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ON THE EXPLORATION AND PEACEFUL USES OF OUTER SPACE

THE EARTH AND ITS ENVIRONMENT IN SPACE

Background paper 1

The full list of the background papers:

1. Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
7. Commercial aspects of space exploration including spin-off benefits
8. Information systems for research and applications
9. Small satellite missions
10. Education and training in space science and technology
11. Economic and societal benefits
12. Promotion of international cooperation

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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development;

Other objectives of UNISPACE III will be as follow:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industry planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

In the preparation of this background paper, contributions from the following organizations have been used: Centre national d'études spatiales, France; Department of Physics, Obafemi Awolowo University, Nigeria; European Space Agency, Paris Headquarters; Indian Space Research Organization, India; Institute of Theoretical Astrophysics, University of Oslo, Norway; National Institute of Aeronautics and Space, Indonesia; National Aeronautics and Space Administration, United States of America; National Space Development Agency of Japan; Solar Physics Subcommission of COSPAR; and the World Meteorological Organization.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France and Cambridge University, United Kingdom of Great Britain and Northern Ireland) as technical editor of background papers 1-10 is gratefully acknowledged.

SUMMARY

The present background paper, entitled “The Earth and its environment in space”, reviews the status of scientific knowledge of the Earth and its environment, including the influence of solar activity on the magnetosphere, ionosphere and upper, middle and lower atmosphere, climate change, ozone depletion and atmospheric pollution by natural and anthropogenic factors. The state of international cooperation in the environmental sciences at the global, regional and local levels, as well as the participation of developing countries, is discussed.

In the next century, the planet Earth faces the potential hazard of rapid environmental changes, including global warming, rising mean sea level, deforestation, desertification and land degradation, ozone depletion, acid rain and a reduction in biodiversity. Such changes will have a profound impact on all countries, yet many important scientific questions remain unanswered. Scientific research shows that the Earth has changed over time and continues to change. Human activity has altered the condition of the Earth by reconfiguring the landscape, by changing the composition of the global atmosphere and by stressing the biosphere in countless ways. There are strong indications that natural change is being accelerated by human intervention. In its quest for improved quality of life, humanity has become a force for change on the planet, building upon, reshaping and modifying nature, often in unintended and unpredictable ways.

There are, however, many uncertainties in climate models, among which are the lack of understanding of clouds and aerosol effects on climate and the role of oceans in global climate change. Thus, observing these parameters from space, as well as the monitoring of greenhouse gases are most important. The depletion of stratospheric ozone is now evident all over the world except in the tropics, with the Antarctic ozone hole as its most conspicuous manifestation. Satellite observations have demonstrated their usefulness in monitoring ozone globally and in observing the global distribution of stratospheric trace species involved in ozone chemistry. However, measurements of ozone altitude profiles should be improved in terms of accuracy, frequency and horizontal resolution.

The variation of solar irradiance is partially responsible for climate change, and the variation of solar ultraviolet irradiance affects photochemical reactions in the upper atmosphere. In order to determine the solar influence on Earth, it is essential to monitor total and spectral solar irradiance, coronal mass ejections and other attributes of solar activity fluctuations, solar wind and energetic particles, and the structure and dynamics of the lower, middle and upper atmosphere. In order to understand the global behaviour of solar-terrestrial interactions, the magnetosphere, ionosphere and upper atmosphere should be viewed as a complex system.

The observational requirements arising from the need to understand more fully the Earth system and to provide services based on that increased understanding are wide-ranging and involve many different measuring techniques and associated data-processing systems. Satellites located in a variety of orbits provide critical and unique global observational platforms from which to monitor the Earth system comprehensively. Data obtained from space are voluminous, and special efforts need to be made to establish an international system in order to appropriately process, archive and freely disseminate them.

Instruments aboard satellites provide the unique ability to make observations and monitor processes on a global basis. Indeed, they provide the only means by which several critical parameters can be studied. They also provide the information necessary to model the Earth system and to make forecasts of short-term and long-term changes of social and economic importance. However, comprehensive ground-based observing systems are also necessary to complement space-based observational systems. In order to harmonize all international efforts in the field of environmental monitoring, it is necessary to establish an integrated global observation and monitoring system.

Moreover, there is a substantive need to build an infrastructure in developing countries so that they can apply the analysis of current and future observations, the results of research and the results of model output (including predictions) towards better management of resources and as a basis for policy decisions regarding the environment as well as socio-economic activity. Some of the knowledge can be directly used for decreasing the impact of natural

hazards, e.g. to monitor and mitigate large-scale wild fires, floods or droughts. Over a longer time scale, this knowledge will lead to more reliable weather and climate predictions. Only by systematically monitoring synoptic data and by making research observations can scientists further their knowledge of the global environment and its variations, so that humankind can better adapt to natural changes and minimize those induced by technology.

It has become abundantly clear that improved scientific understanding, observations and research are required to provide the basis for informal and formal policy decisions regarding environmental issues that lead to a host of resource management, social, health and economic development consequences. These issues are equally important at national, intergovernmental or international levels. No single country or region can undertake the cost or responsibility for the implementation of observational, research and development programmes and projects; associated global services to adequately address the needs of sustainable development are needed.

I. SOLAR-TERRESTRIAL RELATIONS

A. Total solar irradiance and variations of its ultraviolet component

1. The Sun is the primary driver and energy source for atmospheric and ocean circulation systems and the climate at the Earth's surface. At the surface of the Earth, the combination of available solar energy, water and soil nutrients determines to a large extent the plant and animal life possible at any one location (see section III). Solar electromagnetic radiation varies much less at visible and infrared wavelengths than at short (ultra-violet (UV) and X-ray) and radio wavelengths.

2. UV irradiance is a major energy source for the Earth's atmosphere, and small fluctuations in atmospheric parameters (e.g. small changes in total ozone amount) can produce dramatic differences in the solar radiation reaching the Earth's surface. Increasing UV irradiance is known to cause increases in the occurrence of skin cancer and also can affect micro-biological systems by damaging or altering their genetic structure. Measuring small changes in solar UV irradiance will improve the understanding of corresponding changes in the photochemistry, dynamics and energy balance of the middle atmosphere. Variations in short wavelength (UV and X-ray) solar spectral irradiance are much larger than the variations in total solar irradiance. They affect the temperature and chemistry (e.g. ozone, nitric oxide) in the middle and upper atmosphere. Changes in thermospheric circulation alter the electrodynamic structure of the upper atmosphere and, through dynamo action, magnetosphere-ionosphere coupling processes.

3. Cosmogenic isotope records show a 200-year cycle of solar activity and total solar luminosity. There is a possible correlation between shorter time scales of 10 to 30 years, and long-term periodic tendencies towards droughts in some regions of the world. Sunspot cycle length and global average temperature anomalies at the Earth's surface show a high correlation (0.95) over the past 100 years. At present, there is considerable discussion about the reasons for such a high correlation with solar activity fluctuations which, according to satellite observations, appear to be linked with only small changes in total solar irradiation. Probably the greatest correlation between sunspot activity and the Earth's climate occurred between 1640 and 1720, when solar activity in the form of sunspots declined and temperatures in northern Europe fell by about one degree Celsius (C), the period is sometimes called the "Little Ice Age".

4. The only means to measure total solar irradiance outside the Earth's atmosphere is to use instruments on satellites. Such instruments have been available only since 1978, a time interval that is too short for a serious study of the Sun's long-term behaviour. However, there is evidence that long-term variations could be large and as yet undetected by direct satellite measurements. Of recent scientific interest is the fact that the luminosity of the Sun appears to have changed between the minima of solar cycles 21 and 22 by an amount that could, if maintained, produce a 0.5 to 1.0 per cent luminosity change on the cosmogenic time scale required to drive climate events such

as the Little Ice Age. Satellite data show that total solar irradiance reached a low point in 1986, near the minimum of the 11-year solar cycle, climbed to a peak in about 1991, and then declined to another low in 1996.

