly affects catchment erosion processes, and hence sediment supply in the channel. Change in discharge and sediment load in a channel can completely change the *river processes and morphology*. These effects in a particular river reach can be estimated through understanding of connectivity and sensitivity of the landscape.

Some of the research activities which will focus on the issues of large scale earth processes and and their interactions in a changing climate scenario would include the following:

- Theme 1: **Tectonics-climate coupling** - ongoing activity through a DST project to R Sinha, Vikrant Jain, Malay Mukul to focus on long-term control of climate in tectonic processes and vice versa.
- Theme 2: **Catchment processes and landscape dynamics**- new initiative by Vikrant Jain, S. K. Tandon, University of Delhi to assess the relative importance of catchment erosion processes to understand interrelationship between landscape characteristics and sediment production rate as a function of climatic forcings.
- Theme 3: **River dynamics and hydrologic modelling** using remote sensing and GIS- ongoing activity through a MOES project funded to R. Sinha, V. Jain, P. K. Mohapatra, Malay Mukul; aims to investigate the Kosi river in north Bihar plains for understanding avulsion processes and flood risk.
- Theme 5: **Ocean-atmosphere teleconnections**- new initiative by Devesh K Sinha, University of Delhi and Rajiv Nigam, NIO Goa to focus on ocean-atmosphere linkage influencing the monsoonal circulation patterns.

4.2 Focus II: Impact of climate change on water resources and hydrological cycle

Climate change has a significant effect on various components of the hydrologic cycle and would severely impact the water resources. For instance, it has been estimated that the Himalayan glaciers are shrinking at the rate of 10 to 15 meters per year. This is likely to reduce the water supply in India, with the Ganges river expected to lose two-thirds of its July to September flow, which would affect one-third of India's irrigated areas, and lead to *water shortages for more than half a billion people in the whole of South Asia* (See UNDP).

We would look at these impacts under two broad categories: surface water and groundwater as per the expertise of people involved.

For the surface water, the major impact of climate change is due to glacial recession and change in precipitation pattern. Although studies have not been conclusive about the effect of warming on the overall precipitation, there is a nearly unanimous agreement that the climate change would lead to more intense precipitation. This would imply a higher fraction of the precipitation running off to the rivers. Current estimates for India show a figure of about 45% for the fraction of precipitation being discharged into the sea and it is likely to increase due to the effect of climate change. This would lead to more flooding in the rivers and also increase (probably very slightly) the rate of rise of the sea level. On the other hand, higher temperature would probably lead to more evaporation and drier grounds, thereby promoting more infiltration and less run off. While several studies have been performed on basins outside India, there is a lack of experimental and numerical studies for Indian basins. We aim to model these processes and ascertain the net effect of climate change on these components of the hydrologic cycle. Understanding these processes would ultimately lead to techniques for adequately addressing the detrimental effects of climate change on surface water resources.

The projected climate change scenarios predicted by using the regional climate models would be useful to determine the hydrology of the basin in terms of runoff, peak runoff rate etc. Then application of river morphodynamics models using the predicted runoff would tell how the river morphology is going to be affected by the climate change. For this purpose it may be useful to couple the regional climate models like HadRM3H with existing watershed models like ICHARES, SWAT. Then those derived hydrological variables (hydrographs) would be routed using hydrodynamics and morphodynamics models developed in the past or the models like HEC-GeoRAS, MIKE 11, SediMorph etc. This shall also help in investigating the change in river morphology due to the projected flood events.

Further, groundwater is extensively used in India for domestic and irrigation purposes. The percentage of population using it for domestic needs is as high as 80% in the rural areas and any adverse effect on the groundwater resources would critically affect this population. A number of studies have forecasted reductions in groundwater levels due to the effect of climate change, particularly the rise in temperature and change in the precipitation pattern. Also, for coastal areas even a small rise in sea level would cause significant change in the freshwater availability due to intrusion of sea water into the freshwater aquifers. We propose to estimate the effects of climate change on the groundwater resources by using mathematical modelling. Specifically, we would look at the effect of temperature increase and less frequent but higher intensity precipitation (both of which have been shown to result from climate change) on the groundwater levels. The strategies to counter the adverse effects would also be explored. For example, harvesting the rain water to increase infiltration would not only mitigate the effect on groundwater resources, it would also result in reduced flooding.

