Generate Measurements_notObsOnly

June 7, 2018

```
In [43]: import numpy as np
         import math
         import sympy as sym
         from sympy.functions.elementary.trigonometric import atan2
         from scipy.integrate import ode
         from sympy.utilities.lambdify import lambdify
         import Kep_2_Cart
         import Cart_2_Kep
         import filter_functions
         from IPython.core.debugger import Tracer
         import warnings
         import pickle
         import matplotlib.pyplot as plt
         warnings.filterwarnings('ignore')

         #MSIS: https://github.com/DeepHorizons/Python-NRLMSISE-00
         #import time
         from nrlmsise_00_header import *
         from nrlmsise_00 import *
         #SUBROUTINE GTD7D -- d[5] is the "effective total mass density
         #for drag" and is the sum of the mass densities of all species
         #in this model, INCLUDING anomalous oxygen.

         %matplotlib inline
         plt.rcParams['figure.figsize'] = (14.0, 6.0)
         plt.rcParams['xtick.labelsize'] = 14
         plt.rcParams['ytick.labelsize'] = 14
         np.set_printoptions(precision=15)
         sym.init_printing()
         from IPython.display import display
```

Notes: - may want to change the mass and area of the space object to be more representative of a debris object, rather than a satellite

```
In [44]: #define constants
         r_earth_const = 6378136.3 #meters
         omega_const = 7.2921158553e-5
```

```
J_2_const = .00108262617385222
J_3_const = -.00000253241051856772
mu_earth = 3.986004415e14 #m^3/s^2


#Drag:
A_const = 0.9551567 #meters^2; cross-sectional area of satellite
m_const = 10 #kg; mass of satellite
C_D_est = 2.0
theta_dot_const = 7.2921158553e-5 #rad/sec
```

In [45]:
```
#Define Problem Parameters

time_span = 86400
time_step = 120 #10


# meas_type = 1: range and range rate
# meas_type = 2: azimuth and elevation
meas_type = 3


#Measurement Type 1 (Range & Range Rate) Noise:
if meas_type == 1:
    meas1_stan_dev = .1 #meters
    meas2_stan_dev = .01 #meters/sec
#Measurement Type 2 (Az & El) Noise:
if meas_type == 2:
    arcsec_per_rad = 206264.806247 #arcsec/rad
    noise_rad = (1/arcsec_per_rad)  * 5 #5 arcsec noise (suggested by Moriba for a tele
    meas1_stan_dev = noise_rad #radians
    meas2_stan_dev = noise_rad #radians
if meas_type == 3:
    arcsec_per_rad = 206264.806247 #arcsec/rad
    noise_rad = (1/arcsec_per_rad)  * 5 #5 arcsec noise (suggested by Moriba for a tele
    meas1_stan_dev = noise_rad #radians, az
    meas2_stan_dev = noise_rad #radians, el
    meas3_stan_dev = .1 #meters, range


#Date of Simulation Details:
#June 24th, 2017 at 6am (this is the date & time at the beginning of the simulation/orb
year = 2017
month = 6
day_of_month_init = 24
day_of_year_init = 175
hour_init_local = 6
boulder_UT_offset = 6 #Boulder time + 6 hours = UT time
```

```
hour_init_UT = hour_init_local + boulder_UT_offset


# define position and velocity vectors (meters & meters/sec)
#satellite
a = r_earth_const + 400*1e3 # meters
e = 0#.05
i = math.radians(40)#40
cap_omega = math.radians(90)
w = 0
nu = 0
(r_eci, v_eci) = Kep_2_Cart.COE2RV(a, e, i, cap_omega, w, nu, mu_earth)
print('Initial Position (ECI):', np.array(r_eci)/1e3, 'km')
print('Initial Velocity (ECI):', np.array(v_eci)/1e3, 'km')
print('Initial Orbit Altitude:', (np.linalg.norm(r_eci)- r_earth_const)/1e3, 'km')

period = 2*math.pi*math.sqrt(a**3/mu_earth)
print('Period of Orbit:', period/(60), 'minutes')


#Canbera Station (DSS 34) Australia
lat_dss34 = math.radians(-35.398333)
lon_dss34 = math.radians(148.981944)
alt_dss34 = 691.75 #m

r_ecef_dss34 = filter_functions.topo2ecef(lat_dss34, lon_dss34, alt_dss34, r_earth_cons
#print(r_ecef_dss34)

#Madrid Station (DSS 65) -- correct position of Madrid Station
lat_dss65 = math.radians(40.427222)
lon_dss65 = math.radians(355.749444)
alt_dss65 = 834.539 #m

r_ecef_dss65 = filter_functions.topo2ecef(lat_dss65, lon_dss65, alt_dss65, r_earth_cons
#print(r_ecef_dss65)

#Goldstone Station (DSS 13) California
lat_dss13 = math.radians(35.247164)
lon_dss13 = math.radians(243.205)
alt_dss13 = 0 #1071.14904 #m

r_ecef_dss13 = filter_functions.topo2ecef(lat_dss13, lon_dss13, alt_dss13, r_earth_cons
#print(r_ecef_dss13)


#Diego Garcia, British Indian Ocean Territory 7.41173řS 72.45222řE., Space Fence (Dedic
lat_diego = math.radians(-7.41173)
lon_diego = math.radians(72.45222)
```

```
        alt_diego = 0 #m, "sea level"

        r_ecef_diego = filter_functions.topo2ecef(lat_diego, lon_diego, alt_diego, r_earth_cons



        #ADD station on MAUI**********
```

```
Initial Position (ECI): [  4.150411461989742e-13   6.778136300000000e+03   0.000000000000000e+00
Initial Velocity (ECI): [ -5.874456678131549e+00   3.597067283801798e-16   4.929254431987093e+00
Initial Orbit Altitude: 400.0 km
Period of Orbit: 92.560390217187 minutes
```

