Turbulence and Cumulus Clouds

From Chapter 3 of "Atmosphere, Clouds, and Climate" by David Randall

Daniel Yienger

From: http://www.lillini.com/sito/sito2010/html/7catalogo/catalog/content/l08_large.html

AOSC680 - Lecture 11

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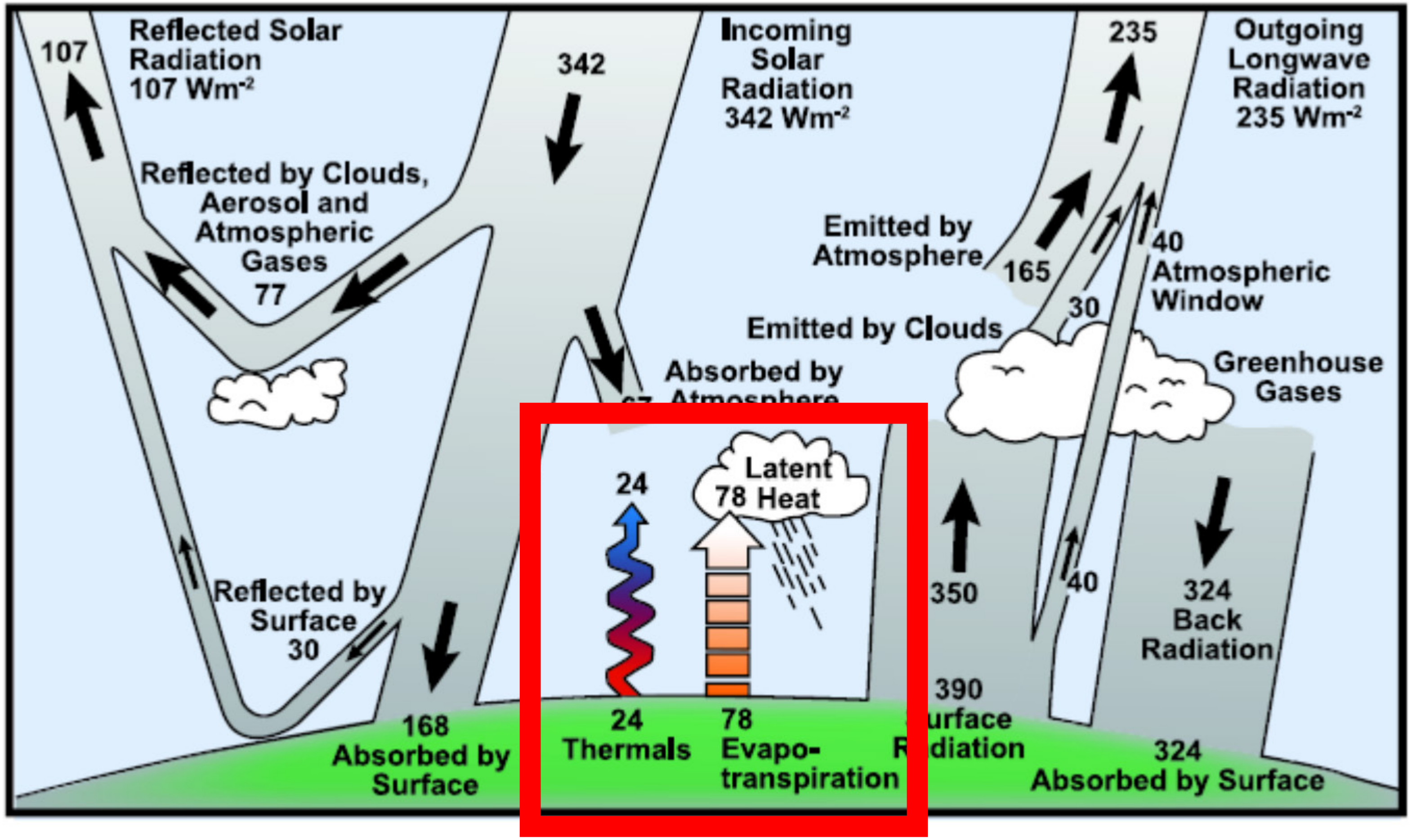
Energy Flows Back Into the Atmosphere



