METR 130: Lecture 5

- Internal Boundary Layers (2-D ABL)
- ABL driven thermal circulations
- Marine Boundary Layers

Spring Semester 2011

May 3, 2011

Reading

- Arya; pages 81-82 (Marine Boundary Layer, MBL)
- Arya; Chapter 14 (Internal Boundary Layers, IBL)
- Garratt
  - Chapter 4.5 (IBL)
  - Chapter 6.3 and 6.4 (MBL and IBL)
  - Chapter 7 (Cloud-topped BL … applicable to MBL)

Internal Boundary Layer

(Development with Downwind Distance, x)

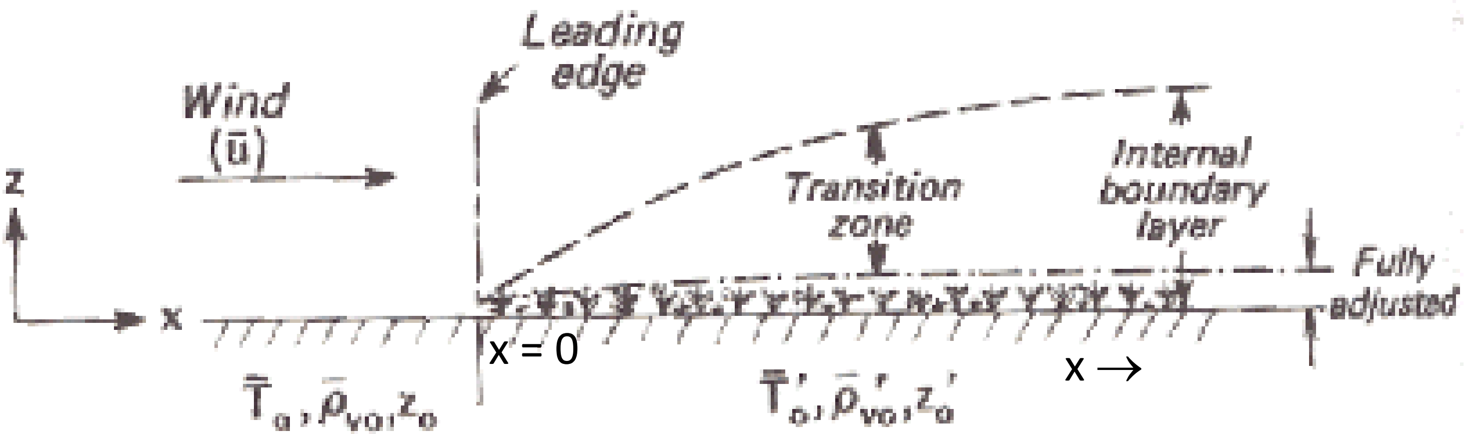


Figure 5.1 The development of an internal boundary layer as air flows from a smooth, hot, dry, bare soil surface (with surface values $\bar{T}_0$, $\bar{\rho}_{v0}$, z_0) to a rougher, cooler and more moist vegetation surface (with new surface values $\bar{T}'_0$, $\bar{\rho}'_{v0}$, z'_0).

