The Atmosphere above the Antarctic Plateau

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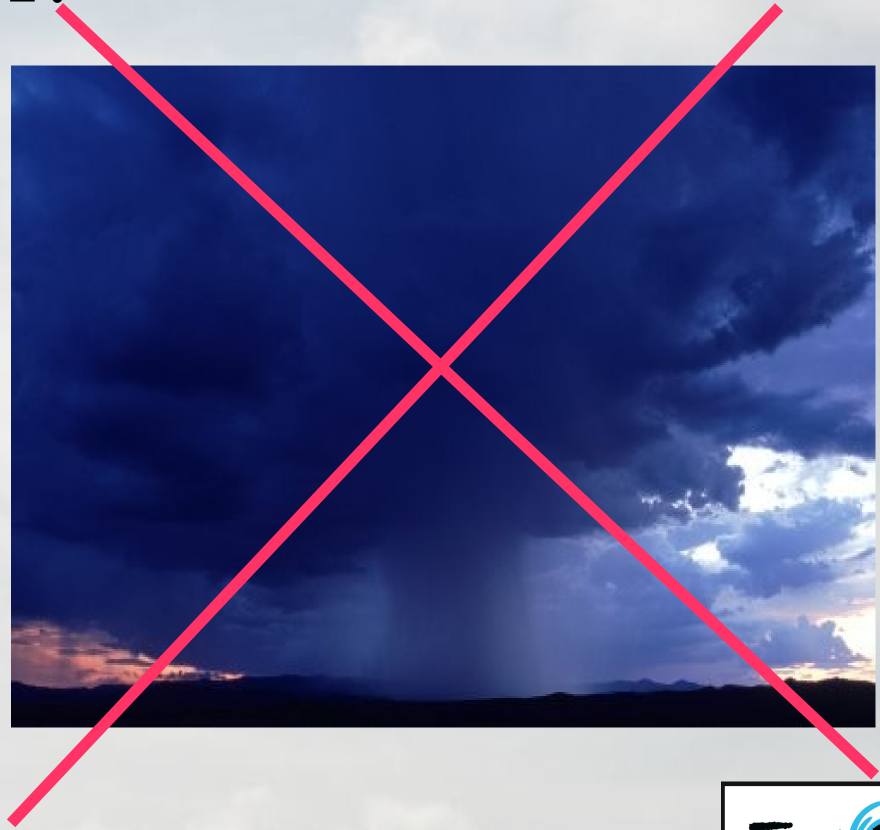
Outline

- Basic meteorology
- Why the Antarctic Plateau?
- Method
- Results near the surface
- General circulation of the atmosphere
- Wind speed at higher altitudes
- Conclusions

Good Weather (?)

- From meteorological point of view:

Boring weather!



- Clear skies
- Cold and dry air
- Weak winds
- Stable stratification

ForOT

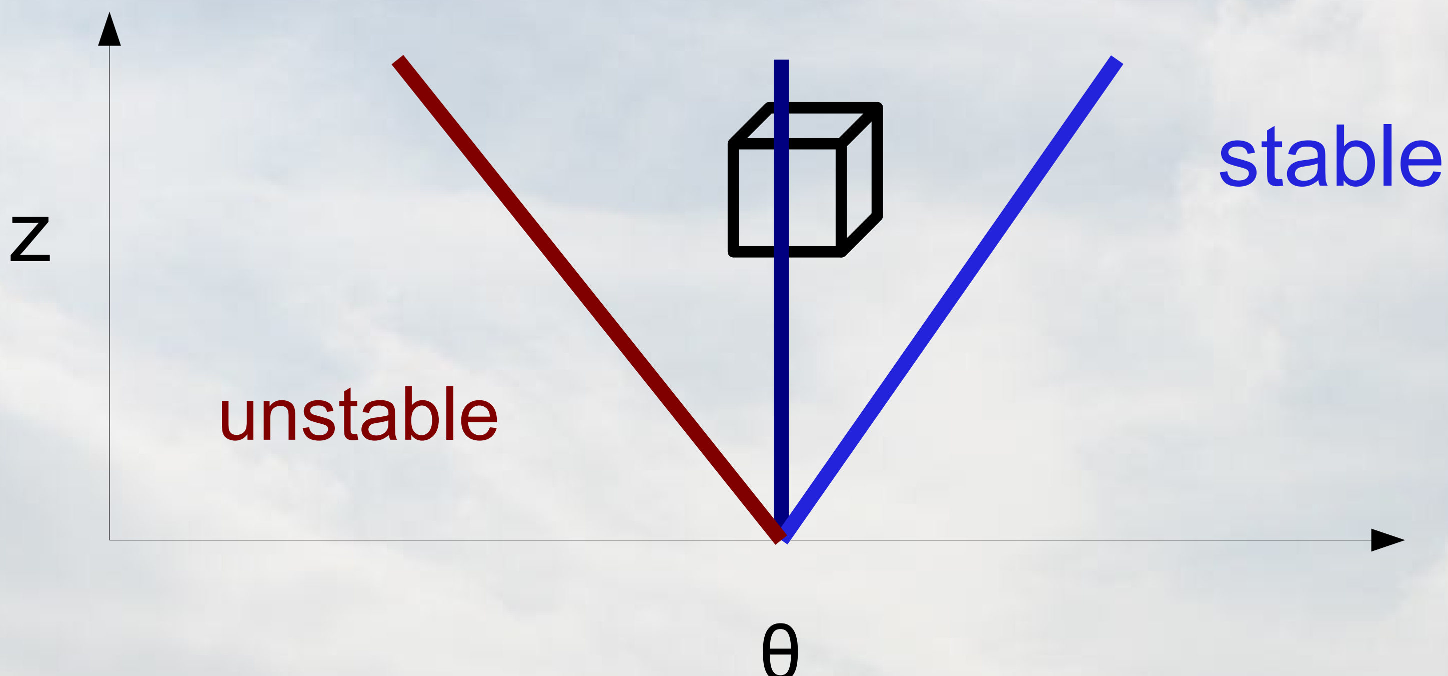
Potential Temperature

- The temperature an air parcel would have if it was brought down from its initial state to a standard pressure, usually 1000 hPa
- Presuming an adiabatic process and dry air
  - Dry adiabatic lapse rate = 9.8°C/km

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

ForOT

Stratification



- Thermal stability
  - Vertical motion is encouraged – unstable
  - Vertical motion is suppressed - stable

Stratification

- The stability also depends on the winds
- Wind shear causes turbulence

- The Richardson number depends on both

$$Ri = \frac{g}{\theta} \frac{\partial \theta / \partial z}{(\partial v / \partial z)^2}$$

ForOT

Stratification

- Critical value, Ri = 0.25
- Ri < 0.25 => unstable stratification
- Ri ≈ 0.25 => neutral conditions
- Ri > 0.25 => stable conditions

Why is this important?

