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- PROTECTION OF THE ATMOSPHERE -

ADDRESSING THE UNCERTAINTIES:

IMPROVING THE SCIENTIFIC BASIS FOR DECISION-MAKING

BACKGROUND PAPER NO. 5

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Protection of the Atmosphere

(Chapter 9 of Agenda 21)

Background report

Addressing the uncertainties: Improving the scientific basis for decision-making *

Contents

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I. Greenhouse gases

A. Progress on the development and use of climate models to determine scenarios or projections of future climate change

1. The concern about climate change resulting from human activities is supported most strongly by results from mathematical climate models. They are essential for furthering our understanding of how the climate system works, for detecting climate change, and for identifying possible 'fingerprints' of climate change resulting from an enhanced greenhouse effect, and other human or natural influences. In particular, they are also essential for predicting the climate changes to be expected as a result of different scenarios of future emissions of greenhouse gases and other factors that could alter the balance between incoming solar radiation and heat radiated back out into space. Significant progress in their development and use has been made over the past decade, and the prospects for continuing progress are a useful pointer to where the scientific research challenges and priorities lie in the immediate future.

2. Climate models have developed over the last 25 years or so into what are now being termed Earth System Models. During that time, models of the main components, atmosphere, land, ocean and sea-ice, have been developed separately and gradually integrated. This coupling of the various components is a difficult process. The atmosphere is the most developed component of such models, but plenty of challenges remain even in that domain. There is now considerable experience and success in dealing also with many land, ocean and ice processes. The current and near-future challenges and aims relate to interactive carbon cycle and atmospheric chemistry modelling. The ultimate aim is to model as much as possible of the whole of the earth's climate system so that all the components can interact and thus the predictions of climate change will continuously take into account the effect of feedbacks. The process of building climate models is therefore a wide-ranging, multidisciplinary and interdisciplinary challenge.

3. The whole business of climate predictions abounds with uncertainties. In particular, large uncertainties in how emissions will grow in the future will be reflected in uncertainties in climate change predictions. In this context, in 1999 the IPCC developed four emissions scenarios based on different story lines for the future. These scenarios had carbon dioxide emissions ranging from about 6 gigatons of carbon (GtC) per year in 2100 (similar to today's value) to about 29 GtC per year in 2100. Such emissions scenarios are being modeled in both simple and more complicated climate models. The spread of the resulting climate responses (including global temperature rise) is further amplified by other uncertainties in the process, not least of which are the uncertainties in other natural and human-induced climate factors (e.g. sulphur emissions), and the uncertainty surrounding the climate sensitivity of the models themselves.

4. Recent projections of greenhouse gases and sulphur dioxide suggest that in the absence of global climate policies, their atmospheric concentrations will increase substantially. The emissions of sulphur dioxide will increase initially for a decade or two, and will then decrease significantly because of concerns over acid deposition. Under this scenario: global mean surface temperatures are projected to increase by about 1-5C between now and 2100, with land areas

warming more than the oceans. While precipitation is projected to increase globally, many of the arid and semi-arid areas of the Earth are projected to become drier. Sea level is projected to increase by between 10-90 cm by 2100. Such a projected climate change could affect water resources, managed and unmanaged ecological systems, human health and human settlements.

B. Status of systems for measuring the build-up of greenhouse gases in the atmosphere

5. The main objective of GAW is to gather information on the chemical composition and related physical characteristics of the atmosphere and their changes over time. As noted above, such information is required to improve understanding of the behaviour of the atmosphere and its interactions with the other domains of the earth system. The information is also essential for understanding processes associated with the long-range transport of specific substances in the atmosphere and the deposition of harmful substances over terrestrial, freshwater and marine ecosystems, and for determining the natural cycling of chemical elements through the global earth system, including the human-induced effects.

6. GAW consists of a number of components designed to provide accessible, high quality atmospheric information at both global and regional levels for a variety of user communities. These components comprise - (a) measuring stations, (b) calibration and data quality assurance centres, (c) data centres and (d) oversight structures.

