GPX History Analysis

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Clear workspace

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

General variables

```
data_path = './data/';
```

Geohits data analysis

Load GPX data for the analysis

```
gpx_data = readtable(strcat(data_path,'gpx_info_processed.csv'))
```

gpx_data = 3414951×5 table

	ID	dt	latitude	longitude	elevation
1	1.0366e+09	0	40.5889	-4.9664	1.1322e+03
2	1.0366e+09	39	40.5890	-4.9664	1132
3	1.0366e+09	53	40.5889	-4.9664	1.1321e+03
4	1.0366e+09	55	40.5889	-4.9664	1.1321e+03
5	1.0366e+09	58	40.5889	-4.9664	1.1321e+03
6	1.0366e+09	61	40.5888	-4.9663	1.1321e+03
7	1.0366e+09	101	40.5888	-4.9664	1.1321e+03
8	1.0366e+09	103	40.5889	-4.9664	1.1321e+03
9	1.0366e+09	105	40.5889	-4.9664	1.1321e+03
10	1.0366e+09	107	40.5889	-4.9664	1.1321e+03
11	1.0366e+09	108	40.5890	-4.9664	1132
12	1.0366e+09	109	40.5890	-4.9663	1132
13	1.0366e+09	110	40.5890	-4.9663	1.1319e+03
14	1.0366e+09	111	40.5891	-4.9663	1.1319e+03

⋮

```
position_tbl = gpx_data(:,["latitude", "longitude"])
```

position_tbl = 3414951×2 table

	latitude	longitude
1	40.5889	-4.9664

	latitude	longitude
2	40.5890	-4.9664
3	40.5889	-4.9664
4	40.5889	-4.9664
5	40.5889	-4.9664
6	40.5888	-4.9663
7	40.5888	-4.9664
8	40.5889	-4.9664
9	40.5889	-4.9664
10	40.5889	-4.9664
11	40.5890	-4.9664
12	40.5890	-4.9663
13	40.5890	-4.9663
14	40.5891	-4.9663

⋮

```
min(position_tbl.latitude)
```

```
ans = 40.2085
```

```
max(position_tbl.latitude)
```

```
ans = 51.5368
```

```
min(position_tbl.longitude)
```

```
ans = -9.2110
```

```
max(position_tbl.longitude)
```

```
ans = 12.2329
```

```
min(gpx_data.elevation)
```

```
ans = -1.7000
```

```
max(gpx_data.elevation)
```

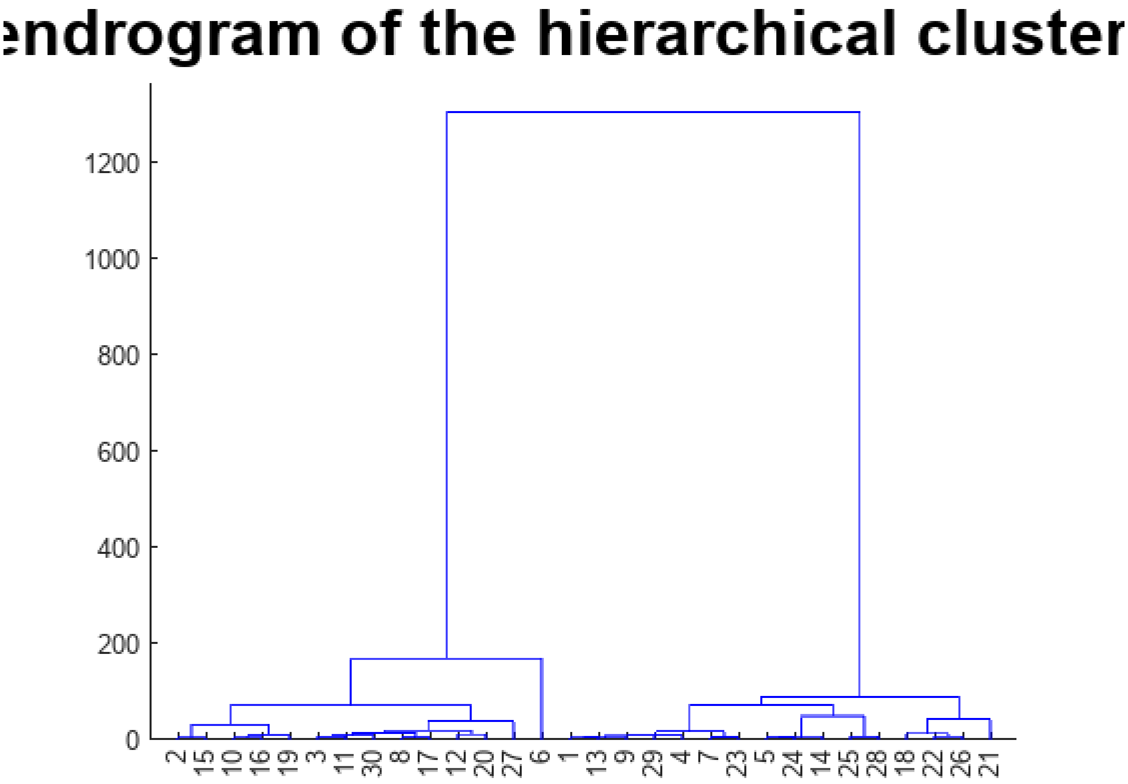
```
ans = 2.8523e+03
```

Try clustering methods

Hierarchical clustering

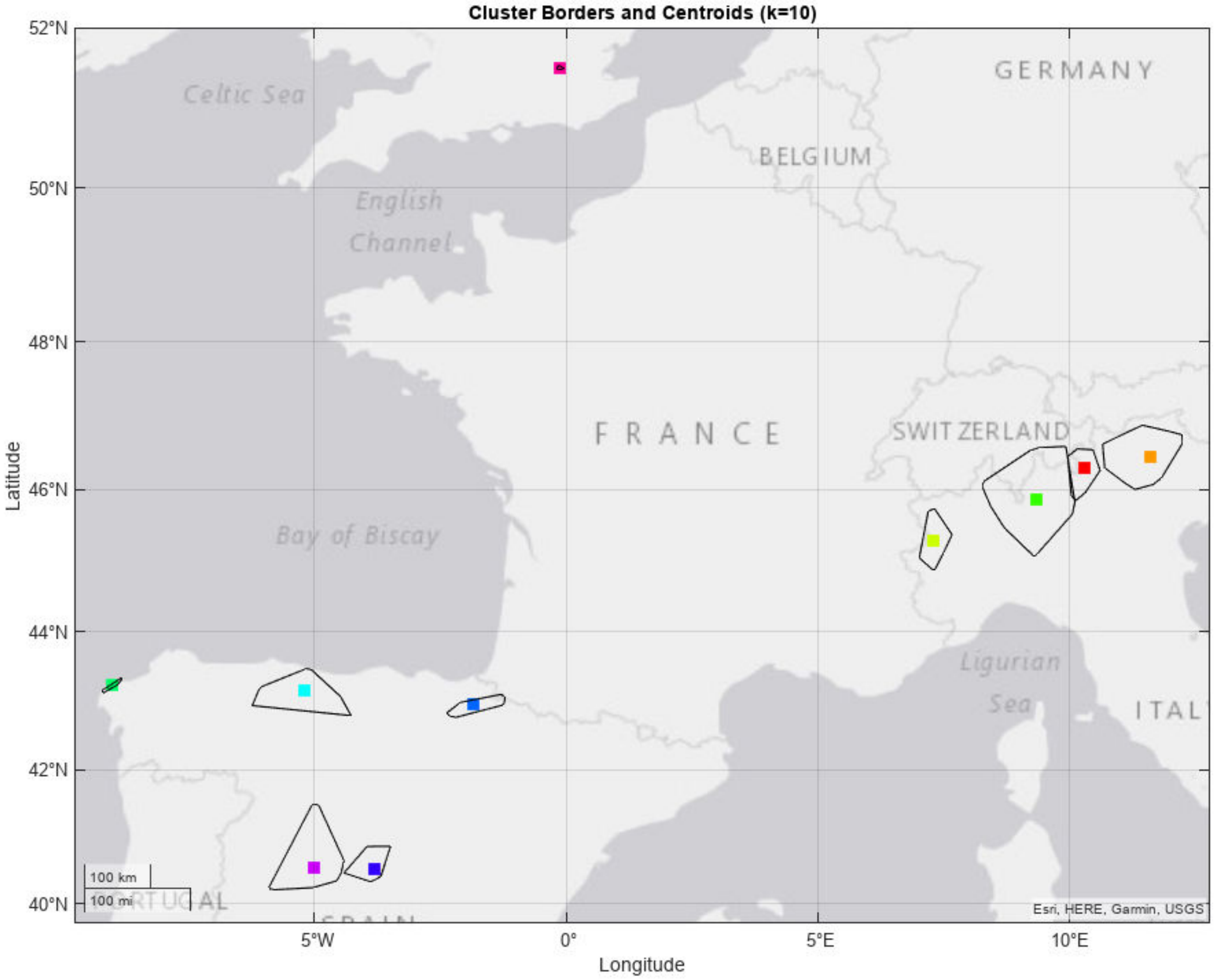
```

% Downsample data using random sampling ( memory issues)
sample_size = 0.005; % Sample 0.5% of the data
```

```
idx = randsample(height(position_tbl), round(height(position_tbl) * sample_size));
position_array = table2array(position_tbl(idx,:));

% Compute pairwise distance using the 'great_circle_distance' distance measure
% D = pdist(position_array, @great_circle_distance);
D = pdist(position_array, "euclidean");

% Perform hierarchical clustering
Z = linkage(D, "ward");

% Plot the dendrogram
figure
dendrogram(Z);
title('Dendrogram of the hierarchical clustering', FontSize=24)
saveas(gcf,strcat('Figures/hier_dendrogram.png') )
hold off
```



