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REVIEW OF THE IMPLEMENTATION OF COMMITMENTS AND OF OTHER PROVISIONS OF THE CONVENTION

RESEARCH AND SYSTEMATIC OBSERVATION

Comprehensive report on the development of the observational networks of the climate system

Note by the secretariat

1. The comprehensive report on the adequacy of the global observing systems which follows responds to a request by the Conference of the Parties (COP) at its third session to the Subsidiary Body for Scientific and Technological Advice (SBSTA), to consider the adequacy of observational systems and to report on its conclusions to the COP at its fourth session (FCCC/CP/1997/7/Add.1, decision 8/CP.3). It was coordinated by the Global Climate Observing System (GCOS) Secretariat in the World Meteorological Organization (WMO), on behalf of the organizations participating in the Climate Agenda.

2. In accordance with the procedure for miscellaneous documents, the report is reproduced in the language in which it was received and without formal editing.

3. The report should be read together with its executive summary (FCCC/CP/1998/7), which also puts forward some possible actions the SBSTA may wish to consider on this matter.

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* Including the ninth sessions of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation.

FCCC/CP/1998/MISC.2

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REPORT ON THE ADEQUACY OF THE GLOBAL CLIMATE OBSERVING SYSTEMS

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NOTE

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1 SUMMARY AND MAJOR RECOMMENDATIONS

> *"The current global observational network is declining. If this decline is not stopped we may, say, twenty years from now, be in a worse situation than today when trying to determine to what extent and how climate is changing. We will have less capability of clarifying to what extent an ongoing climate change might be the result of human activities or be an expression of natural variability in the climate system. A continuous close observation of the climate system is an absolute requirement for dealing adequately with the climate issue."*
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> Prof. Bert Bolin, Chairman-Emeritus of the IPCC, Report to the Seventh Session of the Subsidiary Body for Scientific and Technical Advice on behalf of the Intergovernmental Panel on Climate Change, Bonn, 24 October 1997

In recent years the prospect that the global climate could change as a result of human influence has generated widespread concern. A concerted global response has developed as a result of this potential for human-induced climate change. A United Nations Framework Convention on Climate Change (FCCC) has been ratified and come into force.

The emissions of carbon dioxide and other so-called ‘greenhouse gases’ into the atmosphere are capable of modifying the global radiation balance giving rise to global climate effects. To establish that such anthropogenic influence is occurring requires that the signal be detected against the background of natural variability that is characteristic of the climate system. Scientifically credible advice on the future evolution of the climate and information to guide mitigation and adaptation strategies to address potential impacts of climate change require a continuing supply of selected observational information.

The assumption is commonly made that there are more than enough observations being collected to meet these needs, especially given all the recent improvements in observational technologies. In practice available observations often have major deficiencies with respect to climate needs. These deficiencies have the potential seriously to undermine any decisions made concerning the mitigation of climate change. Problems with the observational record include a lack of consistent long-term records, many gaps in spatial coverage, changes in observational procedures which introduce bias and, for several important observational types, a decline in the quality and number of observations being made.

The third Conference of the Parties (COP) to the FCCC requested (8/CP.3) its Subsidiary Body for Scientific and Technological Advice (SBSTA), in consultation with the Intergovernmental Panel on Climate Change (IPCC), to consider the adequacy of the relevant global observing systems and to report on its conclusions to the COP at its fourth session.

This report concludes that many of the observational requirements are generally known and documented and that many of the observing components are in place, but need substantial augmentations and enhancements to fully serve climate purposes. Fortunately many of the techniques needed to obtain the measurements are currently available and cost-effective, and an appropriate international infrastructure has been identified to facilitate the collection and distribution of climate-related observations.

What is urgently needed is a commitment by nations to provide global coverage for the key variables, to halt and reverse the degradation of existing observing systems, and to exchange information more effectively. Specific improvements are needed in atmospheric, oceanic, and terrestrial systems. It is recommended that each Party should undertake programmes of systematic observations in accordance with national plans, which they should develop in concert with the overall strategy for global climate observations. A positive response to this challenge would significantly advance the implementation of an effective observing system for climate and support the objectives of the FCCC.

MAJOR RECOMMENDATIONS

Recommendation 1

Each Party should undertake programmes of systematic observations including the preparation of specific national plans, based on the overall plans formulated by GCOS and its partner programmes. The national plans should contain commitments to undertake specific implementation actions and be tabled and reviewed at regular intervals at COP sessions.

Recommendation 2

Parties should exchange, with other nations and with appropriate international organizations, those data required to meet climate objectives and the needs of the FCCC. They should take active steps to eliminate any internal barriers to such exchange

Recommendation 3

Parties should actively support capacity development to enable countries to collect and utilize observations to meet local and regional needs. The capacity building programmes of appropriate international organizations could assist countries to acquire and use climate information. If necessary, Parties should reconsider the priorities of funding mechanisms which support the FCCC.

Recommendation 4

Countries should support national meteorological observing systems and particularly ensure that the stations identified as elements of the GCOS networks based on the WWW and GAW are fully operational and that best practices are maintained. Support should be provided to assist countries as needed. The number of stations in the observing networks for atmospheric constituents including ozone, and aerosols when formulated, should be increased. Satellite missions to observe and quantify atmospheric constituents should continue.

Recommendation 5

Countries should actively support national oceanic observing systems and particularly ensure that the elements of the GCOS and GOOS networks in support of ocean climate observations are implemented to the degree possible. Support should be provided to increase the number of surface observations, particularly in remote locations, and to establish and maintain reference stations and repeat sections. Current satellite missions to observe sea surface elevation, wind stress, and temperatures should be continued.

Recommendation 6

Countries should actively support national terrestrial networks and in particular the various observational programmes to collect, exchange and preserve terrestrial variables according to GCOS and GTOS climate priorities. Specific support is required to secure and distribute relevant hydrosphere and cryosphere observations. Ecosystem networks addressing climate impact should be coordinated to provide global and regional databases. There is a particular need to encourage the transition from research to operational status of many of the terrestrial networks. Strong encouragement and financial support, if appropriate, should be given to developing countries to enable them to collect observations in support of warning systems in connection with extreme events exacerbated by climate change, vulnerability and impacts studies, and national and regional sustainable development efforts.

2 INTRODUCTION

Since inhabiting the Earth, humans have adapted and modified their lifestyles in response to the expected average weather conditions (one definition of climate) and their regional and seasonal variations. There has also been an awareness that seasons can vary from one year to the next (now termed interannual variability) but this has been much harder to both predict and accommodate. Humans have also adapted, usually after-the-fact, to long-term variations, now usually referred to as climate change. Such adaptations have often been dramatic in nature, including the wide-spread migration of peoples to other regions.

During the past few decades the international scientific community has sought to understand the Earth's climate, to determine its inherent variability, and to predict and assess climate change. This effort has accelerated recently as a result of the potentially adverse effects that might arise from anthropogenic influences.

Much of our knowledge of climate and its variability is based on three sources of data. The first is the routine collection of atmospheric, ocean and land surface data by meteorological and oceanographic agencies, and a variety of other agencies concerned with terrestrial issues. Such data were usually collected for other purposes (e.g. weather forecasting, aviation and marine operations). Because they were not collected for climate purposes gaps and inadequacies have inevitably appeared. Second is the data base resulting from environmental research projects such as those of the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP). Such data have, more often than not, taken explicit account of climate needs but the projects have limited lifetimes and cannot be expected to satisfy the continuing, long-term need of the FCCC and other users. The third consists of historical or proxy data contained in the ice cores, sediments, tree rings and the like. The availability of these data for climate purposes has been mainly serendipitous.

Although many of the existing observing networks satisfactorily meet their specific objectives (e.g., for weather forecasting, aviation and marine operations, or research programmes), the scientific community engaged in climate research (WCRP, 1997; Spence and Townshend, 1997), and in particular, the Intergovernmental Panel on Climate Change (IPCC, 1996), have identified deficiencies in the observing networks which limit their utility for climate purposes. Clearly opportunism, experimentation and serendipity are not appropriate strategies to secure the needed data for addressing important climate issues. In particular, they are not appropriate to provide the observational requirements implicit in the agreements and considerations of the Conference of the Parties to the FCCC. These requirements must now be explicitly addressed.

The need for action now arises because:

- **Satisfactory global coverage for many of the essential climate variables has not been achieved**. Meteorological networks have large gaps over several continents and much of the ocean (WMO, 1997). Recent declines in the absolute numbers of surface observations have been documented. These gaps in global coverage seriously impact climate assessment and modelling efforts.

- **Regional coverage is not adequate in many areas**. Surface and upper-atmosphere observations from large parts of Africa, Asia, and South America are unavailable (WMO, op.cit.) Ironically, these gaps in regional coverage are often most serious in regions where impacts of climate change are expected to be most severe.

- **Observations of selected variables often do not have adequate accuracy**

or precision to be reliably used as indicators of climate change. Changes in station siting, techniques or methods of observation have often been made with little consideration of the impact on climate records. Resulting instrumental drifts and biases are difficult and often impossible to remove after the fact (Karl et al, 1995).

- **Key data sets, although collected, are often not effectively exchanged.** This problem has many sources and is currently being addressed at various levels. However, for climate, the result is that potentially valuable global or regional data sets are often unavailable to the user communities.

The inadequacies of the present observing systems can, in part, be attributed to the lack of priority given to the gathering, processing and dissemination of climate data. This has led to a number of key deficiencies. There are large gaps in the global sampling pattern of observations. Many variables needed for climate purposes are not systematically observed. Frequently there is a need for costly re-analysis, quality control and calibration projects whose sole purpose is to retrieve and restore the climate signals hidden or lost in the various data bases. Funding for monitoring and observations solely to support the understanding of climate has been weak or absent. In other cases, such as the provision of data for land-surface characterization, few effective policies for sharing data have been established in order to develop appropriate global or regional products.

