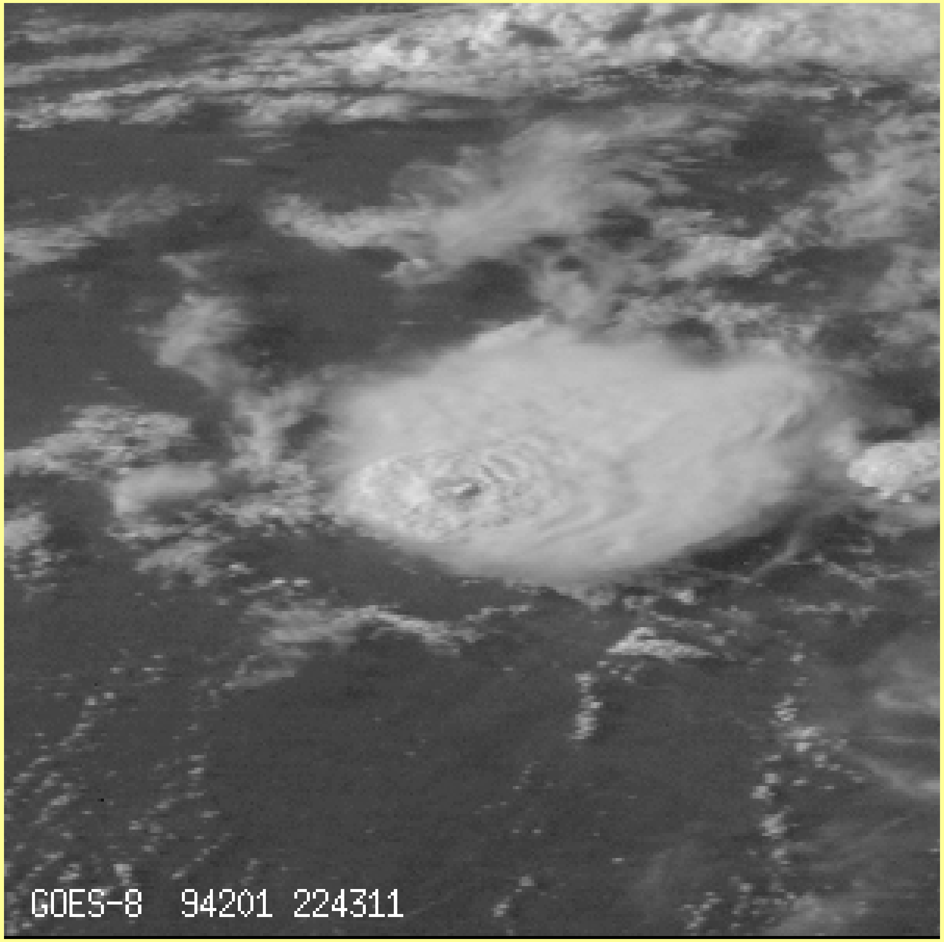
The development and evolution of deep convection and heavy rainfall

Unique in spectra, space and time

The spatial and temporal domains of the phenomena being investigated drive the satellite's spectral needs as a function of space, time, and signal to noise. Nowcasting convection requires frequent imaging and sounding that can only be provided by geostationary satellites.



Focus

- Major focus of this lecture is understanding the organization, development and evolution of deep convection – topics addressed progress from air-mass to severe thunderstorms
  - For detailed information on hurricanes and tropical storms see the lectures in the tutorials portion of the Virtual Resource Library
- At the end there is a section on rainfall
  - For in depth information concerning rainfall see the lectures in the tutorials portion of the Virtual Resource Library as well as link to the International Precipitation Working Group where algorithms and science discussions are available

Goals

- **Understand conceptual models of convective development**
- **Recognize the intrinsic linking between vertical forcing and instability in convective development and evolution**
- **Recognize the underlying importance of differential heating and vorticity generation in the development and evolution of convection**
- **Recognize the importance of surface heating and the various factors that influence it in the development of instability and the atmosphere's ability to support convection**
- **Understand the importance of precipitation and storm outflow to the generating and sustaining convective development and evolution**
- **Recognize the underlying importance of boundary interaction in severe storm development and evolution**
- **Understand the interaction between the storm and its environment as that interaction influences storm lifecycle**
- **Understand the role of vorticity on the local scale in tornado development**
- **Increase the forecasters skill in incorporating satellite data in nowcasting convection and severe convective weather**

Resources

- Information from Virtual Resource Library
  - Text, several tutorials and PowerPoint lectures that together cover this topic in detail
  - Links to imagery and products from the VRL as well as Sponsor and Center of Excellence sites
- Lecture notes accompanying presentation
- Electronic version of paper "Local Severe Storm Monitoring and Prediction"
- Detection of low-level thunderstorm outflow boundaries at night
  - http://www.cira.colostate.edu/ramm/visit/lto.html

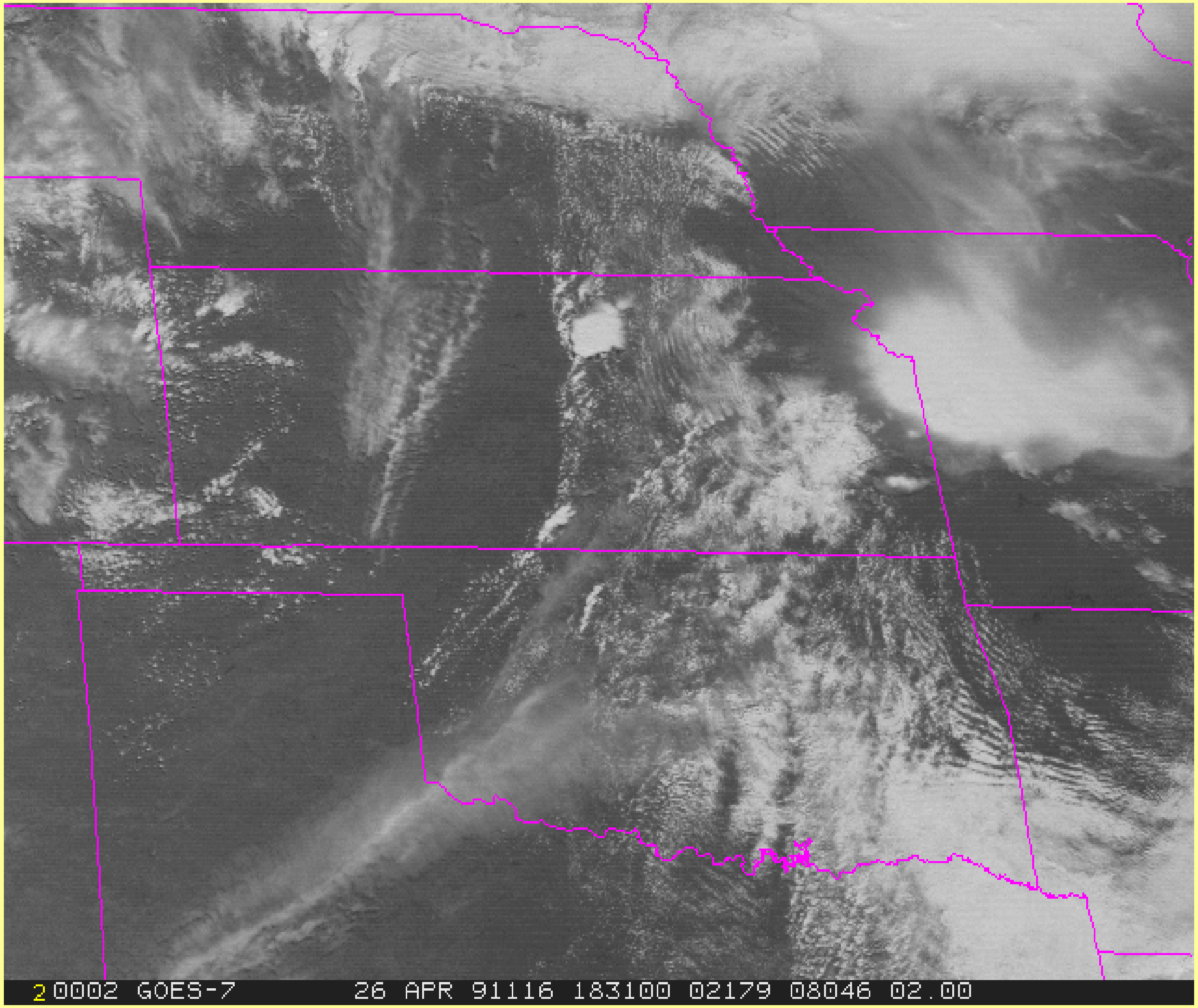
After this Lecture, examples utilizing special data sets may be used to illustrate convective development and evolution.

- In the notes section of some slides there are references to publications in the literature (see notes with this slide).

NOW ON TO MESOSCALE CONVECTIVE DEVELOPMENT AND EVOLUTION

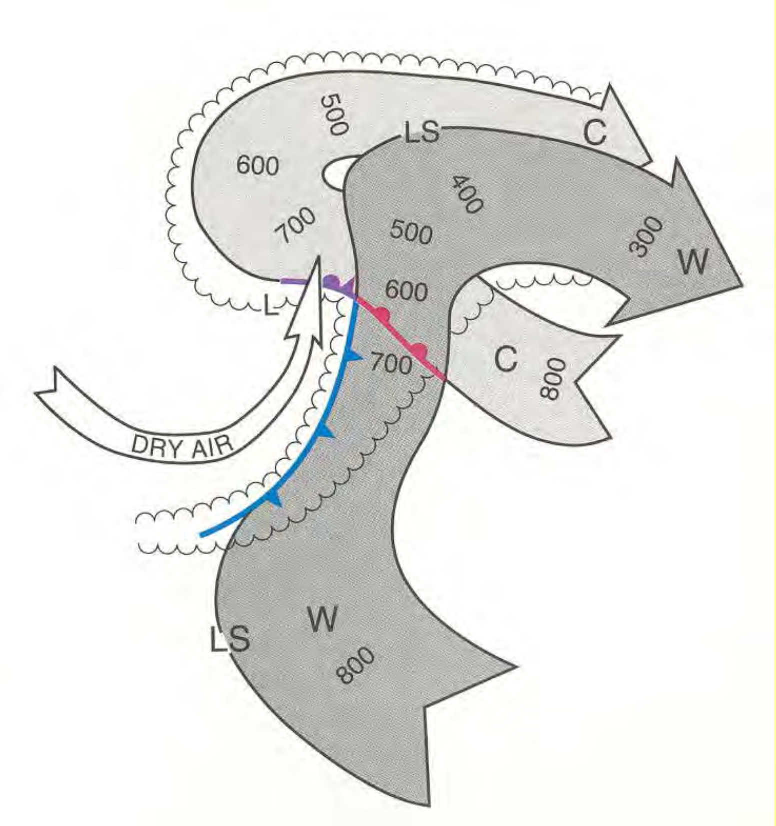
Weather, and weather related phenomena extend across a broad range of scales. In meteorology the link between the synoptic scale and the mesoscale is many times a key factor in controlling the intensity of local weather.

The only observing tool capable of monitoring weather across those scales (and those scales interactions) is the geostationary satellite!

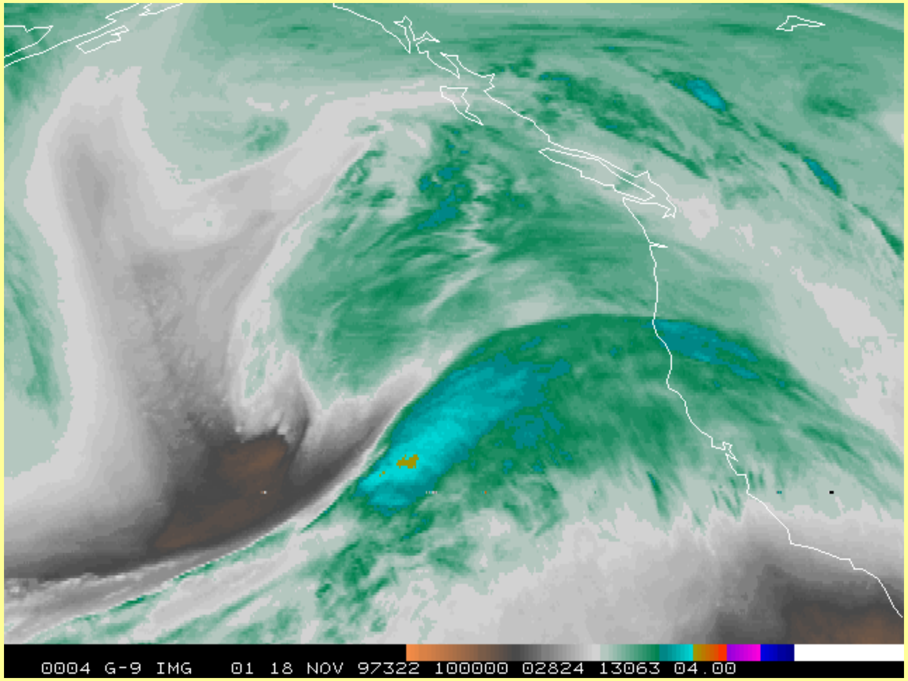


Conceptual models

- **Conceptual models are very important for satellite image analysis and nowcasting**
- **The spatial and temporal domains of the phenomena being observed influence the type conceptual model that is used.**



Conceptual model: of warm and cold conveyors (From Bader et al)

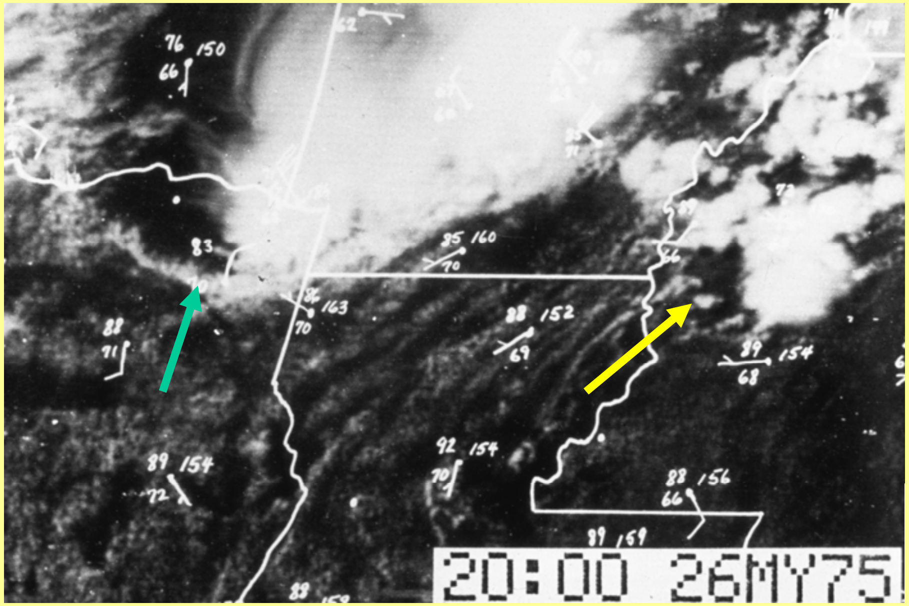


Conceptual models are useful in linking physical processes to image analysis and interpretation

The Advantage of Geostationary Satellite Imagery in Nowcasting the Development and Evolution of Convection

Prior To Geostationary Satellites, The Mesoscale Was A "Data Sparse" Region!

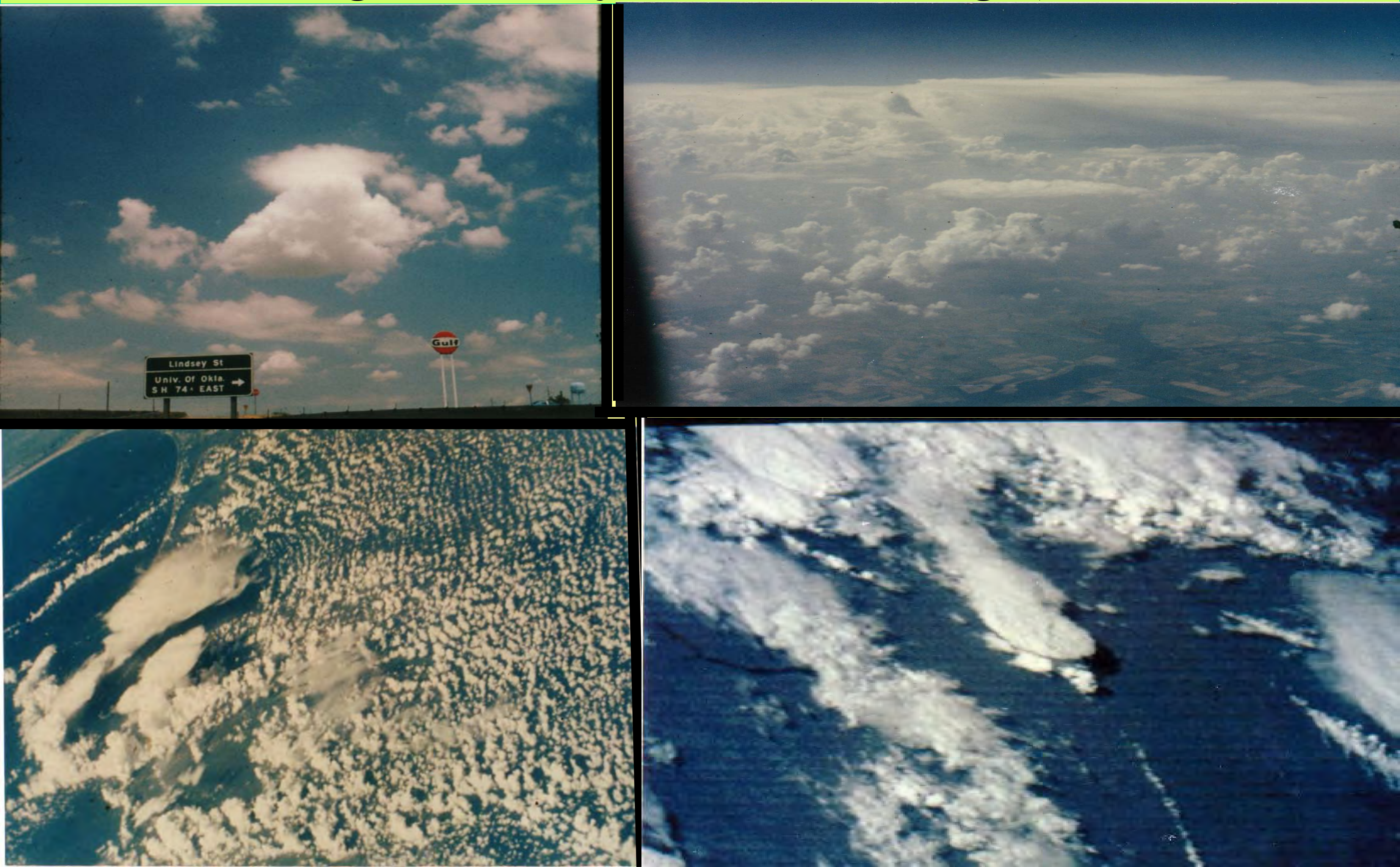
Meteorologists were forced to make inferences about mesoscale phenomena from macro-scale observations. Today's geostationary satellites provide multispectral high-resolution sounding and imagery at frequent intervals. Those data provide mesoscale meteorological information (infrequently detected by fixed observing sites) on the atmosphere's ability to support (and inhibit) deep convection..

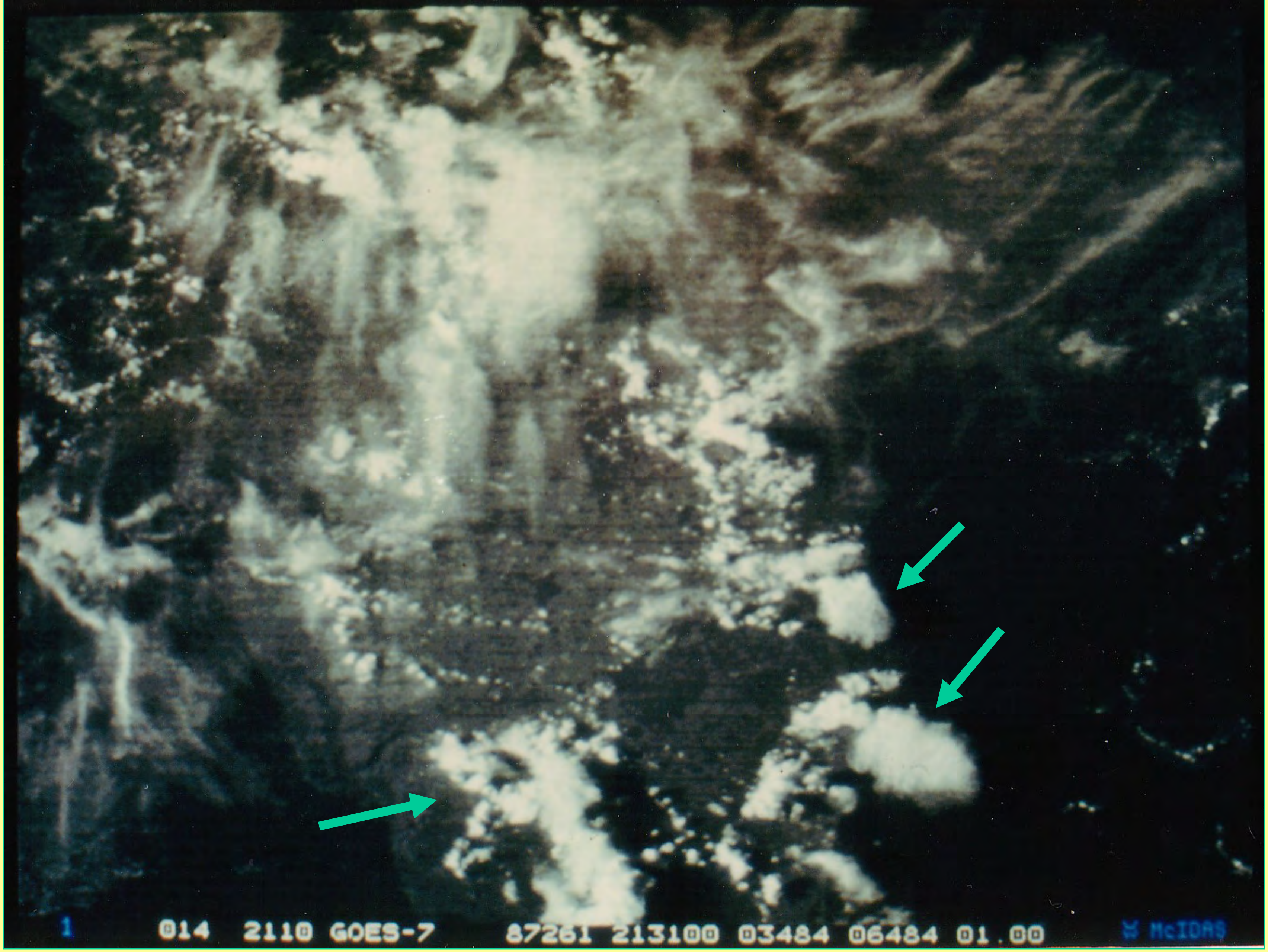


In the example above, note how difficult it is to use surface data alone to identify organized lines of convection, which in this case is a convergence boundary (see next slide)

The Advantage of Geostationary Satellite Imagery in Nowcasting the Development and Evolution of Convection

How Cloudiness viewed from different perspectives: Ground (upper left); Aircraft (upper right); Manned space (lower left); geostationary satellite (lower right)





GOES East is at 75 W above the equator. Florida is at around 85 W and 35 N.

Viewing perspective is an important consideration!!! Thunderstorms and clouds observed by GOES East over Florida. Is there active convection beneath the anvils?

GOES West is at 135 W above the equator. And has a very different view of Florida than GOES East (but a very interesting one!)

Clouds over Florida 15 minutes after the previous figure, but from GOES-West. Notice how because of viewing angle you can see the side, base and top of thunderstorms.

A Few Words About Low Level Water Vapor: The Fuel For Deep Convection

- **Numerical simulations and field experiments suggest that changes in mixing ratio as small at 1 g /kg have significant effects on the developing convection.**

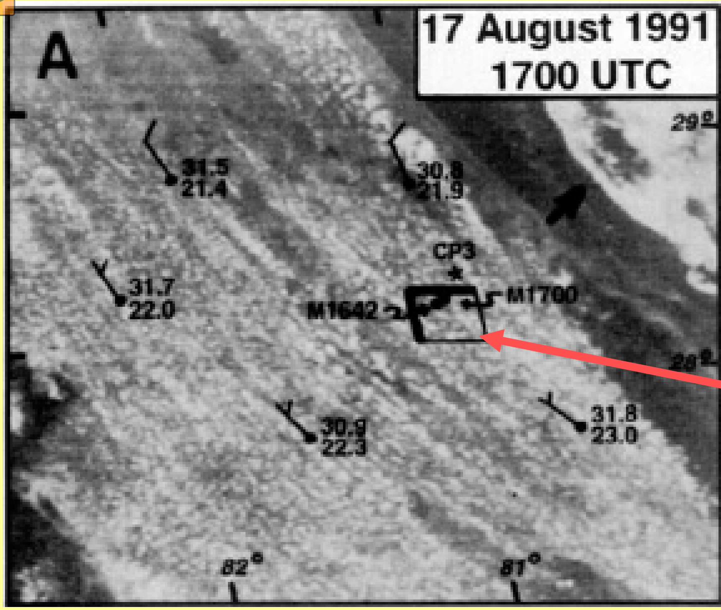
- **Water vapor is a powerful energy source: 1 gm of water vapor evaporated into 1 kg of air (a cubic meter at sea level) will raise that air’s temperature by 2.5 degrees Kelvin!**

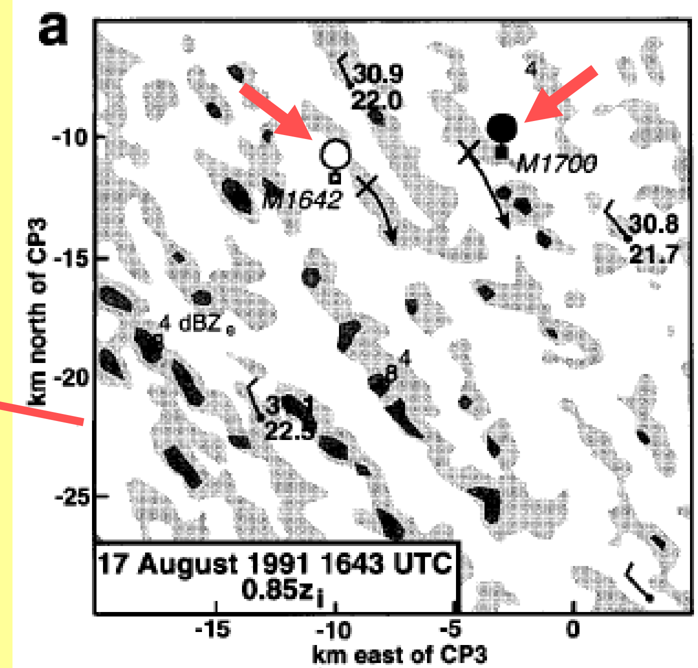
- **If a storm realizes an additional 1.6 grams of water vapor per kilogram of air into its updraft, you have the potential of doubling that storm’s energy!**

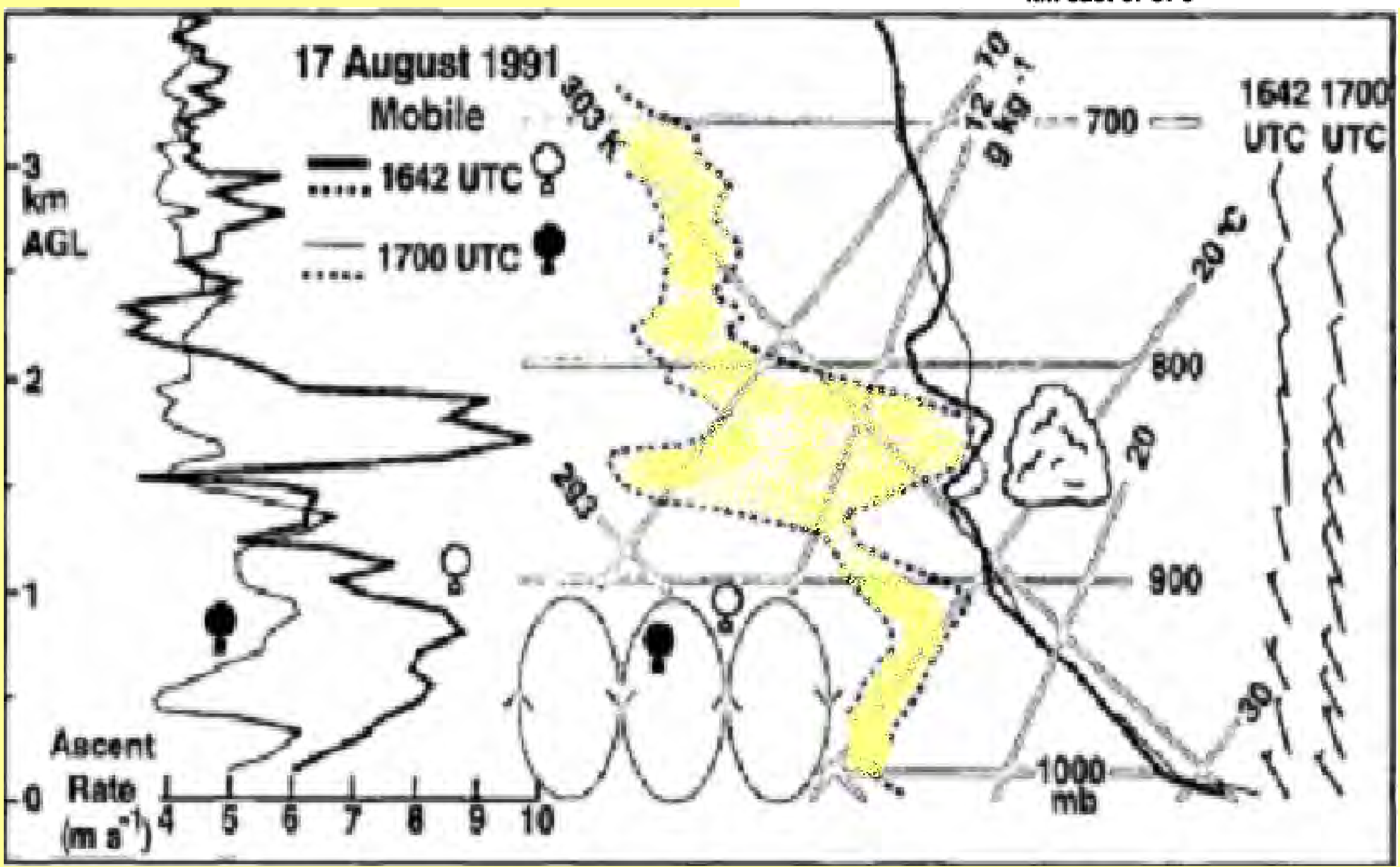
A Few Words About Low Level Water Vapor: The Fuel For Deep Convection

- **Large variations in the atmosphere's ability to support strong convection via low level moisture exists over scales of 25 km or less.**
  - **These moisture fields evolve rapidly as circulations develop and as low level moisture is advected into a region.**

- **Geostationary satellite imagery: capable of mapping at the required high temporal and spatial resolution the state and evolution of the convective environment on the scales necessary to observe it over large areas, accurately, on demand (as revealed by the organization of the cumulus field and its state of development).**







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).

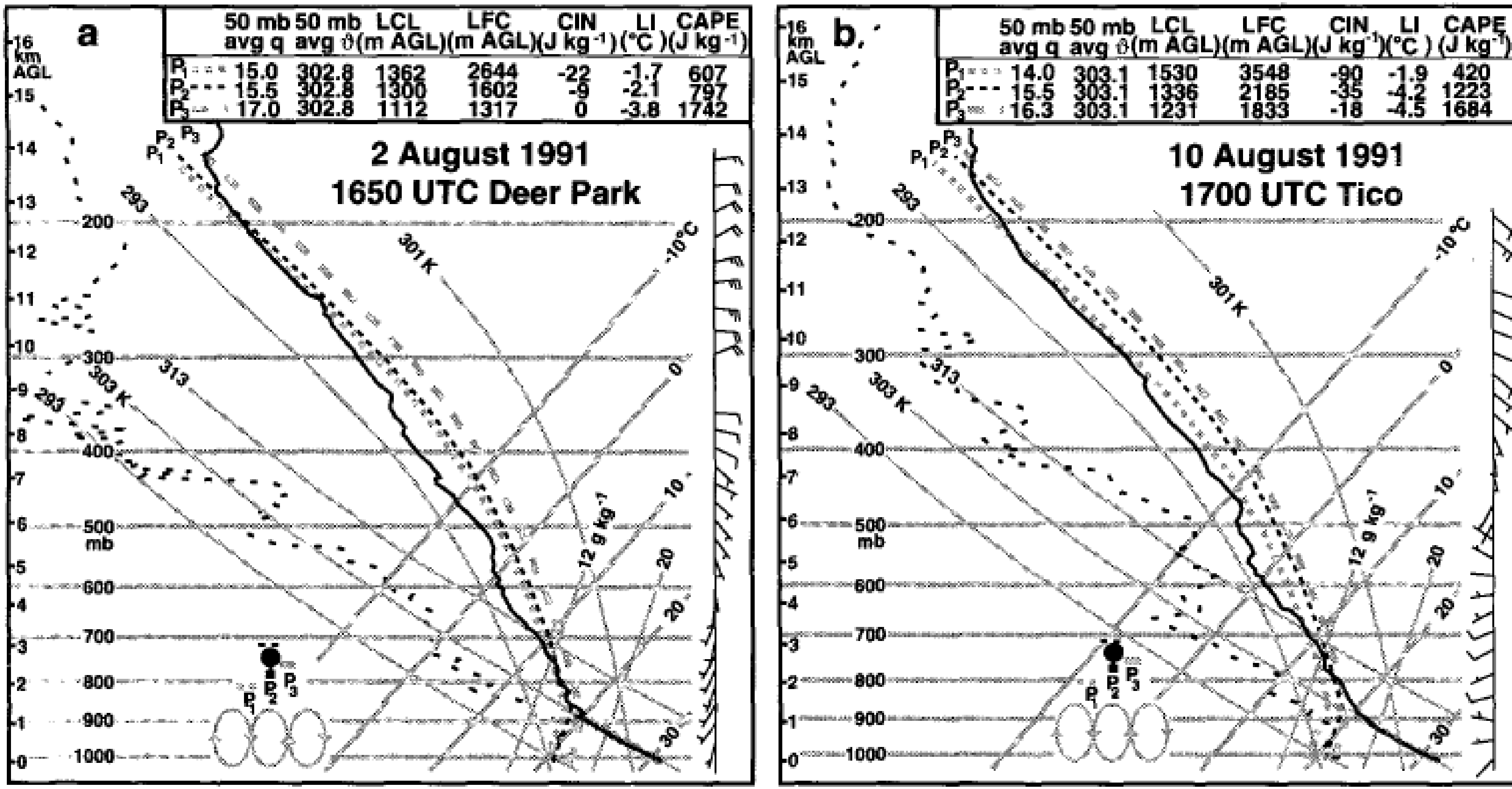
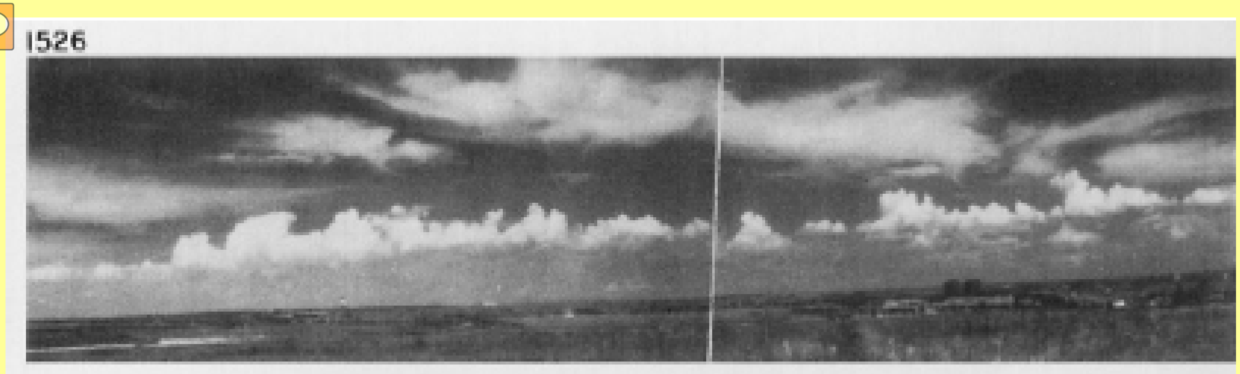


FIG. 9. Full soundings for (a) 1650 UTC 2 August of Fig. 8a and (b) 1700 UTC 10 August of Fig. 8b. Three parcel ascent tracks are shown to indicate the variations depending on low-level mixing ratio values. Parcel 1 (P_1) represents the minimum moisture measured by the aircraft, P_2 represents the parcel 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.



Illustrating the small scale & strong increase in moisture and thunderstorms formation along a convergence line (that eventually resulted in tornadoes).

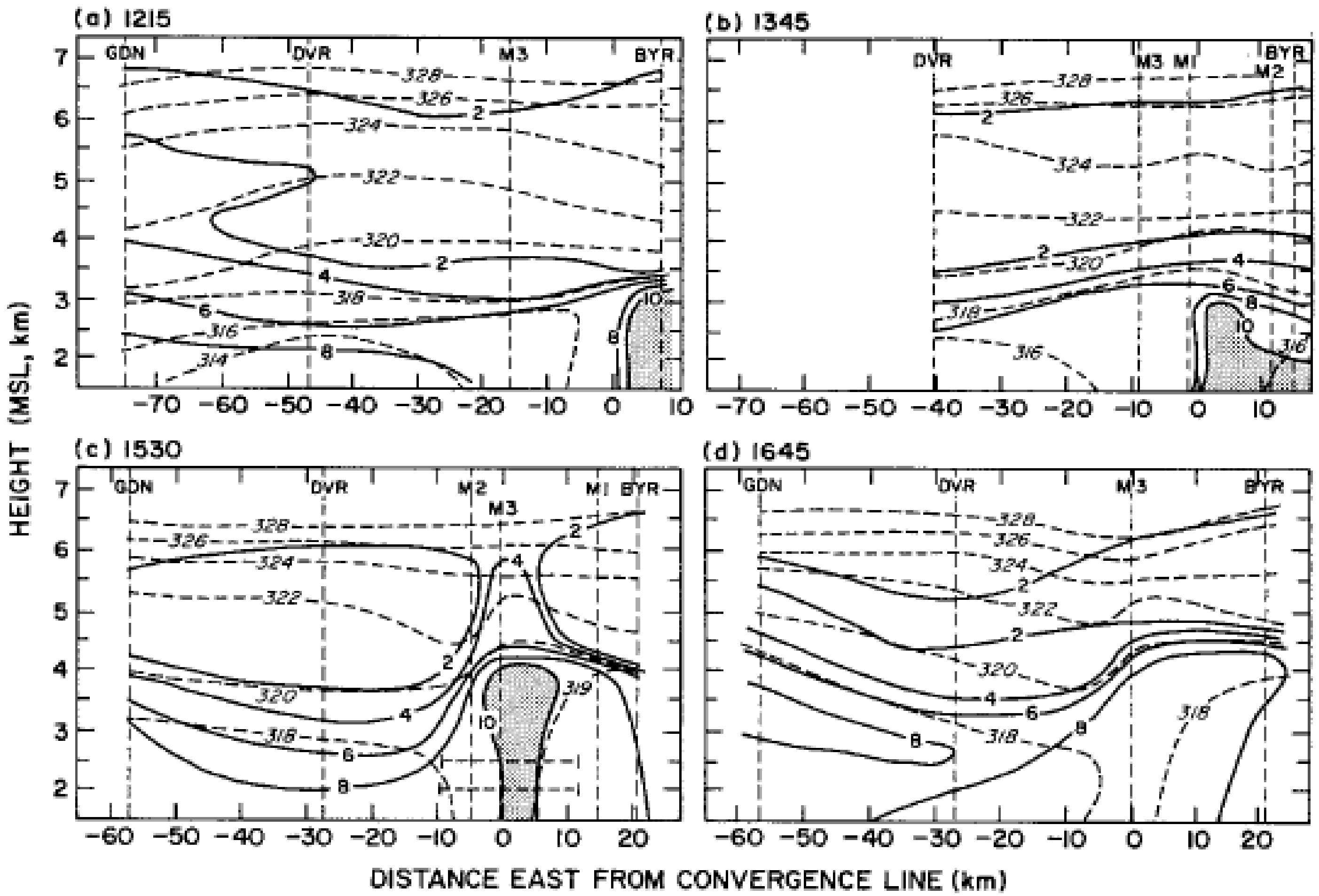
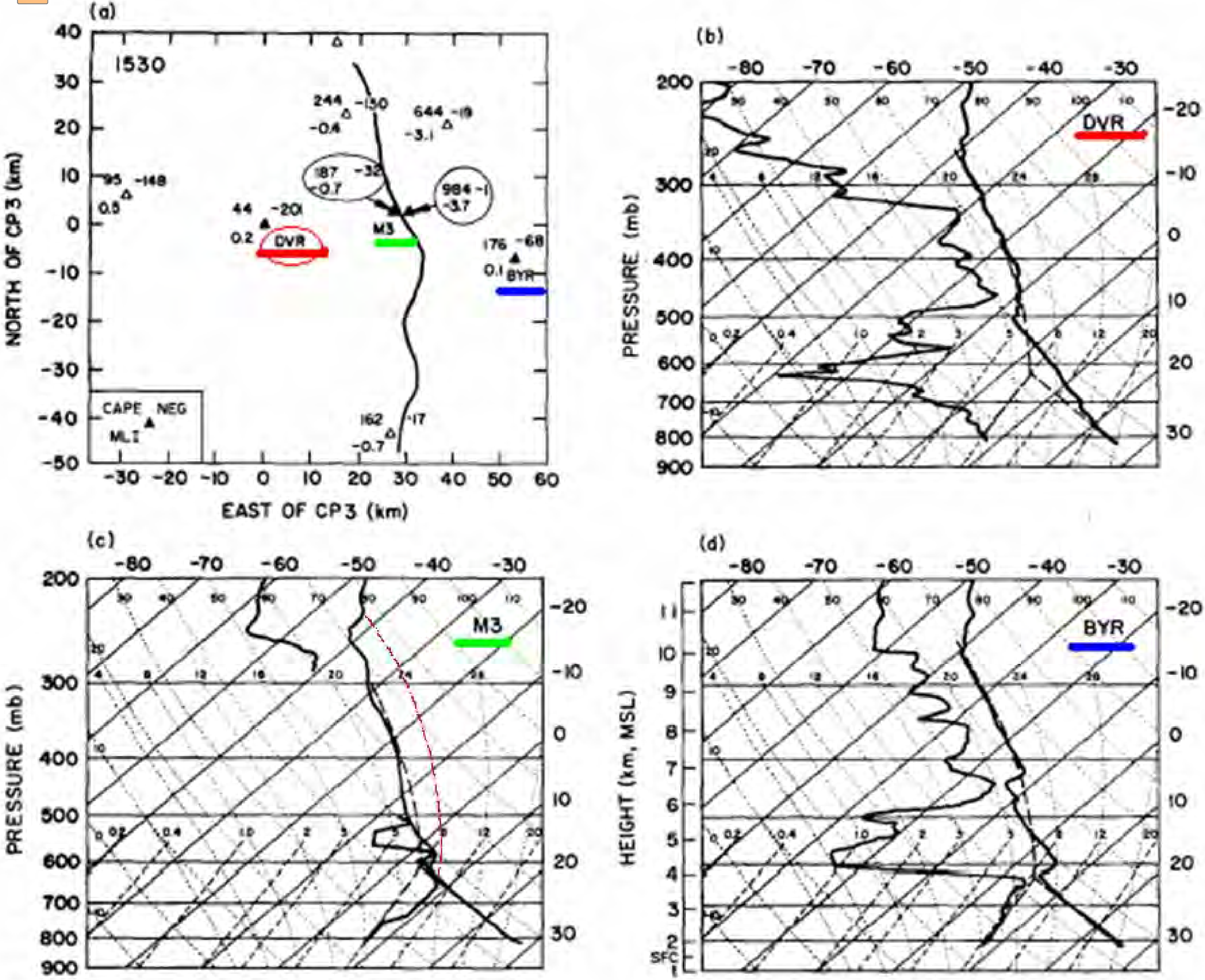


FIG. 16. East–west vertical cross section at four times showing the evolution of mixing ratio and potential temperature (K) as observed by upper-air soundings (vertical dashed lines), aircraft (horizontal dashed line), and mesonet. Shading represents mixing ratios ≥ 10 g kg^{-1}. The zero horizontal coordinate represents the location of the convergence line. The surface altitude averages ~1.6 km MSL.

Note the increase in moisture depth from 1215 Mountain Daylight Time until the convective line first becomes visible as a line of organized cumulus clouds three hours later.



