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DIAGNOSTICS OF INTENSIVE ATMOSPHERIC VORTICES OVER THE MULTIWAVE SATELLITE-DERIVED SOUNDING DATA

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ABSTRACT

Described are two independent methods proposed by the authors of the paper to determine tropical cyclone parameters (effective dimensions of storm and hurricane wind zones, maximum surface wind speed and minimum pressure in the TC center, depth of hurricane "eye" cloud wall, etc.) important for predicting TC motion, for the preparation of storm warnings, for assessing possible damages, etc. The methods are based on the application of remote sounding data for the ocean-atmosphere system in the UV and microwave spectral ranges. The results are given of definite calculations of tropical cyclones in the Atlantic and Pacific in 1998 and 1999 made with the data of the microwave radiometer SSM/I and the ozone mapper TOMS.

1. INTRODUCTION

Remote sounding of the atmosphere-ocean system from space is a most efficient means for studying tropical cyclone (TC) genesis and for obtaining on-line and most complete information on TC parameters. Of most importance are complexized in time and space soundings of vortices in different spectrum wave ranges – from the UV to radio waves. In particular a joint use of the UV and microwave spectrum ranges makes it possible to acquire important information on TC (Nerushev et al, 2001; Nerushev et al, 2000).

The ocean-atmosphere system thermal radiation in the microwave spectrum range is absorbed by clouds less intensively than in the optical and infrared ranges, and its intensity depends on such geophysical parameters as the ocean surface temperature, integral contents of water vapor and cloud liquid water content, precipitation intensity. Just these parameters control the energy processes in the ocean-atmosphere system and are most important when studying TC (Nerushev et al, 2001). Sounding of TC in the UV wave length range allows one to determine the spatial structure and characteristics of ozone layer perturbations induced by TC and significantly depending on its parameters (Nerushev et al, 2000).

The applicability of microwave sounding for determining geophysical fields in a TC zone is significantly limited by the lack of adequate radiation-geophysical models and algorithms for the retrieval of the parameters sought. Thus the radiation-geophysical models existing now are for wind velocities at the ocean surface no more than 20 – 25 m/s (see, for example, Wentz, 1992, 1997). At the same time in the zones of action of intensive atmospheric perturbations – cyclones of tropical and moderate latitudes – the wind velocity often exceeds the hurricane intensity (V ≈ 33 m/s).

Earlier we have shown on the basis of processing and analysis of sounding data for several TC of the Pacific and of 10 TC in the Atlantic obtained by the SSM/I (Special Sensor Microwave/Imager) that a most sophisticated and adapted to the SSM/I data radiation-wind model (Wentz, 1997) developed for standard meteorological conditions does not yet allow with good accuracy to retrieve some important characteristics of the wind field in the vicinity of a TC, in particular, the dimensions of the storm wind zone (V > 17.5 m/s) (Nerushev et al, 2000, 2001). At the same time the presence of intensive precipitation and of a shield of cirrus clouds that completely screen the ocean surface exclude the possibility to apply the model to correctly determine the location and dimensions of the storm wind zone (V > 33 m/s).

The most important characteristic of a TC is its intensity governed by maximum wind velocity (V_m) or minimum pressure in the center (P_0) between which the functional connection exists (Holland, 1980). According to some studies the image caused by TC is proportional to V_m^2 or even to V_m^4. Therefore most promising seems an attempt to determine V_m or P_0 over the radiometric sounding data. The first studies in this direction were made as early as at the end of 1970s – in the beginning of 1980s based on the data from Nimbus-6 microwave radiometers SCAMS (SCAnning Microwave Spectrometer) (cf. Kidder et al, 1980 and references there), and then they were continued in 1980-1990s with the use of the NOAA satellite radiometer MSU (Microwave Sounding Unit) (cf. Velden et al, 1991 and references there). The measurements in the radiometer channel receiving radiation with the wavelength of about 5 mm sensitive to the temperature of the upper troposphere were used. All the works mentioned are common in an indirect determination of TC intensity on the basis of the connection of measured characteristics of the TC upper level temperature anomaly (the so-called warm core) with V_m and P_0. A disadvantage of the method proposed is, as the authors indicate, a low accuracy of determining the center of a TC and location of the temperature anomaly caused by low horizontal resolution of the instruments (≥ 110 km) used.

Thus the parameters of a TC central zone, being most important in the aspect of energy, are not determined on the basis of the microwave radiometric sounding at all or are determined with a great error. A

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way out of this situation can be the elaboration of a semiempirical model based on the presence of connections between the peculiarities of a tropical cyclone brightness image in different channels of a microwave radiometer and the parameters of the TC central zone. Knowing the parameters of the TC central zone (maximum wind velocity, location and dimensions the hurricane wind zone as well the configuration and effective dimensions of the storm wind zone) one can completely reconstruct a smoothed spatial structure of the wind velocity at the ocean surface in the TC action zone.

The goal of the paper is to describe two independent methods proposed by us for determining the parameters of tropical cyclones (effective dimensions of storm and hurricane wind zones, maximum wind speed at the sea surface and minimum pressure in the TC center, thickness of hurricane "eye" cloud wall, etc.) along with average characteristics of wind field spatial structure important for forecasting their motion, preparation of storm warnings, assessing possible damages, etc. The methods are based on the data of remote sensing the system "ocean-atmosphere" in the UV and microwave spectral ranges. The calculation results for tropical cyclones parameters of the Atlantic and Pacific obtained in 1998 and 1999 from the data of the SSM/I microwave radiometer and the TOMS ozone mapper.

2. EXPERIMENTAL DATA

The sounding data of tropical cyclones in the Atlantic and Pacific obtained in 1998 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.

Microwave radiometers SSM/I are operated on board some US satellites of the DMSP (Defense Meteorological Satellite Program) series. The satellites are in the solar quasi-polar orbit with an angle of 98.8^0 and altitude 805 $\pm$ 72 km (Hollinger et al, 1990). The SSM/I radiometer measures the Earth radio radiation in seven channels: 19.35 (v, h); 22.235 (v); 37.0 (v, h) and 85.5 (v, h) GHz (v, h - are the vertical and horizontal polarizations of the radiation accepted, correspondingly) by conic scanning at a constant angle of view to nadir of 45^0 with the vision band of the Earth surface of 1400 km. The spatial resolution on the ground surface for different channels varies within the range of 13 – 69 km.

