The Calculation of a Wind Climatology of the Erzgebirge

D. Hinneburg

Zusammenfassung:

Ausgangspunkt für die Berechnung klimatologisch gemittelter Windgeschwindigkeiten ist die mesoskalige Simulation atmosphärischer Strömungsereignisse, die von der geostrophischen Windgeschwindigkeit gesteuert werden. Der geostrophische Wind wird in 8 Richtungssektoren und Betragsklassen zu je 5m/s eingeteilt, so daß für jeden Sektor bis zu 7 Simulationen auszuführen waren. Die Simulationen wurden mit dem nicht-hydrostatischen Modell GESIMA für eine adiabatisch geschichtete Atmosphäre durchgeführt. Die statistische Mittelung der berechneten Werte erfolgte mit Hilfe einer 10-jährigen Häufigkeitsverteilung des 850hPa-Windes der Radiosondenmessungen von Prag. Ein Vergleich mit den Beobachtungswerten einiger Bodenstationen ergibt Abweichungen bis zu 1m/s über höheren Bergen.

Summary:

Starting from the classification of the geostrophic wind into 8 sectors each of them splitted up into 7 classes by 5m/s, simulations with the non-hydrostatic mesoscale atmospheric model GESIMA were performed assuming adiabatic stratification of the atmosphere for each class. The climatologically averaged wind velocities are obtained by the folding with a ten-years frequency distribution of the geostrophic wind measured by the radio sonde station of Prague. Wind velocities observed at some surface stations indicate, that the simulated values can deviate from them by up to 1m/s on high mountains.

1. Introduction

The wind climatology for an orographically strong structured terrain represents a whole set of climatological values at all local points. The relationship between the individual points is realized by the natural meteorological processes. The orographic structure both effects the actual wind and influences the annual frequency distribution. The statistical mean wind velocity on the mountain ridge can amount to values which exceed the wind outside by a factor up to 2 or more (Pleiss, 1951).

Although the meteorological observations in the Erzgebirge and its environment extend over a long period (Bruhns, 1866; Pollak, 1919; Reichsamt f. Wetterdienst, 1939; Pleiss, 1961; Flemming, 1981), they are restricted to only a few stations. However, with respect to the exploitation of wind energy a complete knowledge of the mean wind distribution is required.

Mesoscale models have succeeded in the application to these problems (Heimann, 1986; Theunert, 1986). The models are controlled by parameters, which can be extracted from statistical analyses of meteorological data (geostrophic velocity, temperature profile). Statistical averaging of the mesoscale model output in accordance with these parameters results in statistical mean values of the calculated data in the same local resolution as managed by the model.

The number of mesoscale model simulations required for a climatological study depends on the number and classification of parameters which specify different meteorological situations or episodes. In the present paper the problem of diversity is decided on behalf of a minimized number and complexity of simulations.

2. Model description

The calculations analysed in this paper are based on the application of the non-hydrostatic mesoscale atmospheric model GESIMA (Kapitza and Eppel, 1992; Eppel et al., 1992). The dynamical part comprises the 3-dimensional determination of local vectors of the wind velocity and of the temperature under the activity of geostrophic pressure, Coriolis force, turbulent diffusion and continuity of mass. The atmosphere is assumed to be incompressible, but thermically expansible. The geostrophic pressure is initialized by a uniform geostrophic velocity.

Additional processes as the thermically induced formation of a static-pressure gradient and diabatic processes caused by radiation and phase transition processes are considered as well as a variable system of boundary conditions. An optional fixing of conditions and properties at the inflow side of the simulation area to force stationarity of flow states is not possible in the model.

A 3-dimensional grid-box system is used. The lowest grid level is identical to the orographic surface and the others are found by interpolating between the lowest and the top level, which is situated strictly horizontal (eta-coordinates).

The model used has been modified in several aspects for the special application as follows. The orographic structures on the inflow sides extend to heights of 100m-600m. The vertical coordinate structure of the initial data set provided by a 1-dimensional simulation had to be adjusted in accord with the inflow side of the 3-dimensional model. An appropriate interpolation scheme was therefore inserted. The initialization of the surface temperatures was coupled with the initialized profile of atmospheric temperatures by means of an interpolation according to the surface heights. The two lowest layers were led strictly parallel to the surface and therefore excluded from the eta-coordinate system. Consequently, the variables are determined for heights of exactly 10m and 40m above ground, independently of the orographical altitude.

