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The role of biospheric feedbacks in the hydrological cycle. The IGBP – BAHC Special Issue

by P. Kabat

The hydrological cycle is strongly modulated by the Earth' s vegetation. This single hypothesis provided most of the ground for establishing BAHC (Biospheric Aspects of the Hydrological Cycle) as one of the IGBP core projects now almost 6 years ago. At the beginning of 1999, BAHC entered an important period of its existence, synthesising its results as part of the overall IGBP science synthesis process. This will result in a series of several comprehensive publications andin the IGBP Open Science Conference to be held in July 2001 in Amsterdam.

How much progress did the international scientific community make over the last 6 years in studying the biospheric aspects of the hydrological cycle and what has been the specific BAHC contribution to this advance? Which of the findings and scientific conclusions can already be generalised to support policy and society efforts to cope with the threats of global and climatic change? And what are the remaining unknowns and open science questions in the area of BAHC that need to be addressed in the near future? These are just a few examples of the type of questions which the BAHC synthesis will address. In this special issue of the Global Change NewsLetter, we present several examples of exciting results which the international research community contributed to the BAHC research agenda. Thus, this newsletter can serve as a preamble and, as we hope, even as a good "appetiser" to our final science synthesis publications.

BAHC, in collaboration with its partner IGBP projects and with ISLSCP/ GEWEX (WCRP), studies the biospheric aspects of the hydrological cycle through experiments and modelling of energy, water, carbon dioxide and sediment fluxes in the soil-vegetation-atmosphere system at a range of spatial and temporal scales. Active regulation of water, energy and carbon fluxes by the vegetation makes it an important factor in regulating the Earth's hydrologic cycle and in the formation of the climate. Consequently, human induced conversion of vegetation cover has been an important driver for climate change. This area of research has undergone an exciting development over the last decade. Amongst many results, those which clearly demonstrate the influence of the terrestrial biosphere on weather and climate formation deserve particular attention. Equally importantly, the terrestrial biosphere plays a significant role in the global carbon balance. Early work under the umbrella of the BAHC and GCTE that initiated the global FLUXNET project suggests that many ecosystems, both in the temperate zone and in the tropics, may act as a substantial sink for carbon. The attention which has

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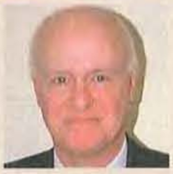

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Key Theme 1:	Energy, Water and Carbon Fluxes at the Patch Scale - FLUXNET
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Key Theme 8:	Development of Global Data Sets

Cross-cutting Theme A: Design, Prioritize and Implement Integrated Terrestrial System Experiments

Cross-cutting Theme B: Scenario Development and Risk/Vulnerability Analysis

been given after the Kyoto 1997 Framework Convention on Climate Change conference to the role of terrestrial carbon sinks in FCCC and IPCC frameworks is probably one of the most convincing arguments for carrying FLUXNET implementation much further beyond its present stage.

Most of the BAHC research agenda, however, is about water. Besides the water cycling between terrestrial and atmospheric systems, we started to address systematically the issue of riverine transport and water quality. Water quality is critical to the sustainability of aquatic habitats, food webs, and commercial fisheries. It is also of enormous importance to the availability of freshwater resources. In this issue we discuss how the changing nature of inland water chemistry is important within a larger Earth System context. The transport of nutrients and toxic substances to the coastal zone through long-distance river transport ultimately links the continental land mass to the oceans. River loadings of nutrients, metals, and pesticides are known to have increased several-fold since the beginning of the industrial era. From numerous individual river basin and coastal zone studies we know that elevated levels of waterborne nutrients are a consequence of human activities. Such site-specific changes in the delivery of land-based constituents collectively impart a biogeochemical signal of continental and global dimension. It has been estimated that riverine transports of inorganic N and P to the world oceans have increased dramatically over the last 150 to 200 years. In Western Europe, for example, this increase is commonly 10 to 20 fold.

BAHC has taken an active and leading role in the newly established IGBP Water Group, which forms the IGBP-wide context for water quality research.

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From the very beginning of its existence, BAHC has been advocating *large-scale land-surface experiments* as a means to address the issue of scaling and land-surface parameterisation in Earth system models (HAPEX-type experiments) and later, to address complex interactions which characterise regional to continental hotspots of global change (LBA-type experiments). Just as the *modus operandi* of IGBP was originally based on discussion and debate among scientists leading to a research agenda to be implemented by funding agencies, the process of initiating experiments was driven by scientists. However, funding agencies now are often reluctant to accept that scientific research defined by scientists will necessarily lead to the useful results they demand. Whether these expectations are for advice to policy-makers, alleviation of poverty in developing countries, or benefits to society as a whole, it is now expected that the beneficiaries of research should also be involved in the definition of the research issues. BAHC is responding to this need with a philosophy of integrated experiments designed in consultation with the users of the research and involving, from the outset, scientists from the whole range of physical and social sciences. As a first step in defining new research priorities in Africa, BAHC has initiated a stakeholder workshop on sub-Saharan freshwater resources, which will be held in Nairobi on 26-29 October 1999. This workshop has the objective of drawing up a blueprint for an integrated study of the hydrological interactions between land use, climate and water resources, which addresses not only natural but also social systems.

Have a good read!

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The role of the land surface in weather and climate: does the land surface matter ?

by A. Pitman, R. Pielke Sr., R. Avissar, M. Claussen, J. Gash and H. Dolman.

Many of those working in land surface processes at local, regional or global scales have no doubt that the land surface plays a key role in weather and climate (e.g. Pielke et al., 1998). Indeed, we work in these areas, in part, because we believe it is an important and relevant field. The role of the land surface ranges from some purely physical influences (e.g the aerodynamic drag on the atmosphere; the role of soil characteristics in controlling soil moisture and runoff) to some major biological influences (e.g. the stomata response to environmental changes). The interaction with the biology, the physical nature of surface-atmospheric interactions and the impact of global change on these processes is part of the primary aim of BAHC.

Throughout the history of BAHC, one of the major foci has been land surface-atmospheric interactions. Originally, BAHC Focus 1 aimed to develop, test and validate 1-dimensional soil-vegetation-atmosphere transfer models (BAHC, 1993). Focus 2 aimed to understand regional scale studies of land surface properties and fluxes. Focus 3 aimed to understand the diversity of biosphere-hydrosphere interactions at large spatial and temporal scales. All of these foci implemented a range of strategies including observational efforts, experiments and modelling studies and all of them try to contribute to answer the question "Does the land surface matter in weather and climate?".

Within atmospheric modelling, there is still rather less confidence that the land surface is as important in the climate system as the IGBP community believe. In the last five years or so, significant evidence has gradually been acquired which, combined, is becoming increasingly hard to dismiss. This evidence comes from a whole range of spatial scales, from point and local measurement all the way up to global-scale multi-century modelling. Here, we present some of the examples which we believe demonstrate that the land surface does matter in weather and climate. We also point to some key gaps in that evidence, which provide some directions that BAHC, together with some of its WCRP partner projects and IGBP in general, may look to in the future.

1. Avissar & Liu, 1996
2. Gash & Nobre, 1997
3. André et al., 1989
4. Pielke & Avissar, 1990
5. Pielke et al., 1991
6. Avissar & Chen, 1993
7. Avissar & Liu, 1996
8. Vidal et al., 1997
9. Eastman et al., 1998
10. Smith et al., 1992
11. Bonan et al., 1992
12. Polcher & Laval, 1994
13. Lean & Rowntree, 1997
14. Henderson-Sellers et al., 1993
15. Xue, 1997
16. Nicholson et al., 1998
17. Chase et al., 1996
18. Chase et al., 1999
19. Zhao et al., 1999a
20. Zhao et al., 1999b
21. Beljaars et al., 1996
22. Xue et al., 1999
23. Eastman et al., 1999
24. Lu, 1999
25. Frenzel et al., 1992
26. Cheddadi et al., 1997
27. Otterman et al., 1984
28. Harvey, 1988
29. Harvey, 1989
30. Texier et al., 1997
31. Claussen, 1997
32. Claussen et al., 1999

Figure 1. Observational and modelling evidence providing support for the role of the land surface at various time and space scales. The blue refers to observational studies while the red refers to evidence acquired via modelling.

Framework

It is rather common in much of IGBP-related science to draw figures with time and space as the axes (e.g. Figure 1 in Sellers, 1992). We make no apology for doing it again since this links the key aspects of those natural systems of interest to us. We have tried to take one additional step, however. Our Figure 1 shows where we believe there is *evidence*, published in the scientific literature, that the land surface does matter to weather and climate. We split this evidence depending on whether it is observational or modelling derived and we review the context of the evidence in more detail below.

This figure appears to show negligible overlap between observational evidence and modelling evidence. Where the evidence does overlap, it is either at the global scale on time scales of centuries (in terms of palaeoclimatic reconstructions), or it is at small scales. This apparent lack of overlap is discussed in the conclusions.

Evidence from microscale, meso-gamma and meso-beta spatial scales (less than 200 km)

Observations

Work from the ABRACOS study (see Gash and Nobre, 1997) provides evidence that the land surface directly affects the atmospheric boundary layer at scales of less than 50 km. For example, the change in the Brazilian Amazon of the vegetation from forest to pasture changes the moisture availability and the characteristics of the surface such that evaporation is reduced. Especially outside of the rainy season, a deeper boundary layer develops over the pasture because of stronger sensible heating. Figure 2, from the Ji-Paraná site, shows an atmospheric boundary layer depth of ~1 km at noon over the forest, increasing to ~1.7 km over the pasture.

Further evidence was obtained from HAPEX-MOBILHY, where the lower albedo of a large pine forest, compared to agricultural land, produced greater sensible heat flux, a deeper boundary layer and clouds over the forest (André et al., 1989). Lyons et al. (1993; 1996) and Xinmei et al. (1995) have also provided some dramatic examples of the impact of land-cover change within the Australian environment.

Modelling

The contrast between land and water generates breezes (i.e., sea, lake, and land breezes), which are mesoscale circulations. The mechanisms involved in the generation of these circulations, and their impact on the weather and the climate, have been described many times (e.g., Pielke, 1984, among many others). Recent investigations have indicated that other landscape discontinuities (irrigated land in arid areas, deforestation, and afforestation) also provide a suitable environment for the development of mesoscale circulations (e.g., Pielke and Avissar, 1990; Pielke et al., 1991; Avissar and Chen, 1993; Avissar and Liu, 1996). For instance, Avissar and Liu (1996) studied the relative contribution of turbulence and mesoscale circulations on clouds and precipitation, in homogeneous and heterogeneous landscapes. Figure 3 illustrates the domains considered for their analysis, and Figure 4 provides the resulting horizontal distribution of accumulated precipitation after one day of simulation.

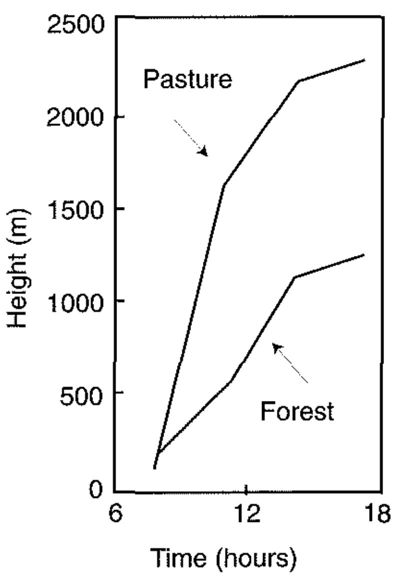


Figure 2. Comparisons of the average measured height of the convective boundary layer over the Ji-Paraná forest and pasture sites (adapted from Gash and Nobre, 1997).

The domains shown in Figures 3d and 3e are spatially homogeneous, hence no mesoscale circulation is generated in these domains, and clouds and precipitation develop as a result of moist, turbulent eddies reaching their level of condensation. The position of these turbulent eddies appears to be random and, not surprisingly, a random-like pattern of accumulated precipitation is simulated. There are, however, significant differences between these two simulations. Thin clouds develop early in the day over wet land. During the morning hours, they are enhanced by the relatively large amount of water injected into the atmosphere from the evaporating land surface. The larger the relative part of the domain covered by wet land, the more water is available in the atmosphere to produce clouds. During the afternoon hours, relatively deep clouds develop as a result of this turbulent process. By contrast, when the domain consists of dry land, clouds are small in both depth and width, if at all created. In general, they do not produce noticeable precipitation. Since there is no supply of moisture from the dry land surface, clouds form only if the atmospheric background is relatively humid. These differences are also obviously reflected in the accumulated precipitation presented in Figures 4d and 4e.

Clearly, in Figure 4a, precipitation concentrates in the originally dry land, where the convergence of the mesoscale circulations generated by the forest-pasture contrast resulted in a strong, moist vertical motion. It is interesting to note that this is also the case in Figure 4b and Figure 4c, in spite of the fact that the mesoscale circulations generated by these domains are relatively weak. Even though no mesoscale circulation developed in the domain shown in Figure 3d, the mean precipitation simulated is larger than in the domain illustrated in Figure 3c. However, when a strong mesoscale circulation develops within the domain (e.g. Figure 3a), the maximum accumulated and mean precipitation in the heterogeneous domain are much larger than in the homogeneous domain.

Further evidence has been provided to demonstrate the role of land-use change in the development of clouds. Figure 5 illustrates the very significant role that landcover type has on deep cumulus convection based on numerical model simulations. Both the left and right figures used identical initial and lateral boundary meteorological conditions for 15 May 1991. However the left figure used the current landscape in the region, while the right figure specified the natural landscape. The simulation with the current landscape was compared with observations but this sensitivity of thunderstorm activity to landscape can not be confirmed in this part of the USA.

Evidence from meso-alpha spatial scales (between 200-2000 km)

Observations

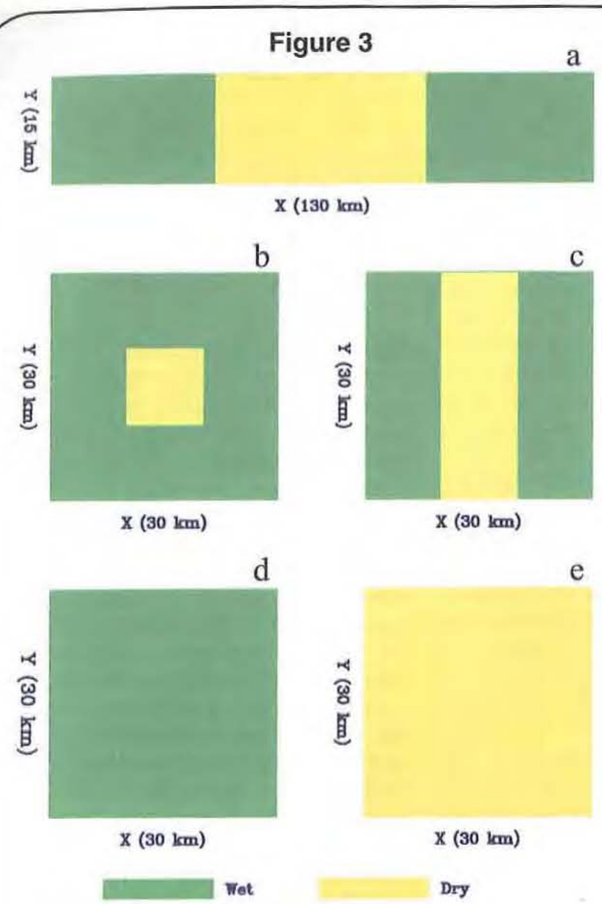
There is some evidence from BOREAS and FIFE regarding the importance of meso-beta effects due to land-surface heterogeneity (Vidale et al., 1997; Eastman et al., 1998; Smith et al., 1992) although the observational data were deliberately collected on days with relatively strong winds (the "golden days"), when theory suggests that meso-beta effects would be small (Dalu et al., 1996). Other evidence comes from HAPEX (André et al., 1989).

The substantial literature on deforestation experiments (see later in this section) provides conclusive evidence that the land surface does matter for climate at the regional scale, at least in the context of climate modelling. Some evidence is now coming forward to provide observational, and smaller scale modelling, support for the climate-model results. Gash and Nobre (1997) review this using results from ABRACOS, which was a major international project carried out between 1990 and 1994 in the Brazilian Amazon.

