ESS5203.03 - Turbulence and Diffusion in the Atmospheric Boundary-Layer : Winter 2020
Notes 2a.

Text: J.R.Garratt, The Atmospheric Boundary Layer, 1994. Cambridge , Also some material from J.C. Kaimal and J.J. Finnigan, 1994, Atmospheric Boundary-Layer Flows - Oxford.

4) Surface Energy Budget. Dimensional Analysis and Similarity, Monin-Obukhov similarity theory. The diabatic surface boundary layer. Other stratified boundary layers (suspended material) G3, G5

Surface Energy Budget

Garratt, Chapter 5: also http://www.atmos.washington.edu/~breth/classes/AS547/lect/lect10.pdf or http://www.colorado.edu/geography/class_homepages/geog_4271_f12/lectures/notes_4.pdf

Idealised surface itself has no heat capacity - but can treat an upper soil, water or a canopy layer with a heat capacity. ($\partial W/\partial t$). Treating water surfaces can be much more difficult.

$$R_{N0} = G_0 + H_0 + \lambda E_0 \quad (+ \partial W/\partial t) \qquad (5.1)$$

Net radiation Ground Heat Flux, Sensible Heat Flux, Latent heat flux/evaporation or condensation

$$R_{N0} = R_{S0}(1-\alpha_s) + \varepsilon_s R^d_{L0} + R^u_{L0} \qquad (5.13)$$

Solar down, R_{S0}, and reflected: Long wave (terrestrial) up and down. Black body radiation, σT^4 where σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} $Wm^{-2}K^{-4}$) and ε_s is the emissivity.$R^u_{L0} = \varepsilon_s \sigma T^4$

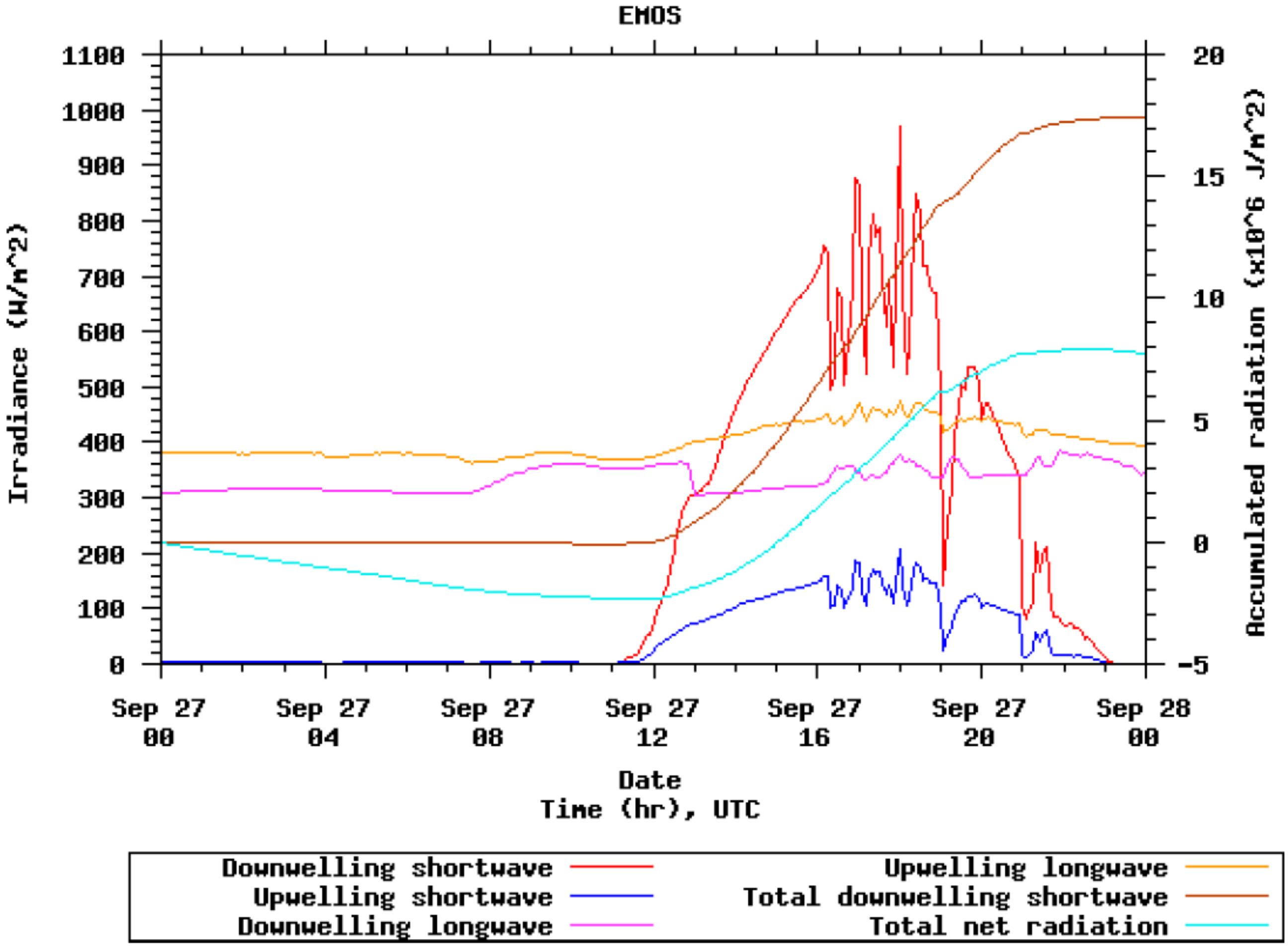
Table 1: Reflectivity values of various surfaces

