ЗАБАБАХИНСКИЕ НАУЧНЫЕ ЧТЕНИЯ 2017

GEOMETRICAL, SPEED AND ENERGY CHARACTERISTICS IN THE BOTTOM PART OF THE TORNADOES AND TROPICAL CYCLONES

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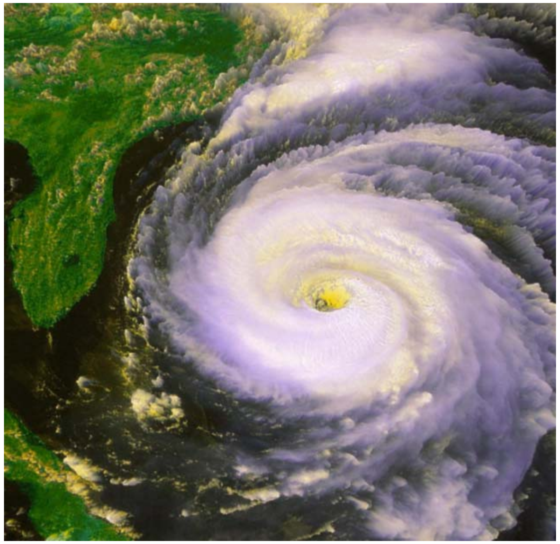
A.G Obuhov, O.V. Opryshko

A natural phenomenon

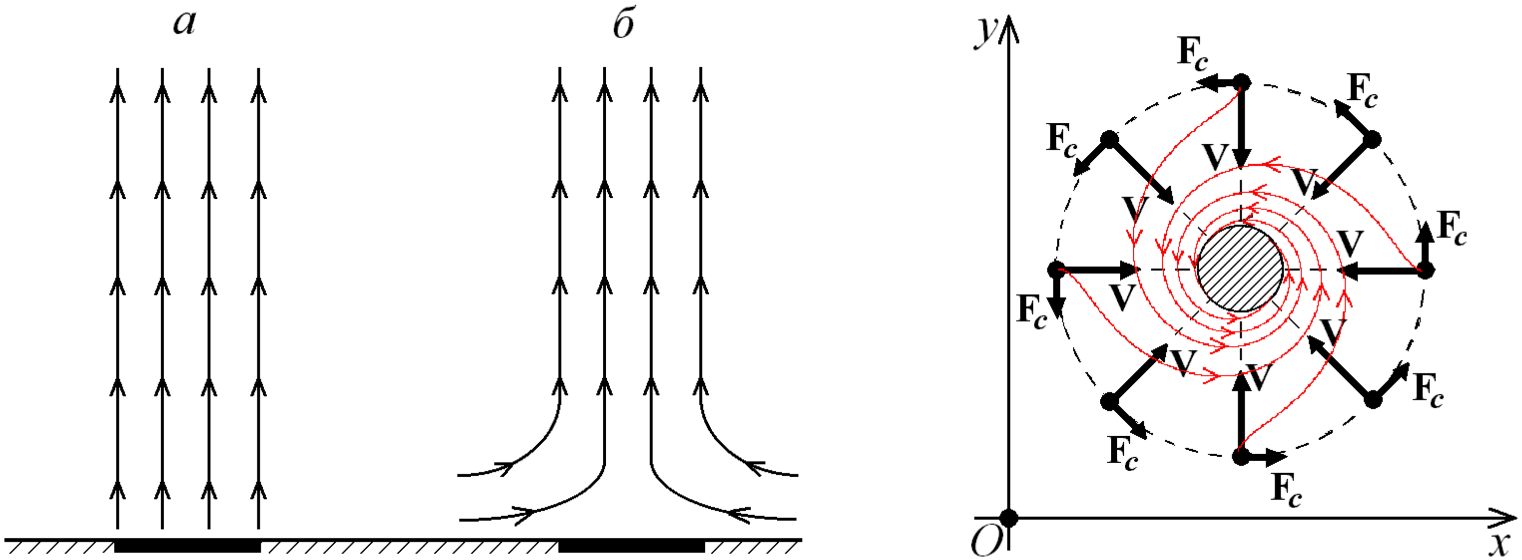


Why there?
How are?
Where does the energy for a long period of existence and destruction?

Bautin S.P. Tornado and the Coriolis force. 2008.

Bautin S. P., Deryabin S. L., Krutova I. Y., Obukhov A. G. Destructive atmospheric vortices and the Earth's rotation around its axis. USURT, 2017.

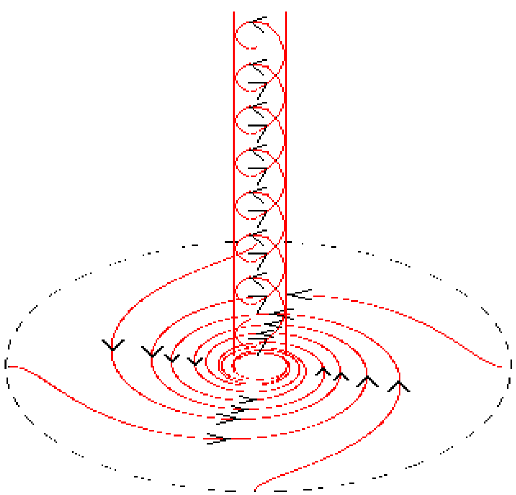
- The emergence of the rising convective flow due to a gradient of a temperature.
- Education bottom part and the appearance in it of air swirling through the action of the Coriolis force.

