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CHROMOSPHERIC ROTATION

II. *Dependence on the Size of Chromospheric Features*

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Abstract. The dependence of solar rotation on the size of the chromospheric tracers is considered. On the basis of an analysis of Ca II K_3 daily filtergrams taken in the period 8 May–14 August, 1972, chromospheric features can be divided into two classes according to their size. Features with size falling into the range 24 000–110 000 km can be identified with network elements, while those falling into the range 120 000–300 000 km with active regions, or brightness features of comparable size present at high latitudes. The rotation rate is determined separately for the two families of chromospheric features by means of a cross-correlation technique which directly yields the average daily displacement of tracers due to rotation. Before computing the cross-correlation functions, chromospheric brightness data have been filtered with appropriate bandpass and highpass filters for separating spatial periodicities whose wavelengths fall into the two ranges of size, characteristic of the network pattern and of the activity centers. A difference less than 1% of the rotation rate of the two families of chromospheric features has been found. This is an indication for a substantial corotation at chromospheric levels of different short-lived features, both related to solar activity and controlled by the convective supergranular motions.

1. Introduction

Evidence for a dependence of the solar rotation rate on the lifetime of the chromospheric and coronal tracers has been found by analysing both Ca II K_3 full disk filtergrams and Fe XIV green line limb data, during the declining phase of solar cycle 20. Tracers which rotate in an almost rigid manner are present at coronal as well as at chromospheric levels and they are characterised by a much longer lifetime than tracers which rotate differentially (Antonucci *et al.*, 1979; Antonucci and Dodero, 1979).

In this paper we extend our discussion by considering the dependence of solar rotation on the size of the rotation tracers. This study is possible at chromospheric level only, since the chromospheric brightness, measured over the whole disk, provides information on the size of tracers, which is not available from the limb data of the green corona. The rotation rate is determined by means of correlation techniques which provide an objective method of analysis, by avoiding the introduction of criteria for selecting the individual rotation tracers. However, an indirect identification of the features which mainly contribute to the determination of the rotation rate is possible on the basis of their lifetime and size.

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In addition, the range of values which these parameters may assume can be established a priori, within certain limits, by choosing an appropriate method of analysis.

2. Size Distribution of Chromospheric Features

Since different features can be distinguished on the basis of their characteristic linear dimensions, the size distribution of chromospheric spatial inhomogeneities has been derived at different latitudes.

The Ca II K_3 filtergrams, daily taken at the Capri Observatory (Kiepenheuer Institut, Freiburg) during the period 8 May–14 August, 1972, have been digitized and reduced to 32 longitudinal series of chromospheric brightness data in the latitude interval 64° N–64° S (Antonucci *et al.*, 1979). That is, for each latitude zone, 4° wide, the chromospheric brightness has been averaged over surface elements 1° wide in longitude, in the interval 64° E–64° W. Then, the longitudinal data series have been corrected for limb darkening and film variations and reduced to a zero mean value.

Histograms of the size of the chromospheric brightness features present on the solar disk have been computed for each filtergram at the different latitudes within the range 64° N–64° S. The linear dimension of a chromospheric feature, or the spacing between elements which show a spatial periodicity, have been defined very simply as the interval (in degrees) between two consecutive zero crossings in the same direction of the longitudinal data series. Since the longitudinal resolution of the data series is 1°, only features exceeding 2° in longitude, or 24 000 km in size, are considered. In Figure 1, the averaged distribution of the size of chromospheric features, present in the period 8 May–14 August, 1972, is shown for each latitude zone, starting from the extreme northern latitude 64–60° N. The average of the histograms of Figure 1 is shown in Figure 2 and represents the average size distribution over the central part of the solar disk within 64° N–64° S and 64° E–64° W. The main feature common to all histograms is the predominance of small-scale structures.

A closer inspection of Figure 1 reveals that the size distribution depends on heliolatitude. In two broad zones at low latitudes, not perfectly symmetric around the equator, small features are less numerous than at higher latitudes. Toward the equator the small-scale population tends to increase again. This suggests that the number of small size features is higher outside the activity zones, since they coincide in latitude with the less populated low latitude belts. For our purposes, the latitudinal dependence of the size distribution of chromospheric features can be analysed by simply dividing the solar disk into three main latitudinal zones, characterized by different distributions. Average histograms are derived for two symmetric zones within 64–24° N and 64–24° S, and for a zone, where solar activity is essentially concentrated, within 20° N–20° S across the equator. The deviations of each histogram from the size distribution averaged over the whole solar surface (Figure 2) are shown in Figure 3.

