Lecture 35 Lecture on Soil Physics, part 1

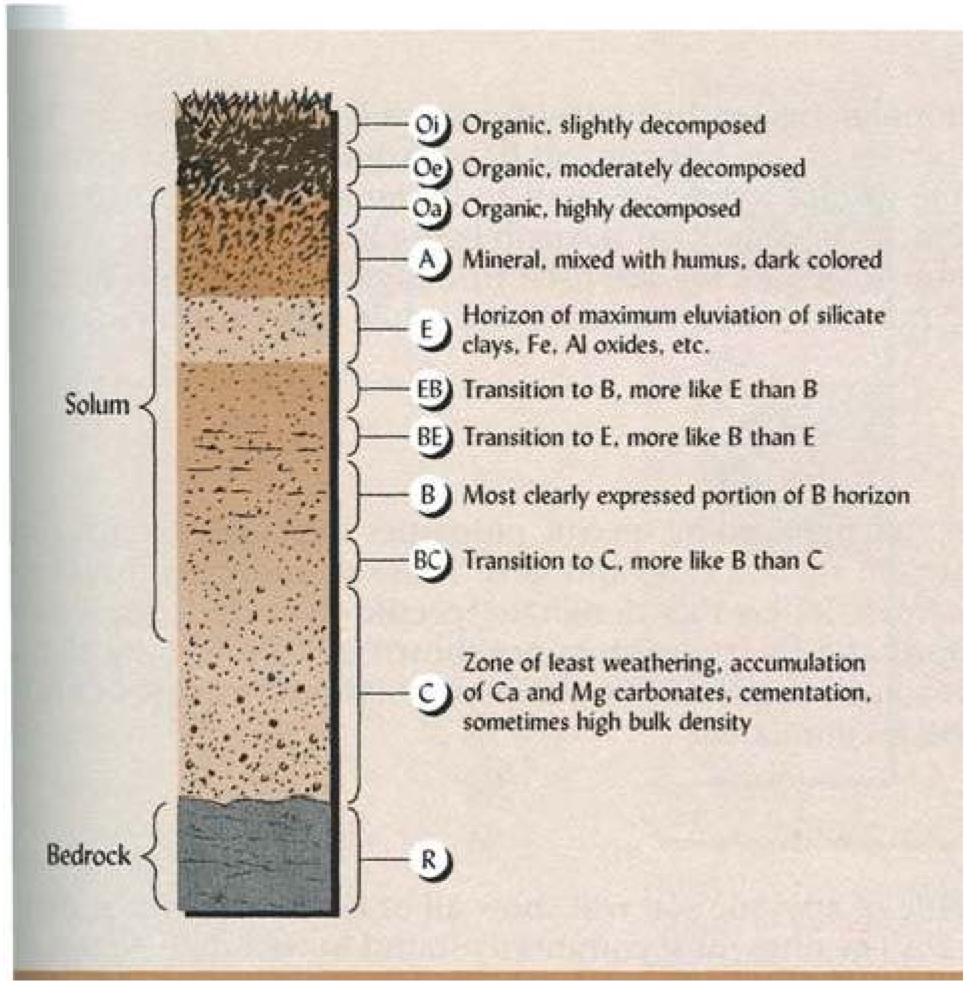
- Soil Properties
  - soil texture and classes
  - heat capacity, conductivity and thermal diffusivity
  - moisture conductivity
  - porosity and diffusion
- Theory, Heat Transfer
  - Heat transfer, Fourier's equation
- Observations
  - Temperature profiles
    - Daily patterns, Phase lags and Amplitudes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

