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VARIABILITY OF ION CONCENTRATION IN AIR OVER THE GROUND AND SEA

A. WISZNIEWSKI[1,*], R. ŻURALSKA[2], M. MZIRAY[3]

[1] Faculty Department of Medical Informatics and Biostatistics,
Medical University of Gdańsk, Poland
E-mail[*]: awisz@gumed.edu.pl (corresponding author)
[2] Faculty Department of Nursing, Medical University of Gdańsk, Poland
E-mail[*]: zuralska@gumed.edu.pl
[3] Faculty Department of Nursing, Medical University of Gdańsk, Poland
E-mail[*]: mmziray@gumed.edu.pl

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Abstract. The main goal of this paper was to analyze the causes of changes of air-ion concentration over sea and land. Changes of ion concentrations in air is often a periodic function of time and can reach several hundred percent of the average. In this paper factors responsible for such phenomenon are analyzed. Presented results support the hypothesis that the main factor is the wind, especially near the surface of the ground or sea. In such areas ion concentration is lower or higher than the average. As the final result the changes of correlation between positive or negative ion concentration and speed of wind can be observed. This work complements similar studies carried out in relation of positive air-ions. The results of these studies are the basis for the consideration of changes in air ionization levels in the cabins of ships, the violation of which, in accordance to the theory, it can be the cause in seamen of occupational diseases.

Key words: atmospheric electricity, air-ions, wind, Baltic Sea.

1. INTRODUCTION

The air ionization level is an interesting parameter because according to published results, it has important influence upon biological phenomena for animals and human. The author of this paper has also investigated this phenomenon [1–6]. Results collected from experiments confirmed that a relatively low increase in ionization level (up to several million ions per $2.6 \cdot 10^{19}$ of all particles contained in 1 cm^3 of air) can trigger real, sometimes strong biological effects [4–6].

In order to confirm such influence, detailed measurements (of ion concentration ($n^{\pm}$) and mobility (μ)) in the natural environmental and various closed environments are necessary) [7–14]. Such measurements are needed to validate if the ionization level in the natural or closed environments can reach a level, high or low enough to influence human beings.

The general conclusion from such set of measurements is that in nearly all cases ion concentration is not harmful according to present norms [1, 9, 10, 13]. Allowed ionization levels never exceed the safe limits also for the near lightning discharges [12]. The only exceptions are in the vicinity of ion generators [11] and ship cabins [14]. Therefore, the results of this and article [15] among others make reference to research the possibility of violations of air ionization levels in the cabins of ships, which can be a cause of the seamen occupational diseases [14].

Investigation into the influence of ionization levels upon human beings gave inconsistent results. Nevertheless interesting phenomena caused by changes in ion concentration ($n^{\pm}$) were observed [5, 6].

One such phenomenon is that a large fluctuation of ionized particle concentration resulted from a relatively small change of physical parameters in the atmosphere. Changes of small ion concentration (with the mobility of $\mu > 10^{-2}$ $cm^2/(V \cdot s)$, including electrons and ions of basic air compounds: O_2^+, O_2^-, N_2^+) are presented in Table 1. The basic precision of measurement is 20 ions per cubic cm. Atmospheric parameters were stable (sunny weather, the average temp. 17 ÷ 23 °C and the stability of atmospheric pressure in the range of several percent). All measurements were done at three different points in the city (Warsaw) with different urban environments (1 – main street with heavy traffic, 2 – suburban area with the low intensity traffic, dispersed buildings and 3 – forest area with dispersed buildings). At each point measurements were repeated approximately 20 times.

Table 1

Exemplary ranges of air-ion concentration levels measured in Warsaw (the author's measurements)

Measurement site	Number of air-ions in 1 cm^3	
	n^-	n^+
Downtown with a high road traffic	45 ÷ 380	60 ÷ 710
Suburbs, minimal road traffic, sparse buildings	70 ÷ 475	40 ÷ 620
Region of dense forestation, very sparse buildings	65 ÷ 680	95 ÷ 440

More detailed investigation into the large dispersion of results observed in Table 1 showed that the ion concentration has a periodic character with an average period of one day. The amplitude of concentration can reach several hundred percent. Such periodic behavior is mainly observed over the sea, but over land it is also present, mainly in open areas. The absence of factors like pollution is also important. An example of such concentration change over land for small ions, (the highest observed by the author [10] is presented in Fig. 1 – time on the horizontal axis for this and all similar diagrams is the apparent solar time).

