Goals for today:

- *Continue Ch. 10, Midlatitude Cyclones*

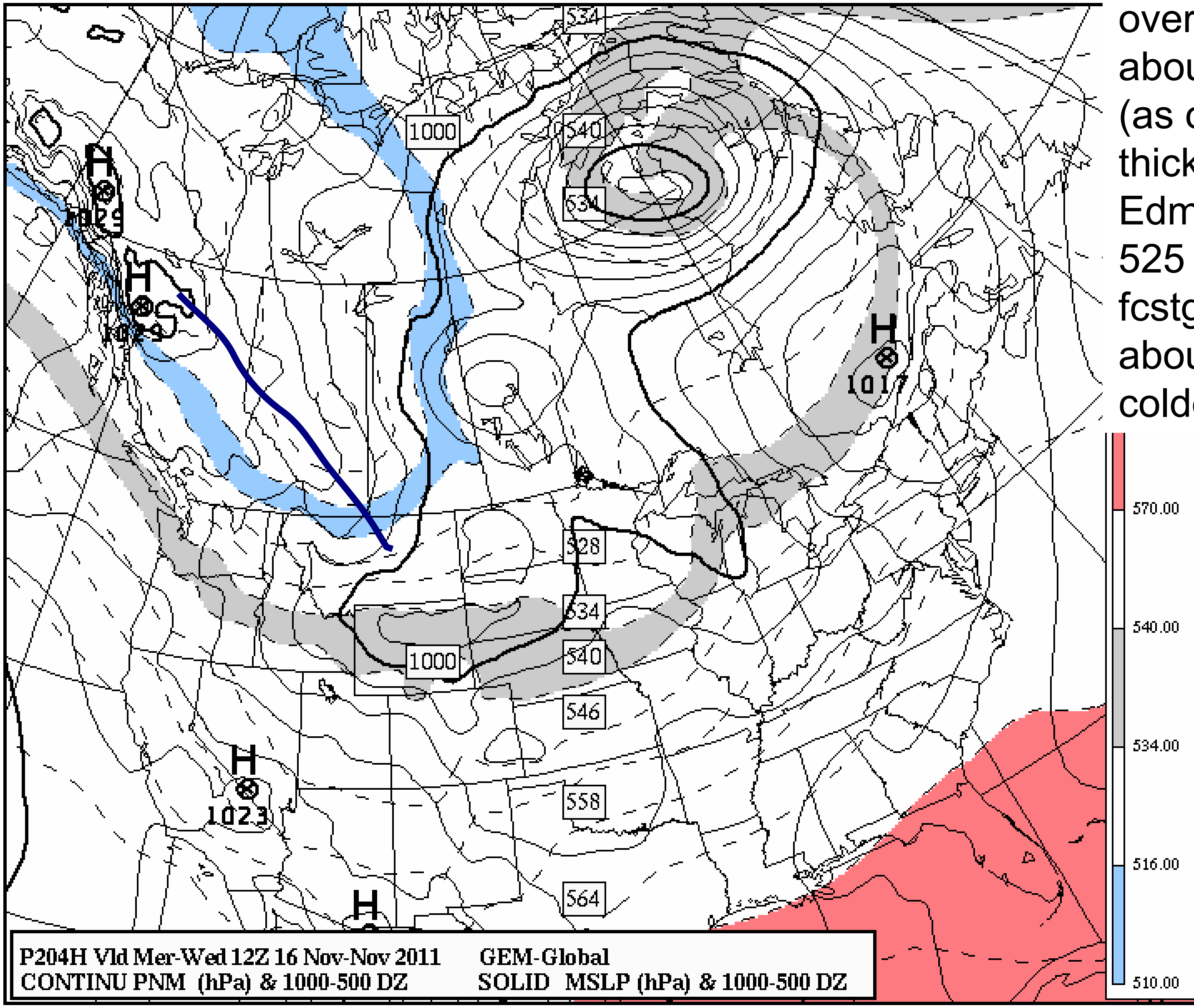
9 Nov., 2011

How the flow aloft factors into cyclone development:

- vorticity and divergence, their connection with each other, and with waves aloft
- short waves (baroclinic waves)
- relative positions of surface storm and upper wave

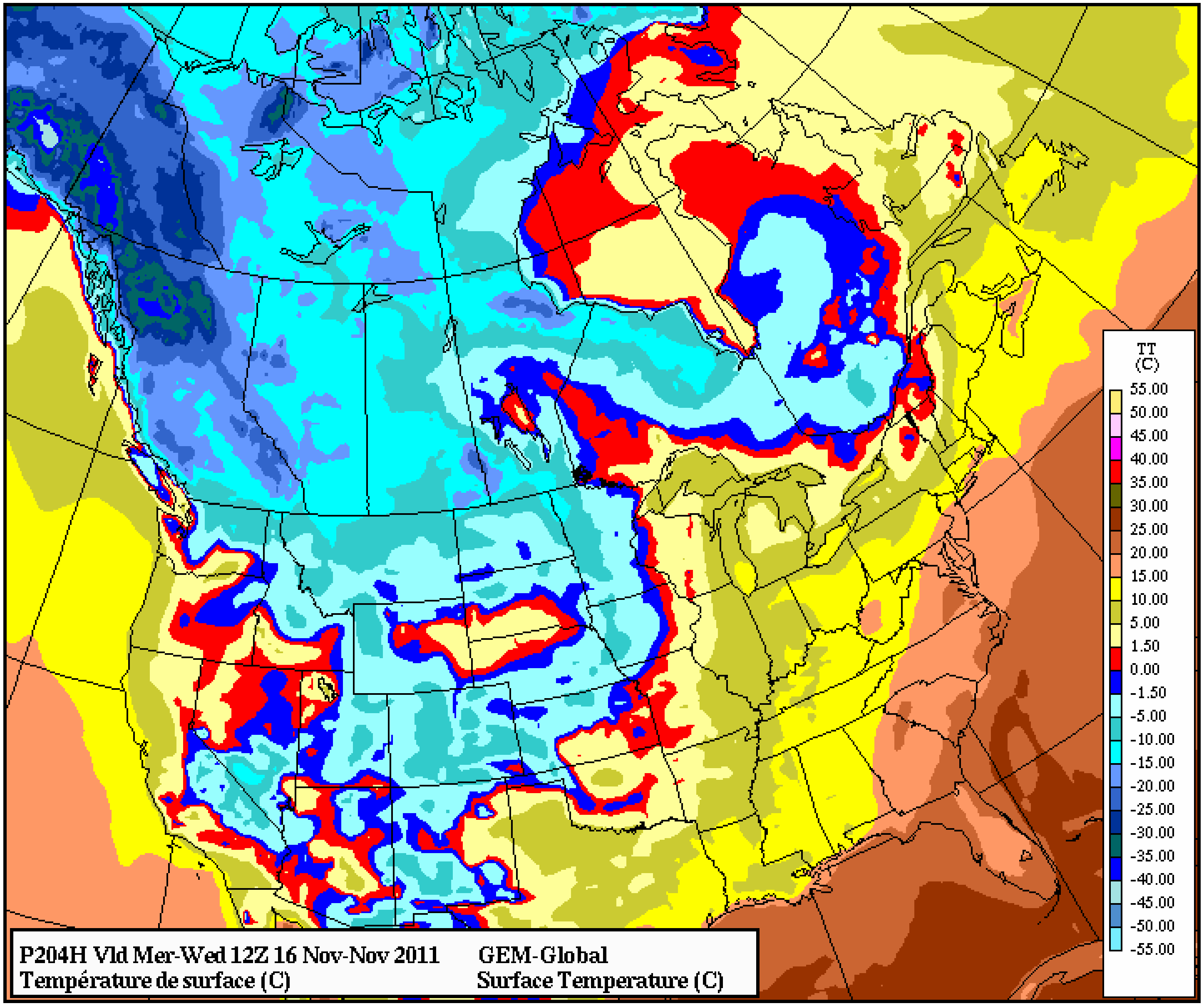
lec24.odp
JDWilson vers 9 Nov. 2011

MSC's GEM Global forecast puts us in very cold air as of next Wednesday

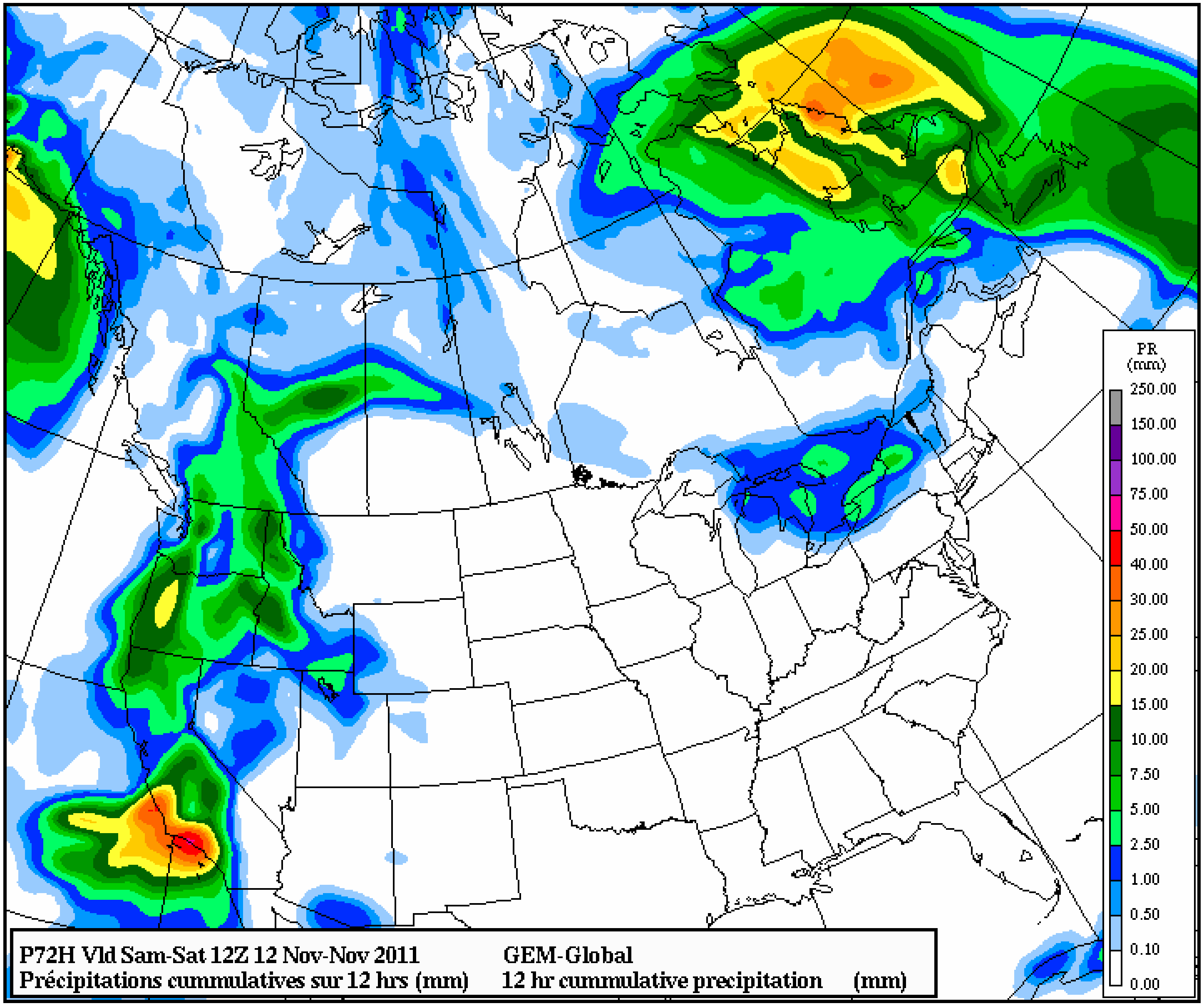


- fcst thickness over Edmonton about 498 dam (as of 12Z today thickness over Edmntn is about 525 dam, thus, fcstg it will be about 13^{o}C colder)

- the 510-516 dam thickness band (shaded blue) is displaced to the south of Edmonton
- axis of an **arctic ridge** through Alberta



- patches of purple in C. Alberta correspond to -15 to -20 Celcius range
- colder patches reflect localized overnight radiative cooling under breaks in cloud?



