Processes Affecting the Annual Surface Energy Budget at High-Latitude Terrestrial Sites in the Canadian Arctic

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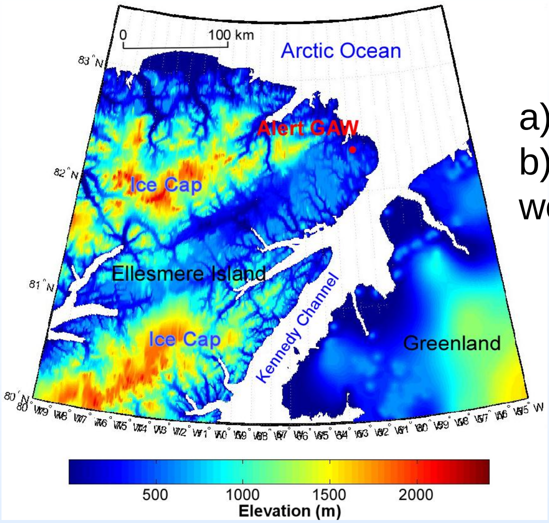
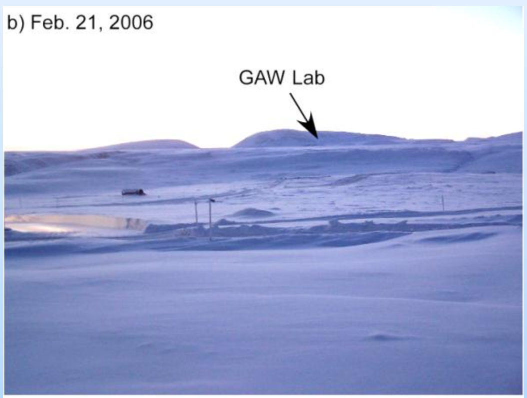
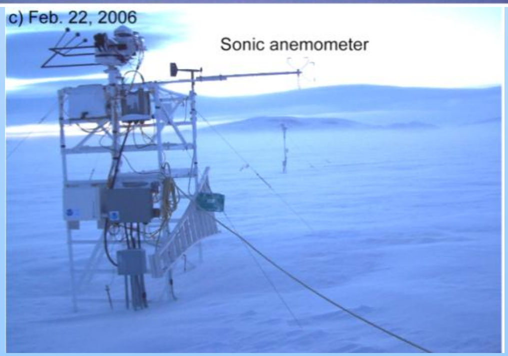
Acknowledgments: This work has been supported by funding from the National Science Foundation and NOAA.

Alert GAW lab



a) Coastal site
b) Mountains to west and south

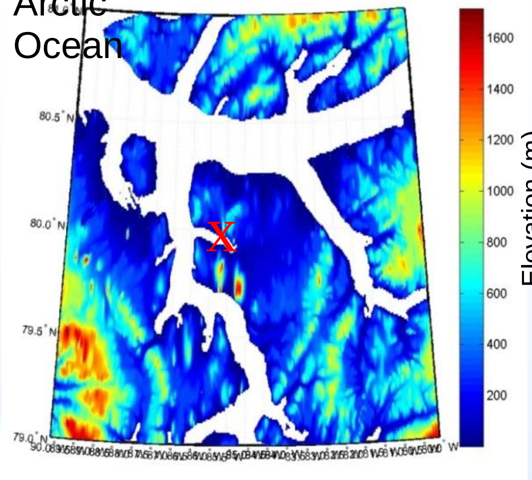




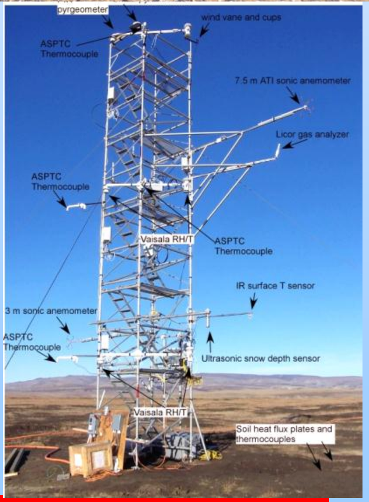
One-level platform
Complete SEB measurements

Eureka

On small fjord ~100 km from ocean
Complex valley and ridge region



Multi-level 10 m tower
No albedo rack



SEARCH Sites

Surface Energy Budget (SEB)

1. Net and atmospheric energy fluxes at the surface (snow, ice, or soil), F_{net}, F_{atm}

$$F_{net} = F_{atm} - F_0 = SW_d - SW_u + LW_d - LW_u - H_s - H_l - F_0$$
$$= SW_{net} + LW_{net} - H_{turb} - F_0$$

where SW_d , Sw_u, LW_d, LW_u are incoming/outgoing shortwave/longwave radiative fluxes; H_s, H_l are turbulent sensible/latent heat fluxes, which are either measured directly (Eureka) or calculated from bulk algorithm (Alert)

