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Future Records of the Past

Ice core records provide a cornerstone of global change research, revealing the patterns of past environmental variability over periods now approaching one million years. The lead article in this issue describes ice core research plans for the coming decade, that include the recovery of a 1.5 million-year record from Antarctica.

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Indian Global Change Workshop

In March 2006, a Global Change Workshop was held at the Indian Institute for Tropical Meteorology in Pune, on the occasion of the meetings of the SC-IGBP and the WCRP JSC. An article summarising the workshop is followed by two detailed papers based on presentations made at the workshop.

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IGBP Science Plan and Implementation Strategy

The IGBP Science Pan and Implementation Strategy for 2006–13 has now been published. Copies can be obtained from the IGBP Secretariat, and electronic copies can be downloaded from the IGBP website. The centrefold of this NewsLetter provides a brief summary.

The detailed illustration shown here and featured on the cover of the Science Plan represents the complex and interactive Earth System that is the focus of IGBP research.

Centerfold

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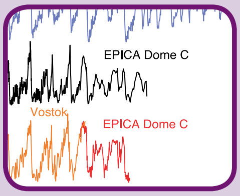

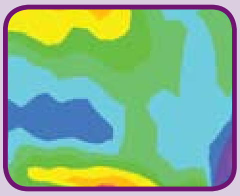

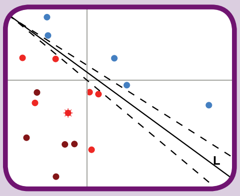

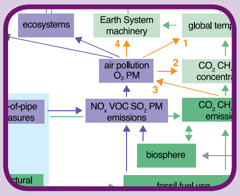

Guest Editorial

Politics, Policy and Science

The Earth System Science Partnership (ESSP) calls for integrated approaches to understanding the Earth System (including interactions between the environment and society) and seeks to develop a framework for global stewardship in order to respond to the challenge of global change. Over the years IGBP has contributed much to the development of Earth System science, but in my opinion, has tended to shun the reality that stewardship includes policy making, and at the end of the day, political action. Perhaps this aspect is considered more within the community of the International Human Dimensions Programme on Global Environmental Change (IHDP), however, I believe this aspect of stewardship should also be actively considered within IGBP.

In a democracy, citizens are represented by politicians who are elected by the people to take decisions for the common good. The legislative texts which politicians need to decide upon are prepared by policy makers – that is, civil servants in national ministries, or governmental institutions like the European Commission. Such preparation usually includes broad consultation with stakeholders.

Scientific research on issues of immediate relevance to society – such as the environment or human health – undoubtedly plays a role in policy making. Scientific research observes the functioning of the world, unravels relationships between human activities and effects that are not immediately obvious, and hence may discover or even predict problems that require political action. This scientific understanding is often critical for finding solutions to the identified problems. The scientific community, through its link with education, also plays an important role in raising public awareness of the issues.

The tasks of scientists, policy makers and politicians can be linked using the concept of "risk" – defined as the chance of losing capital, including quantifiable and non-quantifiable capital. Scientists identify risks and relate them to human activities (risk assessment), while policy makers develop practical solutions to mitigate or adapt to these risks (risk management). Politicians eventually decide which solutions to adopt, and hence they determine the level of risk to be accepted (risk taking).

The scientific community must defend its methods of producing knowledge tested by critical and reproducible observations. But at the same time it must be aware and open to the notion that people and politicians also use other yardsticks to guide their decisions. For example, the setting of environmental targets is not based solely on rational cause-effect relationships unravelled by scientific research; economic, social and ethical aspects are considered as well. This is often seen as a negotiating process – which it is, but it stems in theory from the desire of politicians to reduce the overall risks to society, not simply on any one issue.

An increasing number of commentators are calling upon the scientific community to be responsive to non-specialist interest groups, and to involve them in developing the applied science agenda necessary to more effectively contribute to policy making. The views of scientists on which issues policy makers and society should be informed about, are generally well represented in the scientific literature. However, I believe that the views of society should also be more clearly presented in the scientific literature, that is, if we are serious that science should be responsive to the needs of society.

The problem in this two way communication may partly lie with editors of scientific journals, but undoubtedly, also lies with policy makers who don't reach out to the scientific community with their questions. The underlying problem may be the lack of a suitable platform for science-policy communication.

In a *Discussion* article in this issue I sketch the increasing integration between research and policy in the areas of air pollution and climate change, where integrated assessment models (IAMs) provide a common platform for science-policy discussions. Some such IAMs can be considered operational precursors to the Earth System models advocated by ESSP. In recent years, ESSP – through the Global Change NewsLetter and other means – has proposed many ways to progress Earth System modelling, from models of intermediate complexity to place-based research. In the *Discussion* article I illustrate how it is instructive to consider specific societal problems or policy areas, to see how science, policy and society communicate, and to consider how progress has been made with and through integration.

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21st Meting of the SC-IGBP

The SC-IGBP held its 21st Annual Meeting from 4–7 March 2006, in Pune, India, hosted by the Indian Institute for Tropical Meteorology. A review of IGBP projects showed that IGBP Phase II is well underway. It was clear that while IGBP will retain basic Earth System science as its core mission, it will need to expand its ability to express the results of this science in terms of "the sustainability of the living Earth", as aspired to in the IGBP vision. It was agreed that IGBP Regional Offices be established in Brazil and China to trial ways for developing countries to more easily interact with and contribute to IGBP.

The SC-IGBP Annual Meeting overlapped with the Annual Meeting of the Joint Scientific Committee (JSC) of WCRP, and for the second time in three years SC-IGBP and JSC WCRP conducted a joint session. In addition to jointly reviewing ESSP activities, the IGBP-WCRP joint session was instrumental in creating positive momentum to continue increasing collaboration between the two programmes. This momentum took practical forms, for instance, an IGAC-SPARC initiative to develop a joint activity in atmospheric chemistry. The positive momentum has continued beyond Pune, to the CLIVAR Scientific Steering Group meeting in April 2006, Buenos Aires, where close collaboration was proposed between GLOBEC, IMBER and CLIVAR. These steps to enhance collaboration are important for strengthening ESSP and for developing a common vision for the future of global environmental change research.

The SC-IGBP and JSC WCRP meetings were preceded by a one-day workshop on global change science in India, organised by the Indian IGBP National Committee. At the workshop, presentations demonstrated the high quality of global environmental research in India; three papers in this issue of the Global Change NewsLetter are based on these presentations.

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The Future of Ice Coring: International Partnerships in Ice Coring Sciences

E. Brook, E. Wolff, D. Dahl-Jensen, H. Fischer and E. Steig

Ice cores provide information about past climatic and environmental conditions on time scales from decades to hundreds of millennia, and provide direct records of atmospheric composition. They are cornerstones of global change research, having for example, clearly demonstrated the close coupling of past climate and greenhouse gas concentrations and the occurrence of abrupt climate switches.

As the major Greenland and Antarctic ice coring projects conducted over the last 15 years are now complete, the international ice coring community is planning for the coming decades. The costs and scope of future research require coordinated international collaboration. The International Partnerships in Ice Coring Sciences (IPICS) – a group of scientists, engineers and drillers from 18 nations – has been established to develop this collaboration. IPICS has established the following ambitious four-project framework to both lengthen and improve the spatial resolution of ice core records (both of which are necessary to better understand the role of polar regions in global change):

1. a deep ice coring programme in Antarctica to recover a record of the mid-Pleistocene transition (the shift from 40 to 100 ka climate cycles);
2. a deep ice core programme in Greenland to recover a record of the last interglacial;
3. a bipolar network of ice core records spanning approximately the last 40 ka; and
4. a global network of ice core records for the last 2 ka.

A 1.5 Million-Year Antarctic Ice Core

At present, we live in the latest warm phase of a series of cold-warm oscillations of 100 ka periodicity. Ice core records show that for the last 650 ka variations in atmospheric carbon dioxide and other greenhouse gas concentrations have been closely linked to these climate cycles (Figure 1). However, we still do not fully understand the natural regulation of atmospheric carbon dioxide and the amplifications that make the climate system so sensitive.

The oldest ice core to-date – from the European Project for Ice Coring in Antarctica (EPICA) – extends 800 ka into the past. However, just prior to this time the pattern of climate variability is known to have been different – with 40 ka cycles (Figure 1). The reason for the shift is a major puzzle, but studying the climate-biogeochemistry interactions during and before the transition will help to:

- explain the natural variability that led to the current climate;

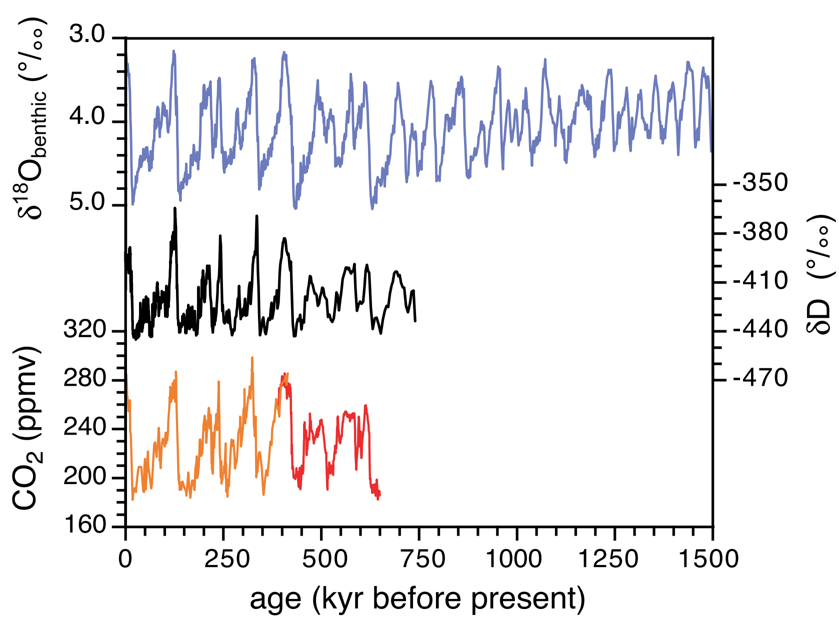

Figure 1. Top: benthic oxygen isotope stack showing the shift from 40 to 100 ka global climate cycles in the mid-Pleistocene [1]; middle: Dome Concordia stable isotope record showing evolution of central East Antarctic climate for the last 800 ka [2]; bottom: combined Vostok (orange) and Dome Concordia (red) carbon dioxide records [3,4].

- test the hypothesis that the change from 40 to 100 ka cycles was caused by a lowering of atmospheric carbon dioxide concentration;
- explain the timescales and processes that control exchange of carbon dioxide (including anthropogenic carbon dioxide) between Earth system reservoirs; and
- provide context for the modern enhanced greenhouse effect.

To study the climate-biogeochemistry interactions during and before the periodicity transition requires a reliable ice core record extending from the present back through several of the 40 ka cycles, that is, at least 1.2 and preferably 1.5 million years into the past.

As ice older than 800 ka certainly exists in Antarctica, the first task will be an iterative one of modelling and surveys to identify potential drill sites in the poorly-surveyed interior of East Antarctica where accumulation rates are low and thick ice is found. Some survey work is planned for the International Polar Year (IPY; 2007–08), and IPICS will assess the results of this work in recommending drill sites. Project implementation planning is being initiated by IPICS, with drilling expected to begin early next decade.

A Greenland Ice Core for The Last Interglacial

Greenland ice cores provide a compelling picture of the abrupt, millennial-scale, climatic flips of the last glacial period. Understanding the cause of these events and their implications for future climate change, is of major research interest and of considerable policy relevance. However, existing Greenland cores are deficient because records of the last interglacial (Eemian) have been incomplete – for example, due to basal melting [5].

The last interglacial is critical as it appears to have been warmer than the present, providing an analogue for the climate we are approaching. Models suggest the Greenland ice sheet will melt under warmer conditions, and the last interglacial can provide test data for such models. Supplementing existing low-resolution records from other archives, a longer Greenland ice core would:

- allow high resolution charting of a full interglacial from inception to termination;
- determine if rapid climate change occurred in the warmer interglacial or the preceding glacial period; and
- relate climate variations from the present and the last interglacial to global warming scenarios.

IPICS plans therefore to obtain a reliable high-resolution Greenland ice core record of the onset of the Eemian and possibly the previous glacial period – a record of at least 140 ka. The first step is identification of a site where the full Eemian record is preserved undisturbed by flow. Radio echo sounding profiles have traced internal layers to 82 ka before present, and suggest the most suitable site is probably in northwest Greenland where ice is 2542 m thick and the Eemian section around 80 m thick with no signs of folding or other distortion. Drilling is expected to occur during the coming IPY.

