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ATMOSPHERIC TURBIDITY AT VALENTIA OBSERVATORY

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Summary

Values of the Angstrom Turbidity Coefficient (β) determined from Solar Radiation observations at Valentia Observatory over the period 1955 - 1971 are analysed. Mean daily turbidity most frequently lies between 0·030 and 0·040 with a median value of 0·047. Turbidity is higher in Summer than in Winter, the highest mean monthly value being in April and the lowest in December/January. The scavenging by rainfall probably has a considerable affect in determining this distribution.

The chief factor determining the turbidity is the air mass type. Continental Tropical air is seldom experienced but for the two months for which means are available the turbidities are higher than for any other air mass. Relatively high turbidities are associated with Continental Polar air and the lowest values are found in Arctic air. The prevailing air mass, Maritime Polar, shows relatively low turbidity and dominates the annual pattern.

There is no evidence of any trend of increasing turbidity during the period.

1. Introduction

Solar radiation observations have been made at Valentia Observatory since September, 1954. Continuous records have been maintained of Global and Diffuse Solar Radiation. A Linke-Feussner thermoelectric iron-clad Actinometer (Kipp and Zonen) was also brought into use at the same time and a schedule of routine observations on direct sunlight has been maintained. The normal schedule was three observations per day at about 10 hrs., 12 hrs. and 14 hrs. G.M.T. when weather and sky conditions permitted. In addition to the measurements of total direct sun, measurements were also made of the intensity of the direct solar beam behind two filters of Schott glass, OG_1 and RG_2. These filters were received from the Radiation Commission of the International Association of Meteorology and calibrated at Davos. A "filter factor" was supplied with each filter so that measurements made behind the filter could be corrected for surface reflection and absorption by the filter. From the measurements of the intensity of the direct solar beam with and without filters a "factor" or coefficient expressing the turbidity of the atmosphere (or amount of aerosol present) can be evaluated.

Since 1971 Valentia has been participating as a Regional air pollution station within the network established by W.M.O. to monitor air pollution. It will be some time before sufficient data can be accumulated from this network to enable any conclusions to be drawn. Thus an analysis of the turbidity data available for Valentia since 1955 may be of interest. The purpose of this paper is to present such an analysis.

2. Site of the Observations

The Observatory, which is in the extreme SW of Ireland, is situated on the SE side of the narrow estuary of Valentia river which runs approximately NE-SW (Fig. 1). It is about 1 Km to the SW of the town of Cahirciveen. The population of Cahirciveen is about 1800 and apart from domestic fires for cooking and heating there are no major sources of pollution. The rest of the area is very sparsely populated. It could be expected, therefore, that regular measurements of turbidity in such a location, remote from sources of artificial atmospheric aerosol would help in establishing a "background level" for the Northern hemisphere.

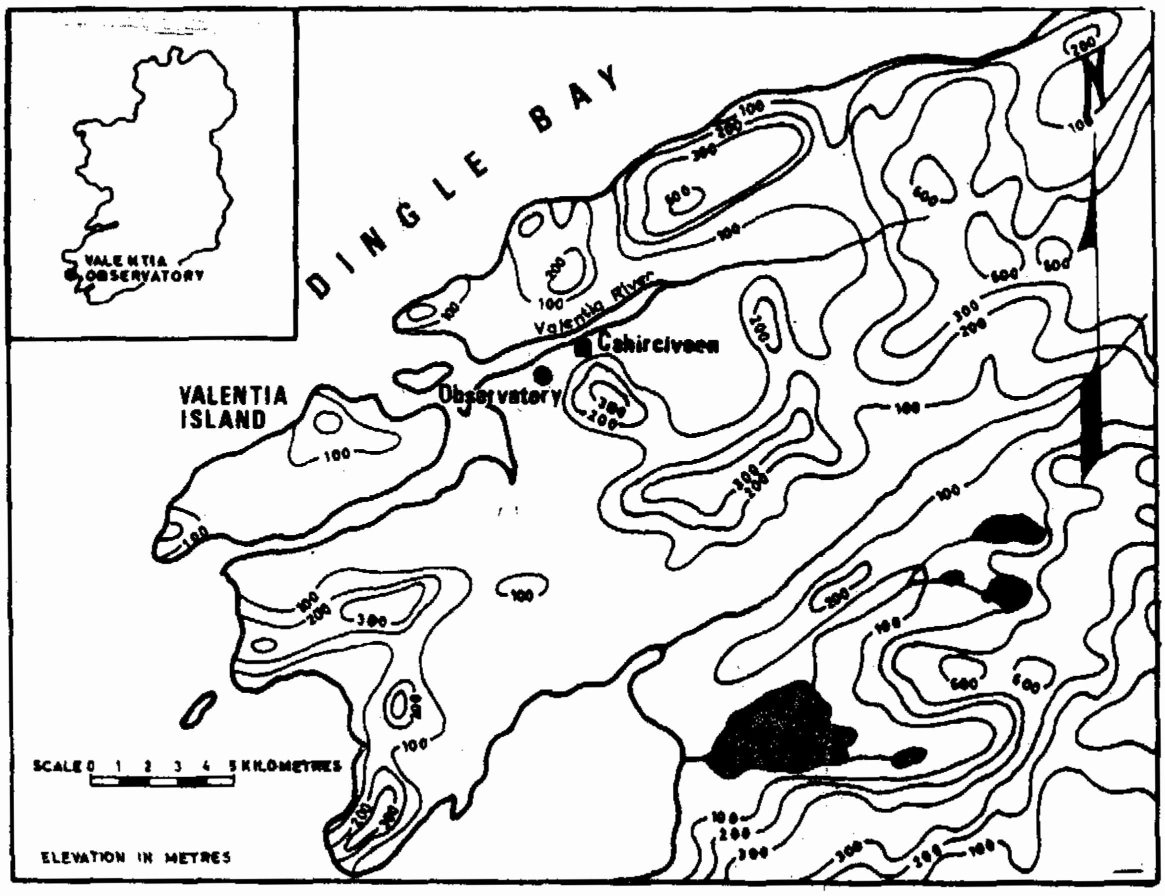

Fig.1 Map showing the site of Valentia Observatory and its environs.

3. The Turbidity Coefficient (β)

The basic relation for the extinction of solar radiation may be expressed as follows:

$$I = \frac{1}{S}\int_0^\infty I_0(\lambda) e^{-A(\lambda)} d\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

I = the radiation intensity measured by the actinometer and expressed in the International Pyrheliometric Scale 1956.

