Storm Top Dynamics

A Review

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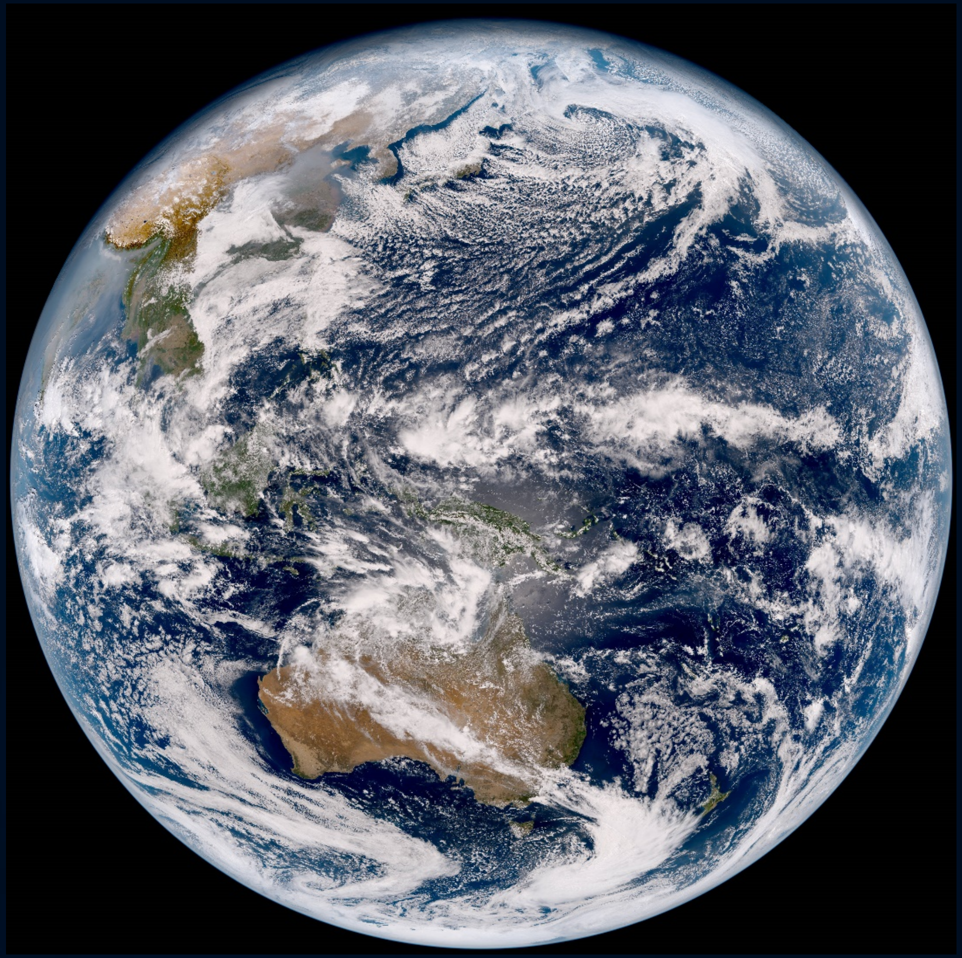
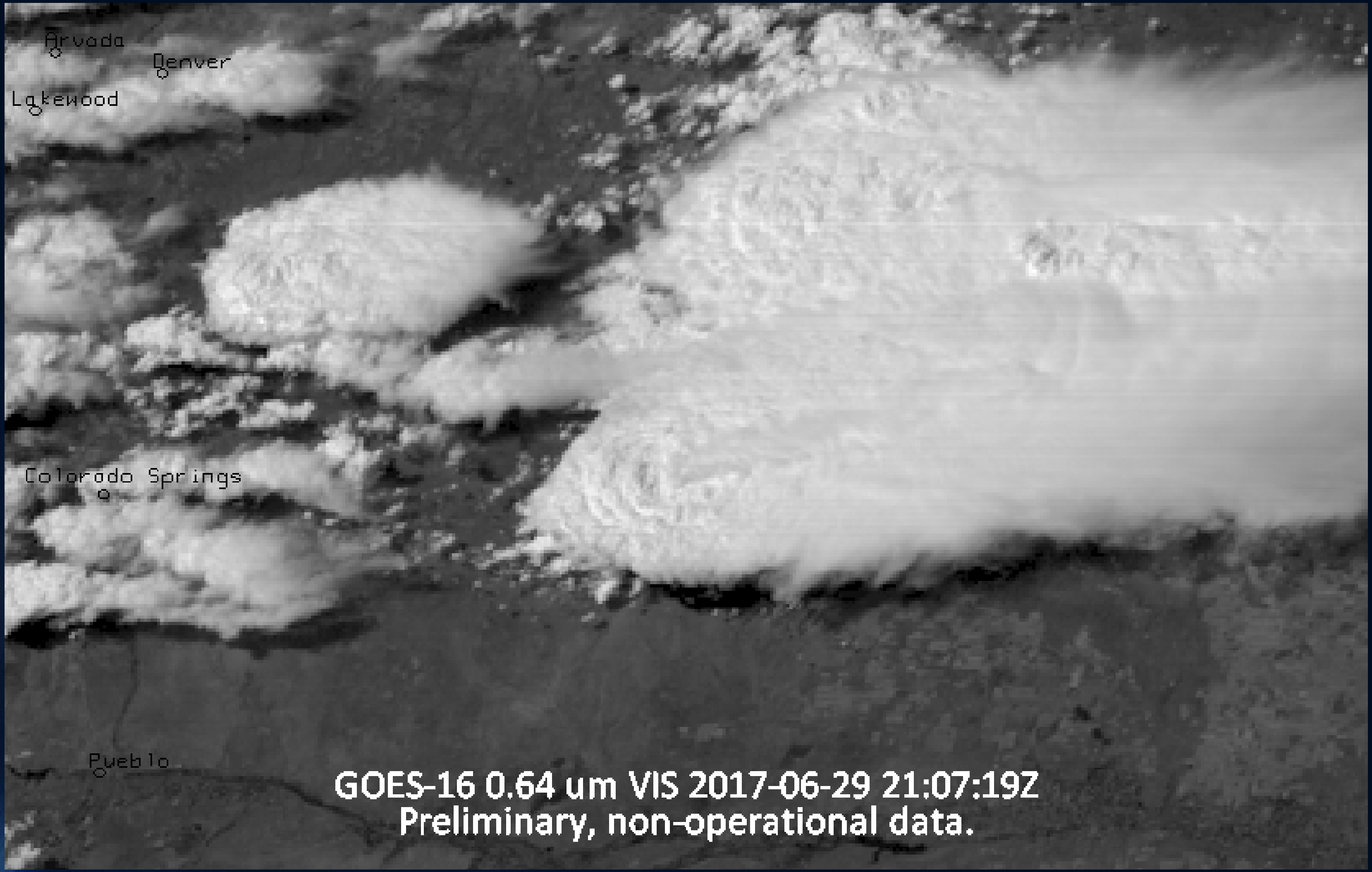
Deep convection in the atmosphere

- Vertical velocity in the atmosphere
  - Large scale – w ~ a few cm/s.
  - Shallow convections – w_{max} ~ a few m/s
  - Deep convections – w_{max} ~ 30 - 60 m/s, even more in some extreme cases
- Deep convections usually organize into a few narrow belts (such as ITCZ and frontal bands)