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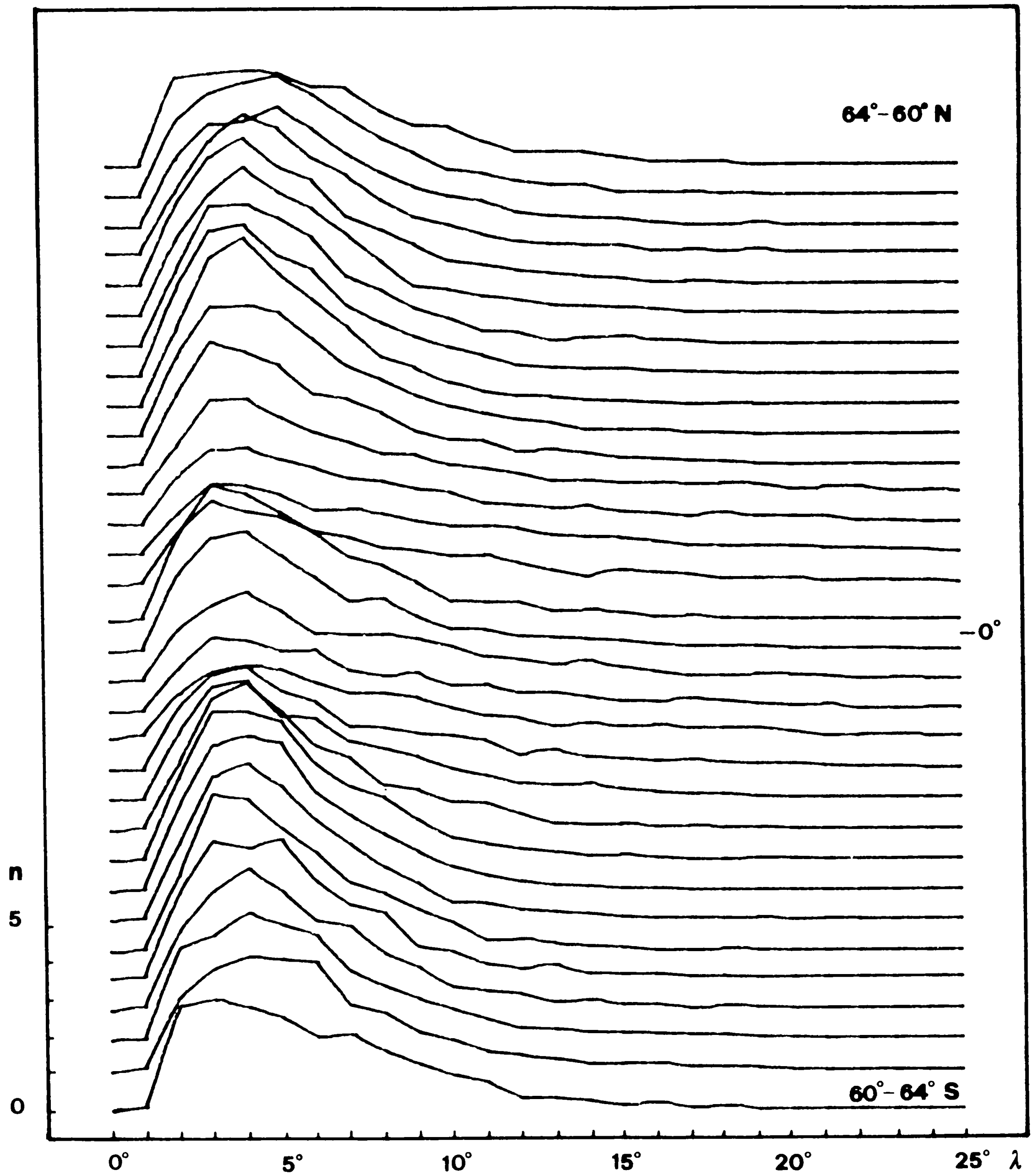

Fig. 1. Histograms of the size of chromospheric spatial inhomogeneities derived by averaging 92 histograms relative to the daily Ca II K_3 filtergrams taken during the period 8 May–14 August, 1972. They refer to 32 consecutive latitude belts 4° wide and have been plotted starting from the histogram relative to the zone 64–60° N.

Chromospheric features fall into two main classes according to their linear dimensions, and the observed occurrence in each class depends on latitude, showing therefore a relationship with the degree of activity present at a given latitude. At low latitudes, for small features, which range from 24 000 to 110 000 km in size (2–9° in longitude), a deficiency of about 8% with respect to the average full disk distribution is observed (for instance, the 23% of features of linear extension of about 4.9 ×

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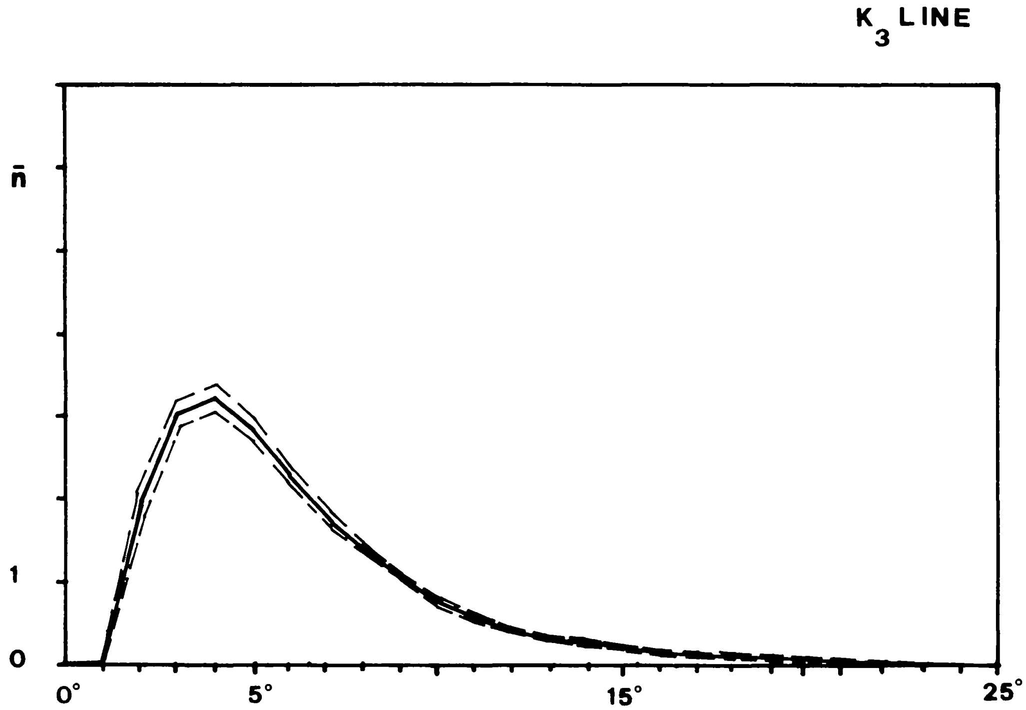

Fig. 2. The average size distribution of chromospheric features has been computed by averaging the 32 histograms plotted in Figure 1. The 68% confidence interval is shown.

$\times 10^4$ km fall within the region 20° N–20° S, while the 35% and 36% fall into the zones 64–24° N and 64–24° S, respectively). On the other hand, chromospheric features ranging from 1.2 to 3×10^5 km in size (10–25° in longitude) are much more numerous in the low latitude zone than elsewhere; in addition, the deviation from the mean distribution increases with the size of the features (17% for features of size of the order of 1.8×10^5 km, or 15° in longitude, and 52% for features exceeding 2.4×10^5 km in size, or 20°). While the number of larger-scale features shows a drastic variation with latitude (only about 52% of features with size 15° and less than 17% of features with size 20° fall outside the activity belt 20° N–20° S), small-scale features are more evenly distributed in latitude. The discriminant size value between the two classes of chromospheric features discussed above is approximately $1.2\times$ $\times10^5$ km.