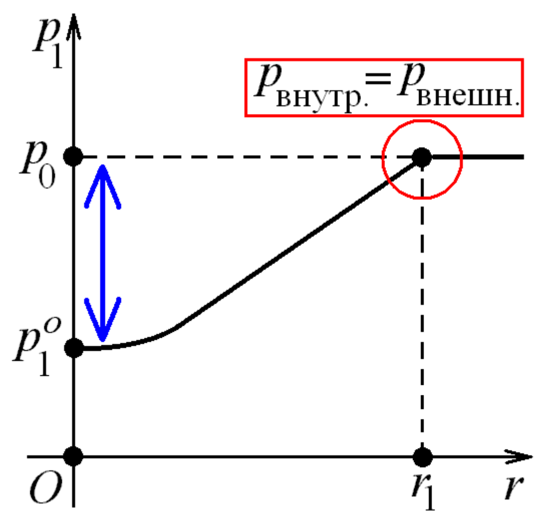


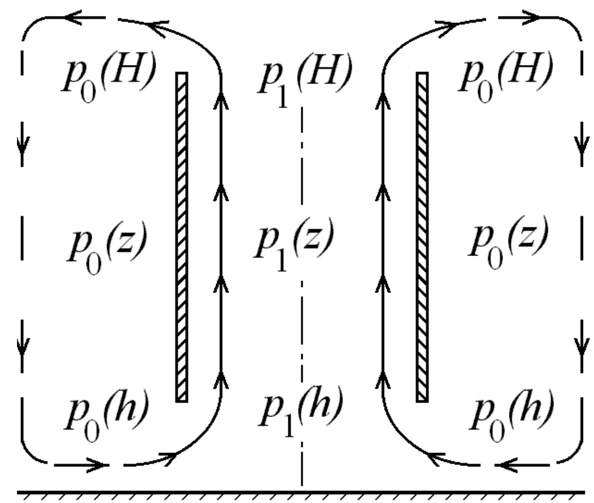
The sun gives energy to the beginning of the vertical movement.
Earth's rotation twists the horizontal movement.

The energy for self-maintenance of stable functioning of the ascending swirling flow

- The Earth's rotation twists the gas in the bottom part.
- Twist the gas is passed into the bottom part.
- The centrifugal force generates in the vertical part of the negative pressure in the vicinity of the axis and the effect of impermeable walls - «pipe with a thrust».
- Outside air is resting by gravity in the tube is pressed from below with the thrust.





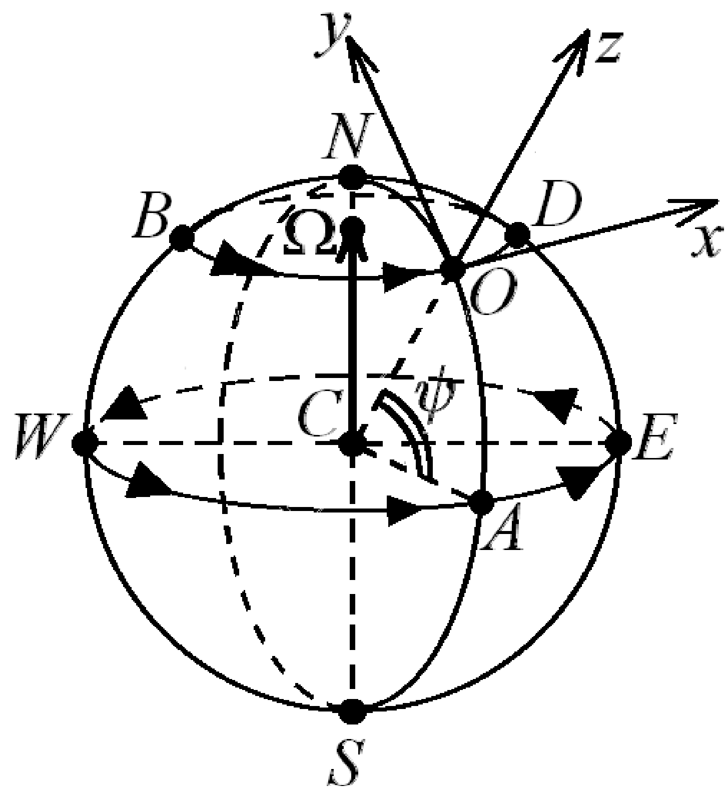


The rotation of air in the vertical part of making stable operation of the entire flow.

The system of equations of gas dynamics

in a rectangular coordinate system rotating with the Earth

$$\begin{cases} c_t + \mathbf{V}\cdot\nabla c + \dfrac{(\gamma-1)}{2} c \,\mathrm{div}\,\mathbf{V} = 0, \\ \mathbf{V}_t + (\mathbf{V}\cdot\nabla)\mathbf{V} + \dfrac{2}{(\gamma-1)} c\nabla c = \\ = \mathbf{g} - 2\mathbf{\Omega}\times\mathbf{V}, \end{cases}$$



$S = \text{const},$

$c = \rho^{(\gamma-1)/2},$

$\mathbf{\Omega} = (0, \Omega_2, \Omega_3),$

$\Omega_2 = \Omega\cos\psi, \quad \Omega_3 = \Omega\sin\psi,$

$\Omega = |\mathbf{\Omega}|.$

Coriolis acceleration present in the equations of motion (the differential form of the law of conservation of momentum) introduces into the gas stream an additional external impulse, that is, changes $m\mathbf{V}$ - the amount of flow !!

