THE EFFECT OF CLOUDS ON THE ABSORPTION OF
SOLAR RADIATION AT THE TOP OF THE
ATMOSPHERE OVER SAUDI ARABIA ESTIMATED
FROM SATELLITE DATA

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ABSTRACT

The purpose of this paper is to investigate the influence of cloudiness on the short wave radiation budget at the top of atmosphere over Saudi Arabia. The data used for this study are derived completely from satellite measurements. Calculations for the top of the atmosphere are based entirely on the measurements of the Earth Radiation Budget Experiment (ERBE). Maps of the absorbed solar radiation for the total earth-atmosphere system are presented for the area of investigation, 15° N - 30° N, latitude and 35° E - 55° E longitude. To infer the contribution of clouds, the concept of cloud radiative forcing is applied to this data set. The mean value of the monthly averaged solar cloud forcing for the area of investigation is calculated for the top of the atmosphere (CF_{TOA}) to be 18±11 Wm\(^{-2}\) for January, 24 ± 7 Wm\(^{-2}\) for April, 11±9 Wm\(^{-2}\) for July, and 10 ±10 Wm\(^{-2}\) for October 1989. Compared to a cloud
free atmosphere, the January mean cloudiness, as it was present, reduces the absorption of solar radiation for the total earth-atmosphere system by about 8%, and for the month of July by about 3%. The reduction percentages due to cloudiness for transition periods during April and October are 7% and 4% respectively.

**Introduction**

It is believed that clouds play a very important role in the earth atmosphere radiation budget. The most common approach to quantifying the interaction between clouds, radiation, and climate is to look at the earth radiation budget at the top of the atmosphere. The discussion of the influence of clouds on the earth radiation budget is generally separated into short wave (0.2 – 5 µm) and longwave between (4 - 100 µm) contributions. In the short wave range clouds usually reflect more incoming solar radiation than the clear-sky surfaces. This albedo effect serves to cool the earth-atmosphere system. In the longwave range, clouds act like greenhouse gas. They absorb a large fraction of radiation emitted from the surface at a high temperature, but re-emit less of it to space due to the low temperature at the clouds tops.

Very precise measurements of the earth radiation budget at the top of the atmosphere are available from the Earth Radiation Budget Experiment (ERBE). Descriptions of the archive and of the first result for the month of April 1985 are presented by Barkstrom et al. (1989). The term Cloud forcing describes the contribution of clouds to the earth radiation budget. The cloud forcing is calculated
from the measured earth radiation budget (all sky conditions) by subtracting the radiation budget of a corresponding clear sky atmosphere. First detailed estimates of this contribution of clouds on the earth radiation budget are performed by Ramanathan et al. (1989). They infer monthly mean clear-sky radiation fluxes at the top of the atmosphere from the ERBE data and calculate the cloud forcing by subtracting the corresponding monthly mean radiation fluxes under all sky conditions. Harrison et al. (1990) present seasonal variations of the cloud forcing and also discuss the zonal dependences. As a result, clouds generally appear to cool the planet. This cooling or, the albedo effect, is dominant especially over the midlatitude during periods of strong solar insolation. For tropical convective clouds having high cloud tops, the two competing effects of long wave and shortwave radiation almost balance each other.

The impact of clouds on the earth's energy balance cannot be described from the top of the atmosphere alone. Clouds change the vertical distribution of radiative heating of the atmosphere and therefore influence climate in a more complex manner (Stuhlmann and Smith 1988a, b). Generally, within the shortwave spectral range, the effect of clouds on the tropospheric heating is believed to be predominantly a surface cooling, whereas within longwave spectral range it is mainly a tropospheric heating. The effect of clouds on the absorption of solar radiation in the atmosphere is, in general, small. Henderson-Sellers and Wilson (1983) estimated the
contribution of clouds to solar absorption to be about 2% of the mean solar insolation. Other estimates are suggested by Gates (1979) with 3%.

In this study, the influence of clouds on the shortwave part of the radiation budget at the top of atmosphere over Saudi Arabia Estimated from Satellite data was discussed. This study discusses the characteristics of the shortwave radiative forcing for the top of the atmosphere for January, April, July, and October 1989. The globally averaged annual mean values of the shortwave radiation budget at top of the atmosphere are divided into two parts. First, shortwave absorption equals 237 Wm\(^{-2}\) and the shortwave reflection equals 105 Wm\(^{-2}\). These values are obtained from satellite data (after Ramanathan et. al. 1989). It is shown in the values above that about 31% are reflected back to space, and the remaining 69% is absorbed by the earth-atmosphere system.

