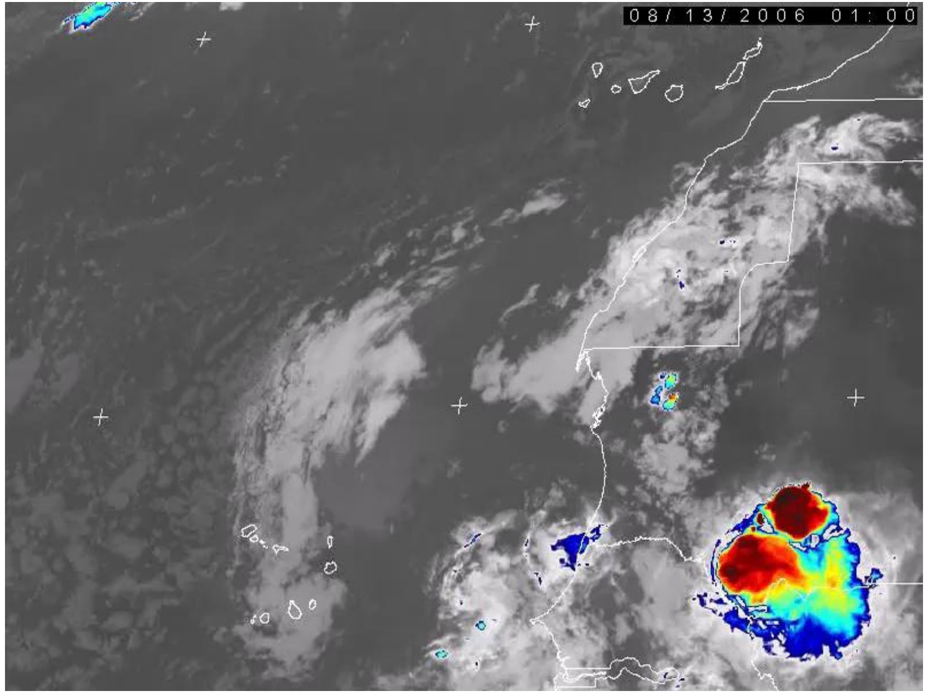
Convective Scale Interaction
or
Let’s just talk about convection



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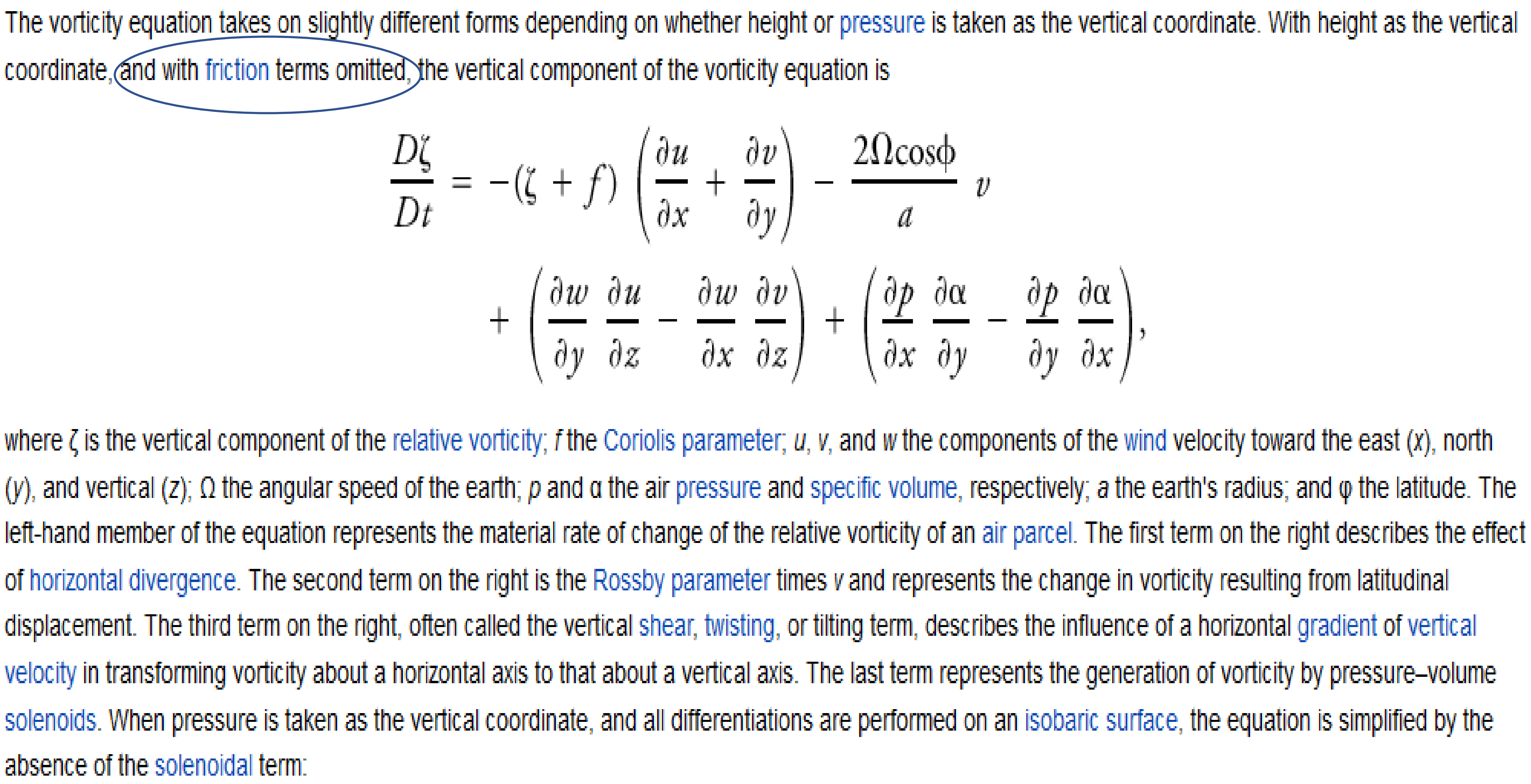
Vorticity Equation: From the AMS Glossary of Meteorology



The vorticity equation takes on slightly different forms depending on whether height or pressure is taken as the vertical coordinate. With height as the vertical coordinate, and with friction terms omitted, the vertical component of the vorticity equation is

$$\frac{D\zeta}{Dt} = -(\zeta + f)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) - \frac{2\Omega\cos\phi}{a}\, v + \left(\frac{\partial w}{\partial y}\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right) + \left(\frac{\partial p}{\partial x}\frac{\partial \alpha}{\partial y} - \frac{\partial p}{\partial y}\frac{\partial \alpha}{\partial x}\right),$$

where ζ is the vertical component of the relative vorticity; f the Coriolis parameter; u, v, and w the components of the wind velocity toward the east (x), north (y), and vertical (z); Ω the angular speed of the earth; p and α the air pressure and specific volume, respectively; a the earth's radius; and φ the latitude. The left-hand member of the equation represents the material rate of change of the relative vorticity of an air parcel. The first term on the right describes the effect of horizontal divergence. The second term on the right is the Rossby parameter times v and represents the change in vorticity resulting from latitudinal displacement. The third term on the right, often called the vertical shear, twisting, or tilting term, describes the influence of a horizontal gradient of vertical velocity in transforming vorticity about a horizontal axis to that about a vertical axis. The last term represents the generation of vorticity by pressure–volume solenoids. When pressure is taken as the vertical coordinate, and all differentiations are performed on an isobaric surface, the equation is simplified by the absence of the solenoidal term:

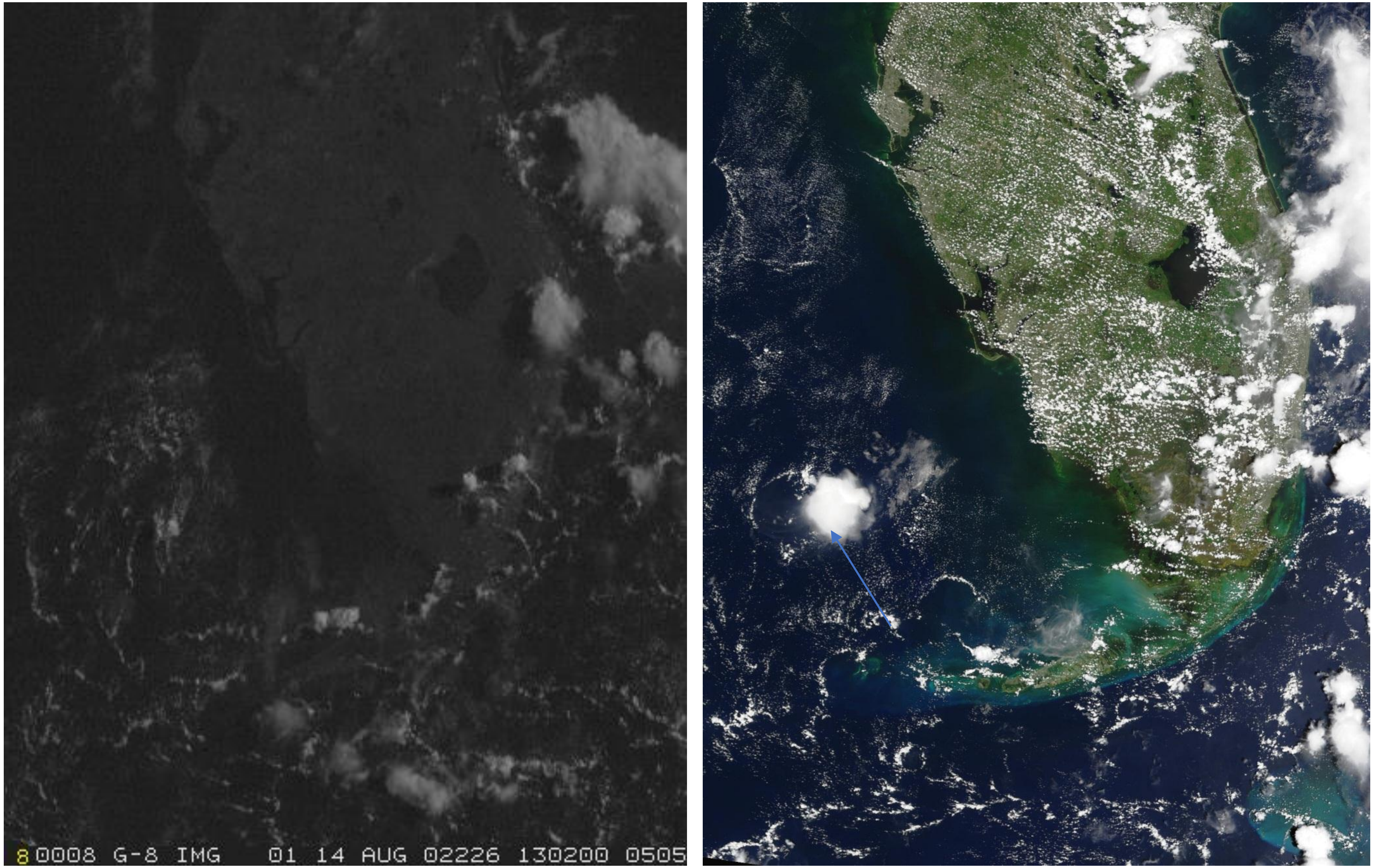
Organized circulation Vorticity – On the local scale

- Convergence on preexisting vorticity
- Tilting of vorticity from one plane to another
- Advection from one place to another
- Differential heating (does not require pre-existing vorticity)
- Friction

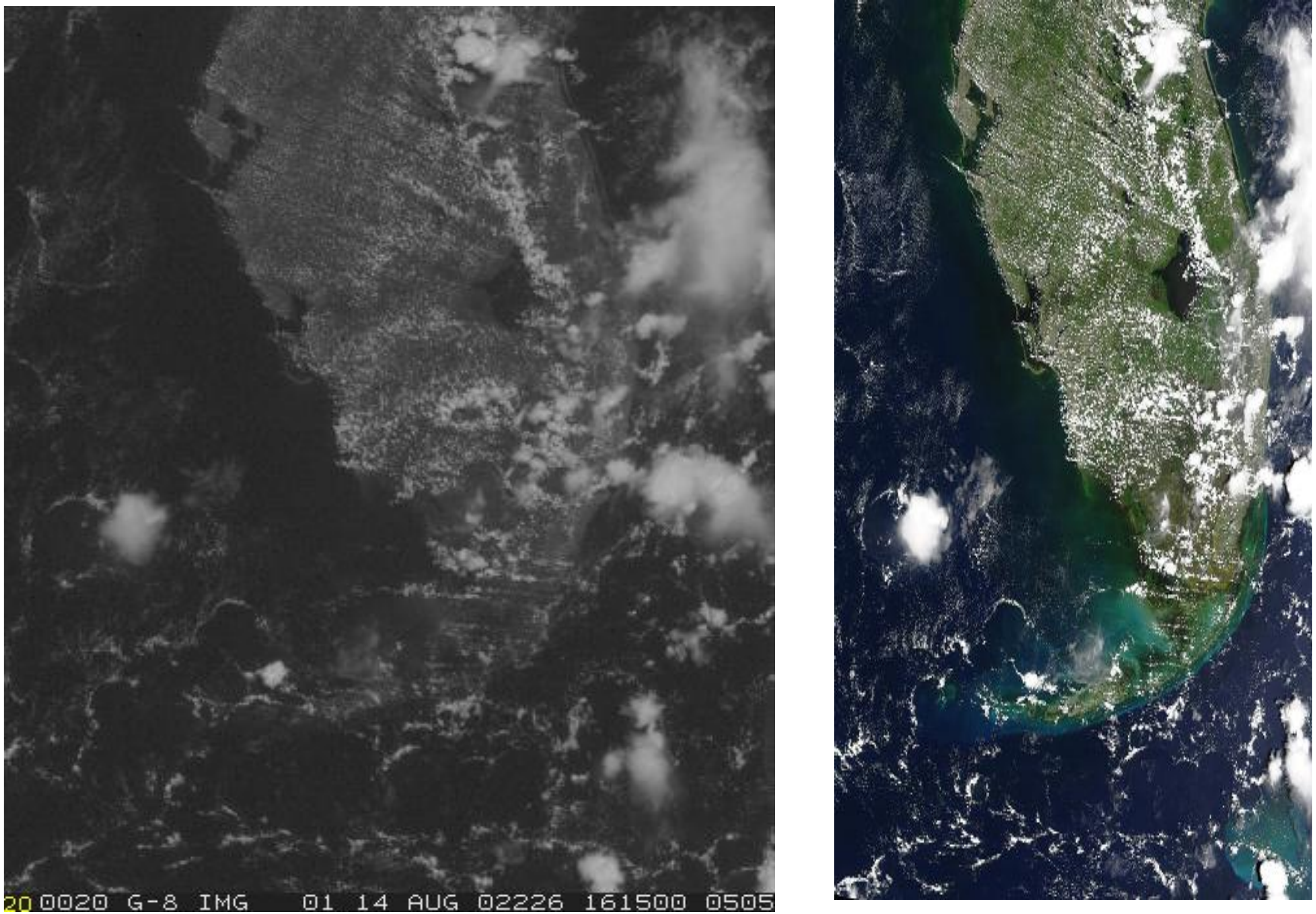
Differential heating examples

- When one thinks of differential heating the land sea breeze phenomena immediately comes to mind.
- Another differential heating mechanism is the thunderstorm itself: through evaporation of rain cooled air a differential heating is developed in a quick and often dramatic fashion.

Observing the process (geostationary) can help analyze polar imagery.



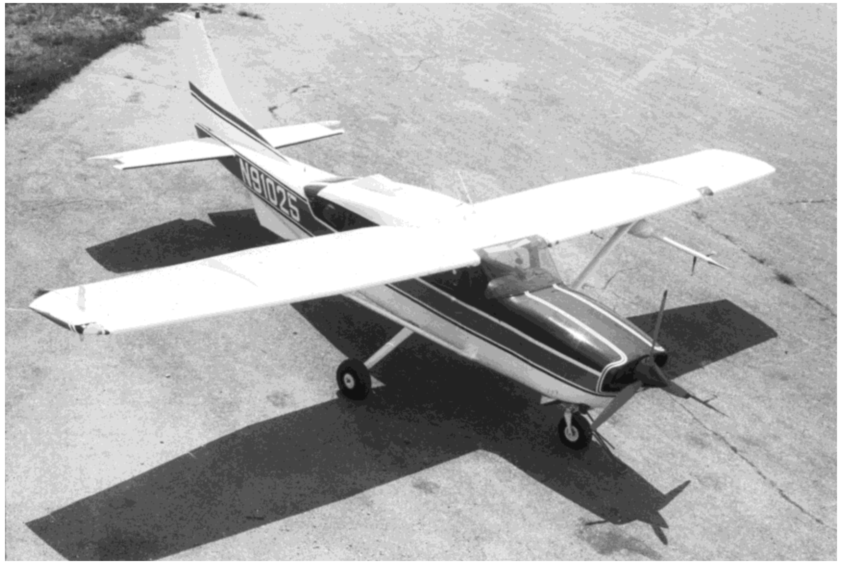
GOES-8 loop from 1033 to 1615 (left) and MODIS true color image near 1615 (right).
While noting the convection over land, pay attention to convection over the ocean.