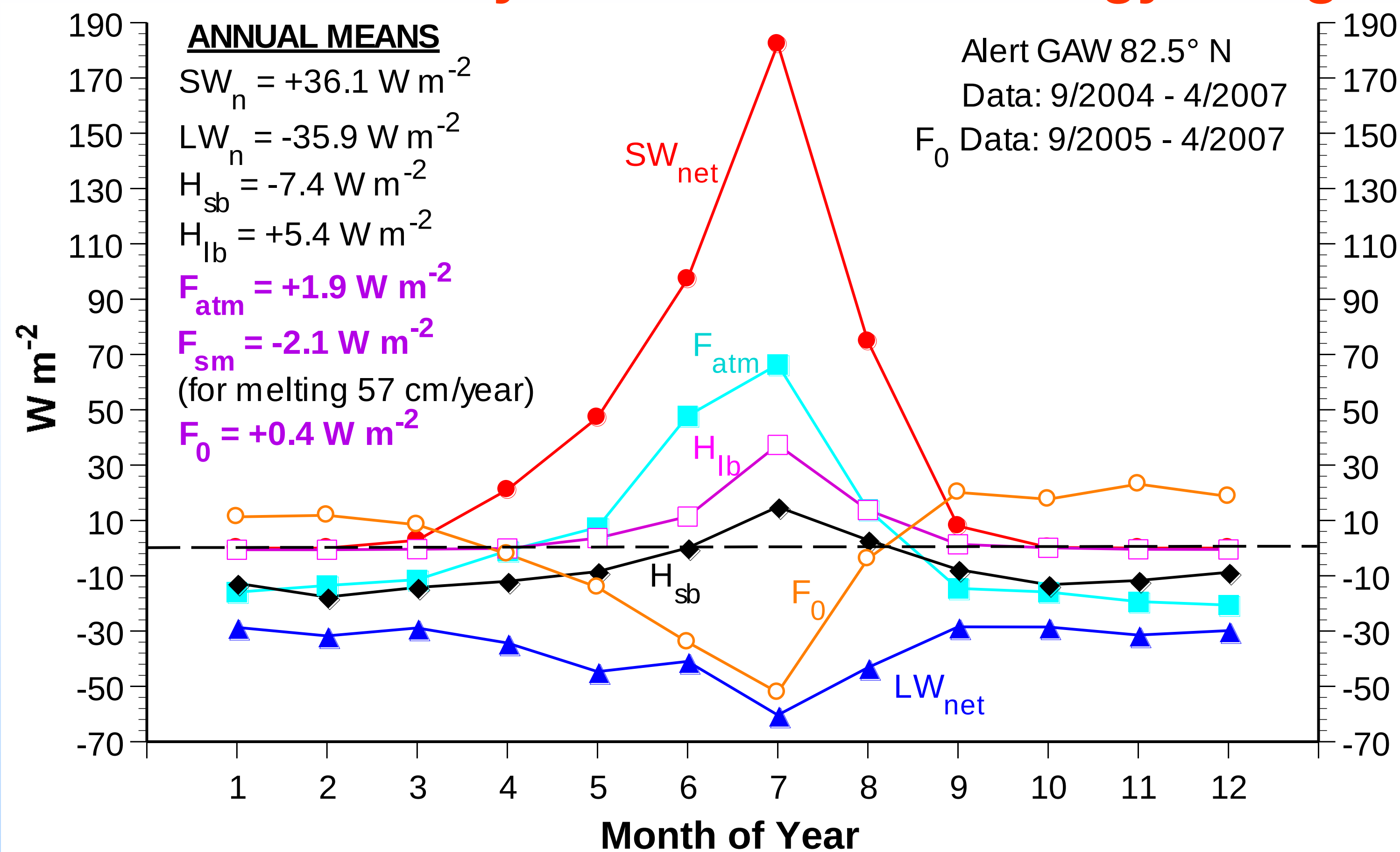
2. Energy flux into our out of soil, F_0 – either measured directly (Eureka only) or calculated from soil temperature profiles (Alert) via

$$F_0 = F_{10} + C_{psl}\frac{\Delta \overline{T}}{\Delta t}\Delta z$$

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

k_{sl} = soil thermal conductivity = 3.0 W m^{-1} K^{-1}
C_{psl} = soil heat capacity = 2.0 x 10^7 J m^{-3} K^{-1}(frozen; 2.6 x 10^7 for unfrozen)
k_{sl}/C_{psl} = thermal diffusivity = 1.5 x 10^{-7} m^2 s^{-1}
n = time index (hourly)

Alert Annual Cycle of Surface Eneregy Budget



MONTHLY

1) F_{atm} cools surface Sep-Mar, warms Jun-Aug
2) All components of F_{atm} significant
3) SW_{net} (summer) & Lw_{net} (year round) largest
4) H_{turb} warm surface in winter & cool Jun-Aug
5) Soil is warmed mid-Apr through mid-Aug

ANNUAL

1) SW_{net} gain & LW_{net} loss nearly balance
2) Surface energy gain by F_{atm} due to residual H_{turb}
3) Average soil energy loss rate is 0.4 W m^{-2}
4) For system balance: F_{atm} + F_0 = -F_{sm}
- error only ~0.2 W m^{-2}

Annual Cycle of Alert GAW Soil Temperatures

1) Active layer (T > 0° C) begins at surface near Jul 2, reaches maximum depth of 77 cm in mid-Aug, and is gone by Aug 22 (51 days).

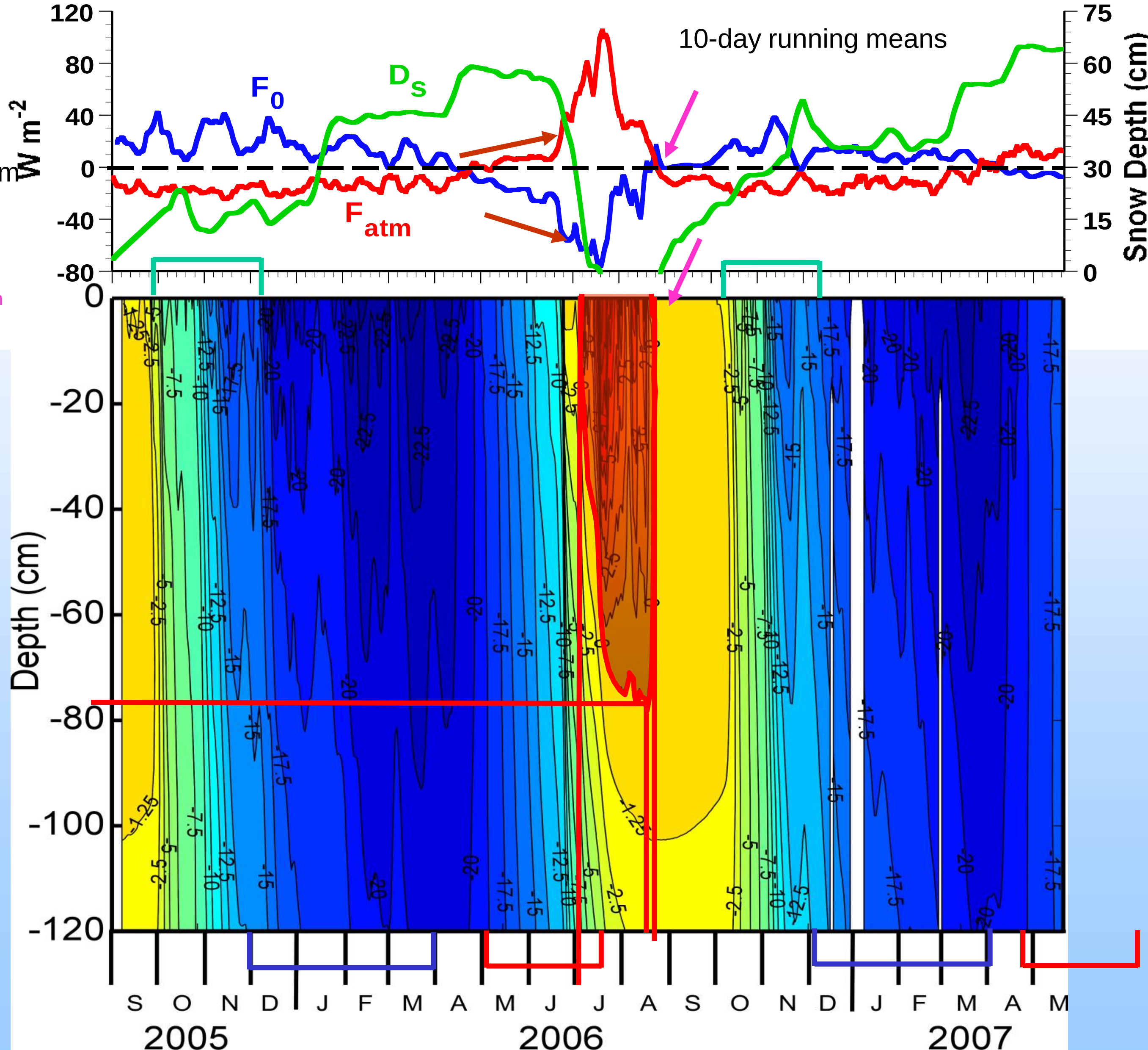
2) active layer disappears when F_{atm} becomes negative and F_0 positive