5. Important scientific issues and objectives include:

(a) Continuing observations and long-term monitoring of solar spectral irradiance;

(b) Modelling solar activity and its fluctuations;

(c) Assessing the interaction between fluctuations in solar radiation and the Earth's climate;

(d) Quantifying through observations and models solar influences on both short-term (weather to seasonal and inter-annual time scales) and long-term (10 to 30 year or decadal) climate variability and change.

B. Earth's magnetosphere, ionosphere and upper atmosphere

6. The response of the global environment to the constantly changing Sun is currently known as "space weather". The impact of solar disturbances on the Earth, however, had been recognized long ago. The solar origin of geomagnetic storms, rapid and irregular fluctuations of the geomagnetic field, which are more intense in the polar regions, and aurorae, which are excited by the entry into the atmosphere of charged particles, were identified even before the space age. It was only during the space age that such phenomena and their disruptive effects on electrical and telecommunications systems came to be better understood.

7. The Sun and its atmosphere are always changing, in a sense having "weather" of their own. The Sun undergoes long-term (10 years or more) "climate-like" variations such as the roughly 11-year solar cycle. This cycle first showed itself in the number of sunspots (dark concentrations of intense magnetic fields emerging from below the Sun's surface) counted on the solar surface as observed by a telescope on the ground. The numbers of sunspots appearing on the solar surface were soon observed to vary with time in an approximately 11-year cycle. This regular increase and decrease in the level of solar activity is called the solar cycle.

8. Although sunspots themselves produce only minor effects on solar emissions, the magnetic activity that accompanies them can produce dramatic changes in ultraviolet and soft X-ray emission levels. Recent space observations have revealed that complexes of sunspots called active regions are the main source of long-lived solar features with enhanced ultraviolet and X-ray emissions. Solar gas, confined by strong active-region magnetic fields into loop-like structures, is heated to temperatures of several million degrees. During times of maximum solar activity, the average level of solar ultraviolet emission can increase to several times the quiet Sun level, while the X-ray intensity shows even greater enhancements. Since active regions usually last longer than the 27-day solar rotation period, the radiation which they emit also vary periodically on this time scale.

9. The Sun appears completely different in an X-ray than in the sky. X-rays are emitted by very hot gases in the outer solar atmosphere, the corona, where the temperature reaches a few million degrees; the much cooler surface of the Sun, at 6,000 degrees, is not hot enough to emit X-rays. As a result, an X-ray image reveals a bright glow for the corona and a black disk for the surface of the Sun. In the corona, the shape and character of the hot gases are controlled by magnetic fields, just as beads move along the string on which they are threaded. As the solar activity cycle progresses from maximum to minimum, the Sun's magnetic field changes from a complex structure to a simpler configuration. Since the Sun's hot gases are controlled by the magnetic field, X-ray images reflect this global change, with an overall decrease in brightness by 100 times.

10. The high temperature of the solar upper atmosphere generates an outward flow of ionized coronal gas or plasma away from the Sun at typical speeds ranging from 400 to 800 kilometres per second. This outflow is known as the "solar wind". The solar wind flows around obstacles such as planets, but planets with their own magnetic fields

respond in specific ways. Under the influence of the solar wind, a planet's magnetic field lines are compressed in a sunward direction and stretched out in a downwind direction. This creates a magnetosphere, a complex, tear drop-shaped cavity around a planet that possesses a magnetic field, such as the Earth. The Van Allen radiation belts are within this cavity, as is the ionosphere, a layer of Earth's upper atmosphere where photoionization by solar X-rays and extreme ultraviolet rays creates free electrons and ions.

11. The geomagnetic field senses the solar wind and its speed, density and magnetic field. Because the solar wind varies over time scales as short as seconds, the interface that separates interplanetary space from the magnetosphere is very dynamic. Normally this interface, called the "magnetopause", lies at a distance equivalent to about 10 Earth radii in the direction of the Sun. However, during episodes of elevated solar wind density or velocity, the magnetopause can be pushed inward to within 6.6 Earth radii (the altitude of geosynchronous satellites). As the magnetosphere extracts energy from the solar wind, its form and structure depends on solar activity, and complex effects, not yet completely understood, are observed.

12. The aurora is a dynamic and delicate visual manifestation of solar-induced geomagnetic activity. Solar wind particles entering the magnetosphere also energize electrons and ions that are trapped there. Particles with sufficient energy can enter the Earth's upper atmosphere, usually near the polar regions. When the particles strike the molecules and atoms of the thin, high atmosphere, some of them start to glow in different colours. During periods of high geomagnetic activity, the regions to which energetic particles penetrate may extend to much lower latitudes. In such cases, aurorae and other geomagnetic disturbances, which could negatively influence human activities, can be observed much farther from the poles than usual (see section II.B).

C. Disturbances of the ionosphere and magnetosphere

13. There are two different types of events on the Sun that trigger disturbances in the Earth's environment. One type is called a "solar flare" because the brightening of a small area on the Sun heralds its occurrence. The other type is called a "coronal mass ejection" (CME) and is, in fact, a huge eruption of material from the solar atmosphere into interplanetary space. Flares and CMEs are not unrelated, but most flares are not accompanied by a CME, and many CMEs occur without a visible flare.

14. When a flare occurs on the Sun, a large increase in electromagnetic radiation follows (mainly photons with energies in the extreme ultraviolet (EUV) and X-ray portion of the energy spectrum). The energetic electromagnetic radiation bursts accompanying flares on the Sun travel at the speed of light and thus arrive at Earth just eight minutes after leaving the flare site, well ahead of any charged particles or coronal material associated with the flare. The direct response of the upper atmosphere to a burst of solar flare ultraviolet and X-ray emissions is a temporary increase in ionization (as well as temperature) in the sunlit hemisphere. The phenomenon, which can vary from a few minutes to hours, is called a "sudden ionospheric disturbance" (SID). The increase of ionization at altitudes below 100 kilometres is especially significant on such occasions.

15. While solar flares affect the ionosphere, CMEs occur when the magnetosphere is disturbed by plasma that propagates through interplanetary space to the Earth after sudden disruptions in the solar magnetic field. A large CME can contain a billion tons of matter that can reach speeds up to 2,000 kilometres per second, considerably greater than normal solar wind speeds of about 400 kilometres per second. Thus, unlike solar flares, which emit enhanced EUV/X-ray radiation, CMEs result in a "cloud" of charged particles (ions and electrons). This cloud often brings with it parts of the solar magnetic field and is often named a "magnetic cloud". The charged particles and the magnetic field will interact with the Earth's magnetic field when the cloud reaches the Earth's orbit, causing a geomagnetic storm.

16. Geomagnetic activity in the Earth's environment can also be caused by solar wind fluctuations that are due to large-scale structuring of the solar surface. The main source of solar wind is from so-called coronal holes. These are regions of the solar corona where the density is lower than average and the temperature and associated solar wind

expansion velocity are higher than average. Their name reflects the fact that they appear dark in X-ray images of the corona owing to their low density. Coronal holes are mostly restricted to the polar regions (called “polar coronal holes”) but can sometimes extend to lower latitudes, down towards the Sun’s equator. When, during the rotation of the Sun, a boundary between the fast solar wind coming from the holes and slow solar wind crosses the Earth, geomagnetic activity is also often enhanced. Because coronal holes are long-lived structures, such disturbances may repeat themselves with the 27-day solar rotation period.

