How good is the boundary-layer in current atmospheric climate models?

Michael Tjernström*, Mark Žagar and Gunilla Svensson
Department of Meteorology, Stockholm University, SE-106 91 Stockholm, Sweden
*Corresponding author: michaelt@misu.su.se
Annette Rinke and Klaus Dethloff
Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany
John Cassano and Michael Shaw
Cooperative Institute for Research in the Environmental Sciences (CIRES) and University of Colorado, Boulder, Colorado, USA
Tido Semmler and Susanne Pfeifer
Max-Planck Institute for Meteorology, Hamburg, Germany
Klaus Wyser and Colin Jones
Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

ARCMIP

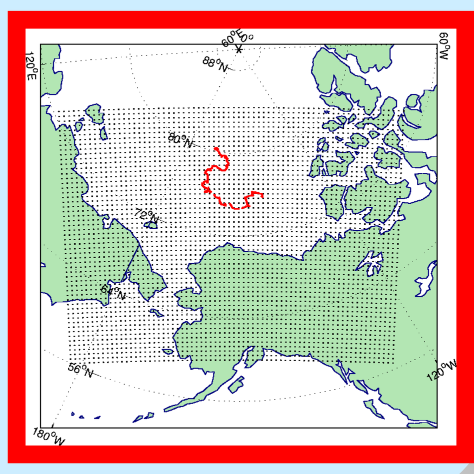
The Arctic Regional Climate Model Intercomparison Project (ARCMIP) aims to improve numerical simulations of regional Arctic climate, and to improve the description of important Arctic climate processes in global models. Using regional modeling facilitates controlled simulations of the local and regional climate by providing accurate analyses as lateral boundary conditions. This also makes possible a direct comparison with observations.

The primary ARCMIP activities thus focus on coordinat-ed simulations with different regional climate models. Output from these models are intercompared, and com-pared to and evaluated using observations from satellit-es, in situ measurements and field experiments. With a reasonably controlled background climate, remaining errors must be due mostly to model deficiencies

The first ARCMIP intercomparison project is using data obtained in 1997/1998 during the SHEBA (Surface Heat Budget of the Arctic Ocean) experiment.

