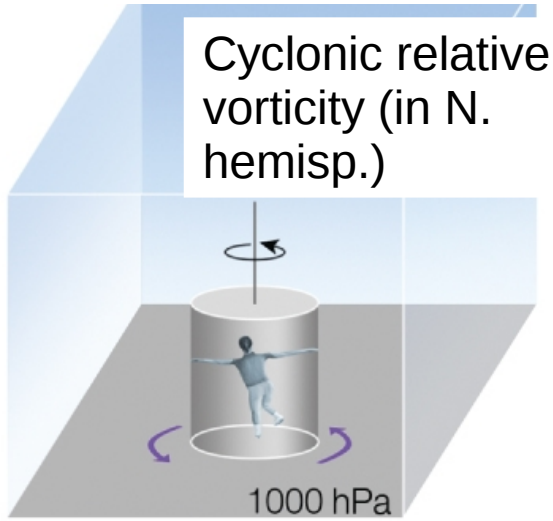
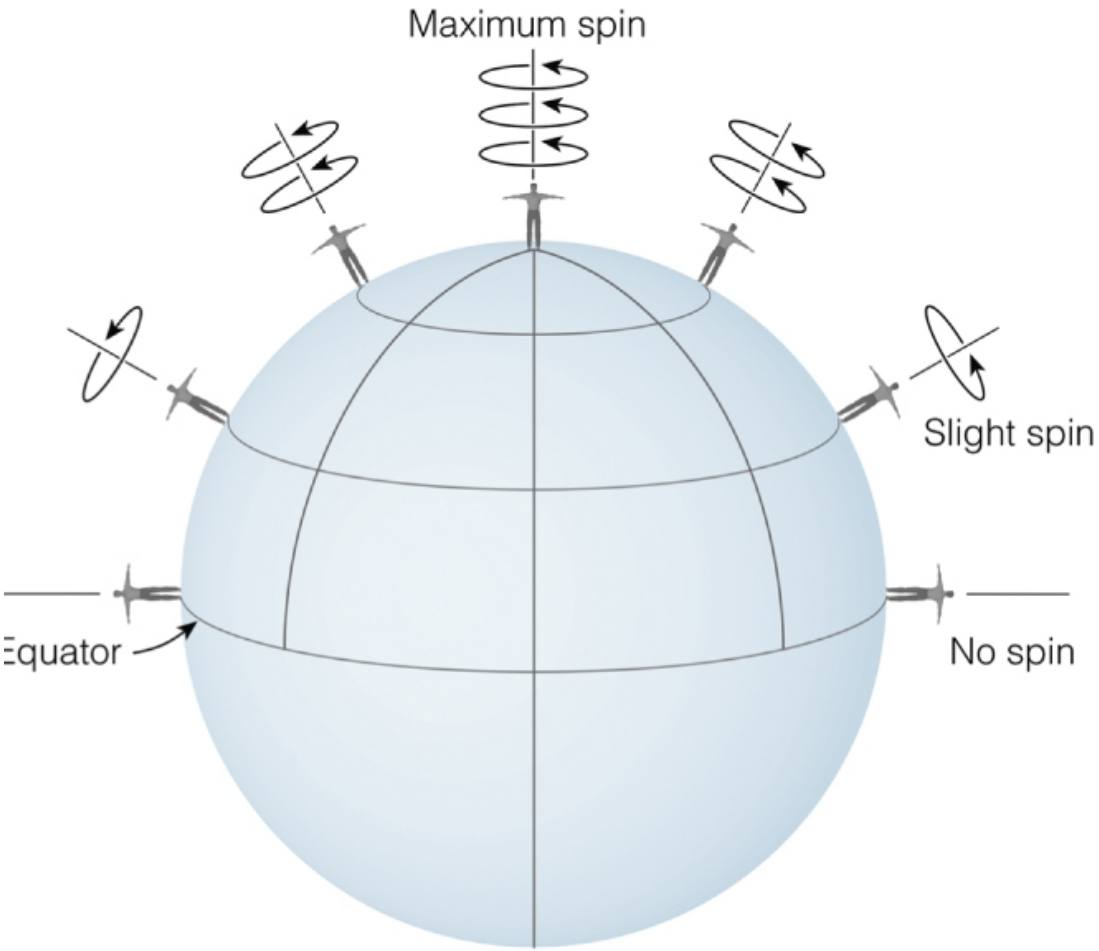
- **vorticity**: rotation of an air parcel about a given axis (our interest is rotation about the local vertical). Units [s^{-1}]

- two contributions add to give the "absolute vorticity"





1. Earth vorticity – the spin a parcel has, even if it is stationary relative to axes fixed to earth, due to rotation of earth. Given by f_c, (the Coriolis parameter), i.e.

$$f_c = 2\Omega \sin\phi$$

$$\text{where } \Omega = \frac{2\pi}{24 \times 3600} \quad (\phi,\ \text{latitude})$$

2. Relative vorticity – rotation relative to axes fixed on earth; positive for counterclockwise (ie. cyclonic) rotation in N. hemisphere

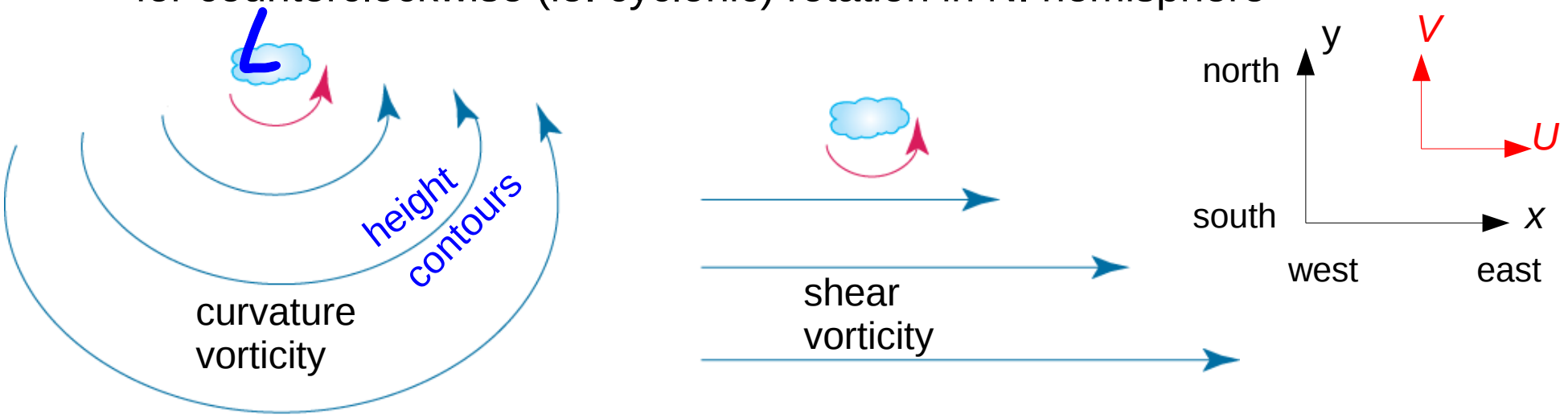


Figure 12.29

Using the Cartesian coordinate system and terminology, the component of relative vorticity along the local vertical is:

$$\zeta_r = \frac{\Delta V}{\Delta x} - \frac{\Delta U}{\Delta y}$$

An equally important property is the horizontal divergence

$$D = \frac{\Delta U}{\Delta x} + \frac{\Delta V}{\Delta y}$$

Absolute vorticity $\zeta_a = f_c + \zeta_r$ (normally positive at mid & high latitudes where f_c is large)

(Simplified) vorticity conservation equation: $\frac{1}{(f_c + \zeta_r)} \frac{\Delta(f_c + \zeta_r)}{\Delta t} = -D$

where $\frac{\Delta}{\Delta t}$ is the time rate of change following a parcel

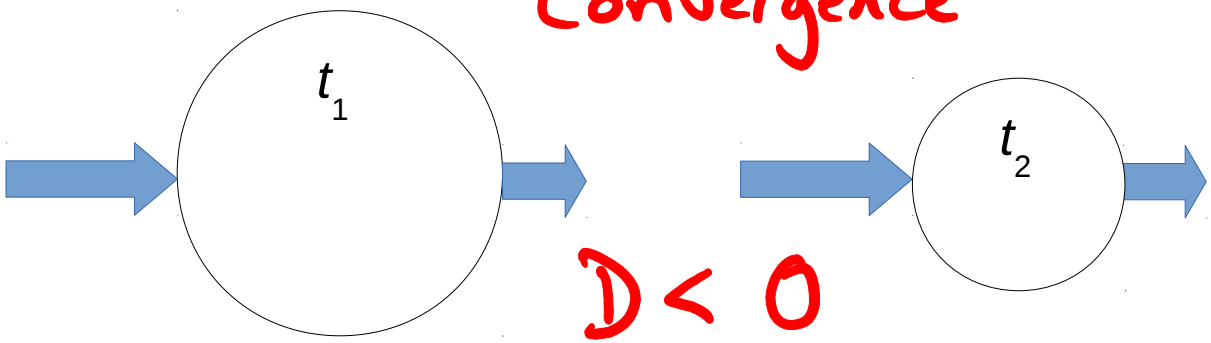
Divergence: D > 0 implies

Convergence: D < 0

} illustrated in 1-dimension

Suppose air is initially moving without relative vorticity, but convergence occurs (D <0):

Convergence



D < 0

Associate regions of convergence with increasing relative vorticity

Shrinkage of areas of the horizontal (or isobaric) plane.

