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A STUDY OF SURFACE TEMPERATURES, CLOUDS
AND NET RADIATION

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SEMIANNUAL REPORT

A Study of Surface Temperatures, Clouds and Net Radiation

The study is continuing and it is focussed on examining seasonal relationships between climate parameters such as the surface temperatures, the net radiation and clouds types and amount on a global basis for the period February 1985 to January 1987. The study consists of an analysis of the combined Earth Radiation Budget Experiment (ERBE) and International Satellite Cloud Climatology Program (ISCCP) products. The main emphasis is on obtaining the information about the interactions and relationships of Earth Radiation Budget parameters, cloud and temperature information. The purpose is to gain additional qualitative and quantitative insight into the cloud climate relationship.

In our previous study we analyzed Nimbus-7 Earth Radiation Budget and cloud data for the year (June 1979 - May 1980). Qualitatively the ERBE and ISCCP data have improved temporal sampling compared to the Nimbus-7 data. This study integrates the analysis of Nimbus-7 data set for the year (June 1979 - May 1980) of ERB and Cloud parameters with the ERBE and ISCCP data sets for two years (February 1985 - January 1987).

Based on our study A draft of the manuscript, entitled "Annual Cycle Correlations for the Earth Radiation Budget, Clouds, and Surface Temperature" was completed, copy of which is enclosed with this report. This manuscript represents the status of our study. The draft of the manuscript describes our study effort and the data sets. It also includes the analysis of zonal means, regional variations, Annual mean, correlation analysis of climate parameters including net radiation, clouds and surface temperature maps and the parameters under study. Emphasis was placed on the variation of net radiation with cloud types geography and surface temperature.

Software and Data-processing

The software tools used in the previous Nimbus-7 study were modified and additional software was developed as required for the new data sets.

(1) IBM-9021 (ESA) and CRAY YMP computer systems of the computer center at NASA Goddard Space Flight Center were used for data processing. The programs and data files were organized on disk on line to the computer system. The data base of the products of ERBE and ISCCP experiments for the purpose of the research and analysis was organized and maintained on the magnetic tapes in the tape library of the

computer center. Data under study was often stored on magnetic disks for fast processing.

(2) Computer programs were designed and developed for analysis and interpretations of data.

(3) Data of clouds and ERB for the same month and the corresponding target areas from ISCCP and ERBE tapes were merged and integrated according to the purpose of the study.

(4) A statistical techniques for the computations of correlation coefficients were used for the analysis of relationships of the data sets of the individual target areas or regions. Both time and space (seasonal and regional) correlations were be considered.

(5) Computer programs in Fortran language for data processing on the IBM 9021 computer were designed and developed.

(6) The correlation and auto-correlation coefficients of ERB and cloud products were used for interpretation and analysis purpose. The correlation coefficients and the appropriate output was displayed both in tabular and graphic forms.

(7) Analytical study was performed to arrive at the results and derive the conclusions.

The data was obtained directly from the Technical Monitor, Dr. Lee Kyle, and the ERB Processing Team which he manages.

Status of the Study

The study continued according to the guidelines in the proposal, however the research also focussed on the meetings and discussions with the NASA technical monitor Dr. H. L. Kyle and colleagues who are involved in the related research work.

FUTURE PLANS COVER:

For the purpose of analysis and interpretation of results monthly averaged data of surface temperature, different types of clouds, and ERB components for each target area of the globe was used. The correlational techniques including auto-correlation was used for interpretation of results.

(1) Multi-variable correlations and regression analysis will be used to analyze the contribution of ERB parameters and surface temperatures to cloud forcing.

(2) A paper will be presented at AGU Spring 1994 at Baltimore.

(3) A paper for publication will be pursued.

(4) In addition the feasibility of extending the study for two or three more years will be examined. ERBS scanners data exists for five years starting in November of 1984. In

addition combined ERBS NOAA-10 data exist for the years February 1984 - January 1989. These data sets are not expected to be entirely compatible with the combined ERBS/NOAA-9 scanner products because of differences in the temporal sampling. Nevertheless it is probable that these longer data sets can be used in the study.

Annual Cycle Correlations
for the
Earth Radiation Budget, Clouds, and Surface Temperature

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Abstract

1. Introduction

Seasonal cycle variations are studied using three years of Earth Radiation Budget (ERB), cloud and surface temperature data. The approximately 23.5° tilt of the Earth's axis of rotation to its orbital plane about the sun is, of course, the principle climate forcing factor. At mid and high altitudes, this results in low solar insolation and surface temperatures during the winters and high insolation and increased surface temperatures during the summer. Near the equator the insolation is high all year round and the variable flow of energy to the higher latitudes becomes a major climate factor. In practice, land and ocean physical differences combined with variable land types help to cause large regional climate differences at any given latitude. We examine these seasonal variations using data from recent satellite datasets and correlation analysis.