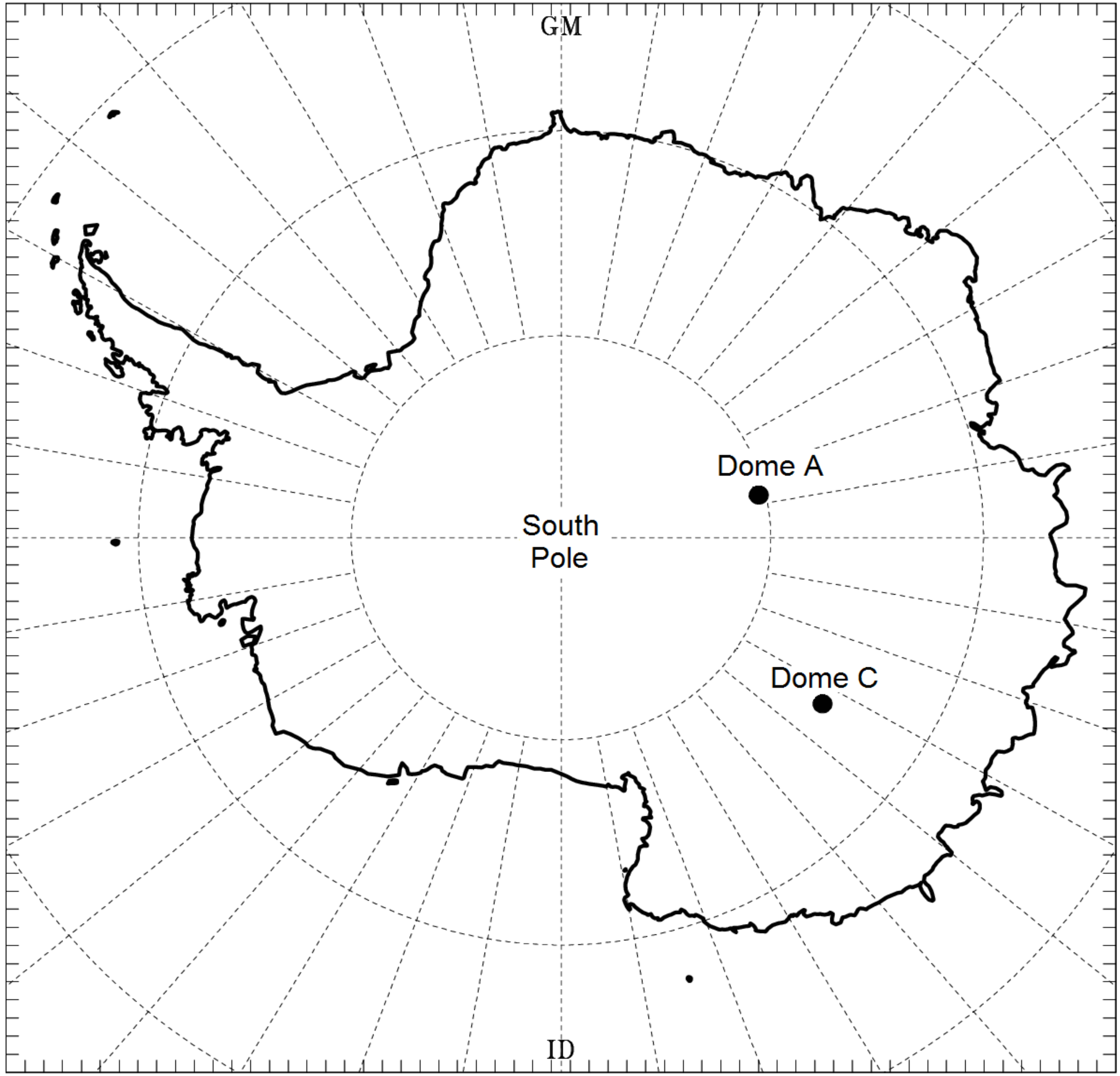
- Ordinary turbulence is favoured by large wind shear and unstable thermal stratification
- Optical turbulence (OT) describes the fluctuations of the index of refraction of the atmosphere
- Where there is 'normal' turbulence one can expect OT, but...
- ...optimal condition for large OT is large wind shear and a STABLE thermal stratification.

Why the Antarctic Plateau?

- Stable atmosphere
- Inversion close to the surface most of the time
- Optical turbulence is concentrated in a narrow surface layer
- No jet stream above the Plateau
- Surface winds have a large directional constancy

The Antarctic Plateau

- Three most interesting sites:
  - South Pole
  - Dome C
  - Dome A
- Measurements from the South Pole and Dome C
- From Dome A only model simulations


GM
Dome A
South
Pole
Dome C
ID

Results from the South Pole

- Strong OT in a 200 m thick surface layer
- Average seeing 1.73''
- Average seeing above 300 m 0.37''

(Travouillon et al. 2003)

Results from Dome C

- The surface layer has a thickness of 36±10 m (Agabi et al. 2006)
- Measured seeing 0.27'', median seeing above 30 m (Lawrence et al. 2004)

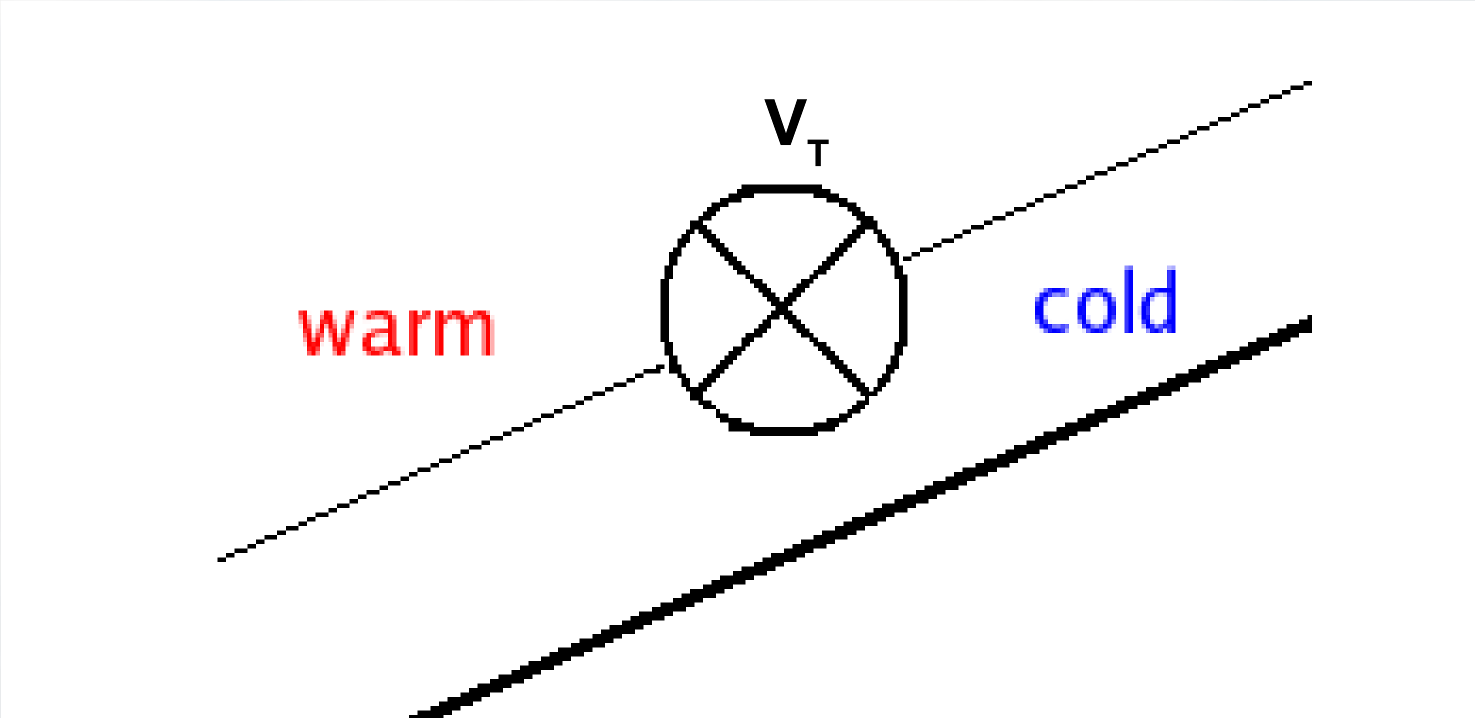
Dome A even better?

- Highest summit of the continent and has an even thinner surface layer
- The surface winds closely follow the topography
- The general circulation implies surface winds directed from the centre of the continent towards the coast
- Local effects imply a similar circulation

ForOT

Dome A even better?

- The surface inversion causes a horizontal temperature gradient => thermal wind
- No inversion winds at the Domes!



Method

- Data extracted from the GCM of the ECMWF (General Circulation Model of the European Centre for Medium-Range Weather Forecasts)
- Every 6h the model gives an analysis of the present state of the atmosphere globally and several forecasts.
- Using the analysis-data to compare Dome A, Dome C and the South Pole
- Particularly the first 150 m

