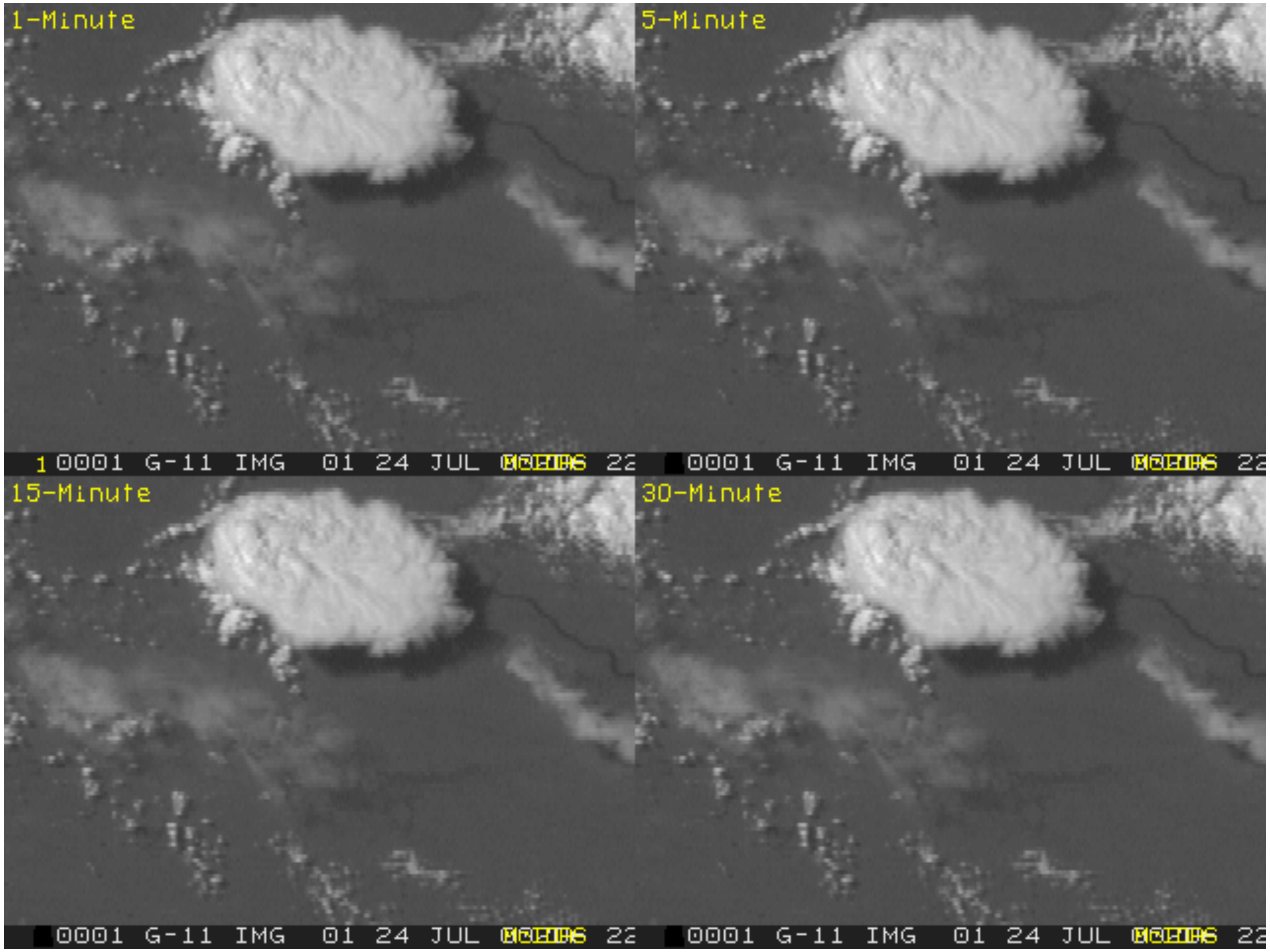
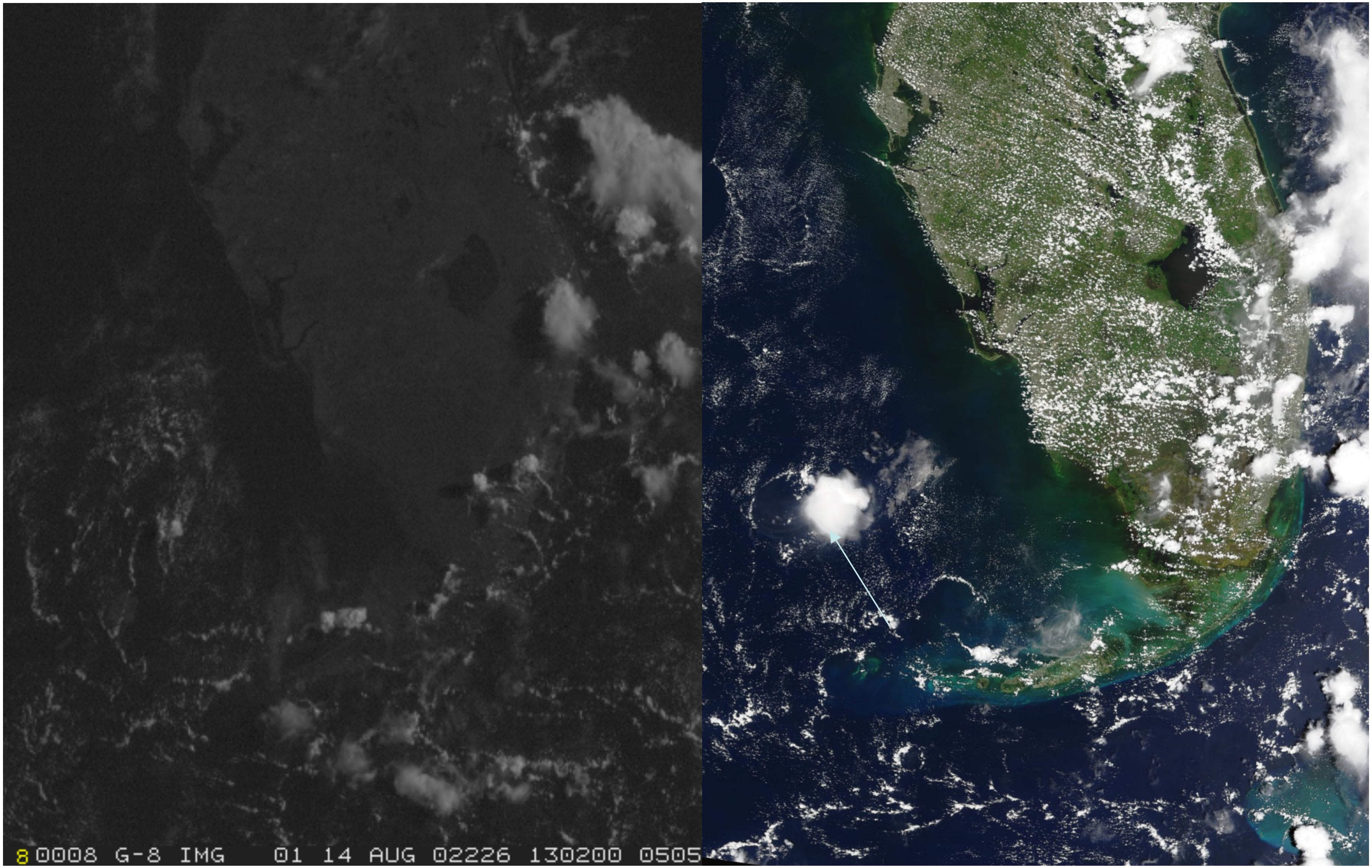
Hyperspectral Infrared Sounding from Geostationary Satellites

James F.W. Purdom, PhD
Senior Research Scientist emeritus
CIRA


1-Minute
5-Minute
15-Minute
30-Minute
1 0001 G-11 IMG 01 24 JUL
0001 G-11 IMG 01 24 JUL

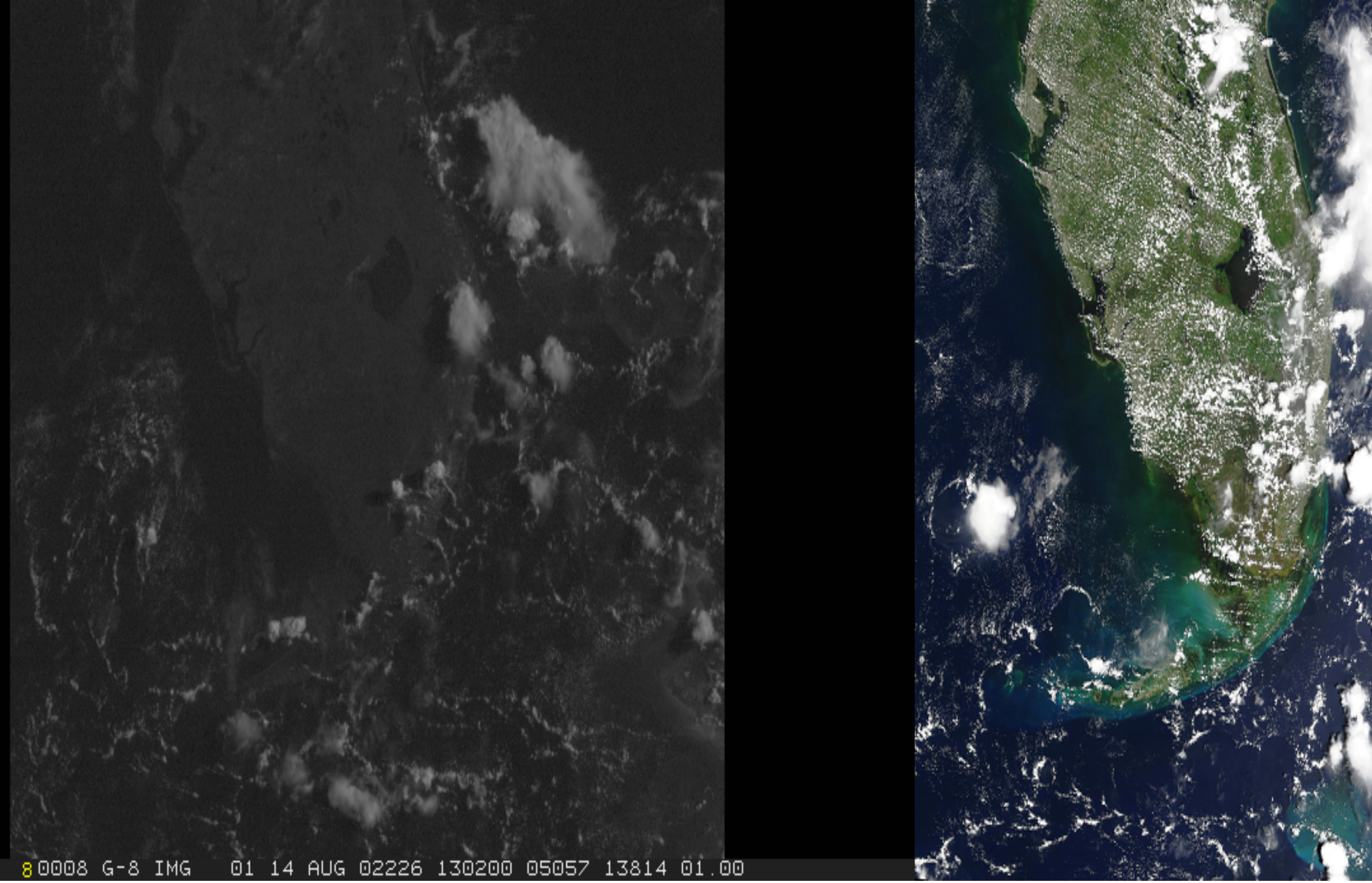
The spatial and temporal domains of the phenomena being observed drive the satellite systems' spectral needs as a function of space, time, and signal to noise.

