parallel_potential

January 21, 2020

1 Curtain Parallel Potential Model

Here I explore the minimum parallel electric potential necessary to lower the mirror point of an electron from 100 km in the SAA (just trapped), to AC6's altitude in the bounce loss cone.

Further, we assume this potential is at the equator, so it will modify the electron's equatorial pitch angle.

We will first pick a curtain observation and use IRBEM to find the minimum altitude and pitch angle change those electrons experienced such that they were observed by AC6 for a prolonged period.

```
In [1]: import pandas as pd
        import numpy as np
        import matplotlib.pyplot as plt
        from datetime import datetime
        import scipy.interpolate #.interp1d

        import IRBEM
        Re_km = 6_371
```

```
In [2]: t_0 = datetime(2015, 8, 27, 23, 4, 44, 500000)
```

1.0.1 Load catalog file to look up AC6 location

```
In [3]: cat_path = '/home/mike/research/ac6_curtains/data/catalogs/AC6_curtains_sorted_v8.txt'
        cat = pd.read_csv(cat_path, index_col=0)
        cat.index = pd.to_datetime(cat.index)
        cat.head()
```

```
Out[3]:                             dos1rate   peak_std   Lm_OPQ    MLT_OPQ      lat  \
        dateTime
        2014-12-19 11:45:30.500000   290.002   2.840199  6.66789  10.71360  62.7607
        2014-12-19 18:17:11.099999   340.002  14.832431  7.24842   7.98180  63.5059
        2014-12-19 18:17:12.300000   340.002  11.704743  7.27972   7.97519  63.5759
        2014-12-19 21:33:52.899999   640.003  14.352735  6.97210   7.45659  70.3503
        2015-03-26 07:31:44.500000   170.001   1.455209  7.08831  10.39770  69.2889

                                         lon      alt  Dist_In_Track  Lag_In_Track  \
```

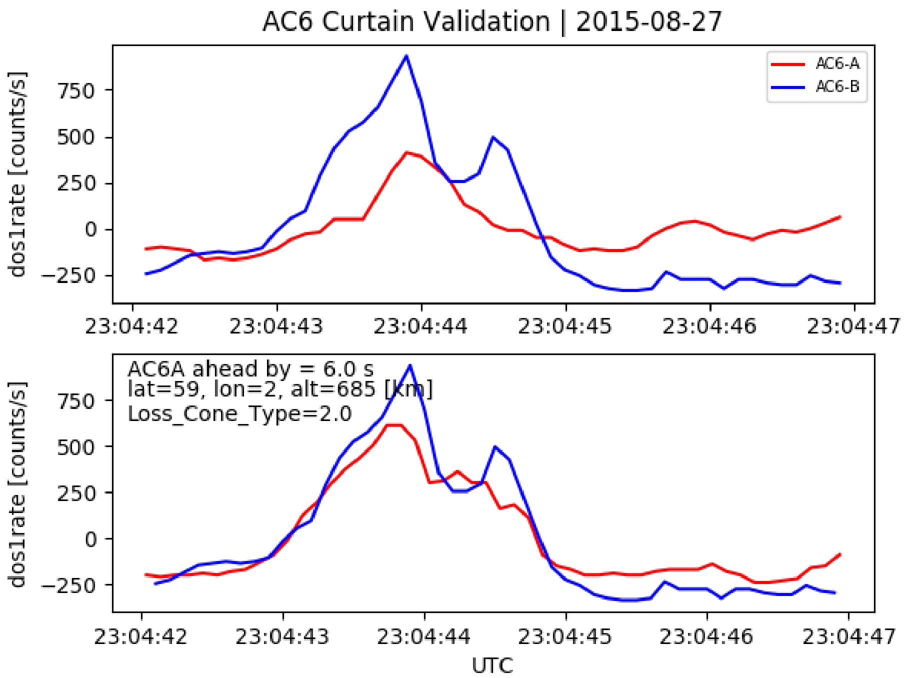
```
dateTime
2014-12-19 11:45:30.500000  -35.6930  662.260       461.176      61.2438
2014-12-19 18:17:11.099999 -134.1340  663.739       463.721      61.5946
2014-12-19 18:17:12.300000 -134.1890  663.824       463.718      61.5946
2014-12-19 21:33:52.899999  170.0450  670.690       464.995      61.7903
2015-03-26 07:31:44.500000   21.2179  632.797       243.682      32.2168

                            Dist_Total  Loss_Cone_Type  flag     AE   time_cc  \
dateTime
2014-12-19 11:45:30.500000     461.422             0.0   4.0   51.0  0.094868
2014-12-19 18:17:11.099999     463.972             1.0   0.0  405.0  0.288474
2014-12-19 18:17:12.300000     463.968             1.0   0.0  405.0  0.090012
2014-12-19 21:33:52.899999     465.247             1.0  20.0   99.0  0.536131
2015-03-26 07:31:44.500000     243.716             1.0   0.0  201.0  0.261325

                            space_cc             time_spatial_A  \
dateTime
2014-12-19 11:45:30.500000  0.870388  2014-12-19 11:44:29.256200
2014-12-19 18:17:11.099999  0.892241  2014-12-19 18:16:09.505399
2014-12-19 18:17:12.300000  0.895632  2014-12-19 18:16:10.705400
2014-12-19 21:33:52.899999  0.841011  2014-12-19 21:33:52.899999
2015-03-26 07:31:44.500000  0.888005  2015-03-26 07:31:12.283200

                                        time_spatial_B  peak_width_A  \
dateTime
2014-12-19 11:45:30.500000  2014-12-19 11:45:30.500000           NaN
2014-12-19 18:17:11.099999  2014-12-19 18:17:11.099999           NaN
2014-12-19 18:17:12.300000  2014-12-19 18:17:12.300000           NaN
2014-12-19 21:33:52.899999  2014-12-19 21:34:54.690299      0.565442
2015-03-26 07:31:44.500000  2015-03-26 07:31:44.500000      0.057192

                            peak_width_B
dateTime
2014-12-19 11:45:30.500000      0.618749
2014-12-19 18:17:11.099999      0.553333
2014-12-19 18:17:12.300000      0.486890
2014-12-19 21:33:52.899999      0.957143
2015-03-26 07:31:44.500000      0.620818
```

