STUDIES OF REGIONS WITH INTENSE TURBULENT MOTIONS BASED ON MSG DATA

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Abstract

A method applied to determine dynamic characteristics of the atmosphere is described. The method is based on the use of heterogeneities of conservative impurity concentrations as tracers and the correlation extremal algorithms. The method makes it possible to determine not only the horizontal wind speed vector but also the eddy diffusivity factor. The calculation results of dynamic characteristics of the middle troposphere are presented. The results were obtained from the information of the atmospheric thermal radiation registered in the water vapor channels (5.35–7.15 µm and 6.85–7.85 µm) of the radiometer SEVIRI aboard the geostationary satellite Meteosat-8. A spatial distribution of the eddy diffusivity factor in the middle troposphere for several months was determined. Determined also were the atmospheric regions where the processes of turbulent diffusion prevail over the processes of horizontal laminar transport.

INTRODUCTION

Dynamic characteristics of the atmosphere (wind speed vector, eddy diffusivity factor) are the major meteorological parameters for weather forecasting, computations of atmospheric impurities migration and solution of numerous fundamental and applied problems of meteorology. It is known that the regions exist in the atmosphere with prevailing laminar or prevailing turbulent motions of air masses. In the latter case the processes of turbulent transfer prevail over the processes of directed transport. Despite a considerable progress in satellite methods used for determining wind field in the atmosphere, some important problems have not been solved yet (Proceedings, 2004). In our belief, the problems include the determination of turbulent characteristics of atmospheric motions. In the paper, the method is considered that allows one to determine not only the horizontal wind speed vector (**V**), but also vorticity (rot**V**) and the eddy diffusivity factor (K_d). Heterogeneities of water vapor concentration field are used as atmospheric tracers. The method is applied for calculations of atmospheric dynamic characteristics from the information on atmospheric thermal radiation registered in the water vapor channels of the radiometer SEVIRI aboard the geostationary satellite Meteosat-8. Main attention is paid to determining K_d in the regions both with prevailing laminar and prevailing turbulent motion of air masses.

PHYSICAL- MATHEMATICAL MODEL OF THE METHOD

The essence of the method is in the determination of kinematic characteristics of a random field by statistical methods. By a random field the satellite derived field of relative humidity U (x, y, t) is meant, where x, y are the axes of a flat Cartesian coordinate system (the positive direction x is towards the east, y – towards the north), t is time. A two-dimension model, as we think, is adequate to satellite information obtained in the water vapor channels. From the physical viewpoint, this implies that the effect of vertical motions in the field U can be neglected. In the work (Nerushev, 1993) it is shown that even at the time intervals between satellite images Δt = 1h, large-scale ordered vertical motions, the typical speed of which does not exceed 2.10^{-2} m/s, will not significantly affect the radiation of the atmospheric layer registered by the satellite device. Small-scale vertical turbulent currents in the cloudless atmosphere (at mountainous-bottom land, breeze and other circulation types) with typical horizontal scales L < 20 – 30 km the rate of which can attain 1 m/s are also unlikely to significantly influence the field U at the intervals Δt = 15 min in satellite images arrival typical of Meteosat-8.

The motion of some separated region of the medium can be expanded into transfer (horizontal wind speed vector **V**), rotation around an instantaneous axis passing through its center (rot**V**) and deformation induced by the diffusion processes. The separation of an element of the medium volume (operating "window") is made by the operator H being the spatial weight function and playing the role of a filter of the upper spatial frequencies. The procedure of identification of such a separation of wind field regions U at time intervals t_1 and t_2 is in finding global extrema of mutual statistical characteristics. Therefore, the determination of the atmospheric dynamic characteristics can be considered as a two-dimensional inverse problem of statistical analysis of a random field. Usually the following assumptions are made on a two-dimensional horizontal field U in the middle troposphere: the field U is continuous, ergodic, Gaussian, quasi-stationary in time, locally homogeneous in space.

From the shifts Δx, Δy, $\Delta\varphi$, at which a global minimum of the spatio-temporal structural function D (Δx, Δy, $\Delta\varphi$, τ) is achieved, two components of transfer rate (V_x and V_y), vorticity (rot**V**) and the rate of temporal evolution (V_e) characterizing real temporal variability ("non-congelation") of the random field U are calculated. The use of the structural function instead of the correlation one makes it possible to decrease the effect of heterogeneity and non-isotropy of the random field U and systematic errors on the calculation accuracy of the statistical characteristics. Note that the values of **V**, rot**V** and V_e calculated so reflect the effect of all the processes contributing into the displacement of the volume of the medium controlled by the operator H (Nerushev, 1993).

