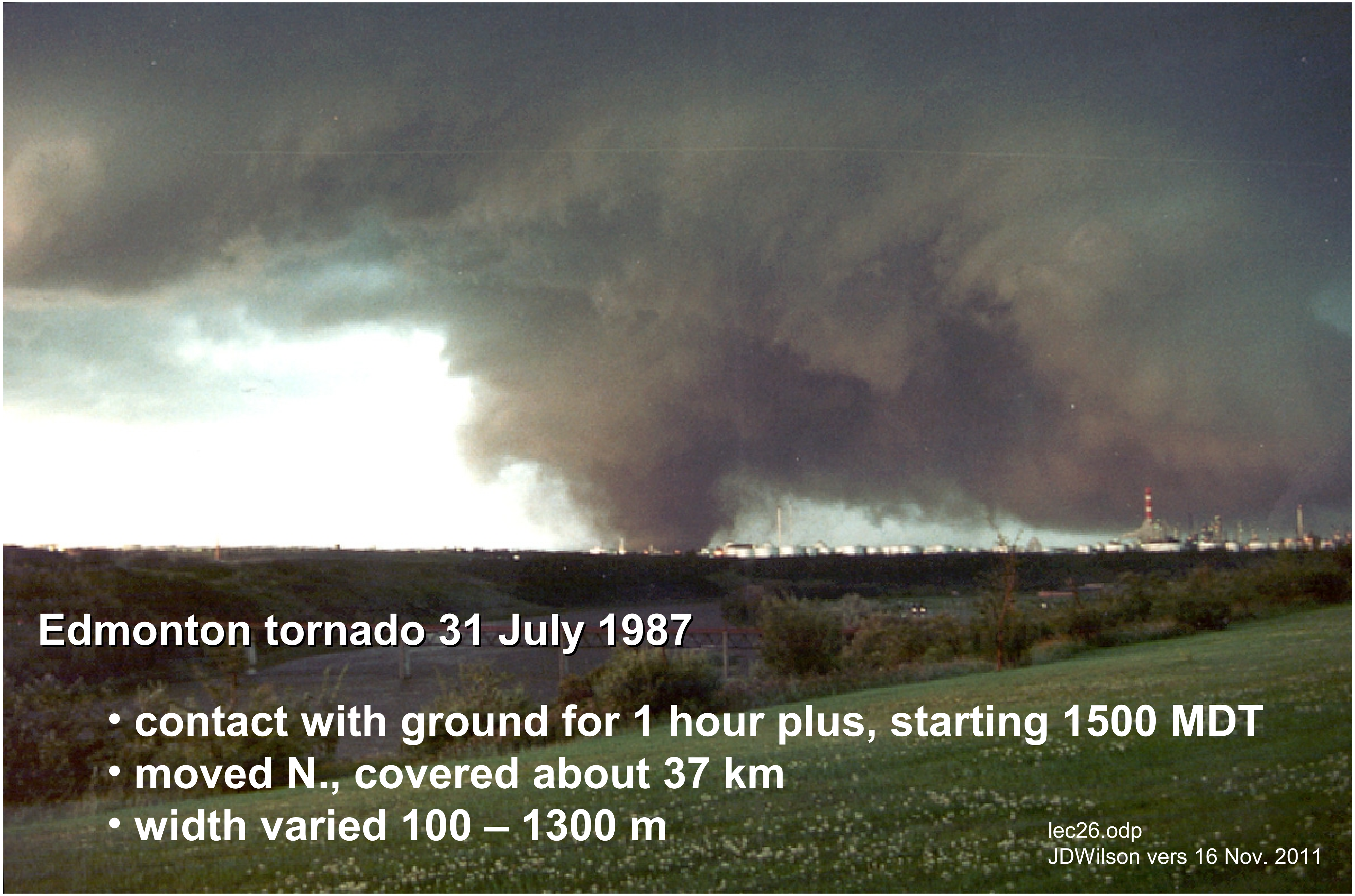
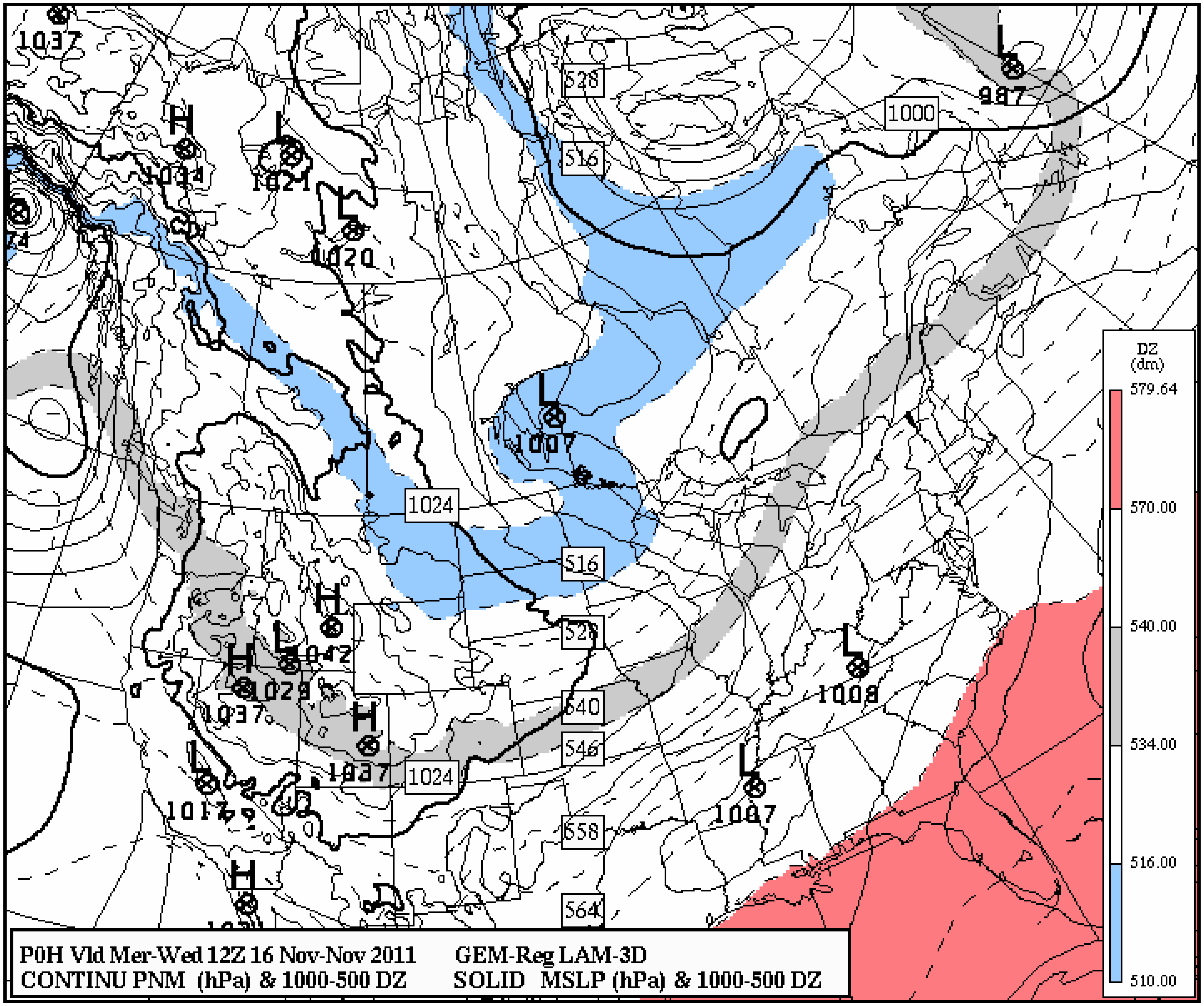
Goal for today:
Finish Ch. 11 “Lightning, Thunder & Tornadoes”

16 Nov., 2011



Lecture of previous Wednesday (9 Nov.) included a 204-hr forecast valid 12Z today. Today's analysis shows a strong qualitative resemblance to that forecast, but the 510-516 dam band...



... (blue) is offset further east than had been forecast. Edmonton's thickness is about 12 dam larger (mean temperature about 6 degrees warmer) than had been forecast.

Severe thunderstorm

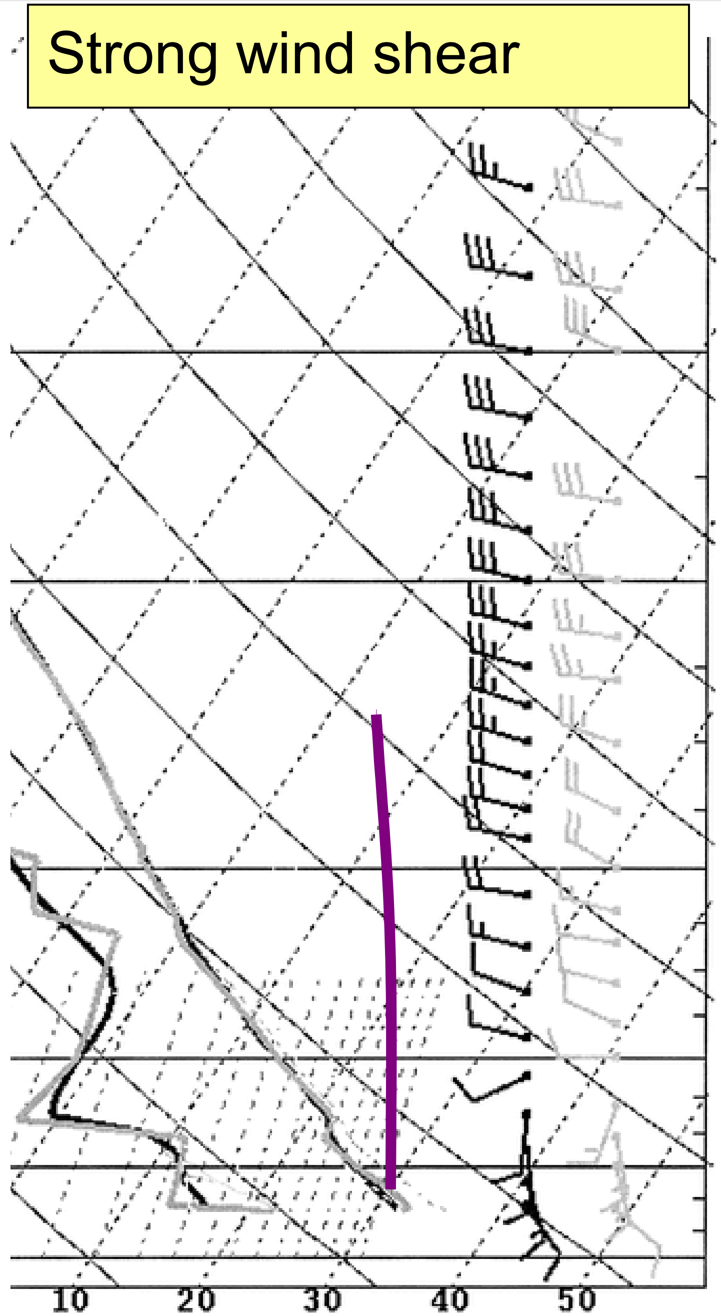
• Definition: wind speeds exceed about 100 kph (technically, 50 knots) and/or hailstones exceed about 2 cm (¾ inch) in diameter and/or generates a tornado

• Favourable mesoscale pattern permits prolonged separation of updraft & downdraft, which reinforce one another

• In addition to the existence of conditional (or potential) instability and buildup of energy at low levels, the key additional ingredient is wind shear (e.g. low level SE or S + mid level SW or W)

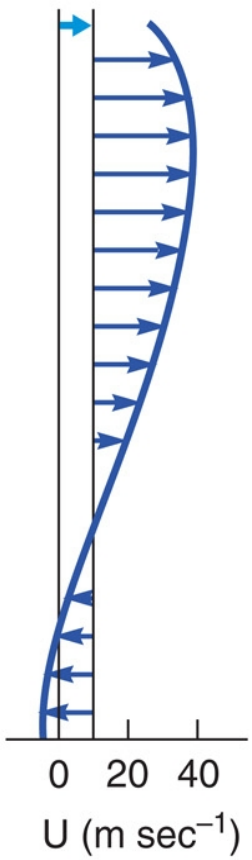
• Thus ingredients are: very moist lower tropos. + instability** + wind shear + trigger