The aim of the present study is to calculate the shortwave radiation budget of the earth-atmosphere system at the top of the atmosphere over Saudi Arabia (15° N -30° N, latitude and 35° E - 55° E longitude) over a period of four months (1989) from satellite data. The shortwave part of the radiation budget is described by the absorbed shortwave flux at the top of the atmosphere,

**Data and Methods**

In the following section, I introduce the dataset and method used in this research for determining the shortwave radiation
budget at the top of the atmosphere. The paper uses data from the satellite platform, earth radiation budget satellite (ERBS). The ERBE consists of 3 satellites, NOAA 9, 10 and ERBS. NOAA satellites were in sun-synchronous polar orbits; while ERBS has an orbit inclined 57 degrees relative to the equator which allows observations at different local times. ERBE has both scanning and non-scanning radiometers. Gridded product at 2.5X2.5 degrees was derived from scanner observations. ERBS scanner began observation in November, 1984 and failed in February 1990. NOAA 9 scanner operated from January 1985 to January 1987, while NOAA 10 from October 1986 to May 1989. A review of the ERBE satellite data processing is given within the papers of Brooks et al. (1986) and Smith et al. (1986).

The monthly mean values of absorbed shortwave radiation at the top of the atmosphere are calculated from the earth radiation budget Experiment (ERBE) data, which were derived from broadband radiation measurements onboard the ERBS platform. Regional annual means are calculated from the monthly mean values of absorbed shortwave radiation at the top of the atmosphere. The ERBE provides monthly mean planetary albedo ($A_p$) and the corresponding clear-sky values ($A_{po}$) that are used to compute the shortwave absorption at the top of the atmosphere $ASW_{top}$:
\[ \text{ASW}_{\text{top}} = I - \text{RSW} = (1 - A_p) I \quad (1) \]

Where \( I \) is incoming solar radiation, \( \text{RSW} \) is reflected solar radiation, and \( A_p \) is the planetary albedo.

The scanner measurements made by ERBS is used exclusively for this paper. There are some difficulties concerning the clear sky monthly mean radiative fluxes. The procedure to derive these regional shortwave radiation fluxes is to select from the instantaneous measurements the minimum albedo for each region during a time period of one month. Problems related to such a procedure are permanent cloud conditions over the one month time period; distinctions between clouds and snow or ice-covered surfaces cause errors in scene identification; and inhomogeneous surfaces characteristics within a \( 2.5^\circ \times 2.5^\circ \) region.

Figure 1a-d shows as results the maps of monthly mean values of all sky \( (A_p) \) Planetary albedo (\%, all sky conditions) for (a) January, (b) April, (c) July, and (d) October for 1989. Figure 2a-d shows as results the maps of monthly mean values of clear sky \( (A_{p0}) \) planetary albedo (\%). for (a) January, (b) April, (c) July, and (d) October for 1989. Clouds dominate the planetary albedo \( A_p \), large values of about 36\% during January and April; and 34\% during July and October are found. In the cloud free case, albedo shows a strong dependence on solar zenith angle for all different types of surfaces. The differences in clear sky albedo between months are mainly related in a change in desert background over the
southeast of Saudi Arabia and a change in vegetation for the southwest region of the area.

**Saudi Arabia estimates of the shortwave radiation budget at the top of the atmosphere**

Maps of monthly mean shortwave radiation budget at the top of the atmosphere, $ASW_{\text{top}}$, for January, April, July, and October 1989; and the annual average for the period January to December 1989 are shown in Figure 3 and Figure 4 respectively. The maps in Figures 3 and 4 reveal the combined effect of solar insolation, surface, and the cloud characteristics on $ASW_{\text{top}}$, the solar insolation that is absorbed by the earth-atmosphere system. The largest values of $ASW_{\text{top}}$ are found for the tropical and subtropical regions with a maximum of 380 Wm$^{-2}$ above the West and Northwest of Saudi Arabia during July and 240 Wm$^{-2}$ above southwest region during January.