Periods of precip are forecast in the next few days; here specifically the 12-hr accumulation (5 pm MST Friday through 5 am MST Saturday) with a bulls-eye (10-15 mm) north of Edmntn

Earth vorticity and relative vorticity

Easy to visualize that a parcel at pole that is stationary w.r.t. earth has rotation in space

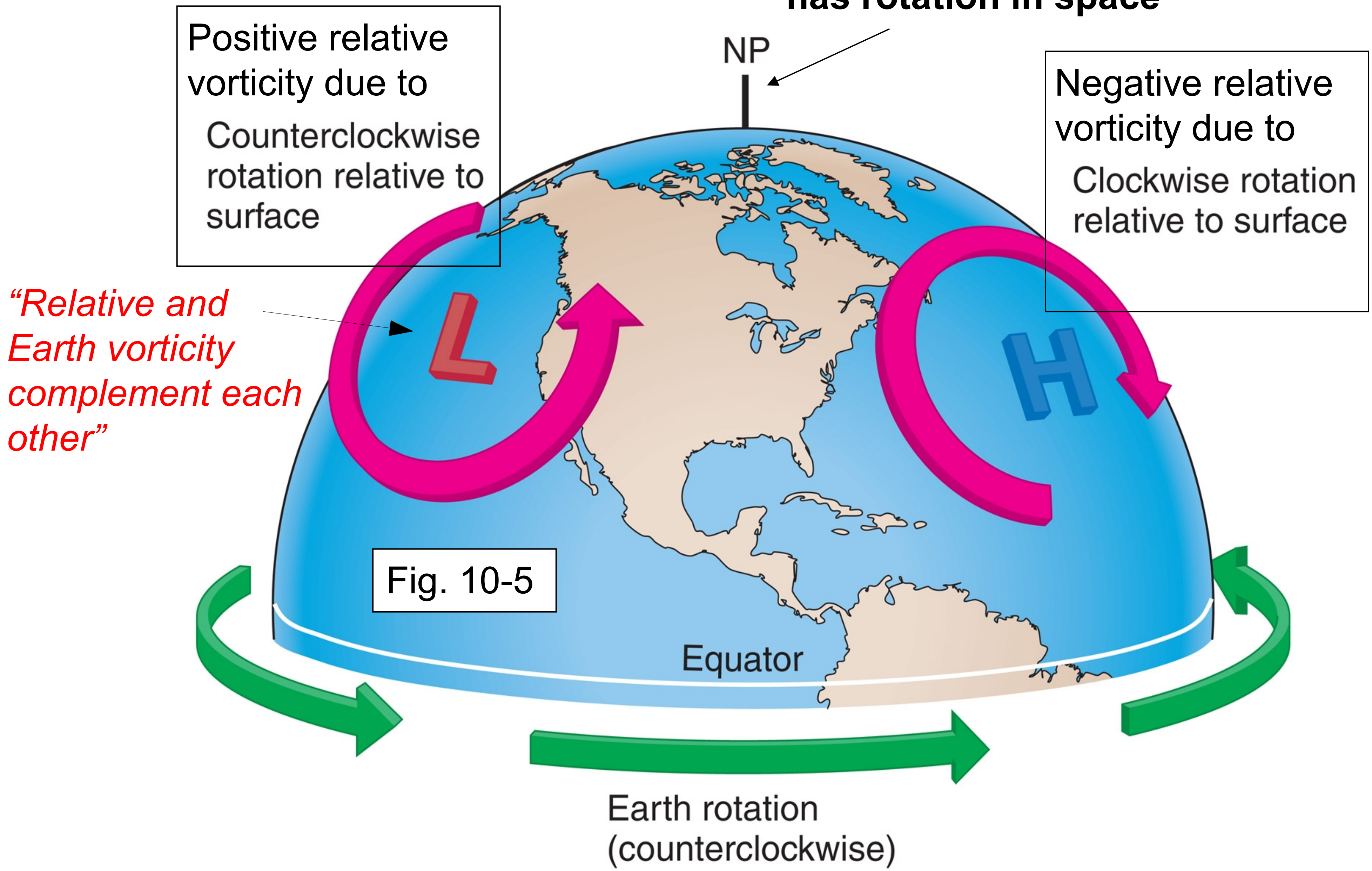


Fig. 10-5

- on equator, no rotation about local vertical (f=0)

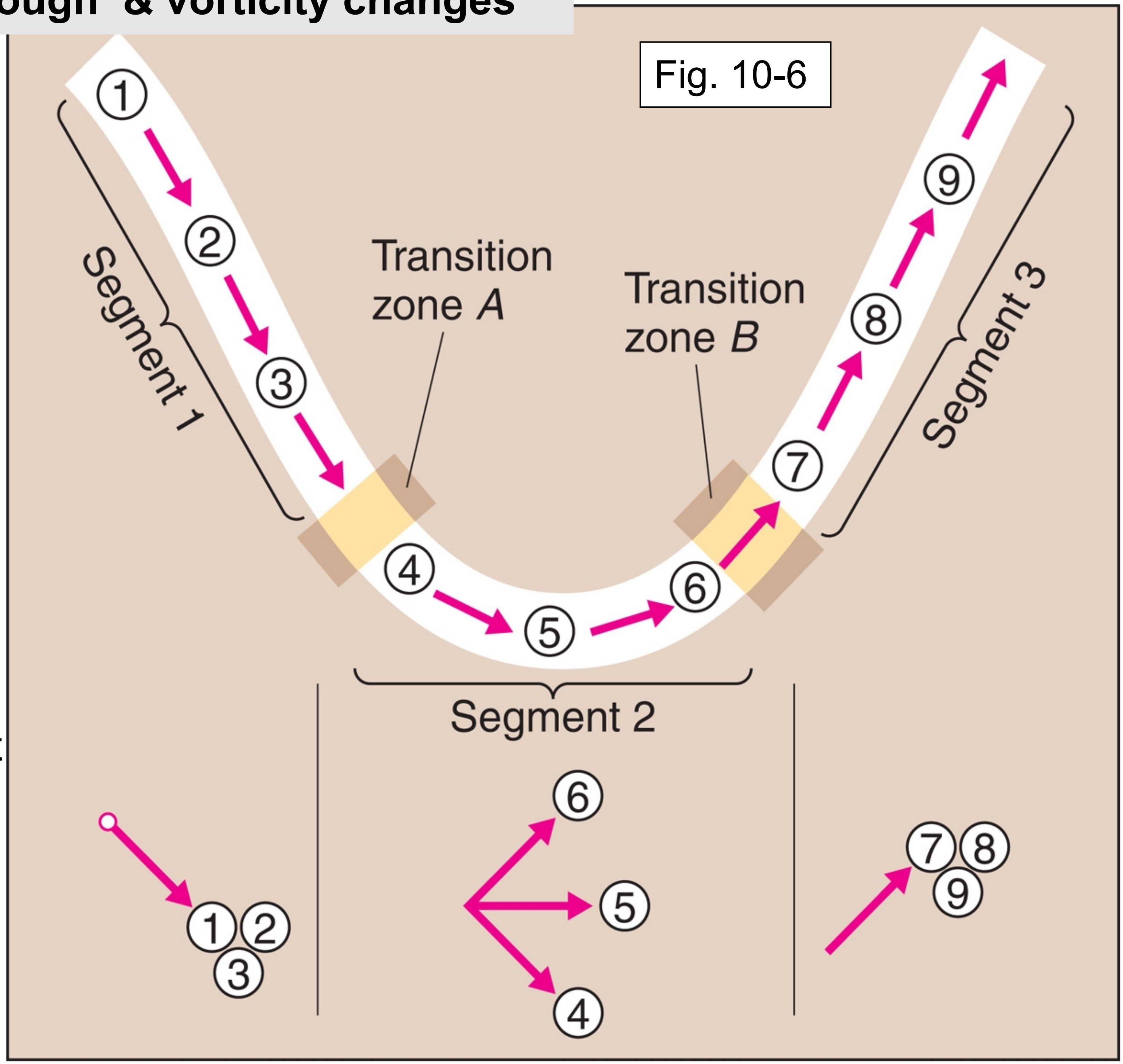
Rossby wave trough & vorticity changes

No relative vorticity at 1,2,3 nor 7,8,9

Positive relative vorticity** at 4,5,6

North-south motion also changes the absolute vorticity, as the earth component (f) changes…

