# Observationally Closing the Arctic Atmosphere-Surface Energy Budget (SEB)

## Subtext 1: Can it be done?

## Subtext 2: The Science of Observations


| | |
|---|---|
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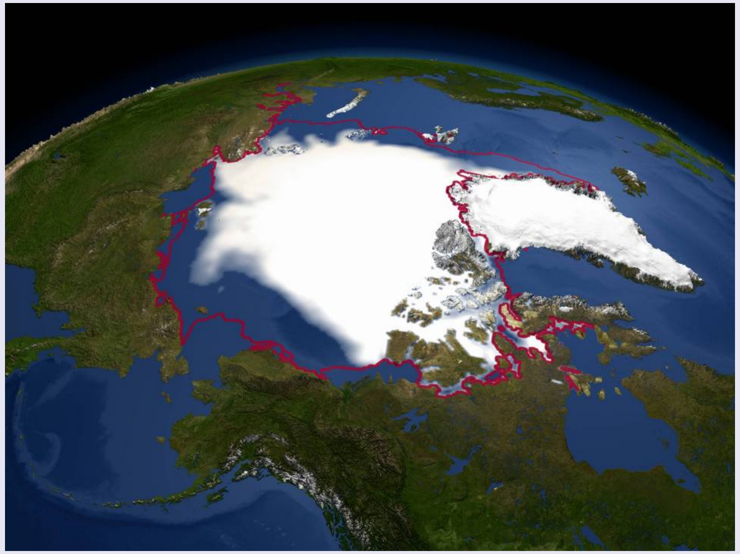