The system of equations of gas dynamics

in a cylindrical coordinate system rotating with the Earth

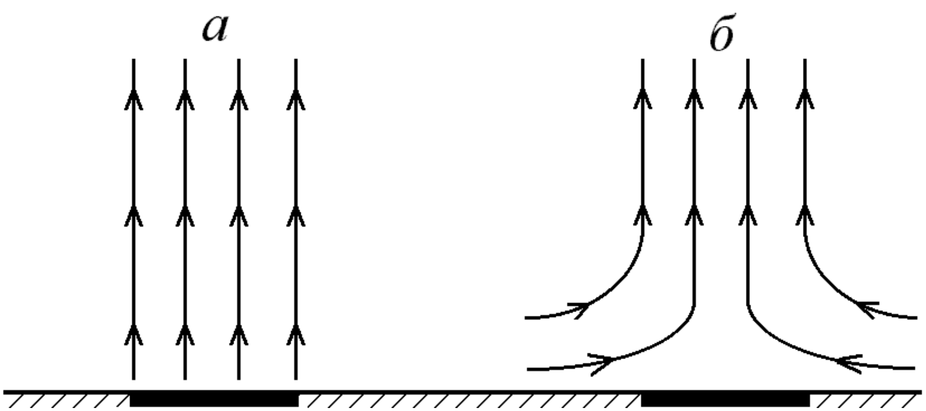
$$\begin{cases} c_t + uc_r + \frac{v}{r}c_\varphi + wc_z + \frac{(\gamma-1)}{2}c\left(u_r + \frac{u}{r} + \frac{v_\varphi}{r} + w_z\right) = 0, \\ u_t + uu_r + \frac{v}{r}u_\varphi - \frac{v^2}{r} + wu_z + \frac{2}{(\gamma-1)}cc_r = av - bw\cos\varphi, \\ v_t + uv_r + \frac{uv}{r} + \frac{v}{r}v_\varphi + wv_z + \frac{2}{(\gamma-1)}\frac{c}{r}c_\varphi = -au + bw\sin\varphi, \\ w_t + uw_r + \frac{v}{r}w_\varphi + ww_z + \frac{2}{(\gamma-1)}cc_z = bu\cos\varphi - bv\sin\varphi - g, \end{cases}$$

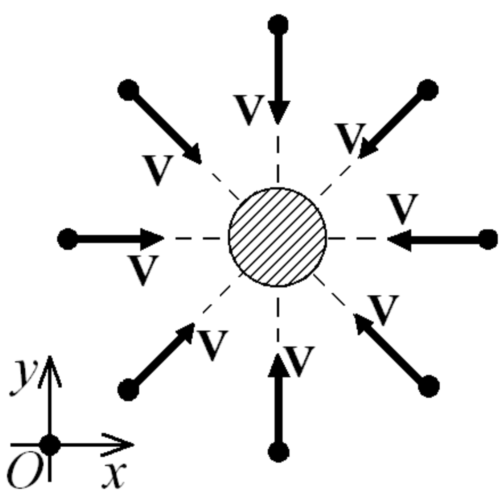
$$c = \rho^{(\gamma-1)/2}, \quad p = \frac{1}{\gamma}\rho^\gamma, \quad a = 2\Omega\sin\psi, \quad b = 2\Omega\cos\psi, \quad \Omega = |\mathbf{\Omega}|$$

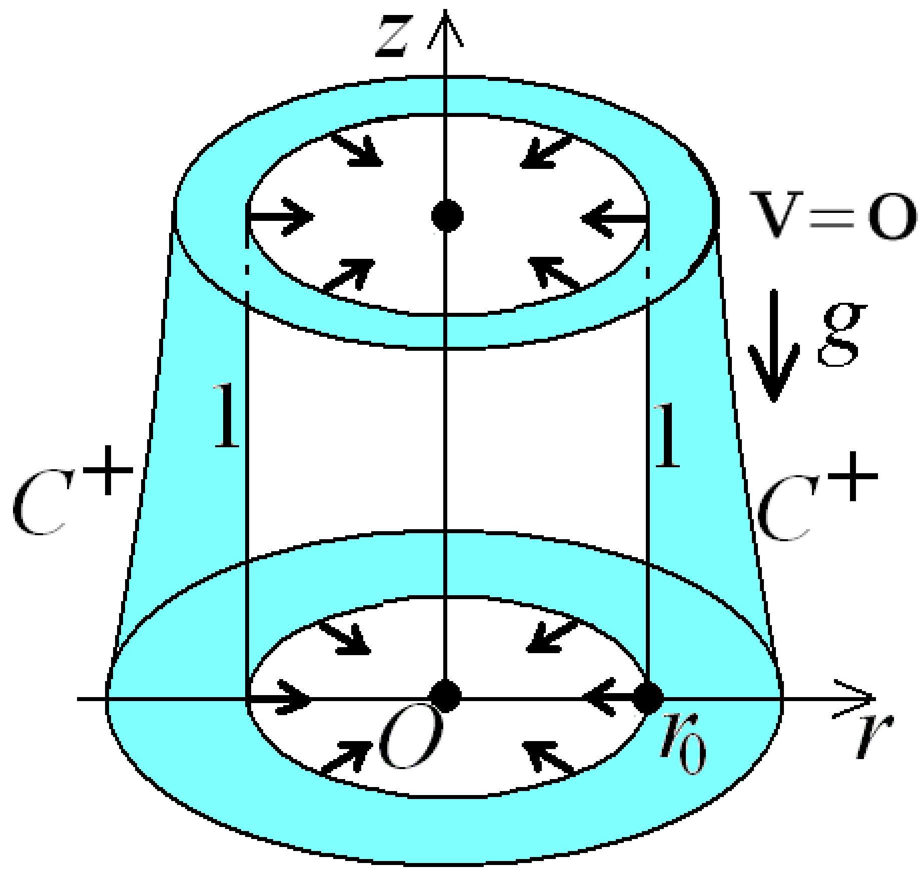
In this case, the system of equations of gas dynamics is clearly part of the independent variable φ.

