Results of E-Layer Drift Measurements at De Bilt

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Results of E-layer drift measurements at De Bilt

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At the beginning of 1969 an elaborate programme of E-layer drift measurements was started at De Bilt. The closely spaced receiver method is being used in combination with an on-line analogue computer which plots the polarity-, auto- and cross-correlation functions of the fading signals.

The following results over 1969 and a part of 1970 are presented and discussed: mean hourly values of the N and E components for each month; harmonic analysis and prevailing winds, comparison between results obtained from the intersection of the correlation curves and from the time shifts for maximum cross-correlation; and comparison with the results from other stations at about the same latitude.

1. Introduction

During 1969 and 1970 an extensive programme of E-layer drift measurements was performed at De Bilt. From an earlier series of drift measurements it had already become clear that a large number of measurements is necessary to make a useful study of the daily pattern of E-layer drift and of its seasonal variations. For this reason the measuring equipment and the evaluation of the results were largely automated.

The closely spaced receiver method was used. Three small loop antennas were placed at the corners of an isosceles rectangular triangle with sides of 92 m. Frequencies between 2.1 and 2.6 MHz were used, the higher ones being used only near the middle of the day if there was too much absorption to get a sufficiently strong echo with the lower ones. The receiver gate circuit selected echoes between 100 and 140 km virtual height. Every quarter of an hour the transmitter was turned on for 1 min to test if an echo was received of sufficient amplitude above background noise and disturbances and in the appropriate height interval. If so, the drift measurement was carried out; for 3 min the signals of the antennas of the N–S base were then compared, followed by a comparison of those of the E–W base for an equal time-interval.

2. Evaluation of the results

For the evaluation of the results an apparatus is used that transforms an echo amplitude signal $u(t)$ into its polarity function sign $[u(t)-\overline{u(t)}]$. This apparatus compares two polarity functions and plots an ample number of points of the auto- and cross-correlation functions immediately after the measurement. The method has been described by the author (Vesseur 1970).

The component of the true velocity v of the drifting pattern over the ground is according to the theory of full correlation analysis (Briggs, Phillips & Shinn 1950)

$$v = d/2\tau_e,$$

d being the distance between the two antennas, τ_e is the time shift for which auto- and cross-correlation are equal (corresponding with the intersection point of both correlation curves). In this way N–S and E–W components of the drift were calculated. To account for the ratio between the velocity of the pattern over the ground and the drift in the ionosphere an additional factor of $\frac{1}{2}$ was applied.

It seems justified to apply the above-mentioned theory of Briggs *et al.* to the correlation functions derived from the polarity functions of the signals. The first argument is that the whole reasoning of Briggs *et al.* can be repeated for the polarity function of the drifting diffraction pattern under the same assumptions as made for the diffraction pattern itself. In the second place is it possible for random variable signals with a Gaussian distribution to calculate the correlation functions of the original signals in a simple way from those of the polarity functions of the signals.

$$C(\tau) = \sin\left[\tfrac{1}{2}\pi\, P(\tau)\right],$$

$C(\tau)$ being an auto- or cross-correlation function derived from the original signals, and $P(\tau)$ the corresponding correlation function derived from the polarity functions of the signals (Lawson & Uhlenbeck 1950; Veltman & Kwakernaak 1961). It is obvious that in this case the time-shift τ_c will be the same for both types of correlation functions. For random variable functions with other than a Gaussian distribution there is no general rule for transforming one set of correlation functions to the other, but if there is a one-to-one relation, the intersection point will stay at the same time-shift.

3. HOURLY MEAN VALUES

The number of measurements made with this method appeared to be large enough to calculate reliable hourly median and quartile values of the N–S and E–W components of the E-layer drift for each month. In calculating these median values, no account is taken of height differences for reflexion on regular or sporadic E. All reflexions between 100 and 140 km virtual height were used. Of course all measurements made during the night hours belong to E_s reflexions, and those during the day for the larger part to reflexions from the regular E layer.

The number of observations available for the calculation of a mean hourly value over a period of a month is between 20 and 80 for a day-hour, about 20 for a night-hour in the summer months and 2 to 15 for those in winter months. Hourly median and quartile values for the first 6 months of 1969 are shown in figure 1 and for the first half of 1970 in figure 2. In both figures a positive value means a drift towards the north or towards the east. Universal time is used throughout. Local time is 20 min in advance of U.T. as the station is situated at 52° 06.1′ N, 05° 10.6′ E.

From figures 1 and 2 certain characteristics of the daily behaviour of the E-layer drift can be clearly seen; e.g. in January, the large drift towards S and W in the morning hours, decreasing about noon, and changing in direction towards N and E in the afternoon; in June the drift is mostly towards N and E and shows only small variations during the whole day.

4. HARMONIC ANALYSIS

From the hourly median and quartile values a harmonic analysis of the daily behaviour of the N–S and E–W components of the drift has been calculated for each month. For each hour, h, a value

$$a_{\mathrm{h}} = \tfrac{1}{4}(q_{\mathrm{u}} + 2m + q_{\mathrm{l}})$$

was calculated, where m is the median value, q_{u} the upper quartile and q_{l} the lower quartile. This was done for the N–S and E–W components separately.

The number of measurements available for the calculation of the median value of a definite hour, n_{h} varies considerably from one hour to another. Each number n_{h} determines the reliability of the corresponding value a_{h}. To take this into account the following method was used.

