EAS270_Ch11_Winds_A.odp
JDW, EAS U.Alberta, last mod. 18 Nov. 2016

We'll consider winds on several different scales

- synoptic scale
- meso- and (very briefly, micro-) scales
- planetary scale (Ch12, General Circulation)

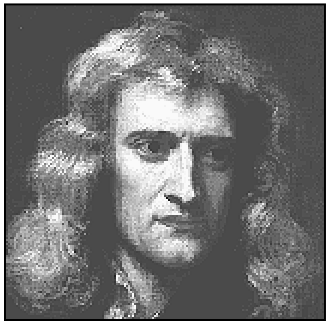
Almost all atmospheric flows (regardless of their scale) are "driven" by a pressure gradient**

The *cause* of the driving pressure gradient most often lies in a temperature gradient

**For flows aloft, equivalently a gradient in the isobaric height

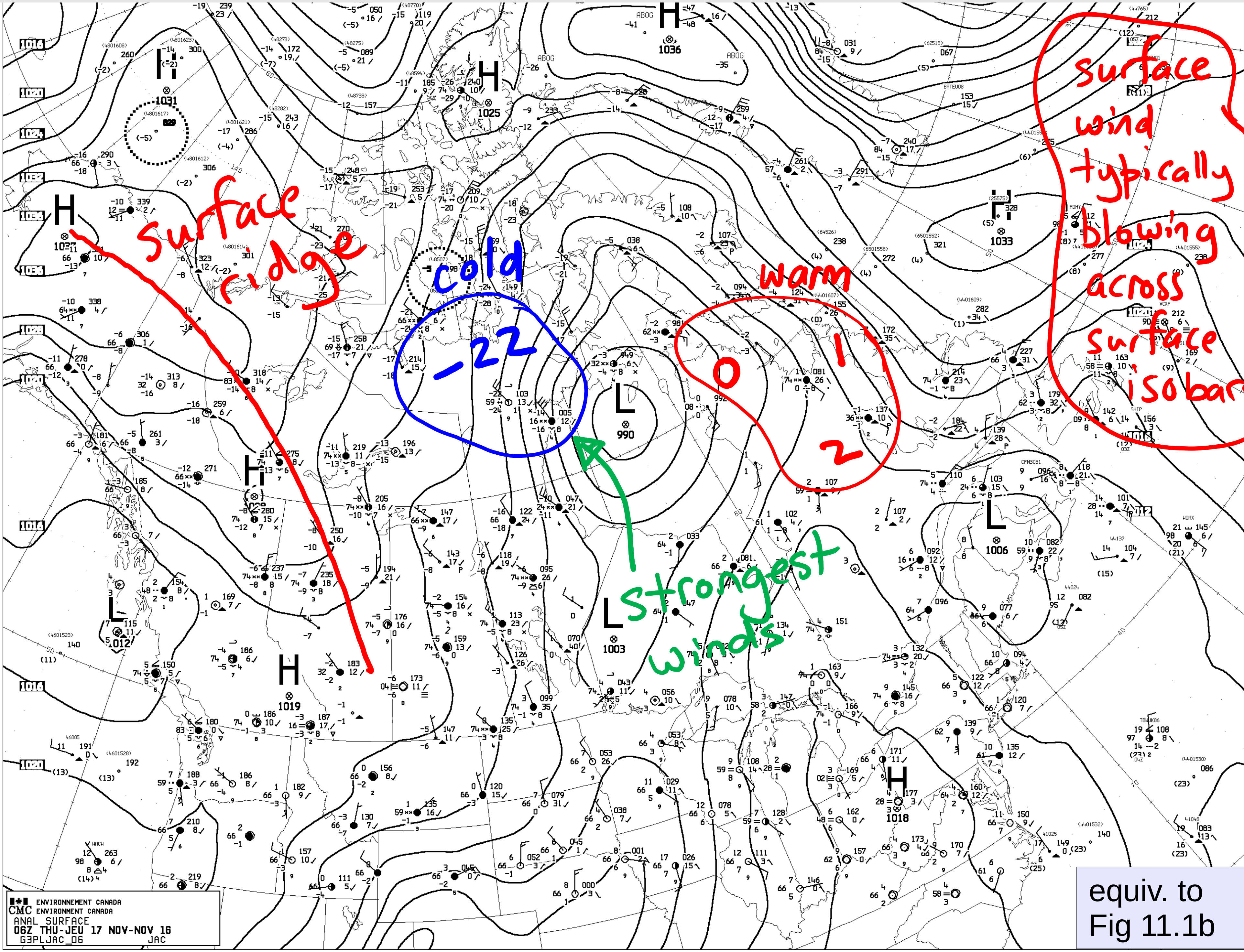
above the friction layer

"In general, upper-air winds flow parallel to height contours on upper-air maps, while surface winds tend to flow at an angle across the isobars on surface weather maps"



