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Mean monthly wind hodographs in the low troposphere in Zagreb*

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The analyses of mean monthly vertical wind profiles in the layer from the ground to 3 km height are shown, on the basis of radiosounding data in Zagreb-Maksimir, at 00 and 12 GMT, 1972–1981. It is shown that a daily variation of vector mean wind extends throughout the considered layer, with more southerly wind direction in the daytime term. However, the local effects, which are very pronounced in the daily variation of speed and direction of the slope and valley winds, are confined to a shallow surface layer. The upper level daily wind variation is attached to the influence of mesoscale mountain circulation in the Alpine region, which, by the entrainment processes, contributes to the low steadiness of the boundary layer winds. These processes cannot be followed directly in the monthly mean vertical wind structure, since the mean wind vectors represent the frequencies of particular wind speed and direction in the individual months and seasons. These frequencies, however reflect the changes in large scale atmospheric circulation and its anomalies, which are responsible for both mesoscale mountain circulation and the behaviour of local boundary layer wind structure.

Due to the known variations of the large scale flow pattern and their influence on anomalous monthly mean wind hodographs, one could expect that the selected 10-year data sampling is not sufficiently representative for the long-term, climatological, wind structure in the lower troposphere of Zagreb. An example for the month of October shows, on the contrary, that the main wind characteristics in the middle (850 hPa) and at the top (700 hPa) of the considered layer remain unchanged if the period is extended to a 30-year set of data.

Hodografi mjesečnih vektorskih srednjaka vjetra u donjoj troposferi za Zagreb

Prikazane su analize srednjih mjesečnih vertikalnih profila vjetra u sloju od tla do 3 km visine na osnovu radiosondažnih podataka za Zagreb-Maksimir u 01 h i 13 h SEV, 1972–1981.

Pokazano je da se dnevno kolebanje vektorskih srednjaka vjetra proteže kroz cijeli promatrani sloj s izraženijom južnom komponentom vjetra u danjem terminu. Međutim, lokalni efekti su ograničeni na vrlo plitki prizemni sloj u kojem se dnevna kolebanja odražavaju u promjeni brzine i smjera vjetra obronka i

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vjetra doline. Dnevna kolebanja vjetra u višim slojevima pripisuju se utjecaju planinske cirkulacije mezorazmjera u Alpskom području, koja interakcionim procesima doprinosi maloj stalnosti vjetra u graničnom sloju. Ovi procesi se ne mogu direktno pratiti u vertikalnoj strukturi mjesečnog srednjaka vjetra s obzirom da vektorski srednjaci prikazuju čestine vjetra određene brzine i smjera u pojedinim mjesecima i sezonama. Međutim, ove čestine odražavaju promjene atmosferske cirkulacije i njezina anomalna stanja koja utječu na planinsku cirkulaciju mezorazmjera, i na ponašanje vjetra lokalnih razmjera u graničnom sloju.

Zbog poznatih kolebanja makrostrujanja u kraćim i dužim vremenskim razdobljima, i njihovog utjecaja na anomalije srednjih mjesečnih hodografa vjetra, moglo bi se očekivati da odabrani 10-godišnji uzorak podataka nije reprezentativan za dugogodišnju, klimatološku, strukturu vjetra u donjoj troposferi nad Zagrebom. Primjer za mjesec listopad pokazuje suprotno, da se osnovne karakteristike vjetra u sredini (850 hPa) i pri vrhu (700 hPa) promatranog sloja bitno ne mijenjaju ako se period produži na 30-godišnji niz podataka.

1. Introduction

Statistical analyses of wind regime in Zagreb (Lisac, 1984; Poje, 1982; Lončar, 1982) indicate a dominant influence of local topography on daily surface wind variations. Since the analyses have shown that a ten-year data set is sufficient to eliminate the influence of large scale wind variations on the local wind regime, we have also used a ten-year period for studying the vertical wind structure in the lower troposphere.

Our intention was to investigate: 1) how far above the ground one can find the local night and daytime wind characteristics, 2) how deep is the layer with diurnal wind variation influenced by the mesoscale circulation in the Alpine region, and 3) how much the details of higher levels wind structure change from month to month under the influence of large scale atmospheric circulation in the long term mean, and circulation anomalies from year in a particular month.

