Inter-Comparisons of Global Surface Albedo and SW Radiation Budgets from Multiple Satellite Missions and Modeling

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Abstract

This study focuses on analysis of shortwave (SW) broadband (BB) satellite observed by scanning radiometers and their inter-comparison with the results of global circulation modeling. Top of the atmosphere (TOA) SW radiation budget datasets are available from multiple satellite missions such as ERBE (1985 to 1990), ScaRaB1/2 (1994 to 1995 and 1998 to 1999) and CERES (1998). We analyzed these observational products as well as inferred surface and atmosphere SW radiation budgets and surface albedo and compared them with different versions of Reanalysis products (Reanalysis-1 of NCAR/NCEP and Reanalysis-2 of NCEP/DOE AMIP-II). Global and tropical monthly mean values as well spatial distributions of monthly anomalies and surface albedo were inter-compared. The distribution of cloud fraction is also evaluated by comparing it with ISCCP-D2 data. In general, the satellite datasets are reasonably consistent between different missions, while there are more substantial differences among the different versions of reanalysis and observations. New Reanalysis-2 SW radiative fluxes and atmospheric absorption compare more favorably with observations than the previous version of the reanalysis. Significant correlation has been detected for differences between observational and modeling data in distribution of cloud fractions and reflected flux. This suggests that cloud generation and parameterization schemes in Reanalysis-2 have to be improved. A decreasing trend over the tropical zone in the TOA SW reflected flux on the order of ~2.5 Wm^{-2} over the last 15 years was detected from satellite data. This general trend is also reproduced by the newest version of Reanalysis. Though the evidence of trend seems to be quite certain, more data are needed to verify this finding with better confidence.

Introduction

One of the highest scientific priorities in climate research is to improve our understanding and capability of modeling the physical processes concerning interactions of solar radiation between the atmosphere, clouds, and the surface. The reason for this is that incoming solar radiation governs entire Earth climate system. Much work has been done to characterize the disposition of Earth's solar radiation budget (Li et al. 1997). A number of satellite missions were conducted during the last three decades that allowed us to determine global, seasonal, and regional variations of the SW radiation budget (Wielicki et al. 1996). Significant progress has also been made in modeling. Nevertheless, the projection of global climate change due to anthropogenic impact is still hindered considerably by inadequate understanding and knowledge of radiative processes and properties in the Earth's climate system (IPCC 1995). Among the most important problems are amount of solar energy absorbed by atmosphere and clouds, and amount of the energy absorbed at the surface level.

As a simple but important diagnosis of model capability in treating radiative processes, the NCAR/NCEP reanalysis data on solar radiative fluxes is assessed by comparing them against a long record of satellite observations from several missions having broadband scanning radiometers. They include ERBE aboard three satellites (ERBS, NOAA-9 and -10), ScaRaB-1 on the METEOR-3/7, ScaRaB-2 on the RESSURS (Kandel et al. 1998) and CERES on the TRMM platform. We applied the algorithms of Li et al. (1993) and Li and Garand (1994) to estimate the surface/atmosphere radiation budget and surface albedo from these TOA observations. Two versions of NCAR/NCEP reanalysis datasets were employed, Reanalysis-1 (Kalnay et al. 1996) and Reanalysis-2 (Kanamitsu 1999). The latter results from a NCEP/DOE AMIP-II follow-on effort to improve modeling and fix known processing problems identified in the former project. Major fixes relevant to the treatment of radiative processes are the update of ocean and land surface albedos and improvement of the shortwave and cloud parameterization schemes.

We present comparisons of a time series of global and tropical zone [20°N-20°S] monthly means. Some comparisons with Reanalysis-2 clear-sky products cannot be completed due to their unavailability at the moment.

TOA SW Reflected Flux and Albedo

The comparisons of global SW TOA reflected flux and albedo are shown in Figure 1. Relative to Reanalysis-1, significant improvement was made in Reanalysis-2. Fluxes and albedos from various satellite missions are consistent overall to each other, which are comparable to the values from Reanalysis-2. Note that the values from CERES/TRMM do not represent global means, but means over a latitude band (42°N; 42°S). Monthly mean series of SW reflected flux and albedo for the tropical zone alone are given in Figure 2a and b. Unlike the case for global means, comparison for the tropical zone shows much larger differences between satellite observations and both Reanalyses. Reanalysis-2 is a little closer to observations by about 10.4 Wm^{-2} on average, but is still ~21 Wm^{-2} (5.2%) higher than the satellite means.

Considering ERBE monthly means for the 1985 to 1989 observation period as the benchmark, anomalies for other satellite data were computed and are shown in Figure 3. Anomalies were also computed for reanalysis data relative to their monthly means averaged over the 1985-1989 period. Monthly anomalies for ScaRaB-2 and CERES are noticeably smaller. The trend may be associated with real climate change or with incomparable spatial and temporal sampling of radiation budget measurements from a 1-satellite mission. It may also be due to a combination of both factors. For ScaRaB-2, this was further complicated by gaps in the data acquisition.

