9.3 AN UPDATED REPORT ON THE DECADAL VARIABILITY OF EARTH RADIATION BUDGET USING THE LATEST ERBE/ERBS WFOV NONSCANNER DATA RECORD

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1. INTRODUCTION

Understanding the exchanges of radiative energy at the top of atmosphere (TOA) is essential for unlocking the secret of the Earth's climate and for improving our knowledge of global climate change. Recent discovery of large decadal variability in observed tropical mean Earth radiation budget (ERB) from overlapping satellite instruments records (Wielicki et al., 2002) has given climate scientists new insights into the complex issues that are affecting the Earth's climate system. This has also pointed to the critical needs for high quality continuous long-term satellite ERB measurements in climate research. This short paper will highlight the key results from a latest study (Wong et al., 2006) on the observed decadal variability of TOA ERB using the updated Earth Radiation Budget Experiment (Barkstrom, 1984) Earth Radiation Budget Satellite (ERBE/ERBS) Nonscanner wide-field-of-view (WFOV) Edition3_Rev1 data set. Comparisons will be make with various publicly available TOA ERB data sets, as well as recently released ocean heat storage data set, to get a consistent view of the changes in the TOA ERB since the mid 1980's.

2. UPDATED ERBS NONSCANNER DATA

The ERBE/ERBS Nonscanner WFOV data set contains a 15-year record (1985-1999) of near global observations (60N to 60S) of TOA outgoing longwave radiation (LW), reflected shortwave radiation (SW), and net radiation (Net). The ERBS is on a 57^{o} inclined orbit and has a precession cycle that allows for complete diurnal sampling of local times in a 72-day period for every region it observes. In the tropics, it will sample the complete diurnal cycle in a 36-day period from both daytime and nighttime measurements. The spatial resolution of the ERBE/ERBS Nonscanner WFOV Shape Factor data set is 10^{o} by 10^{o}. The latest version (Edition3_Rev1) of ERBE/ERBS Nonscanner WFOV data set contains new corrections to account for the effects of the small drop in satellite altitude over the 15-year period and a residual instrument artifact that has not been completely corrected by using the biweekly ERBS nonscanner solar constant observations (Wong et. al., 2006).

The ERBS altitude has slowly dropped from 611 km to 585 km over the 15-year period. The ERBS Edition2 Nonscanner data does not include energy correction due to this minor drop in the satellite altitude (Lee et al., 2003). The estimated magnitude of this altitude drop on the decadal changes of ERB had been reported previously by Wong et al. (2004) and this had resulted in the reprocessing of the entire Nonscanner WFOV Edition2 record into a new Edition3 data set. The main effect of this satellite altitude change is a small decrease (~0.6%) in both TOA LW and TOA SW over the 15-year period. The combined effect of both LW and SW change also moves the original reported tropical mean decadal change in Net radiation from -0.7 Wm^{-2} to 1.4 Wm^{-2}. Both Edition2 and Edition3 Nonscanner data are available at the NASA Langley Atmospheric Sciences Data Center in Hampton, Virginia.

The Edition3_Rev1 is an interim release data set. It includes an additional correction needed to remove a residual SW instrument artifact in the Edition3 data. This residual SW instrument artifact, on the level of 1% over the 15-year period, was discovered during the validation of the Edition3 data set and is most likely caused by non-uniform exposure of Nonscanner WFOV shortwave sensor dome to UV radiation during spacecraft sunrise and sunset during the 15-year period (Smith et al., 2002). The new Edition3_Rev1 data record is constructed by incorporating an user-applied correction to the archived Edition3 data. This user-applied correction, available through the Edition3 data quality summary, only affects the relative partition of energy between LW and SW and does not influence the Net radiation in Edition3 data. Additional discussions on Edition3 changes and

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Edition3_Rev1 correction can be found in Wong et al. (2006).

Table 1 gives a summary of the decadal changes in tropical mean (20N to 20S) TOA ERB between 1980s and 1990s from the last three versions of the ERBE/ERBS Nonscanner WFOV data set. The updated Edtion3_Rev1 data have significantly lower the earlier Edition2 estimate of decadal LW changes. On the other hand, the updated data only have very small effect on the reported decadal SW change. The decadal Net change is now positive. With these latest updates, the decadal changes in tropical mean radiation budget now stand at 0.7, -2.1 and 1.4 Wm^{-2} for LW, SW, and Net radiation, respectively.

