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# Aerosol measurements at the Algarve coast of Portugal

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ABSTRACT

The results of measurements of dust and Aitken nuclei concentrations at the Algarve coast of Portugal, compared with similar measurements in western Germany are reported. The highest mass concentrations of dust in Portugal appear in the summer months. Comparison of wind records leads to the conclusion that considerable amounts of dust are carried from the dry and hot areas of northwestern Africa and the central Iberian peninsula.

## 1. Introduction

With the aid of the Portuguese Meteorological Service we recorded near-ground aerosol concentrations on the Algarve coast from April 1974 to November 1975. These measurements were aimed to get information about the background concentrations of aerosols under clean air conditions on the outermost southwest coast of Europe, compared to results obtained in the densely populated and strongly industrialized Middle Europe (Federal Republic of Germany). The reason for these time-limited measurements was a test, whether this site in an exposed position is a possible location for a background station in a network of air chemical stations.

Knowledge about aerosol concentrations at clean and polluted areas and its time-dependent variations are important for several scientific problems, such as environmental protection, generation, transport and deposition of pollutants and possible climatic changes. In spite of the latter question, knowledge of long-term trends are of interest. Therefore measurements of the background conditions at stations in a very clean rural environment are necessary.

## 2. Measuring equipment

The measuring equipment was placed in a building of a radio and television station (RTP) at Foia situated on a peak of the coastal mountain chain "Serra de Monchique", 900 m above sea level (Fig. 1). Beside the RTP building there is only an inn on the peak of this mountain. The population in the hilly surroundings is very sparse; there are only a few small villages in the Serra region.

The number concentrations of Aitken nuclei ($R < 10^{-5}$ cm) were measured by means of a home-designed photoelectric condensation nuclei counter (Rau and Schmidt, 1970, 1971). Mass concentrations of suspended dust particles ($R < 10^{-2}$ cm) were continuously monitored with a commercial

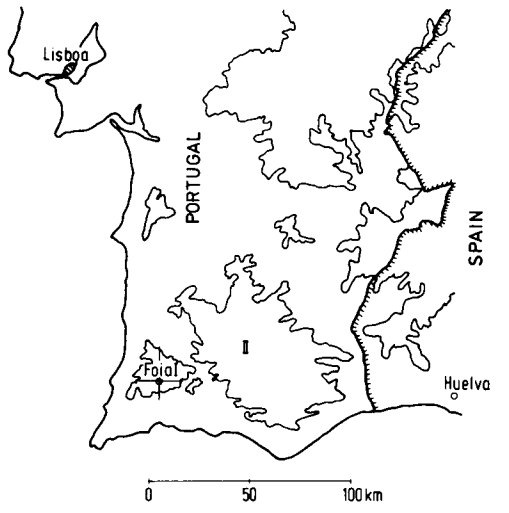


*Fig. 1.* Map of southern Portugal with station Foia. Height curves indicate 200 m. I = Serra de Monchique; II = Serra do Caldeirão.

Table 1. *Average values of dust concentrations at stations in F.R.G. and at Foia, Portugal*

| Station | m.a.s.l. (m) | Years | Instrument | Reference | Average value ($\mu g/m^3$) |
|---|---|---|---|---|---|
| Gelsenkirchen (Ruhr district) | <150 | 1968–1972 | HVS | Köhler | 197 |
| Mannheim (industrial area) | <150 | 1968–1972 | HVS | Köhler | 155 |
| Berlin-Dahlem (‖ to Foia) | <150 | Apr. 1974–Oct. 1975 | DM | Burger | 95 |
| Westerland (Island of Sylt) | <150 | 1968–1972 | HVS | Köhler | 68 |
| Lindau/Harz | <150 | Aug.–Nov. 1973 | DM | Authors | 62 |
| Waldhof (Lüneburger Heide) | <150 | 1968–1972 | HVS | Köhler | 57 |
| Deuselbach (Hunsrück Mountains) | 480 | 1968–1972 | HVS | Köhler | 55 |
| Brotjacklriegel (Bavarian Forest) | 1000 | 1968–1972 | HVS | Köhler | 33 |
| Schauinsland (Black Forest) | 1200 | 1968–1972 | HVS | Köhler | 26 |
| Wank (Bavarian Alps) | 1800 | 1969–1974 | HVS | Reiter et al. | 7 |
| Foia (Portugal, Algarve) | 900 | Apr. 1974–Oct. 1975 | DM | Authors | 12 |

