Table of Contents

HW4

```
clc;clear;close all;
```

```
% Date = October 5, 2020
```

Define necessary variables

```
c   = 2.99792458e8;    % GPS acceptd speed of light, m/s
```

1) Determine the name of the full broadcast ephemeris file (Rinex V2) for September 1, 2020.

fname = "brdc2450.20n";

```
fname = "nist2450.20n"; %Either the broadcast data from NIST or brdc
 work.
```

2) Use the function read_clean_GPSbroadcast.m (or a similar function you find elsewhere or write

yourself) to load the ephemeris data into a numerical array.

```
seconds_in_day = 60*60*24;
tow = seconds_in_day * 2; % Because we are on Tuesday

[gps_ephem,ionoparams] = read_clean_GPSbroadcast(fname,true);
```

3) Write a function broadcast_eph2pos to compute the position of a GPS satellite based on the ephemeris data, for

a specified set of times.

```
t = [0:1:24*60*2]*30+172800;  %Time of week in seconds with 30 sec
 spacing
% t = [0:1:24*60]*60+172800;  %Time of week in seconds with 30 sec
 spacing
WN = 2121*ones(size(t)); % WN = 73*ones(size(t));
T_in = [WN;t].';            %[nx2]
gpsposcheck = zeros(32,3);

PRN = gps_ephem(:,1); % Grab all the prn values from the ephemeris
 file
num_sat = length(PRN); % Obtain the number of satellites we're
 interested in

% Grab the position of all of the satellites in the ephemeris file
for kk = 1:num_sat
    % Use our broadcast_eph2pos file to grab the position of the
 satellite
    [health,pos] = broadcast_eph2pos(gps_ephem,T_in,PRN(kk));
    POS_ecef(:,:,kk) = pos/1000;     %n x 3 x num_sat

    % This is to compare to the gpspos text file!
    if kk <= 30
        gpsposcheck(kk,:) = POS_ecef(1,:,kk);
    end
end
```

4) Choose one or two satellites (PRN’s) to study in detail. Using the broadcast2pos function (or similar code

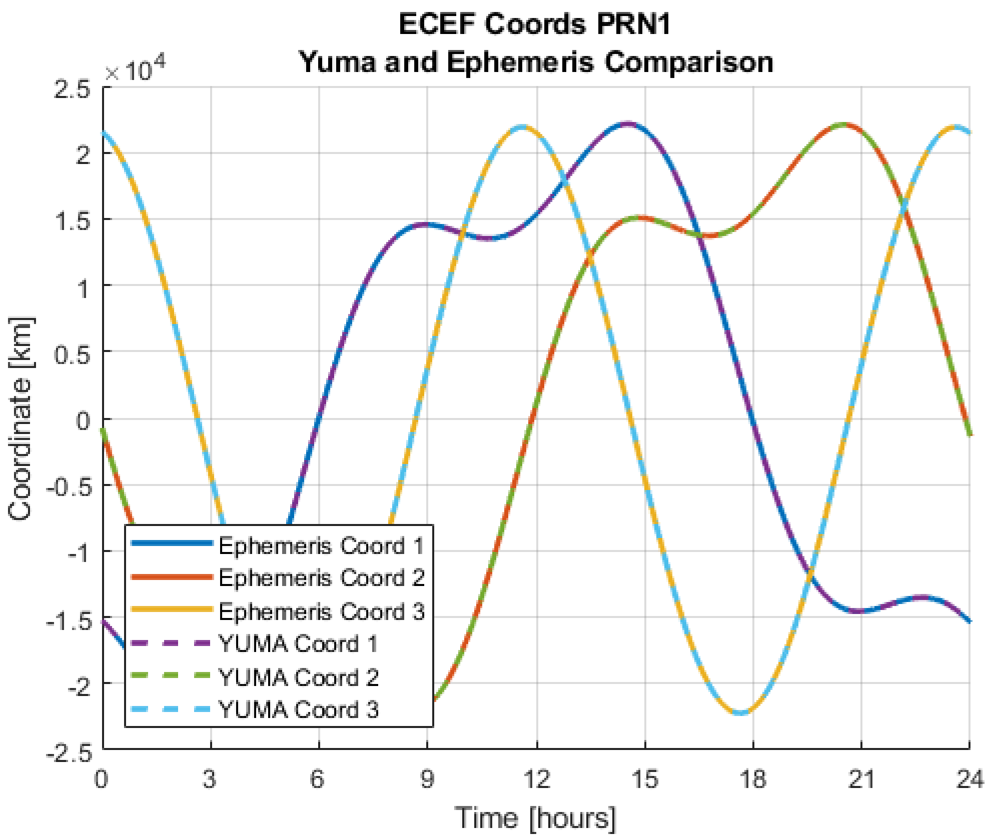
you wrote yourself) from HW3, plot the ECEF coordinates computed based on the almanac for these satellites at an interval of 30 seconds over the entire day. On the x-axis show the time in hours of the day (0-24 hours). On the same graph, plot the ECEF coordinates computed using your new broadcast_eph2pos function for the same times. Compare and discuss the results, using a plot of the differences between them, if that is helpful.