TABLE 1: TOA radiative flux changes (Wm^{-2}) from the 1980s to 1990s from different versions of the ERBE/ERBS Nonscanner WFOV data set. Values are given as tropical mean (20N to 20S) for the 1994-1997 period minus the 1985-1989 period.

Data Source	TOA LW	TOA SW	TOA Net
Edition2	3.1	-2.4	-0.7
Edition3	1.6	-3.0	1.4
Edition3_Rev1	0.7	-2.1	1.4

Figure 1 shows an updated comparison of the new ERBS Nonscanner WFOV Edition3_Rev1 deseasonalized tropical mean (20N to 20S) flux anomalies time series to the same climate model simulations used in Wielicki et al. (2002). The climate models include the Hadley Centre atmospheric climate model HadAM3 (Pope et al., 2000 and Sexton et al., 2001), the National Center for Atmospheric Research (NCAR) model CCM3 (Kiehl et al., 1998), the Geophysical Fluid Dynamics Laboratory (GFDL) climate model (Lau and Nath, 2001), and the GFDL EP (Experimental Prediction) model (Gordon et al., 2000). We also included the National Center for Environmental Prediction (NCEP)-NCAR 50-year Reanalysis, which uses NCEP 4-D assimilation model (Kistler et al., 2001). For all model runs, the deseasonalized tropical mean flux anomalies were calculated as in the satellite data, using the 1985 through 1989 period as the baseline. The comparison between Nonscanner WFOV Edition3_Rev1 deseasonalized LW anomalies and climate models is now in much better agreement, with the exception of the 1998 El Nino anomaly peak, but sizeable differences in deseasonalized SW flux and Net flux anomalies remain. Note that the 1991 to 1993 Mt. Pinatubo aerosol signal was not provided to the climate models for the simulations, and they should not be expected to show these anomalies.

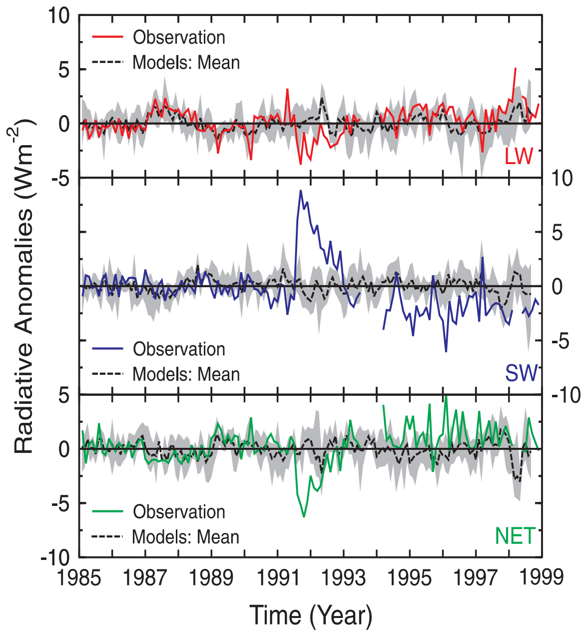

FIG. 1. Comparison of time series of ERBS Nonscanner WFOV Edition3_Rev1 deseasonalized tropical mean (20N to 20S) broadband radiation budget anomalies of longwave (top, red line) shortwave (middle, blue line), and net (bottom, green line) radiation from 1985 to 1999 against the same time series from climate models (dashed black lines are the models mean and the shaded areas are the spread of the minimum and maximum values among models). The climate models are the same models as in Wielicki et al. (2002).

3. COMPARISON WITH OTHER ERB RECORDS

Several other long term satellite-based Earth radiation budget data sets of varying quality are also available to the public. These include the High Resolution Infrared Radiation Sounder (HIRS) Pathfinder outgoing longwave radiation (OLR, Mehta and Susskind, 1999) data set, the International Satellite Cloud Climatology Project (ISCCP) FD data set (Zhang et al., 2004), and the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder ERB data set (Stowe et al., 2002). Since these ERB data sets are derived from narrowband observations, they are not as accurate as the broadband ERBS Noscanner data set (Wong et al., 2006). Figure 2 shows a comparison of the ERBE/ERBS Nonscanner WFOV

Edition3_Rev1 deseasonalized tropical mean (20N to 20S) radiative anomaly record (1985 to 1999) against deseasonalized anomalies from these three narrowband based ERB data sets. All anomalies are determined consistently using the base climatological period (1985 to 1989) as in Fig. 1. For the LW component of the ERB, the four different data sets are consistent with each other during the first half of the data record. During the second half of the data record, the ERBS Nonscanner LW, HIRS Pathfinder OLR, and the ISCCP FD LW are in close agreement. The AVHRR Pathfinder LW, however, shows much lower values than the other time series during the later part of this data record. These problems are the result of instrument intercalibration and satellite orbit change (time of day sampling) as discussed in Jacobowitz et al. (2003).

