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Downward sensible heat flux and decoupling over snow-covered surfaces

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Introduction

$$H = \rho\, c_p\, C_h\, (\theta_a - \theta_S)\, V$$

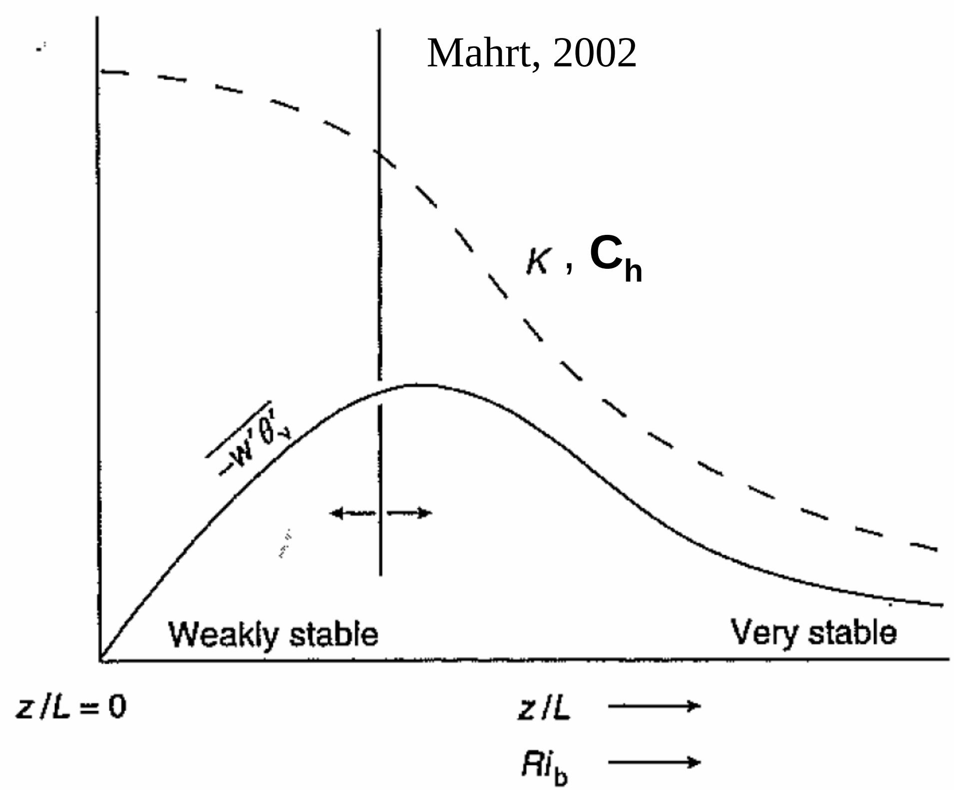
Assume a constant wind speed.

Under stable stratification, increasing $\theta_a - \theta_S$ first results in increasing H, but with increasing $\theta_a - \theta_S$, the thermal stratification increases as well

→ turbulent mixing will be reduced, C_h decreases, which starts to dominate
→ H decreases

