Determining Ground Flux around the Tiksi Station

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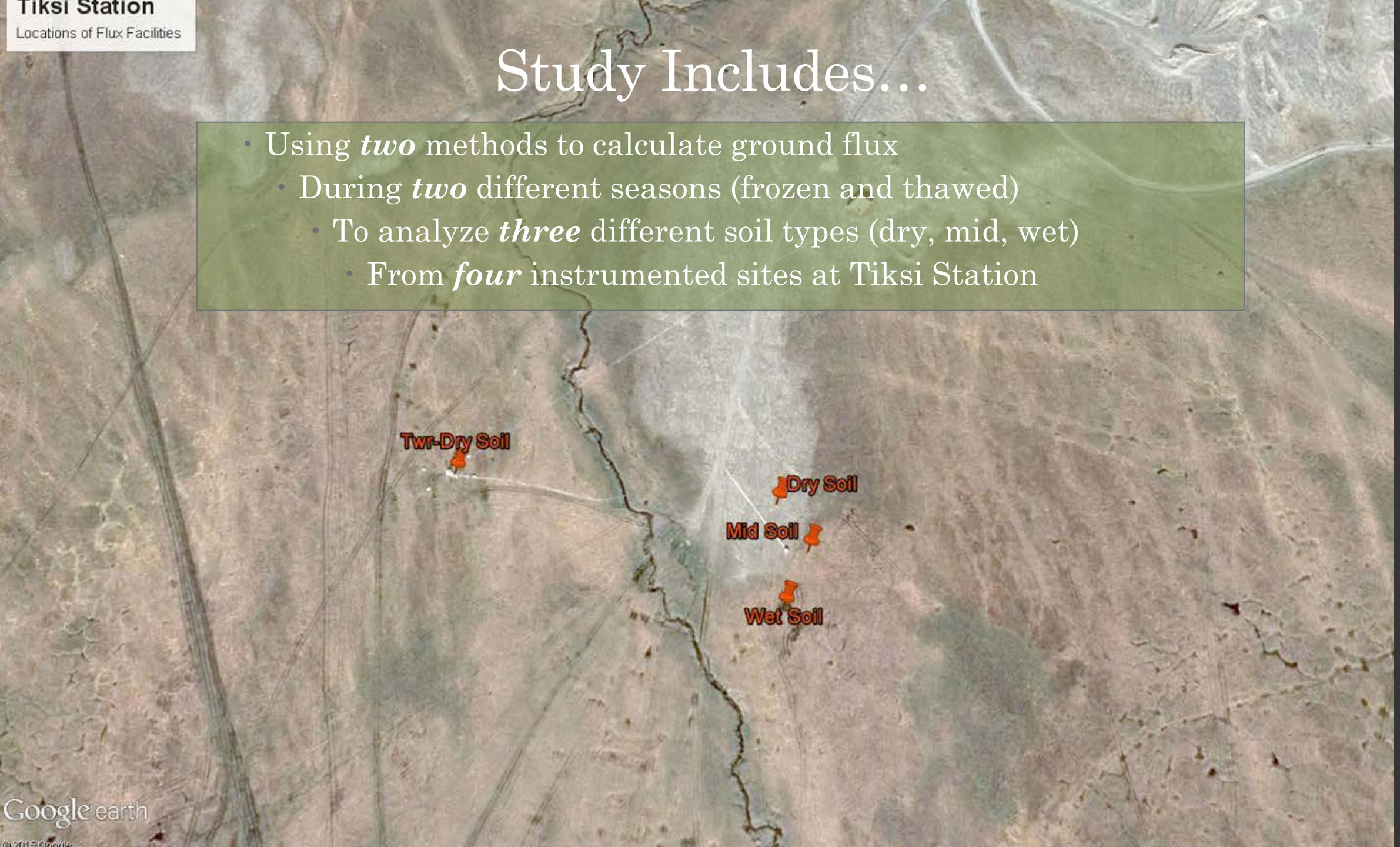
Acknowledgements: Taneil Uttal, Andrey Grachev, Ola Persson, Elena Akish, FMI

Tiksi Fluxtower

March Fluxtower photo by: Vasily Kustov (ftp://ftp.cmdl.noaa.gov/pub/Albee/_Tiksi/Tiksi%20Picture%20folder/2013-02%20Russia-Tiksi%20%28Vasilii%29/DSC02040.JPG)
July Fluxtower photo by: Dmitry Apartsev (ftp://ftp.etl.noaa.gov/psd3/arctic/tiksi/surface_properties/fluxtower/towermet/0_photos/Site_FLUXTOWER/FLUXTOWER_fall_byDima.JPG)

Study Includes…

- Using ***two*** methods to calculate ground flux
  - During ***two*** different seasons (frozen and thawed)
    - To analyze ***three*** different soil types (dry, mid, wet)
      - From ***four*** instrumented sites at Tiksi Station



Background

Net Surface Flux = $Q_R + Q_G + Q_T$

⇕

Net Surface Flux = Radiative Flux + **Ground Flux** + Turbulent Flux [+ **Exchange Processes**]
[+ **Vegetation**]

[Foken, 2008] indicates there are other terms to include

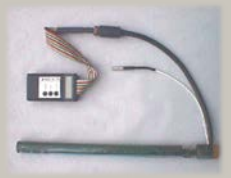
Focus of Presentation: **Ground Flux**

Background photo by: DmitryApartsev

Background

Calculate Ground Flux using Fourier Equation

$$Q_G = -\lambda_s \frac{\Delta T}{\Delta z} - C_s \frac{\Delta T}{\Delta t} \Delta z$$



Two ways to measure Ground Flux:

1. Thermistor instruments

$$Q_G = -\lambda_s \left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}} \right) - C_s \left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})} \right) (z_{10} - z_{sfc})$$

2. Flux Plate instruments

$$Q_G = F_0 - C_s \left(\frac{T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{2(t_{n+1} - t_{n-1})} \right) (z_{05} - z_{sfc})$$

λ_s = soil thermal conductivity [$Wm^{-1}K^{-1}$]
C_s = soil heat capacity [$Jm^{-3}K^{-1}$]
z = depth [meters]
T_{sfc}, T_{05}, T_{10}, T_{15} = soil temperature at depths [degrees Kelvin]
t = seconds per hour time index [hourly]
F_0 = flux plate measurement with calibration applied [Wm^{-2}]
Q_G = conductive heat flux [Wm^{-2}]

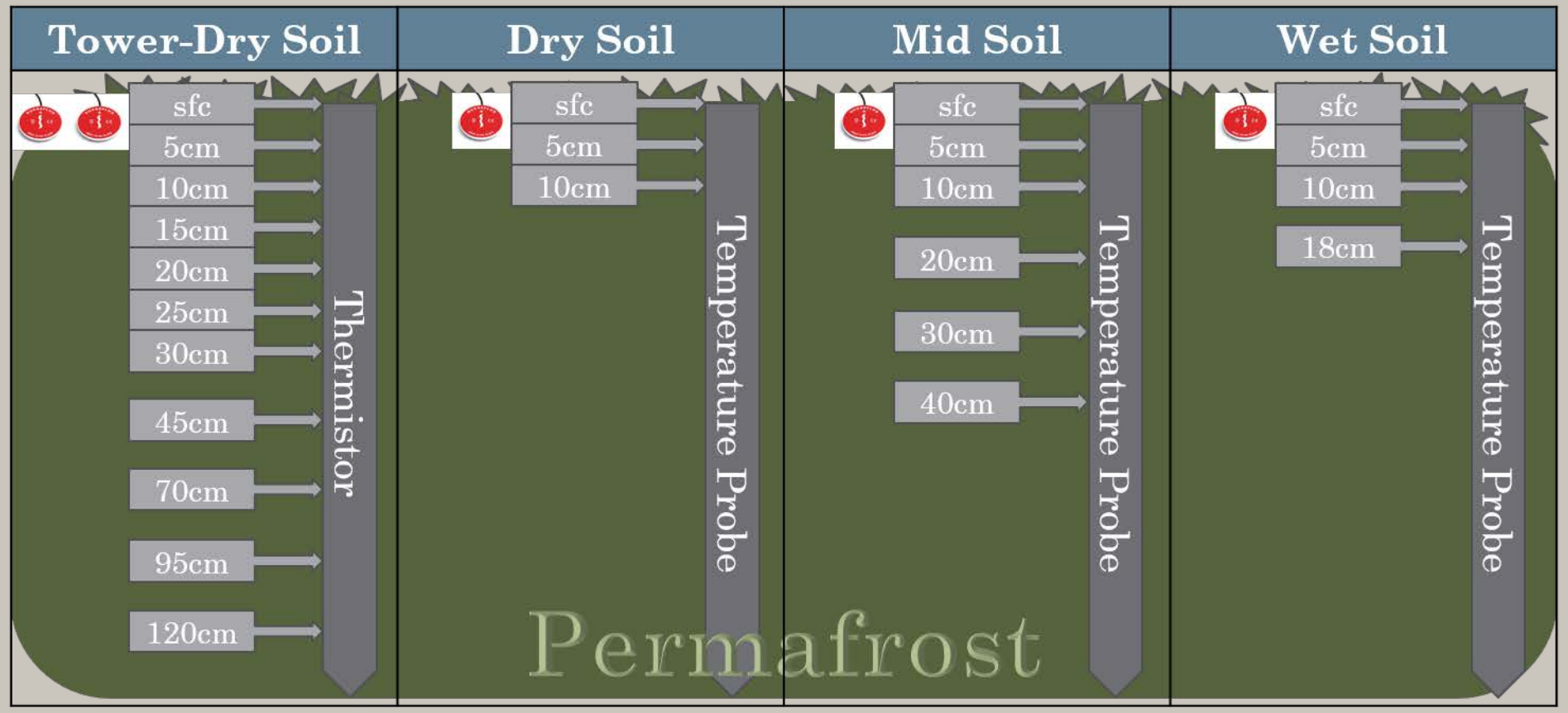
Instrumentation

$$Q_G = -\lambda_s\left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}}\right) - C_s\left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})}\right)(z_{10} - z_{sfc})$$

$$Q_G = F_0 - C_s\left(\frac{T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{2(t_{n+1} - t_{n-1})}\right)(z_{05} - z_{sfc})$$