For each hour two additional values a'_h and a''_h were taken from the adjacent hours and the next adjacent hours

$$a'_h = \tfrac{1}{2}(a_{h-1}+a_{h+1}) \quad \text{and} \quad a''_h = \tfrac{1}{2}(a_{h-2}+a_{h+2}).$$

To a'_h and a''_h we ascribe an equivalent count

$$n'_h = \frac{2n_{h-1}\,n_{h+1}}{n_{h-1}+n_{h+1}} \quad \text{and} \quad n''_h = \frac{2n_{h-2}\,n_{h+2}}{n_{h-2}+n_{h+2}}.$$

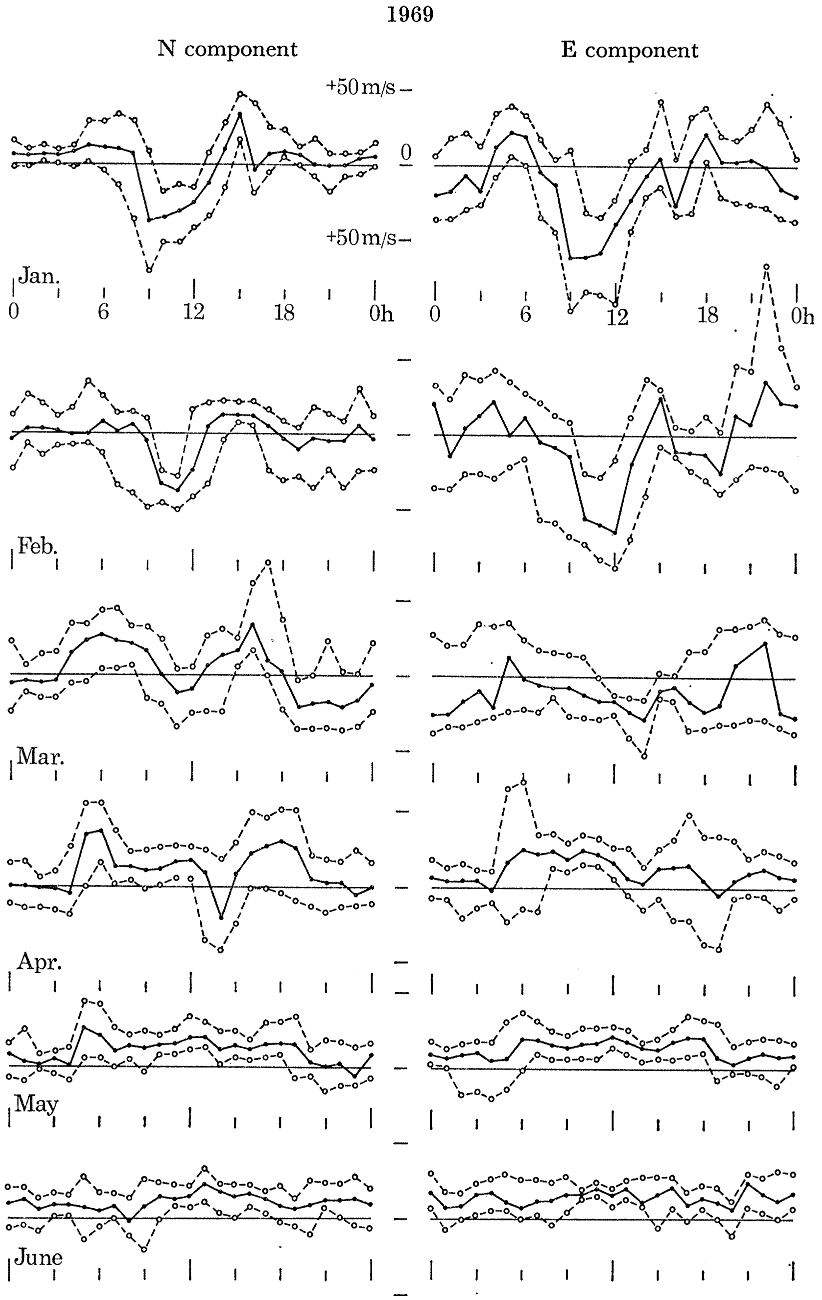

Figure 1. Hourly median and quartile values of the N and E components of E-region drift for the first 6 months of 1969.

Finally we calculate
$$A_{\mathrm{h}} = \frac{n_{\mathrm{h}}\, a_{\mathrm{h}} + n'_{\mathrm{h}}\, a'_{\mathrm{h}} + n''_{\mathrm{h}}\, a''_{\mathrm{h}}}{n_{\mathrm{h}} + n'_{\mathrm{h}} + n''_{\mathrm{h}}}$$

for each hour. The harmonic analysis was directly applied to the series of 24 values of A_{h} so obtained.

