JP2.16 THE ARCTIC BOUNDARY LAYER IN SIX REGIONAL SCALE (ARCMIP) MODELS

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1. INTRODUCTION

The climate forcing, including drivers of climate change, are all parameterized in climate models. There appears, however, to be somewhat of a controversy in climate modeling as to what the often called "model physics" really are. Does it have anything to do with the actual physics of real processes, or are they just a package of tunable statistic relationships of more obscure nature? It has been claimed that it is only present to provide modelers with a handle to turn, to force the models to behave realistically. And, if the actual processes that it should represent are treated poorly, it doesn't matter much as long as the mean results are realistic. However, given how climate is generated in a climate model – and in reality – it is exceedingly clear to us that unless the "model physics" at least attempt to model the actual physics in a realistic way, climate modeling is not very meaningful.

The Arctic is on of the most sensitive areas in the World to climate change. On average in 19 CMIP (Meehl et al. 2000) climate change simulations, the Arctic warms 2.5 times more the global average (Räisänen 2001).

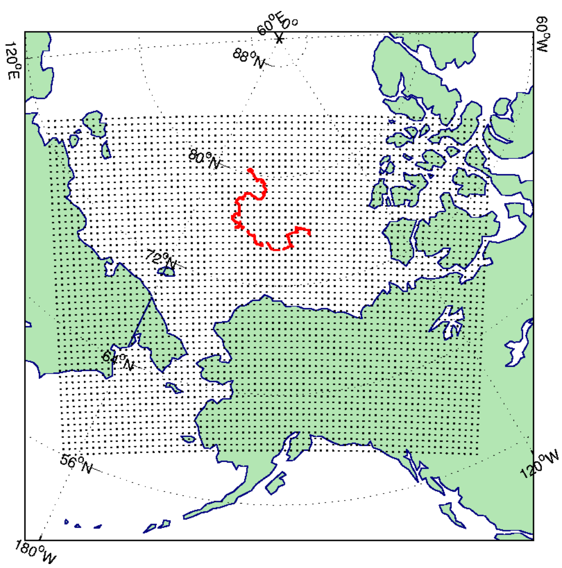

Figure 1. The ARCMIP exp. #1 model domain.

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We see already today signs that global warming have started to impact the Arctic (Serreze et al. 2000, Comiso 2002). Still, the inter-model spread in the CMIP ensemble is largest in the Arctic (Räisänen 2001) and current GCM have problems reproducing today's Arctic climate (Walsh et al. 2002).

The large Arctic climate sensitivity is due in no small part to strong positive feedback mechanisms, the ice/snow-albedo feedback probably being the strongest. An adequate description of the fluxes of heat, water and momentum at the ice surface lay at the heart of a proper representation of this feedback and thus of Arctic climate. An evaluation of these in models has been difficult, due to lack of adequate data. The Surface Heat Budget of the Arctic Ocean (SHEBA, Uttal et al. 2002) experiment now makes this possible. The aim of the Arctic Regional Climate Model Intercomparison (ARCMIP, Curry and Lynch 2002) project is to improve climate models for the Arctic, by comparing models to SHEBA data and to each other.

2. MODELS

The models included in this study are state-of-the-art regional-scale climate models: ARCSym (Lynch et al., 1995), COAMPS^{TM}, (Hodur 1997), HIRHAM (Christensen et al., 1996), Polar MM5 (Bromwich et al., 2001), RCA (Jones et al. 2004) and REMO (Jacob, 2001), see acronyms in Fig. 2. All models were set up with the same horizontal resolution on a common domain, centered on the SHEBA ice-drift track (Fig. 1). They all used the same 6-hourly lateral boundary conditions taken from the ECMWF analyses. Sea- and ice-surface temperatures and ice fraction were prescribed from satellite observations. All models were run for 13 months, starting from 1 September 1997. The experiment is described in detail in Tjernström et al. (2004) and Rinke et al. (2004).

3. RESULTS

In general, the relatively small domain should ensure that the larger-scale dynamics in the models adhere to that of the driving analyses. Some differences between the model ensemble and the analyses, and between individual models, occur even on the synoptic scale (Rinke et al 2004). However, in general all the models follow the lateral boundary forcing quite well. Fig. 2 (top panels) shows the diurnally averaged 2-meter air temperature from all the models for two 3-month periods.

