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The Significance and Interpretation of Ionospheric Drift Measurements in the Low-Frequency Range

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The significance and interpretation of ionospheric drift measurements in the low-frequency range

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Ionospheric drift measurements in the low-frequency range can be shown by comparison with corresponding radar–meteor wind measurements to indicate, in general, very nearly the actual neutral air wind in the 90 to 100 km height region. From many years of such measurements at two stations in the German Democratic Republic, results have been obtained on both the prevailing and the semi-diurnal (tidal) wind components, their seasonal variations, their dependence on the solar cycle and their anomalies during certain major mid-winter stratospheric warmings.

1. Expermental method and results

Ionospheric drift measurements at heights below 100 km can be obtained by the well-known closely spaced receiver method (method D1) if applied in the low-frequency range. Such measurements have been made continuously for many years at two stations in the German Democratic Republic (Kühlungsborn and Collm) using the ionospherically reflected radiation of certain suitable radio transmitters at frequencies between 185 and 272 kHz which are located between 160 and 400 km from the receiving sites (cf., for example Sprenger & Schminder 1967). A map of the drift measuring paths used for these measurements is given in figure 1.

The routine evaluation of fading records (from aerials spaced by about 600 m or 300 m respectively) is carried out by the simple similar-fade method, i.e. by determining a particular drift vector from the time displacements of each individual fade and taking the median of all individual drift vectors within half an hour as representing the actual mean drift. It has been shown by Sprenger & Schminder (1969*b*) that the drift results obtained in this way correspond very closely with the results which would be obtained by the full correlation analysis method (if applied after filtering the original fading curves in order to suppress the long-period fading components according to the findings of Golley & Rossiter (1970) about the necessity of an adequate ratio between the spatial scale of the fading pattern and the aerial separation).

Examples of results of such measurements are shown in figure 2 and indicate the behaviour of the drift vector in the evening hours of typical days in spring, summer, autumn and winter, respectively. (Unfortunately, there are no results available before sunset because of the strong ionospheric absorption of l.f. radio waves during day-time.) The different arrows in figure 2 indicate results obtained from the four different measuring paths of the two observatories at reflexion points separated by distances up to 575 km from each other (cf. figure 1). In spite of these large distances there is, in most cases, very close agreement between the individual results from the different paths. Thus we may conclude that these results are highly significant and that they indicate that the observed drifts have a systematic large-scale character.

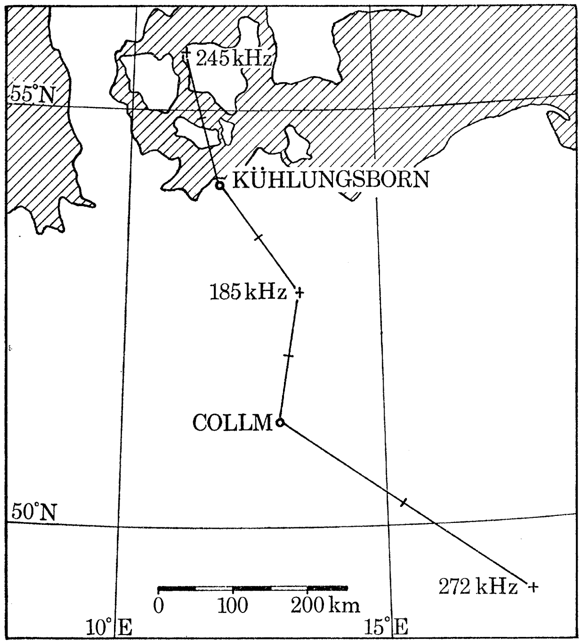

FIGURE 1. Map of the four measuring paths used for ionospheric drift measurements in the l.f. range (method D 1) at the observatories of Kühlungsborn and Collm; the small cross-lines indicate the locations of the reflexion points to which the measurements have to be attributed.

