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SPECIFIC FEATURES OF SPACE-TIME VARIATIONS OF OZONE DURING THE DEVELOPMENT OF INTENSIVE TROPICAL DISTURBANCES

Alexander F. Nerushev & Victor I. Vasiliev

Institute of Experimental Meteorology
82 Lenin Avenue, Obninsk, Kaluga Region 249020, Russia

ABSTRACT

Presented is an analysis of specific features of space-time variations of ozone in the tropical area which has been performed on the basis of processing of the results of special expedition studies in the Atlantic and Pacific in 1987-1990 and the data of observations at the stations of the world ozonometric network over the 25-year period. The existence of a cause-and-effect relation has been revealed between the processes determining tropical cyclone (TC) development, and specific features of variations of the total content of ozone (TCO) and the vertical distribution of ozone (VDO) in the regions of TC action. Characteristic features of day-to-day and daily variations of TCO during TC development have been found. On the periphery of a developing TC, 1-4 days before it reaches the stage of storm, TCO increases, on average, by 5-8%, and a substantial increase in the concentration of ozone occurs in the middle and upper troposphere. The most probable physical mechanisms relating the observed specific features of ozone variations to TC evolution have been suggested. A hypothesis of the possibility of using ozone as an indicator for early prediction of TC development has been substantiated.

1. INTRODUCTION

Space-time variations of the total content of atmospheric ozone (TCO) and its vertical distribution (VDO) in the tropical area are still not clearly understood. Meanwhile, dynamic processes in the tropics, and first of all, intensive vortex disturbances, namely, tropical cyclones (TC), cause considerable deformations of the ozone layer (in some cases, up to several tens of percent). This paper presents a systematized information about specific features of space-time variations of ozone in the regions of TC formation and development, based on the results of special expeditions in the Atlantic and Pacific in 1987-1990 and the analysis of observational data from the stations of the world ozonometric network over the 25-year period (1957-1982) (Nerushev, 1991; Nerushev et al., 1986; 1989; 1990).

2. EXPERIMENTAL DATA AND METHODS OF THEIR ANALYSIS

In order to determine statistical mean characteristics of the space-time variation of ozone in the regions of TC formation and development, we used the data from 15 ozonometric stations in the Pacific and 7 stations in the Atlantic from monthly bulletins (Ozone Data for the World, 1957-1982), as well as the information on tracks and characteristics of 315 Pacific TC and 78 Atlantic TC over the same period.

For the purpose of separating out the TCO variations due to the processes associated with TC formation and development, as well as eliminating the latitudinal and seasonal variations of TCO, we calculated the value $\Delta x = x - \bar{x}$ for each observation, where x and $\bar{x}$ are the daily mean and monthly mean of TCO, respectively.

As indicated by the analysis, the dependences $\Delta x(R, \varphi, t)$, where t is its life time in days, R is the distance from the ozonometric station to the TC center, and φ is the azimuthal angle, are of a great variety. For revealing general regularities, a compositing technique was used, in which individual dependences $\Delta x(R, \varphi, t)$ were averaged. In this case, different stages of TC development were

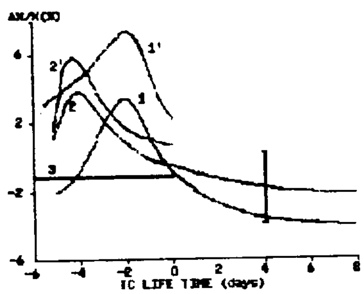

Fig.1. The averaged time dependence of relative TCO variations during the life cycle of Atlantic (1, 1′) and Pacific (2, 2′) TC in the area with radius R = 1000 km (1) and 1500 km (2) from their centers, and in the external area at a distance of 500 km < R < 1000 km (1′) and 600 km < R < 1500 km (2′); 0 - the day of depression intensification into storm, 3 - nondeveloping depression.

considered individually. Note that depending on the maximum wind speed at sea level (V_m), TC can be subdivided into tropical depressions (TD), with V_m< 17 m/s; tropical storms (TS), with 17 m/s ≤ V_m < 33 m/s; and hurricanes or typhoons (T), with V_m ≥ 33 m/s.

The day-to-day and daily variations of TCO were measured in expeditionary conditions in the Atlantic (is. Cuba, 1987 and 1989) and in the Pacific (1990) by automated ozonometer M-124 with wide-band filters, which had a single TCO measurement error of about 6%. The instrument made it possible to measure TCO at 1-min intervals, thus increasing substantially the accuracy of determining the TCO daily mean values.

