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Clear-sky cooling over Arctic sea ice during polar night: Role of leads and wind speed

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Adopted from Kazemir Malevich

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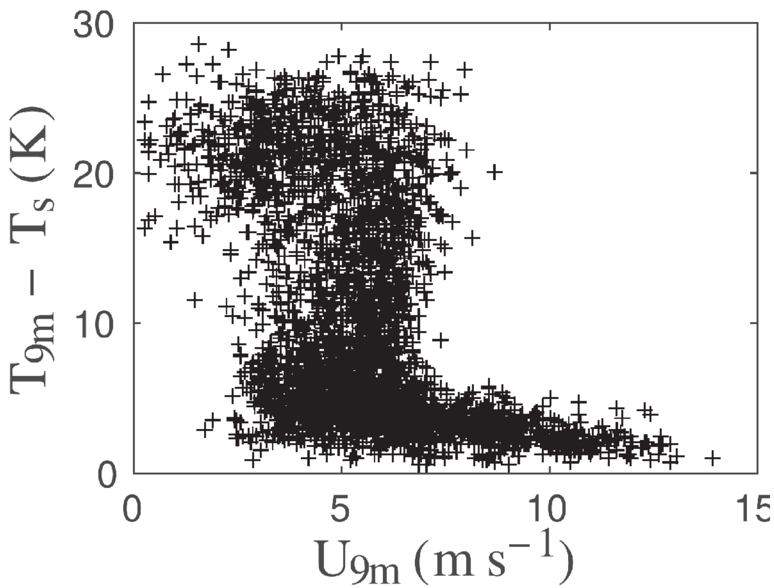
Wind speed and leads

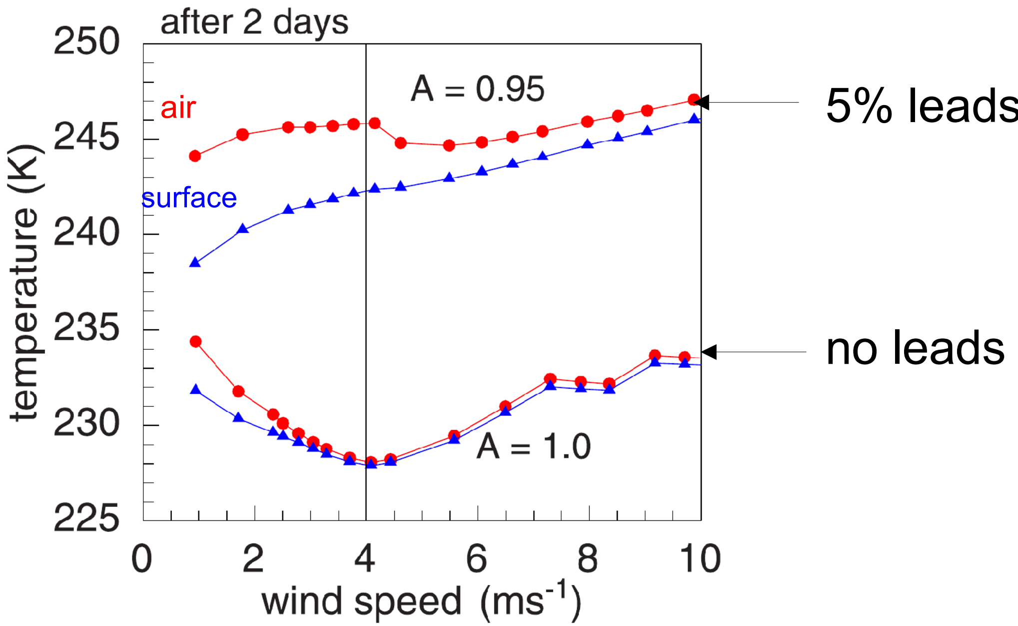
1. Wind speed governs regime transitions from weakly to strongly stable

2. Leads are important sources of heat for the ABL

Dome C, Antarctica, Vignon et al., 2017



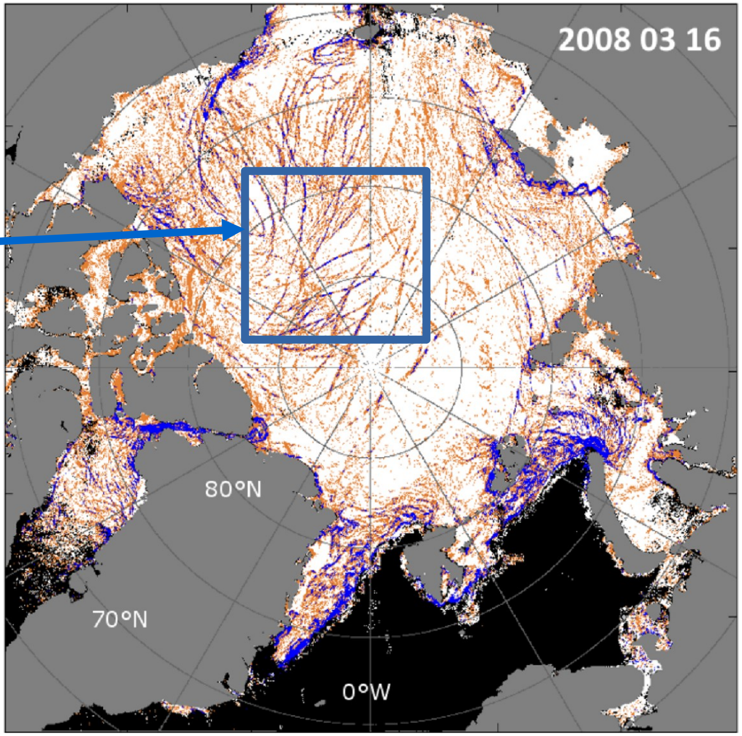
Idealized 1D modelling, Lüpkes et al., 2008



Goal of the study:

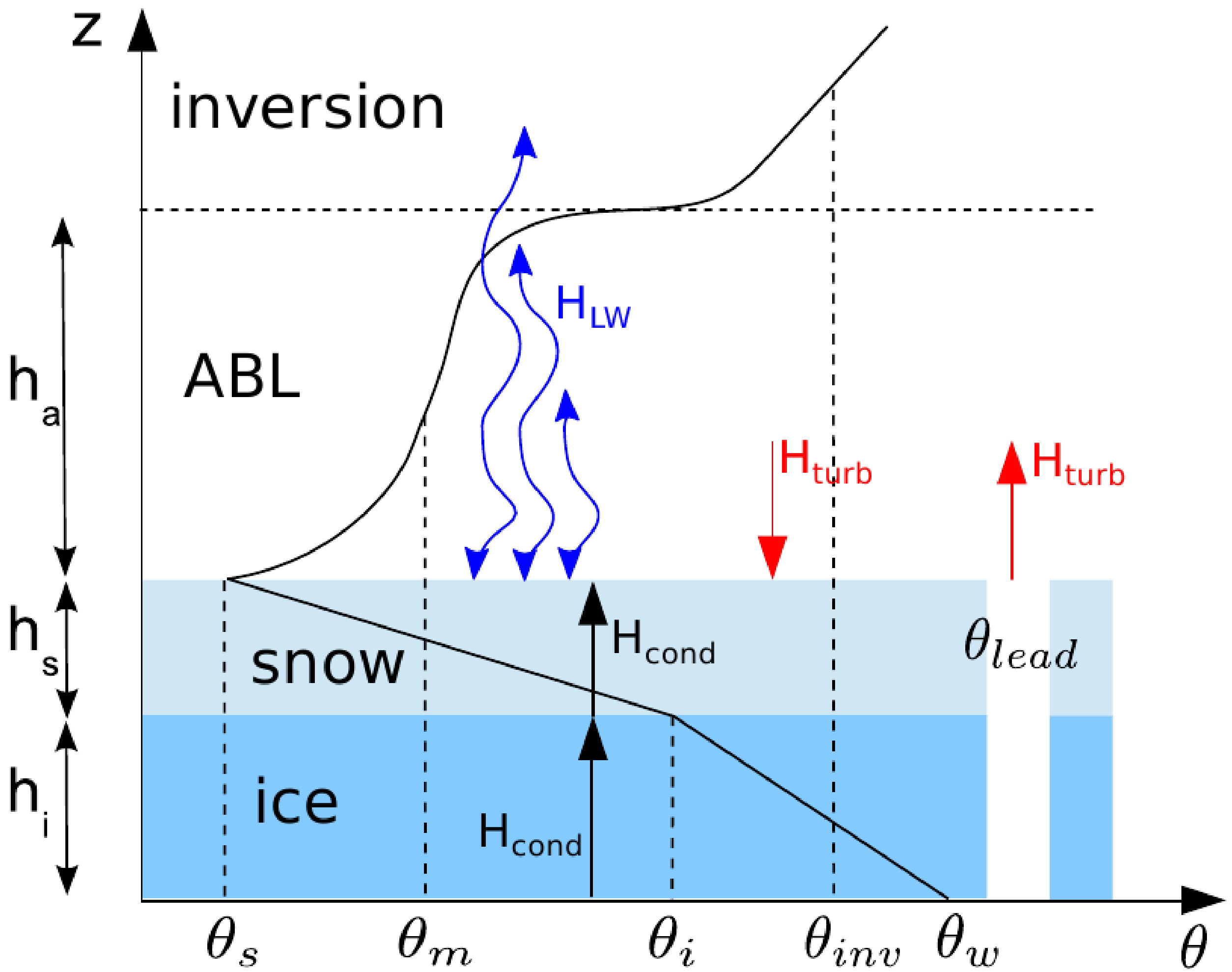
to propose a simple model describing the ABL-sea ice thermal regime that highlights the role of leads and wind speed

We consider a region (e.g. 100x100km) in the Central Arctic where leads are common even in winter

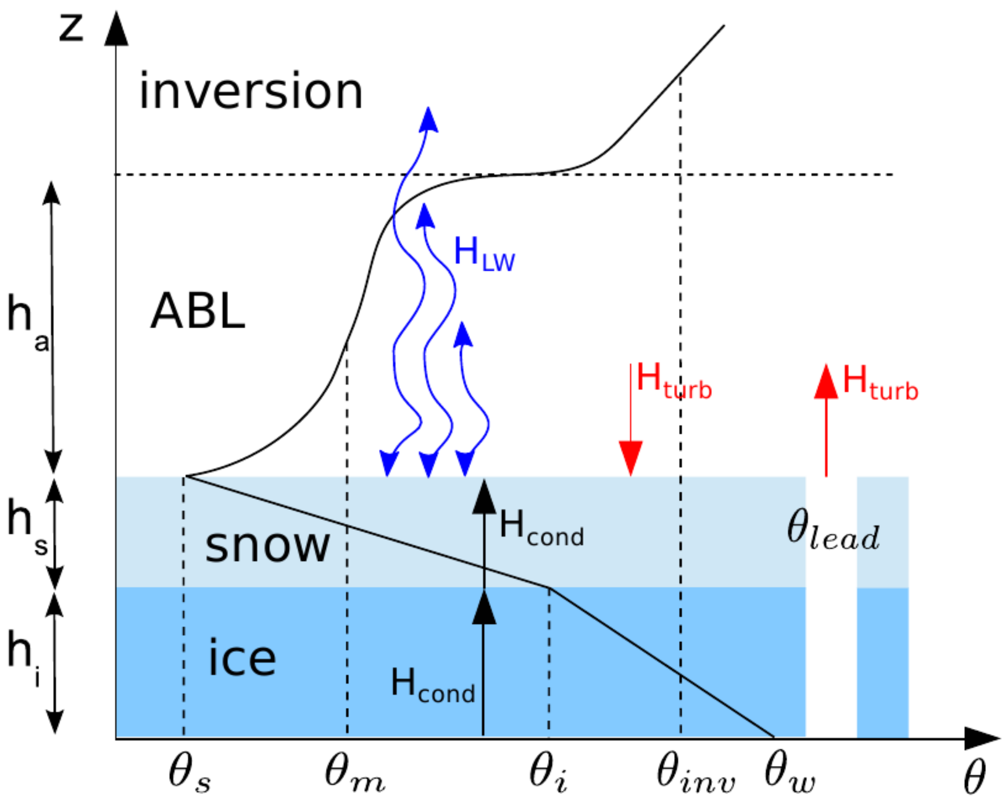


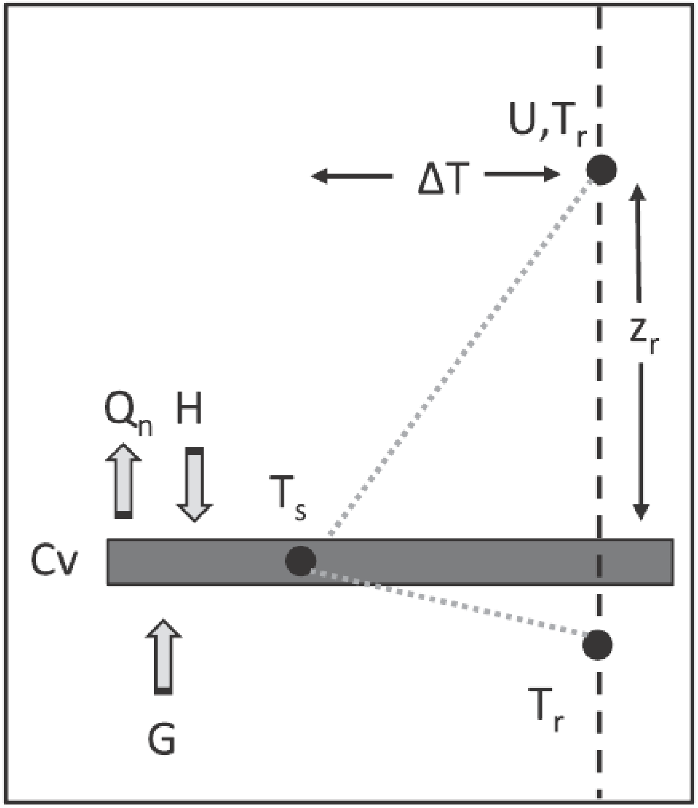
From Willmes and Heinemann, 2016

Simple model



Simple model





Van de Wiel et al. (2017)