A Bipolar 40 ka Network

Recent palaeoclimate reconstructions clearly document the intricate interplay of oceanic, atmospheric, biogeochemical and cryospheric processes in the climate system. However, the reasons for changes in greenhouse gas and aerosol concentrations, sea levels and ice masses as well as their coupling to atmospheric and ocean circulation, are still incompletely understood. Previous ice core records from central Greenland and East Antarctica have defined for a few sites the overall features of glacial and interglacial periods, glacial-interglacial transitions and the characteristics of rapid climate change during the last glacial. However, the spatial evolution of deglaciation and abrupt climate change, particularly the differences between Northern and Southern Hemisphere patterns and the processes responsible for these changes, cannot be diagnosed from single locations. The IPICS “40 ka Network” of temporally synchronised, high-resolution ice cores from both polar regions will provide the necessary data to decipher climate change mechanisms. The 40 ka focus is because of the major Earth System reorganisations of the last glacial-interglacial transition, the climate variations of the Holocene, and the well-dated and documented sequence of abrupt climate changes in Marine Isotope Stage Three (Figure 2). The 40 ka network will:

- determine spatial patterns in environmental parameters related to ocean surface conditions (e.g. sea ice and marine biological productivity);
- construct the sequence of events from 40 ka to present in different geographic areas of both polar regions at the high-

est possible resolution;
- synchronise new records using high-resolution measurements of methane, carbon dioxide and dust, as well as isotopic atmospheric composition;
- quantify the spatial and temporal evolution of rapid climate changes in both polar regions; and
- identify climate modes and teleconnections under different climate boundary conditions (orbital forcing, greenhouse gas concentration and land ice masses).

It is also important to understand the response of major ice sheets to climate change. Ice sheet models differ in their predictions of the extent and thickness of the major ice sheets at the last glacial maximum and their contribution to global sea level. During the ice sheet expansion of the glacial period some modern coastal ice domes may have merged with inland ice. Ice cores from these locations can provide basic information (snow accumulation, temperature, altitude and ice sheet extent) about the changes in the ice mass balance.

A site selection team will identify optimal new core sites and will coordinate individual coring projects. A science plan will be developed to ensure that comparable data sets will be available for all drill sites and to coordinate efforts for process-related studies in parallel to deep ice core drilling. During the coming IPY two new sites will be drilled in the West Antarctic ice sheet [7] and at Talos Dome on the Antarctic Ross Sea coast [8], with other cores to complete the network drilled over the following decade.

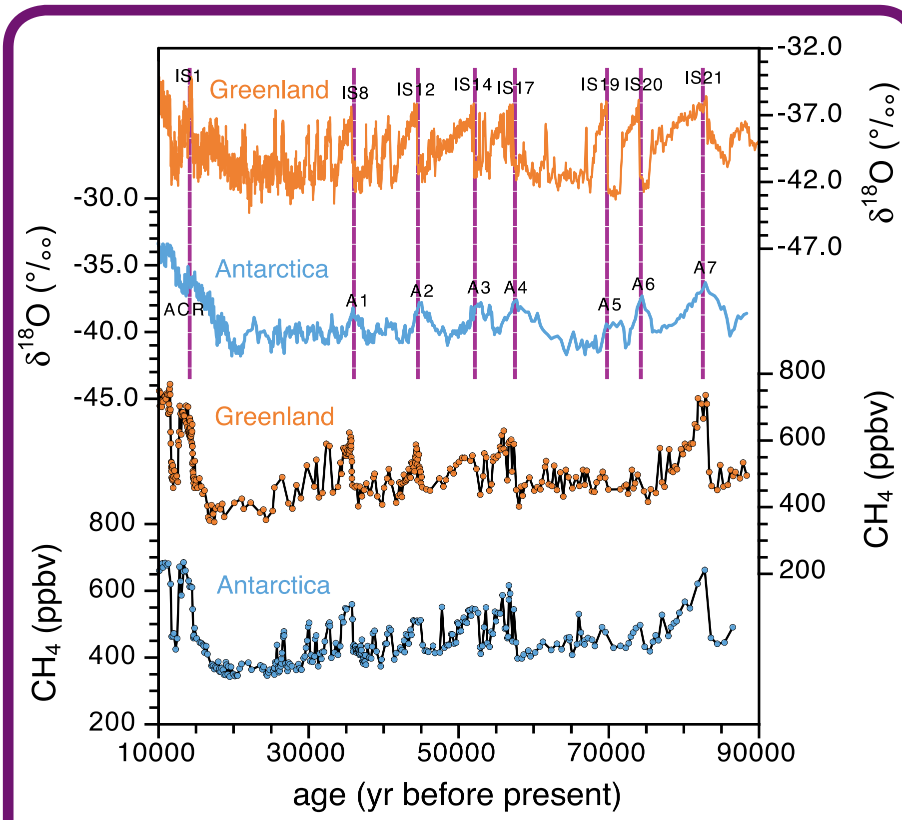

Figure 2. Comparison of climate records from Antarctica and Greenland covering the last 90 ka. The last 40 ka of record contains last glacial-interglacial transition and the best documented abrupt climate shifts in both hemisphere. From [6].

A Global 2 ka Network

Climate variability on decadal to centurial time scales is of too low a frequency to be assessed using the instrumental record, and is too spatially heterogeneous to be adequately characterised by the small number of existing highly resolved, well-dated palaeoclimate records. For example, temperature reconstructions for the past thousand years remain widely debated because there is insufficient data prior to about 1600 AD. The spatial and temporal variability of past precipitation, atmospheric circulation and sea ice extent on these time scales is even less well known. Similarly, while greenhouse gas concentrations are globally well mixed and can be determined from a small number of records, variations in important climate feedback variables, such as continental dust and aerosol concentrations, are highly regional. Improved reconstructions of all of these variables are needed to answer fundamental questions about the natural variability of the climate system, and to put potential anthropogenic climate change in context.

The feasibility of obtaining quantitative climate reconstructions on these time scales, given sufficient number and distribution of highly resolved records, has been recently demonstrated by the International Trans Antarctic Expedition [9] (Figure 3). However, most existing ice core records have insufficient temporal resolution, are too short to allow quantitative reconstructions longer than one or two centuries or do not overlap with satellite observations. The IPICS "2 ka Network" will provide a larger network of ice cores that can contribute to global climate reconstructions, extending the high altitude proxy climate and climate forcing observations to the last two millennia. The 2 ka time frame encompasses both the industrial era and a sufficient prior period to allow statistically meaningful assessment of natural century-scale variability. Important criteria for 2 ka Network records include:

- maximum resolution and precise and accurate dating;
- spatial distribution capturing the dominant climate variability patterns; and
- multiple records from each core, enabling statistically meaningful reconstructions by record combination.

The 2 ka Network will build on results from previous and ongoing ice core networks, including the dozens of cores collected on the Arctic islands, in Antarctica and from high mountains at lower latitudes. While many of these records are only 100–200 years long, they can guide selection of new drilling locations. At other locations existing long records need to be updated, since many provide only limited information after the 1970s (satellite measurement commencement) thus hampering calibration.

Compilation and analysis of existing data will be an important part of the effort, including improved statistical analyses and the use of tracer-enabled general circulation models. International planning and logistics cooperation for core collection and analysis is required. Archiving data at a single World Data site is planned.

Implementing IPICS

IPICS has reached a consensus regarding the four major projects and has established a steering committee and a timeline for future work. "White paper" documents have been finalised for each project and can be viewed at the IPICS web site hosted by PAGES (www.pages-igbp.org/science/initiatives/ipics/white-papers.html). Detailed science and funding plans are under development.

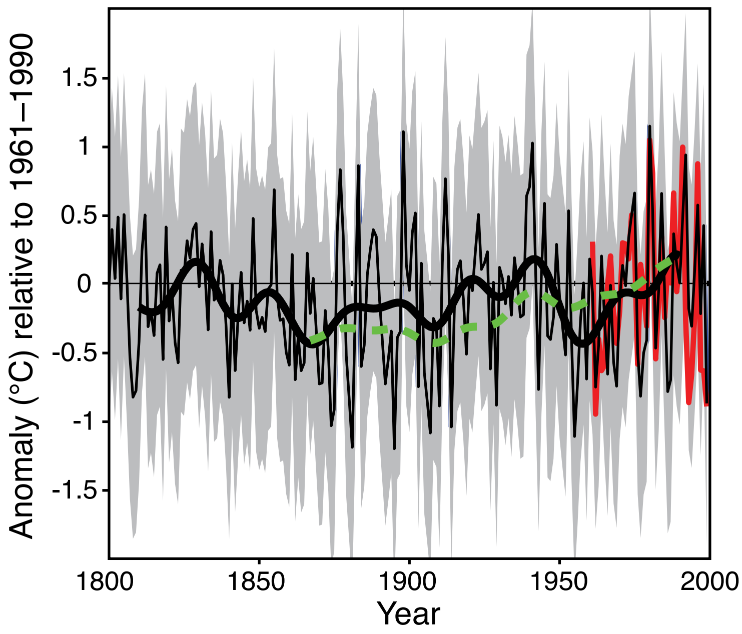

Figure 3. Reconstructed continent-wide average Antarctic temperature anomalies from calibrated ice core stable isotope records. Black lines show annual data, 20-year smoothing (bold), and 2 standard deviation annual uncertainties (grey). Also shown for comparison are annual average Antarctic temperatures from instrumental data (red), and 20-year smoothed instrumental record of Southern Hemisphere temperature (dashed green). From [10].

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Acknowledgments

This article was written on behalf of all the IPICS Steering Committee members; it is based on an article in PAGES News 14(1), 6–9.

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On 3 March 2006 the Indian Institute of Tropical Meteorology, Pune, India, hosted an IGBP Global Change Workshop attended by around 100 delegates. The workshop preceded the annual meetings of the SC-IGBP and the Joint Scientific Committee of WCRP, and comprised an inaugural address from Madhav Gadgil (Indian Institute of Science, Bangalore) and eleven detailed presentations. In the first article below the workshop convener summarises the presentations; the subsequent articles detail two other workshop presentations.

Global Change Workshop – Pune, India

G. Beig

The IGBP Global Change workshop in Pune, India, began with keynote presentations from Carlos Nobre (Chair, SC-IGBP) and AP Mitra (Past Chair, Indian NC-IGBP): Nobre spoke on "Improving the Sustainability of the Living Earth: Challenges for the Next Decade of IGBP Science" and Mitra spoke on "India and IGBP: New Initiatives".

Nobre described tipping points in the Earth System including the Indian summer monsoon, and emphasised the need for integrated approaches to Earth System research that consider the dynamics of both social and bio-physical systems. He stressed that improved Earth System science will be essential for achieving sustainable development, and in this regard he noted the importance of the ESSP joint projects on carbon, water resources, food security and human health.

AP Mitra (National Physical Research Laboratory, New Delhi) provided an overview of current and recent Indian global change research, noting the active participation of Indian scientists in South Asian regional programmes relating to atmospheric aerosols, mega-city urbanisation, climate change impacts in mountain regions and water resources. Under India's initial National Communication project, a suite of activities were undertaken to prepare national greenhouse gas inventories, including development of India-specific emission factors for several sectors. Recent Indian initiatives relevant to IGBP include participation in the international Atmospheric Brown Cloud programme and in the South Asian Rapid Assessment programme of the ESSP Monsoon Asia Integrated Regional Study.

Following the keynote presentations DR Sikka (Department of Science and Technology, New Delhi) discussed "Global Change – An Indian Perspective with Respect to Weather and Climate". He described the major changes in the region over the last fifty years including population increase, industrialisation, deforestation and water resource development, and noted direct consequences such as the increased aerosol loading. Other important changes include a 5% reduction in decadal monsoon rainfall over India in the last 30 years. Sikka outlined past and future field campaigns focussed on the roles of land, atmosphere and ocean changes on the dynamics and long-term changes of the monsoon. He described how biogeochemical cycles, land use change, greenhouse gas emissions and aerosols can all affect the monsoon in different ways.

