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Trends in the characteristics of the annual and semiannual variations observed in the radio wave absorption in the lower ionosphere

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Abstract. The continuous increase in concentration of greenhouse gases in the atmosphere is expected to cool higher levels of the atmosphere. There is some direct and indirect experimental evidence of long-term trends in temperature and other parameters in the mesosphere and lower thermosphere (MLT). Here we look for long-term trends in the annual and semiannual variations of the radio wave absorption in the lower ionosphere, which corresponds to the MLT region heights. Data from central and southeastern Europe are used. A consistent tendency to a positive trend in the amplitude of the semiannual wave appears to be observed. The reality of a similar tendency in the amplitude of the annual wave is questionable in the sense that the trend in the amplitude of the annual wave is probably induced by the trend in the yearly average values of absorption. The phases of both the annual and semiannual waves display a forward tendency, i.e. shift to an earlier time in the year. A tentative interpretation of these results in terms of changes of the seasonal variation of temperature and wind at MLT heights does not contradict the trends observed in those parameters.

Key words. Ionosphere (ionosphere – atmosphere interactions; mid-latitude ionosphere) · Meteorology and atmospheric dynamics (middle atmosphere dynamics)

1 Introduction

The continuous increase of greenhouse gases (carbon dioxide, methane, etc.) in the atmosphere is expected to warm the troposphere but to cool the higher levels of the atmosphere, including the mesosphere and lower thermosphere. Roble and Dickinson (1989) first theoretically estimated that the mesospheric cooling attains about 5 K as a consequence of CO_2 doubling. There is direct and indirect experimental evidence of long-term trends in temperature in the mesosphere. A long series of rocket measurements of mesospheric temperature display a negative trend at all examined sites (Kokin and Lysenko, 1994; Lysenko *et al.*, 1997a). Lidar measurements in southern France show a trend in mesospheric temperatures of about −0.4 K/y (Keckhut *et al.*, 1995). A gradual but steady decrease in the radio wave reflection heights at 164 kHz over more than 30 y was interpreted in terms of the pressure decrease near 80 km due to a trend of about −0.6 K/y in the column-mean temperature between the stratopause and 81.8 km (Taubenheim *et al.*, 1990, 1997). Long-term trends in OH-emission were used to establish a negative trend in temperature near 87 km at about −0.7 K/y (Semenov, 1996). Unfortunately, the observed trends in mesospheric temperature are much larger than those expected by models due to the increase of greenhouse gas content in the atmosphere. Hence their unambiguous interpretation is not sure. There are also trends in the height of centroid of the atmospheric Na-layer (Clemesha *et al.*, 1997) and in the occurrence frequency of noctilucent clouds (Gadsden, 1990). However, the origin of these changes does not necessarily lie in the changes of temperature, other explanations are also possible. The trends observed in the radio wave absorption in the lower ionosphere were interpreted as a consequence of mesospheric cooling (Nestorov *et al.*, 1991; Bremer, 1997). However, trends observed with various radio paths provide an inconsistent pattern (Laštovička *et al.*, 1997), among others due to instrumental drifts and a non-stability of the zero level of absorption. To overcome these problems, relative changes of absorption were used to deduce the trends in the planetary wave activity in the upper middle atmosphere. Some increase of the planetary wave activity was found (e.g., Laštovička *et al.*, 1994; Laštovička, 1997).

The annual variation and the semiannual variation of the radio wave absorption in the lower ionosphere are

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its two most important variations on monthly time scale. Since these two variations are so important for absorption and, consequently, for the lower ionosphere, to examine the long-term trends in both amplitudes and phases of variations is important by itself without considering the phenomenon of seasonal variation.

The combination of annual and semiannual variations basically creates the seasonal variation of absorption. Alternatively, we may study the seasonal variation by examining long-term trends in absorption month-by-month and by their combination to construct trends in seasonal variation and, thus, in combination of annual and semiannual variation. However, the month-by-month analysis of long-term trends is more sensitive to data gaps (e.g., a gap of two weeks does not affect the annual variation but affects substantially the given monthly value) and to some extent to effects of sporadic solar and meteorological events and, therefore, its results are less accurate and reliable. Second, it is difficult, if not impossible, to deduce information on phase trends and/or changes of both annual and semiannual variations from month-by-month trend analysis.

The aim of this work is to establish long-term trends in the annual and semiannual variations of the radio wave absorption in the lower ionosphere as a contribution to the general pattern of long-term changes in the upper middle atmosphere.

The absorption is examined at a constant solar zenith angle, χ, to eliminate the effect of the annual course of the solar zenith angle. The annual variation reflects predominantly both the "regular" winter anomaly and the excessive anomalous day occurrence in winter. The semiannual variation reflects, among others causes, the response of the lower ionosphere to springtime and autumnal circulation transitions, which are associated with a weak absorption.