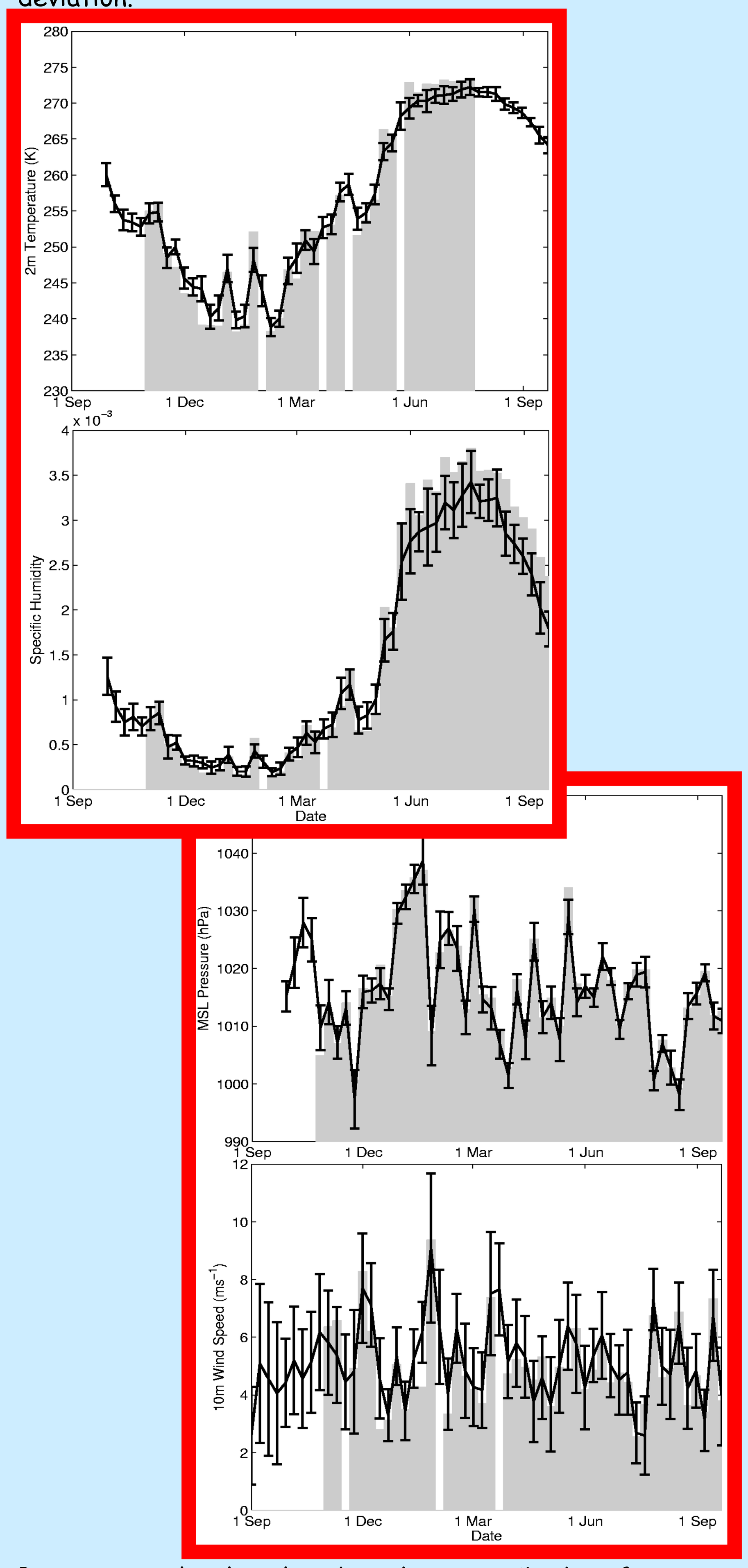
Simulation summary

- *> 1 year long simulation (1 Sep 1997 - 1 Oct 1998)*
- *6 hourly lateral forcing by the ECMWF analyses*
- *Lower boundary forcing by satellite data of SST and of sea-ice temperature and ice fraction*
- *Domain size 3500 x 2750 km*
- *Model resolution 50 km*
- *Comparing model results the observations collec-the SHEBA ice camp*
- *Meteorological mast for & soundings for*



Near-surface parameters

It is not immediately evident that models will follow the parameters specified at the surface and lateral bounda-ries. Some results indicating they do, are illustrated below by model ensemble averages and the inter-model standard deviation.