3) rapid cooling at all levels from early Oct until mid-Nov to early Dec

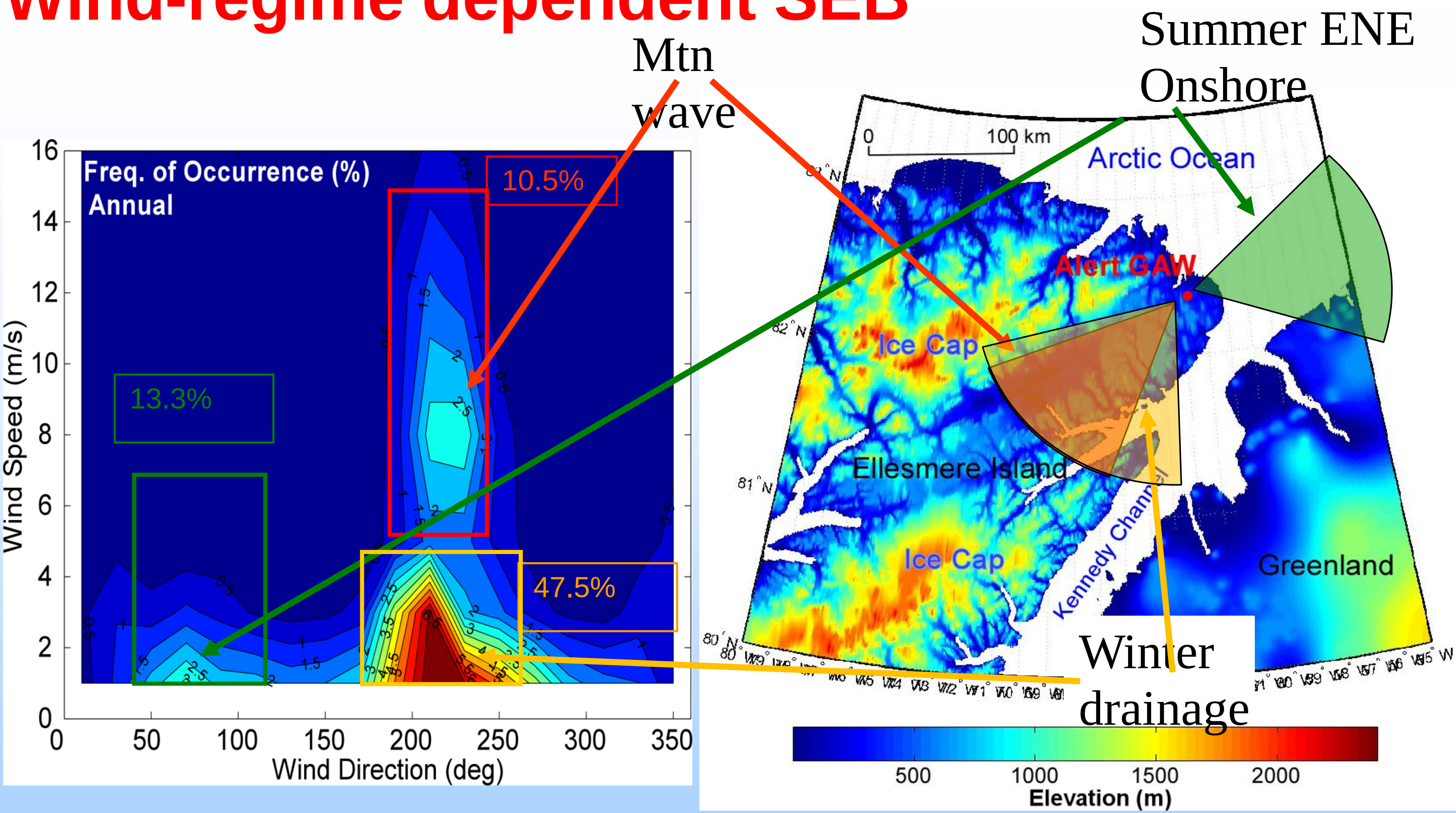
4) gradual cooling (in pulses) until mid-Mar-early Apr when coldest temperatures occur

5) rapid warming throughout from late Apr to mid-Jul

6) rapid increase in F_{atm} leads to rapid decrease in F_0 producing active layer