Spectral Awareness In Terms of Space, Time, Signal to Noise and Scene Characteristics

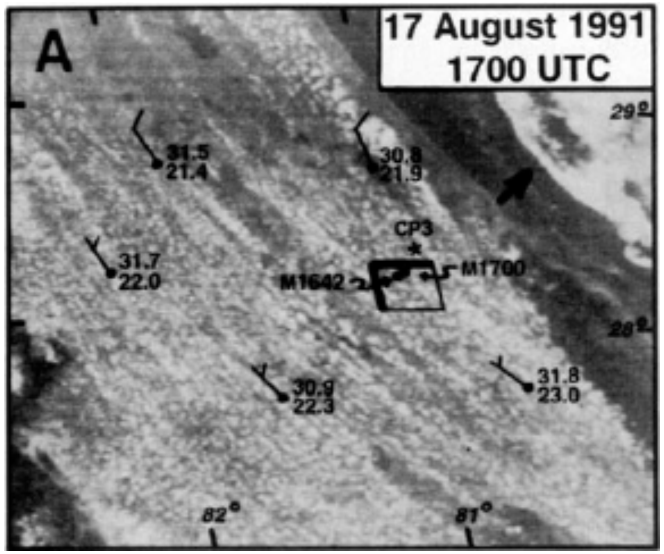


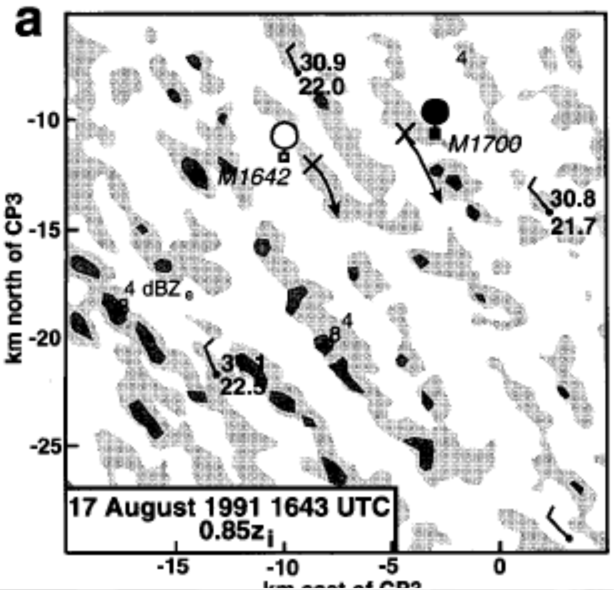
GOES-8 loop from 1033 to 1615 (left) and MODIS true color image near 1615 (right). While noting the convection over land, pay attention to convection over the ocean.

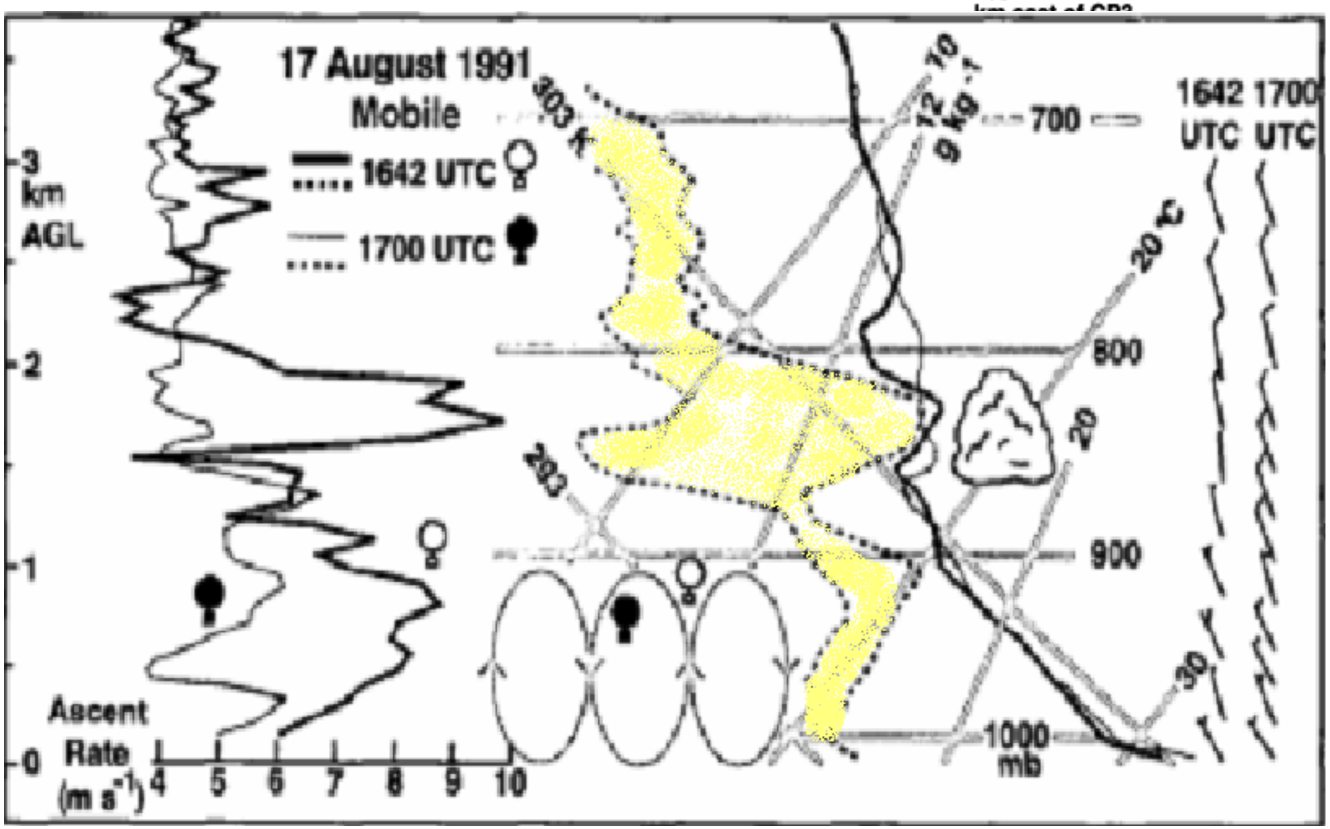
Notice how well the cloud field can be analyzed at 250 meters resolution.



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.

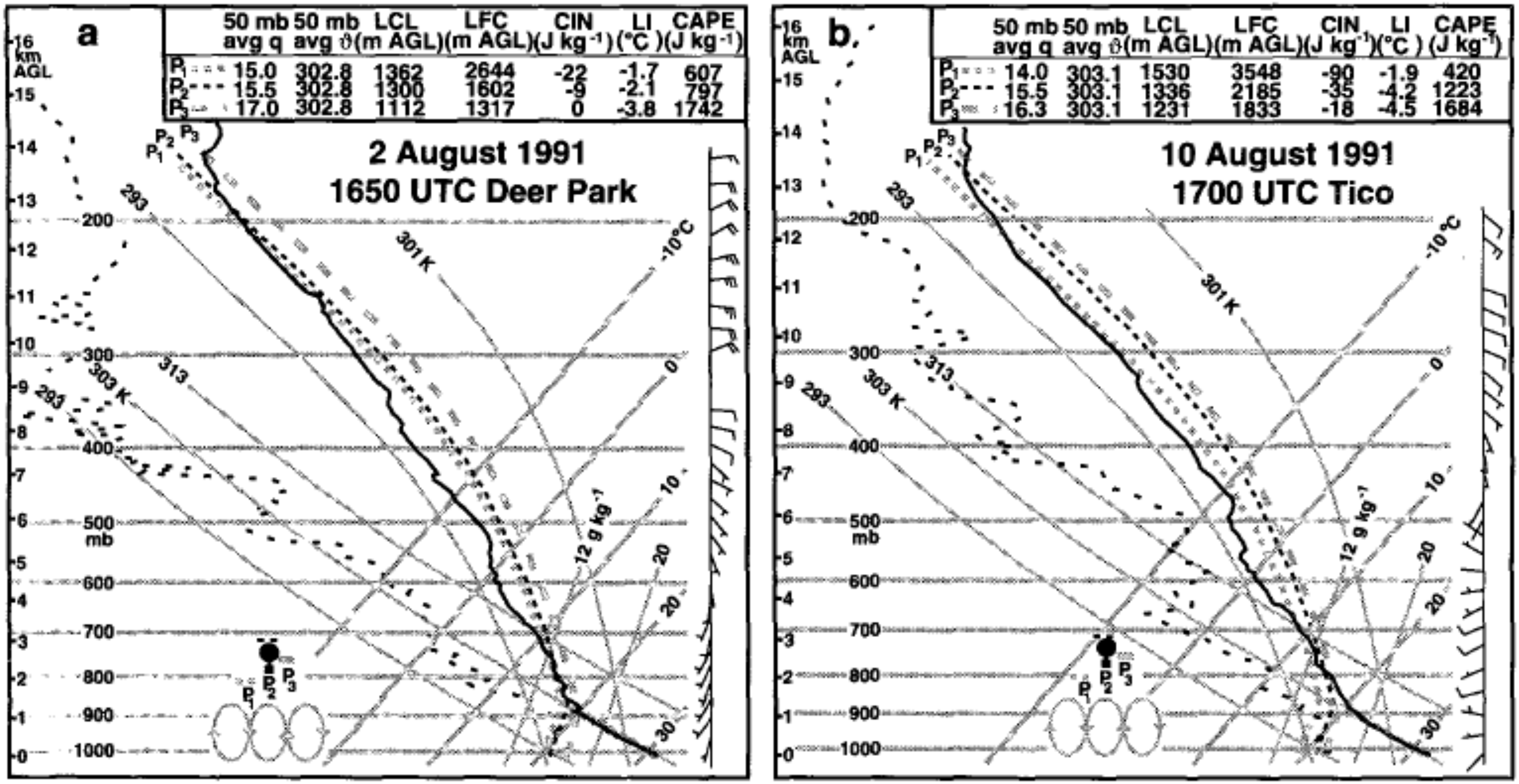






From Weckwerth et al, 1996, Convective Variability within the Convective Boundary Layer Due to Horizontal Convective Rolls, MWR, 769-781.

This study, based on research aircraft flights and special rawinsonde ascents, consistently showed that that the moisture available to support deep convection varied dramatically over very short distances as the convective boundary layer developed; left about 2 g/kg over a distance of about 10 km.



	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

	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.

From Weckwerth study. Refer to the box where differences in moisture dominate the convective potential. Q is mixing ratio in gm/kg, CIN is convective inhibition, CAPE is Convective Potential Energy, LI is Lifted Index, LCL is cloud base upon lifting, LFC is level of free convection (max sfc T).

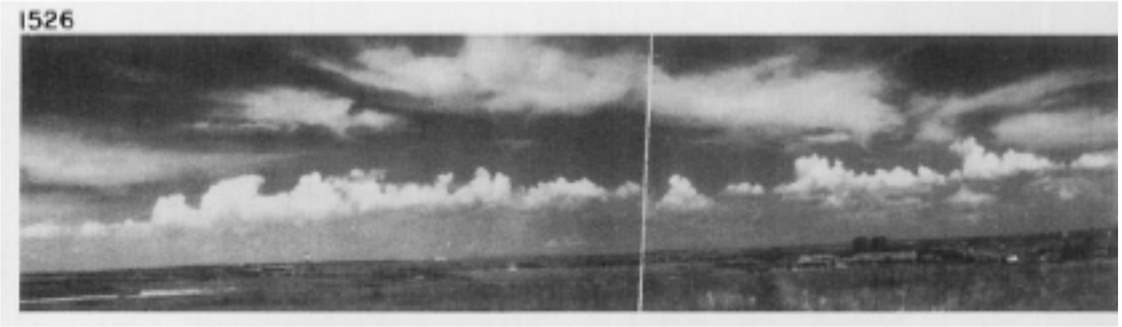
Why Hyperspectral? Both Spatial and Spectral Resolution!!

- Water vapor is the fuel of deep convection.

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

- Numerous studies that have highlighted the importance of accurate estimates of water vapor in predicting convective development and evolution. Numerical simulations and field experiments suggest that changes in mixing ratio as small at 1 g kg−1 have significant effects on the developing convection.