Instruments: DM = Dust Monitor FH 62 A ($\beta$-absorption); HVS = High Volume Sampler + Glass Fibre Filters (gravimetric).

dust monitor, FH 62 A, which is based upon absorption of $\beta$-radiation from a Kr 85 source by the dust layer, deposited on a glass-fibre filter band (Aurand and Bosch, 1967). The aerosol and meteorological data were digitized and stored on punched tape. In addition an analogue registration of the aerosol data on strip-chart recorders was done. The Meteorological Service of Portugal supplied radiosonde wind data of the 850 and 500 mb level.

## 3. Results

### 3.1. *General survey*

In Table 1 the average dust concentration at Foia is listed for the whole time period of measurements together with some data recorded in Germany.

The dust concentration at Berlin-Dahlem, measured by the same type of instrument (Burger 1974/75), refers to the same months as the concentration at Foia. The other data—besides Lindau/Harz—were measured by high volume samplers and glass-fibre filters during longer time periods (Köhler, 1974; Reiter et al., 1975). The dust monitor was tested at Lindau/Harz for 3 months before being carried to Foia, Portugal. It is obvious that as comparable low concentrations of dust particles as found at Foia do occur only at higher altitudes of the Alps (peak of Wank, 1800 m above MSL). At higher locations of the German highlands, the amounts of dust recorded at Foia are exceeded by a factor of 2–3, in rarely populated lowlands by a factor of 4–6, in large cities and central industrial areas by a factor of 8–17. Still greater differences are found comparing the concentrations of Aitken nuclei. At Höchsten, a mountain peak in southwest Germany, at an altitude similar to that of Foia, a concentration higher by a factor of 6 was found in comparison to the recordings at Foia, and at Lindau/Harz, a small place in a rarely populated German lowland area, the concentration was higher by a factor of 12. At both German stations the same type of instrument was used and the measurements took place at the same time as in Portugal.

From these results it is obvious that the south Portuguese coast is an area with very clean air due to its position in regard to the North Atlantic ocean, its thin population and its long distance to the European industrial centres. The concentration of Aitken nuclei varying around $1000/cm^3$ completely corresponds to the picture known from measurements over the North Atlantic ocean and its adjacent regions (Hogan et al., 1975; Schütz, 1974).

In Fig. 2, section A the frequency distributions of the dust concentrations are shown, separated into cases of wind directions from land and ocean, respectively, as are the frequency distributions of Aitken nuclei concentrations in Fig. 3. The low