Note the mesoscale variability in moisture and positive area, of particular interest is the difference between M3 below the developing convective line and BYR to its East in the warm sector

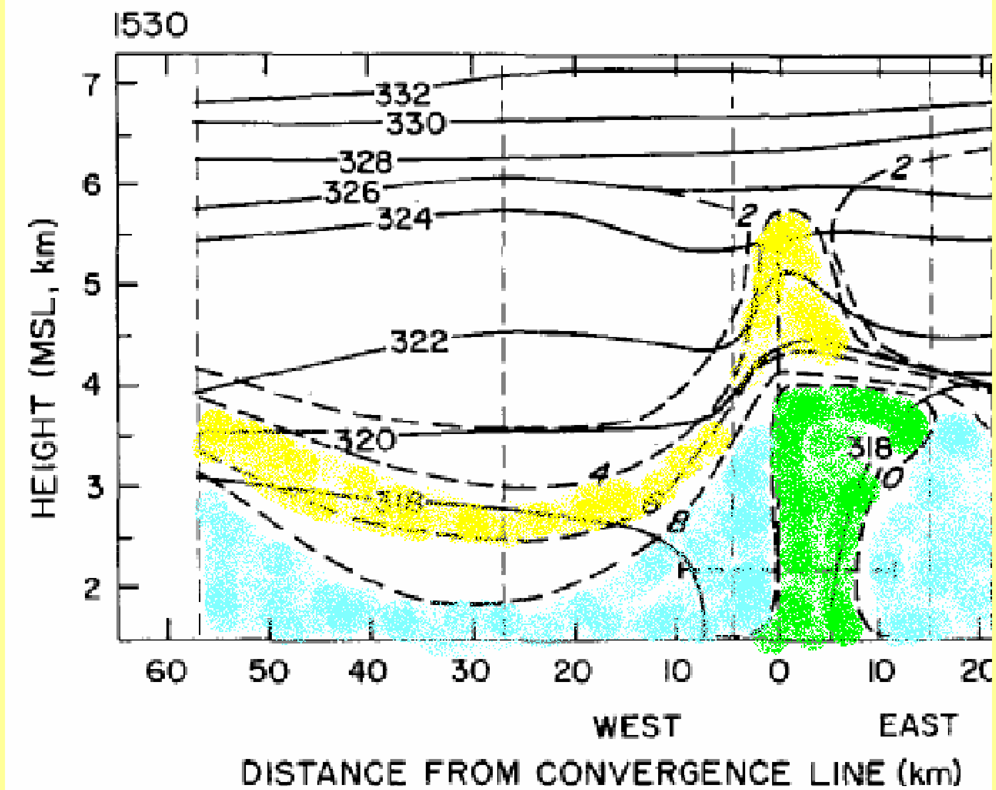
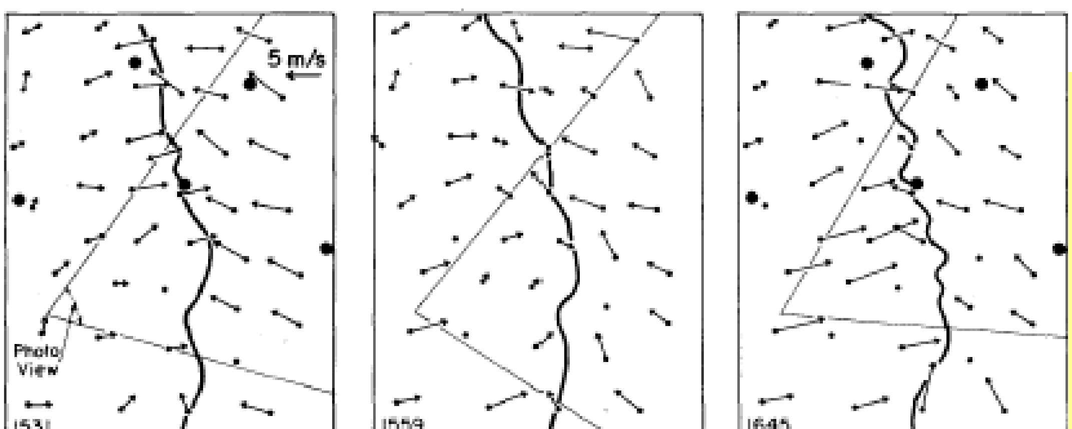
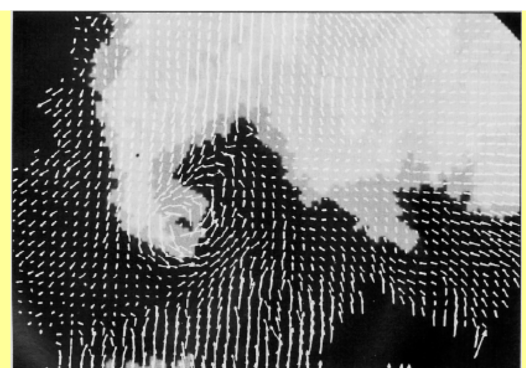
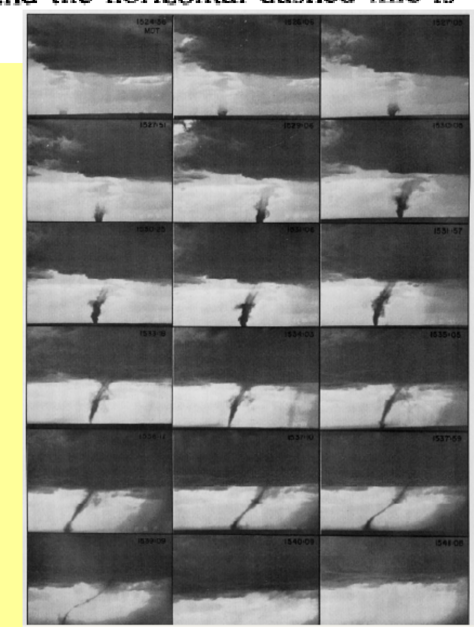


FIG. 6. West-to-east vertical cross section at 1530 MDT through the boundary in FIGS. 3 and 4. Solid contours are potential temperature (K) and the dashed contours are mixing ratio ($g \cdot kg^{-1}$). The dashed, vertical lines are sounding locations and the horizontal dashed line is the NCAR King Air flight path.





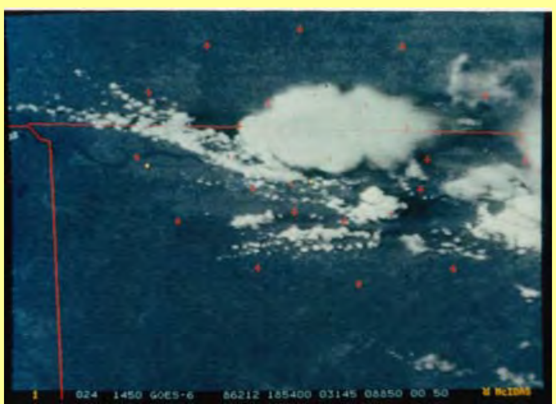


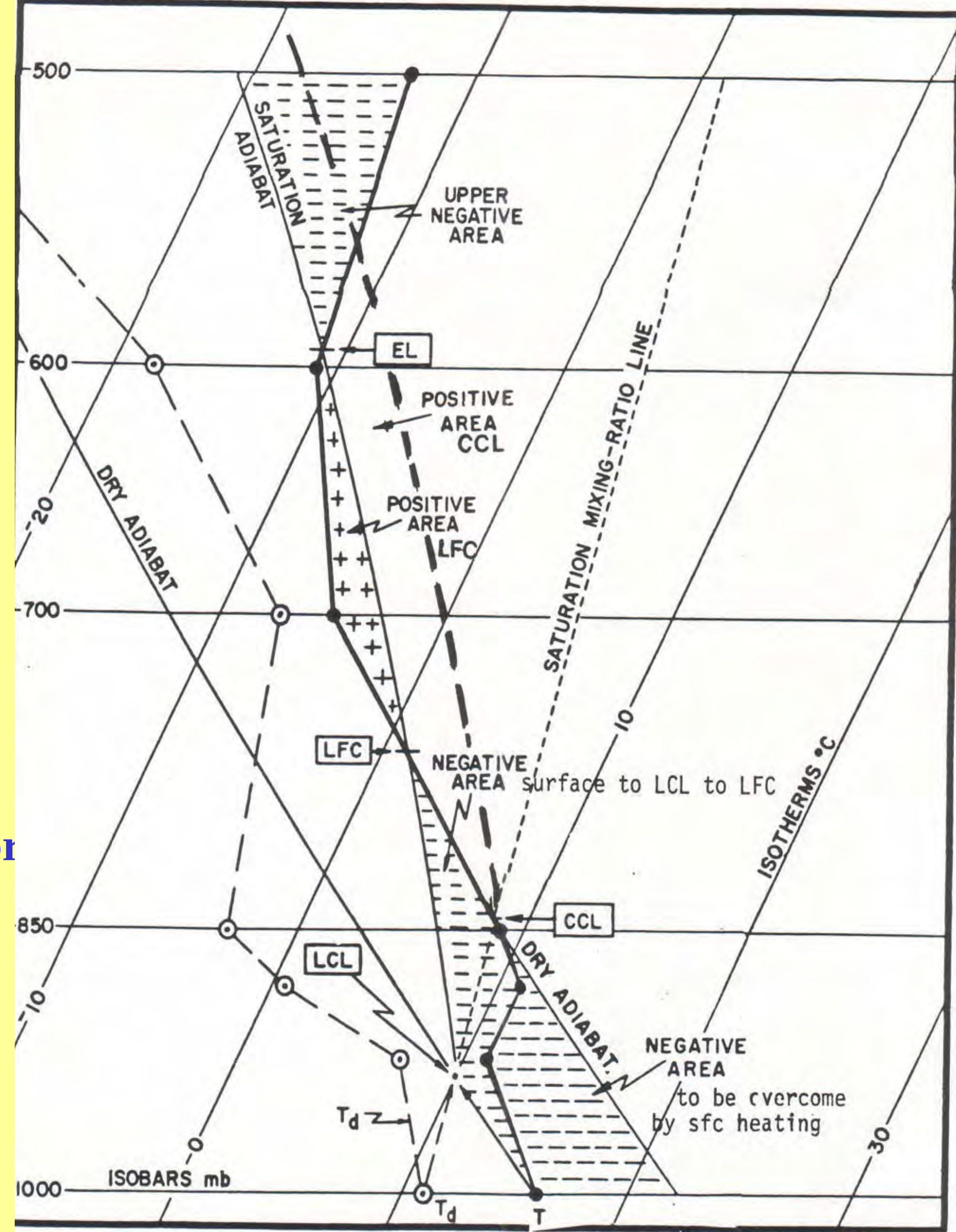
Note the small scale increase in moisture that led to thunderstorms formation along a convergence line (eventually tornadoes).

Variability in the cumulus field. The cumulus are at various stages of development, from fair weather cumulus to mature thunderstorms. Go to next page to view movie illustrating this throughout the day.

Skew-T Log-P Diagram

- We know convection exists, but have we thought about what is required to develop convection
- Let’s talk about this stability diagram
  - Parcel
  - Negative area
  - Energy input
  - **Think back to water vapor and its variation**





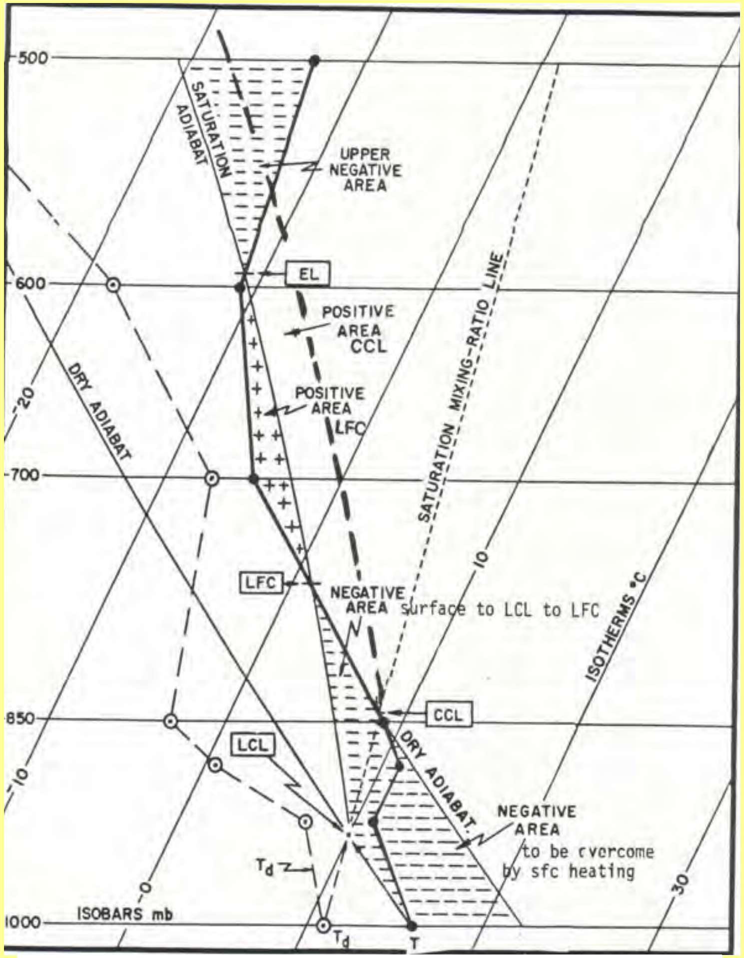
Analysis of perturbation form of vertical equation of motion

- $\delta(w^2/2) = -g\,(\Delta T/T)\,\delta z$

- **Integrate from bottom where w=max to top w=x**

- $(w_b - w_t) = \{(2g\,(\Delta T/T)\,(z_t - z_b)\}^{1/2}$

- **For example if ΔT = 0.5 C, with an average environmental T of 290 C over a height of 290 meters, with a w of 0.1 m/s at the top, then w input at the base is approximately 3.4 m/s: how can this come about?**



The example is not from this skew-T which is only used to remind you of the negative area (LCL to LFC) that must be overcome to get free convection

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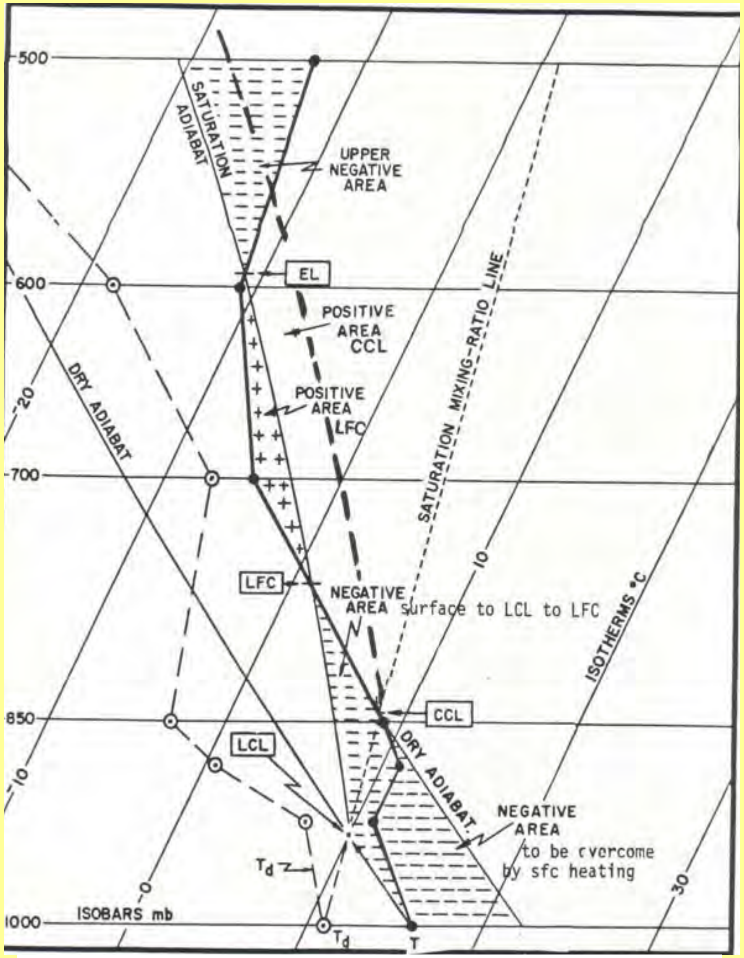

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Localized forcing in organized convergence zones integrated over time

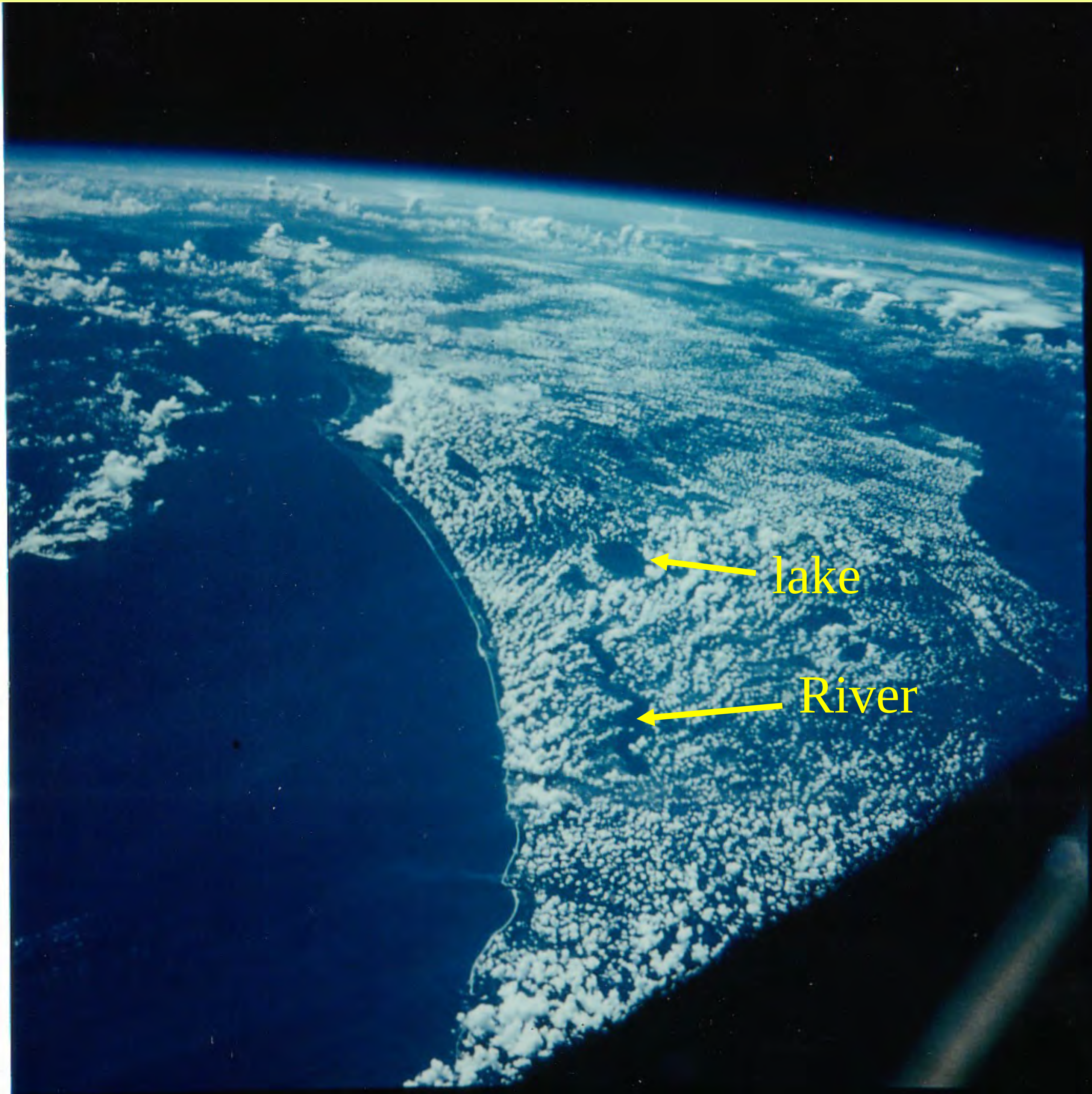
Organized circulation
Vorticity - On the local scale

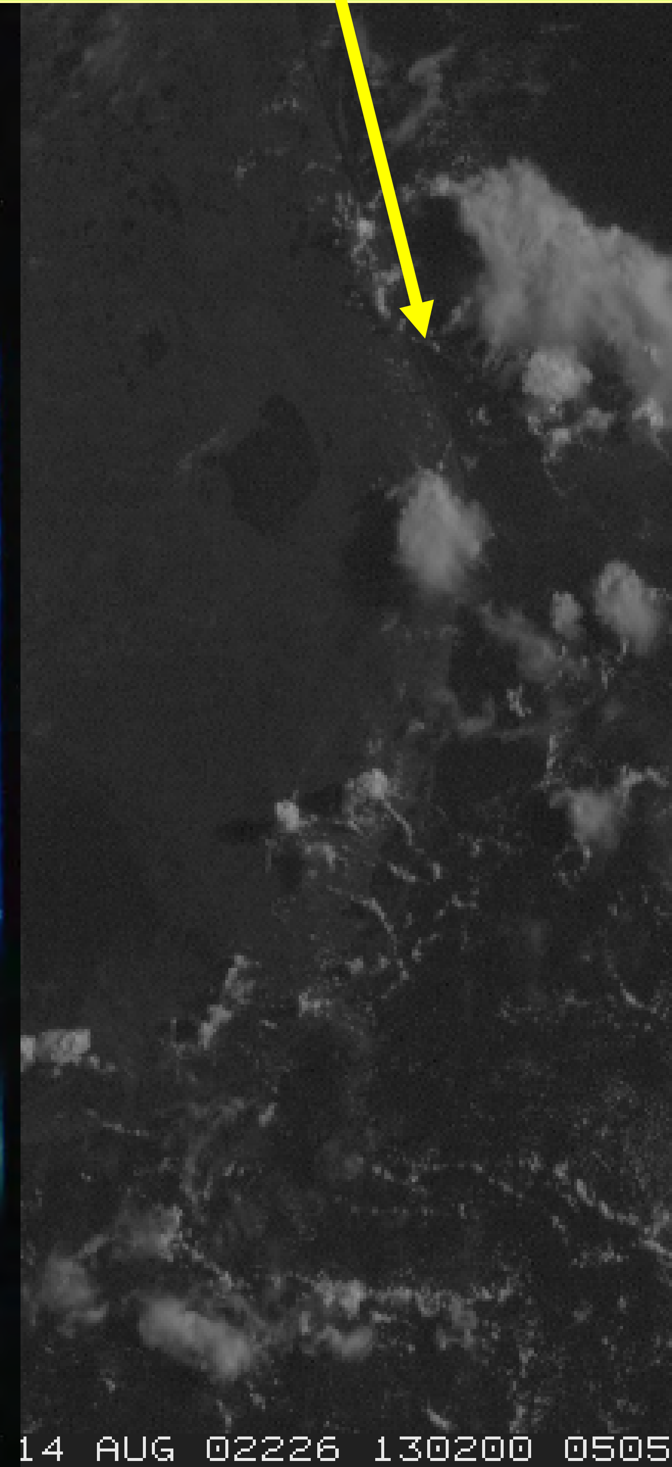
- Convergence on preexisting vorticity
- Tilting of vorticity from one plane to another
- Advection from one place to another
- Differential heating (does not require pre-existing vorticity)
- Friction

Differential heating examples

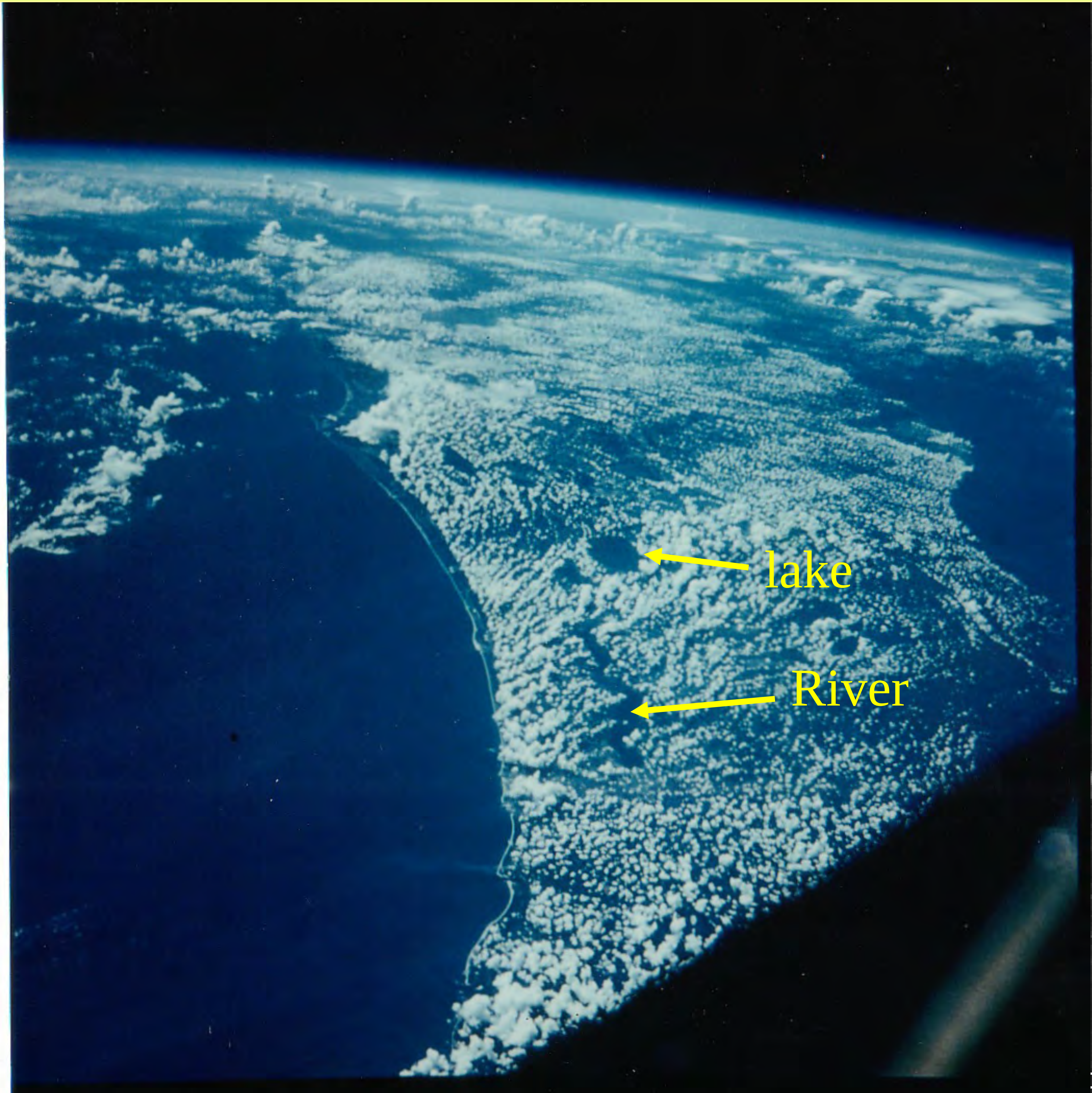
- When one thinks of differential heating the land sea breeze phenomena immediately comes to mind, as do mountain and valley breezes.
- Another differential heating mechanism, to be addressed later, is the thunderstorm itself: through evaporation of rain cooled air a differential heating is developed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

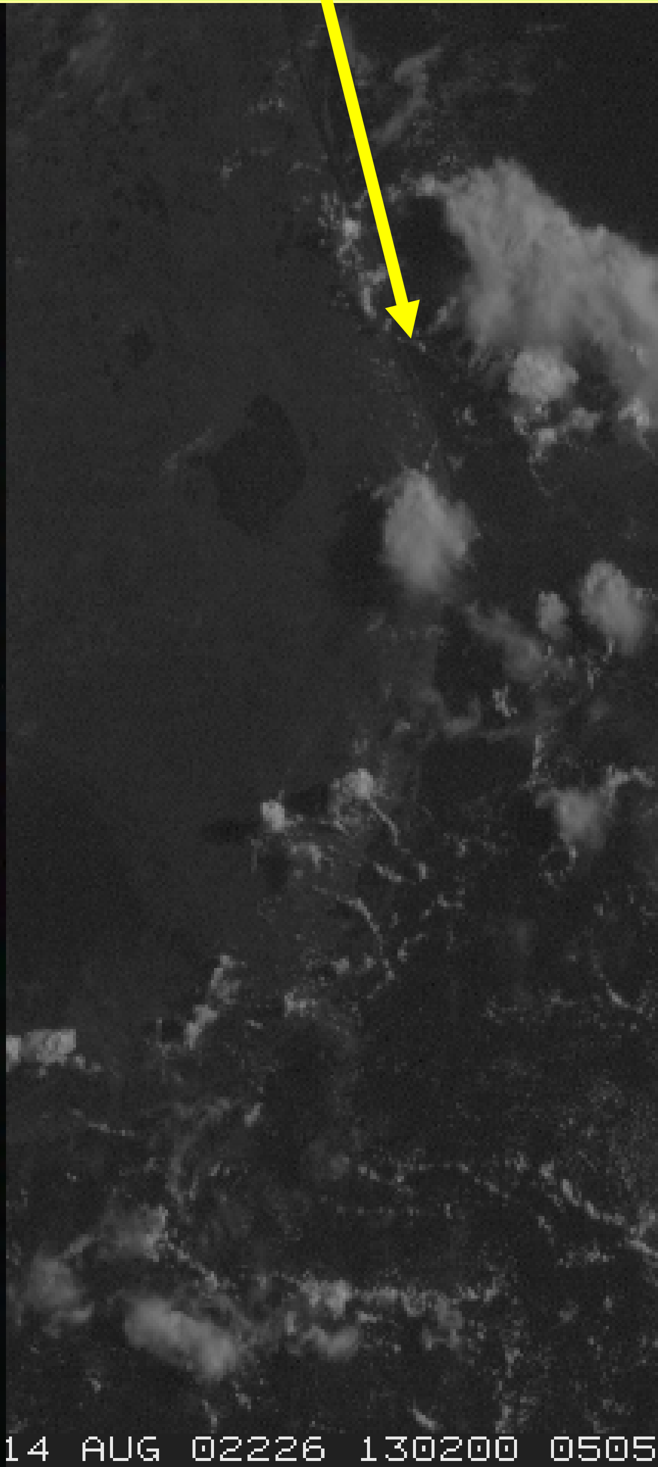
Example of Sea-breeze development (movie next page)



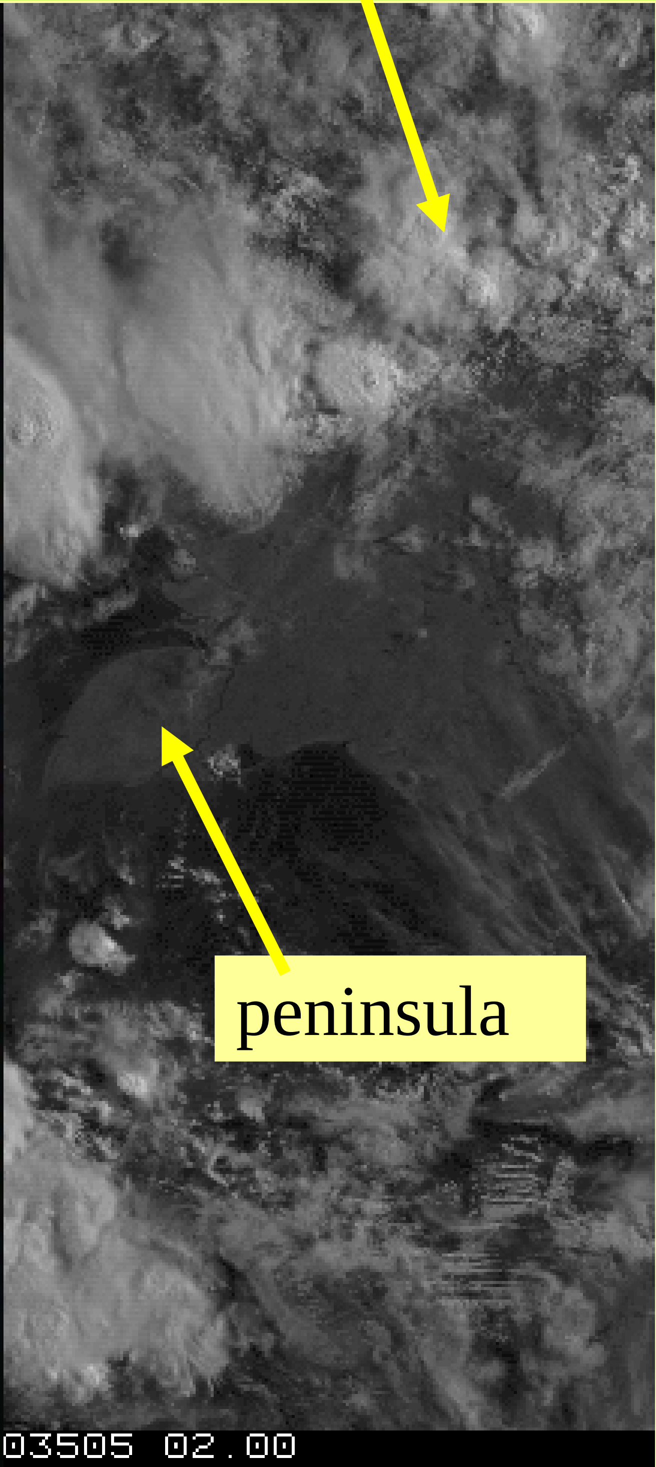


Example of Sea-breeze development

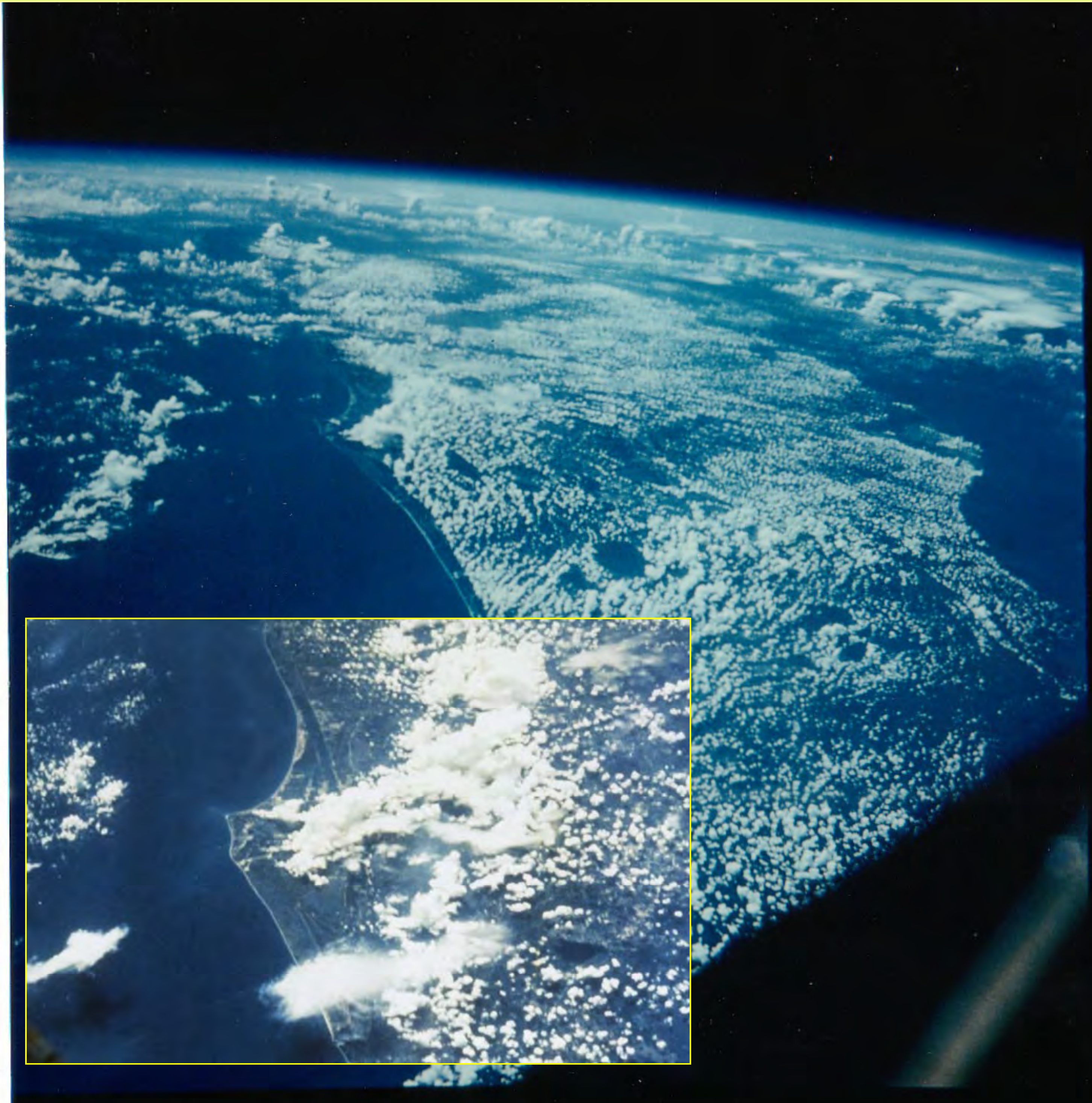


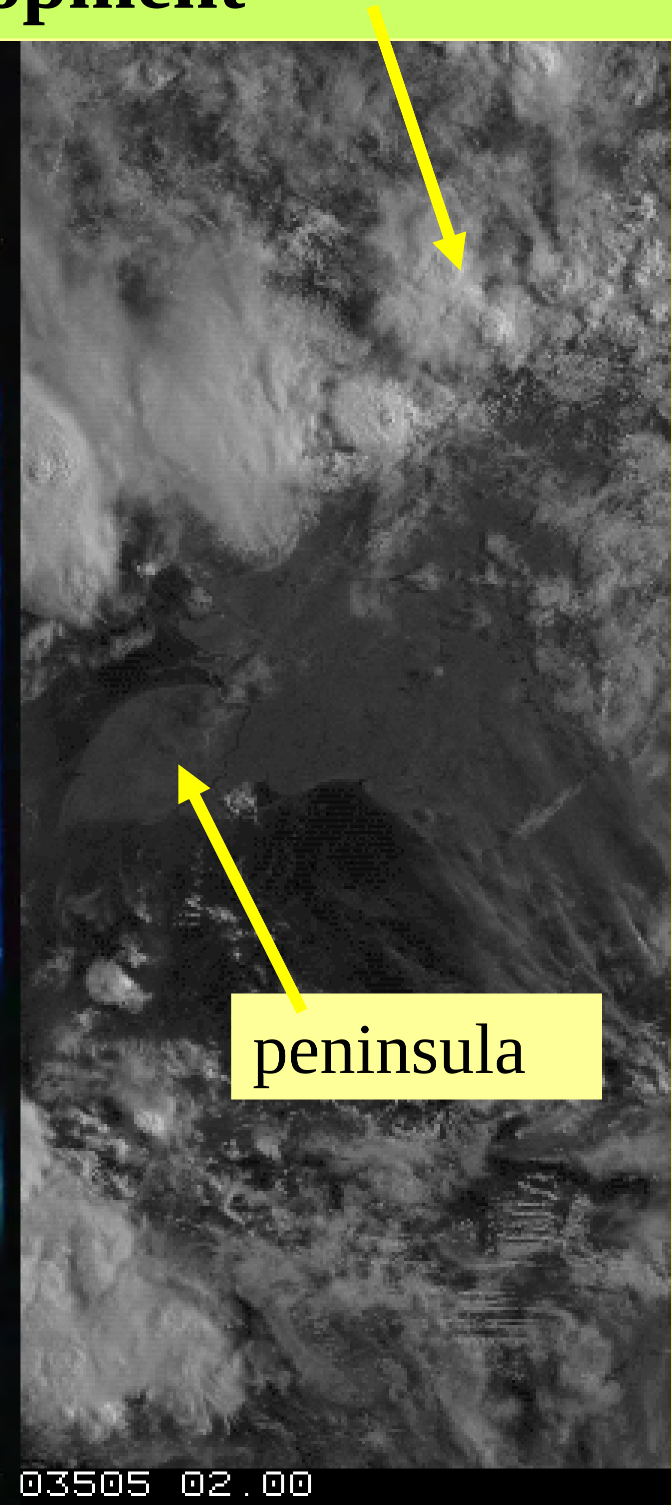


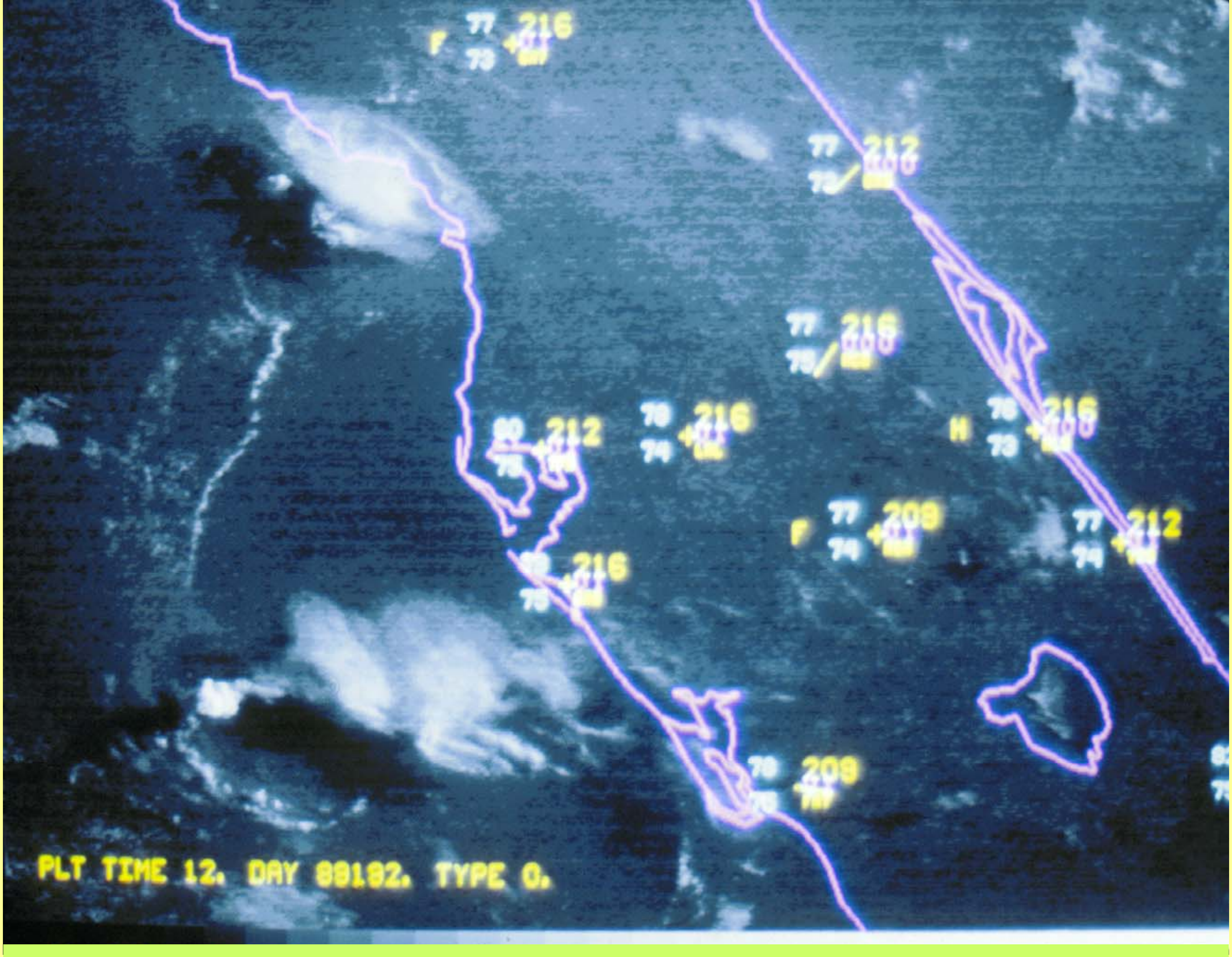
Example of Sea-breeze development (movie next page)