7. With respect to the measuring stations, there are currently 22 global stations including the recent addition of six new stations, all in developing countries. These global stations are located at clean air sites around the world and their programmes are focused on monitoring long-term changes in the composition of the atmosphere, particularly important for determining ozone and greenhouse gas concentrations and trends. In addition to these global sites, over 300 measuring stations have been designated as GAW regional stations. These measuring programmes at these stations concern issues such as the formation of surface ozone with its health impacts, acid precipitation, transport of pollution from distant areas, and the building of a database of aerosol information. Both global and regional stations are owned and operated by countries and their National Meteorological Services or other national scientific organizations, which have been brought together by the WMO under the GAW umbrella. More than 80 countries actively participate in GAW.

8. To ensure high quality data, GAW has established Quality Assurance/Science Activity Centres in Germany and Switzerland for Europe and Africa, Japan for Asia and the Pacific, and the USA for the Americas. There are also several instrument calibration centres in different countries for carbon dioxide, total surface and vertical ozone, precipitation chemistry, aerosol chemistry, solar radiation and a number of other parameters.

9. To collect, process, analyze and distribute the resulting GAW data, six World Data Centres have been established by the WMO: for ozone and ultraviolet radiation (Toronto, Canada), other greenhouse gases (Tokyo, Japan), precipitation chemistry (Albany, USA), surface ozone (Kjeller, Norway), solar radiation (St. Petersburg, Russian Federation), and for aerosols (Ispra, Italy). The GAW data are regularly published and available directly from these Centres to all organizations, scientific institutions and individuals.

II. Protection of the ozone layer

A. Description and implementation of global ozone measuring system to determine the surface and total column ozone around the world (WMO)

10. Following its establishment in 1957 the WMO Global Ozone Observing System (presently operated under the WMO-GAW Programme) network has grown from relative few observing sites to more than 150 today. These stations are located in more than 65 countries around the world. The measurement network consists of a variety of ground based instruments supplemented by balloon-borne instruments at 40 sites distributed around the world. Taken together this suite of instruments is capable of measuring the amount of ozone at the Earth's surface, the total content of ozone in the vertical column of the atmosphere, and the vertical distribution of ozone from the ground up to well into the stratosphere. With respect to the ground-based network, there are three principal types of instruments in use:

- The **Dobson Spectrophotometer**, which has a history of high quality total ozone observations stretching back 70 years. The current the WMO-GAW network includes about 70 stations with many concentrated in the middle latitudes of the Northern Hemisphere (e.g. 33 in Europe). The efforts under the WMO-GAW programme and the importance of maintaining the consistent long-term data set derived from this network have allowed it to survive basically intact.

- The **Brewer Spectrometer** is a high quality instrument that measures ozone and several other atmospheric constituents. Its high performance has led to its deployment at about 40 sites. As with the Dobson instrument, many are concentrated in the same latitude belt with 20 stations operating in the USA. The Brewer stations also form part of the GAW network.

- **Filter Instruments** have had a complex history due to problems with filter instability, which hampers their ability to make long-term measurements. A network of 40 instruments, mostly in the Russian Federation report data to the World Ozone and Ultraviolet Data Centre. The US Department of Energy is providing international assistance aimed at providing more stable filters is currently ongoing.

11. With tropospheric ozone being important for both tropospheric chemistry and climate change, it is regrettable that only a minority of Dobson and Brewer stations regularly undertake observations of the vertical profile of ozone concentrations. The WMO-GAW is continuing its efforts to redress this shortcoming. GAW also uses every opportunity to enhance ozone observations in data sparse regions such as the tropics and Southern Hemisphere. Using funding from the Global Environment Facility (GEF), ozone-monitoring sites have been established in Algeria, Argentina, Brazil, China, Indonesia and Kenya.