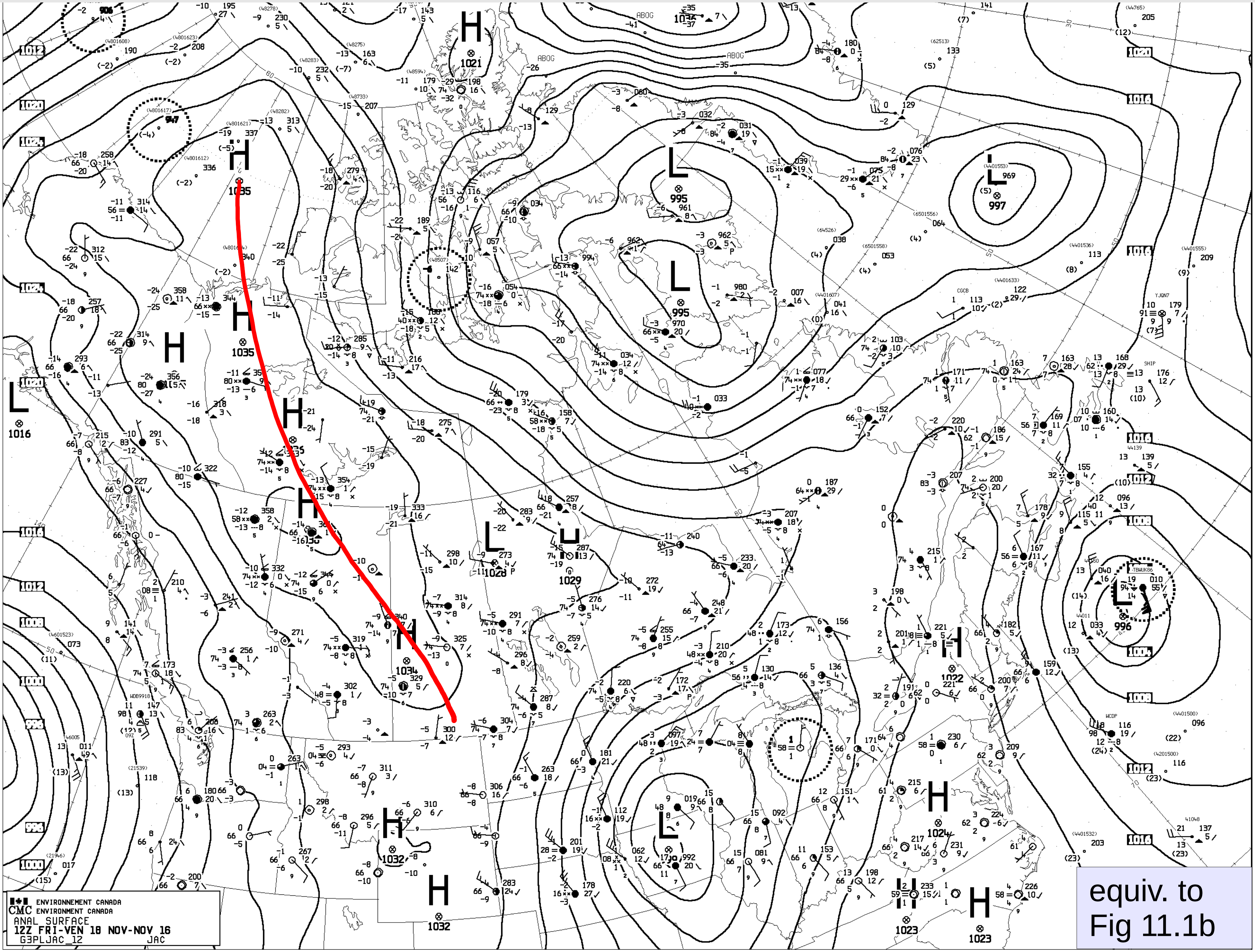
Sir Isaac Newton
1642 - 1727

CMC surface analysis 06Z Thursday 17 Nov. 2016



equiv. to
Fig 11.1b

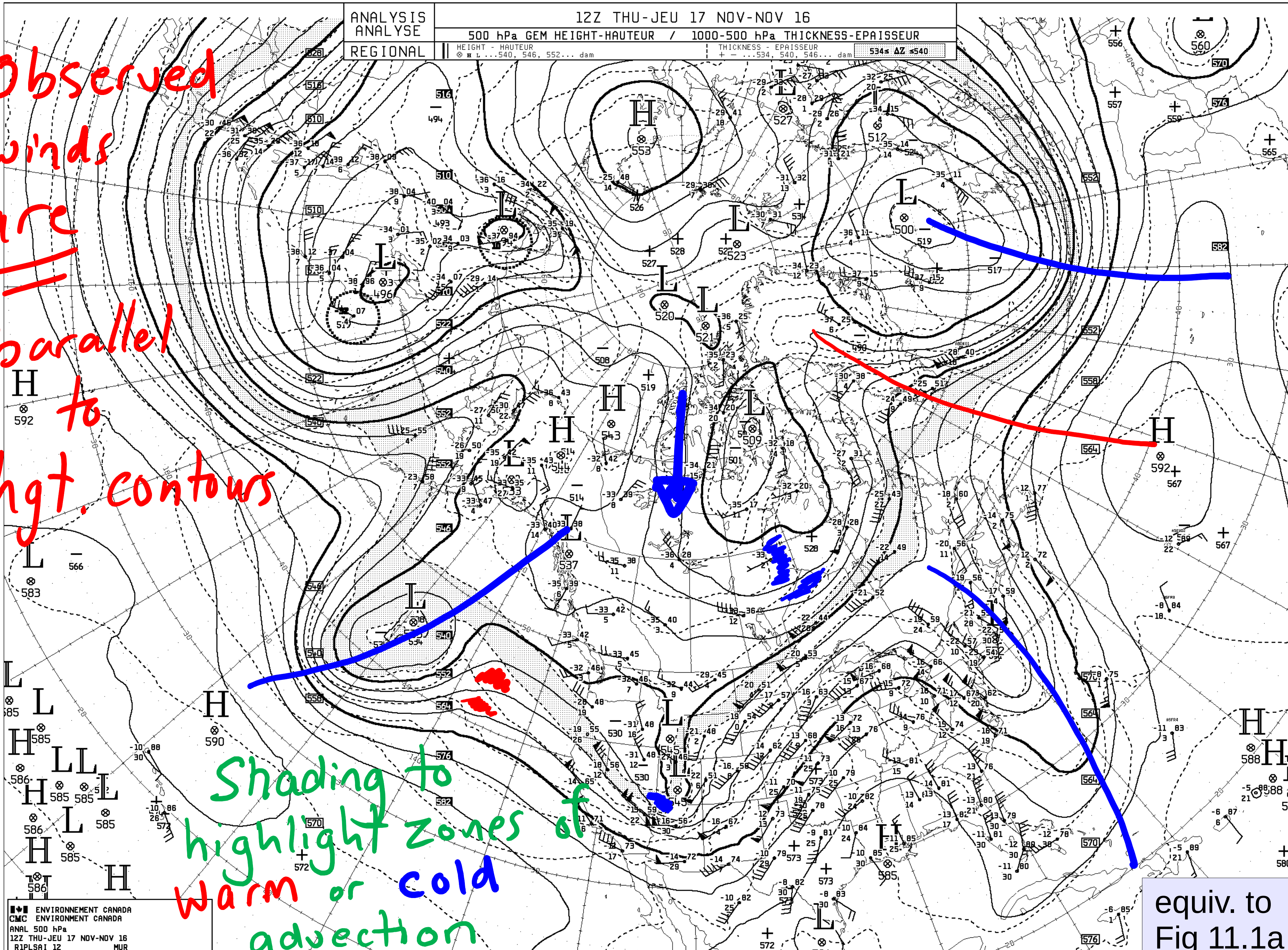
CMC surface analysis 12Z Friday 18 Nov. 2016