In the previous study of this problem (Jurčec, 1985) the mean vertical wind profiles for Zagreb up to 3 km altitude in the spring months 1972-81 have shown an expressed daily wind variation throughout this layer, but with large variability, marked by the low value of steadiness, in the boundary layer. However, the analysis of the wind structure in these months does not give us a clearer idea on the depth of the boundary layer. In particular, the boundary layer theories predict some balance states by which the wind profile would take a form of the Ekman spiral. This was not found in the spring months and could be generally questioned in the region of complex terrain due to possible large vertical motion and divergence field on the local scale (Jurčec and Bajić, 1985) and their dependence on the geostrophic wind field above the variable boundary layer.

The main characteristic of the wind profiles in the above study of spring months was the diurnal wind variability, by which the daytime wind vector mean had a more southerly direction in respect to the night wind. This was not the case only in the mid-layer of March, leading to a question whether such characteristics hold for the winter months. On the other hand it was very expressed in the case of extremely warm May 1979, suggesting that the diurnal wind variation at the higher levels are caused by the mesoscale mountain circulation in the Alpine region, which is particularly effective during the hot spells when the mountain acts as a heat source and sink, and when the differential heating between the mountain tops and the free atmosphere at the same levels causes a strong thermal wind field in the lower troposphere.

The objective of this paper is to present the characteristics of the mean vertical wind profiles, according to the radiosounding data at Zagreb-Maksimir, for the same period (1972–1981) and the same layer (up to 3 km) as in the previous study, but for all 12 months as well as the annual mean values.

2. Vertical distribution of the annual scalar and vector mean wind

Fig. 1 presents vertical profiles of the annual scalar mean wind (wind speed) at 01 h and 13 h MET (00 and 12 GMT) for Zagreb-Maksimir for the period 1972–81 in the layer from the ground (128 m) to 3 km.

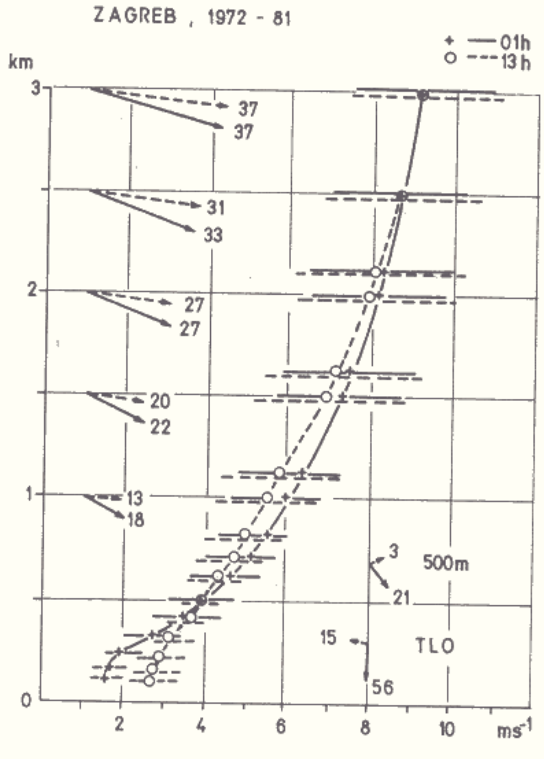

Figure 1. Vertical profiles of annual scalar and vector mean wind in Zagreb-Maksimir, 00 and 12 GMT, 1972–81, at the standard geometric heights: ground (128 m), 178 m, and each 100 m up to 828 m, and each 500 m to 2000 m (2128 m) above the ground. The extremes for 10-year monthly means for scalar values are indicated for both terms, and the steadiness (in percentage) for vector means is written at the end of the arrows.

In the surface layer up to 500 m the wind speed is higher at 13 h in all months. In the first 1 km layer the maximum speeds are reached in April for both terms. Above this level the maximum speed occurs in December. December at the same time has the minimum speed at 01 h in the surface layer up to 50 m, representing, therefore, the month with the largest vertical wind shear in the lowest 1 km layer. The other minima, from 100 m to 3 km at both terms, belong to the month of August.

The annual vector wind mean values indicate the highest steadiness (expressed as a ratio of vector and scalar mean wind) for the 01 h surface wind, the nighttime downslope wind at this locality. Daytime low level winds show a very large variability, and only above 1 km does the steadiness reach the same value as it has at 01 h. An essential characteristic of the mean annual wind vectors is a difference in direction indicating that daytime mean wind has at all levels above the ground more southerly direction with respect to the nighttime wind direction. At the ground level the wind direction at this locality indicates the prevailing easterly up-valley wind direction.

