## Contents



```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        Homework8_main.m
% Author      : Zach Dischner
% Date        : 11/3/2013
% Description : Matlab script for all calculations required for
%               ASEN 5090 Homework 8
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
```

## Questions to Answer (First for ease of grading)

```
type('answers.txt')
```

```
Solutions for the least squares

----------------------------joze2640.onehour-------------------------
East/Sig    Estimate (m) -0.275     |    Sigma (m) 0.301
```

```
North/Sig   Estimate (m) -1.632     |   Sigma (m) 0.405
Up/Sig      Estimate (m) 1.227      |   Sigma (m) 0.757
Clk/Sig     Estimate (m) 199570.997 |   Sigma (m) 0.500

----------------------------onsa2640.onehour-------------------------
East/Sig    Estimate (m) 0.478      |   Sigma (m) 0.306
North/Sig   Estimate (m) 0.622      |   Sigma (m) 0.334
Up/Sig      Estimate (m) -2.056     |   Sigma (m) 0.699
Clk/Sig     Estimate (m) 620.163    |   Sigma (m) 0.425
```

## Setup Work Space

```
clc;clear all;close all
tic;
screen_size = get(0,'ScreenSize');
sw = screen_size(3);    % Screen Width
sh = screen_size(4);    % Screen Height
addpath HW8_files
soln_format = '|  %2.0f | %15.3f | %7.3f | %12.3f | %6.3f | %9.3f | %3.2f | \t\n';
debug = 0;
```

## Setup Problem

```
%------Define Navigation and Observation File
RINEX_FILES = {'joze2640.onehour','onsa2640.onehour'};
nav_msg  = 'brdc2640.12n';

%------Define Orbit determination parameters
params.mu = 3.986005e14;        % Gravitational param [m^3/s^2]
params.we = 7.2921151467e-5;    % Earth's rotation rate [rad/s]

%------Define speed of light
params.c = 299792458; % [m/s]

params.options=optimset('Display','off','TolFun',1e-10,'TolX',1e-10);

%------Elevation Mask
el_mask = 10; %degrees


%------Define Zenith Correction for each site
Tzenith = [2.4086, 2.3858]; %[m]


%------Read navigation message content
nav_data = read_GPSbroadcast(nav_msg); % Returns [n x 25] matrix of sat orbit information
%                  col1: prn, PRN number of satellite
%                  col2: M0, mean anomaly at reference time, rad
%                  col3: delta_n, mean motion difference from computed value, rad/s
%                  col4: ecc, eccentricity of orbit
%                  col5: sqrt_a, square root of semi-major axis, m^0.5
%                  col6: Loa, longitude of ascending node of orbit plane at weekly epoch, rad
%                  col7: incl, inclination angle at reference time, rad
%                  col8: perigee, argument of perigee, rad
%                  col9: ra_rate, rate of change of right ascension, rad/s
%                 col10: i_rate, rate of change of inclination angle, rad/s
```

```
%                  col11: Cuc, amplitude of the cosine harmonic correction term to the argument of latitu
de
%                  col12: Cus, amplitude of the sine harmonic correction term to the argument of latitude
%                  col13: Crc, amplitude of the cosine harmonic correction term to the orbit radius
%                  col14: Crs, amplitude of the sine harmonic correction term to the orbit radius
%                  col15: Cic, amplitude of the cosine harmonic correction term to the angle of inclinati
on
%                  col16: Cis, amplitude of the cosine harmonic correction term to the angle of inclinati
on
%                  col17: Toe, reference time ephemeris (seconds into GPS week)
%                  col18: IODE, issue of data (ephemeris)
%                  col19: GPS_week, GPS Week Number (to go with Toe)
%                  col20: Toc, time of clock
%                  col21: Af0, satellite clock bias (sec)
%                  col22: Af1, satellite clock drift (sec/sec)
%                  col23: Af2, satellite clock drift rate (sec/sec/sec)
%                  col24: blank (zero)
%                  col25: health, satellite health (0=good and usable)
```

## Calculate Pre-Fit Residuals

```
for file_idx=1:length(RINEX_FILES)
```

```
    rinex_file = RINEX_FILES{file_idx};
    fprintf('Processing Rinex file %s\n', rinex_file)
```

```
Processing Rinex file joze2640.onehour
```

```
Processing Rinex file onsa2640.onehour
```

## Read Observation Files, Sort Data

```
    %------Read a-priori receiver position from header of RINEX obs file
    [ fid, rec_xyz, observables ] = read_rinex_header( rinex_file );
    [rec_lla] = ecef2lla(rec_xyz');

    %------Form least squares like variables
    xr = rec_xyz(1); yr = rec_xyz(2); zr = rec_xyz(3);
    X = [xr, yr, zr, 1];

    %------Read Observation file
    obs_data    = read_rinex_obs3(rinex_file);
    cols        = obs_data.col; % Structure of column index descriptions
    %------Make nice column addressing variables (P1_col, P2_col ... etc)
    fields = fieldnames(cols);
    for kk=1:length(fields)
        eval(cell2mat([fields(kk),'_col = cols.',fields(kk),';']));
    end

    %------Only look at first epoch
    [GPSSecAryUn,secs_idx] = unique(obs_data.data(:,TOW_col));
```

```
    PRNS = obs_data.data(: , PRN_col);
    GPSWeekAry = obs_data.data(: , WEEK_col);
    GPSSecAry = obs_data.data(: , TOW_col);
```

```
Read 1000 lines
ans =
        1024           8

Read 1000 lines
ans =
        1238          13
```

## Fetch/Compute Pseudorange Values

```
    %------Allocate
    rho_obs = zeros(1, length(PRNS));
    rho_model = rho_obs;
    el = rho_obs;
    res = rho_obs;
    ionFree = rho_obs;
    sat_prn = rho_obs;
    epoch_iter = 0;
    for sec_idx = secs_idx'
```

```
        epoch_iter = epoch_iter + 1;
```