Thunderstorms seen by meteorological satellites



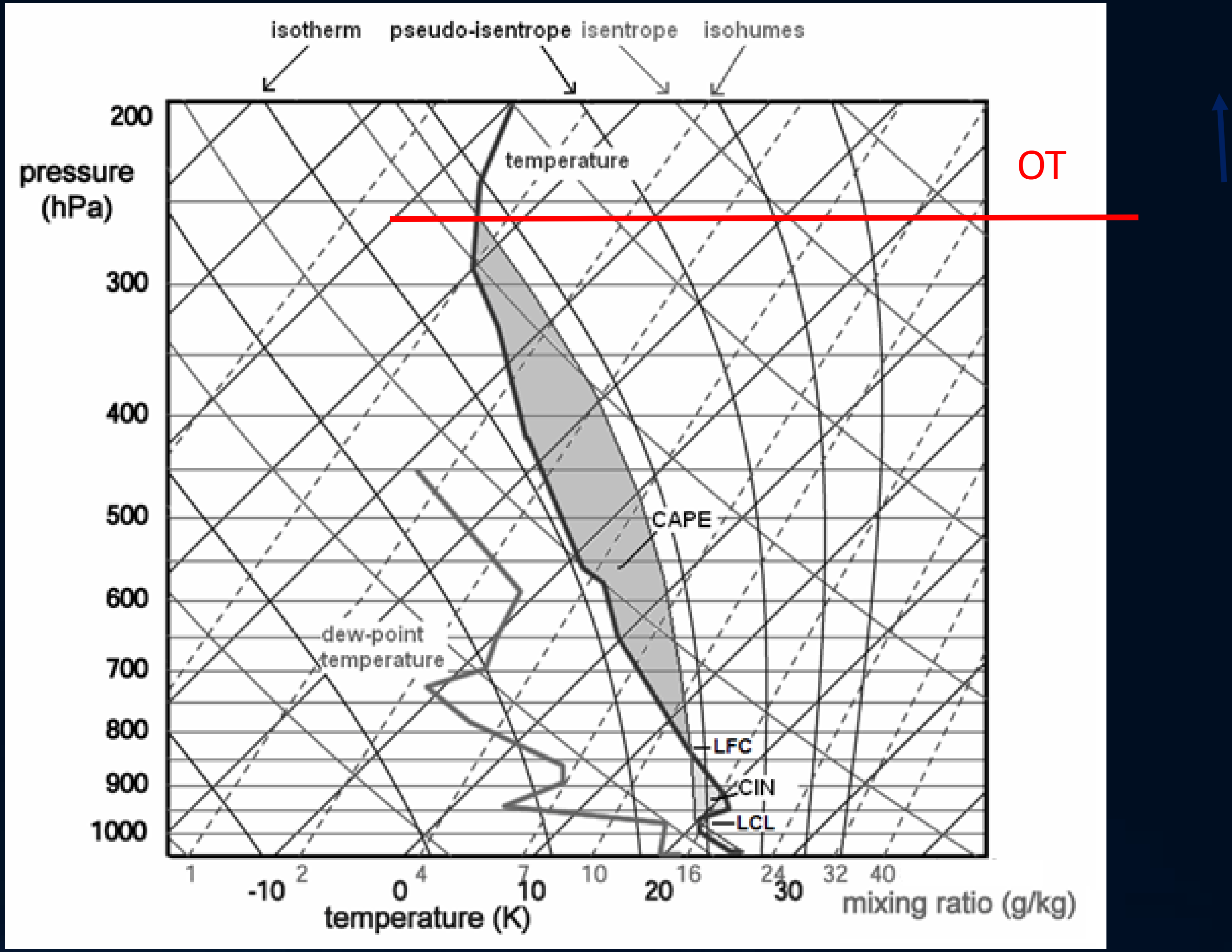
NOAA

Importance of understanding storm top features

- Correct interpretation of satellite data is important for forecasters to better nowcast storm development. The same is true for scientists who use these data for research .
- This talk will present a unified theory on the physical processes responsible for generating satellite –observed storm top features.

- Visible
  - Overshooting top (OT)
  - Jumping cirrus (JC)
  - Above anvil cirrus plumes (AACP)
  - Pancake cloud (PC)
- Infrared
  - Cold-V (or U),cold ring
  - Warm trench (WT)
  - Close-in warm area (CWA)
  - Distant warm area (DWA)
  - Ship wave signature (SWS)

Typical severe storm sounding in US Midwest



Doswell et al., 2002

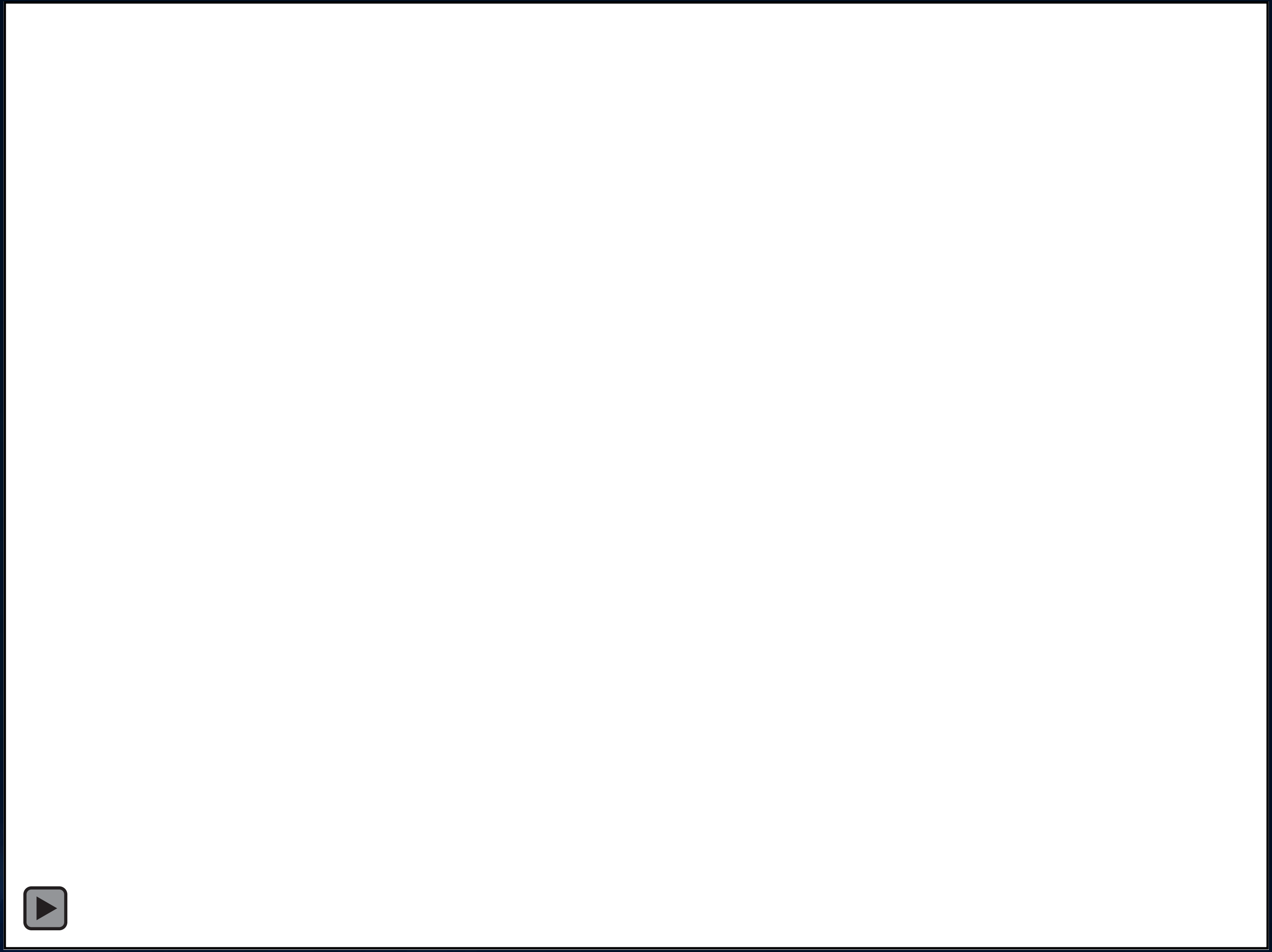
Overshooting (OT)

- Note that the overshooting is defined with reference to the equilibrium level (EL) only. There are two points that need to be clarified:
  - EL is not necessarily the same as the tropopause. In severe storms, however, EL is close to the tropopause.
  - Overshooting does not imply penetration. It may be just simply a distortion of the tropopause. You need other non-adiabatic mechanisms to cause the penetration.

Internal Gravity waves

- Gravity waves are wave motions that utilizing gravity as the restoring force.
- Water waves we usually see on lakes or oceans is also a kind of gravity waves, but it is a surface gravity wave. The vertical motion is limited to a very shallow layer near the surface, and the phase and group velocities are in the same direction.
- But in the atmosphere (as well as in the interior of ocean), the density is stratified so that the gravity waves can also propagate vertically in addition to propagate horizontally. This wave is called the internal gravity wave (IGW).
- The strange character of IGW is that the phase velocity and group velocity are perpendicular to each other.
- This means that the wave energy propagates along the phase line.

