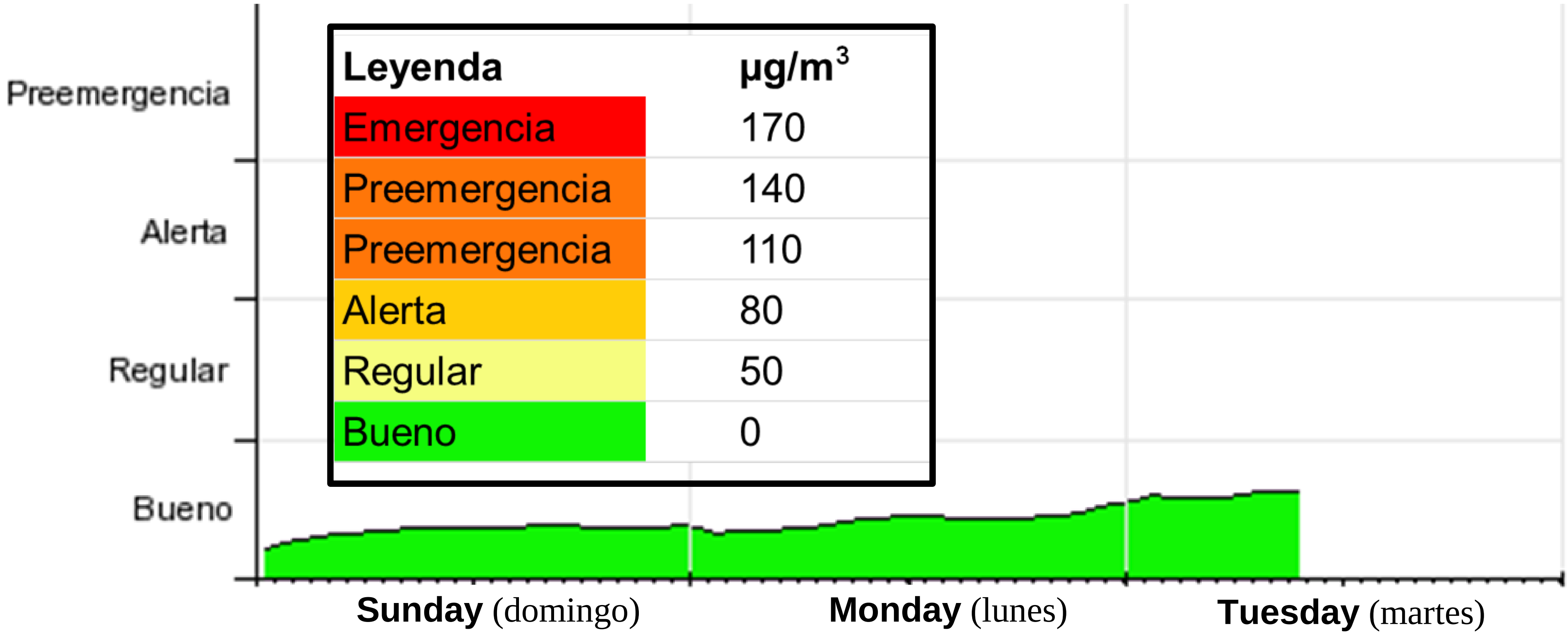
Surface Measurements (Las mediciones de superficie)
24 Hour $PM_{2.5}$ Samples in Santiago (Sep 22/23/24, 2013)



Measurements from the Parque O'Higgins Station. Plot from Sistema Nacional de Calidad del Aire Web Site (http://sinca.mma.gob.cl)

Atmospheric Transport

Forces in the Atmosphere:

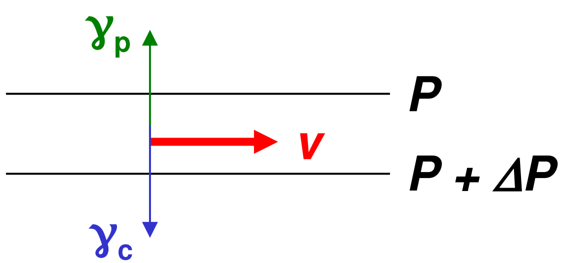
- **Gravity** $\mathbf{g}$
- **Pressure-gradient** $\gamma_p = -(1/\rho)\nabla P$
- **Coriolis** $\gamma_c = 2\omega v \sin\lambda$ → **To Right of direction of motion in Northern Hemisphere and to Left in Southern Hemisphere**
- **Friction** $\gamma_f = -k\mathbf{v}$

ρ - Density
P – Pressure
ω - Angular Velocity of the Earth
V – Speed of Object

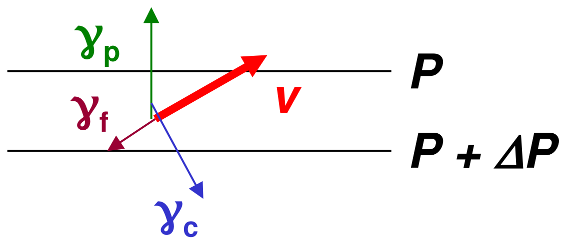
Equilibrium of Forces:

In vertical: barometric law

In horizontal: *geostrophic* flow parallel to isobars

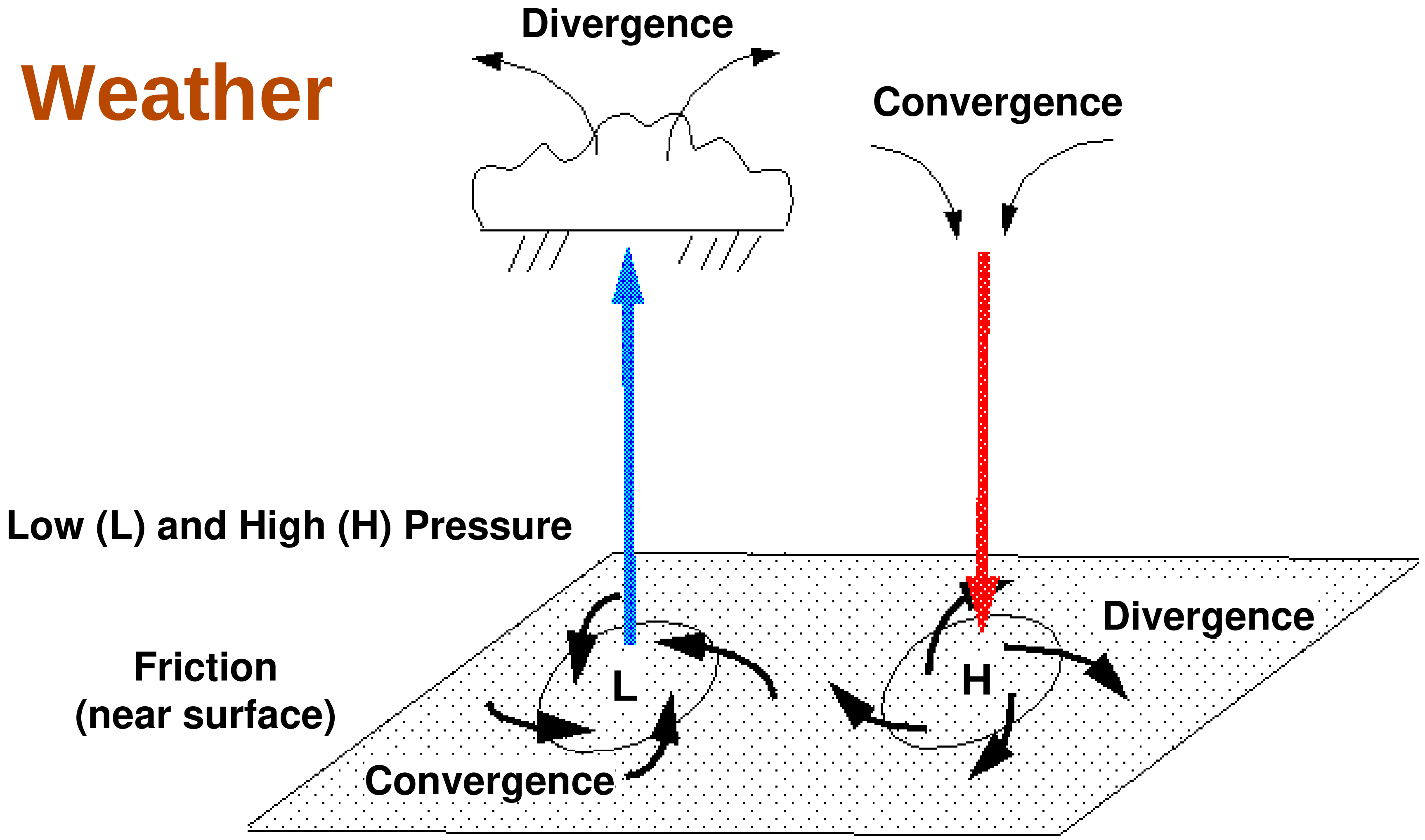


In horizontal, near surface: flow tilted to region of low pressure



Courtesy of Daniel J. Jacob

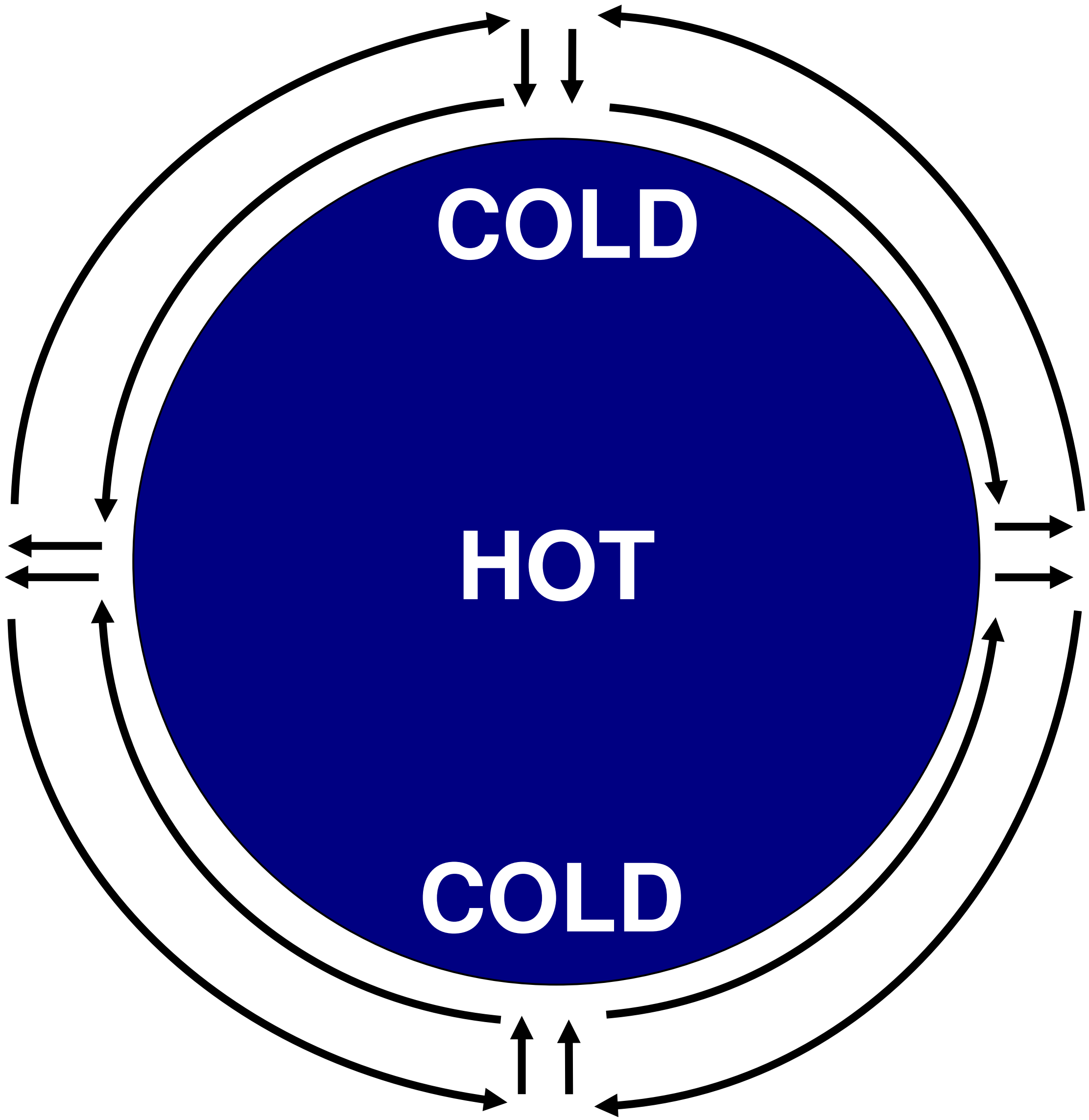
Weather



Air converges near the surface in low pressure centers, due to the modification of geostrophic flow under the influence of friction. Air diverges from high pressure centers. At altitude, the flows are reversed: divergence and convergence are associated with lows and highs respectively.