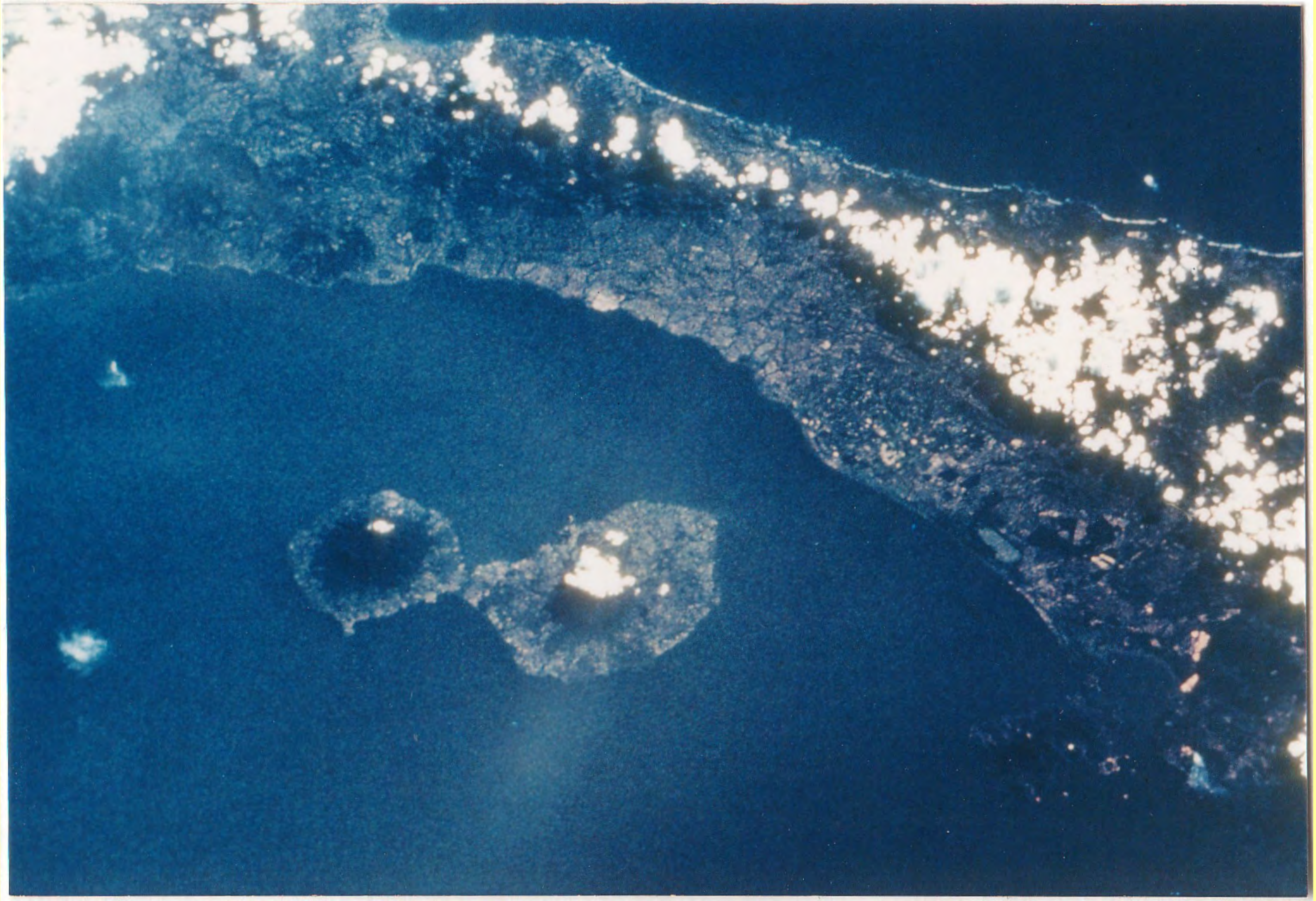
Example of Sea-breeze development



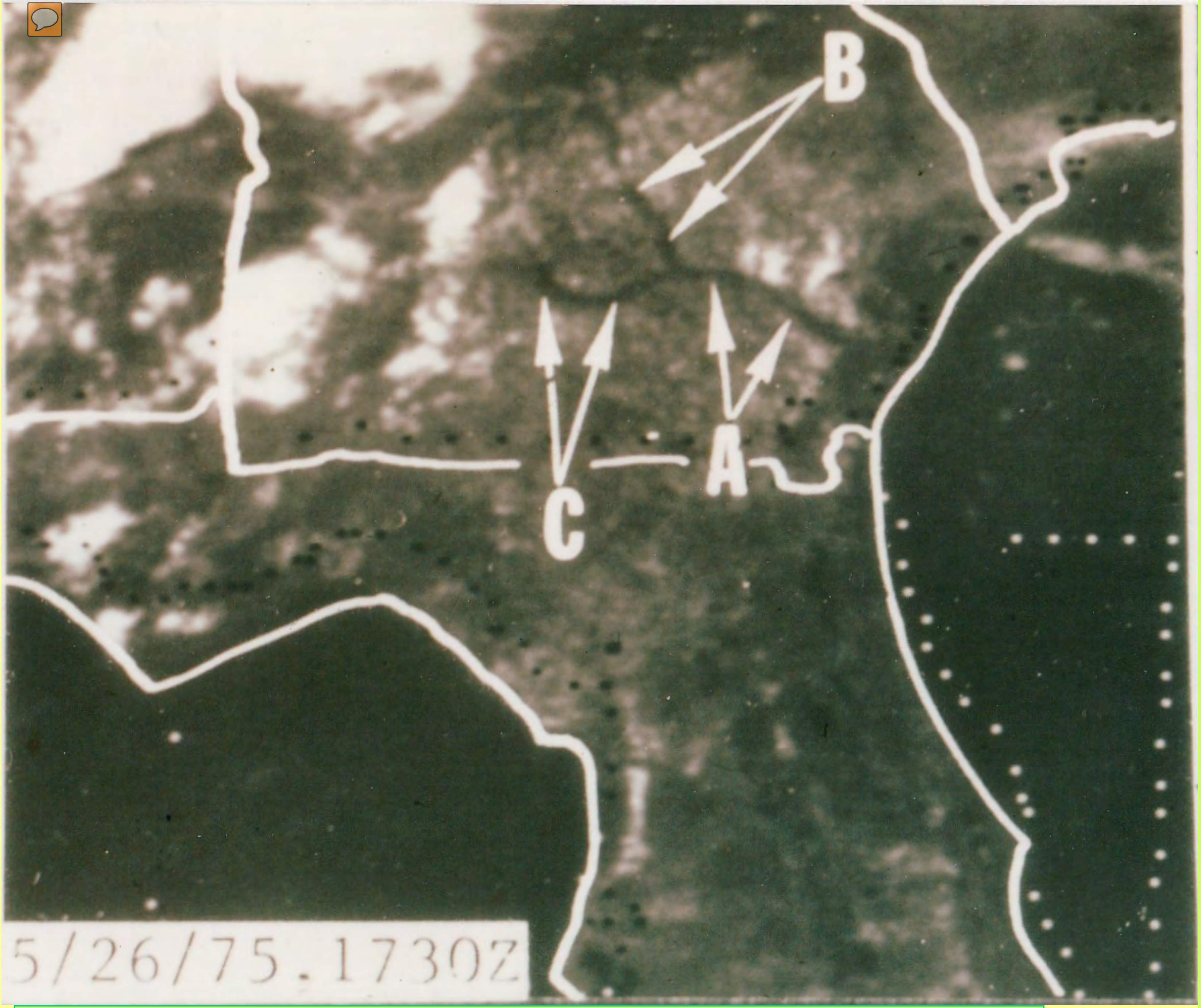




Example of early morning GOES image showing convection along the night time land breeze front. Note coastal curvature effect.

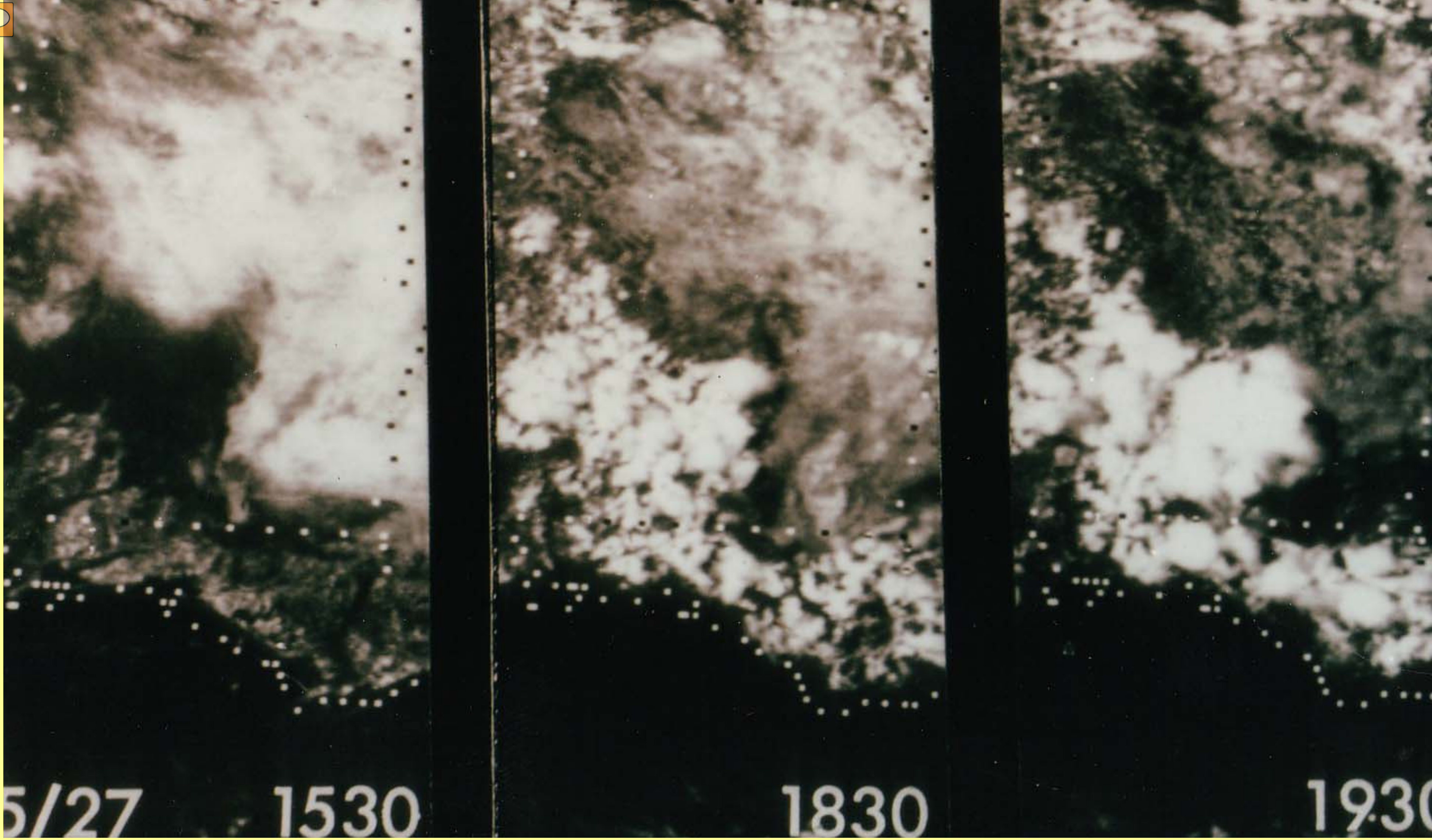


Example of mountain effect on convective development. Note the cumulus over the peaks and compensating subsidence areas.



As with sea breezes, differential heating may play a role in river breeze development. However with rivers their size (the meandering river system) and the prevailing low level flow become very important.

Example of the effect of river breezes in organizing convection



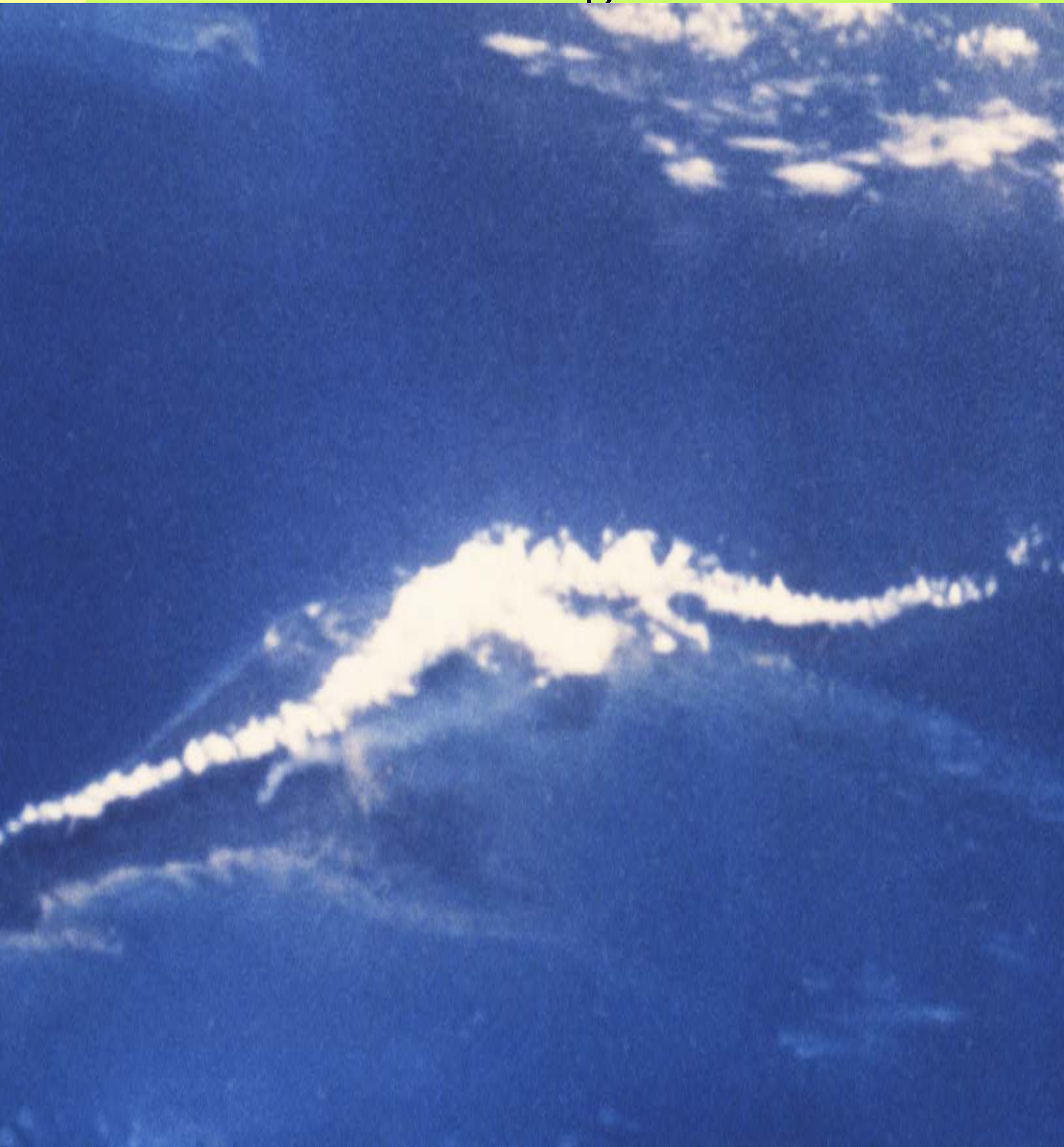
In conditions with light winds, areas of early morning cloud cover can effect afternoon cumulus development due to differential heating between the cloudy and clear regions. Care must be taken in this generalization, as the time of early cloud erosion is crucial in determining that areas ability to support convection later in the day.

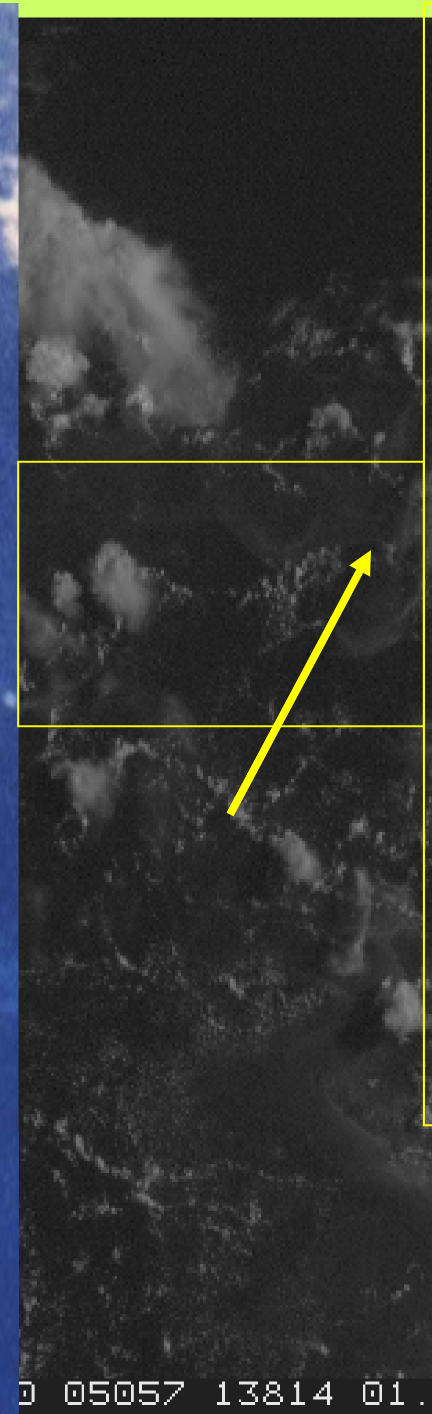
The importance of low level flow with respect to organized convergence zones

- The flow of the air in the boundary layer with respect to the orientation of the convergence zone is important in allowing the parcels to realize their potential to move vertically and eventually form storms.
- If low level air moves too rapidly through a convergence zone it may not rise enough to produce even cumulus cloudiness!

Cumulus development and low level flow with respect to convergence zones over a small island

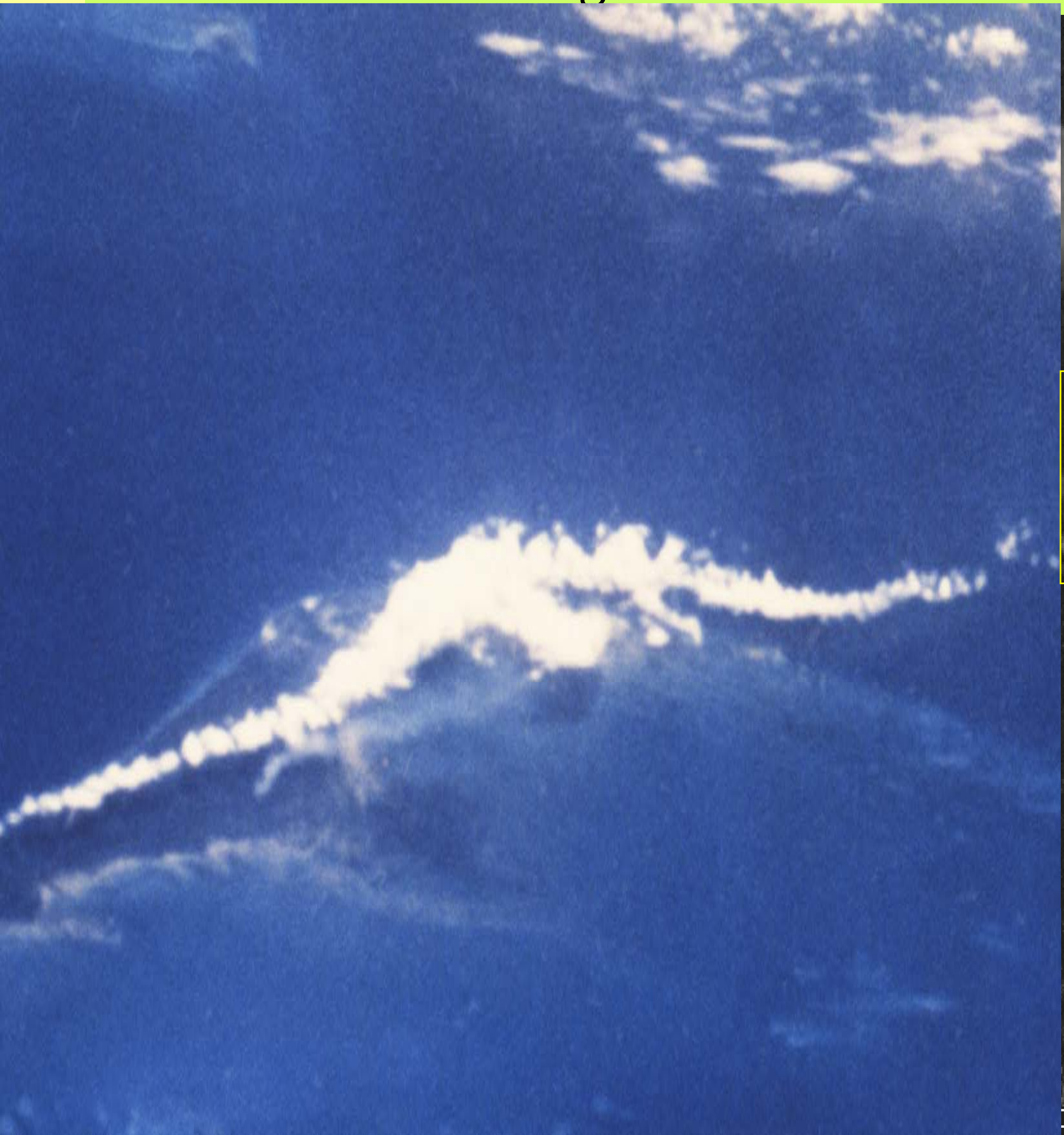
Cumulus development and low level flow with respect to convergence zones over a small island

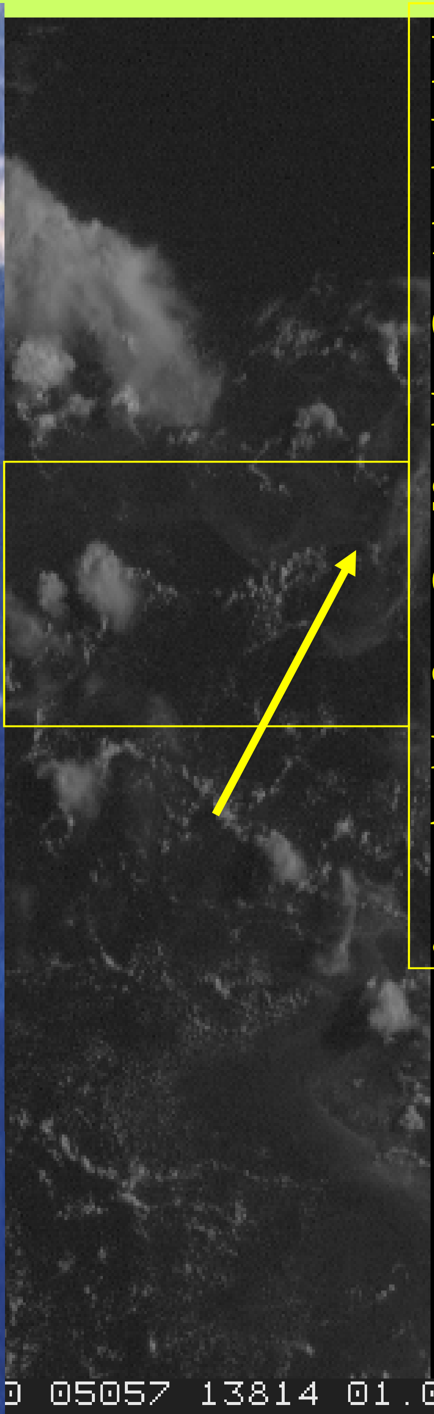




Movie on next page. Note the low level flow and develop-ment of strong convection as the air remains in the conver-gence zone

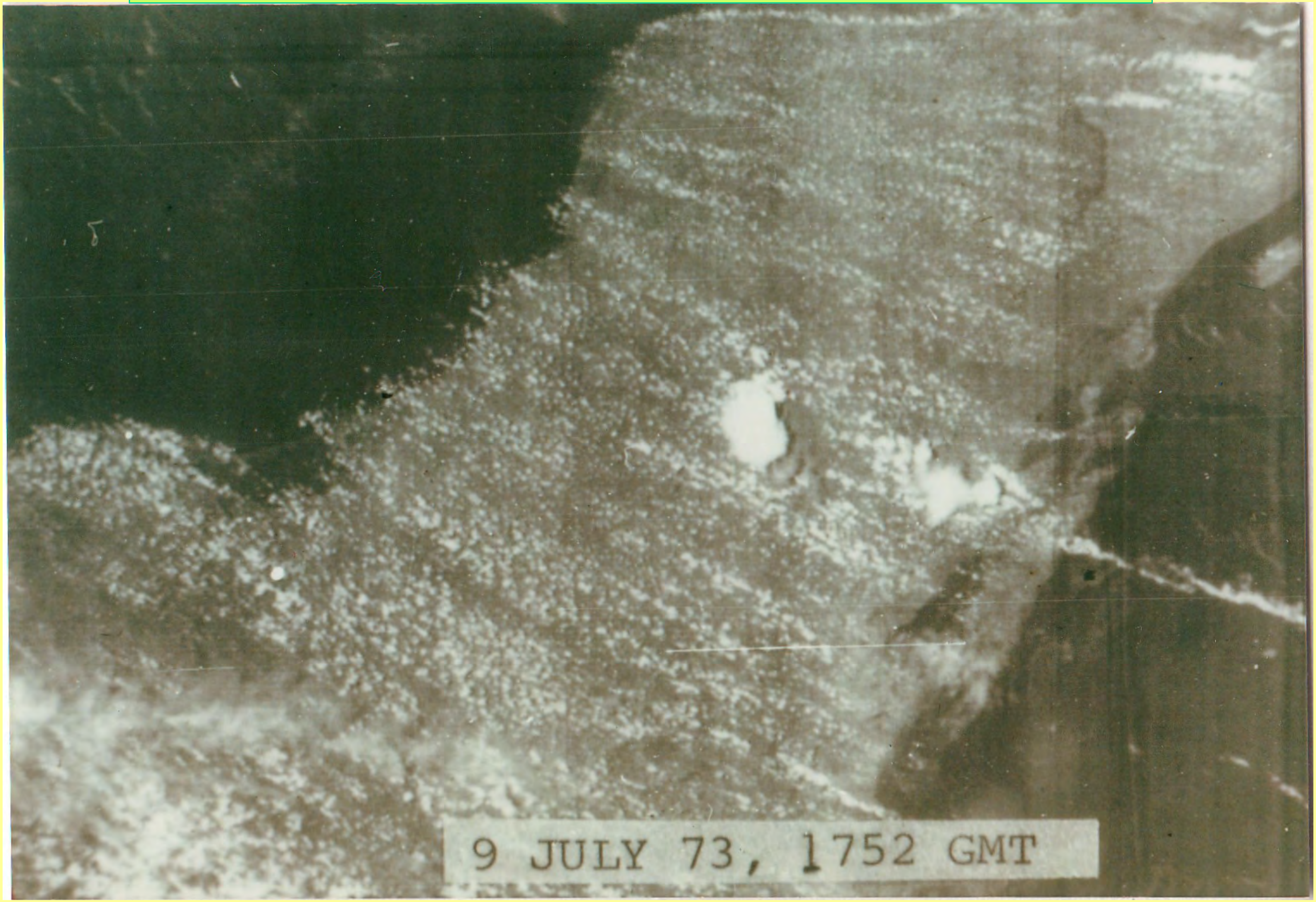
Cumulus development and low level flow with respect to convergence zones over a small island



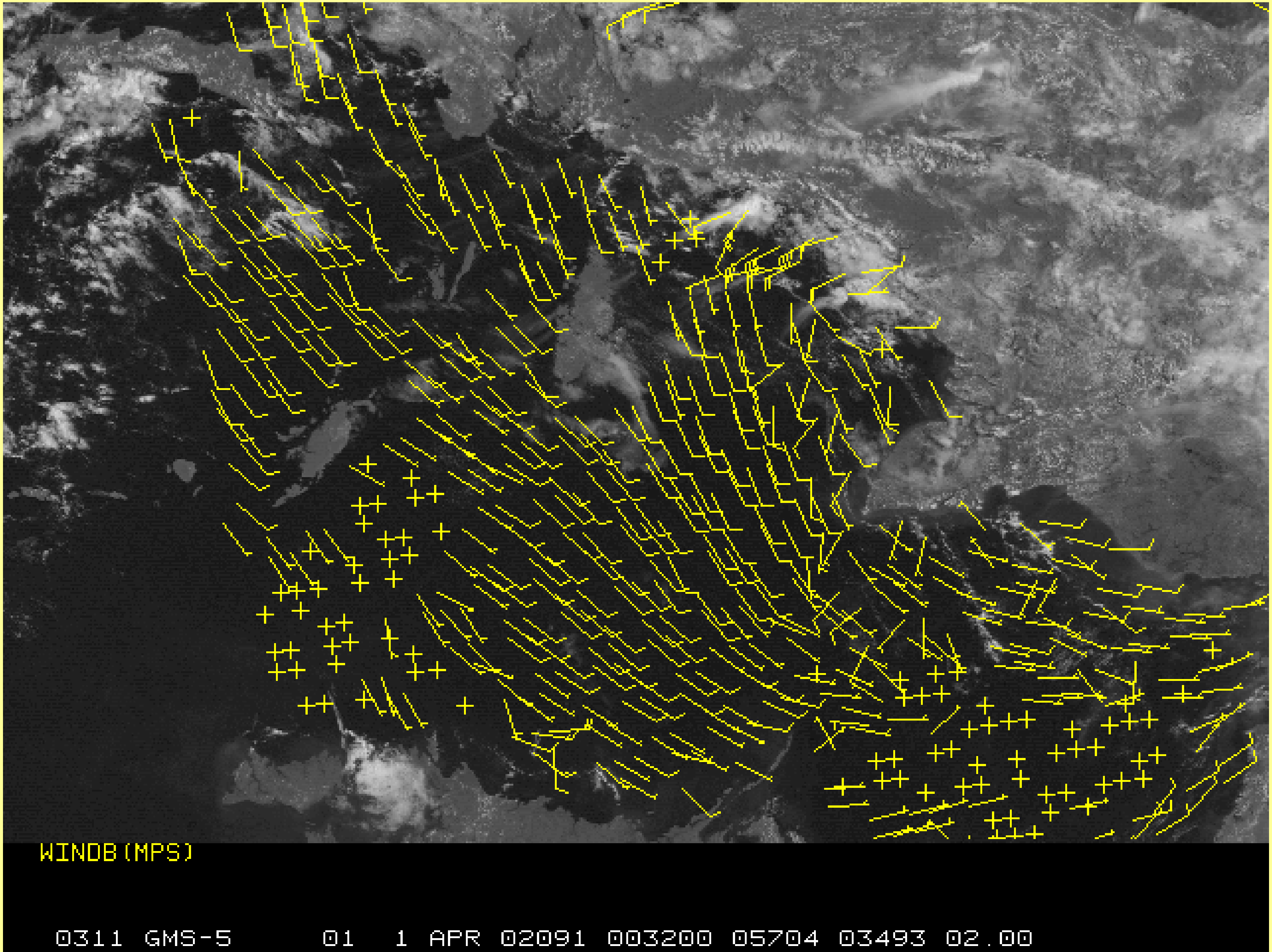


Note the low level flow and develop-ment of strong convection as the air remains in the conver-gence zone

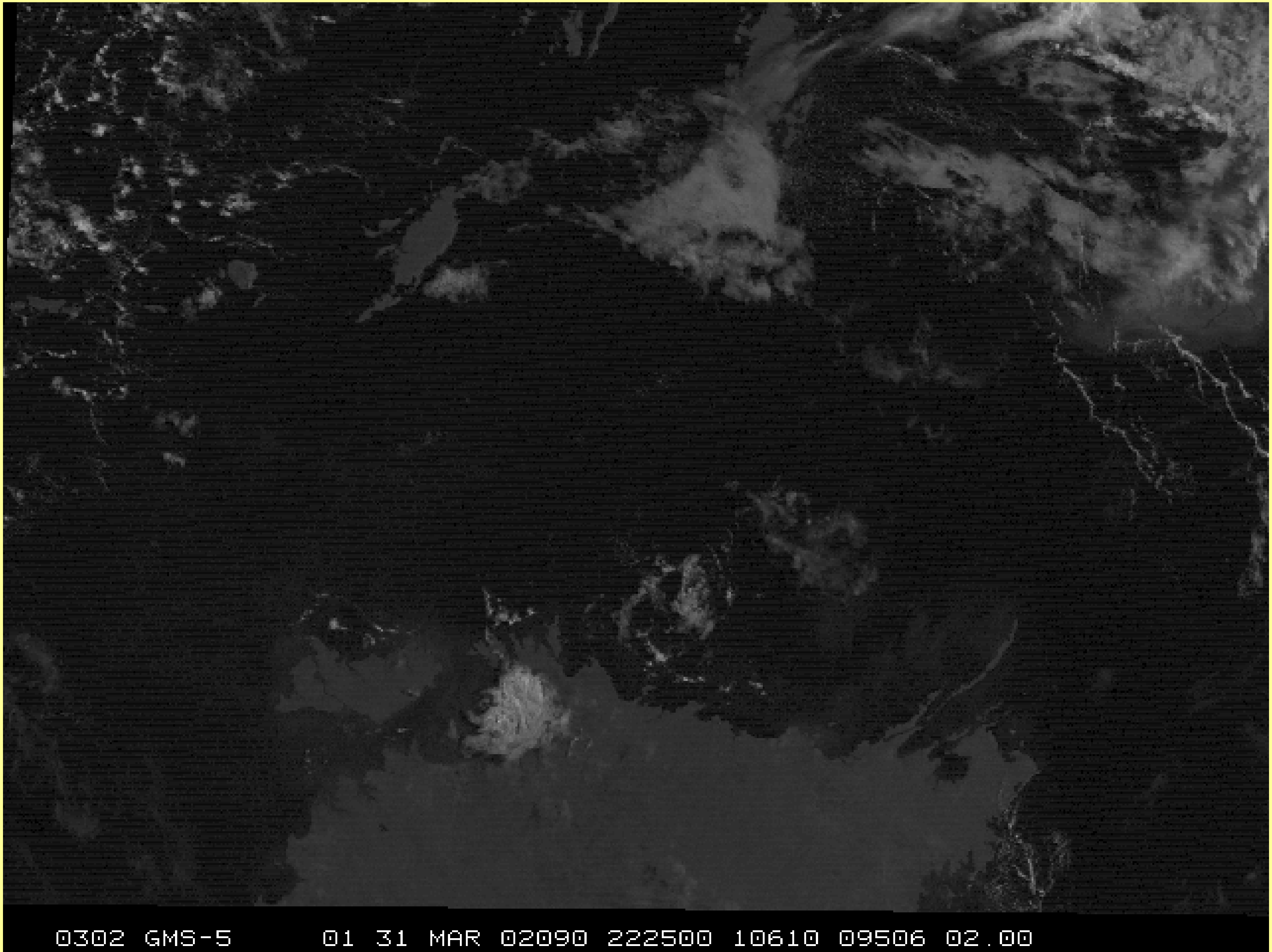
Convection over Yucatan down wind from organized convective line



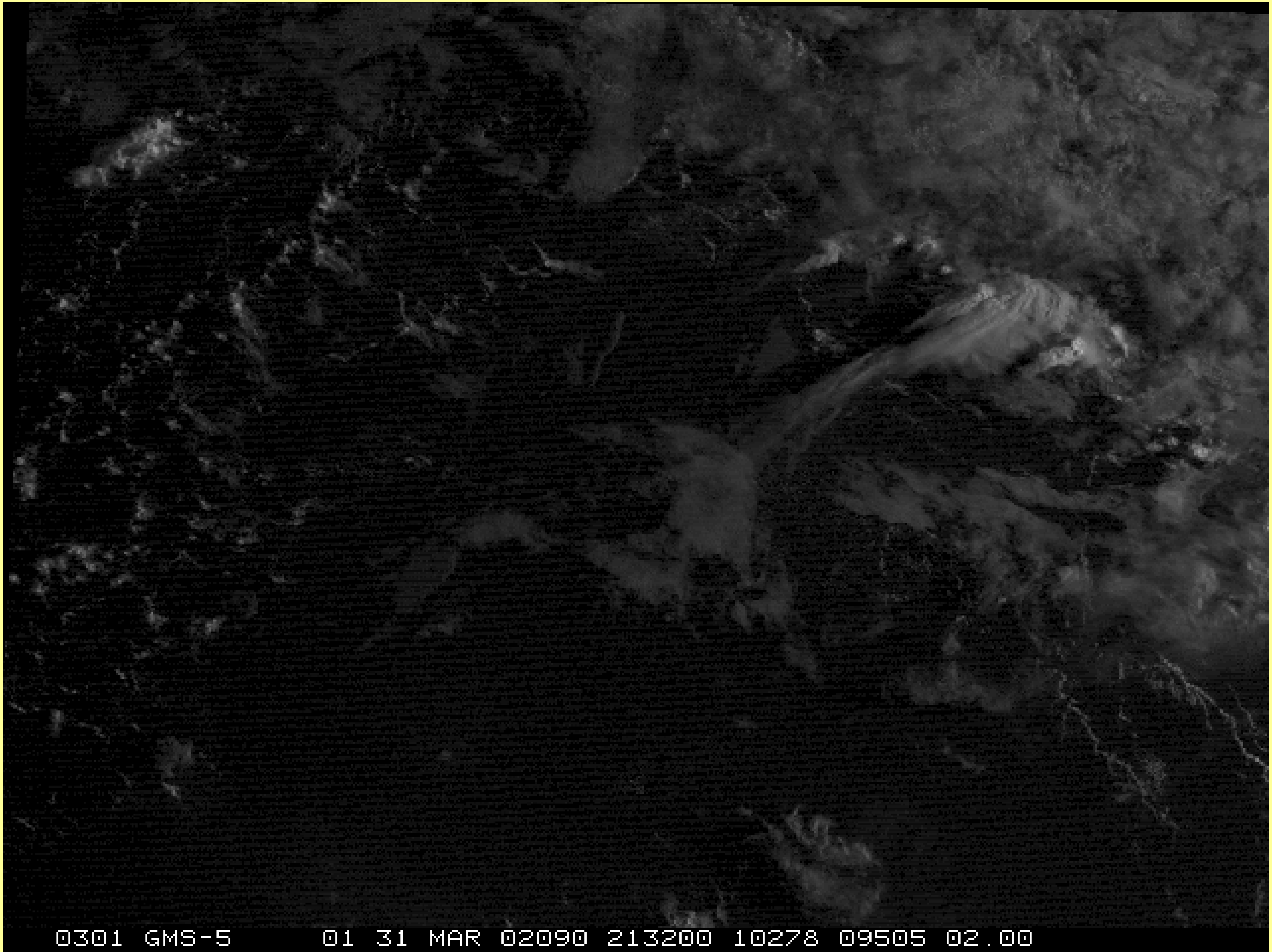
The effect of low level wind flow (boundary layer) on convective development is illustrated by using this slide with the next two slides.



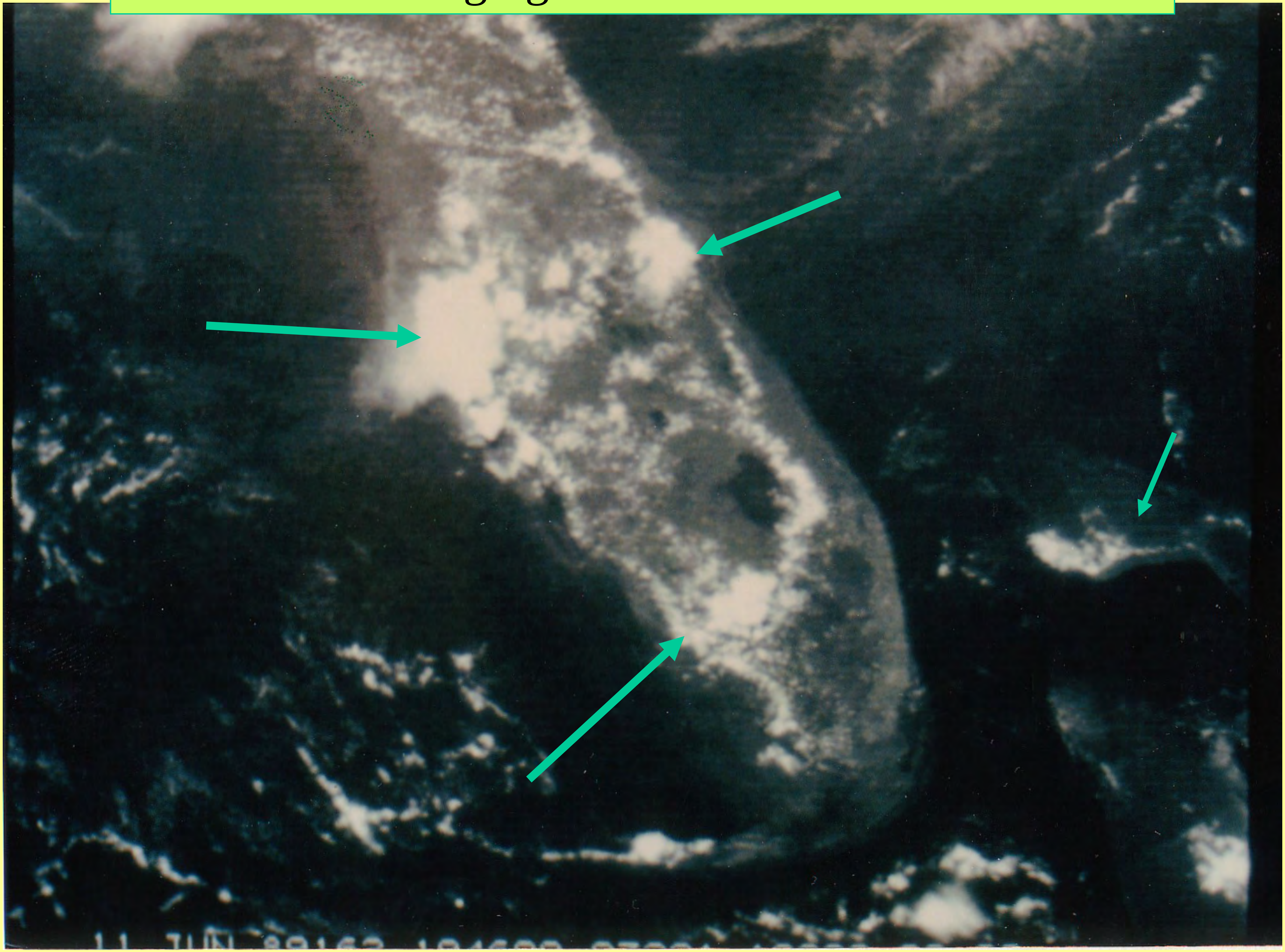
In this large view note the cumulus blowing off shore in Northern Australia. The following slide is over a longer time period and concentrates on the Northern half of the image.

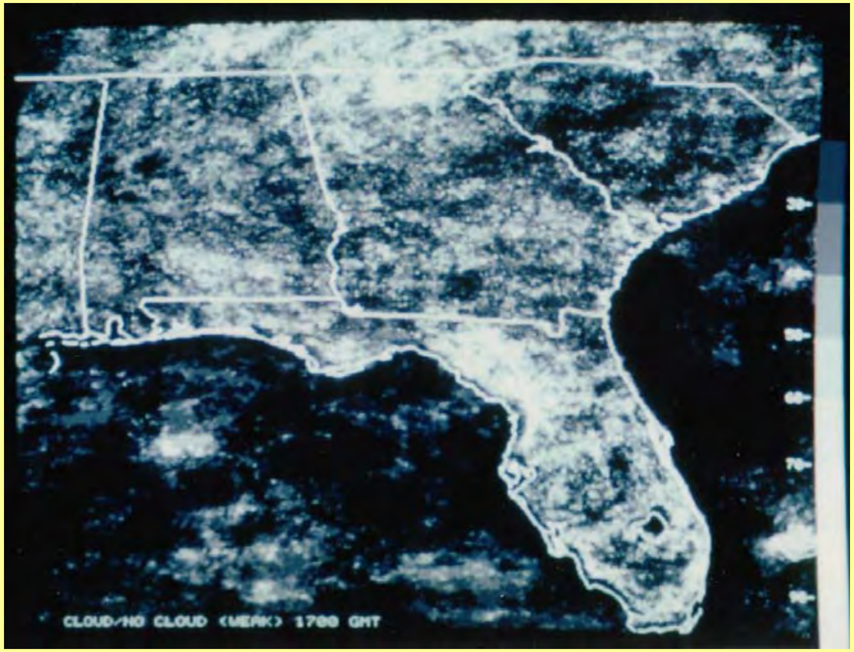


Close up of Northern half of previous movie.