Modelling

A very substantial body of evidence now exists from climate modelling which suggests that perturbations at the surface can impact on the regional-scale climatology simulated by a climate model. Work on deforestation (Bonan et al., 1992; Polcher and Laval, 1994; Lean and Rowntree, 1997; Henderson-Sellers et al., 1993), desertification (e.g. Xue, 1997; Nicholson et al., 1998) and land-use change (Chase et al., 1996; 1999, Zhao et al., 1999a,b) all point to large and statistically significant continental-scale changes in temperature, rainfall and other variables as a result of land-surface change. Some of this work (Chase et al., 1996; 1999; Zhao et al., 1999a,b) provides evidence of large-scale atmospheric adjustment, caused by regional-scale perturbations, leading to geographically remote changes in temperature and precipitation. A key region of the globe appears to be SE Asia, where changes in the land surface appear to cause rather larger global impacts than changes over South America.

In contrast to studies which focus on future changes (e.g. deforestation), Chase et al. (1996, 1999) used a climate model to simulate the impacts of historical leaf-area index (LAI) and vegetation-cover changes on the regional and global climate. They



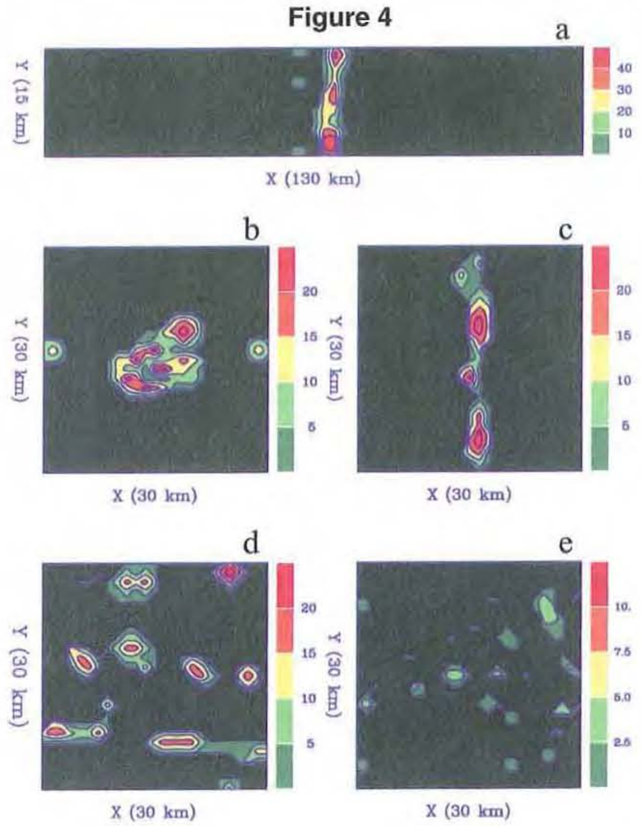


Figure 3. Schematic representation of the simulated domains. Green and yellow areas represent dense, unstressed forest and dry pasture, respectively. The resolution of the numerical grid used to represent these domains was 250 m by 250 m (adapted from Avissar and Liu, 1996).

Figure 4. Accumulated precipitation (mm), at 6 p.m., in the five simulated domains illustrated in Figure 3 (adapted from Avissar and Liu, 1996).

found significant global temperature and precipitation changes, especially at higher latitudes, when a reasonable pattern of observed LAI or vegetation change was imposed. They explained the influence of changes in the tropics on the high latitude Northern Hemisphere winter climate by showing that anomalous Rossby wave propagation developed, causing tropical to high latitude teleconnections. Chase et al.'s (1996, 1999) results were surprising in that other large-scale experiments changing land use (e.g. deforestation experiments) did not obviously cause a global impact. The relatively small perturbation imposed by Chase et al. (1996, 1999) appeared to teleconnect to cause large changes in temperature at higher latitudes and rainfall in the tropics. A repeat of these experiments by Zhao et al. (1999), using a different land-use change pattern and a different climate-model configuration, supported Chase et al.'s (1999) results. For example, Figure 6 shows the seasonally averaged difference in temperature simulated by CCM3 resulting from a 17-year simulation with natural vegetation cover and a 17-year simulation using current land cover. Large areas of the Northern Hemisphere show statistically significant differences in temperature, with common differences of 3-4 K.

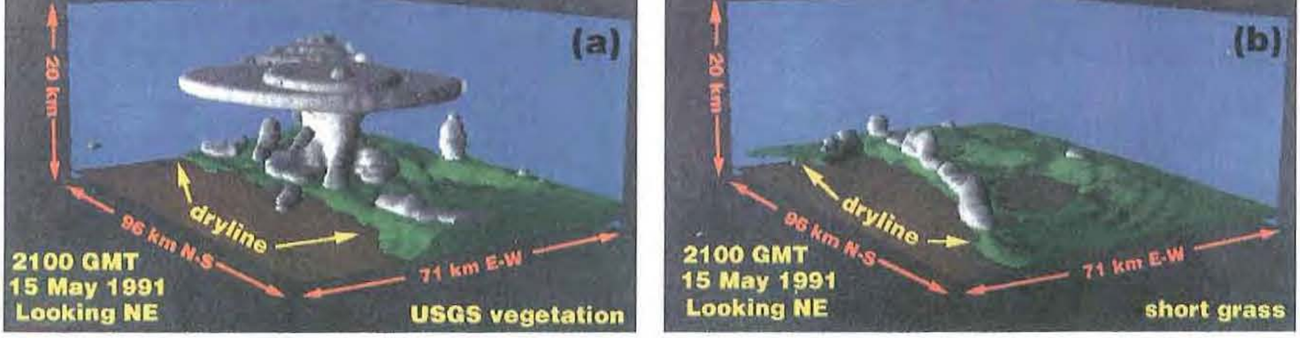


Figure 5. A mesoscale model simulation of clouds at 21 GMT on 15 May 1991 over part of the USA. Left: the model simulation with current landscape and right: using the natural landscape, showing a significant impact on the development of clouds resulting from a change in land cover type (adapted from Pielke et al, 1997).

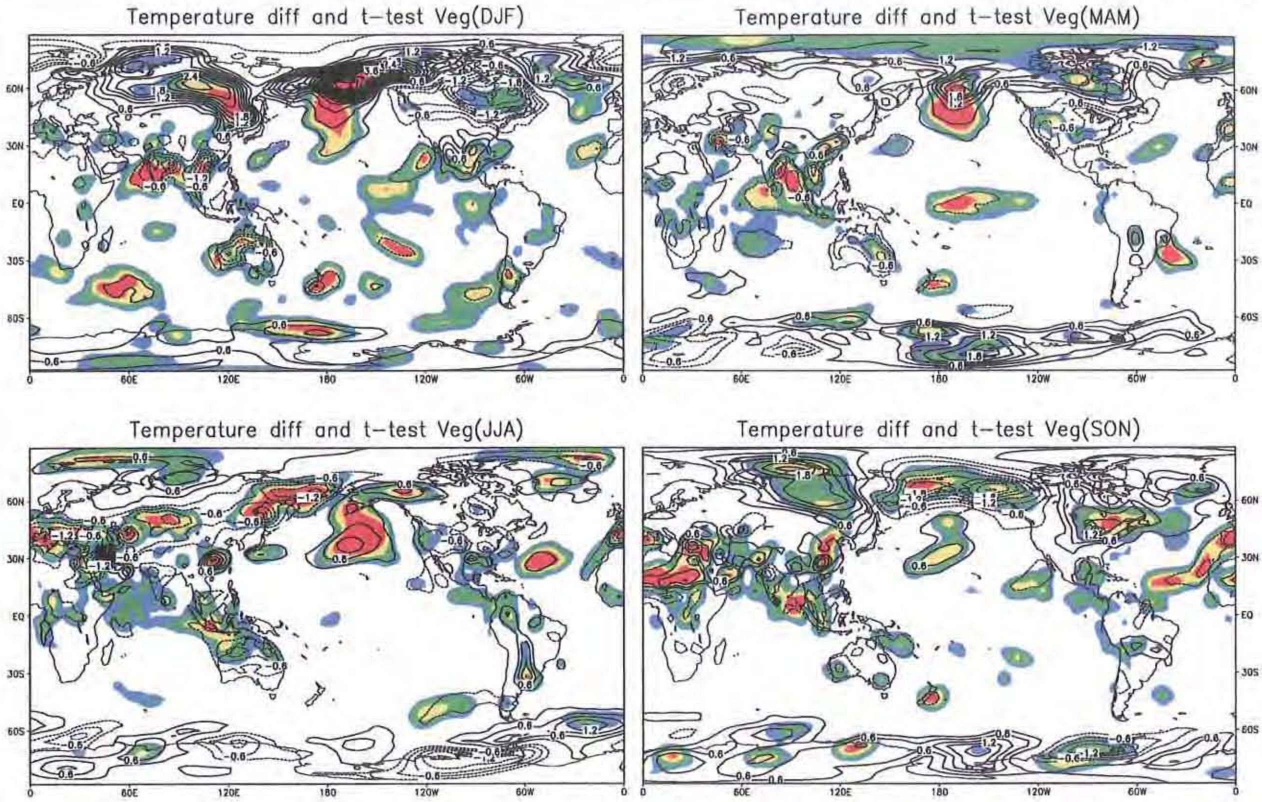


Figure 6. The change (current-natural) in the mean seasonal near surface air temperature (K) for four seasons. Areas of statistical significance, calculated using a two-tailed t-test, are plotted in colour with those regions of 80%, 90% and 95% statistical significance shown (from green to red). Adapted from Zhao et al. (submitted).

In terms of evidence from shorter timescale experiments, and in particular within mesoscale modelling and weather forecasting, some valuable evidence has been produced in the last few years. Beljaars et al. (1996) remains one of the more convincing case studies where the skill of the ECMWF forecast model was shown to be sensitive to the land surface. An improvement in the simulation of land-surface evaporation, one day upstream from the region of the continental US which experienced the severe rainfall events of July 1993, was shown to lead to an improved forecast of precipitation in the model. This is clear evidence that the land surface does matter in the simulation of weather under some circumstances, but it is interesting to note that most of the evidence for the impact of land-surface processes referred to by Beljaars et al. (1996) comes from the climate modelling community. This does not mean land-surface processes are usually not important in weather, but it does imply that the case has yet to be proven that they do. One step in providing further evidence has been made by Xue et al. (1999), who find a sensitivity in the simulation of the onset, evolution and intensity of the Asian monsoon at synoptic and regional scales to the parameterization of the land surface (Figure 7).

On the longer timescales, the feedback between atmospheric and land-surface processes over seasonal time scales has been discussed by Eastman et al. (1999) and Lu (1999). Both of these studies demonstrated that the amount of transpiring vegetation has a significant influence on thunderstorm rainfall over the central grasslands of the United States, and that this rainfall subsequently influences the growth of the vegetation. Eastman et al. (1999) also showed that the biological effect of doubling carbon dioxide in the grassland would have a very significant effect on the regional climate in this region.

Pielke et al. (1998) have also reported both simulations of and data on the impact of land-use change on temperature and precipitation in July and August in southern Florida, USA. Significant land-use change has occurred over southern Florida and if a model is used with 1900 and 1973 land cover, a substantial effect on simulated temperature and precipitation occurs. In terms of temperature (Figure 8) the maximum temperature simulated by the model is warmer. While Pielke et al. (1998) make no claim that the land use change is the only environmental effect influencing temperature and precipitation changes over the century, the landscape changes are clearly important enough to exert a major forcing on these weather patterns at these scales.

So, the modelling evidence is conclusive that regional scale perturbations cause continental-scale changes in climate and there is some evidence that regional-scale land-surface changes, in key regions, can cause significant changes in geographically removed areas via atmospheric teleconnections.

Coupled observed and model evidence from macroscale to global scale

It is at these scales that the global climate models provide a significant amount of key evidence that the land surface actually matters in climate. It is also at these scales that there is significant observational evidence which supports the climate-model results. Using climate-system models we can now demonstrate that land cover changes during the last 7000 years amplified climate variations regionally and globally. Initial variations in orbital forcing appear to be amplified by vegetation-atmosphere feedbacks, as first discussed by Otterman et al. (1984) and Harvey (1988, 1989a,b). The vegetation-snow-albedo feedback arises because the albedo of snow-covered vegetation is much lower for forests than for low vegetation such as tundra. Sensitivity studies in which the response of the climate to changes in land cover is analysed corroborate the importance of such feedbacks (Foley et al., 1994). This positive feedback reduces surface albedo and therefore increases near-surface temperatures which, in turn, favours growth of taller vegetation, reducing surface albedo further (see Otterman et al., 1984; Claussen and Gayler, 1997; Texier et al., 1997).

While biogeophysical feedbacks help to produce a milder climate in the mid-Holocene, the opposite is true for the end of the Eemian warm period (115 ka BP). Studies by Harvey (1989b), Berger et al. (1992, 1993) and deNoblet et al. (1996) show that the vegetation-snow-albedo feedback contributes significantly to Northern Hemisphere cooling. Climate reconstructions and data of fossil pollen compiled by Jolly et al. (1998) and Hoelzmann et al. (1998) indicate that North Africa was much greener than today in the mid-Holocene. Texier et al. (1997), Kutzbach et al. (1996) and Broström et al. (1998) find a weak positive feedback between vegetation and precipitation in this region. Claussen and Gayler (1997) find a stronger feedback which causes an almost complete greening in the western Sahara and some in the eastern part. Claussen and Gayler (1997) and Claussen et al. (1998) explain the positive feedback by an interaction between high albedo of Saharan sand deserts and atmospheric circulation as hypothesised by Charney (1975). They extend Charney's theory by accounting for atmospheric hydrology, i.e. moisture convergence and associated convective precipitation.

How did these biogeophysical feedbacks evolve during the Holocene? Claussen et al. (1999) analyse the desertification of North Africa using the coupled atmosphere-ocean-vegetation model of Ganopolski et al. (1998), but with a dynamic vegetation module. Their simulations suggest that changes in orbital forcing triggered rapid changes in Saharan climate. The study by Claussen et al (1999) also suggests that the end of the African wet period was determined not only by the atmosphere-vegetation feedback in this region, but also by large-scale meridional temperature contrasts which were strongly influenced by vegetation changes at high northern latitudes.

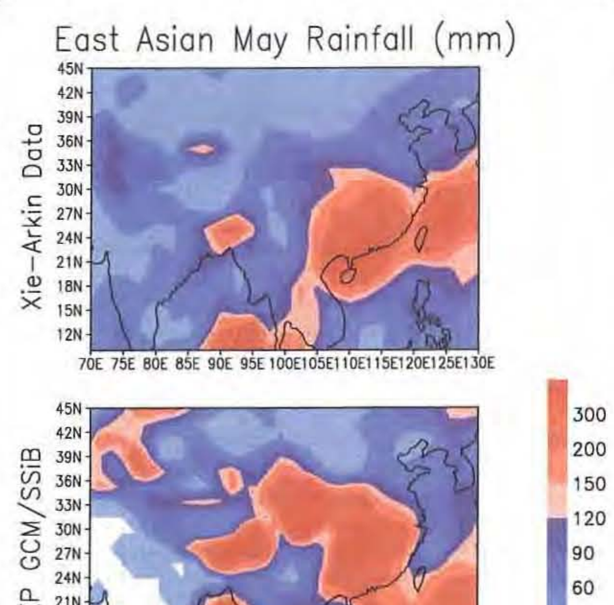


Figure 7. Sensitivity of the simulation of the onset of monsoon rainfall by the NCEP GCM (lower) and the NCEP GCM coupled to a more realistic surface model (from Xue et al., 1999).

Summary

It is quite clear that the land surface can affect the partitioning of water and energy and that changes in the state of the surface can, without question, cause changes in the atmosphere: the question is, are these changes large enough to matter in weather and climate. There are clear cases where the answer to this question can be shown to be "yes", drying after African deforestation and in the Western Ghats in India; changes in the microclimate following Amazon deforestation; US land-use change; or European deforestation. There is also some evidence that the initial state of the land surface exerts a strong control of the subsequent evolution of the climate (Claussen, 1994; Claussen et al., 1998; Foley et al., 1994; Texier et al., 1997) and the implications of this apparent sensitivity in terms of the predictability of climate is discussed by Pielke (1998). We also know that soil moisture anomalies can affect weather, as for the example of Sahel reported in this issue, but the number of examples in the literature are notable by their rarity.