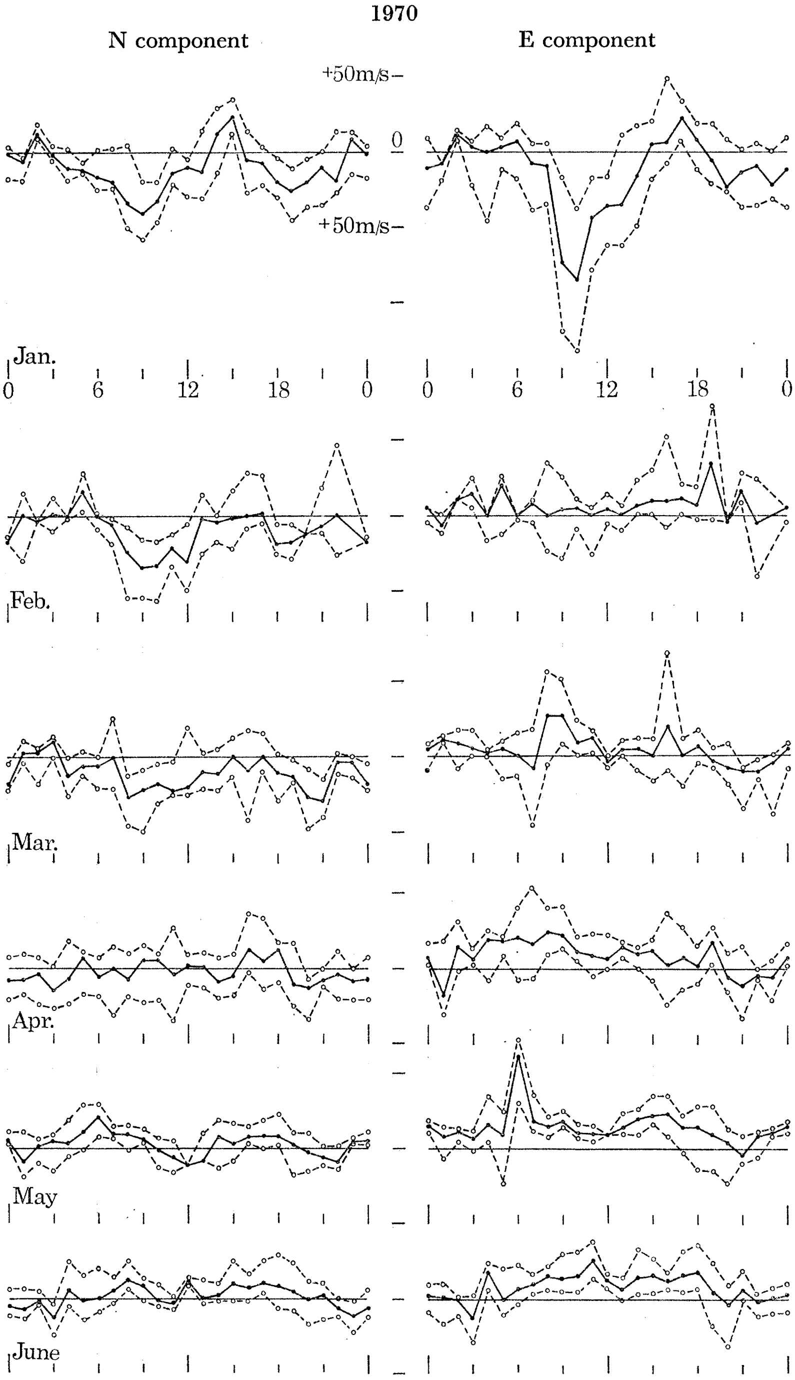

FIGURE 2. Hourly median and quartile values of the N and E components of E-region drift for the first 6 months of 1970.

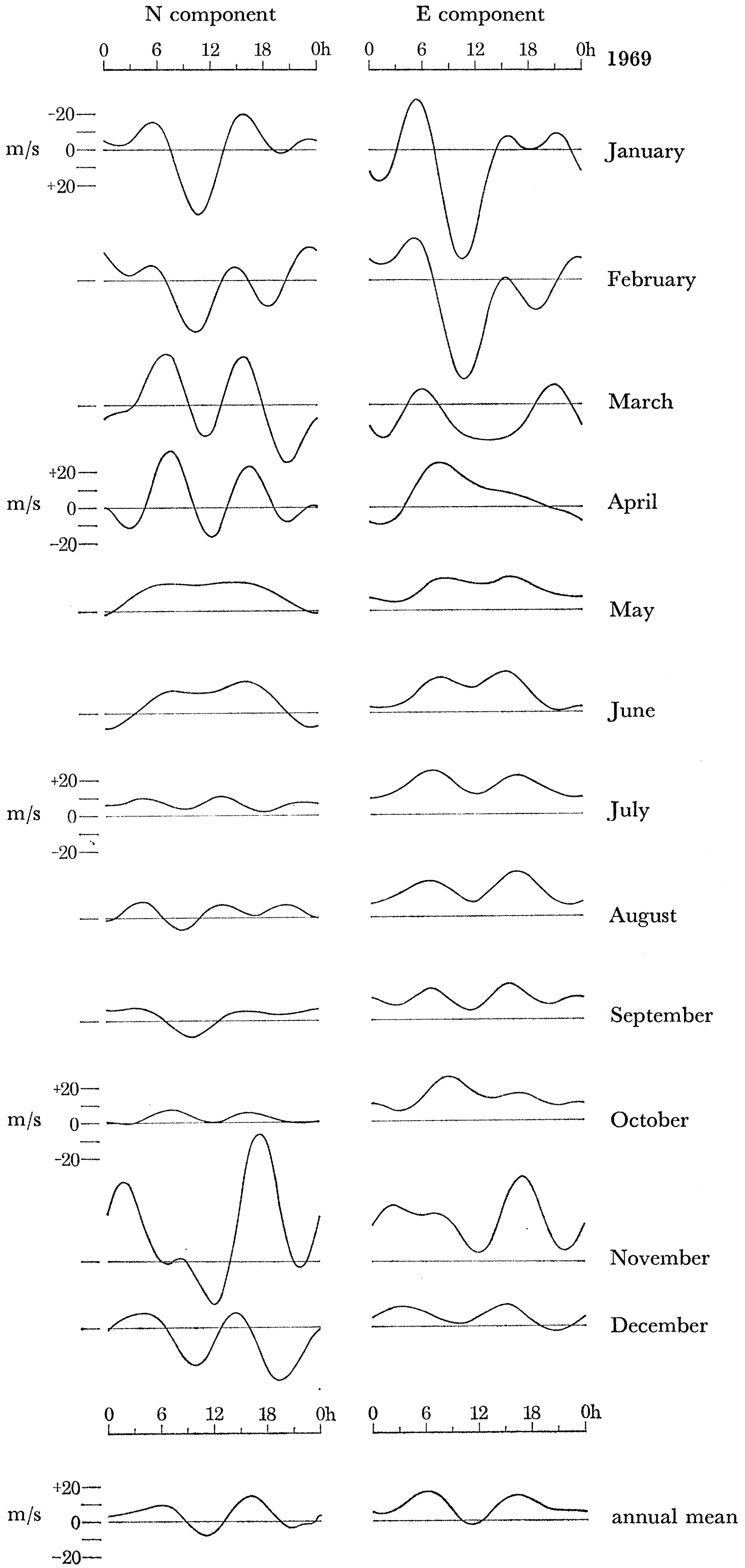

Figure 3. Approximations by Fourier series of the daily behaviour for each month of 1969.