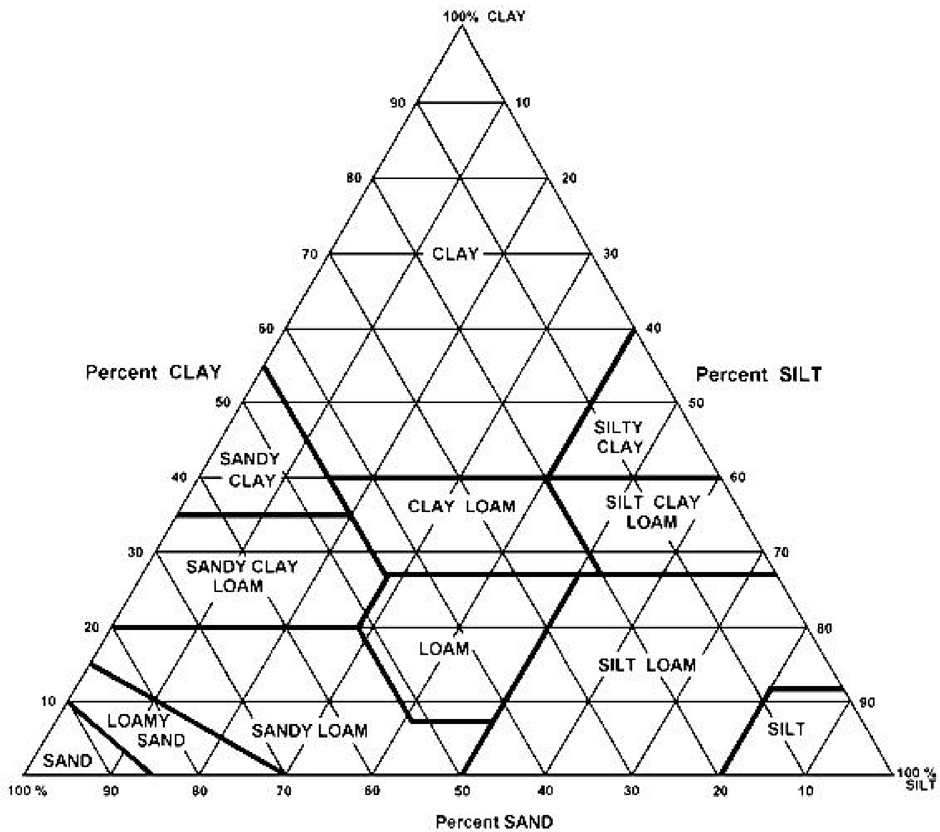
Soil Profile



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

Soil Texture Triangle



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

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

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

Soil Moisture

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

Mass ratio, Mass of water to mass of solid

Volumetric water content

$$\theta = \frac{v_w}{v_t} = w\frac{\rho_b}{\rho_w}$$

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

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

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

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

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

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

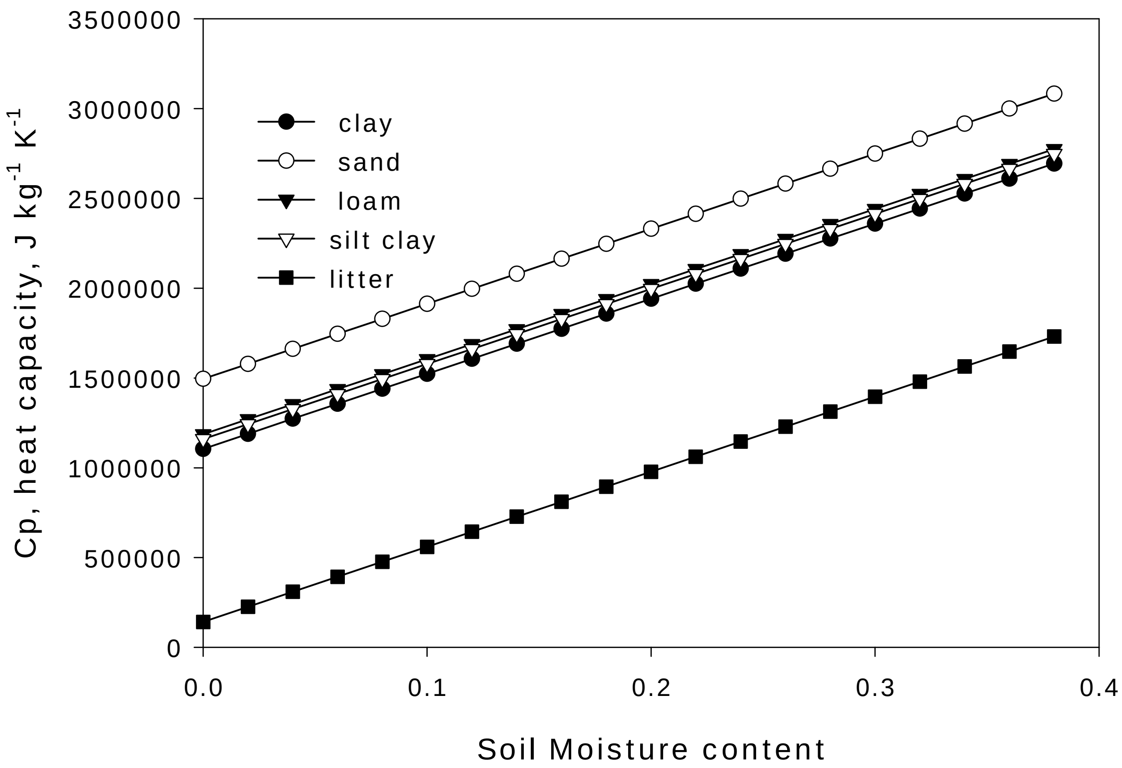
Soil Heat Capacity is a Weighted function of the Mineral Organic and Water components

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

Approximation of Campbell

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

Soil Heat Capacity



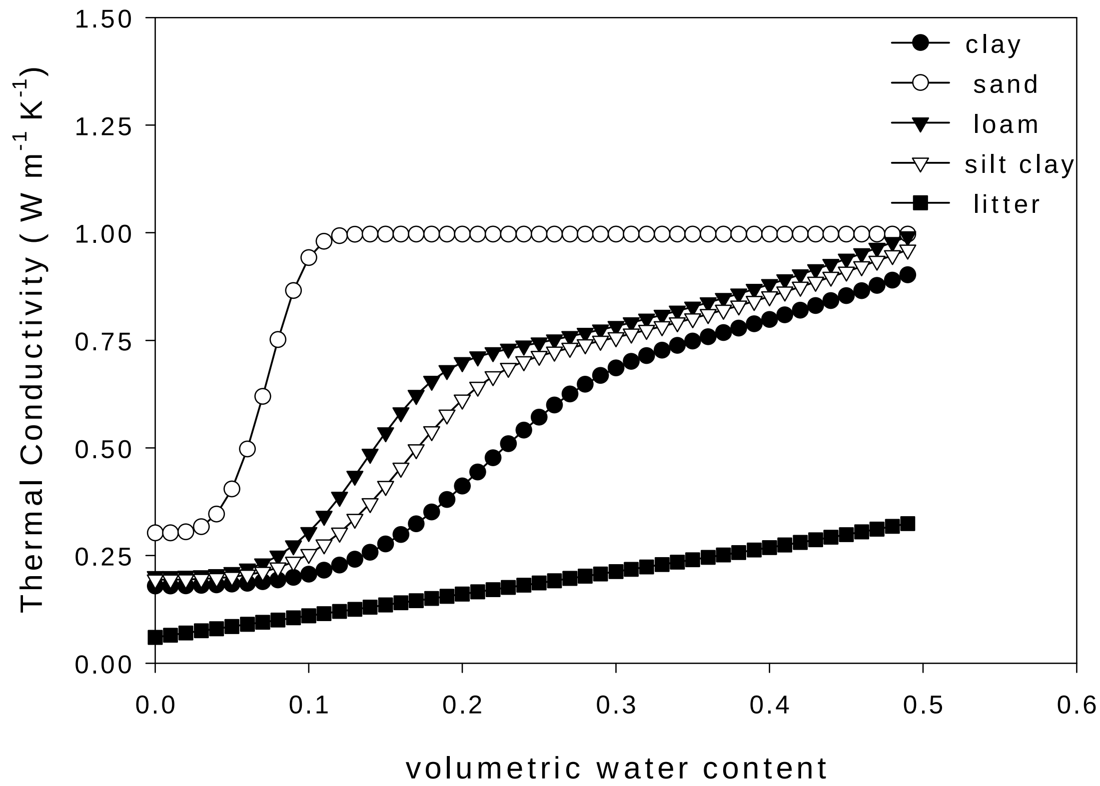
Which Material is the Best and Worst Store of Heat?