17. Important scientific issues and objectives include:

(a) Investigating solar system plasmas and the current systems and magnetic fields associated with them;

(b) Improving the observation and understanding of the physical processes governing the Earth’s thermosphere, magnetosphere, ionosphere and upper atmosphere;

(c) Developing a detailed, theoretically based understanding of the physical processes that constitute the Sun-Earth connection, improving the prediction of geo-effective solar activity and forecasting space weather conditions;

(d) Improving the observations and understanding of solar variability and the mechanisms by which the energy generated in the Sun’s core is released into space;

(e) Characterizing the dynamics, properties and structure of the solar wind as it blows through interplanetary space and interacts with local interstellar medium to form the heliosphere.

II. SPACE WEATHER EFFECTS ON THE EARTH’S ENVIRONMENT

A. Effects on ground services

18. Short-wave radio communications at HF frequencies (3-30 MHz), which are still extensively used for long-distance telecommunications services in various countries, depend upon the reflection of signals from the Earth’s ionosphere. The effects of an SID are an increase in the local electron concentration in the ionosphere, which can cause a total radiocommunication blackout. These increases are caused by solar flare short-wave radiation, but an inflow of energetic particles from a flare and geomagnetic storms also cause disturbances in the ionosphere. The ionospheric changes that occur during disturbed times also increase the incidence of electron density irregularities, leading sometimes to severe variations in the phase and strength of signals sent from the ground to satellites at VHF and UHF frequencies (30 MHz to 3 GHz).

19. Geomagnetic surveys are important tools in the commercial exploration of natural resources, such as the search for oil and gas. However, space weather-related perturbations can create signals in survey data that can be mistaken for signatures of sub-surface resources. Survey schedules or operations must be modified, often suddenly and with significant cost impacts, to avoid contamination of the survey data.

20. Navigation systems such as LORAN and OMEGA are adversely affected when solar activity disrupts their radio wavelengths. The OMEGA system consists of eight transmitters located throughout the world. Aeroplanes and ships use the very low frequency radio signals from these transmitters to determine their positions. During solar events and geomagnetic storms, the system can give navigators information that is inaccurate by as much as several miles. If navigators are alerted that a solar flare event or geomagnetic storm is in progress, they can switch to a backup system.

21. The same disturbance-related changes in the Earth's ionosphere that affect communications introduce changes in the time it takes signals to traverse the ionosphere. The abnormal time delays introduce position errors and decrease the accuracy and reliability of the satellite-based Global Positioning System (GPS), which is used for many range-finding and navigational purposes.

22. Electric power systems on the ground can be affected by the enhanced currents that flow in the magnetosphere-ionosphere system during geomagnetic disturbances. Such disturbances can induce almost direct currents (geomagnetically induced currents (GIC)) in long power lines. For instance, during the 13 March 1989 magnetic storm, GIC caused a complete shutdown of the Hydro-Quebec power grid, resulting in a nine-hour power outage. The power pools that served the entire northeastern United States of America came uncomfortably close to a cascading system collapse.

23. Space weather-induced currents similarly flow in long conductors on the ground such as oil pipelines. These currents create galvanic effects that lead to rapid corrosion at the pipeline joints if they are not properly grounded. Such corrosion requires expensive repairs or can lead to permanent damage.

B. Effects on humans and spacecraft

24. While the damaging effects of radiation and energetic charged particles coming from solar flares have been known for a long time, some of the aspects of solar coronal mass ejections on Earth and artificial spacecraft, such as the impact on communications satellites, have become evident only recently through investigations performed within the international solar terrestrial physics (ISTP) space programme. A reliable prediction of the extent of the Earth-directed CMEs, as well as the probability of the occurrence of flares from which energetic particles can be magnetically guided to Earth, would make it possible to issue alerts to avoid major hazards to astronauts as well as to communications satellites (which can either be temporarily switched off or designed to enter a safe-mode when a cloud of solar plasma reaches the Earth's environment).

25. The upper atmosphere becomes inflated if it is heated by extra energy sources such as auroral charged particles and enhanced resistive ionospheric currents. The resulting increased atmospheric densities at altitudes of 300-500 kilometres significantly increase the number of collisions between satellites and surrounding gas particles. This "increased satellite drag" can alter an orbit enough so that a satellite is temporarily lost to communications links. At times, these effects may be sufficiently severe as to cause the premature re-entry of orbiting objects, such as Skylab in 1979 and the Solar Maximum Mission in 1989.

26. Energetically charged particles that originate from the Sun and from the Earth's magnetosphere impact the surfaces of spacecraft. Highly energetic particles can penetrate into electronic components, causing bit-flips, or errors, in a chain of electronic signals, which can result in spurious, or phantom, commands that appear to spacecraft systems to be directions from the ground. In addition, on-board instruments may generate erroneous data. These spurious commands have caused major failures in satellite systems and have even caused spacecraft to point away from the Earth and lose radio contact.

27. Many failures could probably have been avoided had ground controllers known in advance of impending charged particle hazards. During large solar storms, satellite operators may not even be aware of satellite anomalies because their communications links to the satellites are inoperable due to the geomagnetic storm itself. Less energetically charged particles contribute to a variety of spacecraft surface charging problems, especially during periods of high geomagnetic activity. In addition, energetic electrons responsible for deep dielectric charging can degrade the useful lifetime of internal components.

28. Data on spacecraft anomalies are maintained by the National Oceanic and Atmospheric Administration (NOAA) at its National Geophysical Data Centre (NGDC) at Boulder, Colorado. However, it is often difficult to obtain information on satellite anomalies since many satellite operators are not willing to share such information.

For a period of 25 days in March 1989, in connection with a severe magnetic storm, 46 instances of operational disturbances were reported; the majority were diagnosed to be due to electrostatic discharges resulting from spacecraft charging. Such failures occurred in the Japanese geostationary telecommunications satellite CS-3B in 1989 and the Canadian Anik satellite in January 1994. An Earth-directed coronal mass ejection led to the failure of the Telstar 401 communication satellite in January 1997.

29. Energetic solar protons are a radiation hazard to astronauts on manned space flights. The arrival time in the near-Earth environment can begin within some tens of minutes of the eruption of a solar flare. While low inclination orbits take advantage of the shielding of the Earth's magnetic field, high inclination orbits place a spacecraft outside normal rigidity cut-offs, causing increased dosages. The International Space Station will use a high inclination orbit of about 52 degrees. The prediction and monitoring of solar flares and CMEs should provide essential safety constraints.

30. Radiation exposure to passengers in high-altitude aircraft and, in particular, to crew members who repeatedly make such flights is also of concern. Although the residual atmosphere above an aircraft provides a measure of protection from cosmic rays and solar energetic particles that enter the magnetosphere, there is still concern about flights on polar routes during major solar charged particle events. Radiation sensors on Concorde supersonic jets have shown that passengers and crew sometimes receive a radiation dose equivalent to a chest X-ray. To reduce the risk to aircraft crews and passengers, routine forecasts and alerts are sent through appropriate channels so that a flight in potential danger can consider what course of action to take to minimize radiation exposure.

C. Space weather forecasting: current situation and perspective

31. Space weather forecasting is based on observations of the Sun, from both the ground and space. In addition, several satellites monitor the Earth's environment by measuring key physical parameters. Images of the Sun in various spectral regions and selected spectral lines give information about the occurrence of flares and, together with magnetic field measurements (solar magnetograms), about the probability of flare occurrence in the future. This involves a great uncertainty, since it is not possible to follow the development of active regions on the invisible hemisphere of the Sun. Some types of configurations of the magnetic field of active solar regions have a greater possibility of creating a flare than others. However, it is impossible to predict the time when a flare might occur. Space-borne detectors also monitor the radiative output from the Sun. In particular, the Geostationary Operational Environmental Satellite (GOES) series provide measurements of the solar X-ray flux. A few minutes after a flare occurs, even if ground-based observatories miss the flare owing to night time or bad weather, the enhanced X-ray flux from the Sun gives the first indication of the strength of the flare.

