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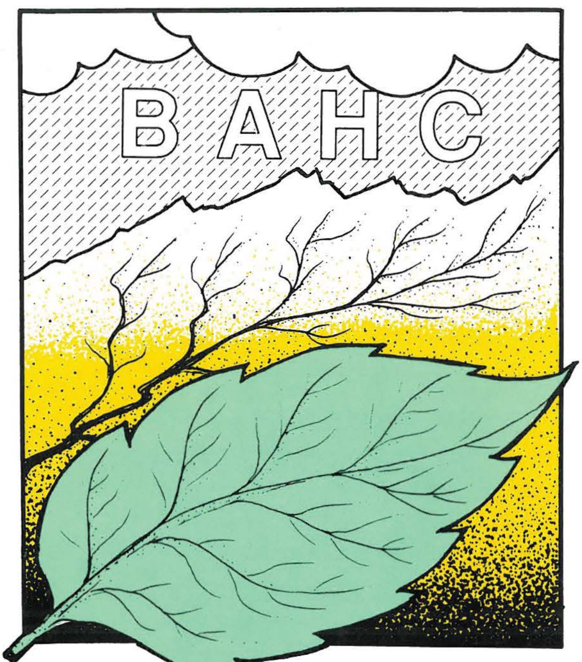


# Biospheric Aspects of the Hydrological Cycle

# The Operational Plan

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1993

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## The Operational Plan

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# Contents

# 1. Introduction

Increasing knowledge about the processes responsible for global climatic change shows that the physical component of the Earth system is intimately interwoven with both the global chemical cycles and the biosphere. Both provide not only boundary conditions for the development of dynamical process models of the atmosphere; they must be understood as integral parts of the whole Earth system. Even under conditions governed entirely by processes in which mankind is not or was not involved, changes in physical parameters of the Earth system always affect biogeochemical cycles as well as life on Earth and vice versa. To explore more closely these interrelationships, the International Council of Scientific Unions (ICSU) decided in 1986 to establish the International Geosphere-Biosphere Programme (IGBP), which received broad intergovernmental acknowledgement by the UN General Assembly in December 1989.

During the last decade there has been a growing awareness of the importance of hydrological land-surface processes in global change models. Climatic model simulations are sensitive to changes in surface albedo, surface roughness, soil moisture, and evaporation, all of which are influenced by vegetation and snow cover. Nevertheless, the role of the biosphere is not sufficiently described in these models and the representation of hydrological processes is one of the weakest and most challenging aspects of the present general circulation models (GCMs). A profound knowledge of eco-hydrological processes at the land surface is needed to assess the impact on freshwater resources of climatic changes and direct human pressures on the biosphere, and hence their effect on the habitability of the Earth. The availability of fresh water, which determines the productivity of natural and managed ecosystems, is becoming one of the most important determinants for sustainable development.

Patterns of precipitation are highly variable, both spatially and temporally. Deserts and rain forests are sometimes just a mountain range apart; extreme droughts and floods periodically devastate large areas. In the event of global warming, regional alterations in precipitation regimes are likely to be of larger ecological and socio-economic importance than the direct consequences of changes in other climatic characteristics such as, for instance, annual mean temperature. These topics will receive overriding attention in the next decades and have already proven to be extremely important in many parts of the world.

In view of the gaps in our understanding of the processes at the land surface and the interaction of vegetation with the continental component of the hydrological cycle, the IGBP decided to establish a Core Project on "Biospheric Aspects of the Hydrological Cycle (BAHC)".

The challenge of understanding interactions across the diversity of processes and scales calls for a new era of collaboration in which the interactions between hydrologists, atmospheric scientists, soil scientists, and ecologists mature to the stage where boundaries between these traditional fields disappear. BAHC will play a key role in this process and intends to contribute to a number of other projects and programmes where phenomena and processes are coupled to, or dependent on, the cycling of water. Water cycles continuously through several systems, from the Earth's surface to the atmosphere, where it participates in the global circulation, and back to the Earth's surface, where it moistens soils and produces runoff into freshwater systems of the terrestrial biosphere, providing the transport medium for many substances crucial for environmental conditions, and the solvent in biogeochemical cycles. It is basic for sustainable development and human welfare. Research is ongoing in the different compartments of the hydrological cycle as well as on the interaction of vegetation and soils with water. The goal is to synthesise the conceptual and physico-mathematical models, which hydrologists and meteorologists apply to describe energy and moisture exchange at the land-surface–atmosphere interface, with the insights gained by plant physiologists, soil scientists, and ecologists about the relationships between vegetation, soils and water availability. While meteorologists and climate modellers work mostly at scales of 100-250 km (the grid width of global climate models) ecologists work mostly at scales of 1 km or less. This gap between the large and the small scales has to be bridged.

BAHC is an interdisciplinary project combining and integrating expertise from many disciplines, in particular ecology, pedology, hydrology, and meteorology. BAHC in this respect has a transfer function: on the one hand developing techniques and algorithms to provide climatic data needed for hydroecological research, thereby translating the results of the World Climate Research Programme (WCRP) into the scales relevant for studies of changes of the conditions at the land surfaces, and on the other hand, providing soil-vegetation-atmosphere-transfer (SVAT) schemes which better reflect the biospheric control of energy and water transfer at larger scales, in particular, the areal pattern of heat and moisture fluxes according to land-surface heterogeneity. BAHC concentrates on investigations at scales where detailed studies of hydroecological processes are feasible in selected areas representing major ecosystems of the world and across boundaries between different ecosystems (ecotones, biome boundaries, etc).

The integration of processes at the continental scale is the research area of the Global Energy and Water Cycle Experiment (GEWEX) of the WCRP, that addresses the large-scale processes of evaporation, including oceanic evaporation, and the transport of global atmospheric water vapour. BAHC will closely interact with GEWEX and will in particular study the changes that are to be expected at the land surface, if climatic changes and human actions continue to affect the conditions at the surface of the Earth. The result of this work should provide improved time-varying boundary conditions for global change studies.

BAHC will also work together with the Human Dimensions of Global Environmental Change Programme (HDP), to identify more precisely the socio-economic implications of regional and global changes in the availability of freshwater (quantity, quality, or both).

A number of tasks defined in the BAHC research plan will be carried out jointly with other IGBP Core Projects and Framework Activities, especially Global Change and Terrestrial Ecosystems (GCTE), Land-Ocean Interactions in the Coastal Zone (LOICZ), and the IGBP Data and Information System (IGBP-DIS). There will also be close collaboration with the projects on International Global Atmospheric Chemistry (IGAC) and Global Analysis, Interpretation and Modelling (GAIM), and the Global Change System for Analysis, Research and Training (START).



Outside the IGBP, other important partners and collaborators include the International Hydrological Programme (IHP) and the Man and the Biosphere programme (MAB) of the United Nations Education, Scientific and Cultural Organization (UNESCO); the United Nations Environmental Programme (UNEP); the International Satellite Land-surface Climatology Project (ISLSCP), part of the Global Energy and Water Cycle Experiment (GEWEX); and the International Association of Hydrological Sciences (IAHS). Details of collaboration are specified in Chapters 5-8.

# 2. Scientific Mandate and Aims

The principle question, that BAHC was designed to address is: **How does vegetation interact with physical processes of the hydrological cycle?** From that, two basic tasks were developed (IGBP Global Change Report No. 12, 1990):

- To determine the biospheric controls of the hydrologic cycle through field measurements, for the purpose of developing models of energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales ranging from vegetation patches to GCM grid cells

- To develop appropriate data bases that can be used to describe the interactions between the biosphere and the physical Earth system, and to test/validate model simulations of such interactions.

BAHC was established as a Core Project within the International Geosphere-Biosphere Programme (IGBP) to address these tasks over the full range of spatial and temporal scales, for different types of landscapes and ecosystems, and under existing and changing conditions. To this end the specific aims of BAHC were defined:

(i) Investigate the biospheric controls of the hydrological cycle, and their climatic, hydrological, and environmental significance

(ii) Improve our understanding of the exchanges of water, carbon, and energy at the soil-vegetation-atmosphere interface

(iii) Assess ongoing changes in land-surface properties due to climatic and other changes that affect the interactions between the biosphere, atmosphere, hydrosphere, and lithosphere at different scales

(iv) Estimate the role of plant communities, terrestrial and freshwater ecosystems in the fluxes of energy, water, carbon, and other substances between land and air, and land and river systems, considering land-surface and subsurface features (in particular biosphere, soil and hydrological characteristics, and their dependence on other land-surface features such as topography)

(v) Improve our capability to model all processes at different scales from the micro- to the 1 - 50 km scale in past, present and expected future conditions, considering climate explicitly

(vi) Provide comprehensive and simplified ecohydrological models to be implemented as components of sophisticated other models

(vii) Provide improved parameter estimation techniques, which can be applied worldwide and make use of generally available databases of ecosystem, soil, and other related properties derived from conventional sources or remote sensing



(viii) Test and validate model simulations and data-processing algorithms for remote sensed data

(ix) Simulate for specified climatic conditions (a) the behaviour of terrestrial ecosystems and freshwater ecosystems in view of the fluxes of energy, water, carbon, and other substances between land and air, (b) changes in biospheric characteristics, and (c) changes in surface and subsurface hydrology.

BAHC as an interdisciplinary project must integrate knowledge and expertise from several natural science fields, in particular, meteorology, hydrology, pedology, and ecology. Accordingly, BAHC has developed a scientific framework for joint research activities, which combine different investigation principles, analytical methods and modelling techniques.

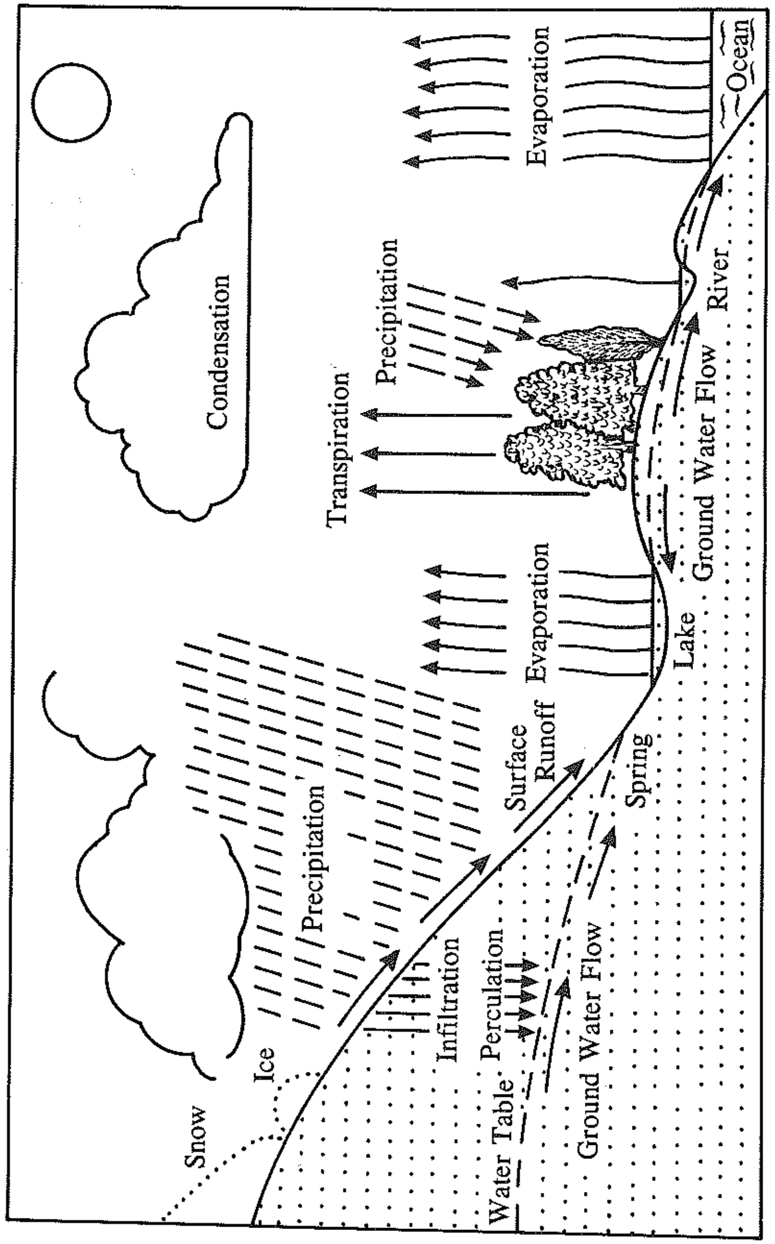



Fig. 1 Schematic representation of the hydrological cycle



# 3. Scope and Main Subjects of BAHC

## The Hydrological Cycle

Moisture and energy fluxes at the land-surface-atmosphere interface, including water phase changes (evaporation, condensation, freezing, and melting) are all intimately linked to the dynamics of the atmosphere and to its energy budget. They form an important part of the hydrological cycle which is schematically represented in Figure 1.

The hydrological cycle shown in Figure 1 along with several other processes generates the Earth's climate; it serves also as a freshwater distillation system. It has two components: the first is associated with the movement of water and energy between oceans and continents due to the general global circulation system of the atmosphere; the second is continent-internal, i.e., water evaporated from the land surface is returned to it as rain or snowfall. The land-generated hydrological cycle components, which are superimposed on the ocean-continent advective cycle component, are in general more efficient. They are determined by energy-water interactions at the land surface, and will therefore change in response to the way that the land surface is developed and managed.

Annually about $5.5 \times 10^5$ km$^3$ water is evaporated from the oceans and land surfaces. The energy necessary to convert this amount of water into vapour corresponds to 36% of the solar radiation absorbed by the whole Earth, namely $1.4 \times 10^{24}$ Joules per year. The evaporated water is transported by the general circulation of the atmosphere, which is driven by the higher-than-average conversion of solar radiation into heat in the tropics and the corresponding excess loss of energy by the emission of infrared radiation to space over the polar regions. To transport the energy from the tropics to the high latitudes, the moist air undergoes a number of convection processes as it circulates in large cells as well as in small eddies over the hemispheres. Due to condensation and precipitation processes that occur along this way, the average residence time of a water molecule in the air is only 10 days. On the average, a total of about $5 \times 10^{15}$ watts is transported from the tropics to the polar regions in each hemisphere, including the contribution of the oceanic circulation system. Thus, the global meridional energy flux is about five times smaller than the power needed for evaporation. As a global average it was estimated that only about 40% of the precipitation falling over continents returns to the oceans by river flow. The other part re-evaporates and falls back to the ground further downwind. On the average, the water imported from the oceans is recycled and precipitated 2.7 times over land before it runs back to the ocean.

About 9% of the water evaporating from the oceans is transported by the global general circulation to the continents. Atmospheric processes modulate its precipitation as rain or snow, which supplies the vegetation, the soils and the subsurface aquifers with water. This import of water from the oceans is crucial for the existence of vegetation at the land surface. Without this transport the land would gradually dry out, exterminating life on its surface.

# Processes and Interactions at the Soil-Vegetation-Atmosphere Interface

The biosphere strongly interacts with the atmosphere by its controls on the return of water back to the atmosphere, as evaporation and transpiration. Therefore, changes in plant cover, due to either natural events or human activities, can have a significant impact on the hydrological cycle, and consequently on the other components of the climatic system.

Vegetation influences the exchange of energy, water, carbon and other substances at the land-surface-atmosphere interface in many ways. Its colour and structure affects the absorption of solar radiation. Leaves and branches increase the surface area for evaporation, intercept part of precipitation, and by increasing friction for air movement increase the thickness of the boundary layer. Leaf litter can affect surface runoff and percolation. The part of precipitation that is intercepted by the plants is more quickly re-evaporated. The water which reaches the soil might run off at the surface or infiltrate to deeper layers, where it replenishes soil moisture or recharges groundwater.

Root growth and decay, and the decomposition of plant organic matter, by soil fauna and microbes, modify the soil texture and structure, affecting infiltration, percolation, and drainage. The combined effects of these processes promote both water penetration and its return to the atmosphere. Thus, the presence of vegetation and the type of the plants determine to a large extent the partitioning of the water into different intermediate reservoirs (Figure 2).

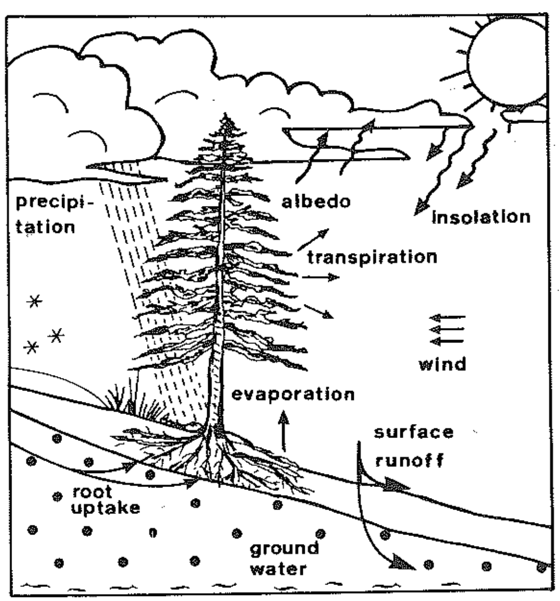



Fig. 2 Above and below-ground vegetation structure, soil properties, and other biological characteristics that strongly influence water and energy exchanges at the land surface



As a result, various soil moisture patterns are observed that vary in space and time according to the heterogeneity in land surface and subsurface conditions, topography, and the non-uniform distribution of rainfall and snow melt. They are critical for many hydrological processes, in particular transpiration, infiltration, and runoff generation. It is therefore essential to assess and represent the relevant topographic, vegetation, soil and geological parameters that control soil moisture, surface and subsurface hydrological conditions; the partitioning of precipitation into different intermediate storage (surface water, soil water, groundwater, snow, and ice); and the flows of water, nutrients and other substances.

After precipitation, some of the intercepted water returns to the atmosphere and evaporation occurs from the plants. The biomass production due to photosynthesis causes water to move upwards from the soils through the roots and stems into the leaves. The intake of carbon dioxide through the stomata is accompanied by the loss of water. The heat consumed by the evaporation process cools the leaves and keeps the temperature within certain limits, which helps to maintain optimal conditions for biomass production. This latent heat returns a substantial fraction of the precipitated water to the atmosphere where it may later be released during condensation. Furthermore, that condensed water (clouds) is available for precipitation downwind. In addition to the transpiration of plants, evaporation from soil has to be considered. It depends on the groundwater level, the structure of the soil in the overlying unsaturated zone and the solar energy reaching the soil surface.

The proportion of precipitation falling as snow is important locally and regionally. Snowfall increases surface albedo. Water can be stored in snow for several months, but may also leave the system within hours. It is ecologically significant that snowpack stores seasonal precipitation, and in many dry areas snowmelt can be the only time in the growing season when soil profiles are moist. In such areas, a high correlation is observed between the water equivalent of the spring snowpack and ecosystem primary production. The protection of vegetation by snow during harsh winters influences timber-line vegetation survival. However, in mesic (less extreme) climates a thick snowpack may impede vegetation development. Finally, changes in the areal coverage and seasonal timing of continental snowpack may be an early and important signal of progressive climatic change.

Intimately related to processes at the soil-vegetation-atmosphere interface are changes in the soils, topography, and vegetative cover. Landscapes are as a rule interconnected by surface drainages and aquifers by precipitation surplus and the run-off of excess soil water (Figure 1). These water movements have to be taken into account in order to understand the interactions between climate, human impacts, and the land surface at a range of scales.

Human activities can cause rapid modification of the characteristics of the landscape and its hydrological function. Individual and societal endeavours, such as agriculture, urbanization, deforestation, and drainage of wetlands, and their associated hydrological features (e.g., dams, irrigation, hydraulic structures, and terraces) continuously change the land surface. These changes not only have socio-economic and ecological consequences at different time scales; they may also have an impact on the climate and on the hydrological cycle, at least at the regional scale. A small additional change in the climate may then heavily distort a delicate equilibrium between natural processes and human requirements.

One of the distortions already observed in many parts of the world is land degradation and desertification. Many effects may come together to start a desertification process: overpopulation, overgrazing, fires, recultivation with unadapted species, over-exploitation of water resources, soil salinization, wind and water erosion, loss and inadequate replacement of nutrients, climatic variability and climatic change. The study of these processes and their mutual interactions requires from BAHC an integrated approach that builds upon detailed investigations of processes in specific ecosystems and climatic regions to direct research into the connections with the general circulation of the atmosphere and its changes with respect to variability, especially at the 1 to 50 km scale, which are studied in the framework of the WCRP.

## Relations between the Hydrological Cycle and Other Cycles

The exchange of energy and water through the land-surface–atmosphere interface controls and is itself controlled by other land-surface–atmosphere exchanges, in particular the exchange of carbon and nutrients, depending on the vigour and growth cycle of the vegetation cover, on land management, including the application of fertilizers, insecticides, and on the movement of water.

The components of the water cycle over land are connected with biogeochemical cycles through plants, composing an interactive biosphere-climate system. Both surface and subsurface waters contain dissolved chemical compounds, which either originate from the soil, or from organic matter decomposition at the soil surface. Other dissolved material resulting from land management practices (fertilizers, insecticides, etc.,) or waste disposal is also transported in this manner. Energy and water interactions of the terrestrial biosphere with the atmosphere on one hand, and water flows through soils, aquifers, and rivers systems on the other, are strongly linked and determine carbon, nutrient, and other fluxes. It has been indicated that vegetation strongly influences the amount and rate of water falling directly at the surface and also the possible runoff at the surface. If the vegetation is sparse, this water might erode large amounts of soil with its nutrients and organic detritus into rivers and into the ocean. Because of the large quantity of materials eroded and dissolved by surface waters, studies of the hydrological cycle must take into account the interactions with geochemical cycles.

Other examples are the production of methane ($CH_4$) in wetlands and the role of snowmelt periods, which can be a trigger for a short, intensive period of annual nutrient mobilization and transport in snow dominated ecosystems. This snowmelt nutrient flush associated with increasing spring temperatures can be the most active time of the entire year for ecosystem trace gas fluxes and photosynthetic activity.

Important subjects to be addressed by BAHC are therefore:

- How do leaf stomata control the exchanges of $CO_2$ and water vapour with the atmosphere, and what are their dependencies on soil moisture?
- What are the quantities of $CO_2$, nutrients and trace gases that are transported with percolating water and subsurface flows into rivers and with river flow into the oceans?



**Table 1. Brief characterization of main types of land-surface heterogeneities**

| Type | Characteristics |
|---|---|
| 1 | Extended distinct land-surface discontinuities such as boundaries between<br>• land and water bodies (oceans, lakes, large rivers, etc.,)<br>• wet and dry land surfaces, in particular boundaries between wetlands, irrigated areas and adjacent dry environments (steppe, savannah, desert, etc.) |
| 2 | Slopes at the margins of mountain ranges or high mountains (issue of topography) |
| 3 | Discontinuities as characterized in (1), but small in size (patch), such as oases, small lakes, small rivers, and wet patches in dry environments |
| 4 | General landscape patchiness in flat and hilly terrain, i.e., mosaic of patches of different vegetation type, soil type, land use |
| 5 | Landscape patchiness as in (4) but overlaid by topography, i.e., with distinct differences in hydrology depending on position, inclination, aspect, and subsurface conditions |
| 6 | Intra-patch heterogeneity in terms of the microscale variability of the soil and plant characteristics, such as field capacity, water holding and infiltration capacity, leaf area index, leaf angle, root depth, etc. |

## The Role of Land-Surface Heterogeneity

Heterogeneity at the land surface is the key to understanding and modelling important land-surface processes, in particular evapotranspiration and runoff formation. Areal heterogeneities in topography, land use, vegetation, and soil properties occur as more or less distinct areal differences, even on small scales, in the subregional meteorological, hydrological and ecological conditions, and accordingly in the energy and moisture fluxes between the land surface and the atmosphere, in the infiltration and runoff formation behaviour, and in many other hydrological and ecological features. Land surface heterogeneity occurs in various forms, differing in the degree of impacts or influence on land-surface processes. Table 1 provides information on main types of land surface heterogeneity to be considered in BAHC.

The complex interrelations, dependencies and feedbacks between the planetary boundary layer (PBL) and the land surface, including vegetation characteristics, are generally not sufficiently understood nor represented in parameterizations of land-surface processes. Therefore, heterogeneity of Types 1-5 should be further studied. In particular the role of topography (Types 2, 5, and 6) in connection with the biospheric structure and characteristics which are dependent on topography requires further study.

Land-surface heterogeneity must be considered in estimation of areal evapotranspiration for patches with individual plants such as those in oases and plantations, surrounded by bare soil. Here, areal evapotranspiration clearly has two components: the transpiration of the trees, and evaporation from bare soil between trees. Depending on the moisture in the upper soil layer, very different partitions of the incoming energy are used for each of the two evaporation components. Models are required which quantify such dependencies at the relevant scale. Land-surface heterogeneity is of special importance in the modelling of the water cycle in arid and semi-arid regions, where often desertification is connected with heavy erosion. Plants almost completely disappear, but the few remaining plants still act as a distributed source of evapotranspiration. The adequate characterization of land-surface heterogeneity in SVAT modelling is one of the greatest challenges for BAHC.

