apex_converter_demo

October 30, 2014

1 apex_converter.py

1.1 Demonstration and Interactive Documentation

This document will demonstrate how to quickly convert large sets of geographic-coordinate data into Modified Apex Coordinates.

1.2 Requirements:

- Python >=2.7
- Python Modules:
  - Numpy (tested with v. 1.7)
  - Matplotlib (tested with v. 1.5)
  - Art Richmond's Modified Fortran Apex Library with Python Bindings (tested with v.0.0.0)
- For Interactive Demo and Test: Ipython (0.12 or later)

This code has been tested on Ubuntu Linux 12.04 and later. ##Contact: Please report any compatability issues or bugs to:
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1.3 Notes:

This tool should only be distributed with the Modified Apex Fortran library and python bindings. These must be correctly installed before using. See the associated README document. To install and compile the python interface, it should only be nessecary to issue: `python setup.py install` in a shell or windows command prompt from the root directory of the apex codebase.

Ipython is a free and open source tool for scientific programming in Python (see http://ipython.org/). It uses a 'cell' style interface for fast and transparent code snippet execution and display, similar to Wolfram Mathmatica.

In [2]:
```
#Make sure apex python bindings are installed correctly
#by importing the module. If you would like to further
#test your apex installation, you can run the unit tests for
#the apex python bindings by issuing python test_apxntrp
#from your command window or shell in the src
#subdirectory of the apex codebase
import apex
#Not including modules other than apex.py
#seems to be a bug or config error in the apex installation scripts.
#Add the path to code manually here.
#--You will have to set this to be correct for your filesystem--
import sys
#Path to apex.pyf and apex_coverter.py
```

```
sys.path.append('/home/liamk/mirror/Projects/apex-python/src')
#Path to satplottools.py
sys.path.append('/home/liamk/mirror/Projects/conjunction/src')
#This module is needed for displaying the docstrings prettily
import textwrap
#This 'magic' function ensures that the code is
#running the newest version
%load_ext autoreload
%autoreload 2
```

1.4 Instantiating the Apex Converter

By creating an apex_converter object, you initialize and store in memory a global grid of points mapping geographic to magnetic coordinates. Interpolation between adjacent points is used to determine the apex location of a particular geographic input. Passing optional parameters allows you to change the extent and resolution of the grid. The epoch parameter dictates the epoch for choosing IGRF coefficients to use for determining the geomagnetic field. Information about the class and the parameters you can set at instantiation can be found in the docstring below.

```
In [3]: #Import the apex_converter module
        import apex_converter
```

```
In [4]: #Make a converter object
        #-----------------------
        converter = apex_converter.apex_converter()
```

```
Initializing lat,lon,alt grid with following parameters:

Epoch, Nvert = 2010.000000, 50.000000

Lat min,max,npts = -90.000000,90.000000,151.000000

Lon min,max,npts = -180.000000,180.000000,251.000000

Alt min,max,npts = 300.000000,900.000000,6.000000

Preparing interpolation tables...
```

```
In [5]: #View the docstring for the class constructor
        print textwrap.dedent(converter.__init__.__doc__)
```

```
Bulk conversion of geographic coordinates to Modified Apex

Uses numpy-style docstrings for clarity.
Parameters described are for class constructor

Parameters
----------
glatmin : float, optional
        Grid boundary: minimum geographic latitude (default=-90.)
glatmax : float, optional
        Grid boundary: maximum geographic latitude (default=-90.)
glonmin : float, optional
        Grid boundary: minimum geographic longitude (default=-180.)
glonmax : float, optional
```

```
        Grid boundary: maximum geographic longitude (default=180.)
altmin : float, optional
        Grid boundary: minimum altitude in km (default=300.)
altmax : float, optional
        Grid boundary: minimum altitude in km (default=900.)
nvert : float, optional
        Grid spacing factor. Determines vertical and lat,lon resolution.
        Recommended values are between 30 and 100. (default=50.)
epoch : float, optional
        Epoch for input into IGRF; the year

Altitude is in km
Latitude and longitude are in degrees. Negative longitude instead of lon>180.
nvert is the grid spacing factor. Recommended values are between 30 and 100.
Larger values will cause the program
to use more memory to build larger interpolation tables,
but interpolation accuracy will increase up to about nvert of 100
See ggrid.f for more information.
```

1.5 Apex Converter Conversion Operations

Apex Converter primarily uses the APXMALL fortran subroutine, which fetches almost all possible information about a particular geographic location. This includes the geomagnetic field at the location, the apex latitude and longitude at the location, the quasi-dipole latitude at the location, and the various apex basis vectors, expressed in geographic east,north,up coordinates.

