A Conservative Framework for Sub-Gridscale Terrain Effects in Air Quality Modeling

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Abstract

Due to numerical stability issues in the dynamics (particularly advection), meteorological models typically perform some sort of smoothing on the terrain data that they use. MM5, for example, typically uses a *3dx* smoothing [UCAR]. As a result, the true mean terrain may be quite different from the modeled terrain. Moreover, there may well be considerable terrain variation within each grid cell. This leads to two kinds of modeling errors:

- Terrain elevation errors at the grid scale, caused by the smoothing; and
- Sub-gridscale terrain variability effects within the grid cells.

For a 15-KM MM5 domain covering the East US, the errors in the mean terrain exceed 200 meters, and the sub-grid scale terrain variability exceeds 1500 meters, in Southern Appalachia. Especially under weakly-forced stable conditions, the corresponding air quality modeling effects can be substantial. In particular, we have the following consequences to these terrain effects:

- Grid scale errors in surface temperatures caused by the misrepresentation of mean terrain, that affect the surface fluxes and the emissions rates for the meteorologically sensitive emissions categories.
- Errors in the modeling of emissions placement and chemical deposition, caused by misrepresentations of how the near-surface atmosphere interacts with the terrain, particularly under weakly-forced stable-flow regimes.

We have implemented versions of the MAQSIP-RT atmospheric chemistry and transport model [Coats et al. 1993] and the SMOKE emissions model [Coats 1996] that attempt to provide first order corrections for these errors, and are currently evaluating the responses of these models to these corrections. The first-order grid scale corrections are quite straightforward to implement, being based upon lapse-corrections near-surface air temperatures using standard atmospheric lapse rates and the gridded terrain-error field. The first-order sub-gridscale terrain parameterization is more complex, and is the main subject of this paper. Note that both of these corrections are relatively simple, in that they continue to use the modeled atmosphere coming from the meteorology model, and except for temperature lapse-corrections do not attempt to model the effects of the difference between smoothed model terrain and the true terrain. There is considerable room for work to be done in this regard, which might substantially improve atmospheric chemistry modeling for weakly forced conditions in complex terrain.

Sub-Gridscale Framework

The basic concept is that for each vertical column in the meteorology model, one computes the layered mass represented by the model's reference atmosphere, and then "pours" that layered mass onto a high resolution representation of the "true" terrain for that vertical column. Then the terrain penetration fractions *TFRAC(L)* represent the fraction of the layer L of this mass filled with solid land-surface instead of atmosphere. (Here, we count layers from the land surface upward, and set *TFRAC(0)* to 1.0 for algorithmic simplification.) The differences

$$SURF(L) = TFRAC(L) - TFRAC(L-1)$$

are the layered surface fractions, representing the fraction of the surface that we regard as being in contact with atmospheric layer *L*.

For surface emissions (area, mobile, and biogenic sources), we use the layered surface fractions to allocate the emissions vertically according to the layered surface fractions.

Similarly, in dry deposition we use the surface fractions both to compute (meteorologically-dependent) layered deposition velocities and to compute the layers of the atmosphere being scavenged by the dry deposition process. For point source emissions, we perform sub-grid scale modification of the stack heights, according to the difference between the elevation of the stack top above mean sea level and the value of the grid scale true mean terrain elevation interpolated to the point source location, subject to the restriction that the stack height may not be negative.

A 15-KM East-CONUS Example

For this example, we use the 163/160-cell 15KM resolution East-CONUS MM5 domain with 31 sigma-layers, the lowest of which has a depth of about 28 meters. The "true mean" gridded terrain elevation for this domain, as computed from USGS 30-second resolution terrain data [USGS], is displayed in Figure 1, below. For this terrain, the error due to smoothing in the MM5 modeled terrain ranges from –248 meters to 299 meters, with greatest errors in the northern and southern Appalachian Mountains, as shown in Figure 2. In these locations, the terrain within each grid cell is quite variable, with standard deviations ranging up to 399 meters as shown in Figure 3, and variability (difference between maximum and minimum for the grid cell) ranging up to 1585 meters as shown in Figure 4.

As shown in Figure 5, when the terrain penetration fractions are computed as above, the highest layer with nonzero terrain penetration fraction is Layer 11, corresponding to a sigma-value of 0.866, an elevation about 1250 meters above ground level. Terrain penetration ranges up to 89% for the lowest layer (Figure 7), 28% for the fifth layer (Figure 8), and 1.07% (and is positive in only two cells) for the tenth layer (Figure 9).

