METR 130: Lecture 2

- Surface Energy Balance
- Surface Moisture Balance

Spring Semester 2011
February 8, 10 & 14, 2011

Reading

- **Arya, Chapters 2 through 4**
  - Surface Energy Fluxes (Ch2)
  - Radiative Fluxes (Ch3)
  - Soil Fluxes, Soil Temperature, Soil Temperature Transport Eq. (Ch4)
- **Arya, Chapter 12.1 – 12.2**
  - Surface humidity fluxes (evaporation, evapotranspiration)
  - Soil Moisture & Soil Moisture Transport Eq.
- **Other stuff to come or ref'd in later slides …**

Why Study Surface Energy (SEB) & Moisture Balance (SMB)?

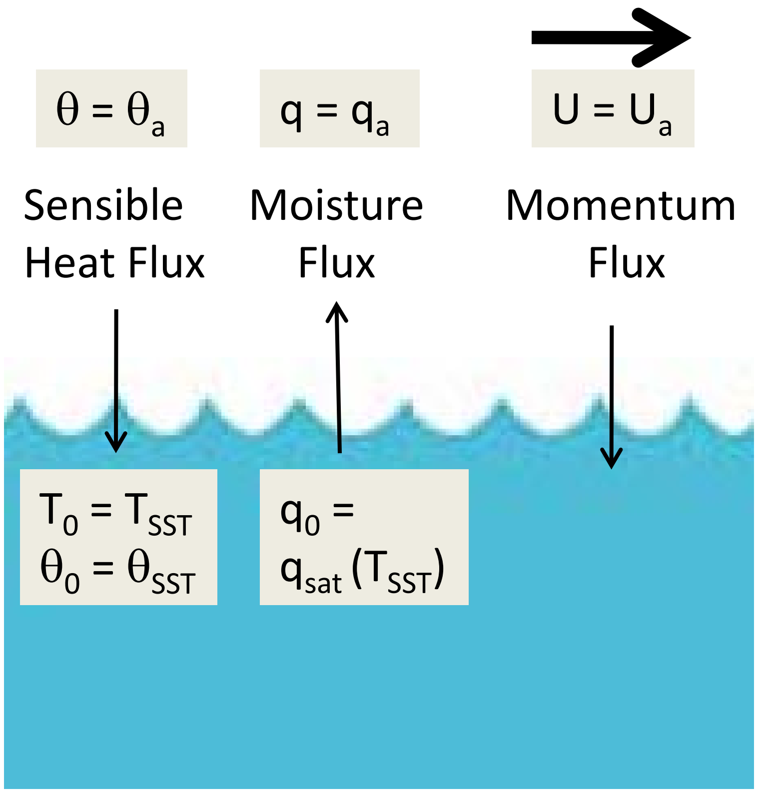
- **Vertical fluxes of heat and moisture to ABL depend on the amount of heat and moisture at the surface**
  - Surface Temperature, T_0 (alt. surface potential temperature, θ_0)
  - Surface Specific Humidity (q_0)
  - Surface Soil Moisture Content (η_0)

- **Stability of ABL (which affects all ABL variables and properties) in large part determined by surface temperature (T0) via SEB and SMB**

- **In models, the surface is the "lower boundary conditions" of the model**

Simple case to introduce some basics things …

(Surface fluxes over water)



T_0/θ_0 are constant, not f(t). For example, specified from SST observations. This is what is typically done in NWP models, since only a short term forecast is needed (~ days). However, what about in climate modeling?

Sensible Heat Flux = $H_S = -\rho_a c_p C_H U_a(\theta_a - \theta_0)$

Moisture Flux = $E = -\rho_a C_Q U_a(q_a - q_0)$

Latent Heat Flux = $H_L = \lambda E = -\lambda \rho_a C_Q U_a(q_a - q_0)$

Momentum Flux = $\tau_0 = -\rho_a C_M U_a^2$

where C_H, C_Q and C_M are turbulent vertical exchange coefficients for heat, moisture and momentum, respectively. These coefficients are in turn functions of stability, and therefore θ_0.
They are unitless.

Units ...

Sensible Heat Flux = $H_S = -\rho_a c_p C_H U_a(\theta_a - \theta_0) \rightarrow (kg_{air}/m^3)\ (J/kg_{air}\text{-}K)(m/s)(K) \rightarrow J/(m^2\text{-}s) \rightarrow W/m^2$

Moisture (Evaporative*) Flux = $E = -\rho_a C_Q U_a(q_a - q_0) \rightarrow (kg_{air}/m^3)\ (m/s)(kg_{vap}/kg_{air}) \rightarrow kg_{vap}/(m^2\text{-}s)$

... as an equivalent liquid water depth. Set kg_{vap} to kg_{wat} and divide by density of water (ρ_w)

$\rightarrow [kg_{wat}/(m^2\text{-}s)] / [kg_{wat}/m^3] \rightarrow m_{wat}/s \rightarrow mm_{wat}/day$ or in_{wat}/day

Latent Heat Flux* = $H_L = \lambda E = -\lambda \rho_a C_Q U_a(q_a - q_0) = (J/kg_{vap})(kg_{vap}/(m^2\text{-}s)] \rightarrow W/m^2$

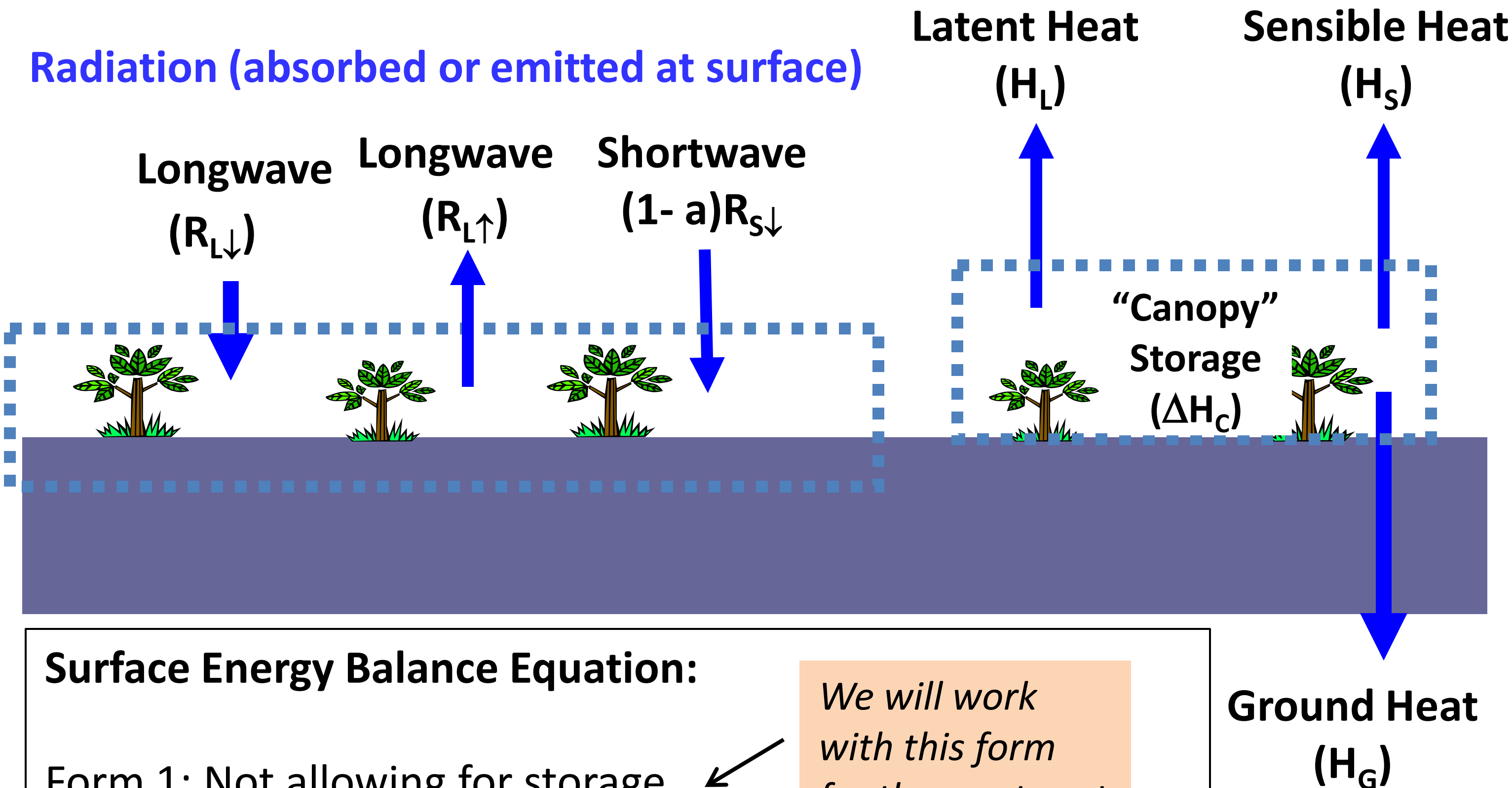
... where λ is the latent heat of vaporization*

