8.7 **SURFACE COOLING PREDICTIONS OF THE COUPLED NMM/WRF PBL AND NOAH LAND SURFACE SCHEMES**

Frank Freedman*, Zavisa Janjic, Michael Ek
NOAA-NCEP, Camp Springs, MD

1. INTRODUCTION

Vertical column-model simulations were performed to examine the surface cooling predictions of the coupled NMM/WRF PBL and Noah land surface schemes. The NMM/WRF PBL scheme is based on the Level 2.5 turbulent kinetic energy (TKE) approach. Model simulations were run for a case of bare soil and another for a case of deep snow cover. The intent was to provide conditions where large surface cooling rates are expected.

One purpose of these simulations is to check sensitivity of the surface cooling predictions to slight variations in the details of TKE schemes. Runs were therefore also made with TKE schemes similar in design to the NMM/WRF scheme, but with slightly different assumptions applied for length scale, eddy diffusivity vertical averaging and eddy diffusivity threshold values.

A second purpose was to check whether conditions where extreme surface cooling is expected will trigger unrealistically large predicted surface cooling rates associated with surface-atmospheric decoupling.

As a result of these exercises, a better understanding of the surface cooling predictions of the NMM/WRF model (and its predecessor ETA model, which is still run operationally) will be obtained. The information obtained will also be useful to understand surface cooling predictions of TKE schemes in general. Such understanding is important, for example, for GCMs that employ TKE schemes, since the majority of perturbation warming predicted by GCMs as a result of increased greenhouse gas concentration occurs near the surface during mid-latitude winter nights, where high surface cooling rates often occur.

***** *Corresponding author address*: Frank R. Freedman, 1505 De Rose Way, #35, San Jose, CA, 95126; e-mail: freedman@air-basics.com.

2. PBL SCHEMES

Four PBL schemes were applied:

a) NMM/WRF - The Level 2.5 TKE scheme used in NMM/WRF. Constraints on turbulence variables are applied so that turbulence predictions obey a series of physical constraints related to the size of turbulence time scale (Janjic 2001).

b) TKE: l-limit - A Level 2.5 TKE scheme with length scale limited in stable conditions so that turbulence time scale ($l/E^{1/2}$, where E is TKE) is proportional to the inverse Brunt-Vaisala frequency.

c) TKE: Smoother – A Level 2.5 TKE scheme with the heat diffusivity computed as the weighted average of the value computed by the TKE scheme at a grid level (weight = 0.6) and the values at the adjacent layer midpoints (weights of 0.2).

d) 'Kh = 1 m2s' - A TKE model with a threshold value of 1 m^2/s on momentum and heat diffusivities.

Each scheme is coupled to the Noah land surface scheme and a surface layer scheme with stability functions calculated in stable conditions from the Holtslag-DeBruin functions up to z/L = 1, and set to a constant above z/L = 1. These schemes are those currently used in NMM/WRF and ETA. For a given value of z/L (L is the Monin-Obukhov length), the Holtslag-DeBruin functions lead to larger surface flux magnitudes than would be obtained from Monin-Obukhov (MO) theory functions.

The main role of the weighted averaging performed in the 'TKE: Smoother' scheme is to incorporate a fraction of the increased surface layer turbulence by virtue of using the Holtslag-DeBruin functions into the heat diffusivity at the first level above the surface. This is achieved since the diffusivity computed from the Holtslag-DeBruin functions is at the midpoint of the first layer above the surface. This diffusivity is assigned a 0.2 weight in the weighted averaging applied to compute the diffusivity at the first model level above the surface, which therefore raises the diffusivity value at the first model level above what we would be the case if it were solely computed from the TKE scheme. The increased value of diffusivity increases the coupling between the surface layer and the PBL in nighttime model predictions.

For the ‘Kh = 1 m2s’ scheme, the 1 m^2/s threshold on diffusivities is met throughout the nights simulated. The effect of the TKE model is therefore only on the daytime portions of the 48-hour simulations. This threshold, which is very high, is that set in the GFS global operational model at NCEP.