The analysis carried out demonstrates that at horizontal parameters of temperature T and partial pressure e of water vapor typical of the atmospheric layers near maxima of weight functions of water vapor channels of the radiometer SEVIRI the influence of variations of e on the variations of the atmospheric radiation intensity registered by the radiometer will be by 3 – 5 times higher than the effect of variations of T. At the same time, the possibility of the prevailing effect of the field T cannot be excluded. As the calculations have shown, such a situation can occur when the horizontal gradients of the field T are by 5 times and more higher than the indicated typical gradients of T equal to $(1 – 8)\cdot 10^{-3}$ K/km. Just such conditions may take place in the region of the polar jet flow and a discontinuity in the tropopause (Ramond et al., 1981). In all other cases, including the regions of subtropical jet currents, the atmospheric thermal radiation registered by the radiometer SEVIRI in the channels of water vapor will be determined by the field U.

CALCULATION RESULTS AND DISCUSSION

The data obtained by the satellite Meteosat-8 were received in Moscow at the Scientific and Research Center of Space Hydrometeorlogy "Planeta" (SRC "Planeta") in the HRIT/LRIT formats. The components of the rate transfer V_x, V_y and vorticity rot**V** were calculated with the relationships

$$V_x=\Delta x/\tau, \quad V_y=\Delta y/\tau, \quad \mathrm{rot}\mathbf{V}=\Delta\varphi/\tau, \qquad (1)$$

where $\tau = t_2 – t_1$, φ is the Eulerian angle of the coordinate system moving together with the separated region of the field. The rate of temporal evolution of V_e characterizing the real temporal evolution ("non-congelation") of the random field U based on the work (Babiy, 1983) was calculated as $V_e = r_e/\tau$, where r_e is the radius of the circle equivalent in the area to the cross section of the horizontal plane of the spatial structural function D (Δx, Δy, 0, 0) for the time moment t_1 at the minimum of the spatio-temporal structural function D (Δx, Δy, $\Delta\varphi,\tau$) at $\tau = t_2 – t_1$. "Non-congelation" of the random field and eddy diffusivity are different forms of one and the same process – temporal evolution of the field, therefore it would be reasonable to think of the existence of a link between the evolution rate V_e and the eddy diffusivity factor K_d. Interpreting V_e as an increment of the radius-vector of a diffusing spot per the time unit, it can be easily shown that for the diffusion two-dimensional model $K_d = a \cdot V_e \cdot r_e$, where a is a dimensionless coefficient approximately equal to unity.

The key problem is in the choice of spatial dimensions of an operation "window" that significantly controls the volume of calculations and accuracy of the characteristics sought. Fig. 1 gives an example of assessment of calculation accuracy for the module (V) of the vector **V** and the eddy diffusivity factor (K_d) at different linear sizes H from the data of water vapor channel 6.2 µm of the satellite Meteosat-8 as for April 2005. Similar dependencies are obtained for the azimuth (AZ) of the vector **V.** The procedure of assessment was based on the calculation of the function

$$F_f(H) = \frac{1}{N}\sum_{i=1}^{N}\frac{|(f_H)_i - (f_{mean})_i|}{SD_i}, \quad (2)$$

where f means one of the characteristics V, AZ or K_d , f_H is a value of the corresponding characteristic at a preset value of H, f_{mean} is a mean value over all the values of H, SD is the standard deviation, the number of calculation points N = 50.