The absolute minimum of the month of January averaged absorption of the earth-atmosphere system, $ASW_{\text{top}}$, of values less than 170 w/m$^2$, is found for the Northern part of the region. These are the regions of the maximum albedo (see Figure 1) due to the maximum cloudiness during winter season and minimum solar insolation (see Figure 5). During the month of April, values tend to increase gradually until it reaches its maximum during month of July. On the other hand, values of absorbed solar radiation during
month of April tend to decrease until it reaches its minimum during month of January (see Figure 3).

The annual averaged solar absorption of the earth atmosphere system ASW_{top} (Figure 4) has its absolute maximum of values larger than 250 Wm^{-2} above the whole region of Saudi Arabia. The values for desert areas within the same area are lower than values for the coastal areas above west and east regions. This difference of ASW_{top} above the desert region demonstrates the influence of the surface albedo on the short wave radiation budget at the top of the atmosphere. The decrease of the absorption ASW_{top}, caused by high surface albedo, is more pronounced for the latitudinal built of the Empty Quarter desert (about 20° – 50° E). Within these latitudes, the surface albedo values reach more than 34 %. Table 1 presents mean and standard deviation for shortwave (SW) radiation budget, albedo, and incoming solar radiation, for both clear sky and all sky at the top of the atmosphere TOA estimated from satellite data. Shortwave absorption for all-sky during 1989 equals 196.4 Wm^{-2} for January, 316 Wm^{-2} for April, 350 Wm^{-2} for July, and 260 Wm^{-2} for October. Shortwave absorption for clear-sky during 1989 equals 214 Wm^{-2} for January, 340 Wm^{-2} for April, 361 Wm^{-2} for July and 270 Wm^{-2} for October.
Table 1: Mean and Standard deviation (stdev) for shortwave (SW) radiation budget and cloud forcing at the top of the atmosphere TOA estimated from satellite data for my area of investigation, 15° N -30° N, latitude and 35° E - 55° E longitude.

<table>
<thead>
<tr>
<th>SW</th>
<th>January</th>
<th>October</th>
<th>July</th>
<th>April</th>
<th>January</th>
<th>October</th>
<th>July</th>
<th>April</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sky</td>
<td>278.58</td>
<td>329.24</td>
<td>463</td>
<td>58.19</td>
<td>345.42</td>
<td>42.22</td>
<td>6.83</td>
<td>30.6</td>
</tr>
<tr>
<td>ATOA (W/m²)</td>
<td>196.58</td>
<td>316.22</td>
<td>350</td>
<td>18.5</td>
<td>260.44</td>
<td>44.22</td>
<td>6.83</td>
<td>30.6</td>
</tr>
<tr>
<td>Albedo(%)</td>
<td>30.6</td>
<td>26.4</td>
<td>24.</td>
<td>2.4</td>
<td>25.4</td>
<td>4.2</td>
<td>2.4</td>
<td>25.4</td>
</tr>
<tr>
<td>Clear sky</td>
<td>214.51</td>
<td>340.12</td>
<td>360</td>
<td>18.2</td>
<td>269.41</td>
<td>41.22</td>
<td>6.83</td>
<td>30.6</td>
</tr>
<tr>
<td>ATOA (W/m²)</td>
<td>23.3</td>
<td>20.4</td>
<td>22.</td>
<td>3.8</td>
<td>22.4</td>
<td>4.1</td>
<td>6.83</td>
<td>30.6</td>
</tr>
</tbody>
</table>

Saudi Arabia regional estimates of cloud radiative forcing on the shortwave radiation budget at the top of the atmosphere

The presented maps of top of atmosphere absorption of shortwave, ASW\textsubscript{TOA}, do not directly allow a separation of the dependence of clouds from that of others like solar zenith angle, surface albedo, or absorption characteristics of the clear sky atmosphere. To estimate the contribution of clouds, I apply the concept of "cloud (radiative) forcing", an approach first suggested by Charlock and Ramanathan (1985). This concept of cloud forcing
has already been used by several authors (e.g. Ramanathan et. al 1989; Harrison et al. 1990) to investigate the influence of clouds on the radiation budget at the top of the atmosphere.

In general, the cloud forcing is simply calculated by taking differences between monthly mean clear sky and all sky radiation fluxes at the top of the atmosphere. In relation to this approach, I calculate the cloud forcing ($CF_{TOA}$) on the absorption of solar radiation as follows:

$$CF_{TOA} = ASW_{TOA}^0 - ASW_{TOA}$$  \hspace{1cm} (2)

The index 0 indicates the clear sky case.