Soil Thermal Properties

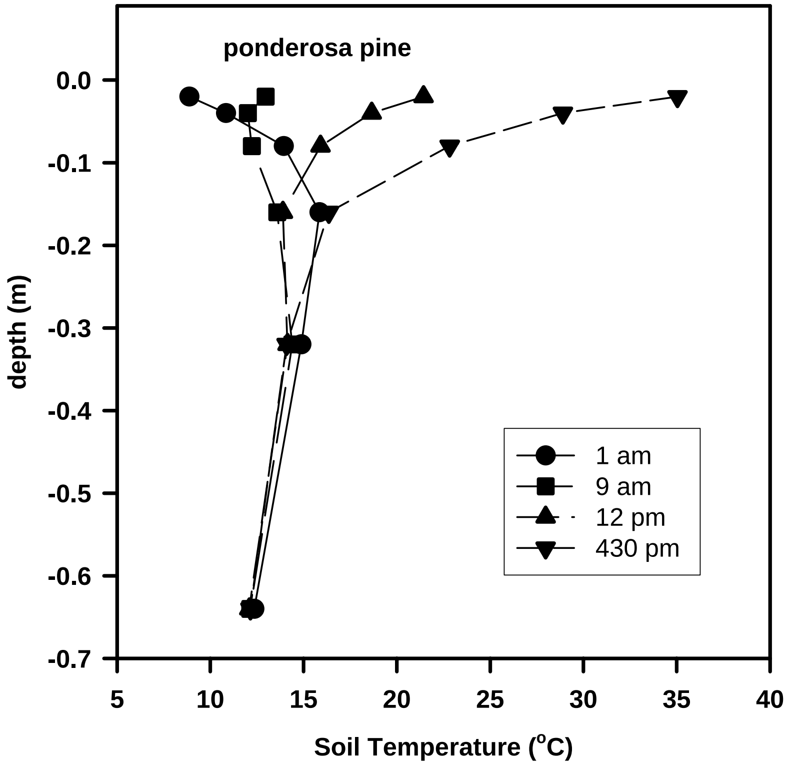
material	Density (Mg m^{-3})	Specific Heat (J g^{-1} K^{-1})	Thermal conductivity (W m^{-1} K^{-1})
Soil minerals	2.65	0.87	2.5
Granite	2.64	0.82	3.0
Quartz	2.66	0.80	8.8
Organic matter	1.30	1.92	0.25
Water	1.00	4.18	0.56
Ice	0.92	2.1	2.22
air	0.0011875	1.01	0.024

Campbell and Norman, 1998

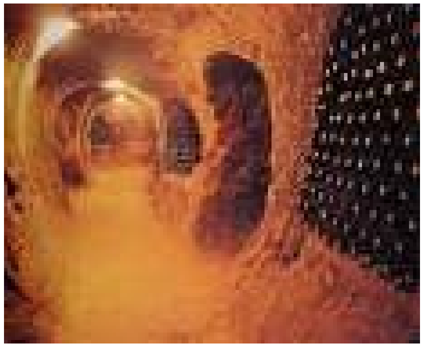
Thermal Conductivity is a function of soil texture and moisture



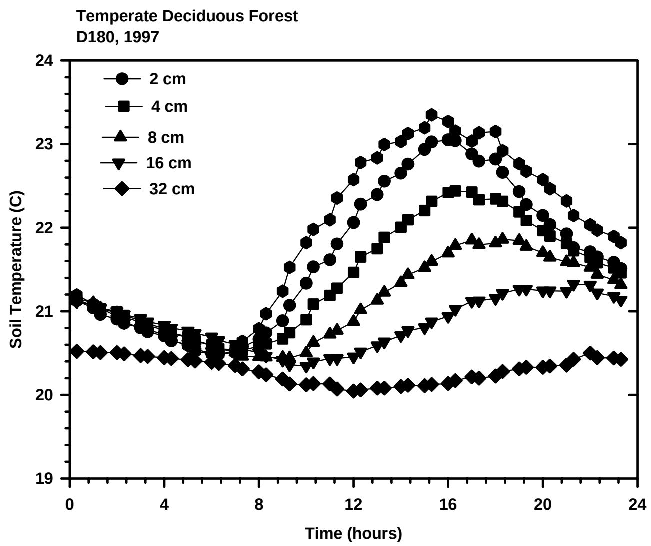
Soil Temperature Profiles



Where do we place the Wine Cellar?



