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MOTIVATION FOR AN ADDITIONAL NEW INDEX OF SOLAR ACTIVITY IN UPPER ATMOSPHERIC MODELS

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ABSTRACT

About 50 000 density values derived by satellite drag have been used to control the CIRA-72 model, the 11 years and the 27 days periodicity in particular. It was suggested that plasma streams of moderate velocity - among others corotating streams coming from coronal holes - may represent a supplementary heat source for the upper atmosphere, as the K_p index do not point out this kind of heating. The galactic cosmic radiation count rate, C_{DR} is provisionally suggested as an additional new index of solar activity.

INTRODUCTION

Our group in the Konkoly Observatory, Budapest, Hungary is considering since many years possible improvements of upper atmospheric models. "Observed" values of total density (ρ_{obs}) have been derived from $\underline{n}$ and $\underline{\dot{P}}$ by formulae of King-Hele, calculated partly from orbital elements published in the literature, partly from optical satellite observations. Corresponding model density values (ρ_{mod}) have been derived to every ρ_{obs} value using different models of the upper atmosphere (CIRA-72, Jacchia-77, DTM), and the ratios $f = \rho_{obs} / \rho_{mod}$ have been analysed as function of different model parameters.

Since the time resolution of the available sets of observations and orbital elements was limited to a few days, either special methods were elaborated (like the introduction of the "equivalent duration" in the investigation of the geomagnetic effect /1/), or only variations with a long enough periodicity have been investigated.

Our data file contains about 50 000 ρ_{obs} -values based on drag data of 63 satellites. The total time interval includes 12 years between 1965 and 1977. Perigee heights vary from 170 to 1050 km. The distribution of the lifetimes - as well as the measurements within the intervals- were uneven. The longest series of data from 1965 to 1977 makes the control of the 11 years effect possible (even for $S_{10.7}$ values differing from those used in the original model construction procedure). Maximum 23 and minimum 3 satellites were available at any time simultaneously. Nevertheless due to the non adequate knowledge of area-to-mass ratios a common treatment of all density data of all satellites in one common datafile was not suitable. Therefore some investigations were carried out separately satellite by satellite.

In cases when we wanted to fit all ρ_{obs} values together, it was supposed that CIRA-72 describes the mean total density correctly, i.e. we multiplied every ρ_{obs} value by $\bar{\rho}_{mod}$ / $\bar{\rho}_{obs}$ for every satellite separately.

On the basis of this material let us now briefly consider all investigated effects indicating which parts of the CIRA-72 model are to be modified or improved! (CIRA-72 is used as a reference model consistently.)

THE GEOMAGNETIC EFFECT

It has been demonstrated already in 1972 that static models like Jacchia-71 consequently underestimate the amplitude of the measured effect during large geomagnetic storms between 200 and 350 km /2/. Our results were confirmed by some other investigators partly referring to in situ measurements /3,4/.

THE 11-YEAR EFFECT

Drag data of 5 satellites with perigee altitudes ranging between 277 and 560 km have been used through the whole cycle of solar activity (1965-1977). We took 90 days average values for $\bar{f} = \bar{\rho}_{obs} / \bar{\rho}_{mod}$ and $\bar{S}_{10.7}$ values respectively. A correlation analysis proved that $\bar{f}$ has a significant correlation to