It is quite obvious to identify features exceeding 1.2×10^5 km in size with active regions; however features of the same size can exist also where no active regions are observed; but their number decreases rapidly with increasing size, as noted earlier. The small-scale population covers the size range characteristic of the chromospheric network pattern, although its spread in size is somewhat larger. Simon and Leighton (1964) found approximately 20 000 to 50 000 km for the linear dimension of supergranular network cells, other observers, however, give also larger values. We suggest that the small-scale population, whose range is defined on the basis of Figure 3, is identifiable with chromospheric network elements, since it seems reasonable to assume that all the spatial periodicities with wavelength smaller than 1.2×10^5 km have the same physical origin. In fact, the distinction of chromospheric features in

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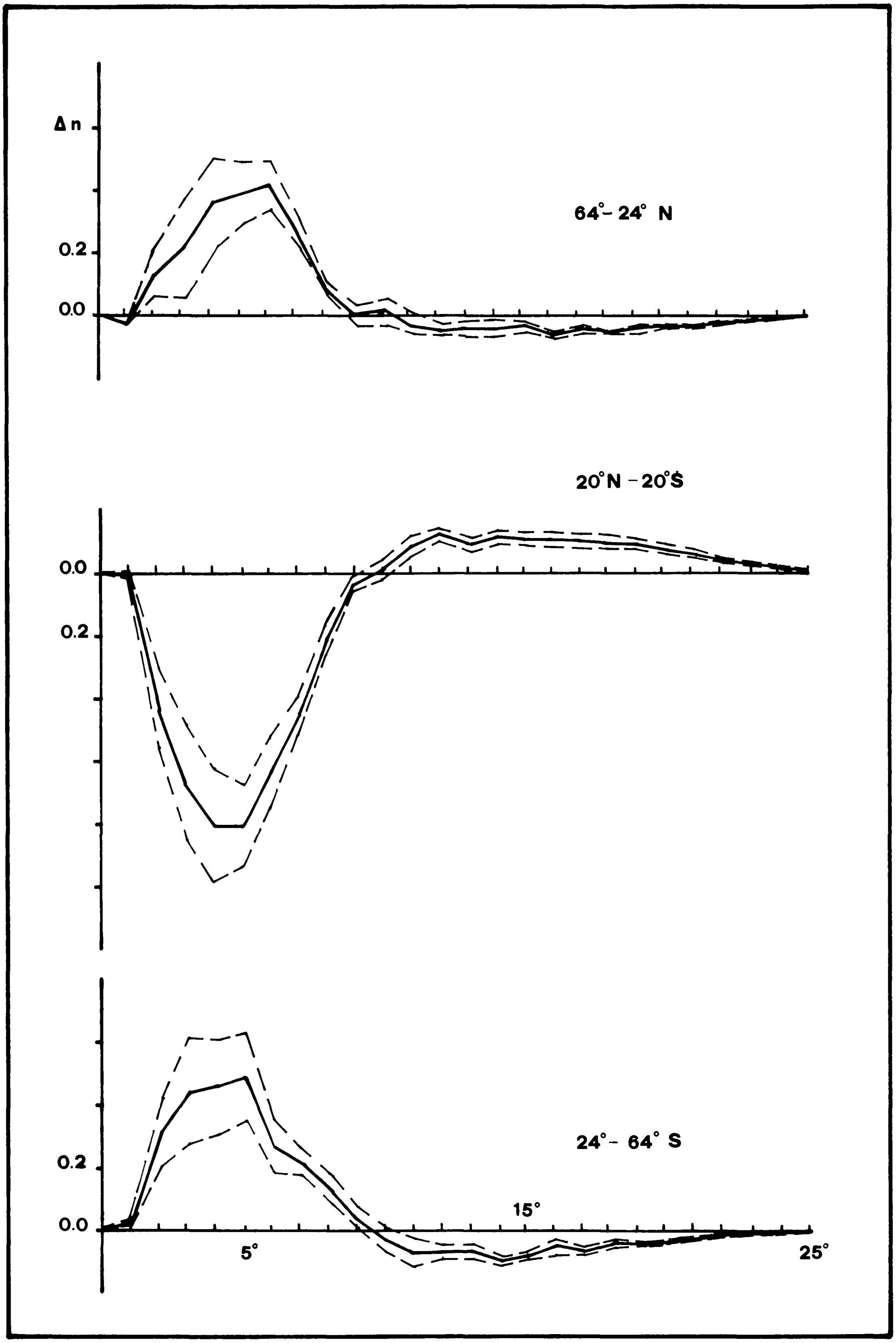

Fig. 3. The latitudinal deviations from the average size distribution shown in this figure represent the differences between the histograms averaged respectively over the latitude zones 64–24° N, 20° N–20° S, 24–64° S and the size distribution averaged over the whole disk surface considered, plotted in Figure 2. The relative 68% confidence intervals are drawn.

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two classes is derived from the relationship between the size distribution and the degree of activity manifestations at different latitudes. The deficiency of chromospheric network cells at low latitudes could be simply related to a blocking effect due to the presence of activity centers over a certain area.

3. Data Filtering and Chromospheric Feature Selection

Chromospheric rotation will be studied separately for the two classes of tracers identified, which will be indicated as small-scale and middle-scale tracers. Appropriate digital filters are designed in order to separate the two ranges of spatial periodicities, corresponding to the two classes of linear dimensions discussed earlier. The response functions and the weighting functions, respectively in the wavenumber and space domain (longitudinal degrees), of the two digital filters are shown in Figure 4. The bandpass filter BP selects middle-scale tracers, hence peaks at the 8th component in the wavenumber domain, which corresponds to a wavelength of 16°.

The response decreases symmetrically from unity to $1/\sqrt{2}$ at wavenumbers corresponding to wavelengths 25.°6 and 11.°6. This is approximately the size range defined for middle-scale chromospheric features.

The high pass filter HP is designed to select the higher wavenumber components, since the contribution of features of size larger than 9° is attenuated by factors exceeding $1/\sqrt{2}$.

The data filtering procedure is illustrated in Figure 5, for a low latitude belt. The original longitudinal series (a) of 128 data, at intervals of 1° from 64° E to 64° W, of the Ca II K_3 brightness is filtered respectively with the BP and HP filters (b). The filtered data represent separately the low and high wavenumber contributions (c). The combination of the two sets of filtered data reproduces the original signal, except for the very low wavenumber components canceled by both filters (d). The chromospheric brightness of a high latitude zone is analysed in Figure 6. In this case the dominant contribution of spatial periodicities associated with the network pattern is evident. By determining the chromospheric rotation rate from the longitudinal series, previously filtered with the BP or the HP filters, the rotational properties of the two classes of tracers we are interested in can be distinguished.