In [46]:
```
#Propogate trajectory
def orbitpropogator_noSTM(t, X_vector, density):
    state = X_vector[0:3]
    state_v = X_vector[3:6]

    x = state[0]
    y = state[1]
    z = state[2]

    #find X acceleration via the F(X) lambdified equation
    x_acc = x_sol_fcn(*state, *state_v, density)
    y_acc = y_sol_fcn(*state, *state_v, density)
    z_acc = z_sol_fcn(*state, *state_v, density)
    X_acc = np.array([x_acc, y_acc, z_acc])

    dx = np.array([state_v, X_acc])
    dx = dx.flatten()
    return dx



def calc_MSIS_density(t, X_vector):

    state = X_vector[0:3]

    (latitude, longitude, altitude, day_of_month, hour) = \
                        filter_functions.calc_lat_lon_from_t_R(t, state, \
                                day_of_month_init, hour_init_UT, month, year, omega

    day_of_year = math.floor(t/86400) + day_of_year_init
    t = t - math.floor(t/86400) * 86400

    if longitude < 0:
```

```
            longitude = longitude + 2*math.pi
    lst = filter_functions.calc_LST(hour, longitude) #lst in units of hours


    lon = 0 #dependent only on lst


    Output = nrlmsise_output()
    Input = nrlmsise_input()
    flags = nrlmsise_flags()
    aph = ap_array()

    for i in range(7):
        aph.a[i]=100
    flags.switches[0] = 1
    for i in range(1, 24):
        flags.switches[i]=1

    Input.doy = day_of_year
    Input.year = 0 #/* without effect */
    Input.sec = t
    Input.alt = altitude/1e3 #convert to km
    Input.g_lat = math.degrees(latitude)
    Input.g_long = math.degrees(lon)
    Input.lst = lst
    Input.f107A = 180 #I believe this is a "nominal" value
    Input.f107 = 180
    Input.ap = 10

    gtd7d(Input, flags, Output)

    density = Output.d[5] #total mass density (grams/m^3, m^3 b/c switches[0] = 1)

    lst_rad = (lst/24) * np.radians(360) #radians

    return density, latitude, lst_rad
```

In [47]:
```
# **Setup Dynamical Model/Equations (Position & Velocity Forecast Model)

#Force equations: two body, J_2, & J_3
x, y, z, J_2, J_3, r_earth, mu, r,  x_dot, y_dot, z_dot, density = \
    sym.symbols('x y z J_2 J_3 r_earth mu r,  x_dot, y_dot, z_dot, density')

U_string = 'mu/r * ( 1 - J_2*(r_earth/r)**2 * (3/2 * (z/r)**2 - 1/2) )'
            #( 1 - J_2*(r_earth/r)**2 * (3/2 * (z/r)**2 - 1/2) ' #J_2 portion
            #'- J_3 * (r_earth/r)**3 * ( 5/2 * (z/r)**3 - 3/2*(z/r) ) )') #J_3 portion
U = sym.sympify(U_string)
U = U.subs(r, sym.sqrt(x**2+y**2+z**2))
```

```
U_diffeq_x = U.diff(x)
U_diffeq_y = U.diff(y)
U_diffeq_z = U.diff(z)


x_acc = U_diffeq_x.subs([(r_earth, r_earth_const), (mu, mu_earth), \
                              (J_2, J_2_const)])
y_acc = U_diffeq_y.subs([(r_earth, r_earth_const), (mu, mu_earth), \
                              (J_2, J_2_const)])
z_acc = U_diffeq_z.subs([(r_earth, r_earth_const), (mu, mu_earth), \
                              (J_2, J_2_const)])



#Add drag to J_2 force equations
C_D, A, m, density, theta_dot, val, val_dot = \
    sym.symbols('C_D A m density theta_dot val, val_dot')

drag_str = ('-(1/2)*C_D*(A/m)*density*'
                'sqrt((x_dot+theta_dot*y)**2 + (y_dot-theta_dot*x)**2 +'
                'z_dot**2)*(val_dot+theta_dot*val)')
drag_symp = sym.sympify(drag_str)

drag_symp = drag_symp.subs([(A, A_const), (m, m_const), (C_D, C_D_est),\
                        (theta_dot, theta_dot_const)])


x_drag_symp = drag_symp.subs([(r, sym.sqrt(x**2+y**2+z**2)), (val, y), (val_dot, x_dot)
x_acc = x_acc + x_drag_symp

y_drag_symp = drag_symp.subs([(r, sym.sqrt(x**2+y**2+z**2)), (val, x), (val_dot, y_dot)
y_acc = y_acc + y_drag_symp

z_drag_symp = drag_symp.subs([(r, sym.sqrt(x**2+y**2+z**2)), (val, z), (val_dot, z_dot)
z_acc = z_acc + z_drag_symp


#print(z_acc)

x_sol_fcn = lambdify((x, y, z, x_dot, y_dot, z_dot, density), x_acc)
y_sol_fcn = lambdify((x, y, z, x_dot, y_dot, z_dot, density), y_acc)
z_sol_fcn = lambdify((x, y, z, x_dot, y_dot, z_dot, density), z_acc)
```