B. Spaceborne ozone measuring systems (WMO in association with space agencies, NASA, ESA, NASDA)

12. During the past two decades the ground-based ozone network has been complemented by satellite measurements, adding considerably to our understanding of upper stratospheric ozone distribution. The principal satellite systems currently operational are:

- **The Stratosphere Aerosol and Gas Experiment (SAGE)** series of instruments determines the concentrations of ozone, water vapour, nitrogen dioxide and aerosol extinction in the stratosphere. It can provide excellent accuracy/precision and vertical resolution.

- **The Total Ozone Mapping Spectrometer (TOMS)** series of instruments make measurements of the total column ozone amount (covering both troposphere and stratosphere). They typically obtain full daily coverage of the sunlit Earth.

- **The Solar Backscatter Ultraviolet (SBUV)** series of instruments measures both total ozone amounts and its vertical distribution although its resolution is low with respect to vertical profiling.

- **The Global Ozone Monitoring Experiment (GOME)** instrument measures total column ozone amounts and vertical profiles of ozone together with total column amounts of a number of relevant trace species. Vertical resolution is low but it is capable of observing vertical profiles in the upper troposphere and lower stratosphere, which SBUV instruments cannot do.

- **The Tiros-N Operational Vertical Sounder (TOVS)** series of instruments, although primarily designed to measure meteorological data but are capable of ozone information, particularly from the lower stratosphere.

13. The coordination, management and operation of the GAW network and satellite-based systems over a period of more than 40 years have required major efforts by a large number of scientists and national institutions. These efforts have enabled the maintenance of a continuous flow of high quality ozone data and information.

III. Transboundary air pollution

A. Radioactive releases

14. The ETEX experiment (European Tracer Experiment), jointly sponsored by the European Commission, the WMO and the International Atomic Energy Agency (IEAE), has been carried out in recent years as a follow-up to joint activities carried out on the validation of long range atmospheric dispersion models using Chernobyl fall out information. In ETEX many characteristics of a real accident situation were simulated:

- A cloud of traceable but inert gas was released, with participants in the exercise being informed of the exact time, location, release characteristics and other local data only after it occurred.
- As soon as possible thereafter, each participant reported a forecast of the plume evolution for 60 hours over the width of Europe to a central point utilising the available meteorological information. The participants updated their forecasts, as new meteorological information became available to them over the 60 hours period.
- The forecasts of surface concentrations were subsequently compared with measured concentrations at 168 stations across Europe.
- The exercise was repeated approximately one month later using a different tracer of the same family.

IV. Urban Air Pollution

15. The Sustainable Cities Programme (SCP) of HABITAT/UNEP and WHO seeks to address the urban air quality issue. In a number of cities participating in the SCP, air pollution has been identified as a priority environmental issue of concern. In this context, the objective of the SCP is to improve the city's air quality management by better managing the city's environment and development interactions. To guide cities, and especially working groups, in this process, the SCP has engaged in the following activities:

(a) *Urban Air Quality Management Handbook with Toolkit*

The development of the urban air quality management **Handbook** with **toolkit**, is an activity now in its final stages, and is designed to facilitate the following:

(i) setting priorities among all air pollution problems
(ii) selecting different response options to address air pollution
(iii) monitoring the effectiveness of the response options

The tools will provide cities with procedures, software and technical know-how that can improve managing urban air pollution problems within the framework of the urban Environmental Planning and Management Process (EPM)

The **Handbook** describes the general principle and procedures in gathering information on urban air pollution problems, formulating strategies and implementing those strategies. It provides guidelines for involving stakeholders setting priorities, evaluating different response options and monitoring implementation.

The **toolkit**, which is a complementary annex of the **Handbook**, further provides cities with information and techniques, clearly described in a simple, less technical format, while supporting the information contained in each section of the **Handbook**.

(b) *The International Conference on Urban Air Quality Management and Transportation Planning Issues*

This conference was held in June 2000 in Salt Lake City, USA. It gave everyone involved in addressing the issue of urban air pollution an opportunity to share experiences and lessons learned with other international development practitioners and decision-makers from the United States of America and other OECD countries as well as developing countries.