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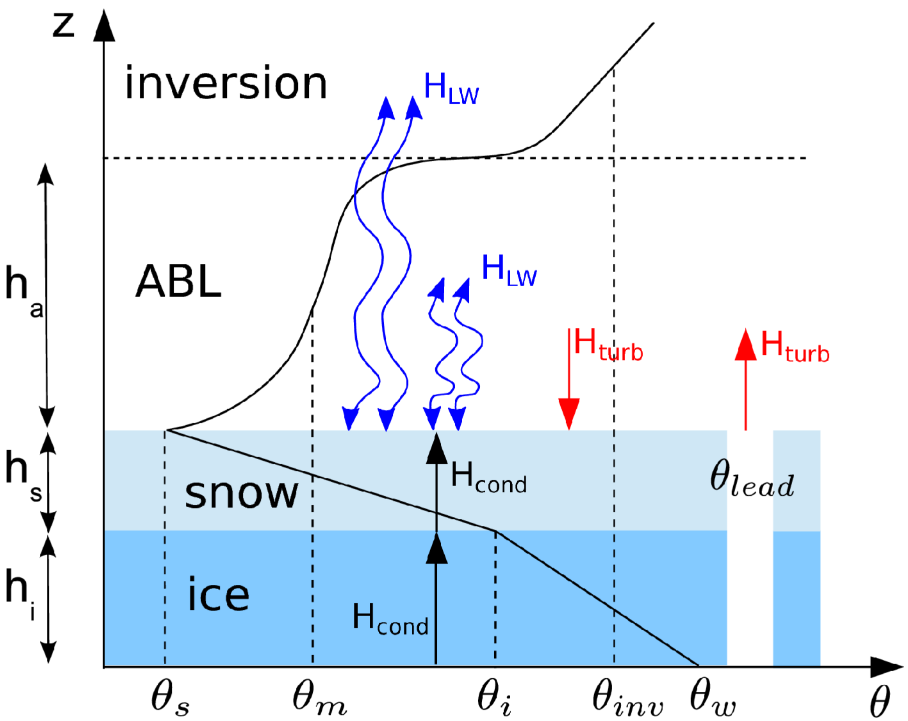
Simple model



All fluxes are represendted in a form:

$$H_{cond} = \lambda_C(\theta_w - \theta_s)$$

$$\lambda_C = \frac{k_s}{h_s}\left[\frac{k_i h_s}{k_i h_s + k_s h_i}\right]$$ <-- thermal conductance

Net longwave radiative flux at the surface:

$$LW = LW_i - \lambda_{Ri}(\theta_s - \theta_{inv}) - \lambda_{Ra}(\theta_s - \theta_a)$$

Simple model

flux-averaging mosaic approach

$$\frac{d\theta_m}{dt} = \frac{U_m}{h_a}\left[AC_{H,s}(\theta_s - \theta_m) + (1-A)C_{H,w}(\theta_{lead} - \theta_m) + \frac{R_{cool}}{U_m} \right] ,$$

$$LW + \frac{k_s}{h_s}(\theta_i - \theta_s) = \rho_a c_p C_{H,s} U_m (\theta_s - \theta_m) ,$$

$$0 = -\frac{k_i}{h_i}(\theta_i - \theta_w) + \frac{k_s}{h_s}(\theta_s - \theta_i) ,$$

Stability-dependent heat transfer coefficient over ice:

$$C_{H,s} = C_{Hn}(1 + \alpha Ri_b)^{-1}$$

1D numerical model

Single-column atmospheric model coupled to a thermodynamic sea ice and snow model — mimics behavior of coarse resolution models

Atmospheric model:

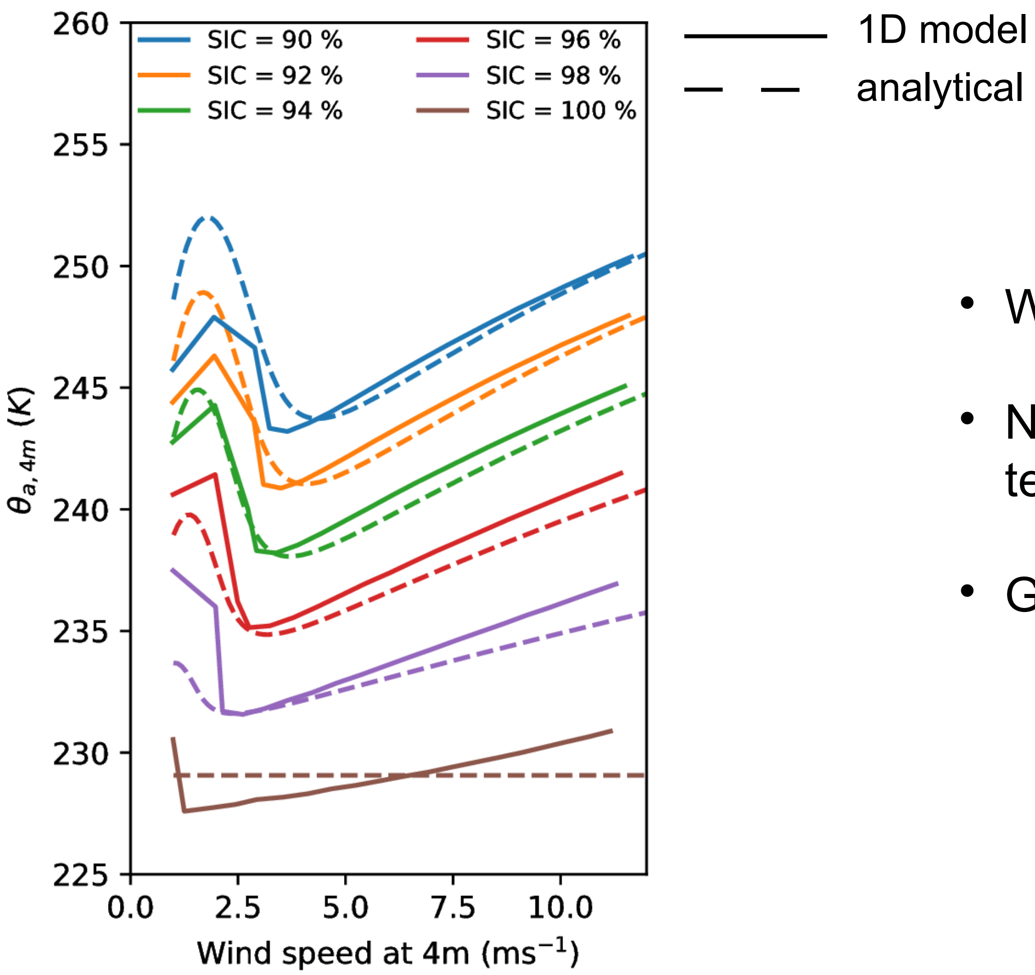
Turbulence closure:
local 1st order in the ABL, SHEBA stability functions in the surface layer (Grachev et al., 2007)