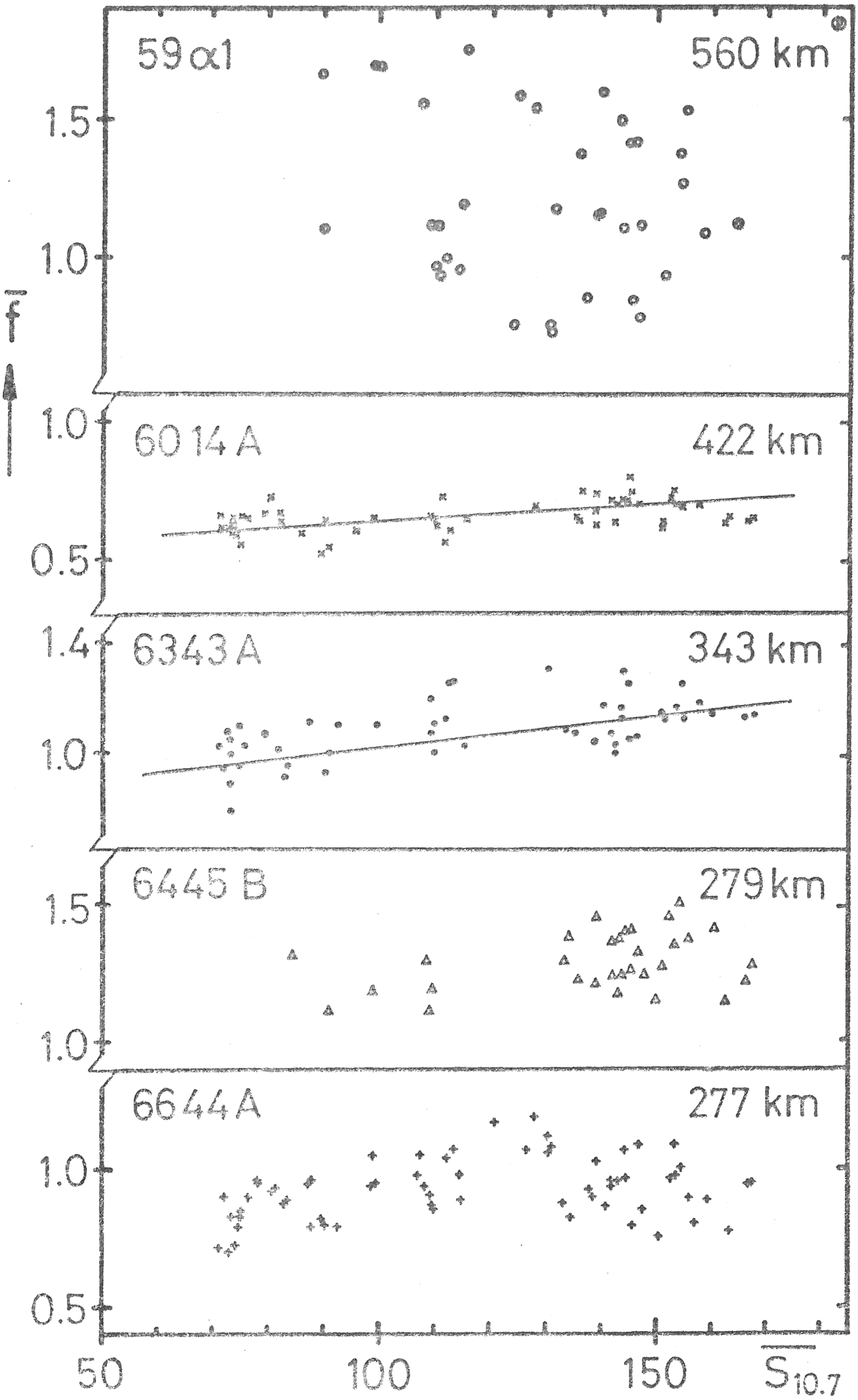

Fig. 1. Dependence on $\bar{S}_{10.7}$ in the 11-year cycle.

$\bar{S}_{10.7}$ in the case of the two satellites having perigee heights at 343 and 422 km respectively (Fig. 1). This result demonstrates that the model is underestimating the increase in total density connected with the increase of $\bar{S}_{10.7}$ - at least in the given height interval. /5/

ANALYSIS OF THE 27-DAY VARIATION

A significant new result of our investigation is connected with the 27-day periodicity attributed to the EUV heating (using $S_{10.7}$ as its index). C_{DR}, the low energy galactic cosmic radiation count rate was suggested as an additional index of this effect.

