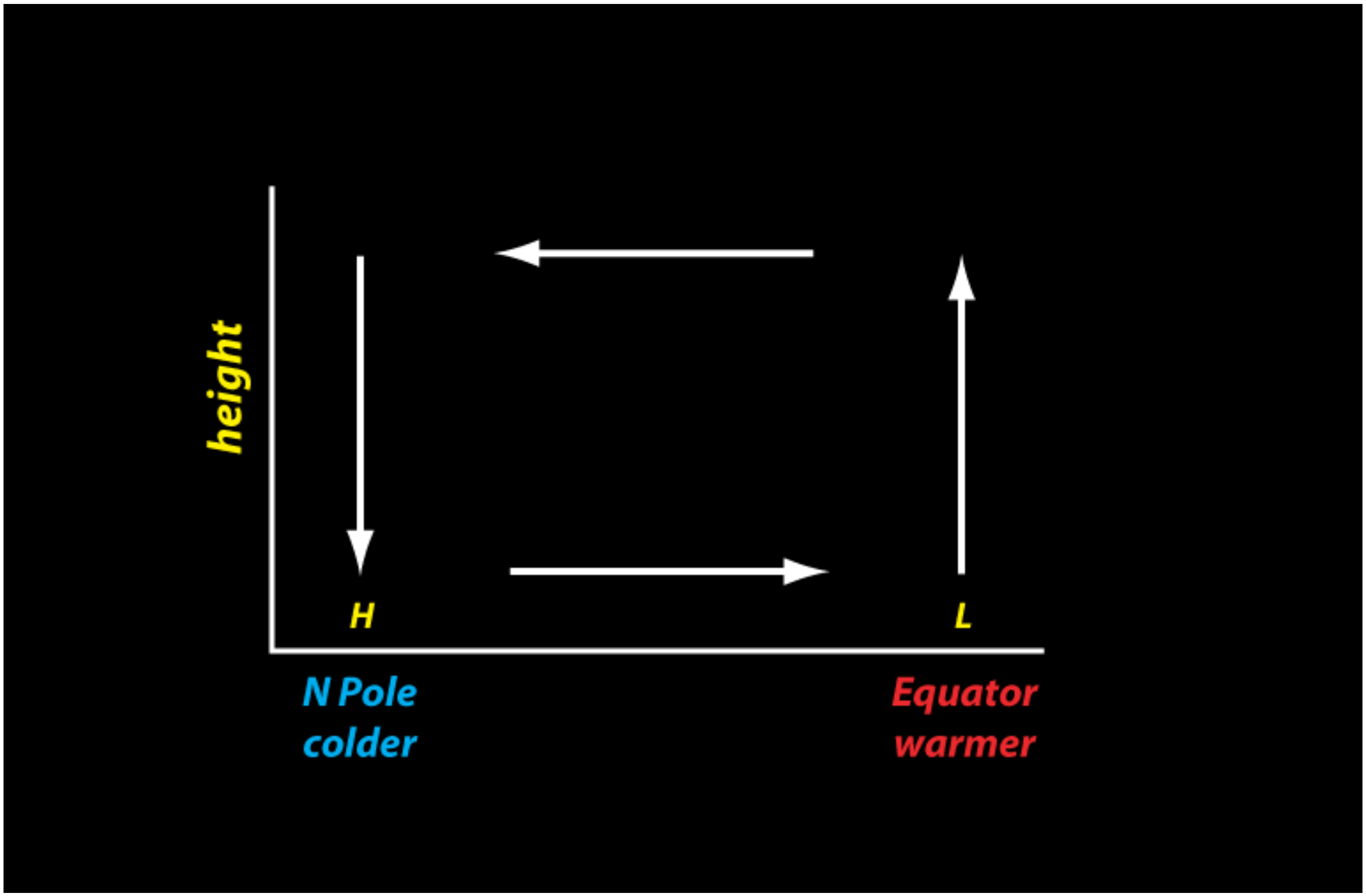
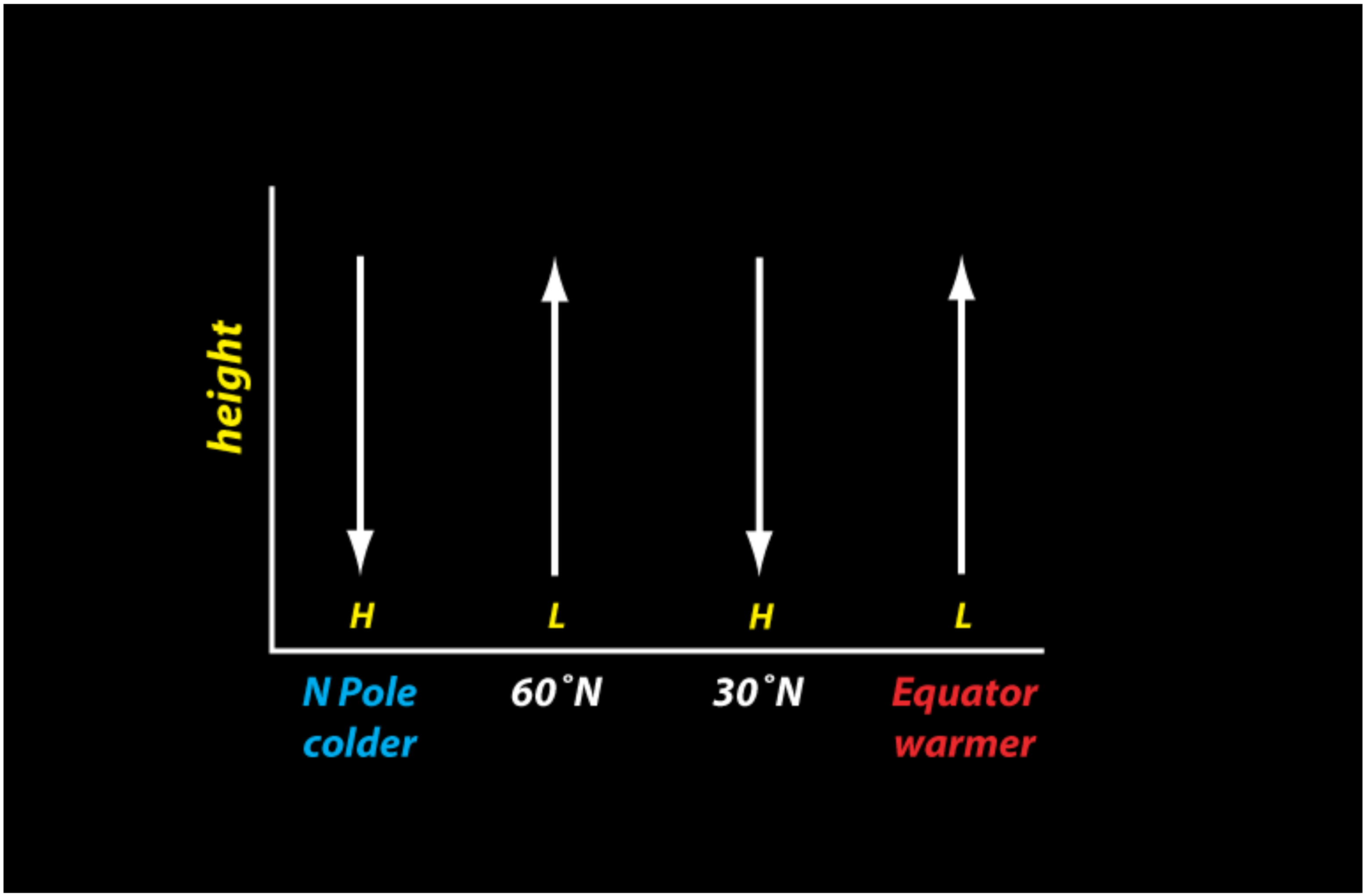
Horizontal temperature gradients, vertical wind shear, and jets

ATM 210 -- Fall 2023 -- Fovell

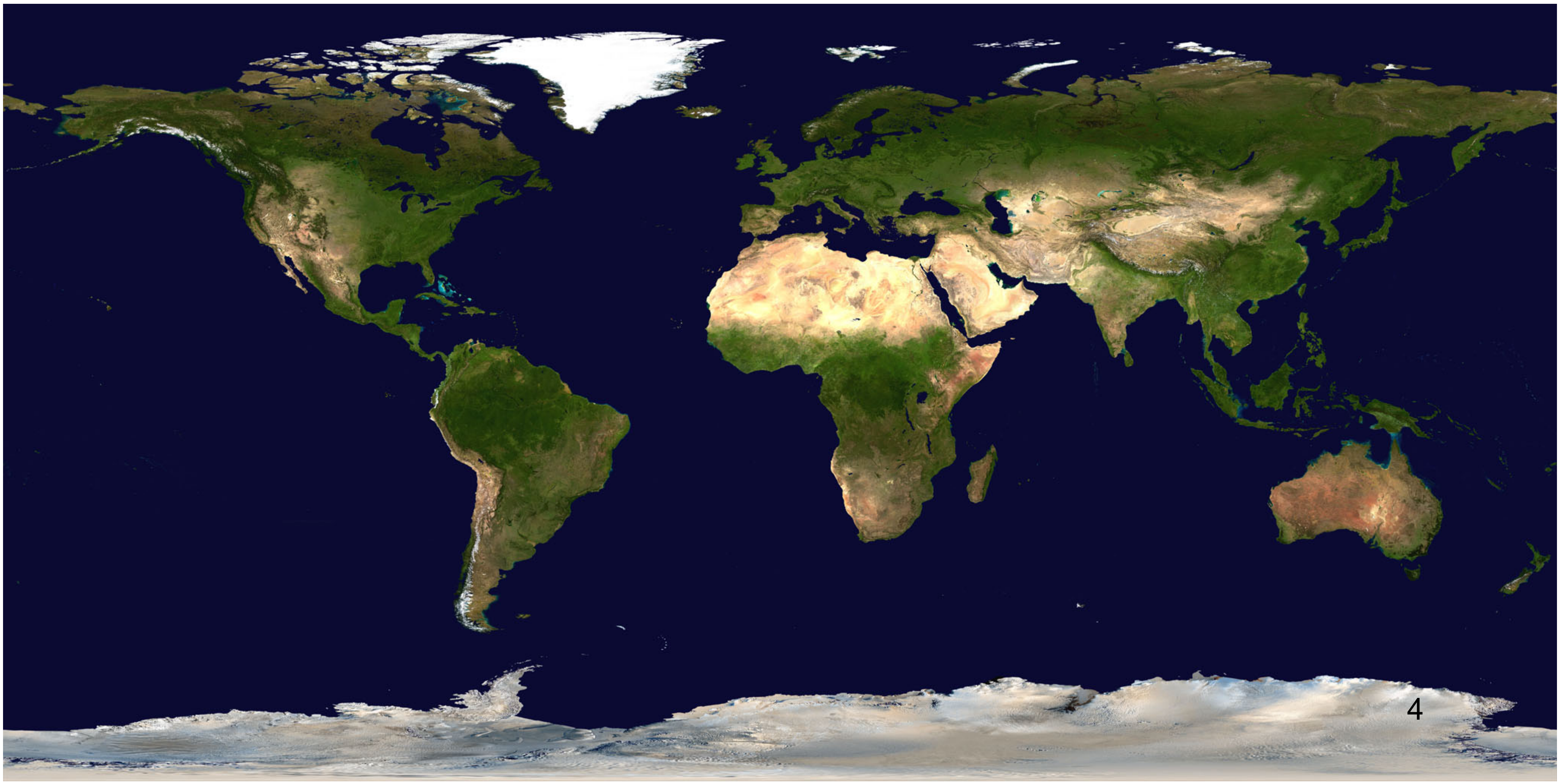
The one-cell model for hemispheric circulation **does not work**



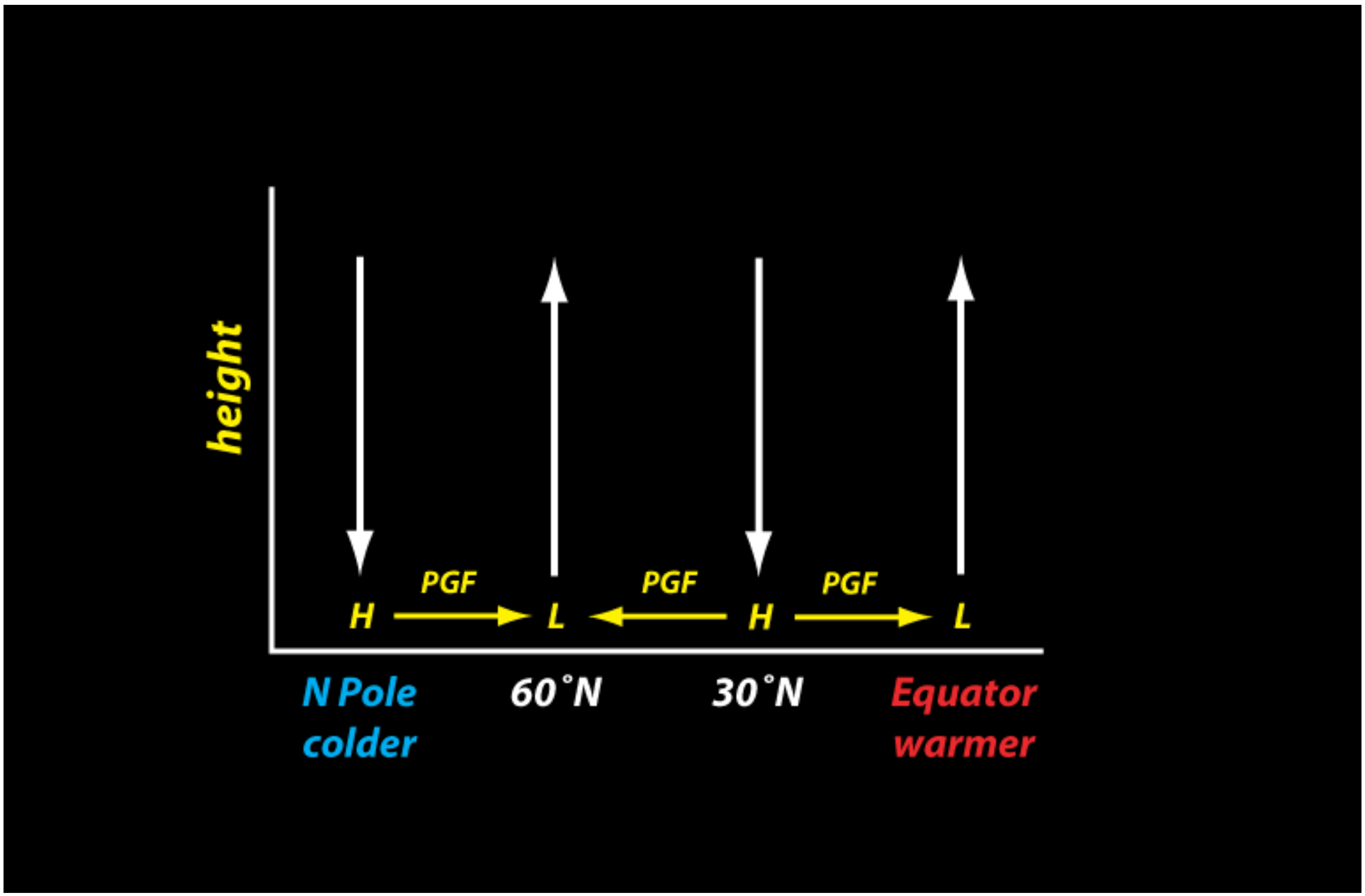
Earth rotation breaks it up into 3 cells per hemisphere, providing preferred latitudes for **storms** and **deserts**