If not rectified, these and similar deficiencies will seriously impact the ability of the scientific community to provide essential information to guide assessments of future climate change and in particular to support the work of the Convention.

3 OBSERVING THE EARTH'S CLIMATE

The Second World Climate Conference recognized the need for a systematic response to provide the full range of climate observations required to understand the climate system, its inherent variability and potential for human-induced change. This led to the establishment of the Global Climate Observing System (GCOS) in 1992. The GCOS is intended to bring the collection of climate data into an "operational" framework, in a similar manner to that which currently exists for weather data through the World Weather Watch (WWW) of the World Meteorological Organization (WMO).

The operation of the relevant components of the observing systems is coordinated and facilitated by a number of international / intergovernmental organizations. These and other agencies[1] have prepared "The Climate Agenda" outlining a strategy for international cooperation in climate research, services, impacts, and more specifically for observations. The Global Climate Observing System (GCOS), which includes the climate aspects of the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), and other observing systems, provides the focus for climate-related observations. These observations are collected through cooperative efforts among relevant national and international organizations.

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[1] The organizations that sponsor the Climate Agenda are the Food and Agriculture Organization (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO) through its Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Programme(UNEP), the World Health Organization (WHO), the World Meteorological Organization (WMO), and the International Council for Science (ICSU).

The two highest priorities for GCOS have been to establish long-term systematic observations in support of global and regional climate change and impact, and to provide the observations needed for seasonal to interannual climate prediction (e.g., El Niño). From the outset GCOS has sought a scientifically rigorous foundation for its design and plans. It has sought to:

1. identify and document the specific requirements for observations based on extensive consultation with the scientific and user communities;

2. evaluate the ability of current and planned observing systems to meet these requirements;

3. transmit recommendations, through its sponsoring organizations, to appropriate national agencies for implementation; and

4. provide oversight for the management of the process.

The GCOS has established a planning structure (GCOS, 1995a) that includes recognized experts from all of the disciplines involved in climate, and fosters close partnerships with both research and operational programmes. It has worked closely with the WWW of WMO, the Global Atmospheric Watch (GAW) of WMO, GOOS and GTOS to avoid duplication and to develop an integrated system of observations. These programmes taken collectively provide an international framework to address the global observing needs related to climate and climate change.

The GCOS plans (GCOS, 1995a, 1995b, 1997) have been built upon existing operational and research activities to the greatest extent possible and recommend new observing components only when absolutely necessary. They specifically address the need to integrate fully both space and surface-based data into the observing system to adhere to guiding principles, which will ensure long-term integrity (GCOS, 1995c).

3.1 National Plans

The responsibility for the actual implementation of the individual components that comprise GCOS lies with national agencies and organizations working within the GCOS framework. Therefore the implementation of GCOS is fundamentally dependent upon the preparation and implementation of national plans. Such national plans containing commitments to undertaking specific aspects of the GCOS agenda, when shared with other nations and the relevant international agencies, would form the basis of an overall plan for the implementation of GCOS. It would then be possible to determine the existence of gaps and/or duplication in activities and to provide regular updated reports to the COP on progress in meeting their requirements.

It is important to note that the climate data identified by GCOS include a range of environmental observations that are collected for many different purposes and potentially can satisfy climate requirements simultaneously. This approach of using specific observations collected for other purposes in a synergistic manner is clearly highly efficient for nations faced with a wide range of financial pressures. However, this synergistic approach is increasingly under threat as both national and international agencies are being forced by budget constraints to focus on their "core" mandates and can only support additional activities if additional financial or human resources can be provided.

Additional resources for climate observations can only be provided if the climate change community, as represented by the Parties, places a value on the data and products tailored to meet its purposes. Not only must it place a value on those data, but it is also reasonable to expect the climate change community to assume responsibility for providing the resources for those activities which are specific to climate change applications, and to adopt a fair share of responsibility for those parts for which there are shared benefits. In summary, Parties should explicitly recognize their shared responsibility for the global observational systems that underpin climate change studies, applications, and assessments in support of the Convention.

Recommendation 1

> *Each Party should undertake programmes of systematic observations including the preparation of specific national plans, based on the overall plans formulated by GCOS and its partner programmes. The national plans should contain commitments to undertake specific implementation actions and be tabled and reviewed at regular intervals at COP sessions.*

3.2 Data and Information Exchange

While the taking of observations lies with specific national agencies, to be useful from a climate change perspective such observations need to be combined into regional and/or global data sets. The creation of such data sets requires that observations be shared with other nations and appropriate international organizations, and ultimately stored in archives for the use of other scientists. (GCOS 1995d). While there is international policy guidance available covering the free and unrestricted exchange and use of meteorological data there is little guidance for much of the remaining climate data included under GCOS (WMO, 1996). As many of the GCOS variables potentially have economic and/or security values associated with them, and as a result of the lack of policy agreement covering their exchange and use, a significant number of the observations currently being taken are not being exchanged and/or archived. Consequently there are large gaps in many of the global data sets for a number of climate variables, including for example precipitation and river flows. Given their prior commitments under the FCCC to cooperate in the field of systematic observations and the development of data archives, the Parties may wish to consider specific mechanisms that would enhance the exchange of climate data for the purposes of the Convention.

Recommendation 2

> *Parties should exchange, with other nations and with appropriate international organizations, those data required to meet climate objectives and the needs of the FCCC. They should take active steps to eliminate any internal barriers to such exchange.*

3.3 Capacity Building

Since the climate and its changing patterns affect all the countries of the world, it is essential that programmes seeking to meet climate needs have global participation. For many of the less-developed countries the simple tasks of information acquisition are beyond their capacity. Unfortunately the potential impacts of climate change in some of these countries are likely to be extensive and potentially severe. Many of the findings and recommendations in this document are addressed to those countries that have the capability to respond. However, for much of the world, the infrastructure is not in place to implement these recommendations. Consequently, programmes to develop capacity must be seen as a corollary to these recommendations.

In some developing (and other) countries, the main motivation for operating an observing system and archiving data may come from an interest in seasonal forecasting and associated monitoring. Thus, the new WMO Climate Information and Prediction System (CLIPS) Project should be used as an important vehicle to maintain and develop observing systems. This exemplifies the ‘multiple use’ philosophy, especially since the technical requirements are similar between seasonal forecasting and secular climate change.

All of the sponsoring organizations of the Climate Agenda and many of the programmes noted in this report have activities in support of capacity building. For this report, it is sufficient to note that all of the observing capabilities require the participation of developed and developing countries alike. The interpretation of these observations in terms of societal impact is intended to be available to all the nations of the world. Participation by some countries may require additional resources that are not readily available through current funding mechanisms underpinning the FCCC. These mechanisms may require adjustments to permit the inclusion of projects designed to improve the systematic collection and exchange of observations.

Recommendation 3

Parties should actively support capacity development to enable countries to collect and utilize observations to meet local and regional needs. The capacity building programmes of appropriate international organizations could assist countries to acquire and use climate information. If necessary, Parties should reconsider the priorities of funding mechanisms which support the FCCC.

4 GOALS AND REQUIREMENTS

4.1 Programme Goals

The complexity of the interactions among the components of the climate system makes it necessary to provide observations that address a number of overlapping goals. Drawing on the experiences of the IPCC in preparing its assessments, the GCOS has established the following goals that the observational programmes must meet to support of specific issues facing the FCCC. These are to:

1. observe and characterize the current climate, including its inherent variability and extreme events;
2. obtain information useful to detect climate change, determine the rate of change and assist in attributing the causes of change;
3. provide observations to determine climate forcing resulting from changing concentrations of greenhouse gases and other anthropogenic causes;
4. provide observations to validate models and assist in prediction of the future climate;
5. contribute observations to understand and quantify impacts of climate change on human activities and natural systems.

These goals are not mutually exclusive -- some observations and products derived from observations will be relevant in addressing several goals. However, it is essential to address all five to provide a sound scientific basis for monitoring and understanding climate, for improving future assessments and for evaluating the efficacy of mitigation policies and adaptation strategies that are of principal concern to the Parties.

4.2 Observational Requirements

It is neither possible nor desirable in this report to fully articulate all aspects of the accuracy, timing and frequency of the climate variables required or of particular instruments and platforms useful for their observation. These specifications are available in various publications of the GCOS[2], its partner observing systems and the climate related research programmes. Rather, using the goals above, the general requirements are reviewed principally in terms of fields to be measured and products to be delivered. The emphasis is placed on the adequacy of observing systems to meet the needs as they are currently understood, and the steps needed to improve the current situation. Clearly this report cannot be the final word on all the necessary changes. As nations change their implementation plans and commitments, the further actions needed to meet the FCCC requirements will need to be updated. As a result, the recommendations focus on the highest priority and most urgent issues as they are known today.

4.2.1 Goal 1: Characterize the current climate

Observe and characterize the current climate, including its variability and extreme events.

This goal is fundamental. Meeting it provides the essential basis for evaluating the Earth's future climate changes. To address it we must first be able to characterize natural variability and describe the significant internal processes of the climate system (e.g., El Niño). Any secular climate change, due to anthropogenic influences is then to be found in the residual signal after the natural variability has been taken into account.

To meet this goal, it is critical to observe variables for solar radiation, the upper atmosphere, surface variables from the land and oceans, and the relevant fluxes and exchanges (e.g., heat, moisture) across the interfaces between atmosphere, ocean, and land. These variables must be measured using techniques that not only determine average conditions but also provide information on rates of change and on extreme events and conditions.

The Atmosphere

For the atmosphere, it is necessary to observe variables from which the atmospheric energy balance components can be derived and these variables include temperature, humidity, winds, and clouds (all measured as a function of height or atmospheric pressure). The derivations are obtained through operational atmospheric models, which produce four-dimensional (4-D) analyses of the fundamental fields. The input data are obtained by an integrated, comprehensive set of measurements provided by complementary surface-based and remote techniques.

Variables from the Surface

The basic set of parameters required at the surface includes temperature, precipitation (including the water equivalent of snow depth), pressure, humidity, winds, sea ice and land surface conditions.

