GLOBAL
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GLOBAL
TERRESTRIAL
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SYSTEM

REPORT OF THE GCOS/GTOS TERRESTRIAL OBSERVATION PANEL

First Session

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Intergovernmental Oceanographic Commission

United Nations Education, Scientific and Cultural Organization

Food and Agriculture Organization

United Nations Environment Programme

International Council of Scientific Unions

World Meteorological Organization

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REPORT OF THE GCOS/GTOS
TERRESTRIAL OBSERVATION PANEL

1. OPENING OF SESSION

1.1 Dr. John Townshend, Chairman of the joint Global Climate Observing System (GCOS)/Global Terrestrial Observing System (GTOS) Terrestrial Observation Panel (TOP) opened the meeting on 28 June at the National Science Foundation in Arlington, VA. He welcomed the participants (Annex I), and invited each to make a brief personal introduction.

1.2 The Chairman briefly reviewed the overall concept of the global observing systems, stressing the importance of the discipline-oriented panels such as the TOP in developing the requirements for observations and in establishing the mechanisms for implementation. He noted that the work of TOP would be critical both to the Joint Scientific and Technical Committee (JSTC) for GCOS and to the Scientific and Technical Planning Group (STPG) for GTOS.

1.3 The Chairman reviewed the provisional agenda which was adopted after brief discussion (Annex II). He suggested working arrangements for the meeting which were accepted by the members of the Panel.

2. INTRODUCTION AND BACKGROUND ON GTOS AND GCOS

2.1 Dr. Spence, Director of the Joint Planning Office (JPO) for GCOS, provided an overview of the GCOS programme, the structure of the planning activities, and the progress made to date. He reviewed the highlights from the inception of the programme at the Second World Climate Conference to the present meeting. The GCOS objectives are to meet the observational needs for climate system monitoring, for climate detection and response monitoring for data for national economic development and for research toward understanding, modelling and prediction. GCOS will be a systematic programme of observations and data management based, as far as possible, on existing systems. The JSTC has developed the concept of an Initial Operational System (IOS), which includes current observational systems, necessary enhancements to these systems which may be recommended and implemented now, and a comprehensive data management system.

2.2 The Director noted that the JSTC, at its Third Session, established several discipline oriented panels and cross-cutting task groups to provide detailed input for the IOS description. For terrestrial/ecosystem observations, the JSTC prepared terms of reference for the TOP which were later reviewed and revised by the STPG (Annex III).

2.3 In subsequent discussions, the members were interested to learn the relationship among the various global observing systems, and among the panels developing their components. The Director clarified the missions of the three proposed systems (GCOS, GTOS and GOOS), and the roles of the various subsidiary bodies. He informed the panel how its activities would be integrated into the GCOS planning. The Panel members urged that clear relationships be established and maintained among the observing systems, and that duplication of effort be avoided as subsidiary bodies are being established.

2.4 Additional discussion focused on the mechanisms available for implementation and potential problems of data propriety, particularly for land use information and socioeconomic information. The need for clear connections between the international planning and the activities of participating countries was also stressed.

2.5 Dr. Norse, the Chairman of the Scientific and Technical Planning Group (STPG) for GTOS, reviewed the objectives, guiding principles, and possible operational forms for the GTOS activities. He noted that GTOS is a proposed global observing system for long-term monitoring and assessment of human-induced changes in both natural and managed ecosystems. Its objectives are to provide the observational framework and basic data essential for the detection and understanding of impacts of regional and global changes on terrestrial and freshwater ecosystems to such changes, and the role of ecosystems in causing change.

2.6 Dr. Norse noted several guiding principles of GTOS: (1) focus on terrestrial systems; (2) complementarity and co-ordination with GCOS and GOOS; (3) user-oriented selection of a core set of parameters; (4) sites to cover the full range of natural and managed ecosystems; (5) application of remote sensing for scaling up from site observations; (6) harmonization of measurement methodologies; and (7) primary execution by national structures.

2.7 Dr. Norse informed the Panel that at the first session of the GTOS STPG, several Working Groups were established to initiate planning activities. Working Groups were charged to address operational aspects, data harmonization, and national needs. The GCOS/GTOS TOP is charged to consider the specific requirements for climate data.

3. OPENING STATEMENT OF THE PANEL CHAIRMAN

3.1 The Chairman reviewed the terms of reference of the panel, and presented his views of the priority actions for the Panel to consider. He suggested a tentative work plan that would prepare an initial report on activities, prepare reports for the JSTC and STPG, develop specific proposals for observations, and develop a strategy and possible mechanisms to implement key components of the Initial Operational System (IOS) for terrestrial ecosystem requirements. He stressed the importance of achieving an effective balance between ground-based and space-based observational components.

3.2 The Chairman presented a sequence of activities for the Panel to accomplish its objectives. He recommended that the Panel:

- Review, revise, and update existing reports on requirements presented in the meeting documents;
- Review current and planned observations of the WCRP, IGBP, HDP as well as other programmes of relevant agencies;
- Identify gaps in observations;
- Review implementation mechanisms and assess their adequacy;
- Prepare recommendations to address deficiencies.

3.3 To provide additional context, the Chairman note-d that GCOS and GTOS have similarities, but some significant differences. GCOS will provide additional climate-relevant components to a relatively sophisticated meteorological system, whereas GCOS will form a significant part of the whole observational infrastructure since there is no terrestrial equivalent of meteorological services to collect and distribute observations and products.

3.4 To conclude, the Chairman postulated where the Panel should be at the end of the meeting. He hoped it would provide a better understanding of current needs, of what is being generated operationally, of what critical gaps exist, and in which areas the continuity of observations is fragile or endangered. He stressed that the Panel should not try to define the "ideal" system, but rather something that is practical and achievable and which could evolve into a more appropriate system.

4. INVITED REPORTS

4.1 Since recently there has been considerable attention given to global observations, the Chairman invited brief reports on recent meetings and documents related to the work of the panel.

4.2 The Director of the JPO reported on the steps taken to date by GCOS in defining terrestrial requirements and recommendations. He briefly reviewed documents prepared for the meeting including the "Report of the GCOS JSTC Task Group on Land Surface Processes" which resulted from a meeting in 1992. That Task Group developed an initial set of requirements and a suite of recommendations. The report was subsequently reviewed at the Second Session of the JSTC. With additional material from the JSTC meeting, eiements of the report were included in the ***GCOS Draft Plan.***

4.3 The Panel was informed of the results of a workshop at Fontainebleau, France sponsored by several international organizations. The workshop focused principally on ***in situ*** sites and stations for measurements of ecosystems.

4.4 The Chairman of the STPG reported on the First Meeting of the Planning Group and the subsequent meeting on Harmonization of Environmental Data. Documents from the various meetings, except the last one, were provided.

5. MODEL CONSIDERATIONS

The Chairman invited participants to present material on relevant model issues. Speakers were asked to focus specifically on the input requirements for models, and the sensitivity of the outputs of such models to various data inputs. Speakers will be asked to consider *inter alia*, input parameters, initial conditions, boundary conditions and validation requirements and they were asked to discuss sensitivity issues associated with the models to provide guidance for parameter selection, observational requirements, or other constraints.

5.1 Global Atmospheric Models

5.1.1 Dr. Verseghy reviewed current global climate models, illustrating her remarks using the Canadian Climate Model. She noted that Numerical Weather Prediction (NWP) models developed for weather forecasting were often the basis of current climate models.

5.1.2 She particularly described the physical parameterizations in the models. Since many of the key processes are smaller than the grid size of the models, separate calculations are performed for several processes including: (1) radiation transfer and absorption; (2) cloud amount and distribution; (3) precipitation; (4) cumulus convection; (5) wave drag and turbulent diffusion; (6) surface transfers of energy, moisture and momentum; and (7) land surface hydrology. Items (6) and (7) were noted for special concern to this panel.

	ATMOSPHERE	LAND
Initial Conditions	Temperature Profile Humidity Winds Clouds	Soil, canopy, snow Temperatures Soil & canopy moisture
Boundary Conditions	Atmosphere composition	Vegetation Types, coverage Seasonal variation of vegetation characteristics Topography Soil Texture, depth
Output Fields	Temperature Humidity Winds Clouds Precipitation	Soil Canopy Snow Temperature Soil & canopy moisture Surface fluxes

Table 1. Initial conditions, boundary conditions, and output fields for atmosphere and land

5.1.3 Dr. Verseghy discussed the initial conditions, boundary conditions, and output fields needed from the atmosphere and the land (see Table 1). She noted in particular the critical dependence on soil moisture, citing that due to its heterogeneity, it will pose problems for observations.

5.1.4 The Panel discussed the requirement for soil moisture in some detail. Issues were raised regarding the depth of soil moisture data required and the horizontal resolution needed. The limitations of both in *situ* and space-based observations were highlighted. The techniques and mechanisms for obtaining appropriate observations of soil moisture were noted to be very difficult, but the panel agreed that such measurements should be given high priority.

5.1.5 Further elaboration of model requirements was developed by Dr. Verseghy and is reported in Appendix 1.

5.2 Terrestrial Effects Models

5.2.1 Due to scheduling difficulties, the speaker identified to provide an overview of such models was unable to attend. Requirements for such models were addressed in discussions of the strategy and the IOS, however.

5.2.2 Dr. Norse described a particular class of terrestrial effects models in the context of the proposed IGBP/HDP Land Use and Land Cover Change (LUCC) programme. He focused particularly on the land use change and socioeconomic driving forces which must be considered in these models, noting the requirement for geo-referenced land cover and use data. The observational information needed for such models typically resides with various nations and international agencies notably FAO. There are major constraints on the availability of data on actual land use and on the socioeconomic driving forces for land use change.