2 Data analysis

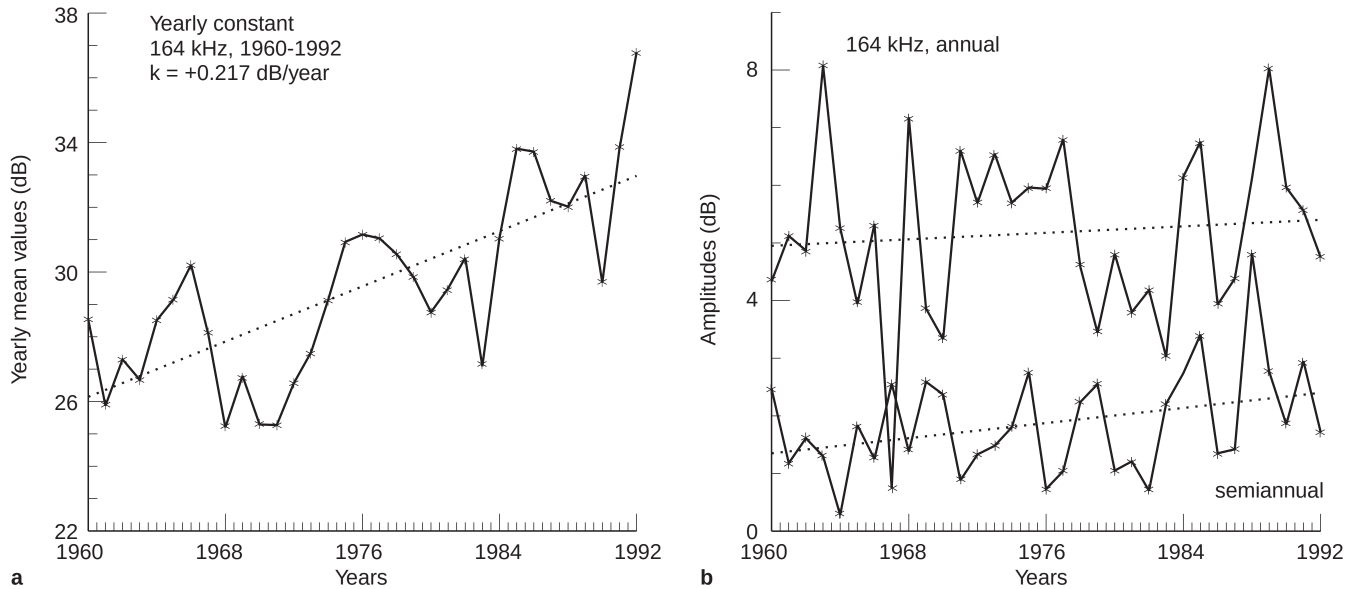
The long-period series of daily values of the radio wave absorption in the lower ionosphere, measured by the A3 method (continuous wave, oblique incidence on the ionosphere) in central and southeastern Europe, are analyzed. We use the measurements along three radio paths, which fulfill the condition of continuous measurements over at least two solar cycles. These basic radio paths are as follows: Allouis-Sofia (164 kHz; reflection point 45.5°N, 13.2°E; noon, for technical reason e.g., data reliability, we do not use data at χ = const.; 1960–1992), Luxemburg-Panská Ves (6090 kHz; reflection point 50.1°N, 10.5°E; $\chi = 75°$; 1972–1996) and Prishtina-Sofia (1412 kHz; reflection point 42.7°N, 22.3°E; $\cos \chi = 0.2$; 1970–1990). In order to have a better coverage of the period studied (1960–1996), we partly use also shorter data series from subsidiary radio paths Kiel-Panská Ves (2775 kHz; reflection point 52.7°N, 12.7°E; $\cos \chi = 0.2$; 1961–1972) and Monte Carlo-Roburent (218 kHz; reflection point 44°N, 7.5°E; $\cos \chi = 0.2$; 1975–1985).

To study the variations of ionospheric absorption, the Fourier decomposition of time series is performed. The seasonal course of absorption is described by the three main components: mean yearly constant (*YC*), annual wave (*AW*), and semiannual wave (*SAW*), derived by the best fit procedure (Mukhtarov and Pancheva, 1992). The *AW* and *SAW* are characterized by their amplitudes and phases. To study trends and long-period variations in the phases of *AW* and *SAW*, a reduction of the phases has to be accomplished first. This procedure is described in detail by Pancheva and Mukhtarov (1996).

Figure 1a shows the course of the *YC* for the 164 kHz absorption over 33 y, Fig. 1b shows the same for the amplitude of the *AW* and *SAW*, and Fig. 1c the same for the phase of the *AW* and *SAW*. An evident positive trend is observed only in the *YC*. The *AW* does not display any evident trend. In particular the weak positive trend in amplitude is statistically quite insignificant, whereas a forward shift in the phase might be real. The amplitude of the *SAW* tends to increase due to a remarkable increase in the second half of the 1980s. As for the phase, we observe a tendency to a forward shift again. Part of the variations in Fig. 1a and b is caused by the 11-y solar cycle; the quasi-biennial oscillation (QBO) seems to contribute, as well. A remarkable effect of the QBO on the amplitude of the *SAW* in absorption was first observed by Laštovička and Knyazev (1990). However, the trends themselves do not seem to be substantially affected by the solar cycle and QBO due to the sufficiently long period under study. Figure 1b shows an evident dominance of the *AW*, its amplitude is on average more than twice as high compared to that of the *SAW*.