Some of the important research themes related to impact of climate change on water resources which would be central to the activities of the proposed center are as follows:

- Theme 1: **Basin-scale assessment of water resources and planning for future** - new initiative proposed by R. Srivastava, Ashu Jain and P.K. Mohapatra t focus on quantification of the available water resources and its availability in changing climate scenario.
- Theme 2: **Integrated water resource management for the Ganga basin** in a changing climate scenario - proposed activity by R. Sinha with Udai P. Singh California, Upamanu Lal, Columbia and U.C. Kothiyari, IITR; consortium proposal submitted to MOEF.
- Theme 3: **Connectivity analysis of a large river**- The Ganga dispersal system- ongoing research of S.K. Tandon, Vikrant Jain, Delhi University to emphasize the aspect of longitudinal connectivity in terms of hydrological and sediment budgets.

- Theme 4: **Flow energy and future trajectory of river systems** in the predicted climate change scenario - new initiative of V. Jain, Delhi University in collaboration with R. Sinha to utilize the concept of stream power distribution to predict the relationship between driving and resisting forces.
- Theme 5: **River morphology-hydrology linkage** - new initiative proposed by U.C. Kothiyari, IITR to focus on application of river morphodynamics models using the predicted runoff to predict the changes in river morphology.

4.3 Focus III: Proxies for paleoclimate analysis

A number of studies have reconstructed climate variability in millennium, centennial, and decadal scales based on statistical correlation of multiple climate proxy (both low- and high-resolution) records. Proxy data commonly used to reconstruct secular trends of paleoclimate variations include analysis of arboreal and grass pollen records, shifts in frequencies and presence/ absence of microfauna,changes in geomorphic patterns associated with shifts in stream flow, speleothems, oxalate residue from lichen, and changes in oxygen and carbon stable isotope ratios in paleosols, carbonates, corals, ice cores, laminated lake/ocean sediments, peat; and solely on tree-ring data. Numerical simulation models also predict climate change for last centuries, and are based on partial data from different sources (e.g. historical, botanical, geomorphological etc.). Although, we know, in general, the secular trends of monsoon variability (mainly precipitation and strength), the exact time-scale of climate fluctuations interpreted by previous studies may be hampered by poor age constraints. Clearly, proxy data from a large number of (well-dated) samples from various locations in the continental, lacustrine and marine environments in India is required to confidently reconstruct southwest monsoon variability in the Quaternary. Then rigorous statistical analysis of the multi-proxy data from various locations can make well-founded climate inferences on the impact of monsoon variability on the evolution and sustainment of major Indian rivers, erosion and deposition history of sediments, and finally, the impact on human civilizations of historical significance. Furthermore, understanding the forcing mechanisms (solar insolation patterns, glacial boundary conditions that affect the regional albedo, atmospheric CO_2 input, sea level change, heat transport by thermohaline circulations etc.) responsible for both millennium and centennial or decadal scale paleoclimate variability in India will significantly improve the uncertainties associated with the current climate models to predict how temperature and precipitation will vary in future in the context of a regional climate system such as the southwest monsoon.

The Centre for Earth Systems and Climate Research will actively pursue multidisciplinary collaborative research efforts (both within the centre and with other climatologists nationally and internationally) to reconstruct the climate history for the past 100 Ka and beyond with respect to the major shifts in Southwest monsoon strength and precipitation from multiple climate proxies archived in sediment records of Indo-Gangetic basin, and other alluvium, lakes, peat bogs, and archaeological material. In particular, proxies such as stable oxygen and carbon isotopic composition of carbonate nodules, paleosols, and clay minerals recovered from well-dated horizons will be utilized aided by detailed sediment chemistry and mineral studies. The research activities in this area would be focused on the following:

- Theme 1: **Paleoclimate and paleovegetation reconstruction** in Northern India using multi-proxy data - new initiative proposed by D. Paul in collaboration with Anindya Sarkar, IITKGP and with Vandana Prasad, BSIP Lucknow.