Effect of the Earth's rotation on tornadoes and tropical cyclones

The characteristic Cauchy problem for a smooth radial runoff







$$\begin{cases} c_t + uc_r + \frac{v}{r}c_\varphi + wc_z + \frac{(\gamma-1)}{2}c\left(u_r + \frac{u}{r} + \frac{v_\varphi}{r} + w_z\right) = 0, \\ u_t + uu_r + \frac{v}{r}u_\varphi - \frac{v^2}{r} + wu_z + \frac{2}{(\gamma-1)}cc_r = av - bw\cos\varphi, \\ v_t + uv_r + \frac{uv}{r} + \frac{v}{r}v_\varphi + wv_z + \frac{2}{(\gamma-1)}\frac{1}{r}cc_\varphi = -au + bw\sin\varphi, \\ w_t + uw_r + \frac{v}{r}w_\varphi + ww_z + \frac{2}{(\gamma-1)}cc_z = bu\cos\varphi - bv\sin\varphi - g; \\ \qquad a = 2\Omega\sin\psi; \quad b = 2\Omega\cos\psi \\ c(t,r,\varphi,z)|_{C^+} = \sqrt{c_{00}^2 - (\gamma-1)gz}; \\ u(t,r,\varphi,z)|_{C^+} = 0; \\ v(t,r,\varphi,z)|_{C^+} = 0; \\ w(t,r,\varphi,z)|_{C^+} = 0; \\ u(t,r,\varphi,z)|_{r=r_0} = u^o(t), \\ u^o(t)|_{t=0} = 0, \quad [u^o(t)]'|_{t=0} = u_* = \text{const} < 0. \end{cases}$$

Conditions on the sound characteristic (for the C^+ conditions)

The specified radial flow (for $u|_{r=r_0} = u^o(t)$)

Bautin S.P. The characteristic Cauchy problem and its application to gas dynamics. 2009.
Bautin S.P. The characteristic Cauchy problem for a quasilinear analytic system // Diff.eq. 1976.

Theorem 1. The problem has a unique analytic solution in a neighborhood of the point M_0 $(t = 0, r = r_0, \varphi = \varphi_0, z = 0)$,

If $\Omega = 0$, the only analytic solution does not depend on φ and the flow is only radial.

If $\Omega \neq 0$:

$$\left.\frac{\partial v}{\partial r}\right|_{C^+} = 0; \quad \left.\frac{\partial^2 v}{\partial r^2}\right|_{C^+} > 0$$

in the case of the Northern Hemisphere;

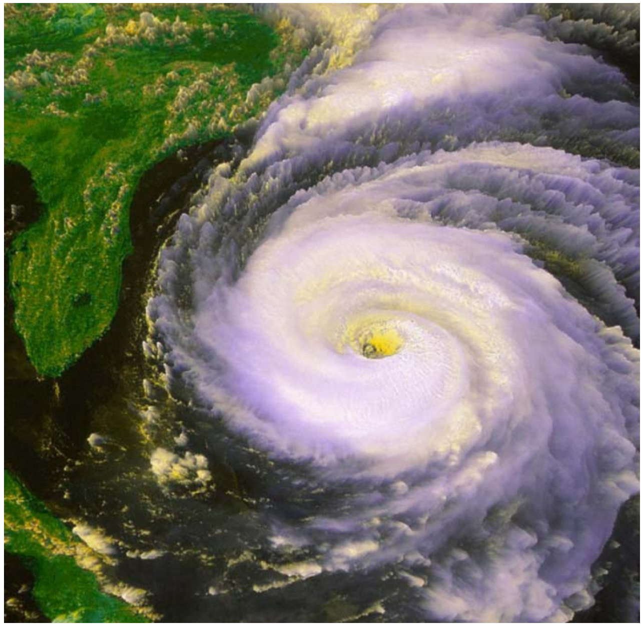
$$\left.\frac{\partial v}{\partial r}\right|_{C^+} = 0; \quad \left.\frac{\partial^2 v}{\partial r^2}\right|_{C^+} < 0.$$

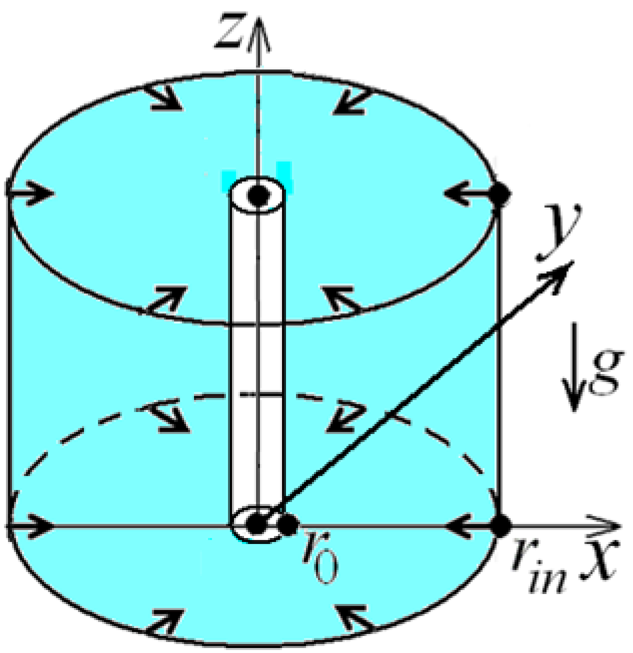
in the case of the Southern Hemisphere.

This proves that the occurrence of the spin gas at $\Omega \neq 0$ in the problem of smooth radial flow caused by rotation of the Earth is only about its own axis.

The characteristic Cauchy problem for a given radial inflow

It will be built at the bottom currents have formed a natural ascending swirling flow.





