DOI:10.28974/idojaras.2022.3.1

IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 126, No. 3, July – September, 2022, pp. 297–304

Heat capacity of the climate system derived from planetary radiation budget measurements

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(Manuscript received in final form June 30, 2022)

Abstract—The new edition of the satellite measured radiation budget data have the smallest ever random and systematic error. From them, mean yearly cycle of the planetary heat capacity has been calculated for the period of 2000–2014. The radiation budget data measured before 2000 have serious systematic error. Using the new radiation budget data as well as the total solar irradiance data, the old yearly radiation budget values have been corrected. From the corrected data, the average heat capacity of the climate system has been calculated for the 1964–2014 half century.

Key–words: satellite measured radiation budget data, yeraly cycle of the planetary heat capacity, average planetary heat capacity of the period 1964–2014.

1. Introduction

Since the beginning of the satellite era, several efforts have been made to measure the state of the energy equilibrium between the Earth-atmosphere system and its outer environment. Even in the early years it was known, that these measured radiation budget data had significant random error (uncertainty). Later became obvious that their systematic error (bias) is large compared to the level that is necessary to the investigation of the energy processes of the climate system. The data from the recent experiment (CERES–Clouds and the Earth's Radiant Energy System) have small random error; however, their systematic error is in the same range as earlier. Therefore, the CERES Team transformed the CERES data into EBAF data; these could be regarded as nearly free from systematic error. The last edition of EBAF data was released in February 2017; this is the CERES EBAF Ed4.0 (*Loeb et al.,* 2009).

The most simple use of the measured planetary radiation budget data is to calculate the heat capacity of the climate system, since the energy exchange of the system with its environment is given by the *NET* radiation, the change of the temperature of the system can be calculated from the outgoing longwave radiation part of the radiation budget as radiation (brightness) temperature. This heat capacity is an effective one: it is the heat capacity of that portion of the climate system that is coupled to the processes determining the outgoing longwave radiation (see *Schwartz,* 2007; *Foster et al.,* 2008).

$$\frac{d(QT)}{dt} = NET\ , \tag{1}$$

where Q is the effective heat capacity, T is the radiation temperature of the outgoing longwave radiation, *NET* is the measured planetary net radiation.

Since the used unit of the planetary *NET* value is W m^{-2}, therefore the unit of Q is W year m^{-2} K^{-1} or W month m^{-2} K^{-1}, depending on the time-period of averaging the *NET* value.

In the first part of this work, the effective heat capacity of the yearly cycle of the climate system is calculated from the March 2000 – February 2015 monthly EBAF Ed.4 data. In the second part, the half-century (1964 – 2014) heat capacity is derived from corrected yearly planetary radiation budget measurements.

2. The heat capacity of the yearly cycle

The EBAF Ed.4 data series starts with March 2000. The data were obtained from the NASA Langley Center CERES ordering tool at http://ceres.larc.nasa.gov/. The heat capacity calculation is made from the average yearly cycle. The radiation temperature change in the yearly cycle is nearly 2 K, while the max - min in the 15 yearly values is 0.2 K only.

The average yearly course of the measured planetary *NET* radiation is not exactly sinusoid and has a 0.66 W m^{-2} imbalance. In *Fig. 1*, two-yearly curves are shown to see better the difference between the measurements and the sinusoid approximation that is used in the calculations. This latter is free from the imbalance, its equation is:

$$NET = 1.78\ \sin(2\pi/12*t) + 7.89\ \cos(2\pi/12*t), \tag{2}$$

where t is the number of the months of the year (more precisely 1/12 part of the year).

