The stable boundary-layer (SBL)

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eas572_SBL.odp
JD Wilson, EAS Ualberta
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From Stull (1988), *An Intro. To Boundary Layer Meteorology* (see also Garratt's Fig. 6.1)

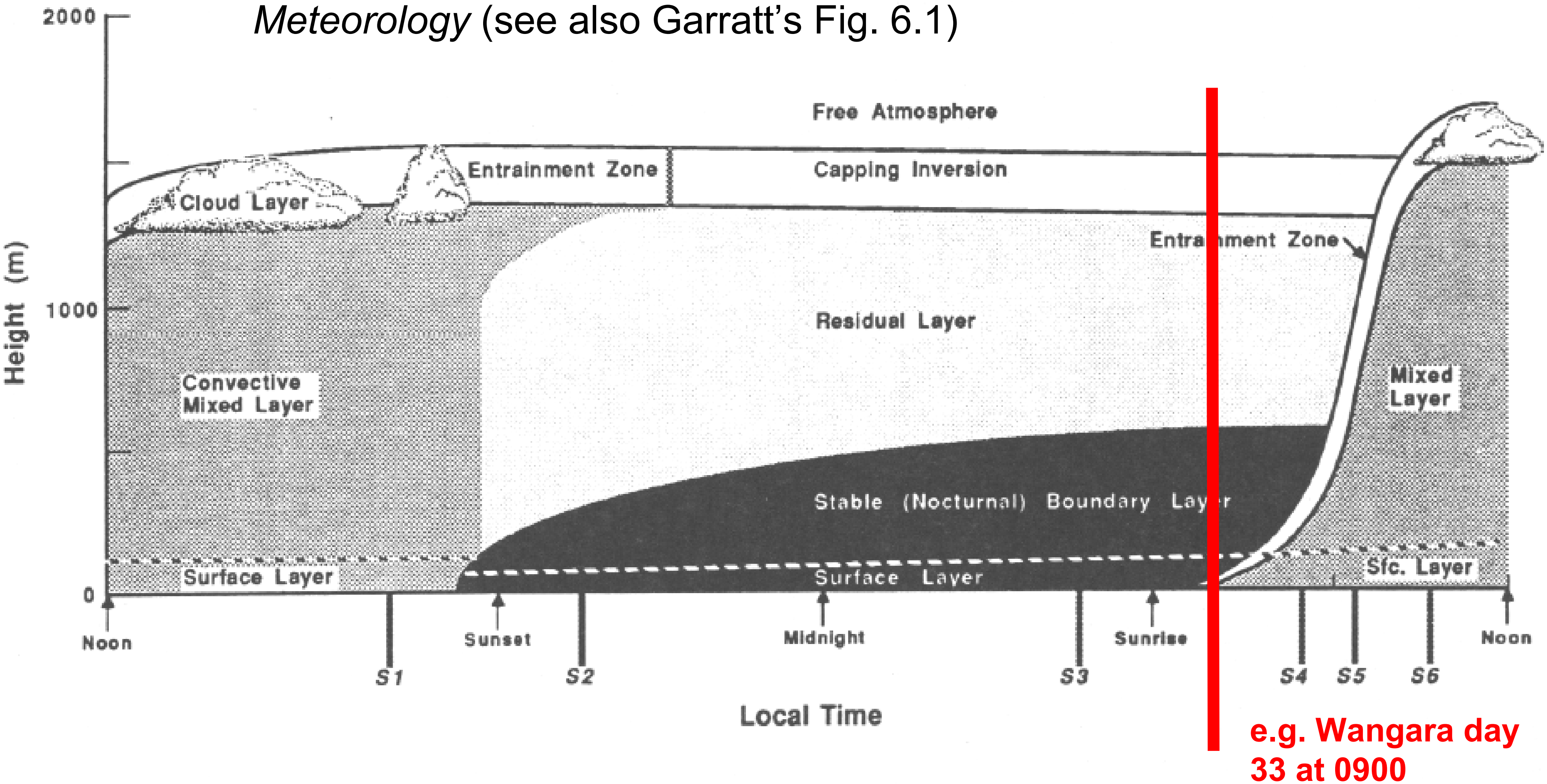
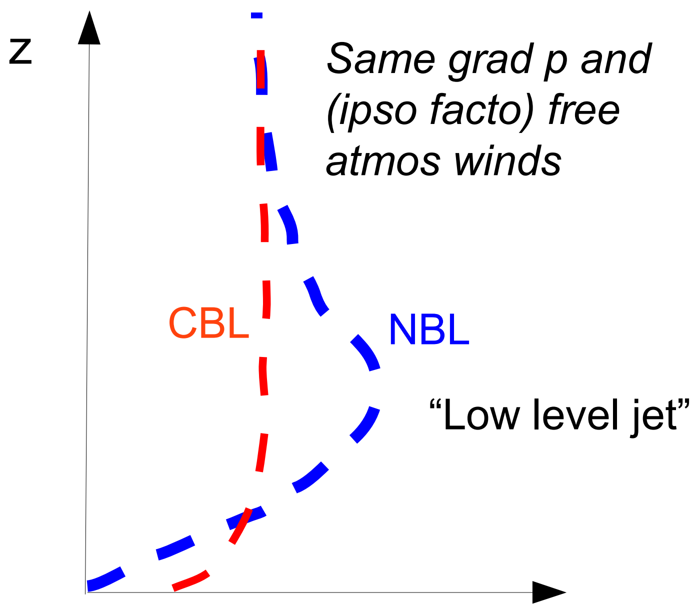
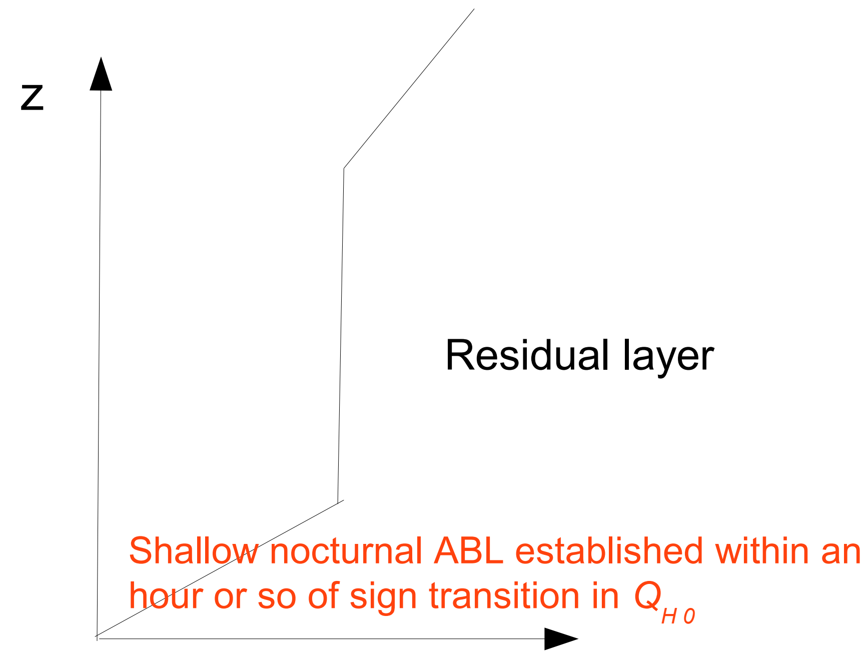