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



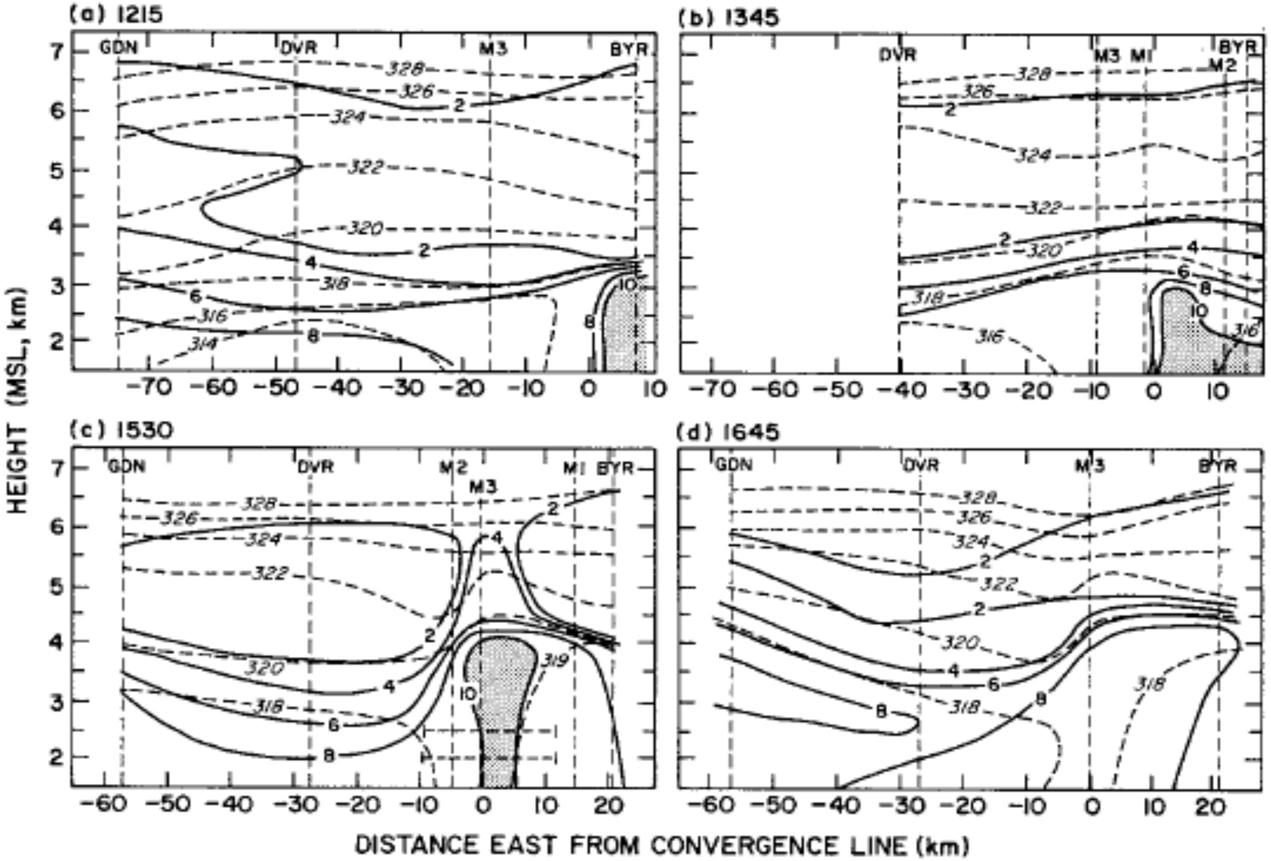
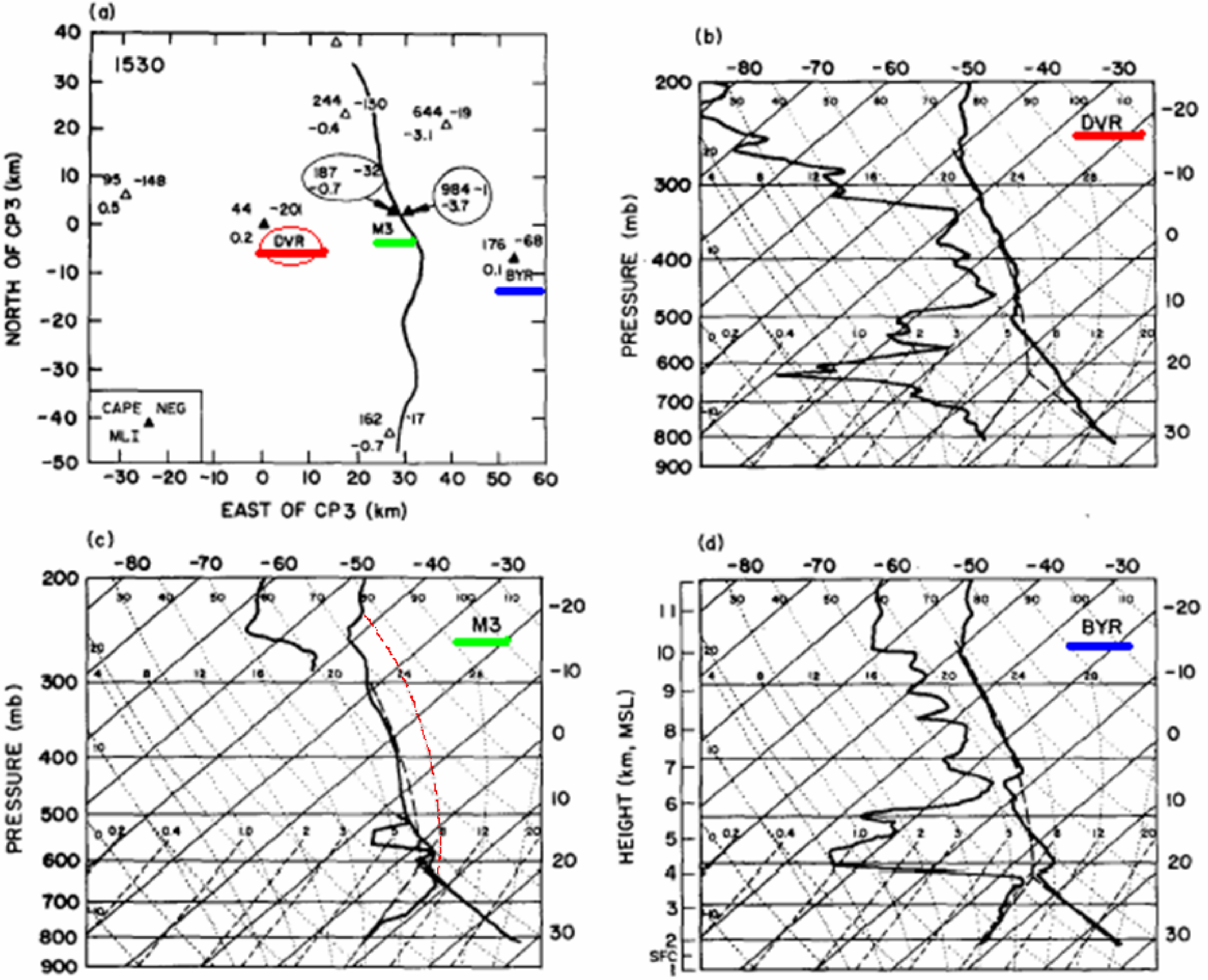
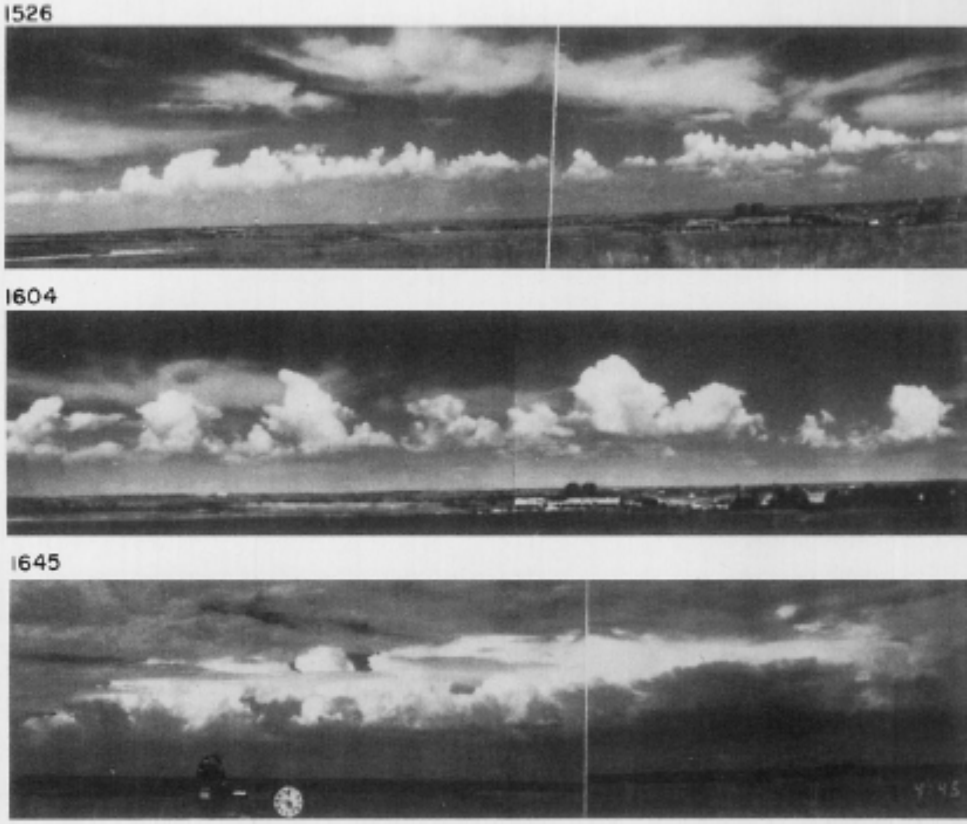


FIG. 16. East–west vertical cross section at four times showing the evolution of mixing ratio and potential temperature (K) as observed by upper-air soundings (vertical dashed lines), aircraft (horizontal dashed line), and mesonet. Shading represents mixing ratios ≥ 10 g kg^{-1}. The zero horizontal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

From Wilson et al, 1988, BAMS, 1328-1348 illustrating the small scale & strong increase in moisture and thunderstorms formation along a convergence line that eventually resulted in tornadoes. Here we see 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. The next slide shows the orientation of the convergence line and soundings simultaneously released at DVR (Denver), BYR (Byers) and M3 (Mobile). The final slide shows the cloud line evolution, Doppler signature with hook echo and the tornado.


(a)
1530
NORTH OF CP3 (km)
EAST OF CP3 (km)
244 -130 -0.4
644 -19 -3.1
95 -148 0.5
187 -32 -0.7
984 -1 -3.7
44 -201 0.2
DVR
M3
176 -68 0.1 BYR
162 -17 -0.7
CAPE NEG
MLI
(b)
DVR
PRESSURE (mb)
(c)
M3
PRESSURE (mb)
(d)
BYR
HEIGHT (km, MSL)
SFC



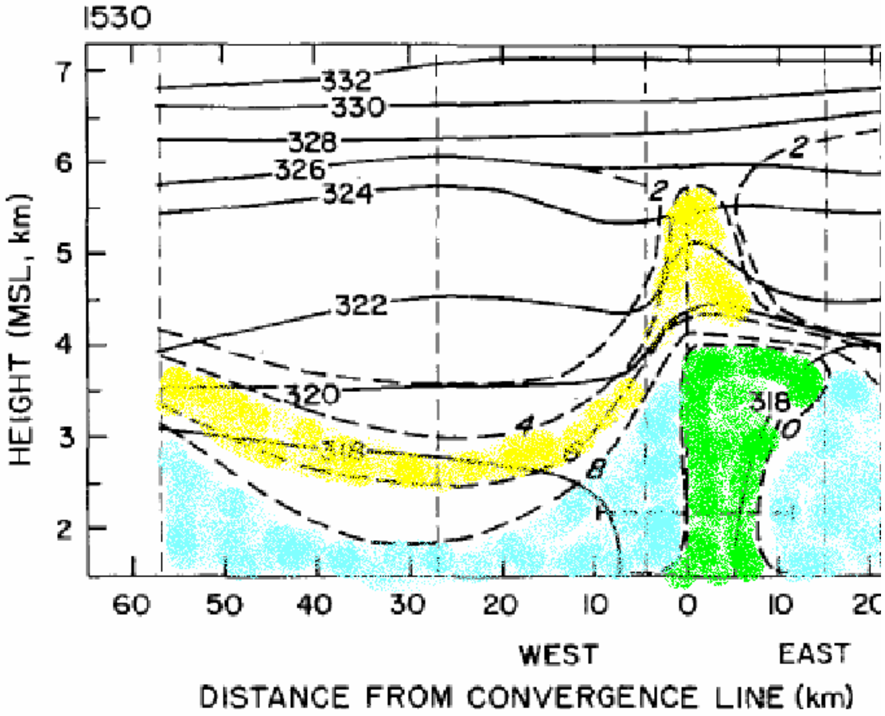
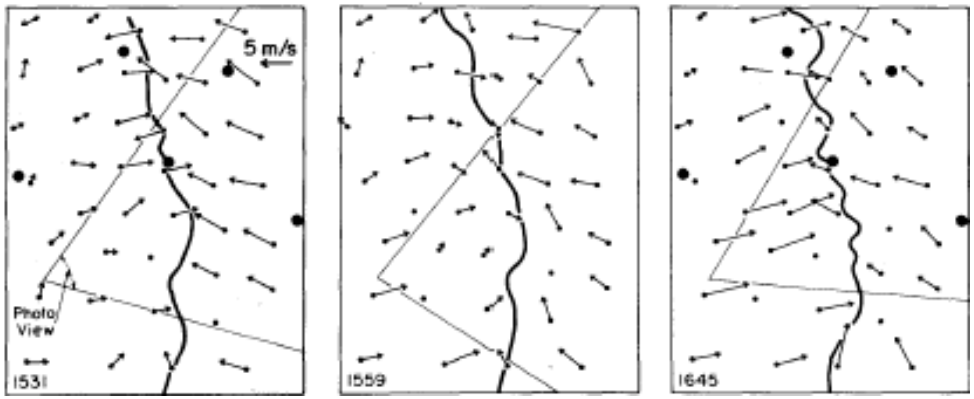
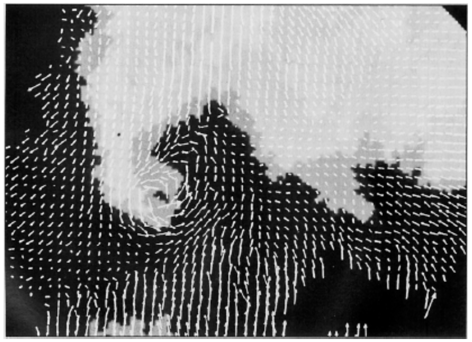
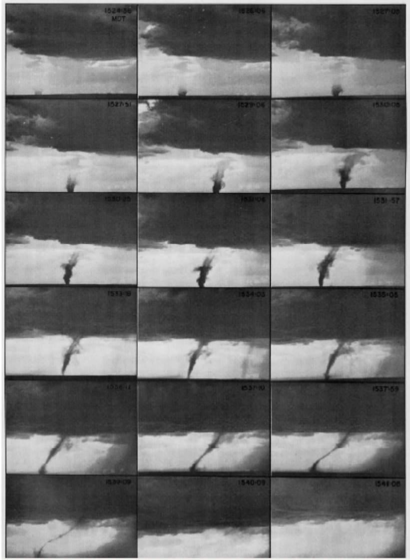