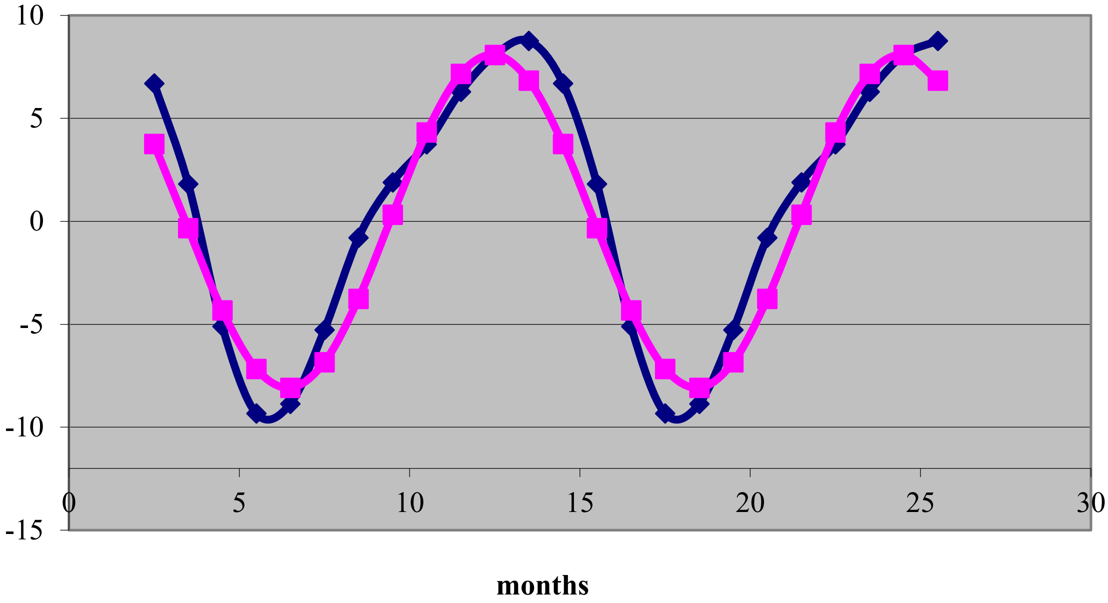

Fig. 1. Two-yearly cycle of the average planetary EBAF *NET* radiation, blue: measured, pink: sinusoid and balanced approximation.

The average yearly course of the brightness temperature and its approximation is shown in *Fig. 2.*

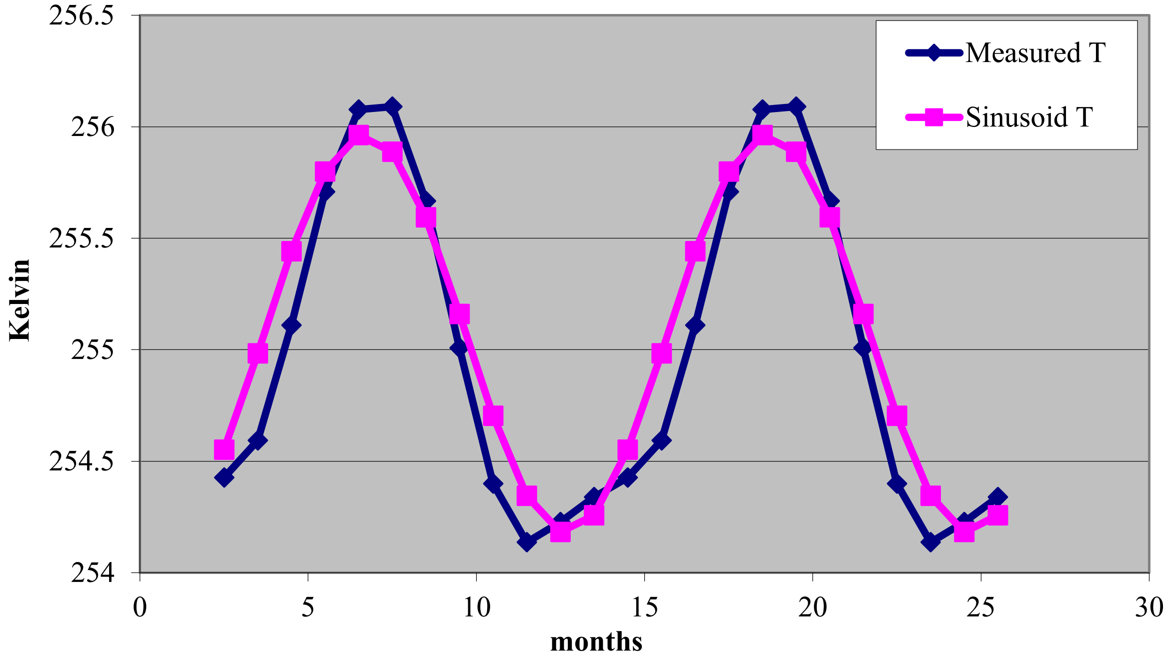

Fig. 2. Mean yearly cycle of the EBAF monthly radiation temperature and its approximation.