32. Even when solar active phenomena are observed, either by ground-based observatories or by satellites, it is very hard to estimate the expected effects on the Earth's environment. Flares are sources of X-rays and energetic charged particles but are only loosely associated with geomagnetic storms. Real time observations of CMEs are a much better tool for monitoring space weather but, even if a CME that is moving towards the Earth is discovered, the enormous distance between the Sun and the Earth leads to large uncertainty in an advance forecast for two reasons. First, the strength and velocity of the particle/magnetic cloud are very difficult to determine accurately based on CME observations. Secondly, the characteristics and the structural dynamics of the particle cloud as it crosses interplanetary space are poorly understood and can only be re-examined once it arrives at satellites near the Earth.

33. A key to accurate, short-term forecasting of new disturbances is a continuous, real-time solar wind observation. Data obtained at libration point L1 (240 Earth radii upstream), where the Earth's gravitational pull is balanced by that of the Sun, provide a 30 to 50 minute warning of when a shock or disturbance in the solar wind will encounter the Earth's magnetosphere. The precise time depends on the solar wind velocity, which can be measured by an instrument aboard a satellite near the libration point L1, which is well outside the influence of the geomagnetic field. Because such satellites are continuously in daylight, they can observe the Sun and the solar wind 24 hours a day,

while all previous solar observatories had a low Earth orbit, and their observations were periodically interrupted because of the Earth's shadow.

34. The first two solar wind monitoring satellites at the libration point (Solar and Heliospheric Observatory (SOHO), since 1995, and Advanced Composition Explorer (ACE), since 1997) will improve the accuracy of space weather forecasts. In addition, they will improve knowledge about the mechanisms that produce solar storms (both flares and CMEs) and how a magnetic shock front travels through interplanetary space before it hits the Earth's environment to create a geomagnetic storm.

35. Some 20 satellites orbiting around the Earth in low orbits or eccentric orbits, or near the libration point, as well as 30 ground-based observatories around the globe, are used by scientists from a dozen countries to monitor the geomagnetic events in the frame of the international solar-terrestrial physics (ISTP) programme. This complex programme has been demonstrating the value of international cooperation and should eventually lead to more accurate forecasts of space weather, both in the short term to issue alerts and in the long term by building a sufficient database to develop better models of solar activity level variations.

36. The last solar minimum was reached in late 1996, and solar cycle No. 23 started in 1997. An increasing number of active regions from the new cycle have begun to appear, and the number of flares and CMEs will continue to increase in the next few years, as will the strength of the events. It is important for society to be more sensitive to space weather activity now and during the upcoming solar maximum in 2000-2003.

III. GLOBAL CLIMATE CHANGE

37. The possibility of unprecedented global climate change largely driven by human activity is a subject of considerable international concern. This concern has been expressed through the United Nations Framework Convention on Climate Change (A/AC.237/18 (Part II)/Add.1 and Corr.1, annex I). The Intergovernmental Panel on Climate Change (IPCC), which was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, has issued periodic scientific assessments of global climate change and its possible impact for the past several years. Model simulations and retrospective predictions correspond to the "observed" global change in temperature of about 0.5 degrees C of warming over the past 100 years, attributed (at least in part) to increasing concentrations of greenhouse gases and amplified by feedback through increasing water vapour etc. IPCC has estimated that global surface air temperatures will increase significantly in the next 100 years. The likely consequences of this warming include changing patterns of temperature and precipitation (rainfall), increased sea-level rise and altered distribution of freshwater supplies. The impact on human health, the vitality of forests and other natural areas, and the productivity of agriculture are all likely to be significant.

38. The global climate at any point in time is a consequence of complex interactions between the solar energy input to the Earth, the atmosphere and atmospheric composition, the oceans (including the mid- and deep-ocean circulation), the hydrological cycle (which includes rivers, lakes, clouds/precipitation processes etc.), the land surface and vegetation/biosphere, the cryosphere (snow and ice fields, ice sheets and glaciers) and the geosphere (continental topography and tectonic changes, volcanic eruptions, Earth rotation etc.). In recent years, two other components were added, namely the chemosphere (various chemical species that are injected into the atmosphere) and the technosphere (i.e. changes in the land surface, the atmosphere, the oceans etc. introduced by current technology and/or social and cultural practices).

39. The global climate will always change. However, the fact that increasing human activity is causing climate change at a much more rapid rate than before is a cause for concern. There may be too little time for adaptation through natural processes such as plant "migration". Even with technology, very long lead times are necessary to accommodate and compensate for the possible impacts of global climate change.

40. The Earth system has gone through very cold and warm periods before. The reasons for past changes were probably the changes of the Earth's orbit around the Sun, fluctuations of solar irradiance, volcanic eruptions and other natural phenomena. Paleoclimatic records in air bubbles trapped in Antarctic ice cores indicate that the concentrations of carbon dioxide (CO_2) and methane (CH_4) show a high correlation with local temperature changes over the past 220 thousand years, even though the timing precision of the analysis precludes an exact determination of which variable leads the other.

41. Recent climate history indicates that there has been a global warming of about 0.5 degrees over the past 100 years. which is generally attributed to increasing concentrations of greenhouse gases CO_2 is injected into the atmosphere during the burning of fossil fuels, methane is emitted by expanding for example rice fields and livestock, and oxides of nitrogen are generated during fossil fuel burning and possibly from fertilizers used in agriculture. Other greenhouse gases are technologically produced molecules called chlorofluorocarbons (CFCs), whose use in air conditioning has been prohibited. The greenhouse warming effect of one molecule of some CFCs is equivalent to about 10,000 molecules of CO_2. CFCs also deplete the ozone layer, thereby permitting increased UV-B radiation to penetrate the atmosphere to the Earth's surface. They are, therefore, doubly dangerous.

42. Computations show that the Earth's average surface temperature of +15° C would be -18° C were it not for the presence of greenhouse gases. The notion of an "enhanced greenhouse effect" refers primarily to the incremental global warming caused by increasing concentrations of anthropogenically introduced "infrared active" greenhouse gases over and above the greenhouse effect caused by naturally occurring greenhouse gases (e.g. water vapour). During the twentieth century, the combustion of fossil fuels and industrial activity have disturbed the equilibrium that has kept the Earth's average temperature at +15° C. The CO_2 levels in the atmosphere have increased from 280 parts per million (ppm) by volume in 1860 to about 360 ppm in 1995. The increased amounts of CO_2 and other greenhouse gases have absorbed more and more infrared radiation, which has contributed to the temperature rise of 0.5 +/- 0.1° C since the nineteenth century. With increasing temperatures and therefore hotter summers and milder winters, glaciers have begun to melt and have led to a rise in the sea level.

43. The understanding of enhanced global warming is complicated by the fact that there are also many natural phenomena causing variability in the climate on inter-annual and inter-seasonal time scales. Examples are the El Niño and the Southern Oscillation (ENSO), periodic variations in rainfall that occurs in the Sahel and in northeastern Brazil, the inter-annual variability of monsoons, Quasi-Biennial Oscillation (QBO) and the decadal and inter-decadal interactions between the atmosphere and ocean.

44. Ongoing satellite missions make, or help derive, key global observations from geostationary and polar orbiting platforms of: atmospheric structure and dynamics (e.g. temperature, water vapour fields, precipitated water, clouds, winds); sea surface temperature; directly measured and derived surface characteristics (e.g. sea level, sea state, sea ice, snow cover, flooding, vegetation index, precipitation amount); land surface characteristics; and selected atmospheric chemical species (e.g. ozone, aerosols, etc.). While most of these observations are now collected on a routine basis as a part of space-based subsystems within the World Weather Watch, there is still a need for additional satellite missions. Future satellite missions will make improved, better calibrated and better geographically located observations of these parameters and, in addition, will monitor key atmospheric constituents such as greenhouse gases, aerosols, chemical precursors to ozone depletion, latent heat fields, wind fields, and ocean biomass and ocean colour.