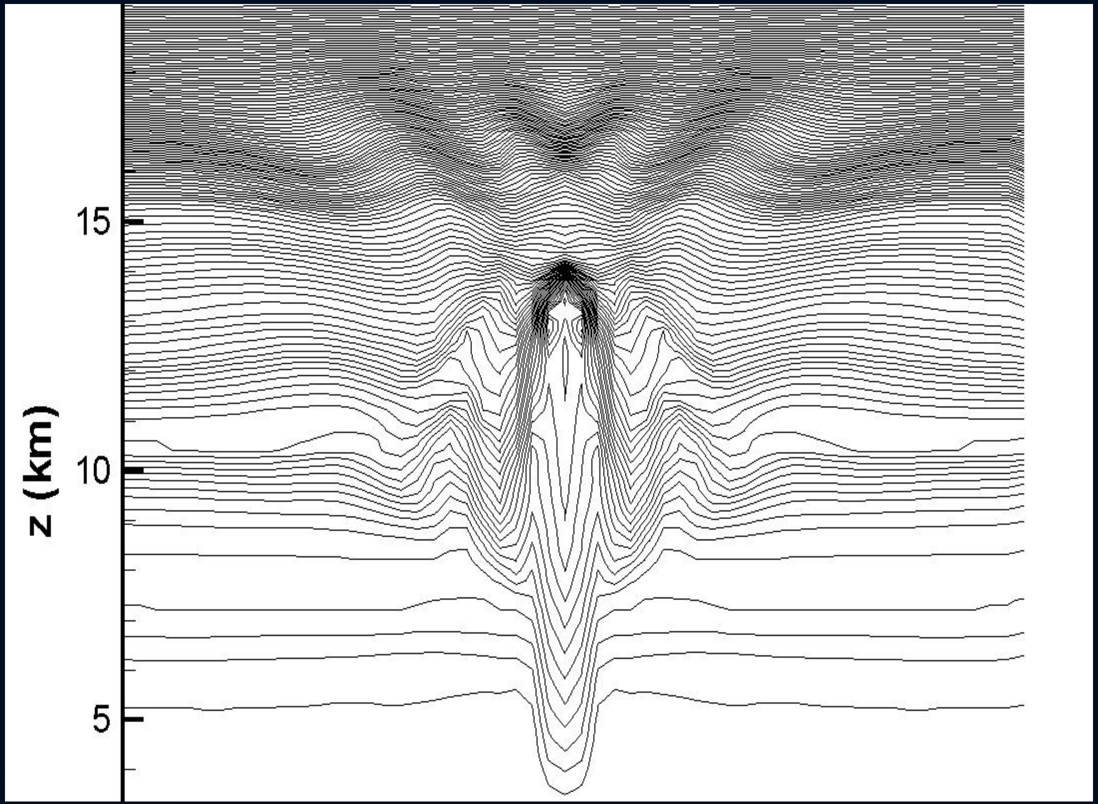
Internal gravity waves in the lab



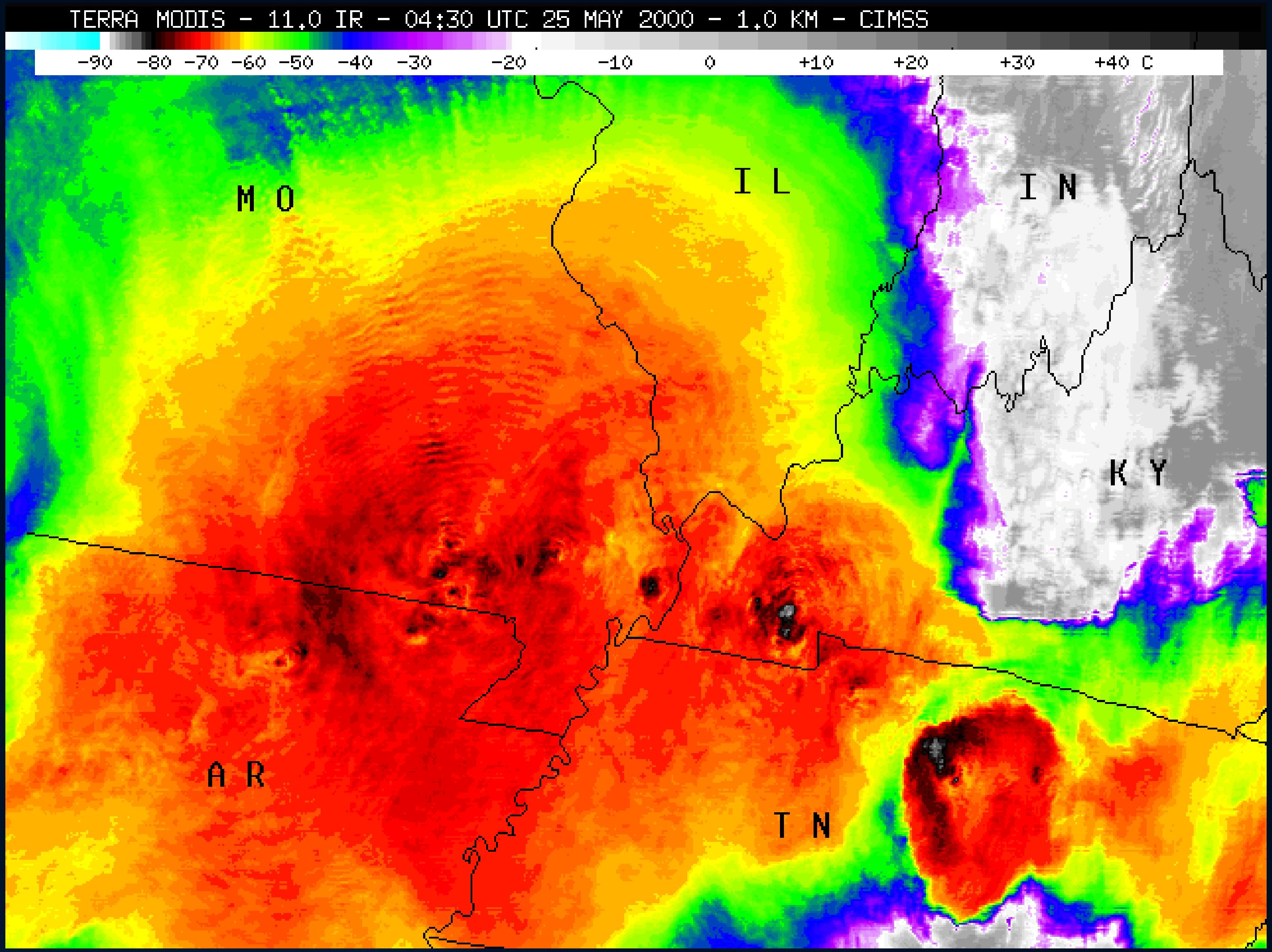
Courtesy of Kyoto University

CCOPE without wind shear

IGW are excited



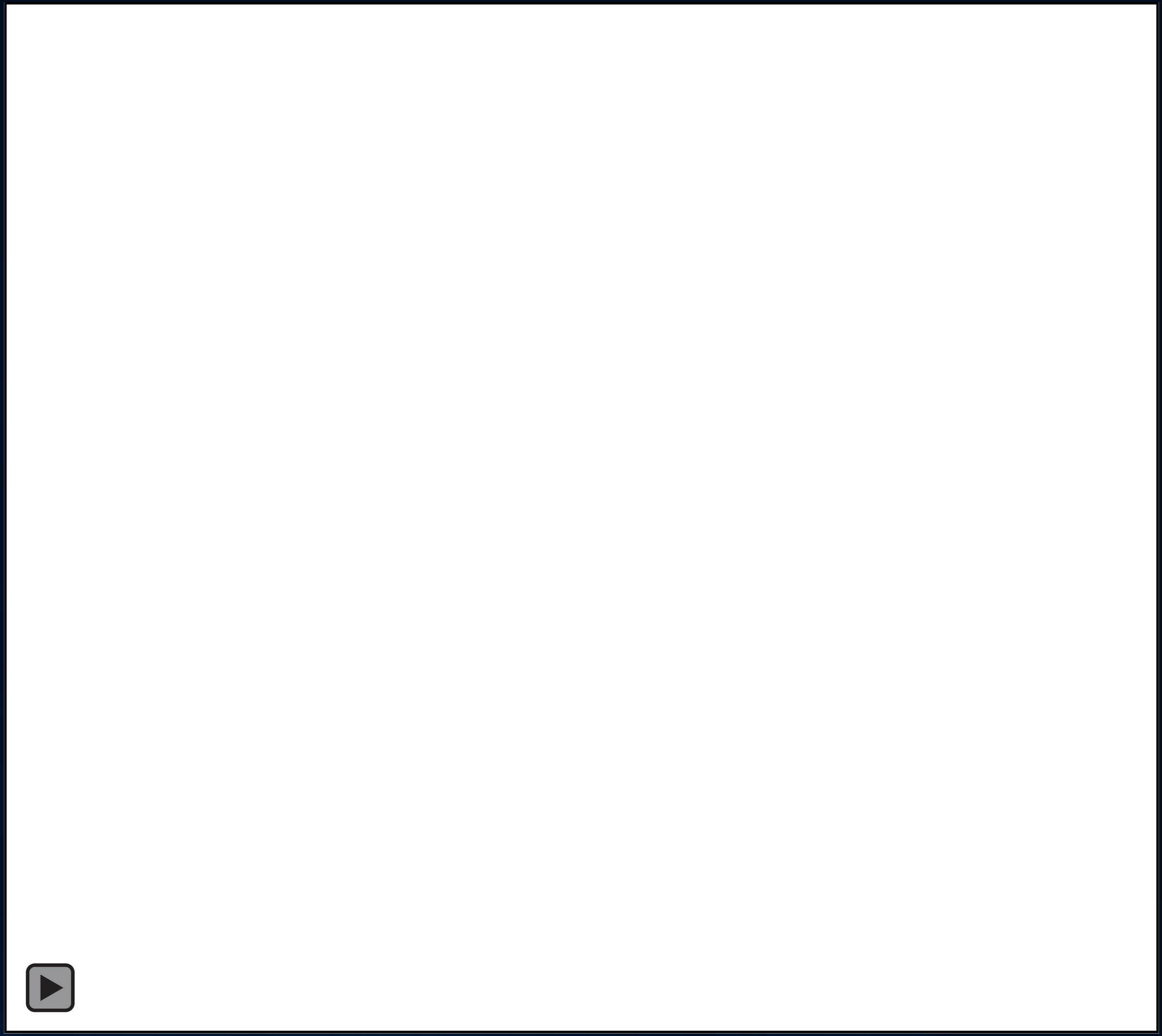
Storm Top Internal Gravity Waves



When wind shear is present, the storm’s updraft becomes an obstacle to the ambient winds—a storm behaves like a moving mountain--Moving source

Now add the wind shear

the wave structure becomes asymmetric



Storm top features as observed by satellites are mainly due to the dynamics of updraft-gravity wave interaction