Sulochana Gadgil (Indian Institute of Science, Bangalore) spoke on "CLIMAG for Sustainable Development: The Challenges Ahead", noting the importance to agriculture of accurate predictions of both El Niño occurrence and characteristics. Analyses of crop yield variations clearly show that the largest yield variations occur in the growing

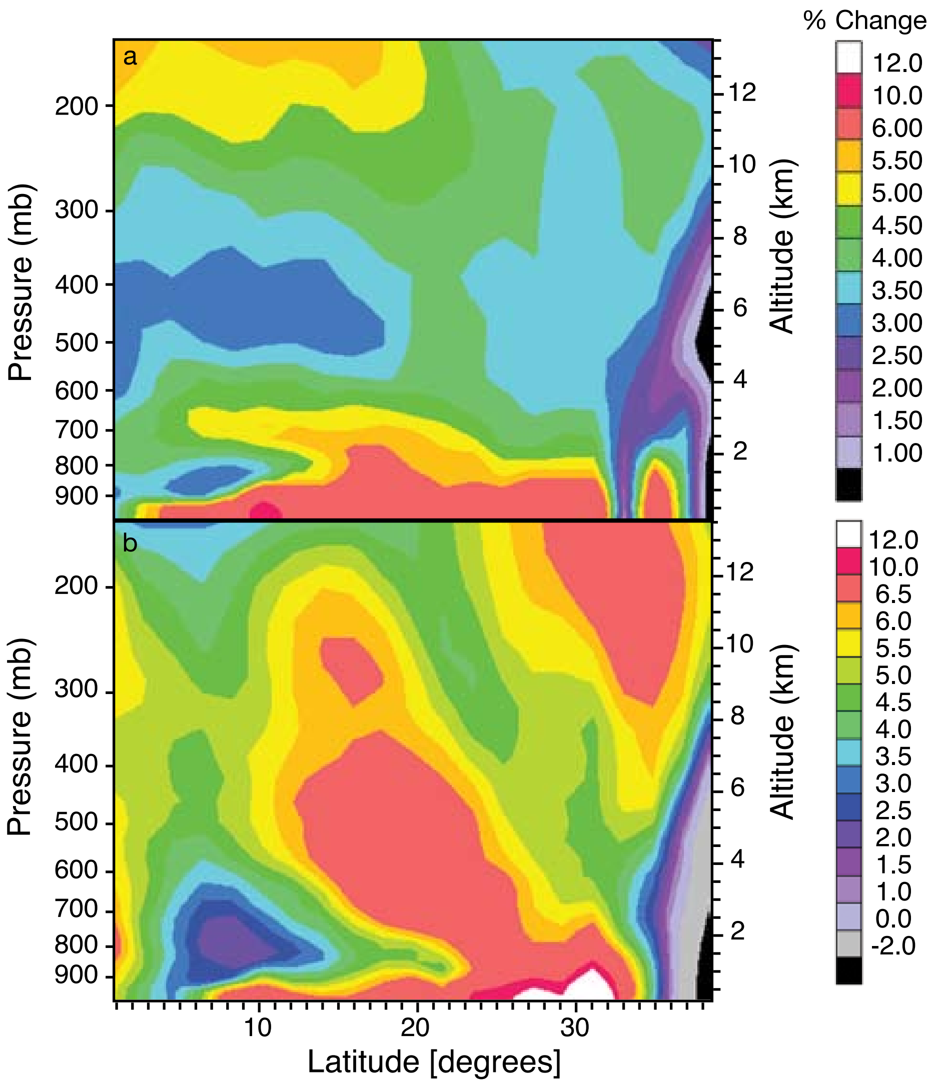

Figure 1. Simulated tropospheric distributions of the percentage change in (a) ozone and (b) carbon monoxide for at 79˚E and between 0–40˚N from 1991 to 2001.

seasons with the highest rainfall, thus improved prediction of these seasons is of greatest value to the agricultural sector. An article based on her presentation can be found in this issue of the *Global Change NewsLetter*.

BN Goswami (Indian Institute of Science, Bangalore) posed the question "How Does North Atlantic SST Influence the Indian Summer Monsoon on Decadal and Longer Timescales?" He explained the close link between the Atlantic Multi-decadal Oscillation (AMO) and multi-decadal variability of Indian summer monsoon rainfall. The AMO, the monsoon multi-decadal oscillation and multi-decadal amplitude modulation of El Niño are now known to all follow a global quasi-sixty-year coupled ocean-atmosphere oscillation. This revelation should improve the predictability of monsoon multi-decadal oscillations. Furthermore, the deep first baroclinic vertical structure of the Indian monsoon indicates that the Indian summer monsoon is not driven by north-south differences in surface temperature, but by the meridional gradient of tropospheric heating.

Gufran Beig (Indian Institute of Tropical Meteorology, Pune) described Indian research in atmospheric chemistry, including work on greenhouse gas emissions and the resultant climate change. He described progress in global and regional scale atmospheric chemistry modelling, GIS-based statistical modelling for gridded emissions inventories, and model simulations of the effects of anthropogenic emissions on monsoon tropospheric pollutant levels (including ozone, nitrogen oxides, carbon monoxide and hydrocarbons) in the Indian tropics. The maximum simulated variations in ozone concentrations for the 1990s are 5–20% near the surface, 5–7% in the lower free troposphere and 3–5% in the upper troposphere for the month of July (Figure 1a). The decadal variation in carbon monoxide for July is highest (10–18%) in the boundary layer around 20–30°N, but in most of the free troposphere, the variation is around 4–8% (Figure 1b). The maximum decadal increase in nitrogen oxides is 20–50% in the boundary layer. The impact of pollutants on ozone concentrations is estimated to be largest during the monsoon, which is characterised by strong convective activity and effects extending up into the free troposphere; this is in contrast to the early post-monsoon. Pollutant emissions are country-specific and systematic inventories are rare in Asia. However, biofuels (wood, kerosene and coal) are a major energy source in rural India (72% of the population), and biofuel combustion is known to be the dominant source of Indian carbon monoxide emissions. The distribution of tropospheric ozone and its precursors over India are significantly affected by such emissions along with long-range transport.

A Jayaraman (Physical

Research Laboratory, Ahmedabad) summarised "Present Understanding on Aerosols and Aerosol Radiative Forcing over the South Asian Region" focussing on Indian studies of aerosol radiative forcing and cloud properties. An article based on his presentation can be found in this issue of the *Global Change NewsLetter*.

GB Pant (Indian Institute of Tropical Meteorology, Pune) discussed progress on "High Resolution Palaeo-Climatic Reconstructions Over India", highlighting the potential of tropical tree-rings for inter-annual resolution climate reconstructions for India for the past few centuries. Dendroclimatic reconstructions of the pre-monsoon summer climate of the Western Himalaya since the early 18th century show no significant long-term trend, and suggest that the summer climate was not much different from the present. Tropical species like teak have shown good potential for reconstructing monsoon variability over the past 300–400 years.

K Rupakumar (Indian Institute of Tropical Meteorology, Pune) described climate change in India and concluded that, in spite of considerable inter-annual variability, the Indian summer monsoon has been relatively stable over the last two centuries on seasonal and national scales. In addition to a general warming (as seen globally), India displays a notable diurnal-seasonal asymmetry in temperature trends. All coupled models suggest general warming and enhanced rainfall (e.g. Figure 2) over India towards the later half of the 21st century under increased greenhouse gases, although the details of rainfall enhancement – especially regional distribution – differ considerably between models.

R Krishnan (Indian Institute of Tropical Meteorology, Pune) described "Coupled Air-Sea Interactions in the Tropical Indian Ocean and Monsoon Environment" stressing that the Indian Ocean is a major control on the dynamics of the Indian monsoon; a weakening of the monsoon over land leads to higher precipitation over the Indian Ocean. Krishnan outlined progress in Indian monsoon predictions (in particular, monsoon droughts and the intra-seasonal variations of the coupled ocean-atmosphere system) as well as remaining challenges.

Finally, Dileep Kumar (National Institute of Oceanography, Goa) discussed IGBP-related marine research in India. He noted that the Arabian Sea is a carbon dioxide source while the Bay of Bengal is a sink, and emphasised that integrated studies focussing on land-atmosphere-ocean interactions are required to monitor climate change in the region.

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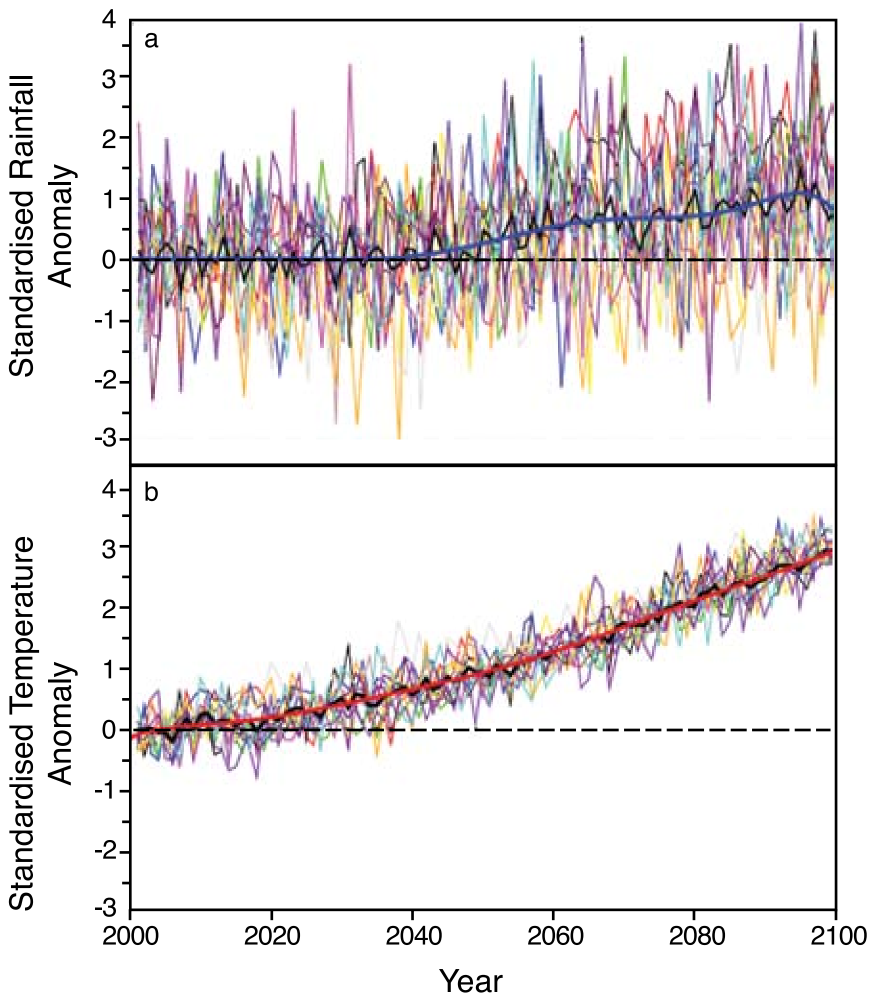

Figure 2. Future scenarios for (a) summer monsoon rainfall and (b) annual mean temperature over South Asia under SRES A2 scenario based on IPCC AR4 coupled model simulations from 13 different models (anomalies relative to current period). The bold black line indicates the all-model mean, and the bold blue (rainfall) and red (temperature) lines indicate a order-10 polynomial fit to all data.

CLIMAG for Sustainable Development: Progress and Challenges

S. Gadgil

Phenomenal advances were witnessed during the 1980s and 1990s in El Niño–Southern Oscillation (ENSO) understanding and prediction, with major contributions from the ten-year Tropical Ocean and Global Atmosphere (TOGA) programme of WCRP. As ENSO is known to have significant impacts on rainfall and hence crop yields in many parts of the world, application of seasonal forecasts in agricultural management began to be explored during the 1990s. With encouragement from WCRP and IGBP, and in partnership with several organisations, START initiated the Climate Prediction and Agriculture (CLIMAG) project to harness predictive ability of climate variability for agriculture.

A major focus for CLIMAG has been the identification of farming strategies tailored to the climate variability of particular rain-fed regions. Since cropping patterns in rain-fed regions have changed markedly in the last three decades, appropriate strategies for new crops and cultivars were required. Farmers' knowledge of the impact of climate variability on these crops and cultivars is inadequate, as the crops and cultivars have not been in use long enough for management practices appropriate to the climate variability of given regions to evolve. Furthermore, the importance of climate variability had been generally overlooked in the period following the Green Revolution (which led to a quantum jump in agricultural production during the 1960s) as the focus had been on irrigated regions where production is largely insensitive to climate variability. The recommended strategies – even for rain-fed agriculture – for the new crops and cultivars of the Green Revolution have been found by farmers to be often inappropriate, because they ignore climate variability. Although the major impact of monsoon variability on Indian agricultural production (and hence the economy) has been recognised for decades, only in the last decade have there been attempts to consider how understanding of monsoon variations could be used in the management of rain-fed agriculture.

An End-to-end Approach

Knowledge of, and predictive ability for climate variability is only useful if it affects the decision making of farmers and/or policy makers. An end-to-end approach is required to link climate variations or predictions for a specific season to agricultural decisions. This involves determining the yields and profits under available management options using crop models validated for the cultivars and region of interest – crop models are now able to realistically simulate responses to climate variability for several crops.

