RADIATION BUDGET OF THE ATMOSPHERIC COLUMN IN THE REGION OF CENTRAL ANATOLIA AND ITS VICINITY

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ABSTRACT

The radiative budget of the atmosphere is computed for Turkey for each season of the year 1968. Computations are based on observational data. The solar radiation reaching the surface is derived from Turkey pyrheliometric network. The long-wave radiation flux is computed on the Elsasser radiation chart, with use of aerological data for the five radiosonde stations Ankara, Istanbul, Izmir, Samsun and Diyarbakır. The planetary albedo is found to be 0.37.

1. *Introduction*

The description of the radiation budget terms is of primary interest to a wide range of scientific and technical activities in agriculture, hydrology and biology. The radiant energy of the sun is practically the only source of energy that influences the nature and pattern of the general circulation and may various processes in the atmosphere and surface layers of the earth's crust.

Until recently, our knowledge of the radiative balance of the atmosphere was based on the important contributions of Simpson (1928, 1929) and Baur and Phillips (1935). Notable among the other heat budget studies dealing with the earth-troposphere system are those of Albrecht (1949), Raethjen (1950), Houghton (1954) and London (1957). Also, relatively complete radiation budgets have been considered for the stratosphere alone, for example, by Ohring (1958) and Murgatroyd and Goody (1958). Burdecki (1957) investigated the changing thermal state of the atmosphere between 100 and 40 mb. Davis (1961) studied the heat budget of the troposphere and lower stratosphere between the earth's surface and 25 mb. Nevertheless, up to the present time, no information is available concerning the radiant energy balance over Turkey. It therefore seems desirable to make a relatively detailed study on the seasonal variation of the atmospheric radiation budget terms over Turkey. For this purpose, central Anatolia was chosen since it has a suitable network of radiosonde stations.

2. *Basic data*

The basic data used in the present study were obtained from the Turkish Meteorological Service aerological records for the five radiosonde stations Ankara, Istanbul, Izmir, Samsun and Diyarbakır. Aerological observations at 1200 GMT daily for the year 1968 were used in the calculations of infrared flux in the atmosphere.

The solar radiation received at the surface was derived from the data for seven pyrheliometric stations Ankara, Florya (Istanbul), Menemen (Izmir), Diyarbakır, Konya, Tokat and Birecik.

The location for radiosonde and pyrheliometric stations are shown in Fig. 1.

3. *Total solar radiation and net short-wave radiation at the earth's surface*

The total of the direct and diffuse solar radiation on a horizontal surface was derived from the data for seven pyrheliometric stations in the area under consideration. Since the pyrheliometric stations were distributed nearly uniformly within the studied region, the mean areal solar-radiation reaching the surface was simply obtained by the arithmetical mean of the observed insolation at the seven stations in the considered area.

The seasonal area-averages of the solar radiation reaching the surface are presented in Table 1. Total solar radiation is, of course, maximum in summer and minimum in winter.

The annual average of 331 ly/day is about per cent of the insolation received at the top of the atmosphere. Since the considered area has an average albedo of 17 per cent, 83 per cent of the insolation is absorbed by the ground. This comprises 44 per cent of the solar radiation received at the top of the atmosphere. The solar energy absorbed by the ground is important for meteorological purposes since it is only the energy which can be used for surface heating and/or evaporation.