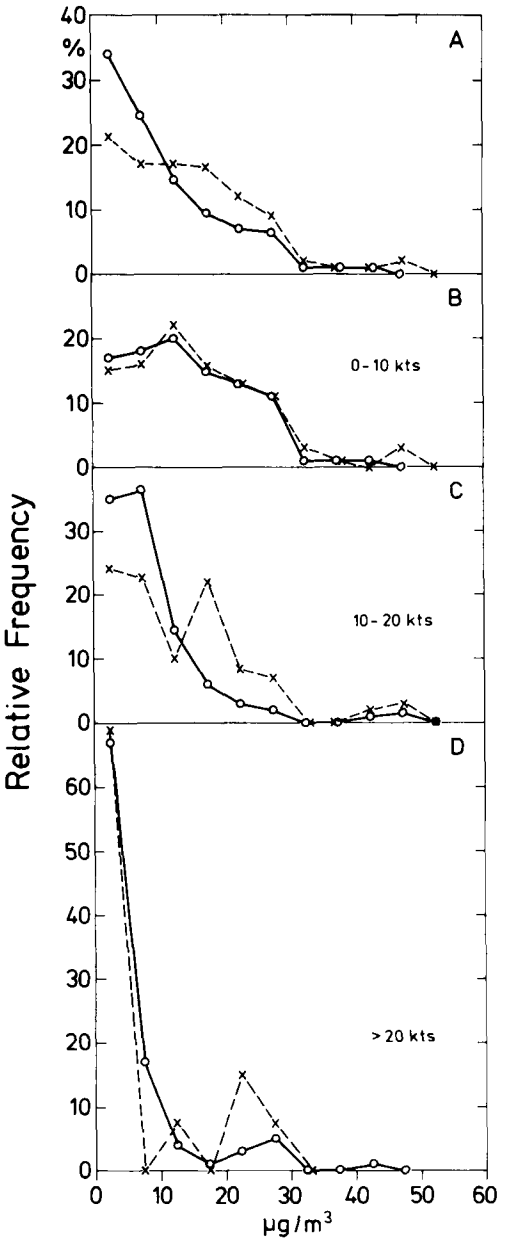


*Fig. 2.* Frequency distributions of dust concentrations at Foia. A: total, April 1974–October 1975; B, C, D: depending on wind velocity steps; O——O wind direction 180°–360° (ocean); x----x wind direction 0°–180° (land).

dust concentrations between 0 and 12 $\mu g/m^3$ are more frequent when the winds blow from the sea, whereas concentrations higher than 12 $\mu g/m^3$,

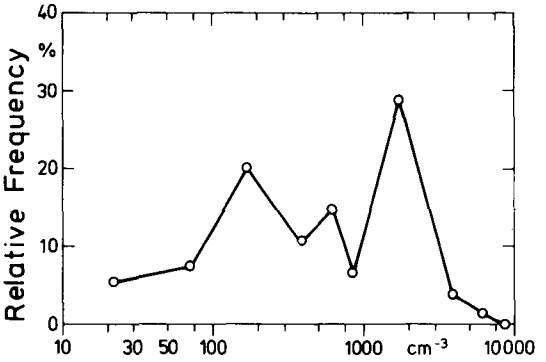


*Fig. 3.* Frequency distribution of Aitken nuclei concentrations at Foia, April–November 1974.

particularly between 15 and 30 $\mu g/m^3$, are more frequent during prevailing continental winds. The frequency distribution of Aitken nuclei concentration exhibits two maxima at about 1700/cm³ and 170/cm³ respectively.

### 3.2. *Daily variations*

The average daily variation of atmospheric dust concentration is marked by a very extended minimum in the morning hours from 8 to 10 a.m. (second half of the night until morning) and a similarly extended maximum in the late afternoon between 3 and 10 p.m. The average daily amplitude is very small in the main winter months but more pronounced in the summer season (Fig. 4, left section). This behaviour can be traced back to the different dust concentrations during both half years (Section 3.3). The average daily variations of relative humidity of the air, also more pronounced in summer and autumn 1974, show a minimum in the afternoon at 12–4 p.m., when the increase of the dust variations starts (Fig. 4, right section). Possibly the drying effect of air and soil, indicated by the daily variation of humidity, enables a more efficient blowing up of dust from the ground.

The average daily variation of Aitken nuclei concentration (Fig. 5) is very similar to that of dust particles, also indicating a very extended minimum in the second half of the night and in the morning hours and higher concentrations from noon to midnight. Fig. 5 refers to the summer months of 1974 only; data of the winter months are missing.