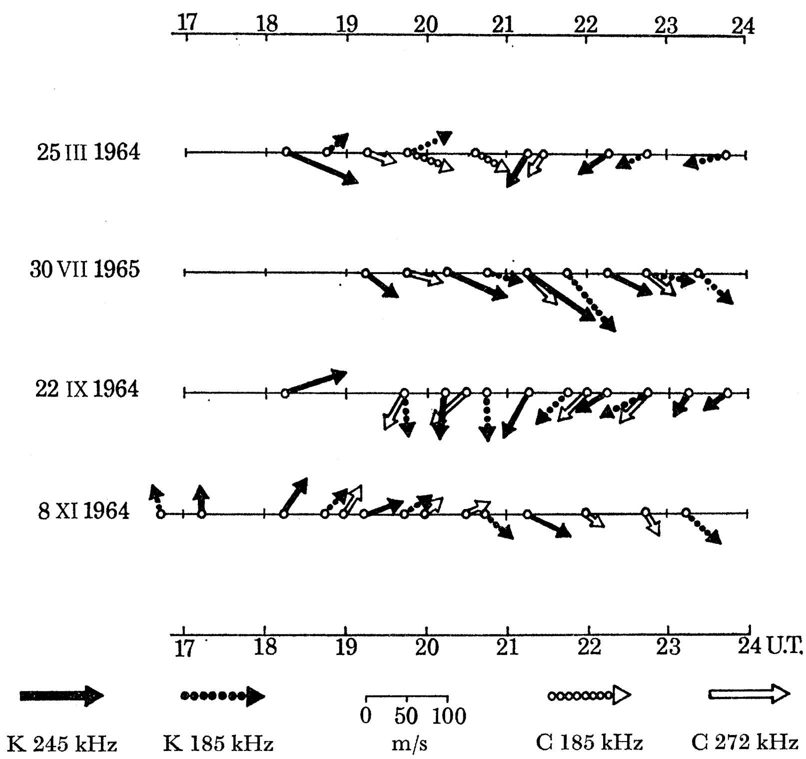

FIGURE 2. Examples of l.f. drift results obtained simultaneously on different measuring paths (indicated by different arrows) at reflexion points separated by distances up to 575 km (K, Kühlungsborn; C, Collm). (From Sprenger & Schminder 1968.)

It has been found that in about 75 % of all cases the agreement between the results from the different paths is similar to that shown in figure 2, including also synchronous rotations or sudden reversals of the observed drift vector. On 20 % of all nights there are similar rotations or reversals, but with phase differences of 1 or 2 h at the different locations, and only on the remaining 5 % of nights are there completely irregular differences between the results from the different paths due to random errors or local effects of some unknown kind.

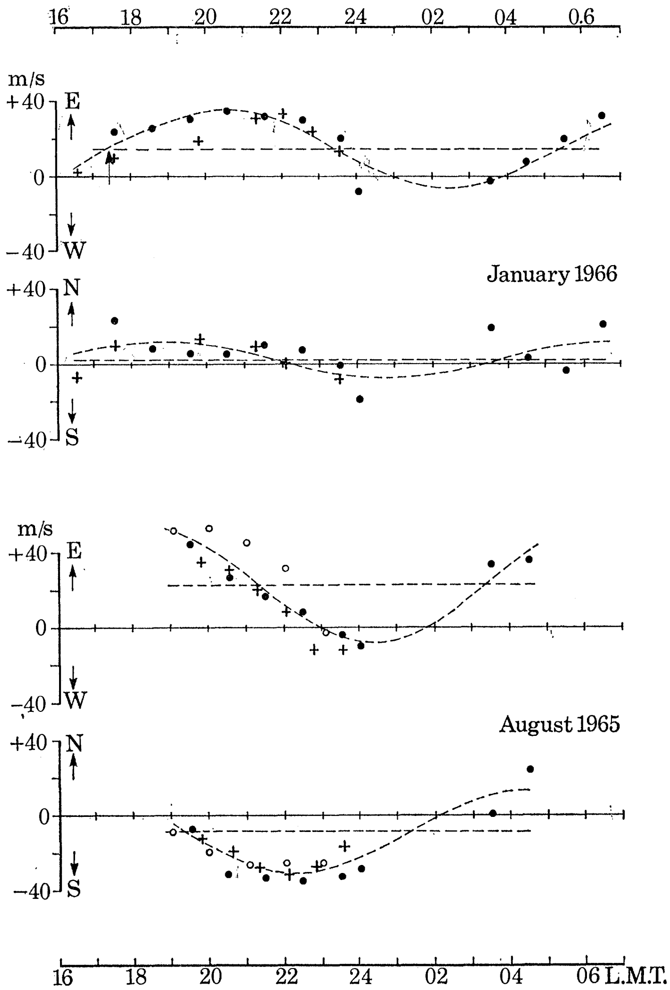

FIGURE 3. Examples of the mean behaviour of the zonal and meridional drift component in the lower ionosphere, as obtained from l.f. drift measurements at Kühlungsborn and Collm during a winter month and during a summer month (dots, circles and crosses: monthly mean values of measurements from different measuring paths; dashed lines: results of 12 h harmonic analysis). (From Sprenger *et al.* 1969, 1971*a*.)

