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Observation Needs for Climate Services and Research

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Abstract

Climate data are usefully applied to many economic and societal sectors. Sustained, high quality and uninterrupted climate observations are vital for the development of all countries, because climate variability and change impact significantly on economies and societies. The sectors treated in this paper include the key areas of human health, energy and water. The special needs for research and for the development of strategies to mitigate and adapt to climate change are also considered. All countries should be encouraged to give high priority to national needs for observations in their national adaptation planning. The full implementation of the Global Climate Observing System is required to ensure that countries are able to understand and manage climate variability and change over the twenty-first century.

Keywords: Needs assessment; health; energy; water; biodiversity and natural resources management; sustainable cities; food security.

1. Introduction

Climate observations are of fundamental importance to a large and increasing number of activities of significance to human societies. They are essential for climate research and climate prediction, and they underpin the climate services and products that are required for informed decision-making. Observations are expected to become more important as societies prepare strategies to adapt to climate change. To fulfil these societal needs, climate observations must be collected systematically on scales extending from the local to global.

In recognition of the importance of climate observations, many communities have invested in the collection and analysis of climate data for more than one hundred and fifty years. Indeed, the creation of the International Meteorological Organization (IMO) in 1873 was motivated largely by the need for international cooperation to ensure that consistent and sustained weather and climate data were collected by all countries. The IMO was succeeded by the World Meteorological Organization (WMO) in 1950, and a major function of its 188 Member States and Territories is the cooperative collection and sharing of environmental data, primarily to support weather and climate services. In practice, many existing climate records are the result of the sustained collection of observations to meet short-term weather forecasting needs for water, agriculture, fisheries and disaster management, as well as a range of commercial and community activities.

In 1992, following the Second World Climate Conference in 1990, the Global Climate Observing System was established in partnership between the WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU). The purpose of GCOS is to ensure that the overall climate observation needs of all countries are met, including data for

(a) Climate monitoring;

(b) Climate change detection and attribution;

(c) Operational climate prediction;

(d) Research;

(e) Climate applications and services;

(f) Assessment of climate variability and change;

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(g) Meeting the requirements of the United Nations Framework Convention on Climate Change (UNFCCC).

Under Articles 4 and 5 of the UNFCCC, Parties to the Convention agree to support and develop mechanisms for the collection and sharing of climate data. Moreover, the Third Conference of the Parties (COP3) to the UNFCCC in Kyoto in 1997 reaffirmed the importance of observations, analysis and research relevant to the various components of the climate system. The COP3 recognized the concerns raised by relevant international organizations about the long-term sustainability of observing systems. Parties were urged to provide necessary resources to reverse the decline in existing climate observing networks, and to support the global and regional observing systems being developed under GCOS.

The GCOS has twice reported to the Parties on the adequacy of the global observing systems for climate. Following its presentation of the Second Report on the Adequacy of the Global Observing Systems for Climate [1], GCOS in 2004 prepared an implementation plan for consolidating and enhancing the global observing system for climate in support of the UNFCCC. Core requirements for climate data are collection in accordance with the GCOS Climate Monitoring Principles (GCMP) and the free and open exchange of data on agreed Essential Climate Variables (ECVs).

The Group on Earth Observations (GEO) was established in response to calls for action by the 2002 World Summit on Sustainable Development and by the Group of Eight (G8) leading industrialized countries. The GEO is coordinating its activities through a ten-year work plan for the Global Earth Observation System of Systems [2], which was prepared in 2005 and in which global observations are identified as being vital to the needs of nine societal benefit areas (SBAs), namely:

(a) Natural and human disasters;

(b) Human health and well-being;

(c) Energy resources;

(d) Climate variability and change;

(e) Water resources;

(f) Weather forecasting;

(g) Coastal and marine ecosystems;

(h) Agriculture;

(i) Biodiversity.

It is clear that climate observations are the essential element in the fourth SBA, climate variability and change. However, the cross-cutting nature of climate means that climate observations are important for all of the other SBAs. The GEO work plan identifies the GCOS implementation plan as the climate observation component of the GEOSS.

Climate observations are needed to address not only global issues, but also to assist communities at regional, national and local levels. The following sections consider climate needs on all these scales and across a range of sectors.

3. Needs assessment

The needs for climate observations can be viewed from different perspectives, because climate underpins so much human activity and affects most natural ecosystems. In this section we first consider a number of general issues that provide a foundation for consideration of climate-related needs of specific sectors of society. We then briefly review the needs for climate observations within a number of economic and societal sectors.