The "Wedge Pattern"

If momentary f-values are plotted against corresponding $S_{10.7}$-values in different altitudes, then there is usually a definite increase in scatter at lower solar activity (Fig. 2a). A very similar pattern has been obtained using drag data of 4 Transit (NNSS) satellites, revolving on 1000 km high, almost circular orbits. Broadcast ephemeris registered at the Satellite Geodetic Observatory, Hungary, by Doppler receivers in 1981 was the source of information in this case /6/. Two of the NNSS satellites have clearly presented the same "wedge pattern" i.e. the same effect is visible even at 1000 km altitudes (Fig. 2b).

A possible explanation of the effect is as follows: if $S_{10.7}$ presents a maximum then not only ρ_{mod} but also ρ_{obs} is always near to peak values. If, however, $S_{10.7}$ is average or minimum, then the corresponding ρ_{obs} value might be either small or large as a consequence of some other mechanism or parameter (not reflected in ρ_{mod}). This effect might be connected with a non satisfactory representation of the geomagnetic effect in the model, but - as it will be demonstrated later - this explanation is not probable.

A Common, Qualitative Analyses of all Data

A rough statistical treatment was applied to all drag measurements of 59 satellites between 1965 and 1972. Nothing else was investigated but the percentage of all satellites showing maxima of any amplitude on the density curve within time intervals of 5 days. It has been demonstrated /7/ that there are considerably more maxima on the ρ_{obs} curves than the ρ_{mod} values