There is also little firm experimental evidence about land surface-atmosphere interaction at large scales. Again, some key examples which IGBP has been instrumental in assisting include HAPEX-Mobilhy, BOREAS and HAPEX-Sahel. These generally relate to short time-scale processes and not "climate". These experiments do provide evidence that the land surface may influence weather, but the jury seems still to be out on how large this influence might be. Similarly, attempts to relate warming of synoptic stations to urbanization/land-use change are generally conjecture and do not provide firm evidence to substantiate firm effects on temperature and rainfall.

Overall, those who conducted the impressive observational studies over the last decade find themselves in rather a similar position to the climate modellers. Both groups find sensitivity of the atmosphere to the land surface. In the case of observations, they tend to be on too short a timescale (see Figure 1) to answer questions about climate or on too large a time-scale to address current questions about the role of land-use change in human-induced climate change. In contrast, Figure 1 shows that there is strong evidence from climate models regarding the role of the surface. But is this real or are the climate models overly sensitive to change? The work by the mesoscale modellers tends to focus on short time scales and specific locations, providing excellent case studies that the surface indeed does affect the boundary layer, but do these changes propagate and persist or are they lost in the noise of natural variability such that they really do not matter?

Fundamentally, there is a gap in the evidence concerning the importance of the land surface. Measurements are generally on far too short a time scale to determine the role of the surface in climate and perhaps also in weather, and modelling tends to focus on unrealistically large perturbations. Climate modelling is on too coarse a scale to answer questions about weather, while mesoscale modelling is on too short a time scale to answer questions about climate. So, what approach can be taken to finally address one of the central thrusts of BAHC? We need long-term measurements over large spatial scales. This need not be expensive, and in fact it

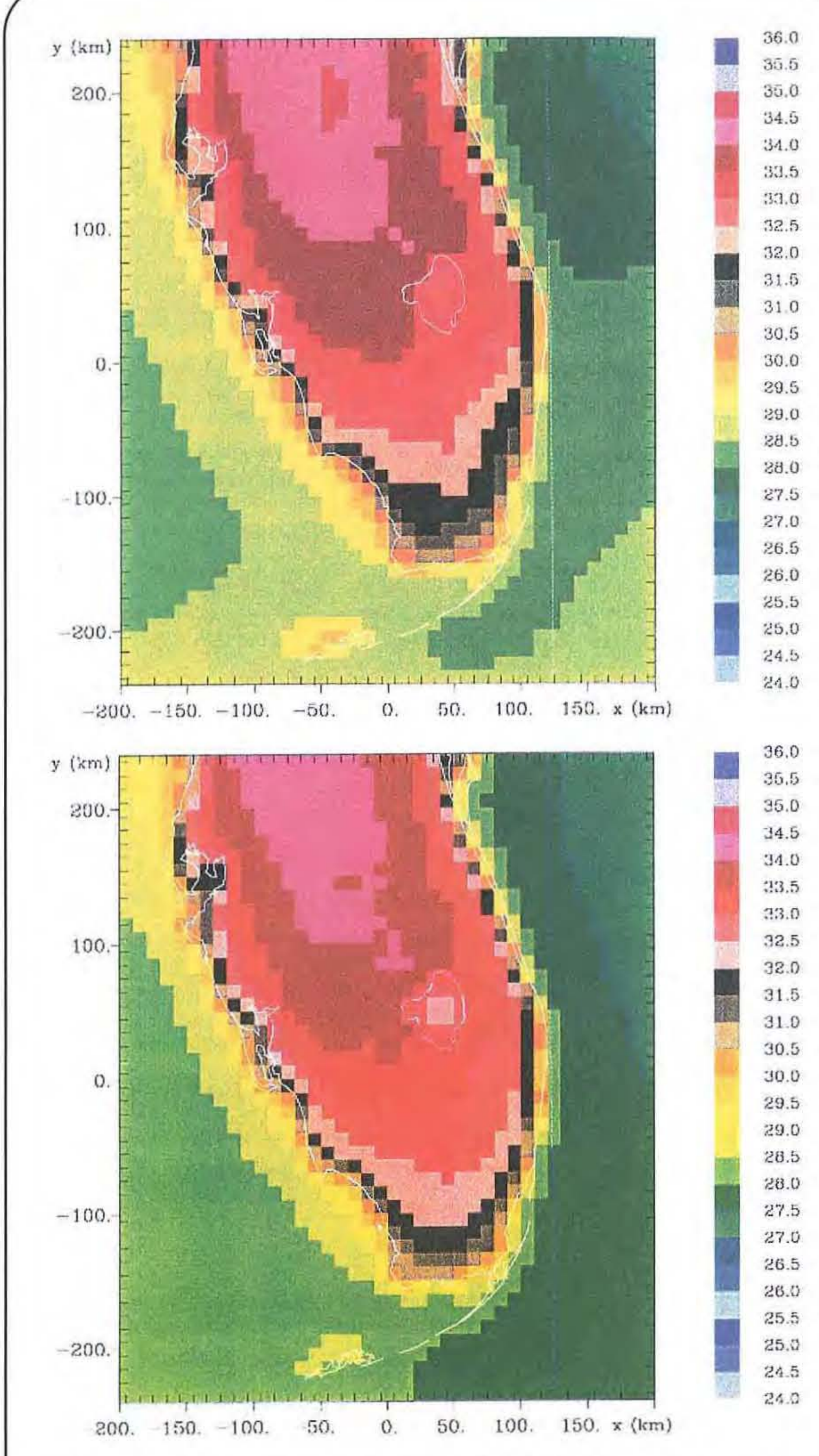


Figure 8. South Florida average maximum temperature (Celsius) during the two-month period for the (a) 1900, and (b) 1973. The average maximum over land for the two-month period increased by about 0.4 degrees C for the 1973 landscape compared to the model run when the 1900 landscape was used. (adapted from Pielke et al., 1998).

is already being done through FLUXNET. These data may provide the long timescale data we need, and when aggregated, these data are approaching being global in extent. From the modelling perspective, more realistic perturbation experiments (e.g. Chase et al., 1999), with a suite of climate models, would help answer the climate question. However, perhaps the final answer will come from simulations of the climate of the 20th Century through links with WGNE (Working Group on Numerical Experimentation) and GEWEX (Global Energy and Water Cycle Experiment) of the World Climate Research Programme. If we can produce high quality simulations of the climate of the 20th Century, ignoring land-use changes, then the question of the role of the land surface in climate might probably be answered in the negative. We do not believe this will be the case. Rather, we suspect that accurate representation of land-use changes will be central to the ability to simulate the climate of the 20th Century. Here then is a key challenge to IGBP: the integration of LUCC, BAHC, GCTE and GAIM.

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The IGBP, in collaboration with the WCRP and the IHDP, is sponsoring a major conference on global change, centred on a number of cross-cutting themes and featuring the latest scientific output from the IGBP synthesis project. The meeting will be organised around an integrated set of plenary lectures, parallel sessions, and poster presentations, and will feature both the integrated results of the international programmes and the rich variety of individual projects which contribute to the programmes.

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WCRP Climate — GLOBAL IGBP CHANGE — IHDP

Land-surface Experiments

by J. Gash and P. Kabat

The need for realistic representation of the land surface in climate models was recognised by the international WCRP and IGBP community in the early 1980s. The large-scale modellers responded by developing land-surface schemes, and the land-surface community responded by starting to collect data in globally important areas, such as Amazonia(1), for which at that time there were no data. But there was little communication between the land-surface community - either experimentalists or modellers - and the large-scale, atmospheric modellers, until the two communities were brought together in 1986 in the first international Land-surface Experiment, HAPEX-MOBILHY(2) (see box).

HAPEX-MOBILHY addressed the question of how to represent a mixed landscape with the single set of land-surface parameters allowed for each point on a GCM grid. As an experiment, HAPEX-MOBILHY demonstrated how teams from several nations and research disciplines could collaborate to produce more together than they could hope to achieve acting individually. FIFE(3), which followed in 1987, studied how remote sensing could be used to improve the description of land-surface processes in global climate models. EFEDA(4) (1991, 1994) and HAPEX-Sahel(5), (1991-1994), looked at desertification: collecting the land-surface data needed to solve the problem of how changes in the land surface in semi-arid regions interact with the atmosphere to influence regional weather and long term climate. An example result of HAPEX-Sahel is given in the following article.

These experiments were based around the philosophy of multiple point measurements from representative vegetation types within a grid square of usually 100 km by 100 km, developed initially through a collaborative effort between WCRP / GEWEX and IGBP / BAHC. Aircraft and remote sensing were used to scale up from plot or field scale up to the grid square scale. Meso-scale meteorological modelling was used as a scaling tool, with atmospheric boundary layer measurements, made using tethered and free flight balloons and aircraft, giving the necessary data. BOREAS(6), which started in 1993, was designed to collect the data needed for modelling the interactions between boreal land cover and climate. CO_2 fluxes were given more emphasis, recognising the need for data to calibrate the new models of carbon/water fluxes. BOREAS adopted a transect approach, with surface measurements concentrated at two points at the southern and northern extremes of the Canadian boreal forest zone and aircraft flying between them, interpolating the flux measurements.

Improvements in the technology also allowed BOREAS to move from campaign mode to the continuous measurements of fluxes throughout the growing season. This approach was taken further by FLUXNET(7), a co-ordinated network initiated by BAHC, of flux measuring stations, each making long-term, continuous measurements of CO_2 and water vapour fluxes. Although mainly in European and North American forests, the FLUXNET sites (http://daacl.ESD.ORNL.Gov/FLUXNET/) are now spread over a wide range of climatic zones and are giving new insight into the seasonal and year-to-year variations in the carbon and water balances. Some recent FLUXNET results from the Mediterranean region are given on page 15 of this issue.

The international nature and perspective of IGBP, and its projects such as BAHC, make it particularly effective in planning large international experiments. But the multidisciplinary nature of IGBP is also proving effective in moving the research from focussed, single-disciplinary studies to integrated, multi-disciplinary projects, which look at a range of interactions and controls on a complete ecosystem and its response to global change. The Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is the first experiment which takes this integrated perspective and comprises simultaneous, co-ordinated studies of the climate, hydrology, ecology and biogeochemical cycling of the Amazon region (11). Work in LBA has now begun with ground measurements at a number of sites distributed all over the Amazon basin and with the first Atmospheric Meso-scale Campaign (LBA-AMC) (described on page 16 of this NewsLetter) just completed.

The series of land-surface experiments is thus continuing to evolve, changing its form and function in response to new priorities. Indeed, one important lesson learnt from this series of experiments is that long-running programmes develop their own momentum and inertia. Equipment, expertise and experience is built up, which can easily create pressure for the design of the next experiment to repeat that of the last. If this happens the experimental design would then reflect our ability to make measurements - i.e. is capacity-driven - rather than the research questions which are to be solved - i.e. is issue-driven. International land-surface experiments are as prone to this risk as any others, especially so if teams or facilities offer their contributions ready-funded. Clear identification of the issues to be resolved is thus the critical first step in the design of an experiment, but the way in which we identify those issues and ensure the relevance of the experiment is also developing. BAHC, in close co-operation with its WCRP partner projects GEWEX and ISLSCP, started now to call for a systematic and integrated approach towards a design of new large-scale terrestrial experiments, based on a comprehensive analysis and consolidation of the data available in the region of interest, preliminary modelling and sensitivity studies, and improved interaction with the scientific and societal stakeholders and their needs (12,13).

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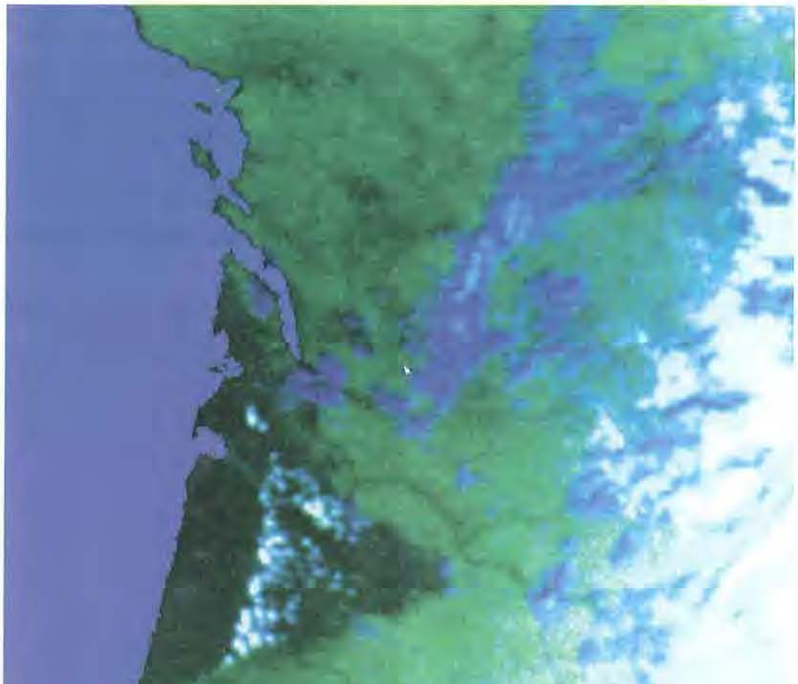
HAPEX-MOBILHY

HAPEX-MOBILHY (2) was the first co-ordinated international experiment which measured all the components of the water and energy budgets simultaneously over a large area of land. The main campaign took place in early summer 1986, over a 100 km by 100 km square in southwest France, an area comparable in size to a GCM grid square. While most of the square was mixed agricultural land, about a third was covered by Les Landes pine forest. There were frequent radiosonde ascents, and measurements of surface fluxes and soil moisture were made over all the principle vegetation types and crops. Other measurements included aircraft fluxes, boundary layer profiling, and surface temperature and stomatal conductance as remote sensing ground truth.

Using this suite of simultaneous measurements it was possible to demonstrate the potential of the land surface to affect atmospheric processes (see pages 4-11 for more discussion). The satellite image in the figure shows distinct cumulus cloud convection over the forest, but clear skies over the agricultural land. Analysis of the surface and radiosonde data showed that evaporation rates from the forest and agricultural land were very similar, but the lower albedo of the forest resulted in more radiation being available for sensible heat flux: this in turn led to a deeper boundary layer with air reaching the condensation level. A meso-scale meteorological model confirmed this interpretation (8) - predicting the observed behaviour of the atmosphere.

Analysis of the HAPEX-MOBILHY dataset led to an understanding of the different options available for representing mixed landscapes in GCMs (9) and it is still a source of material for current research (10).



Satellite image of south west France on 16 June 1986. Cumulus clouds can be seen over the dark green triangle of Les Landes Forest, but not over the agriculture land to the south east of forest. Adapted from a photo by Météo France.

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HAPEX-Sahel
Wet soils increase local rainfall in the Sahel

by C. Taylor

Numerical modelling studies have demonstrated how the land surface can influence rainfall in continental areas, but there has been relatively little observational evidence to confirm this. Previous data analysis has tended to concentrate on time series of rainfall (1). This approach presents problems in isolating the role of surface feedbacks from the external atmospheric factors which generate persistent rainfall anomalies. An alternative approach, using the dense raingauge network (2) operated in HAPEX-Sahel (3), has shown how the land surface can influence the spatial distribution of rainfall. Rain falls preferentially on areas where the soil is wet from a previous, recent storm (4, 5).

Observations indicated a rainfall pattern which repeated itself over a series of storms during the final weeks of the Sahelian wet season in 1992. During this period, a gradient of 270 mm of rainfall developed over a distance of only 9 km (Figure 1). This compares with a long-term, mean annual total of 550 mm. The anomaly was not caused by topography because it did not occur in the same place in other years of the study - similar extreme patterns did occur in other years, but elsewhere in the region.