Typical examples of monthly mean drift results are presented in figure 3, showing – again in good agreement with the results from different measuring paths – the mean behaviour of the zonal and meridional drift components in the course of the night during a winter month and during a summer month. Although the measurements do not cover the whole day, a kind of harmonic analysis has nevertheless been attempted in order to describe the mean diurnal variation in terms of a prevailing component and a semi-diurnally rotating component, which are known to be the two major components at medium latitudes. The method used for this

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purpose consists simply in fitting – separately for the zonal and meridional components – a sine function with a given period of 12 h to the measured values as demonstrated in figure 3. The mean value and the amplitude and phase of this sine function are determined according to the least-squares method and are taken to represent the magnitude of the prevailing component and the amplitude and phase of the semi-diurnal component, respectively. Of course, this procedure is not exact because the 24 h component and the third and higher-order harmonics have been neglected, but it obviously works sufficiently well, as shown by a comparison with corresponding results from radar–meteor wind measurements (Sprenger & Schminder 1968). The phase of the semi-diurnal meridional component, for instance, is always found to be in advance of the semi-diurnal zonal component, thus indicating a clockwise rotation of tidal character.

2. Solar-cycle dependence

From the examples shown in figure 3 the prevailing component and the semidiurnal component are seen to be of nearly equal order of magnitude. This is typical of solar minimum conditions, at least in winter, as found by Sprenger & Schminder (1969*a*). To demonstrate

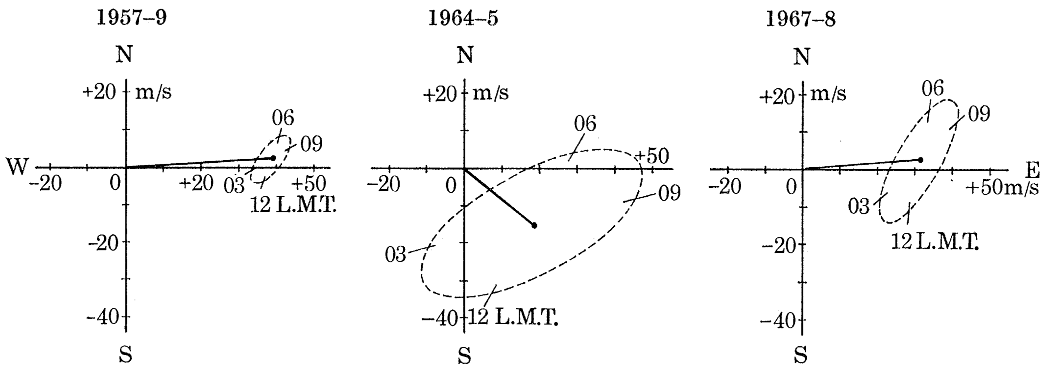

Figure 4. Prevailing and 12 h periodic components (pointers and ellipses, respectively) of the drift in the lower ionosphere during winter at solar maximum (1957–9 and 1967/8) and solar minimum conditions (1964/5) as derived from l.f. drift measurements at Kühlungsborn and Collm. (From Sprenger & Schminder 1969*a*.)

dependence on the solar cycle, figure 4 gives a comparison of the results of harmonic analyses of the mean drift vectors obtained during the winter months of the solar minimum 1964/5 and of the two solar maxima 1957–9 and 1967/8. At solar maximum the prevailing drift is seen to be distinctly greater than at solar minimum (and directed towards the east instead of the south-east), whereas the amplitude of the 12 h component decreases strongly with increasing solar activity, so that the semi-diurnal variation becomes relatively small in solar-maximum years. Comparing the two solar maxima of 1957–9 and 1967/8 with each other in figure 4, we find that during the latter the prevailing component did not become as great and the 12 h component did not become as small as they had been during 1957–9. This is in good agreement with the fact that the solar maximum of 1967/8 was not as strong as that of 1957–9 and leads us to conclude that we are actually dealing with changes due to the solar cycle. A result like this demonstrates the value of such measurements when carried out continuously over many years.

3. Comparisons with results from radar–meteor stations

In order to study the problem of the significance and interpretation of results from l.f. drift measurements, several efforts have been made to compare them with corresponding results of radar–meteor wind measurements (method D 2) which refer to nearly the same height region. Comparisons were first made with the results of Greenhow & Neufeld (1961) at Jodrell Bank and of H. G. Müller (1967, personal communication) at Sheffield, both stations being located at approximately the same latitude as Kühlungsborn and Collm and only about 900 km away

