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16. Abstract

Relationships between time series consisting of daily values of ionospheric and middle atmospheric parameters have been studied applying the methods of spectral analysis. The results indicate cou;ling processes between the different atmospheric regions. These processes are probably related to vertically propagating atmospheric waves. From the coherence estimates for ionospheric and stratospheric time series it is concluded that characteristic oscillations like the well-known 5-day-wave can affect the structure of the ionosphere (as indicated by a structure index derived from ionospheric electron content measurements) by modulating vertically propagating gravity waves.

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STUDY OF THE SYSTEM OF MIDDLE ATMOSPHERE/IONOSPHERE USING REMOTE-SENSING DATA */203

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SUMMARY

Variations in the time series of parameters (daily values) of the ionosphere and the middle atmosphere were studied for their coherence using statistical spectral analysis methods. In this manner diagnosed interactions between the atmospheric regions are traced back to a coupling due to atmospheric waves. Based on the coherence spectra, characteristic oscillations of the middle atmosphere can follow into the ionosphere. This is shown by the example of a 5-day oscillation in which the unexpected high coherence values for the ray density and temperature field of the upper stratosphere and an ionospheric structure parameter appear (determined from spatial changes of the electron content). A possible explanation of this discovery is a coupling of the stratosphere and the ionosphere by gravity waves that are modulated by the well known so-called 5-day waves in the middle atmosphere.

ABSTRACT

Relationships between time series consisting of daily values of ionospheric and middle atmospheric parameters have been studied

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applying the methods of spectral analysis. The results indicate coupling processes between the different atmospheric regions. These processes are probably related to vertically propagating atmospheric waves. From the coherence estimates for ionospheric and stratospheric time series, it is concluded that characteristic oscillations like the well known 5-day wave can affect the structure of the ionosphere (as indicated by a structure index derived from ionospheric electron content measurements) by modulating vertically propagating gravity waves.

1. INTRODUCTION

Interactions between the middle atmosphere and the ionosphere have been repeatedly studied in recent years by Bossolasco and Elena [1], Gregory and Manson [10] and Brown and John [2], among others. The variations of the ionosphere are linked to dynamic processes of the stratosphere in these studies. The variations in the atmosphere layers can be explained by vertically propagating planetary waves [20], [5].

Global ray density measurements by the satellites of the Nimbus series have shown that the winter circulation of the middle atmosphere is characterized by waves of planetary sizes [14]. These waves become active due to impulse transmission on the middle zone wind and due to their dissipation and possibly absorption in the area of the critical layers, that is in the areas with disappearing medium zone wind [4].

The methods of statistical spectral analysis are used in this study in order to investigate quasi-periodic changes in the condition parameters of the medium atmosphere and the ionosphere and their relationship. Oscillations are examined for periods of several days, as is typical for planetary waves. As a basis for the concept of data analysis and for the interpretation of the results, the theory and empirical discoveries for transient planetary waves are used.

2. DATA AND SPECTRAL ANALYSIS

Condition changes of the medium atmosphere, 17 substantial temperature changes, are reflected in the time series of ray density measurements which have been carried out with the aid of the satellites of the Nimbus series. These remote sensing data are stu- /204
died for correlated quasi-periodic changes with suitable available time series of ionospheric data (some of the ionospheric data were obtained from remote sensing data from the ground and some from satellites).

The ray density data of the PMR instruments from Nimbus 6 are only available to us in one form for the 1975-76 winter which is suitable for spectral analysis. We have, therefore, limited our investigations to this period. In addition to the ray density data other time series were selected for the individual atmospheric regions according to the following points of view.

1) Time series measurement sizes of the regions were used which permit at least a qualitative determination on a coupling of the layers based on expected physical relationships.

2) The series are to be developed and available so that their processing can be carried out with the methods used.

Ray density measurements with the PMR instrument have been carried out by Nimbus 6 since 1975. A description of the measurement technique is given in Curtis [3]. Rogers [19] provides a method with which the temperatures of the individual layers can be determined. Four measurement versions (channels) of the PMR-instrument are used in this analysis: the channels (short: Ch from English 'channel') 2115, 2105, 2100 and 3000. The maxima of the appropriate gravity functions for the ray portion from the atmospheric layers are about 45 km, 50 km, 65 km and 80 km in the series of the specified channels [11].

Temperature fluctuations in the middle atmosphere are affected considerably by circulation oscillations or have such oscillations as a result. They, therefore, modulate the ray flow observed from satellites and permit a qualitative conclusion of the ray density oscillations on circulation disturbances. As control parameters for the middle stratosphere temperature data of the 30-mbar area are used. These data were made available to us by the working group on the stratosphere at the Meteorological Institute of the FU in Berlin as 10x10 degree grid point values.