Moreover, several approximations relating to the treatment of temperature were made in the calculations in order to simplify the simulations and to reduce the calculation time. So the diurnal change of temperature and the effect of humidity are neglected with regard to the aim of calculating the climatological average. The atmosphere is assumed to be adiabatically stratified, because the present paper emphasizes the larger wind velocities enforcing stronger mixing in the atmosphere. Eventual inconsistencies are corrected for by means of gauging with observed values (see next chapter).

In order to promote a direct comparison between the simulation results at different positions and to approach as close as possible the surface conditions at the locations of observation stations or potential places of wind energy users, a uniform (Wippermann and Gross, 1981) roughness parameter of 17cm was applied, which is characteristic for un-wooded land (Eppel et al., 1992; Pichler, 1986).

3. Simulations and statistical procedure

The simulation area extends over 150km in west-east and 90km in north-south direction and is situated in that way, that the axial ridge of the Erzgebirge forms the diagonal and the boundaries meet less complex terrain (Fig.1). The simulations use a step size of 3km and a base of 2km for averaging the orographic heights. The vertical grid structure is built up of 16 layers with thickness between 20m at bottom and 2km at the top of the atmosphere (10km), so that a practicable number of 50 x 30 x 16 mesh points is achieved. The individual simulations are controlled by the amount and direction of the geostrophic wind and reach their stationary states after 2-8 hours simulation time depending on the wind velocity and direction.

The numerical resolution (mesh size) of the simulations and of the topography inserted in the model is of large importance for the quality of local representativeness of the results. Since the simulation topography reflecting the mean real stucture may cause local systematic deviations of the simulated from the observed results, the following procedure has been applied to the simulated velocities near the surface.

According to an elevatory formula (e.g. Oke, 1990) the velocities over hills increase by a term which is proportional to the slope H/L of the hill (H: height, L: basis length). The hill slopes were determined for the individual hills by analysing the difference between the real orography (with special regard to the hills) and the orographic field used in the model. The real surface appears as to be built up of the smooth simulation orography and a lot of conical hill-tops sitting upon the simulation surface. The constant of proportionality can be found by comparison with observed velocities. By means of this scheme the results of the 3-km simulations are corrected (not interpolated) for the topography with about 1 km grid resolution.

For the geostrophic velocities the wind statistics at a height of 850hPa of the radio sonde station of Prague was utilized. Figure 2 shows the statistics for the years 1984-93, where the velocities are classified by 1m/s (Jagusch, 1994). The number of simulations was reduced by selecting every 5m/s for the direct calculation and interpolating the simulation results between them. In contrast to Wippermann and Gross (1981), Heimann (1986), or Theunert (1986), no empirical relationships between geostrophic and surface velocities (Tetzlaff and Theunert, 1984; Theunert et al., 1989) were applied. The total number of simulations amounted to 41.

4. Results

To satisfy the aim of this work, the comparison of the calculated with the observed wind velocities is realized on a statistical base for each sector of geostrophic wind direction. For six stations and the period 1991-92 the surface measurements were correlated with the observations at the geostrophic wind height of 850 hPa (Jagusch, 1994). The stations with their heights above ground are the following: Cheb/Eger (14m), Kadan/Kaaden (10m), Karlovy Vary/Karlsbad (12m), Milesovka/Donnersberg (23,5m), Prague (12m), and Usti/Außig (18m).

Corresponding to the observation period, the geostrophic wind statistics of the years 1991-92 has to be applied for folding the simulation results with the statistical frequences. In general the actual topographical environment of an observation station cannot be reflected by the simulations and hence strong deviations may appear.

The ratios and the differences between simulated and observed velocities are specified for the six stations in Tables 1b and 1c, respectively. The geostrophic wind directions in Table 1 are arranged in the order of decreasing contribution to the statistical mean. The largest deviations appear for the stations Eger and Außig and may be referred to a strong non-isotropic behaviour of the surface wind velocities as indicated by the normalized ratios to the geostrophic values given in Table 1a. These ratios are found to be symptomatic for the differences between simulated and observed values.