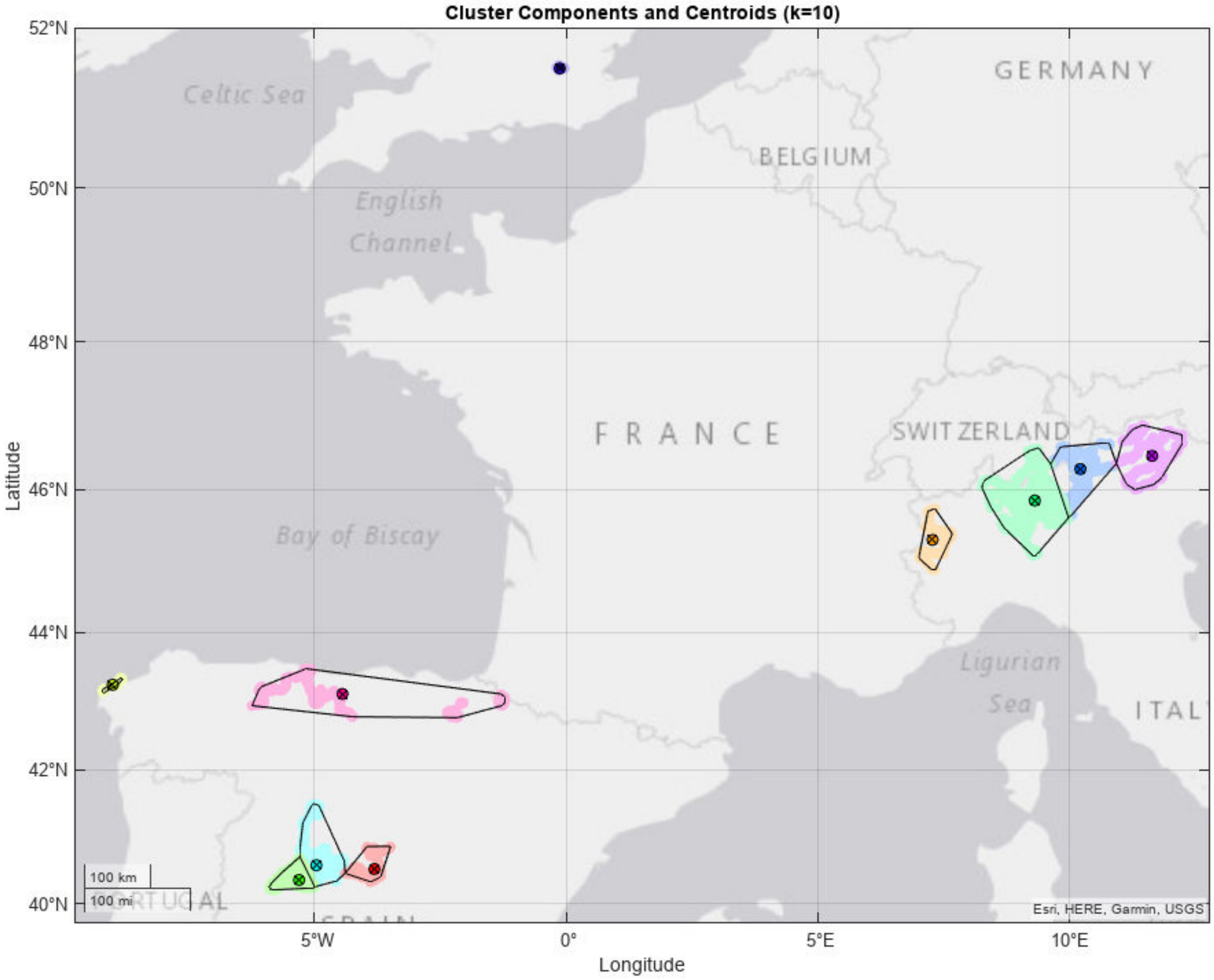
Get centroids and borders

```
% Assign points to clusters using the 'cutree' method
for k = 2:10 % Number of clusters
    T = cluster(Z, 'maxclust', k);

    % Loop over clusters
    centroids = zeros(k, size(position_array,2)); % Initialize centroids array
    borders = cell(k,1); % Initialize borders cell array
    for i = 1:k
        % Extract points in cluster i
        points = position_array(T==i,:);

        % Compute centroid of cluster i
        centroids(i,:) = mean(points,1);

        % Compute convex hull of cluster i
        K = convhull(points(:,1), points(:,2));

        % Store convex hull in borders cell array
        borders{i} = points(K,:);
    end

    %% Plot the clusters

    % Set color map
    colors = hsv(k); % Default Matlab color map

    % Plot the centroids of the clusters
    i = 1;
    geoscatter(centroids(i,1),centroids(i,2),'MarkerEdgeColor', colors(i,:), 'MarkerFaceColor',
    hold on
    for i = 2:k
        geoscatter(centroids(i,1),centroids(i,2),'MarkerEdgeColor', colors(i,:), 'MarkerFaceCol
    end

    % Plot the borders of the clusters
    for i = 1:k
        % Extract points in cluster i
        points = borders{i};

        % Plot the convex hull of cluster i with transparent fill
        geoplot(points(:,1), points(:,2), 'k');
    end

    % Configure plot
    hold off
    % axis equal
    % xlabel('Longitude');
    % ylabel('Latitude');
    title(strcat('Cluster Borders and Centroids (k=',num2str(k),')'), FontSize=24);
    set(gcf, 'Position', [0 0 1200 900])
    % legend(Location='eastoutside')
    saveas(gcf,strcat('Figures/hier_clusters_k',num2str(k),'.png') )
end
```