Momentum Flux = $\tau_0 = -\rho_a C_M U_a^2 \rightarrow (kg_{air}/m^3)\ (m^2/s^2) \rightarrow (kg_{air}/ms^2) \rightarrow [kg_{air}m/s)] / [m^2\text{-}s]$

**This assumes moisture flux is due to evaporation (or condensation if negative), and therefore λ represents the latent heat of vaporization/condensation. If surface is ice or snow covered, then moisture flux would be as sublimation (or deposition if negative), and λ would represent the latent heat of sublimation/deposition.*

Surface Energy Balance
(Arya Chapter 2)

Surface Energy Balance over Land



Surface Energy Balance Equation:

We will work with this form for the most part

<u>Form 1</u>: Not allowing for storage

$(1\text{-}a)R_{S\downarrow} + R_{L\downarrow} + R_{L\uparrow} = R_N = H_S + H_L + H_G$

<u>Form 2</u>: Allowing for storage

$(1\text{-}a)R_{S\downarrow} + R_{L\downarrow} + R_{L\uparrow} = R_N = H_S + H_L + H_G + \Delta H_C$

where R_N is the "net radiation" at surface

Surface Energy Balance

(Sign Convention of Terms)

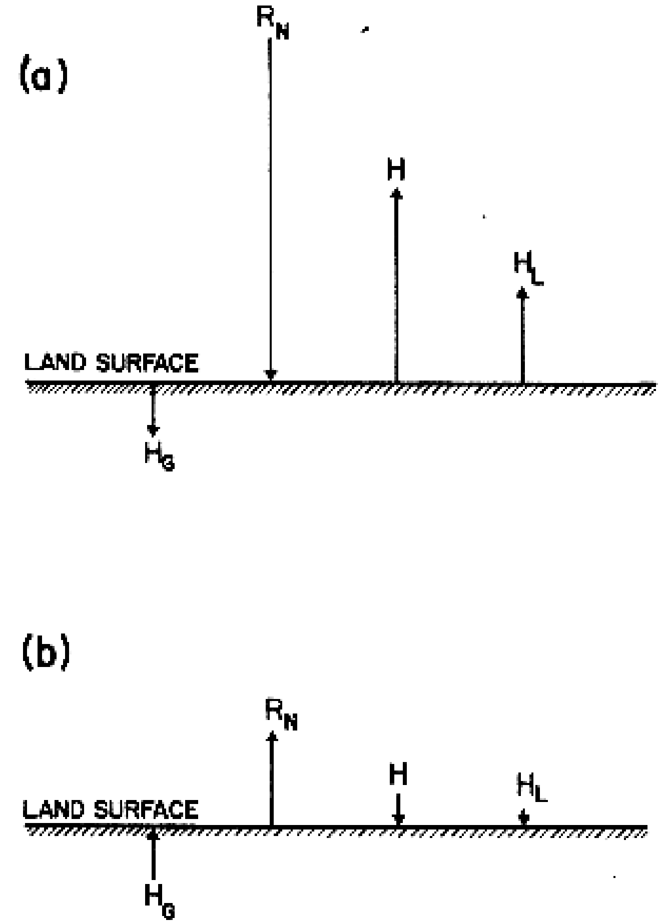
- **Radiation**
  - Solar (R_s): Positive Downwards
  - Downward Longwave ($R_{L\downarrow}$): Positive Downwards
  - Upward Longwave ($R_{L\uparrow}$): Positive Downwards
  - Net Radiation (R_N): Positive Downwards

Positive <u>towards</u> surface

- **Sensible Heat Flux (H_S)**: Positive Upwards
- **Latent Heat Flux (H_L)**: Positive Upwards
- **Ground Heat Flux (H_G)**: Positive Downwards

Positive <u>away from</u> surface

Typical Sign of SEB Fluxes: Day vs. Night
(Arya Figure 2.1)



Typically all positive during day

Typically all negative at night

Fig. 2.1 Schematic representation of typical surface energy budgets during (a) daytime and (b) nighttime.

Remaining Figures
(Arya Chapter 2)

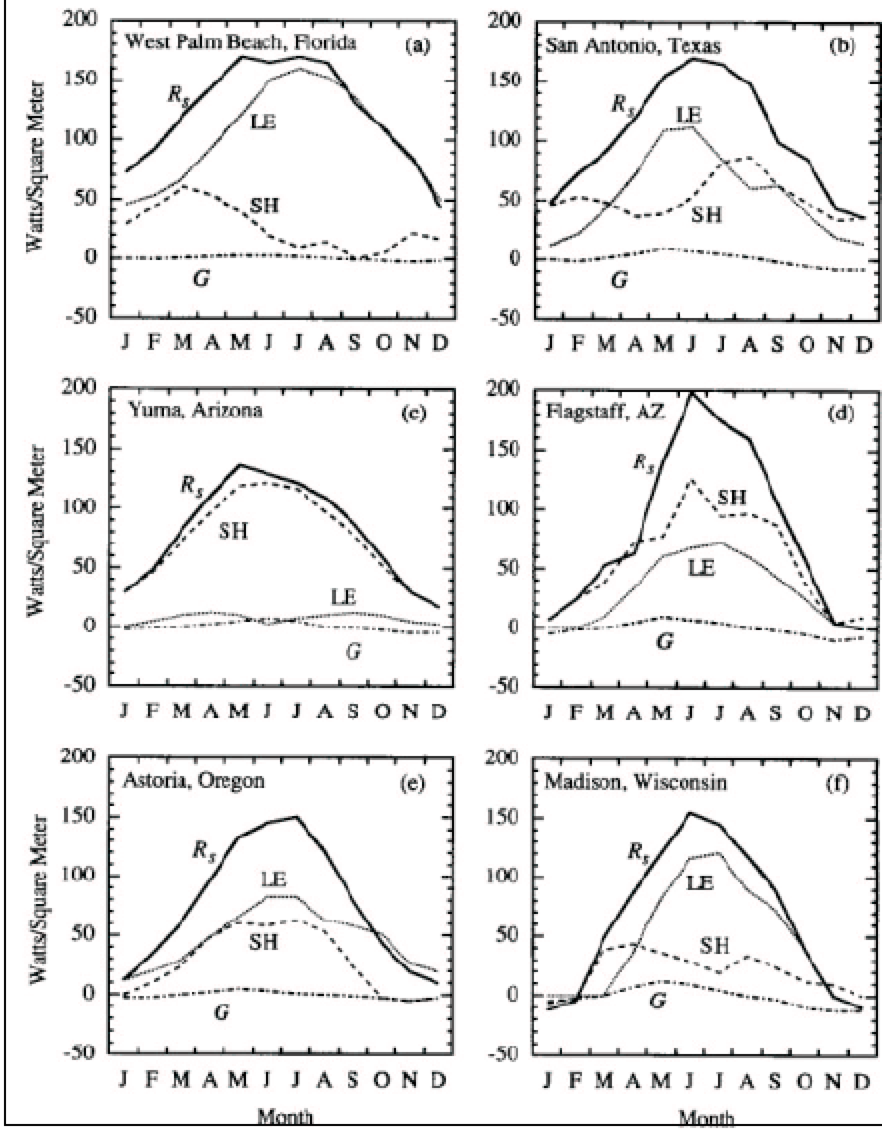
Figure 2.3 (dry lake bed, desert): H_L essentially zero, only H_S and H_G.