- Theme 2: **Decade-to-Century scale climate variability** reconstructed from sedimentological and archaeological Proxies - new initiative proposed by D. Paul, R. Sinha, Sheena Panja.

- Theme 3: **Carbon isotope composition of peat bogs** in India as a proxy to reconstruct century-scale climate fluctuations – new initiative by D. Paul, in collaboration with Anindya Sarkar, IITKGP)

Climate data generated by these projects will be instrumental for Climate Simulation and modelling. The climate model developed will largely be based on the current data obtained by instruments. Robustness of such a model and its ability to accurately predict future climate scenarios will be tested by simulating past climate and reproducing notable fluctuations (such as Little Ice age and Medieval Climatic Optimum during the Holocene etc.) as observed in our paleoclimate data. Since climate change is intricately related to Earth System processes (such as weathering, erosion and soil formation, river characteristics, and river morphology, hydrological cycle etc.), our data will also be useful for Groups I and II. Last but not least, understanding how a regional monsoon climate system in India has varied in the past aided with future predications obtained from Climate models, Focus V can then produce objective and accurate analysis of socio-economic impacts of climate change and recommend key policy-issues for the nation.

4.4 Focus IV: Climate Simulation Modeling

Since the inception of computers, atmospheric simulation is one of the key field in numerical computations. Over fifty years, many software have been written, some of which are free. Some of the popular atmospheric simulation software are MM5 (Mesoscale model), RAMS (Regional atmospheric modeling systems), ARPS (Advanced Regional Prediction), etc. Many of software in this field are fortunately based on spectral method on which IIT Kanpur has significant expertise. Simulation of tropical atmosphere is more difficult than the other regions of the Earth. For India, atmospheric studies and weather predictions become very critical because of strong dependence of people on agriculture. The present atmospheric models are not very accurate for short-term predictions as well as long-term predictions (e.g. seasonal and yearly predictions of monsoons). Advanced nations have both global and regional models. Hence there is a large scope for atmospheric work for India, as well as south-east Asia.

A major focus of this group would to understand the role of aerosols in climate forcings for which we have a significant expertise at IIT Kanpur. Aerosols are suspended particles in air with a typical radii ranging from 0.001 to 10 μm. The anthropogenic component (particles produced by human activities) of the aerosols are known to have a long-lasting effect on the climatic variation. The presence of large amounts of aerosols in the atmosphere blocks the solar radiation, reduces the radiation reaching the surface of the Earth, increases stability of the lower atmosphere, reduced convection, form less cloud and reduces precipitation. However, various models have shown increasing and decreasing tendencies in rainfall during various seasons and various locations in the Asian region. A comprehensive study of observational rainfall data over India showed a reduction in rainfall during the summer and winter seasons over 47-75% of the area of the country, and an increase in rainfall over 54-73% of the area during summer and post-monsoon seasons. The report also showed a decreasing tendency of annual rainfall over the country in recent years.

Keeping our expertise in atmospheric modeling and the activities beig carried out elsewhere in the country, we would like to focus on the following themes:

- Theme 1: **Role of Black Carbon and Organic Aerosols on the Water Cycle and Rainfall over India** – new initiative by S.N. Tripathi and T. Gupta to understand the influence of anthropogenic (mainly black carbon and organic aerosol) on cloud formation and rainfall over Northern India
- Theme 2: **Simulation and Modeling of Atmosphere and Climate** – new initiative by M. K. Verma, S. tripathi and Ishan Sharma to develop a basic code for atmospheric simulations.
- Theme 3: **Assessing Role of In Situ Particle Formation in Aerosol Indirect Effect** - ongoing activity of S. N. Tripathi and O. P. Sharma, IITD which aims for quantitative estimation of gas-to-particle nucleation mechanisms.
- Theme 4: **Understanding the Role of Vehicular Pollution in Climate Modification** for the Indo Gangetic Basin – new initiative by Tarun Gupta and S. N. Tripathi to quantify the overall contribution of SOA to cloud condensation nuclei concentration in the Indo-Gangetic Basin.