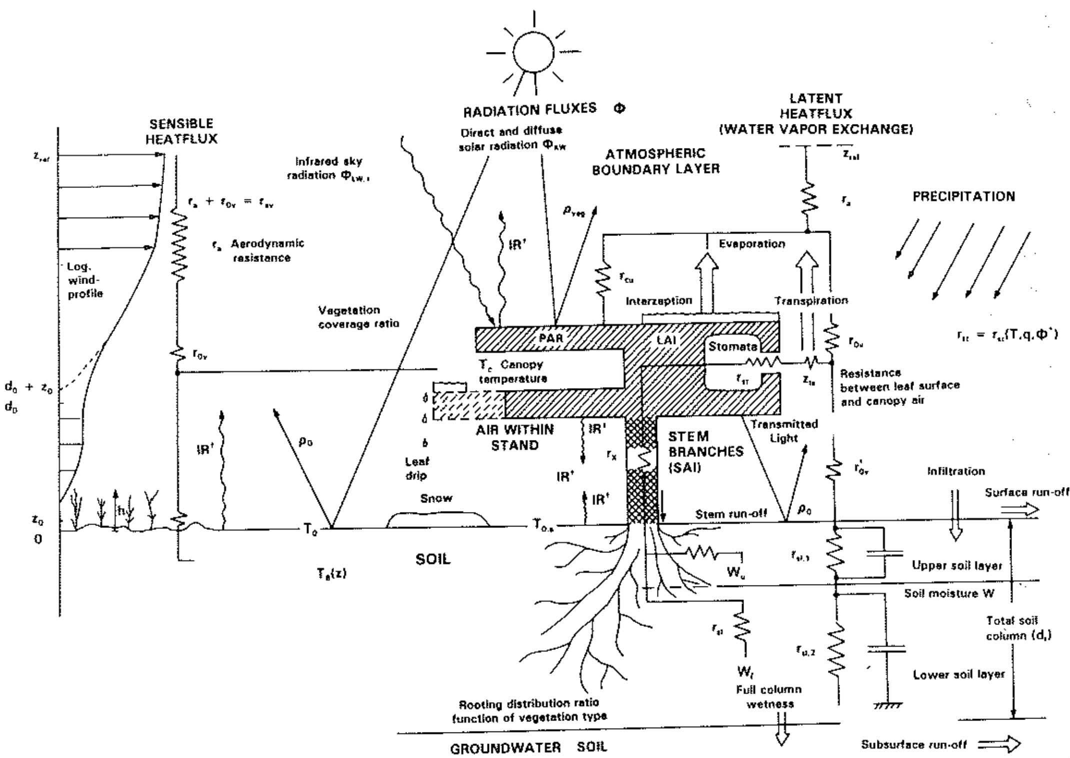



Fig. 3 Electric analogues of water and water-transfer models (Bolle, 1993)



# One-Dimensional Modelling of Soil-Vegetation-Atmosphere Interface Processes

Remarkable progress is being made in Soil-Vegetation-Atmosphere Transfer (SVAT) modelling at the patch scale, where a patch is understood as an area with homogeneous or nearly homogeneous land-surface characteristics and a uniform hydrological regime and ecological structure.

For patches it is acceptable to average the parameters (related to land-surface properties), the state variables, and the fluxes over the homogeneous small area. The general scheme of a complex SVAT model as represented in Figure 3 provides in the middle an illustration of a schematic plant indicating different characteristics, parameters, fluxes, etc., which control energy and moisture transfer. On the left side of the figure smaller second-layer vegetation is represented along with a idealized wind profile as observed in vegetation stands. The lower part of the figure a soil profile, penetrated by plant roots, indicates important soil characteristics and the role of roots

The illustration suggests that in principle a multi-layer modelling approach is required for the vegetation as well as for the soil. Nevertheless, for several purposes single-layer vegetation models have been proven as sufficient. Therefore, primary emphasis has been given to the development and validation of single layer models which adequately model the real multi-layer process.

Patch models are often also applied on larger scales for complex landscapes. This is one of the critical shortcomings of existing climate models, in particular, global circulation models (GCMs), which apply simplified patch-related SVATs to GCM grid areas of about $10^4$ to $10^5$ $km^2$ without explicit consideration of land-surface heterogeneities within a GCM grid cell. It is one of the main tasks of BAHC to overcome of this deficit by providing improved landscape models considering land-surface heterogeneity.

# The Need for Improved Modelling of Complex Landscapes

The following example illustrates the challenges and progress made in extending SVAT modelling to inhomogeneous regions, namely the biome-biogeochemical cycle (BGC) ecosystem simulator developed and applied by Running *et al.* (1989). It is represented in Figure 4 where a single parameter, the leaf-area index (LAI), describes plant behaviour and the control of the main processes in a specific biome type. In addition to LAI, a set of site data and meteorological data is used to describe the specific conditions of the site. All of these data can be derived from satellite imagery so that a general worldwide application might be possible. The main components and steps that are applied in the time integration of the simulation results are shown on the right side of Figure 4.

Figures 4 and 5 represent alternative ways of modelling the same phenomena: heat and moisture exchange at the soil-vegetation-atmosphere interface and the coupled carbon and nitrogen losses and productions, for a patch covered with vegetation of a specific type.

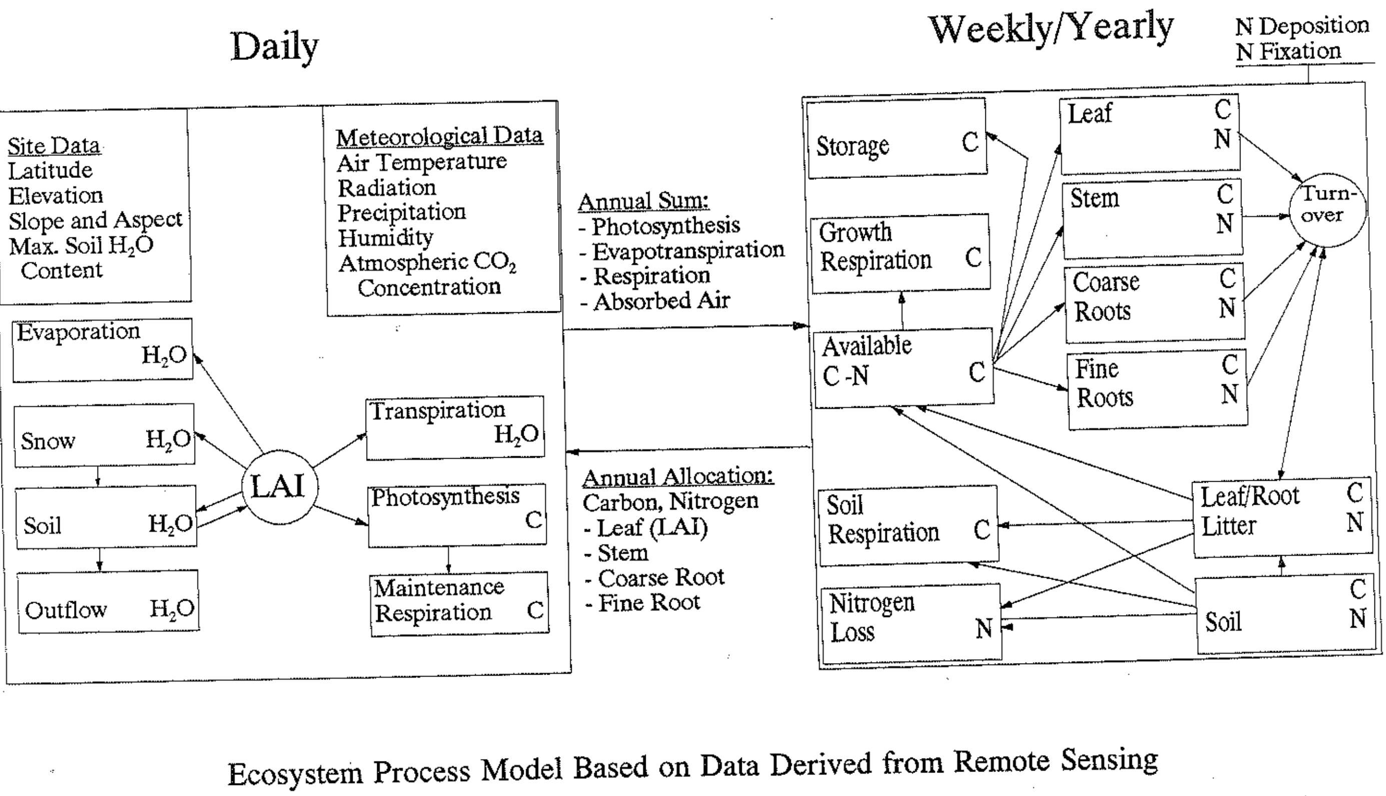



Fig. 4 An example of a SVAT model that integrates water, carbon, and nitrogen cycles with dual time (Biome-BGC) (Running, unpublished)

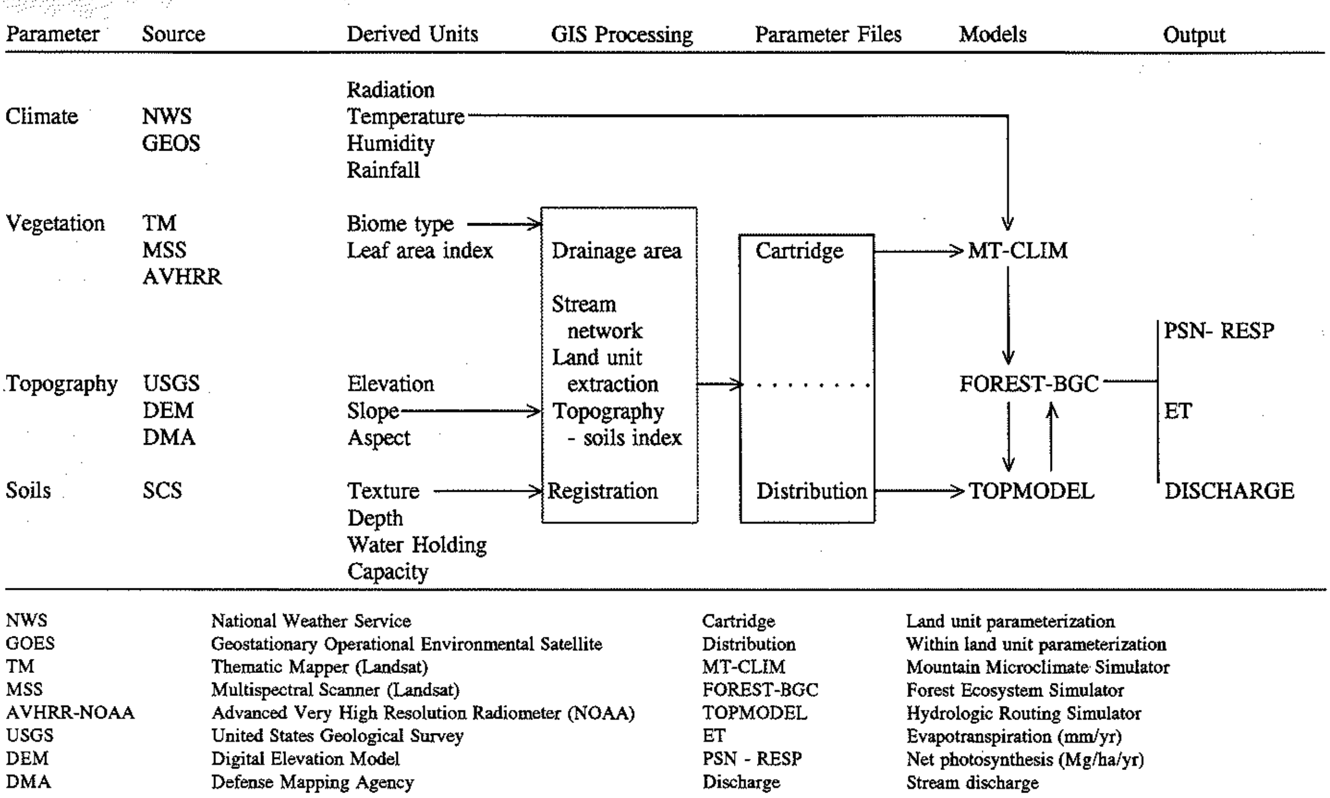



Fig. 5 A flowchart illustrating the components of the regional hydro-ecological simulation system (modified from Running, 1992)

The ultimate goal of SVAT and hydroecological modelling for complex landscapes is to take into account the areal heterogeneity of land-surface properties, driving forces, etc., as well as the long-term dynamics, natural and human-impact induced changes of the biosphere. A general scheme of a landscape and of important phenomena, subsystems, and processes involved is represented in Figure 6. It is often not possible, because of lack of data or because of computer capacity limitations, to model processes in great detail over landscapes. Where data or computer capacity are limited, areal averages are used as parameters, system inputs, and state variables in lumped models. Sometimes distribution functions are inserted to assess areal heterogeneity and improve the model performance. Increasingly models with distributed or semi-distributed parameter functions are applied, but subscale processes must be parameterized.

Large scale modelling presents several difficulties. Nonlinear relationships and differences in model parameterization to be used at different scales, for instance, pose a major problem in the verification of area-integrated approximations of land-surface processes. The description of processes looks quite different whether a *patch* (up to the order of about 100 m) is studied, or a complex landscape or river basin with a mixture of vegetation types, hills, variable depth of the groundwater level, and other differences. The interaction between the different types of vegetation and their competition for water supply, as well as the structure changes of the planetary boundary layer under the influence of topography must be considered.

The atmospheric response to the variability of biosphere and other land-surface characteristics may be small as long as the latter expose high spatial frequencies; however, this is often not the case for larger areas. An important role is played by the ratio of the extension of land-surface segments to the length it takes to build up internal boundary layers in the atmosphere. In applying patch-scale models one should note that calculated surface-atmosphere fluxes, which vary from patch to patch, must be aggregated (upscaled) before useful comparisons can be made with subregional, regional, or global models. Several attempts have already been made in this direction. To illustrate the state-of-the-art a successful, relatively simple approach is presented briefly in Figure 5: the Regional Hydro-Ecological Simulation System (RHESSys). It was introduced by Running *et al.* (1989) and it contains the biome BGC of Figure 4 as a component.

Key characteristics of land-surface processes and systems of complex landscapes such as topography and spatial patterns in soil, vegetation, climatic conditions and hydrological system characteristics (in particular, the stream network, drainage basin structure and area) are represented on the left side of Figure 5. Areal integration is illustrated on the right side beginning with the column "GIS Processing". The system can calculate the most important hydrological and hydroecological processes in forested river basins, including snow melt, evapotranspiration, areal runoff and stream discharge, and related processes. Necessary input data are daily maximum and minimum air temperature, total daily incoming solar radiation, daily total precipitation, leaf area index (LAI, defining vegetation), topographic data (slope, roughness coefficient, etc.,) and soil water holding capacity (field capacity). A special problem of landscape studies is the common lack of site specific climatic information throughout the whole study area; many locations have no meteorological observation data. Areal generalization schemes (weather generators) are required to derive the areal pattern of meteorological information from either a few available measured station data, satellite data, or from GCM simulations (downscaling). A simple example of a weather generator as applied by Running *et al.* (1987) is represented in Figure 7. It considers the diurnal variation of



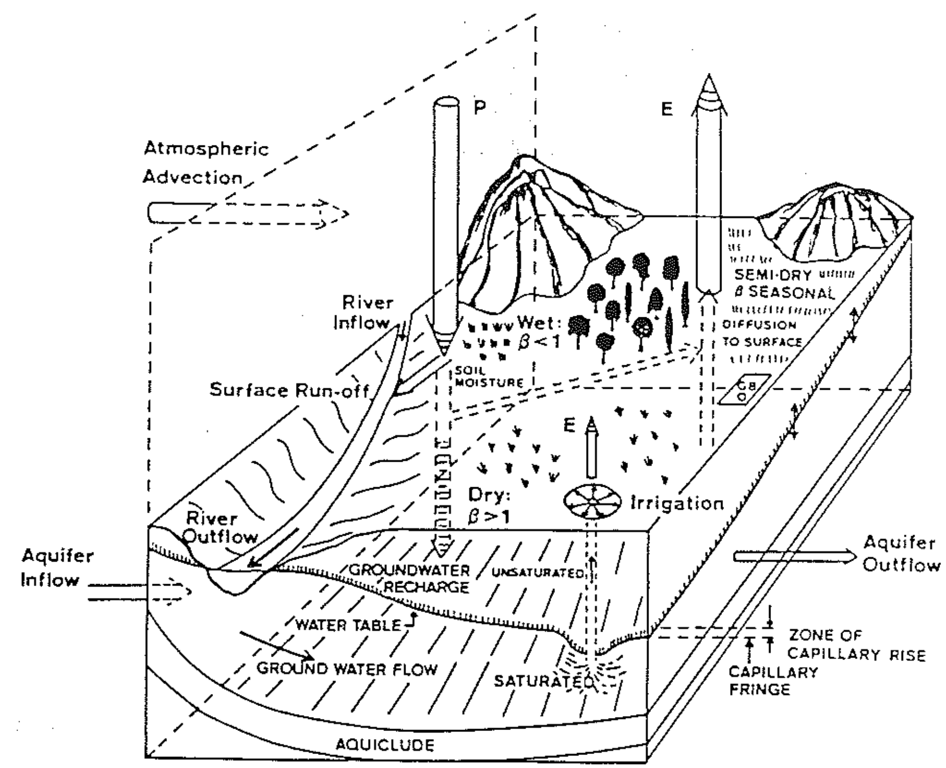



Fig. 6 Schematic representation of a complex landscape and the processes relevant for BAHC (Bolle, 1993)

weather variables, such as air temperature, and their dependence on elevation and the daily variation of those variables. The mountain micro-climate simulator (MT-CLIM) model has two modules, one for the derivation of daily humidity and incoming radiation at places where these data are unavailable, and a section for topographic extrapolation (regionalization) of point weather-station data. It should be noted that preparing the input for the model even with the simplifications in the scheme of Figure 7 requires remarkable effort, in particular concerning the collection, processing, and user-friendly representation of required data. Figure 8 presents a study area modelled by RHESSys. The digital elevation data of Figure 8 (a) can be used as the topographic database for the climatic and hydrologic models. The biome type and the leaf area index LAI shown in Figure 8 (b) are the only external vegetation parameters required to execute the simulations. Other biome specific parameters are listed in internal data files.

Figure 9 illustrates annual forest evapotranspiration in the Seeley-Swan Valley study area, with more detailed spatial resolution from the left to the right. The smaller figure on the right side represents the results for the Soup Creek basin area, a small subarea of the Seeley-Swan Valley.

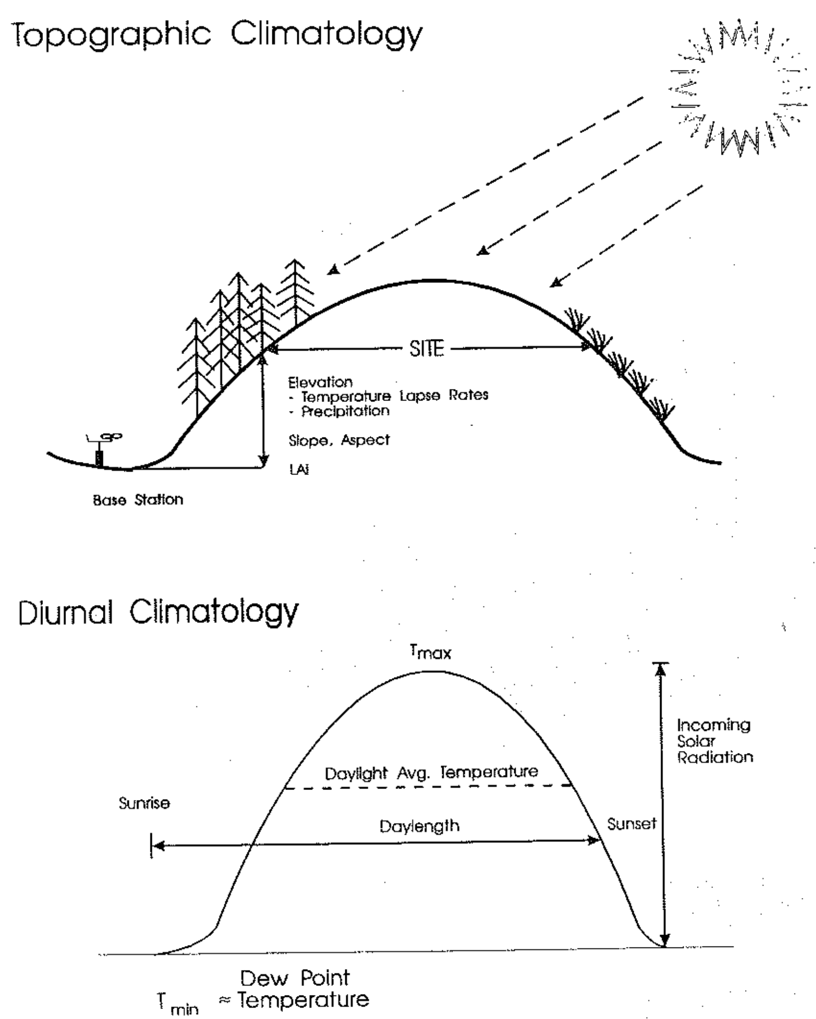



Fig. 7 Logical diagram of a Mountain Climate Generator (MT-CLIM, a simple weather generator)

It can be concluded that a system like RHESSys, even with the simplifications included in its 1 - 50 km scale application, can provide useful information on essential land-atmosphere interface processes controlled by vegetation and on their spatial and temporal variation. However, improved process descriptions and models as characterized in the initial sections are clearly required, and are a subject of the ongoing BAHC research. The most essential task, the reduction of the number of parameters used in detailed SVAT models to a number manageable in GCMs without a loss of accuracy, remains a BAHC challenge.



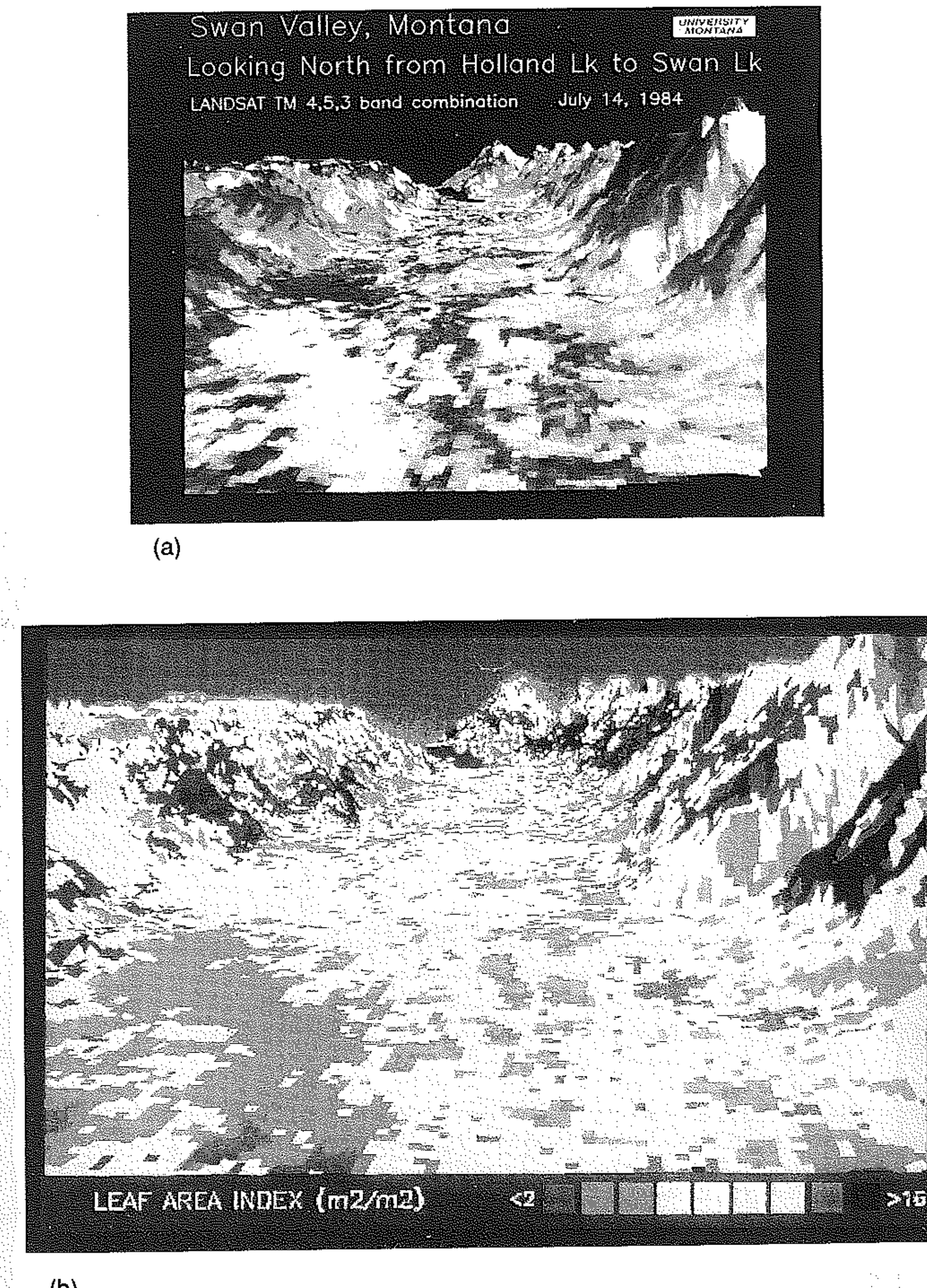



Fig. 8 (a) Digital Elevation Map (DEM) and (b) Leaf Area Index (LAI) of the 1200 km$^2$ Seeley Swan Valley, Montana, USA

Table 2. Spatial scales of significance to BAHC (after Becker, 1992)

| Basic Scales: Atmospheric Sciences and Meteorology | Basic Scales: Hydrology | Basic Scales: Ecology | Length Range (km) | Scales, Areas, and Subjects | Main Data Sources |
|---|---|---|---|---|---|
| macroscale | | | $10^5$ | Global Scale<br>General Circulation Models (GCMs) | |
| | | | $10^4$ | Continental scale | Satellite data |
| mesoscale α | macroscale | | $10^3$ | Regional scale | |
| | | macroscale | $10^2$ | Planetary boundary layer (PBL)<br>River basin<br>Heterogeneous landscapes | Airborne data |
| β | mesoscale | | 10 | | |
| γ | | mesoscale | 1 | Patch scale, Ecotopes<br>Local scale | |
| | microscale | | $10^{-1}$ | | Ground-based data |
| microscale | | microscale | $10^{-2}$ | Single-site scale<br>Single plants, Pedons<br>Single leaves | |
| | | | $10^{-3}$ | | |



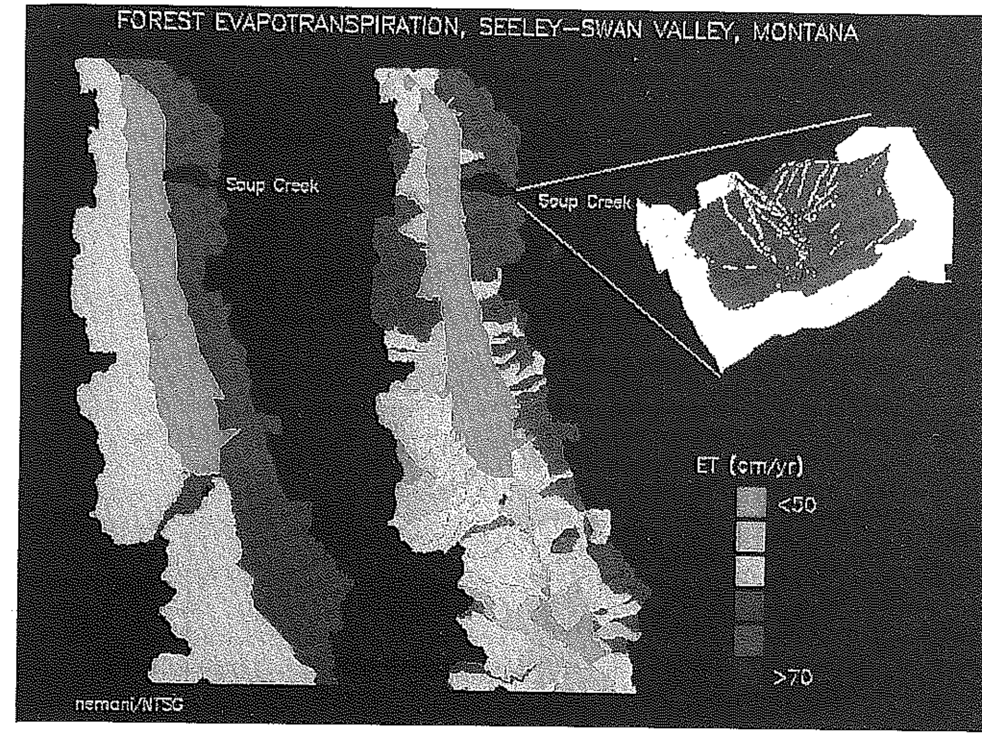



Fig. 9 Mapping of calculated annual forest evapotranspiration of varying levels of landscape resolution using the Regional Hydro-Ecological Simulation System (RHESSys) (Running, unpublished)

## Spatial and Temporal Scales

One of the most critical unsolved problems in land-surface process modelling is the bridging of scales (spatial and temporal). Two problems in spatial scaling have already been mentioned:

(i) the spatial upscaling from patches to regions for large-scale modelling, with consideration of land-surface heterogeneity in different forms characterized before, and

(ii) the spatial downscaling of climatic information for ecosystem and hydrological system modelling and investigation. Such a procedure is called the "Weather Generator" and is addressed by BAHC Focus 4 (see Chapter 8).