**this is due to the curvature of the height contours (Sec. 10-1)

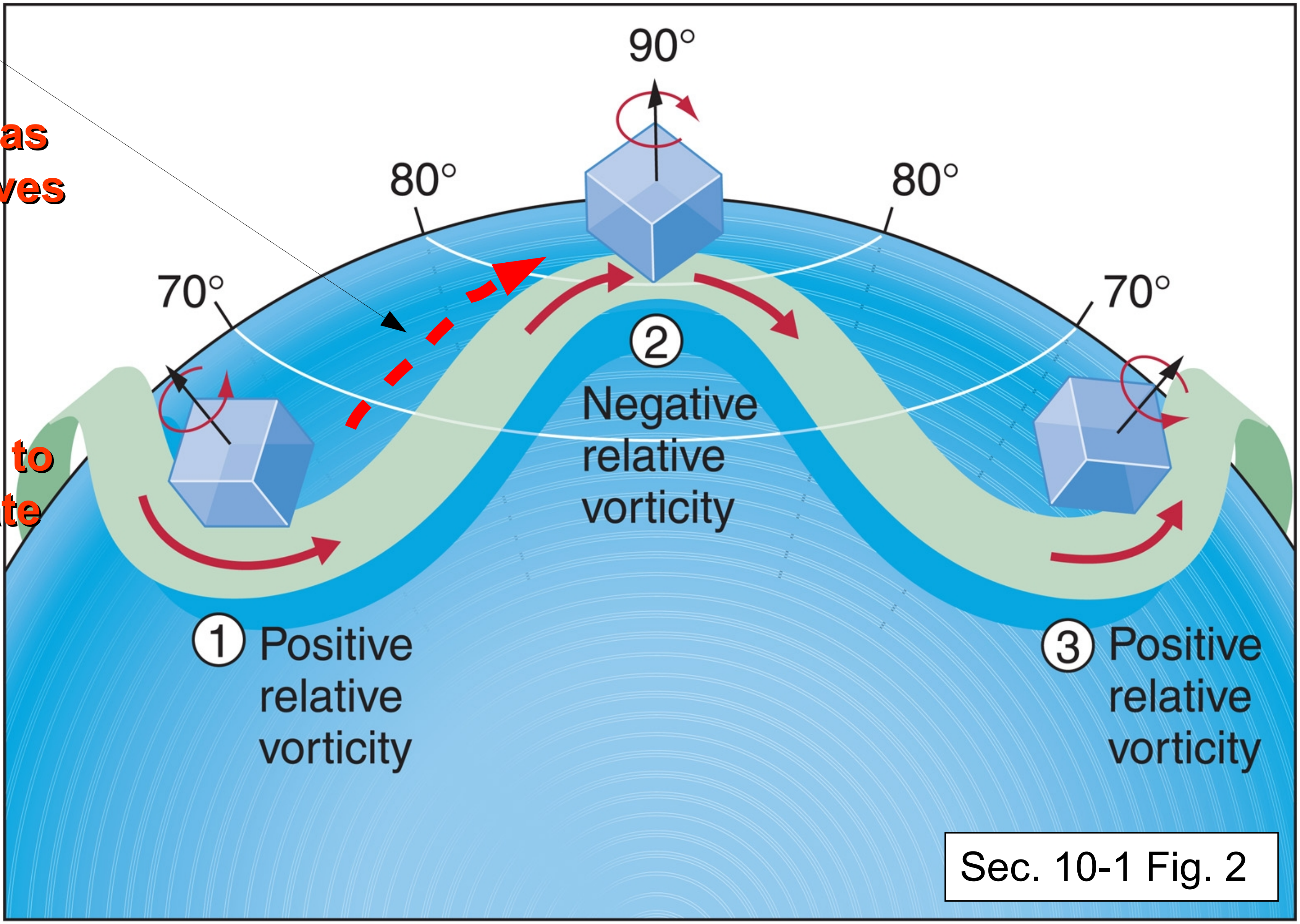


Sec. 10-1. A paradigm for Rossby waves: conservation of absolute vorticity

$$\zeta = \omega_R + f = \omega_R + 2\Omega \sin\phi = \text{const}$$

Earth vorticity increases as parcel moves north

– relative vorticity decreases to compensate



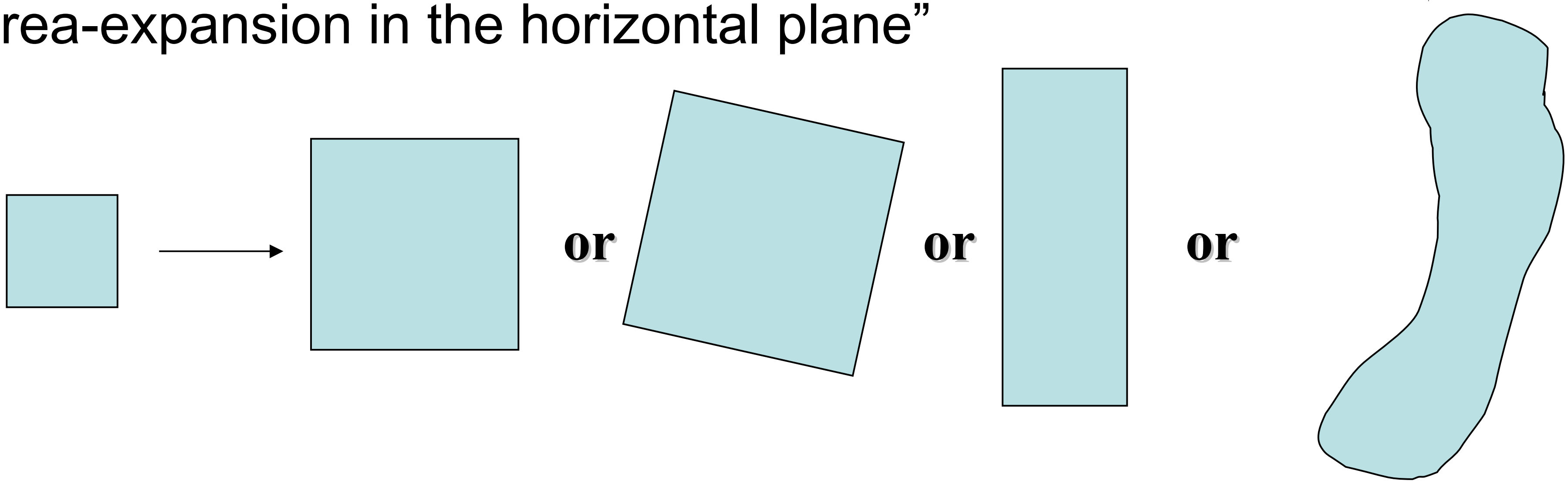
Sec. 10-1 Fig. 2

Interconnection of vorticity with horizontal convergence & divergence

• changes in vorticity matter in relation to storms because they induce a pattern of horizontal divergence/convergence that (in turn) induces vertical motion and surface pressure changes

• divergence is the same thing as negative convergence (just as deceleration is negative acceleration)

• we can think of horizontal divergence (textbook symbol " *div* ") as "area-expansion in the horizontal plane"



• when the cross-section of a rotating column expands – visualize a skater extending her arms – column rotation rate decreases

Vorticity tendency & horiz. divergence aloft: "Vorticity Theorem"–p305

Rate of change of absolute vorticity following an air parcel is:

$$\frac{\Delta \zeta}{\Delta t} \approx - \zeta \ \mathrm{div} \qquad \text{(p305)}$$

- now ordinarily $\zeta > 0$ so

- decreasing vorticity (l.h.s. negative) implies ***div*** > 0 , i.e. positive divergence aloft – this happens in a trough exit region

- increasing vorticity (l.h.s. positive) implies ***div*** < 0 , i.e. negative divergence (= convergence) aloft – happens in ridge exit region

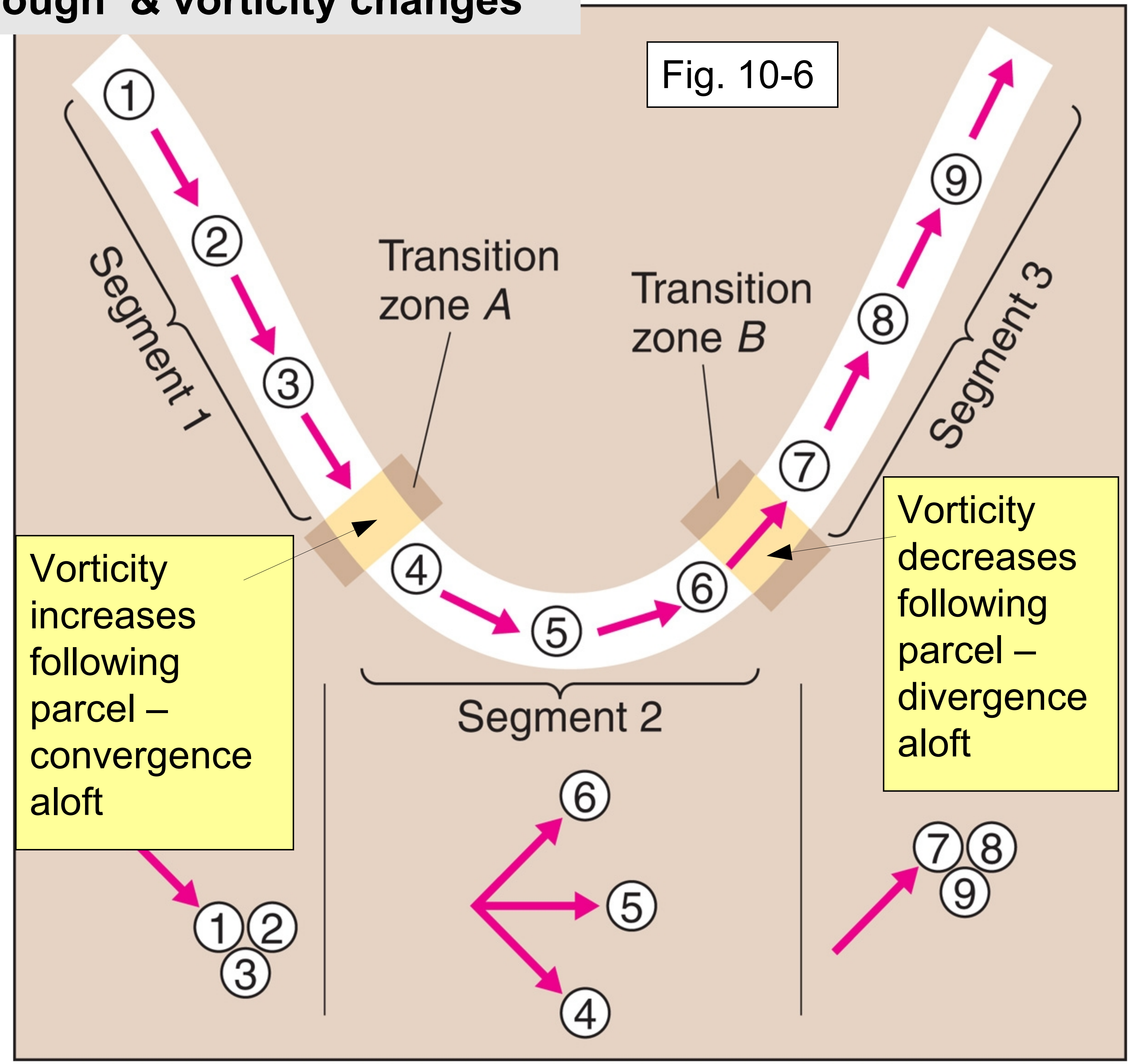
- "Divergence in the upper atmosphere, caused by decreasing vorticity, draws air upward from the surface... this can initiate & maintain low pressure systems"

Rossby wave trough & vorticity changes

No relative vorticity at 1,2,3 nor 7,8,9

Positive relative vorticity at 4,5,6

North-south motion also changes the absolute vorticity, as the earth component (*f*) changes…



Illustrates the ideal collaboration of upper wave & sfc storm

- sfc convergence + upper divergence over L – ascent, cloud & precip
- sfc div + upper conv associated with H
- sfc pressure trend result of a subtle imbalance in conv/div along vertical
- this pattern reliably valid for intense storms
- topography complicates the pattern
- Rossby waves are not the only upper waves – there are also short waves