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



Damping Depth

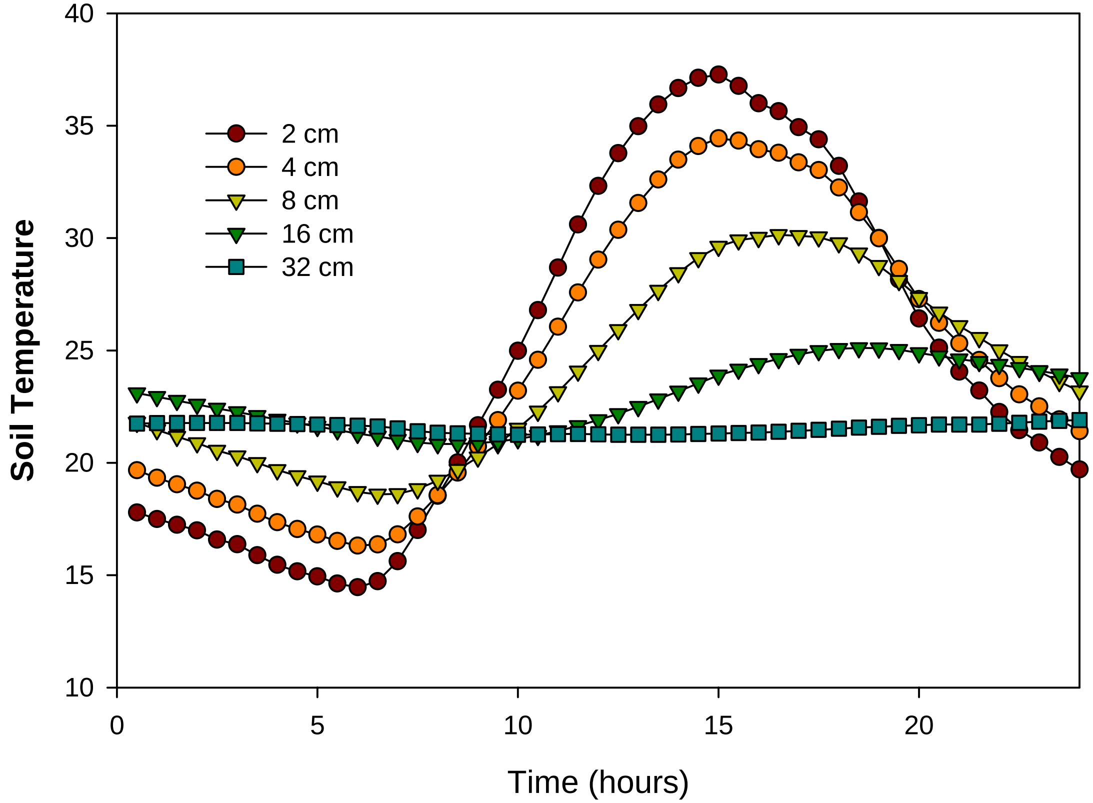
$$D = \sqrt{\frac{2\kappa}{\omega}}$$

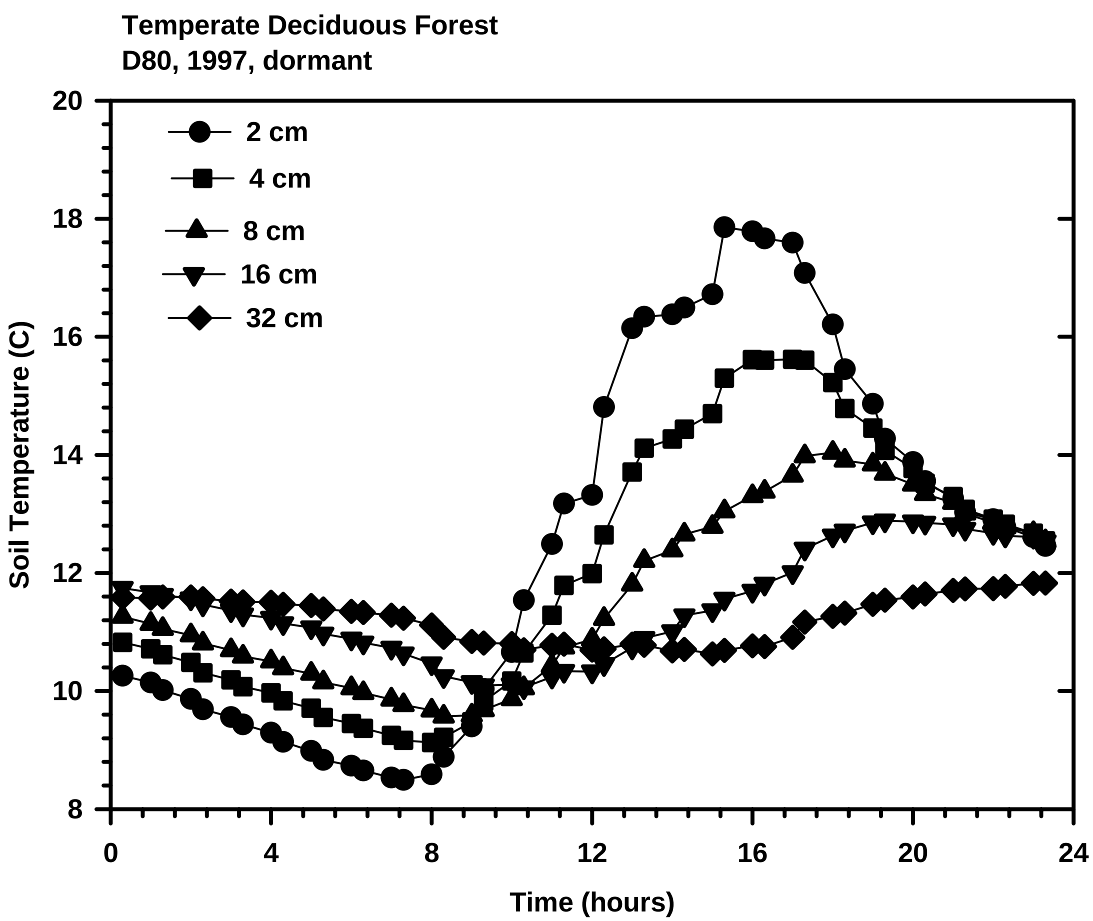
ω is angular frequency (radians per second)