Surface	Details	Albedo
Soil	Dark & wet versus	0.05 -
	Light & dry	0.40
Sand		0.15 – 0.45
Grass	Long versus	0.16 -
	short	0.26
Agricultural crops		0.18 – 0.25
Tundra		0.18 – 0.25
Forests	Deciduous	0.15 – 0.20
	Coniferous	0.05 – 0.15
Water	Small zenith angle versus	0.03 – 0.10
	Large zenith angle	0.10 – 1.0
Snow	Old	0.40 -
	Fresh	0.95
Ice	Sea	0.30 – 0.45
	Glacier	0.20 – 0.40
Clouds	Thick	0.60 – 0.90
	Thin	0.30 – 0.50

Sources: Oke, 1998; Ahrens, 2001

Long wave emissivity

A true black body would have an emissivity of 1 while any real object would have an emissivity less than 1. Aluminum emissivity = 0.04; Cast iron = 0.65; water = 0.95. Wavelength dependent, i.e Temperature dependent. Earth Surface mostly 0.94 - 1.00. Wavelenths 4-16 μm. Planck's law, Wien's displacement law $\lambda max = b/T$.



Typical range of net radiation? -100 Wm^{-2} to + 600 Wm^{-2}.

<u>$G_0 + H_0 + \lambda E_0$</u>

Ground heat flux. $G = - k_s \partial T_s/\partial z$ s = soil. Usually smaller than other terms. Heat storage in cities, urban heat islands.

Partition between Sensible and Latent heat fluxes, Bowen Ratio, $B = H_0/\lambda E_0$

Evaporation and evapotranspiration, stomatal resistance, potential evapotranspiration, CLASS (Diana Verseghy) and other land surface schemes. Coupled air, surface-energy-balance, soil models.

Logarithmic temperature profiles near ground. Thermal roughness length, scalar roughness length.

Surface temperature issues.

Turbulent sensible heat flux $H/\rho c_p = \langle w'\theta' \rangle = -u_* \theta_*$. Definition of θ_*. Can also define q_* for water vapour mixing ratio.

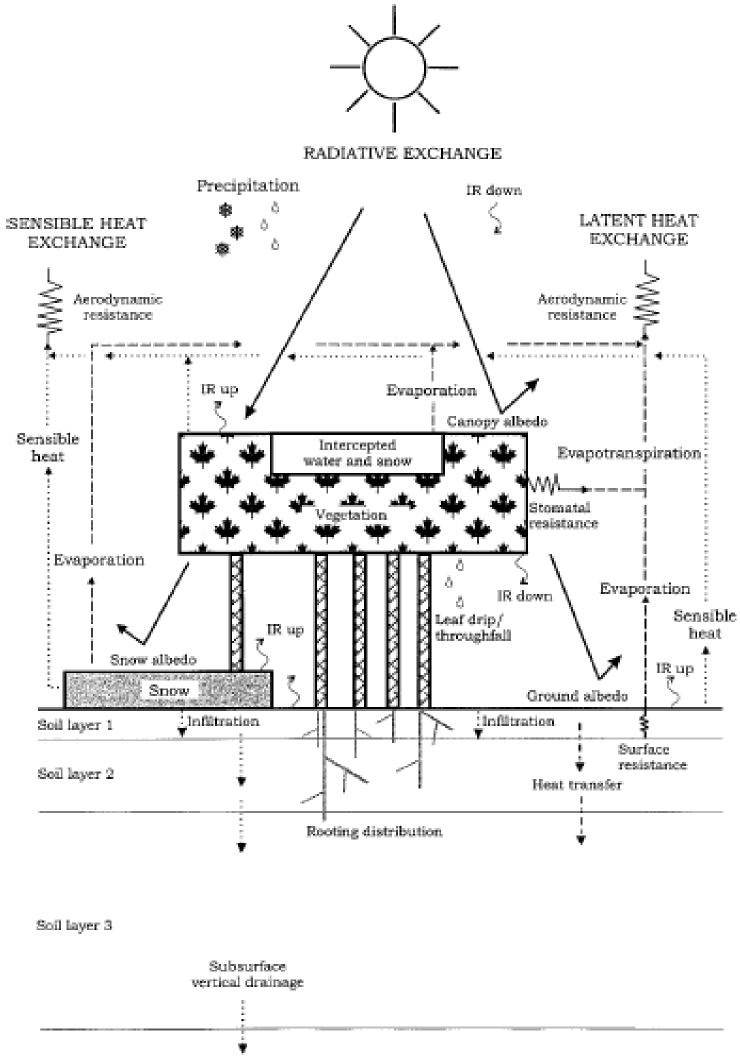


Fig. 1. Schematic diagram of CLASS.

