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**WORKSHOP ON CLOUD PHYSICS AND CLIMATE**

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# CLIMATE SYSTEM MONITORING

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ABSTRACT

This paper describes the Climate System Monitoring (CSM) Project of the World Climate Data Programme (WCDP) which was initiated in 1984 following a recommendation of the 9th Congress of the World Meteorological Organization (WMO) in response to the occurrence of significant climate system anomalies over the last several years with associated economic impact estimated at 10-20 billion US Dollars (world wide). The project is co-sponsored by UNEP/GEMS.

CSM is designed to provide Meteorological and Hydrological Services and other national and international organizations with synthesized information on the state of the climate system (atmosphere - ocean - biosphere - solid earth), and diagnostic insights into significant large-scale anomalies of regional and global consequence. A CSM - Monthly Bulletin has been issued by the WMO since July 1984. A first critical review of the global climate system has been recently undertaken with an emphasis on climatic events over the 3-year period 1982-1984.

Briefly summarized are the data observing, exchange and processing systems coordinated by WMO, operated by Member countries, and from which regular diagnostic analysis are made in order to monitor anomalies. Also highlighted are the significant climatic anomalies which occurred over the period 1982-1984 and cause-effect relationships as possible with our current understanding of the physical processes involved in short and medium term climatic variations. The manner in which the CSM bulletins, climate system reviews and associated global data bases may be used by national and international organizations is also covered.

* The views expressed in this paper are solely those of the author and do not necessarily represent the position of the WMO nor of any other organizations associated with the World Climate Programme.



## 1. INTRODUCTION

Observing the complex climate system requires the measurement of several parameters which collectively describe the state of the system. Measurements taken over a period of time, on a global basis, enable the construction of the history of climate, and studies on climate trends, climate variability and the interactive processes which are involved in causing such changes. The understanding of these processes is vital to formulating the physical-mathematical description of the climate system in numerical models. Beyond time scales of a few days or a week, it becomes important to consider the "total" climate system (atmosphere-ocean- cryosphere land surface).

Due to the multi-disciplinary nature of the climate system, concise, easily readable information needs to be made available to research scientists and technical/managerial/government personnel. As a priority requirement it is considered necessary that a mechanism be formulated, relying on existing research/analyses/operational centres, to compile and disseminate summarized information on the present status of the climate system; changes from past years; indication of trends; and significant events of regional and global consequence.

## 2. CLIMATE SYSTEM COMPONENTS AND PROCESSES

The Outline Plan and Basis for the World Climate Programme (WMO-No.540) defines the climate system as comprising the atmosphere, oceans, cryosphere, land surface:

- THE ATMOSPHERE is the most variable part of the system. The troposphere has a characteristic response or thermal adjustment time of the order of one week while the stratosphere and higher layers of the atmosphere have quite different processes and time scales.

- THE OCEANS in the upper layers interact with the overlying atmosphere or ice on time scales of months to years, while the deeper ocean has a thermal adjustment time of the order of centuries.

- THE CRYOSPHERE, which comprises the world's ice masses and snow deposits, includes the continental ice sheets, mountain glaciers, sea ice and surface snow cover. The changes of snow cover and the extent of sea ice show large seasonal variations while the glaciers and ice sheets respond much more slowly.

- THE LAND SURFACE is here taken to comprise the land masses of the continents, including the mountains and plains, surface rock, soil and vegetation as well as the lakes, rivers and groundwater, which are important components of the hydrological cycle. They are variable parts of the climate system at all time scales. The Earth's surface is an important source of airborne particulates which may be of climatic significance. The soil, in turn, evolves in response to climate and vegetation.

The climate system components are interactively coupled, and thus internal and external processes also need to be considered under climate system monitoring (see Figure 1). Of particular interest are changes in the mean state (or variability) of climate, leading to a redistribution of weather patterns. Climate fluctuations are due to: internal instability or feed back processes; changes in external forcing functions; and man-made or anthropogenic alteration (e.g. through the emission of $CO_2$ and other radiatively active gases).