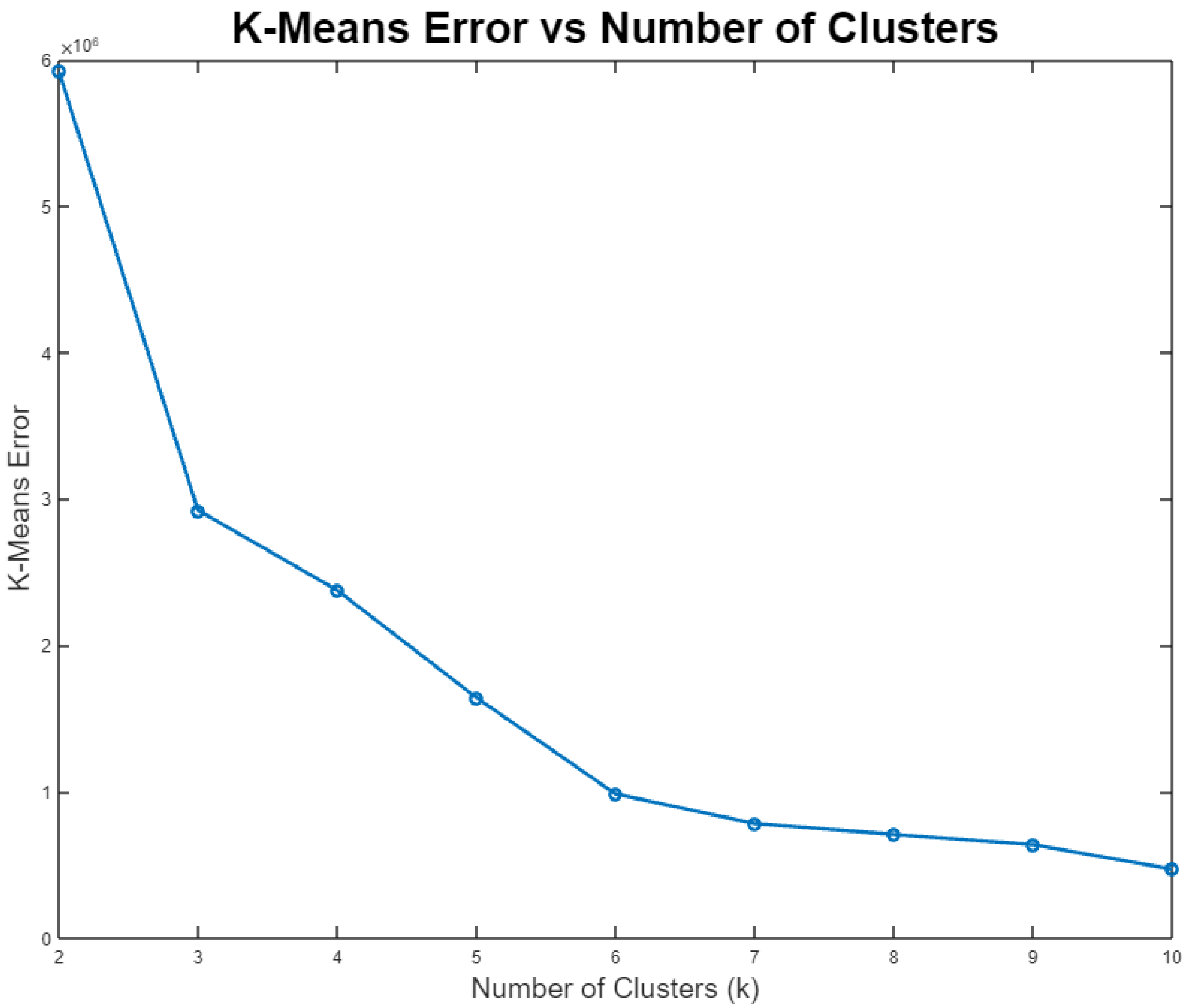


Kmeans

```
% Compute k-means clustering for different values of k
k_values = 2:10;
errors = zeros(size(k_values));
for ii = 1:length(k_values)
    k = k_values(ii);
    [idx, C, sumd] = kmeans(table2array(position_tbl), k);
    errors(ii) = sum(sumd);

    borders = cell(k,1); % Initialize borders cell array
    for i = 1:k
        % Extract points in cluster i
        points = table2array(position_tbl(idx==i,:));

        % Compute convex hull of cluster i
        K = convhull(points(:,1), points(:,2));
        % Store convex hull in borders cell array
        borders{i} = points(K,:);
    end

    %
    colors = hsv(k); % Default Matlab color map
    geoscatter(position_tbl(idx==1,:),'latitude','longitude','filled','MarkerFaceColor',1-color
    hold on
    for jj = 2:k
        geoscatter(position_tbl(idx==jj,:),'latitude','longitude','filled','MarkerFaceColor',1-
    end
    for jj = 1:k
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerFaceColor',1-colors(jj,:),'MarkerEdgeColor',
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerEdgeColor','k', 'Marker','x')
    end
    % Plot the borders of the clusters
    for i = 1:k
        % Extract points in cluster i
        points = borders{i};

        % Plot the convex hull of cluster i with transparent fill
        geoplot(points(:,1), points(:,2), 'k');
    end
    hold off
    title(strcat('Cluster Components and Centroids (k=',num2str(k),')'), FontSize=24);
    set(gcf, 'Position', [0 0 1200 900])
    % legend(Location='eastoutside')
    saveas(gcf,strcat('Figures/kmeans_clusters_k',num2str(k),'.png') )
end
```



```
% Plot the results
plot(k_values, errors, '-o', 'LineWidth', 2);

% Configure plot
xlabel('Number of Clusters (k)', FontSize=16);
ylabel('K-Means Error', FontSize=16);
title('K-Means Error vs Number of Clusters', FontSize=24);
saveas(gcf,strcat('Figures/kmeans_errors.png') )
```



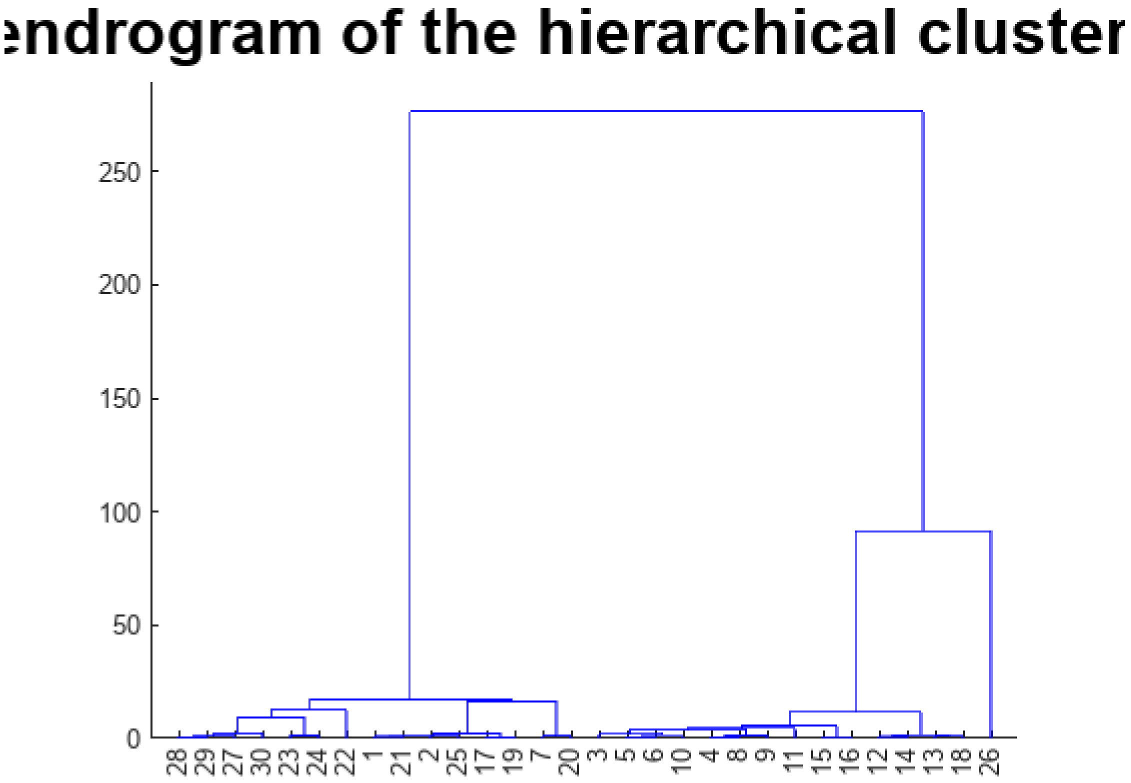
Focus on start/end points

```
% Get starting points (dt==0)
idx_s = gpx_data.dt==0;
% As activities are concatenated, before every start point the table stores
% the end point of previous activity
idx_end = circshift(idx_s,-1);
% Combine both indexes
idx = idx_s | idx_end;

position_array = table2array(position_tbl(idx,:));
```

Hierarchical clustering

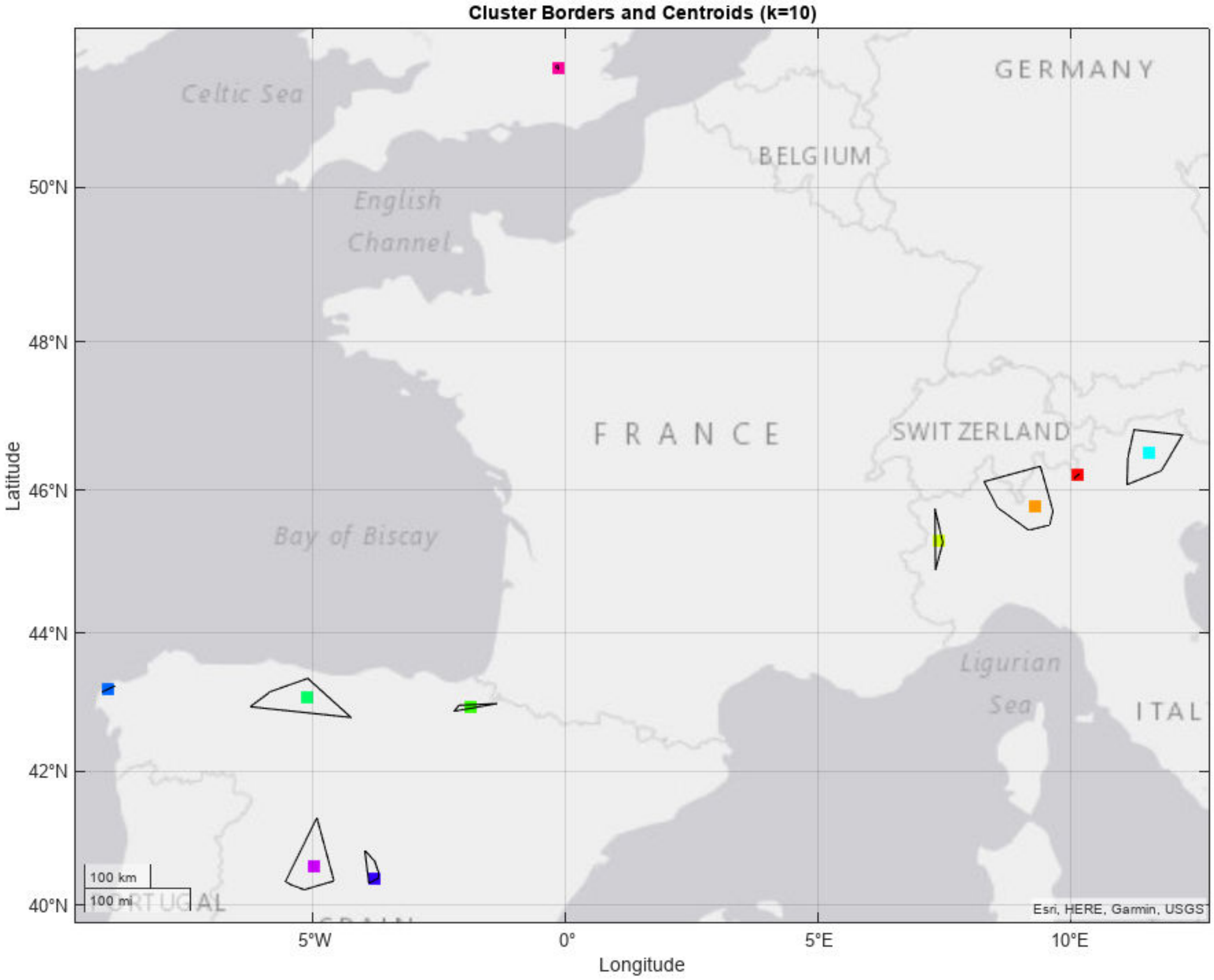
```
% Compute pairwise distance using the 'great_circle_distance' distance measure
% D = pdist(position_array, @great_circle_distance);
D = pdist(position_array, "euclidean");
```

```
% Perform hierarchical clustering
Z = linkage(D, "ward");

% Plot the dendrogram
figure
dendrogram(Z);
title('Dendrogram of the hierarchical clustering', FontSize=24)
saveas(gcf,strcat('Figures/hier_dendrogram_startend.png') )
```