Measurements of the border frequencies of the F2 and E-layers and the absorption of radio waves according to method A1 [17] were selected as indicators for condition changes of the ionosphere. The border frequencies, proportional to the square of the maximum electron density of the present ionospheric layer, reflect changes to the ionization state by their fluctuations. Since such changes can be caused by the transport of neutral and ionized components of the ionosphere, that is by dynamic processes, and a controlling of such processes by the middle atmosphere cannot be excluded, correlated fluctuations in the condition parameters of both atmospheric regions must be expected in principle. This also applies to a much stronger degree for the lower ionospheric layers which are represented here in the range of about 90-105 km [6] by the absorption index for radio waves. The relationship of changes to this index to disturbances in the condition of the stratosphere was already shown in other works, i.e., [21].

The fluctuation index of the electron content, designated by I_N, was available as a parameter for the upper ionosphere. This value is a measurement for the strength of the relative oscillation of the electron content, based on the average electron content and derived from the observations along individual orbits of the polar-rotating NNSS-satellites between about 60 and 40°N in the observation field of the stations Lindau/Harz and Graz (between about 10-15° E longitude). I_N is thus an index for spatial oscillations of the electron content approximately along a longitudinal circular arc of about 20° of latitude. The index shows characteristic fluctuations with the time which leads to the conclusion of the influence of neutral gas transports. It is surprisingly correlated very strongly with changes in the middle atmosphere during various periods in the fluctuation spectrum as will be shown. /205

The border frequencies used were measured in Lindau (51°N, 10°E [12] and the absorption values (A1, measurement frequency 2 MHz) in Juliusruh [54°N, 13°E) [9]. Due to the geographical locations of these stations, the remote-sensing data of the PMR experiment for 52°N, 10°E was selected for comparative analyses.

Auto and coherence spectra of the time series were computed using the methods of the bivariate linear spectral analysis [13]. The analysis of interaction processes is primarily based on the coherence spectra with which a measurement for the correlation between quasi-periodic variations on certain frequencies is obtained. An a priori sought oscillation is then designated as significantly coherent if the coherence value exceeds the 95% confidence limit in the coherence spectrum [13]. Thus high coherence is an indication of coupling processes, related to periodic (wave) processes.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the autospectra of the data series for channel 2115 of Nimbus 6 and the fluctuation index I_N which is to be discussed in place of the remainder of the autospectra. For this the frequency range $0.02\ d^{-1} < f < 0.4\ d^{-1}$ is considered since the spectra could be adulterated by data processing and non-controllable time series structures especially in the high and low frequency range.

The autospectra described reflect the influence of stochastic processes on the time series and can be approximated by the sum of spectra of a "red smoke" and a "white smoke" (spectral density constant with the frequency). For the spectral density (Figure 1) one finds (in the appropriate units, f in d^{-1})

$$c_{11}^2 = \frac{0.65}{(f+0.02)^{3.6}} + 40 \qquad (1)$$

and for the electron content index (Figure 2):

$$c_{11}^2 = \frac{1}{f^2+f_0^2} + 500, \qquad f_0=0.02\ d^{-1} \qquad (2)$$

The second case corresponds to an autoregressive process of the first order in the frequency-dependent portion with a fade time of $T = 1/(2\ \pi \cdot f_0)$ of about eight days. These approximations also include the largest portion of the fluctuations of the spectra in the range of the 95% confidence interval K. For the ray density, however, at $f = 0.2\ d^{-1}$ one finds a maximum which slightly exceeds the confidence limit. In anticipation of the following discussion, it is mentioned that this probably concerns an effect of the so-called 5-day wave [18] which is also indicated in the spectrum for I_N by a relative maximum which is insignificant in a statistical sense.

The autospectra represent physical systems with various maintenance tendencies for fluctuations. Structural changes in the spatial distribution of the electron content are predominantly characterized by time-uncorrelated processes up to relatively high periods (about 15 days). In the upper stratosphere for periods of more than three days, autoregressive processes predominate with increasing maintenance tendencies during longer periods.

Examples for the relationships between quasiperiodic changes /208 in the time series of various data are contained in Figures 3 and 4. They show coherence spectra for two series with spectral density data (Ch 2115/Ch 2105) and ray density and index values (Ch 2115/I_N). The 4-6 day period was designated in order to bring out the significant values in this period range for all coherence spectra.