In [4]:
```
curtain_obs_params = cat.loc[t_0]
curtain_obs_params
```

Out[4]:
```
dos1rate                         890.005
peak_std                         8.37401
Lm_OPQ                           3.83808
MLT_OPQ                         0.411383
lat                              59.3801
lon                              2.14165
```

```
alt                                              685.152
Dist_In_Track                                    45.3006
Lag_In_Track                                     6.03549
Dist_Total                                        45.322
Loss_Cone_Type                                         2
flag                                                   0
AE                                                   745
time_cc                                         0.547989
space_cc                                        0.852933
time_spatial_A        2015-08-27 23:04:38.464510
time_spatial_B        2015-08-27 23:04:44.500000
peak_width_A                                         NaN
peak_width_B                                    0.243307
Name: 2015-08-27 23:04:44.500000, dtype: object
```

From a single spacecraft this looks like two superposed microbursts



1.0.2 BLC Sanity Check

Southern Hemisphere Mirror Point For Locally Mirroring Electrons at AC6

```
In [5]: model = IRBEM.MagFields(kext='OPQ77')
        X = {'dateTime':t_0, 'x1':cat.loc[t_0, 'alt'], 'x2':cat.loc[t_0, 'lat'], 'x3':cat.loc[t

        try:
            model.mirror_point_altitude(X, None)
            print(model.mirrorAlt)
        except ValueError as err:
```

```
            if str(err) == 'Mirror point below the ground!':
                print(err)
            else:
                raise
```

```
Mirror point below the ground!
```

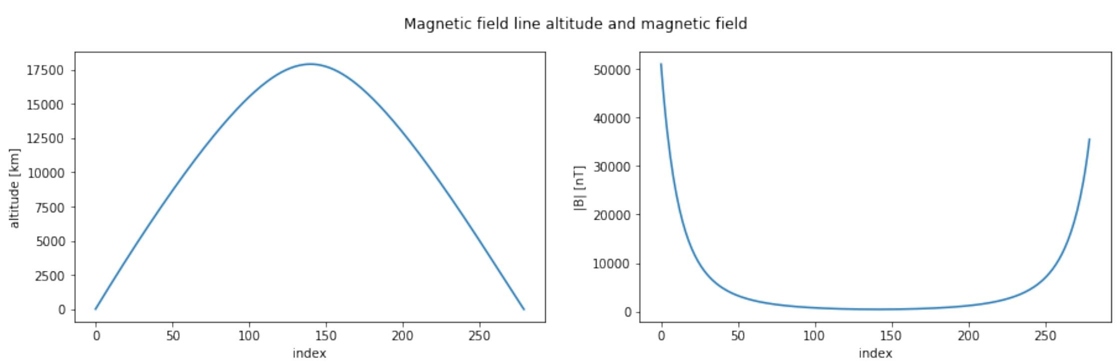
Looks like the mirror point in the southern hemisphere is below the ground - I am very confident that these electrons must have been lost within one bounce.