The Open Ocean

The principal variables to be observed include ocean surface conditions (i.e., temperature and salinity), upper-ocean thermal structure and near-surface velocities, and regular, if only occasional characterization of the deep ocean dynamics and properties.

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[2] All publications are available at the GCOS website (www.wmo.ch/web/gcos/gcoshome.html)

4.2.2 Goal 2: Detect climate change

Obtain information to detect climate change, determine the rate of change and assist in attributing the causes of change

In this report "detect" and "attribute" are used in the sense described in IPCC (IPCC,1992?); that is, to "detect" is to identify statistically significant changes in climate against a background of natural variability and to "attribute" is to assign the cause or causes of such changes to a particular source. Typically, this is done by identifying a combination of measurements that represent the "fingerprints" of a particular cause or symptom of climate change. The postulated symptoms may emerge from climate modelling activities or from testing a specific hypothesis. Such testing is most compelling if correspondence is found between patterns of predicted and measured change.

Meeting the needs of this goal builds upon the information identified under goal 1 and requires particular attention to be paid to the quality and comprehensiveness of the data sets and the methods of processing. These requirements are more related to the care and management of the data and of model products rather than specific variables, so that specific hypothesis can be tested efficiently and effectively.

The emphasis on coherent patterns of change means that the requirements are usually not met by a single instrument or variable, but by an integrated network observing many variables and functioning in a prescribed manner. For measurement, the key is to be able to estimate patterns of change (the pattern may spread over variables and space) with errors that can be quantified.

The importance of detection and attribution to the Parties draws greater focus on those elements of goals 1 and 2 that relate directly to diagnosis of a "fingerprint". The vigour of bottom water formation off Greenland or off the Antarctic ice shelf as an indicator of significant changes in the thermohaline circulation, or the coexistence of stratospheric cooling and tropospheric warming, as predicted by increasing CO2, are examples of what is envisaged. This is an area of active research in which interdisciplinary talents are often required.

4.2.3 Goal 3: Forcing by greenhouse gases

Provide observations to determine climate forcing resulting from changing concentrations of greenhouse gases and other anthropogenic causes

Parties are considering the regulation of carbon emission in order to stabilize greenhouse gas concentrations. To support this goal, it is essential to obtain observations useful to assess, as directly as possible, the efficacy of policies designed to modify forcing. Therefore it is essential to observe the concentration and distribution of atmospheric constituents involved in radiative exchange. The important "greenhouse gases" have been identified (IPCC, 1990). Major elements include water vapour, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), ozone, and chlorofluorocarbon (CFC) compounds. Some of these gases are well mixed horizontally so measurements at a few sites are sufficient. Others have relatively short residence times and are not well mixed, so regional observing is necessary. Uncertainty in the distribution of such constituents contributes significantly to uncertainty in their global warming potential.

Required variables include total solar irradiance, upwelling short- and long-wave radiation at the top of the atmosphere, the surface albedo (reflectivity), concentration and distribution of radiatively significant atmospheric constituents, and properties of aerosols that directly and indirectly influence radiative exchange. Spectral data are required for diagnostic purposes. Care is necessary to discern diurnal influences in long-term records in order to characterize properly the longer-term secular changes.

Problems of this type can arise when there are systematic shifts in the local time of day that an observation is taken.

The Carbon Cycle Variables

Of key importance to the FCCC following the Kyoto Protocol for a legally binding emissions reduction framework, are the variables related to terrestrial sources and sinks of carbon. These variables are required for an understanding of the size and location of the carbon reservoirs, the partitioning of carbon between the oceans and land, and the efficacy of various carbon sinks. A comprehensive full carbon budget will be needed to implement a viable terrestrial carbon accounting methodology. This will also be needed to identify and maximize the potential of terrestrial sinks to reduce the impacts of sources. Measurements of carbon reservoirs and fluxes have consequently received attention in the recommendations of the global observing systems (e.g., sequestration on land and flux of CO2 at the ocean surface) (GCOS, 1997).

4.2.4 Goal 4: Validate Models

Provide observations to validate models and assist in predictions of the future climate

Meeting this goal requires that the integrated and processed fields obtained under goals 1 and 3 be used for model forcing, validation and testing, and for the initial conditions in projections of future climates. The dependency of models on approximate representations for certain processes means there is an additional need for data sets to develop and test these representations (e.g., cloud, ocean convection and land feed-back processes). This report does not suggest that the Parties directly address these needs, important as they are, but does invite the Parties to recognize the relevance of such data collection and process studies, and to provide appropriate support to research programmes in order to find better solutions.

Climate reference data (i.e., fields devoid of spurious trends and uncertainties) are particularly valuable for this goal as they provide the “reality test” for models. The GCOS Upper-Air Network (GUAN) and GCOS Surface Network (GSN), for example, are two sources of atmospheric climate reference data. Sea Surface Temperature (SST) and sea level data sets are important oceanic examples.

Prediction of the impacts of land use changes requires the development of consistent records of surface-based observations of CO2, monitoring of vegetation productivity for small test sites coupled with satellite observations linked to biophysical models, and an understanding of future socio-economic factors controlling land cover conversions.

4.2.5 Goal 5: Impacts of climate change

Contribute observations to understand and quantify impacts of climate change on human activities and natural systems

Many of the variables needed for this goal have been identified as important for one or more of the prior goals or for ancillary applications (e.g., El Niño forecasts). Meeting the needs of this goal provides greater focus on hydrological and carbon cycles, surface fields and coastal phenomena.

The variables to be observed to meet this goal are those that provide insight into various impacts, and are suitable for systematic and sustained measurement. It is assumed that other programmes will be contributing observations of non-physical variables, such as the incidence of diseases or deaths, changes in biodiversity, and socio-economics observations for the assessments of climate change impacts.

The following examples are illustrative of the types of GCOS variables that need to be monitored and the types of impact studies that they will support:

- surface temperature and humidity as a contribution to human health assessment;
- surface precipitation, evaporation, water storage and river flow, coupled with population data and land use practices for water resource management purposes;
- surface temperature, precipitation, evaporation and CO2 concentration directly affecting food and fibre production;
- impacts of rainfall, surface temperature and human land-use conversions on fire frequency and distribution;
- air and sub-surface temperatures coupled with sub-surface ice observations relating to the habitability of areas underlain by frozen ground;
- land-use observations relating to the output of agricultural production as well as to FCCC compliance;
- changes in glaciers and ice sheets, especially with reference to impacts on sea-level rise,
- sea-level rise, storm frequency, storm surge frequency, and resulting coastal inundation.

Observing extreme events in order to detect significant changes in their incidence is of great importance but at the same time particularly difficult. By definition the extreme events are rare so that both continuity and coverage of observations are important. With the improvement in coupled models, and an observing system to test both simulations and projections, there is some hope that observing change, in the frequency and intensity of extreme events is feasible.

5 IMPLEMENTING THE GLOBAL CLIMATE OBSERVING SYSTEM

5.1 General Strategy

The preceding chapter noted that most of the observational requirements are reasonably well known. This does not mean that continued research will not identify new variables, or that the requirements should not be revisited from time to time. It does mean that considerable effort has already been expended on the planning process and, as far as possible, feasible specifications have been developed. Any limitations come primarily from a lack of knowledge (which is in turn is directly limited by a lack of observations) and from uncertainties in emphases that are inextricably linked to social and political issues. It also noted that the technologies for making the observations were in the main also known although there are some clear gaps in some areas as will be shown later. In addition, most of the appropriate international mechanisms exist for the coordination of implementation activities.

This chapter addresses the steps necessary for the implementation of a global observing system for climate. It identifies and calls to the attention of the Parties a number of cross-cutting issues that need to be taken into consideration when nations take action on the specific findings on which the recommendations for action are based. These recommendations, if followed up by nations both individually and collectively, will enable the goals of the previous chapter to be realized.

5.1.1 Comprehensive Strategy

In developing their plans, GCOS took into account three specific aspects of the climate system that the scientists have noted (IPCC, 1995; Karl, 1996):

(a) that the climate change signal is fundamentally global;

(b) the climate change signal involves interactions among all components (land, sea, ice and air); and

(c) that priority must be attached to the creation and maintenance of long records.

The implication from (a) is that Parties need to recognize that in most cases their individual contribution is part of a shared responsibility to meet a global requirement for observations. Each gap in the global network adds to the uncertainty of assessments of climate change. Systematic evaluations of the performance of current observing systems reveal that a number of geographical areas are sparsely covered. Addressing this issue may require the Parties to recognize their shared responsibilities, with resources from the developed countries being invested in regions of the world beyond their respective national borders.

The implication from (b) is that the effort on specifying and implementing the global observing systems should be spread as evenly as possible over the important fields and variables. A biased concentration of effort in one area will be ineffective due to relative weaknesses in others. A comprehensive strategy should therefore be adopted to effectively address the three regimes, atmosphere, ocean, and land. This does not mean, however, that efforts should not be taken to ensure that networks are put in place and maintained to serve particular national and regional needs.

The implication from (c) is that a rigorous quality control of observations is needed to provide long and continuous records to focus on "climate change". Special care must be taken to protect and preserve as many of the key records of the past as possible. Many of the older records are already under threat as a consequence of practical problems including the disintegration of paper media especially in high humidity

Finding 1

The importance of global comprehensive data sets for isolating the important signals of climate variability and for minimizing the uncertainty attached to estimates of climate change should be recognized and acknowledged. Observations with a long uninterrupted record should be given special consideration, as should programmes of data rehabilitation and restoration.

5.1.2 Principles for Creating Long-term Records

As noted above one of the fundamental requirements associated with climate change is the need for long-term records. However, useful long-term records result from careful consideration of and adherence to a number of guiding principles.

Data quality, continuity and homogeneity are three fundamental issues to be addressed in the climate observing system. If appropriately taken into consideration they ensure the creation of a quality climate record, which should be useful to detect changes over long periods.