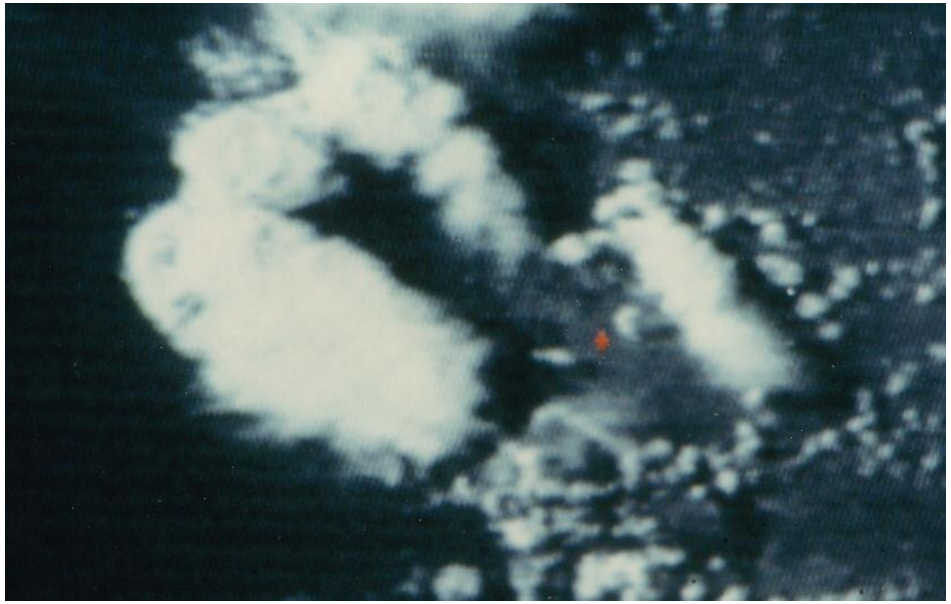


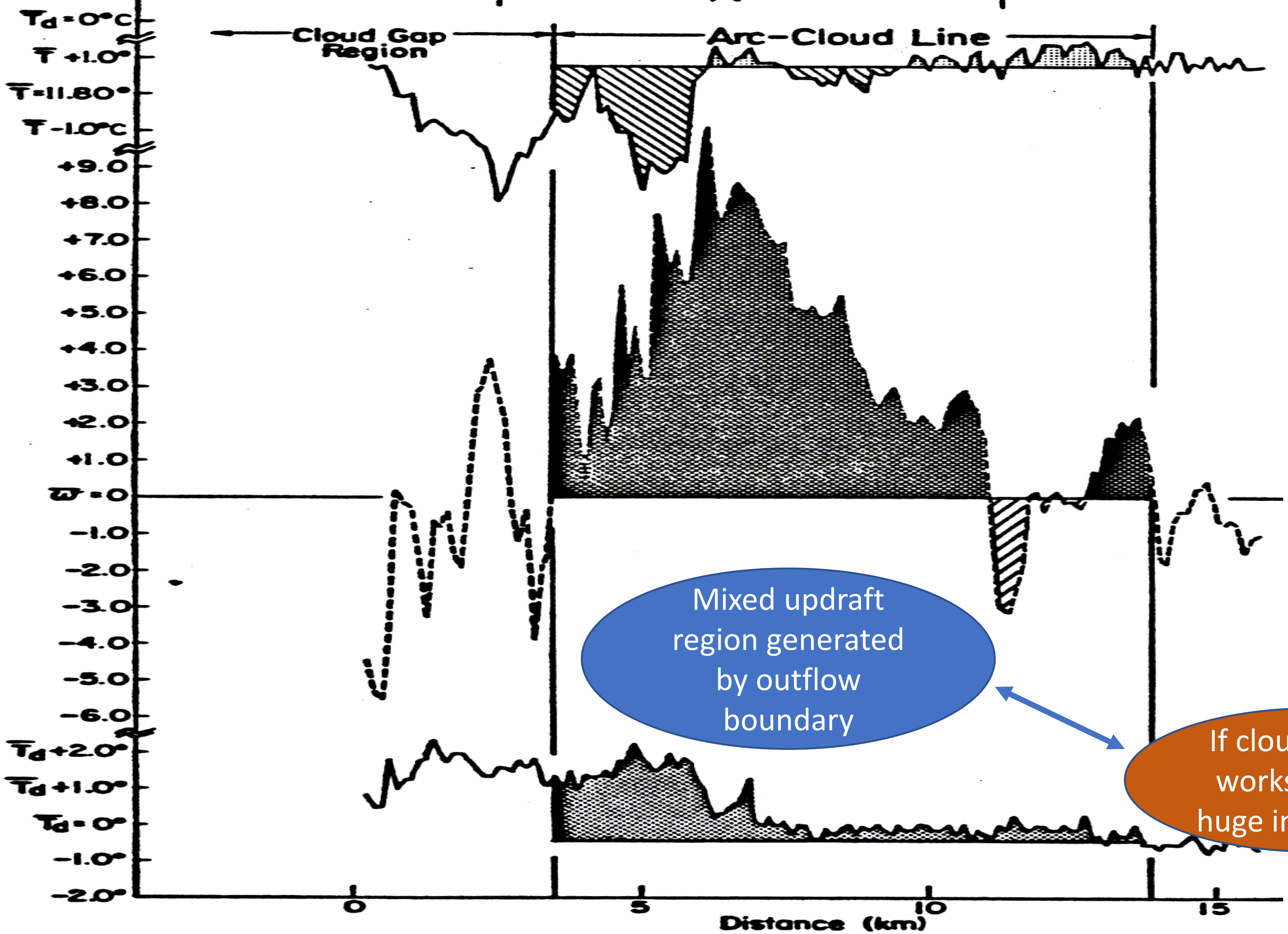
GOES-8 loop, 1615-2332, and MODIS true color image near 1615 (right). While noting the convection over land, pay exceptional attention to convection over the ocean.

Animation of one minute GOES imagery illustrating the role of storm outflow in generating new convection.

A flight through an arc cloud line





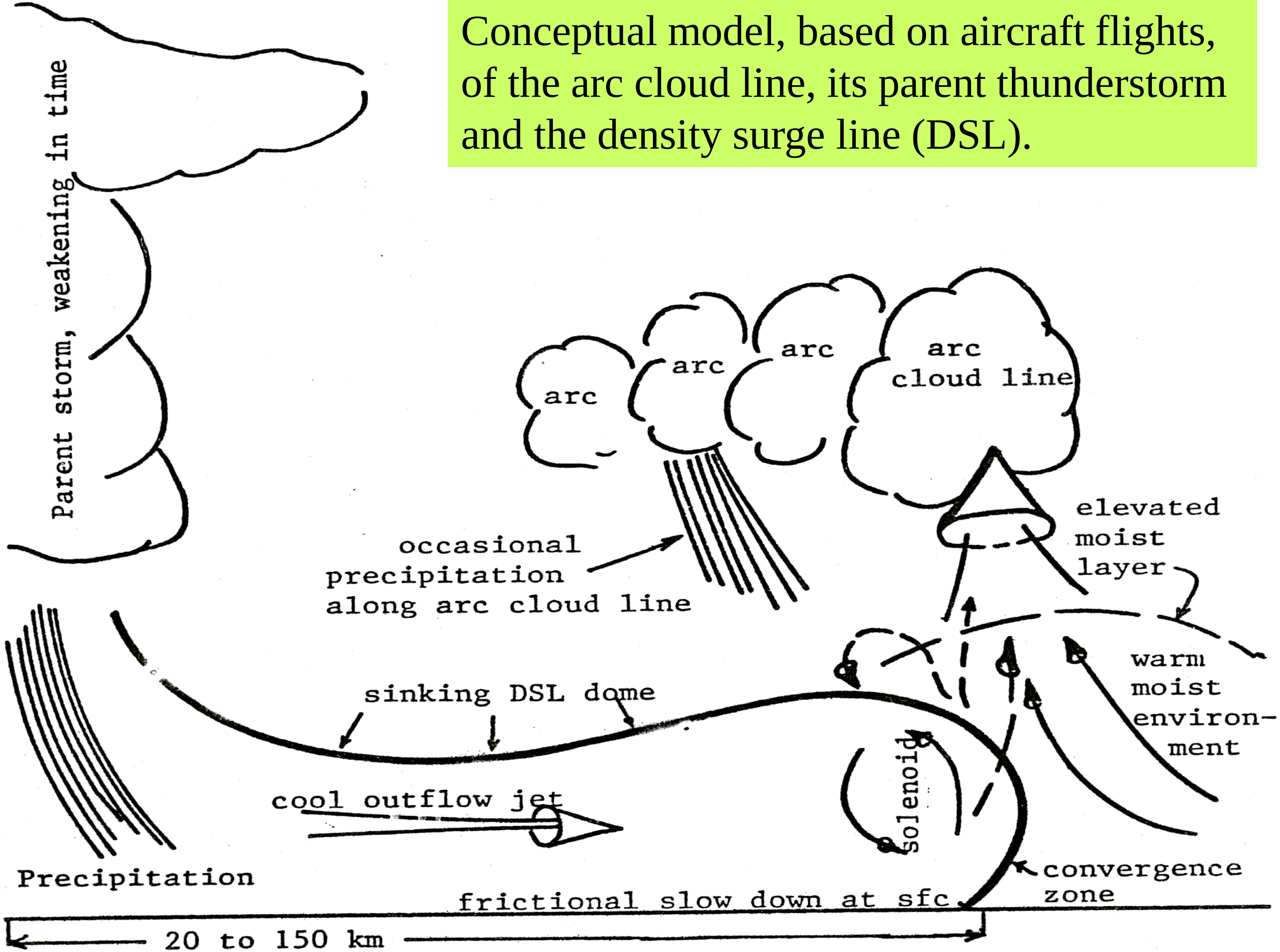


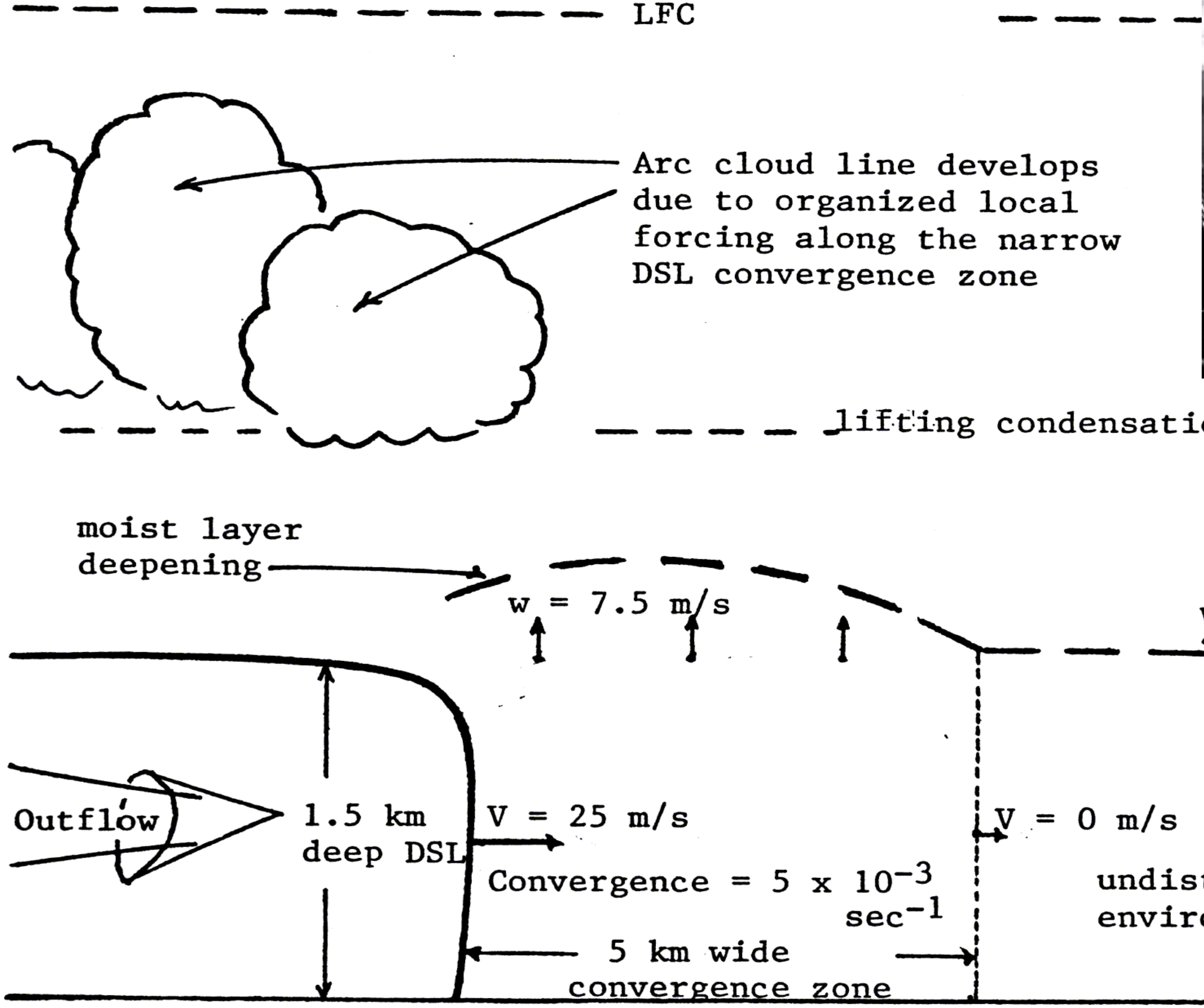
Mixed updraft region generated by outflow boundary

If cloud seeding works, this has huge implications

Aircraft data from penetration of an intense arc cloud’s sub-cloud region

Conceptual model, based on aircraft flights, of the arc cloud line, its parent thunderstorm and the density surge line (DSL).





LFC

Arc cloud line develops
due to organized local
forcing along the narrow
DSL convergence zone

