3. CLIMATE DIAGNOSTICS

3.1 INTRODUCTION

Many of the large-scale and long-term processes associated with climate fluctuations are only poorly understood. In part, this situation exists because general circulation and climate models do not as yet account fully, or properly, for all the physical processes that may be of importance for fluctuations in the climate. This inadequacy of the models stems largely from insufficient knowledge of the various dynamic and thermodynamic processes operating in the Earth-atmosphere system to produce climate fluctuations. In turn, much of this insufficient knowledge is related to incomplete or inaccurate observations of climate parameters over the globe.

There exist long records for measurements of surface (air) temperature, surface winds, surface pressure, precipitation, and other weather elements over well-populated land areas, but very meager records exist for such measurements over sparsely populated land regions and over vast areas of the oceans, particularly in the tropics and the Southern Hemisphere. When records of other quantities are considered, the situation is worse. Relatively good records of tropospheric and stratospheric temperature, pressure, and wind have been built up over the past 30 to 35 years, but, again, these have been deficient in measurements over large portions of the globe. The worst situation arises with regard to those processes that essentially drive the atmospheric and oceanic circulations, namely, the energy sources and transformations. Condensation and evaporation, sensible heat transfer between the surface and the atmosphere, radiation, heat storage in the oceans, transports of heat and momentum in the atmosphere and oceans have all been difficult to measure or derive from existing data networks.

As satellite observations fill in the data voids with global coverage of cloudiness, ice and snow cover, temperatures, winds, radiation budget, precipitation, etc., some substantial advances can be made in monitoring and understanding climate fluctuations. To obtain this understanding, the observations cannot be utilized solely to feed into general circulation and climate models. There must be an accompanying strong program in diagnosing climate fluctuations. This program means detailed studies of climate events, the main emphasis being the assemblage of a host of observations, to develop a clearer physical picture of the nature and causal interrelationships of the climate events. As various types of climate events are studied, physical understanding of the events will be clarified. This information will then lead to well directed efforts in developing better statistical methods for making predictions of climate fluctuations (i.e., long-range weather forecasts) and improving numerical climate prediction models.

There is a wide variety of climate phenomena to which this enhanced diagnostic effort can be profitably applied. Some of the more important phenomena and recommendations for understanding them, using ERBSS data, are given in the following section.

3.2 DIAGNOSTIC STUDIES

3.2.1 Middle and High Latitude Planetary Scale Atmospheric Processes

It is useful to describe the system of meandering jets and vortices that one observes on a weather map in midlatitudes in terms of an average westerly flow upon which are superimposed disturbances of various zonal and meridional scales. The largest spatial scale disturbances, which may be identified as planetary waves, also have long temporal scales of the order of weeks to months. These planetary scale disturbances to the westerly flow are the principal phenomena associated with interannual variations in regional climate (e.g., the unusual weather of 1977). They are believed to be forced by thermal and orographic contrasts between ocean and land surfaces. Their characteristically long time scales and relatively large temperature perturbations subject them to strong influences from radiative processes. Suitable diagnostic studies of the radiative energy budget of the zonal-mean westerlies and the planetary waves may then play an important role in improving one's understanding of regional climate variability.

An example of a phenomenon that has a particularly extreme and persistent effect on regional climate is the interruption of the normal westerly flow in a region by a strong (blocking) anticyclone. Blocking is associated with significant deviations from normal temperature and cloudiness and, thus, may be studied profitably with ERBSS data. For this purpose, the recommended horizontal resolution of 250 km for each day should be adequate, although 10 or more years of such data may be required to obtain enough cases since the time scale is long and the variability, large.

3.2.2 Major Circulation Systems in the Tropics

The major atmospheric systems in the tropics include the intertropical convergence zones, mainly in the Atlantic and central eastern Pacific at about 5° to 10° N; the equatorial cloud-free zones in the Atlantic and central and eastern Pacific;

the three "continental" regions of major convective cloudiness and rainfall over Indonesia, South America, and Africa; and the oceanic, subtropical anticyclones. These tropical systems, which are closely associated with the principal atmospheric and oceanic heat sources, are related to the behavior of such circulation features as the Pacific Walker circulation, the Hadley circulation, and the associated subtropical jet streams in both the Northern and Southern Hemispheres. Yet, until the availability of satellite radiation data, it was virtually impossible to study their behavior.

Satellite radiation data, including ERBSS, vertical sounders, and microwave sounders, are essential for monitoring cloudiness in these regions, including both its temporal and geographical variations, and for estimating the vertical structure of clouds. The latter is of paramount importance in determining whether feedbacks between clouds and the oceanic and atmospheric circulations are positive or negative.

Measurements of rainfall, sea surface temperature, and surface albedo must also be obtained in order to define the heat and energy exchange between sea and atmosphere. The primary short-term usefulness of such diagnoses would be in verifying the accuracy of and in providing input data to global circulation models. For this purpose, radiation components would have to be observed with high accuracy, with a resolution of at least 200 to 250 km, and in time intervals measured in hours or, at most, a few days.