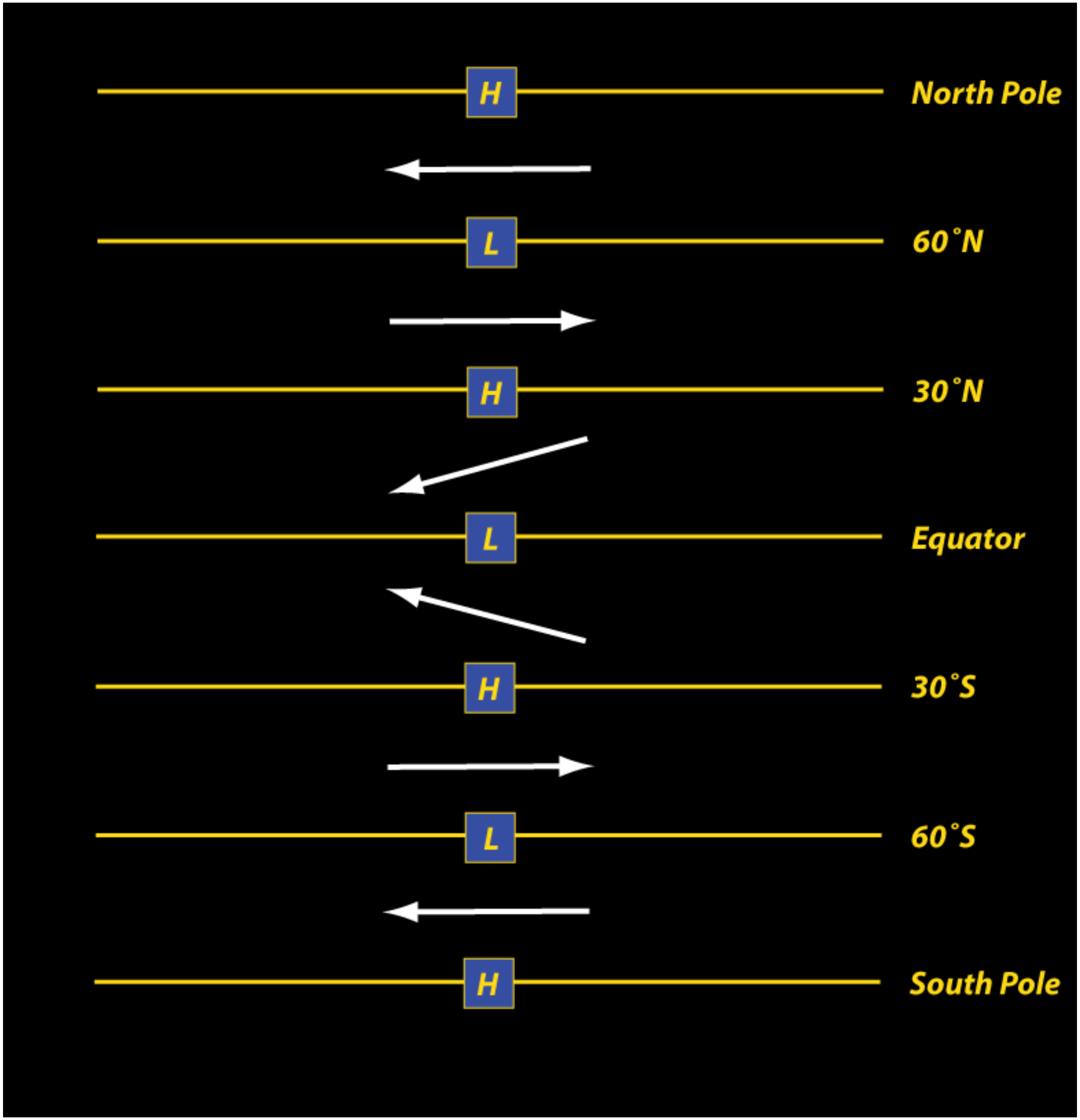


Expect (and largely get) deserts at 30˚N and S…



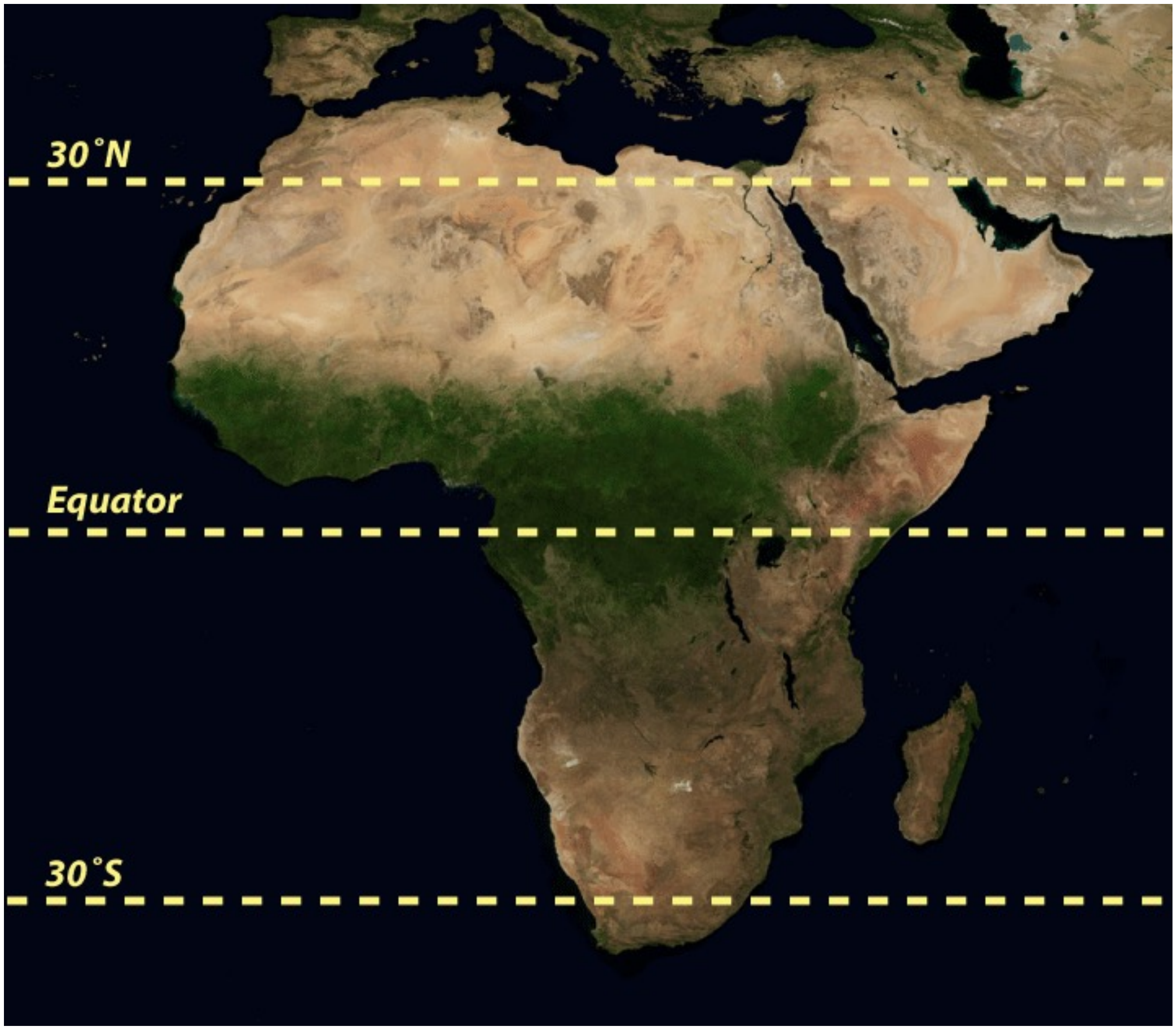
Add the pressure gradients





Near-surface winds for each hemisphere

Convergence & precipitation along the Equator



A few words about air masses

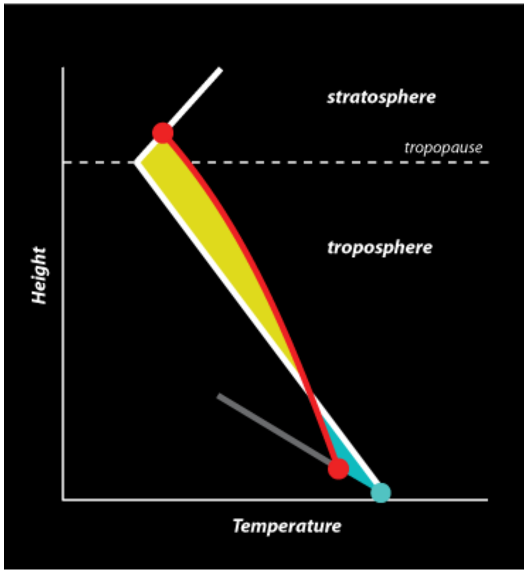
- Four major air mass categories are
  - Continental Polar (cP)
  - Continental Tropical (cT)
  - Maritime Polar (mP)
  - Maritime Tropical (mT)
- In winter, a continental Arctic airmass might also be identified
- Air masses possess **different densities**. Air mass boundaries are **fronts**.

Continental Polar

- In North America, **cP** air is born in Canada.
  - Winter: very cold and dry, and produces our cold air outbreaks
  - Summer: cP air is warmer but still dry
  - The air mass is stable and often cloud-free
    - Stable → resistant to vertical motion, up or down
  - cP air permits strong **radiation inversions** at night, owing to its lack of water vapor (a greenhouse gas) and lack of cloudiness

Maritime Tropical

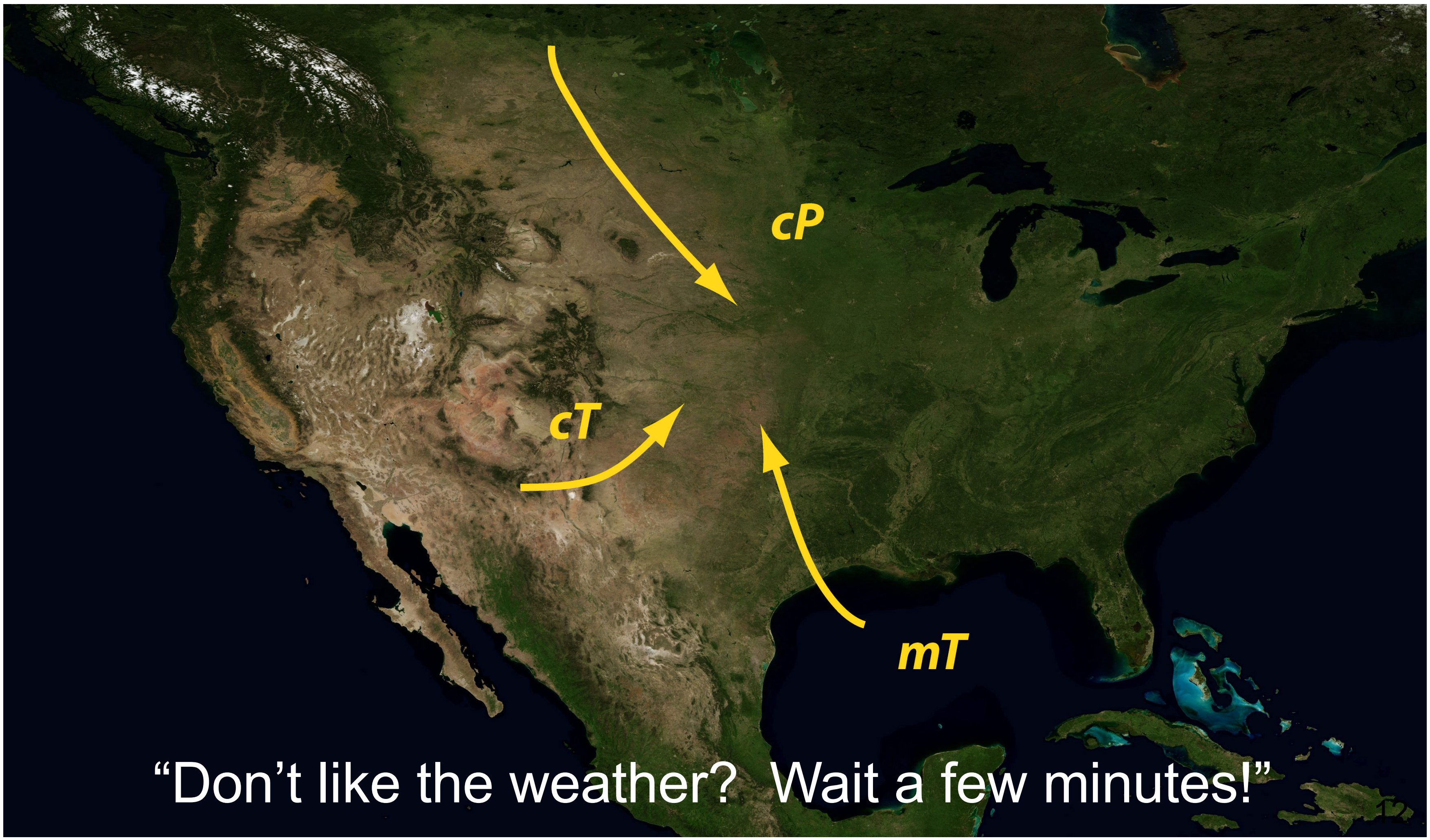
- Our **mT** air comes from the Gulf of Mexico, western Atlantic, and eastern Pacific
  - Always warm and humid
  - The Gulf and Atlantic air is often unstable, with plenty of **CAPE**



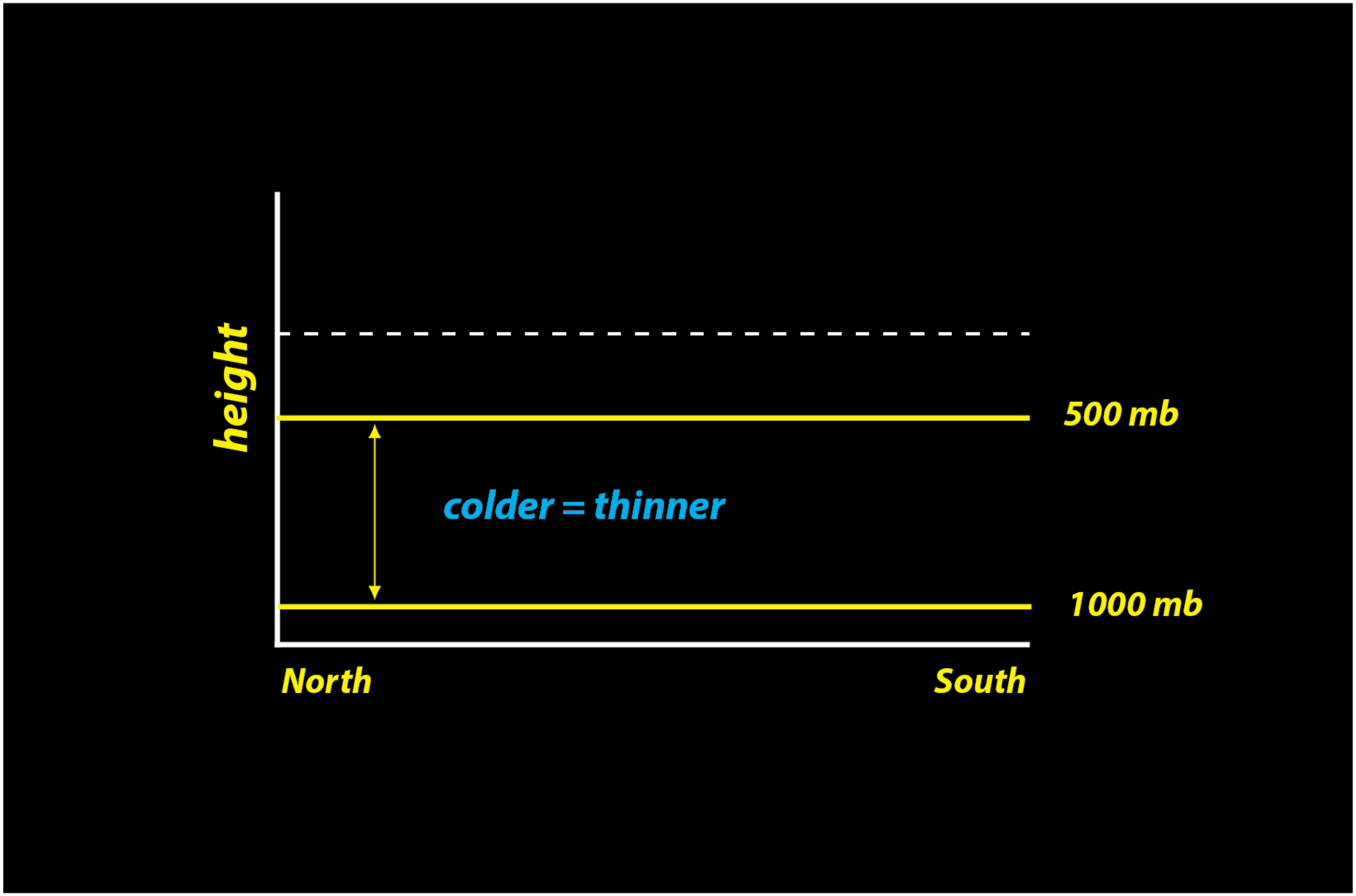
Maritime Polar and Continental Tropical

- **mP** air comes from the north Pacific and Atlantic oceans
  - Cool and humid
  - This air keeps the Pacific Northwest mild and wet in winter
- **cT** air comes from the desert southwestern US and Northern Mexico
  - Only identifiable in summer
  - Then it is **hot and dry**, often with extremely low RH

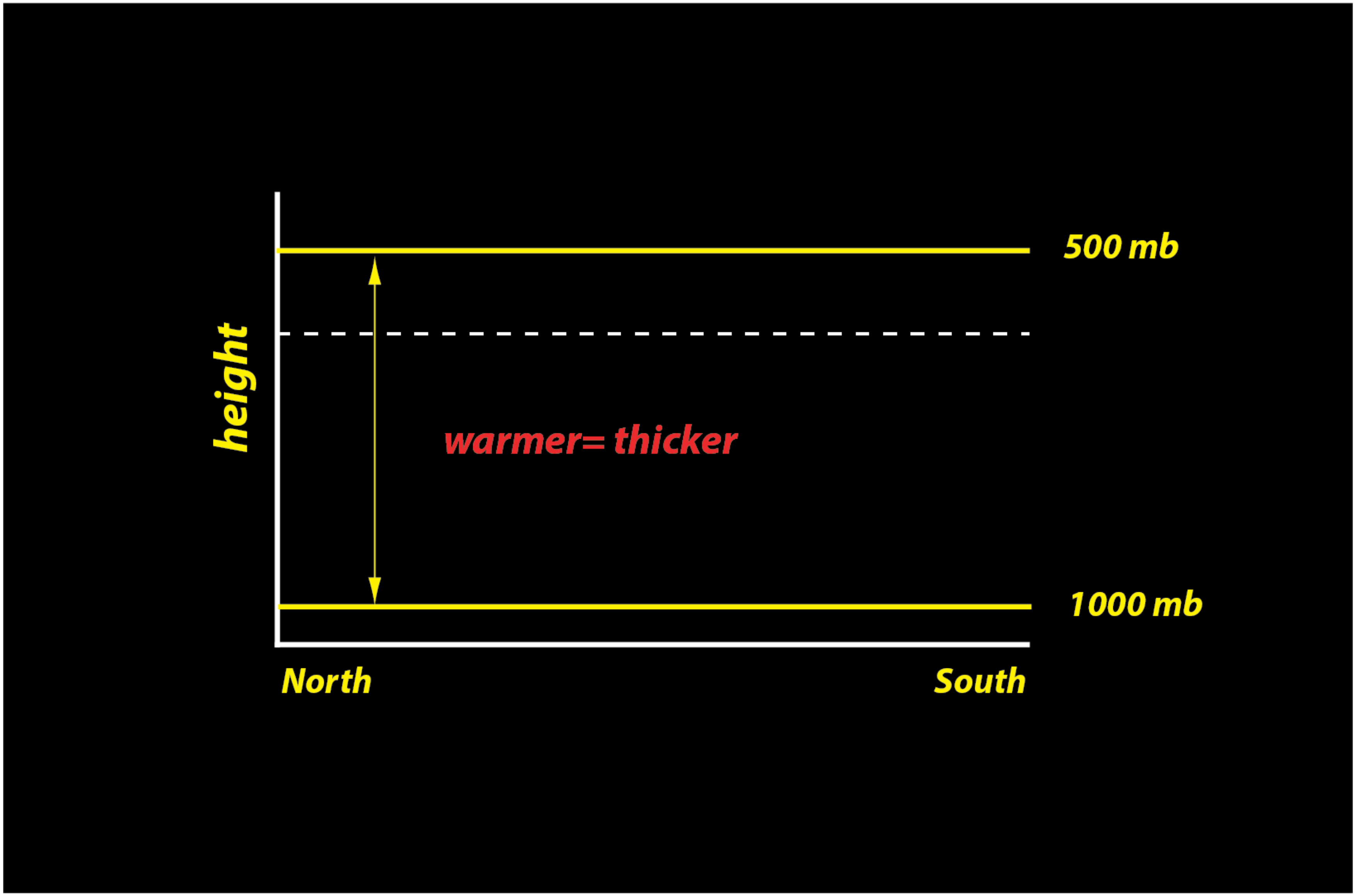
Battlespace: American Midwest. Especially in spring.



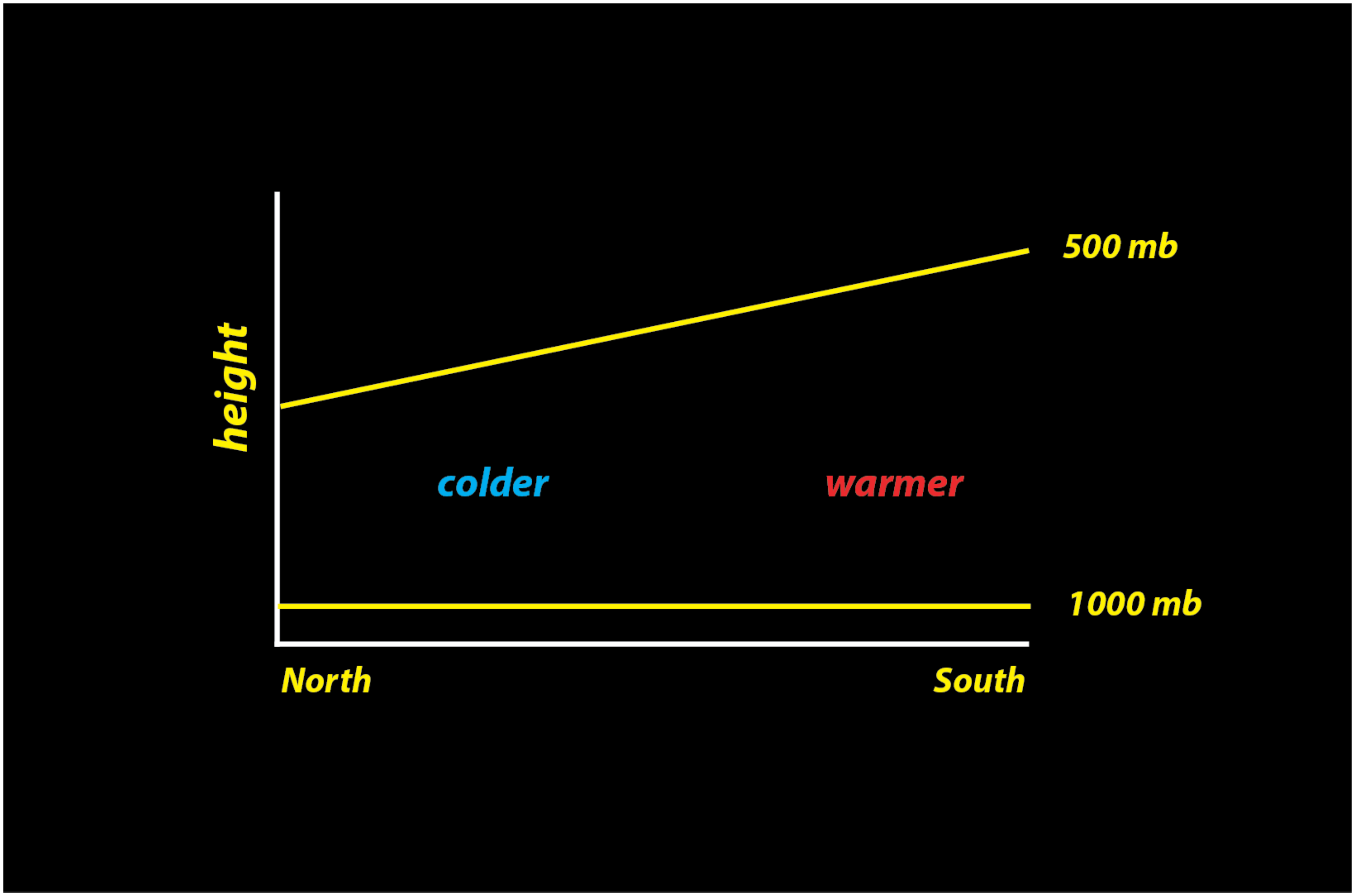
Between 2 pressure levels, fixed amount of mass…