$I_0(\lambda)$ = solar radiation intensity outside the atmosphere at the mean sun-earth distance, as a function of the wavelength (λ) and expressed in the same units as I.

S = the reduction factor for mean solar distance.

e = the base of natural logarithms.

$A(\lambda)$ = the extinction exponent which is a function of wavelength (λ).

The extinction exponent $A(\lambda)$ is composed of three components each of which depends on the wavelength and may be expressed as:

$$A(\lambda) = A_T(\lambda) + A_O(\lambda) + A_W(\lambda) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

$A_r(\lambda)$ = the extinction due to clear dry air according to Rayleigh's theory of scattering by air molecules. It may be taken as $m \times 0{\cdot}00897\lambda^{-4{\cdot}09}$ where "m" is the optical air mass.

$A_d(\lambda)$ = the extinction due to haze which according to the theory of A. Angstrom [1,2,] may be expressed by

$$A_d(\lambda) = m\beta\lambda^{-\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where the wavelength exponent "α" varies from case to case but remaining between 0 and 4. It is a good guide to the distribution of the number of the haze particles as a function of their size. "α" increases when the ratio of the small particles in the atmosphere increases and when the atmosphere contains a high proportion of very large aerosol "α" approaches zero. Angstrom has shown that $\alpha = 1{\cdot}3$ is a very good average value so that extinction due to haze (equation 3) may be written in the form

$$A_d(\lambda) = m\beta\lambda^{-1{\cdot}3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

"β" is then a measure of the quantity of haze in the atmosphere and is known as the Angstrom Turbidity Coefficient.

$A_w(\lambda)$ = the extinction caused by water vapour in the atmosphere.

4. Computation of β

The most direct method of determining β is by measuring the intensity of the direct solar beam in the ultra-violet and visible part of the spectrum ($\lambda < 0{\cdot}630\ \mu$) since in this region the selective absorption by water vapour is negligible and the attenuation of solar radiation is caused only by dry air (Rayleigh scattering) and haze.

The radiation in the ultra-violet and visible parts of the spectrum (i.e. the short wave radiation) is the difference between the total radiation as measured without filter and the radiation passed by the red filter RG_2. If we denote this measured radiation difference adjusted by the filter factor by I_k then

$$I_k = \frac{1}{S}\int_0^{0{\cdot}630} I_o(\lambda)e^{-A_r(\lambda)-A_d(\lambda)}$$

where $A_d(\lambda)$ is given by equation (4).

All the terms of this equation are known except β which can be evaluated from tables such as those given in the Appendix to the Annals of the IGY [3]..

5. Order of Magnitude of β

Following the procedure outlined above β was computed for all occasions when weather and sky conditions permitted observations to be made. Mean daily values were then obtained.

Of the 1162 daily means available the most frequent value was between ·030 and ·040 which range accounted for 16·4% of all days. Values less than ·010 were observed on 1·2% of the days and values greater than ·200 occurred on 2·3% of the observation days. Table 1 shows the percentage frequency of daily means of β falling within various limits. The frequency distribution is also shown graphically on Fig. 2.

TABLE 1

PERCENTAGE FREQUENCY OF DAILY MEANS OF β WITHIN DIFFERENT RANGES

$\beta \times 10^3$	000 to 009	010 to 019	020 to 029	030 to 039	040 to 049	050 to 059	060 to 069	070 to 079	080 to 089	090 to 099	100 to 109	110 to 119	120 to 129	130 to 139	140 to 149	150 to 159	160 to 169	170 to 179	180 to 189	190 to 199	200 or more
Year	1·2	8·3	14·5	16·6	12·8	9·6	7·8	5·6	4·3	3·7	3·0	1·5	2·2	1·9	1·3	0·9	0·6	0·7	0·4	0·7	2·3
Winter	2·0	14·4	18·6	16·6	10·0	7·4	7·4	6·6	4·1	3·5	2·0	0·9	2·0	1·3	0·9	0·2	0·0	0·4	0·4	0·0	1·3
Summer	0·7	4·3	11·9	16·6	14·6	11·1	8·1	5·0	4·4	3·8	3·7	1·8	2·3	2·3	1·6	1·4	1·0	0·9	0·4	1·1	3·0

TABLE 1a

CUMULATIVE PERCENTAGE FREQUENCY OF DAILY MEANS OF β

$\beta \times 10^3$	Less than 010	Less than 020	Less than 030	Less than 040	Less than 050	Less than 060	Less than 070	Less than 080	Less than 090	Less than 100	Less than 110	Less than 120	Less than 130	Less than 140	Less than 150	Less than 160	Less than 170	Less than 180	Less than 190	Less than 200
Year	1·2	9·5	24·0	40·6	53·4	63·1	70·9	76·5	80·8	84·5	87·5	89·0	91·1	93·0	94·3	95·3	95·9	96·6	97·0	97·7
Winter	2·0	16·4	34·9	51·5	61·6	69·0	76·4	83·0	87·1	90·6	92·6	93·4	95·4	96·7	97·6	97·8	97·8	98·3	98·7	98·7
Summer	0·7	5·0	16·9	33·5	48·2	59·2	67·3	72·3	76·7	80·5	84·2	86·1	88·4	90·6	92·2	93·6	94·6	95·5	95·9	97·0