Figure 2 shows the results for 25 y of measurements at 6090 kHz for the *YC* (Fig. 2a), for amplitudes of the *AW* and *SAW* (Fig. 2b), and phases of the *AW* and *SAW* (Fig. 2c). Definite positive trends in the *YC* and amplitudes of both the *AW* and *SAW* are observed together with a clear indication of a positive correlation with the solar cycle. As for phases, the *AW* displays an evident forward trend (observable as a decrease in phase), while the *SAW* shows only a very weak and insignificant forward tendency. In contrast to 164 kHz, the amplitudes of the *AW* and *SAW* are comparable (Fig. 2b).

Figure 3a–c shows the same for the 1412 kHz absorption, with 21 y of measurements. Figure 3a displays a very strong increase of the *YC*, which is statistically quite significant, and again an evident solar cycle modulation. The amplitudes of the *AW* and *SAW* (Fig. 3b) again reveal a strong positive trend, which is expressed better for the *AW*. However, the solar cycle modulation of the *AW* and *SAW* amplitudes is almost absent. The negative trend in phases is strong for the *AW*, which exhibits stronger positive trend in amplitudes. This is similar to the pattern at 164 and 6090 kHz. Phases themselves (not trends in phases) seem to reflect preferentially the impact of the QBO, not of the solar cycle. The amplitudes of the *AW* and *SAW* are again rather comparable.



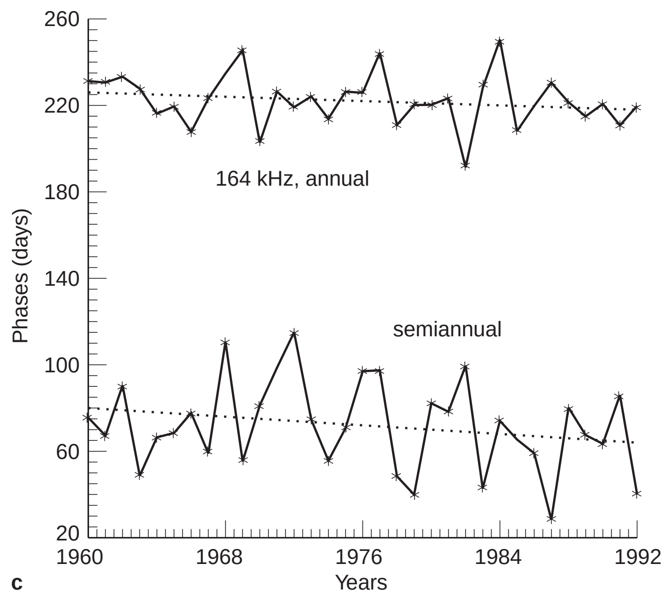


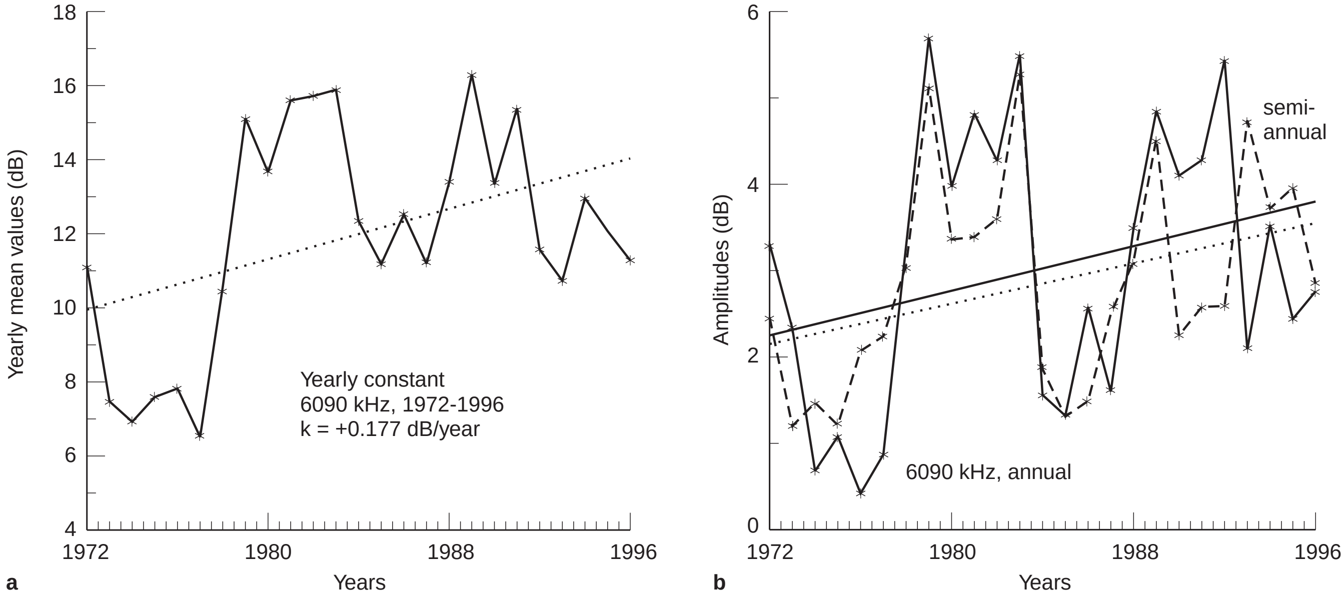
Fig. 1. **a** Trend in the yearly constant (slope = +0.217 dB/y) at 164 kHz, 1960–1992. **b** Trends in the amplitudes of the *AW* (*top curve*; k = +0.015 dB/y) and *SAW* (*bottom curve*; k = +0.033 dB/y) in absorption at 164 kHz, 1960–1992; k – slopes of curves. **c** Trends in the phases of the *AW* (*top curve*; k = –0.245 day/y) and *SAW* (*bottom curve*; k = –0.475 dB/y) in absorption at 164 kHz, 1960–1992; k – slopes of curves