Data quality requires a scientific appreciation of the limitations and attributes of the methods used to collect the data and of the signals that may be embodied in the data. Knowledge of instrument, station, and/or platform history is essential and should be treated with as much care as the data themselves. Calibration, validation and maintenance are also critical to long-term climate monitoring. Experience has shown that quality checks should be implemented as soon as possible after data collection since the amount of information available to guide such checks will be near maximum at that time. This is particularly true for data that are also used for numerical weather prediction, since the processing chain for real-time data generates many statistics that can be used profitably in the climate quality assurance process. Experience has also shown that scientific involvement is important in data quality since many of the climate signals are subtle and can easily be compromised by uninformed practices.

Continuity of observations is critical. Because of the small amplitude of long-term climate signals relative to natural variability, biases introduced either through changed instrument algorithms or altered processing methods are potentially very damaging. Prior to implementing changes to existing systems, or introducing new observing systems, an assessment of the impacts of such changes on long-term climate monitoring should be performed as a standard practice. Processing algorithms and changes in these algorithms also must be well documented.

Homogeneity requires careful attention to actual sampling rates and density. Long-term climate variations are determined by a complex set of interactions and processes acting on a range of space and time scales. The emphasis on "global" observations is a direct consequence since almost all long-term variations have some global-scale aspect. The range of scales and processes implies that we must, to first order, attempt to maintain an even sampling rate and a spatially well-distributed sampling density. We should also endeavour to make the resultant data sets (that is, measures of the key variables) as homogeneous as possible, irrespective of the methods used to collect or process the data. This is particularly critical for detection ("fingerprints") because the methods in use are based on coherent signals. The linking of cause and effect will be compromised by weak links in the data base.

Observing system evaluation is regarded as an essential aspect of the governing principles. Without organized and agreed methods for assessing performance, the observing systems will not achieve their purpose. The value of the data for climate (and to the FCCC) is not assured unless the data streams and observing practices are continuously monitored and checked against the measurement benchmarks.

The performance measures require particular care since there must be a balance drawn between imposing costly and unduly conservative guidelines and those which might comprise the value of the data through less expensive, but less careful, practices. The performance measures should help identify those observation elements/networks that are not performing adequately or are in jeopardy and suggest remedies. These might include addressing the adequacy and availability of expendables (e.g. radiosondes), redesigning algorithms, and developing alternative sampling strategies or new methodologies and products.

Satellite data are playing an increasingly important role in the resolution of climate change issues, in all disciplines, principally because they provide global coverage. There has been some reluctance to use satellite data in the past because of doubts about its quality, particularly with respect to bias, because records are relatively short, and because future availability of data is not guaranteed. The issue of bias remains an outstanding problem and requires special attention, particularly for climate applications.

To implement more effectively the data principles outlined above and to ensure the necessary underpinning of the observational record, the following issues are especially important:

- reducing biases, either from instruments or from samples associated for example with satellite orbit drift;
- ensuring continuity of observations across missions, which requires careful attention to cross-calibration,

checking of algorithms and providing overlaps where possible;

- specifying requirements for complementary data, particularly surface-based samples;
- improving documentation of procedures and corrections, and retaining raw data, so that reanalyses are possible;
- integrating the various data streams, both remote and direct, by the modelling and data assimilation community; and
- improving acquisition strategies for satellite data so that sufficient coverage of data in space and time is achieved.

Finding 2

It is essential to adhere to and promote observing methods and principles that emphasize and value data quality, continuity and homogeneous, long-term records. The need for special care in the handling of satellite data must be recognized.

5.1.3 Composite Global Observing Systems

Understanding climate requires the integration of several different types of observations. These can include satellite observations and *in situ* observations made in the atmosphere, the oceans and at the land surface. Composite global observing systems which consist of a variety of observing systems and techniques are being planned and implemented as effective mechanisms to obtain comprehensive measurements. These systems have the prospect of meeting the needs of many users and of providing cost benefits as a result of economy of scale.

For global issues, specific proposals have so far focussed on the utility of satellite data. Recently an Integrated Global Observation Strategy (IGOS) has been proposed as an activity involving the space agencies through the Committee on Earth Observation Satellites (CEOS), the research community through the International Group of Funding Agencies for Global Change (IGFA), and the sponsoring organizations of the Global Observing Systems (GCOS, GOOS, and GTOS). Its two prime goals are to ensure that there are no gaps in needed temporal and spatial coverage, and no unnecessary overlaps in earth observing systems. This concerted activity is providing much needed co-ordination among the various partners in global observations and its success will clearly have favourable impacts on meeting future needs for climate observations including those of the FCCC.

Finding 3

Composite systems including both satellite and ground-based elements are required to address climate observational requirements. The concept of an Integrated Global Observing Strategy should be supported to facilitate the implementation of long-term observational programmes.

5.1.4 Data Assimilation and Reanalysis

Data assimilation is another tool to assist in creating composite global data sets. The techniques ingest diverse streams of data and provide dynamically consistent products for analysis. Data assimilating models offer major opportunities for enhancing the efficiency of the observing system and for providing a wider and more sophisticated range of products than might otherwise be possible. In effect, data assimilation combines the interpretative and interpolative power of a model with observations of the real world to produce estimates of the pattern and evolution of important fields and the exchanges of some of its constituents that are not directly observable (e.g., heat transfer, the amount of water in the atmosphere and evaporation). These techniques can be seen at their most sophisticated level in numerical weather prediction where data assimilation systems yield regular and accurate estimates of the state of the global atmosphere. However extreme caution must be exercised when the systems are used in true climate models since they have biases, irregularities, or model-dependent errors which, while unimportant for some short-term applications, can create severe problems when used for climate purposes.

Unfortunately these techniques cannot at present be used for other components of the climate system to any significant degree. Ocean data assimilation is an important and growing activity but limitations in the current models, the vastness of the ocean relative to its dominant scales of spatial variability, and lack of knowledge suggests expectations should be conservative. For the land surface processes the situation is still less mature. This caution notwithstanding, the recent reanalysis efforts of several of the leading numerical weather prediction centres have yielded global four-dimensional, multi-parameter estimates with improved temporal consistency and interpretations of data that could not be gained via any other route. Reanalyses offer an important strategy for climate since they enable a consistent application of algorithms and procedures over the period of the data record, thus reducing discontinuities and biases in the analyses (Kalnay et al., 1996).

An additional benefit of models arises from their capability to guide the development and provide oversight of observing systems. Numerical simulations, properly interpreted, provide quantitative measures of the efficacy of observing elements and may be used to ensure that cost-effective observing techniques are employed. They are also useful in detecting systematic biases in particular records.

Finding 4

Data assimilation methods and reanalyses of past climate data using skilled models are important strategic techniques for characterizing and understanding climate variability and change, and in guiding observing system development.

5.1.5 Research Observations.

As noted previously, the plans for GCOS build upon observations from a number of research programmes. While this approach is both necessary and desirable it does present a number of unique challenges. One of the most significant for the Parties is the need to plan for the transition of some of these research programmes to operational systems. By their very design most research programmes have a definite lifetime, ending when the majority of the scientific questions have been answered or the funding runs out. However there may well be a continuing need for the observing activities that were begun under research programme sponsorship. For climate, there is a need to provide mechanisms for transition from the research community to the operational community. This transfer of responsibility requires considerable planning and often the identification of new resources for operational organizations to permit them to assume additional responsibilities. A recent example of such a transition is the Tropical Atmosphere-Ocean (TAO) array. Formerly a research activity under the WCRP, it now receives support from international operational sources. Future opportunities should result from the various maturing WCRP and IGBP projects.

Finding 5

When observing systems developed for climate research programmes have the potential to meet a critical need for long-term monitoring their use for this purpose should be carefully evaluated and when appropriate, plans should be developed to effect a transition from research to operational support.

5.2 Atmospheric Observations

The atmosphere is the principal agent for climate and climate change. The manifestations of weather phenomena, when averaged over time, provide a substantial description of climate. Selected atmospheric variables must be continuously monitored to provide the basic information for analysis of climate. In addition, the composition of the atmosphere controls the critical radiative processes. The presence and distribution of certain gases and particles in the atmosphere must be observed to enable scientific assessments and projections.

5.2.1 Implementation

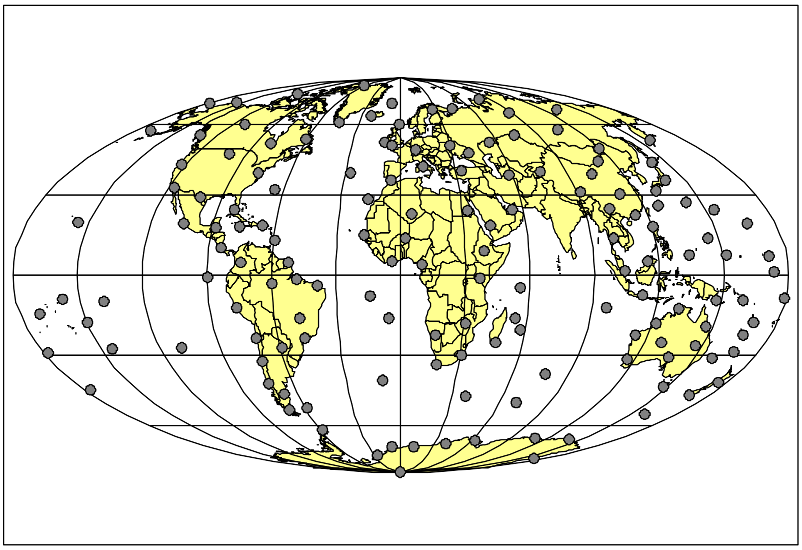
Meeting the requirements for atmospheric observations will be achieved principally through the national meteorological and hydrological services of the various countries. These services coordinate their observing programmes through the WMO and in particular through its World Weather Watch (WWW) for meteorology and Global Atmospheric Watch (GAW) for atmospheric chemistry.