Wind-regime dependent SEB



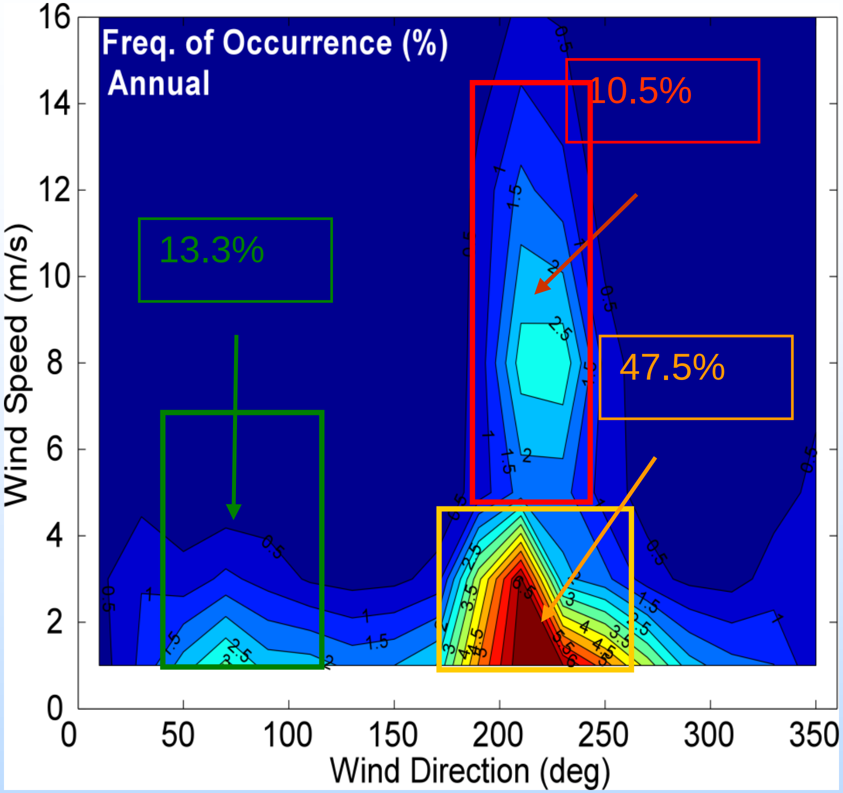
Three wind regimes

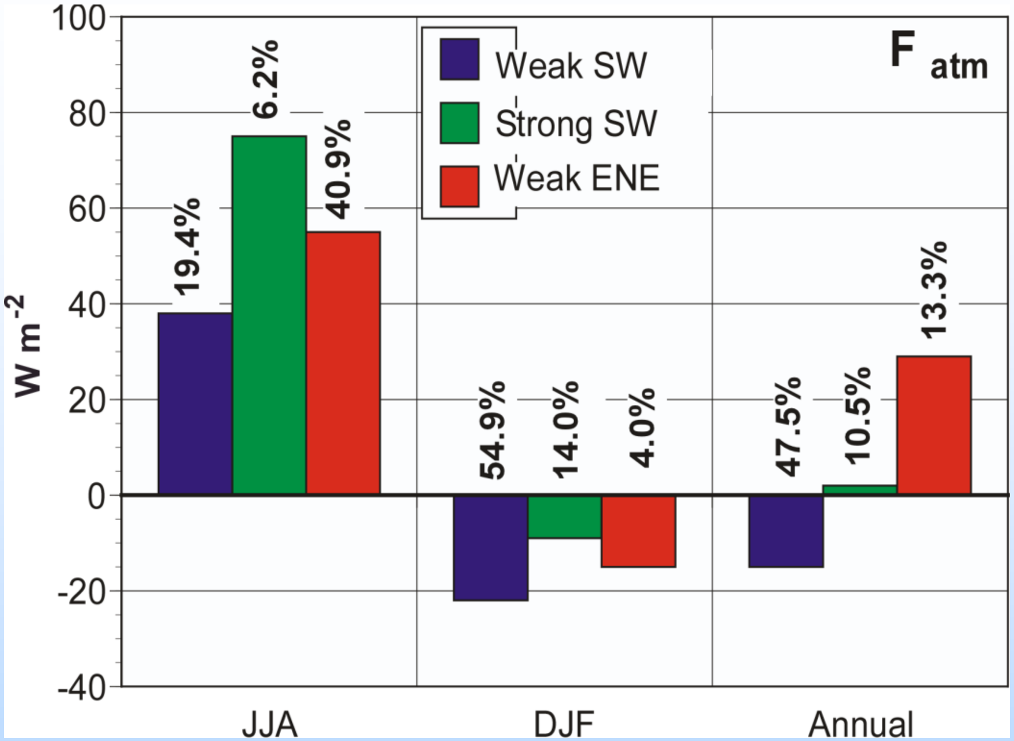
- winter drainage flow

- mountain wave regime distinctly separate from winter drainage flow

- summer sea-breeze

Effects of Local Wind Regimes on Alert GAW SEB





1) strong SW wind regime produces least cooling in winter and strongest warming in summer – likely reason for relatively "warm" winter T_a

2) ENE wind regime produces greatest F_{atm} because it is the dominant summer regime

3) all three regimes crucial for Alert mesoclimate and likely produced by mesoscale processes (downslope winds/mountain waves; sea-breeze)