A dust maximum occurring around 7 p.m. at Königstein/Taunus, (F.R.G.) has been described by Amelung (1966), and measurements of the

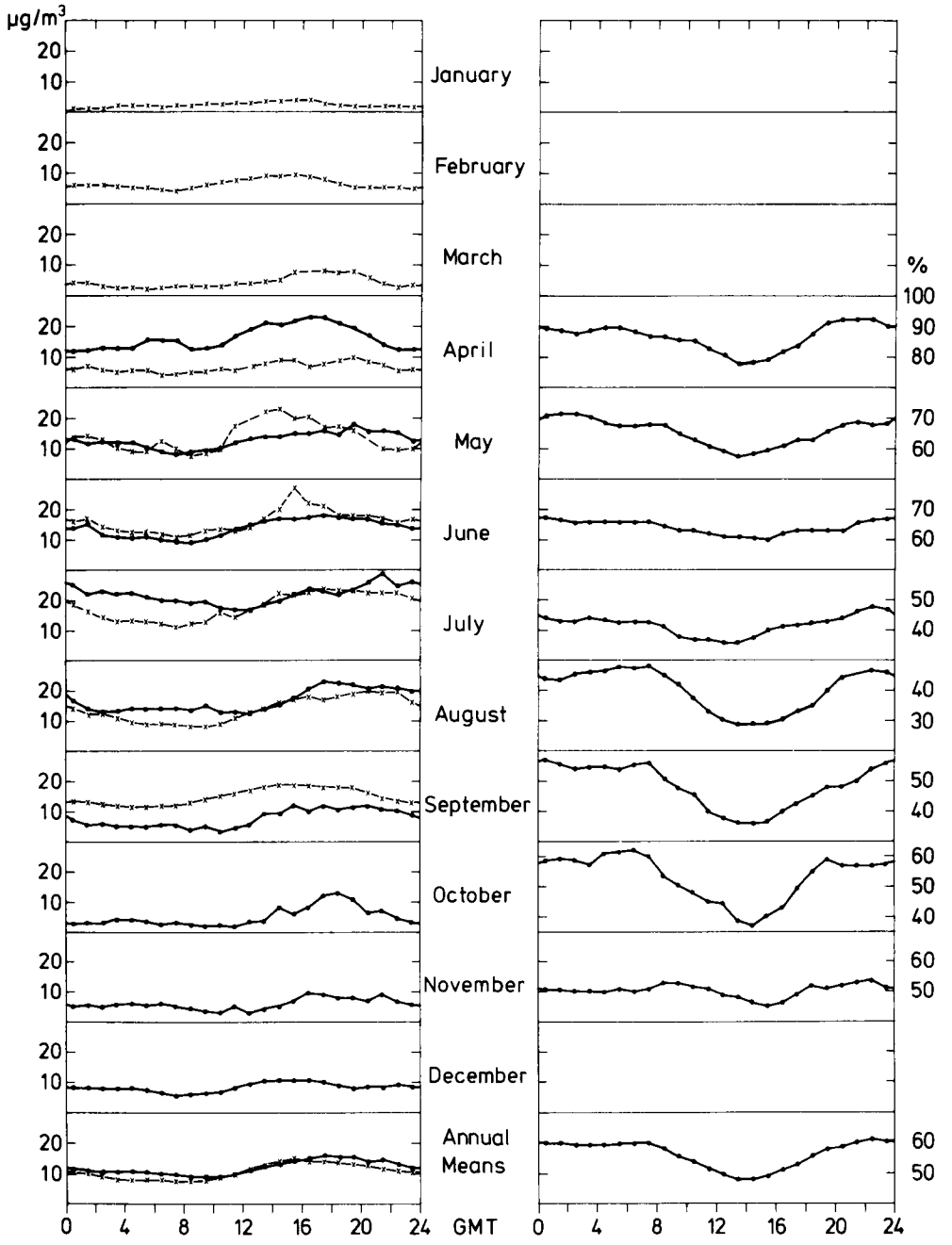


*Fig. 4.* Daily variations of dust concentrations (left) and relative humidity (right) at Foia, monthly means. O——O 1974; x----x 1975.

concentration of chloride particles on the coast of the North Sea in Denmark made by Schmidt (1972a) have shown that the daily maximum of these particles preferably occurred between 10 and 12 p.m. At places on the continent which are influenced by air pollution, a double daily wave in