Among data shown in Figs. 1–3, the solar cycle effect is most pronounced for the *AW* at 6090 kHz. When we compute the slope of the trend without taking into account solar activity, we obtain k = +0.063. When we also include the sunspot number in the multi-parameter regression, then k = +0.054. The main effect of the inclusion of solar activity is the reduction of standard error of k from 0.045 to 0.027, while the difference between k-values is well within the standard error of their determination. This illustrates that solar activity has no substantial influence on trend determination if the data series is sufficiently long.

The subsidiary radio paths with shorter data series, 2775 kHz (12 y) and 218 kHz (11 y) provide results which are generally consistent with the results based on the three main radio paths. For brevity, we do not show the results in graphical form here. The *YC* and amplitudes of the *AW* and *SAW* reveal again a positive trend, and phases, except for the 2775 kHz *AW*, again exhibit a negative trend.

Thus the pattern of trends observed for five radio paths appears to be largely consistent, a positive trend in the *YC* and amplitudes of the *AW* and *SAW*, and a negative trend in phases of the *AW* and *SAW*. The linear trend coefficients are shown in Table 1. The values of trend coefficients for the *AW* phase, 2775 and 218 kHz, and standard deviations shown in Table 1 illustrate the fact that the length of data series comparable with one solar cycle is not long enough to obtain reliable results. It should be mentioned that Bremer (1997) reported negative trends for the yearly values (*YC*) of the multi-frequency LF absorption measured in Germany (further north than our measurements).

According to standard deviations shown in Table 1, the results for the three longer data sets (164, 6090 and 1412 kHz) are more reliable, the statistically most



