Comparison of Mesoscale Model and Tower Measurements of Surface Fluxes During Winter Icing and Storms Program/Atmospheric Radiation Measurement 91

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Introduction

This study is an evaluation of the ability of the Pennsylvania State University/National Center for Atmospheric Research (NCAR) mesoscale model (MM4) to determine surface fluxes to see if measured fluxes should be assimilated into model runs.

Fluxes were compared from a high-resolution (5 km grid spacing) MM4 run during one day of the Winter Icing and Storms Programs/Atmospheric Radiation Measurement (WISP/ARM) experiment (over NE Colorado in winter 1991) with direct flux measurements made from a tower over a representative site by a three-dimensional sonic anemometer and fast response temperature and humidity sensors. This tower was part of the NCAR Atmosphere-Surface Turbulent Exchange Research (ASTER) facility. Also, mean values were compared to check whether any differences were due to the model parameterization or model variables.

Model Parameterization

The "high-resolution" Blackadar parameterization in MM4 was used. This parameterization uses flux-profile relationships applied to values at a single height, z:

$u^* = [kU]/[\ln(z/zo) - phi_m]$

$T^* = [k(T-To)]/[\ln(z/zo) - phi_h]$

$q^* = \{Mk[q-q_s(To)]\}/\{\ln((Ku_*z/K_a) + z/zl)-phi_h\}$

$Ri_b = [g^2(T-To)]/TU^2$

$phi_m(Ri_b<0) = -1.86\ Ri_b \ln(z/zo) -1.07[Ri_b \ln (z/zo)]^2 - \ldots$

$(Ri_b>0) = [-5\ Ri_b \ln(z/zo)]/[1.1 - 5\ Ri_b]$

$phi_h(Ri_b<0) = -3.23\ Ri_b \ln(z/zo) -1.99\ [Ri_b \ln (z/zo)]^2 - \ldots$

$(Ri_b>0) = [-5\ Ri_b \ln(z/zo)]/[1.1-5Ri_b]$

The ASTER site was assigned the land-use category of "Range-Grassland" for which the following values for parameters are used:

zo	Surface roughness height	10 cm
zl	Molecular layer depth	1 cm
M	Moisture availability	0.3

Finally, the following values for constants were used:

k	Von Karman constant	0.4
Pr	Prandtl number	1
K_a	Molecular diffusivity	2.4x10^-5 m^2/s

Results

Variables which are used by the model parameterization were compared to separate the effect of the data and the parameterization in the flux calculation. Since the lowest model level was for a height of 36 m, and the highest ASTER tower was at 10 m, higher data from remote sensors are also shown.

The parameterization for the friction velocity u^*, which is proportional to the square root of the momentum flux, depends primarily on wind speed. For the WISP/ARM experiment, the wind comparison (Figure 1) appears reasonable. The model wind speed generally falls between

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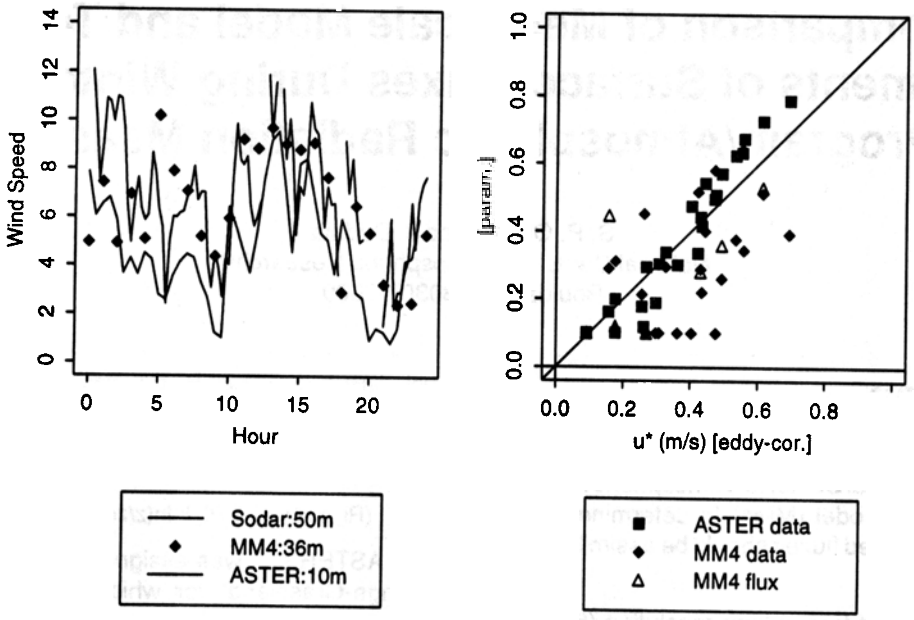