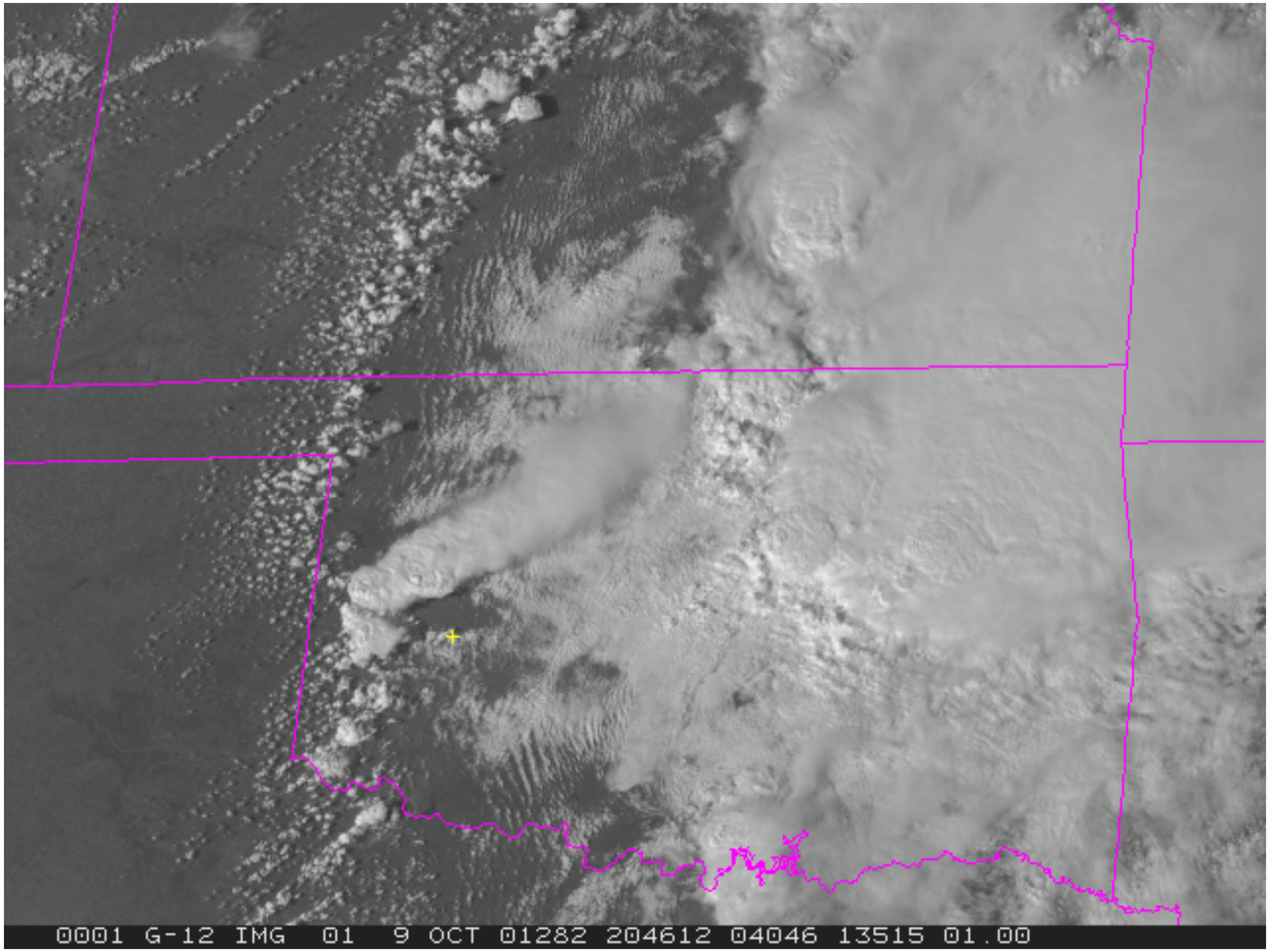
FIG. 6. West-to-east vertical cross section at 1530 MDT through the boundary in FIGS. 3 and 4. Solid contours are potential temperature (K) and the dashed contours are mixing ratio (g · kg⁻¹). The dashed, vertical lines are sounding locations and the horizontal dashed line is the NCAR King Air flight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

