# DETERMINATION OF WIND SPEED NEAR A SEA SURFACE IN INTENSIVE ATMOSPHERIC VORTICES

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## ABSTRACT

A method is described of retrieving a mean spatial structure of wind speed near a sea surface spatial structure in zones of intensive atmospheric vortices action from the data of sounding the ocean-atmosphere system in the microwave wavelength range. The method can be used for vortices with distinct structural parameters – the eye, the eye cloud wall, zones of hurricane and storm winds. Tropical cyclones and polar mesocyclones (Polar Lows) can be in the number of such vortices.

The basic idea of the method is that the knowledge of major structural parameters of atmospheric vortices (effective dimensions of the storm and hurricane wind zones, maximum wind speed and effective dimensions of maximum winds) gives a possibility to determine a mean spatial distribution of wind speed near a sea surface in the whole region of vortex action – from the center to periphery. The structural parameters can be determined on the basis of their connection (found experimentally) with characteristics of the vortex radiobrightness images in different channels of a radiometer. The effective dimensions of the storm and hurricane wind zones can be determined from the data of soundings not only in the microwave but also in the UV wavelength range.

The accuracy of determining the major structural parameters of atmospheric vortices was estimated based on the examples of processing sounding data of tropical cyclones in the Northern Atlantic and North-West Pacific obtained with the use of the microwave radiometer SSM/I and the ozone mapper TOMS and after a comparison with the data of independent measurements. Presented are the calculation results of wind speeds near the sea surface in the tropical cyclones in the Atlantic and Pacific in 1994, 1998 and 1999.

## 1. INTRODUCTION

Remote soundings of the ocean-atmosphere system from space is a most efficient means to obtain on-line and most complete information on the parameters of atmospheric vortices and characteristics of their environment, the wind speed field in the first turn. Important data on the wind speed field near a sea surface makes it possible to develop up-to-date methods of microwave radiometric sounding the ocean-atmosphere system. Up to the present a great body of microwave radiometric sounding data (US satellites Nimbus, NOAA and DMSP) has been obtained for atmospheric vortices, in particular of tropical cyclones (TC) (Kidder et al., 1980; Rodgers et al., 1994; Velden et al., 1983, 1989, 1991). But the applicability of the radiometric method for determining geophysical fields within a TC region is significantly limited by the lack of adequate radiation-geophysical models and algorithms for retrieving the parameters sought. The modern model dependencies of the sea surface radiobrightness temperature on the wind speed V near the sea surfaces are for the range of V values not exceeding 20-25 m/s (Goodberlet et al.,1990; Sasaki et al., 1987; Wentz, 1992, 1997). For mature TC (storms and typhoons) such wind speeds are observed, as a rule, at distances more than 200-400 km from their centers.

For an efficient use of microwave radiometric sounding of the ocean-atmosphere system with the aim of determining the wind speed field near a sea surface it is necessary to estimate the applicability limits of the radiation-wind models available that have been constructed for unperturbed conditions and to develop methods for determining wind field characteristics in central zones of atmospheric vortices where storm and hurricane winds are observed. One of the first step in this direction, as we believe, is in the development of a semi-empirical model based on the existence of connections in the peculiarities of a radiobrightness image of an atmospheric vortex in different channels of a microwave radiometer and characteristics of the wind field in the vortex central zone. Such connections have been found by us earlier on the basis of an analysis of sounding data for the ocean-atmosphere system in the Atlantic and Pacific obtained by the microwave radiometer SSM/I (Nerushev et al., 2001).

The present paper describes the method to determine mean characteristics of the wind field spatial structure in the zones of atmospheric vortex action. The method is based on the use of remote sounding data of the ocean-atmosphere system in the microwave and UV spectral ranges. Given are the calculation results of the wind speed field in the Atlantic and Pacific tropical cyclones of 1994, 1998 and 1999 obtained from the data of the microwave radiometer SSM/I and ozone mapper TOMS.

