Inhomogeneity of Conductive Heat Fluxes around the Tiksi Meteorological Tower

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Background: Tiksi Station

Analysis of the components of the surface energy budget is necessary for better understanding the energy exchanges of the Arctic region. The Arctic field site chosen for this study is located in Tiksi, Russia (71.6N, 128.9E). At Tiksi station a 20 meter meteorological tower is surrounded by five flux plates and four thermistor strings from which conductive heat fluxes can be measured and derived respectively. The flux plates and thermistor strings are distributed in a variety of regimes including wet tundra, mid tundra and dry tundra soils. Conductive heat fluxes from around the Tiksi tower are compared for one winter (March) and one summer (July) month.

July | March

Two Ways to Calculate Conductive Heat Flux:

Thermistors (F_0 = Soil Flux Equation)

$$F_0 = -K_{sl}\left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}}\right) - C_{psl}\left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})}\right)(z_{10} - z_{sfc})$$

Using thermistor strings and soil properties a conductive heat flux can be derived using a soil flux equation, above. The equation uses soil temperature values at depths ranging from the surface to 15cm depth . Soil property constants were identified from past research articles for a specified organic tundra soil type.

K_{sl} = 1.0 W m^{-1} K^{-1} [soil thermal conductivity]
C_{psl} = 2.0 x 10^{6} J m^{-3} K^{-1} [frozen soil heat capacity]
C_{psl} = 2.6 x 10^{6} J m^{-3} K^{-1} [un-frozen soil heat capacity]
z = depth [meters]
T_{sfc}, T_{05}, T_{10}, T_{15} = soil temperature at depths [degrees Kelvin]
t = seconds per hour time index [hourly]
G = flux plate measurement after calibration applied [Wm^{-2}]
F_0 = conductive heat flux [Wm^{-2}]

Flux Plate (F_0 = Flux Plate + Soil Variable)

$$F_0 = G + \frac{\left(\left(T_{05}^{n+1} - T_{05}^{n-1}\right) * C_{psl} * z\right)}{3(t_{n+1} - t_{n-1})}$$

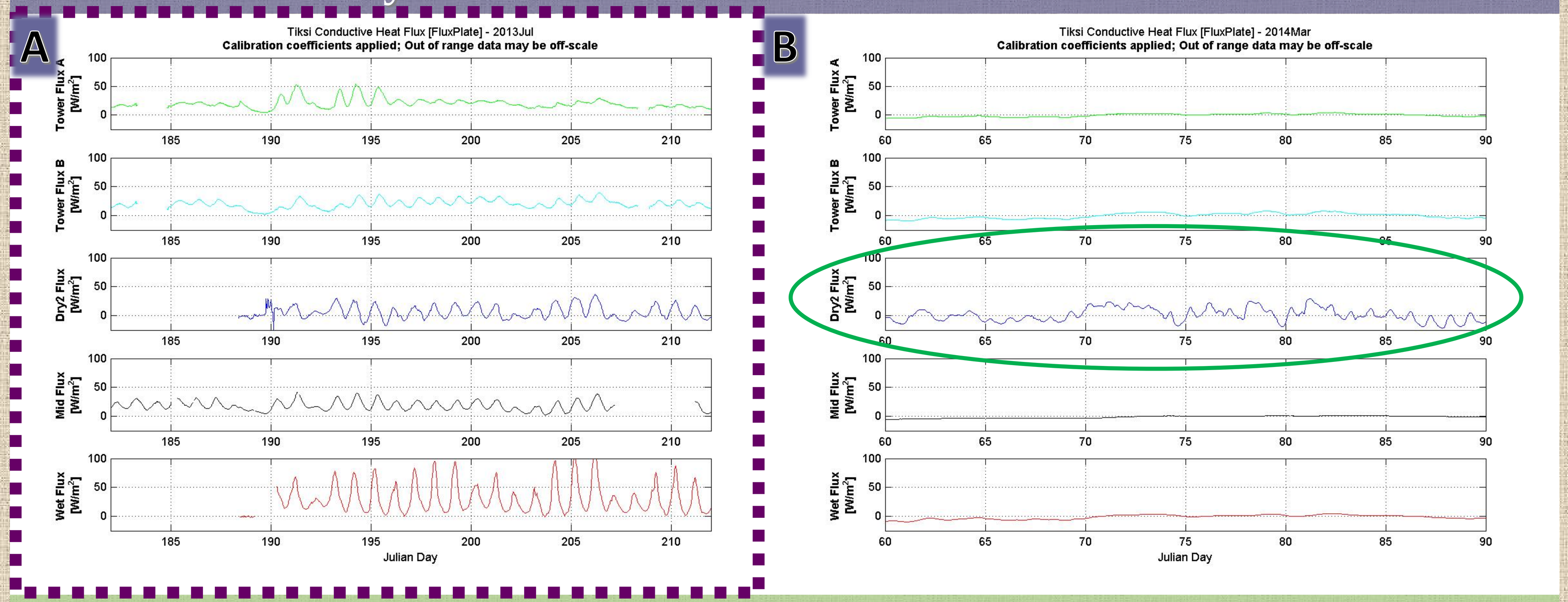
Using a soil flux plate and derived soil variable (via identified soil properties) a conductive heat flux can be derived by adding the two components together, above. The soil variable uses soil temperature values at depths ranging from the surface to 5cm depth (flux plates are located at 5cm depth, so only necessary to have soil data until 5cm depth). Soil property constants were identified from past research articles for a specified organic tundra soil type.