lifting condensation level

moist layer
deepening

w = 7.5 m/s

w = 0

Outflow

1.5 km
deep DSL

V = 25 m/s

V = 0 m/s

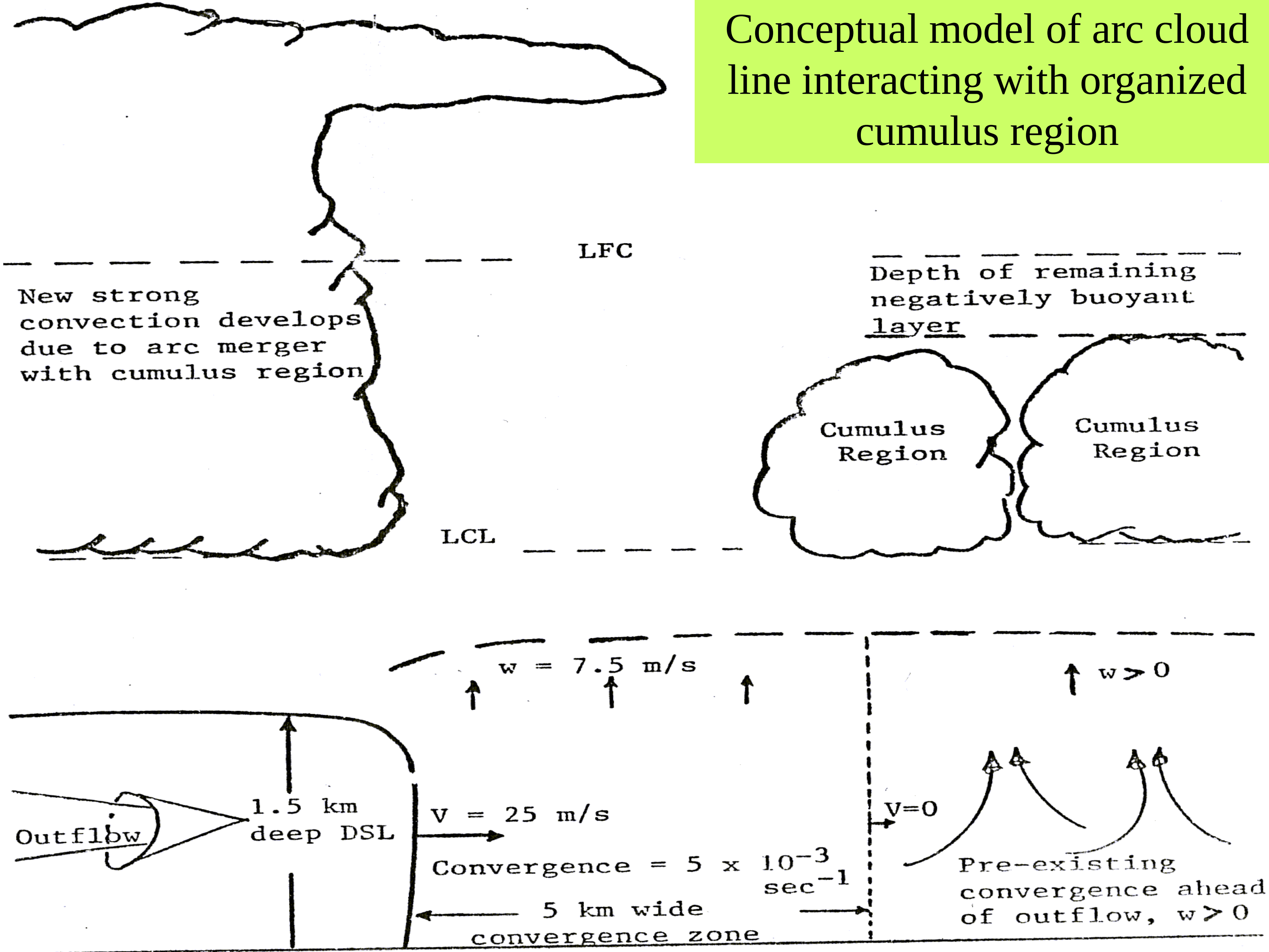
Convergence = 5×10^{-3}
sec^{-1}

undisturbed
environment

5 km wide
convergence zone

Convergence and vertical motion region associated with the arc cloud

Conceptual model of arc cloud line interacting with organized cumulus region



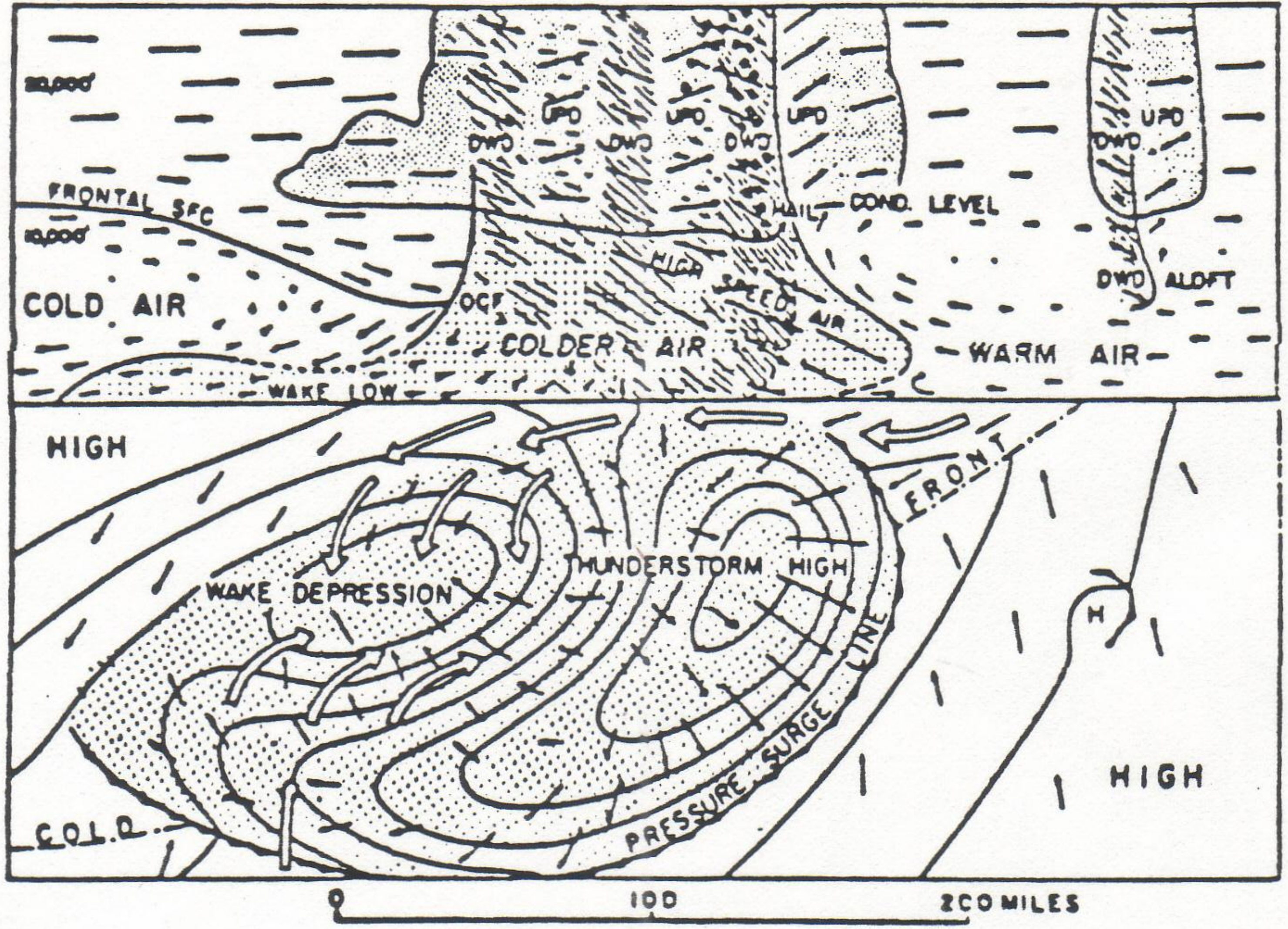


Figure . From Fujita (1955) illustrating the importance of rain-cooled air in the production of the mesoscale high pressure system.

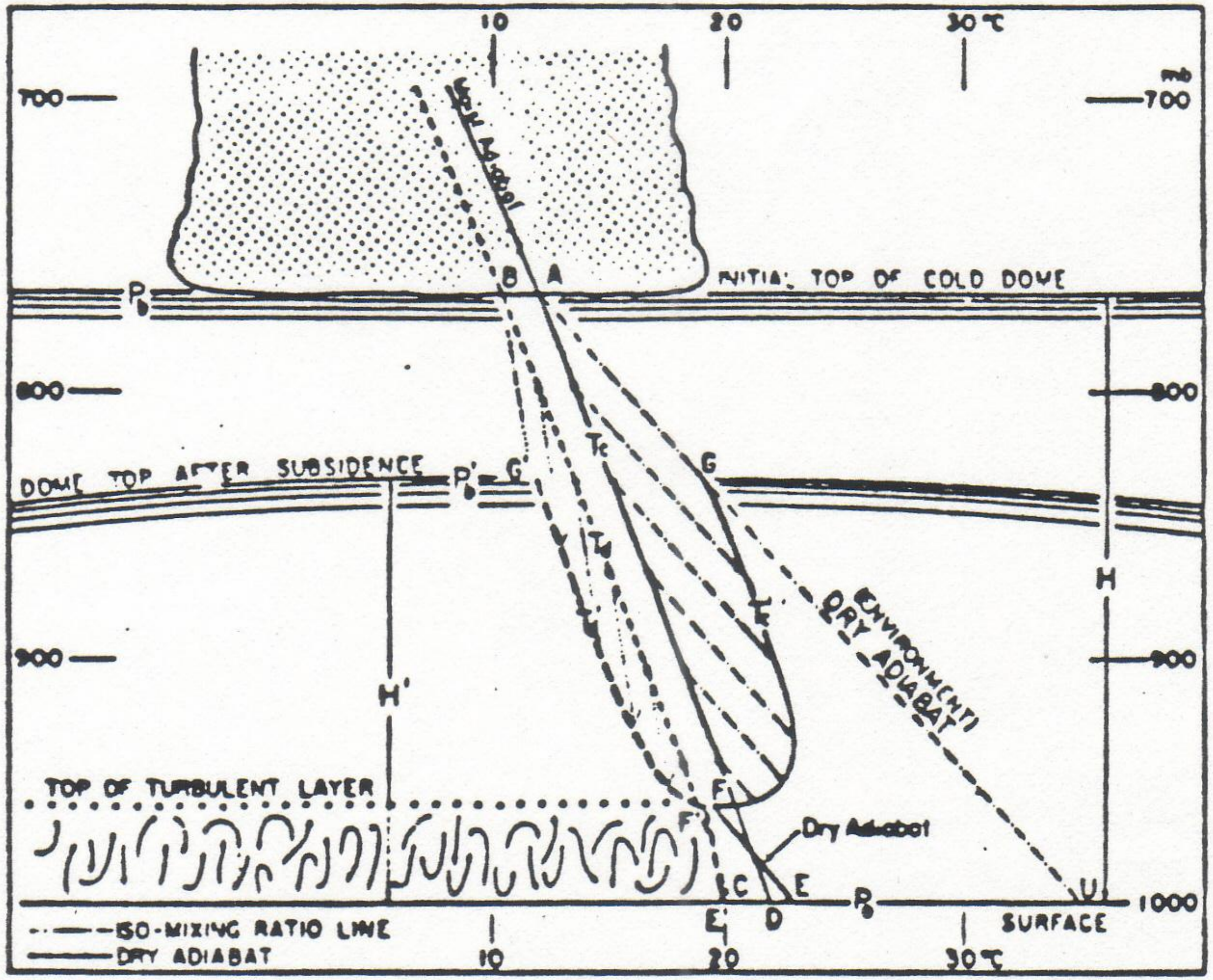
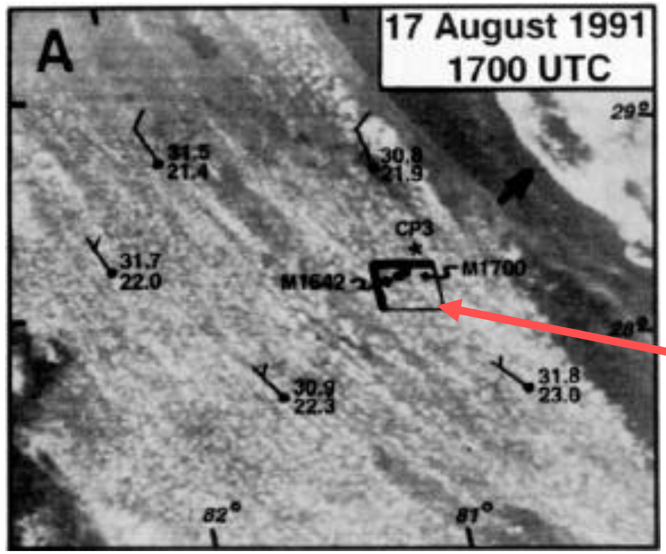
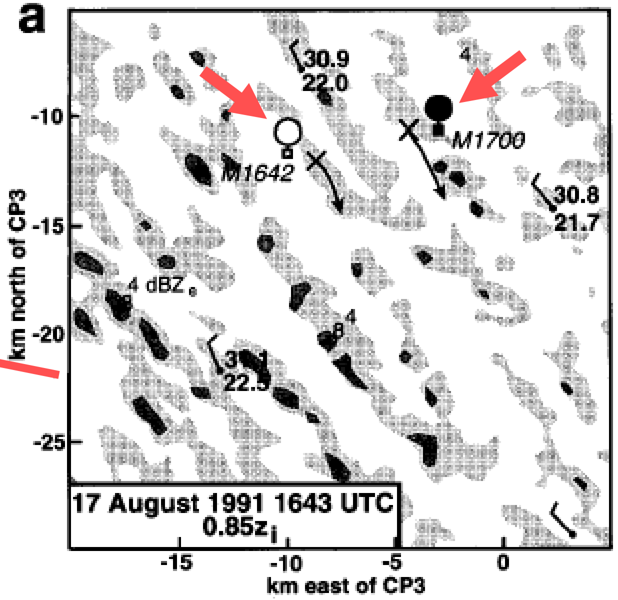
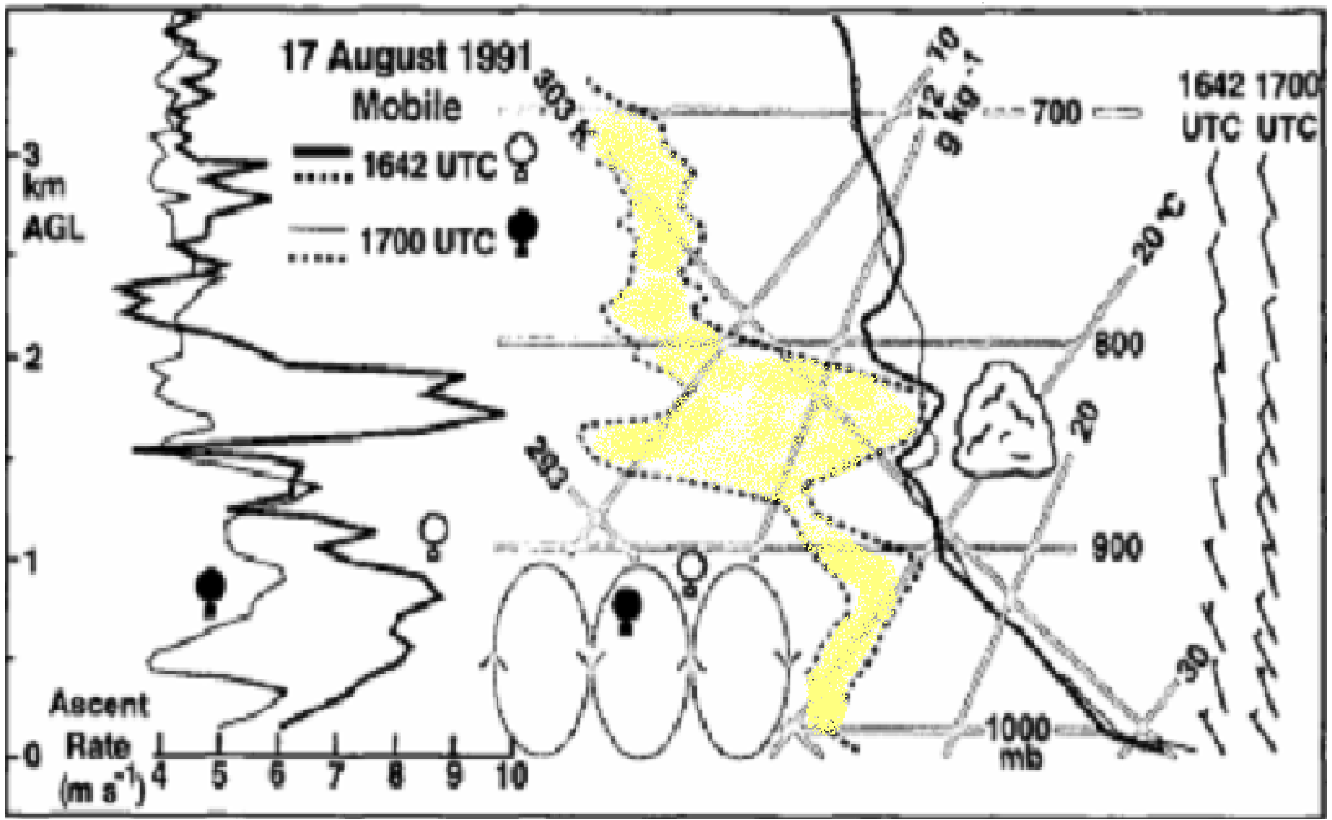


Figure . From Fujita (1959) illustrating the importance of subsidence within the cold dome, after the passage of the thunderstorm system, which leads to clearing in that region.

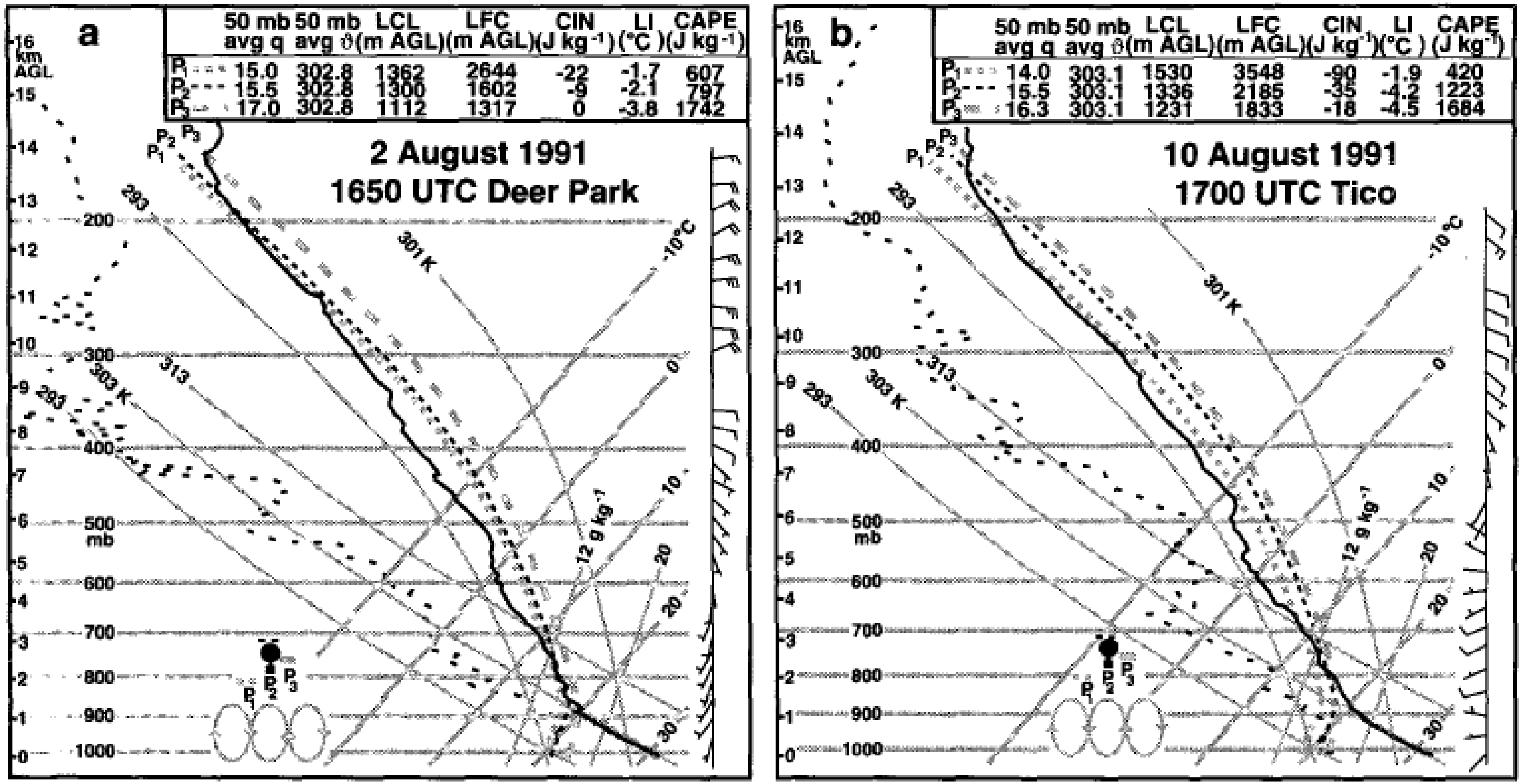




The moisture available to support deep convection can vary dramatically over very short distances as the convective boundary layer develops.