## 2. DESCRIPTION OF THE METHOD AND EXPERIMENTAL DATA

The method for determining mean characteristics of wind speed field spatial structure (V) in the zone of atmospheric vortices action given below can be applied to vortices with distinct structural parameters – the eye, the eye cloud wall, hurricane and storm wind zones. Tropical cyclones and polar mesocyclones (Polar Lows) can be in that number. Dynamically and thermodynamically Polar Laws occurring in winter under the propagation of cold polar air masses towards the open ocean are close to tropical cyclones but are still imperfectly understood. At the same time, their average dimensions (about 200 km) are by several times less than those of tropical cyclones. Let us consider the basic idea of the method in case of a tropical cyclone.

Some parameters important for practice can be separated in the wind speed field spatial distribution in the zone of TC action (Fig. 1). They are: maximum wind speed ($V_m$ ) and the distance from the TC center at which it is reached ($R_m$ ), the distance from the TC center where the wind speed near a sea surface exceeds some certain values, in particular, 34 knots (storm wind) and 64 knots (hurricane wind). The corresponding parameters are called the dimensions of the storm (R34) and hurricane (R64) winds. The parameters mentioned are the input ones for some models of TC motion with the help of which the zones of possible damages are estimated. The values of R34 and R64 are, as a rule, given in storm-warnings in view of the data of independent observations (aircraft reconnaissance, data of drifting meteorological buoys, automatic meteorological stations, images obtained from board the geostationary satellites in the visible and IR spectral ranges, etc.).

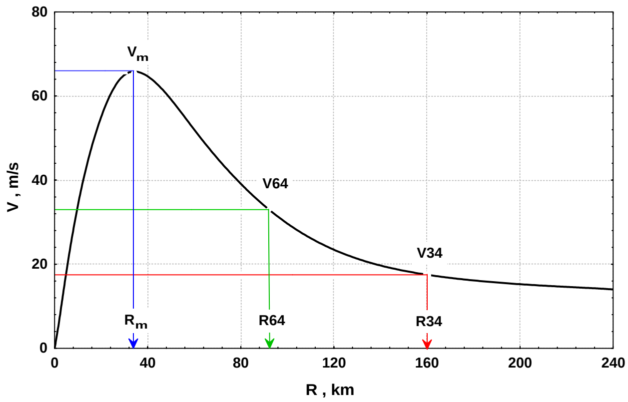


**Figure 1. A schematic representation of the wind radial profile in the tropical cyclone ($V_m$ is maximum wind speed, $R_m$ is the distance from the TC center at which it is attained, R34 and R64 are the dimensions of the storm and hurricane wind zone, V34 = 34 knots = 17.5 m/s, V64 = 64 knots = 33 m/s).**

The semi-empirical method proposed by us (Nerushev et al., 2001; Nerushev and Tereb, 2000) allows one to determine TC major structural parameters ($V_m$ , $R_m$, R34 and R64) on the basis of sounding data in the microwave and UV spectral ranges. The knowledge of these parameters gives a possibility to retrieve a mean spatial distribution of wind speed V near a sea surface. The algorithm to obtain the spatial distribution

V in the whole range of a tropical cyclone action – from the center to its periphery is as follows. The values of $V_m$, $R_m$, R64 and R34 are determined in a TC region for distances $0 \le R \le R34$ from the SSM/I data on the basis of our method (Nerushev et al., 2001). Note that R34 and R64 can be obtained as functions of an azimuthal angle $\varphi$. Then, based on the four values – $V_0(0)$, $V_m(R_m)$, $V_{64}(R64)$ and $V_{34}(R34)$ – a smoothed distribution $V(R, \varphi)$ is constructed. Here $V_0$ is the wind velocity in the TC center (R = 0), $V_{64}$ = 64 kn ≈ 33 m/s, $V_{34}$ = 34 kn = 17.5 m/s. The sea surface wind velocity in the TC center has a constant value close to zero. Here it is considered for certainty that $V_0 = 0$. For the TC periphery at distances R > R34, where the wind velocity is less than the storm speed (V < 17.5 m/s), the spatial distribution V is obtained with the use of the Wentz method (Wentz. 1997).