Figure 2.4 (barley field, low vegetation): Large H_L compared to H_S.
Both surface evaporation and plant transpiration are occuring ("evapotranspiration").

Figure 2.5 (Douglas fir canopy): ΔH_C accounted for; combined with H_G in plot.

Energy Budget Components

Seasonal Cycles



- Seasonal course of R_s due to Sun-Earth geometry
- Moist climates feature near balance of $R_s \sim LE$
- Dry climates feature near balance of $R_s \sim H$
- Others are intermediate
  - Spring vs fall in Texas
  - Summer vs spring and fall in Wisc
- Why is G small everywhere?

Bowen Ratio

- "Bowen Ratio" (B) is the ratio of sensible heat flux to latent heat flux,

$$B \equiv H_S/H_L$$

- Concept is most meaningful during daytime conditions (R_N, H_S & $H_L > 0$)

- **Key Question**: How much of available energy for atmospheric fluxes ('$R_N - H_G$') goes to sensible heat vs. latent heat?

- Typical values …
  - Semiarid regions: 5
  - Grasslands and forests: 0.5
  - Irrigated orchards and grass: 0.2
  - Sea: 0.1

SEB Equation

(In terms Bowen Ratio)

$$H_L = (R_N - H_G)/(1+B)$$

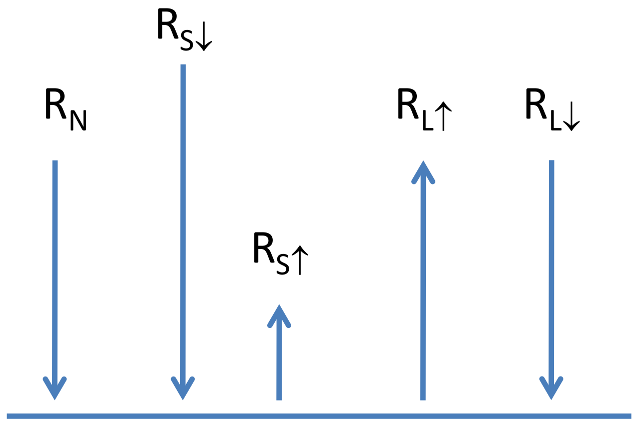
$$H_S = (R_N - H_G)/(1+B^{-1})$$

- **Homework**: Derive above equations on your own …
- Equations can be used to determine H_S or H_L in cases when measurements of these are not available.
- In this case, a constant ratio H_G/R_N is often assumed. Literature supports a range 0.1 – 0.5 (high end of range for night, low end for day).

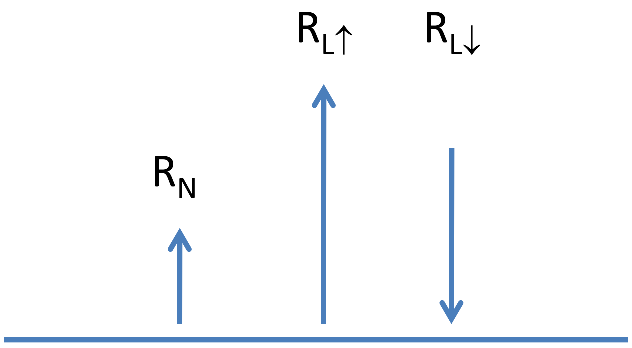
Radiative Fluxes: Arya Chapter 3

(Read 3.1 through 3.3 to refresh on radiation theory, taught in METR60/61)

Schematic



DAY



NIGHT

$R_N = R_S + R_L$

$R_S = R_{S\downarrow} + R_{S\uparrow} = R_{S\downarrow} - aR_{S\downarrow} = (1\text{-}a)R_{S\downarrow}$, where ‘a’ is the ‘surface albedo’

$R_L = R_{L\downarrow} + R_{L\uparrow} = R_{L\downarrow} - \varepsilon_0\sigma T_0^4$

$R_{L\uparrow}$ evaluated based on grey-body emission from surface; ε_0 is surface emissivity.

Solar Radiation

What does R_S depend on?

- Sun angle (time of day & time of year & location on globe)
- Cloud (aerial coverage, LWC, ice, type, height, fog)
- Aerosols (dust, sand, haze, sulfate, smoke, etc … in atm.?)
- Water vapor in atmosphere (why?)
- Surface albedo (soil type, vegetation, ice, snow, concrete, etc …?

Longwave (Terrestrial) Radiation

What does $R_{L\downarrow}$ depend on?

- H_2O vapor, CO_2, CH_4 ("greenhouse gases") content of atm.
- Cloud (aerial coverage, LWC, ice, type, height, fog)
- Atmospheric Temperature as f(z)
- A simple empirical expression (Swinbank, 1963):
  $R_{L\downarrow} = 0.94 \times 10^{-5} \sigma T_a^{\,6}$.
- **Homework**: Does above expression account for all of the above factors determining $R_{L\downarrow}$? If so, how? If unsure, how would you find out?

What does $R_{L\uparrow}$ depend on?

- Surface Temperature
- Surface Emissivity
- $R_{L\uparrow} = \varepsilon_0 \sigma T_0^{\,4}$

Figures 3.4 & 3.5

(Arya Chapter 3)

R_N large and positive during mid-day hours, more or less proportional to R_S.
R_N smaller and negative during night.
Not as much diurnal variation in $R_{L\downarrow}$ (why?)

Measurements of "Skin Temperature" T_{skin}

- T_{skin} is a synonym for surface temperature often used when determined from radiometer measurements.

- From measured upward longwave radiation from surface T_{skin} can be determined from …