The prevailing drift (average drift over 24 h) and the Fourier components of 24, 12 and 8 h period were calculated in amplitude and phase for both the N–S and the E–W components of the drift.

5. Results of harmonic analysis

By adding together the prevailing drift and the other three above-mentioned Fourier components, a good approximation to the daily behaviour of the drift is obtained. The results for each month of 1969 are shown in figure 3. Polar diagrams of the same results for January 1970 and June 1969, together with June 1970, are shown in figures 4 and 5 respectively. In January there is a very clear 12 h tidal influence, in June the 24 h period is stronger. The prevailing drifts for 1969 and for the larger part of 1970 are shown in figure 6. The prevailing drifts during the winter are towards south and west and in the summer towards north and east.

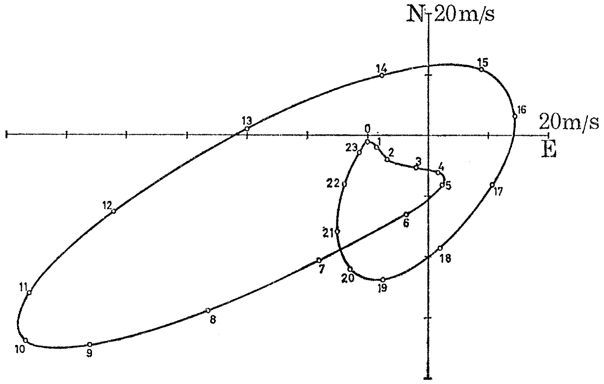

Figure 4. Polar diagram of hourly values of E-region drift for January 1970.

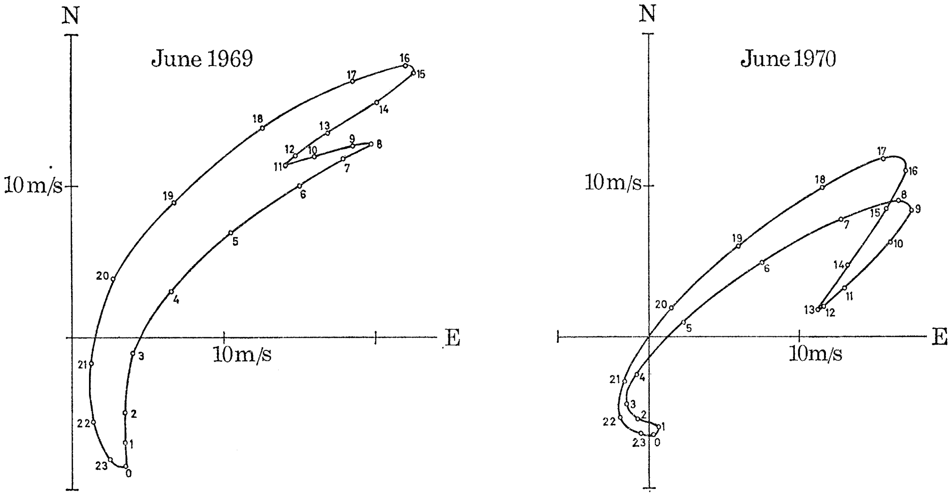

Figure 5. Polar diagram of hourly values of E-region drift for June 1969 and June 1970

In figure 7 the directions of the monthly prevailing drifts at De Bilt over the period mentioned are compared with the results obtained at Freiburg (48.1° N, 7.6° E) from a great many measurements over a period of several years (Harnischmacher & Rawer 1968). The results of Freiburg are given as probability differences for the different directions. The shaded areas in the figure give the most probable directions.

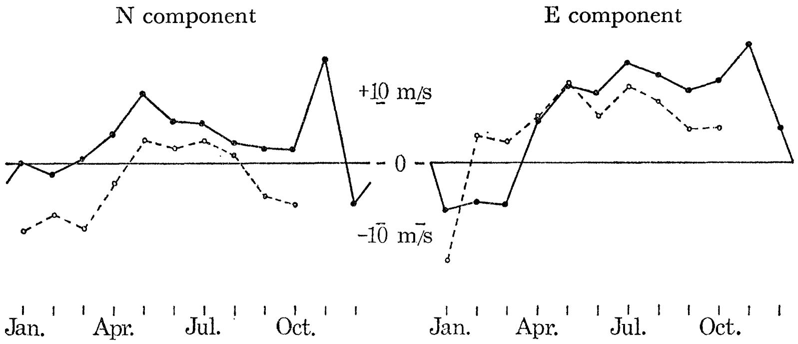

FIGURE 6. Prevailing drifts. —•—, 1969; – – o – –, 1970.

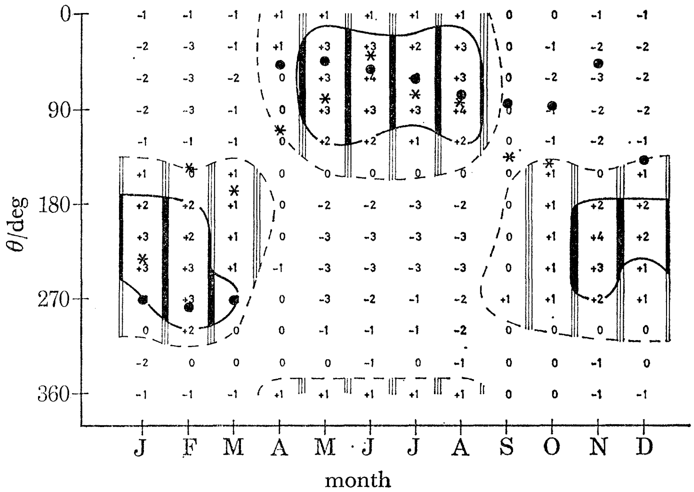

FIGURE 7. Comparison between directions of prevailing drift at Freiburg (average values over several years) and at De Bilt. ●, 1969; ✳, 1970.

