NUNNA LEEKHITH SRI KRISHNA

Uncovering Hidden Climate Adaptation Patterns

Using Clustering and Dimensionality Reduction

Size and Feactures of data set

```
data = readtable("C:\Users\leekh\OneDrive - Amrita vishwa
vidyapeetham\Git\5_climate_change_impact_on_agriculture_2024\climate_change_impact_o
n_agriculture_2024.csv");

% Display first few rows
disp("� Sample Data:");
```

```
� Sample Data:
```

```
disp(head(data));
```

```
    Year       Country             Region            Crop_Type      Average_Temperature_C    Total_Precipitation_mm
    ____    _____________    __________________    _____________    _____________________    ______________________

    2001    {'India'    }    {'West Bengal'    }    {'Corn'     }            1.55                    447.06
    2024    {'China'    }    {'North'          }    {'Corn'     }            3.23                    2913.6
    2001    {'France'   }    {'Ile-de-France'  }    {'Wheat'    }           21.11                    1301.7
    2001    {'Canada'   }    {'Prairies'       }    {'Coffee'   }           27.85                    1154.4
    1998    {'India'    }    {'Tamil Nadu'     }    {'Sugarcane'}            2.19                    1627.5
    2019    {'USA'      }    {'Midwest'        }    {'Coffee'   }           17.19                    975.13
    1997    {'Argentina'}    {'Northeast'      }    {'Fruits'   }           23.46                    1816.4
    2021    {'Australia'}    {'New South Wales'}    {'Rice'     }           25.63                    786.17
```

```

% Display feature names
disp("� Feature Names:");
```

```
� Feature Names:
```

```
disp(data.Properties.VariableNames);
```

```
    {'Year'}    {'Country'}    {'Region'}    {'Crop_Type'}    {'Average_Temperature_C'}    {'Total_Precipitation_mm
```

```

% Display variable types (class of each column)
disp("� Feature Types:");
```

```
� Feature Types:
```

```
summary(data)
```

```
Variables:

    Year: 10000×1 double

        Values:

            Min         1990
            Median      2007
```

```
        Max         2024

Country: 10000×1 cell array of character vectors

Region: 10000×1 cell array of character vectors

Crop_Type: 10000×1 cell array of character vectors

Average_Temperature_C: 10000×1 double

    Values:

        Min         -4.99
        Median     15.175
        Max            35

Total_Precipitation_mm: 10000×1 double

    Values:

        Min        200.15
        Median     1611.2
        Max        2999.7

CO2_Emissions_MT: 10000×1 double

    Values:

        Min          0.5
        Median      15.2
        Max           30

Crop_Yield_MT_per_HA: 10000×1 double

    Values:

        Min         0.45
        Median      2.17
        Max            5

Extreme_Weather_Events: 10000×1 double

    Values:

        Min          0
        Median       5
        Max         10

Irrigation_Access_: 10000×1 double

    Values:

        Min         10.01
        Median     55.175
        Max         99.99

Pesticide_Use_KG_per_HA: 10000×1 double

    Values:

        Min            0
        Median     24.93
        Max        49.99
```

```
    Fertilizer_Use_KG_per_HA: 10000×1 double

        Values:

            Min          0.01
            Median     49.635
            Max         99.99

    Soil_Health_Index: 10000×1 double

        Values:

            Min            30
            Median      64.65
            Max           100

    Adaptation_Strategies: 10000×1 cell array of character vectors

    Economic_Impact_Million_USD: 10000×1 double

        Values:

            Min         47.84
            Median     583.92
            Max        2346.5
```

Clean & Normalize for PCA

Remove target/adaptation label if still present

```
% (Assume 'Adaptation_Strategy' is the target column – change if needed)
if any(strcmp(data.Properties.VariableNames, 'Adaptation_Strategy'))
    data.Adaptation_Strategy = [];
end
```

Handle categorical data (encode them as numbers)

```
data = convertvars(data, @iscategorical, 'cell'); % Convert categoricals to cell
(if any)
data = convertvars(data, @isstring, 'cell');      % Convert strings to cell
data = convertvars(data, @iscell, 'categorical'); % All strings/cells → categorical
data = varfun(@double, data);                     % Convert all categorical →
numeric
```

Normalize (Z-score)

```
X = table2array(data);              % Convert to pure matrix
X_norm = zscore(X);                 % Normalize

% Check dimensions
fprintf("� Final matrix size: %d samples x %d features\n", size(X_norm,1),
size(X_norm,2));
```

```
� Final matrix size: 10000 samples x 15 features
```

