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ENVIRONMENT

Environmental Monitoring Network for India

An integrated monitoring system is proposed for India that will monitor terrestrial, coastal, and oceanic environments.

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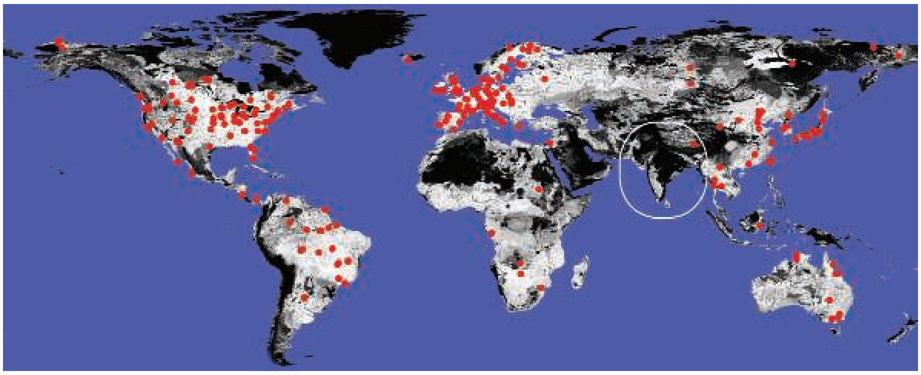
Understanding the consequences of global environmental change and its mitigation will require an integrated global effort of comprehensive long-term data collection, synthesis, and action (*1*). The last decade has seen a dramatic global increase in the number of networked monitoring sites. For example, FLUXNET is a global collection of >300 micrometeorological terrestrial-flux research sites (see figure, right) that monitor fluxes of CO_2, water vapor, and energy (*2*–*4*). A similar, albeit sparser, network of ocean observation sites is quantifying the fluxes of greenhouse gases (GHGs) from oceans and their role in the global carbon cycle (*5*, *6*). These networks are operated on an ad hoc basis by the scientific community. Although FLUXNET and other observation networks cover diverse vegetation types within a 70ºS to 30ºN latitude band (*3*) and different oceans (*5*, *6*), there are not comprehensive and reliable data from African and Asian regions. Lack of robust scientific data from these regions of the world is a serious impediment to efforts to understand and mitigate impacts of climate and environmental change (*5*, *7*).



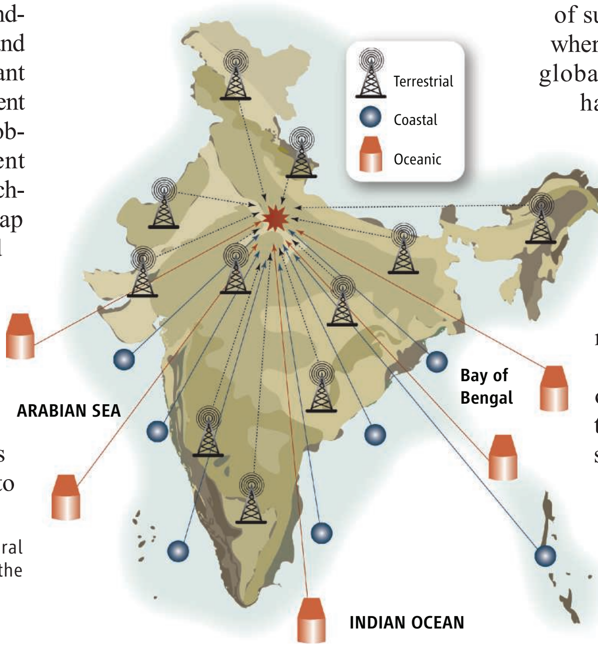
Current monitoring sites in FLUXNET. Sites are shown in red, and global representativeness is estimated by Global Multivariate Clustering Analysis (*24*–*26*). Darker areas are poorly represented by the existing FLUXNET towers. Environmental similarity was calculated from a set of variables (precipitation, temperature, solar flux, total soil carbon and nitrogen, bulk density, elevation, and compound topographic index) at a resolution of 4 km.

The Indian subcontinent and the surrounding seas, with more than 1.3 billion people and unique natural resources, have a significant impact on the regional and global environment but lack a comprehensive environmental observation network. Within the government of India, the Department of Science and Technology (DST) has proposed filling this gap by establishing INDOFLUX, a coordinated multidisciplinary environmental monitoring network that integrates terrestrial, coastal, and oceanic environments (see figure, right).

In a workshop held in July 2006 (*8*), a team of scientists from India and the United States developed the overarching objectives for the proposed INDOFLUX. These are to provide a scientific understanding (i) of the coupling of atmospheric, oceanic, and terrestrial environments in India; (ii) of the nature and pace of environmental change in India; and (iii) of subsequent impacts on provision of ecosystem services. Also, in order to evaluate what will enable India to sustain its natural resources, these goals include an assessment of the vulnerability and consequent risks to its social and natural systems.

Climate change will alter the regional biosphere-climate feedbacks and land-ocean coupling. Although global models reliably predict the trend in the impact of climate change on India's forest resources, the magnitude of such change is uncertain (*9*). Similarly, whereas all oceans show the influence of global warming (*10*), the Indian Ocean has shown higher-than-average surface warming, especially during the last five decades (*11*, *12*). This warming may have global impacts (*13*, *14*), even though the impact on the Indian summer monsoons is not well understood (*15*, *16*). These uncertainties highlight the need for regional models driven by regional data.

As the hypoxia observed in the Gulf of Mexico is related to agricultural practices in the watershed (*17*), Indian Ocean studies also indicate couplings between mainland activities and offshore and



A schematic of the INDOFLUX proposal. Placement of stations reflects different climactic, vegetation, and land-use areas. Final locations will be determined as part of the formal science plan.