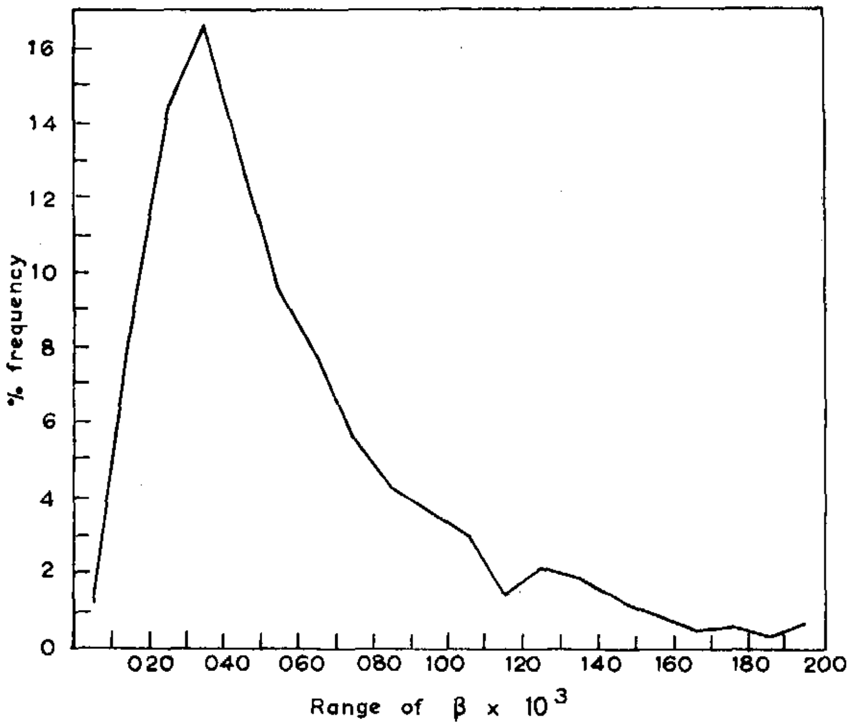

Fig. 2 Frequency of β within various ranges

It must be borne in mind when interpreting these values that since observations are possible only when clear direct sun radiation is available the data are already "typed" as appropriate to fine or fair weather conditions. Such conditions at Valentia are most frequently associated with anticyclonic or ridge of high pressure situations.

Fig. 3 shows the cumulative frequency of daily mean values of β . The median value is ·047 and the lower and upper quartiles are at β = ·030 and β = ·077 respectively. Flowers, McCormick and Kurfis [4] give similar cumulative frequency curves for rural and industrial sites in the U.S.A. Huron is given as a typical rural site and the curve for this site is also

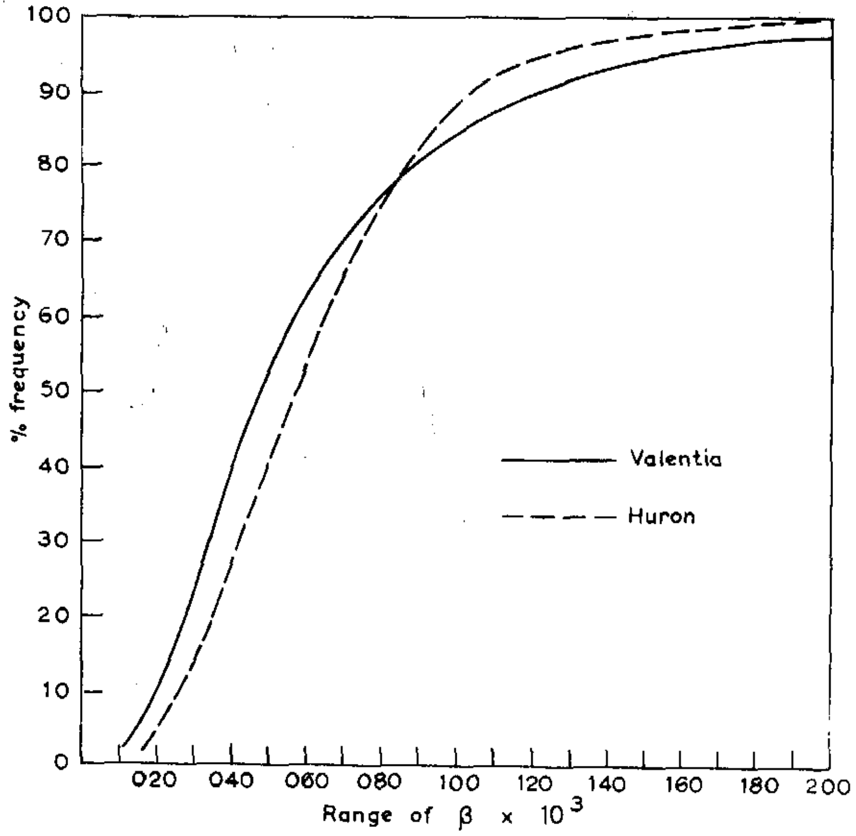

Fig. 3 Cumulative frequency curves for Valentia and Huron

shown on Fig. 3 as closely as it could be transferred from the graph in [4]. It is clear that the turbidity conditions at Huron and at Valentia are very similar. Significant points on the curves give the following:

	Valentia	Huron
Median	0·047	0·057
Lower quartile	0·030	0·038
Upper quartile	0·077	0·080

These values are drawn closer together when it is noted that the Huron figures are for the Volz turbidity coefficient (B) whereas the Valentia figures are for the Angstrom turbidity coefficient (β). In theory, at any rate, the Volz coefficient (B) may be taken as about 7% higher than the Angstrom counterpart (β).

6. Variation of β with Wind Direction

Mean values of β were computed for each wind direction on an 8-point compass. They are given in Table 2 and shown graphically on Fig. 4. Summer and winter are taken as the periods April - September and October - March respectively. Summer turbidities are higher than winter turbidities for each wind direction. The variation of β in both seasons is very similar with highest turbidities being associated with East and South-East winds. This is in accordance with expectations since winds from this sector would be expected to be more polluted as a result of their passage over the industrial centres to the East.

Table 2 Mean values of 10^3 β for various Wind Directions

	North	North-East	East	South-East	South	South-West	West	North-West
Full year	057	057	076	078	064	059	063	059
Winter	038	047	071	054	049	045	049	038
Summer	066	074	088	104	073	067	066	063

The present author analysed the variation of Atmospheric Nuclei content of the air over Valentia [5] and found a pattern very similar to that now found for β . The variation of the Atmospheric Nuclei concentration with wind direction is also shown on Fig. 4 for comparison. The pattern for the variation of β follows closely that for the variation of Nuclei content except for one noticeable wind direction i.e. North-East. The Nuclei concentration is high with winds from this direction. In fact the highest values of Nuclei concentration were found in NE winds in winter. The turbidity, however, shows no similar increase. Perhaps the explanation lies in the fact that winds from this direction pass directly over the town of Cahirciveen which is only 1 Km from the Observatory. Though there is no great industrial source of pollution the smoke and grime from domestic fires could be expected to contribute considerably to the Nuclei content but since the aerosol would be confined to a very shallow layer near the surface the effect on the turbidity would only be marginal.