Recent climate datasets, particularly measurements from satellites, have allowed an improved quantitative understanding of the global climate. The ways in which clouds act to modify surface conditions has received considerable attention (Harrison et al., 1990; Ardanuy, et al., 1991; Sohn and Robertson, 1993). The question of how regional cloud variations are related to surface temperature variations has been examined by Weare (1992 a & b), while Sohn and Smith (1993) have re-examined the question of how

much energy is transported from the equator to the Poles by the Earth's atmosphere and oceans. Kyle, et al. (1991), published monthly maps of the affects, outgoing longwave radiation (OLR), net radiation, surface temperature and total cloud cover for the year (June 1979-May 1980). The present study uses three years of satellite data to examine the seasonal interactions between the surface temperature, clouds, and the top of the atmosphere insolation, reflected shortwave, emitted longwave and net radiation. We started with the 13 month (May 1979-May 1980) Nimbus-7 Earth Radiation Budget (ERB) narrow field of view (NFOV) dataset (Kyle, et al., 1990) and the concurrent Nimbus-7 cloud dataset (Stowe, et al., 1988). The study was then extended to include an Earth Radiation Budget experiment (ERBE) NFOV dataset for the period of February 1985 to January 1987. The combined Earth Radiation Budget Satellite (ERBS) and NOAA9 Product (N9ERBS, NFOV) was chosen (Barkstrom, et al., 1989). The concurrent International Satellite Cloud Climatology Program (ISCCP) products were used in this case (Rossow and Schiffer, 1991). There appears to be a qualitative agreement among the various dataset, but care must be exercised because of some quantitative differences. The characteristics of the various datasets are discussed further in Section 2.

An overview of the mean global net radiation budget, correlation analysis and a discussion of seasonal changes is given in Section 3. An examination of some regional examples appears in Section 4. The discussion and conclusions are in Section 5.

2. Datasets

Four independent datasets were utilized in this study. There were two Earth Radiation Budget and two cloud sets. They differ in algorithms, sensors, sampling procedure and final format. The Earth Radiation Budget products include top of the atmosphere insolation, albedo, OLR and net radiation. The cloud parameters consist of clear, low, mid, high and total cloud fractions with the associated 11 micron black body clear and cloud top temperatures. The surface air temperature is also included. Monthly averages of all parameters were utilized.

The Nimbus-7 ERB and cloud datasets were derived from sensors which made simultaneous measurements. The Nimbus-7 was launched, October 28, 1978 into a nearly circular, sun synchronous orbit, inclined 99.3° to the Earth's equator. Its mean altitude was 955 km. The equator cross times were near noon and midnight. We utilized one year (June 1979-May 1980) of the 13 months of revised ERB scanner products and the concurrent Nimbus-7 cloud products. Both the ERB and cloud climate products are presented as monthly averages on a world grid consisting of 2070 nearly square regions about 500 km on a side. These are sorted into 40 latitude bands, each 4.5° wide. At the equator, these are 80 regions each covering 4.5° of longitude. At each Pole, there are three regions, each 120° of longitude long. There can be no direct comparison with the ERBE products which do not start until November 1980. The ERBE program included measurements from three different satellites; the Earth Radiation Budget Satellite (ERBS) and two operational

meteorological satellites, NOAA-9 and NOAA-10. The purpose was to obtain improved diurnal sampling since the measured regional signals generally vary markedly over a 24 hour period. The ERBS was placed in a non-sun synchronous orbit inclined at 57° to the equator. For latitudes between $\pm 57^\circ$, observations are made for each hour of a day about once every 37 days. The NOAA-9 and NOAA-10 were placed in sun synchronous near polar orbits with respective 2:20 (am/pm) and 7:30 (am/pm) local equator crossing times. The measurement starting dates were: ERBS on November 5, 1984; NOAA-9 on January 5, 1985; and NOAA-10 on November 12, 1986. The NOAA-9 scanner failed January 20, 1987. For global coverage, the ERBS data needs to be merged with the measurements from one or more of the NOAA satellites. However, the various ERBE satellite combinations produce noticeable product variations. These arise from modest calibration and important temporal sampling differences in the three satellite measurement sets. We therefore chose the combined ERBE scanner product for the period February 1985-January 1987. The last three months actually contain data from all three satellites, while the rest of the periods has a combination of ERBS and NOAA-9 measurements. The two combinations are reasonably compatible (Kyle, et al., 1993). The Nimbus-7 and ERBE scanner utilize similar algorithms (Kyle, et al., 1990) and appear to be fairly compatible (see Section 3), but slight calibration differences together with different diurnal sample patterns should produce some regional and even global differences. Table 1 shows the global annual means for the two years. About 0.3 W/m^2 of the

insolation difference of 1.63 W/m^2 seems due to a real change in the Sun. But the rest can be attributed to calibration differences. The exact causes of the other differences are unknown. Small, real year to year differences do occur (Ardanuy, et al., 1992), but in Table 1 systematic errors are considered to be the chief cause. Some regional errors will of course be considerably larger than those shown here.