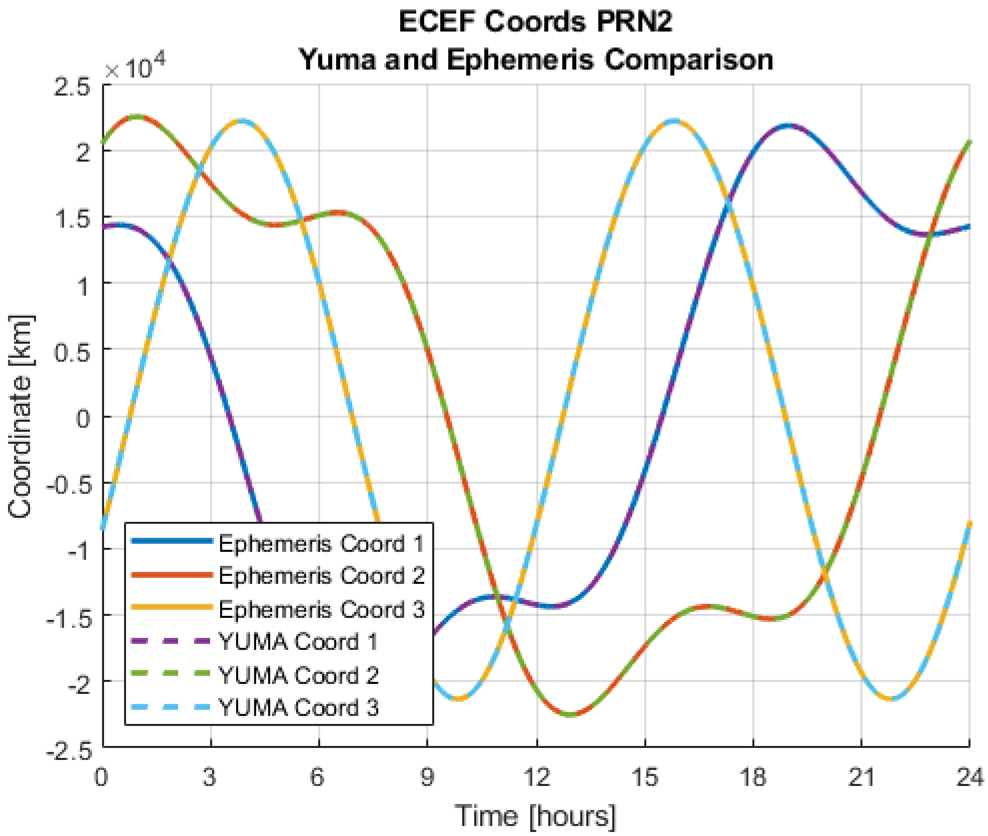
```
prn_sat1 = 1; % I picked PRNs 1 and 2
```

```
prn_sat2 = 2;

% First we filter out the PRNs we want from our ephemeris data
ephem_PRN1 = find(PRN==prn_sat1);
ephem_PRN2 = find(PRN==prn_sat2);

ephem_PRN1_pos = POS_ecef(:,:,ephem_PRN1); % Now we can plot the
 ephemeris positions for satellites with PRN1
ephem_PRN2_pos = POS_ecef(:,:,ephem_PRN2); % Now we can plot the
 ephemeris positions for satellites with PRN2

% Now we grab the positions using YUMA file
[alm,alm_cellarray] = read_GPSyuma('Data/YUMA245.alm',2);
yuma_PRN = alm(:,1);
yuma_num_sat = length(PRN);
for kk = 1:num_sat
    [yuma_health,yuma_pos] = broadcast2pos(alm,T_in,PRN(kk));
    yumaPOS_ecef(:,:,kk) = yuma_pos/1000;     %n x 3 x num_sat
end

yuma_PRN1 = find(yuma_PRN==prn_sat1);
yuma_PRN2 = find(yuma_PRN==prn_sat2);

yuma_PRN1_pos = yumaPOS_ecef(:,:,yuma_PRN1); % Now we can plot the
 yuma positions for satellites with PRN1
yuma_PRN2_pos = yumaPOS_ecef(:,:,yuma_PRN2); % Now we can plot the
 yuma positions for satellites with PRN2

% Now we do our plots... let's just play with the first PRN1 position
time = [0:1:24*60*2]*30/3600;  %Time of week in seconds with 30 sec
 spacing
time = time';

figure; hold on; grid on
plot(time, squeeze(ephem_PRN1_pos(:,1,1)), 'LineWidth', 2) % Plot 1st
 ecef coord
plot(time, squeeze(ephem_PRN1_pos(:,2,1)), 'LineWidth', 2) % Plot 2nd
 ecef coord
plot(time, squeeze(ephem_PRN1_pos(:,3,1)), 'LineWidth', 2) % Plot 3rd
 ecef coord
plot(time, yuma_PRN1_pos(:,1), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 1st ecef coord
plot(time, yuma_PRN1_pos(:,2), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 2nd ecef coord
plot(time, yuma_PRN1_pos(:,3), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 3rd ecef coord
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Coordinate [km]')
legend({'Ephemeris Coord 1', 'Ephemeris Coord 2', 'Ephemeris
 Coord 3', 'YUMA Coord 1', 'YUMA Coord 2', 'YUMA Coord
 3'}, 'Location','southwest')
title({['ECEF Coords PRN1'], ['Yuma and Ephemeris Comparison']})
```

