NOTATION

c, moisture concentration in polymer, g/m^3; τ, time, sec; x, coordinate, m; D, diffusion coefficient, m^2/sec; H, solubility, sec^2/m^2; Δg_τ, increment in mass of polymer sample at a time τ from the onset of sorption, g; Δg_{max}, increment in mass of sample in a state of sorptional equilibrium, g; R, half the thickness of the sample plate, m; γ, polymer density, g/cm^3; g_0, initial mass of sample, g; p, partial vapor pressure of sorbate, Pa; A(f), amplitude—frequency characteristic of filter; σ^2, dispersion of noise signal in measuring channel, g^2; f, frequency, Hz; ω, circular frequency, rad/sec; $\Delta\tau_d$, interval of discretization in filtration, determined by the length of the analog—digital-converter operating cycle and the time of digital analysis of the signal, sec; τ_D, delay time of low-frequency filter, sec; f_0, upper frequency limit on the transmission of the low-frequency filter, Hz; $\Delta\tilde{g}_\tau$, increment in sample mass at point τ after digital filtration, g; T, time of experiment, sec; $|\Delta g'(j\omega)|^2$, spectral energy density of the derivative of the useful signal, g^2; N(ω), spectral energy density of the derivative of the noise signal, g^2; τ, mean square error of filtration, g^2; $\Delta\tau_a$, half the interval of approximation of the sorption-kinetics curve by a second-order polynomial, sec.

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CONVECTIVE INSTABILITY OF A FREE-CONVECTION VORTEX

O. G. Martynenko, A. A. Solov'ev, and A. D. Solodukhin

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The stability of free-convection vortex formations obtained in the laboratory is compared with natural tropical cyclones.

Unstable motion in rotating systems is the explanation for a wide class of phenomena such as tropical cyclones [1-3]. In the present paper we demonstrate the possibility of using laboratory experiments on a model of a free-convection vortex to determine the stability of catastrophic atmospheric vortices of the tropical cyclones type.

The subject of the laboratory study was a strong air-water-vapor vortex in a temperature-stratified flow [3, 4]. The main difference between this model and those studied in [3, 5] is that in this model the role of horizontal velocity gradients in vortex formation is isolated. A vortex with a vertical axis was created in a vortex cell with tangential windows (Fig. 1). Water was heated to nearly the boiling point (70-80°C) in the lower part of the apparatus 1 Humid air formed by evaporation fills a cylindrical column which is forced to rotate at a certain angular velocity. Its degree of twist was measured by the angle at which air masses enter the cell through the tangential windows 2 on the lateral surface. A horizontal velocity shear was created by a system of adjustable cylindrical rings 3 in the upper part of the apparatus. The experimental information was obtained with the help of optical visualization and laser-Doppler anemometry [6].

Analysis of this information [4, 5] confirms that free-convection vortex formations can be found in stable and unstable states. There are two parameters controlling the stability of these vortices. One is the flow angle α (the angle between the velocity vector and the isobars). The second parameter is the relative radius $x_0 = r_0/R_0$ at which the horizontal velocity shear is imparted. Here r_0 is the radius of the opening of the cell from above and R_0 is the outer radius of the device (Fig. 1).

By analyzing tables of stable and unstable states of a free-convection vortex and from the measurements of the radial distribution of the velocity a relation can be established between the quantity x_0 and the parameter B introduced

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A. V. Lykov Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk.

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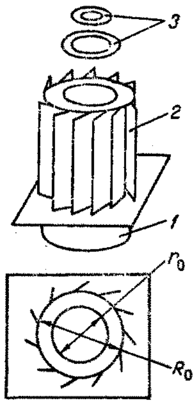

Fig. 1

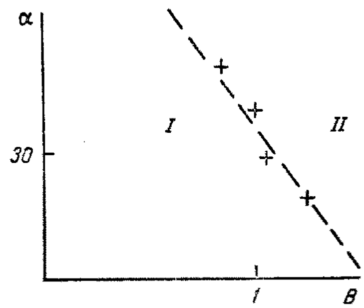

Fig. 2

Fig. 1. Vortex cell for the production of a free-convection vortex with horizontal velocity shear.