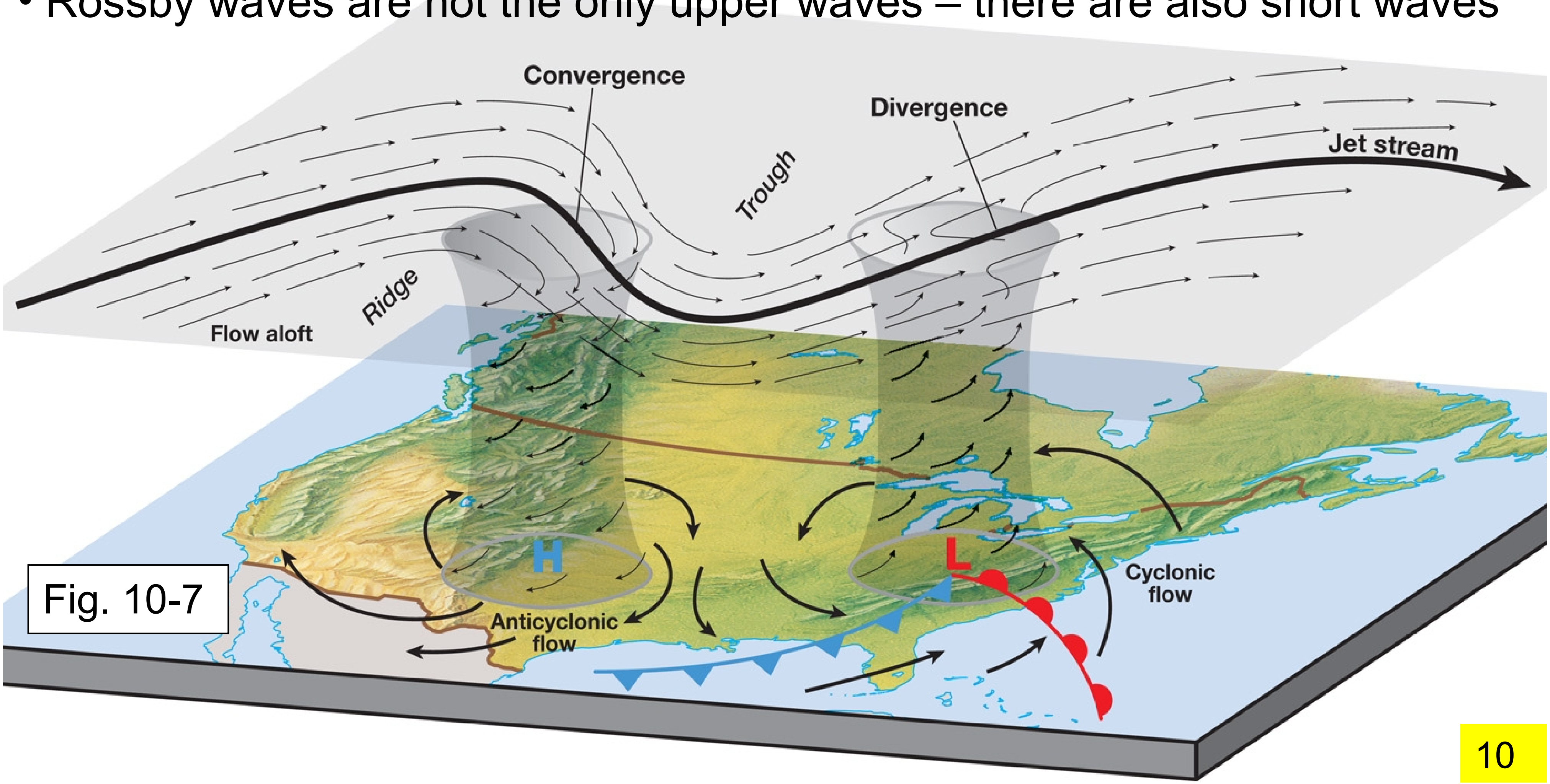


Fig. 10-7

Vorticity of the mid-tropospheric flow is so important that meteorologists display it on mid-troposphere analysis

- green lines are height contours (in dam) – which level?
- vort. maxima are associated with troughs

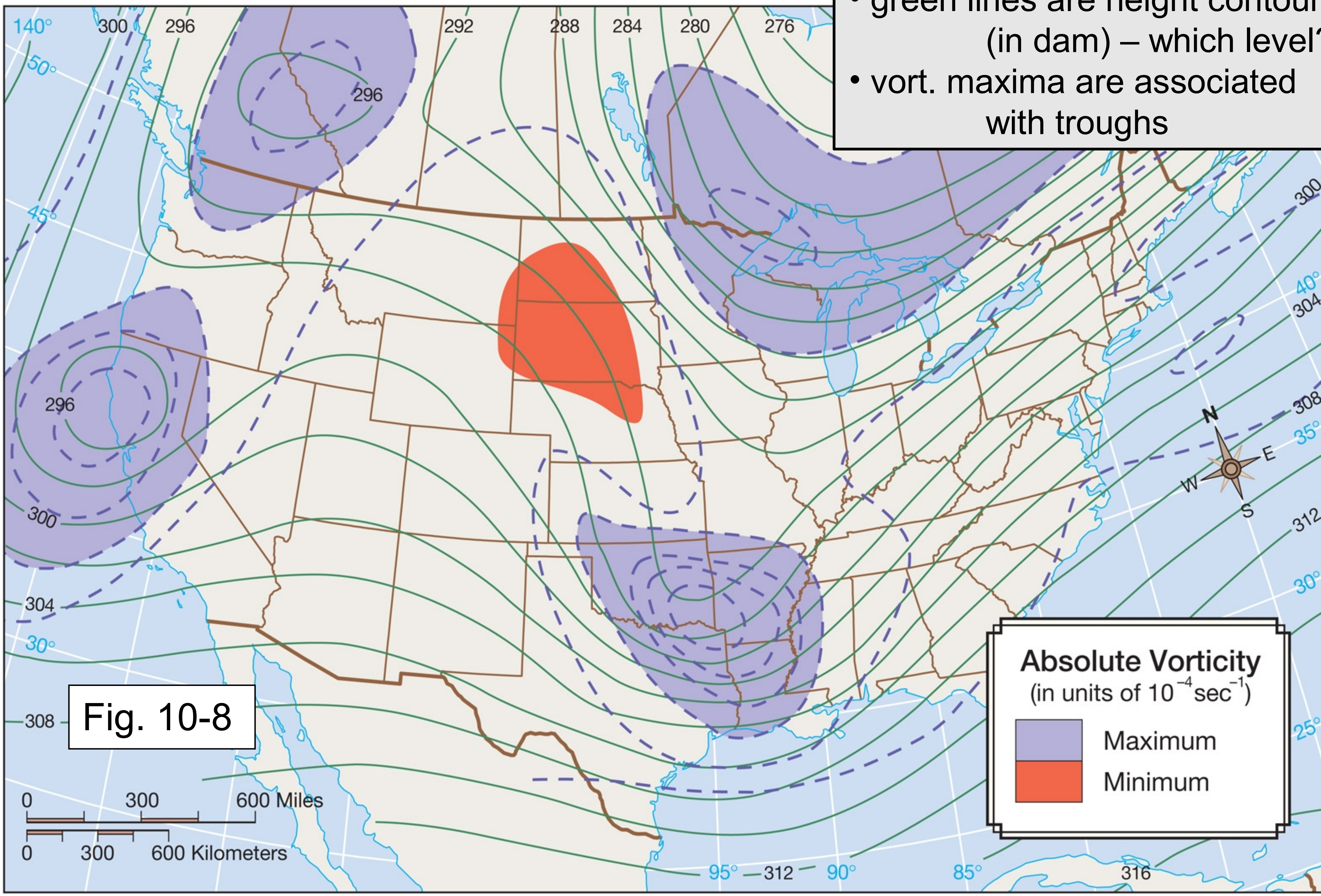
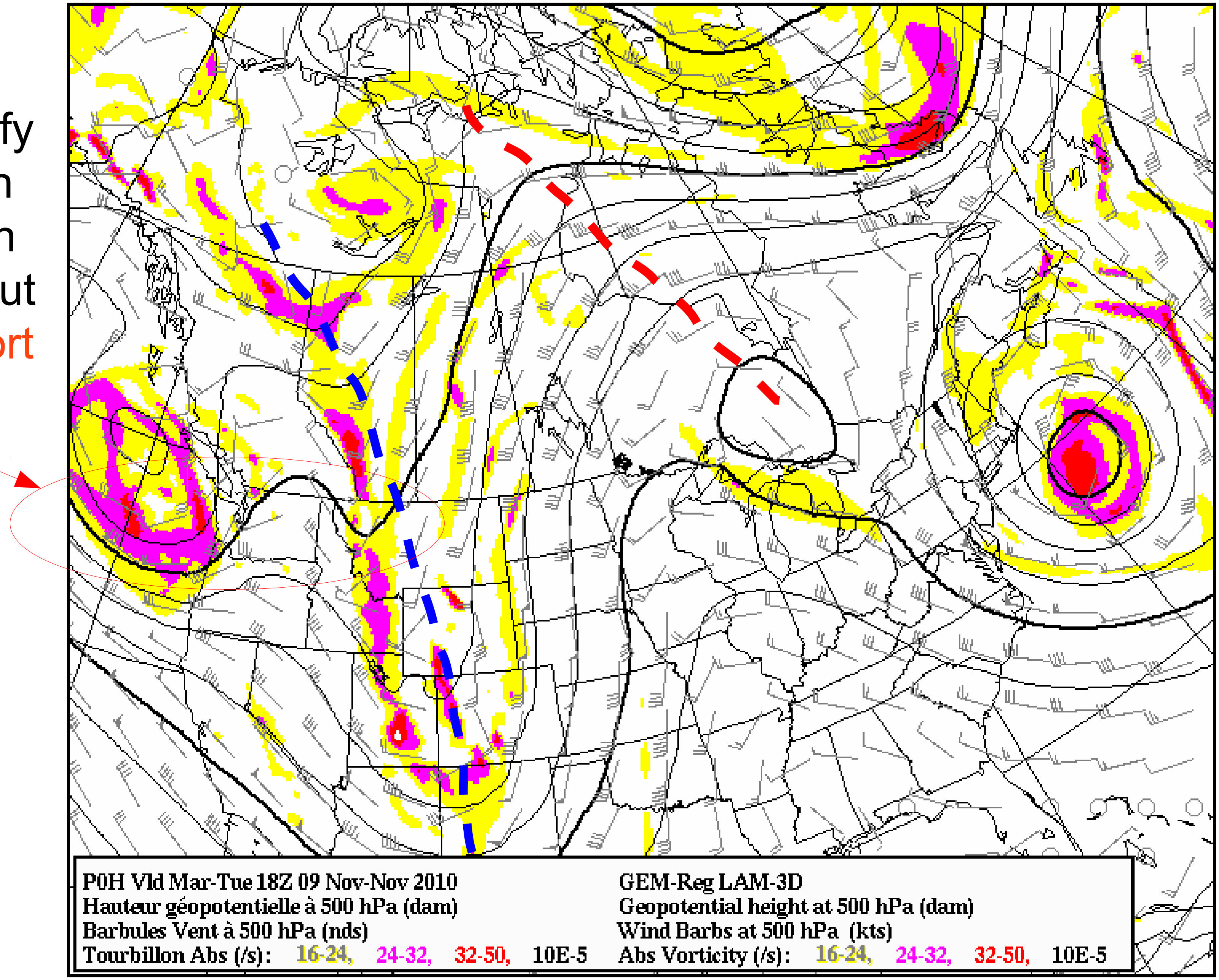


Fig. 10-8

Vorticity at 500 hPa given on CMC forecasts … 500 hPa height + vorticity shading. Darkest shading – largest (cyclonic) vorticity at trough axes

- we can identify vorticity pattern associated with a long wave, but also with a short wave