Favored area for stronger convection development:
Merging Convective Lines





Satellite derived cloud climatologies are often useful in helping understand the effect of local terrain on convective development. This is the subject of an entire lecture in the Virtual resource Library

Thunderstorm development and evolution

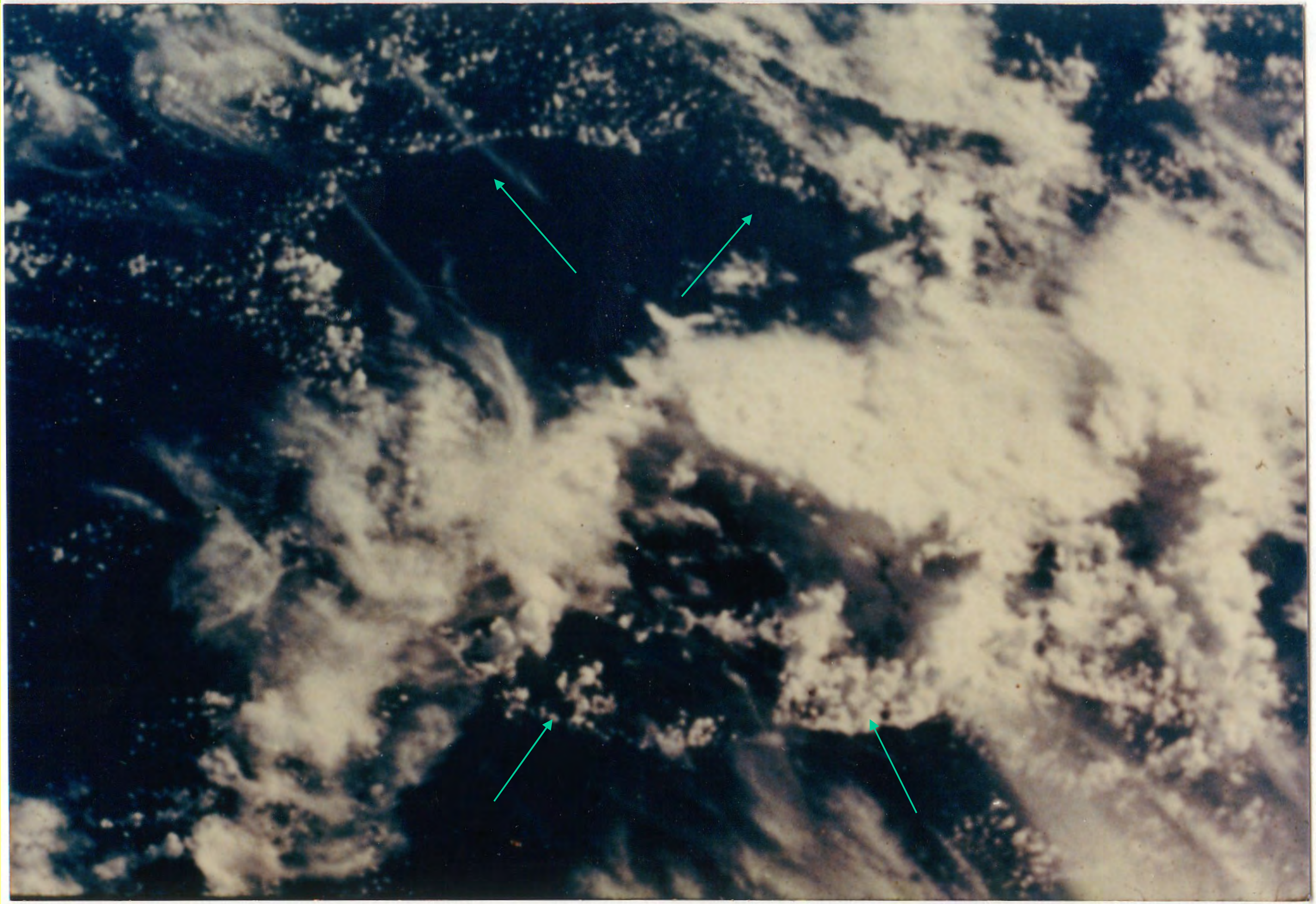
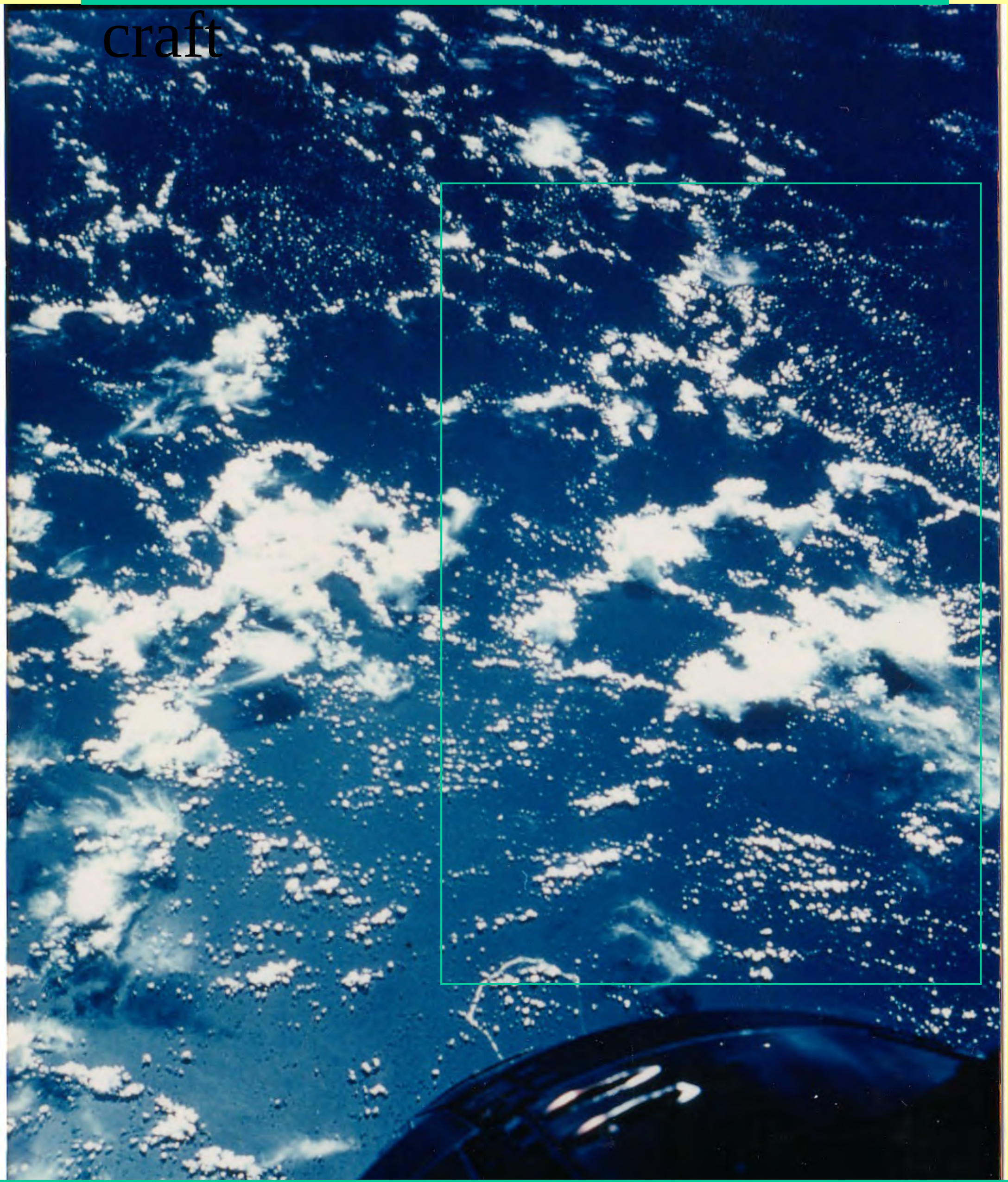
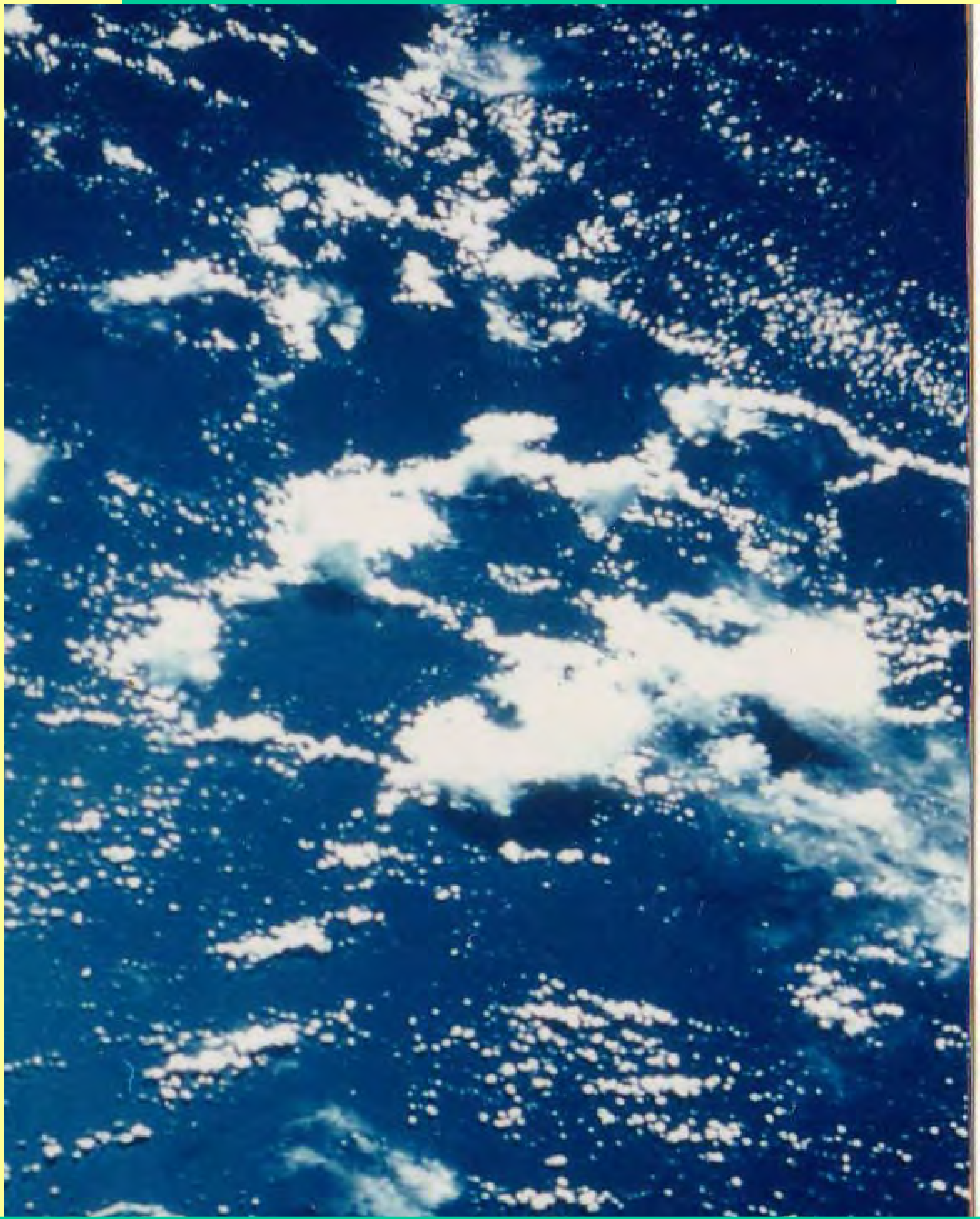


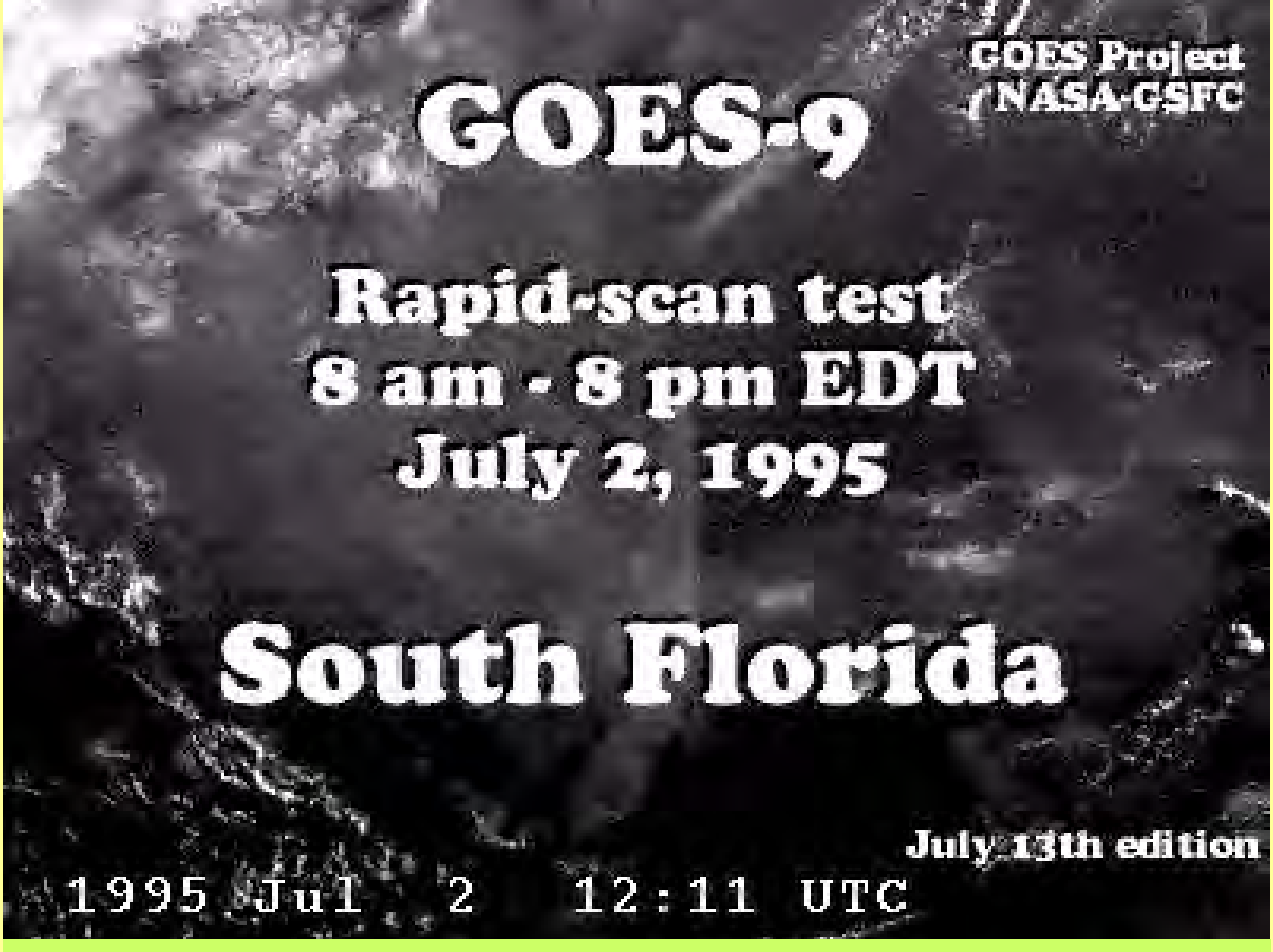
Photo from manned space craft



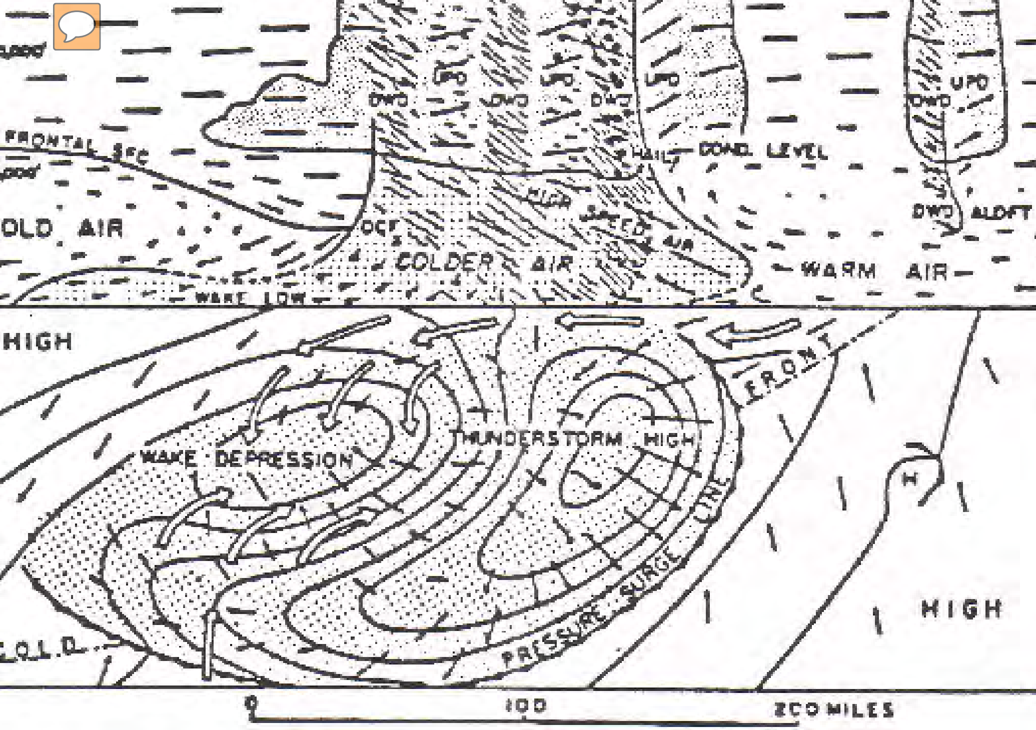
Expansion of inset to right

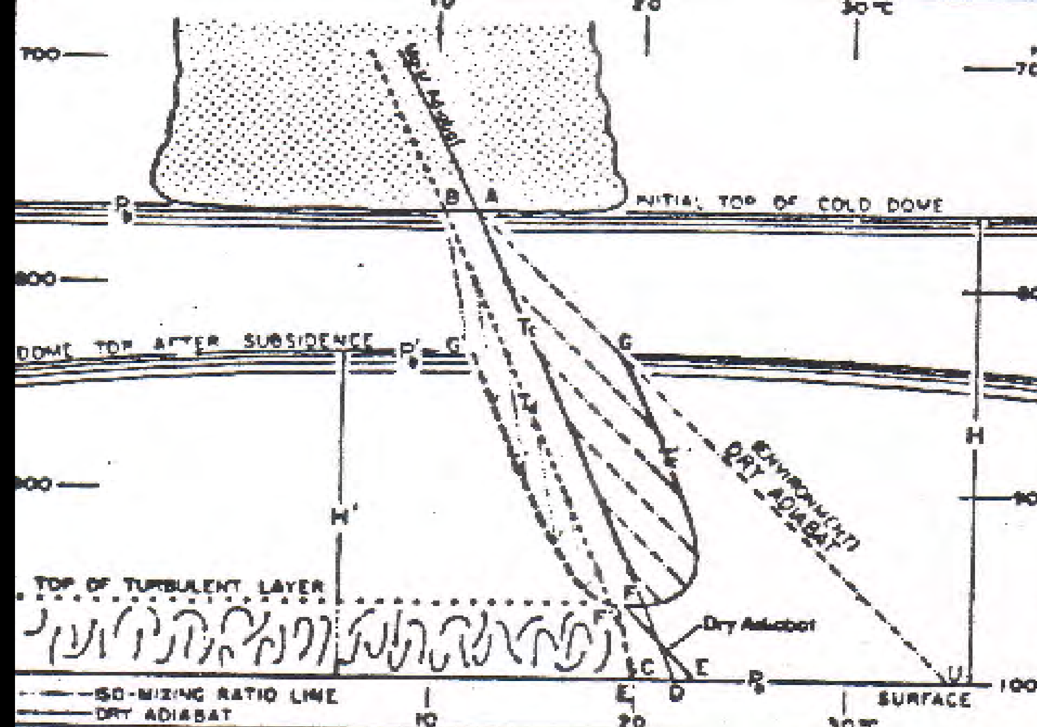


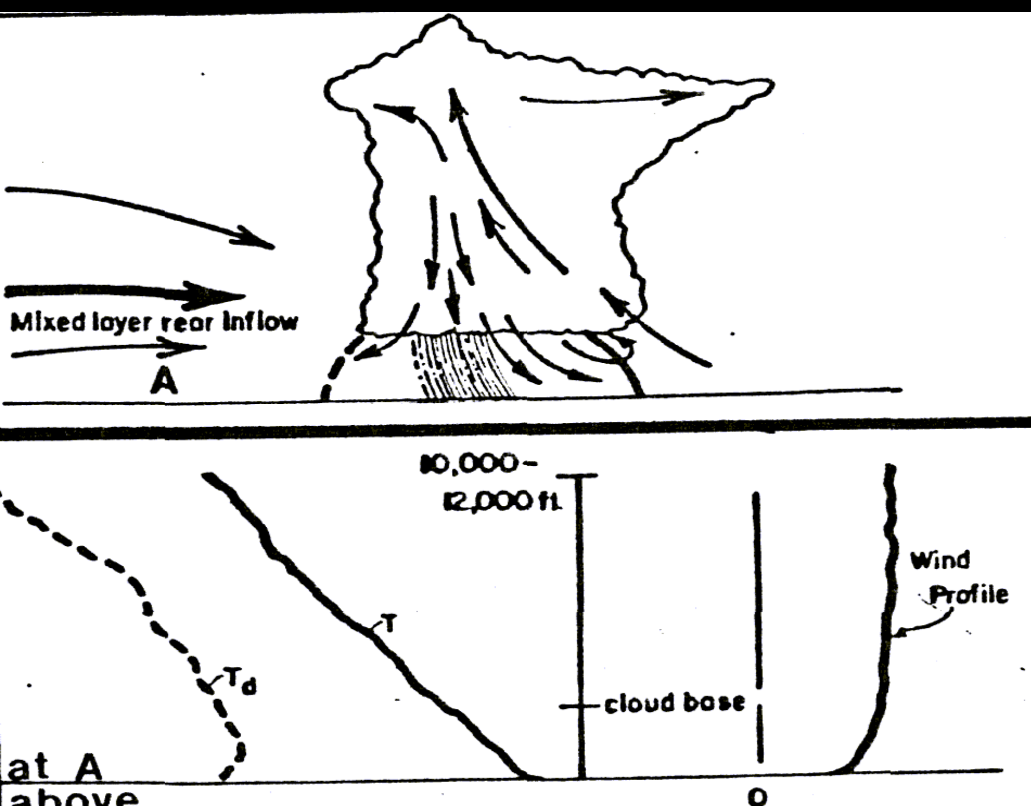
Note that deep convection is confined to lines and favored where the lines intersect. Also note how clear it is within the interior of some convective regions.

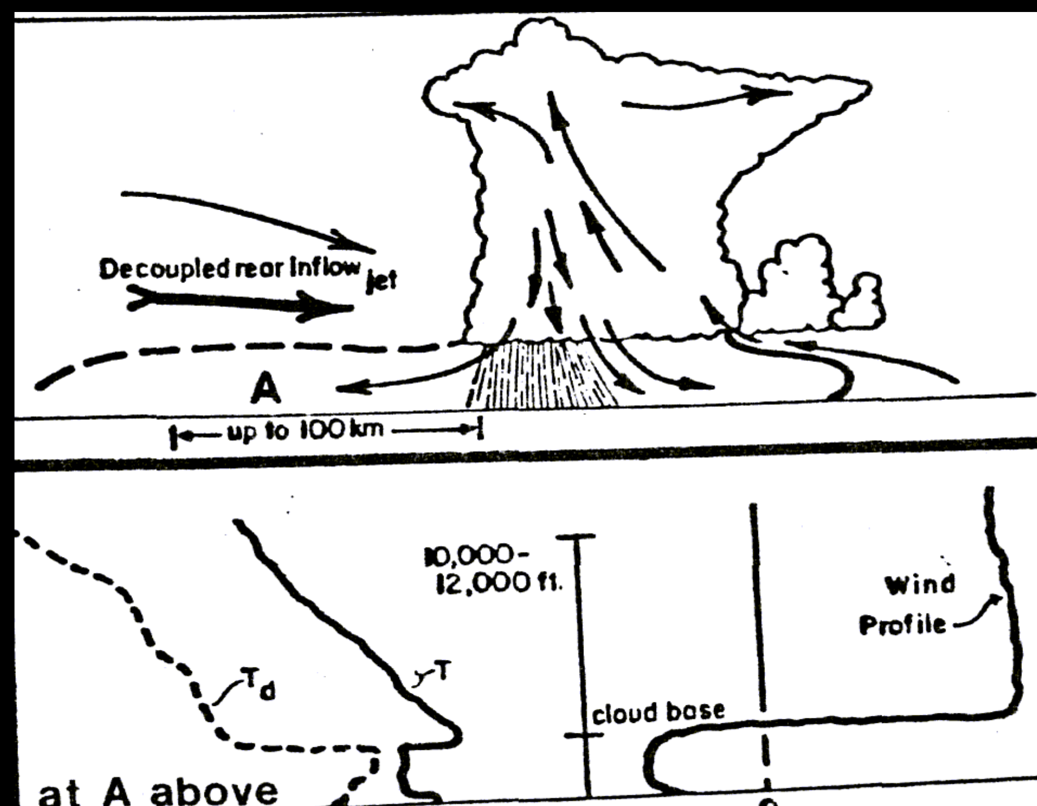


Animation of one minute GOES imagery illustrating the role of storm outflow in generating new convection.

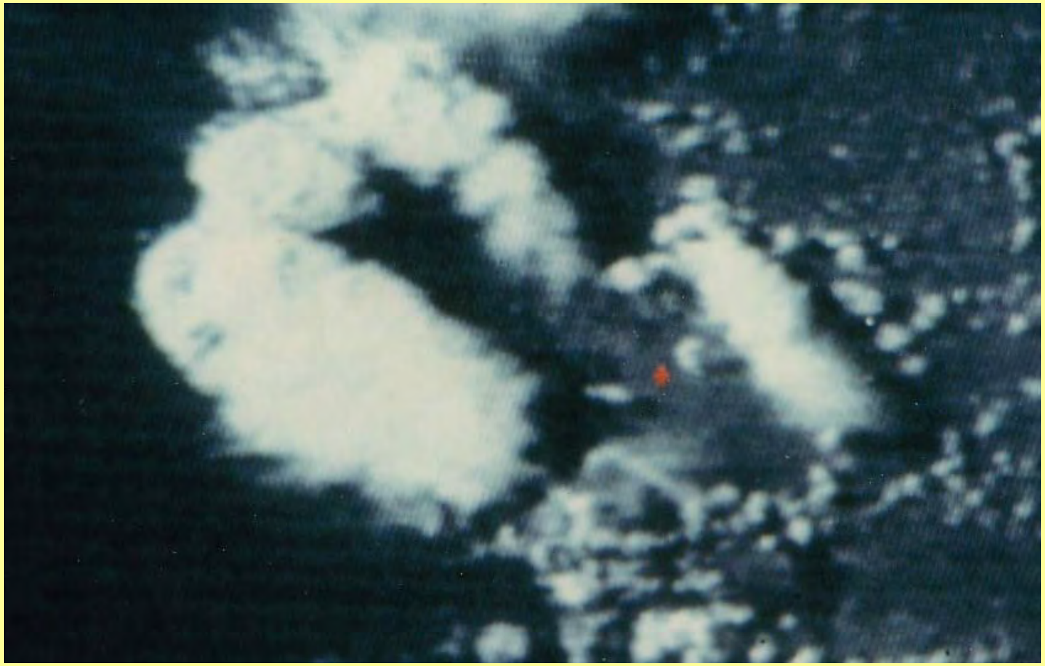

FRONTAL SFC
COLD AIR
UPD
DWD
HAIL
COND. LEVEL
HIGH SPEED AIR
DWD ALOFT
COLDER AIR
WARM AIR
WAKE LOW
HIGH
FRONT
WAKE DEPRESSION
THUNDERSTORM HIGH
PRESSURE SURGE LINE
H
HIGH
COLD
0
100
200 MILES

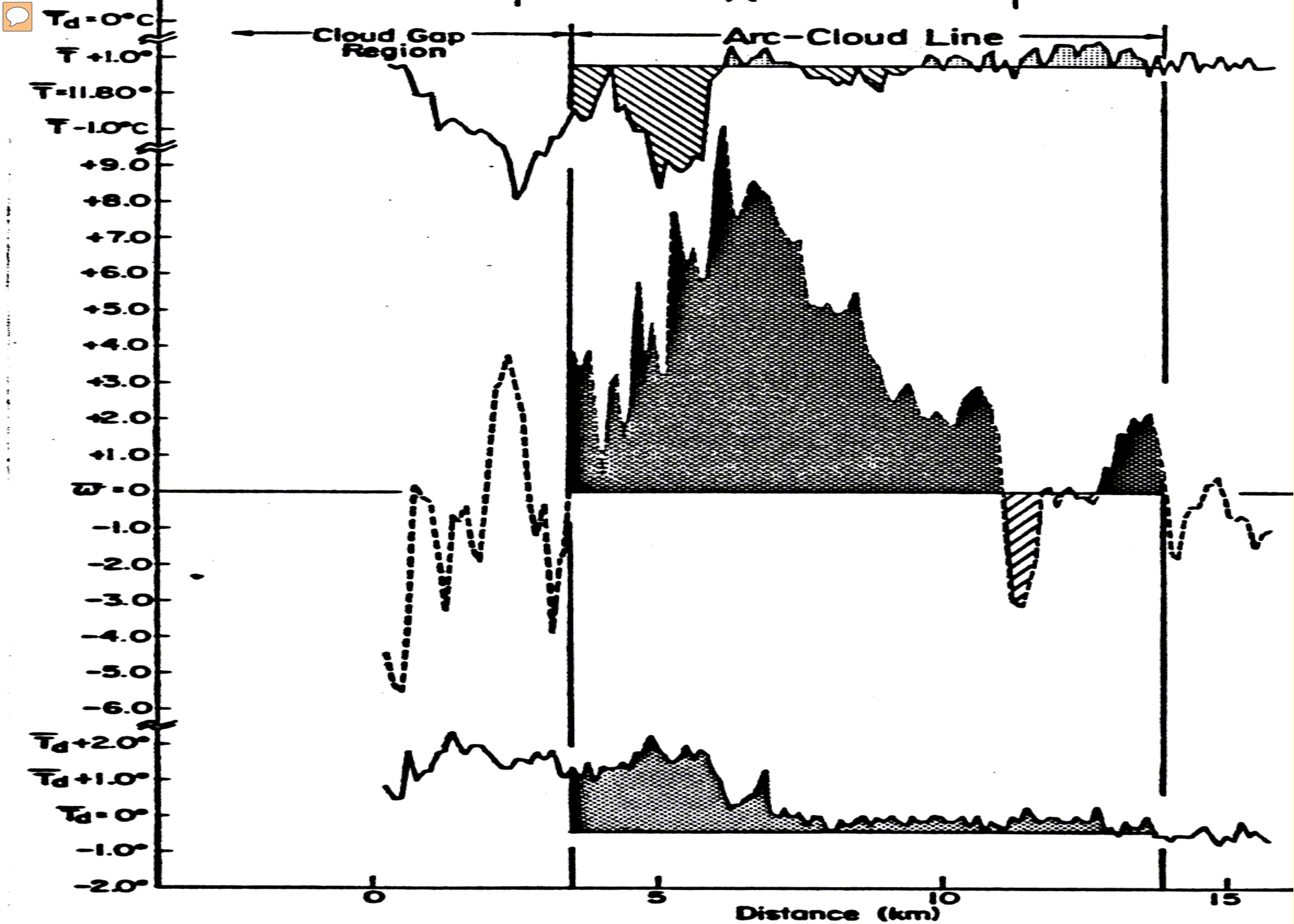

700
INITIAL TOP OF COLD DOME
800
DOME TOP AFTER SUBSIDENCE
900
ENVIRONMENT DRY ADIABAT
H
H'
TOP OF TURBULENT LAYER
Dry Adiabat
SURFACE
1000
ISO-MIXING RATIO LINE
DRY ADIABAT
10
20
30°C


Mixed layer rear inflow
A
10,000-
12,000 ft.
T
T_d
cloud base
Wind
Profile
at A
above
0


Decoupled rear inflow jet
A
up to 100 km
10,000-
12,000 ft.
T
T_d
cloud base
Wind
Profile
at A above
0

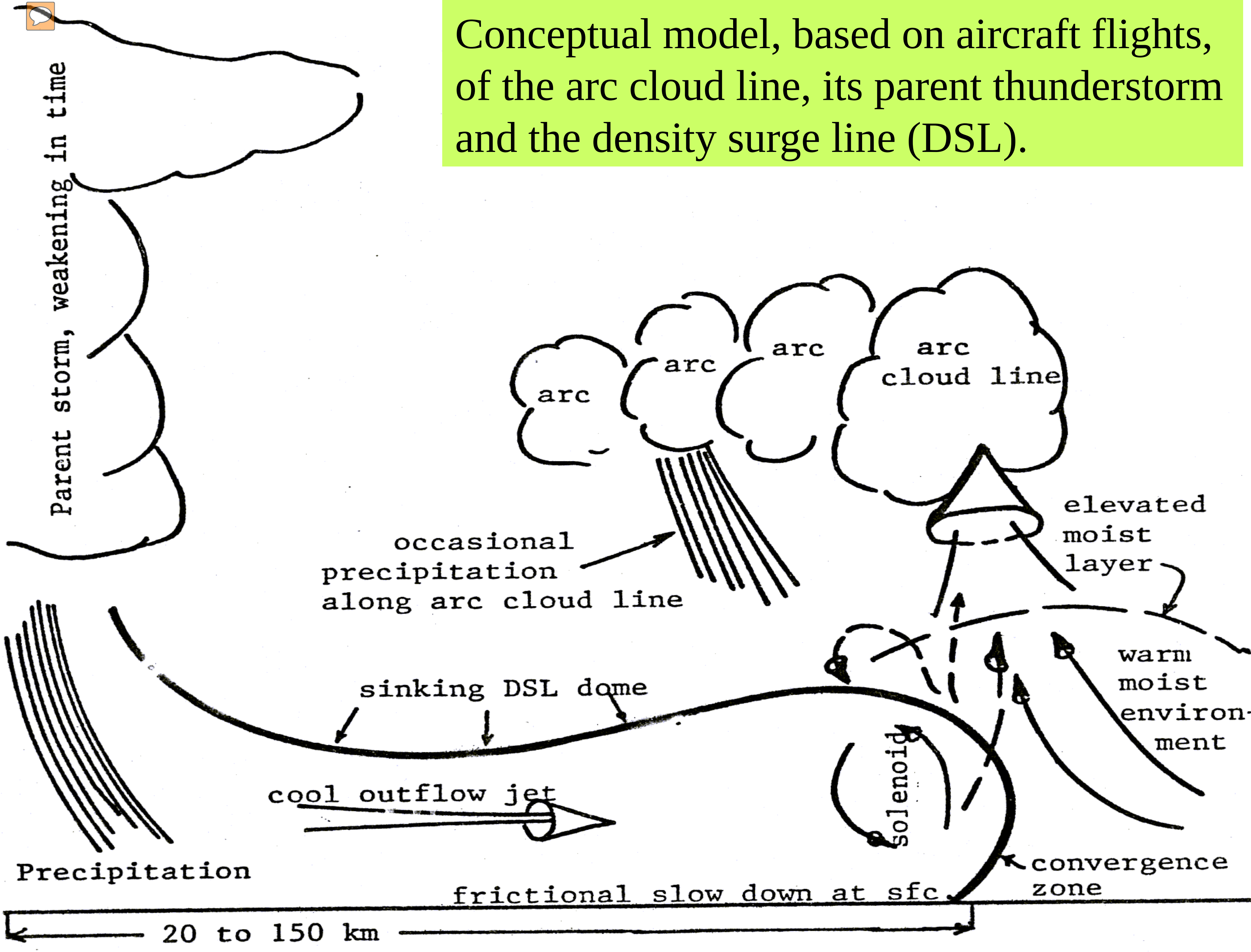
A flight through an arc cloud line





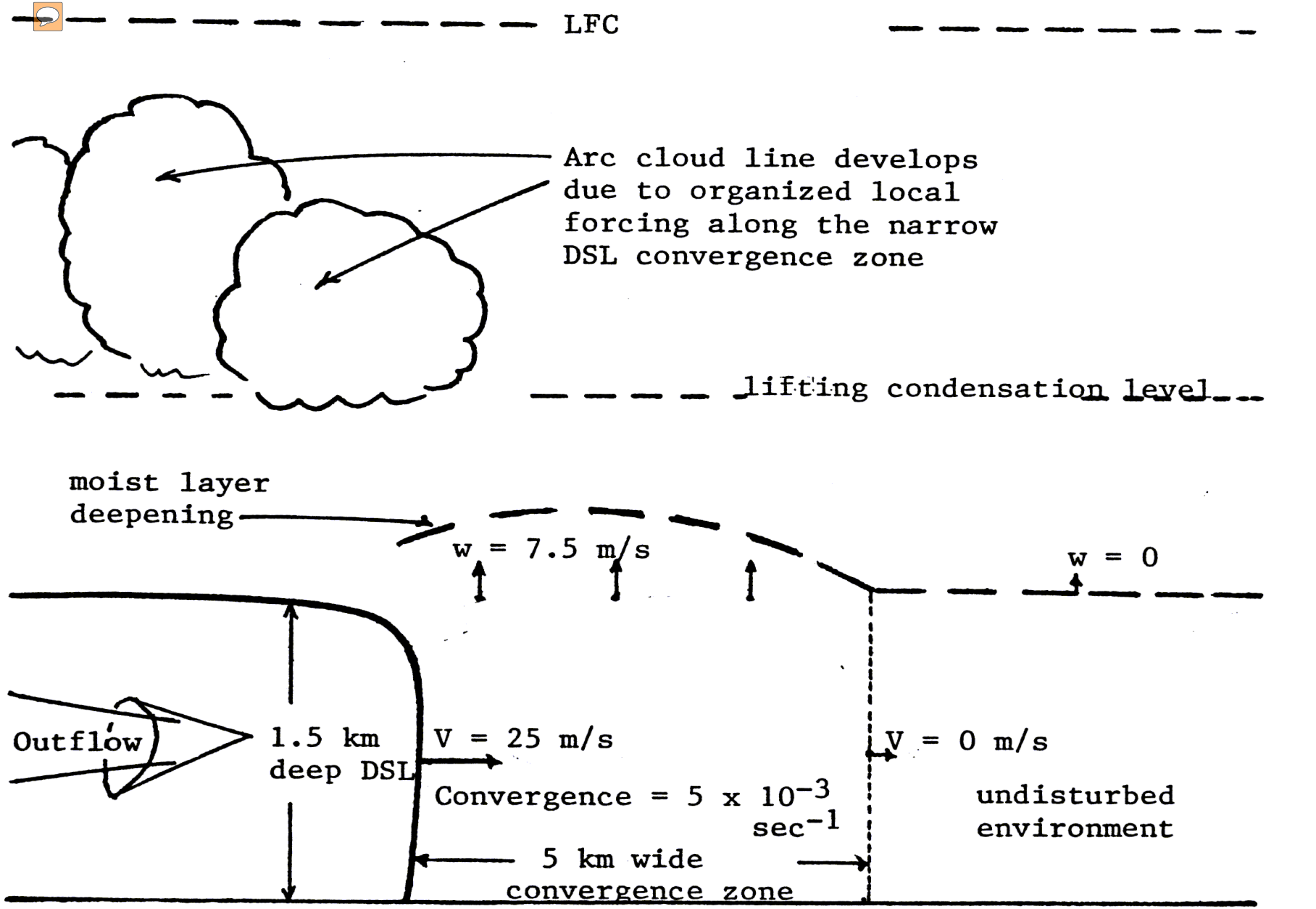
Aircraft data from penetration of an intense arc cloud's sub-cloud region

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



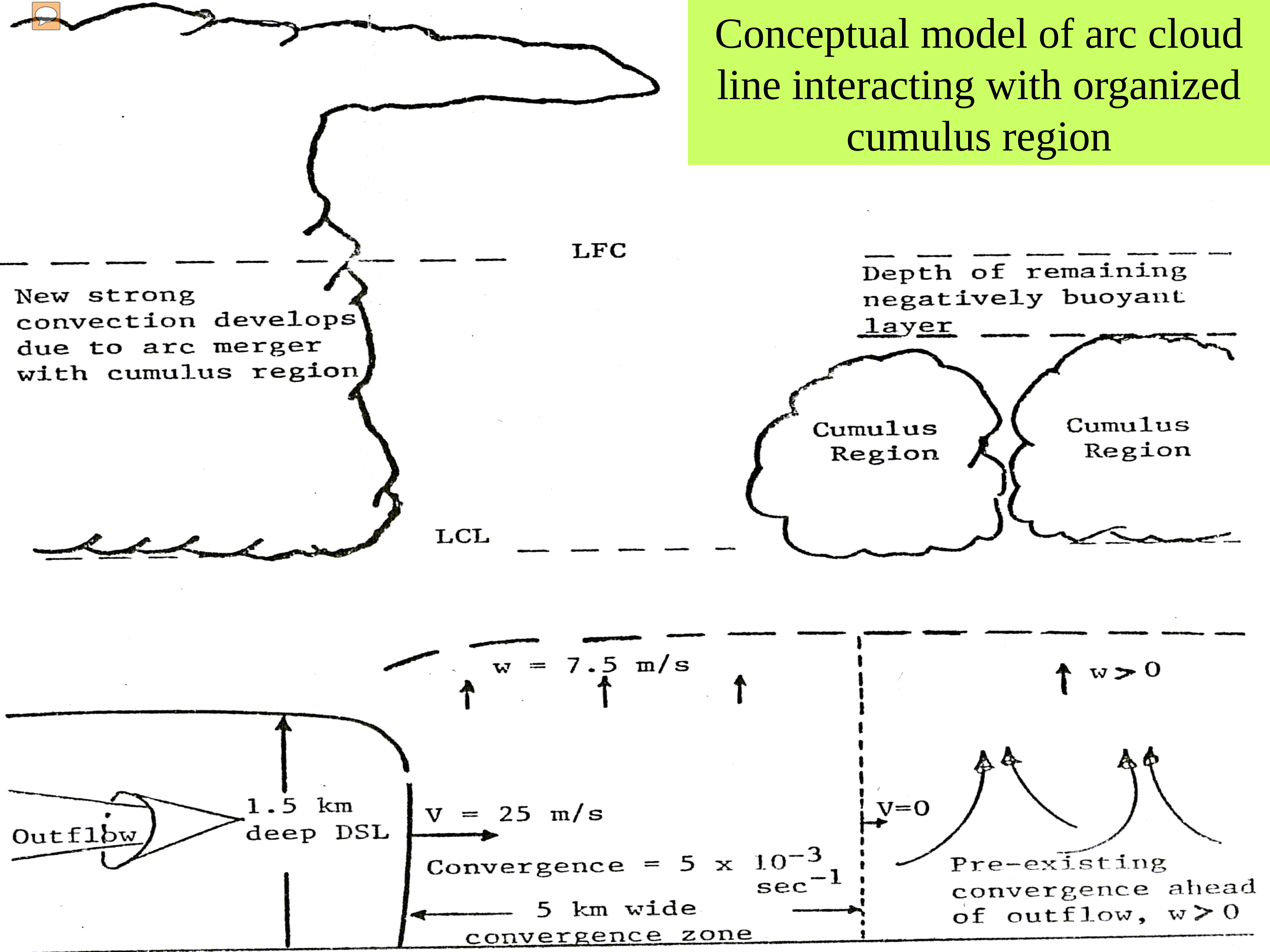
Thunderstorm Outflow Boundaries

- They appear as narrow cumulus lines (on a satellite image) as they advance away from the parent convective region
  - What can you determine from the state of the convection that forms along an outflow boundary
  - What causes new thunderstorm development along some parts of an outflow boundary but not others?



