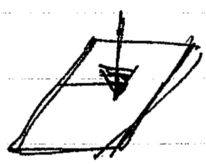
Arya, Chapter 2: Energy budget near the surface

2.1 Energy fluxes at an ideal surface

Flux = amount per unit time passing through a unit area



Energy flux units: $J\,s^{-1}m^{-2}$ or $W\,m^{-2}$.

Ideal surface:

smooth, horizontal, homogeneous, extensive, opaque

Types of energy fluxes:

Net radiation flux	R_N
sensible heat flux	H
latent heat flux	H_L
soil (or water) heat flux	H_G

R_N: mainly solar (downward) in day
IR (upward) at night

H: due to $\Delta T = T - T_s$

mode: conductive near surface,
turbulent (or convective) beyond a few mm.

H is upward in day, downward at night.

H_L: due to evaporation, evapotranspiration, or condensation (dew) at the surface. Occurs due to gradients of water vapor. Heating or cooling of the surface occurs due to latent heat of evaporation during the phase change.

Bowen ratio $= H / H_L = B$.

$H_L = L_e E$, $L_e = 2.5 \times 10^6\ J\ kg^{-1}$, E: evap. rate

H_G: By Conduction through ground (soil, rock). But In water, conduction occurs only at the interface, then convection transports the energy further.

Layer affected by diurnal variations:

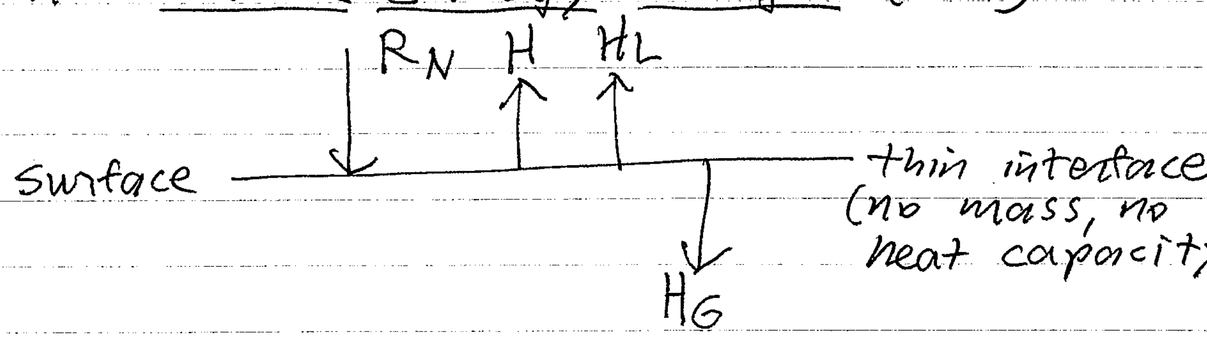
< 1 m for land

several 10's m for lakes, oceans,

(What else is different about energy fluxes into water?)

2.2 Energy Balance Eqs.

2.2.1 Surface Energy Budget (SEB)

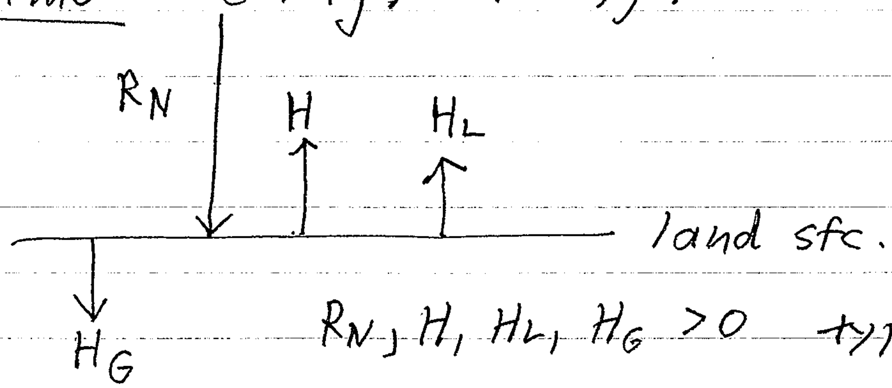


conservation of energy then requires net flux into surface = 0, or

$$R_N = H + H_L + H_G, \qquad (2.1)$$

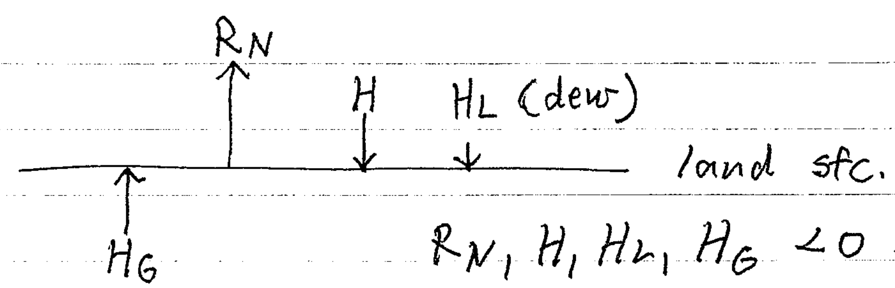
where $R_N > 0$ toward sfc., others > 0 away from sfc.

<u>Day time</u> (Fig. 2.1 (a)):



$R_N, H, H_L, H_G > 0$ typically

<u>Nightime</u> (Fig. 2.1 (b))



$R_N, H, H_L, H_G < 0$ typically

magnitudes smaller than in day except for H_G.

