Lecture 34 Lecture on Soil Physics, part 1

- Soil Properties
  - soil texture and classes
  - heat capacity, conductivity and thermal diffusivity
  - moisture conductivity
  - porosity and diffusion
- Theory, Heat Transfer
  - Heat transfer, Fourier's equation
- Observations
  - Temperature profiles
    - Daily patterns, Phase lags and Amplitudes of soil temperature
    - Seasonal Patterns
- Soil Heat Flux
  - Daily patterns
  - Seasonal Patterns

Ode to Soil

"Darkle, darkle, little grain,
I wonder how you entertain
A thousand creatures microscopic.
Grains like you from pole to tropic
Support land life upon this planet
I marvel at you, crumb of granite! "

Dr. Francis Hole, Soil Scientist (1913-2002)

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If interested in more soil and poetry try these other pages

http://soils.wisc.edu/facstaff/barak/fdh/

http://soils.wisc.edu/facstaff/barak/fdh/hole1.htm and
http://urbanext.illinois.edu/soil/songs/songs.htm

Soil Profile

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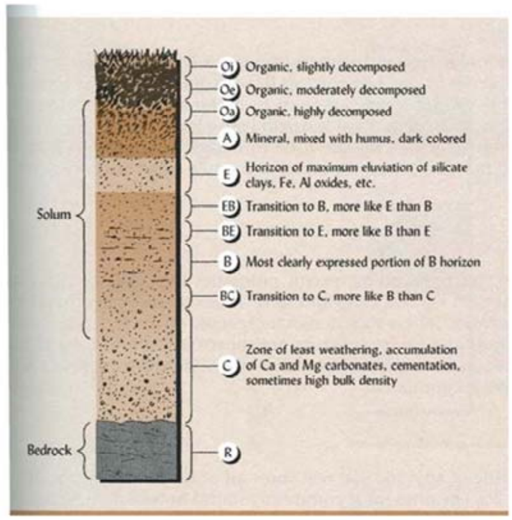
Cross section of soil near the Estero San Antonio. Observe the transition between the brown and black organic layers where roots and microbes have resided and deposited organic matter over time. The transition is the weathering of rock into soil horizon, but depaupered or leached of organic matter

Soil Profile



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Soil is not Dirt, it is alive and forms by having life break down rock into systematic layers and is affected by the incorporation of organic matter and the roles of microbes, roots, soil vertebrates and invertebrates mixing and churning the soil

Soil Components

- Clay
  - < 0.002 mm
  - Crystal lattices, Si, Al, O, OH
- Silt
  - 0.05 to 0.002 mm
- Sand
  - 2 to 0.05 mm
- Gravel
  - > 2 mm

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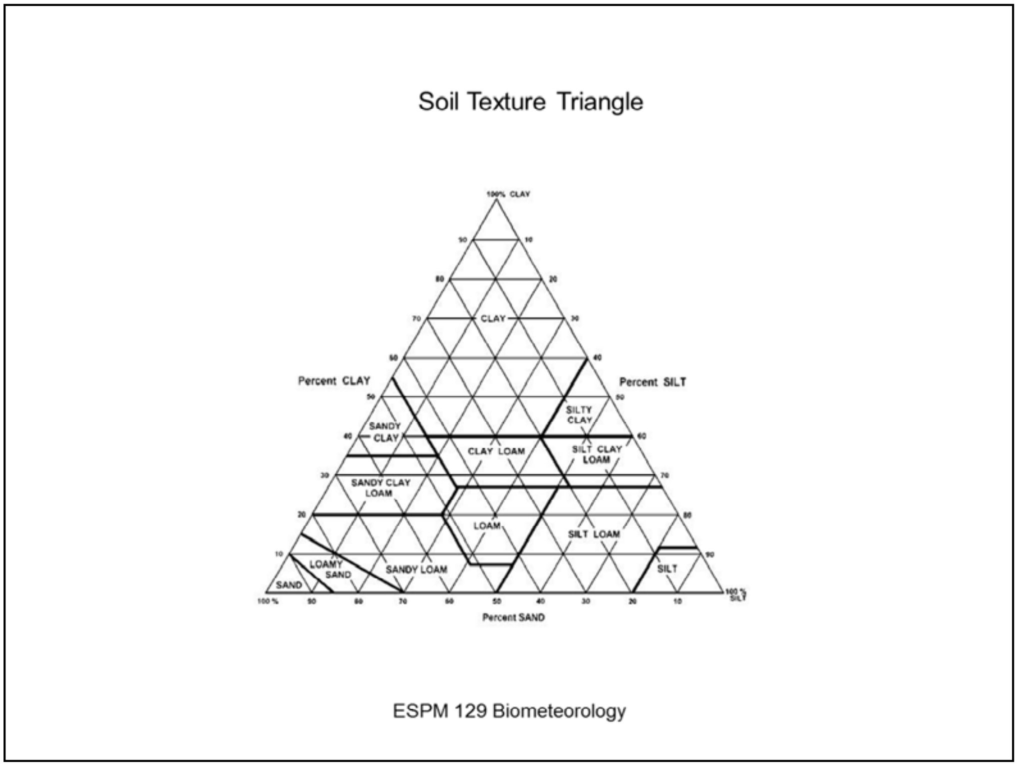
Soils can be broken down into 4 constituent size classes.