Conductive Heat Flux Derived from Flux Plates

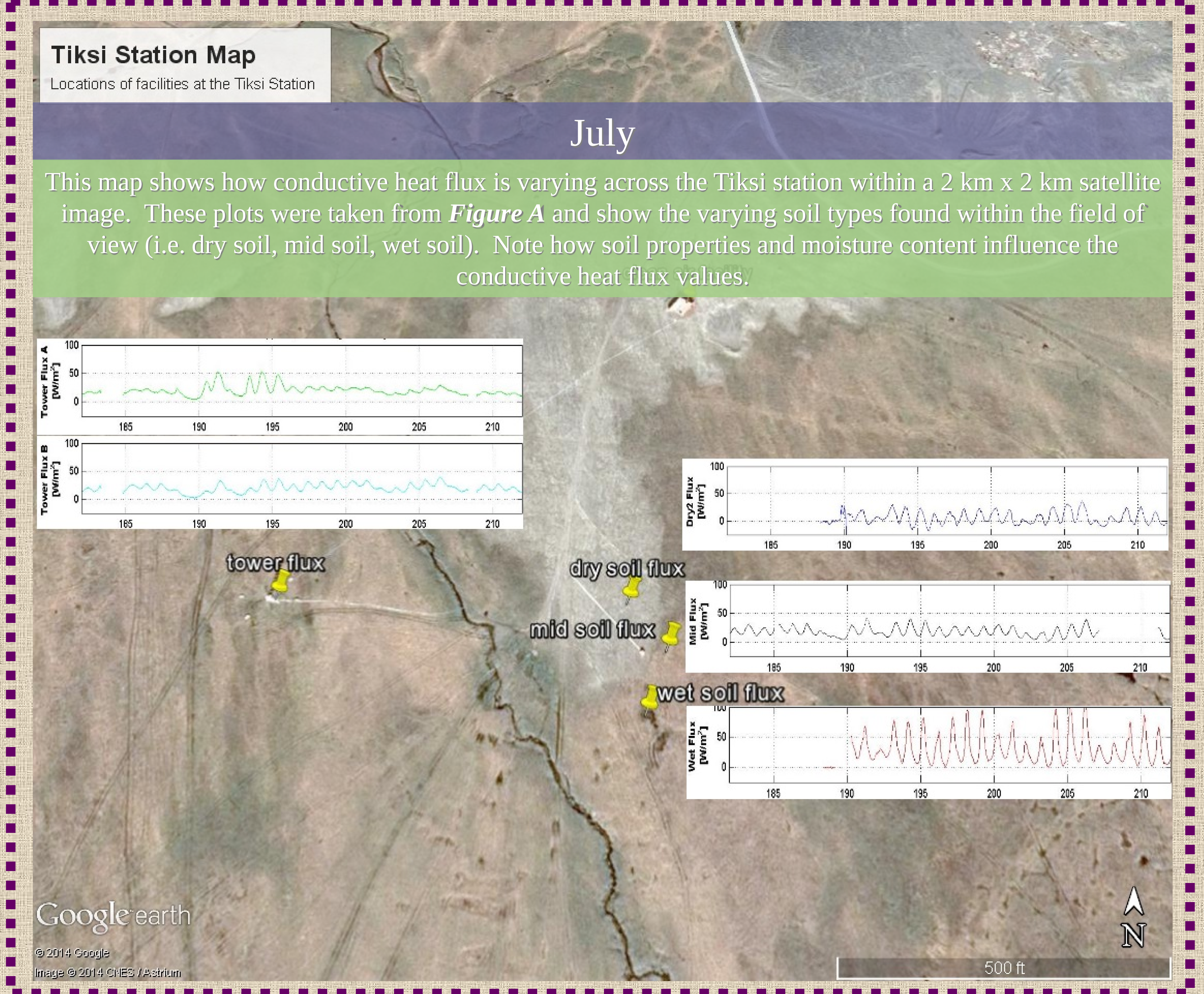
***Figures A** and **B** (below)*

- Conductive heat flux values from five flux plates show noticeable difference in observed flux values across differing soil moisture types
- Conductive heat flux is much more variable in dry soil (***Figure B*** – green circle)
- Noticeably higher magnitude of variability throughout all soil types (***Figure A)***

