User's Guide for Weimer 2005
Electric & Magnetic Potential Models for IDL

The 2005 version of the "Weimer electric potential model," as well as it's twin model of magnetic potentials for mapping field-aligned currents. The twin models are described in these publications:

Weimer, D. R., Improved ionospheric electrodynamic models and application to calculating Joule heating rates, *J. Geophys. Res., 110*, A05306, doi:10.1029/2004JA010884, 2005.

Weimer, D. R., Predicting Surface Geomagnetic Variations Using Ionospheric Electrodynamic Models, *J. Geophys. Res., 110*, A12307, doi:10.1029/2005JA011270, 2005.

This release of the code uses the "Spherical Cap Harmonics," as described in the second paper. Currently the models and graphic utilities are only available as pre-compiled IDL code, which may be run with the (free) IDL Virtual Machine from Exelis.

The utility program in **geoepotplot.sav** plots the electric potentials over a geographic map, as shown in Figure 1. The Graphical User Interface (GUI) window for this program looks like Figure 2 on a Windows machine. On Linux/Unix systems the GUI will have a slightly different look. The IMF may be entered as either a GSM Y-Z magnitude plus clock angle, with the "Use Bt-Angle" option box checked, or entered with both By and Bz components, with the Bt-Angle option unchecked. The AL Index is ignored unless the "Use AL Index" option is checked. The colors shown in Figure 1 will use used if the "blue-red colors" option is set, otherwise the color table will be cyan-green-yellow. The True-Type option uses a solid-fill typeface on screen and image file outputs, such as PNG, otherwise vector (line) fonts are used. PostScript output always uses the native PostScript fonts. If the contour step is zero, then the program will automatically scale the step size. If a contour level is zero, then it is split into two levels at 0. ± 10% of the step size. The "Page Sequence" name is the name of the output file, with the sequence number appended, which automatically increases after each plot.