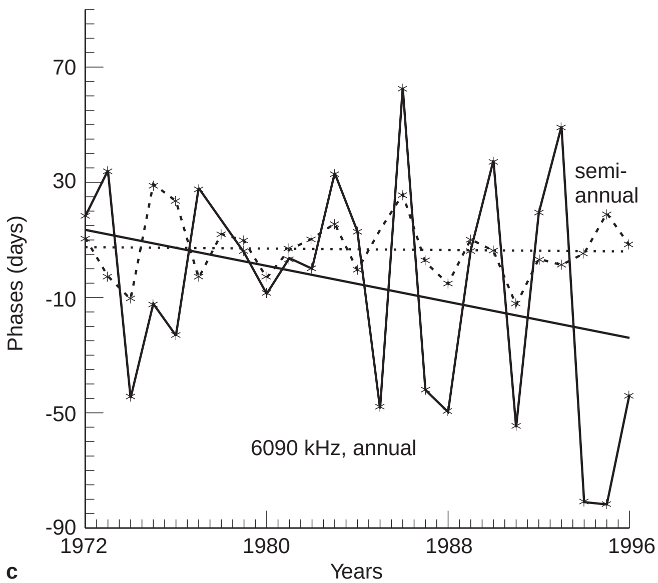


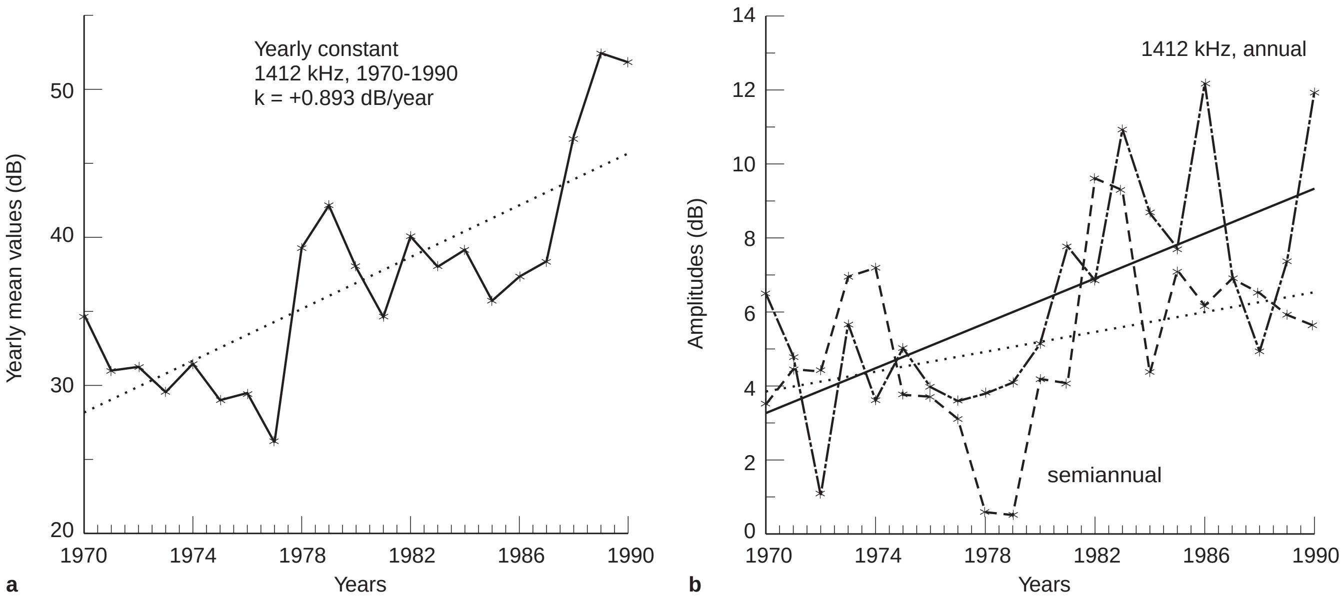
Fig. 2. **a** Trend in the yearly constant (slope = +0.177 dB/y) at 6090 kHz, 1972–1996. **b** Trends in the amplitudes of the *AW* (*Solid curve*; k = +0.063 dB/y) and *SAW* (*dashed curve*; k = +0.059 dB/y) in absorption at 6090 kHz, 1972–1996; k – slopes of curves. **c** Trends in the phases of the *AW* (*solid curve*; k = −1.622 day/y) and *SAW* (*bottom curve*; k = −0.105 dB/y) in absorption at 6090 kHz, 1972–1996; k – slopes of curves

significant being data for 1412 kHz. Their trends in *YC* appear to be quite significant. Their trends in both the *AW* and *SAW* phases are significant at 1σ to 2σ levels and all of the same negative sign. As concerns the *AW* and *SAW* amplitudes, their trends are again significant at 1σ to 2σ levels (and all of the same positive sign), which is not so bad if we consider the mentioned effect of solar activity (solar cycle) on σ, the number of data (years) and the year-to-year variability of spring transition date and sudden stratospheric warmings. All these effects enlarge σ.

Unfortunately, there is some similarity in the time course of the *YC* and the *AW* and *SAW* amplitudes, shown e.g., for 6090 kHz in Fig. 2. Moreover, when we take *YC* trend coefficients in Table 1 as one variable, *AW* amplitude trend coefficients as another variable, and *SAW* amplitude trend coefficients as the third variable, we obtain high correlation coefficients: $r_{YC,\ AW} = 0.82$ and $r_{YC,SAW} = 0.87$. Table 2 summarizes cross-correlation coefficients between the *YC* and *AW*, and the *YC* and *SAW* for all five radio paths separately. They display a positive correlation between the individual yearly values of the *YC* versus the *AW* and *SAW* amplitudes, even though the correlation is not always strong and time lags of maximum correlation usually differ from 0. All this indicates a question to be asked: is the trend in the *AW* and *SAW* amplitudes affected and/or induced by the trend in the *YC*? In other words, the larger the trend in the *YC*, the larger the trend in the amplitudes of the *AW* and *SAW*, or not?

The correction for the trend in the *YC* is made by calculating trends in relative amplitudes of the *AW* (*SAW*), computed as values of the *AW* (*SAW*) amplitudes divided by the *YC*.

Such an approach, with the relative amplitudes ΔfoF2/foF2, was used in examining the solar cycle effect



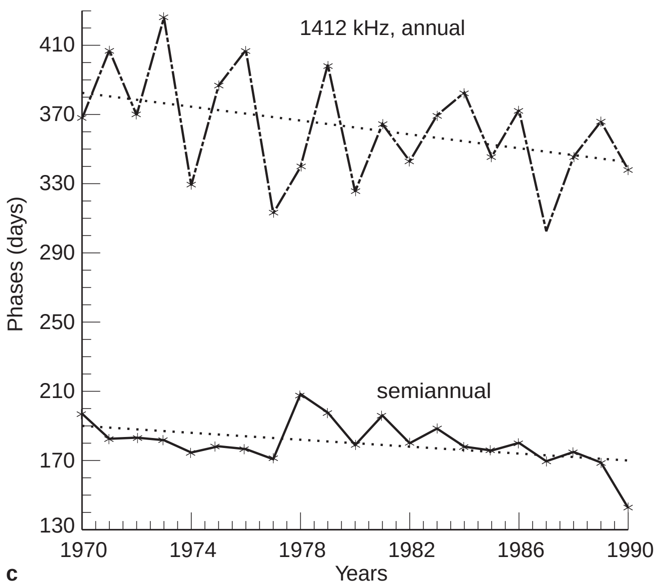


Fig. 3. **a** Trend in the yearly constant (slope = +0.893 dB/y) at 1412 kHz, 1970–1990. **b** Trends in the amplitudes of the *AW* (*Solid curve*; k = +0.304 dB/y) and *SAW* (*dashed curve*; k = +0.136 dB/y) in absorption at 1412 kHz, 1970–1990; k – slopes of curve. **c** Trends in the phases of the *AW* (*top curve*; k = −2.108 day/y) and *SAW* (*bottom curve*; k = −1.037 day/y) in absorption at 1412 kHz, 1970–1990; k – slopes of curves