45. Examples of advanced satellite missions are Advanced Earth Observation Satellite (ADEOS) (Japan), Tropical Rainfall Measuring Mission (Japan and United States), Earth Observing System (United States), ENVISAT (ESA), RADARSAT (Canada), and Sea-viewing Wide Field-of-view Sensors (SeaWifs) (United States). Together, they have been and are being developed to address key environmental issues reflected by the requirements of the World Climate Research Programme, the Global Climate Observing System, the Global Ocean Observing System, the Global Terrestrial Observing System and others (see section VIII).

46. Critical scientific issues and objectives include:

(a) Characterizing and documenting long-term climate variability and trends through systematic global observations of the climate system and its external drivers;

(b) Understanding the nature of key parameters driving changes in the climate system and identifing the causal factors of observed climate variations and feedback processes that govern the response of the climate system;

(c) Assessing the predictable part of long-term climate variability and changes, including regional impacts, through the combined application of observations and global models.

IV. OZONE DEPLETION

47. Ozone is the only greenhouse gas that strongly absorbs solar radiation at the ultraviolet end of the spectrum and primarily in the stratosphere. Stratospheric ozone protects the Earth's surface from harmful solar ultraviolet radiation (especially UV-B) and plays an important role in controlling the temperature structure of the stratosphere by absorbing both incoming solar ultraviolet radiation and outgoing terrestrial long-wave radiation.

48. A reduction in stratospheric ozone can modify surface temperature through two competing processes: (a) more solar radiation transmitted to the surface-troposphere system, thereby contributing to a surface warming; and (b) a cooler stratosphere owing to decreased ultraviolet absorption and less long-wave emission to the troposphere and the surface, leading to a surface cooling tendency. The solar warming (a function of total column amount of ozone) and the long-wave cooling (a function of the vertical distribution of ozone) are of similar magnitude. Thus, the magnitude as well as the increase or decrease in surface temperature depends critically on the magnitude of the ozone change which, in turn, depends strongly on altitude, latitude and season.

49. Because ozone absorbs ultraviolet and infrared thermal radiation, a change in ozone amounts can either increase or decrease the Earth's temperature depending on the change in the ozone profile. A reduction of stratospheric ozone is also thought to have potentially serious biological consequences. An increase in the intensity of UV-B at the Earth's surface is expected to increase the incidence of skin cancer and decrease the productivity of marine biota, thus affecting the biological carbon pump. The latter effect could lead to an increase in the concentration of CO_2 in surface waters and, consequently, the atmosphere. Observing and monitoring the total column ozone content and the vertical distribution of ozone is considered to be of critical importance. Stratospheric ozone is photochemically controlled by species in the oxygen, hydrogen, nitrogen, chlorine and bromine families. The increasing atmospheric loading of halocarbons, in particular CFCs, is thought to be primarily responsible for the ozone hole and is the reason for the regulatory measures agreed upon under the Montreal Protocol.

50. Although isolated ozone column content observations were made in the 1920s, systematic global observations of total ozone to study its long-term evolution started at the end of the 1950s with the Global Ozone Observing System coordinated by WMO and now a component of the Global Atmosphere Watch (GAW). Since 1950, fairly extensive observations of the ozone vertical profile have been carried out using ground-based Dobson spectrophotometers and balloon-borne measurements at many locations around the world.

51. The beginning of ozone observations from satellites raised the difficult question of sensor stability and calibration. Because of insufficient calibration, Antarctic ozone depletion was discovered by ground-based studies in the late 1970s to mid 1980s and not by satellite observations; however, this demonstrates the necessary complementarity between space observation programmes and ground-based observations. Today, ozone satellite observations are a key element in the day-to-day monitoring of stratospheric ozone. They are providing in near real-time a very detailed structure of the horizontal distribution of ozone. Because of their global view, they are an

essential input to the numerical modelling of stratospheric ozone, providing indispensable information for understanding stratospheric ozone processes that lead to its destruction during the Antarctic, or Arctic, springs.

52. The Upper Atmosphere Research Satellite (UARS) of the National Aeronautics and Space Administration (NASA) of the United States has obtained more than six years of global data on atmospheric chemistry, energy input and dynamics. The data have confirmed definitive links between depleted ozone levels and chlorine chemistry and confirmed that technologically produced compounds, primarily CFCs, are the source of the stratospheric chlorine that catalytically destroys ozone. Data from the total ozone mapping spectrometer (TOMS) instrument on board the Nimbus 7 satellite have shown that globally averaged concentrations of total ozone decreased to unprecedented low values in the early 1990s.

53. The ozone hole over the Antarctic produced the lowest values of ozone ever recorded in 1993. During the same period, record levels of UV light were measured at the surface in Antarctica. At one monitoring site, UV-B, the part of the spectrum believed to be the most harmful to living organisms, was recorded at levels 44 per cent higher than in 1992. Ozone concentrations in 1994 were reported to have been as low as the 1993 concentrations. Satellite observations, combined with measured changes in clouds and aerosols, have been used to infer ground-level ultraviolet (UV-B) radiation. Poleward of about 40 degrees latitude, statistically significant increases have been calculated for the period 1979-1992. The largest increases of ground-level UV-B radiation occurred at higher latitudes, in winter and spring. At 45 degrees North latitude (e.g. Portland, Oregon; Minneapolis; Montreal; southern France; northern Italy; Bosnia), the springtime exposure to DNA-damaging and erythemal (sunburn-inducing) radiation has been calculated to have increased by 8.6 and 5.1 per cent, respectively, in the past two decades. Over highly populated areas at 55 degrees North latitude (e.g. United Kingdom of Great Britain and Northern Ireland, Scandinavia, Russia), springtime increases have been even larger.

54. Critical scientific issues and objectives include:

(a) Characterizing the global distribution of ozone, chemically active trace constituents such as photochemical oxidants, aerosols and related meteorological parameters;

(b) Understanding the processes responsible for the chemical transformation of trace constituents, the role of aerosols in affecting atmospheric chemistry and the transport of trace constituents between the troposphere, stratosphere and the upper atmosphere, and between the troposphere and the Earth’s surface;

(c) Modelling quantitatively the trace constituent composition of the troposphere/stratosphere system through the combined application of observations and global models.

V. TECHNOLOGY-INDUCED CHANGES IN THE GLOBAL ENVIRONMENT

55. Technological advances over the past several decades have made a substantial contribution to transportation systems (and mobility), agricultural food production and distribution systems, water availability, power generation and distribution, and indeed the information age but as was realized *ex post facto*, at a considerable cost to the environment. Many technological advances are known to have negative impacts on the environment and on the health of human, plant and animal life.

56. An example of the effect of human activity on the global environment is the pollution of the atmosphere, water and soil. Atmospheric pollution, most visibly caused by the use of fossil fuels as an energy source for transportation,

causes urban smog and acid rain,* which not only damages vegetation, acidifies the soil and causes various health problems but also pollutes rivers and lakes and destroys forests.

57. Biomass burning is a major source of air pollution in many developing countries in the tropics, since the burning of bushes and grasses is the most common way of preparing land for farming. Fires from biomass burning represent a major source of carbon dioxide, nitrous oxide, hydrocarbons and sulphur dioxide in the atmosphere. Biomass burning is a significant source in the emission of methane and could represent one fourth of total methane emission in tropical regions.

58. Pollution of the atmosphere by the emission of sulphur dioxide and sulphur trioxide is one of the problems posed by petroleum refineries in oil-producing countries. Noxious gaseous effluents and gas flaring from petroleum refineries include hydrocarbon vapours. Discharges from manufacturing industries pollute rivers, lakes and, increasingly, the oceans, which were once thought to be reservoirs of infinite capacity to absorb waste. Many coastal zones now have serious problems.