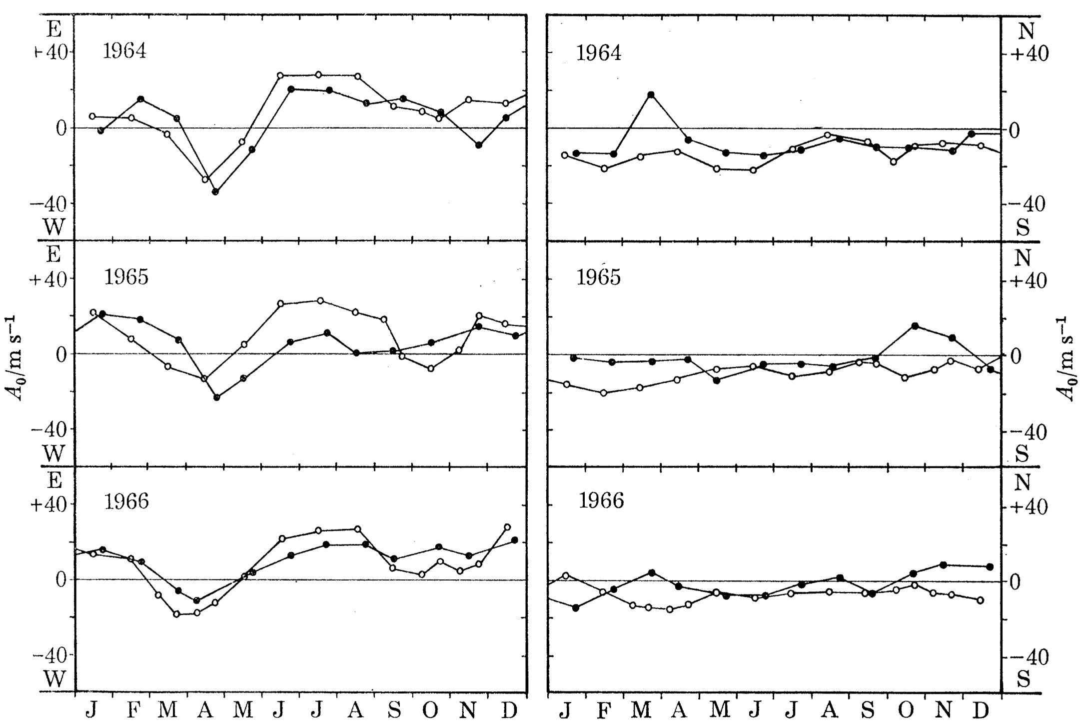

Figure 5. Seasonal variations of the prevailing wind as obtained from radar–meteor wind measurements at Obninsk (filled circles) and from l.f.-drift measurements at Kühlungsborn and Collm (open circles) in the years 1964, 1965 and 1966. (From Sprenger *et al.* 1971*b*.)

in a westerly direction. Very close agreement between the results of the two different observational methods has been found from these comparisons (Sprenger & Schminder 1968), thus implying for the first time that the method of l.f. drift measurements generally gives nearly as good an estimate of the neutral wind in the 90 to 100 km height region as does the method of radar–meteor wind measurements.

Further comparisons have been made in close cooperation with the Institute for Experimental Meteorology (I.E.M.) of the Hydrometeorological Service of the U.S.S.R., using three years of simultaneous measurements of l.f. drifts at Kühlungsborn and Collm and of meteor winds at Obninsk, likewise at nearly the same latitude, but about 1600 km away in an easterly direction. Some of the results of these comparisons, published by Sprenger, Lysenko, Greisiger & Orljanskij (1971*b*), are reproduced in figures 5 to 7, showing monthly means of the meridional and zonal components of the prevailing and semi-diurnal drifts or winds, respectively. In spite of the great distance between the respective locations, the agreement between the results of the