In [48]:
```
#initializations
t_init =  0
t_final = time_span #seconds
t_step = time_step
```

```python
time_array = np.arange(t_init, t_final+t_step, t_step)

#set the initial values for the propogator:
#reference trajectory
y0 = np.array([r_eci, v_eci])
y0 = y0.flatten()

density_array = np.zeros((len(time_array)))
lat_lst_array = np.zeros((len(time_array), 2))

integrator = ode(orbitpropogator_noSTM)
integrator.set_integrator('dopri5', nsteps=1e6, rtol=3e-14, atol=1e-16)
integrator.set_initial_value(y0, t_init)

result = []
result.append(np.insert(y0, 0, t_init))
X_vector = y0
t = t_init
counter = 0

while integrator.successful() and integrator.t < t_final:
    density, lat, lst = calc_MSIS_density(t, X_vector)
    integrator.set_f_params(density)
    integrator.integrate(integrator.t + t_step)
    X_vector = integrator.y
    t = integrator.t
    density_array[counter] = density
    lat_lst_array[counter] = [lat, lst]
    result.append(np.insert(X_vector, 0, t))
    counter = counter + 1


result = np.array(result)

integrator_times = result[:, 0]
X = result[:, [1, 2, 3]]
V = result[:, [4, 5, 6]]
truth_pos_vel = result[:, [1, 2, 3, 4, 5, 6]]
pos_init = X[0]
vel_init = V[0]

#print(day_of_year, t, alt/1000, math.degrees(lat), math.degrees(lon), lst)
```

In [49]:
```python
0.00085738173421523673, -93.325445384706796
```

Out[49]:

$$(0.0008573817342152367, \quad -93.3254453847068)$$

In [50]: #generate measurements

```
if (meas_type == 1) or (meas_type == 3):


    x_s, y_s, z_s, x_sf, y_sf, z_sf, theta, theta_dot, t, x_dot, y_dot, z_dot = \
        sym.symbols('x_s, y_s, z_s, x_sf, y_sf, z_sf, theta, theta_dot, t, x_dot, y_dot

    #define symbolic rho equation
    rho = ('sqrt((x - x_s)**2 + (y - y_s)**2 + (z - z_s)**2)')
    rho = sym.sympify(rho)
    #sub rotation equation of ecef for eci
    rho = rho.subs(x_s, x_sf*sym.cos(omega_const*t) - y_sf*sym.sin(omega_const*t))
    rho = rho.subs(y_s, x_sf*sym.sin(omega_const*t) + y_sf*sym.cos(omega_const*t))
    rho = rho.subs(z_s, z_sf)

    #define symbolic rho dot equation
    rho_dot = ('(x*x_dot + y*y_dot + z*z_dot - (x_dot*x_s+y_dot*y_s)*cos(theta) + \
               theta_dot*(x*x_s + y*y_s)*sin(theta) + (x_dot*y_s - y_dot*x_s)*sin(theta
               theta_dot*(x*y_s - y*x_s)*cos(theta) - z_dot*z_s)/ rho')
    rho_dot = sym.sympify(rho_dot)
    #execute substitutions for rho_dot
    rho_dot = rho_dot.subs(x_s, x_sf)
    rho_dot = rho_dot.subs(y_s, y_sf)
    rho_dot = rho_dot.subs(z_s, z_sf)
    rho_dot = rho_dot.subs('rho', rho)
    rho_dot = rho_dot.subs(theta, omega_const*t)
    rho_dot = rho_dot.subs(theta_dot, omega_const)

    rho_fcn = lambdify(((x, y, z, x_sf, y_sf, z_sf, t)), rho)
    rho_dot_fcn = lambdify(((x, y, z, x_dot, y_dot, z_dot, x_sf, y_sf, z_sf, t)), rho_d


if (meas_type == 2) or (meas_type == 3):

    #x_sf, etc. is the sensor pos in ecef
    #x, y, z is the satellite eci
    x_s, y_s, z_s, x_sf, y_sf, z_sf, theta, x, y, z, t = \
        sym.symbols('x_s, y_s, z_s, x_sf, y_sf, z_sf, theta, x, y, z, t')
    x_L, y_L, z_L, X_L_norm, x_range, y_range, z_range, lon, lat, \
        x_sat_ecef, y_sat_ecef, z_sat_ecef, sen_ecef_norm, omega  = \
        sym.symbols('x_L, y_L, z_L, X_L_norm, x_range, y_range, z_range, lon, lat, \
        x_sat_ecef, y_sat_ecef, z_sat_ecef, sen_ecef_norm, omega')


    #define symbolic rho equation
    azimuth = ('atan2(x_L, y_L)') #step 4
```

```
    azimuth = sym.sympify(azimuth)

    elevation = ('asin(z_L/X_L_norm)') #step 4
    elevation = sym.sympify(elevation)
    elevation = elevation.subs(X_L_norm, sym.sqrt(x_L**2 + y_L**2 + z_L**2))

    #step 3
    azimuth = azimuth.subs([(x_L, -x_range*sym.sin(lon) + y_range*sym.cos(lon)), \
            (y_L, -x_range*sym.sin(lat)*sym.cos(lon) - y_range*sym.sin(lat)*sym.sin(lon
    elevation = elevation.subs([(x_L, -x_range*sym.sin(lon) + y_range*sym.cos(lon)), \
            (y_L, -x_range*sym.sin(lat)*sym.cos(lon) - y_range*sym.sin(lat)*sym.sin(lon
            (z_L, x_range*sym.cos(lat)*sym.cos(lon) + y_range*sym.cos(lat)*sym.sin(lon)

    #step 2
    azimuth = azimuth.subs([(x_range, x_sat_ecef - x_sf), (y_range, y_sat_ecef - y_sf),
            (z_range, z_sat_ecef - z_sf), (lat, sym.asin(z_sf/sen_ecef_norm)), (lon, sy
    elevation = elevation.subs([(x_range, x_sat_ecef - x_sf), (y_range, y_sat_ecef - y_
            (z_range, z_sat_ecef - z_sf), (lat, sym.asin(z_sf/sen_ecef_norm)), (lon, sy

    #step 1
    azimuth = azimuth.subs([(x_sat_ecef, x*sym.cos(theta) + y*sym.sin(theta)), \
                        (y_sat_ecef, -x*sym.sin(theta) + y*sym.cos(theta)), (z_sat_ecef
                        (sen_ecef_norm, sym.sqrt(x_sf**2 + y_sf**2 + z_sf**2))])
    elevation = elevation.subs([(x_sat_ecef, x*sym.cos(theta) + y*sym.sin(theta)), \
                        (y_sat_ecef, -x*sym.sin(theta) + y*sym.cos(theta)), (z_sat_ecef
                        (sen_ecef_norm, sym.sqrt(x_sf**2 + y_sf**2 + z_sf**2))])

    azimuth = azimuth.subs([(theta, omega*t), (omega, omega_const)])
    elevation = elevation.subs([(theta, omega*t), (omega, omega_const)])

    azimuth_fcn = lambdify(((x, y, z, x_sf, y_sf, z_sf, t)), azimuth)
    elevation_fcn = lambdify(((x, y, z, x_sf, y_sf, z_sf, t)), elevation)
```