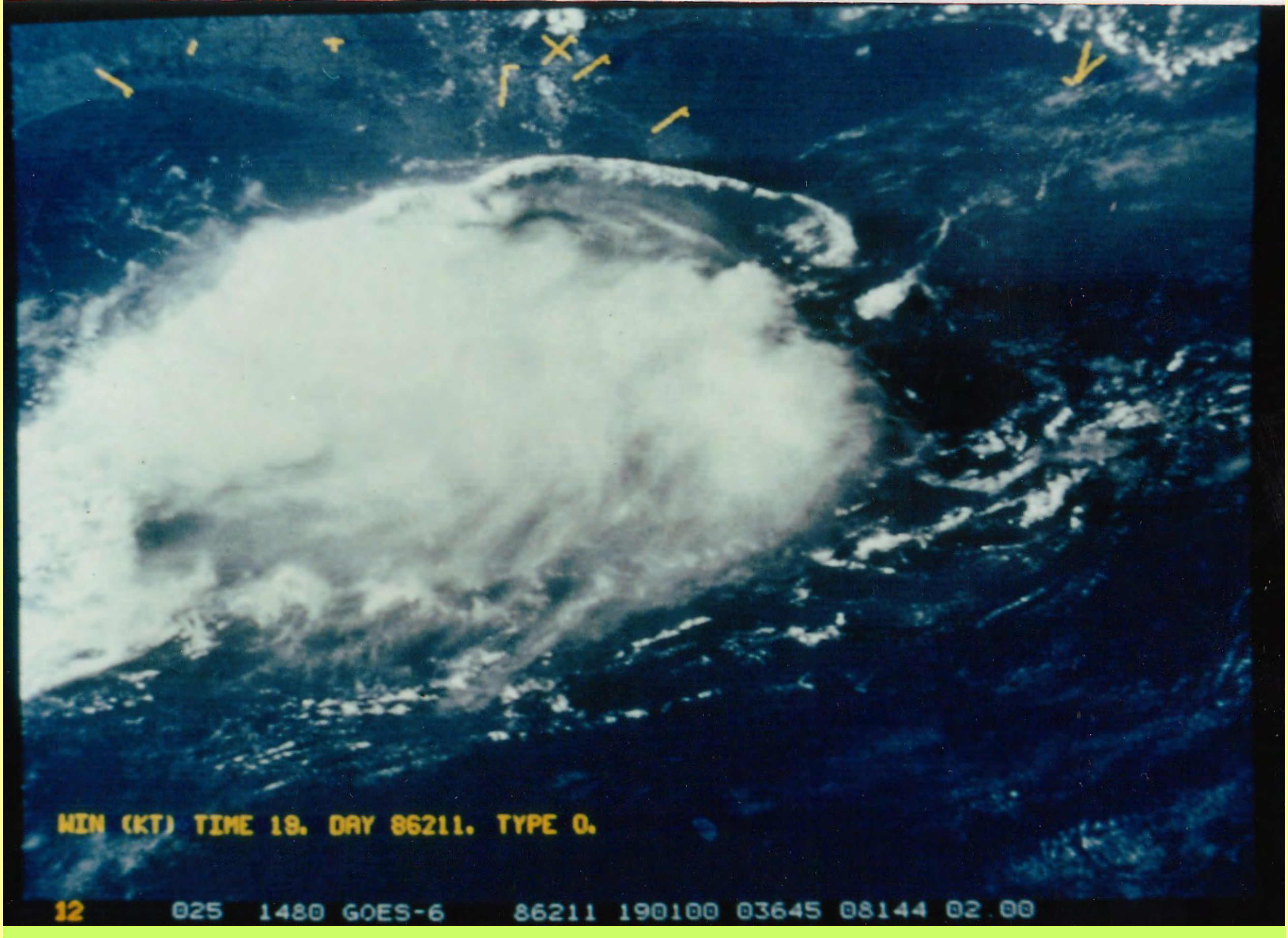
Convergence and vertical motion region associated with the arc cloud

Conceptual model of arc cloud line interacting with organized cumulus region

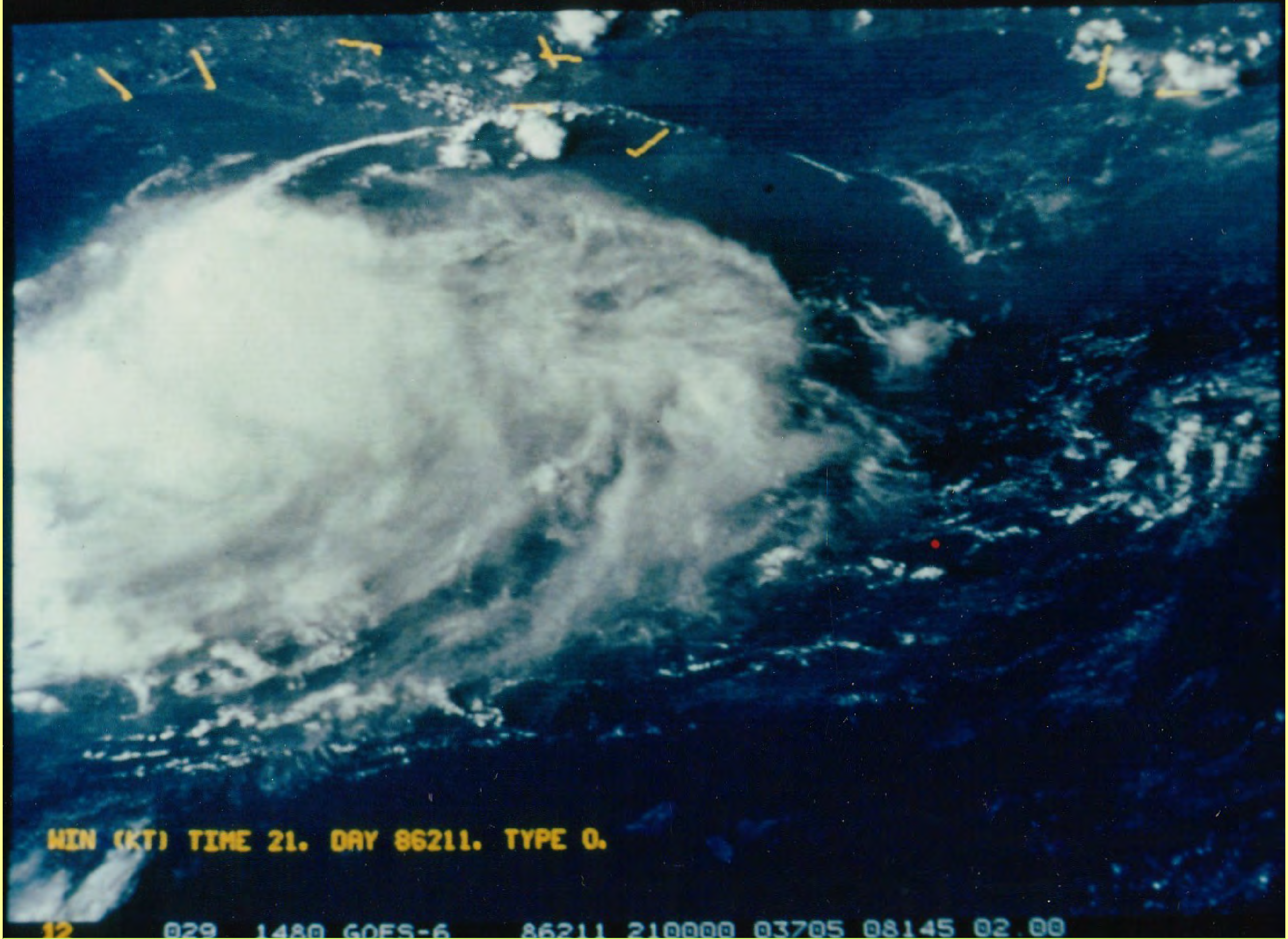


Age of the outflow

- What happens to outflow boundaries as a function of time?
- How can they maintain themselves?
    - What role might vorticity play?
    - What about new showers?
- What happens when outflows merge?
    - Recall the earlier image from a manned spacecraft. What was evident where boundaries merged?

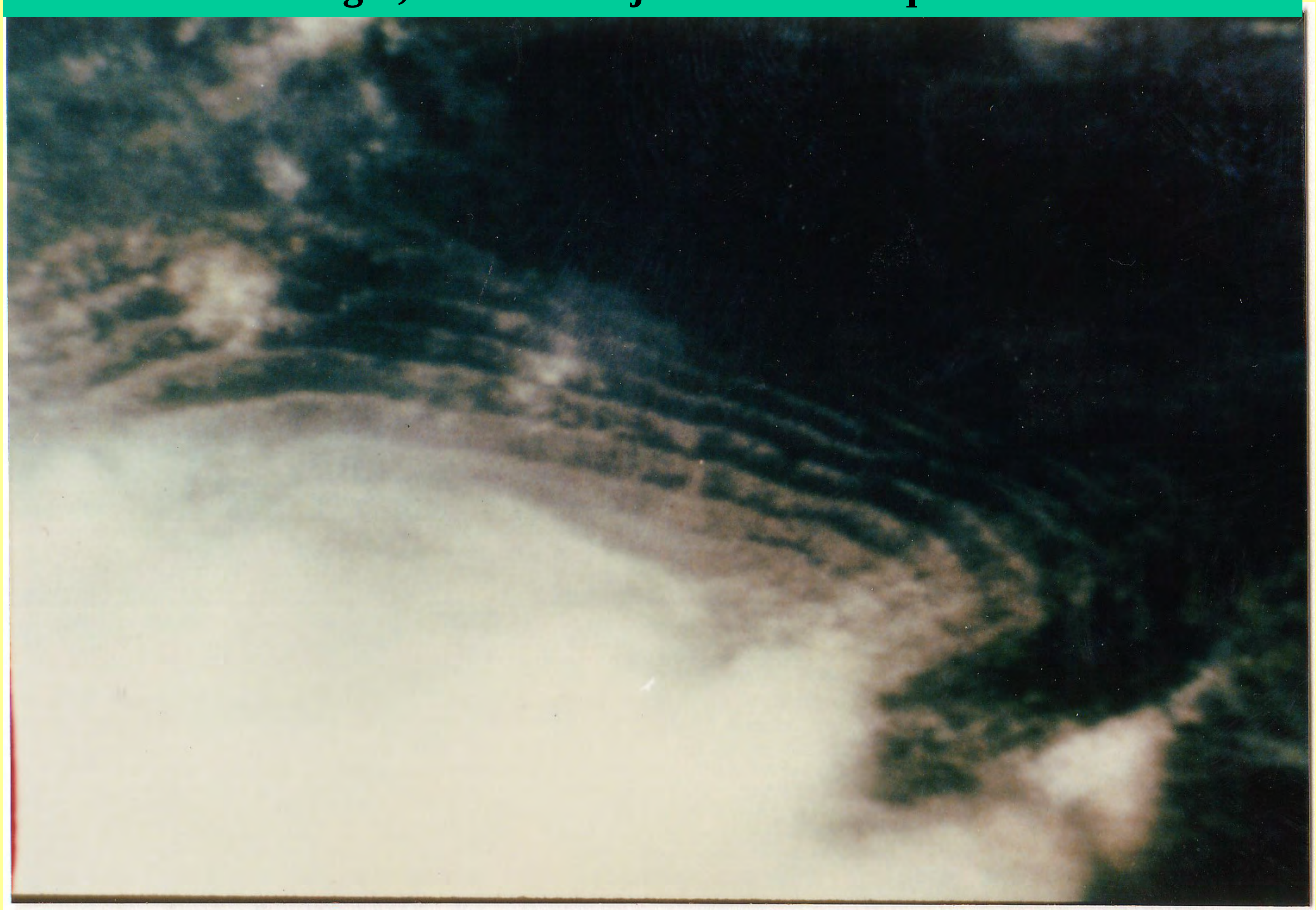


Arc cloud line moving northward from a large convective region over the Gulf of Mexico

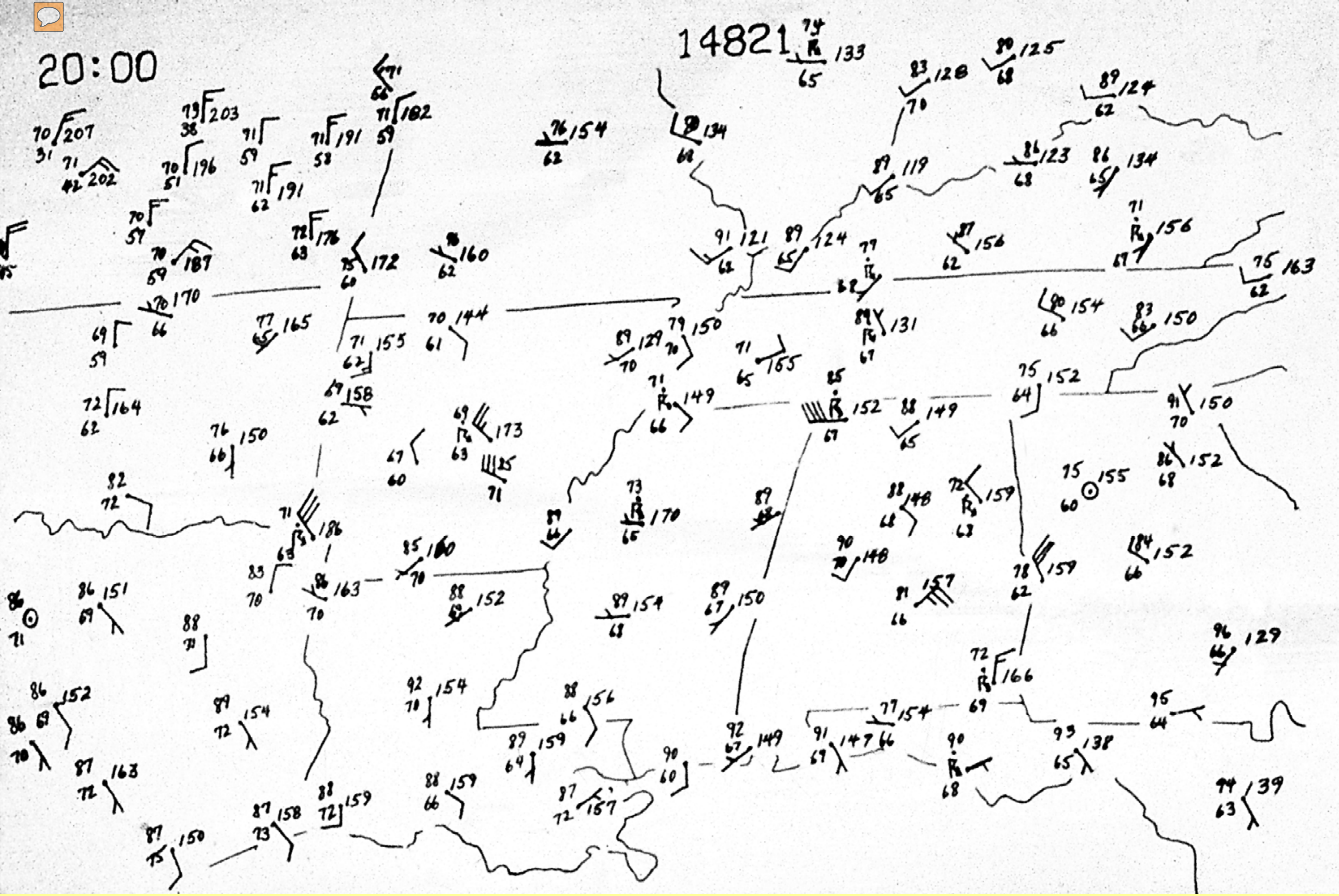


Two hours later the arc cloud line has moved ashore triggering new convection (in preferred locations).

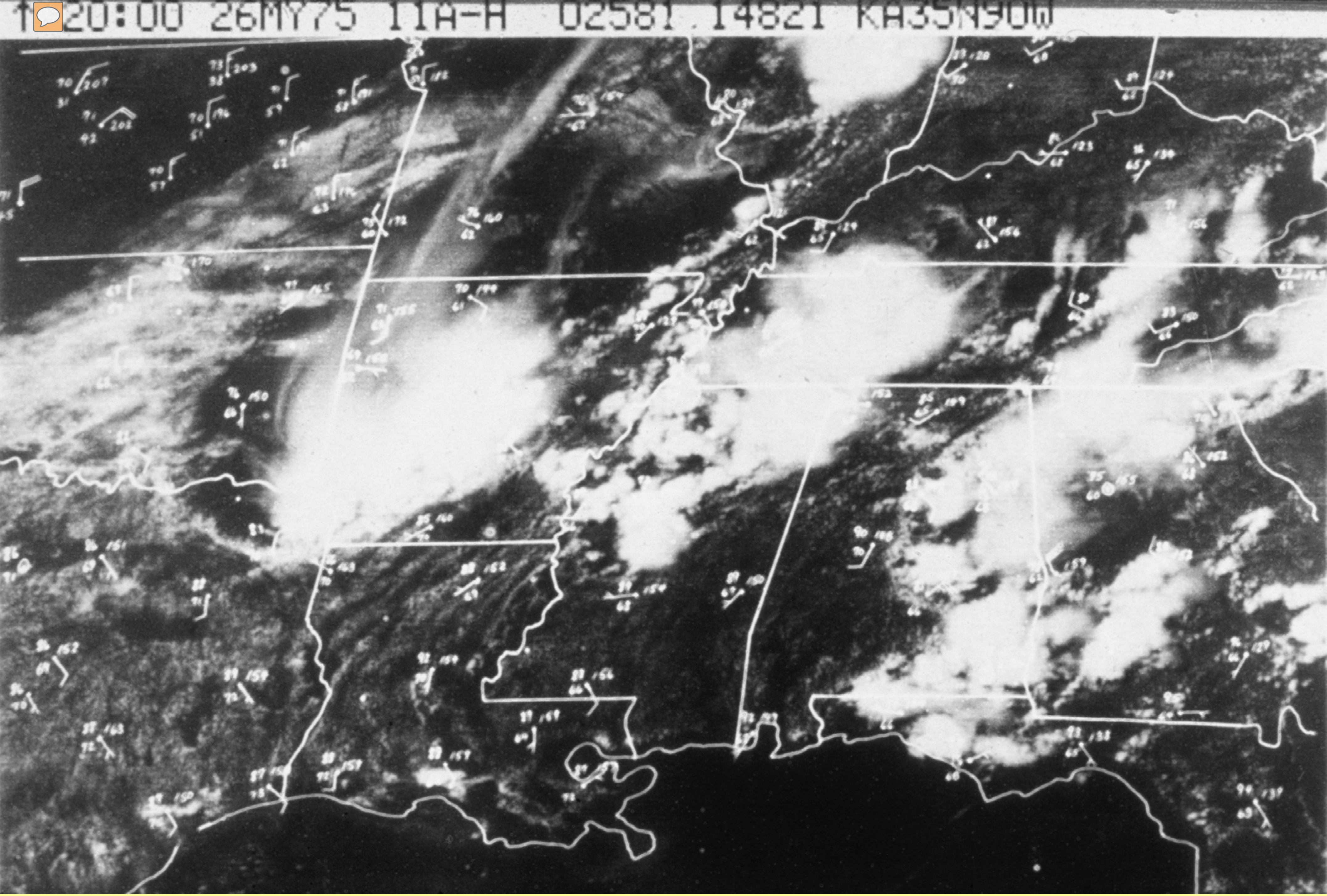
Multiple exposure over time of arc cloud line shown in previous images, which were just two of a sequence.



Notice changes in distance between arcs and their cumulus



What would a mesoscale analysis of this data look like?

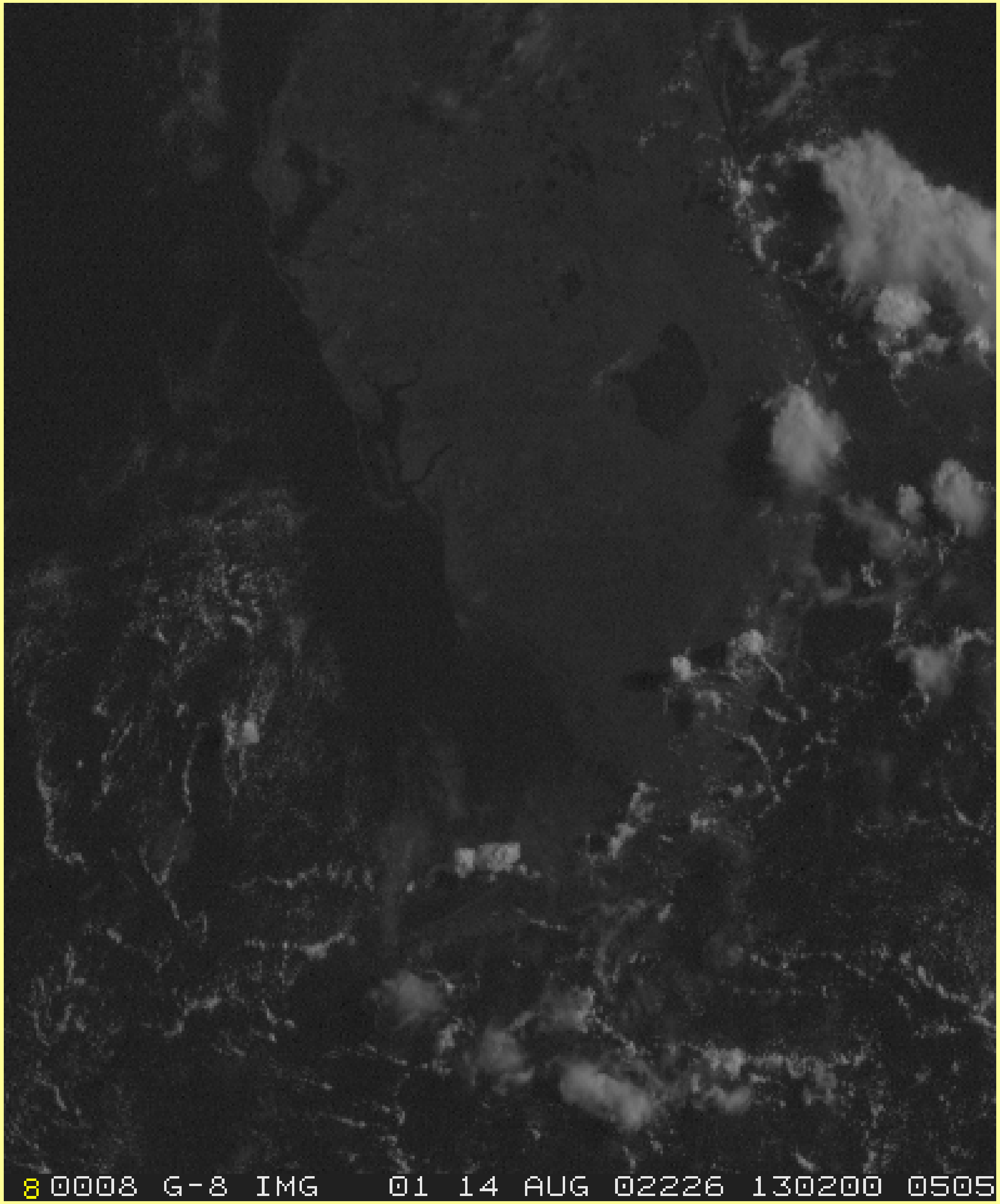


Satellite data guides the mesoscale analysis with mesoscale reasoning

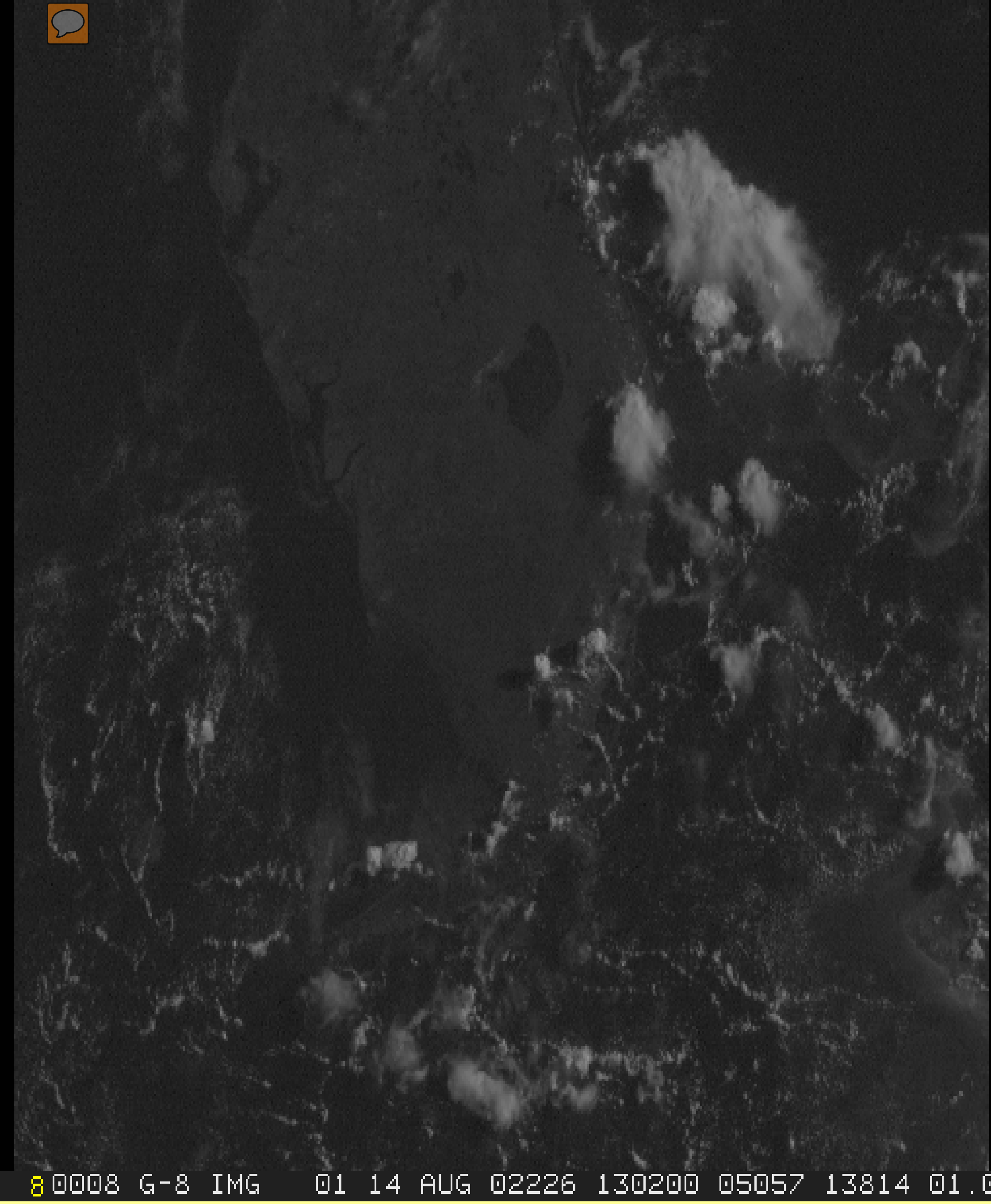
Note where the convection forms: Convective Scale Interaction

Notice how well the cloud field can be analyzed with 250 meter resolution MODIS imagery: here we see the effect of the process.

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.



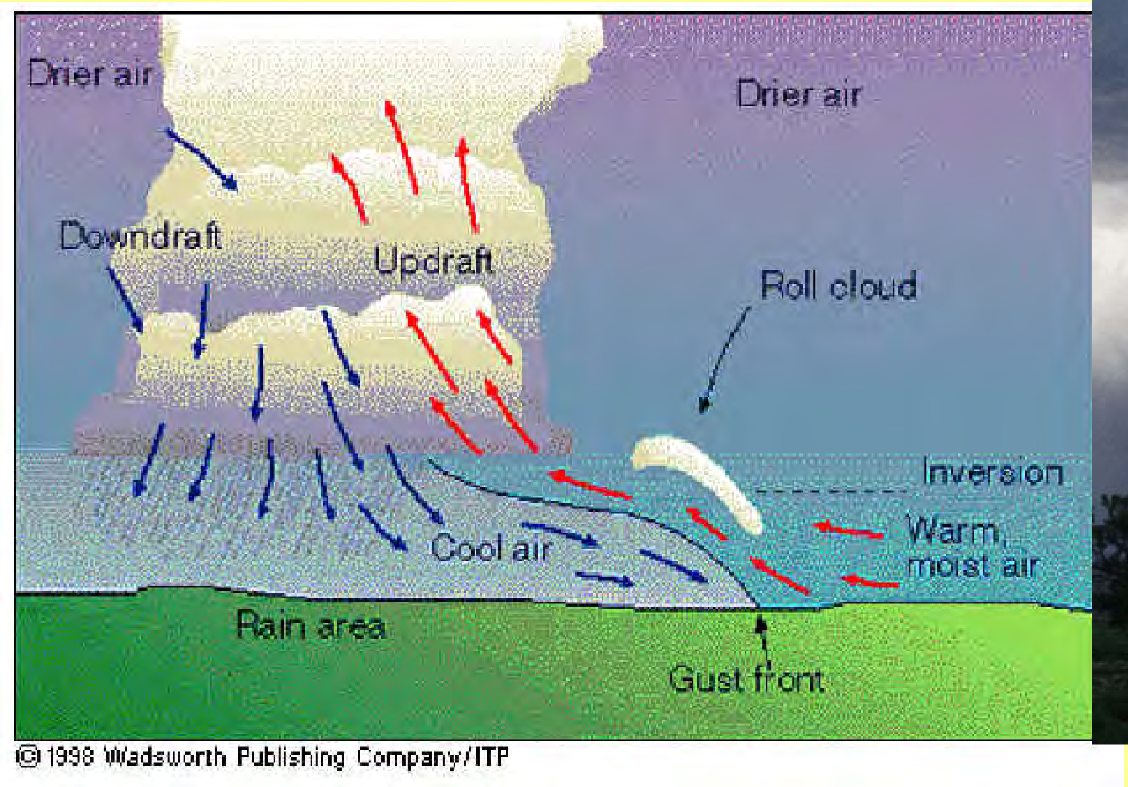
GOES-8 loop for entire day and MODIS true color image near 1615 (right). While noting the convection over land, pay exceptional attention to convection over the ocean.

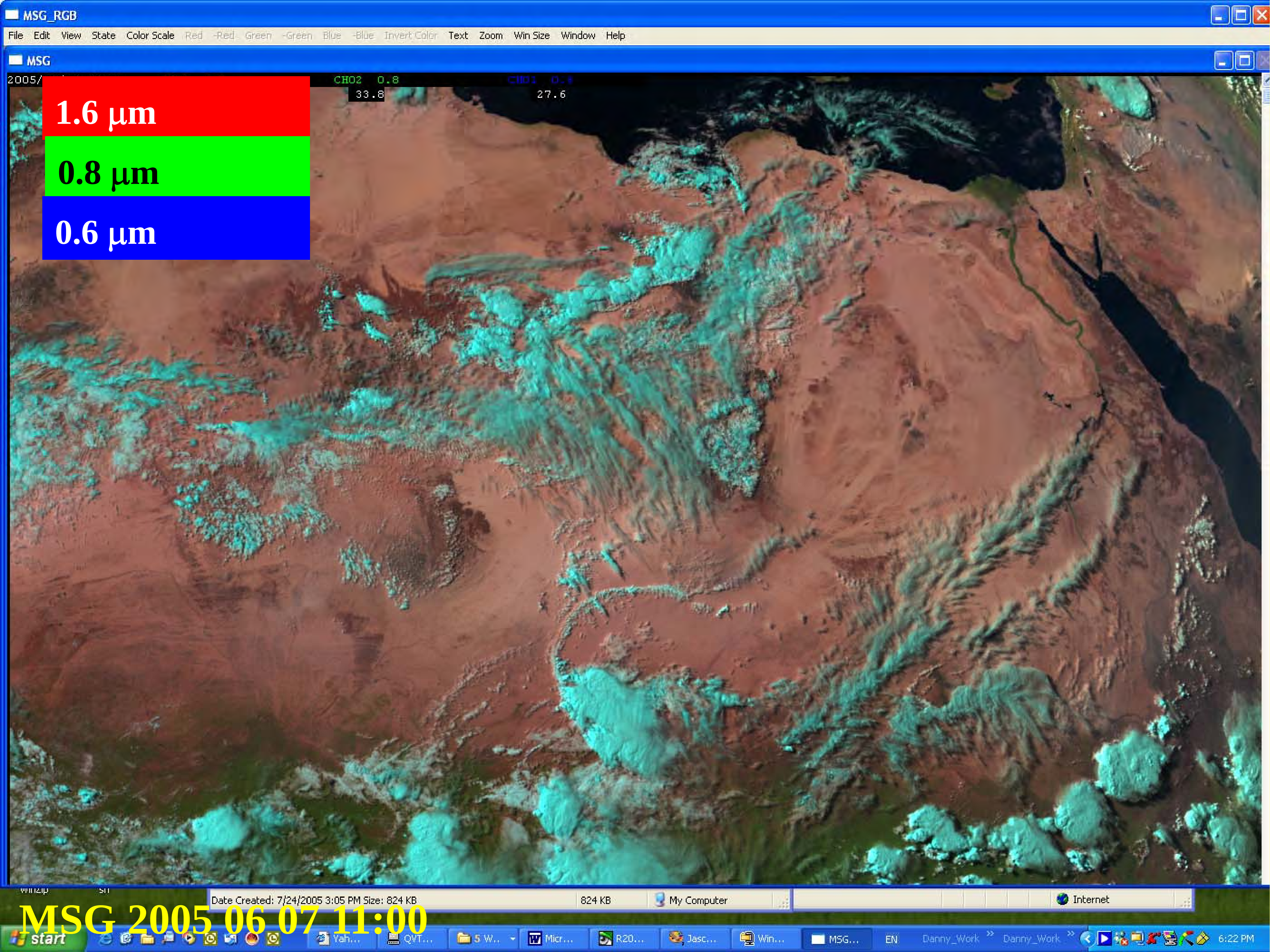
Recent Observations from MSG

Observations of outflow boundaries over Saharan Africa reveal that many dust storms are the result of thunderstorm rainfall into relatively dry air. The dust within the rain-cooled outflow air can be followed using the multi-spectral capabilities of MSG infrared channels at 8.6, 10 and 12 microns. The persistence of these boundaries and their moistened air leads to convective regeneration due to the earlier thunderstorm activity. This is illustrated in the next four slides, the final one in animations.

Rainfall raising dust squalls

Dust squalls triggering rain clouds

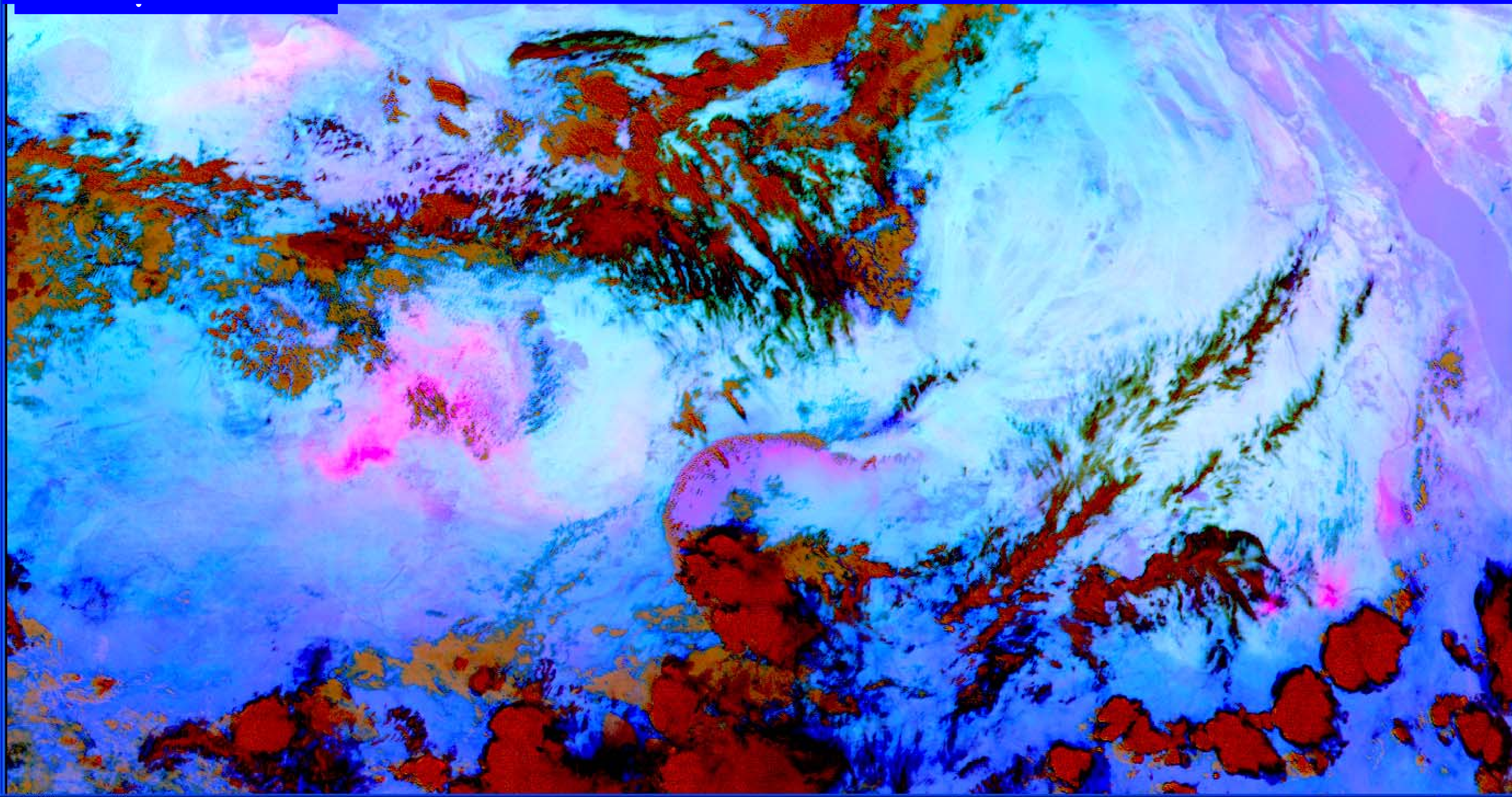



MSG_RGB
File Edit View State Color Scale Red -Red Green -Green Blue -Blue Invert Color Text Zoom Win Size Window Help
MSG
CH02 0.8
33.8
27.6
1.6 µm
0.8 µm
0.6 µm
Date Created: 7/24/2005 3:05 PM Size: 824 KB
824 KB
My Computer
Internet
MSG 2005 06 07 11:00
6:22 PM

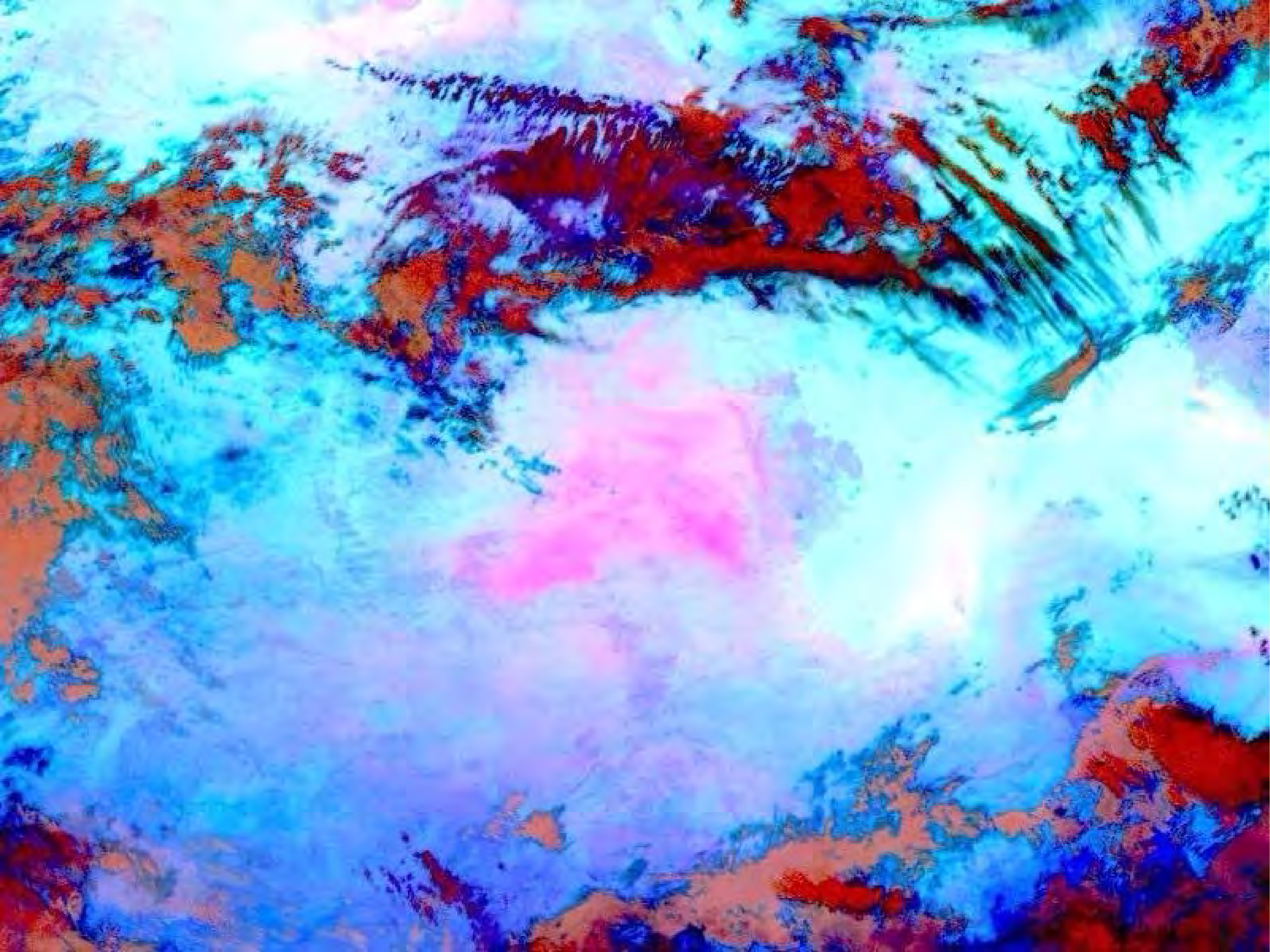
12.0-10.8 µm Dust more red: Dust has negative 10.8-12 µm BTD

10.8-8.7 µm Dust less green on desert background with low ε(8.7)

10.8 µm Dust less blue: Colder than the desert surface



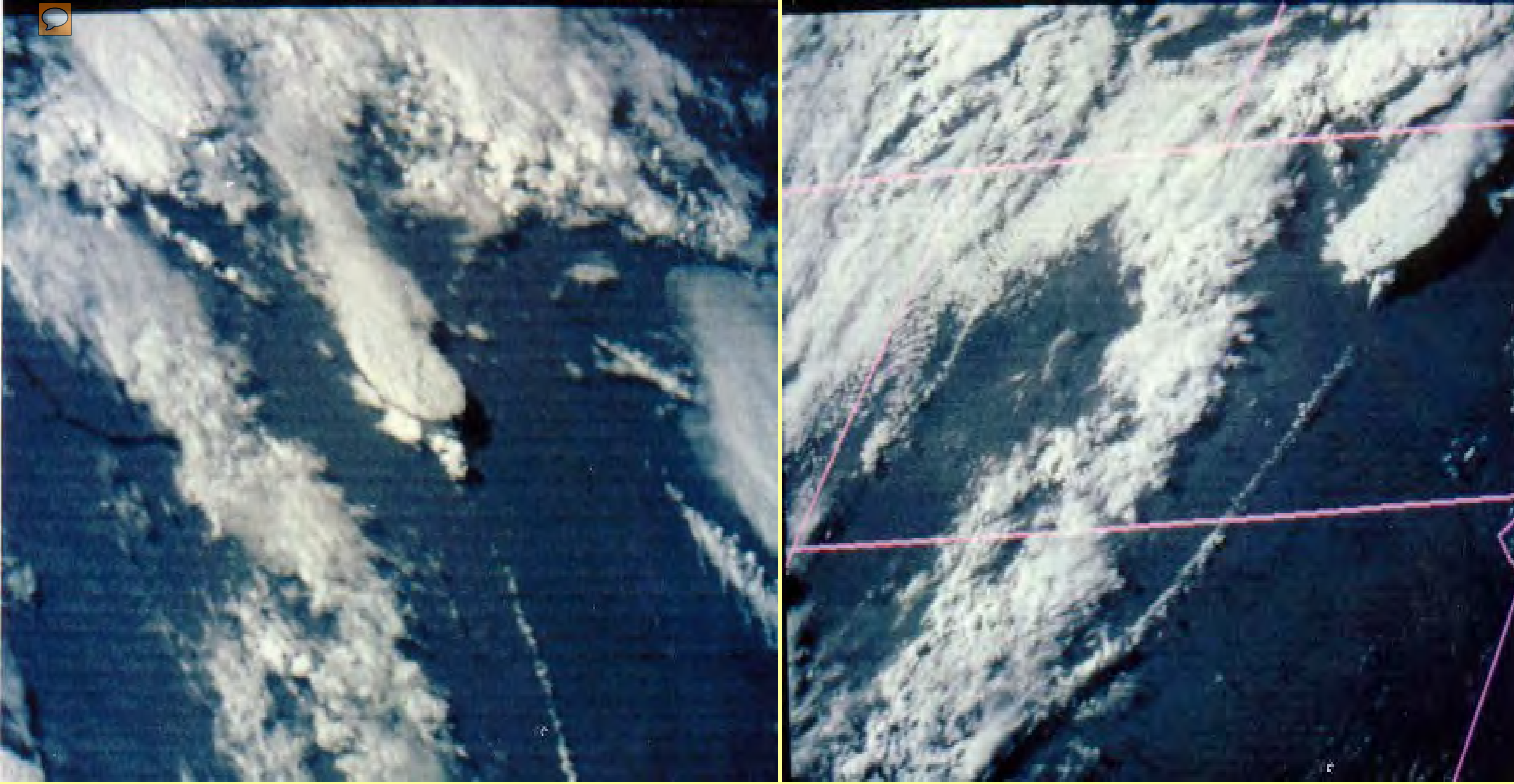
MSG 2005 06 07 11:00



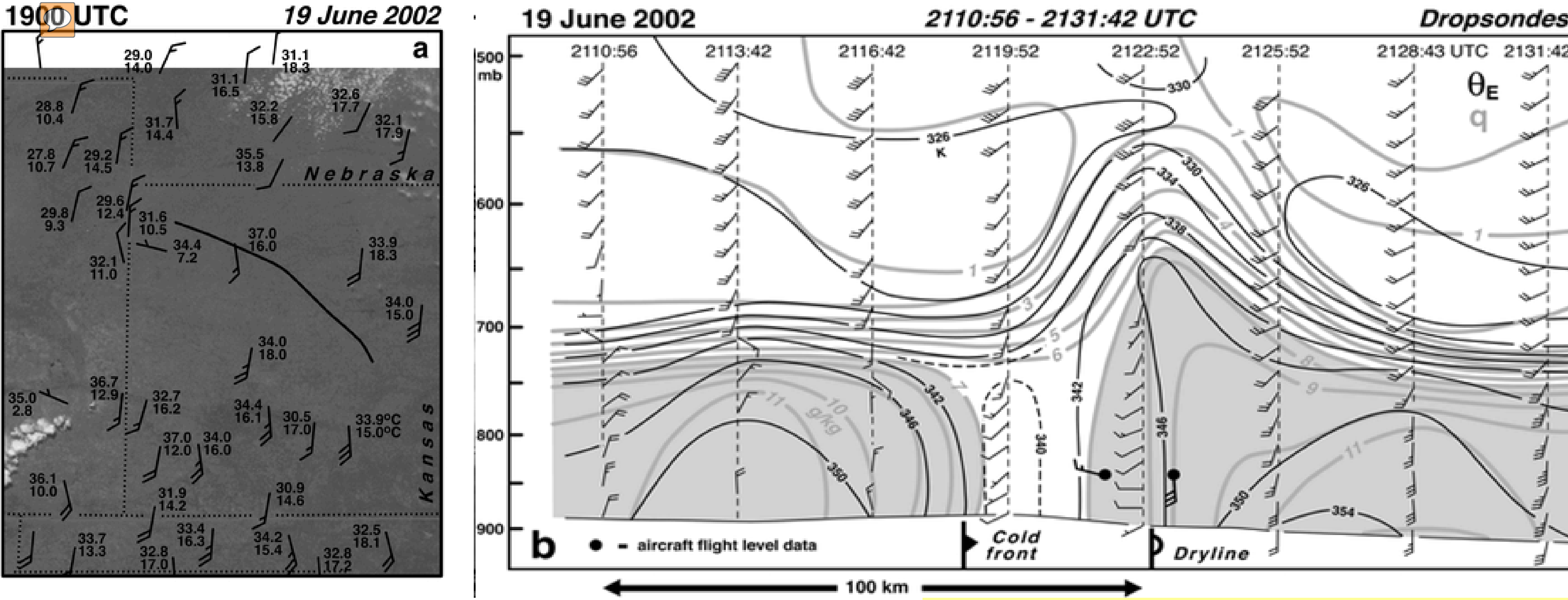
Large scale forcing, convergence zones and organized convection

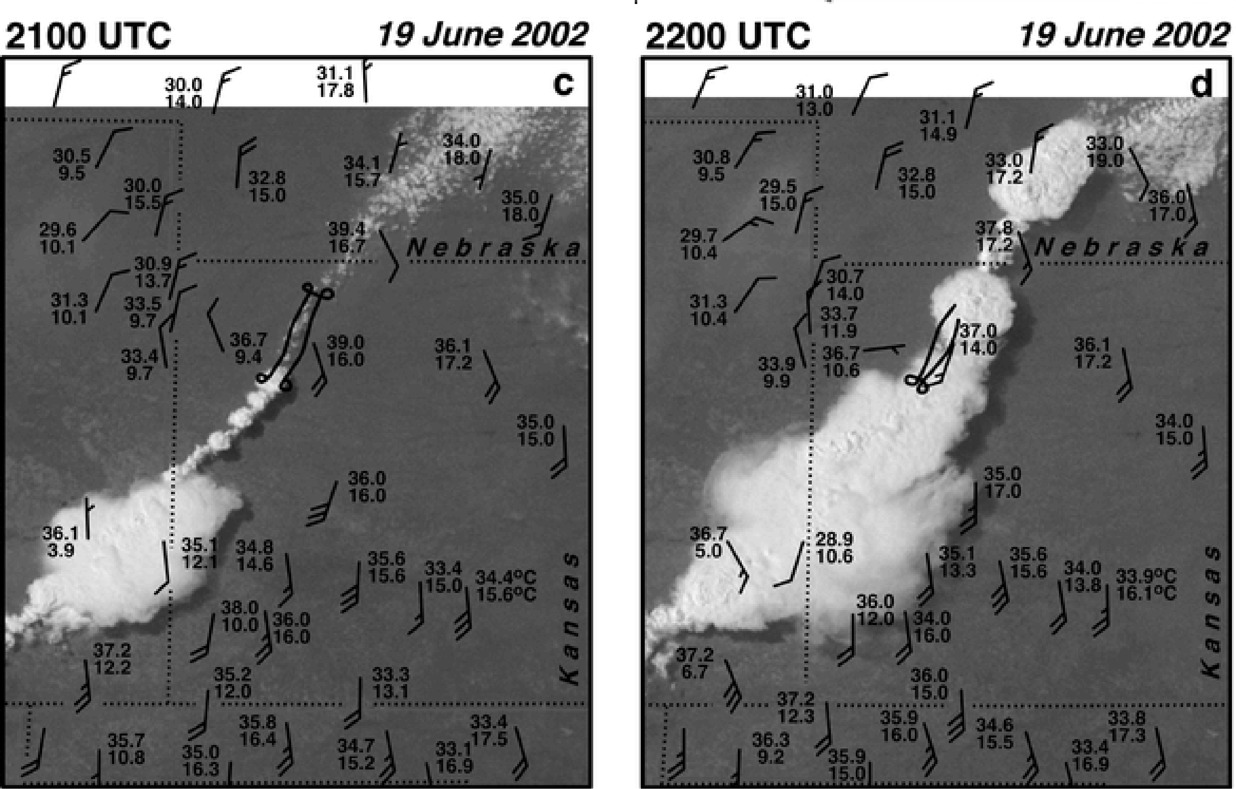
- A short section on large scale forcing and development of storms along synoptic scale convergence zones follows. It focuses on mid-latitude systems, although some of the principles hold for tropical systems. .
- Also included is a discussion on over shooting storm tops and anvil cloud top characteristics
  - **This serves as a lead in for using infrared imagery identifying stronger convection and storms that are likely to be producing heaver rainfall**

Please read accompanying notes section before proceeding with presentation. Detailed notes are not necessarily included with each slide. Some principals may be generalized while others require caution.