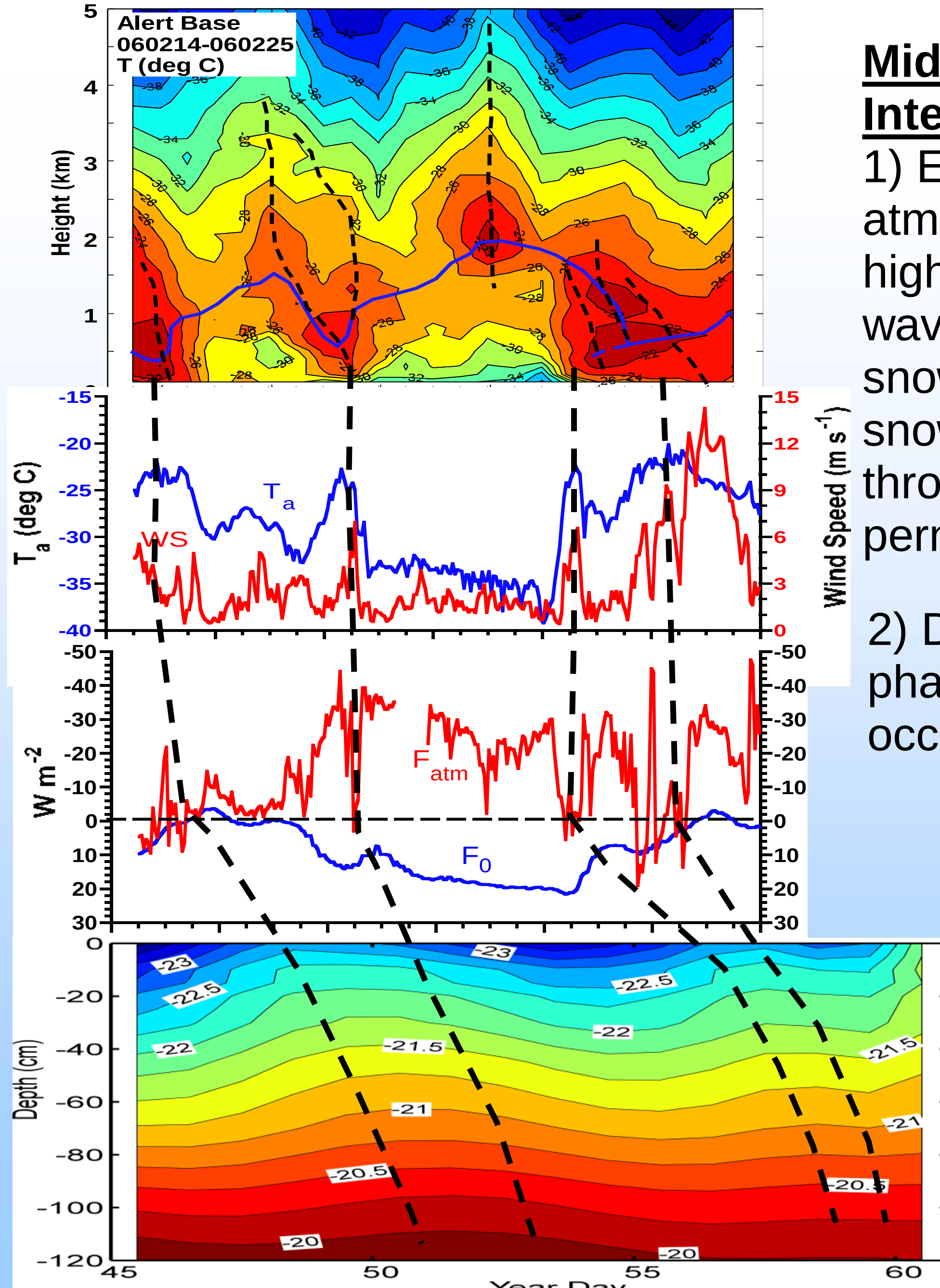
Mid-Winter Atmosphere-Soil Interaction

Atmospheric Temperature 0-5 km

Near Surface Temperature and Wind Speed

Near Surface Measured F_{atm} and F_0

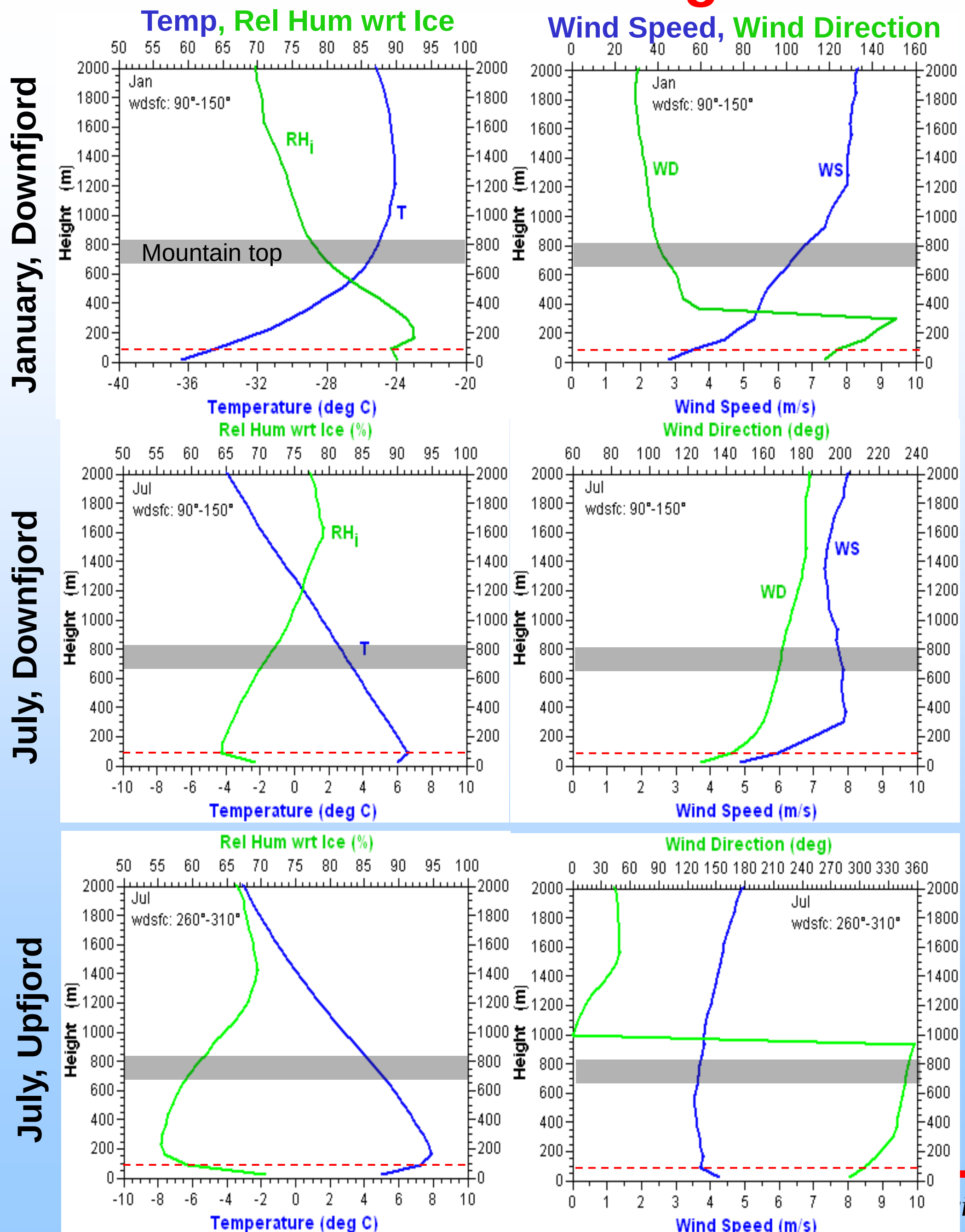
Temperature in soil from surface to 1.2 m depth



1) Effect of descent of atmospheric inversion with high-wind speed mountain waves can be traced to the snow surface, through the snow to the soil surface, and through the soil into the permafrost at 1.2 m depth.

2) Damping, smoothing, and phase lag of thermal wave occurs in snow and soil.

Eureka - Flow regimes & vertical structure



Flow regime and vertical structure

(composites of twice daily soundings 1/1998-12/2004)

1) Fjord-level winds either downfjord or upfjord

2) Inversion always present in fjord

3) Winter inversion deeper than surrounding mountains (grey)

4) Summer inversion very shallow, with tower (red line) frequently above inversion, esp for summer downfjord flow

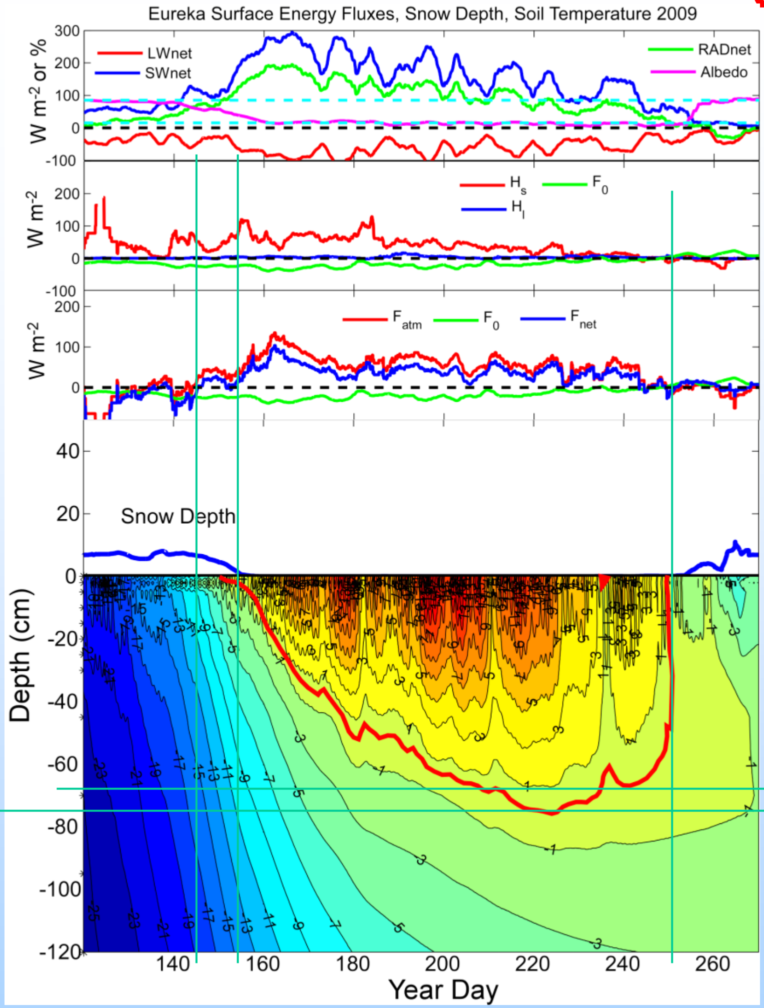
5) Fjord-level air relatively moist; drier at tower