3. TCO AND VDO VARIATIONS DURING THE LIFE CYCLE OF TC

The above-mentioned investigations revealed the existence of a cause-and-effect relation between the observed specific features of TCO and VDO variations in the areas of TC action, and the dynamic processes of different space-time scale which determine TC development or characterize its internal structure. The most essential of these features are as follows.

1. The nature of anomalies of the TCO daily mean field (Δ x) around non-developing depressions differs noticeably from that of depressions

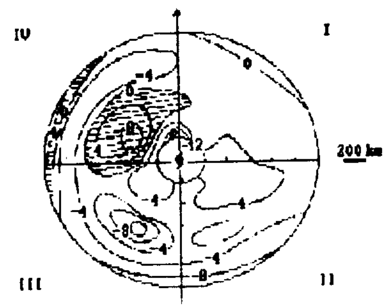

Fig. 2. A compositing space structure of the distribution of TCO daily mean deviations from the background values (in Dobson units) around the centers of Pasific storms and typhoons (the motion direction is indicated by an arrow).

developed to the storm stage. Two to four days before the depression intensification into tropical storm (when the wind speed is as great as 17 m/s), the TCO values on its periphery at a distance 500 to 1200 km to the north of the center increase, on the average, by 5-8%. Fig. 1 plotted by the compositing technique for the whole life cycle of TC, i.e., from depression to hurricane (typhoon), illustrates this specific feature for 78 Atlantic TC and 315 Pacific TC. The concentration of ozone in the middle and upper troposphere increases in the stage of depression intensification into storm by several tens of percent.

2.In the areas of action of a developed TC, i.e., a storm or a hurricane (typhoon) at a distance of up to 1500 km from its center, the space distribution of disturbances of the ozone layer is of a complicated nature. Fig. 2 shows a compositing pattern of anomalies of the TCO daily mean field around the TC center (with Δ x in Dobson units) from the data on 315 TC in the western North Pacific (about 2500 TCO values). In this case, space averaging was performed over the distance intervals Δ R=200 km and the azimuthal angle Δφ = 45° in the coordinate system related to the direction of TC motion. Little data are available for an area of radius R < 200 km around TC. Note that Fig. 2 depicts the averaged space structure of the TCO anomaly field around TC. In some TC, positive and negative TCO anomalies can differ essentially from the averaged ones and amount to as much as several tens of percent.

3. In the stage of tropical storm and hurricane, characteristic oscillations with periods of 3-4 min. and

10-12 min. appear in the spectrum of short-period TCO variations. The nature of such short-period TCO variations is yet to be explained. They may be partly accounted for by internal gravity waves (IGW) generated in the atmosphere by a developing TC (for example, as cumulus congestus clouds break through the tropopause).

4. Based on the satellite data, the American scientists (Rodgers et al., 1990) found increased TCO values in the area of TC eye associated with the intrusion of stratospheric air rich in ozone.

4. PHYSICAL MECHANISMS DETERMINING THE OBSERVED TCO AND VDO VARIATIONS

In our opinion, the nature of the space-time distribution of TCO and VDO anomalies in the area of TC and its surroundings characterizes a complicated pattern of the interaction between the dynamic processes of different space-time scale from long waves (10^3 - 10^4km) to convective cells (1 - 10 km).

For developing tropical depressions (TD), storms (TS) and typhoons (T) the characteristic feature is the presence of the upper-tropospheric trough (UTT) at levels of 300 and 200 hPa to the north-east (for TD) or north-west (for TS and T) of their centers, and the upper-tropospheric eastern jet (UTEJ) with speeds of 15-20 m/s in the 200-100 hPa layer with the axis at a level of 150 hPa at a distance of 1000-1500 km to the south of their centers (Bokhan, 1987).

The interaction of UTT with developing TC, which contributes to its intensification, leads to the enhancement of meridional exchange and the arrival of air masses of the moderate latitudes at the periphery of TC. As evident from the estimates, this mechanism may cause an increase of TCO by 8-20% in the typhoon season (May-November) to the north-east of the TD center or to the north-west of the center of TS and T. By virtue of its location, UTEJ is bound to lead to a small decrease of TCO ($|\Delta x|/x \leq 8\%$) at a distance of up to 1000-1500 km to the south of the centers of TD , TS and T.