The differences for the other stations noticed in Table 1b can also be explained partly. Because of the wooded western surrounding of the station Karlsbad, the wind from directions north-west to south-west is overestimated in the simulations by a factor consistent with the roughness difference. A reverse situation is met at the station Kaaden, that is surrounded in the northern directions by surface mines speeding up the wind. The values at the station Prague indicate a channeling of the wind in the direction south-west/north-east.

It is extracted, that many deviations of the calculated from the observed velocities can be attributed to the local topographical situation near the station, which is not included in the simulations nor in the correction procedure, and that the mean deviation of the simulated velocities does not exceed 0.5m/s. Considering an additional observed velocity value from the station on the Fichtelberg of about 8m/s (Grohmann, 1911; Pleiss, 1961; Meteorolog. Dienst d. DDR, 1983) compared to the simulated velocity of 6.7m/s, the wind over high mountains can differ from observation by about 1m/s.

Figure 3 presents as the final result the simulated mean wind velocity in a height of 40m above ground for the 10-years period 1984-93. The largest values appear over the highest and steepest regions and especially on the singular mountains. Connected regions of high velocity (greater than 5m/s) are found on the west and east ridge of the Erzgebirge and in the Bohemian middle mountains of Düppau to the north-east of Karlsbad and those to the south-west and to the east of Außig. Velocities of up to 9m/s occur only on single hills mostly within these regions.

In order to estimate the effect of a more realistic orography, a small number of simulations was performed with a reduced mesh size of 2km and without averaging the orography, which required 75 x 45 x 16 points and a doubled run time. They show velocities that are on the mountains by about 1m/s larger than in the usual and uncorrected simulations formerly described. Diminishing further on the step size would continue the trend. This fact justifies the corrections, which fit the rougher simulations to the real slopes of the hills.

5. Conclusions

The comparison of the climatological data derived from observations with the results provided by model simulations substantiates that a climatological wind statistics can be derived by means of model results even for complex terrain within an accuracy of 1 m/s. This may be a first tool to separate between regions of different gain of wind energy. The sensitivity studies point out that the representation of the terrain heights is a key quantity in these studies. The simulation results may be improved without correction and gauging, if the data set of orography, the horizontal resolution, and the atmospheric stratification are adapted closer to the reality.

References:

Bruhns, C.: Resultate aus den meteorologischen Beobachtungen angestellt an mehreren Orten im Königreich Sachsen in den Jahren 1828 bis 1863 und an den zweiundzwanzig königl. sächsischen Stationen im Jahre 1864. 1. Jg., Leipzig (1866)

Eppel, D.P.; Claussen, M.; Jacob, D.; Kapitza, H. et al.: GESIMA - Geesthachter Simulationsmodell der Atmosphäre. Reports I-VI. GKSS 92/I/2 - GKSS 92/I/7 (intern), GKSS Forschungszentrum Geesthacht GmbH, Geesthacht (1992)

Flemming, G.: Zur Häufigkeit von südöstlichen Starkwinden am Erzgebirgskamm. Z. Meteorol. 31 (1981) 41

Grohmann, E. (ed.): Das Klima im Königreich Sachsen. C. Heinrich, Dresden-N. (1911)

Jagusch, F.: Unpublished results (1994)

Heimann, D.: Estimation of Regional Surface Layer Wind Field Characteristics Using a Three-Layer Mesoscale Model. Beitr. Phys. Atmosph. 59 (1986) 518-537

Kapitza, H.; Eppel, D.P.: The Non-Hydrostatic Mesoscale Model GESIMA. Part I: Dynamical Equations and Tests. Beitr. Phys. Atmosph. 65 (1992) 129-145

Meteorologischer Dienst der DDR (ed.): Klimadaten der Deutschen Demokratischen Republik - Ein Handbuch für die Praxis. Reihe B, Bd. 4 "Wind", Potsdam (1983)

Oke, T.R.: Boundary Layer Climates. Second edition, Routledge London, New York (1990)