Goddard LW radiation scheme

Sea ice and snow model:

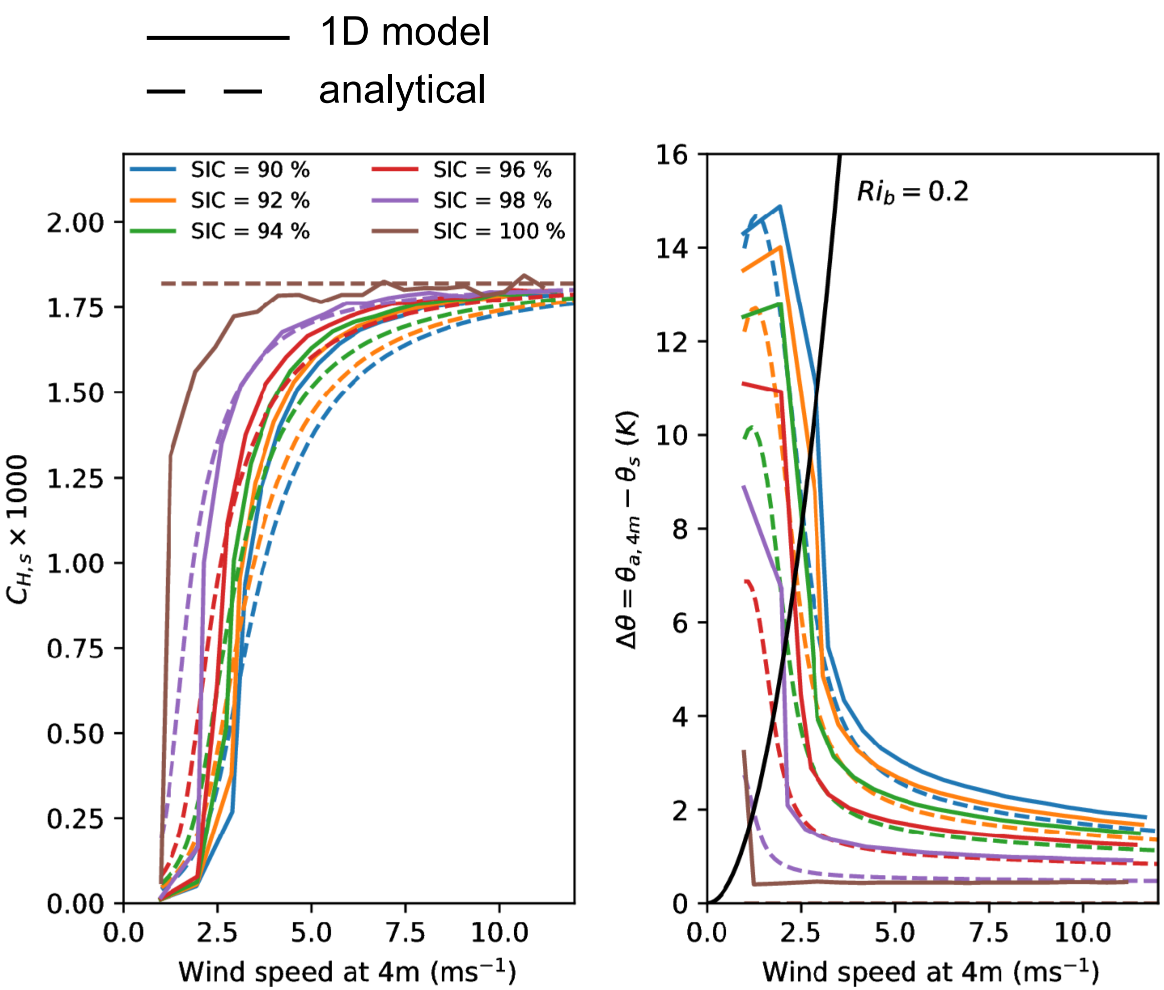
$$\rho_{i,s} c \frac{\partial T_{i,s}}{\partial t} = k_{i,s} \frac{\partial^2 T_{i,s}}{\partial z^2}$$

Steady state



- Warming effect of leads
- Nonmonotonic dependency of temperature on wind speed
- Good agreement between the models