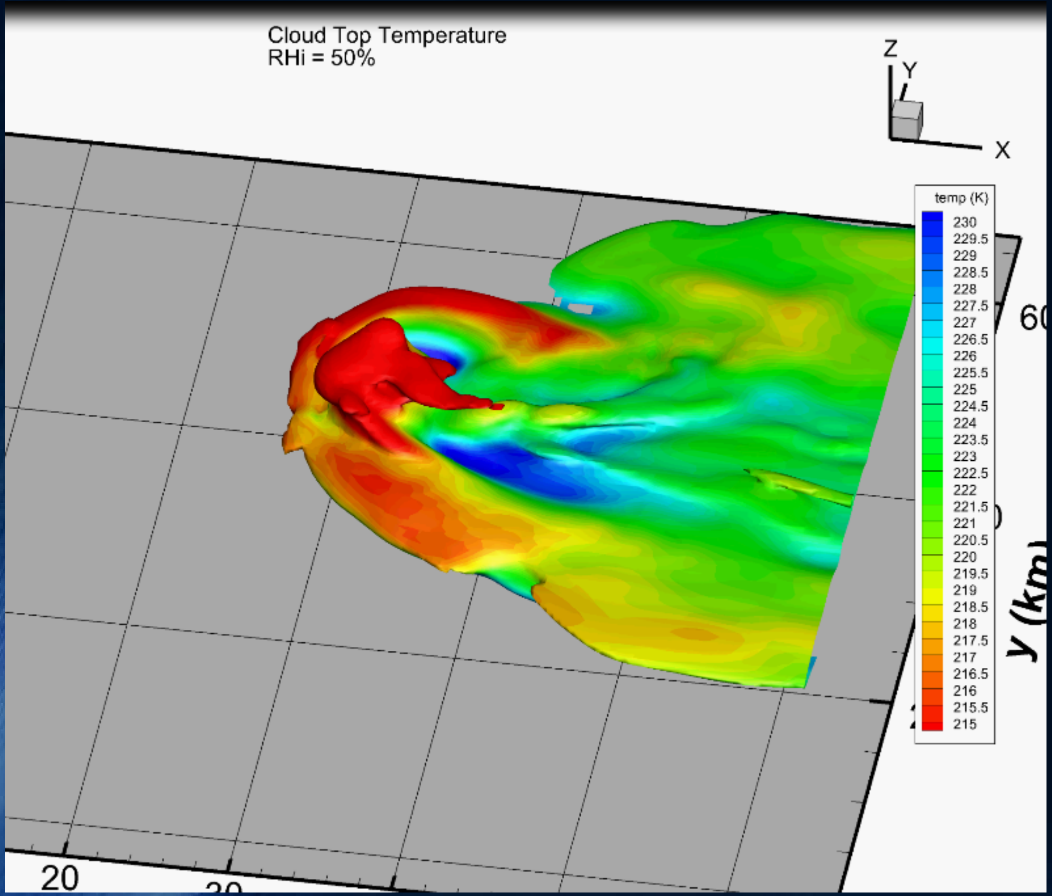
- updraft behaves like an obstacle to the ambient winds
- ambient winds will go around the updraft core to flow downstream

WE SHALL SEE SOME PROVES

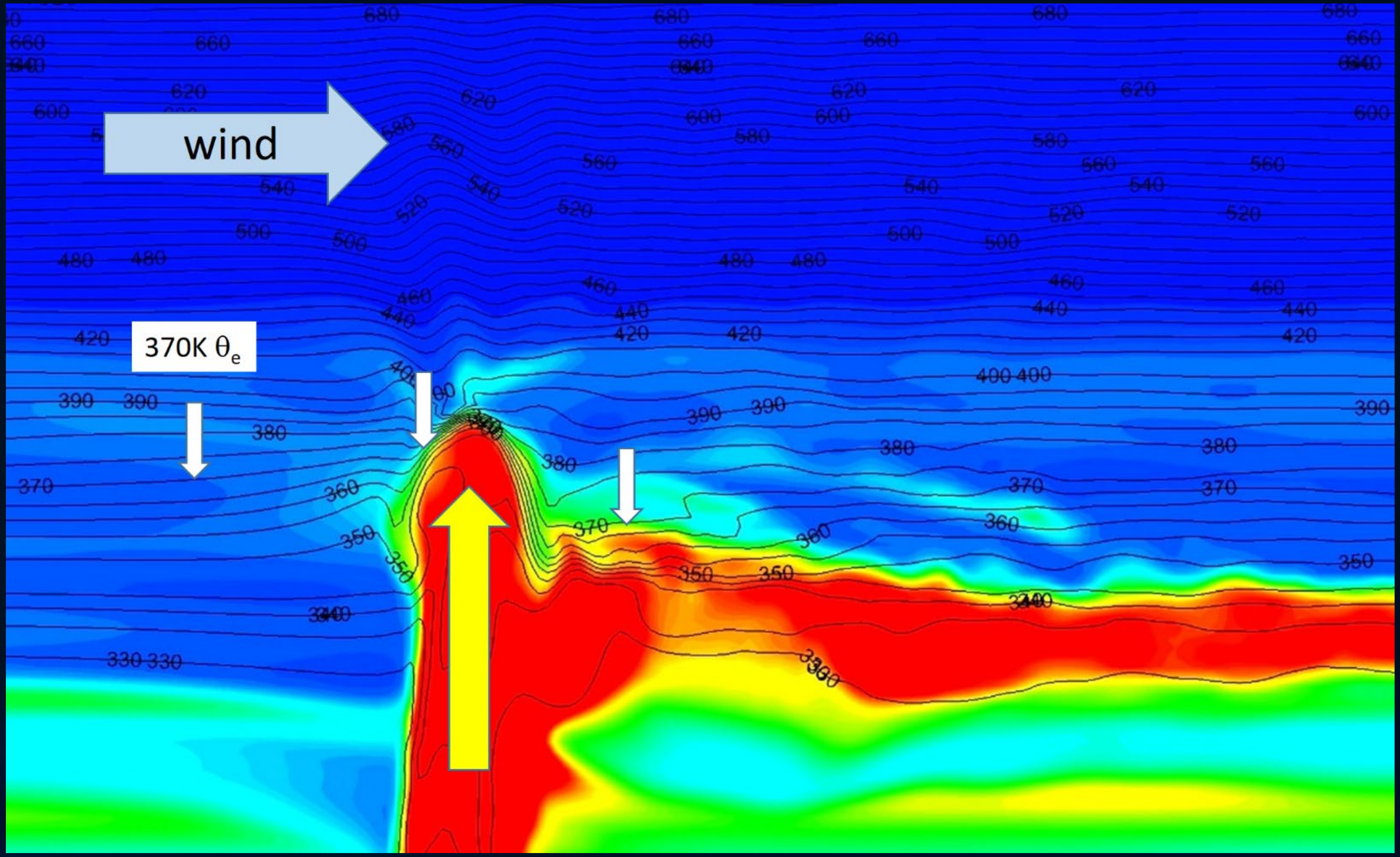
Cloud model simulation of cold-V and warm-cold couplet – again due to the blocking effect.

The upstream air goes around the updraft forming the U or V. The cloud surface is raised, hence cold.

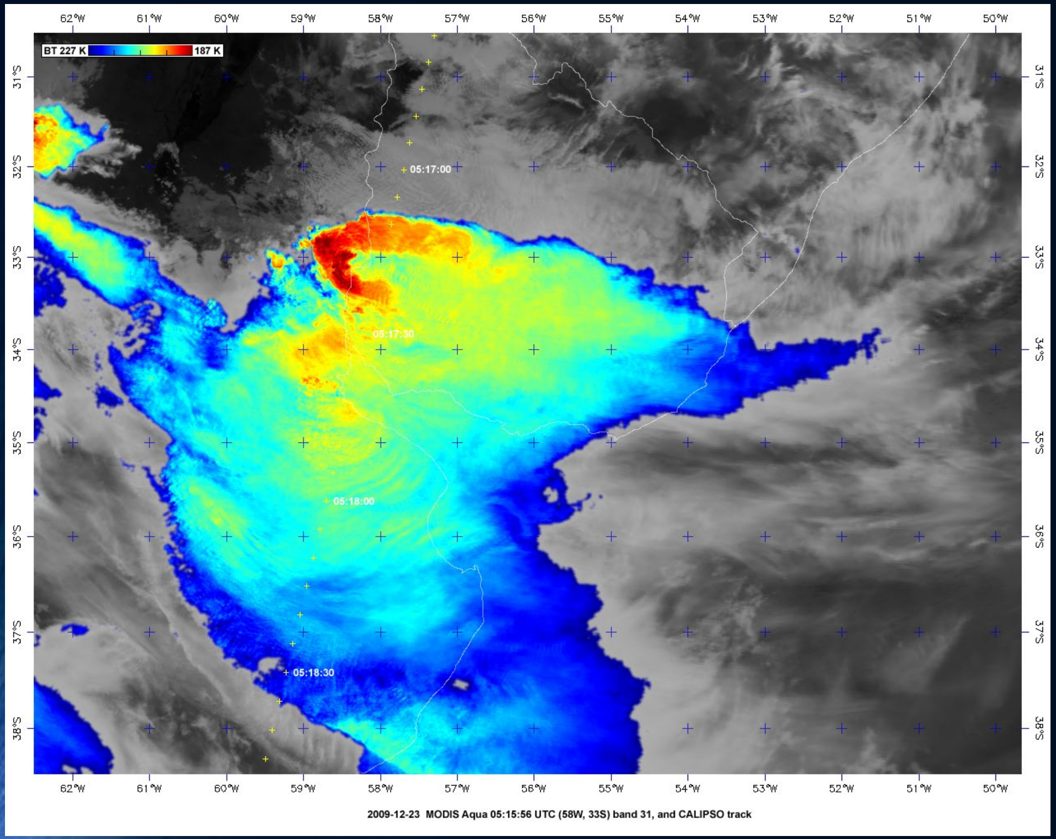
The OT is usually the coldest point. Right downstream the air descends rapidly, resulting in a low and “close in warm area (CWA). The OT and CWA form a warm-cold couplet.