## Calculate "Modeled" Pseudorange

```
        %------Setup Range Finding
        GPS_SOW = GPSSecAry(sec_idx);
        GPS_Week = GPSWeekAry(sec_idx);
        params.Secs = GPS_SOW; %(GPS_Secs(1))  % Seconds used to calculate seconds since epoch

        %------Iterate over epoch satellite data
        Nsats = sum(GPSSecAry == GPSSecAry(sec_idx));
        iter = 0; clear H y
        for sat = 1:Nsats
```

```
            data_idx = sec_idx+sat-1;
            iter = iter + 1;
            PRN = obs_data.data(data_idx,PRN_col);

            %------Calculate Geometric Range
            [R, rel_dt, satXYZ] = getSatGeomRange(rec_xyz', GPS_Week, GPS_SOW, PRN, nav_data, params);
            xs = satXYZ(1); ys = satXYZ(2); zs = satXYZ(3);

            %------Check Elevation Angle
            [az, el(iter), r] = ecef2azelrange(satXYZ', rec_xyz);
            if el(iter) < el_mask
```

```
            iter=iter-1;
            continue
        end
        rel_corr = rel_dt*params.c;

        %------Get clock correction
        sat_clk_t_corr = getSatClockCorrection(GPS_Week, GPS_SOW, PRN, nav_data);

        %------Get Satellite Correction
        sat_corr = sat_clk_t_corr*params.c;

        %------Get Tropospheric Correction
        Tropo_corr = getTropoCorrection(Tzenith(file_idx), el(iter) );
        rho_model(iter) = R - sat_corr + Tropo_corr + rel_corr;
```

## Fetch Observed Pseudoranges

```
        %------Get Observed pseudorange
        P2 = obs_data.data(data_idx,P2_col);

        if sum(strcmp(observables,'P1'))>0
            %------Retrieve P1 as 2nd freq pseudorange
            PorC1 = obs_data.data(data_idx,P1_col);
%             rho_obs(iter) = P1;
        else
            %------Retrieve C1 as 2nd freq pseudorange
            PorC1 = obs_data.data(data_idx,C1_col);
%             rho_obs(iter) = C1;
        end

        %------Use ONLY ionosphere free. Uncomment linesto use what data we have
        if P2==0
            iter=iter-1;
            continue
%             rho_obs(iter) = PorC1;
        elseif PorC1==0
            iter=iter-1;
            continue
%             rho_obs(iter) = P2;
        else
            rho_obs(iter) = 2.5457*PorC1-1.5457*P2;
        end

        %------Populate Least Squares Variables
        H(iter,:) = [(xr-xs)/R, (yr-ys)/R, (zr-zs)/R, 1]; %??? What about clock???
        % same as (rec_xyz' - satXYZ)/R
        y(iter) = rho_obs(iter) - rho_model(iter);

        sat_prn(iter) = PRN;

        if epoch_iter == 1 && file_idx == 1 && debug == 1
            if sat == 1
                fprintf('|_PRN_|________P3_______|___Geom Range___|____satClk____|__rel__|__Tropo___
|___prefit___|\n')
            end
            fprintf(1,soln_format,PRN,...
                rho_obs(iter), R,sat_corr,...
```

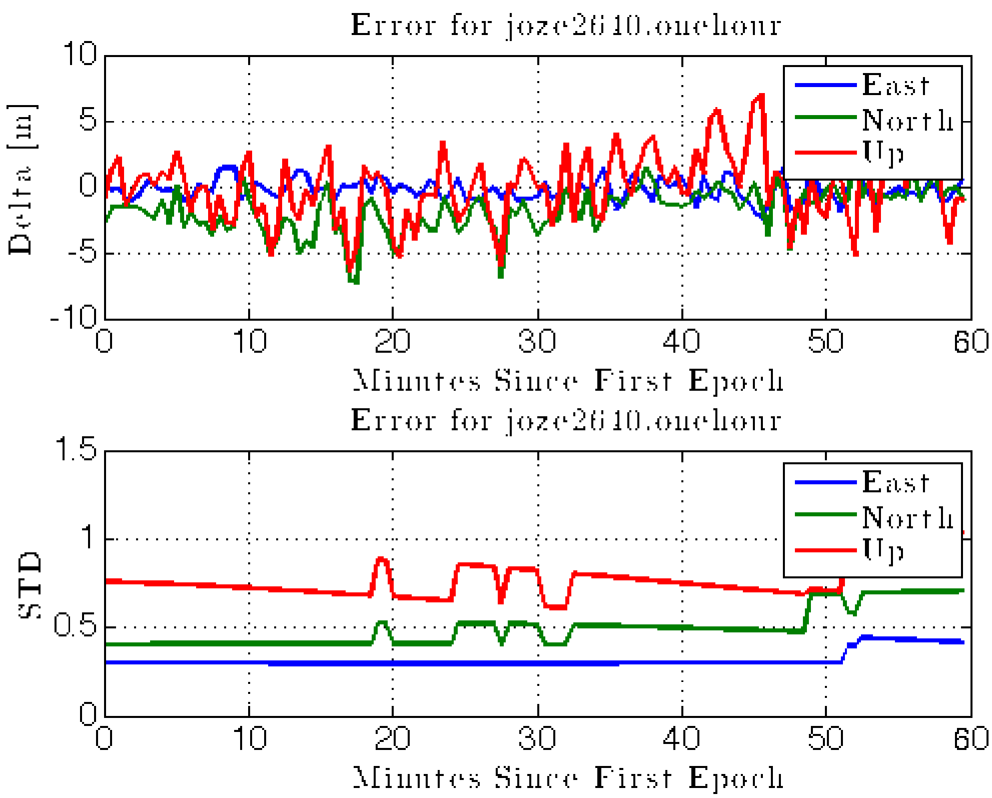
```
                rel_corr,Tropo_corr,y(iter))
        end
```