Fig. 2. Different modes of formation of a free-convection vortex depending on the flow angle α (in degrees) and the Holland parameter B: I) unstable generation mode; II) stable mode; the crosses represent the experimental data of [4]; the dashed line was calculated from (3) of the present paper.

by Holland [7] in an expression for the radial dependence of the tangential velocity

$$v = \left[B \frac{\Delta P}{\rho} \left(\frac{r_m}{r}\right)^B \exp\left(-\, r_m/r\right)^B\right]^{1/2}. \tag{1}$$

Here r_m is the radius at which the velocity v reaches its maximum value. The measurements of the radial distribution of the tangential velocity show that to acceptable accuracy the parameter B (for the vortex model studied here) can be calculated from the formula

$$B = -\frac{1.4}{\ln(0.18 + 0.324\, x_0)}. \tag{2}$$

We see from Fig. 2 that the tabulated results for stable and unstable modes of generation of free-convection vortices taken from [4] are consistent with the calculated results using (2) if the parameter B is related to flow angle by the equation

$$B = 1.56 - 0.015\,\alpha. \tag{3}$$

This relation holds for flow angles $10° \leq \alpha \leq 60°$. Stable vortex states exist when

$$B \geqslant 1.56 - 0.015\,\alpha. \tag{4}$$

We convert from the laboratory flow angles to the latitude of the location of a tropical cyclone by means of the formula

$$\varphi = (90° - \alpha)/\gamma. \tag{5}$$

Here $\gamma = 8$ is a scale factor chosen such that the latitude $\varphi = 5°$ corresponds to $x_0 = 0$ (and $B = 0.81$, according to (2)). This value of the latitude is the lower boundary of the region in which Pacific typhoons are usually generated.

According to Holland [7], the parameter B can be expressed through the ratio of the maximum tangential velocity v_m to the pressure drop ΔP:

$$B = k^2 \rho/e, \tag{6}$$

where $k^2 = v_m^2/\Delta P$ and e is the base of natural logarithms.

From (3), (5), and (6) we obtain a relation which can be used to estimate the stability of natural atmospheric vortices of the tropical cyclone type. It relates the latitude of formation of a tropical cyclone to the parameter k^2 characterizing its intensity:

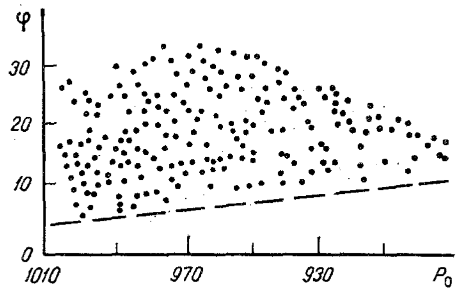

Fig. 3. Latitude dependence of the minimum pressure at the center of a vortex formation. Dashed line: calculated based on analysis of convective stability for the laboratory model vortex of the present paper; points: results of a composite analysis of a series of Pacific typhoons [9]. φ, degrees; P_0, mbar.

$$\varphi = 0.27\,k^2 - 1.7°. \tag{7}$$

In natural observations the intensity of a tropical cyclone is defined in terms of the minimum pressure P_0 at the center. Hence in (7) we transform from the parameter k^2 to the magnitude of the central pressure in a hurricane, using the following expression given by Atkinson and Holliday [8]:

$$k^2 = 11.76\,\Delta P^{0.288}, \tag{8}$$

where $\Delta P = P_b - P_0$, $P_b = 1015$ mbar is the ambient pressure at the edge of the hurricane. Hence we have

$$\varphi = 3.2\,(1015 - P_0)^{0.288} - 1.7°. \tag{9}$$

In (8) and (9) the constants correspond to pressures measured in millibars.

The graphical dependence of the stability of the model vortex is consistent with the analysis of Weatherfold for a series of typhoons of the north-western Pacific [9]. It follows from Fig. 3 that there is a strong correlation between the location of a tropical cyclone of given intensity and the boundary separating the stable and unstable modes of generation. The method given here of converting the data of the laboratory experiments to natural conditions can be used to predict the latitudes of stable tropical cyclones.

NOMENCLATURE

r, radius; ρ, density of air; ΔP, pressure drop between the center of a vortex and its edge; φ, latitude of the location of a natural tropical cyclone.

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