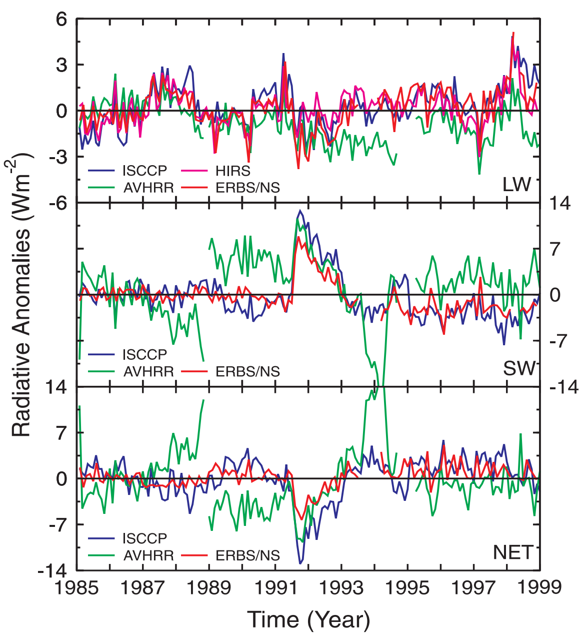

FIG. 2. Time series of deseasonalized tropical mean (20N to 20S) broadband radiation budget anomalies (longwave, shortwave, and net) from 1985 to 1999 from the ERBS Nonscanner WFOV Edition3_Rev1 (red), ISCCP FD (blue), HIRS Pathfinder OLR (pink), and AVHRR Pathfinder ERB (green) data records. Anomalies are defined with respect to the 1985 to 1989 period.

For the SW component of the ERB, the ERBS Nonscanner WFOV Edition3_Rev1 and the ISCCP FD data again agree well with each other over the entire span of the data period. HIRS Pathfinder provides only LW fluxes, so no SW or Net flux comparisons are possible. The AVHRR Pathfinder SW data do not agree well with the two other data sets. The AVHRR data contain large shifts throughout the time series, again consistent with issues of intercalibration and changes in satellite orbit diurnal sampling. The net component of the ERB is the combined effect of both LW and SW fluxes. While both the ERBS Nonscanner WFOV Edition3_Rev1 data and the ISCCP FD data are very similar to each other, the AVHRR Pathfinder Net data again diverge from the other two data sets.

Table 2 further summarizes the results of decadal changes in Earth radiation budget between the 1980s and the 1990s for these four data sets. In general, there is good agreement among ERBS Nonscanner WFOV Edition3_Rev1, HIRS Pathfinder OLR and ISCCP FD data record. All three data set show similar decadal changes in ERB with the same sign and similar magnitude. The AVHRR Pathfinder ERB data set, however, disagrees with the other three data sets in both sign and magnitude. Jacobowitz et al. (2003) showed a promising technique for reducing these data problems in the current AVHRR Pathfinder ERB data set. The corrected AVHRR Pathfinder data set, however, is still under development and is not yet available to the public. An examination of Fig. 4 from Jacobowitz et al. (2003) indicates that the comparable numbers for Table 2 would be about -2.0, +2.0 and 0.0 Wm^{-2} for LW, SW and Net flux, respectively. But intersatellite shifts of 4 to 5 Wm^{-2} occur even in the corrected AVHRR Pathfinder data from Jacobowitz et al. (2003). We conclude that both AVHRR pathfinder and the corrected AVHRR Pathfinder ERB data are not sufficiently accurate to resolve decadal changes in tropical mean or global scale radiative fluxes. They may be more useful for regional climate signals, but these are not compared here.

TABLE 2: TOA radiative flux changes (Wm^{-2}) from the 1980s to 1990s from different ERB data sets. Values are given as tropical mean (20N to 20S) for the 1994-1997 period minus the 1985-1989 period. Dashes are shown where no data is available.