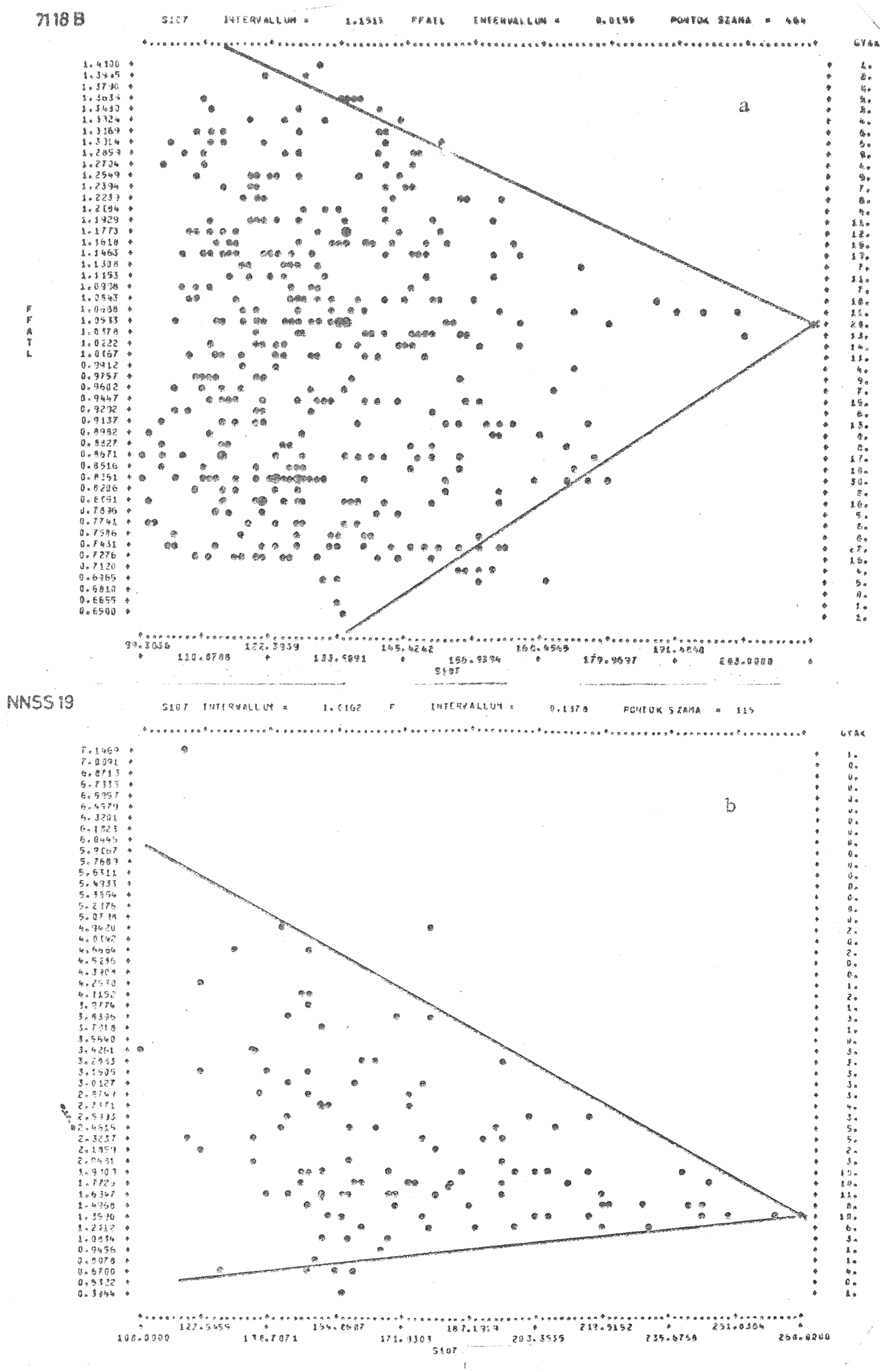

Fig. 2. The "wedge pattern" in different altitudes (281 km and 950 km respectively).

– calculated using $S_{10.7}$ as index of solar activity – would suggest: 158 instead of 74, i.e. more than twice as much as would be expected!

In order to investigate whether the geomagnetic effect is responsible for the additional maxima we constructed two histograms of $\bar{K}_p$ values from 1965 till 1972. The first one (continuous line on Fig. 3) demonstrates the distribution of $\bar{K}_p$ in time intervals when ρ_{obs} maxima are explained by corresponding $S_{10.7}$ maxima; the second (dotted line on Fig. 3) during unexpected peaks on the ρ_{obs} curves. It is obvious that there is no significant difference in the $\bar{K}_p$ distribution, i.e. the appearance of additional maxima cannot be the consequence of an incomplete description of the geomagnetic effect during extreme K_p -values.