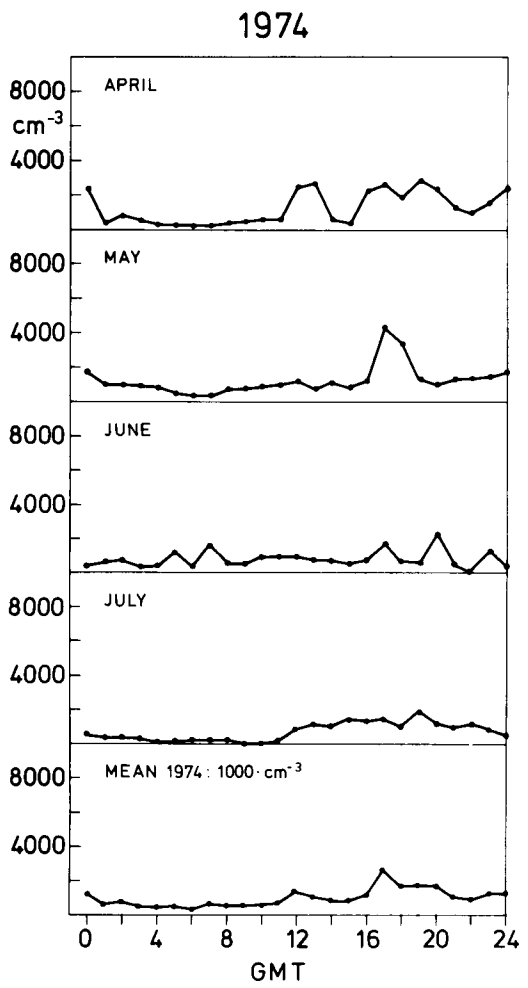


*Fig. 5.* Daily variations of Aitken nuclei concentrations at Foia, monthly means 1974.

Aitken nuclei and dust concentration is evident. Its afternoon minimum can be explained by convection processes (rarefaction of the aerosol near the ground by air transport upwards). Examples of this type of daily variation of dust concentrations at Berlin-Dahlem are presented by Burger and Krbek (1975), for Aitken nuclei measurements in southern German lowlands by Schmidt (1972b). In the reverse case, a maximum of Aitken nuclei concentrations is found in the afternoon at stations on highlands and mountains during the time of minimum concentrations at the lowland stations (Schmidt, 1972b).

### 3.3. *Annual variations*

In Fig. 6 the 5-day means of dust concentrations at both stations Foia and Berlin-Dahlem are plotted as a function of time, as are the concentrations of Aitken nuclei at Foia and at the German stations Lindau/Harz and Höchsten in Fig. 7 (see Section 3.1). In Fig. 6, by comparing the dust concentrations at Foia and Berlin respectively, three remarkable differences can be seen: (1) The dust concentration at Berlin exceeds that found at Foia by a factor of about 8. This result can be explained by the dense population and strong industrialization of Berlin compared with south Portugal. (2) The annual variations of dust concentration at both stations are opposite to each other. The maximum of dust concentration at Berlin occurs during the winter months, whereas there is a minimum at Foia and vice versa in the summer months. This result can be understood as follows: The high concentrations of dust particles at Berlin during the winter season are due to domestic heating as additional dust-emitting sources and to accumulation of aerosols within more frequent stable weather conditions. According to Burger and Krbek (1975) this type of annual variation of dust particles has been regularly found at Berlin since the beginning of measurements in 1964 without exception. On the other hand, in Portugal the wintry exhaust gases of heating are of no importance because of the mild climate and the thin settlement. Therefore the dry summer months, with their higher amount of dust in proportion to the winter months, are reflected by the annual variations of dust concentration. (3) The amplitude of the annual variation of dust concentration at Berlin exceeds that found at Foia by a factor of 5.