For the NEI-99 emissions inventory, there are 279618 point sources in this domain. The stack height corrections obtained from the stack-height adjustment algorithm, when applied to these sources, range from -157.53 to 399.18 meters, with a simple mean of -2.18 meters. When one weights the various stacks by their SO_2 emissions, the weighted mean adjustment to stack height is a very substantial -20.68 meters—nearly the thickness of a near-surface model layer. This represents our human tendency to build major facilities in valleys rather than on mountaintops.

At the AMS Convention, we expect to present an evaluation of the effects of these adjustments on the emissions and air quality modeling results.

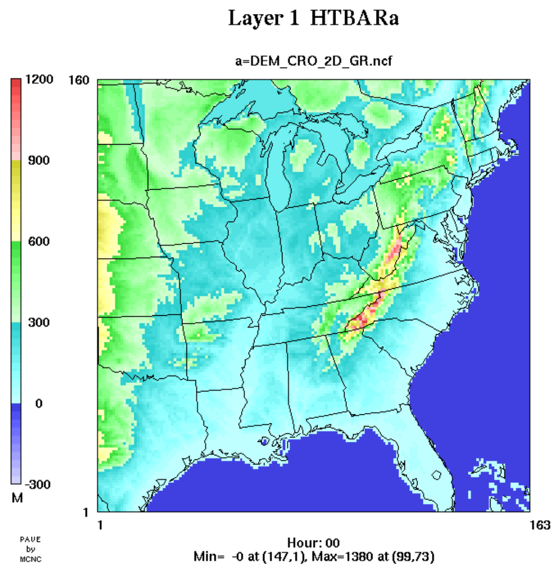

Figure1
15-KM Gridded True-Mean Terrain Elevation (meters)

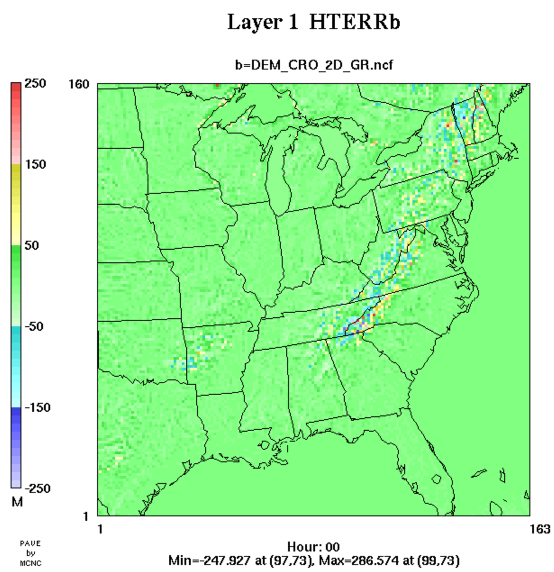

Figure2
MM5 Terrain Elevation Error (meters)

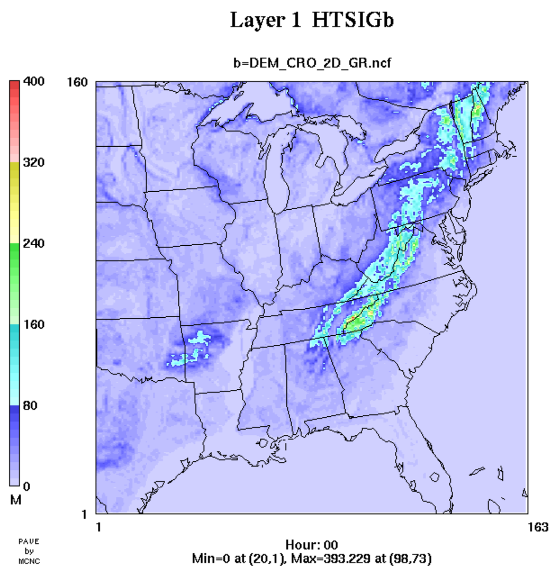

Figure3
Standard Deviation of Terrain Elevation (meters)