4. Rotation Rate Determination

Once the longitudinal data series of chromospheric brightness have been filtered with the HP or the BP filters, the rotation rate for both small-scale and middle-scale features is computed by the same method used for determining the rotation of the average short-lived chromosphere (Antonucci *et al.*, 1979). The daily displacement, due to rotation, of the chromospheric features belonging to the selected class is measured by cross-correlating the chromospheric brightness observed in consecutive days at a given latitude. Hence, the results refer to features with lifetime longer than one day. In the period 8 May–14 August, 1972, 91 pairs of consecutive daily

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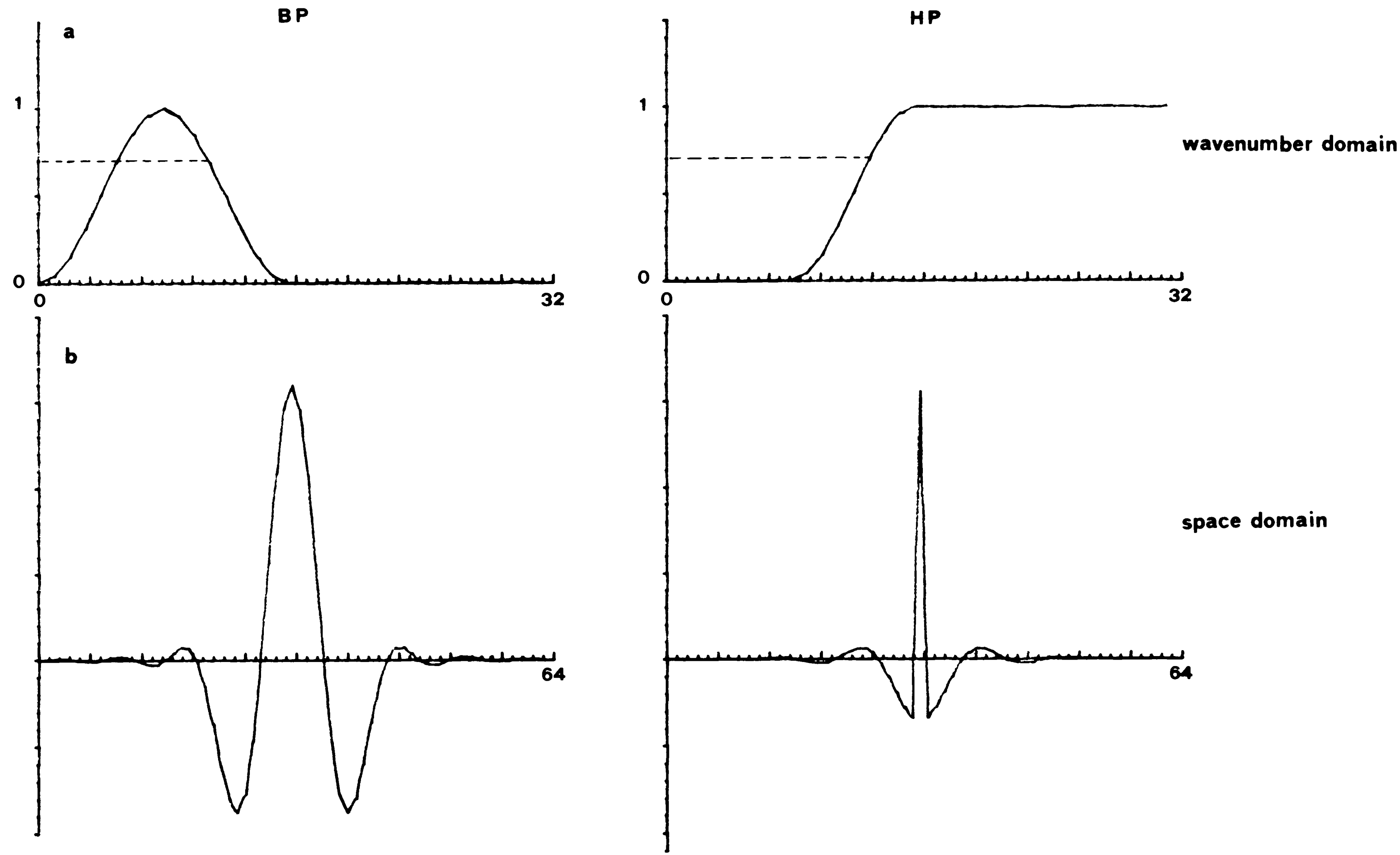

Fig. 4. Response functions in the wavenumber domain and weighting functions in the space domain (in longitudinal degrees) for the band pass and high pass filters. The $1/\sqrt{2}$ attenuation level is drawn for the response functions.

