Tornadoes

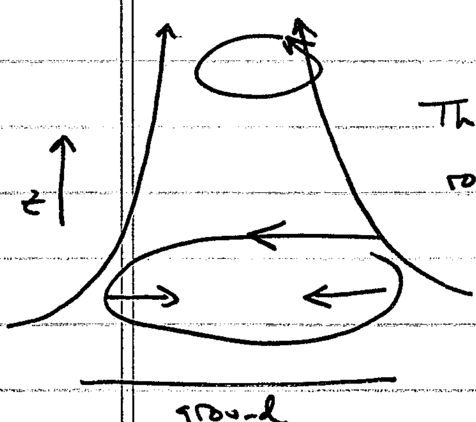
The critical reading from Chapter 5 is: 5.1, 5.2e, 5.3, 5.4 intro, d, e, 5.5a, 5.6

Tornado - strong, rotating column of air (~100 m in diameter) extending from within cloud to ground. Max winds of 50-100 m/s above ground
May contain condensation funnel or simply swirling cloud of dust & debris near ground
Funnel cloud - condensation funnel extending from cloud base but not reaching ground

Type I: forms within a larger parent circulation - rotating supercell type system. These are the "classic" tornadic environments. See Fig. 5.19.

Type II: small weak vortex formed from lift of vortex along preexisting boundary (includes gustnados) see Fig. 5.21

Type I tornados require the formation of a mid-level rotation (see C5-C11) that is combined with low-level convergence in order to accelerate the development of the tornado. The vertical stretching associated with low-level convergence can cut the time for tornadogenesis by a significant degree (see pg 190).

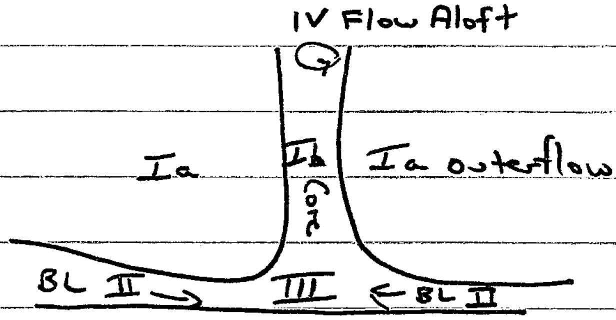


The near surface convergence causes the ascending rotating air to spin much faster & for the vortex to spin up throughout its depth (see Fig 5.18c on pg 191)

Type I Tornado Evolution

1) dust whirl - tornado becomes visible as swirling dust & a condensation funnel pendant extends downward from cloud base
2) Organizing - funnel descends & intensifies
3) ~~Becoming~~ Mature - funnel reaches maximum width & tends to be vertical
(4) Decreasing - shrinks in width & ~~n~~ become tilted
5) Decay - downdrafts destroy favorable environment. Top & base of vertex are sheared apart by ambient winds

Tornado Structure



Ia - outerflow around vortex core Ib
- tends to be not rotating ~~or ...~~

Ib - vortex core

II - surface boundary layer

III - corner region where sfc flow enters vortex. Missiles generated & debris lifted. The vertical pressure gradient is large here

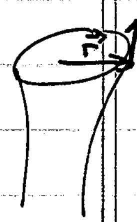
IV - flow aloft

Swirl ratio, S, is a gross measure of potential tornadic strength

$$S = \frac{V}{w} = \frac{\text{tangential wind of core}}{\text{mean updraft speed}}$$

The core Ib extends outward to the radius of maximum tangential winds. There is little exchange between the outerflow Ia & the core Ib. Why doesn't the air penetrate laterally into the core?