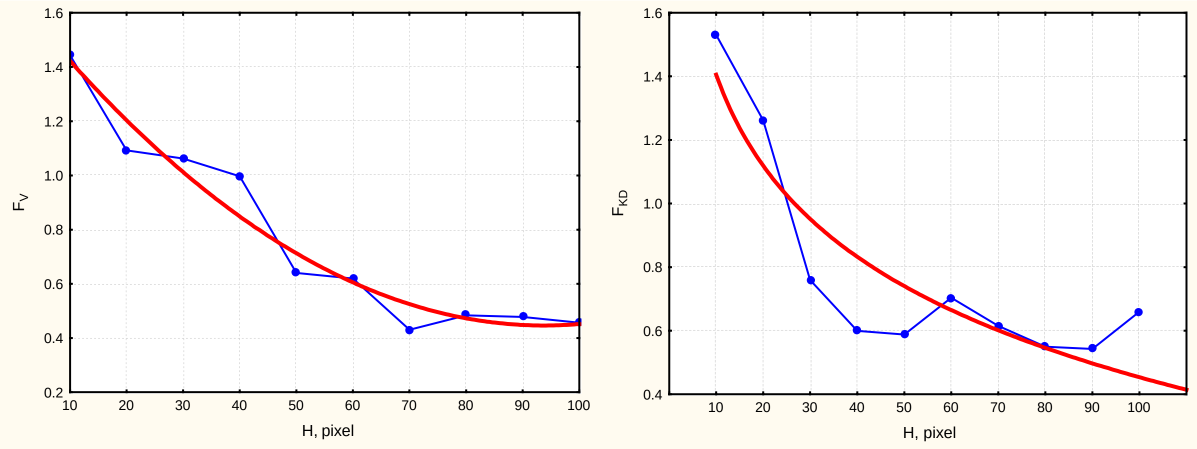

Figure 1: **Assessment of the V module and the eddy diffusivity factor calculation accuracy at different linear dimensions of H from the 6.2 µm water vapor channel for April 2005 (t = 12:00 UTC, Δt = 15 min, the red curve is the approximation).**

One can see that the linear size of the operation "window" (H) of 50 – 100 pixels ensures the calculation accuracy of all the characteristics mentioned that is better than one standard deviation. A decrease of the sizes of H to 10 pixels results in impairment of calculation accuracy by 2 – 3 times. Similar dependencies are obtained for the 7.3 µm water vapor channel as well. All subsequent calculations were made with the operation "window" (H) with the sizes of 50 x 50 pixels.

Figs. 2 – 3 present the examples of calculations of wind speed in the nods of a regular 2.5 x 2.5 deg grid for the regions with a simple laminar flow and with a distinct cyclonic circulation. The data of the 6.2 µm water vapor channel for February, 2006 were used (t = 12:00 UTC, Δt = 15 min). Here are also given the data of an objective analysis of the wind field at the level of 300 hPa (the data of the Russian Hydrometcenter). Statistical characteristics of a comparison of calculation results with the data of the objective analysis are given in the Table.

Data	Channel	No. of vectors	Level, hPa	Module V, m/s		Azimuth V, deg	
				RMS	BIAS	RMS	|BIAS|
10.02.2006	WV 6.2	434	400	9.7	1.5	7.9	10.6
	WV 6.2	514	300	11.6	-2.5	8.5	11.1
	WV 7.3	439	500	10.3	3.3	8.5	11.7
10.03.2006	WV 6.2	565	400	7.9	2.3	8.3	10.4
	WV 6.2	600	300	8.7	-2.8	9.0	10.5
	WV 7.3	514	500	9	3.3	8.5	11.4

Fig. 4 shows histograms of eddy diffusivity factor distribution in the region with a simple laminar flow for several moths. Note that in this region the processes of directed transport prevail over the turbulent transfer process. The character of K_d distribution over its value is rather complex. But it is seen that the basic portion of the distribution curve is concentrated in the region of the values of $K_d \leq 80{,}000$ m^2/s. For February 2006 the values of $K_d \leq 30{,}000$ m^2/s determine about 60% of the distribution curve. A similar picture is observed for the region with the distinct cyclonic circulation.