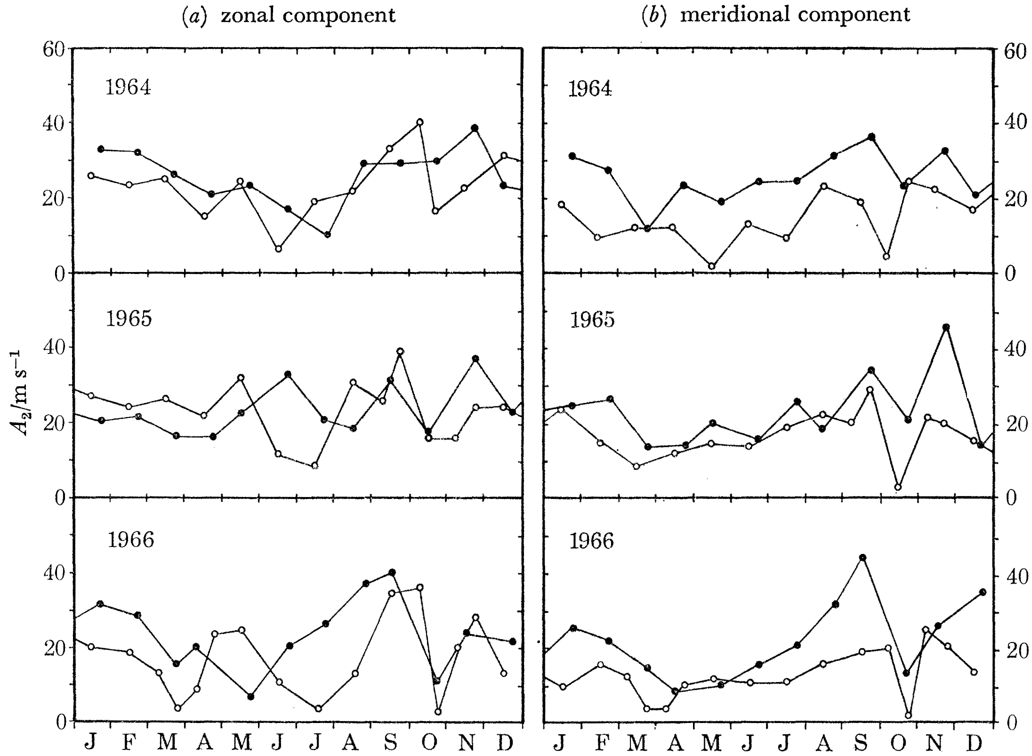

FIGURE 6. Seasonal variations of the amplitude of the semi-diurnal wind component as obtained from radar–meteor wind measurements at Obninsk (filled circles) and from l.f. drift measurements at Kühlungsborn and Collm (open circles) in the years 1964, 1965 and 1966. (From Sprenger *et al.* 1971 *b*.)

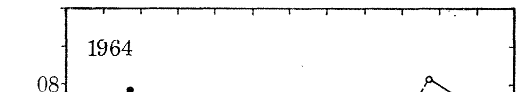

FIGURE 7. Seasonal variations of the phase of the meridional semidiurnal wind component (defined as the local time of occurrence of maximum amplitude towards north) as obtained from radar–meteor wind measurements at Obninsk (filled circles) and from l.f. drift measurements at Kühlungsborn and Collm (open circles) in the years 1964, 1965 and 1966. (From Sprenger *et al.* 1971 *b*).

two different methods is, in general, fairly good. Of course, there are some differences, which need to be studied further, but these are of second order and certainly do not suggest that the drift results are merely apparent motions and not the neutral air wind.

From figures 5 to 7 the general features of the wind systems in the 90 to 100 km height region may be seen as obtained from meteor wind measurements as well as from l.f. drift measurements, both referring to latitudes between 50° and 55° N and to solar minimum conditions. The zonal circulation is found to be directed towards the east in summer and winter with mean velocities mostly around 20 m/s, but to break down or even to reverse temporarily during the transitional seasons (figure 5*a*). The meridional flow is considerably smaller than the zonal one and is, with only a few exceptions, directed predominantly to the south (figure 5*b*). The amplitude of the semi-diurnal wind component is, on the average, approximately of the same order of magnitude as that of the prevailing wind, but shows some irregular fluctuations from month to month which must be studied further. Apart from a pronounced tendency for a deep minimum in October, there is also a slight tendency for smaller values in summer than in winter (figure 6). The phase of the semi-diurnal wind component is found in most cases to be such that the maximum wind towards the north occurs between 04h00 and 08h00 L.T., again there is very close agreement between the results of the two different methods (figure 7).

4. Phase variations during transitional seasons and stratospheric warmings

An interesting and important problem arises from the l.f. drift measurements with respect to the phase variations during the transitional seasons, particularly in autumn. Sometimes, there are strong indications that the variation from October to November (or from September to October, respectively) is not in the sense of retarding phase, as given by the dashed lines in figure 7, but in the sense of quickly advancing phase tending to connect with the time of the preceding maximum at about 19h00 or 20h00 instead of that at about 07h00 or 08h00. If this is true, it would mean that the similarity of phase in winter and summer, as hitherto assumed from the meteor results, is only an apparent one, whereas in reality there might be a change by nearly a full cycle, retarding in spring, advancing in autumn (Sprenger, Greisiger & Schminder 1969, 1971*a*).

Two examples of such indications are given in figures 8 and 9 which show the results for individual days in October/November 1965 and 1968. In other years, and particularly in spring, the day-to-day scattering of the phase during the transitional periods is in most cases considerably larger than, for instance, in October/November 1968 (figure 9), so that – in view of the inevitable ambiguity of the phase in terms of multiples of 12 h – it becomes difficult to discern the actual trend of the phase variation in these cases. Modern theory of upper-atmosphere tides does not exclude the possibility of phase shifts by nearly a full cycle if the effects of the seasonal variation of the stratospheric and mesospheric zonal background wind are taken into account (Ivanovsky & Semenovsky 1971; Greisiger *et al.* 1971).