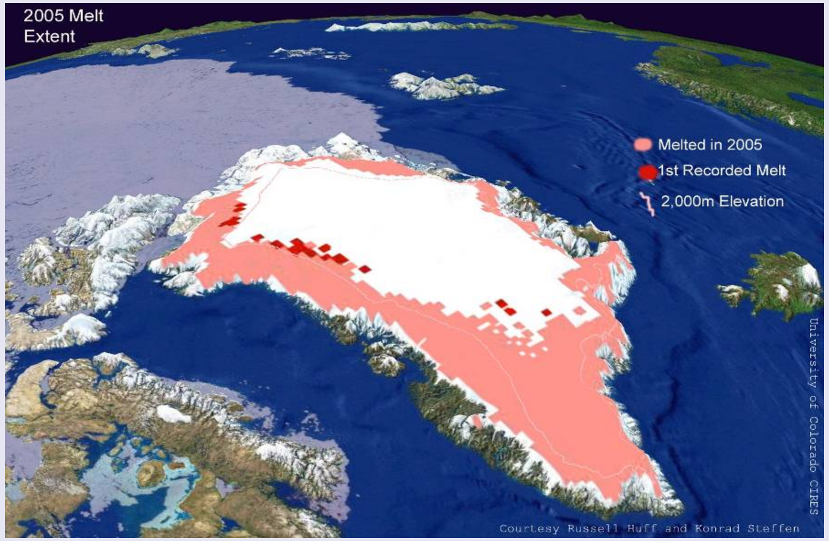
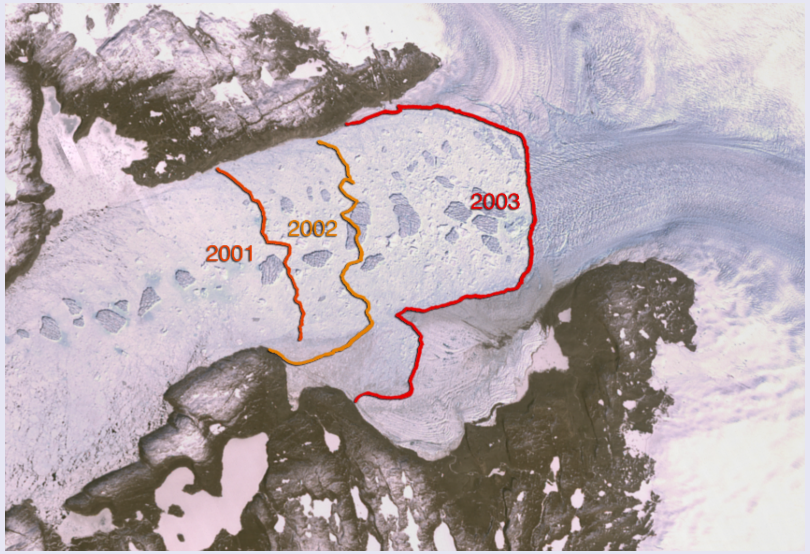
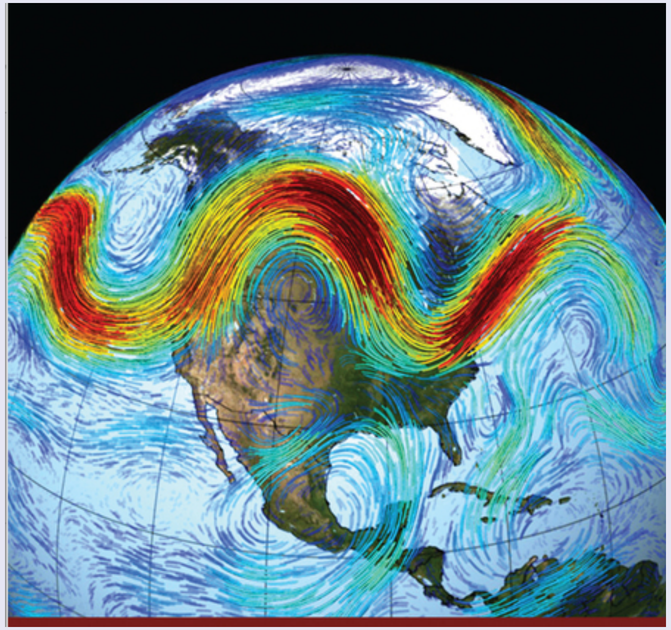
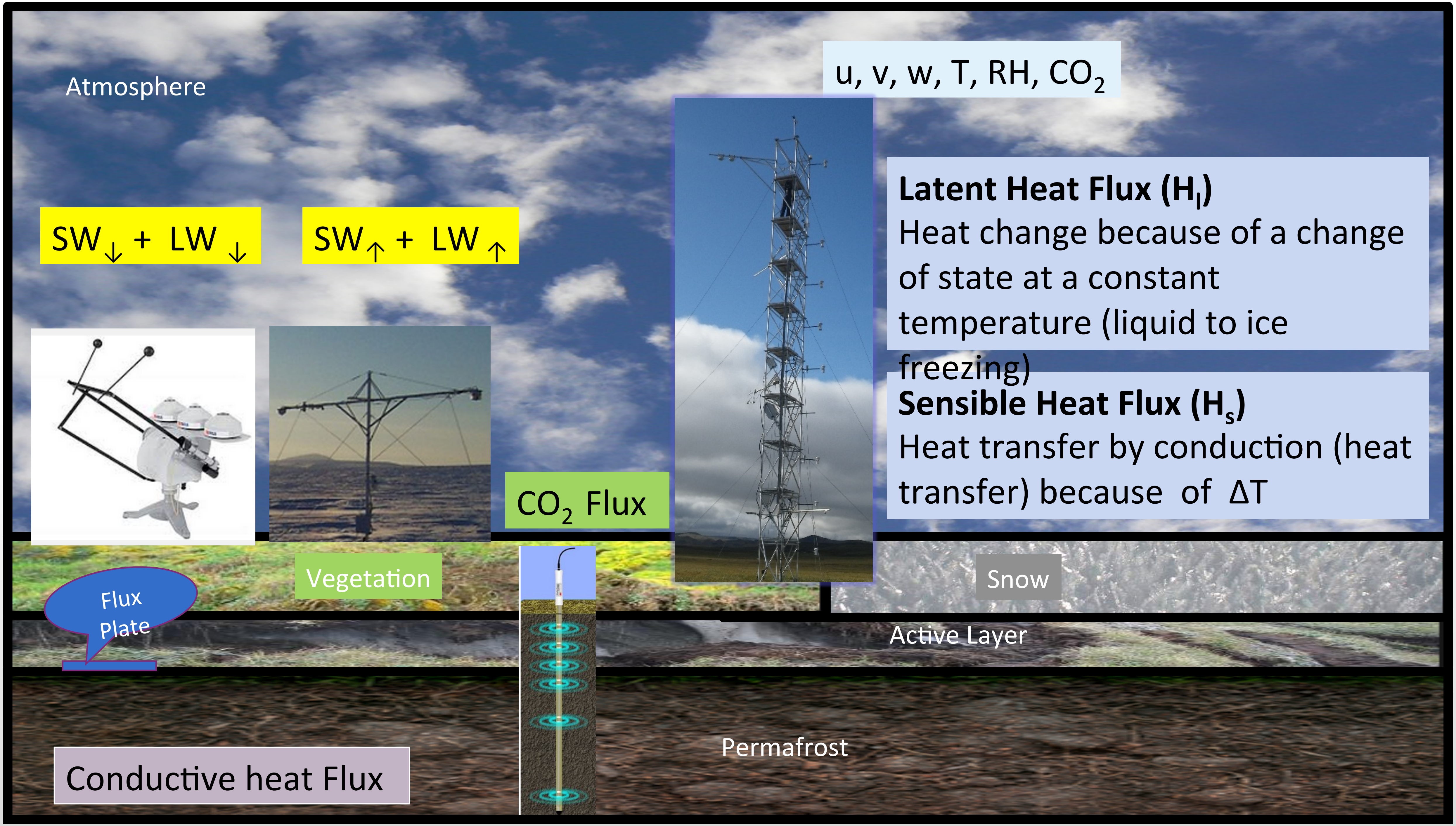
# Why the SEB is important:





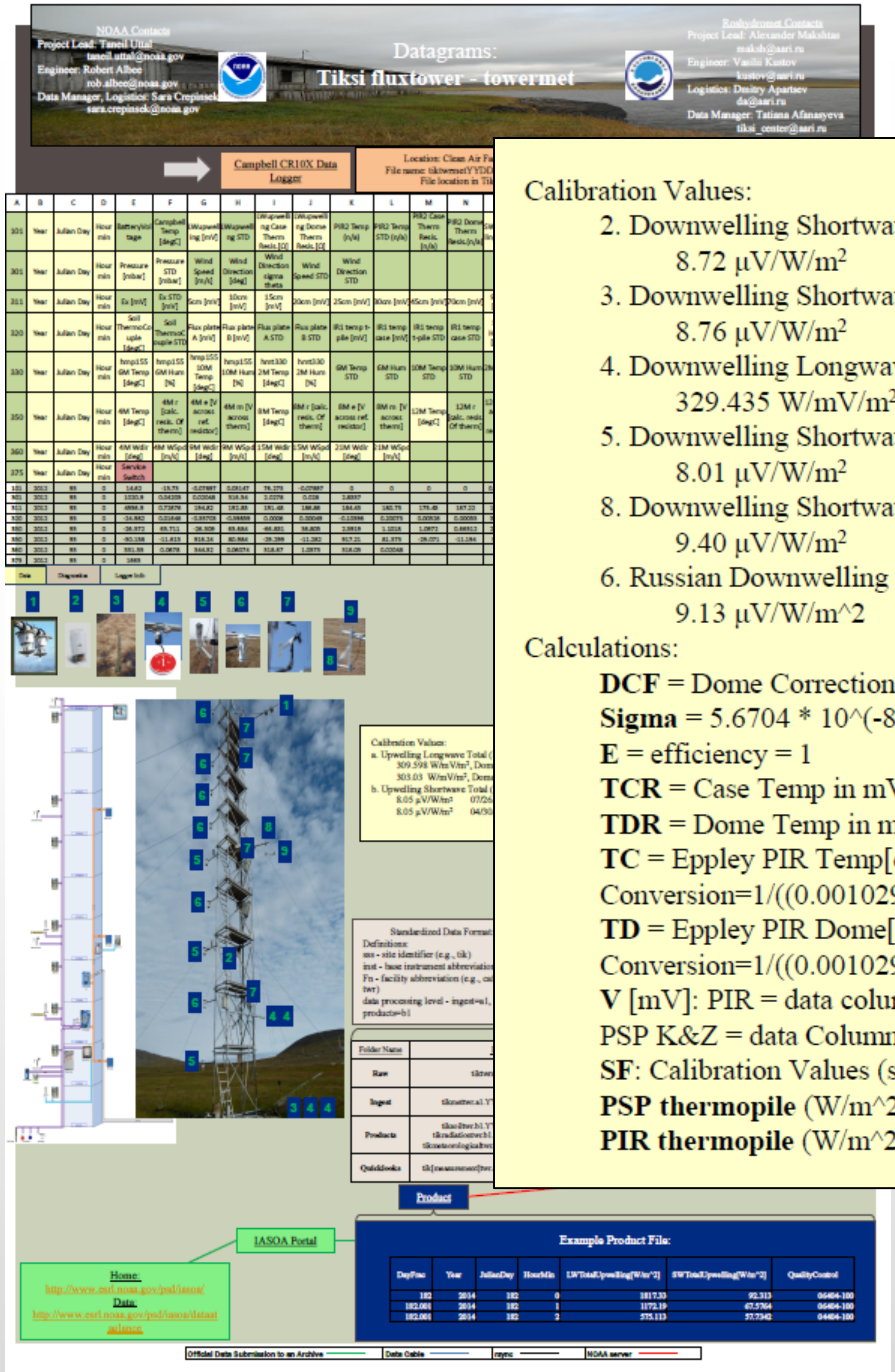



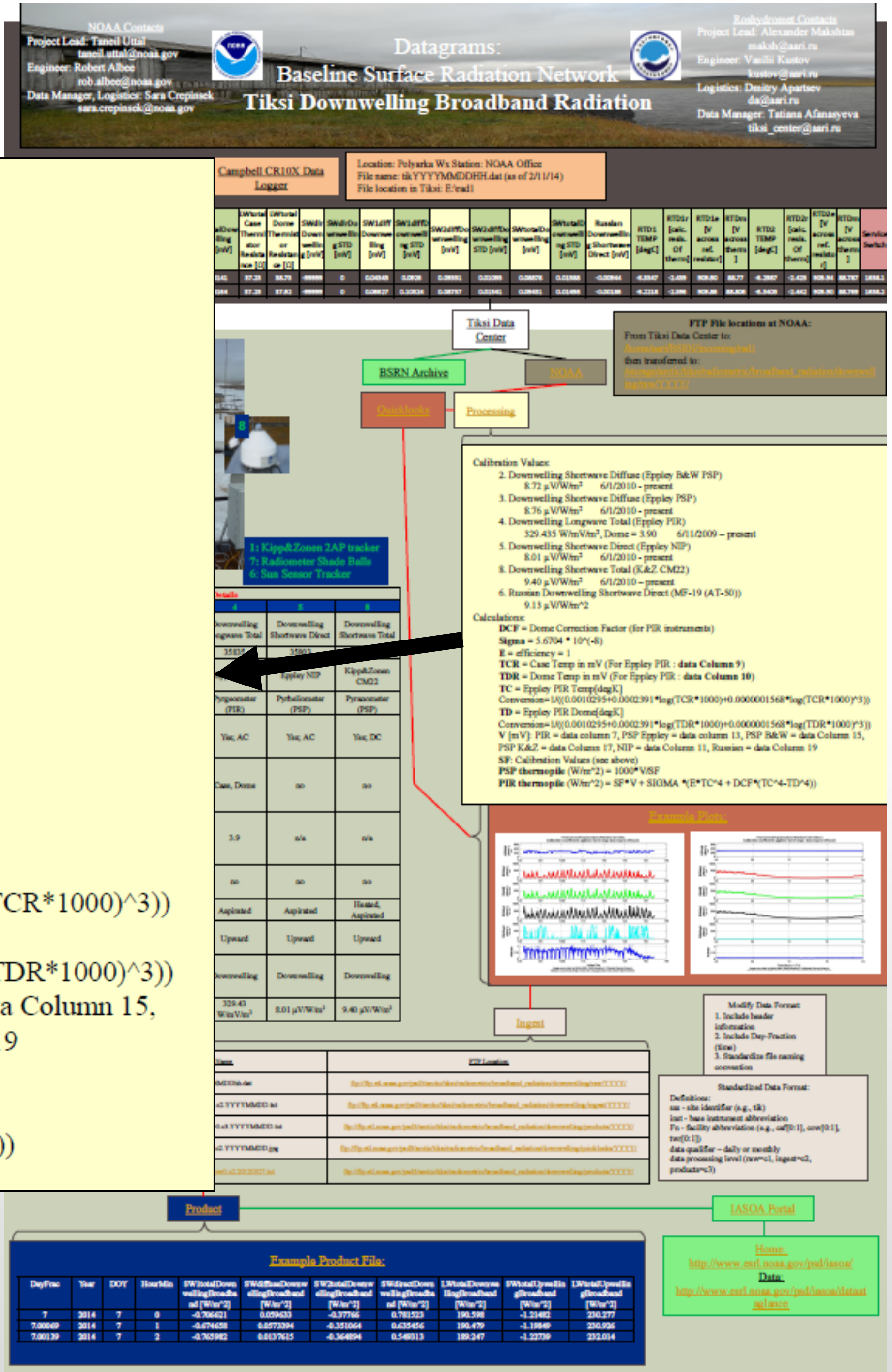





Atmosphere
u, v, w, T, RH, $CO_2$
$SW_\downarrow$ + $LW_\downarrow$
$SW_\uparrow$ + $LW_\uparrow$
Latent Heat Flux ($H_l$)
Heat change because of a change of state at a constant temperature (liquid to ice freezing)
Sensible Heat Flux ($H_s$)
Heat transfer by conduction (heat transfer) because of ΔT
$CO_2$ Flux
Vegetation
Snow
Flux Plate
Active Layer
Permafrost
Conductive heat Flux

# Datagrams




Calibration Values:

2. Downwelling Shortwave Diffuse (Eppley B&W PSP)
   8.72 $\mu V/W/m^2$ 6/1/2010 - present
3. Downwelling Shortwave Diffuse (Eppley PSP)
   8.76 $\mu V/W/m^2$ 6/1/2010 - present
4. Downwelling Longwave Total (Eppley PIR)
   329.435 $W/mV/m^2$, Dome = 3.90 6/11/2009 – present
5. Downwelling Shortwave Direct (Eppley NIP)
   8.01 $\mu V/W/m^2$ 6/1/2010 - present
8. Downwelling Shortwave Total (K&Z CM22)
   9.40 $\mu V/W/m^2$ 6/1/2010 – present
6. Russian Downwelling Shortwave Direct (MF-19 (AT-50))
   9.13 µV/W/m^2

Calculations:

**DCF** = Dome Correction Factor (for PIR instruments)
**Sigma** = 5.6704 * 10^(-8)
**E** = efficiency = 1
**TCR** = Case Temp in mV (For Eppley PIR : **data Column 9**)
**TDR** = Dome Temp in mV (For Eppley PIR : **data Column 10**)
**TC** = Eppley PIR Temp[degK]
Conversion=1/((0.0010295+0.0002391*log(TCR*1000)+0.0000001568*log(TCR*1000)^3))
**TD** = Eppley PIR Dome[degK]
Conversion=1/((0.0010295+0.0002391*log(TDR*1000)+0.0000001568*log(TDR*1000)^3))
