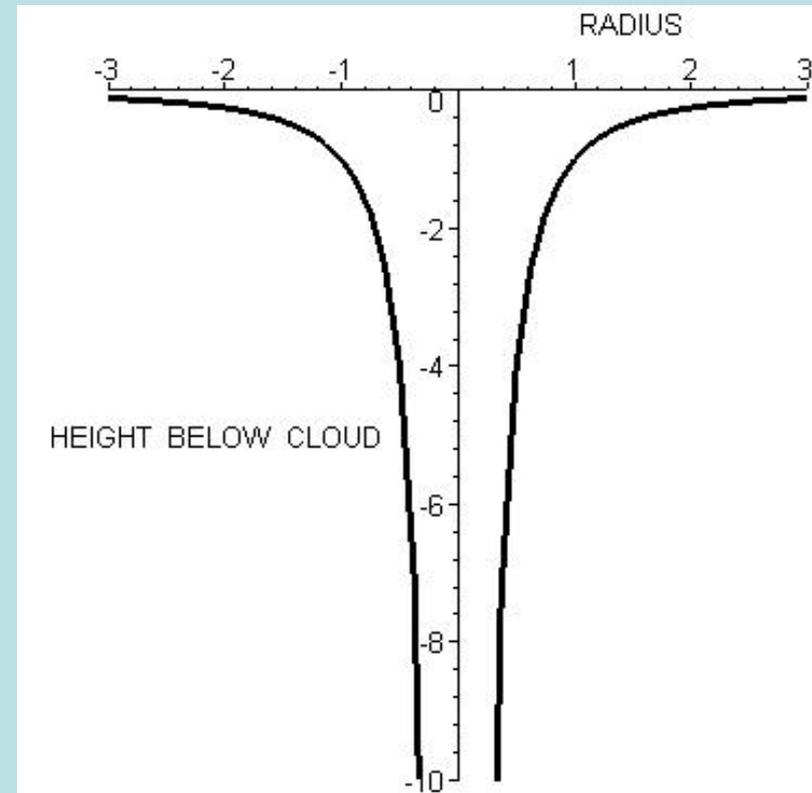# Dynamics and thermodynamics of tornado

Netsivi Ben-Amots

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Why is it so important to know what drives a tornado?

- Tornado is both destructive and fatal.

- Bluestein (1999) wrote that modifying tornadoes is impossible without understanding how they are created.

- Also, trying to alter tornadoes without a theory that can be put to the test is like shooting in the dark.

- Bluestein affirmed that it is not known what is the difference between supercells that spawn tornadoes and those that do not (Drapper, 2013).

- We add that without knowing the difference we cannot increase the warning time beyond the present 13 minutes.

Differences

A hurricane is much larger than a tornado.

The same tori like in a tornado exist in a hurricane too, but much larger.

In hurricane, instead of a cloud above, there is the ocean or sea below.

Dynamics of rotation

We think that a tornado, like anything else, obeys the laws of nature, including laws of physics and laws of dynamics and laws or rotation.

We believe that a tornado, which is a rotating storm, cannot overrule the law of conservation of angular momentum.

The angular momentum L is

$L = m\,v\,r$ (1)

Conservation of angular momentum means constant L. Solving for v

$v = L/(m\,r)$ (2)

The kinetic energy is

$E = (m/2)\,v^2$ (3)

Substituting v from (2) in (3) we get for E:

$E = (m/2)\,[L/(m\,r)]^2 = (L^2/2m)\,/\,r^2$ (4)

- In order to conserve angular momentum L (1) the required energy E (4) has to be larger as the radius r becomes smaller, and energy has to be supplied.

Angular momentum conservation during ballet dance

The ballet dancer cannot decrease his/her radius less than the radius of the body.   But why it is a world record? Why cannot thinner dancers break it? Thinner ballet dancers are less strong, and cannot supply the necessary energy

$$E = (m/2)v^2 \qquad\qquad (3)$$

$$E = (L^2/2m) / r^2 \qquad\qquad (4)$$

for smaller radius r because <u>the angular momentum L is conserved and remains constant</u>. The energy for $v=\omega r$ is also

$$E = L\omega/2 \qquad\qquad (5)$$

Therefore, if the thinner ballet dancer is not sufficiently strong, his/her maximal spinning speed is also lower, being insufficient to break the record.   So, being stronger is a must for achieving smaller radius (and a new world record).

- **For a limited supply of energy, the surrounding rotating air can come close to the axis up to a certain limit radius, but not closer:**

$$r_{LIMIT} = L / \sqrt{2\,m\,E} \qquad (6)$$

- **The limit radius is equal or in some tornadoes larger than the actual radius of the funnel of the tornado.**

- **In other words:**

- *Air outside the pipe of a tornado cannot go into the pipe.*

- **Why? It simply lacks the "ticket," that is, its energy is not sufficiently high "to come in."**

Like in a hurricane, the rotation causes reduced pressure in the pipe of the tornado.

