IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 120, No. 4, October – December, 2016, pp. 353–364

An interpretation of the measured planetary radiation imbalance

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(Manuscript received in final form May 31, 2016)

Abstract—Some time variation properties of the planetary imbalance are shown by using satellite measured radiation budget data. The covered period is 1962–2014. The data have been collected from publications and data bases. The solar incom part of the budget has been homogenized using new total solar irradiance (TSI) values. The positive imbalance increases as well as the time delay between the incoming and outgoing radiation.

Key-words: planetary imbalance, radiation budget, satellite measurements, TSI, response time

1. Introduction

The radiation budget of the planet Earth is

$$\text{NET} = \text{TSI}/4 - \text{REF} - \text{OUT}, \tag{1}$$

where:

- NET is the result of all radiation processes.
- TSI is the total solar irradiance, the number 4 is the ratio of the surface of the sphere to the cross section of the sphere perpendicular to the solar rays, this way TSI/4 is the planetary (global) average solar irradiation at the top of the atmosphere (incoming solar radiation: ICO). The shape of the Earth is not

exactly spherical, the rotational ellipsoid approximation gives 4.002 yearly ratio. *Loeb et al.* (2009) calculated 4.0034. In this work the spherical value is used. It is worth to mention that the few tenth of a percent correction is near to the uncertainity of recently measured TSI values.

– REF is the solar radiation reflected to the interplanetary space by the planet.

– OUT is the longwave radiation emitted to the interplanetary space by the planet. Its value is not a simple response to the incoming/absorbed one.

Eq. (1) does not contain the energy of cosmic rays and radio waves arriving to the Earth from the space, since their energy is negligible to the named ones.

If the climate of the planet is in equilibrium, the yearly average net radiation should be zero, that is the incoming and outgoing radiation is balanced, the possible imbalance should be short living small variations around zero.

To check the actual state of the radiation budget of the Earth, several experts have made serious efforts to construct instruments, develop data processing procedure, estimate the error of the received data, and analyze the received data provided by satellite-born instrumentation since the begining of the 1960's. Some early results directed to the global net radiation are the followings: *Ardanuy et al*. (1992), *Arking* and *Vemury* (1984), *Arking* (1996), *Ellis* and *VonderHaar* (1976), *Gruber* and *Winston* (1978), *Harrison et al.* (1993), *Jacobowitz et al.* (1984), *Kandel et al*. (1994), *Kyle et al.* (1985), *Kyle et al.* (1993), *Loeb et al.* (2009), *MacDonald* (1970), *Ohring* and *Gruber* (1983), *Randel* and *VonderHaar* (1990), *Raschke et al* (1973), *Raschke* (1968), *Spänkuch* (1995), *Stephens et al.* (1981), *VonderHaar* and *Raschke* (1972), *Winston* (1970). The latest global net radiation data are provided by the CERES (Cloud and the Earth's Radiatiant Energy System) project since March of 2000 (*Loeb,* 2015). This project uses all the previous experiences in instrument building, data processing, and personal knowledge, moreover, the data sampling is the best in the history of radiation budget measurements.

The values of yearly global net radiation provided by the above mentioned data sources are between +0.9 and + 5 W/m^2, that is during the past 5 decades, negative radiation imbalance did not exist according to the measured data series. The series were produced by several projects, and there were significant interruptions between the periods covered by different projects. Since the uncertainity of these net radiation data is equal or even larger than the values itself, climate scientists could not use these data series. According to the energy budget investigations of the full Earth system, these values do not fit the system, they are too high.

Using the GISS (Goddard Institut for Space Science) climate model *Hansen et al.* (2005) calculated the planetary radiative imbalance for the period of 1880–2005. From the begining the imbalance generally increases from zero to the order of 1 W/m^2, the increase interrupted by the volcanic eruption for 2–3 years, when the imbalance falls below even –2 W/m^2. The increase is slow until 1960, afterward it is more significant. These results are in good agreement with the ocean heat content data. The heat capacity of oceans gives 93 percent of the planetary heat capacity, therefore, the planetary energy imbalance is almost equal to the change of the heat balance of the oceans.