Table 2 provides insight into the spatial scales relevant to BAHC, with an indication of important areas subjects in modelling and related primary data sources. Analogously, events of different duration that are relevant to BAHC are listed in Table 3.

Table 3. **Durations of events of significance to BAHC**

| Process | Variables | Time: day | Time: year |
|---|---|---|---|
| <u>Weather and Climate</u> | | | |
| Damaging frost | Air temperature at 0 and 2 m | ≤1 | |
| Precipitation | Intensity, Wind velocity mm/day or mm/year | ≤1 | |
| Evaporation | Atmospheric pressure, | | |
| ENSO | Water temperature | ≤100 | |
| Drought cycles | | | 10 |
| Ice age | Glacial extent, Air temperature | | ≥300 |
| <u>Hydrological Cycle</u> | | | |
| Flood | Discharge, Stage, Velocity | ≤10 | |
| Spring ice breakup | Stage | 10 | |
| Snowmelt | Discharge, Stage, Snow cover | ≤100 | |
| Glacier | Altitude | | 10 |
| <u>Biosphere/Ecosystem</u> | | | |
| Burning | Biomass density | ≤100 | |
| Crop planting, harvesting | | | 1 |
| Recovery of temperate climax forest | Height, Species composition | | 300 |
| Recovery of damaged tundra or desert | Species composition | | 300 |

Extreme meteorological events like hurricanes, storm rainfall, and hail, can affect the condition of the vegetative cover severely within a few minutes or hours. Floods can cause similarly rapid changes in the land surface and surface water systems. However, this does not immediately influence the biome or ecosystem. For example, the typical Mediterranean vegetation needs two to three years to react to severe precipitation deficits or changes in other atmospheric inputs such as temperature and radiation. The migration of ecosystems in case of climatic change occurs at even much longer time scales in the order of decades or even centuries, as has been found after the last glaciation.

Land-surface changes normally occur at a slower rate than weather changes, and the feedback of large-scale land-surface changes due to desertification or deforestation is presently still difficult to estimate and certainly depends on the geographical location where these changes occur relative to the major climatic belts. The primary challenge of BAHC is to take into account the aforementioned aspects, and the requirement to develop models capable of describing the range of spatial and temporal scales characterized in Tables 2 and 3.



# Important Land-Surface Properties for Studying Long-term Changes

The variability of land-surface properties needs to be assessed at different scales to investigate the processes that lead to changes that occur in the:

(i) biosphere, including spatial shifts of biome boundaries
(ii) geomorphology, in particular land use and soil conditions
(iii) hydrological conditions, including areal extent of glaciers and snow cover.

The properties relevant to BAHC are given in Table 4. Some of the data and parameters listed in Table 4 can be determined directly on the ground or from satellites. Many of them, however, must be derived from other measured, or estimated characteristics. For instance, soil water holding capacity is generally derived from field capacity, wilting point, and root depth, which can often only be estimated from general information on soil type and vegetation type. Another example is evaporation, derived from radiation, temperature, humidity, and wind data at and above the land surface, and from soil moisture content and distribution below ground. In these cases and in many other similar cases the influencing properties and factors need to be assessed.

Data collection and modelling are complementary activities in summarizing important land-surface properties. Remotely sensed data and other ancillary data, coupled with modelling, sensitivity analysis, and validation of methodologies are very important in the regional and global assessment of all these properties and factors and of their diversity (areal and temporal variability).

Satellite observations provide radiative characteristics globally from the visible to the microwave region of the electromagnetic spectrum at well defined spatial and temporal resolutions. A number of algorithms have been developed to estimate biospheric attributes and other surface characteristics from digital signals and to study biosphere-atmosphere interactions using these data (e.g., Asrar, 1989; Hobbs and Mooney, 1990; Wood, 1991). The challenge is to select the most appropriate algorithms for extracting hydrologically significant biospheric attributes (including the GCTE proposed plant functional types) from remotely sensed data without requiring ground-based measurements. The concept of plant functional types, which includes the definition of a set of biospheric attributes that are critical for predicting plant response to climatic change, summarizes plant attributes important to ecologists. Furthermore, these types could be used for quick estimation of certain SVAT model parameters.

Furthermore, the structure of plant communities plays a significant role in radiation absorption and in determining the exchange coefficients for mass (carbon and water) and momentum in biosphere-atmosphere interactions (Choudhury, 1991; Raupach, 1992). Special research efforts are required to make progress with regard to the role of plant communities. The estimated surface properties from remote sensing classification algorithms should make it possible to distinguish climate-induced changes in land-surface properties from local and regional changes, due to direct anthropogenic impacts such as pollution and urbanization.

Modelling and sensitivity analyses are equally important to data collection in assessing important land-surface properties. Up to now empirical or semi-empirical relations often

**Table 4. Land-surface properties to be used in process studies and other research**

| | |
|---|---|
| Topographic Data | • elevation and exposition (slope and aspect) of plots or elementary unit areas<br>• water-divides of river basins and sub-basins<br>• river basin structure (structure of channel systems including lakes, reservoirs, etc.)<br>• river network characteristics such as channel length, width, slope, meanders, flood plains, geomorphology of the bottom etc. |
| Vegetation and land-use data | • vegetation cover<br>• land cover and land-use data<br>• extension, density, height, permanence (time period when land remains covered) and phenology of vegetation<br>• structure of the canopy, especially leaf area and leaf distribution<br>• structure of the root system, including root depth<br>• canopy and litter water-holding capacities ("interception capacity")<br>• albedo |
| Soil data | • soil type, texture, fabric and structure<br>• porosity, field capacity, wilting point,<br>• water holding capacity, determined by field capacity, wilting point and root depth<br>• hydraulic conductivity, soil infiltration capacity, transmissivity<br>• depth and permeability (hydraulic conductivity) of porous permeable and less permeable soil layers<br>• permafrost conditions<br>• depth of bedrock or impervious layers<br>• quantity of macropores<br>• albedo |
| Climatic data | • precipitation (rainfall, snow depth and snow water-equivalent)<br>• interception and through-fall<br>• net radiative flux and all its components<br>• air temperature<br>• air humidity, wind velocity, etc. |
| Hydrological characteristics | • water levels (surface and ground water)<br>• river discharge and runoff from land surface areas<br>• infiltration into the soil, overland flow<br>• soil water retention, especially in the rooting zone<br>• percolation below the root zone (groundwater recharge)<br>• lateral subsurface runoff within the soil (interflow), above less permeable horizons and lithic contacts<br>• groundwater flow and discharge (base flow)<br>• capillary rise |



have estimated land-surface properties sufficiently. As an example, several relations between Leaf Area Index (LAI) and the Normalized Difference Vegetation Index (NDVI) derived from the National Oceanic and Atmospheric Administration (NOAA) Satellite AVHRR Radiometer Data are represented in Figure 10. These functions were used in regional photosynthesis and evapotranspiration simulations as shown earlier (Figures 4 - 9). The scattering of the points illustrates the uncertainty involved in the relation between NDVI and LAI. Additionally, some uncertainty in the NDVI comes from error in the actually measured data (e.g., radiances), and in the relation of the LAI to plant transpiration and other estimated biosphere characteristics. The first mentioned relation is sensitive to clouds and other phenomena that reduce atmospheric transparency, the second one is approximate (due to the dependence of transpiration on other processes). This means that relations and algorithms applied to derive land surface properties from satellite data generally involve approximations with different degree of uncertainty. Consequently, further research is required to improve both the understanding of the functional relations and the algorithms to reduce the errors of estimates and of predictions of the function.

Furthermore, the spatial resolution of the remote sensing information is of great importance as illustrated in Figure 11, which contains maps of different spatial

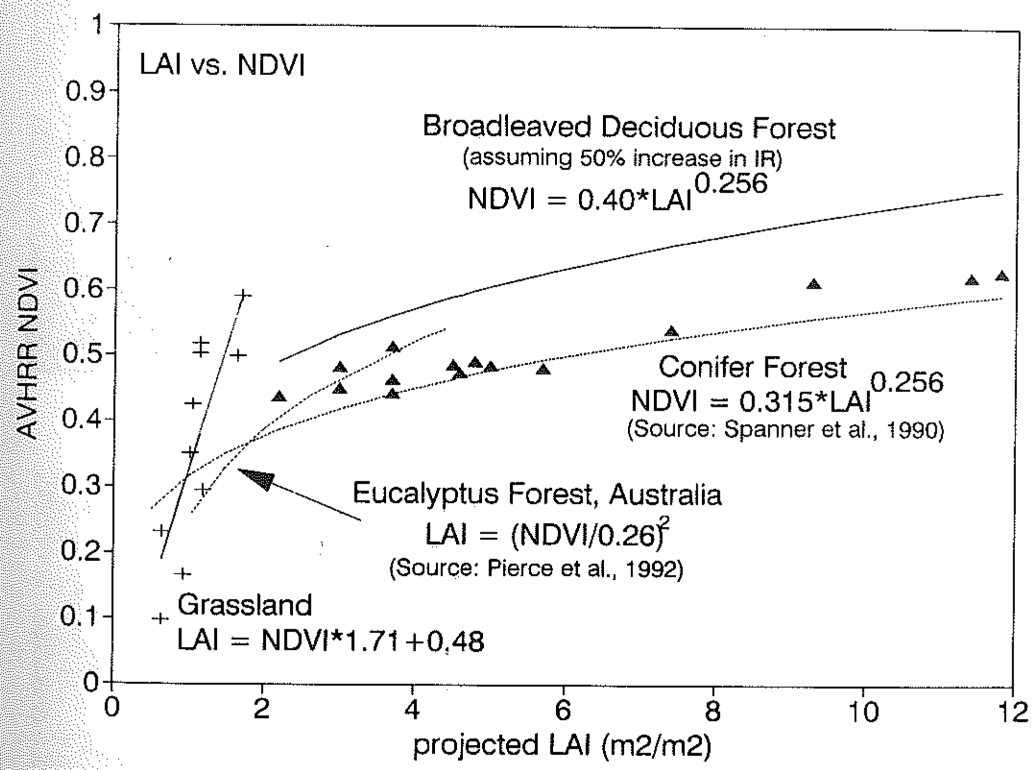
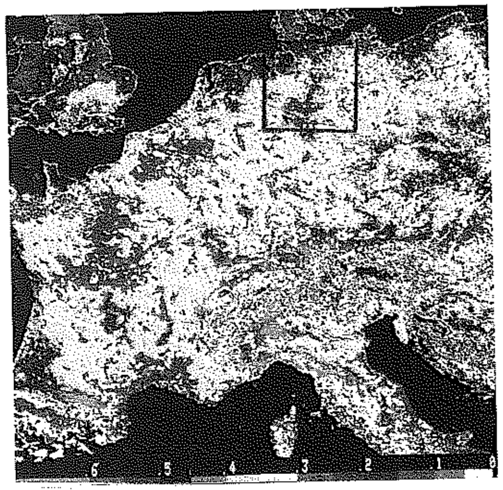
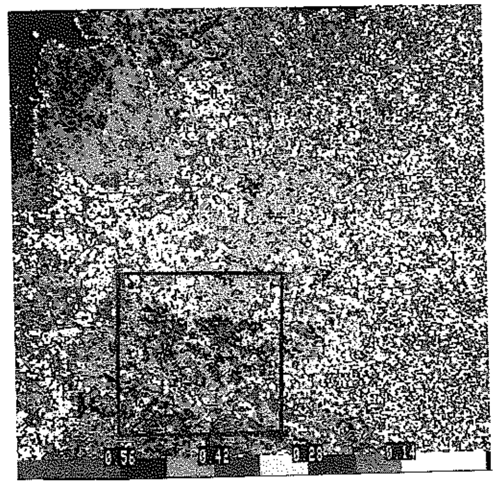


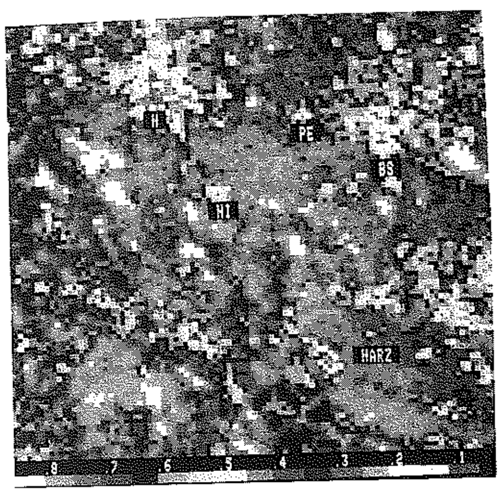

Fig. 10 The functional relations used to translate NDVI into Leaf Area Index (LAI) for four biomes



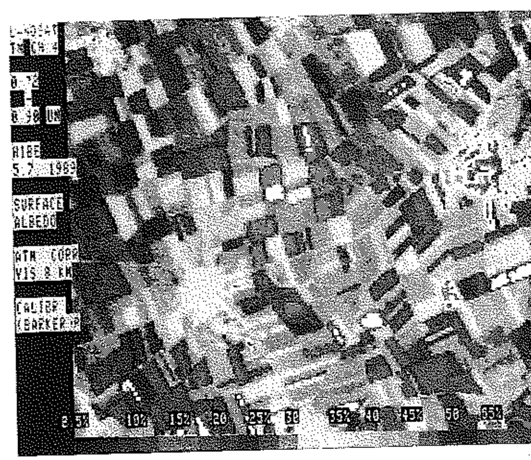
(a)



(b)




(c)



(d)

(e)

Fig. 11 Areal images of different resolution and treatment of a central European study area (provided by Institut für Meteorologie, Freie Universität Berlin)



resolution of estimated biospheric land-surface properties (from satellite and airborne remotely sensed data). In part (a) of Figure 11 the areal pattern of the NDVI over large parts of central and western Europe is shown. The NDVI was derived from NOAA11/AVHRR data as a composite for the period 4 - 6 July 1989. The observations were taken as part of the Longitudinal Land-surface Traverse Experiment (LOTREX)-HIBE89 experiment. Part (b) shows in greater detail the marked square area in part (a). For the study area marked as a square in (b) the corrected NDVI is represented in part (c), illustrating the applied pixel size of 1.2 km$^2$. A considerable jump in information is achieved in part (d) which presents the spectral surface albedo derived from optical Landsat Thematic Mapper (TM) (channel 4) data in a much higher spatial resolution (30 x 30 m$^2$). In this figure the real land-surface structure, namely the areal pattern (mosaic) of patches of different land cover types can be identified clearly. Even more detailed is the representation (e) of a maximum-likelihood classification of different land cover and vegetation types derived from an airborne Dedalus scanner (channels 5, 7, 9) with a spatial resolution of about 3 m.

The example given in Figure 11 illustrates the possibilities to identify the areal pattern of patches with different land cover and vegetation from remotely sensed data. A greater problem is the quantitative estimation of patch or landscape related land-surface properties, characteristics, and parameters as listed in Table 4 and of their spatial and temporal variability. BAHC will use different data sources, in particular data from the aforementioned land-surface experiments to be implemented in cooperation with the International Satellite Land-Surface Climatology Project (ISLSCP), to research in this important area.

One task that concerns the different scales, that must be addressed jointly with IGBP-DIS, is to gather and to summarize worldwide data on vegetation and soils. Although a large amount of relevant data already exists, these data must be assembled - and frequently updated to reflect the changing environment. Observations from space are expected to support such inventories; however, observations with high spatial resolution are not often possible, and medium- and low-resolution satellite observations, although made continuously, might not be sufficiently informative, for instance because of clouds. It is therefore necessary the develop interpolative and corrective methods suitable for processing scenes with some missing or incorrect observations.

# 4. Structure of the BAHC Research Plan

The research plan for BAHC contains four research foci as follows (see Appendix 1 for a list of activities and tasks):

**Focus 1:** Development, Testing, and Validation of 1-dimensional Soil-Vegetation-Atmosphere Transfer (SVAT) Models
**Focus 2:** Regional-Scale Studies of Land-Surface Properties and Fluxes: Experiments, Interpretation, and Modelling
**Focus 3:** Diversity of Biosphere - Hydrosphere Interactions: Temporal and Spatial Variability
**Focus 4:** The Weather Generator Project

**BAHC Focus 1** is the patch-oriented part of BAHC. Its main objective is to investigate the vertical exchange of energy, moisture and trace gases (e.g., carbon dioxide) at the soil-vegetation-atmosphere interface and their dependence on relevant soil and vegetation parameters as well as climatological, hydrological, and other related parameters. At this scale numerous investigations have already been carried out, and a number of SVAT models have already been developed. One of the research directions is to design more comprehensive ecohydrological SVAT models capable of describing more accurately the various complex interrelationships and interdependencies between the different process variables, parameters and influencing characteristics. The other is to derive simplified SVAT models, in particular for use on larger scales, which are capable of simulating the processes with a reduced number of parameters, which can be linked to quantities used in the description of land-surface processes at the larger scales. For this purpose coordinated experiments in patches and in mixed stands are necessary, which may also be nested into the larger experiments of Focus 2.

**BAHC Focus 2** extends the investigations under Focus 1 into two and three dimensions. It is oriented toward experiments in different regions, and therefore takes into account the role of heterogeneity in land use, vegetation type, soil, hydrological and other conditions and includes the effect of topography and lateral surface and subsurface water flow up to a scale of $10^4$ $km^2$. An important subject in Focus 2 is *upscaling*, namely the appropriate representation of the characteristics of larger areas in models which take account of land surface heterogeneity in all its forms. Suitable models, methodologies and algorithms have to be developed, compared with each other, and evaluated, using the data from land-surface experiments. These experiments must provide data sets that allow a proper areal integration and quantification of the fluxes between surface and atmosphere. They are to be conducted in a limited number of areas that will have to be carefully selected, to investigate the most extreme climatic, environmental and ecological conditions. A number of questions cannot be answered by intensive short-term experiments. Therefore, BAHC also intends to initiate longer-term observations and measurements at sites that might be integrated into larger scale experiments. Major emphasis has to be put on the aggregation of land-surface properties and fluxes for inhomogeneous terrain. The experiments also serve for validation of relations between satellite data and land-surface characteristics to make the relations useful in Focus 3.



**BAHC Focus 3** is oriented towards the assessment of the temporal and spatial variability of biosphere-hydrosphere interactions at land surfaces. It aims to conduct, and later to generalize, regional investigations into changes in the status and behaviour of the biosphere and water resources due to global changes (e.g., climate change, direct human impacts) on agriculture and hydrology and the resulting feedbacks to the hydrological cycle and climate. The investigations aim at a better understanding of the complex and multifaceted interactions between climatic, hydrologic, and biospheric systems and to develop models which describe the long-term dynamics of the biosphere and terrestrial ecosystems. Other tasks will address the long-term dynamic consequences of ecosystem diversity on water resources (specifically their role in regulating the release of carbon, sediments, and nutrients from soils to surface and subsurface water), the development of improved methods to determine quantitatively (from remotely sensed data) biosphere and other land-surface characteristics crucial for the parameterization of land-surface processes, and the assessment of changes in the biosphere at the scale of the grid cell of global climate models.

**BAHC Focus 4** is developing suitable procedures, aggregated models and algorithms to provide regional climatic variables, in particular precipitation patterns and extreme events, using large-scale information such as assimilated observations or simulations from GCMs. This localized weather, generated from regional and global information, is required and will be used as input information for 1 - 50 km scale hydrological and ecological investigations. Focus 4 was established to fulfil the requirements of several ecologically and hydrologically-oriented project (GCTE and others, in addition to BAHC), through the provision of climatic data with much finer areal resolution than is currently available from existing networks and global models.

# 5. FOCUS 1: Development, Testing, and Validation of 1-dimensional Soil-Vegetation-Atmosphere Transfer (SVAT) Models

## Introduction

Soil-Vegetation-Atmosphere Transfer (SVAT) models are central tools for the mathematical representation of the critical interconnecting processes controlling energy, water, and carbon transfer between soils, vegetation, and the atmosphere. The overall goal of BAHC Focus 1 is the development, testing, and validation of a suite of SVAT models for global biospheric research. The spatial domain of BAHC Focus 1 is plot or patch oriented (microscale), where a patch is understood as a homogeneous (uniform) land-surface area, where land-surface heterogeneity of vegetation, soil and topographic factors, microclimate and advection effects, are the subject of BAHC Focus 2.

Numerous SVAT models having different degrees of complexity have already been developed and applied (see Geyer and Jarvis, 1991 for review). All these schemes represent approximations of reality and include numerous simplifications of the real process behaviour and of its dependence on the various influencing characteristics and processes. Therefore a first aim in BAHC Focus 1 will be to compare and evaluate existing SVAT schemes against selected data sets from well-investigated test sites, and develop improved SVATs available for universal applicability and appropriately simplified for use within global models. It should be emphasized that SVAT models must represent in a simple way relevant land-surface properties, namely soil, vegetation, climatological, hydrological, biogeochemical factors, if they are to be useful globally.

Ultimately, the energy, water, carbon, and nutrient cycles cannot be represented individually, yet the integration is sufficiently complicated that SVAT models are required. As one example, soil solution chemistry is clearly dependent on the root system hydrologic balance, and in turn influences the nutrient availability and transport to the vegetation, and finally determines the chemical quality of the stream and river discharge. The responsibility of Focus 1 is to contribute to understanding of these interdependencies and interactions and to provide methods and models for terrestrial ecosystem and water resources system investigations, particularly global change studies and simulations.

Because water and energy transfer at land surfaces control key biogeochemical processes, SVAT applications are numerous. These applications may include terrestrial and water resources, soil and litter structure, biogeochemistry, and trace gas fluxes and are particularly influenced by forest and agricultural management practices. Consequently, BAHC Focus 1 studies are valuable for many other studies on environmental quality and global change, and will be closely linked to work within other IGBP Core Projects. For example, GCTE and IGAC will add expertise on the physiological and structural responses of ecosystems to elevated $CO_2$ and on altered



biogeochemical cycles. The ultimate goals will be to provide the scientific basis for an integrative patch-related hydroecological modelling; to identify those land-surface characteristics and parameters which are essential; and to develop approaches for estimating these characteristics and parameters from generally available data, including from satellites.

## Aims

(i) Investigate the processes of vertical energy, water, and other related fluxes, in particular carbon, at the soil-vegetation-atmosphere interface for small uniform areas, and the summary of these data by parameters of 1-dimensional SVAT models that represent different biomes

(ii) Compare and evaluate SVATs, develop improved SVATs as required, and produce simplified SVATs for global implementation in all biome types

(iii) Contribute to defining an effective classification scheme for vegetation functional types for global implementation, based on sensitivity analysis of SVAT variables

(iv) Use SVAT models to analyze the influence of atmospheric $CO_2$ concentration and climatic change effects on hydrologic balances in the biosphere for different climates and biome types.

## Activity 1.1 Validation of SVAT Models: Field Studies of Energy, Water, and Carbon Fluxes

Implementation of SVATs globally will require data from biome types worldwide. To obtain this global data, literature searches will first be done to determine in which biomes SVAT parameters are not available. In these inadequately studied biomes field studies will be planned to improve understanding of SVAT processes. This activity will be executed in close cooperation with the IGBP Core Projects GCTE and IGAC. The main objective of these studies will be to better understand at the patch scale the complex interactive processes of plant growth and behaviour, water, energy and matter exchange (carbon) with the atmosphere and soil, and effects of perturbations due to human activities, for instance elevated $CO_2$, changing land use, biochemistry, vegetation structure, climate, hydrological conditions, etc.