Table 1
Earth Radiation Budget
 Measured Global Annual Means in W/m^2

Source	Insolation	Reflected SW	Emitted LW	Net
Nimbus-7 NFOV June 79-May 80	342.88	104.7	235.97	2.21
ERBS/NOAA-9 Feb 85-Jan 86	341.25	102.1	233.99	5.16

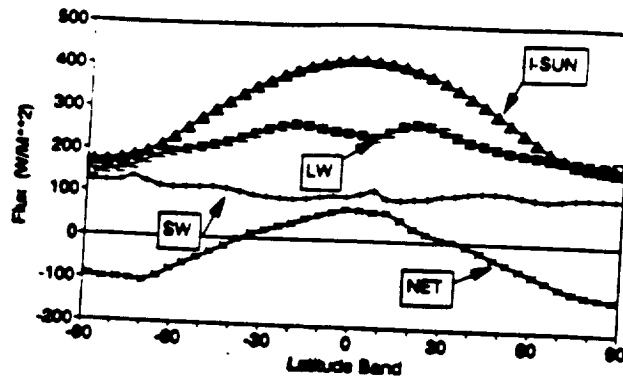
The ISCCP cloud products are derived from scanner measurements from a number of weather satellites operated by several countries (Rossow and Schiffer, 1991). The ISCCP products were started in July 1983 and the program is continuing. The Nimbus-7 cloud products extended through March 1985, thus two of the cloud datasets can be compared in detail.

3. The Mean Annual Net Radiation Budget

3.1 Zonal Means

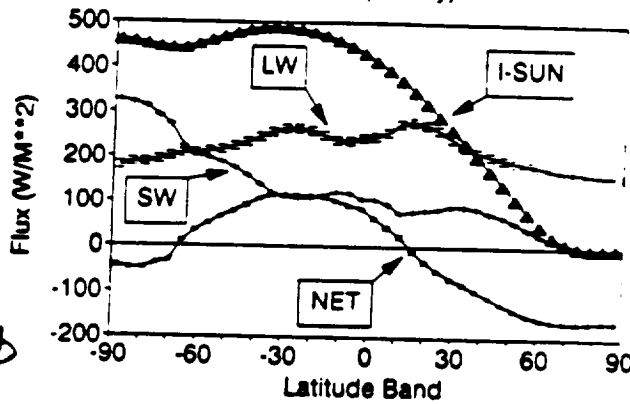
The Earth's Mean Radiation Budget and its seasonal extremes are summarized in Figure 1 in terms of latitude band averages. Nimbus-7 scanner data is plotted for the year (June 1979-May 1980).

ZONAL AVERAGES (ANNUAL) Nimbus-7 (All Sky)



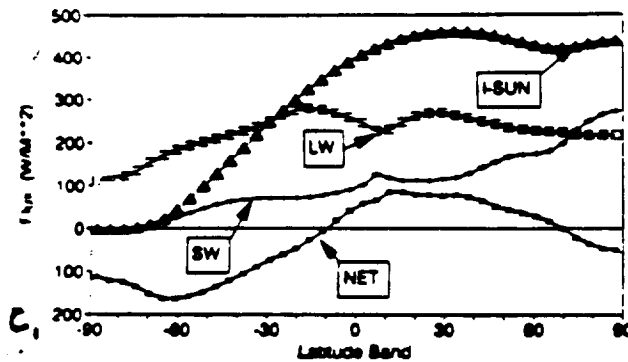
a.

ZONAL AVERAGES (DJF) Nimbus-7 (All Sky)



b

ZONAL AVERAGES (JJA) Nimbus-7 (All Sky)



c.

Figure 1. Nimbus-7 scanner (MLCE) emitted longwave (LW), reflected shortwave (SW), net radiation (NR), and top-of-the-atmosphere insolation, I(sun): (a) annual average (June 1979 through May 1980), and seasonal averages (b) December through February, (c) June through August.

It is qualitatively representative of the latitude band averages observed in the 1980's. The net solar radiant energy absorbed by the Earth and its atmosphere is given by

$$NR = I_{\bullet} - SW - LW \quad (1)$$

where NR is the net radiation
I_• is top of the atmosphere (TOA) insolation
SW is the reflected shortwave radiation
LW is the outgoing longwave radiation (OLR).

Annual averages are shown in Figure 1a. The Earth's climate is dominated by the fact that the mean annual insolation is over twice as large in the tropics as in the polar regions. In addition, a higher percentage of the incident solar irradiance is absorbed at low latitudes. As a result, the regions between approximately $\pm 36^\circ$ of latitude show a positive annual net radiation, while the higher latitudes show a negative balance that must be made up by the transport of energy from the warmer regions by atmospheric and ocean currents. On a reduced scale, the net radiation (bottom curve) mimics the insolation (top curve) with only minor deviations. The diurnally averaged OLR is about 100 W/m² larger in the tropics than at the poles (less for north pole, more for south pole). The diurnally averaged reflected shortwave is nearly independent of latitude, but is slightly higher at the poles. This indicates that the regional albedo is much lower in the tropics than at the higher latitudes with the polar regions being the brightest. While the insolation shows a north/south symmetry, slight but significant asymmetries appear in the other quantities. The OLR is nearly 50 W/m² lower at the south pole than

at the north pole in accordance with the lower Antarctic temperatures. The reflected radiation, however, is slightly larger at the south pole, due to the higher albedo of the southern ice cap. The OLR asymmetry is the larger so that the net radiation is algebraically lower by about 20 W/m^2 at the north pole than at the south pole. In the tropics, a slight peak in the reflected shortwave about 6°N of the equator indicates the mean position of the intertropical convergence zone. A dip in the OLR occurs at the same position. Slight OLR maxima occur in the subtropical high-pressure zones, at about $\pm 20^\circ$ latitude, indicating the cloud minima present.