The Forum aimed to:

(i) promote an active exchange of experiences and ideas among the principal stakeholders dealing with urban air quality, mobile sources and urban transportation planning issues;

(ii) support the development of a network of urban environmental stakeholders that promotes individual participation in exchange and access to data and information; and

(iii) promote stronger linkages among the transportation planning, environmental management and transport technology communities in developed and developing countries.

It focused on three themes: (i) mobile sources and transportation technology options and their impact on urban air quality, (ii) health effects of urban air quality, (iii) integrated air quality planning and management. Toolkits were also introduced during the Forum.

General Findings:

While the Forum did not come up with specific conclusions, several crosscutting themes consistently came up during the four-day meeting. These included:

- The over-arching value of stakeholder involvement. Anyone developing an air quality management plan must ensure the active participation of all the concerned and affected actors in the entire process.
- The critical importance of addressing the institutional issues. More often than not, it is the institutional issues that spell the difference between a successful plan and an unsuccessful one.
- The primary of information. Information is the basis for any planning. Its availability, reliability, the need for sharing of information among various government agencies and among government, the private sector and civil society and the proper use of whatever limited information is available are issues which must be considered in preparing a city's air quality management plan.
- The crucial role of public information, education and communication (IEC). One cannot hope to mobilize others if they do not fully understand what the issues are. Efforts must be exerted to raise public awareness as well as the awareness of the decision-makers.
- Political will is critical to actually making things happen. The support of the political leaders from both the national and local (city) level is absolutely essential for any improvement in the air quality.
- Technology available for air quality management ranges, from very simple low-tech ones to those that are highly technical and complex. If properly used and applied, technology can

have a very big impact on improving the air quality of a given city. The key however, is to chose the technology that is appropriate for the local conditions.

16. A lot of networking on urban air quality management has been catalysed by the Forum. This networking must be continued. Government agencies and internal support programmes need to carry this forward through similar future forums.

17. With the upcoming publication and wide dissemination of the SCOP-AQM Handbook with toolkit, and with support of international programmes, more cities, both within and outside the SCP programme will have access to a practical approach with which to proceed in addressing their different air quality issues as may be specific to each individual cities. The SCP also intends to refine and update the Handbook into a source book through continuous exchange of experience, as well as to introduce a volume on international support programme and experts on urban air quality management.

18. Awareness building and campaigns must continue to influence all concerned stakeholders including city and national governments, with a view to better air quality management.

V. Climate change and climate variability

19. While there are differences between climate models in how they respond to a given emission scenario, studies indicate in general that temperature increases will be greatest at high northern latitudes. This result is due to the melting of sea-ice, which would allow more solar radiation to be absorbed and thus amplify the warming in this region. The warming is also greater over land areas than over the oceans, due to the slow thermal response of the latter. Model projections also show extensive areas where rainfall will become greater, and others where the opposite is predicted; the geographical locations of these features are, however, very uncertain. Indeed, some modelled regional responses indicate significant differences in the changes of temperature, rainfall, soil moisture, etc, with and without the effects of sulphate aerosols. Understanding and resolving these differences are currently high research priorities. Most models suggest that globally averaged precipitation will increases with time as global warming influences the hydrological cycle. Changes would be greatest in high latitudes and in the Indian monsoon, and least in the sub-tropics.

20. Much of the important impacts of climate change are likely to be felt regionally and come largely through local changes in extreme conditions: storms, floods, heat waves, droughts, etc. A key issue then is how climate change will affect individual regions of the globe. There are indications of increases in extremes in some areas, but the significance of the statistics is very difficult to confirm. There is also some evidence that the spatial and temporal patterns of precipitation are changing in the following ways: (1) observed increases in precipitation in mid- and high-latitudes and decreases in the sub-tropics, (2) an increase in heavy precipitation events and a decrease in light precipitation events. Many parts of the world have suffered major heat waves, floods and droughts during the last few years leading to significant economic losses and loss of life. While individual events cannot be linked directly to human-induced climate change, the frequency and magnitude of these types of events would be expected to increase in a warmer

world. In terms of climate-modelling applications, Over the next 5-10 years there will be a major effort in climate-modelling applications to provide more-detailed estimates of regional climate changes, and changes in extreme weather.