The sounding data of tropical cyclones in the Atlantic and Pacific obtained in 1994, 1998 and 1999 by the SSM/I microwave radiometer from the US satellites of the DMSP series; the results of determining the tropical cyclones parameters from storm-warnings based on the data of independent measurements (aerial surveillance, the data of drifting meteorological buoys, of automatic meteorological stations, the images from geostationary satellites in the visible and IR wave length ranges, etc.); fields of mean daily total ozone (TO) and the reflection coefficient in the UV spectrum range of the underlying surface in the zone of action of every TC during its whole life-time over the ozone mapper TOMS are used in the paper.

## 3. ESTIMATION OF STORM WIND ZONE EFFECTIVE DIMENSIONS

The wind speed field near a sea surface in the zones of TC action for V<20 m/s was computed with the model developed by Wentz F. (Wentz, 1997) with the use of a nonlinear algorithm making it possible to account for physical limitations of the parameters sought (Petrenko, 1983). Fig. 2 shows as an example profiles of V (R) in the N-S and W-E sections constructed through the TC centers of the North-West Pacific by Walt (1994) and Tim (1994). A noticeable peculiarity of the V(R) profiles for most of the soundings is in the presence of one or several local maxima of V at distances of 400-1000 from the center. The value of V in a local maximum can by 50% exceed the adjacent values of V (Fig. 2a), and in separate cases the V values in a local maximum reach 20 m/s.

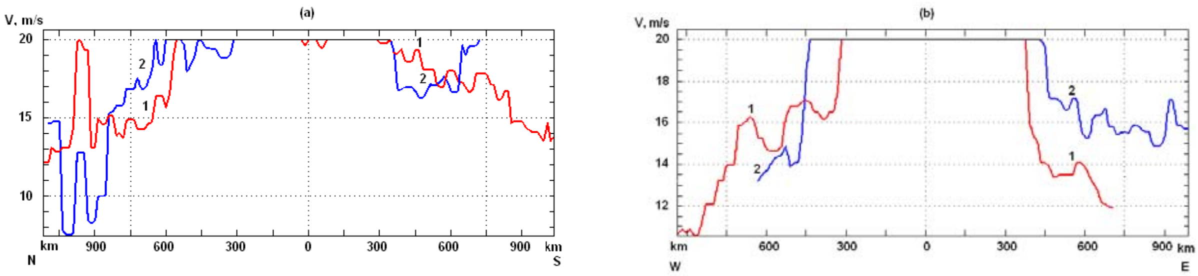


**Figure 2. Dependence of the wind speed V near the sea surface on distance to the TC center in the sections north-south (a) and west-east (b) crossing the centers of TC Walt (1) and Tim (2).**

The analysis of TC fields characteristics demonstrates that the location of the regions of the above V local maxima coincides with the locations of an increased total cloud liquid content, i.e. with the location of spiral cloud bands or separate cloud clusters. A most probable reason of the appearance of the local maxima of V may be, in our belief, the actual growth of V due convergence of the horizontal flux induced by intense vertical air updrafts in cloud clusters. The analysis of comparing accuracy characteristics of the observed and computed values of R34 for three TCs in the Pacific in the season of 1994 shows that a mean relative error in estimating R34 is no more than 10%.

The probability of successful imaging of a TC in the Northern Atlantic by the SSM/I radiometer (the vision band of the Earth's surface from the DMSP satellites is about 1400 km) is considerably higher than for TCs in the North-West Pacific because of their significantly less sizes. Fig. 3 demonstrates a connection of the observed ($R_o34$) and computed ($R_c34$) values of R34 for storms and hurricanes in the Atlantic in 1998 and 1999. The correlation coefficient $r(R_o34, R_c34) = 0.76$ is significant at the level $p<0.05$. The linear connection of $R_o34$ with $R_c34$ explains 58% of the scattering of the points. A mean relative error in the determination of R34 is equal to 23%. Thus the accuracy characteristics in the estimation of the storm wind zone with the use of up-to-date radiation-wind models for TC in the North-West Pacific and Atlantic are close on the whole: a mean-root deviation of computed values from the observed ones is within 10-20%.