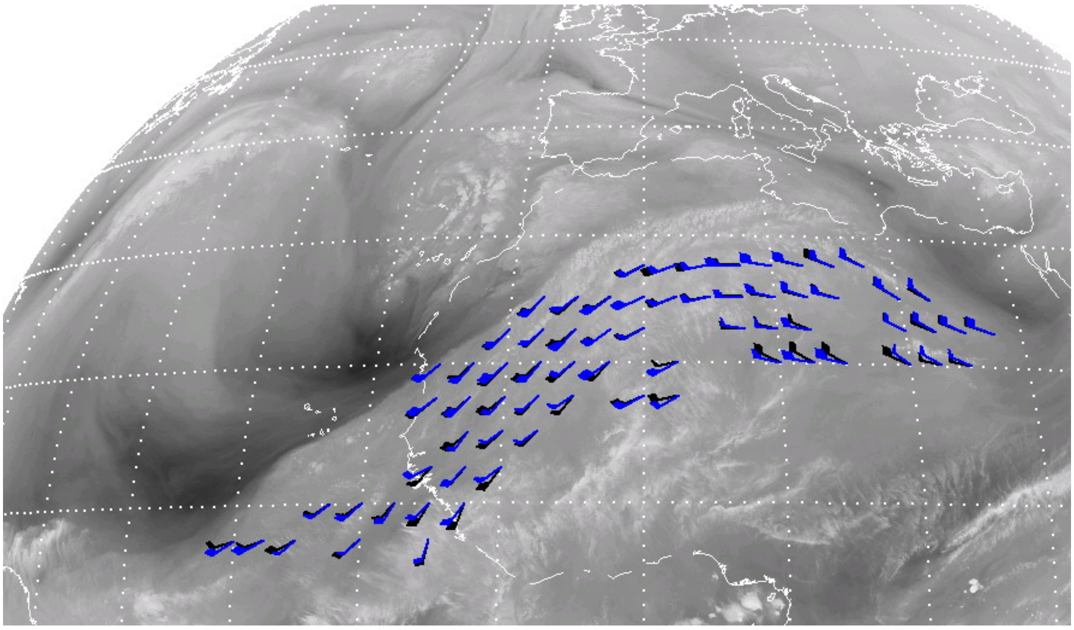

Figure 2: **Wind speed vectors for February 10, 2006, 12:00 UTC in the nods of a 2.5 x 2.5 deg regular grid for the region with a simple laminar flow (blue flags are the calculation results from the 6.2 μm water vapor channel, $\Delta t = 15$ min, black flags are the data of an objective analysis at the level of 300 hPa).**