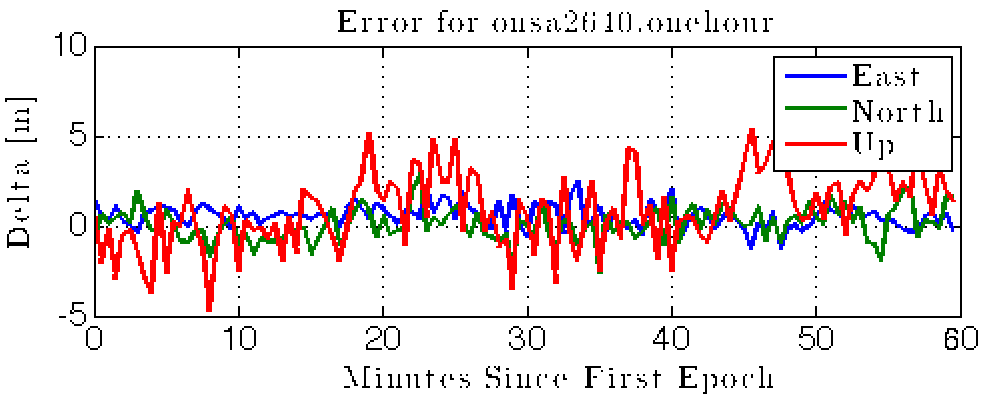
```
        end     % End Satellite Iteration
        %------Obtain least squares correction
        del_x(epoch_iter,:) = transpose((H'*H)\H'*y');
        P = inv(H'*H).*(0.5)^2;

        %------Rotate
        rec_xyz_adj = repmat(rec_xyz', epoch_iter, 1) - del_x(:,1:3);
        rec_lla_adj = ecef2lla(rec_xyz_adj);
        lat_station =  rec_lla_adj(epoch_iter,1);
        lon_station = rec_lla_adj(epoch_iter,2);
        P(1:3,1:3) = rotateCovariance(P(1:3,1:3), lat_station,lon_station);
        sigmas(epoch_iter,:) = sqrt(diag(P))';

        key_epoch = 2;
        if epoch_iter == key_epoch
            fprintf('\n\n----------------------------%s-------------------------',rinex_file)
            rec_xyz_adj = repmat(rec_xyz', epoch_iter, 1) - del_x(:,1:3);
            rec_lla_adj = ecef2lla(rec_xyz_adj);
            [de, dn, du] = ecef2enuv(del_x(key_epoch,1), ...
                                 del_x(key_epoch,2), ...
                                 del_x(key_epoch,3), ...
                                 rec_lla_adj(key_epoch,1),rec_lla_adj(key_epoch,2));
           fprintf('\nEast/Sig (m) %3.3f %3.3f\n',de,sigmas(epoch_iter,1))
           fprintf('North/Sig (m) %3.3f %3.3f\n',dn,sigmas(epoch_iter,2))
           fprintf('Up/Sig (m) %3.3f %3.3f\n',du,sigmas(epoch_iter,3))
           fprintf('Clk/Sig (m) %5.3f %3.3f\n',del_x(key_epoch,4),sigmas(epoch_iter,4))
        end
```

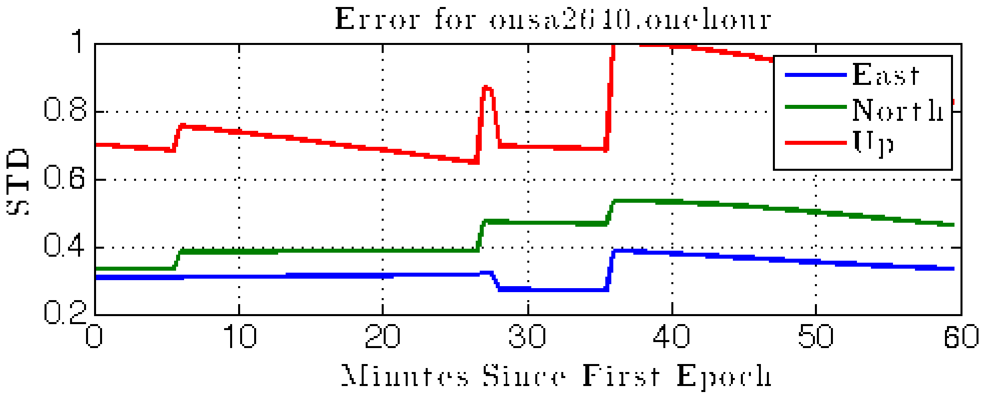
```
----------------------------joze2640.onehour-------------------------
East/Sig (m) -0.275 0.301
North/Sig (m) -1.632 0.405
Up/Sig (m) 1.227 0.757
Clk/Sig (m) 199570.997 0.500



----------------------------onsa2640.onehour-------------------------
East/Sig (m) 0.478 0.306
North/Sig (m) 0.622 0.334
Up/Sig (m) -2.056 0.699
Clk/Sig (m) 620.163 0.425
```

```
    end     % End time iteration


    [de, dn, du] = ecef2enuv(del_x(:,1), ...
                         del_x(:,2), ...
                         del_x(:,3), ...
                         rec_lla_adj(:,1),rec_lla_adj(:,2));
```

```
%   or...
    [xe,yn,zu]=ecef2enu(del_x(:,1),del_x(:,2),del_x(:,3),...
                            rec_lla_adj(:,1),rec_lla_adj(:,2),rec_lla_adj(:,3),oblateSpheroid);

    t = linspace(GPSSecAryUn(1),GPSSecAryUn(end),length(GPSSecAryUn));
    t = (t-t(1))/60;
    figure; subplot(2,1,1);
    plot(t,[de,dn,du])
    xlabel('Minutes Since First Epoch');ylabel('Delta [m]'); legend('East','North','Up')
    title(['Error for ', rinex_file])
    subplot(2,1,2)
    plot(t,sigmas(:,1:3))
    xlabel('Minutes Since First Epoch');ylabel('STD'); legend('East','North','Up')
    title(['Error for ', rinex_file])

%     ecef2enuv()

    %------Remove data with '0' observation
    zs = rho_obs == 0;
    rho_obs(zs) = []; rho_model(zs) = [];
clear del_x H
```