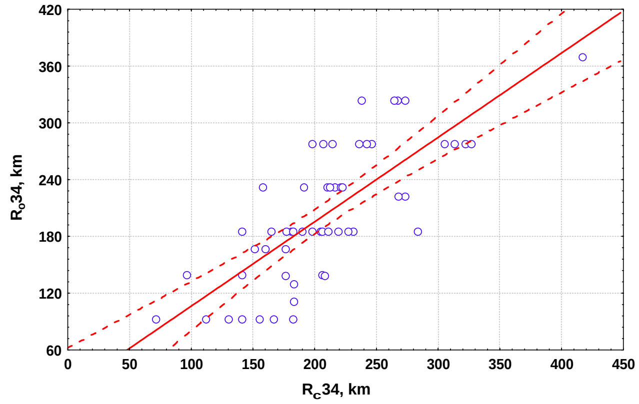


**Figure 3. Dependence of observed values of the parameter R34 on the calculated ones for TC of the Northern Atlantic in 1998-1999. The solid line is the regression line, the dashed lines are its 95% confidence interval.**

It has been shown earlier (Nerushev and Tereb, 2000) that the knowledge of the characteristics of the ozone anomaly generated by a TC (its effective dimensions and extremal depth) gives a possibility to estimate some TC important parameters, in particular, the effective dimensions of the storm and hurricane wind zone (parameters R34 and R64). Important is to compare two independent methods of determining R34 from the sounding data in the UV and microwave wavelength ranges. Such a comparison was made for TC in the Atlantic of 1998 for which the data quasicomplexized with time and space soundings made by the instruments TOMS and SSM/I were available. The results of comparison are given in Fig. 4. Despite a limited data volume (11 points) a good agreement of the R34 values obtained by two independent methods is distinctly seen.

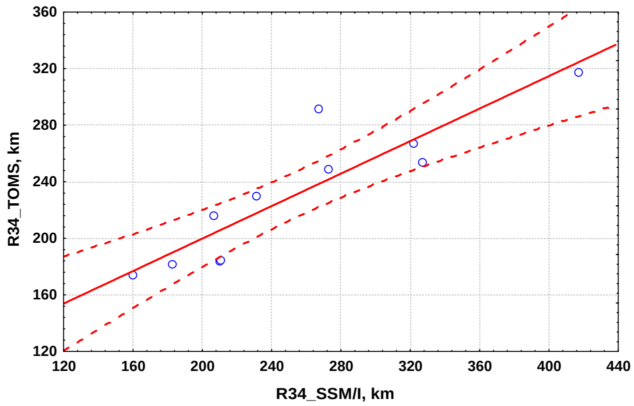


**Figure 4. Connection of effective dimensions of the storm wind zone R34 calculated over the SSM/I and TOMS data for TC in the Atlantic in 1998.**

## 4. ESTIMATION OF CHARACTERISTICS OF TC CENTRAL ZONE

The method for determining the parameters of the TC central zone (the sizes of the hurricane eye, the thickness of the eye cloud wall, effective dimensions of the hurricane wind zone, maximum wind speed) is based on the link revealed by us of typical properties of a central TC zone radiobrightness image in different channels of a radiometer and their radiobrightness temperatures with the above-mentioned characteristics (Nerushev et al., 2001). Without dwelling on the physical sense and the causes of this connection, the algorythms for retrieving these parameters considered in detail in (Nerushev et al., 2001; Nerushev, 2003) we should note some similarity of our method with the Dvorak method (Dvorak, 1975). A significant advantage of our method is that it is based on a quantitative analysis of satellite radiometric data. The method gives a possibility to determine a wider range of TC parameters, in particular, the effective dimension of the maximum wind zone $R_m$, the information on which is obtained at present only with a special aircraft reconnaissance.

Fig. 5 presents a connection of the observed and computed values of the R64 parameter for hurricanes of the Northern Atlantic in 1998 and 1999. The correlation coefficient $r(R_o64, R_c64) = 0.57$ is significant at the level $p<0.05$. The linear connection of $R_o64$ with $R_c64$ explains 32% of scattering of the points. An average relative error in estimating R64 is equal to 44%.