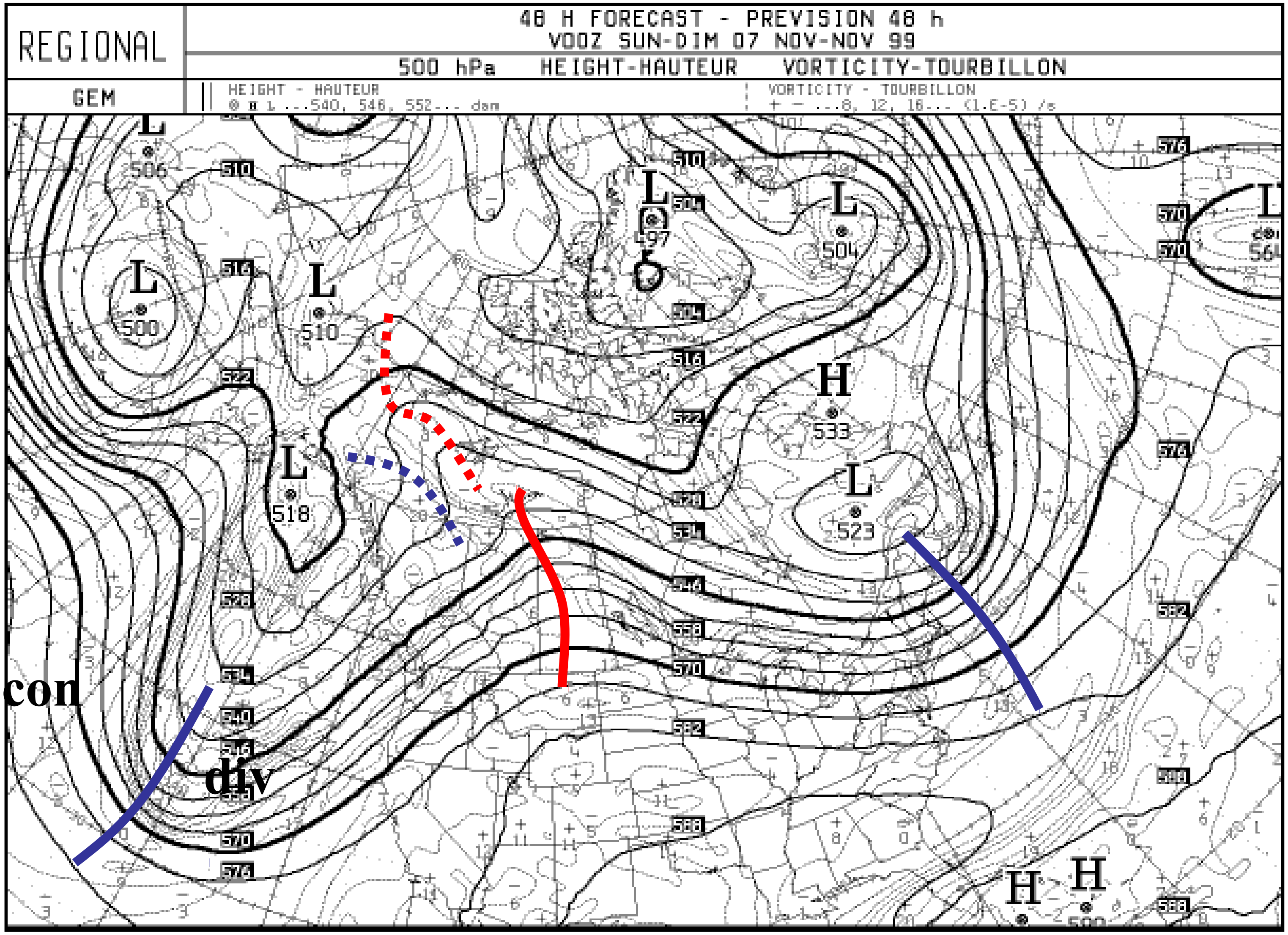


Short (Baroclinic) Waves ("impulses") - - - -   (Sec. 10-3)

Shorter waves are associated with strong *T* & *p* gradients and strong temperature advection.

Cold advection aloft implies sink,
Warm advection aloft implies lift

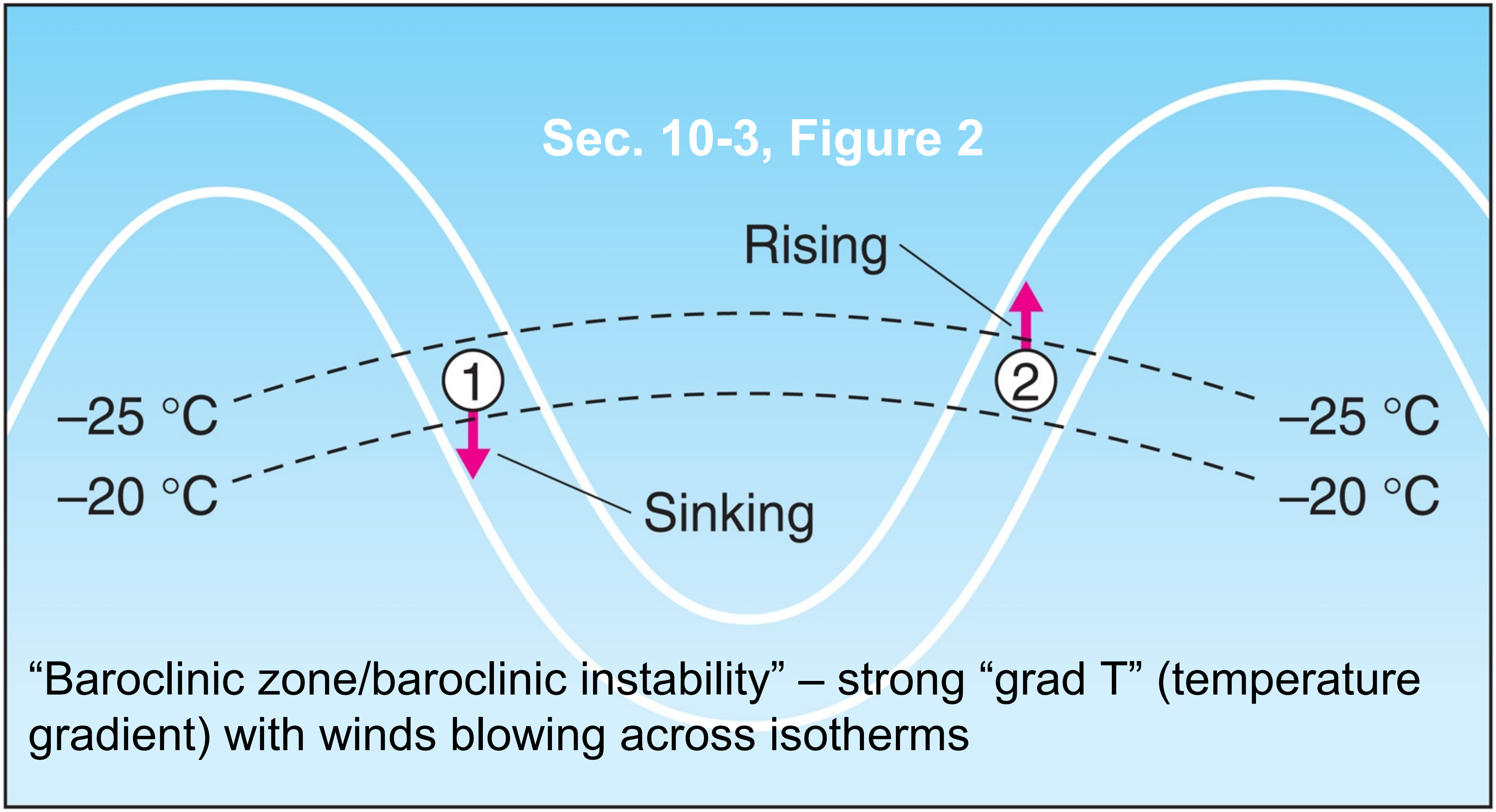
- short wave may move rapidly (downstream)
- deepens when approaching a longwave trough



Here a wave in the flow aloft is configured in relation to isotherms such that temperature advection is occurring (strongest around shortwaves)…