The instrument TOMS realizes the so-called backscattering method in which TO is retrieved over the measurements of incident and reflected solar radiation in the ultraviolet spectrum range. Four channels of the instrument in the spectral range of 312 – 340 nm are used to determine TO and one channel (360 or 380 nm) is used for monitoring the underlying surface. The spatial resolution of the TOMS is about 50 km at measurements in nadir, at inclined sighting the resolution is naturally cruder (Bhartia et al, 1983).

The SSM/I and TOMS data were obtained by us via the Internet from the Global Hydrology and Climate Center, Huntsvill, Alabama and the Goddard Space Flight Center, Greenbelt, USA, correspondingly. The data on the trajectories and parameters of tropical cyclones were obtained from the Hydrometcenter of the Russian Federation. Information from the instrument TOMS is available in the Internet in the form of the so-called grid-files where the latitudinal pitch is 1^0 and the longitudinal one is 1.25^0, that for the equatorial zone corresponds to the spatial resolution of 110 x 140 km^2. For each cell of the grid a mean long-term for the period of 1978-1998 TO value was determined and later on analyzed were not the TO values but their deviations from the mean.

The SSM/I data are archived in the HDF format (Hierarchial Data Format) for separate semiturns. The fragments of measurements corresponding to satellite passages over TC were separated from these data with the help of a special program based on the information on TC trajectories and parameters obtained from The Russian Hydrometcenter. Several hundreds of TC images were obtained in the channels of high and low resolution. For further analysis several tens of them meeting several requirements were selected. In particular, the requirements were the remoteness of the TC center from the continents and islands, TC location in the center of the picture if possible, etc. Due to some obstacles the number of images applicable for determining different parameters of a TC and the wind field over the ocean surface was different. Therefore the information on the number of sounding images over which a certain parameter of TC was determined will be given in corresponding sections.

3. DETERMINATION OF TROPICAL CYCLONE PARAMETERS OVER THE DATA OF MICROWAVE SOUNDINGS

Several parameters important for practical application are separated in the spatial distribution of wind at the ocean surface in the zone of TC action. These parameters are: maximum wind velocity (V_m) and the distance from the TC center at which it is attained (R_m), the distances from the TC center at which the wind velocity exceeds some certain values, in particular, 34 kn (storm wind) and 64 kn (hurricane wind).The corresponding parameters are called the dimensions of the storm (R34) and hurricane (R64) winds. The parameters are the input ones for some models of TC movement with the help of which zones of potential damages are estimated. The values of R34 and R64 in storm-warnings are, as a rule, based on the data of independent measurements (aerial reconnaissance, data of drifting meteorological buoys, of automatic meteorological stations, images obtained by geostationary satellites in the visible and IR wavelength ranges, etc.). As it has been shown by us (Nerushev et al, 2001) the use of sounding data of the ocean-atmosphere system in different channels of the SSM/I radiometer makes it possible to define such important TC parameters as the configuration and effective dimensions of the storm and hurricane winds, maximum wind velocity, the location and dimensions of the maximum wind zone, sizes of the hurricane "eye" etc.

3.1 *Determination of storm wind zone effective dimensions*

The radiation-geophysical models existing at present are intended for wind velocities not exceeding 20-25 m/s at the ocean surface. Therefore one can expect that outside the storm wind zone the use of these models will allow one to obtain a spatial distribution of the wind velocity at the ocean surface adequate to the real situation. The analysis of the microwave radiometric method accuracy in determining the parameter R34 based on the radiation-wind models available was made by us (Nerushev et al, 2001). To determine the ocean surface wind velocity with the SSM/I data we used the model (Wentz, 1997) developed specially for SSM/I and tested with rather a large set of experimental data. The variations of absorption by the atmosphere was accounted for over the integral contents of vaporous moisture Q and liquid water content W in the atmospheric column. As a TC originates at $T \geq 300K$ (Elsberry et al, 1988) and the SSM/I radiometer channels do not, give a possibility to estimate T with rather a high accuracy T = 300K was taken at data processing. The parameters V, Q and W were found over the measurements made in three channels of the SSM/I as 22.235 (v), 37.0 (v, h), correspondingly, with the help of the model (Wentz, 1997) and the nonlinear algorithm (Petrenko, 1983) that permitted to consider the physical limitations for the parameters, in particular, their non-negativeness. As far as the model is intended for standard meteorological conditions, it was assumed that the errors in determining the geophysical parameters should increase with approaching a TC center.

The software developed specially for the purpose makes it possible to simultaneously show on the monitor display several parameters under study in the form of half-tone images and isolines. In particular, the construction of the ocean surface wind velocity V isolines allows for determining the storm wind zone location, shape and effective dimension ($V > 34$ kn = 17.5 m/s). Here the calculated effective dimension of the zone (R_c34) is determined as the radius of the circle equal in the surface area to the region limited by the isoline V = 34 kn. Such an approach removes the necessity to precisely determine the TC center over the radiometric data.

With the use of the above methods and software the fields of wind velocity V at the ocean surface around TC in the North Atlantic of 1998 and 1999 were analyzed. To calculate the storm wind zone effective dimensions (R_c34) 39 images of 10 TC of 1998 and 16 images of 8 TC of 1999 at the storm and hurricane stages appeared applicable. Table 1 shows accuracy characteristics of a comparison of the observed and calculated values of R34. The precision of determining R34 is likely to be considered satisfactory as the mean square of the difference ($R_c34 - R_o34$) equal to 47 km practically coincides with the SSM/I radiometer spatial resolution in the channels used to determine V. A mean square difference ($R_c34 - R_o34$) equal to 47 km is approximately equal to 23% of the mean value R_o34. Such an accuracy in determining the dimensions of the storm wind zone is likely to be satisfactory in view of the fact that the value of 47 km practically coincides with the SSM/I radiometer spatial resolution in the channels used to determine V.