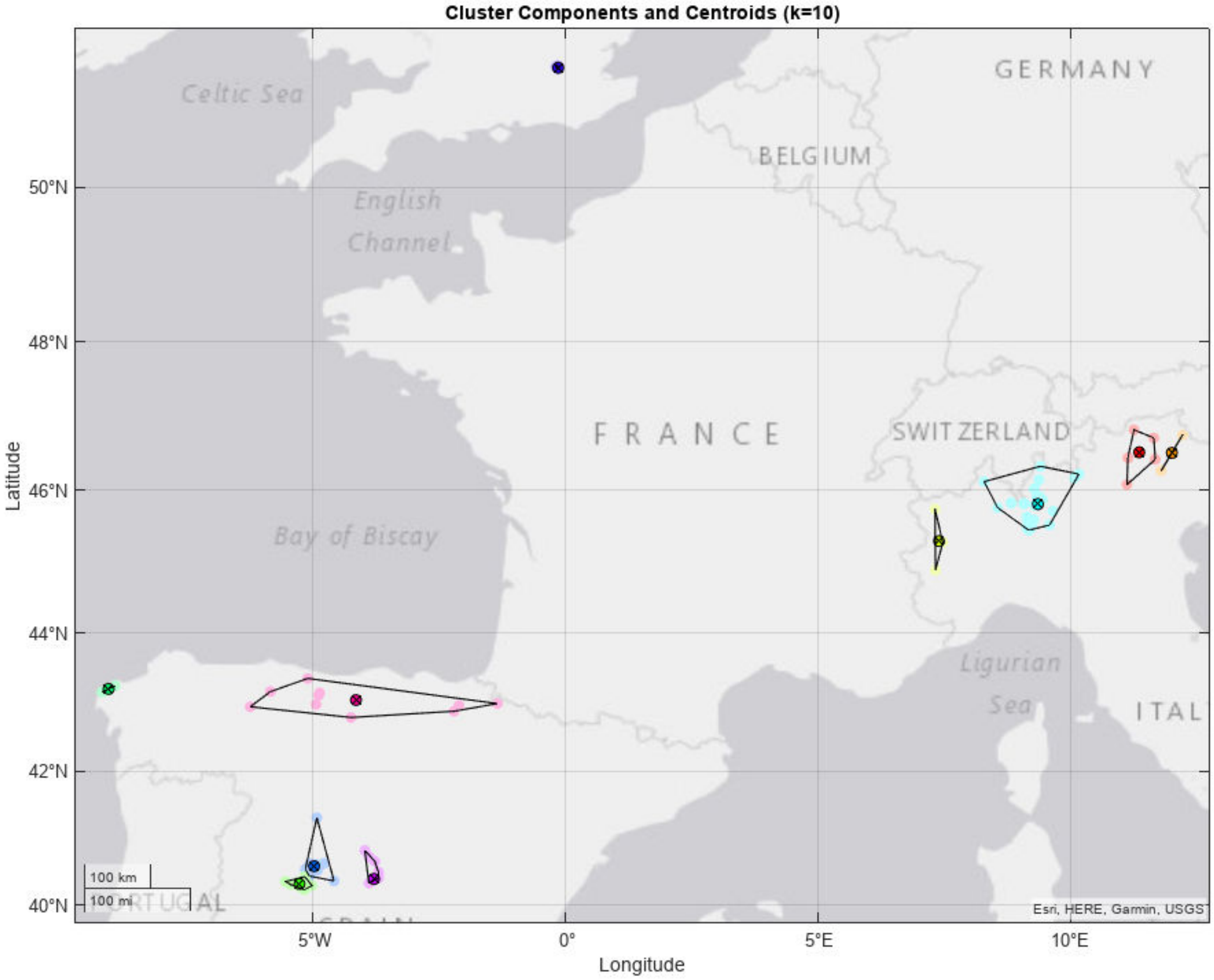
Get centroids and borders

```
% Assign points to clusters using the 'cutree' method
for k = 2:10 % Number of clusters
    T = cluster(Z, 'maxclust', k);

    % Loop over clusters
    centroids = zeros(k, size(position_array,2)); % Initialize centroids array
    borders = cell(k,1); % Initialize borders cell array
    for i = 1:k
        % Extract points in cluster i
        points = position_array(T==i,:);

        % Compute centroid of cluster i
        centroids(i,:) = mean(points,1);

        % Compute convex hull of cluster i
        K = convhull(points(:,1), points(:,2));
        % Store convex hull in borders cell array
        borders{i} = points(K,:);
    end

    %% Plot the clusters

    % Set color map
    colors = hsv(k); % Default Matlab color map

    % Plot the centroids of the clusters
    i = 1;
    geoscatter(centroids(i,1),centroids(i,2),'MarkerEdgeColor', colors(i,:), 'MarkerFaceColor',
    hold on
    for i = 2:k
        geoscatter(centroids(i,1),centroids(i,2),'MarkerEdgeColor', colors(i,:), 'MarkerFaceCol
    end

    % Plot the borders of the clusters
    for i = 1:k
        % Extract points in cluster i
        points = borders{i};

        % Plot the convex hull of cluster i with transparent fill
        geoplot(points(:,1), points(:,2), 'k');
    end

    % Configure plot
    hold off
    % axis equal
    % xlabel('Longitude');
    % ylabel('Latitude');
    title(strcat('Cluster Borders and Centroids (k=',num2str(k),')'), FontSize=24);
    set(gcf, 'Position', [0 0 1200 900])
    % legend(Location='eastoutside')
    saveas(gcf,strcat('Figures/hier_clusters_startend_k',num2str(k),'.png') )
end
```