Fig. 1.7 The boundary layer in high pressure regions over land consists of three major parts: a very turbulent mixed layer; a less-turbulent residual layer containing former mixed-layer air; and a nocturnal stable boundary layer of sporadic turbulence. The mixed layer can be subdivided into a cloud layer and a subcloud layer. Time markers indicated by S1-S6 will be used in Fig. 1.12.



Wind speed



Mean Potential Temperature

Possibility of inertial oscillations in horizontal velocity within the residual layer aloft

$$\frac{\partial U}{\partial t} = -\frac{\partial \overline{u'w'}}{\partial z} + f(V - V_G)$$

$$\frac{\partial V}{\partial t} = -\frac{\partial \overline{v'w'}}{\partial z} - f(U - U_G)$$

$$\longrightarrow \quad \frac{\partial^2 U}{\partial t^2} = -f^2 U + f^2 U_G$$

Conditions that allow the ABL to remain well-mixed overnight:

- strong free atmos. wind to sustain shear production and overcome buoyant destruction of TKE

- heavy cloud cover, preventing rapid sfc cooling by longwave radiation

$$Q^* \equiv K^* + L^* = Q_{H0} + Q_{E0} + Q_G$$

Otherwise, a strong sfc-based inversion develops, with these consequences:

$L^*<0 \rightarrow Q^*<0 \rightarrow Q_H<0 \rightarrow$ buoyant suppression of the vertical motion (thus) TKE, effective in the energy-containing range of scales; w' fed by inter-component transfer (redistribution) alone; lack of energy in w' limits heat and (downward) momentum transport by turbulent convection; light winds (measurement challenge), turbulence may be intermittent; gravity waves; ratio of buoyancy (gT'/T_0) to inertial (u'^2/L) forces becomes large so slight topographic irregularities can result in drainage flows (three-dimensional and intermittent) – see Wyngaard's textbook Eqn. (12.20) where veloc. field parallel to gently sloping sfc contains buoyancy terms

$$\frac{\partial \sigma_w^2}{\partial t} = 2\,\frac{g}{\theta_R}\,\overline{w'\theta'} - \epsilon_{ww} - \frac{\partial}{\partial z}\,\overline{w'\left(\frac{2p'}{\rho} + w'w'\right)} + \frac{2}{\rho}\,\overline{p'\,\frac{\partial w'}{\partial z}}$$

small

Delage (1974; QJRMS Vol. 100) 1-D model of dry SBL – turbulent transport (only)

$$\frac{\partial \overline{u}}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial \overline{u}}{\partial z} \right) + f(\overline{v} - V_g)$$

$$\frac{\partial \overline{v}}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial \overline{v}}{\partial z} \right) - f(\overline{u} - U_g)$$

$$\frac{\partial \overline{\theta}}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial \overline{\theta}}{\partial z} \right)$$

(neglects radiative divergence)

$$\frac{\partial k}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial k}{\partial z} \right) + K \left[\left(\frac{\partial \overline{u}}{\partial z} \right)^2 + \left(\frac{\partial \overline{v}}{\partial z} \right)^2 \right] - \frac{g}{\theta_{00}} K \frac{\partial \overline{\theta}}{\partial z} - \epsilon$$