Two example applications considered below are cotton cultivation in Australia and peanut cultivation in India. There is a rich experience of interaction among researchers, advisors (public and private) and farmers in the development and use of seasonal forecasts in agricultural management in Australia [1,2]. The approach, built on a history of development and use of crop models and simulations to support agricultural decisions in a highly variable environment, involves scenario simulations of crop management to provide expected outcome distributions for specific climate conditions. For example, it has been shown that the optimum row configuration in the absence of ENSO predictions is different from the configuration associated with high profits when the Southern Oscillation Index phase prior to planting is zero, negative or falling.

For rain-fed peanut cultivation in the semi-arid regions of the Indian peninsula it is important to identify the optimum planting date and the optimum plant density. Farmers plant seeds within a specific period (the 'sowing window') when there is adequate moisture due to 'sowing rains'. Farmers found that the official recommendations of planting at the earliest opportunity only during May–July, were inappropriate. They have adopted a sowing window of 25 June–17 August. CLIMAG research [3] showed a high risk of low yield for the recommended early planting in May–June, and a low risk in the sowing window adopted by farmers. The new result, not known to farmers, is that within this window planting after mid-July gives better yields. Analysis of the crop model showed that the critical period when moisture stress can lead to a

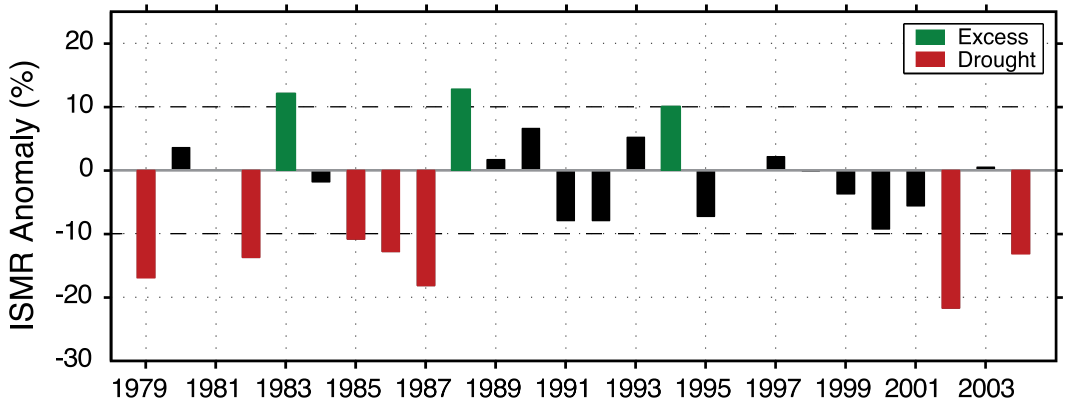

Figure 1. Annual percentage ISMR anomaly values 1979–2004 indicating rainfall excess years (anomaly greater than 10%) and drought years (anomaly less than –10%).

substantial reduction in yield is the pod-filling stage (60–80 days after sowing). Planting after mid-July is beneficial because of the low probability of dry spells in the region after mid-September.

Recent El Niño Challenges

The impacts of the strongest El Niño of the century (1997) and the relatively mild 2002 El Niño were not commensurate with expectations, based on typical prior El Niño years such as 1987 in several countries including Zimbabwe, India and Australia. In 1997, the evolution of a strong El Niño led to a forecast of a high probability of low rainfall for the whole of eastern and southern Africa as early as September. Memories of the devastating droughts of the 1982–83 and 1991–92 El Niño events meant most people prepared for an extremely severe drought. Low-rainfall strategies were successful in southern Africa where rainfall was low, however, further north rainfall was in fact around average, and production opportunities were missed. Farmers expressed intense regret for the loss incurred due to decisions based on the forecast [4].

It is well known that the inter-annual variation of the Indian Summer Monsoon Rainfall (ISMR), is linked with ENSO, with a high propensity for drought during El Niño periods and excess rainfall during La Niña periods. However, the ISMR was above average during the extreme 1997 El Niño and it has been suggested that the link of the Indian monsoon with ENSO had weakened in recent decades [5]. The 2002 failure of the monsoon (Figure 1) was therefore not anticipated, even though it was clear that a weak El Niño was developing. Australia also experienced a far more severe drought in 2002 than in 1997. The experiences of 1997 and 2002 indicate that the impacts of El Niño are not yet fully understood.

For inter-annual variation of the Indian monsoon, another important mode is the Equatorial Indian Ocean Oscillation

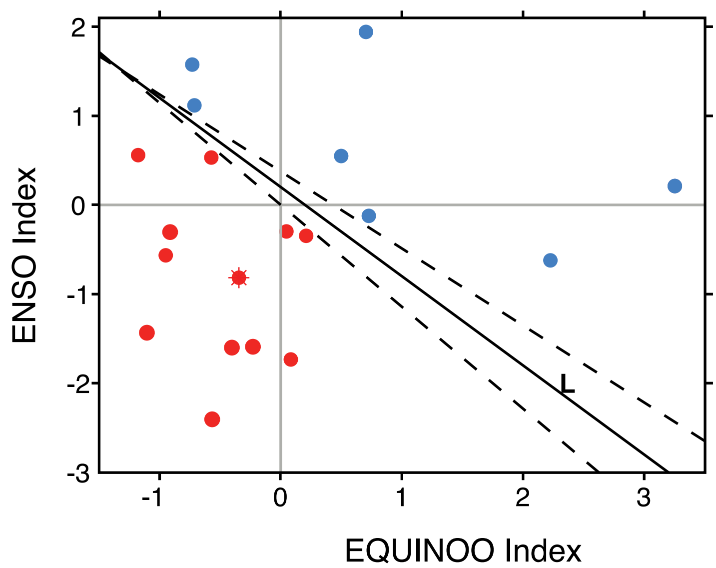

Figure 2. Separation of excess-ISMR years (blue) from drought years (red) according to ENSO and EQUINOO indices, the red star is the last drought of 2004. From [6].

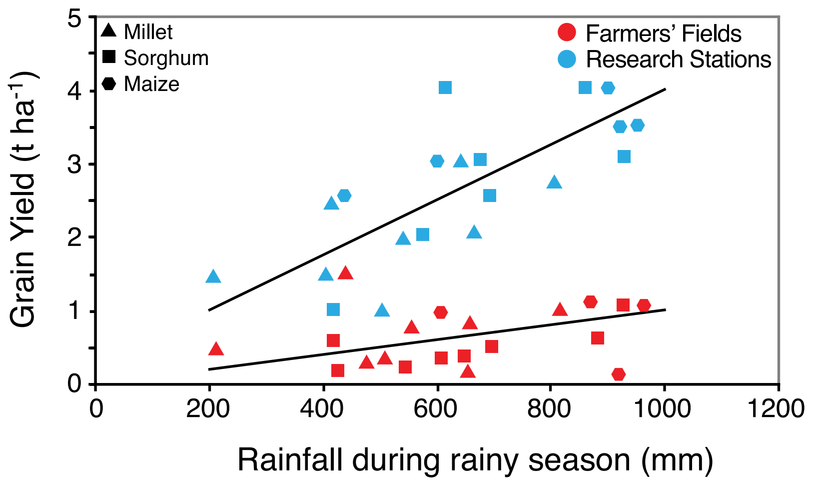

Figure 3. Yield as a function of wet season rainfall for 15 locations in India. Adapted from [9].

(EQUINOO), which is the atmospheric component of the Indian Ocean Dipole mode. The oscillation occurs between a situation in which convection over the western equatorial Indian Ocean is enhanced and convection over the eastern part is suppressed (which is favourable for the ISMR), and the reverse situation. In the phase plane of ENSO and EQUINOO indices there is a clear separation of excess-ISMR seasons from droughts (Figure 2), suggesting a strong relationship of the extremes of ISMR with a composite index with close to equal weighting on each mode [7]. Clearly, further progress in application of seasonal to inter-annual climate variation requires better predictions.

Asymmetry in Response to Rainfall Anomalies

The negative impact of droughts is well known. For India, while the impact of rainfall deficits is negative and large, the impact of above normal rainfall is favourable but small [8]. For sustainable development, this asymmetry in response to rainfall variation has to be addressed. The observed variation between the yields at agricultural stations and farmers' fields according to seasonal rainfall (Figure 3) suggests the reason for this asymmetry. When the rainfall is low, yield in both cases is low, whereas when the rainfall is high, station yields are much higher than farmers' yields hence the "yield gap" (the difference between what is achievable and what is achieved) is large. The major management differences between agricultural stations and farmers' fields are fertiliser and pesticide applications. For rainfed agriculture, such applications enhance yield substantially (and are thus cost-effective) only when there is adequate rainfall. Hence in the absence of reliable seasonal rainfall forecasts farmers do not apply these chemicals. Clearly, if reliable predictions of seasonal rainfall were available to farmers, in good rainfall years they could achieve production increases commensurate with the rainfall and sustainable development could become a reality.

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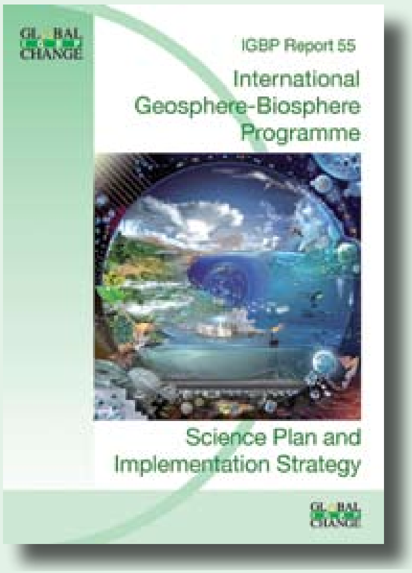
International Geosphere-Biosph

Science Plan and Implementation Strategy



IGBP was formed in 1987 by ICSU to study global change; its vision is *to provide scientific knowledge to improve the sustainability of the living Earth*. IGBP studies the interactions between biological, chemical and physical processes and human systems, and collaborates with other programmes to develop and impart the understanding necessary to respond to global change. The research goals of IGBP are *to analyse the interactive physical, chemical and biological processes that define Earth System dynamics; the changes that are occurring in these dynamics; and the role of human activities in these changes.* The IGBP Science Plan and Implementation Strategy can be downloaded from www.igbp.net; a brief overview is given below.

The Science Plan summarises the key findings of the first phase synthesis which provide the foundation for the second phase, and then presents the outcomes of the second phase planning process. The major outcomes of the research of the first phase of IGBP were (i) an improved understanding of the systemic behaviour of the Earth System; (ii) quantification of the extent of Earth System variability at various time scales, (iii) elucidation of the important role of the biosphere in Earth System functioning; and (iv) a far clearer picture of the changing degree of human influence on the Earth System.

The most compelling picture of Earth System behaviour comes from Antarctic ice cores that reveal strong global environmental oscillations, and provide considerable evidence for the linkages between the physical climate and global biogeochemical cycles over the last 740,000 years (Figure 1). Other palaeo records show strong variations at millennial time scales, including examples of abrupt changes that reflect the complex behaviour of the Earth System. While previously the biosphere was considered to simply be the passive recipient of geophysical changes, it is now recognised that biological processes are intimately coupled to physical and chemical processes in Earth System dynamics. Although analysis of past variability shows that distinguishing human-driven change from natural variability is not straightforward, there is now ample evidence that

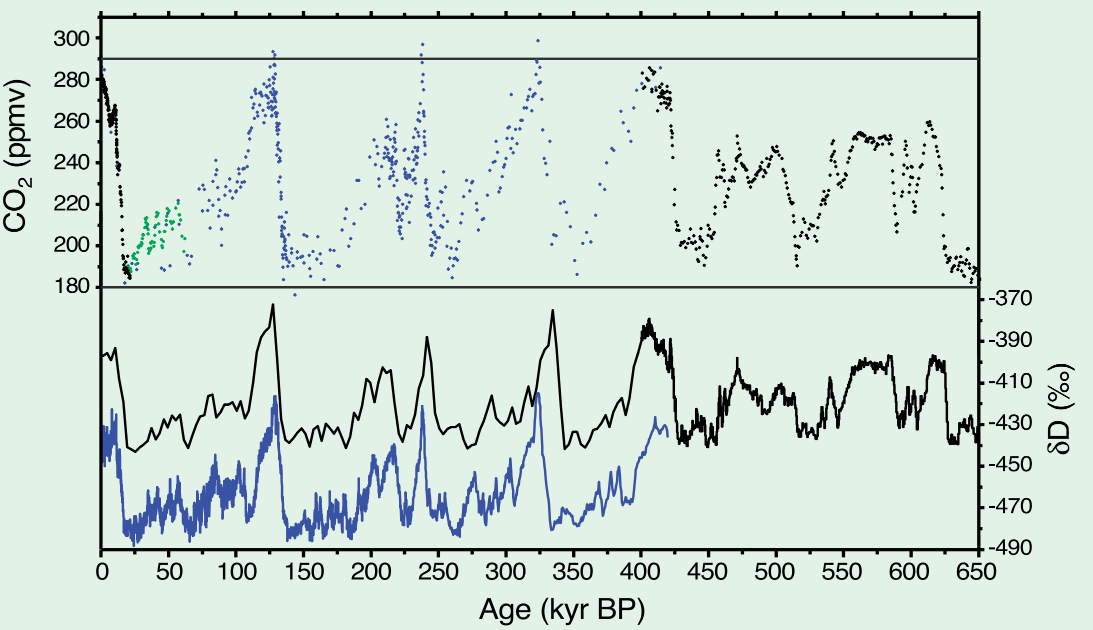


Figure1. Composite carbon dioxide record from Antarctic ice cores from Dome Concordia (black, 0–22,000 and 390–650,000 years ago), Vostok (blue, 0–420,000 years ago) and Taylor Dome (green, 20–62,000 years ago); and composite delta ^{18}O record from Dome Concordia (0–650,000 years ago) and Vostok (0–420,000 years ago). From Siegenthaler et al. (2005) Science 310, 1313-1317.