The fraction of clay, silts and loams determines the soil texture and its soil water holding capacity.

Porosity, **P**, is a function of the volumes of air, $\mathbf{v_a}$, water, $\mathbf{v_w}$ and solid, $\mathbf{v_s}$

$$P = \frac{v_a + v_w}{v_a + v_w + v_s}$$

It is also a function of the soil bulk density, ρ_b

$$P = 1 - \frac{\rho_b}{\rho_s}$$

Mass of soil per unit volume

$$\rho_b = \frac{m_s}{v_t} = \frac{v_s \rho_s}{v_t}$$

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Porosity can be measured directly

Soil Physical Properties

Soil type	Bulk density, kg m-3	Porosity, percent
Peat	0.65-1.1	60-80
Ideal soil	1310	50-60
Clay	1220	45-55
Silt	1280	40-50
Medium to coarse sand	1530	35-40
Uniform sand	1650	30-40
Fine to medium sand	1850	30-35
Gravel	1870	30-40

After Tyndall et al.. 1999

General properties of soil classes

Gravimetric Soil Moisture

$$w = \frac{m_w}{m_s} = \frac{v_w \rho_w}{v_s \rho_s} = \theta \frac{\rho_b}{\rho_l} \qquad \text{g/g}$$

Mass ratio, Mass of water to mass of solid

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Soil moisture can be measured by weighing soil wet and dry.. Note to measure the volumetric water content, cm3/cm3 we also need to know the bulk density

Volumetric water content

$$\theta = \frac{v_w}{v_t} = w\frac{\rho_b}{\rho_w} \qquad \text{(cm3/cm3)}$$

Note: We need to know the Bulk Density!!!

Fourier Soil Heat Budget Equation:
Time rate of Change in Soil Temperature Is a function of the Flux Divergences of Soil Heat Flux, G

$$\rho_s C_s \frac{\partial T}{\partial t} = -\frac{\partial G}{\partial z}$$

$$G = k \frac{\partial T}{\partial z}$$

1768-1830

ρ_s, soil density
C_s, specific heat of soil
k, thermal conductivity

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Jean Baptiste Fourier was a brilliant mathematician, physicist and defined the basic equations for heat transfer… Looks familiar eh? He is famous for Fourier Transforms that are used to compute spectra and transforms time series into frequencies and was an early proponent of the greenhouse effect.

Fourier Heat Transfer Eq

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

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

Thermal Diffusivity

$$\kappa = \frac{k}{\rho_s C_s}$$

We can also express the Fourier Heat transfer equation in terms of a thermal diffusivity

Soil Thermal Properties

material	Density (Mg m^{-3})	Specific Heat (J g^{-1} K^{-1})	Thermal conductivity (W m^{-1} K^{-1})
Soil minerals	2.65	0.87	2.5
Granite	2.64	0.82	3.0
Quartz	2.66	0.80	8.8
Organic matter	1.30	1.92	0.25
Water	1.00	4.18	0.56
Ice	0.92	2.1	2.22
air	0.0011875	1.01	0.024

Campbell and Norman, 1998

Thermal properties of soil constituents is distinct.