In [51]:
```
#calculate measurements for each station
#determine if visible and add to measurement array
measurement_array = []
object_eci_pos_vel = []
lat_lst_array_final = []
density_array_final = []

meas3 = 0

for s in range(len(integrator_times)):


    object_eci = np.array([X[s]])
```

```
time = integrator_times[s] #time since epoch in seconds


elevation1 = filter_functions.calculate_elevation(r_ecef_dss34, object_eci, time, o
elevation2 = filter_functions.calculate_elevation(r_ecef_dss65, object_eci, time, o
elevation3 = filter_functions.calculate_elevation(r_ecef_diego, object_eci, time, o



if((elevation1 < 90) & (elevation1 > 10)):
#if((s > 10) & (s < 20)):
    #print(integrator_times[s], elevation)
    #print('station 34')

    #calculate range and range rate
    if meas_type == 1:
        meas1 = rho_fcn(*X[s], *r_ecef_dss34, integrator_times[s])
        meas2 = rho_dot_fcn(*X[s], *V[s], *r_ecef_dss34, integrator_times[s])
    #calculate azimuth & elevation
    elif (meas_type == 2) or (meas_type == 3):
        meas1 = azimuth_fcn(*X[s], *r_ecef_dss34, integrator_times[s])
        meas2 = elevation_fcn(*X[s], *r_ecef_dss34, integrator_times[s])
        if meas1 < 0:
            meas1 = meas1 + 2*math.pi
    if meas_type == 3:
        meas3 = rho_fcn(*X[s], *r_ecef_dss34, integrator_times[s])

    measurement_array.append([integrator_times[s], 1, meas1, meas2, meas3])
    object_eci_pos_vel.append(*[truth_pos_vel[s]])
    lat_lst_array_final.append(*[lat_lst_array[s]])
    density_array_final.append(density_array[s])


elif((elevation2 < 90) & (elevation2 > 10)):
#if(s < 10):
    #print('station 65')
    #print(*X[s], *r_ecef_dss65, integrator_times[s])

    #calculate range and range rate
    if meas_type == 1:
        meas1 = rho_fcn(*X[s], *r_ecef_dss65, integrator_times[s])
        meas2 = rho_dot_fcn(*X[s], *V[s], *r_ecef_dss65, integrator_times[s])
    #calculate azimuth & elevation
    elif (meas_type == 2) or (meas_type == 3):
        meas1 = azimuth_fcn(*X[s], *r_ecef_dss65, integrator_times[s])
        meas2 = elevation_fcn(*X[s], *r_ecef_dss65, integrator_times[s])
        if meas1 < 0:
            meas1 = meas1 + 2*math.pi
```

```
            if meas_type == 3:
                meas3 = rho_fcn(*X[s], *r_ecef_dss65, integrator_times[s])


            #add to array of observations
            measurement_array.append([integrator_times[s], 2, meas1, meas2, meas3])
            object_eci_pos_vel.append(*[truth_pos_vel[s]])
            lat_lst_array_final.append(*[lat_lst_array[s]])
            density_array_final.append(density_array[s])


        else:
            #print('amosn station')
            #print(*X[s], *r_ecef_amos, integrator_times[s])

            #calculate range and range rate
            if meas_type == 1:
                meas1 = rho_fcn(*X[s], *r_ecef_diego, integrator_times[s])
                meas2 = rho_dot_fcn(*X[s], *V[s], *r_ecef_diego, integrator_times[s])
            #calculate azimuth & elevation
            elif (meas_type == 2) or (meas_type == 3):
                meas1 = azimuth_fcn(*X[s], *r_ecef_diego, integrator_times[s])
                meas2 = elevation_fcn(*X[s], *r_ecef_diego, integrator_times[s])
                if meas1 < 0:
                    meas1 = meas1 + 2*math.pi
            if meas_type == 3:
                meas3 = rho_fcn(*X[s], *r_ecef_diego, integrator_times[s])


            #add to array of observations
            measurement_array.append([integrator_times[s], 4, meas1, meas2, meas3])
            object_eci_pos_vel.append(*[truth_pos_vel[s]])
            lat_lst_array_final.append(*[lat_lst_array[s]])
            density_array_final.append(density_array[s])




    measurement_array = np.array(measurement_array)
    object_eci_pos_vel = np.array(object_eci_pos_vel)
    lat_lst_array_final = np.array(lat_lst_array_final)
    density_array_final = np.array(density_array_final)
```

In [52]:
```
indices = np.where(measurement_array[:, 1] == 1)[0]
print(indices)
indices = np.where(measurement_array[:, 1] == 2)[0]
print(indices)
indices = np.where(measurement_array[:, 1] == 3)[0]
print(indices)
```

```
indices = np.where(measurement_array[:, 1] == 4)[0]
print(indices)
```

```
[305 306 307 353 354 355 356 402 403 404 451 452 453 499 500 501 502]
[284 285 286 332 333 334 381 382 383 429 430 431]
[]
[  0   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35
  36  37  38  39  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  91  92  93  94  95  96  97  98  99 100 101 102 103 104 105 106 107
 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125
 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143
 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161
 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179
 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197
 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215
 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233
 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251
 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269
 270 271 272 273 274 275 276 277 278 279 280 281 282 283 287 288 289 290
 291 292 293 294 295 296 297 298 299 300 301 302 303 304 308 309 310 311
 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329
 330 331 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350
 351 352 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372
 373 374 375 376 377 378 379 380 384 385 386 387 388 389 390 391 392 393
 394 395 396 397 398 399 400 401 405 406 407 408 409 410 411 412 413 414
 415 416 417 418 419 420 421 422 423 424 425 426 427 428 432 433 434 435
 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 454 455 456
 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474
 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492
 493 494 495 496 497 498 503 504 505 506 507 508 509 510 511 512 513 514
 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532
 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550
 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568
 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586
 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604
 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622
 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640
 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658
 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676
 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694
 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712
 713 714 715 716 717 718 719 720]
```