τ is period of fluctuation

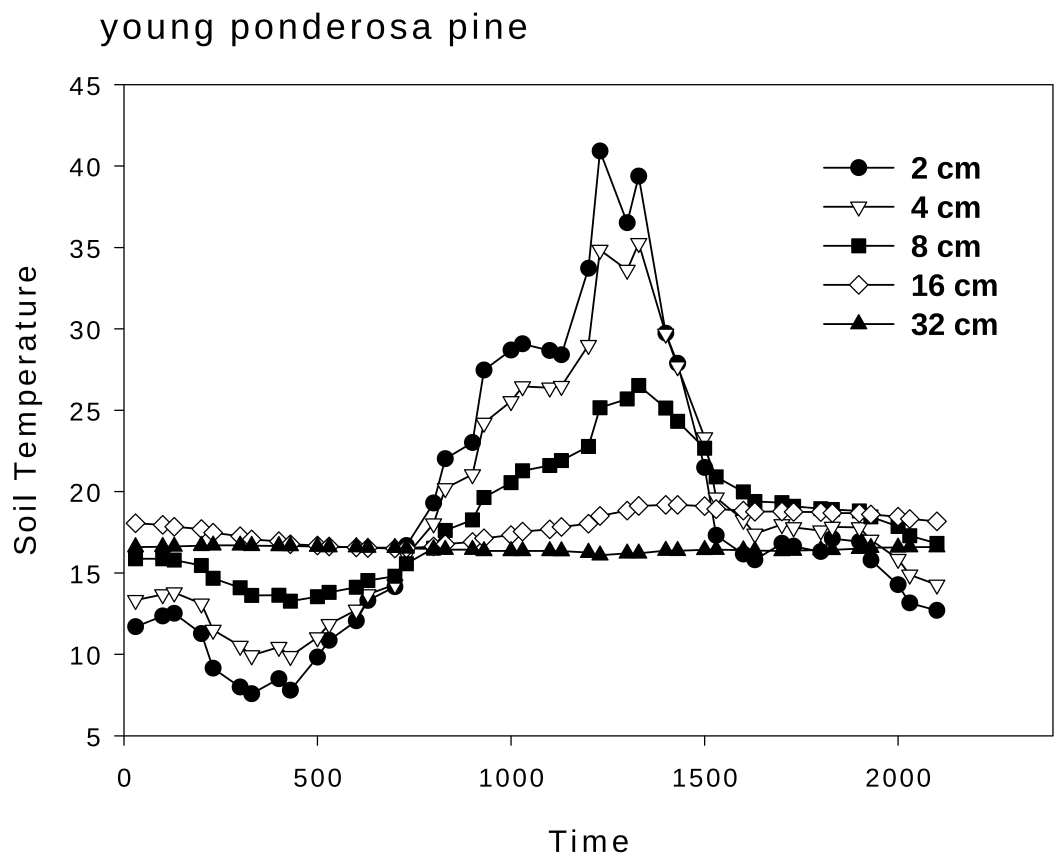
Summer, Dry CA Grassland

Day 204, 2001, Vaira Grassland




Temperate Deciduous Forest
D80, 1997, dormant
2 cm
4 cm
8 cm
16 cm
32 cm
Soil Temperature (C)
Time (hours)
20
18
16
14
12
10
8
0
4
8
12
16
20
24

Less Ideal, Heterogeneous Site



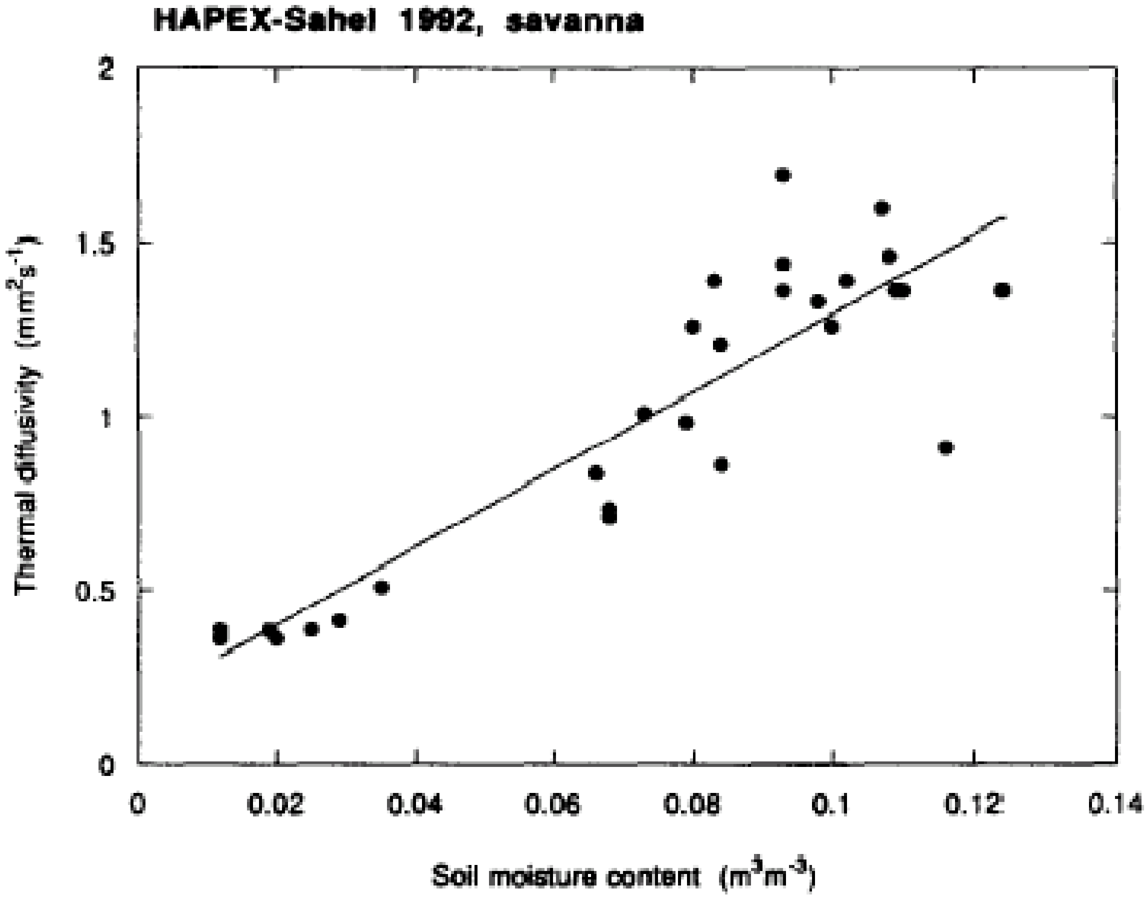
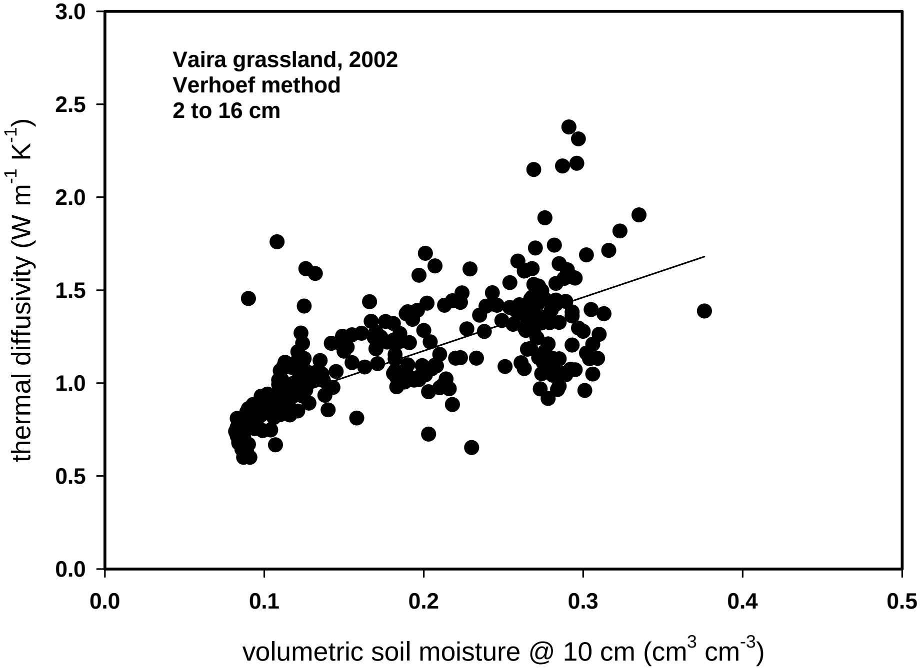


Fig. 5. Relationship between soil moisture content and calculated (Harmonic method) diffusivity for the HAPEX-Sahel experiment.