in the planetary wave type oscillations in *f*oF2 by Laštovička and Mlch (1996). They found that the effect in relative amplitudes was much weaker, i.e., that the effect of solar cycle in the oscillations was largely induced by the solar cycle effect in *f*oF2 itself.

Figure 4 shows trends in the relative *AW* amplitudes. The obtained trends provide an inconsistent pattern. Two data series, 164 and 2775 kHz, which include data from the 1960s, exhibit a tendency to negative trends. The other two data sets, 6090 kHz and 1412 kHz, which do not include data from the 1960s and correspond to slightly higher altitudes in the lower ionosphere, reveal a positive trend. However, these positive trends are remarkably weaker than those shown in Figs. 2 and 3. Thus there is probably no systematic trend in the *AW* amplitudes. The apparent trends shown in Table 1 and Figs. 1–3 are probably induced by the trends in the *YC*. This coincides with the relatively close bond between the *YC* and the amplitude of the *AW*, indicated by Table 2. It should be mentioned that the data shown in Fig. 4 do not exclude the possibility of a change from negative trends before the late 1970s–1980 to positive trends after the early 1980s.

Figure 5 presents trends in the relative *SAW* amplitudes. These trends provide a consistent pattern as opposed to Fig. 4. They are positive as are those in Figs. 1–3, even though all trends are remarkably weaker and, therefore, less statistically significant (mostly insignificant) than those in Figs. 1–3. The trends are not removed by change to relative amplitudes due to the weaker bond between the *YC* and the *SAW* amplitudes (Table 2). The positive trends seem to be stronger in central Europe (2775 and 6090 kHz) than in southeastern Europe.

As a summary, we can say that there is a tendency to a positive trend in the amplitude of the semiannual wave

Table 1. Linear trend coefficients for all five radio paths $\pm 1\sigma$ (standard deviation)

Radio path	Period	*YC* (dB/y)	*AW* amplitude (dB/y)	*AW* phase (day/y)	*SAW* amplitude (dB/y)	*SAW* phase (day/y)
164 kHz noon	1960–1992	+0.217 ± 0.035	+0.015 ± 0.028	−0.245 ± 0.219	+0.033 ± 0.016	−0.475 ± 0.379
6090 kHz $\chi = 75°$	1972–1996	+0.177 ± 0.075	+0.063 ± 0.045	−1.622 ± 1.118	+0.059 ± 0.032	−0.105 ± 0.301
1412 kHz cos $\chi = 0.2$	1970–1990	+0.893 ± 0.165	+0.304 ± 0.081	−2.108 ± 1.103	+0.136 ± 0.082	−1.037 ± 0.432
2775 kHz cos $\chi = 0.2$	1961–1972	+0.303 ± 0.151	+0.088 ± 0.087	+0.307 Unreliable	+0.019 ± 0.064	−0.683 ± 0.428
218 kHz cos $\chi = 0.2$	1975–1985	+0.246 ± 0.184	+0.230 ± 0.223	−15.683 Unreliable	+0.062 ± 0.092	−1.038 ± 0.635

Table 2. Cross-correlation coefficients of yearly values, *YC-AW* and *YC-SAW*, for all five radio paths. Maximum correlation with corresponding time lag (years; + means the *YC* leads), and correlation with no time lag (correlation lag 0) are shown

Radio path	*YC-AW*			*YC-SAW*		
	Maximum correlation	lag	Correlation lag 0	Maximum correlation	lag	Correlation lag 0
164 kHz	0.29	−1	0.10	0.32	−1	0.30
218 kHz	0.75	0	0.75	0.32	+2	0.23
1412 kHz	0.57	+1	0.47	0.42	+4	0.14
2775 kHz	0.74	+1	0.49	0.50	+1	0.08
6090 kHz	0.82	0	0.82	0.73	0	0.73

in the radio wave absorption in the lower ionosphere. The reality of a similar tendency in the amplitude of the annual wave seems to be questionable in the sense that it is probably induced by the trend in the *YC*. The phases of both the annual and semiannual waves display a forward tendency, i.e., shift to an earlier time in the year.

Figures 4 and 5 show that the amplitudes of the *AW* and *SAW* are quite large. They are comparable at 6090 kHz, whereas at other frequencies the amplitudes of the *AW* are larger than those of the *SAW*. Mean *SAW* amplitudes range from 5% to 30% of the *YC*, those of *AW* from 10% to 50%.

