Processes in the Cloud-Atmospheric Boundary Layer-Surface (CAS) System Impacting Arctic Surface Energy Fluxes

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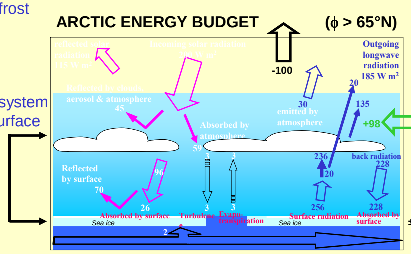
Introduction

Motive

Surface energy fluxes are key for understanding observed changes in Arctic sea ice and permafrost

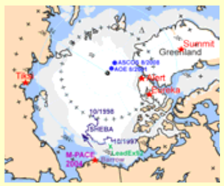
Objective

Determine key atmospheric processes in CAS system controlling Arctic surface energy fluxes



Methodology

- Obtain observations of relevant cloud, boundary-layer, and surface characteristics and fluxes over Arctic sea-ice and at long-term terrestrial sites



- Reveal processes and understand interactions through observation analysis and process-model diagnostics

Surface Energy Budget (SEB) - links elements of CAS system

Atmospheric surface energy flux, F_{atm}

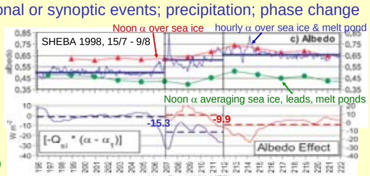
$F_{atm} = Q_{si}(1-\alpha) + Q_{li} - Q_{lo} - H_s - H_l = SW_{net} + LW_{net} - (H_s + H_l) = Rad_{net} - H_{turb}$

$\alpha = Q_{so}/Q_{si}$ – albedo; Q_{si}, Q_{so}, Q_{li}, and Q_{lo} - in/out going SW/LW rad. Fluxes, H_s, H_l - turbulent sensible/ latent heat fluxes

Surface Processes (impacts on Q_{so}, Q_{lo}, H_s, H_l)

Albedo Changes – seasonal or synoptic events; precipitation; phase change

- soil, ice, snow, meltponds



$\Delta SW_{net} = (1-\alpha_1)\Delta Q_{si} - Q_{si2}\Delta\alpha$

$\Delta x = x_2 - x_1$

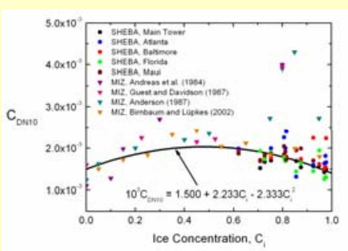
Enhanced roughness and drag (C_D) over summertime sea ice by meltpond and lead edges increases C_H and C_E, and thus H_s and H_l

$H_s = \rho\, c_p\, C_H\, U\, (T_s - T_a)$; T_s, T_a – surface, air temperature, U – wind speed

$H_l = \rho\, L_v\, C_E\, U\, (Q_s - Q_a)$; Q_s, Q_a – surface, air specific humidity

SHEBA, April 23, 1998
smooth snow-covered ice, C_i = 1.0

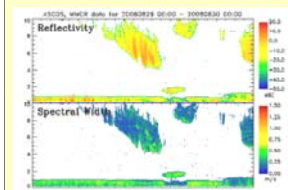
SHEBA, July 27, 1998
many melt pond edges, C_i = 0.75

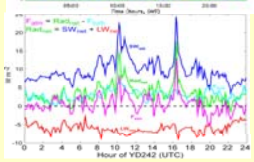


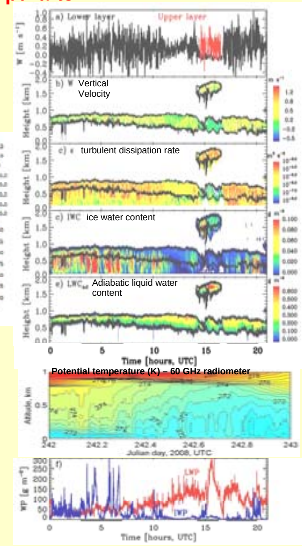
Cloud Processes (impacts on Q_{si}, Q_{li}, H_s, H_l)

Arctic stratocumulus clouds generated by cloud-top cooling or surface-driven updrafts

- modulated by surface, cloud, synoptic processes
- microphysical variations may be related to generation
- generation variations on multi-hour time scales