Phase shifts similar to those during spring and autumn have also been found in winter during certain major stratospheric warmings (Lauter & Sprenger 1968). An example is given in figure 10, which refers to the stratwarm event of December 1960/January 1961 and shows a pronounced drift anomaly in the 90 to 100 km height region some days in advance of the stratospheric warming. A more general picture of the behaviour of the lower ionosphere drift in

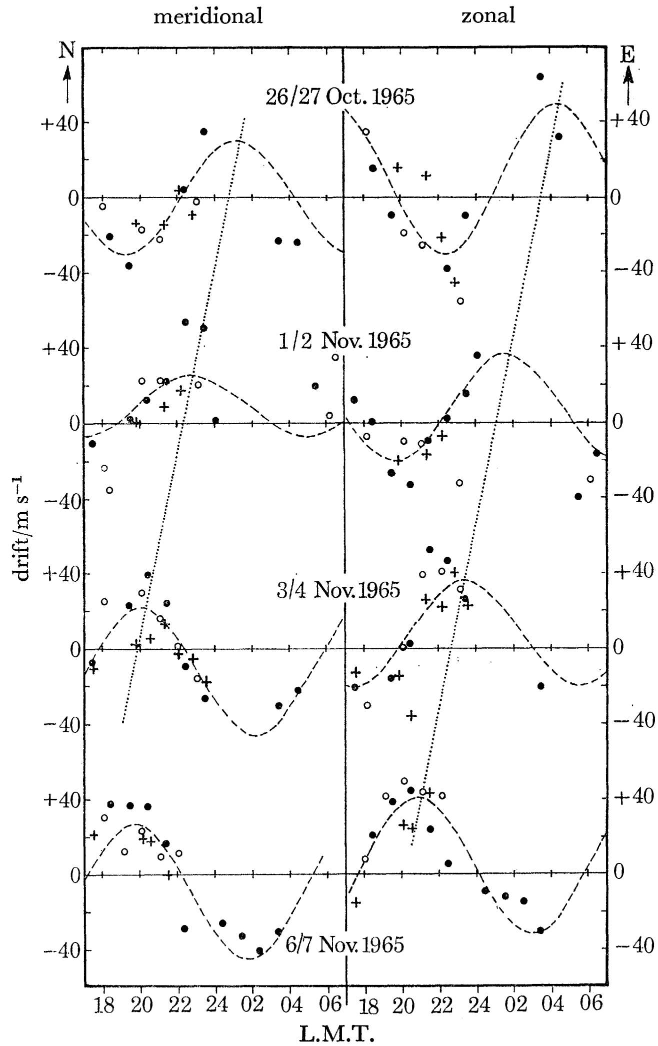

FIGURE 8. Examples of results of l.f. drift measurements (meridional component, V_N, and zonal component, V_E) for some individual days in the transition period from October to November 1965. (Dots, circles and crosses: results of measurements from different measuring paths; dashed lines: results of 12 h harmonic analysis.) (From Sprenger *et al.* 1969, 1971 *a*.)

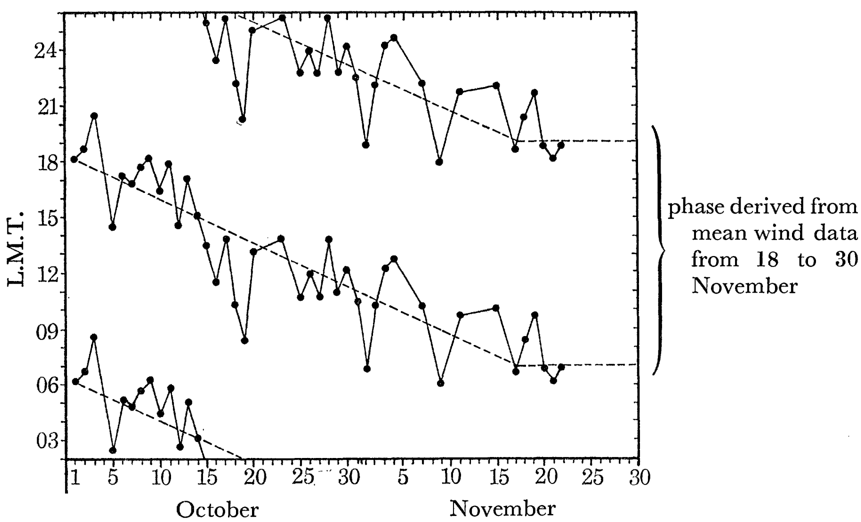

FIGURE 9. Systematic advancing of the phase of the semi-diurnal drift component by about 11 h during the transition from October to November 1968 (dots = phase results of all individual days for which harmonic analysis was possible). (From Sprenger *et al.* 1971 *a*.)