equiv. to
Fig 11.1b

CMC surface analysis 12Z Thursday 17 Nov. 2016

Flow from N. into N. Alberta

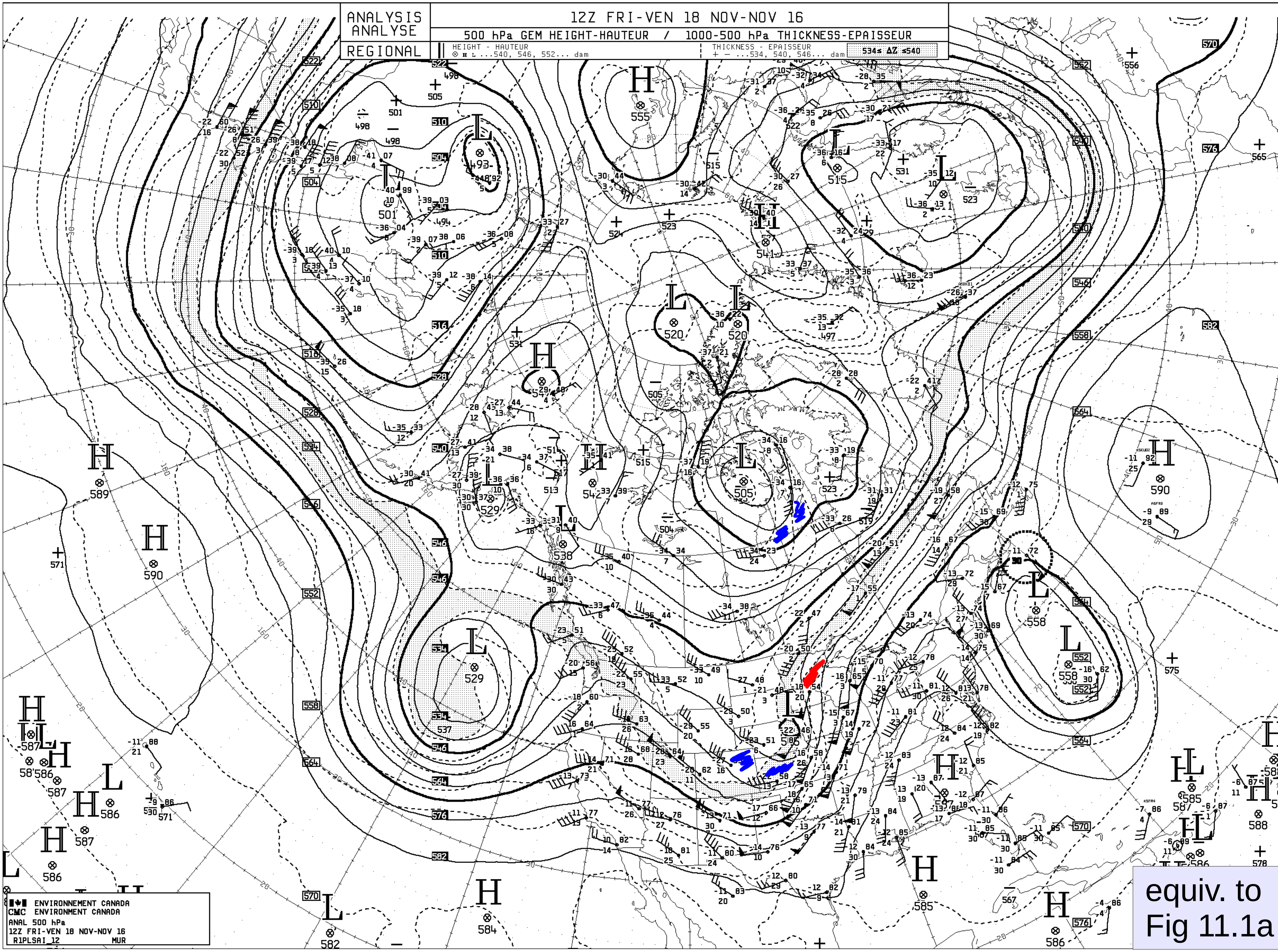


Observed winds are = parallel to hgt. contours

Shading to highlight zones of warm or cold advection

equiv. to Fig 11.1a

CMC surface analysis 12Z Friday 18 Nov. 2016

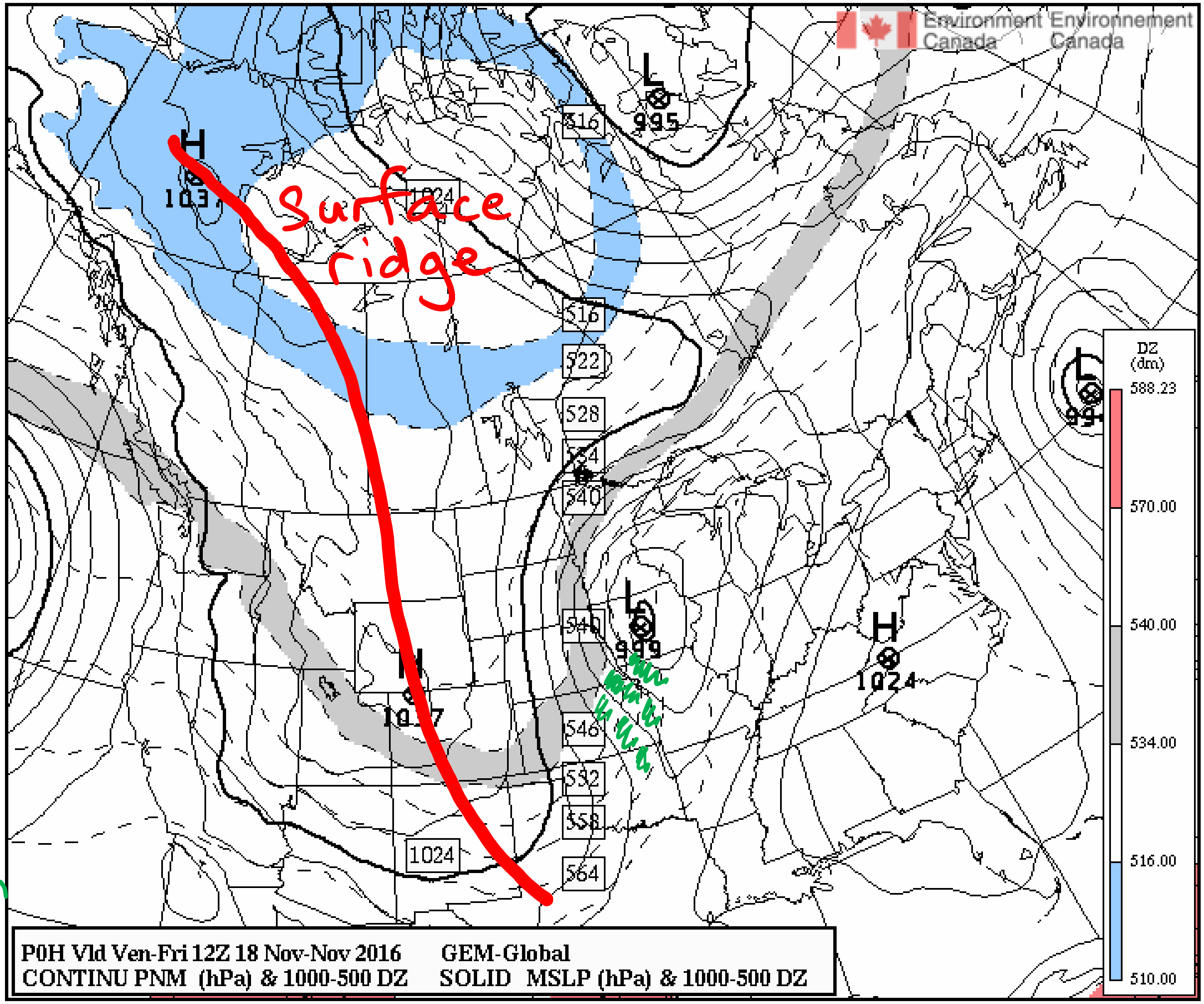


equiv. to
Fig 11.1a

CMC RDPS 0h prognosis valid 12Z Friday 18 Nov. 2016 ("Regional Deterministic Prediction System)

Recall thickness is a surrogate for (mean) temperature

I used green to identify a zone where the low is resulting in cold advection



} grey

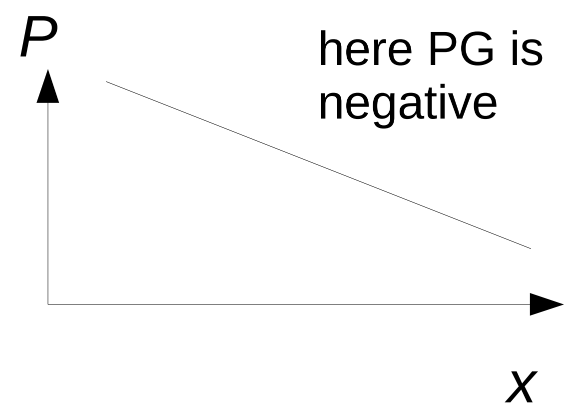
} blue shading

$$F = m\,a \longrightarrow \frac{F}{m} = a$$

Horiz. acceleration of a parcel of air equals net horiz. force per unit mass

"Pressure Gradient"
(along the *x* direction):

$$PG = \frac{\Delta P}{\Delta x}$$



per unit mass

Pressure Gradient Force
(along the *x* direction):

$$PGF = \frac{-1}{\rho}\,\frac{\Delta P}{\Delta x} \quad [\mathrm{m\ s^{-2}}]$$

Magnitude of the
Pressure Gradient Force
(along the *x* direction):