The equation used in the calculations is:

$$T = 255.07 - 0.316\ sin(2\pi/12*t) - 0.837\ cos(2\pi/12*t)\ . \tag{3}$$

Having the formulae for the *NET* radiation and the *T* radiation temperature, the solution of the yearly heat capacity is looked for in the form:

$$Q = Q_0 + Q_1\ sin(2\pi/12*t) + Q_2 cos(2\pi/12*t), \tag{4}$$

where Q_0, Q_1, and Q_2 are constants. The solution of Eq.(1) provides the following values: *1.04, 0.061*, and *0.009* $W\ month\ m^{-2}\ K^{-1}$, respectively. The numbers show, that the yearly course of the effective heat capacity is not really important. The relation between the *NET* and *Q* parameters is shown in *Fig. 3*.

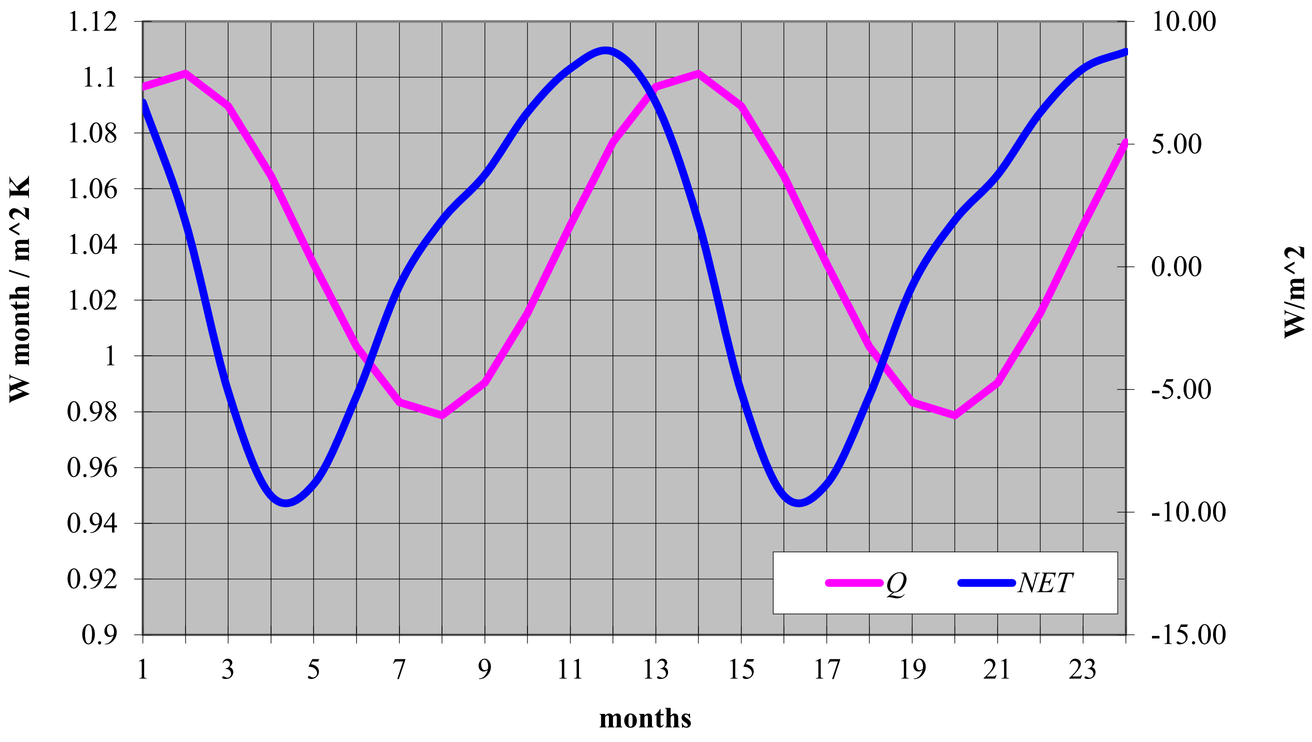

Fig. 3. Mean yearly course of the measured planetary *NET* radiation and of the calculated planetary effective heat capacity.