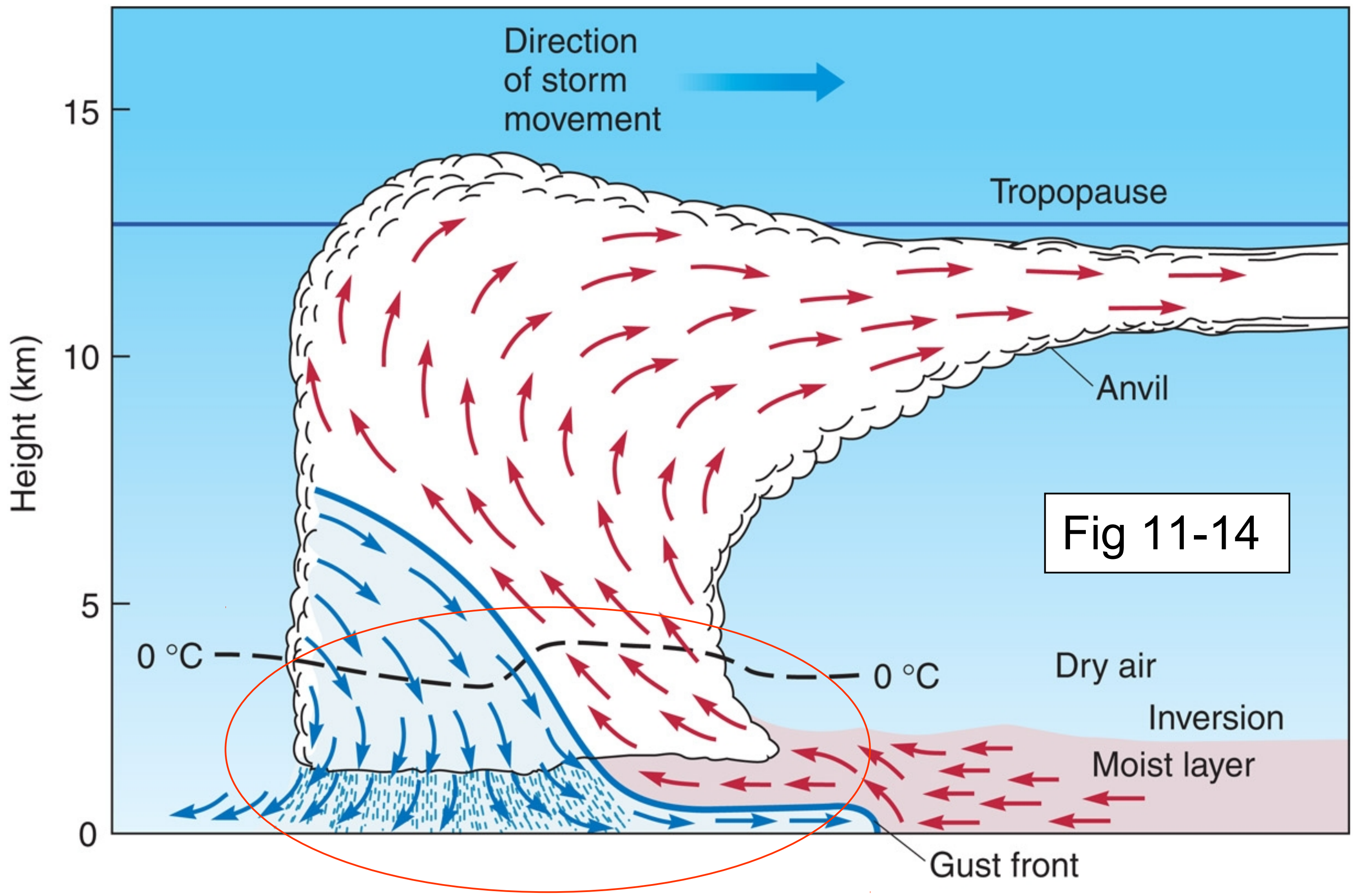
**a store of Convectively Available (gravitational) Potential Energy (CAPE)



Circulation in an intense thunderstorm

Upper region of storm outpaces its base





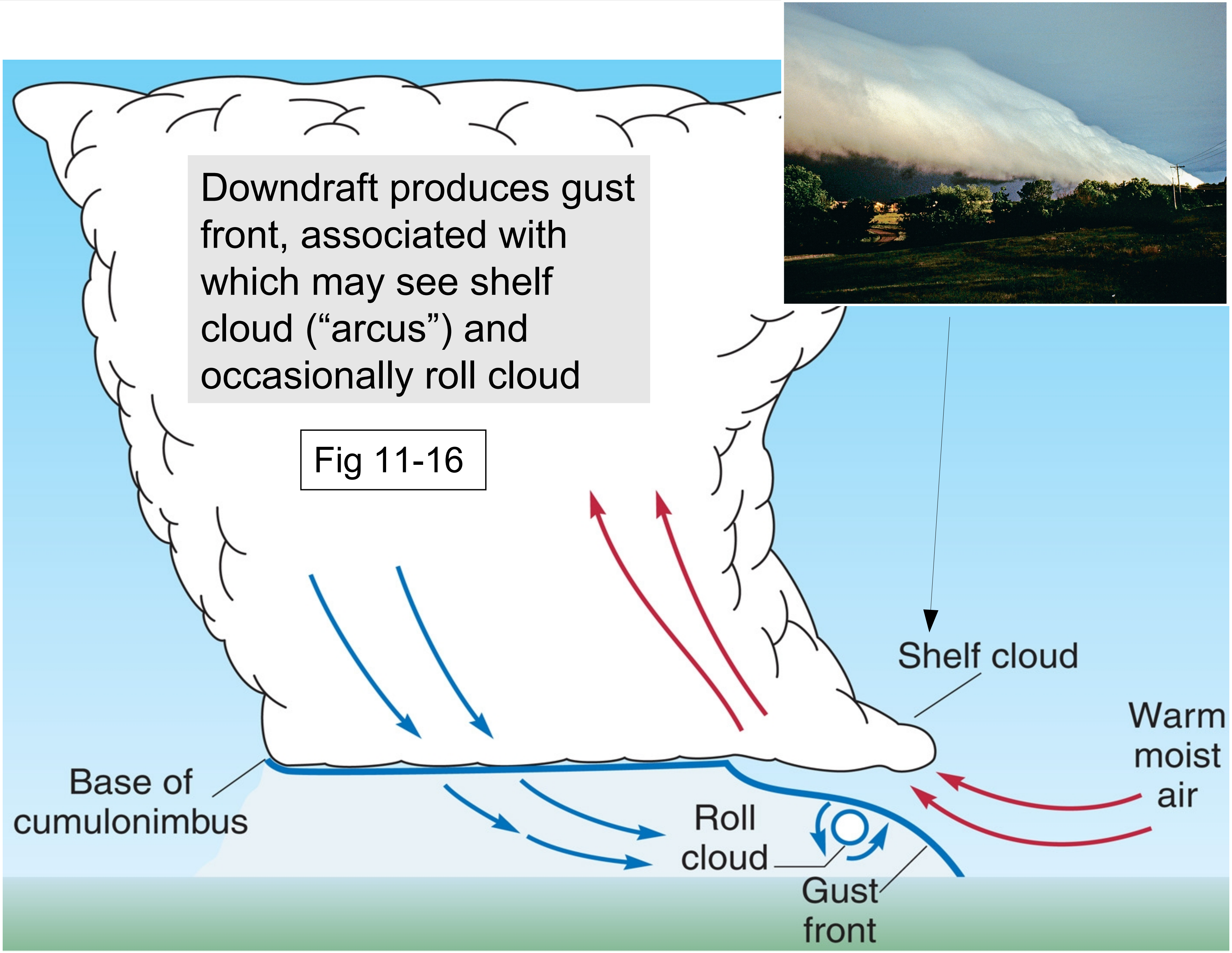
Storm updraft has penetrated the capping inversion

Better seen in 3D animation (e.g. Aguado & Burt DVD; or on YouTube, NCSA's visualization based on computational atmospheric research of faculty at U. Illinois National Severe Storms Laboratory of NOAA) – see also p11, an image reproduced from Edmonton Sun

Circulation in an intense thunderstorm

Downdraft produces gust front, associated with which may see shelf cloud (“arcus”) and occasionally roll cloud

Fig 11-16



Clusters of thunderstorms

• favourable conditions over large area cause clusters of storms that interact – the mesoscale convective system (MCS)

• if cluster is organized linearly, named “squall line”

• else if cluster has form of oval, “mesoscale convective complex”, MCC

• downdrafts from individual cells of an MCS trigger adjacent new cells

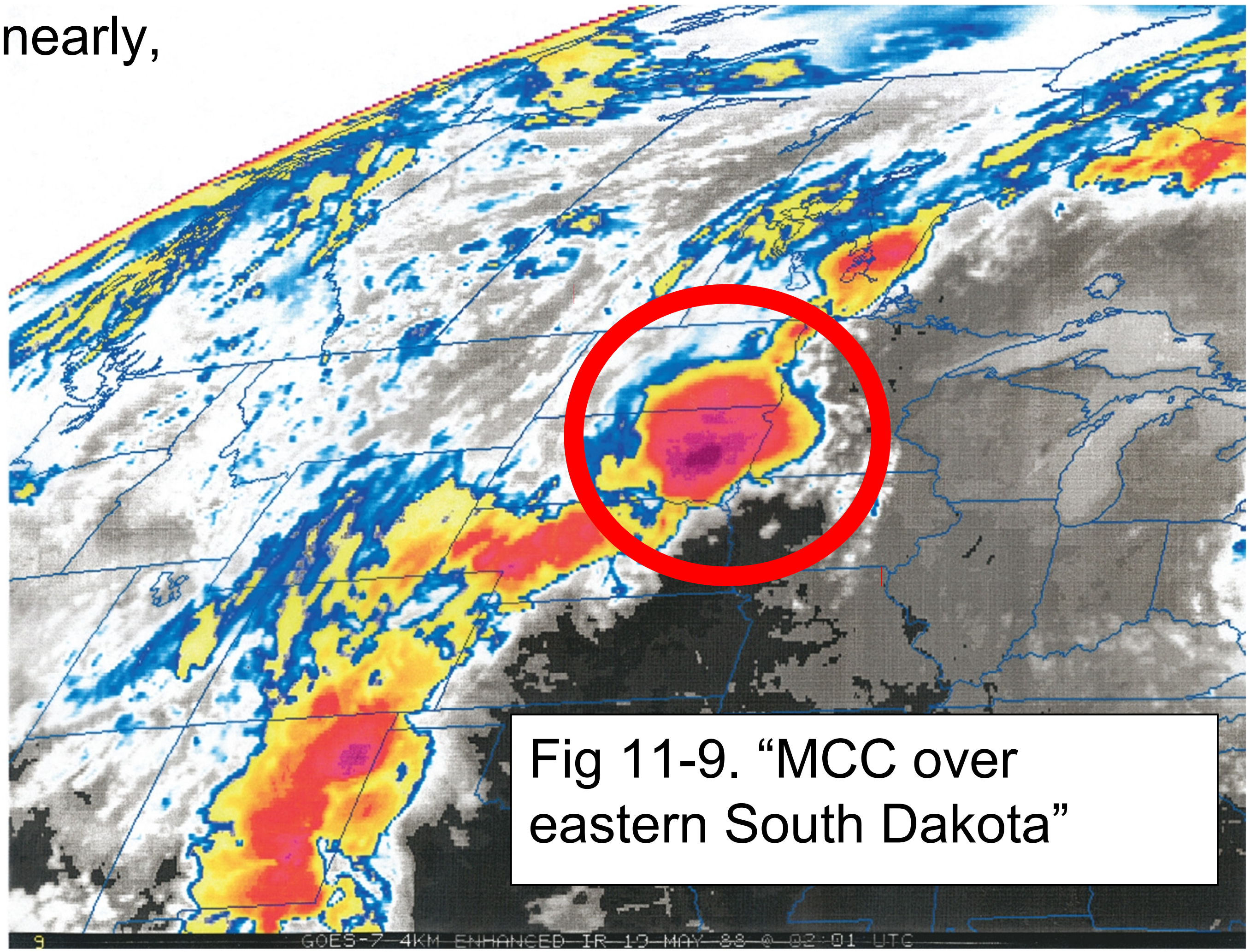


Fig 11-9. “MCC over eastern South Dakota”