$$T_{skin} = (-R_{L\uparrow meas}/\sigma)^{1/4}$$

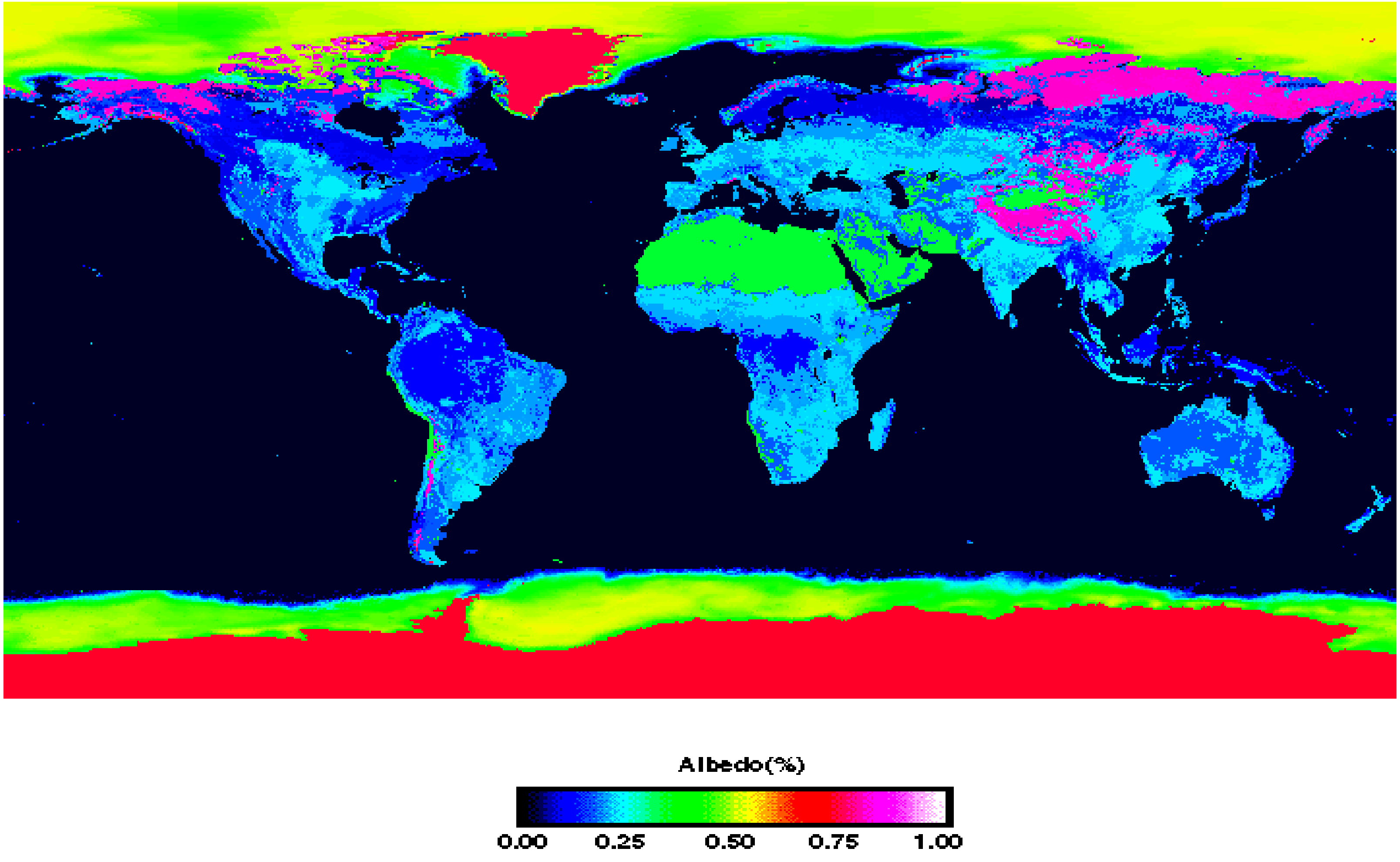
- Note in this case $R_{L\uparrow meas} = R_{L\uparrow} - (1-\varepsilon_0)R_{L\downarrow}$ since radiometer sees both upward emitted longwave from surface, $R_{L\uparrow}$, and the portion of downward longwave that is reflected from surface, $(1-\varepsilon_0)R_{L\downarrow}$.

Surface Albedos (%)

Surface type	Range	Typical value
Water		
Deep water: low wind, low altitude	5–10	7
Deep water: high wind, high altitude	10–20	12
Bare surfaces		
Moist dark soil, high humus	5–15	10
Moist gray soil	10–20	15
Dry soil, desert	20–35	30
Wet sand	20–30	25
Dry light sand	30–40	35
Asphalt pavement	5–10	7
Concrete pavement	15–35	20
Vegetation		
Short green vegetation	10–20	17
Dry vegetation	20–30	25
Coniferous forest	10–15	12
Deciduous forest	15–25	17
Snow and ice		
Forest with surface snowcover	20–35	25
Sea ice, no snowcover	25–40	30
Old, melting snow	35–65	50
Dry, cold snow	60–75	70
Fresh, dry snow	70–90	80

- Snow and ice brightest
- Deserts, dry soil, and dry grass are very bright
- Forests are dark
- Coniferous (cone-bearing) needleleaf trees are darkest

Global Map of Surface Albedo



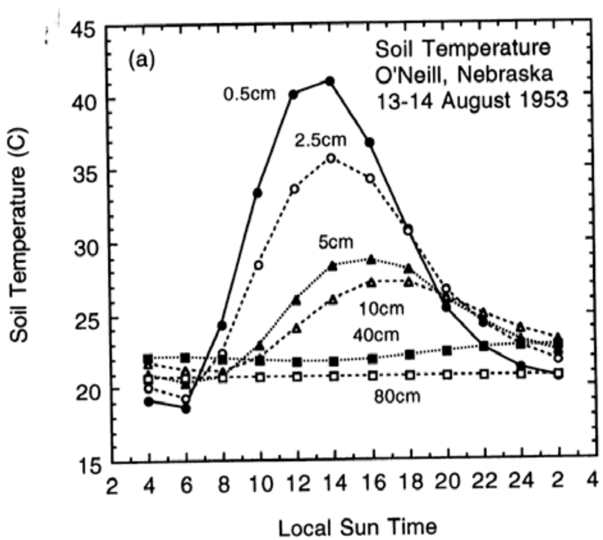
Surface Emissivity (ε_0)

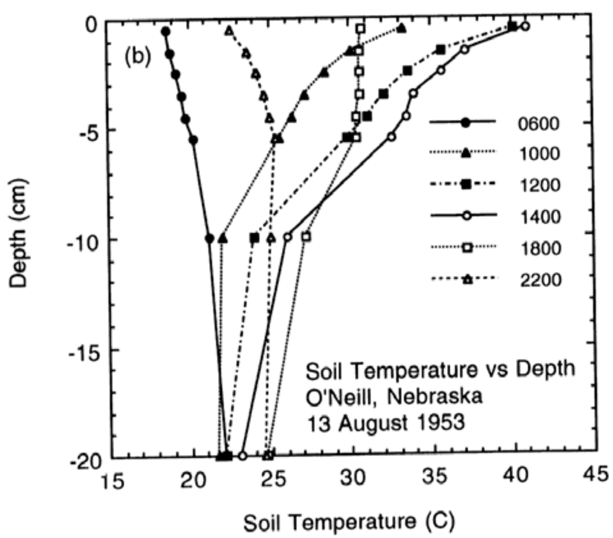
Water and soil surfaces	
Water	92–96
Snow, fresh fallen	82–99.5
Snow, ice granules	89
Ice	96
Soil, frozen	93–94
Sand, dry playa	84
Sand, dry light	89–90
Sand, wet	95
Gravel, coarse	91–92
Limestone, light gray	91–92
Concrete, dry	71–88
Ground, moist, bare	95–98
Ground, dry plowed	90
Natural surfaces	
Desert	90–91
Grass, high dry	90
Field and shrubs	90
Oak woodland	90
Pine forest	90
Vegetation	
Alfalfa, dark green	95
Oak leaves	91–95
Leaves and plants	
0.8 μm	5–53
1.0 μm	5–60
2.4 μm	70–97
10.0 μm	97–98
Miscellaneous	
Paper, white	89–95
Glass pane	87–94
Bricks, red	92
Plaster, white	91
Wood, planed oak	90
Paint, white	91–95
Paint, black	88–95
Paint, aluminum	43–55
Aluminum foil	1–5
Iron, galvanized	13–28
Silver, highly polished	2
Skin, human	95

Ground Heat Flux

(Arya Chapter 4)

Soil Temperature vs. Soil Depth
(Typical Diurnal Variation)





- Relatively large range near surface
  - 25 K diurnal cycle at 0.5 cm
  - Max Temperature around 2 PM
- Damped and delayed response with depth
  - Only 6 K diurnal range at 10 cm
  - Max Temperature around 6 PM
  - Negligible diurnal cycle at 50 cm
- Similar phenomena on seasonal time scales

Soil Heat Flux & Temperature Equations
(Note: Symbols below are different than used by Arya Ch4)

Heat is transferred through soil primarily through **conduction**

Vertical heat flux in soil or rock:
(K_T is thermal conductivity)

$$F_s = -K_T \frac{\partial T}{\partial z}$$

Gradient Transport Theory (GTT): Flux negatively proportional to gradient

Formulate change in storage as a **flux divergence**:

$$C_s \frac{\partial T}{\partial t} = -\frac{\partial}{\partial z}(F_s) = \frac{\partial}{\partial z}\left(K_T \frac{\partial T}{\partial z}\right)$$

Diffusion: Rate of change of a variable governed by flux divergence. Flux formulated according to GTT.

If physical properties (**thermal conductivity**) is constant with depth, can simplify to: ($D_T = K_T/C_s$ is **thermal diffusivity**)

$$\frac{\partial T}{\partial t} = D_T \frac{\partial^2 T}{\partial z^2}$$

Fickian Diffusion: Diffusion equation assuming diffusivity is constant.