Loeb et al. (2009) modified the original CERES data series creating the CERES EBAF (Energy Balanced And Filled) data series to eliminate the deviation between the satellite measured radiation imbalance and the ocean heat content data, moreover, they stated that the probable reason of the deviation is some kind of systematic calibration error of the satellite-born radiometers. This EBAF series has been constructed to serve the purposes of the climate system science.

In this work, the trends in both the EBAF and the previous satellite radiation budget data series are looked for.

2. Data

2.1. TSI

The TSI is not identical to the solar constant (the first solar constant measurement was made by Pouillet in 1838 from the surface), it contains the variations of incoming solar radiation that are due to variations in the solar activity. TSI measurements have been and are made separately from the measurement of other components of the radiation budget. Continuous satellite based TSI measurements are made from November 1978. The first group of modern (cavity) absolute pyrheliometers were constructed by the Eppley Laboratory (J. Hickey), the Jet Propulsion Laboratory (JPL, R. Willson), the Physical Meteorological Observatory Davos (PMOD, C. Frőhlich), and the Royal Meteorological Institut of Belgium (RMIB, D. Crommelynck). From these instruments a standard group is selected that defines the World Radiometric Reference (WRR), the recently official radiometric scale of the World Meteorological Organization (WMO). In 2003, the National Institut of Standards and Technology of USA (NIST) developed a corrected absolute pyrheliometer named Total Irradiance Monitor (TIM), that measures the TSI approximately by 6 W/m^2 lower than the previously mentioned first group. Recently, Finsterle (PMOD) and several collaborators develop the Cryogenic Solar Absolute Radiometer (CSAR) (*Finsterle,* 2015), that is an essentially different new absolute pyrheliometer in development phase. It seems that after 2018, the WMO shall have to decide amongst the above mentioned 3 pyrheliometric scales. Recently, most of TSI users accepts the NIST scale. In the time period of satellite-based planetary radiation budget measurements, only the development of the TSI measuring instrumentation is known precisely.

Some solar physicists groups connected the satellite-measured TSI data to solar models, and this way they constructed TSI data series backward to some hundred years. For the period 1700–2000, *Dewitte* (2014) presented a TSI series. From this series we use the 1950–2000 section, but the values are decreased by 2.5 W/m^2 to transform them to the NIST scale. For the period 2000–2014 we accept the CERES Edition 4 TSI values (*Kratz et al.,* 2015), these are somewhat higher than the Edition 3A ones. In *Fig. 1,* the yearly mean TSI values are shown from 1950 to 2014.