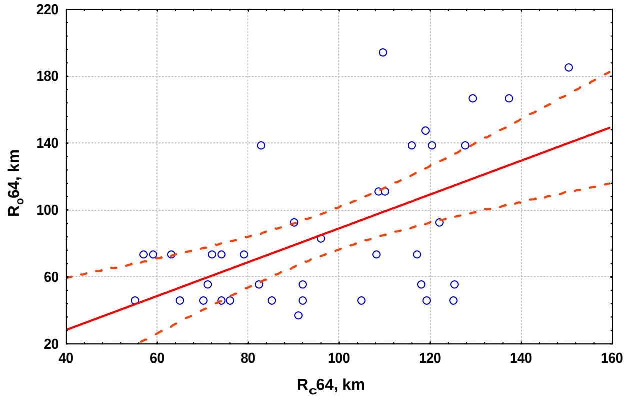


**Figure 5. Dependence of the parameter R64 observed values on the calculated ones for TC of the Northern Atlantic in 1998-1999. The solid line is the regression line, the dashed lines are its 95% confidence interval.**

Fig. 6 shows a connection of maximum wind speeds ($V_m$ ) obtained with the data of independent measurements for TC in the Atlantic in 1998 and 1999 when the radiobrightness temperature of the hurricane eye cloud wall ($T_{ew}$ ) was determined from the SSM/I data in channel 1 9.35 (h). The correlation factor of $T_{ew}$ with $V_m$ for a linear connection is equal to 0.62. From Fig. 6 it is seen that for superhurricanes ($V_m > 65$ m/s) the linear approximation gives greater errors. Numerical experiments have demonstrated that a cubic approximation gives a significantly better result as compared with the linear one thus ensuring an increase of the determination coefficient by about 1.4 times and of the correlation coefficient by about 1.2 times. So it explains more than 50% of variations in the values of $V_m$ . The application of the polynomials higher than the $3^{rd}$ power is weakly seen in the variation of the correlation and determination coefficients. A mean relative error in determining $V_m$ for the TC in the Atlantic mentioned with the use of the cubic approximation is equal to 16%.

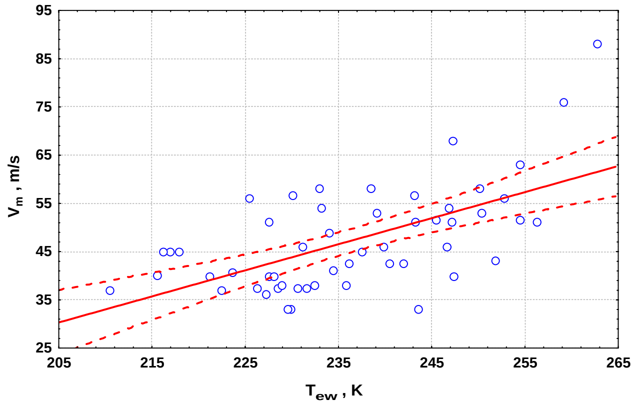


**Figure 6. Dependence of the $V_m$ values obtained over the data of independent measurements for TC in the Atlantic in 1998 and 1999 on $T_{ew}$ found over the SSM/I data in the channel 19.35(h). The solid line is the regression line, the dashed lines are its 95% confidence interval.**