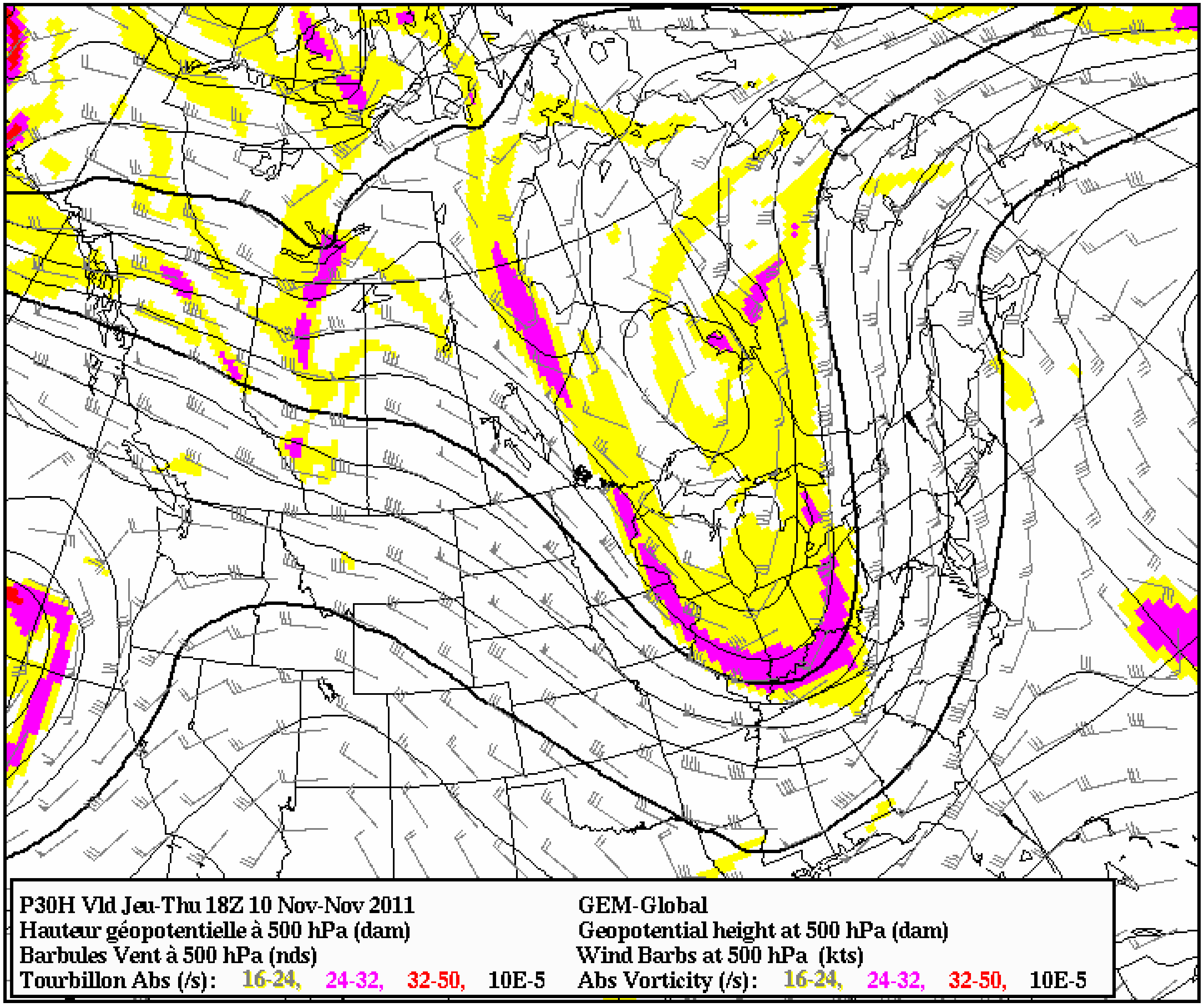
cold advection aloft implies sink

warm advection aloft implies lift

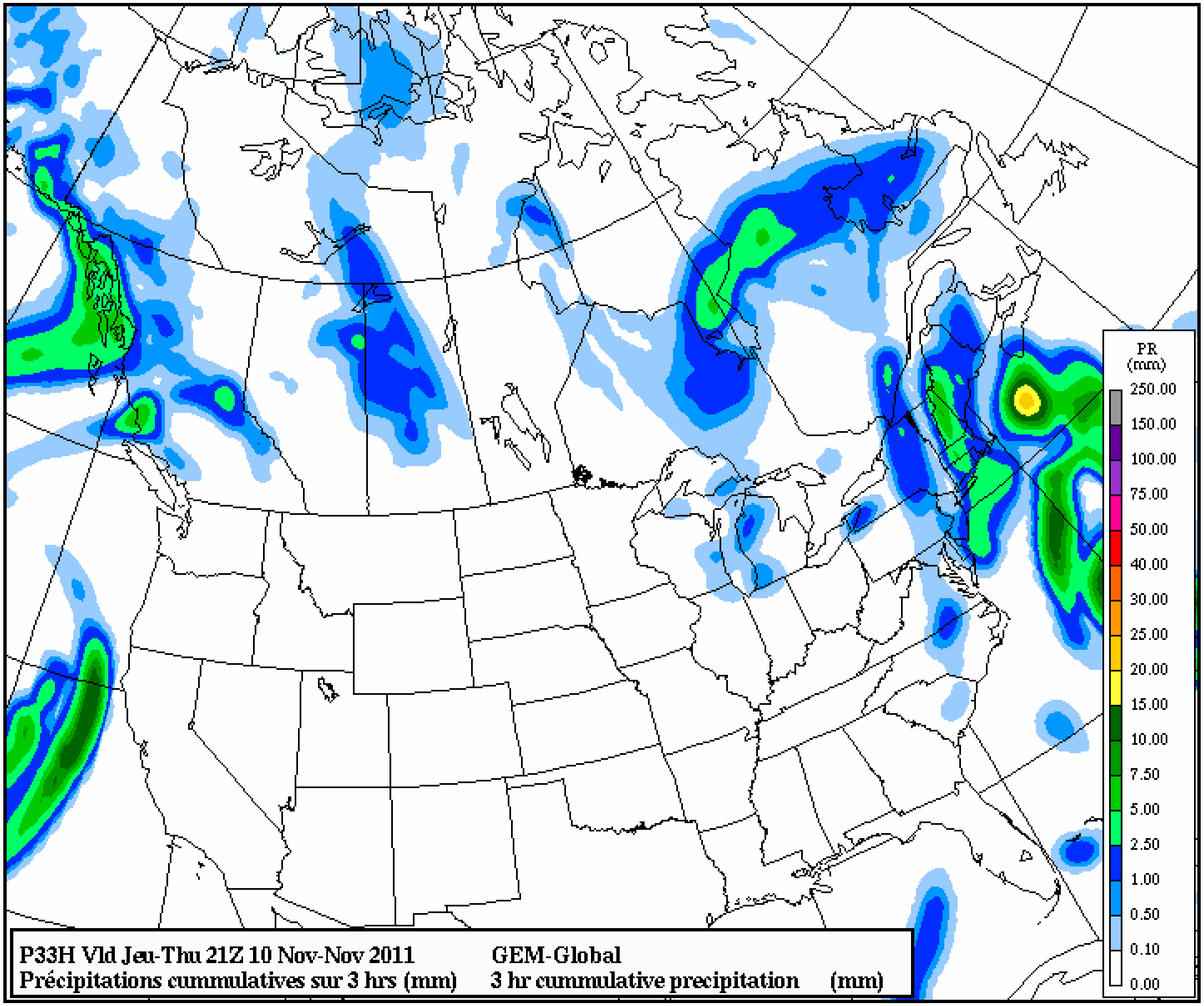


“Baroclinic zone/baroclinic instability” – strong “grad T” (temperature gradient) with winds blowing across isotherms

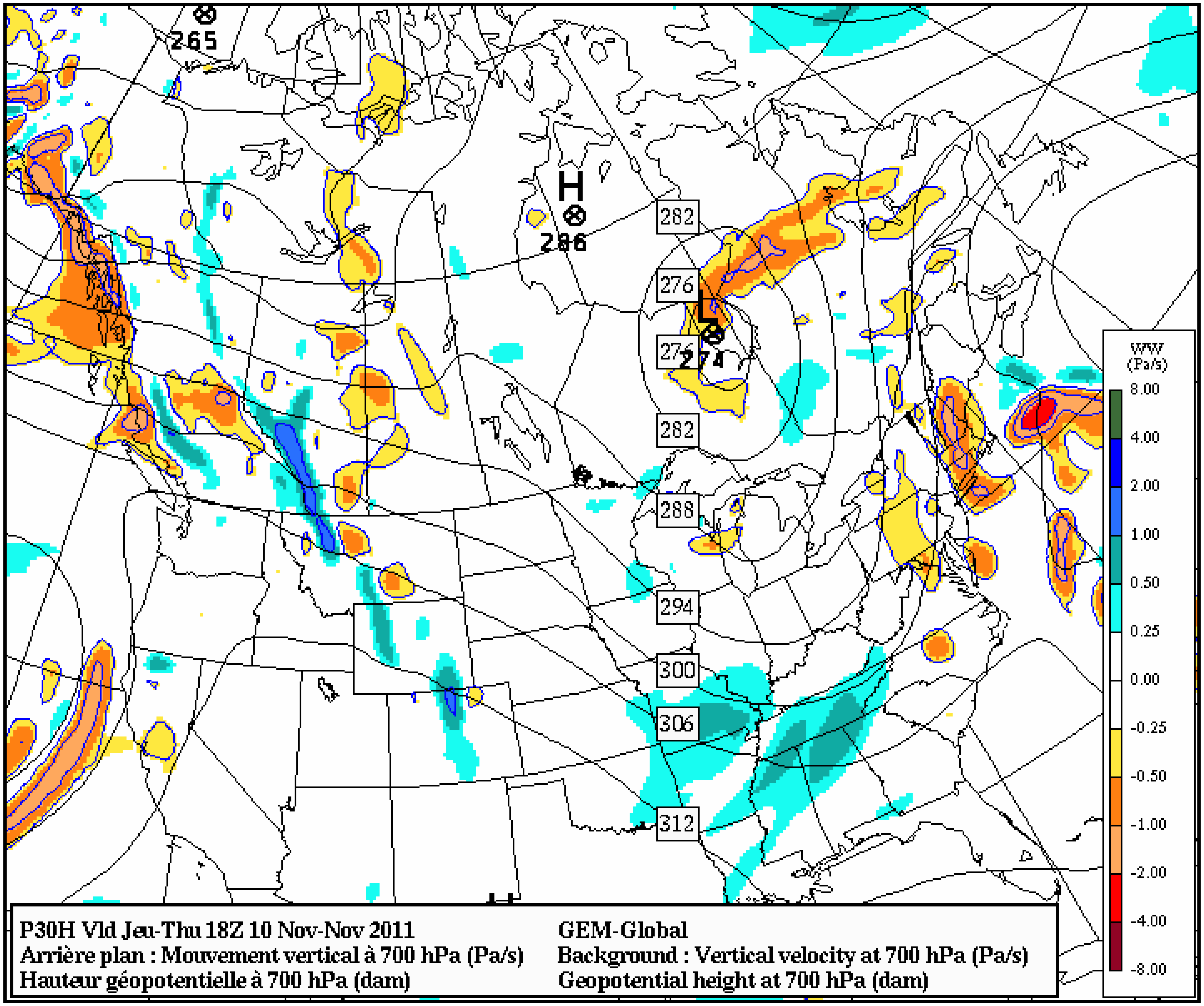
“Barotropic zone/atmosphere – height contours & isotherms parallel



Noted at start of lecture periods of precip are fcst in next few days. Here notice the vorticity maximum associated with a shortwave trough in N. Alberta – see over, precip bulls-eye



3-hr precip bulls-eye is downwind of the vorticity maximum



And the cause? – ascending vertical motion, the orange bulls-eyes (and sink – blue-- in lee of Rockies)

Review – the ideal collaboration of upper wave & sfc storm

• sfc convergence + upper divergence implies ascent… cloud + precip

• sfc pressure trend is the result of difference between low-level convergence & upper level divergence