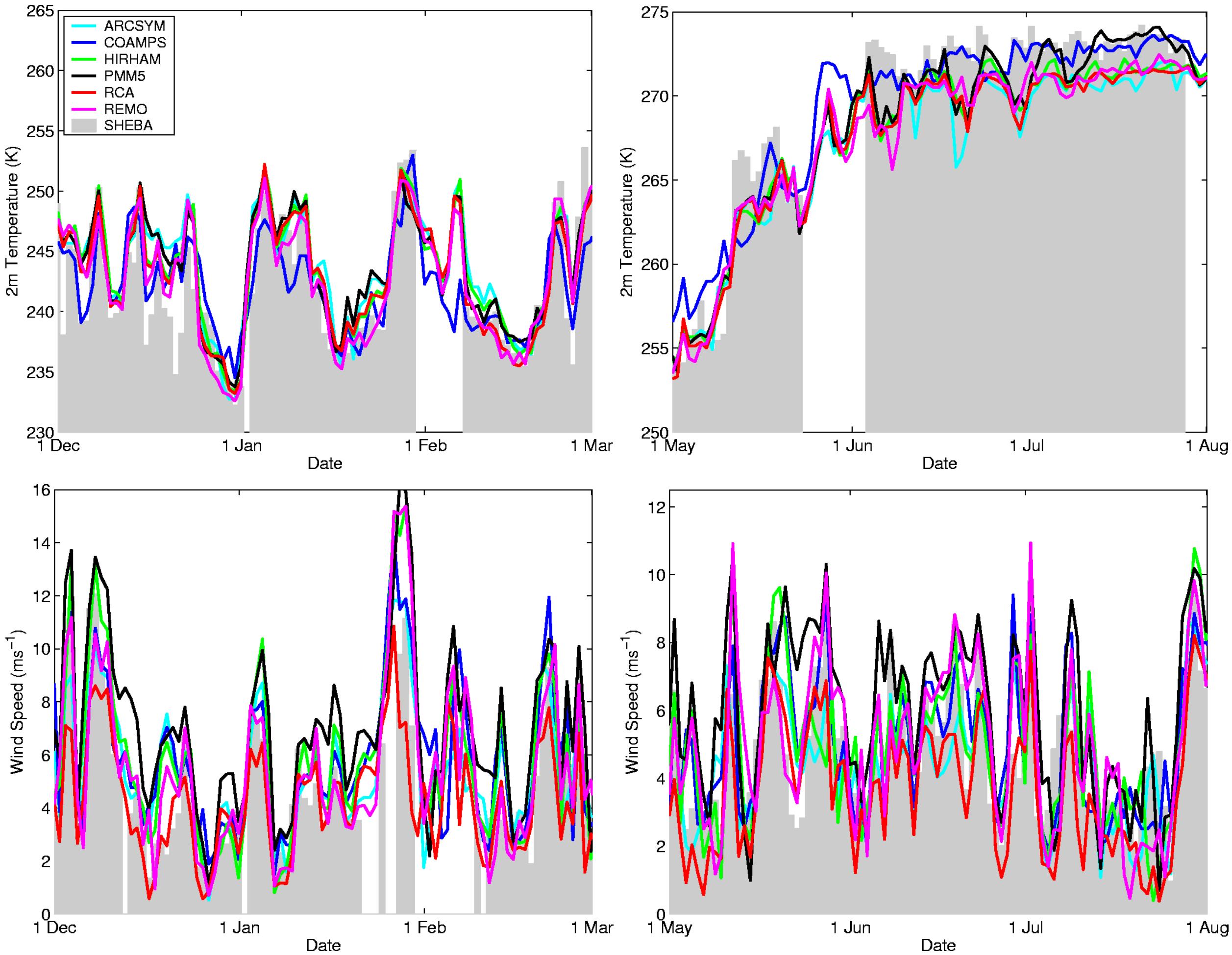

Figure 2. Diurnally averaged 2-meter air temperature during (top left) winter and (top right) spring/summer, and the corresponding wind speed (bottom) for the different models and from SHEBA data, as indicated in the legend.

While the temperature of the ice surface was prescribed, the models are expected to follow the observations. It is therefore somewhat surprising to find some rather large differences between models and observations. During some cold periods in December 1997, many models are ~ 10 ºC too warm, even in the weekly averages. The coldest period, around 1 January 1998, is, however, well captured by all models. In summer the differences are smaller, but with a systematic disparity between some models closer to ~ 0 ºC, the melting point of fresh water, and others closer to ~ -1.8 ºC, the melting point of salty ocean water; the former seems more correct and is also expected during conditions of melting of snow and ice at the surface.