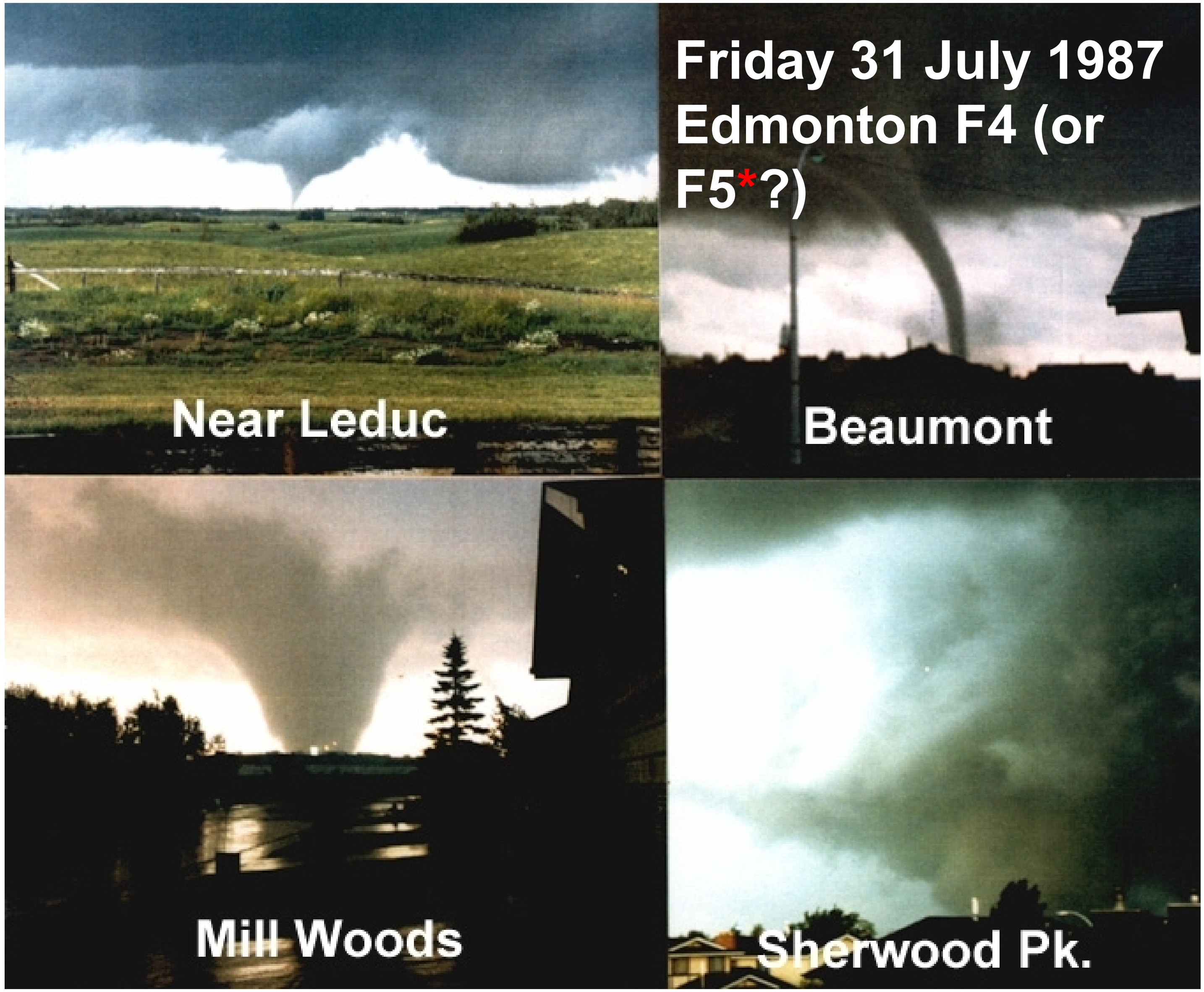
Tornadoes

- always in conjunction with Cumulonimbus?

- diameter usually order 100 m, may be over a kilometer (record: 4 km)

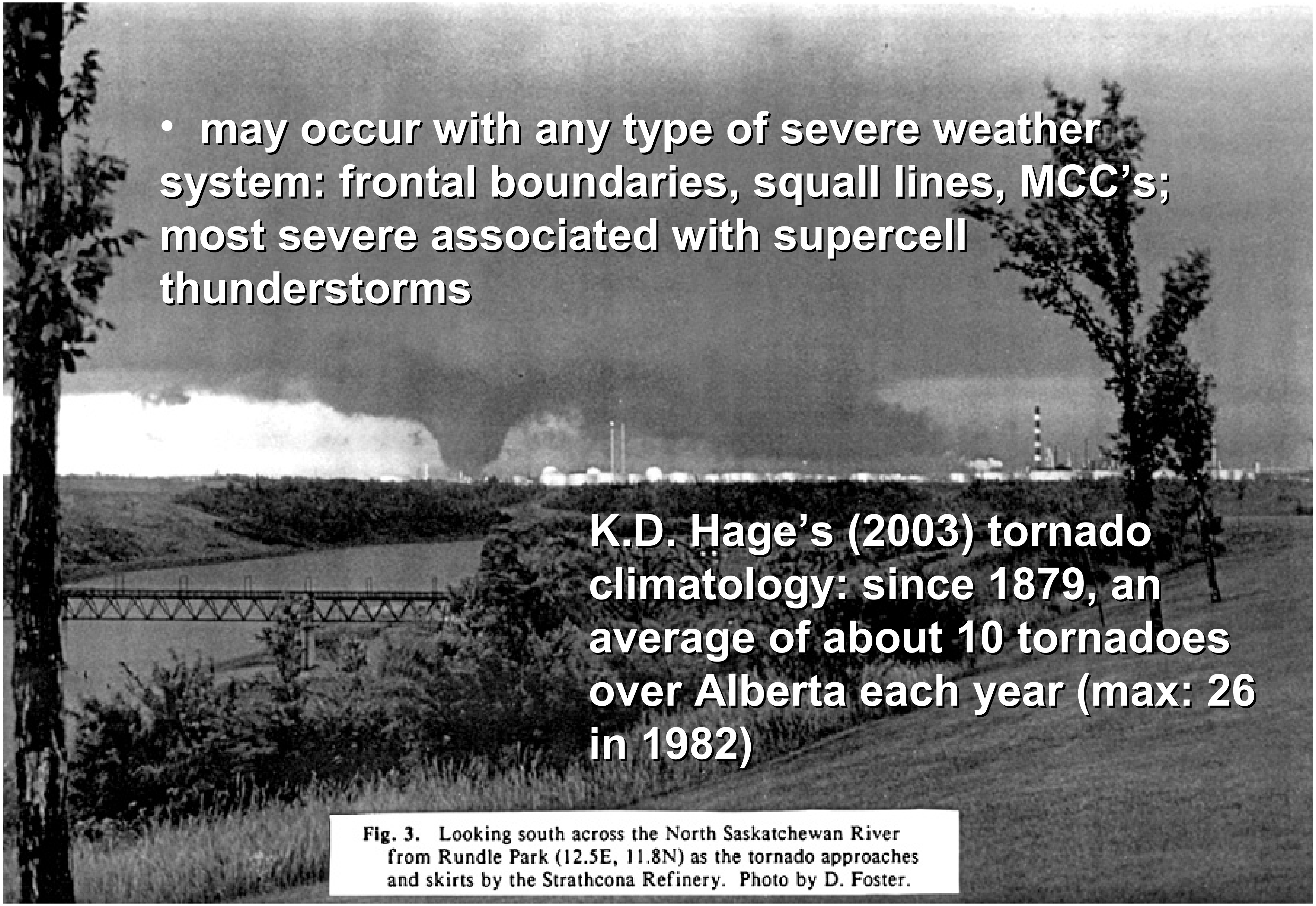
- lifetime minutes to (rarely) hours

- translation speed typically of order 50 kph



*This tornado has been under scrutiny by Environment Canada … as to whether or not it could be considered for an F5 rating... The tornado's maximum recorded wind speed was 416km/h. The wind speed for a F5 tornado is 419km/h. (Wikipedia, Nov. 2010)

Tornadoes



- may occur with any type of severe weather system: frontal boundaries, squall lines, MCC's; most severe associated with supercell thunderstorms

K.D. Hage's (2003) tornado climatology: since 1879, an average of about 10 tornadoes over Alberta each year (max: 26 in 1982)

Fig. 3. Looking south across the North Saskatchewan River from Rundle Park (12.5E, 11.8N) as the tornado approaches and skirts by the Strathcona Refinery. Photo by D. Foster.

Tornadoes

- majority rotate cyclonically
- pressure depression at axis (Δp) up to 100 hPa
- centripetal accel'n (*R* being radius, *V* tangential velocity)

$$\frac{V^2}{R}$$

- pressure gradient force

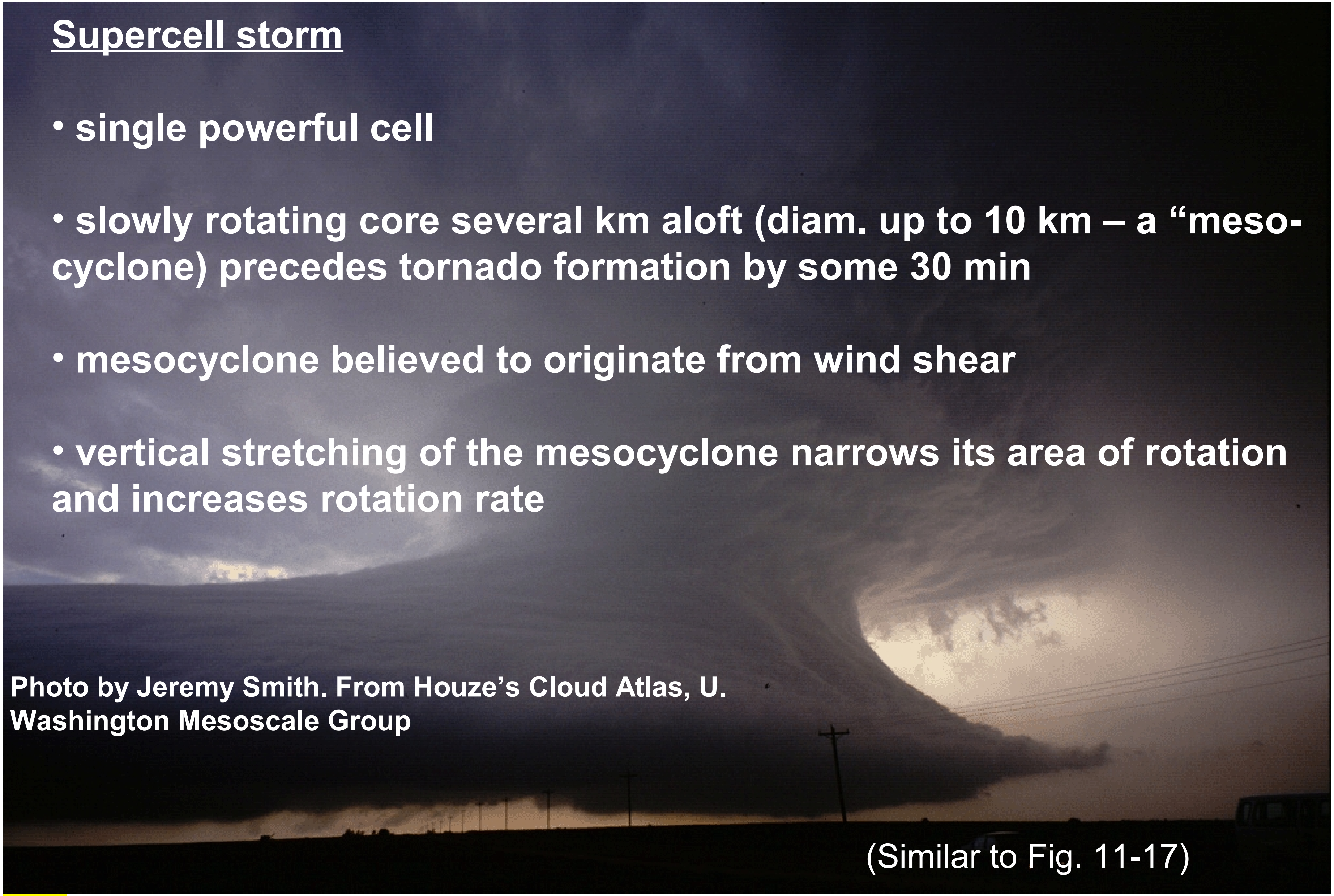
$$\frac{1}{\rho}\frac{\Delta p}{R}$$

- equating,

$$V^2 = \frac{\Delta p}{\rho}$$

(tornado's centreline velocity adds to or subtracts from this rotational speed)