$$|PGF| = \frac{1}{\rho}\,\left|\frac{\Delta P}{\Delta x}\right|$$

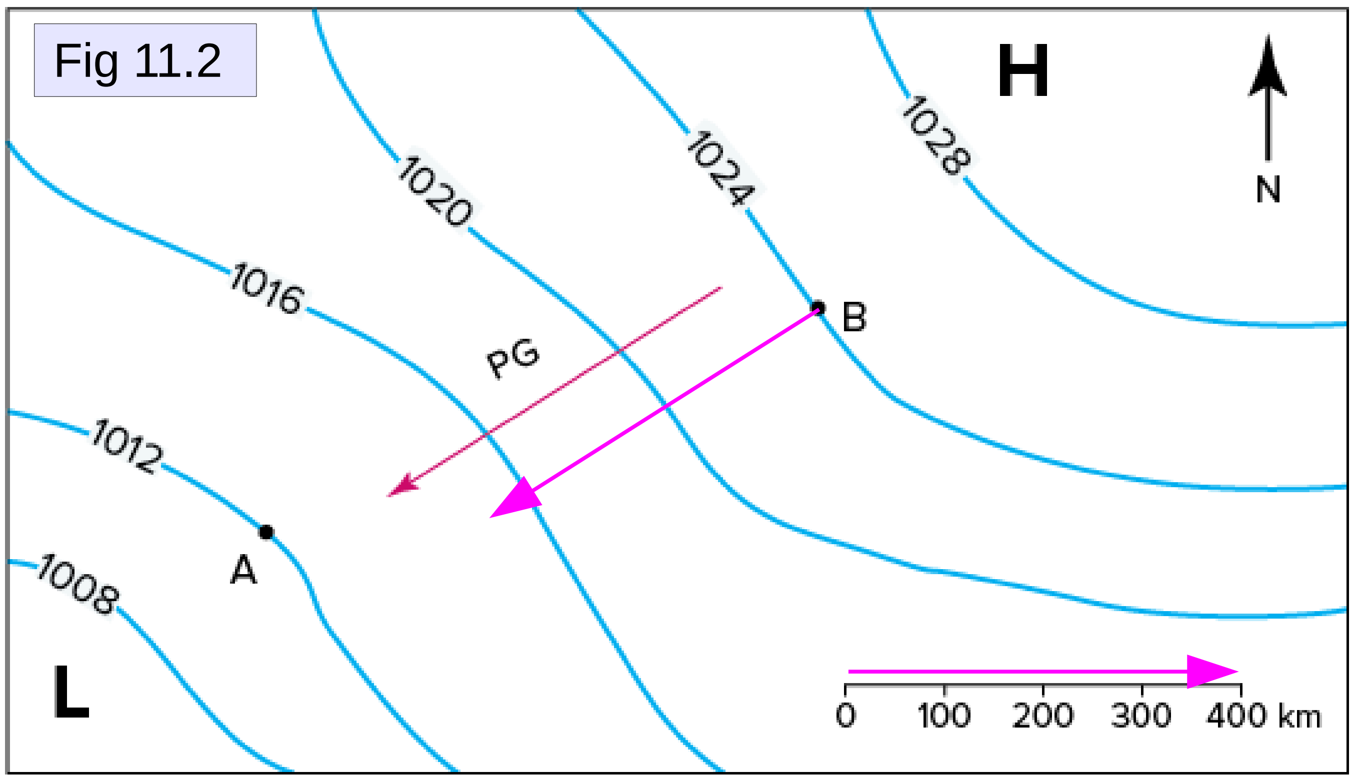
What is the *approximate* magnitude of the pressure gradient force (in MKS units), as based on the arrow based at B? (All three arrows have the same length)

Let $\rho = 1\ \mathrm{kg\,m^{-3}}$

$$|PGF| \simeq \frac{800\ \mathrm{Pa}}{400 \times 10^{3}\ \mathrm{m}} = 2 \times 10^{-3}\ \mathrm{m\,s^{-2}} \quad (\ll g)$$

(We can use a similar procedure to get the height gradient on an isobaric chart)

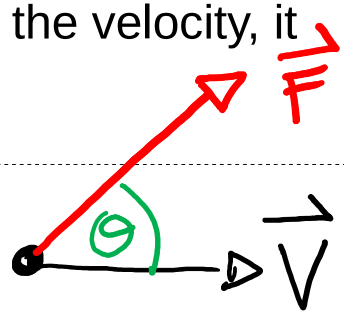
Fig 11.2



- Fictitious force – arises only because we refer the winds to axes fixed on earth, and earth is rotating
- makes freely-moving bodies appear to deflect from straight line motion

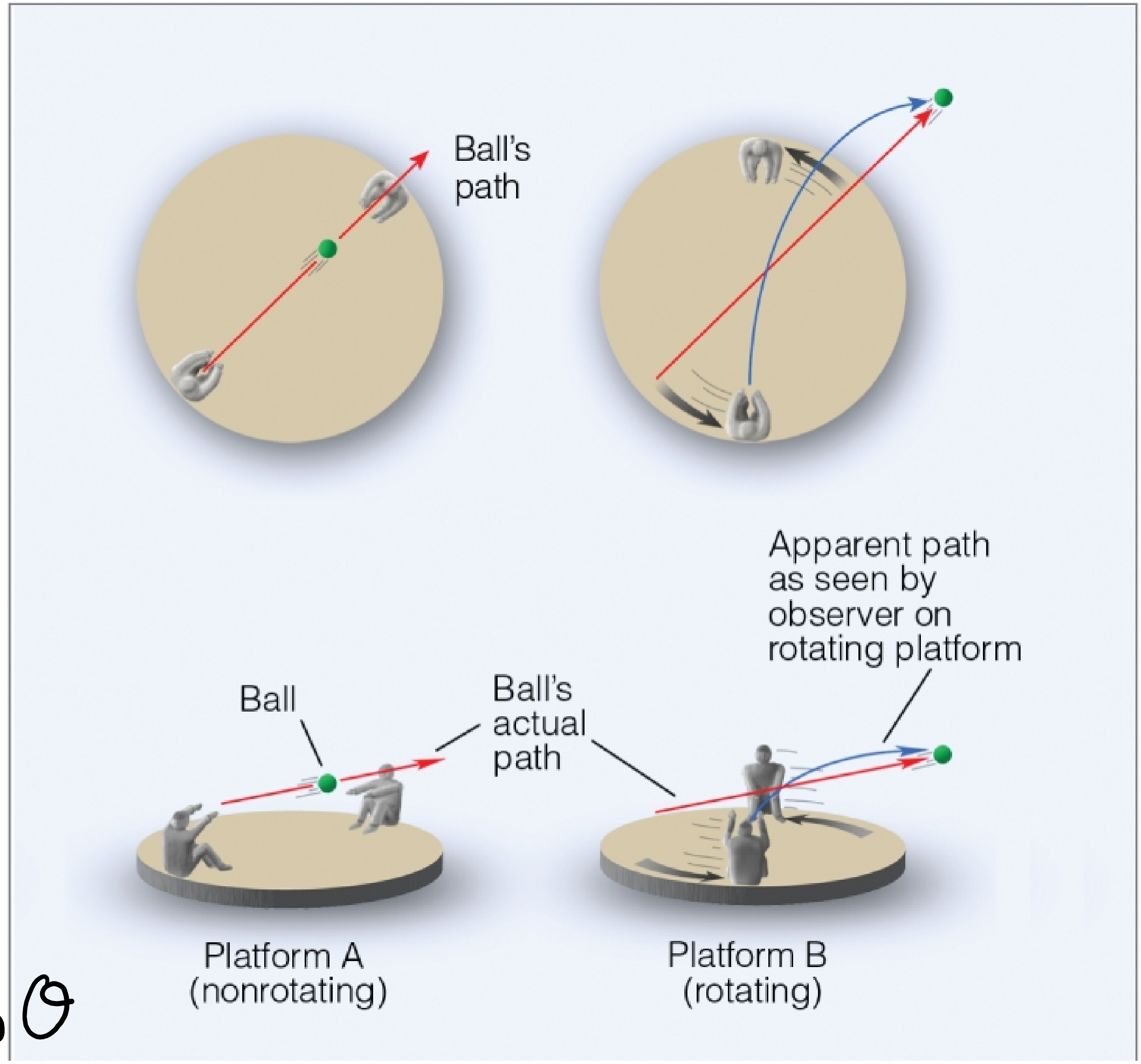
$(\cos 90^\circ = 0)$

- in the N. hemisphere deflection is to the right of the motion
- since Coriolis force is perpendicular to the velocity, it does no work