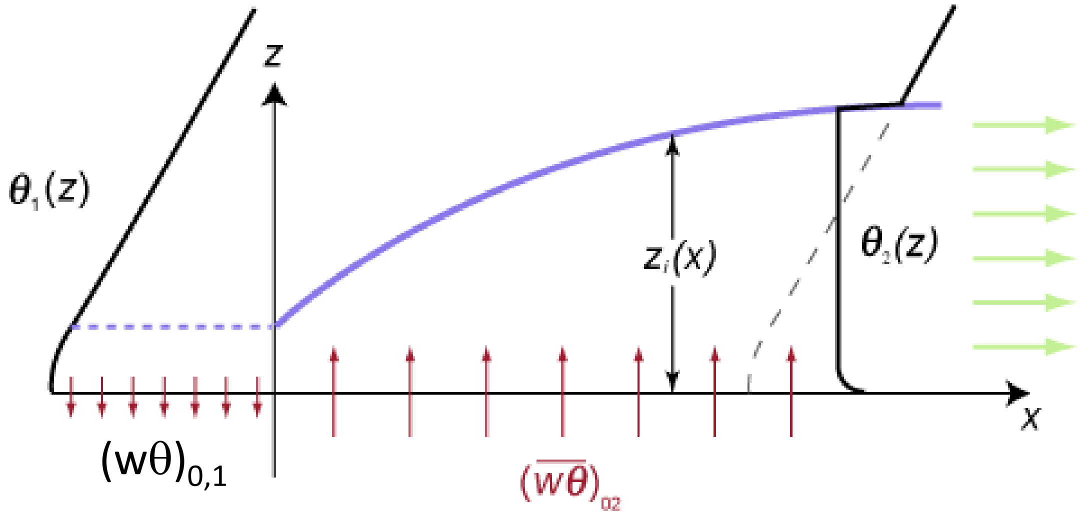
IBL Definitions

Internal Boundary Layer (IBL) – Layer affected by the change in surface conditions as wind flows from over one surface type to over another. The IBL depth grows with Downwind distance x (x = 0 defined as point where surface switches).

"Fully" Adjusted Region – Part of IBL adjacent to surface where flow characteristics Do not have "memory" of original upwind surface, i.e. fully adjusted to underlying surface. Profiles in this region are described by usual 1-D laws (log-law, MO theory). Also called "equilibrium" region.

Transition Region – Part of IBL above Fully Adjusted Region that, while affected, is not in equilibrium with underlying surface. It is in a state of adjustment, and still has memory of original, upstream surface. Traditional 1-D laws do not apply in this region.

Convective Internal Boundary Layer



Convective IBL … upwind stable boundary layer flows over a relatively warmer surface. Note diagram … upwind surface heat flux negative (stable) and downstream positive (unstable).

Stable Internal Boundary Layer: upwind neutral or unstable boundary layer flows over a relatively colder surface. Note downstream evolution of potential temperature profile in diagram.