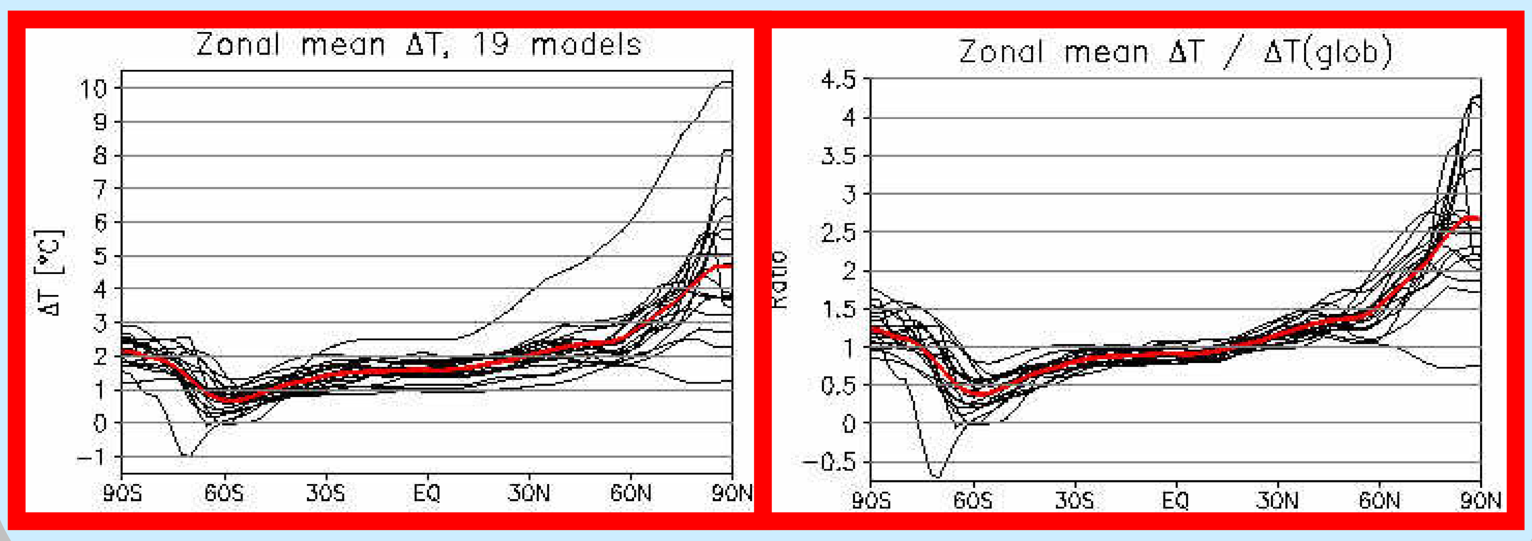


Parameters closely related to the prescribed surface tem-perature are expected to be correct, to within the accura-cy of the observations. This turns out to be at least partly true. Parameters more removed from the boundary condi-tions may deviate more. The fact that surface pressure follows the observations well, and that also wind speed agrees with the observed temporal development, although with scatter, indicates that the model domain is sufficient-ly small that the lateral boundaries realistically constraints the development in the regional models.

The problem

Global climate models (GCM) suggest an amplified climate warming in the Arctic. An ensemble of 19 CMIP models suggests an amplification on average of about 2.5 times the global average. Recent analysis of observations also indicate a more rapid warming in the Arctic, at least over land. In the models, a main reason for the polar amplification of the warming is likely a strong ice/snow-albedo feedback.

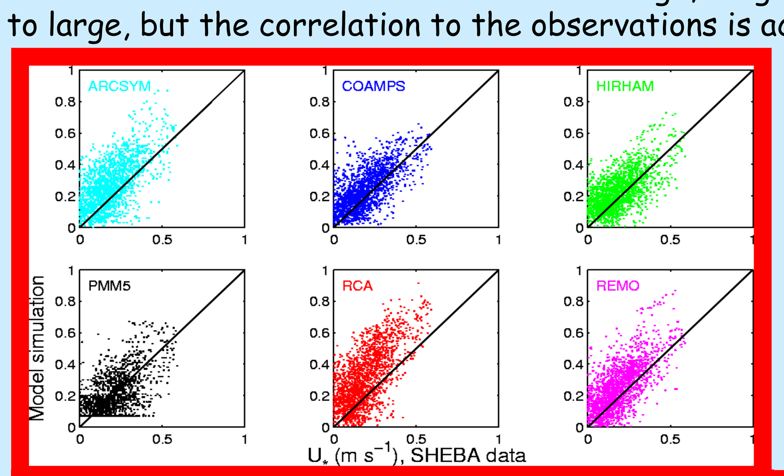
The inter-model spread in the climate-change sensitivity is, however, far larger in the Arctic than anywhere else on Earth. To elaborate further on Arctic climate change, the models must deal adequately with the energy fluxes at the surface and how they may change.



