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Abstract

The paper examines changes in the daily mean global sea level pressure in relation to daily galactic cosmic ray flux and solar radio flux, using the method of selected sample days. The data are taken from the International Geophysical Year 1957/58. The study looks at periods of eight days before to eight days after the sample days (lag-8, lag8). Three investigations have been carried out in which the sample days were selected according to different criteria: a) secondary minimum of the solar radio flux; b) in the five days following the sample day a reduction of at least 0.4 hPa in global sea level air pressure was observed; c) sample days were selected at random.

As cosmic ray flux rises global sea level pressure falls. This fact is explained by the Svensmark Hypothesis, according to which global cloud cover increases in line with increasing values of the cosmic ray flux. If one assumes that increases in the total cloud amount are linked to increases in global precipitation, the consequence is a reduction in the load on the atmosphere and hence a lowering of the total mass of the atmosphere, i.e. of mean global sea level pressure. Since cosmic ray flux enters the atmosphere from the poles, Svensmark and Friis-Christensen observed changes in cloudiness particularly in the middle and higher latitudes. According to my observations the areas of reduced pressure accompanying increased cosmic ray flux are also to be found in these latitudes. Study of mean global sea level pressure supports the Svensmark Hypothesis (cosmic ray flux-global cloud amount forcing).

Zusammenfassung

Es werden die Veränderungen des täglichen mittleren globalen NN-Luftdrucks in Verbindung mit den täglichen Werten der kosmischen Strahlung und der solaren Radioemission mit Hilfe der Stichtag-Methode untersucht. Die Daten stammen aus dem Internationalen Geophysikalischen Jahr 1957/58. Es wird jeweils die Zeitspanne 8 Tage vor bis 8 Tage nach Stichtagen (lag-8, lag8) betrachtet. Es wurden drei Fälle untersucht, wobei die Stichtage nach unterschiedlichen Kriterien ausgewählt wurden: a) am Stichtag besaß die Kurve der Radioemission ein sekundäres Minimum; b) nach dem Stichtag war ein Abfall des globalen Luftdrucks in den folgenden 5 Tagen um mindestens 0,4 hPa zu beobachten; c) die Stichtage wurden zufällig ausgewählt.

Mit zunehmender kosmischer Strahlung fällt der globale NN-Luftdruck. Diese Tatsache wird mit der Svensmark-Hypothese erklärt. Nach dieser Hypothese steigt die globale Wolkenbedeckung mit steigenden Werten der kosmischen Strahlung an. Nimmt man an, dass die Vergrößerung der globalen Wolkenbedeckung mit einer Steigerung der globalen Niederschlagstätigkeit verbunden ist, ist die Folge eine Entlastung der Atmosphäre und damit eine Erniedrigung der totalen Masse der Atmosphäre bzw. des globalen NN-Luftdrucks. Da die kosmische Strahlung von den Polen her in die Atmosphäre eindringt, beobachteten Svensmark und Friis-Christensen die Bewölkungsveränderungen vor allem in den mittleren und höheren Breiten. Nach meinen Untersuchungen sind die Druckfallgebiete bei zunehmender kosmischer Strahlung ebenfalls in diesen Breiten zu finden. Durch die Untersuchungen über den globalen Luftdruck wird die Svensmark-Hypothese (Verstärkung der globalen Wolkenbedeckung durch Anstieg der kosmischen Strahlung) gestützt.

1 Introduction

This paper presents a re-evaluation of earlier studies (KESSLER, 1968a, b) which showed a link between the variations of the total mass of the atmosphere and solar activity (10.7 cm radio flux). The previous explanation for this phenomenon was based on the assumption that radiation fluctuations corresponding to the activity-cycle of the sun influence the heat budget of the global atmosphere. As the global heat budget and the

global water cycle are closely correlated (BAUMGARTNER and REICHEL, 1975; KESSLER, 1985; HANTEL, 1990; PEIXOTO and OORT, 1992), it was assumed that the water content of the global atmosphere changed due to solar activity. Since then changes of the earth's radiation budget, the earth's albedo etc. during the 11-year sunspot period 1979-1991 could be demonstrated by meteorological satellite measurements (ARDANUY et al., 1992).