Pichler, H.: Dynamik der Atmosphäre. Bibliograph. Inst. Mannheim/Wien/Zürich (1986)

Pleiss, H.: Die Windverhältnisse in Sachsen. Abhandl. d. Meteorol. Dienstes d. DDR, Nr. 6 (1951)

Pleiss, H.: Wetter und Klima des Fichtelberges. Abhandl. d. Meteorol. u. Hydrolog. Dienstes d. DDR, Nr. 62 (Bd. VIII) (1961)

Pollak, L.W.: Ergebnisse der anemometrischen Aufzeichnungen des meteorologischen Observatoriums auf dem Donnersberge (Böhmen) in den Jahren 1905-10. Inst. f. kosm. Phys. d. deutschen Univ. in Prag, Prag (1919)

Reichsamt für Wetterdienst (ed.): Klimakunde des Deutschen Reiches. Bd.II, Tabellen, Dietrich Reimer, Berlin (1939)

Tetzlaff, G.; Theunert, S.: Meteorologische Messungen zur Standortwahl für Windenergieanlagen im Küstengebiet. Forschungsbericht BMFT T84,17, Eggenstein-Leopoldshafen (1984)

Theunert, S.: Anwendung eines Mesoskalen-Modells zur Bestimmung des natürlichen Windenergieangebotes im deutschen Küstenbereich. Bericht Inst. Meteorol. Klimatol. Univ. Hannover, Hannover (1986)

Theunert, S.; Tetzlaff, G.; Bufe, H.: Auswertung der Windmeßdaten von 6 Standorten in Norddeutschland. Bericht Inst. Meteorol. Klimatol. Univ. Hannover, Hannover (1989)

Wippermann, F.; Gross, G.: On the Construction of Orographically Influenced Wind Roses for Given Distributions of the Large-Scale Wind. Beitr. Phys. Atmosph. 54 (1981) 492-501

Adresse: Dr. D.Hinneburg, Universität Leipzig, Institut für Meteorologie, Stephanstr. 3
D-04103 Leipzig