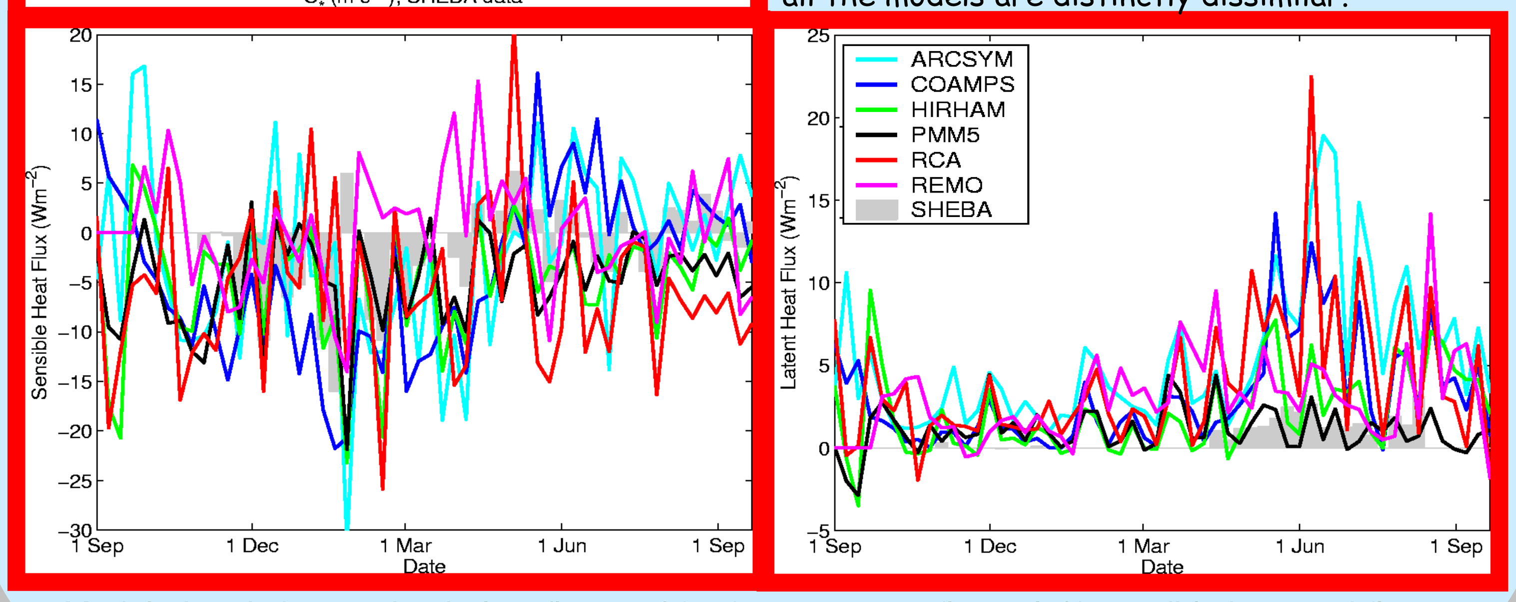
Zonally averaged climate warming in 19 CMIP models (left), scaled by the global average (rigth)

Modeled turbulent fluxes

Modeled *momentum* fluxes are often too large, ranging from only slightly low to almost a factor of two to large, but the correlation to the observations is acceptable. That modeled momentum fluxes are too large is interesting as it is directly related to de-velopment of synoptic scale systems.



The annual bias of the turbulent heat fluxes is small but only because the fluxes themselves are usually small. The *latent heat flux* is typically a factor of 2 - 4 too large while the *sensible heat flux* is marginally better. Annually accumulated heat fluxes are typically an order of magnitude larger than observed, the correlation coefficients to observations are typically smaller than 0.3 and all the models are distinctly dissimilar.