Rate of working by force $\vec{F}$ on body with velocity $\vec{V}$ is

$$W = \vec{F} \cdot \vec{V} = |\vec{F}||\vec{V}|\cos\theta$$



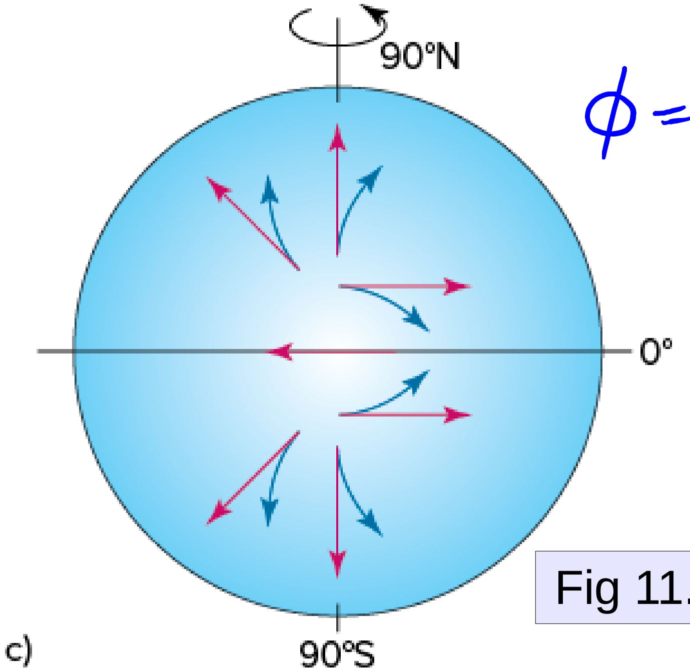


Fig 11.5

ϕ = latitude

- acts on all freely moving objects, irespective of their direction of motion
- magnitude varies with speed *V* and latitude φ of the object
- magnitude of Coriolis Force (per unit mass, perpendicular to the wind)

$$CF = f_c \; V \quad [\mathrm{m\ s}^{-2}]$$

- where "Coriolis parameter"

$$f_c = 2\Omega \sin\phi \quad [\mathrm{s}^{-1}]$$

Earth's rotation rate $\Omega = \dfrac{2\pi}{24 \times 3600}$

(2π radians is one full turn/circle)

Compute the Coriolis parameter at 53.5º latitude

$f_c = 1.17 \times 10^{-4}\ s^{-1}$

CORIOLIS TIME SCALE

$1/f_c \sim 10^4\ s \sim 3\ hr$

CF is unimportant for circulations whose life time is short with respect to $1/f_c$

For steady winds (no change in speed or direction relative to axes fixed on earth) parallel to straightline isobars or height contours, PGF and CF balance.

$$\frac{1}{\rho}\left|\frac{\Delta P}{\Delta x}\right| = f_c V_g$$

** isobars are equi-spaced, parallel, straight lines

~ note that PGF is not changing ~ and at equil., PGF and CF are equal and opposite

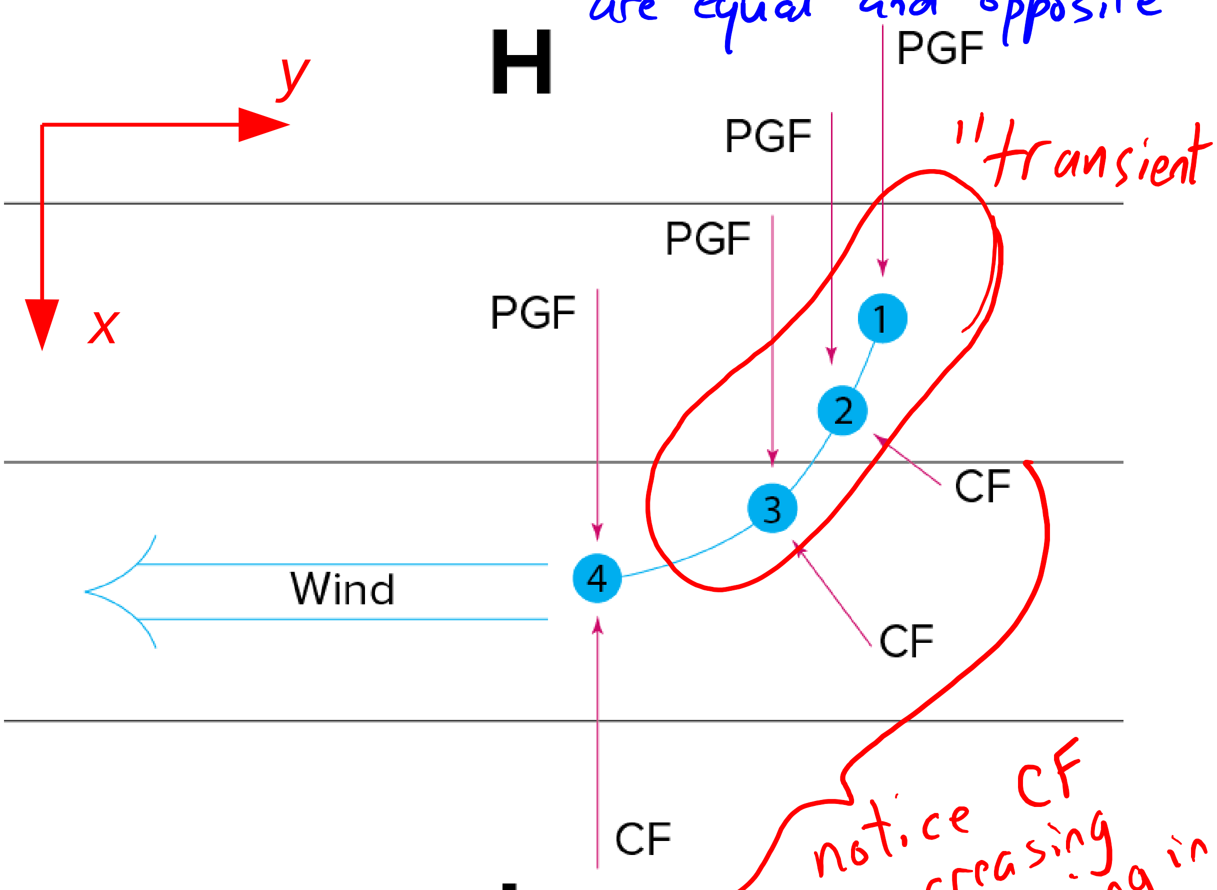


Fig 11.9

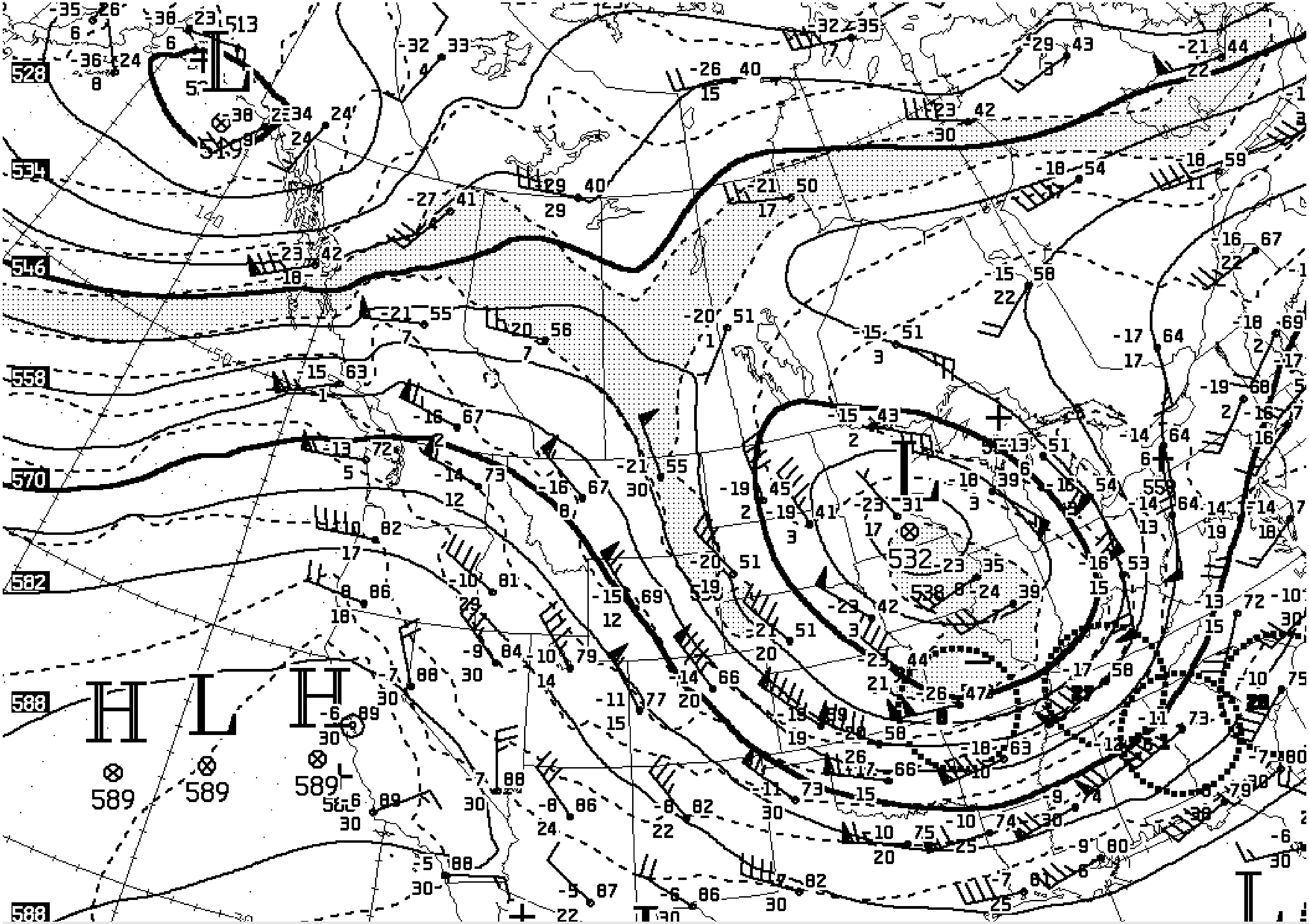
$$V_g = \frac{1}{\rho f_c}\left|\frac{\Delta P}{\Delta x}\right|$$