5.2.2 Meteorology

5.2.2.1 The upper-air network

The upper-air sounding network of the WWW provides the fundamental basis for observations of temperature, humidity and winds as a function of height in the upper atmosphere. These stations, provide information mainly over land surface portions of the Earth. However, a computer-based re-analysis of the data produced by this network has shown that: (1) the total number of radiosondes has declined since 1990 due to reductions in stations principally from the former USSR, Africa, and South America; and (2) the fraction of the globe covered by the network has actually decreased. In particular, the Southern Hemisphere accounts for only about 10% of the total radiosonde data, and few tropical stations reliably contribute.

The GCOS Upper Air Network (GUAN), is a 150-member sub-set of the existing WWW network of upper-air stations that was developed to address the requirement for a consistent and homogeneous baseline of measurements for global climate. The GUAN, if fully implemented, would provide a relatively homogeneous network of upper-air stations having reliable prior records. This baseline data, when augmented by other networks or measurements, would be capable of meeting a wide range of climate applications. The proposed GUAN is a sparse network, and is specifically targeted at detecting temperature change and providing a reference for other atmospheric data sets and model calculations. A set of 'best practices' has been defined and GUAN stations are expected to maintain these standards into the foreseeable future.



Proposed GCOS Upper-Air Network (GUAN)

The European Centre for Medium-Range Weather Forecasting (ECMWF) is monitoring the quality and availability of the temperature, humidity and wind data as a function of height from the stations in the network, and provides a six-monthly summary for use in maintaining the integrity and quality of the network. From the performance report for the period from July to December 1997:

- 10 % of the stations provided fewer than 10 reports of the target of about 360;
- 20% of the stations exhibited either unacceptably large random variations or biases in measured parameters.

This is well short of the satisfactory performance required for the GCOS baseline network and indicates that the GUAN has not yet been implemented to the standard required. One major problem is the lack of priority and hence resources accorded to remote and relatively inaccessible sites. Selection of such sites may be minimized but not avoided in the creation of a homogeneous network. While it is feasible to automate many of the tasks at an upper-air station, including the radiosonde launch, the presence of one or two skilled part-time staff at the station is essential.

Satellites provide global coverage and complement the upper-air stations. However, the majority of satellite samples are not independent, the vertical resolution of satellite retrievals is less than required, and errors are larger than those of the radiosondes. The satellite data have also been 'tuned' frequently, so they are not immediately useful for detection of long-term climate signals.

A potentially significant development is the integration of radiosondes and aircraft observations into a composite system. Where available, aircraft observations add valuable information, particularly on water vapour. For that variable, the new aircraft sensors coming on-stream have great potential. However, they cannot be considered as a replacement for an effective radiosonde network. A similar caution may be expressed about satellite observations of water vapour.

Nevertheless, if and when combined effectively in a truly composite global system including radiosonde observations, wind/height data obtained from geostationary satellites, wind and temperature data from aircraft, and data from other experimental systems, the overall accuracy of the system would be broadly satisfactory for climate purposes. The challenge is to implement and maintain such a system for the long-term.

Finding 6

Countries should ensure that national meteorological stations identified as elements of the GCOS Upper-Air Network (GUAN) are fully operational and adhere to best practices. Implementation of the components of a composite network is essential for the future. In order to meet this objective, financial assistance should be made available when necessary for developing countries.

5.2.2.2 Layer mean temperatures

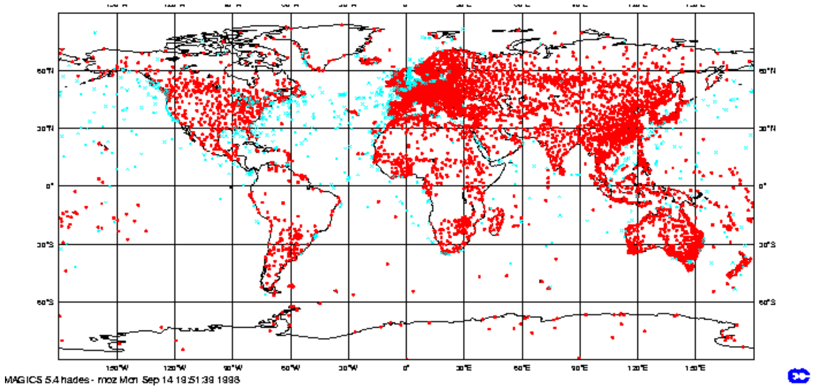
Consistent and unbiased measurement of layer-mean temperatures in the troposphere and stratosphere are required. They provide a means of detecting and quantifying one 'fingerprint' of warming due to increasing concentrations of greenhouse gases (Spencer and Christy, 1993). Satellite-based observations of microwave emissions from atmospheric oxygen provide a possible method for obtaining such data. They have been available from the Microwave Sounding Unit(s) since 1979. Inter-satellite calibration procedures have not been stable over this 20-year period and new instruments are to be introduced soon. For the past record the necessary stability has to be imported from the radiosonde network as described above and from other satellite data sets. In the transition to new instruments it is highly desirable for old and new instruments to be operated in parallel for at least a year to provide continuity of the record. In addition, new satellites should be equipped with station-keeping propulsion to avoid the incorporation of strong diurnal signals into the climate record caused by degradation of satellite orbits.

Finding 7

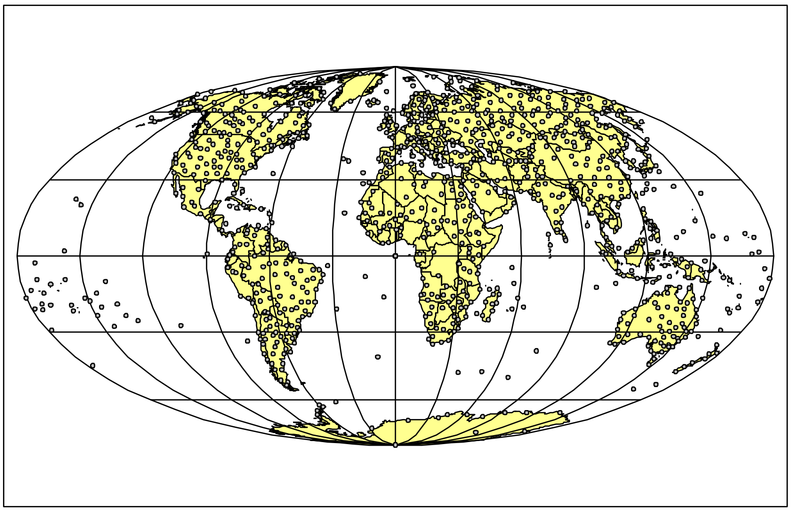
In view of the importance of satellite data time series for global climate monitoring, satellite agencies should be urged to give high priority to long-term data continuity in conformance with climate observing requirements and principles.

5.2.2.3 Land surface meteorological observations

Land surface observations of temperature have been collected and exchanged for many years as part of the WWW and for climate purposes. (see below figure) Data from these networks is clearly not uniform in coverage or in quality. It is proposed to establish a GCOS Surface Network (GSN) for temperature based on a minimum of 1000 land surface stations (Peterson, et al., 1997).Those reliably reporting stations with histories of high quality measurement were selected as the primary candidates for the GSN. In many regions such stations do not exist, so provisional stations have been identified as potential candidates for future inclusion.



Typical Data Coverage of Synop/Ship Observations



Proposed GCOS Surface Network (GSN)

It should be emphasized that this network meets only the minimal requirement for spatial coverage, and that every effort should be made to obtain better coverage in the data sparse regions. It should also be emphasized that the GSN must be supplemented by more densely spaced stations to meet regional or national climate objectives. In this case, the GSN provides global baseline coverage.

Nations operating the stations in the GSN have been invited to provide a full climate record and the past history of the operations of stations (Metadata). Two countries have further offered to provide a repository for the observations and to report on the current and future performance of the stations. The resulting information will be archived at the World Data Centres. These latter centers should hold as complete a historical record of the GSN station data as possible, and strive to obtain older data in digitized form to ensure that the full benefit of the long records is extracted. It should be noted that preliminary monitoring of the performance of the GSN by the Government of Germany has shown that, for the first six months of 1998, fewer than 50% of the GSN stations were reporting their observations and that less than 30% of those stations included all the required parameters.

Finding 8

Countries should ensure that the stations identified as elements of the GCOS Surface Network (GSN) are fully operational and adhere to best practices. Implementation of the GSN is essential for global issues but, in most cases, additional stations will be needed to address regional/national issues. Financial assistance should be made available to developing countries where required.

5.2.2.4 Clouds

Clouds are important elements in the characterization of weather and climate, and play a particularly significant role in atmospheric radiation and in the water cycle. Measurements are currently made using both surface-based and satellite systems. The WCRP includes an International Satellite Cloud Climatology Project based on satellite imagery. The project and its products would benefit from the integration of surface-based observations into the activity. For the future, continuation of cloud observations should be supported.

5.2.2.5 Precipitation

As precipitation is one of the most important climate variables affecting life and natural resources, the observations of it in both liquid and frozen forms is critical. Current practices of measurement include rain (and snow) gauges, radars and recently research satellite instruments, which are proving invaluable in the provision of data over the oceans in tropical areas. These measurements should continue but, additionally, the information gathered must be more effectively shared and integrated to derive analyzed fields and products for national and international users. The WCRP Global Precipitation Climatology Centre (GPCC) is assimilating information provided by participating countries. However, GPCC requires the submission of data from more countries to produce improved global products.