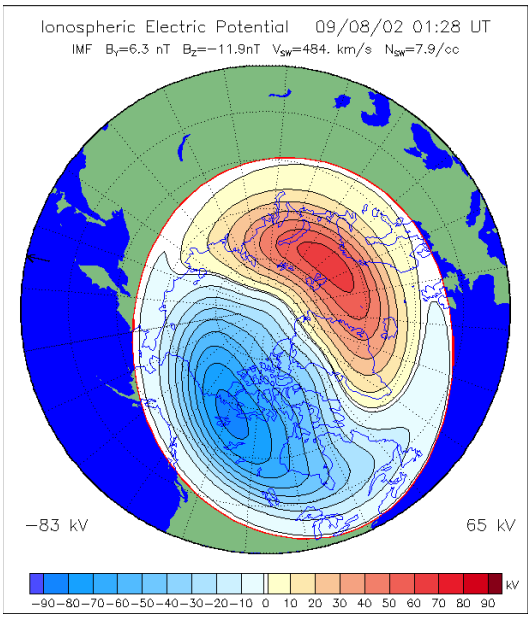

Figure 1

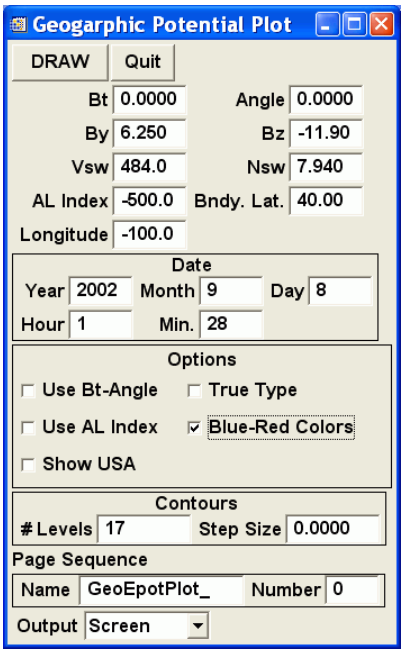

Figure 2

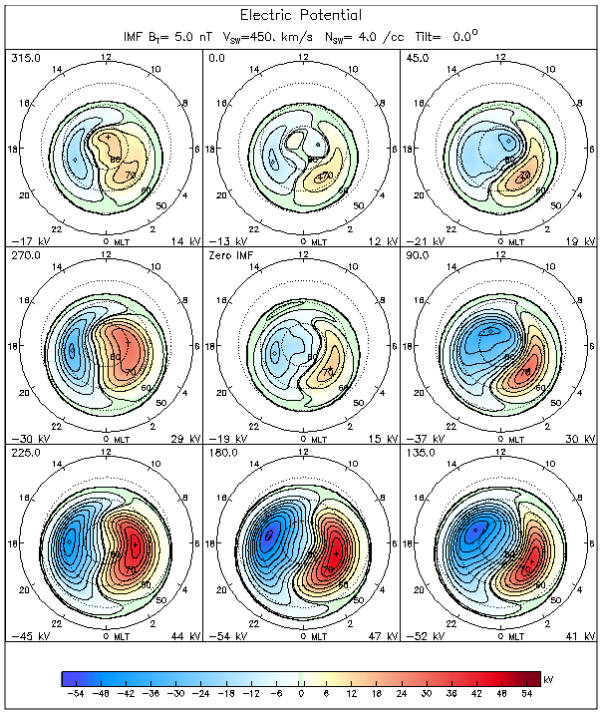

Figure 3

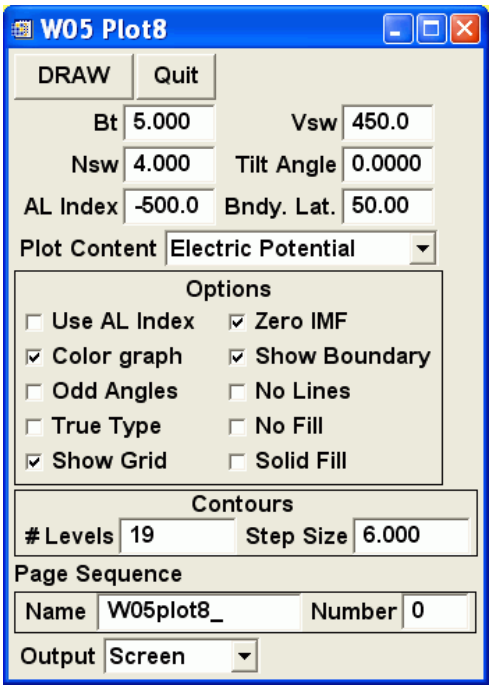

Figure 4

Another program in the file **W05plot8.sav** shows maps in corrected geomagnetic LAT-MLT coordinates at eight different clock angle orientations, as shown in Figure 3, with the user interface shown in Figure 4. The IMF Y-Z magnitude is entered in the box Bt. Either the electric potentials, magnetic potentials, field-aligned current density, or ionospheric Joule heating may be mapped. The currents and heating are calculated at an altitude of 110 km. If the option "Odd Angles" is checked, then a 22.5° offset is added to those shown in Figure 3. If the "solid fill" option is unchecked, then a continuously variable color scale is used. "No Fill" causes only the contour lines to be drawn, without and color shading (dotted lines used for negative levels), and "No Lines" skips the contour lines (usually used with a solid color fill).

The program in **W05plot1.sav** works very much like **W05plot8**, except that it produces just one map for the specified IMF parameters, as in Figure 5. The selections in the GUI work similarly to the other two programs. The dipole tilt angle can be set to any particular angle, or the date and time may be given, and the program will compute the dipole tilt angle for that specific time. If this date option is used, then the IMF values that are entered should correspond to the actual values for this date and time (the program does not calculate these!), otherwise the plot labeling will be misleading. The same caveat applies to the program **geoepotplot**.