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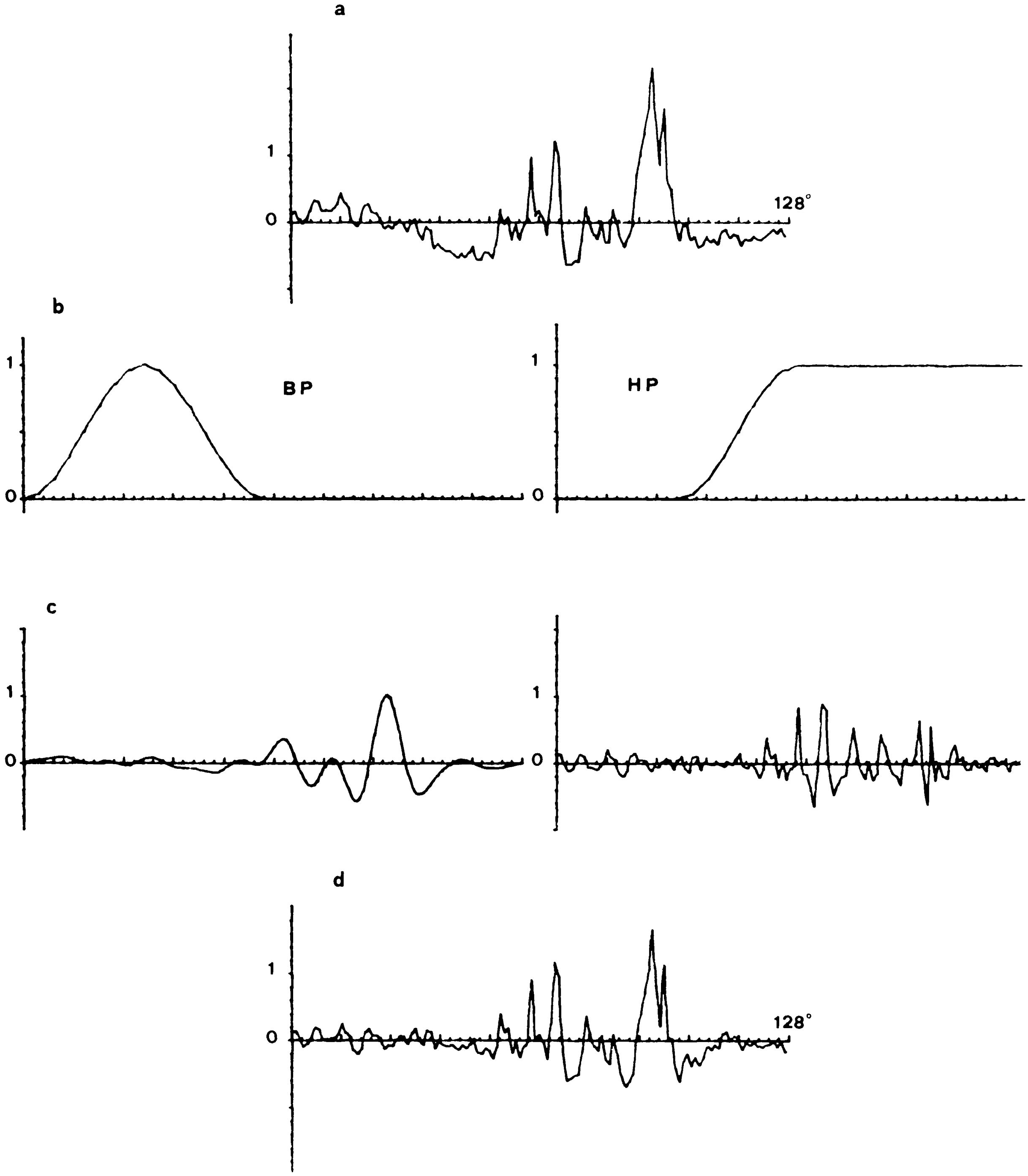

Fig. 5. Illustration of data filtering: (a) Longitudinal series of chromospheric brightness data in the Ca II K_3 line; (b) band pass and high pass filter responses in the wavenumber domain in the range of the first 32 components: $1/128° \leq k \leq 32/128°$ (k wavenumber in degree^{-1}), the attenuation $1/\sqrt{2}$ is shown; (c) longitudinal series respectively filtered with the BP and HP filters; (d) superposition of the two filtered data series plotted in (c). This example of chromospheric data series refers to a latitude zone in the range 20° N–20° S.

filtergrams are available. An average cross-correlation function for each latitude belt is derived by superposing these 91 cross-correlation functions. The individual cross-correlation functions were averaged after a normalization which takes into

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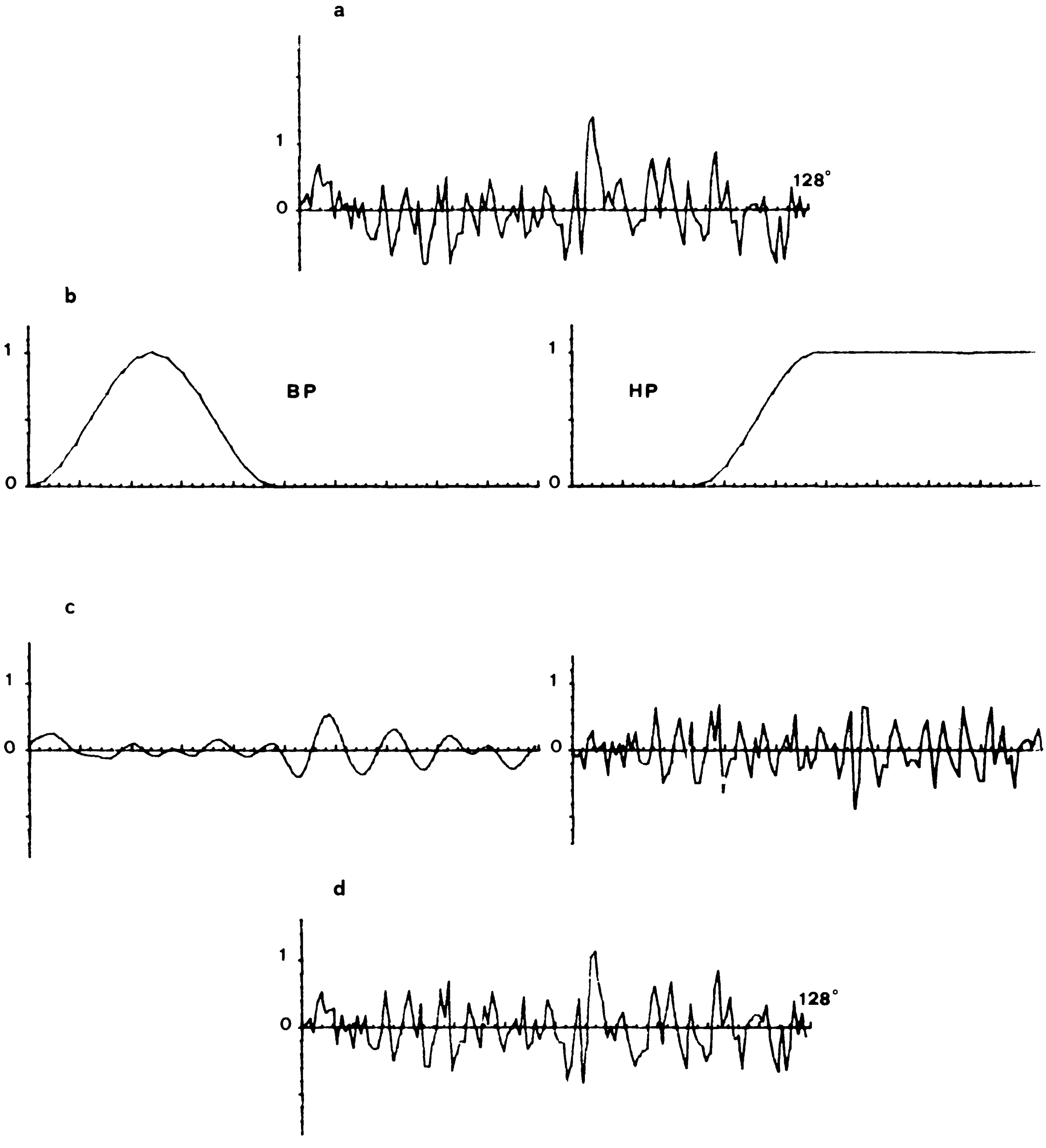