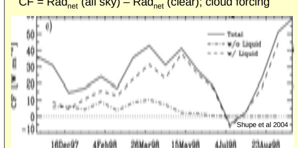


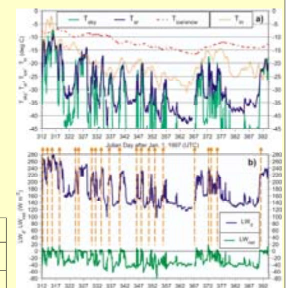


Cloud phase in Sc determine surface radiative effects

- liquid water at cloud top: high longwave emissivity & shortwave reflectivity
- major impact on Q_{si} and Q_{li}
- supercooled liquid maintained through microphysical interactions

CF = Rad_{net} (all sky) – Rad_{net} (clear); cloud forcing

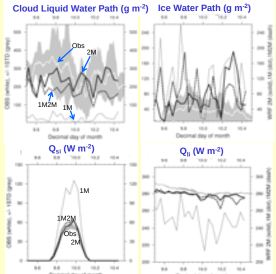


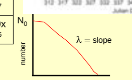


Cloud phase sensitive to microphysical parameterization

- WRF model using M-PACE cloud case at Barrow
- N_0 – size distribution y-intercept value

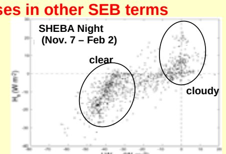
Run	Description	N_{0s}	N_{0r}	N_{0g}	N_{0i}
2M	Two-moment microphysics				
1M	One-moment microphysics	1.0x 10^7	1.0x 10^7	4.0x 10^6	5.0x 10^7
1M2M	One-moment with 2M N_0 values	7.5x 10^5	4.0x 10^9	4.0x 10^6	5.0x 10^6





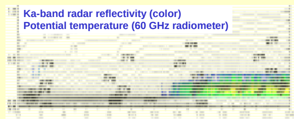
Single Moment Microphysics
prognostic q (mixing ratio)
N_0 – fixed intercept parameter
Double Moment Microphysics
prognostic q, N (mixing ratio, num. conc.) $N_0 = f(q, N)$

Cloud radiative effects produce responses in other SEB terms

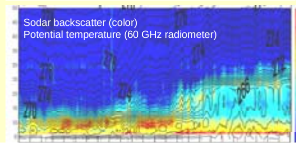


Boundary-Layer Processes (Q_{si}, Q_{so}, Q_{li}, Q_{lo}, H_s, H_l)

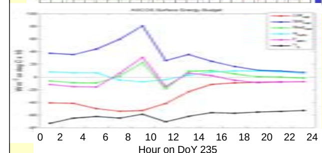
Boundary-layer structure dependent on large-scale, cloud, and surface processes



- cold-air advection aloft destabilizes lowest 700 m
- low-level clouds advect over observation site within cold air



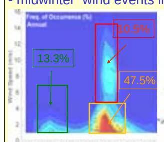
- destabilization at cloud top due to radiative cooling enhances mixing depth from surface to near cloud top

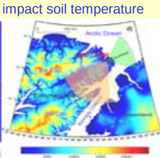


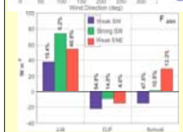
- due to clouds, Q_{si} decreases and Q_{li} increases, though Q_{li} increase limited because $T_{200\,m}$ decreases by 8 K; H_s cools surface
- as result of CAS interactions, F_{atm} and T_s increase only slightly

Boundary-layer dynamic events control mesoclimate of many terrestrial sites

- downslope wind events important for annual SEB at Alert
- midwinter wind events impact soil temperature



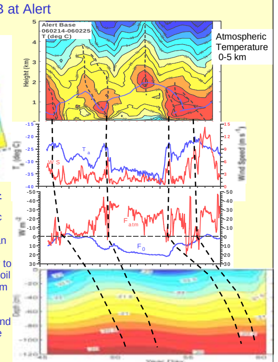




Mid-Winter Atmosphere-Soil Interaction

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

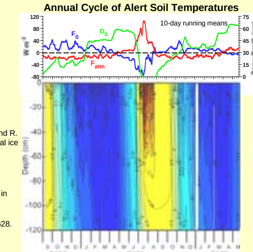
2) Damping, smoothing, and phase lag of thermal wave occurs in snow and soil.



Conclusions

- Continuous energy flux measurements with occasional intensive process-study observational periods – currently only possible at terrestrial sites
- Surface energy fluxes impacted by large variety and scale of CAS processes
- Important that key processes appropriately represented in models to elicit proper physical response to forcing changes

Annual Cycle of Alert Soil Temperatures



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