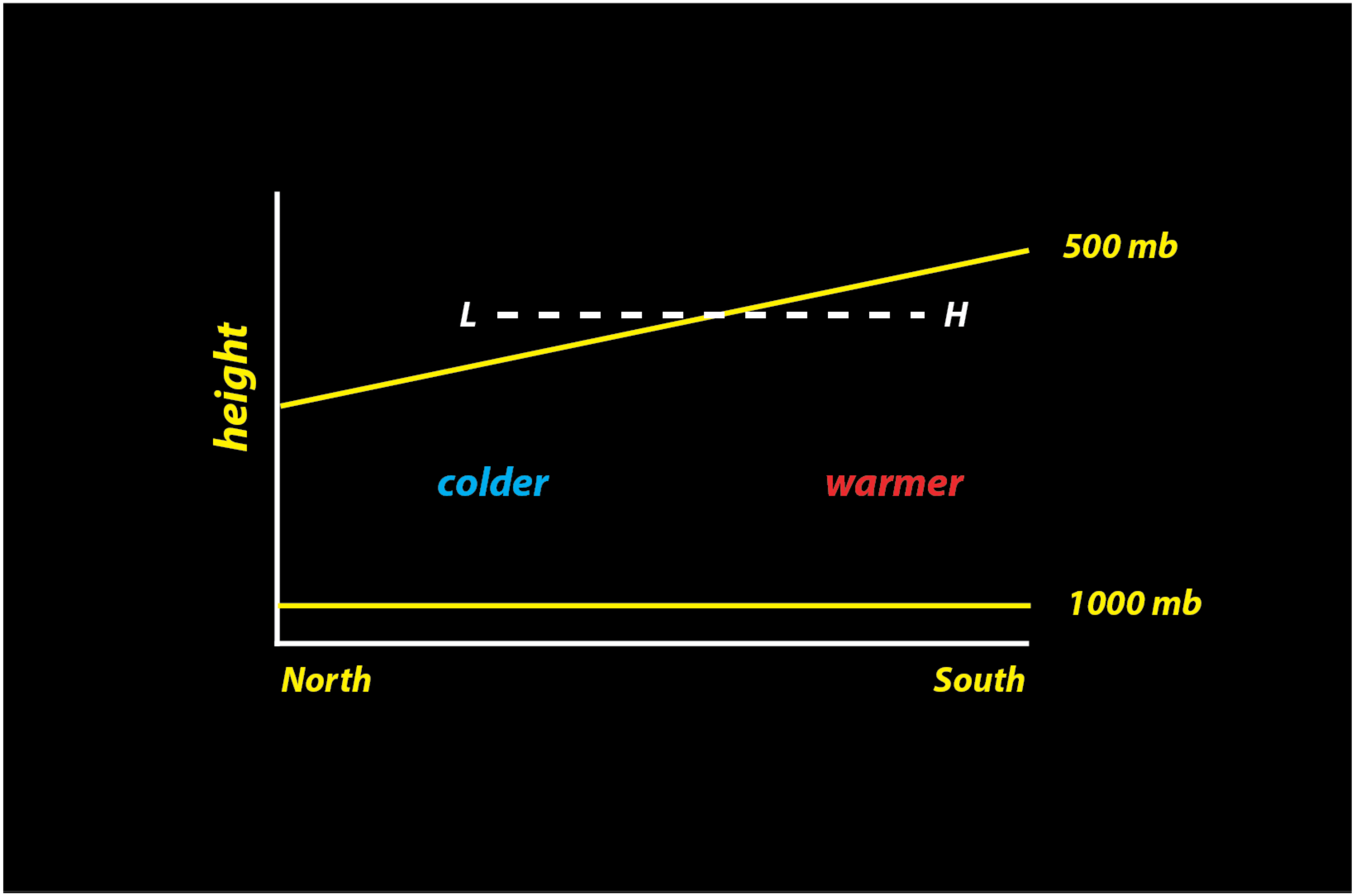
… thickness determined by temperature → **hypsometric**



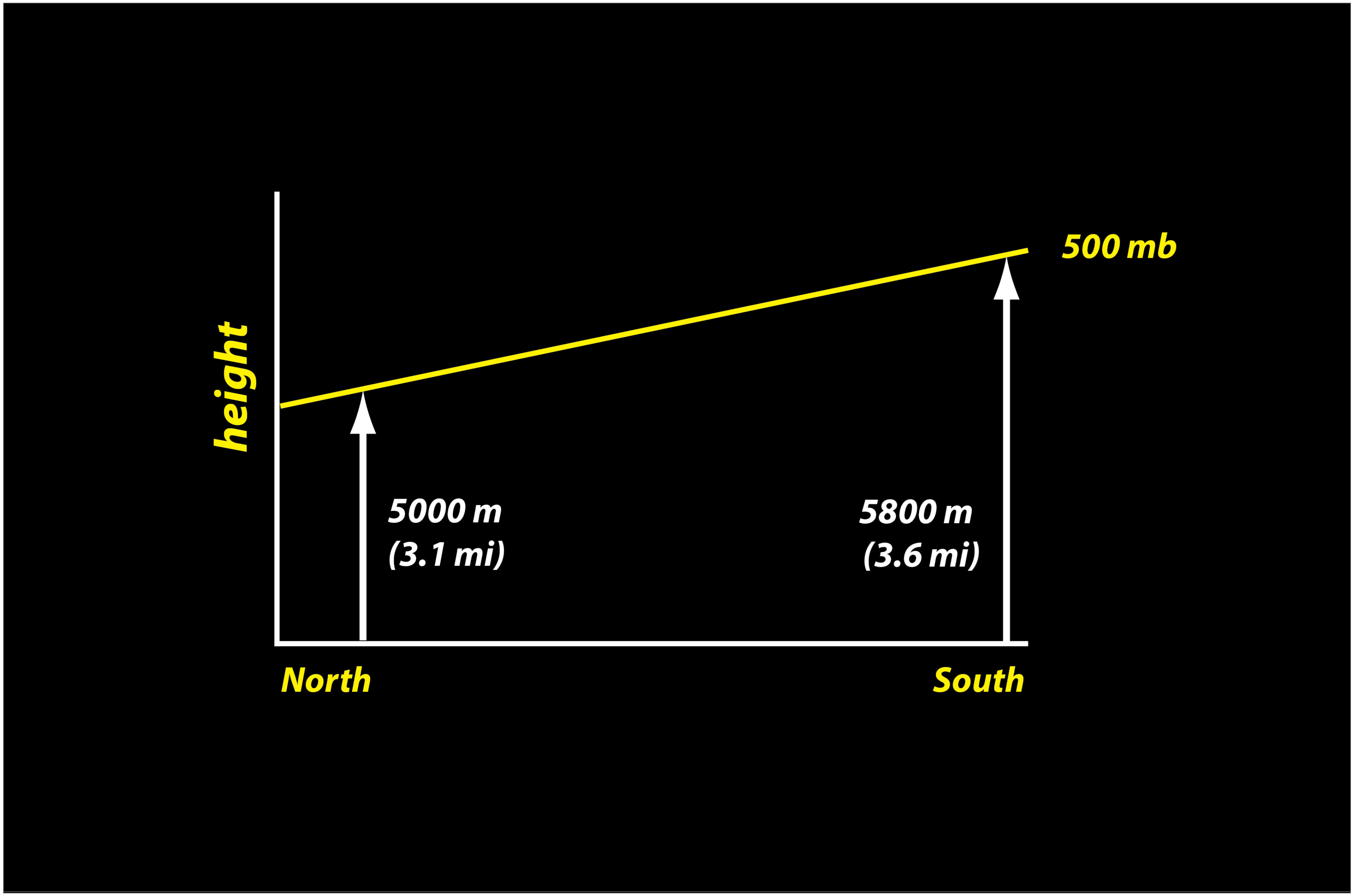
Now introduce a T gradient



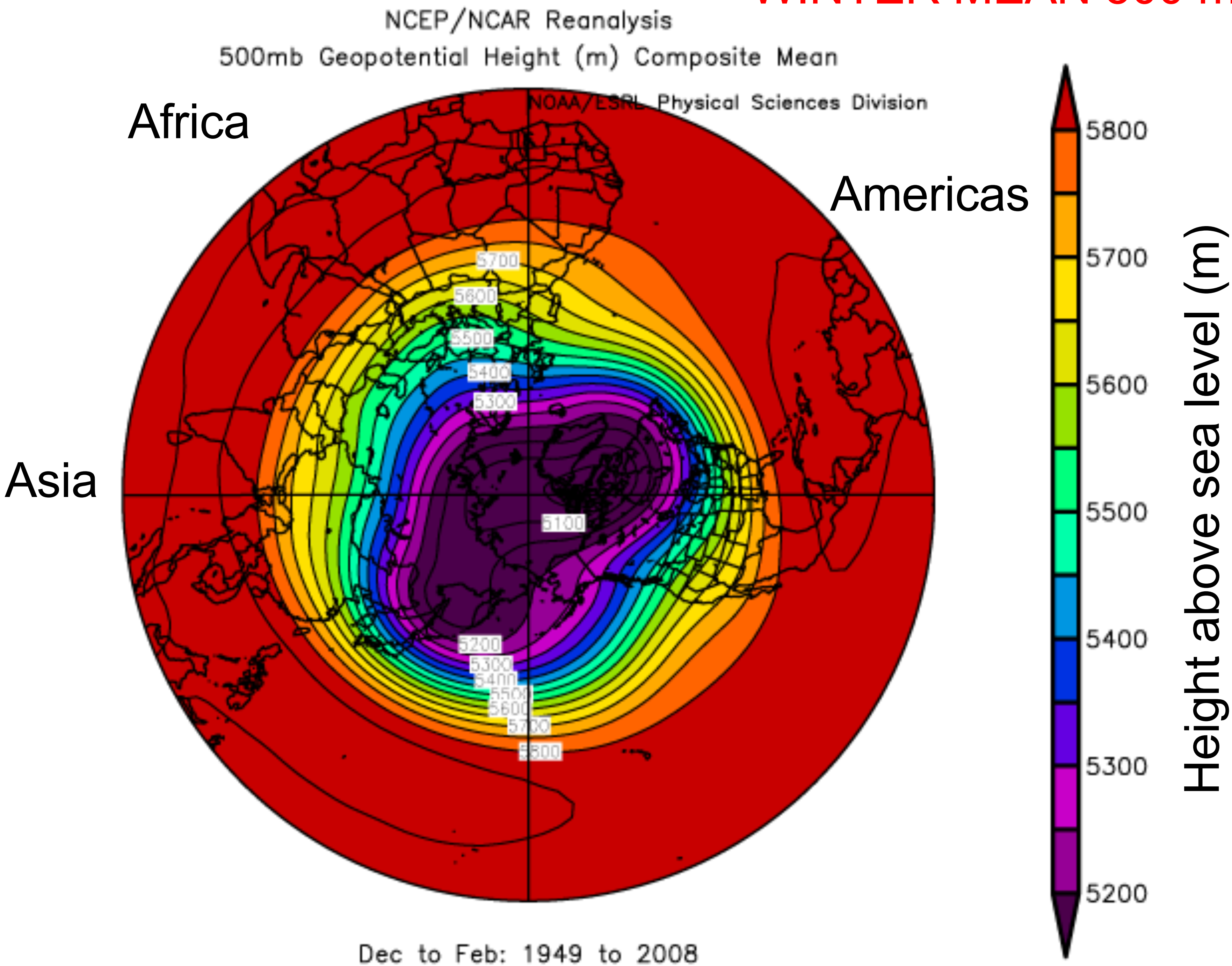
T gradient → p gradient → west to east geostrophic wind



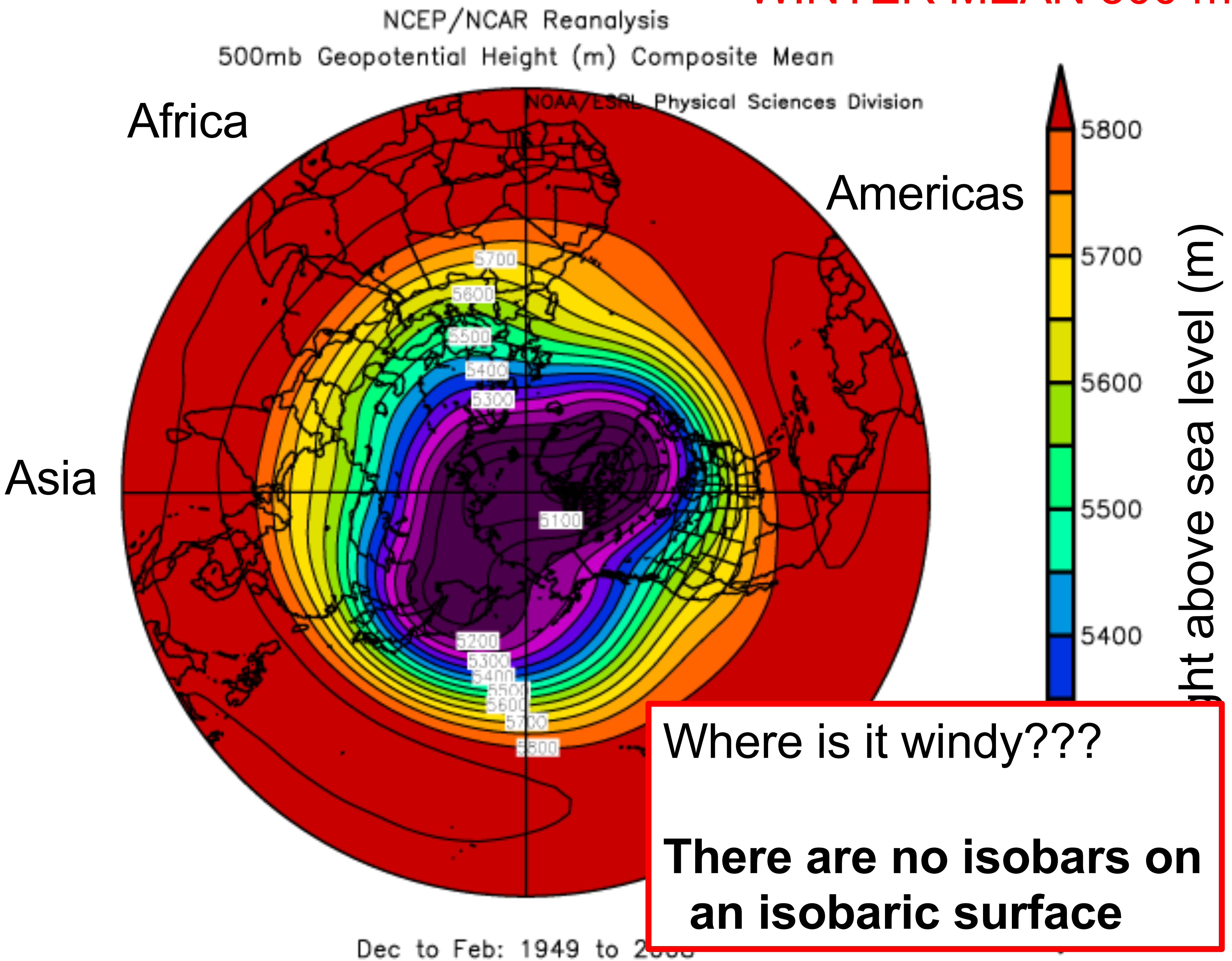
500 mb **height** above sea-level



WINTER MEAN 500 mb height



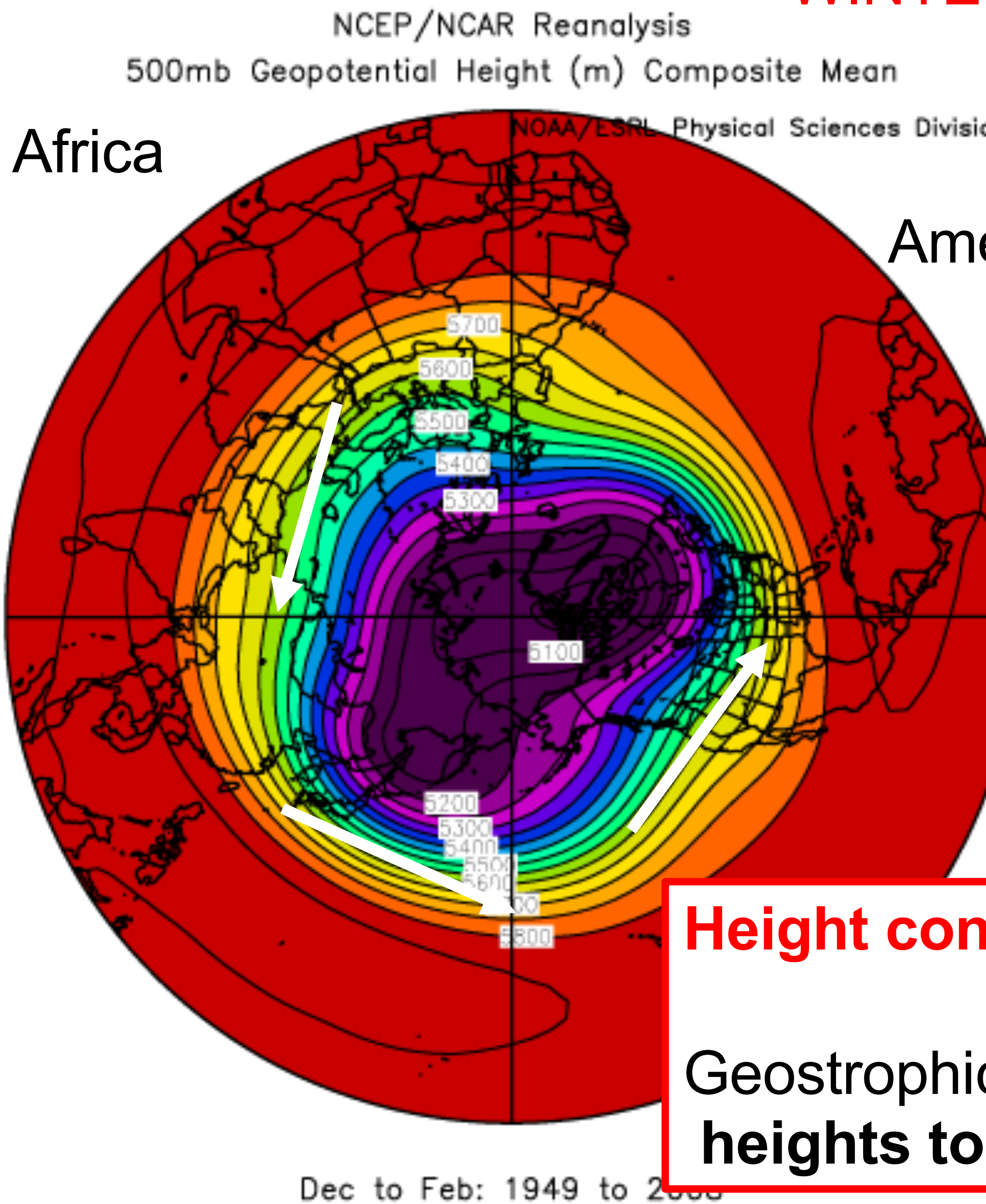
WINTER MEAN 500 mb height

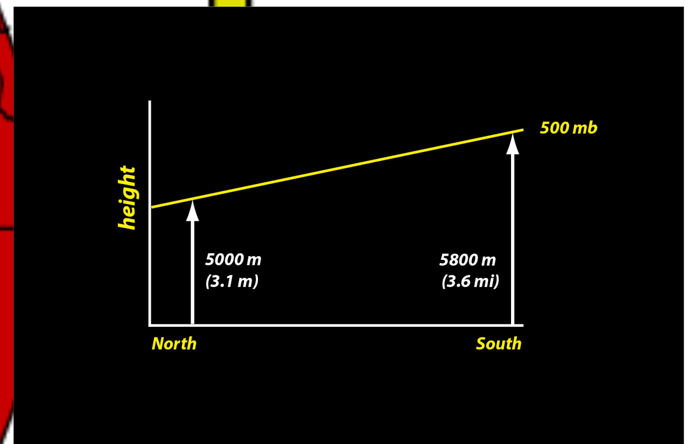


Where is it windy???