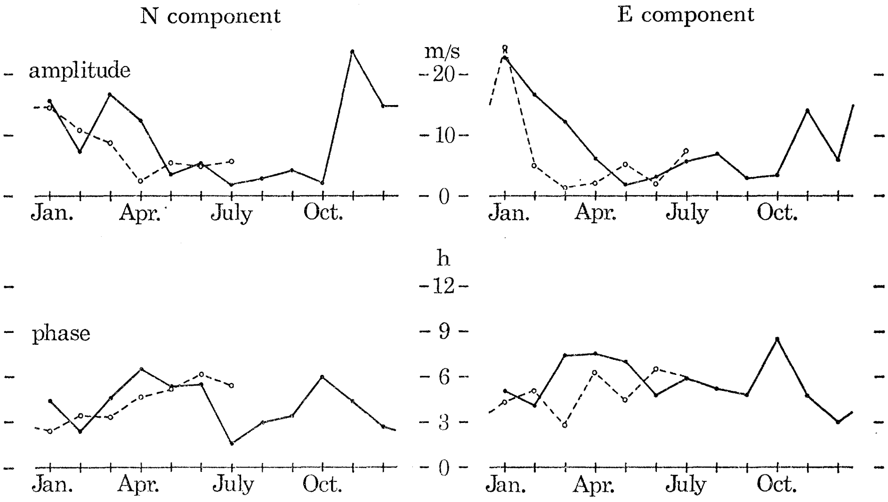

FIGURE 8. Amplitude and phase of the semidiurnal variation of E-region drift. —•—, 1969; – – o – –, 1970.

The seasonal variations of the 12 h tidal component of the drift can be seen in figures 8 and 9. In figure 8 the monthly values of the amplitude and phase for N–S and E–W component of the drift are shown. The phase is given as the time at which the drift has its maximum value

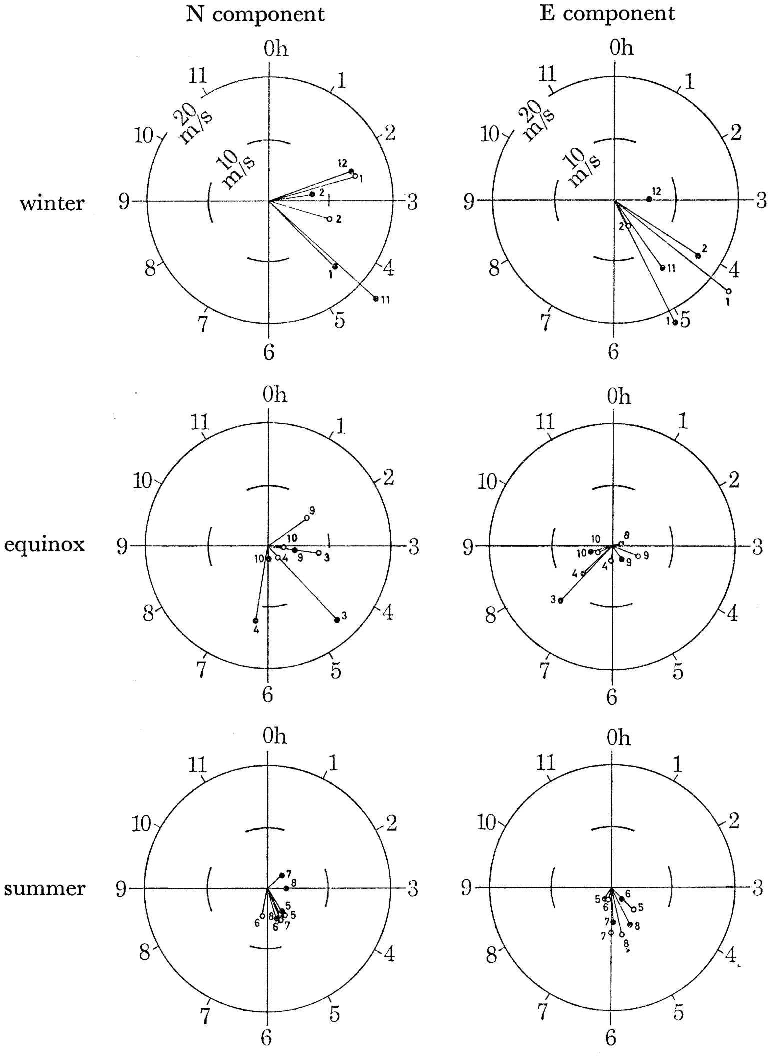

Figure 9. Harmonic dials for the monthly mean N and E components of the semidiurnal variation of the drift. ●, 1969; ○, 1970.

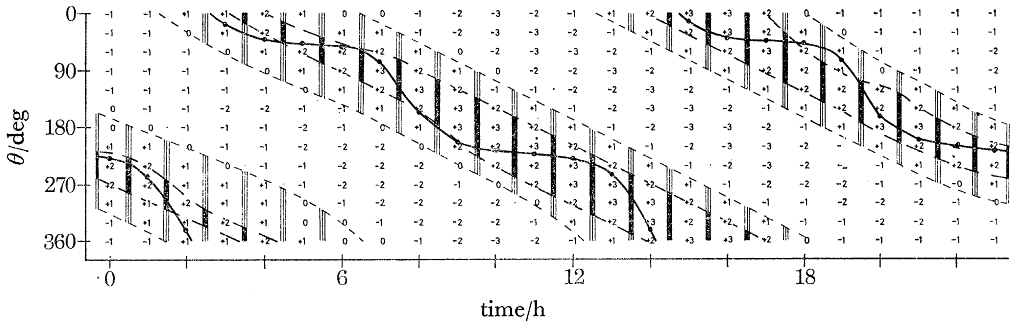

Figure 10. Comparison between directions of semidiurnal variation of E-region drift at Freiburg (average over several years, shown by shaded area) and at De Bilt during 1969 (full line).

towards N (for the N component) or towards E (for the E component). It is clear that the 12 h tide in the E-layer drift is largest in winter (20 to 25 m/s) and smallest in summer (2 to 4 m/s). The phase of the N–S component shows a semi-annual variation, advancing in late winter and late summer.