The dust concentration at Foia during both summer half-years 1974 and 1975 exceeded the amount of dust during the intermediate winter half-year. The corresponding values are, on the average, 14.7 and 13.9 $\mu g/m^3$ respectively for the summer half-years and 7.1 $\mu g/m^3$ for the winter half-year. The dust concentration was even slightly higher in the summer months July and August (16.9 and 16.1 $\mu g/m^3$ respectively). The highest monthly mean was found in July 1974 (21.5 $\mu g/m^3$). The reasons for that are discussed in Section 3.4.

In contrast to the dust concentration, no summer maximum could be seen in the annual variation of Aitken nuclei at Foia during April until November 1974, but a minimum in June and July was found

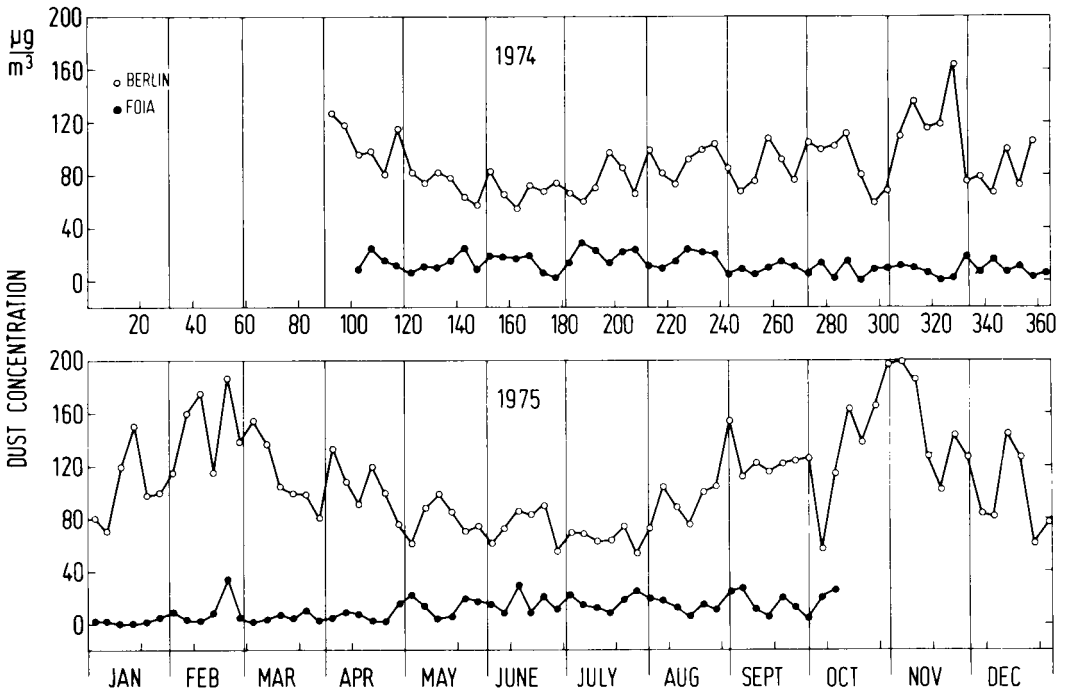


*Fig. 6.* Five-day means of dust concentrations at Foia and Berlin-Dahlem.