59. Advanced agricultural methods have led to high crop yields in some parts of the world, but the excessive use of pesticides and fertilizers contaminate the soil and bodies of water into which they are vented by exhaust, run-off and percolation. Thus, sustainable resource management is becoming a critical issue worldwide, as was confirmed by the United Nations Conference on Environment and Development held from 3 to 14 June 1992 at Rio de Janeiro.

60. The problems of soil and water degradation and environmental damage are not uniquely due to technology. In some developing countries, overpopulation, overgrazing and the use of wood as fuel have led to extensive deforestation and have caused equally serious problems of soil erosion and degradation, desertification, water contamination, loss of biodiversity etc. All of the above are considered non-sustainable practices on account of their increasing impact on the environment.

61. International action has been taken because of the serious consequences of CFCs, which are used as refrigerants, aerosol propellants, foam blowing agents and solvents for cleaning. In many countries chemical industries have been developing alternatives to CFCs. Many Governments have now signed the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted on 16 September 1987 which, together with amendments agreed in London in 1991 and Copenhagen in 1992, requires that the manufacture of CFCs be phased out by the year 1996 in industrialized countries and by 2006 in developing countries. The third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change which took place in 1997 in Japan also considered further actions with respect to ozone depletion in the atmosphere and the role of CFCs and ozone as greenhouse gases.

62. Aeronautical and space transportation systems inject combustion products, including ozone depleting chemicals, into the upper levels of the troposphere and lower stratosphere. At cruise altitudes, aircraft emit nitrogen oxides, which are key elements in ozone photochemistry. Aircraft also emit other chemicals that influence the Earth's radiation budget, namely water, carbon dioxide and soot/aerosols. Aircraft exhaust emitted at cruise altitude persists far longer than that emitted near the ground, making cruise emissions a global issue. Emissions from aircraft also contribute to cirrostratus cloud layers which block solar radiation from reaching the Earth's surface. The precise impacts of these activities are as yet speculative. More careful monitoring and research is required in order to develop guidance to policy makers, particularly as the aircraft industry projects a substantial increase in passenger traffic over the next 20 years.

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*Acid rain is a generic term for any acidic precipitation, i.e. rain, snow, sleet, hail, mist, fog. About 30 per cent of air pollutants mix with water in clouds and eventually fall as precipitation. Sulphurdioxide is the main source of acid rain, with contributions from the oxides of nitrogen.

63. Other technology-induced changes include the impact of urbanization, which leads to urban “heat islands” that alter the local climate, increase water run-off and transport polluting chemicals into bodies of water and the surrounding subsoil, and cause an increased demand for cooling in all countries in the warmer areas of the world.

64. In practice, it is very difficult to distinguish between changes in the global environment caused by human activity and natural changes, such as the solar activity effects described earlier, volcanic eruptions, earthquakes and tsunamis, hurricanes, cyclones, typhoons, floods, droughts and phenomena such as El Niño. The use of remote sensing technology to monitor such effects is discussed in more detail in the background paper on management of Earth resources (A/CONF.184/BP/3).

65. Important scientific issues and objectives include:

(a) Monitoring atmospheric/tropospheric pollutants, aerosols and other chemical species;

(b) Observing and monitoring changes in land use practices and vegetation (including deforestation);

(c) Observing and monitoring the discharge of rivers into inland water bodies and coastal zones;

(d) Understanding the interaction between the by-products of technology and the environment and modelling its impact;

(e) Developing a pollutants’ distribution model at national, regional and global levels;

(f) Observing and monitoring natural effects on the global environment.

VI. WEATHER FORECASTING AND NATURAL DISASTER WARNINGS

66. Weather forecasting has been crucial to all societies for millennia. The weather at any given location is a result of complex interactions between local, regional and global aspects of solar radiation and atmospheric circulation and dynamics. Atmospheric circulation, in turn, is determined by internal dynamic and thermodynamic processes and interactions with oceans, land surfaces and vegetation, and the cryosphere. If a weather forecast is to be extended beyond a few hours, larger geographic areas are involved as also are the dynamics of the interactive components of the Earth system such as the oceans.

67. Modern weather forecasts require the time integration of numerical models, using the most powerful supercomputers available. Using the output from global models, high resolution (nested) regional and higher resolution models are run to provide more specific characteristics of weather systems, such as precipitation amount. Extending weather forecasting beyond 5 to 7 days requires coupled models that take into account the dynamics of changes in the oceans. Major emphasis is now being placed on the development of seasonal to inter-annual prediction capability on account of the lead-times required for the management of natural and industrial resources, such as agriculture, water supplies and energy production and distribution.

68. All of these models require global observational data, normally gathered once or twice a day. *In-situ* observations are made globally approximately every six hours and transmitted to processing centres, where they are combined with space-based data, available on a continuous basis. Using sophisticated data assimilation techniques, weather forecasts can be made for 24 hours to a week; extended-range forecasts up to several weeks or a month are also possible. For seasonal to inter-annual forecasts, which are used to monitor such phenomena as El Niño, atmosphere-ocean coupled models, which require substantially more observations of the Earth system, are used. Current satellite systems describe storm and major weather systems and provide operational data on the temperature and moisture structure of the atmosphere, sea-surface temperatures, winds, and clouds.

69. The accuracy and timeliness of weather forecasts have improved significantly since the launching of weather satellites. Today every part of the globe can be viewed at frequent intervals from both polar orbiting and geostationary satellites. Since the first weather satellite was launched in April 1960, observations from space of the Earth's atmosphere and the weather systems embedded in it have developed rapidly in quality and quantity. The constellation of just five geostationary satellites has the advantage of covering almost the whole globe from "fixed" positions above the equator. These satellites can provide data every half an hour (or at shorter intervals) to capture the development of fast-growing storms. Visual and infrared sensors provide almost continuous day and night coverage. Countries and regions that currently have geostationary meteorological satellites include China (Feng Yun series), Europe (METEOSAT series), India (Indian National Satellite System for Television and Telecommunications (INSAT)) series, Japan (geostationary meteorological satellite (GMS) series), the Russian Federation (Electro series) and the United States (geostationary operational environment satellite (GOES) series).

70. Most operational polar orbiting meteorological satellites are provided by the Russian Federation (Meteor series) and by the United States (NOAA series). The constellation of operational geostationary and polar orbiting satellite systems in support of meteorology will continue to expand in the future. There is an increasing trend of more joint satellite missions, both on a national basis (e.g. by merging military and civilian systems) and through international cooperation. Newly developed environmental monitoring spacecraft include, for example, the METOP Earth Explorer Mission, the Tropical Rainfall Measuring Mission (Japan/United States), Earthwatch (Europe), and polar-orbiting environmental satellites (POES) (United States). These missions will carry more advanced and complex environmental monitoring instrumentation than that included on current missions.

71. The observations collected should be in a form conducive to integrated data assimilation in forecast and prediction models. A primary aim is to improve the capability to predict socio-economically important weather and climatic events and thereby aid operational managers and decision makers involved in the management of resources such as agriculture, water supplies, energy, transport and tourism.

72. Space-based and airborne observations also support the detection and tracking of a broad range of natural disasters such as cyclones and other extreme weather conditions, drought, floods, forest fires and earthquake damage. On longer time-scales, they provide the only source of quantitative information on desertification, deforestation, land degradation etc. Recent and planned missions will also provide critical data and information on volcanic eruptions and their potential impact by monitoring atmospheric aerosols and dust. Improved instruments on board the next generation of satellites will obtain much more accurate data on wind, temperature and moisture fields and on the concentration and distribution of greenhouse gases and gases involved in ozone chemistry.