## 3. CLIMATE SYSTEM FLUCTUATIONS AND THEIR EFFECTS

Climate system fluctuations and their consequences on time scales from weeks to decades and more are briefly described below to provide perspective to aspects of climatic variability which may need to be dealt with . It is underscored that a linear separation of phenomena according to time-scale (for discussion purposes) does not preclude significant interaction between them. Slowly varying fluctuations can modulate higher frequency phenomena and vice-versa.

- One day to a few weeks: weather, effects of which are immediately felt by people, is but a short-term atmospheric system fluctuation due to internal instability processes that aim to re-establish mass, momentum, or heat balance on certain space-time scales. Social and economic impact due to extreme weather events can be high but are usually localized (e.g. wind bursts, flash floods, tornadoes, hurricanes). On a synoptic scale atmospheric models can make predictions up to two weeks. Boundary conditions or coupling with the land surface, hydrology, cryosphere and ocean becomes important beyond the weekly time-scale. Partial longer-term atmospheric memory may exist, indirectly, through the positioning of long-wave systems in the atmosphere which are geographically determined for dynamic and thermodynamic reasons; and for example through the modulating effect of 30-60 day oscillations.

- Months to one year: The annual cycle is strongest in this time range, determined largely by the orbital position of the earth with respect to the sun. The change from summer to winter is due to the tilt of the earth's axis from its orbital plane; the climate system responds to this annual fluctuation in solar radiation (all well known facts). Predicting the severity (cold/ wet, hot or dry) of the next season, however, is not simple. Processes which integrate recent history (e.g. months to a year) with present system state need to be taken into account. Effects are larger (entire national economies can be affected) and the space scale is regional or global.

- One year to 10 years or more: Inter-annual variability involves more components and processes of the climate system. Atmosphere-ocean coupling is of particular significance (e.g. Warm Pacific SST anomalies and the occurence of El-Niño/Southern Oscillation (ENSO) Phenomena). Anomalies associated with ENSO can be persistent (12 to 18 months) and affect large areas of the world (Rasmussen & Carpenter, 1982, 1983). The recurrence period of ENSO events is about 2-7 years. Phenomena such as the quasi- biennial oscillation (particularly its phase) may be of importance. Other fluctuations (of longer-time scales) and external influences may be significant through their modulating effect on atmospheric motion. For example there is evidence that solar activity, lunar effects (gravitational) are related to wet/ drought sequences of fairly long duration (Eddy, 1976 and Mitchell, 1976). The El-Niño signature is also apparent in changes in the earth's angular momentmum (rotation speed/day length). Atmosphere-cryosphere and atmosphere- vegetation/biomass/land surface interaction are likely to play a part in determining variability in the decadel time scale. Economic impact can be substantial (estimated at over 10 billion dollars for the 82-83 El-Niño event). Also of relevance may be mass transports within the fluid core and coupling between the core and mantle which could affect the angular momentmum of the solid earth; assuming conservation of angular momentum, the atmosphere/ ocean could respond to compensate for changes in solid earth rotation speeds.





- 10 to 100 years: Changes in this time scale are usually designated as long-term climate trends - fluctuations here could be influenced by solar radiation variability; increasing concentration of $CO_2$ and other radiatively active gases, aerosols (and the frequency of volcanic activity), interactions with the cryosphere (ice albedo feedback); deep ocean circulation. Impacts are likely to be substantial - wide-spread disruption and dislocation of societies can occur if "anomalous" conditions persist for many years. The situation is further complicated by interaction between climate changes and social practice (e.g. overgrazing, deforestation, desertification) which could affect albedo, moisture recycling mechanisms, radiation balance and consequently climate. Ocean and ice interactions and ocean-atmosphere interactions are significant, as are solar and gravitational influence.

- 100-1000's of years: History documents rather drastic consequences of climatic fluctuations of this time scale. Entire civilizations have been forced to relocate or have been eliminated. Evidence points to major sea-level changes and large-scale floods. Thus the ice-ocean and ocean-atmosphere interaction processes appear to play a dominant role. $CO_2$, solar activity and orbital parameter fluctuations are also likely factors. Volcanic activity may also have played a role.