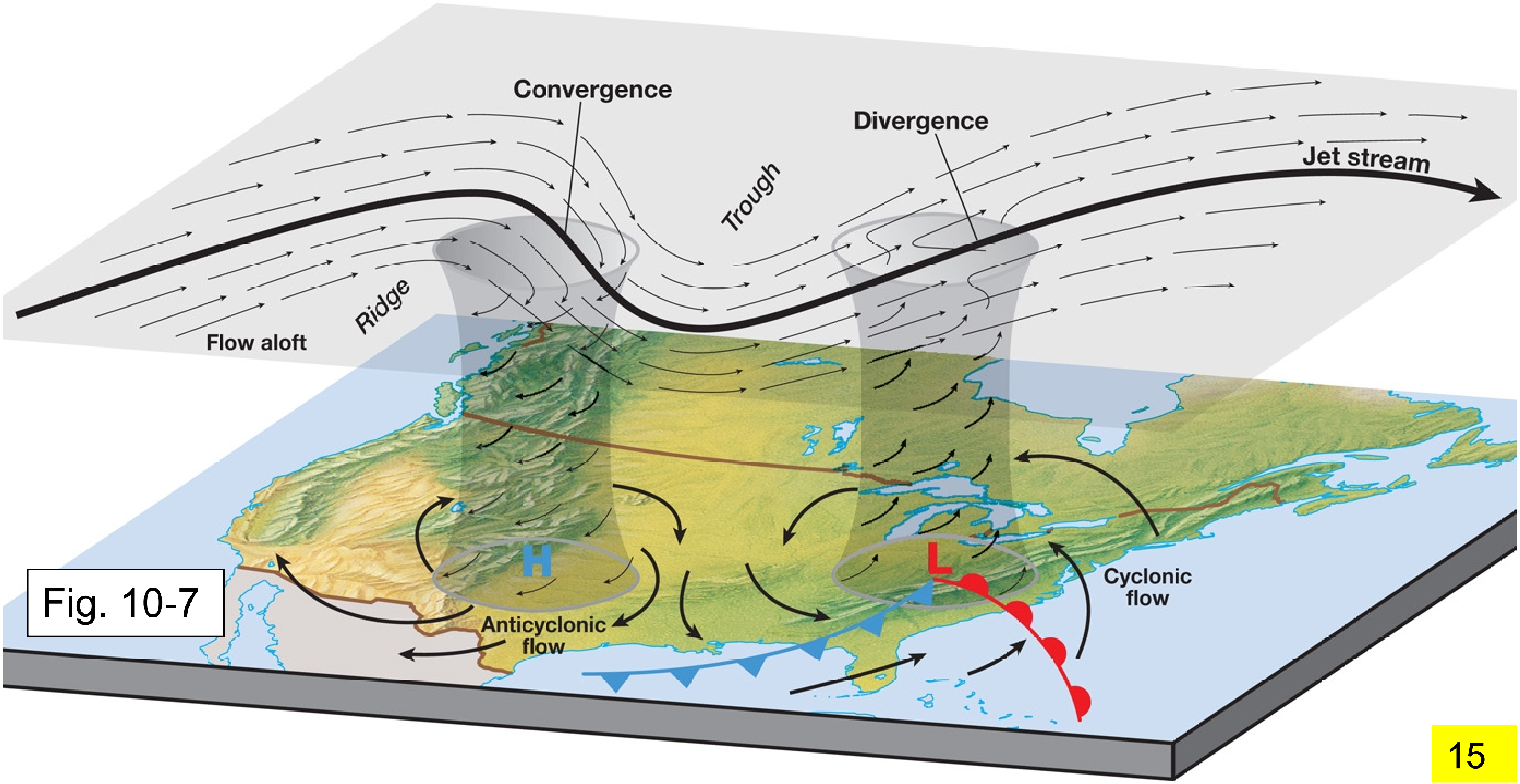


Fig. 10-7

Coupling of conditions aloft with surface weather

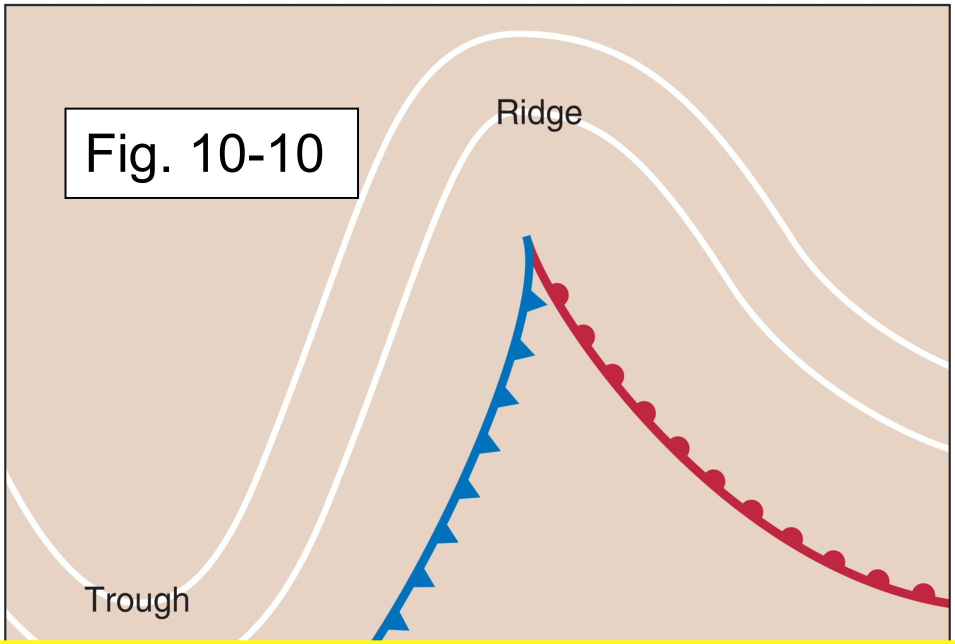
• upper waves initiate/maintain/deepen surface storm – but conversely surface conditions, esp. the temperature distribution, exert an influence on the pressure pattern aloft (which defines the pattern of winds aloft, thus, the waves) – by controlling the pressure lapse rate

• troughs in the waves aloft normally develop "behind" (ie. upstream from) surface cold fronts (ie. low-level baroclinic zones) where in the cold airmass the pressure falls more rapidly with increasing height:

$$\frac{\Delta p}{\Delta z} = -\rho \; g = - \frac{p \;\; g}{R} \; \frac{1}{T}$$

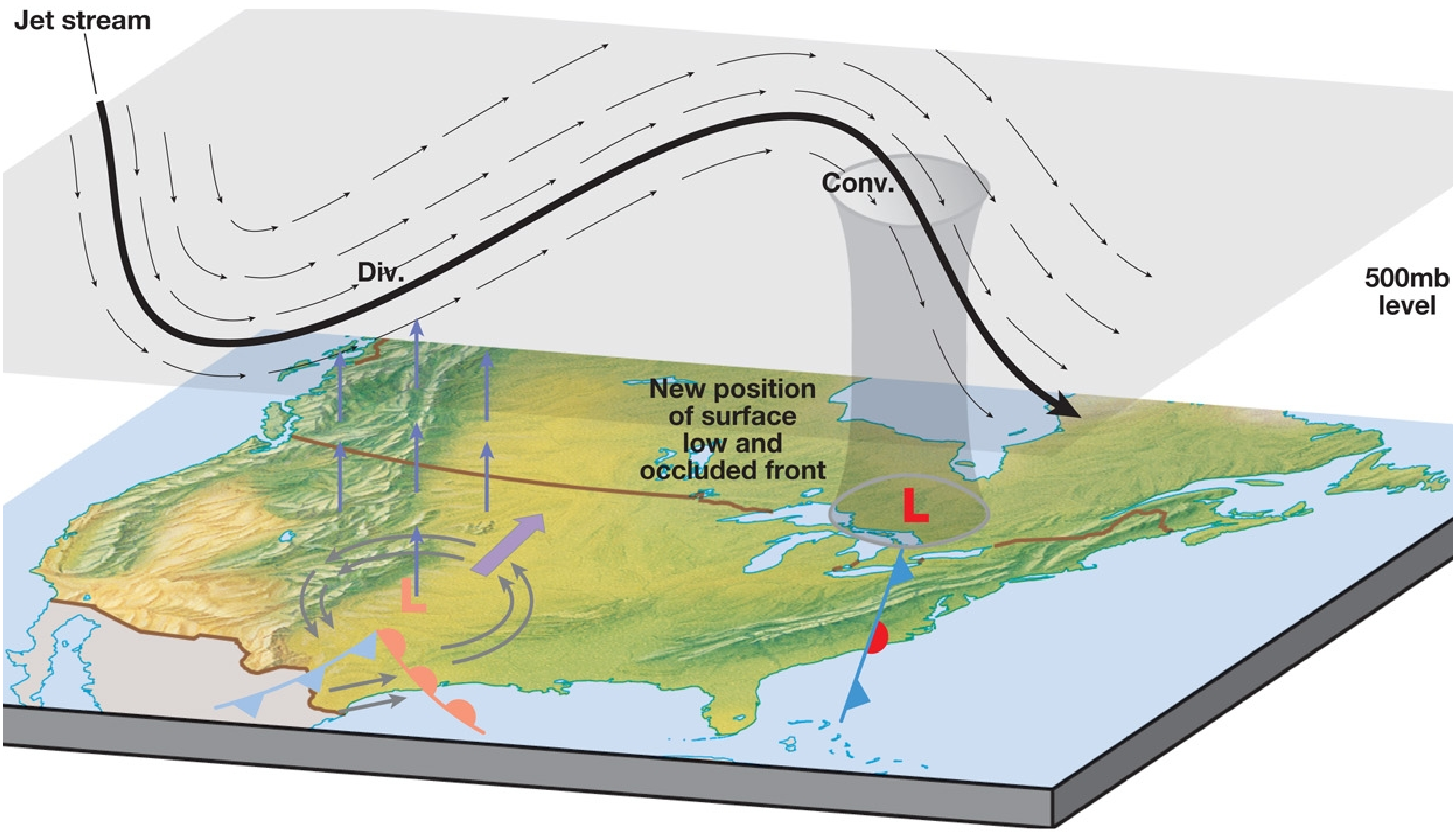
Hydrostatic law (first part of the equation); density eliminated using Ideal Gas Law (second part)

Fig. 10-10



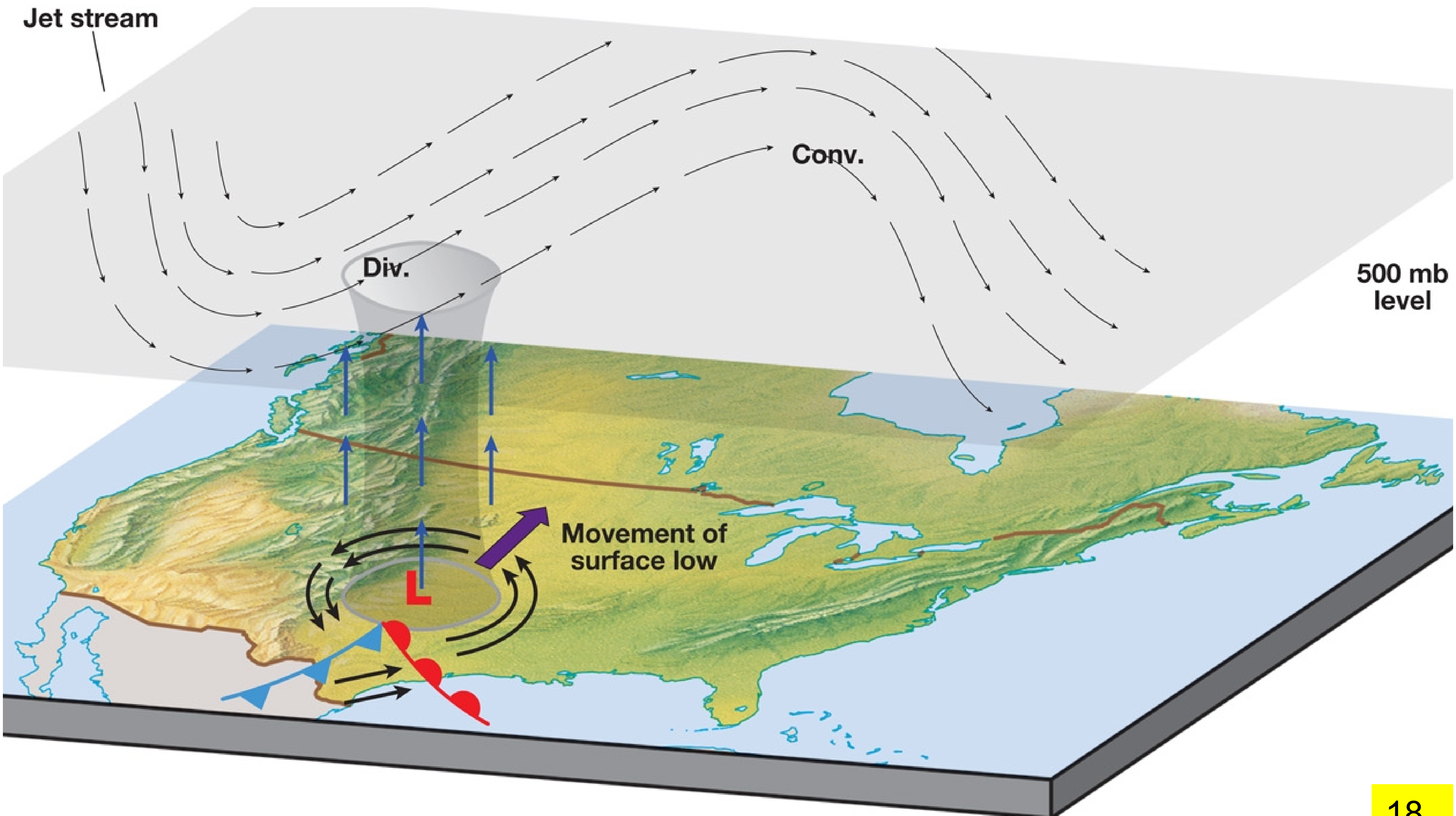
"The usual juxtaposition of surface cold fronts and upper level troughs" (p309)

But here storm's motion has taken it away from the zone of upper divergence and now upper convergence will tend to weaken it



(This is idealized, in that the upper flow pattern has been assumed unchanging)

Here a mature cyclone is well supported by upper divergence, and moving approximately in the direction of the upper stream ("surface systems move in about the same direction as the 500 hPa flow, at about one-half the speed" p318)