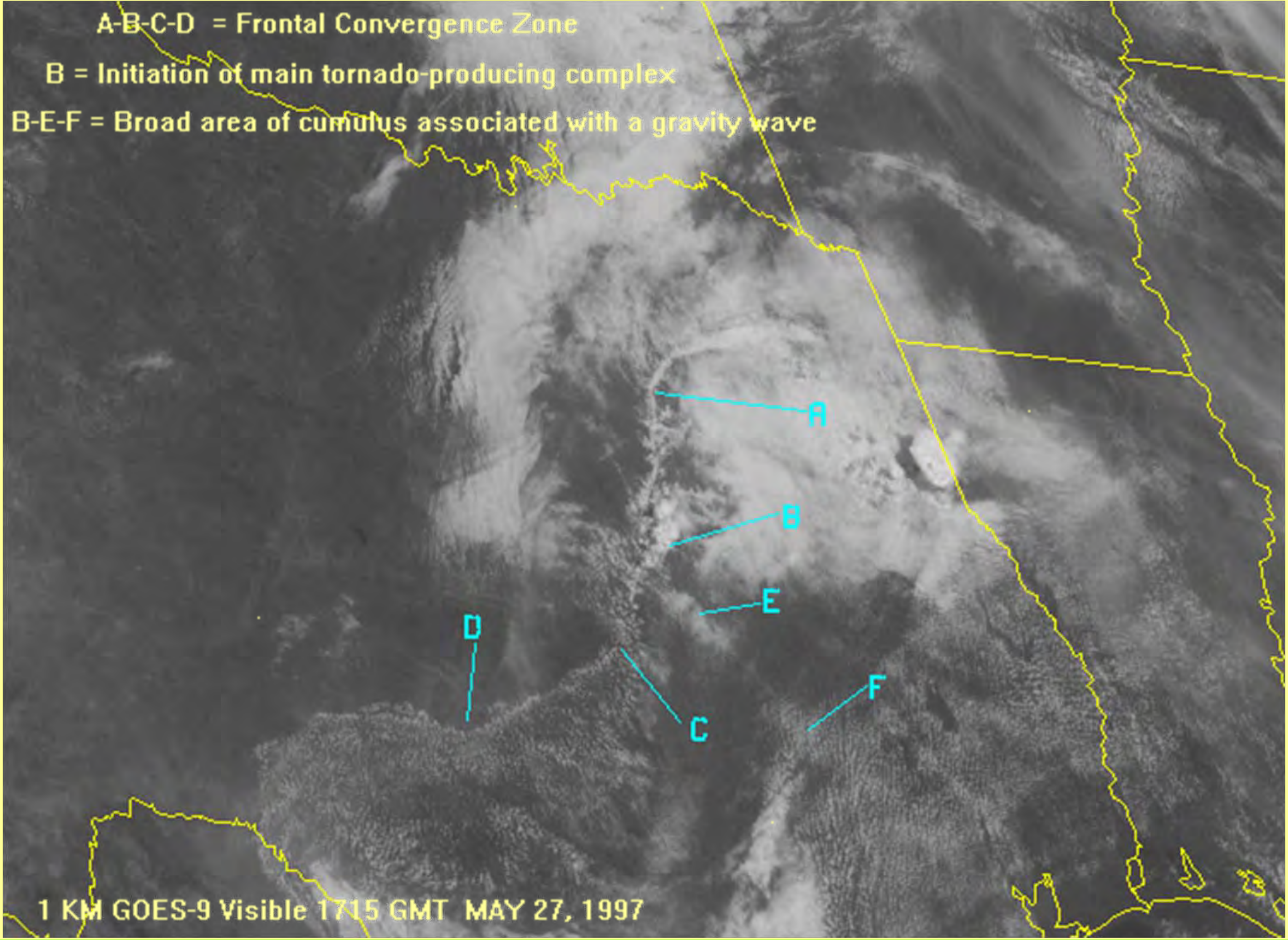


Organized line of cumulus and cumulus congestus are being generated along a well organized convergence zone, with a well formed thunderstorm along that line. Note the difference in perspective when viewing the thunderstorm with GOES East (right) and GOES-West (left). The formation of cumulus along organized convergence lines such as fronts and pre-frontal troughs prior to thunderstorm development is a common feature that allows for better nowcasting of squall line development.

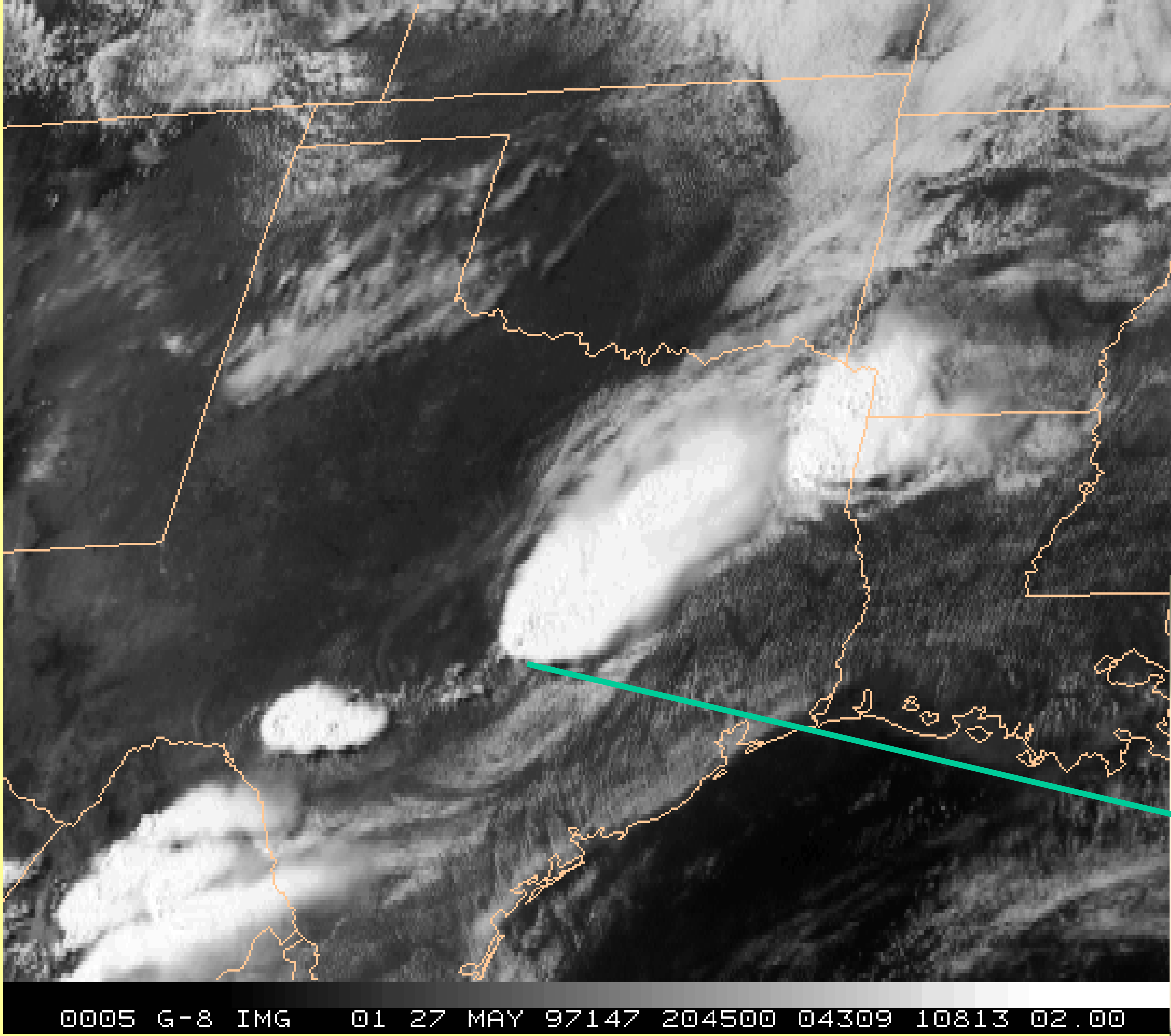




Numerous studies have highlighted the importance of knowing the disribution of water vapor in predicting convective development and evolution. The location where convection initiates is denoted by the upward bulge in the isopleths of mixing ratio (*q*) and $\theta_{[E]}$.



GOES-West view of organized cumulus convection along convergence zone ABCD, with convection being triggered at B by gravity wave EF

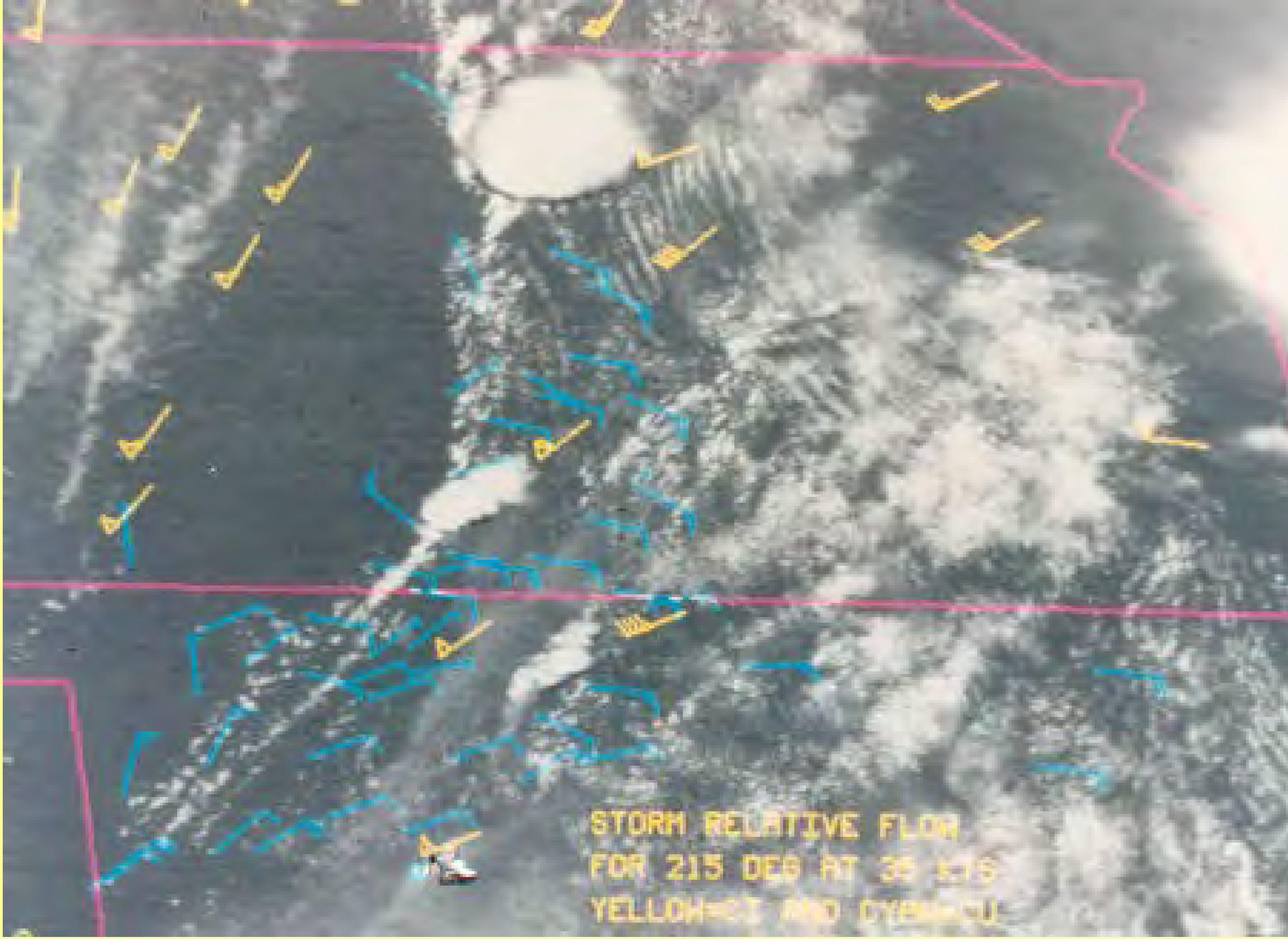


Developed squall line (from GOES East) and tornado

Nowcasting requires information on mesoscale thermodynamic structure of atmosphere, cloud type and vertical wind shear

Important for Nowcasting Convection and Severe Weather

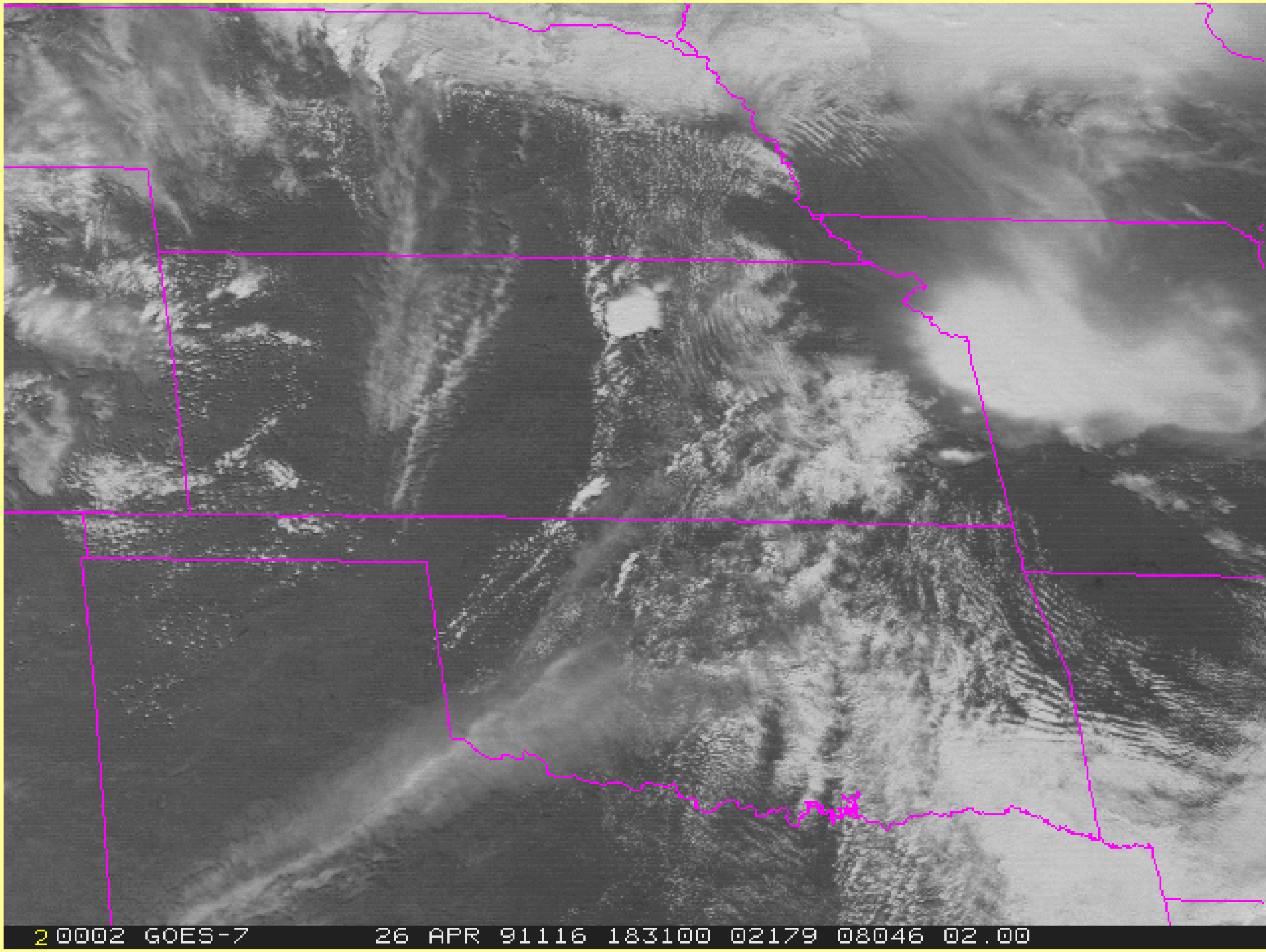
- Vertical wind shear
- Evolving instability field
- Strength of storm produced cold pool
- Updraft strength
- Anvil characteristics
  Development
  Temperature structure
- Storm-environment interaction
- Cloud top rotation
- Storm damage



Thunderstorms developing along a cold front. Note the organization of the developing squall line as well as the cloud field ahead of it.

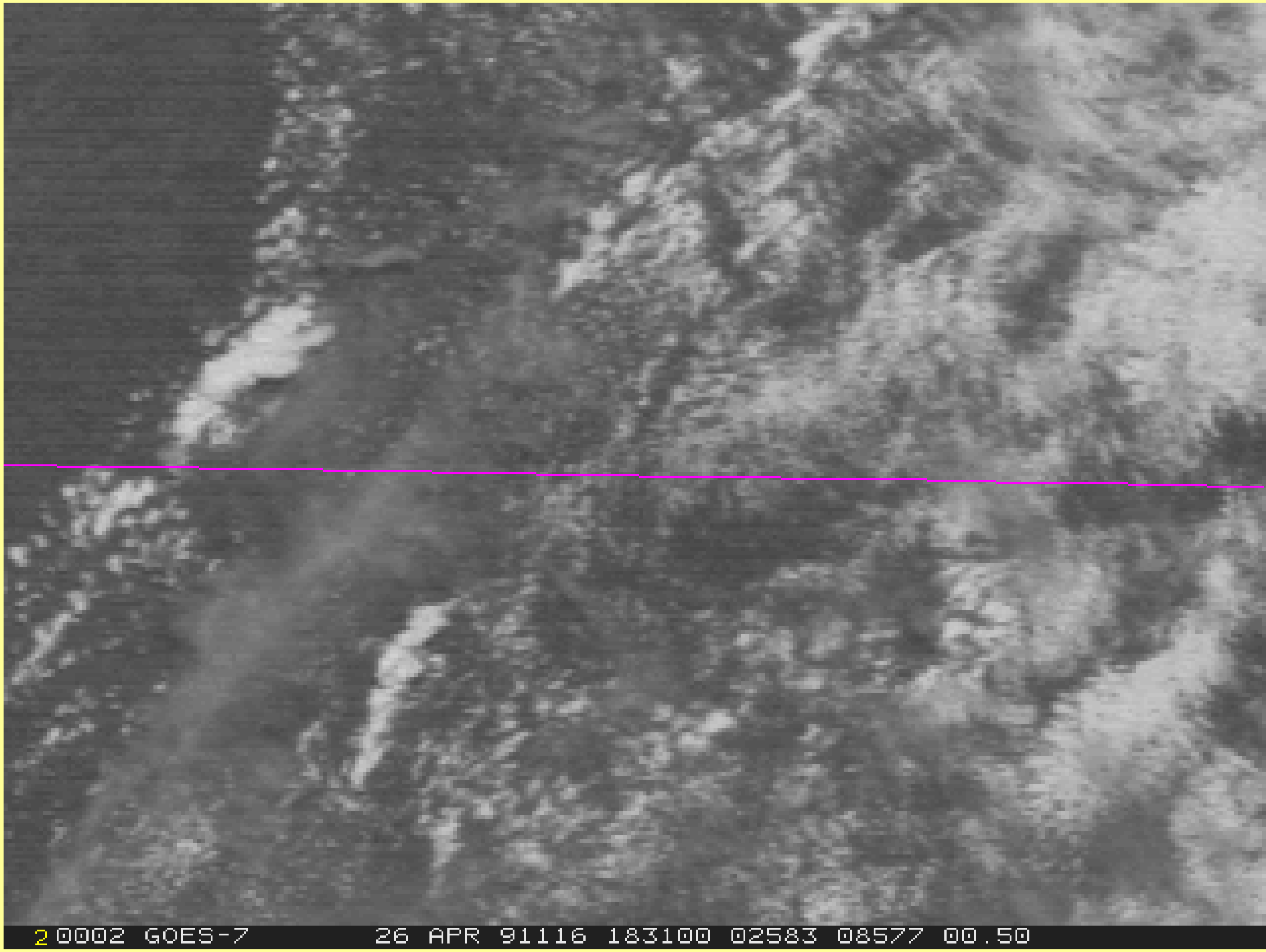
April 21, 1991 Tornado Outbreak

- 2 km visible
- 1831-0030 Z
- **Earth Relative Motion**
- Main severe outbreak across Kansas & Oklahoma
- Note cirrus motion and squall line development



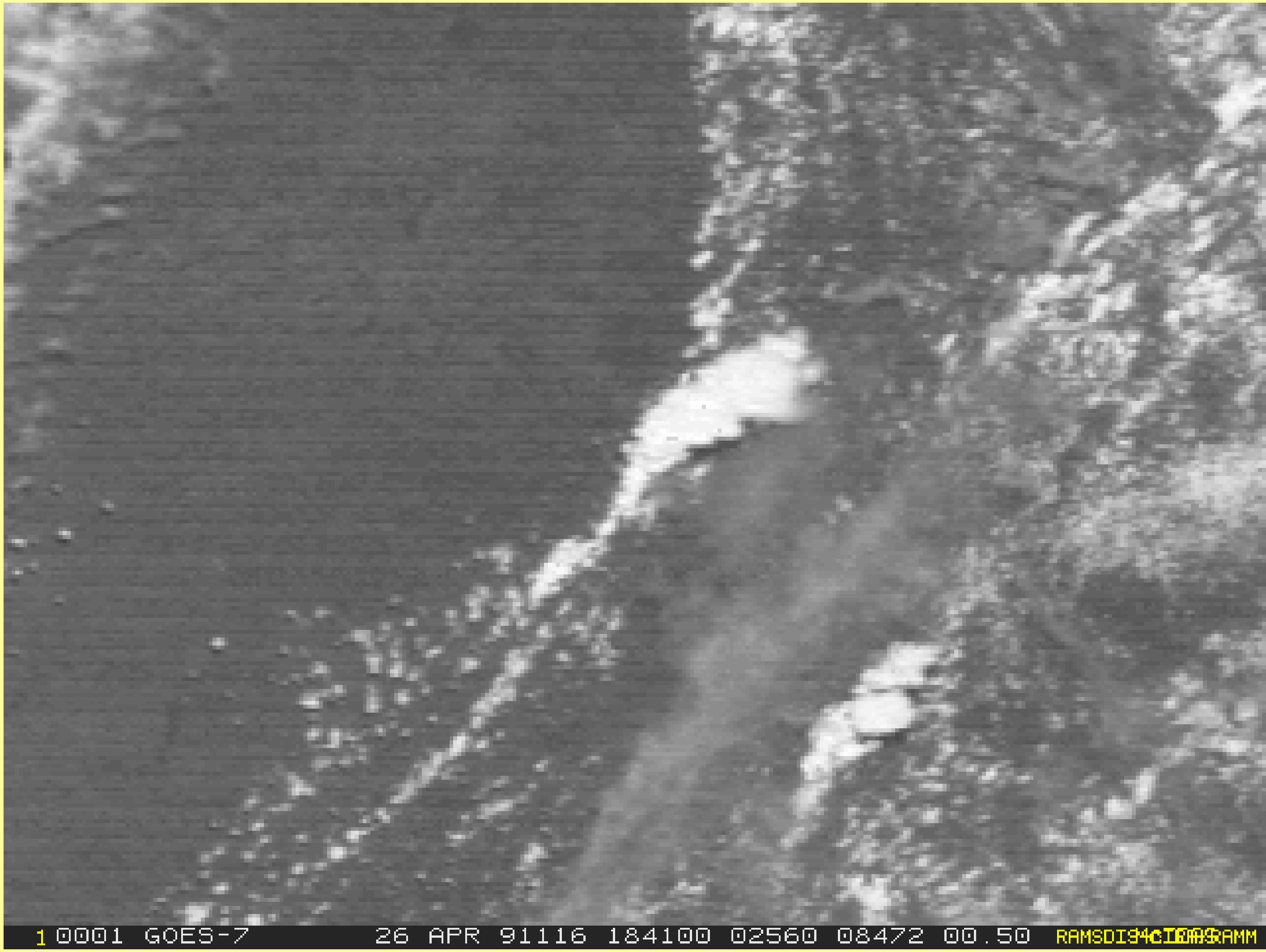
April 21, 1991 Tornado Outbreak

- 1 km visible zoomed to ½ km scale
- 1831-0030 Z
- **Earth Relative Motion**
- Across Kansas & Oklahoma boarder
- Note cumulus flow, overshooting tops and cirrus motions



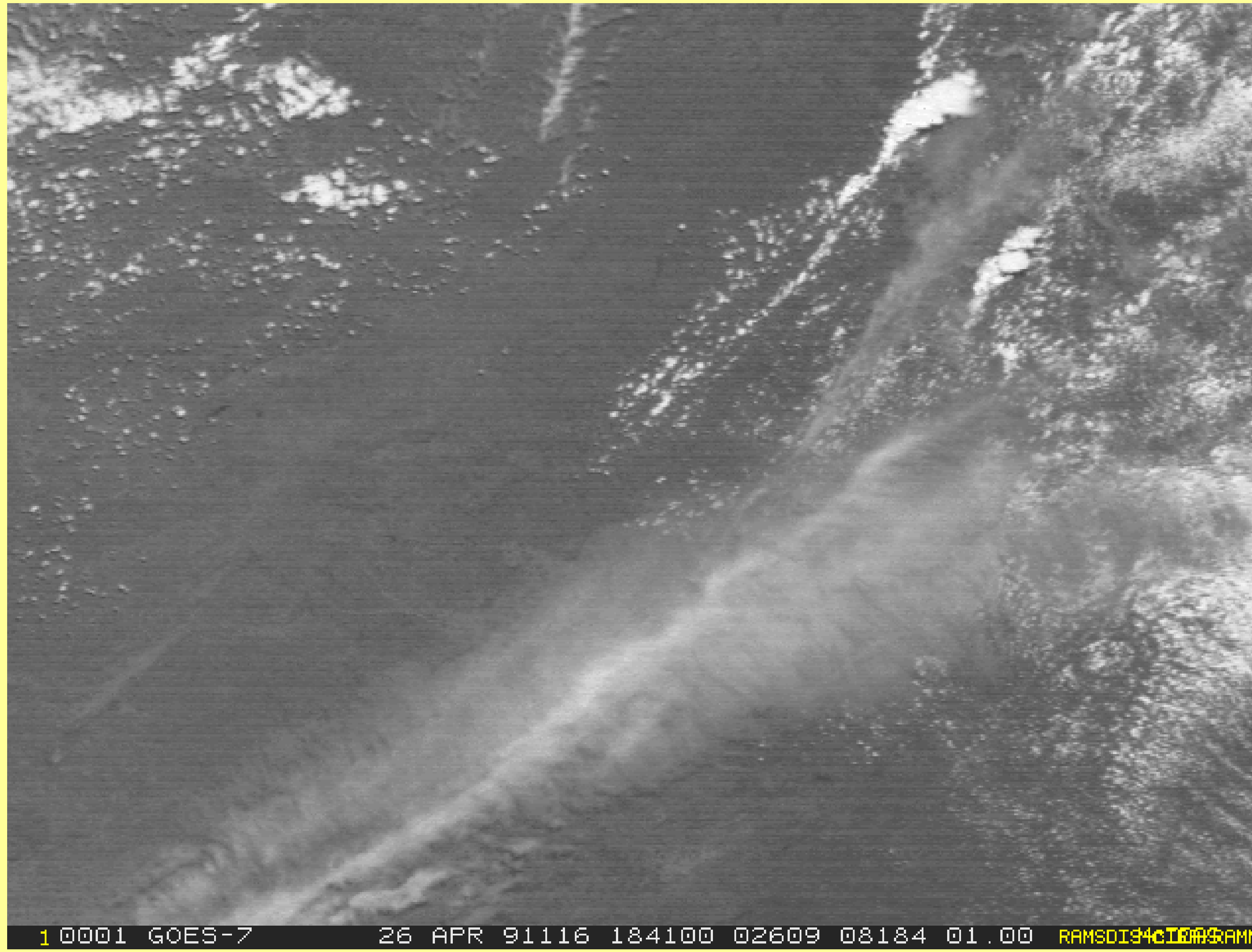
April 21, 1991 Tornado Outbreak

- 1 km visible zoomed to ½ km scale
- 1841-2030 Z
- **Storm Relative Motion**
- Across Kansas & Oklahoma boarder
- Note low level moist flow and shear in cloud layer relative to developing storms and storm effect on low level environment



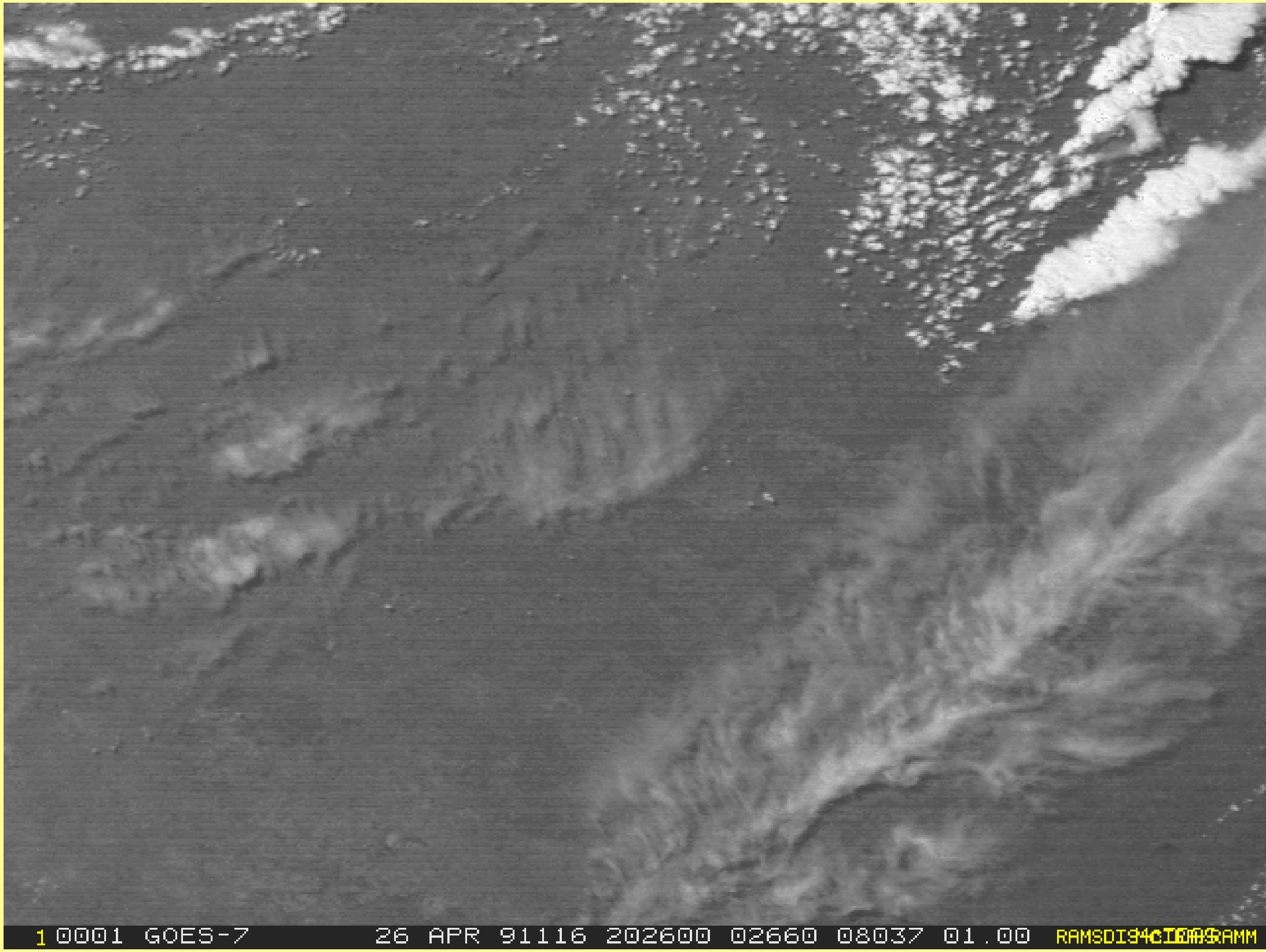
April 21, 1991 Tornado Outbreak

- 1 km visible
- 1841- 0001 Z
- **Storm Relative Motion**
- Across Kansas & Oklahoma boarder
- Note low level moist flow and shear in cloud layer relative to developing storms and storm effect on low level environment

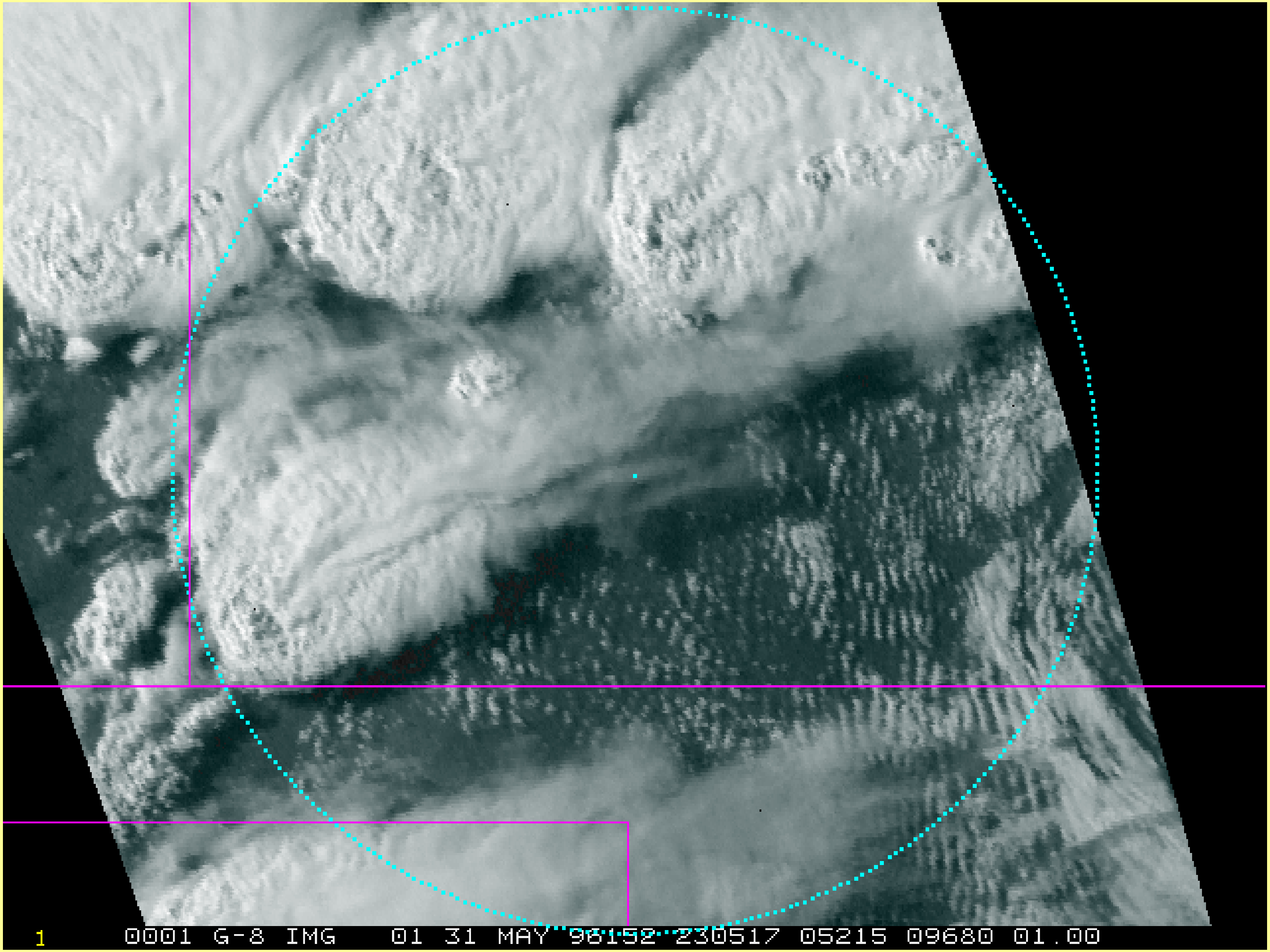


April 21, 1991 Tornado Outbreak

- 1 km visible
- 2026-0001 Z
- **Cirrus Relative Motion**
- Note storm effect on upper flow



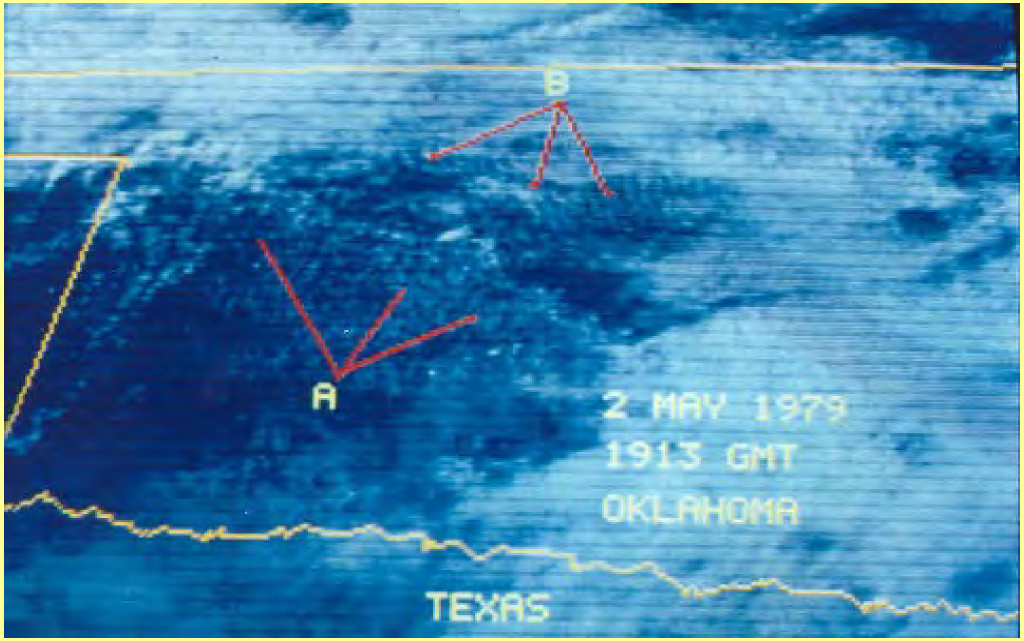
One minute visible imagery of severe storms. Note the cumulus in the warm sector: this appearance is typical of cumulus capped by an inversion layer.
The other capping layer is the tropopause: note the overshooting tops and long plumes of downstream cirrus above the anvil (typical for a long lived super-cell).