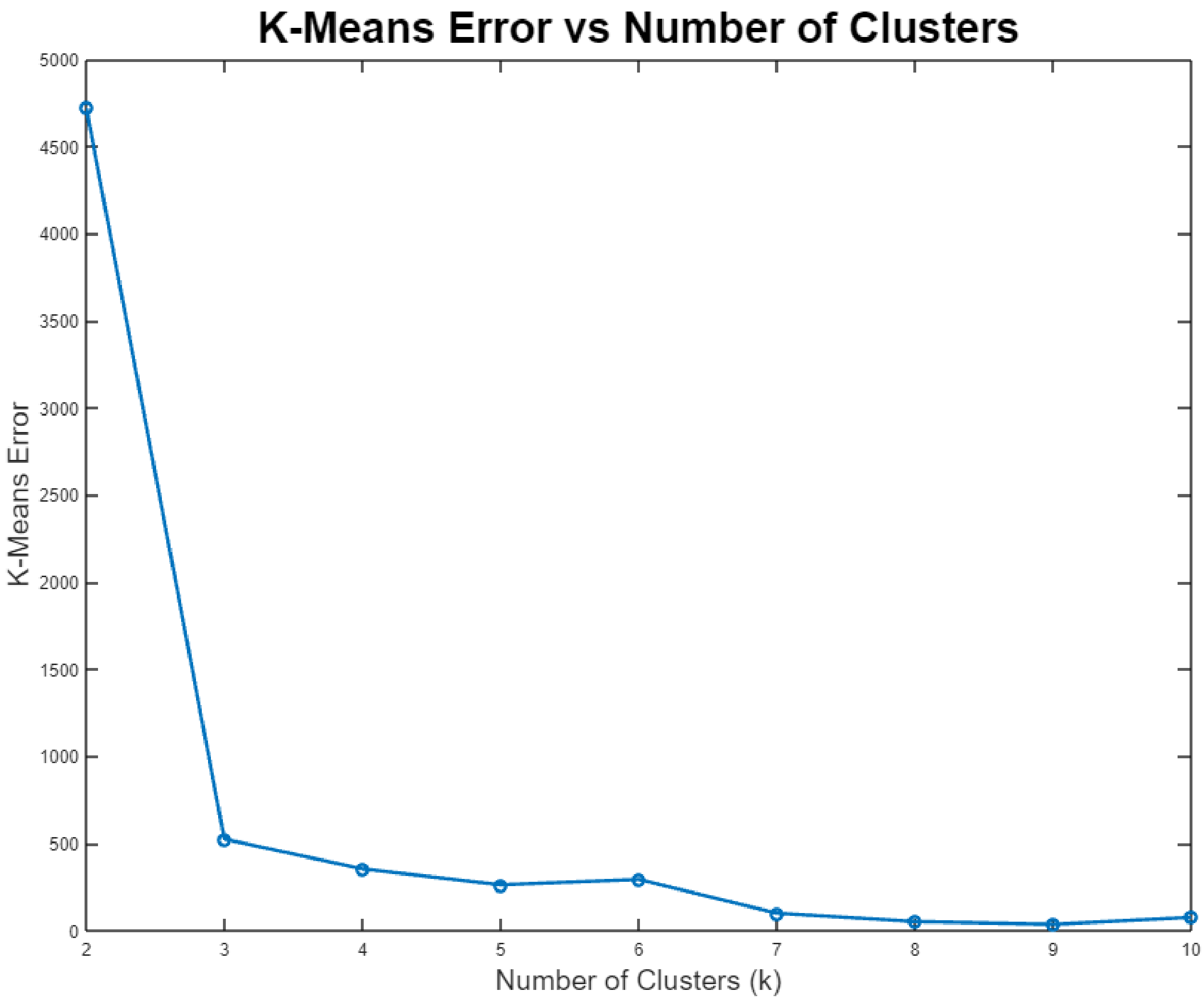


Kmeans

```
% Compute k-means clustering for different values of k
k_values = 2:10;
errors = zeros(size(k_values));
for ii = 1:length(k_values)
    k = k_values(ii);
    [idx, C, sumd] = kmeans(position_array, k);
    errors(ii) = sum(sumd);

    borders = cell(k,1); % Initialize borders cell array
    for i = 1:k
        % Extract points in cluster i
        points = position_array(idx==i,:);

        % Compute convex hull of cluster i
        K = convhull(points(:,1), points(:,2));
        % Store convex hull in borders cell array
        borders{i} = points(K,:);
    end
    %
    colors = hsv(k); % Default Matlab color map
    geoscatter(position_array(idx==1,1),position_array(idx==1,2),'filled','MarkerFaceColor',1-c
    hold on
    for jj = 2:k
        geoscatter(position_array(idx==jj,1),position_array(idx==jj,2),'filled','MarkerFaceColo
    end
    for jj = 1:k
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerFaceColor',1-colors(jj,:),'MarkerEdgeColor',
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerEdgeColor','k', 'Marker','x')
    end
    % Plot the borders of the clusters
    for i = 1:k
        % Extract points in cluster i
        points = borders{i};

        % Plot the convex hull of cluster i with transparent fill
        geoplot(points(:,1), points(:,2), 'k');
    end
    hold off
    title(strcat('Cluster Components and Centroids (k=',num2str(k),')'), FontSize=24);
    set(gcf, 'Position', [0 0 1200 900])
    % legend(Location='eastoutside')
    saveas(gcf,strcat('Figures/kmeans_clusters_startend_k',num2str(k),'.png') )
end
```



```
% Plot the results
plot(k_values, errors, '-o', 'LineWidth', 2);

% Configure plot
xlabel('Number of Clusters (k)', FontSize=16);
ylabel('K-Means Error', FontSize=16);
title('K-Means Error vs Number of Clusters', FontSize=24);
saveas(gcf,strcat('Figures/kmeans_errors_startend.png') )
```



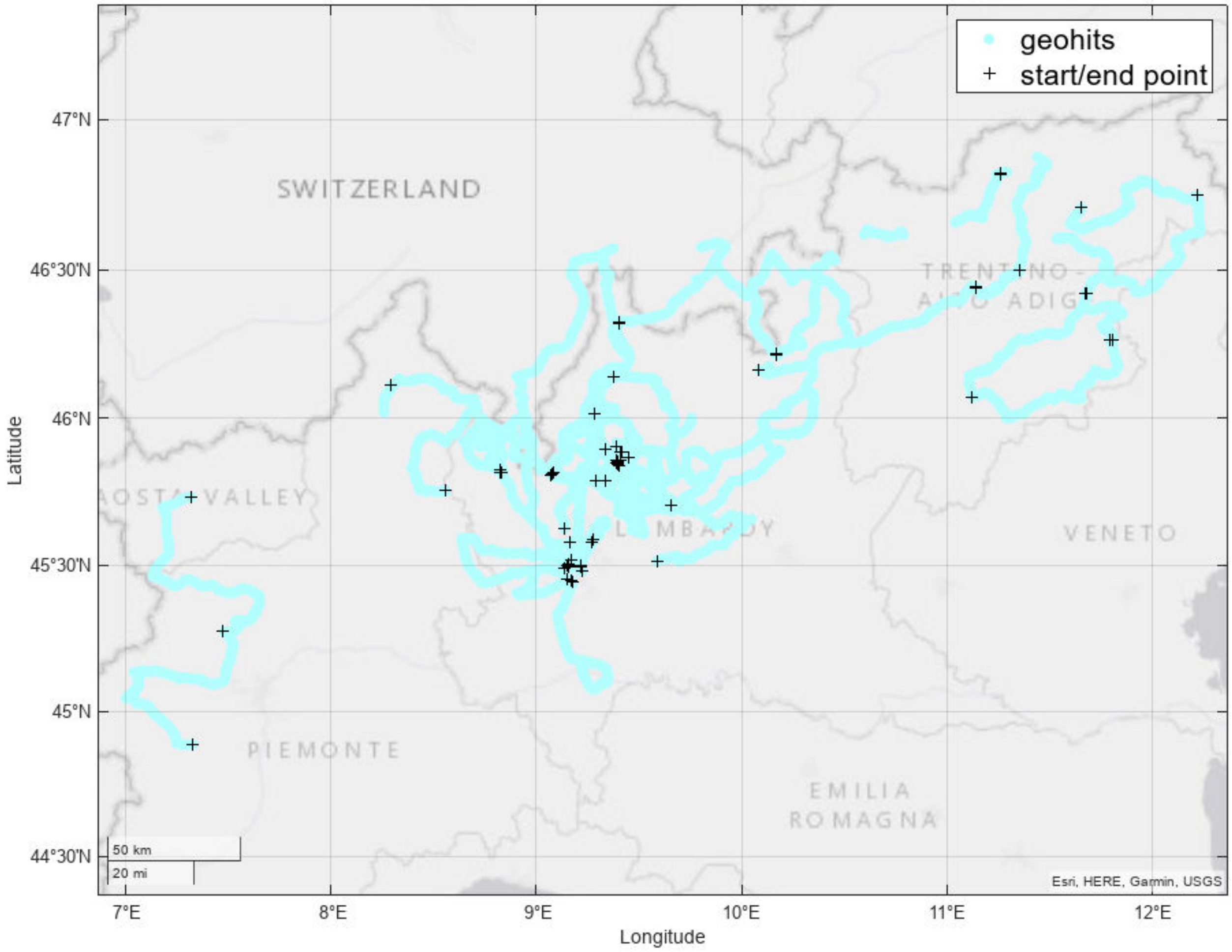
Privacy issues: frequent routes and home location

Focus on Italy activities for not revealing current home location

```
italy_gpx = gpx_data(gpx_data.longitude > 5,:);
italy_position = table2array(italy_gpx(:,["latitude", "longitude"]));

% Get starting points (dt==0)
idx_s = italy_gpx.dt==0;
% As activities are concatenated, before every start point the table stores
% the end point of previous activity
idx_end = circshift(idx_s,-1);
% Combine both indexes
idx = idx_s | idx_end;
italy_startend = italy_position(idx,:);
```

Plot those geopoints

```
colors = hsv(1);
% Plot points over OSM map
% webmap('OpenStreetMap')
geoscatter(italy_position(:,1), italy_position(:,2),'filled','MarkerFaceColor',1-colors(1,:)*0.
hold on
geoscatter(italy_startend(:,1), italy_startend(:,2),'Marker','+','MarkerEdgeColor','k')
hold off
legend('geohits','start/end point', FontSize=16)
set(gcf, 'Position', [0 0 1200 900])
saveas(gcf,strcat('Figures/geohits_italy.png') )
```