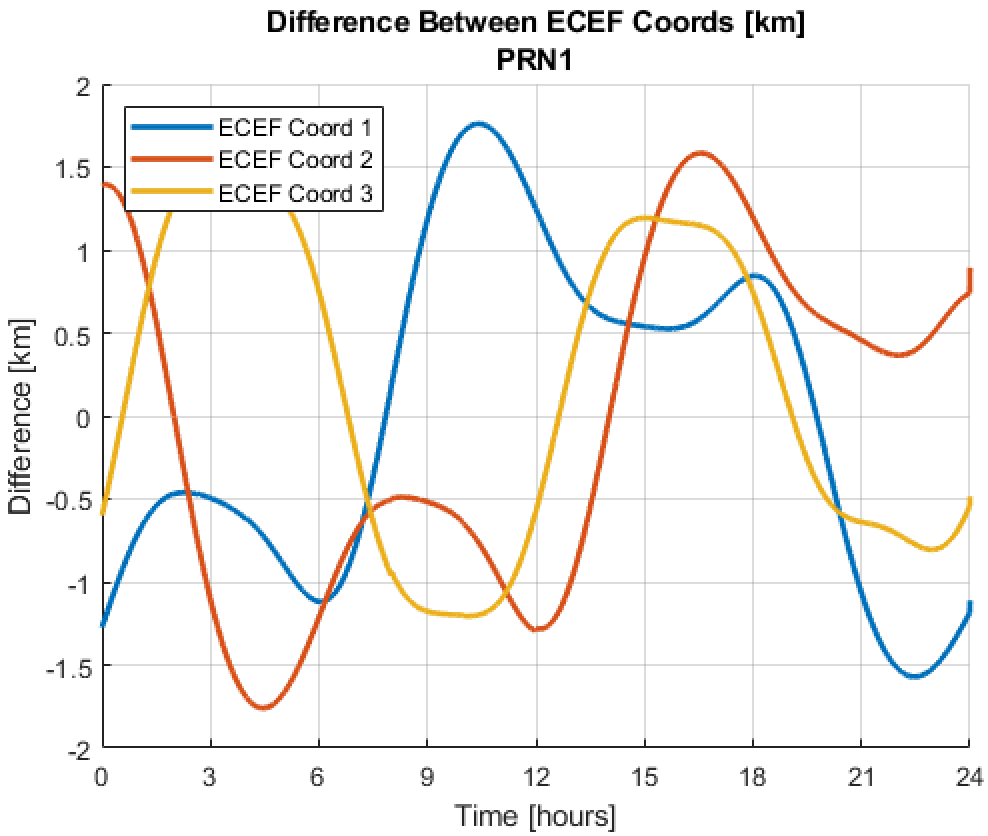
```
figure; hold on; grid on
plot(time, squeeze(ephem_PRN2_pos(:,1,1)), 'LineWidth', 2) % Plot 1st
 ecef coord
plot(time, squeeze(ephem_PRN2_pos(:,2,1)), 'LineWidth', 2) % Plot 2nd
 ecef coord
plot(time, squeeze(ephem_PRN2_pos(:,3,1)), 'LineWidth', 2) % Plot 3rd
 ecef coord
plot(time, yuma_PRN2_pos(:,1), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 1st ecef coord
plot(time, yuma_PRN2_pos(:,2), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 2nd ecef coord
plot(time, yuma_PRN2_pos(:,3), 'Linestyle', '--', 'LineWidth', 2) %
 Plot 3rd ecef coord
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Coordinate [km]')
legend({'Ephemeris Coord 1', 'Ephemeris Coord 2', 'Ephemeris
 Coord 3', 'YUMA Coord 1', 'YUMA Coord 2', 'YUMA Coord
 3'}, 'Location','southwest')
title({['ECEF Coords PRN2'], ['Yuma and Ephemeris Comparison']})

% Now we do diff plots of PRN1 because that maeks more sense to me
diff1 = reshape(ephem_PRN1_pos(:,1,:) - yuma_PRN1_pos(:,1),
 [length(t), length(ephem_PRN1)]);
diff2 = reshape(ephem_PRN1_pos(:,2,:) - yuma_PRN1_pos(:,2),
 [length(t), length(ephem_PRN1)]);
diff3 = reshape(ephem_PRN1_pos(:,3,:) - yuma_PRN1_pos(:,3),
 [length(t), length(ephem_PRN1)]);

f=figure; hold on; grid on
plot(time, diff1(:,1), 'LineWidth', 2)
plot(time, diff2(:,1), 'LineWidth', 2)
plot(time, diff3(:,1), 'LineWidth', 2)
title({['Difference Between ECEF Coords [km]'],['PRN1']})
xlabel('Time [hours]')
ylabel('Difference [km]')
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Difference [km]')
legend({'ECEF Coord 1', 'ECEF Coord 2', 'ECEF Coord
 3'},'Location','northwest')

% Now we do diff plots of PRN2
diff1 = reshape(ephem_PRN2_pos(:,1,:) - yuma_PRN2_pos(:,1),
 [length(t), length(ephem_PRN2)]);
diff2 = reshape(ephem_PRN2_pos(:,2,:) - yuma_PRN2_pos(:,2),
 [length(t), length(ephem_PRN2)]);
diff3 = reshape(ephem_PRN2_pos(:,3,:) - yuma_PRN2_pos(:,3),
 [length(t), length(ephem_PRN2)]);

f=figure; hold on; grid on
```

```
plot(time, diff1(:,1), 'LineWidth', 2)
plot(time, diff2(:,1), 'LineWidth', 2)
plot(time, diff3(:,1), 'LineWidth', 2)
title({['Difference Between ECEF Coords [km]'],['PRN2']})
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Difference [km]')
legend({'ECEF Coord 1', 'ECEF Coord 2', 'ECEF Coord
 3'},'Location','northeast')
```