Wall cloud below a supercell cumulonimbus in Nebraska



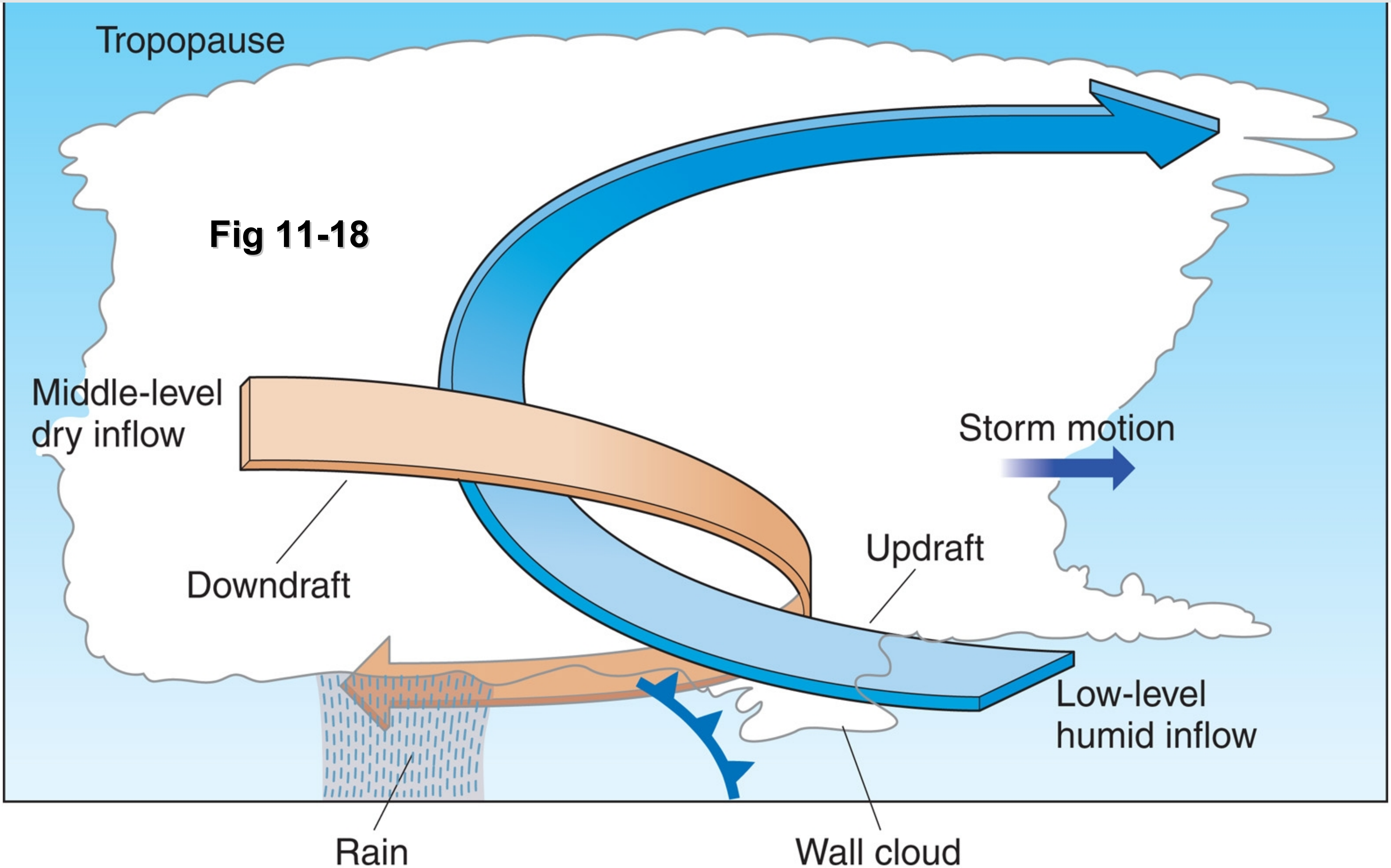
Supercell storm

- single powerful cell
- slowly rotating core several km aloft (diam. up to 10 km – a “meso-cyclone) precedes tornado formation by some 30 min
- mesocyclone believed to originate from wind shear
- vertical stretching of the mesocyclone narrows its area of rotation and increases rotation rate

Photo by Jeremy Smith. From Houze’s Cloud Atlas, U. Washington Mesoscale Group

(Similar to Fig. 11-17)

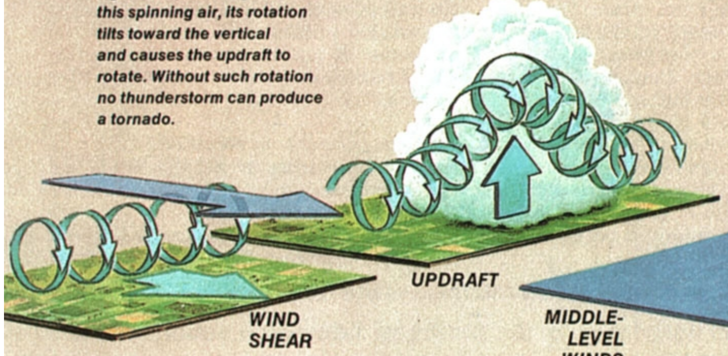
Supercell thunderstorm

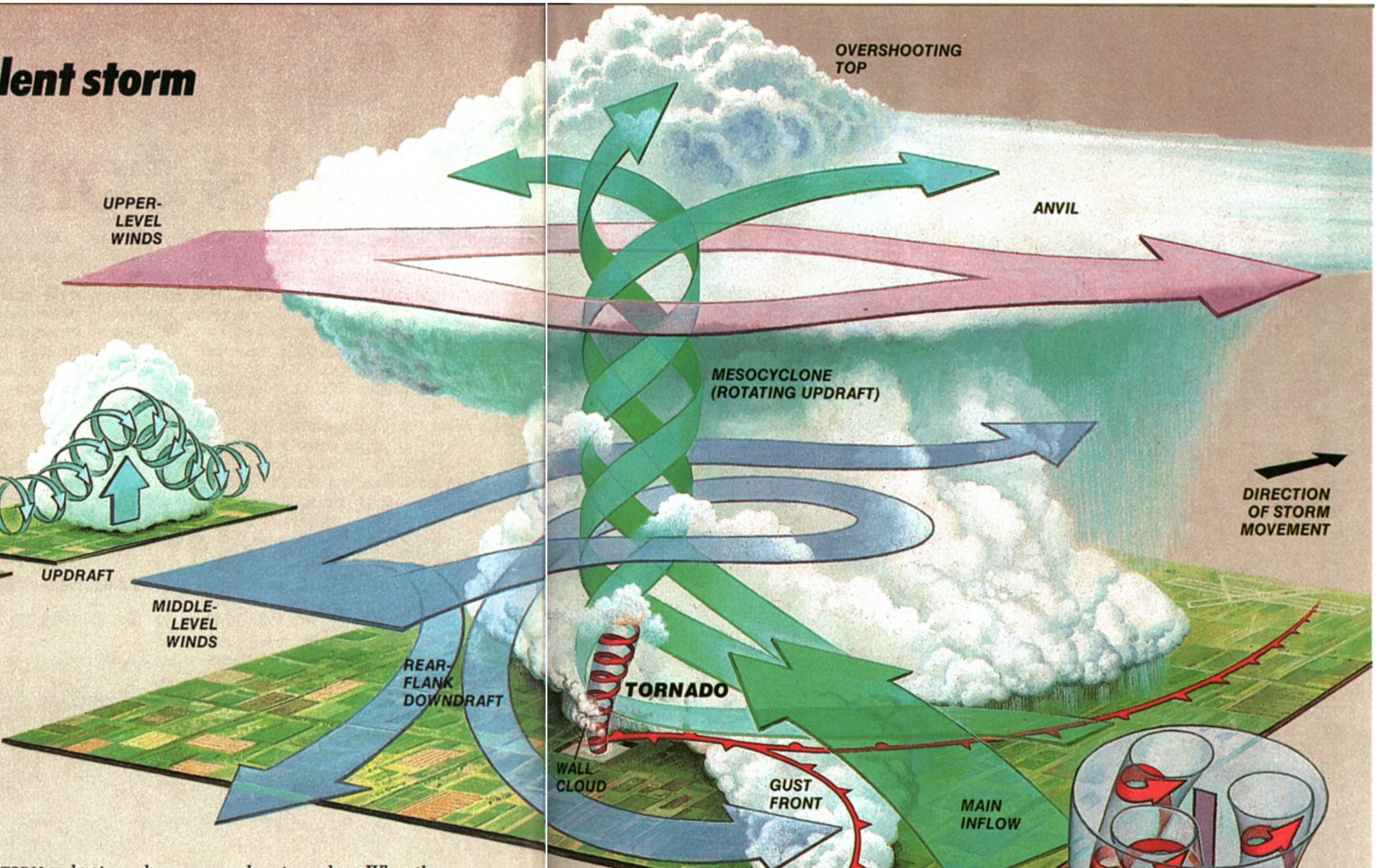


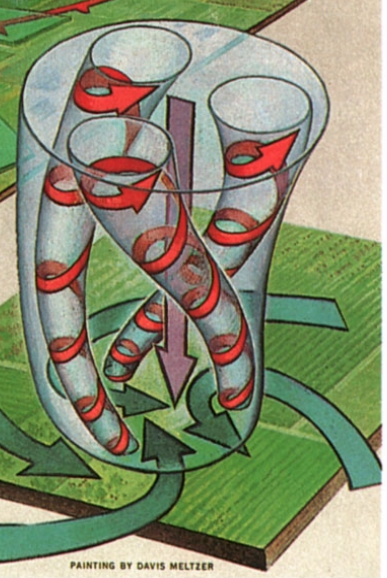
- updraft and downdraft of the single cell “bend and wrap around each other” (p338)

Inside a violent storm

Strong winds flowing over weaker winds can cause the air in between to spin on a horizontal axis, like a pencil rolling along a table (small diagram, below). When a vigorous updraft ingests this spinning air, its rotation tilts toward the vertical and causes the updraft to rotate. Without such rotation no thunderstorm can produce a tornado.







WHY DOES ONE THUNDERSTORM and not another produce a tornado? It depends on how surrounding winds interact with the storm's updraft, the flow of warm, moist air that rises up its core. When the updraft is strong, air being drawn into the storm may surge upward as fast as 100 miles an hour to heights of ten miles or more. This rising column of air will rotate if surrounding winds vary sharply in speed or direction from lower to higher levels. Such a rotating updraft, called a mesocyclone, is the parent circulation of large tornadoes.

Only about half of all mesocyclones, however, produce tornadoes. When they do, the twister usually appears on the storm's rear side, near where a stream of cool air from the rear-flank downdraft spins into the warm, main inflow. Drawing upon the strength of the mesocyclone, the tornado may extend upward through the storm for several miles. Only the most violent last for more than a few tens of minutes.

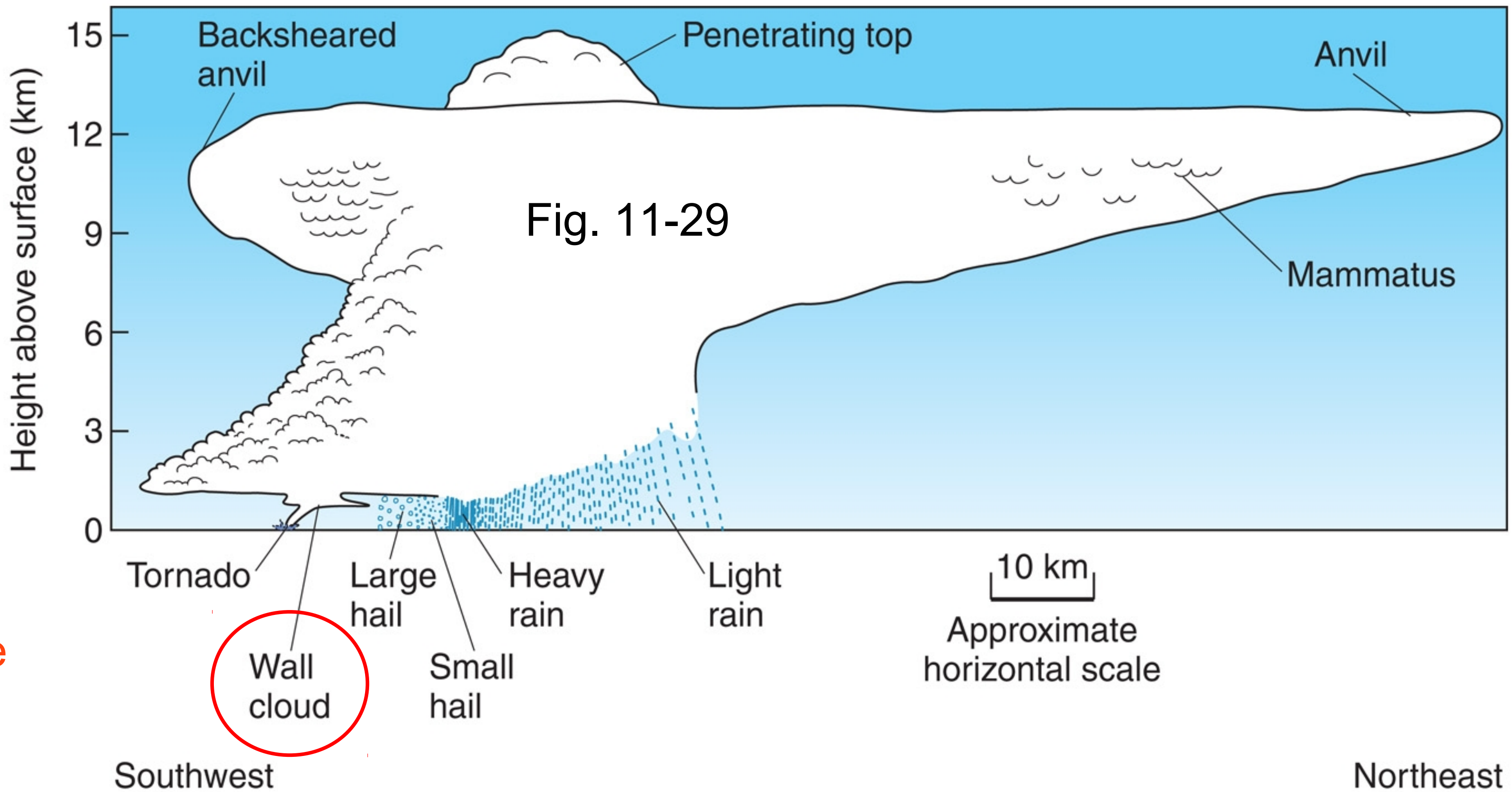
Scientists who scan thunderstorms with Doppler radar report that mesocyclones may appear as much as 20 minutes before tornadoes, offering hope for more accurate, timely warnings.