That is to be built stationary gas flow in a cylindrical domain:

$$\left\{ 0 < r \le r_{in},\ \ r_{in} > 0;\ \ 0 \le \varphi \le 2\pi;\ \ z \ge 0 \right\}$$

$$
\begin{cases}
c_t + uc_r + \frac{v}{r}c_\varphi + wc_z + \frac{(\gamma-1)}{2}c\left(u_r + \frac{u}{r} + \frac{v_\varphi}{r} + w_z\right) = 0,\\
u_t + uu_r + \frac{v}{r}u_\varphi - \frac{v^2}{r} + wu_z + \frac{2}{(\gamma-1)}cc_r = av - bw\cos\varphi,\\
v_t + uv_r + \frac{uv}{r} + \frac{v}{r}v_\varphi + wv_z + \frac{2}{(\gamma-1)}\frac{1}{r}cc_\varphi = -au + bw\sin\varphi,\\
w_t + uw_r + \frac{v}{r}w_\varphi + ww_z + \frac{2}{(\gamma-1)}cc_z = bu\cos\varphi - bv\sin\varphi - g;\\
c(t,r,\varphi,z)|_{z=0} = c_0(r),\\
u(t,r,\varphi,z)|_{z=0} = u_0(r),\\
v(t,r,\varphi,z)|_{z=0} = v_0(r),\\
w(t,r,\varphi,z)|_{z=0} = 0;\\
u(t,r,\varphi,z)|_{r=r_{in}} = u_{in};\ \ u_{in} = \text{const} < 0;\\
v(t,r,\varphi,z)|_{r=r_{in}} = 0.
\end{cases}
$$

The conditions on the contact characteristic

The specified radial flow

A radial runoff in region: $0 < r < r_0,\ r_0 < r_{in}$.

Bautin S.P. The characteristic Cauchy problem and its application to gas dynamics. 2009.
Bautin S.P. The characteristic Cauchy problem for a quasilinear analytic system // Diff.eq. 1976.

Theorem 2. In carrying out the necessary conditions

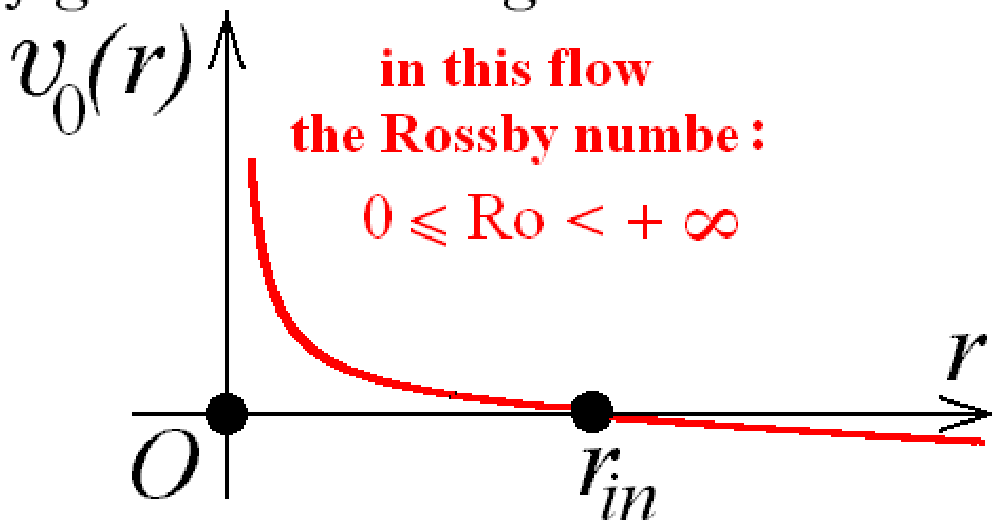
$$\begin{cases} u_0 u_{0r} - \dfrac{v_0^2}{r} + \dfrac{2}{(\gamma-1)} c_0 c_{0r} = a v_0, \\ u_0 v_{0r} + \dfrac{u_0 v_0}{r} = -a u_0 \end{cases}$$

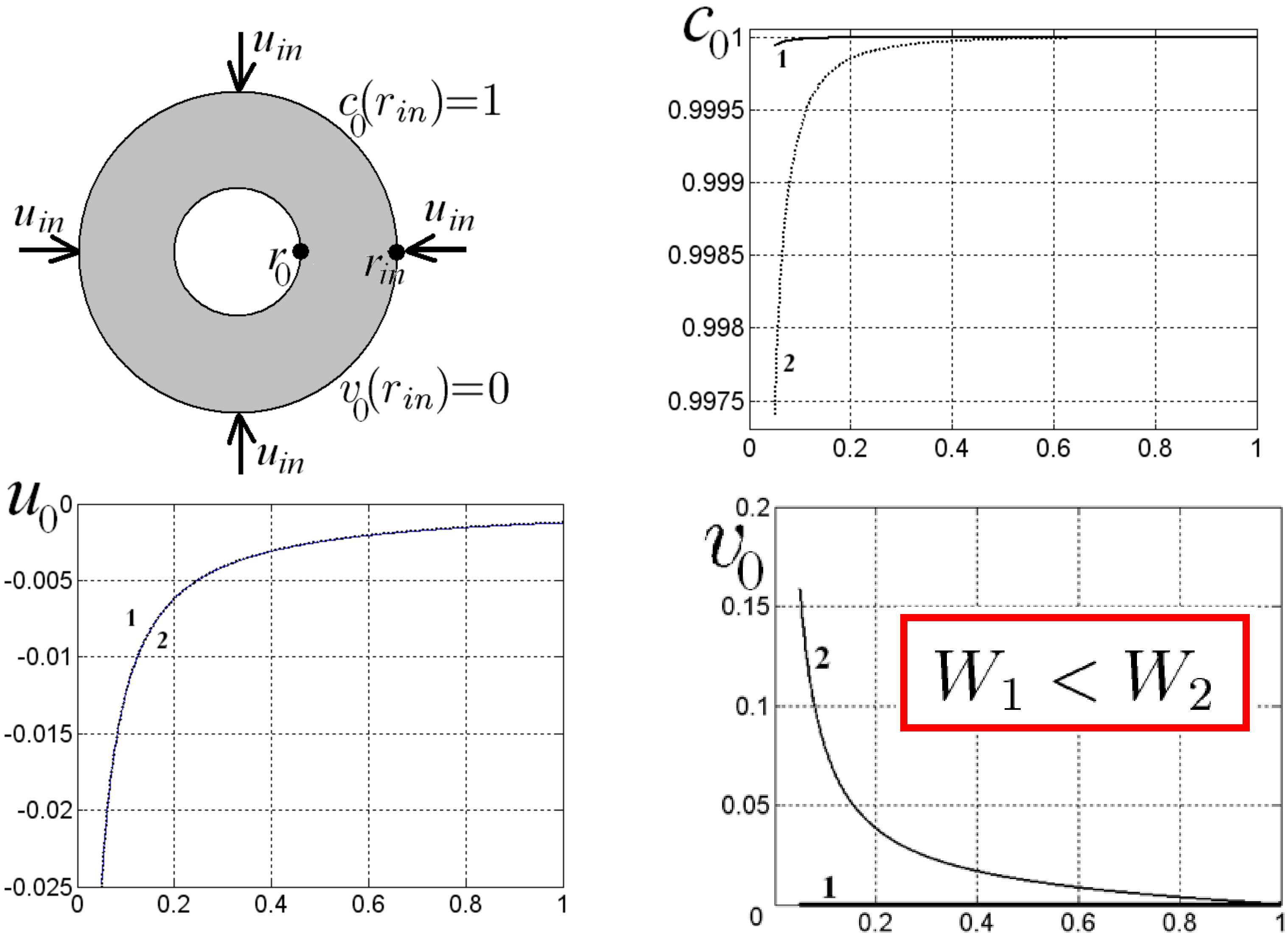
for the solvability problem has a unique analytic solution in the neighborhood of the point $(r = r_{in}, \varphi = \varphi_0, z = 0)$.