Apply PCA & Visualize in 2D

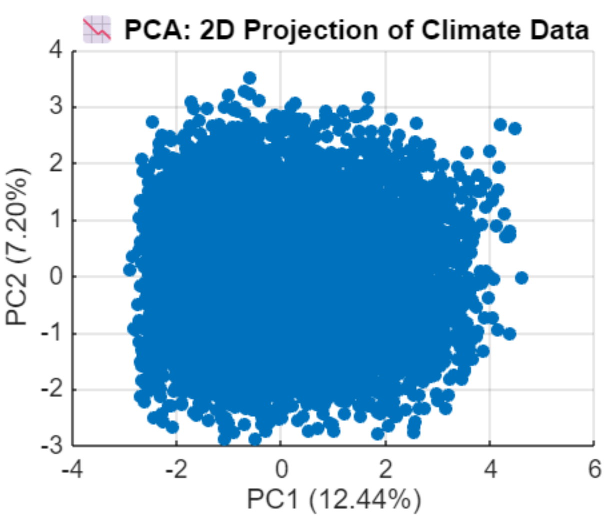
```
% Run PCA
[coeff, score, ~, ~, explained] = pca(X_norm);

% Display how much variance first 2 components explain
fprintf("⍰ PC1 explains: %.2f%%\n", explained(1));
```

```
⍰ PC1 explains: 12.44%
```

```
fprintf("⍰ PC2 explains: %.2f%%\n", explained(2));
```

```
⍰ PC2 explains: 7.20%
```

```

% Plot PCA-reduced data (first 2 principal components)
figure;
scatter(score(:,1), score(:,2), 25, 'filled');
title('� PCA: 2D Projection of Climate Data');
xlabel(sprintf('PC1 (%.2f%%)', explained(1)));
ylabel(sprintf('PC2 (%.2f%%)', explained(2)));
grid on;
```



Apply t-SNE for Better Cluster Visualization

```
% Set random seed for consistent output
rng(42);

% Run t-SNE on normalized data
Y_tsne = tsne(X_norm, ...
              'NumDimensions', 2, ...
              'Perplexity', 50, ...      % Try 30–50 for large datasets
              'Exaggeration', 4, ...
              'LearnRate', 1000, ...
              'Verbose', 1);
```

ITER	KL DIVERGENCE FUN VALUE USING EXAGGERATED DIST OF X	NORM GRAD USING EXAGGERATED DIST OF X
20	2.621301e+01	2.173705e-07
40	2.549734e+01	1.331953e-03
60	2.550012e+01	2.634355e-06
80	2.550039e+01	7.571228e-06

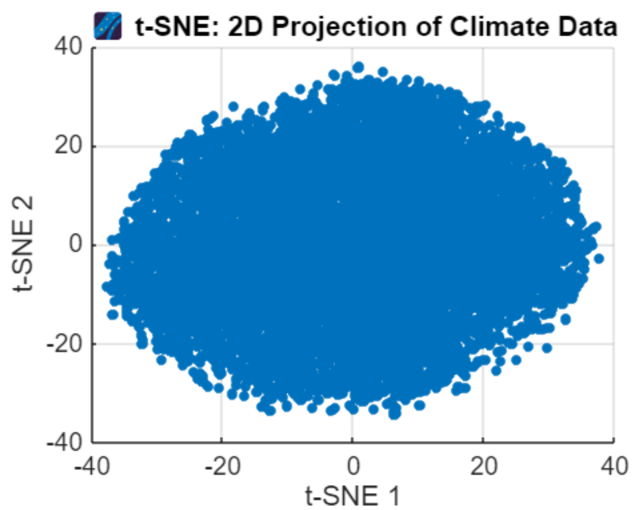
ITER	KL DIVERGENCE FUN VALUE	NORM GRAD
100	4.989905e+00	1.188972e-04
120	4.132310e+00	4.491186e-05
140	3.974825e+00	8.446668e-05
160	3.881011e+00	2.980933e-05
180	3.818606e+00	2.749106e-05
200	3.773438e+00	3.083561e-05
220	3.740088e+00	3.712500e-05
240	3.714074e+00	1.423948e-05
260	3.684711e+00	2.226123e-05
280	3.651682e+00	1.088938e-05
300	3.631255e+00	7.782789e-06
320	3.616459e+00	6.253212e-06
340	3.604403e+00	7.026255e-06
360	3.595029e+00	7.095033e-06
380	3.586537e+00	1.368437e-05
400	3.580077e+00	5.158367e-06