The apex_converter has methods for the following tasks:

- Converting a numpy array of latitude, longitude, altitude points to corresponding Modified Apex locations (*geo2apex()*)
- Converting a numpy array of Apex Longitude to Magnetic Local Time (MLT) (*alon2mlt()*)
- Converting a vector measurement in geographic (east,north,up) made at a geographic location lat,lon,alt to the correspond Modified Apex vector (d1,d2,d3) and location (alat,alon,mlt) (*measurement2apex()*)

The best way to learn about these methods is to view their docstrings (python's internal documentation for methods/functions). This code attempts to follow the spirit of the numpy docstring guidelines:

```
In [6]: print textwrap.dedent(converter.geo2apex.__doc__)
        #textwrap.dedent removes any tabs in the docstring which would make it hard to read
        #when it's displayed here
```

```
Does a simple transformation of observation positions from geographic to apex

Parameters
----------
lat : numpy.array
        Observation Geographic latitudes
lon : numpy.array
        Observation Geographic longitudes
alt : numpy.array
        Observation Altitudes in km
hr=110. : float
        Modified Apex reference height in km

Returns
```

```
-------
alat : numpy.array
        Modified Apex Latitude
alon : numpy.array
        Apex Longitude
qdlat : numpy.array
        Quasi-Dipole Latitude
```

```
In [7]: print textwrap.dedent(converter.alon2mlt.__doc__)
```

```
Converts Apex Longitudes to Magnetic Local Time

Calls apex subroutine apex.magloctm (mag local time)
after setting the IGRF coefficient global variables using
the same epoch as was used to initially
generate the interpolation tables.

Parameters
----------
alon : numpy.array
        a numpy array of length n, apex longitude
year : int or numpy.array
        The year for which to compute the MLT
dayofyear : int or numpy.array
        The day-of-year(s) for which MLT is to be found
utseconds : int or numpy.array
        the second-of-the-day(s) in UT
        of the time for which the MLT is to be found

Options for time argument (year,dayofyear,utseconds) length:
1. All have length 1 for MLT of all alons for a fixed time.
2. Year,and Day of year can have length 1,
        and then UT seconds can have length n
         for different times on same day
3. All can have length n to find the MLT
        of each alon with a unique date and time
        year is year(s) for which MLT is to be found.

Returns
-------
mlt : numpy.array
        The magnetic local time corresponding to alon for
        the times specified
```

```
In [7]: print textwrap.dedent(converter.measurement2apex.__doc__)
```

```
Converts a vector measurement and it's associated location to modified apex coordinates

Transforms measurement vector v [m x 3] in geo east, north, up
to apex. Lat, lon, and alt are [m x 1] vectors of locations association with
Measurements in vector v, hr is reference height

Parameters
----------
lat : numpy.array
```

```
        geographic latitude
lon : numpy.array
        geographic longitude
alt : numpy.array
        geographic altitude
v : numpy.array
        [nx3] vector to transform
hr : float, optional
        Apex reference height in km (default=110.)

Returns
-------
alat : numpy.array
        Modified Apex Latitude of measurement
alon : numpy.array
        Apex Longitude of measurement
v_d : numpy.array
        Vector in Apex 'd' basis
```

1.6 Testing the conversion

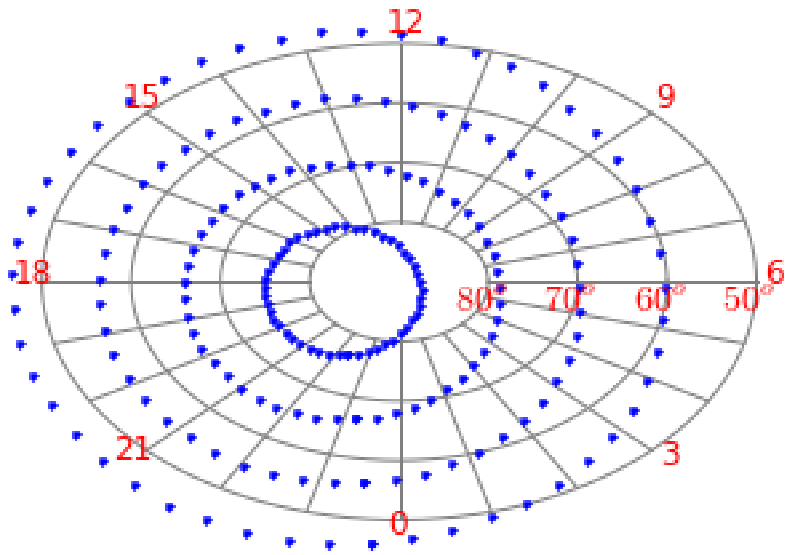
Apex_converter provides a visual self-test method called graphical_test. It generates a series of 'rings' in geographic coordinates at positive or negative 80,70,60,50 degrees latitude, depending on the setting of the `hemisphere` argument. By setting the time of 'aquisition' in UT hours, and the Modified Apex reference height `hr` using named parameter-type arguments, the user can test how data from different geographic locations and times would appear in Apex Coordinates. It visualizes the data in a 'dial plot' format (polar coordinates centered on the Modified Apex coordinates pole (90 degrees latitude)), with the magnetic local time as the azimuthal coordinate, and the absolute value of latitude as radial. ### Method: graphical_test()