1. If $\Omega = 0$, the only analytic solution of the circumferential velocity is identically equal to zero: $v \equiv 0$.

2. If $\Omega \neq 0$, then definitely get the following:

$$v_0(r) = \frac{a(r_{in}^2 - r^2)}{2r}.$$



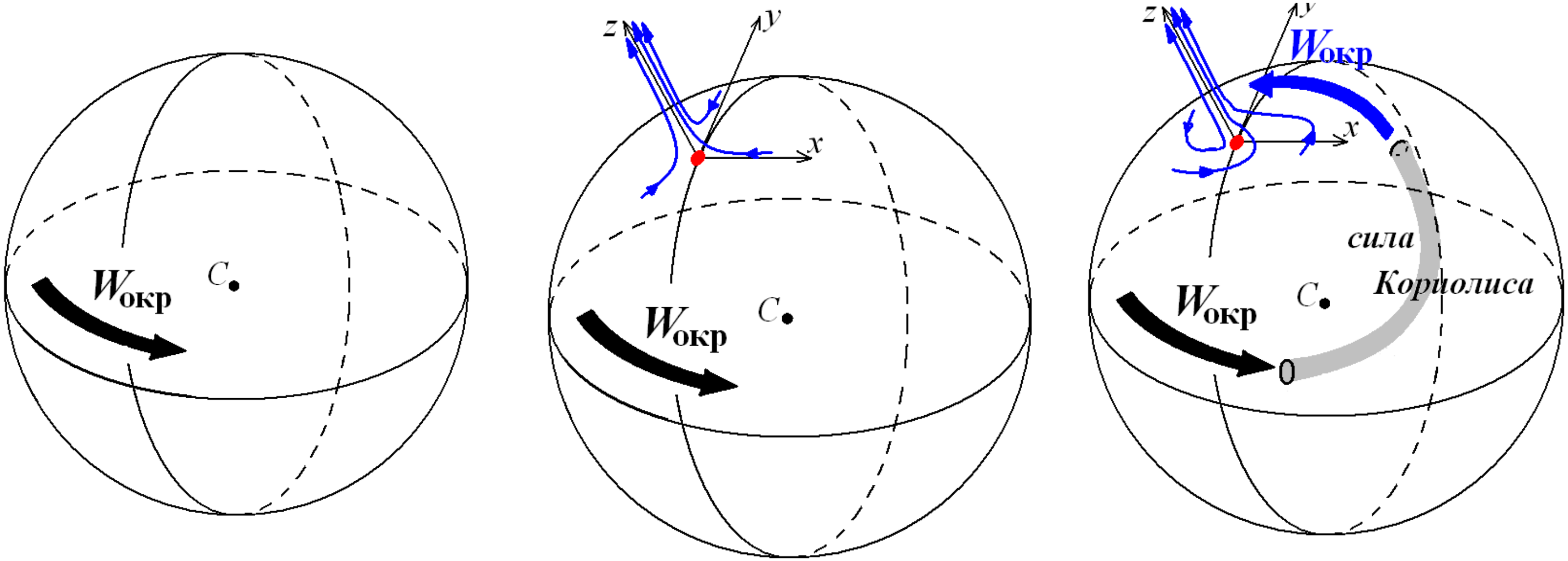


Coriolis force takes part of the Earth's rotational kinetic energy into kinetic energy of rotational motion of a special air flow.

A new natural-scientific fact!

For tornadoes and tropical cyclones
strictly mathematically proved that:

- the cause of the gas swirling in these streams is only the Earth's rotation around its axis;
- the rotational kinetic energy of the movement of air in these flows is taken only from the kinetic energy of the Earth's rotation around its axis.



Flow computations consistent

Tatom F.B., Witton S.J. // Seismological Research Letter. 2001.V. 72. № 1.

