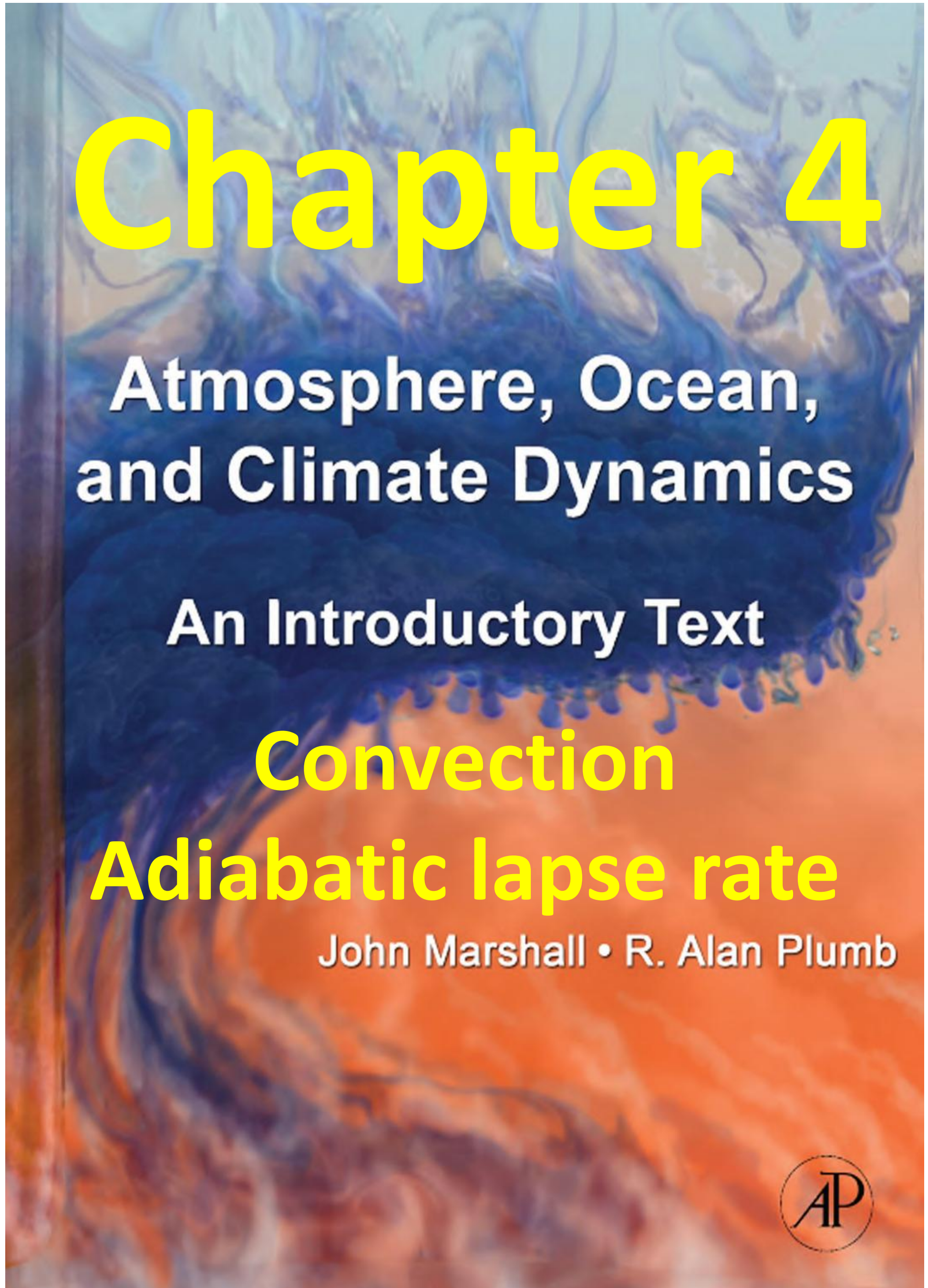
Chapter 4
Atmosphere, Ocean, and Climate Dynamics
An Introductory Text
Convection
Adiabatic lapse rate
John Marshall • R. Alan Plumb
AP