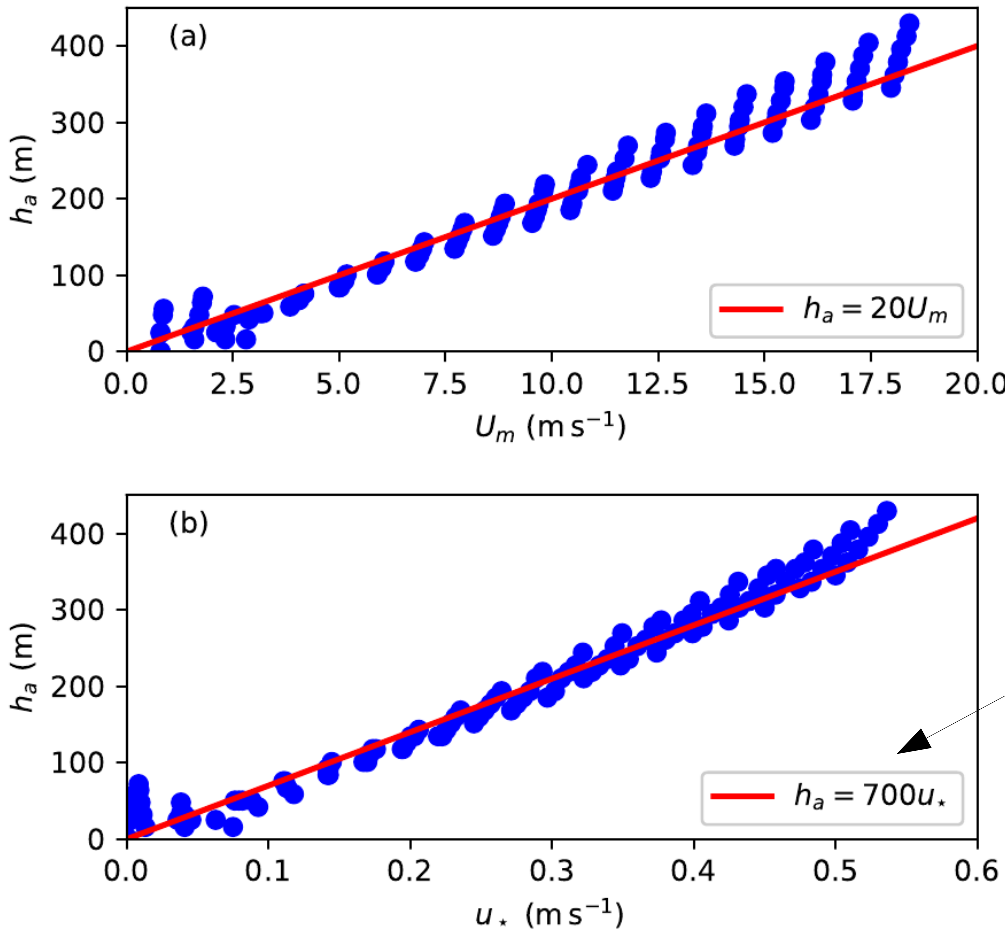
Steady state



- Regime transition: from weakly to strongly stable
- Stabilizing effect of leads (or any other heat source – entrainment, advection)

Nonstationary solutions

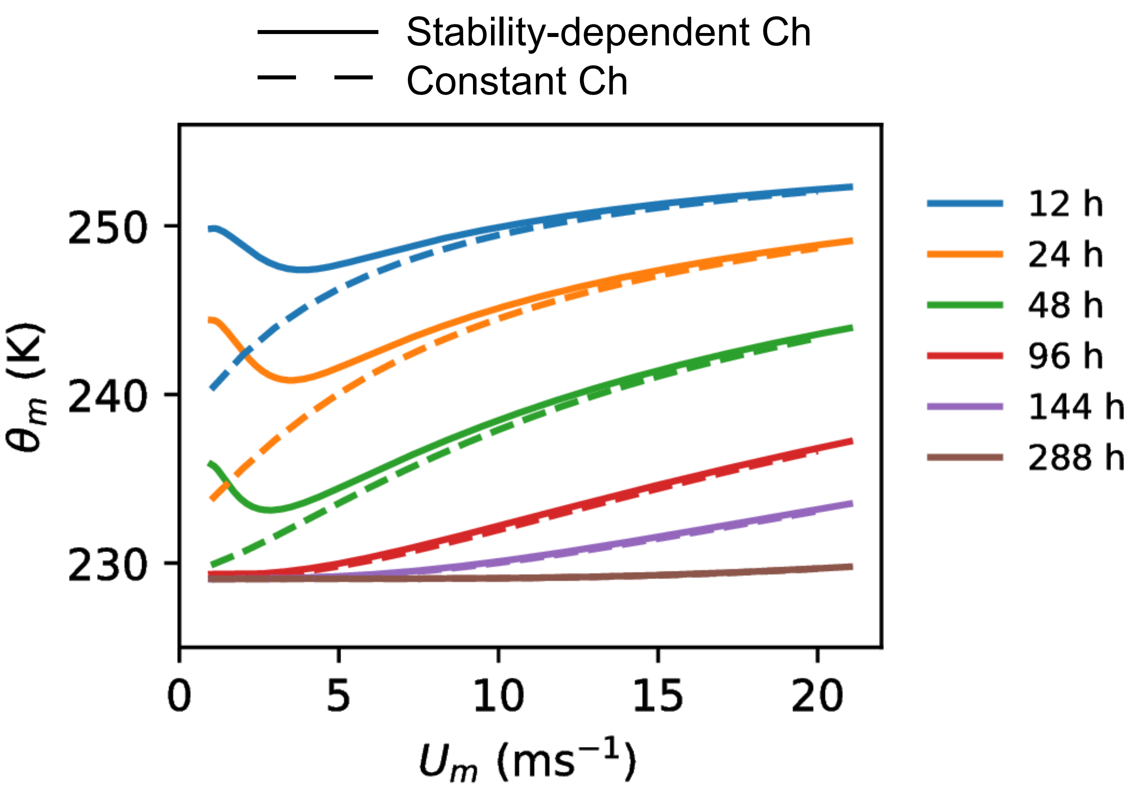
$$\frac{d\theta_m}{dt} = \frac{U_m}{h_a}\left[AC_{H,s}(\theta_s - \theta_m) + (1-A)C_{H,w}(\theta_{lead} - \theta_m) + \frac{R_{cool}}{U_m}\right],$$



Steeneveld et al. (2007)