Left about 2 g/kg over a distance of about 10 km (from a study over Florida , based on research aircraft flights and special rawinsonde data).



a

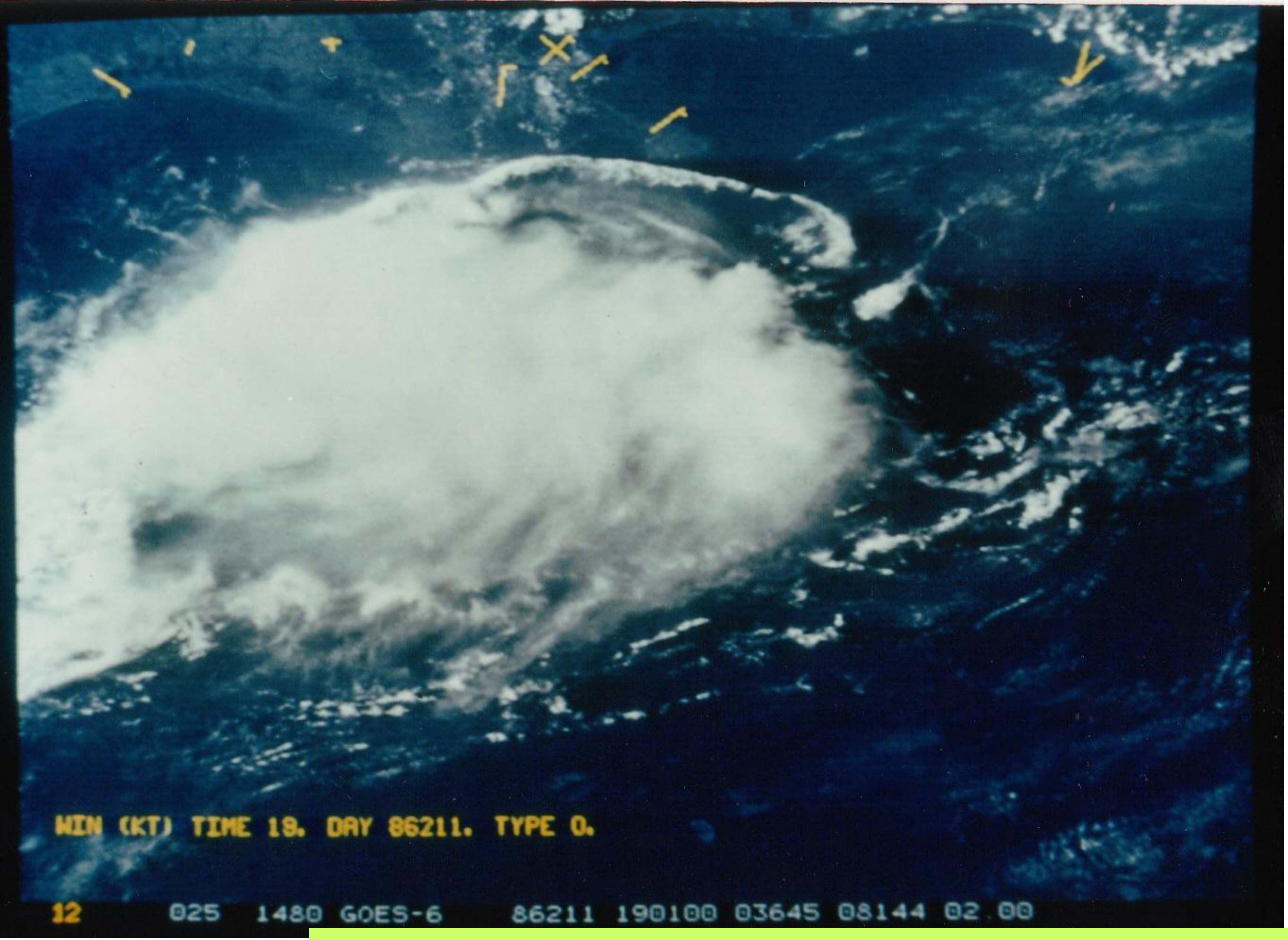
	50 mb avg q	50 mb avg ϑ	LCL (m AGL)	LFC (m AGL)	CIN (J kg^{-1})	LI (°C)	CAPE (J kg^{-1})
P_1	15.0	302.8	1362	2644	-22	-1.7	607
P_2	15.5	302.8	1300	1602	-9	-2.1	797
P_3	17.0	302.8	1112	1317	0	-3.8	1742

b.

	50 mb avg q	50 mb avg ϑ	LCL (m AGL)	LFC (m AGL)	CIN (J kg^{-1})	LI (°C)	CAPE (J kg^{-1})
P_1	14.0	303.1	1530	3548	-90	-1.9	420
P_2	15.5	303.1	1336	2185	-35	-4.2	1223
P_3	16.3	303.1	1231	1833	-18	-4.5	1684

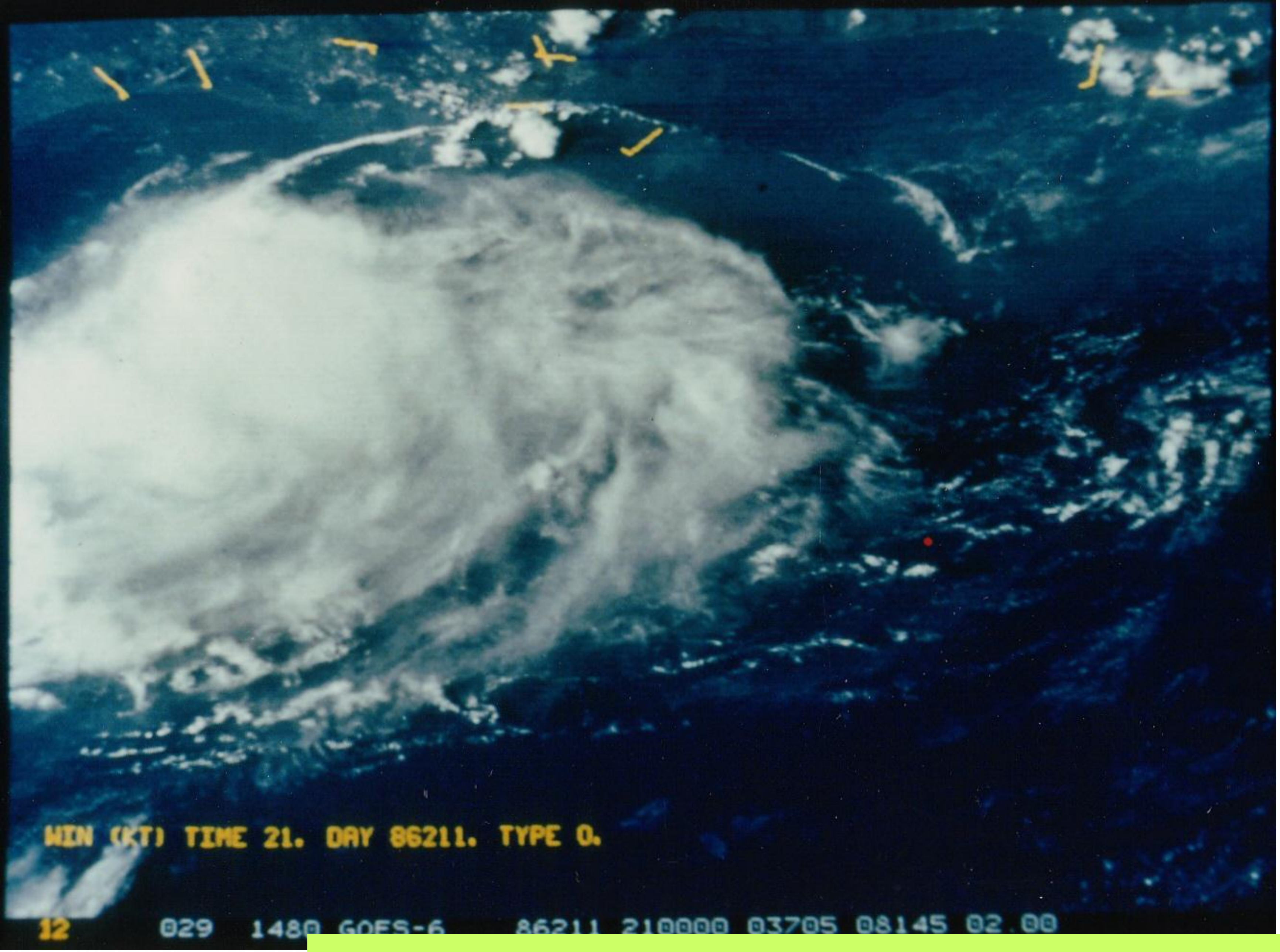
FIG. 9. Full soundings for (a) 1650 UTC 2 August of Fig. 8a and (b) 1700 UTC 10 August of Fig. 8b. Three parcel ascent tracks are shown to indicate the variations depending on low-level mixing ratio values. Parcel 1 (P_1) represents the minimum moisture measured by the aircraft, P_2 represents the parcel ascents expected from the soundings, and P_3 represents both the maximum moisture measured by the aircraft and the parcels producing cloud-base heights determined from photogrammetry. Tables showing stability parameters for the three parcel ascents are shown. Wind barbs are the same as in Fig. 5.

Differences in moisture dominate the convective potential.



Notice how well the arc shaped outflow line is defined. Ahead of the line to the North small areas of convection are developing over land near upper picture center (around the wind barbs)

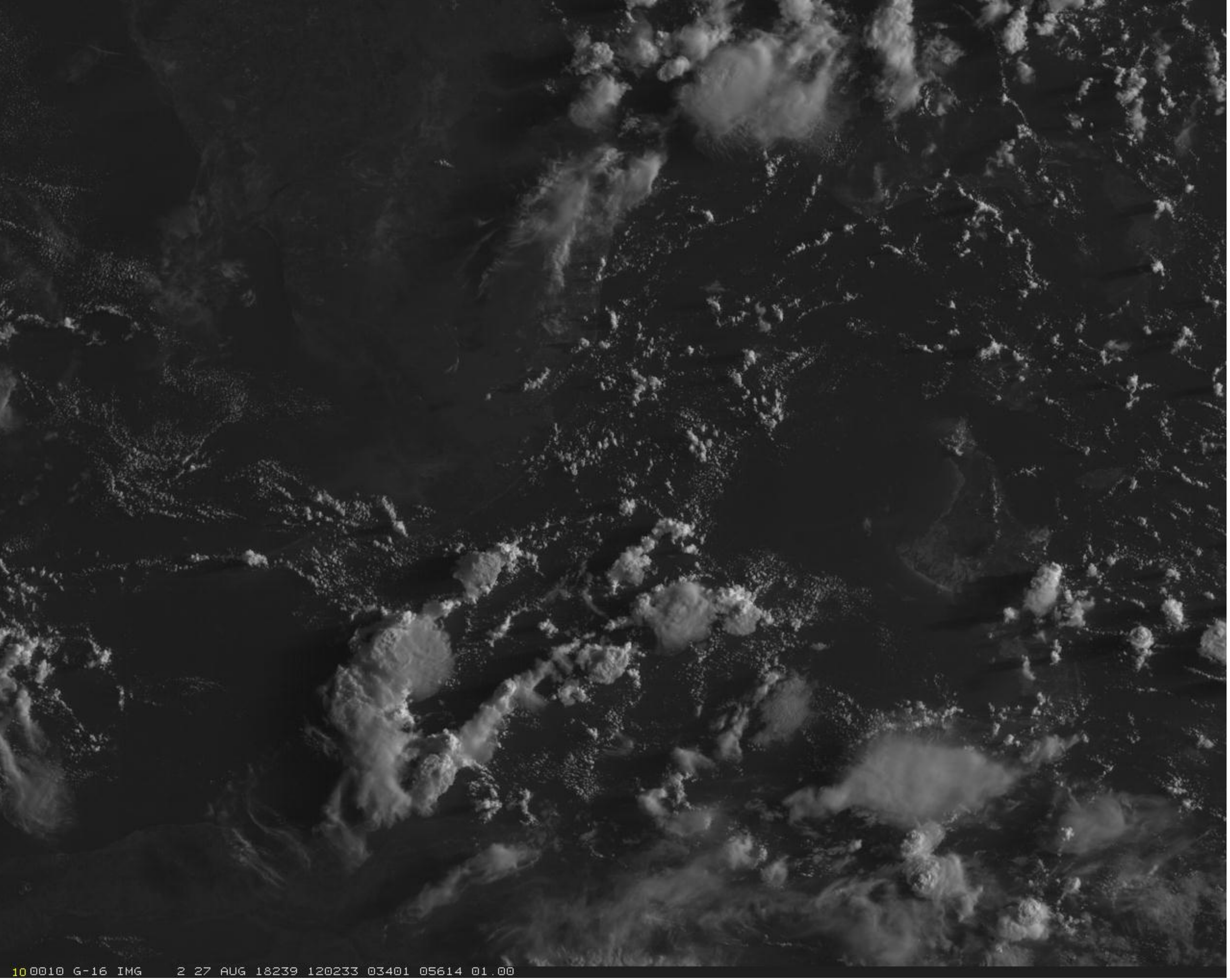
Arc cloud line moving northward from a large convective region over the Gulf of Mexico



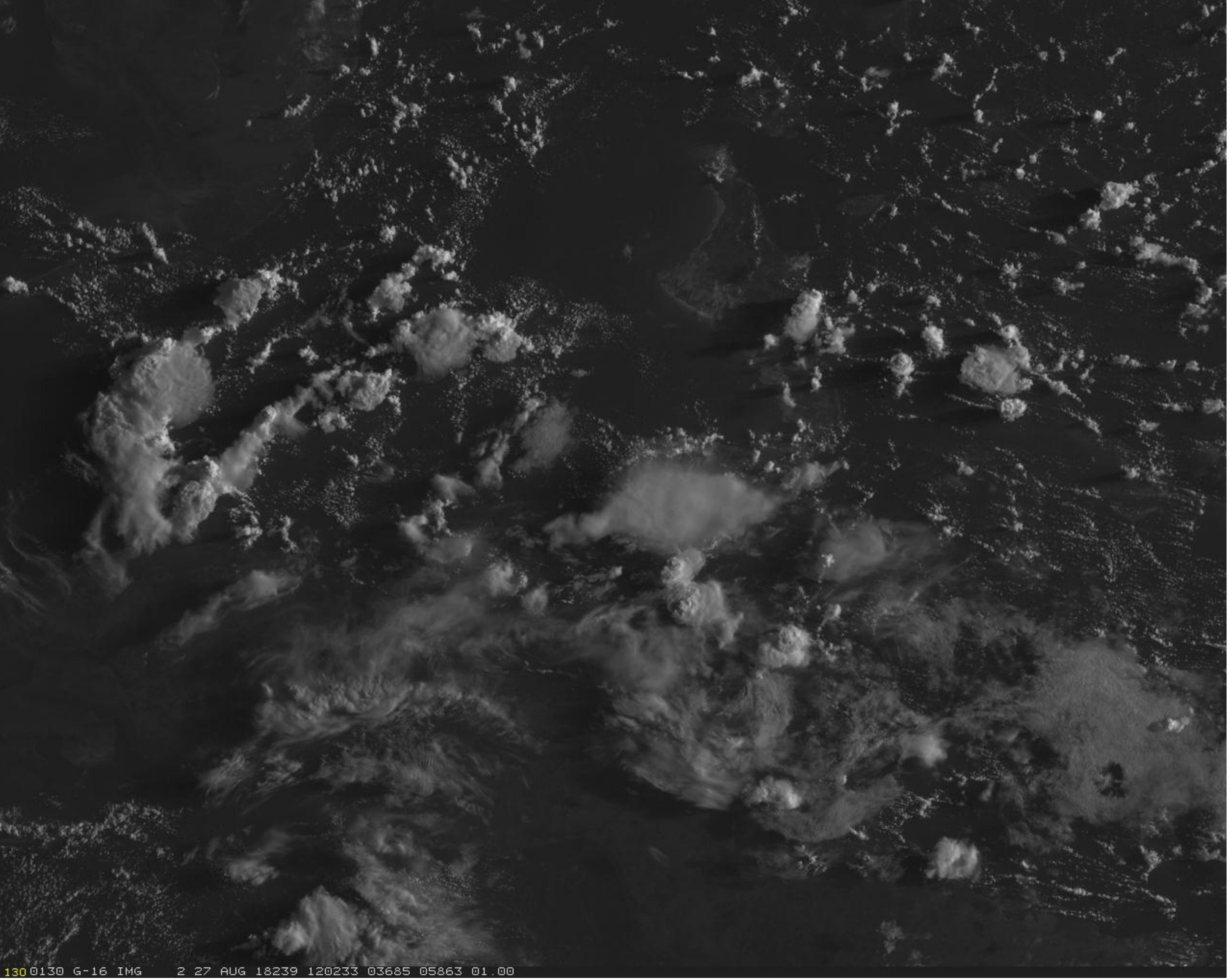
Notice the arc shaped outflow line is still observed but has decreased in cloudiness as it spread out into the Northern Gulf of Mexico (forcing along it has decreased except where its vertical motion has interacted with the convective cloudiness that was developing over land). Vorticity generated due to differential heating has played a key role in holding the arc cloud line together as it moved northward.