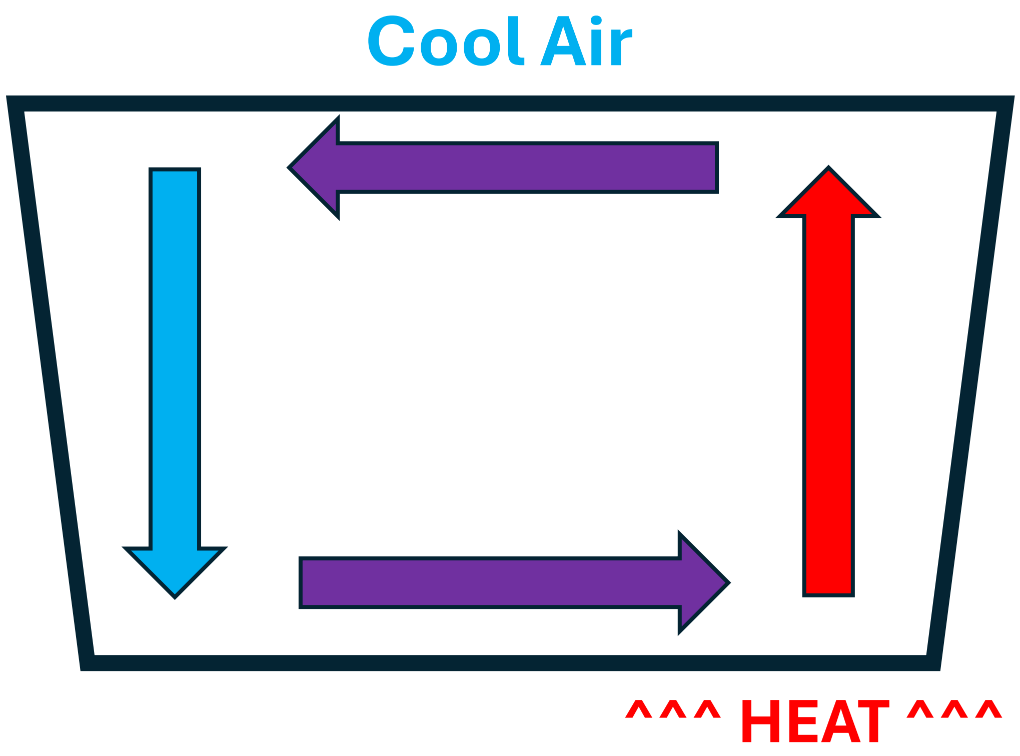
FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Question 1.1, IPCC 2007

Energy Flows Back Into the Atmosphere

cool air above. In a similar way, the upward sensible and latent energy fluxes from the Earth's surface create buoyant, humid patches of air. Warm thermals, with high energy content, break away from the surface, somewhat randomly, and float upward under the influence of buoyancy. In compensation, air with less energy moves downward, around and between the thermals, to fill the gaps that they leave behind. Many thermals can be generated, leading to a fluid dynamical commotion.