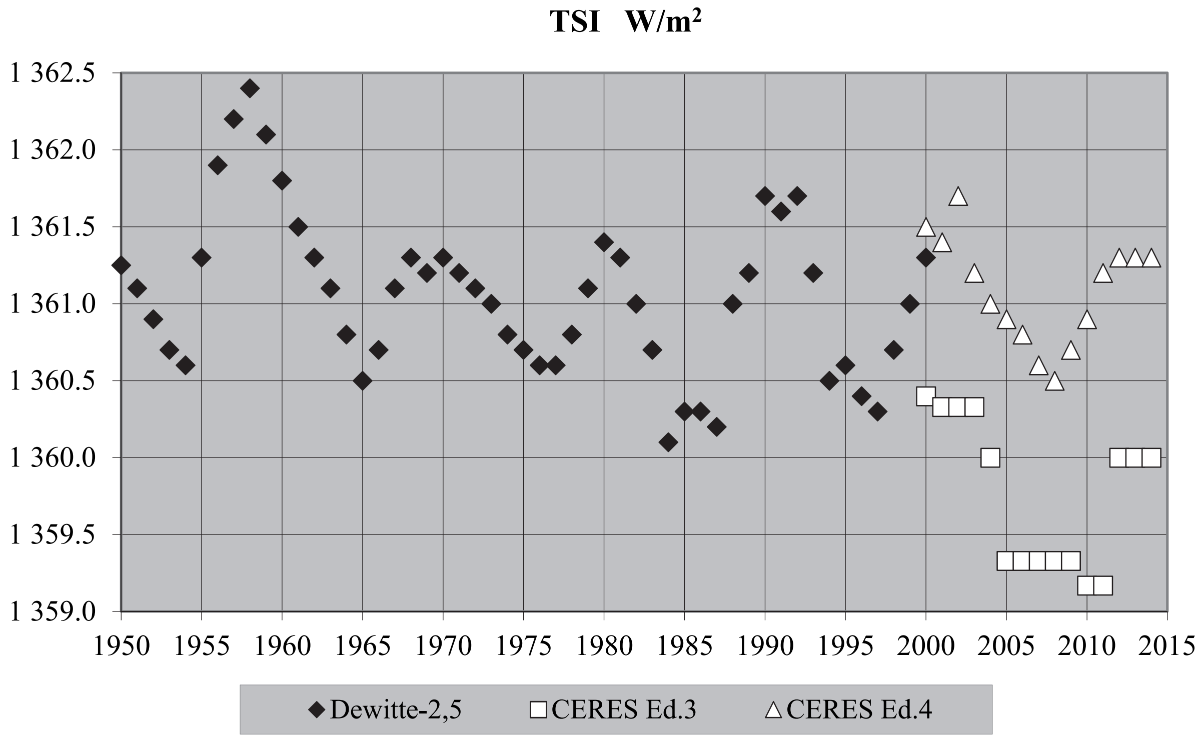

Fig. 1. The yearly TSI values used in this work. The 11 years sunspot cycle is seen clearly.

2.2. Radiation budget of 1962–1995

In *Table 1,* yearly or several yearly net radiation budget data are listed as they available from the named publications or data bases. This way, these data eliminate the variations arising from the yearly change of the Sun-Earth distance. Those published values that belong to period longer than 1 year has been composed from several monthly measured ones to represent the „mean" value of the period.

Table 1. Original data taken from publications and data bases. The numbers in parentheses are calculated from the original ones. Where not written, the unit is W/m^2. Earlier used unit: ly = langley = cal /cm^2.

Time period	Experiment	TSI	Reflected	Albedo	Absorbed	OUT	NET	ICO	Source
1962 – 1966 33 months	TIROS Nimbus-2 ESSA-7	1.95 ly/min		30.0%		0.34 ly/min	0.00 (0.9W/m^2)		*VonderHaar-Raschke*, 1972
1964 – 1971 29 months	TIROS Nimbus-2,3 ESSA-7 ITOS-1 NOAA-1	1360.0	103.3	32.4%	236.7	235.8	0.9	340.0	*Ellis-VonderHaar*, 1976
1964 – 1977 48 months	TIROS Nimbus-2,3,6 ESSA-3,7	1376.0		30.0%		232	9		*Stephens et al.*, 1981
1979	ERB	1372.7	(101.4)			235.8	6.0	(343.2)	*Ardanuy et al.*, 1992
1980	,,	1373.3	(101.2)			236.3	5.8	(343.3)	,,
1981	,,	1372.0	(100.6)			236.4	6.0	(343.0)	,,
1982	,,	1371.7	(101.5)			235.4	6.0	(342.9)	,,
1983	,,	1371.7	(101.5)			235.9	5.5	(342.9)	,,
1984	,,	1371.3	(100.8)			235.4	6.6	(342.8)	,,
1985	,,	1371.5	(101.4)			234.9	6.6	(342.88)	,,
1986	,,	1371.4	(101.1)			235.2	6.6	(342.85)	,,
1985	ERBE	(1362.4)		29.8%		234.0	5.1	(340.6)	Larc NASA S4G data
1986	,,	(1362.8)		29.7%		234.0	5.5	(340.7)	,,
1987	,,	(1363.6)		29.5%		236.0	4.3	(340.9)	,,
1988	,,	(1368.4)		29.5%		237.0	4.2	(342.1)	,,
1989	,,	(1361.6)		29.7%		236.0	4.0	(340.4)	,,
Mar-Sep, 1994 Nov-Dec, 1994 Jan-Feb,1995.	ScaRaB	(1366.0)		29.9%		237.0	2.4	(341.5)	ScaRaB CDs

In this work, the original radiation budget data have been corrected by substituting the original ICO or TSI data by using the TSI data shown in *Fig. 1*. The reflected solar radiation and the outgoing longwave radiation values are kept as in the original series. The corrected yearly imbalance data series is seen in *Fig. 2*. As a try of correcting the reflected and outgoing radiation data, *Shrestha et al* (2015) presented an improved ERBE series, but it is restricted to the 60N – 60S part of the globe.