<u>Closure</u>

$$K = \lambda(z) \sqrt{c_e \, k}$$

$$\epsilon = (c_e \, k)^{3/2} / \lambda$$

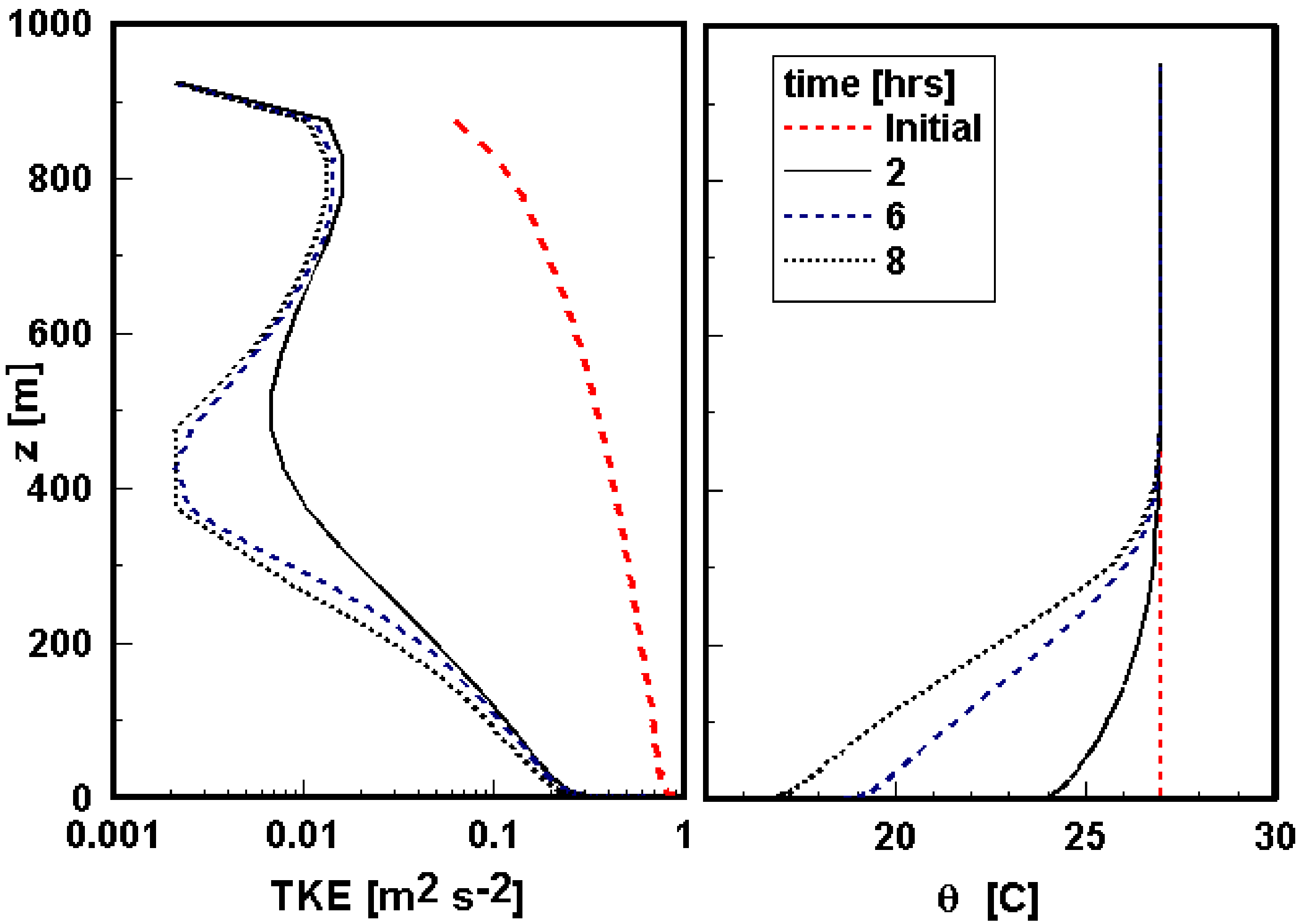
$$\frac{1}{\lambda} = \frac{1}{k_v z} + \frac{1}{\lambda_\infty} + \frac{\beta}{k_v L}$$

Recall that in context of MOST:

$$K_m = \frac{k_{vm} \, u_* \, z}{\varphi_m(z/L)}$$

Initial condition: $\theta(z,0) = \theta_{00}$ and corresponding steady-state wind and TKE profiles from solution of these equations for the neutral state.