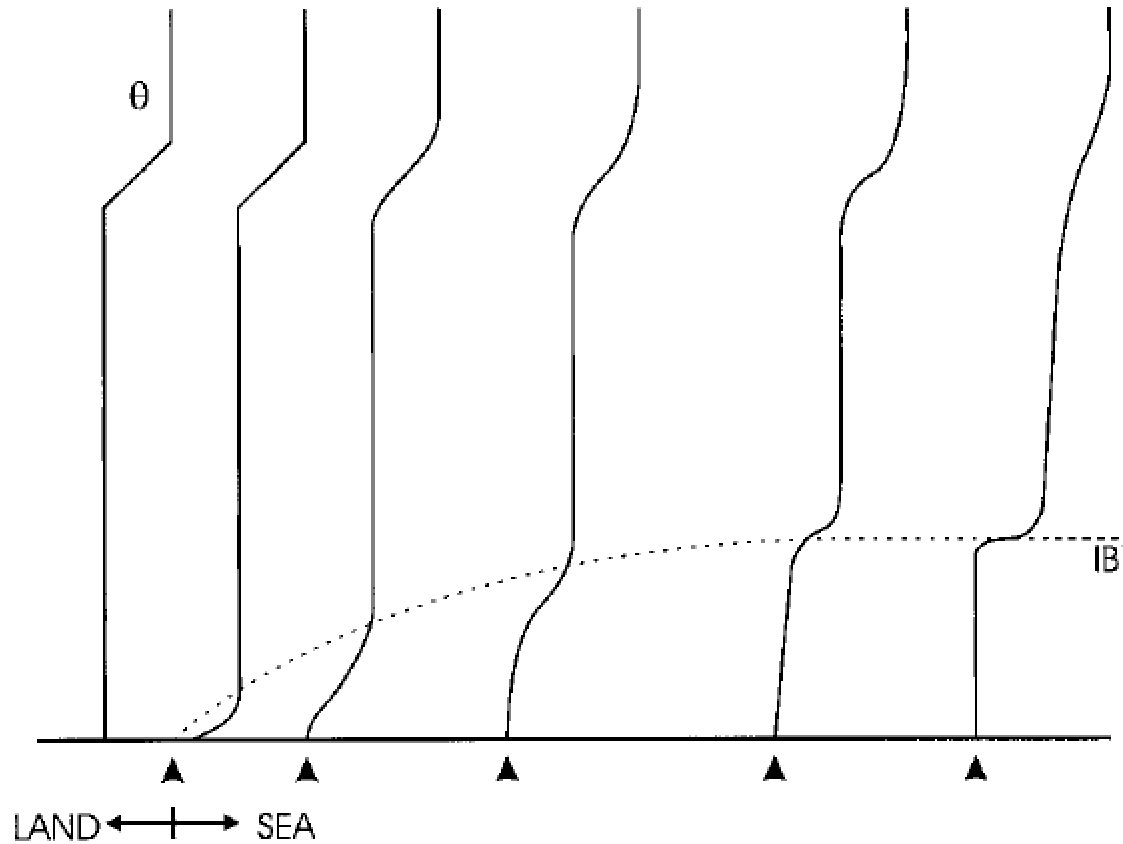


FIG. 2. Idealized representation of the alongwind evolution of the potential temperature profiles for an internal boundary layer. The initial profile is that just prior to advection over the coastline, and shows a deep, well-mixed boundary layer. As the distance from the shore increases, the IBL deepens and its potential temperature approaches that of the sea surface. The original BL inversion is slowly eroded. Ultimately a shallow, well-mixed marine layer may form. The dashed line represents the IBL depth; the arrows indicate the sea surface potential temperature.

IBL: Basic Equations …

$$\bar{u}\frac{\partial \bar{u}}{\partial x} = f\left(\bar{v} - v_g\right) - \frac{\partial \left(\overline{u'w'}\right)}{\partial z}$$

$$\bar{u}\frac{\partial \bar{v}}{\partial x} = -f\left(\bar{u} - u_g\right) - \frac{\partial \left(\overline{v'w'}\right)}{\partial z}$$

$$\bar{u}\frac{\partial \bar{\theta}}{\partial x} = -\frac{\partial \left(\overline{w'\theta'}\right)}{\partial z} + S_\theta^+ - S_\theta^-$$

$$\bar{u}\frac{\partial \bar{q}}{\partial x} = -\frac{\partial \left(\overline{w'q'}\right)}{\partial z} + S_q^+ - S_q^-$$

$$\bar{u}\frac{\partial \bar{\chi}}{\partial x} = -\frac{\partial \left(\overline{w'\chi'}\right)}{\partial z} + + S_\chi^+ - S_\chi^-$$

Balance between horizontal advection, vertical turbulent diffusion, and source/sink terms