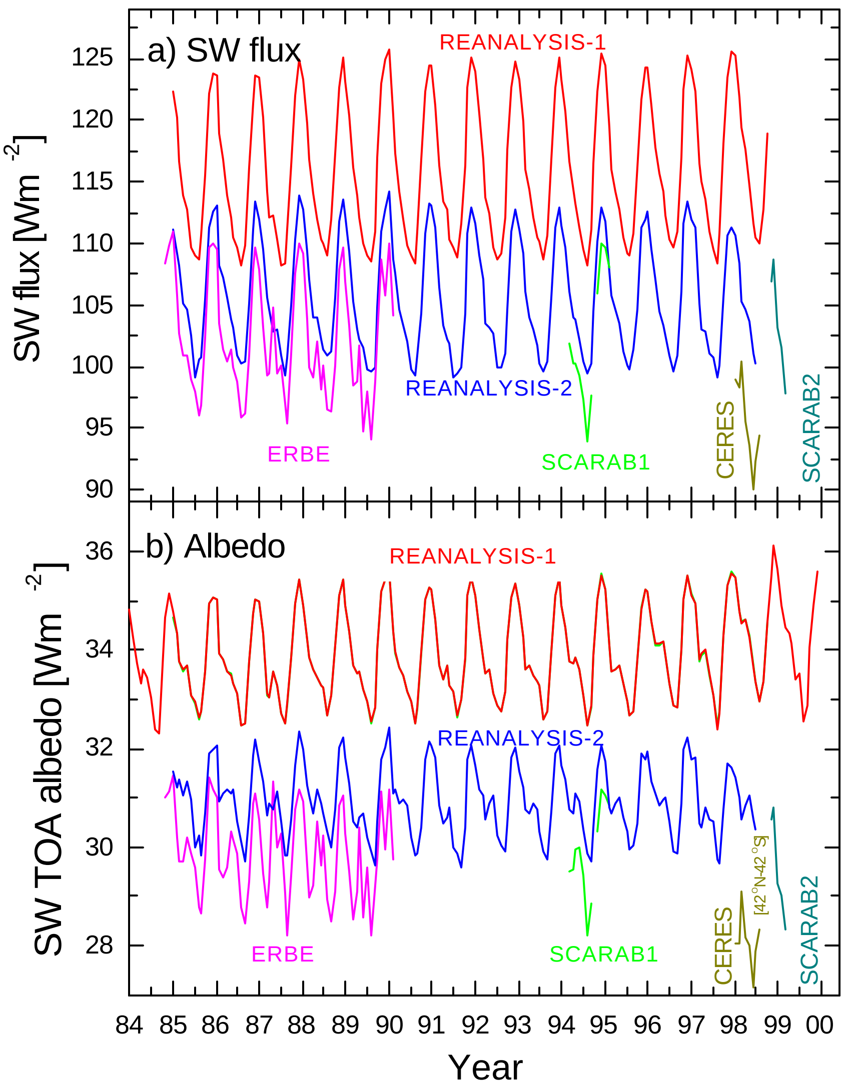

Figure 1. Global monthly mean SW TOA reflected flux a) and albedo b) from different satellite missions and Reanalysis.

There appears to be a similarity in the long-term trends of flux and albedo anomalies between Reanalysis-2 and satellite observations. Both showed slight decreasing trends, with a larger magnitude from satellite observations than from the reanalysis. This, along with the good agreement between ERBE and Reanalysis-2 global mean values, suggests an essential improvement in modeling SW radiation. This is partially attributed to changes made in ocean surface albedo that was assigned unrealistically large values in the original reanalysis as discussed in Kanamitsu et al. (1999). The decreasing trend in TOA reflected SW flux over the last 15 years is especially evident in the tropical zone. The satellite data may be biased to some extent, due to shortcomings in space-time sampling from a single-satellite mission, like CERES or ScaRaB. Coincidentally, the phenomenon is also seen in