### Objectives

- Determine critical SVAT parameters for characterizing different biomes globally, and assessing the availability of these data for each important biome worldwide
- Initiate field studies to produce data for biome types, where inadequate data exist

- Encourage development and calibration of improved instrumentation for SVAT parameter measurement
- Prepare generalized databases of SVAT parameters for global SVAT modelling
- Organize a network of continuous monitoring stations for the ongoing validation of water and $CO_2$ flux processes in SVAT models for different biomes.

The following four tasks are defined for the implementation of this activity:

### *Task 1.1.1 Evaluation of required SVAT parameters for major biome types, and planning of field studies in biomes identified as vegetation functional types where data is needed*

SVAT models often use more than 50 parameters to describe the local soil and vegetation conditions. For global applications a smaller selected number of critical parameters must be chosen for measurement across all biome types. Surface conductance (*gs*) for water vapour transfer determines partitioning of energy into sensible and latent heat, and is the most important biologically controlled vegetation parameter in GCMs. Surface conductance also controls the movement of $CO_2$ between the leaf and the atmosphere and so is a dominant part of the photosynthesis-respiration balance of a canopy. Surface conductance behaviour is determined by a complex combination of biological, biochemical, and physical properties of the entire SVAT system. Bulk surface conductance often describes a multilayered vegetation system generally including one or more layers of plant canopy and soil surface. At present, there exists no entirely mechanistic model of *gs*; a phenomenological model, derived from correlation analysis of site data sets, represents the generally employed alternative. Consequently, field data from all relevant global biome types are needed. In addition, use of these models in a changing global environment is not realistic, so incorporating results of new, enriched $CO_2$ experiments like the Free-Air $CO_2$ Enrichment (FACE) studies in GCTE will be important.

SVAT models also require various canopy structural properties including leaf area index, height, leaf age and architecture. Complex SVAT models must incorporate mixed canopies, for example tree/grass savannah, and the successional development of canopies after disturbances. Soil depth and texture can change on scales of tens of meters, yet some representation of key characteristics is essential.

The primary objective of this task is to provide data of these basic properties that must be available for different global biomes for use in the global SVAT models. This requires that surface conductance (*gs*), canopy LAI and structure, and other relevant hydroecological properties are measured in a network of sites globally. GCTE and BAHC will undertake this task jointly, as GCTE Activity 1.3 and BAHC Activity 1.1.



### *Task 1.1.2 Implementation and coordination of a long-term monitoring network of water and carbon fluxes for terrestrial ecosystems*

There is a great demand to validate SVAT models at a patch scale in order to improve accuracy of simulation and parameterization schemes. Validation of different SVATs must include the simultaneous measurements of water vapour and carbon dioxide fluxes because of the strong coupling of these fluxes in terrestrial vegetation. Although several short-term intensive field campaigns have already been done, and more are planned in Focus 2, there is a growing need of long-term flux measurements on selected ecosystems. Many of the processes driving water and carbon fluxes at ecosystem level are strongly dependent on seasonal changes in climate. Seasonal changes of phenology and biomass production affect significantly the rates and properties of water and carbon exchanges in the atmosphere. Furthermore, extreme events (extreme temperatures, high wind velocity, drought conditions) are not usually considered during short-term field campaign but can have a strong impact on the hydrological cycle - and hence on the evaluation of the improved SVAT schemes at an operational level.

Water-proofed sonic anemometers and fast response closed path analyzers can now provide eddy covariance measurements of water and carbon fluxes at the canopy scale on a long-term basis, at the resolution of around an hour (Baldocchi *et al.* 1988). A number of field test sites in different parts of the world are today available for implementing long-term carbon and water exchanges using these methods and could provide effective sources of data for SVAT testing and remote sensing validation. BAHC Focus 1 will play an important role in coordinating (cooperatively with GCTE) an international network of long-term water and carbon gas exchanges on various ecosystems of the world, and providing the distribution of results for continuous testing and validation of SVAT models in a large variety of conditions.

### *Task 1.1.3 Test and compare the existing methods and instruments for measuring SVAT processes*

A number of methodological challenges exist that limit accurate, regular measurement of critical SVAT variables. These include time degradation of net radiometers, measurement of root activity defining the available soil water supply for vegetation, monitoring of complete canopy transpiration etc. This Task will encourage methodological development in these areas, and efforts in the ongoing intercomparison, and intercalibration of instrumentation for SVAT variables.

Remote sensing is an essential technology for developing global databases of critical SVAT variables such as leaf area index and biome cover type. Although remote sensing goes beyond the 1-dimensional scale defined for Focus 1, it is important that sensitivity analysis of SVAT models be used to define the important variables needed for remote sensing development. This Task will contribute to defining objectives for remote sensing research that will develop SVAT variables needed for global modelling.

*Task 1.1.4* ***Conduct field studies in biomes to study the hydrologic controls of trace carbon transfer processes from soils and vegetation to the atmosphere (with IGAC)***

IGAC will conduct studies on production and absorption of methane, non-methane hydrocarbons and other trace gases in different biomes. Soil fluxes of these trace gases are highly controlled by soil moisture conditions. Canopy fluxes are controlled by surface conductance, and possibly photosynthetic activity of the vegetation. In all of these cases, the hydrologic control of trace gas emission rates is large. In this task BAHC will contribute to the trace gas studies of IGAC with measurement regimes, and SVAT modelling to aid the IGAC goals.

## Activity 1.2 Selection, Evaluation and Improvement of Appropriate SVATs for Patch-Scale Fluxes: Modelling Activity

A variety of SVAT models exists, with origins primarily from either the ecological sciences such as MAESTRO (Wang and Jarvis, 1990), FOREST-BGC (Running and Coughlan, 1988), and BIOMASS (McMurtrie, 1991) or the meteorological sciences such as BATS (Wilson *et al.* 1987) and SiB (Dorman and Sellers, 1989).

Although all SVAT models simulate hydrologic transfers between the soil, vegetation and atmosphere, there is a wide variety in the sophistication of the biological controls represented. SVATs are usually developed from patch scale field data sets, from cuvette and tower measurements, yet are applied ultimately to GCM cell land-surface parameterizations. There are many outstanding questions concerning the degree of biological detail, of stomatal mechanics, of species specific activity, of C3 versus C4 photosynthetic pathways, of multilayer canopy definition, and of leaf phenology - all these issues must be addressed to produce useful SVAT models for global environmental research. In the development of simple globally appropriate SVAT models the bulk canopy, surface conductance, canopy structure definition from LAI dynamics, and soil physical and biogeochemical properties play central roles.

One simple way of modelling *gs* is to consider a maximum surface conductance, *gs*(max), which is modified by environmental factors such as light, vapour pressure deficit, soil-water status, and also by canopy structural parameters including vegetation height and leaf area index (Korner *et al.* 1979). An attainable goal for global SVAT models may be to represent *gs*(max) and LAI seasonal dynamics for all global biome types. It is expected that *gs*(max) and LAI will change as ecosystems change, due to changes in land use and climate requiring a dynamic SVAT simulation.

### Objectives

- Evaluate the range of SVAT structures of varying complexity and resolution currently in use, and to develop new SVAT formulations to address problems that have been identified in current models, using a combination of simulation analysis and comparison against field data. These evaluations will be done only for 



1-dimensional SVAT simulations for vertical fluxes (The implementation of SVATs over varying spatial scales is covered by BAHC activities in Focus 2)

- Based on this first evaluation, to develop a generalization of SVATs for all biomes types. SVAT parameters cannot be defined for each plant species, yet functional differences in vegetation must be represented.

The following three tasks are defined for the implementation of this activity:

*Task 1.2.1* ***Test SVATs against field data sets***

There is a great demand to calibrate and evaluate SVAT models against real field data sets in various biomes and climatic conditions. The continuous water vapour and $CO_2$ flux data from Task 1.1.3 will provide a strong test of the SVAT models for a variety of biomes, and under the full seasonal range of climatic conditions encountered in the regions that are investigated. Additionally, at a minimum, seasonal soil moisture content and canopy leaf area dynamics should be included in these continuous flux data-sets. If possible, with cooperation of GCTE and IGAC, more comprehensive measures of system biogeochemistry would be valuable. This may include net primary production, and litter and canopy chemical content. However, critical simplification of SVAT requirements is needed initially, so that the field data needed are not impossible to obtain.

*Task 1.2.2* ***Compare SVAT formulations that have varying treatment of system structure and develop improved SVATs as required***

The most complex current SVATs explicitly take into account variable leaf age classes, canopy geometry, leaf angle distribution, rooting density and location, stem water capacities and conductivity etc. Evaluation of the necessity of these details in large scale hydrologic and ultimately comprehensive Earth systems modelling is needed. Therefore SVAT formulations based on single "big-leaf" canopy structure and "tipping bucket" soil structure need to be compared against multilayer (of both canopy and soil) SVAT formulations. Moreover, current SVATs often assume continuous average canopy cover, assumptions that are obvious wrong, particularly in savannah vegetation. SVAT improvements for highly heterogeneous canopies, such as sparse open-canopy savannah vegetation need to be developed.

In addition, SVAT model formulations of varying time steps, ranging from hourly to daily and monthly, need to be tested experimentally. While SVATs in GCMs represent land surface parameterizations at hourly intervals or less, some SVATs used in population dynamics models require less time resolution and can be run for centuries. Better understanding of the consequences of these different time steps on SVAT performance is needed.

*Task 1.2.3* ***Evaluate specifically the "limits of simplification" possible in SVAT formulation that will result in model logic for implementations in Focus 2 and 3, GCMs, GAIM and other Earth systems modelling activities***

This task, similar in concept to Task 1.2.2, Focuses specifically on the important question of what limits of SVAT complexity are justified by system variance and model objectives for future SVAT applications. SVATs can be simplified in a number of different ways, and some simplifications are undoubtedly more appropriate than others. Simplification criteria will include evaluation of the necessity of certain SVAT system details, as well as space and time domains of interest, availability of dependable data sets at corresponding scales, and computational efficiency. The constraints imposed by implementation of a SVAT in GCMs and more generally dynamic Earth systems models are particularly important to evaluate. Sensitivity analysis will define the appropriate SVAT structures and prioritize model parameters. The expected result will be a small set of SVAT formulations defined by specific criteria and optimized to specific applications.

The already established Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS) is an important example of the task being proposed here (Henderson-Sellers and Dickinson, 1992).

## Activity 1.3 Definition of Worldwide Vegetation Functional Types for SVAT Model Applications

In order to achieve a worldwide application of improved SVAT models in Earth systems modelling, the development of a classification system is foreseen jointly with GCTE. A functional biome definition optimized for SVAT simulations should be done by examining the sensitivity of proposed SVATs to appropriate structural and functional attributes of different biome type vegetation (Prentice *et al.* 1992). Important coordination is required with the IGBP/HDP Core Project Planning Committee on Land Use/Cover Change to produce a classification logic that can be executed globally.

### Objectives

- Use SVAT sensitivity analysis to help define appropriate functional biome definitions for global vegetation
- Develop and test an organized suite of SVATs for global biome types including representative parameter sets for each biome

The following two tasks are defined for the implementation of this activity:



*Task 1.3.1* ***Use SVAT model analysis to elucidate the critical simplified variables most useful for a unified functional vegetation classification of global biomes***

A functional biome definition optimized for SVAT simulations should be done by examining the sensitivity of proposed SVATs to appropriate structural and functional attributes of different biome type vegetation. This analysis may elucidate basic functional differences of vegetation key to SVAT performance. For example, tree, shrub, grass and forb may define useful categories of vegetation structure. Similarly, needle-leaf versus broadleaf leaf geometry, evergreen versus deciduous leaf habit, annual versus perennial vegetation life cycles, etc., all are important in SVAT model dynamics and could be used to define a functional vegetation classification.

*Task 1.3.2* ***Develop an optimized SVAT model for each functional vegetation class defined***

Once a SVAT related biome definition is complete, SVATs optimized for each biome type should be developed. This task includes summarizing parameters needed for each biome-specific SVAT. It also, in conjunction with IGBP-DIS, should design the global databases of SVAT models and parameters required for use in GAIM and other Earth systems modelling activities.

## Activity 1.4 Use of SVAT Models to Analyze the Influence of Future Global Change on Hydrologic Processes in Different Biome Types and Climates

Previous studies indicate that differing assumptions of the direct effect of $CO_2$ enrichment on stomatal activity, when applied to SVAT models, result in differing responses in surface conductance, evapotranspiration, water use efficiency and ultimately the hydrologic balance of the landscape. Medium term responses of vegetation phenology, decomposition and nutrient availability and canopy leaf area will subsequently influence the hydrologic balance and biogeochemistry of catchments (Running and Nemani, 1991). At longer time scales, simulation of the interactions between climate change and vegetation cover (Smith *et al.* 1992) requires analysis of the effects of changes in vegetation structure and biome shifts on hydrology and biogeochemistry of the land surface. The Free-Air $CO_2$ Enrichment (FACE) experiments planned in GCTE Activity 1.1, soil warming experiments and other experimental results will be incorporated into advanced SVAT models to evaluate the potential hydrologic responses of the biosphere.

### Objectives

- Evaluate the differential responses produced by variable assumptions of stomatal reaction to $CO_2$ enrichment using SVAT models

- Use multiple year SVAT simulations to study ecosystem level responses of leaf area, soil water depletion, and soil temperature increases on decomposition and nutrient availability, snow melt timing and other effects resulting from climatic changes
- Provide a dynamic SVAT model capable of being used as a new land surface parameterization to improve future GCM climate change scenarios

The following three tasks are defined for the implementation of this activity:

*Task 1.4.1* ***Carry out single-year SVAT simulations of direct $CO_2$ responses in different climates and biome types***

Carry out single-year 1-dimensional SVAT simulations of direct $CO_2$ responses of vegetation under current and changed climate scenarios will be carried out for multiple biome types, and the resulting responses of the SVAT system will be analyzed. For this task, results from the FACE experiments of GCTE will be incorporated into the SVAT models.

*Task 1.4.2* ***Carry out multiple year SVAT simulations to study the second-order effect of CO2 and climate change on hydrologic responses***

Carry out multiple year SVAT simulations will be carried out to represent the indirect effects, at the ecosystem level, that $CO_2$ fertilization and climate change may induce on SVAT processes. Initial ecosystem level responses include:

- changes in leaf area
- effects of soil water depletion and soil temperature increases on decomposition and nutrient availability, snow melt timing, and phenological responses in high latitude
- other effects resulting from climatic changes.

*Task 1.4.3* ***Incorporate the dynamic responses of the SVAT from Task 1.4.1 to produce improved multiyear global climate change scenarios***

GCMs are currently run with rather static surface parameterizations to produce the climate change scenarios used for climate change biospheric modelling. By first evaluating SVAT responses at one dimension for different biome types, the GCM land surface parameterizations can be improved, the GCMs re-run and better climatic change scenarios produced.

These improved climatic change scenarios incorporating dynamic SVAT responses can then be used by the IGBP GAIM Task Force for producing comprehensive simulations of the full Earth system to changing climate and other factors.



# 6. FOCUS 2: Regional-Scale Studies of Land-Surface Properties and Fluxes: Experiments, Interpretation, and Modelling

## Introduction

BAHC Focus 2 aims to provide improved quantitative understanding of the regional scale fluxes of energy and water, and of other related substances critical to the development, evolution and changes of hydrological systems and of terrestrial ecosystems. It will be concerned with the extension of the investigations under Focus 1 into the second and third dimension, taking into account the role of land surface heterogeneity and the effects of topography. Currently both of these complicating factors are insufficiently well represented in current larger-scale descriptions of soil-vegetation-atmosphere interface processes.

Investigations under BAHC Focus 2 will necessarily include all those elements of the land surface system which play an active role in controlling the surface fluxes mentioned above on regional scale, namely the terrestrial biosphere including the upper soil layers (with particular attention to the rooting zone), the planetary boundary layer (PBL), surface rivers and reservoirs, and ground water resources.

One research activity is to investigate the process dynamics in the PBL, in particular its ability to *upscale* over larger areas. Other research will focus on the interrelation and interaction between the biosphere and its control of evaporation and transpiration on one hand, and surface and groundwater distribution and runoff on the other. This will be done with particular attention on global biomes undergoing change through direct human interaction or in consequence of climate change. The topographic dependency of hydrological interactions will receive specific attention.

The planning, design and implementation of these experiments is a major component of Focus 2 and, where common interest exists, these activities will be carried out in collaboration with other international programmes, particularly WCRP-GEWEX. The experiments will seek progressively to include more real-world complications, such as land surface heterogeneities, discontinuities, and topography, but also ecological aspects and nutrient cycling, so as to improve the basis for large scale, integrative hydroecological modelling. These last aspects are an important interest of BAHC, but studies involving them will increasingly be made in collaboration with GCTE and IGAC.

The ultimate goal of these regional studies is to provide well-validated, area-integrated models, operating at mesoscale, and capable of describing the soil-vegetation-atmosphere interface processes, including their interdependency with ecosystem characteristics which can be measured at any place on the Earth from ground truth or remotely sensed data.

In summary, Focus 2 is structured around three interrelated study areas, which emphasize:

- the need to better understand the land surface-atmosphere interface processes at the regional scale, including the atmospheric, surface and sub-surface advective processes, and their dependency on land surface heterogeneity, topography, and ecological characteristics

- the provision, through land-surface experiments, of relevant regional-scale data

- the use of the improved understanding and collected data to provide better regional-scale representations of land-surface processes which are applicable at the global scale.

## Aims

(i) Synthesize patch-scale land-surface process descriptions relevant to increasing spatial scales which consider land-surface heterogeneity and topography

(ii) Provide quantitative understanding of water, carbon, and energy cycling at the regional scale for a range of important biomes

(iii) Improve the representation of land-surface-atmosphere interactions within models that simulate global change.

## Activity 2.1 Study of the Effects of Surface Heterogeneity and Topography on Land-Atmosphere Interactions from Patch to Regional Scales

Horizontally homogeneous patches, the simplest local units for the study of land atmosphere interaction, do not exist in isolation. Real landscapes consist of assemblies of patches, which interact both meteorologically and hydrologically through horizontal transfers of energy, water, carbon and nutrients. It is important to study the extent and significance of these advective processes, with emphasis on atmospheric advection between patches of vegetation of differing scale overlying relatively flat terrain, and with emphasis on understanding the consequences of surface and sub-surface water movements in regions with marked topography. Such study will involve the use of coupled surface-atmosphere models, and will draw on experimental data, including the data available from the coordinated regional-scale studies addressed as Activity 2.2. The output of this work will be a dynamical understanding of the effects of horizontal movements of water and energy on surface exchanges. This will provide a base upon which to construct parameterizations of land-atmosphere exchanges at regional scales in heterogeneous terrain, to be undertaken as Activity 2.3, including the development of methods to estimate model parameters from real-world characteristics, ground truth and remotely sensed data.



### Objectives

To quantify, understand, and model the influence of land surface heterogeneity (including topography) on the interaction between the atmosphere and terrestrial surfaces, and of horizontal movements of energy, water, carbon, and nutrients in the planetary boundary layer and in the ground in relation to both surface and subsurface water flow.

The following two tasks are defined for the implementation of this activity:

***Task 2.1.1 Study the effects of land-surface heterogeneities and associated local advection over relatively flat terrain, from patch to regional scales, including local and regional advection and mesoscale circulations***

Surface heterogeneities in level terrain arise from changes in surface cover and soil type, which in turn modulate the surface roughness, albedo, stomatal properties of the vegetation, and water holding properties of the soil. Air flowing over a transition in surface properties develops an "internal boundary layer", a growing layer in which conditions are adjusted to the new surface type. This adjustment process complicates descriptions of exchanges in non-homogeneous terrain, raising the need for exchange descriptions which account for the spatial variability of the underlying surface.

Physically, three kinds of phenomena have been investigated:

- Local advection: the small scale (1 km) evolution of the internal boundary layer and surface exchange immediately downwind of a transition

- Regional advection: the consequences of transitions at a larger scale (10-100 km) for the evolution of the whole PBL and the modulation of surface exchanges

- Mesoscale circulations: thermally induced modifications to the wind field, which further modulate exchange processes.

The required investigations encompass field experiments, but also relate to modelling activities at two levels of sophistication, namely the fully three-dimensional numerical modelling, to rationalize and interpret data sets (to be developed as Task 2.2.3); and the simpler, semi-analytical models which provide the physical basis for regional-scale parameterizations of land-atmosphere exchanges in heterogenous terrain, which will be developed within Activity 2.3.

***Task 2.1.2 Study the meteorological and hydrological modulation of land-atmosphere interactions by topography, from patch to regional scales***

Topography has an obvious effect on the biosphere: directly by topographic-climate-related changes in vegetation cover, and indirectly in response to water flow both across and below the surface which strongly influences the distribution of soil water for biospheric use. One aspect of this task is therefore to quantify and model the biospheric implications of topographically driven surface and sub-surface water flow.

A further aspect is the need to understand and model the above-ground meteorological consequences of topography. It is known that the topography not only significantly influences the surface radiation and wind fields, hence modulating evaporation and the surface energy balance, but also the temperature and humidity fields.

Topographic effects on the wind field occur in different ways depending on slope and the scale of the hills. At the smallest scales (hill height less than a few hundred meters, slope less than 15%) the flow does not separate and is a fairly straightforward modulation by topography of "flat-earth" flow. At height scales of a few hundred meters but with slopes greater than 15%, separation occurs, and this strongly modifies the wind field and hence the energy balance on the downwind side of the hill. At larger scales (mountain heights larger than 1 km), the flow is strongly influenced by the state of stratification of the atmosphere. Phenomena such as the waves, rotors and hydraulic jumps become significant, and extend their influence to the surface energy balance.

In an analogous way, topography has a significant effect on liquid water flow and on soil moisture distribution. In flat, permeable terrain nearly all precipitation infiltrates and ultimately becomes groundwater, and the soil moisture available to plants is primarily determined by the soil properties and rooting characteristics. In hilly and mountainous terrain significant amounts of flow can occur over land and in permeable soil horizons to produce floods and erosion during and immediately after rain or snow melt. In dry periods, subsurface flow often results in increased soil moisture in lower slopes and valleys, giving rise to greener and better developed vegetation than that on the upper slopes. All these effects produce heterogeneities which are specific to mountain and hill-slope, and which often differ characteristically from those in flat lands.

The necessary suite of experimental and modelling activities involved in this Task are similar to those required in Task 2.1.1. but, in view of the area scale at which topography occurs and the need to sample a range of topographic regimes, this Task may best be implemented as a coordinated suite of national experiments at several locations. Examples of such activities are those proposed in Australia as Observation at Several Interacting Scales (OASIS), and joint Franco-German studies already underway in the Rhine region (REKLIP). The coordination and focusing of such studies is an early priority within Task 2.1.2.

## Activity 2.2 Prioritize, Design and Coordinate Regional-Scale Land-Surface Experiments, to Study Vegetation, Atmospheric and Hydrological Processes

The first generation of land-surface experiments increased our understanding of interactions between the upper soil layers, vegetation and the atmosphere. They allowed an initial improvement in parameterization schemes and early development of methods to infer surface parameters and fluxes from remotely sensed variables for selected biomes in specific geographical and climatological conditions. Future experiments will extend the study to different biomes, a requirement for better global models; they will



also include studies along ecoclimatological gradients (so-called transects) to provide information on the responses and feedbacks of ecosystems to environmental change.

A series of such experiments are planned for the 1990s, in semi-arid regions threatened by desertification (central Spain, the Sahel region of Niger and Australia), in the boreal forests of Canada and Scandinavia, and in the tropical rain forests of Amazonia. High priority has also been given to studies in the taiga and tundra regions of Siberia. These studies are in close collaboration with the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP), its associated International Satellite Land-Surface Climatology Project (ISLSCP), and also with other related projects, in particular with GCTE Core Project of the IGBP. The status of such field experiments, over different functional types is summarized in Tables 5 and 6. Four similar large-scale experiments were initiated by GEWEX: GEWEX Continental Scale International Project (GCIP), Baltic Sea Experiment (BALTEX), MacKenzie GEWEX Study (MAGS), and GEWEX Asian Monsoon Experiment (MAGS). (For a review of HAPEX-MOBILHY, a completed experiment in France, see André *et al.* 1986, 1988a, 1988b; Goutorbe and Tarrieu, 1991).

The operation of such long-term monitoring sites will be organized in the future in cooperation with GCTE and other projects since large-scale studies of the dynamics of ecosystems, of their effects on the hydrological and biogeochemical cycles and process characteristics, etc., have a common increasing interest. These studies should also include investigations on the interaction of groundwater with surface waters and with vegetation cover, to get suitable databases for the development of improved ecohydrological models capable of describing seasonal dynamics and changing structure of the various canopies, feedbacks between the biosphere and the atmosphere under changing conditions, as well as the role of extreme events. The models should be tested at least for exemplary ecosystems and landscapes where the required test data are available.

### Objectives

To provide maximum, cost-effective scientific benefit from BAHC-related regional-scale, land-surface experiments by establishing and successively revising priorities, coordinating the timing of resource deployment, advising on design and strategy and by fostering interpretative modelling of the resultant data.

The following four tasks are defined for the implementation of this activity:

#### *Task 2.2.1 Develop and promulgate standards for land-surface experiments*

This task concerns the selection of standards in design and equipment (number and placement) desirable to make the results from land-surface experiments sufficiently comparable and of adequate quality. Some information on cost efficiency will help in making the trade-offs that are increasing commonplace in tight science budgets.