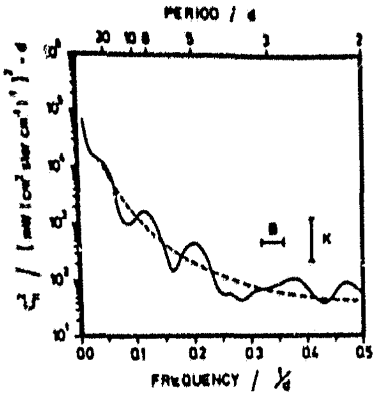

Figure 1

Autospectrum of the data series of the channel 2115 of Nimbus 6. The spectral values $C^2 11$ (variance per frequency unit, 1/d) are shown with the frequency and the periods. The bandwidth is designed by B, the 95% confidence interval with K; dashed curve: approximation of the spectrum from equation (1) (see text). /206

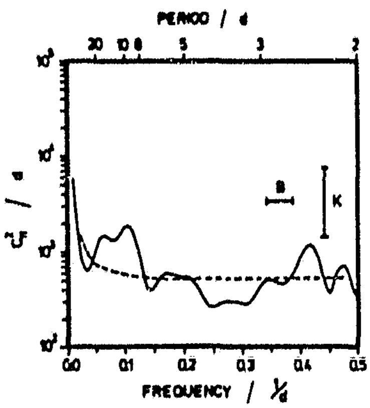

Figure 2

As Figure 1 for the fluctuation index I_N. Dashed: approximation per equation (2) (see text).

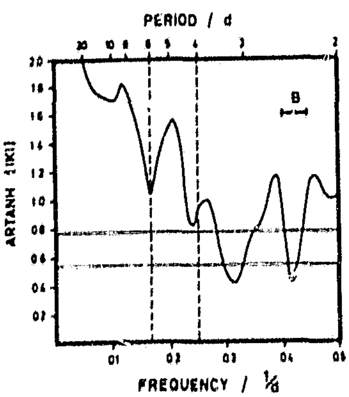

Figure 3

Coherence spectrum of the time series Ch 2115/Ch 2105. Artanh (|K|) (K: coherence) is shown with the frequency (1/d below) and the periods (d, above), according to [13]. The 95% confidence limit is at Artanh (|K|) = 0.55, and the limit increased by $\sqrt{2}$ (for significance control) at Artanh (|K|) = 0.79. The bandwidth B is 0.0443 d^{-1}, the degree of freedom is 12. The maximum retardation is 30 days.

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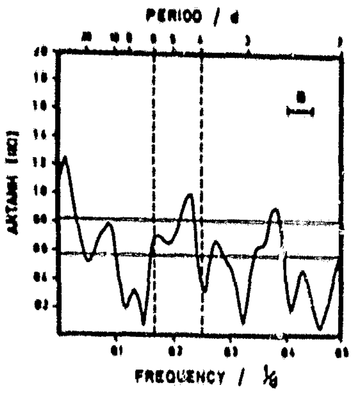

Figure 4. As Figure 3, only for the time series Ch 2115/I_N.

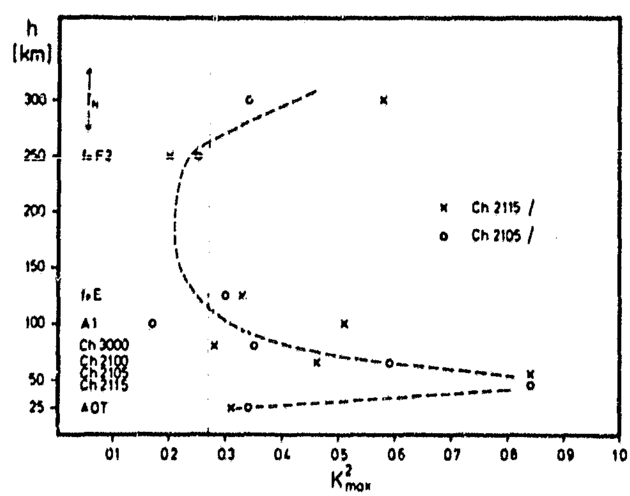

Figure 5. Shown is the dependence on the altitude of the maximum value of the quadratic coherence ($K^2{}_{max}$) from the period range of 4-6 days. The values for the time series Ch 2115 (remaining measurement values and parameters) are designated by an x and those for Ch 2105/(...) by an o. The dashed vertical line at K^2 = 0.27 indicates the 95% confidence limit according to Jenkins and Watts [13]. The designations: AOT: average temperature of the 30-mbar area at 50°N; channels Ch 2115, 2105, 2100, 3000 see paragraph 2; A1: radiowave absorption Juliusruh; foE, foF2: border frequencies Lindau/Harz; I_N: electron content index (see text).