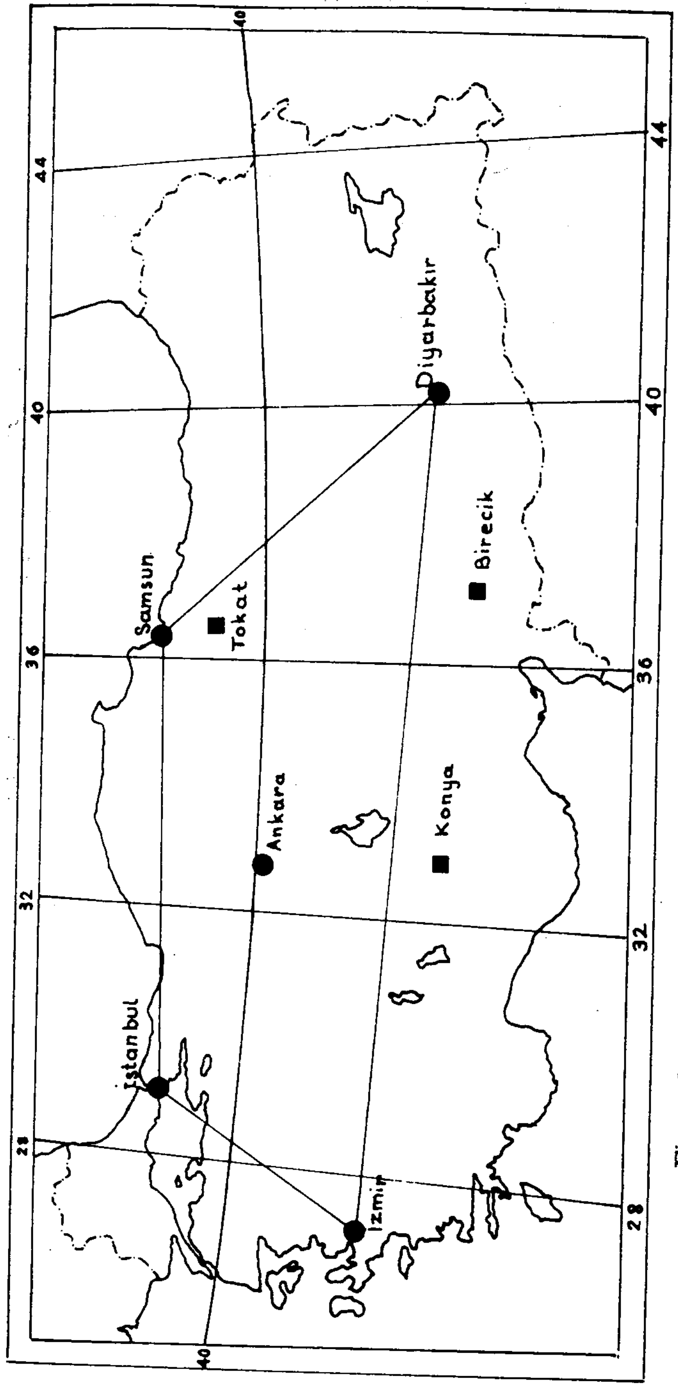

Figure 1. Area used for computations of radiation budget over and in the vicinity of central Anatolia.

● : Radiosonde and pyrheliometric station

■ : Pyrheliometric station

Bottom Short-Wave

Season	*Down*	*a %*	*Up*	*Net*
Winter	167	25	42	125
Spring	396	17	67	329
Summer	518	14	73	445
Fall	244	15	37	207
Year	331	17	55	277

Table 1. Seasonal means of short-wave radiation fluxes (ly/day) at the bottom of an atmospheric column over central Anatolia.

It may be seen from Table 1 that the net short-wave radiation at the surface reaches a maximum value of 445 ly/day in summer and a minimum of 125 ly/day in winter, which corresponds to the times at which the solar energy is at maximum and minimum, respectively.

4. *The surface albedo*

The seasonal values of the surface albedo for the considered region was obtained in the following manner.

To determine the solar radiation absorbed at the surface of the earth, it is necessary to know the albedo of the surface. For this purpose, the percentage cover of different vegetation types in Turkey was extracted from the study by Erkmen (1969), and appropriate values of surface albedo of each type and the average albedos of snow cover in different seasons were obtained from the literature (for instance, Kondratyev, 1969). These albedo values have been weighted in proportion to areal contribution. The weighted area-averages of surface albedo were presented in Table 1. The surface albedo reaches its maximum of 25 per cent in winter and minimum of 14 per cent during summer. The increased albedo during the winter is due to the snow cover.

5. *Planetary albedo*

The total absorption of the solar radiation by the atmosphere over the mean latitude of the considered area was obtained from the study by London (1957). The planetary albedo is then easily derived from the total absorption and the radiation incident on the outer atmosphere.

It may be seen from Table 2 that the planetary albedo varies in response to seasons. It reaches its maximum of 43 per cent in winter and minimum of 33 per cent during the summer. The increased albedo during the winter is due to the greater cloudiness, and higher ground reflectivities due to snow cover.

Top Short-Wave

Season	*Down*	*a %*	*Up*	*Net*	*3/4 A*
Winter	353	43	152	201	76
Spring	742	40	297	445	116
Summer	932	33	308	624	179
Fall	490	37	181	309	102
Year	629	37	235	395	118

Table 2. Seasonal means of short-wave radiation fluxes (ly/day) at the top of an atmospheric column over central Anatolia.

The total planetary albedo when averaged over all seasons is about 37 per cent. This is in good agreement with the earlier estimates of 0.35 by Fritz (1949), 0.34 by Lettau (1954), 0.34 by Houghton (1954), 0.35 by London (1957) and 0.38 by Erkmen (1962).

