**THE NRLMSISE-00 AND HWM-93 USERS GUIDE:**
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## Using the NRLMSISE-00 FORTRAN Subroutines

One of the main strengths of the MSIS/HWM empirical models is that they are designed to be directly incorporated into any engineering and scientific computer model. This eliminated the need for storage of large data sets, as well as subsequent interpolation of the data within these data sets. This section explains how to utilize the NLRMSISE-00 FORTRAN source code in modeling applications. The subroutine Input/Output (I/O) arguments and some common programming pitfalls are provided in this document. Supplemental aspects of the model, e.g. the calculation of the altitude of a constant pressure surface and the manual exclusion of internal components, are also discussed.

The NRLMSISE-00 density and temperature subroutines provide estimates of the density of the seven major atmospheric constituents (O, $N_2$, $O_2$, He, Ar, H, and N), the total atmospheric number density, atmospheric temperature, anomalous oxygen, exospheric temperature, and the altitude of a constant pressure surface. The standard FORTRAN call to NRLMSISE-00 model to obtain the primary output parameters is:

```
...
CALL GTD7(YYDDD,UTSEC,ALT,GLAT,GLON,SLT,AP,F107A,F107,MASS,D,T)
```

In addition to the main subroutine, four additional subroutines are provided for use with GTD7. These are TSELEC, TRETRV, METERS7, and GPH7. TSELEC and TRETRV are used to control various internal components of the model. METERS7 is used to specify the units either, #/cm$^3$ or #/m$^3$, of the density parameter outputs. The routine GPH7 is used to obtain an estimate of the altitude where the atmospheric pressure is equal to a user specified value in millibars.

Typically, GTD7 is called from within a set of nested to loops to obtain point estimates, vertical profiles, 2-d slices, or 3-d volumes of atmospheric temperature and number density. For example, for a 3-d global volume:

```
...
CALL TSELEC(SW)
CALL METER7(.TRUE.)
DO I = 0, NALTS
   DO J = 0, NLATS
```

```
        DO K = 0, NLONS
           SLT = UTSEC/3600. + GLON(K)/15.
           CALL GTD7(YYDDD,UTSEC,ALT(I),GLAT(J),GLON(K),SLT,AP,F107A,F107,MASS,D,T)
           MY_TEMP_VOLUME(K,J,I) = T(1)
           MY_TOT_DENSITY_VOLUME(K,J,I) = D(6)
        ENDDO
     ENDDO
  ENDDO
  …
```

The formal GTD7 subroutine output arguments are listed in Table A1. By default, all number densities are returned in units of particles /cm$^3$. If a called to METER6(.TRUE.) is made prior to calling GTD7 the number densities will be returned in units of partices/m$^3$. Total mass density in g/cm$^3$ is returned as the parameter D(6).

Table A1 – GTD7( ) subroutine model output parameters.

| Output Parameter | **Data Type** | **Description** |
|---|---|---|
| D(1) | Real*4 | Helium number density [He] |
| D(2) | Real*4 | Atomic Oxygen number density [O] |
| D(3) | Real*4 | Molecular Nitrogen number density [$N_2$] |
| D(4) | Real*4 | Molecular Oxygen number density [$O_2$] |
| D(5) | Real*4 | Argon number density [Ar] |
| D(6) | Real*4 | Total mass density [$\rho_{total}$] |
| D(7) | Real*4 | Hydrogen number density [H] |
| D(8) | Real*4 | Atomic Nitrogen Number Density [N] |
| D(9) | Real*4 | Anomalous Oxygen [O*] |
| T(1) | Real*4 | Temperature at altitude (Kelvin) |
| T(2) | Real*4 | Exospheric Temperature (Kelvin) |

Some application may require an estimate of the mean molecular mass <m>, mass density ($\rho$), and/or total atmospheric pressure (P). While mass density and pressure can be obtain from MSIS there are situations where you may wish to calculate them yourself. Mean molecular mass can be determined from the returned number densities by the relation:

$$\langle m \rangle = \frac{\sum_i m_i N_i}{\sum_i N_i} \quad . \tag{1}$$

Here $m_i$ represents the mass of the $i^{th}$ species in amu and $N_i$ the volumetric number density. The total mass density, $\rho$ in g/cm$^3$ (output parameter D(6)) is obtained as:

$$\rho = \mathrm{A}_v \mathrm{N}_{total} < m > , \tag{2}$$

where $A_v$ is Avagadro’s number (6.022e23 g/amu) and $N_{total}$ is the total number density. The total atmospheric pressure in dynes is obtained by:

$$\mathrm{P} = \mathrm{N}_{total}\ \mathrm{k}\,\mathrm{T} , \tag{3}$$

where T is temperature and k is Boltzmann’s constant (1.38066e-23 J/K). Note: 1 dyne = 1e-5 millibars (mb).