In general the phase of the N–S component is advanced by 1 h to that of the E–W component; the result being a clockwise rotation of the vector representing the 12 h tide in the E-region drift. In figure 9 the same results are given in the form of harmonic dials for the N–S and E–W components. The results for the different months have been grouped according to season to show more clearly the seasonal influence.

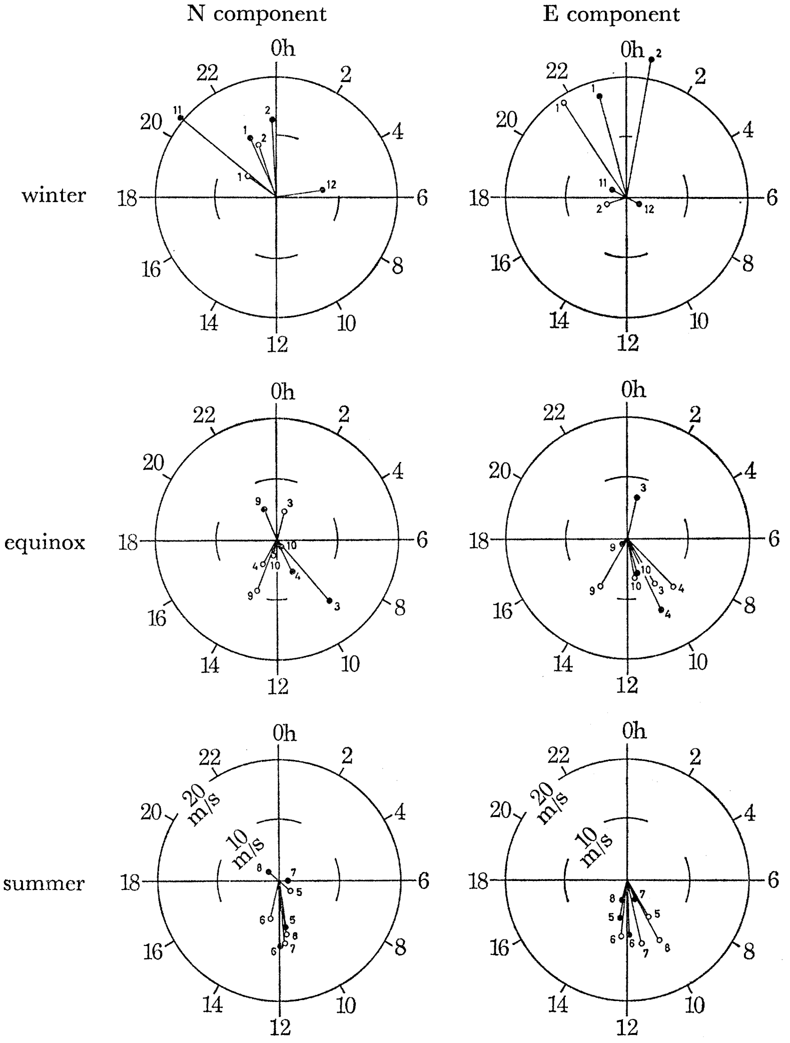

Figure 11. Harmonic dials for the monthly N and E components of the diurnal variation of the drift. ●, 1969; ○, 1970.

The direction of the 12 h tidal component, averaged over the whole of 1969, is compared in figure 10 with the most probable direction for this tidal component derived from the above-mentioned results obtained at Freiburg (Harnischmacher & Rawer 1968). The harmonic analysis for the results of Freiburg has been made with the aim of finding a vector which rotates with constant speed.

Harmonic dials for the 24 h period are given in figure 11. For the 24 h period, a phase reversal is found between summer and winter for both the N–S and E–W components. Transitions take place suddenly close to the equinoxes. Of course there is a difference in reflexion level between day and night during the winter. This level is about 10 to 15 km lower for E_s reflexions (during the night) than for reflexions from the regular E layer (during the day). An important part of the 24 h period observed may be caused by this effect. During the summer this difference is small.