As many as half a dozen smaller twisters may form inside some large ones (right). Low pressure at ground level creates a strong downdraft at the center of the vortex. Secondary vortices then form as downward-flowing air meets air rushing into the tornado. Because these smaller twisters also revolve around the rim of the main one, they often leave complex damage paths.

PAINTING BY DAVIS MELTZER

from the Edmonton Sun

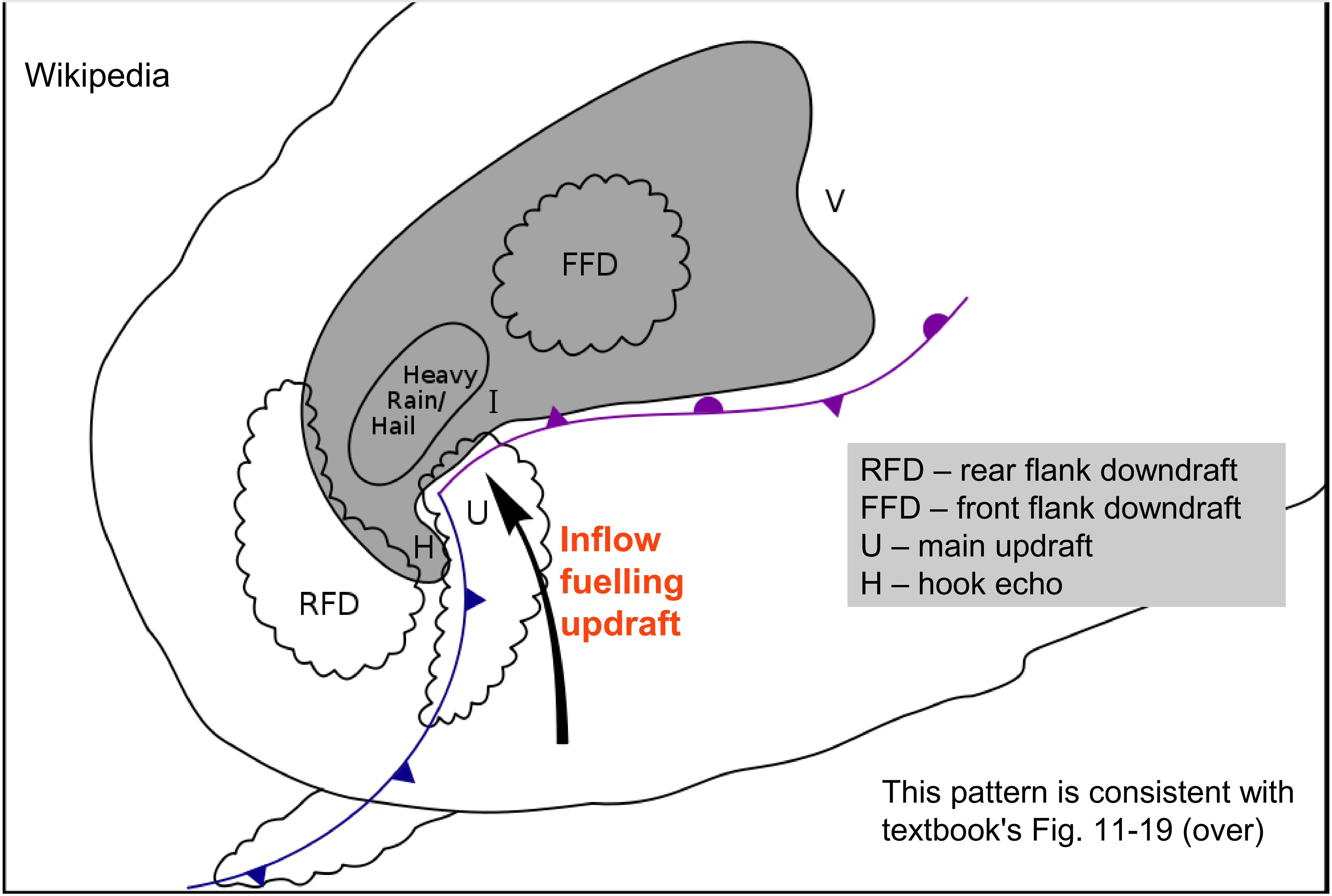
Idealized supercell



Wall cloud forms where humid air from precip zone is drawn into updraft – it protrudes below supercell

Wall clouds most often occur on S or SW flank of supercell, near areas of large hail and heavy rain. The worst supercell tornadoes usually form within or near wall clouds

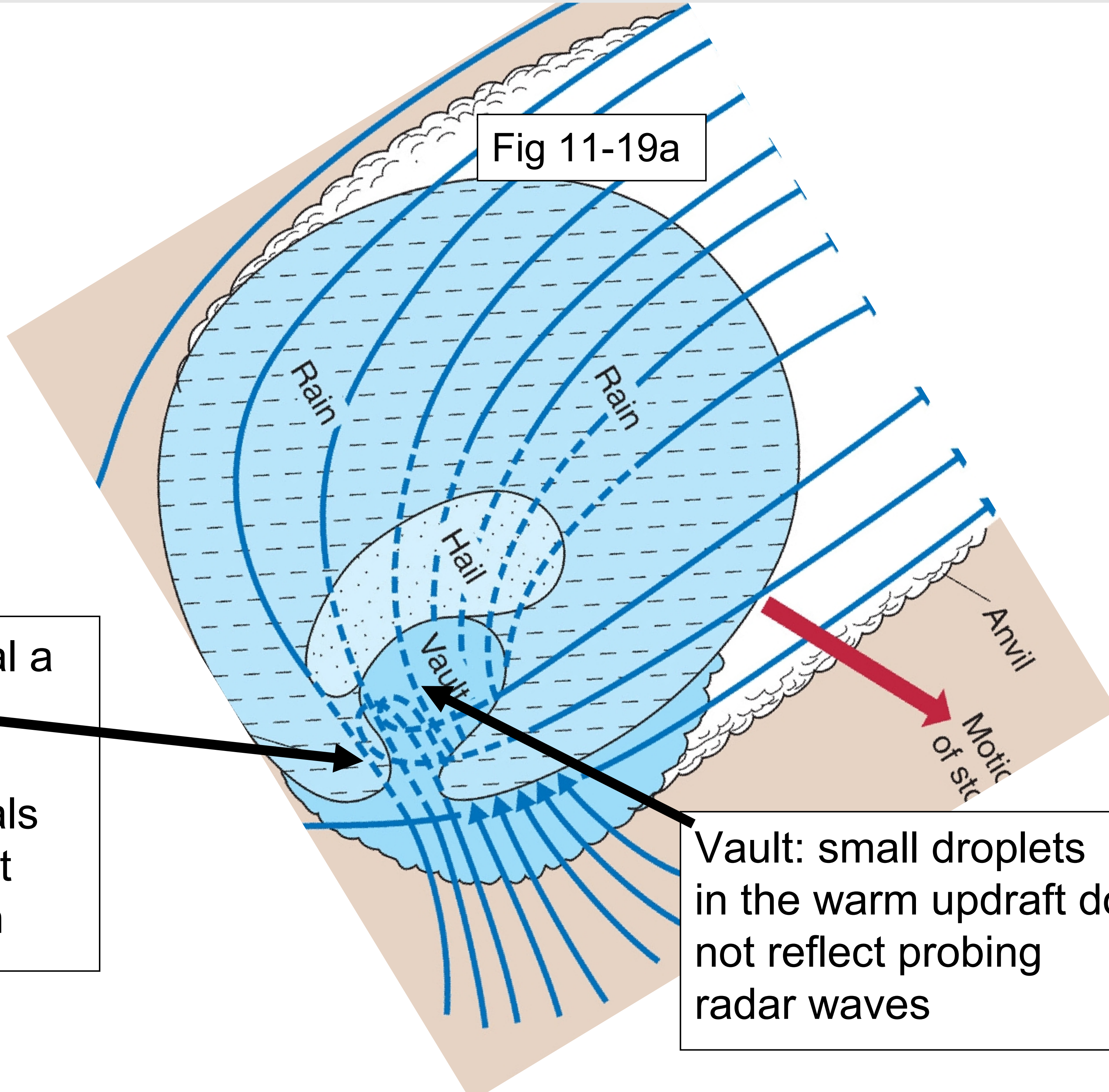
Idealized supercell – view from above



RFD – rear flank downdraft
FFD – front flank downdraft
U – main updraft
H – hook echo

This pattern is consistent with textbook's Fig. 11-19 (over)

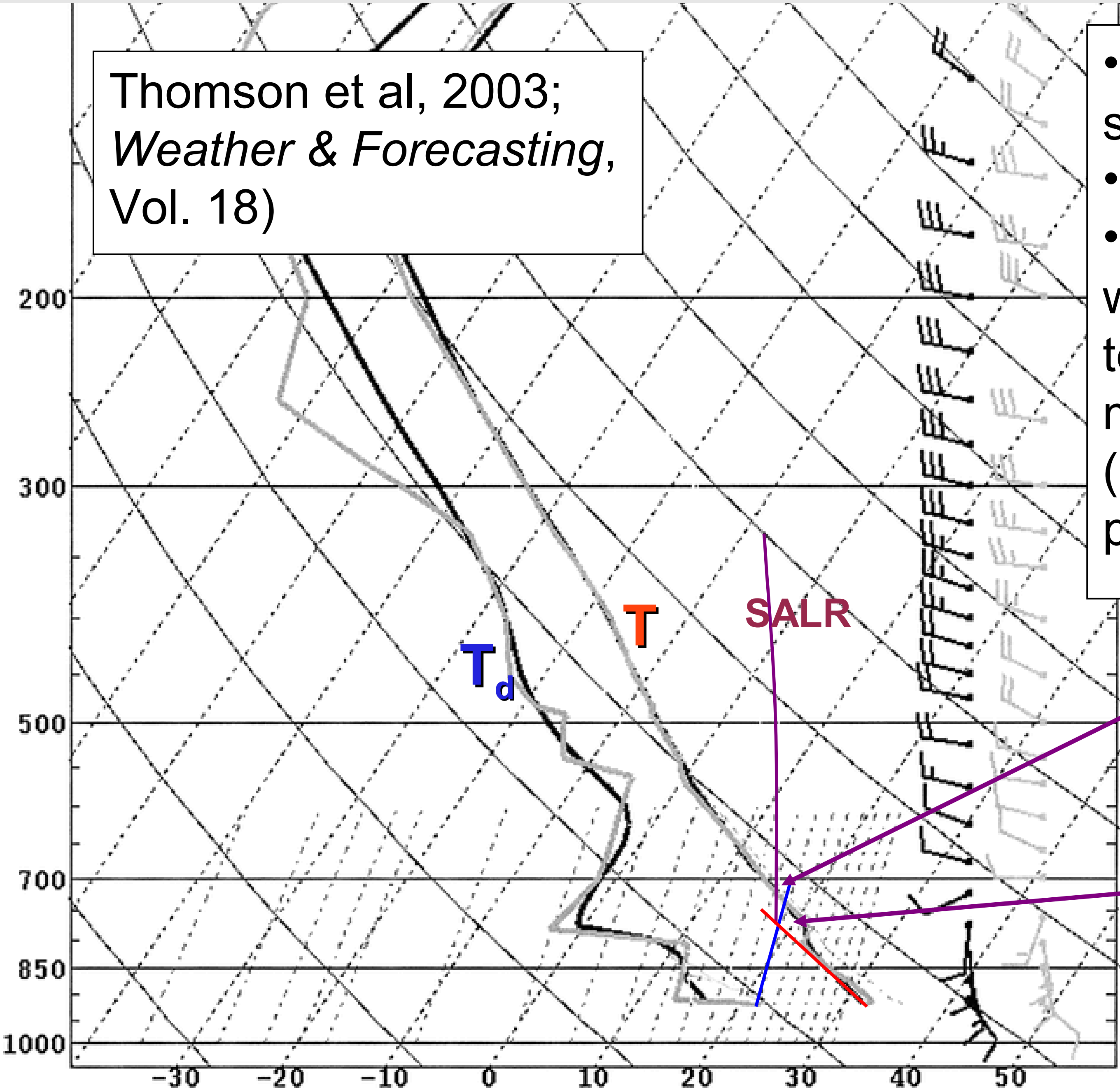
Supercell thunderstorm



- radar may reveal a "hook echo"
- hook echo signals possible imminent tornado formation