$f_c + \zeta_r$ is increasing

If the motion were zonal, then f_c = const., so ζ_r is increasing

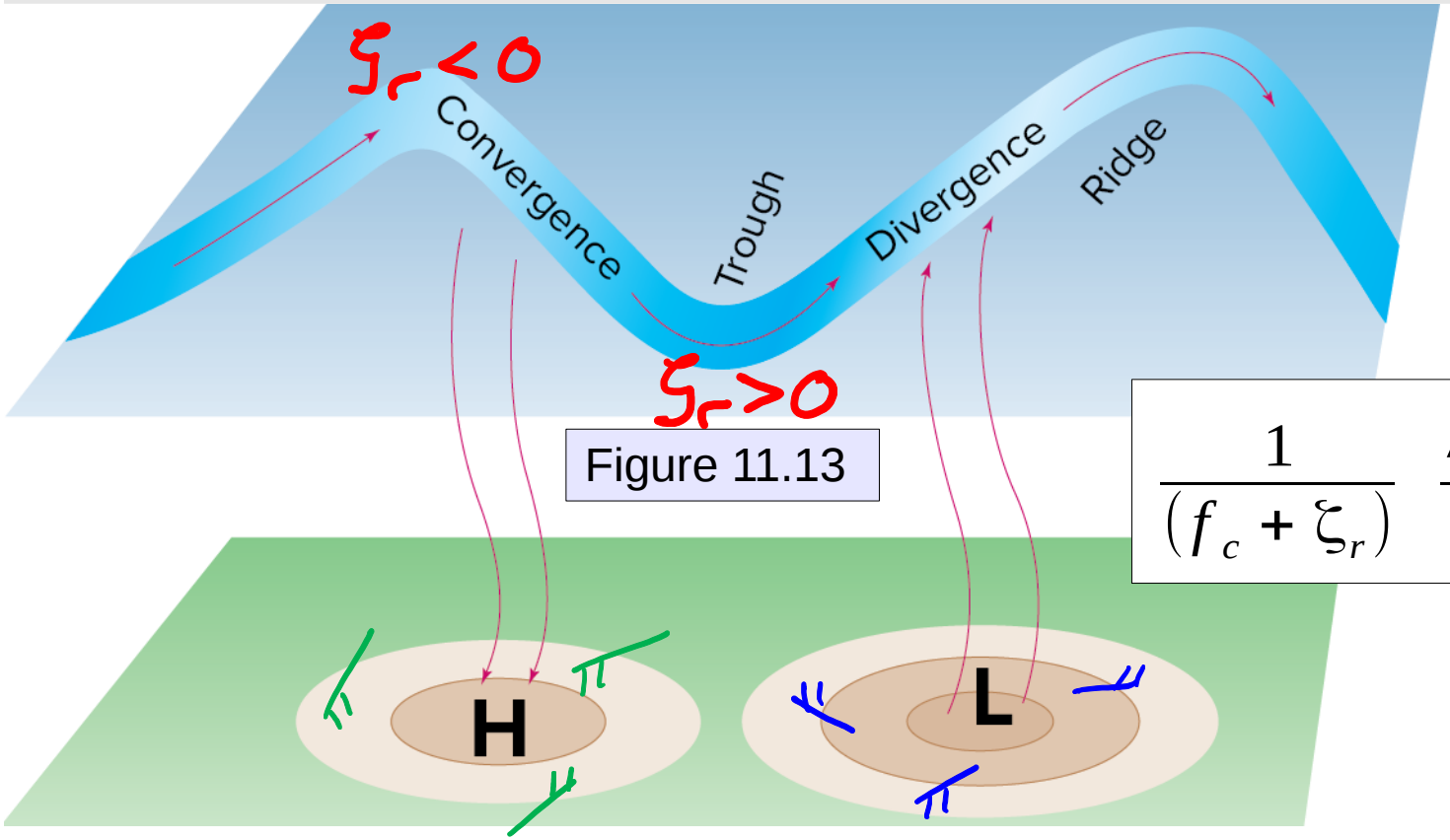


Figure 11.13

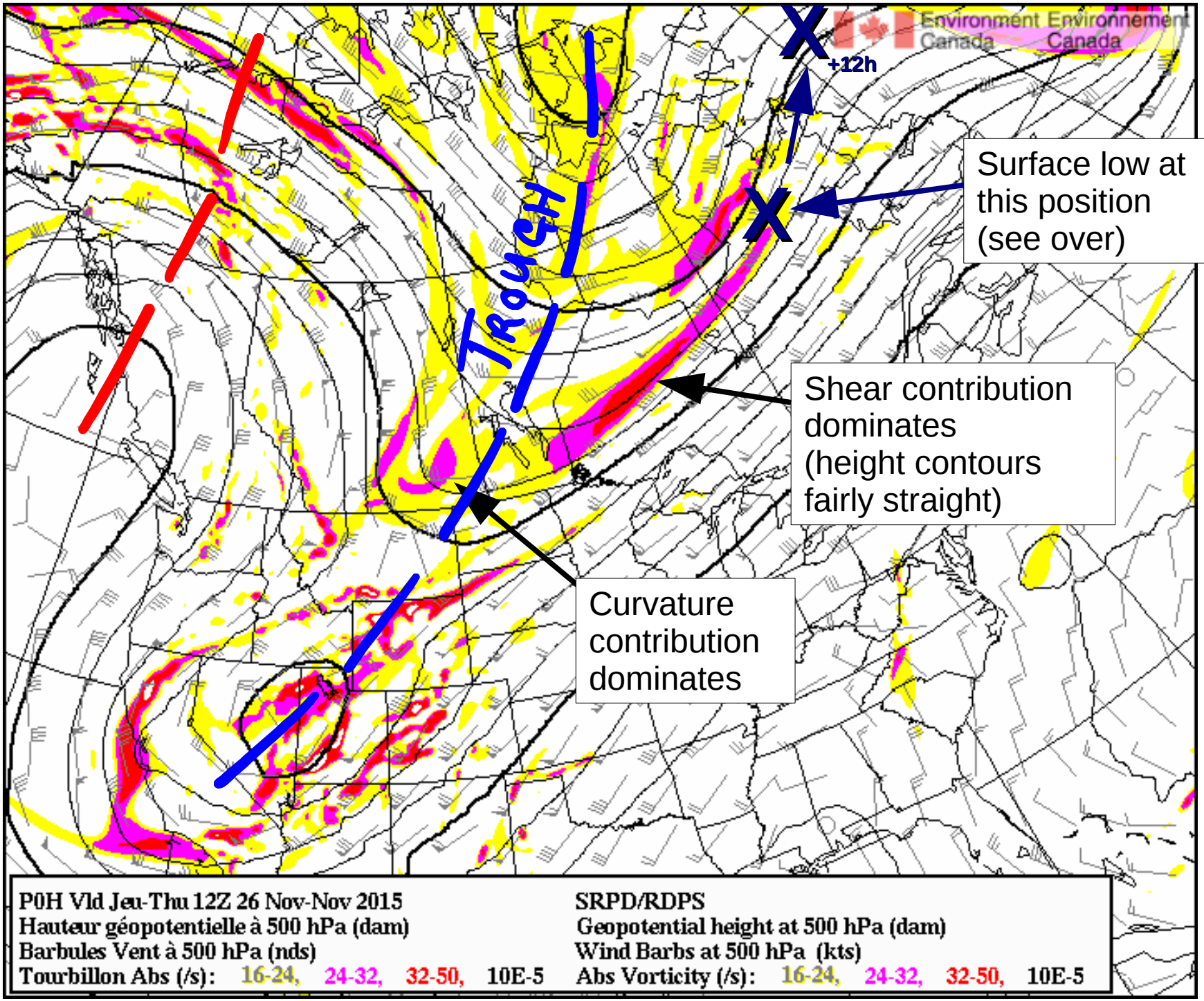
$$\frac{1}{(f_c + \zeta_r)} \frac{\Delta(f_c + \zeta_r)}{\Delta t} = -D$$