- Thermistor Probe: *MRC TP-101*
- Dry, Mid, Wet Temp Probe: *Nokeval, IKES PT100*

- Flux Plates: *Hukseflux HFP01*

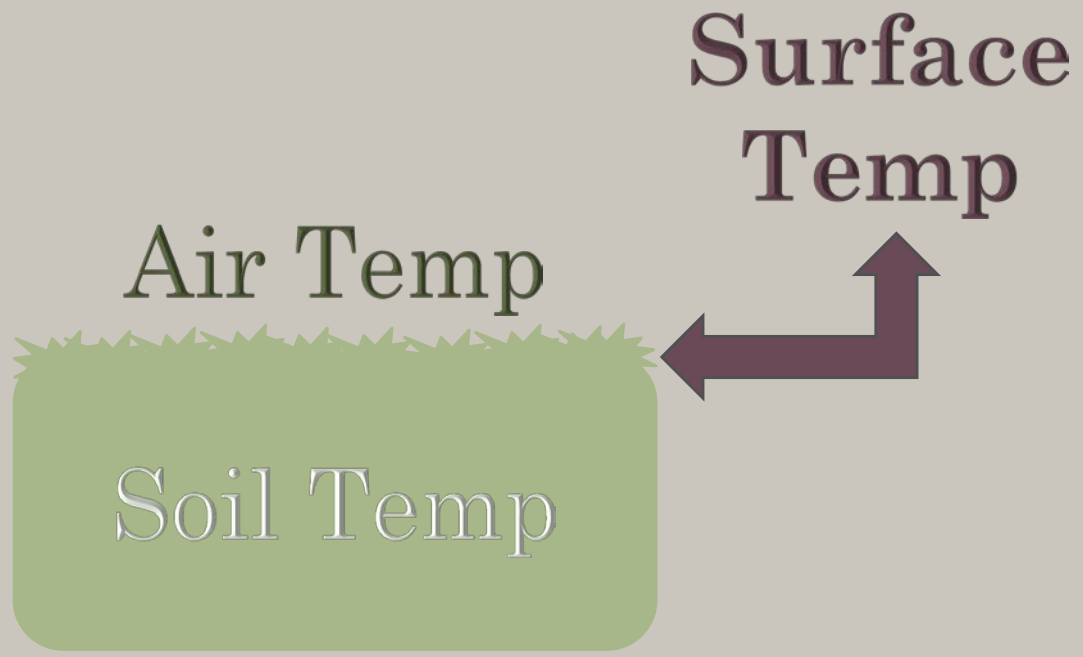


Instrumentation: Surface Temperatures

$$Q_G = -\lambda_s\left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}}\right) - C_s\left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})}\right)(z_{10} - z_{sfc})$$

$$Q_G = F_0 - C_s\left(\frac{T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{2(t_{n+1} - t_{n-1})}\right)(z_{05} - z_{sfc})$$

- Twr-Dry
  - IR surface temperature sensor: *Apogee IRTS-P*
- Dry
  - Surface temperature sensor: *Nokeval, IKES PT100*
- Mid
  - Surface temperature sensor: *Nokeval, IKES PT100*
- Wet
  - Surface temperature sensor: *Nokeval, IKES PT100*



Soil Thermal Properties

$$Q_G = -\lambda_s\left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}}\right) - C_s\left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})}\right)(z_{10} - z_{sfc})$$

$$Q_G = F_0 - C_s\left(\frac{T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{2(t_{n+1} - t_{n-1})}\right)(z_{05} - z_{sfc})$$

What to use for [λ_s] [C_s]?

Site Description	Thermal Conductivity [λ]	Thermal Conductivity Conversion	Heat Capacity [C]	Heat Capacity Conversion	Author/Paper
Air	0.00006 cal cm-1 sec-1 celsius-1	0.02512079 Wm-1K-1			Sellers, 1965
Air	0.026 Wm-1K-1	0.026 Wm-1K-1	1.20 Jm-3K-1	0.0012 MJm-3K-1	Peters-Lidard et al., 1997
Air	0.026 Wm-1K-1	0.026 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-mineral frozen	900 cal m-1 hr-1 celsius-1	62.80197 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-mineral unfrozen	770 cal m-1 hr-1 celsius-1	53.73056 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-organic frozen	100 cal m-1 hr-1 celsius-1	6.978011 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-organic unfrozen	250 cal m-1 hr-1 celsius-1	17.44501 Wm-1K-1			Farouki, 1981
Clay minerals	0.007 cal cm-1 sec-1 celsius-1	2.930759 Wm-1K-1			Sellers, 1965
Deadhorse	0.77 Wm-1K-1	0.77 Wm-1K-1	2.36 MJm-3K-1	2.36 MJm-3K-1	Romanovsky & Osterkamp, 1997
Franklin Bluffs	0.82 Wm-1K-1	0.82 Wm-1K-1	2.30 MJm-3K-1	2.30 MJm-3K-1	Romanovsky & Osterkamp, 1997
Ice	0.0052 cal cm-1 sec-1 celsius-1	2.177135 Wm-1K-1			Sellers, 1965
Ice	2.5 Wm-1K-1	2.5 Wm-1K-1	1883 Jm-3K-1	1.883 MJm-3K-1	Peters-Lidard et al., 1997
Ice (temp 0 degC)	0.00535 cal cm-1 sec -1 celsius-1	2.239937 Wm-1K-1			Farouki, 1981
Ice (temp -20 degC)	0.00581 cal cm-1 sec -1 celsius-1	2.43253 Wm-1K-1			Farouki, 1981
Ice (temp -20 degC)	0.00545 cal cm-1 sec -1 celsius-1	2.281805 Wm-1K-1			Farouki, 1981
Mineral-organic mixture	[0.7, 1.8] Wm-1K-1	[0.7, 1.8] Wm-1K-1			Permafrost Laboratory
Mineral-Soil(gravel)	[2.5, 3.5] Wm-1K-1	[2.5, 3.5] Wm-1K-1			Permafrost Laboratory
Mineral-Soil(Shale)	[1.0, 2.0] Wm-1K-1	[1.0, 2.0] Wm-1K-1			Permafrost Laboratory
Mineral-soil(silt)	[1.3, 2.4] Wm-1K-1	[1.3, 2.4] Wm-1K-1			Permafrost Laboratory
Organic matter	0.0006 cal cm-1 sec-1 celsius-1	0.2512079 Wm-1K-1			Sellers, 1965
Quartz	0.021 cal cm-1 sec-1 celsius-1	8.792276 Wm-1K-1			Sellers, 1965
Quartz	8.4 Wm-1K-1	8.4 Wm-1K-1	1942 Jm-3K-1	1.942 MJm-3K-1	Peters-Lidard et al., 1997
Quartz	8.4 Wm-1K-1	8.4 Wm-1K-1			Farouki, 1981
Soil minerals	2.9 Wm-1K-1	2.9 Wm-1K-1	1942 Jm-3K-1	1.942 MJm-3K-1	Peters-Lidard et al., 1997
Soil minerals	2.9 Wm-1K-1	2.9 Wm-1K-1			Farouki, 1981
Soil organics	0.25 Wm-1K-1	0.25 Wm-1K-1	2503 Jm-3K-1	2.503 MJm-3K-1	Peters-Lidard et al., 1997
Soil organics matter	0.25 Wm-1K-1	0.25 Wm-1K-1			Farouki, 1981
Water	0.00137 cal cm-1 sec-1 celsius-1	0.5735914 Wm-1K-1			Sellers, 1965
Water	0.6 Wm-1K-1	0.6 Wm-1K-1	4186 Jm-3K-1	4.186 MJm-3K-1	Peters-Lidard et al., 1997
Water	0.6 Wm-1K-1	0.6 Wm-1K-1			Farouki, 1981
West Dock	0.60 Wm-1K-1	0.60 Wm-1K-1	2.70 MJm-3K-1	2.70 MJm-3K-1	Romanovsky & Osterkamp, 1997
Units		**Wm-1K-1**		**MJm-3K-1**	
Thawed		0.25		2.503	Peters-Lidard et al., 1997
Frozen		1.375		2.193	Peters-Lidard et al., 1997
To get frozen value I took the average of soil organics and ice					

Soil Constants

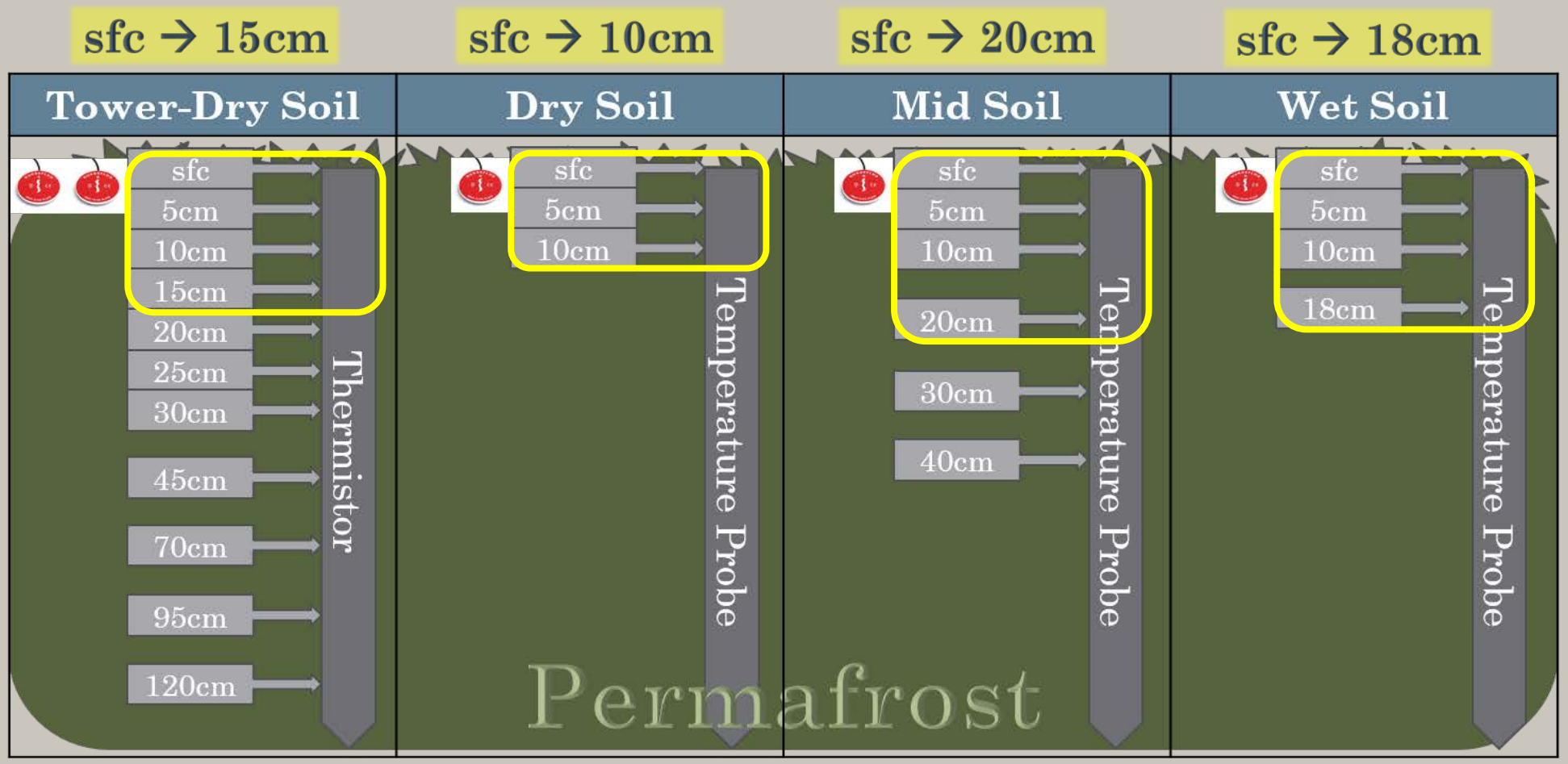
λ_s = thermal conductivity
C_s = heat capacity