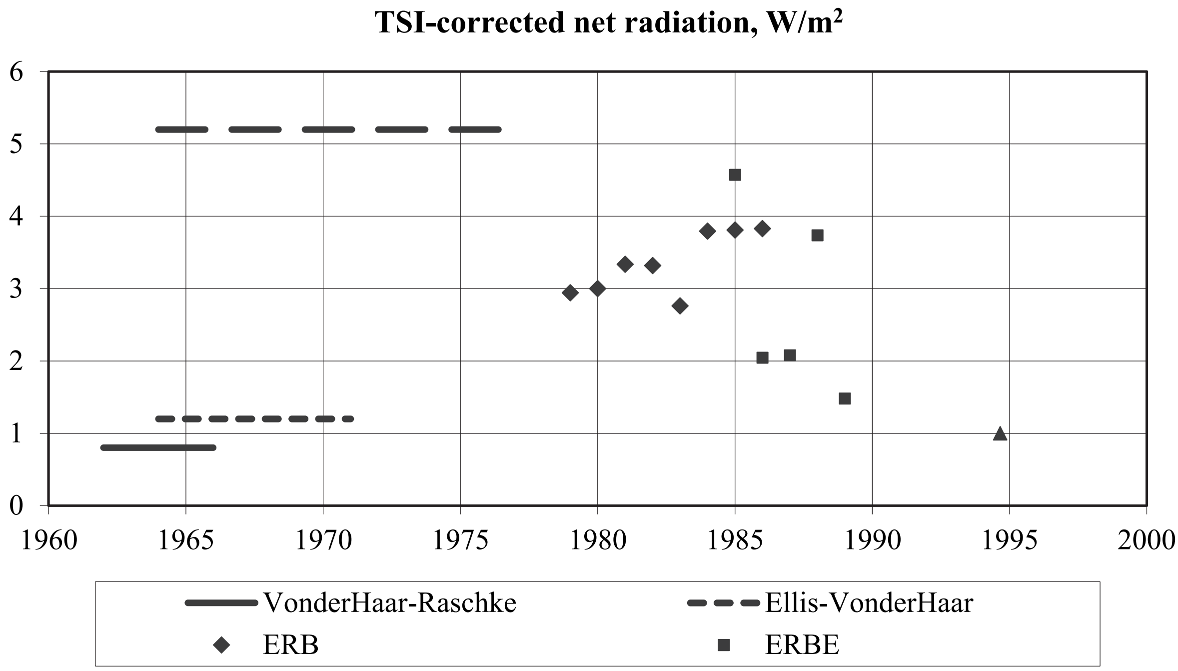

Fig. 2. The used imbalance data for 1964 – 1995. They are corrected to the TSI values seen in *Fig. 1*. The horizontal lines are characteristic to the covered period written in *Table 1*, the dots are calendar year means, except the ScaRaB point that is the mean of March 1994 –Febr 1995. The missing October is filled by interpolation.

2.3. Radiation budget of 2000–2014

Since the March of 2000, continuous high quality annual radiation budget data are available from the CERES Project (*https://ceres.larc.nasa.gov/products*). In this work, the CERES Ed.3A radiation data are used, except that the ICO of Ed.3A is changed to ICO of Ed.4 as mentioned in Section 2.1. The yearly (March-February) values are seen in *Fig. 3* altogether with the EBAF values. These Ed. 2.8 EBAF data are not corrected to the newer TSI (that is they contain the original Ed.3A ICO values), since the EBAF is fitted to the whole energy budget data of the climate system.