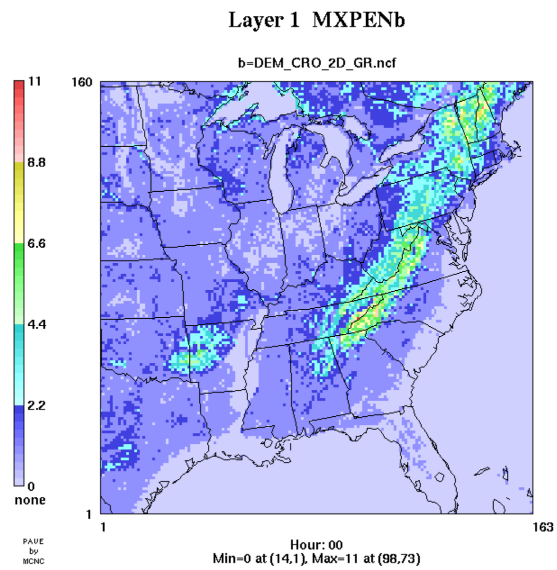

Figure5
15-KM Maximum Terrain Penetration Layer

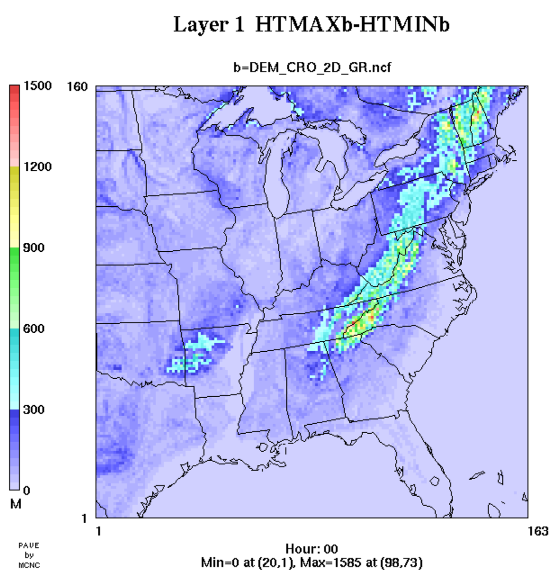

Figure4
15-KM Terrain Variability (meters)

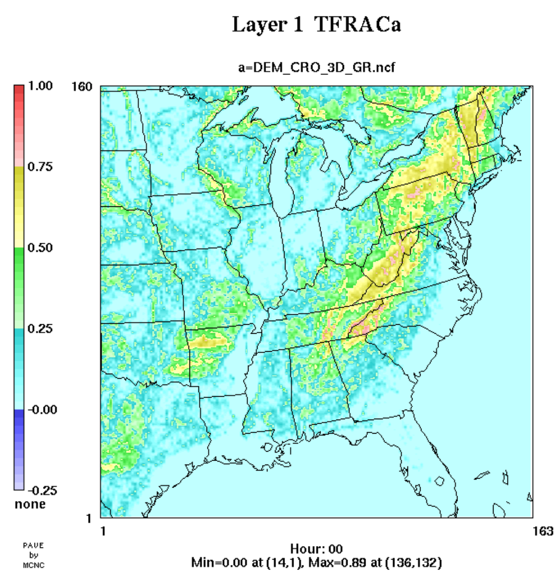

Figure7
Layer 1 Terrain Penetration Fraction

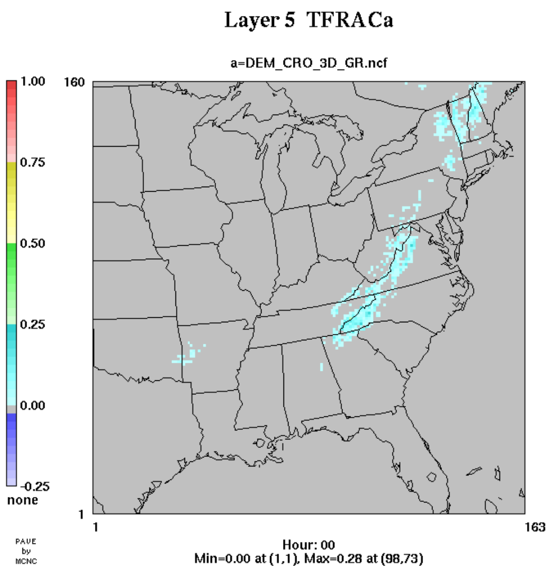

Figure8
Layer 5 Terrain Penetration Fraction

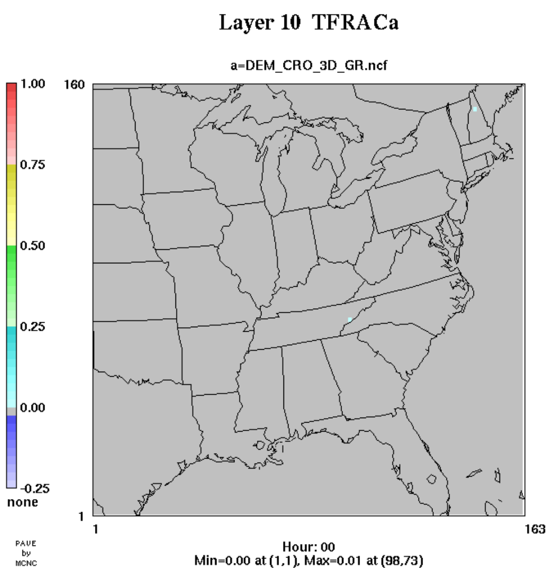

Figure9
Layer 10 Terrain Penetration Fraction

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