Vault: small droplets in the warm updraft do not reflect probing radar waves

Wind shear near a supercell - example



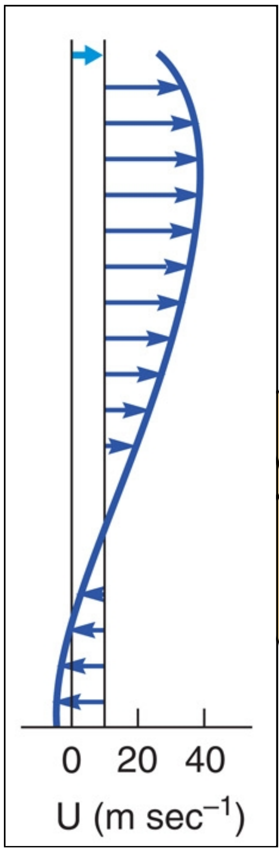
- sounding near a supercell
- note wind shear
- saturated ascent would produce large temperature excess, ie. much "CAPE" (convectively available potential energy)

LFC (parcel following moist adiabat warmer than environ.)

LCL (intersection of dry adiabat thru sfc T with dewpoint lapse rate line thru T_d)

Is vortex tilting the mechanism to produce supercell meso-cyclone?

- how would this explain preponderance of cyclonically rotating tornadoes?



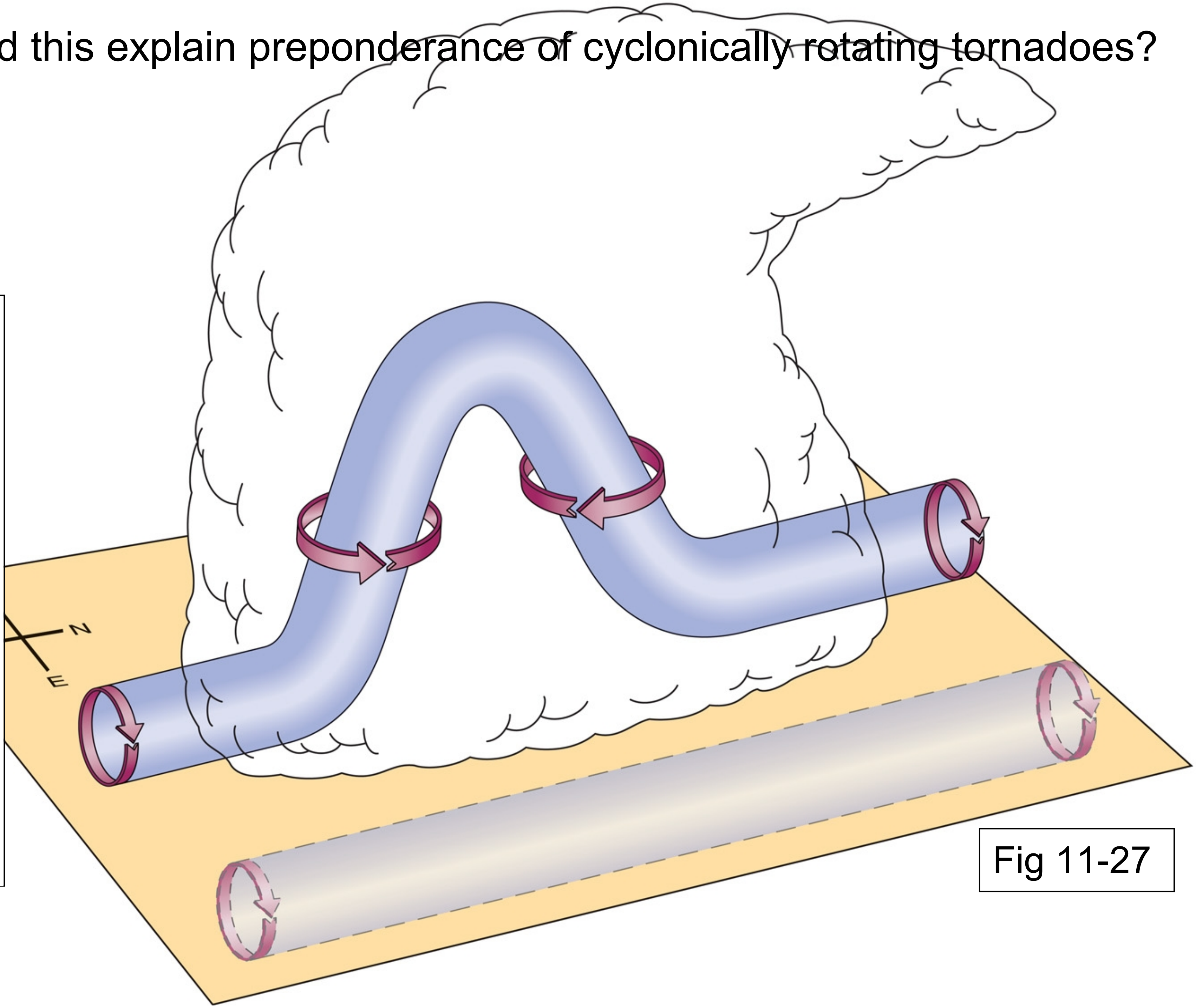


Fig 11-27

Wall cloud & funnel cloud

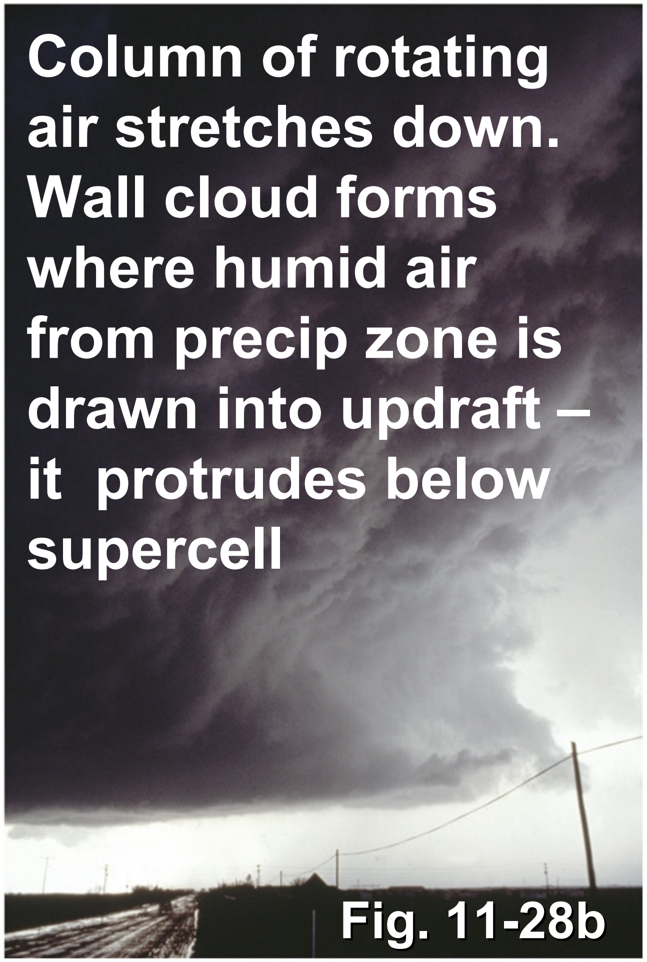


Fig. 11-28b

Funnel cloud – narrow vortex emerges from base of wall cloud – not a “tornado” until contacts ground

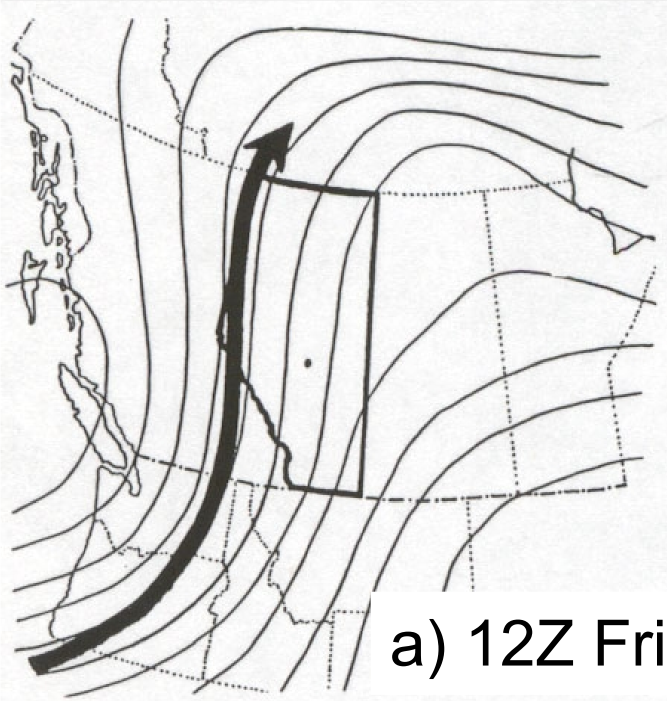
Fig. 11-26a

Meteorology associated with the Edmonton tornado

- EC Weather forecast issued 0500 MDT
  - afternoon thunderstorms heavy at times
  - evening thunderstorms
- Severe Weather Watch issued 1425 MDT
- tornado about 1500 MDT

UA's Dr. Robert Charlton prepared reports on Edmonton's 1987 tornado (F4)

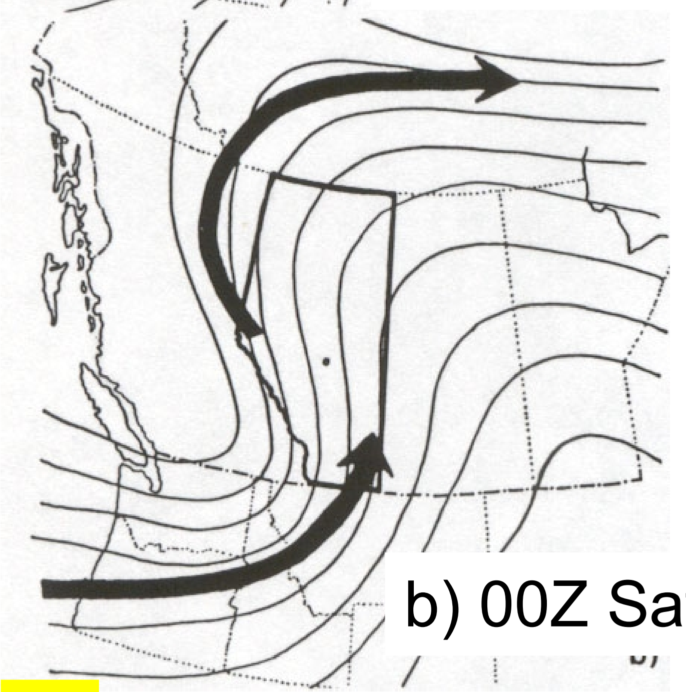
Synoptic setting – Edmonton tornado



a) 12Z Fri 31 July

- Edmonton in 250 hPa trough exit region
- southerly aloft (whereas NE at surface)