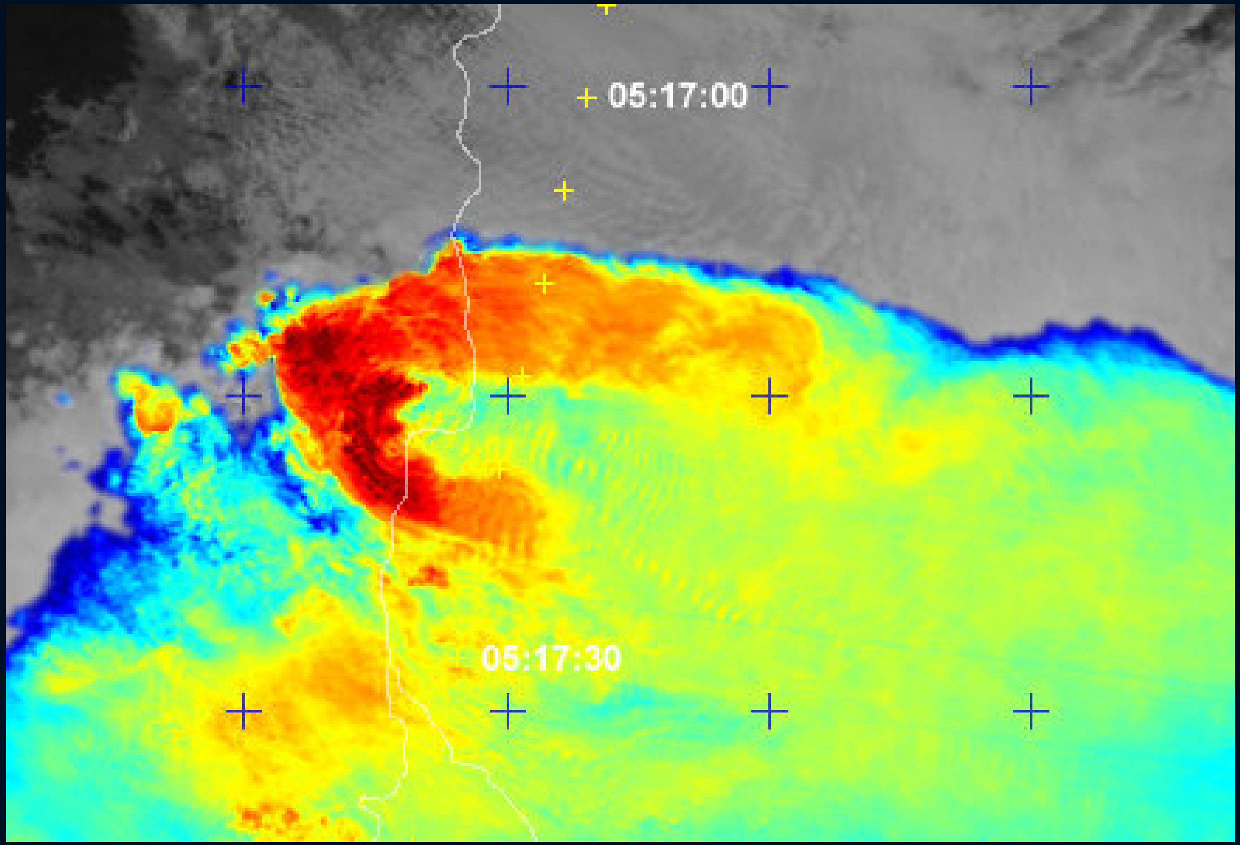


Equivalent potential temperature surface (θ_e) at the storm top



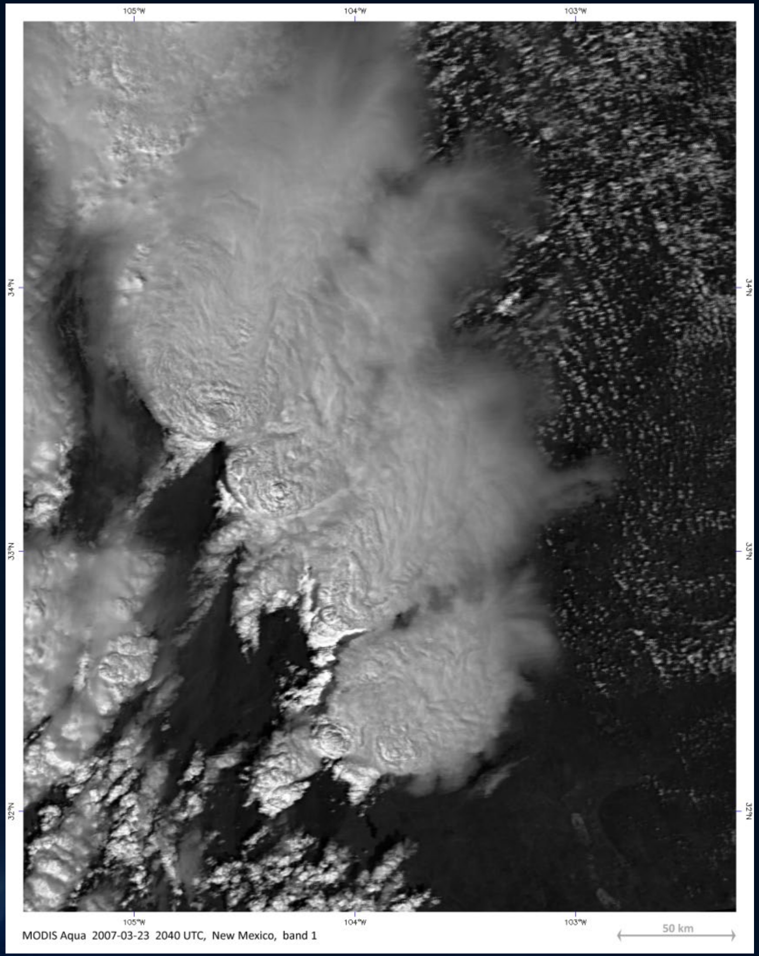
Cold V atop an Argentina severe storm

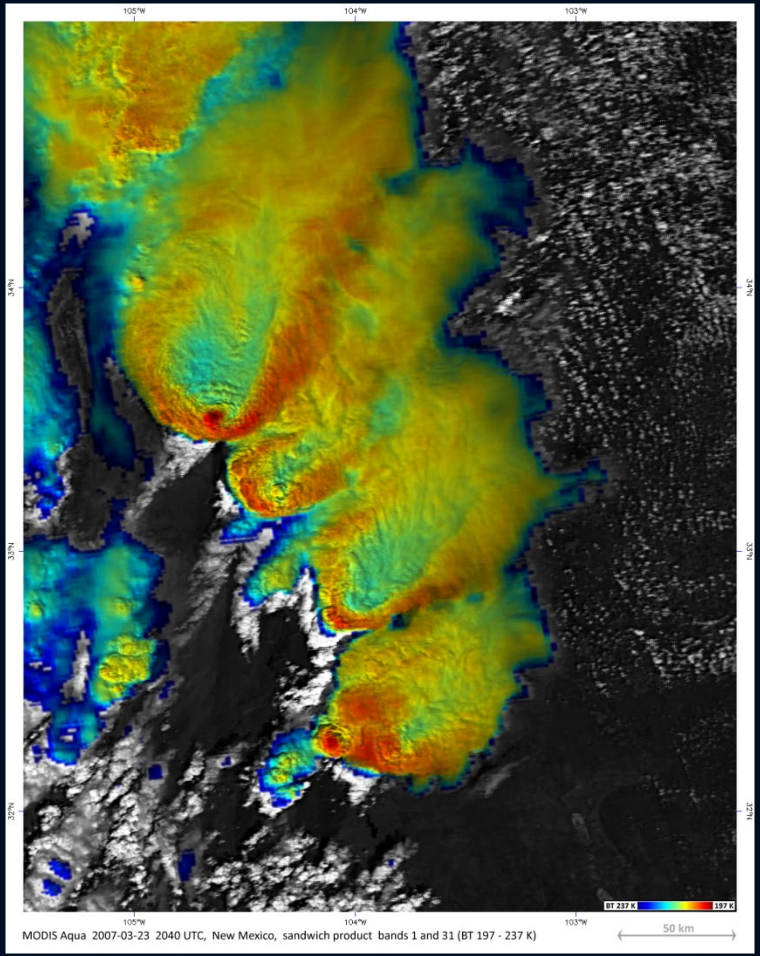




Courtesy of Martin Setvak

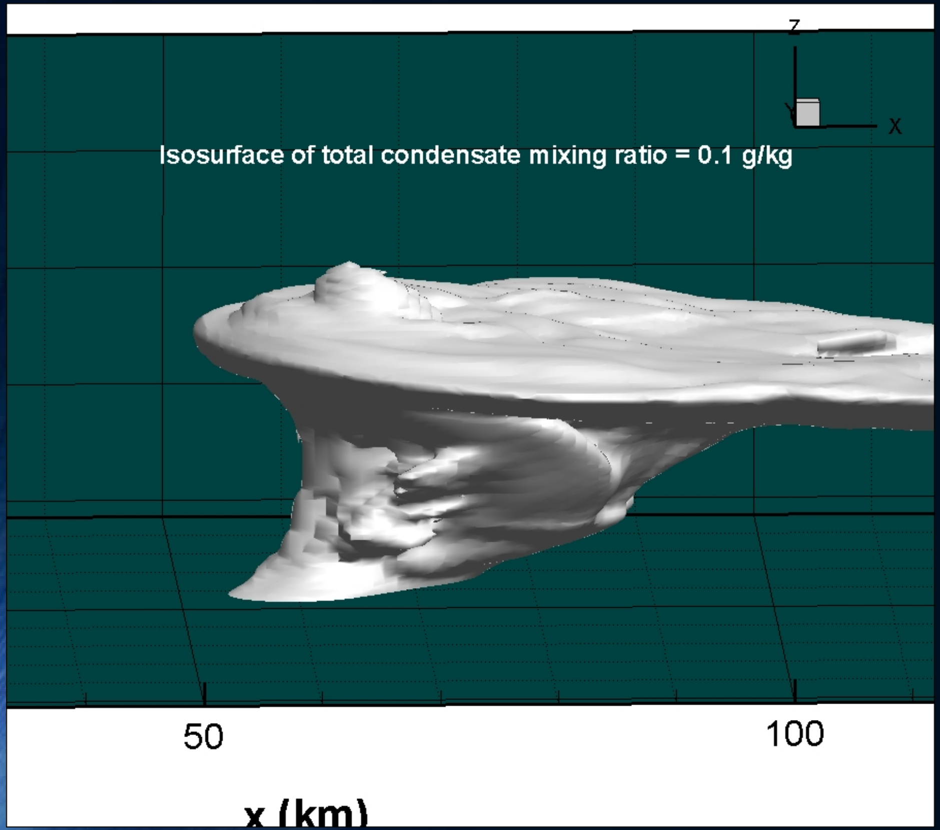
Cold-V and warm-cold couplet

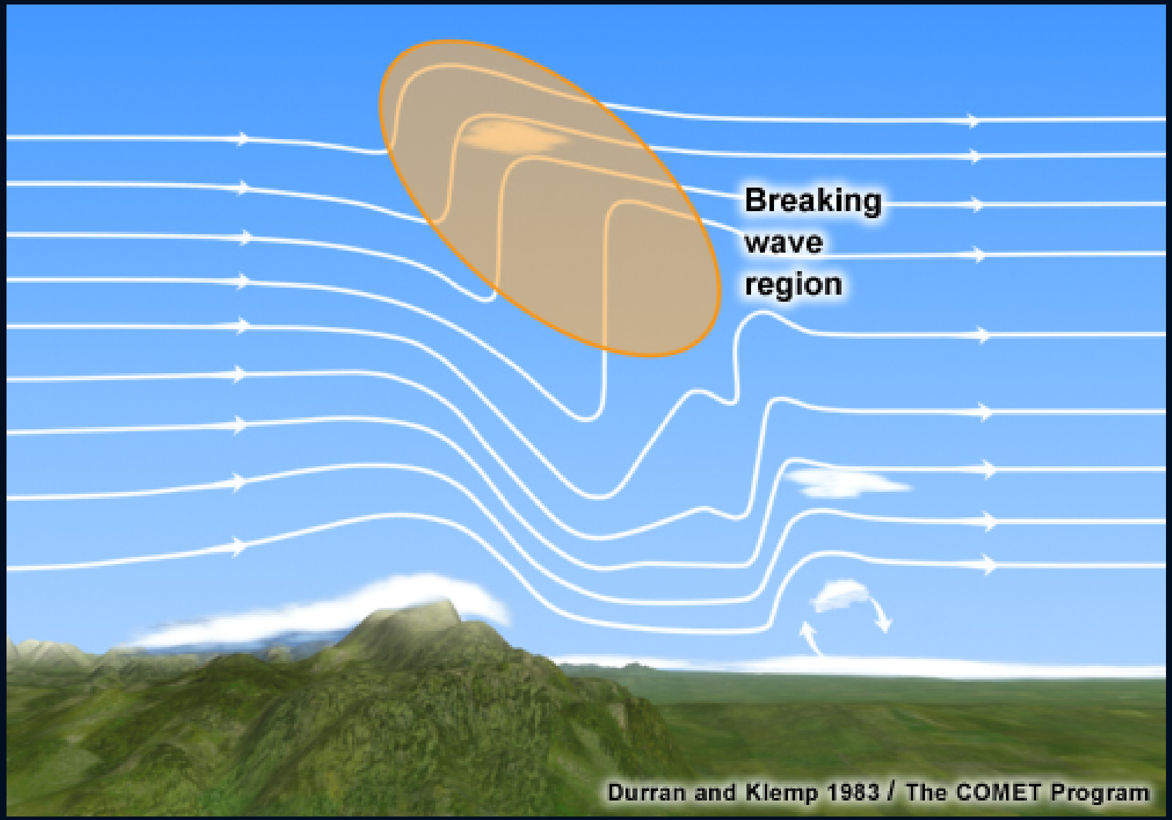




Courtesy of Martin Setvak