**V** [mV]: PIR = data column 7, PSP Eppley = data column 13, PSP B&W = data Column 15, PSP K&Z = data Column 17, NIP = data Column 11, Russian = data Column 19
**SF**: Calibration Values (see above)
**PSP thermopile** (W/m^2) = 1000*V/SF
**PIR thermopile** (W/m^2) = SF*V + SIGMA *(E*TC^4 + DCF*(TC^4-TD^4))

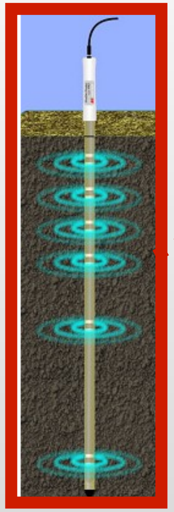
$$(SW_{net} + LW_{net}) + (Q_s + Q_l) + G = R \text{ (residual)}$$

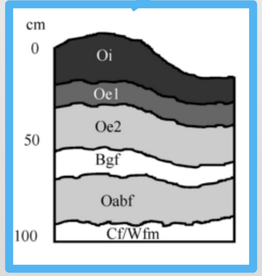
Radiation Fluxes + Turbulent Fluxes + Ground Flux

# Measuring the Arctic Atmosphere-Surface Energy Balance


- Measured
- Working on it
- Need additional obs

$$SW\downarrow + LW\downarrow + \langle Q_s\uparrow\downarrow + Q_l\uparrow\downarrow\rangle_\mu + S_{RFD}\uparrow\downarrow + \langle Q_s\uparrow\downarrow + Q_l\uparrow\downarrow\rangle_M + G\uparrow\downarrow + S_G\uparrow\downarrow + SW\uparrow\downarrow + LW\uparrow + S_P\uparrow\downarrow + S_C\uparrow\downarrow + S_S\uparrow\downarrow = 0$$




SW = Short Wave
LW = Long Wave
Q = Turbulent Fluxes
Subscripts:
s= sensible heat
l = latent heat
μ = microscale
M = mesoscale
G = Soil
S = Storage Terms
Subscripts:
RFD = Radiative Flux Divergence
G = Soil
P = Photosynthesis
C = Canopy temp
S = Snow
↑ = cooling
↓ = warming

$Q_G = G\uparrow\downarrow + S_G\uparrow\downarrow$

# Ground Flux

$$Q_G = -\lambda_s \Delta T/\Delta z - C_s \Delta T/\Delta t\,\Delta z$$

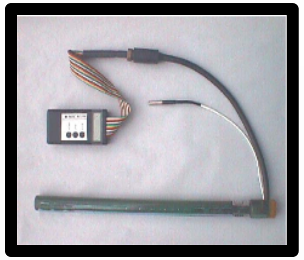
Ground Flux — Conductive Flux — Storage Term

## 1. Flux Plate instruments


$$Q_G = G\uparrow\downarrow - C_s \frac{(T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1})/2}{(t_{n+1} - t_{n-1})}(z_{05} - z_{sfc})$$