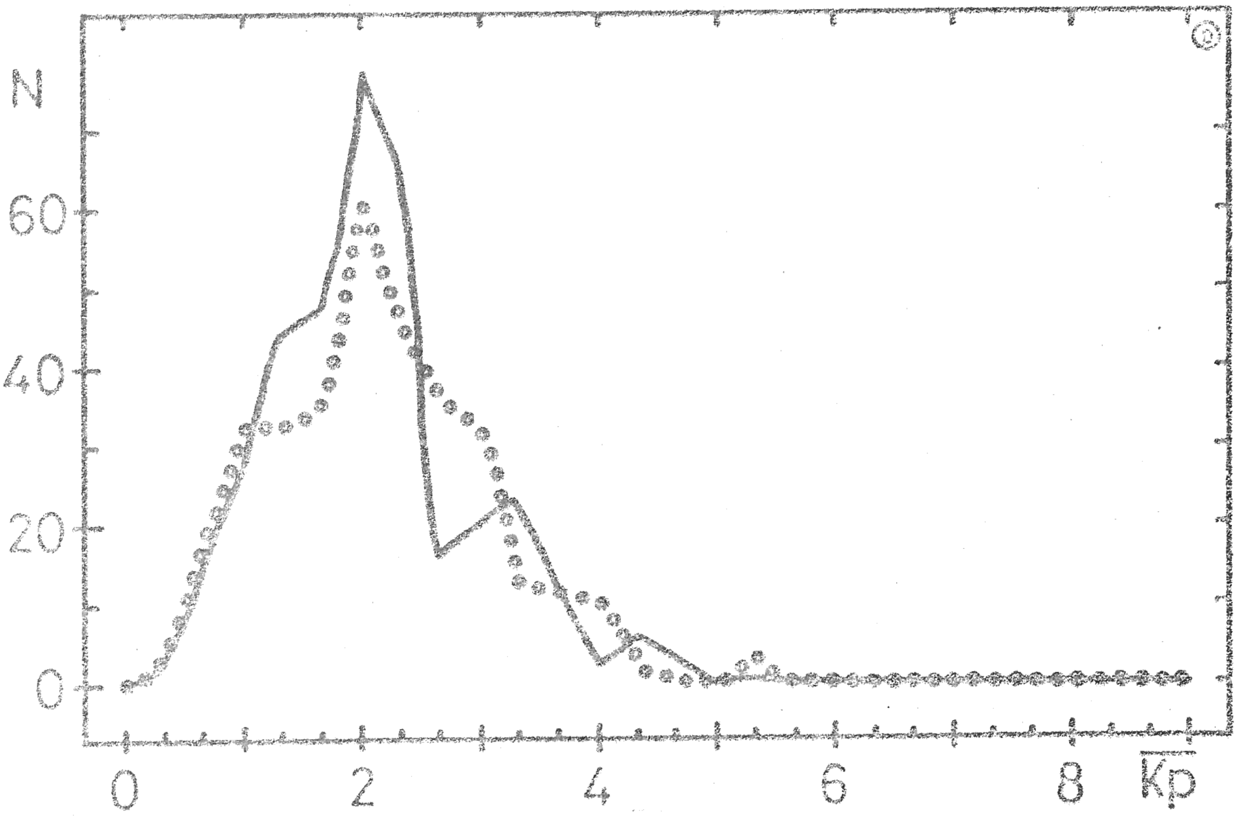

Fig. 3. Histograms for $\bar{K}_p$

Properties of the Unexpected Maxima

The unexpected maxima a. are fitting as well to the 27-day periodicity as corresponding $S_{10.7}$ maxima do /8/, b. are sometimes arranged in sequences of 10 – 12 terms, c. their 27-day periodicity remained remarkably constant during the 7 years of investigation.

Furthermore a careful correlation analysis has proved that these unexpected maxima are almost always preceded by a decrease of C_{DR} a few days earlier. The correlation between ρ_{obs} maxima and C_{DR} minima is significant.

Linear Regression Models

A linear regression model was fitted to the almost continuous series of density data in 1.5 years derived from period changes in the cases of the best observed 4 satellites (6595A,6595B,6558A,6511A). The aim was to determine how many percent of the deviations can be explained by different combinations of the following parameters: h, Ψ_B, $S_{10.7}$, A_p and C_{DR}. Table 1 illustrates that multiple correlation coefficients are increasing continuously if further parameters are also taken into account - and C_{DR} is no exception.

TABLE 1 Multiple Correlation Coefficients

In a linear regression model where the parameters are	The multiple correlation coefficients			
	6595A	6595B	6258A	6511A
h	0.660	0.584	0.829	0.862
h, Ψ_B	0.716	0.637	0.832	0.864
h, Ψ_B, $S_{10.7}$	0.813	0.747	0.839	0.870
h, Ψ_B, $S_{10.7}$, A_p	0.838	0.785	0.854	0.874
h, Ψ_B, $S_{10.7}$, A_p, C_{DR}	0.872	0.836	0.860	0.901

Table 2 on the other hand demonstrates how many percent of the observed density deviations can be explained by the 5 parameters combined together, and how well the total values are represented by the contribution of different parameters alone. Both tables indicate that in the case of all 4 satellites the contribution of the C_{DR} index to the explanation of density variations is important, even larger than that of $S_{10.7}$.