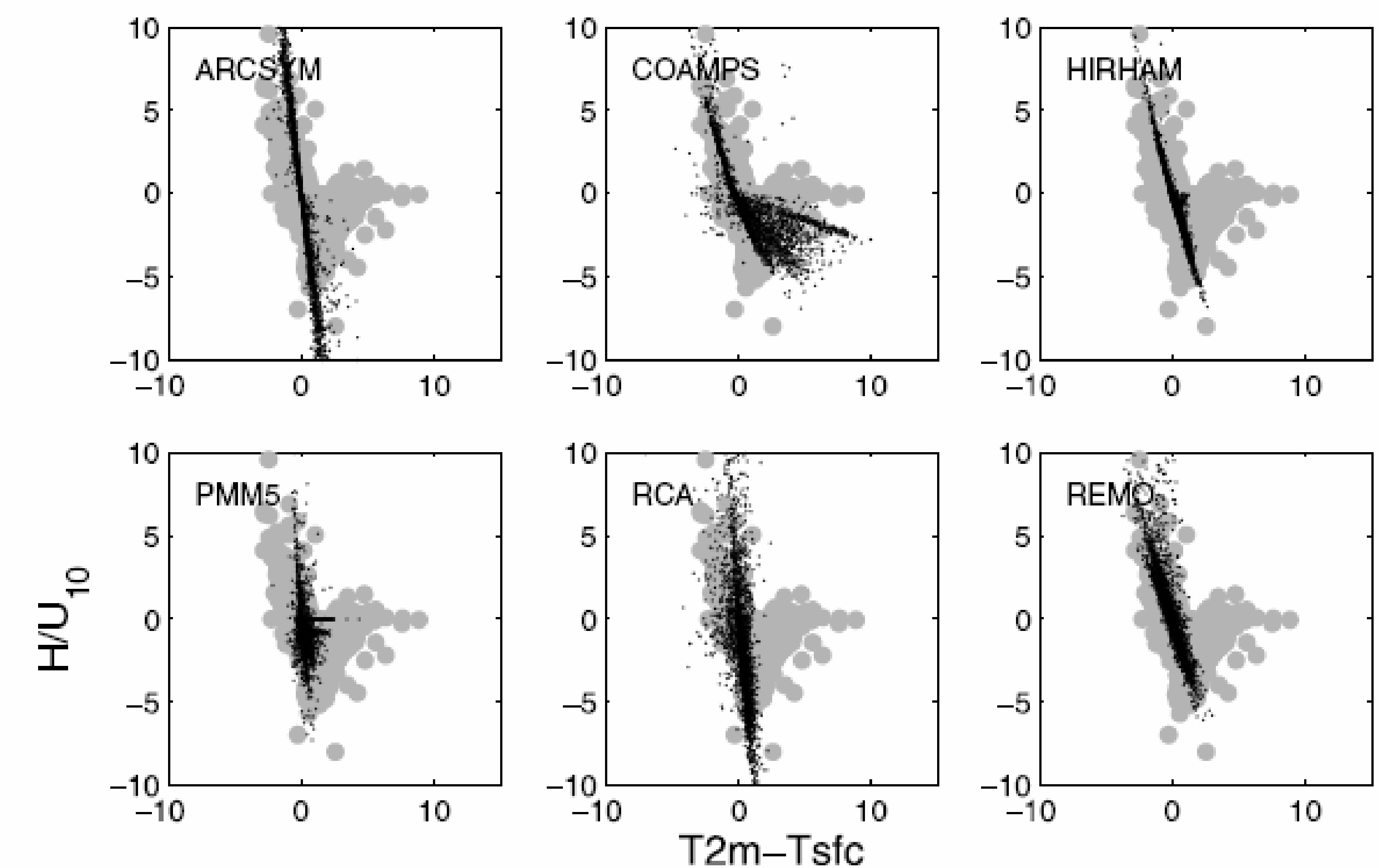
→ positive feedback to the increasing temperature difference

→ decoupling with very large $\theta_a - \theta_S$



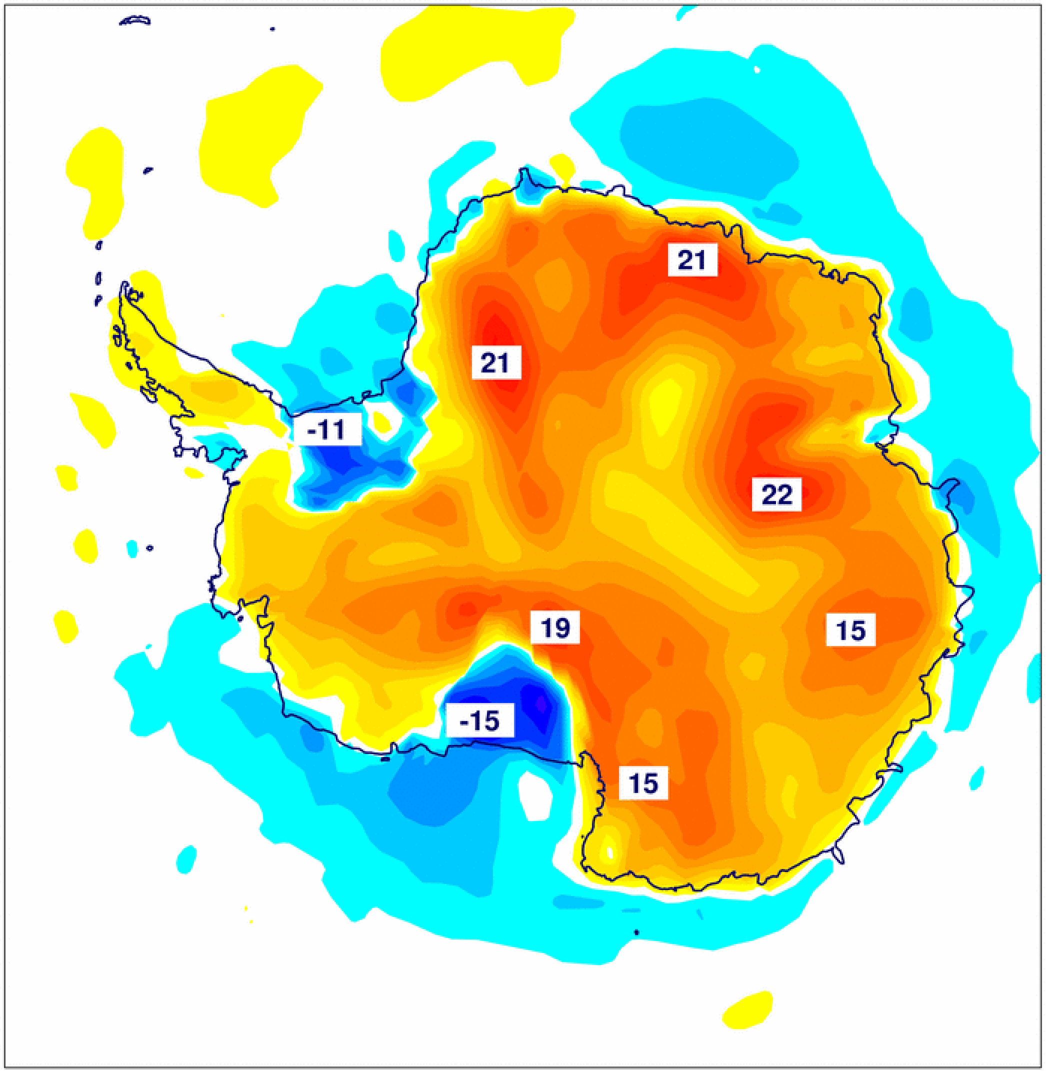
Most models do not well reproduce observations on decoupling