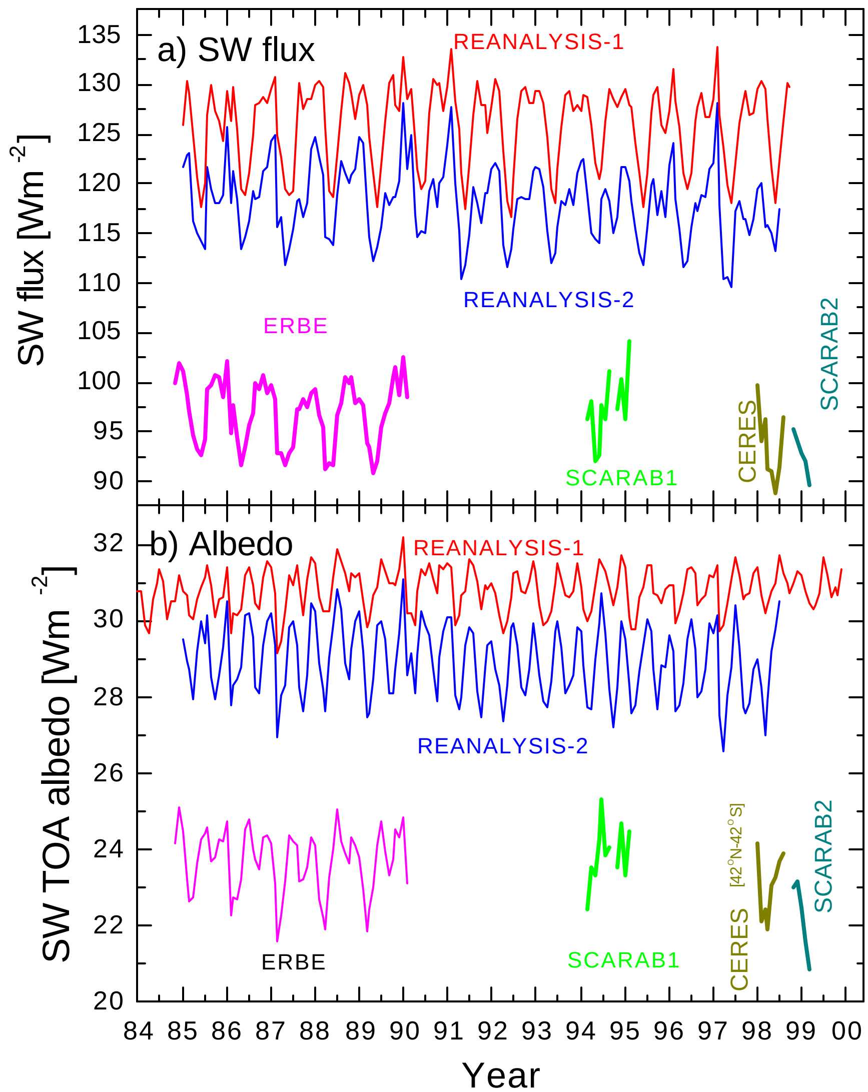

Figure 2. Tropical zone (20°N; 20°S) monthly mean SW TOA reflected flux a) and albedo b) from different satellite missions and Reanalysis

Reanalysis-2. A positive trend in outgoing longwave (LW) radiation was reported from wide-field-of-view radiometers (Wielicki et al. 1999). Monthly mean series of cloud amounts for the tropical zone also show a corresponding decrease in total cloud amount. These findings corroborate with each other. Nevertheless, more data are needed to verify this finding with more confidence.

Atmospheric Absorption, Surface Absorbed Flux, and Albedo

We applied the parameterized algorithms of Li et al. (1993) and Li and Garand (1994) to estimate the atmosphere/surface radiation budget and surface albedo from TOA satellite observations. Precipitable water necessary for computations was taken from a Reanalysis product. Global and tropical zone monthly mean values of surface absorbed flux are shown in Figure 4. The variability and absolute