1.6.1 Arguments:

- npts=50 - number of points per ring
- hemisphere='N' - sets sign of latitudes used for rings. N for >0, S for < 0
- testalt=400. - Altitude of simulated geographical data
- UT=12 - Universal time of aquisition of simulated geographical data
- hr=110.
- saveit=False - Save a copy of the plot as a png file
- plotdir='directory_to_save_to' - Set to wherever you would like the png to save

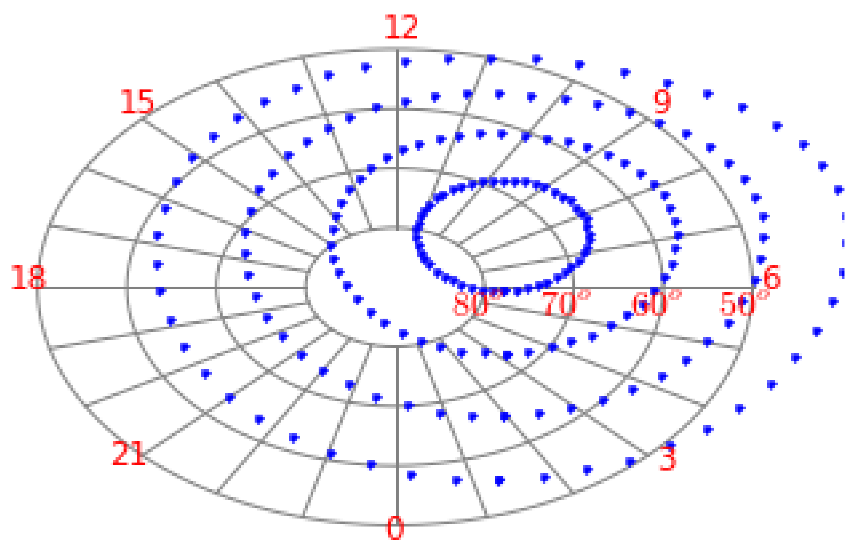
```
In [8]: converter.graphical_test(hemisphere='N',testalt=400.,UT=12.,hr=110.);
```

```
Transforming 200 points from lat,lon,alt to apex...
Computing 200 Apex Longitude values to Magnetic Local Time...
```



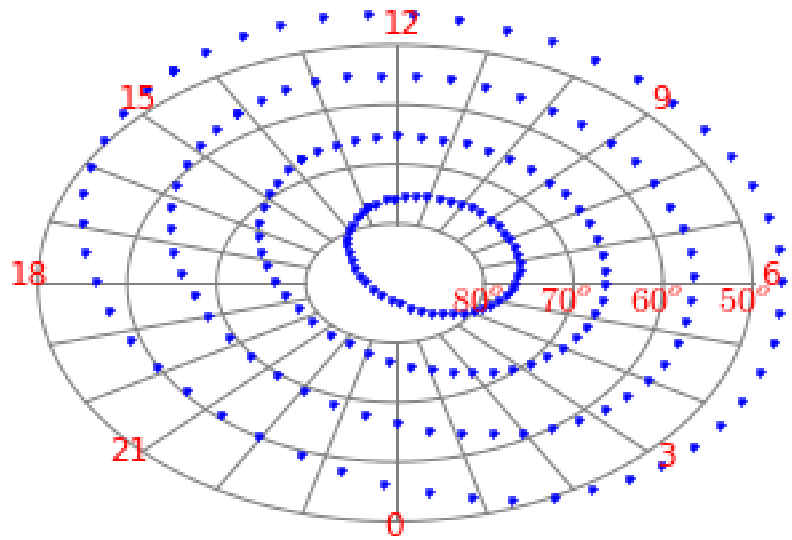

```
In [9]: converter.graphical_test(hemisphere='S',testalt=400.,UT=12.,hr=110.);
```

```
Transforming 200 points from lat,lon,alt to apex...
Computing 200 Apex Longitude values to Magnetic Local Time...
```