Finding 9

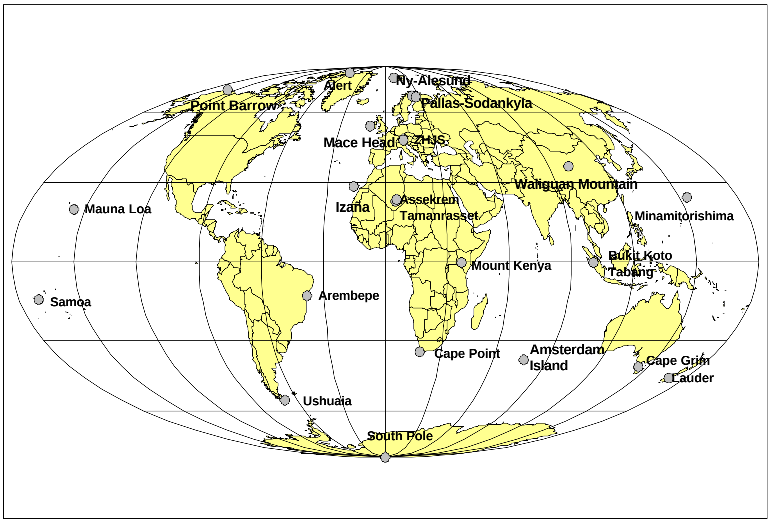
Nations should continue to improve their observing systems for clouds and precipitation. Countries should ensure their ground-based and satellite information is provided for global and regional syntheses.

5.2.3 Atmospheric Composition and Chemistry

5.2.3.1 Atmospheric Composition

The Global Atmosphere Watch (GAW) is an international programme of the World Meteorological Organization to collect, distribute, and archive quality-controlled observations of atmospheric constituents. The global network of about 20 stations samples a number of important greenhouse gases including ozone at the surface, which if fully implemented could provide an essential contribution to GCOS. Current plans should focus on increasing the number of operational programmes at these stations and addressing need for atmospheric aerosol observations.

In cooperation with the GAW, research programmes have developed limited-duration projects to obtain additional information on atmospheric chemistry using aircraft and satellite instrumentation, as well as ground-based sampling. As these programmes mature, recommendations concerning monitoring strategies should become available. Such recommendations would then provide justification for specific monitoring activities of the global observing systems in cooperation with the national agencies responsible.



Global Atmosphere Watch (GAW)

5.2.3.2 Greenhouse Gases

A number of atmospheric constituents have been identified as 'greenhouse gases'. Some have long residence times and are relatively well-mixed in the atmosphere (e.g., carbon dioxide, methane). Several have spatially and temporally variable distributions (e.g., water vapour, CFC's, ozone). For these latter constituents, a comprehensive observing programme must include three-dimensional sampling using surface, aircraft and satellite techniques. Measurement programmes in the lower atmosphere are still in the research domain, although a number of satellite instruments have been proposed to provide information on vertical and horizontal distribution. To date, the only instruments with temporal records of any length are those providing total column ozone.

5.2.3.3 Ozone

Ozone, in addition to being an important 'greenhouse gas', is a strong absorber at ultraviolet wavelengths and intercepts harmful solar ultraviolet radiation in the stratosphere. Stratospheric ozone reduction has been addressed in the Montreal Protocol, which mandated limits on the use of CFC's. For climate, tropospheric ozone is also significant, but is not adequately measured at this time. Profiling instruments are available, but are used only infrequently at a few sites. The GAW stations conduct ozone measurements but the geographic coverage and vertical profiling capability of the network needs to be expanded.

5.2.3.4 Aerosol Measurements

The second assessment of IPCC (IPCC, 1996) cites the important role of atmospheric aerosols in producing regional variations in climate. A few current global climate models have aerosols included, but model developers have had to rely on very tentative observed fields due to the lack of a consistent observing strategy for aerosols. Some useful satellite data may be obtained from the infrared imagers but such data are incidental to the main missions. Several future instruments may provide information more closely meeting the requirements.

The GAW aims to observe the direct and indirect effects of aerosols on climate for but useful interpretation requires the results of process studies and the development of radiative transfer models which are not yet available (WMO, 1996). Since it is certain that surface-based measurements will be essential to complement the satellite measurements and aid their interpretation, an observing programme for these purposes needs to be formulated. In the meantime, an aerosol climatology has been developed from satellite data and an initial global network of around 60 sites has been supported.

Finding 10

Support is needed for GAW to expand its global network, to increase observations in the upper-atmosphere, and to incorporate atmospheric aerosol measurements.

The preceding findings specific to atmospheric observations have been consolidated into a recommendation for action by the Parties to the Convention.

Recommendation 4

Countries should support national meteorological observing systems and particularly ensure that the stations identified as elements of the GCOS networks based on the WWW and GAW are fully operational and that best practices are maintained. Support should be provided to assist countries as needed. The number of stations in the observing networks for atmospheric constituents including ozone, and aerosols when formulated, should be increased. Satellite missions to observe and quantify atmospheric constituents should continue.

5.3 Oceanic Observations

The ocean is a key component of the climate system in that it has a (relatively) large heat capacity and climate “memory”, and it therefore controls the rate of climate change. As an integrator of climate variability, the ocean suppresses and weakens high-frequency variations and "amplifies" (in terms of signal-to-noise ratio) slow variability and climate change signals. An overall scientific assessment of and plan for the systematic observations needed for climate from the ocean were provided by the Ocean Observations System Development Panel (OOSDP, 1995; Nowlin, et al., 1996). Ideally the global observing system for climate change would have the largest concentration of measurements in the ocean to take advantage of these attributes. In reality logistics and their associated costs have prevented wide-spread sampling of the ocean, particularly the deep ocean. Consequently there are very few ocean data sets which could be classed as “climate reference” data sets to provide the basic information on climate change, let alone to develop the analysis and model assimilation tools in the manner done for the atmosphere.

The importance of the global ocean aspects should be re-emphasized. The high latitude oceans are extremely important in the context of climate change. In these regions lie the roots of the deep circulation and consequent sequestration of heat. It is these aspects that are believed to have given rise to dramatic and non-linear changes in climate in the past and could do so again in the future.

5.3.1 Implementation

The importance of continuity, quality and integrity of climate data sets, among other things, underscores the importance of having mechanisms in place that can meet requirements effectively and efficiently, over the long-term. The WWW has performed this role for meteorology and is endeavouring to perform the equivalent role for many of the atmospheric aspects of climate. Such an arrangement has the advantage of using a single mechanism to meet multiple needs, thus drawing greater benefit per unit of resource.

Oceanography and, in particular, ocean climate has some mechanisms and structures available for implementation, but does not have an organization or body that can meet the total needs in an integrated, efficient manner. Groups concerned with this aspect have recommended that the IOC and WMO jointly create a single implementation structure, constructed from the existing elements, whose mission would be explicitly aligned with the provision of ocean climate observations. If established, the body would support the implementation of observations to meet the GCOS and GOOS oceanic requirements for climate.

Finding 11

Support should be provided for the creation of a joint body for oceanography and marine meteorology, as proposed by the IOC and WMO, to implement and maintain the ocean observing system.

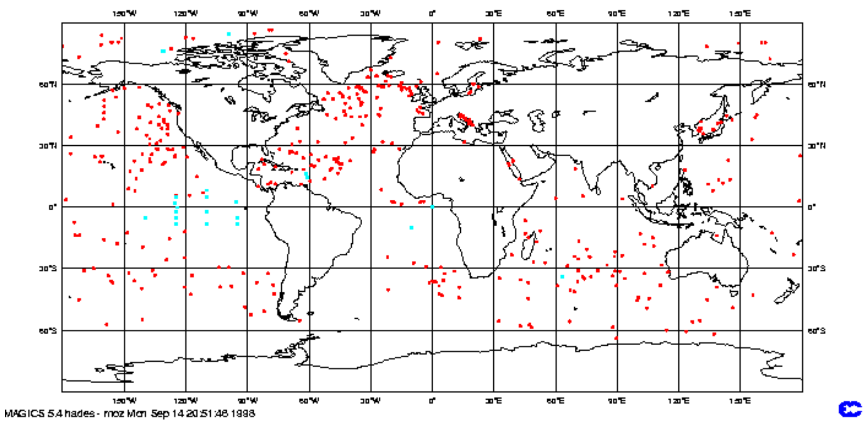
5.3.2 Ocean Surface Observations

5.3.2.1 Surface and Marine Observations

The requirements specifically highlighted Sea Surface Temperature (SST), mean surface pressure, sea ice extent and high quality (reference) sites for validation of air-sea exchanges. Presently these data are supplied by:

- global satellite measurements of SST inferred from the Advanced Very High Resolution Radiometer (AVHRR), with additional estimates available from the Along Track Scanning Radiometer (ATSR) and from some geostationary satellites;
- moored and drifting buoy networks (e.g., the TAO array) measuring, among other things, SST, air temperature, surface wind and mean sea level pressure; and
- a Volunteer Observing Ship (VOS) fleet of merchant vessels measuring SST, surface air pressure, a range of marine parameters and, whenever possible, surface salinity.

For SST, the satellite data offer global coverage at a resolution that is more than adequate for climate purposes. However the data can be affected by anomalous atmospheric aerosol loading and other atmospheric interference, so regular calibration with surface-based data is required. Moreover, because of subtle changes in instrumentation and processing, great care must be taken before such data are used for climate change. The recommended strategy is to blend accurate, high-quality global surface-based data at relatively coarse resolution with less accurate satellite data; the former giving the trend and the latter giving the spatial pattern (Reynolds,1988).



Typical Data Coverage of Buoy Observations

Recently, the number of VOS has declined by about 10% per decade (WMO, 1997). There are problems maintaining stability in the record due to the voluntary nature of the operation and the shipping routes plied by the fleet do not provide homogeneous or complete coverage. The main problem facing the use of moorings and drifters is the lack of long-term commitment to the continuing supply of the platforms and the lack of global coverage. Technological improvements have rendered the system more cost-efficient but the other problems require concerted efforts.

Finding 12

Nations and responsible agencies should support a range of measures to improve the quality, continuity and long-term stability of the surface marine observation networks relevant to climate.

Significant improvements over the last 15 years have led to buoys capable of providing data that enable a number of critical climate processes at the air-sea interface to be described and quantified with satisfactory accuracy. The sensors perform reliably for 6 to 9 months with data both telemetered and recorded on board. Implementing moored buoy programmes at selected locations would provide high-quality accurate reference data to check, verify, and/or calibrate surface meteorological fields, and air-sea transfer processes (e.g. heat transfer and evaporation) from models, remote sensing, and other measurements.