July | March



Figures A** and **B show conductive heat flux values derived from five different direct flux plate measurements with the addition of a soil variable to account for the layer of soil that is placed directly over the flux plates.



This map shows how conductive heat flux is varying across the Tiksi station within a 2 km x 2 km satellite image. These plots were taken from ***Figure A*** and show the varying soil types found within the field of view (i.e. dry soil, mid soil, wet soil). Note how soil properties and moisture content influence the conductive heat flux values.

Area Weighted Conductive Heat Flux from Flux Plates

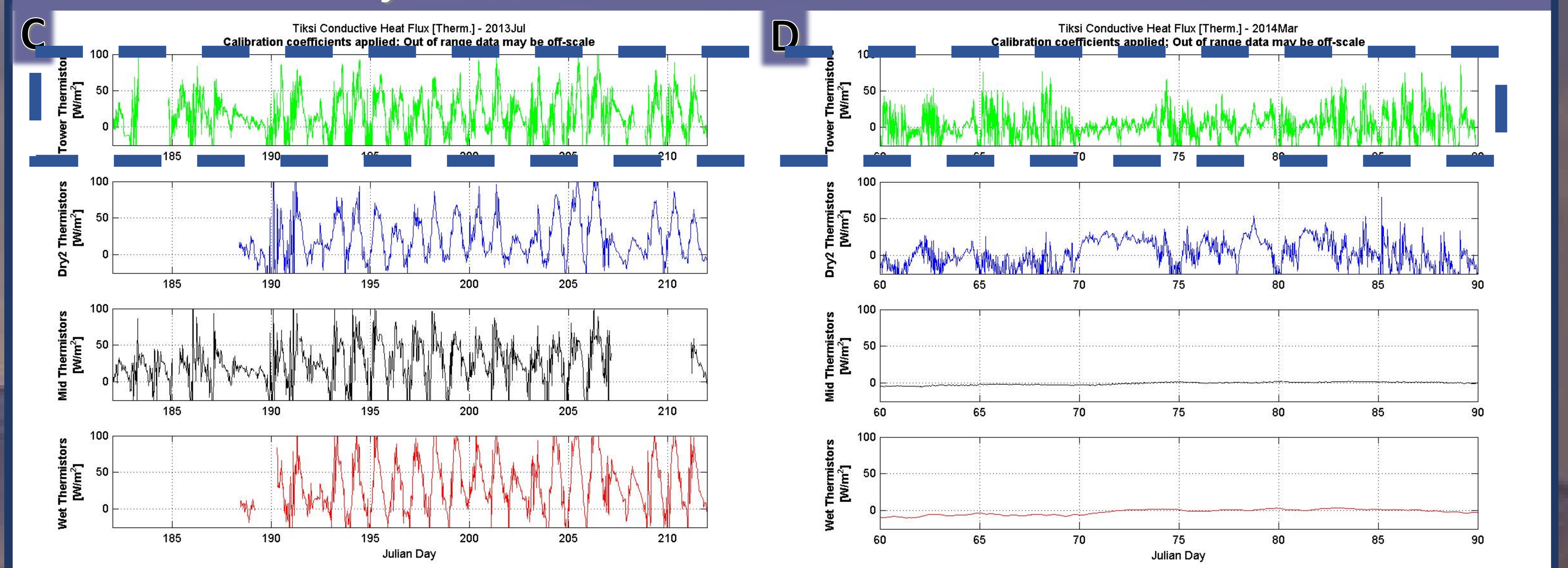
- Conductive Heat Flux Averages for July for individual soil moisture types:
  dry = 6.1191 Wm^{-2} wet = 29.6662 Wm^{-2} mid = 19.5033 Wm^{-2}
- 2 km x 2 km area shows:
  dry = 10% = 0.61191 Wm^{-2} wet = 5% = 1.48331 Wm^{-2} mid = 85% = 16.57783 Wm^{-2}
- July Conductive Heat Flux Average when applying the percentage of each soil type represented in the 2 km x 2km area: **18.67305 Wm^{-2}**