Near-surface wind speeds follow the observed temporal variability well in all models, but there are model-specific systematic biases (Figure 2, lower panels). There are, however episodes when almost all models have a too high winds speed; se for example late Jaunary and mid-December. The opposite does not seem to happen. Annually averaged biases range from ~ -1 ms^{-1} in RCA to ~ 1.5 ms^{-1} in Polar MM5. In some cases, this is consistent with biases in friction velocity (see below).

Seasonally averaged profiles of modeled temperature and humidity bias are shown in Fig. 3, using SHEBA soundings. Two things are obvious from this figure. First, the biases are much larger and more variable below ~ 1 km – roughly on the boundary layer. The larger biases closer to the surface thus indicate deficiencies in the boundary-layer parameterizations, probably also related to errors in the formation of low-level clouds. Note the elevated summer low-level cold bias in practically all models. This is possibly due to an overestimation of cloud-top cooling, either due to an overestimation of cloud amounts or of their optical thickness. Second, different models behave very differently also in the lower free troposphere. In general, errors do not seem to tend to zero with height, in spite of the quite strong constraint set by the lateral boundary conditions on such a small domain. Some models have consistent biases through the year, while others are very variable between seasons. Almost all models are too dry in the lowest kilometer almost all the time; spring seems to be the best season with respect to humidity. The magnitude of this errors can possibly be explained by carrying too much condensed water in the low-level clouds or by having such clouds to often.

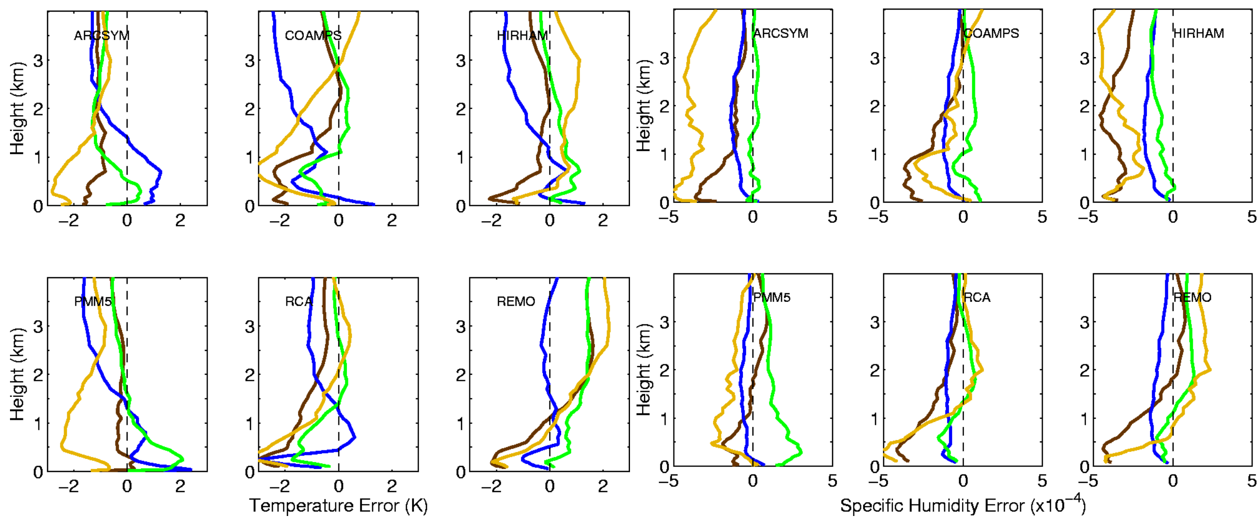

Figure 3. Seasonal averages of (left) temperature bias and (right) humidity profiles. Lines show: fall - black, winter – blue, spring – green and summer – yellow.

Figure 4 shows a scatter-plot of friction velocity (top panel) for each model. These results are mostly acceptable, with some exceptions. The results are at least partly consistent with the wind speed biases in Figure 2, for example the high u_* bias in RCA is consistent with its low wind-speed bias. In the bottom panel of Figure 4 friction velocity is plotted against wind speed for each model; the slope of a regression line through the data represents the square root of the drag coefficient. It is clear that the modeled momentum fluxes deviate from the observations (gray), sometimes significantly. The friction velocity is too high in ARCSyM and RCA, in the latter possibly explaining the low bias in wind speed. Polar MM5 show hard-set lower limit beyond which u_* is set constant and COAMPS™ also has some lower value criteria, apparently dependent on wind speed. The variability – scatter – in friction velocity is also very different in the different models. In ARCSyM this variability is the same and large for all wind speeds, while in COAMPS™ and Polar MM5 it is larger for lower wind speeds. HIRHAM and REMO have almost no such variability at all. High wind speeds are more likely associated with less stratification than low wind speeds and this result probably reflects different stability dependence in the calculation of u* for any given wind speed.