Fig. 6. Data filtering procedure applied to a longitudinal series of chromospheric brightness in the latitude range 64–24°.

account the variability of the time interval between two consecutive observations. The average daily displacement of chromospheric features belonging to a given class is derived from the lag, in degrees, of the positive peak of the average cross-correlation function. Since one day has been used as the time interval between two observations, the lag of the peak directly yields the angular velocity of chromospheric tracers in degree day^{-1}. The average cross-correlation functions for the different latitude belts are shown in Figures 7 and 8 respectively for data filtered with the BP

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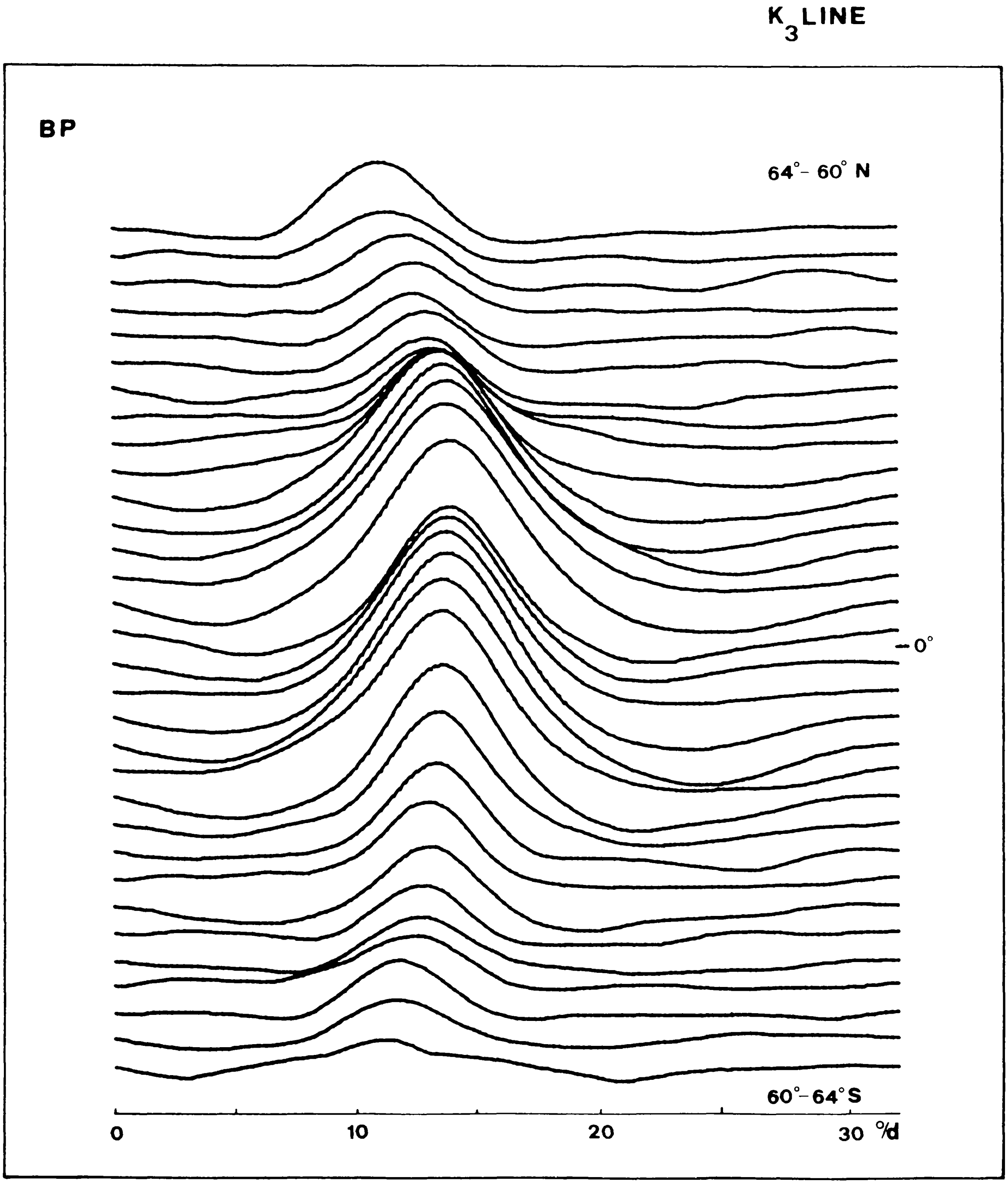

Fig. 7. Average cross-correlation functions of the chromospheric brightness measured in two consecutive days at different latitude zones 4° wide in the range 64° N–64° S, for the period 8 May–14 August, 1972. The lag of the positive cross-correlation peaks represent the displacement of chromospheric rotation tracers in one day interval. That is, the angular velocity, in degree day^{-1}, as function of latitude is indicated by the peak lags, for features of size in the range 25–11° in longitude (BP filter).

and HP filters. Hence, they refer to chromospheric features of size $1.4–3 \times 10^5$ km and $0.24–1.1 \times 10^5$ km respectively. There is no uncertainty in the identification of the cross-correlation peak due to rotation. The angular velocity dependence on latitude is clearly seen for both small and middle-size chromospheric tracers. As is