Tjernström et al. (2005): validation of 6 regional climate models against SHEBA data



But sometimes the decoupling is too strong, as it was in ERA15

Difference between ERA40 and ERA15 in T2m in the Antarctic in July 1989 (Per Kålberg, SMHI)



There are very many different empirical formulae for the stability functions. We compare two of them:

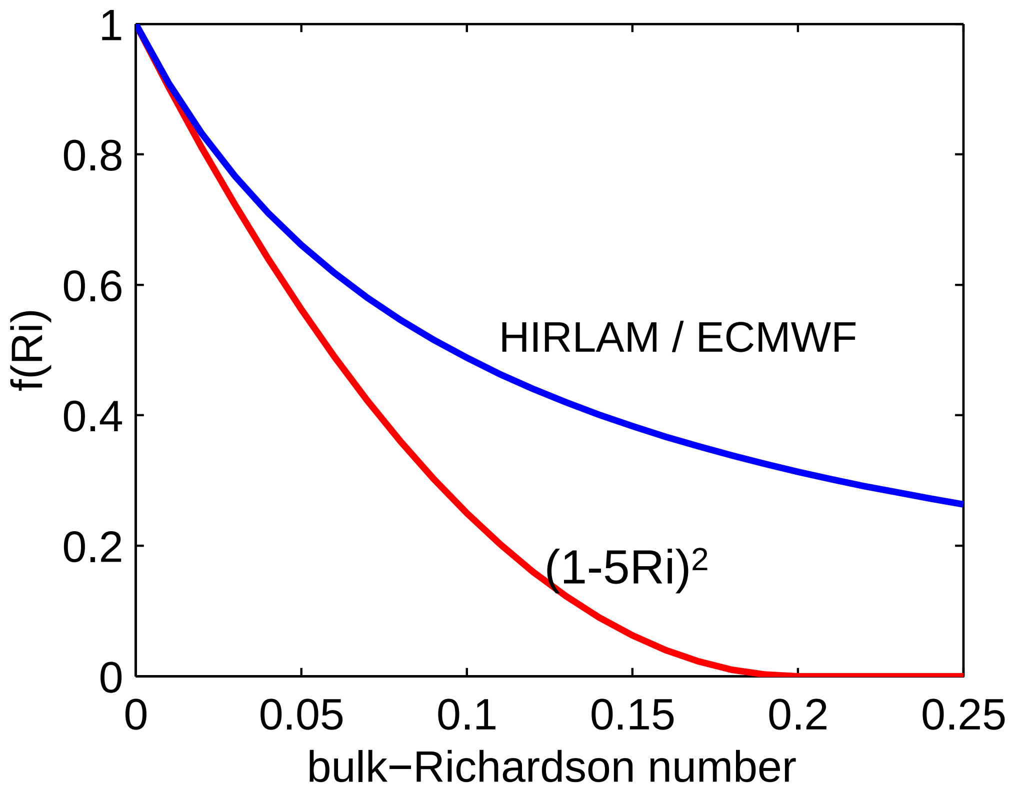
$$C_H = C_{HN} f(Ri)$$

$$f(Ri) = \frac{1}{1 + 10\,Ri\sqrt{1 + Ri}}$$

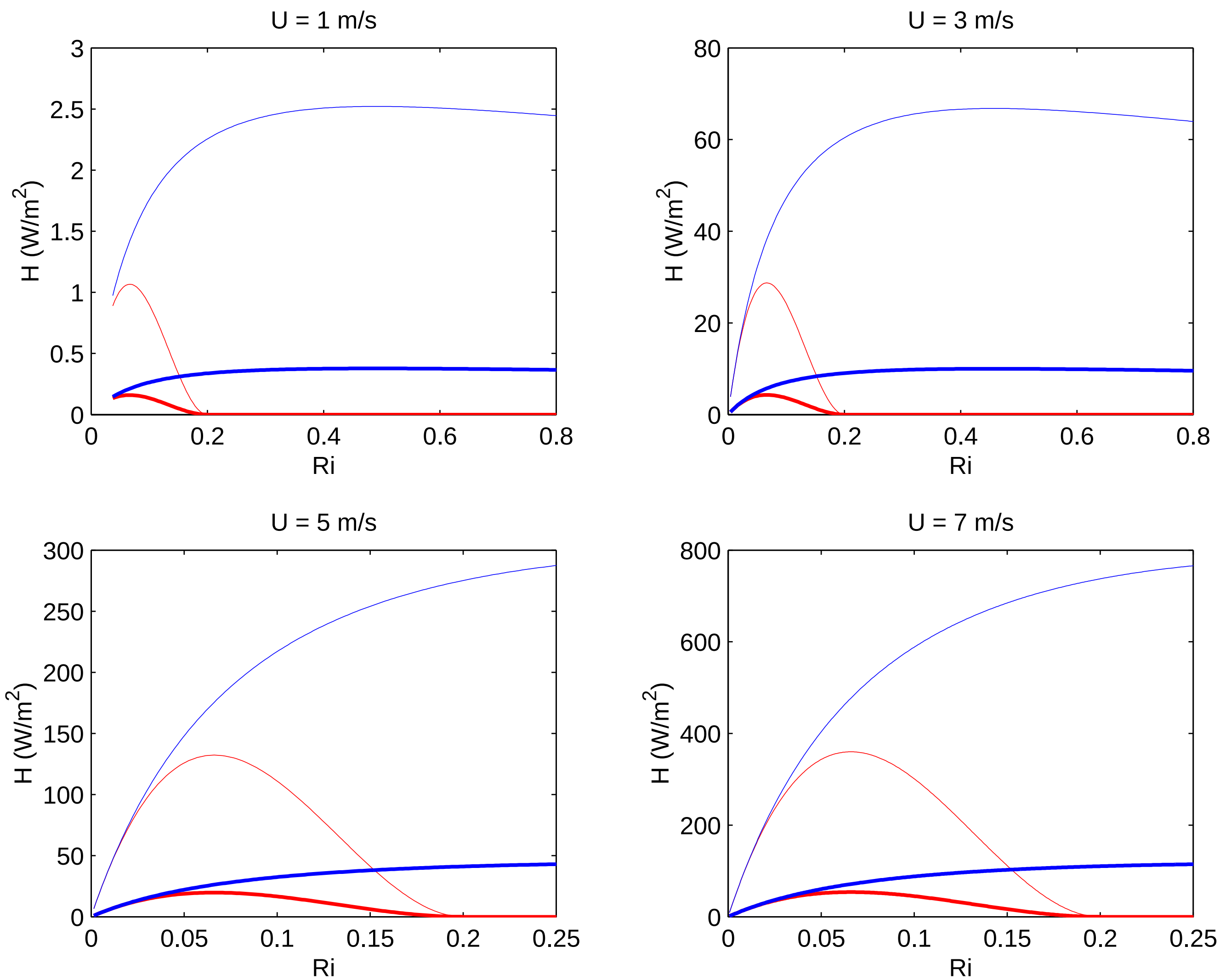
used in HIRLAM and ECMWF

$$f(Ri) = (1 - 5Ri)^2$$

consistent with Dyer (1974) Ψ-function



Theoretical calculations with the Dyer (red) and HIRLAM / ECMWF (blue) functions with z_0 = 0.5 m (thin lines) and 0.001 m (thick lines). $z_T = 0.1 \times z_0$.