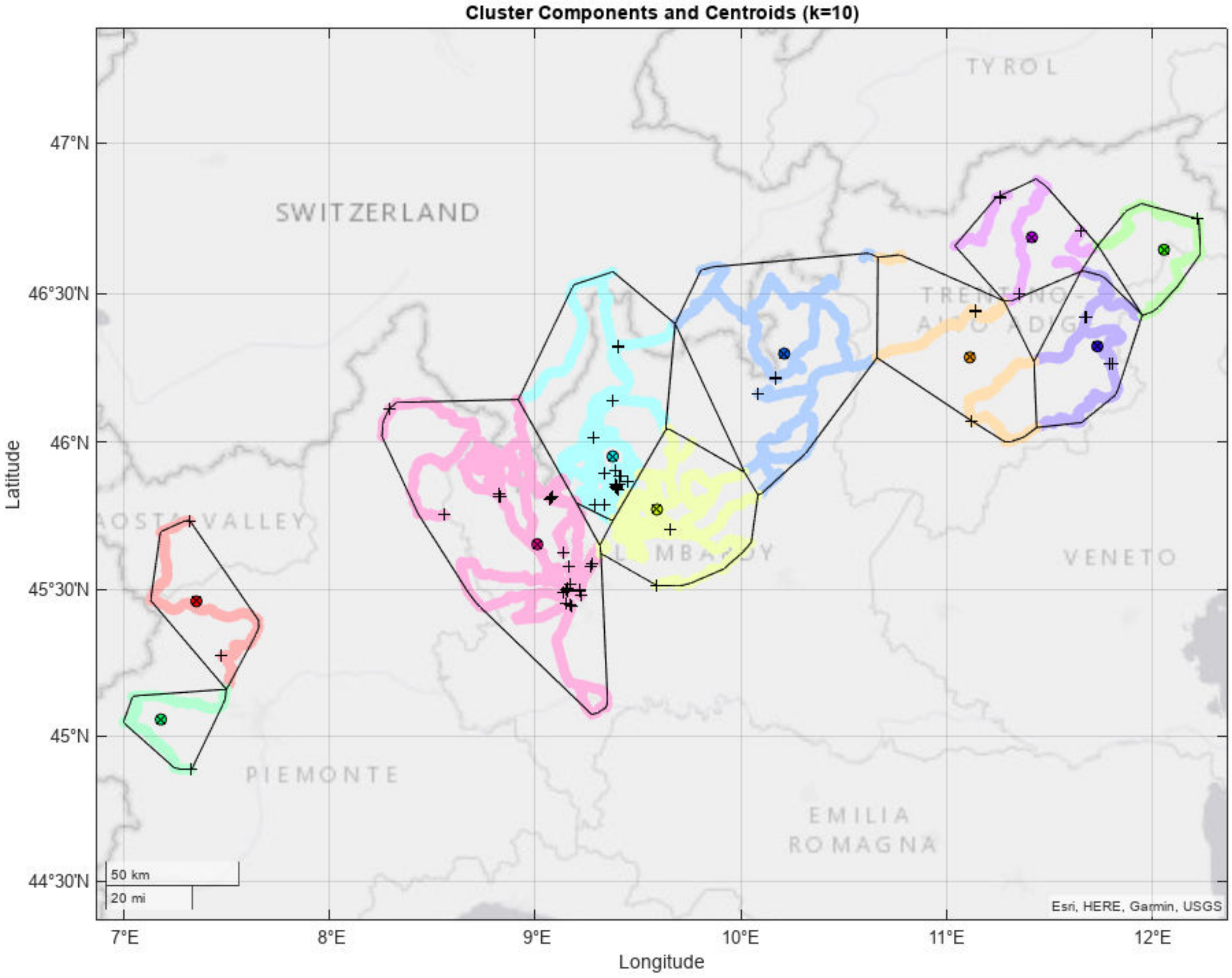


Artificially increase influence of start end points (repeating them N times)

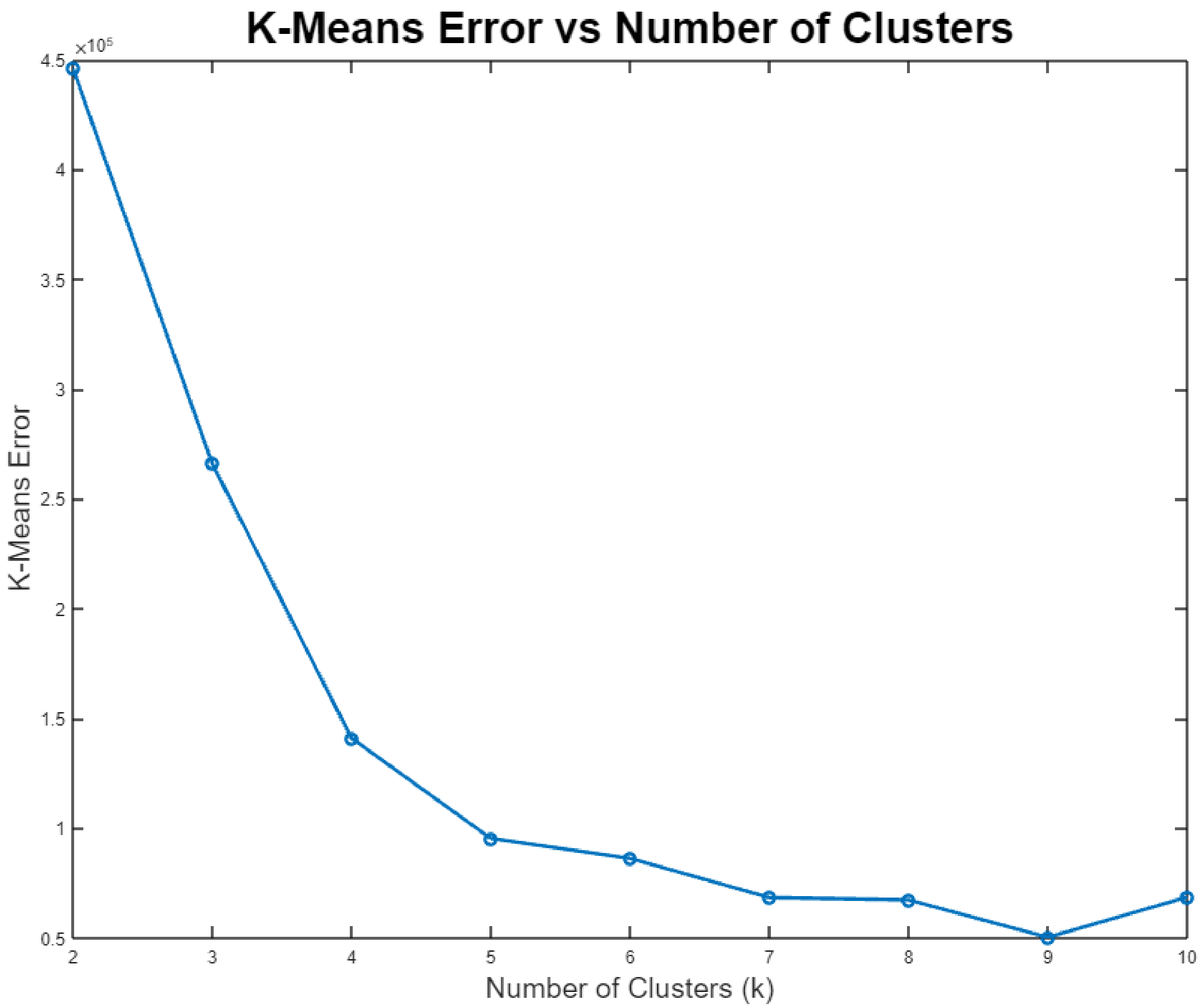
```
N = 1000;
positions_to_cluster = cat(1, italy_position, repmat(italy_startend, N, 1));
```

Clustering with Kmeans

```
% Compute k-means clustering for different values of k
k_values = 2:10;
errors = zeros(size(k_values));
startend_cluster = zeros(size(k_values,1),size(italy_startend,1));
for ii = 1:length(k_values)
    k = k_values(ii);
    [idx, C, sumd] = kmeans(positions_to_cluster, k);
    errors(ii) = sum(sumd);

    borders = cell(k,1); % Initialize borders cell array
    for i = 1:k
        % Extract points in cluster i
        points = positions_to_cluster(idx==i,:);

        % Compute convex hull of cluster i
        K = convhull(points(:,1), points(:,2));

        % Store convex hull in borders cell array
        borders{i} = points(K,:);
    end

    startend_cluster(ii,:) = idx(size(italy_position,1)+1:size(italy_position,1)+size(italy_sta
    %
    colors = hsv(k); % Default Matlab color map
    geoscatter(positions_to_cluster(idx==1,1),positions_to_cluster(idx==1,2),'filled','MarkerFa
    hold on
    for jj = 2:k
        geoscatter(positions_to_cluster(idx==jj,1),positions_to_cluster(idx==jj,2),'filled','Ma
    end
    for jj = 1:k
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerFaceColor',1-colors(jj,:),'MarkerEdgeColor',
        geoscatter(C(jj,1),C(jj,2),'filled','MarkerEdgeColor','k', 'Marker','x')
    end
    geoscatter(italy_startend(:,1), italy_startend(:,2),'Marker','+','MarkerEdgeColor','k')
    % Plot the borders of the clusters
    for i = 1:k
        % Extract points in cluster i
        points = borders{i};

        % Plot the convex hull of cluster i with transparent fill
        geoplot(points(:,1), points(:,2), 'k');
    end
    hold off
    title(strcat('Cluster Components and Centroids (k=',num2str(k),')'), FontSize=24);
    set(gcf, 'Position', [0 0 1200 900])
    % legend(Location='eastoutside')
    saveas(gcf,strcat('Figures/kmeans_clusters_italy_k',num2str(k),'.png') )
end
```