Soil Heat Capacity is a Weighted function of the Mineral Organic and Water components

$$\rho_s C_s = \phi_m \rho_m C_m + \phi_o \rho_o C_o + \theta_w \rho_w C_w$$

Approximation of Campbell

$$C_s = \frac{2400000\rho_b}{2.65} + 4180000\theta$$

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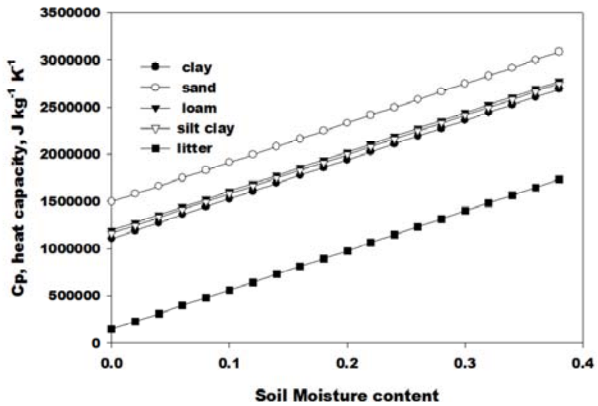
The heat capacity of the soil is weighted by the fraction of mineral, organic and water. Each has its own distinct heat capacity

Soil Heat Capacity



Which Material is the Best and Worst Store of Heat?

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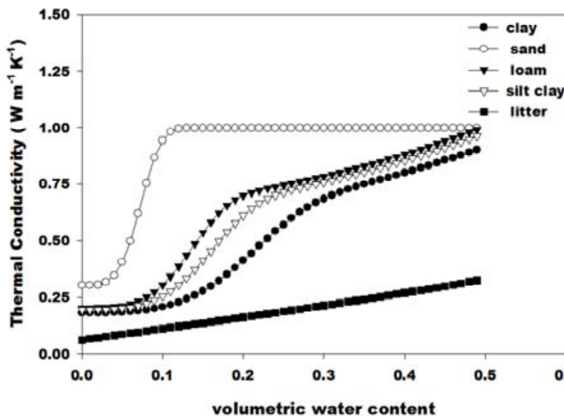
Example of soil heat capacity in terms of water content and texture

Thermal Conductivity is a function of soil texture and moisture



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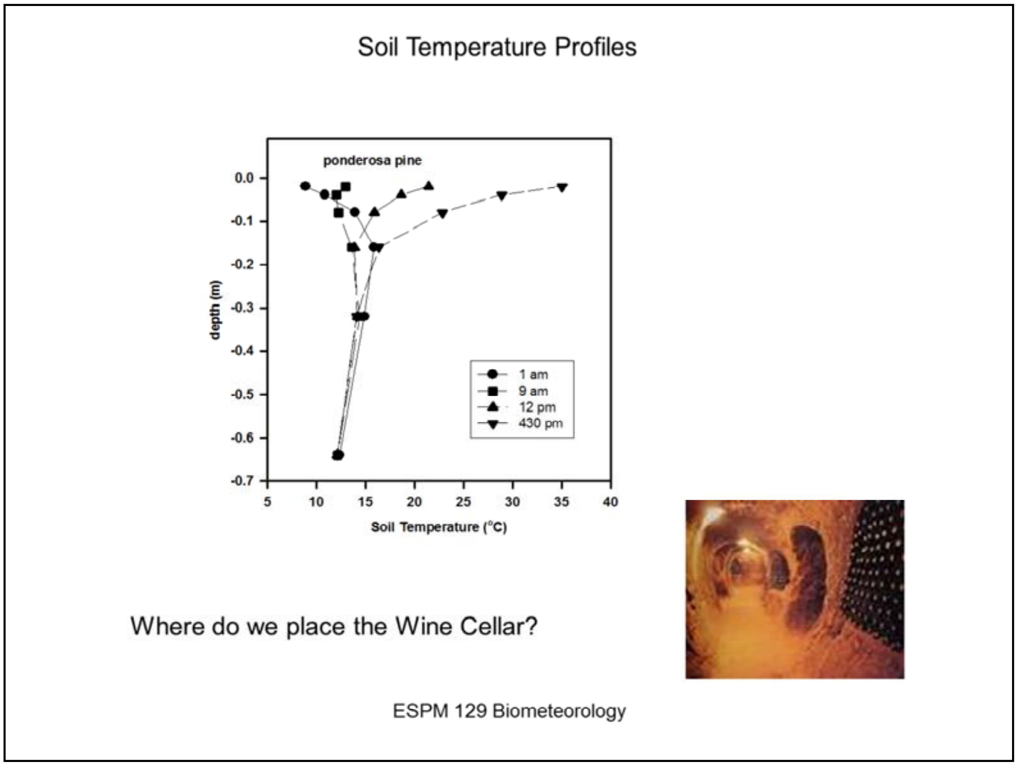
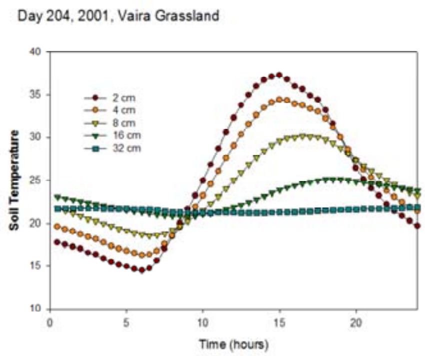
Thermal conductivity varies with moisture and texture, too