73. The methodology and space technology that could be used for natural disaster warning is discussed in more detail in the background paper on disaster prediction, warning and mitigation (A/CONF.184/BP/2).

74. Important scientific issues and objectives include:

(a) Developing remotely sensed observations and using them, together with *in-situ* observations, to monitor, describe and understand climate system variability, ranging from a few days to monthly, seasonal and to inter-annual fluctuations;

(b) Improving the coverage (in space and the parameters/variables needed) for the calibration and validation of present and planned satellite and remote sensing observations;

(c) Improving remote sensing data retrieval algorithms so that the derived geophysical parameters are more representative of direct measurements;

(d) Improving the direct input of globally observed satellite measurements into global models.

VII. SOCIAL AND ECONOMIC ASPECTS

75. In recent years, there has been increasing worldwide recognition of the environmental impacts of technological development, growing populations and economic development and of the finite resources of the Earth system and its ability to support life. Current practices cause considerable damage to natural ecosystems and the life support systems by altering the atmosphere and polluting the air, water and soil of the planet. While the environmental stress caused by each country is different, all nations inadvertently participate (for different reasons) in the process. Much of the damage done may be irreversible if current practices continue.

76. Short-term social and economic benefits have often been the primary drivers of human actions, without due regard to the environmental damages and possible depletion of natural resources. A common belief has been that the Earth's supply of natural resources, as well as its capacity to absorb the impact of human actions, is unlimited. It has taken several generations to understand that this assumption is invalid, even in the case of the oceans that occupy over 70 percent of the Earth's surface. At the present stage of human development, longer-term planning and thinking will be of direct social and economic benefit. In fact, an over-riding concern is that irreversible damage could occur before corrective actions are taken. Of course, it is well understood that it will take some time before industrial, social, economic and cultural practices adjust to this reality. It is also widely acknowledged that immediate or drastic actions could cause serious economic disruption that must be avoided if at all possible. That is, short-term actions can be justified as long as there is a factual understanding that these actions are necessary but cannot be sustained over time. They need to be embedded in comprehensive plans for the long term, based on scientific observations and analysis.

77. Human health has also become an important issue. The destructive impact of El Niño on human habitats and the discharge of agricultural fertilizers (nutrients to coastal algae), pollutants and pesticides (concentrated in oysters,

clams, and shell fish) and contaminants containing heavy metals such as mercury have caused health problems in many regions of the world.

78. International testimony to the above is reflected in many international agreements, among which are the following:

Agenda 21[1] and the work of the Commission on Sustainable Development
The United Nations Framework Convention on Climate Change and the work of IPCC
The United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa
The Convention on Biological Diversity[2]
The Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol.

79. Space-based observations cannot monitor social and economic activity as such but can provide information on global effects of urbanization, deforestation, coastal algae blooms, sediment discharge into the oceans and various other precursors to environmental hazards.

80. Critical scientific issues and objectives include:

(a) Improving scientific knowledge and understanding of global change, which will reduce the vulnerability of human and ecological systems to major environmental changes. More complete and focused scientific research can provide the foundation for building strong national and international societies by advancing economic growth and ensuring adequate food supplies and the availability and quality of fresh water, while ensuring the integrity of the natural environment—the key issue underlying the concept of "sustainable development";

(b) Developing the capability to distinguish between human influences on climate and natural ecosystems and those arising from natural variability;

(c) Developing the capability to understand and predict the social and economic impact of existing practices (technological, social, economic and cultural) that might be detrimental to future generations and national economic/social systems;

(d) Investigating alternate economic development strategies that are less harmful to the environment;

(e) Establishing global monitoring systems to provide the accurate quantitative information needed by policy makers to implement decisions to correct irreversible trends in the health of natural ecosystems and food/water/energy supply systems. Included should be the monitoring (by all countries) of land surfaces, land use, vegetation cover and deforestation, urban expansion, energy and transportation needs etc.;

(f) Developing and implementing the capability to monitor the health of coastal zones and the oceans in general.

VIII. PROMOTION OF INTERNATIONAL COOPERATION IN THE EARTH SCIENCES

A. International research programmes

81. Understanding and modelling the fundamental nature of the Earth system and its environment requires detailed observations of the atmosphere, the hydrosphere and components of the hydrological cycle, the land surface and the biosphere, the oceans, the cryosphere and the radiation budget of the planet. Such an endeavour requires worldwide

cooperation. No single country or region could possibly undertake the task by itself. For this reason, international scientific research institutions have organized three cooperative global change research programmes:

The World Climate Research Programme (WCRP) which is a part of the World Climate Programme

The International Geosphere-Biosphere Programme (IGBP)

The International Human Dimensions Programme of Global Environmental Change (IHDP, formally HDBP)

These and other international programmes are coordinated at several levels, including scientist-to-scientist, agency-to-agency, and Government-to-Government, through a broad range of multilateral and bilateral organizations and arrangements. The International Council of Scientific Unions (ICSU) provides strong leadership for the scientific planning of many of the key international programmes.

82. The issues related to the state of scientific understanding on the global environment are assessed internationally through the involvement of thousands of scientists from over 150 countries in critical reviews of the recently published scientific literature. Recent assessments include those of IPCC, carried out by its three IPCC working groups on:

The state of scientific knowledge with respect to the climate system, including possible changes as a result of human activity

The potential impact of, adaptation to and mitigation measures for global change

Cross-cutting issues, including the economic implications of climate change and of selected emission scenarios

IPCC is currently preparing four special reports in response to requests from the Conference of Parties to the United Nations Framework Convention on Climate Change on: regional impacts of climate change (1997); atmospheric effects of aviation (1998); technology transfer (1999); and emissions scenarios (1999).

B. Coordination of operational and research satellite programmes and missions

83. *Global Climate Observing System (GCOS)*. The objectives of GCOS cover a broad range, including: climate system monitoring; climate change detection; climate impacts and response monitoring, especially in terrestrial ecosystems; data for applications to national economic development; and research towards improved understanding, modelling and prediction of the climate system. GCOS planning takes a broad and comprehensive view of the observational requirements for climate information which need to cover the atmosphere, oceans, land surfaces and the biosphere and cryosphere. Both surface-based and space-based observations are necessary, as is a comprehensive data system. GCOS is a phased programme, building upon the present observational capabilities of the operational and research programmes of participating countries. For the atmosphere, close coordination is maintained with ongoing WMO programmes. GCOS is currently examining the availability of data from operational systems such as the World Weather Watch, the Global Atmosphere Watch and operational hydrology programmes. Based on these assessments, recommendations will be made on enhancements or new observations needed to ensure that climate data requirements are met while the data collected are in concert with existing programmes.

84. The scientific scope of GCOS was thoroughly reviewed and developed in 1995. The detailed scientific plans for GCOS considered the full scope of issues including the requirements of users, the contributions of existing research and operational programmes and data systems, and the participation of both international and national organizations. The scientific scope includes the atmosphere, oceans, land surfaces, cryosphere, hydrosphere and

ecosystem processes. With the completion of these important plans and documents in 1995, GCOS entered the implementation phase in 1996. It is expected that as GCOS continues to be implemented, countries will see benefits not only from improved climate predictions, but also in planning for sustainable development and the assessment of the impacts of climate change on agricultural and natural ecosystems.

85. *Global Ocean Observing System (GOOS)*. Based on long-term monitoring of ocean conditions, GOOS facilitates forecasting of ocean conditions for the benefit of coastal states and national and international marine users. GOOS is being implemented in five phases, culminating in performance monitoring and improvement after 1997. The initial focus of GOOS was on coastal climate, living marine resources and the health of oceans, all of which have requirements for space-based data.