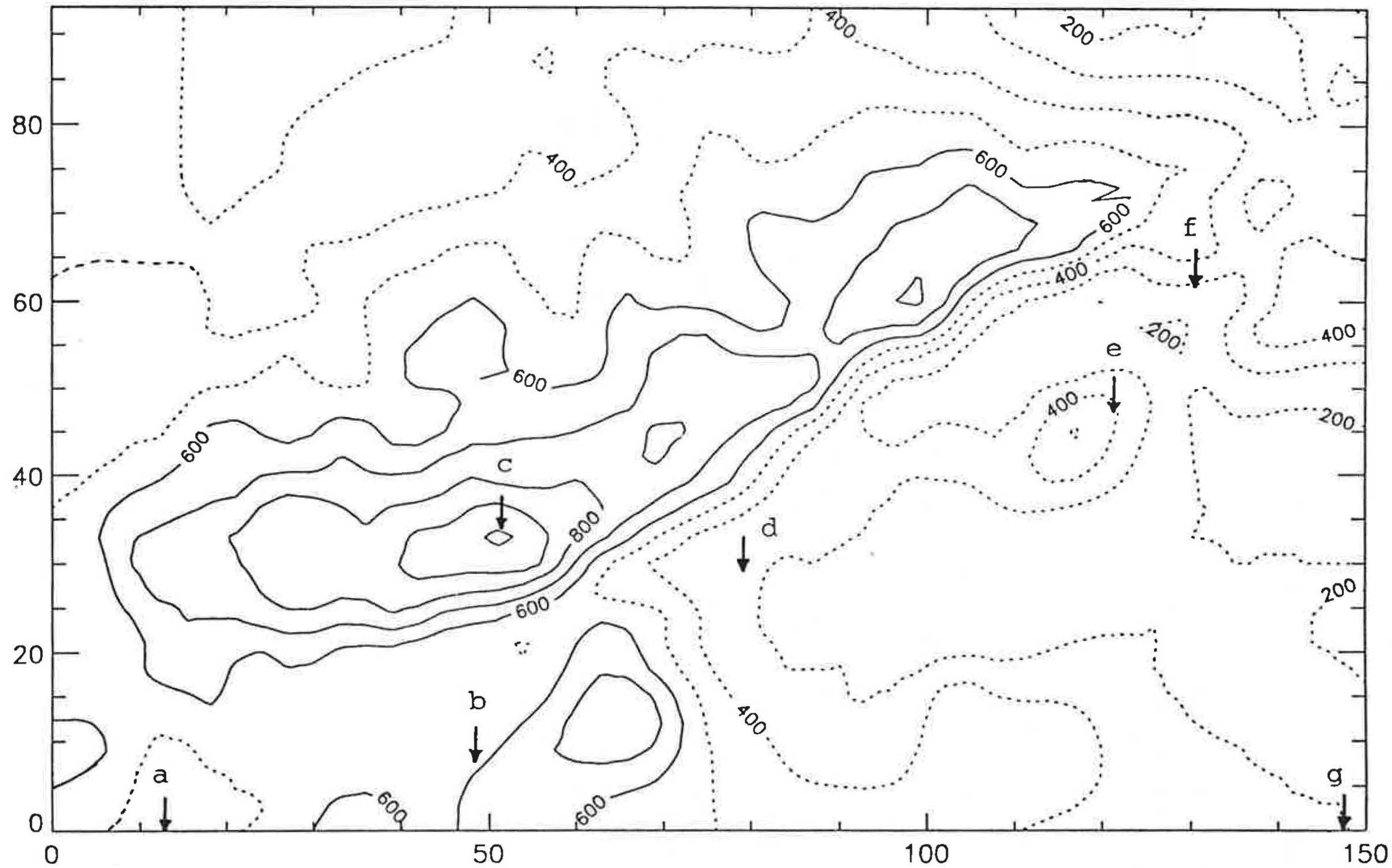

Fig.1: Orography of the surrounding of the Erzgebirge
(mesh size 3km, basis length for averaging 2km)