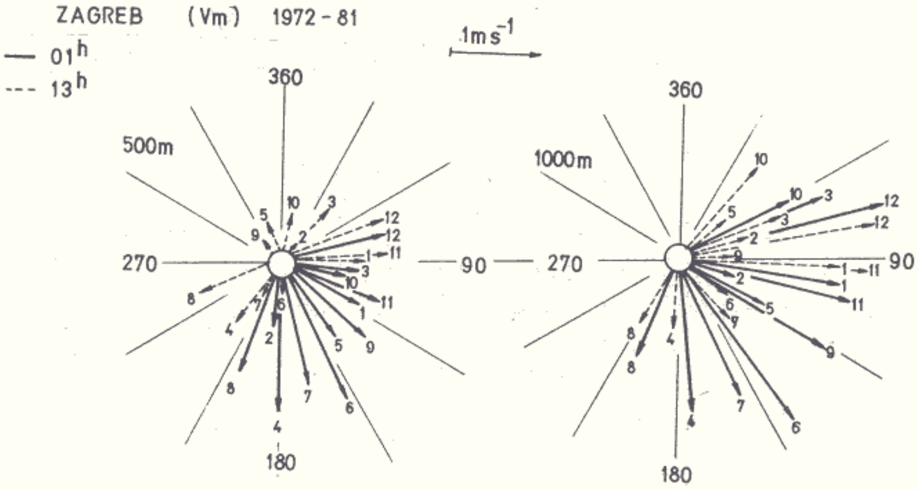

Figure 2. Vector mean wind at the heights of 500 m and 1000 m for all months of the year (indicated by numbers 1 – 12) at 00 and 12 GMT, 1972–81, Zagreb-Maksimir.

To get an idea of the relationship between this annual vector mean and the monthly means in the lower levels, in Fig. 2 the monthly wind vectors are shown at the heights of 500 m and 1000 m. It is seen that the summer months and April have northerly mean winds even at 13 h, although they are much weaker than at 01 h. On the other hand, December at both of these heights, and March and October at 1000 m have SW-WSW wind direction even at nighttime. Surface and higher level wind directions are shown on the hodographs in Fig. 3.

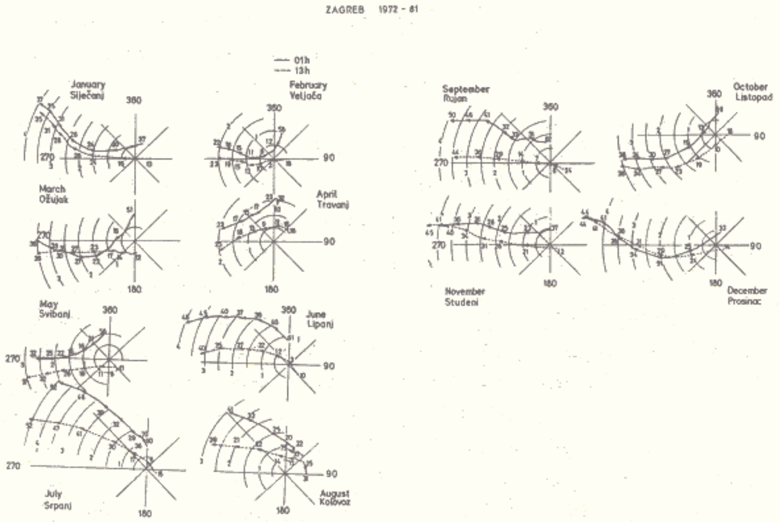

Figure 3. Mean monthly wind hodographs from the ground (128 m) to 3 km at 00 and 12 GMT, 1972–81, Zagreb-Maksimir. Arrows indicate the direction and speed of the wind vector at each 500 m altitude with the numbers indicating the value of steadiness (in percentage) for these heights.

3. Mean monthly wind hodographs

Hodographs of the mean monthly wind vectors are shown in this chapter according to the direction from which the wind blows, as usually presented on the wind rose.

In Fig. 3 the arrows indicate the winds at each 500 m with the value of steadiness marked at the same heights. Surface winds at 01 h show the highest steadiness in the summer months, September and April, with the maximum in August which also has the highest value at 13 h in respect to the other months. Steadiness decreases rather rapidly above the ground with the highest values exceeding 30 % only in June and September at 01 h.

The peculiarity of the April 01 h hodograph is a slow decrease of steadiness in the first 1 km layer in which the northerly winds persist, indicating a very deep layer along the mean downslope wind component. In this month, as well as in summer months, the wind is backing with height even at 13 h, indicating the influence of the prevailing large scale northwesterlies on the low level wind regime.