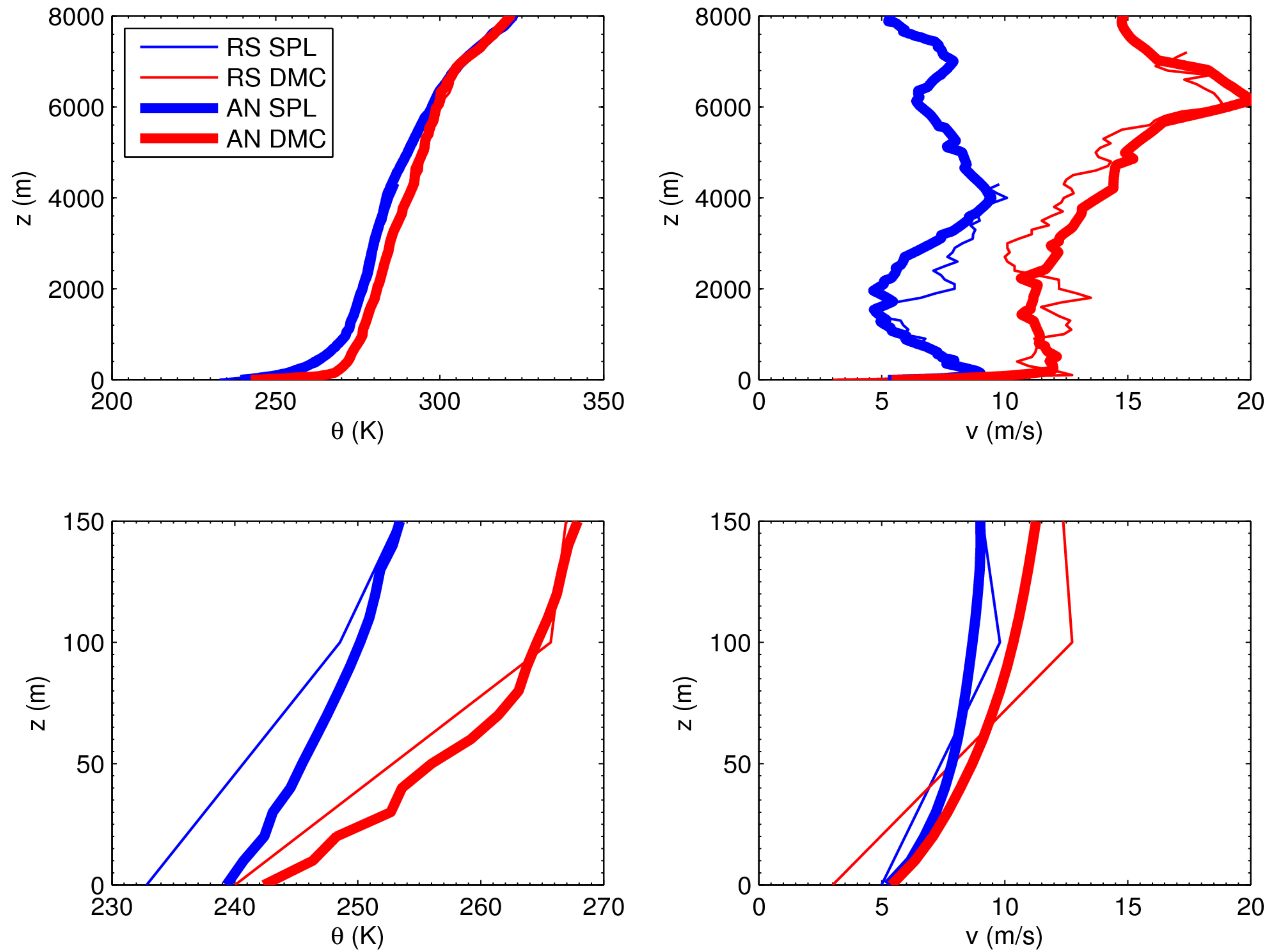
Method

- Every month in 2005, at 00UTC, calculate the median of several meteorological parameters
  - Potential temperature
  - Wind speed
  - The gradients of these
  - Richardson number

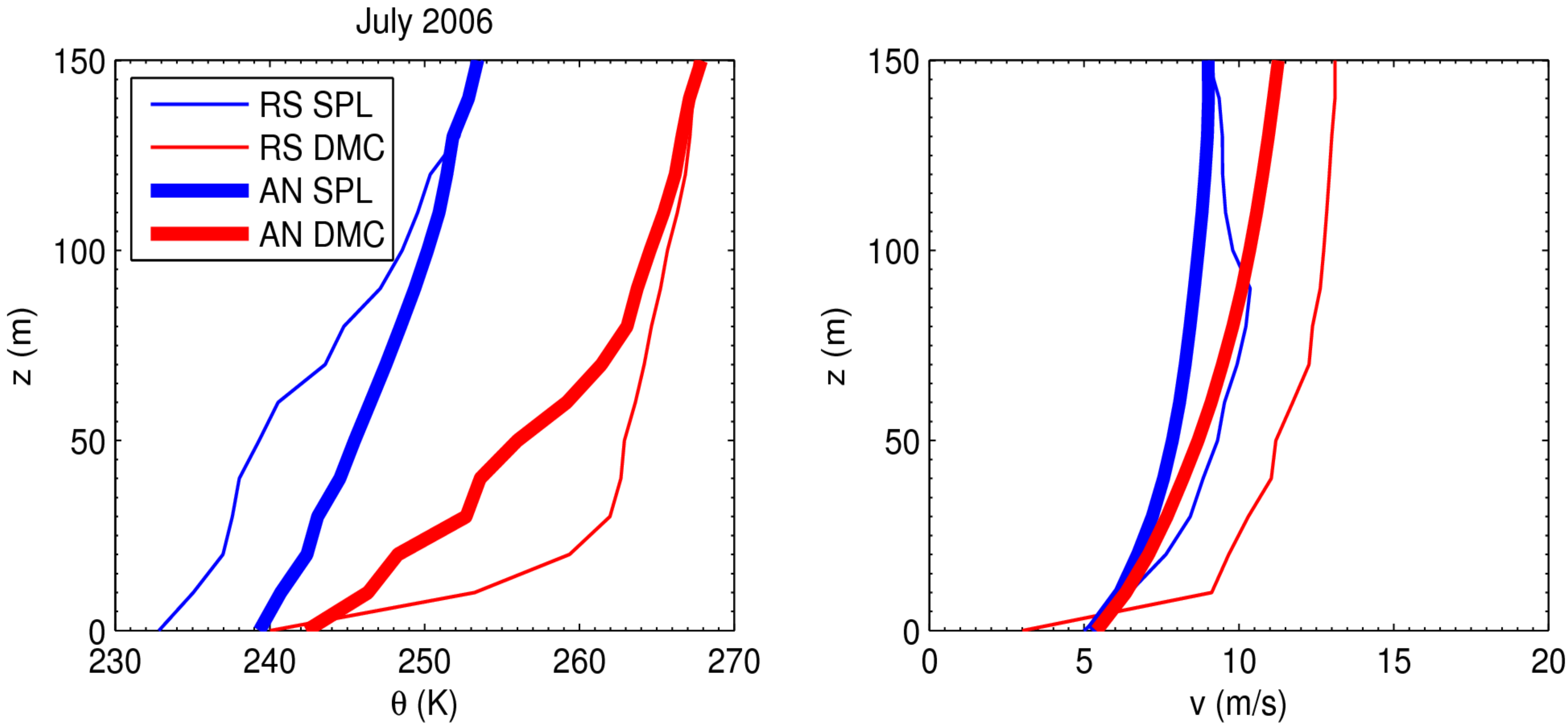
Reliability of the Analyses

- GCM describes the circulation of the entire planet
- Horizontal resolution 0.5° x 0.5°
- Orography is smoothed
- Largest effect near the surface
- Analyses compared with radiosoundings