From trough to ridge, a parcel's relative vorticity decreases in time: cyclonic (positive) relative vorticity in the trough evolves to anticylonic (negative) relative vorticity in the ridge. (Here we neglect changes in earth vorticity)

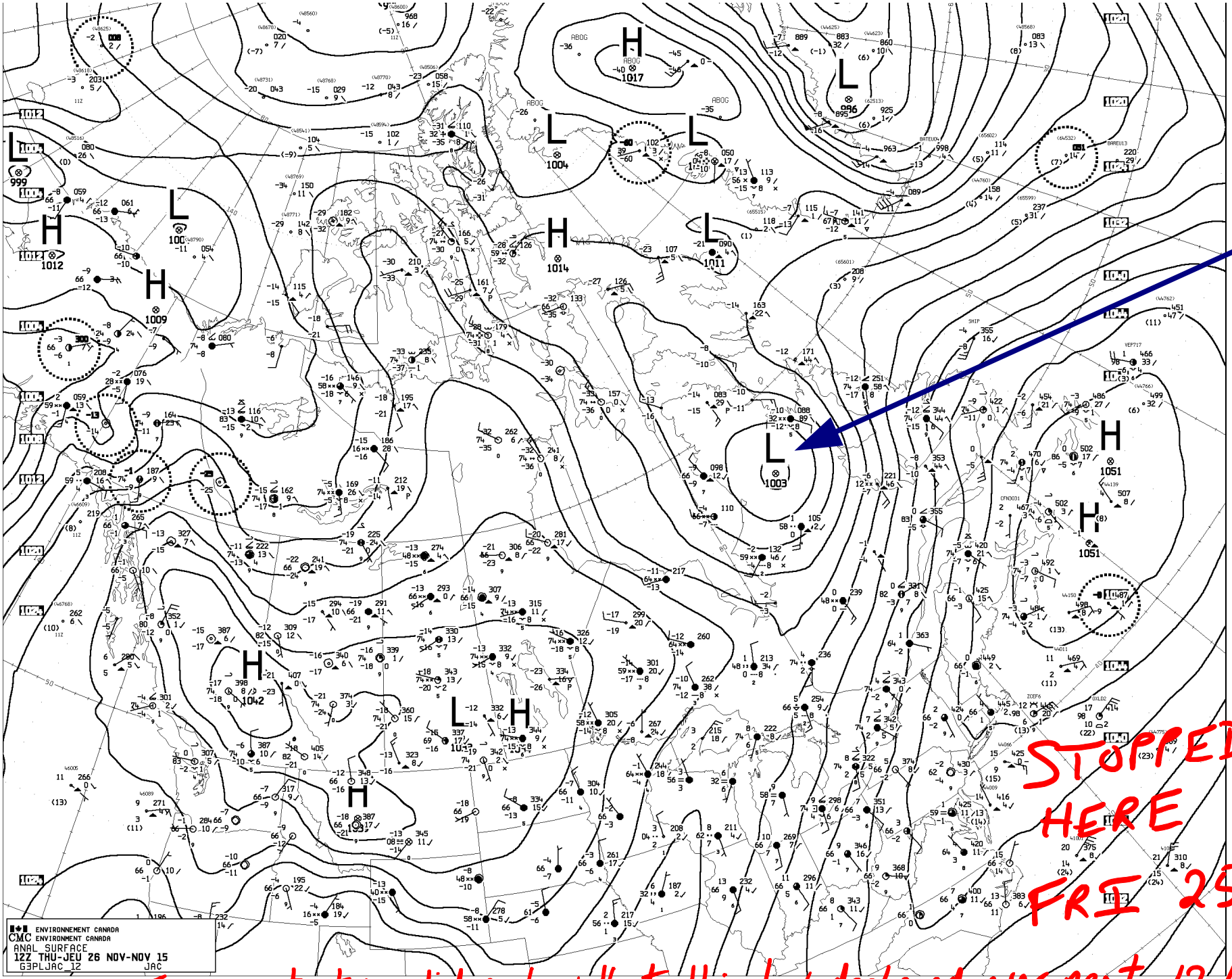
Moving from trough to ridge, $f_c + \zeta_r$ increases, so:

LHS < 0 RHS < 0 $\therefore D > 0$

therefore



Absolute vorticity colour coded

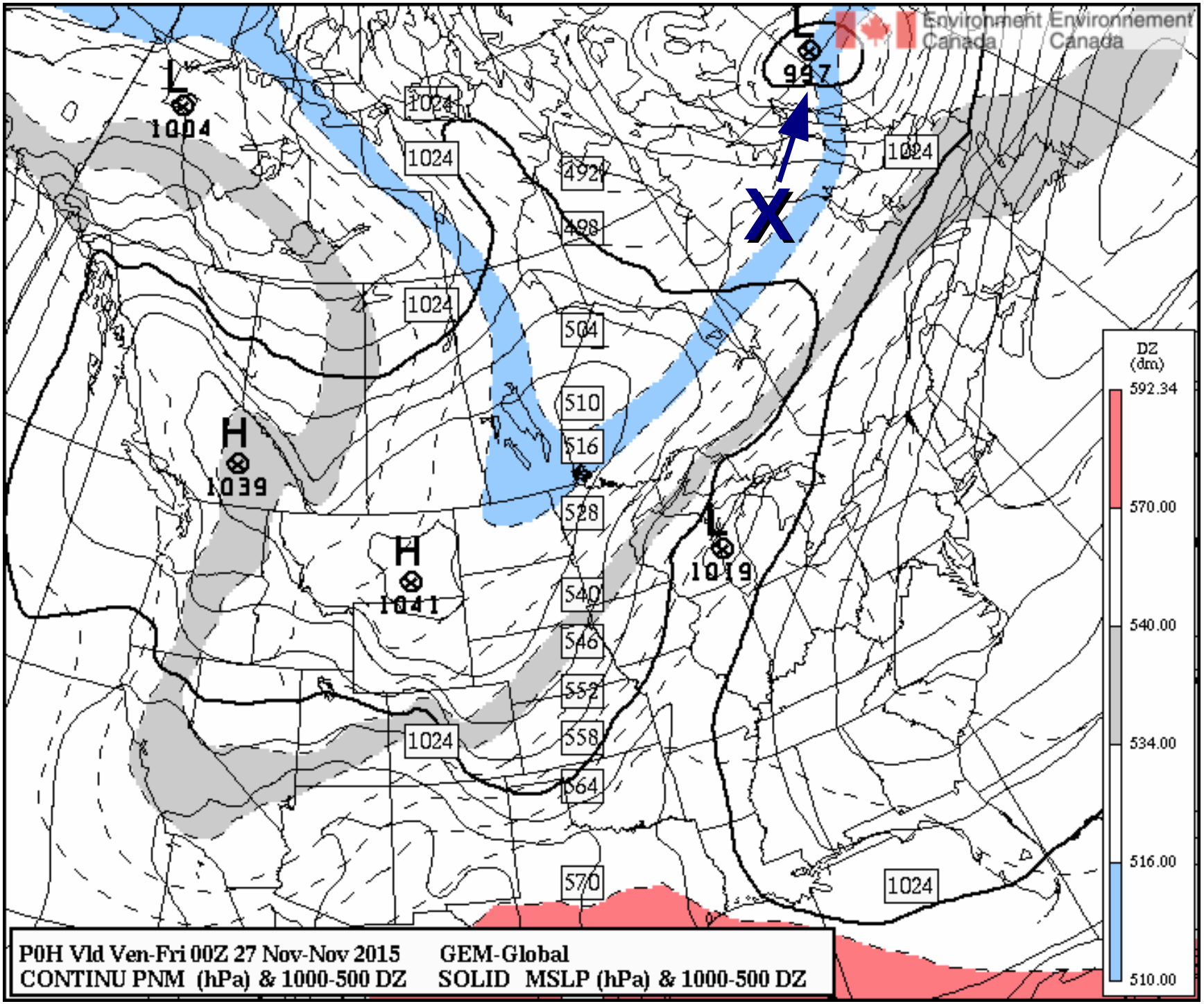


This sfc low lies under exit region of upper trough

STOPPED HERE FRI 25 NOV

The next two slides show that this low deepened over next 12/24 hrs.