5.3 Hydrological Models

5.3.1 Since climate models incorporating hydrological parameters were addressed and documented at the Task Group meeting on Terrestrial Observations, no additional presentations were made.

5.3.2 Additional hydrological variables were identified as required inputs for biogeochemical and ecosystem models. These pertinent requirements were specified in some detail by a sub-group chaired by Dr. Running and these are reported in Appendix 2.

6. CURRENT STATUS OF OBSERVATIONAL SYSTEMS

6.1 *In Situ* Observations

6.1.1 The Chairman invited Panel members to briefly describe the current observational capability.

6.1.2 Dr. Running provided an analysis of the ecological sites in terms of a simple graph relating the number of sites contributing information versus the actual number of variables required. For the typical small number of comprehensive Long-Term Ecological Research (LTER) sites, many variables are required. At the opposite extreme lies the GLOBE programme with many observations, but only a few variables are observed. Dr. Running felt the panel should concentrate on the middle region where few variables are observed, but where there is potential for many thousands of observational sites possible. With this premise, he identified five required observations. In priority order, they are: (1) land cover type; (2) Leaf Area Index (mid-season or peak growing season); (4) live biomass; and (5) annual primary production (NPP). This strategy would emphasize broader and wider spatial coverage rather than comprehensive measurements at fewer sites.

6.1.3 The Panel found the proposal to be an interesting one. It agreed with the premise that more'spatial coverage is more valuable to programmes such as GCOS/GTOS than a few intensely sampled domains, although the latter are critical for other purposes and should be continued.

6.1.4 In the following discussion, some members proposed additional items which should be added to the very short list. Dr. Scholes suggested that land cover type needs to include some consideration of plant functional type (e.g., broad-leafed or needle-leafed) as well as use type (natural, grazed, cultivated) and that inclusion of nitrogen variables would be very highly desirable. In addition, he suggested soil information (especially depth, and clay, sand and organic carbon content) and a measure of the partitioning of NPP to below-ground, such as soil respiration would be important. Dr. Running proposed adding stream gauging, possibly including chemical analysis, lake turbidity and temperatures as well.

6.1.5 On further consideration, it was noted that a nested concept could link the small number of intensely measured sites with a larger number of sites where fewer variables were observed. This concept is discussed further in section 8. Members noted that current status of *in situ* observations has been reviewed in a number of existing documents and drew attention to the following issues:

a) The extensive amount of data currently being collected at various stations and sites throughout the world;

b) The absence of an overall strategy with respect to sampling and definition of the data that needs to be collected;

c) The difficulty faced by some users in obtaining data from existing components of global observing systems such as the World Weather Watch in forms suitable for tasks such as biospheric modelling .

6.1.6 Dr. Zhao presented an overview of the Chinese Ecosystem Research Network (CERN). This network was established to address sustainable uses of natural resources, to provide information on the status of the environment, and to coordinate ecological research. CERN includes activities in research, monitoring, training and establishing field facilities. The Panel noted that the network will be an important component of the global network of ecosystem sites, and should be considered an element of the GCOS/GTOS programmes.

6.1.7 Dr. Serey presented an overview of ecosystem observations in Chile. He described the approach taken to ecosystem monitoring which includes consideration of the populations (community; species based) and process (functional). He illustrated the approach with work in the Torres del Paine National Park at which a comprehensive suite of observations is being taken. The Panel appreciated the systematic approach taken to establish and operate a comprehensive observing programme.

6.1.8 Dr. Karim provided a brief introduction to the situation in Bangladesh. There, agricultural constraints and threats of flooding are paramount considerations. Dr. Karim itemized the variables being measured, and related them to their use in vegetation studies. He noted particular problems, including population growth, human intervention in environmental systems and the continuing vulnerability of the country to natural climate variability due to monsoons and floods. He made clear the important role that GCOS/GTOS may play in such countries (see Section 9).

6.1.9 During subsequent discussions, members raised a number of substantive issues regarding current observational limitations. Dr. Estes, for example, pointed out the lack of data on land surface characterization and population. While some regional data bases exist, much important information at larger scales is not available or is not reliable.

6.1.10 The Chairman asked the Panel also to consider cryospheric requirements. He noted that ice and snow on the land surface are important parameters, particularly in climate modelling efforts, but that GCOS/GTOS had not yet established a forum for generating recommendations in this area. He invited members to provide input during the meeting on cryospheric issues (see Appendix 3).

6.2 Remote Sensing Observations

6.2.1 Dr. Cihlar provided an overview of remote sensing capabilities for terrestrial requirements. He noted that currently the main remote sensing systems needed for terrestrial observation needs fall into two main categories: (1) fine spatial resolution systems such as Landsat, SPOT and IRS; and (2) coarser resolution systems providing more frequent imaging in particular the Advanced Very High Resolution Radiometer of the NOAA series of satellites.

Fine resolution systems

6.2.2 Current optical systems have the ability to satisfy many terrestrial requirements. But major problems of data availability have arisen in recent years because of high costs and very large gaps in coverage during many time periods. Consequently users have been significantly hindered from obtaining the data they require.

6.2.3 Microwave data are becoming increasingly available especially through missions such as ERS-1 and the Shuttle Radar experiments. These data do not yet provide regular global or regional coverage in part because of their reliance on ground receiving stations which are unevenly and too sparsely distributed across the Earth's surface. Increasing experience during the coming months with these data sets will allow their role in GCOSIGTOS to be more firmly established.

Coarse resolution systems

6.2.4 Problems associated with the absence of calibration of the AVHRR sensors has been considerably mitigated by the various vicarious calibration efforts which have been made recently. Reprocessing the data to create more consistent long term data sets is considerably adding to their value. Of considerable concern is the degradation of the orbit of NOAA-l 1 so that its AVHRR is sensing too late in the day to provide data of value for many parts of the world. Thus there will inevitably be a break in the record of the prime data set used for monitoring the Earth's vegetation until the launch of NOAA-13.

6.2.5 Geostationary satellites have been exploited to a relatively modest extent for terrestrial observations to date despite their potential for monitoring intra-diurnal variability of the land surface.

6.2.6 Discussion of requirements for improved remotely sensed data sets can be found in Section 9 and Appendix 3.

6.3 Data Management Issues

6.3.1 While this topic was determined to be more properly the subject of the GCOS Data Management Panel and the GTOS WG III, the Terrestrial Observation Panel members made the following observations:

a) Obtaining data in suitable processed forms is essential to meet user needs;

b) Considerable improvements in data sets for terrestrial purposes especially from the AVHRR have been achieved in recent years;

c) Considerable diversity of formats of the same sensor's data sets (e.g., Landsat) continues to occur and should be reduced or eliminated;

d) A global information system for the surface measurement system described in 8.1 will be required.

7. STRATEGY FOR DESIGN OF A TERRESTRIAL OBSERVATION SYSTEM

7.1 The Panel recognized the need for consideration of a comprehensive design of a terrestrial observing system, which includes the integration of *in situ* observations and satellite remote sensing. The Panel noted that previous documents from GCOS went a considerable way to defining the strategy for the satellite based component.

7.2 To proceed the Chairman proposed three sub-groups be tasked to develop specific elements of the terrestrial/ecosystem observational plan. These would then be integrated as the terrestrial component of the IOS. The three groups were established respectively to: (1) review the *in situ* elements as part of a surface measurement programme and develop a hierarchical approach to site characterization (see section 8); (2) review meteorological and hydrological requirements for biospheric models (Appendix 2); and (3) review components which need to be provided in spatially continuous globally or regionally comprehensive fields and hence which are normally derived from satellite observations (see Section 9). In addition contributions were made by individuals on the needs for GCMs (Appendix 1) and the cryosphere (Appendix 3).

7.3 Future meetings of the Panel will need to establish the data requirements of other modelling communities not considered at its first meeting, including ecosystem models and terrestrial effects models (see Section 5.3) and to further refine the definition of data requirements of the whole range of models requiring terrestrial observations.

8. STRATEGY FOR A GLOBAL SURFACE MEASUREMENT PROGRAMME

8.1 Rationale

8.1.1 The design of the GCOS/GTOS surface measurement programme and the selection of sites must reflect an appropriate balance between three broad overlapping kinds of objectives.

a) To detect changes in terrestrial ecosystems, including managed ecosystems and non-oceanic aquatic systems, with high sensitivity and timeliness;

b) To document, quantify and map status and trends in terrestrial systems;

c) To provide the data needed to develop, calibrate, validate and operate the diversity of models that can be used to give advance warning of global environmental change, and allow mitigation options to be tested.

8.1.2 Terrestrial ecosystems both respond to changes in climate and atmospheric composition, and are major drivers of change, largely through changes in land use and land cover. Models provide a useful organizing framework for data collection, but since the nature of future models is unknown, it is inappropriate to build the entire monitoring strategy around existing models. It is suggested that the relative effort expended in meeting the above three objectives should be in a ratio of approximately 10:60:30.

8.1.3 The Panel observed that these objectives require different sampling strategies. Change detection is favoured by placing samples in the path of probable change. Change quantification and mapping requires a systematic, representative and unbiased sample strategy. Model development requires intensive data collection, but only for a small number of sites which need not be globally representative. Model operation needs spatially continuous and numerically coherent sets of driving variables. This diversity of objectives and requirements make it clear that a single, uniform monitoring system is unlikely to be effective in terms of cost or effort.