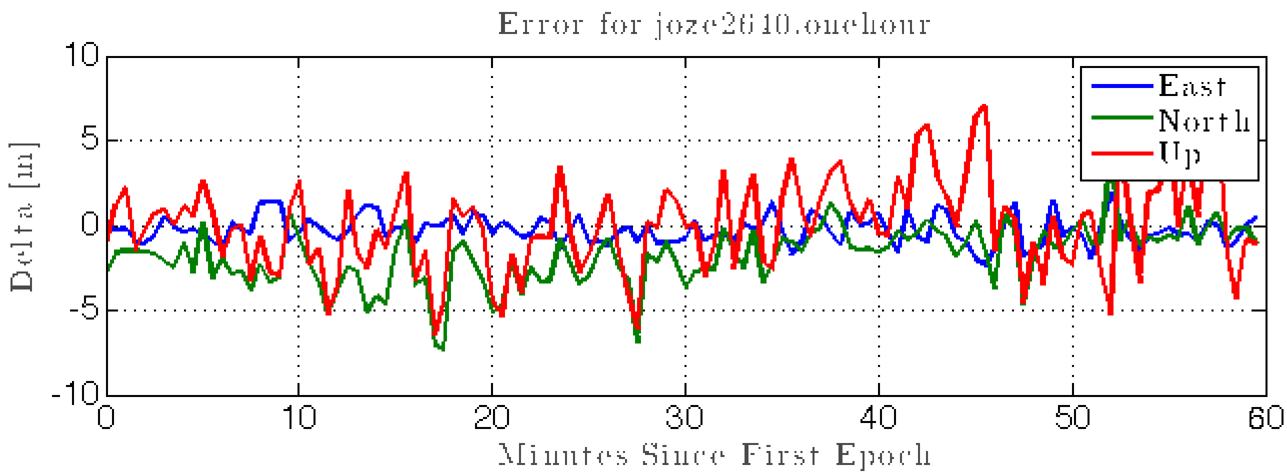


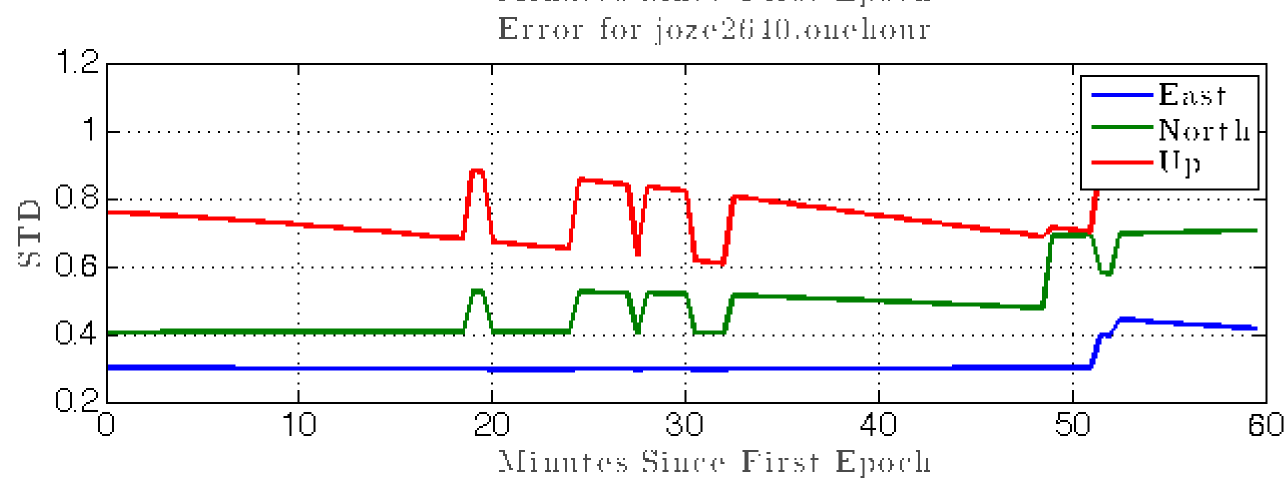



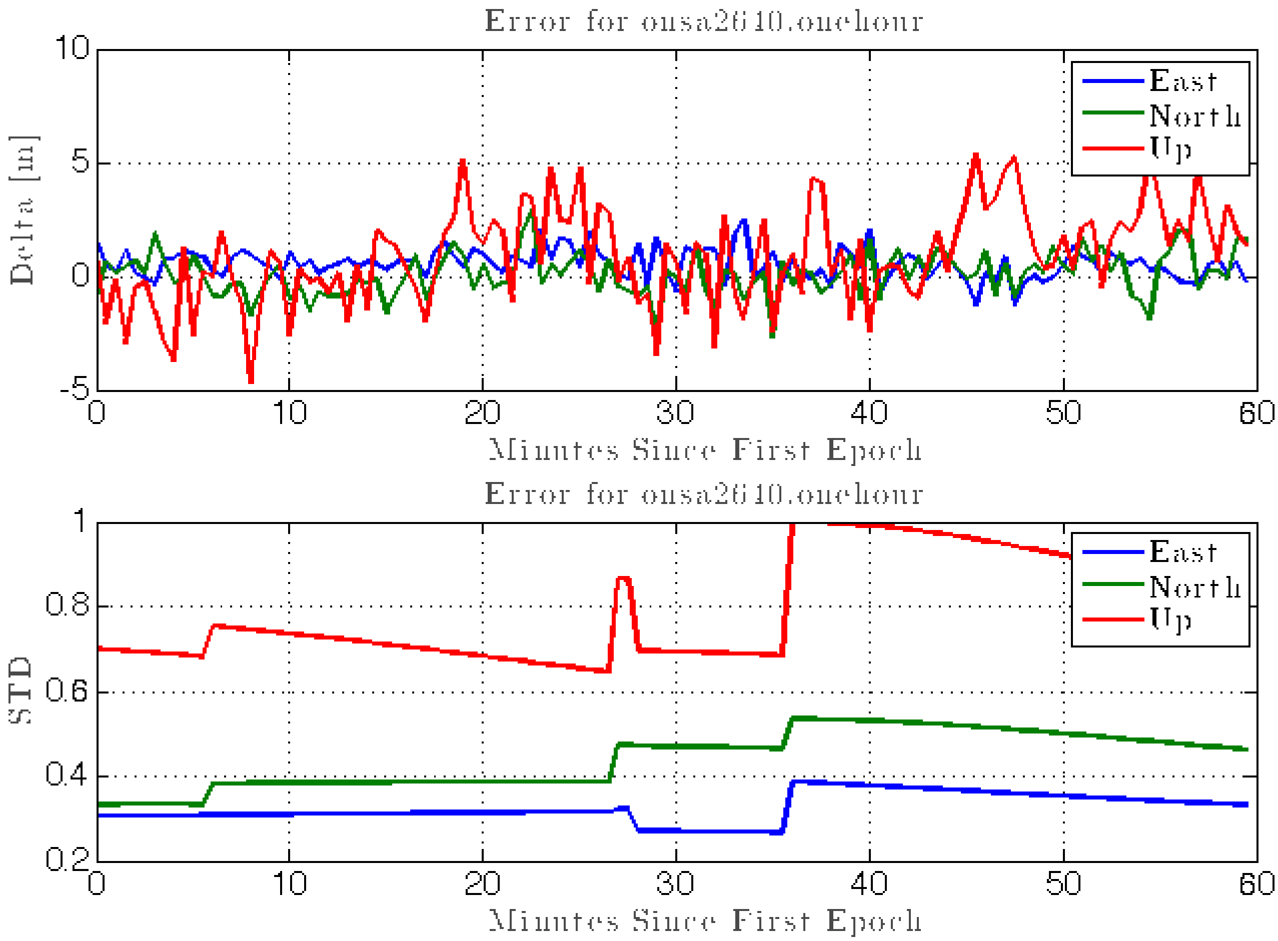

```
end     % End Rinex File Iteration
```

## Clean, Reformat

```
figure_awesome
```


Error for joze2610.onehour
Delta [m]
East
North
Up
10
5
0
-5
-10
0
10
20
30
40
50
60
Minutes Since First Epoch


Error for joze2610.onehour
STD
East
North
Up
1.2
1
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
Minutes Since First Epoch