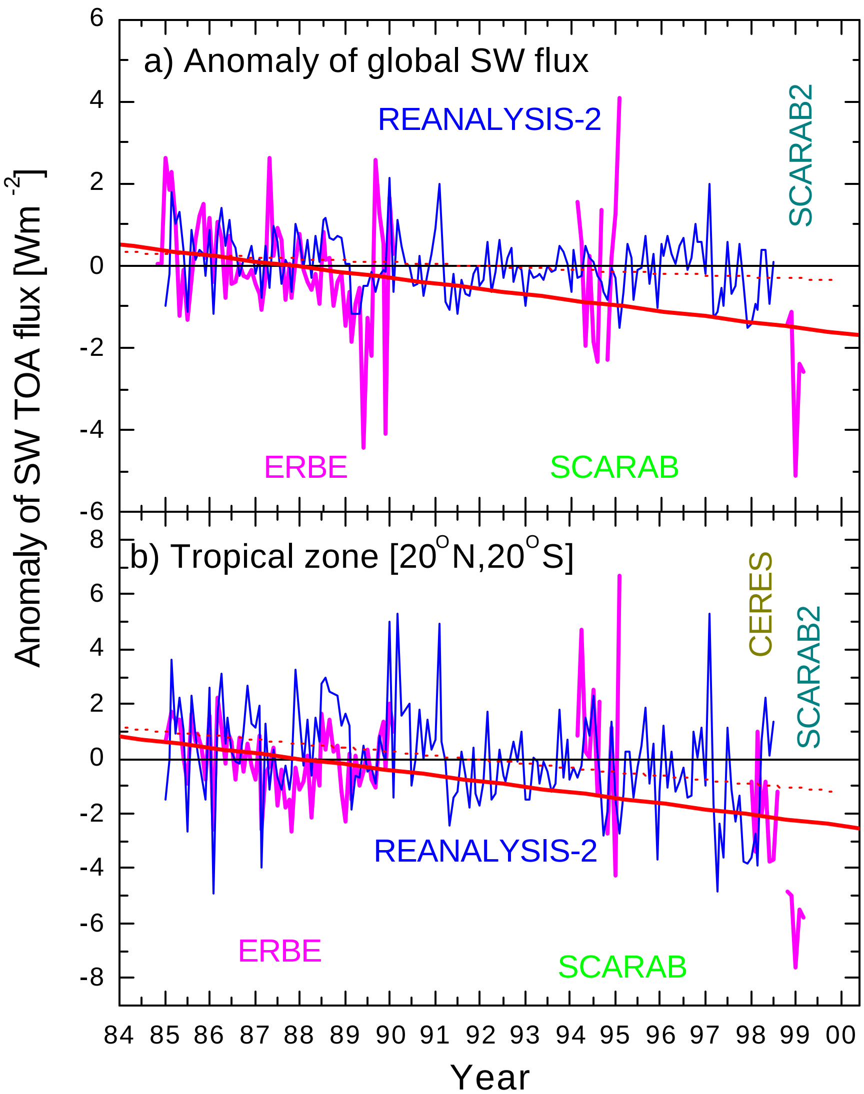

Figure 3. Anomalies of global and tropical monthly means for SW TOA flux and albedo from Reanalysis-2 and satellite missions. Thick line is trend from satellite data; thin dotted line is trend from Reanalysis-2 dataset.

values of surface absorbed flux from the original reanalysis are closer to satellite values than Reanalysis-2 values, which are systematically smaller than satellite values. Given that TOA reflected fluxes from Reanalysis-2 agree better than the original reanalysis with satellite observations, the opposite agreement in surface absorbed flux indicates that radiative transfer governing atmospheric absorption is treated differently in the satellite inversion algorithm and in modeling, which was noted in many GCMs (Li et al. 1997). More realistic modeling results for Reanalysis-2 are also evident in regard to atmospheric absorption. The NCAR/NCEP Reanalysis-1 atmospheric absorption is underestimated by 15.2 Wm^{-2} (4.5%) and 17.7 Wm^{-2} (4.3%) for global and tropical zone mean values correspondingly relative to satellite retrievals for the ERBE period. Similar values for Reanalysis-2 are just 3.1 Wm^{-2} and 3.7 Wm^{-2}, which is about 0.9% with respect to TOA incoming flux.

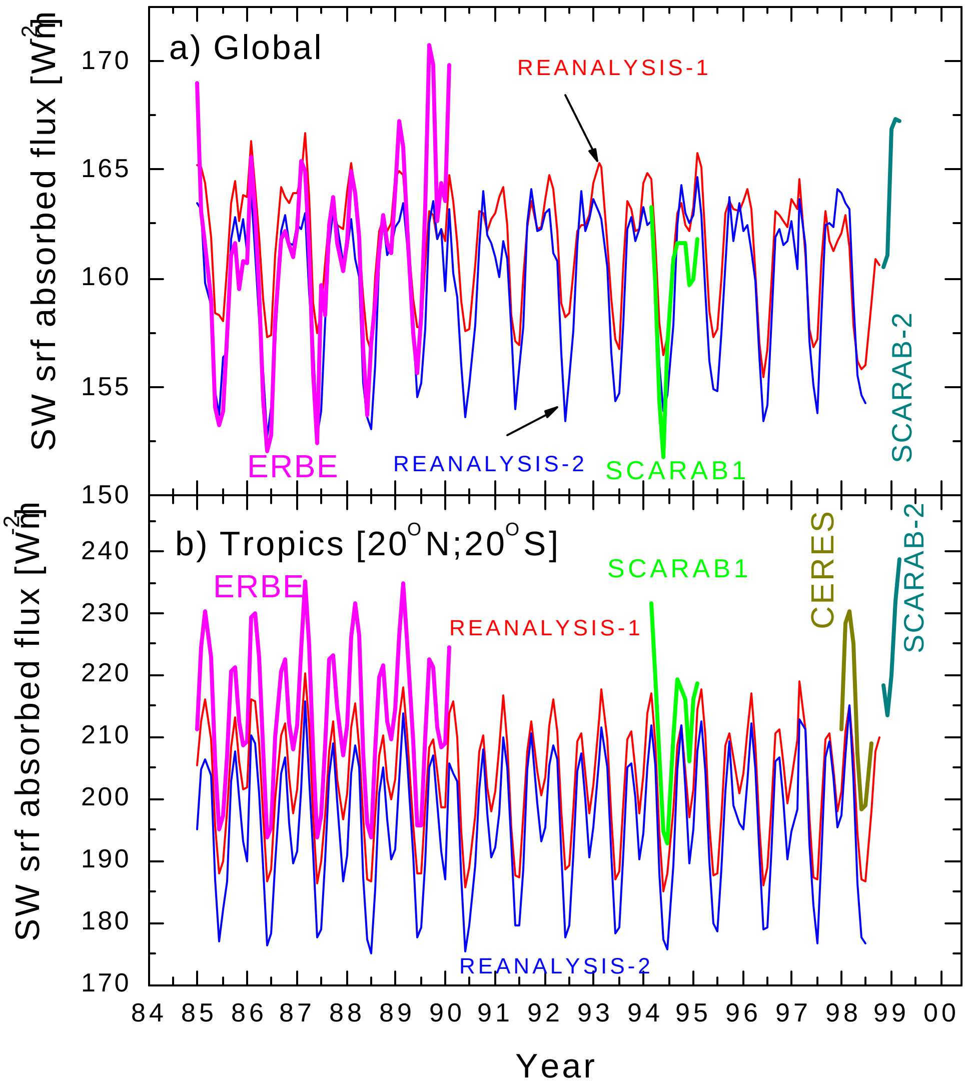

Figure 4. Monthly mean surface absorbed flux estimated from satellite data in comparison to Reanalysis datasets.