Time-dependent solutions: cooling time scale

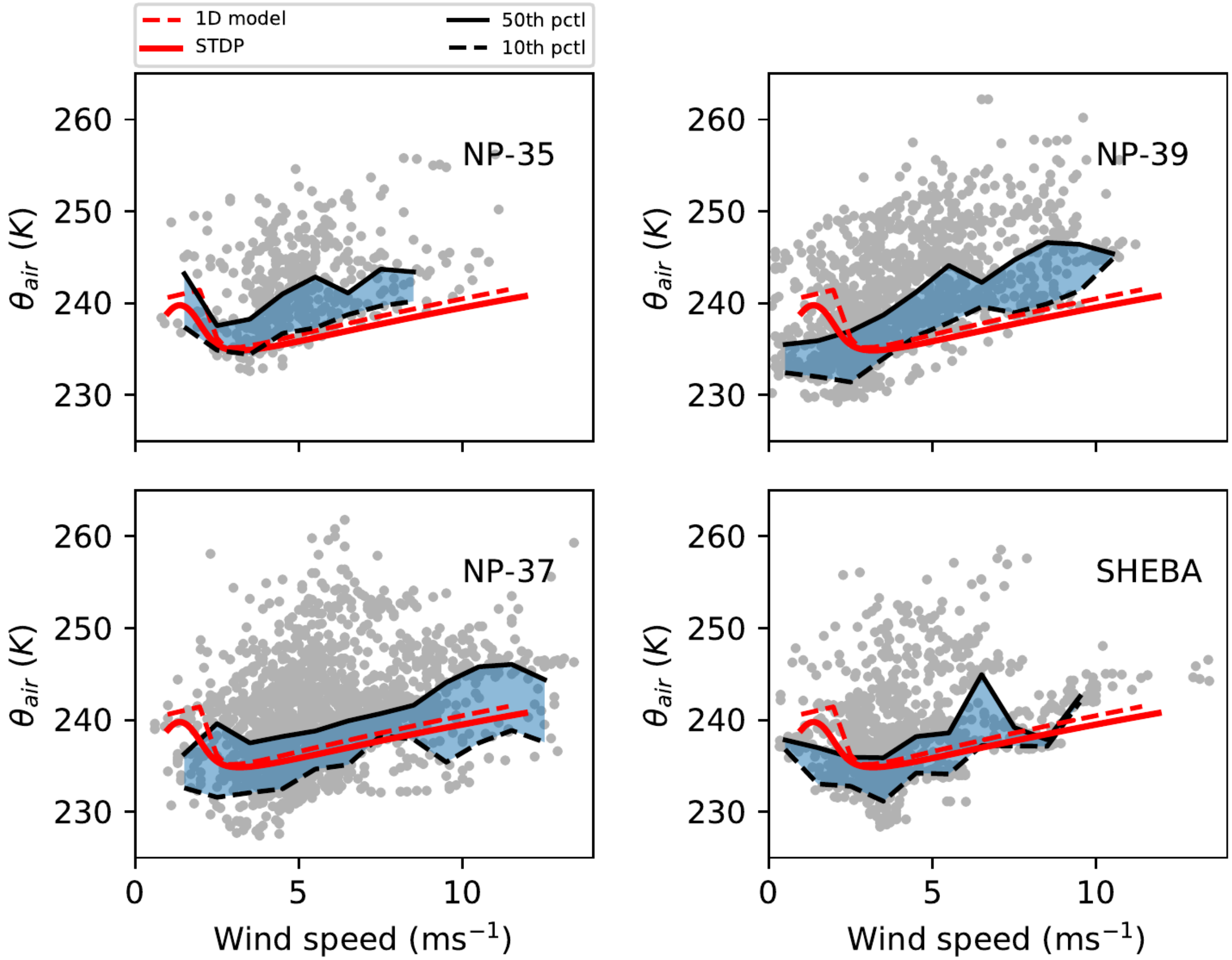
No leads, 100% sea ice concentration



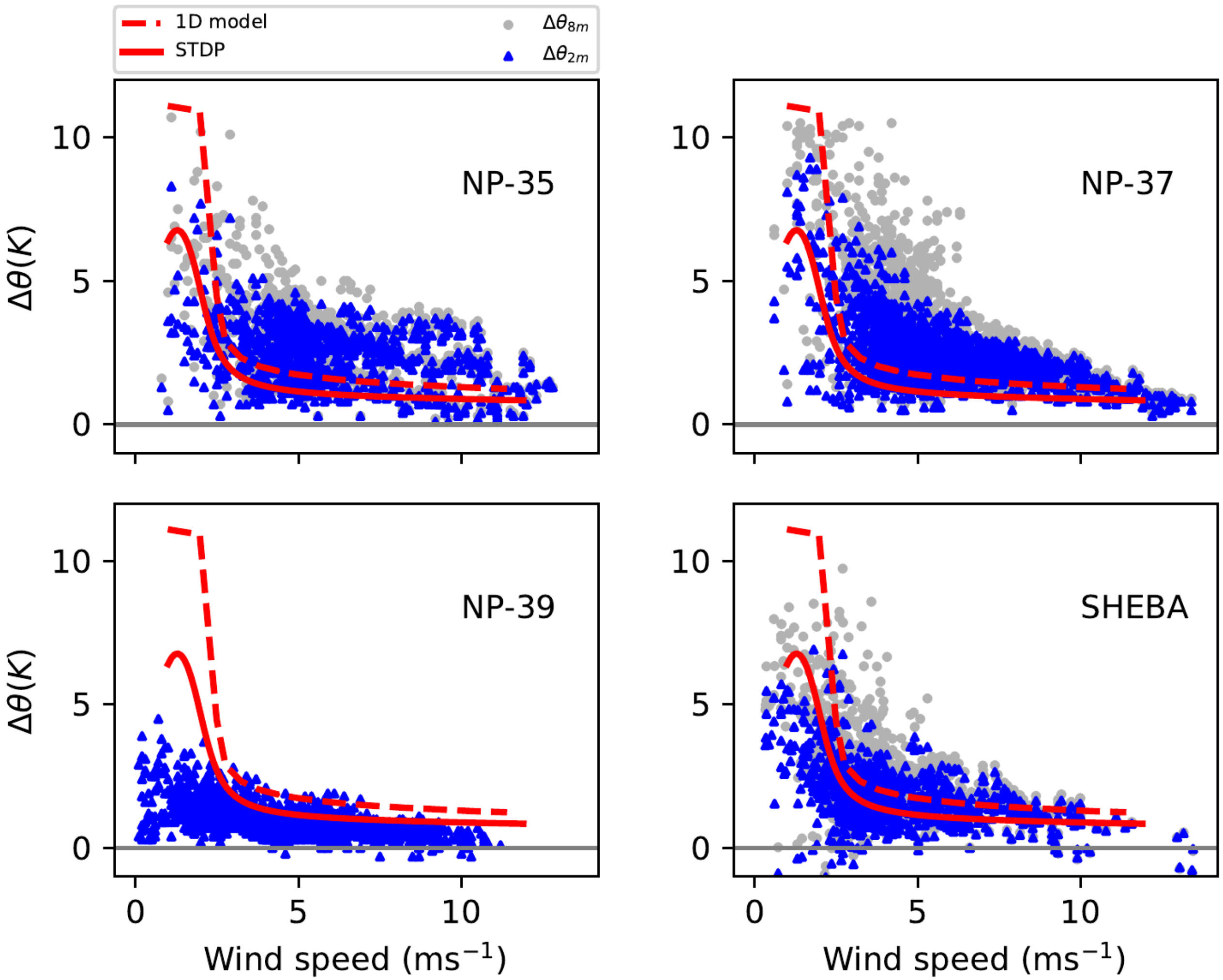
- Nonmonotonic dependency of temperature on wind speed is a robust feature, even without leads!