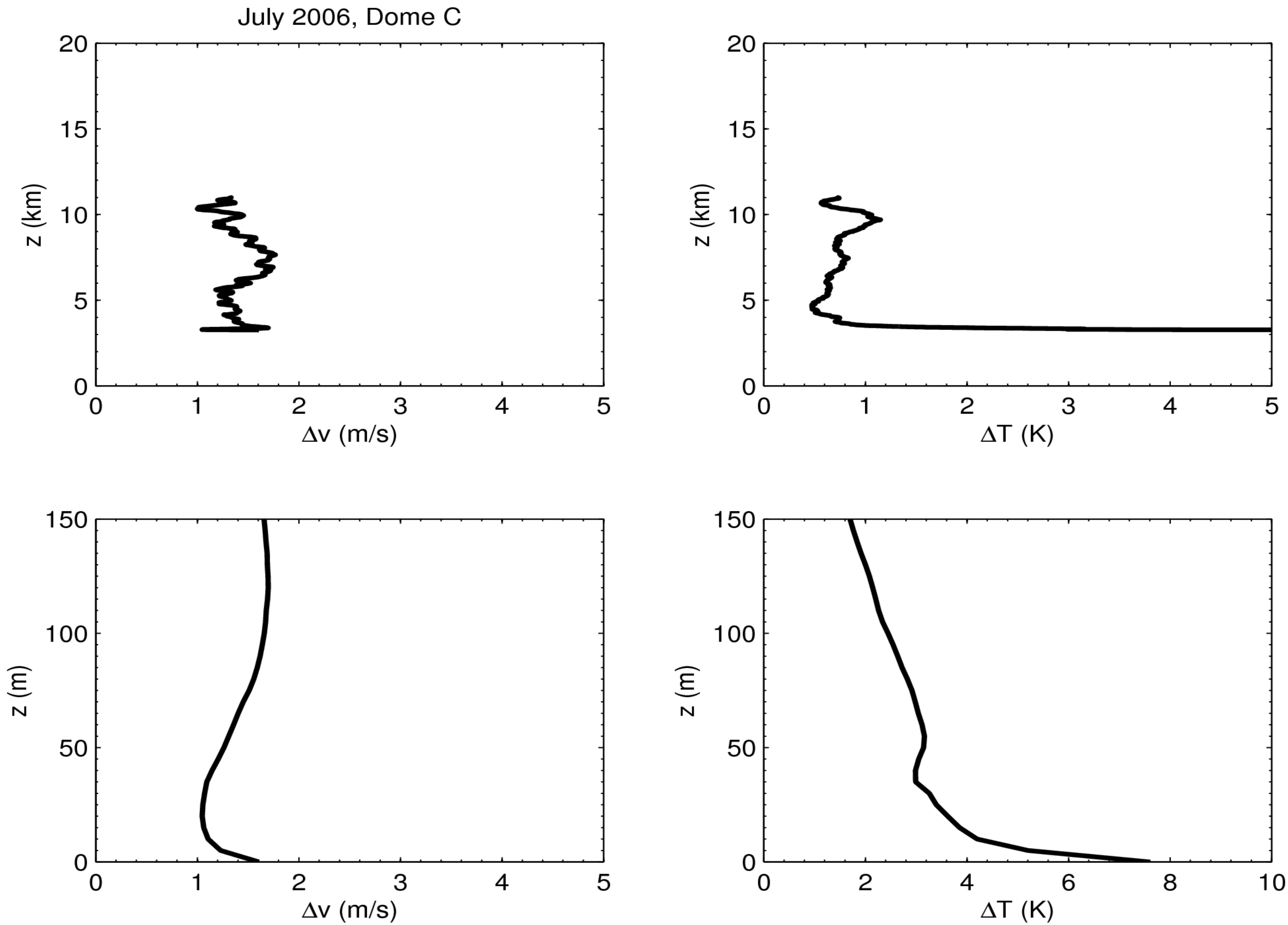
July 2006



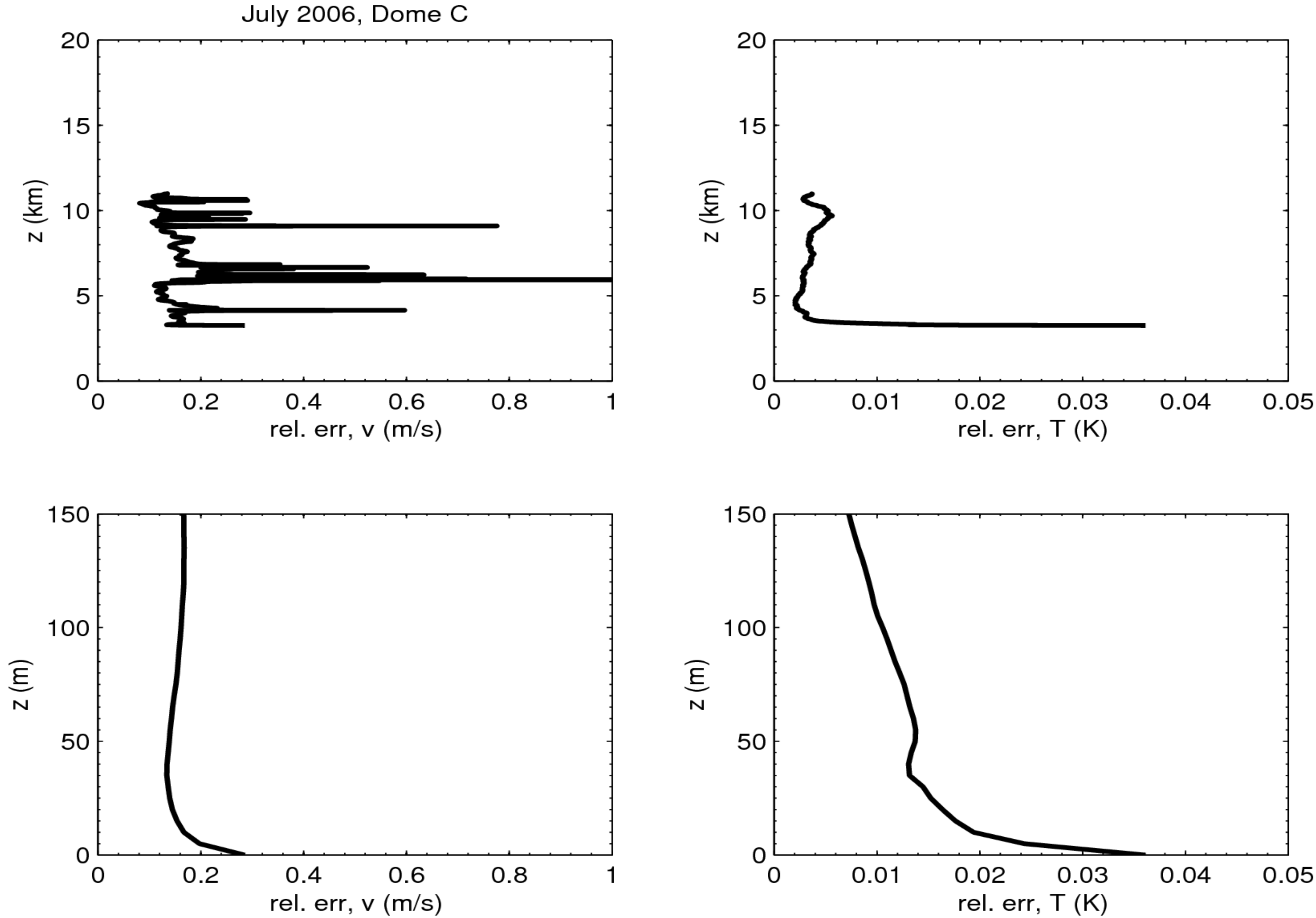
Interpolation step 100 m



Interpolation step 10 m



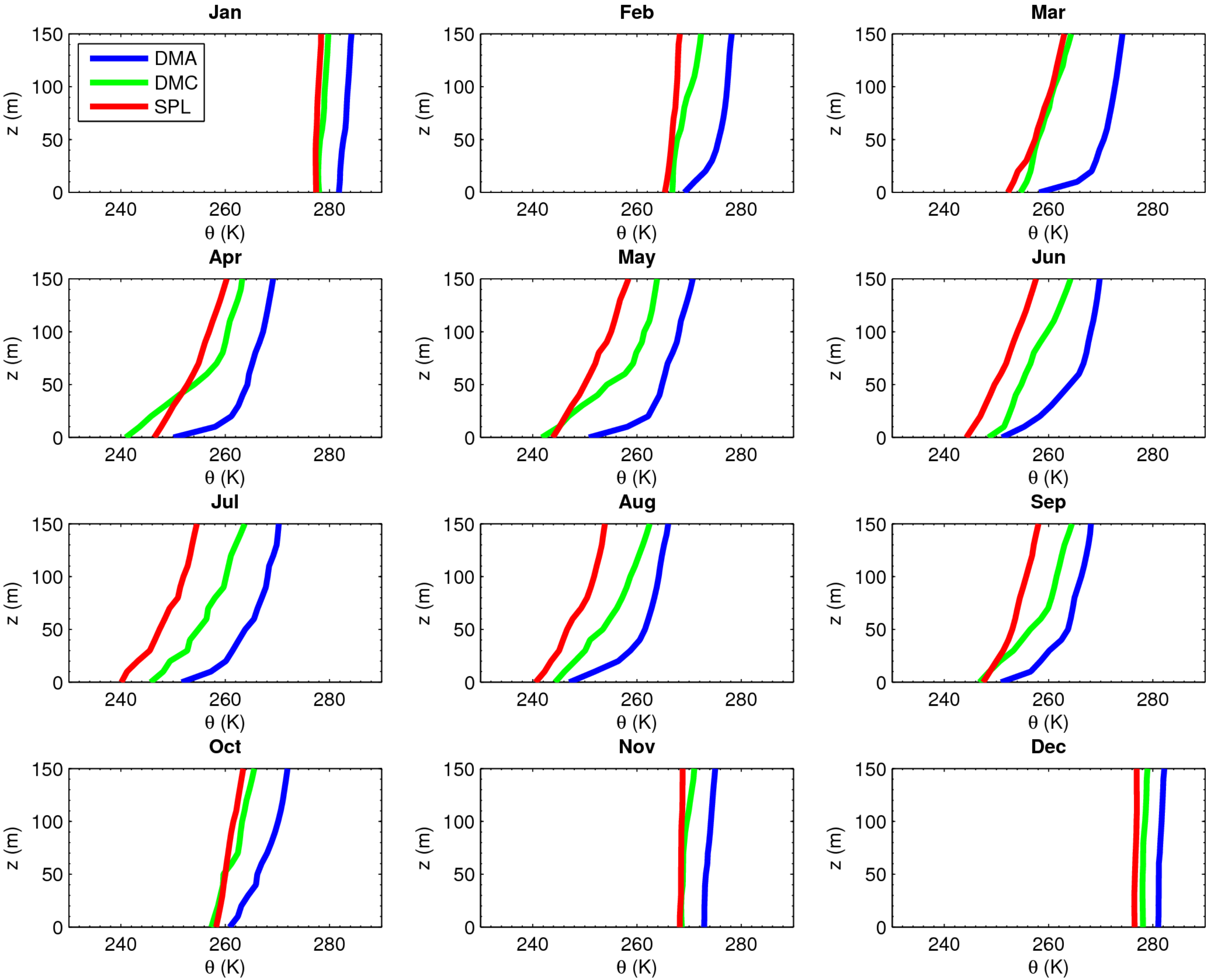
July 2006, Dome C
z (km)
Δv (m/s)
ΔT (K)
z (m)
Δv (m/s)
ΔT (K)