3. The heat capacity of the 1964 – 2014 half century

This period is not covered by continuous satellite radiation budget measurements. The used original data and their sources are listed in *Table 1*.

Table 1. The sources of original planetary radiation budget data

Time period	**Data**	**Source**
1962–1966	Five-yearly mean from 33 monthly measurements	*VonderHaar* and *Raschke*, 1972
1964 –1971	Eight-yearly mean from 29 monthly measurements	*Ellis* and *VonderHaar,* 1976
1964 –1977	Fourteen-yearly mean from 48 monthly measurements	*Stephens et al.,* 1981
1979 –1986	Calendar yearly mean ERB values	*Ardanuy et al.,* 1992
1985 –1989	Calendar yearly mean ERBE values	*Larc NASA S4G data CD*
1994. 03 - 1994.09 1994.11- 1995.02	Monthly ScaRaB values, the missing October have been interpolated	*ScaRaB CD-s* *Kandel et al.,* 1994
2000. 03 - 2015.02	Monthly CERES Ed.3A values	NASA Langley Center CERES ordering tool at http://ceres.larc.nasa.gov/

It is supposed that the several yearly effective heat capacity of the climate system is constant, this way the relation:

$$Q\frac{dT}{dt} = NET \qquad (5)$$

shall be used for the calculation of Q. To obtain realistic value for the heat capacity, all measured components of the planetary net radiation have to be corrected to decrease their systematic error.

The satellites measure the total solar irradiance (*TSI*), the reflected solar radiation (*REF*) and the outgoing longwave radiation (*OUT*). The planetary radiation budget is:

$$NET = ICO - REF - OUT. \quad (6)$$

Taking into account the non-spherical shape of the Earth,

$$4.0032\ ICO = TSI \quad (7)$$

has been used. Continuous satellite measurements of *TSI* are made since November 1978. The previous *TSI* or solar constant values have to be corrected to the newest one (see, e.g., *Major,* 2016). For the period before 1990, the *ICO* values have been changed by those calculated from TSI values by *Coddington al.* (2016). The ScaRaB *ICO*-s have been changed for the whole March 1994 - February 1995 cycle by those derived from the SARR-DIARAD TSI measurements (*Dewitte et al.,* 2004) decreased by 5.512 Wm^{-2} to convert to the NIST pyrheliometric scale. For the CERES period, the EBAF Ed.4 *ICO* values are used for the March-February yearly cycles, started from the March of 2000.

The reflected solar radiation values and the outgoing longwave radiation values have been corrected to the EBAF scale by using the following correction factors:

– sum of monthly EBAF from March 2000 to February of 2015,

– sum of monthly CERES from March 2000 to February of 2015.

The numerical value of the correction of the reflected radiation is 1.01623, that of the outgoing longwave radiation is 1.00545. These corrections have been applied to all data provided by USA experiments including CERES. The ScaRaB measurements have not been changed.

In the calculation, those early measurements that cover more year have been regarded as one-yearly values of the central years of their periods (since they have been compiled from less monthly data, see *Table 1*). All the used yearly radition budget components are shown in *Fig. 4*. The radiation (brightness) temperature values have been calculated from each yearly outgoing radiation, their linear time regression coefficient is 0.285 K $year^{-1}$. The average *NET* radiation is 0.383 Wm^{-2}, this way the effective heat capacity *Q* of the 1964–2014 half century is 13.45 W year m^{-2} K^{-1}.