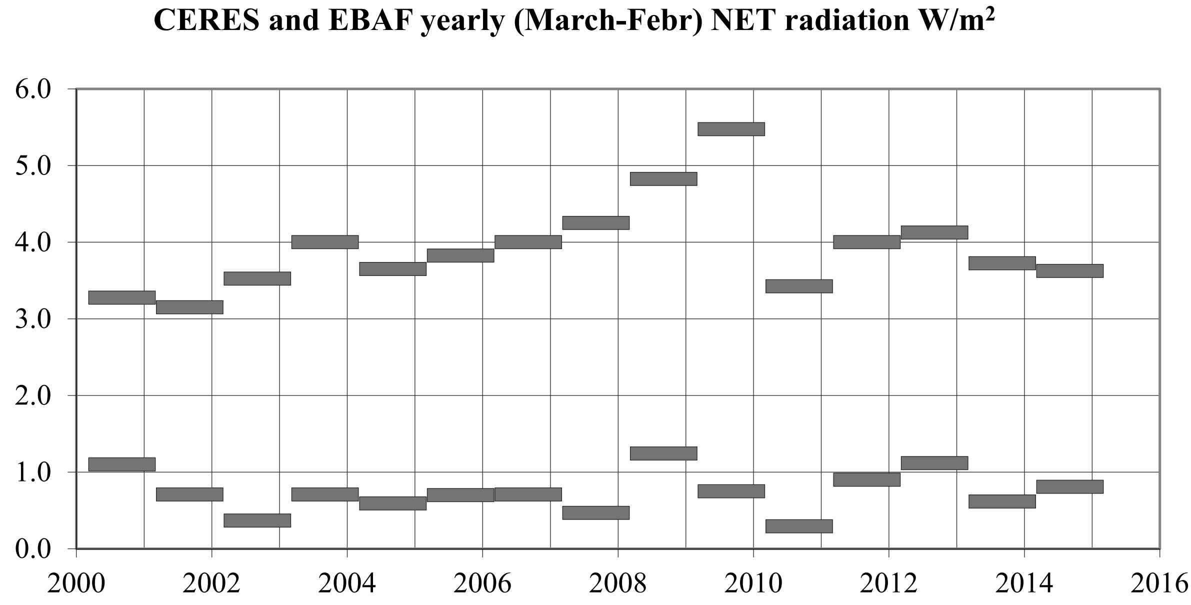

Fig. 3. The radiation balance data for the period of March 2000 – February 2015.

3. Time variations

3.1. The time period of March of 2000 – February 2014

This time period is covered the latest satellite-measured radiation budget data. Looking at *Fig. 3,* the most significant feature in the original CERES data series is the inreasing imbalance between 2000 and 2009, then a sudden decrease in 2010 and a weak increase afterward. The EBAF data do not show such strong variability, however, the year-to-year change is significant compared to the imbalance values itself. The basic statistics of the two series are printed in *Table 2*. Both linear trend coefficients show a slight (compared to the year-to-year variations) increase of the imbalance. In the increase of imbalance, the incoming solar radiation does not play important role, it is decreasing weakly, while the reflected and outgoing radiation are decreasing more significantly. Accordig to the standard deviations, the reflected solar and outgoing longwave radiation are not independent of each other.

Table 2. Basic characteristics of the March 2000 – February 2015 period according to the CERES and EBAF data series.

	EBAF			CERES		
	Mean W/m^2	**Standard deviation W/m^2**	**Trend Wm^{-2}year^{-1}**	**Mean W/m^2**	**Standard deviation W/m^2**	**Trend Wm^{-2}year^{-1}**
ICO	340.0	0.08	–0.0043	340.2	0.09	–0.0045
REF	99.7	0.20	–0.0083	97.9	0.51	–0.0486
OUT	239.6	0.24	–0.0019	238.8	0.24	0
NET	0.7	0.27	0.0059	3.5	0.60	0.0441

3.2. The time period of 1962 – 2014

The data seen in *Fig. 2* plus the original CERES data seen in *Fig. 3* are the satellite-measured yearly radiation imbalance of the last 5 decades. Taking them as one data series its basic statistical parameters are shown in *Table 3*. The trend parameters were calculated using the middle time point of the years or of the time periods the radiation values belong to. The planetary imbalance is increasing during this half century, while the year-to-year variation is much more significant similarly to the 2000 – 2014 period. If the idea of constant systematic calibration error of the satellite-born radiometers measuring the reflected solar and the outgoing longwave values is accepted for the whole period, then according to the high value of the regression coefficient of NET radiation, this error is not a simple additive one.