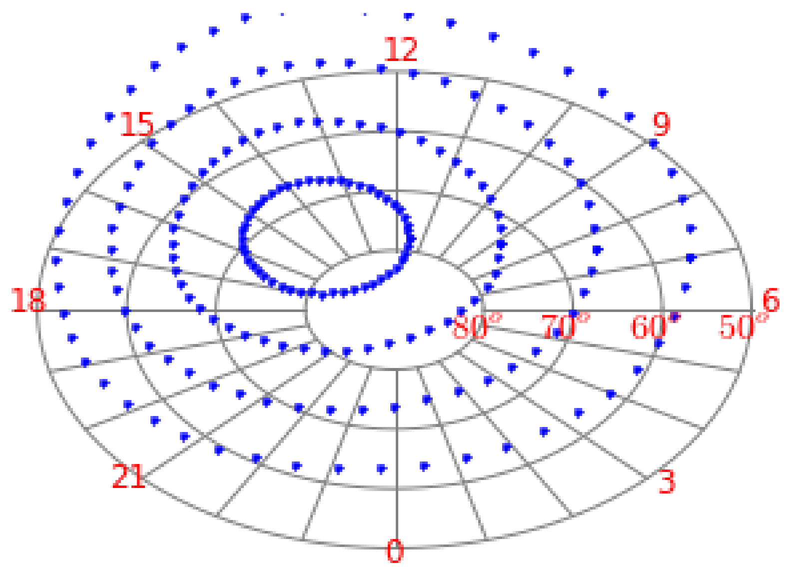

```
In [9]: converter.graphical_test(hemisphere='N',testalt=400.,UT=3.,hr=110.);
```

```
Inputs identical to last run, results already in attribute lastrun

Computing 200 Apex Longitude values to Magnetic Local Time...
```




```
In [11]: converter.graphical_test(hemisphere='S',testalt=400.,UT=18.,hr=110.);
```

```
Transforming 200 points from lat,lon,alt to apex...
Computing 200 Apex Longitude values to Magnetic Local Time...
```



1.7 Converting real observational data points

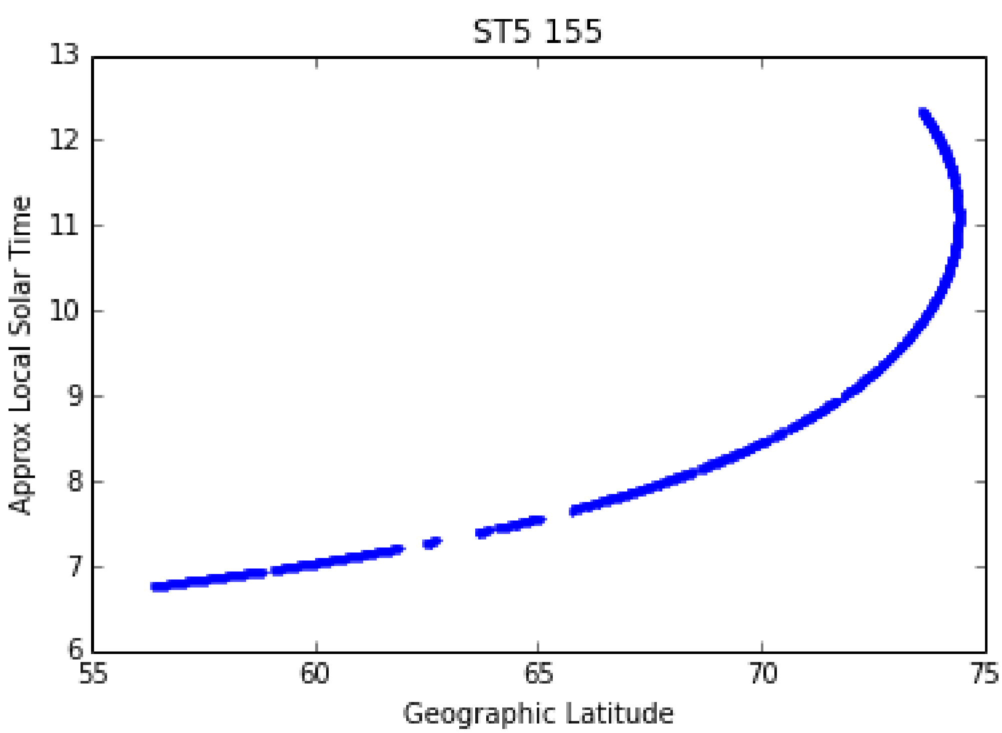
The apex converter software is fully vectorized and can convert large numbers of geographic ephemerides or ephemeris-vector combinations.