This cloud forcing term are calculated as differences of two components which have nearly the same magnitude. Maps of monthly averaged short wave cloud forcing at the top of the atmosphere ($CF_{TOA}$) Wm$^2$ for January, April, July, and October 1989 are presented in Figure 5. In definition above (Equation 2), positive values of cloud forcing (CF) mean that the absorption under clear sky conditions is larger than in the presence of clouds. Negative values indicate a net gain in shortwave absorption due to the presence of clouds. The cooling due to the albedo effect of clouds is on the order of 5-35 Wm$^2$ during the month of January and April. These regions of Maximum cloud forcing are located...
above the northeast and southwest regions. They correspond to those regions with a maximum albedo as an indication of cloudiness as shown in Figure 1. The cooling due to the albedo effect of clouds is on the order of 2-15 Wm\(^{-2}\) during the month of July and October. These regions of minimum cloud forcing are located above the Northeast, South, and Southwest regions. They correspond to those regions with a minimum albedo as shown in Figure 1. Central, Southeast and Northern parts of the country have no cloud effect during months of April and October. Zero values of shortwave cloud forcing are located above Empty Quarter desert and above several subtropical near cloud free regions During month of July, cooling due to the albedo effect is small and is found in southwest of the region due to the presence of mountains and convective activity. For my investigation I calculate the cloud forcing for January, April, July, and October 1989. The cloud forcing at the top of the atmosphere equals 18±11 Wm\(^{-2}\) for January, 24 ± 7 Wm\(^{-2}\) for April, 11±9 Wm\(^{-2}\) for July, and 10 ±10 Wm\(^{-2}\) for October 1989. Thus compared to a cloud free atmosphere, the January mean cloudiness, as it was present, reduces the absorption of solar radiation for the total earth-atmosphere system by about 8%, and for the month of July by about 3%. The reduction percentages due to cloudiness for transition periods during April and October are 7% and 4% respectively (Table2).
Table 2: Shortwave (SW) radiation budget and cloud forcing at the top of the atmosphere TOA estimated from satellite data for my area of investigation, 15° N -30° N, latitude and 35° E - 55° E longitude

<table>
<thead>
<tr>
<th>Month</th>
<th>SW all sky absorption (Wm^-2)</th>
<th>SW clear-sky absorption (Wm^-2)</th>
<th>Cloud forcing/ SW clear-sky absorption</th>
<th>Incoming solar radiation (Wm^-2)</th>
<th>All sky albedo (%)</th>
<th>Clear sky albedo (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>278.</td>
<td>32</td>
<td>8%</td>
<td>278.</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>April</td>
<td>429.</td>
<td>42</td>
<td>7%</td>
<td>429.</td>
<td>66</td>
<td>22</td>
</tr>
<tr>
<td>July</td>
<td>361</td>
<td>11</td>
<td>3%</td>
<td>463.</td>
<td>44</td>
<td>22</td>
</tr>
<tr>
<td>October</td>
<td>350</td>
<td>361</td>
<td>10</td>
<td>345.</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>

Conclusions

The shortwave radiation budget of the earth-atmosphere system is influenced by the amount of solar radiation incident at the top of the atmosphere, the clouds (amount, type), the state of the atmosphere, and the spectral surface reflectance. In this study, I focus my discussion on the contribution of clouds to the shortwave radiation budget. To do so, I apply the concept of cloud radiative forcing to satellite dataset to estimate the cloud forcing on the absorbed shortwave radiation at the top of the atmosphere. Calculations for the top of the atmosphere are based entirely on
measurements of the Earth Radiation Budget Experiment. The absorption of solar radiation at the top of the atmosphere is greatly affected by clouds. An increase in cloudiness over the Southwest of Saudi Arabia with cloud tops at high atmospheric levels (large albedo) should lead to a remarkable reduction of solar radiation absorbed at the Earth atmosphere system.