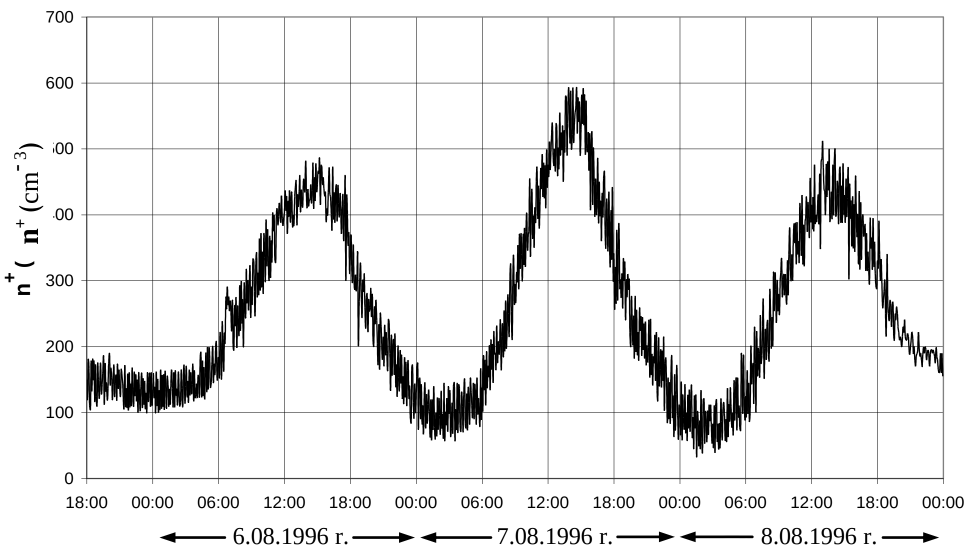

Fig. 1 – Course of the greatest observed values of changes in positive small air-ions concentration in the function of the local solar time, measured on land (acc. to the author – [10]).

Averaging concentration values n^+ from Fig. 1 and overlaying observed changes in small ion concentration n^- gave the graph of $n^{\pm} = f(t)$, presented in Fig. 2. Results were obtained in a suburban area (Gdańsk, Poland), in sunny conditions and temperatures ranging 22.1 ÷ 26.2 ºC.

Results presented in Fig. 2 were among the first obtained by the author [10]. The shape of the graph shows that maximum concentration was correlated with solar noon and minimum with solar midnight. The hypothesis of the influence of solar radiation was proposed. According to present knowledge, all ionizing radiation (with $\lambda < 100$ nm) is totally absorbed in the ionosphere. Estimation showed that observed daily changes can result from as low a transmission of ionizing radiation as 10^{-13} % (for the purposes of estimation, solar constant 1388 J/(m$^2 \cdot$ s), average concentration of ions $n^{\pm} = 400/\text{cm}^3$ and average wavelength on the ground level $\lambda = 550$ nm were used). Such little deviation from the estimated 100% extinction in the ionosphere is most probably possible. However, a more detailed analysis of the development of changes in the air-ion concentration ruled out the hypothesis of the direct influence of the Sun on the ionization of air.