8.1.4 A comprehensive surface measurement programme should be designed to place approximately equal emphasis on four classes of processes. These are:

1) Biogeochemistry: The broad goal is to quantify changes in the major pools and fluxes. The primary focus should be on carbon, including measurements of carbon storage in soils and plants as well as carbon exchanges between ecosystems and the atmosphere and between terrestrial and aquatic ecosystems. Given the critical role of nitrogen and phosphorus as controllers of carbon pools over different time intervals, these elements should be a major focus of observations.

2) Land Use: Because changes in land use are likely to dominate near to medium term changes in both biogeochemistry and in the quality and quantity of goods and services provided by ecosystems to humans, it is critical to quantify changes in patterns of land use and intensity of land management. This should include assessments of land added to or abandoned from agricultural production as well as changes in cropping system, fertilizer and irrigation use, timber harvest practices, and low-intensity management (e.g., rubber harvesting).

3) Biodiversity: The local and regional diversity of genotypes, species, plant and animal functional types, and landscape units have an important place in the global change research and monitoring agenda both in themselves, and through interacting effects on biogeochemistry and land use. The monitoring programme must acknowledge the importance of biodiversity at levels ranging from the genetic to the landscape level. The dramatic spread and often profound ecological consequences of introduced plants and animals over the last few centuries places a high priority on monitoring the status of non-native and especially invasive species.

4) Climate: The interface between climate and terrestrial systems has two major components. One is the terrestrial characteristics that can be used as indicators of climate change. The second is the aspects of climate that are necessary for interpreting or establishing a context for ecological information. Several of the terrestrial characteristics that are useful as indicators of climate change are only indirectly linked to ecosystem structure and function. This class includes parameters like extent and mass of alpine glaciers and size and temperature of shallow lakes. In general, the aspects of ecosystem structure or function that are potentially useful as indicators of climate change, including presence or absence of indicator species, are regulated more by extreme events than long-term mean conditions.

8.2 Design of a Global Hierarchical Sampling Scheme

8.2.1 The Panel proposed a four-level hierarchical system. At the lowest level (IV), a few highly-standardized, easily-collected data items are periodically collected at each of a large number of systematically-distributed sample locations. At the highest level (I), a large number of data items, including expensive, technically-challenging observations, are continuously collected over an extensive target area. This hierarchy will be built primarily from existing experiments, research stations and study sites. The hierarchy is loose in the sense that each level will contain at least some of the components at each lower level, but not all of the lower level sites will be incorporated in higher level sites. Including measurements from all lower levels in the higher level sites will facilitate the spatial integration in the higher level sites and the upward transferability of variables that will maximize the range of interpretations that can be drawn from the lower level observations.

8.2.2 The four levels are characterized as follows:

- The LEVEL I facilities will be a small number of international, regional scale experiments, such as the IGBP Transects, WCRP land-surface parameterization experiments and large catchment studies. Facilities at this level add measurements of processes not quantified at lower levels (e.g., trace gas exchange), and they address mechanisms of spatial integration. The objective is both to characterize processes that involve difficult or expensive measurements and to monitor changes in large-scale processes such as the wind- and water-borne transport of soils and the movement of biota. The proposed IGBP transects, plus the existing or proposed large-scale surface experiments (e.g., HAPEX Sahel, BOREAS, LAMBADA) already total the appropriate order of magnitude. The spatial scale for these sites should include a core area on the order of at least 10 km^2, and studied surroundings of 10^4 km^2 or more. In principle it is not essential that all of the members of this level have a permanent existence, though it would be beneficial if at least some did.

- LEVEL II sites consist of major research centers, usually with a biome, regional or crop focus. There will be at least one (preferably two or three) centre in each of the major biome types (about 20) and a centre for each major crop and plantation forest type for a global total of the order of 100. The emphasis at this level is on understanding processes and on the way processes respond to global change. To provide access to mechanisms, they will involve manipulative experiments in addition to monitoring. Sites at this level will be well-equipped and staffed, with satellite stations or experiments. Hallmark measurements added at this level will include diurnally resolved weather, isotopic studies of soil nitrogen and carbon, and continuous monitoring of fluxes of CO_2, water, and energy. For larger countries, there will be one or a few sites per country. For smaller countries, the LEVEL II sites will be regional centers. The CGIAR crop centers would fit into this level, as would some of the better developed ecological research sites in the US (such as some of the larger LTER), European, and Chinese networks. Together these already total well over 100 sites. Some centers may need to be promoted (or sustained) in the less-developed parts of the world.

- LEVEL III sites will include many of the existing national ecological and agricultural research stations. Their purpose is to provide dynamic data at the sub-annual level (e.g., phenology, net primary production) as well as a spatial context. LEVEL III sites will be of the order of 1000 facilities that each cover areas of approximately 10 km^2. Sites at this level will provide a broadly distributed reference remote sensing as well as direct links to weather station data. It is also the level of direct linkage to weather stations and calibration of remote sensing. They will have small permanent staff and modest facilities (e.g., a weather station, balances, drying ovens, communications). Because an approximate balance across biomes, agro-ecological regions, and farming system types is a high priority, these sites will need to be selected with care. At this level, however, it is not necessary that all ecosystems be represented in proportion to their extent. Probably at least 80% of these stations already exist. Where gaps occur, especially in the developing world, international efforts may be needed to develop new stations.

- LEVEL IV sites will be systematically placed in approximately 10,000 locations. This means that at least a portion of them will be in difficult-to-access locations. It is therefore important that permanent staff are not required, and that the data can be quickly and cheaply obtained through a combination of occasional visits (once every year to once every few years) and remote sensing. The measurements, which will include assays of total soil C and N, management system, and species identities, must have low equipment and technical demands. LEVEL IV sites will consist of precisely geo-referenced sample points possibly as small as 1 ha extent. These will mostly be new, although some countries already have networks in place or in the planning stage.

A summary of the proposed system is presented in Table 2.

8.3 Measurement Strategy

8.3.1 The proposed measurements are intended to capture essential elements of the status and dynamics of terrestrial ecosystems. The hierarchical system of proposed measurements acknowledges the fact that essential measurements span a range of spatial scales and that measuring some of the essential parameters is too expensive or difficult to be replicated everywhere.

8.3.2 The proposed measurements are approximately equally distributed among parameters related to biogeochemistry, land use, biodiversity, and climate. This emphasis reflects not only the charter of GTOS and the terrestrial component of GCOS but also the broad recognition that all of these classes of parameters are major responders to and controllers of global change.

8.3.3 The specific ‘measurements that the Panel proposed capture fundamental aspects of biogeochemistry, land use, biodiversity, and climate. Detailed justification of the individual measurements will need to be made subsequently.

8.3.4 Issues of data management will require careful planning. Maintenance of national data systems may provide a way to utilize existing structures, though these will need to be upgraded in some cases and transferred to second countries in others. The LEVEL II sites could serve as national or regional data centres.

LEVEL	EMPHASIS	EXAMPLES OF VARIABLES
I	A) Spatial integration	i) dynamics of landscape units ii) transport of soils and nutrients iii) airborne flux measurements iv) planetary boundary layer flux methods
	B) Point measurements	i) trace gases
II	A) Spatial integration	i) population structure ii) continuous tower flux of CO_2, H_2O, energy iii) soil moisture
	B) Point measurements	i) diurnally resolved weather ii) complete radiometry iii) isotopic soil and plant studies
III	A) Stocks and fluxes	i) NPP ii) biomass iii) soil C and N by depth iv) atmospheric deposition
	B) Land use	i) management system (cropping, tillage) ii) fertilizer and irrigation
	C) Spatial integration	i) bio and geo diversity ii) habitat spatial structure
	D) Point measurements	i) leaf chemistry. ii) phenology
	E) Daily weather	i) precipitation ii) temperature iii) wind iv) shortwave radiation and PAR
I v	A) Point measurements	i) decadal soil C, N, depth, bulk density
	B) Land use	i) land cover and land use type ii) disturbance
	C) Biodiversity	i) decadal enumeration of vertebrates, invertebrate groups, plants, & microbes ii) decadal status of invading species
	D) Weather	i) interpolated monthly climate from nearest stations

Table 2. Proposed 4-level hierarchical site scheme for a global surface observation system

8.3.5 Appendix 3 provides an initial description of the requirements for surface observations to support the use of satellite data. It seems clear that the system of ground sites described in the present section can also in principle provide much of the support needed for satellite observations.

8.4 Site Selection

8.4.1 The objective is to take maximum advantage of existing facilities while still insuring an appropriate global distribution of measurement sites. The different objectives associated with the LEVEL I through IV facilities impose different criteria for site selection.

8.4.2 LEVEL I sites: These major, intensive sites should be located with a primary emphasis on feasibility, on the spatial diversity of regional ecosystems and land-use patterns, and on the availability of regional process integrators like appropriate watersheds. Capturing the entire range of the earth's major biome types is a critical priority, but the location of the installation within each biome should be opportunistic. At present, there are probably no sites that function regularly as LEVEL I installations, but the upgrade from existing facilities to LEVEL I will only involve modest changes in the programmes at some sites. Measurements at the LEVEL I sites will be a subset of the measurements of the major land-surface experiments (HAPEX, FIFE, BOREAS, BALTEX, etc.), though the transition from intensive field campaigns to continuous monitoring will require careful planning. Several of the LEVEL I sites will probably be drawn from the sites of past or present experiments, including perhaps BOREAS (boreal forest - Canada), ABRACOS (tropical evergreen forest - Brazil), ARCS LAII (Arctic tundra - US), Harvard Forest (temperate mixed forest - US), Oasis (dryland agriculture - Australia), and HAPEX (tropical grassland/scrubland - Niger). The actual sites will probably consist of core areas of 100 km^2 or less, plus a surrounding region of 10^4 - 10^6 km^2. It is critical to design LEVEL I sites so that they include a range of LEVEL II, III, and IV sites.