The changes in the top-of-the-atmosphere insolation drive the seasonal changes in the ERB parameters. At the December solstice the Sun is 23.5°S of the equator, while at the June solstice it is 23.5°N of the equator. Further, because of the eccentricity of the Earth's orbit, the solar irradiance at the Earth is about 6% larger in December and January than in June and July. These seasonal changes are illustrated in Figures 1b and 1c.

In December to February the insolation is 450 W/m^2 or greater from 10°S latitude to the South Pole. However, north of the equator, the insolation drops steadily to zero just beyond the Arctic Circle. The reflected shortwave drops from over 300 W/m^2 at the bright South Pole to zero in the sunless Arctic. Note the steady decline in the reflected shortwave signal from the South Pole to 36°S latitude even though the insolation increases slightly. This is caused by the decrease in the regional albedos

as the Antarctic ice and clouds give way to the relatively clear southern oceans. The high reflectivity in the South keeps the net radiation slightly negative in the Antarctic even when the insolation is large. In this season, the net radiation is positive from 14°N to 66°S latitude. At the North Pole, the net radiation drops to about -170 W/m². In June, July, and August, it is summer in the Arctic, but the Earth is furthest from the Sun so that the insolation is slightly smaller than in December to February. In the June to August season, the net radiation is positive from 70°N latitude to 10°S latitude.

3.2 Regional Variations

3.2.1 Annual Mean Net Radiation Maps

The mean annual net radiation maps for the years (June 1979-May 1980) and (February 1985-January 1986) are shown respectively in Figures 2a and 2b. The similarity of the two figures is striking despite the differences in time and the diurnal sampling differences between the Nimbus-7 and the ERBS/NOAA-9 datasets (see Section 2). Both maps depict non El Nino/Southern oscillation (ENSO) years, which should increase their similarities. At a given latitude, the greatest regional differences in the net radiation occur between 20°N and 30°N latitude. Here the annual mean ranges from more than 40 W/m² over large stretches of the ocean to less than -40 W/m² over portions of the Sahara desert in North Africa. A significant variation also occurs along the equator. Values less than 40 W/m² along the west coast of South America and the east coast of Africa compare with values over 90 W/m² in the Western