The long-term utility of radiation data includes climatic monitoring of clouds in the major tropical atmospheric systems mentioned previously. Indices of tropical atmospheric circulation can be developed either locally in any one of these systems, or by use of the principal components of orthogonal functions. Time series of these indices will be useful in statistical prediction of short-term climate changes in various parts of the Earth. These longer-term data will also be useful in constructing meaningful climate models and as initial input data for these models. Spatial resolution of about 200 to 250 km seems adequate for these long-term studies. However, errors must be treated in a fashion different than those for short-term studies. Thus, fairly large random errors can be tolerated because these can be smoothed out by space and time averaging. It is more important to minimize absolute errors (bias or fractional errors) or else to make them uniform from one satellite system to the next. Perhaps the best way of achieving this goal is to compare the results of different satellite systems wherever they overlap.

The tropics, which constitute roughly half of the surface area of the Earth and account for more than half of the radiative interaction with space, exhibit some fairly regular variations in temperature and cloudiness over a diurnal cycle. Studies of the diurnal cycle using geostationary satellite data are essential to test the reliability of approximations using polar measurements.

3.2.3 Global Scale Energy Cycle

To diagnose key elements of the energy cycle (in particular, generation of available potential energy, heat, and momentum transport in the atmosphere and oceans), a time scale on the order of a week or two and spatial scales on the order of 5° to 10° latitude may be appropriate. ERBSS data will provide the critical energy balance at the top of the atmosphere. Use of these data in the estimation of the generation of available potential energy, for example, will require knowledge of the divergence of the radiative flux over the atmospheric column. In other words, the radiation balance at the surface, as well as that at the upper boundary, is required for this determination. Observations and theoretical-empirical studies suggest that the surface radiation budget can be inferred from the ERBSS data in conjunction with some supplementary information. The atmospheric radiative divergence, in conjunction with atmospheric thermal structure information available from conventional or sounder data, will allow for estimation of the radiative generation of available potential energy.

Heat and momentum transports by the oceans and atmosphere are essential parts of climate dynamics. Global meridional-annual distributions of ERBSS data will define the corresponding ocean-atmospheric transport. Finer scale structure over shorter time periods can be derived after specification of latent and sensible heat exchanges at the surface and across lateral atmospheric boundaries. ERBSS data and the derived surface radiation balance will provide the radiative boundary conditions for the atmospheric column.

3.2.4 Synoptic Scale Systems

With regard to time scales larger than two weeks, the transient synoptic scales are primarily identified with extratropical cyclones and anticyclones, tropical cyclones, cloud clusters, and traveling waves in the westerlies and easterlies. These phenomena play a primary role in the horizontal and vertical transport and conversion of energy within the atmosphere. Their intensity and frequency of occurrence with respect to fixed geographical locations determine, to a large extent, the prevailing circulation and temperature of the larger time scales.

In order to determine the influence of these features in climatic trends, it is important that the longwave and shortwave energy balance of such systems be evaluated over their life cycle in conjunction with the latent and sensible heat components.

Diagnostic studies of radiation quantities related to synoptic scale long waves are needed. In particular, budget studies related to location and behavior of the long wave and to variation in radiational responses of continents compared with oceans are of interest for climate and predictability studies. Of special interest are satellite-based studies of the horizontal and vertical distribution of clouds over oceans as compared with land in the various seasons.

3.2.5 Surface Processes

Radiation budget components, particularly the reflected or absorbed solar radiation values, are of great utility for monitoring the variations in radiative heating at the surface over all portions of the globe. Although combined physical-statistical relationships will need development to attain good quantitative estimates of surface radiative components, the satellite data provide most of the needed information. It is quite likely that direct usage of values of albedo or absorbed solar radiation can provide much quantitative information on surface energetics, particularly in terms of temporal changes or anomalies. Four basic areas of study of surface processes with radiation budget data are indicated.

Oceanic heating. Temporal and spatial fluctuations in albedo, or absorbed radiation, are related to fluctuations in solar heating received at the ocean surface. Where solar radiation is a primary factor (i.e., in the tropics and in the summer half-year elsewhere), these fluctuations are important in the rate of sea surface temperature change. Examination of absorbed solar radiation in conjunction with conventional and experimental surface measurements should provide better insight into the development and maintenance of some of the large-scale sea surface temperature anomalies of both temperate and tropical regions.

Ocean heat transports. When integrated over latitude circles, and utilized in conjunction with estimates of atmospheric heat transport and ocean heat storage obtained from other observations, Earth radiation budget data can be used to estimate meridional heat transports by the oceans (as Oort and Vonder Haar 1976, have shown with earlier data). Further estimates of this oceanic transport with forthcoming sets of radiation budget data, particularly with the First GARP Global Experiment (FGGE) and post-FGGE data sets, should be made and analyzed.