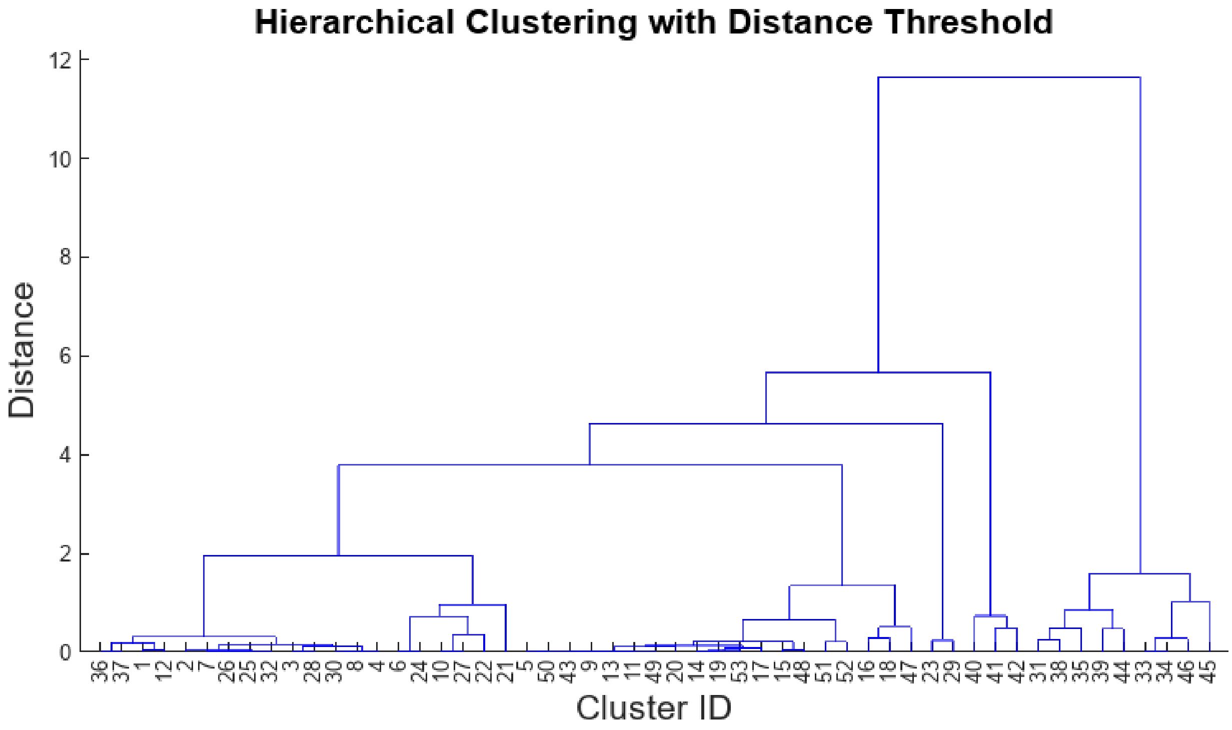


```
% Plot the results
plot(k_values, errors, '-o', 'LineWidth', 2);

% Configure plot
xlabel('Number of Clusters (k)', FontSize=16);
ylabel('K-Means Error', FontSize=16);
title('K-Means Error vs Number of Clusters', FontSize=24);
saveas(gcf,strcat('Figures/kmeans_errors_italy.png') )
```

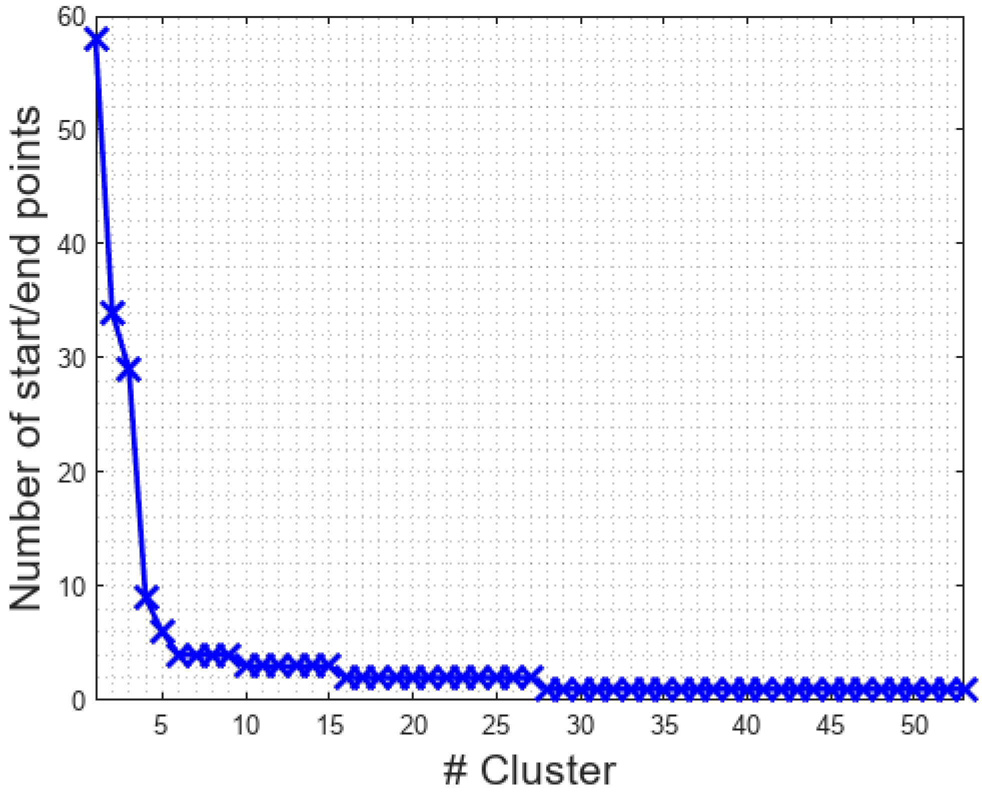


Hierarchical limiting distance threshold on startend

```
% Perform hierarchical clustering with distance threshold
D = pdist(italy_startend,"euclidean");
Z = linkage(D,'ward');

% Plot dendrogram
dendrogram(Z,53)

% Configure plot
title('Hierarchical Clustering with Distance Threshold', FontSize=16);
xlabel('Cluster ID', FontSize=16);
ylabel('Distance', FontSize=16);
set(gcf, 'Position', [0 0 900 450])
saveas(gcf,strcat('Figures/hier_dendrogram_small_clusters_italy.png') )
```



```
% Get very close start/end points to form clusters where elements are less
% than 1km away
T = cluster(Z,"cutoff", km2deg(1), 'criterion', 'distance');

% Count the number of points in each cluster
counts = histcounts(T,max(T));

% Sort clusters by the number of points
[counts, idx] = sort(counts, 'descend');

figure
plot(counts,'-x', color='b', Linewidth=2, Markersize=12)
grid("minor")
xlabel('# Cluster', FontSize=16)
ylabel('Number of start/end points', FontSize=16)
xlim([1,max(T)])
saveas(gcf,strcat('Figures/hier_small_clusters_italy.png') )
```



```
% Get the 3 clusters with the most appearances
top_clusters = idx(1:3)
```

```
top_clusters = 1×3
     6     2     8
```

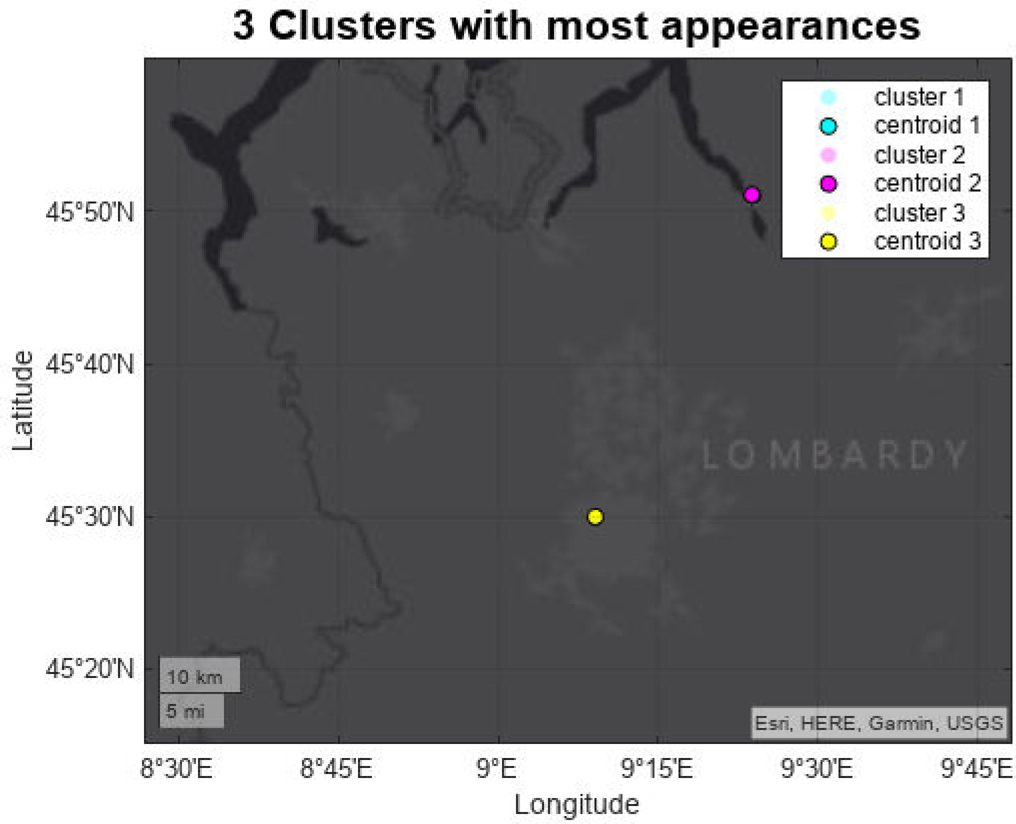
```
% Plot
colors = hsv(size(top_clusters,2)); % Default Matlab color map
geoscatter(italy_startend(T==idx(1),1),italy_startend(T==idx(1),2),'filled','MarkerFaceColor',1
mean(italy_startend(T==idx(1),:),1)
```

```
ans = 1×2
   45.8496    9.3974
```

```
hold on
geoscatter(mean(italy_startend(T==idx(1),1)),mean(italy_startend(T==idx(1),2)),'filled','Marker
for jj = 2:size(top_clusters,2)
    geoscatter(italy_startend(T==idx(jj),1),italy_startend(T==idx(jj),2),'filled','MarkerFaceCo
    geoscatter(mean(italy_startend(T==idx(jj),1)),mean(italy_startend(T==idx(jj),2)),'filled','
    mean(italy_startend(T==idx(jj),:),1)
end
```

```
ans = 1×2
   45.8507    9.3962
ans = 1×2
   45.4994    9.1515
```

```
hold off
geobasemap('streets-dark')
legend('cluster 1', 'centroid 1','cluster 2', 'centroid 2','cluster 3', 'centroid 3')
geolimits([45.25,46],[8.75,9.5])
title('3 Clusters with most appearances', FontSize=16);
saveas(gcf,strcat('Figures/possible_home_locations_1.png') )
```



```
% Get the 2 clusters with the most appearances
top_clusters = idx(1:2)
```

```
top_clusters = 1×2
     6     2
```

```
% Plot
% colors = hsv(size(top_clusters,2)); % Default Matlab color map
geoscatter(italy_startend(T==idx(1),1),italy_startend(T==idx(1),2),'filled','MarkerFaceColor',
hold on
mean(italy_startend(T==idx(1),:),1)
```