Temperature profiles in a sand over the course of a day.

$$T(z,t) = \overline{T} + A(0)\exp(-z/D)\sin(\varpi(t-t_0) - z/D)$$



Damping Depth

$$D = \sqrt{\frac{2\kappa}{\omega}}$$

ω is angular frequency (radians per second)
τ is period of fluctuation

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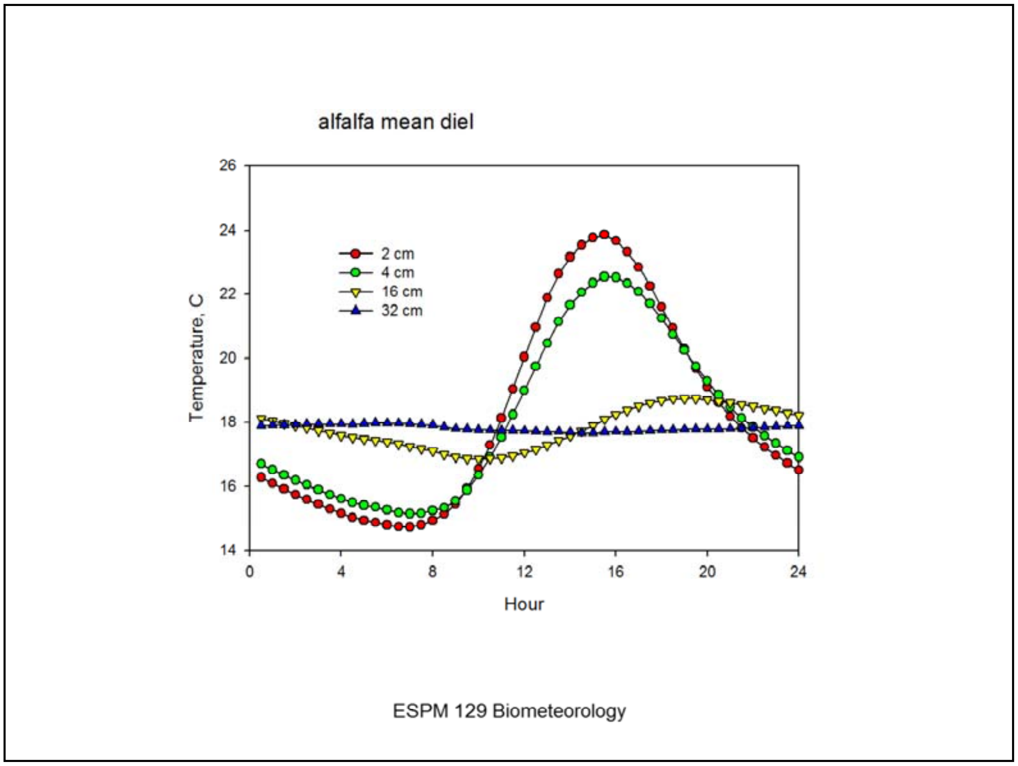
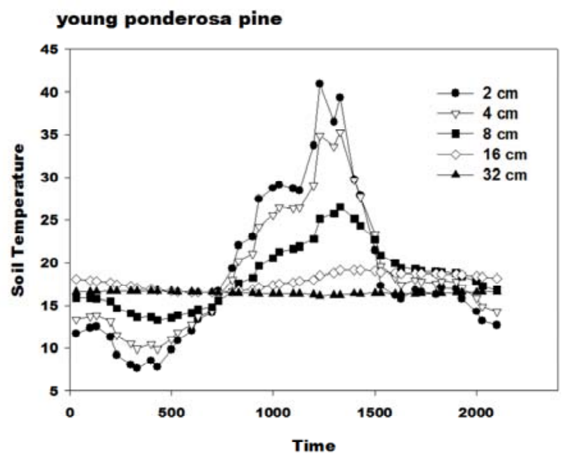
The diel temperature pattern can be simulated with a sine wave whose applied decreases with dept and whose time lag becomes delayed, with time, too. Damping depth is an important property and parameter