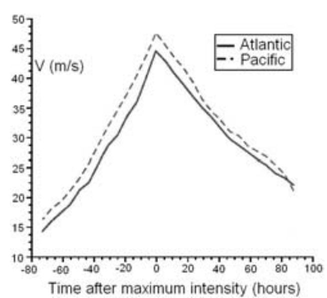
Emanuel K.A. // Journal of the Atmospheric Sciences. 2000.V. 128.

The classification of a tornado on a scale Fujita

tornado class	wind speed, m/s	track width, m	the average length, км	time tornado life, min
$F0$	19 – 32	5 – 15	1.9	2.4
$F1$	33 – 50	16 – 50	4.2	5.2
$F2$	51 – 70	51 – 160	8.7	10.8
$F3$	71 – 92	161 – 508	16.1	20.0
$F4$	93 – 116	547 – 1448	43.8	54.4
$F5$	117 – 142	1609 – 4989	57.1	71.0

ravages of time

Cyclones statistics:



Flat isentropic flow

$$\begin{cases} c_t + uc_r + \dfrac{(\gamma-1)}{2} c\left(u_r + \dfrac{u}{r}\right) = 0, \\ u_t + uu_r - \dfrac{v^2}{r} + \dfrac{2}{(\gamma-1)} cc_r = av, \\ v_t + uv_r + \dfrac{uv}{r} = -au \end{cases}$$

The exact steady flow

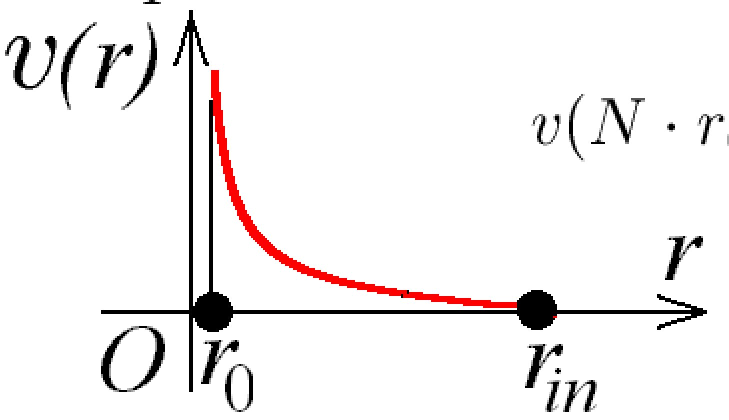
$$c(r) = \left[\frac{A}{ru(r)}\right]^{(\gamma-1)/2};$$

$$F(r,u) \equiv \frac{2}{(\gamma-1)}\left(\frac{A}{ru}\right)^{(\gamma-1)} +$$

$$+ (u)^2 - B + \frac{a^2 r_{in}^4}{4r^2} + \frac{a^2}{4} r^2 = 0;$$

$$v(r) = \frac{a(r_{in}^2 - r^2)}{2r};$$

A, B, r_{in} – const



$$v(N \cdot r_0) \approx \frac{v(r_0)}{N}$$

Given the r_0, V_{wind}, $u_{in} = 0.0001$: r_{in} pick up so that $V_{\text{wind}} \approx \mathbf{V}(r_0) = \sqrt{u(r_0)^2 + v(r_0)^2}$

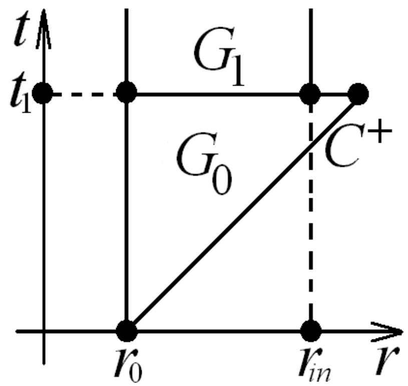
The results of calculations of stationary flows

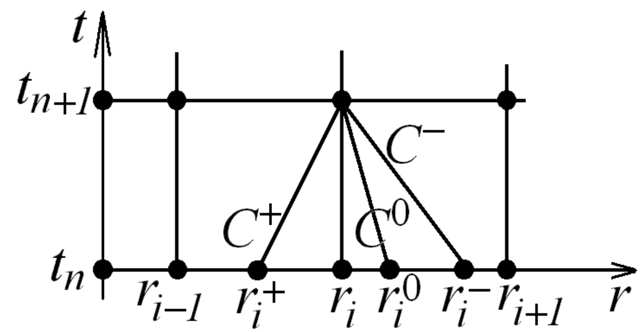
tornado class	V_{wind} m/s	$\lvert\mathbf{V}(r_0)\rvert$, m/s	r_0, m	r_{in}, m	W, Дж	W_v/W
F_{-1}	15	14.95	1	410	$1.1 \cdot 10^6$	0.149
$F0$	19	19.01	2.5	975	$24.78 \cdot 10^6$	0.497
$F_{0.5}$	25.5	25.5	5.0	1765	$0.307 \cdot 10^9$	0.764
$F1$	33	32.97	8.0	2618	$1.895 \cdot 10^9$	0.877
$F2$	51	51.02	25.5	5949	$0.096 \cdot 10^9$	0.973
$F3$	71	70.96	80.5	12522	$3.56 \cdot 10^{12}$	0.994
$F4$	93	93.01	273.5	26450	$132.2 \cdot 10^{12}$	0.9986
$F5$	117	116.98	804.5	50890	$3079.6 \cdot 10^{12}$	0.9996
cyclone	51	53.01	3650	73050	$15.51 \cdot 10^{15}$	0.998
	nature	calcul.	nature calcul.	calcul.		

The values of r_0, $V(r_0)$ for F_{-1}, $F_{0.5}$ entered tornado classes are determined by linear interpolation according to the data of the Fujita scale.