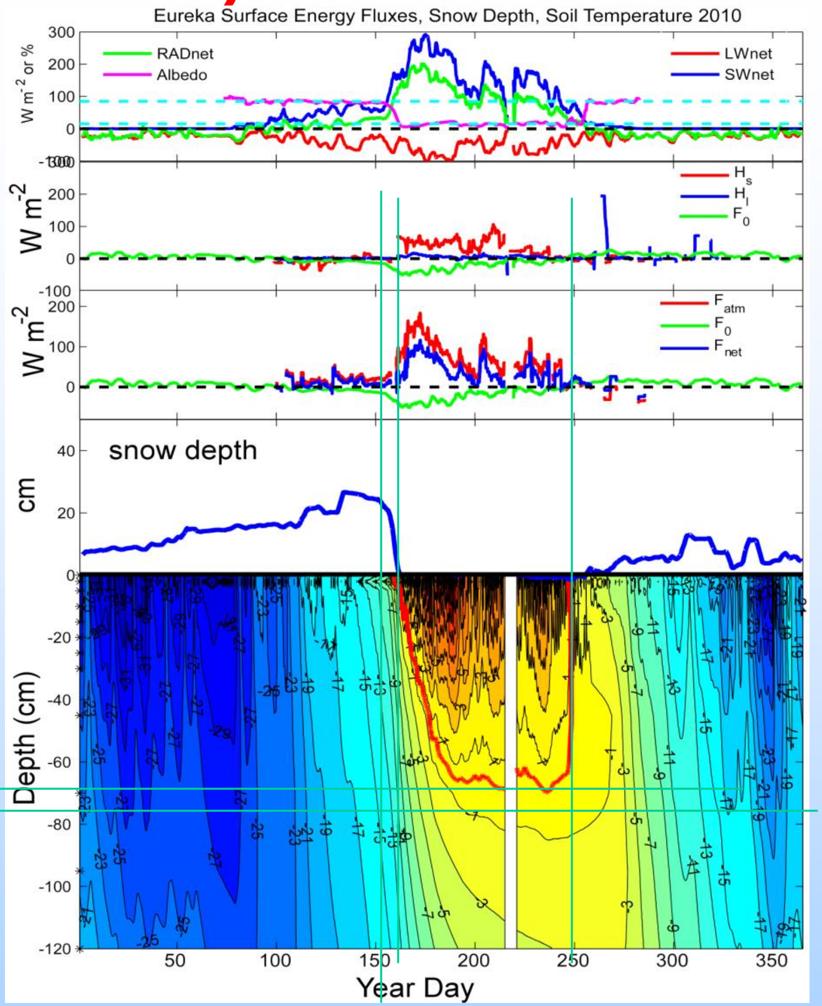
6) Strong directional shear in lowest 600-1000 m;

7) SE flow at tower associated with downfjord flow

8) NW flow at tower associated with upfjord flow

SEB and Tsoil (2009 & 2010)





SW_{net} 150-300 W m^{-2} during summer

LW_{net} strongly negative (~-100 W m^{-2})

Riming problems severely limits quality of winter radiation and turbulence data

Winter soil data suggest atmospheric forcing of high-frequency soil thermal variability

Melt onset (Snow starts melting): YD144, YD151 (May 24, May 31)

Bare ground (soil active layer starts): YD155, YD159 (June 4, 8)

Active layer max depth: 76 cm, 69 cm (YD220-240; July 8-28)

Active layer end: YD250, YD250 (Sep. 7)

Active layer length: 91-95 days

CONCLUSIONS

1) Alert: mesoscale wind regimes (e.g., downslope wind events, sea-breeze, drainage flows) have important impacts on SEB; Eureka: terrain orientation governs lower troposphere flow and structure

2) Midwinter downslope wind events impact soil temperatures despite deep snow at Alert; winter T_{soil} variability suggests the same at Eureka

3) Soil active layer reaches 69-77 cm at both Alert and Eureka

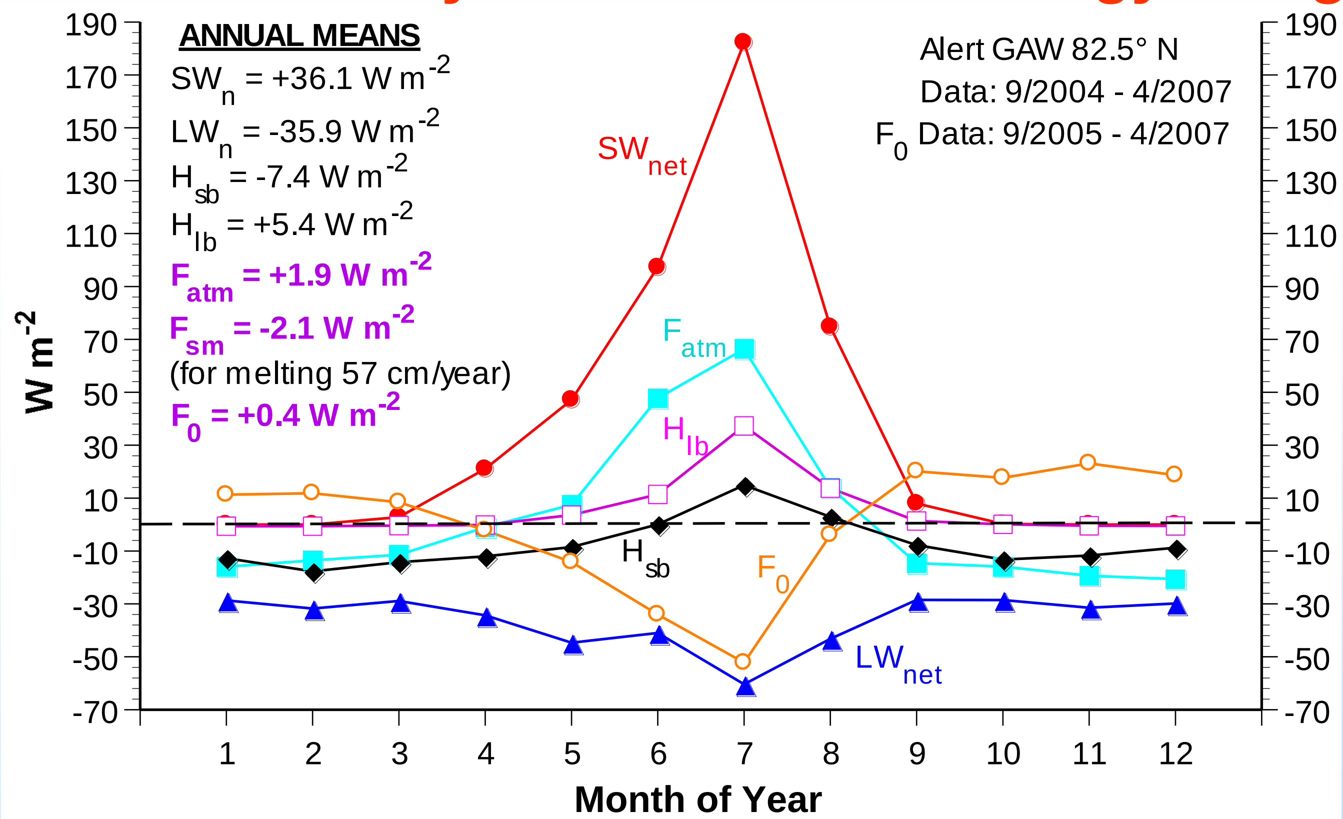
4) Soil active layer persists for 91-95 days at Eureka, 50-55 days at Alert (earlier/later melt onset/end at Eureka; shallow snow at Eureka $\Rightarrow$ SW_{net} large in early summer)