## SUPPORTING FUNCTION - Homework8_main.m

```
type('Homework8_main.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                         Homework8_main.m
% Author      : Zach Dischner
% Date        : 11/3/2013
% Description : Matlab script for all calculations required for
%               ASEN 5090 Homework 8
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `"""""""""""""""""| |""` [_""_-____________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
%% Questions to Answer (First for ease of grading)
type('answers.txt')

%% Setup Work Space
```

```
clc;clear all;close all
tic;
screen_size = get(0,'ScreenSize');
sw = screen_size(3);    % Screen Width
sh = screen_size(4);    % Screen Height
addpath HW8_files
soln_format = '|  %2.0f | %15.3f | %7.3f | %12.3f | %6.3f | %9.3f | %3.2f | \t\n';
debug = 0;


%% Setup Problem
%------Define Navigation and Observation File
RINEX_FILES = {'joze2640.onehour','onsa2640.onehour'};
nav_msg  = 'brdc2640.12n';

%------Define Orbit determination parameters
params.mu = 3.986005e14;        % Gravitational param [m^3/s^2]
params.we = 7.2921151467e-5;    % Earth's rotation rate [rad/s]

%------Define speed of light
params.c = 299792458; % [m/s]

params.options=optimset('Display','off','TolFun',1e-10,'TolX',1e-10);

%------Elevation Mask
el_mask = 10; %degrees


%------Define Zenith Correction for each site
Tzenith = [2.4086, 2.3858]; %[m]


%------Read navigation message content
nav_data = read_GPSbroadcast(nav_msg); % Returns [n x 25] matrix of sat orbit information
%                   col1: prn, PRN number of satellite
%                   col2: M0, mean anomaly at reference time, rad
%                   col3: delta_n, mean motion difference from computed value, rad/s
%                   col4: ecc, eccentricity of orbit
%                   col5: sqrt_a, square root of semi-major axis, m^0.5
%                   col6: Loa, longitude of ascending node of orbit plane at weekly epoch, rad
%                   col7: incl, inclination angle at reference time, rad
%                   col8: perigee, argument of perigee, rad
%                   col9: ra_rate, rate of change of right ascension, rad/s
%                  col10: i_rate, rate of change of inclination angle, rad/s
%                  col11: Cuc, amplitude of the cosine harmonic correction term to the argument of latitu
de
%                  col12: Cus, amplitude of the sine harmonic correction term to the argument of latitude
%                  col13: Crc, amplitude of the cosine harmonic correction term to the orbit radius
%                  col14: Crs, amplitude of the sine harmonic correction term to the orbit radius
%                  col15: Cic, amplitude of the cosine harmonic correction term to the angle of inclinati
on
%                  col16: Cis, amplitude of the cosine harmonic correction term to the angle of inclinati
on
%                  col17: Toe, reference time ephemeris (seconds into GPS week)
%                  col18: IODE, issue of data (ephemeris)
%                  col19: GPS_week, GPS Week Number (to go with Toe)
%                  col20: Toc, time of clock
%                  col21: Af0, satellite clock bias (sec)
```

```
%                  col22: Af1, satellite clock drift (sec/sec)
%                  col23: Af2, satellite clock drift rate (sec/sec/sec)
%                  col24: blank (zero)
%                  col25: health, satellite health (0=good and usable)

%% Calculate  Pre-Fit Residuals
for file_idx=1:length(RINEX_FILES)
    rinex_file = RINEX_FILES{file_idx};
    fprintf('Processing Rinex file %s\n', rinex_file)

    %% Read Observation Files, Sort Data
    %------Read a-priori receiver position from header of RINEX obs file
    [ fid, rec_xyz, observables ] = read_rinex_header( rinex_file );
    [rec_lla] = ecef2lla(rec_xyz');

    %------Form least squares like variables
    xr = rec_xyz(1); yr = rec_xyz(2); zr = rec_xyz(3);
    X = [xr, yr, zr, 1];

    %------Read Observation file
    obs_data    = read_rinex_obs3(rinex_file);
    cols        = obs_data.col; % Structure of column index descriptions
    %------Make nice column addressing variables (P1_col, P2_col ... etc)
    fields = fieldnames(cols);
    for kk=1:length(fields)
        eval(cell2mat([fields(kk),'_col = cols.',fields(kk),';']));
    end

    %------Only look at first epoch
    [GPSSecAryUn,secs_idx] = unique(obs_data.data(:,TOW_col));
    PRNS = obs_data.data(: , PRN_col);
    GPSWeekAry = obs_data.data(: , WEEK_col);
    GPSSecAry = obs_data.data(: , TOW_col);

    %% Fetch/Compute Pseudorange Values

    %------Allocate
    rho_obs = zeros(1, length(PRNS));
    rho_model = rho_obs;
    el = rho_obs;
    res = rho_obs;
    ionFree = rho_obs;
    sat_prn = rho_obs;
    epoch_iter = 0;
    for sec_idx = secs_idx'
        epoch_iter = epoch_iter + 1;

        %% Calculate "Modeled" Pseudorange
        %------Setup Range Finding
        GPS_SOW = GPSSecAry(sec_idx);
        GPS_Week = GPSWeekAry(sec_idx);
        params.Secs = GPS_SOW; %(GPS_Secs(1))  % Seconds used to calculate seconds since epoch

        %------Iterate over epoch satellite data
        Nsats = sum(GPSSecAry == GPSSecAry(sec_idx));
        iter = 0; clear H y
        for sat = 1:Nsats
            data_idx = sec_idx+sat-1;
```

```
            iter = iter + 1;
            PRN = obs_data.data(data_idx,PRN_col);

            %------Calculate Geometric Range
            [R, rel_dt, satXYZ] = getSatGeomRange(rec_xyz', GPS_Week, GPS_SOW, PRN, nav_data, params);
            xs = satXYZ(1); ys = satXYZ(2); zs = satXYZ(3);

            %------Check Elevation Angle
            [az, el(iter), r] = ecef2azelrange(satXYZ', rec_xyz);
            if el(iter) < el_mask
                iter=iter-1;
                continue
            end
            rel_corr = rel_dt*params.c;

            %------Get clock correction
            sat_clk_t_corr = getSatClockCorrection(GPS_Week, GPS_SOW, PRN, nav_data);

            %------Get Satellite Correction
            sat_corr = sat_clk_t_corr*params.c;

            %------Get Tropospheric Correction
            Tropo_corr = getTropoCorrection(Tzenith(file_idx), el(iter) );
            rho_model(iter) = R - sat_corr + Tropo_corr + rel_corr;

            %% Fetch Observed Pseudoranges
            %------Get Observed pseudorange
            P2 = obs_data.data(data_idx,P2_col);

            if sum(strcmp(observables,'P1'))>0
                %------Retrieve P1 as 2nd freq pseudorange
                PorC1 = obs_data.data(data_idx,P1_col);
%                 rho_obs(iter) = P1;
            else
                %------Retrieve C1 as 2nd freq pseudorange
                PorC1 = obs_data.data(data_idx,C1_col);
%                 rho_obs(iter) = C1;
            end

            %------Use ONLY ionosphere free. Uncomment linesto use what data we have
            if P2==0
                iter=iter-1;
                continue
%                 rho_obs(iter) = PorC1;
            elseif PorC1==0
                iter=iter-1;
                continue
%                 rho_obs(iter) = P2;
            else
                rho_obs(iter) = 2.5457*PorC1-1.5457*P2;
            end

            %------Populate Least Squares Variables
            H(iter,:) = [(xr-xs)/R, (yr-ys)/R, (zr-zs)/R, 1]; %??? What about clock???
            % same as (rec_xyz' - satXYZ)/R
            y(iter) = rho_obs(iter) - rho_model(iter);

            sat_prn(iter) = PRN;
```

```
            if epoch_iter == 1 && file_idx == 1 && debug == 1
                if sat == 1
                    fprintf('|_PRN_|________P3_______|___Geom Range___|____satClk____|__rel__|__Tropo___
|___prefit___|\n')
                end
                fprintf(1,soln_format,PRN,...
                    rho_obs(iter), R,sat_corr,...
                    rel_corr,Tropo_corr,y(iter))
            end

        end     % End Satellite Iteration
        %------Obtain least squares correction
        del_x(epoch_iter,:) = transpose((H'*H)\H'*y');
        P = inv(H'*H).*(0.5)^2;

        %------Rotate
        rec_xyz_adj = repmat(rec_xyz', epoch_iter, 1) - del_x(:,1:3);
        rec_lla_adj = ecef2lla(rec_xyz_adj);
        lat_station =  rec_lla_adj(epoch_iter,1);
        lon_station = rec_lla_adj(epoch_iter,2);
        P(1:3,1:3) = rotateCovariance(P(1:3,1:3), lat_station,lon_station);
        sigmas(epoch_iter,:) = sqrt(diag(P))';

        key_epoch = 2;
        if epoch_iter == key_epoch
            fprintf('\n\n---------------------------%s-------------------------',rinex_file)
            rec_xyz_adj = repmat(rec_xyz', epoch_iter, 1) - del_x(:,1:3);
            rec_lla_adj = ecef2lla(rec_xyz_adj);
            [de, dn, du] = ecef2enuv(del_x(key_epoch,1), ...
                                     del_x(key_epoch,2), ...
                                     del_x(key_epoch,3), ...
                                     rec_lla_adj(key_epoch,1),rec_lla_adj(key_epoch,2));
           fprintf('\nEast/Sig (m) %3.3f %3.3f\n',de,sigmas(epoch_iter,1))
           fprintf('North/Sig (m) %3.3f %3.3f\n',dn,sigmas(epoch_iter,2))
           fprintf('Up/Sig (m) %3.3f %3.3f\n',du,sigmas(epoch_iter,3))
           fprintf('Clk/Sig (m) %5.3f %3.3f\n',del_x(key_epoch,4),sigmas(epoch_iter,4))
        end
    end     % End time iteration


    [de, dn, du] = ecef2enuv(del_x(:,1), ...
                             del_x(:,2), ...
                             del_x(:,3), ...
                             rec_lla_adj(:,1),rec_lla_adj(:,2));
%   or...
    [xe,yn,zu]=ecef2enu(del_x(:,1),del_x(:,2),del_x(:,3),...
                        rec_lla_adj(:,1),rec_lla_adj(:,2),rec_lla_adj(:,3),oblateSpheroid);

    t = linspace(GPSSecAryUn(1),GPSSecAryUn(end),length(GPSSecAryUn));
    t = (t-t(1))/60;
    figure; subplot(2,1,1);
    plot(t,[de,dn,du])
    xlabel('Minutes Since First Epoch');ylabel('Delta [m]'); legend('East','North','Up')
    title(['Error for ', rinex_file])
    subplot(2,1,2)
    plot(t,sigmas(:,1:3))
    xlabel('Minutes Since First Epoch');ylabel('STD'); legend('East','North','Up')
```

```
    title(['Error for ', rinex_file])

%     ecef2enuv()

    %------Remove data with '0' observation
    zs = rho_obs == 0;
    rho_obs(zs) = []; rho_model(zs) = [];
clear del_x H

end     % End Rinex File Iteration


%% Clean, Reformat
figure_awesome


%% SUPPORTING FUNCTION - Homework8_main.m
type('Homework8_main.m')

%% SUPPORTING FUNCTION - getSatGeomRange.m
type('getSatGeomRange.m')

%% SUPPORTING FUNCTION - date2GPSTime.m
type('date2GPSTime.m')

%% SUPPORTING FUNCTION - findNearestEphem.m
type('findNearestEphem.m')

%% SUPPORTING FUNCTION - calculateSatellitePosition.m
type('calculateSatellitePosition.m')

%% SUPPORTING FUNCTION - findFirstEpoch.m
type('findFirstEpoch.m')

%% SUPPORTING FUNCTION - getSatClockCorrection.m
type('getSatClockCorrection.m')

%% SUPPORTING FUNCTION - date2GPSTime.m
type('GPSTime2Date.m')

%% SUPPORTING FUNCTION - getTropoCorrection.m
type('getTropoCorrection.m')

fprintf('\nSim took %3.1f seconds to run\n',toc)
```