Diffusion Coefficient (or "Diffusivity"):
Dimensions are always L^2/T (e.g. m^2/s)

Analytical Solution to Soil Temperature Equation

(Details in Arya Ch4, note change in Arya symbols compared to below)

$$\frac{\partial T}{\partial t} = D_T \frac{\partial^2 T}{\partial z^2}$$

- Requires two 'boundary conditions' in z (since PDE is second-order in 'z')
- Specify sinusoidally varying surface temperature of period P = 24 hours.
- $T \rightarrow T_m$ = constant as $z \rightarrow \infty$

solution …

$$T = T_m + A_s \exp(-z/d) \sin[(2\pi/P)(t - t_m) - z/d]$$

where d is a depth scale ("Damping Depth") = $(PD_T/\pi)^{1/2}$

Homework: Evaluate for typical soil conditions. Is value you get for 'd' consistent with your intuition?

Values for Soil Parameters

(see Arya Table 4.1)

Soil parameters are averages over various components of soil. For example, see below for soil heat capacity …

	Specific heat (c_p) (J kg^{-1} K^{-1})	Density (ρ) (kg m^{-3})	ρc_p (J m^{-3} K^{-1})
Soil inorganic material	733	2600	1.9×10^6
Soil organic material	1921	1300	2.5×10^6
Water	4182	1000	4.2×10^6
Air	1004	1.2	1.2×10^3

minerals organics **water** **ice** air

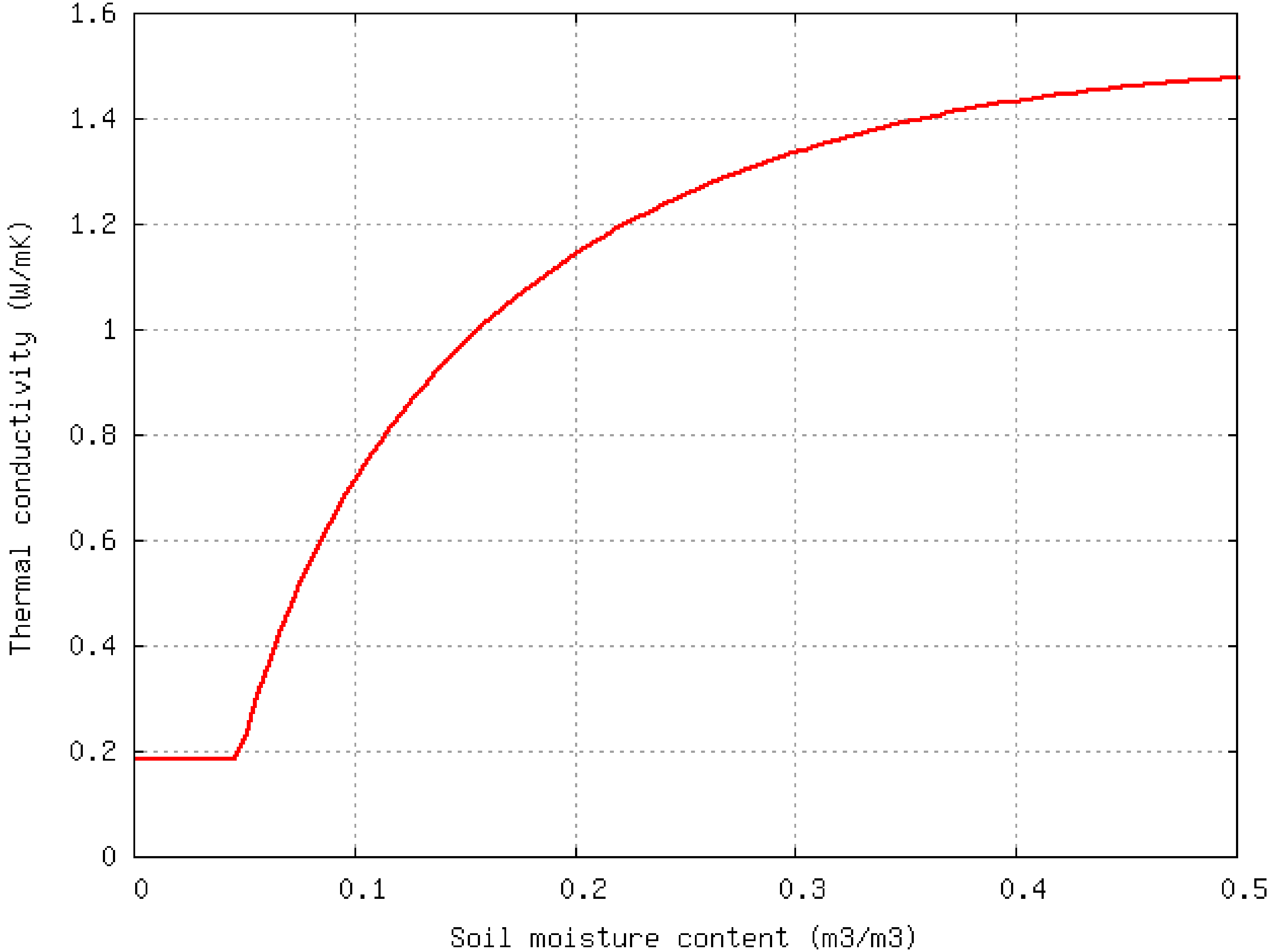
$$C_s = \rho_s c_s f_s + \rho_c c_c f_c + \rho_w c_w f_w + \rho_i c_i f_i + \rho_a c_a f_a$$

heat capacity of soil

volume fraction in soil

Soil is a mixture of several materials, each with quite different physical properties

Thermal Conductivity vs. Soil Moisture Content



Moisture Fluxes
(Evaporation & Evapotranspitation)

- Arya Chapter 12.1 – 12.2
- Arya Chapter 12.4.1 – 12.4.3 and 12.4.5

Evapotranspiration (ET)

- ET = Surface Evaporation (E) + Plant Transpiration (T)
- Two "Stages", Condition, Regimes of ET …
    1. Atmospheric Limited
    2. Surface Limited
- We will focus only on surface evaporation from bare soil in the remained of lecture. Basic concepts are more or less the same when plants, vegetation are included, although physical processes and equations are then different and become more complex.

Atmospheric Limited …

- Abundant moisture supply at surface
- Amount of E limited by atmospheric ability to "take up" moisture.
- Atmospheric limiting conditions: low turbulence (high stability, low winds) and/or RH $\approx$ 100%
- Remember: $E = -\rho_a C_Q U_a (q_a - q_0)$, thus in this case C_Q and q_a are the "limiting" variables
- Upper limit on E determined by setting $q_0 = q_{sat}$.
- Upper limit called "Potential Evaporation" (E_P).

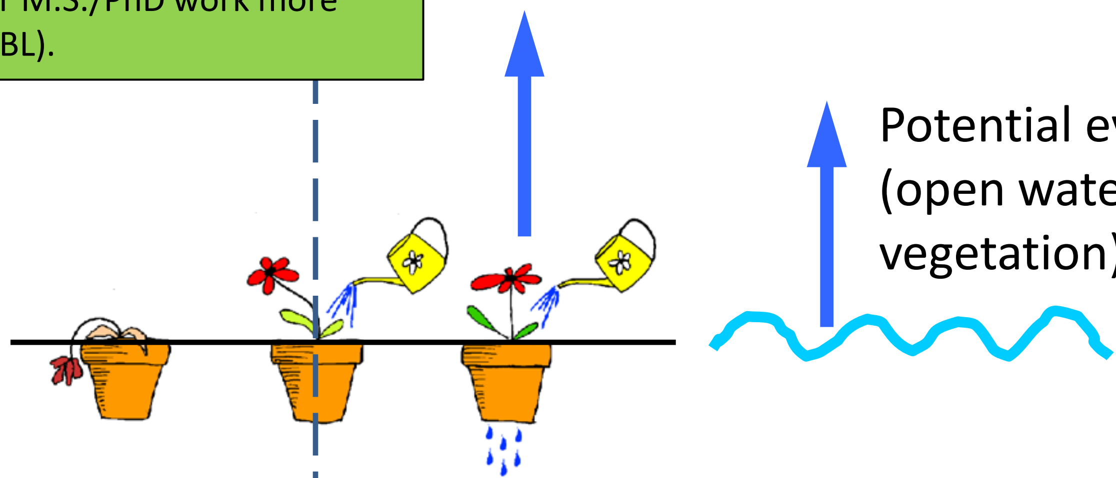
Surface Limited …

- Limited moisture supply at surface.
- $q_0 < q_{sat}$ by significant amount
- In this case, q_0 determined by ability of soil (or plant tissue) to transport moisture upwards from deeper layers of the soil to soil surface (or leaves)
- q_0 is key variable
- q_0 related to surface soil moisture content (η_0) and soil properties for bare soil. These as well as plant tissue properties for vegetated surface.