There are no isobars on an isobaric surface

WINTER MEAN 500 mb height

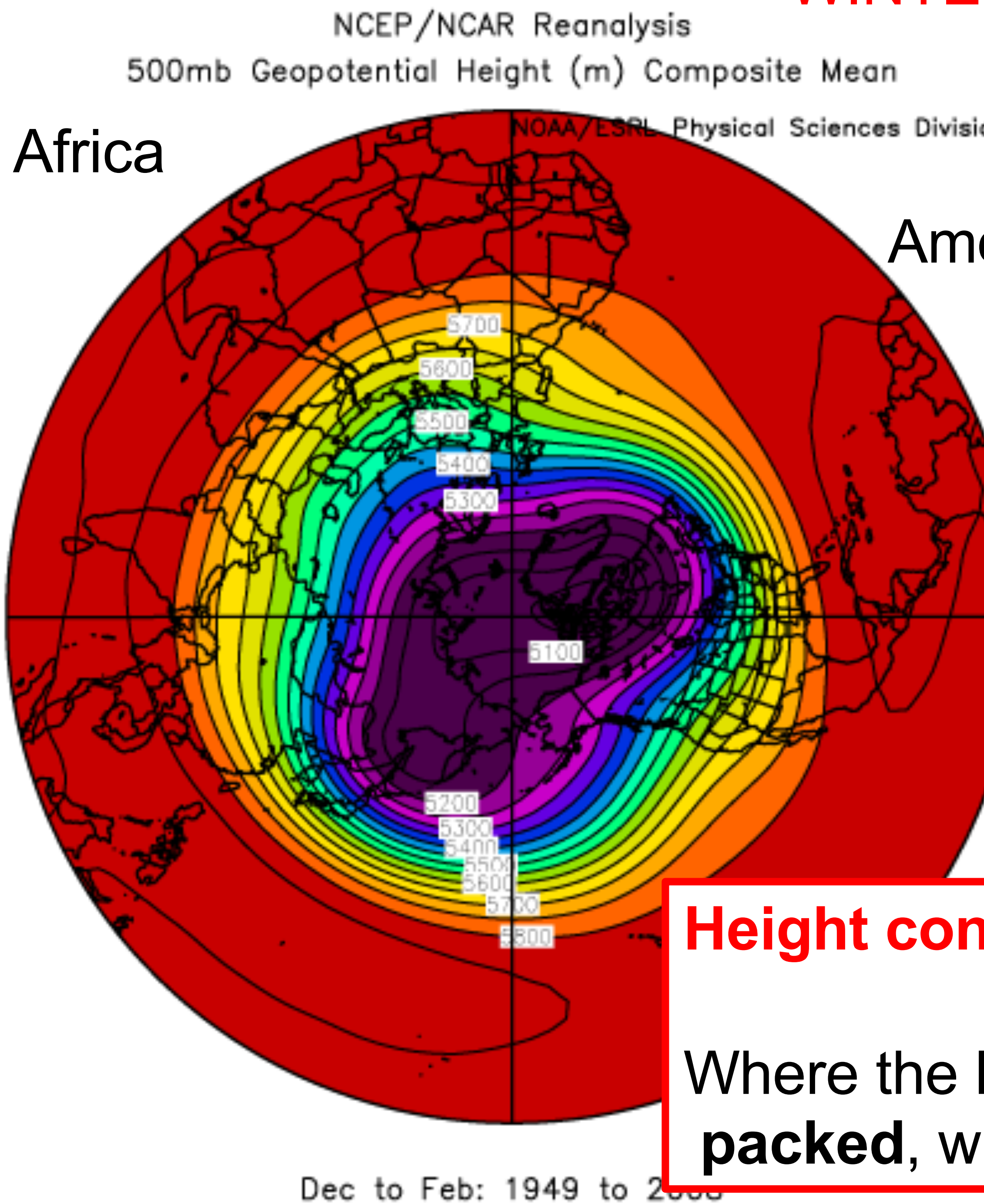


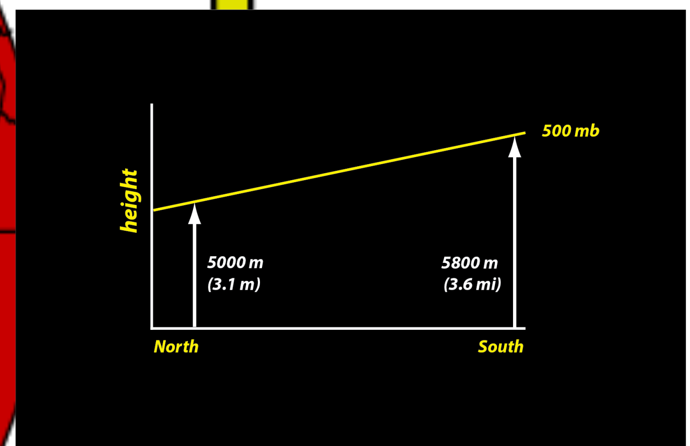


Height contours are like **isobars**

Geostrophic wind blows with **low heights to the left in NH**

WINTER MEAN 500 mb height

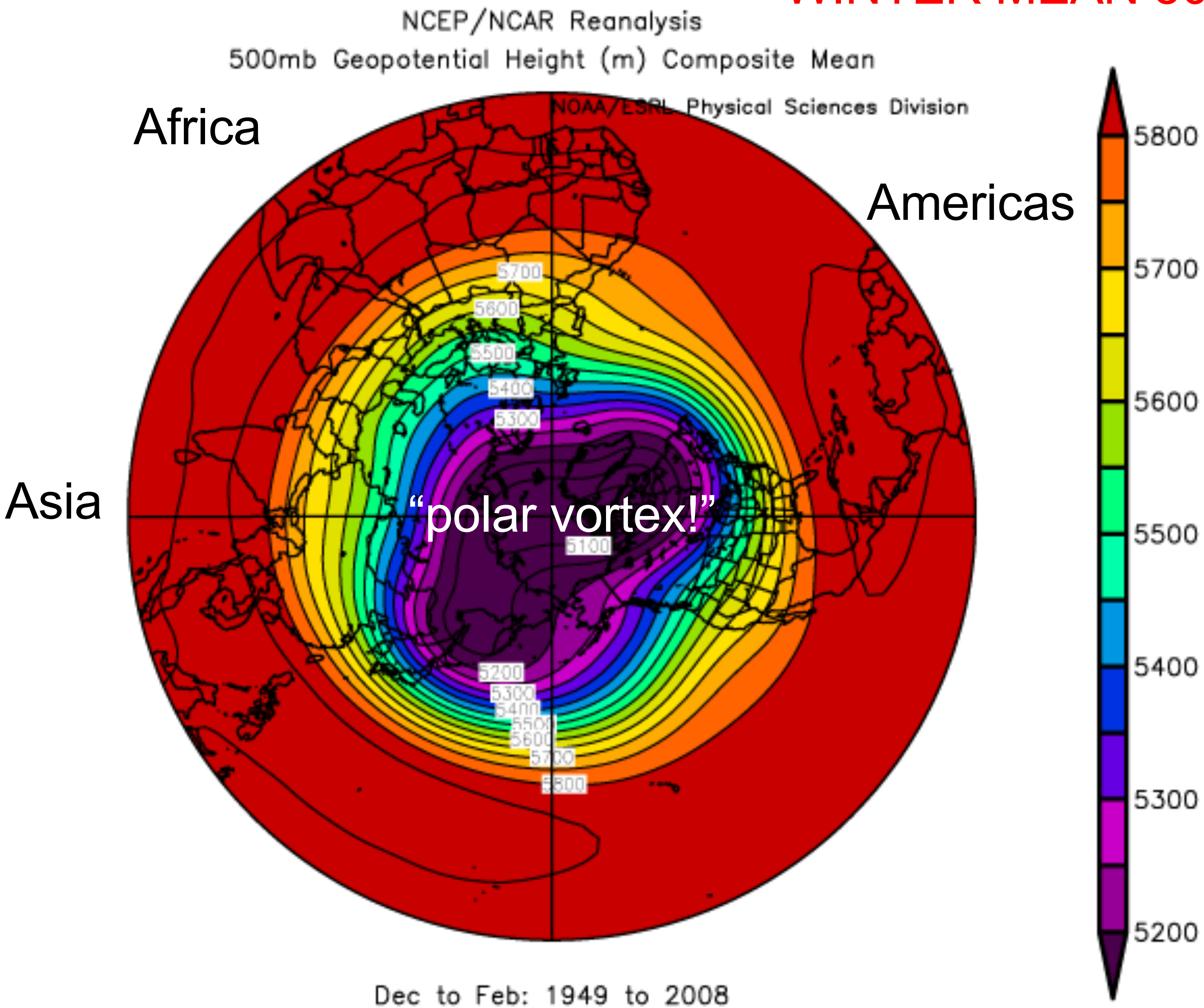




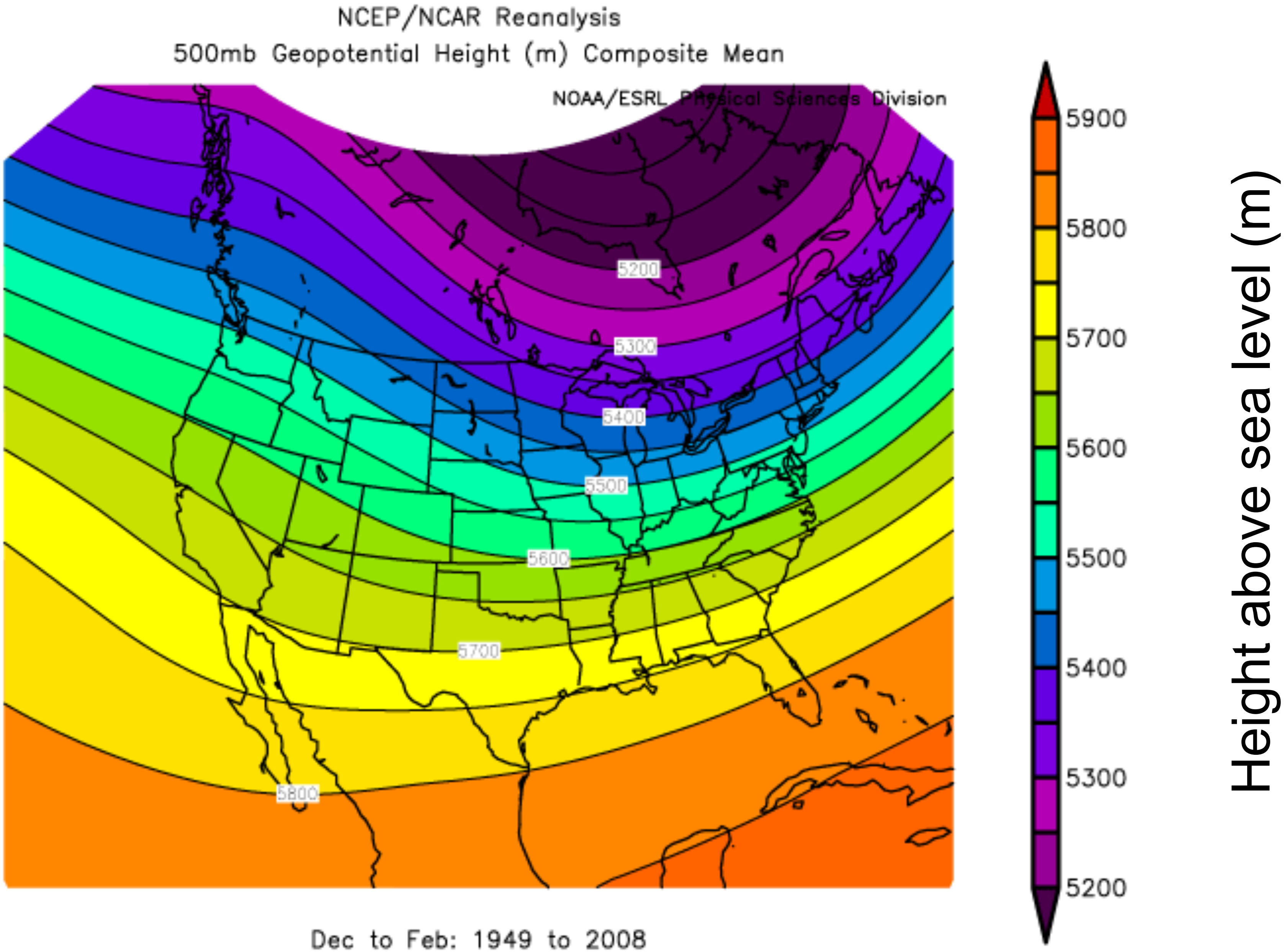
Height contours are like **isobars**

Where the height contours are **packed**, wind is **strong**

WINTER MEAN 500 mb height

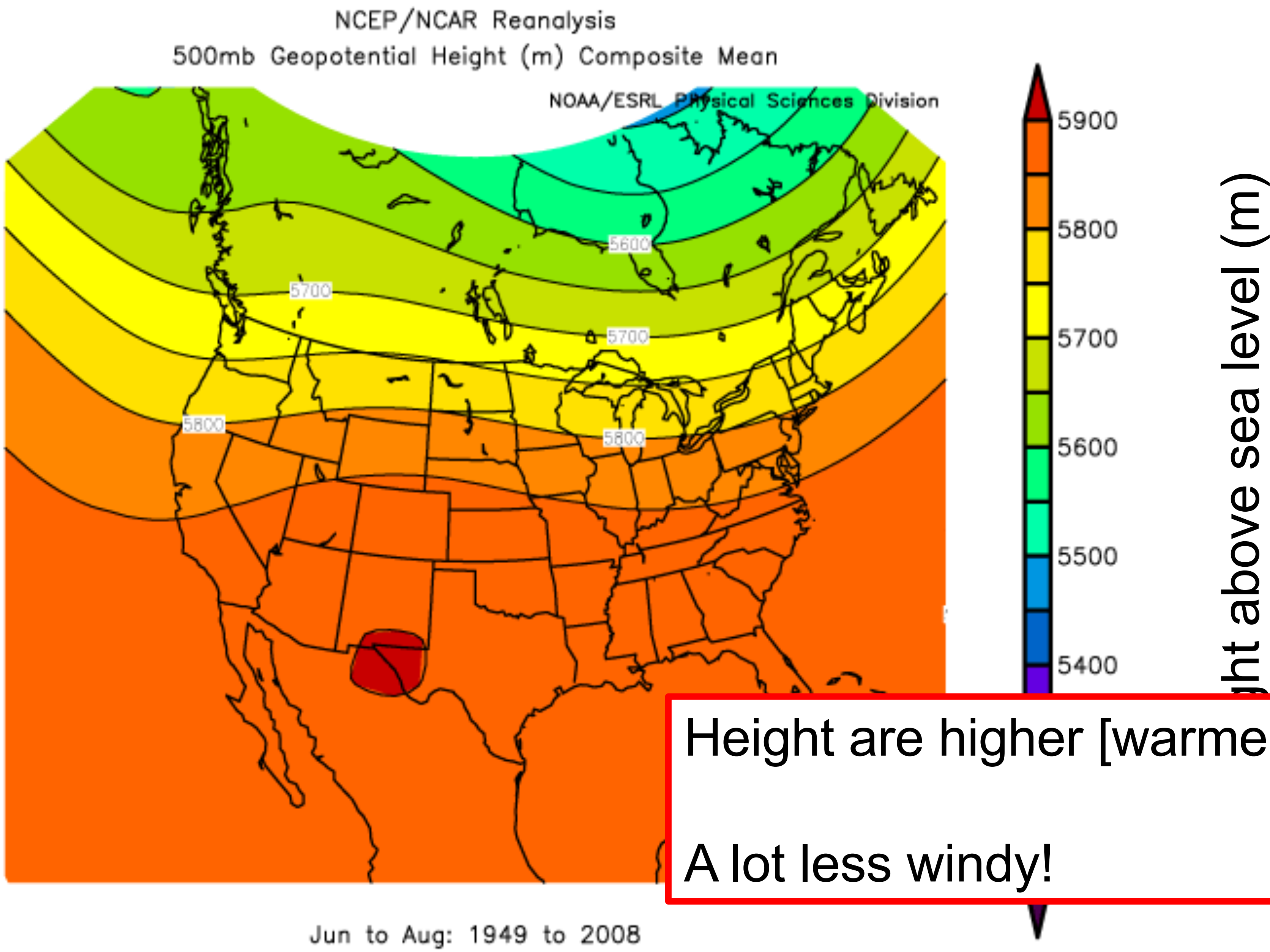


WINTER MEAN 500 mb height



How does this look in the summer?

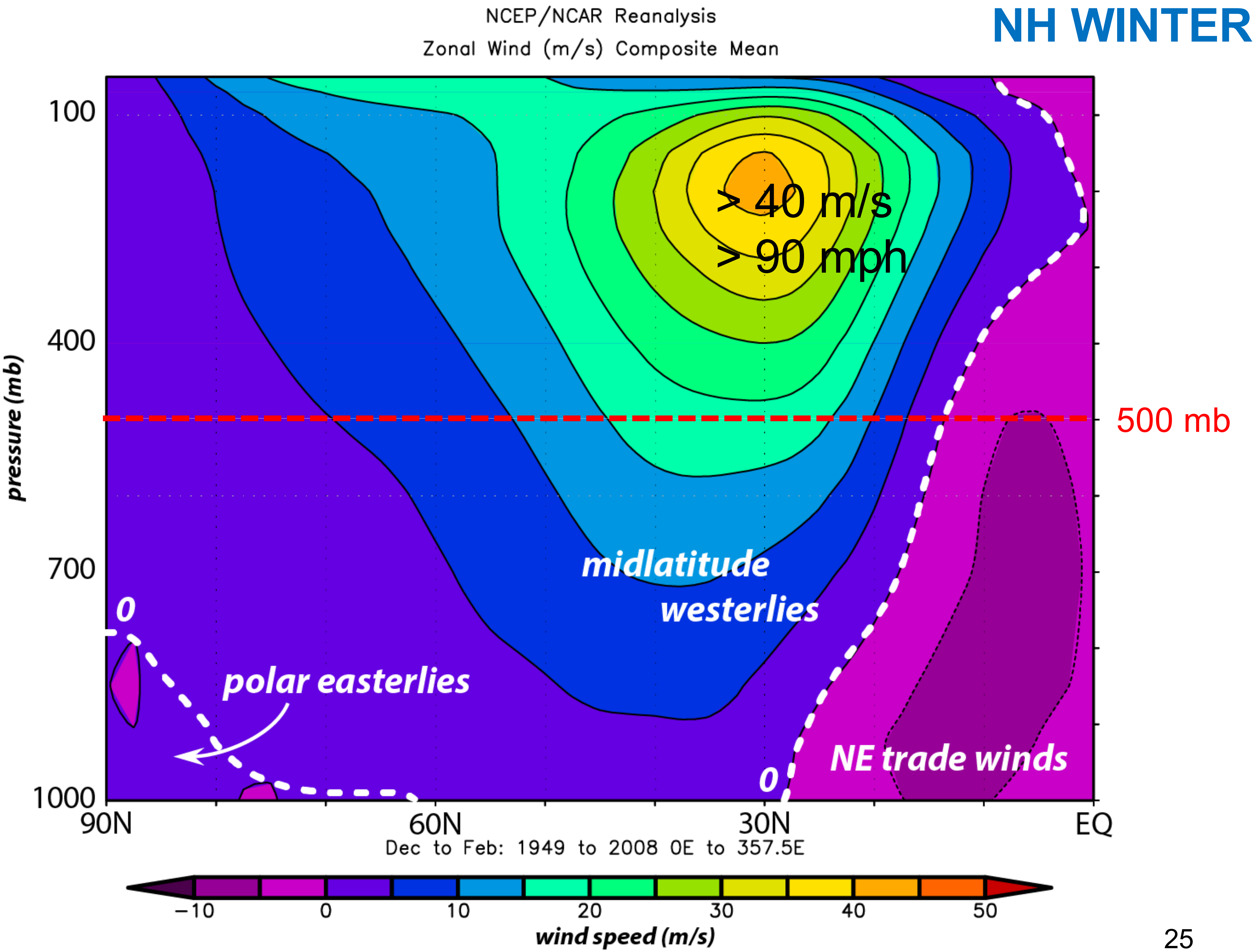
SUMMER MEAN 500 mb height



Height are higher [warmer!]