Numerous studies exist about the connection between global atmospheric water content and the total mass of the atmosphere, or the mean global sea level air pressure (GAP) respectively the mean global sur-

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Figure 1: Normalized daily solar radio flux (10.7 cm) SRF and galactic cosmic ray flux GCR of the International Geophysical Year 1957/58 (1 July, 1957 to 30 June, 1958). The marks indicate days with secondary minimum of SRF.

face air pressure (SCHUMANN, 1954; KESSLER, 1965; RÁKÓCZI, 1979, 1980; TRENBERTH, 1981; BERNHARDT, 1991). These studies have shown that changes in the atmospheric water budget are the principal cause of changes in the global atmospheric mass. The amplitude of the annual GAP cycle lies between 0.4 and 0.5 hPa. The maximum of the GAP occurs in summer of the northern hemisphere and corresponds to the temperature maximum of the global atmosphere and the maximum of the water content of the global atmosphere. The mean global atmospheric water content is ca. 26 mm. It varies in the course of the year by ca. 4 mm (RANDEL et al., 1996). Long-term fluctuations of the GAP and precipitable water are in the same order of magnitude (0.2–0.4 hPa and 2–4 mm [TRENBERTH et al., 1987; WITTMAYER and VONDER HAAR, 1994; CHEN et al., 1996; RANDEL et al., 1996]).

The present study uses daily values of the GAP from

Figure 2: Mean normalized cosmic ray flux mGCR and solar radio flux mSRF, 8 days before until 8 days after a secondary minimum of SRF. Low pass filtered values $(x_1 + 2x_2 + 3x_3 + 2x_4 + x_5)/9$.

the International Geophysical Year IGY 1957/58 (1 July 1957 to 30 June 1958). 1957 was the year with the greatest solar activity in the 20th century. The re-evaluation of earlier work (KESSLER, 1968a,b) uses the results of the Svensmark Hypothesis (SVENSMARK, 1998; SVENSMARK and FRIIS-CHRISTENSEN, 1996) on the link between solar activity, galactic cosmic ray flux (GCR) (Forbush-effect) and global cloud coverage (GCC). According to the Forbush-theory cosmic ray intensity decreases with a growth in solar activity, because the connected increase of the solar wind inhibits by its magnetic field the penetration of the cosmic ray flux into the atmosphere. Because of the shielding effect of the earth's magnetic field the ions of the GCR penetrate the atmosphere from the poles. Svensmark and Friis-Christensen have established that the growing GCR increases GCC and that this link is more pronounced in higher latitudes than in the tropics.

Figure 3: Daily global sea level pressure GAP and normalized daily cosmic ray flux GCR, 8 days before until 8 days after a secondary minimum of SRF. Single (GAP, GCR) and low pass filtered values $(x_1 + 2x_2 + 3x_3 + 2x_4 + x_5)/9$ (mGAP, mGCR).

If global precipitation is suddenly strengthened by a rise of the GCR it is to be expected that the total mass of the atmosphere is diminished and that this will lead to a short-term lowering of GAP. The corresponding pressure decline would be observable particularly in higher latitudes. This will now be demonstrated using data from the IGY. The hypothesis of Svensmark and Friis-Christensen has the advantage that the often noted correlations between solar activity variations and climate fluctuations do not have to be derived directly from total solar irradiance fluctuations (solar forcing over an 11-year cycle only amounts to 0.1%). Solar activity mainly affects the atmosphere indirectly. By influencing the GCR it produces a trigger-effect that changes global cloud cover and accelerates the global precipitation cycle. This influences the planetary albedo and the radiation budget of the earth-atmosphere system.

Figure 4: Daily global sea level pressure GAP and normalized daily cosmic ray flux GCR, 8 days before until 8 days after a fall in pressure of 0.4 hPa within 9 days. Single (GAP, GCR) and low pass filtered values $(x_1 + 2x_2 + 3x_3 + 2x_4 + x_5)/9$ (mGAP, mGCR).

2 The observational data

As a measure of the solar activity daily values of the 10.7 cm solar radio flux (SRF) (following WALDMEIER, 1957/58) are used (Fig. 1). The variations clearly show the solar rotation of 27 days. Daily values of GCR (CRF: Climax Neutron Monitor, University of Chicago, Simpson Group) were taken from the internet¹. Fig. 1 shows the contrary yearly course of SRF and GCR in the year 1957/58.

Weather maps which covered the entire planet earth were developed for the first time for the IGY 1957/58. With the help of these maps daily mean values of sea level pressure of the parallels at intervals of 5 degrees were determined and from this calculations were made of the daily GAP.

The sequences of data of SRF, GCR and GAP were ordered according to sample days and in each case synchronous mean values were calculated for the period of 8 days before until 8 days after the sample day (lag-8, lag8). The sample days were selected by the following criteria: a) The sample day is a secondary minimum of SRF. In the following 9 days the SRF rises by at least 50 units (Figs. 1–3). 13 cases were identified. b) In the 5 days following the sample day a fall in GAP of at least 0.4 hPa was observable. During the 365 days 14 cases were identified (Fig. 4). c) The selection of 14 random sample days was generated by the use of dice (Fig. 5).

3 Results

3.1 Temporal changes in global sea level pressure

Fig. 2 shows the link between the mean SRF and the mean GCR. GCR rises with a weakening of SRF

(Forbush-effect). The sharp rise in the SRF from day+1 (lag1) onwards leads after a delay of 3 days to a steep fall in the cosmic ray curve.