Direct Flux — Storage Term

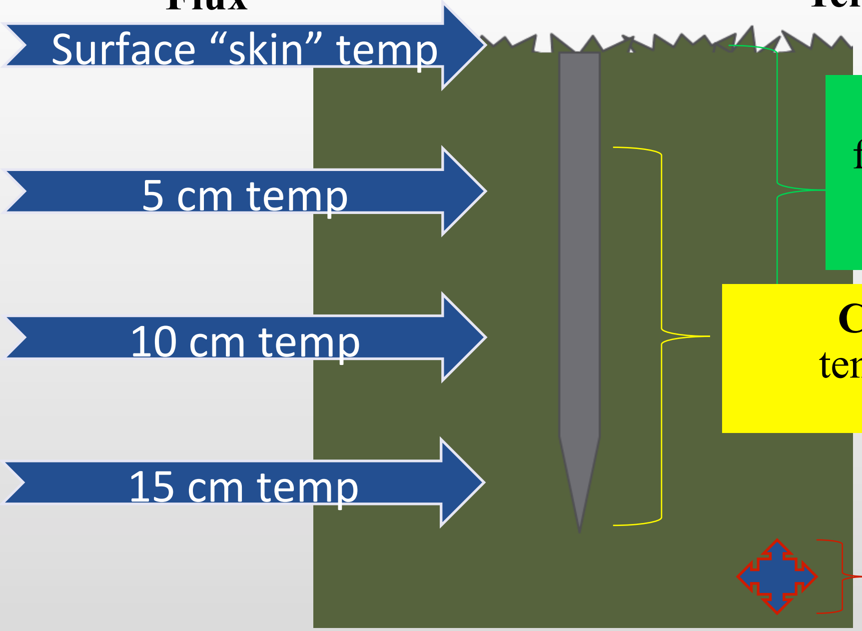
## 2. Thermistor instruments



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

Direct Flux — Storage Term

Issue: Accurate measurements of $C_s$ (soil heat capacity) and $\lambda_s$ (soil conductivity)




**Storage Term:** accounting for any stored energy in layer near surface layer ablove highest T measuremet

**Conductive Flux:** temperature gradient measurements

**Soil Constants:**

soil thermal conductivity, soil heat capacity

## $Q_s$ ↑↓ + $Q_l$ ↑↓ (μ) (M)

# Turbulent Fluxes

**Calculations with eddy covariance methods**

$$\tau = -\rho < w'u' >$$

$$H_S = \rho C_P < w'\theta' >$$

$$H_L = \rho L < w'q' >$$

- Double axis rotation for sonic anemometer tilt correction
- Linear detrending of raw time series (*Kaimal and Finnigan, 1994*)
- Compensation for air density fluctuations (*Webb et al., 1980)*
- Statistical tests for raw time series data (*Vickers and Mahrt, 1997*)
    - *Spike count/removal (Mauder et al., 2013)*
    - *Amplitude resolution*
    - *Dropouts*
    - *Absolute limits*
    - *Skewness and kurtosis*
    - Angle of attack
    - Steadiness of horizontal wind

Issue: Continuity of methodology and large scale advection fluxes

**Estimates with gradient and bulk methods**

$$\tau = \rho K_M (\partial \bar{u} / \partial z)$$

$$H_S = -\rho C_P K_H (\partial \bar{\theta} / \partial z)$$

$$H_L = -\rho L K_W (\partial \bar{q} / \partial z)$$

where according to Monin - Obukhov Similarity Theory

$$K_M = k u_* (z - d) / \phi_m(\zeta)$$

$$K_H = k u_* (z - d) / \phi_h(\zeta)$$

$$K_W = k u_* (z - d) / \phi_w(\zeta)$$

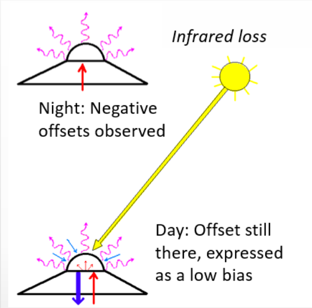
- Fluxes are driven by gradients in u, T, and q
- Fluxes are proportional to friction velocity
- These are simply definitions of KM, KH, KW
- Ohm's Law combined with Similarity

# SW↓ + LW↓ + SW↑↓ + LW↑ Radiation Fluxes

SWD (K-Z CM22), DIFFUSE (Eppley PSP), DIRECT (Eppley (NIP), SWU (Eppley PSP), LWD/LWU (Eppley PIR)

## Quality Control - QCRAD” (Long and Shi 2008)

- “Uses fluxes, 2m temperature, 2m RH (common to all BSRN stations). Primary assumption is that most of the data is “good”.
- Physically possible limits, climatological configurable limits based on relationships between variables.
- Applies correction for IR loss in shortwave measurements (Shi and Long 2007)
- SWD is combination of DIR+DIFF (“SUM”) and GLOBAL: SUM whenever available.





## CALIBRATION

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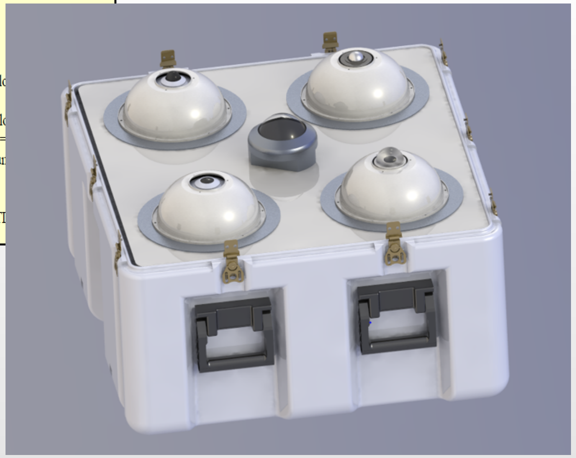