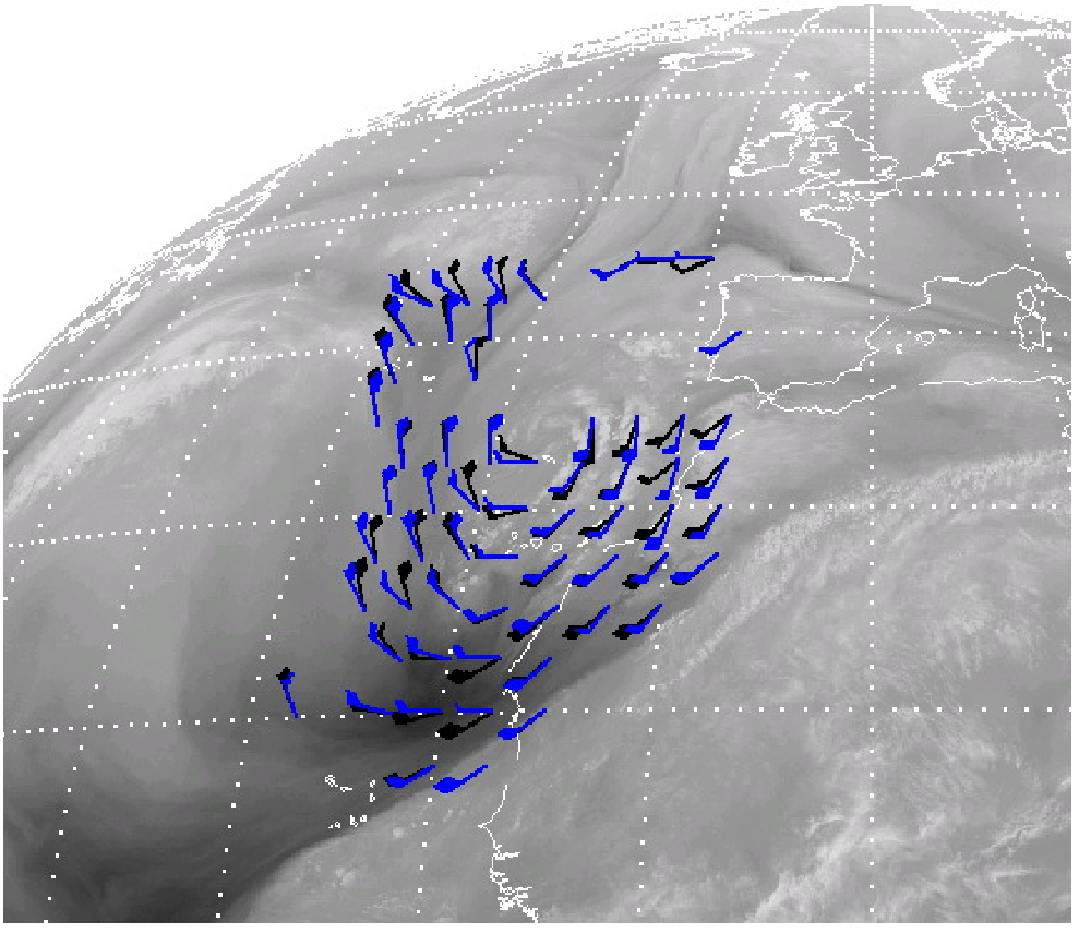

Figure 3: **Same as in Figure 2 but for the range with distinct cyclonic circulation.**

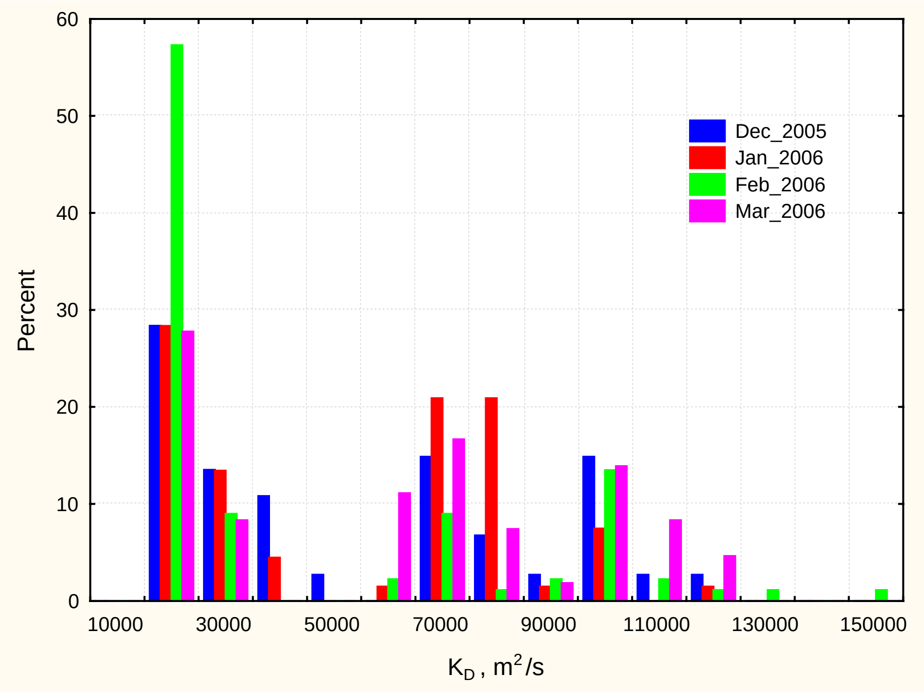

Figure 4: **Histograms of eddy diffusivity factor distribution in the range of a simple laminar flow for December 2005, January-March 2006.**

The location of one region in the Northern hemisphere for February 2006 is shown schematically in Fig. 5. The processes of turbulent transfer in this zone prevail over the processes of directed transport. The rate of temporal evolution of the water vapor field (V_e) is higher than the module of the horizontal wind speed (V). For other months the location of the range and its configuration vary but not significantly. It should be mentioned that this region coincides with the location of the Azores maximum that is one of the centers of atmospheric action.