- Cooling time scale at strong and weak winds is large

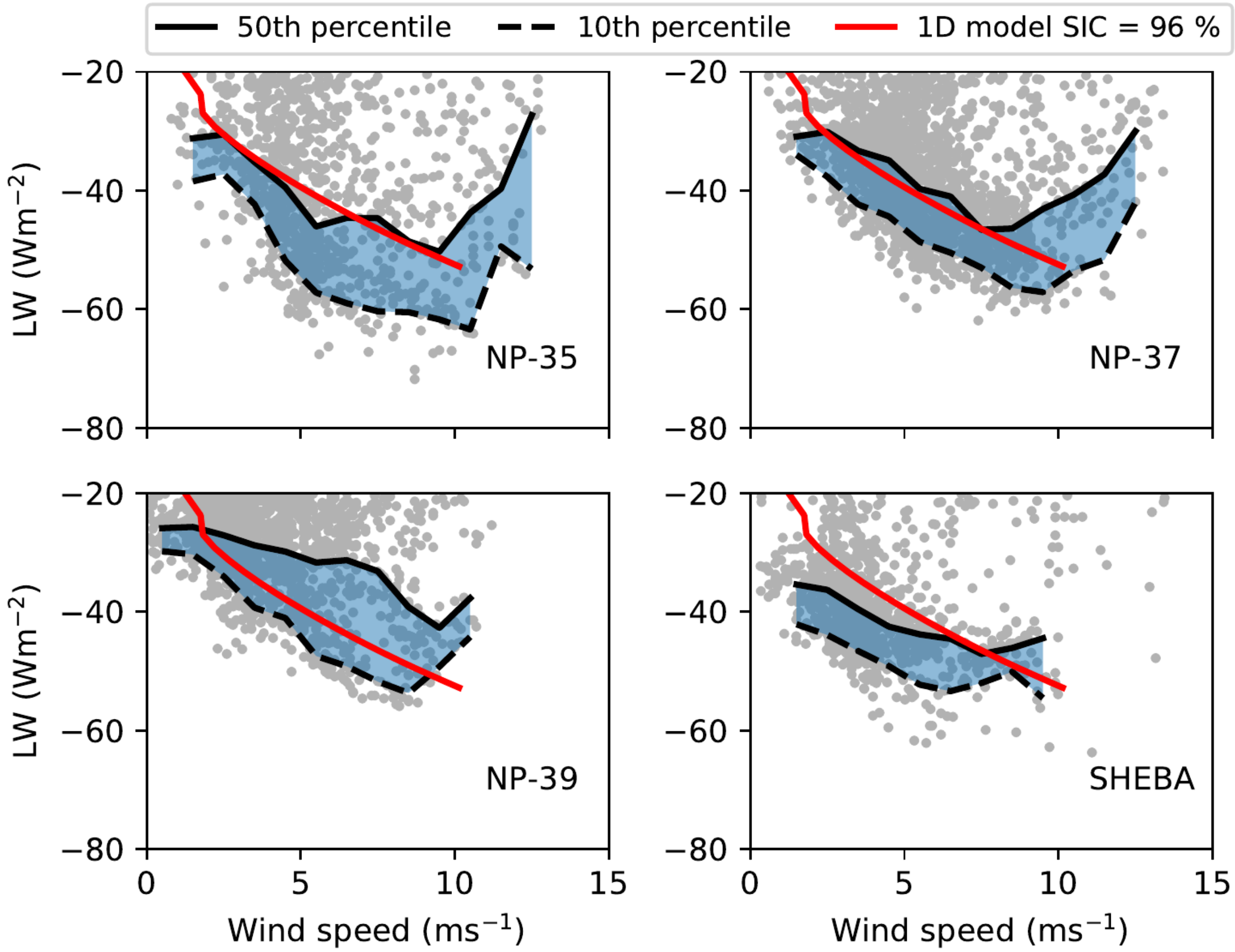
Comparison with observations



Comparison with observations



Comparison with observations



Negative radiative feedback

The effect of leads

$$0 = AC_{H,s}(\theta_s - \theta_a) + (1-A)C_{H,w}(\theta_{lead} - \theta_a)$$

Overland et al., 2000

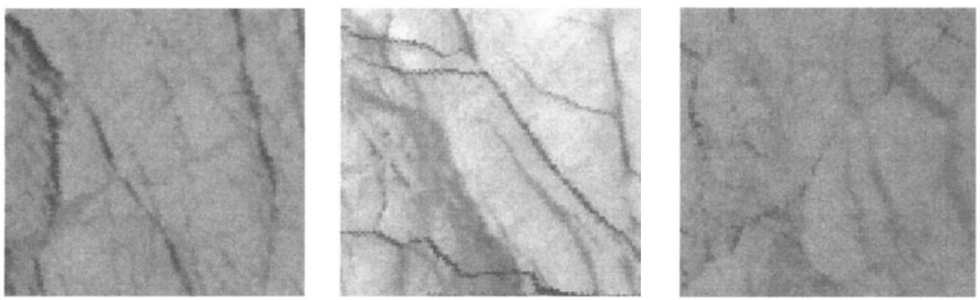
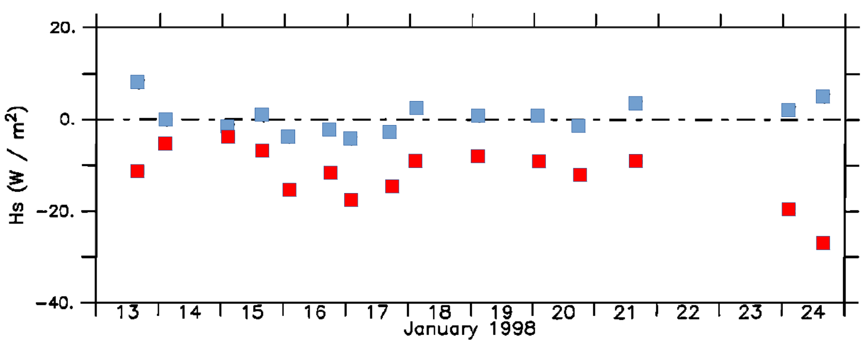


Figure 2. Each square shows 100 × 100 AVHRR pixels centered on the SHEBA camp location for (a) December 10, 1997, (b) January 16, 1998, and (c) February 20, 1998 (see Figure 1). Each pixel is ~1 × 1 km^2.