Randall - Page 58



Widely Spaced Towers

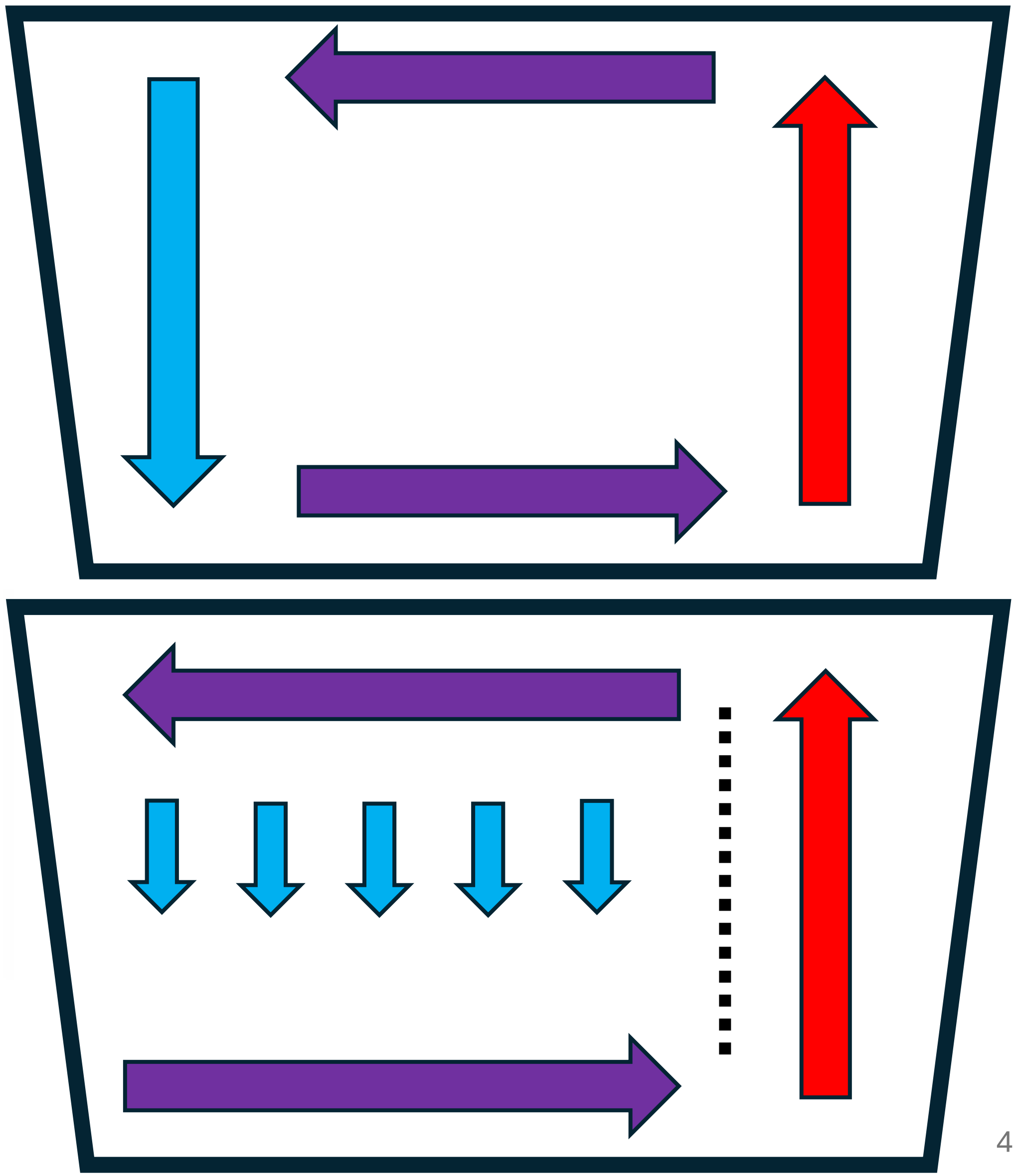
Mass Flow Equation: $\dot{m} = \rho V A$

(Density * Velocity * Area)