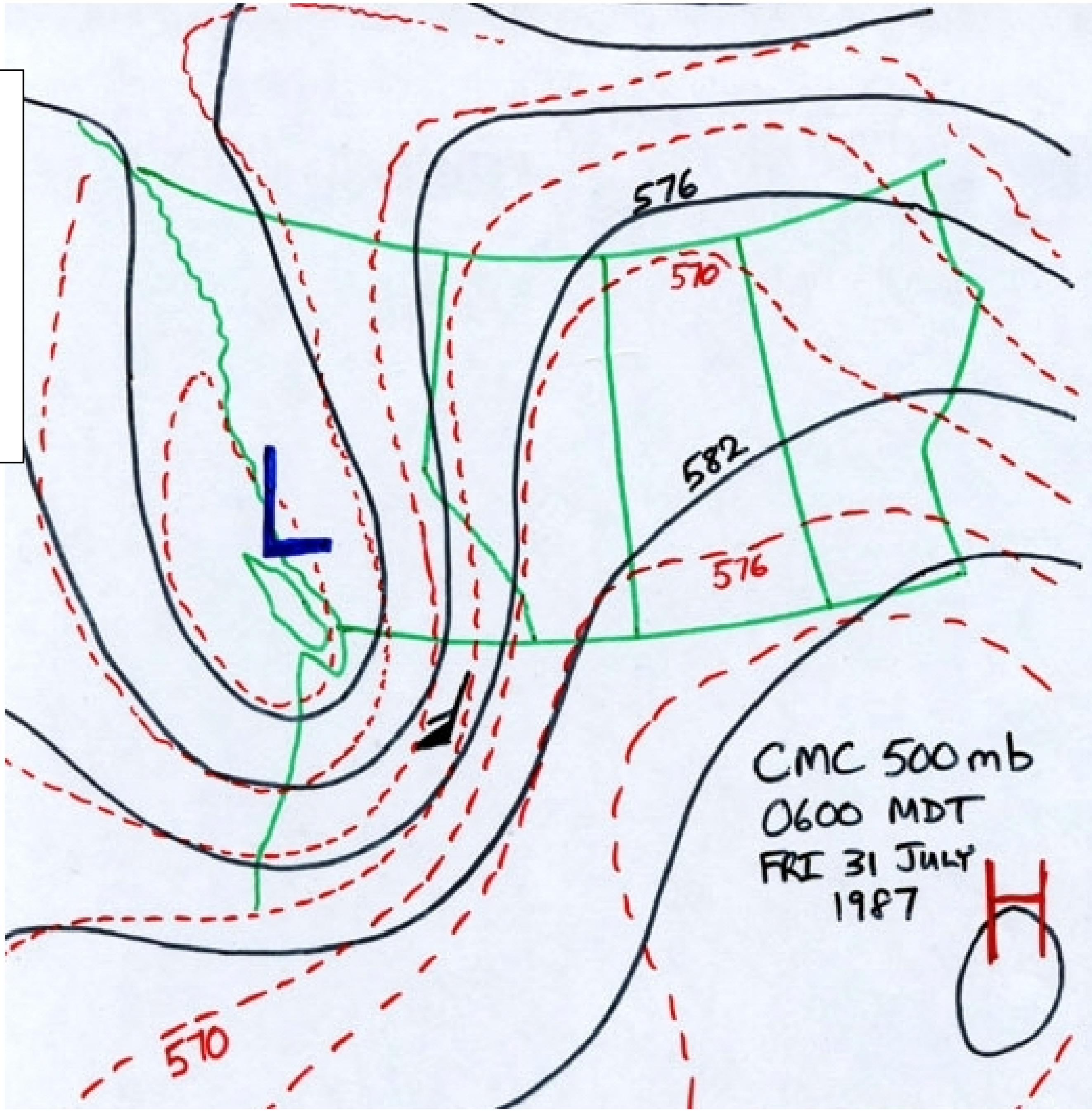
(sharpening trough)



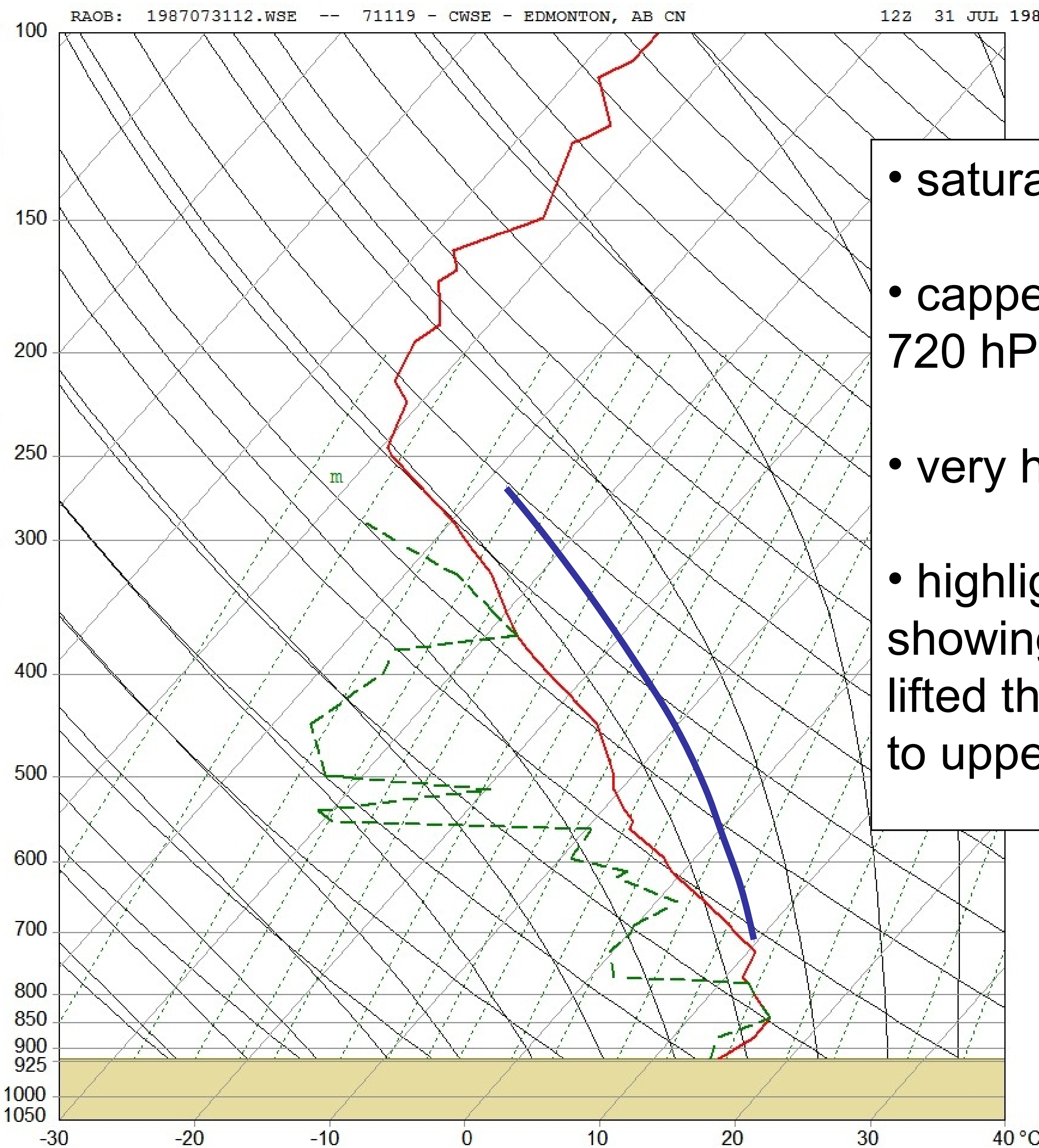
b) 00Z Sat 1 Aug

Synoptic setting – Edmonton tornado

- Edmonton in 500 hPa trough exit region
- Thickness (red dashed lines) ridge over W. prairies (warm)



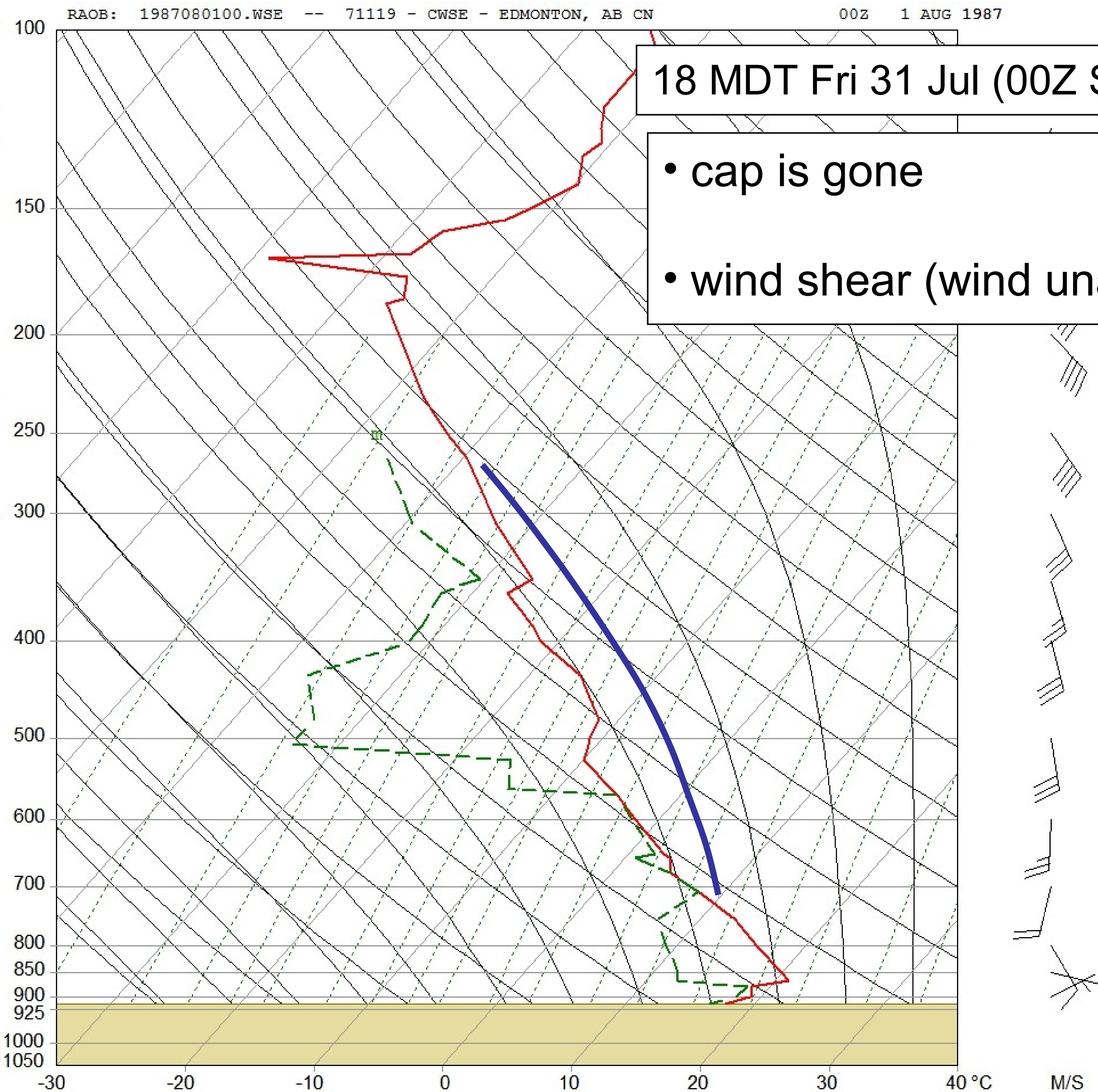
Synoptic setting – Edmonton tornado



06 MDT Fri 31 Jul (12Z)

- saturated layer 850-780 hPa
- capped: absolutely stable 780 – 720 hPa
- very high surface dewpoint
- highlighted – a moist adiabat – showing that a saturated parcel, if lifted through the cap, would rise to upper troposphere