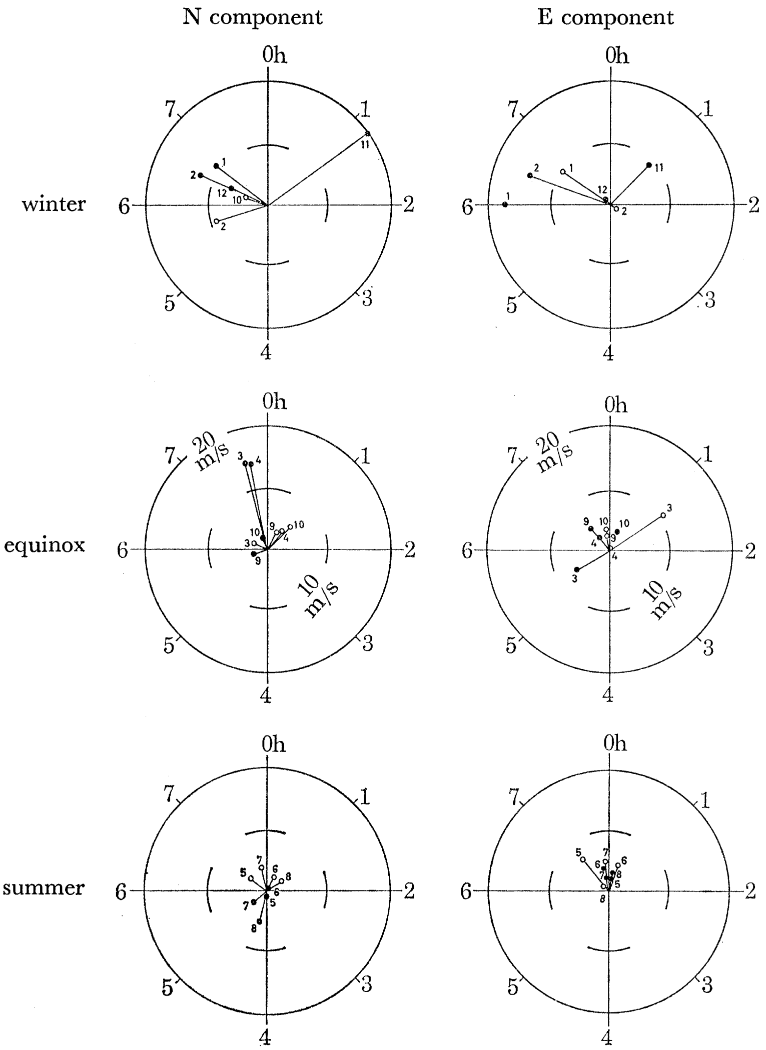

Figure 12. Harmonic dials for the monthly mean N and E components of the terdiurnal variation of the drift. ●, 1969; ○, 1970.

For completeness, harmonic dials of the 8 h period are shown in figure 12. Not much regularity can be seen in its variations over the year.

6. ACCURACY OF THE HARMONIC ANALYSIS

It is possible to estimate the accuracy of the amplitudes and phases obtained for the different components of the harmonic analysis. From the 50 % probability interval given by the difference between upper and lower quartile values and the number of observations for each hour the probable error in the values of a_h are known. Following the usual method of error calculation, the radius of the probable error circles can be calculated around the points given in the harmonic dials. It appears that the errors are somewhat larger for the winter months than for the summer. This is caused by a larger number of night measurements during the summer made possible by more frequently occurring sporadic E in that season. Table 1 gives as an example the prevailing drifts and the amplitudes of the harmonic components for January 1969 and June 1970 together with the radius of their probable error circles.

TABLE 1. RESULTS FOR JANUARY 1969 AND JUNE 1970

		prev. drift/m s^{-1}	24 h ampl./m s^{-1}	12 h ampl./m s^{-1}	8 h ampl./m s^{-1}
Jan. 1969	N comp.	-0.2 ± 1.2	10.7 ± 1.6	15.5 ± 2.1	10.5 ± 2.3
	E comp.	-7.7 ± 2.0	17.3 ± 2.8	22.8 ± 3.7	17.2 ± 5.0
June 1970	N comp.	$+2.4 \pm 0.5$	6.5 ± 0.6	4.9 ± 0.9	2.6 ± 0.8
	E comp.	$+7.6 \pm 0.5$	9.2 ± 0.9	1.9 ± 0.9	3.9 ± 0.7

7. COMPARISON WITH RESULTS OF LOW-FREQUENCY DRIFT MEASUREMENTS

The average daily behaviour of the E-region drift measurements for the different seasons as obtained at De Bilt shows some similarity with the corresponding behaviour derived from the low-frequency drift measurements carried out regularly at Kühlungsborn and Collm (Sprenger

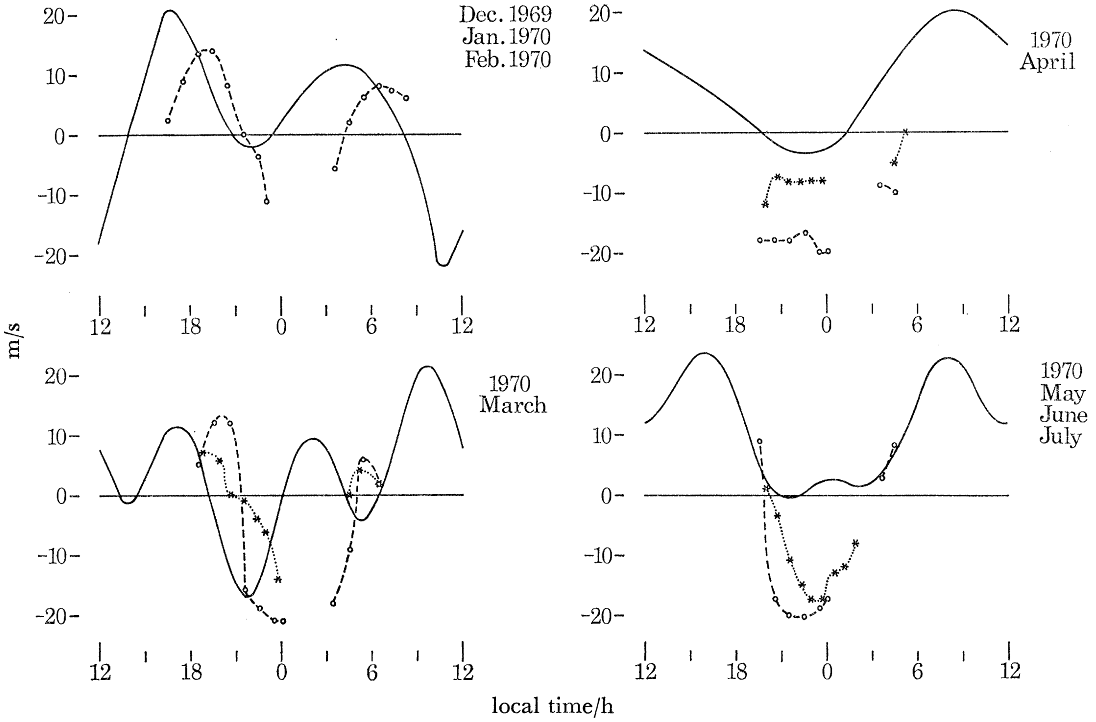

FIGURE 13. Comparison between E components of E-region drift at De Bilt (—) drift in the 95 to 100 km region at Kühlungsborn (○ – – ○) and Collm (★ . . . . ★).

& Schminder 1968) in spite of a height difference of about 15 km in reflexion level which for the low-frequency measurements is about 95 km.