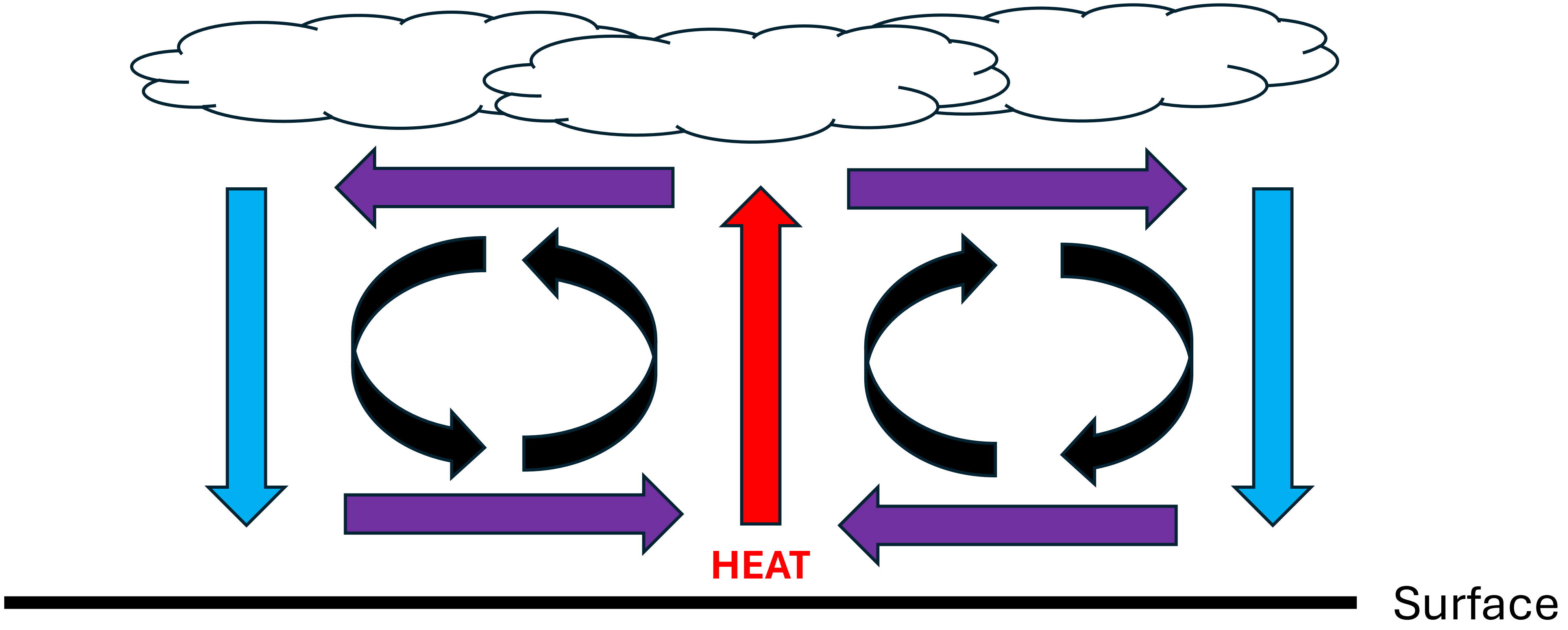
- Mass Flow Up = Mass Flow Down
- Assuming density is constant, an increase in area means a decrease in velocity and vice versa

Figure 3.6. Sketch illustrating a strong updraft, represented by the large arrow, and surrounding weak downdrafts, represented by the small arrows.

The upward and downward mass flows can cancel.



Turbulent Mixing



Why is this important?

Conserved Variables

$$\frac{DO_2}{Dt} = 0. \quad (3.1)$$

Here the symbol $\frac{D}{Dt}$, which is called the "Lagrangian time derivative," denotes the time rate of change *following a (possibly) moving parcel of air.* The Lagrangian time derivative is useful because it allows us to describe what happens to a parcel that is moving around in the atmosphere. In the case of Equation (3.1), the answer is simple: the mass fraction of oxygen does not change as the parcel moves around. We say that the mass fraction of oxygen is "conserved," and that O_2 is a "conservative" variable.

Randall - Pages 64 -65

"Conserved" = No change with respect to time or space

Stratification

On Page 70:
"In Chapter 1, I asked, 'If buoyancy pushes warm air up and cold air down, then shouldn't we find the warm air on top and the cold air below?' Now you see that ***the warm air actually is on top***"

Static Stability and Instability in Dry Air

- Buoyancy forces in a stratified column of air create static stability
  - Stratification inhibits vertical motion
  - A displaced parcel will experience a buoyancy force opposite of the displacement

- The concept of being "stably stratified" is based on two assumptions:
  1. ________________________________
  2. ________________________________