The results may be summarized as follows. The global shortwave radiation budget has been estimated at the top of the atmosphere. Shortwave absorption equals 237 Wm$^{-2}$ and shortwave reflection equals 105 Wm$^{-2}$. The sum of the previous values equals 342 Wm$^2$ which is the global incoming solar radiation. Based only on the satellite retrievals discussed above, I calculate the shortwave radiation budget, albedo, and cloud forcing for my area of investigation, 15° N -30° N, latitude and 35° E - 55° E longitude. Shortwave absorption for all-sky during 1989 equals 196.4 Wm$^{-2}$ for January, 316 Wm$^{-2}$ for April, 350 Wm$^{-2}$ for July, and 260 Wm$^{-2}$ for October. Shortwave absorption for clear-sky during 1989 equals 214 Wm$^{-2}$ for January, 340 Wm$^{-2}$ for April, 361 Wm$^{-2}$ for July and 270 Wm$^{-2}$ for October.

The cloud forcing for January, April, July, and October 1989 was calculated. The cloud forcing at the top of the atmosphere equals 18±11 Wm$^{-2}$ for January, 24 ± 7 Wm$^{-2}$ for April, 11±9 Wm$^{-2}$ for July, and 10 ±10 Wm$^{-2}$ for October 1989. Thus compared to a cloud free atmosphere, the January mean cloudiness, as it was present, reduces the absorption of solar radiation for the total earth-
atmosphere system by about 8%, and for the month of July by about 3%. The reduction percentages due to cloudiness for transition periods during April and October are 7% and 4% respectively.
a) January

b) April
Figure 1: Planetary albedo (%, all sky conditions) for (a) January, (b) April, (c) July, and (d) October for 1989.
a) January

b) April
Figure 2: Clear sky Planetary albedo (%) for (a) January, (b) April, (c) July, and (d) October for 1989.
a) January.

b) April
Figure 3 (a) Absorbed solar radiation at the top of the atmosphere, SWtop, (Wm$^2$) for (a) January, (b) April, (c) July, and (d) October for 1989.
Figure 4 Absorbed solar radiation at the top of the atmosphere, SWtop, (Wm$^2$) (annual average January to December, 1989).
Figure 5. Averaged short wave cloud forcing at the top of the atmosphere (CF$_{TOA}$) Wm$^{-2}$.) For (a) January, (b) April, (c) July, and (d) October for 1989.
References


تأثير السحب على امتصاص الأشعة الشمسية في أعلى الغلاف الجوي على المملكة العربية السعودية مقدرة من بيانات الأقمار الإصطناعية

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كلية الأرصاد والبيئة وزراعة المناطق الجافة - جامعة الملك عبدالعزيز
ن. ب. ٢٠٠٨ - جدة - ٢١٤٣ - المملكة العربية السعودية

المستخلص

الهدف من هذا البحث هو استكشاف ومعرفة تأثير السحب على ميزانية الأشعة الشمسية ذات الوجه القصيرة في أعلى الغلاف الجوي على المملكة العربية السعودية. بيانات المستخدمة في هذه الدراسة مستخرجة من قياسات الأقمار الإصطناعية، وتم بعد عملية حسابات ميزانية الأشعة الشمسية في أعلى الغلاف الجوي بناء على القياسات المستخرجة من تجربة ميزانية الإشعاع فوق الذروة الأرضية (ERBE). تم عرض خرائط الأشعة الشمسية الممتدة لسطح الأرض مع الغلاف الجوي للمستهدفة للدراسة من خط عرض ١٥ شمالي إلى ٣٠ شمالي ومن خط طول ٣٥ شرقي إلى ٥٥ شرقي. لمعرفة مشاركة السحب مع الأشعة الشمسية، طبقت معادلة القوة الإشعاعية للسحب على بيانات المستخدمة. أظهرت النتائج أن المتوسط الشهري للفترة الإشعاعية للسحب في أعلى الغلاف الجوي على المملكة العربية السعودية كالتالي: ١١±٧ لشهر يناير، ١٠±٧ لشهر أكتوبر من العام ١٩٨٩ م. بالمقارنة مع الأجواء الخالية من السحب، يكون تأثير Wm²/سي وهو في هذه الدراسة يخفض من خلال شهر يناير كما هو في هذه الدراسة يخفض من خلال شهر أكتوبر. تؤكد هذه الدراسة متوسط السحب خلال شهر أخرى تكون بنسبه 7% وفي عودة الغلاف الجوي الممتدة من الأرض إلى أعلى الغلاف بنسبة 8% وبنسبة 3% خلا شهر يوليو. و/pg f0 تؤثر نسبة الانخفاض في كمية الأشعة الشمسية الناتجة عن السحب في الفترات الانتقالية خلال شهر أبريل وأكتوبر 7% و 8% على التوالي.

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