Two major aims of Group IV are: (1) understanding how the weather and climate respond to the changes in the atmospheric constituents using sophisticated models and (2) addressing the fundamental problems related to atmospheric fluid flow. Several research themes proposed in this group are strongly interlinked and revolve around the before mentioned two broad aims e.g., in order to achieve the objectives of theme 1, the models will require the complete information on vehicular pollution which will come from theme 4. The new code developed by people involved in theme 4 will be validated by the existing code used by theme 1 participants and, in turn, the latter can also opt to use the new code, which will certainly be simpler while doing major modification compared to the existing ones. So, overall a high level of synergy exists between the four themes of group 4.

4.5 Focus V: Impacts, Economics and policy of climate change - Indian scenarios

While there has been much progress on understanding the complexity and vulnerability of the Earth system, there is the growing recognition that research needs to be translated into action. Science is urgently needed to address how complex social-ecological interactions play out across scales—impacting the Earth system and subsequently affecting local livelihood conditions for all humankind. There are three billion people in urgent need of improved social and economic development, and the global population is expected to increase by another three billion by 2050—on a planet that is increasingly showing signs of limits to its carrying capacity.

Contemporary scientists, environmentalists, policy-makers and governments across the globe are now realizing that the fast pace of economic development, since the industrial revolution of the 19th century, has had a serious impact on the global climate. Since industrialization, the earth's surface temperature has risen by 0.7 degrees and by 2100, the earth's average surface temperature is expected to rise by 1.8 to 5 degrees (UNDP). The increase in earth's average surface temperature is largely due to the *increased production of greenhouse gases, such as carbon dioxide*, in nations throughout the world. The developed countries are emitting such gases more per person, since they have more automobiles and burn more fossil fuels. However, developing countries are also catching up and emitting more of these gases, as they experience greater economic development (see UNDP).

Climate change is also adversely affecting the country's water resources, sea-levels and biodiversity (i.e. forests, and plant and animal species), besides having a *detrimental affect on the lives of millions of rural poor* who derive their livelihoods (food, shelter and incomes) from sectors that are closely tied to natural resources, such as agriculture and allied sectors, and tourism or fishing in coastal areas (UNDP).

During the last two decades, India has recognized the adverse social and economic impacts of climate change (discussed in the previous section), and therefore, has ratified the *United Nations Framework Convention on Climate Change* (in 1993) and the *Kyoto Protocol* (in 2002). India has no specific emission reduction targets under the Kyoto Protocol, but India has been playing an active part in the Kyoto Protocol's **Clean Development Mechanism (CDM)**. In addition, India has joined the **Asia-Pacific Partnership on Clean Development and Climate (APP)**, which comprises of Australia, China, India, Japan, Republic of Korea, and the United States, with the aim "to accelerate the development and deployment of clean energy technologies".

On **June 30, 2008**, Prime Minister of India, Dr. Manmohan Singh, released India's *first* **National Action Plan on Climate Change (NAPCC)**, which underscores current and future policies and programs to address problems relating to climate change in India. The plan emphasizes *the goal of sustaining high economic growth in the country (to raise its standard of living), while developing technical* *and economic measures to deal with climate change, and promote the social and economic development of the nation* (Pew Center on Global Climate Change).