In [53]:
```
#add noise to measurements
```

```
print(np.shape(measurement_array))

#get initial noise values between -1 and 1
meas1_noise = np.random.randn(len(measurement_array))
meas2_noise = np.random.randn(len(measurement_array))

#meas1_stan_dev & meas2_stan_dev defined at the top of code w/ other tuning params

meas1_noise = meas1_noise * meas1_stan_dev
meas2_noise = meas2_noise * meas2_stan_dev

measurement_array[:, 2] = measurement_array[:, 2] + meas1_noise
measurement_array[:, 3] = measurement_array[:, 3] + meas2_noise

if meas_type == 3:
    meas3_noise = np.random.randn(len(measurement_array))
    meas3_noise = meas3_noise * meas3_stan_dev
    measurement_array[:, 4] = measurement_array[:, 4] + meas2_noise
```

```
(721, 5)
```

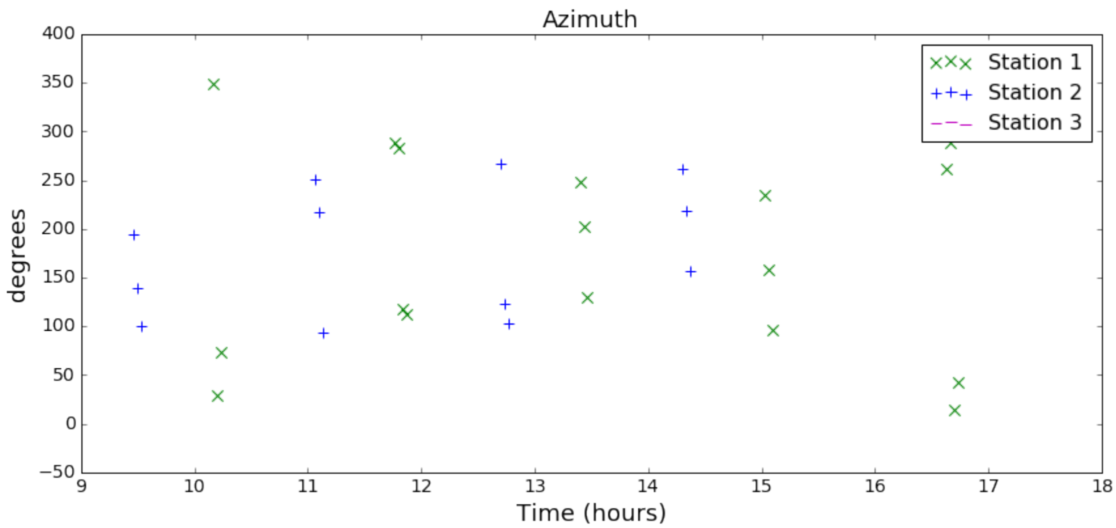
In [54]:
```
# write python dict to a file
#measurement_array, truth_pos_vel, J_3_array
mydict = {'measurement_array': measurement_array, 'truth_pos_vel': object_eci_pos_vel,
                                                                              'lat_lst_array': l

if meas_type == 1:
    output = open('Data Files/meas_range_rangeRate.pkl', 'wb')
elif meas_type == 2:
    output = open('Data Files/meas_az_el.pkl', 'wb')
elif meas_type == 3:
    output = open('Data Files/meas_az_el_range_complexDensity.pkl', 'wb')

pickle.dump(mydict, output, protocol=2)
output.close()
```

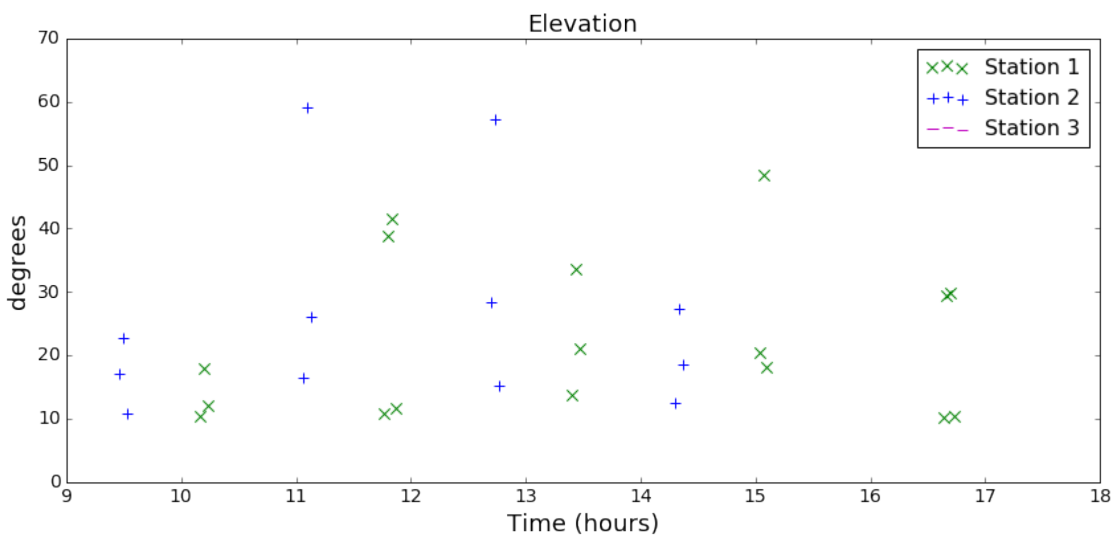
0.1 Analyze Measurements:

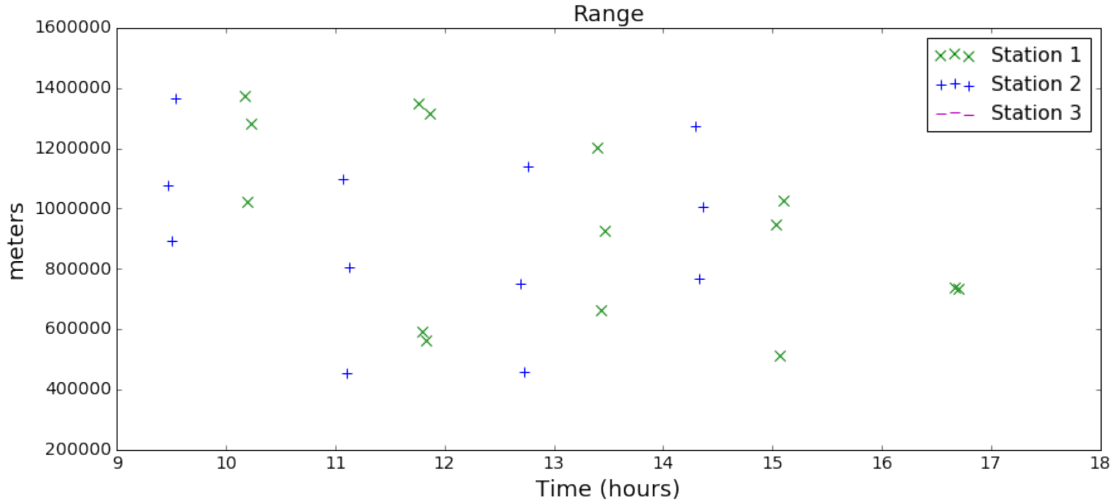
In [55]:
```
legend_names = ['Station 1', 'Station 2', 'Station 3']

if meas_type == 1:

    times = measurement_array[:, 0]/(60*60)

    indices_34 = np.where(measurement_array[:, 1] == 1)[0]
    indices_65 = np.where(measurement_array[:, 1] == 2)[0]
    indices_13 = np.where(measurement_array[:, 1] == 3)[0]
```

```
    fig = plt.figure()
    plt.scatter(times[indices_34], measurement_array[indices_34, 2], s=70, c='g', marke
    plt.scatter(times[indices_65], measurement_array[indices_65, 2], s=70, c='b', marke
    plt.scatter(times[indices_13], measurement_array[indices_13, 2], s=70, c='m', marke
    plt.ylabel('meters', fontsize=18)
    plt.xlabel('Time (hours)', fontsize=18)
    plt.title('Range', fontsize=18)
    plt.legend(legend_names, fontsize=16)
    #plt.ylim([-y_range,y_range])
    #plt.xlim([0,time_hrs[-1]])
    plt.show()
    #fig.savefig('Images/range_meas_basic.png')


    fig = plt.figure()
    plt.scatter(times[indices_34], measurement_array[indices_34, 3], s=70, c='g', marke
    plt.scatter(times[indices_65], measurement_array[indices_65, 3], s=70, c='b', marke
    plt.scatter(times[indices_13], measurement_array[indices_13, 3], s=70, c='m', marke
    plt.ylabel('meters/sec', fontsize=18)
    plt.xlabel('Time (hours)', fontsize=18)
    plt.title('Range Rate', fontsize=18)
    plt.legend(legend_names, fontsize=16)
    #plt.ylim([-y_range,y_range])
    #plt.xlim([0,time_hrs[-1]])
    plt.show()
    #fig.savefig('Images/range_rate_meas_basic.png')


elif (meas_type == 2) or (meas_type == 3):

    times = measurement_array[:, 0]/(60*60)

    indices_34 = np.where(measurement_array[:, 1] == 1)[0]
    indices_65 = np.where(measurement_array[:, 1] == 2)[0]
    indices_13 = np.where(measurement_array[:, 1] == 3)[0]


    fig = plt.figure()
    plt.scatter(times[indices_34], np.degrees(measurement_array[indices_34, 2]), s=70,
    plt.scatter(times[indices_65], np.degrees(measurement_array[indices_65, 2]), s=70,
    plt.scatter(times[indices_13], np.degrees(measurement_array[indices_13, 2]), s=70,
    plt.ylabel('degrees', fontsize=18)
    plt.xlabel('Time (hours)', fontsize=18)
    plt.title('Azimuth', fontsize=18)
    plt.legend(legend_names, fontsize=16)
    #plt.ylim([-y_range,y_range])
    #plt.xlim([0,time_hrs[-1]])
```

```
    plt.show()
    #fig.savefig('Images/az_meas.png')


    fig = plt.figure()
    plt.scatter(times[indices_34], np.degrees(measurement_array[indices_34, 3]), s=70,
    plt.scatter(times[indices_65], np.degrees(measurement_array[indices_65, 3]), s=70,
    plt.scatter(times[indices_13], np.degrees(measurement_array[indices_13, 3]), s=70,
    plt.ylabel('degrees', fontsize=18)
    plt.xlabel('Time (hours)', fontsize=18)
    plt.title('Elevation', fontsize=18)
    plt.legend(legend_names, fontsize=16)
    #plt.ylim([-y_range,y_range])
    #plt.xlim([0,time_hrs[-1]])
    plt.show()
    #fig.savefig('Images/el_meas_basic.png')

if meas_type == 3:

    times = measurement_array[:, 0]/(60*60)

    indices_34 = np.where(measurement_array[:, 1] == 1)[0]
    indices_65 = np.where(measurement_array[:, 1] == 2)[0]
    indices_13 = np.where(measurement_array[:, 1] == 3)[0]


    fig = plt.figure()
    plt.scatter(times[indices_34], measurement_array[indices_34, 4], s=70, c='g', marke
    plt.scatter(times[indices_65], measurement_array[indices_65, 4], s=70, c='b', marke
    plt.scatter(times[indices_13], measurement_array[indices_13, 4], s=70, c='m', marke
    plt.ylabel('meters', fontsize=18)
    plt.xlabel('Time (hours)', fontsize=18)
    plt.title('Range', fontsize=18)
    plt.legend(legend_names, fontsize=16)
    #plt.ylim([-y_range,y_range])
    #plt.xlim([0,time_hrs[-1]])
    plt.show()
    #fig.savefig('Images/range_meas_basic.png')
```