The clear coherence for these periods is ascribed to the influence of the so-called 5-day waves which have been extensively studied in recent years [18], [16]. Geisler and Dickinson [8] computed the structure of a global 5-day Rossby-wave with the zonal wave no. 1 for realistic vertical wind profiles into the mesosphere. In the simulation model the waves showed phase-similarity in all atmospheric layers, and the intensity of the wind disturbance through the wave increases continually with altitude to the mesopause whereby the energy density decreases exponentially. The evaluations of ray measurements of the satellites of the Nimbus series showed that it was a westward wandering wave with a 4.5-6.2 day period [18]. In contrast to the undisturbed summer atmosphere, the waves in the winter atmosphere are supposed to be more difficult to identify due to the strong circulation disturbances. In the correlations of remote sensing data and ionospheric data for the 1975-76 winter that were carried out by us, the oscillation can always be identified. /208

In addition to the well detectable 5-day waves, other periodicities of the troposphere and the stratosphere can also be followed into the ionosphere. Thus, significant coherence values can be identified in nearly all spectra in the period range of 20 --10 days. These results are probably largely attributable to an influence of a characteristic 16-day wave [16]. For brevity, the discussion of periodicities is limited to the 5-day waves that can be well identified.

In Figure 5, it was attempted to depict the altitude structure of this oscillation with the help of the coherence value. For this the ray density series (Ch 2115, 2105) were compared with the other data series. With consideration of the bandwidths of the 5-day oscillations, the maximum values of the quadratic coherence (K^2) were selected from the 4-6 day period range. In Figure 5, they are compared to the altitude range for which the individual series are representative.

Since K^2 can be regarded as the measurement for the coupling processes in the layers examined, Figure 5 can be interpreted in the following manner. The portion of the variations of the analyzed parameters that are correlated with temperature and ray density oscillations in the vicinity of the stratopause clearly subsides to below the threshold value of the 95% confidence level (dashed line) up to the lower thermosphere and then increases again significantly in the upper thermosphere. The values for the 30-mbar temperature permit the identification of the decline in the coherence. This decrease upward and downward is typical for spatial (vertical) correlated stochastic processes in the atmosphere. The extraordinary thing here is that the coherence is clearly above that of the probability range established by the 95% confidence limit up to the lower E-layer. If this limit is used for the definition of a vertical integral scale, then one gets a value of 30-40 km. This large value for the middle atmosphere (usually 10-15 km is expected /2
or one to two altitude scales) is not conceivable without the activity of wave-type processes with vertical propagation or expanded vertical structure. This could be the above mentioned, usually deterministically defined waves with a period of five days. Our results show that the deterministic picture of these waves must be supplemented by a stronger stochastic portion in the space-time changes.

The high coherence of changes in the middle atmosphere and in the lateral structure of the electron content is an unexpected and important result. Theoretical considerations do not support this being a direct dynamic coupling of middle atmosphere and upper and middle ionosphere by planetary waves. Even the coherence spectra for middle atmosphere and ionosphere data series (i.e., foF2) due to their generally very low values do not indicate a direct interaction of this type. On the other hand, there is a series of empirical discoveries that clearly support an indirect coupling between ionospheric processes and the dynamics of the middle atmosphere. The high coherence for I_N and Ch 2115 and 2105 for periods of five days is a further indication.

The vertical propagation of gravity waves from the middle atmosphere into the ionosphere appears to be an indirect coupling mechanism [7]. These could lead to spatial fluctuations of the electron content, and then with sufficiently short fading times as are required for I_N due to the autospectrum (Figure 2). If they are modulated in intensity through interactions with the 5-day waves of the middle atmosphere or in frequency or the direction of the propagation, then appropriate coherent fluctuations in the lateral structure of the electron content are probable. The final explanation of this coupling phenomenon and many similar phenomena depends on the still uncompleted development of a comprehensive theory of dynamic coupling of the middle and upper atmosphere.

4. FINAL COMMENTS

The results of the statistical spectral analysis shows coherent variations in the time series of ray density measurements and other condition parameters for the middle atmosphere and for the ionosphere. The existence of probable dynamic coupling processes with oscillations for periods of 16 and 5 days are especially well known which appear to be related to the observed planetary waves of the same periods. For the theoretical processing of the diagnosed interactions, efficient models are still not available that could include the effect of large area stochastic processes in the atmosphere. The observation of the atmosphere from satellites using remote sensing methods might, as is shown by this short study, make an important contribution to the detection of dynamic coupling processes between the various regions of the atmosphere. The special advantage is the capability to determine large area (global) connections using these methods.

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