5) Surface snow evolution key for formation of soil active layer

6) Winter riming major problem for quality of radiation and turbulence data


Thank you
Спасибо
Tack
Kiitos
Merci
Dankeschön

Alert Annual Cycle of Surface Eneregy Budget



MONTHLY

1) F_{atm} cools surface Sep-Mar, warms Jun-Aug
2) All components of F_{atm} significant
3) SW_{net} contributes nearly 190 W m^{-2} in July
4) LW_{net} loss ~30 Wm^{-2} in winter & ~60 W m^{-2} in July
5) H_{sb} warms surface in winter & cools in July; H_{lb} cools in Jun-Aug
6) Soil is warmed mid-Apr through mid-Aug

ANNUAL

1) SW_{net} gain & LW_{net} loss nearly balance
2) Surface energy gain by F_{atm} due to residual H_{turb}
3) Average soil energy loss rate is 0.4 W m^{-2}
4) For system balance: $F_{atm} + F_0 = -F_{sm}$
- error only ~0.2 W m^{-2}

Annual Cycle of Alert GAW Soil Temperatures

1) Active layer (T > 0° C) begins at surface near Jul 2, reaches maximum depth of 77 cm in mid-Aug, and is gone by Aug 22 (51 days).

2) active layer disappears when F_{atm} becomes negative and F_0 positive

3) weak maximum descends as surface slowly cools, reaching 120 cm depth by early-mid Oct

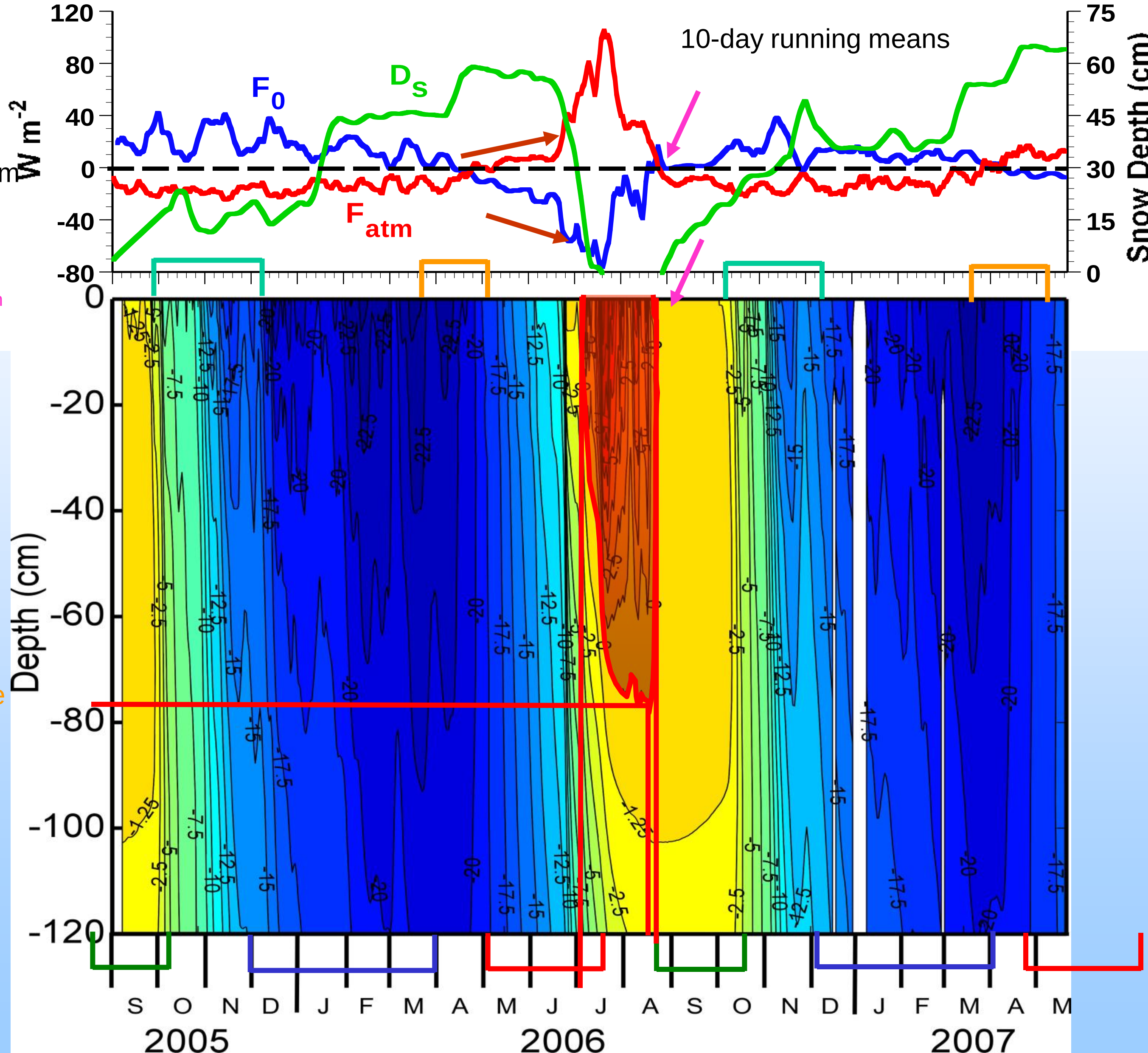
4) rapid cooling at all levels from early Oct until mid-Nov to early Dec