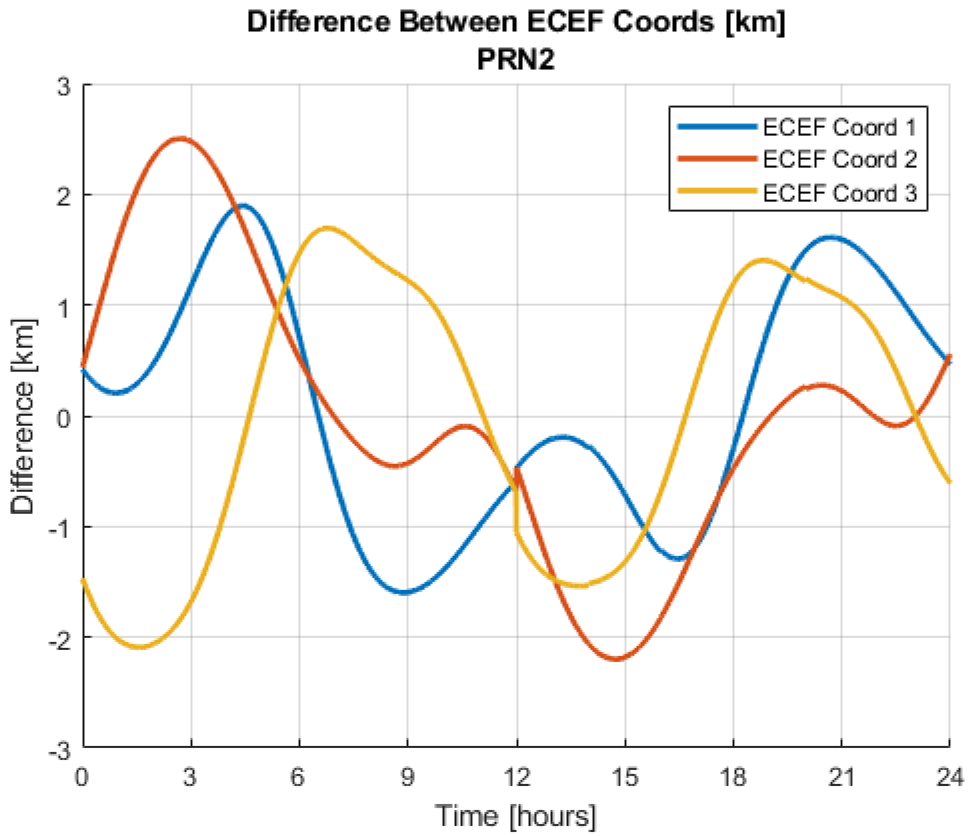




ECEF Coords PRN2
Yuma and Ephemeris Comparison
$\times 10^4$
Coordinate [km]
Time [hours]
Ephemeris Coord 1
Ephemeris Coord 2
Ephemeris Coord 3
YUMA Coord 1
YUMA Coord 2
YUMA Coord 3



Difference Between ECEF Coords [km]
PRN1
Difference [km]
Time [hours]
ECEF Coord 1
ECEF Coord 2
ECEF Coord 3

