Altitude Coordinates in the NCAR TIE-GCM and TIME-GCM

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The purpose of this document is to define the altitude coordinate systems used in the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) and Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM), especially to inform model users as to how to register model output in the vertical dimension.

The TIE-GCM and TIME-GCM use a log-pressure coordinate system, with each pressure level defined as $\ln(P_0/P)$, where $P_0 = 5\times10^{-4}$ dynes/cm^2 = 5×10^{-5} Pascal = 5×10^{-7} hPa = 5×10^{-7} mb. (Native units in these models are cgs, i.e., dynes/cm^2.) This pressure occurs at ~200 km altitude, depending on conditions.

The TIE-GCM vertical coordinate extends from -7 to +7 (~97 km to ~600 km) and the TIME-GCM vertical coordinate extends from -17 to +7 (~30 km to ~600 km). Each integer interval in pressure level is one scale height apart, so the low-resolution (5°x5°xH/2) versions are spaced at half-integer intervals and the high-resolution (2.5°x2.5°xH/4) versions of the models are spaced at quarter-integer intervals:

	Number of Levels	Level Spacing	Bottom Level	Top Level	~Minimum Altitude	~Maximum Altitude
Low-Res TIE-GCM	29	0.5	-7	+7	97 km	600 km
High-Res TIE-GCM	57	0.25	-7	+7	97 km	600 km
Low-Res TIME-GCM	49	0.5	-17	+7	30 km	600 km
High-Res TIME-GCM	97	0.25	-17	+7	30 km	600 km

The height of the pressure surface is defined at each grid point in arrays provided in output history files (in cm). Unfortunately, there are four different possibilities for altitude definition, all slightly different.

First, we define the *geopotential height z.* Geopotential height is the height that the pressure surface would be, assuming that the acceleration due to gravity g is constant at the value used in the model calculations (870 cm/s^2 for the TIE-GCM and 950 cm/s^2 for the TIME-GCM). It is registered to the altitude of the model lower boundary, which can vary horizontally due to the tidal and climatological lower boundary specification. This is the native coordinate system for the models, and so z is included in all history files. However, it is *not* the appropriate altitude coordinate for comparison with real-world data. Also note that this definition of geopotential height is *not* the same as what is used in, e.g., tropospheric meteorology, because it is referenced to value of g that is different from the value of g at the surface (~980 cm/s^2).

The *geopotential height z* is also computed on the geomagnetic grid, and reported as z_{mag} in km.

We can correct the *geopotential height z* to obtain *geometric height z_g.* This is performed inside the models by subroutine zgcalc, using an empirical formulation of the variation of g over the

globe (including centripetal force), and vertical integration, to account for the variation with altitude. It can also be done, using the same subroutine, in the Fortran model processers, and is also available in various IDL processing routines. Geometric height z_g is now forced onto secondary histories (i.e., it is output whether you request it or not) but not on primary histories (because primary histories contain only what is necessary to re-start the model). However, some older secondary history files may not include z_g which necessitates that it be calculated in the post-processing if needed for data comparison.

Now we come to the final complication, which is the distinction between model *interfaces* and model *mid-points*. The interfaces are the native coordinate system of the model grid, as defined in the table above, i.e., at -7.0, -6.5, -6.0, etc.; z and z_g are defined on these interfaces. However, most model output quantities are actually reported at the midpoints, half-way between interfaces in pressure, i.e., at -6.75, -6.25, -5.75, etc. Each midpoint is a half-interval *above* the corresponding interface. All temperatures, winds, neutral mixing ratios, etc., are defined at these midpoints. However, electron density and electric potential are defined at the interfaces:

Field	z	z_g	z_m	T_n	u_n	v_n	O_2	O	N_2	NO	N	N^2D	He	Ne	T_e	T_i	Ω	Φ_E
Specified at	I	I	M	M	M	M	M	M	M	M	M	M	M	I	M	M	I	I

In order to register midpoint quantities in altitude, it is therefore necessary to interpolate from the midpoints to the interfaces. Alternatively, it may be simpler to interpolate z_g from the interfaces to the midpoints. For TIE-GCM 2.0, a new output variable has been added, z_{gmid}, which is geometric height that has been interpolated to the mid points. However, older history files do not include z_{gmid}. As with z_g, it is available on secondary histories but not on primary histories.

In output histories, quantities specified at interfaces are defined by the *ilev* coordinate variable and quantities specified at midpoints are defined by the *lev* coordinate variable. These quantities are generally numerically identical, but their definitions in the files can serve as a reminder of what is defined where. Also, for diagnostic secondary output variables, the *ilev* or *lev* designation indicates where it is defined. For example, the total mass density DEN is defined on the *ilev* interfaces.

Height-related Variables on TIEGCM Secondary Histories:

Z   Geopotential Height (cm)
ZG   Geometric Height (cm)
ZGMID   Geometric Height at Midpoints (cm)
ZMAG   Geopotential Height on Geomagnetic Grid (km)

Variables Z, ZG, and ZMAG are forced onto secondary histories. To save ZGMID to secondary histories, add ZGMID to the fields list in the namelist input file: SECFLDS='ZGMID'