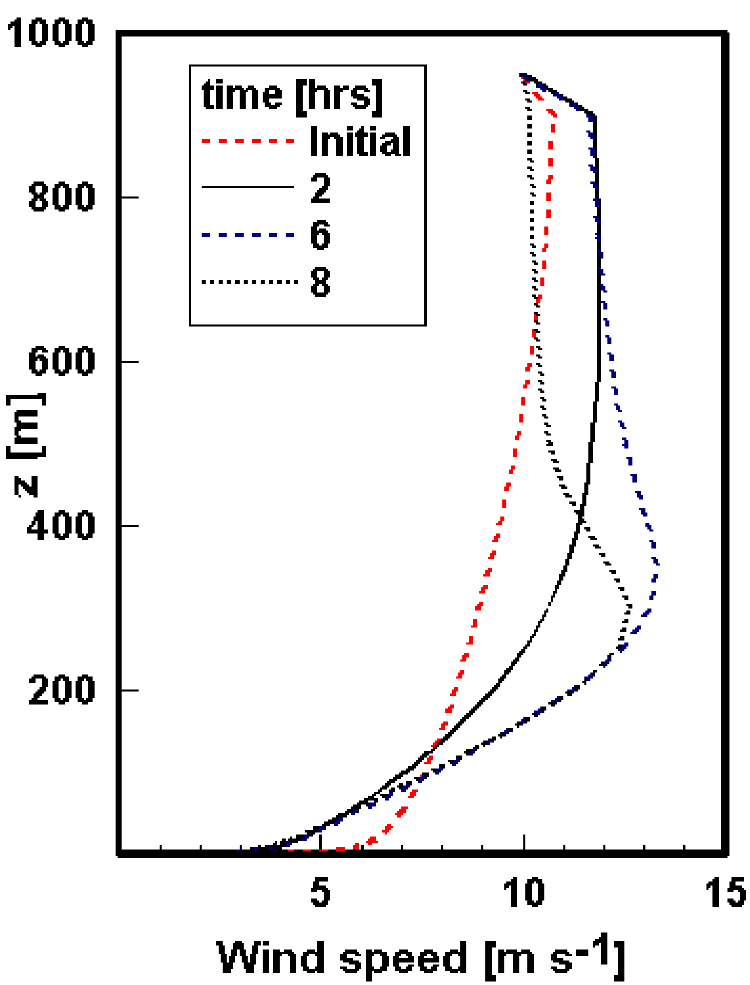
Solution "driven" by an imposed cooling trend in surface temperature



• intensifying surface-based inversion self-limits its own depth h_i

• depth h_t of surface-based mixing layer drops. Mixing continues in residual neutral layer aloft

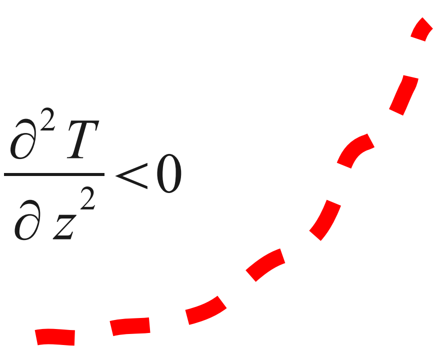
• development of a low-level jet



But André & Mahrt (1982, JAS Vol. 39) showed that the role of nocturnal longwave divergence can be to deepen the ground-based inversion h_i so that it reaches several times higher than the height h_t of the turbulent (ie. stirred) shear layer, at the same time moderating the stratification of that turbulent layer - whereas the convective flux divergence, acting alone, would progressively steepen the temperature gradient as the ground cools, without deepening the inversion.

Ha and Mahrt (2003, Tellus A Vol. 55) computed longwave radiative divergence from both idealized and measured profiles of temperature and humidity, and determined that “radiative cooling increases with the thermal stratification, moisture content, negative curvature of the temperature profile and temperature deficit of the ground surface”

$$\frac{\partial^2 T}{\partial z^2} < 0$$



Importance of radiative flux divergence

With horiz. homog. assumed, $$\rho c_p \frac{\partial \bar{\theta}}{\partial t} = -\frac{\partial Q_H}{\partial z} - \frac{\partial Q^*}{\partial z} \quad \text{where} \quad \frac{\partial Q^*}{\partial z} \equiv \frac{\partial L^*}{\partial z}$$

Schaller (1977; BLM Vol. 11) observed** that "during the clear night radiative cooling exceeds the cooling caused by the sensible heat flux." André et al. (1978; JAS Vol. 35) concluded longwave divergence is "more important than turbulent transport … except close to the ground"

**See also André et al. (1978; JAS Vol. 35), André & Mahrt (1982, JAS Vol. 39), Ha & Mahrt (2003, Tellus A Vol. 55: "Radiative and Turbulent Fluxes in the Nocturnal Boundary Layer")