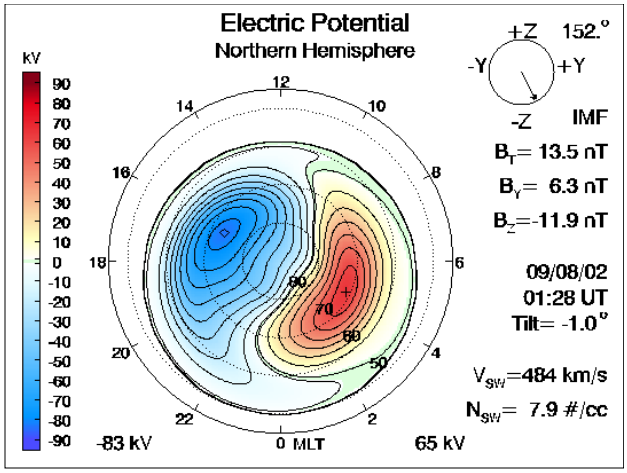

Figure 5

The program in **gridpotentials.sav** has no graphics but will do input and output through data files, which may be useful for some applications. Each time that this program is run it reads a grid definition from the file **potentialgrid.txt** and imf/time values from **imfs.txt,** then outputs results as text to the file **potential.txt**, or to the file **potential.dat** in binary format. This output file will be overwritten every time that the program is run. The text file **potentialgrid.txt** may look something like this:

```
 cgm textfile 24 51 Epot Joule
0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18.
19. 20. 21. 22. 23.
40. 41. 42. 43. 44. 45. 46. 47. 48. 49.
50. 51. 52. 53. 54. 55. 56. 57. 58. 59.
60. 61. 62. 63. 64. 65. 66. 67. 68. 69.
70. 71. 72. 73. 74. 75. 76. 77. 78. 79.
80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90.
```

The format of this file is free-form, but the first line must have either "cgm" or "geo" as the first word in order to indicate if the grid is corrected geomagnetic latitude/MLT (degrees and hours) or geographic latitude and longitude (all in degrees). The next word indices if the output is to be text or binary, then gives the number of longitude/MLT steps (nlon) and the number of latitude values (nlat). After the nlon and nlat specification, there can be up to four additional words or letters that indicate which values go to the output file. If none are given then the electric potential will be output. Only the first letter is significant, and the available values are:

E: electric potential, kV

B or M: magnetic potential, cTm

F: field-aligned current (FAC), $\mu A/m^2$

J: Joule heating, mW/m^2

In this example file only the electric potential and Joule heating will be output, and in the order given. The electric and magnetic potential values are independent of altitude. The FAC and Joule heating are calculated for an altitude of 110 km.

The lines that follow the first, "header" line provide the longitude and latitude values for the grid. The program keeps reading longitude and latitudes values until the specified numbers are reached, so any number of values may be supplied on each line. In this particular example the 24 MLT/longitude values are provided on the two following lines. The 51 degree steps are given on the following six lines.

Another example of the file **potentialgrid.txt** looks like this:

```
geo textfile 36 51
0.000000   10.0000    20.0000    30.0000    40.0000    50.0000
60.0000    70.0000    80.0000    90.0000    100.000    110.000
120.000    130.000    140.000    150.000    160.000    170.000
180.000    190.000    200.000    210.000    220.000    230.000
240.000    250.000    260.000    270.000    280.000    290.000
300.000    310.000    320.000    330.000    340.000    350.000
40. 41. 42. 43. 44. 45. 46. 47. 48. 49.
50. 51. 52. 53. 54. 55. 56. 57. 58. 59.
60. 61. 62. 63. 64. 65. 66. 67. 68. 69.
70. 71. 72. 73. 74. 75. 76. 77. 78. 79.
80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90.
```

As nothing follows the 51 then only the electric potentials will be output.