Additional observations have helped to interpret this surprising result. Instrumented aircraft detected locally moist air over wet soils in the day or two following a storm. These areas were consistent with there being higher evaporation directly from the bare soil surface. A "memory" of previous storms was thus retained by the atmosphere whilst the top soil was drying out. This memory could extend over several weeks if the vegetation responded to the favourable soil-moisture conditions by increasing its leaf area. The rainfall observations suggest that convection is locally intensified when a mature storm such as a squall line (Figure 2) passes over the low-level, moist air. This results in higher local rainfall and a reinforcement of the soil-moisture pattern.

The positive feedback effect has been observed on scales of typically 10 km - comparable with the size of individual storm clouds within squall lines. At this scale, it means that whilst one village can have a good harvest, their neighbours suffer crop failure. Current work, using a fine mesh, mesoscale meteorological model, aims to confirm the soil-moisture feedback hypothesis. Similar processes may also be at work, undetected, over much larger areas, possibly affecting the initiation and life time of these travelling storm systems, which account for over 70% of Sahelian rainfall. Large-scale modelling studies (6) have shown that changes in land surface may affect the occurrence of drought in the region. With the rapid conversion of natural savanna to cropland now occurring in the Sahelian zone, the fact that surface feedbacks can affect rainfall even over a few kilometres provides a warning of the possible consequences of land-use change on future climate.

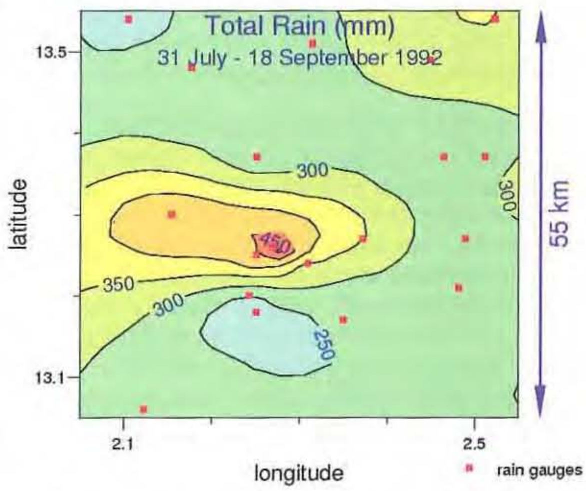

Figure 1. Isohyets of total rainfall (mm) for the final 7 weeks of the 1992 wet season from the EPSAT-Niger Study. The persistent patterns produce totals which differ by as much as 270 mm over only 9 km. This compares with the long-term average of about 550 mm per year.

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Figure 2. An approaching squall line in Niger. Rain in the Sahel falls from these organised squall lines which, typically, occur at two to three day intervals. [Photo by J. Gash]

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MEDEFLU
Summer drought reduces carbon fluxes in Mediterranean forest

by F. Miglietta and A. Peressotti

Preliminary results of the MEDEFLU project are showing the existence of well defined seasonality in the carbon fluxes of Mediterranean forest ecosystems with prolonged drought effects in the summer depressing both photosynthesis and respiration. The Mediterranean climate is typified by cool, wet winters and dry, hot summers with only occasional intense storms.

MEDEFLU measurements of carbon fluxes are showing that most of the carbon is exchanged in the spring, and in the fall immediately after the first rains. However, the data from a number of the MEDEFLU network sites are indicating that the photosynthesis that follows those rainfall events in the late summer or early fall is accompanied by enhanced soil respiration. This increase in photosynthesis and respiration leads to a null, or moderately positive carbon flux (ecosystem net carbon loss), over that period (Figure 1). Evergreen forests like the Quercus ilex (Holm oak) dominated forest in Southern France, and the Mediterranean Macchia forest in Sardinia (Italy), also show some moderate photosynthetic activity during the winter months. The implication is that the mild temperatures and relatively long day length (compared to more northern forests) allow the vegetation to continue to exchange carbon in the winter (Figure 1).

Although it is premature to quantify the net carbon balance at every MEDEFLU site, the data coming from some of those are already showing that carbon accumulation (sink activity) in these forests is moderate. The Macchia forest, for instance, was a net C-sink in the 12 month period ranging from April 1998 to April 1999 (Fig. 2), but the net carbon sequestration was less than 80 kg ha^{-1} $year^{1}$. This compares with some 200 to 400 kg ha^{-1} $year^{-1}$ for more typical EUROFLUX forests (1).

MEDEFLU data are already showing that Mediterranean forests are potentially highly vulnerable to climate change. The finding that the forests are a source of carbon during the late summer drought shows clearly that soil moisture, through its effect on transpiration and soil respiration, is critical in determining the size and sign of the carbon flux. Decreased precipitation around the Mediterranean could thus easily cause substantial carbon losses from these systems, with potential positive feedbacks on the atmospheric balance of greenhouse gases. Moreover, changes in climate may lead to severe land

MEDEFLU

MEDEFLU has the objective of evaluating the surface fluxes of carbon and energy for selected forests in the Mediterranean region. It also aims to analyse the impact of human and natural disturbances on the delicate balance of gains and losses of carbon from forests of differing vegetation composition, to analyse the response of Mediterranean forests to environmental stresses and the biological feedback at ecosystem level, and to provide objective data for the validation of forest models, related to growth, partitioning of primary production, water cycling and hydrology. The project is carried out in selected forests along a transect in the Mediterranean region, encompassing Portugal, Spain, France, Italy and Greece. The research consortium includes partners from 8 different EU countries. The selected sites represent typical vegetation communities and landscape patterns, often representing the result of a common trend in land-use/cover management established in recent times. Continuous flux measurements are being made at each MEDEFLU site to give the seasonal variation in the mass and energy exchanges at the surface. In addition ecological processes are investigated at soil, plant and ecosystem level to understand the variables which control the fluxes of carbon and water. The selected sites have been chosen as representative of the Mediterranean region and encompass a range of climate, soil and land-use/cover variability. This variation will allow a comparative analysis of different responses in terms of process variables and types of land cover and use. The project started in 1998 and all the sites are now fully operational. MEDEFLU is an RTD project funded by the Environment and Climate Programme under the Fourth EU-Framework.

Please visit the MEDEFLU homepage: http://www.iata.fi.cnr.it/medeflu/minute.htm.

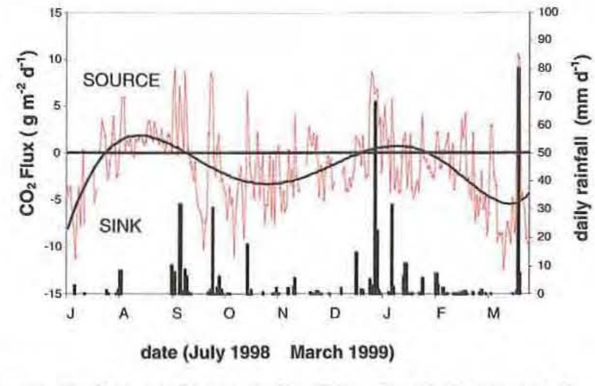

Figure1. Carbon exchange in the *Q.ilex* dominated forest at Puechabon, in the South of France. The red line indicates the net daily flux with negative values being a sink of carbon and the positive a source. The solid line has been fitted. The forest is a net source during the summer drought and a sink in the spring and fall, but some sink-activity is also detectable during the winter months. The graph also shows very clearly that ecosystem flux becomes positive (source) after the major rain events, possibly in response to a sudden increase in heterotrophic respiration. Data from this graph were taken at the Puechabon site by Serge Rambal and co-workers of CNRS-CEFE (Centre d'Ecologie Fonctionelle) of Montpellier and by the Paul Berbigier and co-workers of INRA (Institute Nationale Agronomique) of Bordeaux in France.

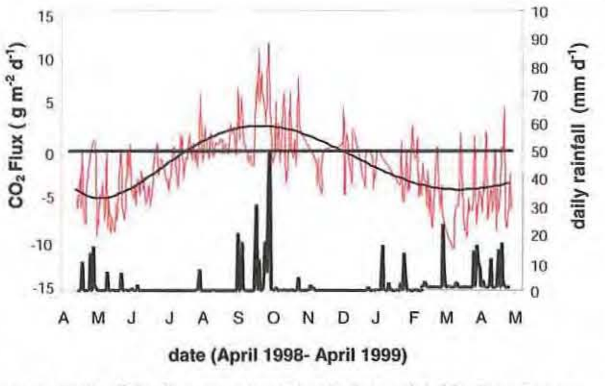

Figure 2. Daily CO_2 flux measurements from the Mediterranean Macchia forest at Arca di Noe in Sardinia (Italy) during the MEDEFLU measurement campaign(1998-1999). Enzo Magliulo, Pierpaolo Duce, Federica Rossi, Teo Georgiadis, Alessandro Zaldei of CNR, Donatella Spano of Sassari University, Gemini Delle Vedove and Marco Pecchiari of Udine University in Italy contributed substantially to the work made at this site. The red line connects daily data points, and the black has been fitted to interpolate the daily points. Data indicate that the site is a source of carbon during the dry late summer and rainy early autumn months. As was found in the Puechabon site in France, the first rains after the summer dry period produce more ecosystem respiration than photosynthesis. The first year's CO_2 balance was –70 g m^{-2} year^{-1}, indicating the ecosystem is a very small sink of carbon and thus sensitive to degradation, even with very small climatic changes.

degradation and finally to desertification. The project is continuing to monitor carbon and water vapour fluxes in this type of Mediterranean ecosystem, so that their potential contribution to the global carbon balance can be determined and the likely consequences of climate change can be predicted.

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LBA-WETAMC
Wet season atmospheric mesoscale campaign in Amazonia

by G. Fisch, M. Assunção Silva Dias, C. Nobre, H. Dolman and S. Rutledge

Over 200 scientists spent January and February 1999 in southwest Amazonia. They were participating in the first field campaign of the Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA). The campaign, known as the Wet season Atmospheric Mesoscale Campaign (LBA-WETAMC) was located within the footprints of two rainfall radars and a network of four radiosonde stations near the town of Ji-Paraná in the Brazilian state of Rondônia. The region contains a large area, about 100 km across, of deforestation and a large area of undisturbed forest. The measurement campaign was a joint venture between scientists (including Brazilians and Europeans) gathering data to investigate the mesoscale processes through which deforestation affects climate, and a mission (LBA-TRMM) in which the USA and Brazil collaborated to validate the output from the NASA tropical rainfall mapping satellite, TRMM.

As well as the radiosondes and rainfall radars, measurements in the campaign included: four tethered balloons and other surface-based boundary layer sounders, and two forest towers: one instrumented for micrometeorology and the other for atmospheric chemistry measurements. Surface-flux measurements were made in the forest, with similar measurements in the deforested pasture. One aircraft made *in situ* measurements of cloud microphysics, while a high-altitude aircraft measured the cloud properties from above the clouds. A dense network of raingauges and disdrometers gave data

Figure 1. A storm approaching the University of Virginia micro-met tower at the ABRACOS Pasture Site during the LBA-WETAMC (photo by G. Fisch).

Figure 2. Juliol Tota of the Brazilian Space Research Institute (INPE) and Steve Greco of the US University of Virginia discussing whether the weather conditions allow the lifting of the tethered balloon at the LBA-WETAMC Rolim de Moura site (photo by G. Fisch).

for use in conjunction with the rainfall radars.

By combining two components, a powerful data set has been produced which will give new insights into tropical meteorology, atmospheric chemistry and hydrology. The campaign provides all the data needed for mesoscale meteorological analysis, and also a wealth of data on atmospheric composition and trace-gas fluxes. Hydrological modelling will benefit from the new data on the extent and duration of tropical rainstorms, and dynamical meteorology from the, previously non-existent, data needed to develop models of moist, tropical convection over land.

Preliminary analyses of the results reveal low sensible heat fluxes, high evaporation and a clean atmosphere with few aerosols. The convective boundary layers over the forest and deforested areas were found to grow to similar heights of about 1000 m - in contrast to previous studies in the dry season where different heights were found. A first international workshop for discussing progress on data analysis is planned for January 2000 - it will be held in Utah, USA. More details of the campaign can be found at the LBA-WETAMC website: http://rond.iag.usp.br.

The measurements have not all stopped. Two of the surface flux stations are continuing to collect data as part of the LBA long-term monitoring programme. Continuous measurements of water vapour and CO_2 flux, radiation, climate and soil moisture are being made at a pair of forest and pasture sites.

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LBA

The Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is a Brazilian-led international experiment designed to generate new knowledge, essential to the understanding of the processes within the ecology, hydrology, biogeochemistry and climatology of Amazonia, the impacts of the different land uses on these processes and the interactions between Amazonia and the global biogeophysical system of the planet. LBA is based around two fundamental questions that will be answered using a multidisciplinary approach.

1) How does Amazonia presently operate as a regional entity?

2) How will changes in land use and climate affect the biological, chemical and physical *modus operandi* of Amazonia, including the sustainability of development in the region and the influence of Amazonia on the global climate?

Further details of LBA can be found on the web-site: http://www.cptec.inpe.br/lba/indexp.html

Land-surface data sets for hydrological and climate modelling

by H. Hoff, R. Hutjes and P. Dirmeyer

An important part of the BAHC mandate includes a contribution to the development of appropriate data bases to describe interactions between biosphere and the Earth system, with a special focus on hydrological, biogeochemical and climate processes. In this task, BAHC collaborates closely with IGBP DIS and with several projects of WCRP, most notably GEWEX (Global Energy and Water Cycle Experiment) and ISLSCP (International Satellite Land Surface Climatology Project), making land-surface and biospheric data accessible and useful to users other than the data collecting scientist, generally requires a form of data consolidation and integration, a task BAHC strongly stimulates.

What kind of data are required?

In response to the data needs for developing, validating, and intercomparison of models, regional and global land-surface data sets have to be compiled and consolidated from several distributed sources. Three modelling areas are particularly important in the BAHC context:

- coupled modelling of components of the climate system and the hydrological cycle - e.g. modelling bi-directional interactions between vegetation and atmosphere.
- modelling of the biogeochemical cycle including transport in the riverine systems.
- integrated models for vulnerability and risk assessments of environmental systems - in particular assessments of global change effects on water resources.

In addition to that, BAHC anticipates a fast development of the needs for "on-line" land-surface and terrestrial data. At a BAHC / ISLSCP workshop on land-surface data in weather and climate models (Paris, May 1998), it was confirmed that more and more weather and climate prediction centres are or may soon be ready to assimilate different kinds of land-surface data (from a single parameter to fluxes) for model initialisation, validation, and operational purposes.

Land-surface data and information are not only required for modelling of land-atmosphere interactions, but also for monitoring, trend detection, and quantification of changes. Examples of such data compilation and analysis tasks are connected to the Kyoto Protocol of the Framework Convention on Climate Change (FCCC) that requires the monitoring of changes in terrestrial carbon stocks and biospheric carbon sinks. Another example is the monitoring of changes in water quality, availability, variability, and extreme events for water resource planning (see Pielke and Guenni this issue).

For most of the global modelling and monitoring applications the data have to be continuous, describing seasonal and inter-annual variability and spanning all major climate and biome types. A particular emphasis has to be on data and information from regions that currently undergo rapid land-use and land-cover change, i.e. the humid tropics and the northern boreal zones.