First Stage: Potential Evaporation (E_P)

E_P solved by setting $q_0 = q_{sat}(T_0)$ in flux equation on previous slides. Alternatively, "Penman Method" enables E_P to be solved using only routinely available measurements at standard reference height (around 2-meters AGL). See Arya 12.4.5 for Penman Method (for your interest … although strongly encouraged for those interested in or requiring for their M.S./PhD work more intensive study of ABL).

Unstressed evaporation or potential evapotranspiration (dry vegetation)



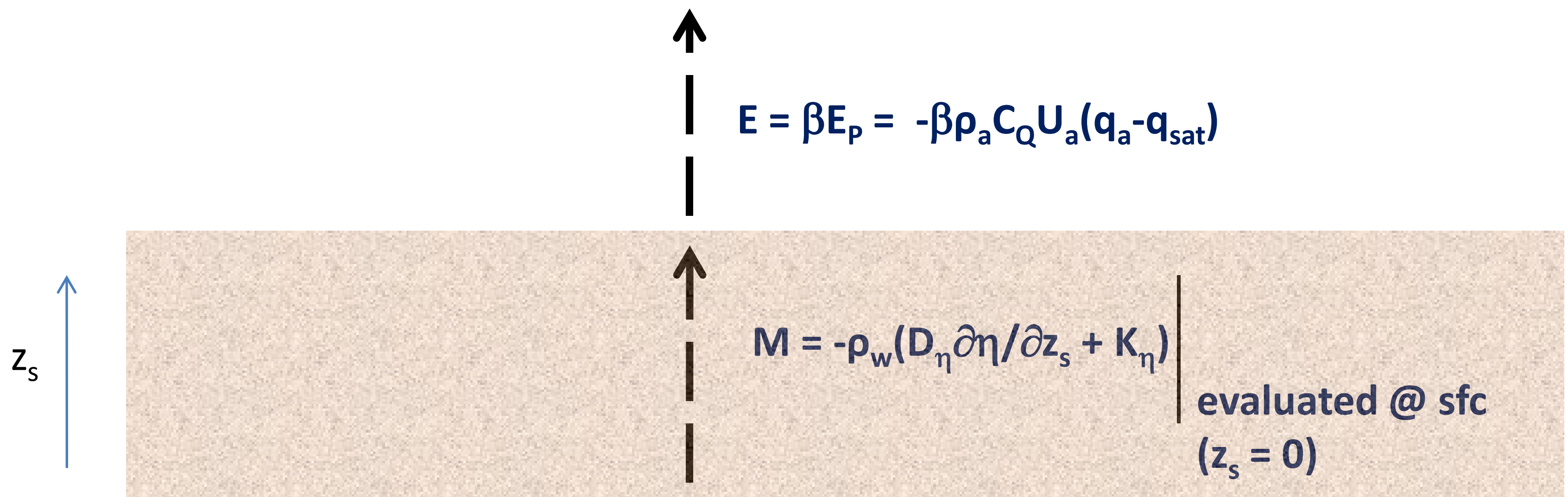
Potential evaporation (open water or wet vegetation)

Soil moisture "wilting point" (η_w)

Soil moisture "field capacity" (η_{fc})

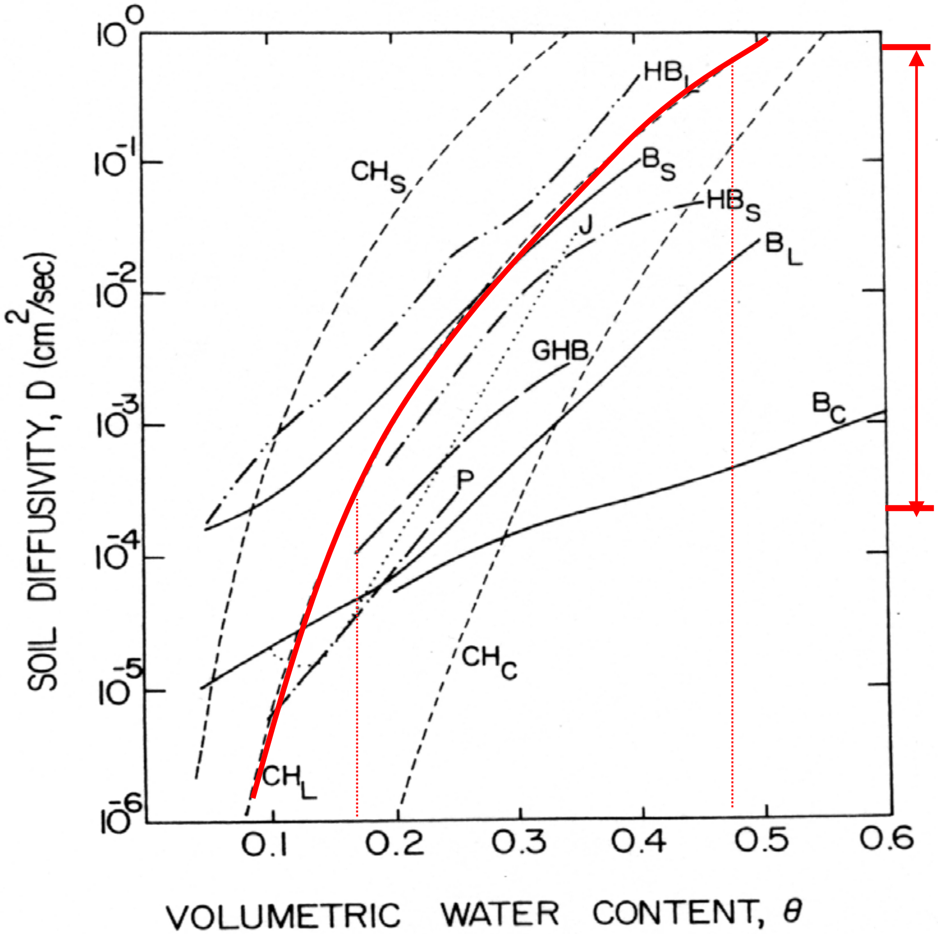
Second Stage: Soil Limited

(Continuity of Moisture Fluxes Across Bare Soil Surface)



- Continuity of fluxes requires E = M, where sfc. soil moisture flux, M, is given above.
- η: Soil moisture content (volume of soil water per volume soil)
- D_η: Soil moisture diffusivity: represents capillary movement of soil moisture ("suction")
- K_η: Hydraulic conductivity: represents gravitational infiltration
- See following slides for $D_\eta(\eta)$ and $K_\eta(\eta)$ relationships (i.e., they are functions of η!)
- β: A factor limiting evaporation based on availability of soil moisture at surface.
- Parameterization used in NCEP WRF (Chen and Dudhia 2001): $\boldsymbol{\beta = (\eta_0 - \eta_w)/(\eta_{fc} - \eta_w)}$
- η_w and η_{fc} are the soil moisture "wilting point" and "field capacity", respectively.

Soil Moisture Diffusivity: $D_\eta(\eta)$



> 3 orders of magnitude !