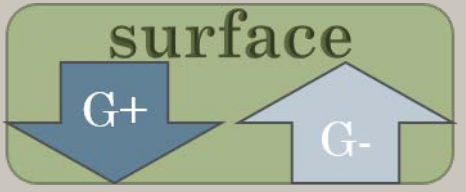
Soil organics [Peters-Lidard et al., 1997]:

λ_s = thawed = **0.25 $Wm^{-1}K^{-1}$**
C_s = thawed = **2.503 $MJm^{-3}K^{-1}$**
λ_s = frozen= **1.375 $Wm^{-1}K^{-1}$**
C_s = frozen= **2.193 $MJm^{-3}K^{-1}$**

Background photo by: Vasily Kustov

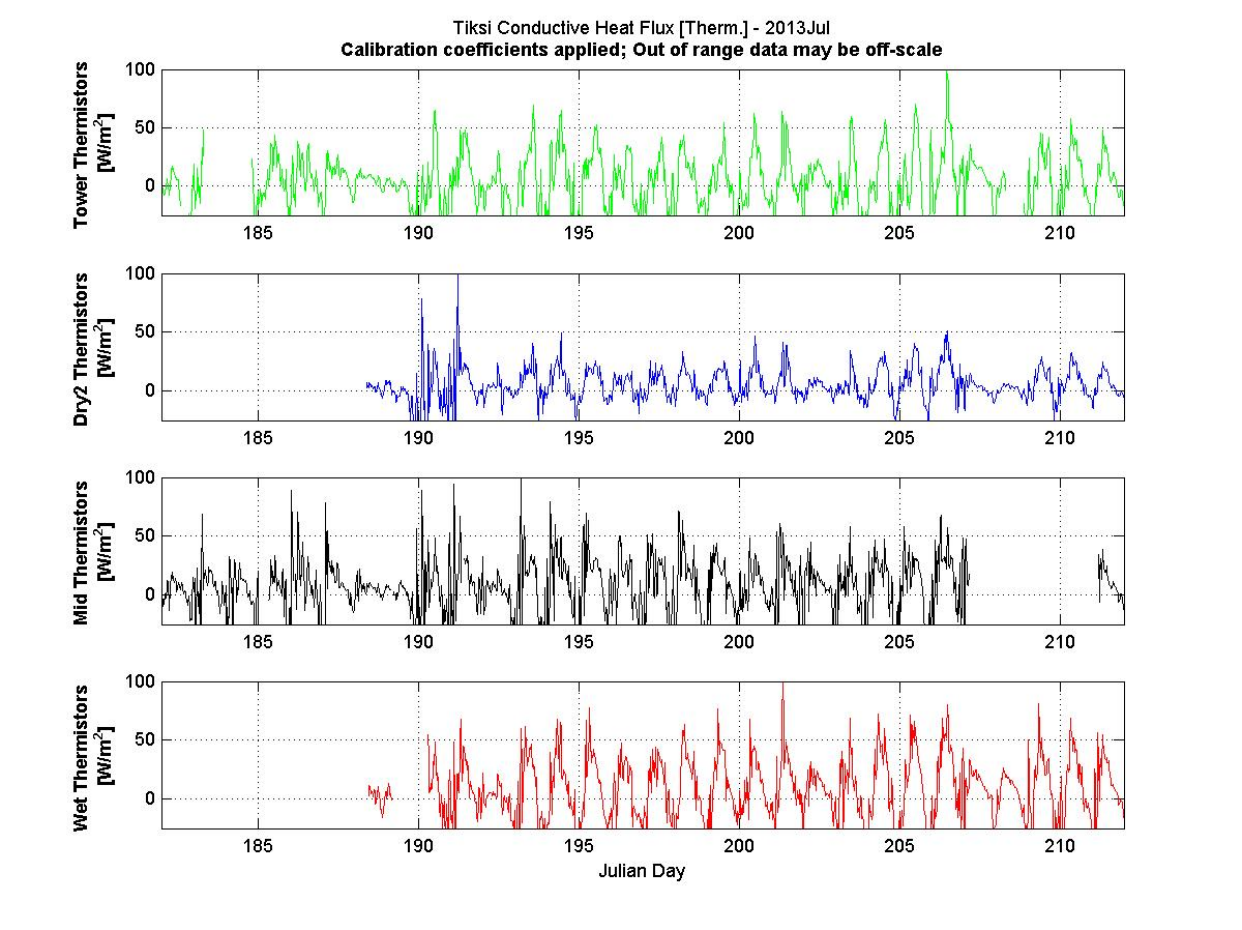
Thermistor Depths Used





Results: Thermistor

July



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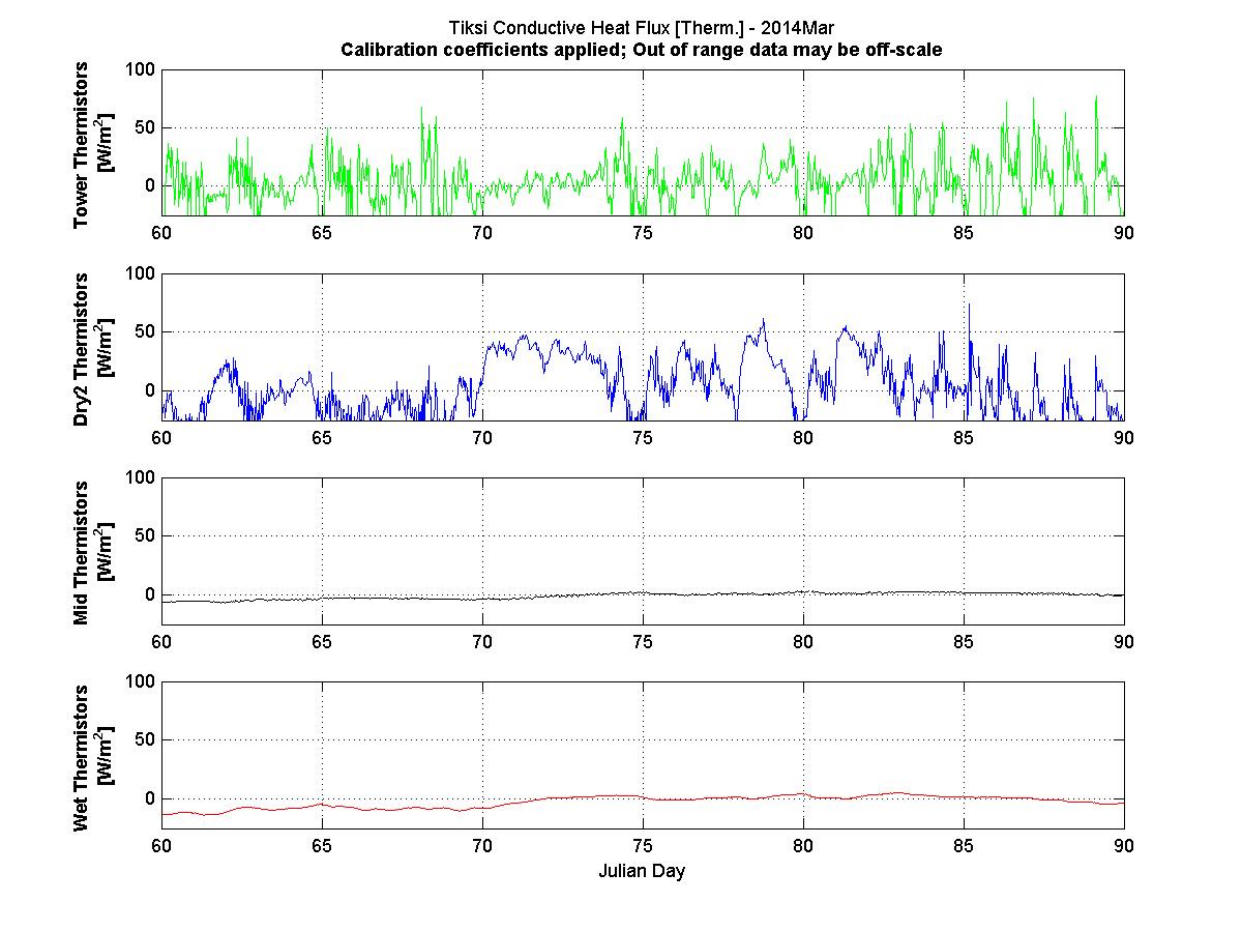
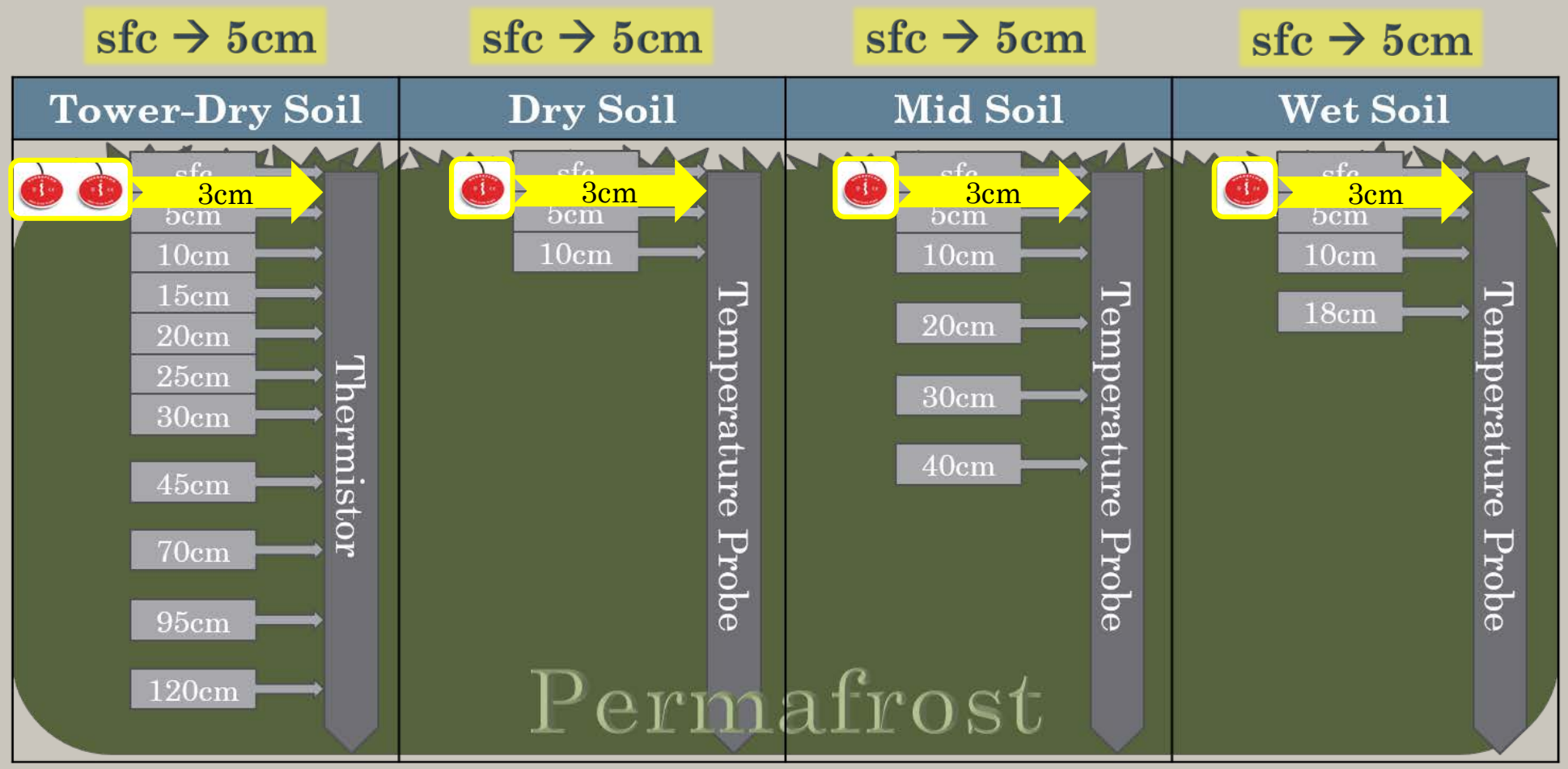
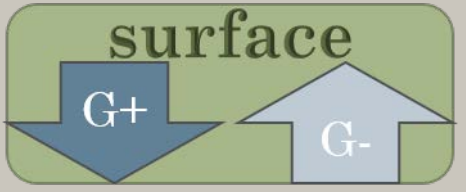