21. The development of knowledge about climate change and climate variability has been based on observations of the climate system covering more than a century coupled with knowledge inferred from information gleaned from various branches of geophysics and the biological sciences. Observations and data management methods along and detailed understanding of the climate system have improved over the past 50 years to the point where it is possible to make predictions on increasingly long time-scales and generate plausible scenarios of future climate.

22. There are several reasons why the earth's climate could change. First are the slow variations in the orbit of the Earth, which affect the amount and seasonal distribution of solar energy reaching the Earth. Second is the 'internal' variability in the Earth's climate system, due especially to interactions on a wide range of time scales between the ocean and the atmosphere. Third are the 'external' climate forcing by natural causes, including changes in the output of the sun and the amount of volcanic dust in the upper atmosphere. Last are the changes in the composition of the atmosphere due to human activities. Before we can claim to have detected a human influence on the recent climate we must first assess and rule out the likelihood that observed changes could be due entirely to the natural variability of the climate system or to changes in natural forcing both internal and external.

23. A good example of the difficulty of dealing with natural, as opposed to human-induced, climate variability are the recent El Niño/La Niña events. Although the 1997-98 El Niño was one of the strongest on record, there have been other almost equally strong ones, even back in the 1870s. It is difficult to say yet with any confidence that there has been a clear change in recent decades in the strength or the frequency of El Niño events. Notwithstanding the continuing scientific discussion on possible recent changes in the nature of El Niño/La Niña events, there is consensus that issues related to climate variability are inseparable from the issues of climate change, whether or not such change is due to human influences. El Niño/La Niña events are part of the systematic recurrence of patterns of extreme weather events. Such long-lasting climate anomalies have enormous societal impacts, especially in developing countries. A concerted effort is required on the part of Governments and non-governmental organisations to develop appropriate policies to mitigate, where feasible, and adapt to climate extremes as a basis for sustainable development.

24. Recent research, especially on the oceans, has also indicated patterns of longer-term climate variability, which may also hold out the prospect of predictability on decadal or even longer time-scales. In particular, sea surface temperature changes in the tropics have displayed decadal trends and strong relationships with long-term rain and drought cycles as well as tropical storm frequency. Also, ocean circulations involving high latitude sinking and distributed upwelling and mixing at lower latitudes are strongly involved in longer time-scales of climate variability. These effects may be crucial in the context of the potential for rapid climate change, especially under the increasing influence of human activity. Key scientific objectives of the Climate Variability and Predictability (CLIVAR) study under the World Climate Research

Programme, include a description and understanding of decadal to centennial climate variability and assessments of the potential predictability of climate for a decade or more ahead. Meaningful decadal forecasts would assist industry in planning for appropriate transitions within the context of a changing climate. They could also pre-empt criticism of policies based on long term global warming in the event of a particular series of years contradicting the longer term trend.

25. The strongest evidence for long-term predictability comes largely from the influence of persistent sea surface temperature patterns on the atmospheric circulation that, in turn, induces seasonal climate phenomena. The most well known of these are related to the El Niño and the southern oscillation (collectively called ENSO) coupled ocean-atmosphere phenomenon in the tropical Pacific Ocean. A key factor in this regard has been the success of the Tropical Ocean and Global Atmosphere (TOGA) programme of the World Climate Research Programme. Amongst its successes the TOGA programme provided an improved physical understanding of the climate system, an improved ability to measure the upper ocean, and the development of increasingly realistic coupled ocean-atmosphere models. Some of these models have already demonstrated skill in predicting tropical sea surface temperatures months to a year or so in advance. In particular, the predictability of El Niño (at least on some occasions) has been demonstrated.