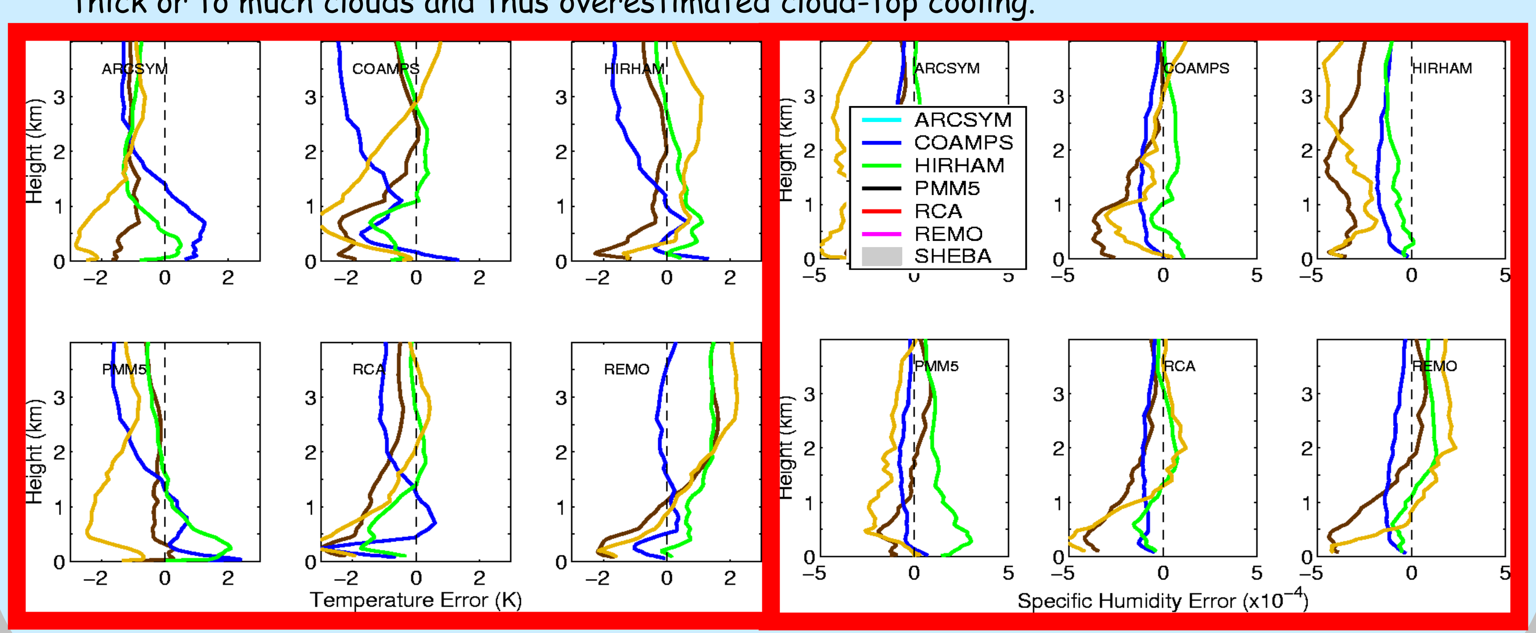


Modeled and observed turbulent fluxes of (top) momentum, (lower left) sensible heat and (lower right) latent heat. Momentum flux is illustrated by a scatter plot, while heat fluxes are shown as time series

Vertical structure

Biases in in the model simulated vertical structure was estimated by comparison to sounding data from SHEBA and is illustrated below the seasonal averages for each model, for temperature and specific humidity. Several things are clear from this comparison:

- There is a significant difference in the error structure, above and below ~ 1 km. The error below 1 km is much larger, indicating problems with the boundary layer in broad sense.
- Even with "perfect" lateral boundary conditions, the error in the free troposphere is signi-ficant and different between the models.
- The error-structure in the boundary layer is indicative of problems with low clouds, specially in summer – see the elevated cold-bias maximum in almost all models, presumably due to to thick or to much clouds and thus overestimated cloud-top cooling.



Bias profiles of temperatur (left) and specific humidity (right) for JJA (yellow), SON (brown), DJF (blue) and MAM (green).

Participating models

In this study we compare the results from six different regional models directly with data from the SHEBA ice-drift experiment.