## SUPPORTING FUNCTION - getSatGeomRange.m

```
type('getSatGeomRange.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                         getSatGeomRange.m
% Author      : Zach Dischner
% Date        : 10/22/2013
% Description : calculate satellite position from GPS ephemeris dataset
%
%
```

```
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : rStation - GPS Rx [x,y,z] coords in ECEF meters
%                 GPS_Weeks - GPS Week time
%                 GPS_SOW - Seconds into week
%                 PRN - Satellite PRN
%                 nav_data - nx25 array of sat data from broadcase
%                   ephemeris
%                 params - structure containing keplarian specs and extra
%                           calculations for sat position
%
% Outputs       : R - Geometric Range value, in meters
%                 rel_dt - clock offset due to relativity (in seconds)
%                 rSat - 3d ECI coordinates of satellite [x,y,z]
%
% History       October 11 2013 - First Rev
%               October 24 2013 - Reformatted output to [R,tk]
%                               - Added check for time field in params,
%                                 other that that in the ephemeris data
%               October 30 2013 - Reformatted output to include XYZ sat
%                                 position
%
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
function [R, rel_dt, rSat] = getSatGeomRange(rStation, GPS_Weeks, GPS_SOW, PRN, nav_data, params)

%------Find Nearest Ephemeris
[epochData,rows] = findNearestEphem(PRN, GPS_Weeks, GPS_SOW, nav_data);
SOW_col = 20;
% Single Row in this case

%------Get Sat Position from Ephemeris data
[rSat,rel_dt] = calculateSatellitePosition(epochData, params);


%------Set up convergence limits
R = 0;
conv_limit = 1e-15;
max_iters = 200;
iter = 1;

%------Iterate and converge on Geometric Range
while(1)
    %------Calculate Geometric Range
    Rtmp = norm( rSat - rStation );

    %------Check for Convergence
    if(abs(Rtmp - R) < conv_limit)
        break
    end

    %------Assign new Range Value now that criterion are passed
    R = Rtmp;
```

```
    %------Check for iteration limit
    if(iter > max_iters)
        fprintf(2,'YO BRO!! Range Calculation not converging!\n')
        break
    end

    %------Increase iteration count
    iter = iter + 1;

    %------Calculate 'Tt', time of transmission
    dt = R/params.c;
%     Tr = epochData(SOW_col);
    Tr = GPS_SOW;
    Tt = Tr - dt;

    %------Recalculate Satellite position
    params.Secs = Tt;
    % to use new time value
    [rSat,rel_dt,params] = calculateSatellitePosition(epochData,params);

    %------Rotate Sat position at time Tr (account for earth's rotation)
    phi = params.we*dt;
    rSat = transpose(rot3(phi)*rSat');

end
rmfield(params,'E_guess');
```