- Millions of years: Fossil and paleoclimatic records point to catastrophic changes approximately every 25-30 million years which were involved with the mass extinction of entire species on the earth. For example the Dinosaurs which existed for over 100 million years (mankind has thus far managed a mere 5 million years) were rather abruptly terminated. Several theories exist - most refer to impact with large comets or asteroids (detected by an abnormal enrichment in iridium or other noble metals) which caused an expulsion of terrestrial dust to such a scale that sunlight was blotted out; or that an unseen companion star to the sun (yet undetected black hole or brown dwarf; Marc Davio et al., 1984) in a highly eccentric orbit initiated intense comet showers. Some evidence (e.g. Mammoths which were instantly frozen and recently excavated in frozen, not fossilized, state) points to abrupt shifts of the earth's axis. A third scenario refers to the large rise and fall of sea level (along with changes in ice cover/extent) which is supported by evidence of extensive black shale deposits, possibly through the extinction of biota by anoxia (A, Hallam, 1984).

Clearly, the inter-annual to decadal (and up to 50-100 years) is of particular interest for climate change which may result from anthropogenic alteration through, for example, the emissions of $CO_2$ and other radiatively active gases. Planning for the future should begin now! The development of technological and policy option requires significant lead time, and besides, implementing policy on alternative energy producing and end-use technology normally takes 20 to 50 years.

## 4. THE EXISTING GLOBAL CLIMATE OBSERVING, DATA EXCHANGE AND PROCESSING SYSTEM

Through international cooperative agreements between Member states, the World Meteorological Organization (WMO) coordinates the operation of a composite Global Observing System (GOS) comprising:

- o Land surface stations (approximately 700 Upper Air and 3500 surface synoptic meteorological stations);
- o A geostationary and polar orbitting meteorological satellite system:
- o Data observing platforms such as ships, aircraft, ocean buoys.





Jointly with UNESCO's International Oceanographic Commission (IOC) WMO coordinates the observation and exchange of oceanographic data. With support from the Global Environmental Monitoring System (GEMS) of the United Nations Environmental Programme (UNEP), WMO operates and coordinates the Background Air Pollution Monitoring Network (BAPMoN).

WMO also coordinates:

- o The Global Telecommunications System (GTS) for the international exchange of data;

- o The Global Data Processing System (GDPS) where the global data exchanged 2 to 4 times per data are assimilated by large computers (e.g. CRAY-XMPs, CYBER-205s) at major centres , and processed. From these centres, forecasts and analysis products are distributed, via GTS to Member countries.

Global data are stored, for research and applications use, at internationa centres such as the:

- o World Meteorological Centres (WMCs - Melbourne, Moscow, Washington-DC);
- o WMO centres for Ozone and Surface Radiation data (Canada, USSR respectively)
- o International Council of Scientific Unions (ICSU), World Data Centres for Meteorology, Oceanography, solar terrestrial and geophysical data.

5. MONITORING THE CLIMATE SYSTEM

To monitor the climate system, the following sub-set of monitoring elements are proposed:

- o Atmospheric structure: global analyses based on currently exchanged upper air data (on GTS). Included should be anomaly fields of selected variables (at specified levels) such as wind, temperature, moisture, pressure, geopotential, streamfunction, velocity potential; and time series information from a few key stations or time series of indices;

- o Ocean: Sea surface temperature (SST) fields (using satellite estimates and ship observations), and time series of SST indices which are indicators of major climatic events (e.g. El-Nino, Southern Oscillation); sea-level, near-surface currents, deep ocean circulation (as available).

