Introduction to Agricultural Meteorology

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1. About agricultural meteorology

Climate and Agriculture in Hokkaido

2.1. Snow plowing to accelerate soil freezing

Hirota et al. (2006). JMSJ 84, 821-833
An aerial view over Tokachi, Hokkaido in winter...
Soil-freezing depth has become shallower, why?

Mean air temp in winter (Dec. - Feb.)

First day of >20 cm snow depth (Days from Nov. 1)

Max frost-depth (cm)

Left-over potato tubers now overwinter to become a weed
Some farmers started plowing snow in the middle of winter...
2.2. Three questions:

• Why does soil freeze?
• Why does snow prevent soil freezing?
• Why does snow keep soil frozen?
3. Mechanisms of energy exchange near the ground

• 3.1. What is energy?
  List up as many kinds of energy as you know.

• 3.2. The law of conservation of energy:
3.3. Energy exchange near the ground
3.3. Energy exchange near the ground

**DAYTIME**

Sky: $I_{\text{sky}} = \sigma T_{\text{sky}}^4$

Sun: $I_{\text{sun}} = \sigma T_{\text{sun}}^4$

Land: $I_s = \sigma T_{s}^4$

$$R_n > 0$$

$$S > 0$$

$R_n - C - \lambda E = S$
3.3.1. Energy balance equation

\( Rn - C - \lambda E = S \)

- **\( Rn \):** Net radiation
- **\( C \):** Sensible heat
- **\( \lambda E \):** Latent heat
- **\( S \):** Heating (\( S > 0 \)) or cooling (\( S < 0 \)) the ground
3.3.2. Radiation

• What is radiation?

Every object emits radiation whose extent and wavelength being dependent on its temperature: 
\[ R_e = \sigma T^4 \], where \( R_e \) is the total amount of radiant energy emission per unit area per unit time (W m\(^{-2}\)), \( \sigma \) is the Stefan-Boltzmann constant (5.67x10\(^{-8}\) W m\(^{-2}\) K\(^{-4}\)), and \( T \) is the Kelvin temperature (K).
Radiation at various wave length

Adapted from Jones (2014)
Shortwave and longwave radiations.

The Sun’s surface 6000 deg. K
Earth’s surface 300 deg. K (27 deg. C)

\[ I = \sigma T^4 \]

Note: Scale of the left y-axis for short wave radiation is $10^6$ times that of the right y-axis for long wave radiation.

Adapted from Jones (2014)
Fig. 1a. Energy exchange near ground surface

\[ Rn > 0 \]

\[ I_{\text{sun}} = \sigma T_{\text{sun}}^4 \]

\[ I_{\text{sky}} = \sigma T_{\text{sky}}^4 \]

\[ \text{Land} \]

\[ S \]

\[ P_s \]

\[ T_s \]

\[ \lambda E \]

\[ V \]

\[ Pa \]

\[ Ta \]

\[ Rn - C - \lambda E = S > 0 \]
Fig. 1b. Energy exchange near ground surface

\[ Rn - C - \lambda E = S < 0 \]

\[ I_{sky} = \sigma T_{sky}^4 \]

\[ I_s = \sigma T_s^4 \]
3.3.3. Sensible heat transfer

• Heat conduction
  • Transfer of the molecular movement energy of the matter caused by the direct contact with another matter.
  • An example: In snow layer, energy is transferred between points A and B in proportion to the temperature difference between the points with the constant called \textit{thermal conductivity}.

\[
C = \frac{(T_A - T_B) k}{D}
\]
3.3.3. Sensible heat transfer

• Mass transport
  • Transfer of energy by the transport of matter with higher/ lower temperature.
  • A relevant example is the heat transfer by wind over the ground surface. Wind at temperature $T_a$ exchange the energy with ground surface at temperature $T_s$ in proportion to the wind speed $V$. 
3.3.4. Latent heat transfer

Evaporation and condensation:
• Transfer of the molecular momentum energy of the matter caused by the phase transfer between liquid and gas.

Melting and freezing:
• The same as above but between solid and liquid.
Fig. 1c. Energy exchange near ground surface

Winter ave.

\[ I_{\text{sun}} = \sigma T_{\text{sun}}^4 \]

\[ I_{\text{sky}} = \sigma T_{\text{sky}}^4 \]

\[ Rn = 0 \]

\[ S = \sigma T_s^4 \]

\[ Rn - C - \lambda E = S < 0 \]
Winter ave.

Fig. 2a. Energy transfer in soil

\[ C = \frac{(T_s - T_i) k}{L} \]

\( k = 0.40 \)

Why soil freezes.
Winter ave.  

Why snow prevents soil freezing.

\[ C < 0 \]

\[ C = \frac{(T_{ss} - T_s) k_{snow}}{D} \]

\[ C = \frac{(T_s - T_i) k}{L} \]

\[ k_{snow} = 0.05 \]

\[ k = 0.40 \text{ or } 0.56 \]
Fig. 2. Energy transfer in soil after snow plow

Winter ave.

After soil is frozen.

\[ C \approx 0 \]

\[ C = \frac{(T_s - T_i) k}{L} \]

\[ k = 0.56 \]
Fig. 2. Energy transfer in soil with snow cover

Winter ave.

Why snow keeps soil frozen.

$C \sim 0$

$k_{snow} = 0.05$

$C = (T_{ss} - T_s) \frac{k_{snow}}{D}$

$k = 0.56$
Now, the practice is diffusing to another region of Hokkaido along with a reinvention: snow compaction.

Photo by Hirota (2016)
Quiz: Why does the snow compaction help the soil freezing?
Choose among the three:

• A. Soil gets more water.
• B. Snow conducts heat faster.
• C. Snow surface becomes cooler.
Winter ave.

Fig. 3. Energy transfer in soil after snow compaction

\[
C < 0
\]

\[
C = \frac{(T_{ss} - T_s) \text{kice} / D'}{L}
\]

\[
C = \frac{(T_s - T_i) \text{k}}{L}
\]

\[
k = 0.40 \text{ or } 0.56
\]

$k_{\text{ice}} = 2.18$