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connexion with stratospheric warmings is given in figure 11, derived from five such events in the years 1958 to 1966. As may be seen from a comparison of figures 11 *a* and *b*, the drift anomaly consists mainly in an alteration of the phase of the diurnal or semi-diurnal tidal drift component, which becomes similar to that during the final warming in the last decade of March (figure 11 *c*). This is not surprising since a stratospheric warming temporarily changes the stratospheric structure similar to what happens quite normally later on in spring.

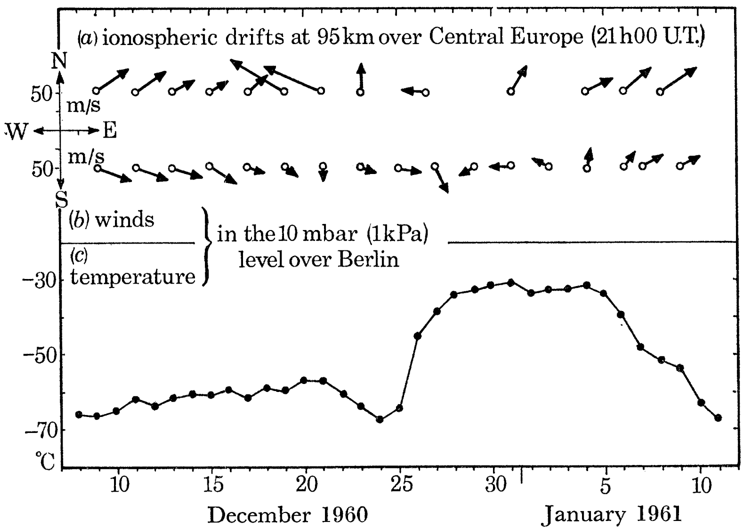

FIGURE 10. Example of an anomaly of drift direction in the lower ionosphere in connexion with a sudden stratospheric warming. (From Lauter & Sprenger 1968.)

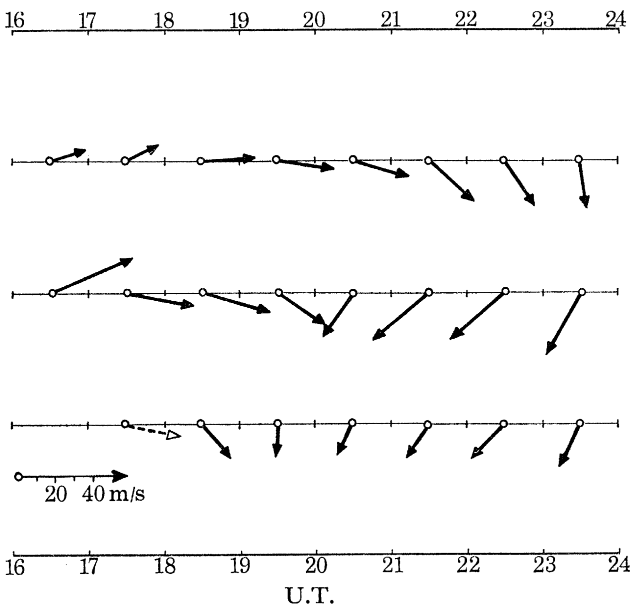

FIGURE 11. Mean diurnal variation of the drift vector in the lower ionosphere during five stratospheric warmings (*b*), compared with the normal variation during winter (*a*) and during late March (*c*). (From Lauter & Sprenger 1968.)

5. Comparisons with *in situ* radar–meteor observations

Recently a new and more direct attack on the problem of the significance and interpretation of the l.f. drift measurements has been made at Kühlungsborn, with our institutes again co-operating closely. A radar equipment of the I.E.M. was installed at Kühlungsborn in order to make meteor wind measurements in exactly the same area as the l.f. drift measurements. A diagram of this experiment is given in figure 12 showing the arrangement in the NW–SE vertical plane. The radar beam was directed towards the SE in order to include the reflexion points of the drift measuring paths 185 kHz-Kühlungsborn and 185 kHz-Collm (cf. figure 1). Alternately, however, every other half hour it was directed towards the NE in order to obtain the other wind component also since the meteor method gives only the line of sight component of the wind velocity.

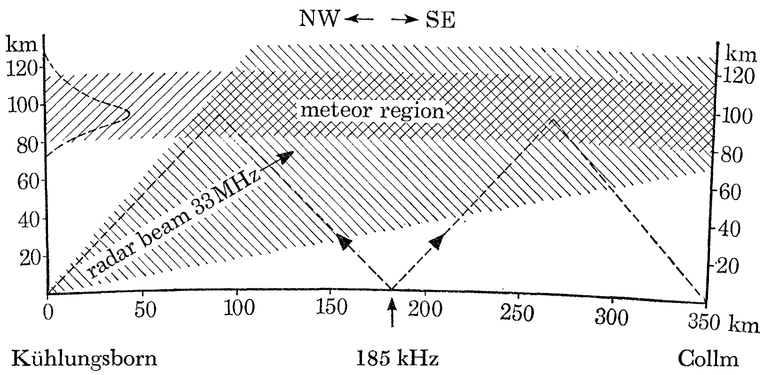

Figure 12. Diagram of an experiment for direct comparison of l.f. drift measurements (185 kHz) at Kühlungsborn and Collm with simultaneous radar–meteor wind measurements in the same area. (Simplified representation with respect to the direction of the measuring path 185 kHz-Collm which in reality is about 50° out of the plane of this diagram.) Upper left: Height profile of the relative probability distribution of meteors.