3.1 General issues

The functions of monitoring and prediction support most climate services, and it is appropriate to consider the general features of these functions before considering the needs of specific sectors. There are also cross-cutting issues associated with the collection and management of climate data, including the role of research, the complementary roles of satellite and in situ observations, the requirements for socio-economic data, the production of integrated gridded datasets and data access. In this section, we also briefly discuss political issues concerning the relevance of climate data to global security and the need for regional equity and capacity-building in the collection and management of climate observations.

3.1.1 Climate monitoring

Many decisions in society depend upon the prevailing climate of the region of interest. For example, airports should be located in areas where wind shear is relatively infrequent, different crops should be grown in different climate zones and dams should be built in catchments that have regular rainfall. The key element in having confidence in knowledge about the prevailing climate of a region is through analysis of long-term, high-quality observation records. Thus, there is a fundamental need for systematic and sustained climate observations across the world.

These systematic observations are needed not only for local and regional applications, but also to support research and analysis relevant to the various components of the global climate system. Global climate change provides a specific challenge for climate monitoring, not only through the need for global coverage, but especially because the rate of change of climate variables (such as temperature and rainfall) tends to be small compared with the background noise of natural climate variability. Thus, particular attention to the quality and consistency of observations is needed, and for this purpose GCOS [1] has developed a set of Climate Monitoring Principles to guide the collection, archiving and analysis of observations for climate monitoring.

3.1.2 Operational climate prediction

Meteorologists provided the first science-based prediction service for communities. From the start of the twentieth century, there was a focus on short-term weather prediction, where the current state of the atmosphere gives a reasonable first estimate for the future, that is, persistence of current conditions. The development of supercomputers has been closely aligned with progress in numerical weather prediction over the last fifty years. The accuracy of future predictions of the atmosphere is critically dependent upon the accuracy and scope of observations of the past and continued observations of the current state of the atmosphere [3].

Even while weather prediction was under early development a century ago, it was recognized that there may be predictability in the slower modes of the climate system, especially through phenomena such as the Southern Oscillation [4]. Systematic observations helped clarify the important role of the ocean in driving seasonal to interannual variability in the coupled atmosphere–ocean climate system. Particularly over the last thirty years, seasonal climate prediction has become an accepted public (and commercial) service in many parts of the world. Accurate specification of the past state of the atmosphere, ocean and land surface is needed to assure the accuracy of climate predictions.

There is an increasing need in society for information about the future state of the climate system some years and even decades ahead. This need is leading to the development of decadal prediction systems [5] that attempt to account for slow changes in the climate system to support applications such as estimates of future energy demand for heating and cooling in cities. Such prediction systems will place even more demand on the need to enhance the range of climate variables that are observed systematically.

3.1.3 Research

In Section 3.2 we consider the observation needs for research. Here, however, we need also to emphasize the role of research in assuring the quality and integrity of all climate observations. Climate research underpins all aspects of the collection, archiving, analysis and application of climate data [6]. The quality of climate observations is assured through associated research that ensures that the instrumentation and measurement techniques are appropriate and that the data are interpreted correctly. The scope and accuracy of climate forecasts are dependent upon research to develop and assess climate prediction systems.

Research using sustained climate monitoring data provides information on the operation of the overall climate system, as well as maintaining the quality of the observing system. In order to understand the basic processes associated with the climate system, research also requires project-based high quality climate observations, which may be collected through field studies of limited duration.

3.1.4 Satellite and in situ observations

The increasing capabilities and number of Earth-observing satellites are providing corresponding increases in the range and number of climate data available to support climate services and research. It is important to ensure that these data are readily accessible to all nations for application at all levels. However, it is also important that the increasing amount of satellite data is complemented by in situ observations, which are needed both to calibrate and evaluate remotely sensed data and to provide high quality data at high spatial and temporal resolutions to support local monitoring and analysis. Moreover, a number of the GCOS Essential Climate Variables, such as the wind near the land surface, or salinity and temperature profiles in the oceans can only be measured from in situ instrumentation.

3.1.5 Integrated gridded datasets

While the climate records at specific sites are essential as the basis of climate science and applications, we need to know the spatial variations of variables such as wind, temperature and rainfall across a region for many purposes. Such mappings or analyses involve interpolation between the sites where climate observations are taken, and they need to be prepared using consistent methods of interpolation to produce gridded datasets. Furthermore, the analyses of different variables should be dynamically consistent, so that the datasets can be considered to be integrated in the sense that the variations in one variable are consistent with those in all the other variables. Over the last twenty years, the technique of reanalysis [7] has been shown to provide integrated gridded datasets, which are spatially and temporally consistent. Global reanalysis has become an essential element of international climate science, requiring very substantial resources and cooperation and providing valuable products for both research and application communities.