When analysing the Atmospheric Nuclei data McWilliams [5] suggested that the chief source of aerosol in winds from an Easterly direction was the industrial areas of central England. The turbidity data would confirm this for the winter season. In summer however, the most turbid air arrives at Valentia from the South-East in which case it would generally have come

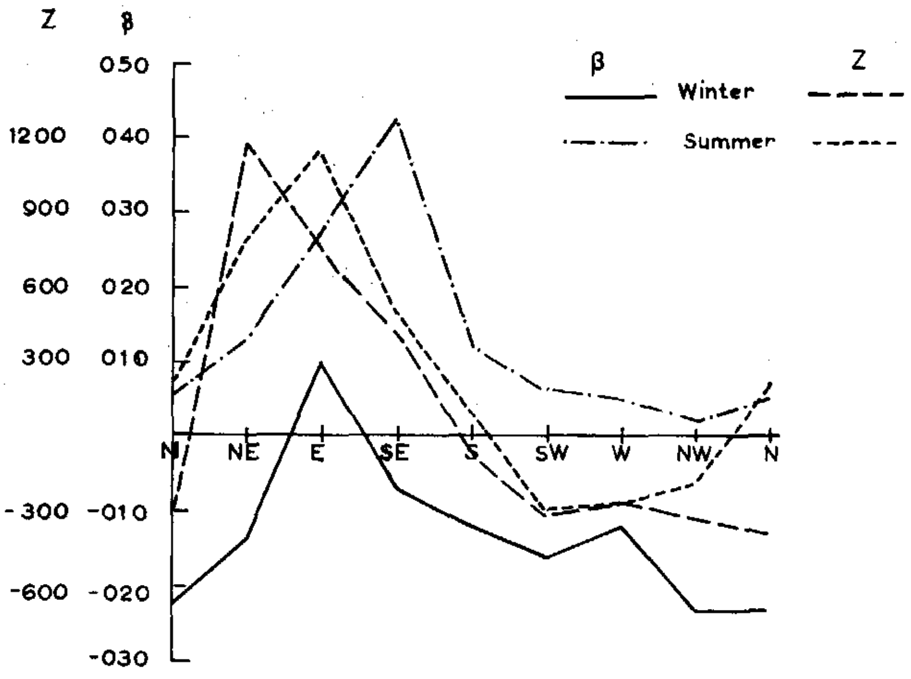

Fig. 4 Variation of β and Z (Atm. Nuclei Count) with Wind Direction (Deviation from Annual Mean Values)

from the European Continent after a fairly long passage over the sea. Lovelock [6] also found that winds from Continental Europe arriving at Bowerchalke in Southern England during Summertime were much more turbid than the air from the industrial regions closer at hand and to the North.

If we eliminate the winds with an Easterly component the remaining winds arrive at Valentia either directly from the Atlantic or after only a very brief passage over sparsely populated countryside. These winds in the sector South through West to North have been classified in [5] as "sea winds". They show a uniform value of turbidity slightly above the overall long period annual mean during the summer and generally very clear air, considerably below the overall annual mean, during the Winter season.

7. Variation of β with Synoptic Air Masses

Wind direction can only indicate in a general way the origin of the aerosol in the air. A better criterion is probably the air mass classification. The type of air mass over Valentia at the time when turbidity observations were made was supplied by the Central Analysis and Forecasting Office of the Irish Meteorological Service. The mean turbidity associated with each air mass for each month of the year was computed and the result is shown on Fig. 5.

Highest turbidities are found in Continental Tropical (cT) air. This type of air mass is however very rarely experienced at Valentia and values of turbidity are available only for two months in the year i.e. May and October. The values are entered for these months on Fig. 5 (cT) and can be seen to be higher than the corresponding monthly mean for any other air mass. It is clear, however, that the chief contributor to high turbidity in all months of the year is air of Continental Polar (cP) origin.

What may be considered as the normal background value of turbidity at Valentia is represented by the curve for Maritime Polar (mP) air. This is by far the most frequent air mass over Valentia and is roughly represented by what have been referred to above as "sea winds".

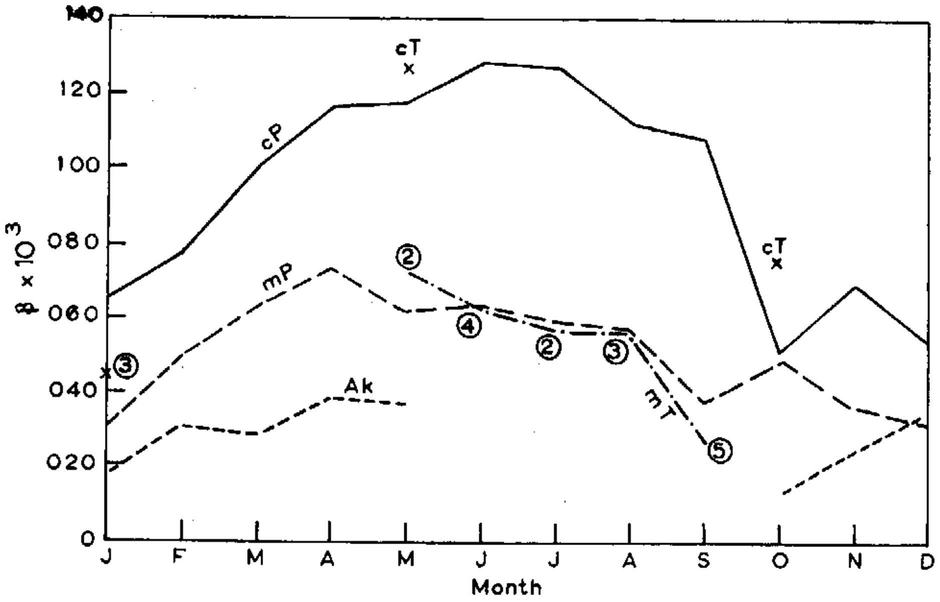

Fig. 5 Variation of β with Synoptic Air Mass.

Maritime Tropical (mT) air in its true sense is not conducive to turbidity measurements at Valentia. It is generally accompanied by low clouds and drizzle and seldom suitable for radiation measurements. The few turbidity measurements obtained when the air was classified as maritime tropical are insufficient to provide reliable monthly means. The means obtained have, however, been entered on Fig. 5, the circled figure beside each mean showing the number of days on which the mean was based. These rather doubtful values would suggest that the air mass in question was little different from Maritime Polar.

The lowest values obtained were in Arctic air (Ak). The monthly differences were small indicating that turbidities are always low in Ak.