For the same 4 satellites partial correlation coefficients have been determined between the density and the corresponding C_{DR} curves as well. After remov-

TABLE 2 Linear Regression Model

How many % of the scatter is explained by	Satellites			
	6595A	6595B	6258A	6511A
a linear regression model including h, Ψ_B, $S_{10.7}$, A_p, C_{DR} together	77%	74%	85%	84%
alone by h	27%	23%	62%	54%
alone by $S_{10.7}$	9%	8%	5%	1%
alone by C_{DR}	25%	27%	11%	9%

ing the effects due to the height, Ψ_B, $S_{10.7}$ and A_p, all correlations proved to be significant even at a significance level of 99.9% (see Table 3)

TABLE 3 Partial Correlation Coefficients

After removing the effects of h, Ψ_B, $S_{10.7}$, A_p between the density and C_{DR}	for satellites			
	6595A	6595B	6258A	6511A
the partial correlation coefficients	-0.317	-0.361	-0.179	-0.389
Student t	5.60	6.70	3.20	5.45
t for 95% sign. level	1.97			
t for 99.9% sign. level	3.30			

As $S_{10.7}$ and C_{DR} are not independent parameters, a factor analysis was carried out with the most important 5 parameters to density values ρ_{obs} of the 4 best satellites separately. Results are given in the first 4 lines of Table 4. The investigation was extended to all satellites of normal excentricity where the number of density values, N, was more than 160. The results are summarized in the next 6 lines of Table 4. Mean values of the parameters as well as corresponding errors are given for the first 4, for the next 6 and for all 10 satellites respectively.

It is obvious that C_{DR} is one of the most important model parameters. Errors values indicate that C_{DR} is as stable parameter as e.g. $S_{10.7}$ or Ψ_B.

TABLE 4 Factor Analysis

Sat.	h	N	parameters for					multi. correl. coeff.
			h	Ψ_B	$S_{10.7}$	A_p	C_{DR}	
6258A	200	510	−0.778	+0.118	+0.095	+0.087	−0.081	0.842
6595B	210	362	−0.363	−0.201	+0.304	+0.214	−0.252	0.838
6595A	220	341	−0.451	−0.236	+0.283	+0.131	−0.234	0.859
6511A	260	176	−0.426	−0.382	+0.066	−0.019	−0.258	0.840
Mean parameters:			−0.504 (±0.226)	−0.175 (±0.118)	+0.187 (±0.123)	+0.103 (±0.098)	−0.206 (±0.084)	
7118B	281	474	−0.501	−0.477	+0.187	−0.088	+0.080	0.704
6445B	290	1815	−0.769	−0.287	+0.126	+0.009	−0.119	0.863
6644A	300	1857	−0.559	−0.507	+0.227	+0.003	−0.169	0.775
6014A	425	2856	−0.059	−0.450	+0.391	−0.026	−0.395	0.851
59 η	517	222	−0.140	−0.456	+0.443	+0.005	−0.421	0.727
6104A	580	166	−0.560	+0.267	+0.179	+0.259	−0.333	0.793
Mean parameters:			−0.431 (±0.274)	−0.318 (±0.297)	+0.259 (±0.128)	+0.027 (±0.119)	−0.226 (±0.193)	
Mean parameters: of all 10 sat.			−0.461 (±0.234)	−0.261 (±0.263)	+0.230 (±0.125)	+0.058 (±0.112)	−0.218 (±0.152)	

INTERPRETATION

Based of the properties of the unexpected maxima we concluded that probably corotating streams originating from solar coronal holes are responsible for the whole phenomenon. They may represent an additional heat source for the upper atmosphere, besides the well-known 27-day component of the EUV heating (characterized by $S_{10.7}$ as an index). On the contrary to the geomagnetic effect, which is carrying the energy almost immediately, this additional heating mechanism transfers the energy to the upper atmosphere with a longer time delay of several days. The energy may be stored for a time in the plasmasphere before it propagates to the neutral atmosphere. Some ionospheric parameters refer to this kind of delay even in the case of geomagnetic storms ("after effect").