These standards could be a precursor to an experimenters′ manual. The standards would specify the scales, methods and data processing arrangements that would assist in the design of a successful experiment. These standards and guidelines would gather le 5. Past, present, and proposed large-scale land-surface experiments ($10^3$ - $10^6$ $km^2$)

| me | Country | Years | Region | Content | Main result / Aims |
|---|---|---|---|---|---|
| PEX- OBILHY | France | 1986-1988 | Agricultural and forest areas, SW France | Full HAPEX programme | Mesoscale models and their analysis, water balance |
| E | USA | 1987-1989 | Reserved prairies of Kansas | Full ISLSCP and HAPEX programme | Improved interpretation of remote sensing data, development of SVAT models, water balance |
| REX | Russia | 1988, 1991 | Agricultural, urbanized and flood plain areas in forest - steppe zone (black soil), 50 km south of Moscow | Primarily HAPEX programme in 1988 and ISLSCP programme in 1991 (but without boundary layer turbulent measurements; $CO_2$ only in 1991. | Spatial variability, 2-D heat balance and boundary layer models, upscaling, seasonal changes in vegetation cover, 1-D hydrological models |
| RACOS | Brazil | 1990-1994 | Tropical rain-forest and clearance areas, Amazonia | Tower micrometeorology, remote sensing, ecology, hydrochemistry, water balance, plants and soils physics | Energy fluxes (in progress) |
| IFE | China | 1990-1994 | Mountain glaciers, deserts, irrigated agriculture (oases) and pastures in various regions of China | Full HAPEX programme without boundary layer turbulent measurements; special attention to dust-storms | Spatial variability, heat and water balances |

**le 5 continued ...**

| | | | | | |
|---|---|---|---|---|---|
| EDA | Spain | 1991-1995 | Semi-arid area including irrigated, non-irrigated and wild bushy areas in Castilla La Mancha | Full HAPEX programme and $CO_2$ fluxes | Mesoscale and boundary layer modelling, 1-D hydrological models, SVAT modelling, upscaling of remote sensing data, flux balances |
| LIP | Germany, France, Switzerland | 1991-1999 | Mountain forests, agricultural and urban areas in the upper and middle Rhine valley | Micrometeorology, remote sensing data and heat fluxes | Mesoscale modelling, spatial variation |
| PEX- l | Niger | 1992 | Savannah, pastures in Sahel | Full ISLSCP and HAPEX programme | Experiments in horizontal hydrological processes (data obtained) |
| EAS | Canada | 1993-1996 | Boreal forests, Albert province | Full ISLSCP and HAPEX programme, plus ecology | Understanding the biological and physical processes for upscaling from local to regional and global scales |
| IS | Australia | 1993-1996 | Semiarid regions with irrigated oases | Full HAPEX programme | Study advection in microscale and mesoscale. Energy and mass transfer processes, including trace gases exchange |
| EX | Sweden | 1994-1996 | Boreal forests, agricultural areas, lakes | Full ISLSCP and HAPEX programme | Improve understanding and prediction of exchange processes in soil-vegetation-atmosphere systems (at regional scale) |

Table 6. Important land-surface experiments at the $10^4$ - $10^6$ $km^2$ scale

| Name | Country | Years | Region | Content | Main result |
|---|---|---|---|---|---|
| LOTREX | Germany | 1988, 1989 | Agricultural area in Hildesheimer Börde | Full HAPEX programme; more meteorology than hydrology | Mesoscale and SVAT modelling, upscaling of remote sensing data |
| Lockeyer-Sleigh | Australia | 1992 | Grass and open woodland, Lockeyersleigh Catchment, New South Wales | Surface and boundary layer heat fluxes, $CO_2$ fluxes, remote sensing from aircraft, radio-measurements | Comparison of surface fluxes, ground truth and aircraft measurements and boundary layer models |
| Tver | Russia | 1990-1994 | Central forest reserve with coniferous and swamp forest NW of Moscow (Nelidovo, Tver Region) | GIS (soil and vegetation cover), remote sensing, ecology, micrometeorological and plant physiological measurements | Land-surface - atmosphere interface processes (in progress) |



information from the practical experience of a number of field researchers and data analysts. The information would be summarized for regional-scale experiments. Costs would also be reviewed and ranges of acceptable costs component-by-component will be published. Cost ranges will also be reported for units of information when the costs can be clearly allocated. This would help greatly in the initial planning of further experiments because the spatial extent, need for data processing, suitable methods available, and a range of possible costs could be quickly estimated.

***Task 2.2.2 Define scientific priorities and coordinated timing of activities for major regional-scale land-surface experiments in different biomes***

Among the scientific issues to be addressed as high priorities are the following:

- What role does the northern hemisphere, high-latitude land biome play in the global carbon cycle; more specifically, can it account for the "missing carbon"?
- What impact would continued large-scale tropical deforestation have on regional and global climate, and on regional hydrology?
- What are the links (if any) between surface hydrological and biophysical processes and drought in semi-arid areas?
- What is the role of tundra regions in the global carbon cycle?

**Table 7. Experiments for different biomes with provisional schedule**

| Priority Topic | Experiment Location | Provisional Timing 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|---|
| Desertification | Mediterranean/ Spain (EFEDA, ECHIVAL FEDA) | ++ | .. | .. | ++ | .. | ++ | .. |
| | Niger (HAPEX-Sahel) | .. | ++ | .. | .. | .. | .. | .. |
| Boreal Forest | USA/Canada (BOREAS) | | | ++ | ++ | -- | .. | .. |
| | Sweden (NOPEX) | | | | ++ | ++ | .. | ++ |
| Tropical Forest | Brazil (LAMBADA) | -- | -- | -- | -- | -- | -- | ++ |
| Taiga/Tundra | to be defined, most probably in northern Europe (Russia) in 1998-1999 | | | | | | | |

.. monitoring effort, interpretation
-- small-scale (single-site) experiments
++ large-scale (multiple-site) experiments

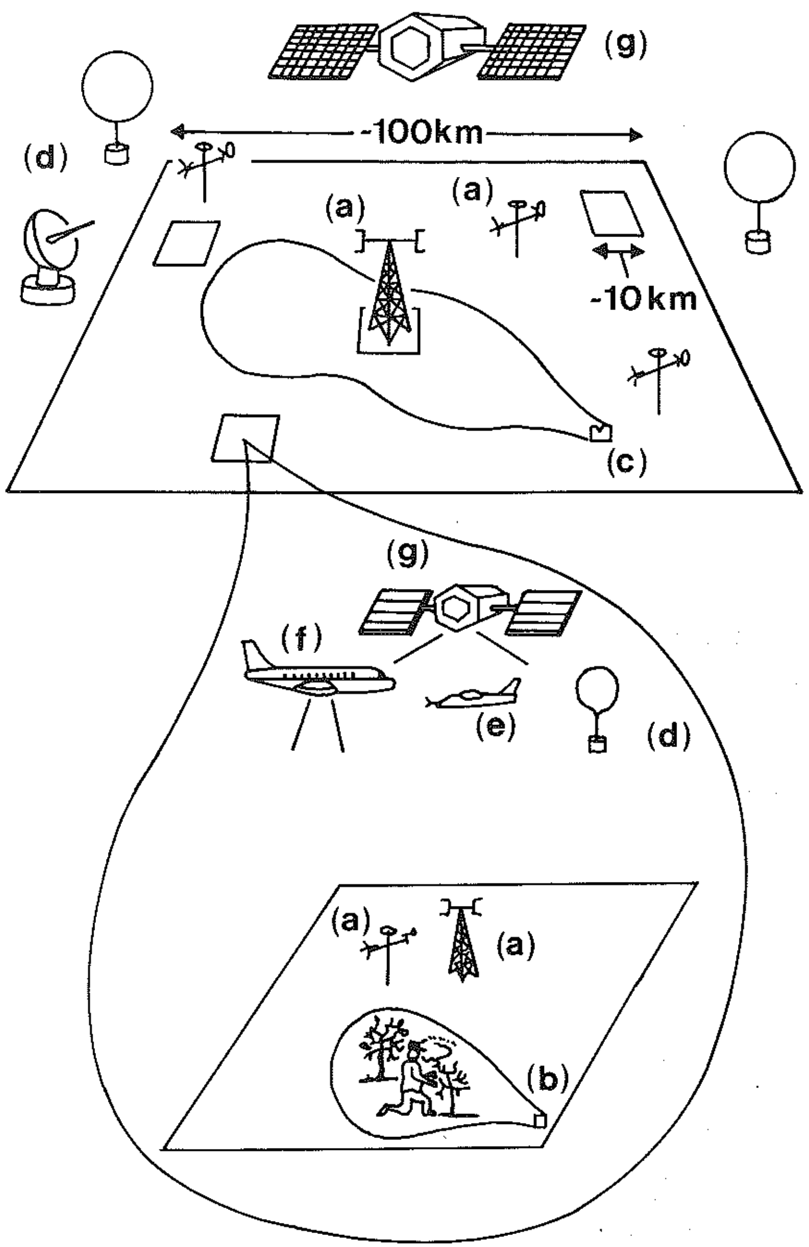



Fig. 12 Framework of measurement network for major land-surface experiment, including supersites



Over the next four years, priority will be given to implementing the major experiments identified in Table 7. These experiments were selected to represent major important biomes. BAHC will therefore concentrate its activities on these experiments at this time. In the period 1995 - 2000 BAHC Activity 2.2 will focus on two multidisciplinary observational studies. Planning of the Amazonian study has already begun, and the wide ranging nature of the required observations are such that collaboration will be sought with WCRP-GEWEX, GCTE, IGAC and UNESCO as appropriate. The tundra study provisionally scheduled for 1998-99 will require the creation of methods and instruments suitable for cold climate observations. NOPEX (Northern Hemisphere Climate Processes Experiment) will provide important opportunities for advancing such developments. Other experiments of similar scale are the HIE-EH River Field Experiment (HEIFE) and OASIS; however, they are not currently regarded as top priorities within the BAHC framework.

Continuous updating of experimental priorities is the central and ongoing action of BAHC Task 2.2.1, a function which is implemented in close liaison with the joint IGBP/WCRP Working Group on Land Surface Experiments. Meetings of the BAHC Focus 2 Committee will be held at least annually to review progress in understanding land-atmosphere interactions, to invite input on proposed experiments and, on the basis of these, to report on recommended priorities.

In view of the complex, international nature of the regional-scale experiments to be carried out under BAHC Focus 2, and recognising the fact that experiments of this size place heavy demands on financial resources available at international level, the BAHC Scientific Steering Committee (SSC) will be very selective in the regional-scale experiments it supports. The criteria to be applied in selecting experiments will include the global importance of the issue to be addressed by the experiment; the completeness of the data which will be collected, and its inclusion of biospheric variables; the interdisciplinarity of experimental approach; provision for the quality control and dissemination of data; and the demand on resources, relative to existing commitments for BAHC-sponsored experiments.

***Task 2.2.3*** ***Provide overall design of specific components and strategy of future regional-scale, land-surface experiments, and stimulate participation by other international programmes***

The components of the Earth system which must be documented during regional-scale land-surface experiments include the active soil layers (particularly the rooting zone), water resources and rivers at the catchment scale, the nature of the ground (either bare or vegetated) and the overlying canopy, and the boundary layer of the atmosphere above.

The current recommendation is that the overall domain of regional-scale experiments should be on the order of $10^4$ km$^2$ so as to allow characterization of processes relevant to the size of the grid in global models (Figure 12). Resource restrictions necessarily mean that it is impossible to intensively instrument the whole of an area this large. In consequence the currently recommended strategy is to include densely instrumented experimental systems in smaller so-called supersites, typically 100-400 km$^2$, preferably located in well-instrumented river catchments where basin outflows and the nutrient content of water can be monitored. Such supersites will include a number of homogeneous patches of the type studied under Focus 1. The choice of scale for supersites is further influenced by the desire to allow studies of atmospheric merging of patch-scale surface heterogeneity, to facilitate airborne flux measurements, and to allow investigation of remote sensing methods at the scale of several pixels.

One or more patches, and ideally one full supersite within the experimental area, should be equipped and maintained to provide a long-term, multi-year record of fluxes (heat, moisture, carbon dioxide), meteorological data, vegetation variables and parameters, physical soil properties, hydrological variables, and sun photometry for atmospheric corrections. Such a long-term site should remain in operation for a period consistent with the observation of climate and vegetation changes; i.e., for at least 5 years, and ideally 10 years.

Additional long-term monitoring sites are required within and, where appropriate, along eco-climatological gradients extending outside the primary mesoscale study site. Such sites will be used for hydroecological and biogeochemical observations; their operation should be organized in cooperation with GCTE and other projects - since large-scale studies of the dynamics of ecosystems, of their effects on the hydrological and biogeochemical cycles and process characteristics, as well as their response to climatic and hydrologic forcings have a common increasing interest. These long-term studies should also include investigations on the interaction of groundwater with surface waters and with vegetation cover, to get suitable databases for the development of improved ecohydrological models capable of describing seasonal dynamics and changing structure of the various canopies, feedbacks between the biosphere and the atmosphere under changing conditions, as well as the role of extreme events. Long-term monitoring sites have been a recommended but poorly implemented feature in past regional-scale experiments, but it is envisaged that institutional and infrastructure development, some fostered by START, will aid their provision in future observational studies.

Long-term monitoring at a single site does not by itself provide the data necessary to achieve the spatial integration needed to investigate parameterization schemes for global models. During the intensive phase of an experiment, which should ideally last one year or more, meteorological and hydrological data should be acquired from a *regional mesoscale network* (100 to 300 km radius). This extended study area should correspond to a catchment if possible. Specifically, temperature, humidity, precipitation (rain radar), wind vector and profile data, airborne eddy-flux measurements, soil moisture and remotely sensed data must be collected at sufficient spatial and temporal resolutions. A particularly important use of these data is to initialize and validate mesoscale atmospheric models. If necessary, operational meteorological and hydrological networks should be augmented during the intensive period.

Stratified sampling techniques should be used to determine the placement of equipment on different land-surface types during the intensive experiment periods. Where possible, measurements of fluxes, surface hydrological and biophysical properties should be concentrated and coordinated with observations appropriate to remote sensing studies. This coordination further justifies the concentration of experimental resources at selected supersites, rather than distributing them more uniformly over a larger area.

It is important that the instrumentation used in regional-scale experiments is calibrated and intercalibrated and, for certain variables such as net radiation, that this calibration is relevant to the climate of the study site. *In situ* intercalibration of sensors is therefore



a necessary component to be included in the experimental design. Repeated calibration and intercalibration is required for sensors used in long-term monitoring.

The timely exchange of data between regional-scale experiments is desirable, and is essential in the case of paired studies jointly addressing the same global issue such as the European International Project on Climate and Hydrological Interactions Between Vegetation, Atmosphere, and Land Surfaces (ECHIVAL) Field Experiment in a Desertification-threatened Area (EFEDA), the Hydrological Atmospheric Pilot Experiment (HAPEX) in the Sahel, the Boreal Ecosystem-Atmosphere Study (BOREAS), the Observation at Several Interacting Scales in Australia (OASIS), and the Northern Hemisphere Climate Processes Experiment (NOPEX). Equally, the rapid propagation of data from regional-scale experiments throughout the scientific community is necessary in order to allow their use in interpretative modelling (Task 2.2.3), and in the development of regional-scale descriptions of land/atmosphere interactions (Activity 2.3). For this reason BAHC will publish and propagate technical guidance and standards on databases and data storage formats. Further, within the restrictions of ongoing technical development, BAHC will foster the use of common data storage and data distribution systems.

It is likely that aspects of the design of regional-scale experiments will change substantially in response to the scientific issues they address, but some common attributes are considered necessary to fulfil BAHC objectives. Particularly important in this regard are the establishment of long-term monitoring sites, and the provision of mesoscale measurement networks. Under Task 2.2.2, BAHC will organise conferences and symposia at international meetings to continuously review the design of regional-scale experiments.

### *Task 2.2.4 Develop interpretative 3-dimensional mesoscale atmospheric and hydrological models to synthesize and up-scale results from regional-scale land-surface experiments*

It is now known that high-resolution mesoscale (at about 100 km scale, see Table 2) modelling, especially of atmospheric processes, provides an effective complement to regional-scale land-surface field experiments. For conditions observed during any given regional-scale experiment, it is valuable to run such an atmospheric mesoscale (100 - 300 km scale) model with a grid size comparable to the scale at which patch measurements are taken at supersites, over a domain encompassing the entire region under experimentation.

Such runs provide a check on the internal consistency of the data collected, provide interpolation of the data parts across the experimental domain which have been monitored with less density, and represent the most flexible tool to study area-integrating processes. Further, since they can easily be formulated with different grid resolutions, they also allow to study the applicability of the parameterization schemes at quite different spatial scales.

The same is true of models of the surface and subsurface hydrological processes (soil moisture dynamics, infiltration and overland flow, lateral subsurface flows, ground water recharge, basin outflows), and in particular of the gauged supersite river basin mentioned above. One of weaknesses of past experiments is that this counterpart to atmospheric process modelling has been inadequately developed. However, it is increasingly needed in order to close the water, nutrient and other cycles, particularly at larger scales. Task 2.2.3 will provide coupled hydroecological-atmospheric models which operate at microscale (< 1 km) and at short mesoscale (10 km) to investigate upscaling from patch to grid scale, and to provide a bench mark calculation of aggregate fluxes against which the simpler models developed within Activity 2.3 can be compared.

## Activity 2.3 Develop Generalized Parameterization Schemes for Land-Surface Processes at the Regional Scale

Although it is clear that land-surface processes are a major component for the description of the Earth system, their parameterization within models that simulate global change is currently not sufficiently exact. Most land-surface parameterization schemes presently used in global models are based on the simple concept that exchanges are controlled by:

(i) the atmospheric demand, which drives the amount of momentum, heat, or mass which can be removed from, or fed into, the atmosphere; and

(ii) the energy and mass at the surface available for the exchange between the soil and the vegetation and the atmosphere.

This approach appears to be a basically correct. The outstanding, but important (if not crucial) remaining problem is that the governing laws should be correctly applicable as spatial averages which account for the diversity of surface conditions encountered within model grid squares, an objective which is far from fulfilment.

### Objectives

Develop land-surface parameterization schemes for further implementation within models of global change, with particular emphasis upon:

- Taking account of the most significant physical, biophysical, and ecological processes
- Retaining sufficient simplicity to allow their realistic incorporation into global models
- Paying appropriate attention to the subgrid-scale heterogeneities in land-surface properties.

Three tasks have been defined for the implementation of this activity:



### *Task 2.3.1 Compare and assess the results from various land-surface experiments and their transferability to all regions of the globe*

A series of intensive field studies of coupled processes involved in the interaction between the atmosphere and the land-surface have been made and are planned as multinational collaborations in a range of geographical locations and climatic regimes as Activity 2.2. Others are planned to be implemented on a national or regional level.

Task 2.3.1 will compare the understanding arising from these major experiments through international workshops and conferences, with a view to identifying common insight into how best to parameterize physical and biophysical controls at regional scale. Particular emphasis will be given to distributing the data from these experiments as widely as possible using easy-to-read media such as CD-ROMs, and on propagating the understanding generated by such experiments through publications.

### *Task 2.3.2 Develop methods to infer the parameters required in representations of land-surface processes from remotely sensed data*

Before a representation of land-surface processes can be used efficiently in a global model, it is necessary to parameterize and validate it. Regional-scale experiments allow testing of such parameterization schemes from physical and ecological principles, but only for selected cases corresponding to major biomes and particular climatic conditions.

Although the developed schemes are valid for the specific conditions in which experiments are made, there remains the need to extend the use of such schemes over a broad range of biomes for actual and anticipated conditions. This requires that input parameters can be collected globally. Since satellite data is global in nature, satellite remote sensing can potentially contribute to this task, but research is required to define the extent of this contribution, and the methods through which this contribution can be made.

Advanced remote-sensing measurements (often collected experimentally using prototype sensors on research aircraft) and the new sensors of the next generation of satellites are needed to verify that parameterization schemes perform equally well for a broad range of conditions. The studies of advanced remote sensing techniques within this task will focus on extending the geographical and temporal availability of the parameters needed for implementing regional-scale models at global scale using data from existing satellites; in addition, effort will be made to facilitate the use of new sensors on the next generation of polar-orbiting platforms.

### *Task 2.3.3 Develop simplified areally integrated representations of land-surface processes for implementation within models of global change*

A number of schemes for representing land-surface processes are available with different degrees of resolution in space and time (e.g., Dickinson and Kennedy, 1991; Sellers, 1991; Vörösmarty and Moore, 1991). With respect to the assessment of areal heterogeneity, the different schemes may be classified as lumped, semi-distributed or distributed (Becker and Serban, 1990). In addition; the number of levels represented both above and below ground differs. In hydrological modelling at scales of >50 km, the semi-distributed approach (applied in combination with statistical distributions to specify the areal variability of important land surface characteristics) has currently gained some preference (e.g., Avissar, 1991; Avissar and Pielke, 1989; Becker, 1992; Entekhabi and Eagleson, 1991; Famiglietti and Wood, 1991; and Wood, 1991).

Task 2.3.3 will test and evaluate the different representational schemes (models) using the detailed information collected in the framework of large-scale land-surface experiments, taking full account of the areal pattern and time variation of atmospheric forcing, (e.g., modulation of available energy by partial cloudiness), the availability of water (e.g., spottiness of rainfall distribution), and the difference in land-surface properties which result from variability in vegetation cover, soil type, and the presence of water and nutrients in soils. Research efforts in this direction will be carried out in close cooperation with ISLSCP of GEWEX.

The different existing schemes will be classified with respect to the appropriate mode and scale of their application, the input information and parameters they require, and the quality of the simulation they give, these being judged in relation to the degree and simplicity they have. The ultimate goal is to develop a new generation of land-surface parameterization schemes, which are as simple as possible, but which have enhanced recognition of subgrid-cell–scale spatial variability and make the best use of remotely sensed data. Such models are viewed as the main final products of Focus 2.



# 7. FOCUS 3: Diversity of Biosphere - Hydrosphere Interactions: Temporal and Spatial Variability

## Introduction

Interactions between the hydrological cycle, the biosphere, and the physical climate system involve a large number of processes that operate over a continuous range of spatial and temporal scales. With processes ranging from stomatal regulation of evapotranspiration to continental-scale hydrologic discharge, with spatial scales ranging from single plant to the entire globe, and with temporal scales ranging from minutes for GCM time steps to centuries or millennia for climate related vegetation changes, the challenges in this area stretch the traditional definitions of research fields. The challenge of understanding interactions across this diversity of process and scale requires that hydrologists, atmospheric scientists, and ecologists interact without the traditional boundaries of their separate disciplines.

To identify changes associated with the climate, Focus 3 addresses aspects of all three critical continua—processes, space, and time—with studies designed to complement the ongoing and planned activities of a number of other international programmes, projects and studies, especially the other BAHC foci, the IGBP Core Projects on Global Change and Terrestrial Ecosystems (GCTE) and Land Ocean Interactions in the Coastal Zone (LOICZ), and the WCRP Global Energy and Water Experiment (GEWEX). These other activities will incorporate the fundamental advances necessary to form an infrastructure that is both a supplier to, and a consumer of, information about the processes addressed by Focus 3.

This focus primarily encompasses the long-term (seasonal to decadal and longer) dynamics of the coupling between the terrestrial biosphere, the hydrological cycle, and the physical climatic system. At the short end of this temporal scale, dynamics are regulated primarily by a combination of natural and anthropogenically driven changes in ecosystem structure and function, including climatic and atmospheric change. At the longer temporal scales, climatic change associated with orbital variations set the tempo.

Focus 3 consists of studies to extend the models and associated structures (e.g., vegetation classes, plant functional types) to larger spatial and temporal scales. Two motivations for the focus on understanding long-term dynamics and their consequences are given. First, major changes in ecosystem structure, e.g., the replacement of forest by grassland, are likely to have impacts on water resources and the physical climate system that are larger than those of short-term changes in ecosystem function (e.g., a change in leaf area index or stomatal conductance). Models of the coupled Earth system designed to simulate periods longer than a few years will need protocols for predicting ecosystem changes and the impacts of those changes on water resources and climate. Second, the great diversity of the Earth's ecosystems, which is a product of these long-term dynamics, demands a systematic approach to characterizing ecosystems with respect to their impacts on the hydrological cycle, including effects on evapotranspiration, albedo, hydrologic discharges, and waterborne transport of carbon, sediment, and nutrients.

To develop a predictive understanding of biospheric change, one must understand complex and multifaceted interactions between climatic, hydrologic, and biospheric characteristics. Although all measurable climatic and hydrologic variables influence biosphere directly or indirectly, analysis of biospheric changes have been to a large degree qualitative. To understand changes in global diversity we must identify and quantify changes in biospheric attributes regulating the hydrologic cycle.

Many - but not all - future changes in hydrologically significant biospheric attributes are likely to be due to climatic change (whether natural or anthropogenic). One important component of the global change problem is how to distinguish land-surface change due to climatic influence from that caused by other factors, including human impacts. This will probably be difficult for locally and regionally driven changes, because not only do past conditions affect ecosystems and other surface characteristics, but also because many of the important impacts are not immediately visible. Feedback effects could counter or amplify the effect of human activities. Another problem arises in respect of the spatial extent, duration, and intensity of the influencing factors.

The studies of long-term dynamics within Focus 3 fall into three main classes. Activity 3.1 involves studies in the temporal domain. Activity 3.2 assesses the long-term dynamic consequences of the ecosystem diversity on water resources, specifically their role in regulating the release of carbon, sediments, and nutrients from soils to surface and subsurface water. Activity 3.3 provides the data and methods necessary to extend the long-term dynamic models developed in Activity 3.1 to large areas of sparse ground truth data. It is designed to characterize the present and future diversity of terrestrial ecosystems, with emphasis on quantifying the parameters most important in interactions with the hydrological cycle and the physical climatic system.

## Aims

(i) Explore the long-term dynamics of the interactions between terrestrial ecosystems and water resources in response to incremental forcing resulting from natural variability (including climatic variability) and direct anthropogenic forcing

(ii) Develop better models of the mechanisms regulating the transfer of carbon, soil, and nutrients from terrestrial ecosystems to surface and subsurface water, including feedbacks between the loss of these materials and ecosystem structure and function

(iii) Develop approaches for improving the quality and to increase the extent of the global data necessary for characterizing the biospheric aspects of the hydrological cycle and its connections with biogeochemical cycles and with the Earth's climate.



# Activity 3.1 Temporal Integration

Interactions between the terrestrial biosphere and the water cycle are sensitive to the condition of the terrestrial biota, the state of water in soils, aquifers, lakes and rivers, snowpack and ice, trends and variations in the climatic system, and interactions among these components. These dynamic processes present significant challenges since the phenomena are, and will continue to be, influenced by anthropogenic change and in many regions ground data are sparse (see Activity 3.3).