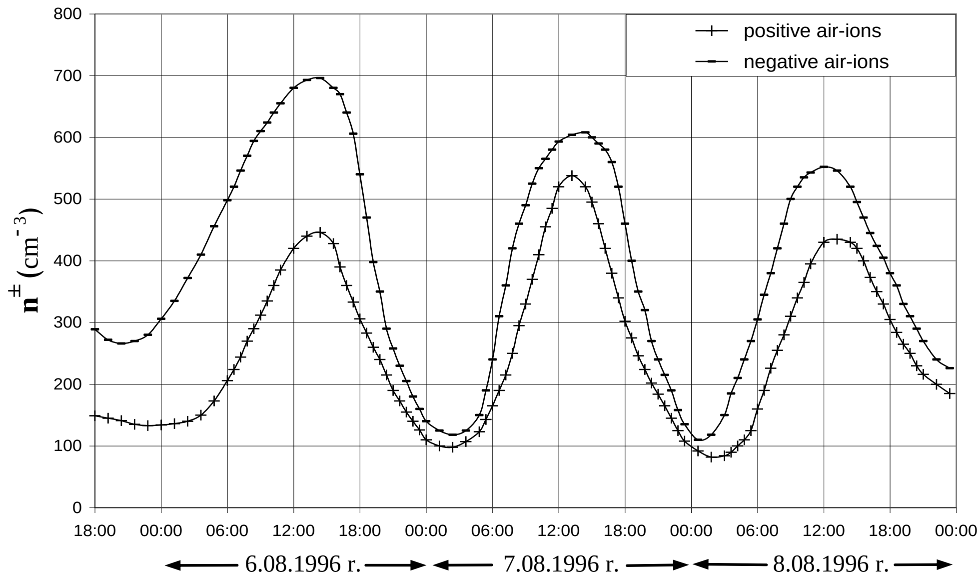

Fig. 2 – Course of the greatest observed values of averaged changes in small air-ions concentration in the function of local solar time, measured on land (acc. to the author – [10]).

Failure of the presented hypothesis comes from the fact that the changes presented in Fig. 1 and Fig. 2 are not always observed – despite the daily rhythm of changes in the position of the Sun, the ion concentration may be reasonably stable and changes in air density are only caused by changes in its temperature. Moreover, similar changes can shift the maxima and minima according to the exact time of the solar noon or midnight by up to several hours. The shape of the graph (Fig. 3) depicts the negative ion concentration observed on a still vessel anchored on the open sea.

Recognition of the fact that the correlation between extremes of ion concentration and sun position (Fig. 2) is only accidental necessitated finding another explanation for the periodic changes of ion concentration.

Possible explanations of such behavior occurred during analysis of the paper by Yackerson [16]. The author measured variability of the electric field intensity near the earth's surface according to wind speed. The graph depicting dependence of wind velocity and ion concentration as a function of time for the period of one (not defined) month (http://ael.physics.ue.ee – September 2007) was presented by scientists from Tartu University. In spite of poor precision in the presented data it is possible to recognize the opposite phases of both phenomena.

The main cause of the presented phenomena can only be the downward movement of radon [16–19]. The main source of energy for particle ionization in the lower atmosphere is the radioactivity of the air (4.6 ion pairs $cm^{-3}s^{-1}$) and isotopes in the ground (3.5 ion pairs $cm^{-3}\,s^{-1}$) [17, 18]. Cosmic radiation is only responsible for 1.9 ion pairs cm^{-3} s^{-1}. Radon ^{222}Rn is the main isotope responsible for ion production in air [16, 17, 19]. A high density of radon is responsible for greater concentration of this gas in the lower atmosphere during calm weather, which is the main source of air ionization. The movement of air layers caused by the wind leads to a decrease in the density of radon in the lower layers of the atmosphere, where during windless conditions the density of radon is much higher. This decreases the level of ionization of these layers.

However, proving this hypothesis required carrying out more precise measurements than the ones which were taken by scientists from Tartu University. Because it turned out that observing opposite phases traveling along common paths $n^{\pm}$ and $\mathbf{v}_w$ required specific conditions, mentioned in the next chapter, to be met which were difficult to fulfil. Only then, the functional links are observed between $n^{\pm}$ and $\mathbf{v}_w$.

Further analyses also showed that some of observed effects were connected with the method of measurement of the air-ion concentration. Therefore, in order to explain those effects, in the next chapter the structure and operation of the air-ion concentration measurement device (ionometer) is discussed.