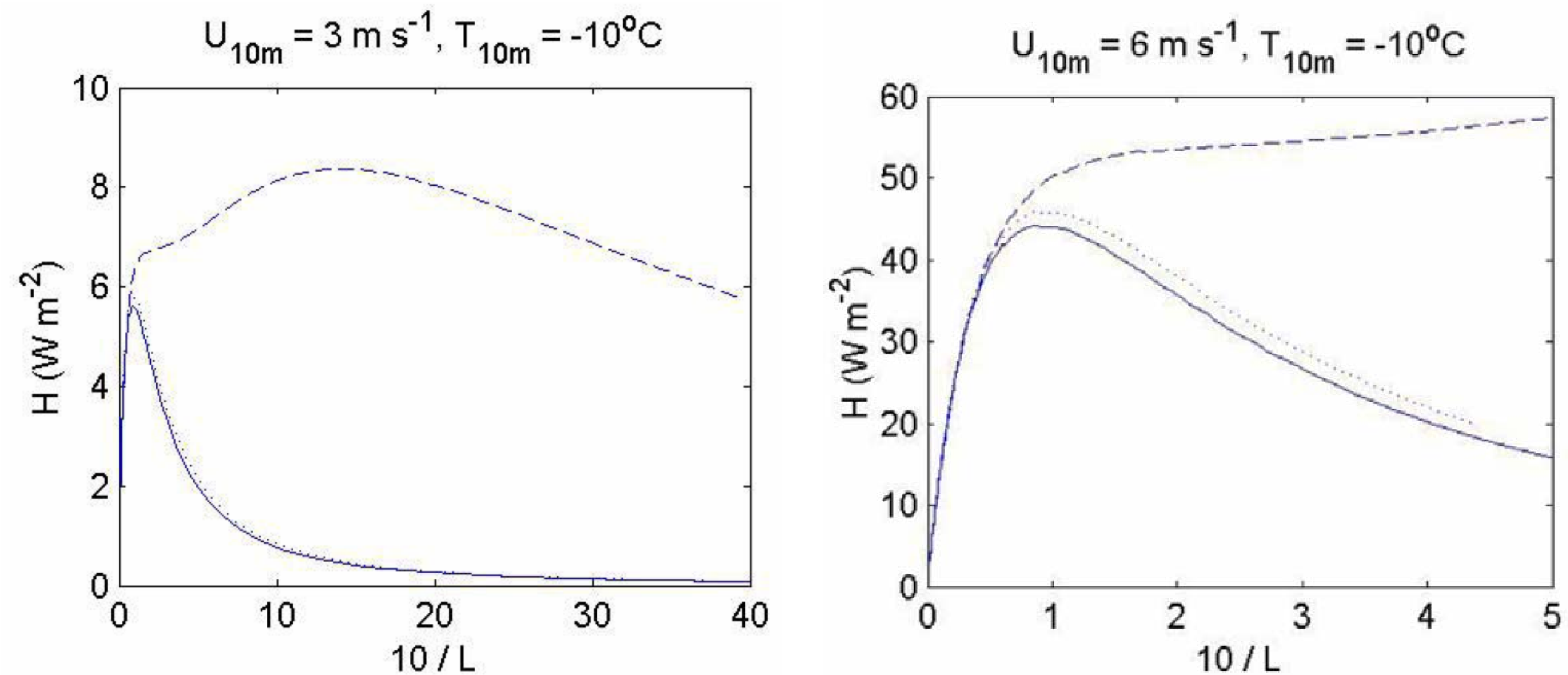
Ri corresponding to the maximum H is independent of the wind speed and roughness lengths.

Differences between the results based on Dyer and HIRLAM / ECMWF functions are large:

strong stability function → small Ri yields the maximum H

Large differences also occur between various empirical Ψ-functions with 10/L as an argument

	10/L for the max H	
Högström (1988)	0.86	(dotted line)
Dyer (1974)	0.88	(solid line)
Holtslag and de Bruin (1988)	14.2	(dashed line)