Weather in relation to pattern of upper winds

• upper patterns often persist, sometimes for longer than weeks, and in that case are associated with distinct anomalies (eg. a persistent drought)

• a zonal flow over a wide region lessens the likelihood of storm development and is indicative of relatively uniform temperature

• conversely, highly meridional flow reflects the existence of temperature non-uniformity and implies favourable circumstances for storms

• upper flow influences storm motion: storms tend to move along the direction of the 500 hPa flow, but at about half the speed

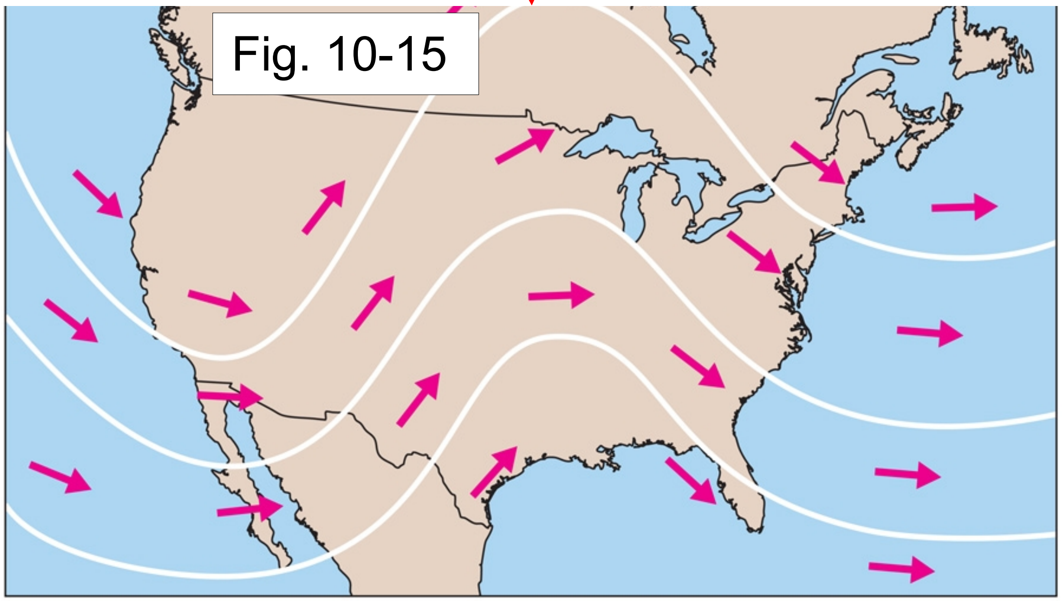
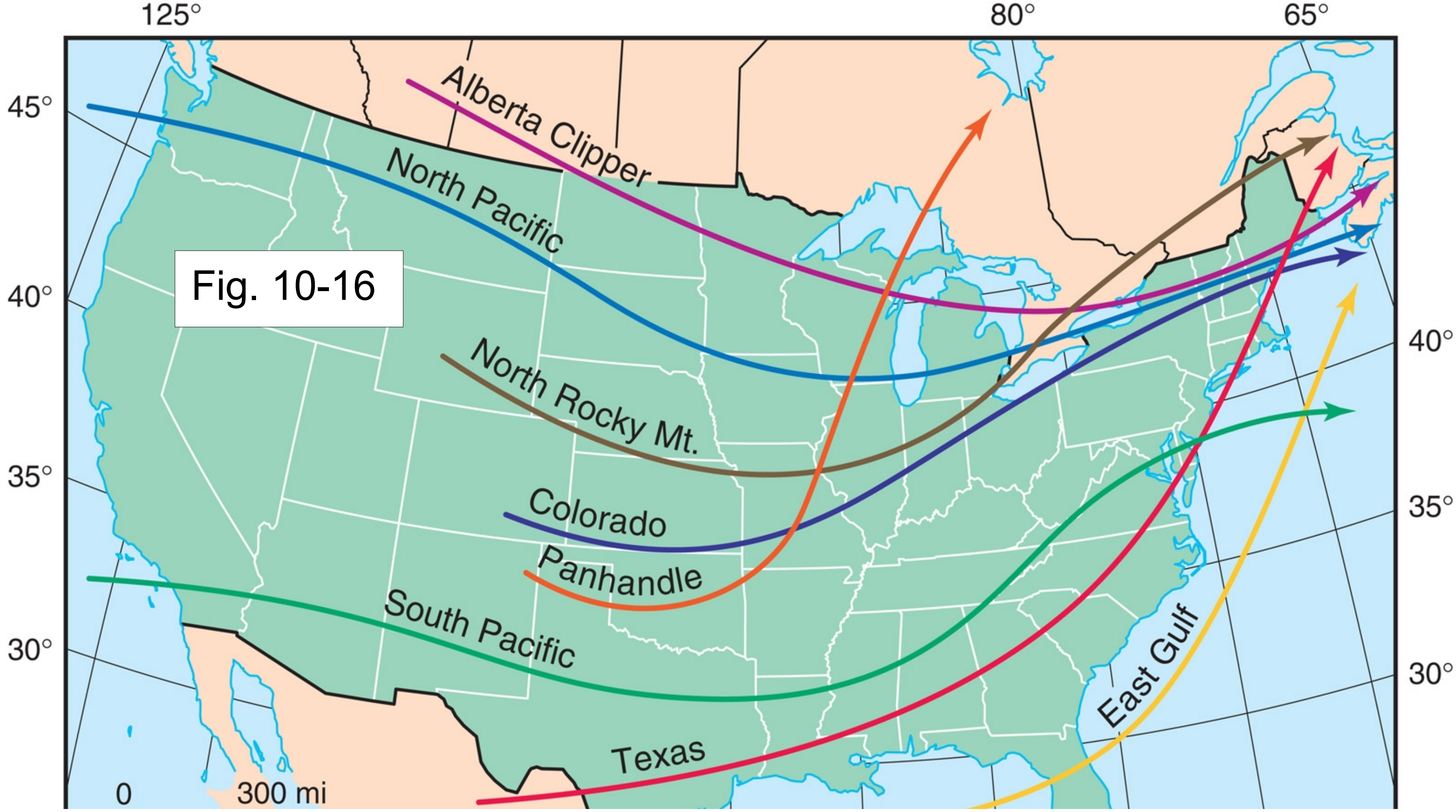


Fig. 10-15

Storm paths and the Alberta Clipper

• two paths (of winter storms) across North America are "particularly common." Corresponding storms the Alberta Clipper and Colorado Low

• Alberta Clipper associated with weakly non-zonal flow across the continent and a cold front separating cold Cdn air mass from milder air in U.S.



The Alberta Clippers "generally move SE from the lee of the Cdn Rockies toward or just north of Lk. Superior… with less than 10% of cases tracking S. of the Great Lakes"

"A Synoptic-Climatology and Composite Analysis of the Alberta Clipper", Thomas & Martin, 2007: *Weather & Forecasting*, Vol. 22 , 315-333

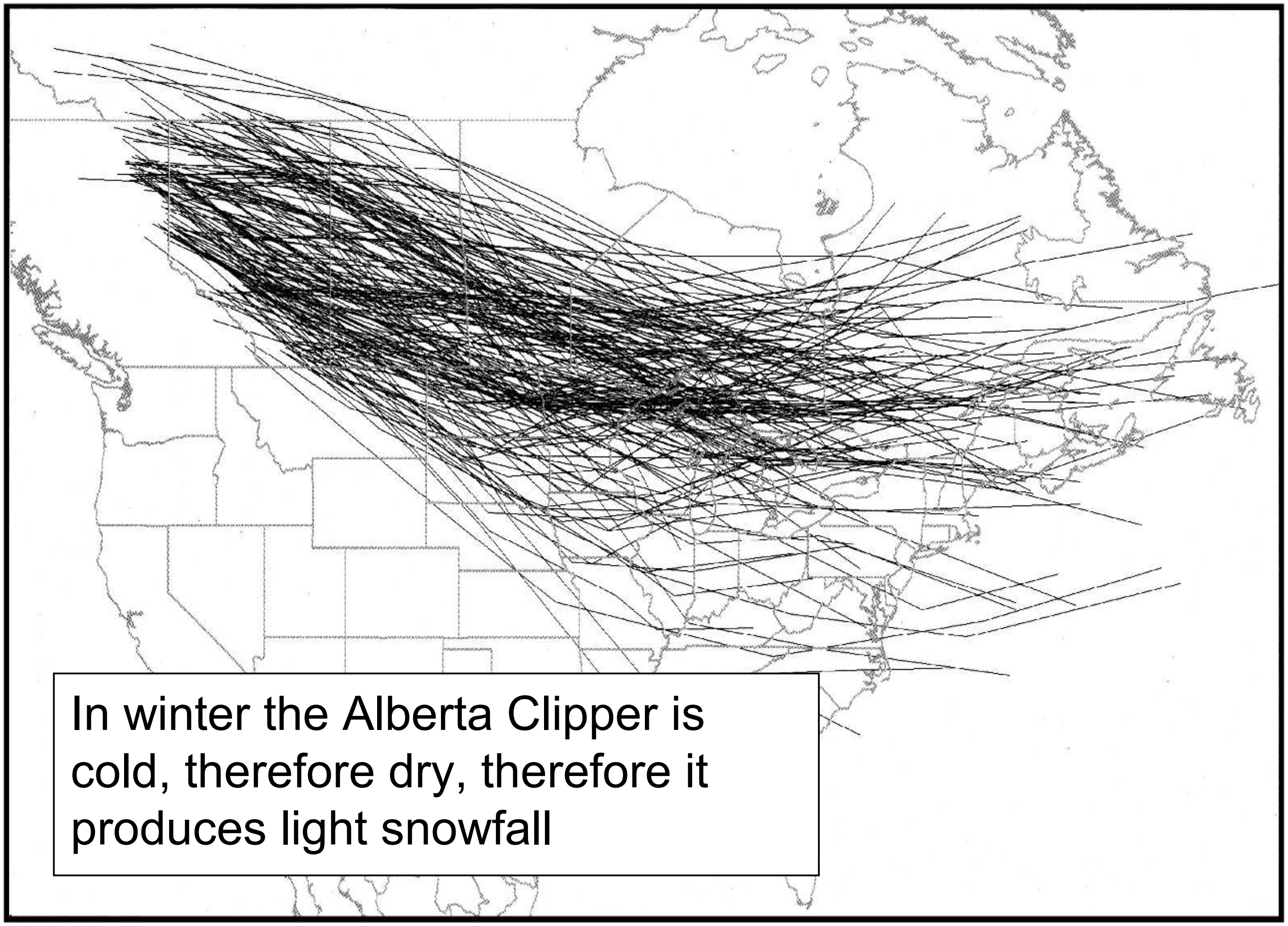


FIG. 1. Storm tracks of all Alberta clippers in the climatology out to 60 h after departure.

Summary:

• upper waves play a role in initiating and maintaining or deepening the surface storm

• this role being exerted via the locations of the divergence & convergence zones aloft

• "divergence in the upper atmosphere, caused by decreasing vorticity, draws air upward from the surface and provides a lifting mechanism for the intervening column of air. This, in turn, can initiate and maintain low pressure systems at the surface" (p306)

• but conversely surface conditions, esp. the temperature distribution, exert an influence on the pressure pattern aloft (which as we know, defines the pattern of flow aloft, thus, the waves) – by controlling the pressure lapse rate