Table 1. A comparison of the calculated over the SSM/I radiometer data (R_c34) and observed (R_o34) values of the parameter R34

Parameter	R_c34, km	R_o34, km	$R_c - R_o$, km	$(R_c - R_o)/R_o34$
Arithmetic Mean	209	203	6	0.03
Mean Square			47	0.23

Fig. 1 gives a connection of observed R_o34 and calculated R_c34 values of the parameter R34.

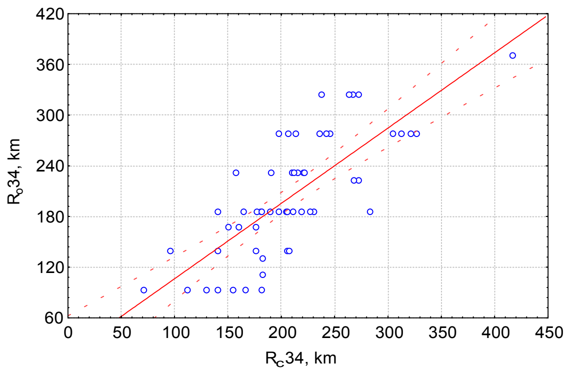


Fig. 1. Dependence of observed values of the parameter R34 on the calculated ones for TC of the Northern Atlantic in 1998-1999

The solid line in Fig. 1 is the regression line, the dashed lines are its 95% confidence interval.

The linear regression equation describing the connection of the observed (R_o34) and calculated (R_c34) values of the storm wind zone effective dimensions has the form of

$$R_o34 = 11.084 + 0.892^* R_c34 \qquad (1)$$

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.

3.2 *Determination of the hurricane zone effective dimensions*

The semiempirical method proposed for determining the effective dimensions of the hurricane wind zone is based on the connection revealed by us of typical features of the TC central zone brightness image obtained in the channel of 85.5 (h) GHz with the dimension of the hurricane wind zone R64 – an average distance from the TC center within which the wind velocity is V > 64 kn (≈ 33 m/s). The analysis of a great number of radio images of TC made it possible to state that the radio-images of a tropical depression, a storm and a hurricane at the frequency of 85.5(h) GHz practically for all the images analyzed are different. The image structure observed at the hurricane stage has typical characteristics: a light region of increased radiobrightness temperatures in the TC center is encircled by a dark ring of decreased brightness temperatures followed by a quasi-closed zone of increased brightness temperatures. Fig. 2 gives the images of TC Gert at the tropical depression stage (12.09.99) and at the hurricane stage (15.09.99) as an illustration for the above-said. The arrows indicate the locations of the regions mentioned.

A comparison with the data of TC soundings within the visible and IR wave ranges allows one to consider the bright central region the hurricane "eye". The dark ring is the image of the hurricane "eye" cloud wall. Table 1 gives the average characteristics of the hurricane "eye" and cloud wall calculated on the basis of sounding data for the TC in the Atlantic mentioned above. The "eye" radii given in Table 1 are in good agreement with the values found from the data of more than 500 radar and aircraft measurements (<r> = 26±16 km).

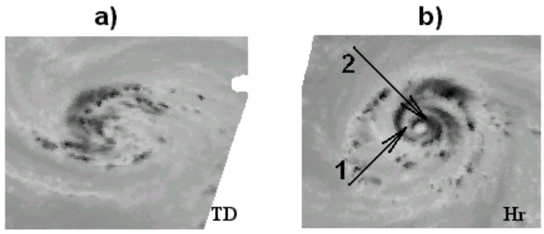


Fig. 2. Brightness images of TC Gert at the stage of tropical depression (a) and hurricane (b). Arrow 2 indicates the decreased brightness temperatures, arrow 1 is the location of increased ones coinciding with the hurricane wind zone.

Table 2. The values of the hurricane "eye" mean radius (<r>) calculated over the SSM/I radiometer data, its standard deviation ($\sigma_{<r>}$), mean radiobrightness temperature of the "eye" at the frequency of 85.5 (h) GHz ($<T_e>$) and its standard deviation (σ_T); the cloud wall average width ($<\Delta r>$), its mean radiobrightness temperature at the frequency of 85.5 (h) GHz ($<T_{\Delta r}>$) and their standard deviations ($\sigma_{<\Delta r>}$ and σ_T) for hurricanes in the Atlantic in 1998 and 1999.

Year	"Eye" characteristics "				Cloud wall characteristics			
	<r>, km	$\sigma_{<r>}$	$<T_e>$, K	σ_T	$<\Delta r>$, km	$\sigma_{<\Delta r>}$	$<T_{\Delta r}>$, K	σ_T
1998	23	7	259	14	29	7	234	15
1999	33	6	254	10	33	9	235	7

A most probable cause of the radiobrightness temperature decrease at the frequency of 85.5 (h) GHz around the TC center is in the existence of vigorous ice clouds in the hurricane "eye" wall that accompany, as a rule, the lower cumulus rain-producing clouds. "Warmer" radiobrightness temperatures of the first quasi-closed zone are most likely induced by the location of this zone beyond the boundaries of the central system of cumulus rain-producing and cirrus clouds, where scattering on ice crystals is low and the radiobrightness temperature at the frequency of 85.5 (h) GHz is governed by radiation of water vapor and liquid droplet clouds. The hurricane "eye" increased radiobrightness temperature is in a similar way determined mainly by radiation of water vapor and liquid droplet clouds in the lower troposphere almost always present in the "eye".

It has been stated that the hurricane wind zone dimensions observed (R_o64) coincide with the location of the above-mentioned first quasi-closed zone of increased radiobrightness temperatures in the 85.5 (h) GHz, and the radiobrightness temperature itself in this zone varies in rather a narrow range. For hurricanes of 1998 an average temperature in the 85.5 (h) GHz channel (<T85h>) appeared to be equal to 278K at a standard deviation σ = 9K. Relative constancy of <T85h> allows one to introduce a quantitative criterion for defining the hurricane wind zone effective dimensions, namely, the range of radiobrightness temperature variation T85(h) according to which the location of the first quasi-closed zone around the TC center is found.