6. *Net short-wave radiation at the tropopause*

To estimate the net short-wave flux at the tropopause it is assumed that 3/4 of the total absorption of insolation occurs below the level of the tropopause (Erkmen, 1962). Then, short-wave net radiation at the tropopause (SW_n) is given by

$$SW_n = SW_{nt} - (A/4)SW_t = SW_{nb} + (3A/4)SW_t \qquad (1)$$

where;

SW_{nt} : net short-wave radiation at the top of the atmosphere, positive downward,

SW_{nb} : net short-wave radiation at the bottom of the atmosphere,

A : total atmospheric absorption of solar radiation,

SW_t : incoming solar radiation on a horizontal surface at the outer boundary of the atmosphere.

In equation (1) the assumption of one-fourth absorption of the incoming solar radiation above the tropopause seems to be sufficiently realistic. According to London (1957), the average total absorption ise about 18 per cent of the insolation at the top of the atmosphere; about 3 per cent of this is due to ozone absorption which occurs practically only above 20 km. Therefore, the ratio of absorption below 20 km to the total absorption is 15/18 (= 83%). By assuming the total absorption below the tropopause as 75 per cent. about an 8 per cent allowance has been made for water vapor absorption between 20 km and tropopause. The results of the estimates of the net short-wave radiation at the tropopause have been presented in Table 2.

7. *Calculation of long-wave radiation flux*

All computations of long-wave radiation flux were performed on the radiation chart devised by Elsasser (1942, 1960). A. minor error in the construction of the Elsasser chart can be compensated for by the definition of a corrected optical path as

$$u' = 0.5\,u\,(p/p_o)$$

where u is the optical depth for water vapor within any layer in the atmosphere, p the pressure at the level considered and p_o the standart atmospheric pressure. This correction was used for all the long-wave calculations.

8. *Net long-wave radiation at the earth's surface*

The result of calculations of the net long-wave radiation is included in Table 3. The outgoing terrestrial radiation is relatively

uniform with seasons. It reaches a maximum value of 852 ly/day in summer when the soil surface is warmest, and a minimum of 632 ly/day in winter when the soil is coldest.

Bottom Long-Wave

Season	*Down*	*Up*	*Net*
Winter	491	632	-141
Spring	561	728	-167
Summer	679	852	-173
Fall	603	761	-158
Year	584	743	-160

Table 3. Seasonal of long-wave radiation fluxes (ly/day) at the bottom (station level) of an atmospheric column over central Anatolia.

The net long-wave radiation reaches a maximum intensity (173 ly/day) in summer and a minimum (141 ly/day) in winter, being greater in spring than in fall. This is explained by the seasonal variation in surface temperatures, unstable lapse rates, and cloudiness.

9. *The net long-wave radiation flux at the tropopause*

In order to compute the net long-wave radiation flux at the tropopause, the downward radiation through the level of the tropopause is assumed to come from a mean layer in the lower stratosphere extending from the tropopause to about 20 km. To a first approximation, this layer can be characterized by an isothermal lapse rate (see, for instance, Kochanski, 1955) and a nearly zero vertical gradient of specific humidity of water vapor (Dobson and Brewer, 1951). Although other constituents such as ozone and corbon dioxide play a dominant role in the radiation budget of the stratosphere, their effect on the tropospheric heat balance is quite negligible (London, 1952).

The total optical depth for water vapor in the stratosphere was calculated under the assumption that the specific humidity is constant with height. In that case we have

$$u = 0.62\, e_t/g$$

where e_t, the actual vapor pressure at the tropopause, is determined by the relative humidity at the tropopause given by London (1957) and observed temperature at the tropopause over Turkey.

The result of calculations of net long-wave radiation at the tropopause is given in Table 4. The intensity of the net long-wave flux at the tropopause is remarkably more intense in summer than in winter. It varies from about 210 ly/day in winter to about 581 ly/day in summer over the considered area. It is interesting to note that in winter the values of the net radiation at the tropopause are not much greater than those at the surface. However, in summer differences are considerably larger. This is explained by the fact that the lower troposphere ise relatively warm and moist in summer. The minimum during the winter corresponds to low moisture and to stable thermal stratification.

Tropopause Long Wave

Season	*Down*	*Up*	*Net*
Winter	51	261	-210
Spring	56	487	-431
Summer	64	645	-581
Fall	59	371	-312
Year	58	441	-387

Table 4. Seasonal means of long-wave radiation fluxes (ly/day) at the tropopause over central Anatolia.