8.4.3 LEVEL II Sites: The 100 or so LEVEL II sites will be chosen to include the earth's major climate zones, ecosystem types, and land management practices. The actual siting will depend more on existing infrastructure and feasibility than on strict spatial guidelines, but the priority on capturing the broad range of ecosystem types may require developing some new sites, though not more than about 20% of the total.

8.4.4 Since the proposed measurements emphasize a mix of point measurements and spatial studies, the spatial context for each site will be a priority. The best spatial contexts will include large enough regions of relatively homogeneous ecosystems to allow careful assessments against remote sensing, but enough diversity to allow access to a broad range of ecosystem structure and dynamics.

8.4.5 The LEVEL II Sites will serve as primary locations for capacity building in developing regions. This capacity building will range from collaborative research programmes in relatively developed areas to basic courses, student exchanges, and structured field experiences in lesser developed sites. Much of the emphasis will be on training the scientists who will manage the LEVEL III and LEVEL IV sites. Some of the siting decisions will be adjusted to reflect the needs for training and access in developing regions.

8.4.6 LEVEL III Sites: These are the sites that are most congruent with the existing networks of agricultural and ecological research stations in China, Europe, the US, and other countries. The requirement for permanent staffing and frequent measurements will necessitate locating the sites where there is reasonable access, funding, and interest. Though there will be a need for some sites in unrepresented areas, the number of new sites at this level should be a small fraction of the total. Since these sites will provide a primary link with remote sensing observations, selection criteria will include an emphasis on reasonable spatial homogeneity over the scale of a few km, but this emphasis should not preclude the selection of sites in mountainous zones or in regions with heterogeneous land use or disturbance.

8.4.7 LEVEL IV Sites: For these sites, spatial representativeness is the highest priority. Because the measurement suite is limited and access is infrequent, they can be sited wherever necessary to ensure representativeness. With on the order of 10,000 sites globally, there will be approximately one site every 100 km, though the question of whether the best sampling design is strictly regular will require a careful assessment of the statistical issues. A few of these sites may be established research stations, but all should be subjected to the prevailing local management. In fact, it may be best to guard the locations, so that the land management is not altered in response to the research status. It may also be appropriate to continuously add sites so that impacts of the research designation can be estimated. If each of the LEVEL III sites services a number of LEVEL IV sites, the LEVEL IV monitoring will have minimal impacts on personnel and equipment requirements.

8.5 Capacity Building

8.5.1 The training potential represented by the LEVEL II sites will be an important component of capacity building and should make a contribution toward the establishment of self-sufficient LEVEL III and IV sites in developing regions. There will, however, be some regions that are so poor or so politically unstable that no monitoring sites will be established internally. Where possible, the international community should consider developing monitoring stations, especially LEVEL IV sites, in these regions, but the statistical issues of missing regions should also be addressed. Establishing the relevance of the proposed measurements for local and regional issues can make major contributions toward motivating the establishment of sites in developing regions.

9. GLOBAL AND REGIONAL SCALE OBSERVATIONAL REQUIREMENTS

9.1 Introduction

9.1.1 The Panel recognized the need for the comprehensive design of a terrestrial observation system, which includes the integration of satellite remote sensing, and *in situ* observations. The Panel noted that previous documents from GCOS went a considerable way to defining the strategy for the satellite-based component.

9.2 Data Acquisition Strategy

9.2.1 As long-term programmes, GCOS and GTOS require a long-term, comprehensive strategy of observations from space. The strategy should be developed in close consultation with the research and operational user communities. It needs to take into consideration programmes presently underway and planned, to identify gaps and work out ways of addressing these. Although the actual data acquisition is carried out by national space agencies, coordination through an international body such as CEOS will help considerably in ensuring that a comprehensive acquisition programme is established and maintained. Continuity of measurements must be a high priority in formulating such a programme, especially with regard to a minimum set of critical variables.

9.2.2 The development of a long-term strategy should be based on a critical examination of data requirements identified by the user groups. The degree to which these requirements may be met by present or planned, approved satellite missions may then be determined by considering the parameters of the platforms and sensors of interest. For data meeting this test, arrangements must be made with space agencies operating such satellites for the acquisition and archiving of these data. For critical data needs which are not met by present or planned satellites, the feasibility of obtaining the data from space platforms should be determined. A potential satellite mission concept should be developed through discussions within the GCOS and GTOS communities and presented to the relevant national space agencies and international bodies such as CEOS.

9.2.3 A critical example where an effective data acquisition strategy is urgently needed relates to high resolution satellite data essential for reliable land cover/land use information. The absence of a coordinated acquisition strategy means that for many time periods large areas of the world have few high resolution data, considerably hindering the monitoring of trends in global land cover and use change.

9.3 Archiving and Access

9.3.1 The maintenance of long-term archives and access to the data are critically important for the success of GCOS/GTOS. Agreements are required to ensure that the useful data are archived indefinitely, are properly documented, and are readily available to the user community. From the user's perspective, the cost of the data is one of the most important considerations, and in the end it will decide whether the data are used or not. An example of a successful programmes to establish consistent long term data archives is the U.S. Pathfinder Program for data from several sensor systems such as the AVHRR. Safely archiving data sets has not always been achieved, for example many of the Landsat data from the 1970's have been permanently lost.

9.3.2 The above requirements for archiving and access are not unique to GCOS and GTOS, and they raise a number of complex financial, policy, and coordination issues. Other international groups address these in detail, most notably the International Earth Observing System (IEOS). Regarding data costs, IEOS proposed the COFUR principle (Cost Of Filling User Request) for research and applications users, and it developed a set of guidelines for establishing the costs of a given data type. GCOS and GTOS should work closely with these groups to ensure that the long-term data needs are met.

9.3.3 The GCOS/GTOS strategy for archiving and access must first ensure that useful satellite data presently archived by various agencies, especially the oldest data sets, are not lost or rendered inaccessible over time. This will require the assistance of the research community and of the national agencies and international data centers maintaining the data. Secondly, a comprehensive strategy for future data collection must be developed, using existing agreements or mechanisms to the full possible extent. This strategy should then be refined in collaboration with the space agencies and submitted for adoption to the appropriate bodies.

9.3.4 Access to data is at times severely hindered by pricing policies. Recent efforts by CEOS to define policies so that satellite data for scientific environmental use is made available at relatively low cost are welcomed and should be extended beyond the current pilot projects underway in coordination with the IGBP.

9.4 Priority Data Sets

9.4.1 Priority data sets are those data which are important to several GCOS/GTOS objectives, and are or can be made available within a short time period so that they can constitute part of the IOS. Appendix 3 summarizes the requirements for a number of key land variables. The rationale for and parameters of these data sets are described below, using a modified format developed at the GCOS JSTC-II meeting. Additional tables of variables were developed in "Towards a Global Terrestrial Observing System (GTOS)", IGBP Report 26.

9.4.2 As Appendix 3 shows the observations fall into a number of categories. Categorical data on land use and land cover are crucial variables. Because of the small size of units of change, monitoring change will often require high spatial resolution data if reliable estimates of change are to be obtained.

9.4.3 Several variables needed to characterize and estimate the photosynthetic and evapotranspiration processes of vegetation are required including the seasonal vegetation index profile, the fraction of photosynthetically active radiation absorbed by the vegetation, the leaf area index and the amount of incoming photosynthetically active radiation.

9.4.4 Observations of biomass are also needed though accurate estimates challenge current remote sensing capabilities.

9.4.5 Snow cover and snow water equivalent are crucial cryospheric variables required by many modellers.

9.4.6 A high quality topographic data base is essential for a wide range of requirements and will have to be developed if the full potential of future observation systems such as EOS are to be realized.

9.4.7 Another essential global data base relates to soil properties which have to be made available in consistent spatially comprehensive forms for many modelling activities.

10. THE INITIAL OPERATIONAL SYSTEM - TERRESTRIAL COMPONENT

10.1 Development of a comprehensive description of the Initial Observation Plan was beyond the grasp of the first meeting of the Panel. Nevertheless a number of key elements were recognized:

a) the need for an international coordinated hierarchical system of sample sites for surface observations;

b) the need for continuing data from both fine and coarse resolution remote sensing systems;

c) the need for improved global topographic and soils data bases;

d) the need for information systems to handle the in *situ* and remotely sensed data.

10.2 An international hierarchical system of sample sites for surface observations is required. This can be built on the numerous existing sites found throughout the world where observations are currently being carried out. Considerable international coordination will be required to ensure consistency in the observations made at these sites. Surface sites are essential for the reliable observation of the complex interactions associated with both natural and anthropogenic drivers. They are also essential to assist the calibration and interpretation of satellite data.

10.3 Surface meteorological variables should be provided through the WWW, probably with some changes in the form of their products to ensure that users of GTOS obtain the data sets they need.