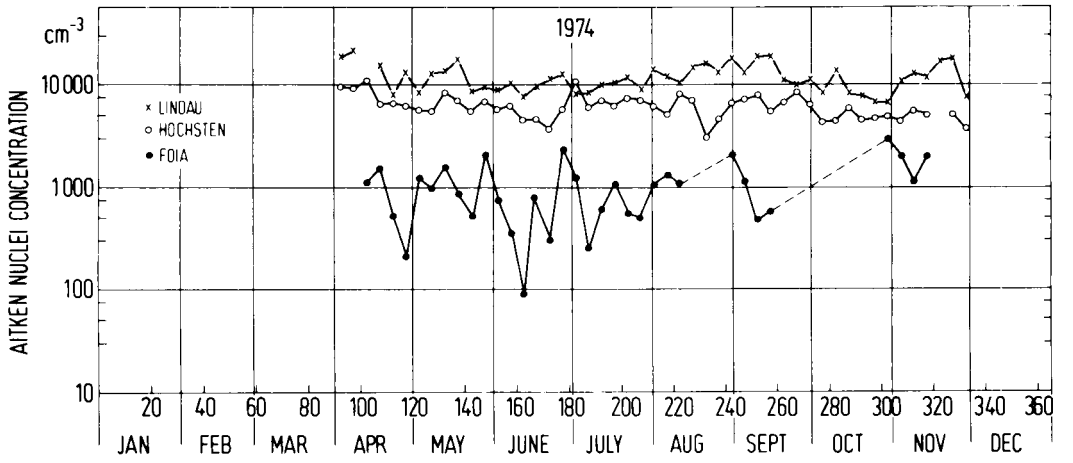


*Fig. 7.* Five-day means of Aitken nuclei concentrations at Foia (900 m), Höchsten/SW-Germany (830 m), and Lindau/Harz (140 m).

followed by an increase until late autumn. Since the dispersion aerosols originating from fireplaces are very effective condensation nuclei, this type of aerosol may be thought of as being influenced by the human settlements along the Algarve and Atlantic coast and in the lowlands northeast of the Serra de Monchique, particularly in the autumn and winter season in connection with the occurrence of poorly interchangeable weather conditions (see wind rose of Aitken nuclei in Fig. 8). In

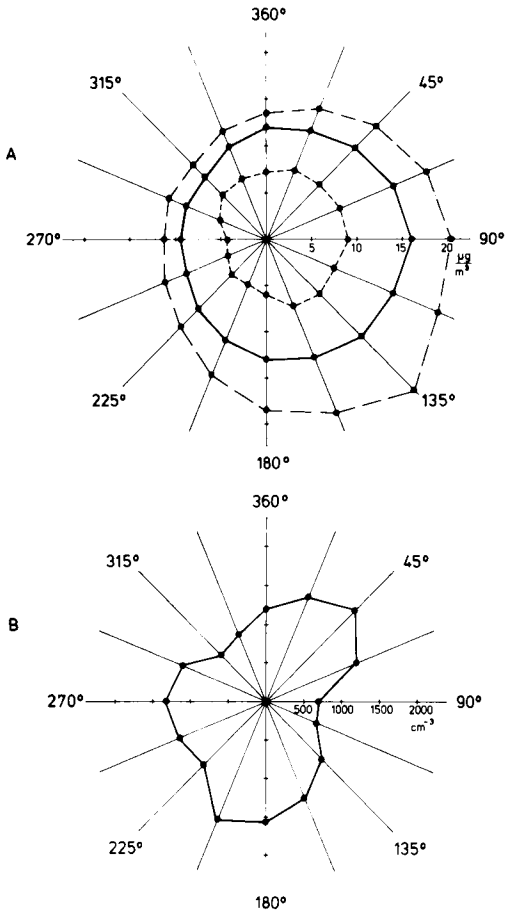


*Fig. 8.* Averages of dust concentrations (A) and Aitken nuclei concentrations (B) at Foia, compared with wind directions. O——O Total; O- - - -O winter (October–March); O-·-·-O summer (April–September).

spite of this possible influence the annual variation of Aitken nuclei at Foia occurs on an essentially lower concentration level than at central European stations.

### 3.4. *Distribution depending on wind directions*

Fig. 8A and B demonstrate the average concentrations of dust particles and Aitken nuclei, respectively, depending on the wind direction. To calculate these figures, the 850 mb radiosonde wind data of Portuguese meteorological stations were used (~ 1500 m above MSL). Wind values of this level are hardly influenced by surface conditions and in nearly all cases quite similar to wind direction data of the free atmosphere (500 mb level).