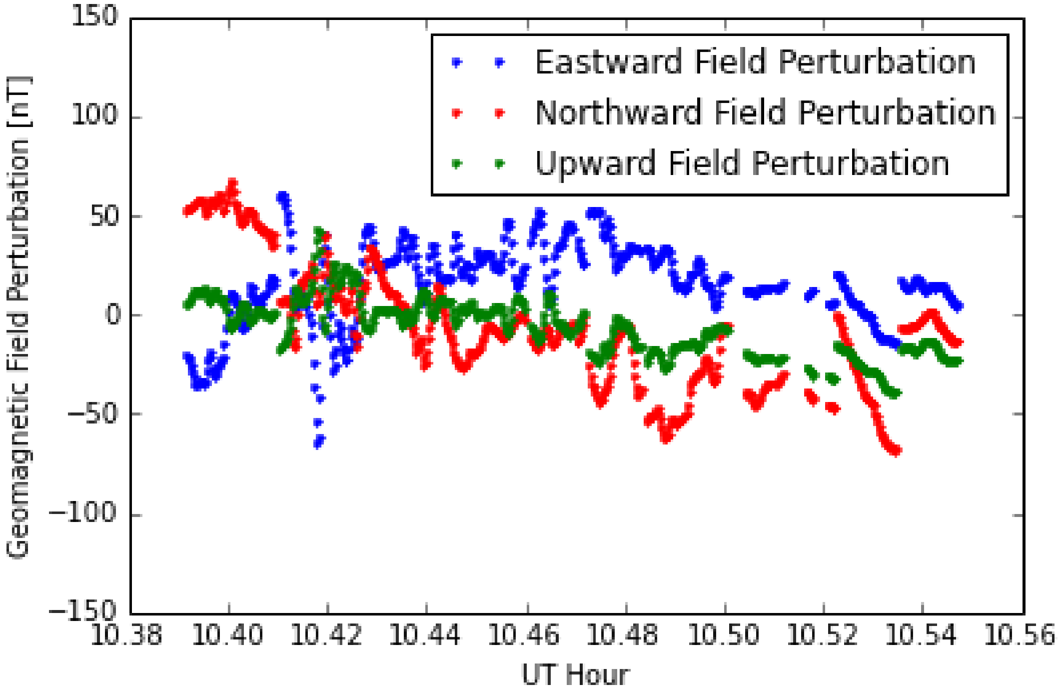
This example will use a small sample (500 pts) of data from the NASA ST5 mission. The orbit of this spacecraft is highly elliptical, with a periapse of around 300 km, and an apoapse of around 4500 km. This provides a bit of a challenge for bulk apex conversion because it requires a very large vertical range. Also, the accuracy of the IGRF field model is lower at higher altitude because of the greater succeptibilty to perturbation of the field at this altitude.

In [29]:
```
import datetime
import matplotlib.pyplot as pp
import satplottools
data = numpy.genfromtxt('st5_155_test.txt',delimiter=',')
#Load up the data from a comma-seperated text file and splice out the appropriate variables
year = data[:,0]
month = data[:,1]
day = data[:,2]
hour  = data[:,3]
minute = data[:,4]
second = data[:,5]
MLT = data[:,6]
B_GEO = data[:,10:13]
IGRF_B_GEO = data[:,22:25]
R_GEO = numpy.column_stack((data[:,35],data[:,36],data[:,34]))
#lat,lon
lat = R_GEO[:,0]
lon = R_GEO[:,1]
#Convert to -180 to 180 longitude instead of 0 to 360
lon[lon>180.] = lon[lon>180.]-360.

#Compute the day of year using a python 'lambda' function (very handy!)
date2doy = lambda y,mo,d,h,m,s: float(datetime.datetime(y,mo,d,h,m,s).timetuple().tm_yday)
dayofyear = date2doy(int(year[0]),int(month[0]),int(day[0]),0,0,0)

#Compute the second of the day
secofday = second+minute*60.+hour*3600.

#Estimate the local solar time
lst = secofday/3600. + lon/180.*12.

#Convert radius to altitude using an older standard radius,
#but the one that is used in the apex fortran code
Re = 6371.2 #km
alt = (R_GEO[:,2]-1.)*(Re)

#Show the sample ephemeris
f1 = pp.figure()
ax = pp.axes()
ax.plot(lat,lst,'b.')
ax.set_xlabel('Geographic Latitude')
ax.set_ylabel('Approx Local Solar Time')
ax.set_title('ST5 155')

#Compute the magnetic perturbation by subtracting the main-field model value
```