5) gradual cooling (in pulses) until mid-Mar-early Apr when coldest temperatures occur

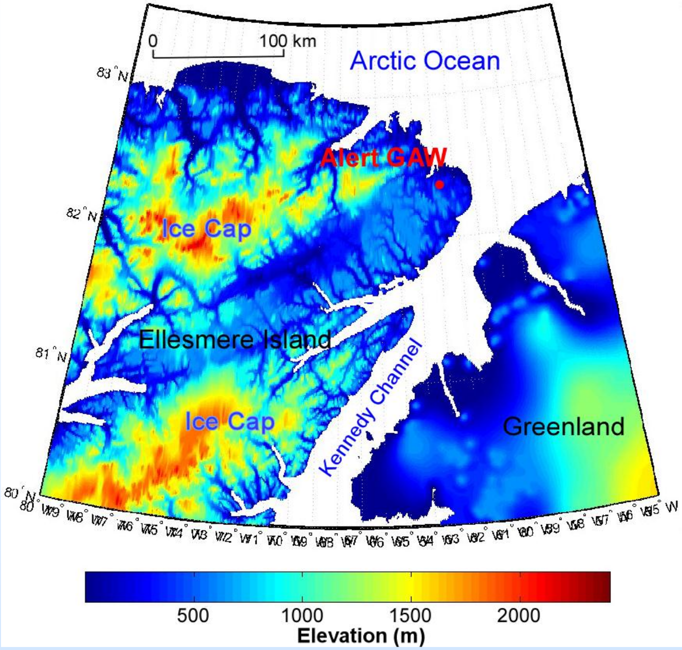
6) as surface begins to warm, profile minimum descends from surface to 120 cm by early-mid May

7) rapid warming throughout from late Apr to mid-Jul

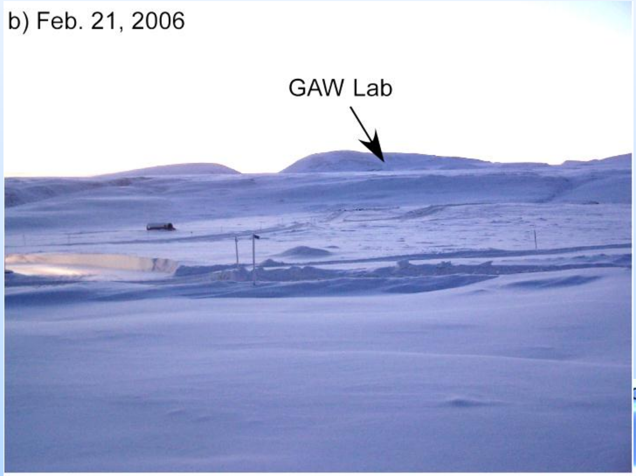
8) rapid increase in F_{atm} leads to rapid decrease in F_0 producing active layer

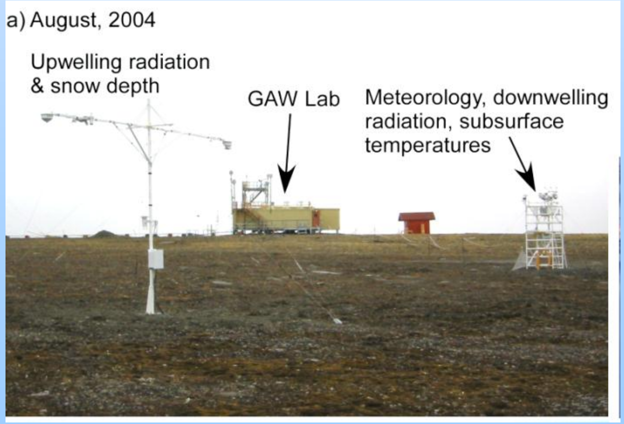


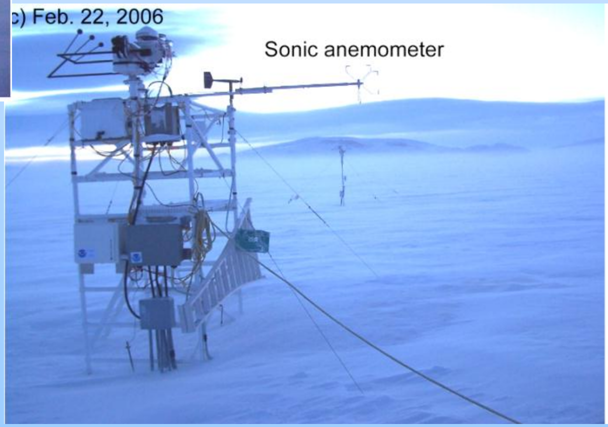
Site Description – Alert (Northern Ellesmere Island 82.3° N)



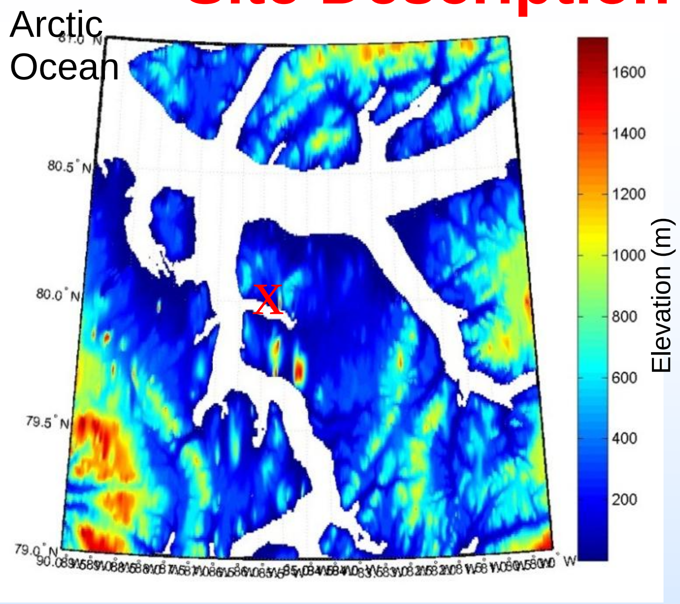
Alert regional and local topography and coastlines. Observations made at GAW lab (Baseline Observatory) 7 km S of coast at 170 m elevation.







Site Description – Eureka (Ellesmere Island 80.0° N)



Eureka regional and local topography and fjords. "R" shows location of radiosondes and radar. "F" shows flux tower at 80 m elevation