Most typical data which are part of the BAHC land-surface data effort include:

- land-cover parameters characterising soils and vegetation on a global scale, including its

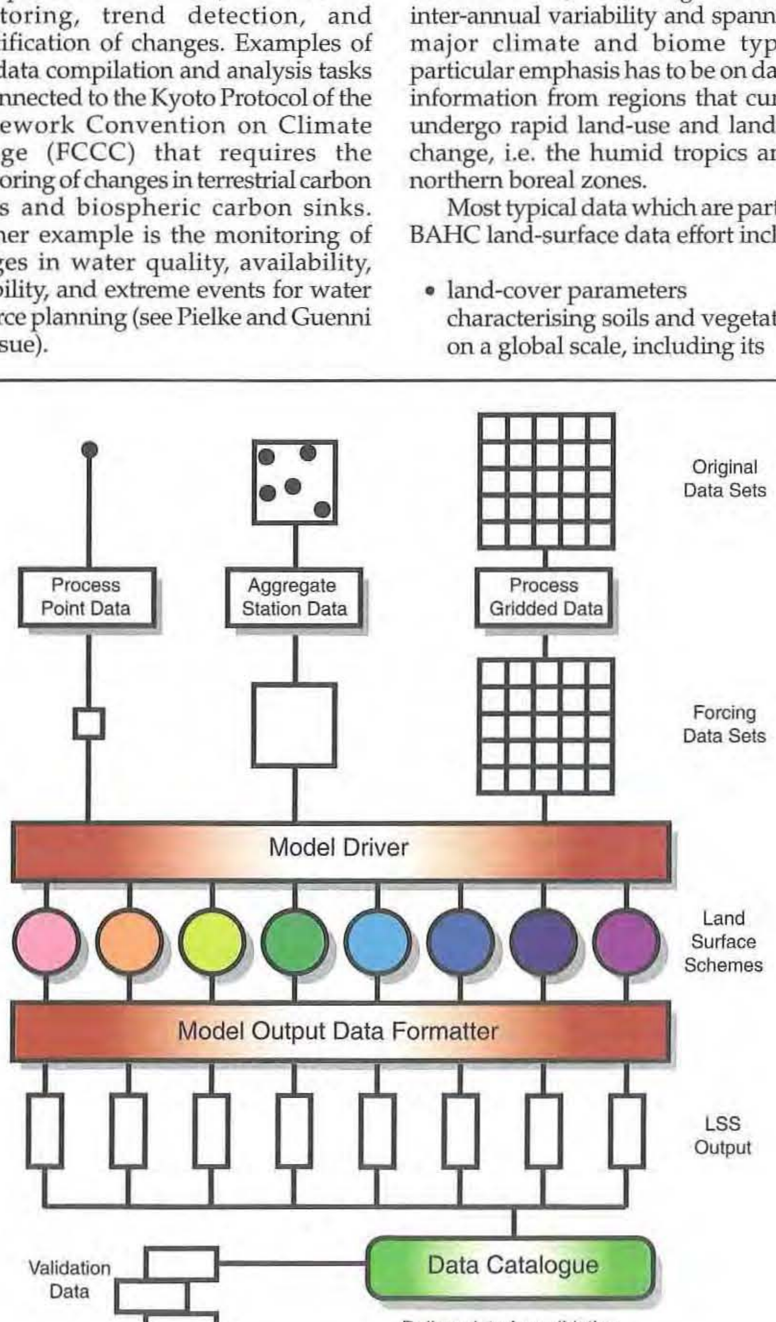

Figure 1. Schematic illustration of the production of consolidated data sets to be used in model initialisation, validation, and model inter-comparisons as part of the land-surface data consolidation strategy, shared by BAHC, GEWEX Working Group of Numerical Experimentation (WGNE) and ISLSCP (courtesy of P. Dirmeyer, COLA).

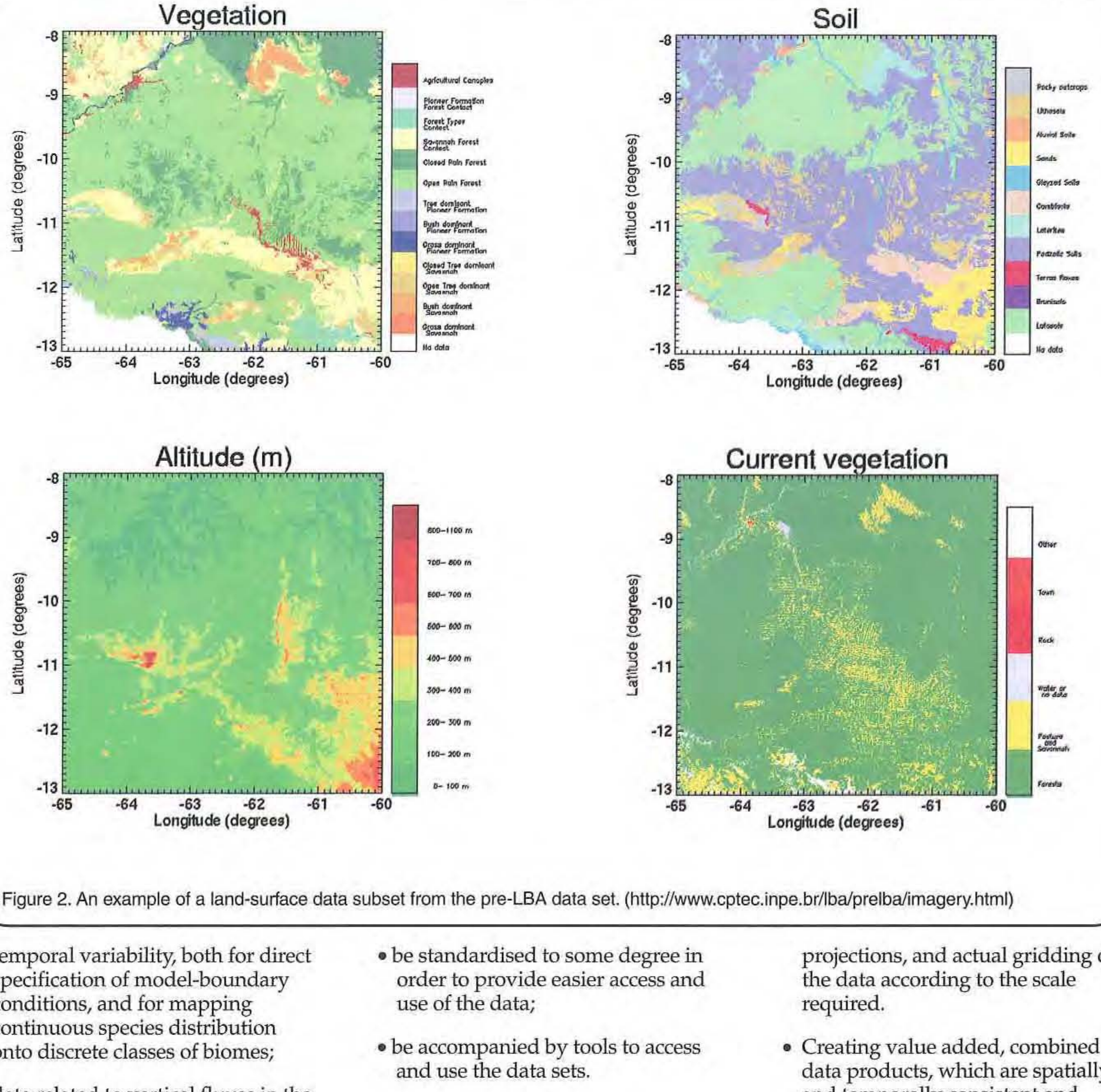

Figure 2. An example of a land-surface data subset from the pre-LBA data set. (http://www.cptec.inpe.br/lba/prelba/imagery.html)

temporal variability, both for direct specification of model-boundary conditions, and for mapping continuous species distribution onto discrete classes of biomes;

- data related to vertical fluxes in the soil-vegetation-atmosphere system;
- hydrological and hydro-meteorological variables derived from remote sensing;
- long-term and large-scale time series of soil moisture and runoff;
- data related to lateral fluxes of water and constituents in riverine systems.

The consolidated data sets to which BAHC contributes, have to meet the following requirements:

- be global in coverage;
- have common spatial grids;
- allow to derive multi-resolution products;
- be standardised to some degree in order to provide easier access and use of the data;
- be accompanied by tools to access and use the data sets.

What is data consolidation?

Several of these applications require consolidated data sets, including data harmonisation and standardisation. There are several components and levels of data consolidation (compare Figure 1):

- Quality enhancement by proper and uniform documentation, formatting, and data screening.
- Dealing with the scale gaps in the data - methodological developments with regard to scaling, averaging and aggregation techniques and procedures.
- Integration by linking and co-registering data from various sources that are often used in the same context, including matching of spatial and temporal resolutions, projections, and actual gridding of the data according to the scale required.
- Creating value added, combined data products, which are spatially and temporally consistent and include "overlays" of different types of land-surface and meteorological data. One of the best examples of this data type is the ISLSCP Initiative I global data product (http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ISLSCP/islscp_i1.html)

Quality enhancement

Quality enhancement is part of the data processing from raw data to the final product. It involves reformatting for consistency, uniform documentation and metadata extraction for inter-operability, and data screening, e.g. detection and removal of "outliers" and spikes, filling of gaps, etc. Different levels of quality assurance are defined, depending on the product specifications. Quality assurance and control is normally done by the original data collector; BAHC is focussing on facilitating links between different data providers regarding the uniformity and consistency in QA/QC procedures.

Scaling and aggregation of land-surface data

The "aggregation problem" has been recognised as a worrying source of uncertainty since the early days of Earth system modelling. For many years, modellers working on numerical weather prediction, climate modelling and on carbon-cycle modelling, have applied methods and paradigms developed and validated at very small spatial and short temporal scales, directly into regional- or global-scale models. This procedure frequently involved a "scale jump" of three orders of magnitude, e.g. plot-level data were used to describe land surface - atmosphere exchanges for grid cells of several hundred kilometres. BAHC, in co-operation with ISLSCP, had in the past one of its main research foci on the issue of up-scaling and aggregation in land-surface processes (e.g. Michaud and Shuttleworth, 1997)

Scaling of data and information may be required either from small to large scales (both in space and time) or vice versa (downscaling and disaggregation). Spatial aggregation (upscaling) aims at a spatially averaged representation of landscape heterogeneities, e.g. of vegetation cover, soils, topography and physical properties. There are basically two different approaches to deal with subgrid-scale variability when modelling soil-vegetation-atmosphere fluxes. Either the distribution of a parameter found within a particular grid box is replaced with an "effective" value, weighting somehow the relative areas, which allows the model to simulate a single aggregate flux. Or the model simulates fluxes for a discrete set of parameter values found within a particular grid box, and then averages the fluxes weighted by the relative areas (so-called "tile" or "mosaic" approach). In both cases, a high resolution observed land-surface data set is the starting point for scaling and aggregation procedures. The strategy in BAHC focuses on producing spatially averaged data fields at multiple scales, which allows for both, "aggregated" and "distributed" modelling.

Downscaling of information, e.g. to the scale needed for vulnerability and risk assessments, involves different approaches, i.e. stochastic and dynamic techniques. Some of these techniques have been developed within the former Focus 4 of BAHC (Bass et al., 1996). Within the stochastic approaches, empirically observed relationships are established between the large-scale circulations and the local atmospheric conditions. Local information is reproduced from the global data. Dynamic approaches use the output from the Global Circulation Models or Numerical Weather Prediction Models as lateral boundary conditions for Limited Area Models.

Integration and dedicated regional data products

An example of integrating data from different sources is the data and information system of LBA, to which BAHC actively contributes. Aiming at integration across scales and disciplines, data from a variety of LBA modules, including field data, remote-sensing images and model results are integrated and made available for other groups. This integration of data and information supports e.g. co-locating field experiments and campaigns, coupled modelling, and assessment of global change effects in the Amazon region. The implementation of such a system for data integration does not need to be centralized. A distributed system, using available web technologies, can provide such integrated data products. BAHC has recently contributed to the development of a pre-LBA data set, an effort led by Brazil, which is a compilation of the major data sets of regional experiments that took place in Amazonia during the last 20 years (Fig. 2). The first release of Volumes 1-3 of the Pre-LBA CD-ROMs are now available (marengo@cptec.inpe.br)

Examples and links to land-surface data initiatives to which BAHC contributes:

FLUXNET

This initiative is closely linked to BAHC Key Theme 1. A growing number of flux measurement stations globally is working under the FLUXNET scheme for standardised measurements and data management.
http://daacl.ESD.ORNL.Gov/FLUXNET/

RIVDIS

This activity is closely linked to BAHC Key Theme 6. RIVDIS is building a global integrated database and archive on lateral transport of water and constituents (see Vörösmarty and Meybeck this issue).
http://www.rivdis.sr.unh.edu/

Land-surface Experiments

High-resolution data from a number of regional land-surface experiments are integrated into regional and global products, as part of BAHC's Cross Cutting Issue A. These eperiments cover all major climatic regions of the Earth, from northern boreal zones to central tropics.

Examples are: the Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA), the Boreal Ecosystems Atmosphere Study (BOREAS), the Baltic Sea Experiment (BALTEX), the GEWEX Continental-scale International Project (GCIP).

LBA: http://www.cptec.inpe.br/lba/

BOREAS: http://boreas.gsfc.nasa.gov/BOREAS/BOREAS_Home.html

BALTEX: http://w3.gkss.de/baltex/baltex_home.html

GCIP: http://www.ogp.noaa.gov/gcip/

The International Satellite Land Surface Climatology Project (ISLSCP) Initiative I and II

The ISLSCP Initiative I Global Data Product is now available at: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ISLSCP/islscp_i1.html

BAHC will contribute to the Initiative II of ISLSCP, which will produce an enhanced consolidated global data set for land-atmosphere models. Compared to Initiative I, Initiative II is improving spatial resolution (0.5 degree) and temporal coverage (1987-1997) of the data and in many instances uses improved algorithms. It also integrates data from additional sources. BAHC will contribute to this initiative aggregated land-surface parameter fields, derived from existing high-resolution data, such as produced by IGBP DIS or land-surface experiments. Statistics on relative area and parameter-size distribution and conversion tools for different spatial resolution are also part of the BAHC contribution.

GSWP

The Global Soil Wetness Project (GSWP) of ISLSCP produces a 2-year global data set of soil moisture, temperature, runoff, and surface fluxes by integrating one-way uncoupled land-surface process models (LSPs) using externally specified surface forcing and standardised soil and vegetation distributions, namely, the ISLSCP Initiative I data. Soil wetness is an important component of the global energy and water balance, but currently unknown over most of the globe. The role of BAHC in this integration effort is mostly in validation of products against consolidated (field) data from land-surface experiments.
http://grads.iges.org/gswp/

IGBP DIS

BAHC in co-operation with IGBP DIS has defined a number of integrated data products that serve various IGBP programme elements. For these data sets, production methods are established and data access is facilitated. In order to provide access to distributed IGBP data and information, BAHC supports the IGBP DIS information harvesting and IGBP metadatabase activities. This system is now operational and indexes a number of BAHC web sites.
http://mercury.ornl.gov/servlet/igbp

IGBP DIS is going to develop "regional data bundles". BAHC suggests to use the data and information within LBA. This integrated regional experiment with its data and information system may serve as a model for other regional data efforts within IGBP.

An overview of additional BAHC activities and data products can be found on the BAHC homepage at: http://www.PIK-Potsdam.DE/~bahc/

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BAHC and the Initiative for Collaborative Research on "Global Change in Mountain Regions"

by A. Becker

Mountain regions represent valuable and partly unique settings to detect and analyse global change processes because of strong altitudinal gradients, which cause significant variation of climatic, hydrological, cryospheric and ecological properties over short distances.

Thus, the IGBP has recently endorsed a new Initiative on "Global Change and Mountain Regions" (Becker and Bugmann, Eds. 1999,). This Mountain Research Initiative strives to link and coordinate existing research, to initiate new projects where required, and to foster multi-disciplinarity.

The Initiative is structured around four Activities that describe integrated interdisciplinary research:

Activity 1: Long-term monitoring and analysis of indicators of environmental change in mountain regions;

Activity 2: Integrated model-based studies of environmental change in different mountain regions;

Activity 3: Process studies along altitudinal gradients and in associated headwater basins;

Activity 4: Sustainable land use and natural resource management.

BAHC and GCTE, by organizing with the support of START a workshop in Katmandu/Nepal (March/April 1996) on Predicting Global Change Imapcts on Mountain Hydrology and Ecology (see IGBP Report No. 43), acted as initiators of this initiative. They have been joined now by LUCC and PAGES as additional partners.

Within the BAHC science agenda as a contribution to the Mountain Research Initiative a special theme has been introduced on Mountain Hydrology and Ecology (BAHC Key Theme 7). Work under this theme is planned on the following activities in close coordination with GCTE, PAGES and LUCC and in cooperation with other programmes outside of the IGBP community as well, among others GEWEX and UNESCO for example:

(1) Small scale studies of hydrological processes and their dependence on topographical, ecological and other controlling characteristics along altitudinal gradients connected with studies in small mountain headwater basins.