A comparison of the above qualitative pattern of the TCO field deformation around the TC center under the influence of large-scale systems with the experimental data presented in Fig. 2, taking into consideration the mean direction of TC motion to the west - north-west, enables us to state that on the whole, the large-scale features of the TCO field deformation around TC are most probably due to the action of UTT and UTEJ. The observed increase of TCO on the periphery of TD in the stage of its intensification into storm also can be fully explained by the above mechanism of meridional exchange (interaction of TC with UTT, invasions of cold air).

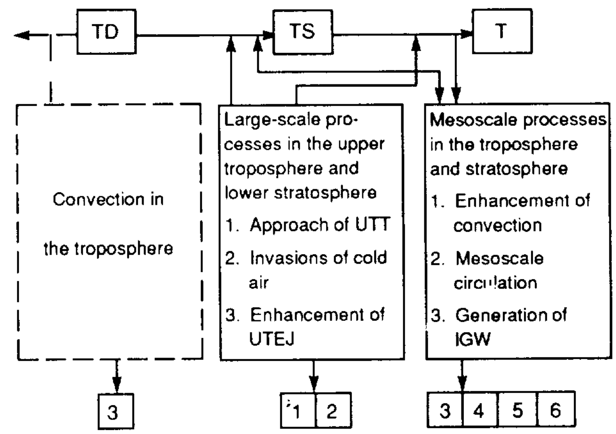

Fig. 3. The main observed TCO and VDO anomalies and their most probable origin.

1 - increase of TCO and ozone concentration in the upper troposphere and lower stratosphere to the north of the center of TD and TS;

2 - decrease of TCO and ozone concentration in the upper troposphere and lower stratosphere to the south of the center of TD and TS;

3 - decrease of TCO and ozone concentration in the troposphere in the active area and on the periphery;

4 - local increase of TCO and ozone concentration in the lower stratosphere and troposphere in the active area and on the periphery;

5 - increase of TCO in the "eye" of TC;

6 - short-period oscillation of TCO (T<10 min.).

The circulation systems of the TC itself create small-scale disturbances of the ozone field showing themselves against the background of the anomalies which are due to the influence of the large-scale processes. In this case, as shown in our studies (Nerushev et al., 1986), the vertical ordered motions in the upper troposphere and lower stratosphere of mesoconvective scale (10 - 10^2km) and of cloud cluster scale (10^2 - 10^3km) play a leading role. Depending on their space distribution, sign and value, both a decrease and an increase of TCO may occur in the active area (up to several tens of percent) and on the periphery of TC, as well as substantial changes of VDO of the corresponding sign.

Fig. 3 presents a simple schematic of cause-and-effect relations between the main specific features of TCO and VDO variations during TC development from depression to hurricane (typhoon), and the dynamic processes which, in our opinion, determine these features.

A qualitative assessment of the sign and value of the TCO field anomalies (Δx in Dobson units) around TC occurring under the influence of the dynamic processes of different space scale is given in the table, based on the published experimental data on TCO variations in the area of TC action. Considerable TCO anomalies in the active area of TC ($\lvert \Delta x \rvert < 100$ Dobson units) observed in individual intensive cyclones apparently indicate that the stratospheric layers are drawn into the circulation system of TC.

From the results presented we can conclude that the use of the data on TCO and VDO variations as indicators for early prediction of TC development is very promising and feasible. It is best to obtain the required information on TCO and VDO by remote space techniques.

Table. Approximate values of TCO anomalies (Δx in Dobson units) around TC occuring under the influence the dynamic processes of different space scale.

Dynamic process, characteristic size	Area of TC, stage of development			
	Active area $E < 300$km		Periphery $500km < E < 1500km$	
	TD	TS,T	TD	TS,T
Long waves 10^3–10^4km			$0 < \Delta X < 60$ (north of the center) $-20 < \Delta X < 0$ (south of the center)	
Cloud clusters 10^2–10^3km	$\lvert \Delta X \rvert < 30^{*)}$		$\lvert \Delta X \rvert < 20^{*)}$	
Mesoconvective 10–10^2km	$\lvert \Delta X \rvert < 30^{*)}$	$\lvert \Delta X \rvert < 100^{*)}$ (in the 'eye' $\delta X > 0$)	$\lvert \Delta X \rvert < 20^{*)}$	

*) The sign of Δx is dependent on the direction of vertical velocity in the stratosphere.

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