A clear example of convective scale interaction driving the development and evolution of thunderstorm activity under weak synoptic forcing.

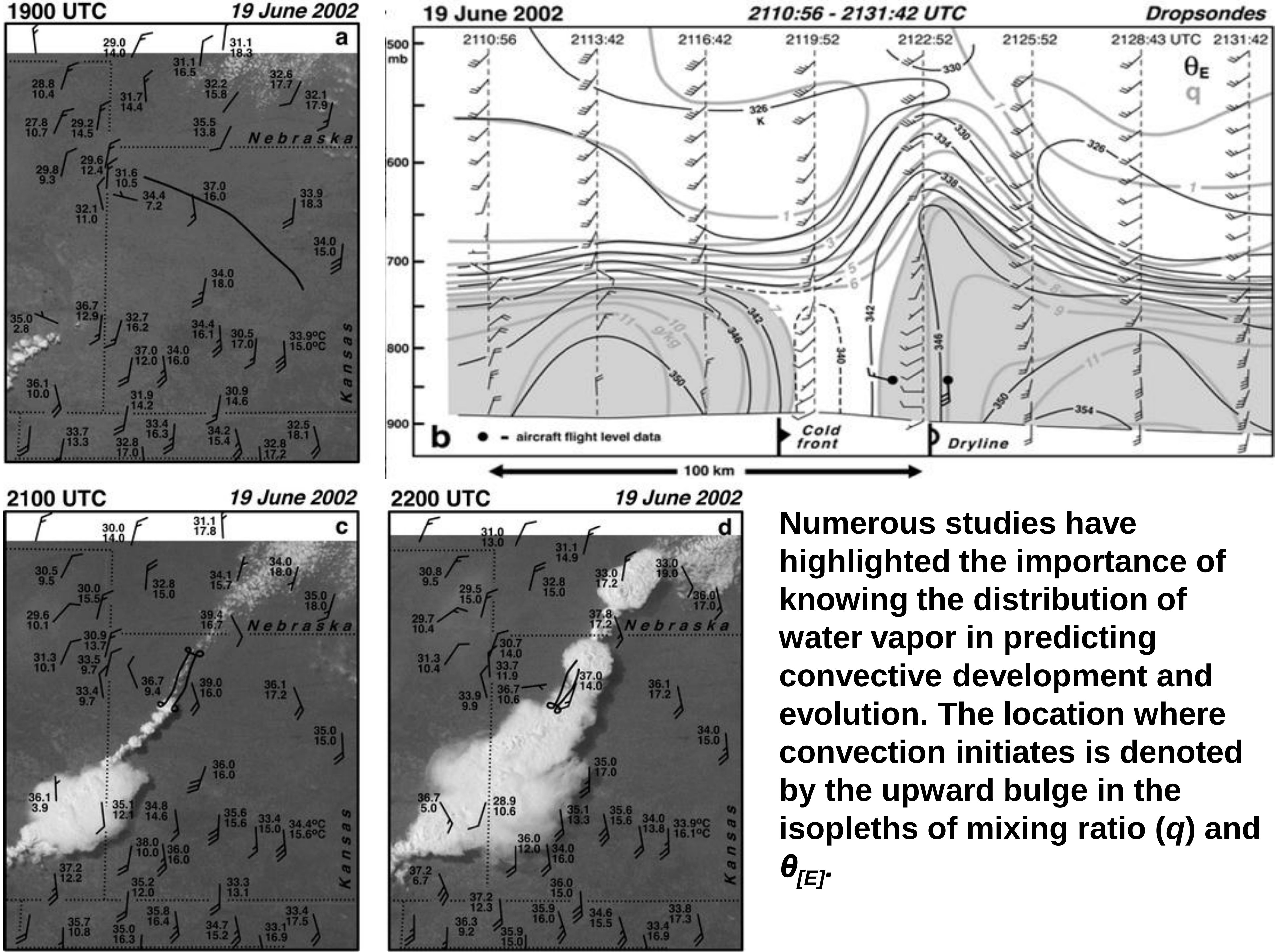
Two hours later the arc cloud line has moved ashore triggering new convection (in preferred locations).



Convective cloud movement over the ocean South of Florida, 27 August 2018 at 5 minute intervals. Try and follow the evolution of the cloud field – fairly easy to do if concentrate on one small area.

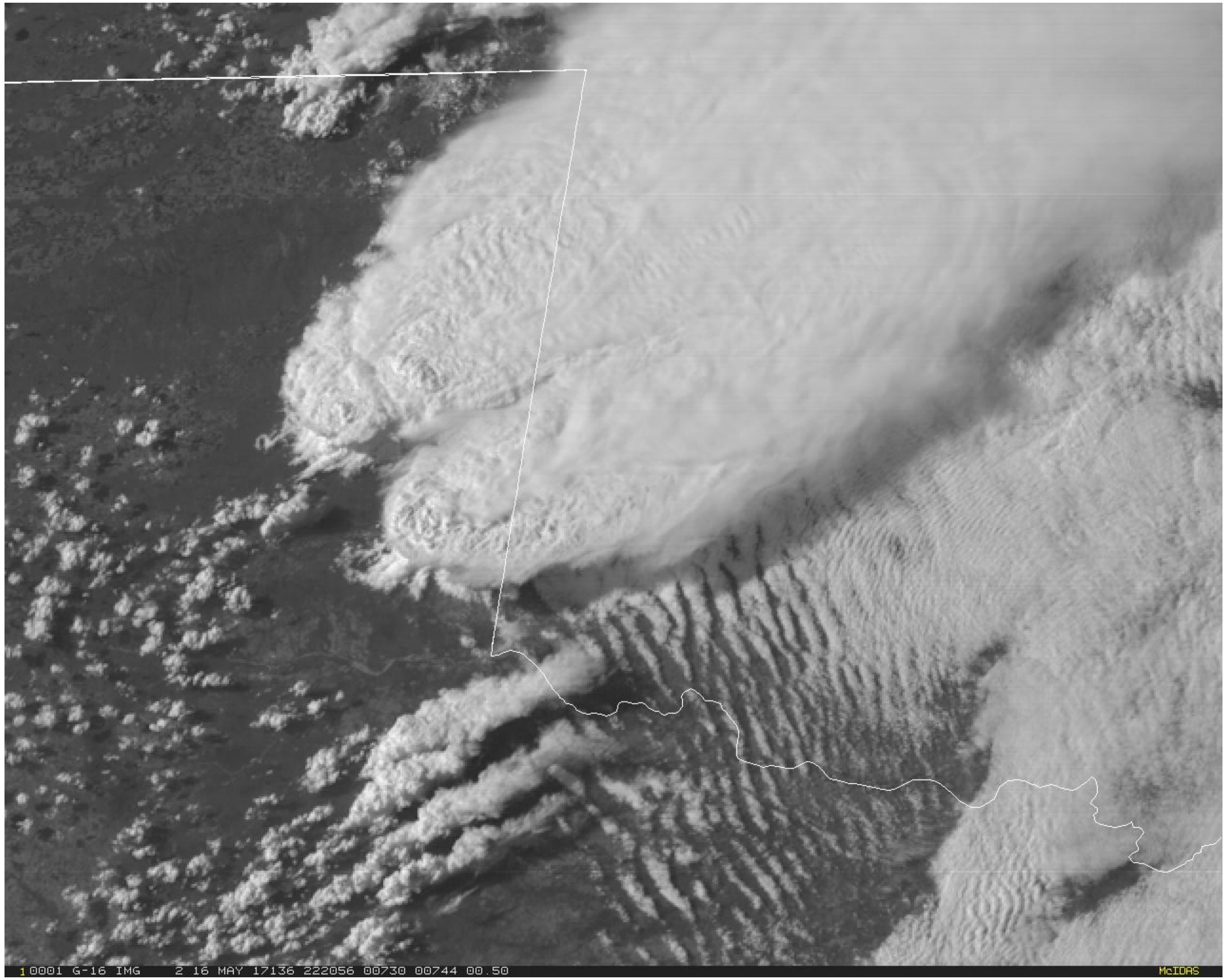


Convective cloud movement over the ocean South of Florida, 27 August 2018 at 5 minute intervals in cloud relative animation mode. Try and follow the evolution of the cloud field – fairly easy to do since mean cloud movement has been removed. Notice the stability of the cloud lines and the development and subsequent demise of convection on those lines. These small outflow boundaries provide stability to the cloud line circulation system – with lack of strong friction the rotation in the lines lead to their longer life times, awaiting their interaction with other cloudy regions for longevity.



Numerous studies have highlighted the importance of knowing the distribution of water vapor in predicting convective development and evolution. The location where convection initiates is denoted by the upward bulge in the isopleths of mixing ratio (*q*) and $\theta_{[E]}$.

We’ve moved to 5-10 minute global imaging with the possibility of 30 second to 1 minute interval rapid scanning of mesoscale sectors



One
minute
interval
visible
loop

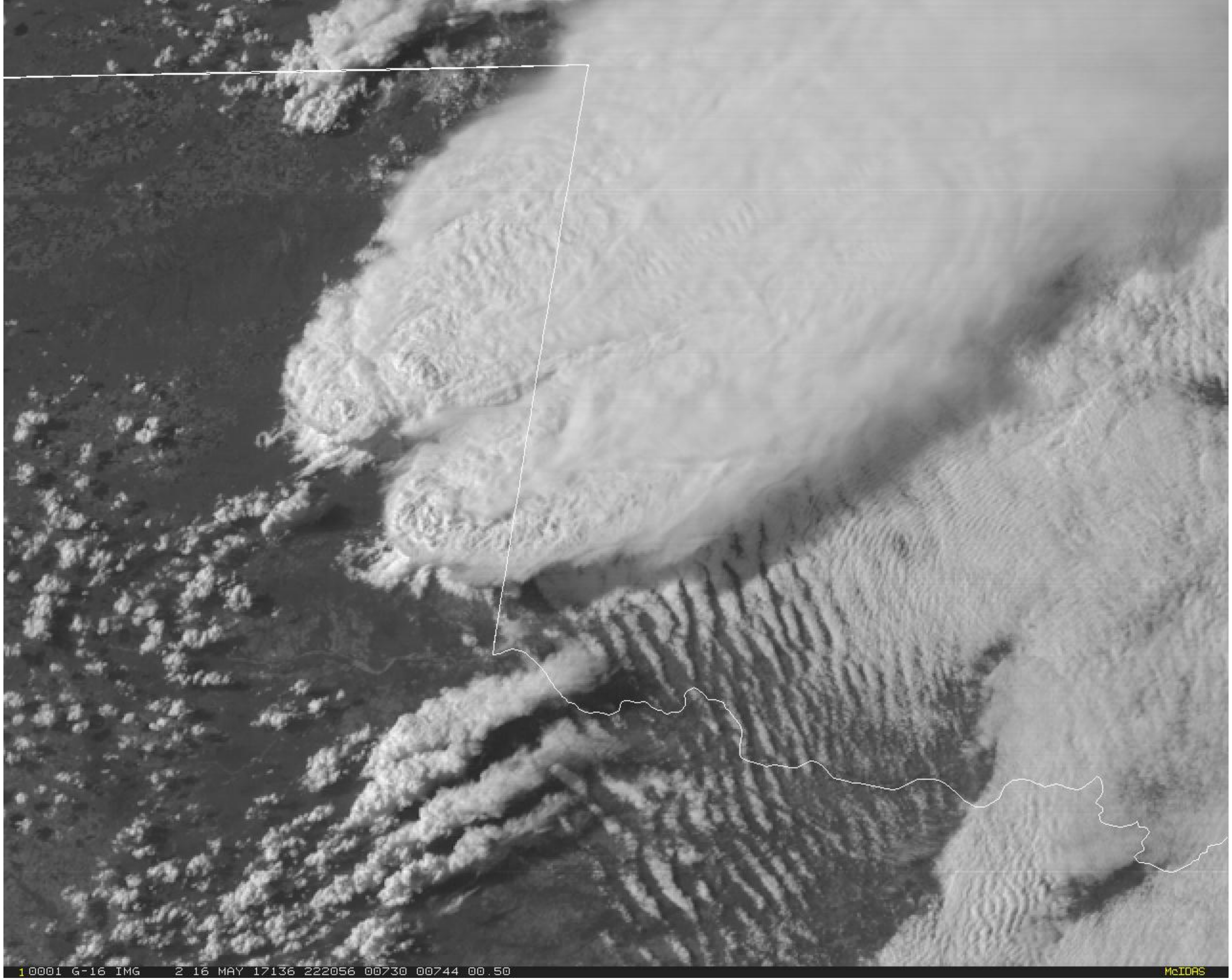
Organized circulation Vorticity – On the local scale

- Convergence on preexisting vorticity
- Tilting of vorticity from one plane to another
- Advection from one place to another
- Differential heating (does not require pre-existing vorticity)
- Friction

Two things to note in this animation.

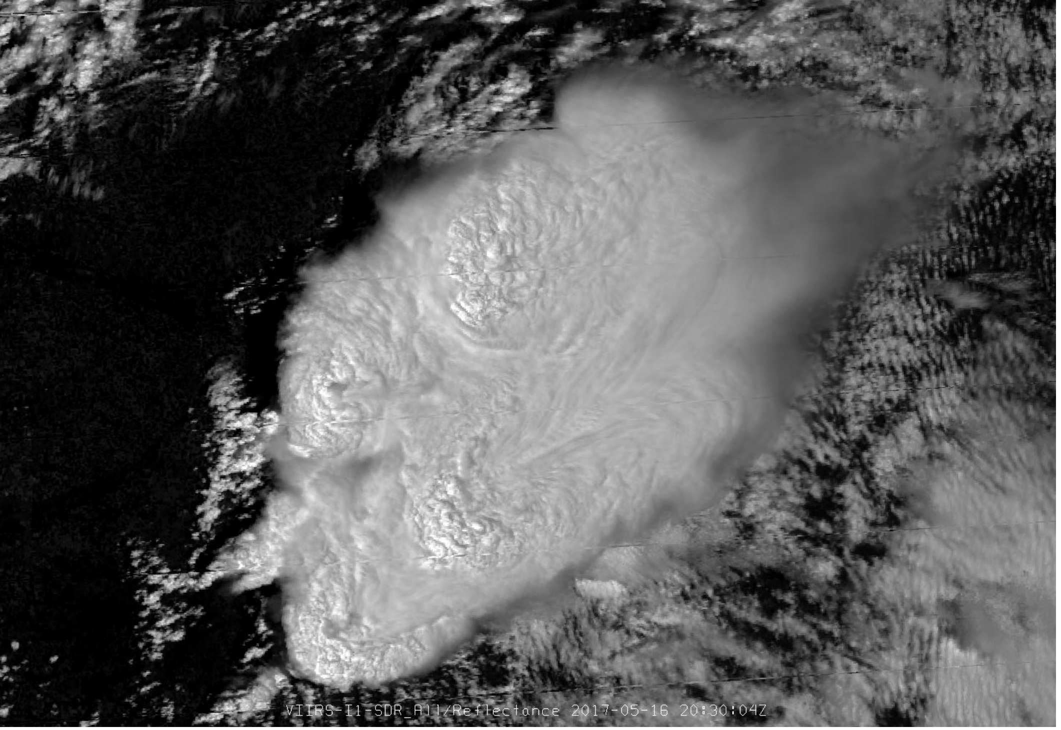
1) The cloud streets moving Northward in the loop appear to be almost rolling, which actually is a reflection of shear across that stably capped cloud street layer (water clouds).
2) Inspect of the North most storm at the beginning of the animation: as it evolves the cloud streets can be seen being “tilted” upward into the storm due to increasing vertical motion and buoyancy.