10. *Net radiation*

Net short-wave and net long-wave fluxes represent the two basic component of the total radiative budget of the earth's surface and any level in the atmosphere; only their sum gives the desired information on the gain and loss of radiative heat at a specified level of the atmosphere.

The net radiation (R) at any level is given by

$$R = SW_n + LW_n \qquad (2)$$

Here SW_n and LW_n are the net short-wave and net long-wave radiation fluxes, respectively.

The result of computation of net radiation for the ground level and tropopause are presented in Table 5 and 6, respectively. It may be seen from Table 6 that in winter there is a net loss of energy while in summer there is a net gain of energy in the atmospheric column considered. The magnitude of the net gain is much larger than that of the loss. The net radiative flux at the tropopause when averaged over all seasons is about 11 ly/day. Its positive sign indicates that on an annual basis there is a net radiative heat gain for the troposphere over the area being considered.

Bottom Net Radiation

Season	SW_n	LW_n	*Net*
Winter	125	-141	-16
Spring	329	-167	162
Summer	445	-173	271
Fall	207	-158	49
Year	277	-160	117

Table 5. Seasonal means of net-radiation fluxes (ly/day) at the bottom of an atmospheric column over central Anatolia.
(SW : Short-wave radiation
LW : Long-wave radiation)

Tropopause Net Radiation

Season	SW_n	LW_n	*Net*
Winter	201	-210	-9
Spring	445	-431	14
Summer	624	-581	43
Fall	309	-312	-3
Year	395	-384	11

Table 6. Seasonal means of net-radiation Fluxes (ly/day) at the tropopause over central Anatolia.

11. *The heat budget*

The heat balance between the surface of the earth and the atmosphere is of considerable interest. This balance involves a flux of latent heat and of sensible heat, in addition to the radiational items. The mean upward flux of latent heat can be computed from the mean rainfall. Computation of annual average rainfall totals for the considered year were made by using the annual rainfall amounts observed at twenty-two rainfall stations distributed as uniformly as possible over the study area.

The seasonal distribution of the computed latent heat released to the atmosphere is shown in Table 7. The last line of Table 7 gives an estimate of sensible heat transport to the atmosphere.

	Winter	*Spring*	*Summer*	*Fall*	*Annual*
Latent heat	93	81	31	58	66
Sensible heat					51

Table 7. Heat transport to atmosphere (ly/day)

The flux of sensible heat is a micrometeorological problem, and no attempt has been made by the writer to make an independent estimate of its magnitude. But this quantity can be an estimate in terms of what is required to maintain an energy balance. Since we do not estimate the seasonal heat storage nor the changes in internal energy of the atmosphere it is possibly only to include the sensible heat term on an annual basis when the storage and internal energy terms are assumed zero. There is no doubt, however, that the sign of the vertical transport of sensible heat is correct (i.e., from ground to atmosphere). This result is consistent with recent estimates of London (1957), Houghton (1954) and Erkmen (1962).

12. *Conclusions*

The present investigation has yielded preliminary quantitative data on the radiation budget components over Turkey and has allowed an assessment of possibility of determining the radiation balance of Anatolia from surface and aerological observations. Since the weather and circulation pattern for the period of time - the year

1968 - were fairly representative of the mean conditions over the area considered, the results obtained in the present study may be of value in future studies on the radiation budget over Turkey. Moreover, the studies of this type are also essential to a quantitative understanding of atmospheric circulations, and it is hoped that certain portions of this paper will be useful in efforts along these lines.

ÖZET

Radyasyon bütçesi bileşenlerinin tanımı, tarım, hidroloji ve biyolojideki teknik ve bilimsel faaliyetlerle çok yakından ilgilidir. Güneşin radyasyon enerjisi, genel dolaşımın modeli ve karakterini, arz yüzeyi tabakalarındaki ve atmosferdeki çeşitli prosesleri etkileyen tek enerji kaynağıdır.

Şimdiye kadar Türkiye'de radyasyon enerjisi bütçesine ait herhangi bir malumat mevcut olmadığından, Türkiye'ye ait atmosferik radyasyon bütçesinin mevsimlik değişimi üzerinde detaylı bir çalışma yapılması arzu edilmiştir. Bu amaçla, elverişli radyosonde istasyonlarına sahip olan Orta Anadolu Bölgesi seçilmiştir. Araştırmada kullanılan malûmat Ankara, İstanbul, Samsun, İzmir ve Diyarbakırdaki radyosonde istasyonlarının 1968 yılına ait aerolojik verileridir. Arz yüzeyine gelen güneş radyasyonu, Ankara, İstanbul, Menemen, Diyarbakır, Konya, Tokat ve Birecik'teki pirhelyometrik istasyonların 1968 yılına ait verilerden elde edilmiştir.