10.4 Satellite data from sensors with spectral bands in the visible and near infrared capable of being used to monitor the photosynthetic activity of vegetation are essential both for the insight they give to the functioning of vegetation systems, but also because they are needed for estimating the fluxes of energy and water between the atmosphere and land surface. Such sensors have to collect data on a daily basis so that data sets can be assembled such that the obscuring effects of clouds are minimized. Current uncalibrated systems, such as the AVHRR, provide substantial problems for users. Future calibrated and radiometrically more sensitive sensors (e.g., MODIS of the EOS, the Vegetation instrument of SPOT 4, and the ATSR of ERS-2) should provide a basis for the IOS. The AVHRR instrument will continue to be of considerable importance for the IOS due to its unique length of data record. However, considerable effort should be devoted to ensuring the stability of overpass time of polar orbiters carrying these sensors.

10.5 Fine spatial resolution sensors will be an essential component of the IOS especially relating to their role in monitoring global land cover and land use change. Several sensor systems currently are in orbit or are scheduled to be launched which can contribute to the fulfilment of this role: these sensors include the HRV of SPOT, the Thematic Mapper of Landsat and sensors on board Indian and Japanese satellites. Experience has clearly demonstrated that in the case of data from such systems the existence of sensors in orbit is no guarantee that the needs of the scientific community will necessarily be met. As part of the IOS acquisition, archiving and processing strategies must be developed along with the formulation of pricing policies to ensure that data are available with appropriate temporal frequencies and sufficient spatial coverage.

10.6 As well as the observations made with satellite and surface systems it is necessary that data sets describing less dynamic components of the environment are also collected. In particular the Panel recognized the importance of a global topographic data set and improved global soils data bases as essential for the IOS.

10.7 Data and information systems to process, handle, archive and distribute the data from both the surface and satellite components of the IOS will have to be developed. It will be necessary to develop systems which facilitate: (1) the integrated use of *in situ* observations collected throughout the world; (2) the integrated use of satellite observations from sensors from different platforms including those from different space agencies; (3) the integration of satellite and *in situ* observations; and (4) provision of data in forms readily assimilated by models, monitoring and early warning systems.

11. IMPLEMENTATION PLAN

11.1 Considerable additional planning work is needed to create a workable implementation plan: in particular discussions are needed between the TOP and the Space Observational Panel of GCOS and the Data Management Panels of GCOS and GTOS.

11.2 The Panel recommended that the Surface Measurements programme and its development primarily be the responsibility of GTOS (in consultation/cooperation with GCOS) given the amount of detailed ecological observations required. An appropriate international agency needs to be identified to take on the responsibility for implementing this component.

11.3 *In situ* observations of meteorological observations clearly should largely be carried out through the World Weather Watch, though there must be efforts to ensure that the users outside of the forecasting communities receives data sets in forms more appropriate to their needs.

11.4 For effective implementation of the plans of GCOS and GTOS their roles relative to other related activities need to be under continuous review. For example, the development of the World Hydrological Cycle Observing System (WHYCOS) must be considered in relation to GCOS and GTOS.

11.5 Many of the remote sensing components of the IOS are either in existence or there are firm funding commitments for their implementation. Currently of greater importance than the availability of the hardware is to develop policies and funding to ensure that data sets are acquired, archived and made available to users of GCOS/GTOS in forms and at prices that allow them to fulfil their goals.

11.6 Some components of the IOS are not firmly secured even in principle. These include the global topographic data base and the global soils data base. Strong efforts must be mounted to ensure that the agencies capable of creating these data bases clearly understand the needs of GCOS/GTOS, and that the appropriate data bases are created in a timely fashion.

11.7 The draft version of the IOS needs to be discussed with the sponsors of GCOS and GTOS to ensure that its recommendations meet their needs. Liaison with international coordinating bodies such as CEOS should be carried out through the representation of GCOS on their committees and working groups and through relevant components of the sponsoring agencies such as the IGBP and UNEP-GRID.

11.8 Associated with the successful implementation of the IOS, there are a number of issues especially relevant to developing countries:

a) the institutional capacity of national research and operational systems needs to be developed and strengthened to permit many countries to actively participate in the GCOS/GTOS programme;

b) it will be essential to establish sites within research or operational institutions with the necessary equipment and expertise. It will also be necessary to provide training to develop the capacity of the local scientific and technical communities;

c) to develop models experts from different regions of the world should be invited to participate. In this way core groups may be formed to address particularly important classes of model problems. This will be most effective if modellers from developed and developing countries are able to collaborate. Some institutions providing such opportunities are now under discussion, particularly regarding seasonal-to-interannual climate models;

d) since it is essential to obtain long-term data from selected sites, funding for an extended period must be marshalled. In many cases, national governments may be unable to fully provide such financial support and it will need the co-operation of other countries or international agencies. As part of the GCOS/GTOS strategy, assistance should be made available to obtain needed resources.

In implementing these issues with regard to developing countries use should be made, as appropriate, of existing international programmes such as the joint training and research activity of START co-sponsored by IGBP/WCRP/HDP and UN programmes such as UNITAR.

12. PANEL REPORT AND RECOMMENDATIONS

12.1 The Terrestrial Observation Panel identified as a high priority the need to develop a balanced integrated system of ground and satellite terrestrial observations to fulfil the goals of GCOS and GTOS.

12.2 A review of the needs of various modelling activities was carried out by the Panel. From this review it is recognized that the models had a very wide diversity of observational requirements in terms of spatial, temporal and accuracy of terrestrial observations and that no single set of observations will meet all needs.

12.3 Only a partial review of model needs was carried out and will need to be expanded in future meetings to consider models such as terrestrial effects and ecological models.

12.4 In terms of *in situ* observations the Panel recognized the extensive amount of data currently being collected throughout the world, but noted the absence of an overall strategy with respect to sampling and definition of the observations that need to be made.

12.5 A global hierarchical system is proposed for the collection of surface observations, characterized by four different levels of increasing intensity and sophistication of observations; with these increases the number of sites decline. At level IV it is anticipated that there will be 10,000 sites worldwide, whereas at level I there will only be between 10 and 50 sites.

12.6 This surface system should take maximum advantage of existing facilities while ensuring a representative set of the Earth's surface properties. To ensure the latter will require capacity building in developing countries.

12.7 The surface measurements programme and its development be primarily the responsibility of GTOS in consultation with GCOS, given the amount of detailed ecological observations required. An appropriate international agency needs to be identified to take on the responsibility for implementing this component.

12.8 Fine and coarse resolution data from existing remote sensing systems have the potential to satisfy the needs of many users, but the resultant data sets have substantive limitations due to factors such as acquisition strategies, pricing policies and changing overpass times of satellites.

12.9 The Panel recognized the improvements in the availability of long-term data sets produced by data reprocessing and recommended efforts should be continued to maintain existing data sets and to improve the internal spatial and temporal characteristics of other data sets.

12.10 Reduction in the diversity of formats of remotely sensed data is recommended.

12.11 Requirements for high priority observations have been identified. Some crucial variables remain difficult to observe reliably: notable among these are soil moisture and biomass and research is recommended to improve their quality.

12.12 Existing global data sets of topography and soils remain inadequate for many requirements and steps to improve their quality are proposed.

13. CLOSURE OF MEETING

The meeting closed at 3.30 pm June 30th 1994.

Annex I

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Annex II

Agenda

1. Opening of the Session

2. Introduction and Background on GCOS and GTOS

3. Opening Statement of the Panel Chairman

4. Invited Reports
   - 4.1 GCOS Task Group Meeting
   - 4.2 Fontainebleau Workshop
   - 4.3 First Meeting of STPG for GTOS
   - 4.4 Harmonization of Environmental Data Workshop

5. Model Consideration
   - 5.1 Global Atmospheric Models
   - 5.2 Hydrological Models
   - 5.3 Terrestrial Effects Models

6. Current Status of Observational Systems
   - 6.1 *In situ* Observations
   - 6.2 Remote Sensing Observations
   - 6.3 Data Management Issues

7. Strategy for Design of a Terrestrial Observational System

8. The Initial Operational System (IOS) -- Terrestrial Component

9. Implementation Plans

10. Panel Report and Recommendations,

11. Closure of the Meeting

Annex III

Terms of Reference for the GCOS/GTOS Terrestrial Observation Panel

Recognizing the need for specific scientific and technical input concerning terrestrial observations for climate purposes, the Joint Scientific and Technical Committee (JSTC) for the Global Climate Observing System (GCOS) and the Ad hoc Scientific and Technical Planning Group (STPG) for a Global Terrestrial Observing System (GTOS) have jointly established a Terrestrial Observation Panel with the following terms of reference.

Terms of Reference:

- o In accordance with the GCOS Plan, and in cooperation with the GTOS STPG, to plan, formulate and design a long-term systematic observing system for those terrestrial properties and attributes which control the physical, biological and chemical processes affecting climate, are affected by climate change or serve as indicators of climate change, and which are essential to provide information concerning the impact of climate and climate change;

- o To review the needs of the user communities for climate related data and to ensure timely provision of data sets at appropriate space and time scales and in suitable forms, paying particular attention to the needs of developing countries;

- o To develop a strategy based on the concept of the Initial Operational System (IOS) which includes the assessment of existing operational systems, the determination of deficiencies and the recommendation of necessary enhancements, and a comprehensive data system;

- o To seek review and support for implementation from other relevant research or operational programmes (e.g., WCRP, IGBP, WWW, GAW, WHYCOS, GEMS, GRID, etc.) and to collate, review, publish, and prioritize data requirements and observing system specifications;

- o To coordinate activities with other GCOS and GTOS panels and task groups to ensure consistency of requirements with the overall programmes;

- o To recommend actions to address the gaps in present and planned systems;

- o To report regularly to the JSTC and STPG.