To calculate the hurricane wind zone effective dimensions (R_c64) on the basis of the above-mentioned method 38 frames appeared appropriate (21 for TC of 1998 and 17 for TC of 1999) at the hurricane stage. After the high-frequency noise was removed radial cuts were constructed from the TC center with the step of 45^0 (8 cuts) with the length of 300 km. The values of radiobrightness temperatures were taken along the line of a cut, based on which corresponding values of $R_{ic}64$ were determined. The value of R_c64 was calculated as the arithmetic mean of the values of $R_{ic}64$ found. Table 3 shows accuracy characteristics of a comparison of the observed and calculated values of R64. From the analysis of the results it follows that the calculated values of R64 are somewhat higher than the observed ones. The mean arithmetic value of the difference (R_c64 – R_o64) is about 13 % and the mean square is 44 % of a mean value of R_o64.

Table 3. A comparison of the calculated over the SSM/I radiometer data (R_c64) and observed (R_o64) values of the parameter R64

Parameter	R_c34, km	R_o34, km	R_c - R_o, km	(R_c - R_o)/R_o34
Arithmetic Mean	97	86	11	0.13
Mean Square			38	0.44

Fig. 3 presents the connection of the observed and calculated values of the parameter R64. The linear regression equation describing the link of the values of observed (R_o64) and calculated (R_c64) for the hurricane wind zone effective dimensions has the form of

$$R_o64 = 12.107 + 1.012 * R_c64 \quad (2)$$

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.

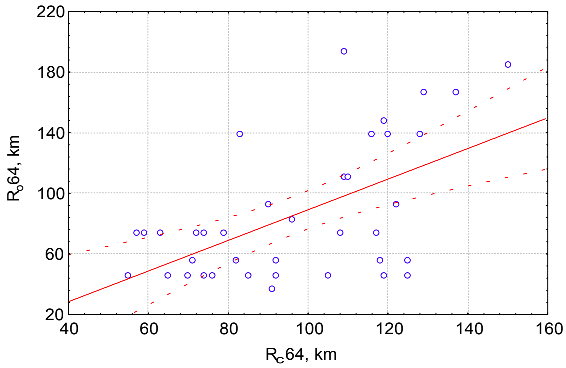


Fig 3. Dependence of the parameter R64 observed values on the calculated ones for TC of the Northern Atlantic in 1998-1999. The solid line is the regression line, the dashed lines are its 99% confidence interval

3.3 *Determination of tropical cyclone intensities*

The connection of typical characteristics of TC brightness images revealed at the frequency of 85.5 (h) GHz with the TC structural parameters makes it possible to approach the problem of determining V and P based on the data of microwave radiometric soundings. The analysis demonstrates that a mean brightness temperature in the zones at the hurricane stage described in the previous Section has a significant correlation link with V_m and P_0. The highest correlation is typical of the brightness temperature of the dark ring (the cloud wall of the hurricane "eye", T_{ew}) at the frequency 19.35(h) with V_m and P_0.

Fig. 4 gives the connection of the V_m and P_0 values obtained over the data of independent measurements for the TC in the Atlantic in 1998 and 1999 with T_{ew} found over the SSM/1 data in the 19.35(h) channel. The number of images that was found applicable for determining the connection indicated appeared to be 32 for 1998 and 21 for 1999. From Fig. 4 it is seen that for superhurricanes ($V_m \geq$ 65 m/s) the linear approximation gives considerable errors. Numerical experiments have shown that the cubic approximation gives rather a better result as compared with the linear one providing an increase of the determination coefficient by about 1.4 times for V_m and 1.3 for P_0. It explains 60% of variations in the values of V_m and 51% of variations of P_0. The use of the polynomials of the degrees higher than the 3rd one weakly affects the variations of the coefficients of correlation and determination.

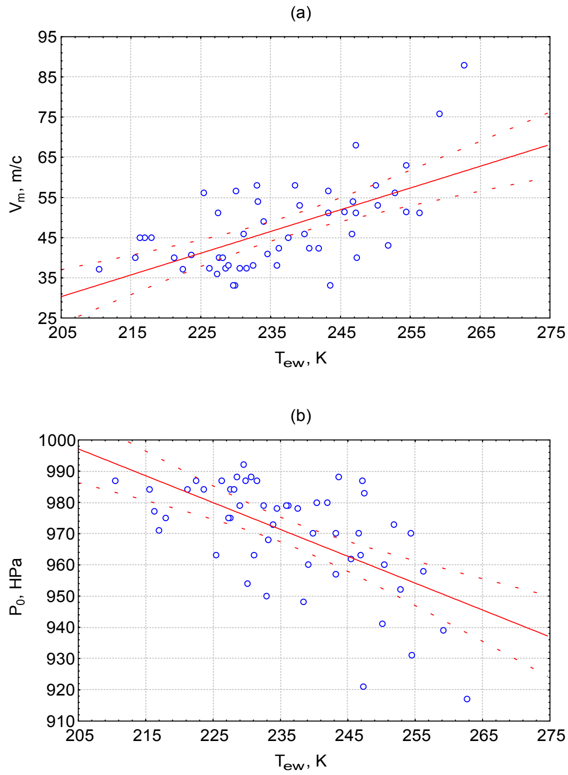
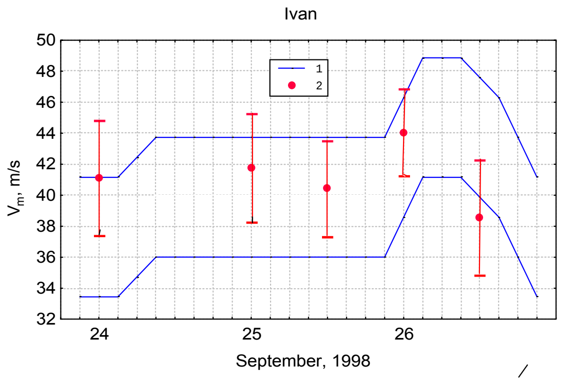


Fig. 4. Dependence of the V_m (a) and P_0 (b) values obtained over the data of independent measurements for TC in the Atlantic in 1998 and 1999 on T_{ew} found over the SSM/I data in the channel 19.35(h)

It is of interest to compare the results obtained for separate TC with a temporal trend of parameters over the data of independent measurements. Fig. 5 shows such a comparison made with the account for the parameter V_m for two TCs: Ivan and Jeanne (September of 1998) mostly supported with the SSM/I data during several successive days. The information on V_m is given in storm-warnings as a range of probable values. Fig. 5 gives the upper and lower limits of this range. The 95%-confidence level of the V_m parameter variation retrieved from the SSM/I data is indicated. As it follows from the analysis of Fig. 5 in most cases the values of the parameter V_m retrieved and taken from storm-warnings with the account for the limits of their variation coincide.