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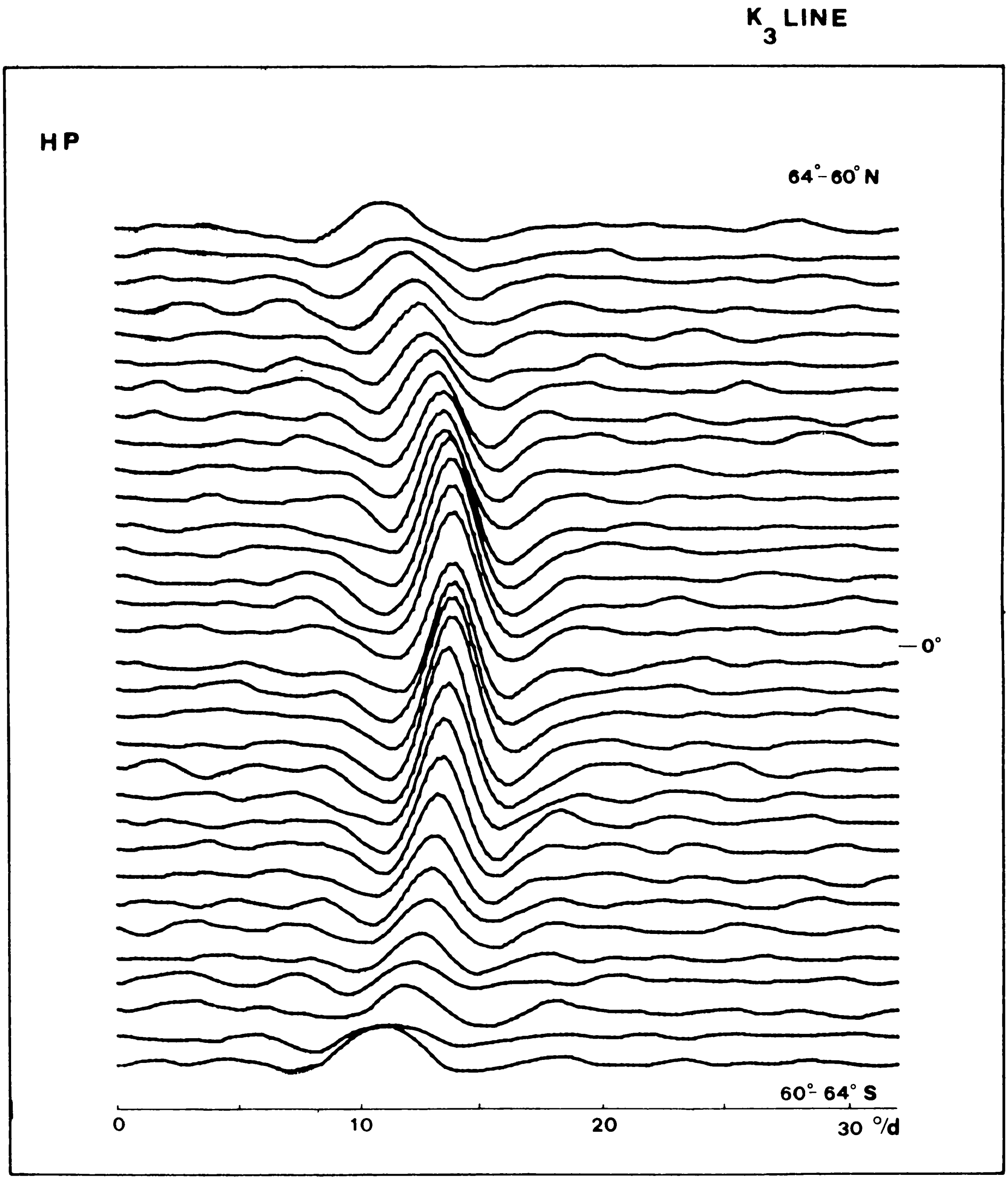

Fig. 8. Average cross-correlation functions for HP filtered data. The cross-correlation peaks indicate the angular velocity, in degree day^{-1}, as function of latitude for chromospheric tracers of size smaller than 9° in longitude.

seen in Figures 7 and 8 the magnitude of the cross-correlation coefficient also depends on latitude; the highest correlation is found at 10° N and S (0.72 and 0.48 respectively for middle and small-size tracers). The variation of the amplitude of the cross-correlation peak (shown in Figure 9) which is larger for tracers of broader dimensions could be due to visibility as well as to lifetime effects.

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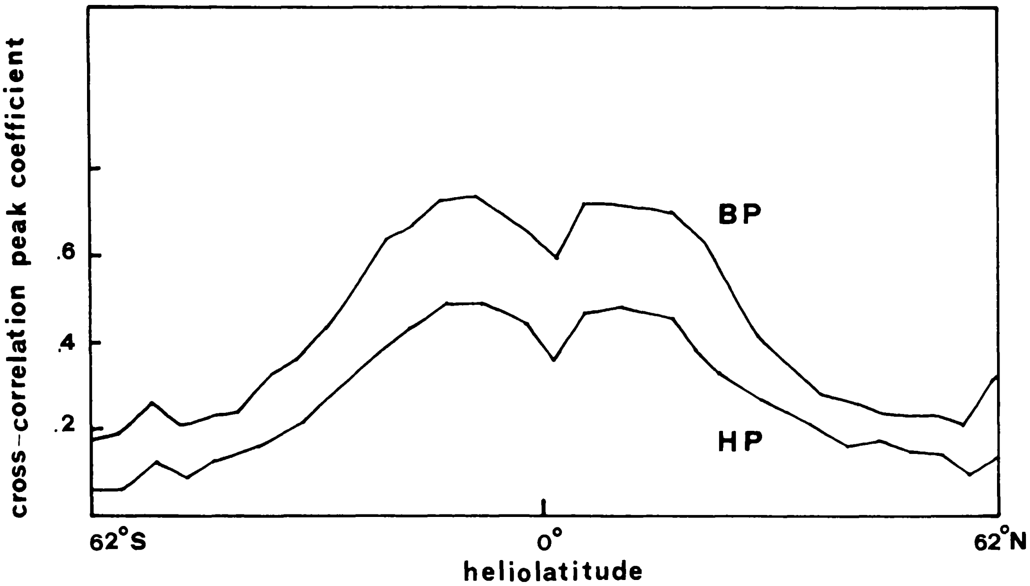

Fig. 9. Amplitude of the cross-correlation positive peaks, revealing the daily displacement of rotation tracers, versus heliolatitude for BP and HP filtered data.

The rotation profiles derived for chromospheric tracers of small and middle-size, which have been respectively identified with features related to solar activity, at least at low latitudes, and with chromospheric network elements, are compared in Figure 10. These results are best represented within 48° in latitude by the following expressions for sidereal rotation in degree day^{-1}:

$$\omega = 14.67 - 2.50 \sin^2 \varphi, \qquad \sigma = 0.02 \text{ (small-scale features)},$$

and

$$\omega = 14.50 - 2.54 \sin^2 \varphi, \qquad \sigma = 0.05 \text{ (middle-scale features)},$$

where φ is the heliolatitude and σ is the rms deviation of the data points from the fitted curves. In Figure 10, the rotation rate derived by Antonucci *et al.* (1979) for the average chromospheric pattern (no filter has been applied to the chromospheric data) is also shown for comparison and is represented within ±48° in latitude by the expression: $\omega = 14.66 - 2.79 \sin^2 \varphi$; $\sigma = 0.05$.