Courtesy of Daniel J. Jacob

The Hadley Circulation: Global Sea Breeze



Explains:
- Intertropical Convergence Zone (ITCZ)
- Wet tropics, dry poles
- Easterly trade winds in the tropics

But… Meridional transport of air between Equator and poles results in strong winds in the longitudinal direction because of conservation of angular momentum; this results eventually in unstable conditions.

Courtesy of Daniel J. Jacob

Tropical Hadley Cell

- Easterly "trade winds" in the tropics at low altitudes
- Subtropical anticyclones at about 30° latitude

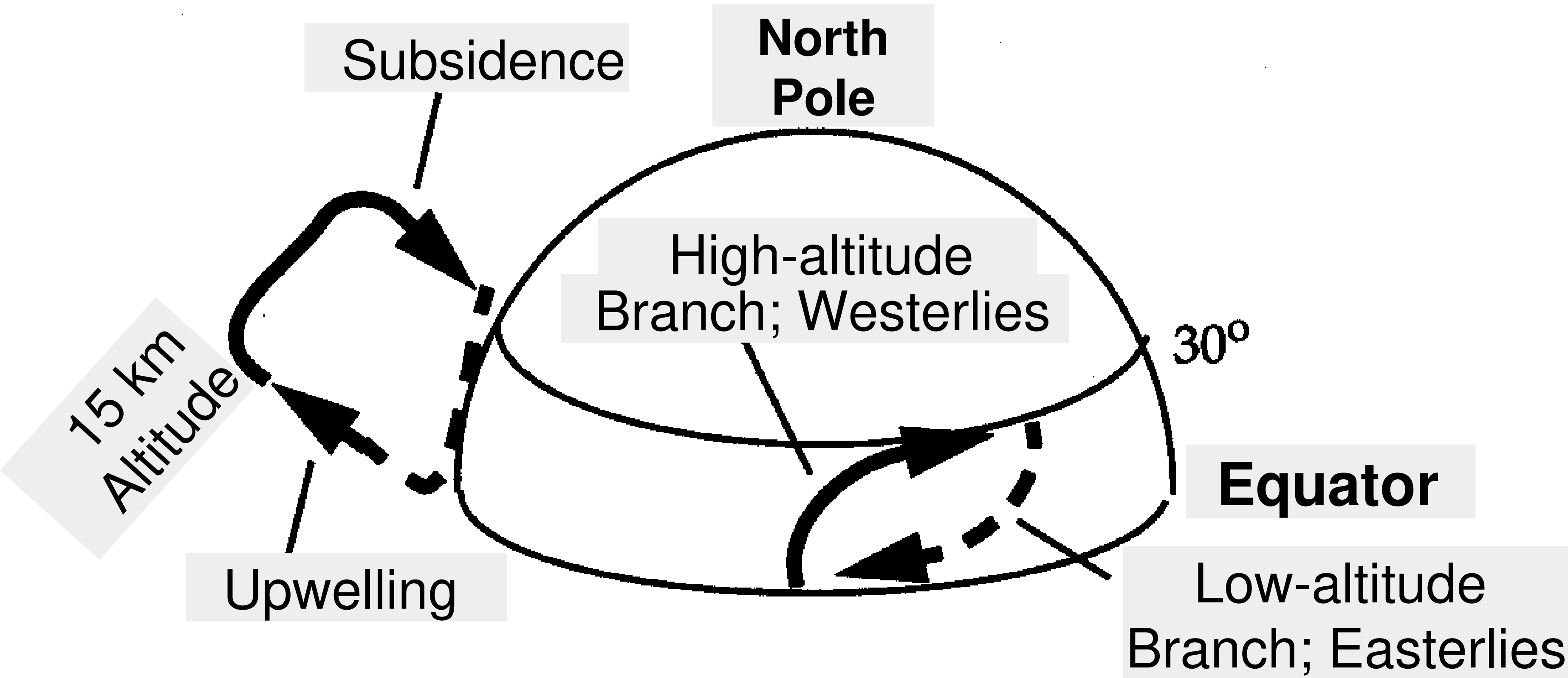
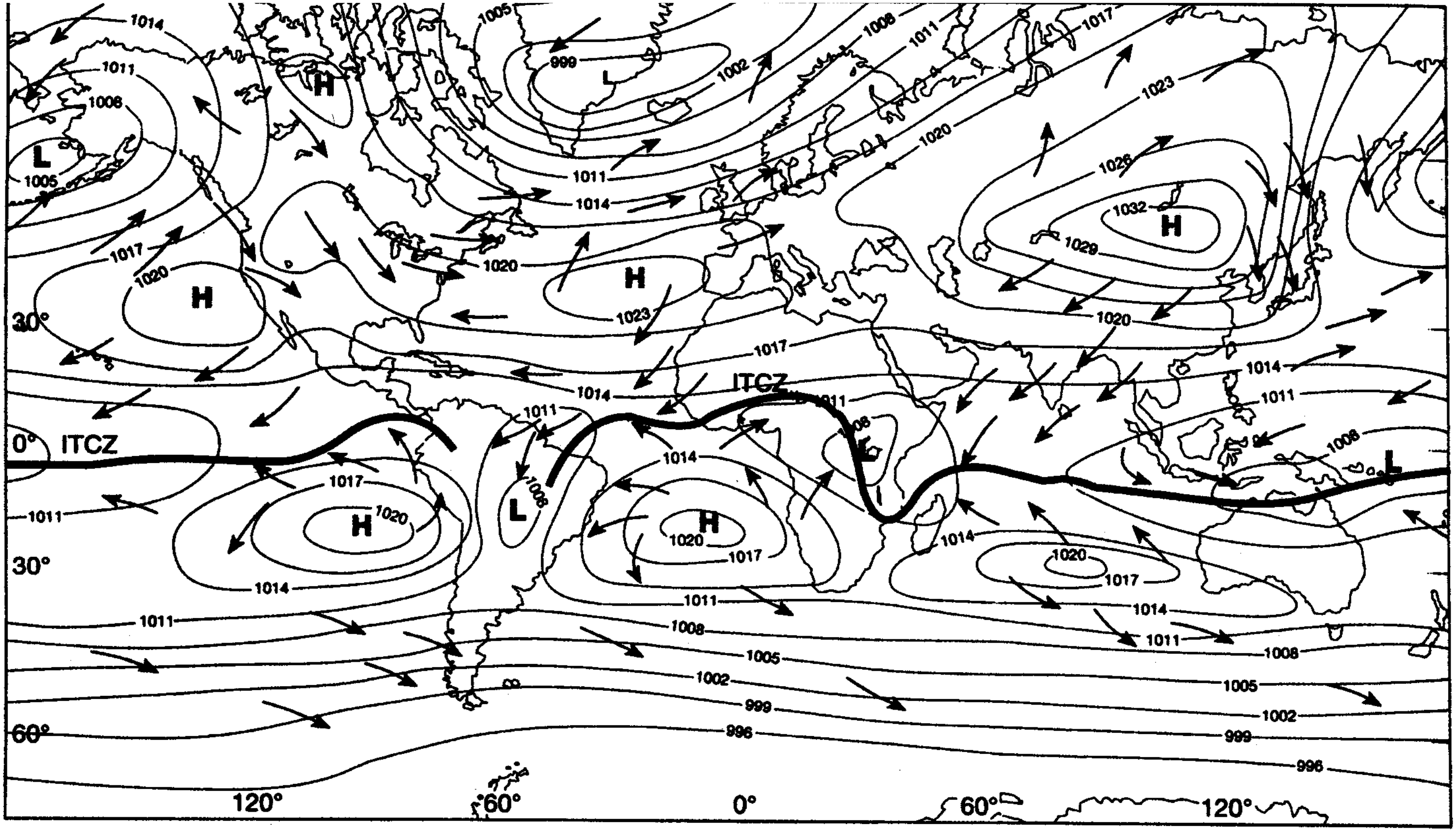


Fig. 4-11 Northern Hemisphere Hadley Cell.

Courtesy of Daniel J. Jacob

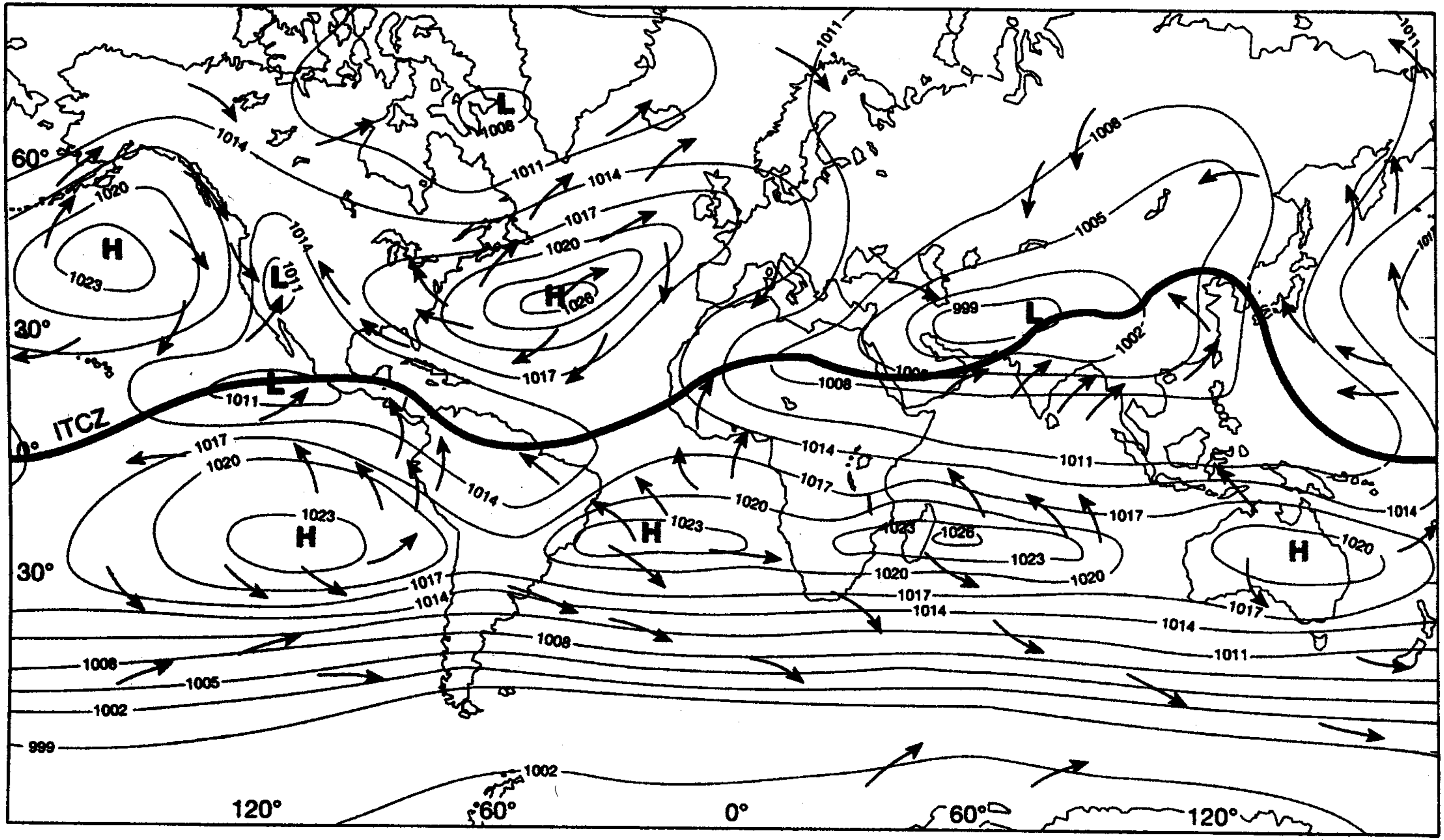
Climatological Surface Winds and Pressure