## ICING

**Issues: quality control, calibration and icing**

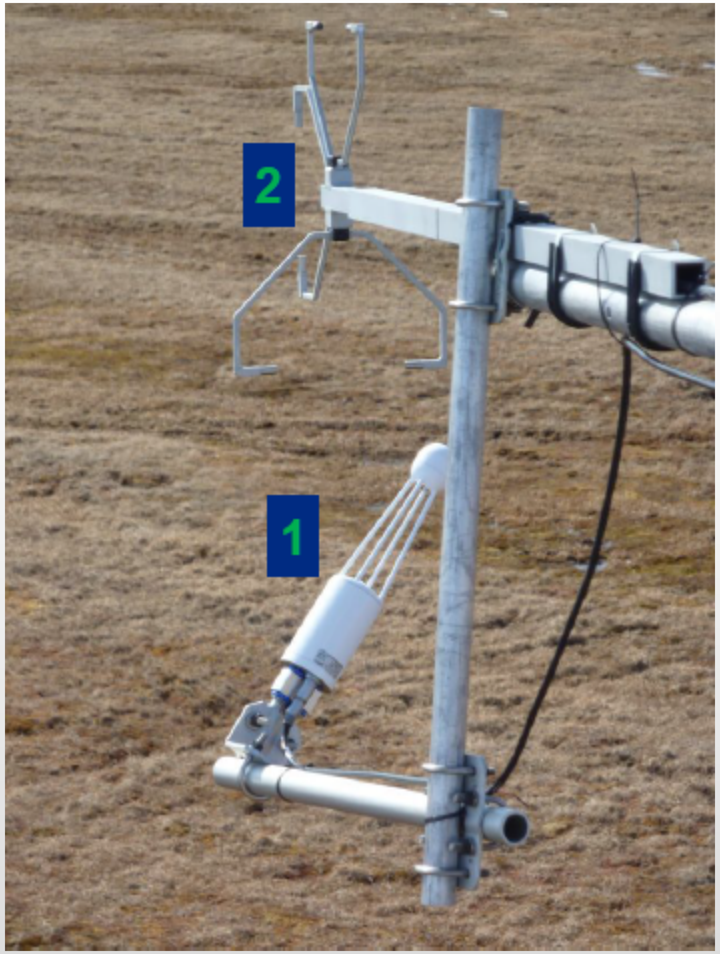
$S_P \uparrow\downarrow + S_C \uparrow\downarrow$

# Vegetation Fluxes and Storage

How much energy is stored by photosynthesis? 479 kJ of energy is stored per mole of $CO_2$ fixed into photosynthetic products. For example, a canopy assimilation rate of 10 [\mu mol/m^2 s] equates to energy flux of 4.79 ~ 5 [W/m^2]. The photosynthesis storage term (as well as the storage term because of changes in leaf temperature) is relatively small but important for understanding impacts of the changing climate on the ecosystem.

- (Nobel P.S. (1991) "Physicochemical and Environmental Plant Physiology" (Chapter 7.1, page 321)