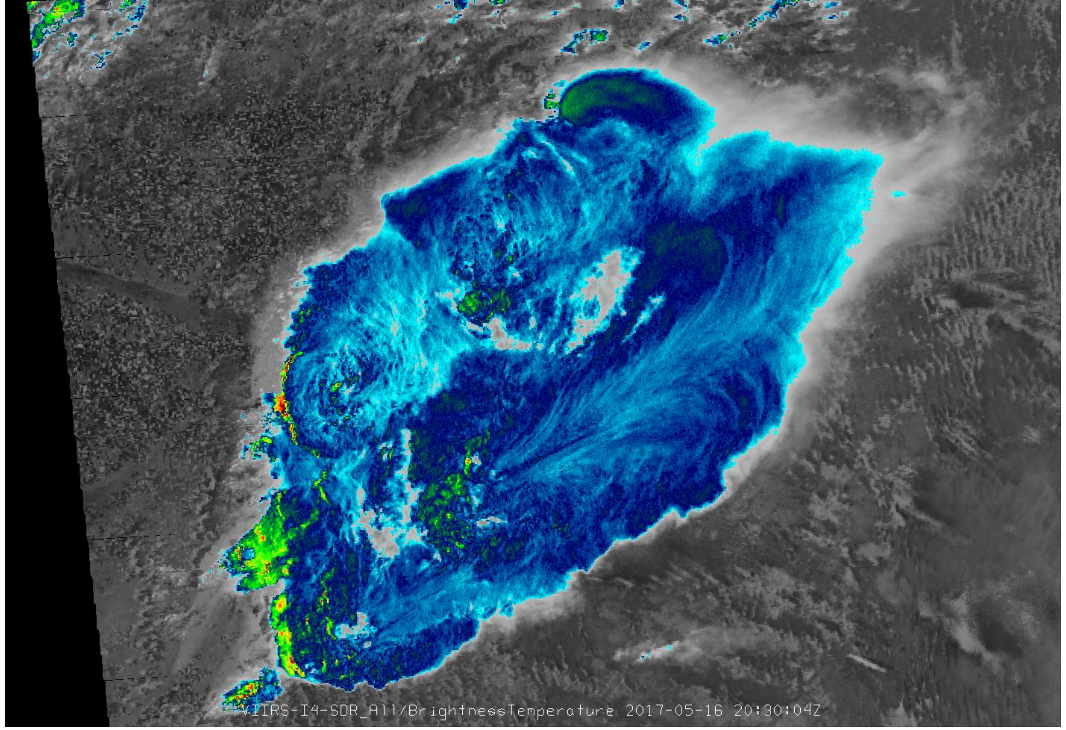
$$\left(\frac{\partial w}{\partial y}\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right)$$

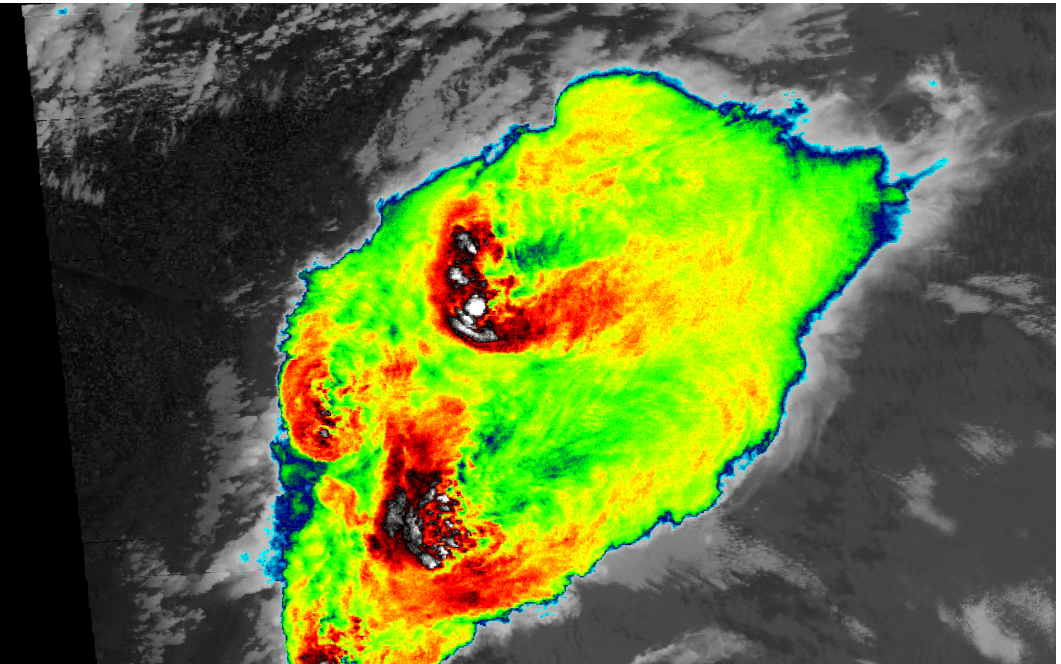


One minute interval visible loop illustrating that In organized strong convection the tilting of vorticity from one plane into another can have a dramatic effect on a thunderstorm’s development and severity.

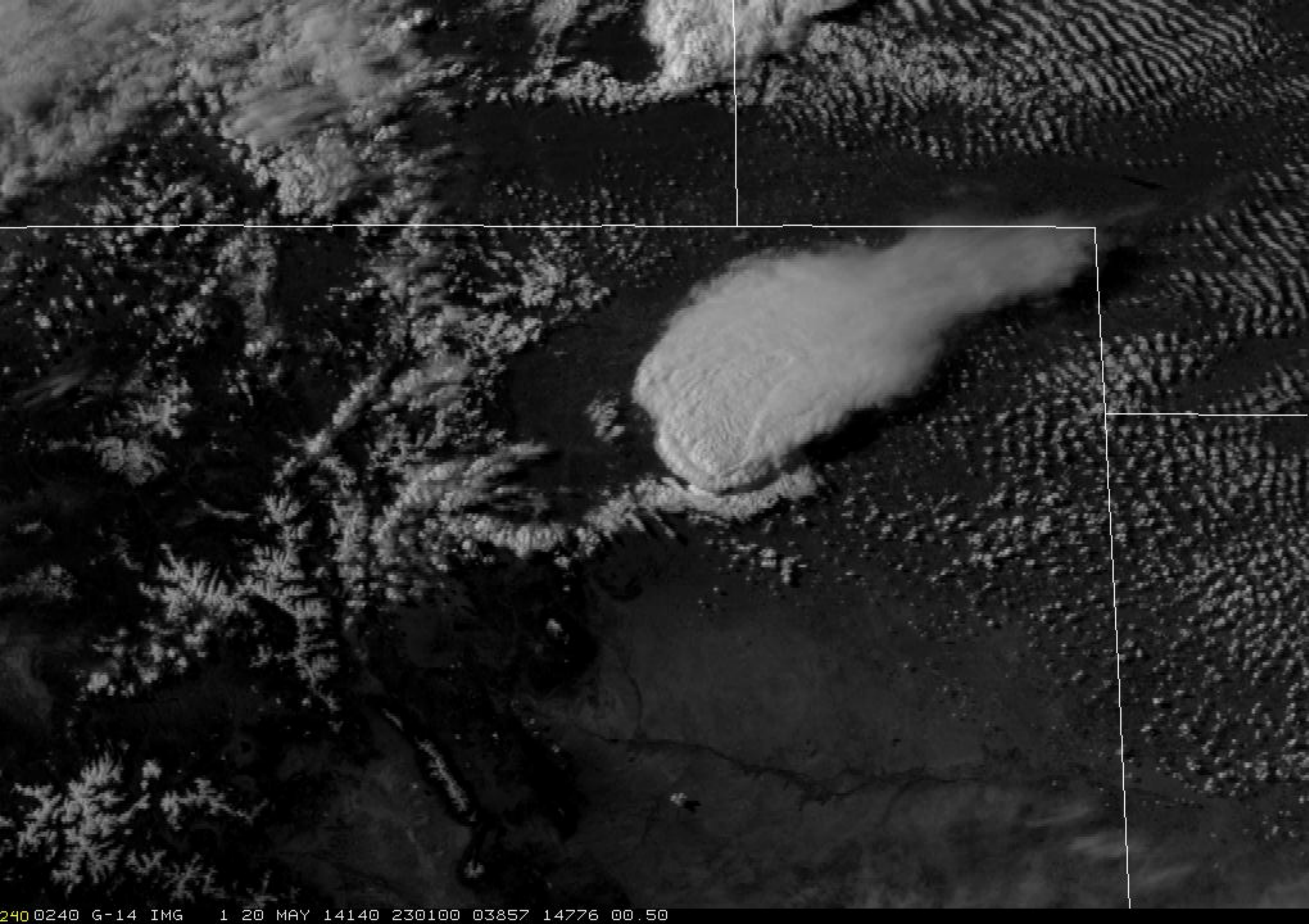
Notice the smooth plumes that are downwind from the overshooting top area.



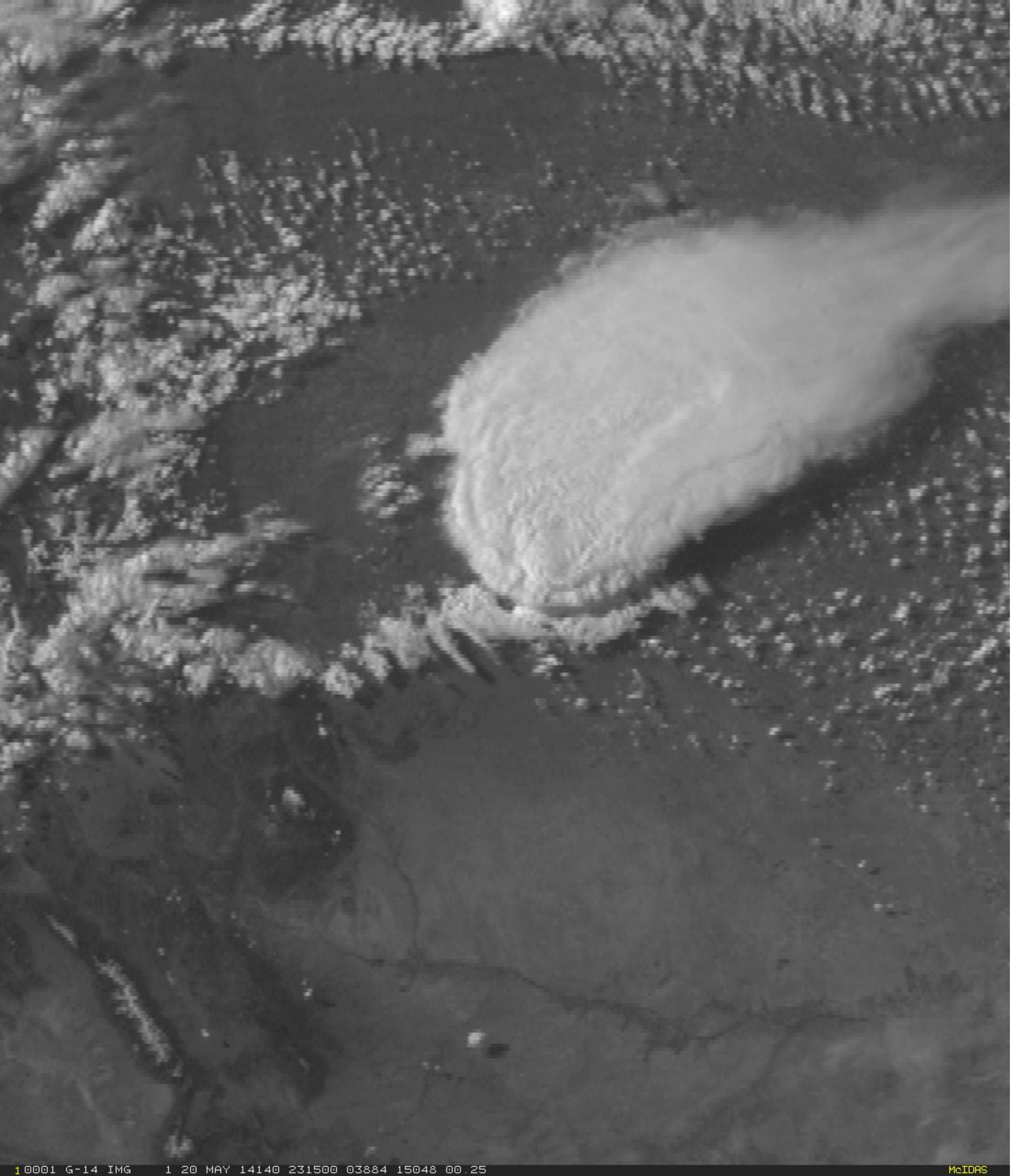




VIIRS Visible (top left) enhanced 3.9 micron (top right) and enhanced 10.3 micron (bottom left). These images are a few hours prior to the animations shown above, but note the characteristics of the downwind above anvil plume from the overshooting top area which is distinctly colder (white regions enclosed within black and red areas). Note the plume area in this example is warmer (green in 10.3 micro) and brighter (blueish white in 3.9 micon).

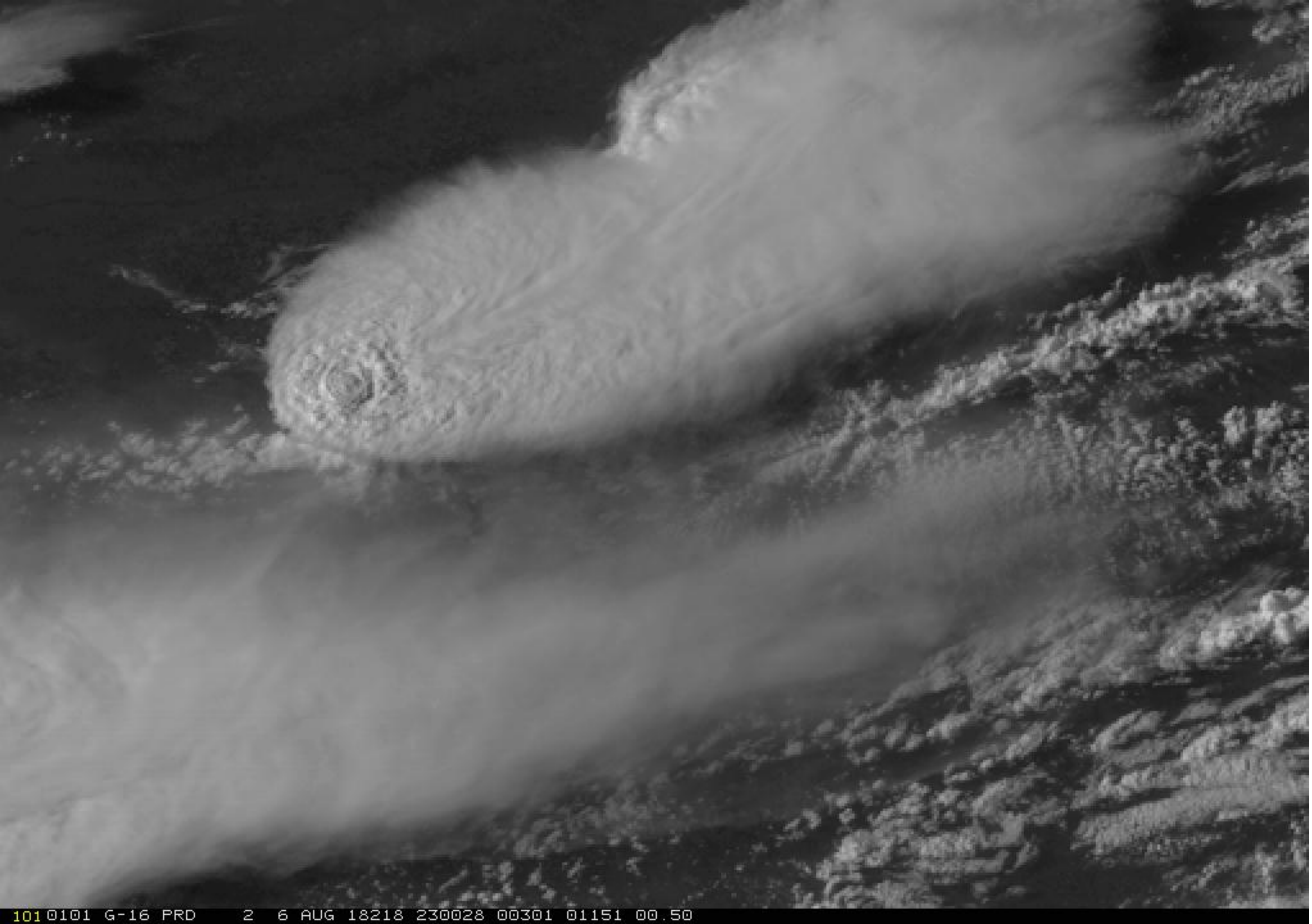


One minute interval animation of severe storm over Northeast Colorado on the afternoon of May 20, 2014. The loop period is about one hour. Notice the smooth plumes extending downwind from the storm overshooting top area.