Since the updraft behaves like an obstacle, it is essentially a “moving mountain”, and hence should excite mountain waves. Wave breaking often occurs in the lee side.



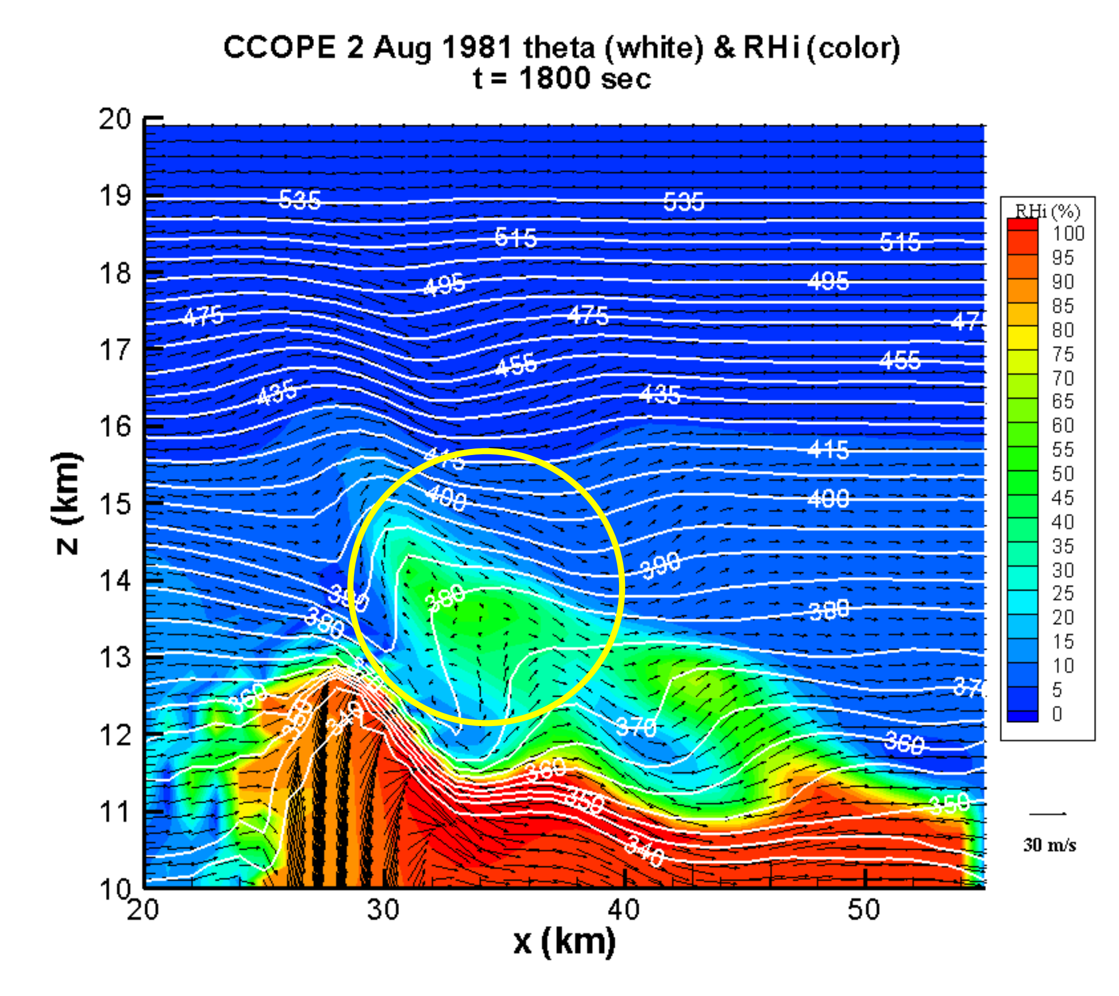


Jumping cirrus (JC) and Above anvil cirrus plumes (AACP)

MANIFESTATION OF WAVE BREAKING

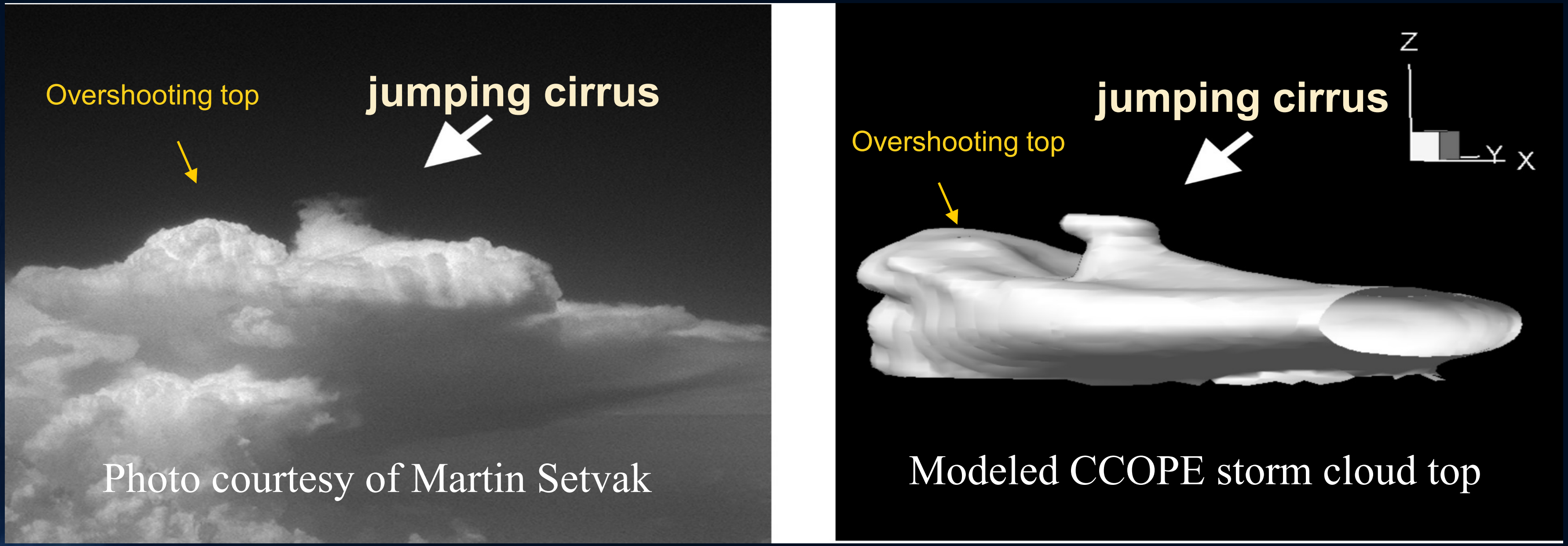
Jumping cirrus (JC) and Above anvil cirrus plumes (AACP)