Variations in snow and ice. Temporal and spatial fluctuations in snow and ice cover have substantial influences on the surface and atmospheric heat budgets. Albedo, or absorbed solar radiation, and outgoing longwave radiation over regions of variable snow and ice cover should be excellent indicators of this principal heating influence on climate. Energy budget studies of large snow and ice regions can be carried on with the use of these and other available data, and the influences of these variations in snow and ice on the atmospheric temperature field can be better determined.

Variations in surface albedo associated with changes in vegetative cover and wetness. Values of albedo, or absorbed solar radiation, in the absence of clouds can be used to monitor various spatial and temporal variations in the surface energy budget over land areas. This monitoring can contribute to a better understanding of such problems as the advancement or retreat of grassland at the edge of deserts, and the consequent effects on changing the amount of solar heating made available to the atmosphere in such regions.

3.2.6 Influence of Aerosols and Trace Gases on Earth Radiation Budget Data

A considerable number of sensitivity studies dealing with effects of particulate aerosols on the radiation balance indicate that, in most cases, small, but significant, changes are likely. If these changes are wide enough on a spatial scale and persist long enough in time, then the Earth-atmosphere system will be affected by variations in aerosols. Stratospheric aerosols originating from volcanic activity may be prevalent for several years or longer; the well-documented eruption of Agung, in recent time, produced changes in the Earth's albedo estimated to be on the order of a few percent. Tropospheric aerosols in large concentrations, such as are seen streaming from the Sahara in satellite imagery, produce changes in the radiation balance that should easily be detected by ERBSS. The spatial scales of these aerosol systems range from regional to synoptic, and events are variable in intensity. Nevertheless, long-term trends in intensity have been documented and, therefore, a resulting change in regional climate is conceivable. The time scale of these trends is on the order of five years.

Aerosols over land surfaces are less conspicuous to satellite observations, but significant changes in the radiation balance have been theoretically estimated and, in some cases, determined experimentally from aircraft platforms. These aerosols could produce changes in the radiation balance that might be erroneously attributed to changes in cloudiness or surface cover; therefore, some supportive measurements should be made to clearly separate such possible ambiguities.

Changes in global CO_2 (increases), N_2O (increases), and O_3 (decreases) that may result from anthropogenic activities, i.e., increased coal burning as a source of CO_2 and increased usage of agricultural fertilizer as a source of N_2O and NO_x, should affect the radiation budget by means of surface temperature changes. However, the ability to sense surface temperature changes on the order of about $1^{\circ}K$ (corresponding to about 4 W/m^2) would be needed from future instrumentation in order to see these trace gas effects.

3.3 RECOMMENDATIONS

Following are two lists containing the Working Group's recommendations for (A) performing diagnostic studies using ERBSS data, and (B) making measurements of radiation budget and auxiliary data sets needed for these studies.

A. Recommended Diagnostic Studies Using ERBSS Data

(1) Space and time variations in radiative heating components at Earth's surface (principally solar component)

(a) Heating of ocean surface

(b) Deducing oceanic heat transport

(c) Snow and ice and their effects on atmospheric heating

(d) Heating of land surfaces and effects on atmospheric heating, including cloud influences and surface albedo changes

(e) Solar energy available at surface for crop growth and solar energy utilization

(2) Space and time variations in radiative heating components over tropical regions

(a) Intertropical convergence zone

(b) Continental compared with oceanic convection

(c) Monsoon circulations

(d) Equatorial dry zone and subtropical anti-cyclones

(3) Space and time variations in radiative heating components over extratropical regions in relation to the circulation and land-sea distributions (both surface and cloud influences)

  (a) Long waves and transient waves

  (b) Jet stream

  (c) Blocking anticyclones

(4) Atmospheric energy cycle variations

  (a) Hemispheric and global energetics

  (b) Regional energetics (e.g., Sahara)

(5) Diurnal variations in radiation-cloudiness using geostationary information

(6) Aerosol influences on radiation budget

  (a) Cognizance of volcanic eruptions

  (b) Studies of influence of dust in radiation budget

B. Recommendations for Radiation Budget Data Sets and Auxiliary Data

(1) Homogeneous radiative data set to continue for 20 years.

(2) Need for resolution as high as 200 to 250 km for studies 1 to 5 in List A.

(3) Maximum utilization of data from other sensors aboard TIROS-N in conjunction with studies using ERBSS data. In general, in all radiation budget studies, other pertinent data sets must be readily available.

(4) Need for estimating vertical cloud structure and radiative heating within the atmosphere in connection with most studies in List A.

3.4 REFERENCES

Oort, A., and T. Vonder Haar: On the Observed Annual Cycle in the Ocean-Atmosphere Heat Balance over the Northern Hemisphere. *J. Phys. Oceanogr. 6,* (1976), 781-800.