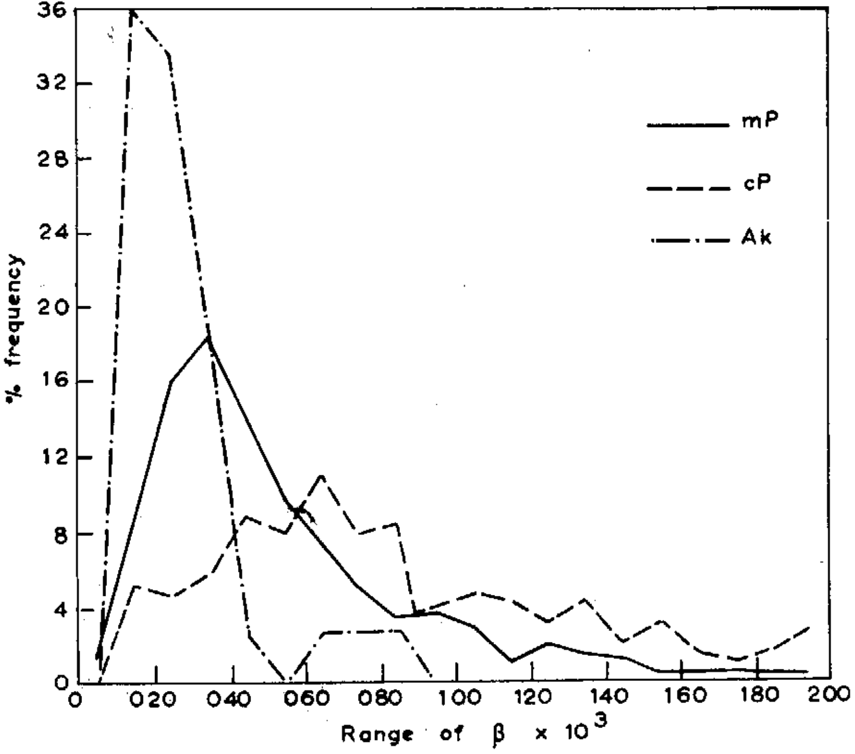

Fig. 6 Percentage frequency of β with Synoptic Air Mass

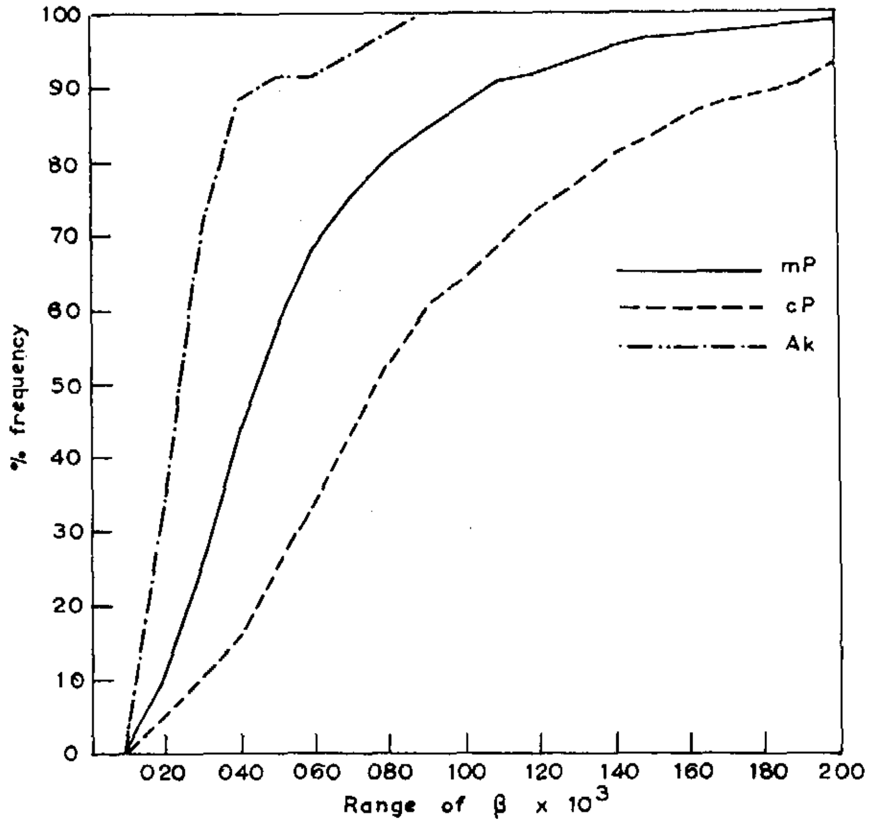

Fig 7 Cumulative frequency of β with various Air Masses

There are no values for the months June - Sept. since Arctic air does not penetrate so far South during these months.

Continental Polar air over Valentia is usually associated with an anticyclone centred over Scandinavia or North Europe, the air sweeping across Europe and Southern France to Ireland. The high turbidities associated with Continental Polar air would again appear to confirm Lovelock's conclusion that air from Continental Europe is more heavily laden with aerosol than that from the industrial regions of England.

Fig. 6 shows the percentage frequency distribution of β for each of the three main air masses and Fig. 7 shows the corresponding cumulative frequency curves. Tropical air is not included due to the paucity of observed data.

The cumulative curve for Ak shows the smallest spread of turbidities between the lower and upper quartiles at β = 0·017 and 0·033 respectively. The median value of β is 0·024.

Maritime Polar, the prevailing air mass at Valentia, shows lower and upper quartiles at β = 0·030 and 0·069 respectively with a median value at 0·044.

The frequency distribution for Continental Polar air is typical of air which has been polluted by passage over industrial zones. The distribution is fairly uniform over the range of turbidities observed, with lower and upper quartiles at β = 0·050 and 0·125 respectively. The median value is at β = 0·077.

About 7% of the turbidities observed in Continental Polar air exceeded 0·200, whereas only 1·4% exceeded this value in the case of Maritime Polar air. None of the values observed in Arctic air exceeded 0·090 and only 11% exceeded 0·040.

8. Seasonal Variation

Monthly and annual mean values are given in Table 3 and the average annual variation for the full 17 year period is shown on Fig. 8. Similar annual variation curves for Davos, Adrigole (about 45 Km from Valentia) and Bowerchalke in Southern England are also shown. The Davos values are taken from [7] and the Adrigole and Bowerchalke values from [6]. They all show the now familiar higher values of turbidity during the summer months and relatively low values during the winter months. Apart from the differences in absolute value the most noticeable feature is the occurrence of the peak value for Valentia in April, whereas the others, apart from Adrigole have a peak in June/July. The Adrigole curve does show an April peak but has its highest value in September. However, the Adrigole values are based on only two years data (1970 and 1971) as compared with the Valentia 17 year period. Many writers attribute the general high summer values to the increased instability during spring and early summer resulting in convection currents carrying quantities of aerosol into the higher atmosphere, the general atmospheric subsidence in winter months producing an opposite cleansing effect. Lovelock suggests that the denser summer-time aerosol is probably an end product of the atmospheric photochemistry of air pollutants under summer conditions and that Continental Europe is the principal source. If we refer again to Fig. 5 we see the annual variation of the Valentia data with respect to the principal air masses. The curve for mP air is almost identical with the overall annual variation curve for all observations at Valentia, the peak value again appearing in April. In the case of the Continental Polar air the peak value occurs in June - July. The time at which the peak occurs at a particular site would, therefore, appear to depend to a great extent on the prevailing air mass.