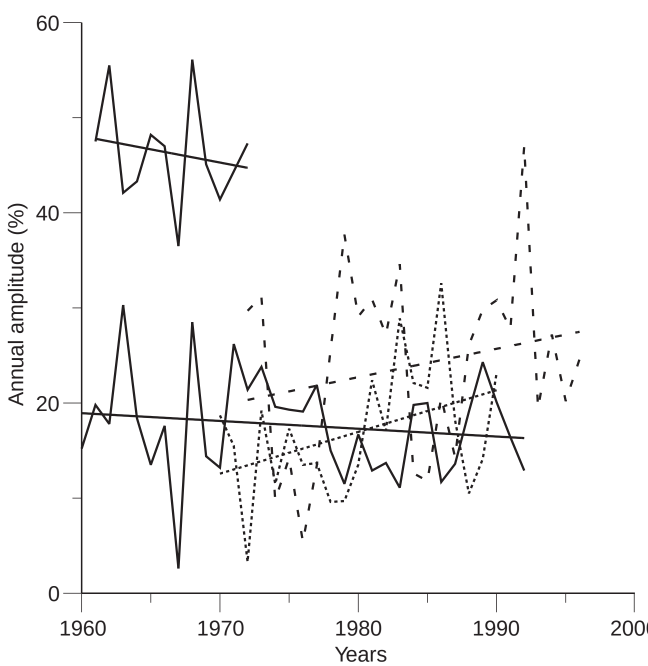


Fig. 4. Trends in the relative amplitudes of the annual wave (*AW*/*YC*) in absorption at 2775 kHz (*solid curve*, *top*), 164 kHz (*solid curve*, *bottom*), 1412 kHz (*dotted curve*) and 6090 kHz (*dashed curve*)

3 Interpretation of results

For a correct interpretation of these results, it is necessary to mention the altitude regions, where the absorption arises (or at least its predominant part). These are: 164 kHz, heights of about 65–70 km; 218 kHz, heights of about 80–85 km or slightly lower; 2775 and 1412 kHz, heights of about 90–95 km and by about 1 km higher, respectively (the 1412 kHz radio

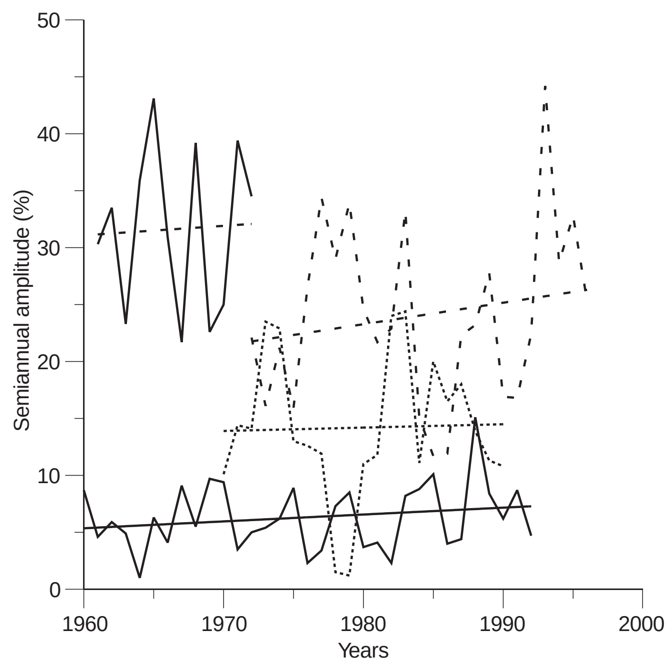


Fig. 5. Trends ($\pm 1\sigma$) in the relative amplitudes of the semiannual wave (*SAW*/*YC*) in absorption at 2775 kHz (*solid curve*, *top*; k = +0.083 %/y, insignificant), 164 kHz (*solid curve*, *bottom*; k = +0.060 ± 0.053 %/y), 1412 kHz (*dotted curve*; k = +0.029 %/y, insignificant) and 6090 kHz (*dashed curve*; k = +0.189 ± 0.218 %/y); k – slopes of curves

path is much shorter and, therefore, has slightly higher equivalent vertical frequency); 6090 kHz, heights of about 95–100 km. The differences in heights contribute to a certain difference in results between various radio paths.

Bremer (1998) interpreted the observed negative trend in the LF radio wave absorption in terms of decreasing pressure and, thus, of decreasing temperature in the mesosphere. The positive trend in the 164 kHz absorption in the lowest ionosphere was interpreted in terms of temperature decrease, as well (Nestorov *et al.*, 1991), because this very long radio path has different radio-physical characteristics.

Annual and semiannual amplitudes of winds near 95 km as well as the yearly mean prevailing wind itself were found to weaken remarkably at higher middle latitudes at stations Obninsk, Kuhlungsborn and Collm by Portnyagin and Merzlyakov (1997). They interpreted the weakening of both the annual and semiannual variations in terms of an increase of the upward influx of gravity wave energy from below, which was more isotropic.