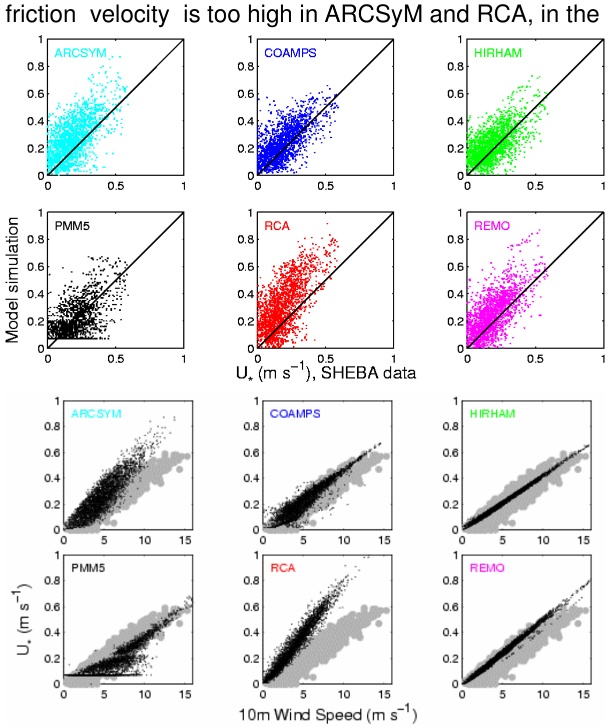

Figure 4. Scatter plot of modeled against observed friction velocity (top) and modeled friction velocity against 10-m wind speed (bottom) from 3-hourly data.

Given the difficulties to model clouds, the surface radiation fluxes (not shown) are relatively accurate in many models, and the modeled temporal variability follows the observations quite well. While some models have rather large biases of typically ± 30 Wm^{-2}, the over-all results are somewhat promising. The largest concern here is that the net error is often the result of compensating errors in the different component of the flux. Thus, the net errors become sensitive to different processes. Coping with cloud problems then does not necessarily solve the problem, since eliminating the bias in one component of the flux may easily contribute to make the bias in another component of the flux worse.

In a direct comparison of the turbulent heat fluxes, all models fail badly (Figure 5). None of the models is similar to any of the other models, and neither model shows any significant similarity to the observations. The correlation coefficients between modeled and observed fluxes are consistently below ~ 0.3 and modeled biases of especially latent heat is relatively large. The annually accumulated net errors (not shown) are very large but partly compensating. Still, plotting the sensible heat flux scaled by the wind-speed against the low-level temperature difference, most models capture the observed functional behavior well, with the exception of the most stable conditions. Again, the slope of the almost linear de-