Soil temperature from alfalfa on Twitchell Island, peat/mineral soil

Less Ideal, Heterogeneous Site



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10 *A. Verhoef et al. / Agricultural and Forest Meteorology 78 (1996) 1–18*

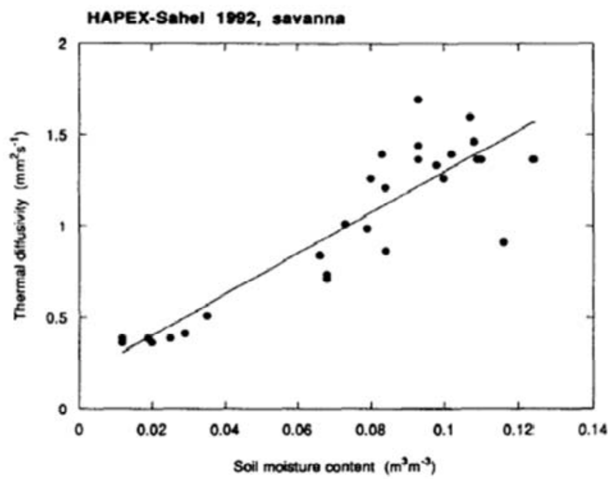

Fig. 5. Relationship between soil moisture content and calculated (Harmonic method) diffusivity for the HAPEX-Sahel experiment.

$$\kappa = \frac{\omega}{2}\left[\frac{z_2 - z_1}{\ln(A_1 / A_2)}\right]^2$$

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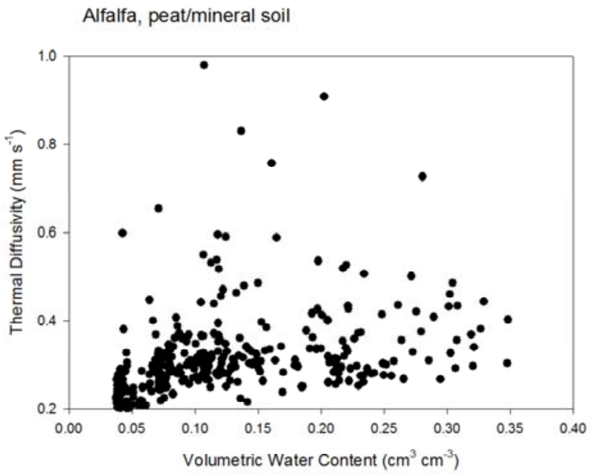
We can calculate damping depth with some simple models, like this one from Verhoef. A is amplitude, omega is 2 pi/period, z is depth

Amplitude Method



$$\kappa = \frac{\omega}{2}\left[\frac{z_2 - z_1}{\ln(A_1 / A_2)}\right]^2$$

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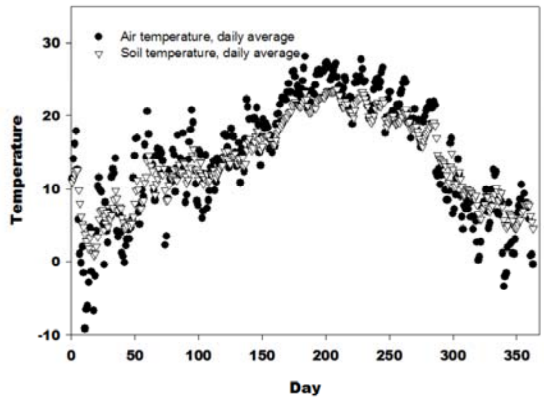
Calculation of thermal diffusivity at our alfalfa field on a peat/mineral soil