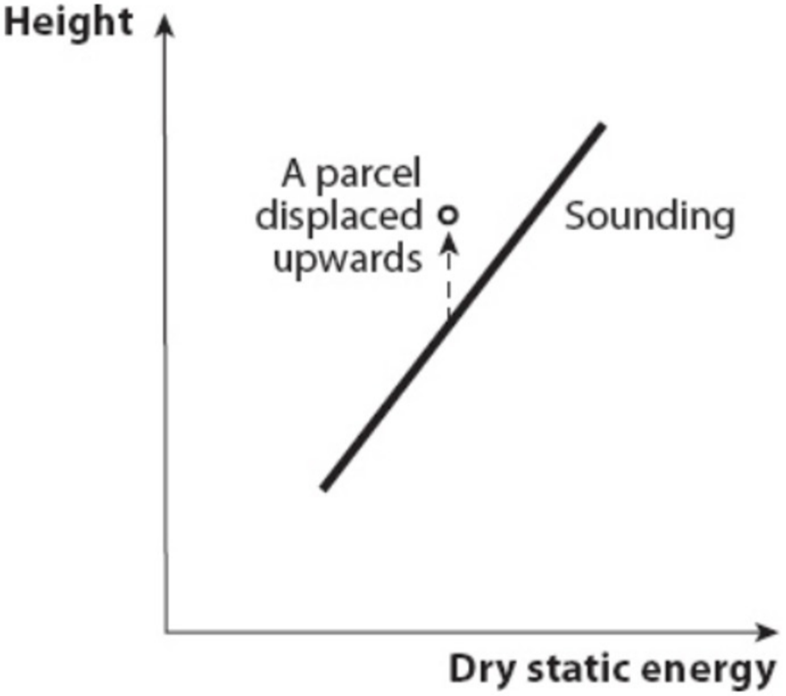


Figure 3.3. Sketch illustrating a parcel that is displaced upward in a statically stable sounding, for which the dry static energy increases upward.
The parcel is assumed to conserve its dry static energy.

Cumulus Instability

Water condensing puts more energy into a parcel of air, making it positively buoyant and dry static energy no longer conservative

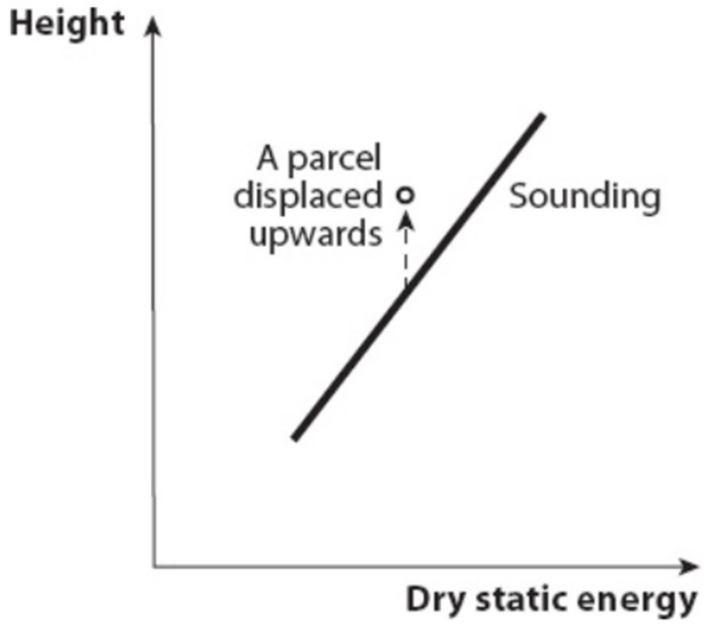
New Conserved Value, Moist Static Energy:

$$h \equiv s + Lq$$

(Dry static energy + Latent energy)

$$\rho \frac{Dh}{Dt} = Q_{rad}$$

Given that $Q_{rad} = 0$, moist static energy is conserved even through phase changes