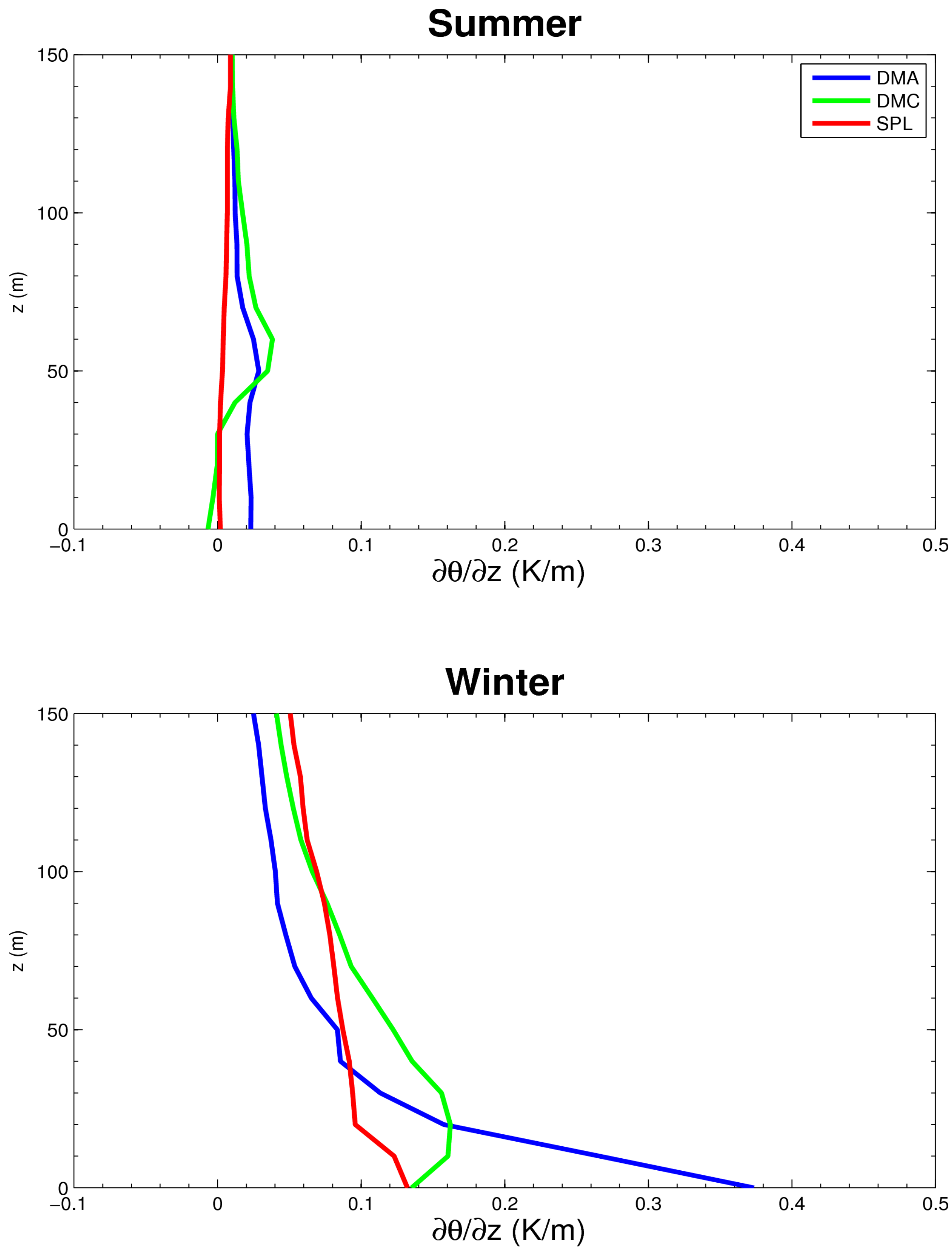
July 2006, Dome C
z (km)
rel. err, v (m/s)
rel. err, T (K)
z (m)
rel. err, v (m/s)
rel. err, T (K)

Potential Temperature

- During the dark period of the year, due to radiative cooling, the ice surface is colder than the atmosphere above
- Temperature inversion near the surface
- If the temperature increases as the height increases the stratification is thermally stable

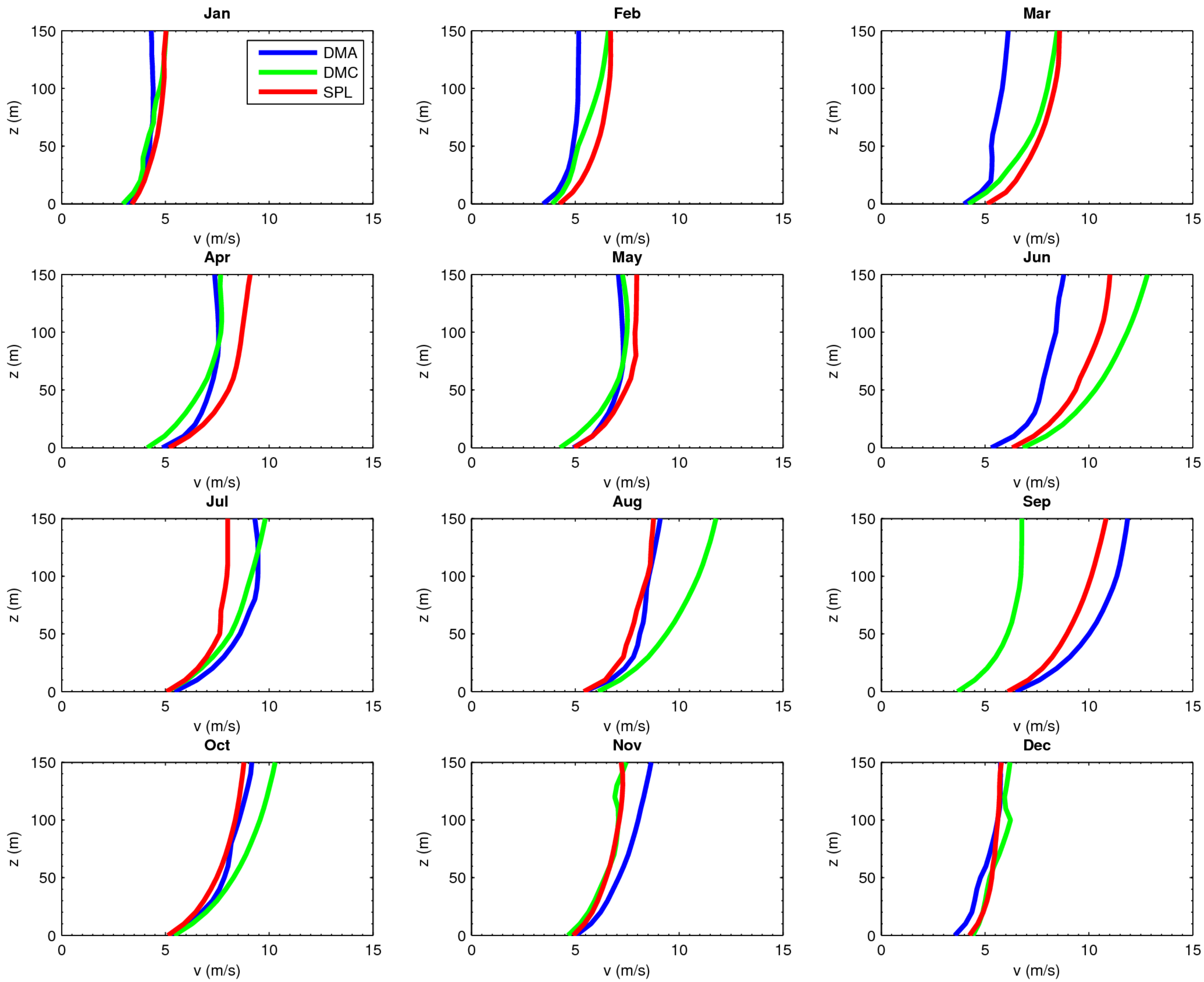


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DMA
DMC
SPL
z (m)
θ (K)
0
50
100
150
240
260
280