where x runs perpendicular to isobars and V_g runs // to them. Can re-express this using the height gradient,

$$V_g = \frac{g}{f_c}\left|\frac{\Delta Z}{\Delta x}\right|$$

At given latitude and elevation, V_g depends only on the PGF

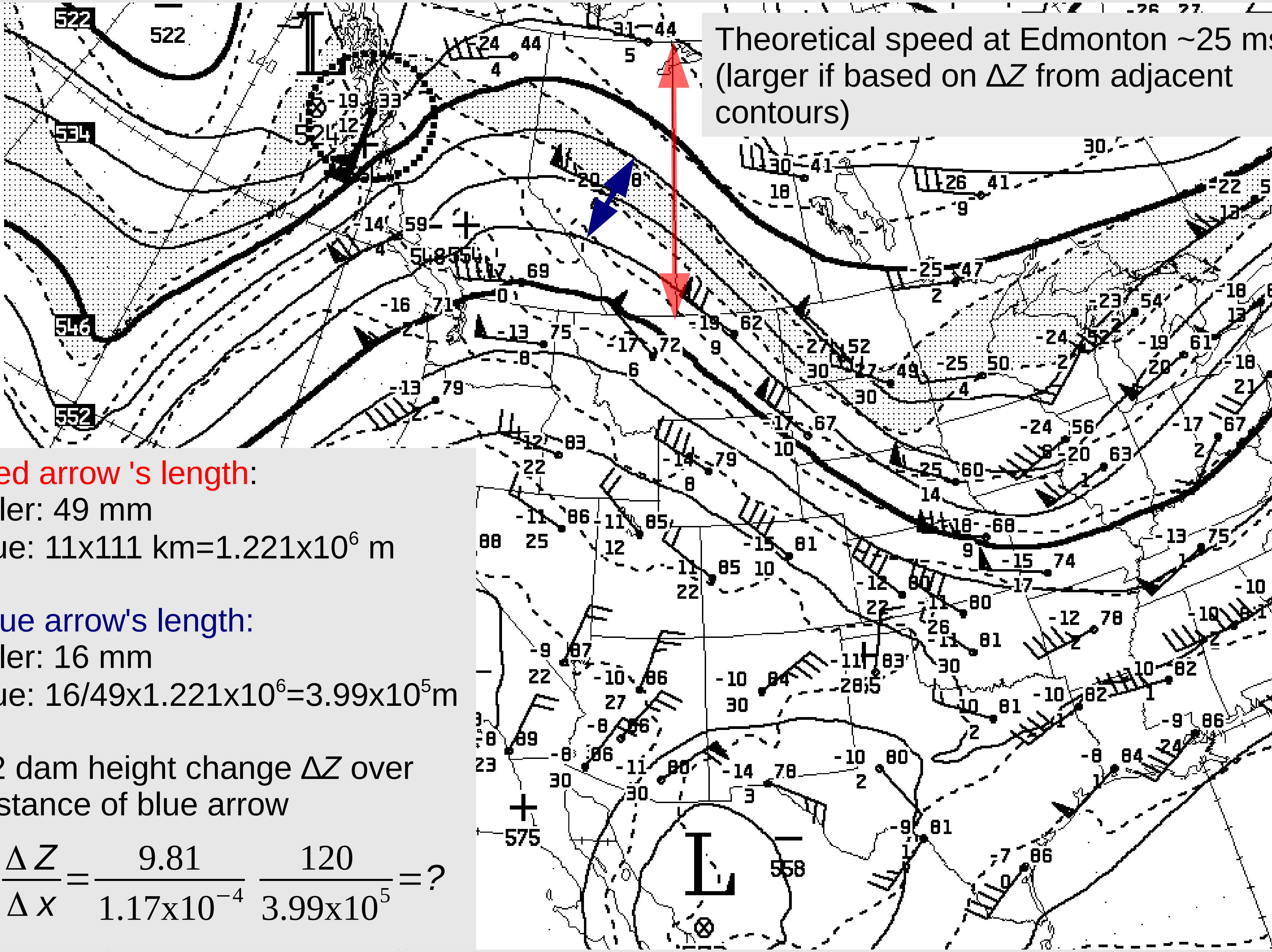
Ch11. Does the isobaric chart confirm the Geostrophic law? YES, It's a good theory



CMC 500 hPa analysis 12Z Thurs 18 Oct. 2012 (and see earlier example for 17 Nov. 2016)

Ch11. Does the isobaric chart confirm Geostrophic law? (Estimate speed at Edmonton) 8/12

Theoretical speed at Edmonton ~25 ms^{-1} (larger if based on ΔZ from adjacent contours)



Red arrow 's length:
ruler: 49 mm
true: 11x111 km=1.221×10^6 m

Blue arrow's length:
ruler: 16 mm
true: $16/49\times1.221\times10^6=3.99\times10^5$m

12 dam height change ΔZ over distance of blue arrow

$$\frac{g}{f_c}\frac{\Delta Z}{\Delta x} = \frac{9.81}{1.17\times10^{-4}}\ \frac{120}{3.99\times10^5} = ?$$

CMC 500 hPa analysis 00Z Thurs 6 Nov. 2014

- CF smaller in magnitude than PGF
- therefore speed $V < V_g$
- difference between PGF and CF is the centripetal acceleration V_{gr}^2/R
- "subgeostrophic" flow around a low