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human activities are having a major influence on the Earth System, such that it has moved well outside the range of variability exhibited over at least the last half million years.

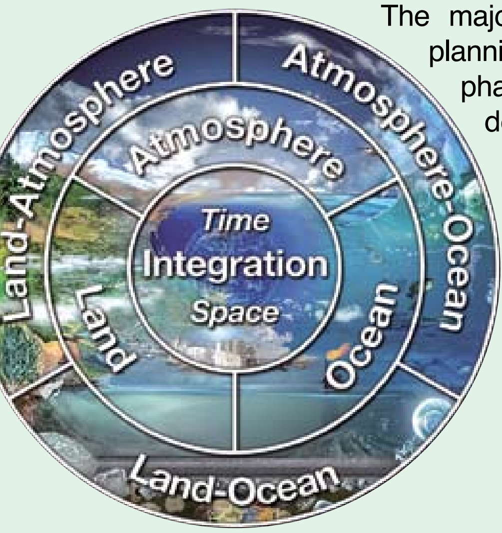

Figure 2. Scientific structure of IGBP projects.

The major outcomes of the planning for the second phase of IGBP are (i) the definition of a new scientific structure that reflects far more clearly and completely the structure and functioning of the Earth System (Figure 2); and (ii) the development of an inter-disciplinary and integrative Earth System science agenda. The new scientific structure is based on a suite of both new and refocused projects that reflect the three major Earth System compartments (land, ocean and atmosphere), the interfaces between these compartments and system-level integration through time and space. There are nine separate IGBP projects spanning the Earth System compartments, interfaces and system-wide integration:

- International Global Atmospheric Chemistry;
- the Global Land Project which builds on the land-oriented projects of the first phase of IGBP;
- Global Ocean Ecosystem Dynamics and Integrated Marine Biogeochemistry and Ecosystem Research which collaborate on ocean research;
- the Surface Ocean–Lower Atmosphere Study;
- the Integrated Land Ecosystem–Atmosphere Processes Study;
- Land-Ocean Interactions in the Coastal Zone;
- Past Global Changes which continues its integrating palaeo research; and
- Analysis, Integration and Modelling of the Earth System which spearheads integrative activities of IGBP.

IGBP recognises that collaboration with research partners is increasingly necessary for comprehensive Earth System science – especially collaborations with social scientists in order to achieve a balanced analysis of the coupled human-environment system. While many collaborations will be important for the second phase of IGBP, participation in the Earth System Science Partnership is expected to be increasingly important (Figure 3), and will be a key mechanism by which IGBP seeks to provide relevant research results to guide policy formulation, particularly with respect to sustainable development. In addition to working with research partners, IGBP recognises that progress in Earth System science will increasingly require integration of observations (especially spaced-based) and modelling.

IGBP will increasingly engage with assessment processes and with policy makers. This completes the triangulation between global change research, Earth observations and global environmental assessments and policy (Figure 3). IGBP will continue to contribute to the assessments of IPCC and MEA, and as an apolitical but politically-relevant organisation will work to help bridge the gap between the international scientific community, policy makers and the public.

IGBP will continue its successful approaches to implementation including: building research networks to tackle focused scientific questions; promoting standard methods; undertaking long time-series observations; guiding and facilitating construction of global databases; establishing common data policies to promote data sharing; undertaking model inter-comparisons and comparisons with data; and coordinating complex, multi-national field campaigns and experiments. In addition, IGBP will facilitate comprehensive interactions between modellers and experimentalists and will forge an international institutional network for Earth System science.

IGBP National Committees will continue to be essential to research planning and implementation, enabling a dialogue between national and international research. IGBP will continue to invest strongly in research capacity building activities (particularly in developing countries), primarily through project-level activities, and often in collaboration with START or regional capacity building organisations and networks.

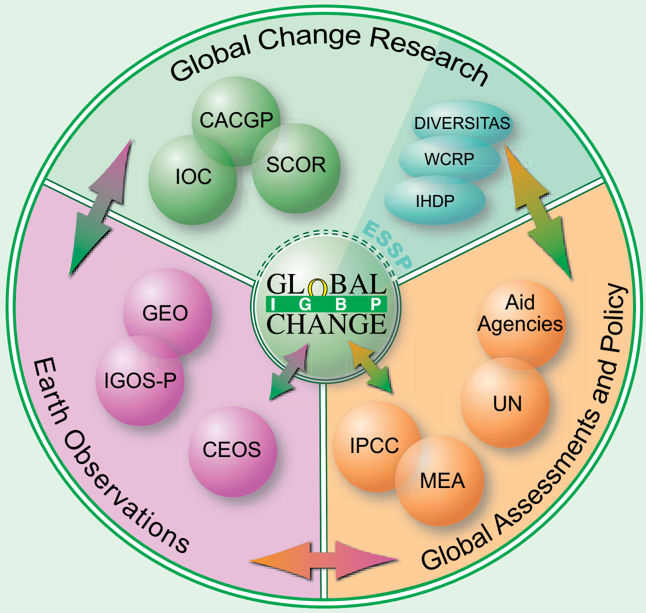

Figure 3. An IGBP-centric view of the triangulation between global change research, Earth observations and global assessments and policy.

Aerosols and Their Radiative Forcing Over South Asia

A. Jayaraman

Using aerosol optical depth measurements from the Moderate Resolution Imaging Spectro-radiometer (MODIS), regions with high concentrations of coarse and/or fine aerosols have been identified [1]. Coarse particles are generally "natural" (for example, wind-blown dust and sea salt), whereas fine particles are generally anthropogenic (for example, sulphates and soot). The South Asian region has the double distinction of having high concentrations of both coarse and fine particles, due to wind-blown dust from the arid regions to the west, and *in situ* production of various sub-micron size particles associated with rapid regional economic growth.

An international field experiment in the waters of the tropical Indian Ocean in the late 1990s (the Indian Ocean Experiment – INDOEX) focussed the attention of scientists in the region on the effects of aerosols on the climate [2]. INDOEX was unique for the region because it revealed for the first time the considerable aerosol radiative forcing over the tropical Indian Ocean during the winter, due to aerosols from mainland India transported by the northeast monsoon winds [3,4]. It also showed that radiation trapping within the atmosphere is much larger than top-of-atmosphere (TOA) forcing. For example, for the surface, atmosphere and TOA, aerosol radiative forcings for the tropical Indian region have been estimated at -14±3, 14±3 and 0±2 Wm^{-2} respectively – considerably higher than the corresponding global average values for CO_2 forcing of 1, 1.6 and 2.6 Wm^{-2} [2]. Positive forcing implies a gain in radiation energy leading to atmospheric warming, while negative forcing implies atmospheric cooling. CO_2 forcing is a fairly uniform global phenomenon with a large positive forcing, while aerosol radiative forcing is a regional phenomenon with strong spatial and temporal variations. Although strong aerosol radiative forcing is spatially confined, it causes large perturbations in global wind circulation and hence the global climate.

INDOEX generated important new research questions for the region. For example: (i) what is the nature of aerosol forcing over the data-sparse Bay of Bengal? (ii) what is the nature of aerosol forcing over mainland India? and (iii) how does aerosol forcing in the region change during the summer when the southwest monsoon is active? To answer such questions detailed experimental campaigns were launched by the Indian Space Research Organisation (ISRO) using existing facilities including the high-altitude balloon launch facility in Hyderabad, the government research vessel *Sagar Kanya* and an instrumented vehicle (including micro-pulse LiDAR) for detailed aerosol studies. Aerosol and trace gas measurements were also taken at permanent stations distributed across the entire country. Cruise experiments in the Bay of Bengal (2001–03) revealed higher aerosol concentrations than in the Arabian Sea and the tropical Indian Ocean, especially during winter when the prevailing northeast wind flushes aerosols and precursor gases from mainland India to the Bay of Bengal from whence they are advected to the Indian Ocean [5]. These high concentrations lead to large aerosol radiative forcings of -34.1, 24.6 and -9.5 Wm^{-2} for the surface, atmosphere and TOA respectively – higher than over the Indian Ocean north of the inter-tropical convergence zone.

ISRO land campaigns have been conducted specifically to understand the geographical distributions of key physical and chemical properties of aerosol over mainland India. For example, in early 2004 nine instrumented vehicles converged on Hyderbad from different directions making aerosol and trace gases measurements *en route* (Figure 1). After a week of measurement intercomparisons the vehicles returned to their respective origins taking further measurements. These measurements covered more than a million square kilometres over the course of a month, and generated a wealth of information on important aerosol parameters including size, mass concentration, optical depth, and scattering and absorption coefficients.

Among the interesting results obtained were those for aerosol absorption spectra. Soot particles (from fossil fuel combustion) absorb radiation in inverse linear proportion to radiation wavelength, whilst aerosols from biofuel combustion (or other origins) absorb more strongly in the lower wavelengths. From these differences it has been shown that 15–30% of absorbing aerosols in rural areas of the Indian peninsular are not sourced from fossil fuel combustion [6]. Over the coastal

Figure 1. Tracks of instrumented vehicles during February 2004 measurement campaign and various diurnally averaged aerosol radiative forcing (Wm^{-2}) measurements over South Asia; top=TOA, middle=within atmosphere, bottom=surface.

region fine particles contribute more to the total aerosol mass, while in the interior coarse particles are relatively more abundant [7]. The aerosol properties measured over the Indian peninsula suggest aerosol radiative forcings of -27.5, 22.7 and -4.8 Wm^{-2} respectively for the surface, atmosphere and TOA [8] – higher than over the north Indian Ocean and the Arabian Sea, but less than over the Bay of Bengal (Figure 1).

It is now clear that aerosol radiative forcing (particularly the trapping of radiation within the atmosphere) is high over mainland India and the surrounding oceans during winter. Forcing can be even higher in summer due to increased solar flux, higher concentrations of wind-blown dust and higher mixed-layer depths which accommodate more aerosols vertically. However, several issues remain; for example, in a global change context, it is necessary to delineate the forcing due to anthropogenic aerosols from that of natural aerosols. It has been shown that the forcing due to dust advected from Africa and Arabia over the Indian Ocean during summer can be as much as 50% higher than the forcing measured in INDOEX during winter [9]. Additionally, the direct effect of aerosols on the microphysical properties of clouds is not well quantified. As the summer monsoon advances through South Asia during May–June, there are strong interactions between clouds advancing northwards and aerosols already over the land mass. How particle distributions directly and indirectly affect monsoon advancement (and hence the geographical distribution of summer precipitation on which a major part of the regional economy depends) is entirely unknown.

Research priorities include obtaining an accurate picture of relative aerosol sources for the region, and improving the understanding of aerosol-cloud interactions; both will require international collaboration on technology development and modelling. The current climate for aerosol research in India is very favourable with new programmes and more active aerosol research groups than a decade ago. Before long, clear advice for policy makers should emerge from the growing understanding of the effects of aerosols on the climate.

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Portuguese Earth System Science Conference

The first all-Portuguese-speaking Earth System Science conference was held at the University of Lisbon from 22–24 March 2006 with 64 attendees. Five sequential sessions considered the conference themes of Land, Ocean, Atmosphere and Climate, Coastal Zones, and Population and Society. Each session comprised four presentations, the first of which were invited plenary talks providing theme overviews and introducing Portuguese aspects of important case studies and research programmes. Overview highlights included: (i) for Land, the Large Scale Biosphere-Atmosphere Experiment in Amazonia; (ii) for Ocean, the Global Ocean Observing System (a component of the Global Earth Observing System of Systems); (iii) for Atmosphere and Climate, the CARBOSOL project studying past and present aerosol conditions over Europe and their implications for climate; (iv) for Coastal Zones, a study of large Portuguese estuary basins and their emissions into both the atmosphere and the Atlantic ocean; and (v) for Population and Society, various multidisciplinary studies highlighting the “sustainability triangle” of environmental, economic and social sciences.