Summer months and September have also the largest difference in the wind direction between night and day time at higher levels. This supports our already mentioned results of the mesoscale mountain circulation influence on daily wind variation throughout the considered tropospheric layer in the warm season. Since the well known mountain characteristic during the warm season is a heat low (as a heat source) during the daytime, and a high (a sink) at the night time, a cyclonic (anticyclonic) circulation is superimposed on a day (night) flow pattern. Thus, the upper level diurnal wind variation in our analysis is interpreted by the changes in the geostrophic flow due to mountain heating (and cooling) effects. They are particularly effective in the summer time (June to September) when the diurnal changes are largest, but the analysis suggests that these effects exist throughout the year.

The smallest difference between night and daytime upper level winds are in November and December. December and March are the only months in which 01 and 13 h hodographs do not follow the diurnal variation feature in the middle layer. This is probably due to a frequently formed elevated temperature inversion in these months, causing a decoupling of the higher and lower layer flow with zero-vertical wind shear in the vicinity of extreme (minimum or maximum) winds. The examples are shown in the author's recent paper based on the analyses of ALPEX SOP data in Zagreb (Jurčec, 1986).

As indicated in the introduction, when taking over this study we were hoping to learn more about the wind behaviour in the boundary layer, and possibly get an estimate of the boundary layer height based on the wind structure. This seem to be a difficult problem and probably cannot be answered on the basis of the mean wind structure as presented here. Two reasons could be given, at least, as the explanation of this difficulty.

First, the mean wind vectors do not necessarily present the prevailing winds in the boundary layer, but they express their frequencies in the particular month and a sampling data set. Thus, backing of the wind, indicating NW winds in the nocturnal boundary layer may be due to an equal frequency of northerlies (or a deep layer of downslope night winds) and of the westerly flow, with none of the NW winds indicated by their vector's mean, as it is almost the case at 500 m for October in Fig. 4.

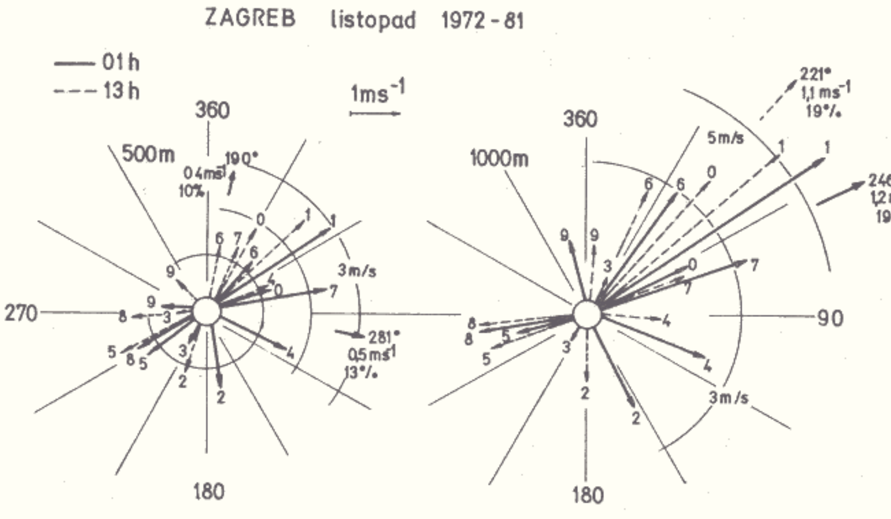

Figure 4. Mean monthly wind vectors at 500 and 1000 m altitude for October of particular years in the 1972–81. period. Numbers indicate years according to the last figure (2 is 1972, 0 is 1980, etc.) and the arrows with indicated direction speed and steadiness are 10–year vector means for October at 00 and 12 GMT from Fig. 2.

Second, mean vector's wind direction could be the result of a realistic wind distribution, but with a few very anomalous cases entering the particular data sampling. Such a case could be in the boundary layer nighttime hodograph in August, representing the only example in which turning of the wind with height resembles the theoretical Ekman spiral, assuming that the wind is geostrophic above the height of 1 km. However, there are years in which the flow associated with high pressure or Azores ridge dominates over this region, with prevailing NE winds in the lowest layer. Since this flow remains during the daytime, the 13 h hodograph of this month indicates backing of the wind, which is opposite from the veering expected in the Ekman layer. Another example is the October hodograph in which only the daytime wind profile resembles the predicted by the Ekman layer theory. October is the only month with the mean SW wind in the upper levels and we will look more closely at the particular year profiles of this month in order to ilustrate what is said above.