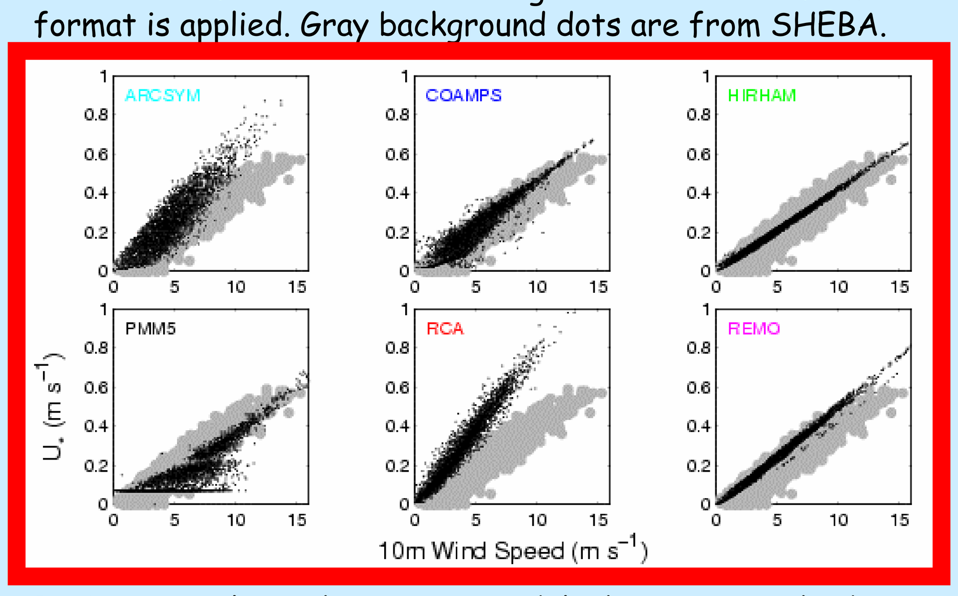
The participating models were:

- ARSyM, CIRES, University of Colorado, USA
- Polar MM5, NCAR/Penn State but run at CIRES, USA
- COAMPS™ US Naval Research Laboratory, but run at Stockholm University, Sweden
- HIRHAM developed in Germany and Denmark and run at the Alfred-Wegener Institute, Potsdam, Germany
- REMO from the Max-Planck Institute for Meteorology, Hamburg, Germany
- RCA, developed from HIRLAM at the Rossby Centre, Norrköping, Sweden

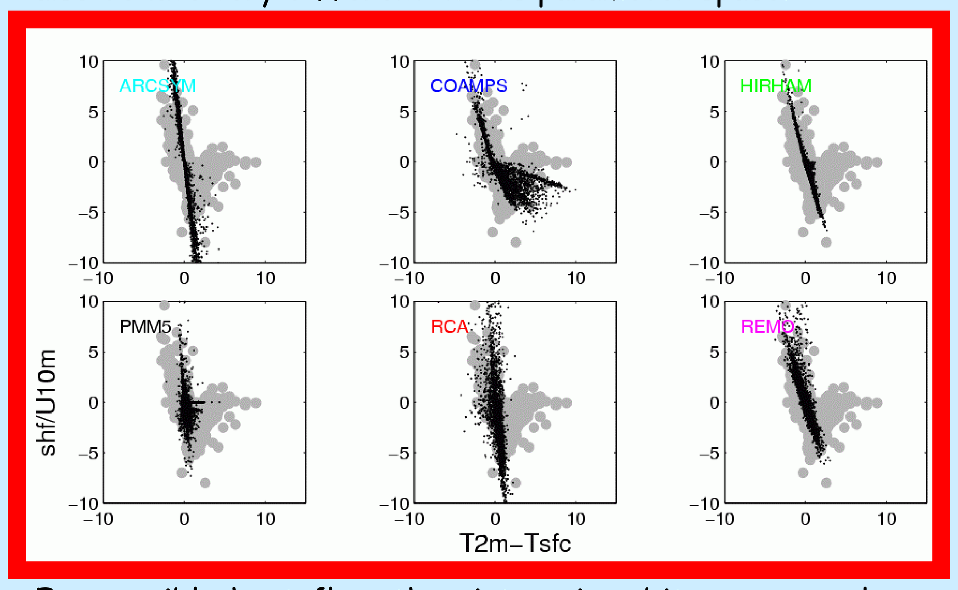
All simulations were carried out the same way, running from 1 September 1997 through September 1998. The model domains and horizontal resolutions were the same in all models. All models used the same 6-hourly updated ECMWF operational analyses at the lateral boundaries, and the same specified sea- and ice-surface temperatures from AVHRR and ice fraction from SSM/I measurements. The models all have their different parameterizations and use different vertical resolution and numerical methods.