The authors were members of an indo–U.S. bilateral workshop on INDOFLUX. Affiliations are provided in the supporting online material.

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coastal ecosystem processes, with characteristics that differ dramatically between the Arabian Sea and the Bay of Bengal (*18*). Countries in the Indian subcontinent (India, Pakistan, and Bangladesh) collectively rank among the highest in the ratio of total population to length of coastline, as well as in ratio of land area to length of coast. This suggests that land-use effects on coastal processes and vice versa (i.e., sea-level rise), will be extreme. For developing countries such as India, with a large rural population dependent on the agricultural sector and natural resources, it is imperative to implement scientifically informed policy decisions and management strategies (*19*).

INDOFLUX will help assess the status of the environment in the Indian Subcontinent and surrounding oceans and will create a baseline from which to evaluate future environmental changes. India's current GHG liability is roughly 1 billion metric tons annually (*20*). India is presently a non–Annex I country in the Kyoto Protocol of the United Nations Framework Convention on Climate Change and is exempt from binding GHG emissions targets, but as it makes the transition to a developed economy, its status could be revised. India has called for a comprehensive, long-term monitoring network to accurately assess India's GHG inventory and its vulnerability and adaptation to environmental change (*20*). The proposed INDOFLUX system will provide a map of sources and sinks for carbon and GHGs from various Indian landscapes and will help develop strategies for mitigating domestic and global emissions. In addition to assessing the GHG footprint of ecosystems in the region, the INDOFLUX will also help evaluate the impact of environmental change on ecosystem services provided by them.

The DST has requested about U.S. $50 million for the next 5 years to implement the INDOFLUX network. The money is now earmarked in the 11th 5-year plan. However, for the funds to be released, the scientific community must present a formal plan to the cabinet during the current fiscal year (April 2007 to March 2008).

INDOFLUX will build on ongoing national scientific programs. For example, the India Meteorological Department has initiated a climate-related environmental monitoring program that includes sampling of CO_2 concentrations at various stations. The National Physical Laboratory and their collaborators have assessed the GHG footprint for India (*20*). The Bose Institute operates a facility at Darjeeling for a comprehensive study of the atmospheric environment of the Eastern Himalayas. Similarly, the Indian Space Research Organization's Geosphere-Biosphere program collects flux data for GHGs, mainly to understand surface-atmosphere interactions. The National Institute of Oceanography has carried out studies of physical and biogeochemical ocean processes, and the Indian National Centre for Ocean Information Services has been a partner in the Argo program (*21*) to measure ocean temperature and salinity.

Variables for Indoflux Monitoring

Parameters	Terrestrial	Marine
Net radiation balance	X	X
PAR	X	X
Aerosol optical thickness	X	X
Fluxes of CO_2 heat, energy, & momentum	X	X
Evapotranspiration	X	
Wind speed and direction	X	X
Air temperature	X	X
Land–use change	X	
Precipitation	X	
Soil moisture	X	
Soil temperature	X	
Sea surface temperature		X
Light attenuation		X*
Soil nutrients (C, N, P)	X	
Nutrients (NH_4^+, NO_3^-, PO_4^{3-}, DON, DOP), organic and inorganic C	X	X*
Nutrient loading in runoff		X
Nutrients (Fe, Si)		X*
Atmospheric nitrogen deposition	X	X
Temperature and salinity		X*
Dissolved oxygen		X*
Total suspended solids		X*
Primary production/ standing biomass	X	X
Aerosol deposition	X	X
Biogenic gas flux (CO_2, CH_4, N_2O, DMS)	X	X
Soil respiration	X	
Aquatic respiration		X
Leaf area index	X	

*Profiles in the marine enviornment.

Representative environmental variables to be measured at individual monitoring stations of the INDOFLUX network. Parameters will be finalized as part of the formal science plan. PAR, photosynthetically active radiation.

Most of these efforts occur under the aegis of various organizations and are not sustained; furthermore, the data sets generated are often not integrated. A unique feature of INDOFLUX is the intention to integrate different ecosystem data from the start. Each station in the network will monitor several variables (see table, above). The volume of national-level data generated will require dedicated and secure data warehousing facilities, as well as high-powered computing facilities to convert data into predictive insights through dynamic models.

The sustained observation network should be created in a phased manner under one agency such as the DST, with support from other departments and ministries. This will immediately serve to increase the return on investments in similar programs by the participating agencies. It will also ensure that INDOFLUX will be a comprehensive network that integrates not only the land, coasts, and oceans but also relies on a multiagency partnership for its operation and governance.

This new program has a critical opportunity to develop protocols, data and metadata standards, and cyber infrastructure to ensure interoperability with other international observing systems projects. Indeed, the validity and global relevance of INDOFLUX and other regional networks is predicated on efficient reciprocal data-sharing and communication protocols with global partners in real time. With the data generated, the scientific community can deliver the necessary scientific foundation for the development of long-term, defensible government policies to tackle environmental change and to meet our obligations under international accords. The data will support economic and strategic cooperation and collective actions internationally.

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Supporting Online Material

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ERRATUM

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Policy Forum: "Environmental monitoring network for India" by P. V. Sundareshwar *et al.* (13 Apr. 2007, p. 204). On page 204, in the first column, first paragraph, the next-to-last sentence, the reference citation (*3*) should be (*2*) and "not" should read "no." The corrected sentence is "Although FLUXNET and other observation networks cover diverse vegetation types within a 70°S to 30°N latitude band (*2*) and different oceans (*5*, *6*), there are no comprehensive and reliable data from African and Asian regions." The authors were members of an Indo-U.S. bilateral workshop on INDOFLUX. In the legend to the first figure, reference citations (*24–26*) should be (*22–24*). In the credit line, the word "(SOURCE)" should be removed.