a-Cheb
b-Karl. Vary
c-Fichtelberg
d-Kadan
e-Milesovka
f-Usti
g-Prague

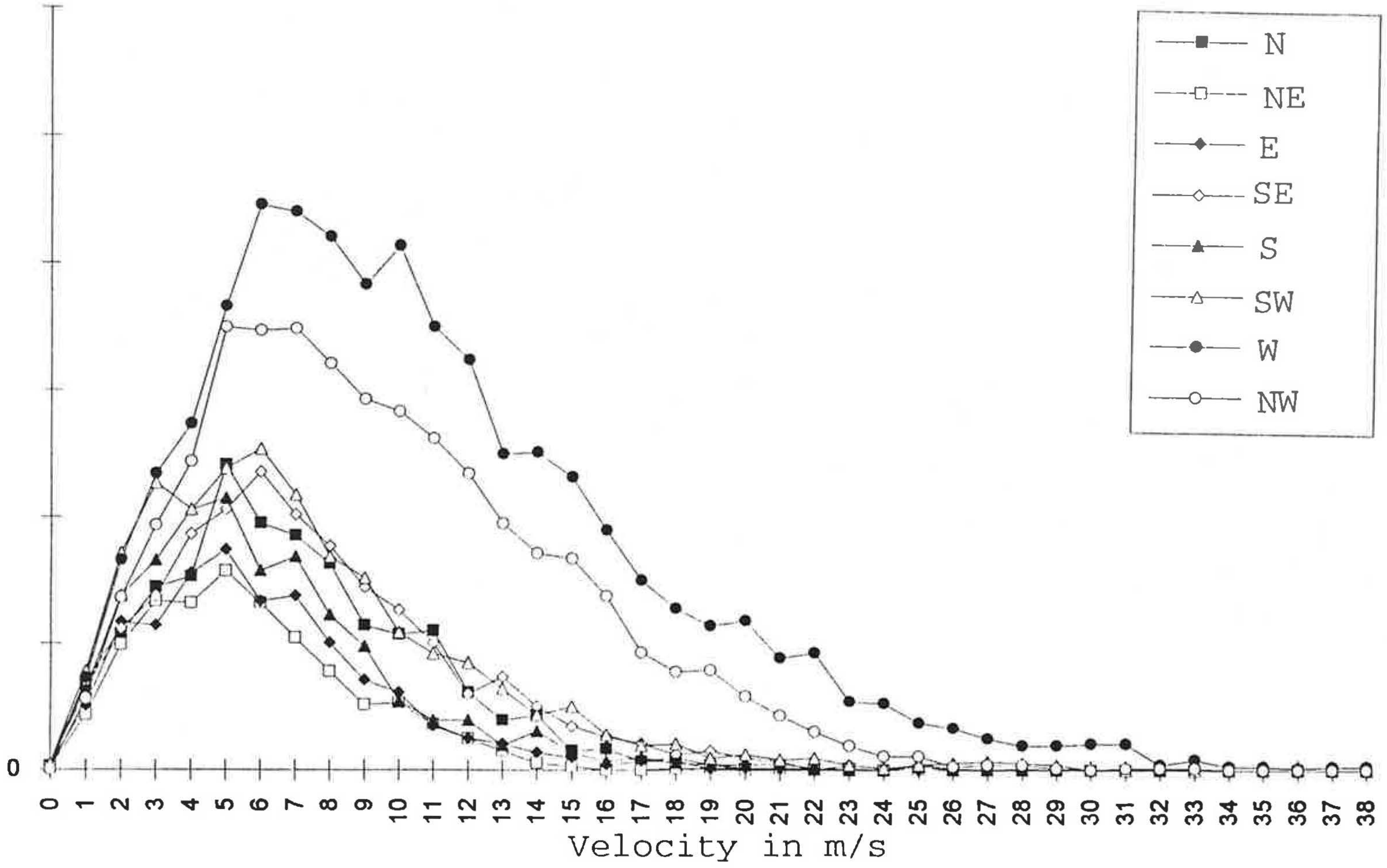

Fig.2: Frequency distribution of the wind velocity at
850hPa of the station Prague for 1984-93
(by F.Jagusch)