In order to accomplish the panel will:

- o Determine and document significant user/participant needs;

- o Review existing reports and studies concerning requirements for the terrestrial/ecosystem measurements to meet climate objectives of GCOS/GTOS;

- Review the current and planned observational activities of:

  i) the relevant core projects and activities of WCRP (e.g., GEWEX, ISLSCP, ISCCP, etc.) and IGBP (e.g., GCTE, BAHC, DIS, GAIM, etc.),

  ii) the Human Dimensions of Global Change Programme (HDP) (especially those on land use and land cover change),

  iii) relevant programmes of international agencies (e.g., ICSU, WMO, UNESCO, FAO, UNEP);

- Identify major gaps in current and planned observing systems; propose prioritized options to address these gaps;

- Review existing information systems, particularly regarding their capability to provide the climate community with the terrestrial/ecosystem data needed;

- Review existing mechanisms to implement measurements and data management, assess their ability to meet existing and foreseen needs for terrestrial/ecosystem data, and recommend mechanisms as appropriate;

- Publish and update GCOS/GTOS studies as planning documents;

- Make recommendations as appropriate.

Chairman: Dr. John Townshend, USA

Appendix 1

LAND OBSERVATIONS FOR GENERAL CIRCULATION MODELLING

A 1.1 Validation

A 1.1.1 A distinction has to be drawn between numerical weather prediction (NWP) models and general circulation models (GCMs). NWP models predict a future state of the atmosphere on short time scales (of the order of a few days), based on a set of initial conditions. Their initial conditions are derived from model fields incorporating assimilated observed data at the initial time. Validation is carried out by comparing model predictions of atmospheric state at the final time with observations.

A 1.1.2 GCMs, on the other hand, simulate the evolution of the atmosphere over long time scales, of the order of years. Because the atmosphere is a chaotic system, predictions of actual future instantaneous atmospheric states cannot be made with any confidence over periods longer than a few days. Validation of 5 cm output is therefore carried out by comparing model output fields with multiple-year averages of observed fields (usually summarized as monthly averages). These must be provided on global grids, at resolutions equal to or greater than the model grid. At present this is generally quite coarse for GCMs of the order of 3-4° in the horizontal; however, in order to fulfil future needs in anticipation of increasing or variable model resolution, observational data will probably be required within the decade on scales of the order of a few (l-50) km.

A 1.1.3 Large-scale features of the free atmosphere can be validated using NWP model output obtained by 4-dimensional data assimilation of observed variables. However, the terrestrial and near-surface fields (surface fluxes, soil moisture, screen temperature, etc.) are not useful for validation, since they are heavily influenced by model parameterizations of unresolved, sub-grid scale processes, and are therefore highly model-dependent. Validation of scan-generated surface fields must therefore be undertaken on the basis of remotely-sensed data and surface observations.

A 1.1.4 Data relating to the surface thermal regions, such as surface radiative temperature and albedo, are fairly readily obtainable from satellite observations, which are essentially measurements of radiance. Work along these lines (such as the SRB project) is heartily endorsed by the Terrestrial Observations Panel. ·However, data relating to the hydrological cycle present a much more difficult problem. The following variables, roughly in descending order of importance, constitute a short list of basic information required for validation.

a) *Precipitation.* This parameter derives the land surface hydrology in the same way that incoming solar radiation drives the surface thermal regime. It is, unfortunately, also one of the most difficult variables to measure in a spatially comprehensive manner. The work ongoing under the GPCP is endorsed in this regard.

b) ***Runoff.*** On an annual time scale, the correct simulation of surface runoff, together with precipitation, provide indirect validation of the surface evapotranspiration rate. The collection of runoff data also presents for fewer problems than that of evapotranspiration, which is both difficult to measure and highly spatially variable. The efforts of the GRDC in this regard are commended, and countries worldwide should be encouraged to contribute to the database. To complement the database, however, two things are required: a global digital map of basin boundaries for the catchments being monitored, and a series of corrections to the raw data, describing the amount of water removed from the river for human use (irrigation, municipal water supplies, etc.).

c) *Snow mass. The* ongoing collection of snow extent data using visible satellite imagery provides useful first-order validation data for snow modelling in GCMs. However the actual modeled variable is snow mass (water equivalent). A rigorous validation of the performance of GCMs with regard to the simulation of snow requires the development of a long-term database of snow mass.

d) *Soil moisture.* Climate simulations, unless multi-decadal, can be markedly sensitive to initial soil moisture, particularly for deep soils. Ongoing efforts to produce global soil moisture climatologies are therefore to be encouraged, despite the problems of spatial heterogeneity. This item is placed at the bottom of this list, not because it is not important, but due to the severe difficulties associated with its measurement. An alternative to direct observation might involve the modelling of soil moisture on a continuing basis, using a high quality soil data base, updated meteorological observation (e.g., from the World Weather Watch) and constraints based on streamflow records.

A 1.2 Boundary Conditions

A 1.2.1 To enable the realistic modelling of surface fluxes, the characteristics of the land surface must be specified in such a way as to reflect as accurately as possible ambient conditions. Information is therefore required on land cover, vegetation characteristics, and soil parameters.

A 1.2.2 Land cover can, at the simplest level, be divided into water, ice, urban area, vegetation and bare soil. At the next level, “water” can very usefully be subdivided into lakes/rivers and wetlands and “vegetation” into broadleaf trees, needle leaf trees, crops and grass. This basic information is required to enable a reasonable and realistic treatment of sub-grid scale surface heterogeneity. A reliable topography database will also become increasingly important as GCM resolution increases.

Appendix 2

HYDROLOGIC OBSERVATIONS FOR BIOSPHERIC MODELLING

A 2.1 There are a wide range of needs for hydrological purposes as such. In the present appendix we consider only those required for the biospheric modelling.

A 2.2 Runoff

A 2.2.1 Global biospheric priorities for hydrologic data are somewhat different than hydrologists define. For example, although the Global Runoff Data Centre is organizing river discharge data sets, biospheric models need **areal** gridded runoff estimates, not point data from river mouths. Also, river carbon and nutrient transport from land surfaces are needed by global ecologists. This biogeochemical data is not commonly taken at standard hydrographic stations.

A 2.2.2 Accurately defined spatially gridded precipitation and runoff can, by standard hydrologic mass balance logic, provide the only spatial evapotranspiration data estimates possible. Given system capacitances, no more than monthly time resolution of these runoff and ET data may be possible. However the hydrologic and bio-geochemical cycle (BGC) models require daily precipitation data for driving models.

A 2.3 Surface Wetness

A 2.3.1 Although for many ecological purposes soil moisture to l-2 m depth is preferred, some utility of a surface wetness variable can be defined. Of course surface energy partitioning reacts most quickly to surface (as opposed to soil profile) wetness. Also nutrient decomposition, trace gas fluxes and seed germination are ecological processes where surface wetness would be useful if available spatially at high time frequency. A daily global surface wetness observation may be possible from satellite born active radar or passive microwave sensors.

A 2.4 Evapotranspiration

A 2.4.1 Most global biogeochemistry models compute ET, at anywhere from daily to monthly time steps. Recent technological advancements now make the concept of a global water (and CO,) tower-based flux network possible.

A 2.4.2 Although realistically only approximately 10 sites may be possible to support this technology and cost, even a well distributed 10 sites of ***continuous*** annual ET would be immensely valuable for calibrating and/or validating global biospheric models. The IGBP/BAHC project is taking the lead of hosting a workshop to advance this idea of a global continuous flux network.

A 2.5 Surface Meteorology

A 2.5.1 The WMO WWW co-ordinates the daily surface weather observations (approximately 30,000 daily reports) in addition to other atmospheric observations. These raw data are transmitted via a global telecommunications system to various weather service offices around the world, and incorporated into models for weather analysis and forecast products for subsequent distribution. Limited error checking, missing data filing, calibration, etc. are done consistently. However, for purposes of terrestrial/ecosystem use, many of the observed variables should be organized, archived and made available in alternative formats.

A 2.5.2 There are two primary additional requirements by the global biospheric modelling community. First, the raw point data needs to be spatially extrapolated to a global grid, to a suggested 0.5 x 0.5 degree resolution. This spatial extrapolation and averaging should be done in the context of a global topographic database.

A 2.5.3 Second, the standardized daily maximum-minimum temperature and precipitation are only a partial set of needed variables. The highest priority for biospheric modelling is daily incoming short-wave or PAR radiation, and absolute humidity, with wind speed and direction a lesser requirement. The derivation of radiation and humidity data from the original temperature and precipitation observations needs to be done with a consistent logic and algorithms. To some extent the global 4DDA forecasting models are the closest current methodology for ingesting daily observations, error checking, spatial extrapolation, and derivation of additional variables. GCOS may want to archive and distribute a quality controlled 4DDA output as a global surface daily climatology. The IGBP BAHC Focus 4 “Weather Generator” project is exploring these issues.

A 2.5.4 The importance of infrequent extreme meteorological events is possibly unique to biospheric science. Minimum temperature extremes, particularly frost events, have profound control over vegetation. Wind extremes such as hurricanes occasionally but substantially alter vegetation. Major flooding events or particularly intense periods of precipitation also are quite important. It is essential that archived climate data must not be aggregated if the result is to remove the record of such extreme events.

Appendix 3

KEY OBSERVATIONS REQUIRED AT GLOBAL AND REGIONAL SCALES IN CONTINUOUS FIELDS

A 3.1 This appendix lists in Table A 3.1 some of the key land variables needed as spatially continuous data sets. This represents an incomplete provisional statement. Some key variables have not yet been included such as soil moisture and not all sections are complete. This information is included in this incomplete state to indicate the direction of the GCOS/GTOS Terrestrial Observation Panel conclusions.