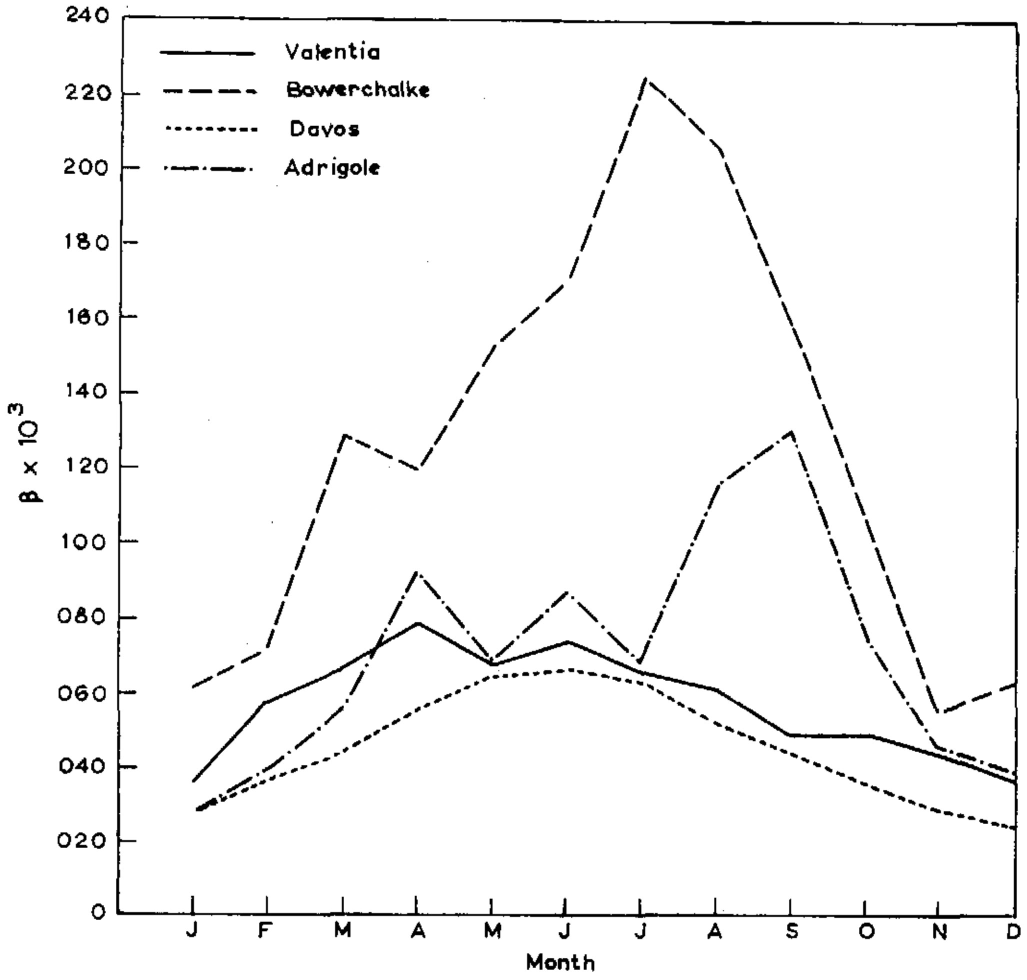

Fig. 8 Annual Variation of Turbidity.

In the case of mP air, which prevails at Valentia, the range between summer and winter turbidity values is considerably compressed as compared with air of continental origin. This could well be due to the fact that the atmospheric photochemical and biological sources of summer aerosol would not be such major contributors in the case of maritime air as in the case of air arriving from continental areas.

Another factor which probably plays a part in the annual variation of the turbidity is the rainfall. McWilliams [5] found in the case of atmospheric nuclei that rain caused a reduction in the nuclei content amounting to about 30%. Other writers found a similar "washing out" effect.