Data Source	TOA LW	TOA SW	TOA Net
ERBS Edition3_Rev1	0.7	-2.1	1.4
HIRS Pathfinder	0.2	-	-
AVHRR Pathfinder	-1.4	0.7	0.7
ISCCP FD	0.5	-2.4	1.8

4. COMPARISON WITH OCEAN HEAT STORAGE DATA

Willis et al. (2004) provides new estimates of annual global ocean heat storage for 1993 to 2002 using a combination of improved in-situ temperature profile sampling and constraints on thermal expansion from satellite global ocean altimeter observations. The major advantage of this data set over previous ocean estimates is the use of global altimeter data to supplement sparse in-situ sampling in the southern hemisphere oceans. On a global annual scale, the changes in TOA net radiation and ocean heat storage should be in phase and of the same magnitude. This is due to the fact that all other forms of heat storage in the Earth system are factors of 10 or more smaller than ocean heat storage (Levitus, 2001). Previous ocean heat storage data sets required 5 to 10 year averages to reduce sampling errors. The Willis et al. (2004) analysis demonstrated a sampling error of 0.4 Wm^{-2} (1-sigma) for global annual ocean heat storage.

Figure 3 gives a direct interannual comparison of these new ocean heat storage data from 1993 to 2003 against those from the 12-month running mean ERBE/ERBS Nonscanner WFOV Edition3_Rev1 and CERES/Terra FM1 Scanner ES4 Edition2_Rev1 net flux anomalies. The CERES/Terra Scanner results are global and the ERBE/ERBS Nonscanner results cover 60N to 60S (or ~87% of the Earth surface). The net flux anomalies are calculated with respect to the 1985 to 1989 period. They are basically deseasonalized anomalies similar to those show in Fig. 1. A 12-month running mean filter has been applied to the TOA radiation data to reduce the temporal sampling noise and to match-up directly with the corresponding time scale of the ocean heat storage data. The ocean heat storage data (WIllis et al., 2004) is available only in annually smoothed seasonal data. The drop in the global ocean heat storage in the later part of 1998 is associated with cooling of the global ocean after the rapid warming of the ocean during the 1997-1998 El Nino event (Willis et al., 2004). While spatial sampling error is the dominant source of uncertainty in the ocean data, absolute calibration uncertainties dominate the radiation budget data. For a comparison of interannual variations, however, we can remove the mean calibration uncertainty by requiring agreement for the average of all overlapping data for each instrument time series (e.g. 1993 to 1999 average for ERBS and ocean heat storage). Note that WIllis et al. (2004) estimate the 10 year average uncertainty in ocean heat storage from 1992 to 2002 as ~0.2 Wm^{-2}. The interannual variability of the net flux anomalies in Fig. 3 from the ERBS Nonscanner WFOV and CERES Scanner agree very well with the interannual variability of the ocean heat storage data. The agreement is within the ocean heat storage sampling uncertainties, with 1-sigma difference in the anomalies of 0.4 Wm^{-2}. The two times series are in phase with each other, consistent with the constraint of planetary energy balance.

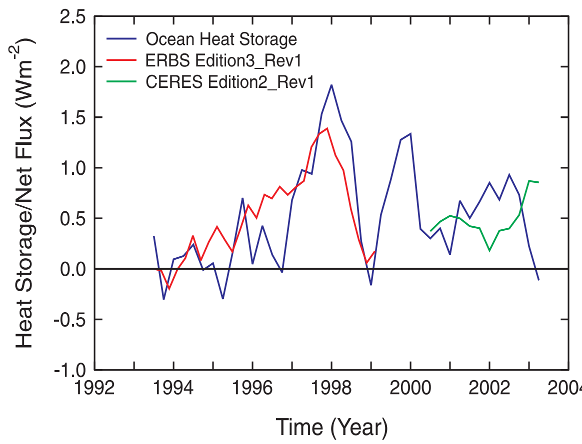

FIG. 3. Interannual comparison of global ocean heat storage (blue) against global net flux anomalies from ERBE/ERBS Nonscanner WFOV Edition3_Rev1 (red) and CERES/Terra FM1 Scanner ES4 Edition2_Rev1 (green) for a 10-year period form 1993 to 2003.

This is a remarkable result given the totally independent physical measurement and sampling of the ocean heat storage data and the ERB data sets. The net flux anomalies within a single decade can be as large as 1.5 Wm^{-2} according to both the ERB and the ocean heat storage data. The data agree that the ERBS Nonscanner WFOV net radiation anomalies shown in Fig. 3 are accurate to better than 0.5 Wm^{-2}, which is consistent with the estimated uncertainty of the ERBS WFOV Edition3_Rev1 data set (Wong et al., 2006). The large 1.5 Wm^{-2} changes is most likely dominated by changes in cloudiness since aerosol radiative forcing estimates for this period show no large changes beyond the 1991-1993 Mt. Pinatubo cooling.