Note here one circumstance that follows from the analysis of comparison of the parameters R34, R64 and V observed and calculated (Figs. 1, 3 and 5). It seems a little strange that the TC intensity and the dimensions of the storm and hurricane wind zones remain constant for two or three days as it follows from the data of independent observations (TC Danielle, Ivan, Jeanne), while the radioimages of these TC noticeably change. This makes the basis for doubt in the adequacy of the data from storm-warnings to the real situation. It is thought that the data of microwave radiometric soundings may give a more objective information on TC parameters.



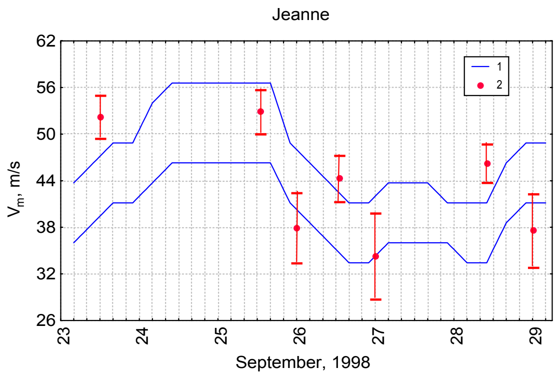


Fig. 5. V_m data from SSM/I and storm-warnings. 1 – storm-warnings, 2 – SSM\I

3.4 *Determination of the sea surface wind field average structure*

The results presented above make it possible to determine an average spatial distribution of the sea surface wind velocity V in the whole range of a tropical cyclone action – from the center to its periphery. The algorithm to obtain the spatial distribution V is as follows. The values of V_m, R_m, R64 and R34 are determined in a TC region for distances $0 \leq R \leq R34$ from the SSM/I data on the basis of the above methods. Note that R64 and R34 can be found as functions of the azimuthal angle φ. 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).

Fig. 6 gives as an example averaged over φ smoothed profiles of V(R) in the central part of hurricane Dannielle (1998) for several days of its life calculated with the above-mentioned algorithm. The curves are constructed over the experimental point with the use of the spline method. The trend of the curves V(R) in Fig. 6 for $R > R_m$ is approximated with a high accuracy by the dependence of the type of $V(R) \sim R^{-\kappa}$. In this case κ varies from 0.72 (curve 2) to 0.54 (curve 4).

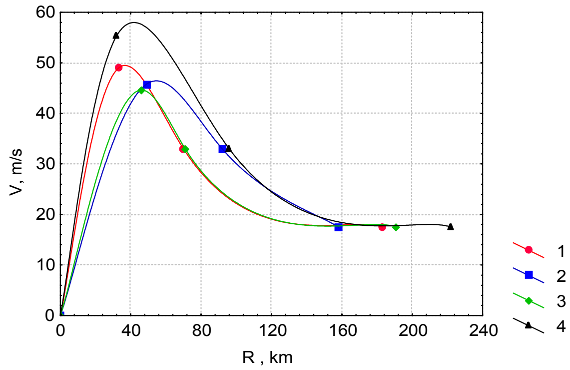


Fig.6. Smoothed profiles of V(R) for several days of hurricane Dannielle (1998) life-time calculated with the above algorithm. 1 - 25.08 (time of sounding - 20:40 UTC), 2 - 30.08 (1:17 UTC), 3 - 30.08 (13:46 UTC), 4- 31.08 (1:05 UTC)

Fig. 7 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.

4. DETERMINATION OF TROPICAL CYCLONE PARAMETERS OVER THE SOUNDING DATA IN THE UV SPECTRUM RANGE

Tropical cyclones affect the ozone layer causing perturbations of total ozone (TO) and vertical distribution of ozone concentration (VDO) with various spatiotemporal scales (Nerushev, 1994). The perturbations showing themselves as specific deviations from the background values can be registered with the help of existing instrumentation and carry information on the energy and dynamics of the atmospheric processes that generated them as well as on the characteristics of the media through which they propagate. They can be a suitable tool for solving the problems of diagnisis and prediction of dangerous atmospheric phenomena, tropical cyclones in their number. The ozone layer perturbations by tropical cyclones were studied on the basis of satellite data in some works (Rodgers et al, 1990; Stout et al., 1992). But there the problems of ozone perturbation characteristics dependence on TC parameters were not considered gradually.