ITER	KL DIVERGENCE FUN VALUE	NORM GRAD
420	3.575768e+00	9.400943e-06
440	3.572023e+00	4.950986e-06
460	3.568257e+00	5.693681e-06
480	3.564565e+00	5.828479e-06
500	3.560917e+00	5.452719e-06
520	3.557778e+00	6.649233e-06
540	3.554906e+00	4.776360e-06
560	3.552204e+00	7.606639e-06
580	3.549472e+00	4.701826e-06
600	3.546971e+00	5.714703e-06
620	3.544603e+00	6.567361e-06
640	3.542359e+00	5.887754e-06
660	3.540465e+00	4.835699e-06
680	3.538753e+00	6.103111e-06
700	3.537018e+00	6.131870e-06
720	3.535517e+00	5.254160e-06
740	3.533771e+00	4.660387e-06
760	3.532303e+00	5.106789e-06
780	3.530618e+00	4.828924e-06
800	3.529498e+00	6.814321e-06

ITER	KL DIVERGENCE FUN VALUE	NORM GRAD
820	3.528047e+00	5.201445e-06
840	3.527133e+00	4.734612e-06
860	3.526426e+00	5.406661e-06

```
|      880 |    3.525495e+00 |    4.411281e-06 |
|      900 |    3.524343e+00 |    5.418972e-06 |
|      920 |    3.523189e+00 |    7.367750e-06 |
|      940 |    3.521854e+00 |    5.755747e-06 |
|      960 |    3.520831e+00 |    5.060109e-06 |
|      980 |    3.519866e+00 |    1.137271e-05 |
|     1000 |    3.518794e+00 |    5.710414e-06 |
```

```
% Plot t-SNE result
figure;
scatter(Y_tsne(:,1), Y_tsne(:,2), 15, 'filled');
title('� t-SNE: 2D Projection of Climate Data');
xlabel('t-SNE 1');
ylabel('t-SNE 2');
grid on;
```



jump to UMAP (it’s spicier than t-SNE for structure-preserving)

UMAP Setup in MATLAB

```
which run_umap
```

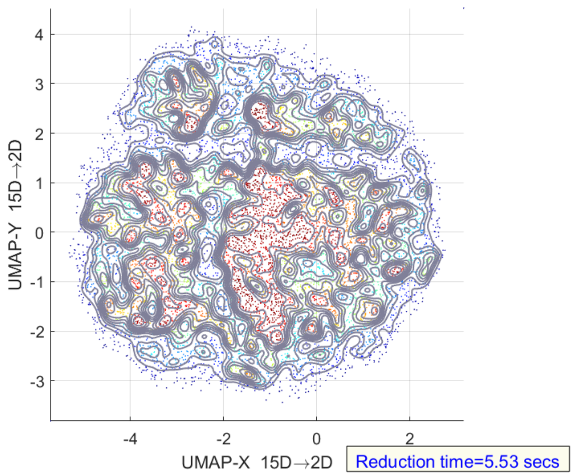
```
C:\Users\leekh\AppData\Roaming\MathWorks\MATLAB Add-Ons\Collections\Uniform Manifold Approximation and Projection (U
```

Run UMAP on Normalized Data

```
% Run UMAP to reduce dimensions to 2
[umapOut, umapStruct] = run_umap(X_norm, 'n_components', 2);
```

```
UMAP & UST (v4.4), Herzenberg Lab, Stanford University,
    Original inventors: Leland McInnes, John Healy & James Melville
    MATLAB/C++/Java/Python implementors/evolvers: Connor Meehan, Jonathan Ebrahimian & Stephen Meehan


ans = 

    javahandle_withcallbacks.edu.stanford.facs.swing.ImageButton
```