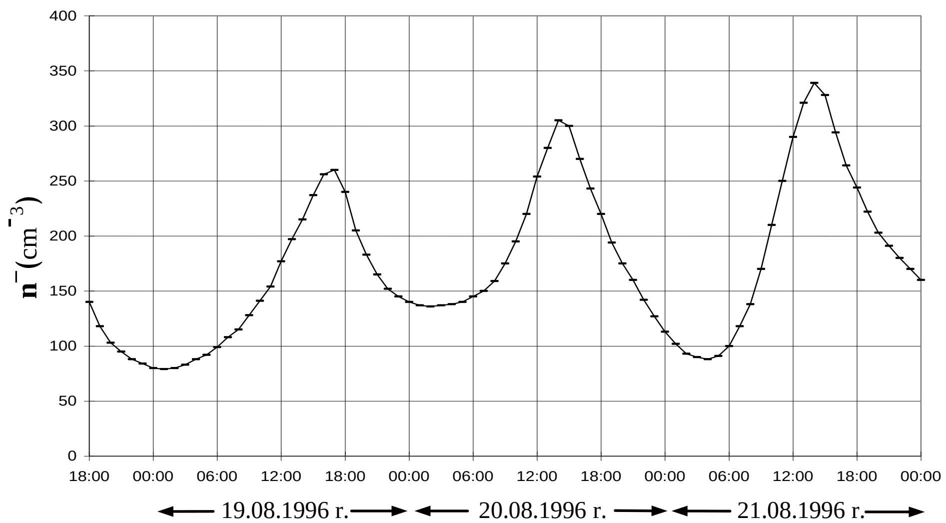

Fig. 3 – Changes in small negative air-ions concentration measured at sea (acc. to the author – [10]).

2. MATERIAL AND METHODS

Atmospheric charge was measured using a Gerdien cylinder instrument (Fig. 4). Originally designed to measure the conductivity of the air, the Gerdien method is now widely used to measure the density of air-ion. The set-up used in charge concentration measurements was one of a series constructed by the Institute of Nuclear Physics in Krakow (INP). The idea of the measurements involves measuring the flow of ions suspended in air and those deposited on the highly insulated electrode in the centre of the cylinder.

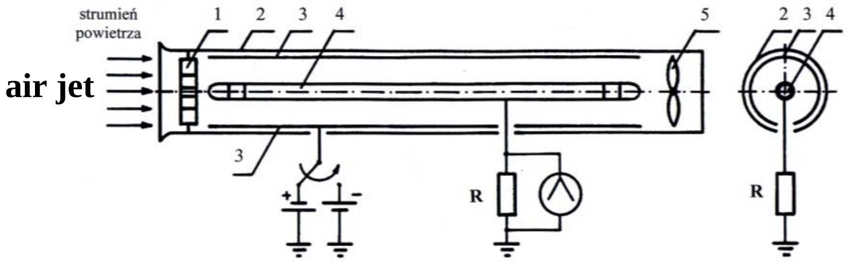

Fig. 4 – Cross-section of a meter measuring the global concentration of air-ions; markings: 1 – coaxial cylinders, 2 – test chamber, 3 – voltage electrode, 4 – collective electrode, 5 – vane, R – height-ohm resistor of the electrometer.

The recorded voltage at resistor R relates to the number of ions per unit volume of air. The atmospheric air with charged particles flows through slits between a set of coaxial cylinders with controlled electric potentials between them. The slits calm the turbulent inflow of air at the input of the instrument. The ion's trajectory is deflected in the electrostatic field towards the axis of the cylinder. The air pumped from outside entered the instrument chamber at the rate of $6.25\times10^{-4}\ \mathrm{m^3\ s^{-1}}$. The relatively high inlet flow rate, the large diameter of the chamber (12 cm), and length of the electrode (32 cm) allowed us to reduce signal fluctuations, to obtain a greater sensitivity and to record charged particles over a relatively wide spectrum of ion mobility.