3. SIMULATION DESIGN

Two cases are run:

a) Bare soil – Silty clay loam, initial volumetric soil moisture content of 0.12.

b) Deep snow – initial snow depth of 0.5 meters and snow water equivalent of 0.1 meters.

Each case is run for 48 hours starting at 0600 LST. A geostrophic wind speed of 5 ms^{-1} is specified.

Downward longwave radiation is computed from a simple “emissivity” radiative transfer model with atmospheric emissivities due to water vapor and carbon dioxide computed from empirical functions. Initial atmospheric specific humidity profiles were such to obtain a relative humidity of between 50 and 75 percent at most layers. Shortwave radiation is computed from a specified sine curve. Surface emissivity was equal to one.

4. RESULTS

4.1 *Bare Soil*

Surface temperature (T_s) predictions of the four schemes for the run over bare soil are shown in Figure 1. Except for the ‘Kh = 1m2s’ run, there is little difference among the schemes. The magnitude of surface cooling during the nights also is not excessive, indicating that surface flux magnitudes are strong enough to allow a “buffer” against a mainly upward versus downward longwave radiation balance in the surface energy balance equation (such a balance tends to lead to runaway surface cooling). For example, the average surface flux magnitudes during the two nights computed in NMM/WRF run are approximately: G = 19 W/m^2 (ground heat flux), H = 12 W/m^2 (sensible heat flux), E = 17 W/m^2 (latent heat flux), each directed towards the surface. Similar values are found for the other schemes.

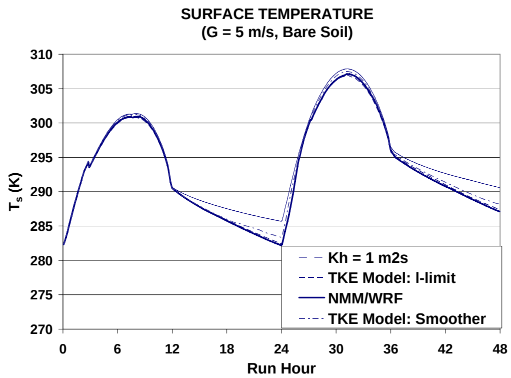

Figure 1: Surface temperature predictions for schemes listed in Section 2 for a 48-hour simulation over bare soil. Run hour zero corresponds to 0600 LST.

The average values of heat diffusivities at the first model level above the surface over the two nights for each scheme are listed in Table 1. It is seen that the difference of values between the ‘TKE: Smoother’ and ‘NMM/WRF’ scheme is just over a factor of two. From Figure 1, however, it is seen that there is very little difference between the surface temperature predictions of these schemes. The is largely because ground heat transfer is strong enough in this case to “make up” for the less surface sensible and latent heat fluxes caused by lower atmospheric vertical mixing in the ‘NMM/WRF’ scheme versus ‘TKE Smoother’ scheme. The large threshold value of 1 m^2/s on diffusivities applied in the ‘Kh = 1m2s” scheme, however, provides more efficient coupling of the atmosphere to the surface during the nights, which is reflected in the relative warming compared to the other schemes at nights computed by the ‘Kh = 1 m2s’ scheme (Figure 1).

Table 1: Average heat diffusivities over the two nights at the first model level above the surface for the schemes listed in Section 2. Bare-soil run.

Scheme	K_h (m^2/s)
NMM/WRF	0.038
TKE: l-limit	0.042
TKE: Smoother	0.095
Kh = 1m2s	1

4.2 *Deep Snow*

Surface temperature (T_s) predictions of the four schemes for the run over deep snow are shown in Figure 2. Excluding the 'Kh = 1m2s' run, there is still little difference among the schemes, although the variation is slightly greater during the first night than was seen for the bare soil run. More strikingly, the magnitude of surface cooling during the nights is now very large - dropping to a temperature of below 240K, which is probably excessive and an indication of surface decoupling. Average surface flux magnitudes during the two nights for the NMM/WRF scheme are approximately: G = 10 W/m^2 (ground heat flux), H = 14 W/m^2 (sensible heat flux), E = 1 W/m^2 (latent heat flux), each directed towards the surface. Similar values are found for the other schemes, except for the 'Kh = 1m2s run' which yields significantly larger H and E magnitudes.