Summer
DMA
DMC
SPL
z (m)
∂θ/∂z (K/m)
Winter
z (m)
∂θ/∂z (K/m)

Wind Speed

- Surface winds are expected to be weaker above the domes
- Inversion winds should be absent there
- Surface winds will then be more similar to the geostrophic wind


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DMA
DMC
SPL
z (m)
v (m/s)
0
50
100
150
0
5
10
15

Wind Speed

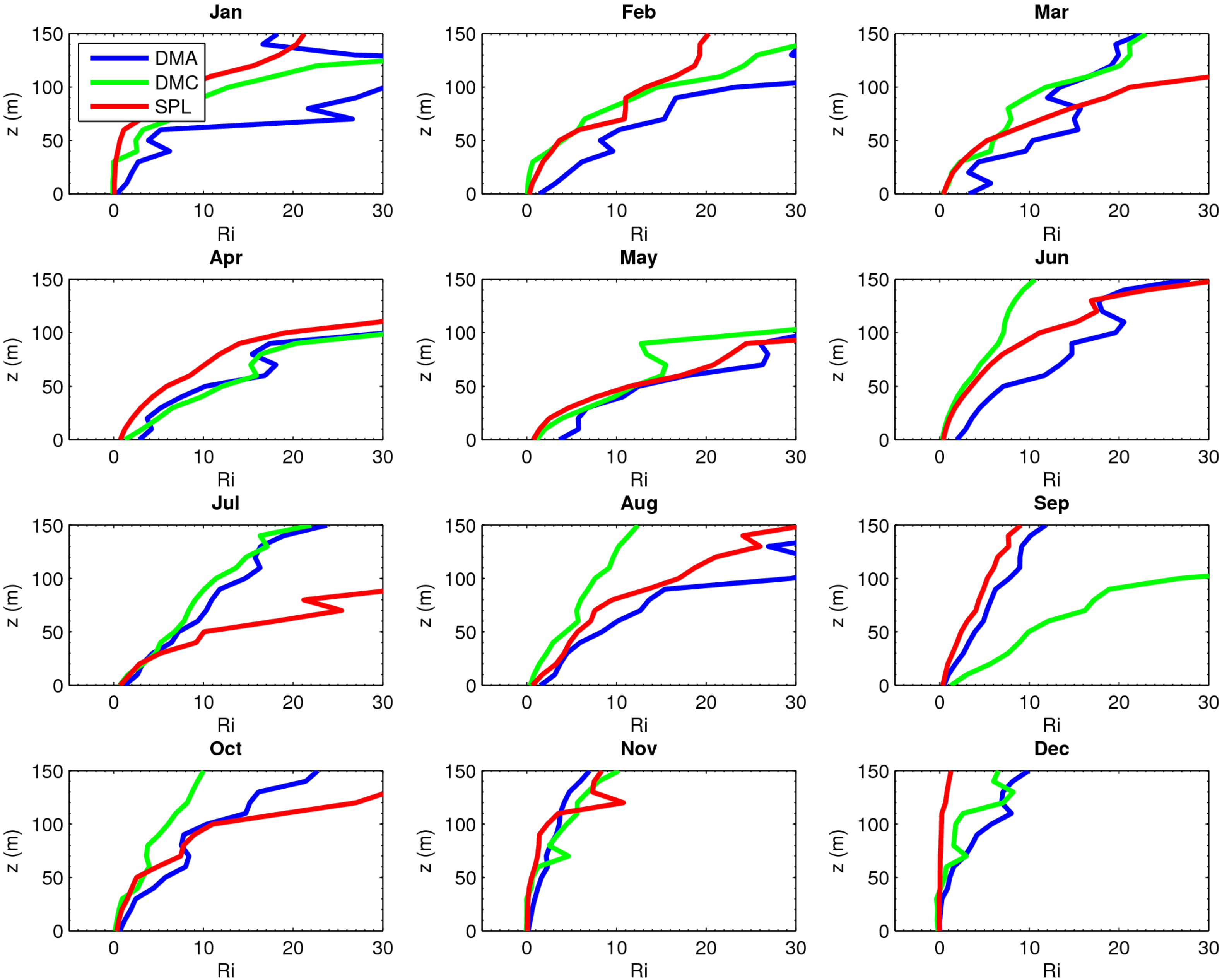
- No distinct difference in the strength of the wind between the three sites
- The gradient of the wind speed at the lowest level is largest for Dome A in all months

ForOT

Richardson Number

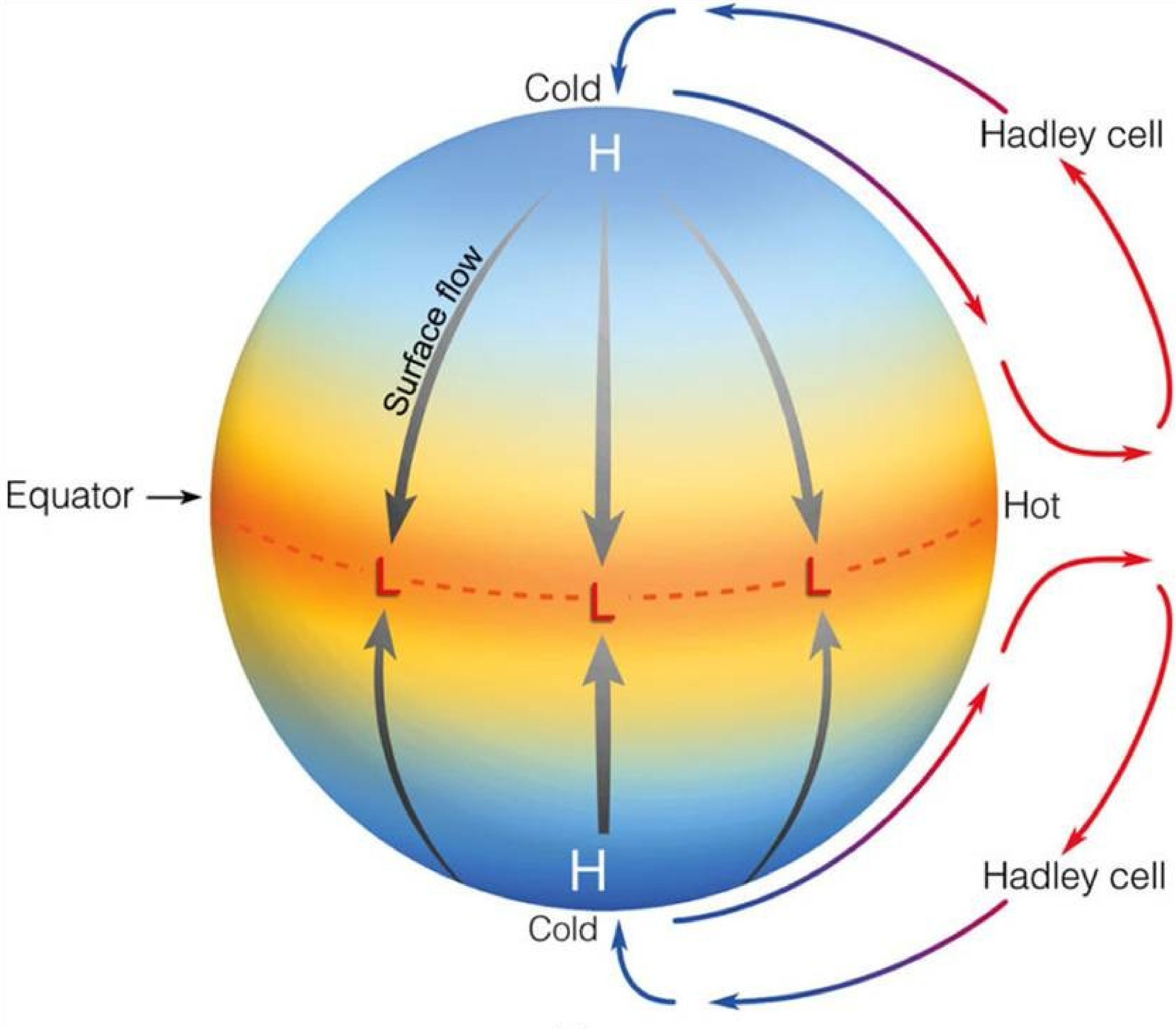
- Ri > 0.25 => the stratification is stable
- During winter all median values in the first 150 m are stable
- During the summer months the stratification is less stable