Finding 13

Responsible national agencies should support the establishment of oceanic climate reference sites to obtain data for calibrating models and satellites.

Remote sensing is the recommended approach for measuring sea-ice extent. While the methods are mature, there is a lack of coordination with respect to methods and data handling. Enhanced observing systems are needed, particularly in the Southern Hemisphere. Sea-ice thickness (volume) remains a key variable but, at present, can only be measured by surface-based systems.

Finding 14

Noting the importance of measurements from the ice-covered regions of the ocean and, consistent with the emphasis on global homogeneity, national agencies should endeavour to maintain the Arctic programme and implement an enhanced programme for the Antarctic. For ice extent it is recommended that better documentation of the data stream be provided.

5.3.2.2 Sea level observations

The Global Sea Level Observing System (GLOSS), under the auspices of the IOC, is based on a network of long-term sea level observing sites. To meet the global and temporal requirements, sea level observations for climate require a dual strategy. The preferred observing approach comprises:

- precision satellite altimetry for global sampling, at approximately 10 day intervals;
- approximately 30 sea level gauges for removing temporal drift;
- additional gauges at the margins of the altimeter (e.g., continental coasts and high latitudes); and
- a programme of geodetic positioning.

An alternative observing system, proposed due to the lack of guaranteed availability of satellite altimetry data and the lack of experience and confidence in the application of altimetry to measuring long-term trends, comprises:

- a globally distributed network of sea level measurements as detailed in the GLOSS Implementation Plan (IOC, 1997), with emphasis on sites with continuous, high-quality long-term records; and

- a programme of geodetic positioning.

Finding 15

Increased national participation is required to implement GLOSS plans for measuring sea level change and to ensure long-term continuity of the surface network. In addition, satellite altimetry for climate change and programmes for geodetic positioning should be supported.

5.3.3 Ocean Subsurface Observations

Perhaps the single most important weakness in the ocean observing system for climate is the lack of an oceanic counterpart to routine and regular atmospheric analyses. Such products would serve many purposes -- climate change being one of the more important. In order to meet this requirement a significant enhancement to the surface-based observing system, complemented by high-quality and accurate altimetric data, is required. The present system is based mainly on the ship-of-opportunity expendable bathythermograph program. It provides about 50,000 temperature profiles covering 0-750 meters of depth, but they are unevenly distributed because of the reliance on volunteer merchant vessels and various moored arrays, the most notable being the TAO array straddling the equator in the Pacific. These systems provide a basis for meeting the requirements but are severely limited in terms of global coverage, the lack of salinity measurements, and limitations in profile depth.

Finding 16

Support is required for the programme to enhance the observing system for the global oceans, which emphasizes need for sampling to greater depth (1500 - 2000 meters) in data sparse regions. Both temperature and salinity profiles are needed.

A prospectus for a major enhancement to ocean observing systems has been produced based on "vertical profiling float technology". It seems likely that such an enhancement with global coverage at around 250 - 300 km resolution , and profiling on about a fortnightly cycle with high-precision temperature and salinity measurements, can be implemented at reasonable cost. Continuous satellite altimetry coverage should be provided to support this programme.

The fundamental importance of high quality, deep ocean measurements was noted earlier. Considering the legacy of climate observations from past measurement programmes, it is recommended that the requirement for deep ocean measurements be addressed through a regular top-to-bottom trans-ocean measurement programme, with a full suite of hydrographic and tracer measurements, and the maintenance and enhancement of the network of time-series stations. As part of the carbon inventory, it is desirable to be able to model carbon coming out of the upper ocean, using remotely sensed ocean colour, SST, and time-series of CO2 concentrations, nitrate, fluorescence and physical variables at key sites. Both modelling and research are required.

For the estimates of the variability of meridional heat and fresh water fluxes, measurements are required at key latitudes with station spacing that resolves mesoscale variability, (25 - 100 km, resolution) with a repeat time to be determined based on the experience of the World Ocean Circulation Experiment (WOCE). To track the formation water masses with specific characteristics, measurements to resolve interannual variability are required at a station spacing adequate to sample each region.

Finding 17

A programme of deep, trans-ocean sections, at locations and frequencies to be determined, is needed to monitor heat, freshwater and carbon circulation in the ocean.

Time series stations provide long records with temporal resolution that is short compared with the characteristic scale of the dominant variability. They often yield measurements of important chemical and biological variables. These attributes make such data sets powerful for climate change studies.

Finding 18

The implementation and maintenance of time-series stations to provide high-quality, climate records and to calibrate and validate ocean carbon-cycle models and satellite ocean colour instruments are required.

5.3.4 Carbon Exchange at the Ocean Surface

Measurements of key elements of the oceanic carbon cycle are important. The technology for routine unattended observations of CO2 exchanged through the air-sea interface has now been developed and is ready for operational use on unmanned buoys and Volunteer Observing Ships. Similarly, the value of satellite ocean colour data is greatly enhanced with time series of carbon exchange, fluorescence and nitrate to enable characterization of the seasonal cycles. Hydrographic sections with tracers such as carbon isotope ratios, CFCs and methane are needed at regular intervals (i.e., 5 - 10 years) (see subsurface ocean measurements).

Finding 19

Observations are required of the exchange of carbon across the air-sea interface. Available techniques include underway sampling and fixed buoys. Research is needed to better characterize the process of carbon uptake.

The preceding findings specific to oceanic observations have been incorporated into a recommendation for action by the Parties to the Convention.

Recommendation 5

Countries should actively support national oceanic observing systems and particularly ensure that the elements of the GCOS and GOOS networks in support of ocean climate observations are implemented to the degree possible. Support should be provided to increase the number of surface observations, particularly in remote locations, and to establish and maintain reference stations and repeat sections. Current satellite missions to observe sea surface elevation, wind stress, and temperatures should be continued.

5.4 Terrestrial Observations

Recent research indicates the critical role of land cover and land cover changes for the functioning of the Earth system in general and the biosphere and the climate system in particular (Walker et al., 1997). Many complex interactions and feedbacks in and between these systems are apparent. This role becomes clearly obvious when assessing recent changes in the carbon, the hydrological and the nitrogen cycles (Vitousek et al., 1997). Unfortunately the current observation systems do not allow an adequate description and evaluation of changes in the terrestrial environment. Reliable information on land-use and land-cover change is essential, for example, to quantify the recent impacts of climate change on vegetation (Myneni et al., 1997). The linkages between land use, land cover and moisture availability are also well established. Therefore, both vegetation characteristics and hydrological variables are critical. Several of the latter relate directly to the viability of water supplies, while others, such as glaciers, are potent indicators of climate change; some variables, such as snow cover, are important forcing functions. Being able to quantify and understand changes in all these terrestrial properties allows one to make more educated projections of plausible future changes. Gaps in data availability and quality have been identified in the recent climate assessments of IPCC (IPCC, 1996a, 1996b, 1996c), the biodiversity assessment (Heywood & Watson, 1995) and UNEP's Global Environmental Outlook (UNEP, 1997).

5.4.1 Implementation of Terrestrial Observing Systems

Plans for long-term consistent observation of terrestrial variables including terrestrial ecosystems, hydrology (including the cryosphere) have been proposed through GCOS and GTOS (GCOS, 1997). The large heterogeneity and diversity of terrestrial data, however, is a major constraint in defining adequate global terrestrial networks. This has led to inefficient organizational structures at the international level, and consequently frameworks for making terrestrial observations are very much weaker than those developed for atmospheric observations by WMO, or even for oceanographic observations. The Implemention of more appropriate networks and the strengthening existing ones would lead to a significant improvement in the collection of terrestrial observations.

Finding 20

Current international implementation mechanisms for terrestrial observations should be reviewed by the relevant international bodies. Changes necessary to ensure the maintenance and improvement of climate-related terrestrial observations should be enacted.

5.4.2 Land Use and Land Cover Change

Adequate observation of land-cover conversion and modification has been problematic until recently. Many assessments have relied on (sub-)national administrative land-use statistics, which are difficult to associate with spatially explicit data derived from satellite imagery. It has further been shown that the spatial methods, such as those used by FAO, which rely on the sampling of small percentages of Landsat-class imagery create unreliable estimates of land cover change (Sanchez-Azofeifa, 1997). Efforts are needed to develop more reliable comprehensive statistics of global land cover and land cover change. The starting point for these statistics should be the IGBP 1km resolution global mapping initiative (DISCOVER) and other high resolution monitoring by Landsat-class instruments of key regions as proposed for example by the Global Observations of Forest Cover (GOFC) initiative. This effort will require the support of the scientific community and the cooperation of space agencies in ensuring the long-term supply of fine resolution data comparable to that available from Landsat-class instruments. Efforts must be initiated to integrate these high resolution observations with socio-economic data on land use and land cover data.

Finding 21

Support should be provided for the implementation of more reliable procedures of land use and land cover change. Space agencies should be encouraged to ensure the acquisition and exchange of appropriate fine and medium resolution data on a regular basis.

5.4.3 Terrestrial Primary Productivity

Land-use change and the burning of fossil fuels add about 7 Gigatons of carbon per year (GtC/yr) to the atmosphere. Oceans and the terrestrial biosphere sequester respectively 2.0 and 1.5 GtC/yr, while the remainder increases the atmospheric concentration (about 3 ppmv per year). The current net terrestrial carbon sink thus accounts for about one fifth of the global net carbon exchange. Unfortunately, the precise location(s) and dynamics of this terrestrial sink are still largely unknown. Apart from reliable monitoring of land use change, especially with regard to forestry, more reliable estimates of carbon assimilation by terrestrial vegetation and soils are needed. Estimates of primary productivity as a result of photosynthesis and assimilation (photosynthesis minus respiration) require a combination of surface-based observations and satellite remote sensing data coupled with ecosystem and biospheric models. Reliable location and quantification of terrestrial sinks and sources will require a commitment to the GAW global flask sample network. Precise calibrated isotopic analysis requiring centralized and standardized facilities is essential. The emerging network of land-based CO_2 flux towers is crucial for the validation of satellite and model-based estimates of productivity. The quality of satellite data for this purpose requires careful calibration and the maintenance of constant overpass times. As mentioned earlier this can be achieved through appropriate implementation, operation and calibration of polar-orbiting satellite systems.