In view of the above background, there are a number of issues which will be addressed by this group relating to the impacts, economics, policy and politics of climate change:

- Theme 1**: Greenhouse Gas Emissions** - new initiative by P. Kulshreshtha, Sarani Saha to assess the carbon traiding and to calculate the efficiency gains achieved by moving from the current CAC regulatory regime to the tradable emissions permit system in India.
- Theme 2: **Water Pollutants** - new initiative by P. Kulshreshtha, Sarani Saha to assess past and current regulations in India to control water pollution, to review the existing permits trading markets for water pollutants in other countries and critically examine the feasibility of developing a permits trading market for water pollutants in India
- Theme 3: **Environmental flow in the Ganga river** for sustainable biodiversity (ongoing activity of R. Sinha, P.M. Prasad, Vikrant Jain
- Theme 4: **Socio-economics, policy and negotiations of climate change** (new initiative of P. Murli Prasad and Anoop Singh to pursue research in economics of climate change, UNFCCC and the Kyoto Protocol, clean development Mechanism (CDM), Operationalising India's NAPCC, politics of climate Negotiations etc.

5.0 Expected outcome

5.1 Coordinated research programmes

The major research outcome expected is to promote multi-disciplinary research for a better understanding of the climate change and its impact on water resources, agriculture, and socio-economic aspects of society. The center would carry out leading edge research that would help the society from overcoming the challenges posed by the adverse impacts of climate change. The centre will contribute significantly towards capacity building in the area of earth systems and climate research. Not only that the exchange of ideas would benefit the participants within the institute but a specialized manpower would be created through PhD students and post-doctoral fellows. It is expected that research activities at the centre will lead to generate a refined Global Circulation Model that can be used to accurately understand regional climate dynamics and predict climatic variations in future as a result of natural and anthropogenic forcing. Further, the interim reports and research publications from all participants and students would consolidate the Indian research in this area in a major way.

A major outcome would be in terms of the development of a comprehensive data base on the status of climate research and relevant information for dissemination at various levels. The strategies developed through public participation programmes would be extremely rewarding in terms of preparing the society for the impacts of climate change and their own contribution for mitigation.

5.2 Manpower development

One of the foremost requirements for promoting climate research is to develop and multiply the requisite manpower. While several researchers across the country may be working on related issues, a large picture and multi-dimensionality of the climate research is not very clear. It is proposed to correct this situation by conducting several short-term courses, workshops and training programmes. Some suggested topics are:

(a) Short term courses:

- Earth surface processes
- Global climate change
- Proxies for Paleoclimate Reconstruction
- Application of stable isotopes in Hydrology, Ecology and Environmental Science
- General circulation models
- High Performance Computing related to atmospheric applications
- Neural networks

(b) Workshops and training programmes::

- Analytical techniques in Stable Isotope Ratio Mass Spectrometry
- Aerosol measurements and data interpretation
- Geomorphic mapping and terrain evaluation
- Sub-surface mapping techniques

(c) Development of a teaching programme (degree programme): Although several participants of the center are currently offering courses in related areas, it is hoped that we would be able to develop M. Tech. and PhD programme in the area of earth and climate science in future.

5.3 Knowledge dissemination

(a) Public participation programmes: Apart from carrying out high level research, it is also planned to organize activities related to public awareness and participation in terms of the impact and adaptability to climate change. We will also invite senior students from local high schools/colleges to visit our center in order to increase awareness about our climate and environment. In addition, we will arrange to visit and deliver lectures in these institutes.

(d) Invited lectures: It is planned to invite distinguished scientists and engineers across the country and overseas to deliver special lectures on their research as well as interact with the climate centre.

(e) National/International conference: It is proposed to organize a national conference every two years and an international conference at the end of 5 years to highlight the research carried out at the center and to develop interaction with other researchers across the country and overseas.

6.0 Endnote

It is important to realize that status quo is not the best option to deal with the urgency of the impacts of climate change. These impacts would generally occur in the form of externalities: unpriced damages imposed by one party on another. Apart from developing a thorough scientific understanding of the problem, these externalities need to be internalized by application of various economic instruments, regulatory mechanism and voluntary public participation. The proposed interdisciplinary centre on Earth Systems Climate Change Research at IITK would be extremely useful to initiate academic activities in the areas of science, engineering, economics, management and policy of climate change and would help in understanding of the forcing factors and for developing mitigation strategies.