## SUPPORTING FUNCTION - date2GPSTime.m

```
type('date2GPSTime.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                         date2GPSTime.m
% Author      : Zach Dischner
% Date        : 10/11/2013
% Description : Convert a date type object into [GPS_Weeks, GPS_SOW] time
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `"""""""""""""""""| |""` [_""_-____________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : utcDate - Satellite PRN number
%
% Outputs       : [GPS_Weeks, GPS_SOW]-weeks and seconds of week
%
% TODOS         : Vectorize!
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
function [GPS_Weeks, GPS_SOW] = date2GPSTime(utcDate)
```

```
gps_week_start = 'January 6 1980 00:00:00';
modnum = 0; % modnum = 0 for no modulo
tmp = mod((datenum(utcDate) - datenum(gps_week_start))/7,modnum); % (Difference in days)/7 = difference
in weeks
GPS_Weeks = floor(tmp);
GPS_SOW = round((tmp-GPS_Weeks)*7*24*3600);
```

## SUPPORTING FUNCTION - findNearestEphem.m

```
type('findNearestEphem.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        findNearestEmph.m
% Author      : Zach Dischner
% Date        : 10/11/2013
% Description : Function to return all emphimeris data from a nav data
%               array
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : PRN - Satellite PRN number
%                 GPSWeeks - GPS week number (modded or no?)
%                 GPSSOW - GPS Seconds of week
%                 navData - A full array of all emphimeris data, fetched
%                            from navigation file
% Outputs       : emphData - Single row (struct?) of emphemeris data per
%                            sat PRN at time [gps_weeks, gps_seconds
%
% History       Oct 11 2013 - First Version
%               Oct 22 2013 - Added return for rownums
%               Oct 24 2013 - Changed PRN matching to ismember(), to allow
%                                for array matching of PRNs
%               Oct 31 2013 - Changed all terms to datenums, to account for
%                                week changeover
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

function [ephemData,rownums] = findNearestEphem(PRN, GPS_Weeks, GPS_SOW, navData)

% weeknums = nav_ephem(:,19);
% secofweeks = nav_ephem(:,17)
% sec_diff = abs(navData(:,17)-GPS_SOW);
% rownums = find( (sec_diff) == min(sec_diff) & ismember(navData(:,1),PRN) & navData(:,19)==GPS_Weeks);
% rownums = find( navData(:,17)<=GPS_SOW & ismember(navData(:,1),PRN) & navData(:,19)==GPS_Weeks);
GPSNUMBOOL = 1;
epoch_time = GPSTime2Date(GPS_Weeks, GPS_SOW, GPSNUMBOOL);
nav_time   = GPSTime2Date(navData(:,19),navData(:,17), GPSNUMBOOL);
datediff = abs(nav_time-epoch_time);
rownums = (datediff==min(datediff) & ismember(navData(:,1),PRN));
```

```
ephemData = navData(rownums,:);
```

## SUPPORTING FUNCTION - calculateSatellitePosition.m

```
type('calculateSatellitePosition.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        calculateSatellitePosition.m
% Author      : Zach Dischner
% Date        : 10/24/2013
% Description : calculate satellite position from GPS ephemeris dataset
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--.._____
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : ephem - Satellite ephemeris dataset
%                 params - structure containing keplarian specs and extra
%                           calculations for sat position
%
% Outputs       : [rk]-3d ECI coordinates of satellite
%
% History       October 11 2013 - First Rev
%               October 24 2013 - Reformatted output to [rk,tk]
%               October 30 2013 - Added params to return, check for a
%                                   better Ek guess (to speed up 'find')
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
function [rk,dt_rel, params] = calculateSatellitePosition(ephem,params)

%-----Extract all ephemeris components to make life easy and epicer
ephem = num2cell(ephem);
[prn,M0,delta_n,ecc,sqrt_a,Loa,incl,perigee,ra_rate,i_rate,Cuc,Cus,Crc,Crs,Cic,Cis,...
    Toc,IODE,GPS_week,Toc,Af0,Af1,Af2,nil,health] = deal(ephem{:});
A = sqrt_a^2;
%------Correct Mean Motion
n0  = sqrt(params.mu/(A)^3); % Calculated mean motion [rad/s]
n   = n0 + delta_n;                 % Corrected Mean Motion

%------Correct Time
tk  = params.Secs-Toc;

%------Mean Anomaly
Mk = M0 + n*tk; % Mean anomaly

%------Eccentric Anomaly
if isfield(params,'E_guess')
    guess=params.E_guess;
else
    guess=0;
end
```

```
Ek = fsolve(@(Ek) (Ek)-ecc*sin(Ek)-Mk,guess,params.options);
params.E_guess = Ek;

%------True Anomaly
vk = atan2(      (sqrt(1-ecc^2)*sin(Ek)/(1-ecc*cos(Ek))), ...
                      ((cos(Ek)-ecc)/(1-ecc*cos(Ek)))   );

%------Argument of Latitude
Phik = vk + perigee;

%------Second Harmonic Perturbations
del_uk = Cus*sin(2*Phik) + Cuc*cos(2*Phik);
del_rk = Crs*sin(2*Phik) + Crc*cos(2*Phik);
del_ik = Cis*sin(2*Phik) + Cic*cos(2*Phik);

%------Corrected argumet of latitude, radius, inclination
uk = Phik + del_uk;
rk = A*(1-ecc*cos(Ek)) + del_rk;
ik = incl + del_ik + i_rate*tk;

%------Position in Orbit Plane
xkp = rk*cos(uk);
ykp = rk*sin(uk);

%------Corrected Longitude of ascending node
Omegak = Loa + (ra_rate - params.we)*tk - params.we*Toc;

%------Earth Fixed Coordinates
xk = xkp * cos(Omegak) - ykp * cos(ik) * sin(Omegak);
yk = xkp * sin(Omegak) + ykp * cos(ik) * cos(Omegak);
zk = ykp * sin(ik);

%------Relativity time shift
dt_rel = 2*sqrt(params.mu)/params.c^2 * ecc * sqrt_a * sin(Ek);
rk = [xk,yk,zk];
```