Atmospheric pressure as low as 0.9 atmospheres was measured in tornado funnels.

The reduced pressure within the funnel tries to suck whatever it can from wherever it can. From where?

Not from out of the funnel – it will break either the conservation of energy or the conservation of angular momentum.

Not from below – the ground is there.

What is left?

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What is above?

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Not from out of the funnel – it will break either the conservation of energy or the conservation of angular momentum.

Not from below – the ground is there.

What is left?
  ONLY FROM THE <u>CLOUD</u> ABOVE.

Differences

In a hurricane there is the ocean beneath.

The reduced pressure in the central eye of a hurricane sucks moisture and vapor from the ocean below.

The flow in the center of a hurricane is upward.

The flow in the center of a tornado is **downward**, starting from the cloud

Now, what is in the cloud? It depends on whether the cloud base is rich with water vapor. If so, the funnel of the tornado sucks water vapor from the cloud above.

If the water vapor condense within the funnel, then a few things happen:

1) The funnel becomes opaque as a cloud.

2) The pressure decreases even more.

3) Most important, latent heat is released, adding and supplying additional energy to the tornado.

If no sufficient water vapor is present at the cloud base, then:

1) Either a tornado is not spawn,

2) Or, the existing tornado ceases.

We believe that this is the long wanted information about the difference between a cloud that can spawn a tornado, and a cloud that cannot.

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What can be done?

Develop sufficiently precise instruments for remote infrared measurements.

From where is the necessary precision determined?

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- **Bluestein and Golden (1993) cite Leverson et al. (1977) who measured in waterspouts**

  "a central region of ≈0.3^{o}K warmer than ambient temperatures."

The shape of the funnel

- **The Newtonian potential of rotating fluid can be obtained by integrating the centrifugal force:**

$F = mv^2/r$ (7)

The potential

$\int (Fdr)/m = \int [v^2(r)/r]dr$ (8)

Substituting $v = L/mr$ of (2) with L constant and for variable r in (7) one gets:

$\int Fdr/m = \int [(L/mr)^2/r]dr = -[(L/m)^2/2]/r^2 + \text{Const}$
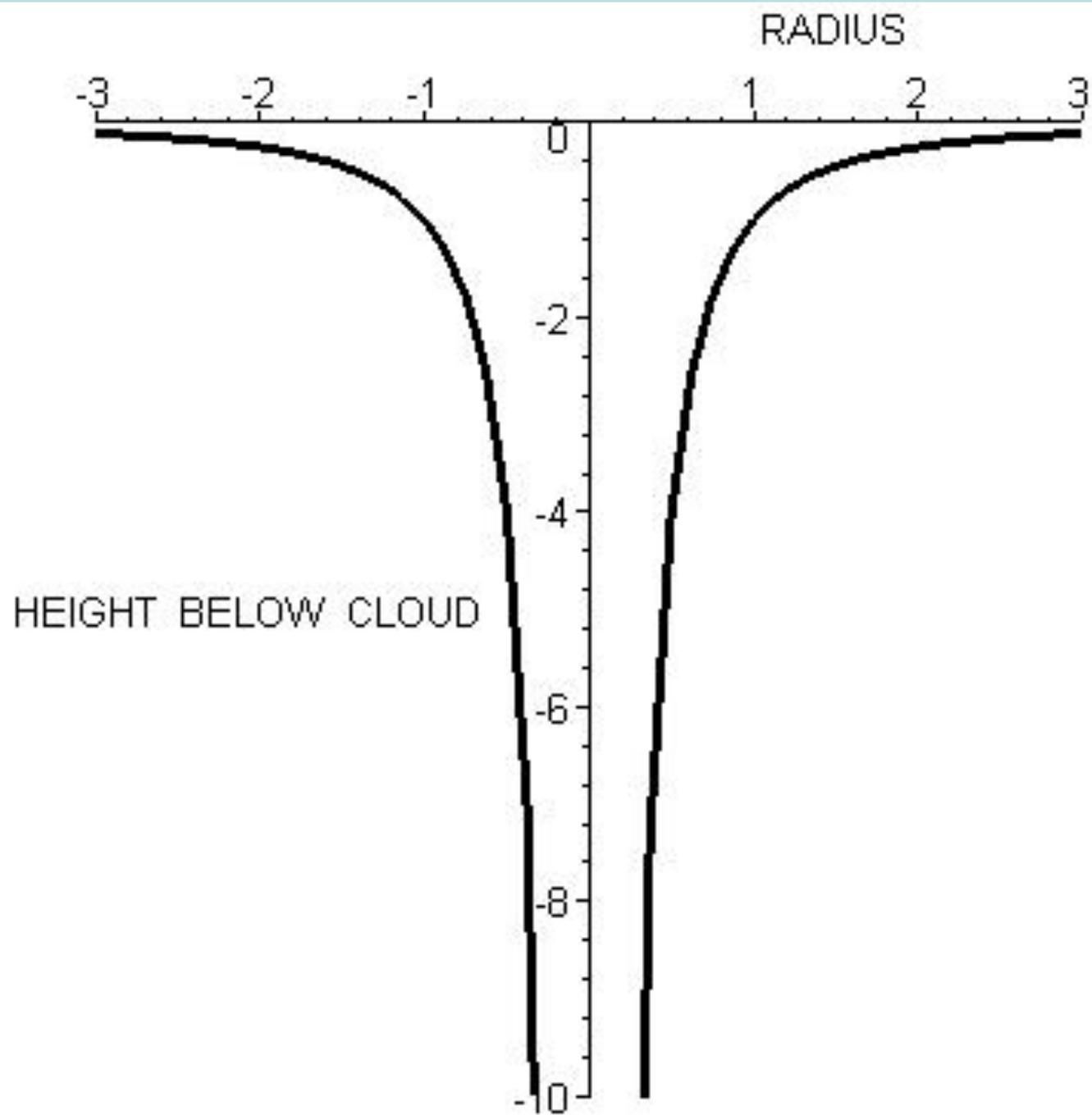
(9)