How about water surfaces? Some IR radiation absorbed at (close to?) the surface, some penetrates.

Flow over the sea (Garratt 4.4) ...... Coupled models or specify SST.

Monin-Obukhov Similarity Theory - MOST

Constant flux layer - momentum (u_*^2) and heat ($H/(\rho c_p)$ or buoyancy fluxes $\langle w'\rho'\rangle$.

Relationship between gradients and fluxes Garratt 3.3,

$$\partial U/\partial z = (u_*/kz)\,\Phi_M(\zeta) \qquad (3.23)$$

Buckingham Pi theorem: $\pi_1 = (kz/u_*)\partial U/\partial z$: $\pi_2 = z/L = \zeta$, where $L = -u_*^3/[k(g/\theta)\langle w'\theta'\rangle] = u_*^2/[k(g/\theta)\theta_*]$ is the Obukhov length. $\pi_1 = F(\pi_2)$ or 3.23.

Argue that g affects buoyancy only via g/θ so can use that combination, then,

5 Variables: $\partial U/\partial z$, u_*, z, g/θ, $H/(\rho c_p)$. 3 Dimensions L,T,K so 2 π s as above.

Furthermore any dimensionless turbulence property will be a function of ζ alone, e.g , $\langle w'^2\rangle/u_*^2$.

$$\partial \Theta/\partial z = (\theta_*/kz)\,\Phi_H(\zeta) \qquad (3.24)$$

Why is this important? Provides universal relationships which can be determine experimentally.

For history see http://www.bayceer.uni-bayreuth.de/mm/en/pub/pub/42525/Foken_2006.pdf

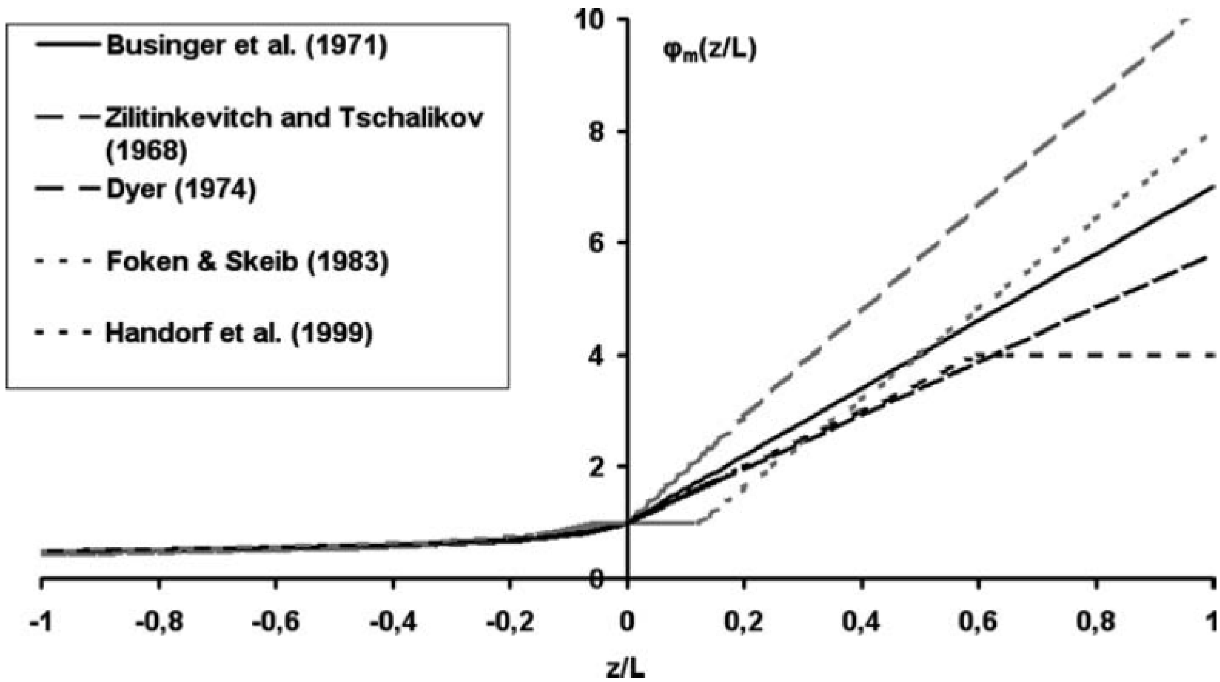


Figure 3. Universal function according to different authors in the modification by Högström (1988).

For stable situations $\Phi_M(\zeta) \approx 1 + \beta\zeta$ with $\beta \approx 5$. leads to $U = (u_*/k)\,[\,\ln(z/z_0) + \beta\zeta\,]$.