The wind rose of Aitken nuclei indicates, as pointed out in Section 3.3, some local human influence by lowland settlements. Whenever the wind was blowing from the rarely populated chain of mountains Serra de Monchique (NW and NNW) and Serra do Caldeirão (E and ESE), the lowest concentrations of nuclei were measured. The peaks of the wind rose are pointed at northeast (valley of Mira river) and south (environment of Portimão and Lagos).

The wind roses of dust concentrations in Fig. 8A account for the peculiar annual varition, indicating maxima during the summer season and very low minima during the winter months. They suggest that the occurrence of dust particles is decisively influenced by the climatic conditions of the Iberian peninsula and the northwestern coast of Africa. As is well known, this climate is marked by hot and dry summers and mild and wet winters (Csa according to Köppen's classification). In the longitudinal valleys between the large chains of mountains in Spain even steppe climate can be met (BS). The wind rose holding for the summer half-year is peaked at wind directions from northeast to south, the maximum of 22.7 $\mu g/m^3$ occurring at southeast. From this it may be concluded that the highest average dust concentrations at Foia during the summer season are caused by transport of dust particles from the hot and dry areas of northwestern Africa over that part of the Atlantic ocean, extending in front of the Gulf of Cadiz and, to a slightly less degree, from the hot and dry districts of Spain. Winds from these directions are indeed less frequent than winds from the Atlantic ocean, the former being due to a position of the Azorian high pressure region shifted far to the northeast towards central Europe. But it follows from Fig. 8A that higher dust concentrations have also been found at wind directions from the Atlantic ocean during the summer than at wind directions from the land (N–E–SE) during the winter. This means that the level of dust concentration must be raised on a large scale during the summer, not only above land areas but also above the adjacent parts of the ocean, at least close to the coastlines.

These conclusions are corroborated by studying the European weather maps in all single cases in view of general circulation and air mass movements. Thus, transports of dust or nuclei from the humid central European areas are very unlikely.

On the other hand, dry dust particles originating

from very arid continental districts may be transported very far by winds of suitable direction, even over the oceans. This is well known from a number of more recent investigations. In the last few years special interest was taken in problems such as the transport of dust particles from the Sahara desert by the trade winds far over the Atlantic ocean (Schütz, 1974, 1977; Winkler, 1975) and, in connection with it, the whirling up of dry dust over various parts of the Libyan Sahara desert (Schütz and Jaenicke, 1974). From the results obtained by Schütz, by measurements on board the German research ship *Meteor*, it also turned out that the concentrations of dust and aerosols in the air, within the region of trade winds, are increasing on approaching the African continent. According to the graphical mappings by Hogan et al. (1973) there have been found, from the ocean towards the continents, increasing concentrations of Aitken nuclei along the entire North African and west European coast.

The interesting question as to whether or not the results of a series of measurements made by an integrating instrument recording the concentrations of atmospheric aerosols near the Atlantic coast are indicative of the occurrence of maritime aerosols (sea spray), must be answered negatively. From Fig. 2, sections B, C, D, it follows that in the case of wind velocities > 20 knots there are no essential differences concerning the frequency distribution of dust concentration between wind directions from the land and seaside, respectively. The same holds also for low wind velocities (0–10 knots). Only in the middle range of 10–20 knots have there been found higher concentrations during winds blowing from the land side. At high wind velocities the dry dust from the continent apparently dominates the seaspray, at least during the summer.

## 4. Acknowledgements

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## ИЗМЕРЕНИЯ АЭРОЗОЛЯ НА БЕРЕГУ АЛГАРВЕ В ПОРТУГАЛИИ

Сообщаются результаты измерений концентраций ядер конденсации, пылевых и Айткена, проведенных на берегу Алгарве в Португалии, которые сравниваются с аналогичными измерениями в Западной Германии. Наибольшие массовые концентрации пыли наблюдаются в летние месяцы. Сравнение с полями ветра позволяет сделать вывод, что значительные количества пыли приносятся из сухих и жарких областей Северозападной Африки и центральной части Пиренейского полуострова.