Diurnal cycle of SEB is "forced" by R_N. H, H_L, H_G are <u>responses to</u> this forcing.

<u>Local SEB depends on many factors:</u>
insolation; cloud amount, height; near-sfc. atmospheric T, q, u, v; sfc. characteristics such as wetness,

plant cover, albedo; topography (slope, orientation, etc.)

Determination of H, H_L from R_N, H_G:

1. Measure R_N and H_G.
2. Estimate Bowen ratio; $B \equiv H/H_L$.
3. Use Eq (2.1):

$$H = \frac{R_N - H_G}{1 + B^{-1}} \qquad (2.2)$$

$$H_L = \frac{R_N - H_G}{1 + B} . \qquad (2.3)$$

(Verify that $H/H_L = B$.)

Example Prob. 1

For Wangara exp. (central Australia):

$$\frac{H_G}{R_N} = 0.30 \text{ (day)}, \; 0.52 \text{ (nite)}$$

Assume $B = 5.0$. Est. H, H_L for

$R_N = 250 \text{ W m}^{-2}$ (day), -55 W m^{-2} (nite).

Sol'n

$H_G = 0.30 \times 250 = 75 \text{ W m}^{-2}$ (day)

$= -0.52 \times 55 = -29 \text{ W m}^{-2}$ (nite)

From (2.2), (2.3):

$$H = \frac{250 - 75}{1 + 0.2} = 146 \text{ W m}^{-2} \text{ (day)}$$

$$H = \frac{-55 + 29}{1 + 0.2} = -22 \text{ W m}^{-2} \text{ (nite)}$$

$$H_L = \frac{250-75}{1+5} = 29 \ \mathrm{W\,m^{-2}} \quad \text{(day)}$$

$$H_L = \frac{-55+29}{1+5} = -4.4 \ \mathrm{W\,m^{-2}} \quad \text{(nite)}$$

(Verify that energy balance is satisfied.)

day : $250 = 146 + 29 + 75$ ✓

nite : $-55 = -22 - 5 - 28$ ✓

<u>Water surface SEB</u> : $H \ll H_L$; little diurnal variation due to large heat capacity of water layer affected; R_N is difficult to measure since solar radiation penetrates surface.

2.2.2 <u>Energy budget of a layer</u>

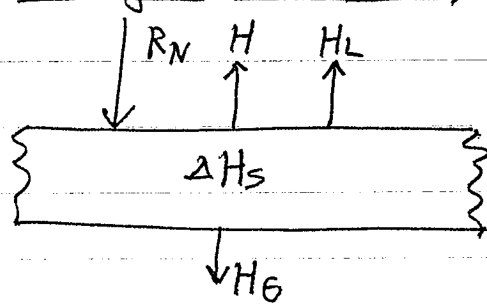


Fig. 2.2(a)

$$R_N = H + H_L + H_G + \Delta H_s \quad (2.4)$$

Energy budget now includes a storage rate term, ΔH_s:

$$\Delta H_s = \int_{\text{layer}} \frac{\partial}{\partial t}(\rho c T)\, dz \quad (2.5)$$

ρ: density, c: specific heat capacity, T: temperature.

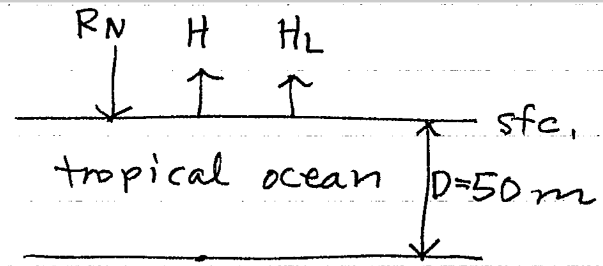
Example Problem 2

$B = 0.1$

$R_N = 400\ \mathrm{W/m^2}$

H? H_L?

$(\partial T/\partial t)_m = 0.05\ \mathrm{K/day}$



no flux out of layer

$$\Delta H_s = \rho c D \left(\frac{\partial T}{\partial t}\right)_m$$

(note typo in text)

$$= 1000\ \frac{\mathrm{kg}}{\mathrm{m^3}} \times 4180\ \frac{\mathrm{J}}{\mathrm{kg\,K}} \times 50\mathrm{m} \times 0.05\ \frac{\mathrm{K}}{\mathrm{day}} \times \frac{1}{86400\ \mathrm{s}/\mathrm{day}}$$

$$= 121\ \mathrm{W/m^2},$$

So $H + H_L = R_N - \Delta H_s = 400 - 121 = 279\ \frac{\mathrm{W}}{\mathrm{m^2}}$

(typo in text)

Then, using $H_L = H/B$, $H + H/B = 279\ \mathrm{W/m^2}$,

so $$H = \frac{279}{1 + 1/B} = \frac{279}{1+10} = 25.4\ \mathrm{W/m^2}$$

$$H_L = H/B = 254\ \mathrm{W/m^2}.$$

$$E = H_L/L_e = \frac{254\ \mathrm{W/m^2}}{2.5\times10^6\ \mathrm{J\,kg^{-1}}} = 1.02\times10^{-4}\ \mathrm{kg\,m^{-2}s^{-1}}$$

$$\frac{E}{\rho_w} = \frac{1.02\times10^{-4}}{10^3} \times 86400\ \frac{\mathrm{s}}{\mathrm{day}} = 8.8\ \mathrm{mm/day}.$$

2.2.3 Energy budget of a control volume

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