Figure 1. Time series of wind speed from ASTER tower measurements at 10 m, MM4 calculations for 36 m, and sodar measurements at 50 m. Also shown is a scatter plot of u* calculated from the MM4 parameterization by the model, external to the model using MM4 data, and external to the model using ASTER measurements.

the ASTER measurement at 10 m and a nearby sodar measurement at 50 m. The u* comparison shows that fluxes calculated by MM4 are within a factor of 2, however better agreement is expected. The u* comparison also shows values manually computed from the MM4 hourly wind speed data, since values of fluxes computed by the model were only available every 4 hours for these runs. These values again show quite a bit of scatter about a 1:1 line. Finally, u* values computed from the wind speed measured by ASTER agree quite well, indicating that the parameterization works when appropriate data are used.

The parameterization for T*, which is proportional to the sensible heat flux, depends primarily on the air-ground temperature difference. Figure 2 shows that air temperatures from MM4 were higher at night and lower during the day than ASTER measurements, which is expected since the MM4 values are for a height of 36 m, though the magnitude of this change is too large. Radio acoustic sounding system (RASS) measurements of temperature at 500 m always are lower, presumably because 500 m is above the height of the nighttime boundary layer. Ground temperatures from MM4 are much lower during the night and rise approximately to the air temperature measured by ASTER at 1 m during the day. The infrared surface temperature measured by ASTER does not agree better with the model since it exhibits a much larger diurnal change. A soil temperature measurement made at 3 cm depth shows a similar diurnal change to the model, but has a lag due to the time required to heat the soil. Thus, the air-ground temperature differences are too large from the model at night, however this is seen to have little effect on T* (the positive values). During the day, the model values of T* agree well with the ASTER eddy-correlation measurements; however, values calculated by applying the parameterization to the ASTER 1 m air or surface temperature measurements were quite high and low, respectively. Therefore, MM4 appears to produce ground temperatures which are consistent with its flux parameterization, and these temperatures are representative of a height between the surface and 1 m.

The parameterization for q*, which is proportional to the latent heat flux, depends on the air-surface humidity gradient, with the surface value calculated from saturated conditions at the ground temperature. The model humidity