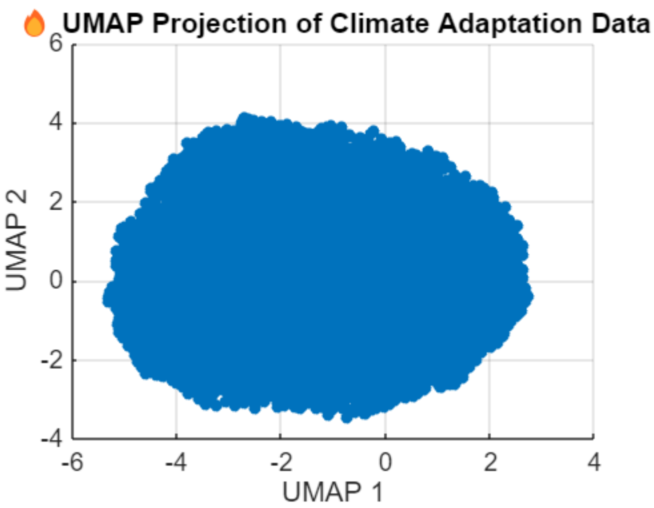
```
Parallelizing UMAP with MATLAB's 12 assigned logical cores for nn_descent_tasks, sgd_tasks
 Running basic (ub) reduction, v4.4
(ub=basic, us=supervised, ubt=template, ust=supervised template)
min=-11.50, max=1.50
mins:    -1.6946     -1.5733      -1.663     -1.5882     -1.7643     -1.7534     -1.7168      -1.793     -1.5733
maxs:     1.677      1.5583      1.7506      1.5484      1.7231      1.7242      1.7176      2.7646      1.5854
UMAP(method=MEX, n_neighbors=15, n_components=2, metric='euclidean', n_epochs=[], learning_rate=1, init=spectral, m
ans =
  Contour with properties:

    EdgeColor: [0.5000 0.5000 0.6000]
    LineStyle: '-'
    LineWidth: 1
    FaceColor: 'none'
    LevelList: [0.0151 0.0183 0.0204 0.0221 0.0235 0.0249 0.0264 0.0282 0.0308 0.0412]
        XData: [256×256 double]
        YData: [256×256 double]
        ZData: [256×256 double]

  Show all properties
```




```
UMAP reduction finished (cost 5.84 secs)
 Finished basic (ub) reduction
```

Plot the UMAP Projection

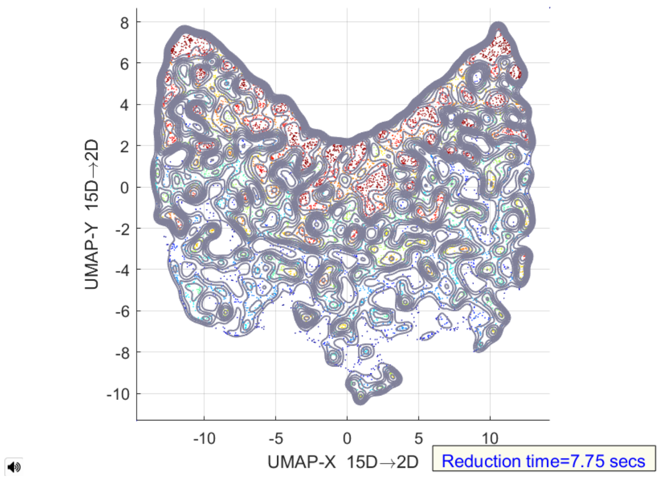
```
figure;
scatter(umapOut(:,1), umapOut(:,2), 20, 'filled');
xlabel('UMAP 1');
ylabel('UMAP 2');
title('� UMAP Projection of Climate Adaptation Data');
grid on;
```



Method	Global Structure	Local Structure	Interpretability	Verdict
PCA	□ OK	□ Weak	□ Linear	Basic baseline
t-SNE	□ Poor	□ Strong	⚠ Random-ish	Over-clusters
UMAP	□ Good	□ Very strong	□ Preserved	**� Best balance**

```
[embedding, umapStruct, clusterIdentifiers] = run_umap(X);
```

```
UMAP & UST (v4.4), Herzenberg Lab, Stanford University,
    Original inventors: Leland McInnes, John Healy & James Melville
    MATLAB/C++/Java/Python implementors/evolvers: Connor Meehan, Jonathan Ebrahimian & Stephen Meehan


ans =

    javahandle_withcallbacks.edu.stanford.facs.swing.ImageButton

Parallelizing UMAP with MATLAB's 12 assigned logical cores for nn_descent_tasks, sgd_tasks
 Running basic (ub) reduction, v4.4
(ub=basic, us=supervised, ubt=template, ust=supervised template)
UMAP(method=MEX, n_neighbors=15, n_components=2, metric='euclidean', n_epochs=[], learning_rate=1, init=spectral, mi
ans =
  Contour with properties:

    EdgeColor: [0.5000 0.5000 0.6000]
    LineStyle: '-'
    LineWidth: 1
    FaceColor: 'none'
    LevelList: [0.0019 0.0023 0.0026 0.0029 0.0032 0.0035 0.0038 0.0041 0.0046 0.0069]
        XData: [256×256 double]
        YData: [256×256 double]
        ZData: [256×256 double]

  Show all properties
UMAP reduction finished (cost 8.11 secs)
 Finished basic (ub) reduction
```