Annual Course in Soil Temperature



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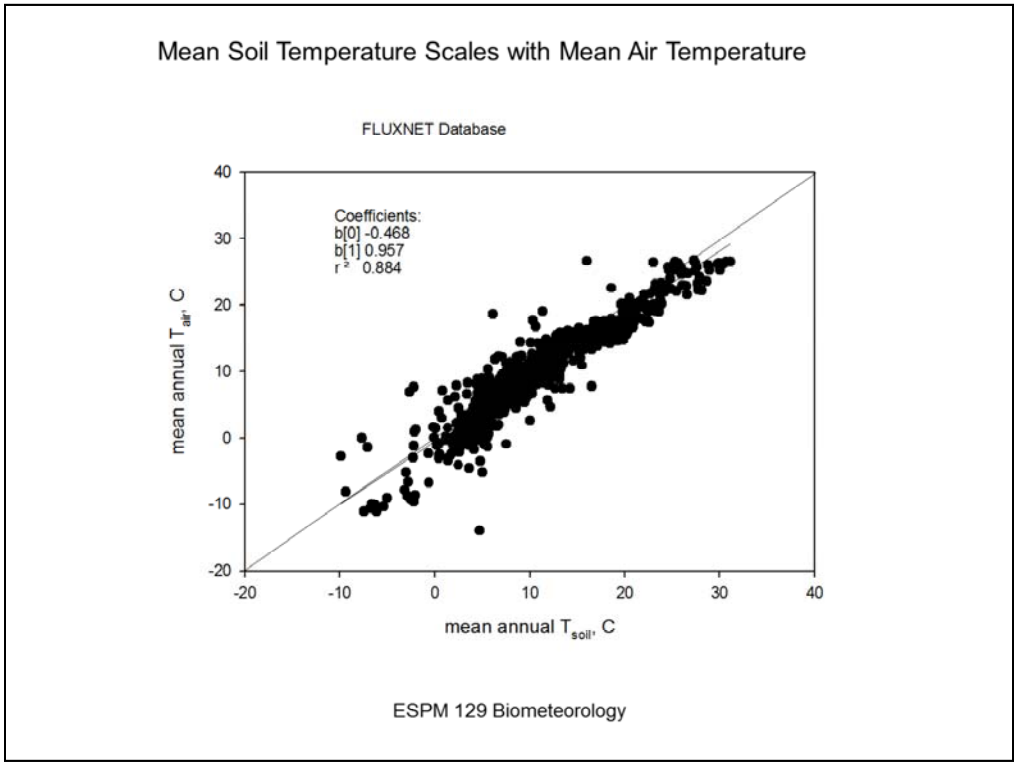
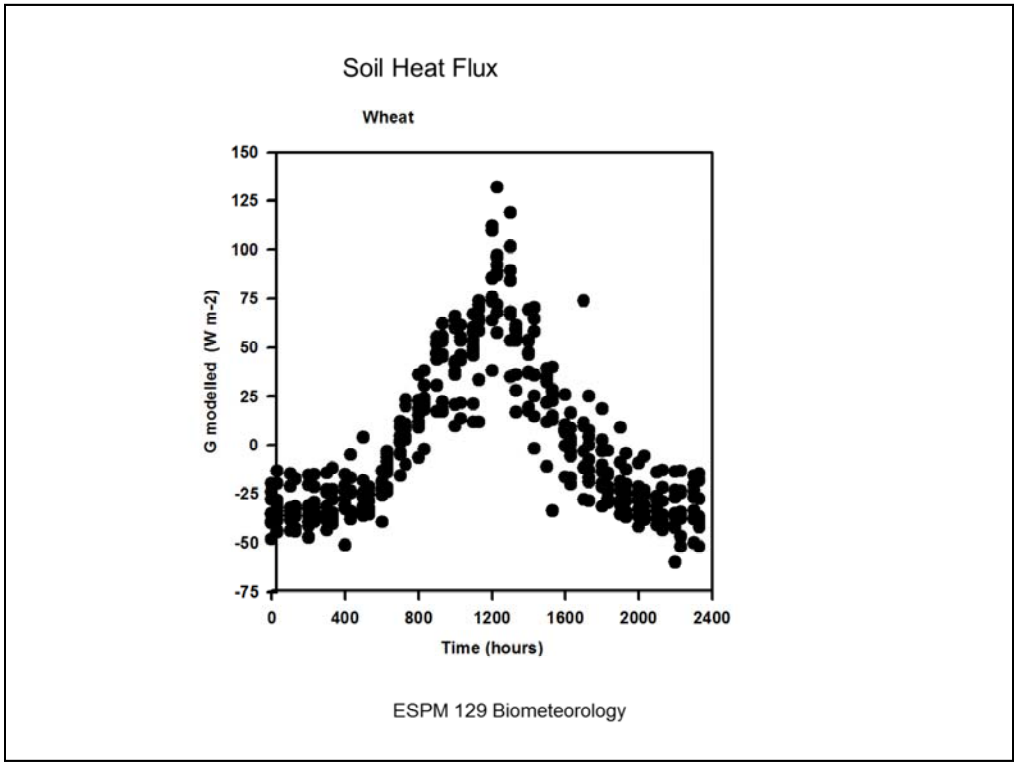
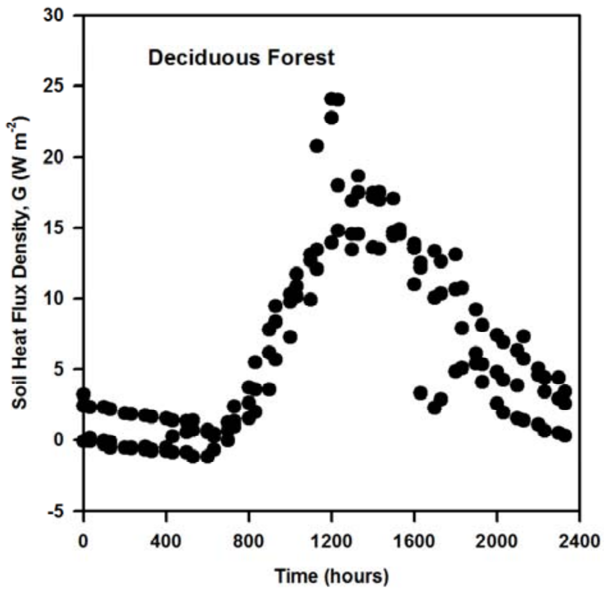
Year trends in soil and air temperatures. Heat stored in the soil can be used to drive geothermal heat pumps and save energy.