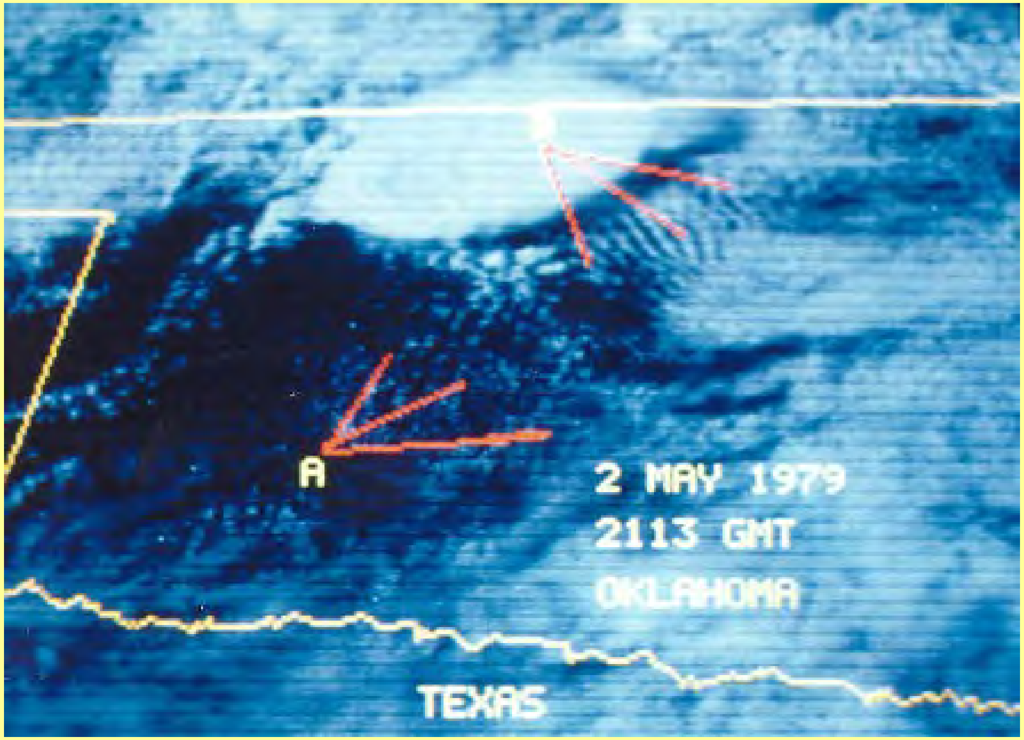


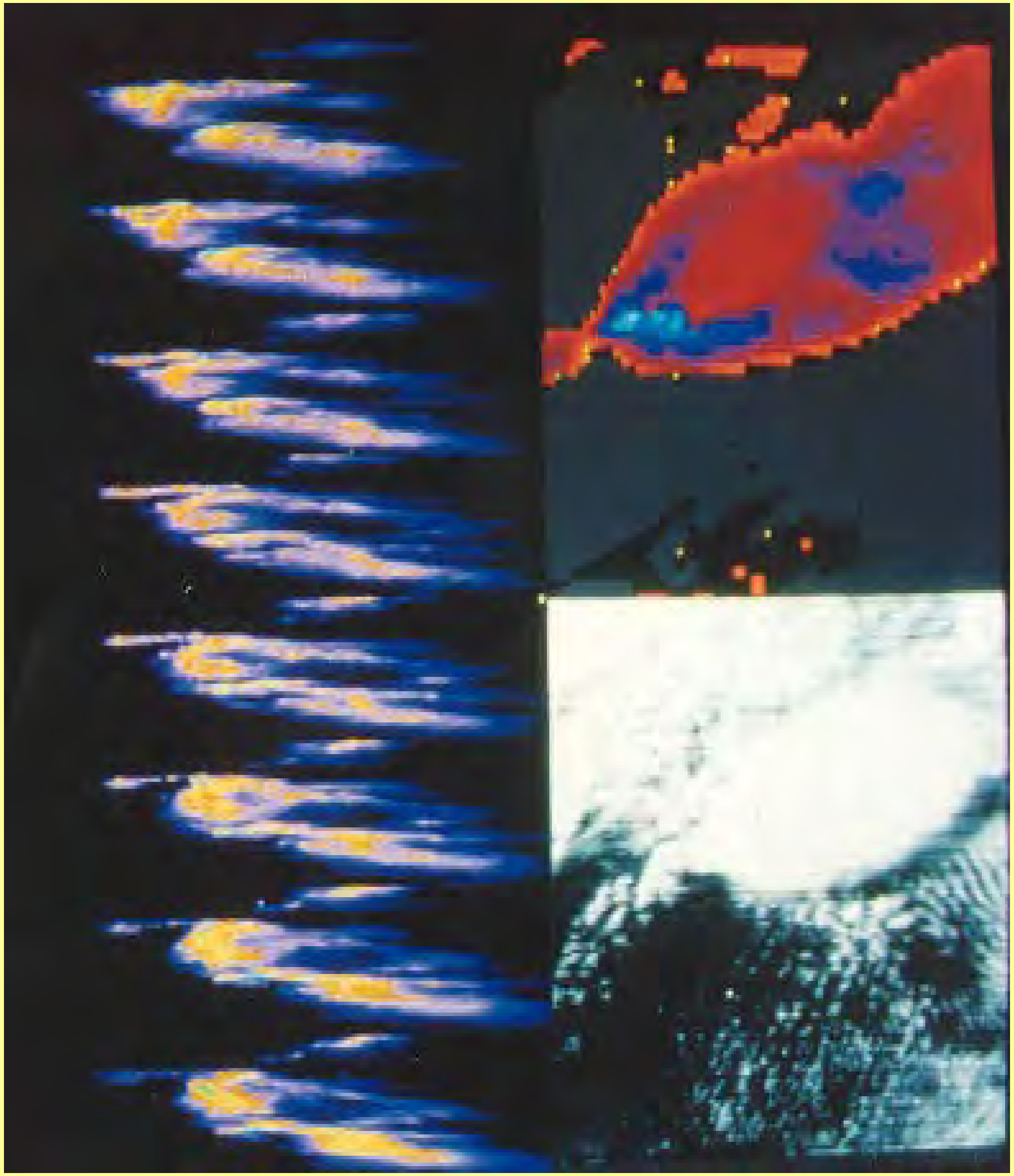
Vorticity - On the local scale Helping a storm become severe

- Convergence on preexisting vorticity
- Tilting of vorticity from one plane to another
- Advection from one place to another
- Differential heating
- Friction

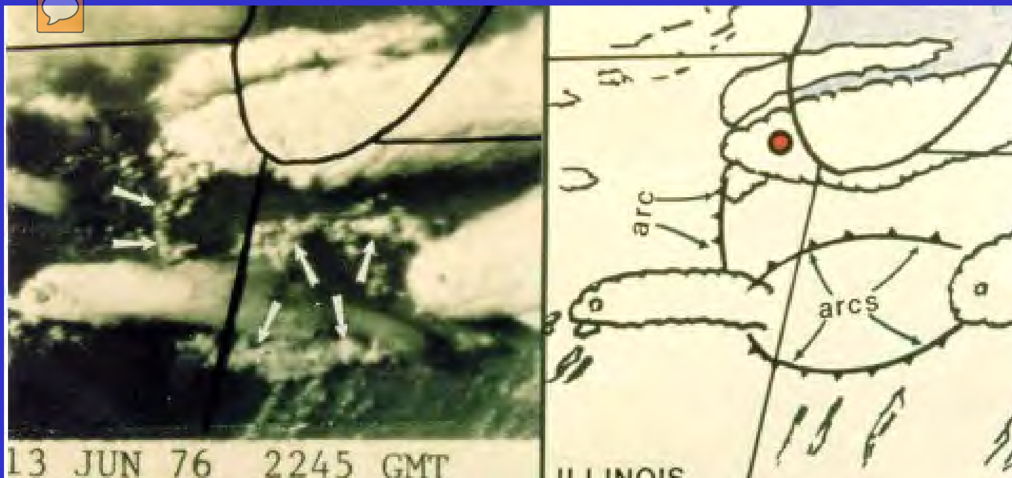
Severe Storms Like Boundaries

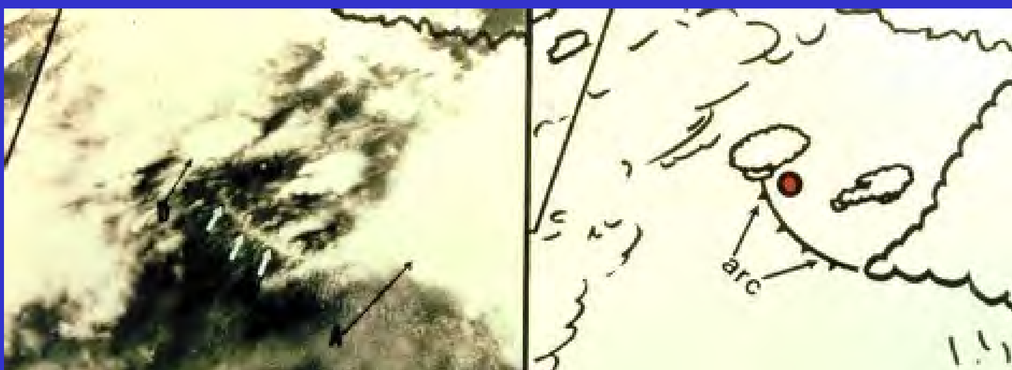


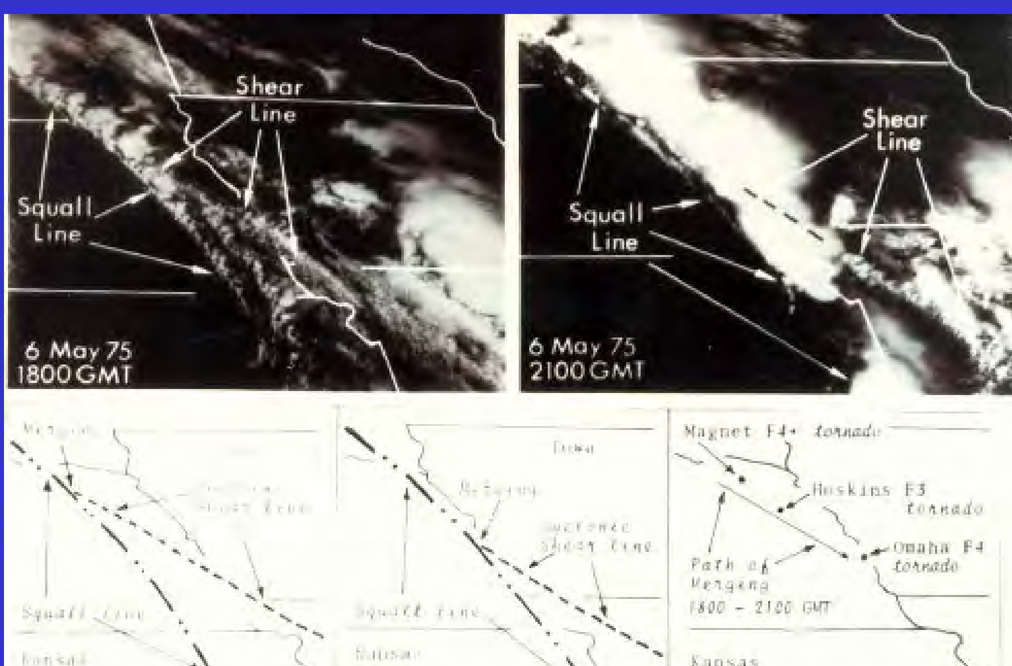


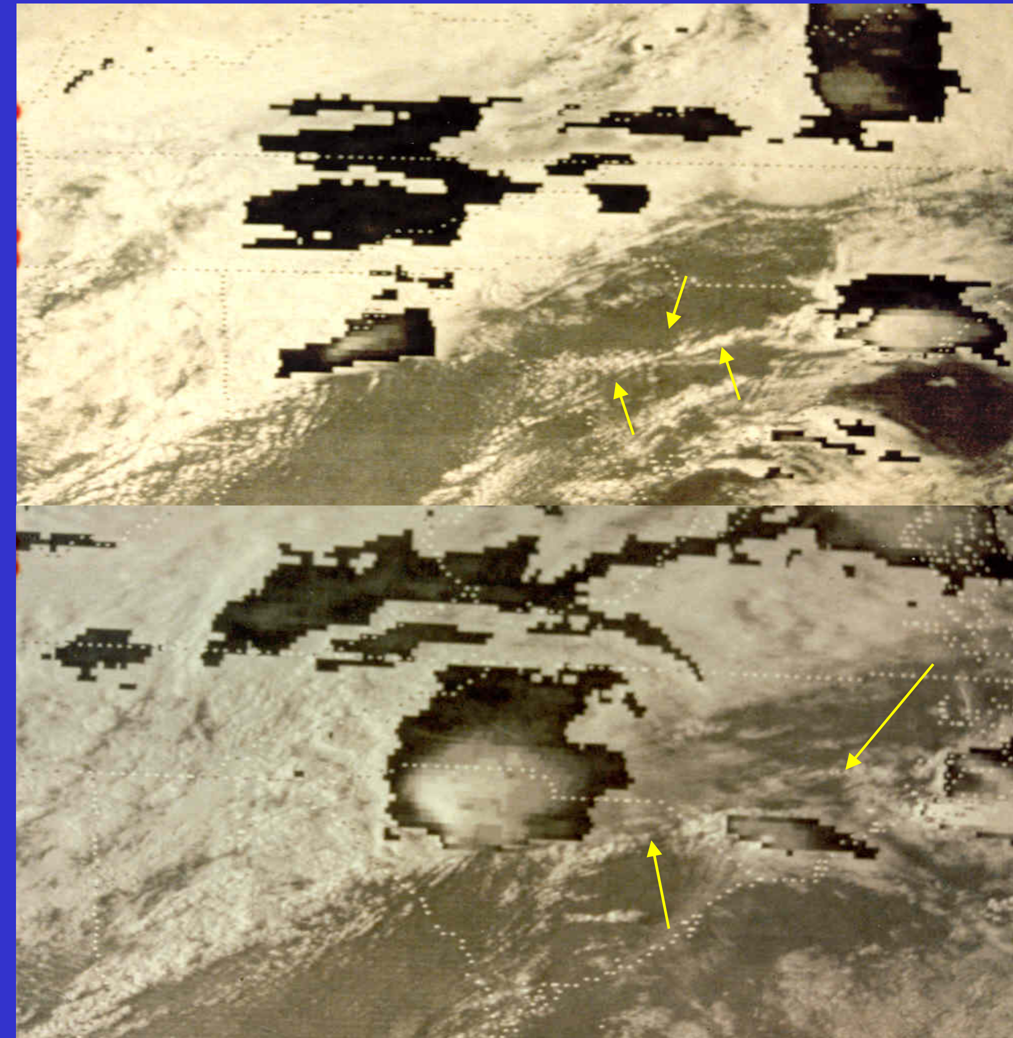


•Interaction along a boundary depends on both the storm's and boundaries characteristics

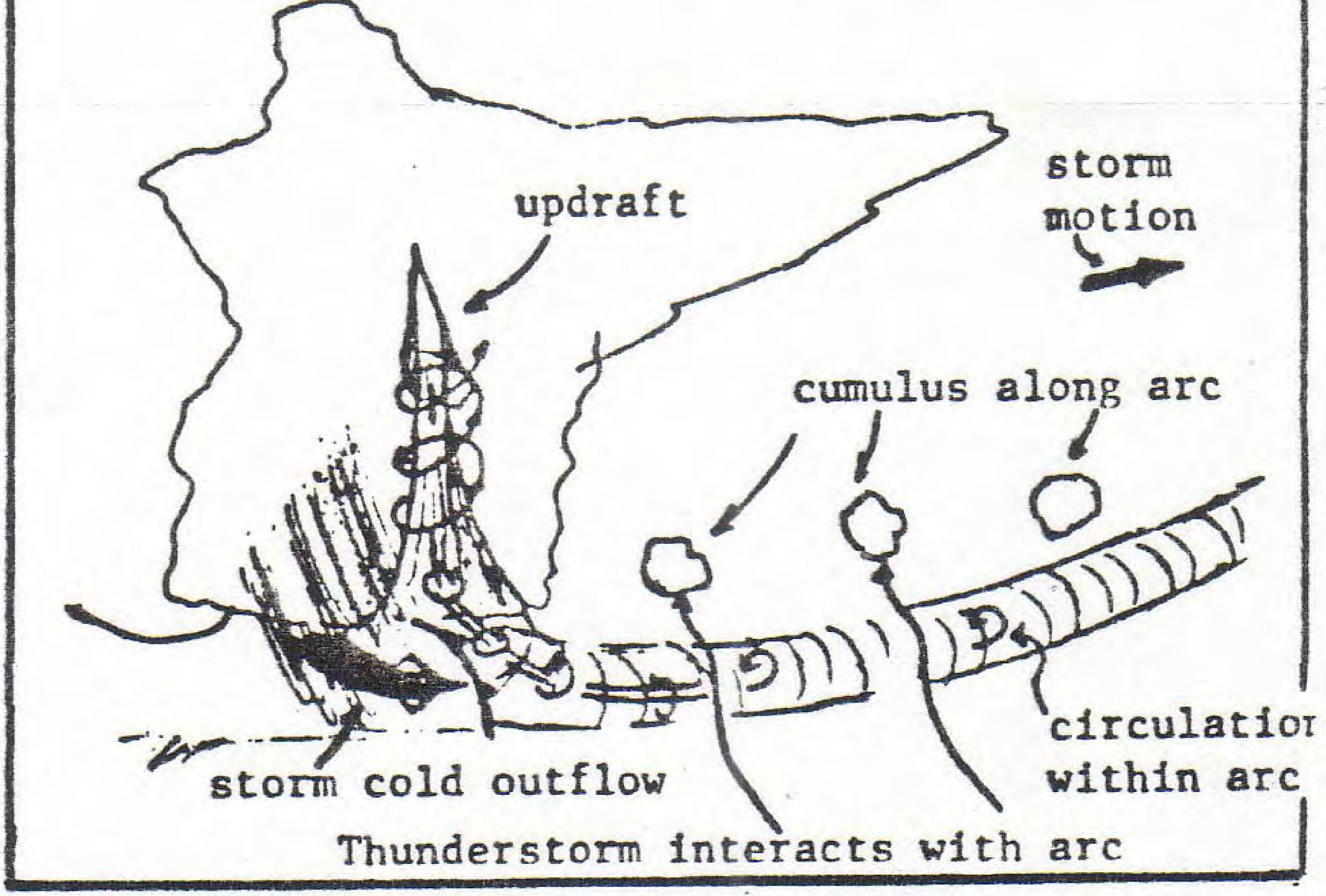

arc
arcs
13 JUN 76 2245 GMT


arc


Shear Line
Squall Line
6 May 75 1800GMT
Shear Line
Squall Line
6 May 75 2100GMT
Magnet F4+ tornado
Hoskins F3 tornado
Omaha F4 tornado
1800 - 2100 GMT
Kansas



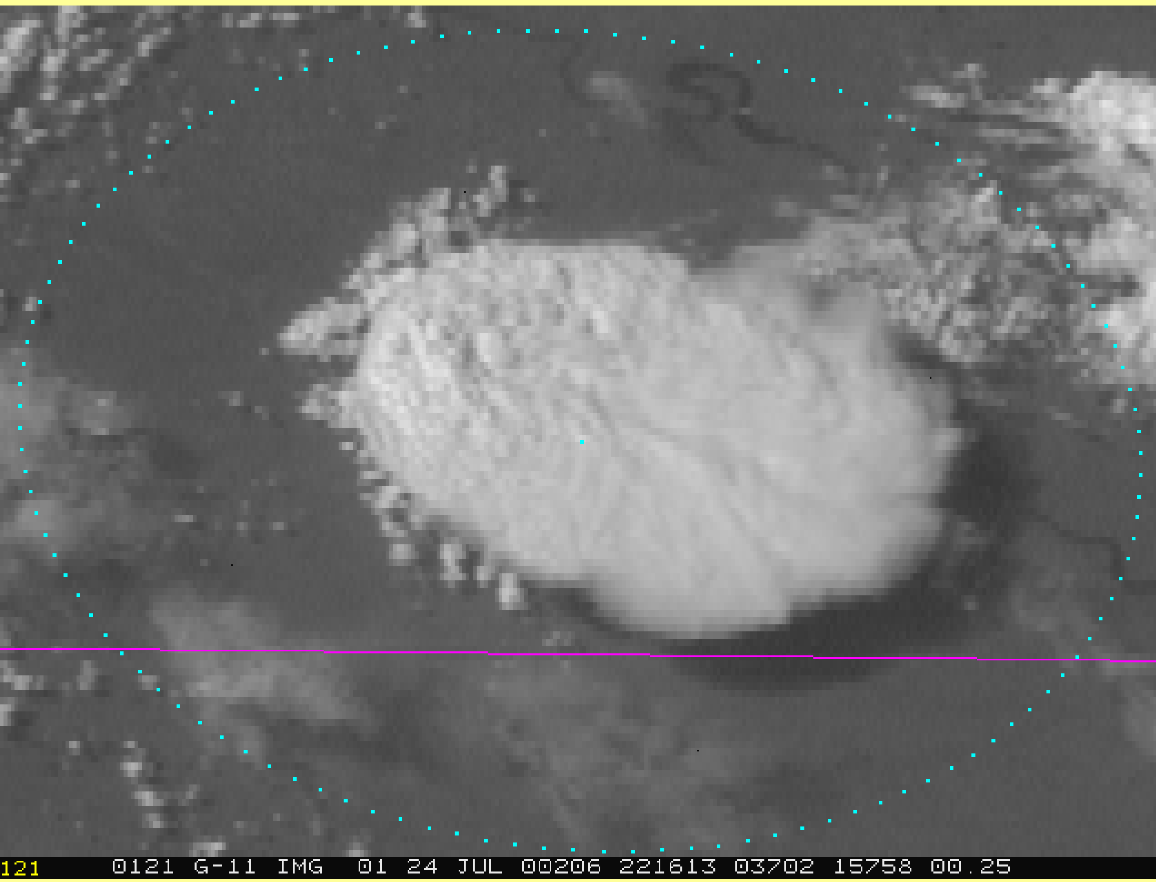

arc
Path of tornadoes and severe weather
1840 GMT 16 June 73
ILLINOIS



Conceptual model of storm interacting with preexisting boundary. As the storm moves along the boundary low level vorticity along the boundary is tilted into the plane of the thunderstorms updraft where it undergoes stretching in the vertical.

Conceptual model: severe thunderstorm

- **Conceptual model of a super cell severe thunderstorm that interacts with and modifies its local environment, leading to its becoming severe (see also accompanying text).**



One minute interval GOES imagery

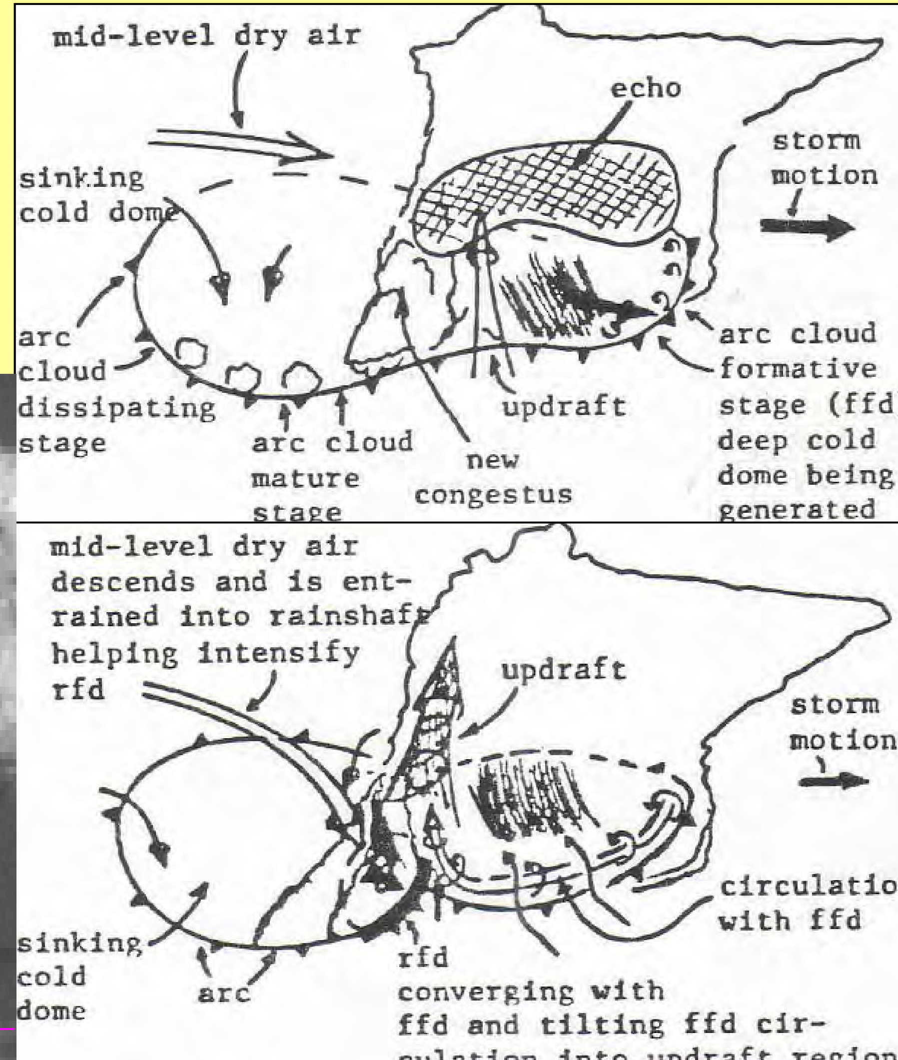
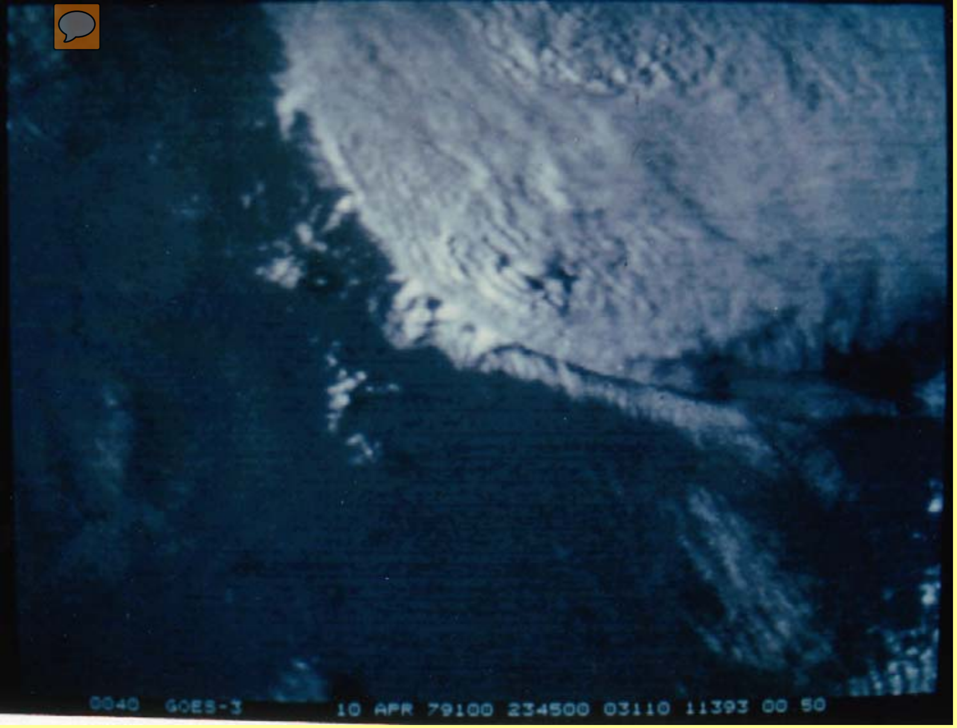
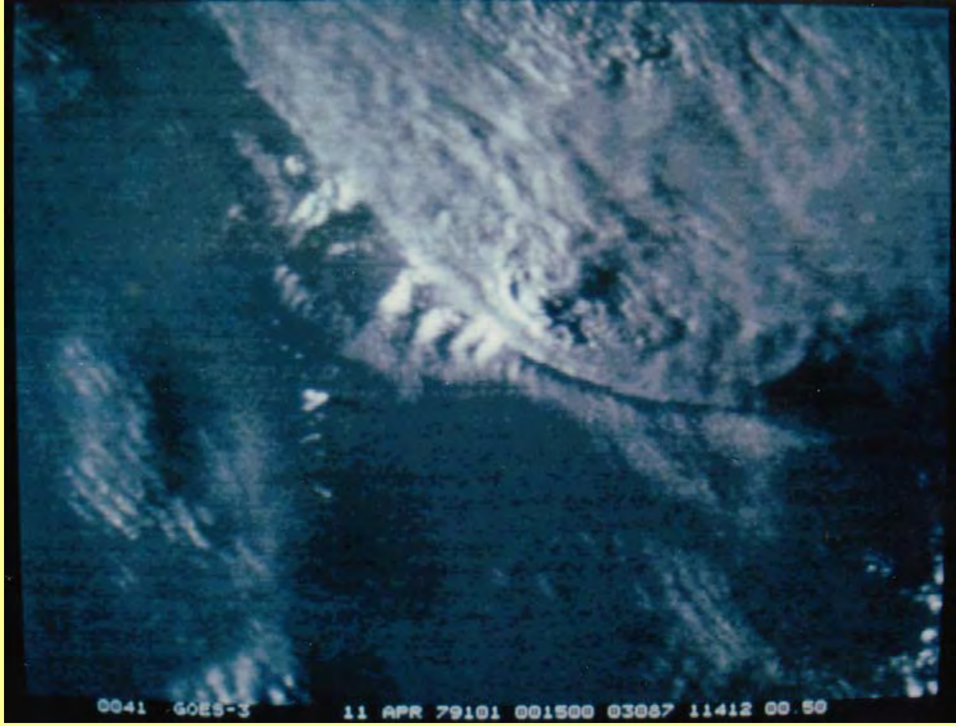


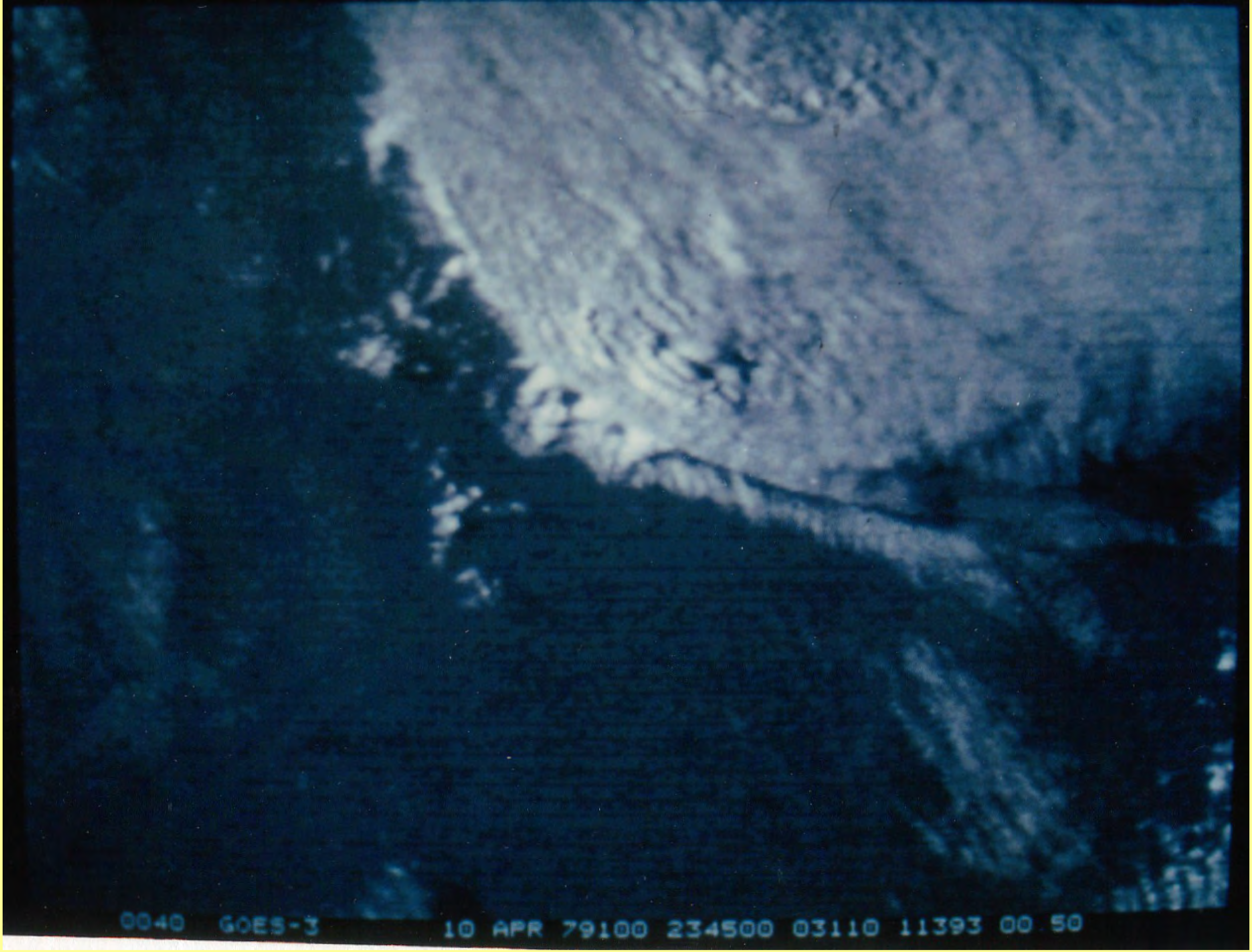
Figure 14. Early (top) and mature (bottom) stages of super-cell's life..



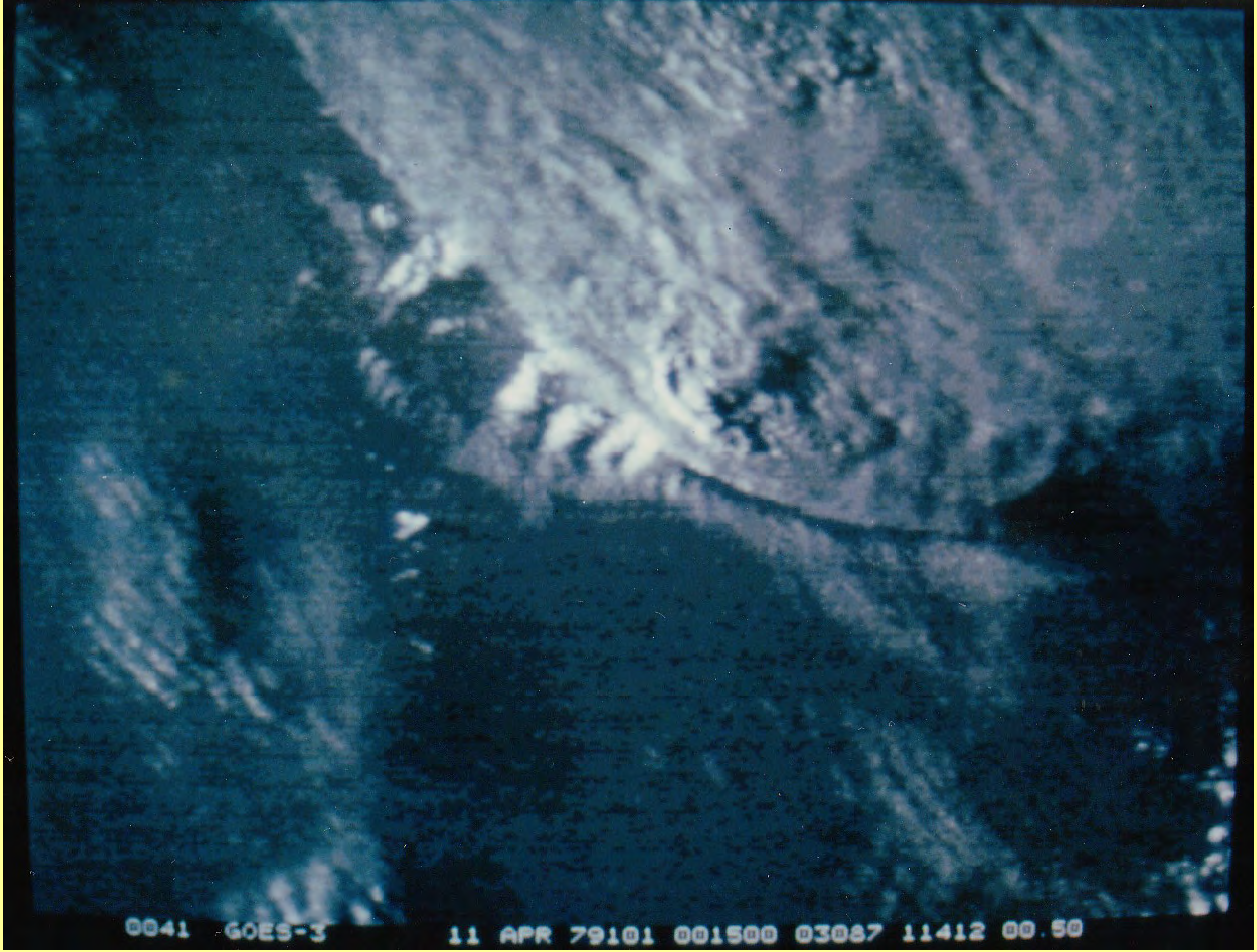
Wichita Falls, TX tornadic storm at 2345 GMT, Apr 10, '79



Wichita Falls, TX tornadic storm, 30 minutes later

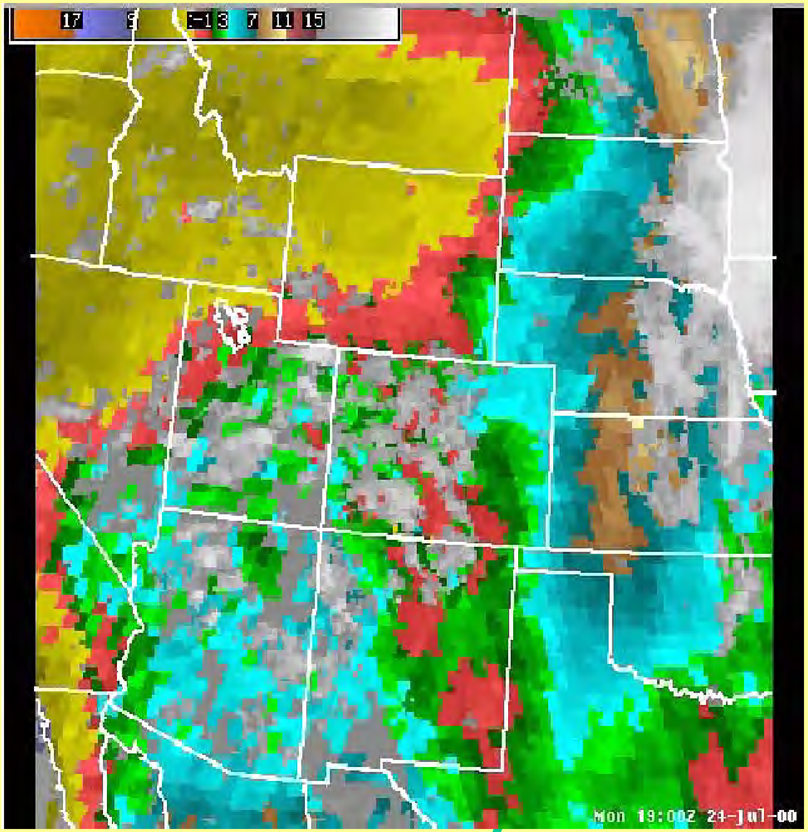


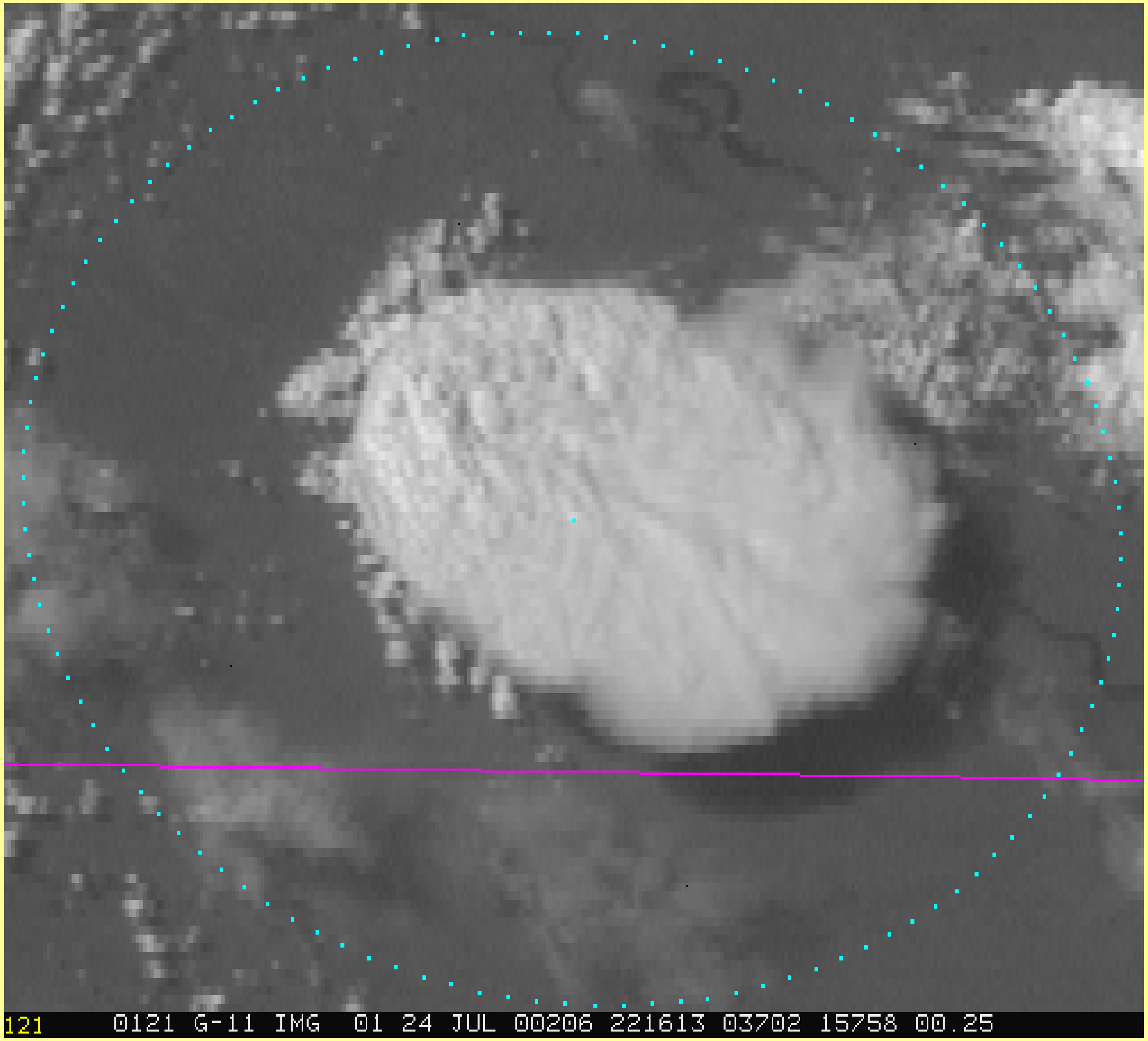
Wichita Falls, TX tornadic storm at 2345 GMT, Apr 10, ‘79



Wichita Falls, TX tornadic storm at 0015 GMT, Apr 11, '79

Imagery and sounder data



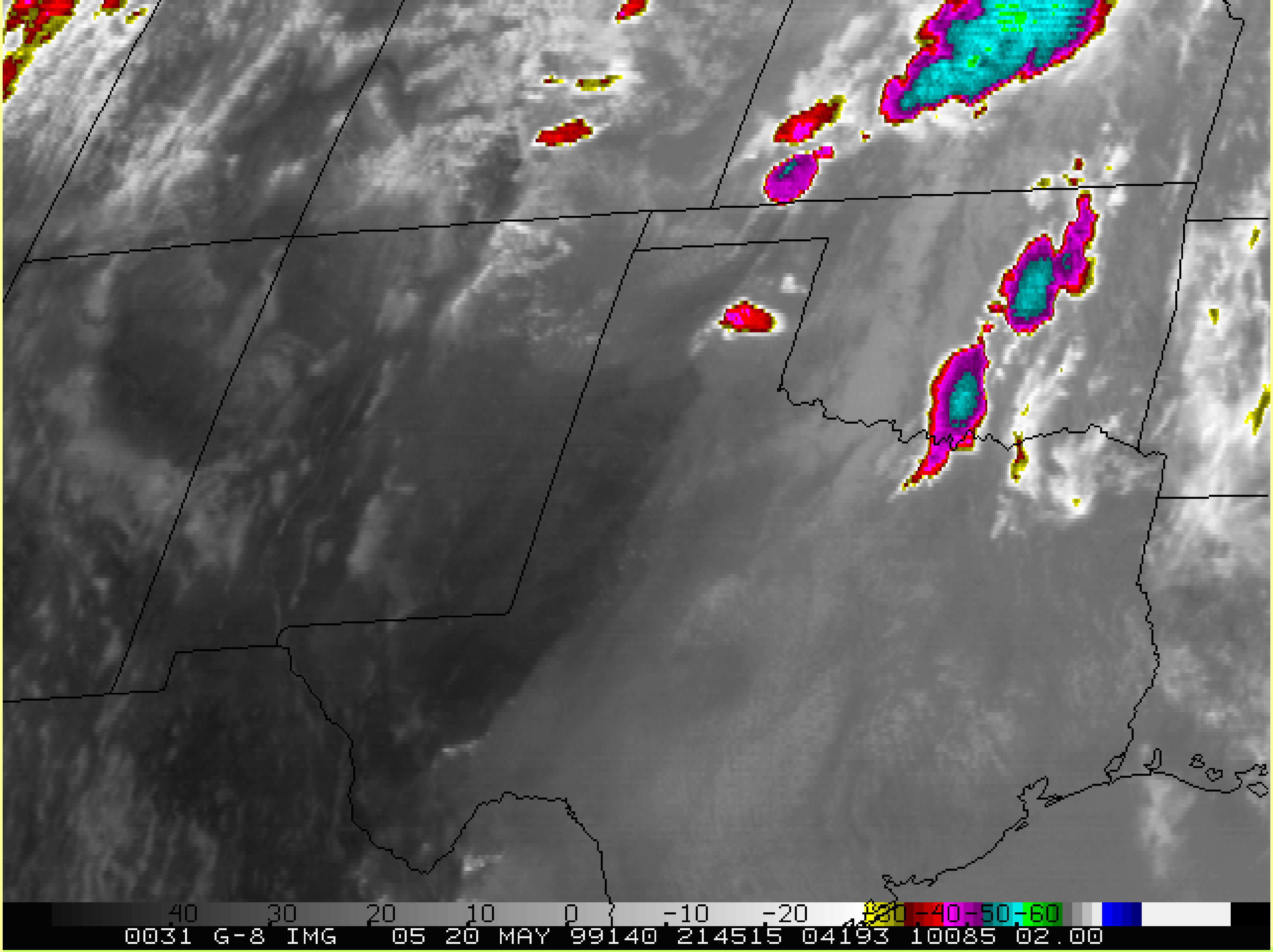


Instability field from GOES over severe storm area and severe storm at one minute interval (right)

The Nature of Convective Development and Evolution Differs Between Daytime and Nighttime

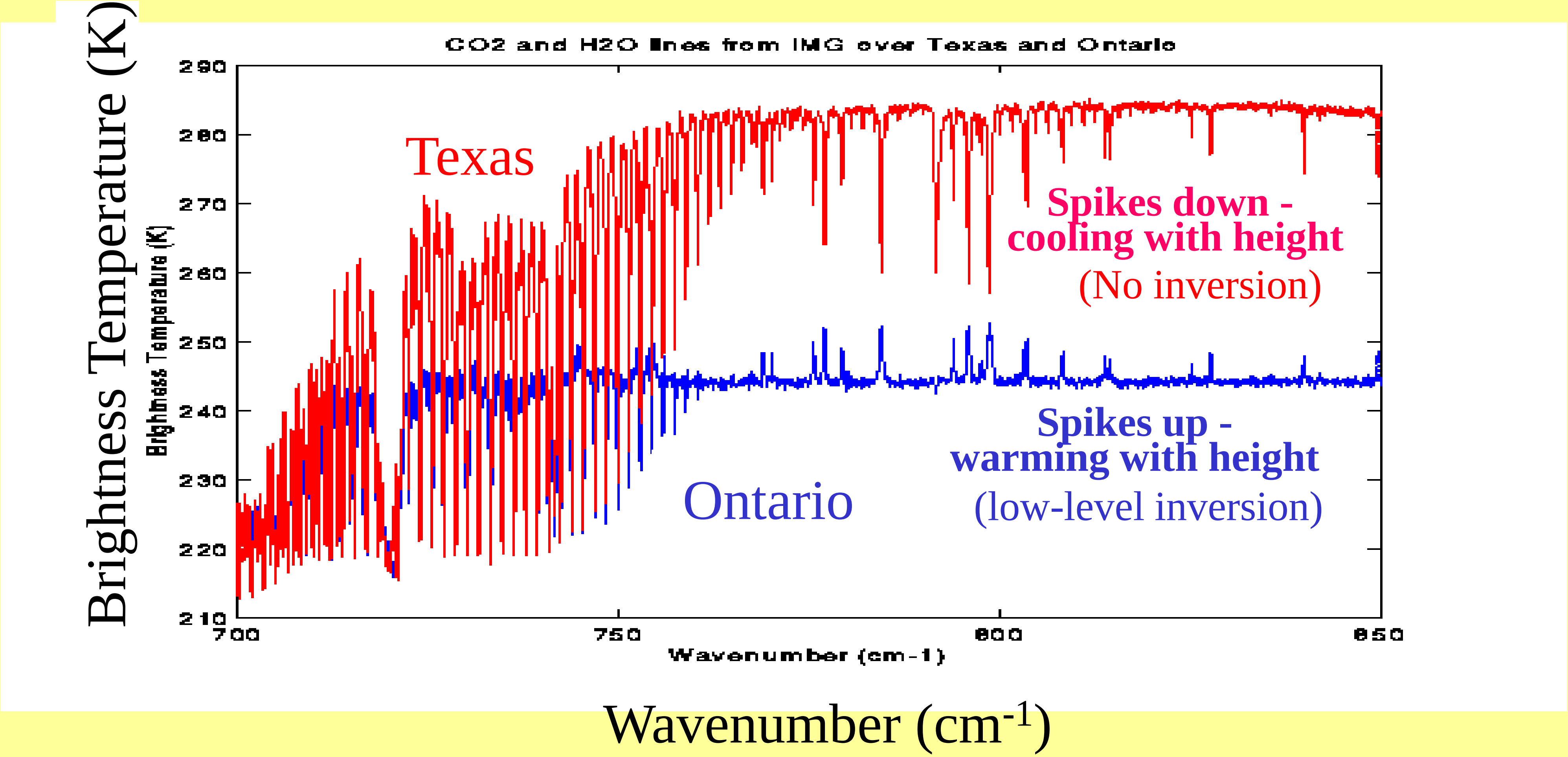
- The afternoon initiation episodes were primarily surface based and the nocturnal were elevated.
- The surface-based initiations occurred mostly during the afternoon and early evening, and the elevated initiations during the night and early morning.