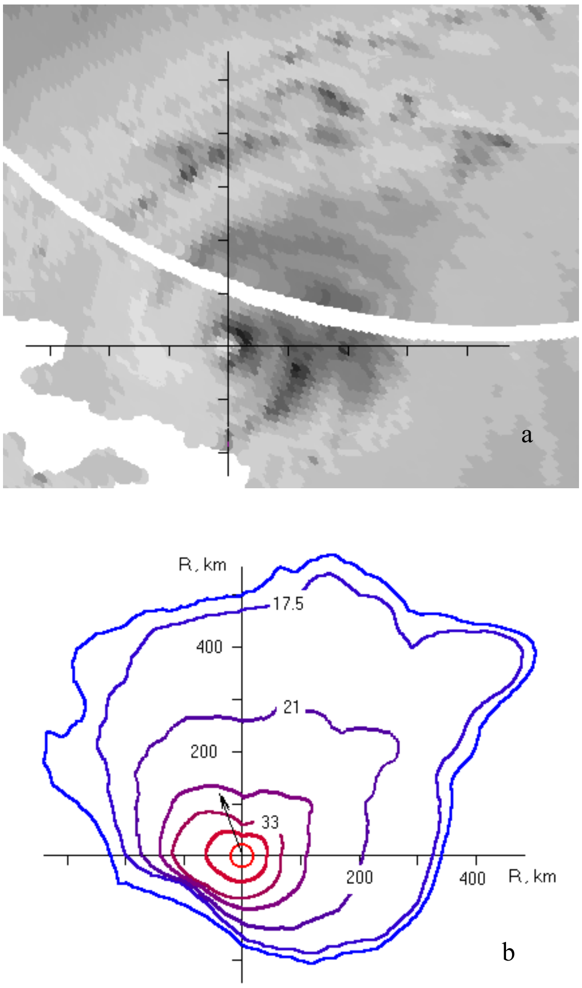


Fig. 7 Radiobrightness image of hurricane Bonnie (23.08.1998 at 13:33 UTC) at the frequency of 85.5 (h) GHz (a) and a smoothed spatial structure of the sea water wind field for R > R_m calculated with the use of the method described (b)

The analysis of the errors in assessing TO shows that the negative ozone anomaly can be considered a real one and not caused by the measurement errors if its absolute value is more than 5-6 D.U and the effective dimensions are more than the region of 30% albedo. As is shown (Tereb, 1998) the measurements of TO by the backscattering instruments have a methodical error that shows itself in underestimation of TO at measurements over the TC active zone. Nevertheless it would be natural to expect that the real and “visible” (those “seen” by satellite ozonometers of the TOMS type) ozone anomalies generated in the ozone layer by the TC circulation systems are connected. In such a case the “visible” spatial dimension and the depth of the ozone anomaly would depend on the energy of these systems.

The most important parameters controlling a TC power that are included in storm-warnings are its intensity characterized by maximum wind velocity V_m and the dimensions of the storm (R34) and hurricane (R64) wind zones, i.e. average distances from the TC center within which the wind velocity at the ocean surface exceeds 34 and 64 kn, correspondingly. Let us consider the influence of these parameters on the dimensions and depth of the ozone anomaly. The dimension of the anomaly will be characterized by the radius of the circle equal in surface area to that of the negative ozone anomaly with the outer boundary corresponding to minus 6 D.U. (it will be denotes as $R_{6D.U.}$) and the ozone anomaly depth will be characterized by its extreme depth ΔX_{max} , i.e. by maximum negative deviation of TO.

As an example in Fig. 8 the map of TO deviations from the long-term averages and in Fig. 9 the map of the underlying surface reflectivity in the zone of Bonnie-98 action (Northern Atlantics, 23.08.98) are shown. The center of the cyclone for the nearest observation time according to the storm - warnings is shown by the cross-hairs. Some discrepancy between the TC center position and the area of maximum reflectivity in Fig. 9 is likely to be explained by the error in the TC center determination and by some difference between the observation time and the time of the TO satellite measurements. In Fig. 10 the image of this TC in the visible spectral interval by the GOES satellite for approximately the same time is shown. The size of the image is $21.4^0 \times 19.4^0$. When analyzing these figures it is possible to conclude that the size of the active TC zone (the circular shaped form covered with clouds) is equal approximately to 6-7^0. Albedo values exceeding 60% correspond to this region. The positions of the areas with the albedo exceeding 60 % in Fig. 9 and the areas of the maximum negative TO deviations in Fig. 8 are in good agreement.

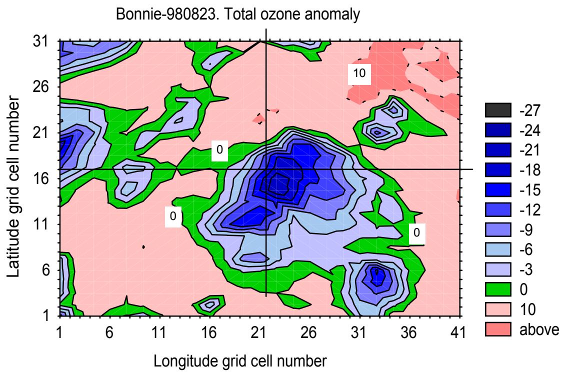


Fig. 8. The map of TO deviations from the long-term averages in the zone of Bonnie-98 action

For the analysis 7 TC of the North Atlantic and 7 TC of the North-West Pacific of 1998 at the storm and hurricane stages were chosen that could be considered as isolated ones, i.e. the cloud systems of which could be distinguished from the environment. The requirement of TC isolation is caused by the fact that for a non-isolated TC the dimensions and the depth of the ozone anomaly (as well as its shape) would be governed not only by the processes in the TC in itself but also by the processes of interaction of the TC and the environment. TO deviations from the long-term average value needed for the analysis were calculated for the grid of the size of 30^0 in latitude and 50^0 in longitude. The sampling was made for the data necessary in such a way that the TC center as for the local noon was in the grid center that assisted the following analysis. The radii of the storm and hurricane wind zones and the values of the maximum wind velocity were taken from storm-warnings.

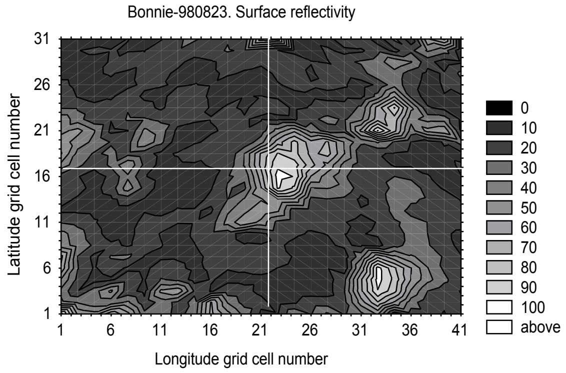


Fig. 9. The map of the underlying surface reflectivity in the zone of Bonnie-98 action