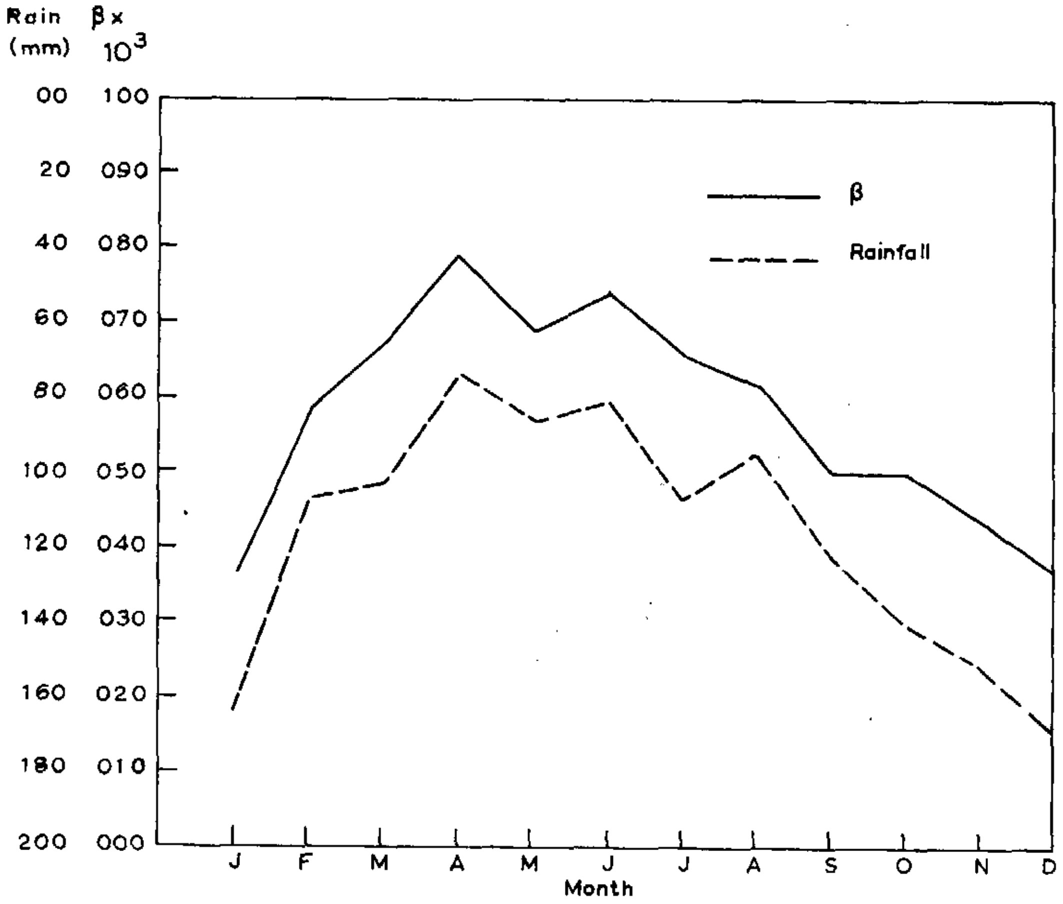

Fig. 9 Annual Variation of β and Rainfall.

In Fig. 9 the turbidity annual variation curve for all observations is shown with the curve of normal monthly rainfall amounts as measured at Valentia. The rainfall normals are based on a 30 year average and are plotted inversely to facilitate comparison with the turbidity curve. The parallel trend of the two curves is very striking. The highest turbidity and the minimum rainfall coincide in the month of April. Wetter months show reduced turbidity and the clearest air is found in the months Dec. - Jan. which have the maximum rainfall. It would appear, therefore, that the scavenging effect of rainfall plays a considerable role in the control of the aerosol content of the air at Valentia

9. Turbidity Trends

The possible modification of climate and weather due to an increase in atmospheric pollution has been receiving considerable attention by scientists in recent years [8,9]. An increase in the CO_2 content of the atmosphere and an increase in atmospheric aerosol content are among the principal factors which could cause a reduction in the incident solar radiation. The general

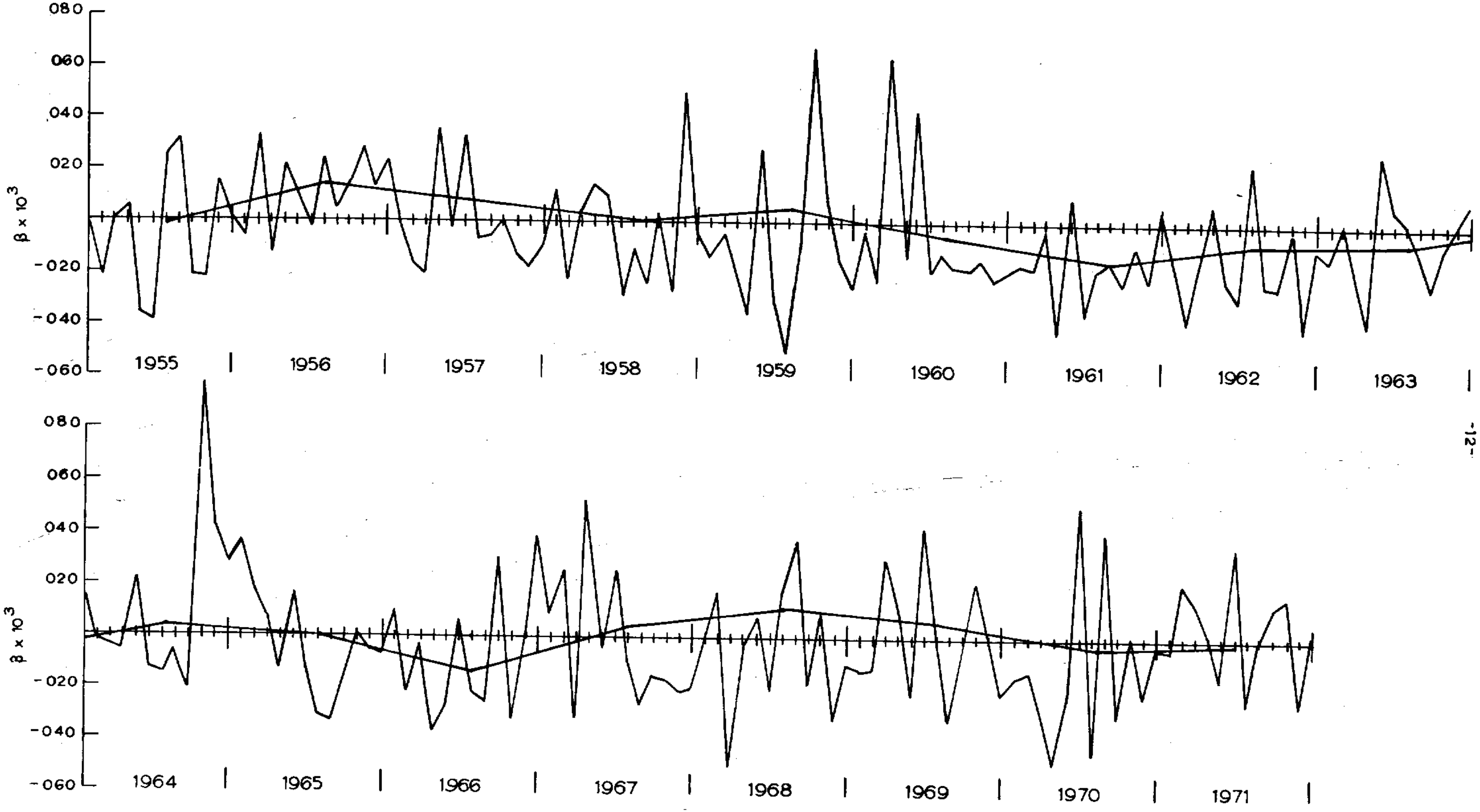

Fig. 10. Departures of Individual Monthly Values of β from Overall Monthly Means.

atmospheric warming which could be expected from the reported steady increase in the CO_2 content of the atmosphere has not been observed. In fact the opposite has been noted in [10,11]. The world wide reduction in mean annual air temperature reported to have started about 1940 has been attributed by a number of writers to a universal increase in atmospheric turbidity. Values given by McCormick and Ludwig [12] suggest that at Washington (U.S.A.) there has been a total increase of about 57% between 1905 and 1964 and at Davos (Switzerland) an increase amounting to 88% between 1920 and 1958. Peterson and Bryson [13] in a study of the observations at Mauna Loa Observatory, Hawaii show an increase in turbidity of about 30% in the ten year period 1958 - 68. The trend was masked by a very rapid increase in turbidity in 1963 resulting from the eruption of Mount Agung in the East Indies in March, 1963, but the authors concluded that the effect of the Mount Agung eruption was of a temporary (though prolonged) nature and that most of the increase was the result of a long term world wide turbidity increase.