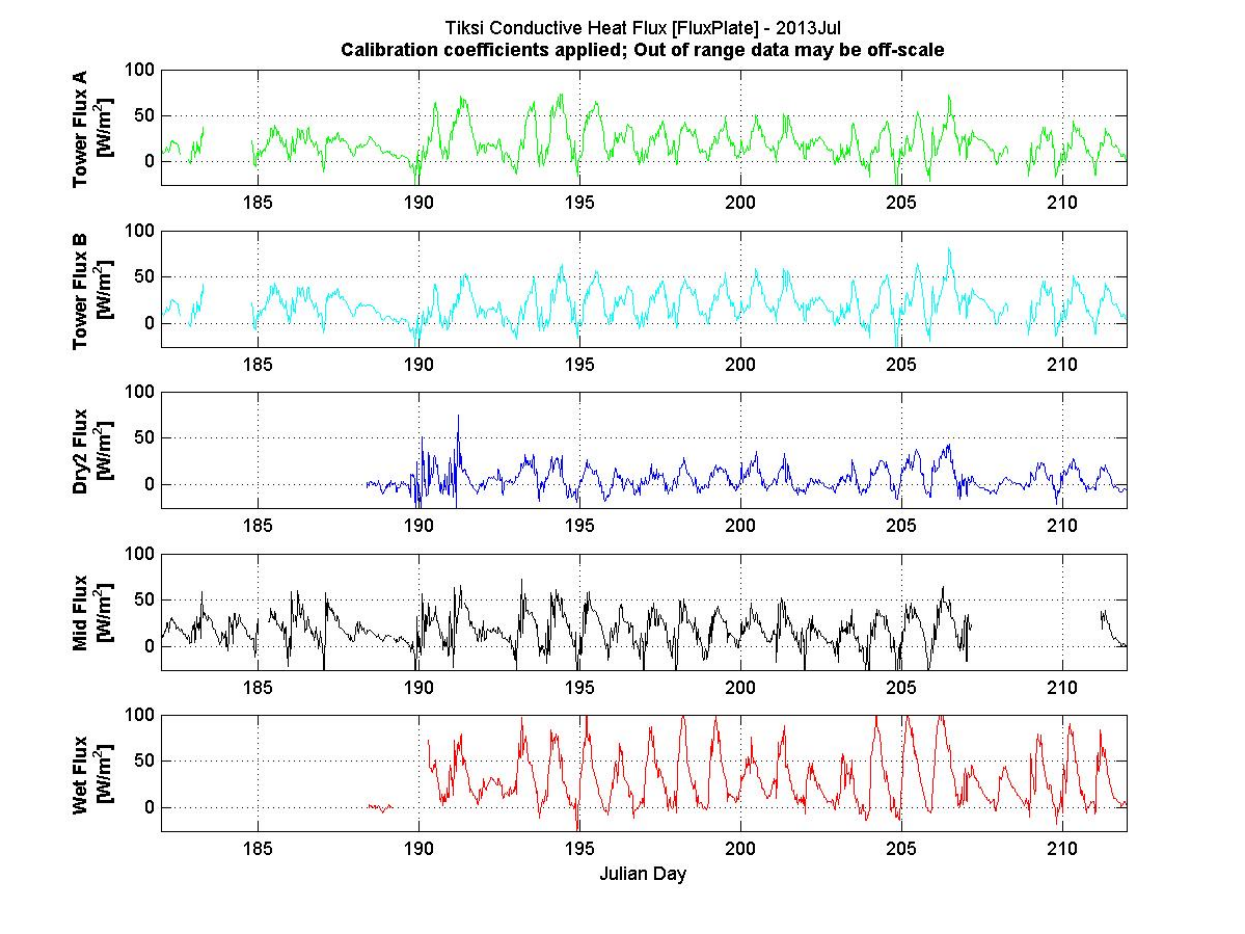
Flux Plate Depths Used



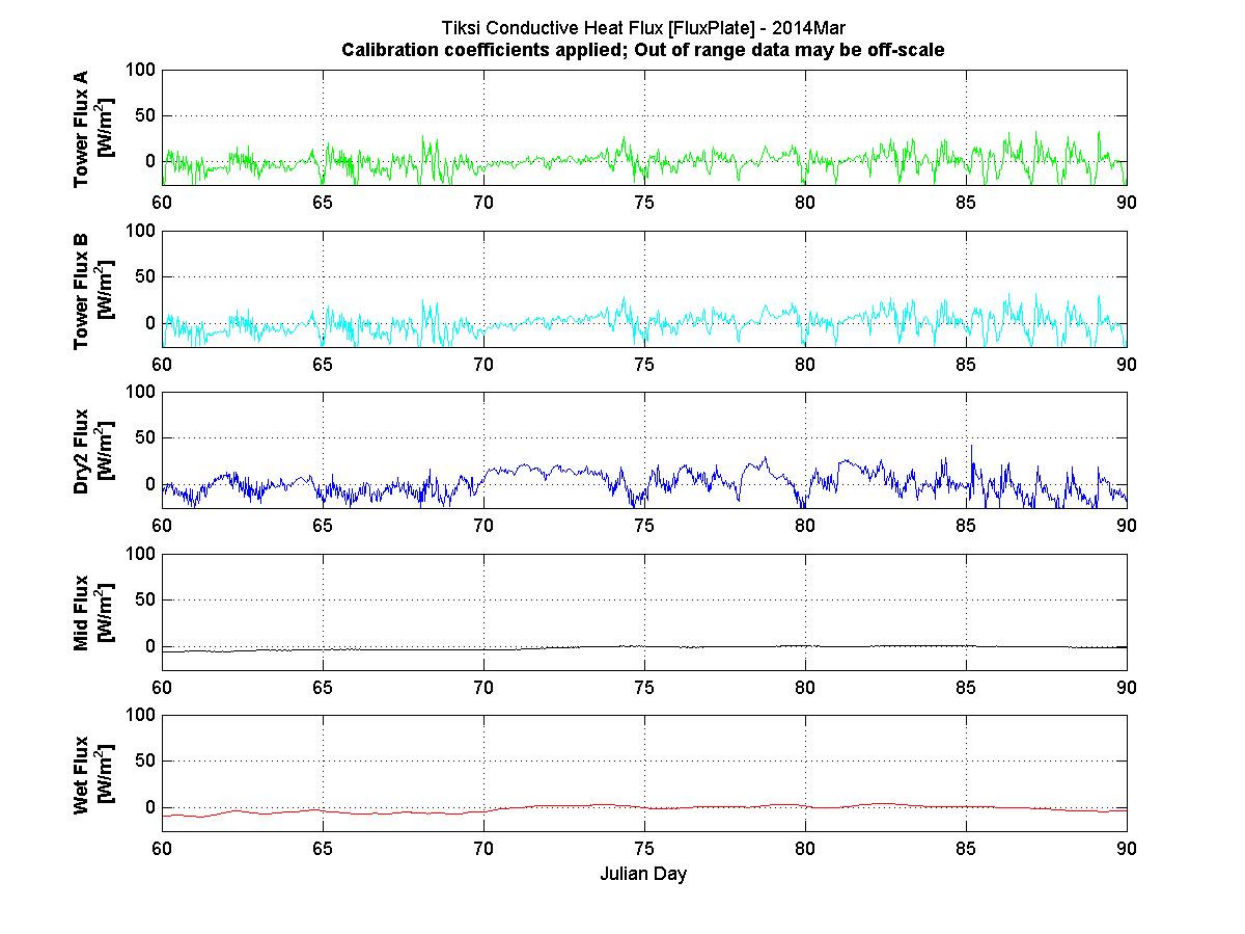


Results: Flux Plate

July

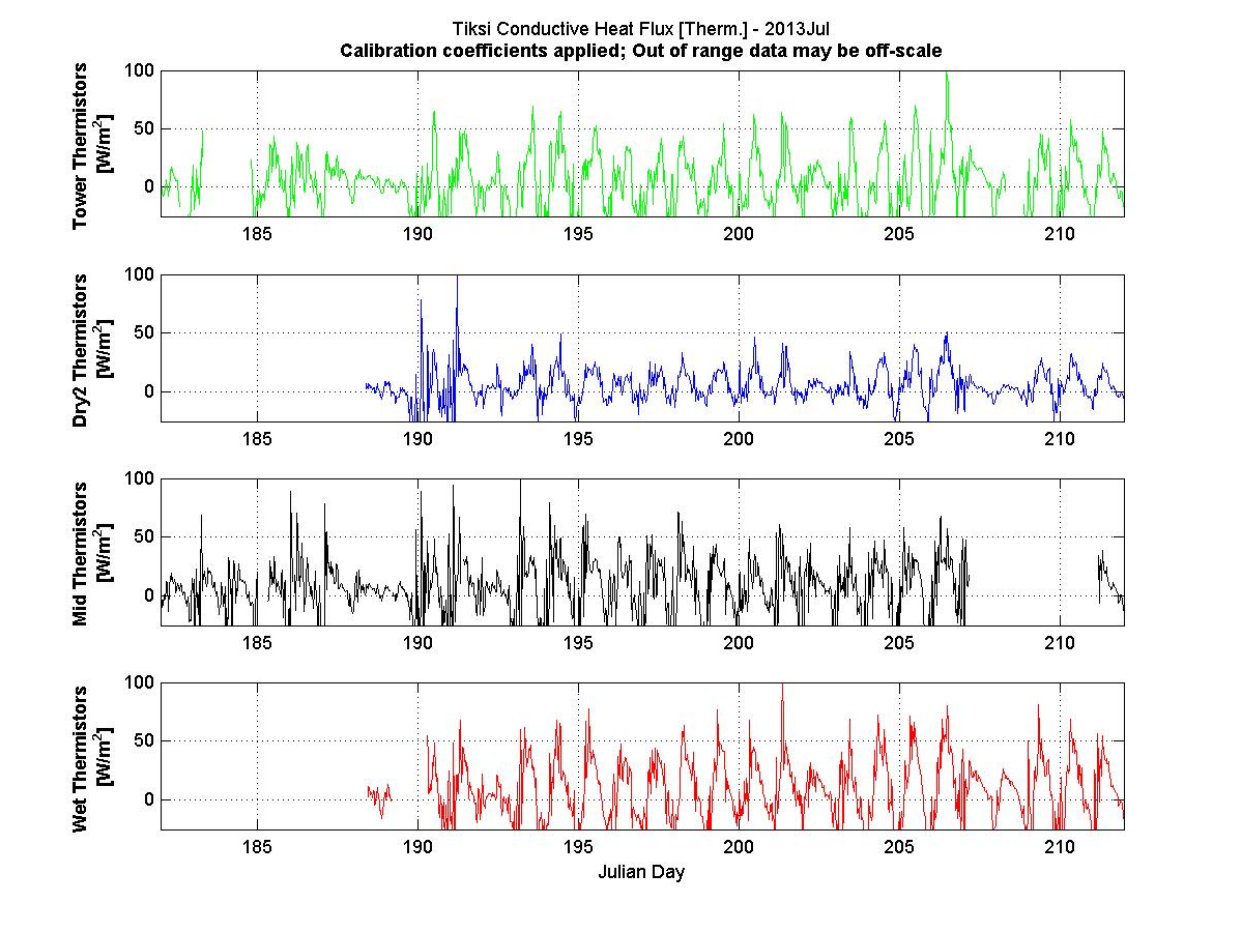


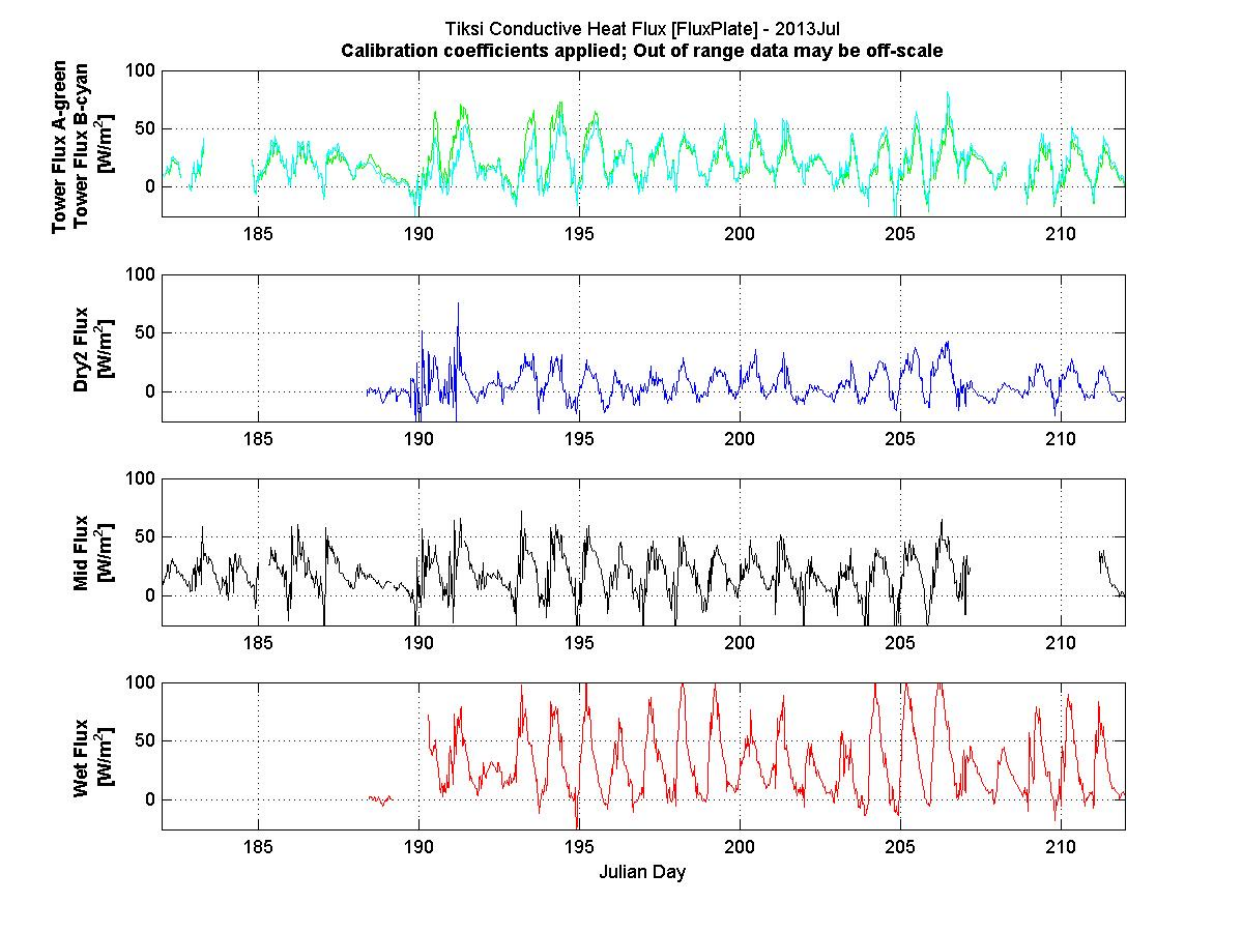
March



Thermistor vs. Flux Plate

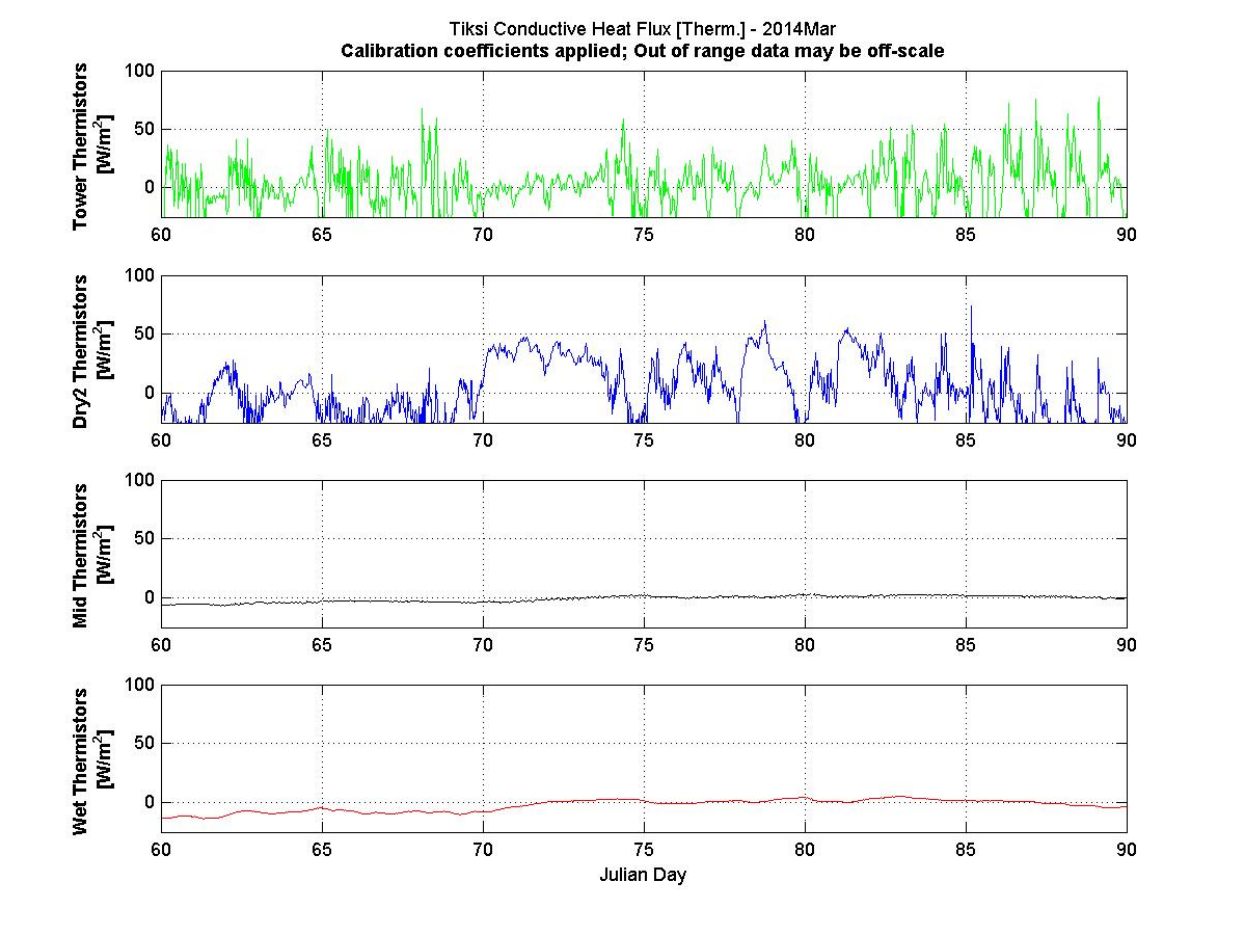
July