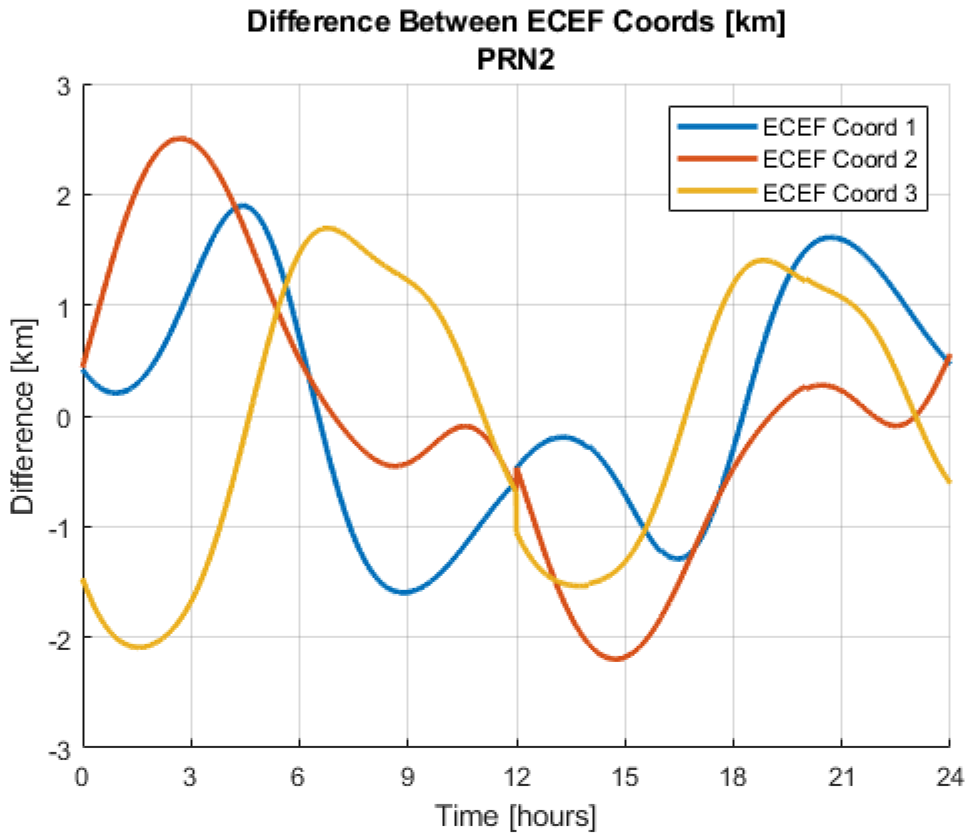


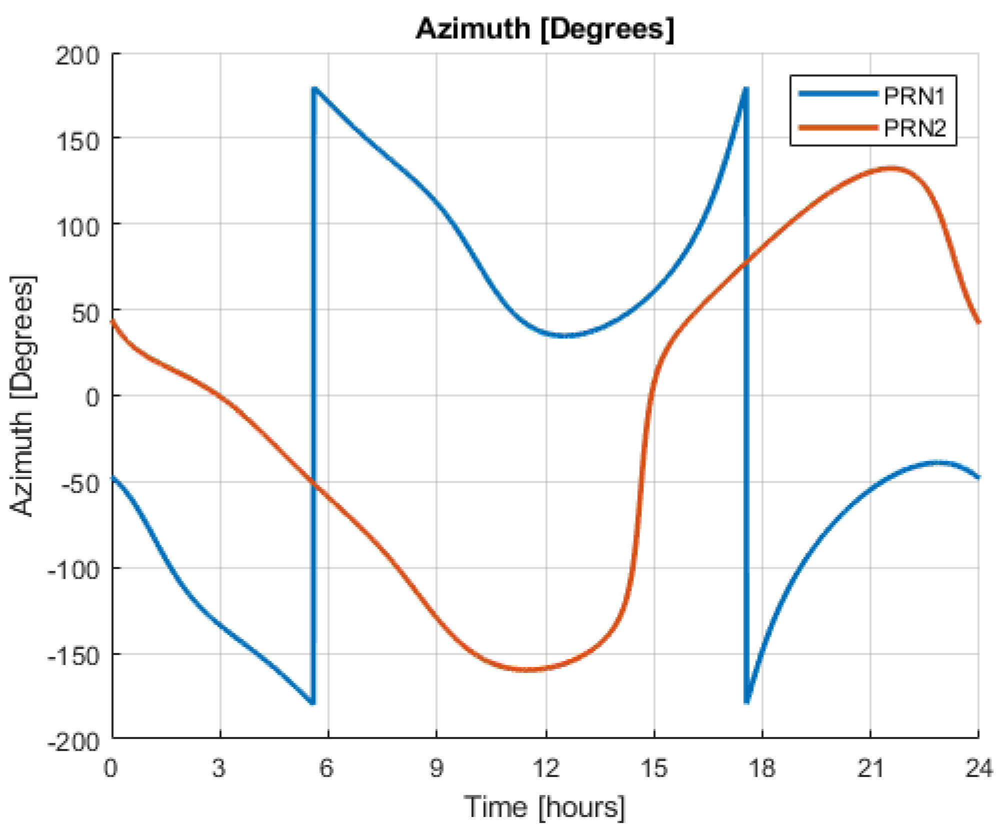
5) Using the compute_azelrange function you wrote in HW3, find the range, azimuth, and elevation from