Additionally, this experiment was supplemented by intermittent pulse transmissions from the 185 kHz transmitter in order to determine the exact height of the reflexion level. The height values obtained by these measurements were between 90 and 95 km, even long after midnight, thus confirming that there is no severe diurnal variation of the reflexion height in the course of the night and a very close coincidence with the central height of the meteor region. A relative height profile of the probability distribution of meteors is given in the upper left of figure 12, showing a peak probability at about 95 km and an occurrence of 90 % of all meteors within the height region between about 80 and 115 km.

The results of comparisons between l.f. drifts and meteor winds which extended over 4 weeks during September/October 1970 are not yet completely available and will be published elsewhere (Lysenko & Sprenger *et al.* 1972). Only preliminary information can be given here, based upon 18 nights of simultaneous measurements by the two methods. Two different kinds of results have been obtained during this period. During the first part of the measuring period, lasting from 19 September to 6 October and characterized by a very stable phase of the semidiurnal component, i.e. by nearly constant values of the phase from day to day, fairly good agreement between the l.f. drift and meteor wind results has been found. Some examples of results of individual days from this period are shown in figure 13. Afterwards, from 8 to 18 October, there were very strong fluctuations of the phase from day to day in the l.f. drift results as well as in the meteor wind results. In detail, however, the agreement between the results of the two methods was worse during this time than during the period before. An interpretation of this finding has yet to be found and will certainly require a continuation of such comparisons over longer periods of time for different circulation régimes.

Nevertheless, a preliminary conclusion which may now be drawn is that apart from certain exceptions the l.f. drift measurements generally approximate the average real motion of the neutral air in the 90 to 100 km height region. Similar conclusions have already been drawn by

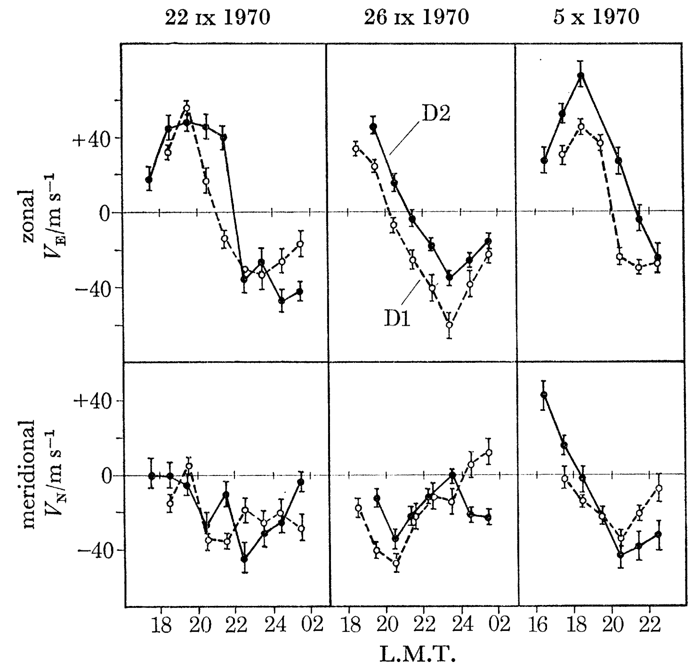

FIGURE 13. Examples of results of simultaneous l.f. drift and radar–meteor wind measurements in the same area on individual days in autumn 1970. —•—, meteor wind measurements (D2); – – o – –, l.f. drift measurements (D1); vertical bars, margins of errors.

Müller (1968, 1970) and also by Rossiter (1970) for E-region drifts compared with meteor winds by extrapolating between the different height regions. On the other hand, from comparisons between meteor winds and ionospheric drifts obtained in the same height region by the use of partial reflexions, Rossiter (1970) found many cases of pronounced disagreement between the results. To a certain extent this is in contrast to our findings presented in this paper and seems to confirm the suggestion made by Rossiter that the discrepancies are inherent in the method of partial reflexions being sensitive, for example, to the effects of internal gravity waves propagating through the atmosphere. The l.f. drift method, however, deals with total reflexions and therefore mainly with irregularities produced by turbulence and driven by the wind.

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