Fig. 2. Examples of the dependence of soil hydraulic diffusivity on volumetric soil water content for loam (HB_L, Hanks and Bowers, 1962); (J, Jackson, 1973); (GHB, Gardner *et al.*, 1970); silt loam (HB_S, Hanks and Bowers, 1962); clay (P, Passioura and Cowan, 1968); results approximated from Gardner (1960) for sand (B_S), loam (B_L), and clay (B_C); relationship from Clapp and Hornberger (1978) for sand (CH_S), loam (CH_L), and clay (CH_C).

Hydraulic Conductivity: $K_\eta(\eta)$

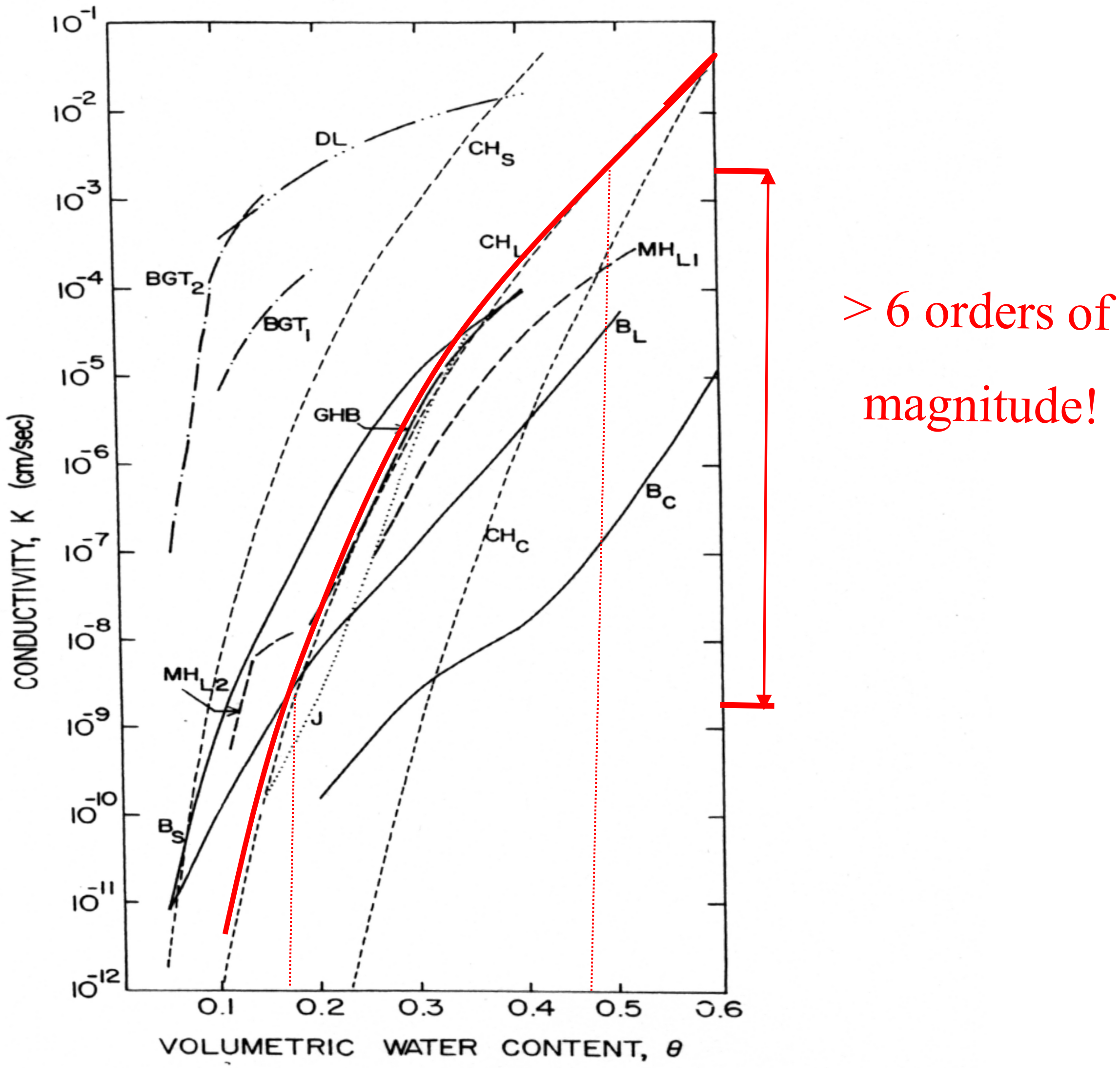


Fig. 3. Examples of the dependence of hydraulic conductivity on volumetric soil water content for sand (DL, Day and Luthin, 1956); (Black *et al.*, 1970, 0–50 cm-BGT$_1$, 50–150 cm-BGT$_2$); loam (J, Jackson, 1973); (MH$_{L1}$ and MH$_{L2}$, Marshall and Holmes, 1979); (GHB, Gardner *et al.*, 1970); results approximated from Gardner (1960) for sand (B$_S$), loam (B$_L$), and clay (B$_C$); relationship from Clapp and Hornberger (1978) for sand (CH$_S$), loam (CH$_L$), and clay (CH$_C$).

Soil Moisture: Wilting Point, Field Capacity, Porosity

η: volumetric soil moisture ($m^3\ m^{-3}$)

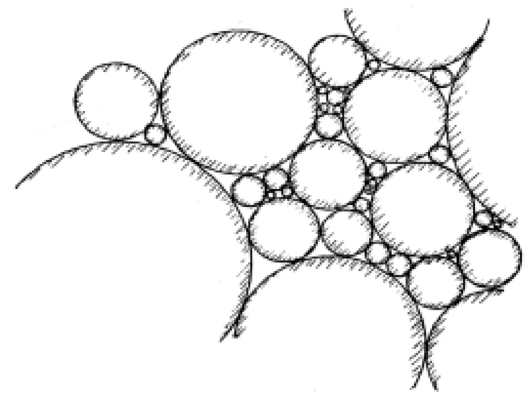


Fig. 4.1. Packing of polydisperse particles (hypothetical).

wilting point, η_w
~0.15

field capacity, η_d
~0.30

porosity, η_{sat}

~0.45
(i.e. 45% of soil is composed of pours)

Soil moisture availability ($m^3\ m^{-3}$)

Field Capacity (FC or η_{fc})

- –Soil water content where gravity drainage becomes negligible
- –Soil is not saturated but still a very wet condition

Permanent Wilting Point (WP or η_{w})

- –Soil water content beyond which plants cannot recover from water stress (dead)
- –Still some water in the soil but not enough to be of use to plants

SOIL MOISTURE PROPERTIES
(FAR LEFT THREE COLUMNS)

PARAMETERS IN STD. CLAPP AND HORNBERGER EQUATIONS FOR SOIL MOISTURE DIFFUSIVITY AND HYDRALIC CONDUCTIVITY
(FAR RIGHT THREE COLUMNS)

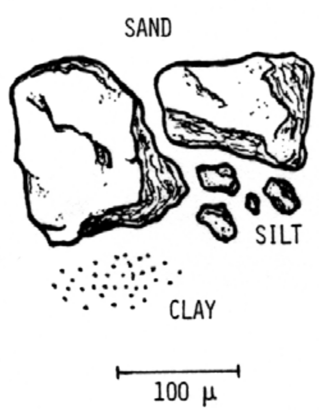
Table 3. Derived Soil Hydraulic Properties