ForOT


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DMA
DMC
SPL
z (m)
Ri

General Circulation

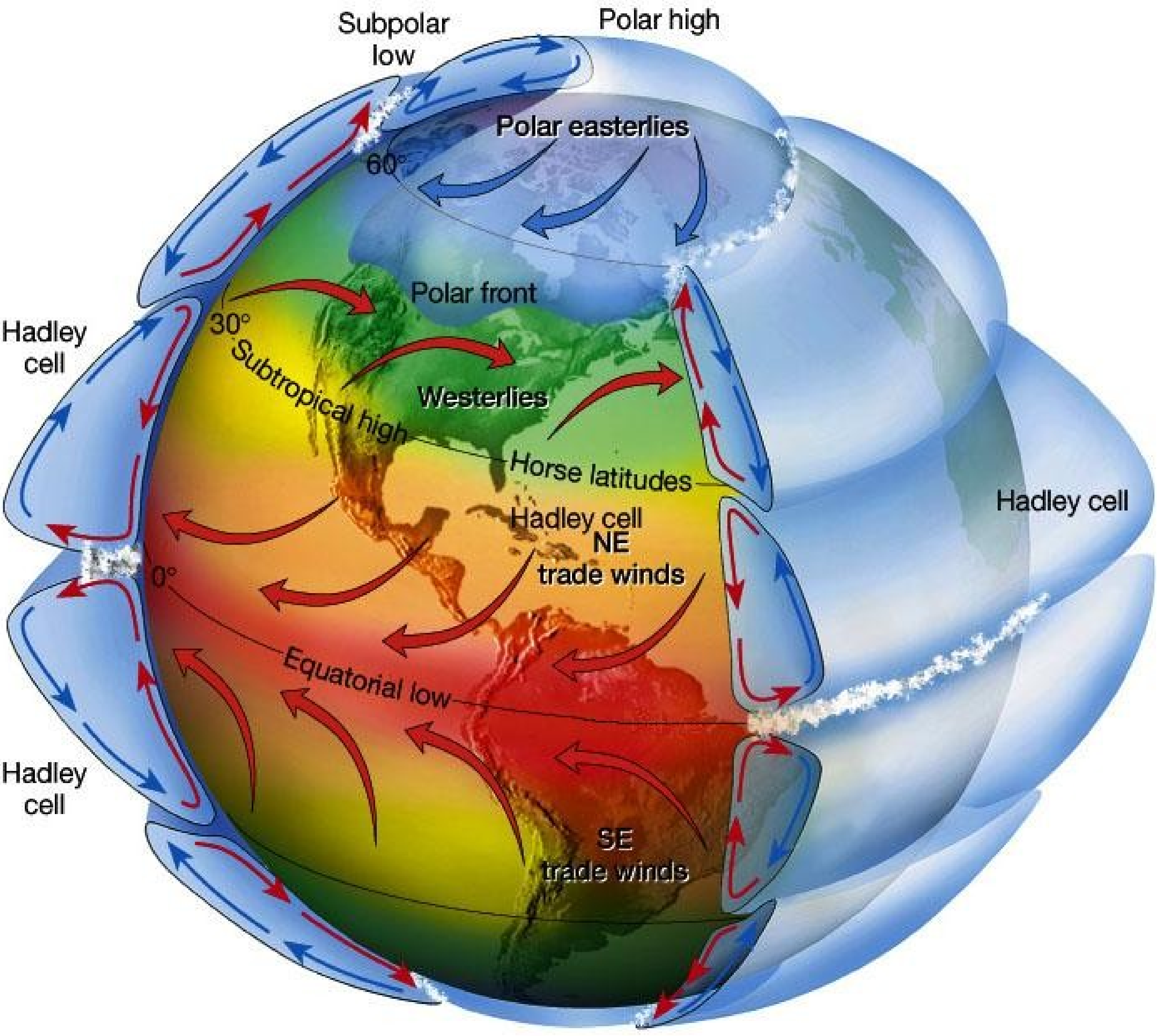
- The sun heats the atmosphere
- Most heating occurs at the equator
- Warmer air rises
- Colder air sinks


Cold
Hadley cell
H
Surface flow
Equator
Hot
L
L
L
H
Hadley cell
Cold

(a)

General Circulation

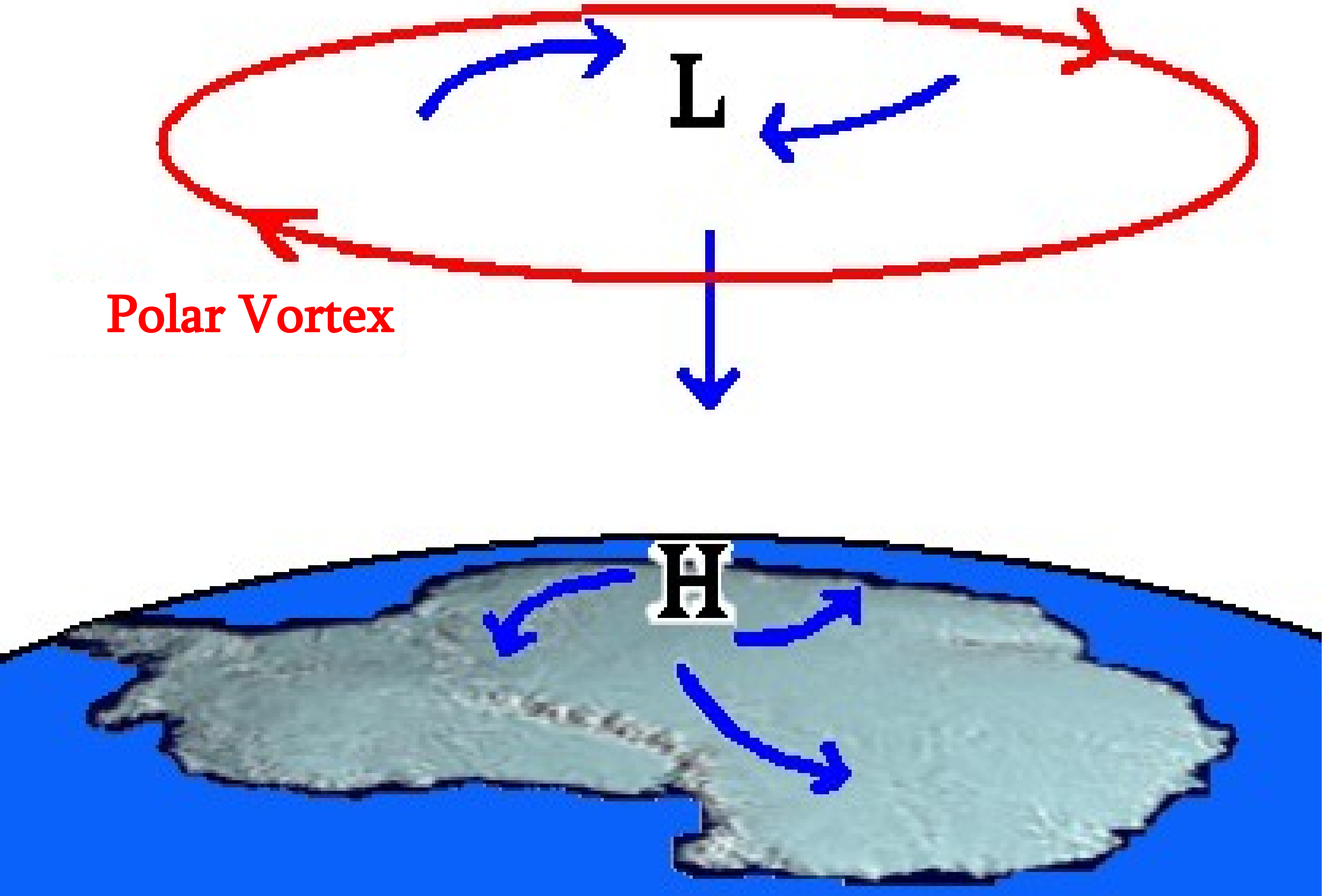
- The Earth rotates
  - Coriolis force
- Three cells in each hemisphere
- Pattern changes with season
- Moves south of the equator during the northern hemisphere's winter.