NIMBUS-7 MLCE NET RADIATION JUNE 79-MAY 80

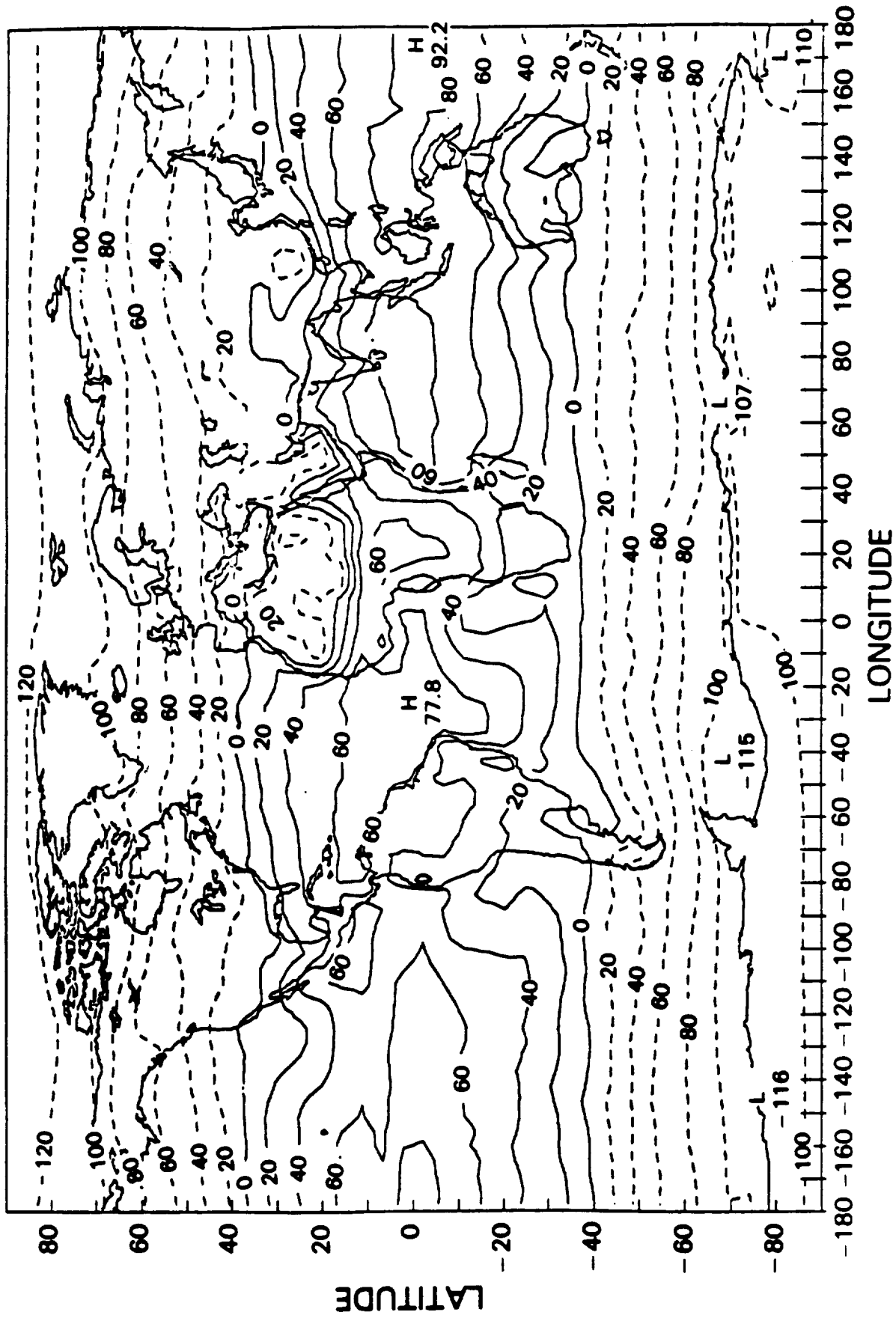


Fig. 2a

N9ERBS SCANNER NR FEBRUARY 85-JANUARY 86

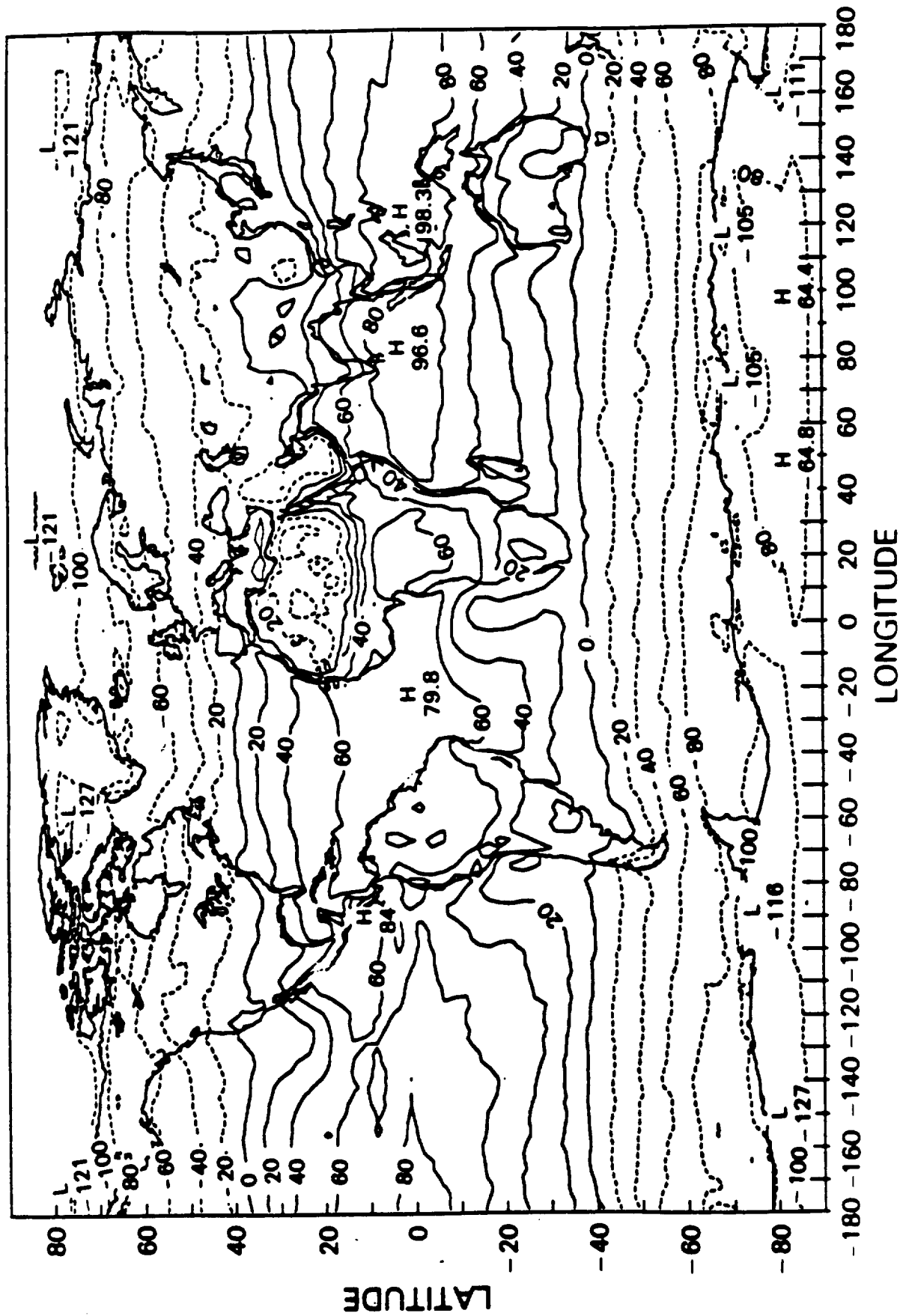


Fig 24

Pacific and in the Indian Ocean. Significant but less dramatic differences also occur regionally between 20°S and 30°S latitude. The maps show that more heat is lost at the North Pole than at the South. But the ERBE map in particular shows a large variation from -64 W/m² to -127 W/m² in various regions of the Antarctic continent. As mentioned in Section 2, the ERBE format presents more regional detail near the poles than does the Nimbus-7 procedure. While the finer resolution introduces additional noise, the observed differences may well be real. During the six months, South Pole night atmospheric winds carry heat from the Southern oceans to the cold, sunless continent. Thus it is reasonable that the coastal regions both receive and lose more heat than the high South Polar Plateau.

The reasons for these observed regional differences depends both on regional physical differences and atmospheric and oceanic dynamics. In general oceans are darker than land and will therefore absorb more of the incident solar energy. In general, the drier a land region is the higher its albedo and the less insolation is absorbed. The Sahara has a higher albedo than most deserts. Many regions of the Sahara have a surface albedo as high or higher than that of other cloud covered regions. In addition, dry land has a low heat capacity. Thus, in sunshine the surface heats quickly and reradiates much of the absorbed energy. Both the surface temperature and the emitted longwave show a very strong diurnal signal over deserts. Oceans, on the other hand, have a high heat capacity and a much less variable diurnal and seasonal

surface temperature than does land.

Variations in regional cloud zones are also important factors. In general, clouds are brighter and colder than the surface. Thus, they tend to increase the reflected shortwave and decrease the emitted longwave radiation. As discussed in Dhuria and Kyle (1990), cloud type is more important than cloud amount in modifying the regional net radiation. Low, thick clouds off the west coast of South America and Southern Africa are highly reflective, but also have relatively warm cloud tops. Thus, they sharply reduce the net radiation in these regions. However in the equatorial Indian Ocean and Western Pacific large fields of high, thin cirrus clouds often cause an increase in the net radiation.