- Wilson and Roberts, 2002: Summary of Convective Storm Initiation and Evolution during IHOP: Observational and Modeling Perspective. *Monthly Weather Review:* Vol. 134, No. 1, pp. 23–47.



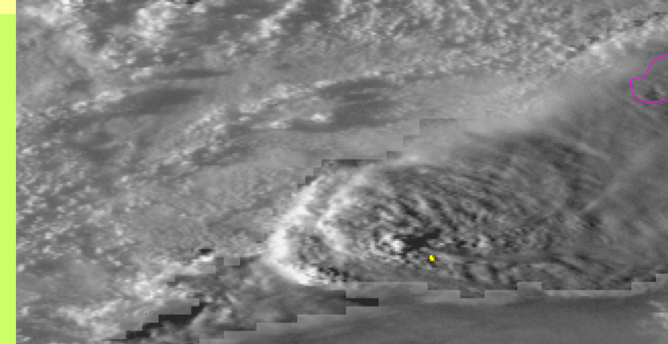
Viewing dry and moist boundary layers – daytime to night

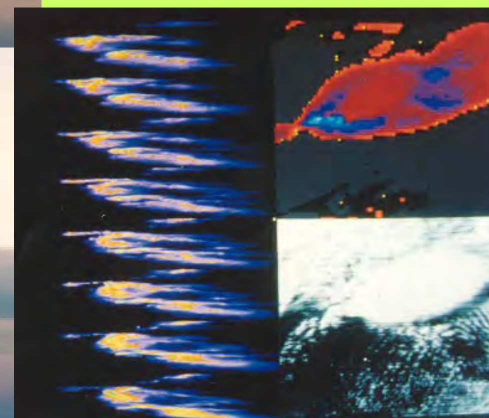
Detection of Temperature Inversions Possible with Hyperspectral IR

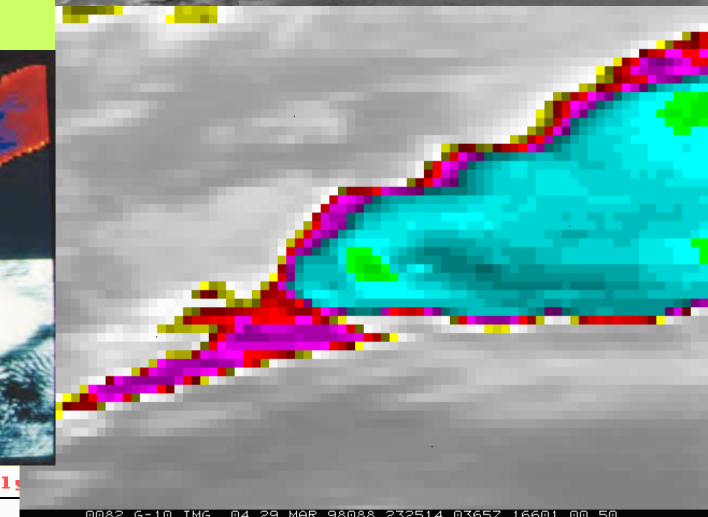


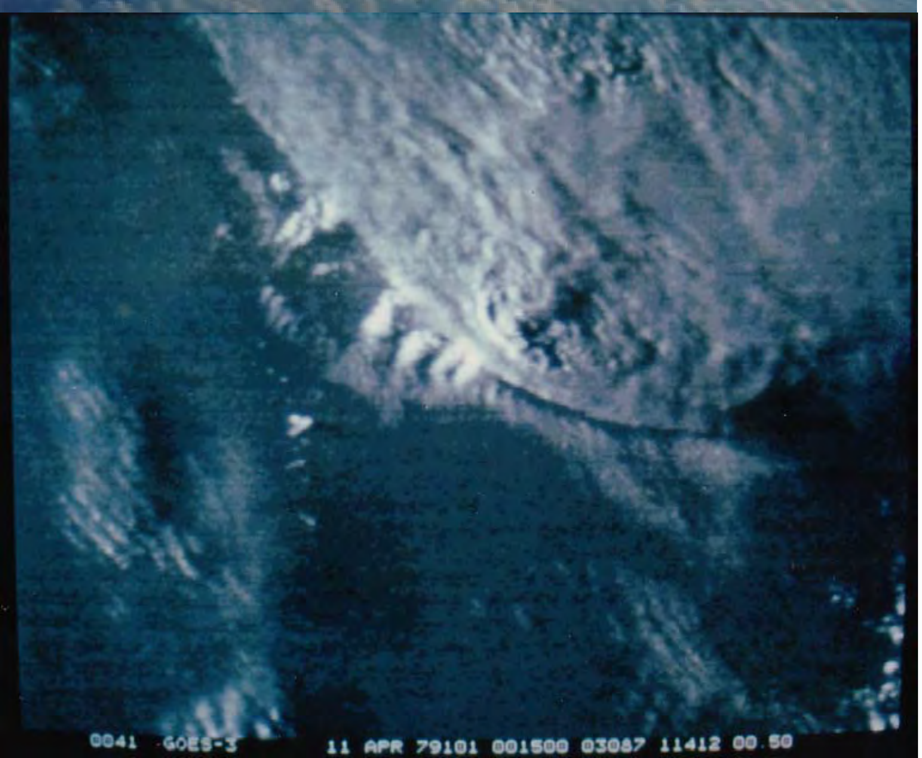
Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.

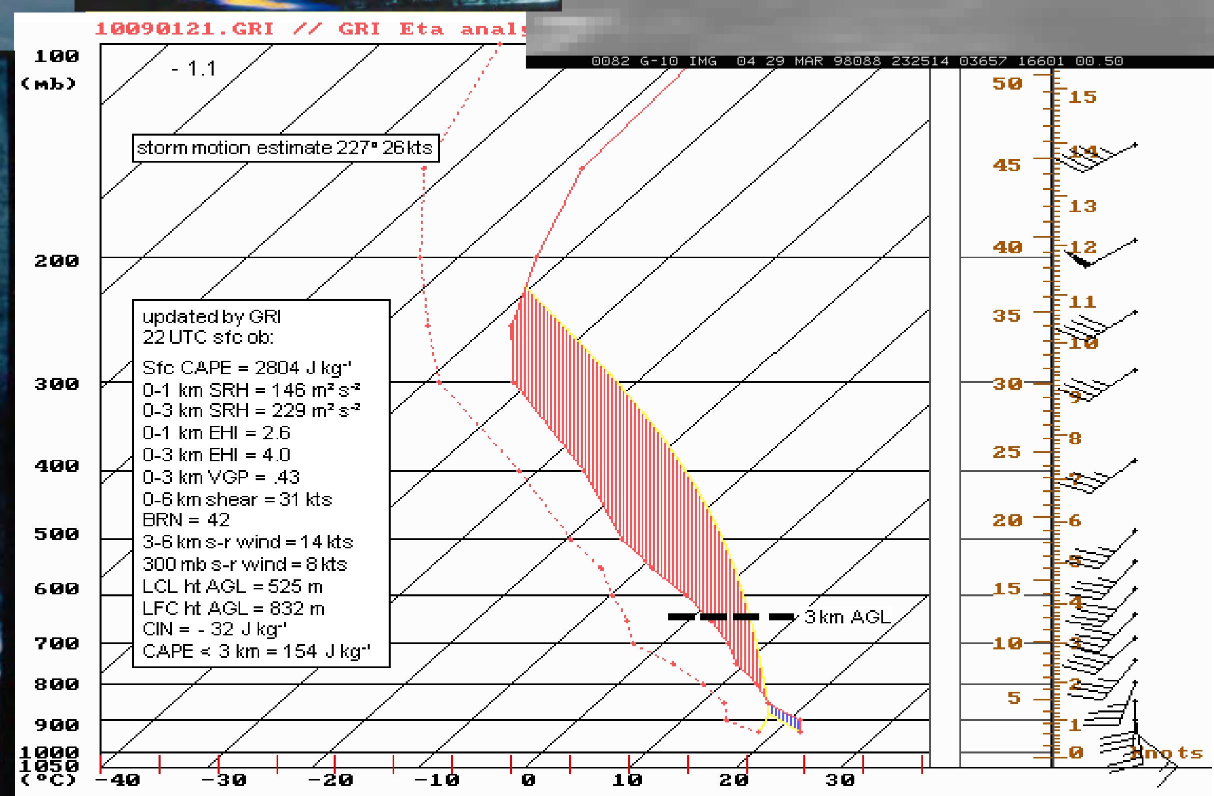
Storm cloud top structure as a proxy for severe weather and heavy rainfall

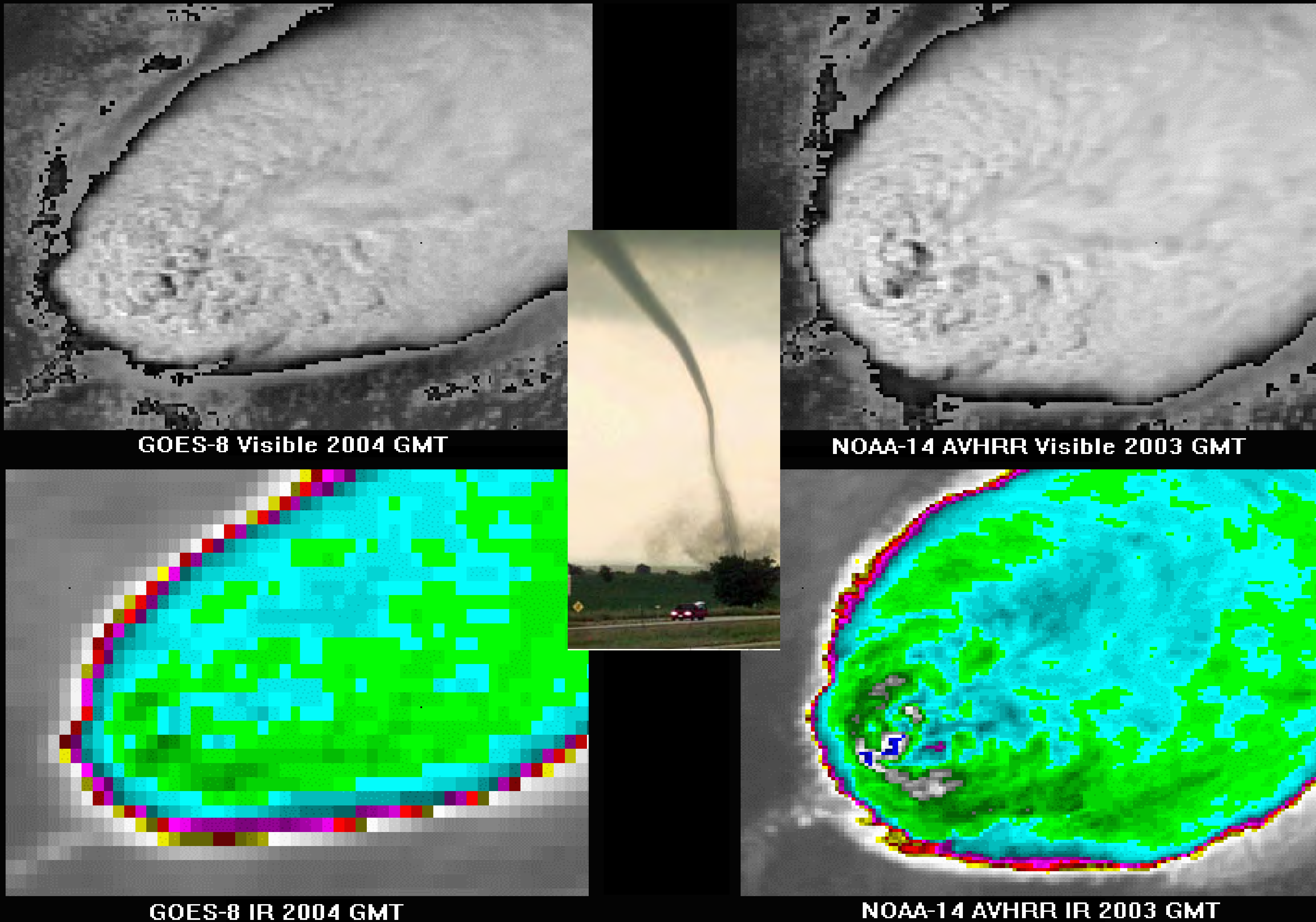




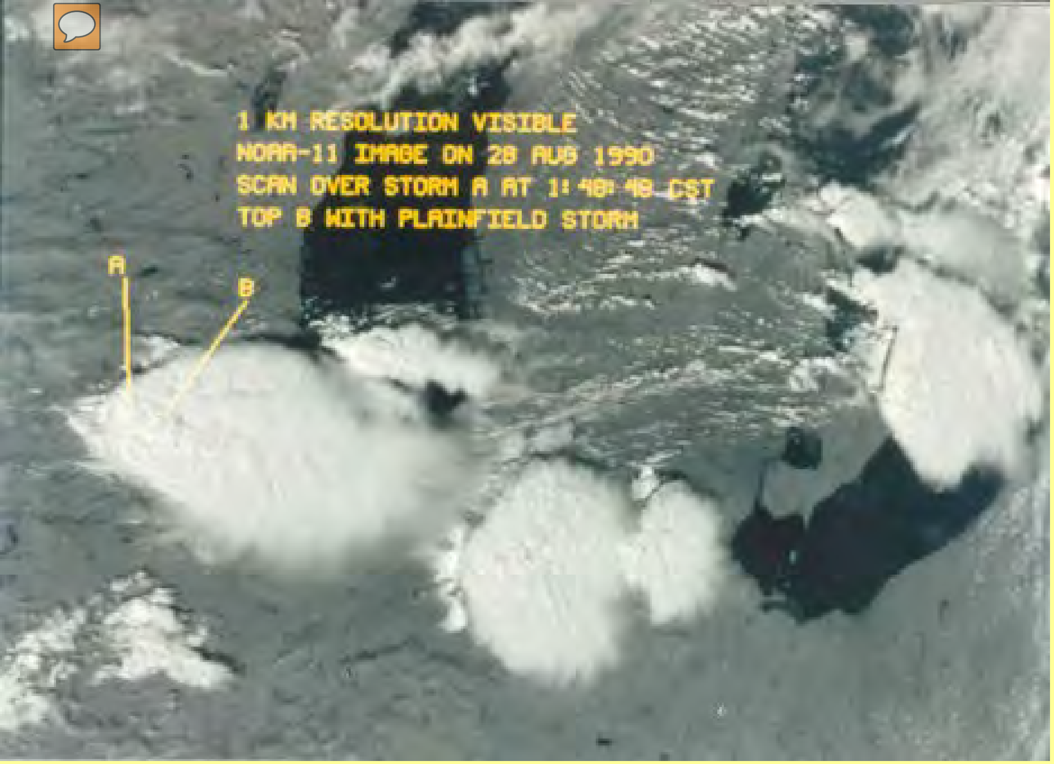


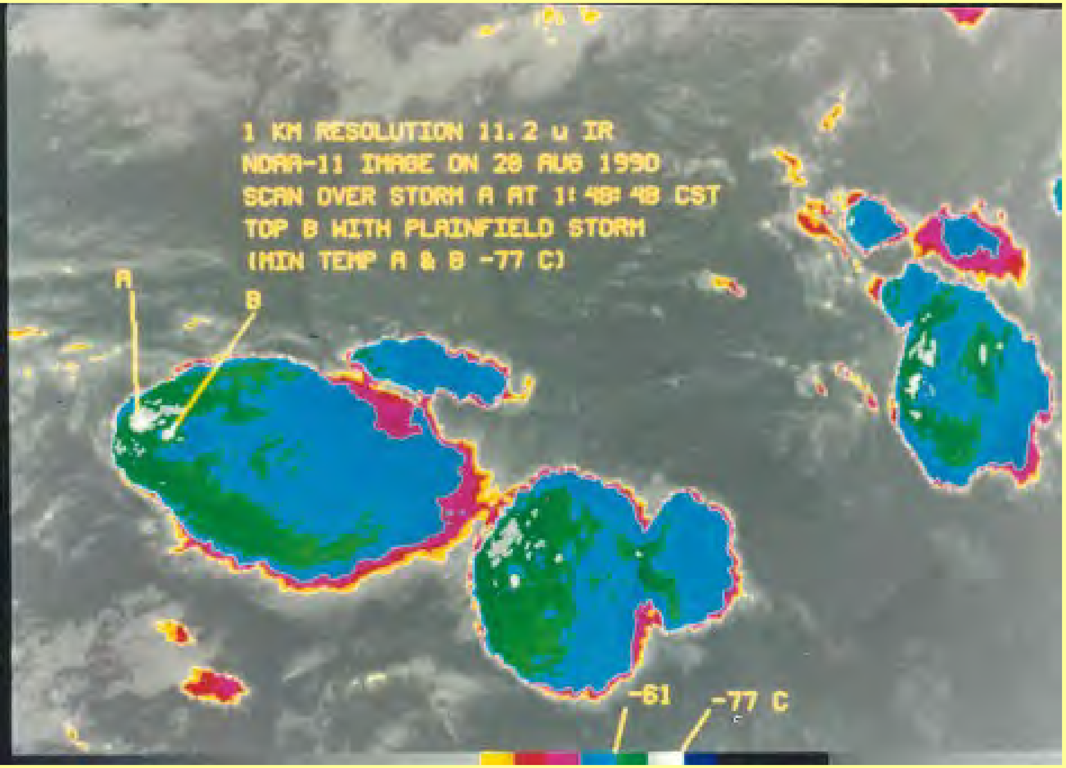




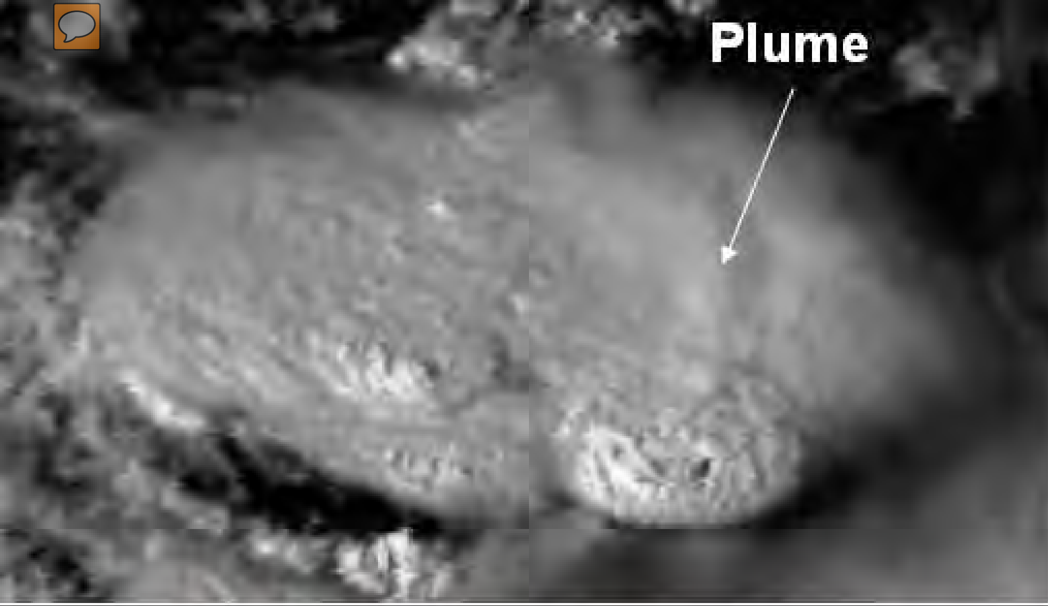


Comparison of cloud top for Jarrel, Texas, tornadic storm with GOES on left and AVHRR on right.

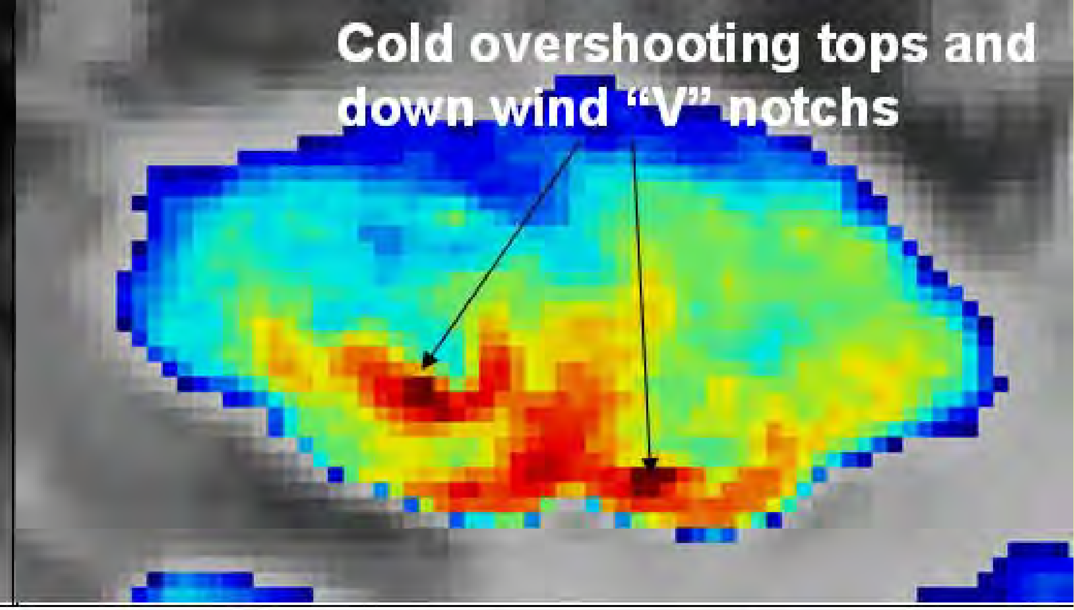




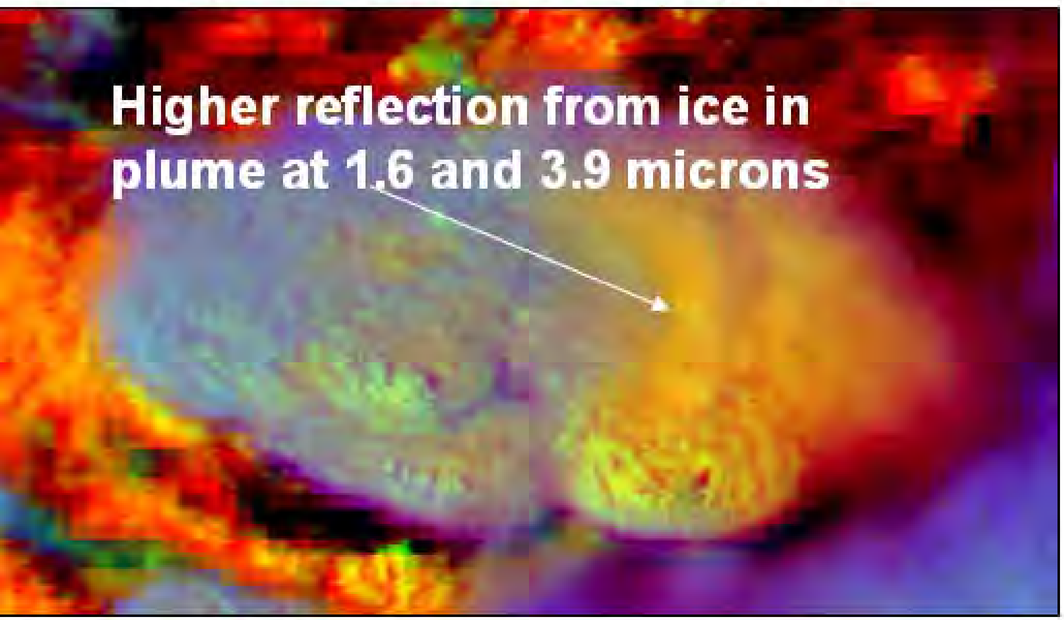
Different characteristics of anvils and overshooting tops are revealed by using different channels. Shown here are AVHRR visible (upper left), 3.7 microns (upper right with special enhancement across anvil top) and 10.7 micron IR



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

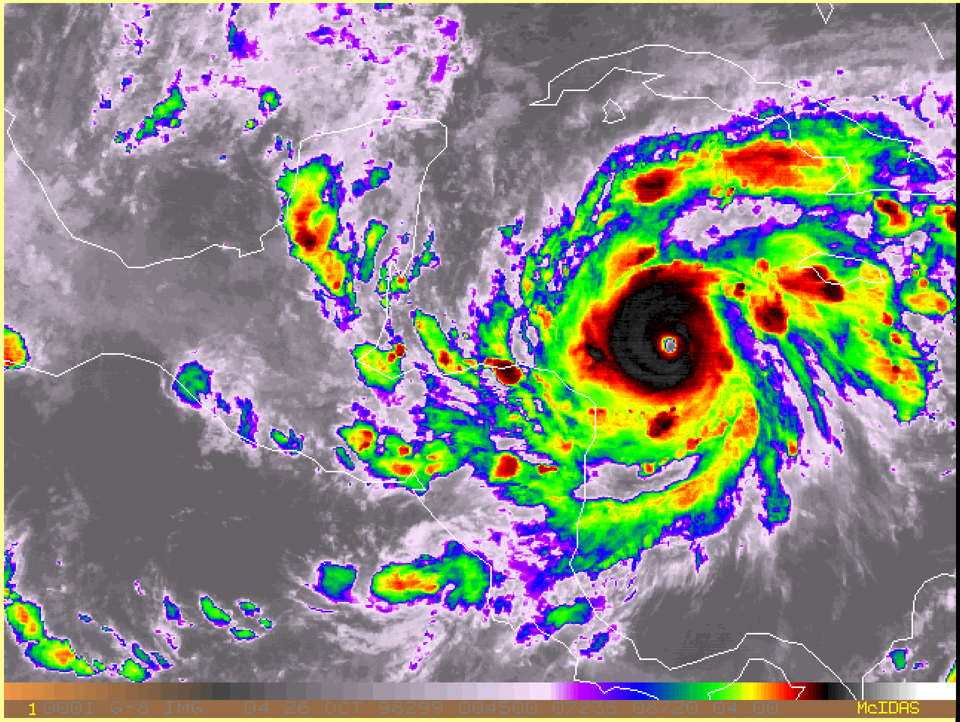
Figure 27: Thunderstorm tops over Europe from MSG on 29 July 2005 at 14:30 UTC. This case, presented by Martin Sevtak at the EUMETSAT Users' Conference showed higher reflection from ice in the plume at thunderstorm top in 1.6 and 3.9 microns, likely due to smaller cloud particle size and related to updraft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

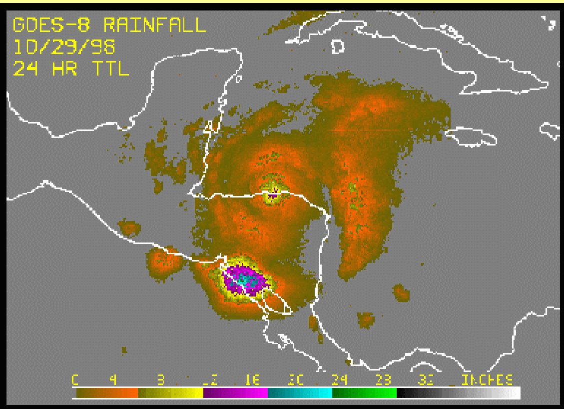
Rainfall

- **Infrared techniques** Precipitation rates are primarily estimated from cloud top temperature. Numerous other factors, including the cloud-top geometry, the available atmospheric moisture, stability parameters, radar, and local topography, are used to further adjust the rain rate.
- **Microwave techniques** Precipitation rates are primarily based on microwave scattering by cloud ice and absorption and emission by cloud water.
- **Blended techniques** generally use information from microwave sensors as a baseline to help calibrate rainfall estimations from infrared sensors.

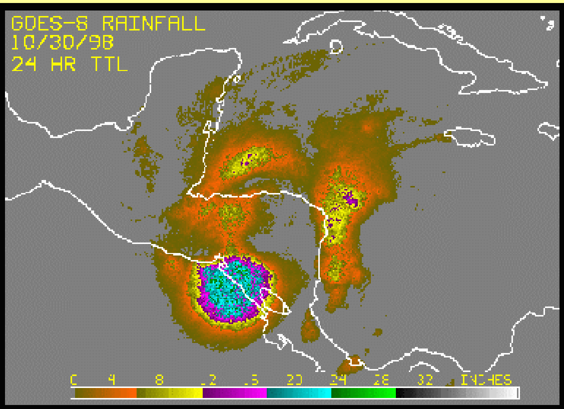
Precipitation – Cloud Water and Ice
(Key Interactions and Potential Uses)

Frequencies: AMSU	Frequencies: SSM/I	Microwave Processes	Potential Uses
31 GHZ 50 GHz 89 GHz	19 GHZ 37 GHz 85 GHz	• Absorption and emission by cloud water: o Large drops/high water content o Medium drops/moderate water content o Small drops/ low water content	• Oceanic cloud water and rainfall • Oceanic cloud water and rainfall • Non-raining clouds over ocean
89 GHz	85 GHz	• Scattering by cloud ice	• Land and ocean rainfall

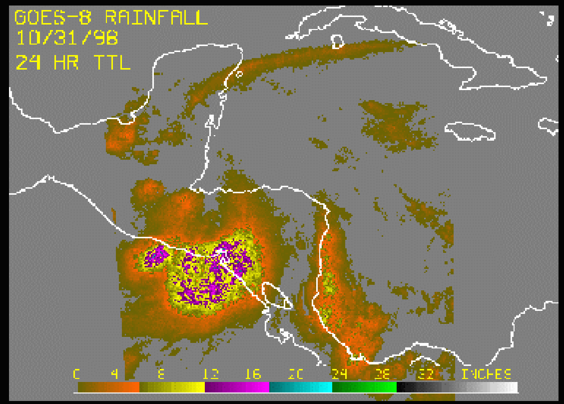




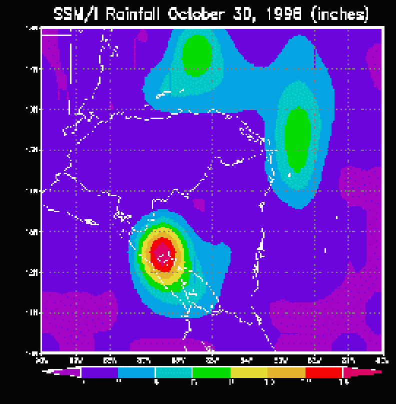
mitc1029.gif



mitc1030.gif

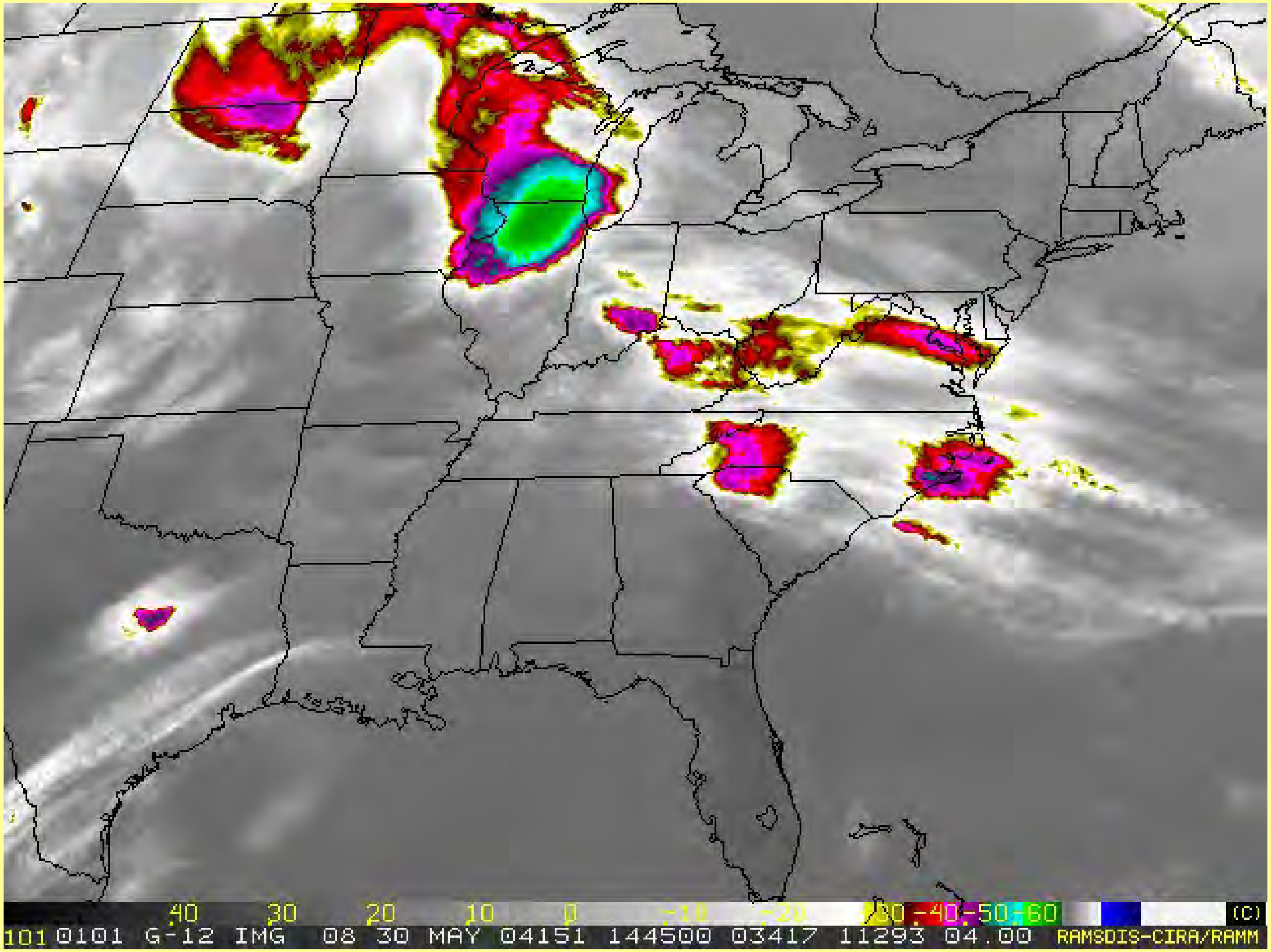


mitc1031.gif



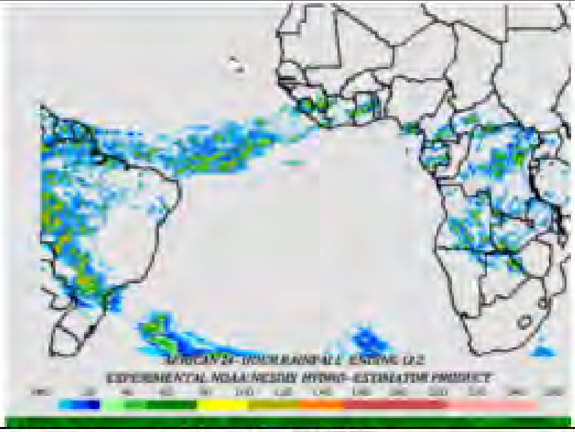
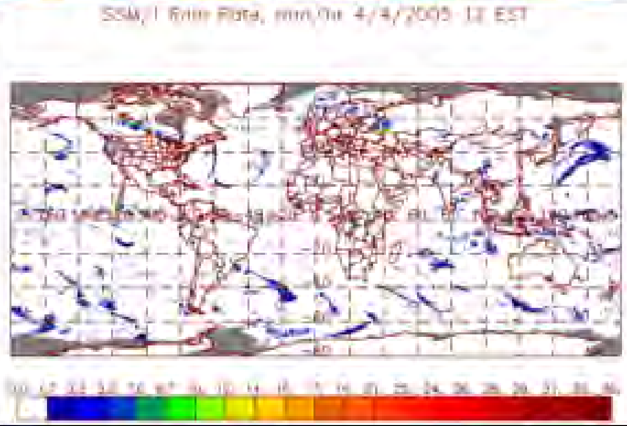
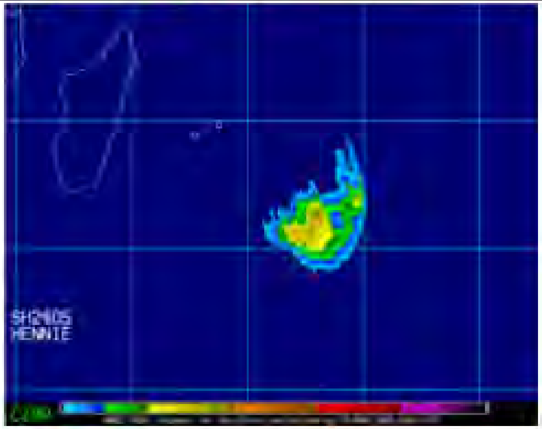
mitch3.gif

Sometimes a simple average of sequential geostationary infrared images over a few hours will reveal areas of heavy persistent rainfall



In this example heavy convective rainfall occurred over Illinois (green) where half hourly infrared images over a two hour period ending at 1445 GMT were averaged.

Near real time rainfall and rain rate products are available from the Web Based Products link on the VRL

Precipitation, Flash Flood	Variety of products from NESDIS Office of Research and Applications **Flash Flood Home page** from Hydro-estimator can look at various parts of the world	
Precipitation, Global	**3 hourly blended** microwave and IR precipitation estimations. Close-ups of selected regions also available.	
Precipitation, Global rain rate	The **rain rate product** from SSM/I is a measurement of the rainfall intensity over the Earth's surface. Indeterminate data can result from the polar ice caps or certain areas in the Sahara desert. This product is updated every four hours. Can click on area of image to zoom in.	
Precipitation, Tropical Storm Rainfall Potential	Tropical Rainfall Potential Product **(TRAP) derived** from AMSU data with current rain rate and forecast 24 hour accumulation and storm positions. Access TRAP from the left banner on the CIRA AMSU page. For other rainfall products derived for tropical storms see **Tropical Storms** below.	

CGMS IPWG International Precipitation Working Group

Home | Meetings | Reports | Newsletter | Algorithms | Products | Validation | Training | Links | CGMS | WMO | Contact us | News

There is also a link on the VRL to the International Precipitation Working Group (IPWG) for products, algorithms, tutorials and more!

CSU:	Climate Rainfall Data Center
EUMETSAT:	Multi-sensor Precipitation Estimate (MPE), experimental
GPCP:	GPCP products
	GPCP Geostationary Satellite Precipitation Data Center (GSPDC)
	GPCP Global Precipitation Analysis
LaMMA:	Blended MW-IR over Italy and Central Mediterranean
NASA-GSFC:	Global Precipitation Analysis
	GPCP-1DD data
	TRMM Data Organized by Data Product Groups
	TRMM Online Visualization and Analysis System (TOVAS)
	TRMM HQ 3B40RT data
	TRMM VAR 3B41RT data
	TRMM Combined HQ VAR 3B42RT data
NOAA-NCDC:	Global analyses of monthly precipitation derived from satellite and surface measurements
	SSMI Global Gridded Hydrological Products
NOAA-NESDIS:	Microwave Surface and Precipitation Products System
	Tropical Rainfall Potential (TRAP)
NOAA-NWS:	Climate Prediction Center - Global Precipitation Monitoring
NRL Monterey:	Satellite Products
University of Birmingham:	EURAINSAT/A 1.0 product