Manifestation of wave breaking



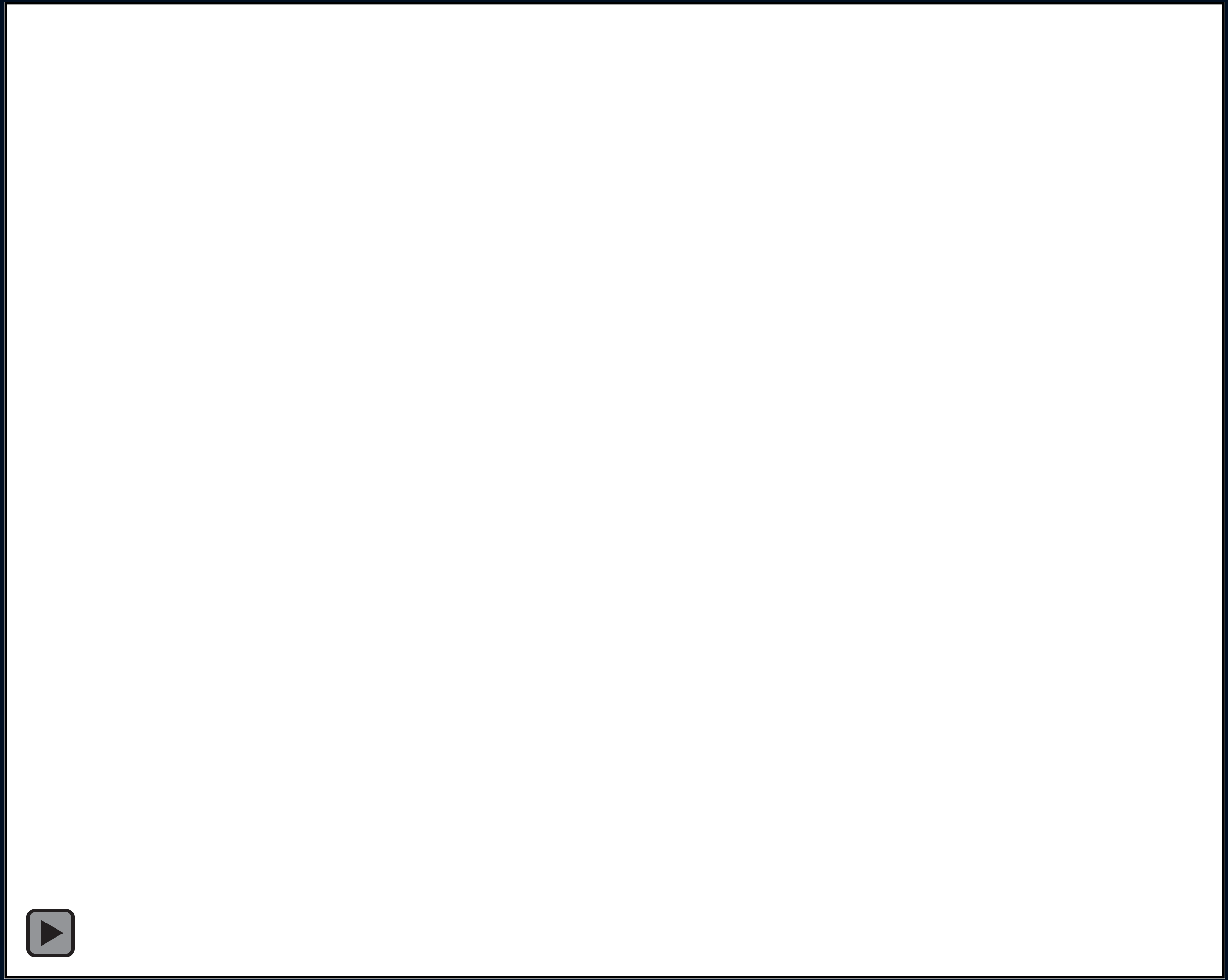
Fujita (1974, 1982, 1989) observed jumping cirrus above severe storms – they are also due to wave breaking