3.1.6 Socio-economic data

The value of climate data to societies has long been recognized, and the analysis of such data is routinely used to optimize public and commercial decision-making. However, as an increasing number of societal activities and natural systems are found to be affected by climate fluctuations, there is an increasing demand for data associated with the dependent phenomena. These concomitant data are often socio-economic in character and not readily available or accessible. It will be important for societies to monitor a wide range of socio-economic variables so that the impacts of climate variability and change on human systems can be properly assessed and managed.

3.1.7 Data access

Climate data, observed from either in situ or satellite platforms, are collected by individual countries or unions of countries. It is sometimes argued that these data should be treated in economic terms as private goods in order to recognize their commercial value. However, careful analyses suggest that climate data are best treated as public goods [8], where the value of any one country's holdings is enhanced when combined with the holdings of other countries. On this basis, the UNFCCC recognizes the public good nature of climate data and requires the Parties to the Convention to promote access to and exchange of climate data. Similarly, WMO and IOC promote the free and open exchange of data among Member states and territories.

Despite these requirements and exhortations to share climate data, there remain impediments to data access in some regions. While the impediments are sometimes due to misunderstandings of the economic value of pooled data, they are often associated with the resource (human, technological and scientific) limitations of some countries. Concerted international efforts are needed to ensure that historical climate records are transferred to digital format and that climate records are analysed and receive proper quality control. In order to maximize the benefit from national climate records, each country should have at least the capacity and capability to collect, and analyse its own climate data exercising quality control. These activities need to be carried out in a cooperative and consistent manner so that both the data and the analyses can be readily compared across regions and across the world [9].

A policy of open access to climate data needs to be supported by the technology and systems to ensure that the data are readily accessible. The WMO Information System (WIS) is the coordinated global infrastructure for telecommunication and management of weather, climate, water and related data. It is being designed to meet the global requirements for routine collection and dissemination of observed data and products, and it will support data discovery, access and retrieval services. The WIS will also be the core component of GEOSS for weather, climate, water and disaster SBAs.

3.1.8 Global security

Stable societies depend upon the availability and quality of a number of basic natural resources that are significantly affected by climate. These resources include fresh water, land suitable for agriculture, fibre, food and energy. Geographical differences in the global distributions of these resources provide challenges for global security, as countries strive to manage their natural resources while interacting with their neighbours. It is apparent that global climate change is affecting the distributions and quality of these sources, and so it will be important that such changes are recognized and managed by all countries [10].

Economic and political security across the globe will require an understanding of the nature and magnitude of climate variations and changes. This understanding will be based on continuing observations of climate on global, regional and national scales.

3.1.9 Regional equity and capacity-building

Climate data are vital to communities at all levels of development. For this reason, virtually all countries in the United Nations General Assembly are Members of WMO. However, the best endeavours of many countries with limited resources to collect and share data fall short in providing the data needed both to satisfy their national needs for climate services and their aspiring contributions to regional and global monitoring of climate. To attempt to remedy this situation and facilitate the participation of developing countries in systematic observation, the UNFCCC invited the GCOS Secretariat to organize a series of regional capacity-building workshops. Between 2000 and 2006 the GCOS Secretariat held workshops in ten developing regions of the world. These workshops helped participants from some 180 countries identify deficiencies in their climate observing networks and the priority observing system needs of each region.

Subsequent to each regional workshop, GCOS assisted each region in the development of a Regional Action Plan. All GCOS Regional Workshop Programme Reports and Regional Action Plans may be accessed through the following Website: http://www.wmo.int/pages/prog/gcos/index.php?name=rwp. Collectively, these Action Plans contain summary proposals of over 115 projects addressing priority observing system needs. Common needs include sustaining and improving operational observing networks; recovering historical data; improving national and regional coordination; education, training, and capacity-building; and national planning and reporting. However, even three years after the workshop programme concluded, and despite repeated calls by the Conference of the Parties to the UNFCCC to assist developing countries, implementation of the GCOS Regional Action Plans has been only marginal in most regions. The biggest challenge is the lack of adequate funding. Clearly, much remains to be done, and, as the recent *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008* [11] points out, capacity-building support remains small in relation to needs. The value of climate data to nations as well as to the global community, means that efforts to assist all countries to monitor their climate and to analyse the associated data must be improved and sustained.