Finding 22

The GAW global flask sample network and centralized calibrated isotopic analysis should be supported as well as the plans for the long-term CO2 flux tower network. Space agencies should acquire and exchange well-calibrated satellite data, based on consistent over-pass times for monitoring terrestrial primary productivity.

5.4.4 Fires

Globally, fires are an important source of aerosols and greenhouse gases, a sensitive indicator of the disturbances associated with the adaptation of vegetation to a changing climate, and an increasingly important hazard in both developing and developed countries. The occurrence of fires is strongly linked with variability in the climate system (e.g., El Niño) and regional decreases in moisture availability under climatic change. There is currently no integrated global observing system for fires which combines satellite data sources with surface-based observations, although several research projects have demonstrated its technical feasibility. This variable has strong links to land use and land cover observations -- fire is an important agent of land cover change and emissions from fires depend on the type of land cover burned. The rapidity of change due to fires compared with other land cover conversions requires separate consideration of its observation. Satellites scheduled for launch will be capable of providing adequate remotely sensed data. What is needed is a long-term commitment to the acquisition of the required satellite observations, a data handling and processing effort to supply the needed fire products and the linkages to the appropriate *in situ* observations.

Finding 23

An operational integrated global observation system capable of providing timely information on fires and their impacts, based on current and planned satellite systems, should be established.

5.4.5 The Hydrological Network

5.4.5.1 Runoff, soil moisture and groundwater storage

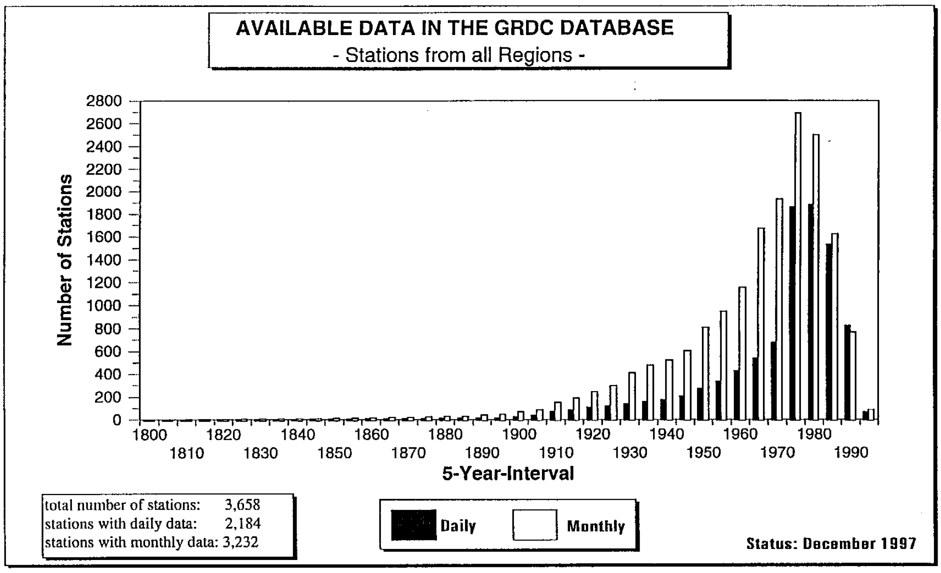
Existing mechanisms for the assembly of water resource information at the spatial and temporal scales required for global assessments are either weak or nonexistent. For some observations, international institutional mechanisms are in place. For example, the Global Runoff Data Centre (GRDC) collects and compiles data sets on river runoff observations. These data sets are however incomplete. Having initially supplied observations, many nations have now ceased supplying the GRDC with the required data, while others have never supplied data. Global coverage is therefore limited and reduces the value of GRDC data sets for many comprehensive assessments.

The WMO Commission for Hydrology is presently drafting a plan to monitor the flow of about 195 major rivers which would cover about 95% of all run-off, accurate to around 4%. The key element to the success of the plan is to improve and enhance international data exchange.

In some parts of the world there are major gaps in observations, even on major rivers, which is largely a result of the decline of observations during the last few decades. This deterioration is being partially addressed by the WMO Hydrology and Water Resources programme through the World Hydrological Cycle Observing System (WHYCOS), with funding from the World Bank. Currently the initiative is addressing a number of critical areas of the world including Africa and South and Central America. Plans to extend the programme to other regions will be developed.

Runoff data are only a proximate indicator for many hydrological processes. For environmental assessments and scientific purposes there is a crucial need to obtain comprehensive data on water availability and quality. These are required to address irrigation potential in order to define food security, and to assess human health and sanitation standards and levels. Any observation system that adequately supplies data to address such issues needs to emphasize many more components of the hydrological cycle. In addition to runoff data, soil moisture observations become important. Under many circumstances remote sensing data are inadequate and hence the most liberal policies of data exchange are needed with regard to surface-based observations.

In addition in those areas where human development is heavily dependent on ground water resources which are already under great pressure, there is a need for selected data to understand and anticipate the quantitative and qualitative changes resulting from climate change.



GRDC Data flow, Dramatic drop in last ten years

Finding 24

It is urgent to address the inadequacies of the hydrological network and in particular the timely exchange of data for the discharge of major rivers and other hydrological variables.

5.4.5.2 Glaciers and Ice Sheets

Glaciers are sensitive indicators of climate change. Observed glacier fluctuations contribute important information connected with the detection of natural and man-induced climate change. Included are secular rates of change in energy exchanges at the earth/atmosphere interface, pre-industrial variability in these exchanges, possible acceleration trends of ongoing and potential future changes and spatial patterns of observed changes as related to regional patterns of computer-simulated climate change. Many data have been collected through the auspices of the World Glacier Monitoring Service (WGMS). However there is no inventory for over half of the world's glaciers and no high-resolution global map of land ice areas. Many mass balance survey programmes have been discontinued, while in some regions there have been few observations of any kind. Remote-sensing at various scales (satellite imagery, aerophotogrammetry) and Geographical Information System (GIS) technologies must be combined with digital terrain information in a fusion and downscaling approach to overcome the problems of earlier satellite-derived preliminary inventories (resulting in area determination only) and to reduce costs and time of compilation. For quantifying retreat and mass loss, glaciers with characteristics optimal for deriving "climate signals" must be selected, i.e. relatively clean glaciers with adequate response times (decades), clearly defined geometry and stable dynamics. With accelerated warming, larger glaciers would continue downwasting rather than retreating. Repeated mapping or profiling with a combination of laser altimetry and kinematic Global Positioning System (GPS) positioning is needed, especially with regard to meltwater production and sea level rise. The infrequency of Landsat coverage in cloudy regions has meant that images are not available for all areas. In some cases extensive survey records, maps and air photographs are at risk of becoming inaccessible and are at risk of loss.

Ice sheets in the Antarctic and Greenland contain most of the non-ocean water on Earth. Since they both are above sea level, melting contributes to sea level rise. Monitoring the state of both ice sheets is essential. Surface based, and satellite based observations are needed.

Finding 25

Glacier and ice sheet mass balance surveys should continue using surface, aerial, and satellite techniques. Geographically representative glaciers should be added to the plans for the future. Countries with data should consider preserving their records in accessible formats and media and contributing them to archives for future use.

5.4.5.3 Permafrost

Perennially frozen ground or permafrost underlies about 25 percent of the Earth's land surface. It is widespread in northern North America, northern Eurasia, north-east China, the Tibetan Plateau and in high mountain regions. Frozen ground has major consequences for cold region hydrology and is important in the surface energy balance. Up to now, it has been largely neglected by climate modellers due to limited knowledge of its characteristics and poor understanding of appropriate processes. Global warming will have major consequences in areas of frozen ground. Warming of such areas leads to thawing of the frozen ground, particularly where there is a high ice content, this in turn causes ground settlement or subsidence, creep on gentle slopes and landslides on steep slopes. These effects often produce severe damage to buildings, transportation routes, pipelines and other structures unless specialized engineering techniques are used. Extensive amounts of data from thermal wells and other surveys are in existence but are often proprietary or in poorly accessible government archives. Many oil and gas exploration company archives are not open and in addition are at risk due to economic circumstances.

A partial inventory of frozen ground data is maintained by the International Permafrost Association (IPA) and the World Data Centre (WDC-A) for Glaciology. Selected information and data on the Circumpolar Active Layer Permafrost System (CAPS) has been made available. This archive needs to be completed through digitizing and assembling existing records from North America and Asia. It will be important to seek partnerships with industry to ensure data will be made available for climate studies when confidentiality is no longer essential. These and related data should be digitized and archived in accessible form.

Finding 26

The collection of permafrost observations should continue. Existing data should be rescued and made widely accessible to further the understanding of the impacts of climate change and to allow assessments of the socio-economic impacts of these changes.

The preceding findings specific to terrestrial observations have been incorporated into a recommendation for action by the Parties to the Convention.

Recommendation 6

Countries should actively support national terrestrial networks and in particular the various observational programmes to collect, exchange and preserve terrestrial variables according to GCOS and GTOS climate priorities. Specific support is required to secure and distribute relevant hydrosphere and cryosphere observations. Ecosystem networks addressing climate impact should be coordinated to provide global and regional databases. There is a particular need to encourage the transition from research to operational status of many of the terrestrial networks. Strong encouragement and financial support, if appropriate, should be given to developing countries to enable them to collect observations in support of warning systems in connection with extreme events exacerbated by climate change, vulnerability and impacts studies, and national and regional sustainable development efforts.

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