Conductive Heat Flux Derived from Thermistors

***Figures C** and **D** (below)*

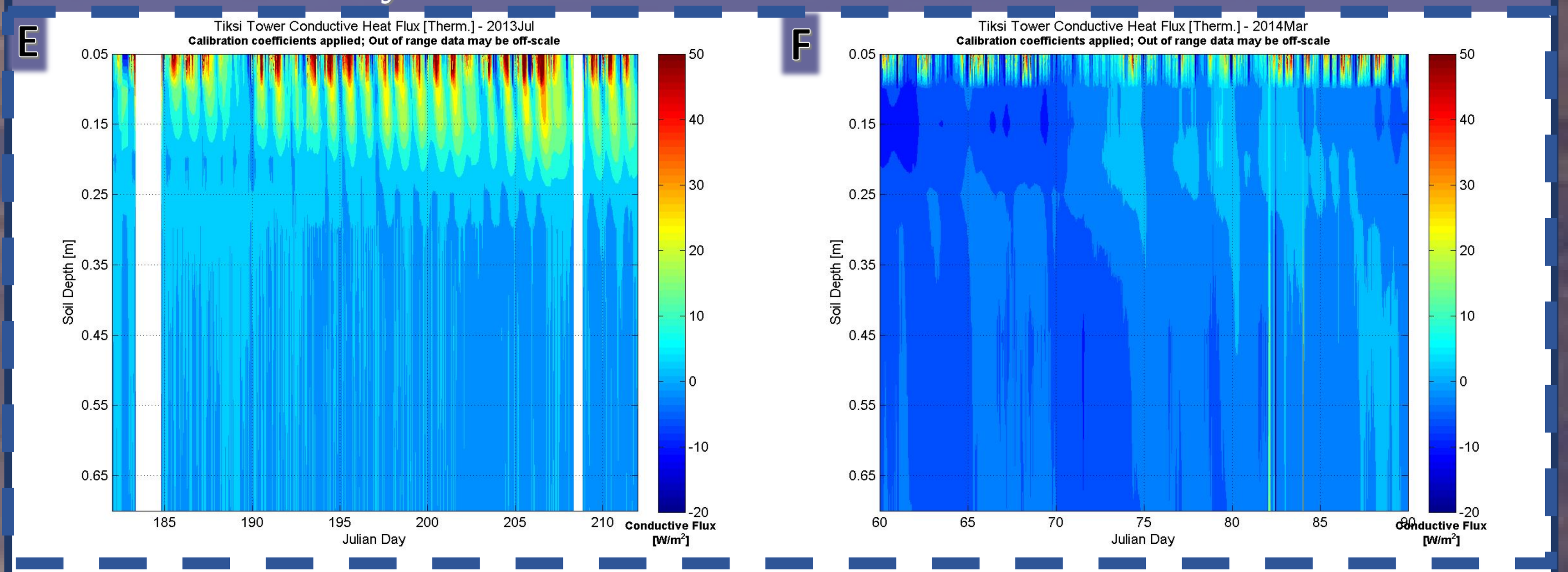
- Variability between conductive heat flux values derived from thermistors was greater in July than March
- Dry soil types are more variable in winter months since no water to freeze in dry soil (***Figure D***)
- Wet soil type is the most variable during summer months (***Figure C***)

July | March



Figures C** and **D show conductive heat flux values derived from a soil flux equation using measurements from four different soil thermistor strings for the months of July (thawing permafrost) and March (frozen permafrost).

July | March



Figures E** and **F show contour diagrams of how conductive heat flux at the tower dissipates into the permafrost during the months of July (thawing permafrost) and March (frozen permafrost).

Conductive Heat Flux Depth Contour Maps

***Figures E** and **F** (above) – Tower Thermistor only*

- Conductive heat flux values dissipate almost completely around 30cm depth in tundra soil
- During July (***Figure E***) conductive heat flux values higher than ~5 Wm^{-2} dissipate around a depth of 30cm
- During March (***Figure F***) conductive heat flux values higher than ~5 Wm^{-2} have a shallower flux dissipation around a depth of 10cm

Conclusion

- Frozen state of permafrost in March shows more stability as conductive heat flux goes to zero
- Thawing state of permafrost in July shows more variability in conductive heat flux
- Conductive heat flux values differ greatly across the site due to the active layer experiencing thawing differently
- Conductive heat flux value will be very dependent on soil and water properties at an instrument's location (i.e. soil thermal conductivity and soil heat capacity)
- Range in conductive heat flux values can vary between 25-50 Wm^{-2} at one specific Arctic station
- Contour plots show how conductive heat flux values dissipate through the permafrost during thawing months

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