1.0.3 Mirror points for trapped particles

Trace the field line connected to AC6 and find the mirror point altitude above AC6 of bareley trapped electrons - defined as electrons with a 100 km mirror point altitude in the SAA.

```
In [6]: output_dictionary = model.trace_field_line(X, None) # Trace the magnetic field line.
        field_line_dict = {'x':output_dictionary['POSIT'][:,0], 'y':output_dictionary['POSIT']
                          'z':output_dictionary['POSIT'][:,2], 'blocal':output_dictionary['blocal']
                         'alt':Re_km*(np.linalg.norm(output_dictionary['POSIT'], axis=1)-1)}
        field_line_df = pd.DataFrame(data=field_line_dict)
        interp_index = np.linspace(0, len(output_dictionary['POSIT'][:,0])-1, num=10000)
```

```
In [7]: _ , ax = plt.subplots(1, 2, figsize=(15, 4))
        ax[0].plot(field_line_df.alt); ax[0].set(xlabel='index', ylabel='altitude [km]')
        ax[1].plot(field_line_df.blocal); ax[1].set(xlabel='index', ylabel='|B| [nT]')
        plt.suptitle('Magnetic field line altitude and magnetic field');
```



Interpolate the field line values

```
In [8]: def interp_df(df, new_index):
            """
            Return a new DataFrame with all columns values interpolated
            to the new_index values.
            """
            df_out = pd.DataFrame(index=new_index)
```

```
    df_out.index.name = df.index.name

    for colname, col in df.iteritems():
        df_out[colname] = np.interp(new_index, df.index, col, right=np.nan)

    return df_out

field_line_interp = interp_df(field_line_df, interp_index)
```

1.0.4 Find the magnetic field strength at 100 km in the southern hemisphere and estimate by how much the electron's mirror point must have lowered

```
In [9]: southern_mp_trapped = field_line_interp[field_line_interp.alt > 100].iloc[-1]
        southern_mp_trapped
```

```
Out[9]: x              0.455764
        y              0.309929
        z             -0.853187
        blocal     33716.817123
        alt          100.354565
        Name: 278.3024302430243, dtype: float64
```

Now use the local b field at 100 km altitude in the SAA to find the altitude in the northern hemisphere that has the same magnetic field strength

```
In [10]: northern_mp_trapped = field_line_interp[field_line_interp.blocal < southern_mp_trappe
         northern_mp_trapped
```

```
Out[10]: x              0.603544
         y              0.023170
         z              0.982677
         blocal     33654.932946
         alt          977.715098
         Name: 5.3294329432943295, dtype: float64
```

Now find out the difference in altitude - by how much the electron's mirror point needed to lower in one bounce and be observed by AC6

```
In [11]: ac6_blocal = field_line_interp[field_line_interp.alt > curtain_obs_params.alt].iloc[0
         print(f"The electron's mirror point must have decreased by at least "
               f"{round(northern_mp_trapped.alt - curtain_obs_params.alt)} km "
               f"into a {round(ac6_blocal - northern_mp_trapped.blocal)} nT stronger field str
```

```
The electron's mirror point must have decreased by at least 293.0 km into a 4283.0 nT stronger
```

1.0.5 Estimate the change in pitch angle from the trapped to the precipitating particle.

First find the equatorial magnetic field strength

```
In [12]: b_equator = model.find_magequator(X, None)['bmin']
         print(f'Equatorial magnetic field strength = {round(b_equator)} nT')
```

```
Equatorial magnetic field strength = 478 nT
```

The equatorial pitch angle is defined as

$$\alpha_{eq} = sin^{-1}\left(\sqrt{\frac{B_{eq}}{B_m}}\right)$$

```
In [13]: alpha_initial = np.arcsin(np.sqrt(b_equator/southern_mp_trapped['blocal']))
         alpha_final = np.arcsin(np.sqrt(b_equator/ac6_blocal))
         d_alpha = alpha_initial - alpha_final

         print(f"Initial pitch angle = {round(np.rad2deg(alpha_initial), 2)} degrees")
         print(f"Final pitch angle = {round(np.rad2deg(alpha_final), 2)} degrees")
         print(f"Pitch angle change = {round(np.rad2deg(d_alpha), 2)} degrees")
```

```
Initial pitch angle = 6.84 degrees
Final pitch angle = 6.45 degrees
Pitch angle change = 0.39 degrees
```

Now find the parallel potential (I worked out the math on paper).

```
In [14]: potential = 35E3 * np.cos(alpha_initial) * ((np.tan(alpha_initial)/np.tan(alpha_final
         print(f'Minimum electric potential is {round(potential)} Volts')
```

```
Minimum electric potential is 4413.0 Volts
```

2 Misc

2.0.1 35 keV electron bounce period in the area near the BLC

Calculate the bounce period for locally mirroring, 35 keV electrons near the BLC region. This is only an apprimixation to see if the bounce period is anywhere near the 4-8 second AC6 in-track separations when these curtains were observed.

```
In [15]: X = {'dateTime':t_0, 'x1':cat.loc[t_0, 'alt'], 'x2':cat.loc[t_0, 'lat'], 'x3':-30}
         model.bounce_period(X, None, 35)
         print(f'35 keV electron bounce period is {round(model.Tb, 2)} seconds')
```

```
35 keV electron bounce period is 1.53 seconds
```