$$V_{gr} = V_g - \frac{1}{f_c}\frac{V_{gr}^2}{R}$$

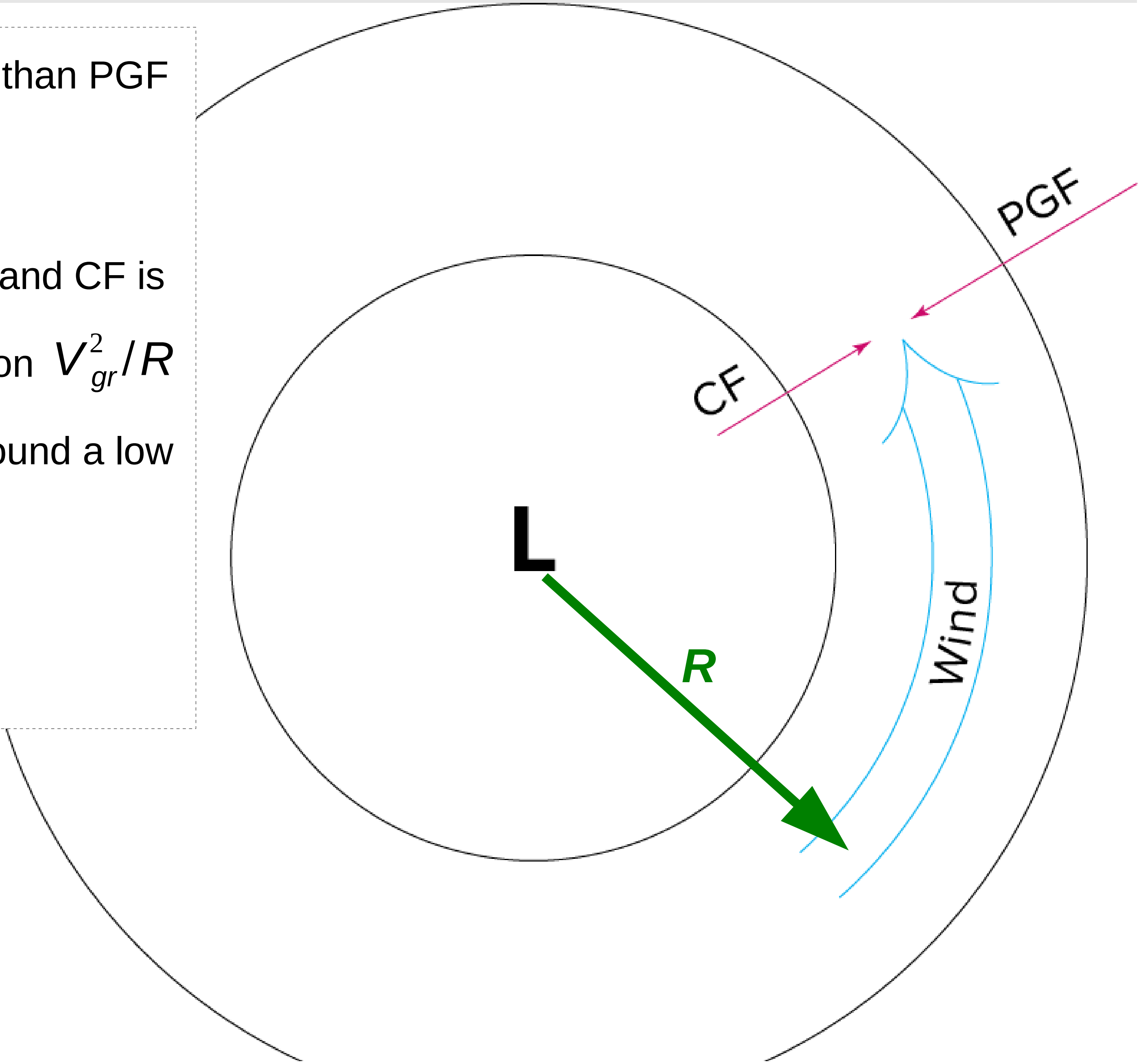


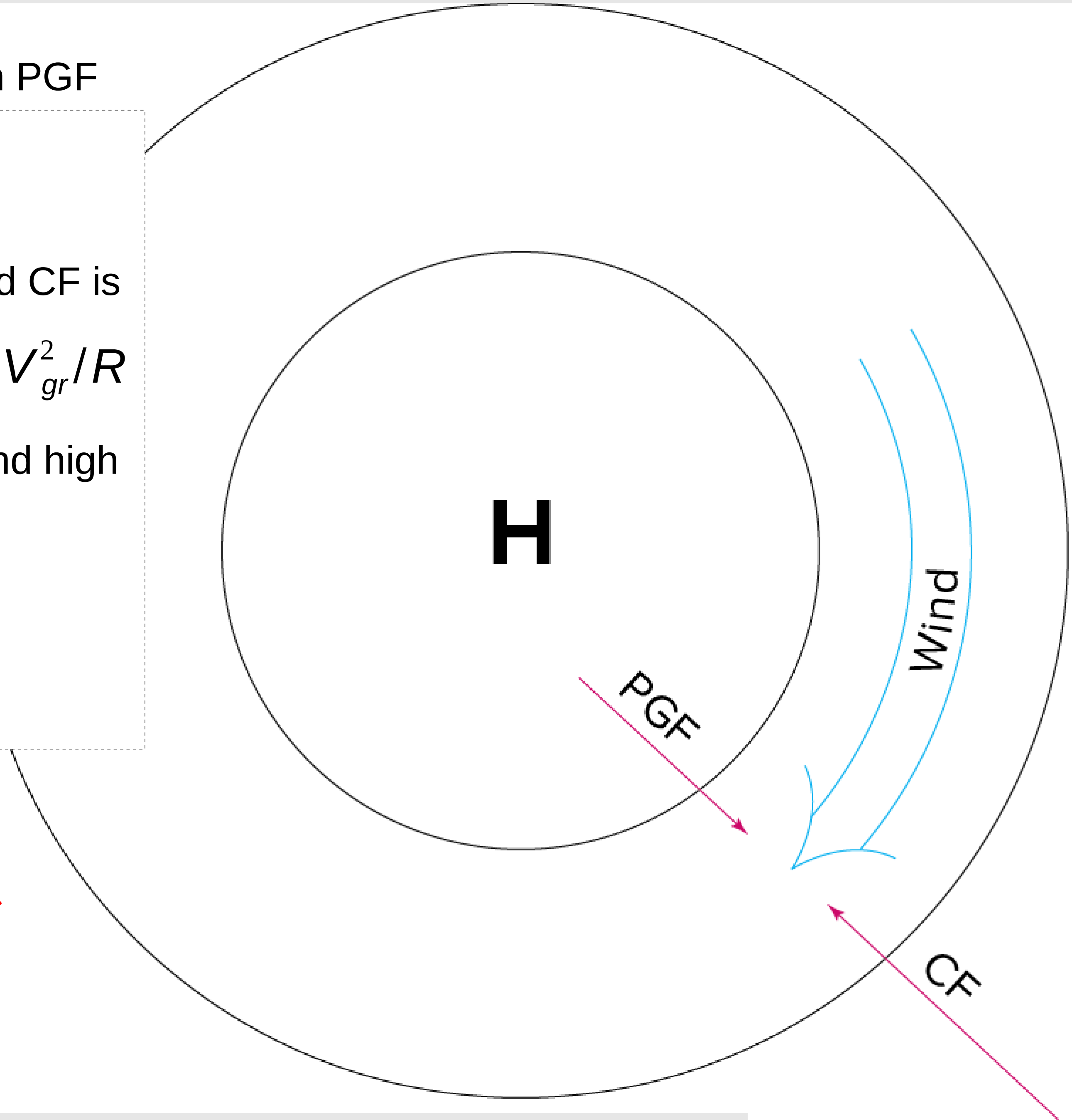
Fig 11.10b

Sec 11.2.2 Gradient wind–constant speed along *curved* isobars above the friction layer 10/12

- CF larger in magnitude than PGF

- therefore speed $V > V_g$
- difference between PGF and CF is the centripetal acceleration V_{gr}^2/R
- supergeostrophic flow around high

$$V_{gr} = V_g + \frac{1}{f_c}\frac{V_{gr}^2}{R}$$



But PGF in region of highs is usually much weaker than near lows

"For the same pressure gradient force, winds are faster around highs (ridge axes) than they are around lows (trough axes)" (p274)

Fig 11.11

moving away from ridge axis, heights fall

moving away from trough axis, heights rise

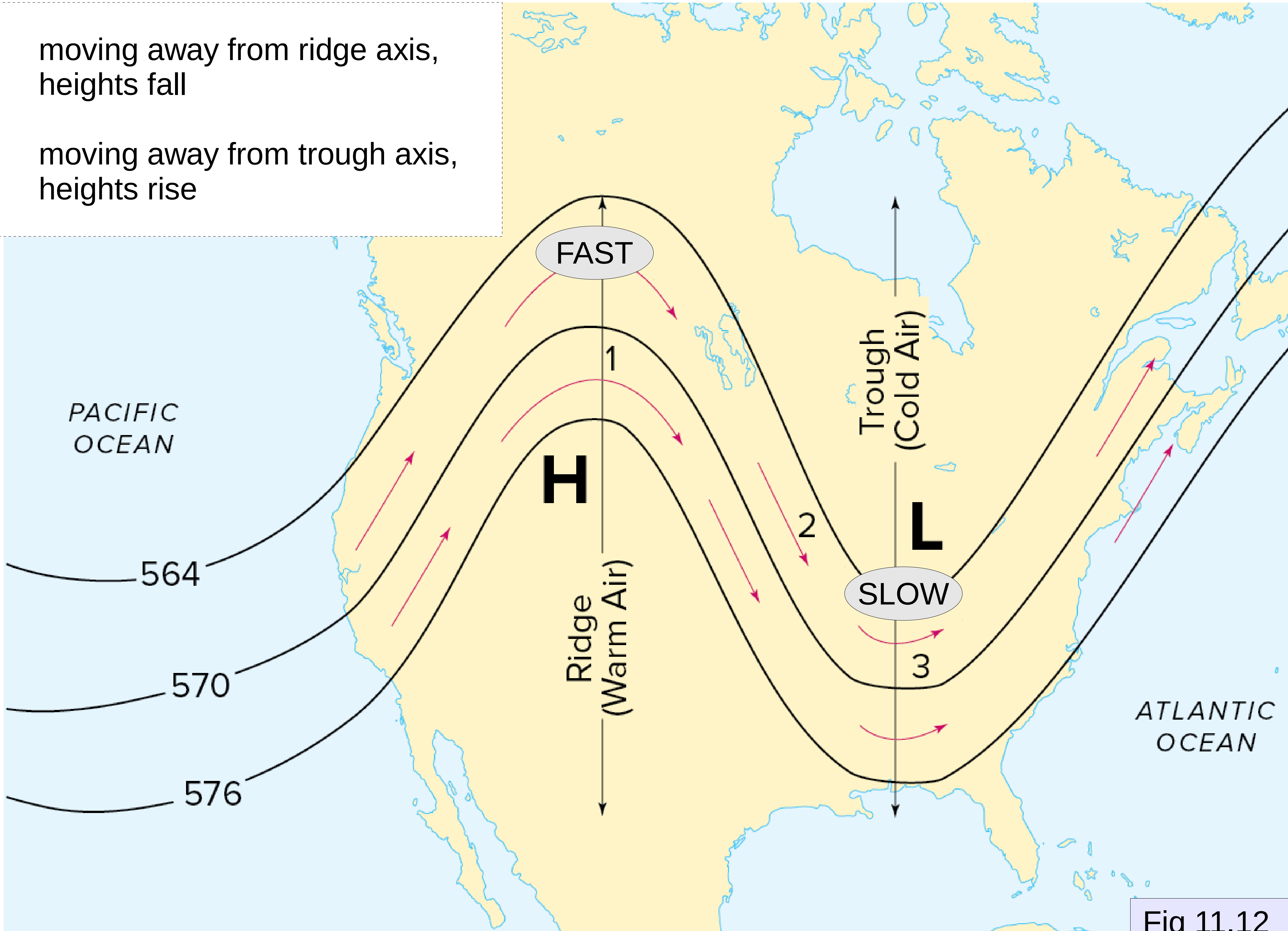
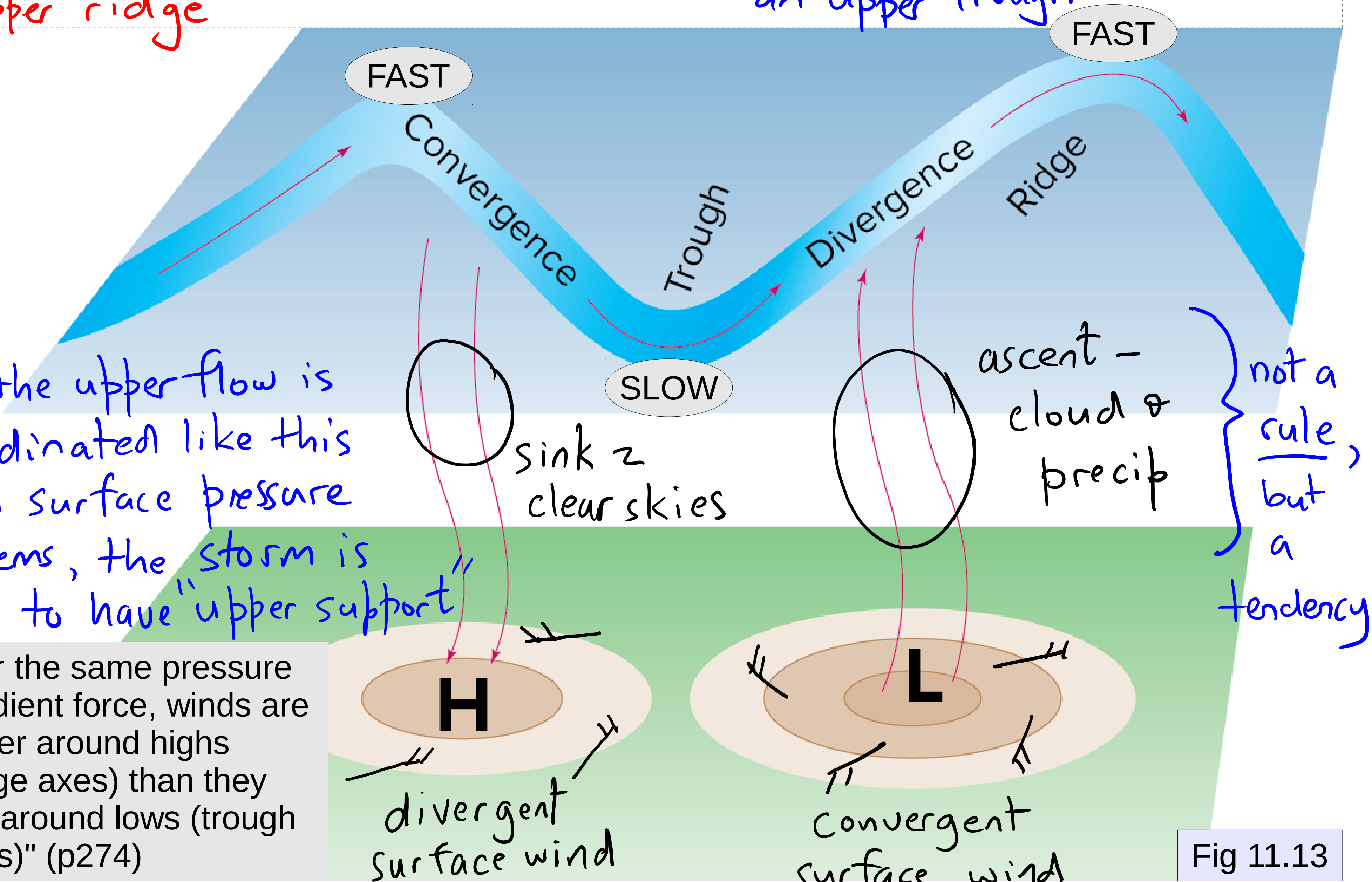


Fig 11.12

Surface high is liable to form downwind of an upper ridge

Surface low is liable to form downwind of an upper trough



If the upper flow is coordinated like this with surface pressure systems, the storm is said to have "upper support"

"For the same pressure gradient force, winds are faster around highs (ridge axes) than they are around lows (trough axes)" (p274)

Fig 11.13

Topics/concepts covered

- ideal relationships between the orientation and speed of the winds aloft (in the free atmosphere, i.e. above the ABL) and the height contours
  - geostrophic wind: steady flow along straight contours
  - gradient wind: accelerating flow parallel to curved contours
- how to evaluate the geostrophic wind given an isobaric chart
- convergence and divergence zones associated with waves in the flow aloft