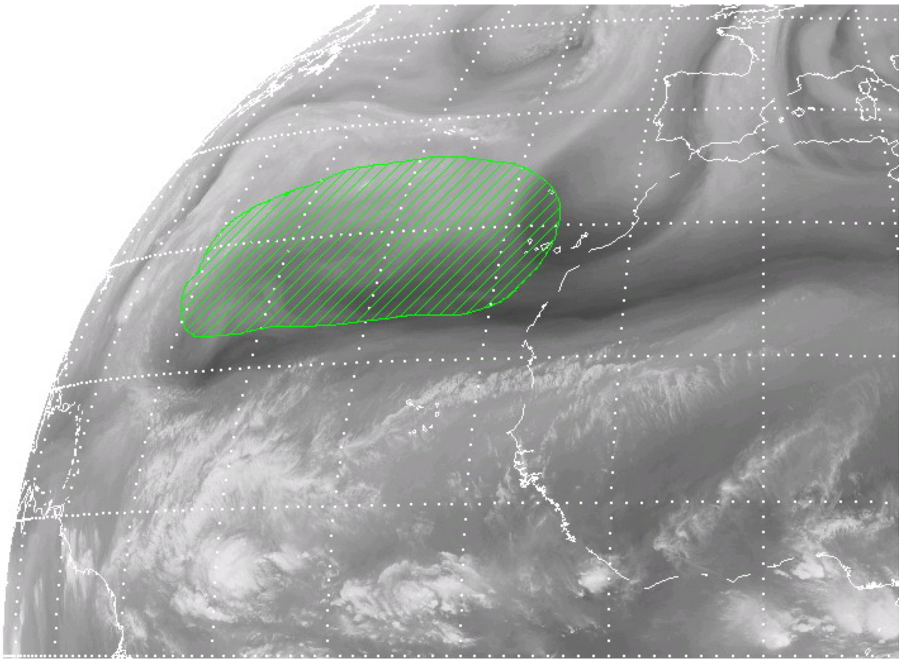

Figure 5: **Location of the range (February 2006) in the Northern hemisphere where the processes of turbulent transfer prevail over the processes of directed transport.**

The histograms of the eddy diffusivity factor distribution for winter are given in Fig. 6 for such regions for both hemispheres. The total number of calculation points for each month is about 1,600. It is seen that the histograms have two local maxima – in the range of (20,000 – 40,000) m^2/s and 100,000 m^2/s, the latter being the highest. Unfortunately, we have not found any data on K_d for appropriate heights with which our calculation results could be compared. Nevertheless, it could be said that calculated values of K_d in the order of the value are well compared with the existing representation of the atmospheric horizontal eddy diffusivity factor.

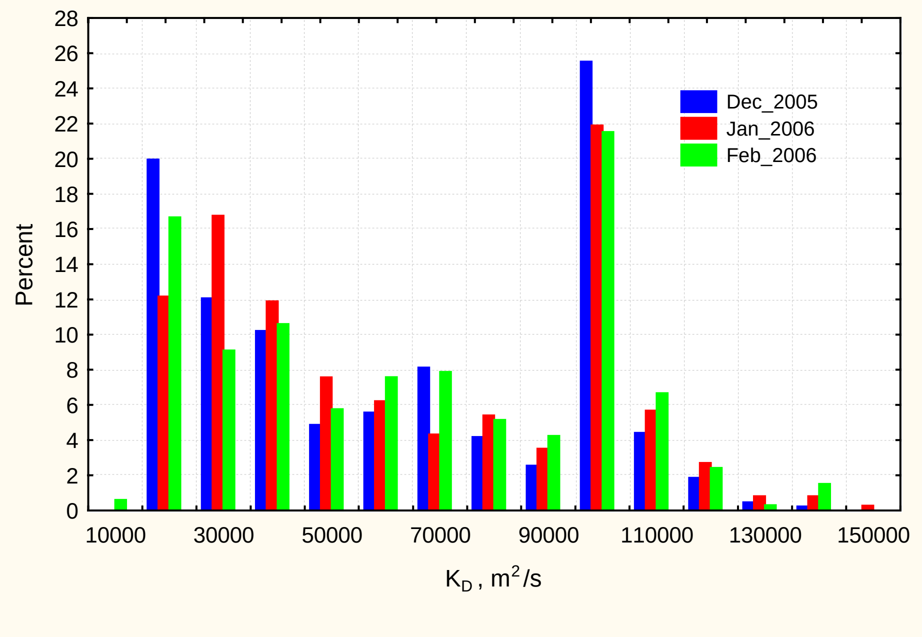

Figure 6: **Histograms of eddy diffusivity factor distribution for the regions with $V < V_e$ for both hemispheres for winter of 2005 -2006.**

It would be interesting to compare the values of K_d for the regions with prevailing laminar ($V > V_e$) and prevailing turbulent ($V < V_e$) motion of air masses. Fig. 7 presents the histograms of the distribution of K_d values in such regions for February 2006.