The formal input arguments to the GTD7 subroutine are listed in Table A2. **Caution, no input argument bounds checking is done internally by the NRLMSISE-00 subroutines. The use of**

**external consistency checks to insure that all input arguments are specified correctly is recommended.** The acceptable ranges, caveats, and parameter descriptions will now be described.

Table A2 – The GTD7 subroutine input arguments.

| Input Parameter | **Data Type** | **Description** |
|---|---|---|
| IYD | Integer*4 | Year and day number expressed 'yyddd' format. |
| SEC | Real*4 | Universal time in seconds |
| ALT | Real*4 | Altitude in kilometers |
| GLAT | Real*4 | Geodetic latitude in degrees |
| GLON | Real*4 | Geodetic longitude in degrees |
| SLT | Real*4 | Apparent solar local time in fractional hours. |
| AP(7) | Real*4 | Geomagnetic solar activity indices (see below) |
| F107A | Real*4 | 81-day average $F_{10.7}$ cm radio flux (see below) |
| F107 | Real*4 | The previous days $F_{10.7}$ radio flux (see below) |
| MASS | Integer*4 | Mass number (see below) |

IYD is year and day number in 'yyddd' format, where 'yy' represents the last two digits of the year and 'ddd' represents the day number starting at 001 for January 1. Note that the 'yy' portion of this parameter is not utilized in the model calculations. In addition, NRLMSISE-00 does not contain adequate seasonal resolution to distinguish between the atmospheric characteristics on day 000 and day 001, or day 365 and day 366, etc. Therefore, potential programming issues regarding leap years or 4 digit Y2K problems are moot.

UTSEC represent the universal time in seconds (0. – 86400.0). SLT is an apparent solar local time expressed in fractional hours. Acceptable values range from 0.00 to 24.00 hours. This argument **is not** civil local time as determined using international time zones. SLT parameterizes the migrating solar tidal components of the upper atmosphere. These tidal components are driven by atmospheric absorption of solar radiation, travel with apparent location of the sun and are therefore dependent on the apparent solar local time. **Spurious estimates can result if the UTSEC, SLT, and GLON input parameters are inconsistent.** Depending on the programming implementation, either of the following relations should be used:

Universal Time *[sec]* = (Solar Local Time *[hrs]* - Longitude *[deg]* / 15.) * 3600.
Solar Local Time *[hrs]* = Universal Time *[sec]* / 3600. + Longitude *[deg]* / 15.

ALT is the tangent point altitude of the desired estimate expressed in kilometers. Acceptable values range from 0 to 1000 km. Spurious output or run-time errors will result if GTD7 is called with an altitude less that zero. GLAT is the geodetic latitude in degrees. The acceptable ranges for latitude are ±90.0 degrees. GLON is the geodetic latitude in degrees. Note that the GTD7 subroutine will accept longitudes ranging from ±360.00 degrees with positive values for east longitude and negative values for west longitude.

AP is an array of geomagnetic activity indices. These input parameters provide statistical proxies for the current of level of geomagnetic activity. These activity levels can dramatically affect the composition and temperature in the atmosphere above 90 km. These indices are based on routine measurements from global network of magnetometers and can be obtained publicly on the world-wide-web [e.g. ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/]. Real-time values and/or predictions, are available to for use as well [e.g. http://www.sec.noaa.gov/ftpmenu/index.html].

The NRLMSISE-00 models operated in two modes, a standard output mode and storm-time output mode. In the standard output mode, the model only considers the daily average $A_p$ geomagnetic activity index. In this case, AP(1) should be set to the daily $A_p$ value. Subsequent AP values within the array are ignored. Note that for output below 90 km the AP parameter has little or no effect on the model results. Therefore for cases where no output above 90 km is required a value of AP = 4.0 can be used. **When information about the atmosphere above 90 km is required, and geomagnetic activity levels are significant, the storm-time output mode should be used.** The NRLMSISE-00 model can be put in it's storm-time mode by calling the TSELEC subroutine (once) before calling GTD6 (see next section). In storm-time mode, the required AP arguments are listed in table 3. Values for the $A_p$ range from 0 to 400 and by definition can only take certain discrete values. For more information on $A_p$ indices consult the Handbook of Geophysical and the Space Environment [*A. S. Jursa, 1985; NTIS Document# ADA 167000*], for example when converting from measured/operational $K_p$ values.