(2) Regional scale studies along transects across different large mountain ranges and in associated complex mountain river basins, coupled with mesoscale hydrological and atmospheric modelling.

(3) Identification and long term investigation of hydrological, including cryospheric, indicators of global environmental change and of their relation to ecological and other indicators.

(4) Development of an integrated approach to analyse strategies for sustainable development in mountain regions taking into account different scenarios of land use/cover and climate change.

Preparatory steps towards the initialisation and implementation of research under these activities have been taken. Anybody interested in this research is encouraged to contact the BAHC IPO, Sabine Lütkemeier (Sabine.Luetkemeier@pik-potsdam.de), to receive more information.

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Vulnerability assessment of water resources to changing environmental conditions

by R.A. Pielke, Sr. and L. Guenni

Approaches to assess vulnerability

Water is an essential component of life both in terms of its quality and quantity; however, this resource is threatened. For example, as reported in the Economist (May 29, 1999, page 102), while 90% of the world's population have enough water at present, by 2050 more than 40% of the population are estimated as facing some water shortage. The access to safe water is even more serious. According to the same article in the Economist, developing countries often have very limited access to safe water supplies. Only about 30% of the rural residents of Brazil, for example, currently have access to safe water.

An important question, therefore, is how vulnerable are water resources to variations and changes in environmental conditions? What are the thresholds that must be reached before adverse responses occur in the water resource? Environmental conditions include weather, land-use change, population growth, industrialization, and so forth.

As an example, a critical component of a water resource can be a dam used for water supply at a given location and a particular aspect of this water resource can be the life span of the dam. Water resources can be affected, for instance, by silting produced by land degradation and deforestation occurring in the watershed served by the dam. A critical question, therefore, is how severe must the land degradation be before the dam reaches its maximum silting level, thereby causing water shortages for the local population? Can this threshold be quantified?

There are two basic procedures to assess the effect of environmental conditions on water resources:

- the scenario approach
- the endpoint approach

The endpoint approach refers to the assessment of the sensitivity of a particular aspect of the water resource at a particular location to the entire spectrum of environmental stresses. The limits of tolerance of an actual water resource to environmental variability and change are evaluated. The scenario approach provides a procedure to assess risk, since the probabilities of reaching critical thresholds can often be evaluated.

Figure 1 illustrates schematically how an integrated endpoint assessment can be performed. An important aspect of this approach is that changes in the endpoint (i.e. the water resource) can feedback to affect the scenarios. For example, local deforestation of the watershed could alter the precipitation, and, therefore, influence subsequent vegetation regrowth and runoff.

There are restrictions in the applications of both approaches. The scenario approach limits the assessment of the spectrum of environmental stresses, unless the entire suite of possible stresses are considered. Moreover, the scenario approach, as normally applied, does not permit feedbacks between the water resource and the environmental stresses. However this approach allows for sensitivity analyses of a given environmental stress while keeping the remaining conditions fixed. The endpoint approach, while it can be comprehensive in terms of thresholds, cannot, by itself, provide an assessment of the probability of occurrence. Probabilities are needed in order to quantify risk.

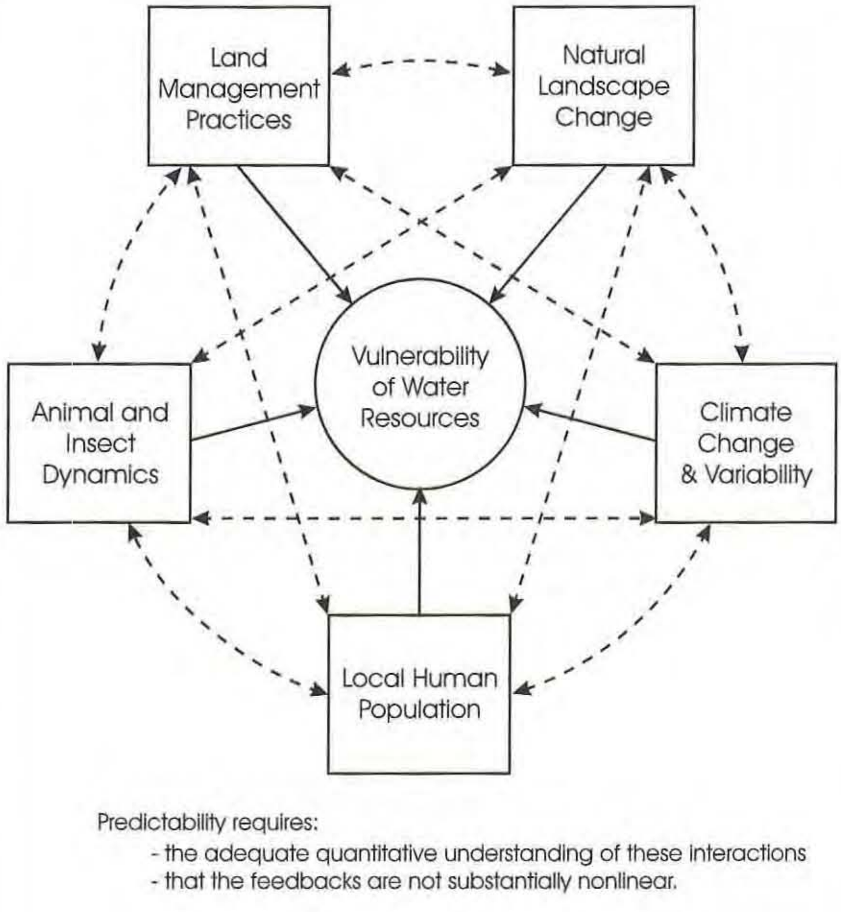

Figure 1. Use of ecological vulnerability/susceptibility in environmental assessment (adapted from Tenhunen and Kabat, 1999)

Examples of the application

There is a rich literature on the assessment of vulnerability in the engineering community. The construction of a dam, for example, requires the evaluation of earthquake hazards, extreme rainfall events and silting in the reservoir.

There are several examples of this approach. El-Ashry (1993) presents an analysis of the relation between per capita income and population without safe water, the urban population without adequate sanitation, municipal waste per capita, and other environmental effects. His study illustrates the need to assess the spectrum of threats to the water resources. Vörösmarty (1999, personal communication) has investigated the vulnerability of drinkable water to weather and to population changes. Schulze (1998) has explored the relative importance of changes in weather patterns and land use as they influence South African hydrology. Other examples of vulnerability assessment are reported in Downing et al. (1999), and Pielke, Jr. (1998).

Determination of plausible scenarios

Determination of plausible scenarios in order to determine risk - the range of realistic scenarios needs to be constructed. These scenarios need to encompass all of the environmental stresses listed in Figure 1.

In this section, we present procedures for generating weather scenarios. The following methods can be used to create these scenarios: physically-based statistical models (Guenni, 1997; Wilby et al., 1998), paleorecords, historical records, worst cases based on the permutation of the historical record, General Circulation Model (GCM) simulations resulting from prescribed perturbations (doubled CO_2, IPCC, 1995; landuse change, Chase et al., 1996; regional enhancement of aerosols), and the use of limited area models with specified changes at the lateral and/or surface boundaries (Mearns et al. 1999; Copeland et al. 1996).

Each of these methods to generate scenarios has value; however, by themselves they are incomplete. For example, GCM models provide the numerical representation of the mean features of the global atmosphere. They operate at resolutions of hundreds of kilometers and their ability to represent the current long-term atmospheric conditions is most realistic on the larger spatial scales. Many examples of the deficiencies of the global GCMs in simulating basic local climatic variables such as surface-air temperature and precipitation, however, have been presented (Cubasch et al., 1996; Risbey and Stone, 1996). Subgrid scale topography, land cover and water bodies have major impacts on local maximum and minimum temperatures, precipitation, incident radiation, and humidity. The variability in these factors needs to be well represented when used as inputs to water resource endpoint models.

Downscaling approaches have been introduced in an attempt to provide local resolution data. The original Weather Generator project used this procedure to provide high spatial resolution data from the very coarse information produced by the GCMs (Bass et al., 1996). Different approaches to downscale include the stochastic and dynamic techniques. With the stochastic approaches, empirically observed relationships are established between the large-scale circulation and the local atmospheric conditions. Large-scale information can be taken from GCM outputs or from reanalysis products (e.g. NCEP, Kalnay et al. 1996). Stochastic methods are then used to reproduce local information from the global data. With the dynamic approaches, output from the GCMs or reanalyses are used as lateral boundary conditions for Limited Area Models (LAMs).

If the GCMs had the ability to reproduce the system with the required spatial resolution, a dynamic downscaling step would not be considered. But global models cannot resolve variability at a local scale. Downscaling approaches have value since they can be used for the validation of GCMs and LAMs under current climate conditions. Both methods attempt to resolve a scale problem that enables a comparison of GCM and LAM simulations with the point observations of climate variables. On a broader sense, the description of the relationships between the large-scale circulation and the local climate can provide a useful insight into the physical causes of natural variability at the local scale (Zorita and von Storch, 1997). In the stochastic downscaling approaches, the established relationships between the large-scale circulation and the local climate reduces the number of degrees of freedom in the modeled atmospheric variables since additional independent information is used to explain the signal in the local climate variability.

Under current atmospheric conditions downscaling techniques have proven to be a valuable approach since the method considers most of the known direct effects on climate, e.g. the current landscape, and the important feedbacks to the atmosphere. (e.g. prescribed sea surface temperatures). But under atmospheric change conditions; e.g. increased CO_2, all the non-linear feedbacks have not been included in the GCMs (e.g. Robock and Graf, 1994; Trenberth, 1999). Even if they were, if the feedbacks are sufficiently nonlinear, there will be a temporal limit to predictability of the Earth's climate system; Pielke (1998). And also, there is no guarantee that the links between the large-scale circulation and the local climate remain unchanged in an altered climate. This fact poses a limitation also on the stochastic approaches.

As a result of the limitations on this predictive capability of GCMs, in the context of climate change, they are only going to have value within the scenario framework (due to the lack of representation of all the important external and internal forcings, and because of the significance of non-linear feedbacks; Oreskes et al., 1994).

The use of the paleorecords, historical data, and worst case permutations of this historical data permits another type of procedure to specify realistic climate change and variability. Variability includes increased persistence of wet and dry periods, changes in seasonal precipitation and spatial extent, and enhanced intensity of extreme events. The use of actual data permits a quantitative evaluation of the probability of a scenario occurring, based on what occurred in the past. Such an assessment is essential in order to evaluate risk. The assignment of realistic probabilities to future climate conditions resulting from anthropogenic changes (both at the global, regional and local scales), however, is a difficult, if not impossible task.

Conclusion

The assessment of vulnerability of water resources (i.e. the endpoint) to environmental variability and change provides information of direct societal relevance. Important thresholds where negative effects would occur in water resources, for example, can be evaluated using a vulnerability focus. However, scenarios need to be constructed in an attempt to quantify the risk. It must be recognized, however, that due to the limits in our ability to predict future environmental conditions, including climate, the assessment of risk necessarily will include significant uncertainty. It is important, however, that even if quantitative probabilities cannot be assigned, that the entire spectrum of plausible scenarios be considered, and not just a limited subset.

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Riverine transport and its alternation by human activities

by C. Vörösmarty and M. Meybeck

Water quality is critical to the sustainability of aquatic habitats, food webs, and commercial fisheries that serve as a major protein source for humans. It is also of enormous importance to the availability of freshwater resources serving a large and rapidly industrializing global population. We believe that the changing nature of inland water chemistry is important within a larger Earth Systems context. The transport of biotically active materials (nutrients and toxic substances) to the coastal zone through long-distance river transport ultimately links the continental land mass to the oceans. And, since it is believed that more than 90 percent of the world's fisheries catch depends in some way on the estuarine / coastal ocean and more than 50% of the human population resides within the coastal zones of the world, riverine transport and its alteration by humans constitutes a relevant global change and habitability issue.

Within this context, water engineering works — impoundment, withdrawal, interbasin transfers, and net water consumption — have significantly fragmented river corridors and their connections with the ocean. This produces a severe distortion of natural hydrographs leading to the potential loss of critical habitat, biodiversity, and altered material transport. Further, river loadings of biotically-active elements, metals, and pesticides are known to have increased several-fold since the beginning of the Industrial Era. From numerous individual river basin and coastal zone studies (e.g. the Baltic region; Mississippi River / Gulf of Mexico; North Sea; Northern Adriatic; the Black Sea) we know that elevated levels of waterborne nutrients, shifts in nutrient limitation, coastal eutrophication, toxic phytoplankton blooms, and bottom-water hypoxia are a consequence of human settlement and industrialization. Such site-specific changes in the delivery of land-based constituents collectively impart a biogeochemical signal of continental and global dimension. It has been estimated that riverine transports of inorganic N and P to the world oceans have increased several-fold over the last 150 to 200 years and it has been difficult to identify the population of truly pristine rivers. In certain regions, as in Western Europe, this increase is commonly 10 to 20 fold.

Drainage basins are a convenient organizing unit for large-scale hydrological and nutrient flux studies. Through river networks, spatially-distributed runoff and mobilized materials are collected and focused through river corridors which link disparate landscapes, for example high mountain source areas to coastal plains. River networks perform a natural integration of these processes and provide, through judicious sampling of water and constituent fluxes at discrete monitoring stations, a low-error estimate of otherwise difficult to quantify, spatially-distributed biogeochemical fluxes. In our contemporary world, river basins comprise a complex amalgam of natural landscapes, human-dominated landscapes, natural and controlled river channels. Since riverine fluxes are sensitive indicators of global change either related to climate change or to direct human impacts on continental aquatic systems, a comprehensive analysis of river basin behavior appears warranted from a larger global change perspective.

History of BAHC Research in River System Transport

A critical attribute of the terrestrial water cycle is its capacity to exchange both matter and energy, and a primary focus of early BAHC activities was the interaction between the land surface and atmosphere. By 1993, however, the BAHC Operational Plan (IGBP Report No. 27) presented several drainage basin-related concepts that were formally adopted during its execution phase. Among several others, a specific task directed at studies of the mobilization and fate of water and constituents through river basins set the stage for our current riverine transport work.

At the same time that BAHC began pursuing its initial work on drainage basins, there emerged an awareness of the relevancy of the changing nature of river systems as a legitimate component of the global change issue. This awareness took the form of several international workshops and symposia, newly-established research programs, and key papers in the peer-reviewed literature. In December of 1994, with the aid of PAGES and LOICZ, BAHC convened a three-day scientific workshop in Durham, New Hampshire, entitled "Modeling the Delivery of Terrestrial Materials to Freshwater and Coastal Ecosystems". The approximately 30 workshop participants were drawn from several Project Elements of the IGBP including BAHC, PAGES, LUCC, GAIM, and LOICZ. Representatives also attended from UNESCO, IAHS, and GEMS-Water (Global Environmental Monitoring System) as well as from the general scientific community active in the area of drainage basin and riverine transport analysis.

The Durham Workshop report (IGBP Report No. 39) provided a community consensus on important issues regarding fluvial transport through which the IGBP can take a leadership role. It was recognized that IGBP could make a significant contribution by providing (a) flux inventories for water and biogeochemical constituents, (b) an identification of the controls on terrestrial mobilization and aquatic transport of materials to the world's coastal zones, (c) an analysis of critical feedbacks due to human activities on biogeochemical systems, and (d) an identification of feedbacks due to drainage basin alteration on human society.