Using this kind of detector for the measurement of air ion concentrations is associated with a particular complication, which can influence the results obtained. This complication arises from the fact that some of the so-called heavy air-ion, *i.e.* having low mobility, may not be registered in this device. This is the case for low-mobility particles which are being aspirated with the air into the chamber at such a long distance from its centre that they can traverse the whole chamber without reaching the collecting electrode 4. It is further complicated by the fact that particles having the same mobility can still reach the collecting electrode 4, provided they are induced to the chamber closer to its centre. Although this limitation can be overcome by acquiring the spectrum of the ion current, which upon integration yields of air-ion concentration (the construction and principle of the operation of this type of detectors have been thoroughly discussed in [1]), but in such a case another difficulty arises. The acquisition of a single ion current spectrum takes from about a dozen minutes to half an hour, during which time the air-ion concentration cannot change. These measuring devices are therefore entirely useless to perform such measurements as discussed here, where the very changes in air-ion concentrations versus time were the subject of the research.

The fact that the ion meters described in previous paragraphs can only partially register heavy air-ion is associated with an important feature of these devices, *i.e.* threshold mobility (μ_l). This determines the mobility value above which a given device registers 100% of air-ion (ionized particles of $\mu < \mu_l$ will also be registered, but only in part the percentage of which is difficult to estimate). The threshold mobility value depends in turn on the geometrical parameters of the measuring chamber (above all its length and cross-section radius) and voltage applied across the electrodes 3 – see Fig. 4 [1].

Some high-end measuring devices permit extremely low-level settings of the μ_l value; the device therefore registers all but a part of very heavy air-ion, which, in a widespread opinion [17, 19], have no significant influence on living beings anyway (this theory is not always corroborated by the author's own research – see [9]). The measuring devices used in the research conducted in preparation of this paper also belonged to this group; while making the measurements of air-ion concentration, the threshold mobility value was set to $\mu_l = 0.00148\ cm^2\ V^{-1}\ s^{-1}$ (to give a sense of scale, the mobility of all basic ionized particles exceeds $1\ cm^2 V^{-1}\ s^{-1}$).

Although the threshold mobility value was set to such a low level whilst performing the research presented here, it was proven that the partial inability of the measuring devices to register very heavy air-ion drastically changes (see below) the mutual relationships on timing diagrams depicting the changes in air-ion concentration and wind speed during measurements taken on land in comparison to those taken at sea.

In order to test the hypothesis that significant and frequent cyclical changes in air-ion concentration are a result of wind removing the lower layers richer in radon, it was necessary not only to measure changes of the $n^{\pm}$ value, but also the simultaneous determination of the wind speed $\mathbf{v}_w$. Both these measurements were carried out in multi-hour cycles both over the ground (both measurement devices were then placed about 1 m above ground) and over the sea surface. Yet while it is fairly simple to carry out such measurements over the sea surface (see below), performing this kind of research over the ground becomes very difficult. The preliminary experiments showed that the opportunity to observe the relationships between the changes of the $n^{\pm}$ and $\mathbf{v}_w$ requires the following conditions to be met:

1. The measurement must be carried out in an area free of pollution of any kind (factory smoke, car exhaust, etc. completely distort the registered values of air-ion concentration);
2. Wind direction must be constant for at least 24 hours, alternatively it may change slowly enough for the persons supervising the measurement to be able to keep the axis of the ion meter perpendicular to the direction of the wind;

allowing the wind to influence the air flow in the measuring chamber distorts the registered values of air-ion concentration as the speed of the wind is measured in m/s and the speed of the air in the chamber in tens of cm/s. In practice, this condition makes it necessary to perform this kind of research in an open and extremely flat terrain [20];

3. While the wind direction is constant, its speed has to vary, but in a restricted range of $\approx 2 \div 12$ m/s; the lower level is limited by the results of measurements obtained by Yackerson [16], the higher by the preliminary research done for this work (it has been proved that at wind speeds in excess of $\mathbf{v}_w \approx 12$ m/s, ascending and descending air currents occur in the atmosphere strong enough that the changes of air-ion concentration are no longer regular); this research has also shown that the amplitude of $\mathbf{v}_w$ changes must reach the level of at least 3 m/s;
4. The weather must be maximally stable for the whole duration of the measurement, with a complete lack of precipitation; not only rain, or snow, but even a slight fog causes a complete distortion of the measurements of the changes in air-ion concentration (small air-ion concentration plummet and heavy air-ion concentration, which are only partially registered, rise).