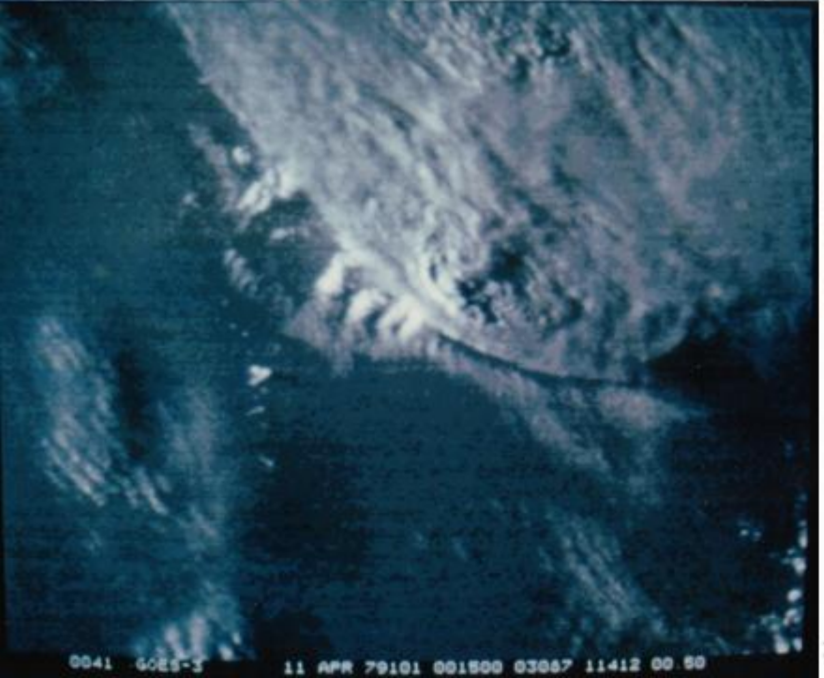
Zoom in of 20 May 2014 storm with about a 20 minute animation and in a storm relative mode (storm overshooting dome is center point of movie (notice how the ground moves, not the storm allowing you to study storm top behavior in greater detail)).

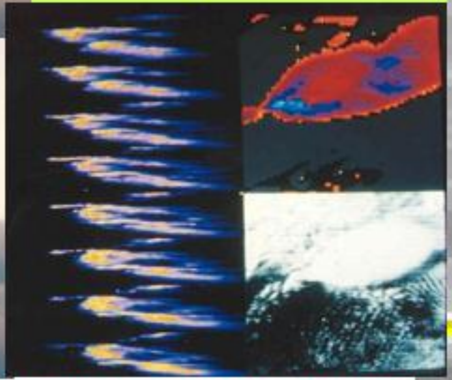
Of note here are the small waves downwind of the anvil that are in the apparent plume generation region as well as the domes apparent pushing back against the ambient flow with anvil cirrus going around the dome on either side of it.

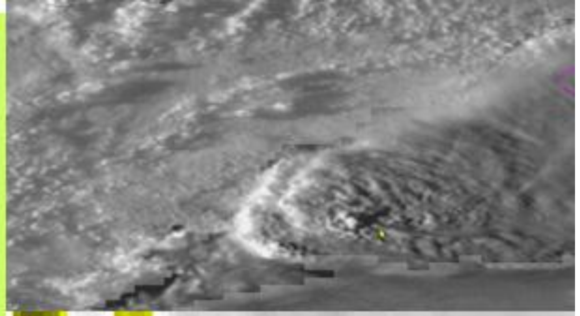


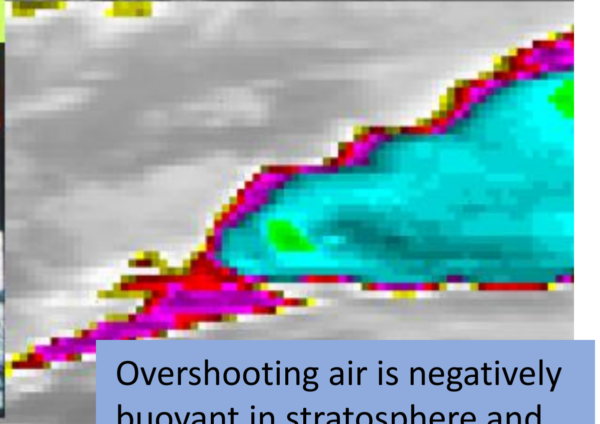
500 meter GOES-17 visible channel imagery at 500 meter resolution and 6.7 second interval between images. Animation is for one hour late in the afternoon. The complexities of the flow associated with the dome reveal that much of the cirrus diverting around the dome are part of the dome itself, a living updraft region. The cirrus plume is being continuously generated “behind the dome”, note the pulsing in its generation region. At times during the movie wave clouds are visible beneath the plume.

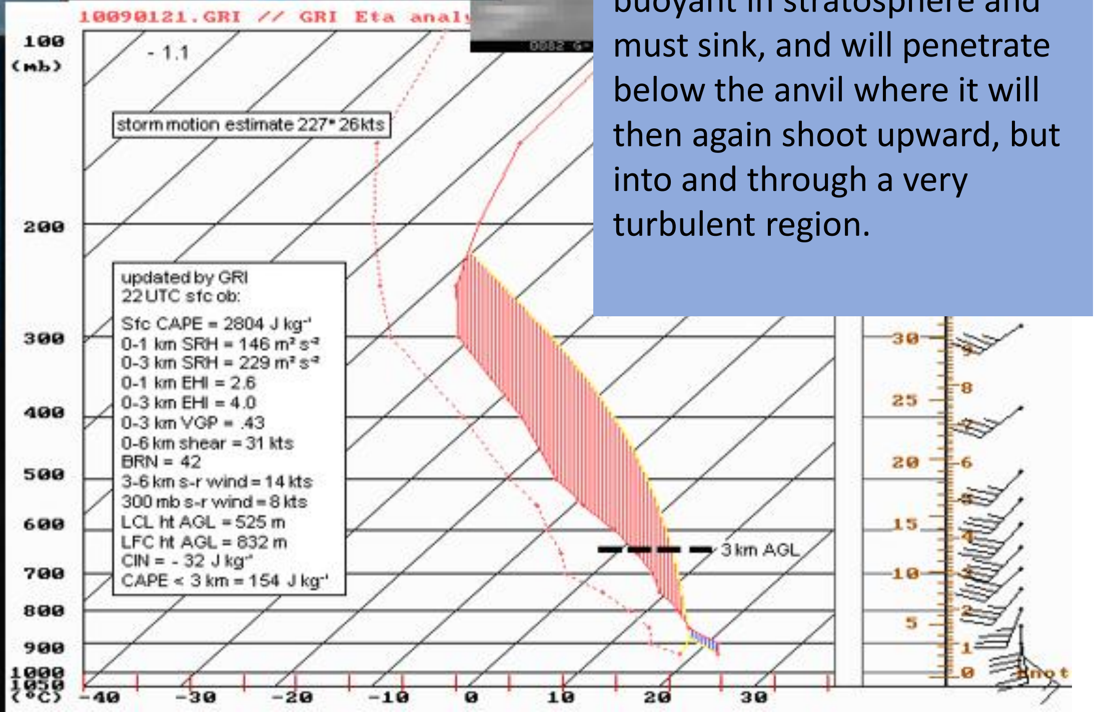
Storm cloud top structure as a proxy for severe weather and heavy rainfall











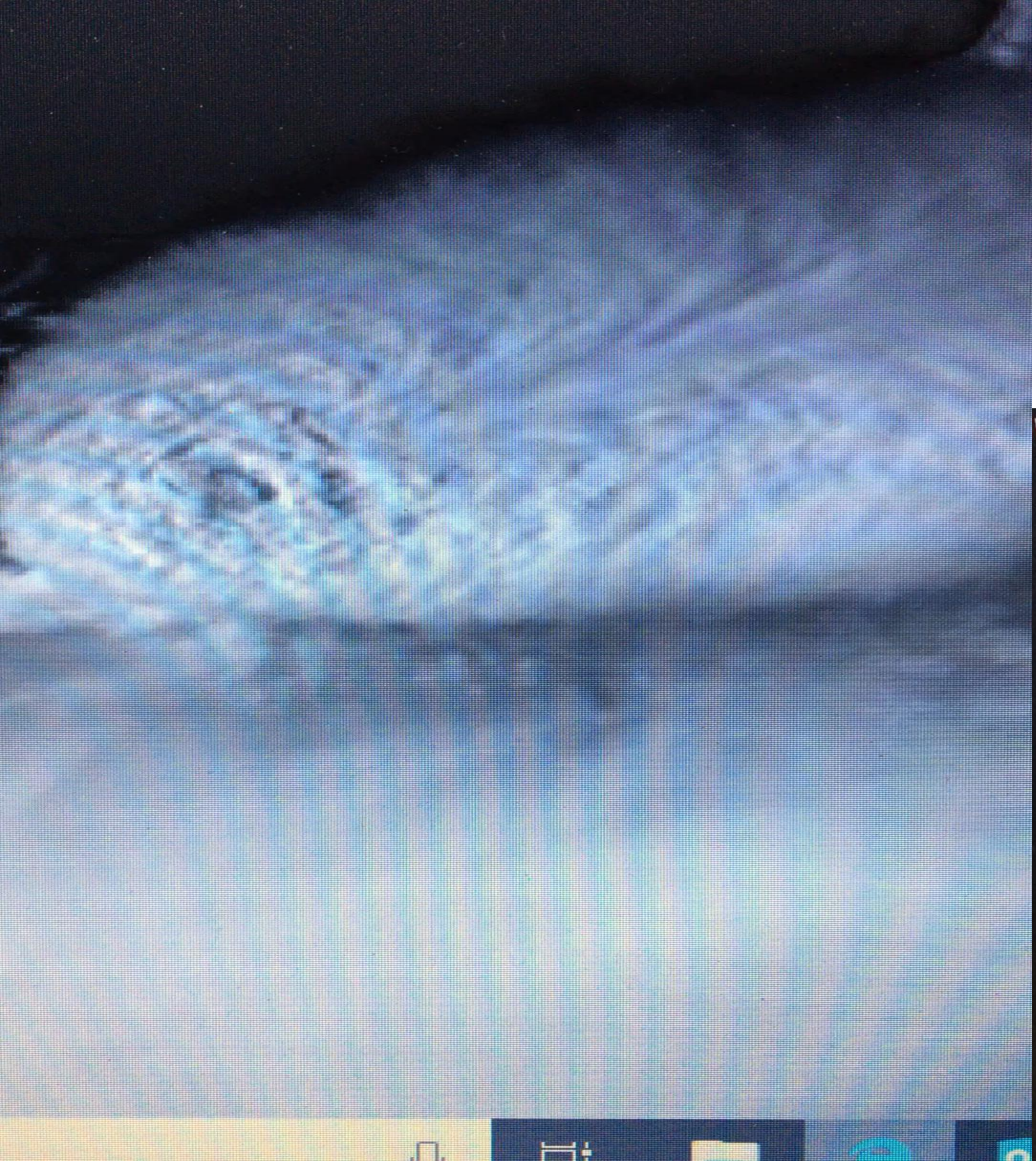
storm motion estimate 227° 26kts

updated by GRI
22UTC sfc ob:

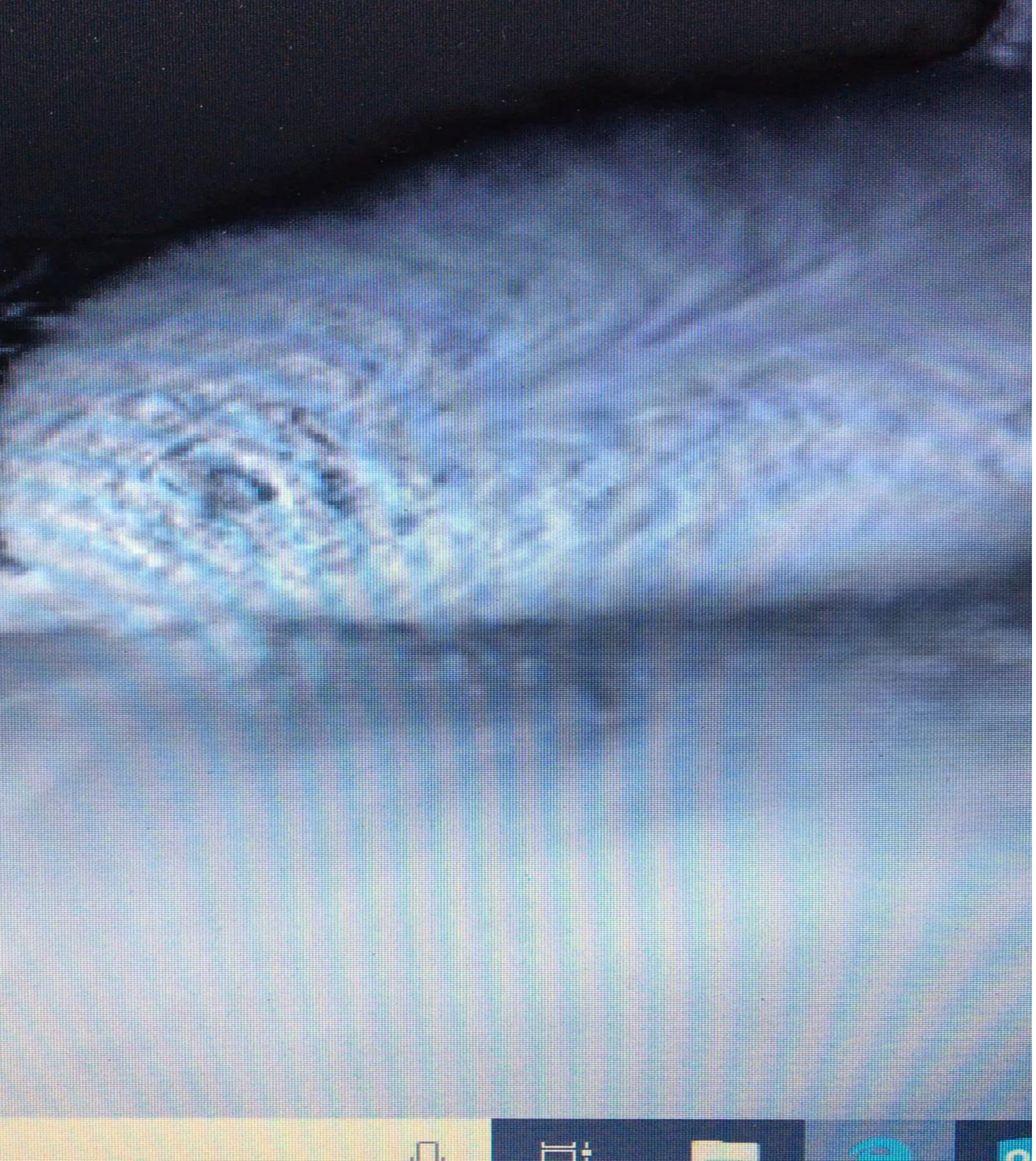
Sfc CAPE = 2804 J kg^{-1}
0-1 km SRH = 146 m^2 s^{-2}
0-3 km SRH = 229 m^2 s^{-2}
0-1 km EHI = 2.6
0-3 km EHI = 4.0
0-3 km VGP = .43
0-6 km shear = 31 kts
BRN = 42
3-6 km s-r wind = 14 kts
300 mb s-r wind = 8 kts
LCL ht AGL = 525 m
LFC ht AGL = 832 m
CIN = - 32 J kg^{-1}
CAPE < 3 km = 154 J kg^{-1}

Overshooting air is negatively buoyant in stratosphere and must sink, and will penetrate below the anvil where it will then again shoot upward, but into and through a very turbulent region.