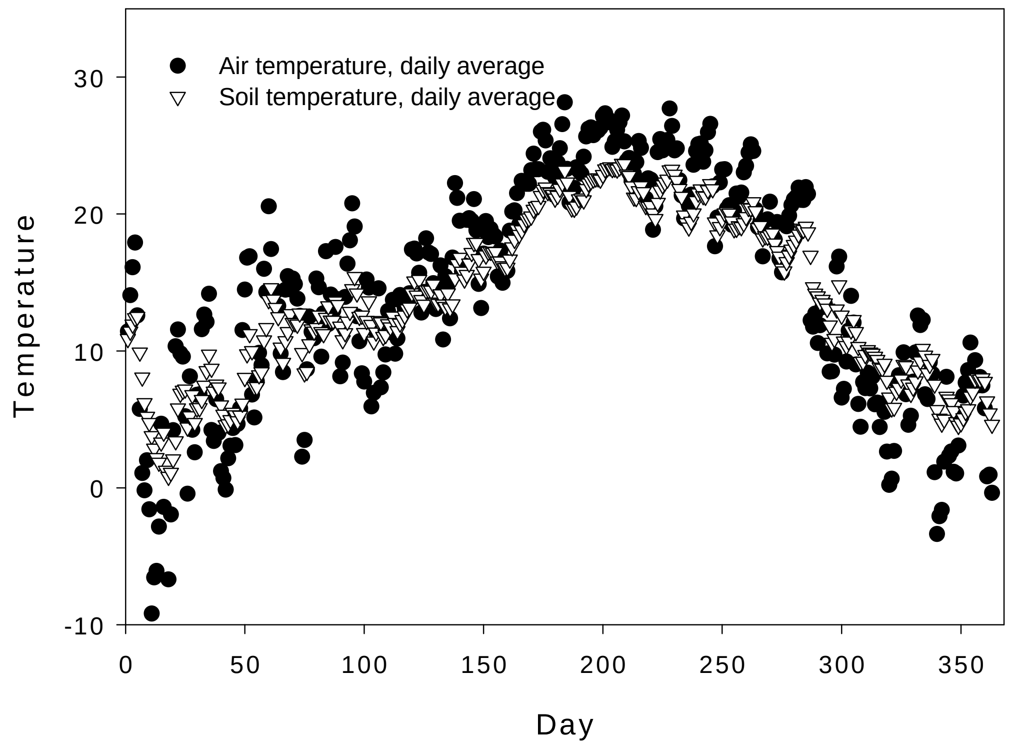
$$\kappa = \frac{\omega}{2}\left[\frac{z_2 - z_1}{\ln(A_1 / A_2)}\right]^2$$