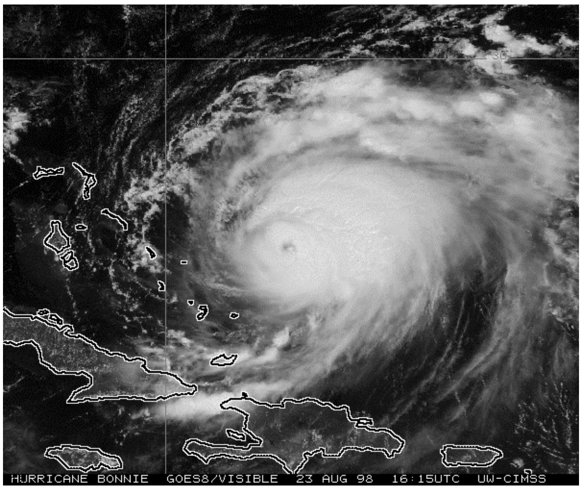


Fig. 10. The image of Bonnie-98 in the visible spectral interval by the GOES satellite

The calculation results of the correlation links of the parameters characterizing the negative ozone anomaly and the parameters characterizing the TC power show that the highest link of the ozone anomaly dimensions R was observed for the effective dimensions of the storm (R34) and hurricane (R64) wind zones. The corresponding correlation coefficients significant at the 0.05 level are equal to: 0.62 and 0.69 for the Atlantic, 0.66 and 0.56 for the Pacific. The connection of the ozone anomaly dimensions with V_m is weaker both for the Atlantic and for the Pacific. The extreme value of the ozone anomaly ΔX_{max} has a significant correlation link with the dimensions of the storm and hurricane wind zones (the correlation coefficient is equal to minus 0.57 for both cases) only for the TC in the Atlantic, the correlation between ΔX_{max} and V_m being insignificant. For TC in the Pacific the value of ΔX_{max} practically does not depend on the parameters governing the TC power.

Fig. 11 presents the dependencies of the ozone anomaly effective dimensions $\Delta X \leq -6$ D.U. ($R_{6D.U.}$) and its “visible” extreme value (ΔX_{max}) on the effective dimensions of the storm wind zone R34 for the Atlantic TC. This dependence (as well as the dependence of the hurricane wind zone dimensions) describes rather adequately by the equation of a linear regression. At the same time rather a high dispersion of the ΔX_{max} values and of $R_{6D.U.}$ relatively to the regression straight line is likely to be explained by the effect of not only the dimensions of the storm and hurricane wind zones but also by some additional causes, in particular, by the outflow jets.

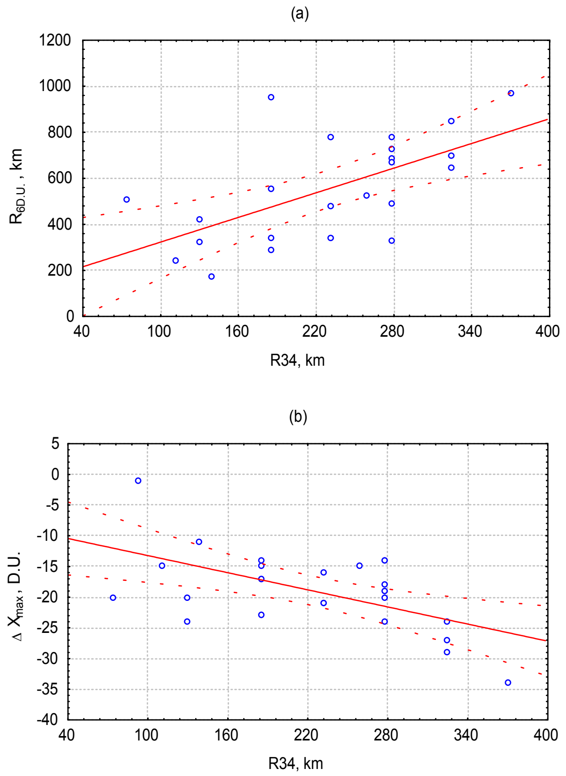


Fig. 11. Dependency of the ozone anomaly effective dimensions with $\Delta X \leq -6$ D.U. (a) and its "visible" extreme value (b) on the effective dimensions of the storm wind zone R34 for TC in the Atlantic

The linear connection equations $R_{6D.U.}$ and ΔX_{max} with R34 and R64 for the TC in the Atlantic have the form of

$$R_{6D.U.} = 145 + 1.78 \times R34,$$
$$R_{6D.U.} = 252 + 7.20 \times R64,$$
$$\Delta X_{max} = -8.58 - 0.046 \times R34,$$
$$\Delta X_{max} = -12.5 - 0.173 \times R64,$$

where R34, R64 and $R_{6D.U.}$ are expressed in km and ΔX_{max} are in D.U.

For the range of variations of the storm wind zone radius typical of the Atlantic the value of R is almost 2 – 4 times more than R34. Fig. 12 as an example for the hurricane Bonnie (22.08.98) over the data of the TOMS and SSM/I instruments given are the negative ozone anomaly with $\Delta X < -6$ D.U. and the isoline of the surface wind velocity V = 34 kn. The surface areas of the ozone anomaly and of the storm wind zone differ by about 12 times, correspondingly the effective linear dimensions differ by 3.5 times. The dimensions of the ozone anomaly indicate, as we believe, that the circulation processes of the TC make a contribution in the perturbations of the TC field at significant (up to 1000 km) distances from the center. As a rule, at such distances the anticyclonic circulation is observed in the upper troposphere.

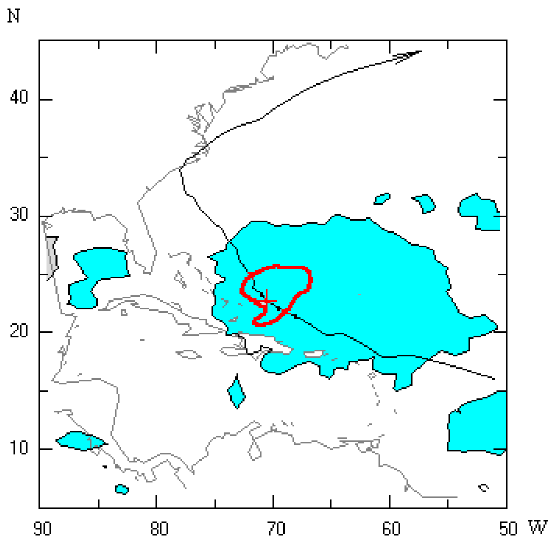


Fig. 12. The ozone anomaly with $\Delta X < -6$ D.U. around the center of TC Bonnie (cross) and the isoline of the surface wind velocity V = 34 kn

The dependencies of the ozone anomaly effective dimensions with $\Delta X < -6$ D.U. on the effective dimensions of the storm and hurricane wind zone for the TC in the Pacific are given in Fig. 13 a, b.