The correlation studies following, together with the seasonal studies in Section 4, examine some of those regional differences in more detail.

3.2.2 Correlation Analysis

3.2.2.1 Background

Clouds affect the net radiation in a complex fashion, depending on their cloud top reflectivity and temperature. Thick clouds are highly reflective while thin clouds allow much of the incident solar radiation to pass through. High clouds have a lower cloud top temperature than the surface and they act as a greenhouse blanket. The lower surface of a cloud absorbs the longwave radiation from below, some of which it radiates back down. The upper surface gives off longwave radiation at its own low temperature. However, the thickness and altitude of the clouds

depends both on local conditions and complex interregional atmospheric circulation patterns.

The present correlation study considers the feedback loop diagrammed in Figure 3. In local equilibrium, with no atmosphere, the absorbed shortwave depends just on the insolation and the albedo A . The surface temperature, T_s , increases due to the shortwave but also cools by emitted radiation. The presence of an atmosphere and surface water allows additional cooling due to evaporation, the formation of clouds, and also energy transport by both the oceans and the atmosphere. In Figure 3, energy transport and the heating and cooling due to greenhouse gases and aerosols are considered only indirectly through their effects on the listed, observational parameters.

In this section we will use linear correlation analysis to find regions where there are strong relationships among parameter pairs. We are particularly interested in the effect of the various parameters on the net radiation and on the surface temperature.

The linear correlation, $r(x,y)$, is the measure of the validity of the relationship

$$y = a + bx \quad (2)$$

where x and y are two observed variables and a and b are constants. Correlation is discussed in any book on statistics (see for instance, Devore, 1982) and is given by