26. Sea surface temperature patterns, which tend to persist for several months or longer, can have a strong influence on seasonal atmospheric features, especially in the tropics. Motivated by this realisation, experimental techniques using global-scale patterns of historical sea surface temperatures have been used with some success since the mid-1980s to make experimental forecasts of seasonal rainfall in selected tropical regions; in particular, for parts of Brazil, Australia and Africa. More recently, research and development in this field have also turned to extratropical seasonal-to-interannual predictability and prediction, and the prospects for an operational global-scale capability based on the use of global climate models. To this end, one of the overall research priorities for the World Climate Research Programme over the next decade is to assess the nature and predictability of seasonal to interdecadal variations of the climate system at global and regional scales. This challenge is being addressed through the major study of Climate Variability and Predictability (CLIVAR), which focuses on the role of the coupled ocean and atmosphere within the overall climate system, with emphasis on variability, especially within the oceans, on seasonal to centennial time-scales. Practical targets over the next 5-10 years include improvement and extension of the capability for skilful seasonal-to-interannual forecasts and the assessment of potential predictability of climate over the decade ahead.

VI. Role of systematic observations

27. The Global Climate Observing System (GCOS) was established in 1992 to facilitate the required improvements and the current status and recent developments related to the three domain-specific observing systems that comprise GCOS are summarized below.

A. Atmospheric Observations

28. The principal global networks for atmospheric observations related to climate are the GCOS Surface Network (GSN), the GCOS Upper Air Network (GUAN), and the Global Atmosphere Watch (GAW). GSN and GUAN are part of the WMO's World Weather Watch and provide data on meteorological parameters, including temperature, pressure, precipitation, wind velocity, and humidity. Both networks were designed on subsets of stations from the available meteorological networks. The aim is to provide an acceptable density in coverage worldwide, while at the same time maintaining the high quality in performance necessary for climate observations. In certain parts of the world, however, high quality stations providing consistent observations either do not yet exist or are difficult to sustain. Some stations selected for the networks currently do not report or are sporadic in the frequency and quality of the transmitted data. It remains an important challenge to find ways to upgrade stations to desired specifications and to sustain the required observing programmes on a long-term basis.

29. There are several reasons why gaps and deficiencies occur in the networks, but problems can usually be traced to lack of funds, especially in developing countries, to buy modern equipment, to carry out day-to-day operations and to provide adequate training. Problems not directly related to funding (e.g., reports that are not communicated according to established formatting and coding standards) are likely to be overcome as feedback from network monitoring is provided to the stations concerned. Performance monitoring for both the GCOS Surface and Upper Air Networks is now fully operational. The Deutscher Wetterdienst and Japan Meteorological Agency monitor the GSN while the European Centre for Medium-Range Weather Forecasts monitors the GUAN. Data for both networks are archived at the World Data Centre A (WDC A) in the United States.

B. Oceanographic Observations

30. Ocean observing networks, like atmospheric and terrestrial observing networks, are critical to understanding climate change and climate variability. Both space-based and *in situ* networks measure sea surface temperature, winds, waves, salinity, sea level, sea ice properties, surface and sub-surface currents, and other observations. In general, ocean observing networks are not as developed as atmospheric networks, and large and significant network gaps exist across vast expanses of ocean space, especially in the Southern Hemisphere. Nevertheless, important progress in developing ocean observing networks has been made in the last several years, and the Global Ocean Observing System (GOOS) is steadily developing into an ocean analogue of the World Weather Watch. The GOOS climate module is the ocean component of GCOS; hence, the two observing systems collaborate closely on improving ocean observations for climate.

31. Some recent developments and challenges were discussed at the First International Conference for the Ocean Observing System for Climate, held in San Rafael, France in October 1999. Some of the most important Conference conclusions are noted below.

32. Measurements of sea surface temperatures are made from satellites, voluntary observing ships (VOS), and drifting surface buoys. These need to be both continued and strengthened, with

increased focus given to the quality and accuracy of the long-term record and, for high-resolution products, to improved integration of the available remotely sensed data. Coverage by VOS and drifting surface buoys remains poor in some areas.

33. The El Niño/Southern Oscillation (ENSO) Observing System was set up in the Pacific to understand, monitor, and predict ENSO variations. It consists of a network of VOS lines, drifting and moored buoys, and island and coastal sea level stations. The detailed configuration of the network will likely change as knowledge and models improve; however, maintenance of the network is of high priority.