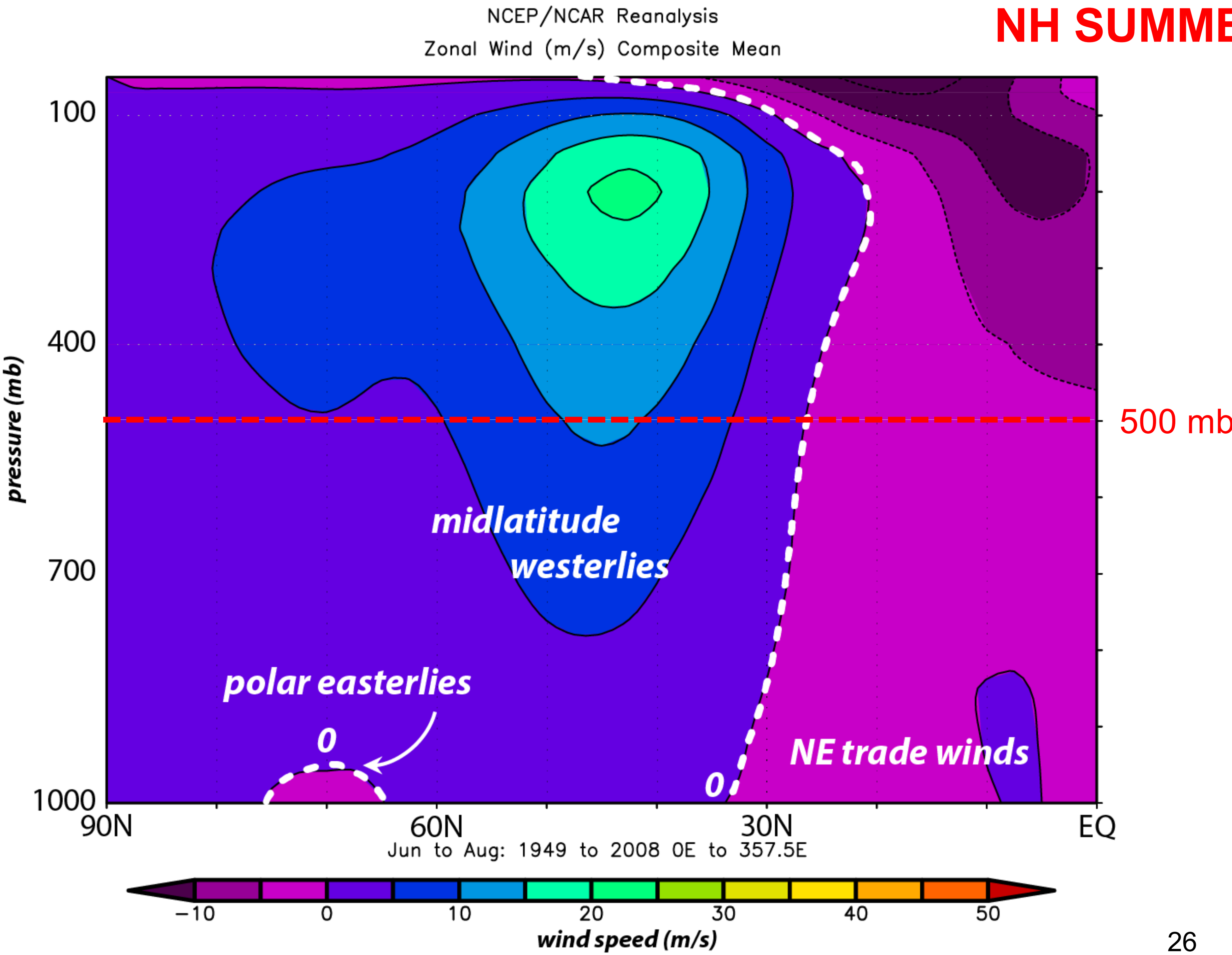
A lot less windy!

NH WINTER



ZONAL WIND = west-east component

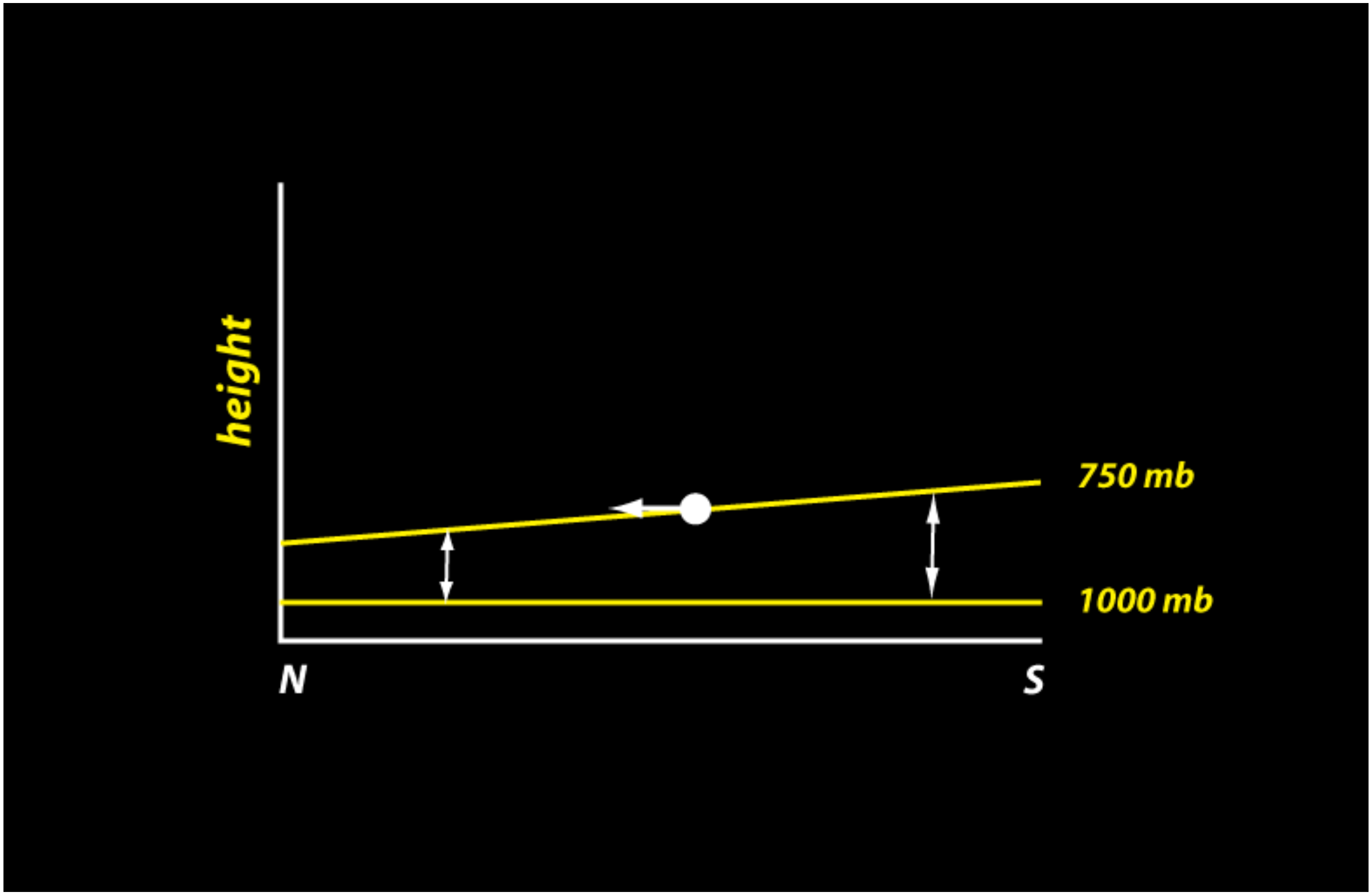
NH SUMMER



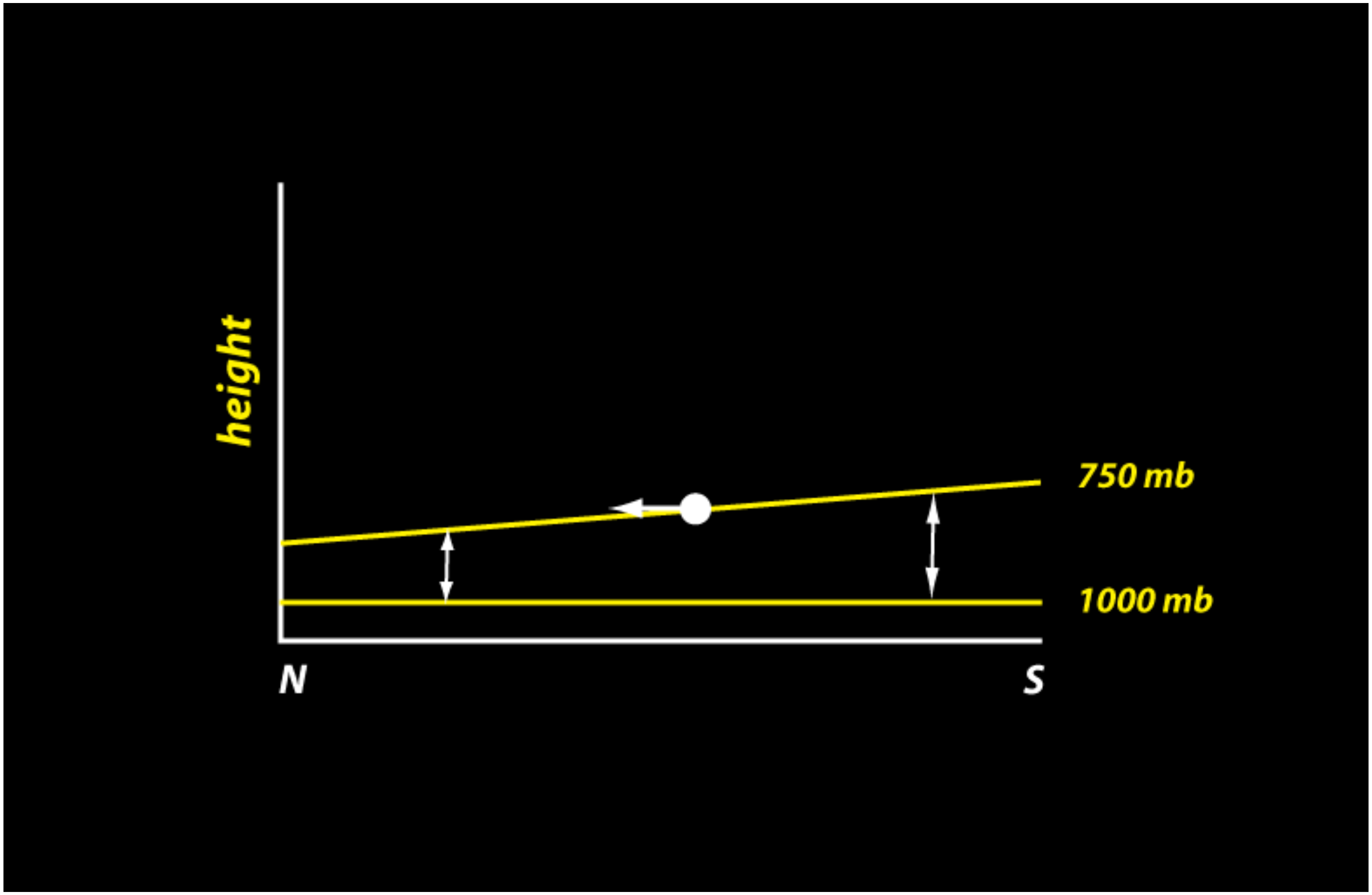
ZONAL WIND = west-east component

What we see…

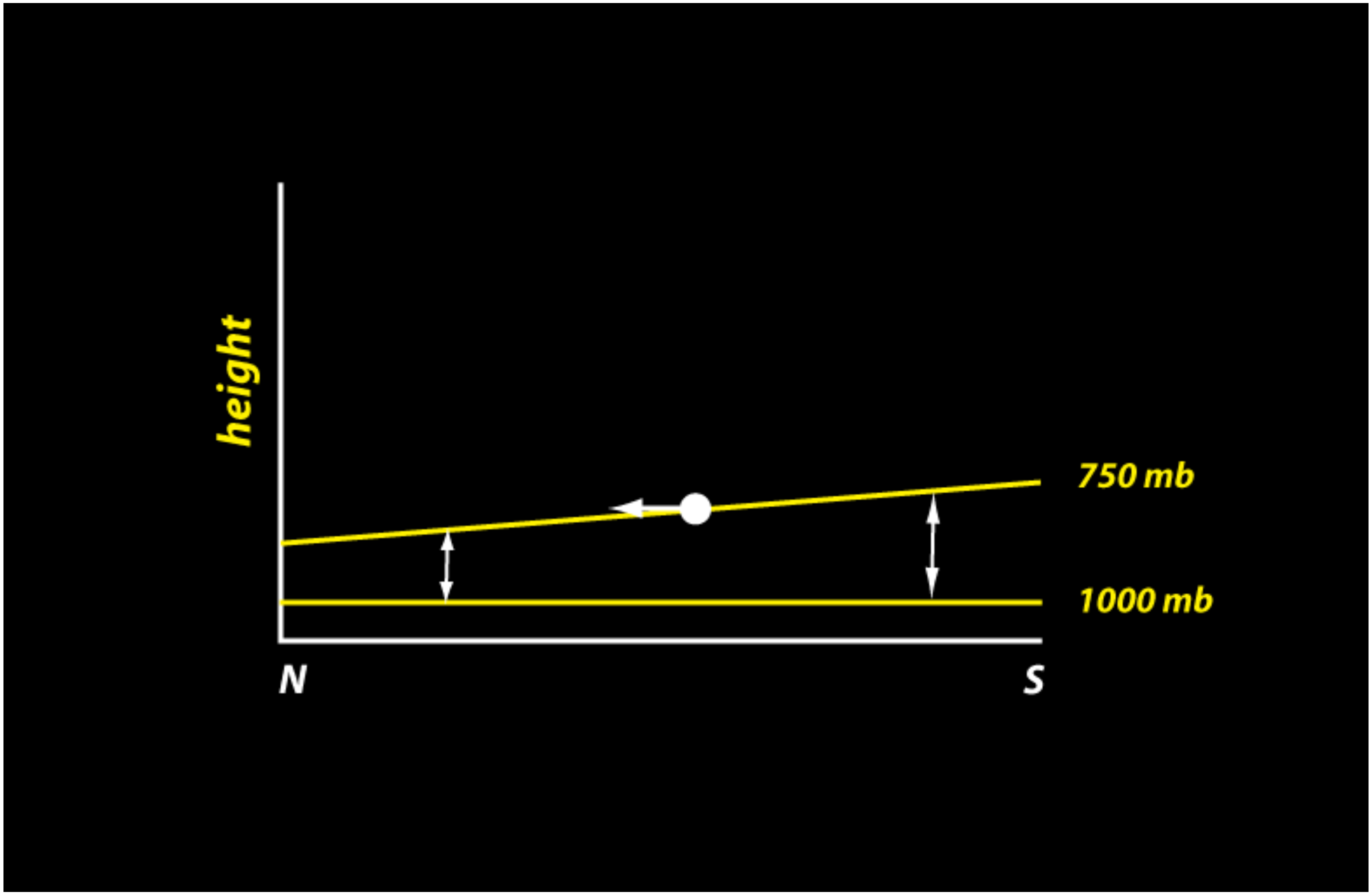
- Polar easterlies are quite shallow
  - Wind becomes westerly farther above
- Midlatitude westerlies get very strong
  - Over 90 mph in the mean in winter
- West-east (zonal) component of NE trade winds is not strong but is very deep
- Everything is weaker in summer



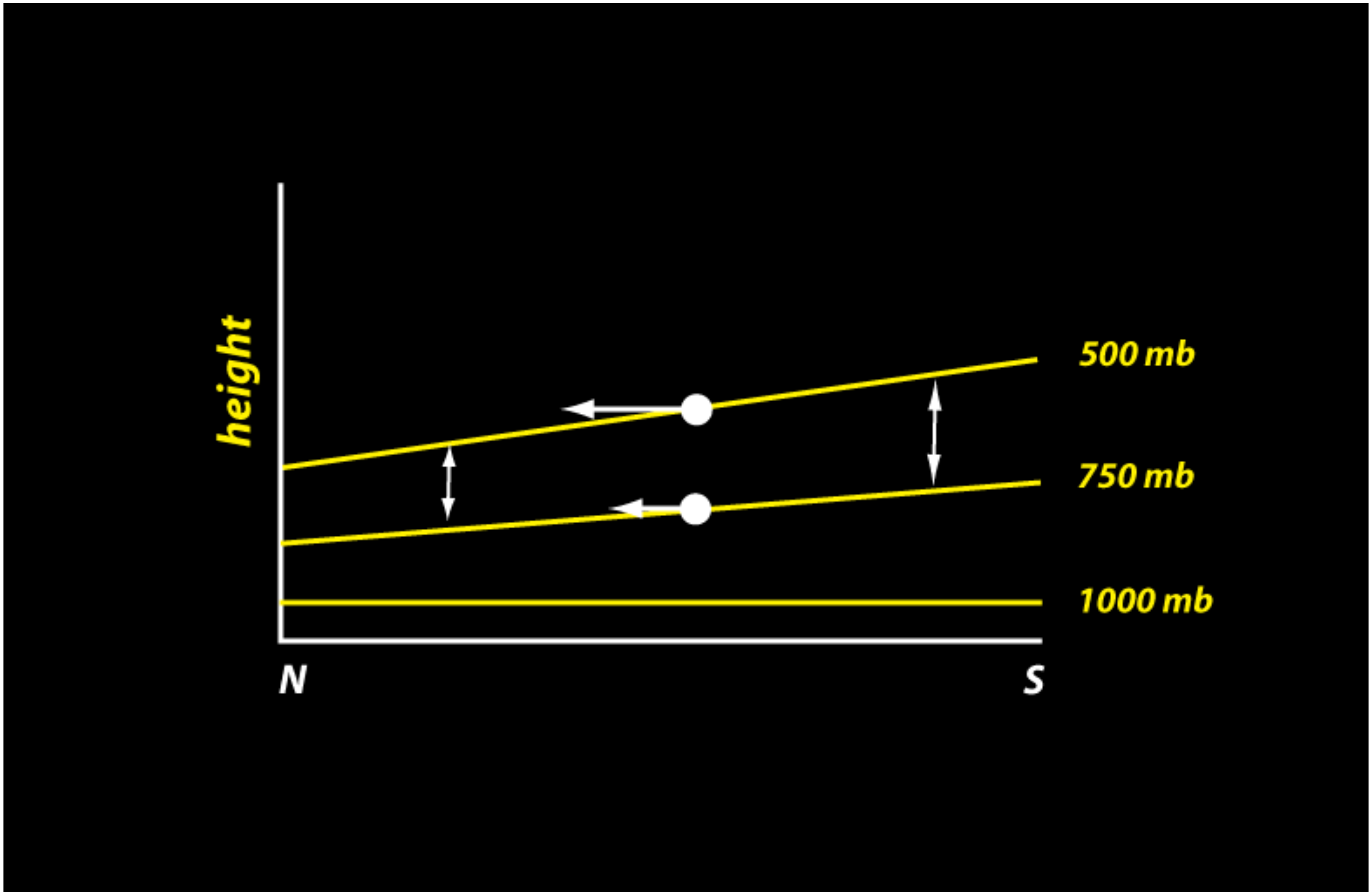
How and why the midlatitude westerlies vary with height