In addition to a total of 20 oral presentations, over 35 posters were on display. A special evening session on Portuguese science and expansion of the 15–16th centuries highlighted the Portuguese contribution to the emerging realisation of the period concerning the expanse and opportunities of the global ocean, and the recognition of the experimental method as the rational approach to enquiry.

Importantly, the conference formed a task group to develop a proposal for an ESSP Integrated Regional Study to be promoted by the Portuguese scientific community in cooperation with the wider European scientific community. The conference concluded with a decision for the Portuguese IGBP National Committee to evolve into a Global Change National Committee.

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Reproduction of the 12-panel world map printed in 1507 by German cartographer Martin Waldseemüller. This was the first world map to incorporate the 15th century discoveries of Portuguese and Spanish explorers, and was the first map to use the word “America” – albeit to label what is now known as Brazil. The map reflects the so-called Age of Discovery and the search for an alternative to the eastern Mediterranean route to the spice markets of the Far East. When Vasco da Gama sailed around the Cape of Good Hope in 1488, the Portuguese concentrated their efforts to the south and east. The Spanish, who agreed to divide the world in two with the Portuguese in the Treaty of Tordesillas (1494) sailed west. The protuberant African continent can be considered a metaphor for the knowledge breakthroughs of the time.

Climate change and air pollution have, to a large extent, a common cause – emissions from fossil fuel burning. Up until now however, these two problems have been addressed by separate policies. This article explains the reasons for this separation, but also describes how the natural and socio-economic sciences are intersecting to support more integrated and effective policy.

Climate Change and Air Pollution – Research and Policy

Climate Change and Air pollution

The facts are well known. Society's demands for energy, transport and commodities have been easily satisfied by the availability of cheap fossil fuel. The combustion of fossil fuel leads to emissions of greenhouse gases (GHGs): carbon dioxide in particular, but also methane and nitrous oxide. GHGs accumulate in the atmosphere, warming its lower layers and causing knock-on effects in the Earth System. Carbon dioxide is chemically rather inert and hence difficult to remove from combustion emissions. The main strategy for reducing carbon dioxide emissions therefore – and thus the cornerstone of any long-term climate policy – is emission prevention. Prevention can be achieved by structural changes in the energy sector (i.e. improved efficiency and carbon-free renewable energies) and by behavioural changes (i.e. reduced energy use).

Fossil fuel combustion also emits conventional air pollutants: carbon monoxide, volatile organic compounds, carbonaceous aerosols ("soot"), nitrogen oxides and sulphur dioxide. Some of these compounds react in the atmosphere to form secondary pollutants such as ozone, particulate sulphate, nitrate and organic matter, which impact on ecosystems and human health. Developed countries have reduced these impacts initially by improving energy production efficiency and, more recently, using cheap end-of-pipe emission control technologies.

Current Policy Separation

Reducing fossil fuel use would address both climate change and air pollution. However, fossil fuels provide over 80% of the current global energy supply, and will continue to be the dominant energy source for decades to come. Furthermore, GHGs differ from conventional air pollutants in their physico-chemical properties, leading to differences in the relative atmospheric longevity and ease of removal from combustion effluents. Currently therefore, and in recent decades, separate policy frameworks have been developed for air pollution and climate change.

Air pollution policy has developed faster than climate change policy, primarily because of cheap end-of-pipe control technologies for air pollution derived from fossil fuel combustion. Successful air pollution abatement is also due to short pollutant lifetimes, which mean impacts occur relatively close to emission sources, hence allowing local-regional scale solutions. Conversely, long-lived GHGs mix throughout the global atmosphere, with climatic effects than cannot be traced back to specific sources or regions. Climate change policy therefore requires global commitment, irrespective of local-regional emissions and impacts.

Towards Policy Integration

In recent years it has been increasingly recognised that air pollution and climate change are linked in several ways, and that they could be beneficially addressed by integrated policy [1]. The push for policy integration comes mainly from consideration of implementation costs. This is particularly true in developed countries, where cheap air pollution control technologies are already widely implemented, and further reductions are likely to require structural and behavioural measures. In developing countries current economic growth and the supporting development of energy production systems, provide the opportunity to tackle air pollution and GHG emissions simultaneously. Immediate investments in existing carbon-free energy technologies would seem to be the solution. However, for major developing countries it is economically attractive to use large domestic coal reserves, hence end-of-pipe technologies will be required both for air pollution and for GHGs. For GHGs, end-of-pipe technologies such as carbon dioxide capture and storage are still in the research and development stage.

Policy integration means finding the mix of end-of-pipe, structural and behavioural measures that meet air pollution and climate change targets at the lowest cost. Finding this optimal mix is achieved using integrated assessment models (IAMs), which describe some or all of the interactions shown in Figure 1. For air pollution policy IAMs consider the purple boxes of Figure 1 (thumbnail a), and optimise for the cheapest mix of end-of-pipe controls that meet human health and ecosystem condition targets. For current climate change policy (where targets are expressed as GHG emission reductions, cf. Kyoto Protocol) IAMs consider the green boxes in Figure 1 (thumbnail b), and optimise for the cheapest mix of structural and behavioural measures that meet emission reduction targets. However, the ultimate goal of climate change policy is not to reduce GHG emissions, but to "avoid dangerous anthropogenic interference with the climate system" [2]. Hence climate change policy should consider the green and light blue boxes in Figure 1 (thumbnail c).

First-level policy integration requires IAMs to consider the purple and green boxes simultaneously, and optimise for the cheapest mix of end-of-pipe,

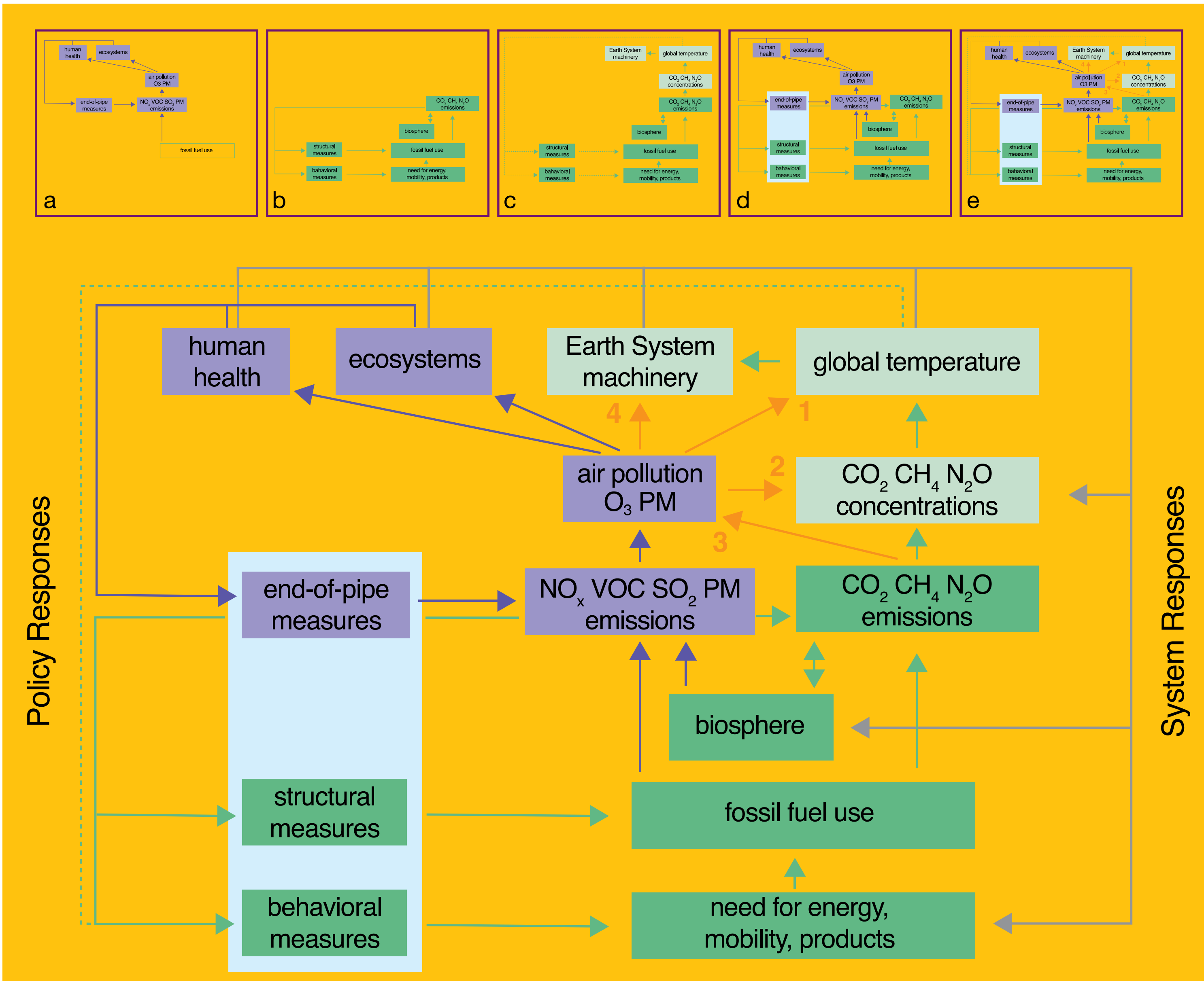

Figure 1. Air pollution policy takes fossil fuel use for granted, and considers how control of air pollutant emissions by end-of-pipe measures produces change in the purple boxes. Climate change policy considers how control of GHG emissions by structural and behavioural measures produces change in the green boxes. Policy integration considers how a simultaneous implementation of all three types of emission controls (light blue rectangle) produces change in all boxes. Policy integration must also consider the effects of air pollutants on the climate system and vice versa (orange arrows).

structural and behavioural measures that meet both GHG emission and air pollutions targets (thumbnail d). Second-level integration – integration of "dangerous-interference-avoidance" policy with air pollution policy – would require consideration of all boxes in Figure 1 (thumbnail e), and optimisation for the cheapest mix of end-of-pipe, structural and behavioural measures that avoid dangerous interference with the climate system and meet air pollution targets.

For second-level integration, several processes in the atmosphere-climate system must be considered – processes by which air pollution can affect climate, and by which climate change can affect air pollution. These processes (see numbers on Figure 1) include:

1. the radiative impact of conventional air pollutants: ozone is a potent GHG, whereas aerosols – depending on their chemical composition – either reflect or absorb solar radiation [3];
2. the effects of tropospheric ozone, and hence the oxidizing capacity of the troposphere, on the atmospheric lifetime and concentrations of methane [4];
3. the role of methane as a precursor for background tropospheric ozone [4]; and
4. the immediate effect of aerosol pollution on cloud and precipitation formation, and hence on local and possibly regional atmospheric circulation and the water cycle [5,6].

In moving from optimising either air pollution or climate change policy only, to first-level and then second-level integration, requires increasingly complex IAMs. In Europe, the RAINS model [7] has been used to optimise air pollution policy. RAINS already integrates economics and technology with atmospheric chemistry, since before the impacts of air pollutants can be calculated, a good description is required of their atmospheric transport, transformation and eventual removal. The POLES model [8] – a model of European and global energy demand and supply with a carbon dioxide emission module – has been used to develop climate change policy. Other than the carbon dioxide emission module, POLES contains no description of the climate system. A first-level integration might be possible by combining RAINS and POLES, however, second-level integration would require the inclusion of a climate model able to calculate the effect of GHGs and conventional air pollutants on the climate system. Models with this capability are still under development, but do not lend themselves to the multiple calculations required in optimisations. Models of intermediate complexity [9] are therefore required.

In the integrated system of Figure 1, policies are a feedback that aim to control the effects of fossil fuel combustion. There are also inherent feedbacks in such a system; for example, the effects of pollution or global warming on various components of the system such as the biosphere or society. Considerable research is required to understand just how strong policies can or should be, given the existence of such inherent feedbacks. IAMs used in policy making to date, are unsuitable for such research as they do not capture the full complexity of the system. However, integrated models are emerging that couple economics, atmospheric chemistry, climate and ecosystems, and which through sensitivity runs, are starting to explore the effects of policies and inherent feedbacks [10]. It appears therefore, that air pollution and climate change policy and science are now mature enough to allow a systematic approach to policy integration. This provides an example of concrete progress in Earth System modelling.

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The author thanks Markus Amann, Peter Bergamaschi, Frank Dentener, Giacomo Grassi, Adrian Leip and Julian Wilson for discussions, and the ACCENT Network of Excellence (www.accent-network.org) for providing the context for this article.