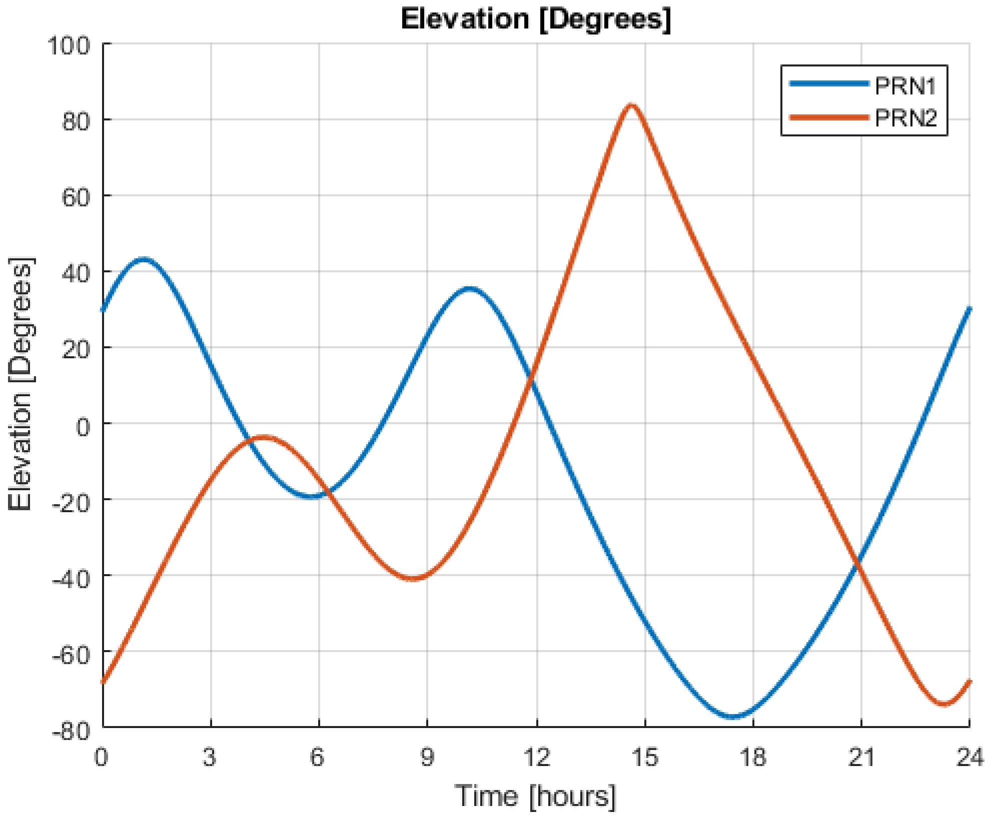
your satellite(s) to the NIST IGS Site for the entire day. Use the GPS positions you calculated using your new function based on the ephemeris, not the almanac. Plot each of these versus time in hours of the day.

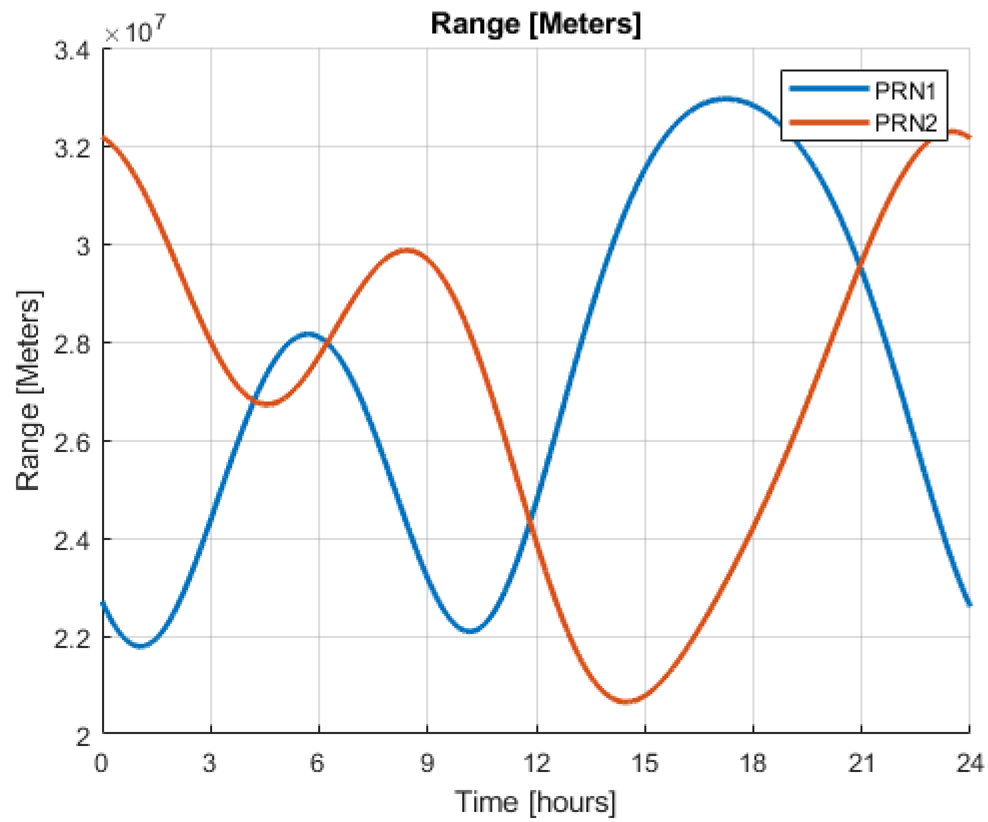
```
NIST_ecef = [-1288398 -4721697 4078625]; %ECEF coordinates in meters x
 y z
nistECEF = [NIST_ecef];
num_NIST_ecef = size(nistECEF,1);    %number of NIST_ecef locations

num_time = size(t,2);
for kk = 1:2
    [health,pos] = broadcast_eph2pos(gps_ephem,T_in,kk);
    for tt = 1:num_time
        [azt(tt,kk,1),elt(tt,kk,1),ranget(tt,kk,1)] =
 compute_azelrange(NIST_ecef,pos(tt,:));
    end
    if kk == 1
        satPos1 = pos;
    else
        satPos2 = pos;
    end
```

```
end

% Plot Azimuth for Problem 5
f=figure; hold on; grid on
plot(time, azt(:,ephem_PRN1(1)), 'LineWidth', 2)
plot(time, azt(:,ephem_PRN2(1)), 'LineWidth', 2)
title({['Azimuth [Degrees]']})
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Azimuth [Degrees]')
legend({'PRN1', 'PRN2'})

% Plot Elevation for Problem 5
f=figure; hold on; grid on
plot(time, elt(:,1), 'LineWidth', 2)
plot(time, elt(:,2), 'LineWidth', 2)
title({['Elevation [Degrees]']})
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Elevation [Degrees]')
legend({'PRN1', 'PRN2'})

% Plot Range for Problem 5
f=figure; hold on; grid on
plot(time, ranget(:,1), 'LineWidth', 2)
plot(time, ranget(:,2), 'LineWidth', 2)
title({['Range [Meters]']})
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Range [Meters]')
legend({'PRN1', 'PRN2'})
```