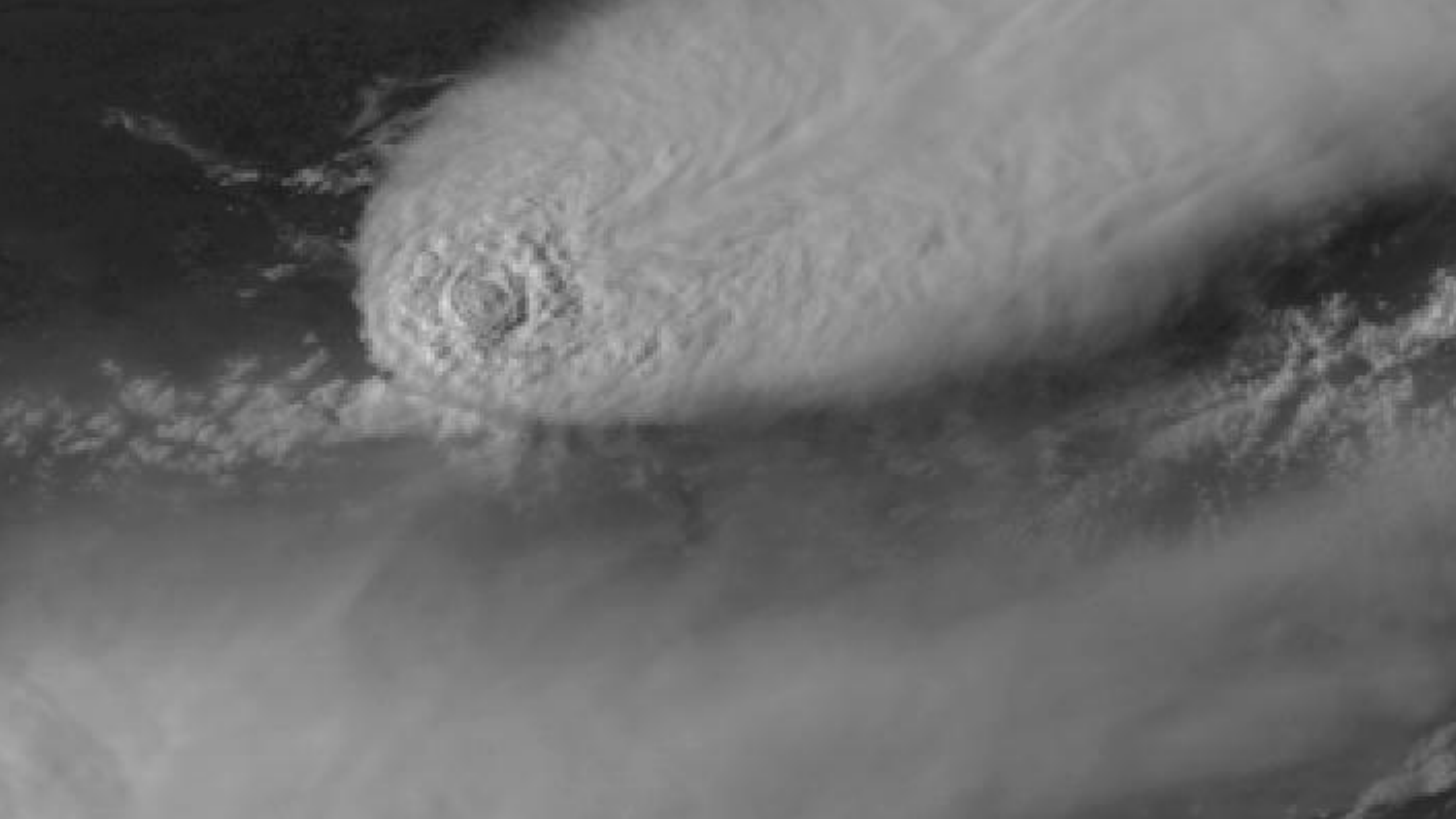
We've been looking at this storm top structure (smooth cirrus downwind from anvil, many times a difference in anvil temperature often called a "v notch" with colder anvil top along the legs of the "v notch" with warmer downstream from the overshooting top, and that is very very (almost always) associated with a severe storm (hail, tornadoes or damaging wind). The question has been why the downstream, near continuous smooth cirrus plume above the anvil (which is many times warmer (but will depend on the tropopause structure)). It's associated with a continuous intense updraft that penetrates into the stratosphere, that doesn't collapse but rather interacts with environment acting much like an obstacle to the ambient flow, but one with buoyancy and its own flow to take into account.

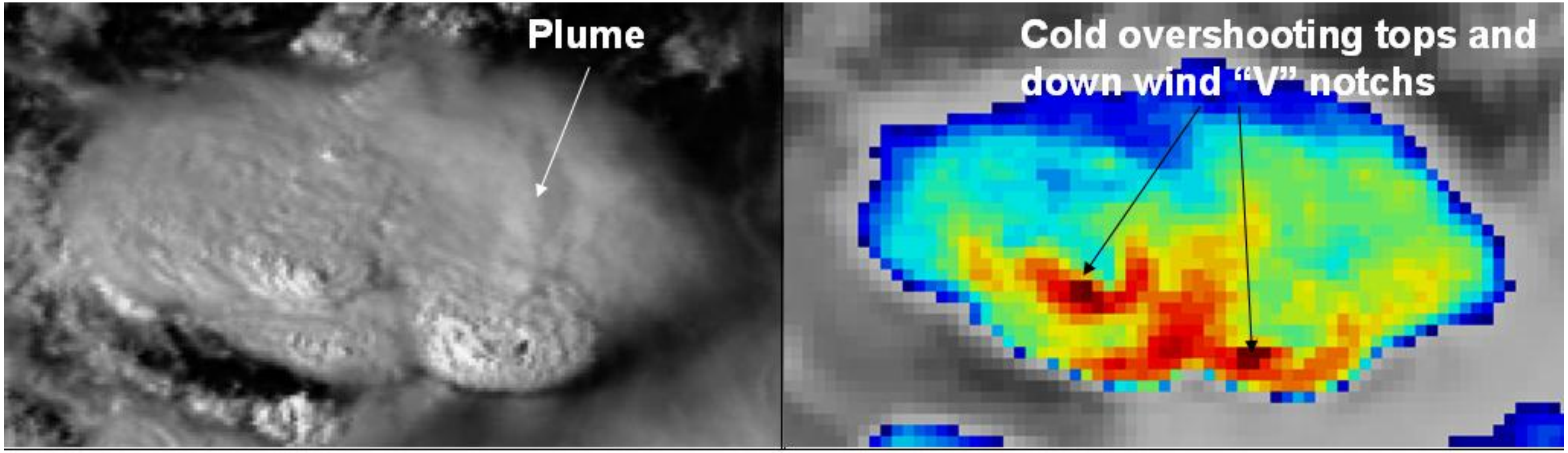


Expansion of the 6.7 second GOES-17 animation and that of a rock embedded in a stream flow. Notice the turbulent region on the downflow side of the rock. Similar, but not exactly the same things occur downstream from the overshooting top region of many severe thunderstorms, but depend on atmospheric tropopause structure and anvil level wind flow relative to the thunderstorm updraft as it penetrates into the stratosphere.



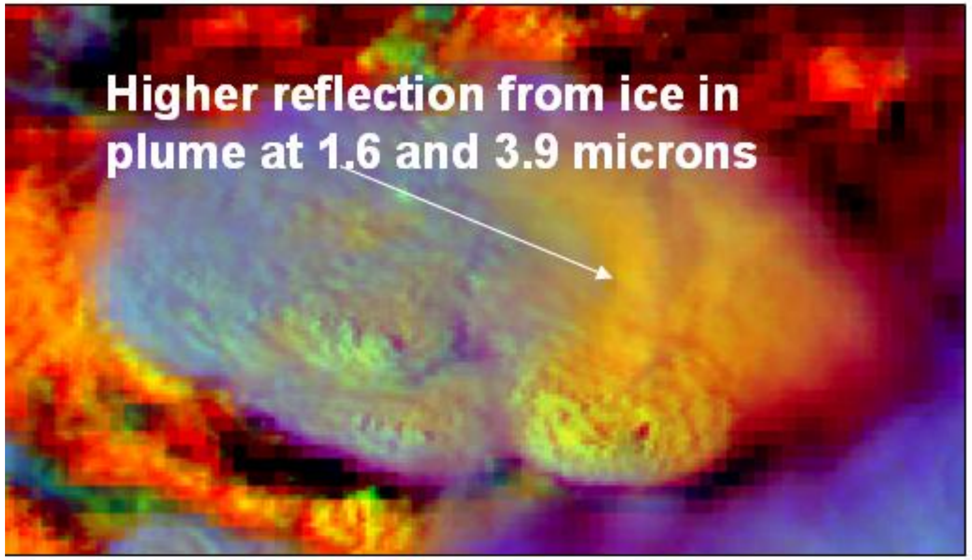
Expansion of the 6.7 second GOES-17 animation and that of a rock embedded in a stream flow. Notice the turbulent region on the downflow side of the rock. Above the turbulent structure dynamics similar to those that form the altocumulus standing lenticularis cloud form provide a mechanism that allow for the ice crystals from overshooting top which have descended into the anvil area only to become positively buoyant once again and ascend through the turbulent region. Unlike the acsl cloud (as above) the mechanism id fed with small ice crystals which are long lived.





MSG High Resolution Visible (HRV)

MSG Enhanced 10.7 micron IR



MSG 3 channel color image using HRV, 1.6 and 3.9 micron channel data

Figure 27: Thunderstorm tops over Europe from MSG on 29 July 2005 at 14:30 UTC. This case, presented by Martin Sevtak at the EUMETSAT Users’ Conference showed higher reflection from ice in the plume at thunderstorm top in 1.6 and 3.9 microns, likely due to smaller cloud particle size and related to updraft characteristics. Cold over-shooting top and “V” notches are clearly shown in the 10.7 channel image, as are the plume brighter reflection from the right-most storm.

So, what of our new capabilities with these new satellites? A confirmation of some old with some new insights.

- Vorticity on the local scale is of exceptional importance in the organization, development and evolution of deep convection from differential heating mechanisms as land/sea breezes to more complicated interactions related to the development of thunderstorm outflow boundaries and those boundaries interactions with local cumulus and clear regions.
- In organized strong convection the tilting of vorticity from one plane into another can have a dramatic effect on a thunderstorm’s development and severity.
- Well defined above anvil plumes downwind from a thunderstorm’s overshooting top are an indicator of a long lived “supercell” type storm. They are similar to an altocumulus standing lenticularis cloud (acsl) mechanism mechanism wise, but also reflect the result of the storm’s continuous updraft characteristics coupled with strong turbulence and mixing downwind of the overshooting area. Unlike the acsl, this cloud is composed of ice crystals which do not evaporate in the “trough” of the wave generation mechanism, That the plume can extend for long distances and its continuous nature speaks to the longevity of its generating mechanisms; a

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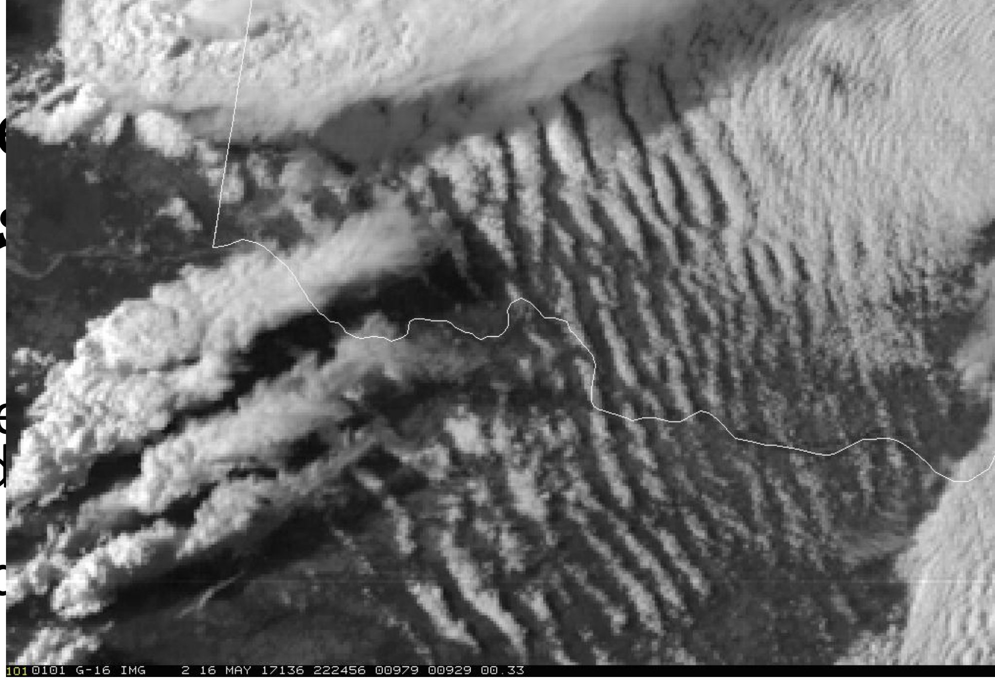
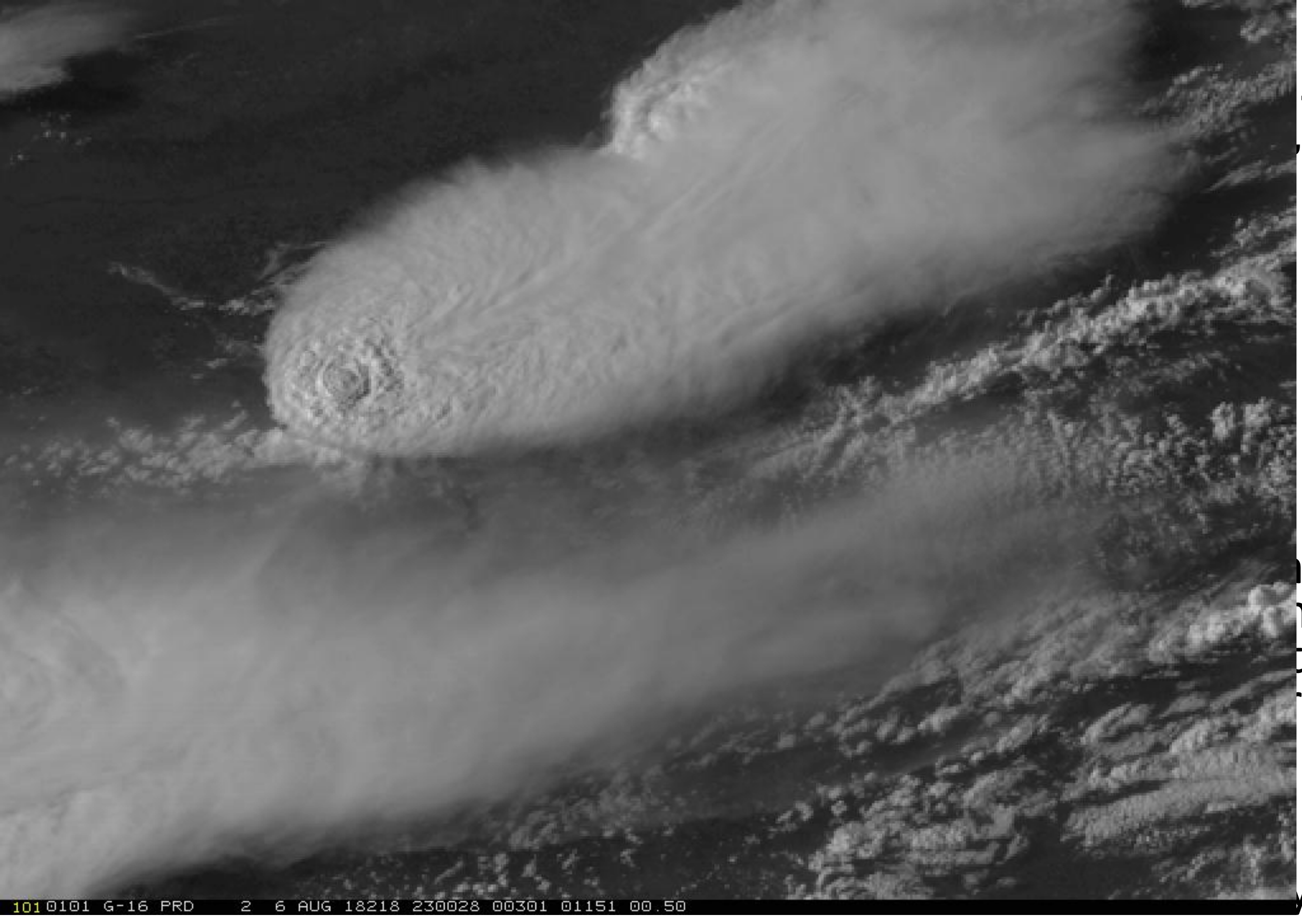


- Vorticity on the local scale is of exceptional importance development and evolution of deep convection from d mechanisms as land/sea breezes to more complicated development of thunderstorm outflow boundaries an interactions with local cumulus and clear regions.

- In organized strong convection the tilting of vorticity from one plane into another can have a dramatic effect on a thunderstorm’s development and severity.
- Well defined above anvil plumes downwind from a thunderstorm’s overshooting top are an indicator of a long lived “supercell” type storm. They are likely the result of the storm’s continuous updraft characteristics coupled with strong turbulence and mixing downwind of the overshooting area. That the plume can extend for long distances as a continuous plume speaks to the longevity of its generating mechanisms.



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- Well defined above anvil plumes downwind from a thunderstorm’s overshooting top are an indicator of a long lived “supercell” type storm. They are likely the result of the storm’s continuous updraft characteristics coupled with strong turbulence and mixing downwind of the overshooting area. That the plume can extend for long distances as a continuous plume speaks to the longevity of its generating mechanisms. Upwind the storm’s continuous updraft spreads out into the flow causing blocking as in normal flow around an obstacle (local high pressure and diversion around the updraft region) while downwind it adds its velocity to the ambient flow causing a lowering of pressure as it sinks beneath the anvil only to reemerge into an exceptionally turbulent region where it mixes with that cloudy air and again overshoots providing a source of smaller ice particles (likely in part due to collision with ice particles within the turbulent region) in the stratosphere where a downstream cloud generation mechanism similar to that for altocumulus standing lenticularis awaits their arrival.