Unfortunately, whilst carrying out the measurements presented in Figs. 1 and 2, showing the greatest and most regular changes in air-ion concentration ever observed by the author of this paper while taking measures of these particles, the wind speed was not registered, as the hypotheses concerning its influence on the n^- and n^+ had not been suggested yet at that time. Later attempts to recreate the changes in $\mathbf{v}_w$ values (*e.g.* based on weather station data) were bound to be ineffectual because "blowing out" of radon is a local effect, therefore the measurement of n^-, n^+, and $\mathbf{v}_w$ values must be obtained in the same place and time.

That caused a necessity to repeat comprehensive measurements, which proved quite difficult to realize in practice as they required all four conditions listed above to be met simultaneously. While it was found that if the conditions are breached only slightly, changes in air-ion concentrations also occur, they tend, however, to lose their cyclic character to a smaller or larger extent. This is why only after having obtained several dozen measurements was it possible to select a few such results which fully corroborated the hypothesis that it is the "blowing out" of radon which is responsible for the occurrence of cyclic changes in n^- and n^+ concentrations.

The situation is much simpler when this kind of research is being performed at sea, where condition 1 from the list above is always met. When the ship is anchored, placing the ion meter perpendicular to its axis, automatically meets condition 2 as well. Therefore, the problem in this case is limited to the appropriate weather conditions being stable for the whole duration of the measurement, as stipulated in points 3 and 4 above.

While performing the research at sea, the ion meter was placed about 2 m, and the anemometer about 10 m above the surface.

3. RESULTS

The hypothesis predicting the relationship between wind velocity (measures used: wind speed transducer WAA 151 and wind direction transducer WAV 151) and the changes in air-ion concentration (negative ions in this case) was most clearly confirmed by the measurement, whose results are shown in Fig. 5. The measurement was taken at the time shown under the figure, in an open terrain on the outskirts of Pruszcz Gdański (Poland).

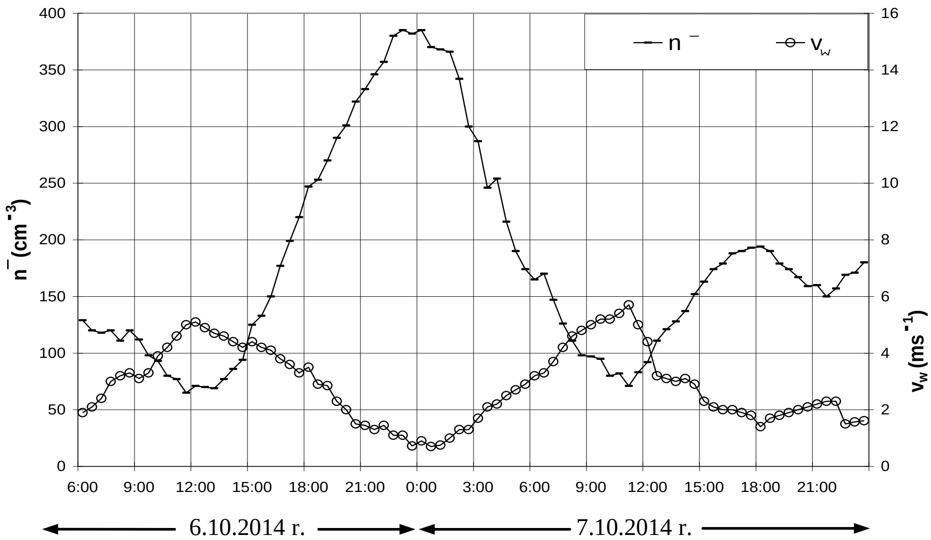

Fig. 5 – Changes in negative small air-ions concentration and the wind speed measured on land.

The *x* axis values in this and the following graph (Fig. 5) correspond to the true solar time.