Difference Between ECEF Coords [km]
PRN2
ECEF Coord 1
ECEF Coord 2
ECEF Coord 3
Difference [km]
Time [hours]
3
2
1
0
-1
-2
-3
0
3
6
9
12
15
18
21
24


Azimuth [Degrees]
PRN1
PRN2
Azimuth [Degrees]
Time [hours]
200
150
100
50
0
-50
-100
-150
-200
0
3
6
9
12
15
18
21
24


Elevation [Degrees]
PRN1
PRN2
100
80
60
40
20
0
-20
-40
-60
-80
Elevation [Degrees]
0
3
6
9
12
15
18
21
24
Time [hours]


Range [Meters]
$\times 10^7$
PRN1
PRN2
3.4
3.2
3
2.8
2.6
2.4
2.2
2
Range [Meters]
0
3
6
9
12
15
18
21
24
Time [hours]

6) Now recompute the range accounting for the signal travel time and coordinate frame rotation as described in the

attachment. Add this updated range to the previous range plot and compare the results. What is the largest difference you found?

```
% COMPUTING THE EXPECTED RANGE:
% The expected range of interest is the distance between the position
 of the GPS satellite at the time of transmission
% (Tt) and the GPS receiving antenna at the time of reception (Tr). To
 compute this distance, both positions must be
% represented in the same coordinate frame - we use the ECEF
 coordinate frame at the time of reception (Tr).
satECEF = satPos1; % We'll do this for just one sattelite

TOL = 1e-8;

not_converged = true;

satECEF = satPos1;
% Choose one satellite
while not_converged
    % 1) Compute the GPS satellite poisition in ECEF at Tr based on
 the
    % broadcast ephemeris

    % Compute GPS satellite position at recieved time for rough idea
 of range
    % to satellite using an assumed location of reciever
    Tr = ranget(:,1) / c; % Calc for first satellite

    % 2) Use an a priori value for the receiver coordinates (RX) to
 find geometric range R = |rGPS – rRX|
    for tt = 1:num_time
        [~, ~, rGPS] = ECEF2llh(satECEF(tt,:));
        [~, ~,  rRx] = ECEF2llh(nistECEF); % assumed location of
 reciever is location for NIST
        R(tt) = abs(rGPS - rRx);

    end
    % 3) Compute the time of transmission: Tt = Tr – R/c (use the real
 speed of
    % light, NOT 3e8), it's usually 70-100 milliseconds
    Tt = Tr  - R'/c;

    % 4) Compute the satellite position at Tt in ECEF at Tt based on
 the broadcast ephemeris.
    newt = Tt*30+172800;  %Time of week in seconds with 30 sec spacing
    newT_in = [WN;newt'].';
    [health, new_pos] = broadcast_eph2pos(gps_ephem, newT_in, PRN);
```

```
    % 5) Rotate the satellite position to ECEF at Tr. (wE is the
rotation rate of the Earth)
    w_e = 7.2921151467e-5; % earth rotation rate [rad / sec]
    for kk = 1
        for tt = 1:num_time

            phi = w_e * (Tr(tt, kk)-Tt(tt, kk)); % amount of rotation
the earth moved during time of transmission
            cosPhi = cos(phi);
            sinPhi = sin(phi);

            rotation_matrix = [cosPhi, sinPhi, 0; -sinPhi, cosPhi, 0;
0, 0, 1];
            rot_pos(tt ,: , kk) = (rotation_matrix *
new_pos(tt,:).')';

        end
    end

    % 6) Compute a new geometric range using this position for rGPS, R
= |rGPS – rRX|
    for jj = 1:num_NIST_ecef
        NIST_ecef = nistECEF(jj,:);      %grab the appropriate
NIST_ecef location
        num_time = size(t,2);
        for kk = 1
            for tt = 1:num_time
                satECEF = rot_pos(tt,:,kk);
                [~,~,new_ranget(tt,kk,jj)] =
compute_azelrange(NIST_ecef,satECEF);
            end
        end
    end

    % 7) Repeat steps 3-6 until convergence. (If it takes more than
two iterations, something is wrong).
    sprintf('Tolerance: %0.5g',abs(new_ranget(1,1) - ranget(1,1)))
    if abs(ranget(1,1) - new_ranget(1,1)) < TOL
        not_converged = false; % Go back to beginning :)
    end
    ranget = new_ranget;

end

% Plot Range
figure
hold on; grid on;
plot(time, ranget)
title({['Problem 6 Range [Meters]']})
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Range [Meters]')
```

```
legend({'PRN1', 'PRN2'})
```

```
ans =

    'Tolerance: 2.2153e+06'
```

```
Index in position 1 exceeds array bounds (must not exceed 1).

Error in HW4_script (line 221)
        [~, ~, rGPS] = ECEF2llh(satECEF(tt,:));
```