While the collection and analysis of climate data is important for supporting many national activities, there are increasing numbers of international requirements for systematic climate monitoring. For example, the UNFCCC has recognized the contribution to global emissions of greenhouse gases from deforestation, and a project, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN–REDD), has commenced. Activities such as UN–REDD and the global monitoring of greenhouse gas emissions are leading to the need for systematic climate observations based on international agreement or regulation.

3.2 Sectoral needs

It is useful to consider the needs for climate data in a range of community sectors. In fact the applications of climate data continue to grow, so the sectors considered here should be treated as examples. We first discuss sectors identified for special consideration at World Climate Conference-3.

3.2.1 Human health

Climate is a major determinant of human health; that is, as the temperature and humidity moves outside relatively narrow bands, the well-being of humans is reduced. Health effects can be direct, such as through increased heat stress in periods of sustained high temperature, or indirect, such as through respiratory diseases induced by particulate pollution in the air, through changes in the distribution of insects and animals that carry human diseases and through changes in water quality. In some regions, these impacts on human health are expected to be exacerbated in a changing climate [12].

As many health effects tend to be quite localized, it is important that climate observations are maintained at local scales, especially in urban areas. These climate observations include not only physical variables such as temperature and humidity but also chemical variables such as sulphur dioxide, oxides of nitrogen and aerosols. Such observations need to be analysed in conjunction with concomitant health data.

3.2.2 Energy

In many regions the local climate has a substantial impact on the availability and use of energy. Hydroelectricity is a source of energy in some mountainous areas. As global warming is starting to influence the seasonal cycle of snow and glacier melt, the operation of such power plants is being affected. Wind and solar power generation is clearly dependent on climate information, both for selecting sites for infrastructure and for sustained operation [13]. Decadal-scale climate fluctuations or climate change shifts may affect the long-term efficacy of wind and solar power sources in some regions. Thus, climate prediction is becoming an important capability in the management of natural sources of energy where energy availability varies with weather and climate fluctuations.

Energy is used to mitigate the effects of climate on communities through artificial heating and cooling systems. As regional warming becomes discernible, energy usage in summer is expected to increase, and the power industry will make use of climate models to provide estimates of the associated changes in seasonal loads. Climate information is also needed for the design of energy efficient buildings for all seasons.

The continuing quest for alternative fuel sources is leading to increasing reliance on biofuels. While first generation sources are questionable on several grounds, second generation sources from crop and forest products are dependent upon equitable climates. Third generation sources may be grown in regions where the climate and water quality are not optimal for conventional crop and forest production. Hence, climate information will be essential to decision-making on where best to locate biofuel sources.

3.2.3 Fresh water

In many regions of the world, the availability of fresh water is becoming an important limiting factor on the development of communities. Water resources control grazing patterns and crop irrigation, and influence inland fishing and aquaculture capacity. Moreover, waterways and lakes are often key elements of transport and communications infrastructure. While some of the local challenges can be attributed to past practices in water management, it is clear that decadal-scale variations and secular changes in regional climate are now affecting water availability in some regions [14]. Changes in transboundary water resources are an increasing source of tension between countries. Tensions arise both from scarcity and from the problems of managing excess. Flood risk forecasting across national boundaries, whether from rivers or lakes, is difficult enough under stable climatic conditions; changes in climate and the ability to predict their consequences are increasing concerns. While transnational issues are a concern for the international community, similar regional tensions can occur in individual countries where access to fresh water varies across the country.

The increase in evaporation associated with continuously rising temperatures will need to be recognized and managed in the future. This and other climate impacts will interact with societal decisions on water rights and water use, both within a nation's territory and among regional neighbours.

Monitoring of climate variables associated with the availability and quality of fresh water requires systematic observations of the basic atmospheric variables, such as precipitation, temperature and wind, as well as hydrological variables that characterize the storage and movement of water at the land surface. The atmospheric variables allow the flux of water across the atmosphere–land interface to be estimated accurately, while the hydrological variables such as streamflow and soil moisture allow the water budget across catchment areas to be calculated. Given the increasing use of groundwater for human consumption in many parts of the world, it is important to place greater effort on the monitoring of groundwater storages and changes.