Comparison of surface albedo between Reanalysis-2 and ERBE-based retrievals is shown in Figure 5a and between Reanalysis-1 and ERBE-based retrievals in Figure 5b for January and July. Unlike its previous version, Reanalysis-2 shows much better agreement with satellite retrievals. Average differences are between ±0.02-0.04 in absolute units, except for areas with strong seasonal changes due to snow/ice cover.

Cloud Amount

Cloud cover is one of the most fundamental variables affecting both TOA and surface fluxes. A comparison is thus made of cloud fractions from Reanalysis-2 and the ISCCP-D2 data product. Figure 6 reveals that Reanalysis-2 underestimates cloud amounts on a global scale and in the tropical zone.

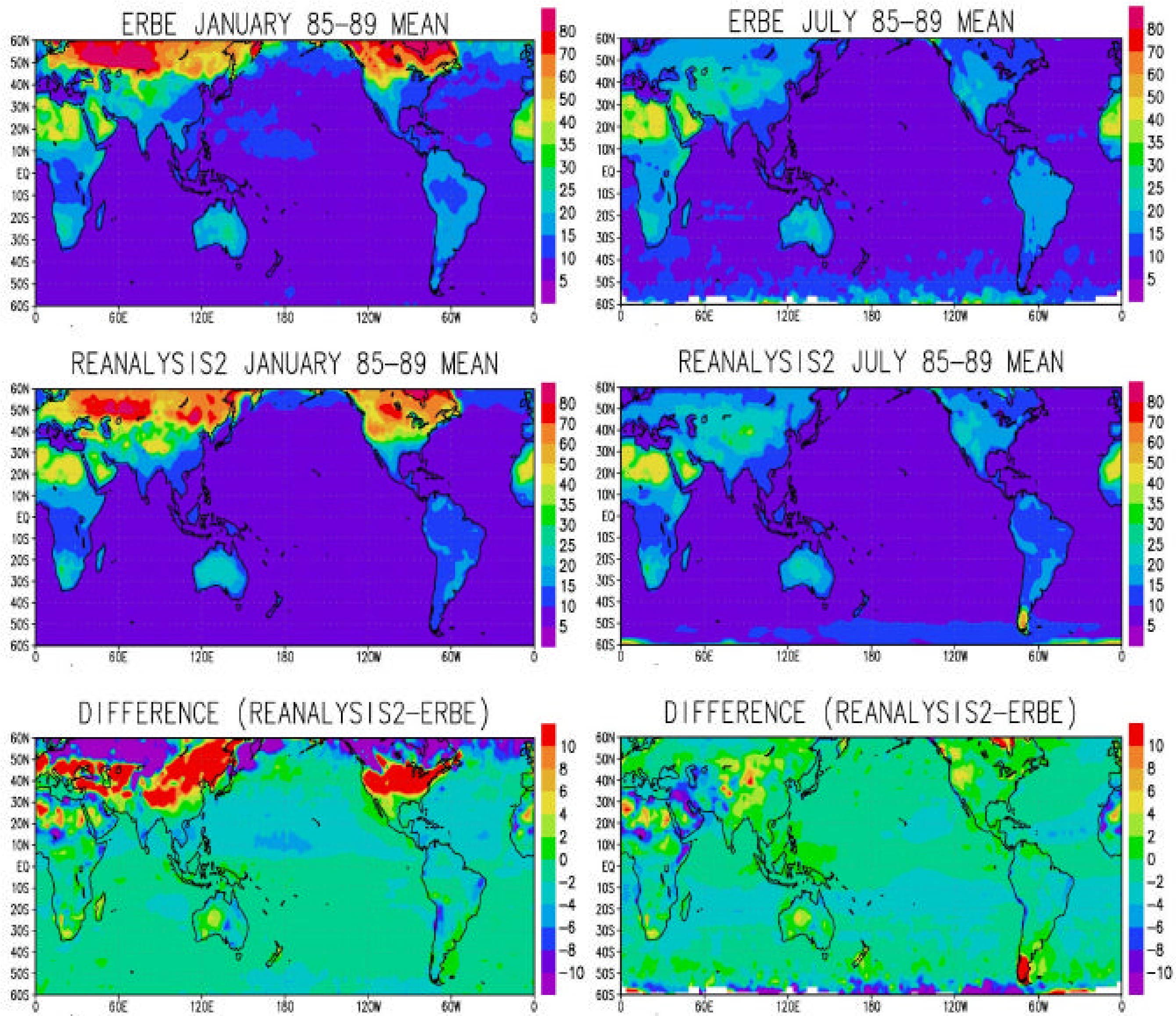

Figure 5a. Comparison of surface albedo retrieved from ERBE data and Reanalysis-2. Averages of monthly mean values for January and July for period of 1985 to 1989, as well as differences, are shown.

Average values are 55.2% and 57.2% respectively, at global and tropical zone scales from Reanalysis-2. The ISCCP-D2 corresponding means are equal to 67.6% and 62.6%. Underestimation of cloud fraction and overestimation of SW reflected flux in the tropical zone suggests that Reanalysis-generated clouds are more reflective.