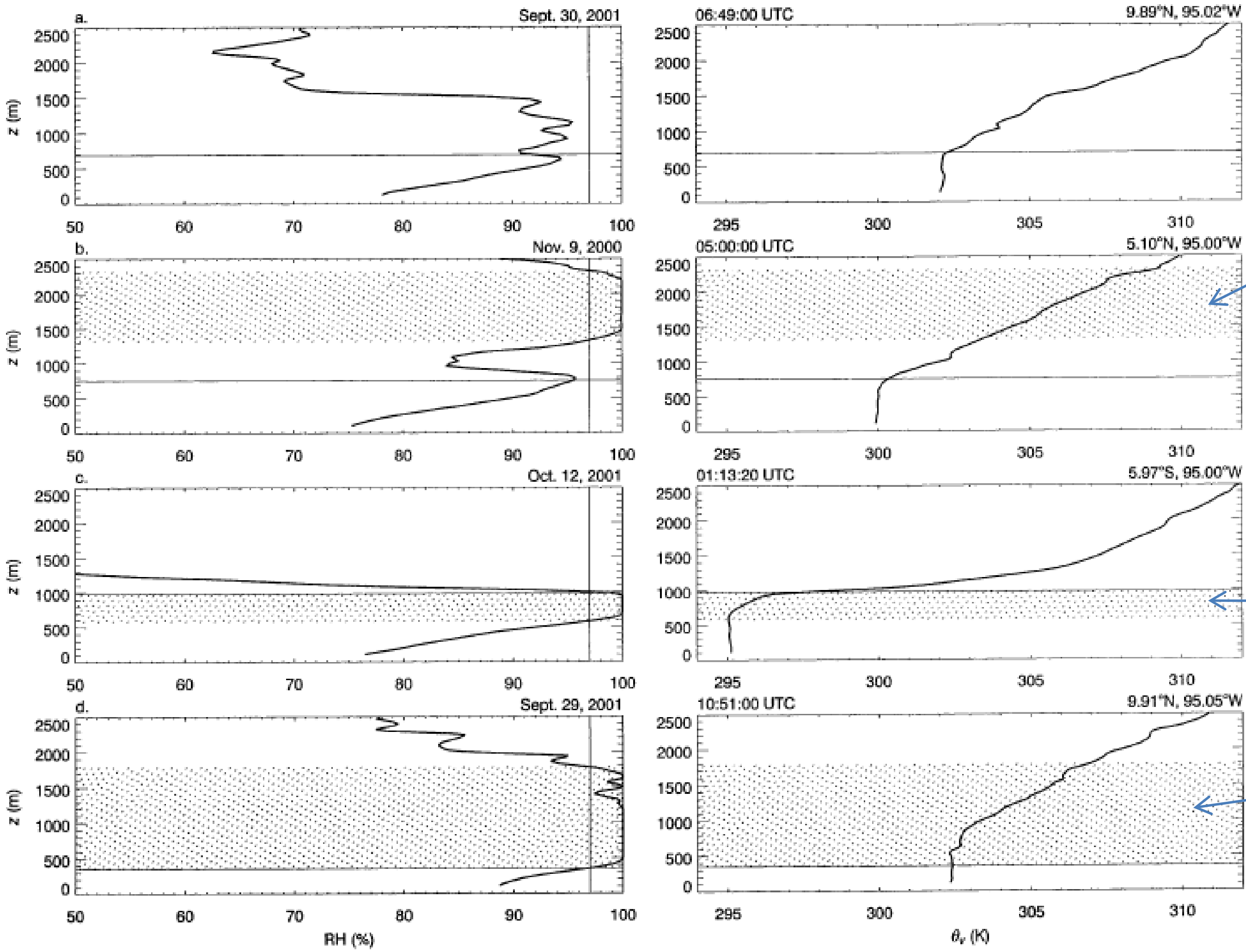
2-D

- ***Profiles are f(x,z)***
- ***IBL depth = f(x)***

Marine Boundary Layer

Measurements in Equatorial Eastern Pacific (Zeng et al. 2004, Journal of Climate)

Relative Humidity (%) **Potential Temperature (K)**



Clear sky (no clouds)

"Decoupled" Cloud Layer

Thin Cloud Layer

Thick Cloud Layer

FIG. 2. Typical vertical profiles of the (left) relative humidity (RH) and (right) virtual potential temperature (θ_v) for four different situations: (a) clear sky, (b) decoupling between ABL and cloud layer, (c) thin cloud layer, and (d) thick cloud layer. Superimposed in each profile are the sounding-derived ABL height (horizontal solid line) and cloud layer (shading).

Marine Boundary Layer

- Entrainment Processes
  - Cloud Top Radiative Cooling
  - Wind Shear across entrainment zone
  - Gravity waves breaking
- Surface Processes
  - Change in SST
  - Surface ocean waves, increased roughness

Converting Between Potential Temperature (θ) and Temperature (T) in ABL

Poisson Equation (exact relationship, see any standard textbook) …

$$\theta = T\left(\frac{1000}{p}\right)^{\kappa}$$

P is pressure in millibars
$\kappa = R_d/c_p = 0.286$

Logarithmically differentiating (see any textbook) and assuming …

a) hydrostatic relationship to map p to z
b) ratio $\theta/T \approx 1$ (valid for ABL, not so in free atmosphere)

Can be shown …

$$\frac{dT}{dz} = \frac{d\theta}{dz} - \Gamma_D \quad \Rightarrow \quad T - T_0 = \theta - \theta_0 - \Gamma_D z \quad \Rightarrow \quad \boxed{T = \theta - \Gamma_D z}$$

Integrating both sides w/ respect to z

Letting $T_0 \approx \theta_0$ (i.e. $p_0 \approx 1000$ mb)

Use this expression to convert from θ to T. Remember, RH (via qsat) depends on T, not θ. This is why you need to use this expression in part d of Hw#4 Problem 2