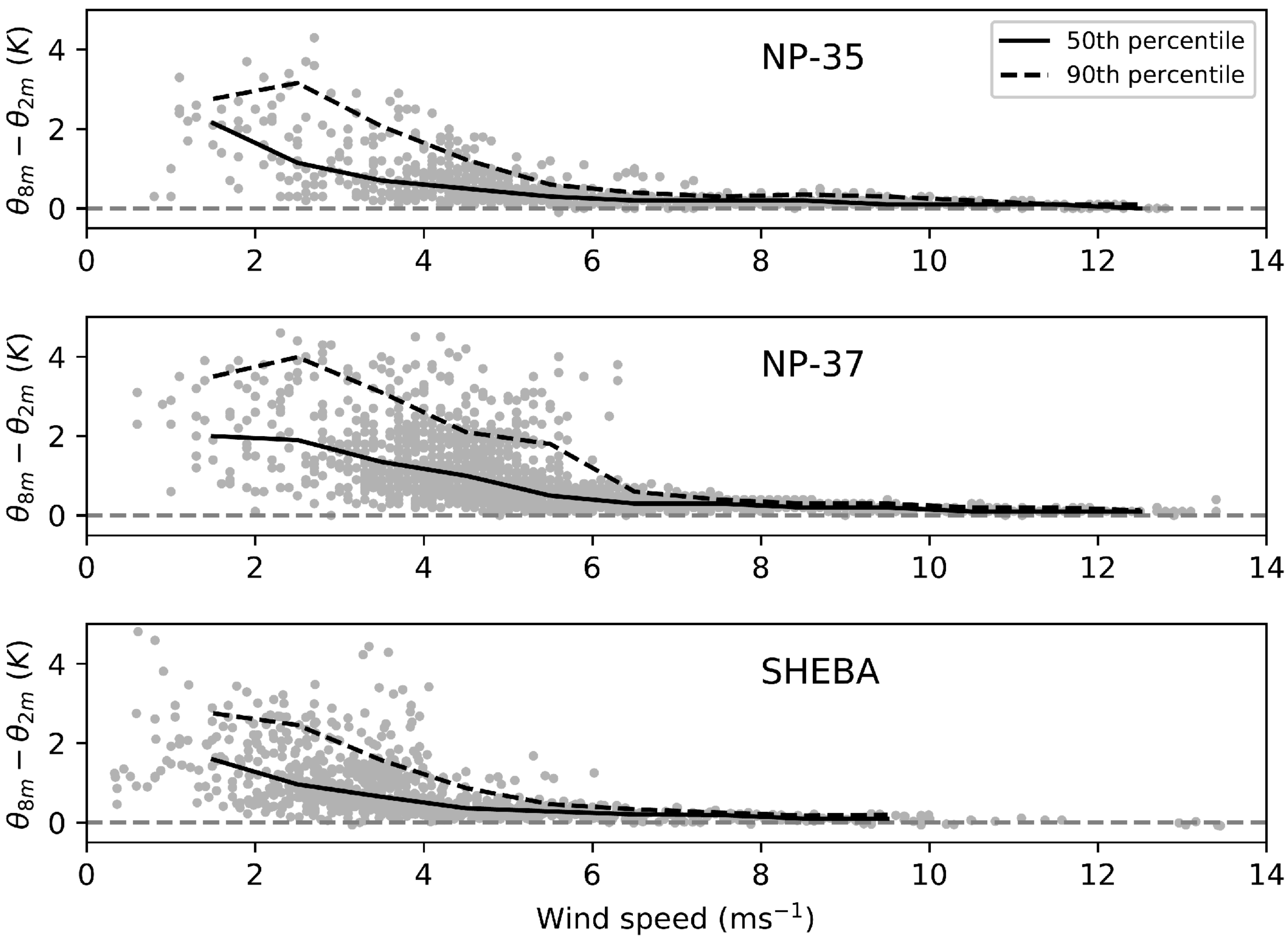


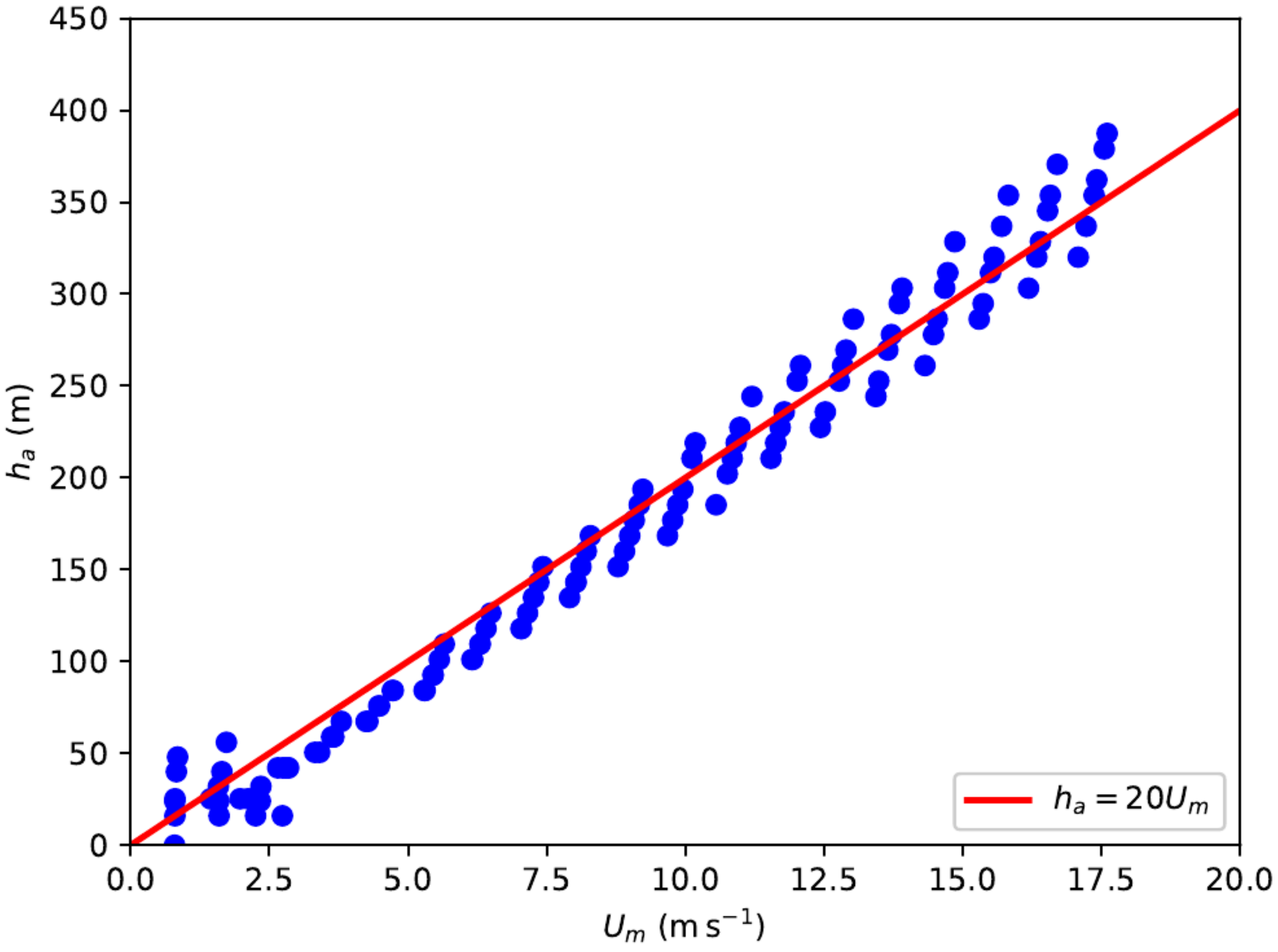
- Regionally averaged (100x100 km)
- Observed at the SHEBA ice floe

Conclusions

- Even a small change in SIC results in strong warming
- Leads influence stability over the ice floes
- Nonmonotonic temperature-wind depndency due to: i) leads, ii) cooling time scale dependency on wind speed
- Regime transitions: from weakly to strongly stable
- Negative longwave radiative feedback
- Simple model performs well

Drawing by Edward Wilson during the Scott expedition to the South Pole


NP-35
NP-37
SHEBA
50th percentile
90th percentile
$\theta_{8m} - \theta_{2m}$ (K)
Wind speed (ms^{-1})
0
2
4
6
8
10
12
14



450
400
350
300
250
200
150
100
50
0
h_a (m)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
U_m (m s^{-1})
$h_a = 20U_m$