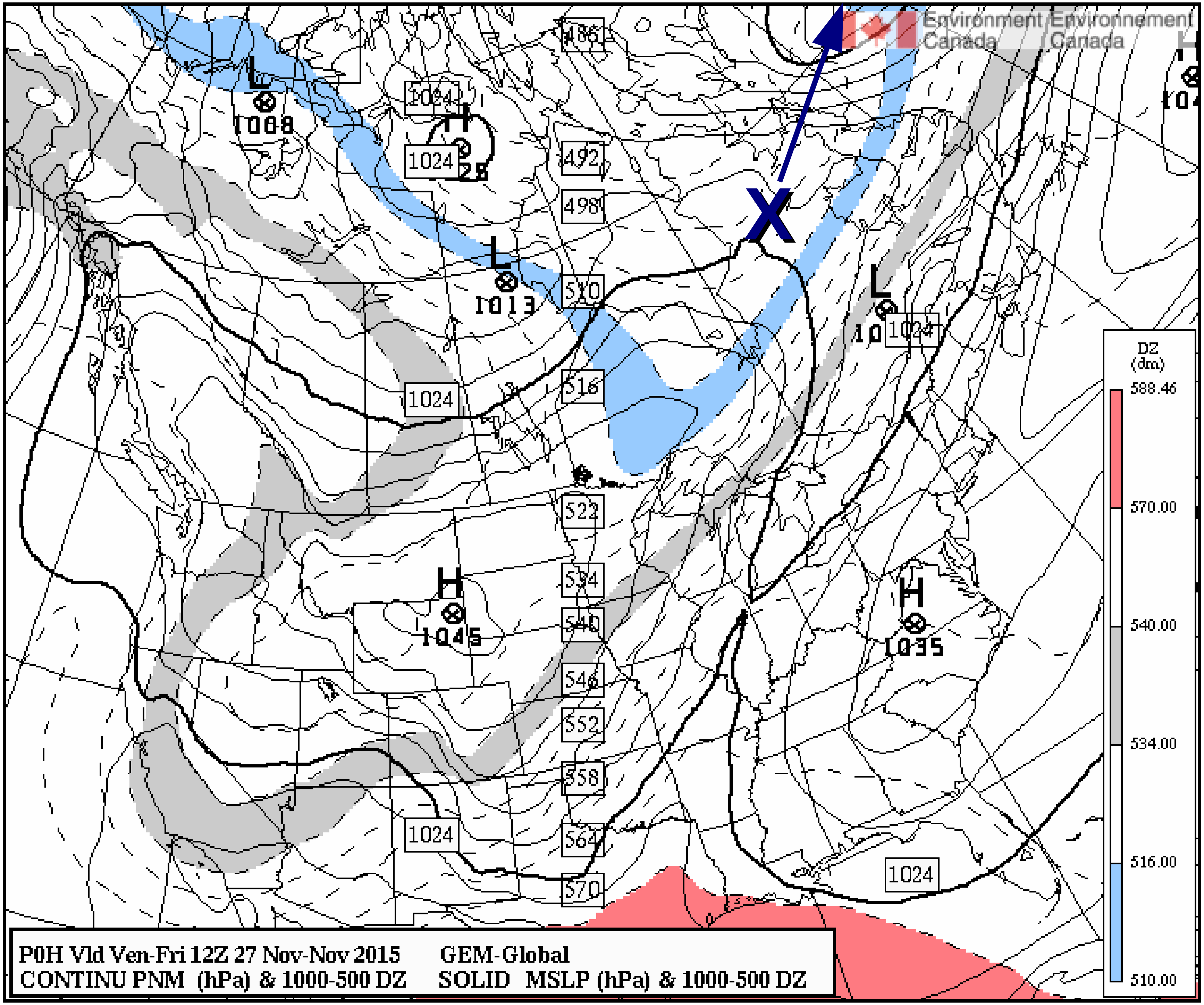
Ch 12. A surface low that lies beneath an upper trough exit region has "upper support" 6a/17



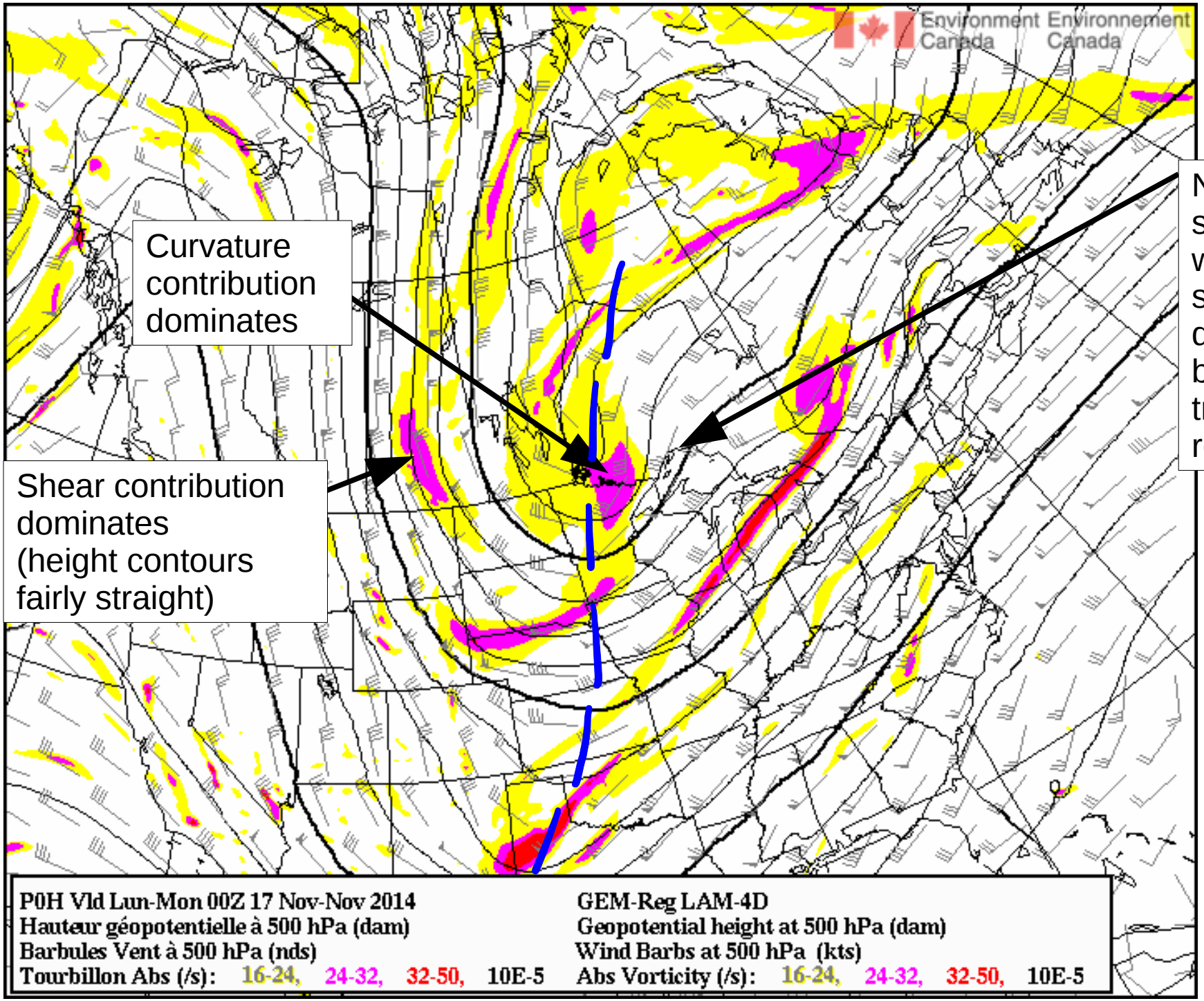
Over 12 h the low has deepened from 1003 to 997 hPa