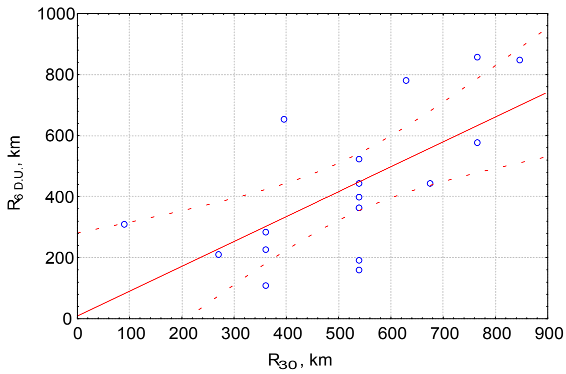


Fig. 13a. Dependencies of the ozone anomaly effective dimensions with $\Delta X < -6$ D.U. on the effective dimensions of the storm wind zone for TC in the Pacific.

When comparing the above results for the TC in the North Atlantic and North-West Pacific one can denote that the connection of the dimensions of the negative ozone anomalies $R_{6D.U.}$ with the dimensions of the storm wind zone is similar both for all the North Atlantic and North-West Pacific TC. But in contrast to the Atlantic TC for the TC in the Pacific the value of $R_{6D.U.}$ does not practically depend on V_m even at the stage of TC intensifying, a the maximum depth of the ozone anomaly ΔX_{max} generally does not depend on the parameters controlling the TC power.

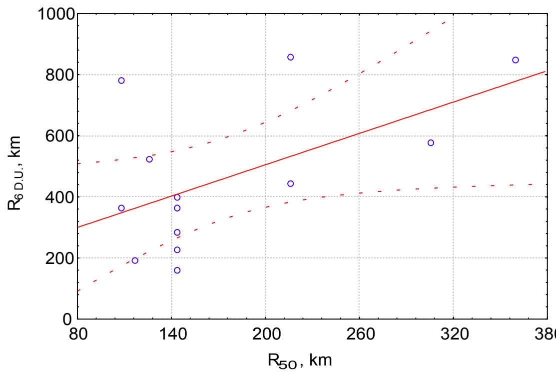


Fig. 13b. Dependencies of the ozone anomaly effective dimensions with $\Delta X < -6$ D.U. on the effective dimensions of the hurricane wind zone for TC in the Pacific

Of interest is to compare two independent methods for determining TC parameters: from the data of remote sensing in the UV and microwave wavelength ranges. Such a comparison of relatively effective dimensions of the storm wind zone (the parameters R34) has been carried out for the TC in the Atlantic in 1998 for which the data of quasi-complexized over time and space data obtained with the instruments TOMS and SSM/I were available. The comparison results are given in Fig. 14.

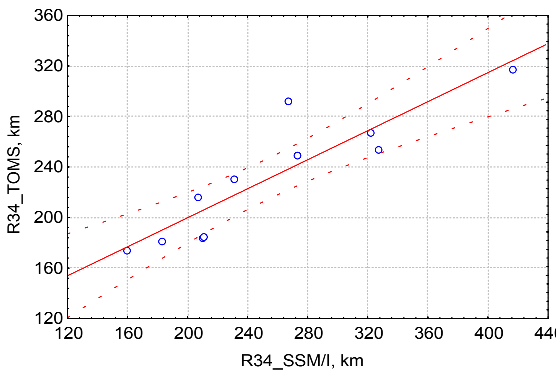


Fig. 14. Comparison of two independent methods for determining effective dimensions of the storm wind zone

Despite rather an incomplete data sample (11 points) reasonable agreement of the R34 values obtained with the use of two independent methods is distinctly seen.

5. CONCLUSION

Two independent methods are proposed to determine tropical cyclone parameters over the data of satellite soundings in the UV and microwave spectrum ranges. The method for determining most crucial TC characteristics from the data of the ocean-atmosphere system soundings in the microwave spectrum range is based on the connection of radiobrightness images of a tropical cyclone in the radiometer high-frequency channel and the TC structural parameters. The method allows one for determining the configuration and effective dimensions of the storm and hurricane wind zones, maximum wind speed at the sea surface and minimum pressure in the TC center, maximum wind radii, the sizes of the hurricane "eye" and the "eye" cloud wall thickness. Based on the results of comparison of tropical cyclone soundings in the Atlantic in 1998 and 1999 made with the microwave radiometer SSM/I with the data of independent observations accuracy of the determination of the TC parameters mentioned has been estimated. The method makes it possible to determine a smoothed spatial distribution of the sea surface wind speed in the whole zone of cyclone action – from the center to the periphery.

The method for determining TC parameters over the data of soundings within the UV spectrum range is based on the connection of characteristics of the negative ozone anomaly over the cyclone center generated by a developing TC with its energy parameters. It is shown that the most close link of the negative ozone anomaly characteristics determined on the basis of the TOMS mapper data is traced with the effective dimensions of the storm and hurricane wind zones. The linear regression equations are obtained that connect the ozone anomaly characteristics with the parameters R34 and R64. The differences are statedfound in the ozone field disturbances induced by tropical cyclones in the Atlantic and Pacific.

Good agreement is obtained for the storm wind zone effective dimensions for the TC in the Atlantic. The dimensions were determined with the use of two independent methods – from the data of soundings of the ocean-atmosphere system in the UV and microwave wave ranges.

The methods proposed can efficiently supplement each other. They are promising in the development and advancement both in search of optimal sounding frequencies and in stating marked physical dependencies of the radiation received from the parameters sought and for improving the instrumentation resolution that would make it possible to locate the devices at a geostationary platform for practically continuous monitoring of the subjects studied.

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