If such an additional heating is functioning in connection with corotating streams, it can be active all the time, only that without the presence of a shock wave, index K_p is not registering the slow or moderate velocity streams of solar origin. Nevertheless the Earth's magnetosphere, working as a dynamo, can gain energy from such a stream as well. The efficiency of the dynamo, however, is varying with the south component of the interplanetary magnetic field (IMF). If magnetic irregularities of any kind - as e.g. those carried by corotating streams - change the geometry of the IMF, the efficiency of the dynamo might change if the magnitude of the south component is changing.

The Time Delay Problem

Because of the rotation of the Sun, a 27-day periodicity is expected in density variations (as a consequence of IMF variation) modulated by the corotating streams coming from coronal holes. This variation is, however, shifted by several days with respect to the EUV heating if only because of the difference between the velocity of the EUV and corpuscular radiation respectively. This is the first component of the time delay.

The energy carried by corpuscular streams is stored in the plasmasphere. This may represent the second component of the time delay.

For some unknown reason, the particles stored in the plasmasphere sometimes do precipitate in a large quantity. May be this phenomenon is not as spectacular as that during geomagnetic storms. The energy is transferred into the neutral component of the upper-atmosphere through the ionosphere by charge exchange and collision. The time delay may be longer than at times of geomagnetic storms. This can be the third component of the whole delay.

Heating Variations by Time and Place

The position of the Earth is changing with respect to the magnetic equator of the Sun (and also with respect to the IMF which is under the influence of the coronal holes of the North and South hemispheres alternately). This variation makes a periodicity of half year probable, as the Earth is merging deeper into the IMF originating from one hemisphere for half a year, then for the other half of the year it is merging deeper into the IMF of the other hemisphere. This variation may be just one component of the semiannual effect, which is not explained yet by any usual heating mechanism.

Independently from the geometry a 11 years variation could be expected as well, because of the 11 years cycle of the solar activity. The coefficient of $\bar{S}_{10.7}$ (used to represent the EUV heating in the models) very probably manifests the combined effect of both heating mechanisms.

The precipitation may occur in the auroral region but particles of the ring current are able to deposit energy above the equatorial territory as well /9/. There are some recent investigations arguing for an equatorial nocturnal heating that can not be attributed to EUV radiation /10, 11/. This kind of heating may be a real nocturnal heat source of corpuscular origin, or a precipitation from the equatorial ring current, all around the equator, the dayside part of which is considered as EUV heating in all models. If a larger coefficient of $S_{10.7}$ is used in a model, the observed discrepancy remains undiscovered.

If there is such an additional, retarded magnetospheric heating in action, then - as already mentioned - there should be a 27-day, a semiannual and a 11-year cycle in the density fluctuations. These variations are, however, not identical with fluctuations caused by changes in the EUV heating, but rather manifest themselves as a superposition.

CONCLUSIONS

When constructing new CIRA models of total density, beside a revision of coefficients of previously known effects (geomagnetic, 11-year cycle etc.) there is a need that the possibility of a retarded magnetospheric heating mechanism, giving rise to density fluctuations, should be taken into account. It has been demonstrated by various statistical investigations that variations of total density characterized by a 10 - 20 day cycle are dependent not only on changes of $S_{10.7}$, so the introduction of an additional parameter is necessary.

Earlier we suggested C_{DR}, the galactic cosmic radiation count rate (as measured continuously on the surface of the Earth by a super neutron monitor at Deep River station, USA) as a suitable index of this additional energy flux. This suggestion was based on a rough statistical estimate of a rich material, as well as on a more sophisticated analysis of the best cases. Both investigations proved that a considerable part of density fluctuations can be explained if C_{DR} is added to existing model parameters and a one day time delay is used. Nevertheless we are convinced that the time delay of ρ_{obs} with respect to C_{DR} is varying as a complex function of the heating process, which makes the inclusion of C_{DR} as a new parameter difficult. For this reason as far as we are unable at present to express the dependence of the storage time explicitly on different parameters, we are not suggesting a definite new atmospheric model.

The aim of another series of investigations would be to follow the energy transport from the solar wind through the plasmasphere to the neutral upper-atmosphere and suggest a more suitable representation of this effect in future CIRA-models.

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