Mean annual soil and air temperatures relate well.



Soil heat flux



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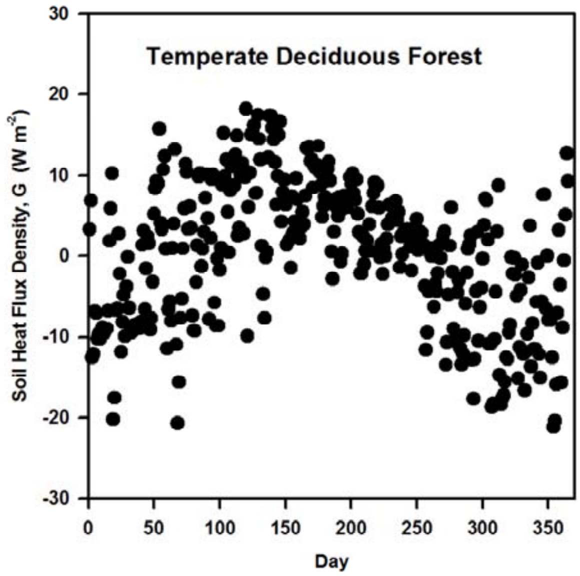
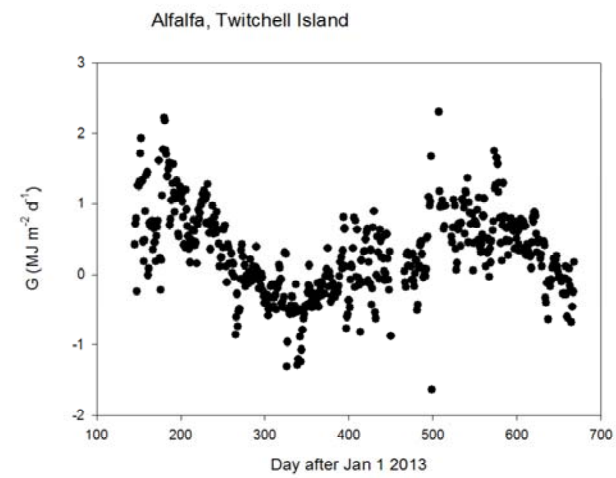