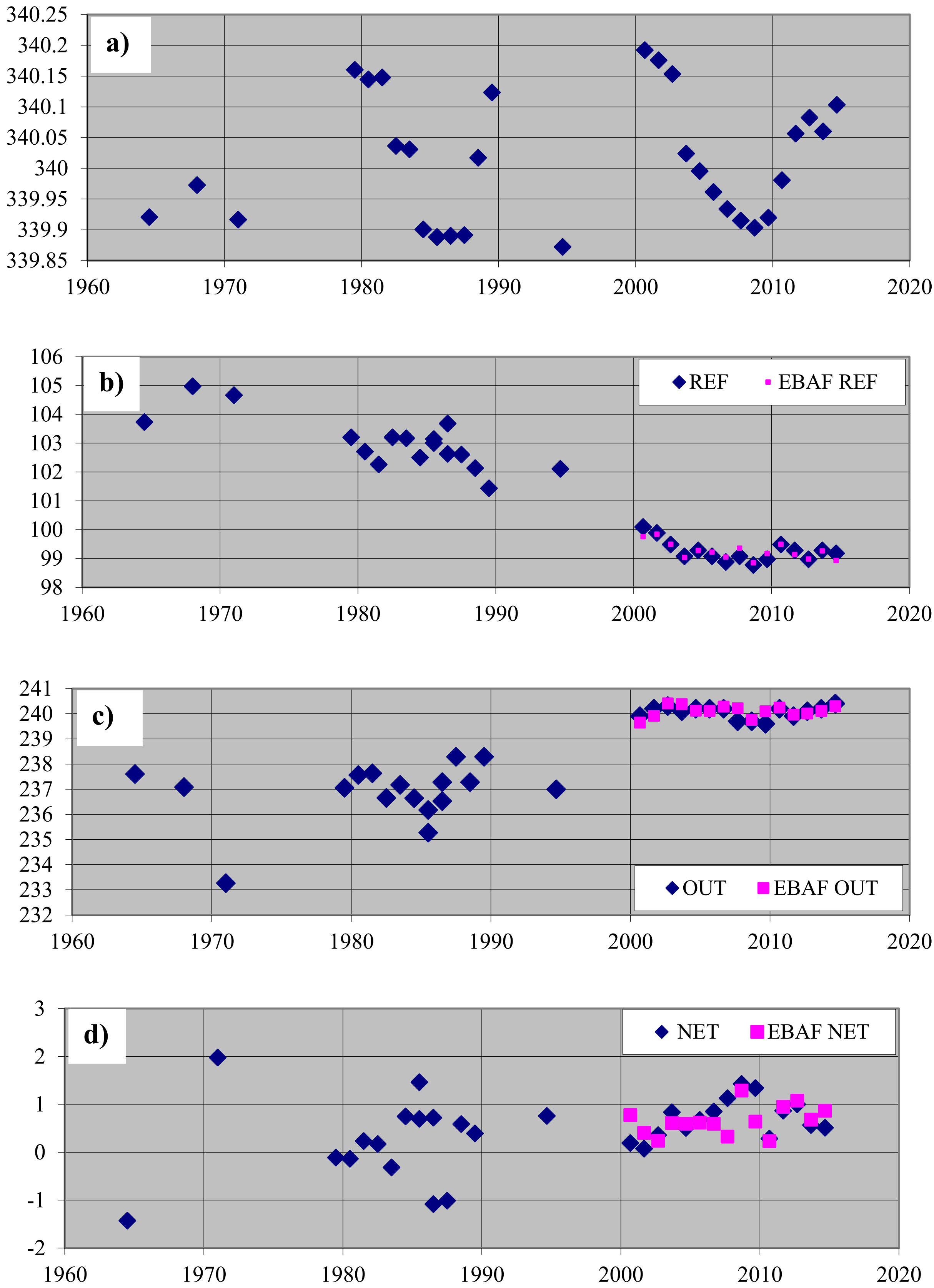

Fig. 4. The yearly corrected radiation budget values used in the calculation of the heat capacity. a) *ICO*, b) *REF*, c) *OUT*, d) NET. The corrected CERES and the EBAF values are not exactly the same.

4. Results

- The effective heat capacity coupled to the radiation temperature of the yearly cycle of the outgoing longwave EBAF radiation is 1.04 W month m^{-2} K^{-1}, the yearly amplitude is 0.06 W month m^{-2} K^{-1}.
- The effective heat capacity (Q) of the 1964–2014 period derived from measured and corrected planetary radiation budget measurements is 13.45 W year m^{-2} K^{-1}, a little larger than that of the yearly cycle.
- The corrected yearly *REF* radiation values show a consequent decrease in the full period, except the last 10 years.

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