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}} \quad (3)$$

EXPECTED RELATIONSHIPS

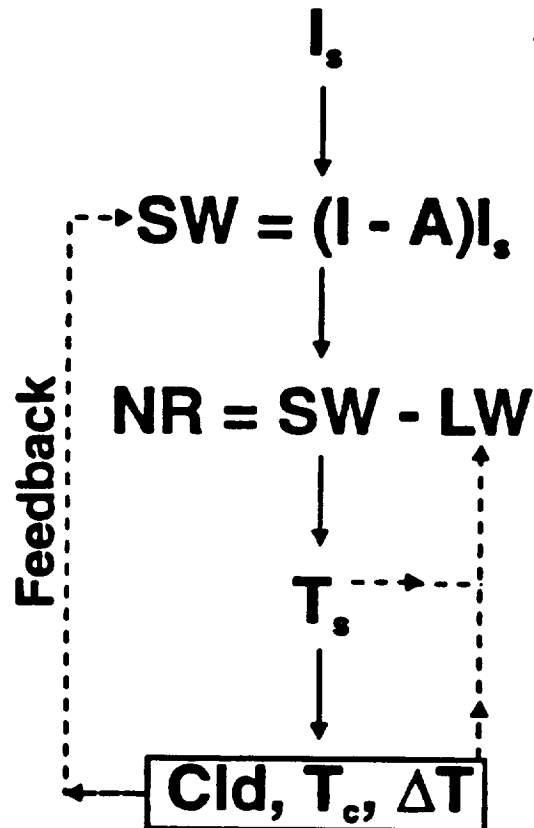


Figure 3: T_s and T_c are respectively the surface and cloud top temperatures while ΔT is their difference. I_s is the insolation, while SW , LW and NR are the absorbed shortwave, emitted longwave and net radiation; Cld is the cloud fraction and A is the top of the atmosphere albedo.

The response of T_s to variations in NR will depend upon the heat capacity of the surface, energy convection by oceanic and atmospheric currents plus other responses.

Because of the normalizing denominator, the values of r can range from -1 to +1. Values near ±1 show that a strong linear relationship does exist, while values closest to zero indicate that x and y vary almost independently of each other. The numerator is termed the covariance when normalized in the form

$$cov = \frac{1}{N} \sum (x_i - \bar{x})(y_i - \bar{y}) \quad (4)$$

where N is the number of terms in the set (x_i)
 \bar{x} is the mean of (x_i)

It determines both the sign and strength of the relationship.

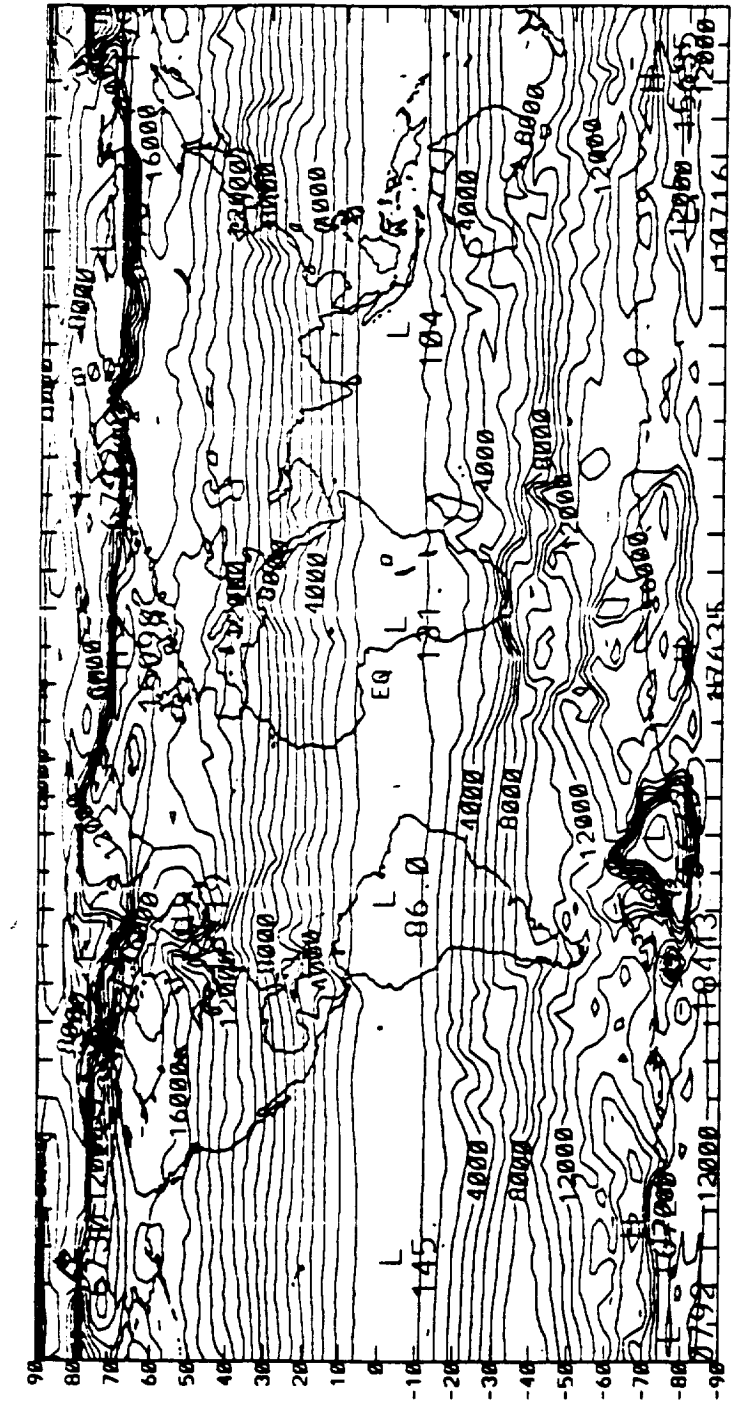
3.2.2.2 Analysis

Except for a few equatorial regions the net radiation has a correlation close to +1 with the insolation. This is shown in Figure 4a. The covariance (Figure 4b) ranges over two orders of magnitude. It is very high in the polar regions with their strong summer/winter differences in the insolation (Figure 1b and 1c), but drops to relatively small values along the equator. This relationship is merely another expression of the importance of the seasonal changes as the major driving force in the Earth's climate.