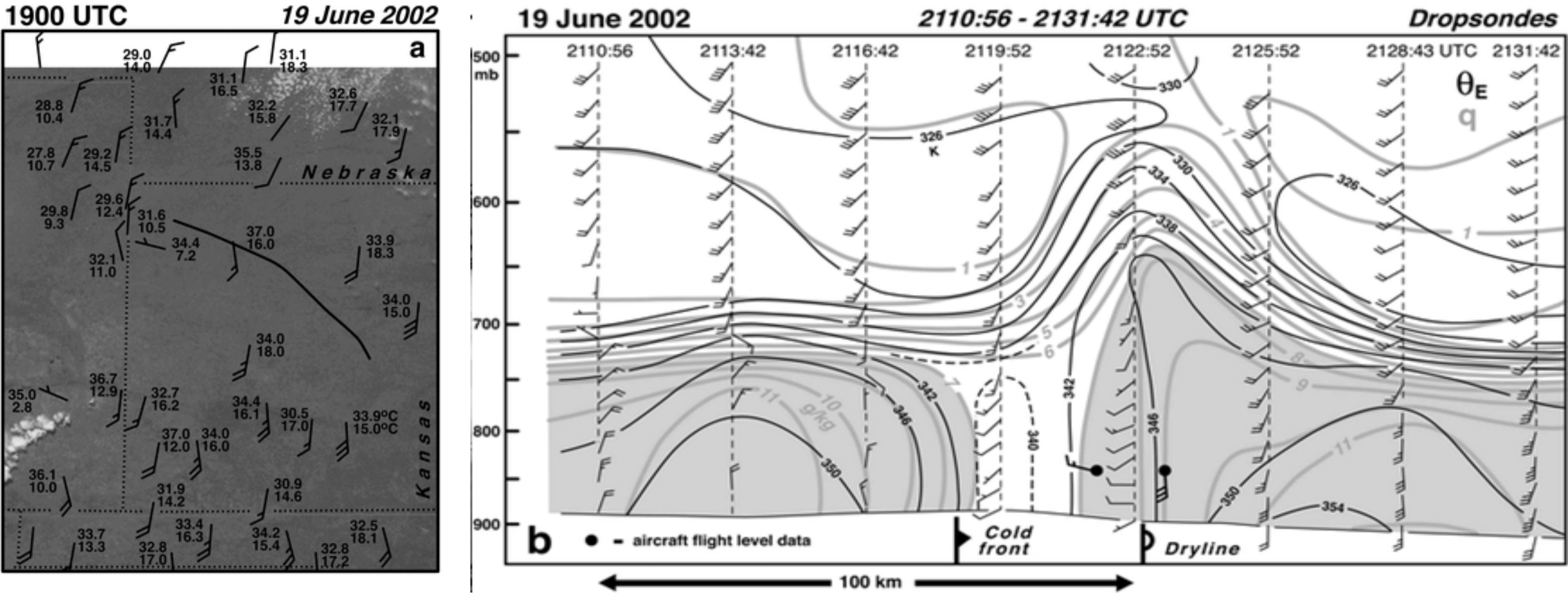


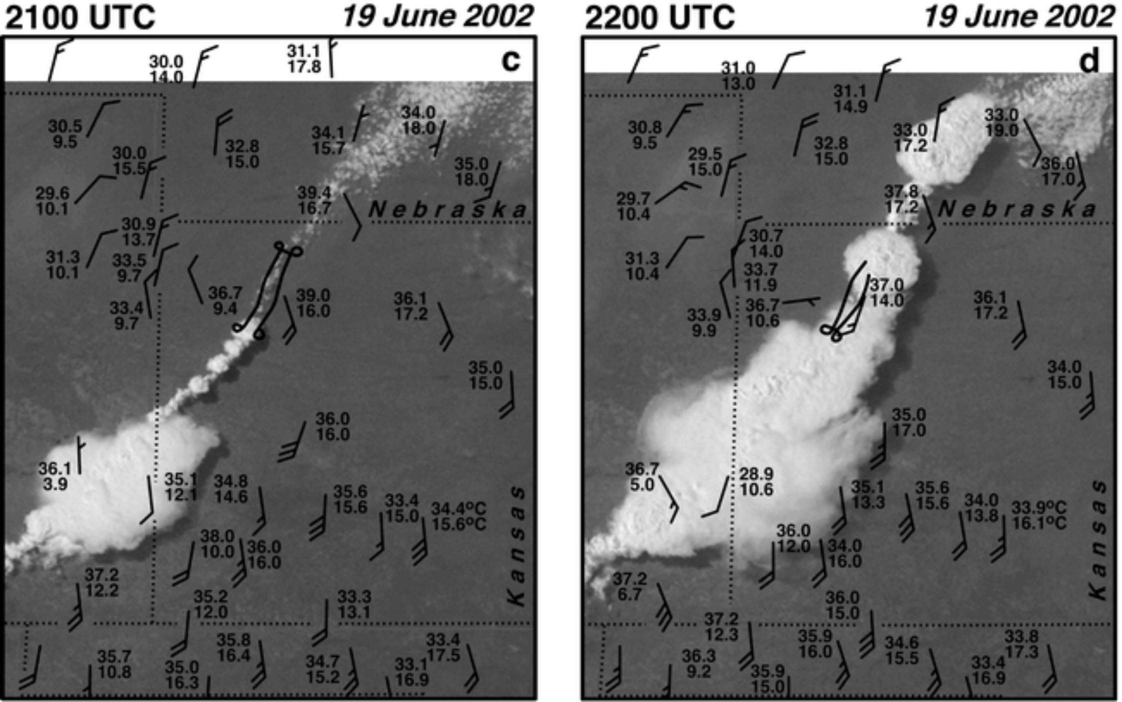




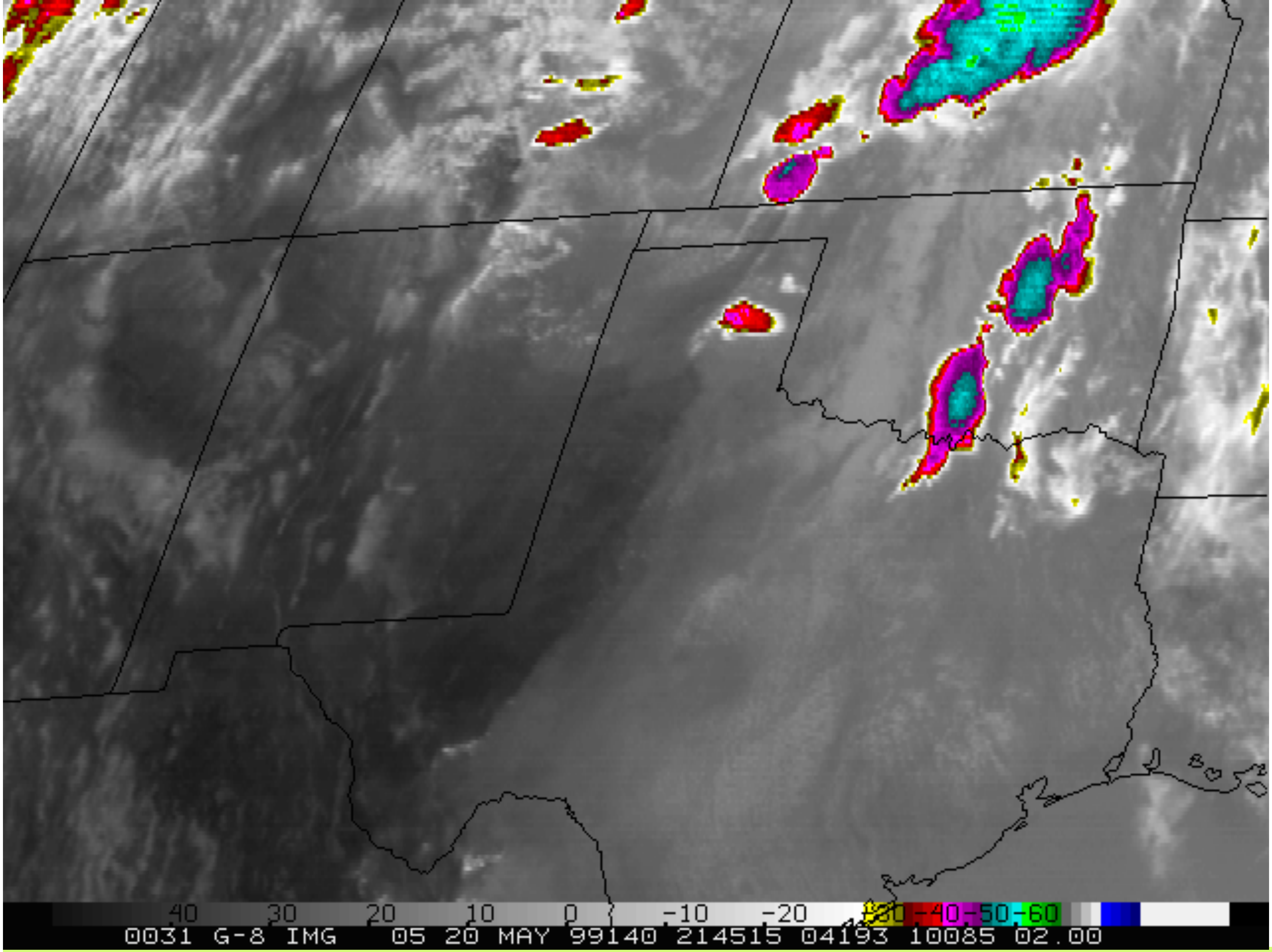
From Wilson et al, 1988, BAMS, 1328-1348 illustrating the small scale & strong increase in moisture and thunderstorms formation along a convergence line that resulted in tornadoes.


0001 G-12 IMG 01 9 OCT 01282 204612 04046 13515 01.00





Numerous studies have highlighted the importance of knowing the disribution of water vapor in predicting convective development and evolution. Recently, from Murphey et al 2006. MWR, 406-429 from IHOP experiment. “The location where convection initiates is denoted by the upward bulge in the isopleths of mixing ratio (q) and $\theta_{[E]}$.”



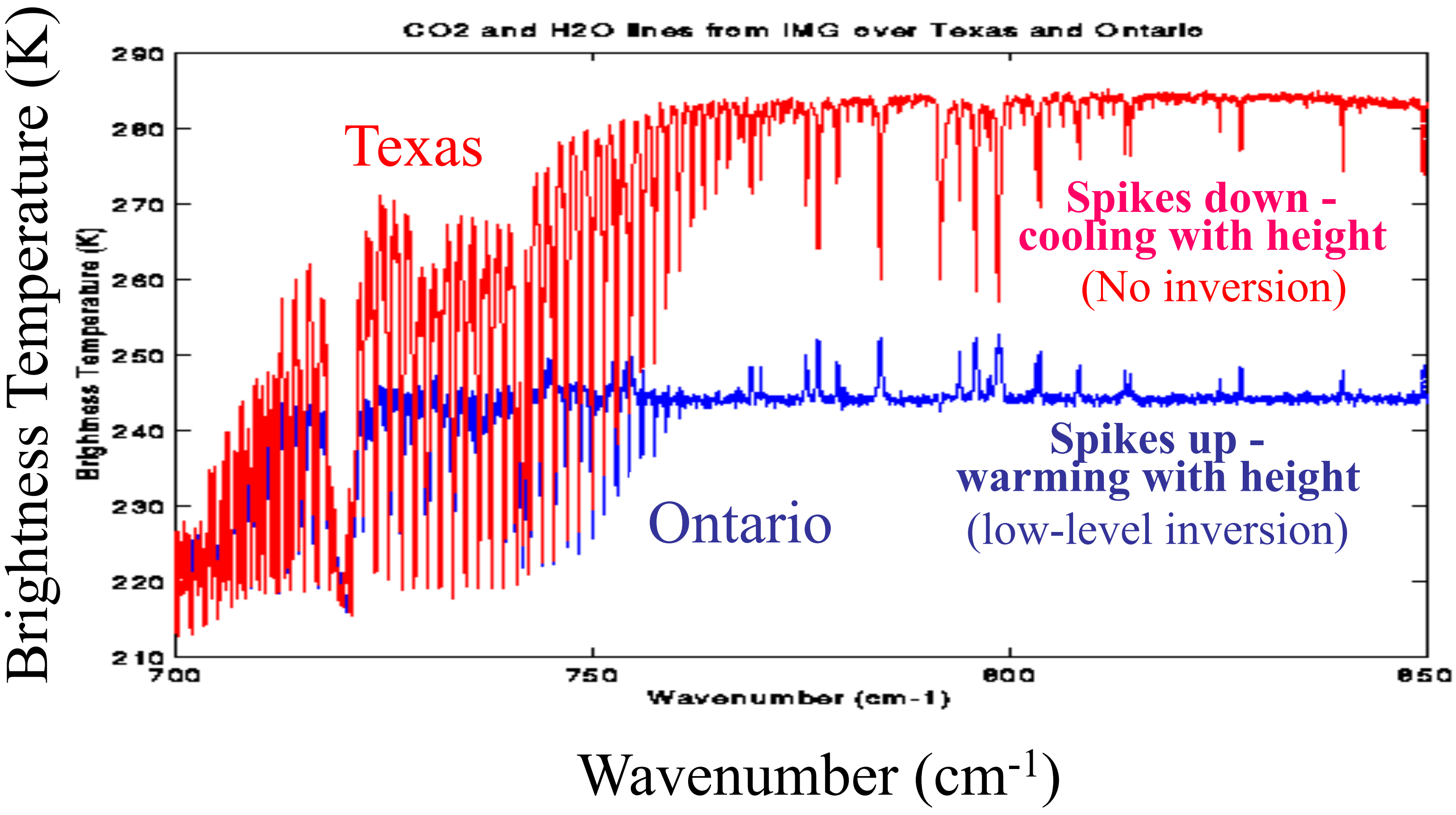
Transition from moist to dry boundary layer air over West Texas – daytime to night

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

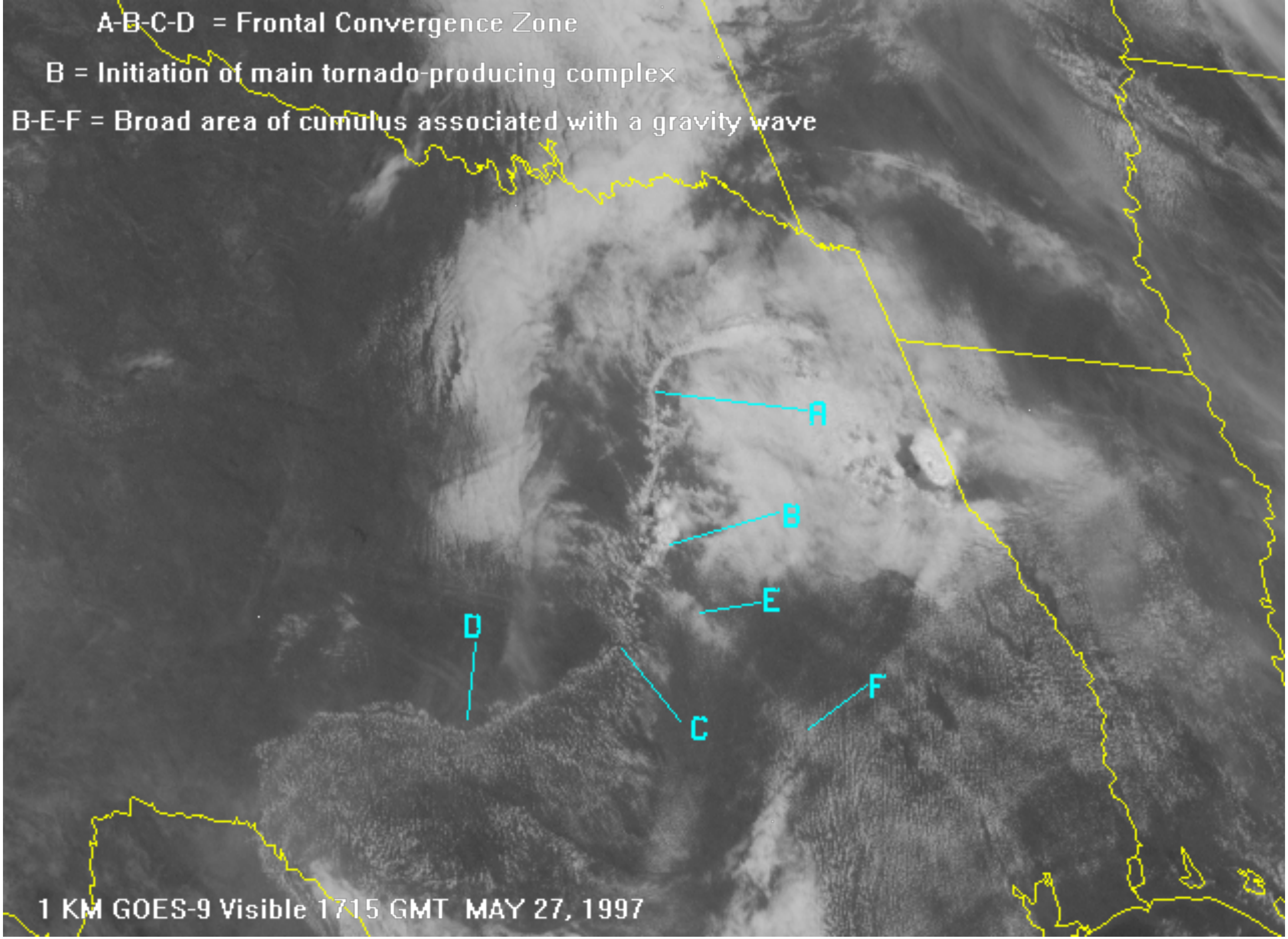
- The afternoon initiation episodes were primarily surface based and the nocturnal were elevated. The surface-based initiations occurred mostly during the afternoon and early evening, and the elevated initiations during the night and early morning.

- 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.