- o Cryosphere: Information on snow cover, sea ice, sea ice boundaries, sea ice thickness, elevation of continental ice sheets and glaciers, ice sheet boundaries, ice sheet thickness, movement of ice sheets and glaciers; and information (grid fields) as obtainable from satellite observations;

- o Land surface, hydrology and vegetation: Information, in addition to precipitation, on for example water run-off/streamflow, soil temperature, soil moisture, vegetation cover, deserts/desertification, water storage (snow, lake, etc.);





- o Precipitation: Representative global fields of precipitation are not easy to obtain, even over land areas, on a routine basis. Coverage over oceanic areas pose special problems. However, quantitative information (using ground based and satellite derived measurements) and anomaly fields are useful, including time series of precipitation indices;

- o Radiation budget: Selective information on planetary radiation budget components (albedo, emission), equator to pole gradients, solar constant, solar UV flux, surface albedo;

- o Atmospheric composition: Summarized information on $CO_2$, chlorofluoro carbons, ozone, stratospheric/ tropospheric aerosols and turbidity as available.

6. THE CLIMATE SYSTEM MONITORING (CSM) PROJECT OF THE WORLD CLIMATE DATA PROGRAMME (WCDP) OF WMO

The monitoring and study of the climate system and associated interactive processes is complex and multidisciplinary. Accordingly the CSM Project of the WCDP has been formulated to: (a) coordinate activities and (b) provide information to specialists and international organizations so that significant events and changes are brought to their attention expeditiously and in a simple concise form. It is expected that this will also foster a better awareness of climate and of research which must incorporate aspects of other disciplines outside the mainstream of each individual field of research and analyses.

Under the CSM project four types of activities are being carried out, with associated output products:

(i) The issue of a Monthly CSM Bulletin: This bulletin contains as a standard feature (for the reference month) a global analysis of temperature and precipitation anomalies and statistics by region and country which indicate the persistence of hot/cold, wet/dry events. Also included are time-series of selected indices and detailed climate diagnostic information for the month before;

(ii) The issue of special advisories: Through monitoring the global climate system, if there are indications that a particular sequence of climatic events are likely to affect a particular country or countries in a region, a special advisory will be issued, contingent on the availability of relevant information from data analyses centres. An example would be the onset of an El-Nino event. Once established a special advisory would indicate the regions which are likely to be affected, and how, based on past occurences;

(iii) The issue of an Annual CSM Summary on the state of the climate system and significant large-scale anomalies. This would contain simple/concise text supported by a selection of standard products such as:

- globally analyzed fields (and anomalies) of surface temperature, sea level pressure, precipitation, surface and upper air (e.g. 500 mb, 200 mb) circulation/wind, sea surface temperature (SST), sea-level (sub-regions), satellite derived outgoing radiation/albedo/cloud, snow/ice cover; and as possible/available estimates of vegetation cover/biomass, changes in desert margins.





- time series of indices and area (key) averaged parameters of for example SST, sea level, snow cover, sea-ice, precipitation (selected areas e.g. drought prone); surface temperature (selected areas); trade wind index, zonal flow indices/blocking indices; aerosol, $CO_2$ and trace gases (selected stations); and as possible global angular momentum and earth rotation (day length) changes, solar activity, geomagnetic index (as relevant);

- measures (as possible) of proxy climate indicators (effects/impacts);

- statistics indicating the persistence of key climatic events (e.g. drought).

The annual issue will contain a combination of standard and non-standard products. For the reference year, globally analyzed fields and anomalies will generally pertain to seasonal averages (and deviations); e.g. summer/winter. Time series will cover several years to provide perspective to significant anomalies. Aperiodically, special topic/event/climate-system-discipline reviews will be included, prepared by specialized centres. Examples are effects of orbital parameter changes, paleoclimatology (tree ring/ ocean sediment based climate reconstructions - leading to present times); glaciology (glacier and ice sheet fluctuations and climate change - mini ice ages); past $CO_2$ fluctuations (reconstructions from proxy data) and apparent effects. These special articles would provide a reference to the state of the present climate system.

(iv) Biennial scientific reviews, which comment on significant anomalies, causes/teleconnections, and consequences of social and economic significance. The first such review was issued in June 1985 entitled "The Global Climate System - A Critical Review of the Climate System during 1982-1984". This review also provided a scientific basis for monitoring the climate system.

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