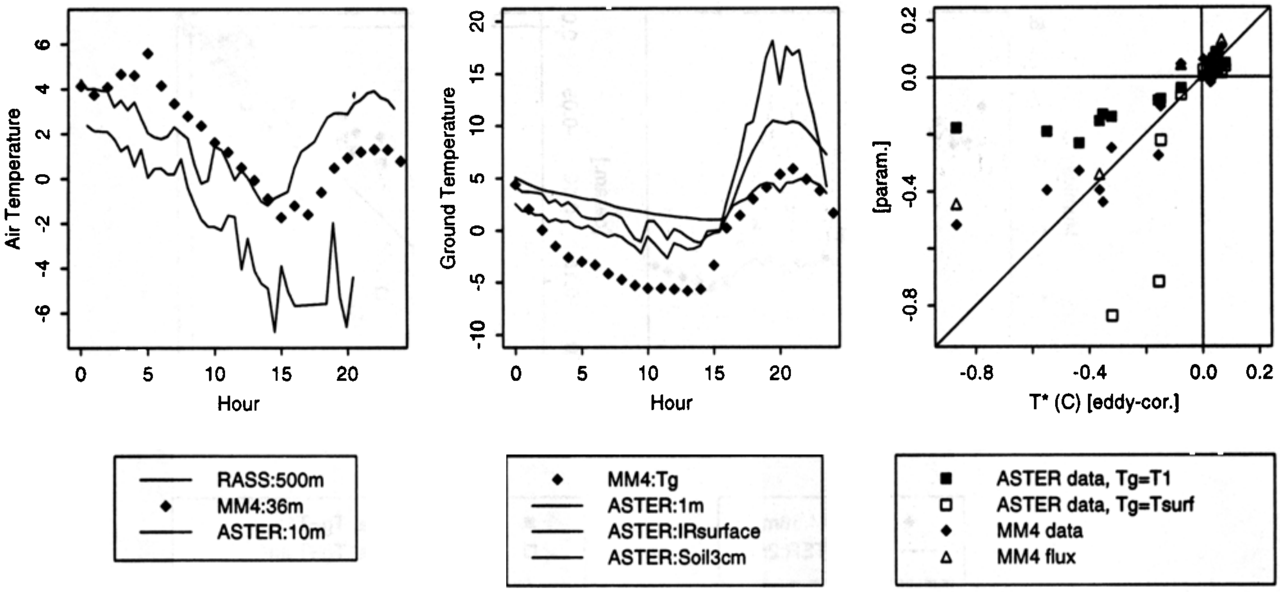

Figure 2. Time series of air and ground temperature from ASTER measurements, MM4 calculations, and RASS measurements. Also shown is a scatter plot of T* calculated from the MM4 parameterization by the model, external to the model using MM4 data, and external to the model using ASTER measurements with Tg set to both the infrared surface temperature and to the lowest measured air temperature.

values (Figure 3) are reasonably close to the only measurement of humidity made by ASTER for much of the period, though a frontal passage was too early by about 5 hours. The q* comparison shows that MM4 underestimates the flux by about 50%. However, using the ASTER 1 m air or surface temperature measurements for the ground temperature yields values for q* which bracket a 1:1 line. Apparently, the conclusion from the T* comparison that the ground temperature should be between the surface and 1 m remains unchanged. Since the T* comparison from the MM4 data used the same ground temperature as the q* comparison, it must be concluded that good T* agreement was due to the low daytime MM4 air temperatures.

Conclusions

- The momentum flux parameterization works well for these data, with the observed differences probably due mostly to areal averaging by the model.
- The sensible heat flux parameterization is very sensitive to the value used for the ground temperature; however, using the model air and ground temperatures gave fluxes which agreed quite well with direct measurements.
- The latent heat flux also is sensitive to the ground temperature. The model data yielded values which were low by about 50%.

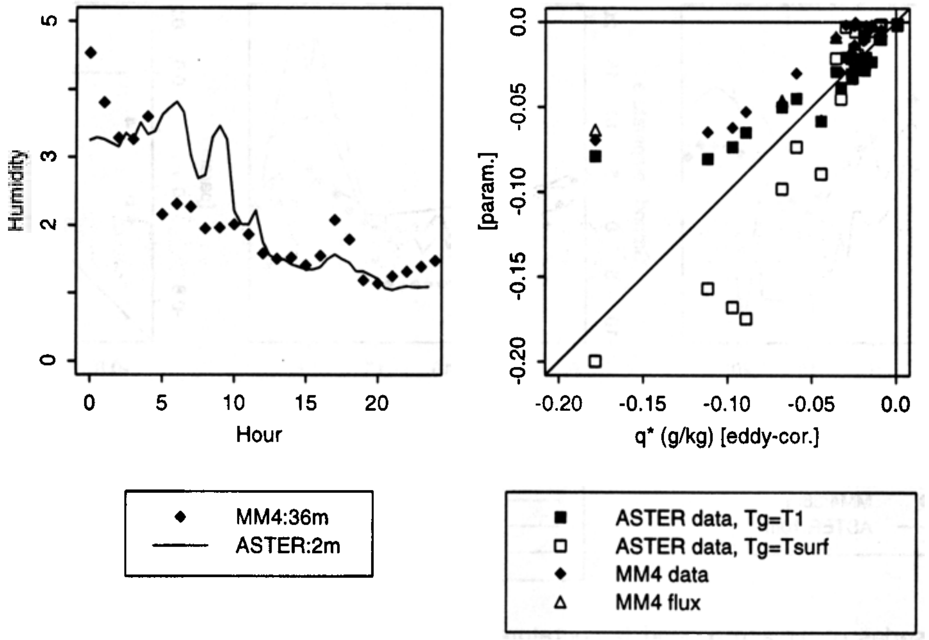

Figure 3. Time series of specific humidity from ASTER measurements and MM4 calculations. Also shown is a scatter plot of q^* calculated from the MM4 parameterization in the same manner as in Figure 2.

The appropriate ground temperature probably is the air temperature at the height of the roughness length.

Future Work

Data will be examined from another case (the Storm-Scale Observations Regional Measurement Program-Fronts Experiment Systems Test [STORM-FEST] experiment in N Kansas during early 1992) to determine if the results shown here are specific to the flow regime during WISP/ARM. Aircraft measurements will be added to the comparison (available during STORM-FEST) to examine possible differences between tower point sampling, aircraft line sampling, and model area averaging.