Table 3. Basic statistics for the period of 1962 – 2014

	Mean W/m^2	**Standard deviation W/m^2**	**Trend Wm^{-2}year^{-1}**
ICO	340.2	0.106	0.0017
REF	99.7	2.126	–0.1328
OUT	237.1	1.802	0.1006
NET	3.4	1.135	0.0339

4. Time delay between incoming and outgoing radiation

Fig. 4 shows the monthly CERES values of absorbed solar (short wave) and emitted longwave radiation. As it is expected, the yearly variations of the absorbed radiation (~ 15 W/m^2) exceed that of the emitted (long wave) ones (~ 8 W/m^2). The phase shift (response time) between the two waves is approximately a half year. The time delay between the absorbed and outgoing radiation depends not only on the thermal inertia of the planet but on the longwave transmissivity and emissivity properties of the atmosphere. The positive imbalance is seen clearly, the shortwave curve goes higher than the longwave one. Similar figure were prepaered by *Ardanuy et al.* (1992) for the period of 1979 – 1986.

The time delay (phase shift) between two waves could be measured by the time difference between the maxima and minima. Since the EBAF data fits better to the climate system than the original CERES ones, to quantify the response time between the planetary radiation income and outcome the differences of the dates of EBAF OUT yearly max and the yearly Perihelion, as well as that of EBAF OUT yearly min and the yearly Aphelion are taken. The astronomical dates have been obtained from http://aa.usno.navy.mil/data/EarthSeasons.php.

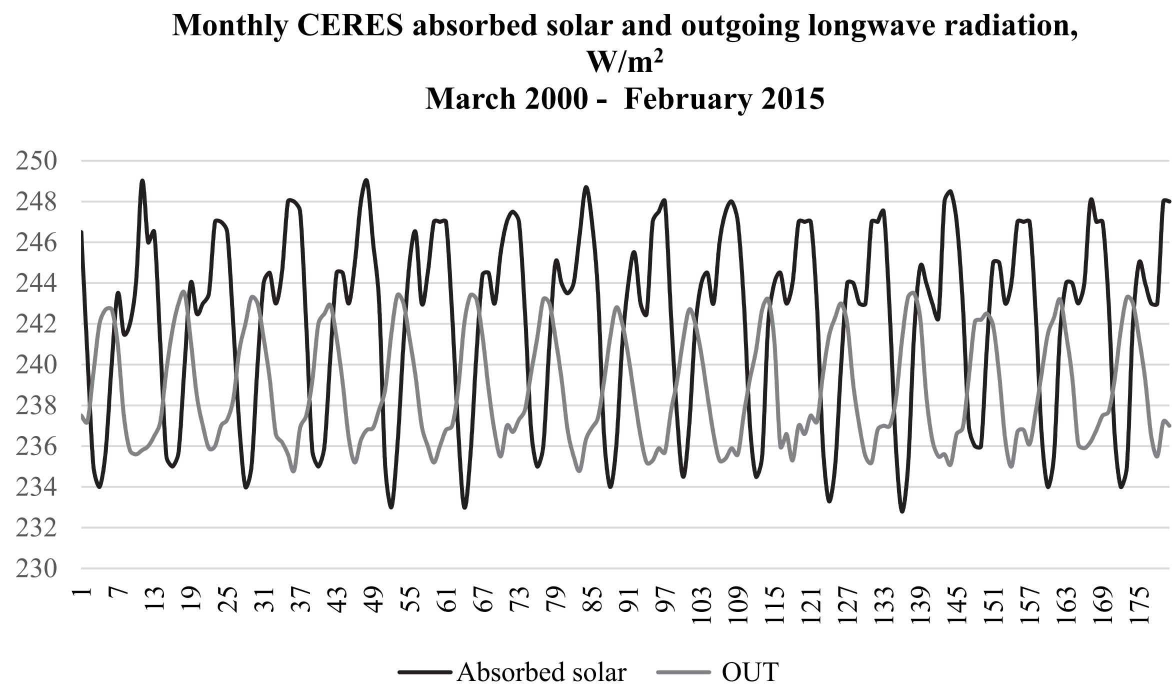

Fig. 4. Monthly global absorbed solar radiation and outgoing emitted radiation from the CERES data series.

Since the date of the peak values of OUT data are not well defined, two kinds of smoothing have been applied:

- the monthly values were taken into account instead of daily ones,
- a second order polinom were fitted to 5 monthly values around the expected dates, the dates of peak values of these polinoms were taken as peak dates of outgoing radiation.