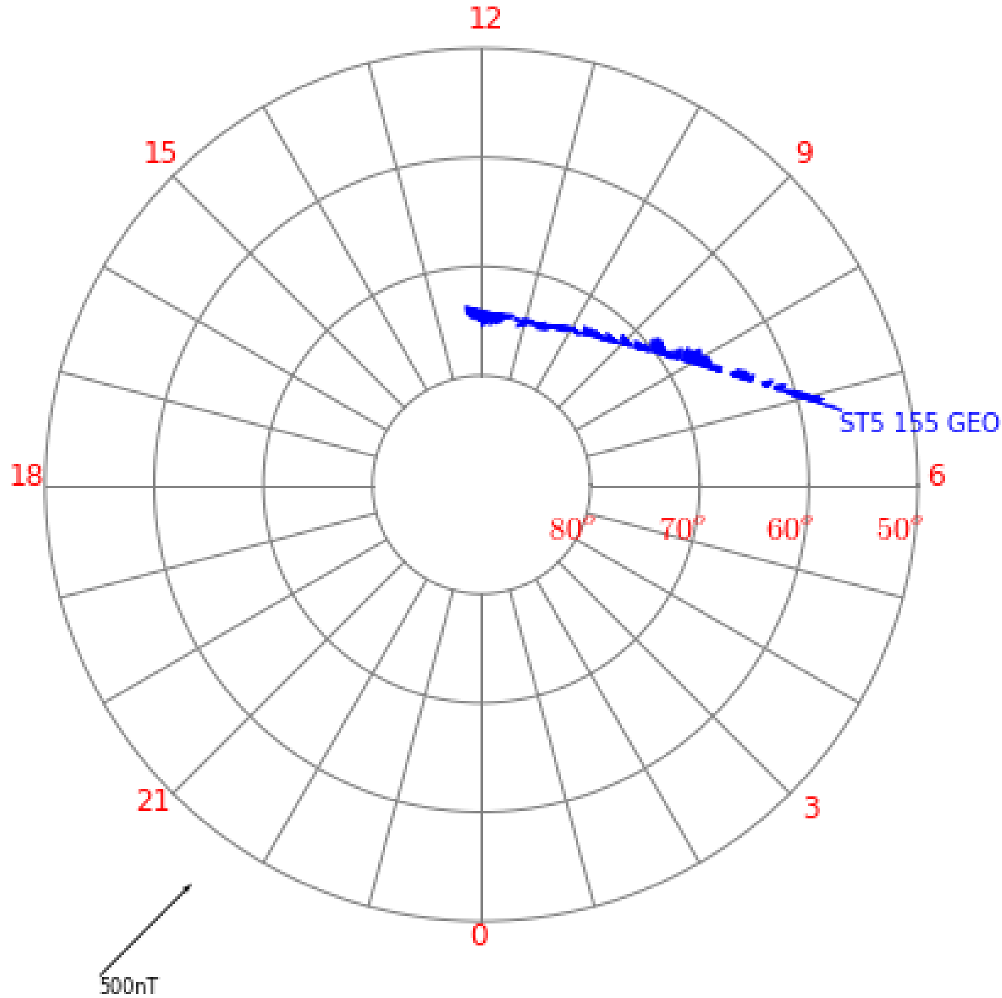
```
dB_GEO_east = B_GEO[:,0]-IGRF_B_GEO[:,0]
dB_GEO_north = B_GEO[:,1]-IGRF_B_GEO[:,1]
dB_GEO_up = B_GEO[:,2]-IGRF_B_GEO[:,2]
dB_GEO = numpy.column_stack((dB_GEO_east,dB_GEO_north,dB_GEO_up))

f2 = pp.figure()
ax2 = pp.axes()
ax2.plot(secofday/3600,dB_GEO_east,'b.',label='Eastward Field Perturbation')
ax2.plot(secofday/3600,dB_GEO_north,'r.',label='Northward Field Perturbation')
ax2.plot(secofday/3600,dB_GEO_up,'g.',label='Upward Field Perturbation')
ax2.set_ylabel('Geomagnetic Field Perturbation [nT]')
ax2.set_xlabel('UT Hour')
ax2.set_ylim([-150,150])
ax2.legend()

f22 = pp.figure(figsize=(8,8))
ax22 = pp.axes()
vplotdata_geo = numpy.column_stack((secofday,lat,lst,dB_GEO[:,0],dB_GEO[:,1]))
satplottools.draw_dialplot(ax22)
satplottools.vector_plot(ax22,vplotdata_geo,satname='ST5 155 GEO',latlim=50.,max_magnitude=500
```

```
Out[29]: <matplotlib.axes.AxesSubplot at 0x4dc6090>
```





Eastward Field Perturbation
Northward Field Perturbation
Upward Field Perturbation
Geomagnetic Field Perturbation [nT]
UT Hour
150
100
50
0
−50
−100
−150
10.38
10.40
10.42
10.44
10.46
10.48
10.50
10.52
10.54
10.56