Similar shape, size, orientation and occur at similar relative location

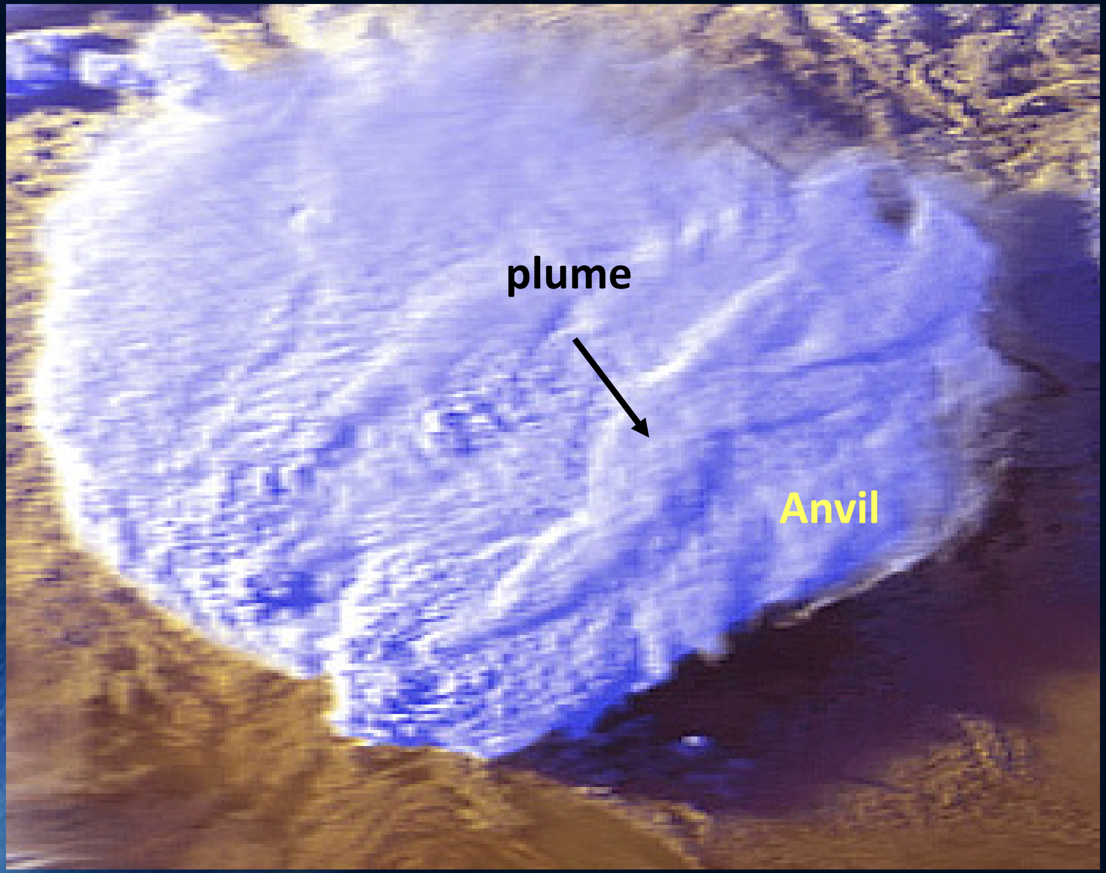


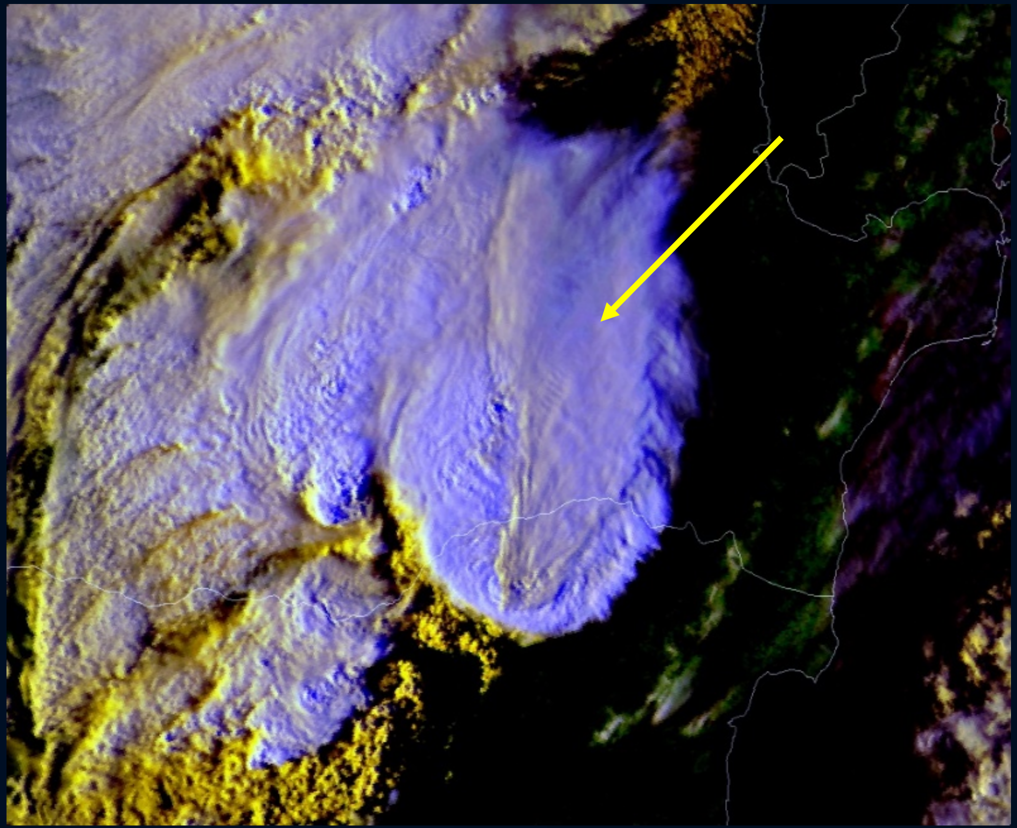
From: Wang (2004, GRL)

Jumping cirrus (JC)



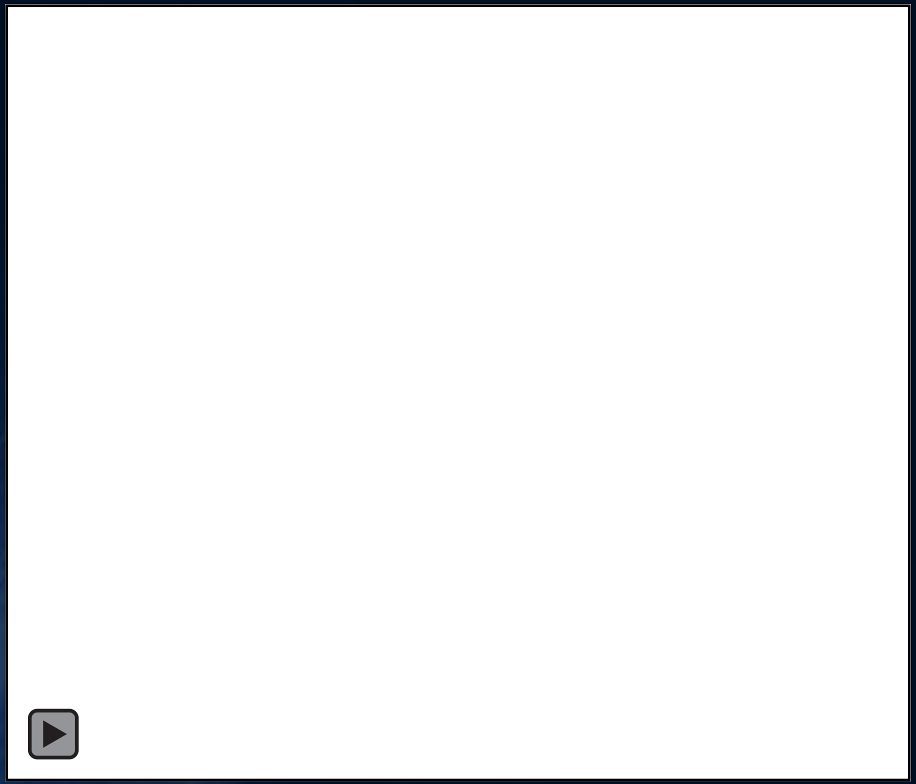
Above-anvil cirrus plumes (AACP)

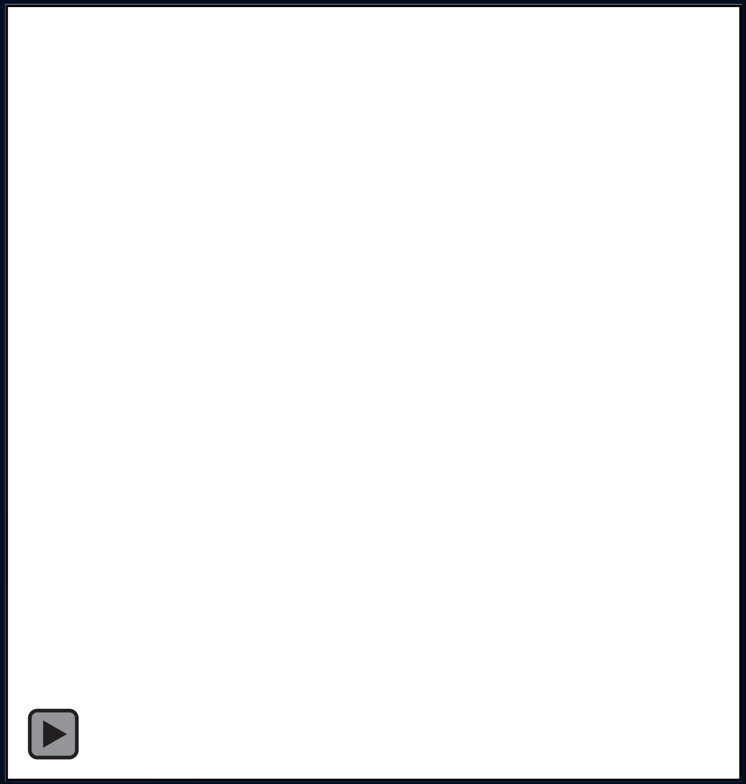




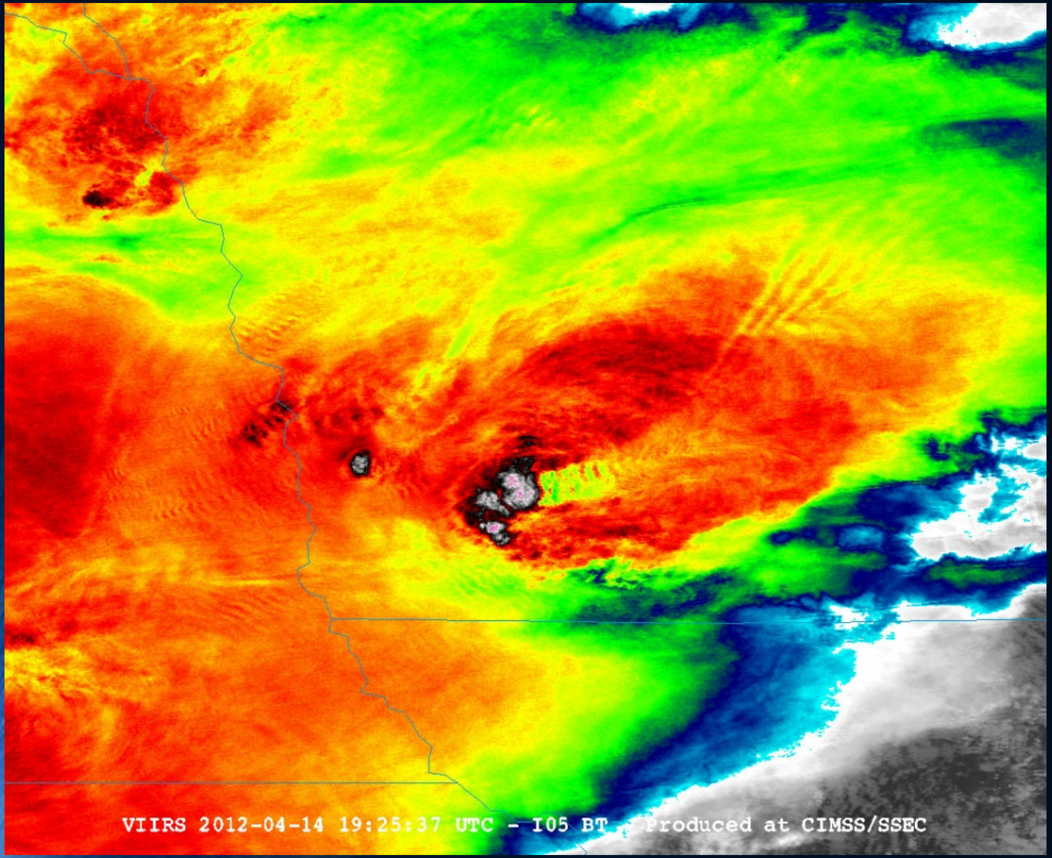
courtesy of Martin Setvak

Recent examples from GOES-16





The same blocking effect also causes ship wave-like feature



Courtesy of Kris Bedka

One theory can explain all these observed features

- The blocking effect of the updraft causes the ambient winds to go around it and to raise the cloud surface upstream, forming the cold-V
- The same blocking effect (moving mountain) causes the lee wave feature forming the warm-cold couplet
- The wave breaking due to the lee waves generates JC and AACP
- The blocking effect also causes storm top ship waves
- WIND SHEAR! Satellite data can be used to study wind shear climatology

The End

THANK YOU