Parallel to the measurements of the changes in the n^{-} value, shown in Fig. 5, the fluctuations in the n^{+} concentrations were also registered at random (due to device limitations) during that time. They proved to identically match the shape of the n^{-} changes diagram (therefore the graph for n^{+} has not been provided), with the sole exception that the n^{+} concentration values were roughly 10% lower than the n^{-} values (a similar ratio can be observed in Fig. 2). This results from the idea of measuring the parameters described above. The mobility values of negative air-ions are higher (due to the influence of free electrons); in natural background conditions the mean mobility of negative air-ions amounts to about 2.2 $cm^2\,V^{-1}s^{-1}$, and positive to about 1.17 $cm^2\,V^{-1}s^{-1}$ [10]. This actually causes a shift in their ion current spectra, which results in a limited detection of a greater number of positive air-ions even by measuring devices set to such a low threshold mobility value as was established for the research results presented here: $\mu_l = 0.00148\ cm^2\ V^{-1}\ s^{-1}$. This, however, does not influence the shape of the changes in air-ion concentrations vs. time.

Identical research performed at sea, however, yielded different results. At the time when the measurement presented here in Fig. 3 was obtained, just as in the case of the first measurements taken on land, the hypothesis concerning the relationship between the wind velocity and the changes in air-ion concentrations has not yet been suggested. Since, however, on a research vessel (S.Y. "Oceania", which was anchored in the Baltic Sea at position $\varphi = 54°50{,}2'$ N, $\lambda = 19°20'$ E while performing this measurement) all atmospheric parameters are continually registered, it was possible to retrieve the $\mathbf{v_w}$ values, which were subsequently superimposed on Fig. 3, yielding the graph shown in Fig. 6 (changes of the negative air-ion concentration and of the wind speed shown in this graph had been determined a long time ago, however, only now has the functional behaviour of the parameters been compared, allowing for observation of mutual correlations).

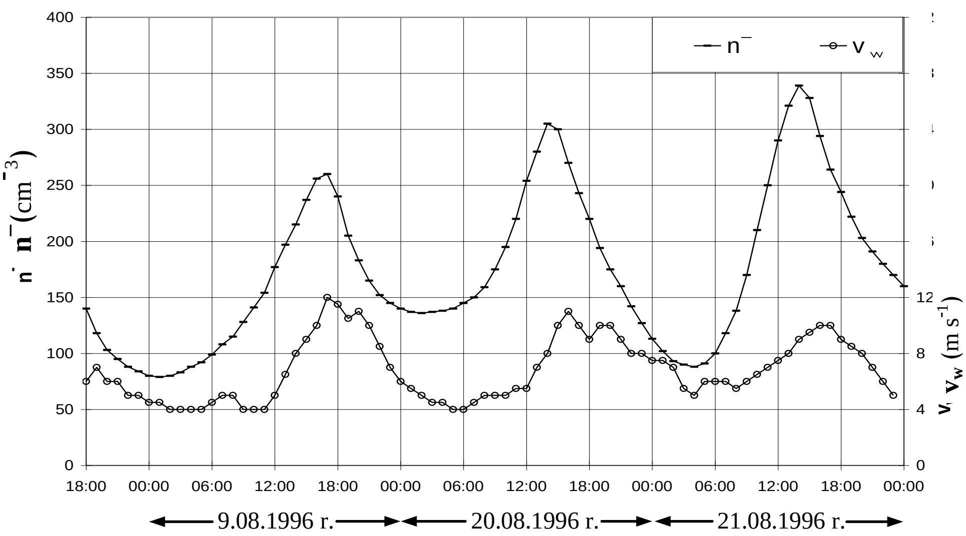

Fig. 6 – Changes of negative small air-ions concentration and the wind speed measured above the surface of the sea.

It can be seen in the diagram, however, that in this case the minimum and maximum values of n^{-} and $\mathbf{v_w}$ occur in the same phase, for a change.

Yet greater discrepancies, in comparison to the measurements carried out on land, could be seen in the measurements of positive air-ion concentration over the sea surface. In this case, it was not possible to observe any correlation between the values of n^{+} and $\mathbf{v}_w$ at all. Further research into this effect, however, enabled its proper interpretation, which will be explained below, during the discussion of the results.