## 5. DETERMINATION OF MEAN CHARACTERISTICS OF WIND SPEED FIELD NEAR SEA SURFACE

In view of the algorythm described in Section 2 wind speed fields near the sea surface were computed for some tropical cyclones of the Atlantic in 1998 and 1999 for the whole region of their action – from the center to periphery. The values of TC major parameters were computed over the data of remote soundings with the algorytms described in Sections 3 and 4. Fig. 7 shows as an example the V(R) profiles averaged over the azimuthal angle $\varphi$ in the central part of hurricanes Floyd (1999) and Gert (1999) calculated for several days of their life. The curves were constructed over the experimental points by the spline method. Here it has been assumed that the values of $V_m$ are reached at the inner and outer boundaries of the hurricane eye cloud wall. The curves of V(R) at $R > R_m$ for both hurricanes are with a high accuracy approximated by the known dependence of the type of $V(R) \sim R^{-\alpha}$. In this case an average value of $\alpha = 0.78 \pm 0.21$ for the hurricane Floyd and for hurricane Gert an average value of $\alpha = 0.58 \pm 0.19$. On the whole, this is in a good agreement with an average value of $\alpha = 0.6$ at distances of R = 100 – 300 km from the TC center obtained in some works on the basis of processing a great number of observation data.

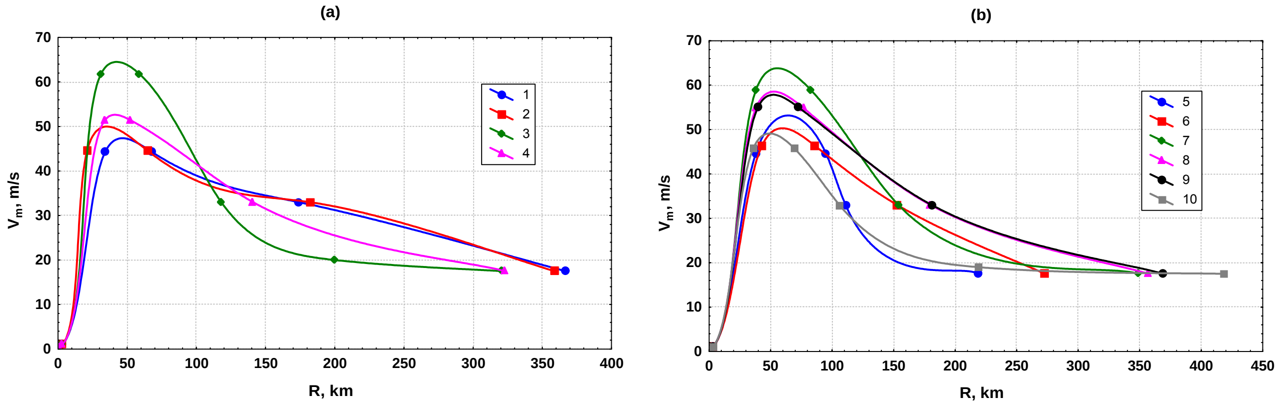


**Figure 7. Averaged over the azimuth radial profiles of wind speed near the sea surface calculated with the use of the above described algorythm for several days of hurricane Floyd (a) and Gert (b) life in the Atlantic in 1999. 1 – 10.09.99 (time of sounding is 21:31 UTC), 2 – 11.09.99 (10:04 UTC), 3 – 13.09.99 (01:14 UTC), 4 – 13.09.99 (13:45 UTC), 5 – 13.09.99 (23:17 UTC), 6 – 14.09.99 (11:52 UTC), 7 – 15.09.99 (09:15 UTC), 8 – 17.09.99 (00:09 UTC), 9 – 18.09.99 (12:42 UTC), 10 – 19.09.99 (10:05 UTC).**

Fig. 8 shows radiobrightness image of hurricane Bonnie obtained on 23.08.1998 at 13:33 UTC at the frequency of 85.5 (h) GHz and a smoothed spatial structure of the sea water wind field $V(R,\varphi)$ for $R > R_m$ calculated with the use of the method described. Here the isolines V between $V = V_m$, V = 33 m/s and V = 17.5 m/s are made with the spline method. A classical asymmetry of the wind field near the sea surface is distinctly revealed: to the right from the direction of motion the wind speed is higher than that to the left. This is caused by adding (at the right) or subtracting (at the left) of velocities of the steering flow and circulation systems of the tropical cyclone.

