

# Impact of a new diffusion scheme in improving simulations over steep topography

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## 1. Introduction

In the fall of 2004, the final version of MM5 (version 3.7) will be released. This version will contain a more sophisticated horizontal diffusion scheme (Zängl 2002) provided by Günther Zängl (University of Munich).

Zängl (2002, 2004) and Zängl et al. (2004) suggested that in regions of complex topography, particularly at high model resolution ( $dx < 5$  km), the horizontal diffusion scheme plays a crucial role in the MM5 model's ability to correctly forecast the near-surface temperature field, thermally driven wind systems and orographic precipitation events.

The new diffusion scheme was originally tested with version 3.3 (January 2000 release) of the MM5 code. This paper will report on the effect this new scheme will have in the standard MM5 code, as it will be released in version 3.7.

A complete list of all the changes planned for version 3.7 is described in Dudhia (2004).

## 2. New diffusion scheme

The Fifth-Generation Mesoscale Model (MM5), developed at The Pennsylvania State University and the National Center for Atmospheric Research (NCAR; Grell et al. 1994), has a terrain-following sigma-coordinate system. Zängl (2002) suggested that in these types of models, errors may be introduced when calculating diffusion along sigma surfaces in mountainous areas, especially for fields having a strong vertical stratification (i.e. temperature and moisture). For example, it turned out that the current diffusion scheme in the MM5 tends to inhibit the formation of nocturnal temperature inversions in narrow valleys.

If diffusion is calculated truly horizontally, these errors may be reduced. At high elevations this is easily done, by simply interpolating between vertical coordinate surfaces. Closer to the ground, this is no longer as easy. At these low levels truly horizontal

computation may be impossible to do without intersecting the ground.

Close to the ground, there are a few options:

- Switching back to diffusion along sigma surfaces (e.g., Ballard and Golding 1991). In narrow valleys, this option may retain some errors.
- Using one-sided, truly horizontal diffusion (Li and Atkinson 1999). This option may not be possible at all grid points, as it may still intersect the ground in narrow valleys. Further, if applied to temperature, this option tends to dampen slope wind circulation in valleys.
- Applying the full coordinate transformation to the horizontal diffusion operator. This option corrects the effect of sloping coordinate surfaces with vertical derivatives. However, in cases where the height difference between adjacent grid points greatly exceeds the vertical distance between the coordinate surfaces, large numerical errors may still be introduced into the model. This option is also computationally expensive.

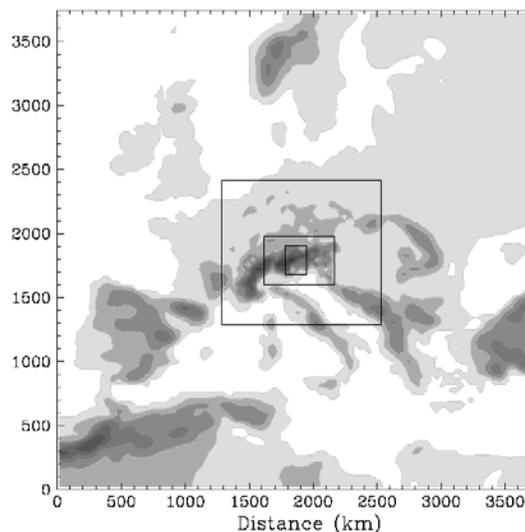


Fig 1: Model domains used in modified diffusion tests

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In MM5 version 3.7, the modified diffusion scheme is implemented as follows:

Upper Levels:

- Truly horizontal diffusion is applied at all model levels where this is possible without intersecting the lowermost half-sigma surface at any grid point of the domain. The number of levels that will fall into this category will depend on the steepness of the topography. In this category, vertical interpolation between the coordinate surfaces is done linearly with height except for the water vapor mixing ratio for which a third-order polynomial interpolation is used<sup>1</sup>.

Lower levels:

- Due to the damping effect one-sided truly horizontal diffusion has on the slope wind circulation, this option is used for the moisture variables only.
- For temperature, a transition from centered truly horizontal diffusion to orography-adjusted sigma diffusion is used in the lower model levels. Orography-adjusted sigma-diffusion means that the diffusion coefficient depends (for each horizontal direction separately) on the height difference between the grid points involved in computing the diffusion. It is essentially zero in the presence of steep slopes, implying that diffusion in a narrow valley is computed in along-valley direction only. Details on the transition between the two diffusion types can be found in Zängl (2002).
- In addition, a temperature gradient correction is applied to the sigma diffusion of temperature. This correction is based on the fact that, for a given vertical temperature gradient, sigma diffusion induces no errors when the vertical gradient is subtracted from the temperature field before computing the diffusion.

MM5 Model parameters:

- The modified diffusion scheme is implemented as option "ITPDIF=2" in the MM5 code. This is an addition to the original ITPDIF option, where ITPDIF=0 uses "temperature sigma-diffusion" and ITPDIF=1 uses "perturbation temperature sigma-diffusion".
- An additional option "TDKORR" is used with the modified diffusion scheme. This

option deals with the temperature gradient correction at surface level. TDKORR=1, will use ground temperature, while TDKORR=2 uses one-sided differencing of air-temperature.

### 3. Tests done with pre-release v3.7 MM5

Whereas the papers by Zängl describe the effect of the modified diffusion scheme as implemented in several of the older MM5 versions, from 3.3 onwards, all the tests described in this paper were done with a standard pre-release version 3.7 MM5 code.

The model runs were done with four 2-way nested domains (fig 1), the grid sizes of the domains being 37.8, 12.6, 4.2 and 1.4 km, respectively. Tests were done with different settings of ITPDIF and TDKORR. The results of these tests will be presented at the workshop.

### References

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<sup>1</sup> The polynomial interpolation is not mentioned in Zängl (2002) because it was implemented later.