As an example, Figure 7 shows the spatial distributions of SW reflected flux and corresponding cloud amount averaged over the ERBE period 1985 to 1989 for the month of July. One can see a close similarity in the patterns of the differences between SW TOA reflected flux and cloud amounts. This suggests that the cloud generation and parameterization schemes in Reanalysis-2 need improvement.

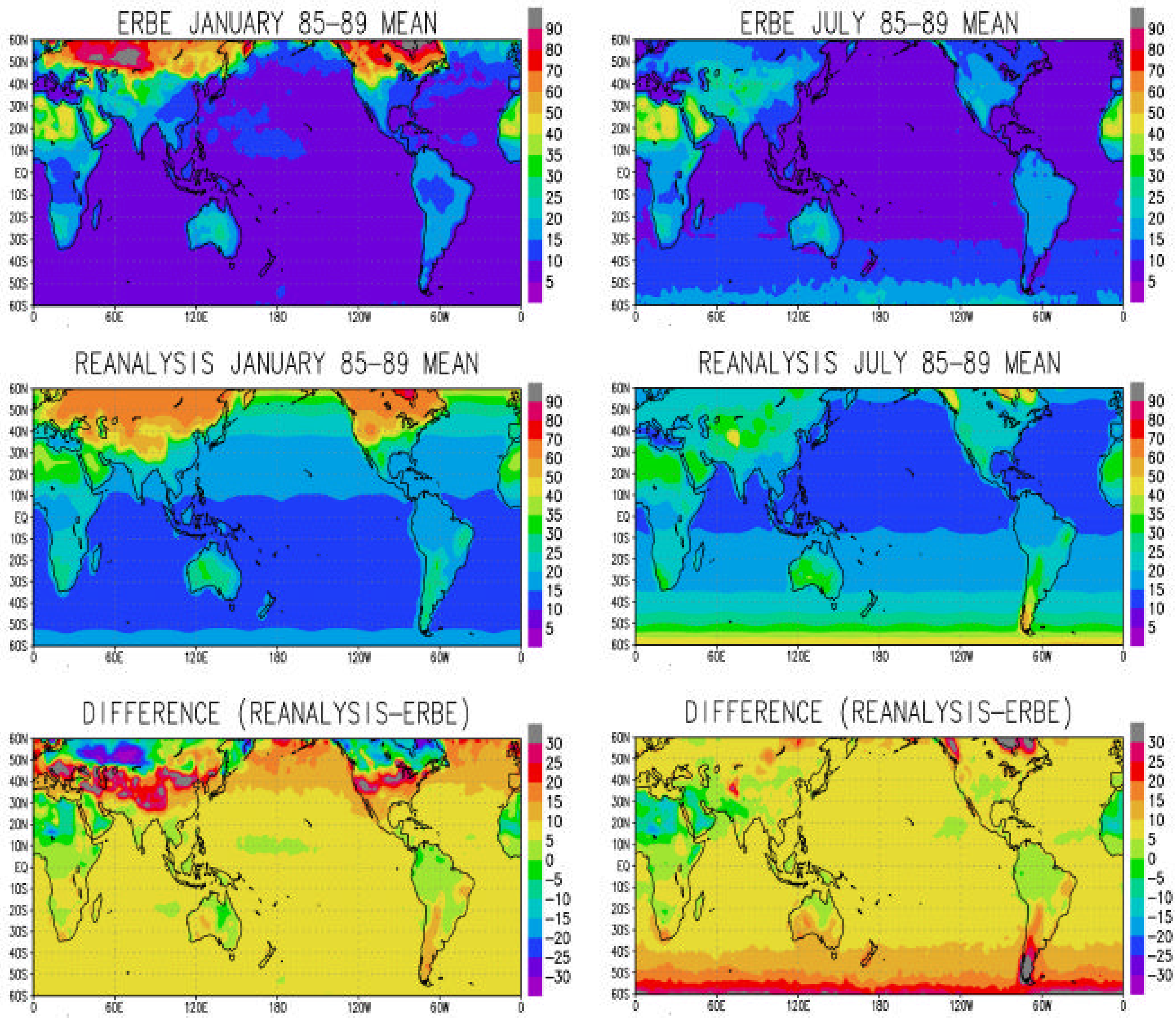

Figure 5b. The same as in Figure 5a but for ERBE data and Reanalysis-1. Note much larger differences between two data sets than ones shown in Figure 5a.

Conclusion

Overall statistics are presented in Table 1 for all satellite missions and Reanalysis. The numbers for ERBE project correspond to absolute flux values. For all other comparisons they are given as departure from ERBE values. The numbers in square brackets denote fluxes in [%], which were derived by normalization to year-mean SW incoming flux at the TOA level for globe and tropical zone respectively.