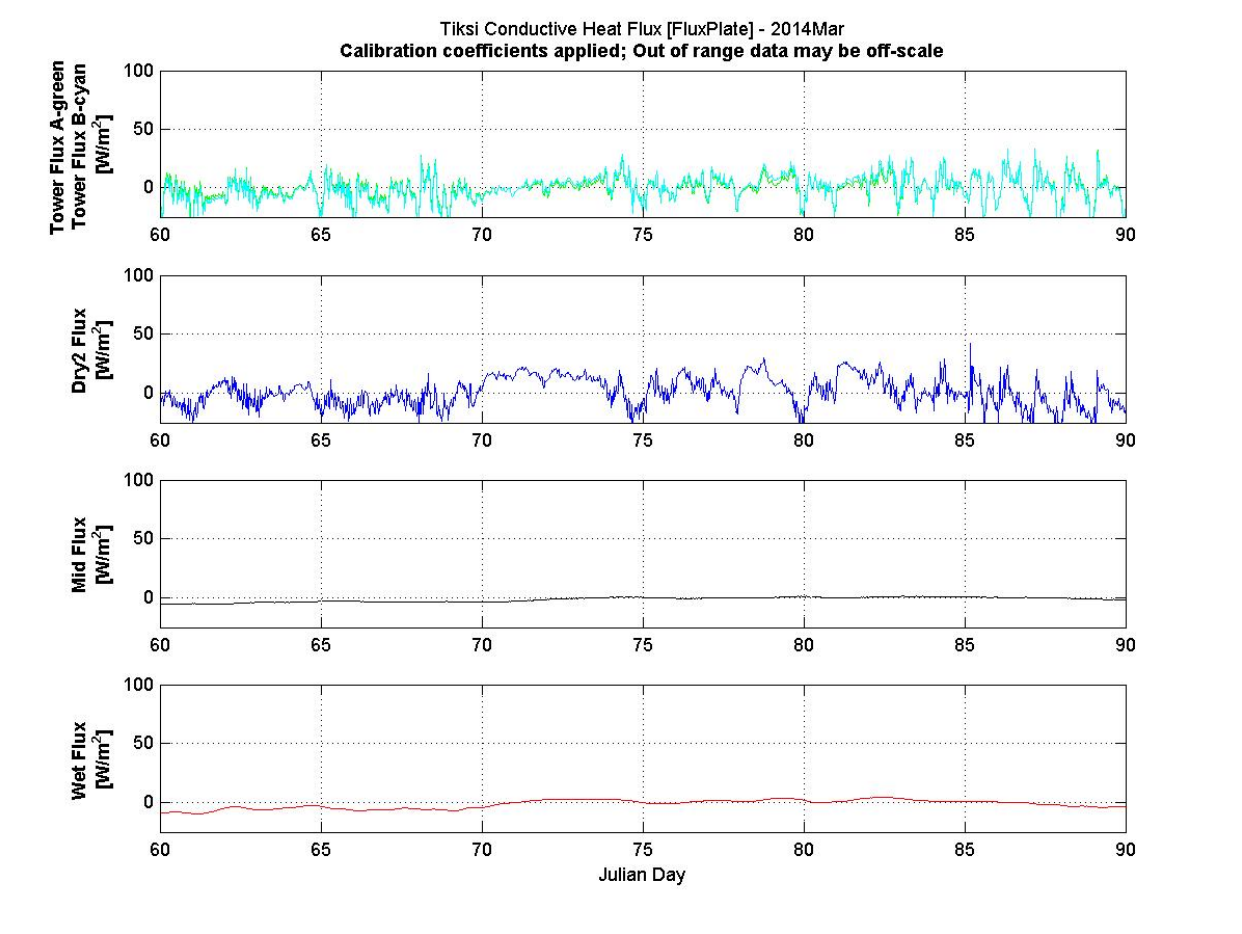




Thermistor vs. Flux Plate

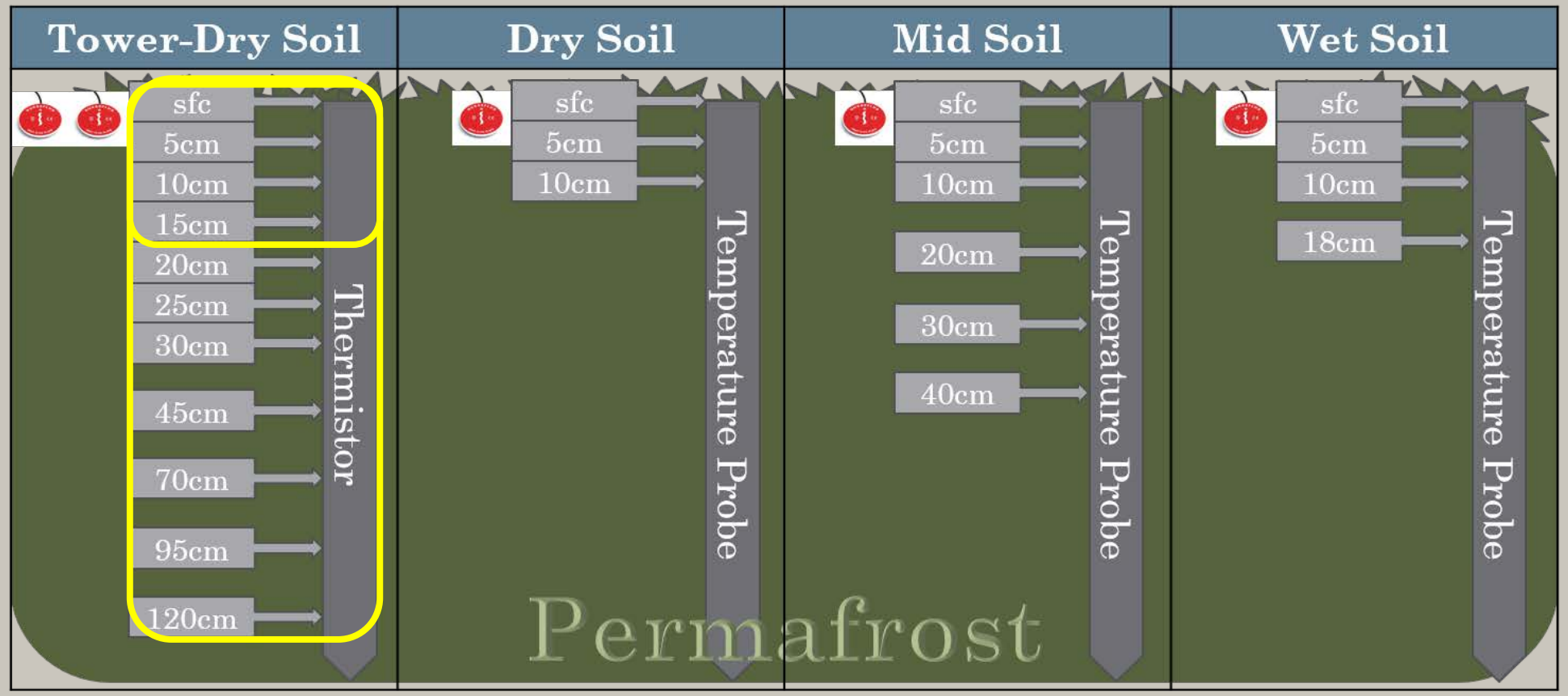
March

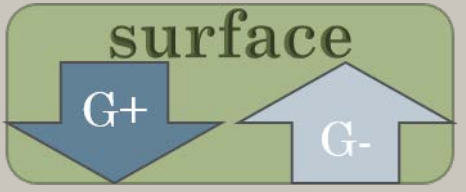




Tower Thermistor Depth Analysis

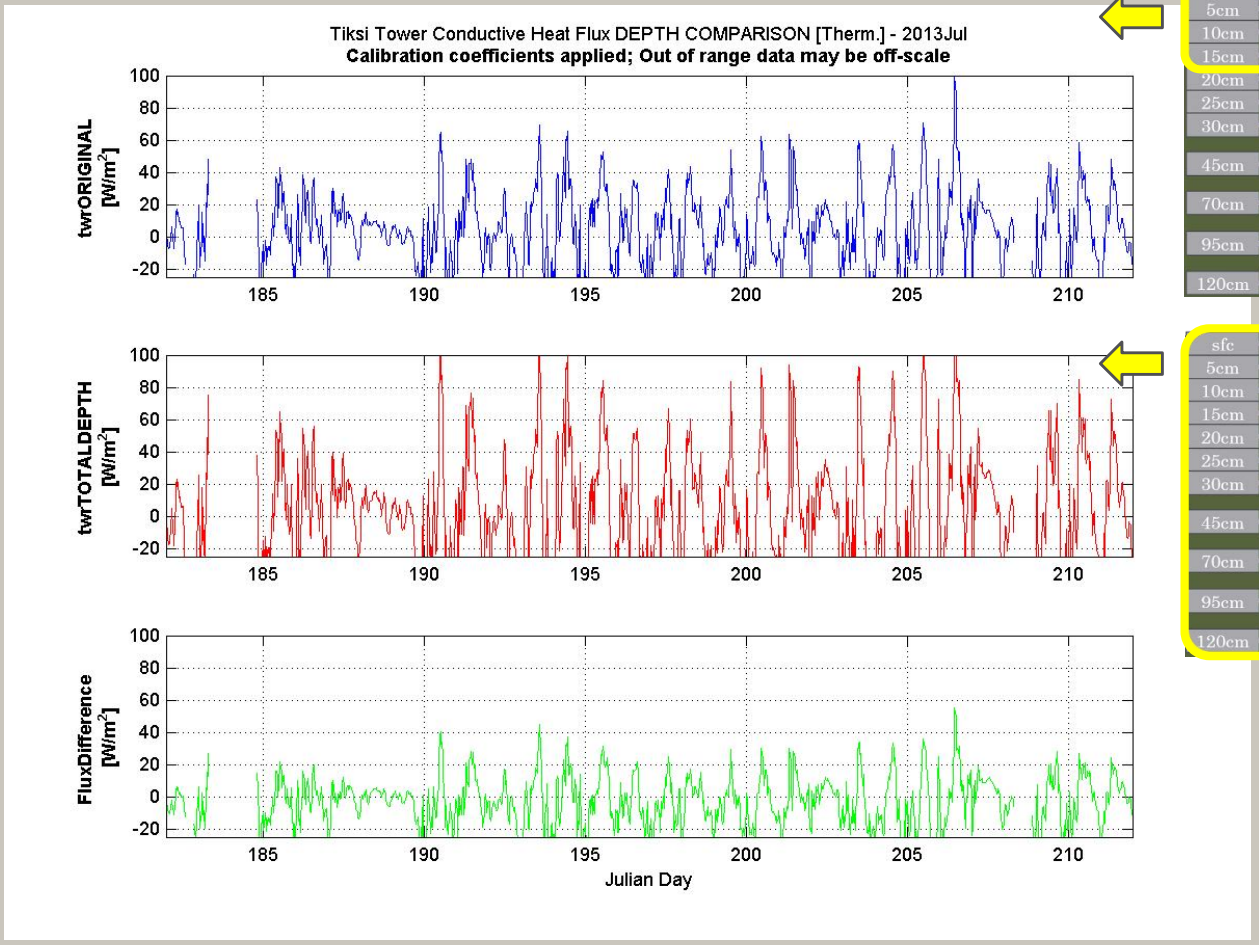
sfc → 15cm VS. sfc → 120cm

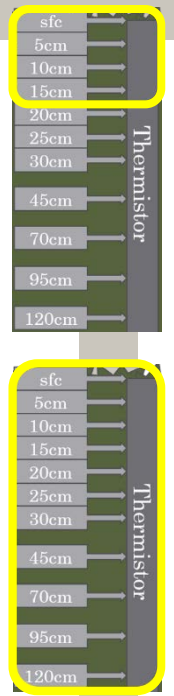




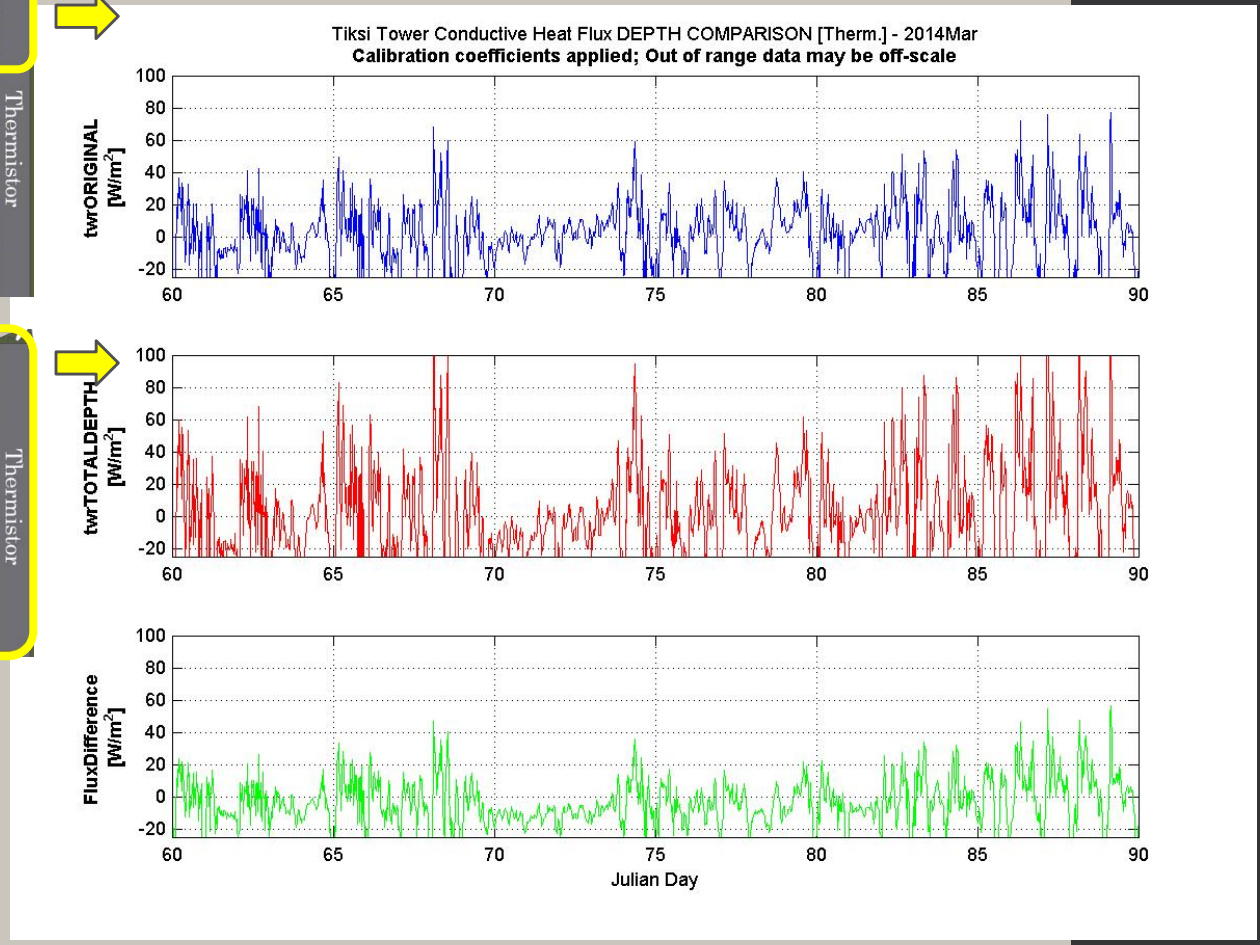