Consider M - angular momentum of the core $M = \vec{V} \times \vec{r}$ or $M = Vr$



If air is displaced a distance δ radially, then

$$\frac{d^2\delta}{dt^2} = -\frac{1}{r^3}\frac{\partial M^2}{\partial r}\delta$$

Inside of the maximum tangential velocity $\frac{\partial M^2}{\partial r} > 0$ & since r^3 is +

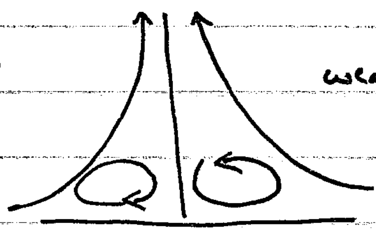
Then if δ is − (moving towards vortex axis), then it will get accelerated outwards back towards the original location

if δ is + (moving away from vortex axis), then it will get accelerated inwards back towards its original location

So, the vortex is <u>stable</u> to radial displacement - air is not going to accelerate inward or outward significantly from Ia to Ib

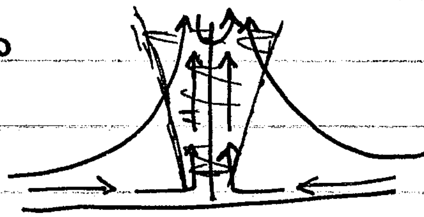
As shown in Fig 5.29, as the swirl ratio is increased (stronger tangential velocity relative to ~~than~~ updraft speed), the characteristics of the core evolve.

(a) No tornado

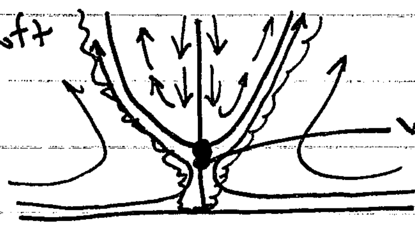


weak swirl - updraft but not good sfc convergence

b) Weak tornado
sfc convergence



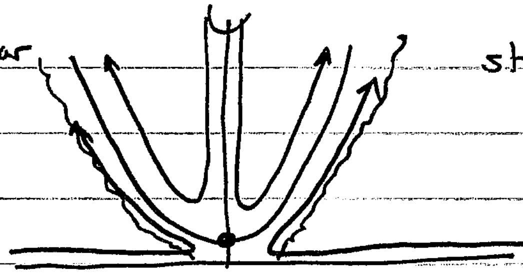
c) Downdraft aloft in core



broad condensation funnel aloft

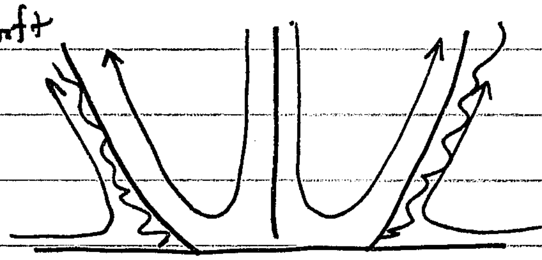
vertical stagnation point

d) Downdraft near ground



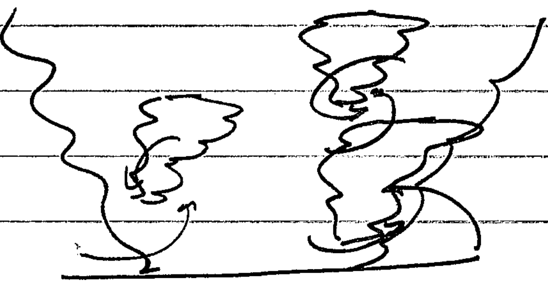
stagnation point near ground

e) Central downdraft on ground



corner region now a donut around tornado

f) Even higher S
suction vortices within large tornado



The basic explanation for why pressure is low in the core of the tornado (whether rotating clockwise or counterclockwise) was given on pg C8. Given the schematic streamlines in the above figures you should be able to get a sense of the local pressure gradients driving the vertical motions. Although there are a variety of theoretical arguments, the main point is that in the developing stages as the vortex subsidence region descends it is insufficient to raise the pressure enough to "fill" the vortex.