4. SUMMARY

Continuous monitoring of the Earth's Radiation field at the top of the atmosphere (TOA) is essential for understanding climate and climate variability on Earth. This short paper highlights the key results from a latest study (Wong et al., 2006) on the observed decadal variability of TOA ERB using the updated ERBE/ERBS Nonscanner WFOV Edition3_Rev1 data set. Comparisons are make with various publicly available TOA ERB data sets, as well as recently released ocean heat storage data set, to get a consistent view of the changes in the TOA ERB since the mid 1980's.

The original and Edition2 ERBE/ERBS Nonscanner WFOV data contain small systematic errors that can affect the interpretation of decadal changes. Specifically, ERBS altitude slowly dropped from 611 km to 585 km over the 15-year period. This introduces a 0.6% correction to the decadal changes reported in a previous study. This altitude correction has been used to produce an updated ERBS Nonscanner WFOV Edition3 data set. The ERBS Nonscanner WFOV SW sensor dome transmission corrections determined by biweekly solar constant observations appear to have underestimated the change by about 1% over the first 15 years of the mission. This additional 1% correction to the SW sensor is not currently incorporated into the archived WFOV Edition3 data set and can result in an additional 1 Wm^{-2} correction to the decadal changes in both LW and SW fluxes. The drift correction, however, is available to data users through the WFOV Edition3 data quality summary so they can apply the correction to the WFOV Edition3 data and convert them into WFOV Edition3_Rev1 data. Overall, the combined effects of altitude correction and SW sensor drift correction change the values of the reported decadal changes in tropical mean (20N to 20S) Earth radiation budget in TOA LW/SW/Net radiation between the late 1980s and the 1990s from 3.1/-2.4/-0.7 Wm^{-2} to 0.7/-2.1/1.4 Wm^{-2}, respectively.

Comparison of decadal changes in ERB with existing satellite-based decadal radiation data sets shows very good agreement among ERBS Nonscanner WFOV Edition3_Rev1, HIRS Pathfinder OLR, and ISCCP FD data sets. The AVHRR Pathfinder ERB data set, however, does not compare well against the ERBS Nonscanner WFOV and the two other ERB data sets, either in the normal AVHRR Pathfinder data, or in the corrected AVHRR Pathfinder data. Discontinuities in the AVHRR data remain too large for detection of the climate changes shown in the other data sets.

Comparison of interannual variability of net flux anomalies between ocean heat storage data and the broadband ERB data sets shows remarkable agreement in both phase and magnitude of these two very different types of data sets. The ocean heat storage data agree with the level of interannual variability found in the radiation data. This variation is larger than known variations in aerosol or other radiative forcings in the late 1990s, and suggests a closely linked variation in global ocean heat storage and global cloud net radiative forcing. Because phase lag is not expected between these two variables, it remains unclear if slight changes in ocean surface temperature and surface heat fluxes are changing clouds, or if clouds are changing ocean heat storage.

The results showed here further demonstrate the need for improving the quality of the current and future ERB climate data record through a) advancing instrument absolute calibration and instrument stability performance with new technologies, b) reducing possible gaps in the climate data record with overlapped missions through advanced planning, and c) adding independent ERB observations with independent analysis to confirm climate change surprises. These are not easy tasks, but they are needed to fully understand our changing climate system. Additional information about this study can be found in Wong et al. (2006).

Acknowledgments. The authors would like to thank Dr. Joel Susskind (NASA GSFC) for providing the HIRS Pathfinder OLR data set. The research of J. Willis described in this paper was carried out at Jet Propulsion Laboratory under a contract with NASA. The ERBE/ERBS Nonscanner WFOV S10N and the CERES/Terra FM1 Scanner ES4 data are provided by the NASA Langley Atmospheric Sciences Data Center in Hampton, Virginia. These data are also available directly on-line from their web site at eosweb.larc.nasa.gov. The ISCCP FD data set is obtained directly on-line from the ISCCP web site at isccp.giss.nasa.gov. The AVHRR Pathfinder ERB data set is obtained on-line from the NOAA web site at www.saa.noaa.gov. The NASA Science Mission Directorate through the CERES project at NASA Langley Research Center funded this study.

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