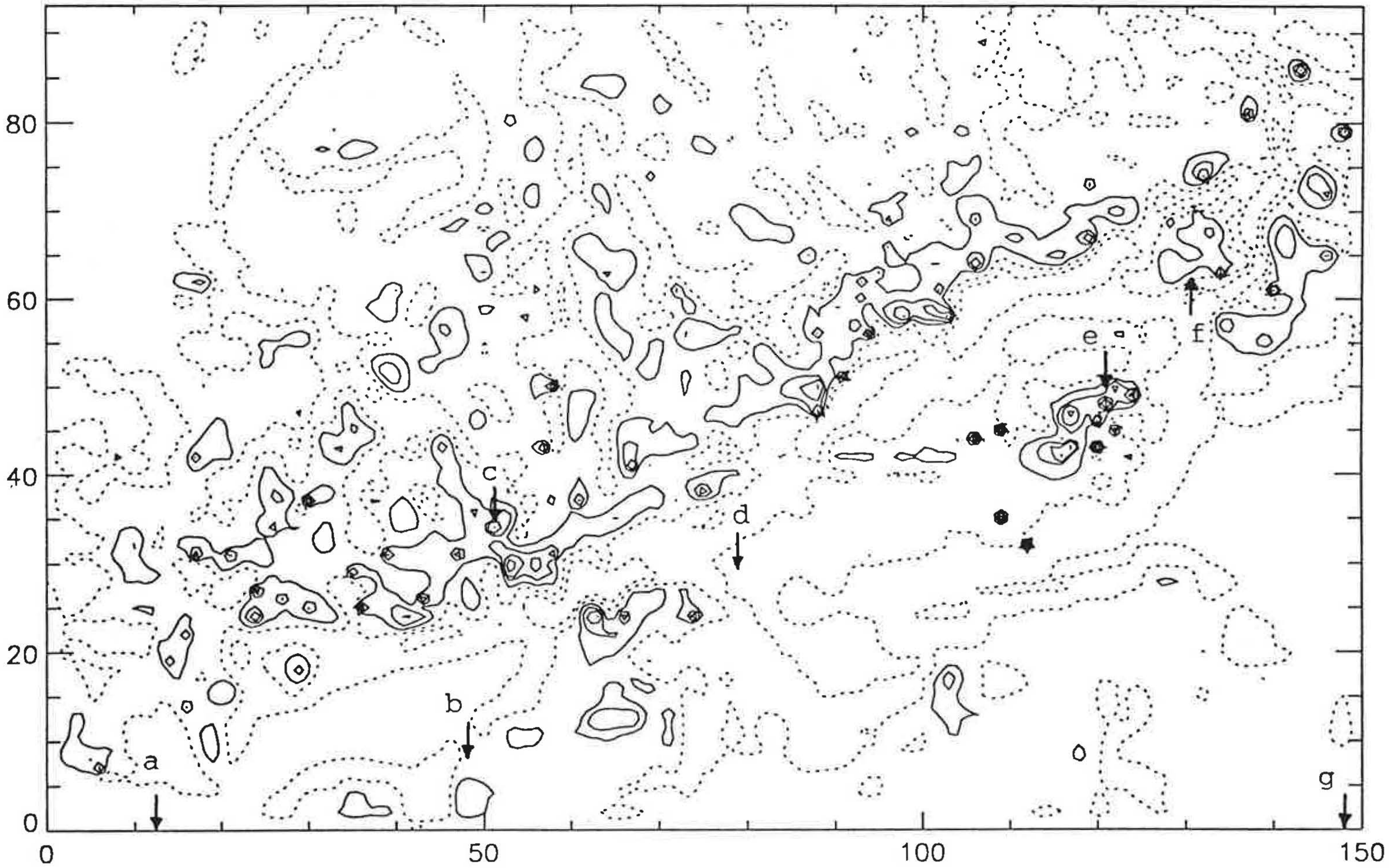

Fig.3: 10-Years mean velocity at 40m above ground
(... 4.0, 4.5 m/s;
___ 5.0, 5.5, 6.0, 7.0, 8.0 m/s)

Locations see Fig. 1

	Cheb	Karl.	Kadan	Mil.	Usti	Prague
a)(v(obs.)/v(obs.,tot.))/(v(geostr.)/v(geostr.,tot.))						
W	0.94	0.91	0.93	0.88	0.79	0.98
NW	0.85	0.98	1.03	0.95	0.95	1.00
SW	1.31	1.02	0.94	1.08	1.02	1.08
SE	1.10	1.08	0.98	1.23	0.93	0.93
N	0.99	0.99	1.08	1.01	1.47	1.09
S	1.17	1.04	0.98	1.41	1.19	1.04
E	1.04	1.16	1.03	1.05	1.15	0.89
NE	1.16	1.26	1.27	1.01	1.69	1.10
Total	1.00	1.00	1.00	1.00	1.00	1.00
b) v(sim.) / v(obs.)						
W	1.58	1.22	1.09	1.13	1.73	0.87
NW	1.65	1.12	0.89	1.03	1.22	0.94
SW	1.16	1.14	1.00	0.96	1.34	0.62
SE	1.48	1.07	1.06	0.94	1.51	0.97
N	1.58	1.15	0.88	1.01	0.88	0.80
S	1.37	1.13	1.02	0.83	1.20	0.87
E	1.53	0.97	0.96	1.00	1.19	0.98
NE	1.30	0.88	0.74	0.90	0.76	0.78
Total	1.50	1.12	0.98	1.02	1.32	0.84
c) v(sim.) - v(obs.) in m/s						
W	1.7	0.8	0.4	1.2	2.2	-0.7
NW	1.6	0.4	-0.5	0.3	0.7	-0.3
SW	0.5	0.4	0.0	-0.3	0.9	-1.5
SE	1.1	0.2	0.2	-0.5	1.2	-0.1
N	1.2	0.4	-0.4	0.1	-0.4	-0.8
S	0.7	0.3	0.0	-1.3	0.5	-0.4
E	1.1	-0.1	-0.1	0.0	0.5	-0.1
NE	0.6	-0.4	-0.8	-0.6	-0.9	-0.7
Total	1.3	0.4	0.1	0.2	1.0	-0.7

Table 1: Comparison between simulated and observed velocities