Azimuth
degrees
Time (hours)
Station 1
Station 2
Station 3
400
350
300
250
200
150
100
50
0
−50
9
10
11
12
13
14
15
16
17
18


Elevation
degrees
Time (hours)
Station 1
Station 2
Station 3
70
60
50
40
30
20
10
0
9
10
11
12
13
14
15
16
17
18



In [56]:
```
density_array = np.zeros(len(object_eci_pos_vel))
times = measurement_array[:, 0]/(60*60*24)


for index in range(len(object_eci_pos_vel)):


    t = measurement_array[index, 0]
    X_vector = object_eci_pos_vel[index, :]


    density = calc_MSIS_density(t, X_vector)
    density_array[index] = density




y_range_min = .5e-12
y_range_max = .1e-11

fig = plt.figure()
plt.scatter(times, density_array, s=70, c='m', marker='x')
plt.ylabel('Atmospheric Density (kg/m^3)', fontsize=18)
plt.xlabel('time (days)', fontsize=18)
plt.title('MSIS Atmosphric Density at Measurement Times', fontsize=18)
#legend_names = ['Simple', 'Complex']
#plt.legend(legend_names, fontsize=16)
plt.ylim([y_range_min,y_range_max])
plt.show()
fig.savefig('density_dif_sampling.png')
```

```
---------------------------------------------------------------------------

ValueError                                Traceback (most recent call last)

<ipython-input-56-2ca2f1b614a0> in <module>()
 13
 14     density = calc_MSIS_density(t, X_vector)
---> 15     density_array[index] = density
 16
 17


ValueError: setting an array element with a sequence.
```

In [ ]:
```
# write python dict to a file
#times, xyz pos, xyz vel
mydict = {'truth_xyz': result}
if meas_type == 1:
    output = open('Data Files/truth_range_rangeRate.pkl', 'wb')
elif meas_type == 2:
    output = open('Data Files/truth_az_el.pkl', 'wb')

pickle.dump(mydict, output)
output.close()
```

In [ ]:
```
np.shape(lat_lst_array_final)
```

In [ ]:

In [ ]: