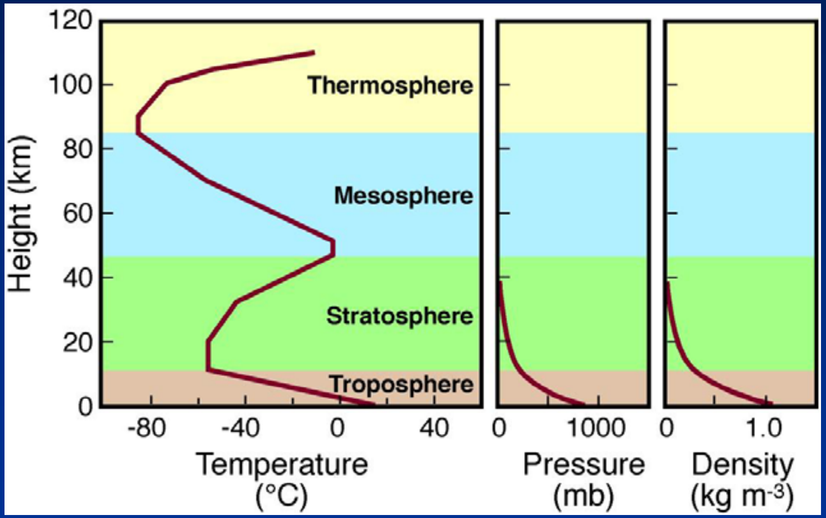
Standard atmosphere

Pressure (mb)	Typical height (ft)	Typical height (m)
1013.25	0	0
1000	370	110
850	4780	1460
700	9880	3010
500	18280	5570
300	30050	9160



Whiteman 2000

Pressure decreases exponentially with altitude

Horizontal Variations in Pressure

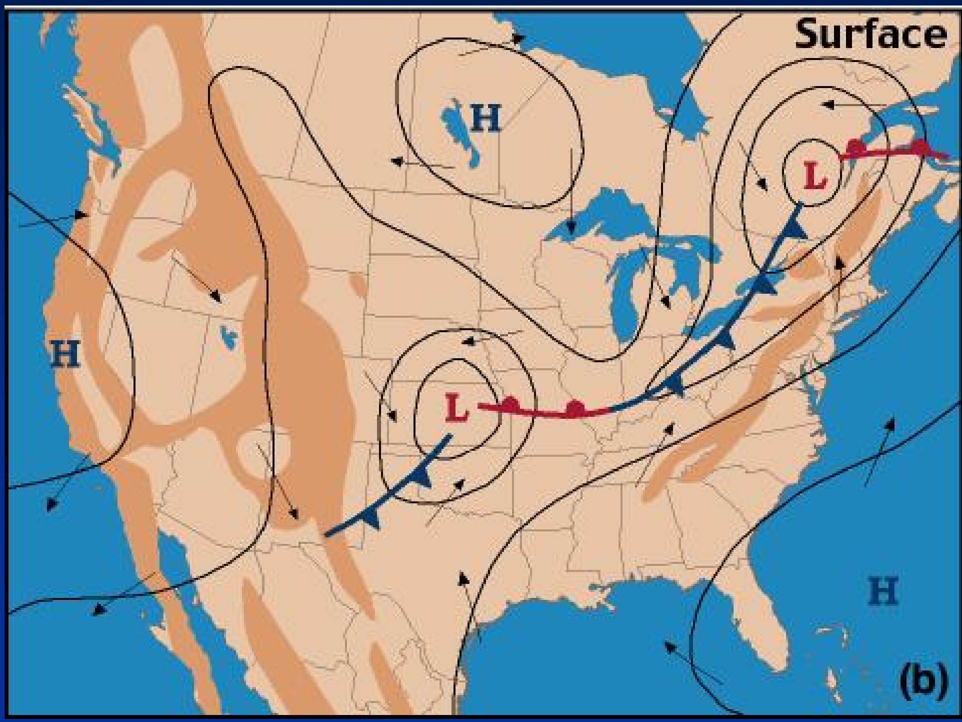
- Pressure changes more rapidly in the vertical than in the horizontal
  - Vertically: 1000-850 mb in 1500 m
  - Horizontally: order 10 mb in 1000 km
  - Horizontal pressure gradient force is weaker than vertical pressure gradient force
- Environment tends to be in hydrostatic balance with very small motion in the vertical (vertical pressure gradient force balanced by gravity)

Horizontal Wind Accelerations

- Horizontal accelerations in wind are due to imbalance between:
  - horizontal variations in mass (pressure)
  - non-inertial (Coriolis) force due to rotation of earth
  - frictional effects (near the surface)

Choice of Vertical Coordinate

- Use height as vertical coordinate?
- How does pressure vary horizontally on a surface of constant height?
  - Sea level pressure "map"
  - 1500 m pressure "map"
  - Contour values of equal pressure (isobars)
  - Force due to inequitable distribution of mass defined by pressure gradient force



Sea level pressure analysis

Sea Level Pressure

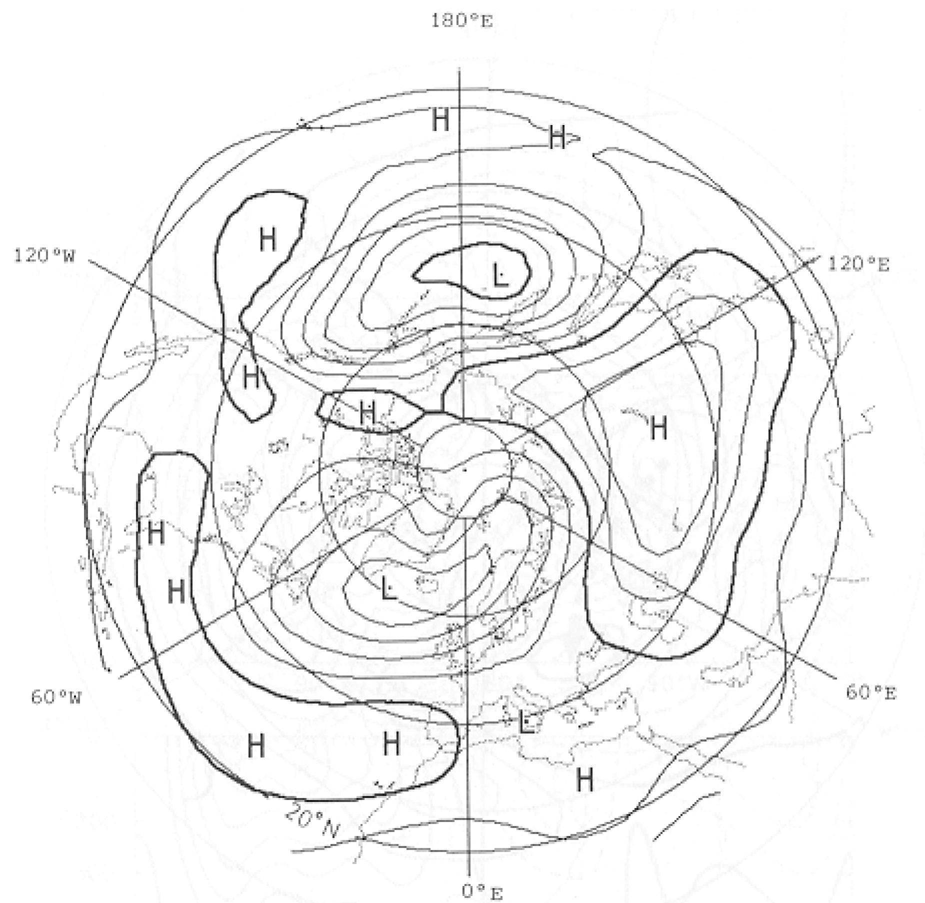
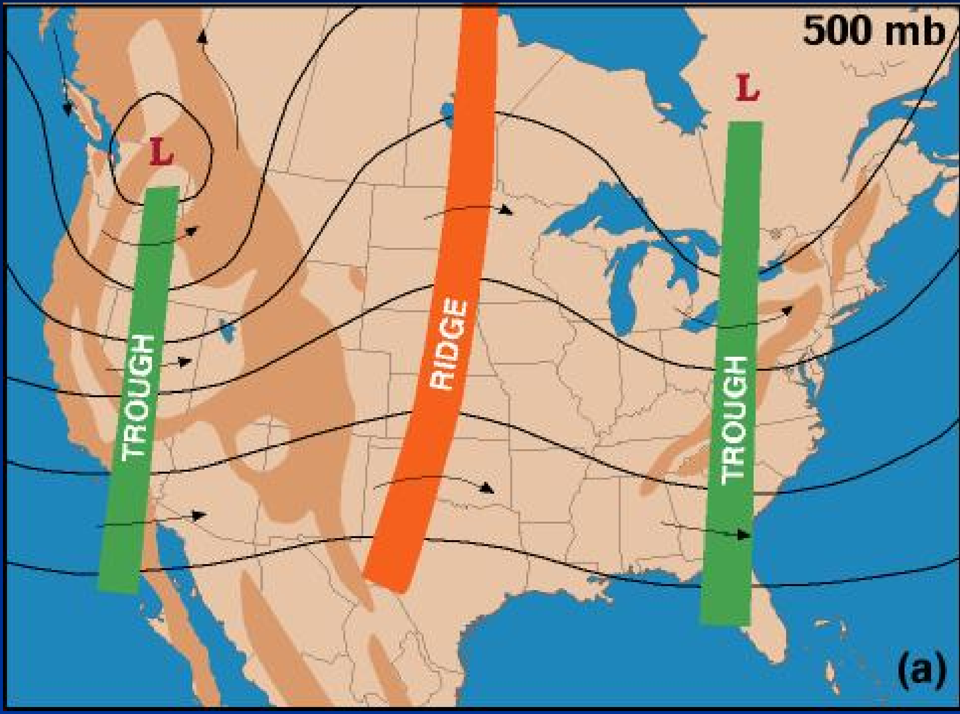


Fig. 2.6. Climatological mean sea-level pressure field for January, derived from the same data source as Fig. 2.2. Contour interval 4 mb; the 1000 and 1020 mb contours are thickened. For comparison with the corresponding field derived from NMC data, see Blackmon *et al.* (1977) or Lau *et al.* (1981). The outer latitudinal circle is 20°N.

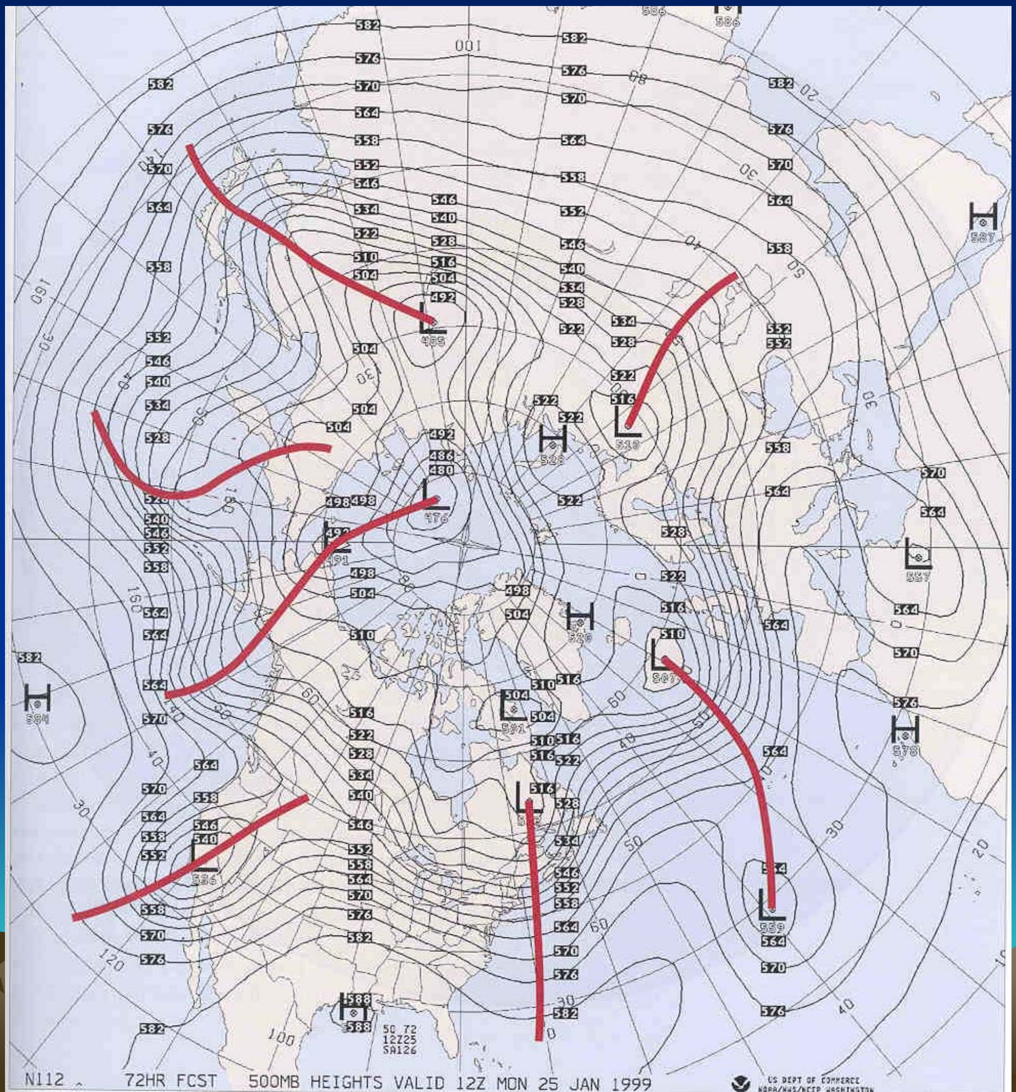
Choice of Vertical Coordinate

- Use pressure as a vertical coordinate?
- How does height vary horizontally on a surface of constant pressure?
  - 1000 mb height "map"
  - 500 mb height "map"
  - Contour values of equal height (isoheights)
  - Force due to inequitable distribution of mass defined by height gradient force



500 mb Height analysis

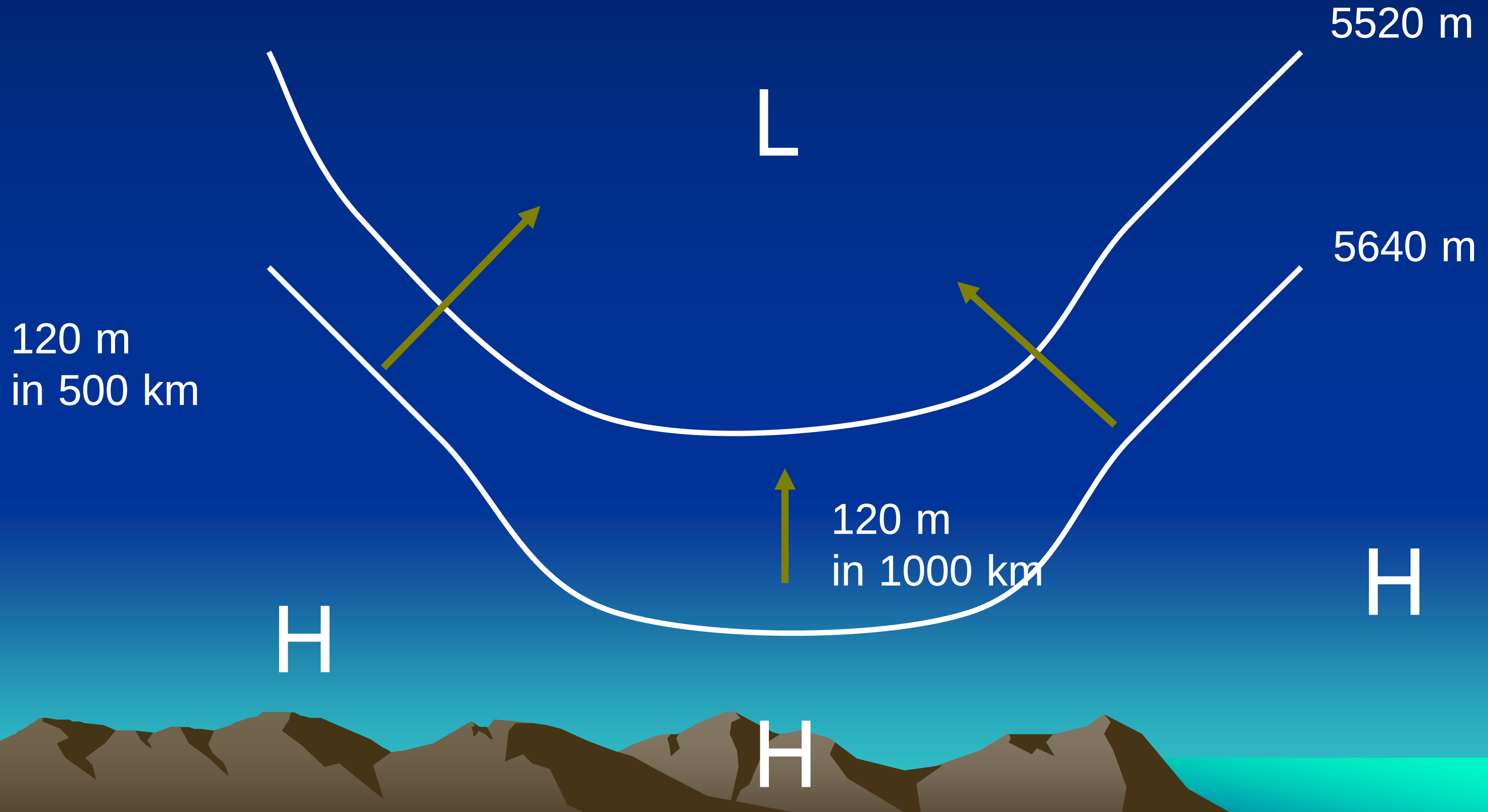
Ridges/Troughs in the Troposphere



Whiteman (2000)

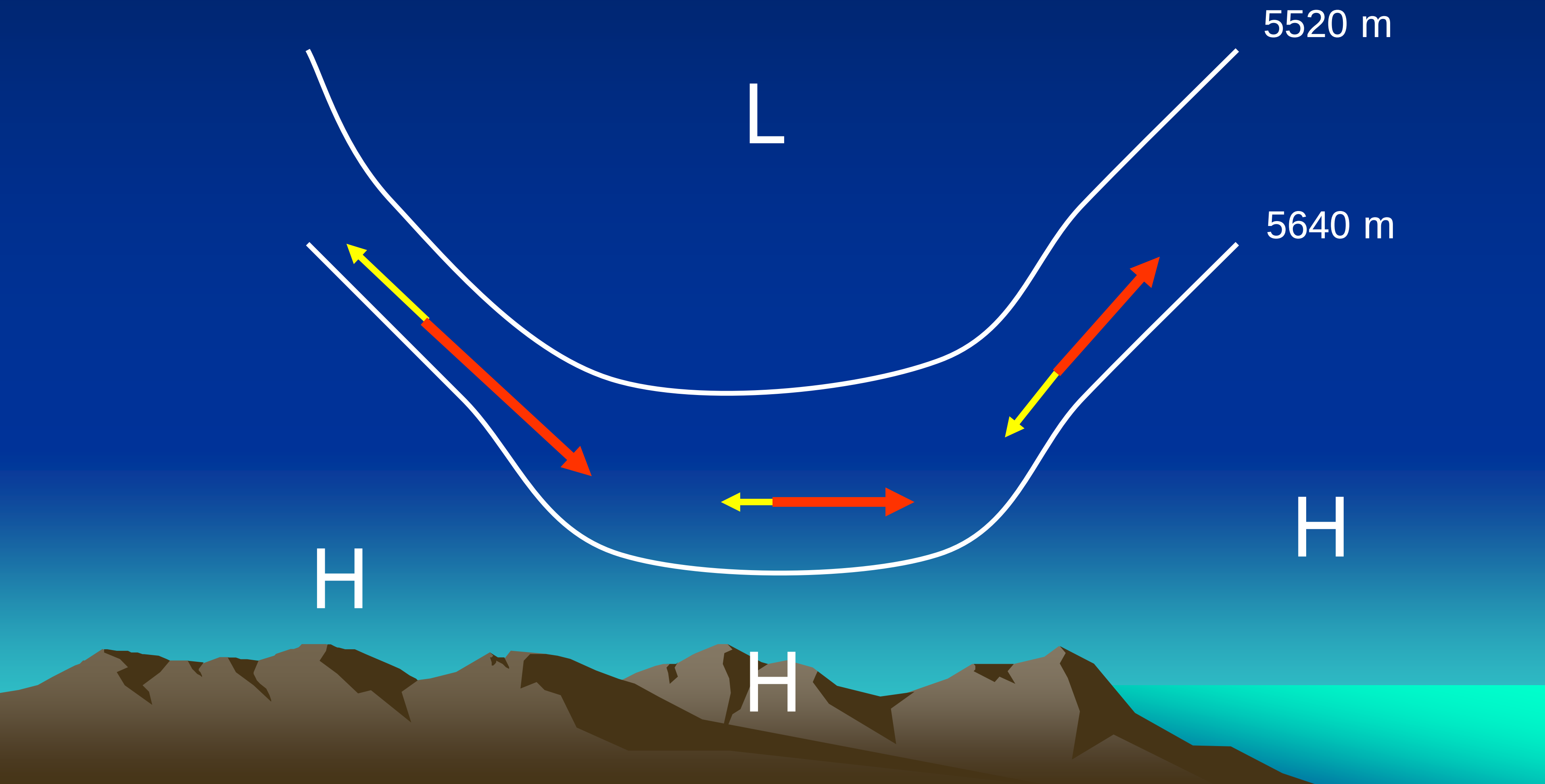
Height Gradient Force

Directed from High Height to Low Height
Magnitude proportional to distance between isoheights



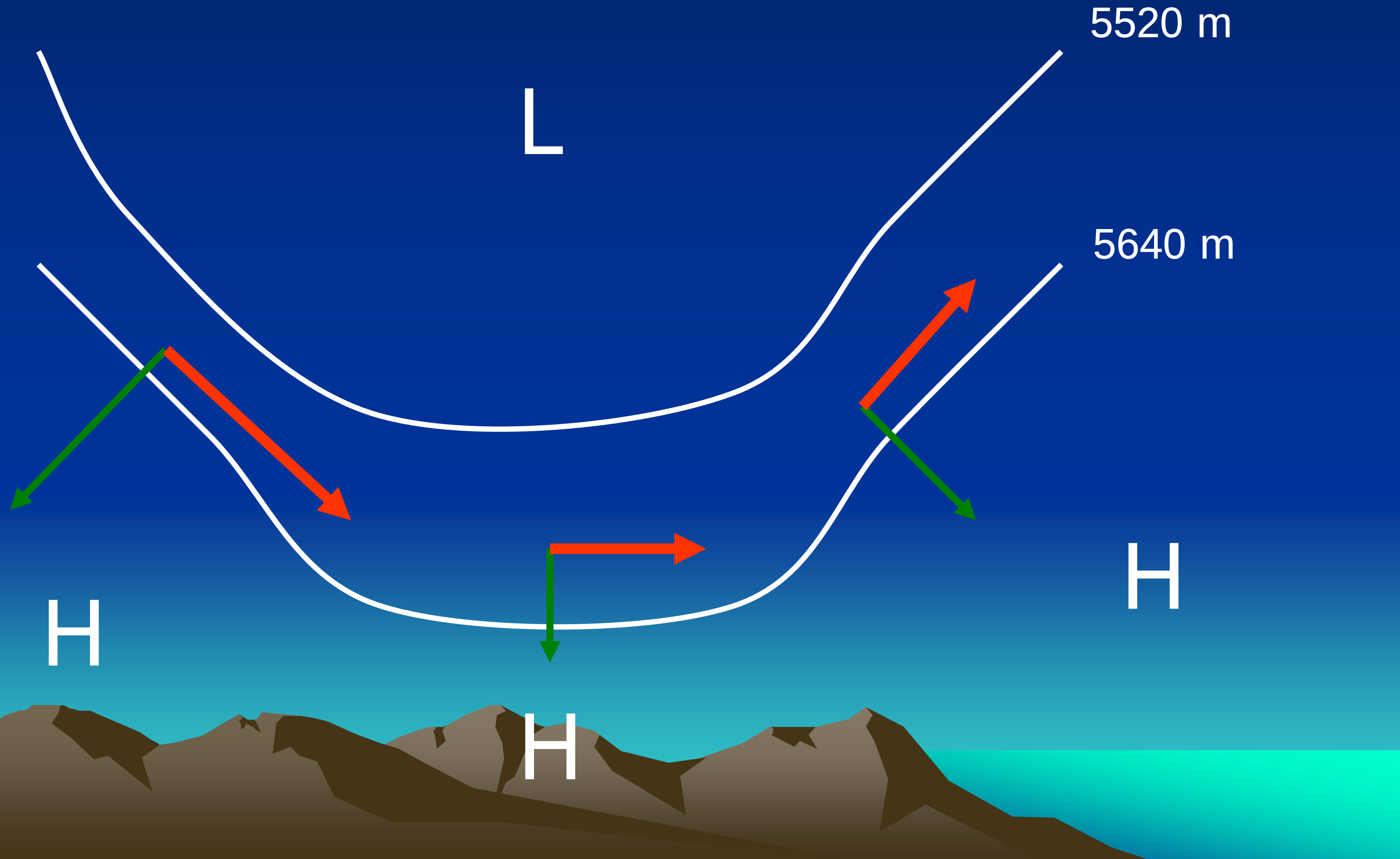
Frictional Force

Directed behind wind
Magnitude proportional to wind speed



Coriolis Force

Arises due to rotation of earth
Directed perpendicular to wind (to right in NH)
Magnitude proportional to latitude and wind speed

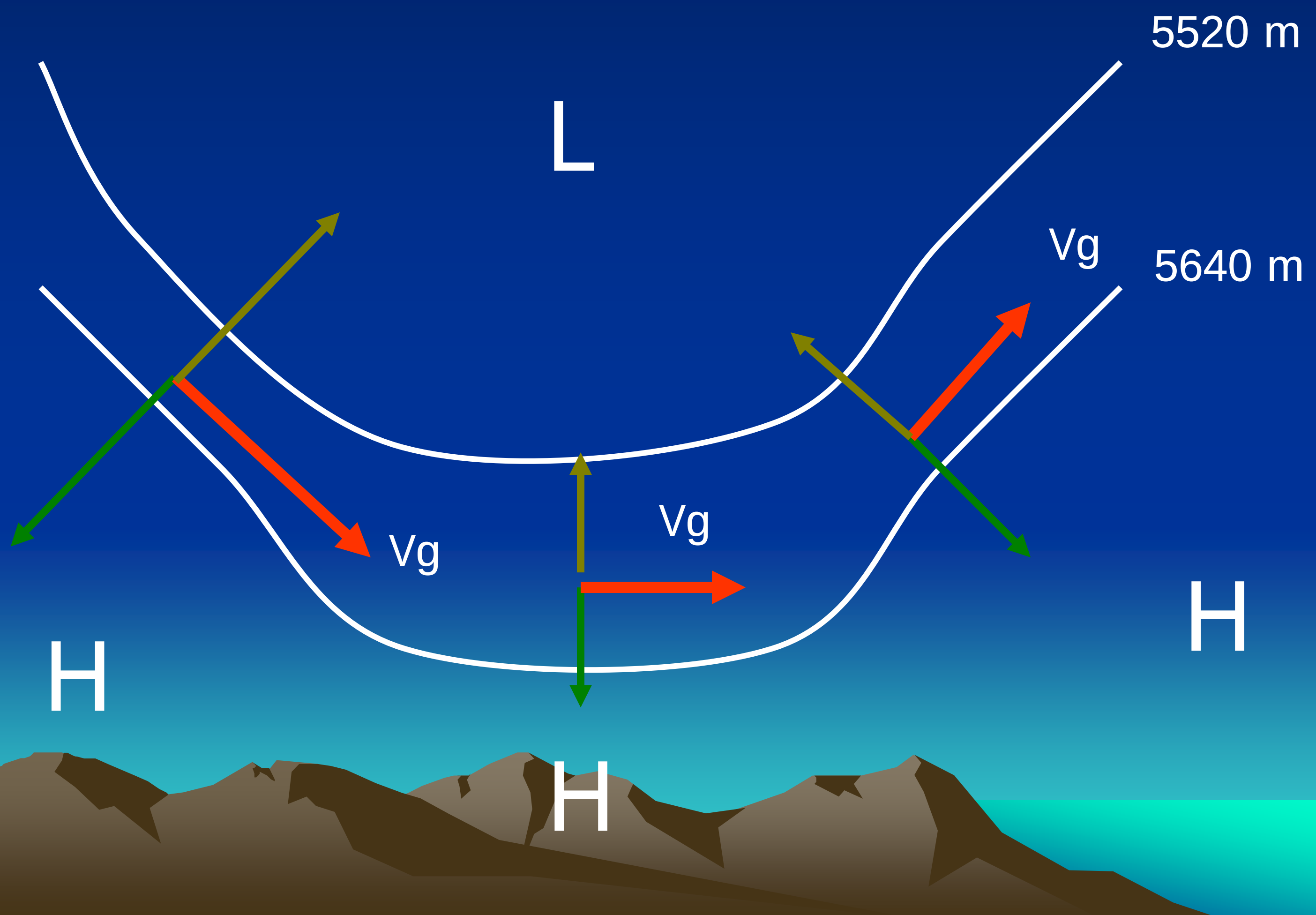


Geostrophic Balance

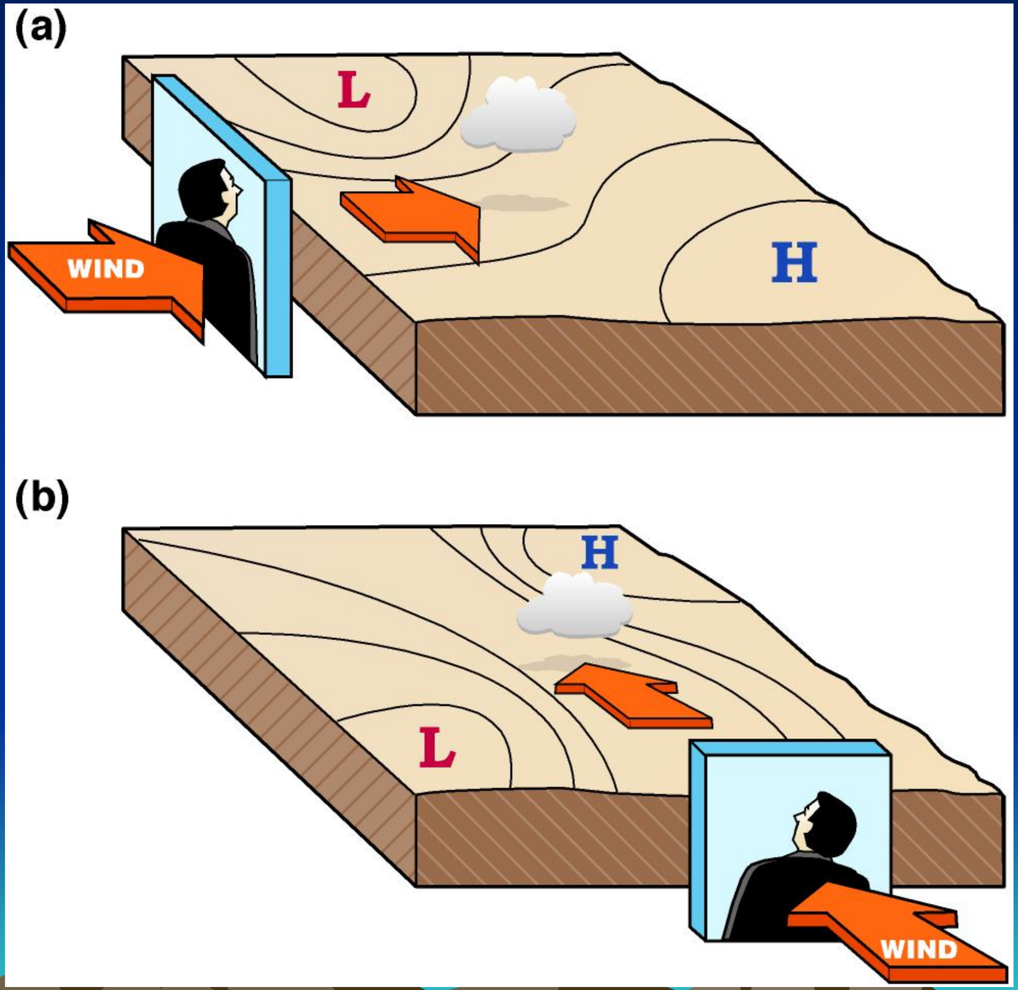
- Ignore friction for the moment
- Distribution of mass evolves in space and time
- Wind speed and direction tends to adjust in order to maintain balance between pressure (height) gradient and Coriolis forces
  - For example, if pressure (height) gradient increases locally, wind speed increases locally to compensate
- Even as the mass field changes, we can define the geostrophic wind V_g as the wind that is in balance with the pressure (height) gradient force at each instant
- So V_g varies in time and space as the mass field changes in time and space

Geostrophic Wind V_g

Directed parallel to pressure (height) contours
Low height (pressure) to the left of the wind
Magnitude proportional to pressure (height) gradient



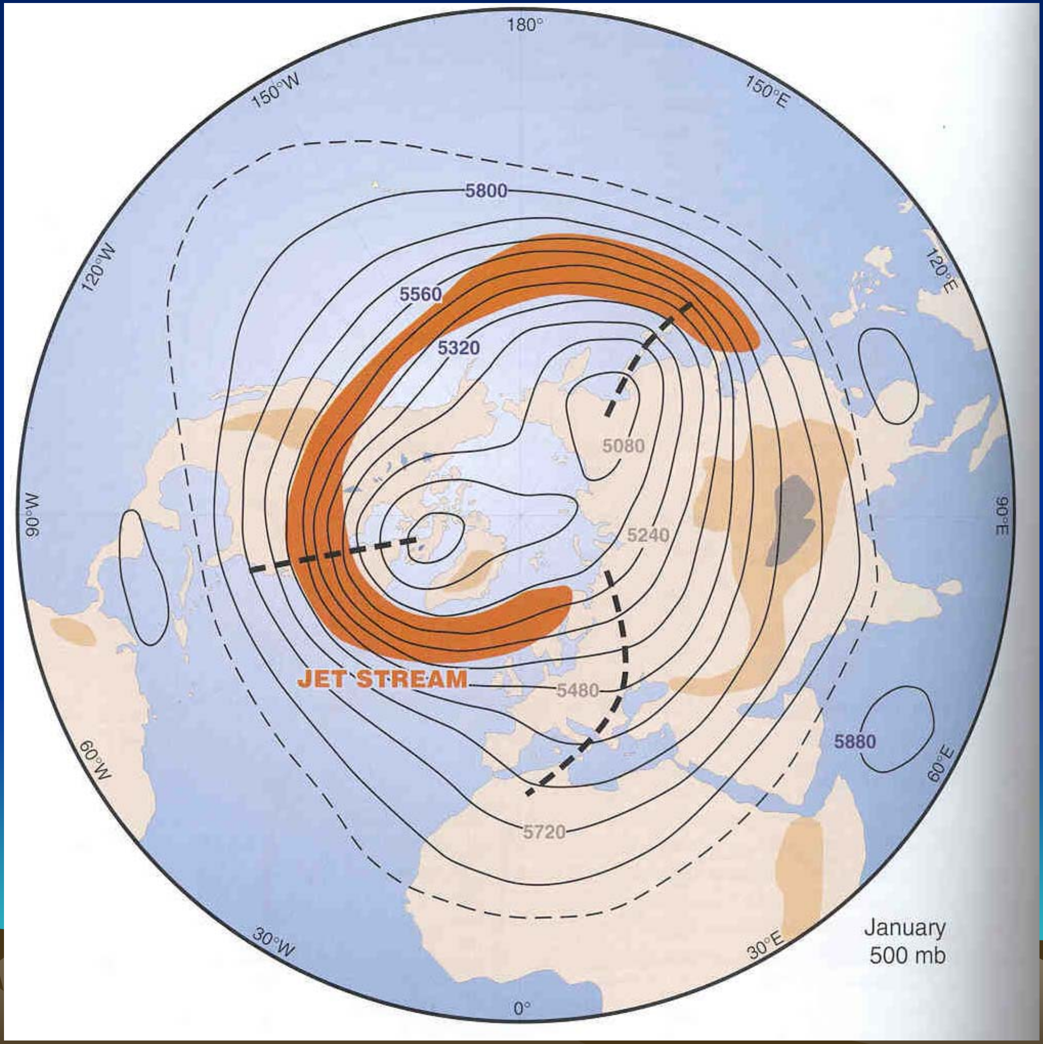
Buys-Ballot rule (Northern Hemisphere)



"If the wind blows into your back, the Low will be to your Left (and the high will be to your right)."

This rule works well if the wind is above the earth's boundary layer, not channeled by topography, etc.

January Mean Height



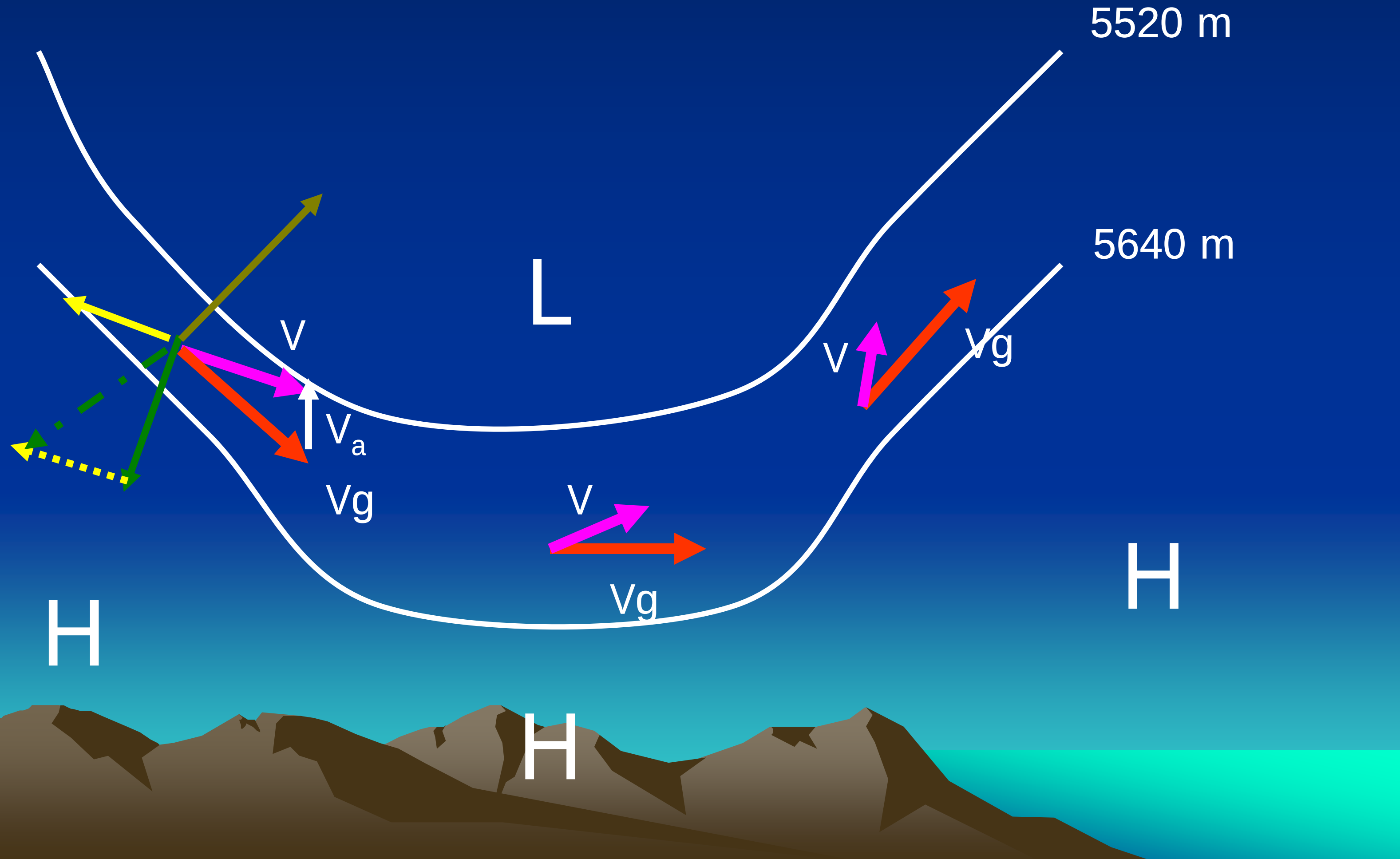
Whiteman (2000)

Ageostrophic Wind

- To zeroth order the actual wind V tends to be close to the geostrophic wind in the free atmosphere
- The difference between the actual wind V and the geostrophic wind Vg is the ageostrophic (nongeostrophic) wind
- Ageostrophic wind is large when
  - Friction is important
  - Height contours are strongly curved

Ageostrophic Wind V_a

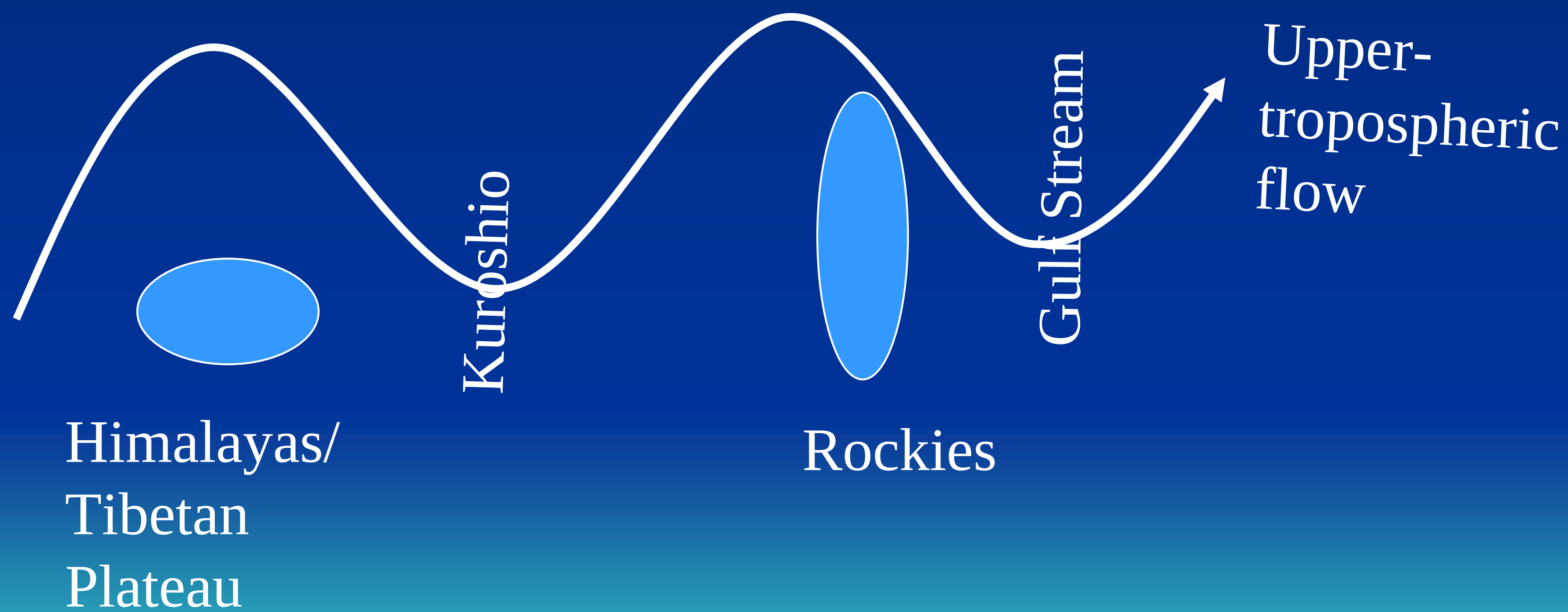
- If friction important, balanced wind will have component directed towards low height (pressure)
- Balanced wind V will be weaker in magnitude than geostrophic wind