The link between the GCR and GAP is demonstrated in Figs. 3 and 4. In Fig. 3 the GAP and GCR data are arranged according to the secondary minimum of the SRF (Fig. 2). The fall in the GAP from lag-5 to lag2 is connected to a rise of the GCR.

According to the Svensmark-Hypothesis the degree of GCC grows with a rise in the GCR. The assumption is justified that thereby the global precipitation also increases. From this in turn it follows that the total mass of the atmosphere is reduced. Unfortunately we do not yet know in detail how the process of condensation depends on the GCR. It is conceivable, for example, that beyond a certain threshold of GCR condensation can be increased no further. This would explain the short time difference between GAP-minimum and SRF-maximum. As GCR falls sharply GAP rises again.

Following the t-test the difference between the mean GAP on day (lag-5) and day (lag2) is assured with 87% probability. For the corresponding difference between the mean GAP on day (lag2) and day (lag5) the probability is 89%. As long as other influences (e.g. longitudinal change of the Polar front dependent on SRF, DEFANT and DEFANT, 1958) on global precipitation cannot be eliminated, a higher degree of statistical assurance cannot be expected.

For the second test (Fig. 4) the sample days are selected in relation to particular features of the GAP curve. This selection also confirms that the strongest reductions in GAP are linked to an intensification of GCR. For this selection of data the GCR-minimum is on day (lag-1) for the actual curve and on day (lag-4) for the smoothed curve and thus precedes the strong fall in pressure. The scale of the co-ordinates in Figs. 3, 4 and 5 was selected to permit direct comparison.

Figure 5: Daily global sea level pressure GAP and normalized daily cosmic ray flux GCR, 8 days before until 8 days after randomly chosen sample days. Single (GAP, GCR) and low pass filtered values $(x_1 + 2x_2 + 3x_3 + 2x_4 + x_5)/9$ (mGAP, mGCR).

¹ http://ulysses.uchicago.edu/NeutronMonitor/neutron_mon.html

The third test shows that a random selection of the sample days does not lead to marked changes in either curve.

Figure 6: Sea level pressure change of latitude mean values (hPa). Black columns: from day (lag-5) to day (lag0). Day (lag0) is the day with secondary minimum of the solar radio flux. White columns: from day (lag0) to day (lag5).

3.2 Spatial changes of sea level pressure

Due to the effect of the earth's magnetic field the particle stream of the cosmic ray flux penetrates the atmosphere from the poles. It is therefore to be expected that its effects will be particularly noticeable in the higher latitudes. Fig. 6 shows the changes of sea level pressure mean values of the parallels from day (lag-5) to day (lag0) and from day (lag0) to day (lag5). The reduction of atmospheric mass due to precipitation from day (lag-5) to day (lag0) can be observed particularly in the higher latitudes ($> 30^{\circ}\text{N}$ and $> 50^{\circ}\text{S}$). These findings support the Svensmark-Hypothesis. The areas of increased pressure from day (0) to day (+5) lie in the middle and higher latitudes. The following explanation seems plausible. With a decrease of precipitation-forcing due to reduction of GCR clouds dissolve increasingly. Thereby solar global radiation rises at the surface of the earth. Thereby there is also more energy available for evaporation at the earth's surface. Growth of water vapour in the atmosphere due to increased evaporation and decreased precipitation lead to an increase in the total mass of the atmosphere.

4 Conclusion

The changes in daily GAP in the IGY 1957/58 are subject to a new interpretation by the application of the Svensmark-Hypothesis. It is assumed that an increase in the degree of cloud cover on the planet earth is linked to an increase in global precipitation. The temporal pattern of the changes in pressure can be explained using

the Svensmark-Hypothesis. The fact that the greatest fall in pressure during a rise in GCR is particularly noticeable in the higher latitudes gives further support to the Svensmark-Hypothesis. Unfortunately we do not have satellite data about GCC during the IGY which would lend further support to the findings presented here. It would be desirable if, with the improved possibilities of satellite observation now available, it could be demonstrated on a daily basis that a link exists between an increase in GCC and an increase in global precipitation, in order to establish a direct link between the loss of mass in the atmosphere and precipitations. We also need to examine whether, apart from an increase in precipitation thanks to the galactic cosmic ray flux, there also occurs a simultaneous increase in precipitation thanks to changes in the longitude and intensity of the Polar front (transformation of low into high index types of the atmospheric circulation and vice versa, according to RIEHL et al., 1952; DEFANT and DEFANT, 1958; SUDA, 1976) or in the connection with other global cycles (e.g. Madden-Julian-Oscillation, other solar activity cycles etc.)

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