3.2.4 Biodiversity and natural resource management

In considering biodiversity and natural resource management, we focus on natural ecosystems and the particular role of forests as a natural resource. To a first approximation, vegetation (and associated ecosystems including the full range of biological diversity) can be estimated through reference to the local climate alone. Thus, it is clear that natural ecosystems are very responsive to variations and changes in climate [15]. In many areas of the world, natural ecosystems are threatened not only indirectly by changes in local climate but also by direct human activities that change the local use of the land. In order to understand and properly manage these complex interactions, it is necessary to make systematic observations of the climate, ecosystem functions and relevant human activities.

Forests cover about a third of the Earth's land surface, and they play an important role in regulating the climate through their influence on energy, water and gas exchanges with the atmosphere. They also play an important role in our social, cultural and economic lives. Forests are home to tens of millions of humans and are the richest reservoirs of biological diversity on the planet. They are dependent on climate for their distribution, notwithstanding human attempts to clear them. Drought, changing fire patterns, increased wind-throw from storms, changing populations of attacking insects and retreating permafrost all affect the distribution of forests.

Accurate information on climate is therefore vital to determine threats to these essential ecosystems. The distribution of the forests is increasingly being taken into consideration as a climate controlling, and even a climate change mitigation, factor. Monitoring and prediction of climate will be vital for these strategies, such as the UNFCCC activity on reducing emissions from deforestation and forest degradation in developing countries (UN–REDD), to be effective.

The consideration of natural ecosystems needs also to include the marine environment, which supports a range of services, from fisheries to tourism. Many of these ecosystems and their associated services are under threat from human activities, including the runoff of chemicals from coastal land areas and the gradual increase in temperature associated with the enhanced greenhouse effect. Monitoring of these ecosystems requires systematic observation of key physical, chemical and biological variables.

3.2.5 Sustainable cities

In many countries, there is a trend towards increasing urbanization, so the impacts of climate variability and trends on urban areas need to be well understood. Detailed climate observations and the associated socio-economic data need to be collected systematically and analysed carefully to ensure that optimal strategies are developed to manage climate impacts. Issues to be understood and managed include:

(a) The impact of urbanization on regional climate;

(b) Building design to mitigate and adapt to climate changes;

(c) Urban planning to optimize energy use, especially for transport;

(d) Human health impacts of air quality and physical climate changes;

(e) Management of water supply and drainage systems;

(f) Urban planning to mitigate and adapt to sea-level rise;

(g) Urban planning to provide security against fire and flood risks;

(h) Transport and communication corridors between urban areas and between rural communities and urban areas;

(i) Security and efficiency of electricity services.

In many instances, the value of climate data relating to urban areas is greatly enhanced when combined with socio-economic information on human activities in the region.

3.2.6 Food security

For millennia humans have used knowledge of the seasons to grow crops to support stable communities. While modern technology and wealth mean that some communities are able to overcome many of the challenges of local climate, agriculture in most parts of the world remains vitally dependent upon regional rainfall to support both irrigated and rainfed crops. Irrigated agriculture accounts for about 70 per cent of all freshwater consumption worldwide, and more than 80 per cent in developing countries. Improved climate forecasting has the potential to greatly enhance agricultural productivity and to support the sustainability of agriculture on marginal lands.

The challenges for agriculture are being exacerbated in some regions as climate change modifies the local temperature and rainfall regimes [16]. Moreover, limited land availability, combined with rising human population, continually forces agriculture into more marginal land. The location of land suitable for grazing or for crop production will change as climate changes, and the need for forecasting or early warning of herd collapse or crop failure due to drought (or heavy rain and wind-throw) or shifts in disease incidence (plant and animal) is already very real. Long-term monitoring of basic climate variables, related to the fluxes of energy at the surface, is essential if we are to plan for changes in the location, extent and productivity of agricultural and grazing lands.

3.2.7 Disaster mitigation and management

As the global population increases and as urbanization increases, human settlements become more exposed to threats of natural disasters. Much urbanization tends to be in coastal areas, and this process exposes populations to sea-level rise, storm surges and tropical cyclones in the sub-tropics. About 46 million people currently live in flood-prone areas, and sea-level rise could double the number of people at risk over this century. There is evidence that, associated with climate change, rainfall over land is becoming more intermittent and heavier, and this trend could increase the threat of flash flooding and other storm damage. Wildfires and their catastrophic consequences for urban settlements are of increasing concern [17], where climate affects not only fuel loading and condition but also intensity, spread and even ignition.