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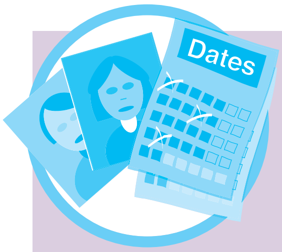
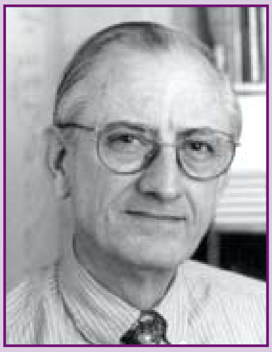


New Roles and Faces

New SC-IGBP Members

ICSU has approved the appointment of three new members of the SC-IGBP (Henry Jacoby, Kon-Kee Liu and Olga Solomina) for initial three-year terms (2006–08). Additionally, Jozef Pacyna joins the SC-IGBP in an *Ex officio* capacity – approved by the IGBP Officers and IHDP Officers as the chair of the LOICZ SSC for 2006–08.



Henry (Jake) Jacoby is a Professor of Management in the MIT Sloan School of Management and co-director of the MIT Joint Program on the Science and Policy of Global Change. An undergraduate mechanical engineer from the University of Texas (Austin), he holds a PhD in Economics from Harvard University. Jake has made major contributions to the study of policy and management in the areas of energy, natural resources and environment – including five books. Public involvement has included chairmanship of the Massachusetts Governor's Emergency Energy Technical Advisory Committee (1973–74); and service on the National Petroleum Council (1975–83), the Climatic Impact Committee of the US National Academy of Sciences (1973–75), the AAAS Panel on Climate and Water Resources (1986–89), the NAS-NAE Committee on Alternative Energy R&D Strategies (1989–90), a study by the US Office of Technology Assessment of "Systems at Risk from Climate Change" (1992–93) and an NRC Panel on Metrics for Global Change Research (2004–05). In 1998–99 he was Environmental Fellow of the American Council on Capital Formation. His current research and teaching is focused on economic analysis of climate change and its integration with scientific and policy aspects of the issue.

E-mail: hjacoby@mit.edu

Commonly known as KK, Kon-Kee is a professor at the Institute of Hydrological Sciences, National Central University in northern Taiwan. His current research focus is numerical modeling of aquatic biogeochemical systems, including reservoirs, coastal waters and marginal seas. Originally, KK trained at the University of California (Los Angeles) as an isotope geochemist, specialising in stable isotopes of nitrogen. Since then KK has organised some large field campaigns exploring the biogeochemistry of the East and South China Seas. As a member of the JGOFS SSC and leader of the JGOFS-LOICZ Continental Margins Task Team he advocated for the significance of continental margins in global biogeochemical cycles. The continental margins bordering highly populated coastal zones are likely to be greatly affected by global change, and their biogeochemical processes may have significant feedbacks to the climate system. KK hopes to help plan and implement further research on continental margins within IGBP, especially under LOICZ and IMBER.

E-mail: kkliu@ncu.edu.tw

Olga graduated from the Moscow State University with a degree in history, but changed tack and completed her post-graduate studies in glaciology. Her current scientific interests are in glacier variations and palaeoclimatic reconstructions (mostly dendochronology-based), and in combining data from these studies with ice core records. Olga is contributing to the 4th IPCC assessment as a lead author on the palaeoclimate chapter; her book "Mountain Glaciation of Northern Eurasia in the Holocene" was published in 1999. Olga served on the PAGES SSC (2002–04) and is a member of the council of the International Glaciological Society. As a field scientist Olga's research has taken her to glaciers in the Pamirs, Tien Shan, Altay, the Caucasus, Kamchatka, Kunashir, Sakhalin, the Urals, the Alps, the Andes and Antarctica. She is based at the Institute of Geography of the Russian Academy of Science, and is a corresponding member of the Academy.

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Jozef is a Director of the Center for Ecological Economics at the Norwegian Institute for Air Research and is Professor of Chemistry at the Gdansk University of Technology, Poland. He holds an MSc in Chemical Engineering, a PhD in Environmental Engineering and a Doctor Habilitus in Chemistry from the Technical University of Wroclaw, Poland. Jozef has held visiting professorships at the University of Michigan (1992–93) and the Chalmers University of Technology in Gothenburg, Sweden (1991–95). He was adjunct professor at the University of Michigan (1993–2000). From 2002–05 Jozef coordinated the EU programme on the European Land Ocean Interactions in the Coastal Zone (ELOISE). From 1999–2004 he served on the LOICZ SSC, and has also served on the IOC Coastal Panel of the Global Ocean Observing System (GOOS). Jozef's main expertise is in biogeochemical cycling and fluxes of nutrients, heavy metals, persistent organic pollutants and radionuclides, particularly in coastal areas. He is currently a partner the EU CARBOCEAN project on behaviour of carbon in the marine ecosystem.

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New Chair, GECAFS SSC

Diana Liverman has been appointed as the new chair of the GECAFS SSC. Diana is the Director of Oxford University's Environmental Change Institute and holds the University's first established Chair of Environmental Science. Her research has focused on environmental change and policy, including climate change and its impacts, the social causes and consequences of land use change, and environmental management in the context of globalisation. Diana's former positions include Director of the Center for Latin American Studies at the University of Arizona, Interim Dean of Social and Behavioural Sciences at the University of Arizona, Associate Director of the Earth System Science Centre at Penn State University and assistant professor of Geography at the University of Wisconsin-Madison. She has served as chair of the US National Academy of Sciences Committee on the Human Dimensions of Global Environmental Change and as chair of the Latin American Studies Association Environment section; co-chair of the Scientific Advisory Committee for the Inter-American Institute for Global Change; and as a member of advisory committees for NASA, NOAA and the US National Center for Atmospheric Research. Diana holds degrees from University College London, the University of Toronto and the University of California (Los Angeles).

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IGBP Secretariat

Beatriz Balino has been appointed as Deputy Director, Natural Sciences at the IGBP Secretariat for one year while Wendy Broadgate is on maternity leave. Beatriz has a PhD in marine biology from the University of Bergen, Norway, and has conducted basic research into plankton dynamics and ecosystem modelling, and applied research on marine pollution and marine aquaculture. She was Assistant Executive Officer at the JGOFS IPO in Bergen from 1996–2001, where she helped coordinate JGOFS research and outreach, as well as dealing with data management issues. Since 2001Beatriz has been a Science Coordinator at the Bjerknes Centre for Climate Research in Bergen. Originally from Uruguay, Beatriz settled in Norway 20 years ago, and is fluent in English, Norwegian and Spanish. We welcome Beatriz back to the IGBP family and look forward to working with her.

E-mail: beatriz@igbp.kva.se

Clemencia Widlund left the IGBP Secretariat in February 2006 after over five years of dedicated service as Administrative and Financial Officer. Clemencia efficiently organised many meetings and processed hundreds of travel claims, and was the first point of contact for many people in the network. Her enthusiasm, skills and warm personality will be missed. All at the IGBP Secretariat wish her the best of luck.

A replacement for Clemencia has been recruited and is expected to commence with the IGBP Secretariat in early June 2006; until then administrative enquiries should be directed to Charlotte Wilson-Boss (charlottew@igbp.kva.se).

In the *Profile of a Scientist* section we aim to feature "early-career" scientists who are making important contributions to Earth System science and to IGBP. We strive to achieve gender, discipline and developed/developing country balances in this section, and the Editor welcomes suggestions for scientists to profile.

Profile of a Scientist: Opha Pauline Dube

Pauline is a lecturer in the Department of Environmental Science at the University of Botswana, Gaborone, Botswana. It was the political environment in southern Africa during her early years that made her aware of the links between local and global events: "at that time there were liberation struggles occurring all around Botswana, and through secondary school and university I interacted with students from around southern Africa and was exposed to international issues." "My brother Elmon" says Pauline "was a great inspiration, following and debating international issues, particularly those with implications for equity and social justice in Africa."

Pauline's rural agrarian upbringing taught her the importance of links between climate and rural livelihoods. "Herding family livestock – one of my early tasks – opened my eyes to the richness of semi-arid environments, but also to the unpredictability of the resource base and hence the need for flexible livelihood systems" she says; "memories of the late-1960s drought remain vivid, but so are the green years of plenty in the early 1970s." With this background Pauline studied geography and subsequently joined the University of Botswana to work on remote sensing: "satellite data is fascinating – in one image there are layers of environmental information at different spatial and temporal scales".

In her early career Pauline focussed on land degradation and desertification in Africa, as livestock production is very important in semi-arid Botswana and desertification is a real concern. "It was my interest in desertification that took me to the first African global environmental change (GEC) meeting in Niamey, Niger in 1993" she recalls. "At that meeting I met Thomas Rosswall – mentor for my early career, and now Executive Director, ICSU – who in spite of a different background shared my concerns on the implications of GEC for Africa, and recognised the need to build African GEC research science capacity."

After the Niamey meeting Pauline worked hard to establish an IGBP National Committee in Botswana, which she says "was not easy, as few people understood GEC, let alone the multitude of acronyms". The Botswana National Committee has grown with GEC science, and in the late 1990s it became the Botswana Global Environmental Change Committee to accommodate new international initiatives including IHDP. Pauline's interests in GEC now focus on sustainable development, capacity building, capacity enabling and poverty reduction: "for me, GECAFS is a key activity, and I am currently contributing to a GECAFS science plan for Southern Africa."

Pauline's interest in dry environments led her to be lead author for the IPCC Third Assessment Report chapter on Africa, focussing on climate change and desertification: "participating in IPCC was a mammoth learning experience: the diverse range of GEC scientists… the huge volume of literature to cover and to condense into just a few paragraphs for policy makers… I vowed 'never again' ". But when the IPCC Fourth Assessment began Pauline accepted the role of lead author for the "Ecosystems" chapter.

Since 2002, Pauline has led a project on impacts of climate change vulnerability and adaptation in Botswana in the Limpopo Basin: "this was another eye-opener – particularly addressing community workshops on climate change in their local language". Pauline notes "communities have considerable knowledge of the climate and natural resources of their region, most of which is downplayed when development programmes are put in place." Currently, Pauline is a co-author on an adaptation synthesis book chapter on past coping strategies at community level, and how these can form valuable lessons for planning climate change adaptation.

"For Africa, adaptation to climate change cannot wait for tomorrow – it is a *now* issue if climate change impacts are to be manageable", says Pauline, "I have seen some of my dreams achieved – for example, building a GEC research network in Botswana – but there is much yet to be done to catch up with international GEC science and make significant contributions to development agendas." Pauline concludes that "for me, the best way to incorporate GEC in my university teaching is in a *Gender and Environment* course – the only problem is that it has become so popular that course enrolments have tripled!"

IGBP and Related Global Change Meetings

A more extensive meetings list is held on the IGBP web site at www.igbp.net.