The shape of the funnel

Adding the gravitational potential *gz*

$gz = [(L/m)^2/2]/r^2 + \text{Constant}$ (10)

which has a shape similar to tornado funnel at the mature stage and similar to Feynman's (1965) figure 40-12 of solution of an incompressible fluid circulating around a draining hole.

See Figure next.

Energy calculations: height

Approximating as the paraboloid of Newton's bucket

$$z = v_c^2/2g + \text{constant} \qquad (11)$$

where v_c is the circumferential velocity

(used for tornado as early as Ferrel 1893)

We substitute g=9.8[m/sec^2] and the maximum measured wind velocity

v_c =512[km/hour]=142.2[meter/sec], and get:

$$z = 142.2^2/(2*9.8) + \text{const} \qquad (12)$$

Energy calculations: height

We replace in (12): constant= (Latent heat) * Efficiency / g

z =

1032[meters]+ (Latent heat)∗Efficiency/g

Substituting latent heat of condensation of 532 Kcal/kg, and 427 kg-meter per Kcal, we get z=

1032[meters]+ (532* 427)∗Efficiency/9.81

Or

z=1032[meters]+ 23160∗Efficiency[meters]

More thermodynamics

Water vapor from the cloud above was sucked into the funnel. What happens next?

The pressure in the funnel is lower, causing condensation into water droplets.

Condensation decreases the volume, thus further reducing the pressure.

Condensation releases heat, which heats up the droplets.

More power

The strong centrifugal force in the fast rotating funnel drives out the water droplets in up to 3-4 seconds. Where do the water droplets go?

Tornado power

The hot drops from the funnel arrives at the ascending air flow, and transfer their heat to it.

This increases its buoyancy.

This in turn increases the flow of winds inward.

Angular momentum conservation increases the velocity of the rotational winds.

Bottom line:

Heat energy in the cloud was transformed into fast destructive rotational winds.

Energy calculations: power

Volume per second$= \pi D^2 V_{DOWNWARD}/4$

Weight per second= Volume per second*4.2%*1.4*18/29*0.88

Power=Latent heat* Weight per second

Power=532*4270*π*4.2%*1.4*18*0.88/29/4*D^2 V

Power=57300*D^2 V

Energy calculations: power

Assume tornado 200 m diameter

Assume downward wind 20 m/sec

Assume saturated 4.2% moisture

Assume height 1 kilometer

Power=57300*D^2 V

57300*200*200*20 watt

Result: 47500 Megawatts

≈40 large power stations

Energy calculations :power

Assume tornado 2000 m diameter

Assume downward wind 20 m/sec

Assume saturated 4.2% moisture

Power=57300$*$D^2 V

57300*2000*2000*20 watt

Result: 4750000 Megawatts

≈4000 large power stations

Energy calculations: power

Assume tornado 2000 m diameter

Assume downward wind 2 m/sec

Assume saturated 4.2% moisture

Power=57300*D^2 V

57300*2000*2000*2 watt

Result: 475000 Megawatts

≈400 large power stations

Conclusions

Most of the energy of the tornado comes from vapor from the cloud above.

This information may be utilized for increasing the warning time by *precise* remote infrared measurements of temperature that will tell whether a certain cloud may spawn a tornado,

and thus increase the warning time.

There is also hope that in the far future this information may help to weaken a tornado or perhaps even stop it.

☺☺ ☺

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