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Cumulus Instability

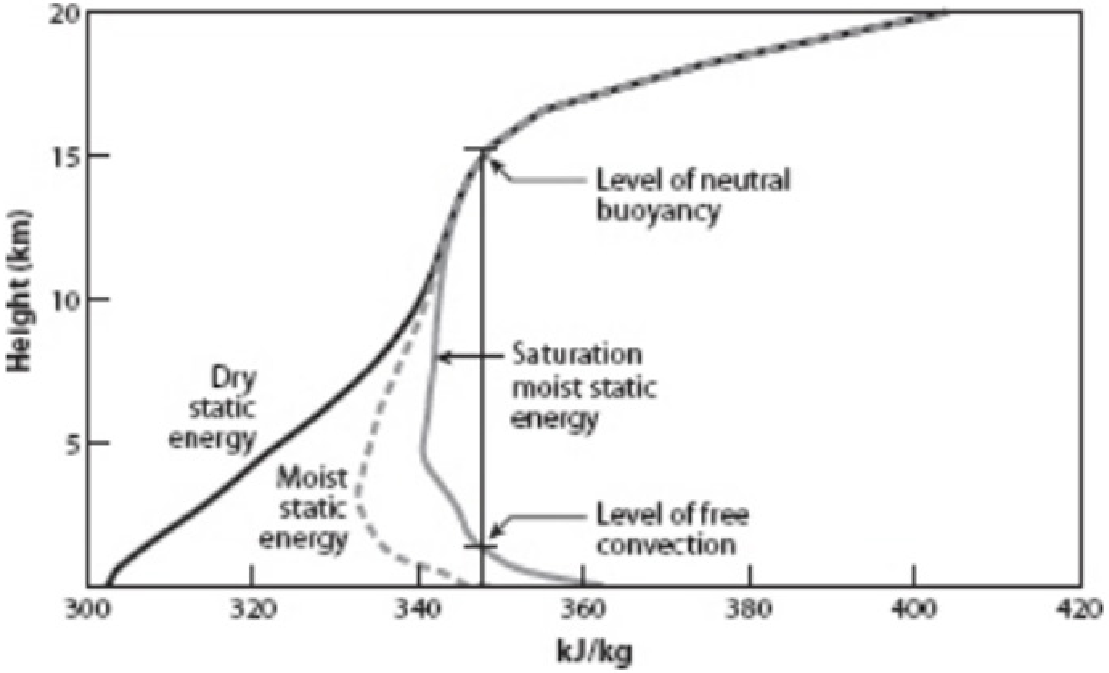
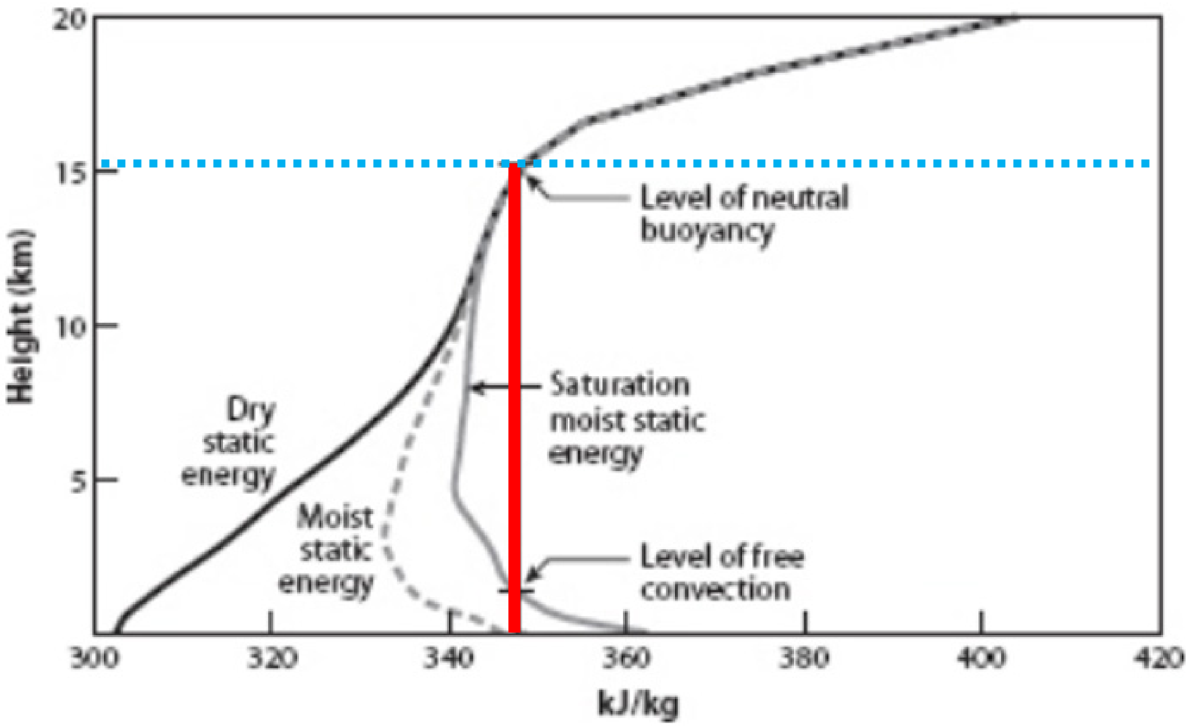


Figure 3.5. The observed vertical distribution of the moist static energy (dashed curve), for January, in kJ kg^{-1}.