SCOR Working Group Workshop: Virus Ecology in Marine Systems

01–03 June, Vancouver, Canada

Contact: web.bio.utk.edu/wilhelm/scor.html

NCAR Summer Colloquium: The Art of Climate Modelling

04–16 June, Boulder, USA

Contact: www.asp.ucar.edu/colloquium/2006

Tourism and Climate Change Mitigation

11–14 June, De Spreeuwel, The Netherlands

Contact: www.ihdp.uni-bonn.de/Pdf_files/e-clat-Flyer.pdf

20 Years of Nonlinear Dynamics in Geosciences

11–20 June, Rhodes, Greece

Contact: www.aegeanconferences.org

HOLIVAR Open Science Meeting

12–15 June, London, UK

Contact: www.holivar2006.org

GLOBEC/EUR-OCEANS Summer School

18–28 June, Dragerup field station, Denmark

Contact: www.eur-oceans.org/eamr/school

NERC Earth Observation Conference

21 June, Edinburgh, UK

Contact: www.nerc.ac.uk/funding/earthobs/conference/index.shtml

6th International Symposium on Advanced Environmental Monitoring

27–30 June, Heidelberg, Germany

Contact: ademrc.gist.ac.kr

IGU Conference: "Regional Responses to Global Changes: A View from the Antipodes"

03–07 July, Brisbane, Australia

Contact: www.igu2006.org

3rd Annual Meeting Asia Oceania Geosciences Society

10–14 July, Singapore

Contact: www.asiaoceania-conference.org

SCAR Open Science Conference

12–14 July, Hobart, Australia

Contact: www.scarcomnap2006.org/scarosc.php

Euroscience Open Forum

15–17 July, Munich, Germany

Contact: www.esof2006.org

WMO Climate Risk Conference

17–21 July, Espoo, Finland

Contact: wmo2006@fmi.fi or www.livingwithclimate.fi

Impact of Global Change on Land Use Management in Latin American Tropical Ecosystems

17–28 July, Göttingen, Germany

Contact: www.tropical-resources.uni-goettingen.de/Course_program.7.0.html

Western Pacific Geophysics Meeting

24–27 July, Vienna, Austria

Contact: www.agu.org/meetings/wp06

Summer School: Monitoring Natural Hazards from Space

25 July–03 August, Alpbach/Tyrol, Austria

Contact: michaela.gitsch@ffg.at

3rd ENVISAT Summer School: Earth System Monitoring and Modelling

31 July–11 August, ESRIN, Frascati, Italy

Contact: envisat.esa.int/envschool

International Conference on Regional Carbon Budgets

16–18 August, Beijing, China

Contact: www.icrcb.org.cn

5th International NCCR Climate Summer School: Adaptation and Mitigation

27 August–01 September, Grindelwald, Switzerland

Contact: www.nccr-climate.unibe.ch/summer_school/2006/scope.html

17th International Sedimentological Congress

27 August–01 September, Fukuoka, Japan

Contact: www.isc2006.com

ALTER-Net Summer School: Biodiversity and Ecosystem Services

27 August–08 September, Peyresq, France

Contact: www.pik-potsdam.de/alter-net

Carbon Management at Urban and Regional Levels

04–08 September, Mexico City, Mexico

Contact: gcp-urcm@nies.go.jp or www.gcp-urcm.org

Joint IGAC-CACGP–WMO Symposium: Atmospheric Chemistry at the Interfaces

17–23 September, Cape Town, South Africa

Contact: www.atmosphericinterfaces2006.co.za

World Water Week

20–26 August, Stockholm, Sweden

Contact: www.worldwaterweek.org

Sustained Indian Ocean Biogeochemical and Ecological Research

03–06 October, Goa, India

Contact: www.ian.umces.edu/siber

Lysimeters for Global Change Research
04–06 October, Neuherberg, Germany
Contact: www.gsf.de/lysimeter-workshop

Water, Ecosystems and Sustainable Development in Arid and Semi-arid Zones
09–15 October, Urumqi, China
Contact: www.ephe.sorbonne.fr/watarid/watarid_en.htm

15th PICES Annual Meeting
13 October, Yokohama, Japan
Contact: www.pices.int/meetings

IHDP-APN Workshop: Institutional Dimensions of Global Environmental Change
13–26 October, Chiang Mai, Thailand
Contact: www.ihdp.org

Oxygen Minimum Systems in the Ocean
24–26 October, Concepcion, Chile
Contact: www.cona.cl/scor/oms.htm

Rapid Climate Change International Science Conference
24–27 October, Birmingham, UK
Contact: rapid.nerc.ac.uk/rapid2006

2nd International Young Scientists' Global Change Conference
07–08 November, Beijing, China
Contact: ysc@agu.org

ESSP Open Science Conference: Global Environmental Change – Regional Challenges
09–12 November, Beijing, China
Contact: www.essp.org/essp/ESSP2006

Berlin Conference on the Human Dimensions of Global Environmental Change
17–18 November, Berlin, Germany
Contact: web.fu-berlin.de/ffu/akumwelt/bc2006

International Conference on the Humboldt Current System
27 November–01 December, Lima, Peru
Contact: www.uea.ac.uk/env/solas/meetings.html

IDGEC Synthesis Conference
06–09 December, Bali, Indonesia
Contact: fiesta.bren.ucsb.edu/~idgec/science/synthesis.html

AGU Fall Meeting
11–19 December, San Francisco, USA
Contact: www.agu.org/meetings/fm06

2007

International Dialogue on Science and Practice in Sustainable Development
23–27 January, Chiang Mai, Thailand
Contact: www.sustdialogue.org

SOLAS Open Science Conference
06–09 March, Xiamen, China
Contact: www.uea.ac.uk/env/solas/meetings.html

Pin Board

The Pin Board is a place for short announcements and letters to the Editor. Announcements may range from major field campaigns, new websites, research centres, collaborative programmes, policy initiatives or political decisions of relevance to global change. Letters to the Editor should not exceed 200 words and should be accompanied by name and contact details.

Matsuno to Japan Academy

Taroh Matsuno – member of the SC-IGBP – has recently been granted honorary membership of title the Japan Academy. The Japan Academy is an honorary organisation for highly distinguished senior scientists having only 137 members.

Carbon Balance Management

BioMed Central has launched a new open access, peer-reviewed online journal "Carbon Balance Management" which cover all aspects of research results aimed at a comprehensive, policy-relevant understanding of the global carbon cycle. Editors-in-Chief are Georgii Alexandrov (Russian Academy of Sciences), Robert Dickinson (Georgia Institute of Technology) and Takehisa Oikawa (Tsukuba University). See www.cbmjournal.com for more information.

New Popular Books on Climate Change

Raising public awareness and understanding of the latest global change research is an ongoing challenge. Two new books have been published that deal with the history, science and politics of climate change: "The Winds of Change: Climate, Weather, and the Destruction of Civilizations" (Eugene Linden, published by Simon & Schuster) and "The Weather Makers: The History and Future Impacts of Climate Change" (Tim Flannery, published by Allen Lane).

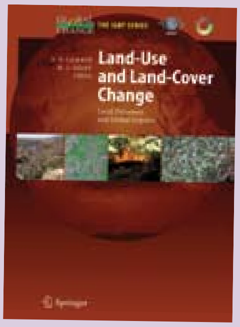
Executive Officer for GWSP

The Earth System Science Partnership (ESSP) seeks an Executive Officer to coordinate the research and outreach activities of the Global Water System Project (GWSP). GWSP is based at the Centre for Development Research (www.zef.de) of the Rheinische Friedrich-Wilhelm's University, in Bonn, Germany. The appointee will be a senior scientist with an established track record in water-related research and research management. More information about GWSP and the position can be obtained from www.gwsp.org or by contacting Eric Craswell (eric.craswell@uni-bonn.de). Applications should be submitted before 19 June to the ESSP Coordinator: Martin Rice (mrice@essp.org).

Translations of IGBP Publications

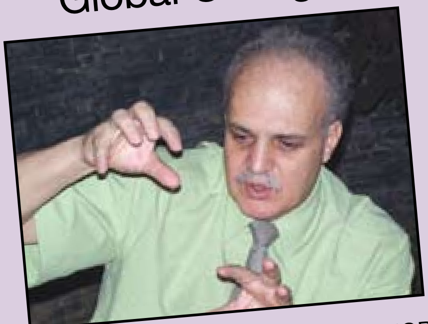
The Chinese Academy of Sciences is contributing greatly to the dissemination of IGBP science results and research agendas. A full translation of the IGBP synthesis volume "Global Change and the Earth System – A Planet Under Pressure" has been undertaken and is being published by Springer. Translations of the Science Plans & Implementation Strategies for GLP, iLEAPS and IGAC are also in progress.

LUCC Synthesis Volume



The synthesis book of the IGBP-IHDP Land-Use and Cover Change project has been completed and is being published by Springer in the IGBP Series for release in early May. Titled *Land-Use and Land-Cover Change: Local Processes and Global Impacts*, the volume is edited by Eric Lambin and Helmut Geist. The book presents recent estimates of the rates of change in major land classes and describes causative mechanisms for land change. Aggregated globally, the multiple impacts of local land changes are shown to significantly affect aspects of Earth System function.

Getting to Grips With Global Change



SC-IGBP Chair, Carlos Nobre (SC-IGBP Meeting, Pune, India)

Agriculture and Climate

Springer has recently published "Agriculture and Climate Beyond 2015: A New Perspective on Future Land Use Patterns" (Environment and Policy, Volume 46, Brouwer F and McCarl BA (Ed.s), a volume containing several chapters reporting on the research of the now complete LUCC project of IGBP and IHDP.

Encyclopaedia of Earth

The Earth Portal (earthportal.net) is calling for contributions from qualified editors and authors to an *Encyclopaedia of Earth* that aims to provide a single comprehensive and definitive electronic encyclopaedia about the Earth with particular emphasis on the interaction between society and the natural spheres of the Earth. The *Encyclopaedia of Earth* will be free to access and free of advertising, and will be published by the Environmental Information Coalition, National Council for Science and the Environment (www.ncseonline.org). For topic areas see earthportal.net/EP/eoe/eoetopics and for more information see earthportal.net/EP/steward.

STOP PRESS – GLP

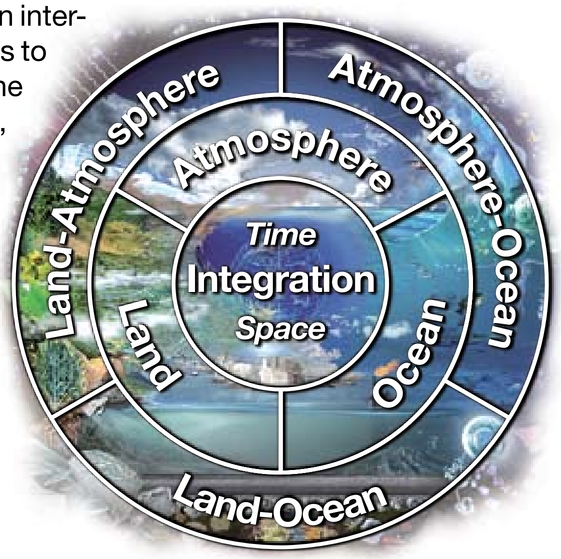
Anette Reenberg – Professor at the Institute of Geography, University of Copenhagen – has been appointed as the new Chair for the Global Land Project (GLP). An International Project Office is being established at the University of Copenhagen and recruitment of an Executive Officer will commence very soon. A position announcement will appear in late May 2006 on www.igbp.net, www.ihdp.org, and www.ku.dk and applications will close at the end of June. Information regarding GLP can be found at www.globallandproject.org.

Erratum

Global Change Newsletter 64 incorrectly attributed Figure 2 in the Costanza et al. article (pg. 21). The correct original source for the figure is: *Berglund BE, Larsson L, Lewan N, et al. (1991) Ecological and social factors behind the landscape changes. In: Berglund BE (Ed.), The Cultural Landscape During 6,000 years in Southern Sweden. Ecological Bulletin 41, 425-445. Blackwell, Oxford.* The Editor apologises for the error.

The International Geosphere-Biosphere Programme

IGBP is an international scientific research programme built on interdisciplinarity, networking and integration. The vision of IGBP is to provide scientific knowledge to improve the sustainability of the living Earth. IGBP studies the interactions between biological, chemical and physical processes and human systems, and collaborates with other programmes to develop and impart the understanding necessary to respond to global change. IGBP research is organised around the compartments of the Earth System, the interfaces between these compartments, and integration across these compartments and through time.



IGBP helps to

- develop common international frameworks for collaborative research based on agreed agendas
- form research networks to tackle focused scientific questions and promote standard methods
- guide and facilitate construction of global databases
- undertake model inter-comparisons
- facilitate efficient resource allocation
- undertake analysis, synthesis and integration of broad Earth System themes

IGBP produces

- data, models, research tools
- refereed scientific literature, often as special journal editions, books, or overview and synthesis papers

- syntheses of new understanding on Earth System science and global sustainability
- policy-relevant information in easily accessible formats

Earth SystemScience

IGBP works in close collaboration with the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP), and DIVERSITAS, an international programme of biodiversity science. These four international programmes have formed an Earth System Science Partnership. The International Council for Science (ICSU) is the common scientific sponsor of the four international global change programmes.

Participate

IGBP welcomes participation in its activities – especially programme or project open meetings (see meetings list on website). To find out more about IGBP and its research networks and integration activities, or to become involved, visit our website (www.igbp.net) or those of our projects, or contact an International Project Office or one of our 78 National Committees.

Contributions

The Global Change NewsLetter primarily publishes articles reporting science undertaken within the extensive IGBP network. However, articles reporting interesting and relevant science undertaken outside the network may also be published. Science Features should balance solid scientific content with appeal to a broad global change research and policy readership. Discussion Forum articles should stimulate debate and so may be more provocative. Articles should be between 800 and 1500 words in length, and be accompanied by two or three figures or photographs. Articles submitted for publication are reviewed before acceptance for publication. Items for the Pin Board may include letters to the Editor, short announcements such as new relevant web sites or collaborative ventures, and meeting or field campaign reports. Pin Board items should not exceed 250 words.

Photographs should be provided as tiff files; minimum of 300 dpi. Other images (graphs, diagrams, maps and logos) should be provided as vector-based .eps files to allow editorial improvements at the IGBP Secretariat. All figures should be original and unpublished, or be accompanied by written permission for re-use from the original publishers.

The Global Change NewsLetter is published quarterly – March, June, September and December. The deadline for contributions is two weeks before the start of the month of publication. Contributions should be emailed to the Editor.

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