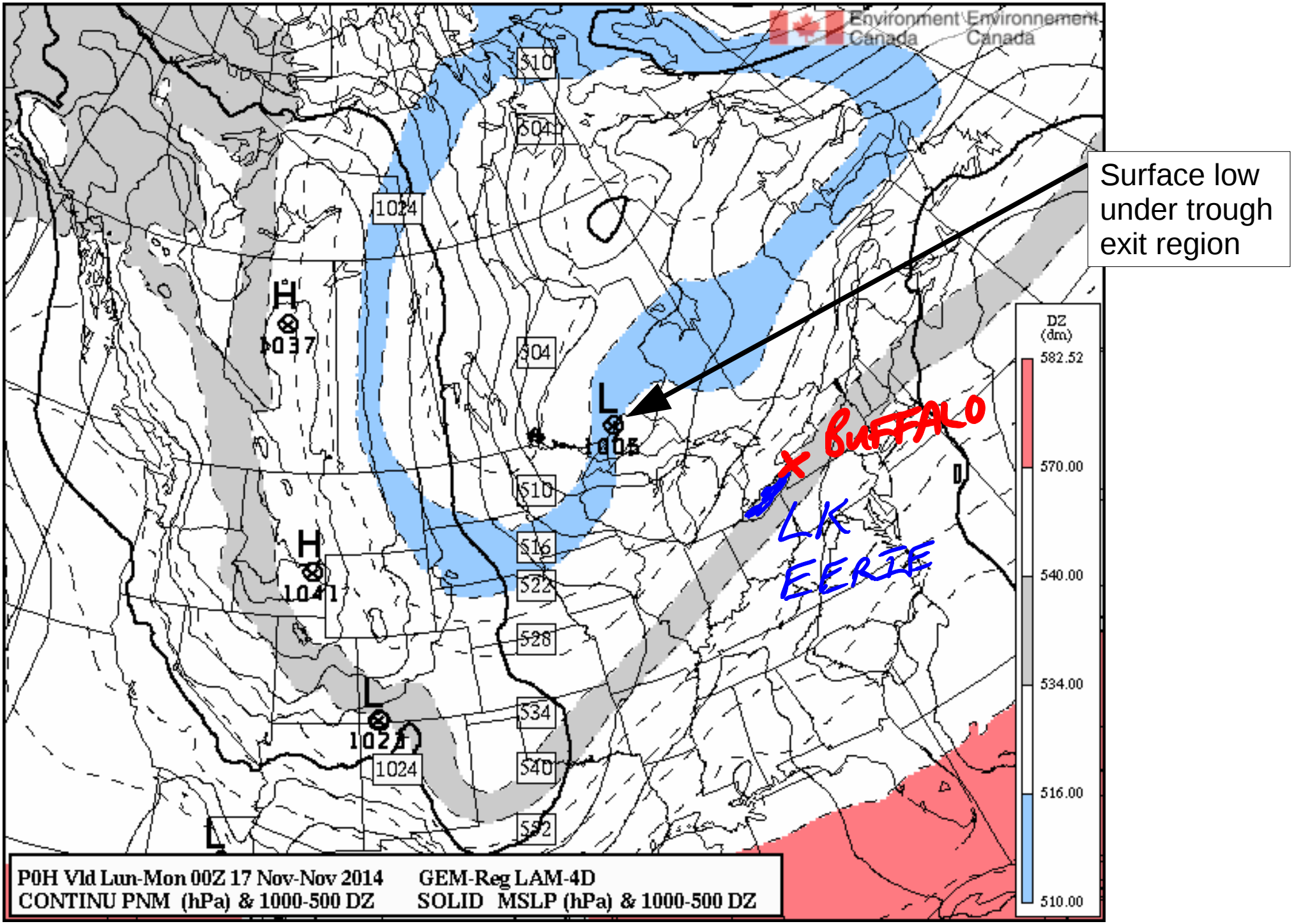
X marks the position of the surface low as of 12Z on 26 Nov

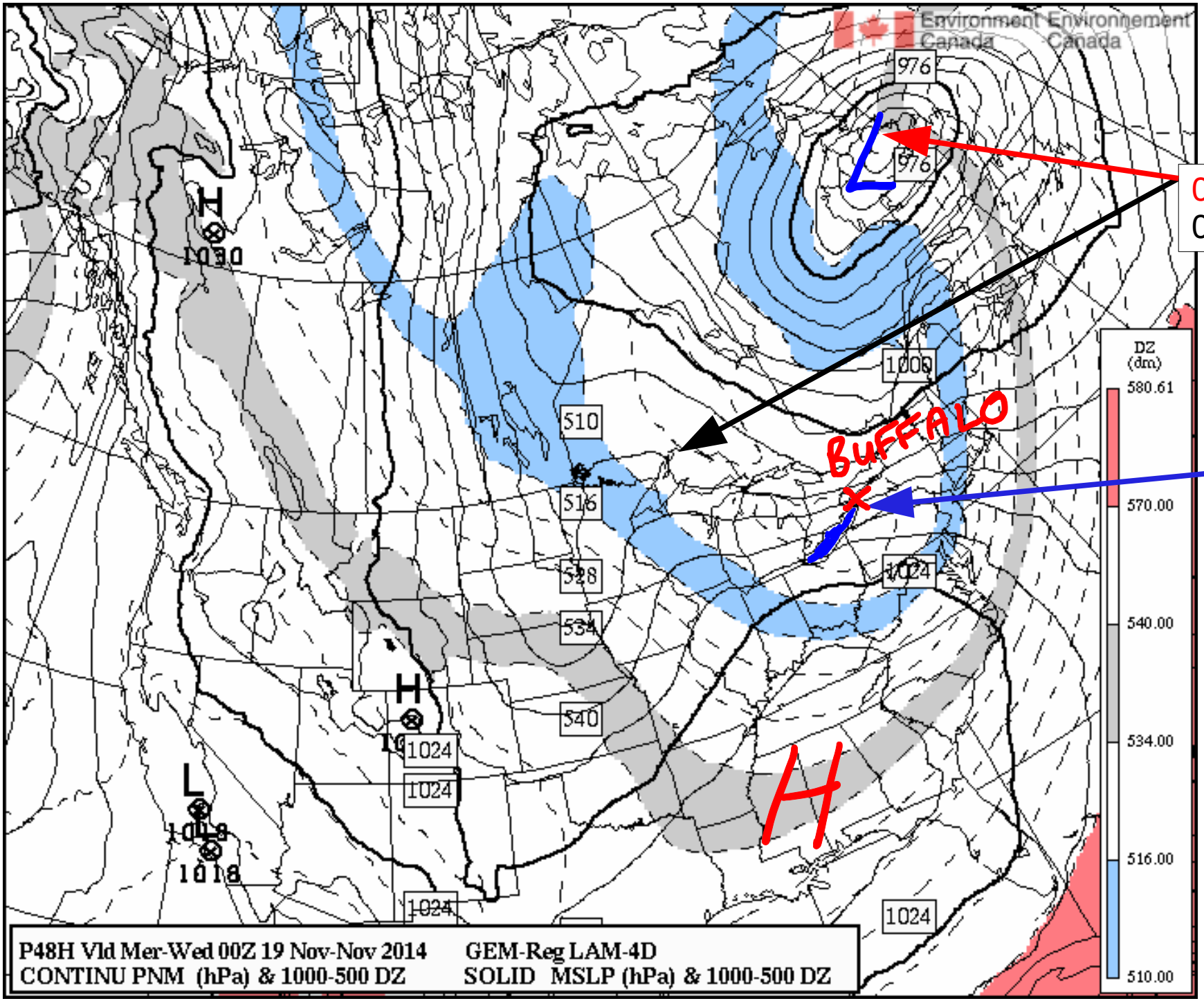
Ch 12. A surface low that lies beneath an upper trough exit region has "upper support" 6b/17



Over 24 h the low has deepened from 1003 to 983 hPa


Environment Canada
Environnement Canada
Curvature contribution dominates
Shear contribution dominates (height contours fairly straight)
Next page shows there was a surface low directly below the trough exit region
Absolute vorticity colour coded
P0H Vld Lun-Mon 00Z 17 Nov-Nov 2014
Hauteur géopotentielle à 500 hPa (dam)
Barbules Vent à 500 hPa (nds)
Tourbillon Abs (/s): 16-24, 24-32, 32-50, 10E-5
GEM-Reg LAM-4D
Geopotential height at 500 hPa (dam)
Wind Barbs at 500 hPa (kts)
Abs Vorticity (/s): 16-24, 24-32, 32-50, 10E-5