The file **imfs.txt** provides the IMF and tilt angle (or date) values to be used for calculation of the electric potentials on the specified grid. There may be more than one line in this file, and for every line the program sequentially writes the values on the entire grid, to the output file **potentials.dat**. Each line has the IMF B_y and B_z values (nT), the solar wind velocity (km/sec), solar wind number density (#/cc), and year, month, day, and hour (eight numbers per line). Alternatively, only five numbers per line may be given, providing the dipole tilt angle in degrees in place of the year, month, day, and hour. This alternative format may not be used if geographic coordinates are being used, as the program needs a date/time in order to calculate MLT at each location. It is assumed that the grid is in the northern hemisphere, and that the provided IMFs have already had the proper time delays applied. Usually a 45-min running average should be used for computing the IMF values. For every line in **imfs.txt** the program will output **nlat x nlon** values using the format **13F8.3**, and repeated up to four times for each quantity that was requested. If the binary format is chosen, then the IDL XDR format is used, and the each array of grid values is output using **writeu,unit,fltarr(nlat,nlon)**.

All of these programs may be run in the IDL Virtual machine by double-clicking on the .sav file in a Windows or Mac file manager, or if using Unix/Linix/Mac give the command **IDL -vm='geoepotplot.sav'** at a terminal/shell prompt. If a licensed version of IDL 6.0 or above is available the files may be "restored" at the IDL prompt, then executed by typing the procedure name (same as file, but without .sav extension).

The basic model routines may also be used in licensed IDL by "restoring" the file w05plot1.sav at the IDL command prompt. To set the IMF conditions for the models the procedure SetModelis executed with the arguments:

SetModel, angle, Bt, Tilt, SWVel, SWDen,[ALindex], PATH=path

or

SetModel, By, Bz, Tilt, SWVel, SWDen,[ALindex], /YZ, PATH=path

The Alindex parameter is optional. If the data files **W05SCEpot.xdr, W05SCBpot.xdr**, and **W05SCBndy.xdr** are in the same directory as **w05plot1.sav**, then the path keyword does not need to be provided. After the call to **SetModel**,the functions **EpotVal, BpotVal, mpFAC,** and **JouleHeat** may be used to get the electric potential in kV, the magnetic potential in cTm (see reference papers), the field-aligned current density in $\mu A/m^2$, or the heating in mW/m^2. These functions are called with the parameters **(lat, mlt, INSIDE=inside, OUTSIDE=outside)**, with the latitude and MLT being degrees and hours in Modified Apex Geomagnetic Coordinates. The optional keywords return logical arrays set to 0 or 1 to indicate if the given points are within the boundary circle having non-zero potentials, as described in the reference paper. As the last two functions depend on altitude they also have an optional keyword ALT to give the altitude in km, otherwise 110 km is assumed. The procedures **efield** and **bfield** are also available, called with the parameters **lat, mlt, north, east, ALT=alt**. These procedures return the north and east components of the vector electric field (mV/m) or magnetic field (nT) perturbation due to the FAC above the ionosphere.

Other functions that are available in **w05plot1.sav** are **TO_MLT(maglong)** and **TO_MAGLONG(mlt)**, to convert between magnetic longitude and magnetic local time, and **Tilt_Angle()**, to return the dipole tilt angle. Prior to calling these functions, the procedure

EARTHTRANS,year,month,day,hour must be called to calculate the position of the Sun and various coordinate system transformation matrices and angles.

The files that are provided are:
Pre-compiled IDL programs: geoepotplot.sav , W05plot8.sav, W05plot1.sav, and gridpotentials.sav
The model coefficient data files: W05SCEpot.xdr, W05SCBpot.xdr, and W05SCBndy.xdr
Lookup-tables used for "spherical cap harmonics" in the model programs: SCHAtable.xdr
Customized color tables: newcolor.tbl
Data files with interpolation tables used for converting between geographic and geomagnetic Apex coordinates in the Northern hemisphere: GeotoCgmNorth.xdr and CgmtoGeoNorth.xdr
Supplemental map files, used only by the program geoepotplot.sav, for drawing the largest inland lakes, in "low" resolution: lakelow.dat and lakelow.ndx

Daniel Weimer
Center for Space Science and Engineering Research @Virginia Tech.
Resident at: National Institute of Aerospace
100 Exploration Way
Hampton, VA 23666
Phone: 757-325-6908
E-mail: dweimer@vt.edu