Results: Flux Depth Comparison

July



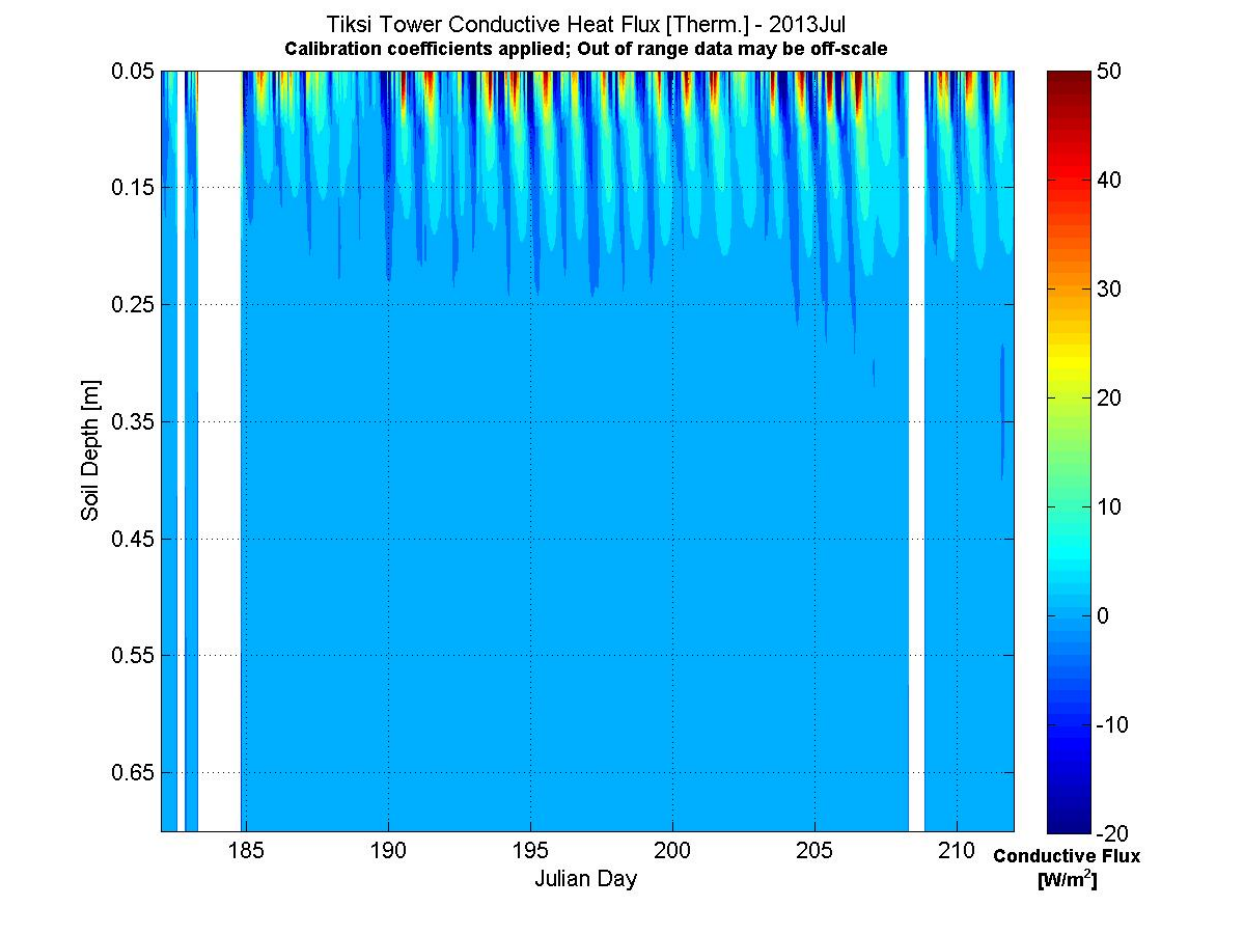


March

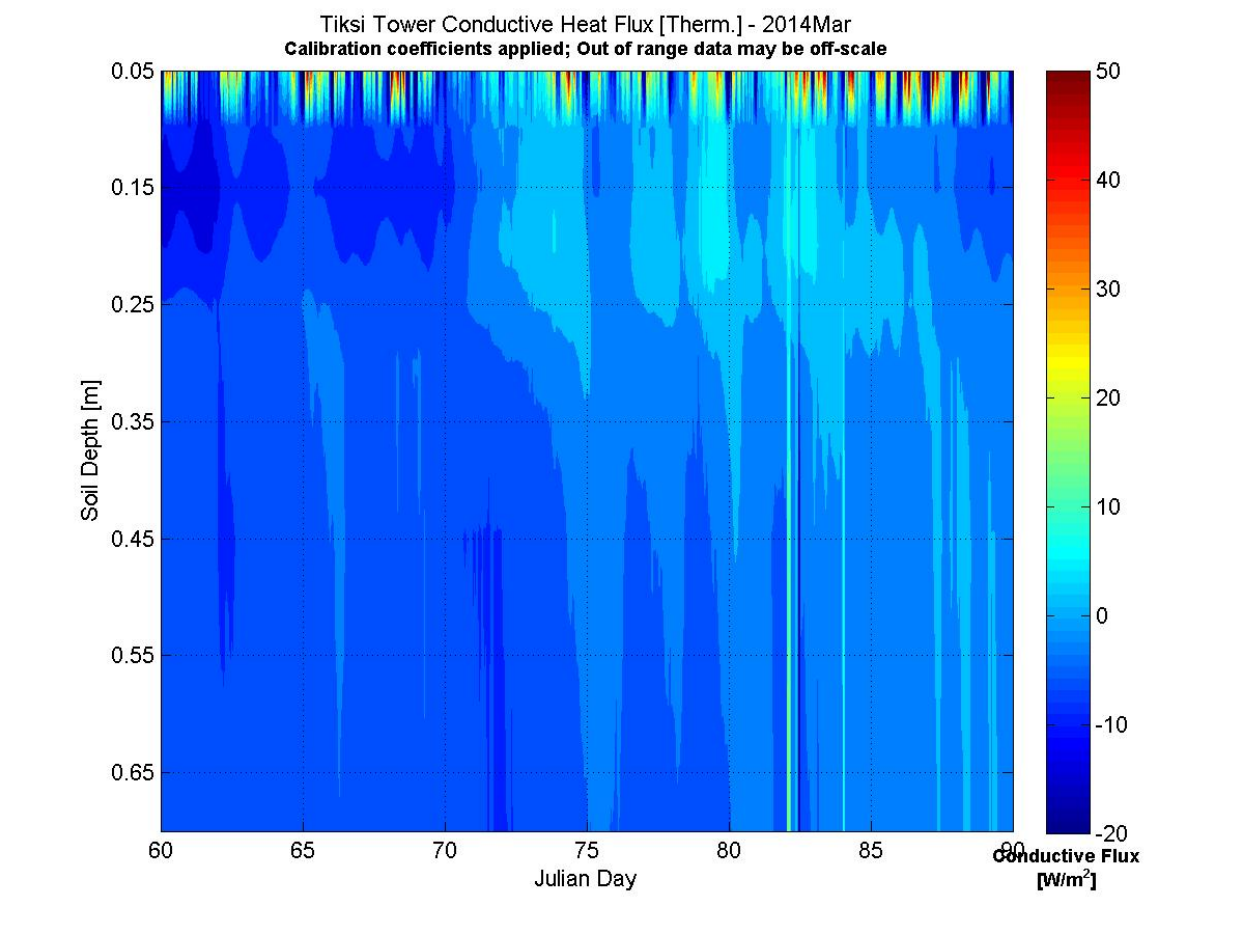


Results: Tower Thermistor Flux Distribution

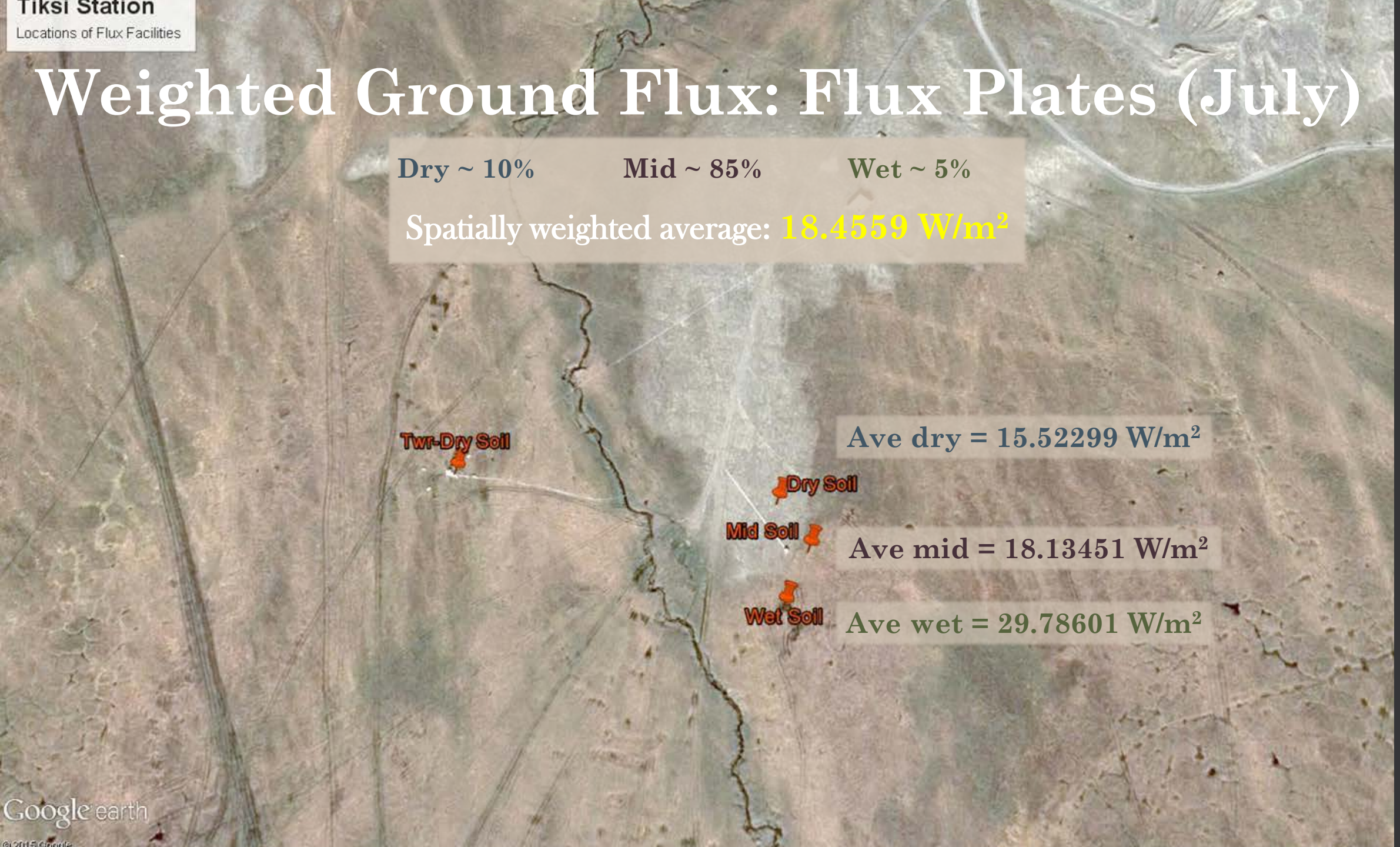
July



March



Weighted Ground Flux: Flux Plates (July)



Dry ~ 10% Mid ~ 85% Wet ~ 5%

Spatially weighted average: 18.4559 W/m^2

Ave dry = 15.52299 W/m^2

Ave mid = 18.13451 W/m^2

Ave wet = 29.78601 W/m^2

Paper: Next Steps

- Soil Constants: Heat Capacity [C_s], Thermal Conductivity [λ_s]
  - Determine soil constants for soil type (dry, mid, wet)
  - Determine soil constants for frozen or thawed permafrost conditions
- Determine best thermistor depth to generate Ground Flux value
  - How storage term changes with depth
- Apply Philips factor [f_p] to flux plates
  - Correct difference of heat conductivity [λ_s] between soil and flux plate [Liebenthal et al., 2005]

Questions?

Background photo by: Vasily Kustov