## SUPPORTING FUNCTION - findFirstEpoch.m

```
type('findFirstEpoch.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        findFirstEpoch.m
% Author      : Zach Dischner
% Date        : 10/24/2013
% Description : Function to return all emphimeris data from a nav data
%               array
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--.._____
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : navData - Navigation dataset.
% Outputs       : emphData - rows (struct?) of emphemeris data for
%                            the first epoch
%                 rows - row indices of the first epoch datasets
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

function [emphData,rows] = findFirstEpoch( navData )

weeknums = navData(:,19);
secofweeks = navData(:,17);

n_epochs = length(navData);
epochs = zeros(n_epochs,1);
for ii =1:n_epochs
    epochs(ii) = datenum(GPSTime2Date(weeknums(ii),secofweeks(ii)));
end

rows    = find(epochs==min(epochs));
emphData = navData(rows,:);
```

## SUPPORTING FUNCTION - getSatClockCorrection.m

```
type('getSatClockCorrection.m')
```

```
function [tcorr] = getSatClockCorrection(GPS_Weeks, GPS_SOW, PRN, nav_data)
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        getSatClockCorrection.m
% Author      : Zach Dischner
% Date        : 10/24/2013
% Description : Function to return all emphimeris data from a nav data
%               array
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--.._____
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
```

```
%                                `"'-.    """""  \\/
%                                     `"""""""""""`
% Inputs         : PRN - Satellite PRN number
%                  GPSWeeks - GPS week number (modded or no?)
%                  GPSSOW - GPS Seconds of week
%                  navData - A full array of all emphimeris data, fetched
%                             from navigation file
% Outputs        : t_corr - Satellite clock correction
%
% History        Oct 24 2013 - First Rev
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

%------Get ephemeris dataset
[eph_data,tmp] = findNearestEphem(PRN, GPS_Weeks, GPS_SOW, nav_data);

%------Define readibility indices
Af0_col = 21;   %Af0, satellite clock bias (sec)
Af1_col = 22;   %Af1, satellite clock drift (sec/sec)
Af2_col = 23;   %Af2, satellite clock drift rate (sec/sec/sec)
SOW_col = 17;   %Toe, reference time ephemeris (seconds into GPS week)

%------Fetch Correction Constants
Af0 = eph_data(Af0_col);
Af1 = eph_data(Af1_col);
Af2 = eph_data(Af2_col);

t_eph = eph_data(SOW_col);
dt = GPS_SOW - t_eph;

%------Calculate clock correction
tcorr = Af0 + Af1*(dt) + Af2*(dt)^2;

end %function
```

## SUPPORTING FUNCTION - date2GPSTime.m

```
type('GPSTime2Date.m')
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                        GPSTime2Date.m
% Author      : Zach Dischner
% Date        : 10/24/2013
% Description : Convert a date type object into [GPS_Weeks, GPS_SOW] time
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--.._____
%                  `"""""""""""""""""| |""` [_""_-___________"_/
%                                    | |   /..../`'-._.-'`
%                                ____| |__/::..'_
%                               |\ ".`"` '_____//\
%                               `"'-.    """""  \\/
%                                    `"""""""""""`
```

```
% Inputs        : [GPS_Weeks, GPS_SOW]-weeks and seconds of week
%
% Outputs       : utcDate - Satellite PRN number
%
% TODOS         : Vectorize!
%                 Build in mod options
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
function utcDate  = GPSTime2Date(GPS_Weeks, GPS_SOW, GPSNUM_BOOL)
% gps_week_start = 'January 6 1980 00:00:00';
gps_weeks_start = 723186;   % datenum(gps_week_start) Save time
%------GPS date in numerical form, since Matlab's 'epoch'
GPS_Num = (GPS_Weeks+GPS_SOW/7/24/3600)*7 + gps_weeks_start;
if nargin == 3
    if GPSNUM_BOOL == 1
        utcDate = GPS_Num;
    else
        utcDate = datestr(datevec(GPS_Num));
    end
else
    utcDate = datestr(datevec(GPS_Num));
end
```

## SUPPORTING FUNCTION - getTropoCorrection.m

```
type('getTropoCorrection.m')

fprintf('\nSim took %3.1f seconds to run\n',toc)
```

```
%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
%                         getTropoCorrection.m
% Author      : Zach Dischner
% Date        : 10/30/2013
% Description : Retrieve tropospheic correction from simple model (in
%               meters)
%
%
%                 __...____________________          ,
%                `(\ [ ===NCC-1700===--|__|) ___..--"_`--..______
%                  `""""""""""""""""| |""` [_""_-___________"_/
%                                   | |   /..../`'-._.-'`
%                               ____| |__/::..'_
%                              |\ ".`"` '_____//\
%                              `"'-.   """""  \\/
%                                    `""""""""""`
% Inputs        : ZenithCorr - Zenith delay [meters]
%                 el - elevation angle in degrees
%
% Outputs       : TropoDelay - Delay value [meters]
%
% History       October 30 2013 - First Rev
%
% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

function TropoDelay = getTropoCorrection(ZenithCorr, el)
TropoDelay = abs(ZenithCorr/sind(el));
```

```
Sim took 306.9 seconds to run
```

*Published with MATLAB® R2013b*