In the outgoing radiation the dates of max peaks vary between July 23 and 31, while those of min peaks between December 29 and January 25. The first derived time difference between the max peaks has been established between the date of max OUT in July 2000 and the date of Perihelion in January 2000. The first one between min peaks has been derived from the date of min OUT in January 2001 and the date of Aphelion in July 2000. *Fig. 5* shows separately the 15 – 15 values between the maxima and minima. The linear trend gives a slight increase in both cases.

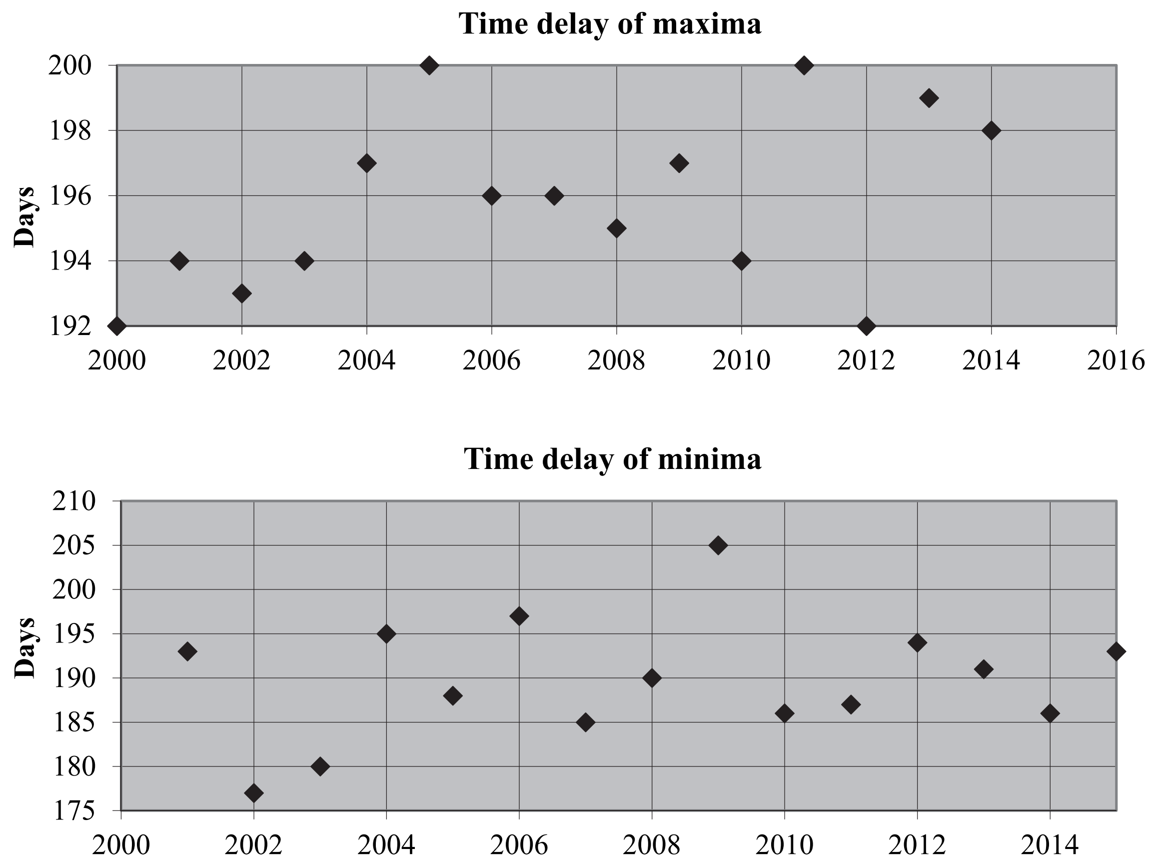

Fig. 5. Time difference (days) between the incoming solar radiation and the EBAF outgoing radiation. Upper panel: difference of max peaks, lower panel: that of min peaks.

5. Conclusion

More efforts would be necessary to correct the REF and OUT components of the radiation budget data measured by satellites before 2000 to better connect the planetary radiation imbalance to the global climate processes.

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