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Observations

SHEBA, Arctic Ocean, 76°N,
one year 1997-1998

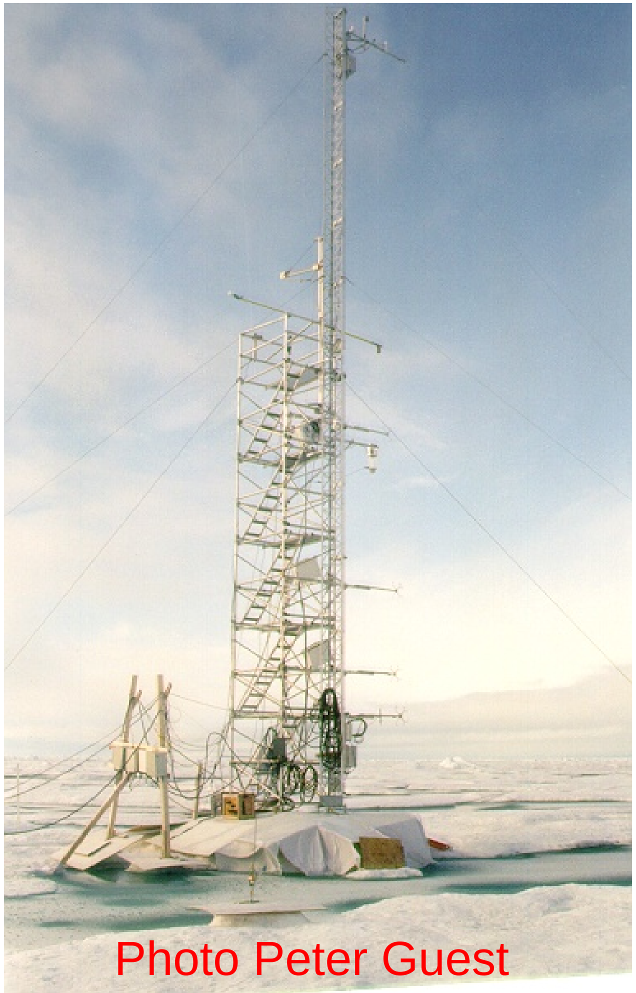
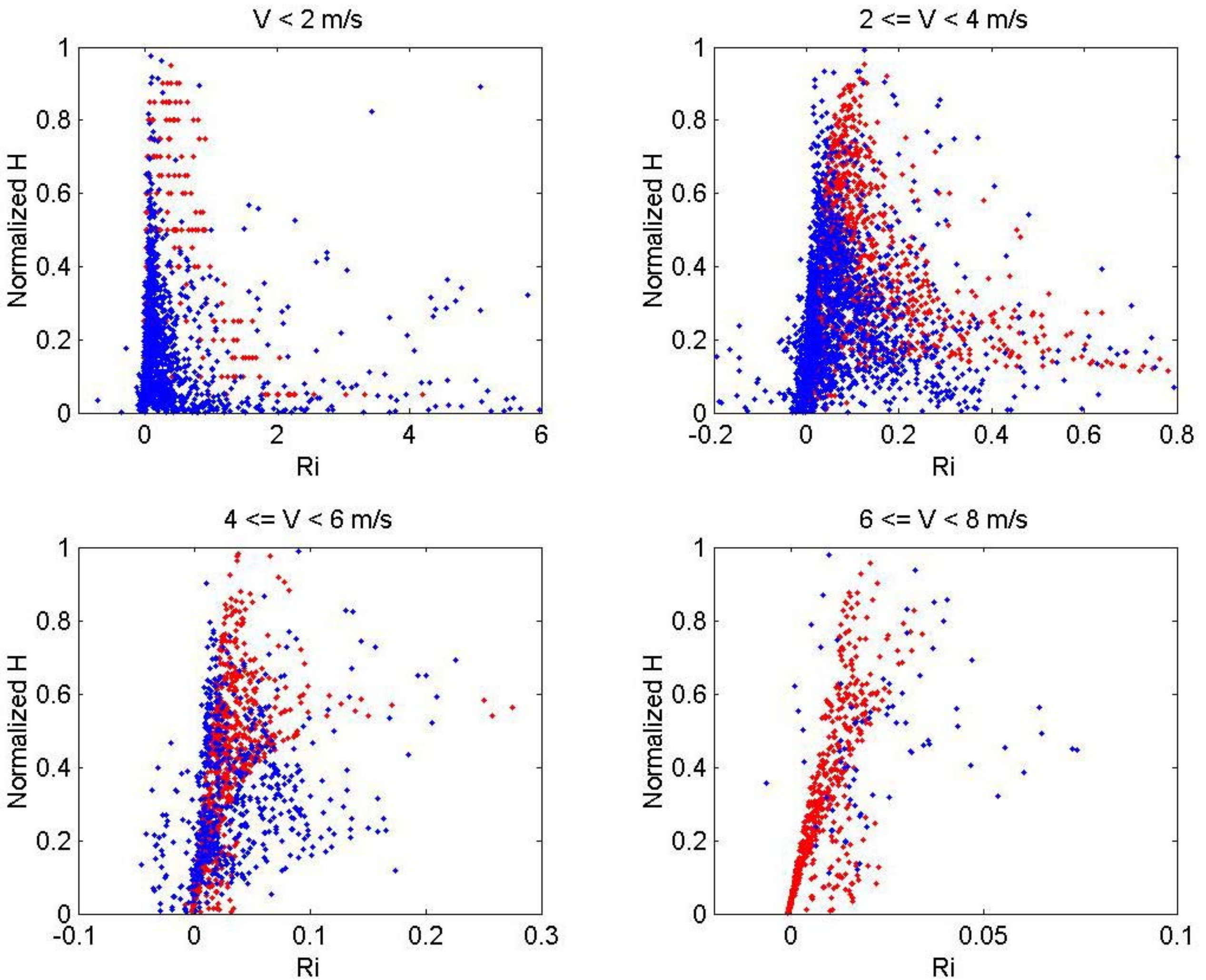


Photo Peter Guest

Sodankylä, Finland, 67°N,
2 winters, 1999-2000, 2002-2003

Results: SHEBA and Sodankylä, normalized fluxes (H/H_{max})