34. Recent advances in technology have made possible important advances in surface-based observing capabilities. One consequence has been the launching of a major new international initiative, the Argo programme. This program will introduce a global array of some 3000 sophisticated ocean buoys to undertake large-scale sampling of temperature and salinity from the surface of the ocean to a depth of 2000 meters. The program will be implemented over the next five years.

35. Our understanding of ocean dynamics and capacity to predict ocean and climate variations and monitor climate change has been greatly improved by the availability of precise measurements of ocean topography from space. Further progress can be made by supplementing remotely sensed data with a network of surface-based measurements to calibrate satellites and to produce accurate global determinations of sea level change.

36. The Automatic Shipboard Aerological Programme (ASAP) uses balloon-borne radiosondes launched from ships to measure vital upper air data from remote ocean areas in support of GCOS. One or more new observing programs, to be established using ships traversing remote areas of the Southern Hemisphere, will greatly help fill gaps in this region.

C. Terrestrial Observations

37. Terrestrial observations for climate encompass measurements of the terrestrial properties and attributes that control the physical, biological, and chemical processes affecting climate; are affected by climate change or climate variability; serve as indicators of climate change; or relate to impacts of climate change. Numerous types of observations fall into these categories, and the need for improved terrestrial observations for most parameters is great. For the most part, global-scale terrestrial networks have not been developed to the same extent as atmospheric networks, and the necessary links to create global networks have not yet been forged across countries and regions. GCOS collaborates with the Global Terrestrial Observing System (GTOS) in addressing terrestrial climate-related observations. Important recent advances have occurred in global permafrost, glacier, terrestrial carbon, and hydrology networks.

38. The Global Terrestrial Network for Permafrost, established in 1999, is not yet fully developed. In certain countries where permafrost occurs, lack of resources for implementation and continuing operations is a problem. The permafrost layer is one of the most sensitive indicators of climate change. The network is designed to provide the data needed to determine changes in the conditions of the permafrost layer globally and will be used in assessing the

impacts of climate change. Monitoring of permafrost is also important because warming and thawing of perennially frozen ground could release substantial amounts of new carbon from subpolar peatlands, with potentially large positive feedbacks to climate change.

39. Systematic observations of glacier fluctuations, like permafrost observations, provide a sensitive indicator of climate change. The World Glacier Monitoring Service (WGMS) in Switzerland has collected observations of glaciers, which have been made in some parts of the world for over 100 years. The WGMS now manages the recently created Global Terrestrial Network for Glaciers. Measurements are made of the mass balance of glaciers, as well as of volume, area, and length. Currently, the distribution of observations, particularly of mass balance, is less than ideal. Glaciers in some parts of the world are under-observed, while those in the Alps and Scandinavia are over-represented.

40. The measurement of carbon fixed in vegetation and soil has become increasingly important given the needs of the UNFCCC for data on terrestrial carbon sources and sinks in the global carbon cycle. A Global Carbon Theme is currently being developed by the Integrated Global Observing System (IGOS) Partners to address these needs. This effort will benefit by the participation of the International Geosphere Biosphere Program, as well as from the extensive related work on carbon sequestration being carried out by the Intergovernmental Panel on Climate Change. Also, the Global Observations of Forest Cover network (GOFC) is expanding. Observations will provide timely and consistent information about forests worldwide and, in the future, about all types of land cover using an appropriate combination of space-based and near-earth data.

41. National hydrological services and a variety of regional and international networks measure such important hydrological variables as surface water discharge, surface and ground water storage fluxes, precipitation, evapotranspiration, snow water content, and water use. However, at present, an integrated global network of stations collecting hydrological data for climate-related purposes does not exist. An important step in creating such a network was taken in June 2000, when formal discussions were launched to establish a Global Hydrological Network for Climate Monitoring, to be implemented jointly by GCOS, GTOS, and the WMO's Hydrology and Water Resources department.