Say little to no isobaric tilt at 1000 mb, but it’s **colder to N**

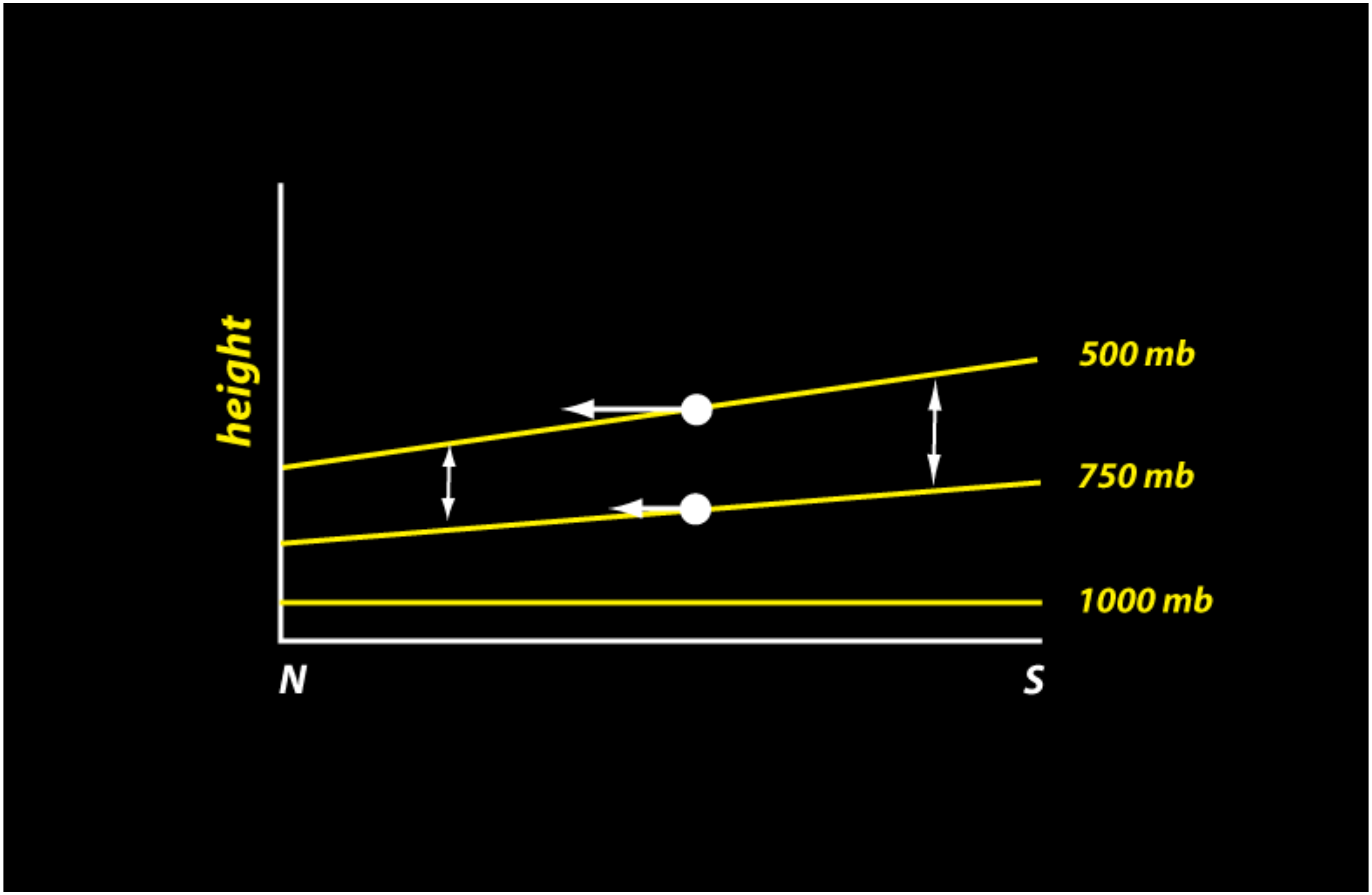


750 mb PGF points N, so geostrophic wind W → E

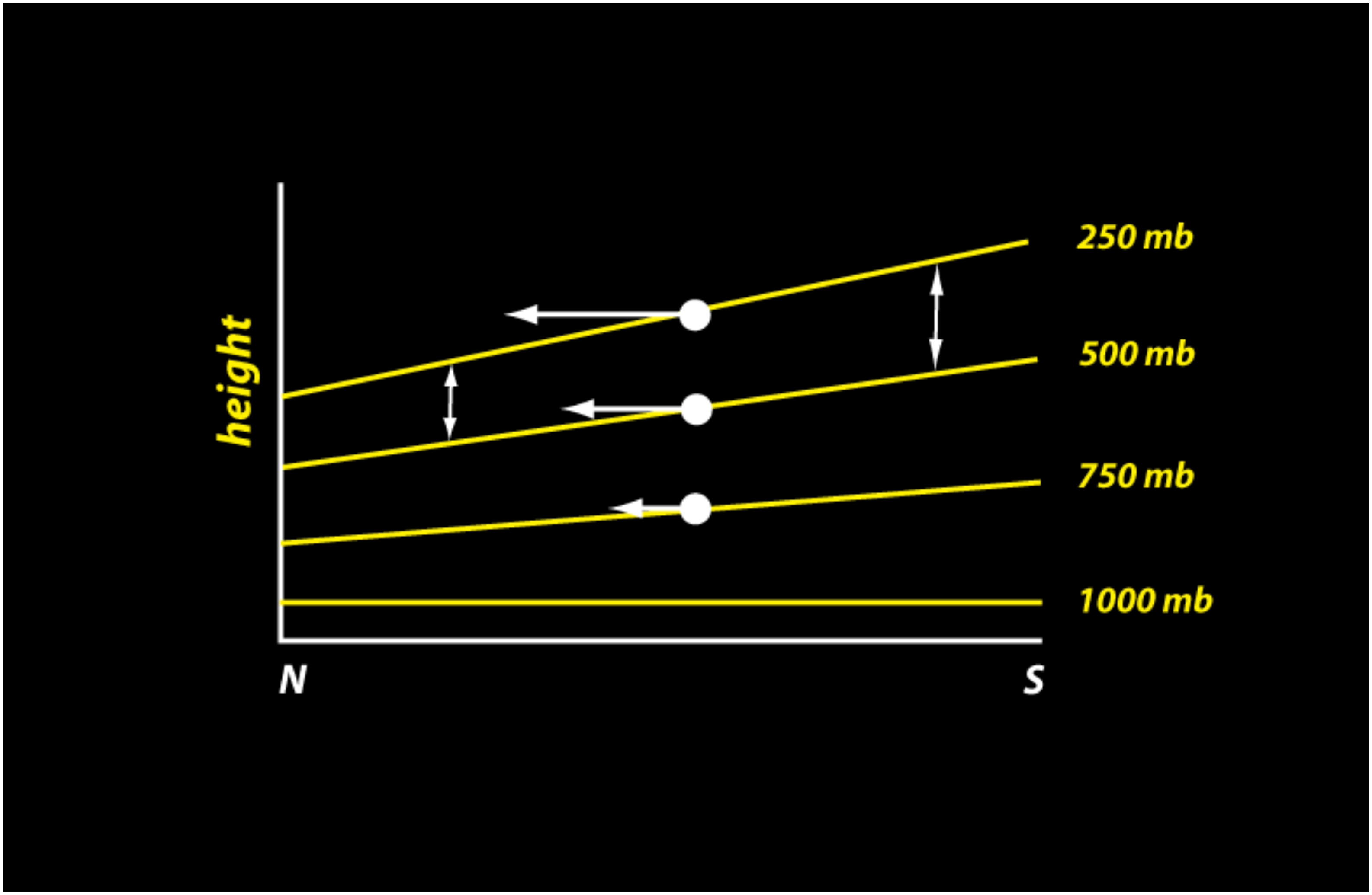


Still colder to N by 500 mb.

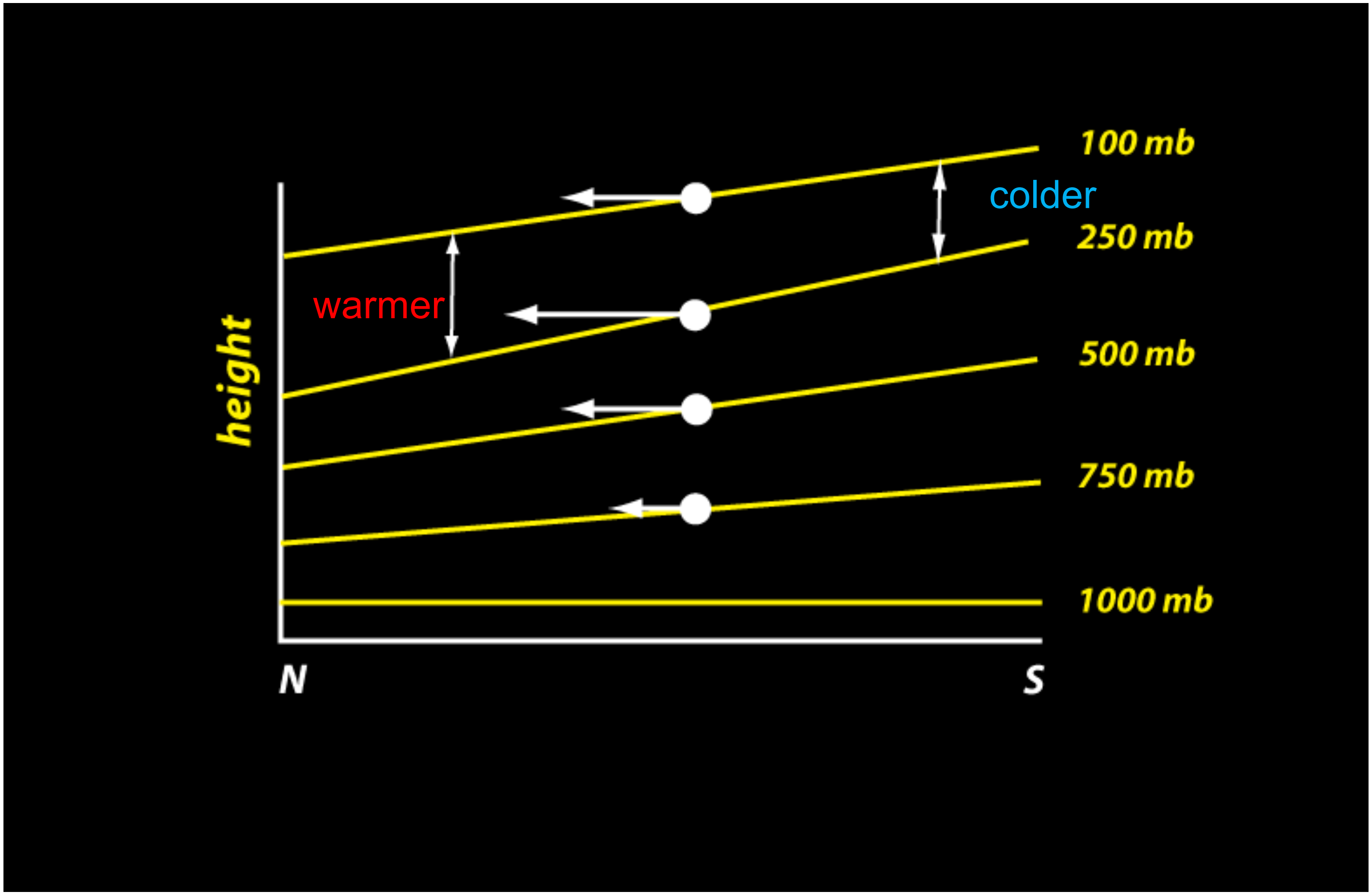
500 mb tilts even more.



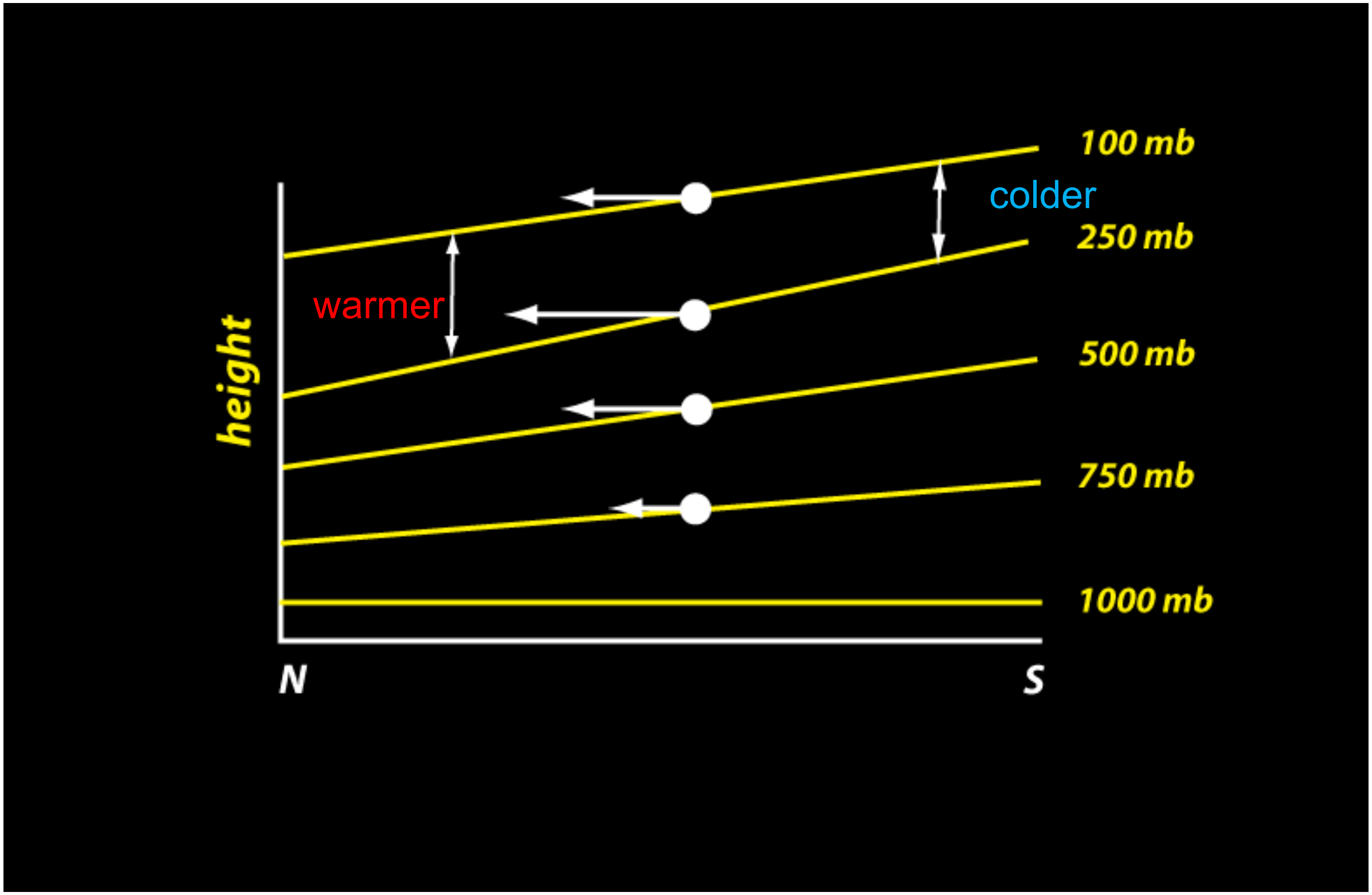
PGF pointing N is **larger** so westerly geostrophic winds at 500 mb are even **faster**



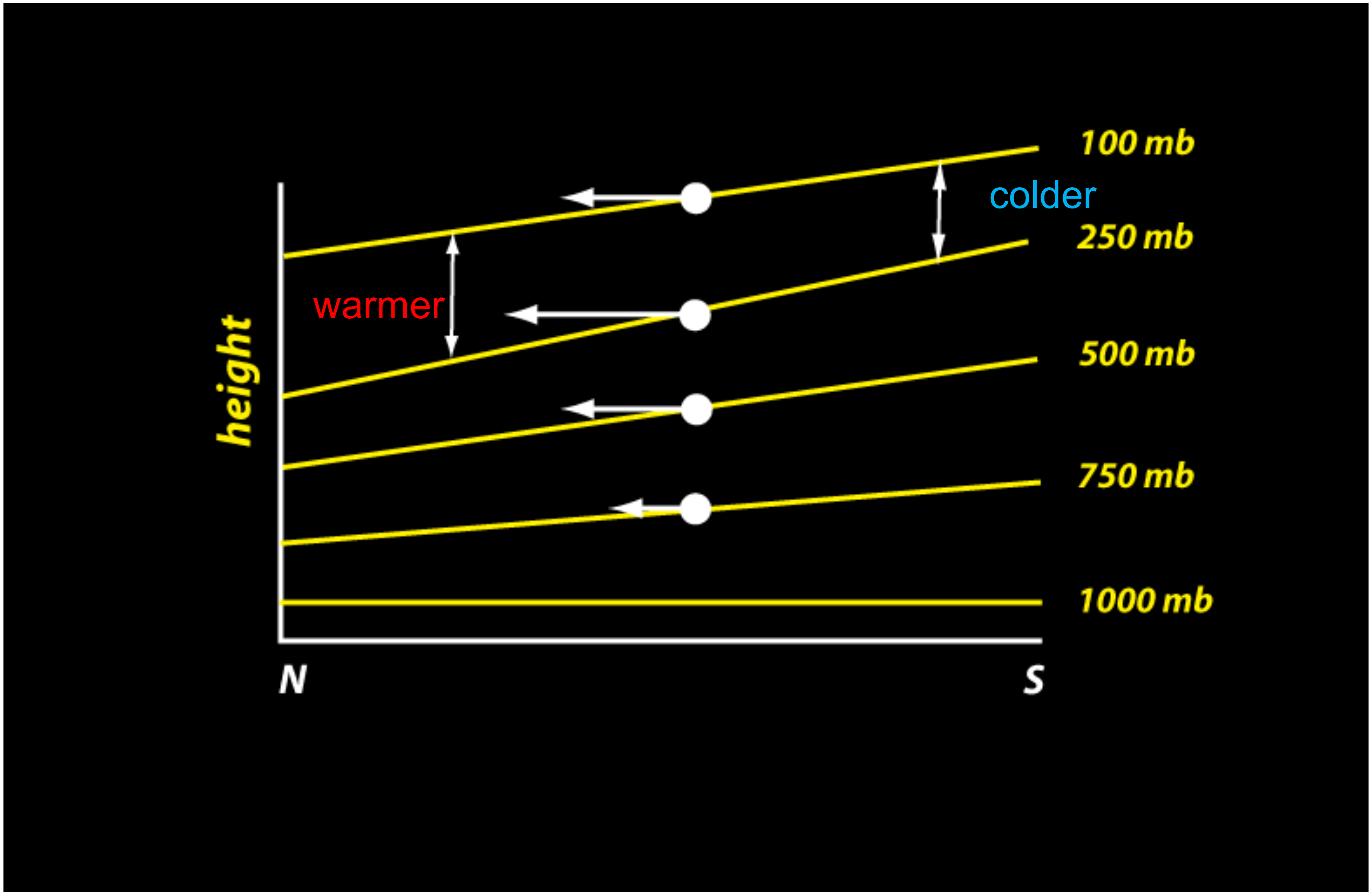
Even stronger winds at 250 mb. Keeps going???



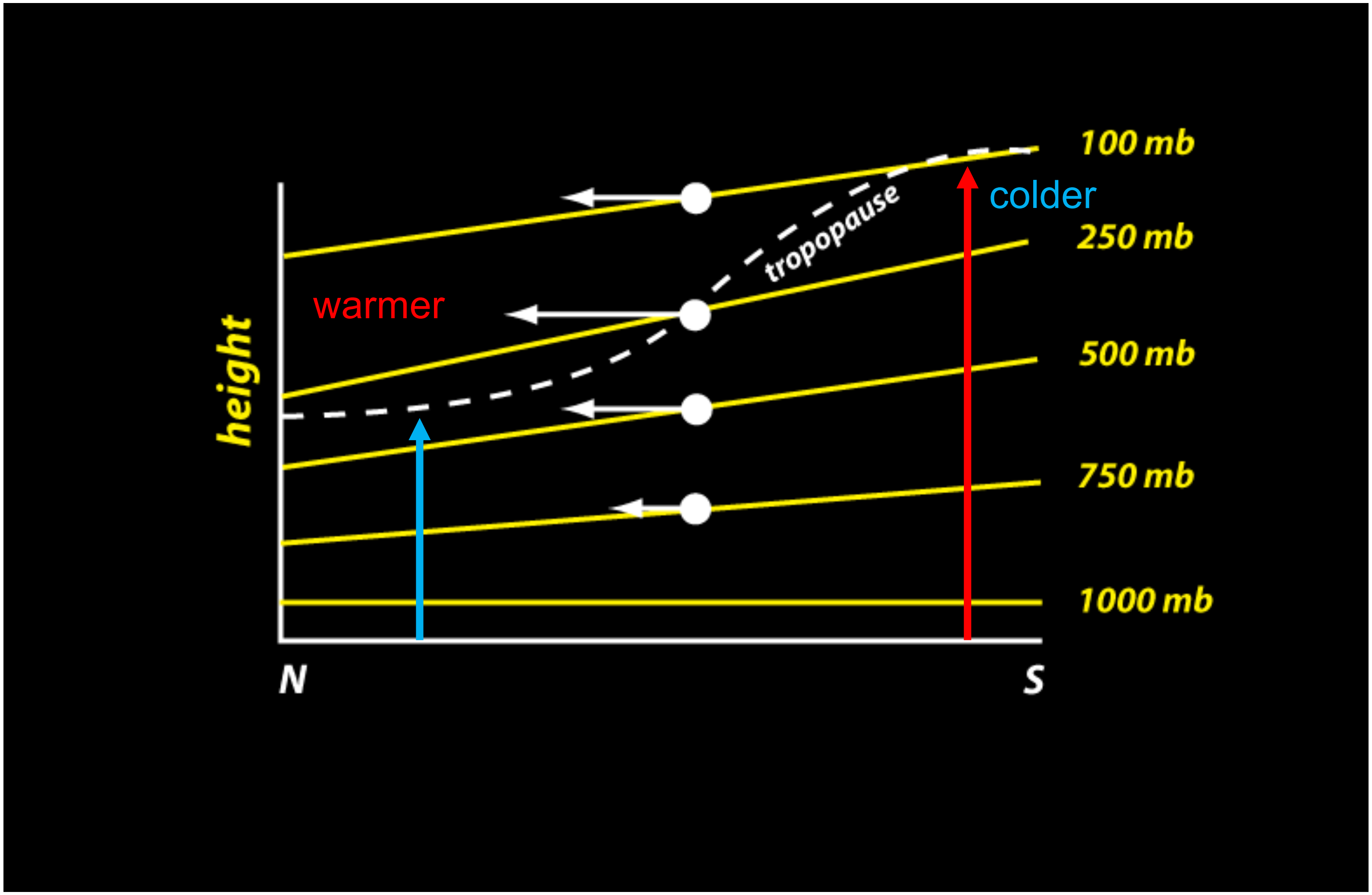
NO. 250-100 mb layer warmer to N. Even in **winter**!