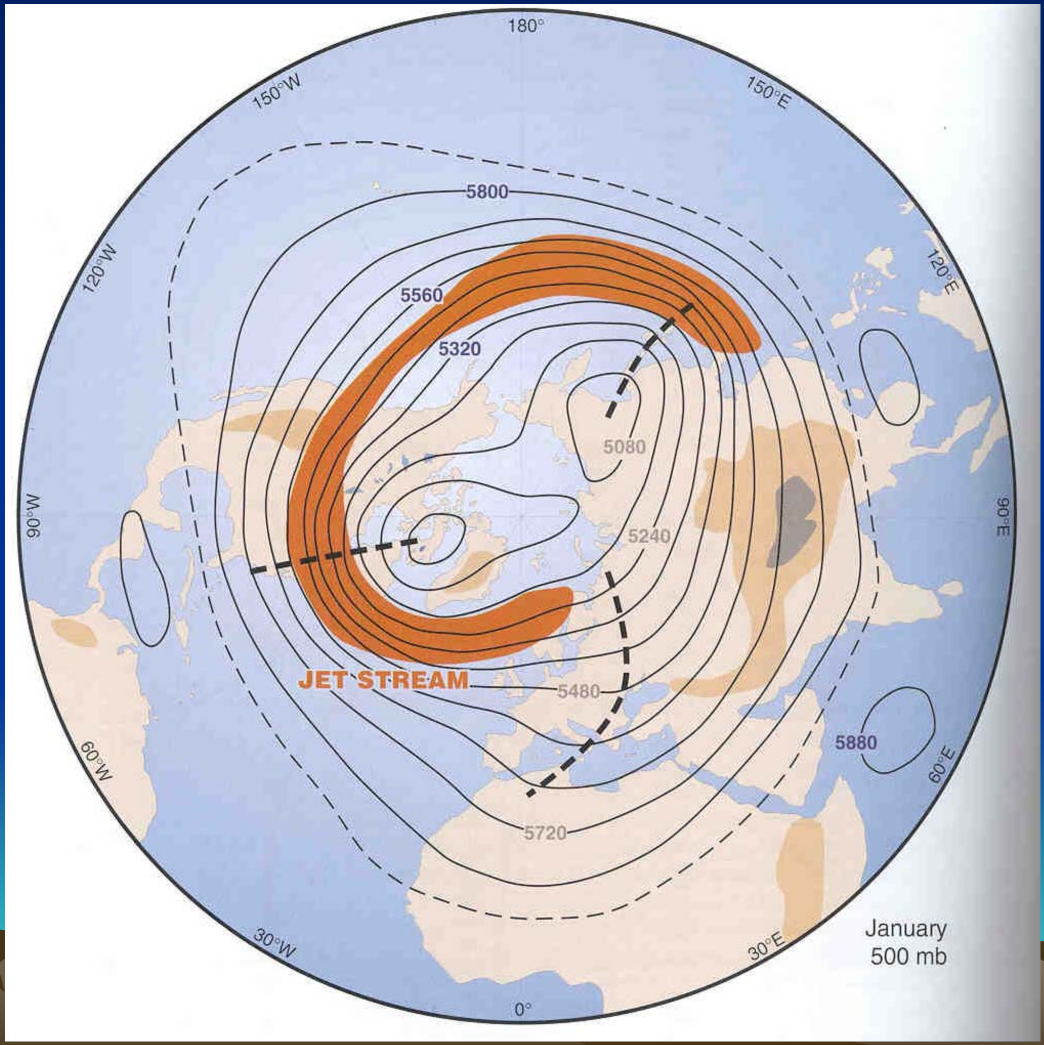
Planetary-Scale Mountain Waves

- Planetary-scale waves are observed that remain fixed with respect to the earth's surface:
- Possible causes are geographic distribution of:
  - Mountains (Charney and Eliassen 1949)
  - Land/sea differences and inequitable distribution of sensible and latent heating (Smagorinsky 1953)
- After 30 years of debate, answer settled that both are important, but mountains perhaps a little more so

Gross-simplification of planetary-scale stationary waves



January Mean Height



Whiteman (2000)

Jet Stream

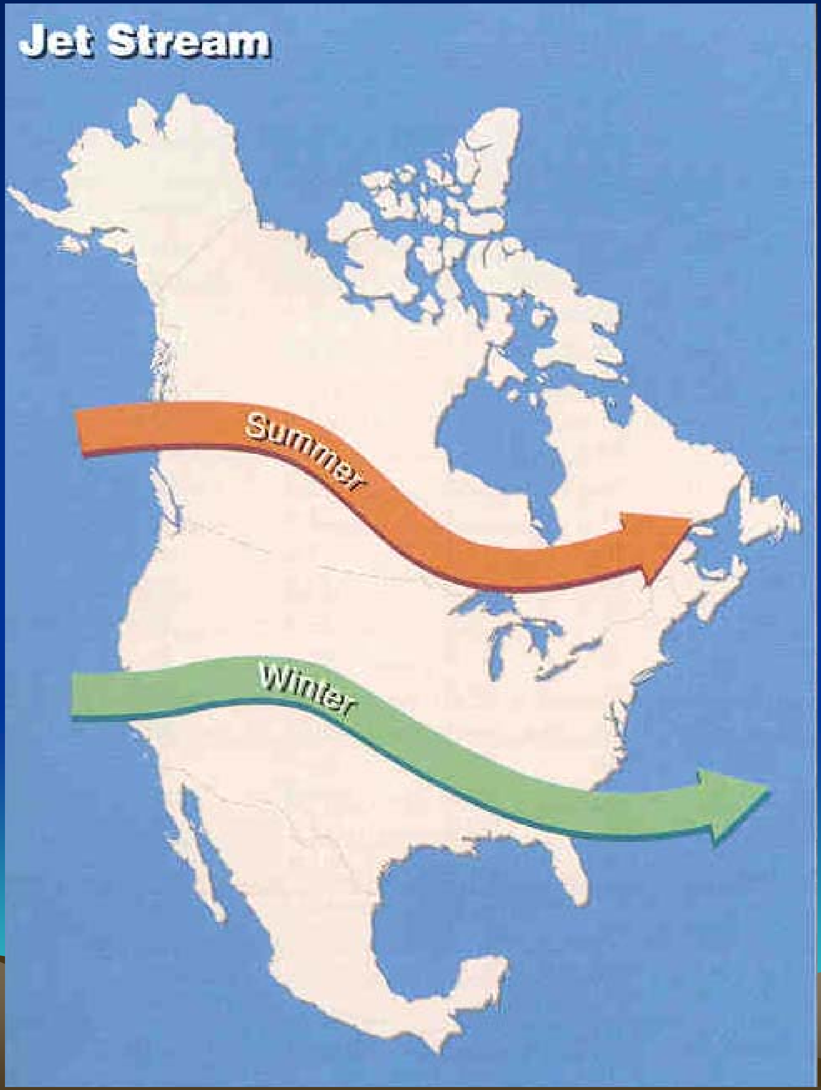


Figure 5.8 The mean position of the jet stream in winter is over the central United States, but it shifts north into Canada in the summer.

Whiteman (2000)

Cyclogenesis

- The formation of intensification of low pressure systems (cyclones)
- Often occurs in the lee of major mountain barriers

Areas of Cyclogenesis

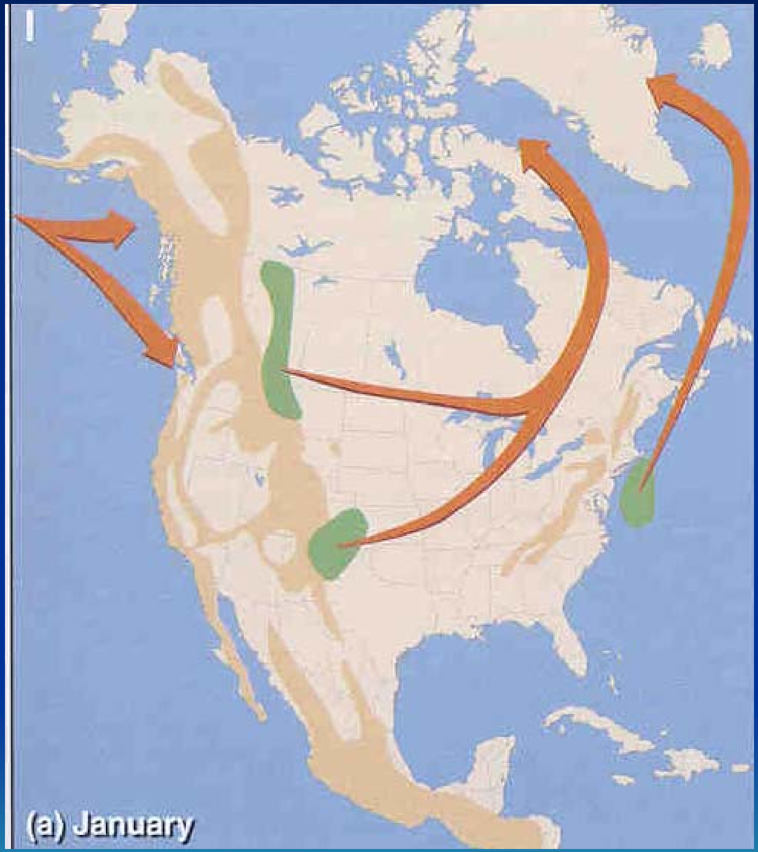


Figure I Locations (green areas) of frequent (a) January and (b) July cyclogenesis in North America and the most likely paths of the cyclones. (Adapted from Zishka and Smith, 1980)

Whiteman (2000)

Anticyclogenesis

- Formation or intensification of a high pressure system (anticyclone)