Soil texture class	Total Porosity (%)	Field Capacity (cm^3/cm^3)	Wilting Point (cm^3/cm^3)	Sat. soil matric pot. (m)	Sat. hyd. cond. (m/s)	'B' Parameter
Sand	39.5/ 33.9/ 43.7	0.174/ 0.084/ 0.091	0.068/ 0.021/ 0.033	0.121/ 0.069/ 0.001	1.76e-4/ 7.23e-6/ 5.83e-5	4.05/ 2.79/ 3.76
Loamy sand	41.0/ 42.1/ 43.7	0.179/ 0.145/ 0.125	0.075/ 0.059/ 0.055	0.090/ 0.036/ 0.001	1.56e-4/ 2.18e-6/ 1.70e-5	4.38/ 4.26/ 4.65
Sandy loam	43.5/ 43.4/ 45.3	0.249/ 0.222/ 0.207	0.114/ 0.099/ 0.095	0.218/ 0.141/ 0.011	3.47e-5/ 8.11e-7/ 7.19e-6	4.90/ 4.74/ 4.90
Silt loam	48.5/ 47.6/ 50.1	0.369/ 0.360/ 0.330	0.179/ 0.176/ 0.133	0.786/ 0.759/ 0.064	7.20e-6/ 4.35e-7/ 1.89e-6	5.30/ 5.33/ 4.20
Loam	45.1/ 43.9/ 46.3	0.314/ 0.286/ 0.270	0.155/ 0.138/ 0.117	0.478/ 0.355/ 0.037	6.95e-6/ 5.23e-7/ 3.67e-6	5.39/ 5.25/ 4.56
Sandy clay loam	42.0/ 40.4/ 39.8	0.299/ 0.251/ 0.255	0.175/ 0.143/ 0.148	0.299/ 0.135/ 0.053	6.30e-6/ 6.90e-7/ 1.19e-6	7.12/ 6.77/ 7.02
Silty clay loam	47.7/ 46.4/ 47.1	0.357/ 0.382/ 0.366	0.218/ 0.247/ 0.208	0.356/ 0.617/ 0.106	1.70e-6/ 3.15e-7/ 4.17e-7	7.75/ 8.72/ 6.75
Clay loam	47.6/ 46.5/ 46.4	0.391/ 0.340/ 0.318	0.250/ 0.213/ 0.197	0.630/ 0.263/ 0.064	2.45e-6/ 3.79e-7/ 6.39e-7	8.52/ 8.17/ 7.97
Sandy clay	42.6/ 40.6/ 43.0	0.316/ 0.292/ 0.339	0.219/ 0.205/ 0.239	0.153/ 0.098/ 0.587	2.17e-6/ 1.12e-6/ 3.33e-7	10.40/ 10.73/ 10.92
Silty clay	49.2/ 46.8/ 47.9	0.409/ 0.374/ 0.387	0.283/ 0.259/ 0.250	0.490/ 0.324/ 0.149	1.03e-6/ 2.08e-7/ 2.50e-7	10.40/ 10.39/ 8.73
Clay	48.2/ 46.8/ 47.5	0.400/ 0.394/ 0.396	0.286/ 0.283/ 0.272	0.405/ 0.468/ 0.431	1.28e-6/ 1.51e-7/ 1.67e-7	11.40/ 11.55/ 10.16

Notes: Values given as Clapp et al. [1978]/Cosby et al. [1984]/Rawls et al. [1982]

Soil Texture

- Soil is a 3-phase system, consisting of
  - ❑ Solid minerals and organic matter
  - ❑ Water trapped in the pores
  - ❑ Moist air trapped in the pores
- See classic USDA "texture triangle
- Note size range of sand, silt, clay …



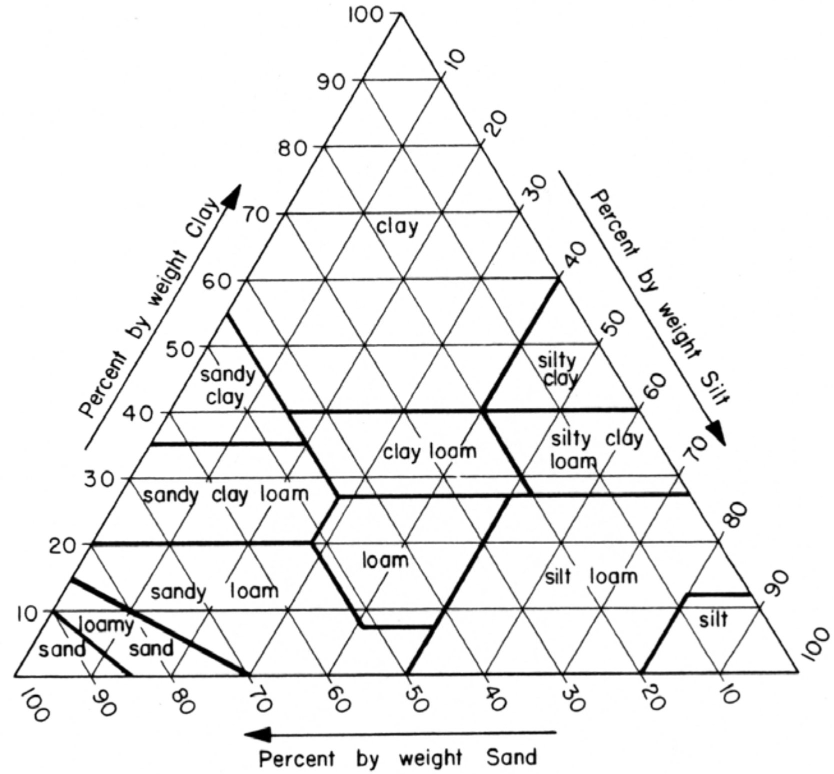


Fig. 3.5. Textural triangle, showing the percentages of clay (below 0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2.0 mm) in the basic soil textural classes.

Summary:

(Coupled Energy and Moisture Balance Equations over Bare Land)

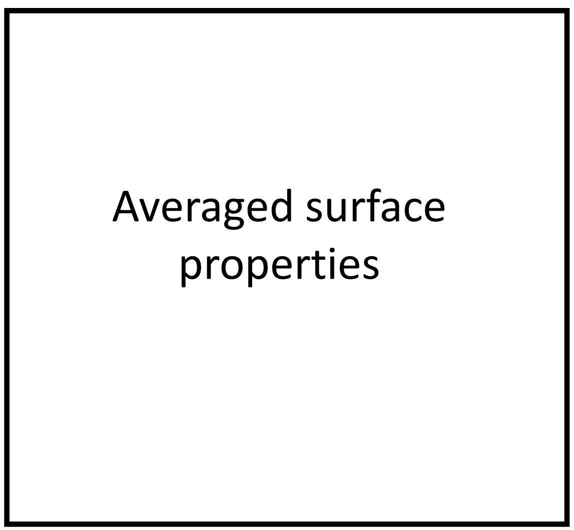
Modeling Considerations
(NWP, Meso and Climate Modeling)

- Representation in models called a “Land Surface Model” or “Land Surface Parameterization”.
- How to characterize heterogeneous surface in grid model? See next slide.
- Complexity of surface. Soil, low vegetation, forests, snow, ice, urban, and others. Lots of variability within each of these. Knowledge of needed modeling parameters for the various land surface types is still spotty.
- Soil moisture initialization.
- Land use & land cover data undergoing ongoing improvement.

Characterizing surface heterogeneity in grid models

(Mixture vs. Tile approach)

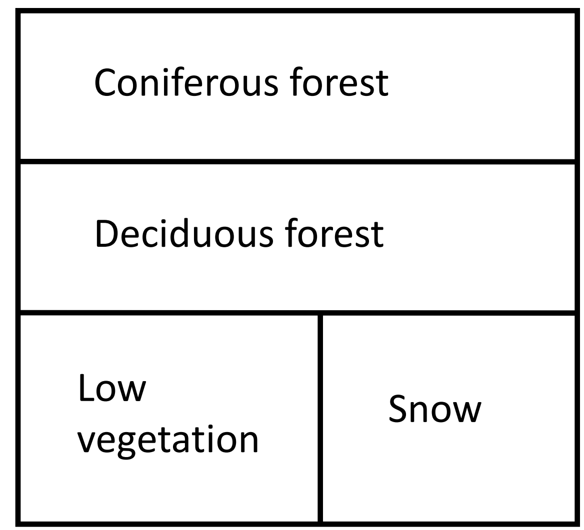
The Mixture approach



One value each for parameters like LAI, albedo, emissivity, aerodynamic resistance,… per grid square. One single energy balance.

Most schemes somewhere in between

The Tile approach



All individual sub-surfaces have their own set of parameters as well as separate energy balances.