Issue: need better integration with ecosystem colleagues

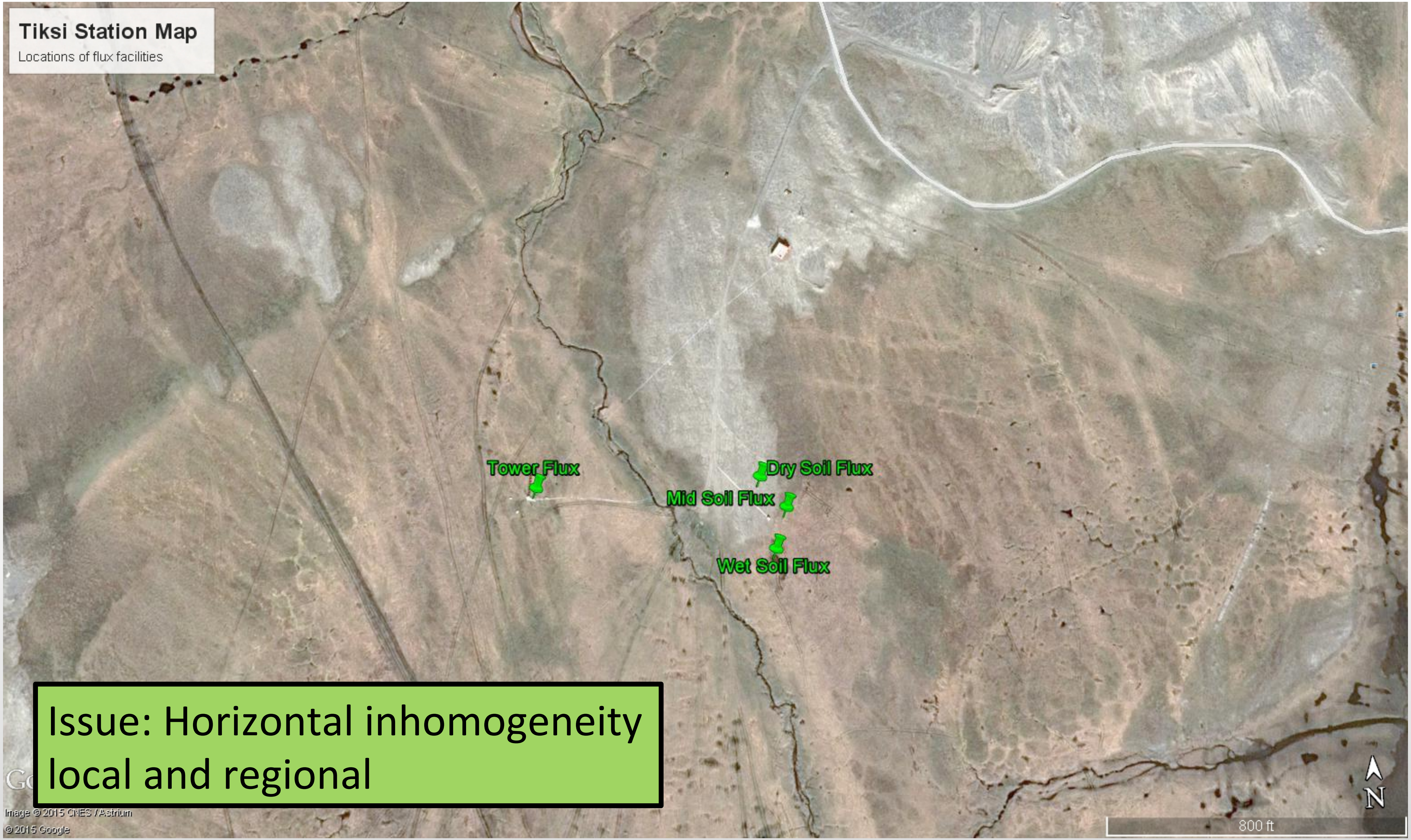


$S_s$ ↑↓

# Snow Fluxes and Storage

- Storage through freeze/melt processes
- Snow chemistry as a source sink of CO2 Fluxes

Issue: need better integration with snow physicists




Issue: Horizontal inhomogeneity local and regional

# Specialist: Ground Flux and Storage

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| Site Description | Thermal Conductivity [ ] | Thermal Conductivity Conversion | Heat Capacity [C] | Heat Capacity Conversion | Author/Paper |
|---|---|---|---|---|---|
| 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 |
| 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 |
| Quartz | 0.021 cal cm-1 sec-1 celsius-1 | 8.792276 Wm-1K-1 | | | Sellers, 1965 |
| Clay minerals | 0.007 cal cm-1 sec-1 celsius-1 | 2.930759 Wm-1K-1 | | | Sellers, 1965 |
| Organic matter | 0.0006 cal cm-1 sec-1 celsius-1 | 0.2512079 Wm-1K-1 | | | Sellers, 1965 |
| Water | 0.00137 cal cm-1 sec-1 celsius-1 | 0.5735914 Wm-1K-1 | | | Sellers, 1965 |
| Ice | 0.0052 cal cm-1 sec-1 celsius-1 | 2.177135 Wm-1K-1 | | | Sellers, 1965 |
| Air | 0.00006 cal cm-1 sec-1 celsius-1 | 0.02512079 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 |
| 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 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 |
| 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 |
| 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 |
| 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 |
| Mineral-organic mixture | [0.7, 1.8] Wm-1K-1 | [0.7, 1.8] Wm-1K-1 | | | Permafrost Laboratory |
| Mineral-soil(silt) | [1.3, 2.4] Wm-1K-1 | [1.3, 2.4] 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 |
| 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 | | | Farouki, 1981 |
| Soil organics matter | 0.25 Wm-1K-1 | 0.25 Wm-1K-1 | | | Farouki, 1981 |
| Water | 0.6 Wm-1K-1 | 0.6 Wm-1K-1 | | | Farouki, 1981 |
| Air | 0.026 Wm-1K-1 | 0.026 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 |
| Ice (temp 0 degC) | 0.00535 cal cm-1 sec -1 celsius-1 | 2.239937 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 |
| 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 |
| **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** | | | | | |