Significant progress has been made in understanding distinct components of the Earth system, in particular the dynamics of the atmosphere and terrestrial biosphere (IPCC, 1990; Committee on Global Change, 1990). Atmospheric general circulation models (AGCMs) are steadily evolving from rather crude representations of atmospheric physics with relatively coarse spatial scales to models that include more realistic physics at much finer scales. Trial efforts have been made at incorporating active chemistry into AGCMs. Terrestrial ecosystem models treating the biogeochemistry of carbon and nitrogen have appeared at both regional and continental scales (Parton *et al.* 1987, McGuire *et al.* 1992, Raich *et al.* 1991, Costanza *et al.* 1990, Running *et al.* 1989) and also globally (Melillo *et al.* 1993).

The structure of plant communities plays a highly significant role in radiation absorbtion and in determining the exchange coefficients for mass (carbon and water) and momentum in biosphere-atmosphere interactions (Choudhury, 1991; Raupach, 1992). The partitioning of assimilated carbon between above and below ground parts will determine spatial and temporal variations of roots, which ultimately will transfer soil water to the atmosphere. Complex interactions among energy, water and nutrients are involved in this root:shoot partitioning of assimilated carbon (Wilson, 1988). Canopy conductance is a significant parameter in most of the SVATs, which is also determined through interactions among areal environment, root-zone soil water and nutrients (Schulze and Hall, 1982). A direct role of roots and complex interactions among carbon, water, and nutrients appear inconspicuous at large spatial scales; canopy conductance is considered to provide the overall effect.

Sensitivity of large-scale evaporation and other hydrologic components to various biospheric attributes depends upon the model formulation. We need to improve our understanding to formulate the principles and methodologies of identifying and quantifying critical biospheric attributes regulating the hydrological cycle at continental and global scales.

Recent attempts at enhancing the treatment of the land-surface boundary layer within AGCMs, e.g., the Simple Biosphere Model (SiB) and Biosphere-Atmosphere Transfer Scheme (BATS) model, have recognized the importance of terrestrial vegetation in exchanges of water and energy (Sellers *et al.* 1986; Dickinson 1984). These models couple the land, biosphere, and atmosphere, but they do so only in order to quantify the short-term exchange of water and energy and they do not take into account land-surface heterogeneity within GCM grids. Work at the regional scale by Running and co-workers have explicitly linked models of $CO_2$ exchange and transpiration by modelling fluxes across the leaf boundary. These models, however, have not explicitly nested the calculations within an interactive atmospheric model. Coupled models are studied in Task 3.1.1.

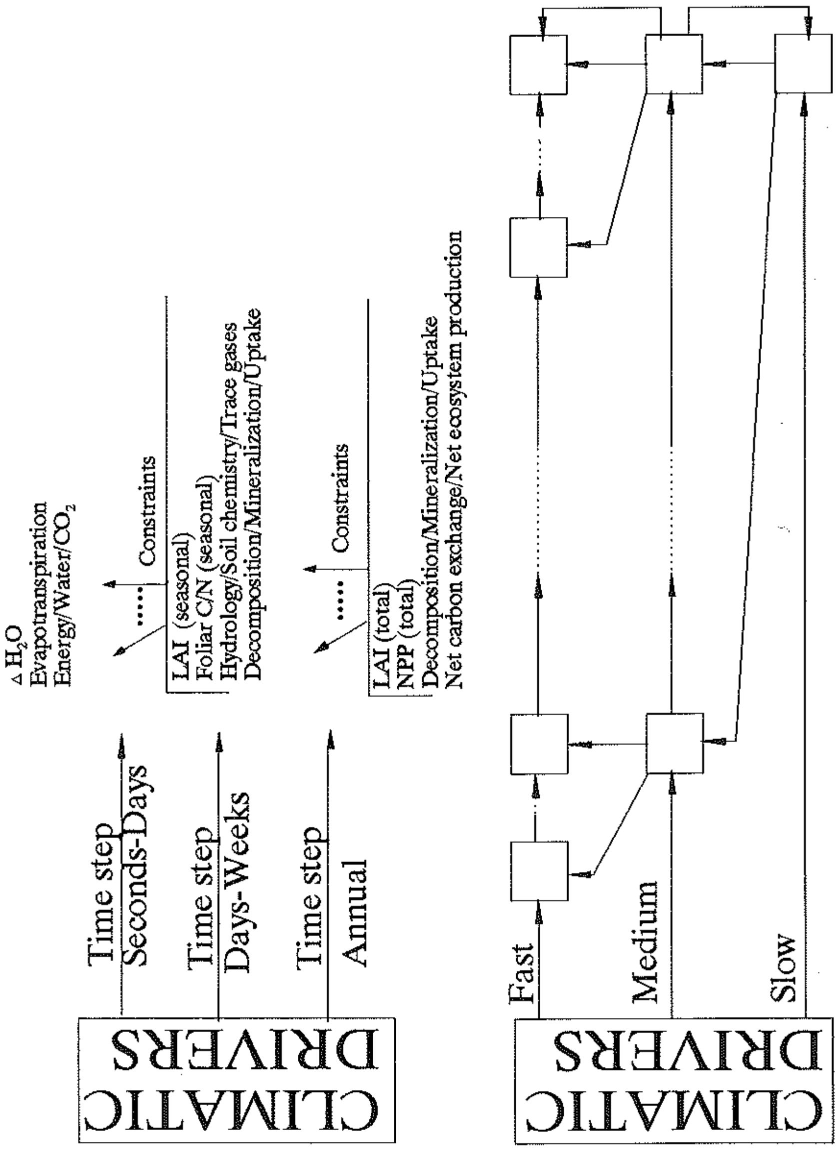



Fig. 13 Temporal scaling scheme



The drivers of these interactions operate at a variety of temporal scales as shown in Figure 13. The metabolic activities of terrestrial plants regulate the most rapid interactions between the soil vegetation system and the atmosphere, on the order of seconds to days. These determine latent heat, energy, water and $CO_2$ exchange. Intermediate processes, from days to weeks, include the development of leaf area, soil water balances, trace gas exchanges, decomposition of soil organic materials, and the cycling of nutrients. Longer term, annual dynamics encompass net primary productivity, ecosystem production, long-term changes in carbon, and nutrient pools in plant tissue and soils. Over decades, climatic change and change in land use can cause significant shifts in biome distribution and land surface parameters.

At each step toward longer temporal scales, the climate system integrates the finer scaled processes and applies feedbacks onto terrestrial ecosystems. At the finest time horizon, temperature, radiation, humidity, and winds regulate plant transpiration. On longer time scales, integrated weather patterns regulate biological processes such as when leaves emerge or are excised, uptake of nitrogen by autotrophs, rates of organic soil decay and turnover of inorganic nitrogen. The effect of climate at the annual or interannual scale defines the net gain or loss of carbon by the vegetation, its water status for the subsequent growing season, and its ability to survive and reproduce.

Integration across temporal scales cannot be considered in isolation of the spatial integration which will be done in Activity 2.3. The dynamics of the hydrologic cycle begin at the SVAT (patch) level, progress to hillslope and catchment scales, pass into the realm of mesoscale resolutions, and finally to the continental and global scale. Unique dynamics are present at each step along this pathway, and the time horizon useful to consider in SVAT models (down to the order of minutes) is of little direct value in large catchment studies (with time scales of days to weeks) or climate change studies (years to decades). Thus, to fully understand interactions between the land surface and the atmosphere, we will need to integration over time scales spanning several orders of magnitude as shown in Table 2.

Activity 3.1 concentrates on coupled changes in ecosystems, climate, and freshwater resources. However, the exchange of $CO_2$, as well as waterborne constituents, is intertwined with surface and subsurface hydrology.

## Objectives

- Improve our understanding of how long-term dynamics of the terrestrial biota impact the water cycle, and vice versa
- Explore the impacts of direct human modification of the water cycle (i.e., groundwater depletion, deforestation, engineering schemes) on ecosystems, and consequences for catchment dynamics
- Quantify the role of the terrestrial biota in modulating the responses of regional hydrology to natural climatic variations, for example ENSO, periodic drought, flooding, and volcanic eruptions

- Improve several descriptions of the long-term dynamics of interactions between ecosystems, climate, and water resources (hydroecological models) for future modelling of the coupled Earth system

The following three tasks are defined for the implementation of this activity:

### *Task 3.1.1 Extension of SVAT models to greater time and space scales*

The purpose of this task is to develop a comprehensive methodology that extends high resolution SVAT dynamics to progressively longer time and larger space scales. Therefore, this activity will develop in close collaboration with BAHC Foci 1 and 2 using the drainage basin as the common unit. This will facilitate a nested approach to progress from fine to synoptic scales, as described under Focus 2. Hydro-ecosystem models will be calibrated and tested (Running, 1989; McGuire *et al.* 1992) at a variety of scales, nesting these simulations first within catchment hydrology models, later within mesoscale atmospheric models (Focus 2) and finally within GCMs. Modelling experiments using either population based ecosystem models (Pastor and Post, 1988; Solomon, 1986) or biophysical drivers (Emanuel *et al.* 1985) have shown significant redistributions of ecosystems with GCM derived climates representing greenhouse induced climatic change.

Such experiments will be important but will lack the capacity to explore feedbacks between the vegetation and atmosphere. BAHC will therefore participate in the development of linked atmosphere-hydrosphere models over the continental landmass using the methods outlined above. Results will have a direct bearing on the distribution of functional land covers and the global distribution of land surface parameters. Development of these models will involve close collaboration with GCTE and GAIM. The data requirements will be addressed through Activity 3.3 and other IGBP projects.

Initial Task 3.1.1 efforts will extend these analyses beyond scenarios of biome redistribution to explore the impact of independently derived GCM climate fields on surface and subsurface hydrology and biogeochemical fluxes. These will include studies of $CO_2$ exchange similar to those of Melillo *et al.* (1993).

### *Task 3.1.2 Consequences of episodic events and greenhouse forcing*

Climate biosphere interactions encompass both natural climatic variability on the order of years as well as greenhouse forcing on the scale of years to decades. The natural climatic variations of interest to both hydrologists and biologists include events such as extended drought, low river flow, and floods. Such events have been linked to remote forcing associated with sea surface temperature anomalies (Nicholls, 1989; Richey *et al.* 1989; Trenberth *et al.* 1988), and it is important to understand how both the water cycle and biosphere function are affected. Analyzing these events will require detailed time series of climatic forcing fields and runoff derived principally from observational data (e.g., WCRP Global Precipitation and Runoff Data Centres) and the Focus 4 Weather Generator. These data sets will initially be used to drive the first suite of ecosystem-hydrology models and to validate the fully coupled ecosystem hydrology atmosphere models. Understanding such phenomena will require active linkage to other IGBP projects, namely GAIM and GCTE. It also requires coordination with IGBP-DIS and monitoring activities associated with Activity 3.3.



The models and database development will help to establish both the direction and magnitude of year to year variations in water, carbon, and nutrient dynamics and examine the effects of transient climatic phenomena such as the El Niño/Southern Oscillation (ENSO). For this analysis, decadal and longer time series should be assembled. A possible time series could be assembled from 1979 to 1988, corresponding to the Atmospheric Model Integration Project (AMIP). This also permits integration with satellite remotely sensed data such as the NOAA-AVHRR, the Scanning Multichannel Microwave Radiometer data sets, and the special microwave imager sensor data. The data requirements are addressed within Activity 3.3, in coordination with IGBP-DIS and other international studies (e.g., ISLSCP).

The isotopic carbon record ($^{13}C/^{12}C$) has yielded important insights into the coupling of atmosphere, oceans, and terrestrial biota. Observational records linked to inverse modelling experiments (Keeling *et al.* 1989; Volk, 1989; Siegenthaler, 1990) show that during the periodic ENSO events there is an apparent net source of carbon from the terrestrial biosphere, possibly linked to decreased net primary production because of decreased rainfall over the tropical land mass (Siegenthaler 1990). The Terrestrial Ecosystem Model (TEM) of Raich *et al.* (1991) supports such a hypothesis, in so far as $CO_2$ exchange for South America was found to be highly sensitive to water availability in tropical ecosystems. Isotope tracers have a rich history of use in a variety of hydrologic settings (Gat and Gonfiantini, 1981; Salati and Vose, 1984)

### *Task 3.1.3 Consequences of direct anthropogenic forcing*

Direct anthropogenic change encompasses land use alteration such as forest clearing, agriculture, grazing, and urbanization. Deforestation, for example, has a significant impact on the local water cycle including both water quantity (increase in runoff) and quality changes (nutrient leaching, erosion). On a regional scale, wholesale destruction of forests may create negative feedbacks whereby reduced recycling of water depresses net evaporation which in turn creates persistent reductions in rainfall.

Dickinson and Henderson-Sellers (1988), Lean and Warrilow (1989), and Shukla *et al.* (1990) confirmed this in modelling studies of deforestation of Amazonia. Although these studies have been important to the understanding of regional hydrology, they apply the somewhat unrealistic condition of complete deforestation within the basin. The nature of land use and its associated impacts are far more complex, including spatial and temporal heterogeneity overlaid with potentially diverse patterns of revegetation. These dynamics span many years and there is a need to understand how a shifting mosaic of such recovery trajectories influence catchment dynamics, specifically the partitioning of water among evapotranspiration, storm and base flow, aquifer and soil water recharge. This will require a successional model of ecosystem processes. See Figure 14 for an example of this type. This understanding must be secured at a variety of spatial and temporal scales.

These dynamics cannot be viewed in isolation from the dynamics of other constituents. Following disturbance, ecosystems can lose significant quantities of materials as previous retention mechanisms are destroyed. Recovery progresses along characteristic trajectories of response, depending in large measure on growth limitations imposed by the constituent in question (Figure 15). The nature of land use is also important to consider. In arid and semi-arid regions, sustained irrigation results in increased soil salinity and reduced productivity. Grazing limits infiltration capacity, often increasing

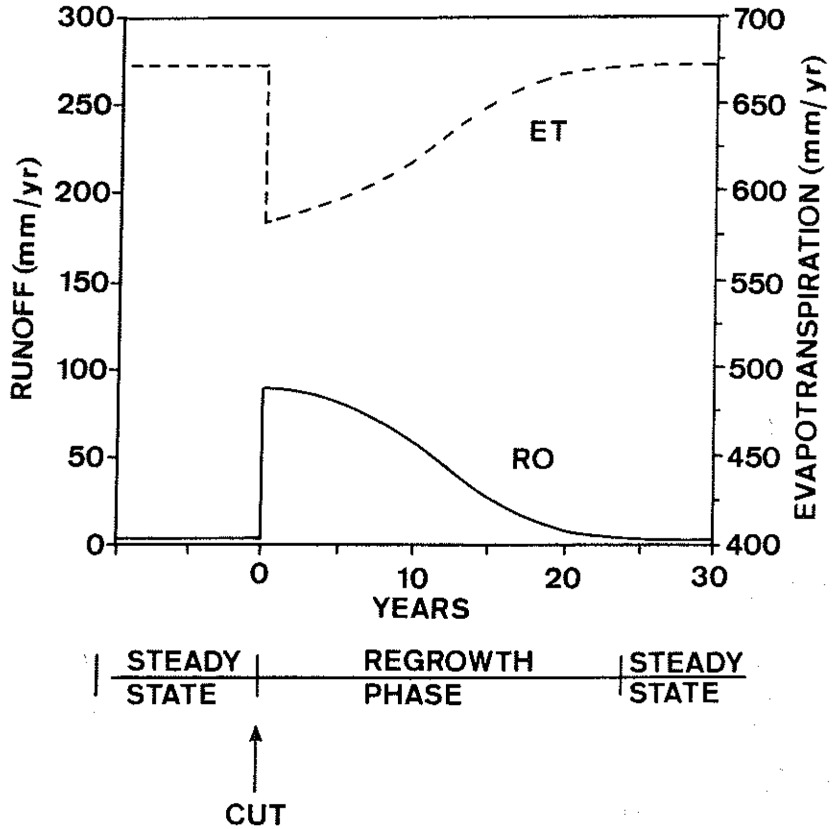



Fig. 14 Impact of disturbance and recovery on water balance elements in an African woodland determined using a simple water balance model (Vörösmarty *et al.*, 1991)

the potential for flooding while reducing groundwater levels. Downstream ecosystems will therefore experience a greater throughput of water, enhanced wetland inundation and a potential increase in trace gas exchange with the atmosphere. Downstream aquatic communities are also affected by changes in the delivery of sediment, organic materials and nutrients.

This Task will also include an assessment of water engineering and irrigation works at both regional and continental scales. This is important for two reasons. First, it will provide a more complete picture of how human modification of the landscape influences the atmosphere. Secondly, it is important to help identify the effect of climatic variation and change on water resources planning.



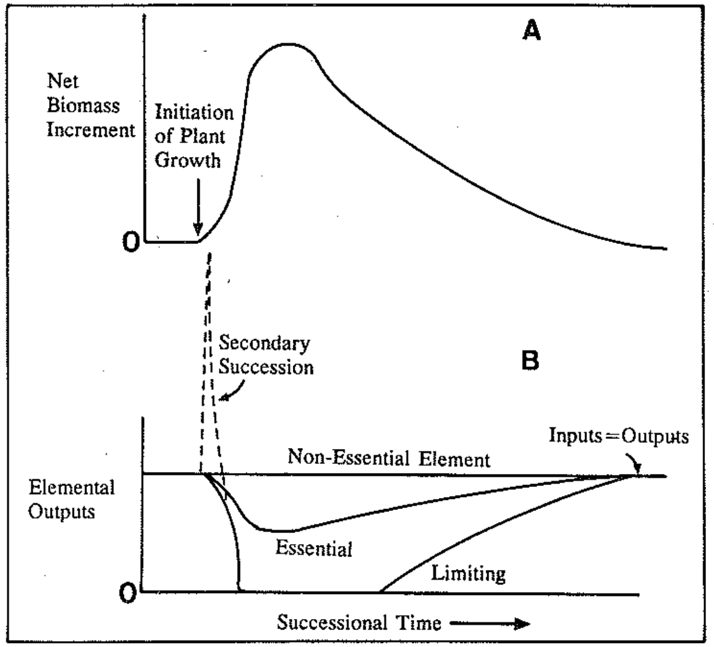



Fig. 15 Generalized recovery curves for biomass and constituents in disturbed ecosystems (Vitousek and Reiners, 1975)

## Activity 3.2 Waterborne Transport of Soil, Nutrients, and Carbon

This activity will be concerned with the mechanisms that regulate the transfer of substances from ecosystems to water, primarily in regions relatively remote from the coastal zones.

One aspect is the increasing extent of degradation of natural resources, including freshwater resources, in particular the implications of the biosphere and the direct human impacts (e.g., waste water release).

### Objectives

- Quantify the role of the terrestrial biosphere in regulating the delivery of carbon, nutrients, and soil to surface and subsurface water, at catchment and larger scales
- Quantify the impacts on terrestrial ecosystems of the loss of nutrients, soil and carbon to surface and subsurface water

Two tasks have been defined to implement this task:

*Task 3.2.1 Biospheric control of waterborne transport*

The control of the terrestrial biosphere on the delivery of carbon, nutrients and other substances to surface and subsurface water bodies, along with overland and subsurface flows (interflow, percolation, seepage) will be investigated. Overland and subsurface flows are highly dependent on the structure and function of the biosphere. The improved understanding and modelling of these dependencies is a primary objective.

It is also important to consider the feedbacks of waterborne transport of carbon, nutrients and other substances on the biosphere and on the behaviour of ecosystems. These need to be better understood, and improved models need to be developed.

*Task 3.2.2 Integrating waterborne transport at the river-basin scale*

All releases of individual ecosystems like biomes, patches of different type, complex heterogenous land-surface areas, river catchments etc., are integrated in larger rivers and transported downstream toward the coastal zone. This integration process needs to be investigated and modelled, starting from small areas and extending to large river basins. The main objective is to understand river loads of carbon, nutrients and other substances for budgeting over large areas, river basins and finally continents.

For this activity, close cooperation with other IGBP Core Projects, especially GCTE and LOICZ, and with programmes like GEWEX and IHP, is required.

## Activity 3.3 Land-Surface Characterization for Assessment and Modelling where Ground Data are Sparse

One of the greatest challenges to progress in global change research is obtaining sufficient data - to detect small changes, to extend models developed from local and regional experiments to large areas where ground (truth) data are sparse, and to run global models sophisticated enough to capture the most important processes. Some of the data-acquisition problems arise due to the absence of appropriate satellite sensors, but many others are far simpler, resulting from difficulties in calibrating satellite data or from a paucity of high quality surface observations. Questions of data availability and reliability resonate throughout IGBP and other components of the international global change research effort, but enough of the issues are unique to BAHC to justify its major involvement in this area.

Specifically, BAHC requires global data sets of the parameters required to run current and future land-surface/atmosphere parameterizations for different types of global models of the coupled Earth system including GCMs. For some of the parameters, e.g., absorbed photosynthetically active radiation (APAR), the unresolved issues are primarily technical. For others, e.g., maximum stomatal conductance, the questions are scientifically complex, and are unlikely to be resolved without some combination of new



sensors, new techniques for extracting parameters from the existing sensors, and new research to identify appropriate surrogates for important parameters on the ground.

The need to characterize the diversity of the Earth's surface extends beyond biome classification. Non-biological boundaries (e.g., areal extent of glaciers and snow cover) and soil nutrients are equally essential because their changes, directly and through feedback, modify the biosphere and its regulation of the hydrological cycle. The roles of carbon assimilation and partitioning between root and shoot are also comparably important.

Before it is possible to characterize the diversity of terrestrial ecosystems, it is necessary to develop a useful classification system. The concept of plant functional types (plants grouped by attributes that are critical for predicting responses to environmental change) is central to the GCTE modelling work on vegetation/climate interactions. Defining functional types for the BAHC objectives of parameterizing SVATs and mesoscale models is a Task 1.3.1 (of Focus 1). It is not only a high priority for BAHC-related models but also for testing whether functional types defined for different uses produce similar classifications.

The suite of characteristics (described in Activity 3.1) that influences short-term biosphere-atmosphere feedbacks is relatively well known, though satellite indices for deriving these characters need to be improved. Techniques for assessing vegetation structure, especially below-ground structure, are especially weak. The physical structure of plant communities plays a highly significant role in radiation absorption and in determining the exchange coefficients for mass (carbon and water) and momentum in biosphere-atmosphere interactions (Choudhury, 1991; Raupach, 1992). Simulations using convective boundary layer models show that net radiation and canopy conductance are major determinants of evaporation at regional scales (McNaughton and Spriggs, 1989). Future progress depends not only on improvements in quantifying the parameters visible to remote sensing, but also on better models of parameters for which only associated variables can be sensed, and the integration of these efforts.

A number of algorithms have been developed to extract biospheric parameters and to study biosphere-atmosphere interactions using satellite data (Asrar, 1989; Hobbs and Mooney, 1990; Wood, 1991). These algorithms are, however, quite limited, and a clear rationale is needed for development and selection of algorithms appropriate for extracting biospheric parameters affecting the hydrologic cycle.

### Objectives

- Develop the understanding essential for the proper construction of algorithms for obtaining biosphere characteristics of critical hydrologic significance from remotely sensed data, alone or in combination with data from other sources
- Provide the quantitative data necessary for implementing advanced descriptions of biospheric regulation of the hydrologic cycle in simulation and predictive models of global change.

The following two tasks are defined for the implementation of this activity:

*Task 3.3.1* ***The global distribution of biospheric characteristics for hydrosphere coupling***

Data sets of biospheric attributes need to be assembled. Both remotely sensed and conventional observations will be needed. Very little systematic data is currently available for spatial and temporal variations of roots and other plant characteristics, which are currently known to impact the hydrological cycle (such as leaf area index and fractional cover). A number of algorithms (empirical and physically based) for estimating biospheric parameters using remotely sensed data have been developed (cited above in Task 3.3.1).

Remotely sensed data provide direct information about the radiative characteristics, from which biospheric attributes need to be derived using models of varied complexity. Uncertainties in the derived attributes stem from model formulation, inaccuracies in the calibration of remotely sensed data, atmospheric effects and non-uniqueness of the relation between any particular biospheric attribute and the observed radiances. The physical basis of these algorithms has been developed from simulations using radiative transfer models, which have been idealized. Improved simulations are needed to capture the diversity and heterogeneity of the land surface (woody component, clump leaves etc.,) and effort along this line is just beginning (Myneni *et al.* 1992).

Even with these uncertainties, optical remote sensing has made significant contribution towards quantifying land surface attributes. These data have been used as indicators of absorption of photosynthetically active radiation (PAR) by plant canopies, surface conductance, soil moisture, vegetation type, photosynthesis and biomass production (Nemani and Running, 1989; Choudhury and Fung, 1989). Microwave observations have given promising results for surface-layer soil moisture, seasonal inundation, wetland areas and vegetation characteristics in arid and semi-arid areas (Wood, 1991). Global optical and microwave data from satellites now span more than a decade, which has allowed analysis of interannual variations (Choudhury, 1990). Remarkable progress has been achieved in estimating precipitation from microwave and optical data from satellites; monitoring of snow line and onset of melt (Ohring *et al.* 1991); surface temperature patterns; the seasonal inundation area of major rivers; the extent of wetlands; and significant changes of water table (Wood, 1991). A methodology is needed to quantify over long-time periods the biospheric attributes that control the hydrological cycle.

A major challenge will be the development of inversion procedures (algorithms) to obtain biospheric attributes from coarse spatial resolution remotely sensed data acquired over spatially heterogeneous areas - particularly since relations between biospheric parameters and observed radiances are generally nonlinear. To reduce the uncertainties in derived parameters, systematic effort needs to be directed at formulating and selecting the most appropriate algorithms to develop global data sets of critical biospheric attributes regulating hydrological cycle. New challenges are likely to appear in the development of these data sets as a better understanding of these attributes is obtained.



*Task 3.3.2* ***Biosphere-hydrosphere monitoring in developing countries***

Global monitoring and archiving of biospheric and hydrospheric characteristics is required for many purposes within global change research programmes. This task has to be fulfilled by several IGBP Core Projects in cooperation with IGBP-DIS, START and with other related programmes (e.g., GEWEX and its project ISLSCP).