4. Mean wind vectors and examples of monthly hodographs in October

Fig. 4 illustrates the mean vector winds for each year of the considered 10-year data set at both terms for two heights 500 m and 1000 m. It is seen that at 500 m most vector directions are from NE and SW. These are generally prevailing winds in this region due to air flow around the mountains (both the Alps on the mesoscale and the Medvednica mountain on the local scale) in stably stratified low tropospheric layers. 10-year mean vectors, therefore, do not represent these monthly means, and their interannual variations are expressed by the low steadiness. At 1000 m 10-year mean vectors already give better presentation of the SW winds, with the largest magnitudes in October 1981 and 1976. In the opposite direction are the wind vectors in 1978 and 1975. The hodographs for these years are shown in Fig. 5.

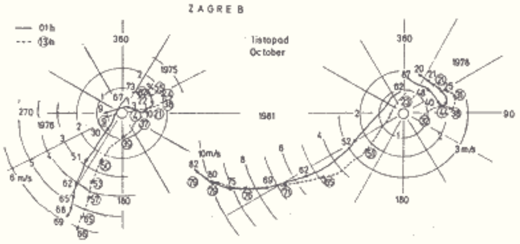

Figure 5. Selected hodographs of the mean monthly wind vectors of October for the years 1975, 1976, 1978 and 1981 at 00 and 12 GMT from the ground level (128 m) up to 3 km. Arrows are placed at each 500 m altitude with the corresponding value of steadiness. Speed could be estimated from the arc plotted for each 1 m/s.

In 1978 the night wind indicates very high steadiness, fast veering of the winds with height in the first kilometer, and then slowly backing but remaining of NE direction up to

3 km. In 1975 the NE wind vector is found in the lower 2 km, and changing to the west direction at the top of the layer but indicating a very low steadiness. These wind vectors will decrease the magnitude of the SW longterm wind vector in the lower levels, but they will not have a large effect on the upper level longterm mean. The latter would, therefore, bear the seal of the strongest winds direction from the data sampling.

The hodograph of 1981 further suggest that the strong upper level winds result from the large scale anomaly flow with high persistency, which at the same time does not allow the development of mesoscale mountain circulation and a large diurnal wind variation.

If the anomalies of particular years could largely influence the mean vector wind, one could expect that the 10 year data set is not long enough to represent the longterm mean wind vector at higher levels. To check this we have calculated 30-year mean vector $(\bar{V}_m)$ and scalar (V_s) winds (m/s) with the standard deviation (σ) and steadiness (S) for 01 h at 850 hPa and 700 hPa with the following results:

	1972–1981						1956–1985					
hPa	direction	V_m	$\lvert V_m \rvert$	σ	V_s	S	dir.	V_m	$\lvert V_m \rvert$	σ	V_s	S
850	249°	1.9	2.8	2.8	7.5	25	245°	1.8	3.2	3.5	7.6	23
700	258°	3.6	4.3	3.7	9.3	39	255°	3.2	4.5	4.3	9.4	34

The comparison shows that there is not much difference in the scalar and vector mean if the period is increased, only the magnitude of the vector mean and the standard deviations are larger, which could have been expected.

5. Conclusion

Longterm (1972–81) hodographs of the mean monthly wind vectors reveal the diurnal variations in the entire low tropospheric layer from the ground to 3 km height. However, the surface diurnal variation, with very steady downslope winds and more variable E to S daytime winds (upslope or up-valley) influenced by the local topography, comprise a very thin layer. Most of the diurnal variation followed by the monthly hodographs in a deep low tropospheric layer are attributed here to the mesoscale mountain circulation of the large Alpine massif. The interaction of two circulations (local and mesoscale) by the entrainment processes, are believed to be responsible for the large wind variability in the atmospheric boundary layer, and for the backing of the winds with height, contrary to what would be expected by the boundary layer theories.

However, the long term mean vertical wind variation, aside from the daily variation, depends on the large scale atmospheric circulation. The anomalies of this distribution, and, therefore, the selected 10-year period may not be representative for the climatological wind profiles in particular months. The comparison of the mean wind at 850 hPa and 700 hPa for the month of October in 1972–81 and 1956–85 does not indicate the essential differences. This means that the observed particular year anomalies do not have a very large return periods. Of course, this need not be the case for the other months, and remains to be seen in the future studies on this subject.

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