Temperate Deciduous Forest
Soil Heat Flux Density, G (W m^-2)
30
20
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
Day



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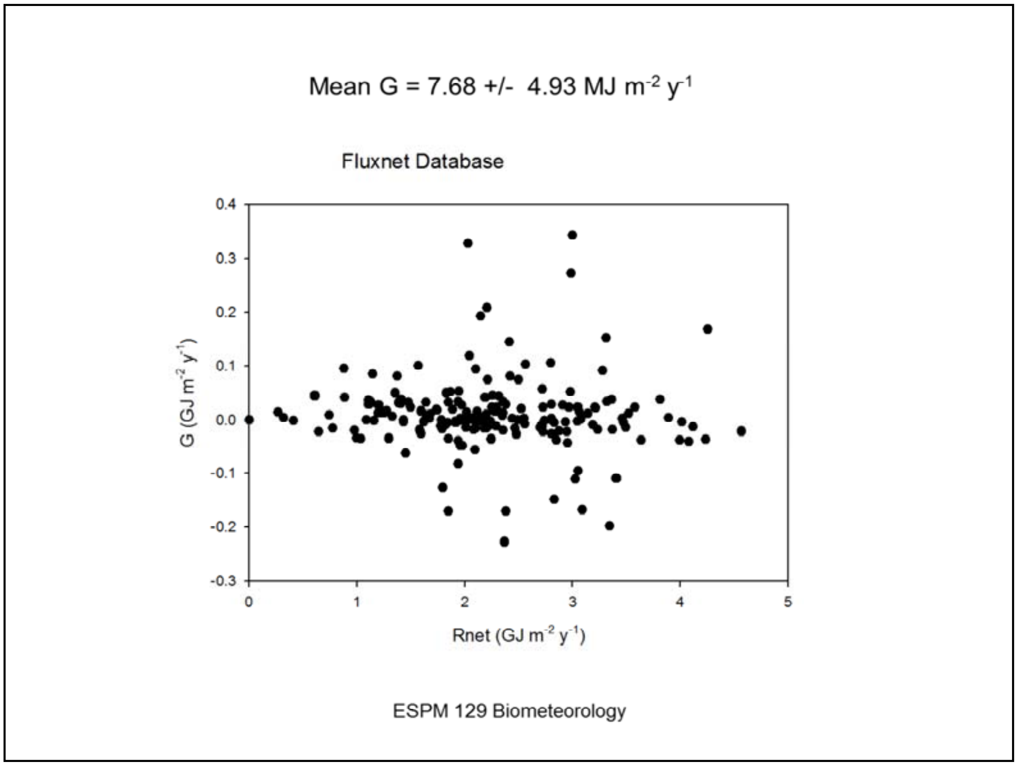


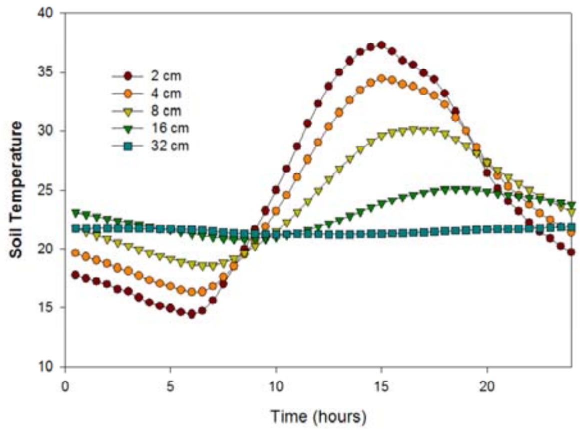
Over a year Soil Heat flux is close to zero

Summary Points

- Soils consist of a mixture of silt, sand and clay and organic matter. Together, these components affect the soil's texture, water holding capacity and heat capacity and conductivity.
- Sand has the highest heat capacity and conductivity and litter/organic matter the lowest, when dry. Heat capacity and conductivity of all soils increase in a non-linear manner with soil moisture.
- The amplitude of the temporal course of temperature (daily/annual) decreases and becomes more lagged (relative to air temperature) with soil depth.
- Soil heat flux averaged over the course of a day or year is close to zero
- There is a close correspondence between mean soil temperature and mean annual air temperature.

Summer, Dry CA Grassland

Day 204, 2001, Vaira Grassland



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