In many developing countries there are special problems regarding data availability, with severe shortages of information on landforms, vegetation and hydrology posing major obstacles to any sophisticated analyses. One of the potentially most useful products from BAHC would be the development of techniques for addressing these information shortages. Some of the most appropriate technologies may be globally applicable, for example remote sensing, but others may involve creative ways to obtain or interpret surface data obtained from ground observations, such as, river gauges, micrometeorologic observations, and vegetation surveys. Remotely sensed data could allow spatial extrapolation when calibrated and validated against locally acquired data. The objective of this task is to address special issues in applying general procedures to conditions in developing countries, in particular for enhancing data relevant for the estimation of hydrologically significant parameters. Close collaboration with the regional initiatives of START is envisaged, and many useful working links have already been made.

# 8. FOCUS 4: The Weather Generator Project

## Introduction

To improve our understanding of how ecosystems and hydrological systems behave under current and future climates, information is required on regional and sub-regional patterns of atmospheric input to these systems. General Circulation Models (GCMs), which attempt to simulate global climate and climate change in response to forcings such as increasing atmospheric greenhouse gas concentrations, operate at spatial resolutions of several hundreds of kilometers. However, climate information is needed at much higher resolutions than the GCMs can presently provide for ecological and hydrological research.

The need for greater spatial resolution in GCMs is widely recognized. With improved resolution, additional atmospheric physics, better specification of topography and surface mass and energy fluxes can be included in climate simulations. Within the global modelling community, three different approaches exist in this area of research. In part of the community, the opinion exists that, with further developments in computer capabilities, the information from the physical climate system needed for ecosystem development research may in the future be deduced from global models. Future generations of supercomputers are expected to support a reduction in the grid cell size of global models which would allow inclusion of regional landscape features. In the second approach under discussion, a finer grid is used only over those regions of interest, thus increasing the grid cell size over the rest of the globe. The third approach involves the nesting of mesoscale models for particular regions into global models. While these developments will result in improved GCM products, it is unlikely that any of these new generation models will meet the needs of spatially explicit models of ecosystems or hydrological systems.

The variables estimated explicitly in GCMs (pressure, temperature, moisture and wind fields of the free atmosphere) relate to atmospheric circulation on regional to hemispheric scales. Subgrid scale topography, land cover and lake effects have major impacts on local maximum and minimum temperatures, precipitation, incident radiation, humidity and the stochastic properties of these variables and all of these variables are needed in ecosystem and hydrologic models. It is therefore necessary to *downscale* (disaggregate to a small spatial extent) and interpolate the information derived from the global models and from coarse scale observations. This can be accomplished through the use of the present knowledge about the physics and statistics of weather elements, and their interaction with the biosphere, hydrosphere and land topography. In addition, the current generation of GCMs do not produce estimates of many of the climatic variables needed in ecological and hydrologic models. Methods to generate such estimates from GCM products must also be developed. The collection of algorithms and methods for the generation, downscaling, and interpolation of appropriate climatic variables is the so-called Weather Generator. The development of this Weather Generator is the central activity of BAHC Focus 4.



Three tasks have been identified within this central activity. The first task is the development of procedures for the spatial and stochastic analysis of weather data so that the weather may be simulated at higher spatial and temporal resolutions than those provided by existing weather station networks. The second task is the development of the downscaling algorithms which link broad scale atmospheric information to the statistical simulation models developed in the first task. This will permit the conditioning of these models on the broad scale outputs of GCMs while maintaining observed topographic and landscape spatial dependencies. The third task involves research on the physical basis for downscaling. This task should provide guidance to the development of the statistical models in order to enhance the validity of these models in changed climates.

An important aspect of Focus 4 is to ensure that the infrastructure is set up to document, maintain, distribute and test further developments to the Weather Generator. While this will ensure the ongoing development of the collection of algorithms that will comprise the Weather Generator, it will also include a reference GCM output that will have been used in the development of this project. The reference output will be available to various users for use with the Weather Generator, and it will allow intercomparison between new and existing algorithms.

The proposed Weather Generator will directly serve the needs of BAHC Foci 1,2 and 3, GCTE Focus 2 and indirectly GCTE Focus 3. In addition, the findings of GEWEX-GCIP and the Cloud System Study (GCSS) are expected to interface directly with the development of the Weather Generator, with respect to global and large scale precipitation. It is also expected that the Weather Generator will take full advantage of future improvements in spatial resolution of GCMs.

## Aims

The Weather Generator project proposes to:

(i) Define, jointly with GCTE and the other foci of BAHC, the ingredients of a Weather Generator

(ii) Coordinate the development, jointly with the contributing WCRP projects, of methods to downscale the coarse scale information of global models into the scales needed for ecosystem and hydrologic research

(iii) Test the results of this downscaling procedure with simulated and empirical data sets of present day climate

(iv) Facilitate distribution and use of the Weather Generator and associated data sets.

It is the responsibility of BAHC to direct research in Focus 4 and to coordinate the worldwide efforts in this area. It will do so by initiating three main activities, as follows.

## Activity 4.1 Data Requirements for Ecological and Hydrological Studies and Related Management Purposes

Mathematical models are being used to study the effects of climatic variation and climate change on ecosystems and watersheds. Climatic variation and change also affect related weather-sensitive practices in agriculture, forestry, range management and water management. The models require climatic and meteorological inputs that are not routinely available as standard products from observational networks and climate models. In addition, when data are available they are often at too coarse resolution in space and time, and the uncertainty is too large or not specified. The information needed about the input from the atmosphere may also vary for different models and different regions, and these requirements may change with further developments in both the modelling and understanding of ecosystems and watersheds.

### Objectives

The objective of this first activity is to compile information regarding the climatic data, the allowable uncertainties, and the appropriate time-space resolution required for ecological and hydrological research as well as the related management practices. The data requirements will be defined jointly with GCTE as far as ecosystems are concerned and must be defined by the general BAHC community with respect to hydrology. BAHC Focus 4 will also seek the input of research communities with related interests in agriculture, forestry and water management.

The following three tasks are defined for the implementation of this activity:

*Task 4.1.1* ***Identify the major research questions for which improved climatic data are required***

In order to properly assess the data requirements of the various disciplines it is necessary to identify the major questions which these data are intended to address. Each of these questions may require different data or data at different resolutions. For example, questions of crop production may have higher accuracy and precision requirements than questions regarding ecosystem dynamics. Efforts must be directed at an early stage to identify and document these issues.

*Task 4.1.2* ***Assess the current climatic data inadequacies in ecology, hydrology and related management sciences***

Focus 4 of BAHC will document the inadequacies in the currently available climatic data for ecological and hydrological research and the related management activities. This includes the following problems:

- data not available as direct observations or as model output
- data uncertainty
- inadequate data resolution



*Task 4.1.3* ***Specify the required parameters, resolution and allowable uncertainties for various user communities***

BAHC Focus 4 will have to produce a list of the required parameters that the various user communities require (see also Tasks 4.2.1 and 4.2.2). This list of parameters will be prioritized in terms of minimum requirements, additional requirements and optimal requirements. Each parameter will be specified, by model, in terms of allowable accuracy or total uncertainty, and require spatio-temporal resolution. In ecology a minimal data set might include daily global radiation, maximum and minimum temperature, and precipitation. Additional variables could include humidity and wind speed while the optimal set would include daily solar radiation by wavelength, dewpoint temperature, and the occurrence of extreme events.

## Activity 4.2 Development of the Weather Generator

Activity 4.2 is the central activity of BAHC Focus 4. Its primary aim is to coordinate the development of methods for providing stochastically simulated atmospheric inputs to ecosystem and hydrological models in both current and projected future climates. Though these inputs are required across the wide range of spatial and temporal scales addressed by BAHC Foci 1, 2, and 3, they are most often required at scales which are typically modelled on a daily time step at spatial resolutions of at most a few kilometers. This spatial resolution is well below the resolution of most existing meteorological observation networks, and particularly so for variables other than precipitation and temperature.

### Objectives

The objective of the second activity is to coordinate the development of the Weather Generator. This has been divided into three interrelated tasks.

Task 4.2.1 will assemble a comprehensive set of procedures for the spatial and temporal analysis of weather data obtained from a variety of point, radar and remotely sensed data sources. From these analyses, the basic spatial and stochastic models will be constructed. These models will provide the means of extending observed weather data in time, by stochastic simulation, for a variety of risk assessment applications. They will also provide the means to simulate weather at unobserved locations by spatial interpolation of stochastic weather model parameters. These models will therefore address major gaps in the analysis of ecosystems and hydrological systems in the current climate. They will also play a fundamental role in the analysis of future climate, by providing the link to the downscaling methods developed under the second task.

Task 4.2.2 will address the critical gap which exists between global climate models and ecosystem and hydrologic models of the land surface. Due to the coarse horizontal resolution of GCMs, these simulations can describe only the vary large scale atmospheric circulation patterns which are inadequate for ecosystem and hydrologic models. Simple empirical methods to increase the resolution such as interpolation of GCM output have proved inadequate (Giorgi and Mearns, 1991). More recent semi-empirical approaches derive relationships between large scale and local surface variables. The Weather Generator project proposes to use semi-empirical approaches to translate large scale, coarse resolution GCM information into the local, high resolution statistical models of surface climate variables referred to in Task 4.2.1.

The third Task in Activity 4.2 is concerned with the physical processes that are described stochastically by Weather Generator algorithms. These physical processes involve exchanges of energy and matter across different scales. BAHC Focus 4 is particularly concerned with the relationship between the fluxes of precipitation, latent heat and sensible heat at the sub-grid scale and GCM grid cell resolutions. The effort afforded to describing this relationship is not only relevant to an improved parameterization of Weather Generator algorithms, but it is also relevant to the aims of BAHC Focus 2.

### *Task 4.2.1 Analyze spatially and temporally weather and simulate it stochastically*

This task is composed of three subtasks which address respectively the development of point stochastic models, the development of spatial analysis and interpolation methods, and the development of spatio-temporal stochastic models. It is expected that the last of these will ultimately provide the most physically-meaningful parameterizations which can be most directly coupled to the large scale circulation patterns of the current atmosphere and the outputs of GCMs. However, separate point time-series analyses and spatial analyses are essential preliminary steps which have applications independent of the assessment of the impacts of climate change.

There is a vast literature on point stochastic models of precipitation at a point but relatively little on point statistical models of coordinated weather variables. Much of the development of point precipitation models has been directed towards the development of continuous time models since these describe directly the occurrence structure of precipitation. However, these models have yet to reach a widely agreed standard form although a truncated power of a normal distribution (Stidd, 1973) shows particular promise for space-time analysis. Approaches to the coordinated stochastic simulation of weather variables generally follow the scheme proposed by Richardson (1981). These methods condition related weather variables on the occurrence and non-occurrence of rainfall. This conditioning is often only weakly defined. More direct, process-based relationships between weather variables need to be further explored.

Spatial analysis techniques will play an integral role in the spatial disaggregation of stochastic weather models. The best of these techniques, optimum interpolation, geostatistical methods (Cressie, 1991) and thin plate splines (Hutchinson, 1991a) have essentially the same formal structure, but important practical differences with respect to parameter estimation techniques and numerical implementation. Important from the point of view of the spatial analysis of weather parameters is the incorporation of topographic influences (Hutchinson, 1991b) and other landscape effects where appropriate. Equally important is the capacity to adequately account for the sometimes spatially correlated errors attached to the quantities to be interpolated. This is particularly relevant in facilitating the incorporation of statistics from observation periods of short duration in order to ensure that the most dense data networks are available for spatial interpolation. Validation of these spatial interpolation techniques is also clearly essential.



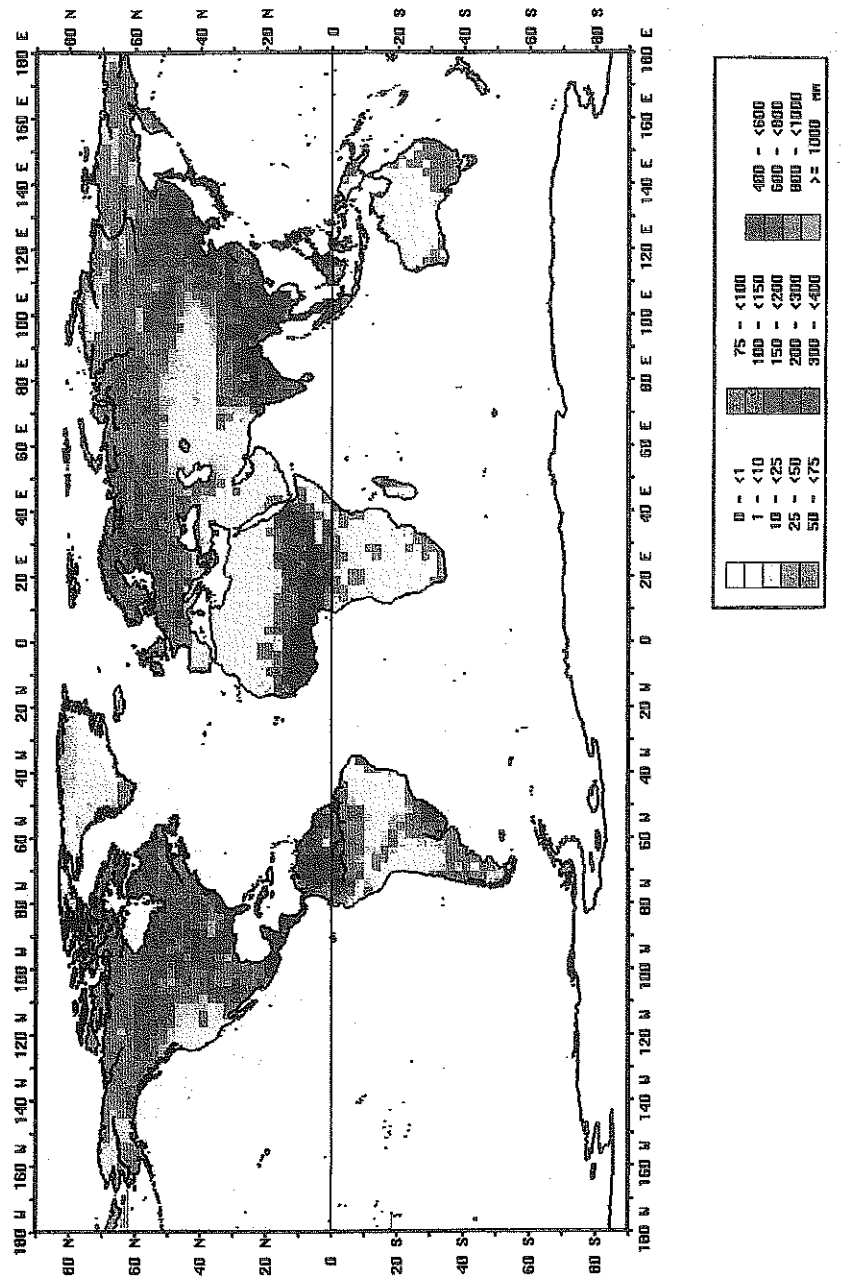


Fig. 16 Global monthly areal mean precipitation totals on a grid of 2.5 degrees over land for August 1987 (GPCC, Offenbach a.m. Germany)

Stochastic spatio-temporal weather models are desirable for several reasons. They have the potential to better match the actual space-time phenomena of the weather. Ideally the parameters of these models have direct physical interpretations, or equivalently, obey physically-based constraints. Two complementary areas can be identified within this sub-task.

The first is the development of space-time stochastic models from ground-based point data. As with the development of point stochastic models, most attention has been directed towards precipitation (Eagleson *et al.* 1987), although there is a clear need to simulate other weather variables. In order to construct accurate models from limited data, it is important to identify the spatial dependencies of the parameters of these models. Certain normalized weather anomalies, for example, can have very broad spatial correlation structures which are independent of topography, unlike the corresponding non-normalized quantities. Space-time stochastic models which incorporate dependencies on large scale circulation patterns (Bárdossy and Plate, 1992; Hay *et al.* 1992; Wilson *et al.* 1992) form an important recent development which relates directly to the downscaling Task 4.2.2.

The second area concerns the development of spatio-temporal stochastic precipitation models from satellite and radar imagery, data sources that describe the detailed spatial structure of daily and shorter duration rainfall (Figure 16). Recent work includes that of Bell (1987), Kerr *et al.* (1989); Milford and Dugdale (1989). Moreover, the incorporation of both ground-based point data and spatially distributed remotely sensed data in the development of space-time weather models shows great promise in addressing the downscaling problem.

*Task 4.2.2 Evaluate semi-empirical approaches for downscaling from GCMs*

One of the requirements of the proposed Weather Generator is the production of high resolution weather information from coarse spatial scale of a GCM. An important component of this requirement is linking of observed large scale circulation patterns to local surface variables, a procedure known as downscaling. These relationships are then applied to large scale circulation patterns that are derived from a GCM. A conceptual diagram of downscaling is presented in Figure 17. A more detailed representation of this procedure as it fits into a full hydrological or ecological analysis is presented in Figure 18. Currently, four semi-empirical approaches are recognized (Giorgi and Mearns, 1991). The most direct semi-empirical approach is the simple addition of GCM change projections to all station data within GCM grid cells (Mearns *et al.* 1991). This approach assumes that fine scale forcing of the atmosphere is unchanged over the climate change period.

The second approach involves the statistical linkage of weather types or synoptic patterns to general circulation attributes commonly produced by GCMs. The spatial detail is derived from observation stations within patterns or types, and it is scaled to GCM output or coarse-scale observations. (Wilks, 1989; Bárdossy and Plate, 1992). The third method, the perfect prog (PP) approach, involves regressing observed surface weather against observed measures of the free atmosphere to build the model then driving the changed surface weather using GCM free atmosphere measures (Wigley *et al.* 1990). The fourth method uses the model output statistics (MOS) approach. Observed surface weather is regressed against a base (no change) GCM free atmosphere output to build the model. GCM model output, resulting from alterations of the boundary conditions, can then be used to estimate changed surface weather.



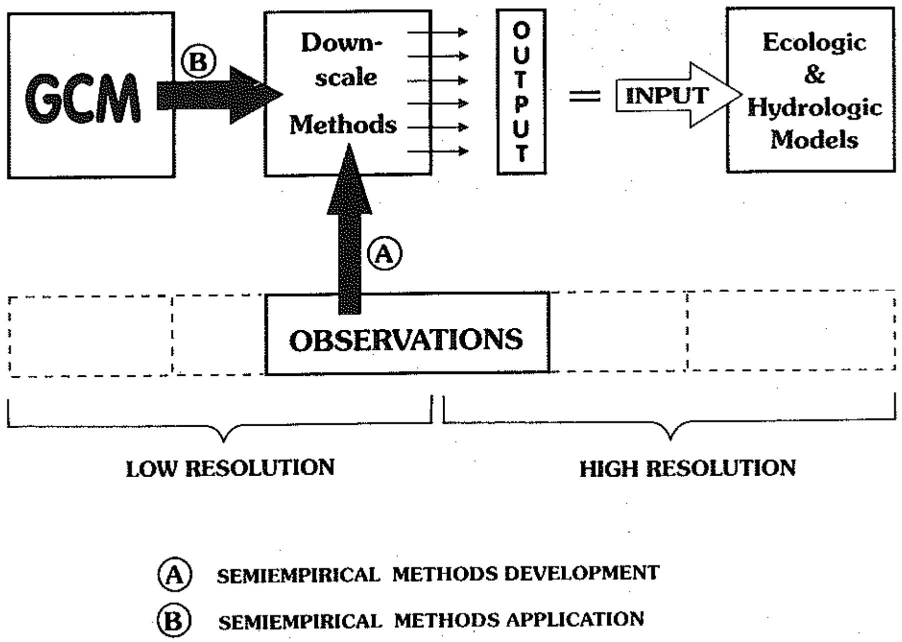



Fig. 17 Conceptual diagram of downscaling (B. Hayden, University of Virginia)

These four methods of downscaling will be evaluated and tested for use in the Weather Generator. Each of these semi-empirical methods downscales the grid cell quantity to a spatial resolution defined by the density of the ground-based observation network. For precipitation measurements the distance between stations is in the order of 50 km, but in many parts of the world the observation networks are less dense. These densities are inadequate to meet all of the needs of the ecological and hydrological communities. Thus the development of downscaling methodologies must be linked to the spatio-temporal analyses described in Task 4.2.1.

*Task 4.2.3 Develop a physical understanding of the Weather Generator*

The central physical concept behind the downscaling aspect of the Weather Generator is scale interaction in the atmosphere. General circulation dynamics are related to synoptic weather regimes; these are related to convective scale dynamics, and these in turn to boundary layer processes. Energy and mass is exchanged between these scales both from large scale to small scale and vice versa. It is these scale interactions that provide the physical bases for the stochastic surrogates used in the Weather Generator. Understanding these physical bases will facilitate the development of the Weather Generator and increase confidence in its applications.

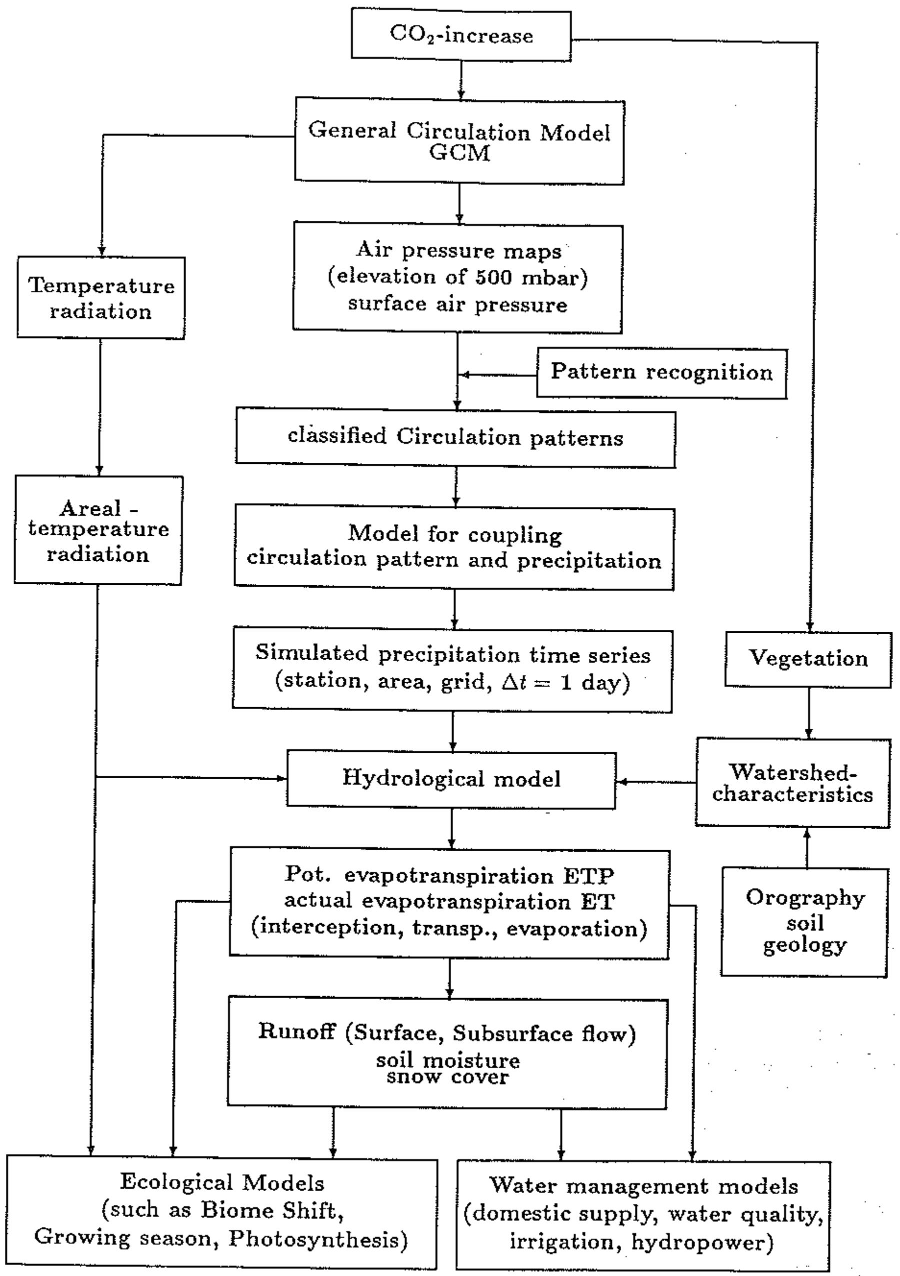



Fig. 18 Conceptual model for the calculation of regional hydrologic and ecological effects of climate change (Bárdossy and Caspary, 1991)



For the purposes of BAHC Focus 4, emphasis is placed on the fluxes of precipitation, latent heat and sensible heat and the recovery of the profile of the subgrid scale, nonaveraged fluxes from the averaged grid scale quantities (Yanai *et al.* 1973; Hantel, 1987). The primary goal of Task 4.2.3 is to elucidate the physical relationship between the observed fluxes at the subgrid scale resolution and the average fluxes at the resolution of a GCM grid cell. The physical relationship will be examined by means of selected case studies representative of different weather events in specific regions at different spatial and temporal scales.

## Activity 4.3 Facilitate Access to the Weather Generator and Databases

One of the primary functions of BAHC Focus 4 is to act as an interface between the climate modelling community (and associated researchers) and the user community. The former consists of GCM modellers, those involved with satellite, radar and ground-based observations, and international programmes and projects such as IGBP-DIS, WCRP, Global Precipitation Climatology Center (database) (GPCC) and Global Climate Observation System (GCOS). The latter community includes ecologists, hydrologists, and workers in related fields of agriculture, forestry, geography and water management. The Weather Generator will fulfil part of this function through the translation of output, provided by the climate community, into inputs required by the various user communities. This liaison function will also be fulfilled through the establishment of linkages with both communities in the implementation of the Weather Generator concept.

Accessibility to the Weather Generator comprises not only the documentation but a means of distributing the algorithms and communicating the results of ongoing improvements. It is also necessary for BAHC Focus 4 to facilitate access to both the historical climate records and GCM output used in development and testing of the Weather Generator.