A slight systematic tendency for chromospheric network elements to rotate faster than chromospheric active regions, and features of comparable size, is suggested at all latitudes. However the difference in rotation rate does not exceed 1% and just exceeds the uncertainty due to the scattering of data points about the fitted curves. Hence, only a slight dependence on the size of chromospheric features in the range considered, i.e. 24 000–300 000 km, is suggested by our analysis.

As noted earlier in this analysis we take into account tracers with lifetime exceeding one day, that is, short-lived features mainly contribute to the rotation rate that has previously been determined.

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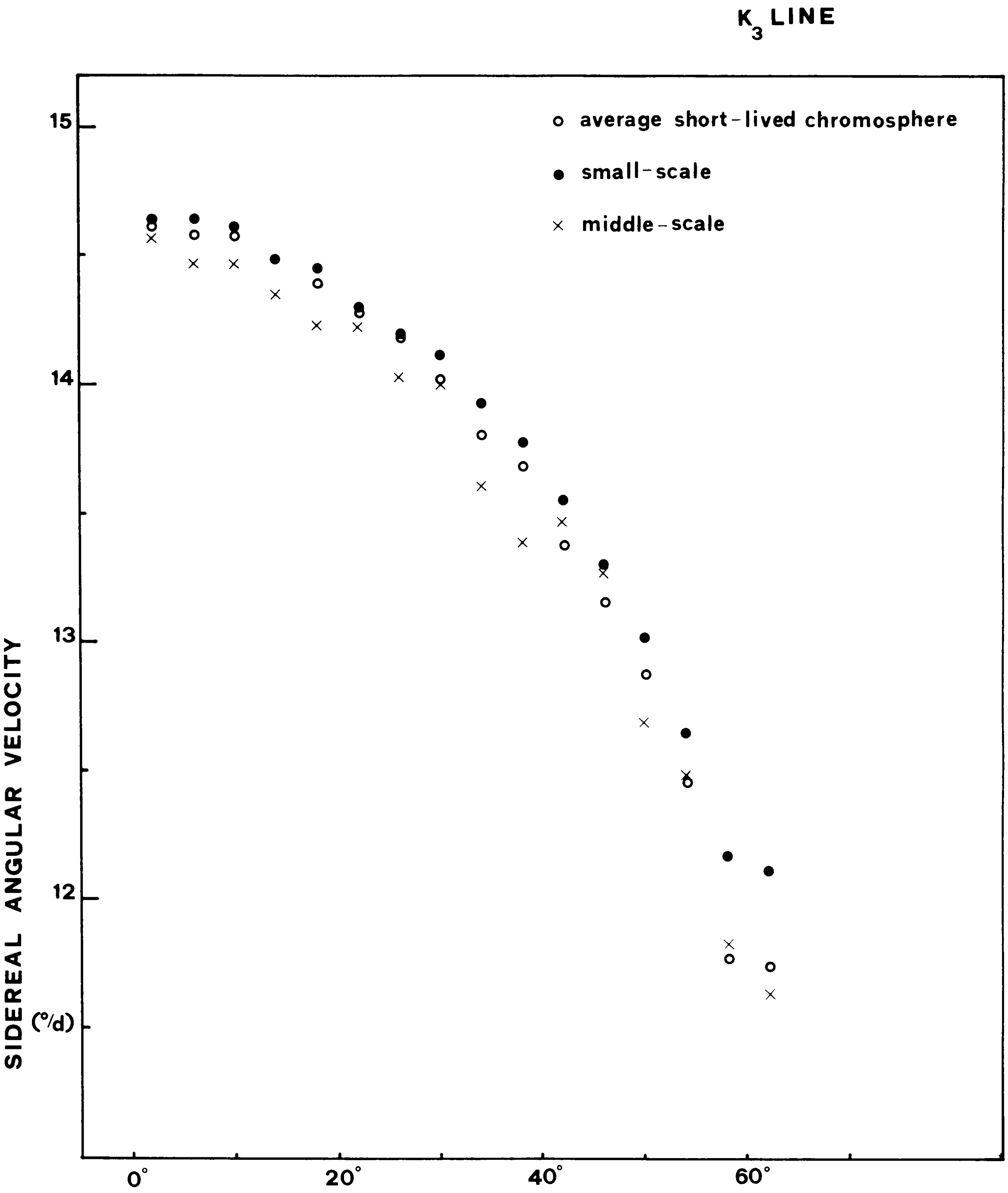

Fig. 10. Comparison of the rotation rates of the average pattern of the short-lived chromosphere (Antonucci *et al.*, 1979), of the chromospheric network (small-size features) and of active regions (middle size features), for the period 8 May–14 August, 1972. The values of both hemispheres have been averaged.

Unfortunately, the method here used to establish the dependence of rotation on the linear dimension of tracers cannot be safely applied for very large-scale chromospheric patterns, that is, corresponding to wavelengths larger than 25° in longitude, since the information on such patterns is contained in few very low wavenumber components which are influenced by spurious effects, probably not

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completely canceled by the corrections performed. Therefore, we are not able to verify by studying the daily displacement of tracers whether the long-lived (lifetime longer than 27 days) and rigidly rotating features observed in the Ca II K_3 line during 1972–1973 are part of a very large-scale chromospheric structure as suggested (Antonucci *et al.*, 1977).

In conclusion, chromospheric features with sizes within 24–300 10^3 km and lifetime exceeding one day, exhibit approximately the same differential rotation, although a tendency for smaller features to rotate faster is found. This difference however does not exceed 1%. That is, the different short-lived features both representative of the quiet chromosphere and associated with solar activity, such as network pattern elements and active regions respectively, do corotate at chromospheric levels.

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References

Antonucci, E.: 1979, *Proceedings Solar Rotation Workshop – Catania*, p. 204.
Antonucci, E. and Dodero, M. A.: 1079, *Solar Phys.* **62**, 107.
Antonucci, E., Azzarelli, L., Casalini, P., and Cerri, S.: 1977, *Solar Phys.* **53**, 519.
Antonucci, E., Azzarelli, L., Casalini, P., Cerri, S., and Denoth, F.: 1979, *Solar Phys.* (in press).
Simon, G. W. and Leighton, R. B.: 1964, *Astrophys. J.* **140**, 1120.

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