Table 3 - $A_p$ indices required for Storm-time mode

| | **Desciption** |
|---|---|
| AP(1) | Daily $A_p$ index |
| AP(2) | 3-hr $A_p$ index corresponding to the current time |
| AP(3) | 3-hr $A_p$ index for 3 hours before current time |
| AP(4) | 3-hr $A_p$ index for 6 hours before current time |
| AP(5) | 3-hr $A_p$ index for 9 hours before current time |
| AP(6) | An average of eight 3-hr $A_p$ indices from 12 to 33 hours prior to the current time |
| AP(7) | An average of eight 3-hr Ap indices from 36 to 59 hours prior to the current time |

The F107A and F107 input parameters represent proxies for solar Extreme Ultraviolet (EUV) radiation. EUV flux is probably greatest single factor in the determining the quiet-time state of the thermosphere above 120 km in the NRLMSISE-00 model. It also effects the 80. to 120. km region to some degree. As with the $A_p$ indices values for these parameters may be obtained in the world-wide-web, geophysical publications, or though official government channels (NOAA, DOD, NASA, etc). As with $A_P$, the F107 parameters current have little or no effect on the model output below 90 km. In these cases a default value F107A = F107 = 150.0 should be used.

Finally, the MASS parameter is used to specify the calculation of number densities within the model. When MASS = 48, then all of the model constituent number densities are calculated in table A1 are calculated. This is typically the most common way to operate the model. The MASS number, however, can be set to other numbers in order to calculate and return the value of a single species at a significant times savings. Furthermore, if MASS = 0 then only temperatures are calculated, at a significant time savings.

*Using TSELEC with GTS7*

The TSELEC subroutine is used toggle various internal harmonic components of the models. This routine is provided for storm time mode, special applications, and scientific model evaluations. To toggle or set a particular internal model component '`CALL TSELEC(SW)`' can be used. The input argument SW is a 25 element real array containing; 0.0 for off, +1.0 for on, or +2.0 for main effects off, but cross terms on. Table 4 provided the internal components effect by each switch. Note that if no call to TSELEC is made prior to calling GTD7 the default values for all of the model switches is 1. In addition, the subroutine TRETRV(SW) can be used to obtain the current state of these switches. This is the most common use of TSELEC is to place the model in storm time mode. To do this SW(9) should be set to a value of -1.0. The second most common use of TSELEC its to eliminate tidal, or local time variations in order to obtain the zonal mean states [e.g. SW(7), SW(8), SW(14), and SW(10) = 0.0]. Use of the other model switches is at your own risk.

Table 4 – Internal GTD7 components affected by TSELEC

| SW( ) | Component | SW( ) | Component |
|---|---|---|---|
| 1 | $F_{10.7}$ effect on mean (Solar EUV variations) | 14 | Terdiurnal tidal harmonics |
| 2 | Time independence | 15 | Departures from diffusive equilibrium |
| 3 | Symmetrical annual harmonics | 16 | Bates-Walker $T_{infinty}$ variations |
| 4 | Symmetrical semiannual harmonics | 17 | Bates-Walker $T_{120}$ variation |
| 5 | Asymmetrical annual harmonics | 18 | $T_{node(1)}$ variation |
| 6 | Asymmetrical semiannual harmonics | 19 | Bates-Walker shape factor (s) variations |
| 7 | Diurnal tidal harmonics | 20 | $T_{node(2)}$ variations |
| 8 | Semidiurnal tidal harmonics | 21 | Bates-Walker $N_{120}$ variations |
| 9 | Daily $A_p$ effects (Geomagnetic effects) | 22 | $T_{node(3)}$ variations |
| 10 | All UT/longitude effects | 23 | Turbo scale height variations |
| 11 | Longitudinal variations (Stationary waves) | | |
| 12 | UT and mixed UT/longitude | | |
| 13 | Mixed $A_p$/UT/longitude interactions | | |

*Using GTH7 to determine the altitude and temperature at a given pressure*

The subroutine GHP7 provides an NRLMSISE-90 model estimate of the geodetic altitude of a given atmosphere pressure level. The GHP7 function call is nearly identical to that of GTD7,

```
...
CALL GHP7(IYD,SEC,ALT,GLAT,GLONG,STL,F107A,F107,AP,D,T,PRESS)
```

The notable difference is in the inclusion of the parameter PRESS and the absence of the MASS parameter. In input parameter, PRESS, is the atmospheric pressure expressed in millibars (mb). The altitude of the pressure surface in kilometers is returned via the existing ALT argument, in addition to also returning the typical GTD7 output parameters. This altitude is determined in the NRLMSISE-00 model by hydrostatic equilibrium considerations. Note that this subroutine slightly more calculation intensive then GTD7.

## Using the HWM-93 FORTRAN subroutines

This section explains how to use the HWM-93 FORTRAN source code in software applications. The subroutine Input/Output (I/O) arguments, as well as common programming pitfalls are provided in this section. Please read the section on using the NRLMSISE-00 FORTRAN subroutines prior to reading this section. The standard FORTRAN call to the HWM-93 model is:

```
...
CALL GWS5(IYD,SEC,ALT,GLAT,GLONG,STL,F107A,F107,AP,W)
```

In addition to the main wind model subroutine, two additional subroutines are provided to control the behavior of GWS5. As in GTD7 – the subroutine TSELEC is used to adjust the various internal components of the model. Like GTD7 – GWS5 is typically called from within a set of nested to loops to obtain profiles, slices, or volumes of the zonal and meridional components of the horizontal wind.