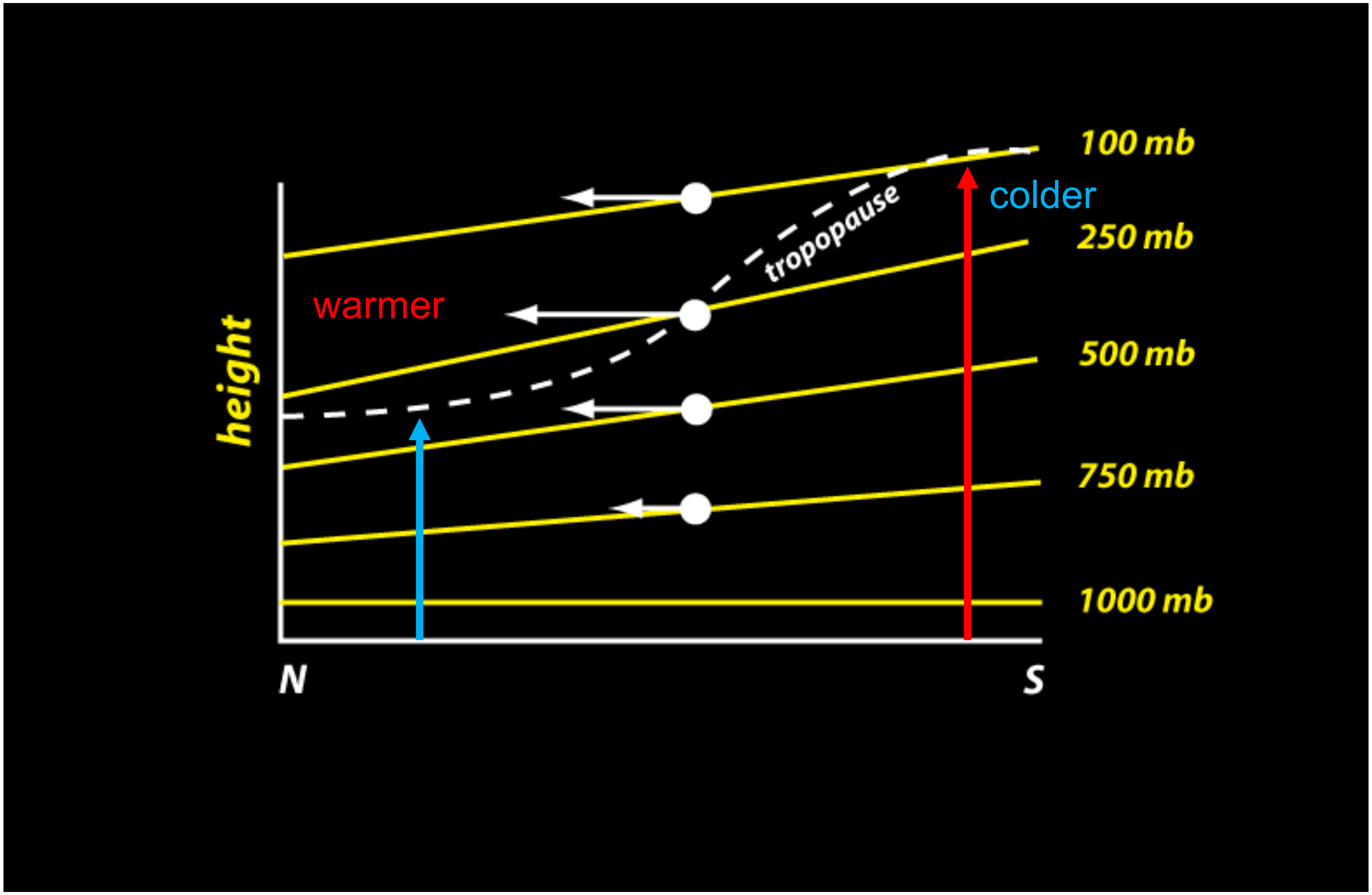
The tilt starts decreasing. The PGF starts getting smaller. Winds decrease.



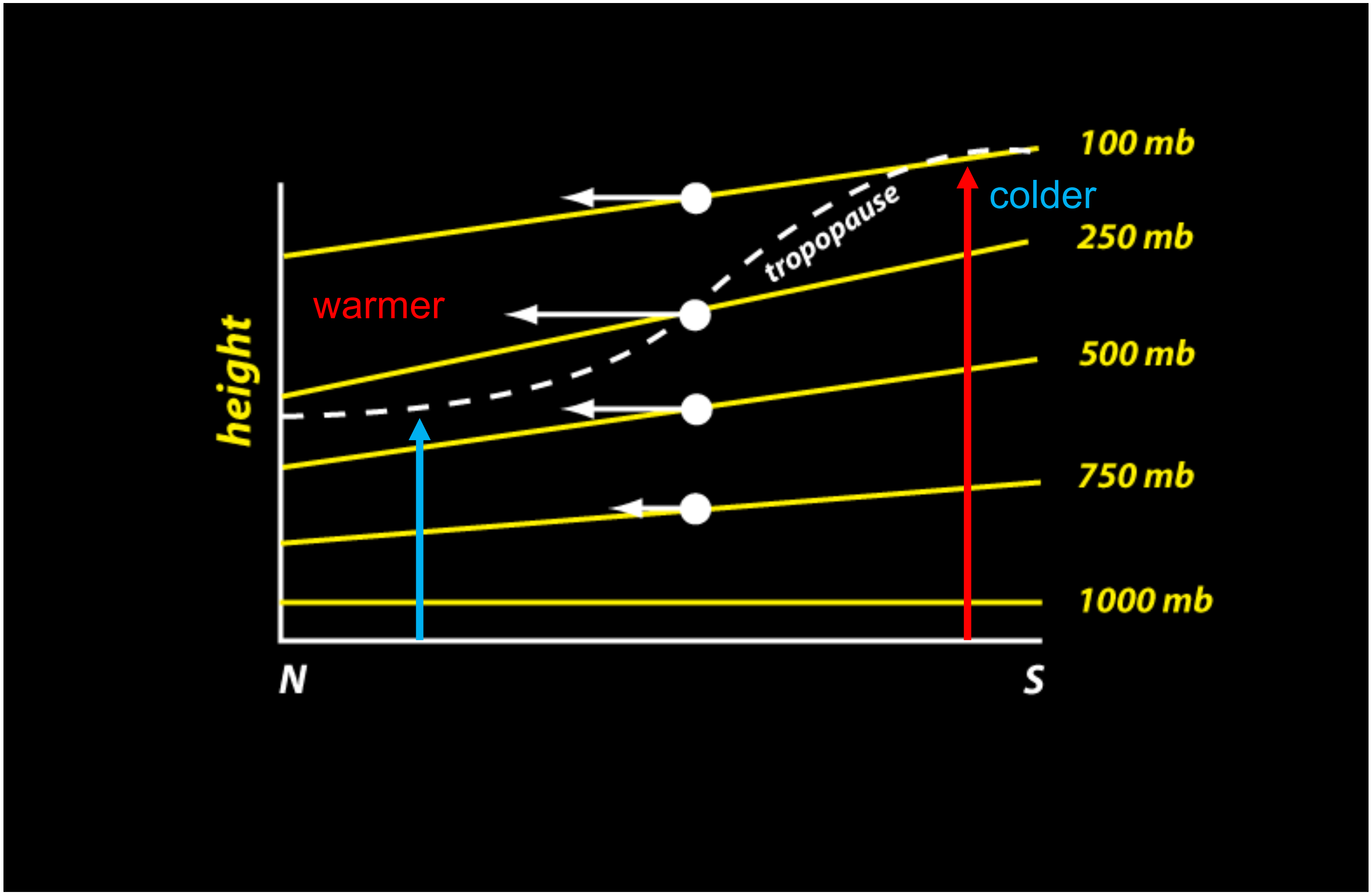
Why? On N side, you're already in the **stratosphere**!



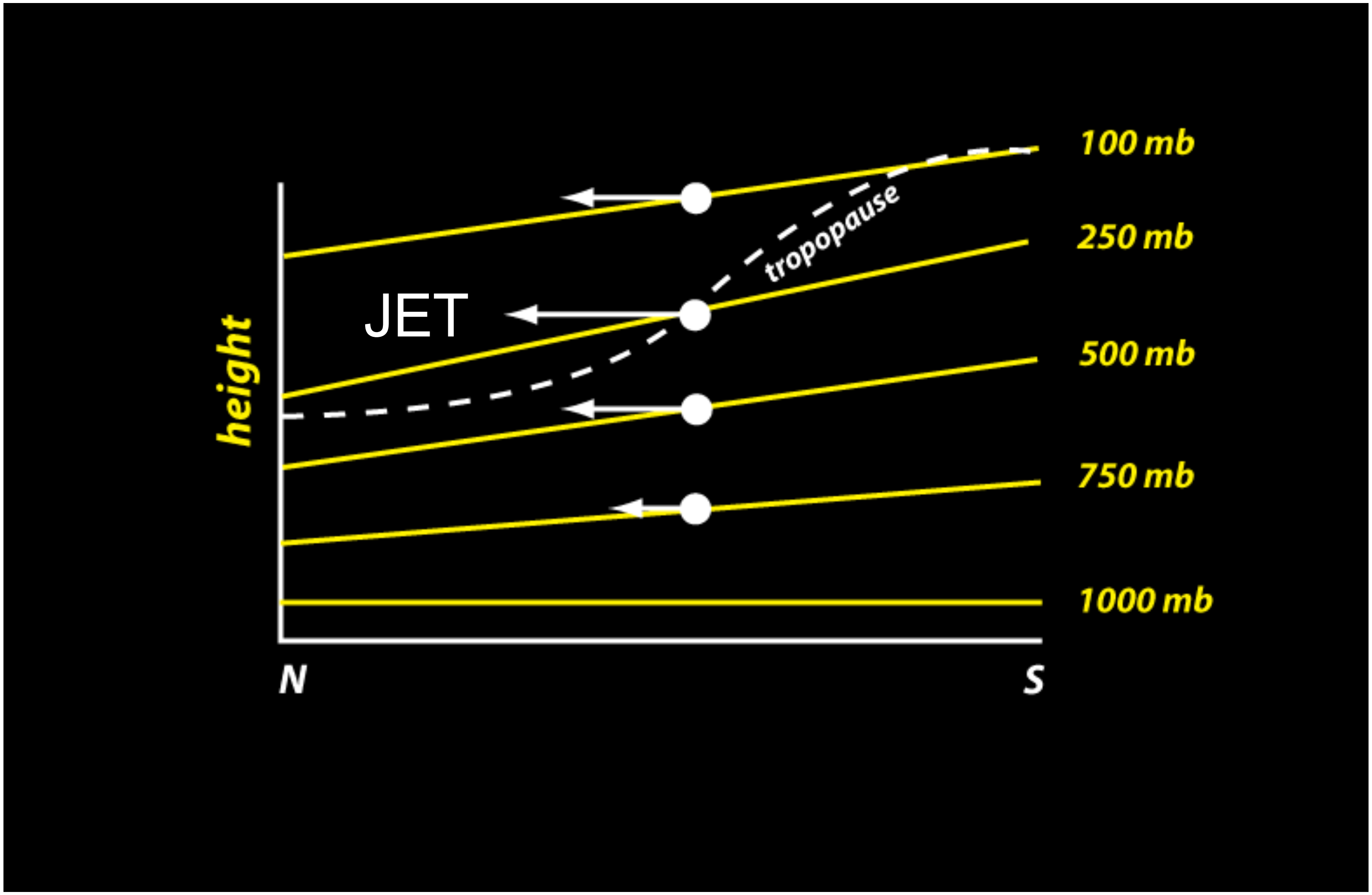
Troposphere is thinner where colder, thicker where warmer



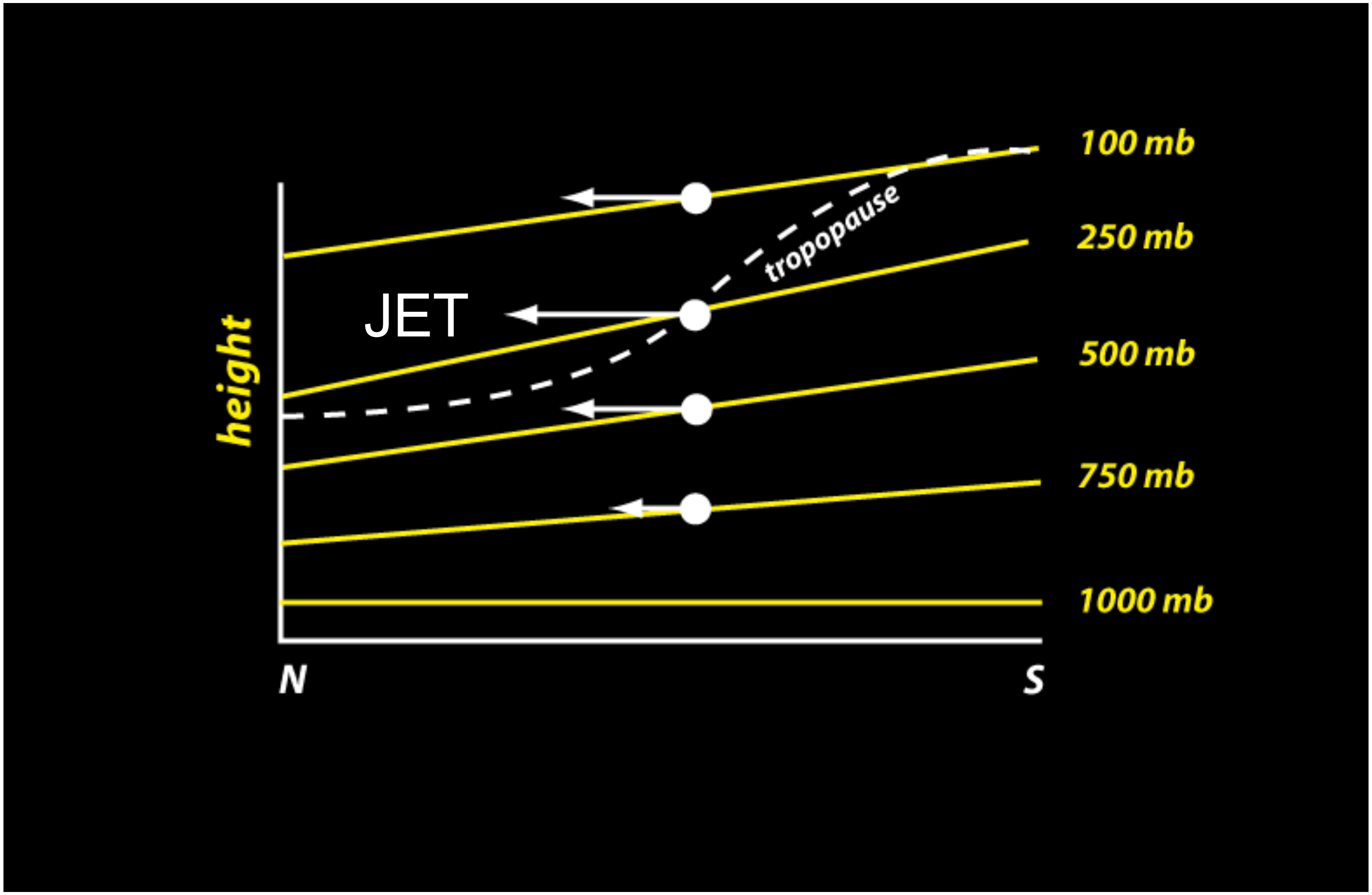
The westerly wind increased while it was colder to N…



… when it **stopped being colder** to N, the westerly wind stopped increasing with height

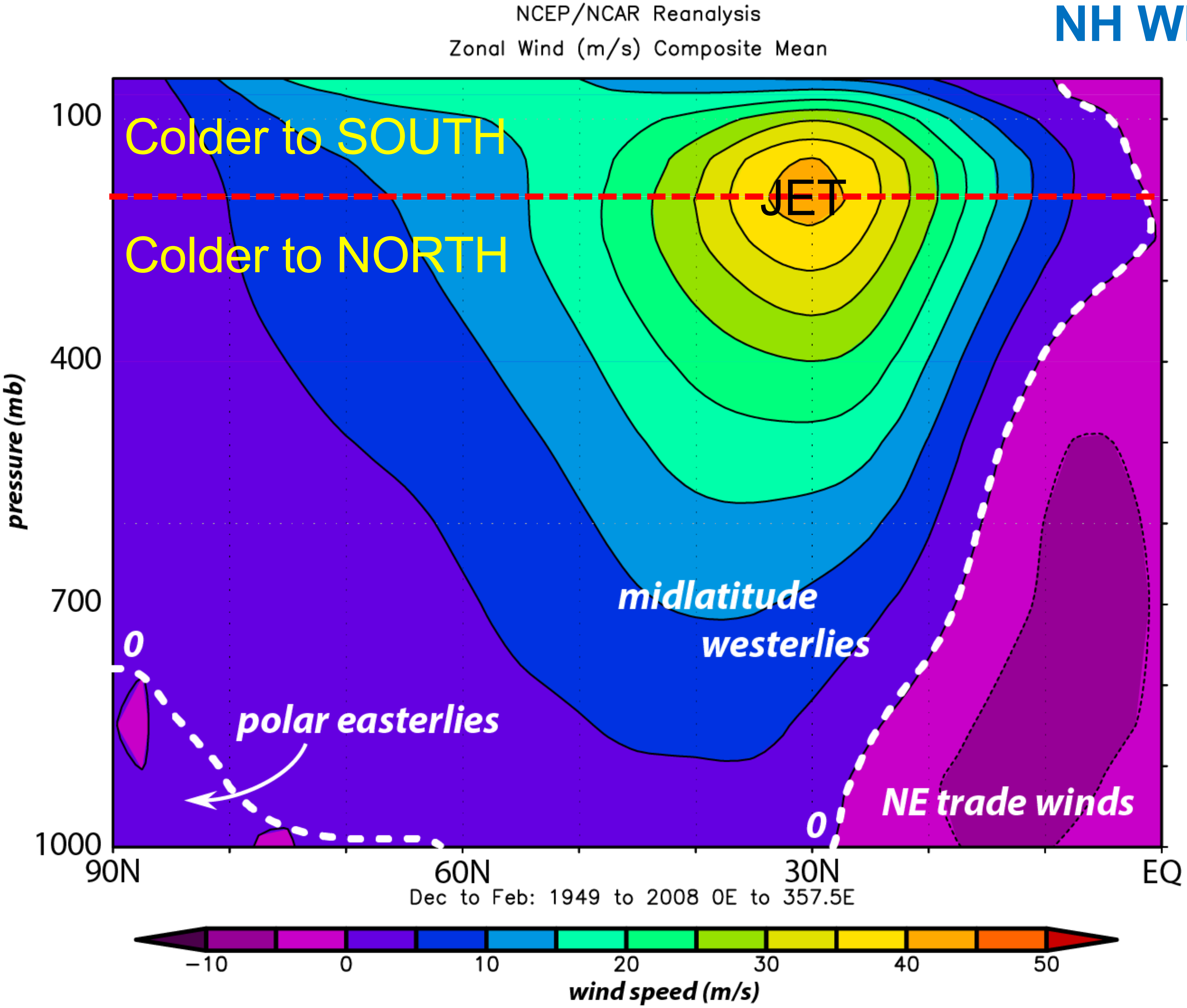


Where N-S PGF largest → fastest W-E winds (JET)