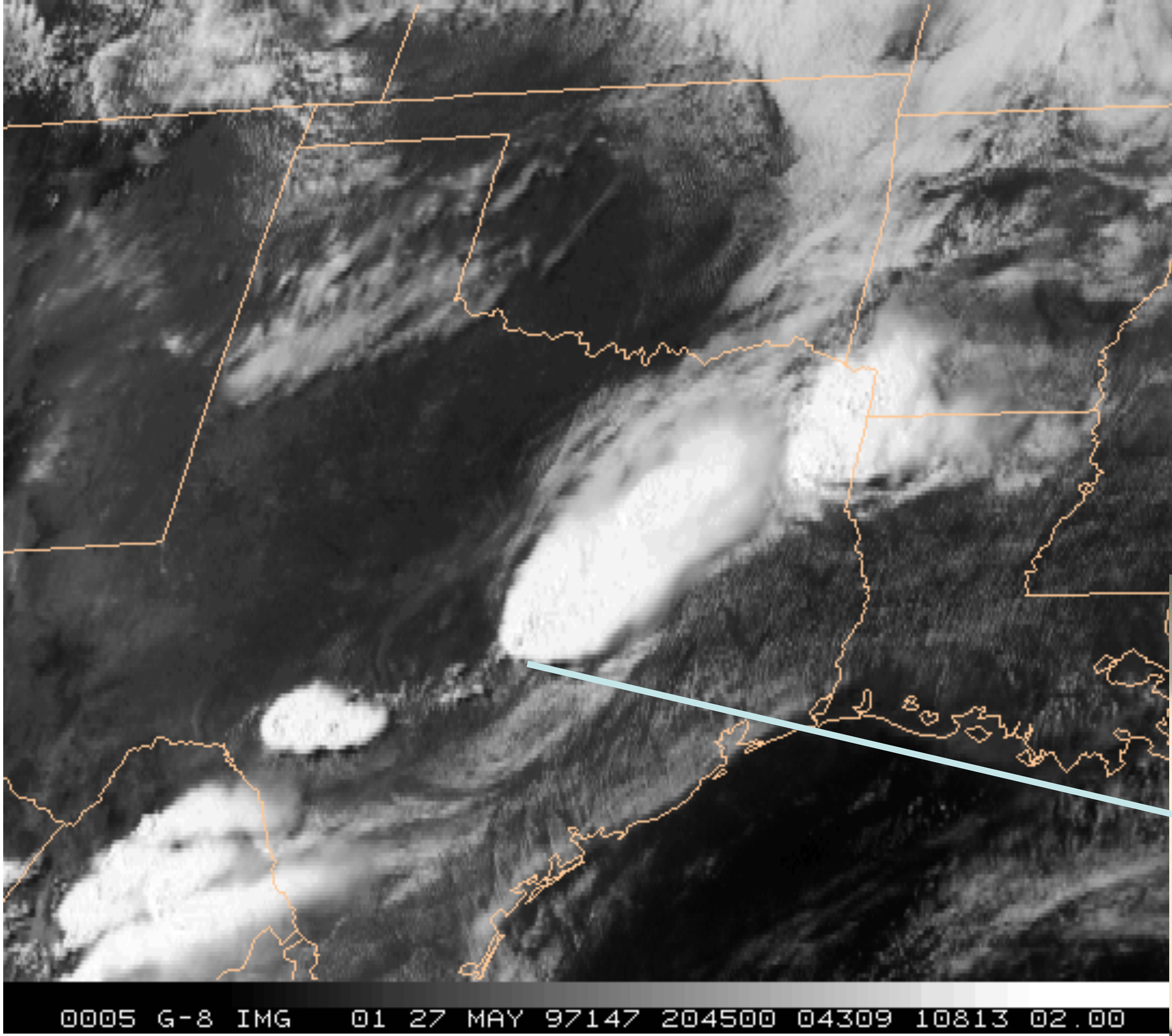
Detection of Temperature Inversions Possible with Hyperspectral IR

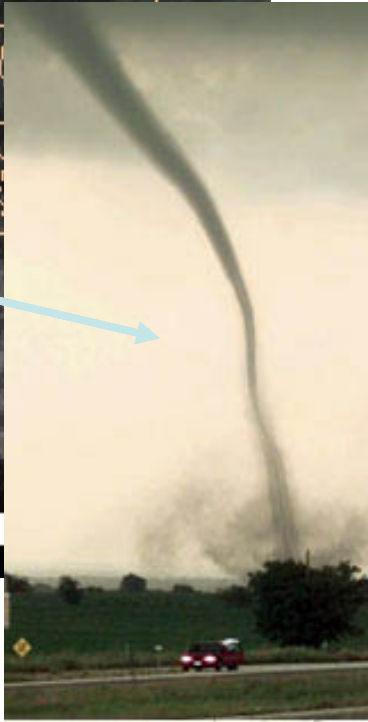


Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.

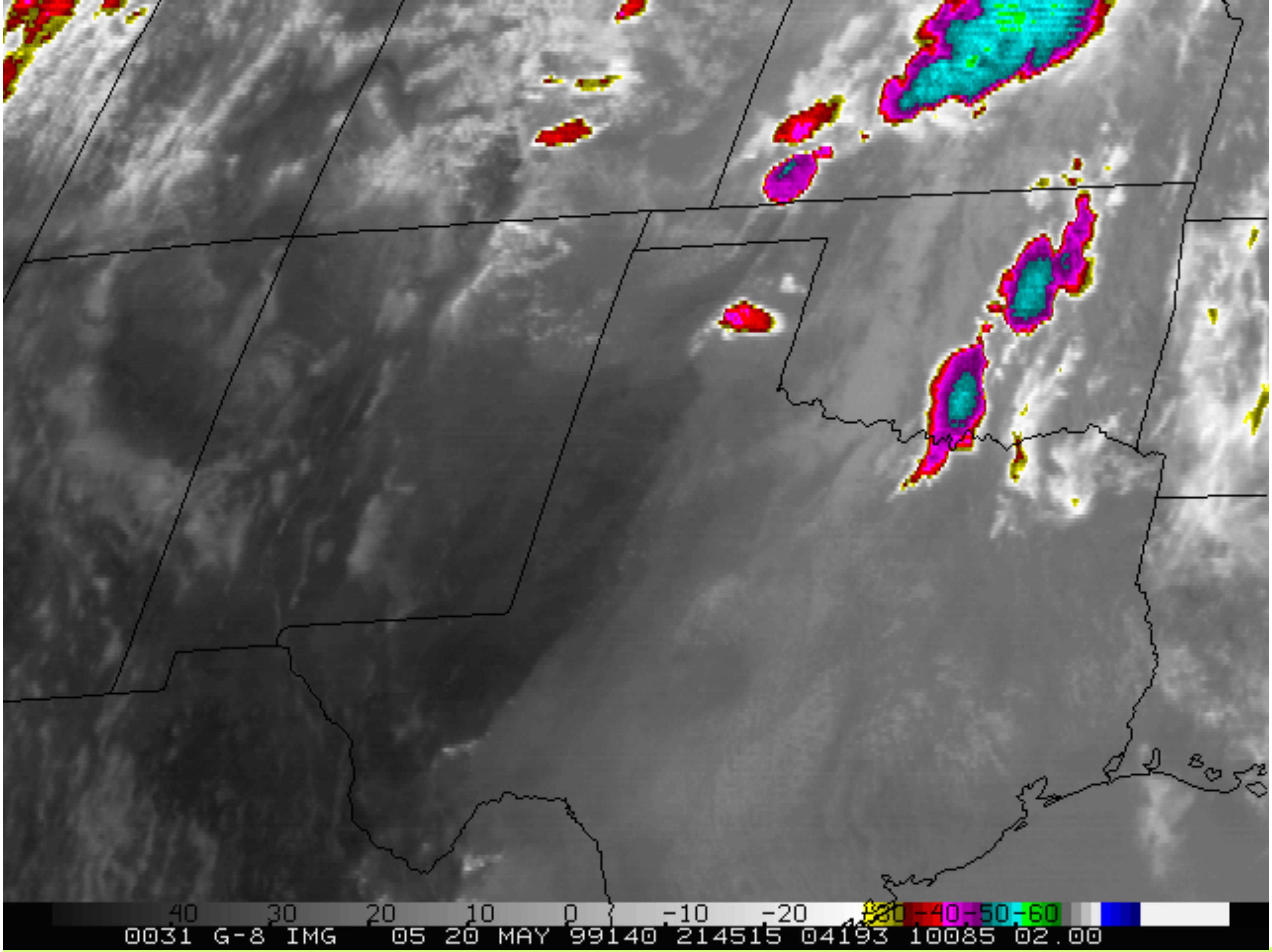


Pre squall line convergence zone along a stationary front





Developed squall line and tornado



Transition from moist to dry boundary layer air over West Texas – daytime to night

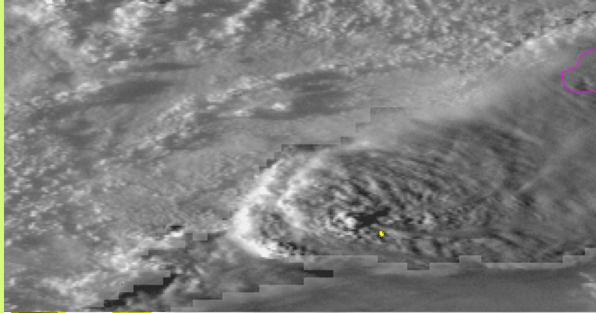
Conclusion

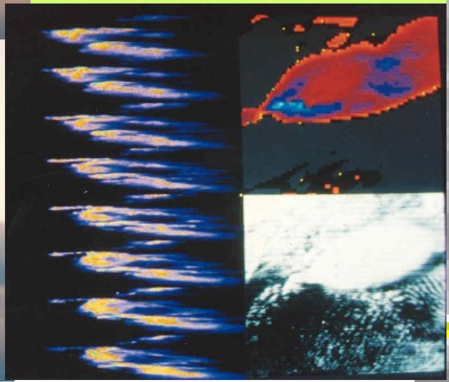
- **Field experiments using ground based mesonets, Doppler radar, fixed and mobile rawinsondes, satellite imagery, and research aircraft equipped with specialized measurement devices continue to show that large variations in the atmosphere's ability to support strong convection exists over scales of 25 km or less. These moisture fields evolve rapidly as circulations develop and as low level moisture is advected into a region.**

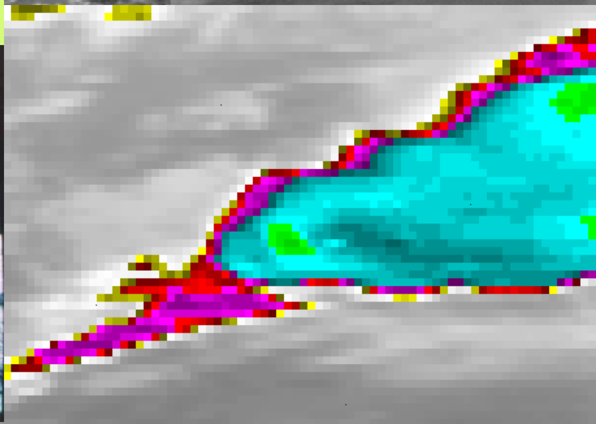
- **Geostationary Hyperspectral Sounding: There is no other instrument or measurement system capable of mapping at the required high temporal and spatial resolution the state and evolution of the convective environment on the scales necessary to observe it over large areas, accurately, on demand.**