86. Several aspects of GOOS are being implemented through national and regional efforts, as follows:

(a) Six pilot projects in the Baltic, Arctic, Mediterranean Sea, Black Sea, North West Shelf and Atlantic to be implemented by the Euro-GOOS Association, comprising 22 operational agencies from 14 countries;

(b) The Tropical Ocean and Global Atmosphere (TOGA) programme and the TOGA Automated Observations (TAO) array of moorings for ENSO predictions in the tropical Pacific, led by the United States;

(c) The PIRATA array in the tropical Atlantic, led by Brazil;

(d) The five coastal GOOS projects being developed in the United States.

In addition, GOOS is developing a Global Ocean Data Assimilation Experiment (GODAE) to learn how to assimilate collections of satellite and other data into advanced numerical models.

87. *Global Terrestrial Observing System (GTOS)*. This system was established in 1996 by five international organizations: UNEP, Food and Agriculture Organization of the United Nations (FAO), United Nations Educational, Scientific and Cultural Organization (UNESCO), WMO and ICSU. Unlike the global observing systems that exist for climate and for oceans, no single organization can provide comprehensive information (or the means for gaining access to it) on land and water resources, biodiversity and pollution impacts. The central mission of GTOS is to address this problem by linking existing networks and terrestrial observing systems to provide policy makers, resource managers and researchers with access to the data needed to detect, quantify, locate, understand and warn of changes (especially reductions) in the capacity of terrestrial ecosystems to support sustainable development. This is achieved by focusing on five issues of global concern: changes in land quality; availability of freshwater resources; loss of biodiversity; pollution and toxicity; and climate change.

88. *Global Observing Systems Space Panel (GOSSP)*. GOSSP was established in 1997 to coordinate the scientific requirements arising from GCOS, GOOS and GTOS under the auspices of the United Nations system of programmes and specialized agencies with the objective of developing an integrated strategy for the implementation of space-based global observing systems.

89. *Committee on Earth Observation Satellites (CEOS)*. CEOS is an informal international organization of national space agencies that coordinates national programmes for the observation of the Earth system from space-based systems. CEOS is currently undertaking an analysis of all satellites, sensors and data products in operation or planned over the next 10 to 15 years and of the requirements of the major international scientific and intergovernmental user organizations. The study is expected to establish priorities and provide an opportunity for CEOS members to fill gaps and reduce overlaps voluntarily. Since late 1995, CEOS has focused discussions on the space component of IGOS.

90. *Integrated Global Observing Strategy (IGOS)*. The IGOS concept arose from the realization that the integration of existing and new worldwide observing capabilities into a coherent system or family of systems would most efficiently serve the needs of society. It would be the joint product all agencies involved in the collection and analysis of both space-based and *in situ* data. A reliable, cost-effective source of global data would be a valuable resource for a variety of important applications, such as understanding and predicting environmental stresses, planning the allocation of energy resources and assessing agricultural productivity. IGOS is a coordinating mechanism intended to provide an international forum for developing partnerships between data users and data providers for the definition and complementary funding of global observing programmes. This mechanism will serve to promote the continuity of data and the transition from research to operational systems. It will also minimize data gaps and reduce unnecessary redundancy.

91. The purpose of IGOS is:

(a) To provide a framework for a coherent set of user requirements so that providers can respond to them;

(b) To reduce unnecessary duplication of observations;

(c) To assist in improving the allocation of resources between different types of observing systems;

(d) To make possible the creation of improved higher-level products by facilitating the integration of multiple data sets from different agencies and national and international organizations;

(e) To provide a framework for decisions on continuity and spatial comprehensiveness of key observations;

(f) To identify situations where international arrangements do not exist for the management and distribution of key global observations and products;

(g) To assist in the transition of systems from research to operational status through improved international cooperation;

(h) To improve understanding by Governments of the need for global observation by presenting an overview of current system capabilities and limitations.

C. Participation of developing countries

92. The participation and active involvement of developing countries in the research and observations that are needed to better understand the processes that govern changes in the global system is crucial. Developing countries are often located in environmentally sensitive areas, for example in semi-arid regions of Africa and Asia; global changes have a dramatic impact on these areas. Also, developing countries are not just passive objects in the process of global change. On the contrary, they have a major impact on global change, as evidenced by forest fires in Indonesia, biomass burning in Africa and deforestation in the Amazon basin.

93. Although developing countries have limited resources to implement extensive research or observation programmes, the benefits of collaborative activities with developed countries are substantial. Such collaboration has been encouraged by the United Nations system, non-governmental international scientific organizations, such as the International Council of Scientific Unions, and various other non-governmental organizations and foundations. The benefits for developing countries are particularly clear in the area of applications for the products of global observing systems and the output products of monitoring (e.g. El Niño and its impacts), global models and assessments of the state of the Earth’s environmental system.

94. The United States Geological Service, in partnership with the United States Agency for International Development and the Ministry of Environment of Senegal, has been developing a long-term monitoring framework to better understand and document the rapid changes occurring in Senegal's environment. Geographers, ecologists and social scientists are working together as a team to better understand the human dimensions of environmental change, using biophysical data collected over time at hundreds of field sites and satellite remote sensing data.

95. Over a 30-year period, satellite remote sensing data have been used to map trends in soil erosion, forest degradation from charcoal production, deforestation, agricultural expansion, the breakdown of the traditional fallow agricultural system, habitat fragmentation and the loss of biodiversity. These trends are based on comparisons between the earliest high-resolution declassified satellite images from the Corona Program of the United States, acquired in the mid-1960s and Land remote sensing satellite (LANDSAT) images from the 1980s and 1990s. Since 1986 and 1988, respectively, Systeme pour l'observation de la Terre (Experimental Earth observation system (SPOT) and Indian remote sensing satellite (IRS) images have been extensively used worldwide for continuous monitoring of land use, vegetation and the environment. In addition, land use/land cover change is being analysed through aerial videography and advanced spatial modelling. The monitoring framework is applicable to Africa and other parts of the world, including the United States.

96. Many developing countries such as China, India, Morocco and others, are very active in global environmental research; some, such as Indonesia, Lebanon and Nigeria, are starting cooperation programmes. Many developing countries are located near the equator, where specific effects in the ionosphere and upper atmosphere take place. Because there is a deficit of ground observatories in this region, maximal effort should be directed towards strengthening the local infrastructure and facilities. At the same time, data evaluation methodology and theoretical research should not be overlooked.

97. Examples of collaborative arrangements involving the direct participation of developing countries are the emergence of regional research and applications networks throughout the world such as those in the Asia-Pacific region (APN), in Europe-Africa (ENRICH), and in the Americas. Sixteen countries have signed an agreement to establish the Inter-American Institute (IAI) for Global Change Research; the IAI Directorate is located by the IAI Executive Council at the National Institute for Space Research of Brazil. The international commitment to build capacities for global change research in the developing world is further reflected in the Global Change System for Analysis, Research and Training (START), a joint effort of IGBP, IHDP and WCRP. The START regional research networks promote focused research and training on regional issues of global importance, integrate and synthesize research results, and provide input to decision makers at national and regional levels.

98. Developing countries still tend to be under-represented on *in situ* data gathering programmes. The concerns of developing countries are relevant particularly in the context of the GTOS programme, which could usefully have greater input from *in situ* data gathering stations in developing countries. Of the three global monitoring systems (CGOS, GOOS, GTOS), the land focus of GTOS is the most relevant to developing countries, but GTOS is the least developed of the three systems. Activities of IGOS in promoting the continuity of data and the transition from research to operational systems can certainly be of substantial help to developing countries.

Notes

[1]*Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992* (United Nations sales publication, Sales No. E.93.I.8 and corrigenda), vol. I: *Resolutions adopted by the Conference*, resolution 1, annex II.

[2]See United Nations Environment Programme, *Convention on Biological Diversity* (Environmental Law and Institutions Programme Activity Centre), June 1992.