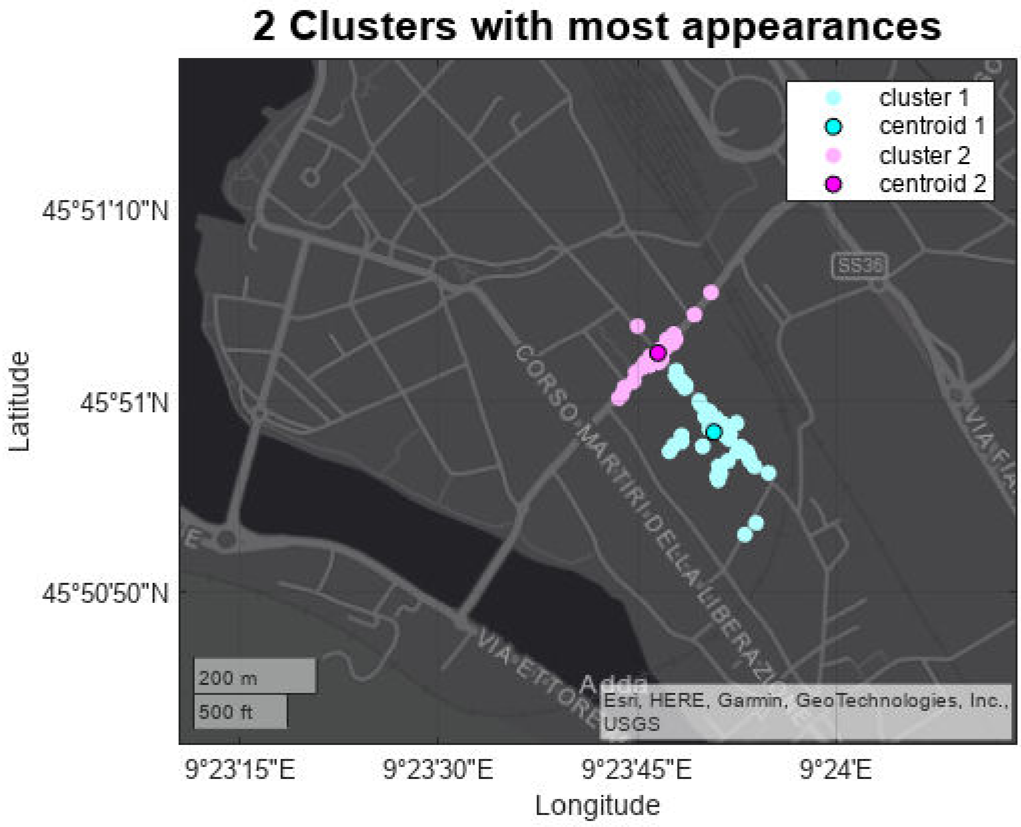
```
ans = 1×2
   45.8496    9.3974
```

```
geoscatter(mean(italy_startend(T==idx(1),1)),mean(italy_startend(T==idx(1),2)),'filled','Marker
for jj = 2:size(top_clusters,2)
```

```
    geoscatter(italy_startend(T==idx(jj),1),italy_startend(T==idx(jj),2),'filled','MarkerFaceCo
    geoscatter(mean(italy_startend(T==idx(jj),1)),mean(italy_startend(T==idx(jj),2)),'filled',
    mean(italy_startend(T==idx(jj),:),1)
end
```

```
ans = 1×2
   45.8507    9.3962
```

```
hold off
geobasemap('streets-dark')
legend('cluster 1', 'centroid 1','cluster 2', 'centroid 2')
geolimits([45.845,45.855],[9.39,9.40])
title('2 Clusters with most appearances', FontSize=16);
saveas(gcf,strcat('Figures/possible_home_locations_2.png') )
```



```
top_clusters = idx(3)
```

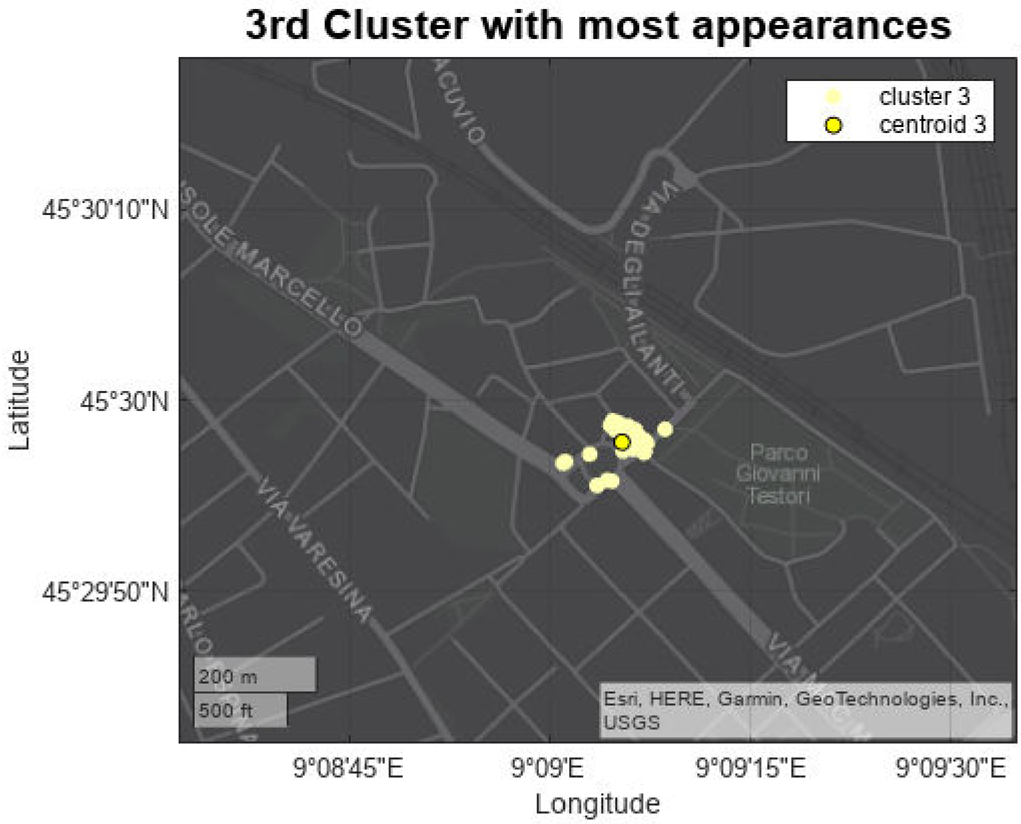
```
top_clusters = 8
```

```
% Plot
% colors = hsv(size(top_clusters,2)); % Default Matlab color map
hold on
geoscatter(italy_startend(T==top_clusters,1),italy_startend(T==top_clusters,2),'filled','Marker
mean(italy_startend(T==top_clusters,:),1)
```

```
ans = 1×2
```

```
    45.4994    9.1515
```

```
geoscatter(mean(italy_startend(T==top_clusters,1)),mean(italy_startend(T==top_clusters,2)),'fi
hold off
geobasemap('streets-dark')
legend('', '','', '','cluster 3', 'centroid 3')
geolimits([45.495, 45.505],[9.146,9.156])
title('3rd Cluster with most appearances', FontSize=16);
saveas(gcf,strcat('Figures/possible_home_locations_3.png') )
```



Save data to plot with format in python/leaflet maps

```
home_clusters = table(T, italy_startend(:,1), italy_startend(:,2), 'VariableNames', {'Cluster_
writetable(home_clusters, strcat(data_path,'home_locations.csv'));
```

Aux Functions

```
function d = great_circle_distance(p1, p2)
    % Cast input arguments to single or double
    lat1 = single(p1(1));
    lon1 = single(p1(2));
    lat2 = single(p2(1));
    lon2 = single(p2(2));

    % Convert latitude and longitude to radians
    lat1 = deg2rad(lat1);
    lon1 = deg2rad(lon1);
    lat2 = deg2rad(lat2);
    lon2 = deg2rad(lon2);

    % Earth's radius in km
    R = 6371;

    % Compute Great Circle distance
    d = acos(sin(lat1) * sin(lat2) + cos(lat1) * cos(lat2) * cos(lon1 - lon2)) * R;
end
```