4. DISCUSSION

The high precision of the measuring devices used in the realization of this work, as well as rigorous adherence to the conditions, listed in the previous section, which applied to performing measurements, made it possible to observe the almost perfect match between the minimum and maximum values of air-ion concentration and the minimum and maximum wind speed values, as seen in Fig. 5. This constitutes a final confirmation of the hypothesis about the "blowing out" of radon causing the occurrence of periodic changes. Therefore, the close positions of the maximum air-ion concentration and true noon shown in Fig. 1 and 2 must have been accidental: apparently during that measurement being taken the wind must have been abating at about noon, picking up speed again at later hours.

Actually, the coincidence of minimum and maximum values of n^{-} and $\mathbf{v}_w$ on the timeline during performing the measurements above the sea surface also confirms the hypothesis that the blowing out of certain particles from lower atmospheric layers causes the occurrence of air-ion concentration fluctuations. Over the sea, the atmospheric layer adjacent to the water surface contains smaller amounts of negative small air-ions compared to the atmospheric layers above it [21–24].

There are two causes of this state. The first is the already mentioned much more effective attachment of H_2O particles by small air-ions located near water, and therefore their faster transitions into the heavy air-ion form. These in turn, for the reasons which have already been discussed here, are only partially registered by ion meters, or not registered at all. The second reason is that a thick layer of water does not allow the radon emitted from the seabed to pass.

The atmosphere directly adjacent to its surface is, therefore, in comparison to the layers adjacent to the ground, automatically deprived of an additional ionization source, coming from the radiation of this element in soil.

This is a very important fact, as radon contained in the crust produces a comparable amount of air-ions to radon contained in the air, which effectively almost doubles the n^{-} value in the layer adjacent to the ground. But for the screening effect of water, the radiation of radon from the crust would compensate for the loss of small air-ions over the surface of the sea and the air layer adjacent to the surface would not have such a large deficit of these particles. In the present situation, however, turbulent diffusion causes the “blowing out” of the air depleted of small air-ion and its influx from the higher layers of the atmosphere. This leads to the establishment of a proportional correlation, as seen in Fig. 6, between the values of n^{-} and $\mathbf{v}_w$.

Further research yielded the explanation of the fact, mentioned during the presentation of results, that in contrast to the research performed over the ground, no correlation could be observed between the values of n^{+} and $\mathbf{v}_w$ above the sea surface, as the n^{+} concentrations there were changing in a similarly chaotic fashion [15]. It was shown that the effects related to the blowing out of the positive air-ion, described in this work, are in the case of the atmospheric layer adjacent to the water surface dominated by the so-called Blanchard effect [21–23]. The effect is that the wind is carrying away positively charged bubbles of air rising up from the sea water. But because such bubbles are more numerous than air-ions by orders of magnitude, this effect dominates all other physical phenomena which could affect the changes in the concentrations of positively charged particles in the atmosphere. That it was the air bubbles which produce the effect of the change in n^{+} concentration (their number is directly proportional to the number of positive air-ion above the sea surface) was confirmed during the research on the atmospheric ionization state performed by the author of this paper during subsequent cruises (the Blanchard effect was until then considered only a hypothesis) and published in [15].

5. CONCLUSIONS

The research performed on changes of air-ion concentration over the land and sea allowed the following conclusions to be formed:

● Changes of small air-ion concentration of both charges *versus* time over the ground are sometimes cyclical in character, of approximately sinusoidal shapes, with an amplitude which, in extreme cases, can amount to several hundred percent of the baseline n^{-} and n^{+} values. This phenomenon is caused by the movements of the wind, which leads to a decrease in the density of radon in the lower layers of the atmosphere, which, in the absence of wind, is much higher. Considering that the wind speed often changes in daily cycles, this is reflected in air-ion concentration changes, which are also cyclical but occur in opposite phases.

● The concentration of small negative air-ions over the sea surface show cyclical changes, which are caused, like above the ground, by the movements of the wind. In contrast to the cycles observed above the ground, the fluctuations of the n^{-} value over the sea remain in the same phase as the local wind speed. This is a consequence of lower small air-ion content in the atmospheric layers adjacent to the sea surface, resulting in an increase in the ionization level whenever the ions are blown out. The deficit of small ionized particles directly above the sea surface is in turn a consequence of their fast transitioning into heavy air-ions in these areas and the screening effect on radon of the thick sea water layer.

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