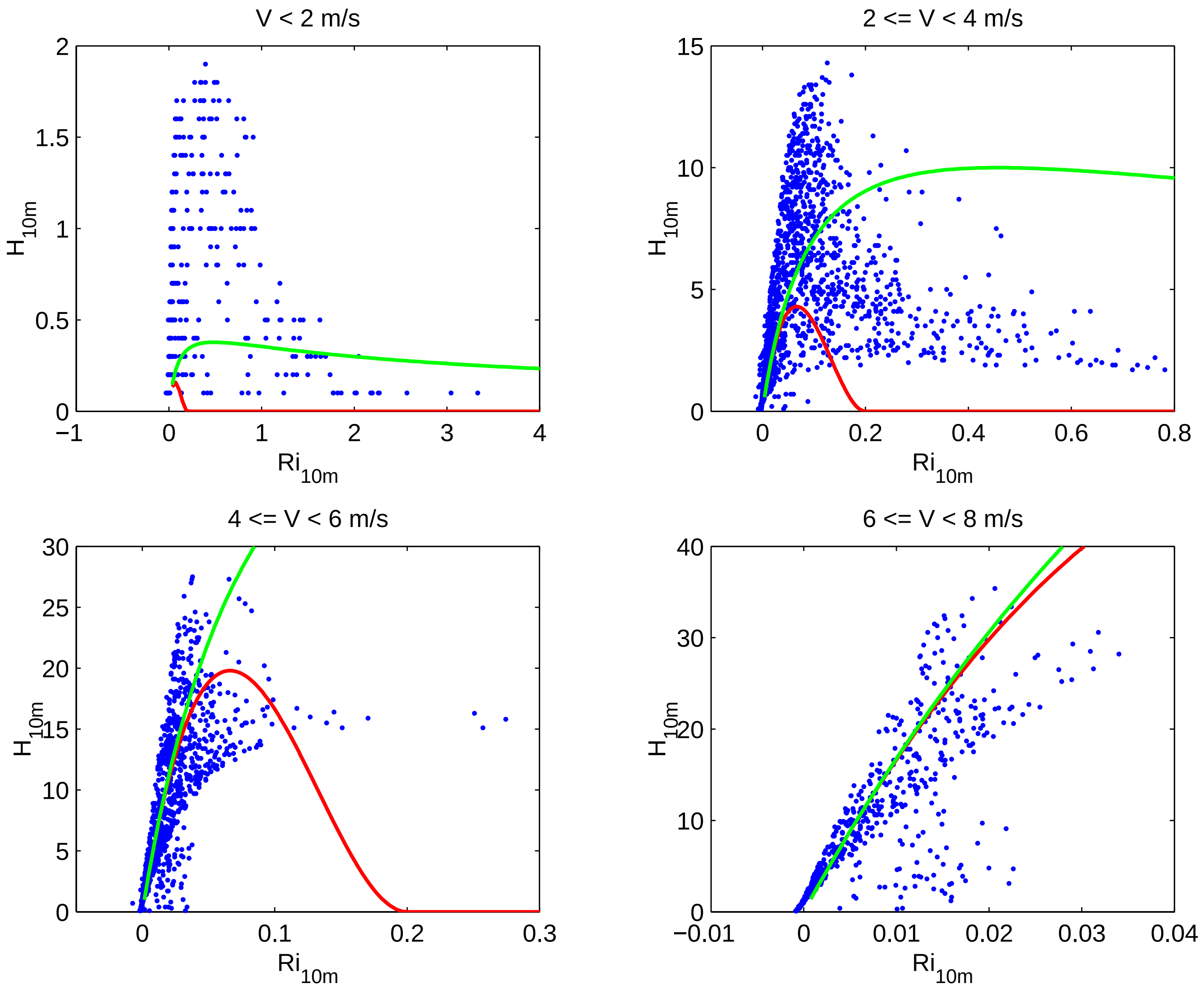


SHEBA and Sodankylä data are qualitatively similar.

Max downward H is reached with slightly smaller Ri in Sodankylä than SHEBA.