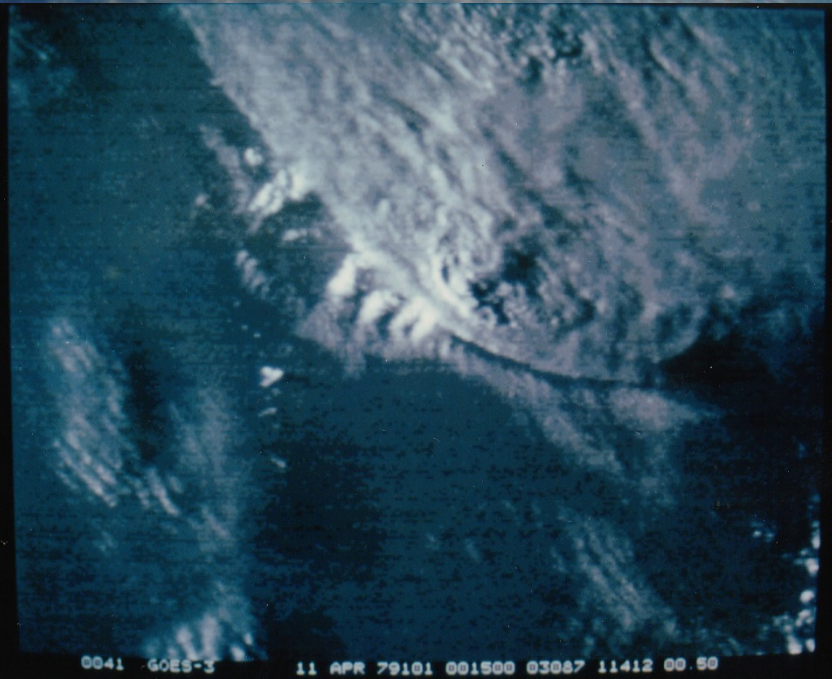
Overshooting Tops

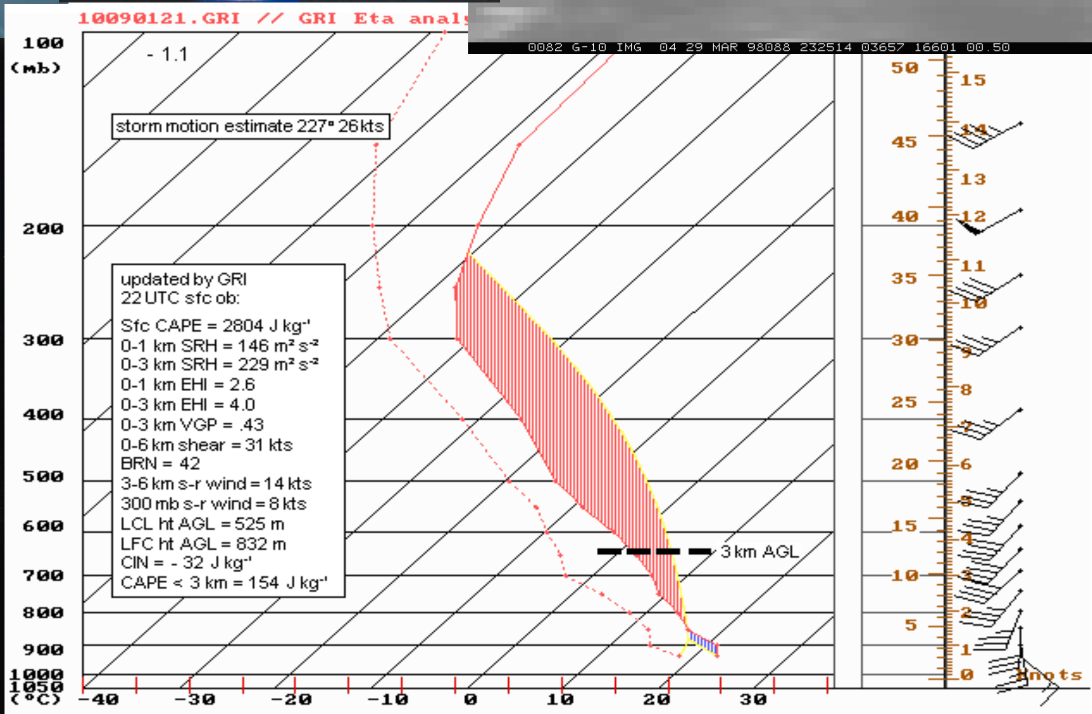
What do they mean?







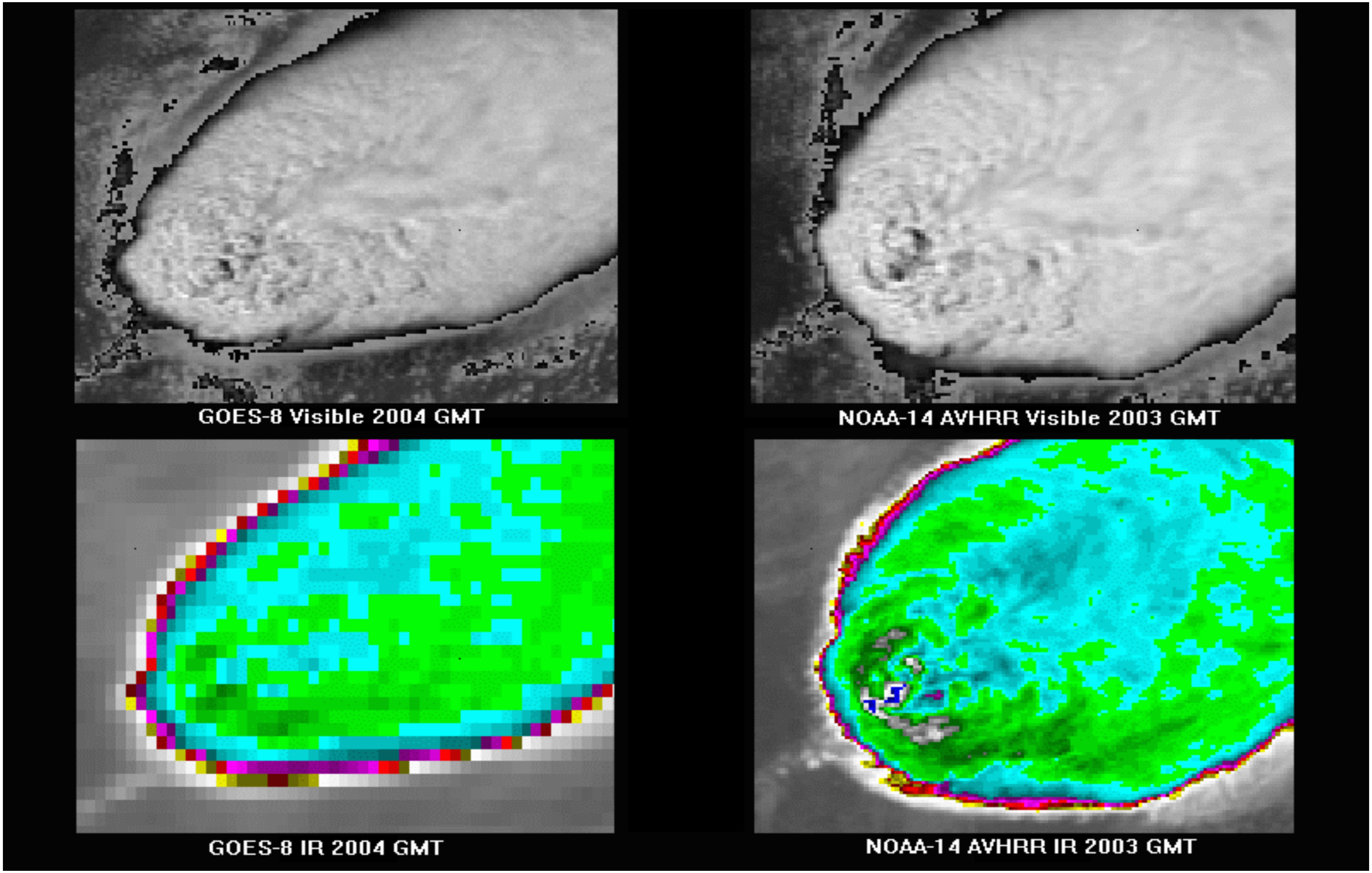




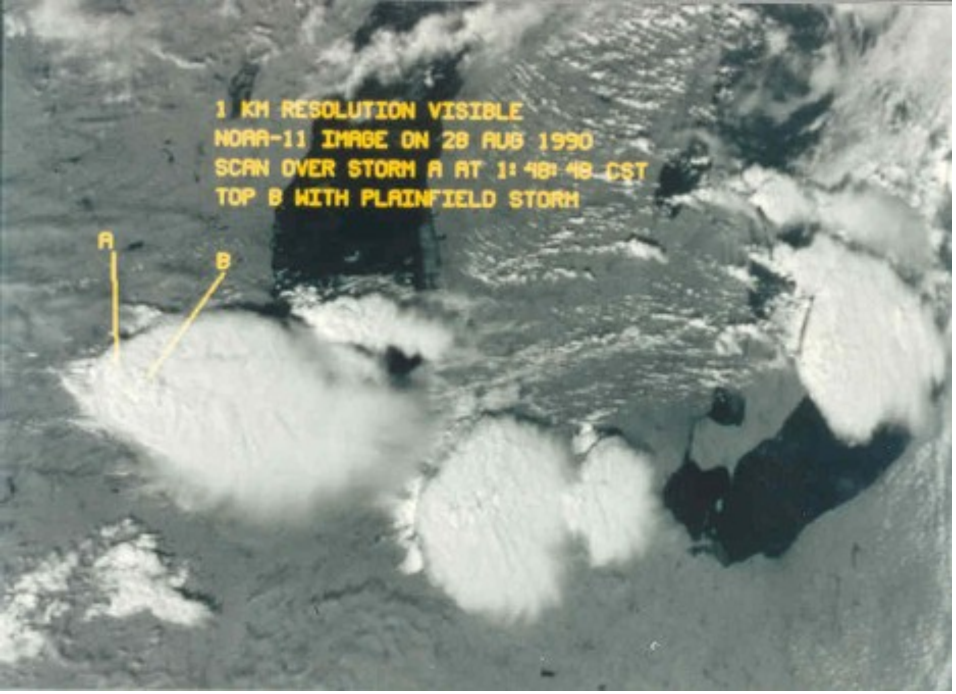
storm motion estimate 227° 26kts

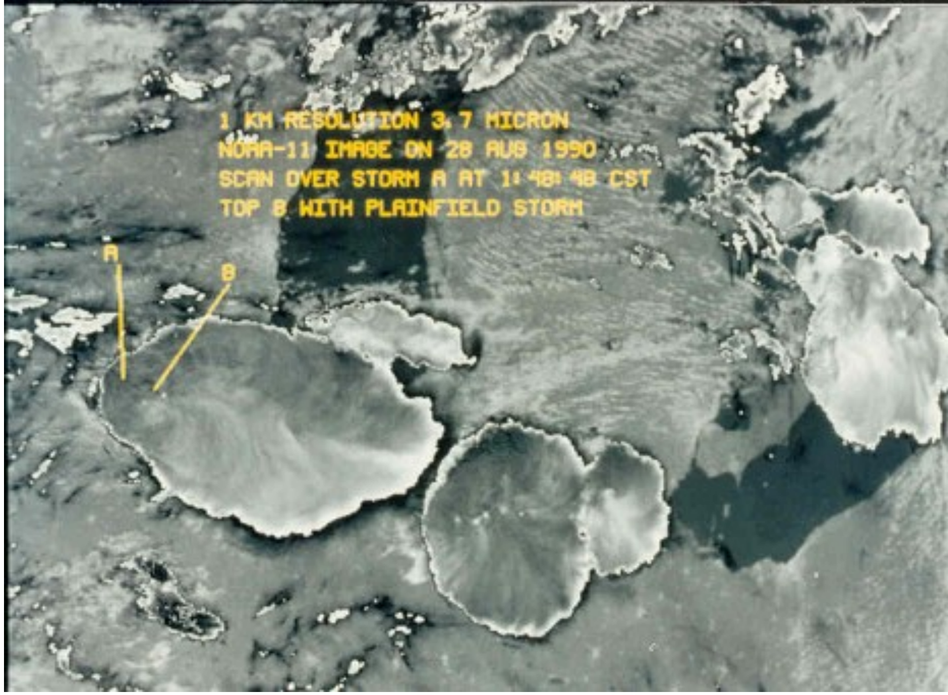
updated by GRI
22 UTC sfc ob:

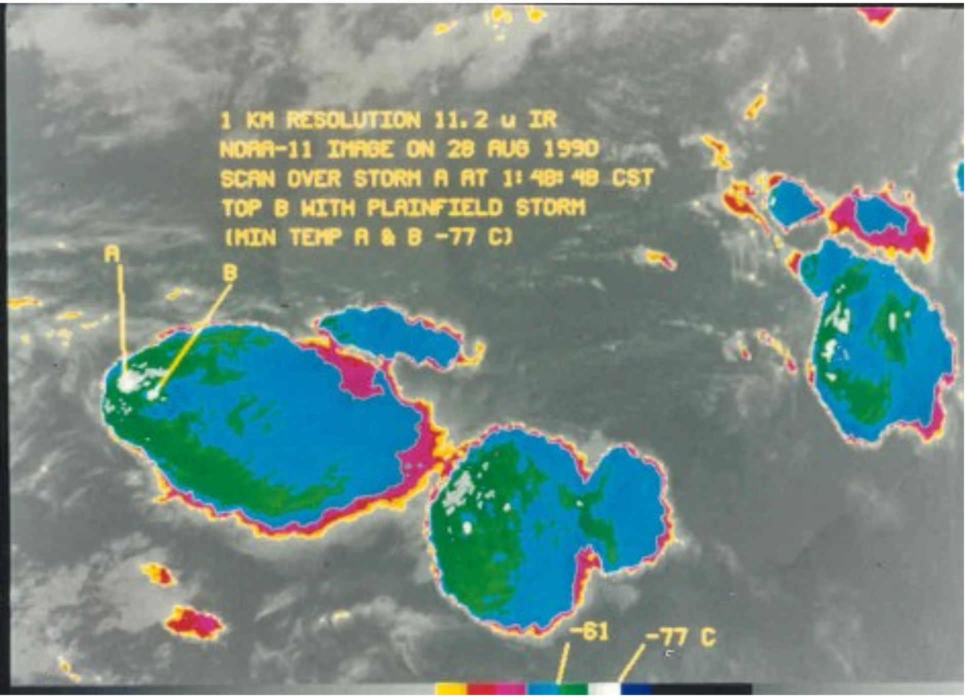
Sfc CAPE = 2804 J kg^{-1}
0-1 km SRH = 146 m^2 s^{-2}
0-3 km SRH = 229 m^2 s^{-2}
0-1 km EHI = 2.6
0-3 km EHI = 4.0
0-3 km VGP = .43
0-6 km shear = 31 kts
BRN = 42
3-6 km s-r wind = 14 kts
300 mb s-r wind = 8 kts
LCL ht AGL = 525 m
LFC ht AGL = 832 m
CIN = - 32 J kg^{-1}
CAPE < 3 km = 154 J kg^{-1}