Subpolar low
Polar high
Polar easterlies
60°
Polar front
Hadley cell
30°
Subtropical high
Westerlies
Horse latitudes
Hadley cell
Hadley cell
NE trade winds
0°
Equatorial low
Hadley cell
SE trade winds

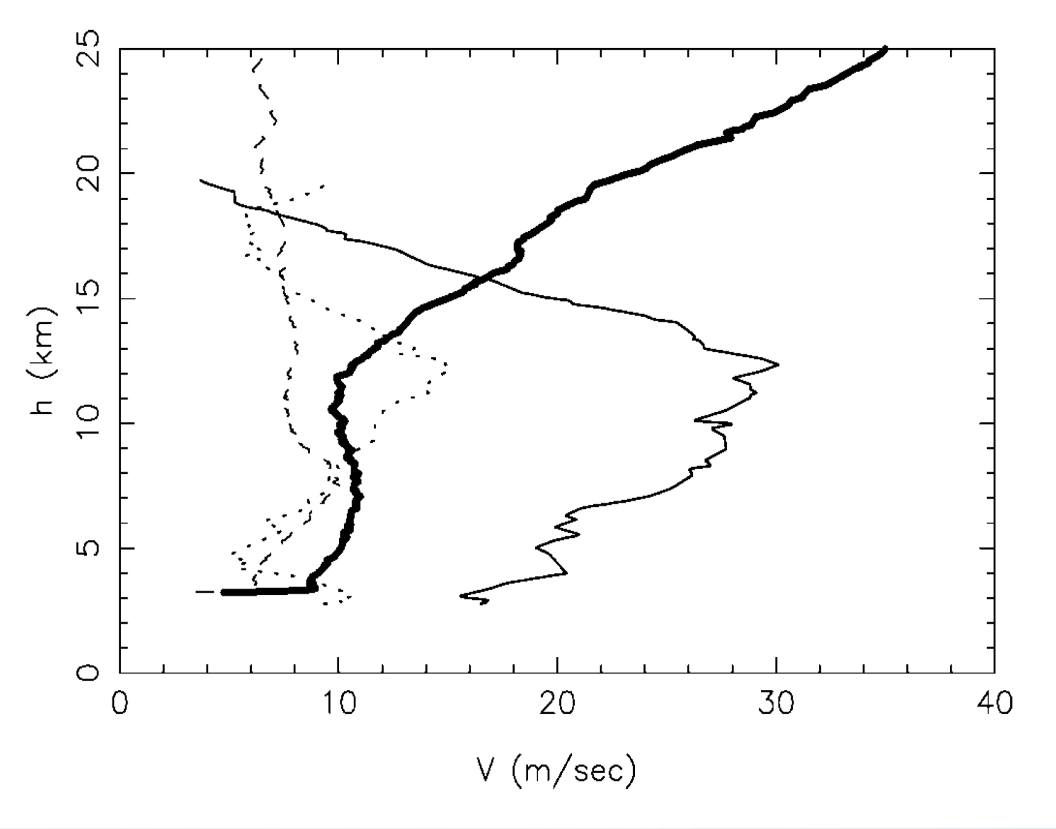
Polar High

- At the poles the cold air sinks
- This creates a semi-permanent high pressure near the geographic south pole.
- At high levels this creates a circulation pattern known as the Polar Vortex
- Vertical extent: the middle troposphere (≈4 km) to the middle of the stratosphere


L
Polar Vortex
H

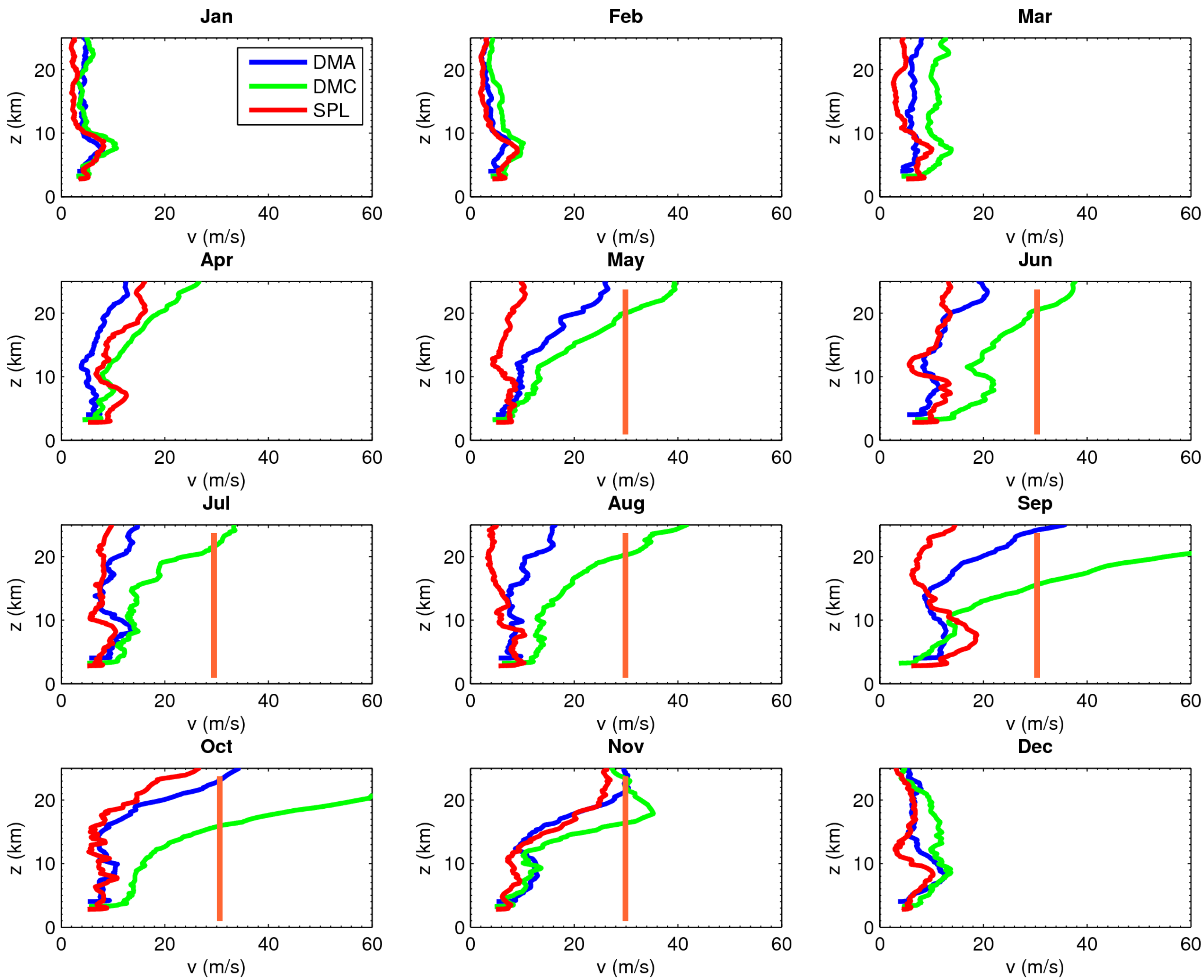
Wind Speed up to 25 km

- No jet stream is visible
- Usually the jet stream is defined as where the wind speed exceeds 30 m/s, at the height 300 hPa (≈10 km)



Geissler & Masciadri 2006

FOROT


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DMA
DMC
SPL
z (km)
v (m/s)
0
10
20
0
20
40
60

Conclusions

- The potential temperature and the Richardson number indicate that, nearest the ground, Dome A is more stable
- The wind speed of the analyses tells nothing of the difference in wind speed near the surface
- At altitudes it is smallest for the South Pole and largest for Dome C

Conclusions

- The ECMWF analyses are smoothed out and cannot accurately describe the surface layer
- Conclusions derived from these data should be taken with caution
- Measurements are needed!
- Use a mesoscale model (Méso-NH) that should be able to describe the surface in greater detail