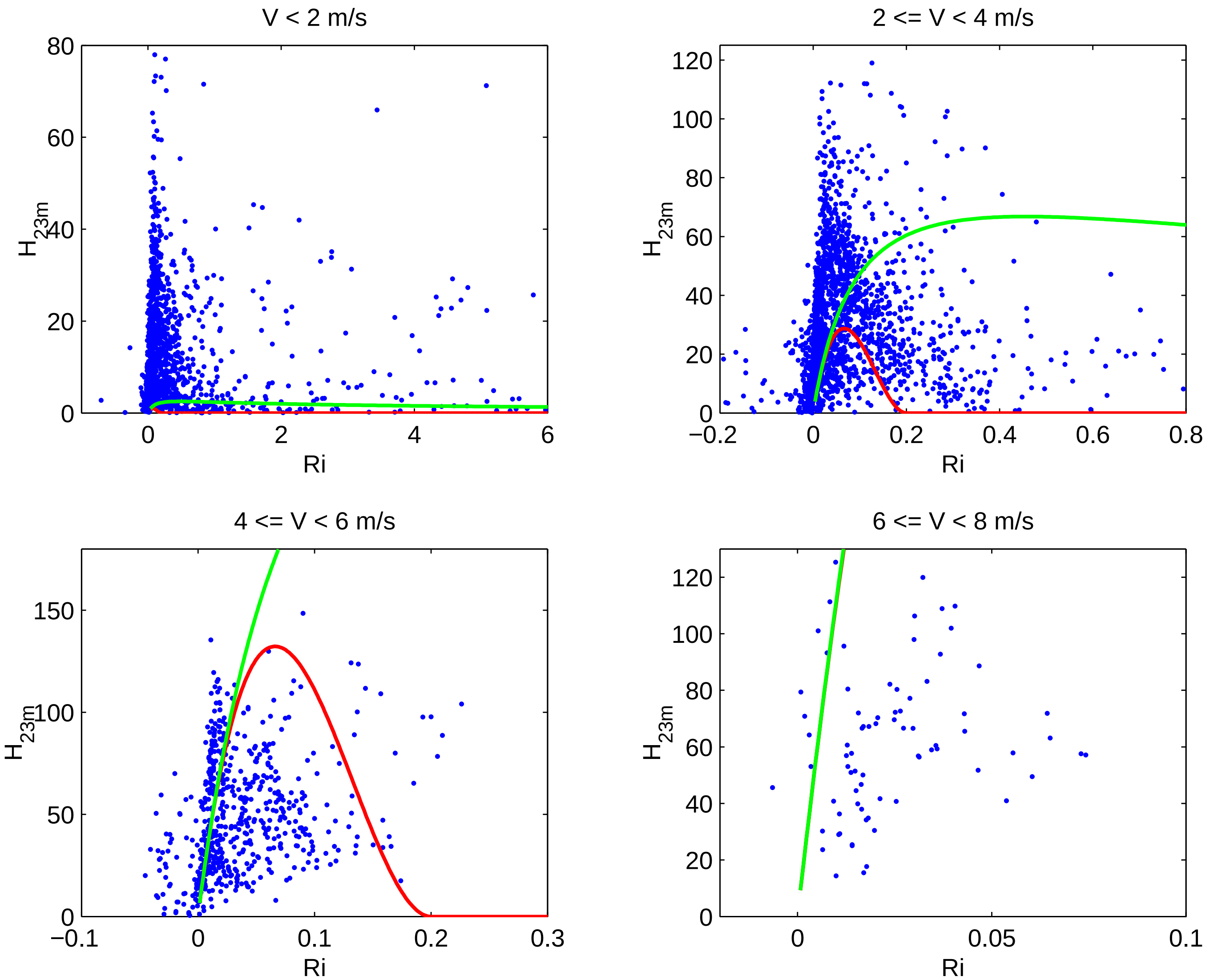
At least in SHEBA, Ri corresponding to Hmax depends on the wind speed:
0.4 for V < 2 m/s
0.1 for 2<V< 4 m/s
0.05 for 4<V<6 m/s

SHEBA results with Dyer (red) and HIRLAM / ECMWF (green) functions



- -The HIRLAM / ECMWF function does not reproduce the observed peaks in H
- - Dyer form not bad for the Ri corresponding to the peak
- - when V < 4 m/s, too small fluxes with the Dyer form

Sodankylä results with Dyer (red) and HIRLAM / ECMWF (green) functions



The results are qualitatively similar to those of SHEBA:

- reasonable Ri for the peak H with Dyer form

- no peak with HIRLAM/ECMWF form

For V < 2 m/s, the flux magnitudes are strongly under-estimated by the bulk parameterizations

↑ non-local fluxes

Conclusions

- Models very sensitive to the Ri corresponding to the maximum downward heat flux
- SHEBA data show a wind speed dependence of the Ri corresponding to the maximum flux, but literature-based parameterizations do not
- Except of that, SHEBA and Sodankylä data are roughly in agreement with the Dyer formula, but strongly disagree from the formulas used in the HIRLAM and ECMWF models
- The flux magnitudes at SHEBA and Sodankylä differed a lot, but the stability dependence was only slightly different compared to the drastic differences between literature-based functions
- Decoupling may pose a problem for model numerics, and this is one reason why many models prefer to apply weaker stability functions
- Weaker stability functions also implicitly account for the background turbulence usually present in large grid cells e.g. due to topographic variations and surface heterogeneity

→ Many models would probably benefit from stronger stability functions, but we cannot recommend these for all conditions

However, if HIRLAM or ECMWF model has a systematic warm bias in T2m in winter, among the first things to do would be to modify the stability function over flat surfaces.