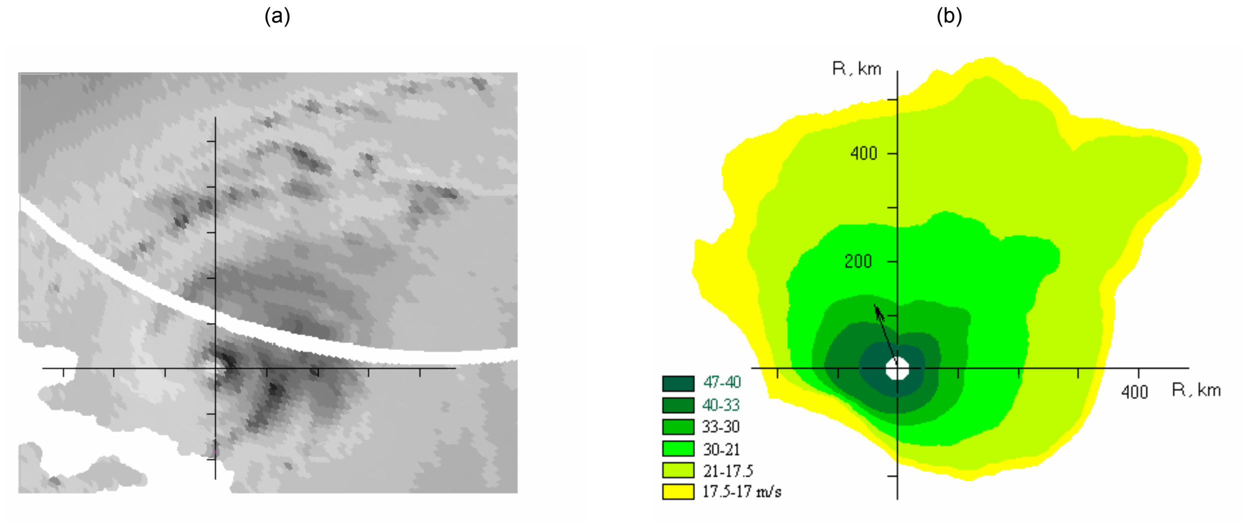


**Figure 8. Radiobrightness image of hurricane Bonnie (23.08.1998 at 13:33 UTC) at the frequency of 85.5 (h) GHz (a) and a smoothed spatial structure of the sea water wind field for $R > R_m$ calculated with the use of the method described (b).**

## 6. CONCLUSIONS

The method for retrieving a mean spatial structure of the wind speed field near a sea surface in zones of intensive atmospheric vortices action from the sounding data of the ocean-atmosphere system in the microwave wavelength range has been developed. The method consists of retrieving major structural parameters of atmospheric vortices (effective dimensions of storm and hurricane wind zones, maximum wind speed and effective dimensions of maximum winds zone) and in determining on their basis a smoothed spatial distribution of the wind speed near the sea surface V in the whole zone of the vortex action – from the center to periphery. It has been shown that some parameters of the vortex, in particular, effective dimensions of storm and hurricane wind zones, can be found over the sounding data not only in the microwave but also in the UV wavelength range.

The method described is applicable for vortices with distinct structural parameters – the eye, the eye cloud wall, zones of hurricane and storm winds. Tropical cyclones and polar mesocyclones can be named in their number. The probability of a successful microwave sounding of polar mesocyclones, the average sizes of which (about 200 km) are by several times less than the sizes of tropical cyclones, should be significantly higher.

The method has been tested with the data of soundings of tropical cyclones of the Northern Atlantic and North-West Pacific in 1994, 1998 and 1999 made by the microwave radiometer SSM/I and ozone mapper TOMS. By comparing the data of computations with the data of independent measurements estimated was the accuracy of determining most important structural parameters of atmospheric vortices. It has been shown that a mean relative error in the determination of the storm wind zone effective dimensions is within the limits of 20%, and that of the hurricane winds is within 40%. A mean relative error in estimating $V_m$ is equal to 16%.

The calculation results for wind speed fields near the sea surface in certain tropical cyclones show that the method reasonably retrieves typical properties of the wind spatial distribution both in the cyclone central zone and at its periphery. This confirms adequacy of the results obtained with the method to actual conditions under which tropical cyclones exist.

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