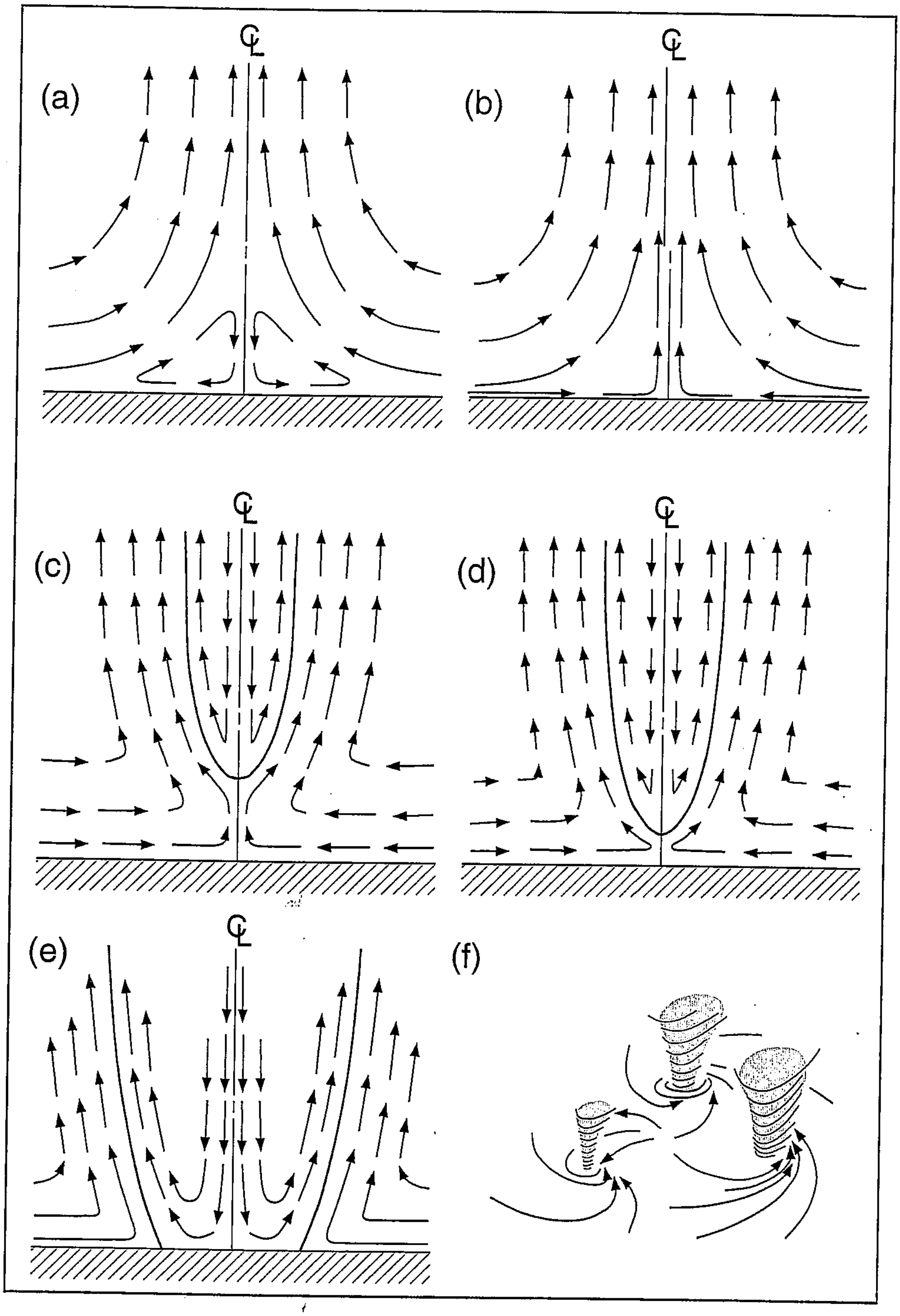


FIG. 5.29. Effect of increasing swirl ratio, *S*, on tornadic vortex flows. (a) Very weak swirl—flow in boundary layer separates and passes around corner region and there is no tornado; (b) Low *S*—smooth-flowing one-cell weak tornado; (c) Moderate *S*—end-wall boundary layer erupting upward into strong smooth-flowing end-wall vortex that breaks down near the top of the boundary layer into a turbulent two-cell vortex aloft: (d) Slightly higher *S*—drowned vortex jump (DVJ) with the defining characteristic of the vortex-breakdown stagnation point very close to the ground; (e) Turbulent two-cell tornado at higher *S*—the central downdraft now impinges on the ground, eliminating the stagnation point aloft, inflow in the boundary layer erupts upward in a now-annular corner region, and the core radius increases rapidly with *S*; (f) Large *S*—tornado "splits" into multiple vortices (2, 3, . . . , 6 as *S* increases). (Modified from Davies-Jones 1986.)