Though no observations are available at Valentia for the earlier dates referred to in the case of Washington and Davos, the continuous series of observations from 1955 to 1971, using the same instruments and filters, provides an opportunity of confirming, or otherwise, the reported trend as far as Valentia is concerned.

For this purpose Fig. 10 shows the departures from the monthly average turbidity for the full 17-year period. Since the monthly values of β showed a distinct annual variation the plotted value for each individual month is the departure from the normal value for that month, the normal value for each month being based on the data for the full period. There is no evidence of any long term trend as reported by the researchers mentioned above. Individual months show considerable departures but the background level at the end of the period remains unchanged from that observed at the beginning of the period. The annual mean values for each year are also shown on the diagram. This curve indicates a fairly long period, small amplitude oscillation in the mean annual turbidity background on which are superimposed the irregular monthly departures, no doubt associated with the frequent changes in wind direction and air masses which are typical of the Valentia latitude and geographical position.

The higher monthly departures are usually associated with an eruption of Continental Polar air from Northern and Central Europe. The highest peak occurred in October, 1964. However, this particular monthly mean was based on only four observations, three of which resulted in abnormally high values. The air was Continental Polar associated with an anticyclone centred over Northern Germany, the East/S.East wind bringing the air across central Europe and over England tó Ireland.

In para. 7 above it was suggested that the turbidity in mP air may be considered as representative of the normal background turbidity at Valentia. Fig. 11 shows the secular variation of β in mP air (shown as deviations from the overall annual mean value). The main feature of the variation is the drop in turbidity from 1956 to 1961 followed by a gradual recovery to normal value. In the case of the seasonal variation it was found (para. 8 above) that the seasonal pattern followed closely the seasonal pattern in rainfall. Hence the secular variation in total rainfall as measured at Valentia is also shown on Fig. 11 (plotted inversely). There is a considerable similarity in trend suggesting again, as in the case of the seasonal variation that the washing out effect of rainfall plays a considerable part in the control of the aerosol content of the air at Valentia.

The results, however, do not support the theory of a long term trend of increasing turbidity. In a period during which the instruments, our knowledge of them, and observational techniques have been undergoing

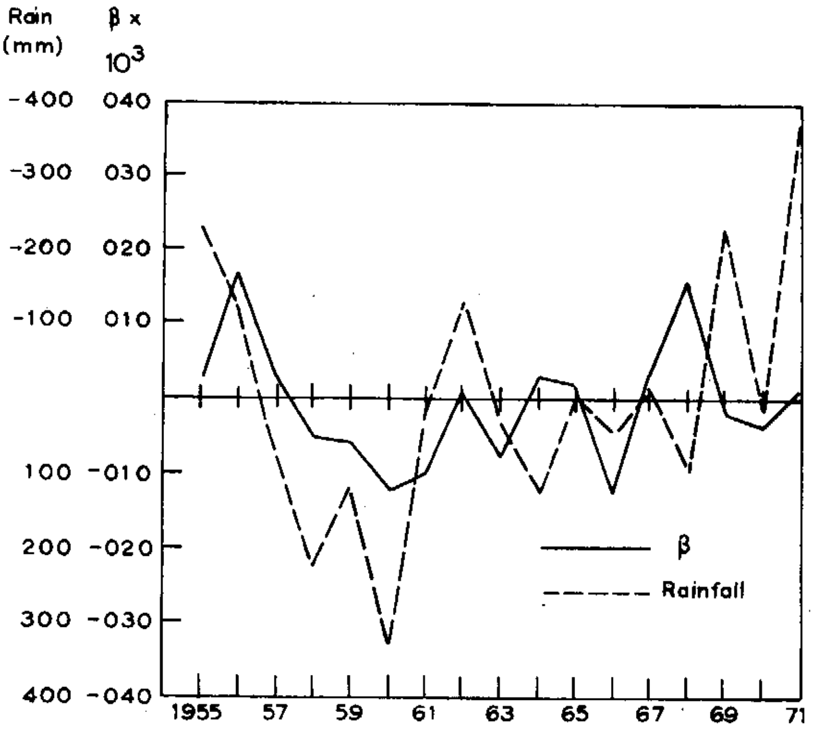

Fig. 11 Secular Variation of β and Rainfall (As Deviations from 17 Year Mean).

considerable improvement there must be some doubt as to the absolute value and comparability of observations separated by a span of up to 50 years. Moreover, Fig. 11 shows that, at least at Valentia, varying degrees of increasing or decreasing trend could be calculated depending on the terminal years used in the computation.

It is interesting to note that McCormick, who with Ludwig [12] used the Washington and Davos data to show a large world wide increase in the last half century later found [4] when analysing, with Flowers and Kurfis, data observed at a variety of stations in the U.S.A. for the period 1960 - 66 that there was no evidence of such a trend.

Dogniaux and Sneyers [14] analysed a 20 yearperiod of turbidity data at Uccle, Brussels, which included the 17 year period covered by the Valentia data, and found only a very small but insignificant increase in the turbidity. Though some increase in local turbidity must be expected at sites close to industrial development areas the Valentia data would appear to indicate that there has been no general world wide increase in turbidity especially in rural areas remote from the sources of man made pollutants.

10. Conclusion

The analysis of 17 years of measurements of the Angstrom turbidity coefficient at Valentia shows:

10.1. Mean daily turbidity most frequently lies between ·030 and ·040 with a median value of ·047.

10.2. Highest turbidities are observed in winds from an East and South East direction.

10.3. For all wind directions turbidities are higher in summer than in winter.

10.4. Mean monthly value is highest in April and lowest in Dec./Jan.

10.5. The chief factor determining the turbidity is the air mass type. Continental Tropical air was experienced in only two months of the year but the observed turbidity was higher than that for any other air mass for the corresponding months.

Otherwise, Continental Polar air was associated with highest turbidities in each month of the year.

Maritime polar air, the prevailing air mass, showed relatively low turbidity and seems to dominate the overall annual turbidity pattern.

10.6. The scavenging effect of rainfall would appear to have a considerable influence on the annual and secular variation.

10.7. There is no evidence of any trend of increasing turbidity during the period.

Acknowledgements

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