The MM5 vertical coordinate system

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The MM5 vertical coordinate system is based on the definition of a reference state, hydrostatic and constant with time. The reference state is determined by a constant temperature profile defined as follows:

$$T_0(z) = T_{SFC0} + A \ln \left[\frac{p_0(z)}{p_{00}} \right] \quad (1)$$

where three constants need to be defined. Sea-level pressure p_{00} is set to 105 Pa. The constant reference temperature at pressure p_{00} (i.e., T_{SFC0}) is frequently set to 270, 280, 290, 300 K in polar, midlatitude winter, midlatitude summer, and tropical conditions, respectively. The temperature difference between p_{00} and p_{00}/e (i.e., A) is usually taken as 50 K, but should be extracted from typical domain soundings. Reference pressure $p_0(z)$ as a function of z can be calculated using the hydrostatic relation $d(\ln p) = -\frac{g}{RT} dz$ and Eq. 1, as follows:

$$p_0(z) = p_{00} \exp \left[-\frac{T_{SFC0}}{A} + \sqrt{\left(\frac{T_{SFC0}}{A} \right)^2 - \frac{2gz}{AR}} \right]. \quad (2)$$

By replacing z with h(x,y), the terrain elevation at each point (x,y), one obtains an expression for $p_{SFC}(x, y)$, the (constant) surface pressure of the reference state:

$$p_{SFC}(x, y) = p_{00} \exp \left[-\frac{T_{SFC0}}{A} + \sqrt{\left(\frac{T_{SFC0}}{A} \right)^2 - \frac{2gh(x, y)}{AR}} \right]. \quad (3)$$

Furthermore, by solving for z, one obtains an expression for the elevation z of each level with pressure p_0:

$$z = -\frac{R}{g} \left[T_{SFC0} \ln \left(\frac{p_0}{p_{00}} \right) + \frac{A}{2} \ln^2 \left(\frac{p_0}{p_{00}} \right) \right] \quad (4)$$

Note that the reference state is uniquely a function of z, thus two points that are located at the same elevation have the same values of T_0 and p_0. The reference state pressure p_0 is used in the definition of the MM5 vertical σ-coordinate:

$$\sigma = \frac{p_0 - p_{TOP}}{p_{SFC} - p_{TOP}}, \tag{5}$$

where p_{TOP} is the constant pressure at the domain top. Each value of σ defines a surface in space, over which lay the points of the MM5 grid. Since p_0, p_{TOP}, and p_{SFC} are constant in time, σ-surfaces are also fixed in time. Values of σ range from zero at the model top to unity at the surface. Note that two gridpoints located at the same elevation z, such as points 2 and 3 in Figure 1, have the same values of p_0 but not necessarily the same values of σ, because p_{SFC} is a function of terrain elevation h(x,y). Furthermore, two gridpoints with the same σ value (such as points 1 and 2 in Figure 1) can be characterized by different values of both p_{SFC} and p_0, and therefore they can have different elevations. The lowest σ-level follows terrain exactly (because p_{SFC} is uniquely a function of h(x,y)), while subsequent levels flatten with altitude up to the completely flat top level. Thus, the σ-system is "terrain influenced" and not "terrain following".

Eq. 5 is used as follows. First, the values of σ for all the desired vertical levels need to be defined. Generally, more vertical levels are needed close to the ground, where high vertical resolution is necessary to correctly simulate surface processes. Second, $p_{SFC}(x, y)$ is calculated via Eq. 3. The reference state pressure p_0 of each gridpoint lying on a σ surface can be determined from Eq. 5:

$$p_0(x, y, \sigma) = \sigma \left[p_{SFC}(x, y) - p_{TOP}\right] + p_{TOP}. \tag{6}$$

For each gridpoint, MM5 computes the pressure perturbation from the reference state $p\prime(x, y, \sigma)$, such that the actual pressure at a given point (x,y,σ) is:

$$p(x, y, \sigma) = p_0(x, y, \sigma) + p\prime(x, y, \sigma), \tag{7}$$

where the value of $p_0(x, y, \sigma)$ is given by Eq. 6.

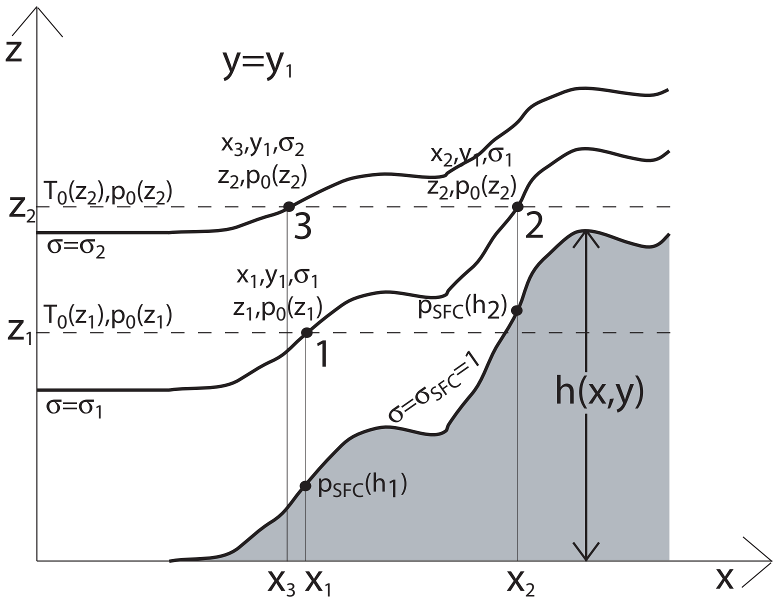

Figure 1: Details of the σ-surfaces in MM5.