Areas of Anticyclogenesis

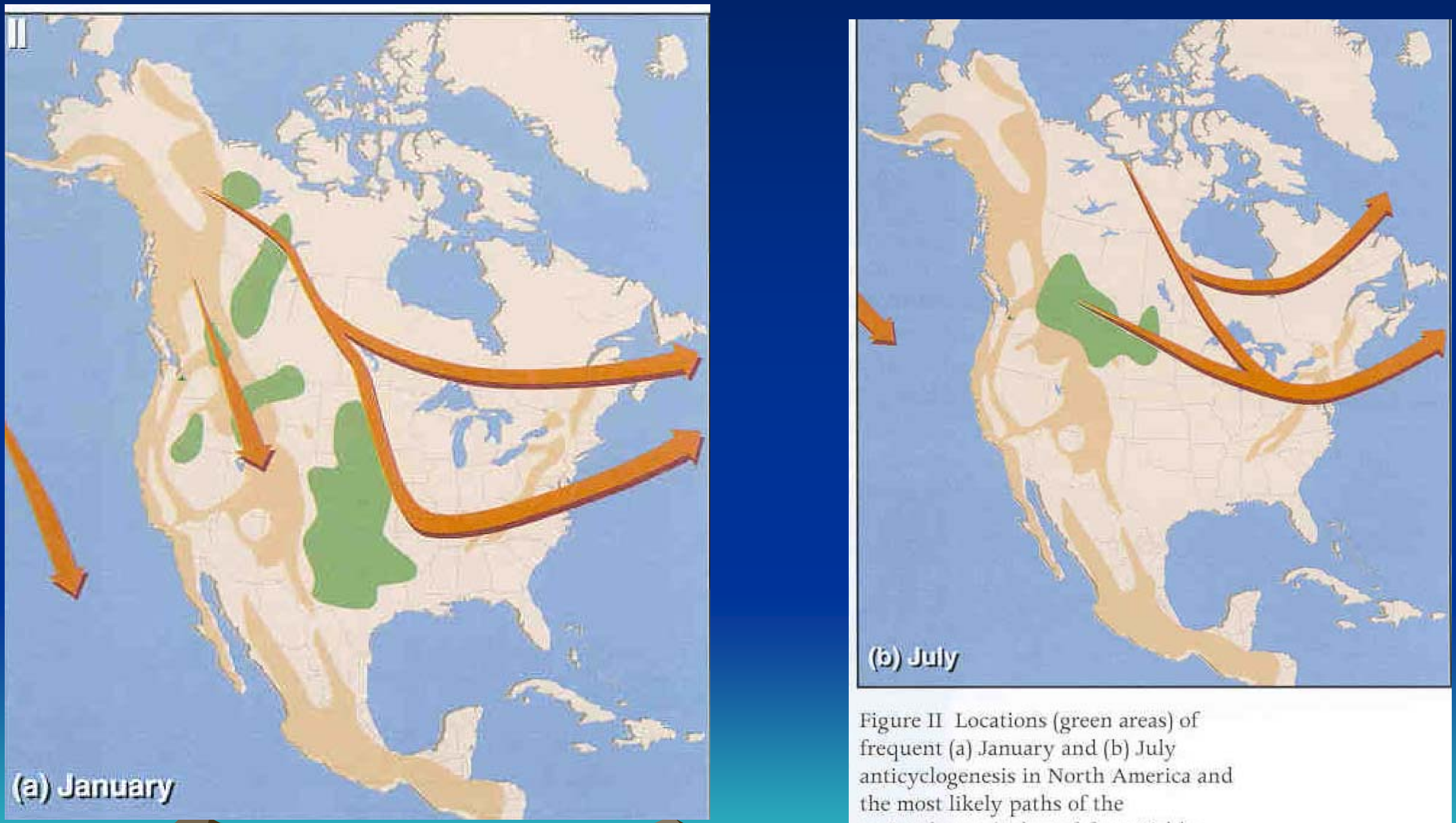


Figure II Locations (green areas) of frequent (a) January and (b) July anticyclogenesis in North America and the most likely paths of the anticyclones. (Adapted from Zishka and Smith, 1980)

Whiteman (2000)

Conservation of Potential Vorticity

- Quantities that are conserved (unchanging) are good tracers
- Potential vorticity tends to be conserved for large scale motions in the atmosphere
- PV = rotation/depth of fluid
- PV = η/p = $(\zeta+f)$/p
- $\eta = (\zeta+f)$ = absolute vorticity
- ζ = relative vorticity: local rotation about vertical axis. Cyclones have positive spin in NH
- f = planetary vorticity: spin due to rotation of earth about its axis. Earth has positive spin in NH

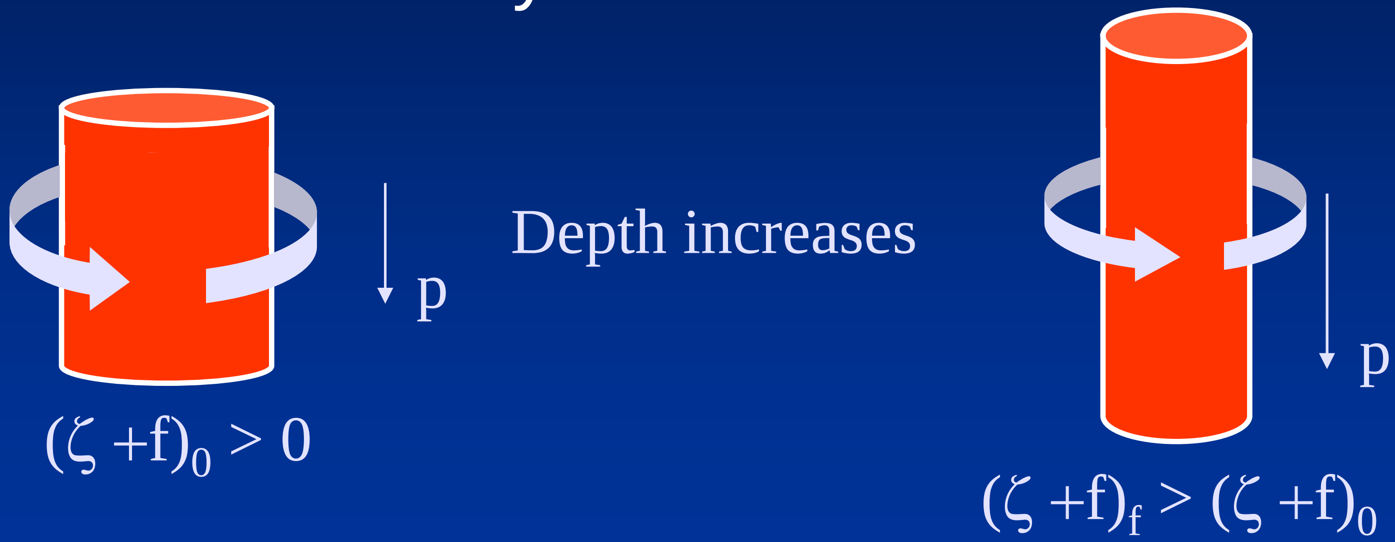
Potential Vorticity

- If the depth of the fluid decreases, then the absolute vorticity must decrease

- Parcel must acquire anticyclonic absolute vorticity
- A parcel with an initial cyclonic rotation could decrease ζ (cyclonic rotation weakens or becomes anticyclonic), decreasing f (parcel moves equatorward), or both

Potential Vorticity

- If the depth of the fluid increases, then the absolute vorticity must increase



- Parcel must acquire cyclonic absolute vorticity
- A parcel with an initial cyclonic rotation could increase ζ (cyclonic rotation strengthens), increase f (parcel moves poleward), or both

How can we make or strengthen a cyclone?

- Need to increase low-level cyclonic vorticity
- Must stretch low-level fluid columns
- To stretch the column, we need middle-tropospheric ascent, near-surface descent, or both

Development of Lee Side Trough