Araştırma bölgesinin yeryüzü albedosu, bölgedeki çeşitli yeryüzü örtülerinin literatürlerdeki albedolarına dayanarak hesaplanmıştır. Uzun dalga radyasyon akımlarına ait hesaplar Elsasser radyasyon diyagramıyla yapılmıştır.

Sonuç olarak, bölgeye ait yıllık ortalama yüzeysel albedo 0,17, planeter albedo 0,37 olarak bulunmuştur. Yeryüzündeki net kısa-dalga radyasyonunun yıllık ortalaması 277 ly/gün, tropopozdaki net kısa-dalga radyasyon akısı ise 395 ly/gün olarak bulunmuştur. Ayrıca, yerdeki net uzun-dalga radyasyonunun yıllık ortalaması 160 ly/gün olarak hesaplanmıştır. Yeryüzündeki efektif radyasyon 117 ly/gün, tropopozdaki efektif radyasyon ise 11 ly/gün olarak bulunmuştur.

Antalpi akısının mikrometeorolojik bir problem olması nedeniyle, bu terimin sadece yıllık ortalaması kalan metoduyla hesaplanmış olup, bu akının yeryüzeyinden atmosfere doğru olduğu bulunmuştur.

REFERENCES

Albrecth, F., 1949 : Über die Warme-und Wasserbilanz der Erde. Ann. Meteorol., 2, 129-143.

Baur, F., and H. Philipps, 1935 : Der Warmehaushalt der Lutfhülle der Nordhalbkugel im Januar und Juli und zur Zeit der Aequinoktien und Solstitien. Gerlands Beitr. Geophys., 47, 218-223.

Bernhardt, F., and H. Philipps, 1958 : Die Raumliche und Zeitliche Verteilung der Einstrahlung, der Ausstrahlung und der Strahlungsbilanz im Meeresniveau. Academie-Verlag, 227 pp.

Burdecki, F., 1957 : A study of the heat field of the atmosphere. J. Meteor., 14, 206-234.

Davis, P.A., 1961 : A re-examination cf the heat budget of the troposphere and lower stratosphere. Scientific Report No. 3, AF 19 (604)-6146. Research Division, College of Engineering, New York University., 115 pp.

Dobson, G.M.B., and A.W. Brewer, 1951 : Water vapor in the upper air. Compendium of Meteorology, Amer. Meteor. Soc., Boston, Mass., 311-319.

Erkmen, M.M., 1962 : The heat budget of the atmospheric column in the region of Wisconsin. Sixth part of the Ph. D. Thesis., The University of Wisconsin., 75-117.

Erkmen, M.M., 1969 : Regional distribution of aerodynamic roughness parameters over Turkey. Journal of the Department cf Forestry, The University of Istanbul., vol. 19, Ser. A., 95-103.

Elsasser, W.M., 1942 : Heat transfer by infrared radiaticn in the atmosphere. Harvard Meteorological Studies. No. 6, Harvard University Blue Hill Meteorological Observatory., 107 pp.

Elsasser, W.M., with M.F. Culbertson, 1960 : Atmospheric radiation tables. Meteor. Monographs, 4, No. 23, Amer. Meteor. Soc., 44 pp.

Houghton, G.H., 1954 : On the annual heat balance cf the northern hemisphere. J. Meteor., 11, pp. 1-9.

Kochanski, A., 1955 : Cross sections of the mean zonal flow and temperature along 80 West. J. Meteor., 12, 95-106.

London, J., 1952 : The distribution of radiational temperature change in the Northern Hemisphere during March. Geophys. Research Paper No. 18, A. F. C. R. C., Cambridge, Mass.

London, J., 1957 : A study of the atmospheric heat balance. Final Report, Contract No. AF 19 (122)-165. Research Division, College of Engineering, New York University., 99 pp.

Murgatroyd, R.J., and R.M. Goody., 1958 : Sources and sinks of radiative energy from 30 to 90 km., Quart. J.R. Meteor. Soc., 84, 225-234.

Ohring, G., 1958 : The radiation budget of the stratosphere. J. Meteor., 15, 440-451.

Raethjen, P., 1950 : Kurzer Abriss der Meteorologie Dynamisch gesehen. Teil 11. Warmehaushalt der Atmosphare. Heft I. Geophys. Einzelschriften, Geophys. Ins. d. Univ. Hamburg.