In order to understand vulnerability and manage weather-related extreme events, it is vital to have good quality climate records. Because extreme events are infrequent (by definition), these records need to be long-term and temporally homogeneous.

3.2.8 Climate change mitigation and adaptation

The GCOS Implementation Plan of 2004 specifies the global observing system required to meet the needs of the UNFCCC, and thus to support activities to mitigate and adapt to climate change. That plan, while focused on the global-scale requirements, emphasizes the need for regional and national climate networks to ensure that appropriate data are available to develop strategies for managing climate change at these smaller scales.

The capability to manage climate change tends to be linked to the state of development of a nation. Climate change impacts are expected to be significant in many less developed countries. In order to promote regional equity in the capability to manage climate change, it will be important for capacity-building and technology transfer processes to be utilized to ensure that all countries can collect, analyse and share climate observations.

Recognizing the importance of the need to consider and prepare for the impacts of climate change, the UNFCCC initiated the Nairobi Work Programme on Impacts, Vulnerability, and Adaptation to Climate Change in 2006. In response to the UNFCCC call for information on the role organizations could play in implementing this work programme, the GCOS Secretariat provided information on the role of observations in support of adaptation. The design of effective adaptation strategies, GCOS noted, will depend in many instances on the ability to accurately predict future climate variability and change, using methods, including regional models, to downscale global-scale predictions. Such methods, however, can only be used when detailed regional observations are available. Thus, adaptation responses require denser observing networks than needed for global models.

Observations are critical to validate the accuracy of models and to improve them. However, at the present time, in many countries neither the quality nor quantity of observations needed by global and regional models used to predict climate are adequate to support and verify the models so as to allow the reliable projections needed for adaptation purposes. In order to meet adaptation needs, models will need to be improved and observation networks and data use strengthened, especially in vulnerable areas. In many instances, countries will also need to be convinced of the benefits of sharing their national level data for use in regional and global models. There is also a tendency for many to use the available models without a thorough understanding and appreciation of the uncertainties and constraints associated with their use; hence, training in the management of data and the appropriate use of models and model outputs is also a necessity.

The UNFCCC is also encouraging thinking about adaptation by promoting the development of National Adaptation Programmes of Action. About 40 least developed countries to date have drafted such plans, but few have considered observing system issues. It would be useful for such issues to be considered when developing or refining NAPAs and national communications reports.

3.2.9 Research

Observations are critical to research aimed at understanding and predicting climate at scales from local to global. Indeed research is required to manage human activities in all the sectors mentioned in this paper. However, while researchers make use of all climate data collected to support economic and societal sectors, they have additional needs for climate data.

These needs can be at the small scale, where field studies are used to clarify the details of specific climate processes, such as cloud–radiation interactions. The needs can also be for sustained global observations of variables, such as global cloud cover, that are needed to monitor and understand the overall climate system. Research often requires observations to be taken at greater precision or accuracy or frequency than needed for other purposes.

4. Summary and Recommendations

Climate data are usefully applied to many economic and societal sectors. Because the number of sectors continues to grow, the sectors treated in this paper should be considered as examples. The sectors discussed include the key areas of human health, energy and water. The special needs for research and for the development of strategies to mitigate and adapt to climate change are also considered.

(a) Sustained, high quality and uninterrupted climate observations are vital for the development of all countries, because climate variability and change impact significantly on economies and societies.

(b) The full implementation of the Global Climate Observing System is required to ensure that countries are able to understand and manage climate variability and change over the twenty-first century.

(c) Climate data should be recognized as public goods, where the value of any one country's holdings is enhanced when combined with the holdings of other countries. A particular example of the value of data sharing is in the opportunities presented by the development and application of regional modelling and other downscaling methods in the design of adaptation strategies.

(d) The operation of climate networks at national, regional and global levels depends upon continuing research and development to assure the quality of the overall system and to optimize the benefits from the observations.

(e) All countries should be encouraged to give high priority to national needs for observations in their national adaptation planning. For example, a section on climate observing system needs should be included in National Adaptation Programmes of Action when these are prepared or revised.

(f) The Regional Action Plans prepared during the GCOS Regional Workshop Programme address important priority observing system needs in their respective regions. However, few of the projects contained in the plans have been implemented to date, and many will likely need to be updated and/or elaborated. Every effort should be made by developed countries to assist in funding the Regional Action Plans projects. In general, support for capacity-building should be increased in developing regions, and developed countries should make a long-term commitment to assist developing countries in maintaining their observing networks.

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