(January)

Courtesy of Daniel J. Jacob

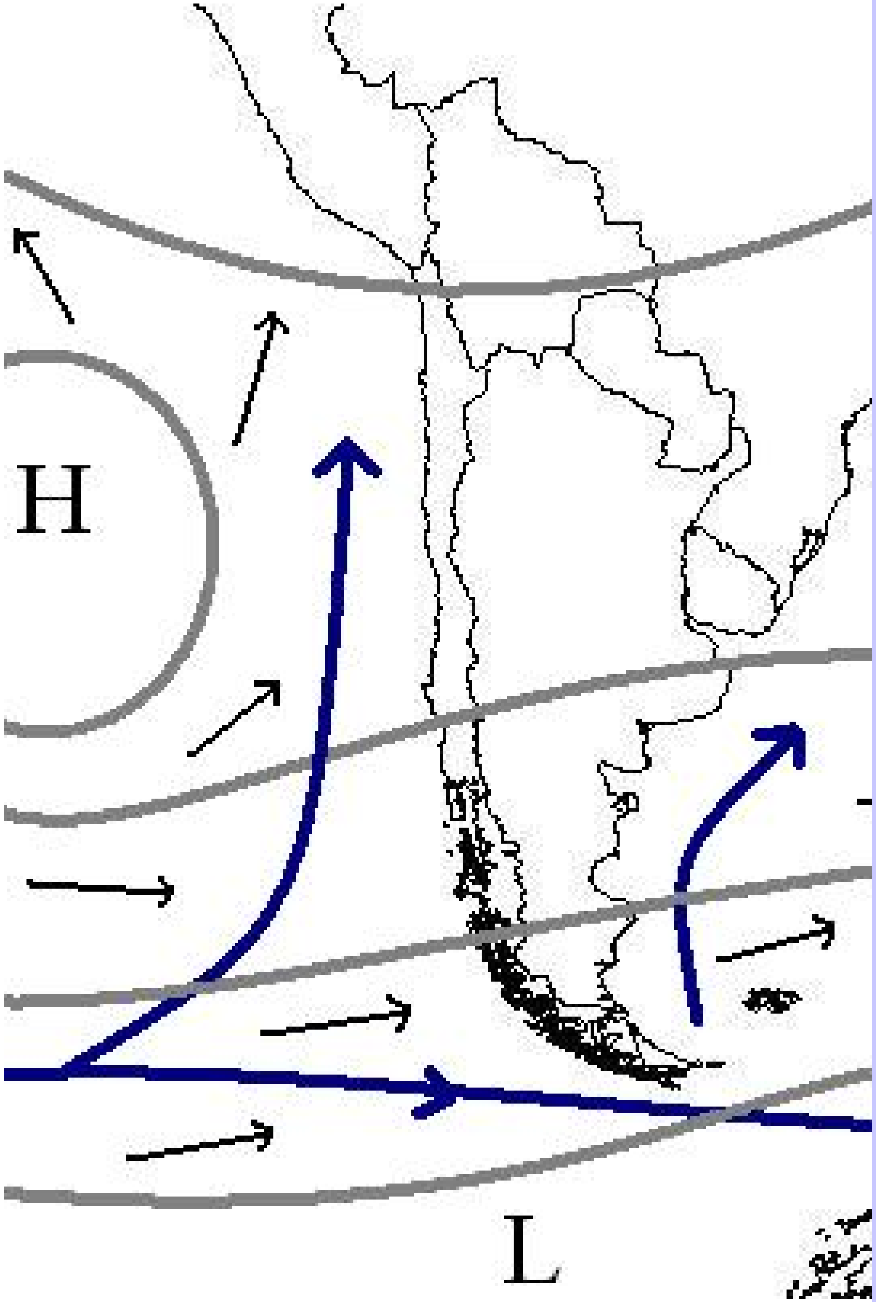
Climatological Surface Winds and Pressure

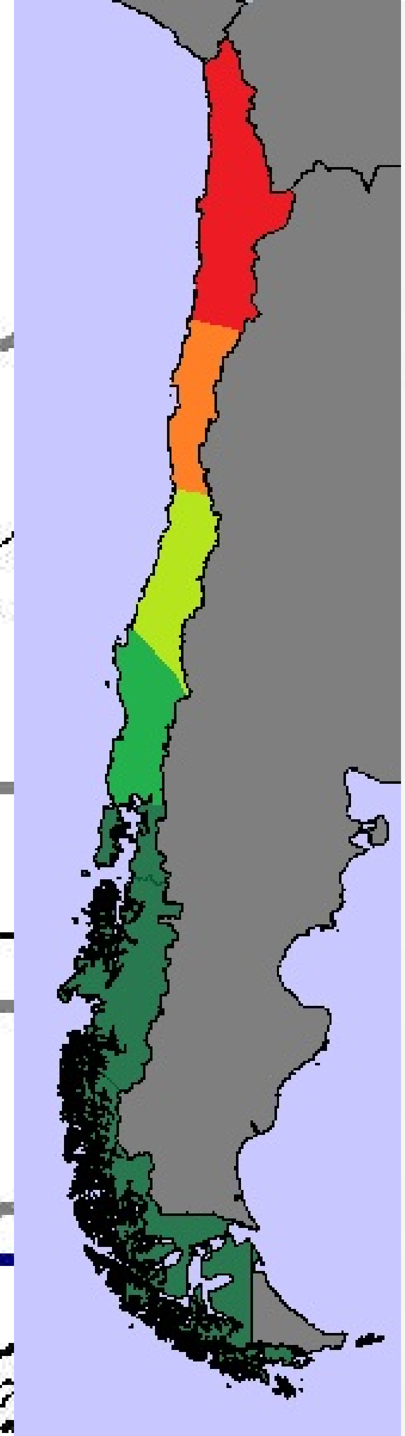


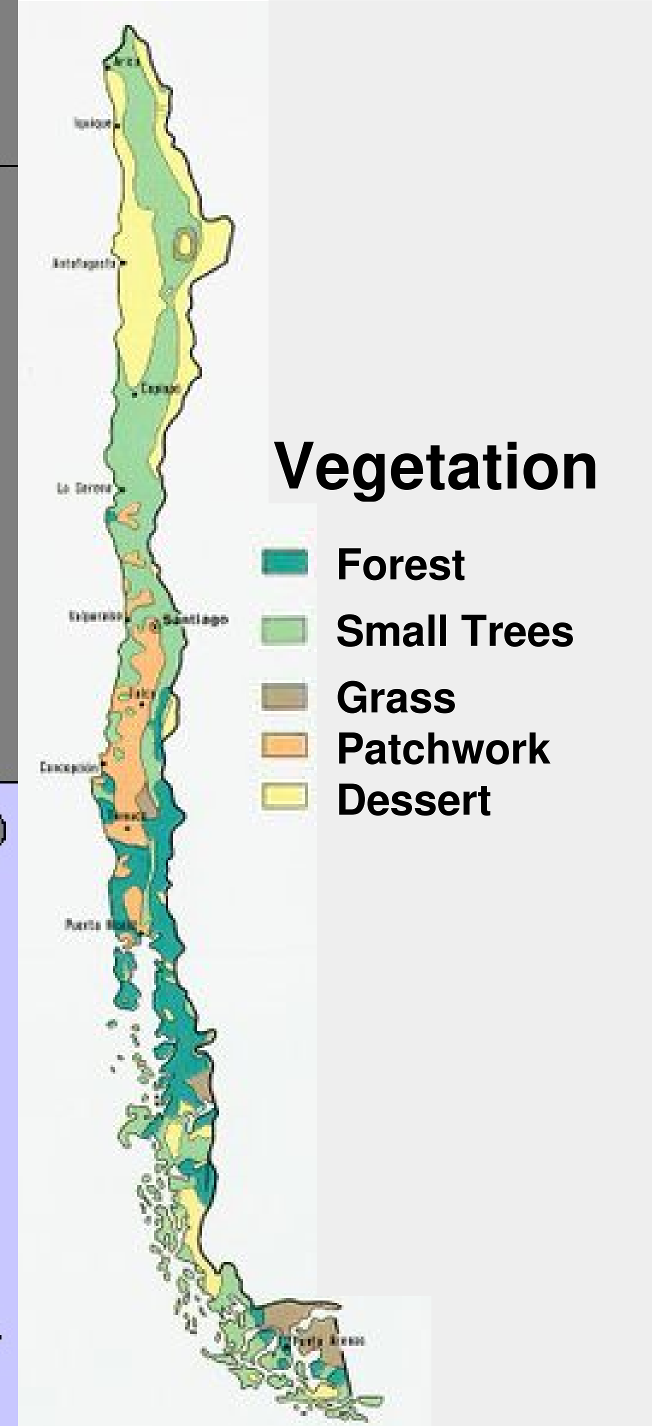
(July)

Courtesy of Daniel J. Jacob

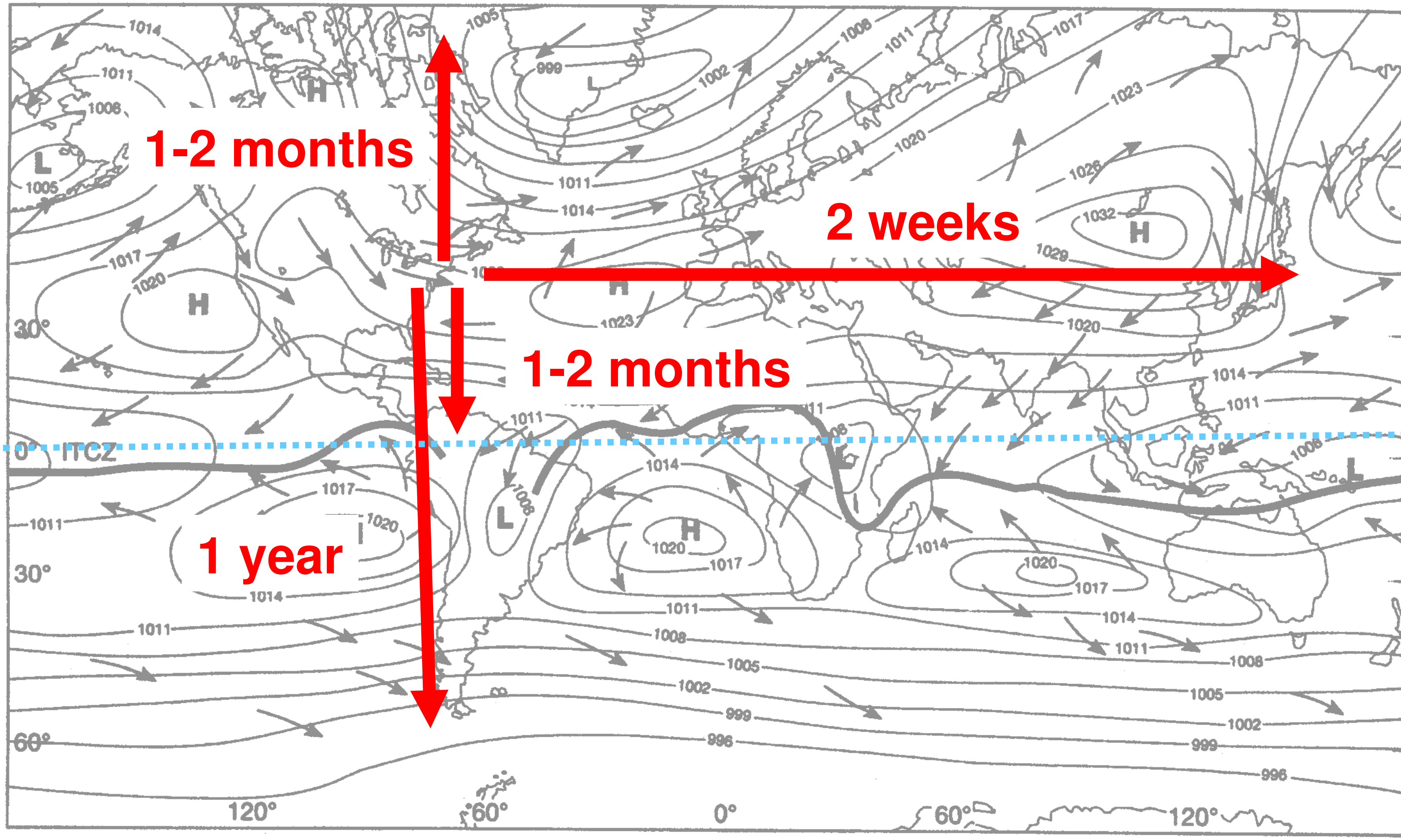
Climate of Chile







Time Scales for Tropospheric Transport

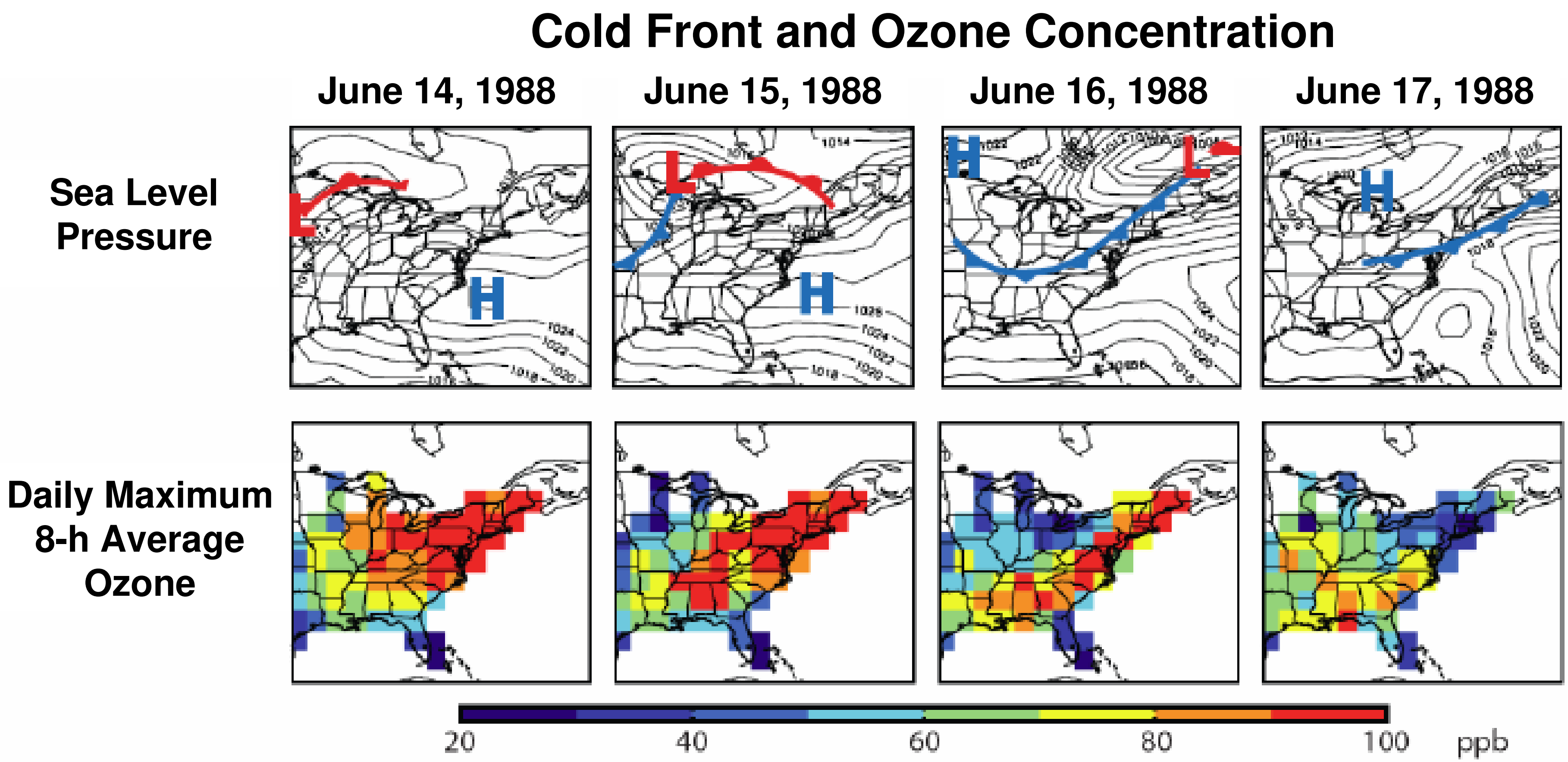


(a) January

3 months time scale for transport from the surface to the tropopause.

Courtesy of Daniel J. Jacob

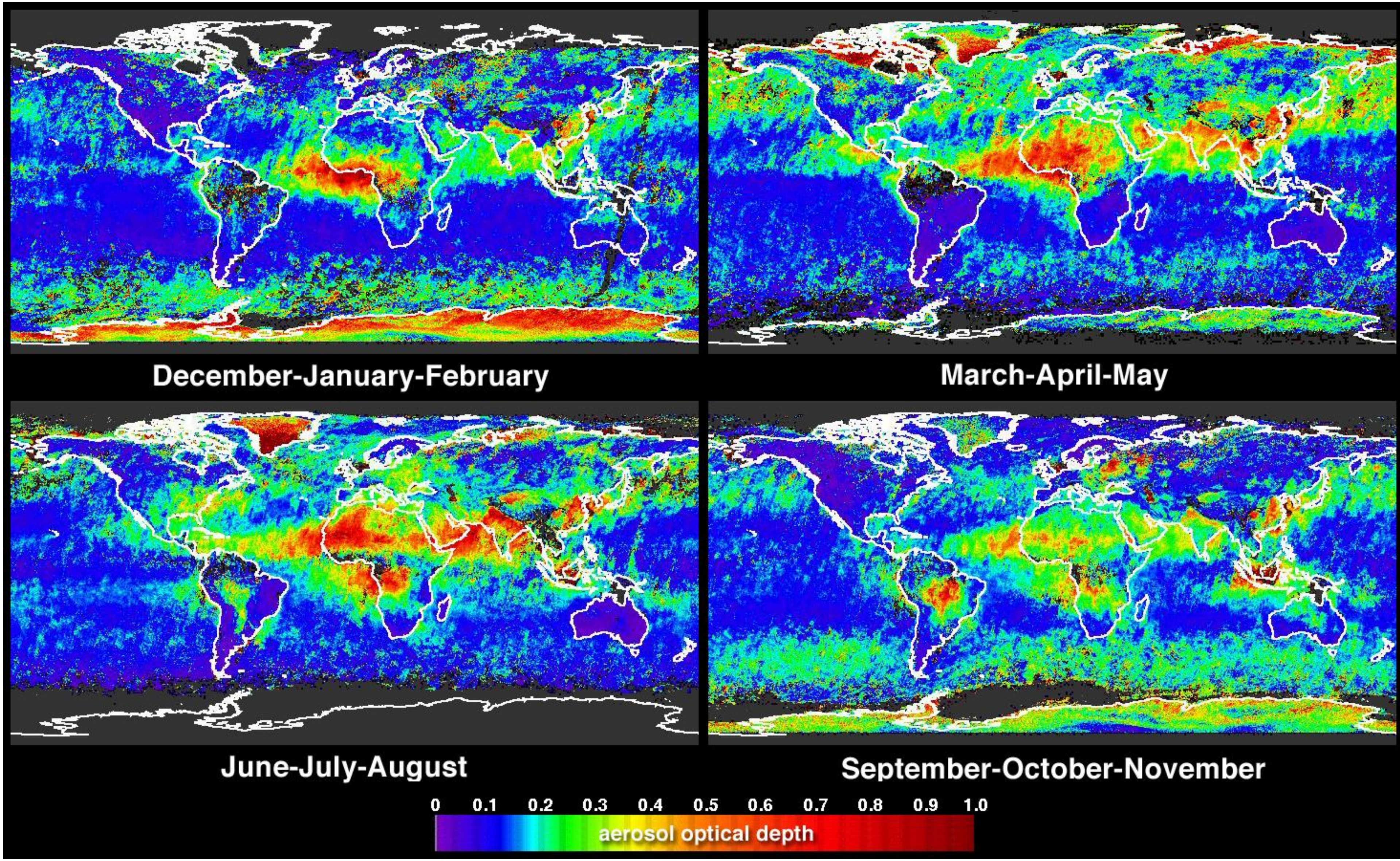
Importance of Mid-latitude Cyclones for U.S. Ventilation



- **Cold fronts associated with cyclones tracking across southern Canada are the principal ventilation mechanism for the eastern US**
- **The frequency of these cyclones has decreased in past 50 years, likely due to greenhouse warming**

Courtesy of Daniel J. Jacob *Leibensperger et al. [2008]*

MIRS Aerosol Optical Depth

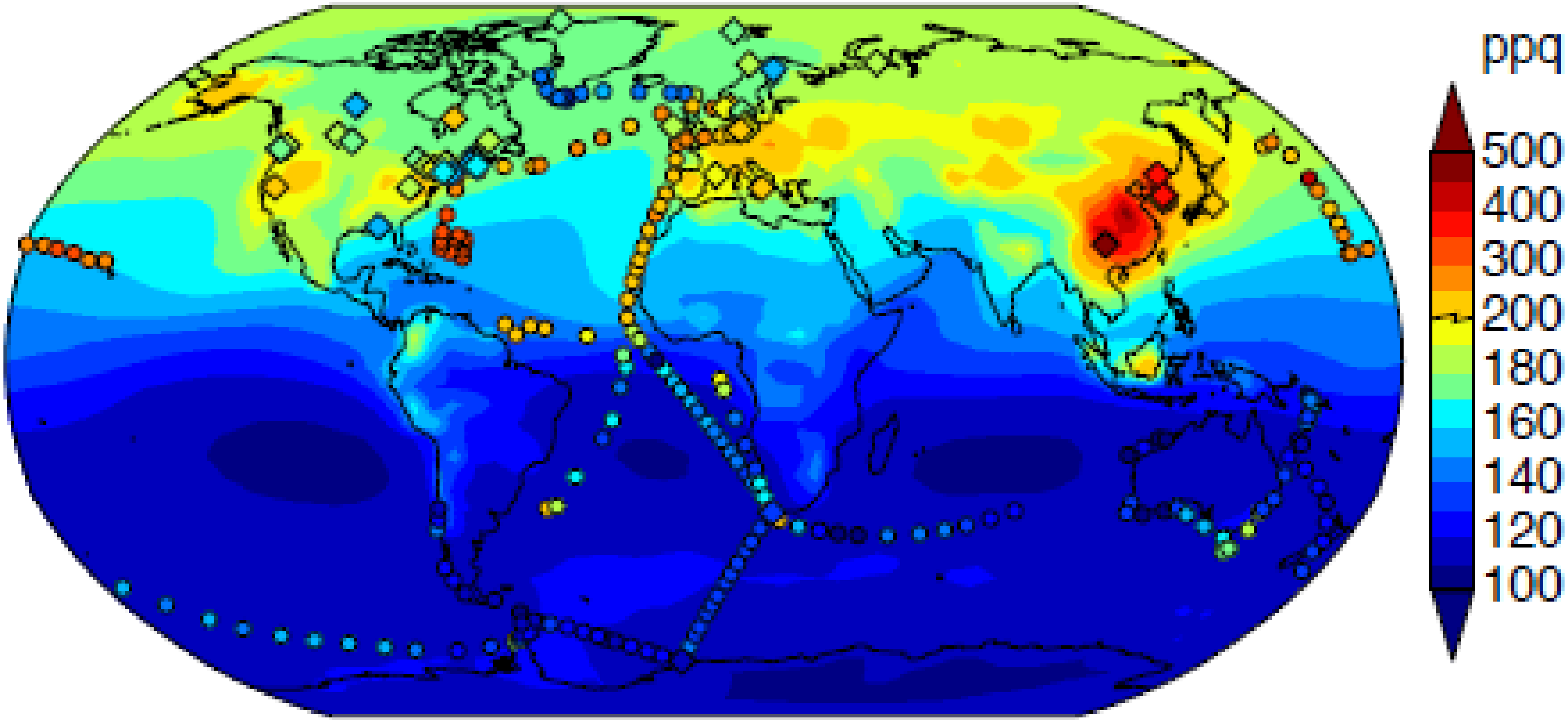


What about surface PM measurements in North Dakota?

Source: http://photojournal.jpl.nasa.gov/catalog/PIA04333

Global Distribution of Atmospheric Mercury

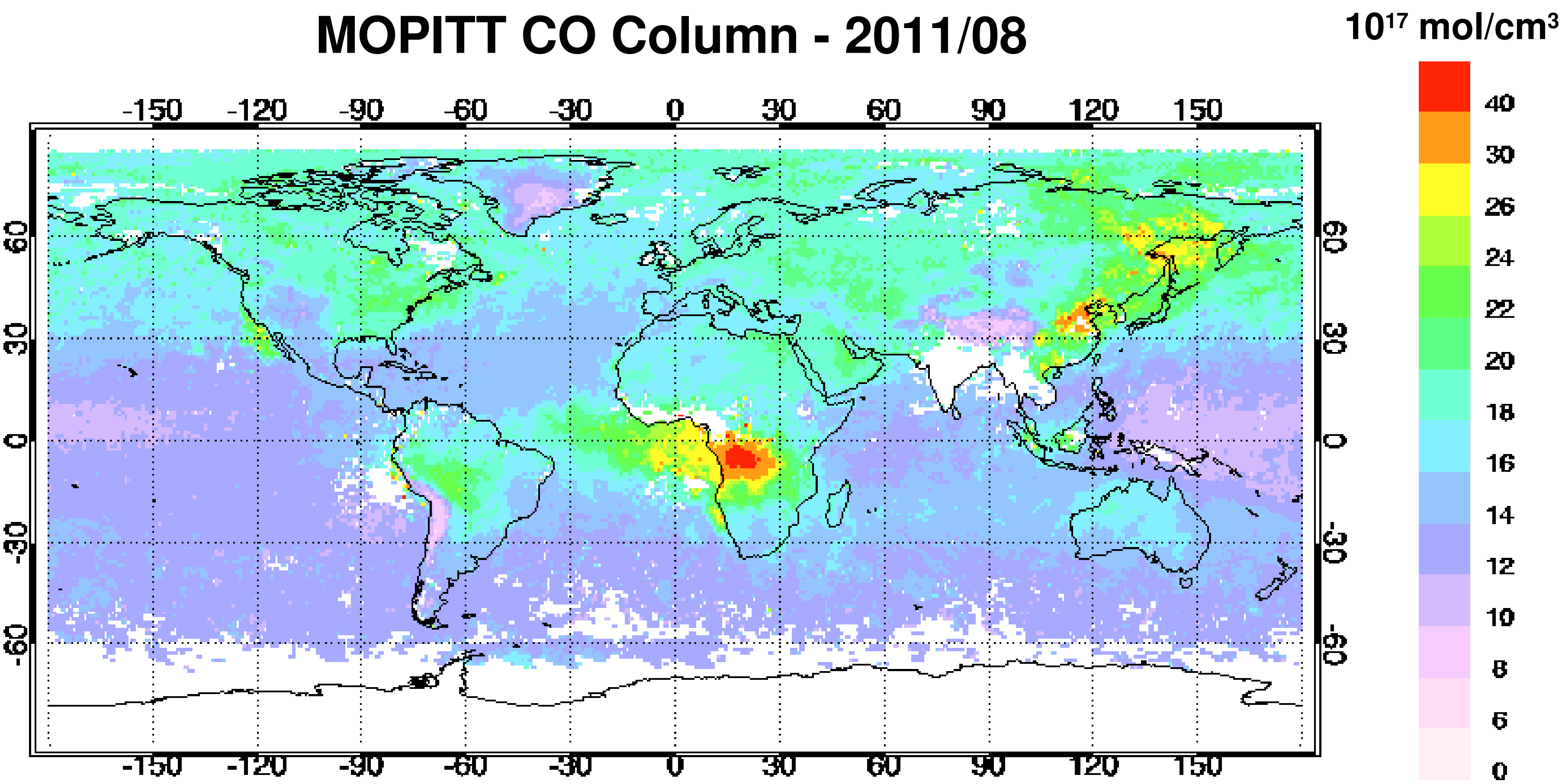
Annual Mean Concentrations: Observed (circles) and Model (background)



Holmes et al. [2010]

Courtesy of Daniel J. Jacob

Monthly Averaged Carbon Monoxide

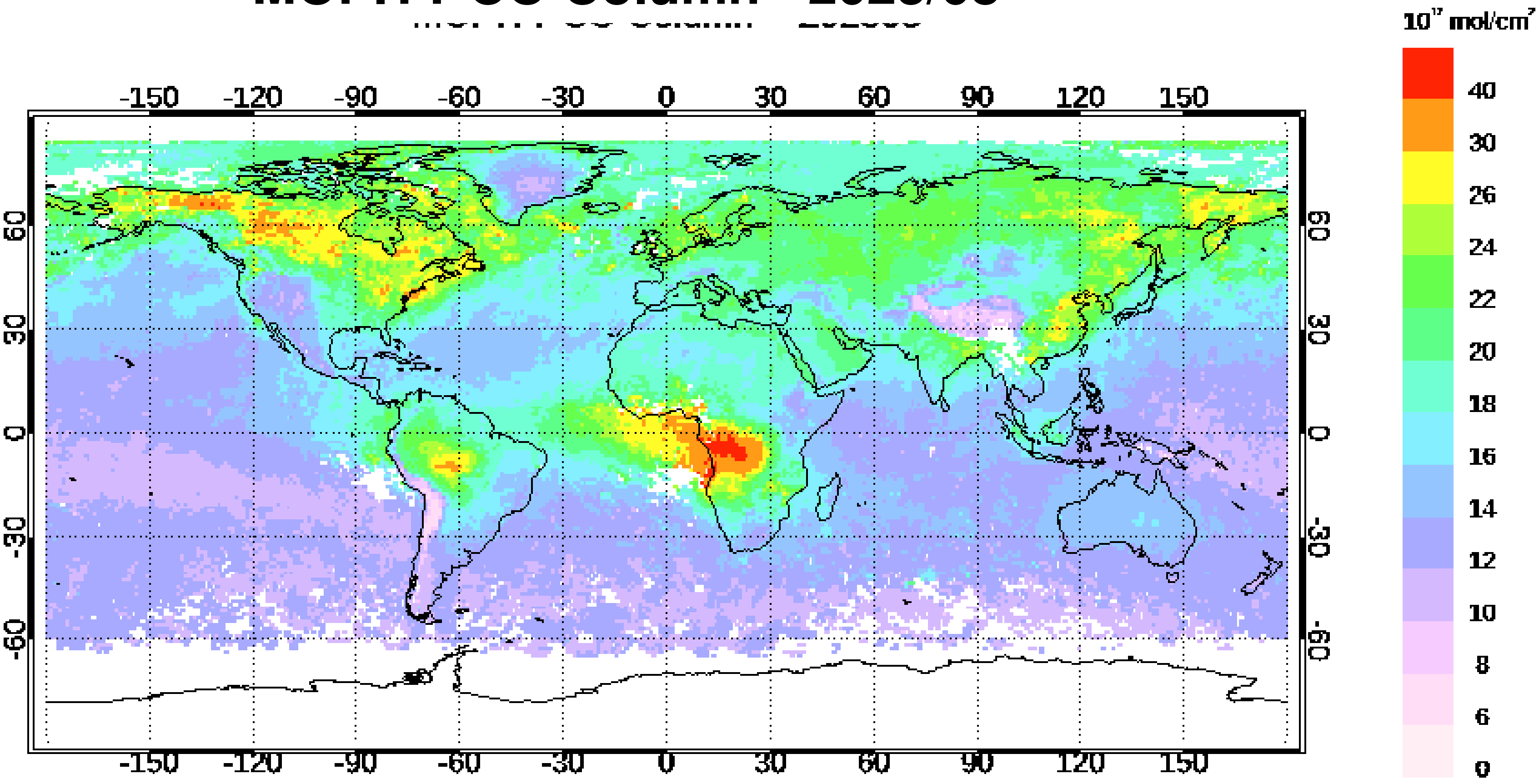


Source: Incomplete Combustion
Sink: Atmospheric Oxidation
Lifetime: 2 months

Source: NCAR Atmospheric Chemistry Division (http://www.acd.ucar.edu/mopitt/visualize.shtml)

Monthly Averaged Carbon Monoxide

MOPITT CO Column - 2023/08

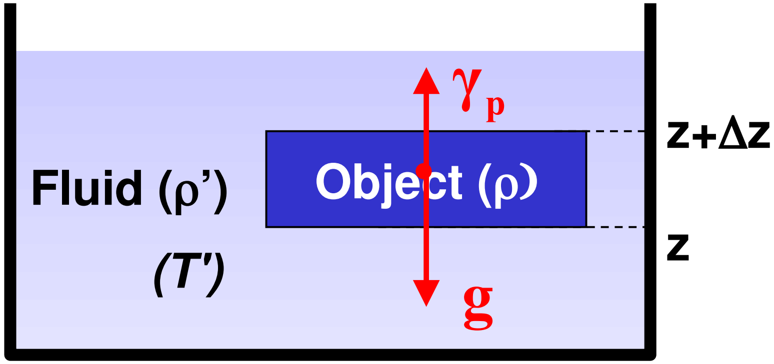


Source: Incomplete Combustion
Sink: Atmospheric Oxidation
Lifetime: 2 months

Source: UCAR Atmospheric Chemistry Division (https://www.acom.ucar.edu/mopitt/MOPITT/data/plots9j/maps_mon.html)

Vertical Transport: Buoyancy

Consider an object (density ρ) immersed in a fluid (density ρ'):



P(z) > P(z+Δz)

Therefore, pressure-gradient force (Y_b) on object directed upward

Optical Turbulence (Thermosonde)

Buoyancy Acceleration (upward) : $\mathrm{Y}_b = \mathrm{Y}_p - g = \frac{\rho' - \rho}{\rho} g$

For air, $\rho = \frac{M_a P}{RT}$ **so ρ↑ as *T*↓** *Remember p ~ 1/T (Ideal Gas Law)*

Barometric law assumes *T = T' therefore* $\mathrm{Y}_b = 0$ (zero buoyancy)

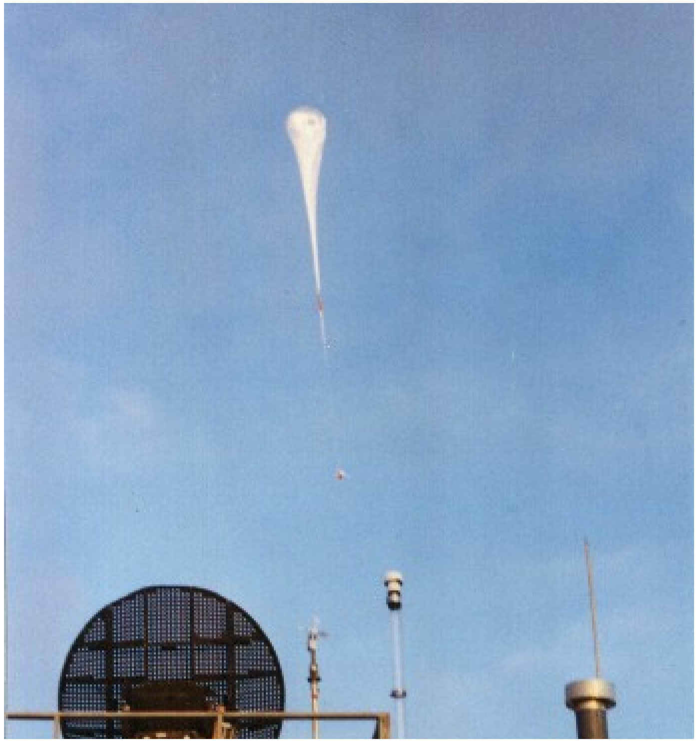
T* – *Temperature of Object
T'* – *Temperature of fluid

T $\neq$ ***T'* produces buoyant acceleration upward or downward**

Courtesy of Daniel J. Jacob

Helium Balloon

If a object (for example, Helium filled balloon connected to instrument package) is lighter than the fluid in which it is immersed, it is accelerated upward (see video).



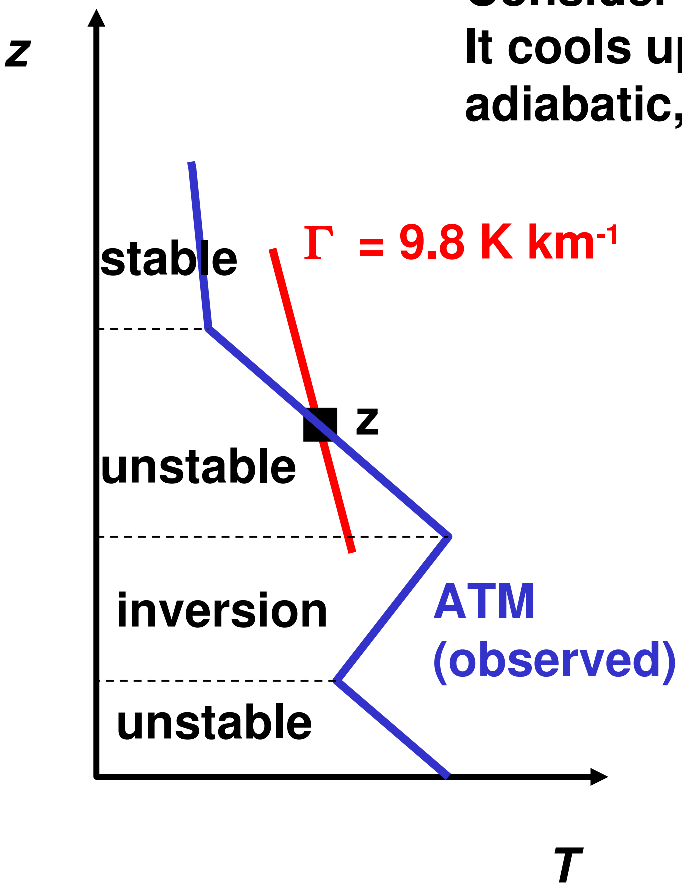
CCN counter balloon package shortly after launch at Laramie, Wyoming, on January 22, 1997.

CCN counter balloon package shortly after launch at Laramie, Wyoming, on September 5, 1996.

Atmospheric (ATM) Lapse Rate and Stability

"Lapse Rate" = $-dT/dz$

Consider an air parcel at *z* lifted to *z+dz* and released. It cools upon lifting (expansion). Assuming lifting to be adiabatic, the cooling follows the adiabatic lapse rate Γ:



$$\Gamma = -dT/dz = \frac{g}{C_p} = 9.8 \text{ K km}^{-1}$$

What happens following release depends on the local lapse rate $-dT_{ATM}/dz$:

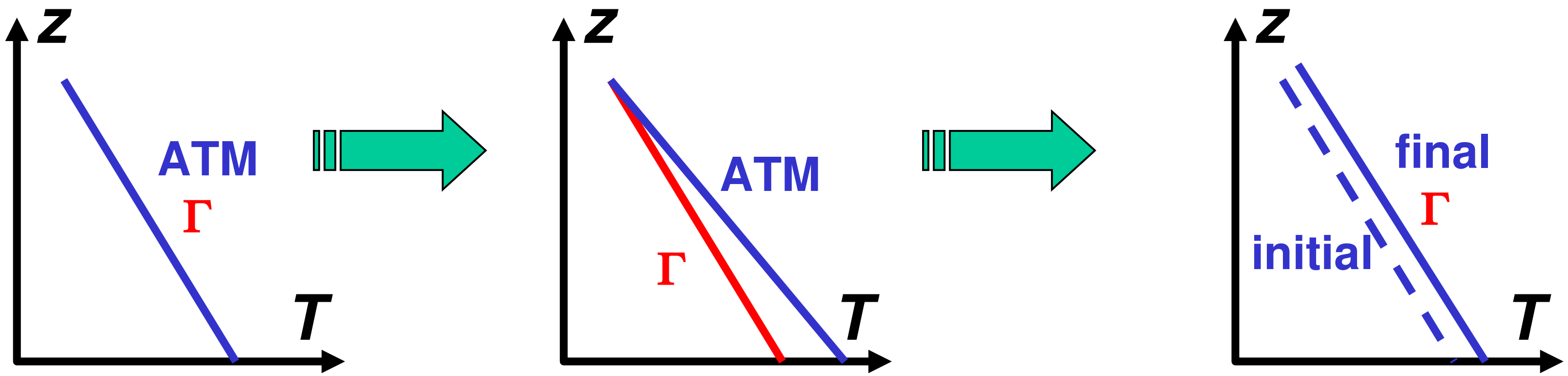
- $-dT_{ATM}/dz > \Gamma$ upward buoyancy amplifies initial perturbation: atmosphere is *unstable*
- $-dT_{ATM}/dz = \Gamma$ zero buoyancy does not alter perturbation: atmosphere is *neutral*
- $-dT_{ATM}/dz < \Gamma$ downward buoyancy relaxes initial perturbation: atmosphere is *stable*
- $dT_{ATM}/dz > 0$ ("inversion"): very stable

Atmospheric stability against vertical mixing is determined by its lapse rate.

Courtesy of Daniel J. Jacob

What Determines the Lapse Rate of the Atmosphere?

- **An atmosphere left to evolve adiabatically from an initial state would eventually tend to *neutral* conditions ($-dT/dz = \Gamma$) at equilibrium**
- **Solar heating of surface and radiative cooling from the atmosphere disrupts that equilibrium and produces an unstable (convective) atmosphere:**



Initial Equilibrium State: $-dT/dz = \Gamma$

Solar heating of surface/radiative cooling of air: unstable atmosphere

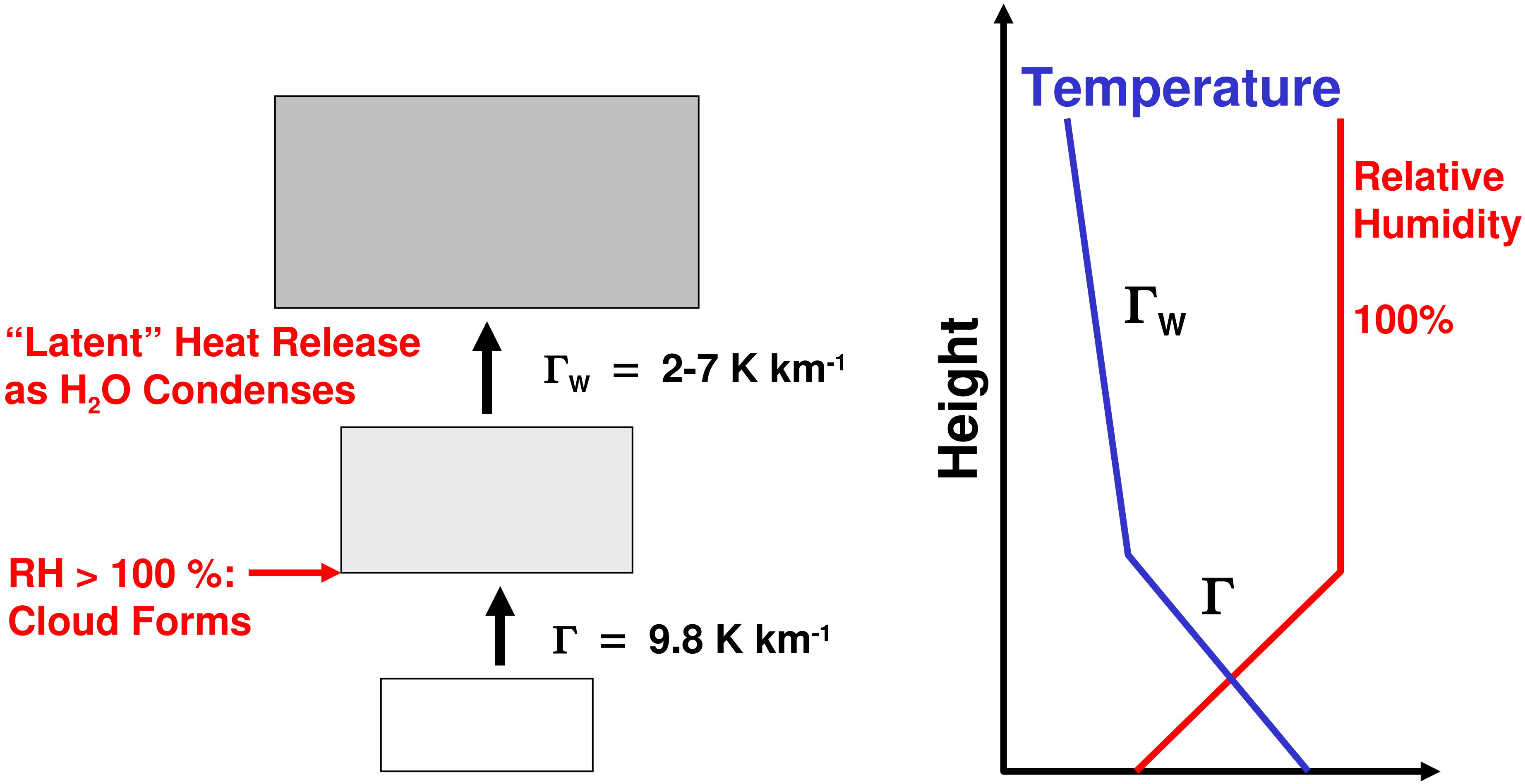
Buoyant motions relax unstable atmosphere back towards $-dT/dz = \Gamma$

- **Fast vertical mixing in an unstable atmosphere maintains the lapse rate to Γ. <u>Observation</u> of $-dT/dz = \Gamma$ is sure indicator of an unstable atmosphere.**

Courtesy of Daniel J. Jacob

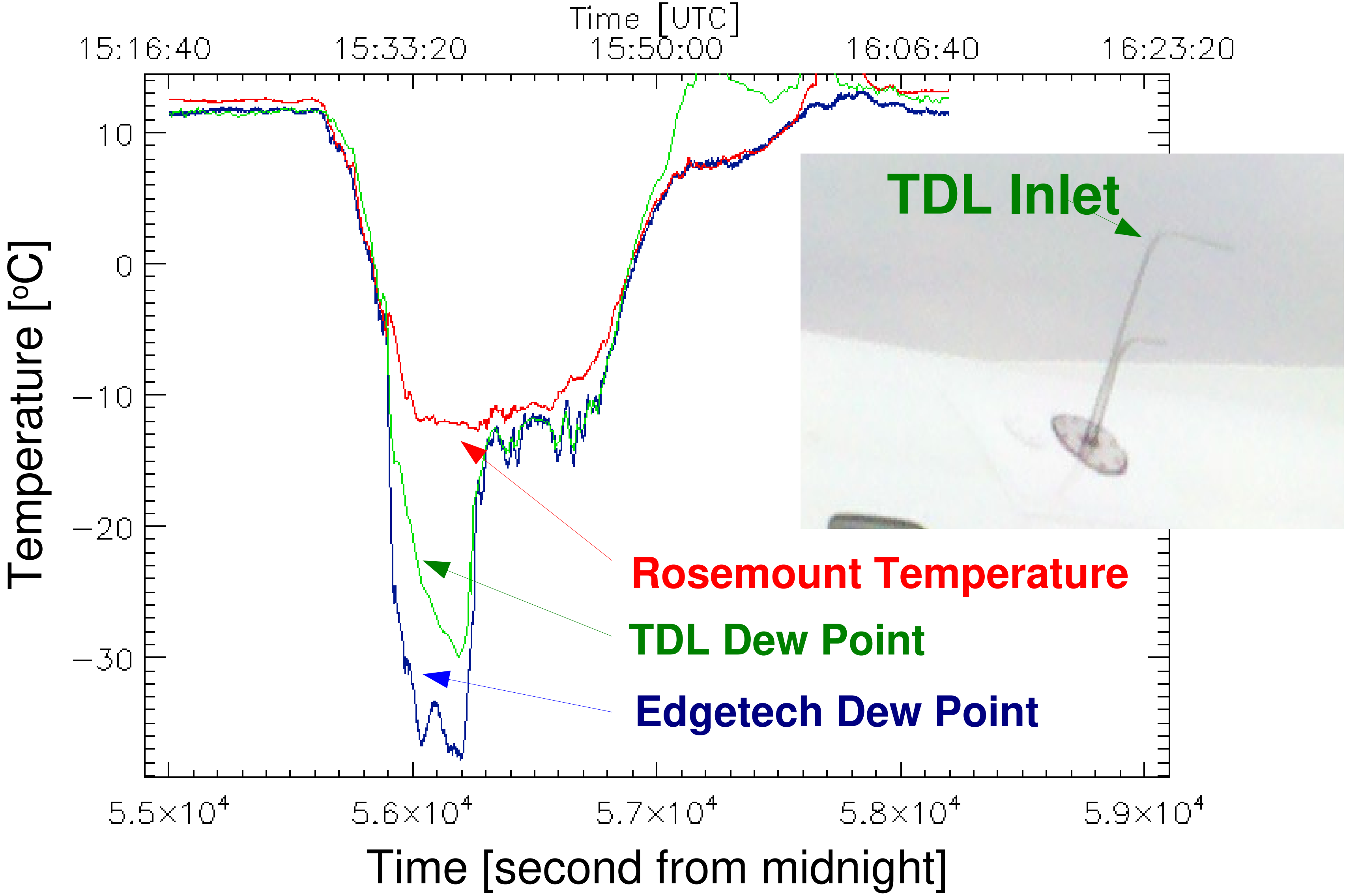
In Cloudy Air Parcel, Heat Release from H_20 Condensatin Moifies Γ

Wet Adiabatic Lapse Rate Γ_W = 2-7 K km^{-1}



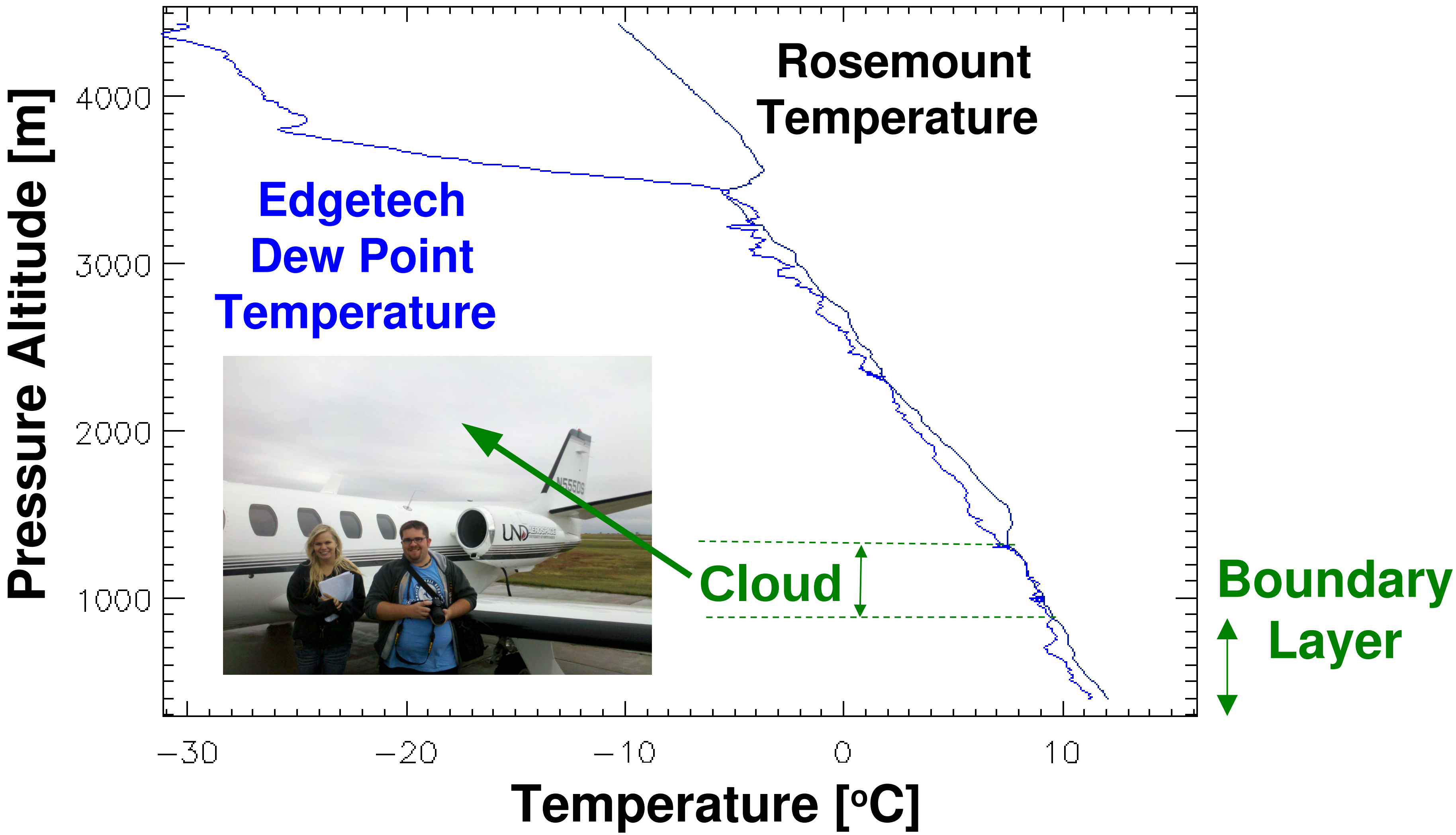
Courtesy of Daniel J. Jacob

Citation Flight: 2011/09/20

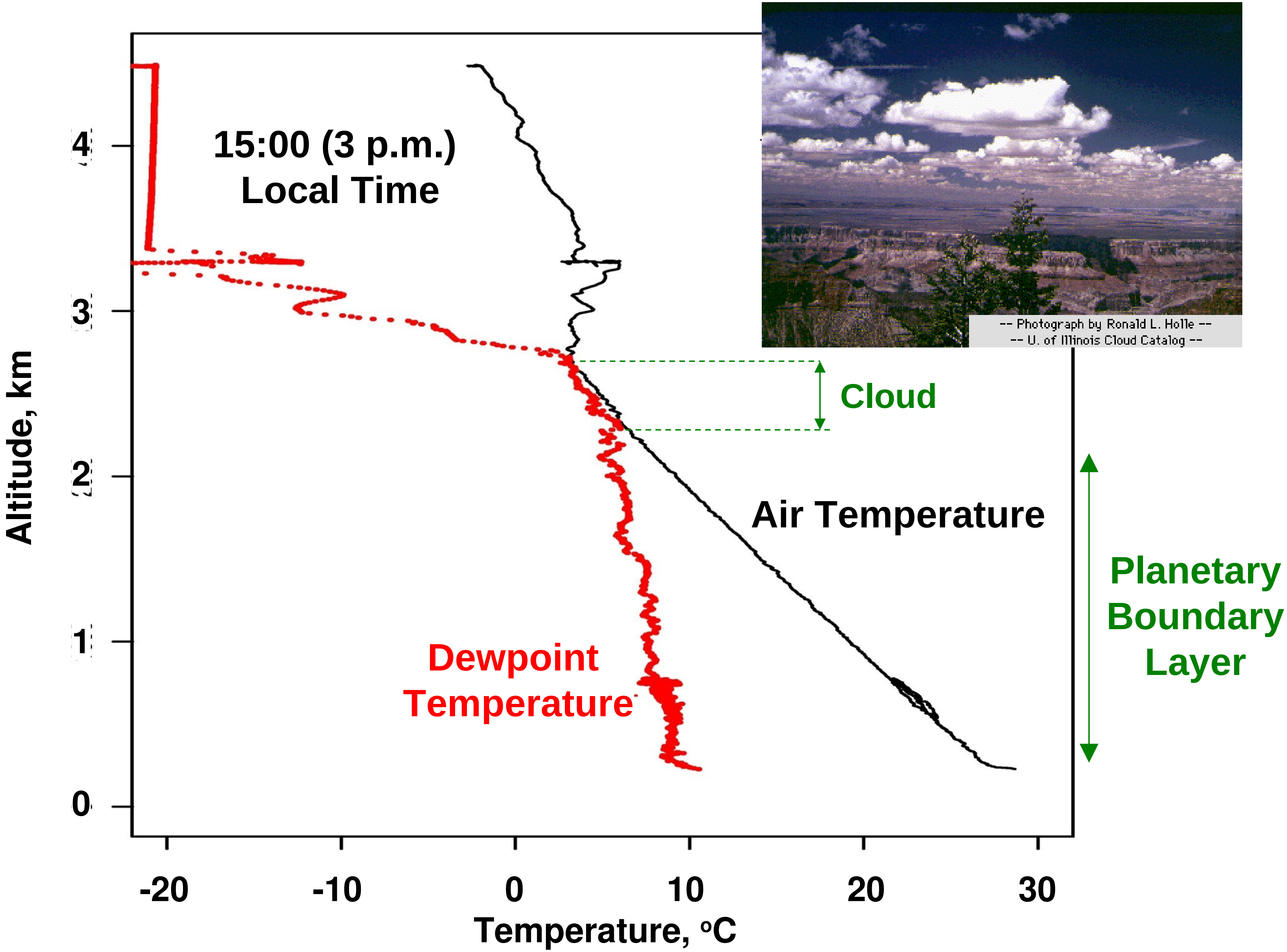


Time series for 2011/09/20 University of North Dakota's Citation Research Aircraft flight from the Grand Forks airport.

Citation Profile: 2011/09/20



Ascent profile in Grand Forks obtained with the University of North Dakota's Citation Research Aircraft between 55,635 and 55,975 sfm (~10:30 local) from the Grand Forks airport.



Courtesy of Daniel J. Jacob

Subsidence Inversion

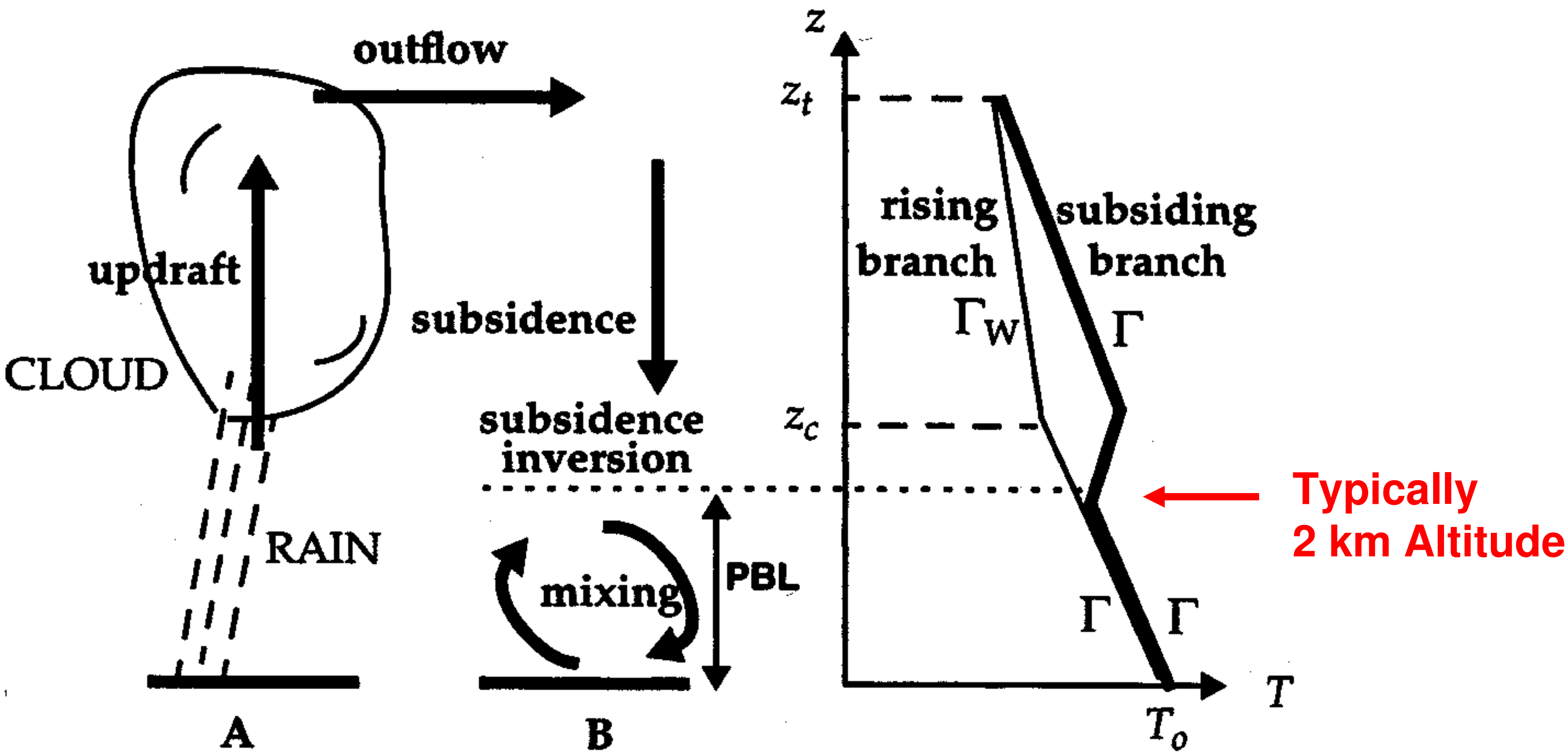
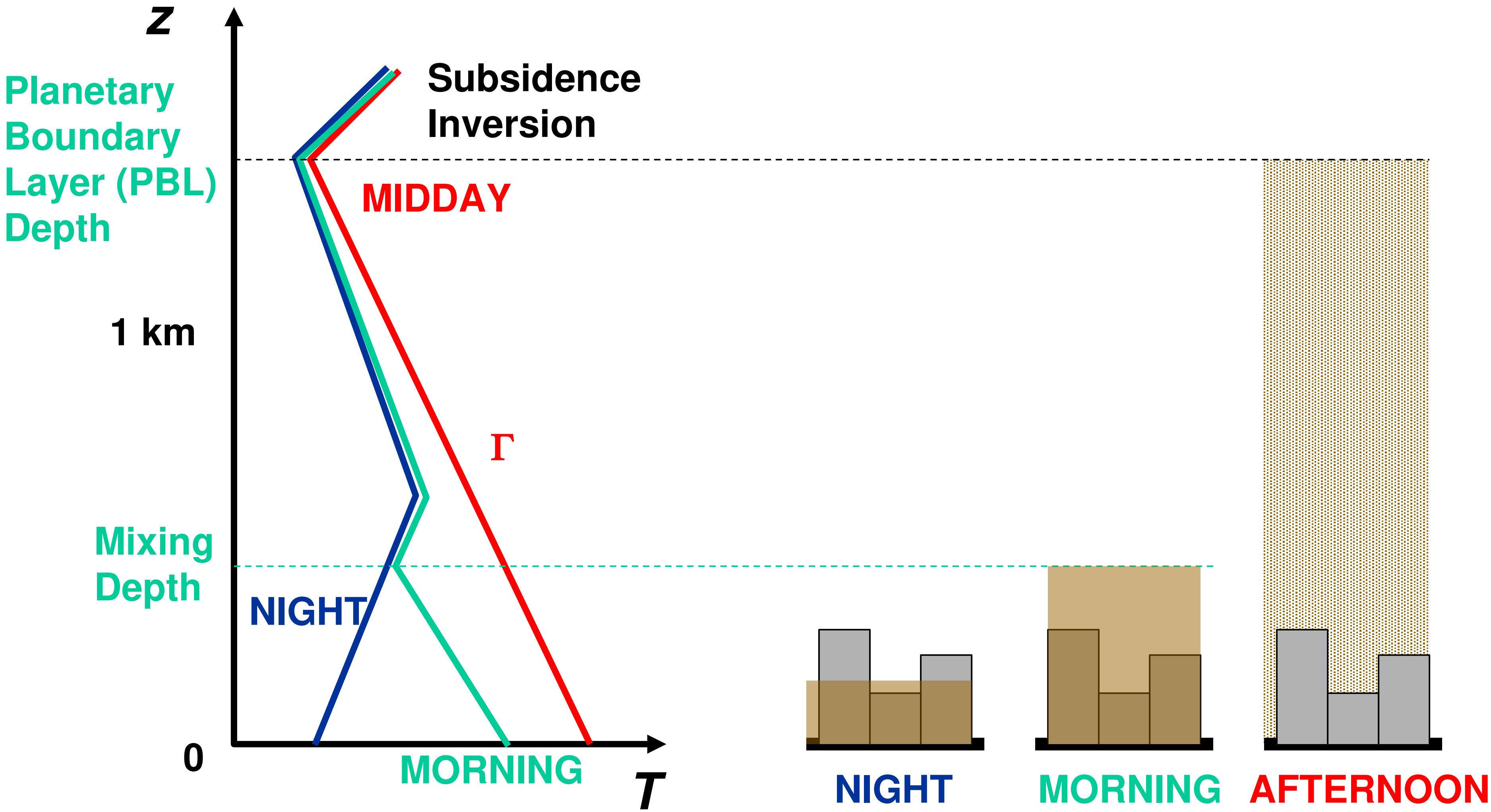


Fig. 4-17 Formation of a subsidence inversion. Temperature profiles on the right panel are shown for the upwelling region A (thin line) and the subsiding region B (bold line). It is assumed for purposes of this illustration that regions A and B have the same surface temperature T_o. The air column extending up to the subsidence inversion is commonly called the planetary boundary layer.

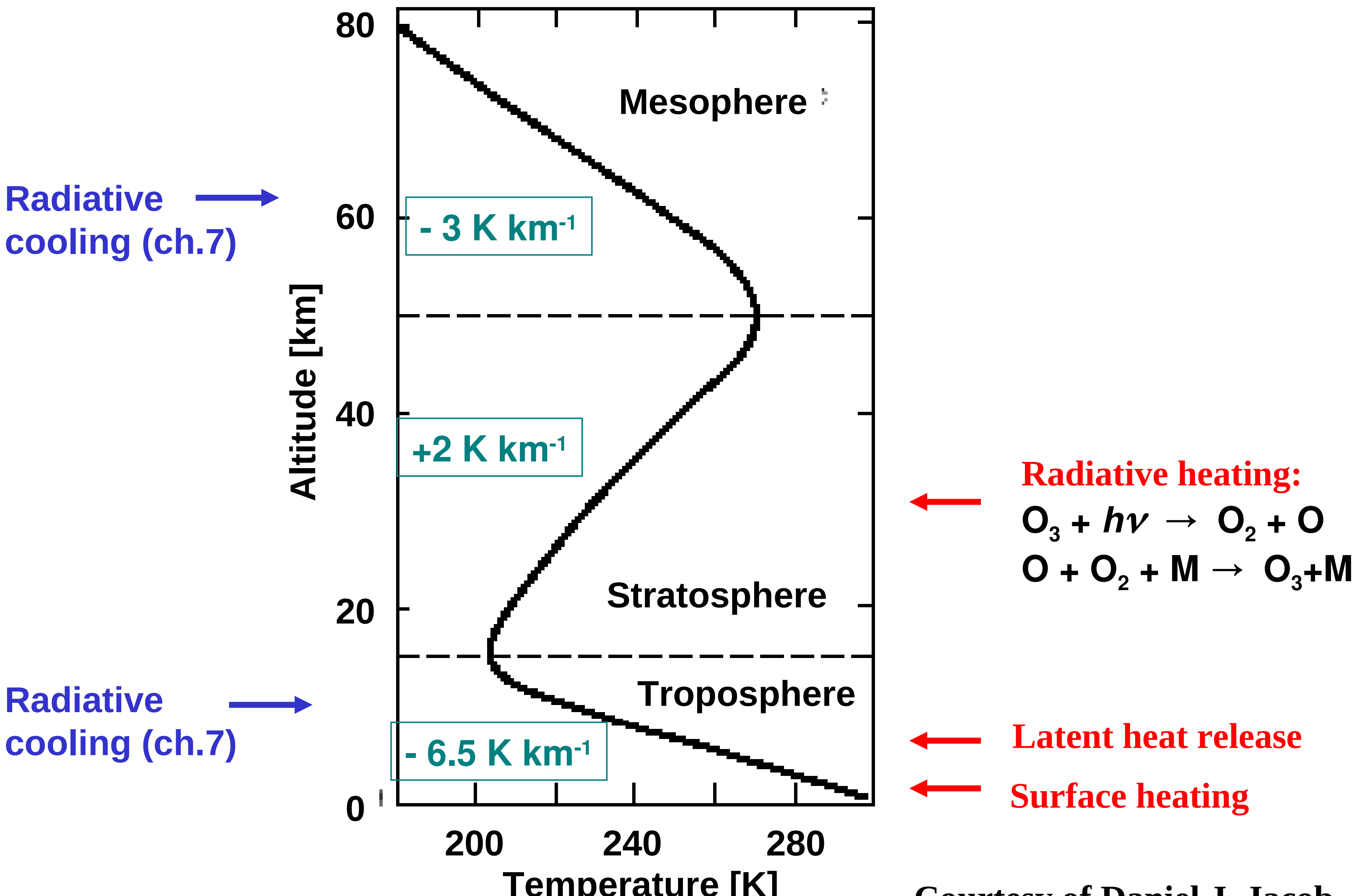
Courtesy of Daniel J. Jacob

Diurnal Cycle of Surface Heating/Cooling Ventilation of Urban Pollution



Courtesy of Daniel J. Jacob

Vertical Profile of Temperature
Mean Values for 30 ⁰N, March

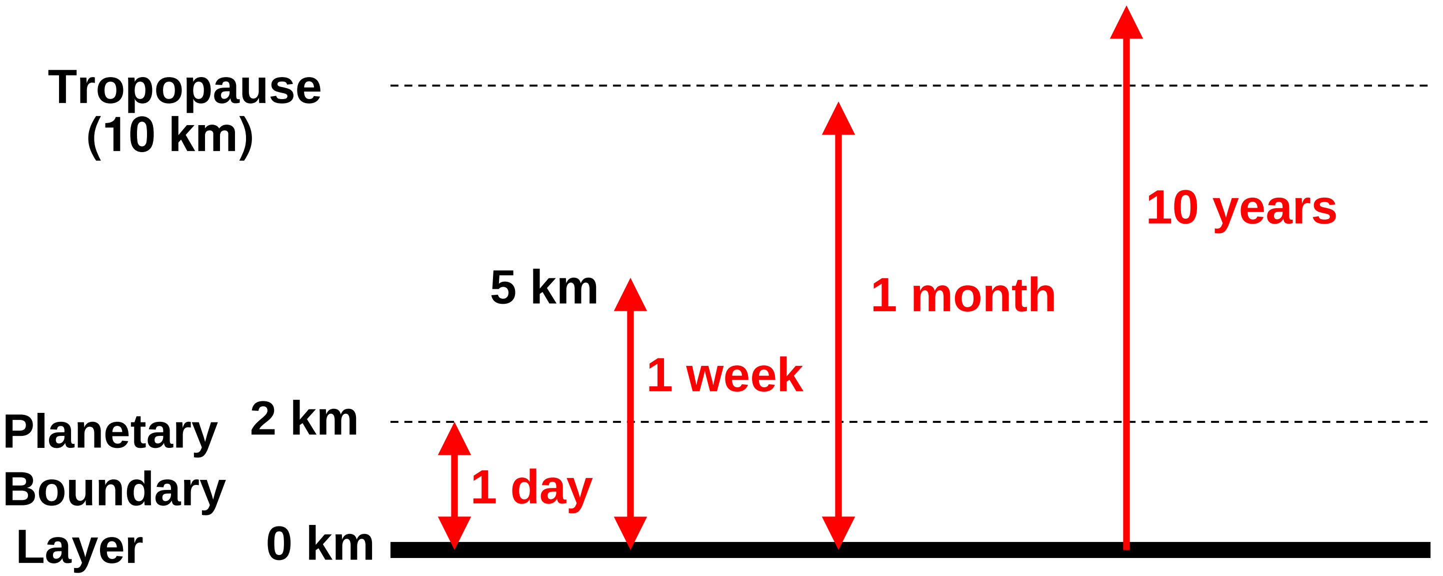


Courtesy of Daniel J. Jacob

Typical Time Scales for Vertical Mixing

Estimate time Δt to travel Δz by turbulent diffusion:

$$\Delta t = \frac{(\Delta z)^2}{2K_z} \quad \text{with } K_z \sim 10^5 \text{ cm}^2\text{s}^{-1}$$



Courtesy of Daniel J. Jacob