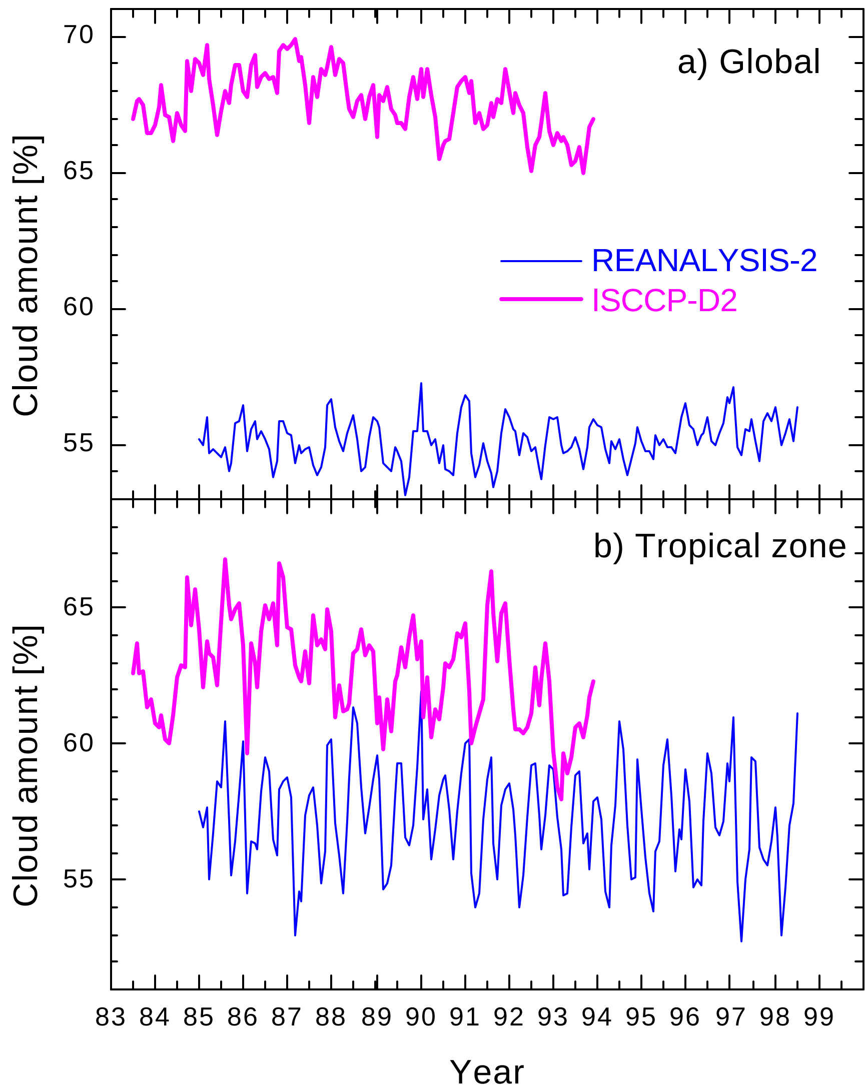

Figure 6. Monthly mean values of cloud amounts from Reanalysis-2 and ISCCP-D2 data for globe and tropical zone. Thick upper curves correspond to ISCCP-D2 data; thin lower curves correspond to Reanalysis-2 data.

The comparison shows that ScaRaB and CERES global and tropical mean SW TOA reflected fluxes, surface absorbed fluxes and atmosphere absorbed fluxes are within +1.3: -2 Wm-2 of the ERBE corresponding mean values, while ScaRaB-2 quantities show more difference, up to ±6 Wm^{-2}. The disagreements between SW radiation budget components seem to be within observational uncertainty and natural variability governed by variations in cloudiness, water vapor and aerosol, etc. Modeled SW fluxes exhibit sound inter-annual and seasonal variability. Comparison of spatial distribution of SW reflected fluxes and cloud amounts, suggests that cloud generation and parameterization schemes, in both Reanalyses, is one of the sources for disagreement and thus needs improvement. Overall, radiative quantities from Reanalysis-2 data are superior to the previous reanalysis, but significant disagreements

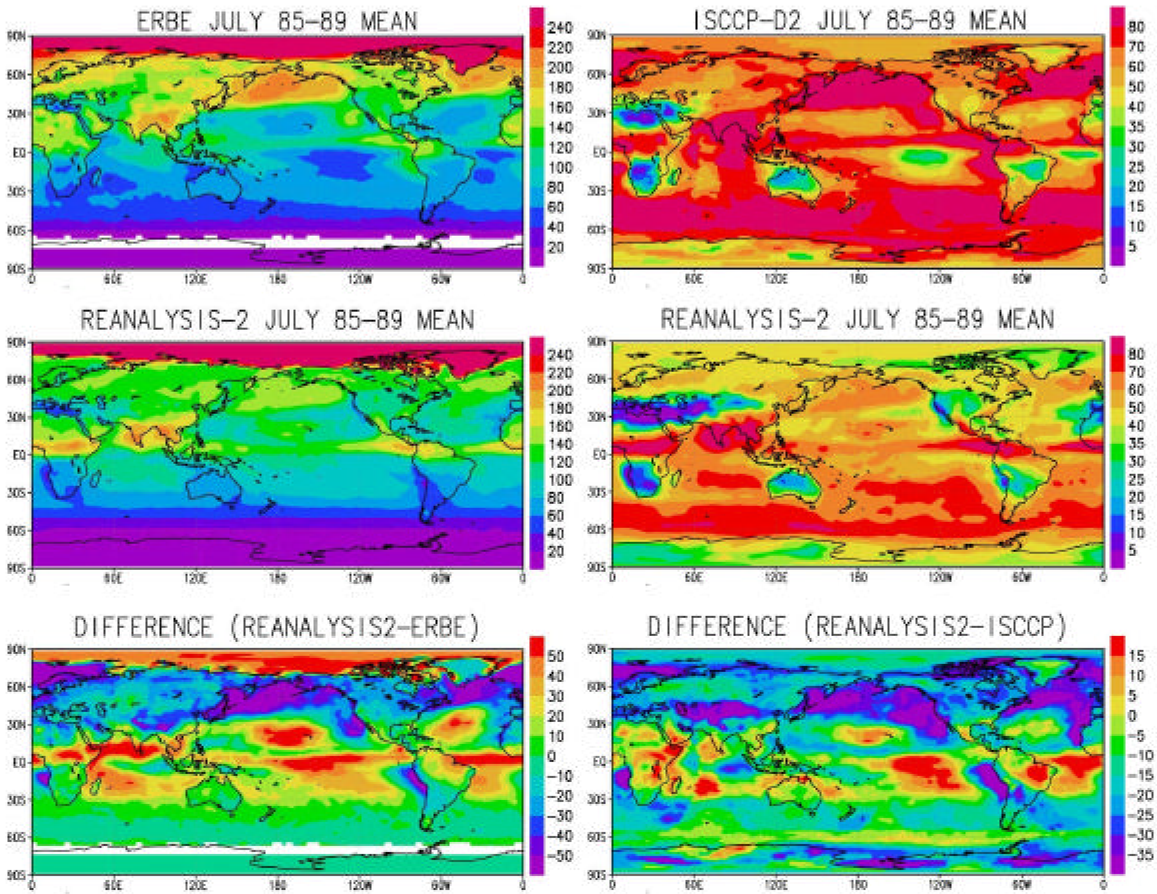

Figure 7. The distribution of TOA SW reflected fluxes and cloud amount for July averaged over 1985 to 1989. Fluxes are from Reanalysis-2 and ERBE. Cloud amounts are from Reanalysis-2 and the ISCCP-D2 product.

still exist, especially in the tropical zone. Moreover, both satellite and reanalysis reveal a long-term trend of decrease in TOA reflected flux with a magnitude of ~2.5 Wm^{-2} over the last 15 years in the tropical region.

Acknowledgments

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Table 1. Overall statistics for satellite and model data.

	All-Sky		Clear-Sky	
	GLB Wm^{-2}[%*]	TRO Wm^{-2}[%]	GLB Wm^{-2}[%]	TRO Wm^{-2}[%]
	SW TOA flux			
ERBE	102.0 [29.8]	95.6 [23.5]	53.7 [15.7]	50.2 [12.3]
ScaRaB	+0.2 [+0.1]	+1.1 [+0.3]	0.0 [0.0]	-1.6 [-0.4]
CERES/TRMM	-	-2.0 [-0.5]	-	-1.7 [-0.4]
ScaRaB-2	-2.5 [-0.7]	-5.7 [-1.4]	-1.9 [-0.6]	-3.7 [-0.9]
Reanalysis	+13.9 [+4.1]	+29.3 [+7.2]	+1.1 [+0.3]	-0.3 [-0.1]
Reanalysis-2	+3.7 [+1.1]	+21.3 [+5.2]	-	-
	SW surface absorbed flux			
ERBE	160.2 [46.9]	212.9 [52.4]	211.7 [61.9]	262.5 [64.7]
ScaRaB	-0.9 [-0.3]	-1.5 [-0.4]	+0.2 [+0.1]	+1.2 [+0.3]
CERES/TRMM	-	+0.7 [+0.2]	-	+0.4 [+0.1]
ScaRaB-2	+1.5 [+0.4]	+6.3 [+1.6]	+1.2 [+0.4]	+5.2 [+1.3]
Reanalysis	+1.3 [+0.4]	-11.6 [-2.9]	+9.4 [+2.7]	+12.5 [+3.1]
Reanalysis-2	-0.6 [-0.2]	-17.6 [-4.3]	-	-
	SW atmosphere absorbed flux			
ERBE	79.8 [23.3]	97.5 [24.1]	76.6 [22.4]	93.3 [23.0]
ScaRaB	+0.7 [+0.2]	+0.4 [+0.1]	-0.2 [-0.1]	+0.4 [+0.1]
CERES/TRMM	-	+0.7 [+0.3]	-	+1.3 [+0.3]
ScaRaB-2	+1.0 [+0.3]	-0.6 [-0.2]	+0.7 [+0.2]	-1.5 [-0.4]
Reanalysis	-15.2 [-4.5]	-17.7 [-4.3]	-10.5 [-3.0]	-12.2 [-3.0]
Reanalysis-2	-3.1 [-0.9]	-3.7 [-0.9]	-	-

Note: The numbers in square brackets [ ] denote percentage relative to mean incoming solar TOA flux.

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