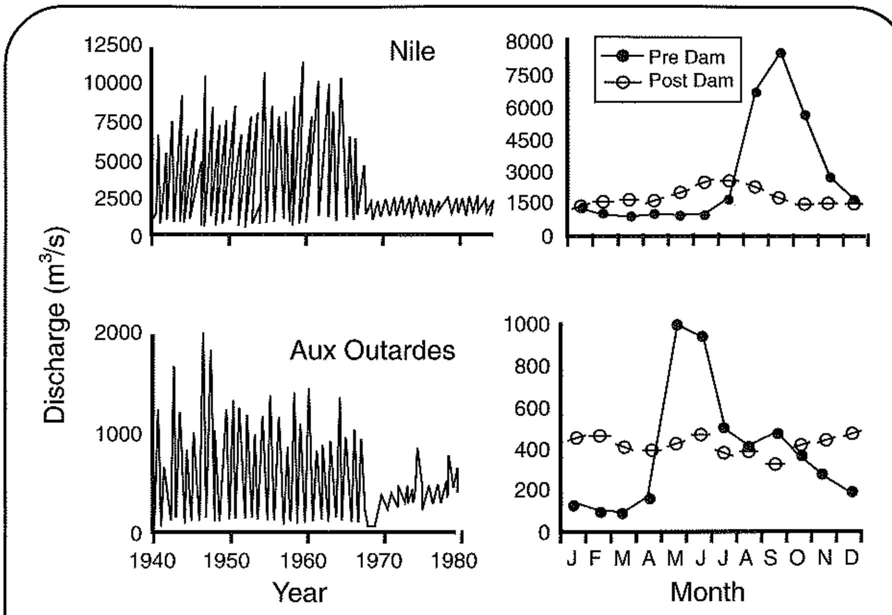

Figure 1. History of flow distortion by impoundments in two heavily-regulated rivers. Nile discharge is recorded just below the Aswan High Dam; the Aux Outardes site is near the river mouth. It is not difficult to identify in each case the time at which a dam was constructed and reservoir filled with significant changes to discharge regime before and after impoundment. Note reduced flows for the Nile due to lake evaporation and water use for irrigation. Note also the shift in the timing of the hydrograph in both cases, resulting in a major distortion of runoff. Such environmental changes are virtually instantaneous changes and a fundamental component of contemporary river systems, and hold important consequences for global sediment and nutrient transport, aquatic habitat and biodiversity, and waste processing. (Data from http://www.csrc.sr.unh.edu/hydro/welcome.html).

In addition, understanding the eminent role that mountains play as primary source areas of water and constituent fluxes through riverine systems and thus in the global water and biogeochemical cycles, another workshop was organised in Kathmandu, Nepal (March/April 1996) which resulted in the IGBP Report No. 43 "Predicting Global Change Impacts on Mountain Hydrology and Ecology". It was organized by the IGBP Core Projects BAHC and GCTE with support from START and attended also by representatives of LUCC. It finally led to the creation of an "Initiative for Collaborative Research" on "Global Change and Mountain Regions" (Becker and Bugmann, 1999) where BAHC, GCTE, LUCC and PAGES participate as primary partners. (A brief summary of this initiative is given in a separate box in this newsletter.)

Current BAHC Project Research

The recent reorganization of BAHC led to the creation of BAHC Key Theme 6, which provides the framework for quantifying and assessing the impacts of global change on river basins. The Key Theme's specific aim is to improve our understanding of the relative and distinctive contributions of climate change and anthropogenic activities on observed riverine fluxes. A central scientific question surrounds this work:

What are the key controlling factors that define the transport of water, particulate material, C, N, P, and Si through river systems and how have changes in these factors altered the linkages between the continental land mass and the world's oceans in the past, under contemporary conditions and into the future?

It is explicitly recognized that terrestrial water and material transport are linked, highly dynamic over both space and time, and reflect a complex interplay among climatic forcings, topography, land cover and vegetation. Through Key Theme 6 we recognize that humans have had an important hand in defining the nature of riverine fluxes due to land-cover and land-use change, population growth, industrialization, urbanization, and possibly greenhouse warming. Direct modifications of continental aquatic systems as river damming, water diversion, irrigation, wetland filling are definitively changing the water balance and the river material fluxes from the local to global scales.

However, fluvial systems have also changed substantially over a geological time frame, well before any significant, direct impacts from human society. Identifying the nature of these forcings is a major theme articulated by the IGBP more generally and we see an important opportunity for BAHC to collaborate with other Programme Elements.

We have organized our research around several suporting questions which collectively seek to formulate an overall research agenda on fluvial transport within BAHC. The research associated with these questions has a two-fold objective. The first seeks to achieve a better quantification of river basin fluxes over several time frames. The second objective is to explore the primary controlling factors that lead to observed patterns of riverine water and material flux. Our initial focus is on contemporary and past conditions as preparation for the analysis of future conditions. The combined inventory / process-level approach using multiple time frames provides a benchmark against which future system states can be measured. Three hypotheses have been formulated to organize our work:

HYPOTHESIS 1

The natural rates of water and material transport across drainage basins and within river systems of the world have varied significantly over the last 18 000 years. Prior to the growing influence of humans, the predominant controls have been derived from climate variability.

Over the last 18,000 years the architecture of river systems and rates of fluvial water and material transport have changed dramatically due to several natural forcings: (1) climate change affecting runoff; (2) variable sea level; (3) variations in the distribution and storage of water in ice caps; and, (4) occurrence of giant lake systems (>100,000 km^2) at the boundaries of ice caps and in endorheic (internal) basins. This is a critical global change question since all of these factors have themselves varied dramatically over both space and time. Understanding past changes and the response of river systems to these natural variations will be a key to understanding the future state of global river systems. A comparative analysis is required to test this hypothesis, contrasting contemporary, historical, and paleo-time frames. The mapping and characterization of present-day river basins without significant human influence is a convenient starting point.

HYPOTHESIS 2

Human activities from the beginning of the period of sedentary agriculture to the Industrial Era have significantly altered the rates of water and material transport across drainage basins and river systems of the world. These activities have been the major force shaping the character of contemporary fluvial transport.

Beginning about 6 000 years ago with the advent of sedentary agriculture, humans have progressively altered the mobilization and transport of constituents from the land mass. Today global river fluxes of water and riverborne material likely have been much more dramatically affected by human activities than by recent climate change, particularly over the last 100 years.

Owing to these several factors, this particular question needs to be addressed through a set of parallel efforts focusing on the global reduction of river-water discharge to oceans and internal basins, the simultaneous global increase in land erosion counter-balanced by a marked reduction of sediment transport due to reservoir siltation, and global changes in aquatic nutrient chemistry and carbon transport.

These changes involve direct alteration of both the fluxes of water per se and of particulate and dissolved materials. Water transport is already significantly affected in regions like the Gulf of California, Mediterranean Sea, Arabian Sea, Aral Sea where river inputs have been lowered from 25% to 100% due to reservoir building, massive irrigation, water transfer. Dramatic and virtually instantaneous changes are recorded in water fluxes measured at river discharge monitoring stations before and after impoundment, as shown in Figure 1.

Global sediment flux has been greatly increased through erosion on human-managed lands but simultaneously reduced through reservoir siltation. The global reduction in sediment transport due to trapping in reservoirs can be estimated conservatively at 20-30% of the present-day aggregate transport. Some biogeochemical fluxes, for example for N and P, have been already multiplied by a factor two to three on a global scale and up to 20 on a regional scale like to the North Sea. These changes represent a collective alteration of natural fluxes due to point-source pollution and non-point runoff, such as from industrial agriculture. There is also mounting evidence that the stoichiometric changes (nutrient:nutrient ratios for nitrogen, phosphorus and silica) in riverborne nutrient concentrations are adversely influencing coastal zone productivity, brought about by increased pollution from the landscape and trapping of materials within impoundments.

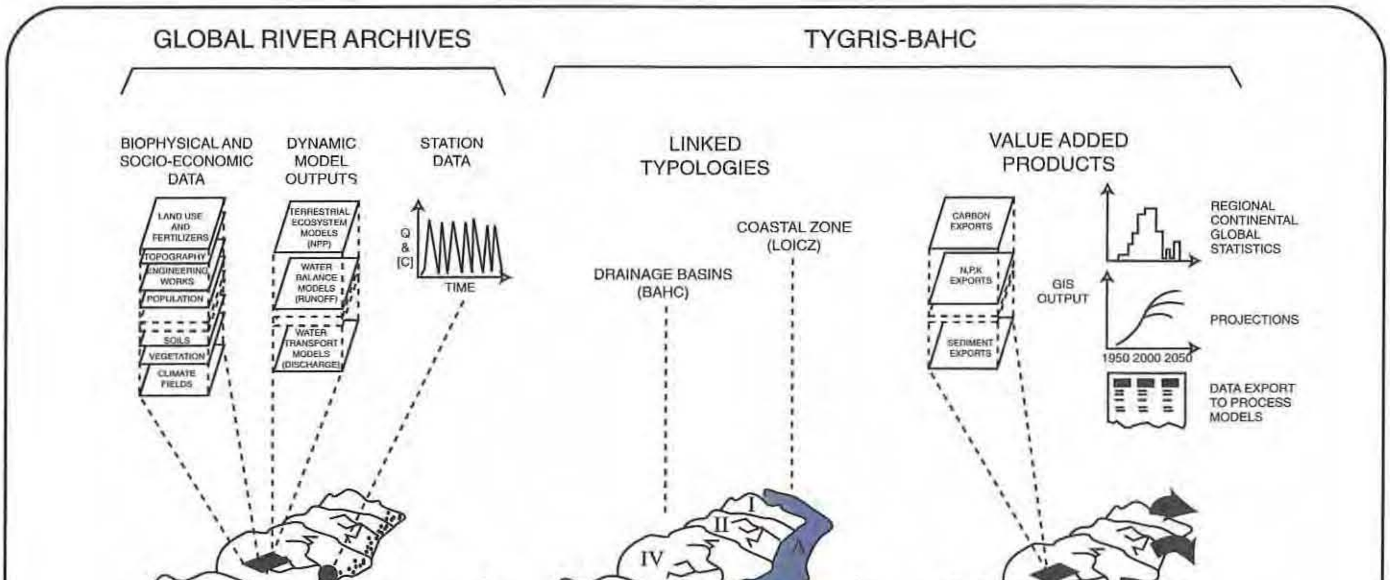

Figure 2. The overall framework of the TYpology of Global RIver Systems (TYGRIS-BAHC) information system to be used in global-scale analysis of inland water transports to the coastal zone.

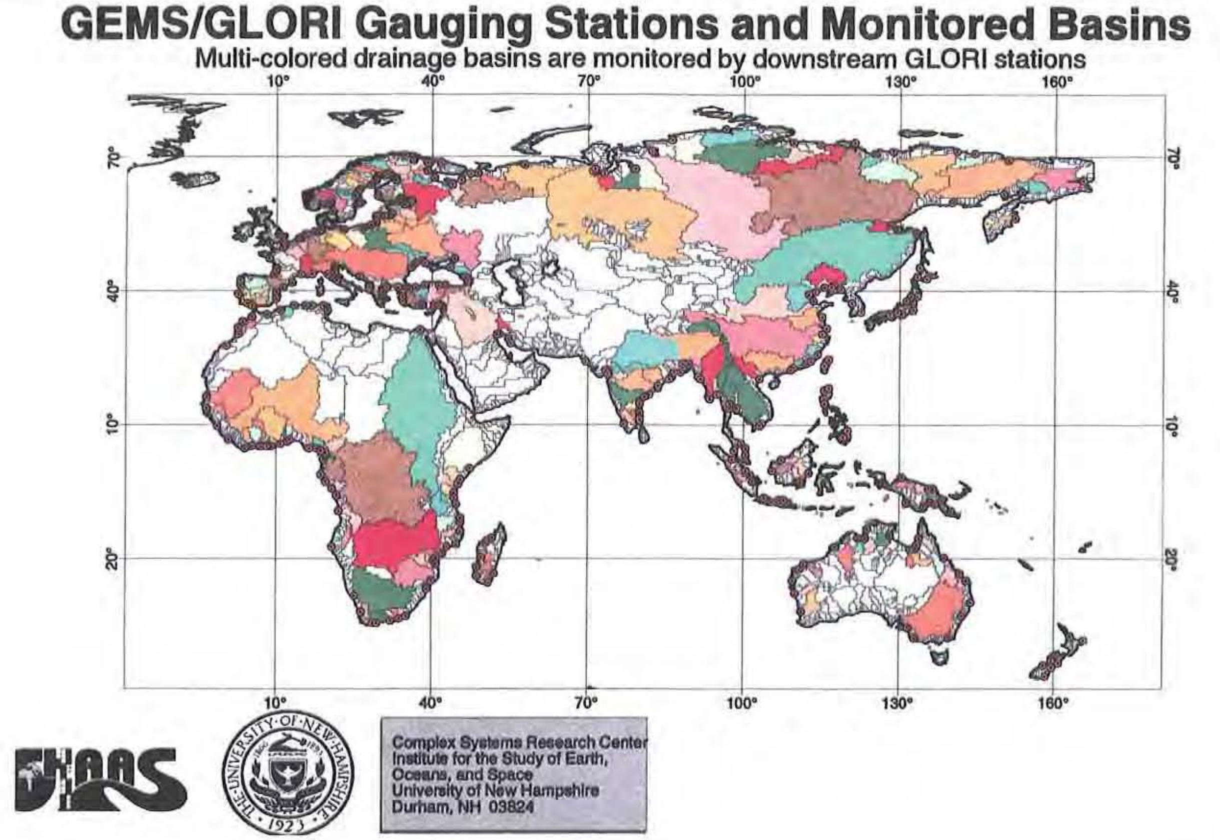

Figure 3. The geographic co-registration of the GEMS-GLORI (Global River Inputs to the Ocean) river chemistry data base to TYGRIS-BAHC provides important calibration and validation data sets for models of riverine transport.

HYPOTHESIS 3

Potential climate change and direct anthropogenic activities will produce unprecedented changes in water and material transport across populated drainage basins and river systems of the world over the next 100 years.

The mean residence time for water transported by rivers within the hydrological cycle — from its source in the atmosphere, through soils, and fluvial networks — is on the order of only a few months. For rivers themselves, this turnover time is on the order of about two weeks, except for few river systems influenced by large lakes, suggesting that these systems are and will continue to be sensitive indicators of global anthropogenic change. Indeed, river transport is one of the fastest changing global fluxes through the myriad of processes that both accelerate water and material flux (e.g. deforestation, rapid urbanization) and decelerate these transports (e.g. reservoir construction that traps sediment and enhances evaporation). This question is therefore highly linked to (1) global climate change, (2) population growth, (3) projected rates and levels of economic development particularly of irrigated agriculture, and (4) the evolution and enforcement of environmental regulations.

To develop a prognostic capability, we will focus on river system response in the face of several agents of ongoing global change, namely, climate variability, greenhouse warming, accelerated erosion due to land conversion and poor land management, water engineering, elevated nutrient flux from point and non-point source pollution. An additional and important element to consider is the purposeful regulation, through environmental protection laws, of emissions that discharge directly into water bodies and those associated with atmospheric deposition. For some classes of riverine material a major reduction of anthropogenic river fluxes has already been achieved through environmental control measures, for example for metals and phosphorus in North America and in some Western European rivers such as the Rhine.

TYGRIS-BAHC

A computer-based analysis tool is currently under construction to help pursue our research agenda. It is a characterization scheme, or TYpology of Global RIver Systems (TYGRIS-BAHC), using geographically-referenced attributes organized within a topological hierarchy of flow pathways through drainage basins. Once developed, TYGRIS-BAHC would be used in conjunction with models and multi-regression techniques to identify key controlling factors on drainage basin flux.

The need for such a system is clear. At present we can develop, at best, but a highly fragmented picture of the state of world rivers based on the observational record alone. This is certainly true for discharge (currently data for only about 55% of the land mass is routinely monitored and released) and the situation is even worse for constituents. For example, no more than approximately 25% of the globe's discharge is monitored for inorganic N. These models will be calibrated and validated using river discharge and water quality data sets from existing monitoring programs such as those developed at WMO for river discharge and at UNEP/WHO for water quality (GEMS-Water). Parallel efforts will then be directed toward characterizing river basins at selected, well-documented periods within the period of intensive agriculture and the last 18,000 years.

The overall organization of TYGRIS-BAHC is shown in Figure 2. Five components constitute the system:

- A data bank of geographically referenced information characterizing the world's drainage systems. The global TYGRIS-BAHC is initially organized at 30-minute spatial resolution, incorporating several data sets already available over the global domain (Table 1), many developed through ongoing IGBP initiatives. Over 6000 drainage basins can be delineated at 30' spatial resolution. Enhancements to this resolution can be easily made as emerging needs dictate, for example made possible by the emergence of IGBP 1-km land cover and topography data sets. At any scale, these GIS-based data sets will serve as the raw material by which the world's drainage networks can be characterized.