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

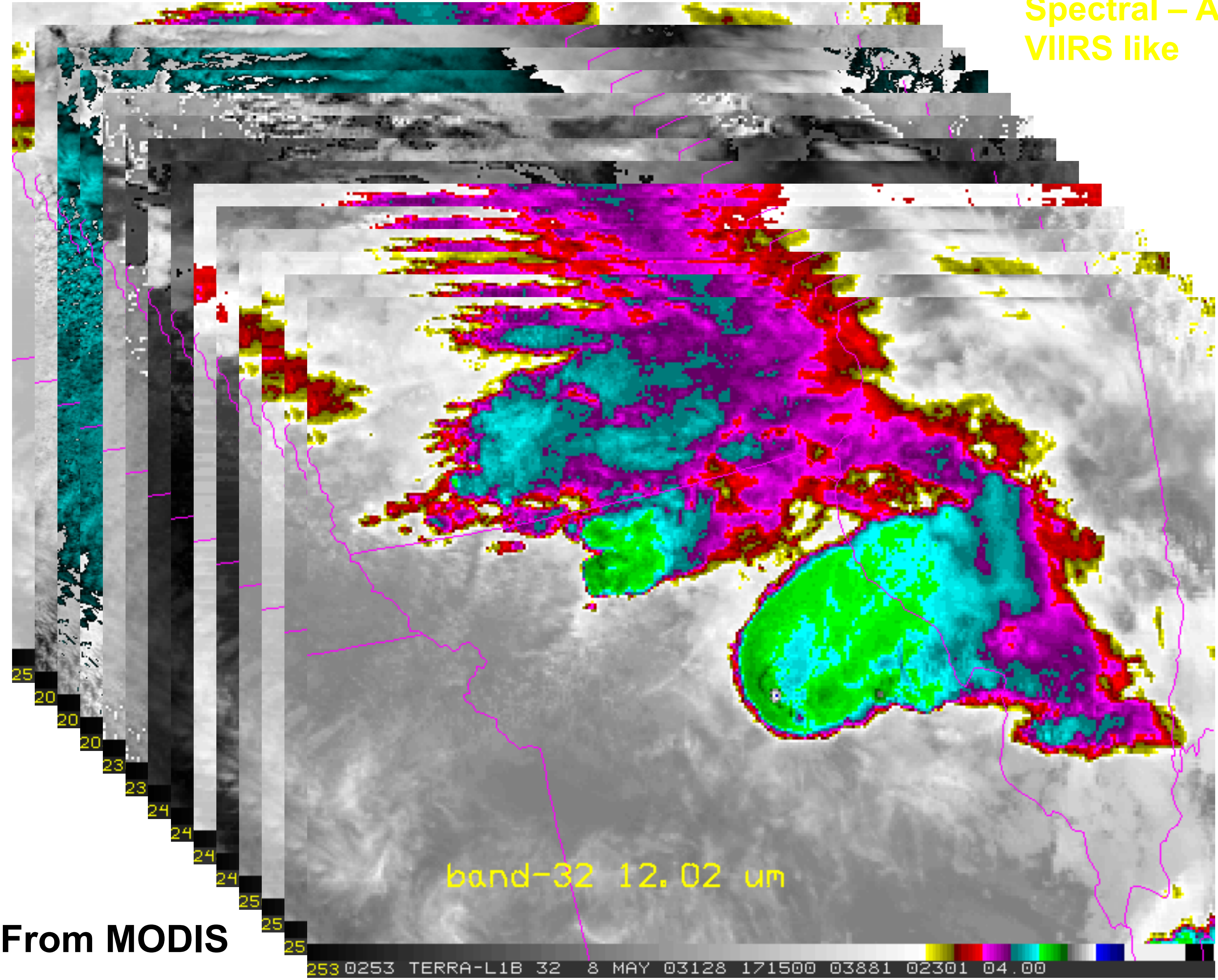




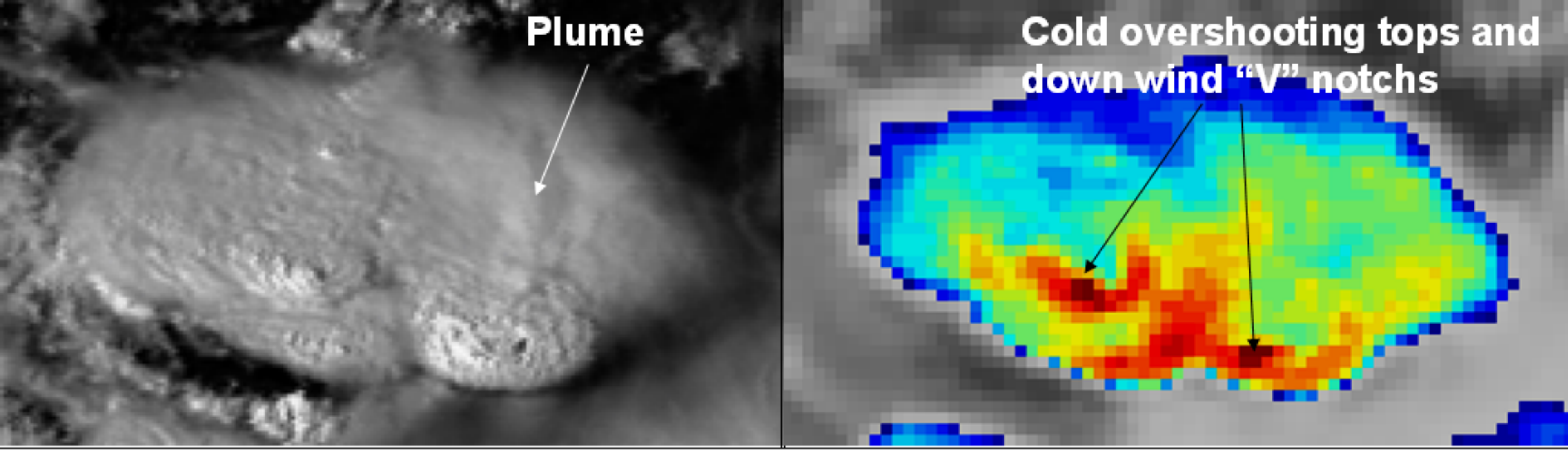


Different characteristics of anvils and overshooting tops are revealed by using different channels. Shown here are AVHRR visible (upper left), 3.7 microns (upper right with special enhancement across anvil top) and 10.7 micron IR

Spectral – ABI and VIIRS like

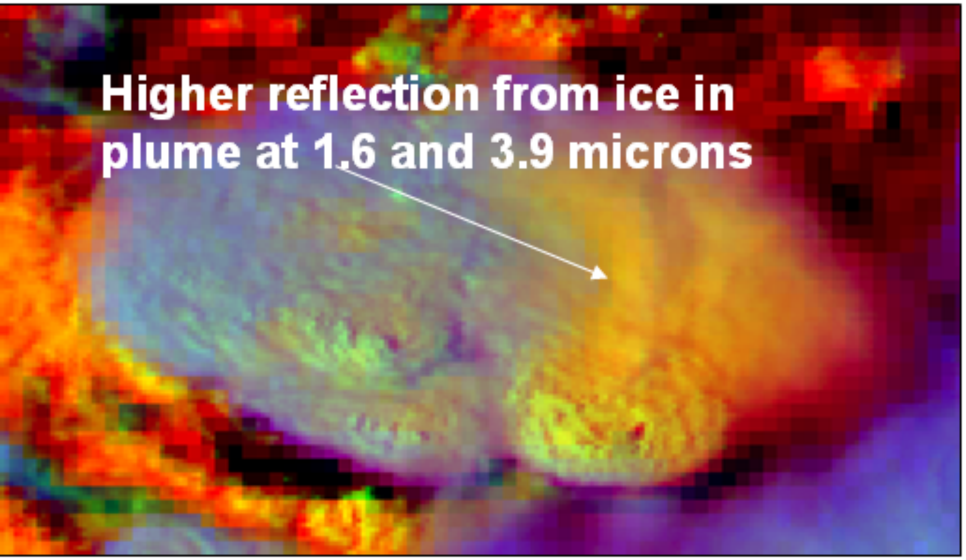


From MODIS



MSG High Resolution Visible (HRV)

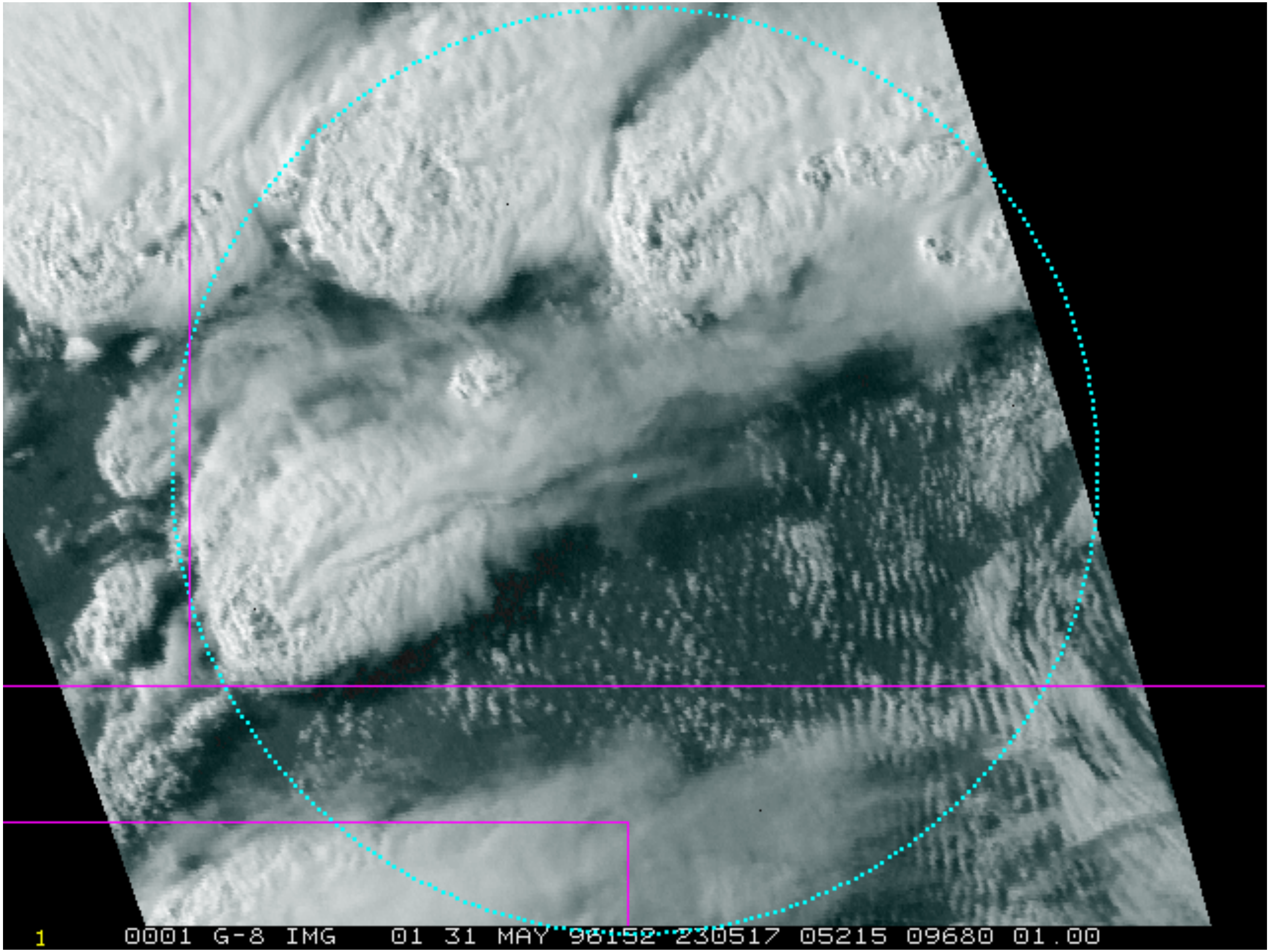
MSG Enhanced 10.7 micron IR



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.

One minute interval visible imagery



Conclusion

- **Field experiments using ground based mesonets, Doppler radar, fixed and mobile rawinsondes, satellite imagery, and research aircraft equipped with specialized measurement devices continue to show that large variations in the atmosphere's ability to support strong convection 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 Hyperspectral Sounding: There is no other instrument or measurement system 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.**