Analyses of regular rocket soundings at Heiss Island, Volgograd, Thumba and Molodezhnaya yield an evident trend of cooling in the mesosphere (Kokin and Lysenko, 1994; Lysenko *et al.*, 1997a). These data also show an evident increase of both the annual and semiannual amplitude in temperature in the mesosphere of middle and high latitudes over the period of 1964–1994, this increase being as high as almost a factor of two (Lysenko *et al.*, 1997b). On the other hand, no significant change of phases of either waves was observed. These findings are in qualitative agreement (as to sign of changes) with those expected as a consequence of increasing concentration of greenhouse gases in the atmosphere.

We do not want to discuss trends in the yearly constants (yearly mean values). Our results agree with those of Nestorov *et al.* (1991) but rather contradict those of Bremer (1998) for the LF absorption. The daytime HF-MF radio waves, used prevailingly in this study, reflect from the steep bottomside E-region. Comparatively small changes of the electron density gradient in this region can result in a positive or negative trend in absorption. The change of this gradient under the effect of increasing greenhouse gas concentration is almost unpredictable. Thus it is basically impossible, or at least very difficult, to interpret unambiguously the observed trends in the daytime absorption itself.

As concerns the observed positive trend in the *SAW* amplitude in absorption, the results indicate two competing factors. The observed weakening of the semiannual wave in winds near 95 km means a weakening in the semiannual variation of the downward transport of nitric oxide from the thermosphere (heights of about 105–110 km) by the vertical wind component; however, it does not involve transport by turbulent diffusion. This should result in a partial weakening of the semiannual variation of electron density. On the other hand, the observed substantial increase in the semiannual wave in temperature will increase the semiannual wave in electron density through the temperature dependence of the electron loss rate via dissociative recombination and, moreover, in the collision frequency which is proportional to pressure. Since the non-deviative absorption at a fixed height is approximately proportional to the product of electron density and collision frequency, the increase of the semiannual wave in temperature should remarkably increase the *SAW* in absorption. The same scenario is also valid for the *AW* in absorption. A mutual interplay of these two opposite effects may result in the observed tendency to strengthening of the *SAW* in absorption and even in a possible change of sign of the trend in the *AW* in absorption.

Unfortunately, available information does not make it possible to estimate quantitatively the effect of weakening of the *SAW* and *AW* in winds. However, we can try to estimate the effect of the *SAW* and *AW* in mesospheric temperatures.

Laštovička (1975) made a simple analysis of the effect of changes of atmospheric density, pressure and temperature on absorption. Assuming no other change in the atmosphere than the change in temperature between 90–100 km, we obtain from formulas of Laštovička (1975) the following:

$$N_{\max}/N_{\min} = (\mathrm{T}_{\max}/\mathrm{T}_{\min})^{1/2}, \quad \nu_{\max}/\nu_{\min} = \mathrm{T}_{\max}/\mathrm{T}_{\min}$$

where N is electron density and ν collision frequency. The absorption at a fixed height is approximately proportional to the product of electron density and collision frequency, i.e.:

$$\mathrm{L}_{\max}/\mathrm{L}_{\min} = (\mathrm{T}_{\max}/\mathrm{T}_{\min})^{3/2}$$

Let us assume the increase of *SAW* in temperature to be a factor of 1.5. This results in the reduction of the *SAW* for absorption at a fixed height by a factor of 1.84.

Such a calculation is an oversimplification, of course, because there are also related changes of density, there is an opposite change in the *SAW* in the nitric oxide concentration due to changes in winds, and there is a slight change of reflection height with a possibility that absorption may arise at a slightly different part of electron density profile with a slightly different gradient, etc. Nevertheless, even such a simple calculation shows that the observed changes in the *SAW* amplitude might be attributed to the related changes in the neutral atmosphere parameters.

On the other hand, we have no explanation for the observed forward trend in phases of both the *AW* and *SAW* in absorption. According to Manson (private communication, 1999) and Jacobi (private communication, 1999), there has been no study of trends in dates of spring reversal of circulation near 95 km, but data probably do not seem to indicate a significant trend, only a large variability.

4 Conclusions

Long-term trends in the annual and semiannual variations of the radio wave absorption in the lower ionosphere were studied with the use of data from five radio paths located in central and southeastern Europe. The results may be summarized as follows:

1. A consistent tendency to a positive trend in the amplitude of the semiannual wave is observed.
2. The reality of a similar tendency in the amplitude of the annual wave is questionable in the sense that it is probably induced by the trend in the yearly average values of the absorption themselves.
3. The phases of both the annual and semiannual waves display a forward tendency, i.e., shift to an earlier time in the year.
4. A tentative interpretation of these results in terms of changes of the seasonal variation of temperature and wind in the mesosphere and lower thermosphere indicates that the assumption of the neutral atmosphere origin of the observed changes in the amplitude of the semiannual wave in absorption is quite reasonable. However, we have no interpretation for the trend in phases of either the annual or the semiannual wave.

Further investigations into interpretation of these experimental findings with the use of future, more complete information on changes/trends in the *SAW* and *AW* in the neutral atmosphere, appears to be necessary. On the other hand, our findings do not contradict the trends observed in the mesosphere and lower thermosphere in other parameters.

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