Unsteady calculations flat bottom pieces of destructive atmospheric vortices

$$
\begin{cases}
\left.\dfrac{dR}{dt}\right|_{C^+} = f_1(r,c,u,v)|_{C^+}\,, \\[2ex]
\left.\dfrac{dL}{dt}\right|_{C^-} = f_2(r,c,u,v)|_{C^-}\,, \\[2ex]
\left.\dfrac{dv}{dt}\right|_{C^0} = f_3(r,u,v)|_{C^0}\,,
\end{cases}
$$





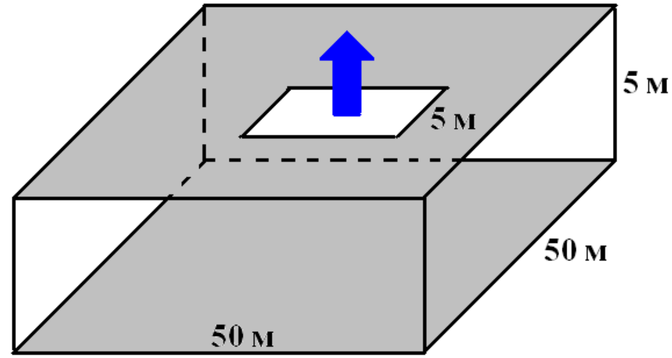
flow class	time to steady-state flow, **h**	r_0, **m**	r_{in}, **km**
$F0$	3.1	2.5	0.975
$F1$	4.6	8.0	2.618
$F2$	6.8	25.5	5.949
$F3$	8.3	80.5	12.522
$F4$	13.3	273.5	26.450
$F5$	13.6	804.5	50.890
	27.4	3650	73.050
	calcul.	**nature calcul.**	**calcul.**

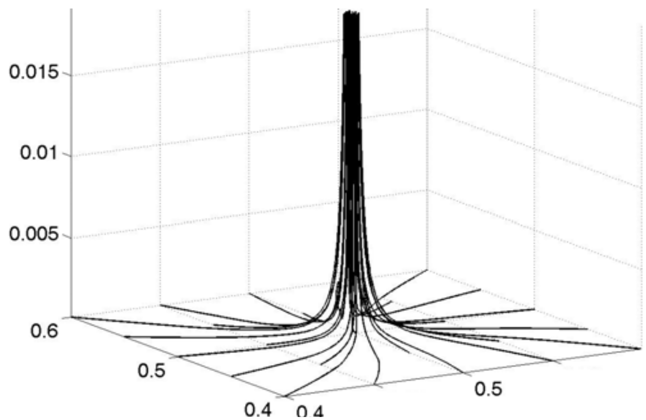
Calculations unsteady three-dimensional flows

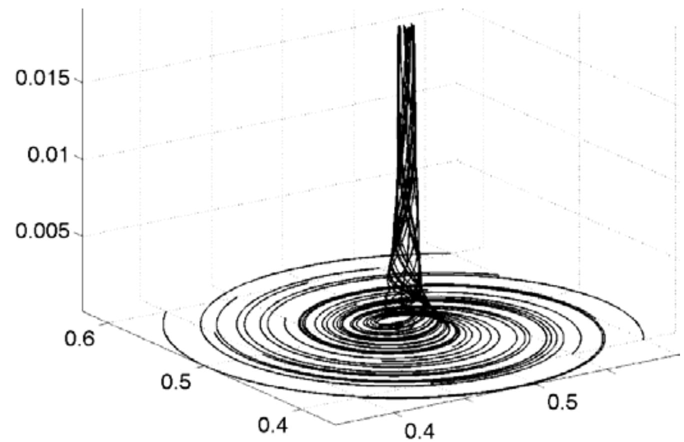
The complete system of Navier-Stokes equations

$$
\begin{cases}
\rho_t + \mathbf{V}\cdot\nabla\rho + \rho\,\mathrm{div}\,\mathbf{V} = 0, \\
\mathbf{V}_t + (\mathbf{V}\cdot\nabla)\ \mathbf{V} + \frac{T}{\gamma\rho}\nabla\rho + \frac{1}{\gamma}\nabla T = \mathbf{g} - 2\mathbf{\Omega}\times\mathbf{V} + \\
+\frac{\mu_0}{\rho}\left[\frac{1}{4}\nabla\left(\mathrm{div}\,\mathbf{V}\right) + \frac{3}{4}\Delta\mathbf{V}\right], \\
T_t + \mathbf{V}\cdot\nabla T + (\gamma-1)T\,\mathrm{div}\,\mathbf{V} = \frac{\varkappa_0}{\rho}\Delta T + \\
+\frac{\mu_0\gamma(\gamma-1)}{2\rho}\left\{\left[(u_x - v_y)^2 + (u_x - w_z)^2 + (v_y - w_z)^2\right] + \right. \\
\left. +\frac{3}{2}\left[(u_y + v_x)^2 + (u_z + w_x)^2 + (v_z + w_y)^2\right]\right\}, \ \mu_0, \varkappa_0 = \mathrm{const}
\end{cases}
$$

Calculation of «air blowing from the bottom up» experiment







blowing speed, m/s	5	10	12	15	20
W, Дж	$3.5 \cdot 10^3$	$1.4 \cdot 10^4$	$4.2 \cdot 10^4$	$6.5 \cdot 10^4$	$2.5 \cdot 10^7$
W_v/W	0.19	0.22	0.45	0.58	0.97

Conclusion

1. Construct a solution of a system of equations of gas dynamics, taking into account the forces of gravity and Coriolis consistent with the data of field observations of tornadoes and tropical cyclones.

2. These solutions are strictly mathematically determine that a twist flow and tornadoes and tropical cyclones gives only the Earth's gives only the Earth's rotation around its axis.

3. Geometric and speed characteristics of streams in which the kinetic energy of the rotational flow more than half of the kinetic energy of the flow.

Thanks!

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