Additional Figures: Figure 5: Correlation of surface temperature and OLR.

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COVARIANCES NETR AND INSL



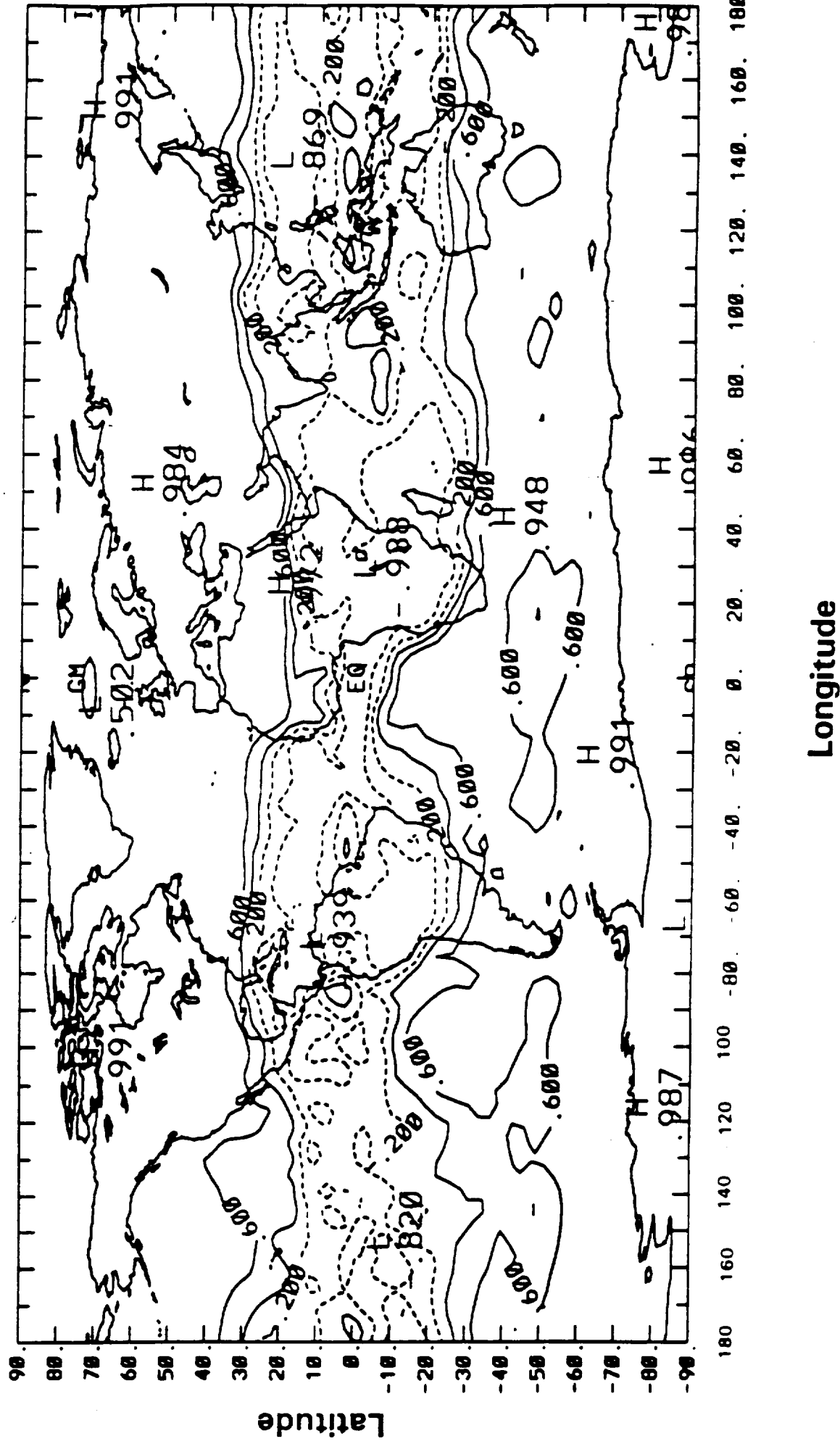
LONGITUDE

CONTINUUM: MIN 0 0000001.00 10 14000 CONTOUR INTERVAL OF 1000 0 PLOT: 31* 12070.

FIGURE 5

Nimbus-7: Correlation of Surface Temperature with LW (TOA)

During the annual cycle, contour interval 0.4, --- indicates negative correlation.



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