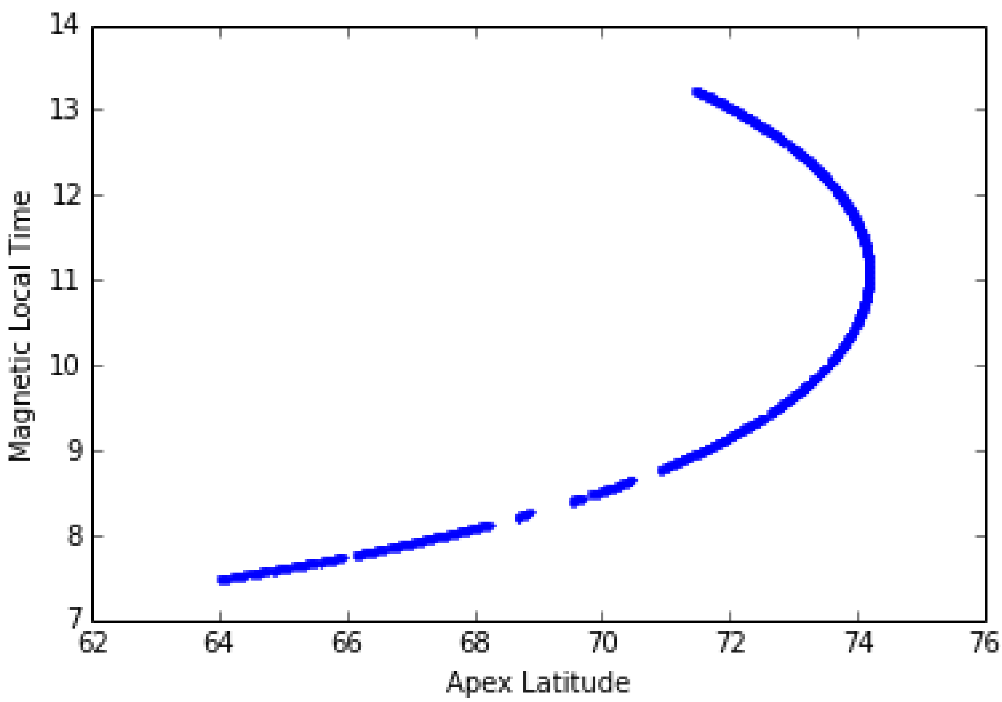


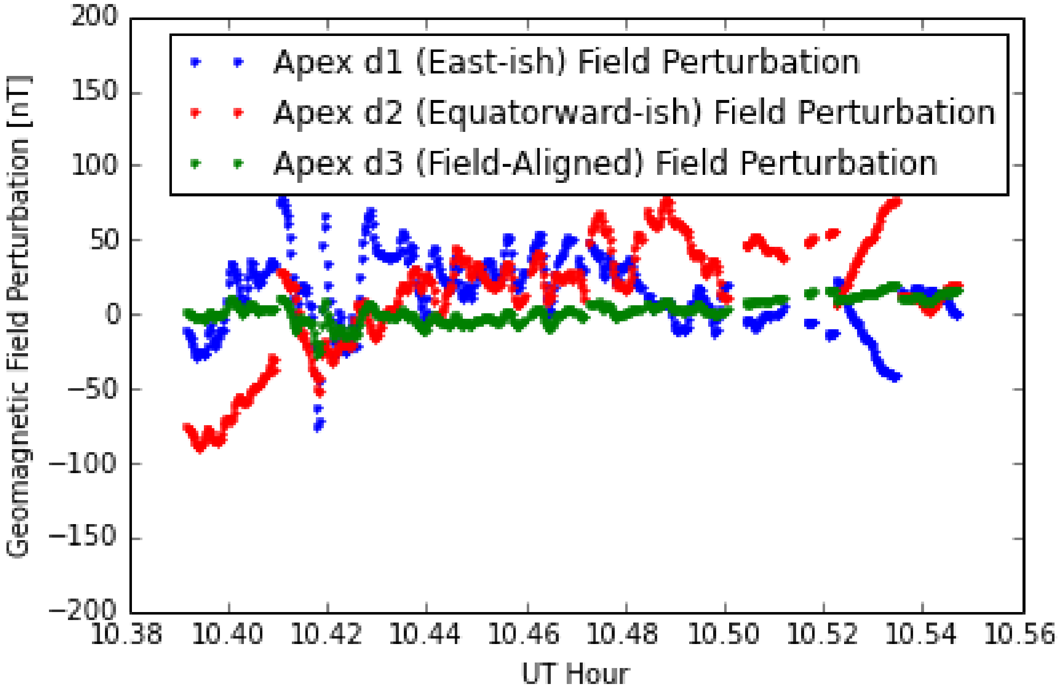

```
In [24]: #Make an apex converter with fairly high resolution
         #(see section titled 'Initialize Apex Converter')
         st5converter = apex_converter.apex_converter(epoch=2006.,nvert=40.,altmin=100.,altmax=4000.)

         #Convert the measurement to apex coordinates using a reference height of 110 km.

         alat,alon,dB_apex = st5converter.measurement2apex(lat,lon,alt,dB_GEO)

         #Convert apex longitude to magnetic local time
         mlt = st5converter.alon2mlt(alon,2006.,dayofyear,secofday)
```