Comparing with the values for bare soil given above, the larger cooling rate over deep snow appears to be due to less downward latent heat flux and smaller ground heat flux. The high static stability caused by the surface cooling inhibits vertical transfer needed to maintain latent heat flux (sensible heat flux values are about the same, but this is only because of the large vertical temperature gradient that develops in the deep snow run), and the depth of the snow layer combined with the small thermal conductivity of snow decreases ground heat flux compared to the case of bare soil. Taken together, therefore, there is less flux available to offset the negative net radiation, leading to very large surface cooling rates.

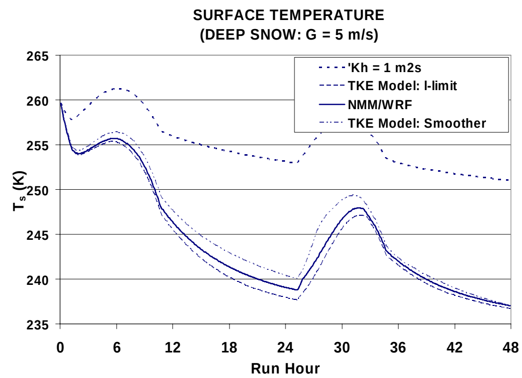

Figure 2: Surface temperature predictions for schemes listed in Section 2 for a 48-hour simulation over deep snow. Run hour zero corresponds to 0600 LST.

The average values of heat diffusivities at the first model level above the surface over the two nights for each scheme are listed in Table 2. It is seen that the variations among the schemes lead to large differences in diffusivities during the night. From Figure 2, however, there is still very little difference between the surface temperature predictions of these schemes, except for 'Kh = 1m2s where the high threshold value on diffusivity is enough to maintain fluxes to a level where cooling to more reasonable temperatures is attained. Such a high value for diffusivity, however, is probably unrealistic. The more realistic variations in turbulence parameterization made to obtain the other schemes, on the other hand, all give decoupling – even though the diffusivities vary by as much as three orders of magnitude (Table 2).

Table 2: Average heat diffusivities over the two nights at the first model level above the surface for the schemes listed in Section 2. Deep-snow run.

Scheme	K_h (m^2/s)
NMM/WRF	0.0078
TKE: l-limit	0.00006
TKE: Smoother	0.033
Kh = 1m2s	1

4. CONCLUSIONS

Based on the above results the following preliminary conclusions are reached.

Variations in the details of TKE schemes have little effect on nighttime surface temperatures in so far as preventing surface decoupling. The results for the first night of the deep snow run, however, suggest that variations on the order of 2K are possible from variation in TKE scheme details, which could help predictions of models that have modest, systematic warm or cold biases at night.

Observations of turbulence during very stable nights during the CASES99 and FLOSS experiments show very weak turbulence. As shown in Freedman and Ek (2004) for CASES99 data, such weak turbulence is associated with two-meter temperatures that were warmer than predicted using MO-theory, which predicted the weak turbulence correctly. This suggests that turbulence transport may not be the process by which near-surface temperatures stay warmer than often predicted by models in very stable nights. Instead, one may wish to examine more carefully how, for example, longwave radiative flux divergence near the surface is accounted for in models.

Another area that could be examined for the case of snow cover is the treatment of surface emissivity. Slater et al. (2001), for example, mention that observations of surface emissivity are as low as 0.85 over deep snow, which could have a large effect on surface and near-surface air temperatures versus the case if an emissivity of one were applied.

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