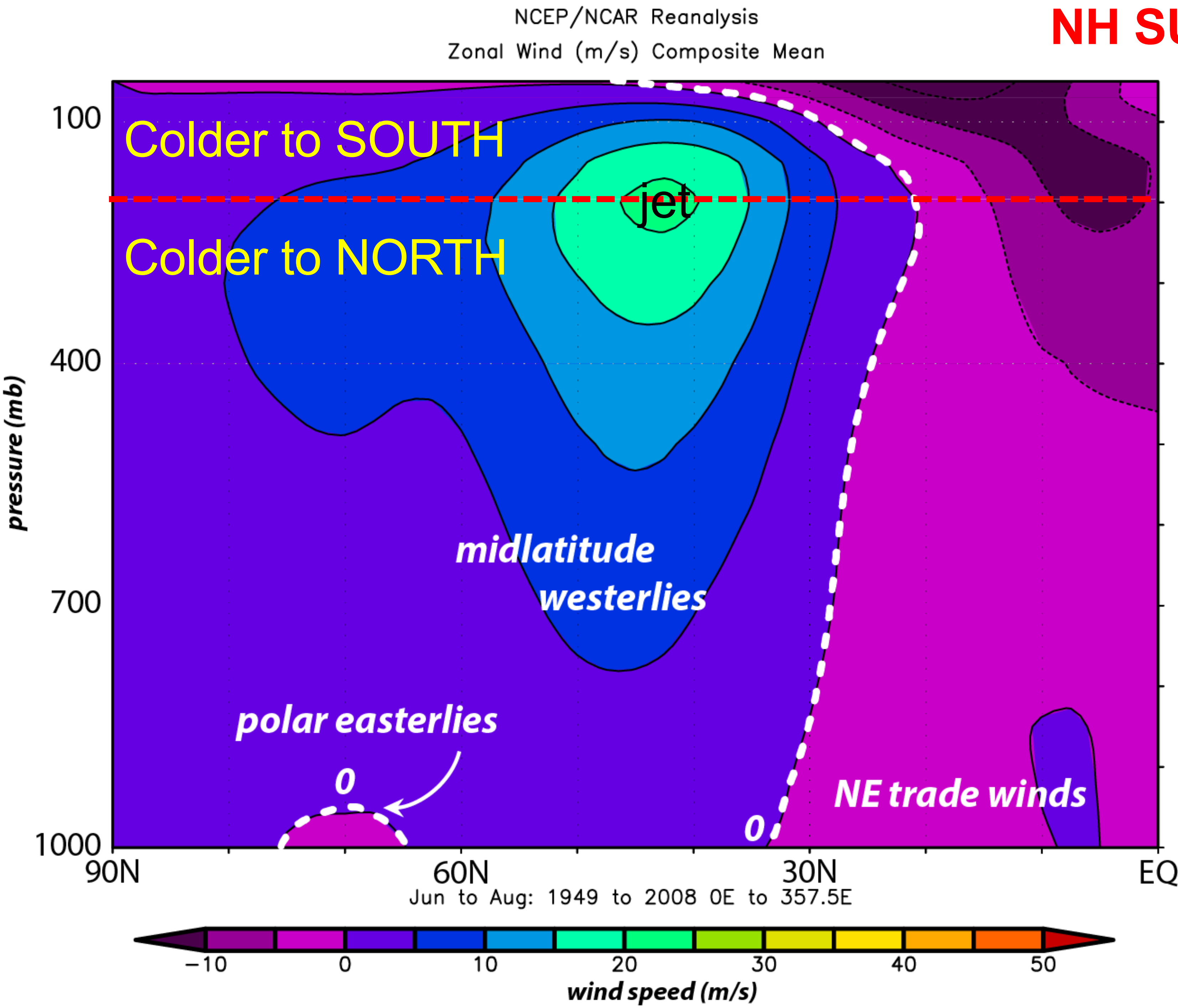
We've found the **midlatitude westerly jet stream**

NH WINTER



NCEP/NCAR Reanalysis
Zonal Wind (m/s) Composite Mean
Colder to SOUTH
JET
Colder to NORTH
midlatitude westerlies
polar easterlies
NE trade winds
0
0
100
400
700
1000
pressure (mb)
90N
60N
30N
EQ
Dec to Feb: 1949 to 2008 0E to 357.5E
−10
0
10
20
30
40
50
wind speed (m/s)

NH SUMMER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Jun to Aug: 1949 to 2008 0E to 357.5E
−10
0
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20
30
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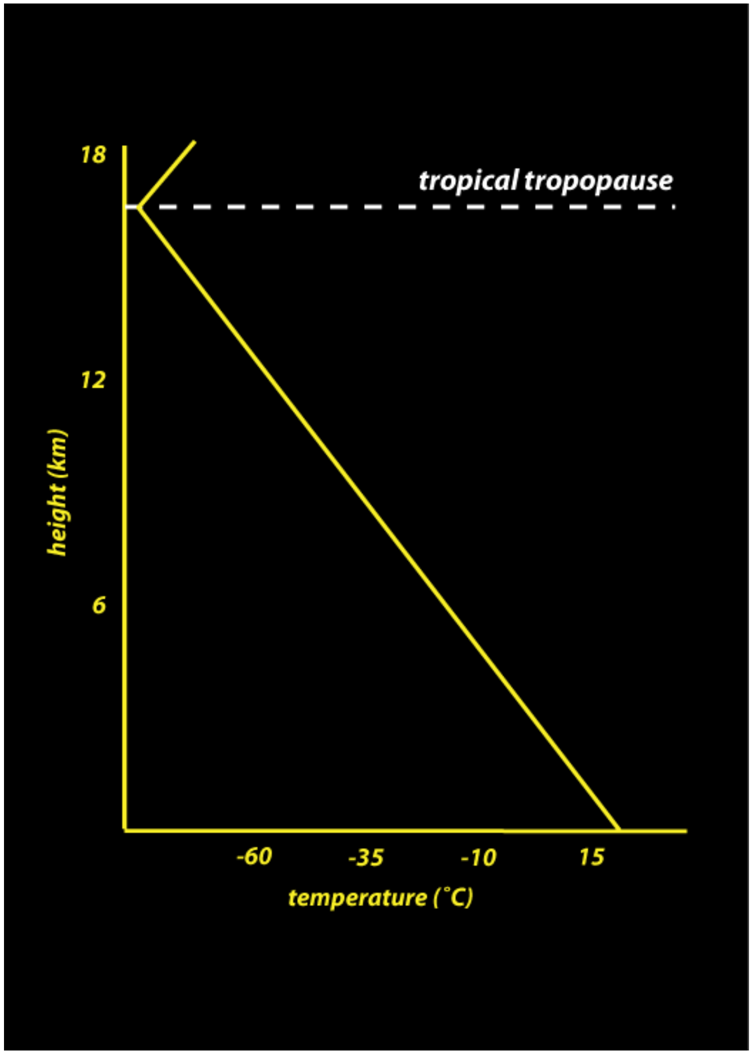
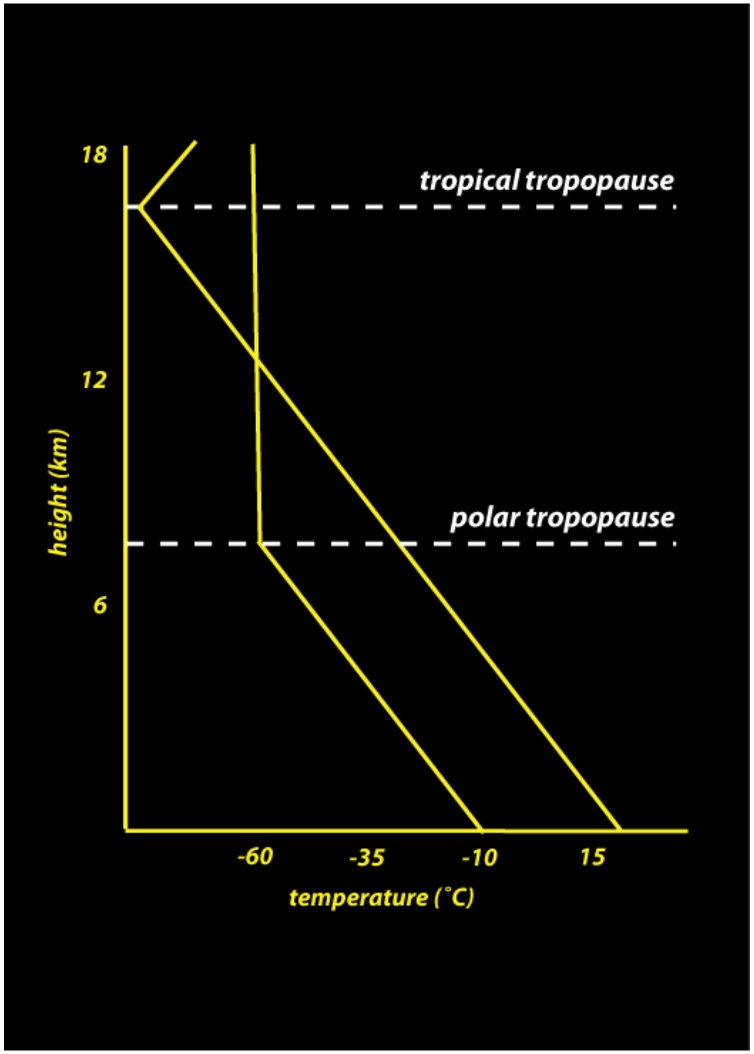
wind speed (m/s)



The tropical troposphere is **deep** and the tropopause is high [albeit only 17 km or 11 mi up!]

Temperature decreases with height quickly over a deep layer

The tropical tropopause is **very cold** [-80˚C or -112˚F]

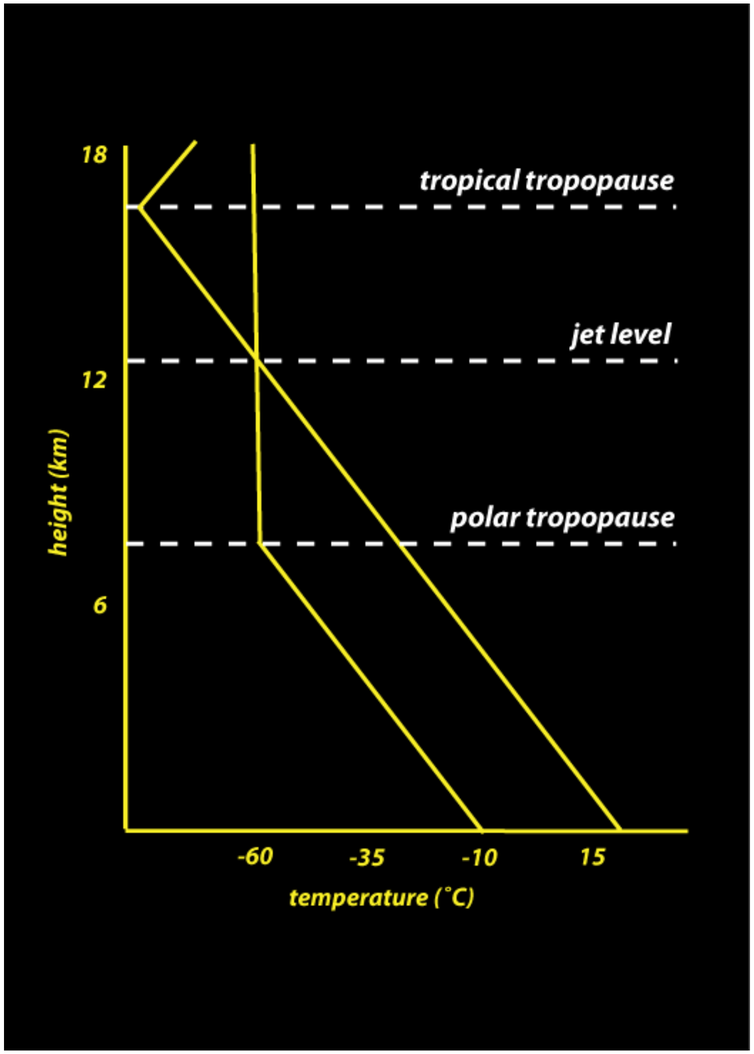


The polar troposphere is **shallow** because it is much **colder**

Isobaric surfaces tilt down to the N

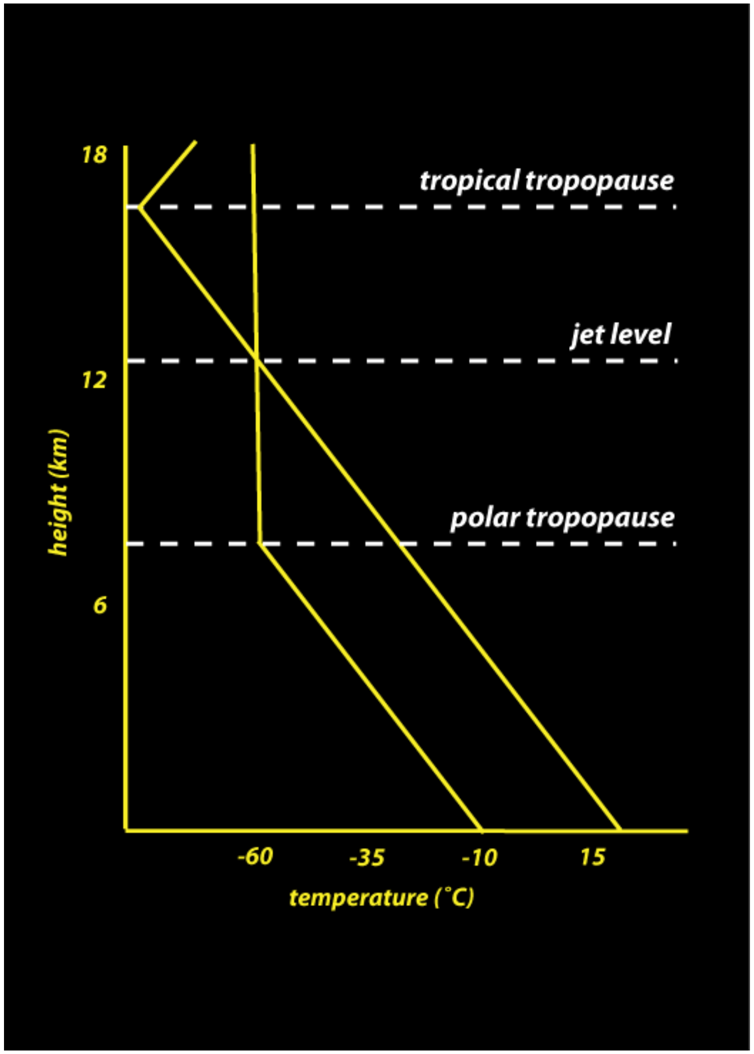
Above the polar tropopause is the polar stratosphere

The polar stratosphere doesn't actually get warm, but it **stops getting colder**



There is a height where the **tropical and polar temperatures are the same**

That is the height of the midlatitude westerly jet



The surface geostrophic winds in midlatitudes are **westerly** (W → E) {3-cell model}

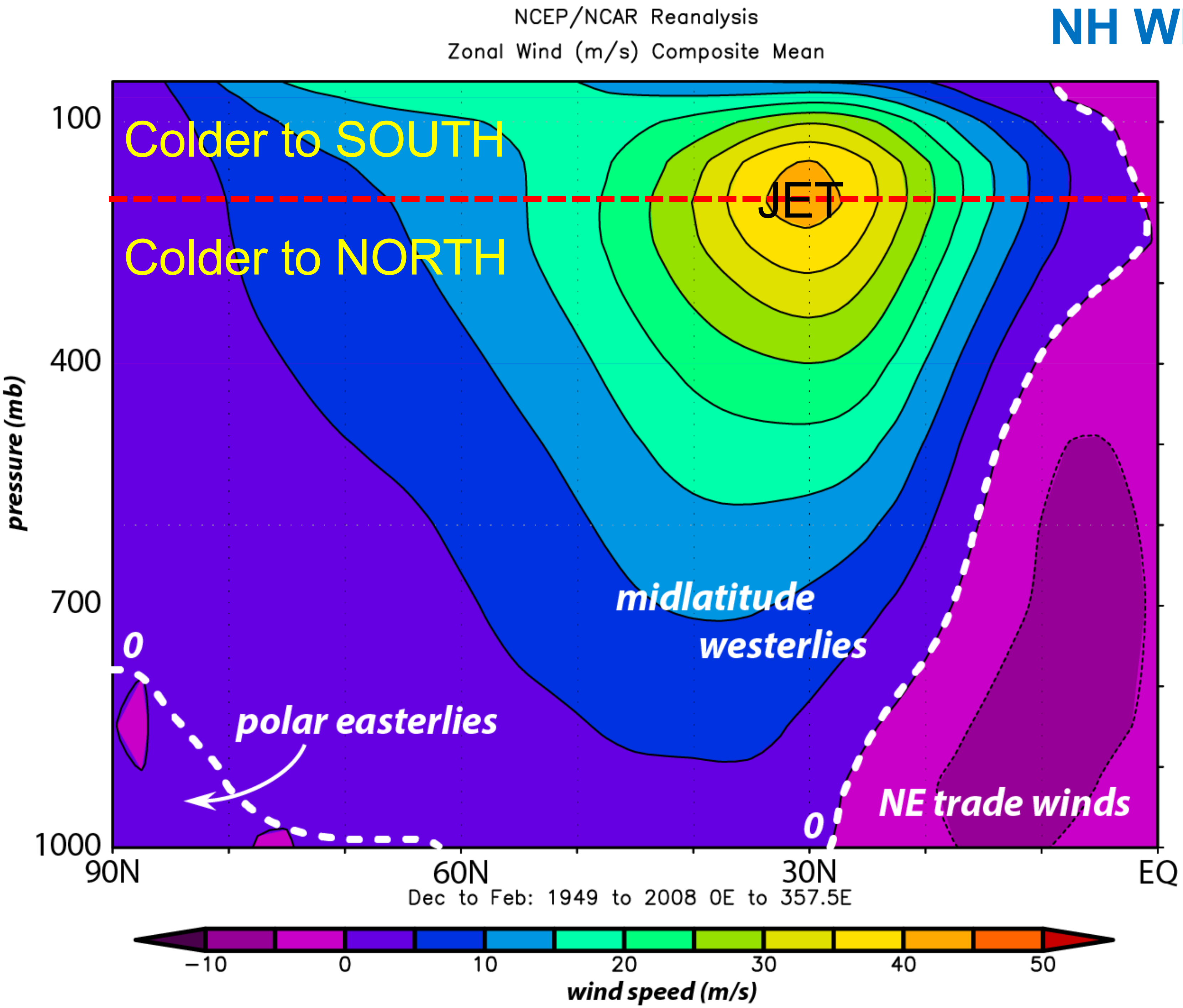
The westerly winds increase with height **as long as it is colder to N**

When it stops being colder to N, the midlatitude westerlies have maxxed out → **JET**

Above that level, the midlatitude westerlies get weaker

The winds could even turn around to easterly! That happens in **summer**. In the **mesosphere**.

NH WINTER



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wind speed (m/s)

Recap #1

- T differences → p differences → winds
- Mass between two isobaric surfaces is fixed but thickness depends on temperature (hypsometric)
- When PGF points N → geostrophic wind is directed W to E [westerly wind] in NH
- The NH midlatitude westerly wind increases with height while it is colder to N
- The NH polar easterlies decrease with height because it's colder to N

Recap #2

- **Stops** being colder to N above about 250 mb or so, **even in winter**
  - Closer to equator: **still in troposphere** → T decreases quickly with height (about 7˚C/km)
  - Closer to pole: **already in stratosphere** → T either increases with height or stops decreasing
  - Polar troposphere is shallower because it is colder
- Where the N-S T gradient vanishes: **the midlatitude westerly jet**
- This is **vertical wind shear**
- Vertical wind shear helps organize **thunderstorms**, especially in the Midwestern battlespace

Claim

- **Tornadoes** are intense, small-scale circulations, too small in scale for Coriolis force to matter *directly*, but…
- … they are made possible because it is colder to the N
- … because they require the **vertical wind shear** that the N-S T gradient produces
- … which they then convert into **horizontal rotation**

[end]