A 3.2 Surface observations to support satellite observations

A 3.2.1 Surface observations to support satellite data analysis are required by scientists developing or validating algorithms for extraction of biophysical parameters from satellite data; individuals responsible for the production and quality control of such parameters from satellite data will also require such data.

A 3.2.2 Satellite-derived quantities for surface monitoring are usually retrieved quantities, not the basic measured radiances. The retrieved quantities range from standard geophysical parameters such as surface temperature, to simple indices such as vegetation index and percent ice cover, presence or absence quantities like snow cover, or complex derived surface properties such as land cover type or leaf area index (LAI). The algorithms for deriving these quantities vary in complexity, but all involve calibration, cloud detection, correction for viewing and illumination geometry, and retrieval. Even the most carefully designed algorithms can introduce biases in the product, and ongoing changes and improvements to algorithms that occur in any operation can affect the nature or magnitude of the biases.

A 3.2.3 Episodic environmental events such as volcanic eruptions, changes in sensors, spacecraft orbit drift, etc., can all affect the stability of the measurements and must be removed to achieve a climate-quality time series data set. When routine conventional observations are available they can be used to overcome the problems in calibrating and validating long-term data sets. The satellite atmospheric soundings are continually matched to radiosondes and the retrieval system periodically tuned. For example the AVHRR sea surface temperature product is tuned to a set of continually operating buoys that measure sea surface temperature. These procedures compensate for instabilities in the products. For some current and planned satellite land surface products there exists at present no acceptable routine ground observations that can be used to calibrate, stabilize, and validate the products.

A 3.2.4 The satellite variables include insolation, photosynthetically active radiation (PAR), albedo, surface (skin) temperature, and vegetation properties. Surface data are thus important to establish the accuracy and precision of methods for extracting surface parameters from satellite measurements, and for ensuring that the resulting algorithms remain insensitive to potential systematic trends which may affect their performance (due to instrument drift, land cover changes, changes in surface processes or interactions due to climate, etc.).

A 3.2.5 To be useful, the surface measurements must be obtained over an area, in the time frame(s) and using methods compatible with satellite measurements. This affects the size and location of the area; type, timing and frequency of variables measured; and methods for recording and reporting the data. The following requirements are proposed:

site characteristics: insofar as possible, the selected area should be spatially homogeneous (or homogeneously heterogeneous, with variability that can be feasibly quantified) with respect to land cover and use, topography and soils;

geographic distribution: to validate satellite products for use globally, a representative range of climates and land cover types should be included. The distribution needs to be examined in terms of the size and significance of the individual biomes, key processes taking place, and the feasibility of making the appropriate measurements.

A 3.2.6 Observations required include the following:

global insolation, PAR, downward longwave, upward shortwave and longwave (the latter two measurements on a tower if available);

standard surface meteorological observations (temperature, humidity, wind speed, precipitation, cloud conditions, snow cover, snow depth) and a relatively nearby (within about 100 km) radiosonde station. Precipitation observations should be made using 4 to 5 rain gauges at each site to reduce the variability. Snow cover and snow water equivalent should be measured at each raingauge location;

atmospheric aerosol loading or turbidity values for the correction of satellite radiances;

land cover with spatial resolution 10 - 30 m, classes hierarchically compatible with the global land cover products but with more thematic detail;

seasonal and annual changes in land cover (phenology and disturbance), including spatial distribution within the site;

vegetation description: vegetation type, dominant species, height, live biomass (leaves, stems), LAI, soil surface cover, canopy structure;

surface and upper air measurements, including atmospheric transmission (coincident with satellite data acquisition);

net CO_2 flux between the surface and the atmosphere;

canopy chemistry (lignin and N);

surface soil temperature.

A 3.2.7 The frequency of measurement will be variable, depending on the parameter, particularly for reflected visible radiation and vegetation index. Satellite observations are area averages, while ground observations are point values. This difficulty can be surmounted by assuming time averages of ground meteorological observations to be equivalent to spatial averages in the satellite pixel or retrieval target. Therefore the weather observations for satellite validation should be integrated over time intervals of 30 minutes or one hour.

A 3.2.8 The minimum area size is likely to be no smaller than 5 by 5 km, and may be much larger depending on the sensor.

A 3.2.9 There is a need to define in detail the measurement requirements and to ensure that selected surface sites meet the criteria and are able to provide the data.

A 3.3 Needs for Soil Characterization

A 3.3.1 Soils are important in global biogeochemical studies because of their chemical composition (they store 2/3 of terrestrial carbon and are an important source of nutrients) and physical properties (the role is a porous medium for water storage and movement) and the interactions between these properties are what influences the rates of decomposition, carbon storage, moisture availability, trace gas production, and nutrient supply. Soil scientists have developed two types of information, soil maps of regional and global coverage, and chemical and physical measurements on soil pedons, when combined provide important spatial information concerning soil characteristics. There are shortcomings in both data sources that limit their current usefulness in global studies. These shortcomings are addressed by a couple of international efforts that should be encouraged.

A 3.3.2 Currently the best global soil map is the UNESCO-FAO Soil Map of the World, recently released in digital forms at a scale of 1:5 million. While this represents a comprehensive and valuable resource, it does not allow soil classes to be located accurately enough. Most map polygons contain a mixture of soil types with only general information provided concerning their relative areal extent and no information provided concerning their location within large polygons. There are plans to develop a new world soil map (SOTER) at a 1: 1 million scale and in addition provide precise information on proportions of polygons occupied by various soil types, topographic position, and descriptions of their chemical and physical properties. This SOTER project is expected to be completed in 10 to 20 years. Development of this important resource should be encouraged and supported especially if its time for completion of the work could be shortened.

A 3.3.3 As an interim project to provide usable soil information at the global scale, IGBP-DIS has initiated a project in conjunction with the major international and national organizations concerned with the creation of large area soils data bases to assemble presently available pedon data and develop methods of representing important soil chemical/physical properties spatially using the current Soil Map of the World or an interim SOTER map at a 1:5 million scale. This is scheduled to be completed in 1998.

Table A.3.1 Tabulation of the priority observations needed at global and regional scales in continuous fields.

1: LAND COVER

Users:

GCM modellers, BGC modellers (global, regional), ecosystem modellers, climate impact modellers; also regional analysts/planners.

Rationale:

Several land cover maps are available. However, there are large disagreements due to different methodologies used to prepare them. What is needed is an adequate characterization of the spatial distribution of actual vegetation cover. For historical periods, current methods probably cannot be improved. For the recent past, present, and future, land cover will optimally be provided by remote sensing. For spatial extrapolation purposes the spatial resolution in general does not have to be great. One to five km is finer than most investigators are currently using, but not finer than the scale over which significant variations in vegetation processes occur. It is important to distinguish land cover categories using criteria related to carbon storage and turnover. Olson, et al (1984) suggested a scheme that resulted in about 30 categories that included possibilities for mixed pixels at a 0.5 degree resolution. At a finer spatial scale and using different methods or tools, other classification schemes will undoubtedly be necessary. However, it is thought that 20 - 40 categories of land cover would be adequate. For wetland categories that have special carbon dynamics, higher spatial resolution may be required. A rationale for change detection and parameters is required.

Frequency of measurement:

Full mapping: Once every 5 years; Change detection: Annual
(Note: A really good change detection programme should remove the need for remapping until a better data source becomes available; this would mean the change detection procedure can identify the new land cover type.)

Spatial resolution of measurement:

10s: 1 km for global coverage, 30 m for regional to local coverage;
Post-10s : 0.25 - 0.5 km for global coverage, 30 m for regional to global coverage.

Accuracy/precision required:

Highly dependent on application. For example 80% global accuracy may be sufficient for operation of **GCMs,** but for accurate estimation of changes in carbon stocks for carbon modelling, accuracies of better than 95 % are required.

R&D **needed:**

Validation of classification methodology.

Present **status**:

Global coverage can be obtained from the Global 1 km AVHRR data set (lo-day composite images over 18 months) which will be completed in 1995. A methodology for regional land cover mapping was demonstrated in North America. Methodologies for change detection using 1 km-type data are under development; this work needs to be strengthened and expanded to various parts of the globe. Special techniques need to be used for fire detection and mapping. The further development, validation and implementation of these should be encouraged.

High resolution coverage is provided by high resolution satellite data (Landsat, SPOT, etc.). The methodologies for mapping have been well demonstrated. Methodologies for change detection continue to be developed, with operational techniques expected in 2 - 3 years. Significant regional coverage is feasible with newly obtained and archived data.

A good representation of wetlands distribution is especially important for BGC studies. At the global level, it will be more reliably derived by combining satellite data outputs with soil (possibly also DCW vegetation and topographic) data.

Action required:

Near term

- Endorse completion of the initial global 1 km AVHRR data set;
- Promote continuation of the Global 1 km AVHRR project to provide a continuing series of global observations;
- Promote validation of cover mapping methodology for 1 km data in various regions;
- Encourage development of robust change detection algorithms.

Mid-term:

- Promote expanded use of high resolution data for land cover mapping for large areas (national to regional levels);
- Promote generation of global data sets with higher spatial resolution from existing or new sensors.

2: LAND USE 1

Users:

BGC modellers, ecosystem modellers.