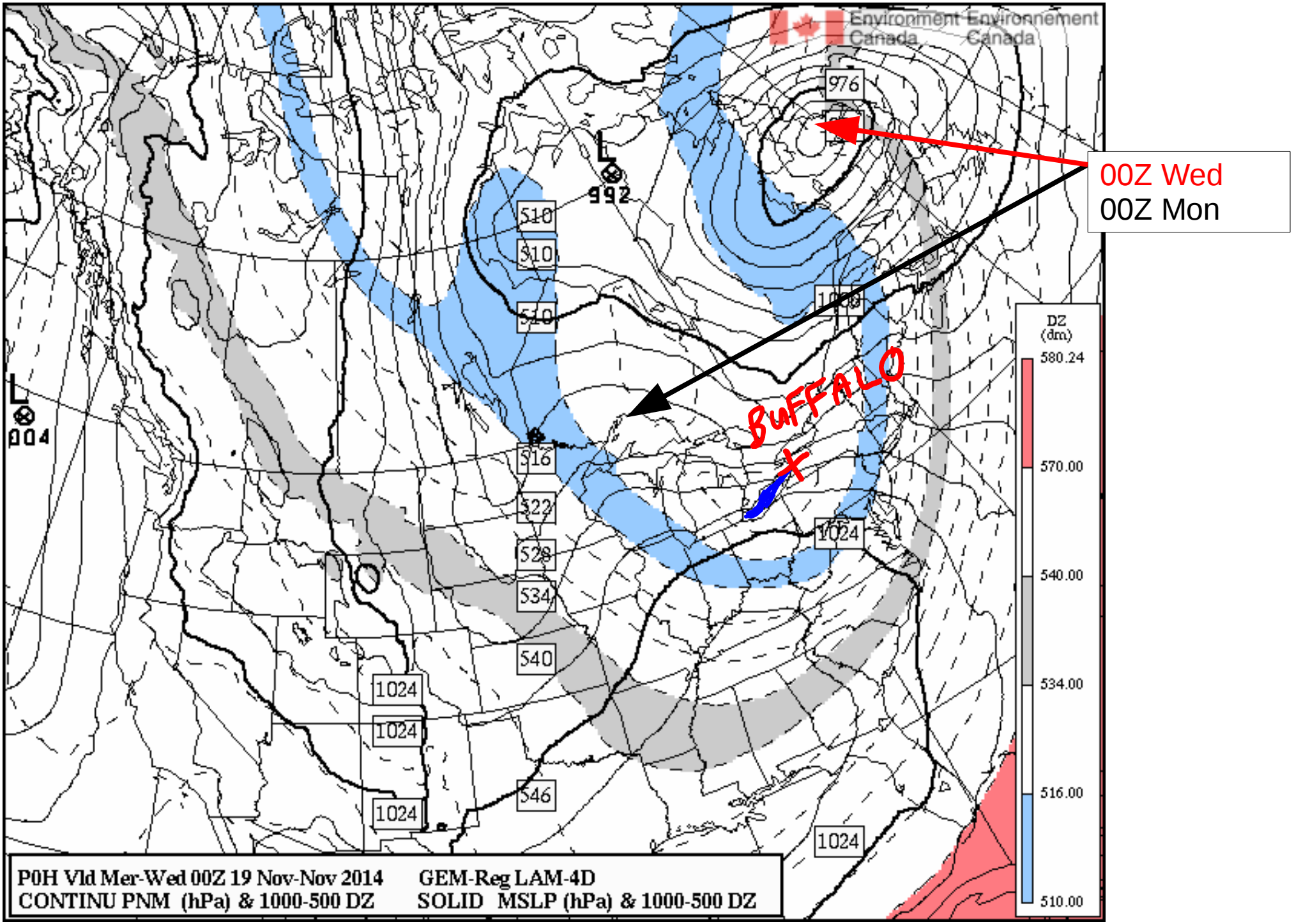

Environment Canada
Environnement Canada
Surface low under trough exit region
BUFFALO
LK ERIE
DZ (dm)
582.52
570.00
540.00
534.00
516.00
510.00
1024
1037
1041
1021
1005
510
504
304
516
522
528
534
540
552
P0H Vld Lun-Mon 00Z 17 Nov-Nov 2014 GEM-Reg LAM-4D
CONTINU PNM (hPa) & 1000-500 DZ SOLID MSLP (hPa) & 1000-500 DZ



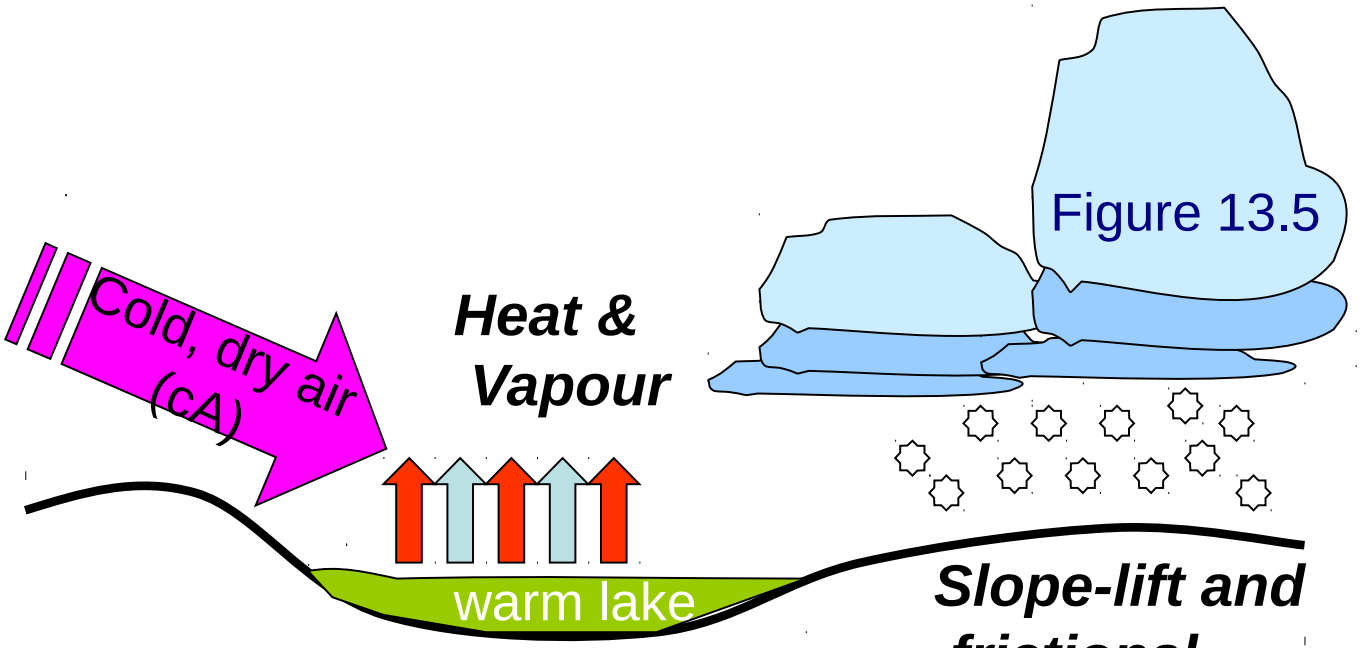
00Z Wed
00Z Mon

Note: strong [redacted] flow of cold air over Lk. Eerie, which resulted in lake effect snowfall

Ch 12. Incipient surface low supported by upper divergence – **verification of 48h prog** 10/17

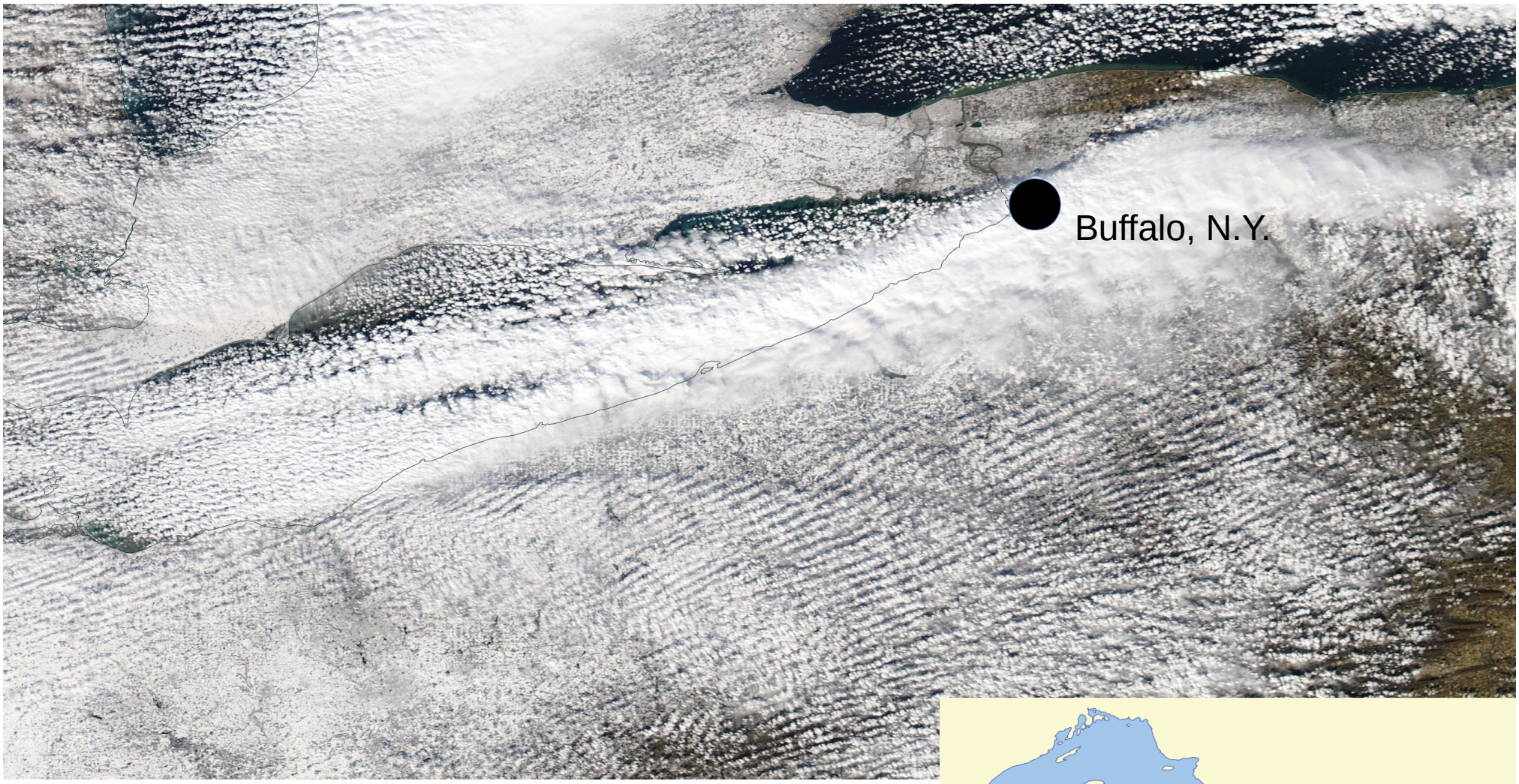


Depew, N.Y.