7. Download the NIST rinex observation file for September 1, 2020. Use the function read_rinex_obs8 or

another version that you find or write yourself to read the RINEX file and extract all of the measured C1 and P2 pseudoranges for the satellite you chose. Plot these pseudoranges versus time in hours of the day.

```
fname = "DATA\nist2450.20o";

prn1_rdata = read_rinex_obs8(fname, [1]); % Grab PRN1 data
prn2_rdata = read_rinex_obs8(fname, [2]); % Grab PRN2 data

% Grab C1 and P2 for PRN1 and Plot
prn1_C1 = prn1_rdata.data(:,4);
prn1_P2 = prn1_rdata.data(:,8);
```

Plot C1 and P2 for PRN1

```
figure; hold on; grid on % Create figure
plot(1:1:length(prn1_C1), prn1_C1, 'LineWidth', 2)
plot(1:1:length(prn1_P2), prn1_P2, '--', 'LineWidth', 2)
% Make plot pretty
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Pseudoranges [km]')
legend({'C1', 'P2'})
title({['Pseudoranges C1 and P2'], ['PRN1']})
```

Grab C1 and P2 for PRN1 and Plot

```
prn2_C1 = prn2_rdata.data(:,4);
prn2_P2 = prn1_rdata.data(:,8);

% Plot C1 and P2 for PRN2
figure; hold on; grid on
plot(1:1:length(prn2_C1), prn2_C1, 'LineWidth', 2)
```

```
plot(1:1:length(prn2_P2), prn2_P2, '--', 'LineWidth', 2)
xlim([time(1), time(end)])
xticks([0:3:24])
xlabel('Time [hours]')
ylabel('Pseudoranges [m]')
legend({'C1', 'P2'})
title({['Pseudoranges C1 and P2'], ['PRN2']})
```

8) Describe the visibility results for the three locations.

Compare the measured pseudoranges to your predicted range. Briefly explain what might be the source of any differences between them. (To do this part, create a time vector from the observations and compute the predicted range for those times.) The range calculated in problem 6 has the same order of magnitude as the pseudoranges. This could be becausse sp3 files are re-calculated every epoch and it takes a much longer time to calculate these but they are more accurate.

Functions

Problem 1 function

```
function [lat,lon,h] = ECEF2llh(xyz)
R = 6378.137e3;             %SemiMajor axis of ellipsoid (meters)
f = 1/298.257223563;% flattening parameter of ellipsoid
e2 = 2*f-f^2;       %square of eccentricity of ellipsoid.

lambda = atan2d(xyz(2),xyz(1));     %Longitude (deg)
p = sqrt(xyz(1)^2+xyz(2)^2);
r =sqrt(sum(xyz.^2));

phi_gd = asind(xyz(3)/r);   %initial guess for geodetic latitude (deg)
tolerance = 1e-8;
dif = 1;
while dif > tolerance %iterate until delta is small

    C = R/sqrt(1-e2*sind(phi_gd)^2); %Radius of curvature in the
 meridian
    tan_phi_gd = (xyz(3)+C*e2*sind(phi_gd))/p;
    phi_gd_new = atand(tan_phi_gd);   %Geodetic latitude (deg)
    dif = abs(phi_gd_new - phi_gd);      %difference between guess and
 new
    phi_gd = phi_gd_new;            %set old to new
end

h = p/cosd(phi_gd)-C;       %ellipsoidal height (meters) above surface
lat = phi_gd;               %latitude (deg)
lon = lambda;               %longitude (deg)

end

% Problem 2 function
function A = ECEF2ENU(lat,lon)
```

```
    lam = lon;
    phi = lat;
    a1 = [1,0,0;...
        0,sind(phi),cosd(phi);...
        0,-cosd(phi),sind(phi)];
    a2 = [-sind(lam),cosd(lam),0;-cosd(lam),-sind(lam),0;0,0,1];
    A = a1*a2;
end

%Problem 3 function
function LOS_ENU = compute_LOS_ENU(nistECEF,satECEF)

%a) compute the vector pointing from NIST_ecef location to satellite
    elos_ECEF = satECEF - nistECEF;  %line of site vector from
 NIST_ecef to satellite

%b) normalize it to a unit vector
    elos_norm = elos_ECEF/sqrt(sum(elos_ECEF.^2));

%c) transform the unit vector from ECEF to ENU
    [lat,lon,h] = ECEF2llh(nistECEF); %get latitude and longitude of
 NIST_ecef
    ENU_matrix = ECEF2ENU(lat,lon);

    LOS_ENU = ENU_matrix*elos_norm.';
end

%Problem 4 function
function [az,el,range] = compute_azelrange(nistECEF,satECEF)
    los_enu = compute_LOS_ENU(nistECEF,satECEF);
    range = sqrt(sum((nistECEF-satECEF).^2));   %distance btwn
 NIST_ecef and sat
    r = sqrt(sum(los_enu.^2));                  %always 1? weird
    az = atan2d(round(los_enu(1),5),round(los_enu(2),5));   %azimuth
 (deg)
    el = asind(los_enu(3)/r);                   %elevation (deg)
end
```

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