A minimum occurs in the tropics, about 5 km above the surface. The vertical profiles of the dry static energy (solid black curve) and saturation moist static energy (solid gray curve) are also shown. The thin vertical line represents the moist static energy of a parcel rising moist adiabatically from near the surface, conserving its moist static energy. The parcel is positively buoyant whenever the thin vertical line is to the right of the dashed line, that is, from about 1 km to 15 km above the surface. Further explanation is given in the text. The plots are based on time averages of data collected during a field experiment called TOGA COARE.

Cumulus Instability

- Dry / Moist / Saturated Moist static energy curves are for the environment
- Red line is the moist static energy of an ascending parcel of air
- Blue dotted line is the Level of Neutral Buoyancy, which is approximately at the top of the troposphere / start of stratosphere
- Energy increases in stratosphere due to O_2 and O_3 absorbing radiation
- Level of free convection is the point where a parcel becomes positively buoyant
  - Point where parcel MSE > environmental SMSE
- The area between the parcel's moist static energy curve and the environmental saturation moist static energy curve is proportional to _____________.



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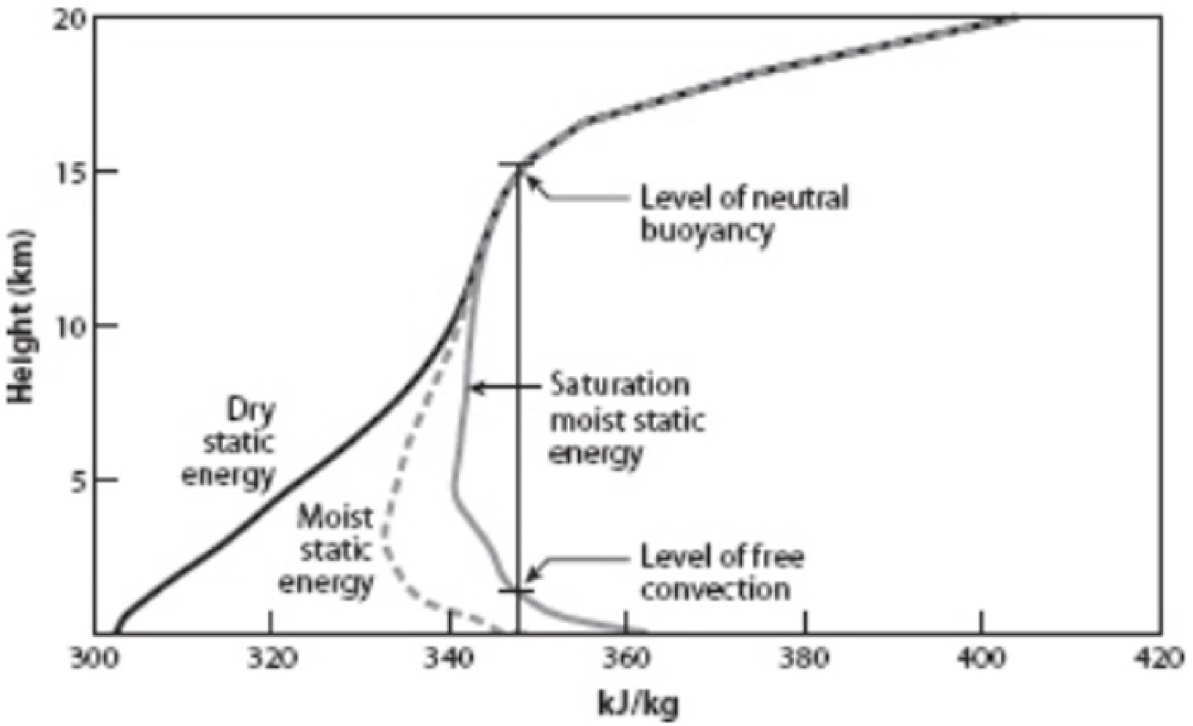
What Determines Intensity?

CAPE – Convectively Available Potential Energy

How do you generate CAPE?

What analogy did Randall use and why?



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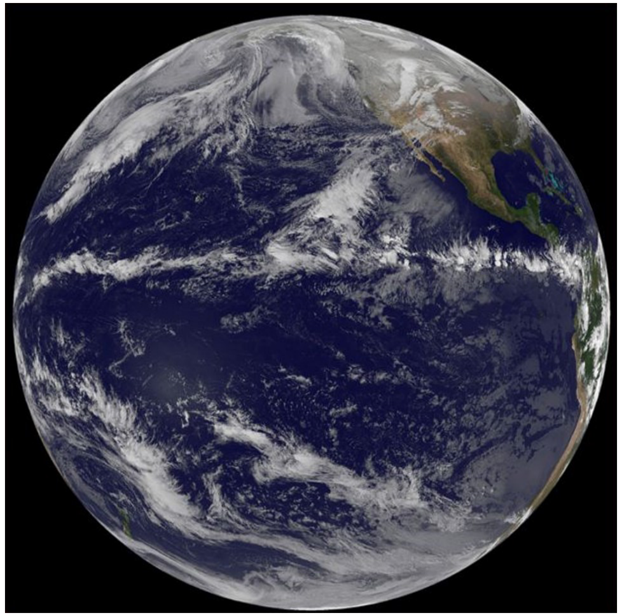
Cumulus Fluxes of Energy

Table 3.1
Net energy transports out of the ITCZ.

Layer	Moist static energy transport out of the ITCZ, in units of 1016 J s-1
Lower troposphere	-3.67
Upper troposphere	3.80

Source: Adapted from Riehl and Malkus (1958).



From: https://eos.org/research-spotlights/tropical-rainfall-intensifies-while-the-doldrums-narrow

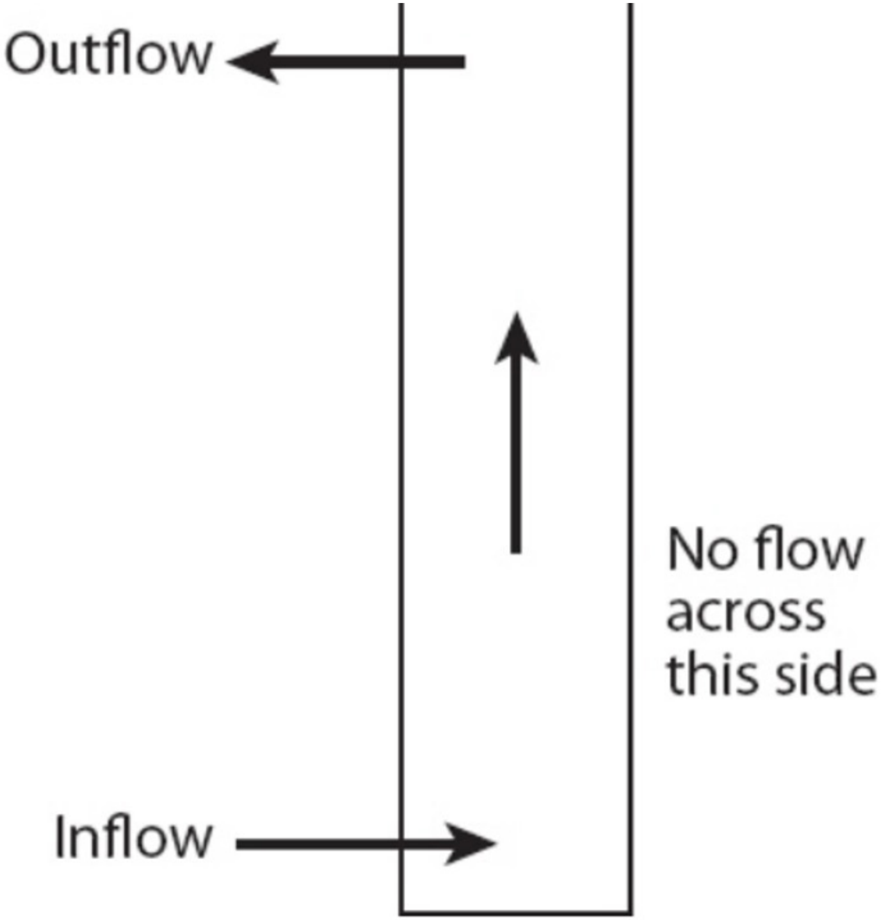


Figure 3.7. The flow through the Intertropical Convergence Zone, as analyzed by Riehl and Malkus.

Next Lecture: Energy Flows and Climate Feedback

- Next Reading:
  - Randall Ch. 4 “How Energy Travels from the Tropics to the Poles” (56 Pages)