The formal GWS5 subroutine output arguments are returned in the argument W, which is a 2 element `real*4` array. The first element W(1), is the meridional wind component (northward +) and the second element W(2), is the zonal wind component (eastward +). Both components are returned in units of m/s.

The formal input arguments to the GWS5 subroutine are listed in Table A1. **Caution, no input argument bounds checking is done internally by the HWM-90 subroutines. The use of external consistency checks to insure that all input arguments are specified correctly is recommended.** The acceptable ranges, caveats, and parameter descriptions are described now.

Table A1 – The GWS5 subroutine input arguments.

| Input Parameter | **Data Type** | **Description** |
|---|---|---|
| `IYD` | `Integer*4` | Year and day number expressed yyddd format. |
| `SEC` | `Real*4` | Universal time in seconds |
| `ALT` | `Real*4` | Altitude in kilometers |
| `GLAT` | `Real*4` | Geodetic latitude in degrees |
| `GLON` | `Real*4` | Geodetic longitude in degrees |
| `SLT` | `Real*4` | Apparent solar local time in fractional hours. |
| `AP(2)` | `Real*4` | Geomagnetic solar activity indices (see below) |
| `F107A` | `Real*4` | 81-day average $F_{10.7}$ cm radio flux (see below) |
| `F107` | `Real*4` | The previous days $F_{10.7}$ radio flux (see below) |
| `W(2)` | `Real*4` | Set to 9898. to ignore a wind component |

The input arguments, IYD, SEC, ALT, GLAT, GLON, SLT, F107A and F107 are identical the NRLMSISE-00 arguments of the same name. One difference, however, is that the AP input parameter is a two element array of geomagnetic activity indices. These input parameters provide statistical proxies for the current of level of geomagnetic activity, which can influence wind velocities in the atmosphere above 90 km. These indices are based on routine measurements from global network of magnetometers and can be obtained publicly on the world-wide-web or published sources. Real-time values and/or predictions of these indices are also available from NASA, NOAA, and the DOD. The HWM-93 models operated in two modes, standard mode and storm-time mode. In standard mode, the model accepts and utilizes only one $A_p$ activity index. In this case, AP(1) should be set to the daily $A_p$ value. The value of AP(2) is ignored. For HWM-93 output below 90 km the AP input parameters have little or no effect. For cases where no output above 90 km is required a value of AP = 4.0 should be used. The model can be placed in storm-time model by calling the TSELEC subroutine once before calling GWS5 (see below). In storm-time model AP(2) should be set to the current 3-hour Ap index.

Lastly, the output parameter W can be set to reduce the computation cost if output for only one wind component is needed. More specifically if either W(1) or W(2) is set to 9898.0 then that component will not be evaluated by the GWS5 subroutine.

*Using TSELEC with GWS5*

The TSELEC subroutine can be used to toggle the various internal components of the HWM-93 model. The same general calling conversions for TSELEC, as in MSISE-90, apply. However, the elements corresponding to the SW input array are slightly different. The following twenty-five GSW5 models components can be toggled/adjusted using TSELEC(SW):

Table 5 – Internal GSW5 components affected by TSELEC

| SW( ) | Component | SW( ) | Component |
|---|---|---|---|
| 1 | $F_{10.7}$ effect on mean (Solar EUV variations) | 14 | Terdiurnal tidal harmonics |
| 2 | Time independence | 15 | No Effect |
| 3 | Symmetrical annual harmonics | 16 | Exospheric wind velocity variations |
| 4 | Symmetrical semiannual harmonics | 17 | All 120 km wind variations |
| 5 | Asymmetrical annual harmonics | 18 | All zonal node 1 variations |
| 6 | Asymmetrical semiannual harmonics | 19 | All wind vertical derivative variations |
| 7 | Diurnal tidal harmonics | 20 | No effect |
| 8 | Semidiurnal tidal harmonics | 21 | No effect |
| 9 | Daily $A_p$ effects (Geomagnetic effects) | 22 | No effect |
| 10 | All UT/longitude effects | 23 | No effect |
| 11 | Longitudinal variations (Stationary waves) | 24 | All B fields (Divergence) |
| 12 | UT and mixed UT/longitude | 25 | All C fields (Curl) |
| 13 | Mixed $A_p$/UT/longitude interactions | | |

The second most common use of TSELEC its to switch off tidal (or local time) and longitudinal variations - SW(7), SW(8), SW(14), and SW(10)- to obtain zonal averages.