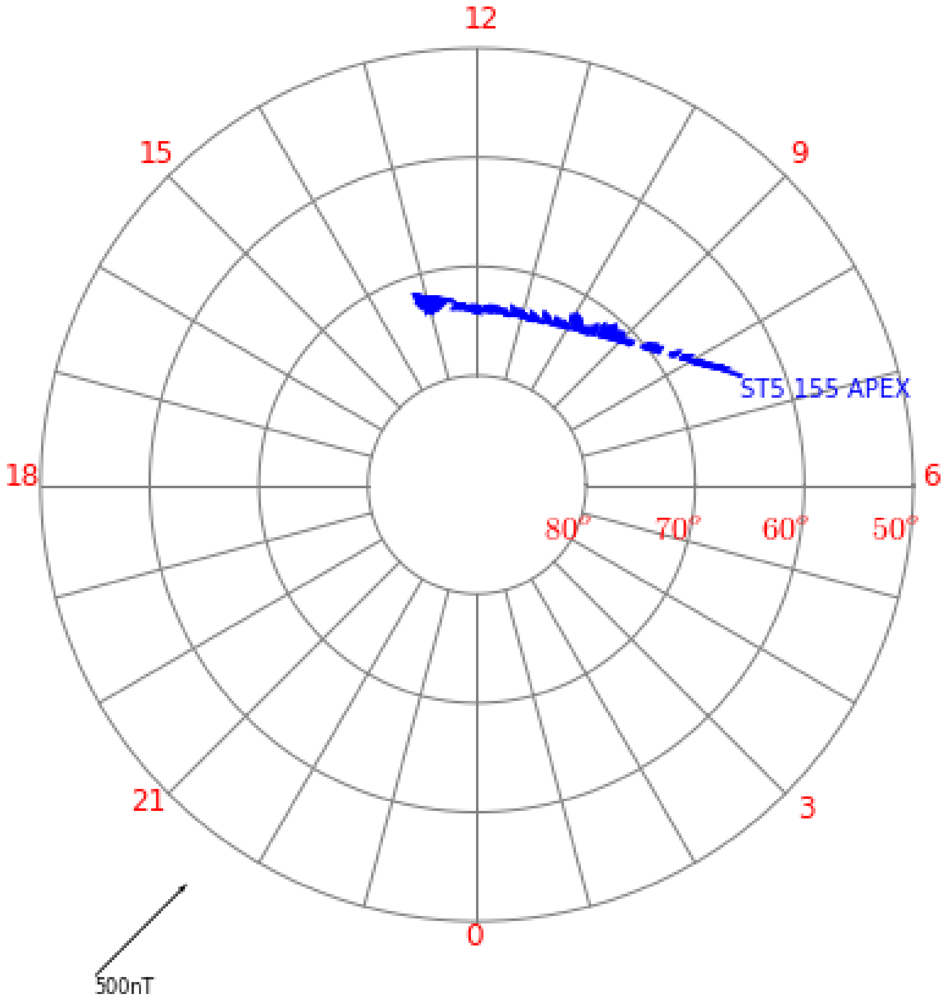
```
Initializing lat,lon,alt grid with following parameters:

Epoch, Nvert = 2006.000000, 40.000000

Lat min,max,npts = -90.000000,90.000000,121.000000
```

```
Lon min,max,npts = -180.000000,180.000000,201.000000

Alt min,max,npts = 100.000000,4000.000000,17.000000

Preparing interpolation tables...
Transforming 500 points from lat,lon,alt to apex...
Computing 500 Apex Longitude values to Magnetic Local Time...
```

```
In [31]: f3 = pp.figure()
         ax3 = pp.axes()
         ax3.plot(alat,mlt,'b.',label='ST5 155 Track, Apex')
         ax3.set_xlabel('Apex Latitude')
         ax3.set_ylabel('Magnetic Local Time')

         f4 = pp.figure()
         ax4 = pp.axes()
         ax4.plot(secofday/3600,dB_apex[:,0],'b.',label='Apex d1 (East-ish) Field Perturbation')
         ax4.plot(secofday/3600,dB_apex[:,1],'r.',label='Apex d2 (Equatorward-ish) Field Perturbation')
         ax4.plot(secofday/3600,dB_apex[:,2],'g.',label='Apex d3 (Field-Aligned) Field Perturbation')
         ax4.set_ylabel('Geomagnetic Field Perturbation [nT]')
         ax4.set_xlabel('UT Hour')
         ax4.set_ylim([-200,200])
         ax4.legend()

         f5 = pp.figure(figsize=(8,8))
         ax5 = pp.axes()
         vplotdata_apex = numpy.column_stack((secofday,alat,mlt,dB_apex[:,0],-1*dB_apex[:,1]))
         satplottools.draw_dialplot(ax5)
         satplottools.vector_plot(ax5,vplotdata_apex,satname='ST5 155 APEX',latlim=50.,max_magnitude=50

Out[31]: <matplotlib.axes.AxesSubplot at 0x3f79390>
```




Apex d1 (East-ish) Field Perturbation
Apex d2 (Equatorward-ish) Field Perturbation
Apex d3 (Field-Aligned) Field Perturbation
Geomagnetic Field Perturbation [nT]
UT Hour
200
150
100
50
0
−50
−100
−150
−200
10.38
10.40
10.42
10.44
10.46
10.48
10.50
10.52
10.54
10.56


12
9
15
18
6
ST5 155 APEX
80°
70°
60°
50°
21
3
0
500nT