Specialist: TurbulenceTerms

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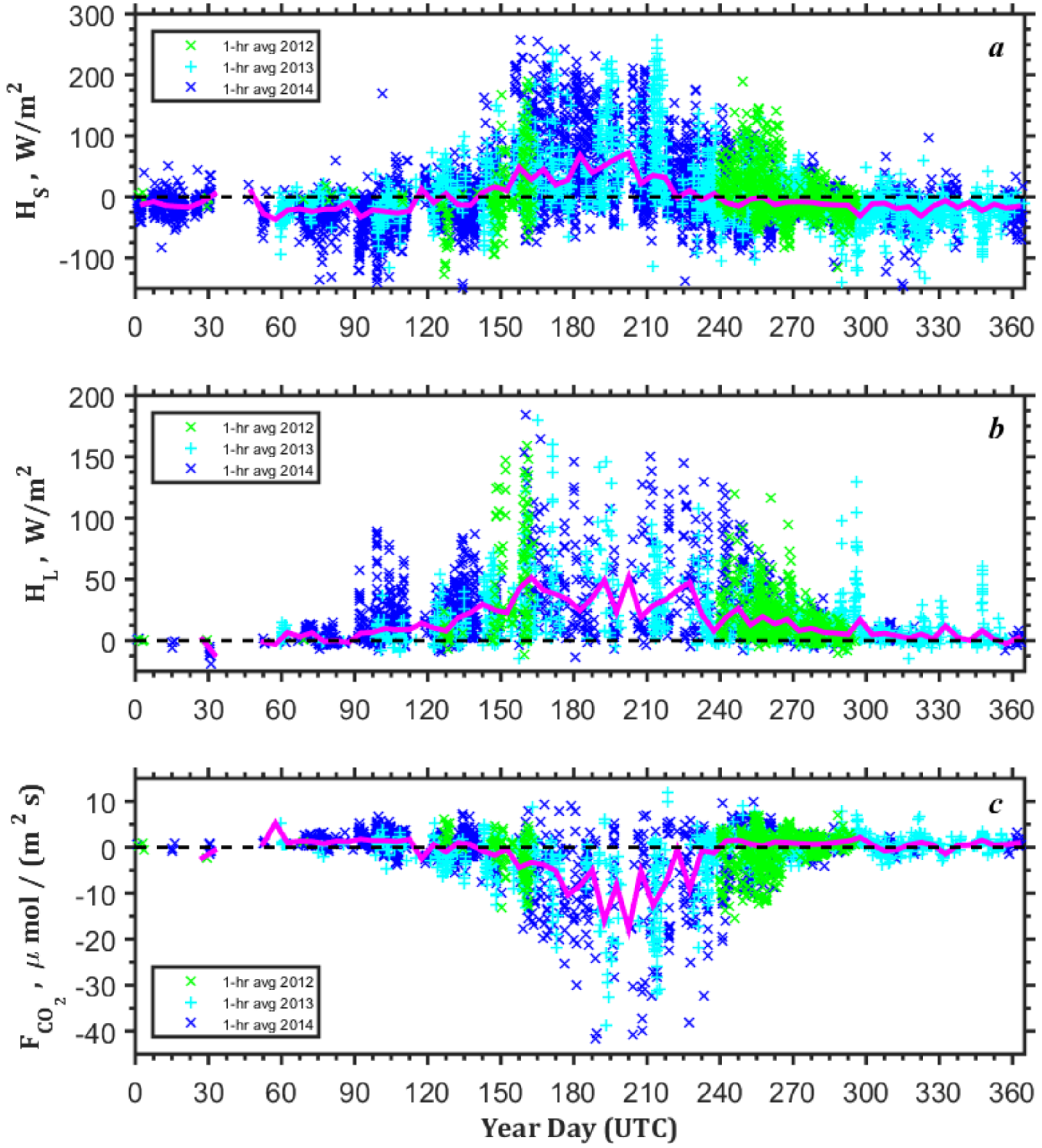
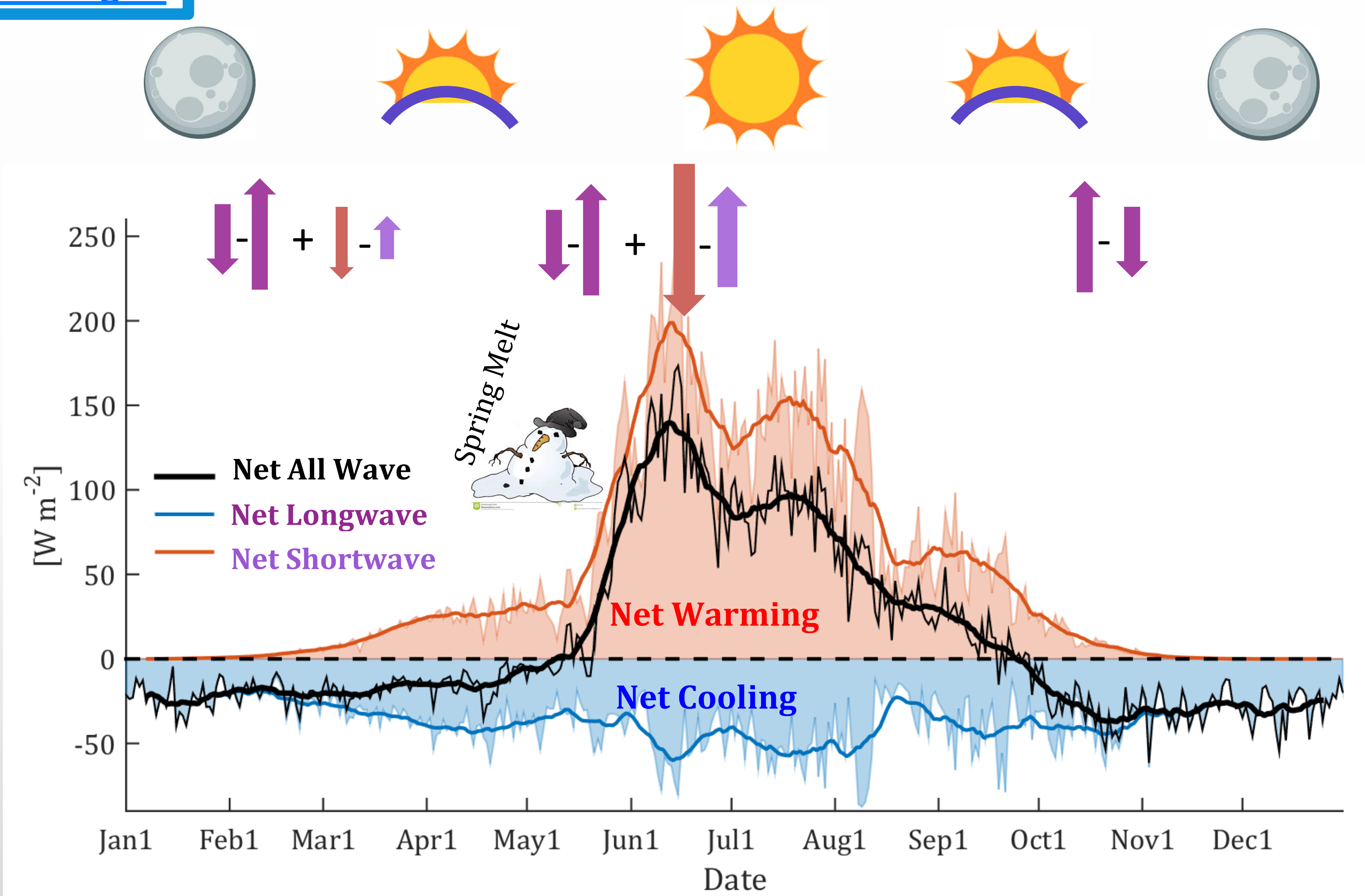


Specialist: Radiation Terms
christopher.j.cox@noaa.gov

# Net Radiation Budget, Tiksi 2012-2014



# SUMMARY

- Models without observations are video games

  Kathy Sullivan (Under Secretary of Commerce for Oceans & Atmosphere and NOAA Administrator)

  Town Hall Meeting in Boulder  Colorado

- You only really measure voltages and resistances therefore observations are just models

  Robin Webb (Director NOAA/Physical Science Division) when I quoted Kathy Sullivan to him in the hallway