Synoptic setting – Edmonton tornado

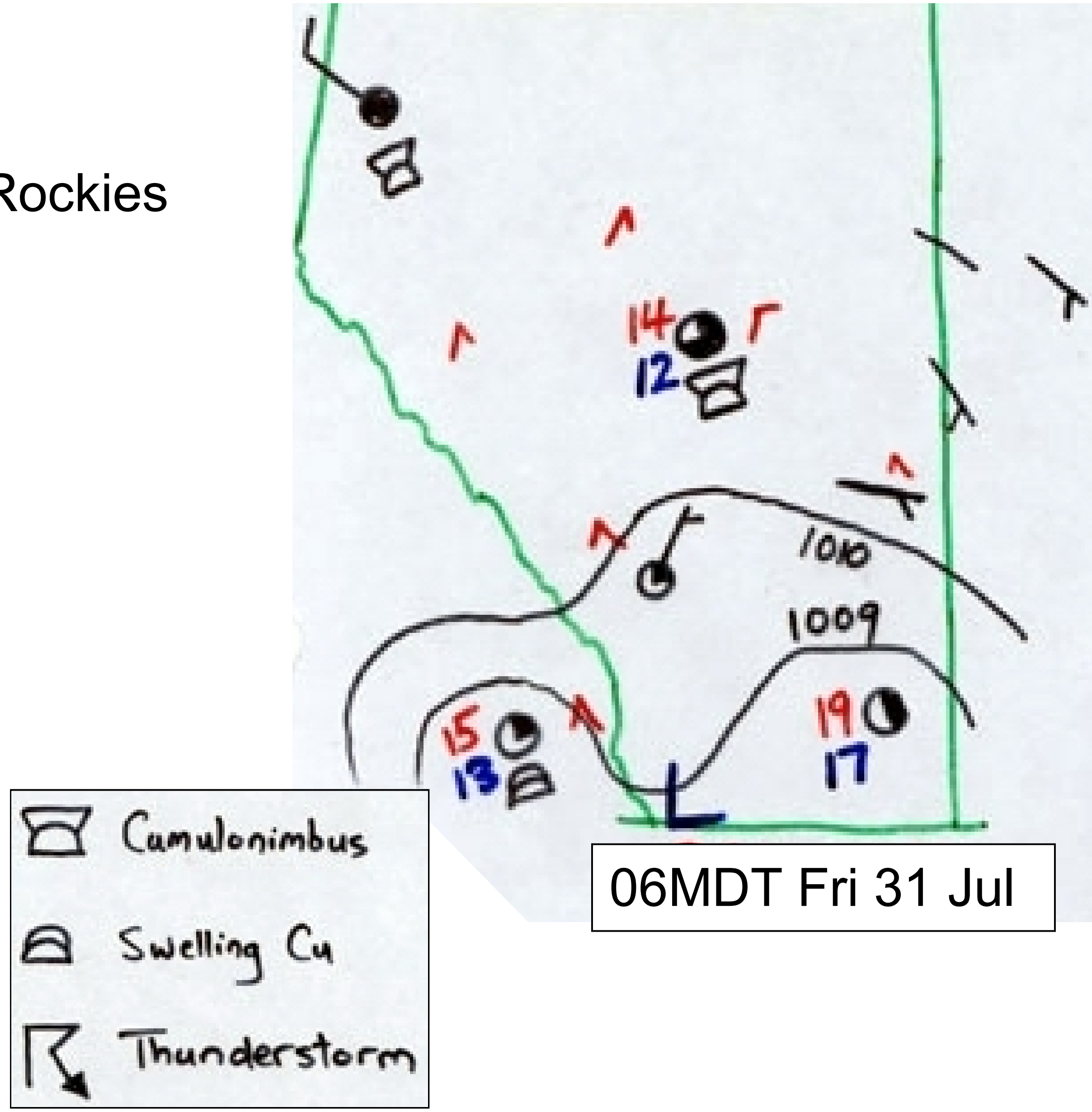


18 MDT Fri 31 Jul (00Z Sat 1 Aug)

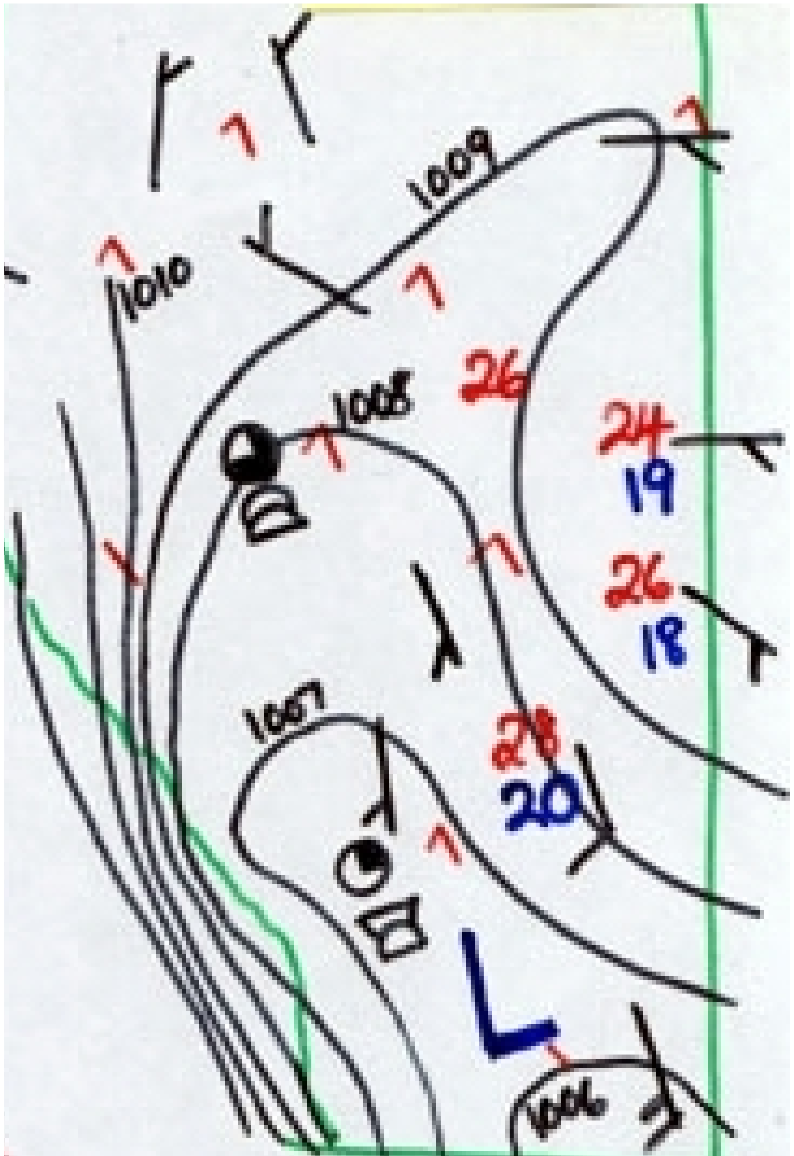
- cap is gone
- wind shear (wind unavail previous sndg)

Edmonton tornado

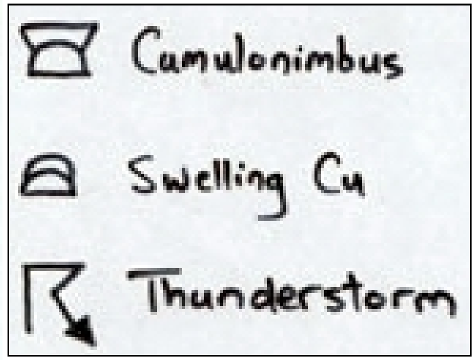
- low-level upslope towards Rockies
- Cumulonimbus at 0600
- high T_d
- weak low in SW Ab

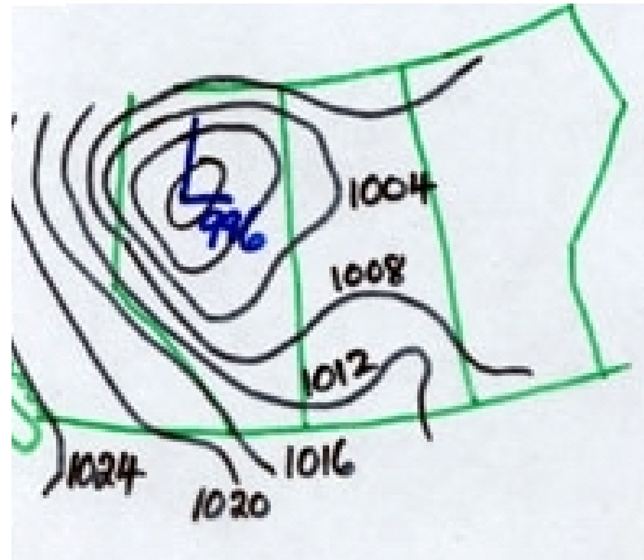


06MDT Fri 31 Jul



12MDT Fri 31 Jul





06MDT Sat 1 Aug

- dewpoints near 20°C, a near record
- colliding sfc winds (convergence)
- rapidly deepening surface trough

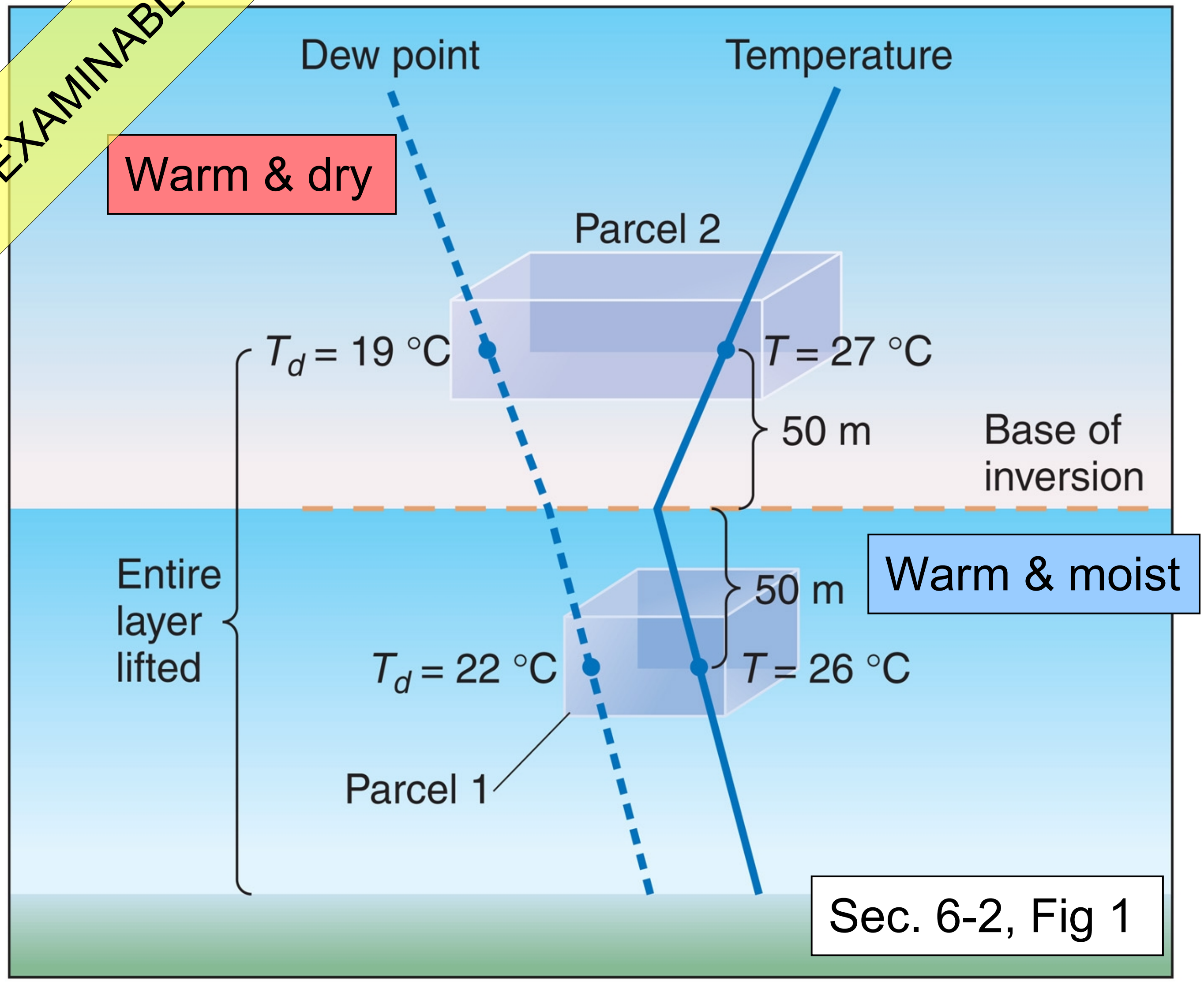
Potential Instability

- dewpoint lapse rate 2°C per kilometer
- imagine both parcels lifted 500 m… lower parcel $(T,T_d)=(21,21)$ but upper $(22,18)$
- lift a further 500 m… lower parcel evolves* to $(T,T_d)=(18.5,18,5)$, upper to $(17,17)$
- column has been destabilized – lower parcel now warmer than upper

NOT EXAMINABLE

- elevated inversion common in lee of Rockies due to subsidence (“capping inversion”)

*assuming SALR is 0.5°C per 100 m of ascent



Sec. 6-2, Fig 1