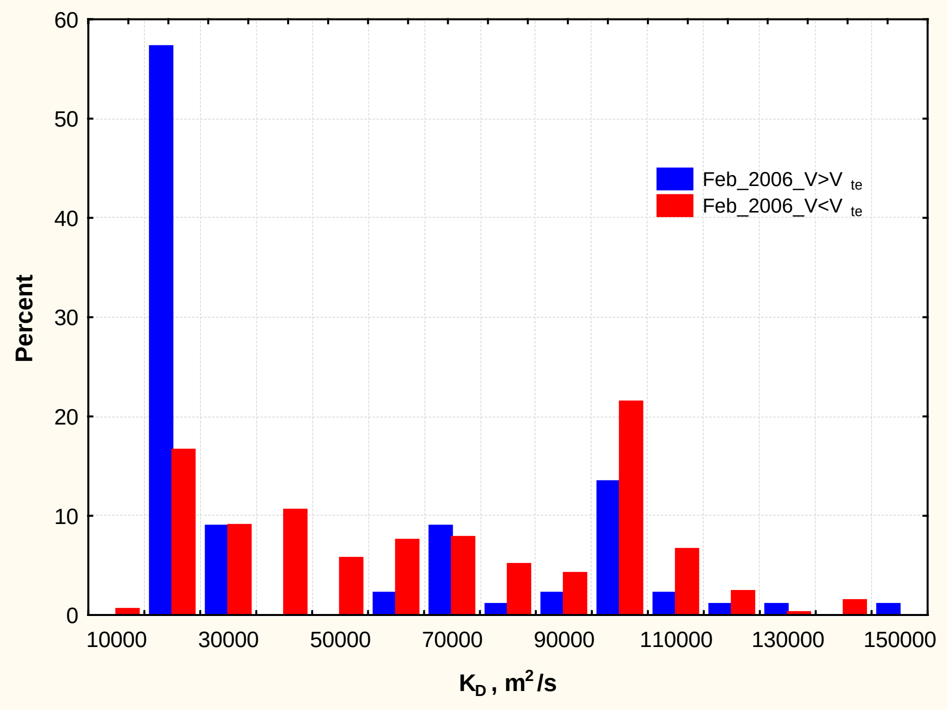

Figure 7: **Histograms of eddy diffusivity factor distribution for February 2006 in the ranges of $V > V_e$ (blue) and $V < V_e$ (red).**

It is seen that if for the regions with the prevailing laminar flow the presence of a sharp maximum in the distribution curve is typical in the range of 10,000 $m^2/s < K_d < 30{,}000\ m^2/s$, then for the regions of the prevailing turbulent motion of air masses a smooth distribution of K_d with a relative maximum at $K_d \sim 100{,}000\ m^2/s$ is characteristic.

CONCLUSION

In conclusion we will formulate the main results of our work and prospects of its development.

1. The method is described that is used for the determination of the atmospheric dynamic characteristics from the information on the atmospheric thermal radiation in the water vapor absorption band allowing one to determine not only the horizontal wind speed vector but also vorticity and the eddy diffusivity factor.

2. The method is used to calculate the horizontal wind speed vector and the atmospheric eddy diffusivity factor from the data registered in the water vapor channel of the radiometer SEVIRI of the geostationary satellite Meteosat-8 in December 2005 – March 2006.

3. Revealed are the regions in the middle troposphere where the processes of turbulent diffusion prevail over the processes of horizontal laminar transfer. It is shown that in these regions the typical values of the horizontal eddy diffusivity factor are much higher than in the regions with a prevailing laminar flow.

4. Further development of the method will make it possible to determine from the data of atmospheric soundings in the wavelengths of 6.2 and 7.3 µm the wind speed vertical component within the 300 – 500 hPa layer. This will demand to solve not a two-dimensional but a three-dimensional inverse problem of the statistical analysis of a random field.

5. The method developed could be in future applied for revealing from the data of remote sounding of the regions of intense turbulence at such complex weather phenomena as jet streams, cyclones of tropical and moderate latitudes, frontal zones, etc.

6. For a correct assessment of the accuracy and capabilities of the method it would be desirable to compare our calculations of the wind speed vectors with the EUMETSAT data based on the same data arrays.

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