"Totally Insane! Buffalo Suburbs May Have Set a Record for 24-Hour Snowfall in a Populated Area" By Tom Yulsman | November 19, 2014 2:03 am

"The national record for snowfall in a 24-hour period is 76 inches, up in the mountains of Colorado. Some suburbs of Buffalo approached that amount on Tuesday – "possibly the highest 24hr snow in a populated area," the National Weather Service Tweeted late Tuesday night." (http://blogs.discovermagazine.com/)

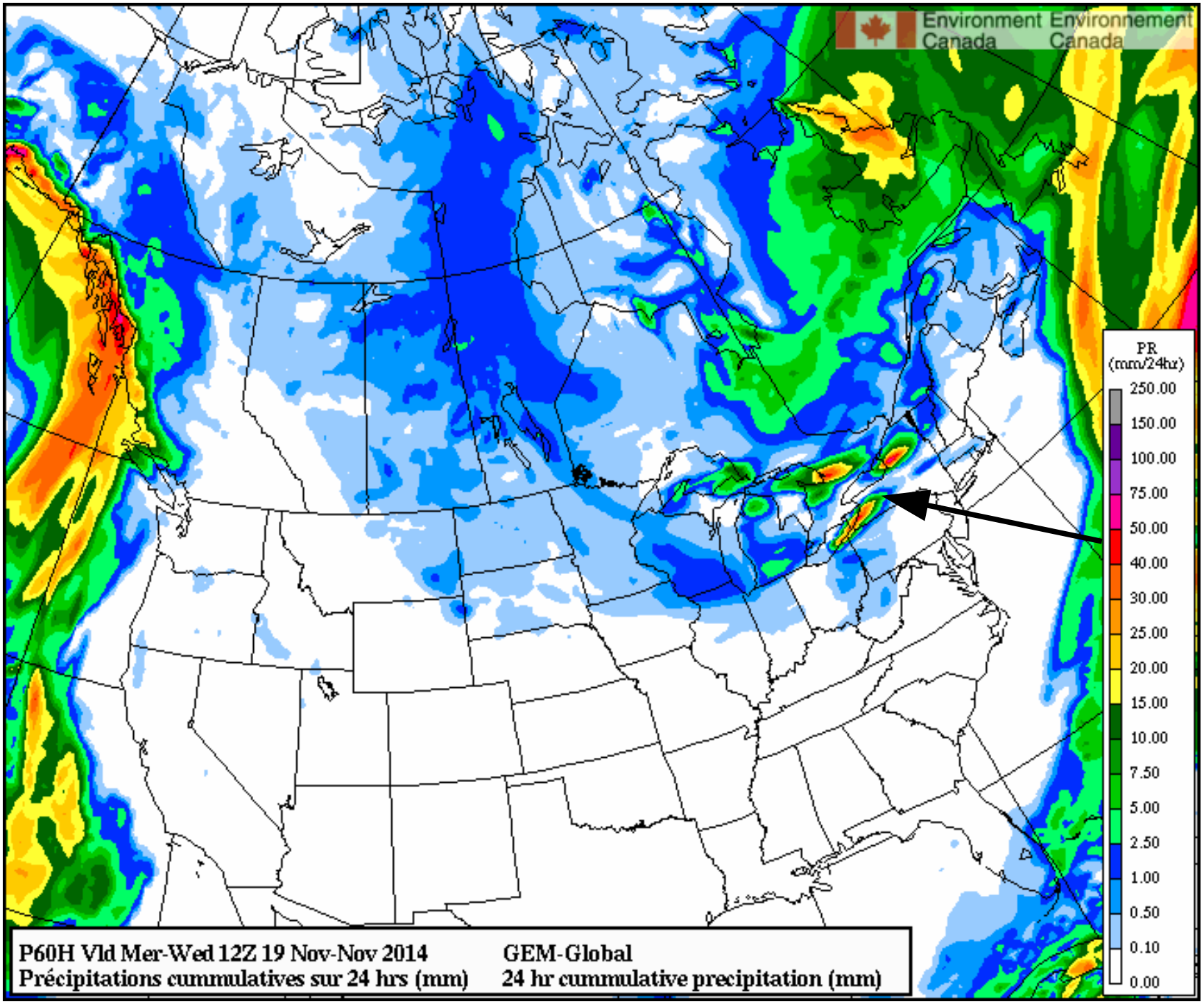


Cloud streets – roughly aligned with the wind direction

Thus the wind traveled over a long "fetch" of the warm lake surface before reaching the downstream shore, and Buffalo

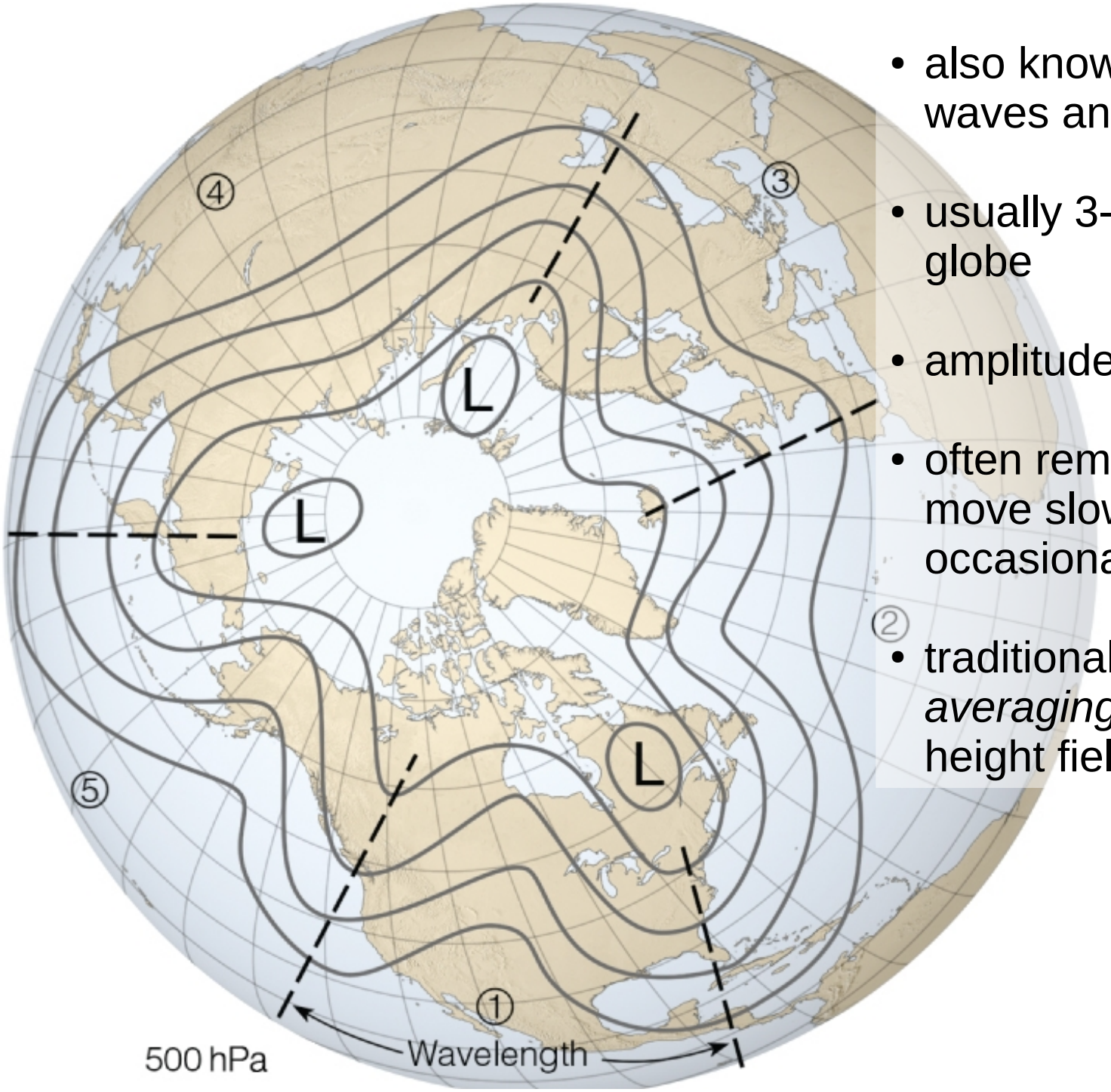
Global Environmental Multiscale (Canada's NWP model)