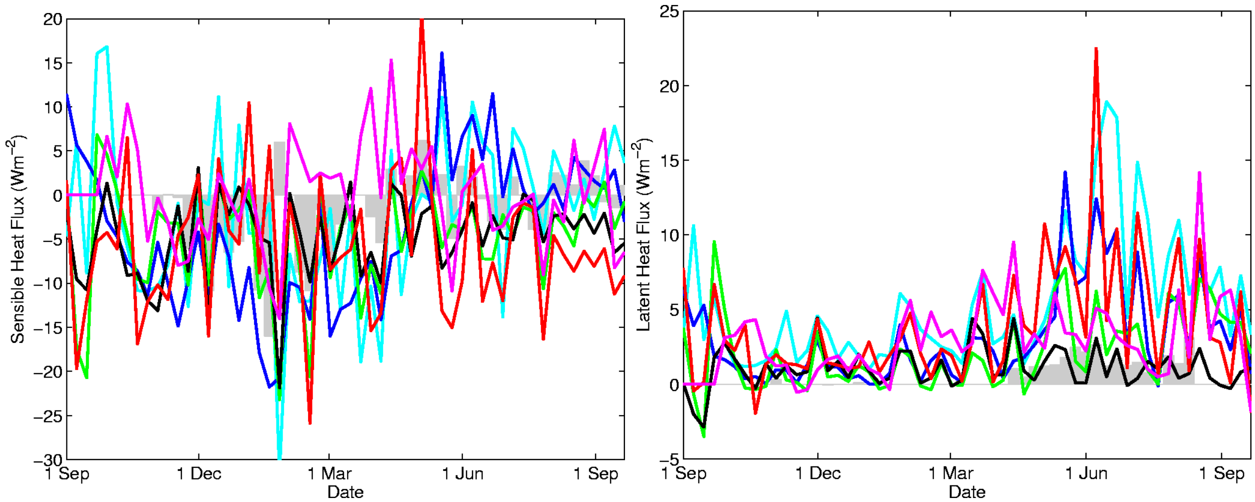

Figure 5. Time series of weekly averaged sensible (left) and latent (right) heat flux for the whole year for all models. Legends are as in Figure 2.

pendences reflects the value of the heat transfer coefficient. This is too large in Polar MM5 but only slightly low in some other models. The region on the stably stratified side, where the measurements indicate a strong dependence of the heat transfer coefficient on stability, is absent in all models except COAMPS^{TM}. For the latent heat flux the situation is worse; the scaled dependences are very different between the models, in particular in RCA and REMO.

4. Discussion

In this study, the model boundary conditions were constrained both by analyzed conditions on the lateral boundaries and by prescribing the surface temperature over the ocean from satellite observations, both for open water and for sea ice. In this sense it reflects a "best case scenario": this is how good – or bad – these models are when the larges scale dynamics and surface temperatures are reasonably well known. The study reveal some systematic errors in temperature and wind speed and heat fluxes that have a reasonable functional dependence, but with time series that has almost no correlation to the observations at all. The fact that the functional behavior of the heat fluxes is reasonable indicates that the problem lies not only in the boundary layer formulations even though the largest errors appear here. Some results also indicate that many models have a problem with low-level clouds, but the errors in the lower free troposphere are also large.

It is our belief that the over-all result is a consequence of model tuning. The description of the turbulent friction in these models was probably tuned to optimize the surface pressure development, to ensure reasonable development of synoptic systems. These are sensitive to the cross-isobaric mass flux, which is a function of the turbulent friction. In this process, the actual friction accomplished was of less importance, as long as cyclones and anti-cyclones obtained the correct spin-up and spin-down. The modeled turbulence then has to "pick up the slack" from other unknown deficiencies in the models. Non-linear feedbacks between the wind speed, static stability and turbulence – and clouds – then adjust to a new unrealistic balance, disrupting all the calculated turbulent fluxes. The results are often superficially nice representations of the Arctic mean climate, but often for the wrong reason. If these models, on the other hand, were to be coupled to an ocean model, including sea-ice, we suggest that the end-results may easily become a quite poor representations of current conditions. We leave the consequences for the reliability of Arctic climate change simulations for the reader to ponder upon.

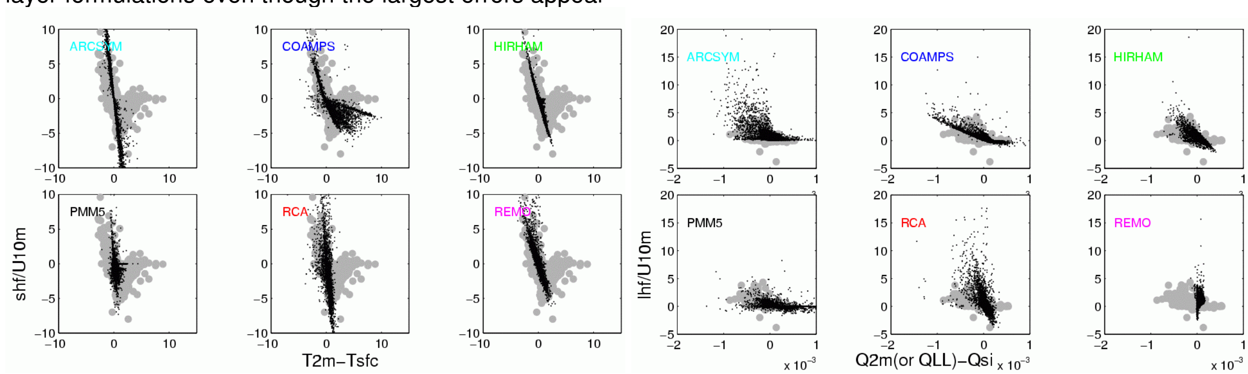

Figure 6. Sensible heat flux divided by 10-meter wind speed, against the temperature difference between 2 meters and the surface (top), and the correspondingly scaled latent heat flux against surface humdidty difference (bottom)

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