Rationale:

One of the most controversial components relating to the global carbon cycle concerns the magnitude of release and uptake of CO_2 resulting from human activities. Currently, the most authoritative accounting of these fluxes is based on interpretations of land use statistics compiled by FAO. A more objective system that can be updated annually, rather than every five years, may be possible using remote sensing of land-cover change (possibly combined with agriculture and forestry production statistics, and socioeconomic spatial data such as population and transportation). Landsat is perhaps one of the most appropriate data streams for land-use monitoring. While the methodology for using this data to produce a land-use product is still a research issue, it is important that this data stream continue to be archived and made accessible.

Frequency:

Annual, observations during growing season.

Spatial:

5 m - 1 km depending on the spatial heterogeneity of land use; at least 30 m for many regions.

Frequency of measurement:

Once every 5 years.

Accuracy/precision required:

To be determined.

R&D needed:

Development of regionally-specific relationships between land cover and land use. Definition of the lowest acceptable spatial resolution (also regionally specific, depending on land use heterogeneity).

Present status:

Land use maps have been completed for many specific areas of the world. These efforts were based on various data sources and are not generally compatible with each other. A consistent, hierarchical classification system is presently under development; this is to be encouraged.

Action required:

Near-term

Complete the development of land use classification scheme;

Identify areas of the world for which acceptable and accessible products exist; compile these into a consistent data base;,

Carry out pilot studies for filling the critical gaps in coverage using land cover mapping procedure and the relationships between land cover and land use; validate preliminary products.

Mid-term

To be determined.

3. SEASONAL VEGETATION INDEX PROFILE (SVIP)

Users:

Climate, ecosystem, BGC modellers.

Rationale:

SVIP provides information on the intensity of ecosystem activity during the growing season, thus permitting estimation of energy and mass exchange with the atmosphere.

Frequency of measurement:

Daily.

Spatial resolution:

10s: **1 - 8 km;**
Post-10s: **0.25 -** 1.0 km.

Accuracy/precision required:

Within 10% of true value.

R&D needed:

The main challenge is to obtain precise corrections for artifacts in raw data (e.g., from sensor calibration, atmospheric effects, bidirectional effects).

Present status:

SVIP based on NDVI or SR has been used extensively in recent years. Two projects (Pathfinder and the global AVHRR 1 km project) produce the initial data set from which SVIP can be produced. These data sets require further refinements for use by the modellers. Such methodologies are becoming available but their further development and validation is to be encouraged.

Action required:

Near-term

Encourage continuation of the global AVHRR 1 km and Pathfinder projects;

Stimulate production of SVIP data sets.

Mid-term

Replace SVIP by derived variables such as FPAR and LAI.

14. FPAR

Users:

Climate, ecosystem, BGC modellers.

Rationale:

Essential quantity for understanding relationship between incoming solar radiation its absorption for photosynthesis and the impact of the latter on evapotranspiration local terrestrial energy balance, carbon sequestration an other biogeochemical cycling.

Frequency of measurement:

Daily, to derive a product every 10 - 30 days.

Spatial resolution:

10s : **1 - 8 km;**
Post-10s: **0.25** - 1.0 km.

Accuracy/precision required:

10s: **10-20%** of true value;
Post-10s: **5-10%** of true value.

R & D needed:

Methods for deriving **FPAR** need to be developed and validated for different biomes and different satellite data sources (resolution, spectral bands).

Present status:

Definitive algorithms are not yet available. Methodology development is being undertaken in various projects (e.g., FIFE, **BOREAS**). The capability to produce experimental data sets has been demonstrated through ISLSCP. However, these data have not been validated in sufficient detail.

Action required:

Near-term

Stimulate production of FPAR data sets using ISLSCP or similar approaches, to provide initial data sets for the user community. These products should use the best available knowledge at the time, the method should be explained in detail, and its limitations (insofar as known) should be outlined.

Mid-term

Endorse and encourage the development and validation of FPAR algorithms for various biomes.

5. LEAF AREA INDEX (LAI)

Users:

Climate, ecosystem, BGC modellers.

Rationale:

see SVIP.

Frequency of measurement:

10s:	Once per growing season in N & S hemisphere (peak green period);
Post-10s:	Daily, to derive a product every 10 - 30 days.

Spatial resolution:

10s:	1 - 8 km;
Post-10s:	0.25 - 1.0 km.

Accuracy/precision required:

10s:	15 - 25 % of true value;
Post-10s:	5 - 15% of true value.

R&D needed:

Methods for deriving LAI need to be developed and validated for different biomes and different satellite data sources (resolution, spectral bands).

Present status:

Definitive algorithms are not yet available. Methodology development is being undertaken in various projects (e.g., BOREAS). The capability to produce an experimental data set has been demonstrated through ISLSCP. However, these data have not been adequately validated.

Action required:

Near- term

Stimulate production of LAI data sets using ISLSCP or similar approaches, to provide initial data sets to the user community. These products should use the best available algorithm, the method used should be explained in detail, and its limitations (insofar as known) should be outlined.

Mid-term

Endorse and encourage the development and validation of LAI algorithms for various biomes.

6. INCOMING PHOTOSYNTHETICALLY ACTIVE RADIATION (IPAR)

Users:

Climate, BGC and ecosystem modellers.

Rationale:

The PAR is the energy source for the growth and development of vegetation. Through photosynthesis, radiant energy in the 0.4 to 0.7 mm band is converted to chemical energy that is the source of vegetation activity.

Frequency of measurement:

Daily.

Resolution:

5 by 5 km.

Accuracy/precision required:

10 Watts per square meter.

R&D needed:

To be determined.

Present status:

To be determined.

Action required:

To be determined.

7. BIOMASS

Users:

Ecosystem and carbon modellers.

Rationale:

Biomass is a key variable in modelling carbon uptake and redistribution within the ecosystem. Woody biomass is of most interest.

Frequency of measurement:

Once every 5 years.

Spatial resolution:

To be determined.

Accuracy/precision required:

To be determined.

R&D needed:

Research is required to determine the feasibility of estimating live biomass from satellite data; radar measurements presently offer the best prospect. Imaging laser sensor technology is also promising but no space borne missions are planned

Present status:

Highly experimental.

Action required:

Near-term
: Currently it is uncertain how to obtain biomass data to meet modelling needs within the next 5 years.

Mid-term:
: Encourage R&D on biomass estimation.

8. SNOW COVER AREA AND SNOW WATER EQUIVALENT

Users:

Climate, BGC modellers.

Rationale:

The presence or absence of snow cover is very important in determining the nature of the atmosphere-surface interaction. Snow cover changes surface albedo and surface energy balance. Snowpack liquid water content in some regions is a major input to soil moisture for seasonal vegetation growth. Mapping of permafrost has many similar ecological uses.

Snow cover dramatically changes surface albedo, thus global snow cover mapping is clearly important for climate modelling. In addition, snow melt, or the time derivative of change in snow/water equivalence, is important in recharging soil moisture where it influences evapotranspiration, nutrient cycling, seed germination and vegetation phenology, among many other biotic processes. Consequently, the global mapping of snow melt rates at 5-10 day intervals would be preferred for ecological purposes. However, global organization of such data may be questionable due to the limited spatial representation of ground snow surveys.

A comprehensive statement of cryospheric needs is still required.

Frequency of measurement:

Daily.

Spatial Resolution:

50 by 50 km, or finer, if available.

Accuracy/precision required:

Area - nearest 25 by 25 km desirable
Snow water equivalent - 5 mm of water.

R&D needed: Present passive microwave algorithms work fairly well in areas with limited topography and with short or little vegetation cover. Significant problems exist in forested and mountainous areas. Research should be encouraged on the development of algorithms for these conditions.
Present status: Ground networks of periodic snow depth/snow water field measurements already exist in the US, Canada, Scandinavia, Russian Federation and some former Russian states. Organizing a data archive of this database would be desirable as a GTOS activity. Satellite and aerial photo based mapping of snow cover is already done by NOAA in the US at the National Snow Centre in Minnesota.
Action required: To be determined.

9. TOPOGRAPHY

Users:

Ecosystem modellers concerned with land cover change and deforestation as it affects carbon cycle. Hydrological cycle modellers, including GEWEX and BAHC projects. Remote sensing specialists carrying out high quality image rectification for change detection purposes.

Rationale:

Topographic data are necessary to properly quantify the interactions between the solar radiation, water, and the heterogeneous land surface, including the measurements of these interactions from remote platforms.

Frequency of measurement:

Once for a given spatial resolution.

Spatial resolution:

One km for use with AVHRR data (and for regional applications);
10 m - 30 m for high resolution data and for hydrological modelling.

Accuracy/precision required:

Vertical: 100 m with AVHRR data, 5 m - 20 m for higher resolution requirements and for hydrological modelling

R&D needed:

To be determined.

Present status:

In the near term, only topographic data presently available can be realistically expected to form the basis for global and regional data sets. The best quality global topographic data sets are presently classified, and although discussions have been held to have them declassified, they are not available. The presently available digital chart of the world contains elevation information from 1: 1 ,OOO,OOO ONC maps, with coarse vertical resolution. Most of the world land mass has been mapped at 1:250,000, thus providing a good basis for digital elevation data with a grid spacing of 100 m. It should be noted that the vertical accuracy of the above data sets is likely to be marginal at best. For many local or regional applications higher resolution topographic data will be required (150,000 or higher).

Action required:

Near-term

- Work toward the release of the highest resolution global data set presently available;
- In parallel, evaluate the utility of DCW topographic data.

Mid-term

- Pursue the availability of higher resolution topographic data (1:20,000 to 150,000) for regional to continental applications.