Ch 12. Did GEM foresee the NY lake effect snow? Yes, days in advance

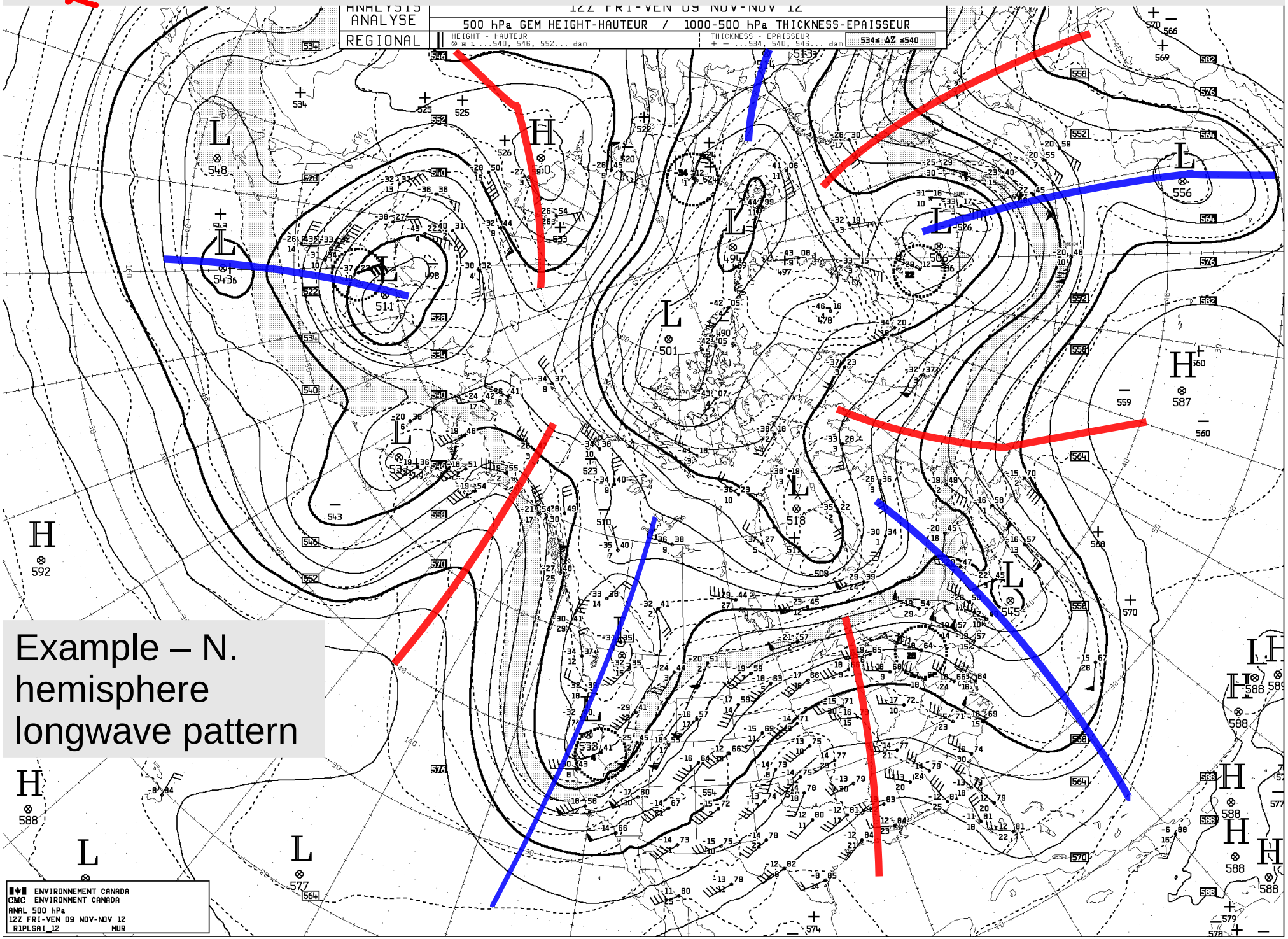


Numerical Weather Prediction

50 mm liquid water, approx. 50 cm snow



- also known as planetary waves and as long waves
- usually 3-7 waves around globe
- amplitudes vary
- often remain stationary or move slowly eastward – occasionally move westward
- traditionally defined by *averaging* the 500 hPa height field for several days

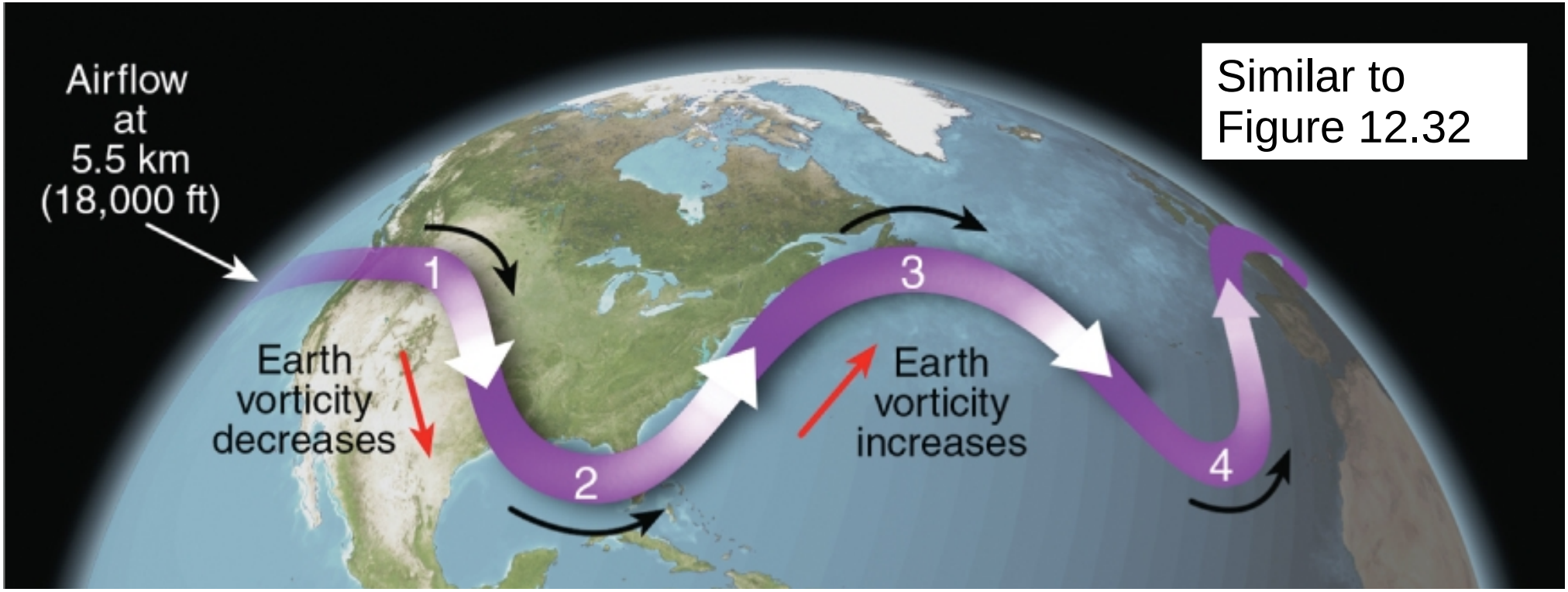


Example – N. hemisphere longwave pattern

Suppose that, *following the motion of a parcel*, the absolute vorticity was conserved:

Then $f_c + \zeta_r = \text{const.}$

This is definitely not *exactly* true (if so, it would contradict the earlier argument that divergence occurs in a trough exit region) – but it suggests we needn't be surprised about the waviness of the flow aloft



Topics/concepts covered

- contribution to relative vorticity by wind shear and curvature
- vorticity conservation equation and the link between vorticity changes and divergence
- vorticity patterns on the 500 hPa analysis
- the longwaves (Rossby waves)

plus

- demonstration of the impressive skill of modern Numerical Weather Prediction