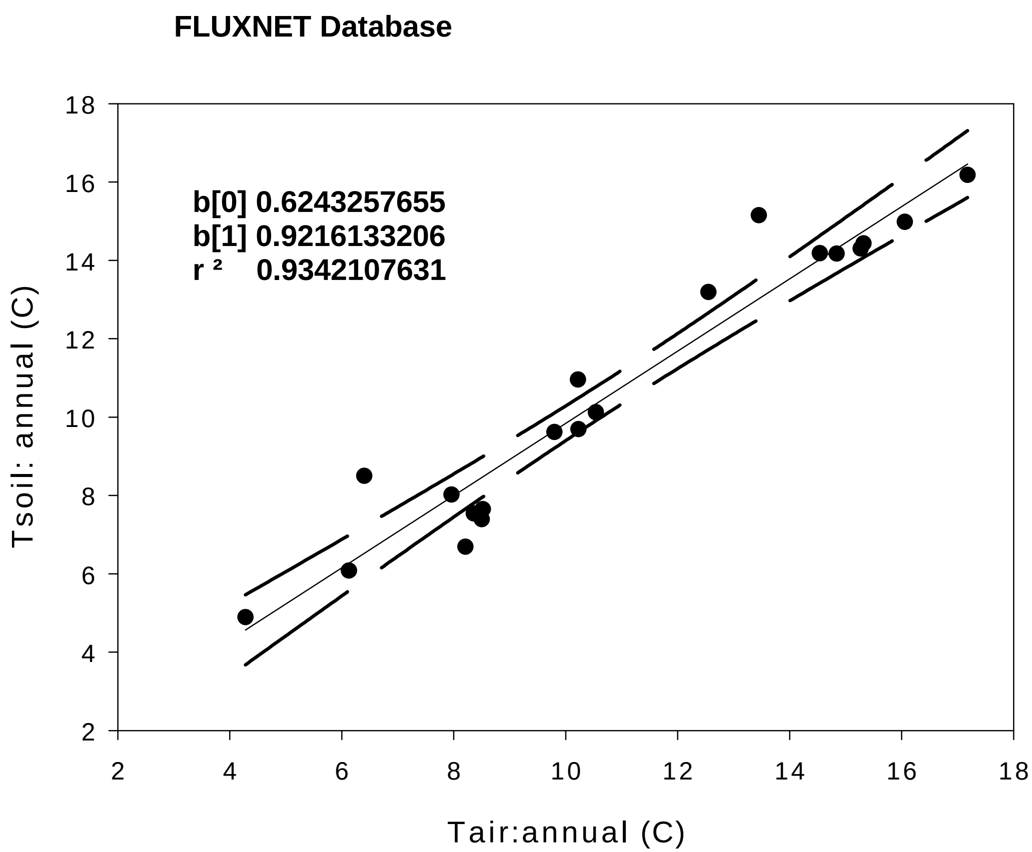
Amplitude Method

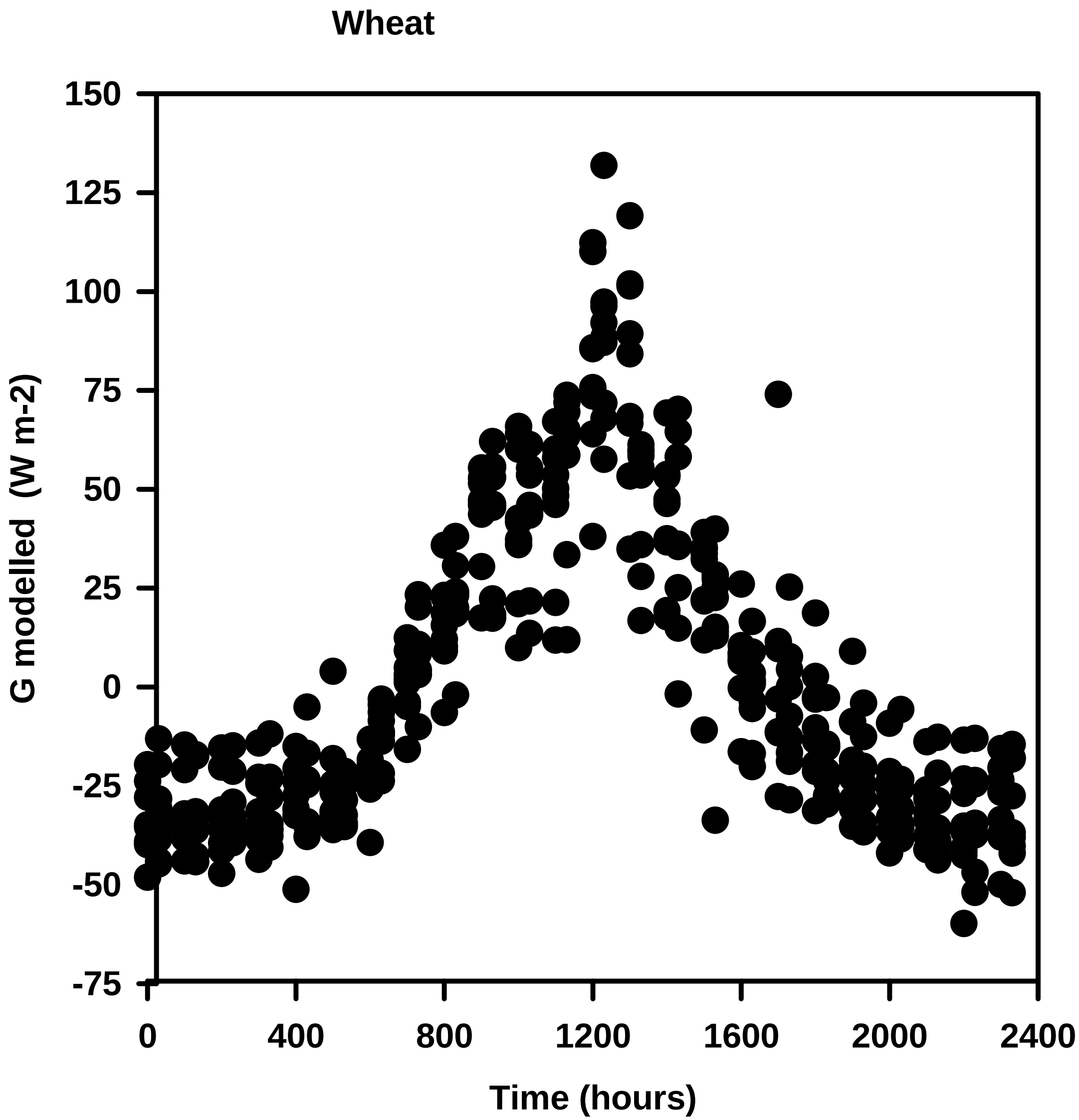
$$\kappa = \frac{\omega}{2}\left[\frac{z_2 - z_1}{\ln(A_1 / A_2)}\right]^2$$