Figure 13 shows a comparison of the average daily behaviour of the E components over a period of three winter months, for March 1970, April 1970 and over a period of three summer months of 1970. To facilitate comparison the time scale is so placed that midnight is in the middle. The results of all three stations have been reduced to local time. The positions of the reflexion points are 53.4° N, 12.6° E for Kühlungsborn and 50.5° N, 15.3° E for Collm. Low-frequency drift measurements are only possible during the night, so the comparison has to be limited to the night hours. During the winter a time shift exists between the results of both methods; the phase of the E-region drift advancing about 2 to 3 h compared with the drift of the 95 km level. From March to April 1970 there is in the results of all three stations a distinct change in character. For the summer months, the maximum drift towards the west occurs just before midnight for both levels.

A further comparison of the results of E-region and low-frequency drift measurements seems worth while, especially to study time-shifts in the daily behaviour for both levels.

8. COMPARISON BETWEEN APPARENT AND TRUE DRIFT

From the records of the cross-correlation functions the time-shift τ_0 for maximum cross-correlation can easily be obtained. From the pair of time-shifts τ_{on} and τ_{oe}, belonging respectively to the N–S and E–W antenna base, the components of the apparent drift velocity are calculated by the formulae

$$v'_{\text{n}} = \frac{\tau_{\text{on}}\, d}{2(\tau_{\text{on}}^2+\tau_{\text{oe}}^2)} \quad \text{and} \quad v'_{\text{e}} = \frac{\tau_{\text{oe}}\, d}{2(\tau_{\text{on}}^2+\tau_{\text{oe}}^2)},$$

where d is the distance between two antennas along an axis. The factor 2 accounts for the ratio in drift velocity between the reflexion level and the ground. The time-shifts corresponding to maximum cross-correlation are in general equal to the mean time differences found from the similar-fades method. As the similar-fades method and the calculation of the drift from the mean or median time differences is often used, a comparison between apparent and true drift velocities can be useful especially for hourly mean values.

For the month of January 1969 the hourly median values of the N–S and E–W components of the apparent drift velocities have been determined. To compare these medians with those of the true velocities, calculated from the intersection points of the correlation curves, both sets of values were first converted to total velocity and direction for each hour. In this form a better comparison is possible, because the direction should be the same for true and apparent drifts.

Figure 14 shows in the upper part the median hourly values of the total velocities of true and apparent drifts. As expected, the apparent velocities are always the larger ones. The ratio between both velocities during the day, when the larger velocities occur, is only slightly larger than 1; and the ratio is largest during the night hours for E_s reflexions. In the lower part of the figure, the directions of the mean hourly true and apparent drift velocities are compared. In general they agree well, the variations from hour to hour being somewhat smoother for the apparent velocities than for the true ones.

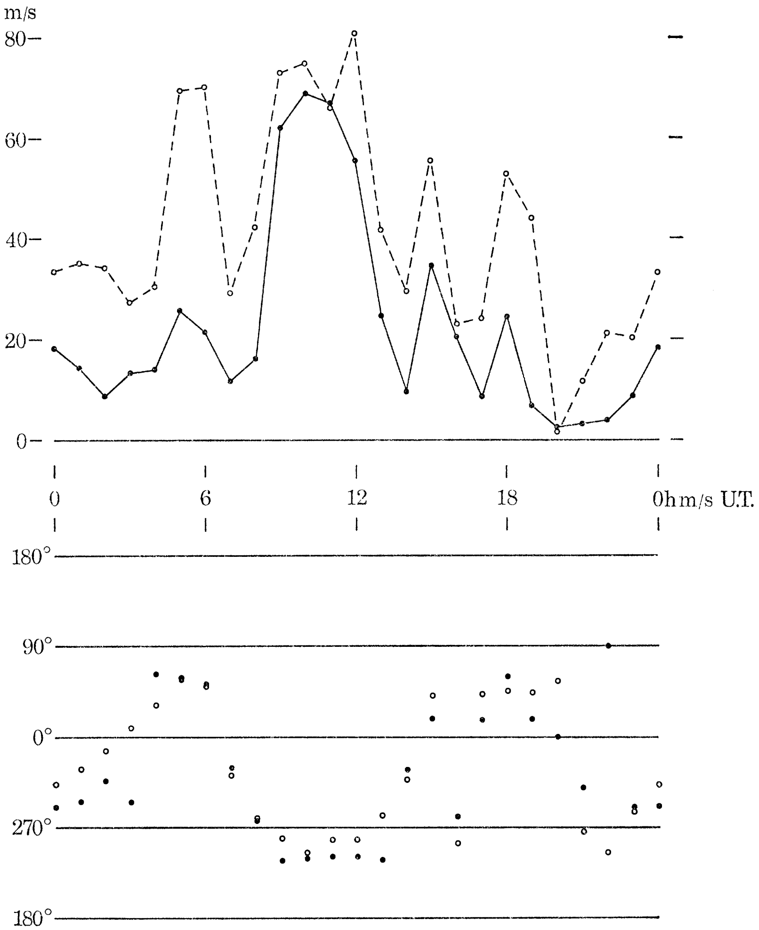

Figure 14. Comparison between hourly mean values of the true (●) and apparent (○) drift over January 1969.

9. Conclusion

From a sufficient number of E-region drift measurements, monthly patterns of the daily behaviour of the drift in this region can be derived. These patterns show characteristic seasonal variations. Although from the theoretical point of view, drift measurements in this height region probably do not reveal the wind in the neutral gas and it is doubtful if they even represent real bulk movements of electrons under all circumstances, it is worthwhile continuing these measurements. The tidal components of drift obtained must at least be related to the tidal movements in the neutral atmosphere. This relation should sooner or later become clear from comparisons with drift measurements and vapour-trail wind measurements or with meteor reflexions, a technique which reaches to heights over 100 km. The results already obtained by drift measurements will then make a contribution to the knowledge of tidal movements in the E region.

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