- Data from water monitoring programs representing both water quantity and quality. These are available both from global archives (e.g. GEMS-Water, WMO-Global Runoff Data Center) and regional-to-continental scale holdings (e.g. Arctic Mapping and Assessment Programme). A specific Durham Workshop recommendation was the development of a 30-year time series of information by which to characterize the contemporary state of rivers, documenting their "mean" condition as well as their inter and intra-annual variability. An active and ongoing collaboration between BAHC and the existing monitoring programs will be essential. A linkage of the GEMS-GLORI (Global River Inputs to the Ocean) data base to TYGRIS-BAHC has recently been completed (Figure 3).
- A framework to derive a global river basin classification system that can be used in a set of first principle models of drainage basin water and material fluxes. This basin classification system will use information from the TYGRIS-BAHC biophysical data sets in conjunction with the river monitoring data to develop a set of rules by which information from well-monitored watersheds can be extrapolated to unmonitored basins. This typology will be applied to various classes of models to derive time and space-varying fluxes. A close collaboration with GEMS-Water, IGBP PAGES and LOICZ, and relevant commissions of the International Association of Hydrological Sciences (IAHS) is envisioned.
- A product generation component that can be used to produce maps and summary statistics. TYGRIS-BAHC will facilitate scientific visualization of the spatial patterns of drainage basin response. This will be called upon as well to produce regional, continental, ocean basin, and global-scale summaries of riverine fluxes.
- Integration of geographically-referenced process models within the overall GIS framework. These will include prototype horizontal transport models predicting time-varying discharge. Support could also be given toward, for example, the development of IGBP suspended sediment transport models in collaboration with the PAGES Fluvial Transport Group. Eventual linkage to Earth System Models currently under development through GAIM can also be envisioned.

Support for IGBP and Other Water-related Initiatives

The development of TYGRIS-BAHC is intended to catalyze drainage basin research both within IGBP and with other affiliated organizations and programs such as IAHS, WMO, UNESCO, WHO/GEMS-Water, SCOPE (Scientific Committee on Problems of the Environment). TYGRIS-BAHC figures prominently in SCOPE-N

TABLE 1. Proposed initial contents of the GIS data bank of TYGRIS-BAHC version 1.0. These data sets are at a variety of resolutions, from 1 km to 0.5 degree (lat. x long) for gridded data and from 1:1M to 1:80M for maps. There are also local site-specific data. Several data sets are already available in computerized format. A full listing including detailed citations are given in the Durham Workshop Report (IGBP Report No. 39).

- **Watershed Boundaries and River Networks**
- **Digital Topography**
- **Surface Attributes**
  - Potential vegetation
  - Land cover
  - Soils
- **Geology /Lithology / Age**
- **NO_y Deposition**
- **Population**
  - Human
  - Livestock
- **Climate**
  - Temperature
  - Precipitation
  - Radiation
  - Winds,vapor pressure
- **Industrial / Demophoric Indices**
- **Sewage Collection Rate and Treatment**
- **Water Balance Elements**
  - RO, ET, Δ storage
- **Water Engineering Works**
  - Major diversions, dams, etc.
- **Hydrogeographic Attributes**
  - Groundwater resources
  - River density
  - Lake density and attributes
  - Wetland density and connectivity
- **Fertilizer Inputs**

activities in attempting to globally map anthropogenic loadings of N from the land mass to the coastal zones of the world. These estimates will be made on the more than 6000 individual drainage basins simulated within TYGRIS, which in turn will be loaded as boundary conditions to the LOICZ coastal zone typology system for nutrients.

These activities will also support the newly-formed IGBP Water Group (now headed by M. Meybeck) which forms the IGBP-wide context for drainage basin research. The charge of this group is to integrate the several individual elements of the IGBP Programme Elements dealing with the inland waters issue and to coordinate these efforts both within the IGBP and with other international organizations such as the World Meteorological Organization (WCRP, GEWEX, ISLSCP), Global Climate / Terrestrial Observational Systems (GCOS/GTOS), UNESCO's International Hydrological Programme, UNEP/WHO-GEMS-Water, IHDP (International Human Dimensions Programme on Global Environmental Change), and ICSU (International Council for Science) Data Centers.

A Major Challenge: Deterioration of Monitoring Network Data Holdings

The scientific basis for developing this knowledge will ultimately depend on an appropriate data base management system as well as modelling tools. We recently convened a Workshop on Global Hydrological Data Sets at the IAHS IUGG Congress in Birmingham, bringing together experts from both the water sciences, water policy, and state-of-the-art digital data management fields. It was recognized that no matter how sophisticated our computing and hydrological software systems become, they will simply remain inadequate without basic information on water quantity and quality data, and information that is of high quality and relevance to the study of freshwaters at the global scale. As the water sciences community struggles to cope with the disastrous loss of monitoring stations in regions such as Africa and the former Soviet Union, it becomes increasingly important to inventory, collect, and in some cases "rescue" precious data sources. Even in relatively well-monitored parts of the globe, there has been a sustained decrease in monitoring capacity. For example, the US Geological Survey has recently been abandoning about 80 gauging stations per year.

Arming the community with such data sets will be an increasingly critical challenge into the 21st century. With this goal in mind, we propose the development of a Global River and Drainage Basin Archive Series that can supply the water sciences and management communities with a coherent suite of information resources upon which to monitor the status of freshwaters, analyze the role of drainage basins in the global change question, and promote the wise use of increasingly scarce water resources. We envision the Archive Series as a multi-year effort involving several international organizations and scientific contributors.

The Global River and Drainage Basin Archive Series will serve as a repository for basic information on river discharge, river and lake chemistry, and the biophysical attributes of drainage basins. Each volume in the Archive Series would be developed by community consensus, geographically co-registered to detailed maps, provided with a common naming convention, systematically checked for errors, tabulated in a standardized format, and distributed widely in digital form. A meta-data base listing hydrological data sets described at the IUGG Global Data Sets Workshop is currently being constructed (see: http://www.csrc.sr.unh.edu/hydro/welcome.html) in the hopes of creating an initial focal point for such data resources.

The archives could be built around several topical areas and foster IGBP interactions with other agencies dedicated to the water sciences. For example, one topical area could be contemporary river discharges bringing together information from prior UNESCO river archives, data from the WMO-Global Runoff Data Center, and individual researchers. A CD-ROM is currently being pressed which combines WMO station hydrological archives and 30-minute spatial resolution river networks which will be available freely and without restriction. Data from the GEMS-Global River Inputs to the Ocean project (GEMS-GLORI) (Figure 3) will also soon be available on CD-ROM and together with the runoff data base can be considered as the first release of the Archive Series. Additional subjects could be water use for irrigation, flow regime alteration by impoundments, nutrient chemistry changes in developing region drainage basins, changes in suspended sediment flux, and the changing status of water chemistry in inland lakes and reservoirs. A specific global data base on pristine river chemistry is also in progress.

Given the importance and tremendous scope of this effort, the Global River and Drainage Basin Archives Series will need to be supported by a broad spectrum of international agencies, including IGBP, GEMS-Water / UNEP / WHO, UNESCO, and IAHS. Scientific sponsorship would be from IGBP and several of its individual Programme Elements (i.e. BAHC, PAGES, LOICZ), UNESCO-IHP technical groups, GEMS-Water / UNEP / WHO, WMO's Global Runoff Data Center, and the International Lake Environment Committee (ILEC). The scientific networking capabilities of UNESCO, WMO, and IAHS should facilitate the assembly of interested participants, and when each volume is complete, dissemination to a wide audience of scientists and environmental managers. Funding for the initiative could be from UNEP/GEMS/GEF and individual national agencies. We strongly recommend the IGBP take the lead in facilitating workshops and expert working group activities to help stem the tide on this significant loss of scientific information.

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People and Events

Sheila Lunter joins GCTE

In July the IGBP Secretariat lost someone important, but happily enough our loss was GCTE's gain. Sheila Lunter, the IGBP Information Officer, realised a long standing dream and exchanged the cool (invigorating?), dark (inspiring?) and lengthy (well, lengthy) winters of Stockholm for the more benign climate of Canberra, Australia, where she is replacing Rowena Foster, who is on maternity leave. We are sure all of IGBP will miss her. We certainly do already miss her cheer here in Stockholm as winter approaches us (and Sheila slides into summer), and we wish her well down under. We have every confidence that this particular Sheila will make her mark on GCTE and Australia.

Courtesy of J. Morais

LUCC International Project Office in transition

After a period of three and a half years of distinguished work at the LUCC International Project Office Xavier Baulies is moving back to the Institut Cartogràfic de Catalunya in Barcelona. Xavier's role was instrumental in setting up and guiding an IPO from Science Plan to full implementation phase. Many of us will always treasure the stimulating scientific meetings organised by the LUCC IPO with the proverbial Catalan hospitality, especially the complementing magic moments when Xavier's gifted 'bass' voice reminded us that art is another reason for us to carry on doing science.

An 'interim' IPO has been established at the IHDP Secretariat in Bonn, c/o Ms Ike Holtmann, e-mail: holtmann.ihdp@uni-bonn.de,http://www.uni-bonn.de/ihdp/lucc

Manuel Barange joins GLOBEC as Executive Officer

Manuel Barange grew up in Barcelona (Spain), where he completed a B.Sc. (Hon.) in 1986. He conducted post-graduate studies at the Instituto de Ciencias del Mar (ICM, Barcelona, Spain) and at the Sea Fisheries Research Institute (SFRI, Cape Town, South Africa), obtaining a PhD in 1991 on the ecology of euphausiids in the Benguela upwelling system. Following a post-doctoral project on the acoustic assessment of Antarctic krill he joined the fisheries acoustics team of the SFRI in 1993, and became head of its Surveys Division in 1996.

He has conducted research on euphausiid ecology, zooplankton and fish aggregative behaviour, vertical migration and trophic ecology of fish, survey design and acoustic assessment of pelagic and semi-demersal fish populations; Manuel has published over 50 peer-reviewed papers on these topics. He has also participated actively in the administrative and scientific management of the SFRI (now Marine and Coastal Management), particularly in regional and international initiatives on the dynamics of fisheries resources and their physical environment in the Benguela. After a decade in southern Africa, Manuel will join GLOBEC as Director of the IPO on October 1st, based at the Plymouth Marine Laboratory. A dual citizen of Spain and South Africa, Manuel Barange is married to RenTe, an Irish citizen born in Zimbabwe and has two children.

GLOBEC are also currently recruiting a Deputy Executive Officer, to fill a position supported by the University of Plymouth and with special responsibility for data issues. Together with Andrea Watson, Media Co-ordinator, this will complete the GLOBEC IPO team.

SURFACE OCEAN LOWER ATMOSPHERE STUDY (SOLAS) OPEN SCIENCE CONFERENCE

DATE: 20-24 February 2000

LOCATION: Damp (near Kiel), Germany

R.A. Duce (rduce@ocean.tamu.edu) P.S. Liss (p.liss@uea.ac.uk) Co-Chairs SOLAS Conference Planning Commitee

SOLAS is a potential new interdisciplinary research effort whose planning to date has been sponsored by IGBP, and SCOR with additional financial support from the European Union and with considerable interest from WCRP. The scientific focus for the proposed effort is the interaction between the atmosphere, climate, and marine biogeochemical processes. SOLAS would benefit from the work of several previous projects, principally IGAC, JGOFS and WOCE, and would be linked to CLIVAR. More information on SOLAS can be found at: http://www.ifm.uni-kiel.de/ch/solas/main.html

The purpose of the SOLAS Open Science Conference is to communicate and discuss these and other related ideas with as wide a group of interested scientists as possible.

The conference will be organised around a set of scientific questions to be presented in plenary talks and reviewed in discussion groups. Other topics have been chosen as well for presentations and discussion groups, mostly reviewing current skills and projected needs and capabilities for investigating ocean-atmosphere interactions.

Plenary speakers and topics are:

- Meinrat Andreae, Germany: How much might marine biological sulphur emissions change, and would such changes have climatic implications?
- Richard Barber, U.S.: How much might the atmospheric delivery of marine nutrients, such as iron and nitrogen, change, and would such changes have global implications?
- Andy Watson, U.K.: Are changes in marine biogeochemistry in the next century likely to have a significant influence on the net oceanic uptake of carbon dioxide?
- Scott Doney, U.S. and Peter Liss, UK.: Physical and biogeochemical perspectives on how changes in climate-driven physical forcing might affect upper ocean biogeochemistry and air-sea fluxes.
- Barry Huebert, U.S.: Are changes in the marine emissions of gases and particles likely to have a significant influence on atmospheric chemistry?
- Neil Blough, U.S.: Are changes in the spectrum and intensity of radiation likely to affect the production of trace gases in the surface ocean?
- Bill Jenkins, UK.: Observational and modelling aspects of mixed layer physics in SOLAS.
- David Farmer, Canada: Air-sea flux measurement techniques in SOLAS
- James Yoder, US.: What is the role of remote sensing in SOLAS?
- David Karl, U.S. and Graeme Pearman, Australia: What are the roles of marine and time series in SOLAS?
- Veronique Gargon, France: Modelling biogeochemistry in the upper ocean.
- Len Barrie, Canada: Modelling oxidation and aerosol processes in the marine atmosphere.

Poster sessions are also planned, further details to be announced.

The conference will be hosted by the Institut für Meereskunde, Kiel, Germany, and will be held in Damp, which is a resort village and conference centre on the Baltic coast just north of Kiel.

A registration fee of DM190 (approx. US$100) will be charged. Some funds are being sought to cover some travel costs but this support will be very limited and is designed to encourage attendance of younger scientists and those from developing countries. Registration deadline is November 1, 1999.

Further conference informaton is available at:

http://www.ifm.uni-kiel.de/ch/solas/meeting.html

Downloadable files of the conference registration form with full instructions can also be obtained from this site.

Enquiries about the conference or registration procedure can be directed towards the local host for the SOLAS Open Science Meeting:

Ute Weidinger - Conference Organizer

Institut für Meereskunde, Düsternbrooker Weg 20, 24105 Kiel, GERMANY.

Phone/Fax: +49 (431) 597 3811,
E-mail: solas@ifm.uni-kiel.de

Science Communicator

for the

International Geosphere-Biosphere Programme (IGBP)

The International Geosphere-Biosphere Programme (IGBP) invites applications for the position of Science Communicator. The IGBP is an international research programme under the auspices of the International Council for Science (ICSU). It has as its objective to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. Research is planned by Core Projects, based throughout the major regions of the world, on the distinct sub-components of the Earth system, as well as by three new cross-cutting activities on carbon, water and food/fibre, to which the Core Projects contribute.

The person we seek will further develop the profile of IGBP's research programme, while building the corporate identity of IGBP as a whole, leading up to a major open science conference in July 2001 in Amsterdam, and beyond. IGBP operates within sensitive political arenas to deliver science-based information on global change.

The position is based at the IGBP Secretariat (8 person staff) in Stockholm, Sweden and reports to the Executive Director of IGBP. The successful candidate will:

- have highly developed editing and communication skills, verbal and written, and experience as a working journalist
- have well developed interpersonal skills
- be fluent in English
- have experience in public information delivery, particularly in a scientific environment
- be willing to travel extensively
- be able to initiate and manage a large and complex workload to tight deadlines and be responsible for communications outcomes
- have the capacity to deliver global media campaigns

The Science Communicator, to be appointed initially for a 3-year period, will be an employee of the Royal Swedish Academy of Sciences in Stockholm, where the IGBP Secretariat is located. The salary is negotiable and will take due account of the experience and qualifications of the candidate and the costs and benefits of living in Stockholm.

Applications that systematically address the selection criteria and include brief, representative examples of previous work and a curriculum vitae, must be received no later than 5th November 1999 by the Executive Director of IGBP, IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Fax: (+46-8) 16 64 05, E-mail: sec@igbp.kva.se

Key selection criteria and position description, as well as further information on IGBP, are available from Will Steffen, IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel (+46-8) 16 64 48, Fax: (+46-8) 16 64 05, E-mail: sec@igbp.kva.se, Webpage: http://www.igbp.kva.se

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