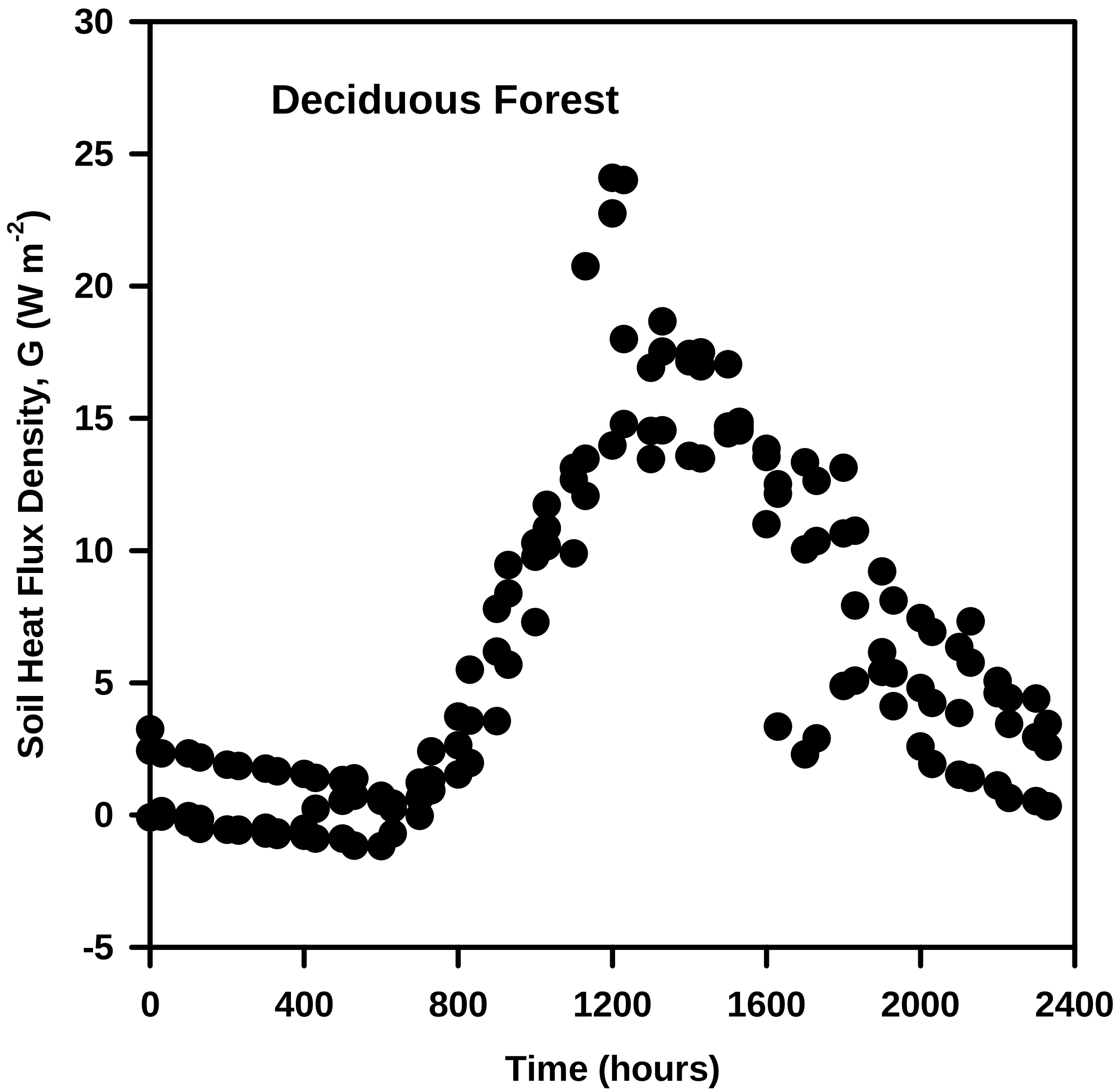
Annual Course in Soil Temperature



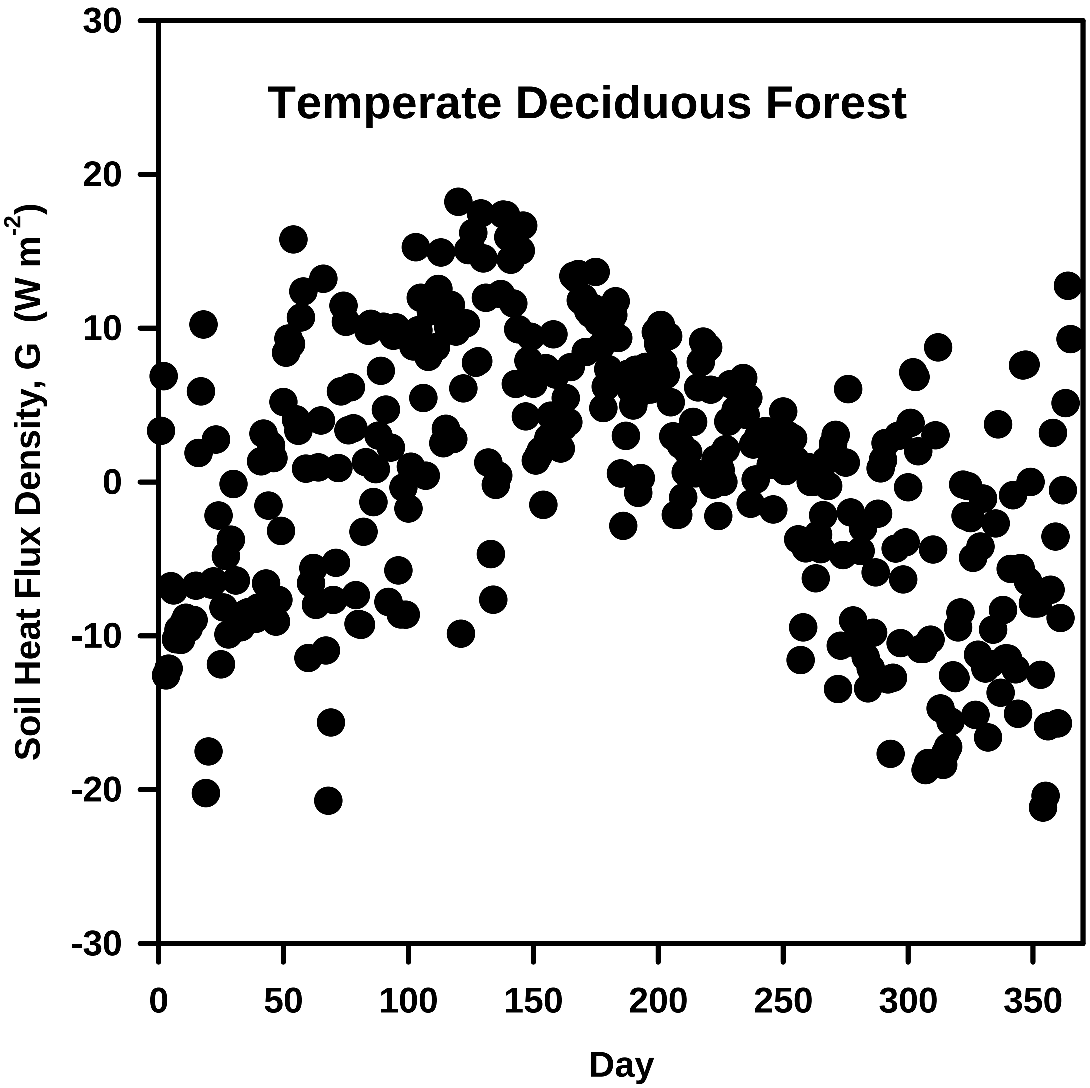
Mean Soil Temperature Scales with Mean Air Temperature




Wheat
G modelled (W m-2)
150
125
100
75
50
25
0
-25
-50
-75
0
400
800
1200
1600
2000
2400
Time (hours)



Deciduous Forest
30
25
20
15
10
5
0
-5
0
400
800
1200
1600
2000
2400
Time (hours)
Soil Heat Flux Density, G (W m-2)


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

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.