Alto Cumulus
Lenticularis

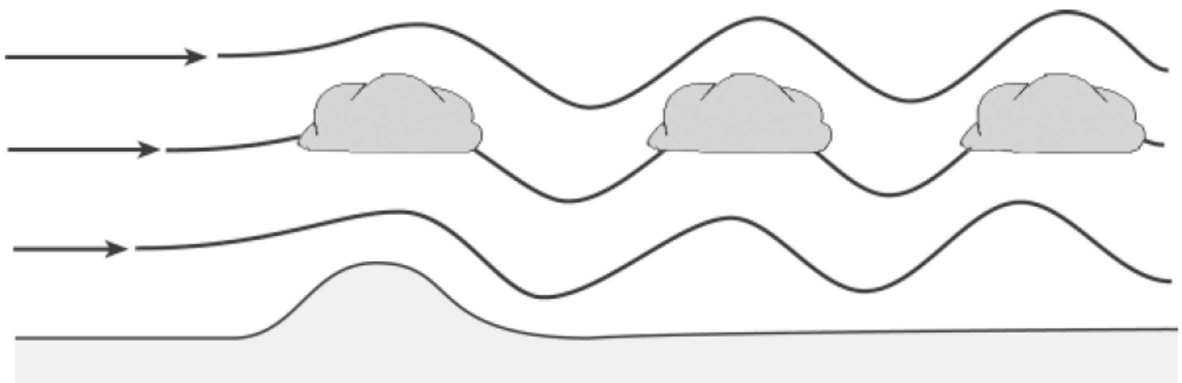

FIGURE 4.13. A schematic diagram illustrating the formation of mountain waves (also known as lee waves). The presence of the mountain disturbs the air flow and produces a train of downstream waves (cf. the analogous situation of water in a river flowing over a large submerged rock, producing a downstream surface wave train). Directly over the mountain, a distinct cloud type known as lenticular (''lens-like'') cloud is frequently produced. Downstream and aloft, cloud bands may mark the parts of the wave train in which air has been uplifted (and thus cooled to saturation).