### Objectives

The objective of Activity 4.3 is to facilitate access to the Weather Generator as well as the databases used in its development. This has been partitioned into three tasks.

Task 4.3.1 will produce an index to available climatic records, weather observations and GCM output used in the development, testing and application of the Weather Generator. The goal of Task 4.3.2 is to coordinate the development of the necessary infrastructure for maintaining and distributing the Weather Generator. This will also include the documentation of the algorithms comprising the Weather Generator and the provision of a reference GCM equilibrium and transient simulation data set for common community wide intercomparison studies using the Weather Generator. Task 4.3.3 is concerned with the communication of ongoing developments in the Weather Generator, as well as acting as a liaison between the climate community and the user community.

*Task 4.3.1* ***Compile an index to databases used in the development of the Weather Generator***

BAHC Focus 4 will compile an index to those data used in Weather Generator development, testing and applications. This index will provide information as to the availability of both the GCM outputs, climate records, and weather observations used in algorithm development and testing. In addition the index will provide information on the contents and difficulties encountered in using the databases. The index will be made available upon request, and copies will be issued to representatives of other programmes, such as WCRP, and their component projects.

*Task 4.3.2* ***Develop the required infrastructure, storage and distribution of the Weather Generator***

The Weather Generator is seen as a collection of algorithms or individual weather generators for specific applications. An important task of BAHC Focus 4 is to develop an infrastructure to make the collection of algorithms available to the various user communities. This not only includes the documentation but storage, maintenance and distribution of the Weather Generator. In addition, a reference GCM output, both in equilibrium and transient modes will be selected and made available to provide a common basis for the testing and intercomparison of the Weather Generator algorithms. The reference simulation output will also be made available for use in Weather Generator applications.

*Task 4.3.3* ***Communicate Focus 4 activities***

Improvements are expected in both the low resolution data used to drive the Weather Generator and the collection of algorithms comprising the Weather Generator. These improvements will be reported, on an annual basis, in the BAHC Newsletter. The first report issued by BAHC Focus 4 will contain a compendium of currently existing weather generator algorithms. An internal publication, for members of BAHC Focus 4, will be distributed on a semi-annual basis. As part of this task BAHC Focus 4 will endeavour to establish linkages with and between the climate community and the community of potential users. These linkages will strengthen the Weather Generator project and accelerate its development.



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# Appendix 1: BAHC Foci, Activities, and Tasks

## FOCUS 1: Development, Testing, and Validation of 1-dimensional Soil-Vegetation-Atmosphere Transfer (SVAT) Models

**Aims:**

(i) Investigate the processes of vertical energy, water, and other related fluxes, in particular carbon, at the soil-vegetation-atmosphere interface for small uniform areas, and the summary of these data by parameters of 1-dimensional SVAT models that represent different biomes

(ii) Compare and evaluate SVATs, develop improved SVATs as required, and produce simplified SVATS for global implementation in all biome types

(iii) Contribute to defining an effective classification scheme for vegetation functional types for global implementation, based on sensitivity analysis of SVAT variables

(iv) Use SVAT models to analyze the influence of atmospheric $CO_2$ concentration and climatic change effects on hydrologic balances in the biosphere for different climates and biome types

### Activity 1.1 Validation of SVAT models: field studies of energy, water, and carbon fluxes

Task 1.1.1 Evaluation of required SVAT parameters for major biome types, and planning of field studies in biomes identified as vegetation functional types where data is needed

Task 1.1.2 Implementation and coordination of a long-term monitoring network of water and carbon fluxes for terrestrial ecosystems

Task 1.1.3 Test and compare the existing methods and instruments for measuring SVAT processes

Task 1.1.4 Conduct field studies in biomes to study the hydrologic controls of trace carbon transfer processes from soils and vegetation to the atmosphere

### Activity 1.2 Selection, evaluation and improvement of appropriate SVATs for patch-scale fluxes: modelling activity

Task 1.2.1 Test SVATs against field data sets

Task 1.2.2 Compare SVAT formulations that have varying treatment of system structure and develop improved SVATs as required

Task 1.2.3 Evaluate specifically the "limits of simplification" possible in SVAT formulation that will result in model logic for implementations in Focus 2 and 3, GCMs, GAIM and other Earth systems modelling activities

### Activity 1.3 Definition of worldwide vegetation functional types for SVAT model applications

Task 1.3.1 Use SVAT model analysis to elucidate the critical simplified variables most useful for a unified functional vegetation classification of global biomes

Task 1.3.2 Develop an optimized SVAT model for each functional vegetation class defined

### Activity 1.4 Use of SVAT models to analyze the influence of future global change on hydrologic processes in different biome types and climates

Task 1.4.1 Carry out single-year SVAT simulations of direct $CO_2$ responses in different climates and biome types

Task 1.4.2 Carry out multiple year SVAT simulations to study the second-order effect of

CO2 and climate change on hydrologic responses

Task 1.4.3 Incorporate the dynamic responses of the SVAT from Task 1.4.1 to produce improved multi-year global climate change scenarios

## FOCUS 2: Regional-Scale Studies of Land-Surface Properties and Fluxes: Experiments, Interpretation, and Modelling

**Aims:**

(i) Synthesize patch-scale land-surface process descriptions relevant to increasing spatial scales which consider land-surface heterogeneity and topography

(ii) Provide quantitative understanding of water, carbon, and energy cycling at the regional scale for a range of important biomes

(iii) Improve the representation of land-surface-atmosphere interactions within models that simulate global change

### Activity 2.1 Study of the effects of surface heterogeneity and topography on land-atmosphere interactions from patch to regional scales

Task 2.1.1 Study the effects of land-surface heterogeneities and associated local advection over relatively flat terrain, from patch to regional scales, including local and regional advection and mesoscale circulations

Task 2.1.2 Study the meteorological and hydrological modulation of land-atmosphere interactions by topography, from patch to regional scales

### Activity 2.2 Prioritize, design and coordinate regional-scale land-surface experiments, to study vegetation, atmospheric and hydrological processes

Task 2.2.1 Develop and promulgate standards for land-surface experiments

Task 2.2.2 Define scientific priorities and coordinated timing of activities for major regional-scale land-surface experiments in different biomes

Task 2.2.3 Provide overall design of specific components and strategy of future regional-scale, land-surface experiments, and stimulate participation by other international programmes

Task 2.2.4 Develop interpretative three-dimensional mesoscale atmospheric and hydrological models to synthesize and up-scale results from regional-scale land-surface experiments

### Activity 2.3 Develop generalized parameterization schemes for land-surface processes at the regional scale

Task 2.3.1 Compare and assess the results from various land-surface experiments and their transferability to all regions of the globe

Task 2.3.2 Develop methods to infer the parameters required in representations of land-surface processes from remotely sensed data

Task 2.3.3 Develop simplified areally integrated representations of land-surface processes for implementation within models of global change

## FOCUS 3: Diversity of Biosphere - Hydrosphere Interactions: Temporal and Spatial Variability

**Aims:**

(i) Explore the long-term dynamics of the interactions between terrestrial ecosystems and water resources in response to incremental forcing resulting from natural variability (including climatic variability) and direct anthropogenic forcing

(ii) Develop better models of the mechanisms regulating the transfer of carbon, soil, and



nutrients from terrestrial ecosystems to surface and subsurface water, including feedbacks between the loss of these materials and ecosystem structure and function

(iii) Develop approaches for improving the quality and to increase the extent of the global data necessary for characterizing the biospheric aspects of the hydrological cycle and its connections with biogeochemical cycles and with the Earth's climate

### Activity 3.1 Temporal Integration

Task 3.1.1 Extension of SVAT models to longer scales

Task 3.1.2 Consequences of episodic events and greenhouse forcing

Task 3.1.3 Consequences of direct anthropogenic forcing

### Activity 3.2 Waterborne transport of soil, nutrients, and carbon

Task 3.2.1 Biospheric control of waterborne transport

Task 3.2.2 Integrating waterborne transport at the river-basin scale

### Activity 3.3 Land-surface characterization for assessment and modelling where ground data are sparse

Task 3.3.1 The global distribution of biospheric characteristics for hydrosphere coupling

Task 3.3.2 Biosphere-hydrosphere monitoring in developing countries

## FOCUS 4: The Weather Generator Project

**Aims:**

(i) Define, jointly with GCTE and the other foci of BAHC, the ingredients of a Weather Generator

(ii) Coordinate the development, jointly with the contributing WCRP projects, of methods to downscale the coarse scale information of global models into the scales needed for ecosystem and hydrologic research

(iii) Test the results of this downscaling procedure with simulated and empirical data sets of present day climate

(iv) Facilitate distribution and use of the Weather Generator and associated data sets

### Activity 4.1 Data requirements for ecological and hydrological studies and related management purposes

Task 4.1.1 Identify the major research questions for which improved climatic data are required

Task 4.1.2 Assess the current climatic data inadequacies in ecology, hydrology and related management sciences

Task 4.1.3 Specify the required parameters, resolution and allowable uncertainties for various user communities

### Activity 4.2 Development of the Weather Generator

Task 4.2.1 Analyze spatially and temporally weather and simulate it stochastically

Task 4.2.2 Evaluate semi-empirical approaches for downscaling from GCMs

Task 4.2.3 Develop a physical understanding of the Weather Generator

### Activity 4.3 Facilitate access to the Weather Generator and Databases

Task 4.3.1 Compile an index to databases used in the development of the Weather Generator

Task 4.3.2 Develop the required infrastructure, storage and distribution of the Weather Generator

Task 4.3.3 Communication of Focus 4 activities

# Appendix 2: General Timetable for BAHC Research 1993 - 1998

## FOCUS 1: Development, Testing and Validation of 1-dimensional Soil-Vegetation-Atmosphere Transfer (SVAT) Models

**Objective 1** Assessment of the required global data to:

- determine critical SVAT parameters for characterizing different biomes globally
- plan, initiate, and conduct field studies in biomes where data are needed
- test and compare the existing methods and instruments for measuring SVAT parameters
- prepare generalized databases of SVAT parameters
- implement and coordinate a network of continuous (long-term) monitoring stations for water and $CO_2$ fluxes to validate SVATs for different biomes

*(in cooperation with GCTE and IGAC)*

**Objective 2** Evaluation of differently structured SVATs and development of new SVATs for patch-scale fluxes as required

**Objective 3** Contribution to the definition of an effective classification scheme for vegetation functional types usable for global operation by using SVAT model analysis to elucidate the most useful, critical simplified variables and to develop and test optimized SVATs for each functional vegetation class defined
*(in cooperation with GCTE)*

**Objective 4** To apply SVATs of different complexity for simulations and prediction of the influence of future global change on hydrologic processes in different biome types and climates, of direct $CO_2$ responses in different climates and biome types (using GCTE FACE), and of dynamic responses of the biosphere
*(in cooperation with GCTE)*

### Scheduled Workplan, Products, and Milestones:

Dec.
1993 Editors' meeting to prepare a summary report on measurement and first generalization of canopy conductances (to be published)

1994 Workshop to discuss the contribution of BAHC towards an improved generalized classification system for functional land cover types

1995 Surface conductance workshop on the comprehensive validation of SVATs, updated functional relations, and updated estimation techniques for SVATs (report, publication, proposal development). **Milestone**: Publication of state-of-the-art SVATs

1995 International symposium on SVAT modelling, parameterization schemes, and associated estimation techniques. Guidance material on SVAT applications (symposium proceedings, proposal development)

1996 Workshop on vegetation functional type classification (in cooperation with GCTE) (report, proposal development)

1997 International symposium on SVATs, their usefulness for predicting the effects of future global change on hydrologic processes in different biome types and climates

1997-
1998 **Milestone**: Book publication on the evaluated SVATs with application guidelines.



## FOCUS 2: Regional-Scale Studies of Land-Surface Properties and Fluxes: Experiments, Interpretation, and Modelling

**Objective 1** Development of a revised strategy and requirements for the implementation of regional-scale land-surface experiments, taking into account new needs and priorities, in particular:

- the need for coupled investigations of meterological, hydrological, ecological, biogeochemical and other related environmental phenomena and processes;
- the need to combine intensive short-term measurement campaigns in the planetary boundary layer (PBL) with long-term observation and measurement of hydrological and ecological variables and phenomena, including discharges, waterborne transport, vegetation characteristics, biogeochemical cycle components, etc.
- the real-time processing of selected measured state and flux variables using appropriate process and budgeting models (at least in selected, better instrumented sites and river basins)

*(in cooperation with GCTE, IGAC, GEWEX/ISLSCP and UNESCO)*

**Objective 2** Development and implementation of a concept and subsequent research programmes which take into account additional research tasks and requirements in regional-scale experiments, in particular

- the role of topography in BAHC-related investigations and modelling
- small-scale boundary layer advection effects due to landscape patchiness and areal heterogeneity of vegetation cover in connection with topography
- comprehensive use of remotely sensed data

*(in cooperation with GEWEX/ISLSCP and other projects)*

**Objective 3** Implementation, interpretation of results, and summary of scientific results of regional-scale land-surface experiments with special attention to:

- improved areal integration (upscaling) techniques for large-scale modelling
- improved algorithms to derive land-surface parameters (in particular vegetation functional types) from satellite data
- improved and new methods to use conjunctively ground-based data and airborne and satellite remotely sensed data to take into account the effects of land-surface heterogeneities and topography on the formulation, development, and extension (to two and three dimensions) of SVAT models

*(in cooperation with GEWEX/ISLSCP, GCTE, IGAC, and other projects)*

### Scheduled Workplan, Products, and Milestones:

| Experiment | Intensive Field Measurements | Interpretation | Derivation of Results and Conclusions |
|---|---|---|---|
| EFEDA | 1991-1994 | 1991-1996 | 1993-1995 |
| HAPEX-SAHEL | 1992 | 1992-1997 | 1992-1997 |
| BOREAS | 1993-1995 | 1995-1997 | 1995-1997 |
| NOPEX | 1993-1995 | 1995-1997 | 1997-1998 |
| LAMBADA | 1997-1998 | 1998-2000 | 1998-2000 |
| TUNDRA | after 1998 | after 2000 | after 2000 |

1993 Planning meeting of the Amazon experiment (Sao José dos Campos, Brazil, 8-11 Sept. 1993); draft description of the revised strategy and of guidelines for its application (report, publication in 1994, and proposal development)

1993 Workshop on the biospheric aspects of the hydrological cycle in mountain areas

(St. Moritz, Switzerland, 27 Nov-1 Dec 1993); (research concept for mountain basins, publication in 1994, and proposal development)

1995 International symposium on regional-scale land-surface experiments (let us save the capitals letters until the meeting is formally announced) to present and discuss results from past experiments (EFEDA, HAPEX-Sahel) and ongoing experiments. **Milestone:** Scientific report summarizing the symposium results, publication as a book in 1995, proposal development

1996-97 Reports of findings from individual experiments

1998 Editors' meeting to prepare a book that summarizes the general findings of all aforementioned regional-scale experiments and develop regional-scale experimental concept for general application (products: improved models, tools, technologies, etc.)

1998-99 **Milestone:** book publication (as described above)

## FOCUS 3: Diversity of Biosphere - Hydrosphere Interactions: Temporal and Spatial Variability

**Objective 1** Development of improved understanding and models of the interactions between terrestrial ecosystems and water resources, emphasizing the scale of years and centuries and effects of natural variability, incremental forcing from climate change, and direct anthropogenic forcing. Central issues concern consequences of anthropogenic modification of the landscape (e.g. river confinement and drainage plain development) and natural variability (e.g., ENSO and volcanic eruptions on freshwater resources.
*(in cooperation with GCTE and PAGES)*

**Objective 2** Development of models of the mechanisms regulating the transfer of carbon, soil, and nutrients from terrestrial ecosystems to surface and subsurface water, including feedbacks between the loss of these materials and ecosystem structure and function
*(in cooperation with GCTE and LOICZ)*

**Objective 3** Development of approaches for better utility and availability of global data sets necessary for describing biospheric characteristics of the hydrological cycle, including its connections with biogeochemical cycles and with the earth's climate system. The development of algorithms using remotely sensed data for assessing these hydrologically significant characteristics, their temporal changes as well as spatial shifting of critical ecosystem boundaries (biome boundaries, summer snow line, etc.,) in order to quantify the ecological resources of special hydrological importance (hereafter, hydroecological resources) is necessary for the development of high-quality land-surface descriptions including developing countries.
*(in cooperation with IGBP-DIS, and other IGBP and WCRP projects)*

### Scheduled Workplan, Products, and Milestones:

1994 The ecosystem component of long-term models of the coupled Earth system capable of simulating past (reconstructed), present, and future conditions. (workshop, publication, and proposal development)

1994 Ecological modification of drainage basins: effects on freshwater resources. (Workshop, publication, and proposal development)

1994 Quantifying global hydroecological resources - (international symposium and proceedings, emphasizing both remotely sensed data and ground-based measurements)

1995 The waterborne loss of carbon, soils, and nutrients from ecosystems (international symposium and proceedings)



1995 Quantifying global hydroecological resources (objective 3) (series of workshops in different regions, emphasizing problems in developing countries)

1996 The ecosystem component of long-term models of the coupled Earth system (workshop)

1997 Ecological modification of drainage basins: effects on freshwater resources (international symposium and proceedings, on progress since 1994 workshop)

## FOCUS 4: The Weather Generator Project

**Objective 1** Define the ingredients of a Weather Generator, data requirements for ecological and hydrological studies and related management purposes:

- establish data requirements (parameters) that are expected from the Weather Generator
- establish which of those requirements can be met by the Weather Generator
- define the allowable uncertainties, and the appropriate time-scale resolution

*(in cooperation with GCTE)*

**Objective 2** Coordinate the development of procedures, aggregated models and algorithms to provide regional climatic variables, in particular precipitation patterns and climatic variability, using large-scale information such as assimilated observations or simulations from GCMs (downscaling). These methods will provide stochastically atmospheric inputs to ecosystem and hydrological models in both current and projected future climates.
*(in cooperation with GEWEX-WCRP and other WCRP projects)*

**Objective 3** Facilitate access to the Weather Generator and associated data-sets:

- act as an interface between the climatic modelling community (GCM modellers), communities involved with satellite, radar and ground-based observations) and the user community (ecologists, hydrologists, related fields of agriculture, forestry, geography and water management, etc.)
- make the algorithms available to the user communities, including documentation, storage, maintenance and distribution of the Weather Generator
- circulate communications and reports on updating and improvements

*(in cooperation with IGBP-DIS, GPCC, GCOS, and other projects esp. in WCRP)*

### Scheduled Workplan, Products, and Milestones:

1993 Establish the data requirements (including ecological and hydrologic data requirements, specifying spatial and temporal resolutions and tolerable errors) to be met by the Weather Generator (Activity 4.1) and develop the physical understanding of the Weather Generator (Task 4.2.3). (Workshop in Bratislava, Slovakia, 15-18 September 1993; report, proposal development)

1994 Symposium on the Weather Generator, in particular on downscaling methods, jointly with WCRP, GCTE, IGBP-DIS; **Milestone:** 1994 symposium proceedings (to appear in 1995)

1995 **Milestone:** book publication, summary of results of 1994 symposium, and editors' meeting to develop and finalize the text

1996 Workshop on different open questions; update on activity 4.3

1997 Symposium on BAHC-Focus 4 achievements; **Milestone:** final report and Weather Generator(s) (that consists of downscaling procedures, aggregated models, and algorithms to provide regional climatic variables from simulations and/or remote sensed evaluation, empirical tests, and physical understanding) made available in 1997 or 1998

# Appendix 3: Membership of BAHC Scientific Steering Committee

(September 1993)

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# Acronyms, Abbreviations, and Glossary

| | |
|---|---|
| AGCM | Atmospheric General Circulation Model |
| AMIP | Atmospheric Model Integration Project |
| APAR | absorbed photosynthetically active radiation |
| AVHRR | Advanced Very High Resolution Radiometer |
| BAHC | Biospheric Aspects of the Hydrological Cycle (IGBP Core Project) |
| BALTEX | Baltic Sea Experiment |
| BATS | Biosphere-Atmosphere Transfer Scheme |
| BGC | biogeochemical cycle |
| BOREAS | Boreal Ecosystems Atmosphere Study |
| ECHIVAL | European International Project on Climate and Hydrological Interactions between Vegetation, Atmosphere, and Land Surfaces (part of the European Programme on Climate and Natural Hazards (EPOCH)) |
| EFEDA | ECHIVAL Field Experiment in Desertification-threatened Area |
| ENSO | El Niño/Southern Oscillation |
| FACE | Free-Air $CO_2$ Enrichment |
| GAIM | Global Analysis, Interpretation, and Modelling (IGBP Task Team) |
| GEWEX | Global Energy and Water Cycle Experiment |
| GCIP | GEWEX Continental-Scale International Project |
| GCM | General Circulation Model |
| GCOS | Global Climate Observation System |
| GCSS | GEWEX Cloud System Study |
| GCTE | Global Change and Terrestrial Ecosystems (IGBP Core Project) |
| GPCC | Global Precipitation Climatology Center (database) |
| HAPEX | Hydrologic-Atmospheric Pilot Experiment |
| HAPEX-MOBILHY | Hydrological Atmospheric Pilot EXperiment–MOdélisation du BILan HYdrique |
| HDP | Human Dimensions of Global Environmental Change |
| HEIFE | HIE-He River Field Experiment |
| IAHS | International Association of Hydrological Sciences |
| IGAC | International Global Atmospheric Chemistry (IGBP Core Project) |
| IGBP | International Geosphere-Biosphere Programme |
| IGBP-DIS | Data and Information System (IGBP Framework Activity) |
| ICSU | International Council of Scientific Unions |
| IHP | International Hydrological Programme |
| IPCC | Intergovernmental Panel on Climate Change (WMO/UNEP) |
| ISLSCP | International Satellite Land-Surface Climatology Project (part of GEWEX) |
| JGOFS | Joint Global Ocean Flux Study Project (IGBP Core Project) |
| LAI | leaf area index |
| LAMBADA | Large Scale Atmospheric Moisture Balance of Amazonia Using Data Assimilation |
| LOICZ | Land-Ocean Interactions in the Coastal Zone (IGBP Core Project) |
| LOTREX | Longitudinal Land-surface Traverse Experiment |
| MAB | Man and the Biosphere (UNESCO) |
| MOS | model output statistics |

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| MT-CLIM | Mountain Climate Model |
| NOAA | National Oceanic and Atmospheric Administation |
| NOPEX | Northern Hemisphere Climate Processes Experiment |
| NDVI | Normalized Difference Vegetation Index |
| OASIS | Observation at Several Interacting Scales |
| PAGES | Past Global Changes (IGBP Core Project) |
| PAR | photosynthetically active radiation |
| PILPS | Project for Intercomparison of Land-surface Scheme (of GCIP project of GEWEX) |
| PBL | planetary boundary layer |
| PP | perfect prog (approach) |
| REKLIP | Regional Climate Project (REgio-KLIma-Projekt) |
| RHESSys | Regional Hydro-Ecological Simulation System |
| SiB | Simple Biosphere Model |
| SSC | scientific steering committee |
| START | Global Change System for Analysis, Research and Training (IGBP/WCRP/HDP) |
| SVAT | Soil-Vegetation-Atmosphere Transfer |
| TEM | Terrestrial Ecosystem Model (See Raich *et al.* (1991)) |
| TM | thematic mapper |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Education, Scientific and Cultural Organization |
| WCRP | World Climate Research Programme |

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| biome | A complex biotic community covering a large geographic area and characterized by distinctive life forms of climax species (Lapedes, 1978). |
| downscale | The disaggregation of large-scale parameters and statistics to a smaller-scale |
| *gs* | surface conductance |
| *gs*(max) | maximumum surface conductance |
| model | A mathematical representation of a process or a system that includes explicitly one or more equations |
| parameterization scheme | A series of statistical calculations or classifications to summarize the data in descriptive statistics for the purpose of future modelling |
| representation | A summary of data (graphical, statistical, or otherwise) about a process, system, phenomenon, or subject |
| patch | A homogenous (uniform) land-surface area |
| supersite | An area typically a densely instrumented river basin often of 100-400 $km^2$ extent where river outflows and the nutrient content of water can be monitored. Patches are usually included. |
| upscale | The aggregation of statistics or parameters to a larger-scale |



# IGBP Reports

(Listing limited to Reports still in print)

No. 12 The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)

No. 13 Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Edited by P A Matson and D S Ojima. (1990)

No. 14 Coastal Ocean Fluxes and Resources. Edited by P M Holligan. (1990)

No. 15 Global Change System for Analysis, Research and Training (START). Report of the Bellagio Meeting. Edited by J A Eddy, T F Malone, J J McCarthy and T Rosswall. (1991)

No. 16 Report of the IGBP Regional Workshop for South America. (1991)

No. 17 Plant-Water Interactions in Large-Scale Hydrological Modelling. (1991)

No. 18.1 Recommendations of the Asian Workshop. Edited by R R Daniel. (1991)

No. 18.2 Proceedings of the Asian Workshop. Edited by R R Daniel and B Babuji. (1992)

No. 19 The PAGES Project: Proposed Implementation Plans For Research Activities. Edited by J A Eddy. (1992)

No. 20 Improved Global Data for Land Applications: A Proposal for a New High Resolution Data Set. Report of the Land Cover Working Group of IGBP-DIS. Edited by J R G Townshend. (1992)

No. 21 Global Change and Terrestrial Ecosystems: The Operational Plan. Edited by W L Steffen, B H Walker, J S I Ingram and G W Koch. (1992)

No. 22 Report from the START Regional Meeting for Southeast Asia. (1992)

No. 23 Joint Global Ocean Flux Study: Implementation Plan. Published jointly with SCOR. (1992)

No. 24 Relating land use and global land cover change. Published jointly with HDP. (1993)

No. 25 Land-Ocean Interactions in the Coastal Zone: Science Plan. Edited by P M Holligan and H de Boois. (1993)

No. 26 Towards a Global Terrestrial Observing System (GTOS): detecting and monitoring change in terrestrial ecosystems. (Report of Fontainebleau Workshop). Edited by O W Heal, J-C Menaut and W L Steffen. Published jointly with UNESCO/MAB (1993)