Scaled turbulent fluxes

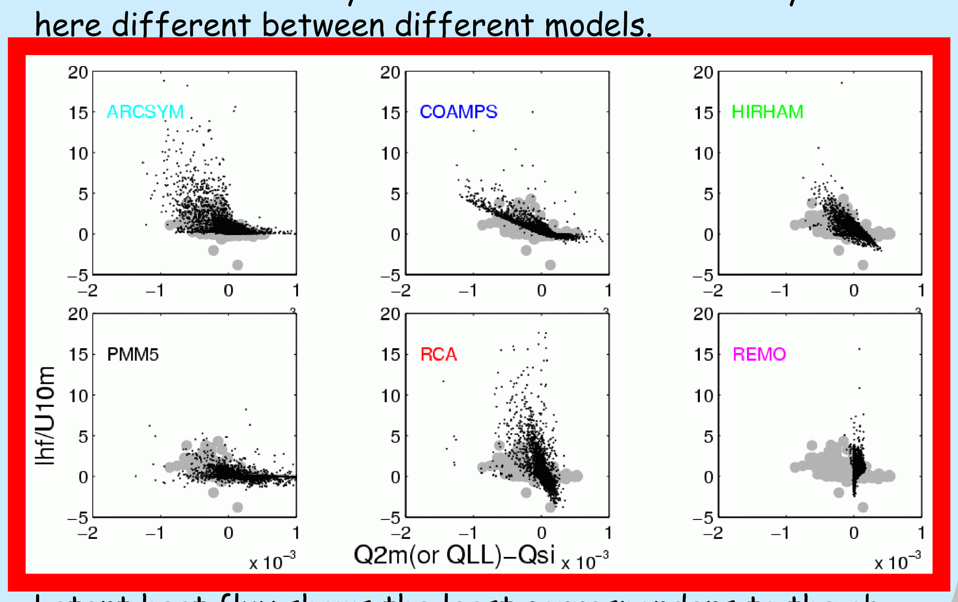
A simple scaling makes it possible to investigate potential reasons for the failure by the models to estimate the tur-bulent heat fluxes. Below a scaling based on a bulk-formula format is applied. Gray background dots are from SHEBA.



It is very clear that some models have to much drag, probably due to a too large roughness. Different models also behave very different in this parameter space.



For sensible heat flux, the picture is a bit more complex. Models show a similar behavior; only one makes an attempt to deal with the very stable cases. The variability is also here different between different models.



Latent heat flux shows the least correspondens to the ob-servations. The model sensitivity to resolved-scale variables is very large for latent heat flux

Conclusions

Six models boundary-layer results are compared for a year-long simulation of the so-called SHEBA year. The relatively small domain ensures that all models synoptic scale develop-ment follows the prescribed boundary conditions well, al-though deviations do occur.

- Surface friction is reasonable, well correlated with the ob-servations but often too large.
- Modeled turbulent heat fluxes has a small annually averag-ed bias, but has no significant correlation to the observa-tions at all, and temporal errors can be very large, cer-tainly larger than the typical surface net-energy balance.
- Annually accumulated heat-fluxes are an order of magnitu-de in error, but sensible and latent heat compensate.
- Scaled turbulent fluxes are, however, reasonably adequate.

One may speculate as to why the actual fluxes are so poor, when they seem to follow a single scaling and the resolved-scale variables are also relatively good.