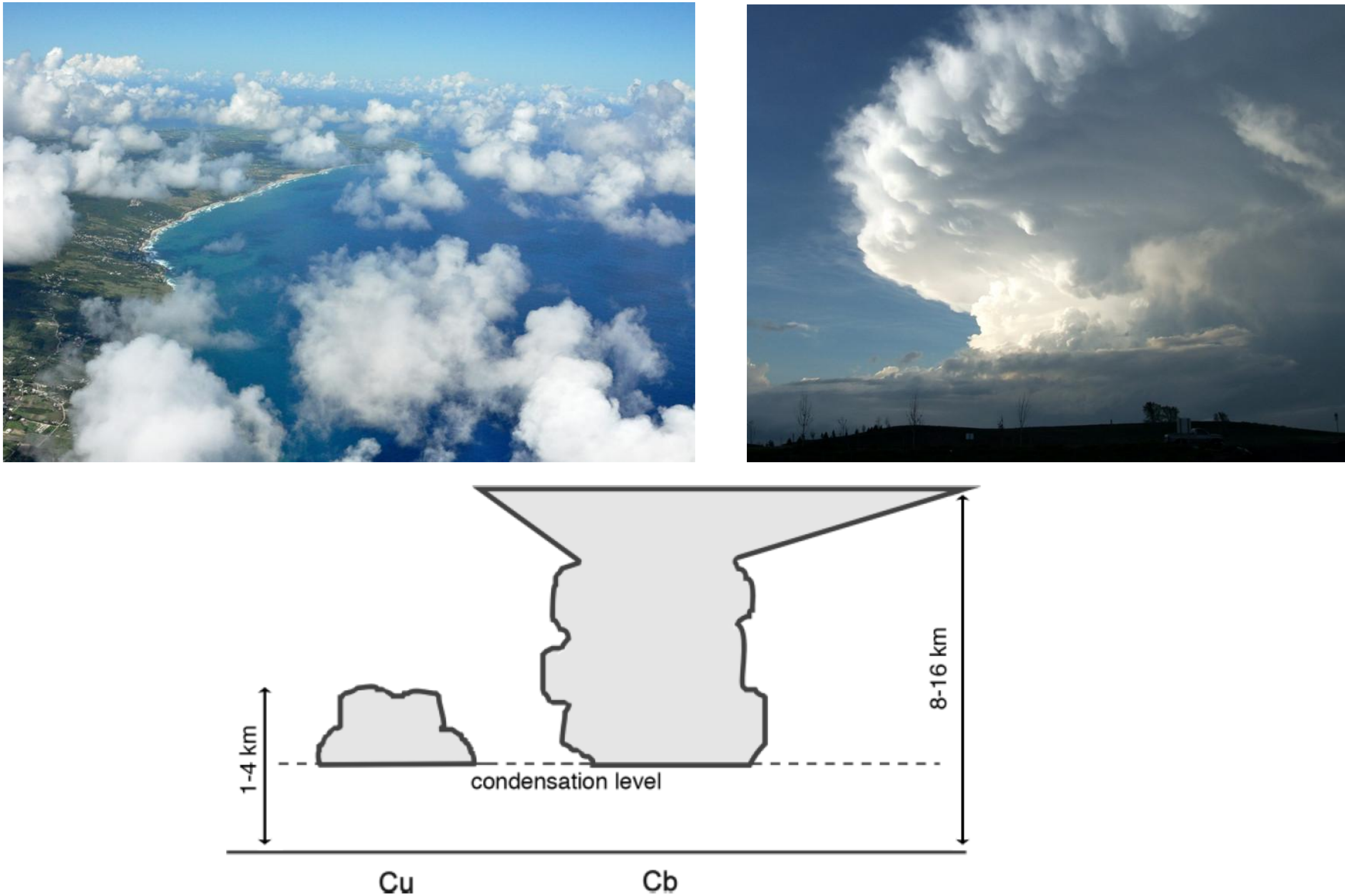

FIGURE 4.20. Schematic of convective clouds: Cu = cumulus; Cb = cumulonimbus. The condensation level is the level above which $q = q_*$. Cb clouds have a characteristic "anvil," where the cloud top spreads and is sheared out by strong upper level winds.

First law of thermodynamics

Consider a parcel of ideal gas of unit mass with a volume V, so that $\rho V = 1$. If an amount of heat, δQ, is exchanged by the parcel with its surroundings then applying the first law of thermodynamics $\delta Q = dU + dW$, where dU is the change in energy and dW is the change in external work done,[4] gives us

$$\delta Q = c_v dT + p dV, \tag{4-11}$$

where $c_v dT$ is the change in internal energy due to a change in parcel temperature of dT and pdV is the work done by the parcel on its surroundings by expanding an amount dV. Here c_v is the specific heat at constant volume.

Adiabatic lapse rate

Perfect gas law $$p = \rho R T$$

Hydrostatic equation $$\frac{\partial p}{\partial z} = -\frac{gp}{RT}$$

First law of thermodynamics $$\delta Q = c_v dT + p dV$$

Under adiabatic conditions:

$$\frac{dT}{dz} = -\frac{g}{c_p} = -\Gamma_d, \qquad (4\text{-}14)$$

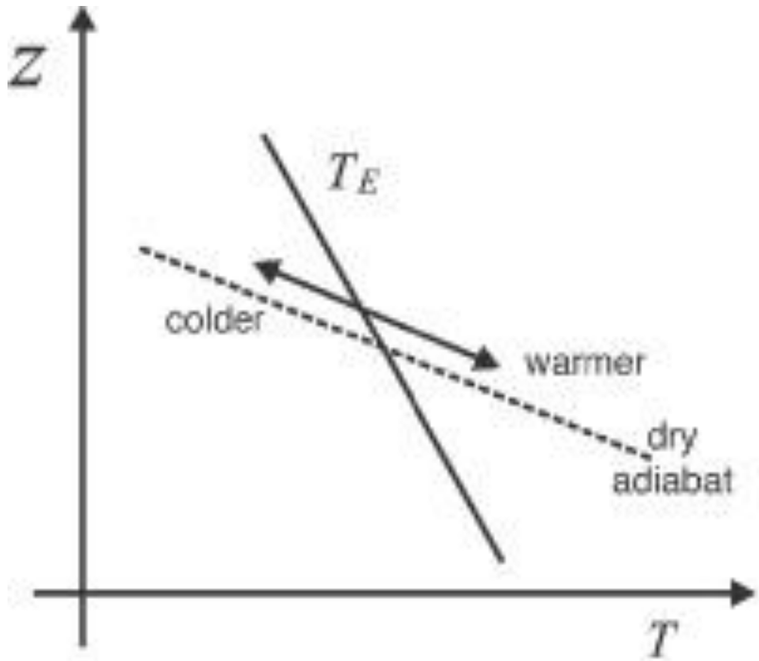

Figure 4.10: The atmosphere is nearly always stable to dry processes. A parcel displaced upwards (downwards) in an adiabatic process moves along a dry adiabat (the dotted line) and cools down (warms up) at a rate that is faster than that of the environment, $\partial T_E/\partial z$. Since the parcel always has the same pressure as the environment, it is not only colder (warmer) but also denser (lighter). The parcel therefore experiences a force pulling it back toward its reference height.

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Stability

$$\left.\begin{array}{c}\text{unstable}\\ \text{neutral}\\ \text{stable}\end{array}\right\}\text{ if }\left(\frac{dT}{dz}\right)_E\left\{\begin{array}{l}<-\Gamma_d\\ =-\Gamma_d\\ >-\Gamma_d\end{array}\right. . \tag{4-15}$$

Therefore, a compressible atmosphere is **unstable if temperature decreases with height faster than the adiabatic lapse rate.**

Dry adiabatic lapse rate: ~10 K/km

Potentiell temperatur (θ)

Perfect gas law $$p = \rho R T$$

First law of thermodynamics $$\delta Q = c_p dT - \frac{1}{\rho} dp$$ Eq. 4.12

Under adiabatic conditions $\delta Q = 0$:

Integrerer fra referansenivå T_0 og p_0

$$\frac{dT}{T} - \kappa \frac{dp}{p} = 0 \quad \Rightarrow \quad T_0 = T\left(\frac{p_0}{p}\right)^{\kappa} \qquad \kappa = R/c_p = 2/7$$

Potentiell temperatur $\theta \equiv T_0$ er bevart ved adiabatiske prosesser

Stability

$$\left.\begin{array}{c}\text{unstable}\\ \text{neutral}\\ \text{stable}\end{array}\right\}\ \text{if}\ \left(\frac{d\theta}{dz}\right)_E \left\{\begin{array}{l}<0\\ =0\\ >0\end{array}\right. . \qquad (4\text{-}18)$$

Saturated adiabatic lapse rate

dT/dz ved kondensasjon/fordampning av vann (gassfase 🡐/🡒 væske). Dvs. med frigjøring av latent varme

Spesifikk fuktighet (q): Masse (kg) av vanndamp pr. masse (kg) av luft
q_*: Spesifikk fuktighet ved metning
L: Spesifikk fordampningsvarme for vann (2.5×10^6 J/kg)

$$q = \frac{\rho_v}{\rho}, \qquad (4\text{-}23)$$

$$q_* = \frac{e_s/R_vT}{p/RT} = \left(\frac{R}{R_v}\right)\frac{e_s}{p}, \qquad (4\text{-}24)$$

$$de_s/dT = \beta e_s \qquad (1.4)$$

Kan vise:

$$-\frac{dT}{dz} = \Gamma_s = \Gamma_d\left[\frac{1 + Lq_*/RT}{1 + \beta Lq_*/c_p}\right], \qquad (4\text{-}28)$$

Weaker than dry adiabatic lapse rate : $\Gamma_s < \Gamma_d$

Ranging from 3 to 10 K/km

Equivalent potential temperature
Saturated conditions

Under adiabatic conditions:

$$\theta_e = \theta \exp\left(\frac{Lq}{c_p T}\right), \qquad (4\text{-}30)$$

Ekvivalent potensiell temperatur:
All latent varme frigjøres, luftpakken senkes tørr adiabatisk til referansenivået

Equivalent potential temperature θ_e is conserved

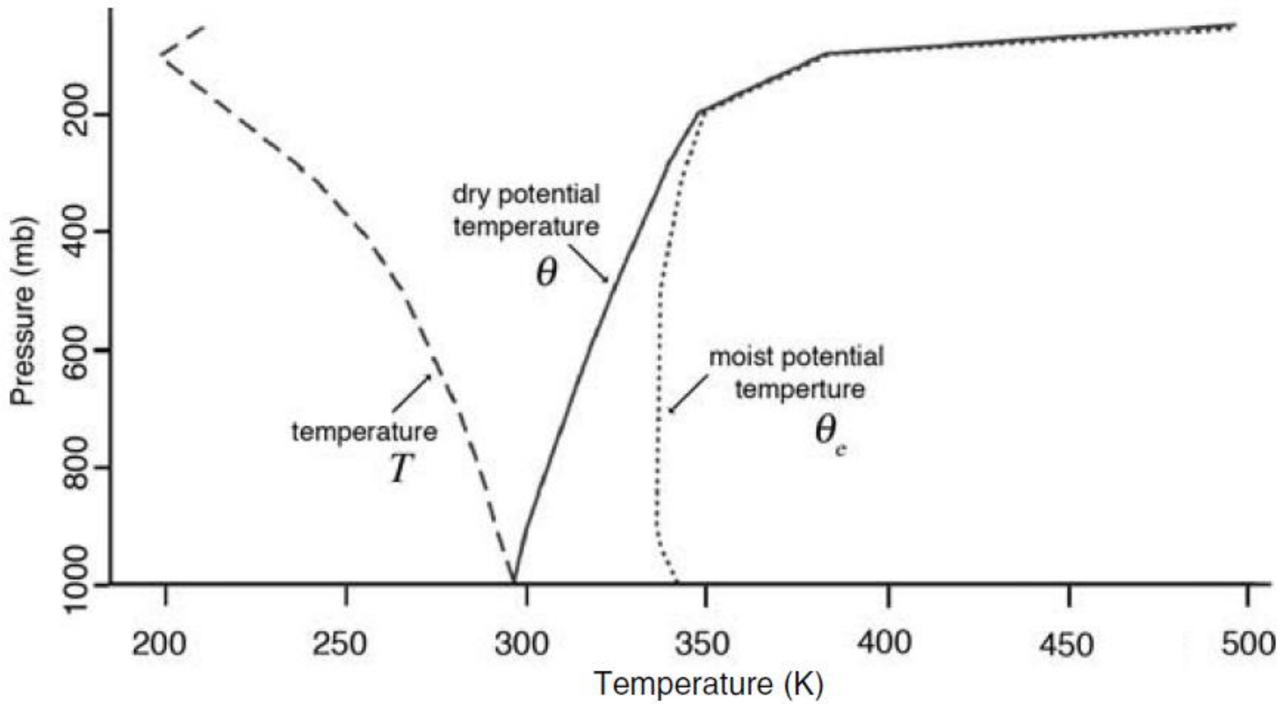

FIGURE 4.9. Climatological atmospheric temperature T (dashed), potential temperature θ (solid), and moist potential temperature θ_e (dotted) as a function of pressure, averaged over the tropical belt ±30°