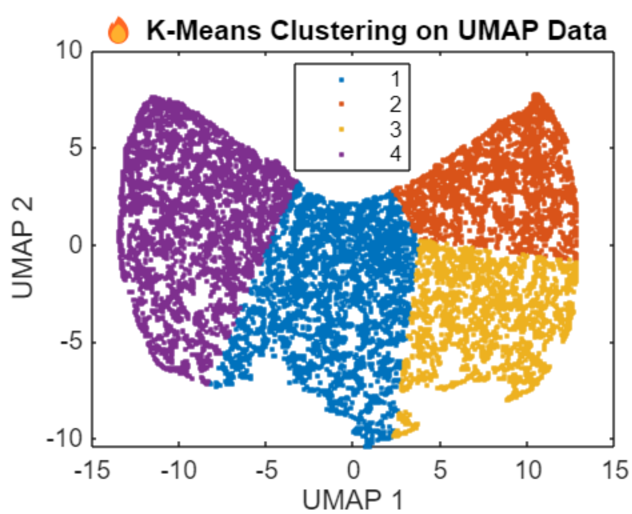



```
reducedData = embedding;
```

Clustering in MATLAB

K-Means Clustering

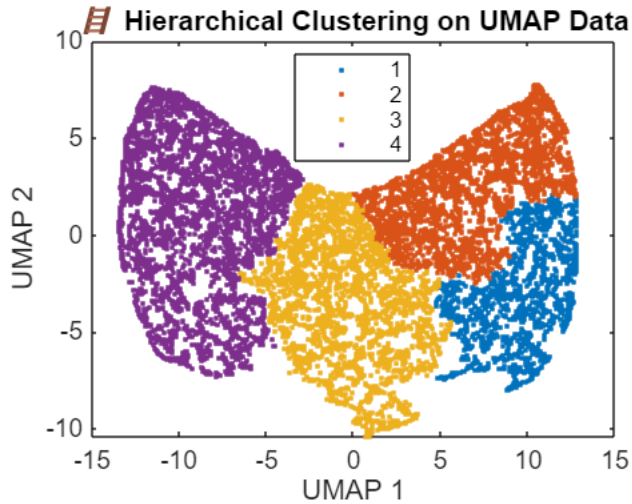
```
k = 4; % try different values like 3, 5, 6
[idx_kmeans, C] = kmeans(reducedData, k);

figure;
gscatter(reducedData(:,1), reducedData(:,2), idx_kmeans);
title('� K-Means Clustering on UMAP Data');
xlabel('UMAP 1'); ylabel('UMAP 2');
```



Hierarchical Clustering

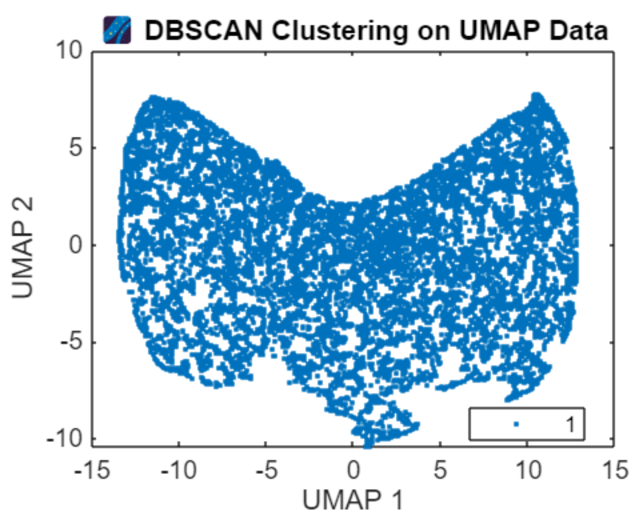
```
Z = linkage(reducedData, 'ward');
idx_hier = cluster(Z, 'Maxclust', 4);
```

```
figure;
gscatter(reducedData(:,1), reducedData(:,2), idx_hier);
title('� Hierarchical Clustering on UMAP Data');
xlabel('UMAP 1'); ylabel('UMAP 2');
```



DBSCAN

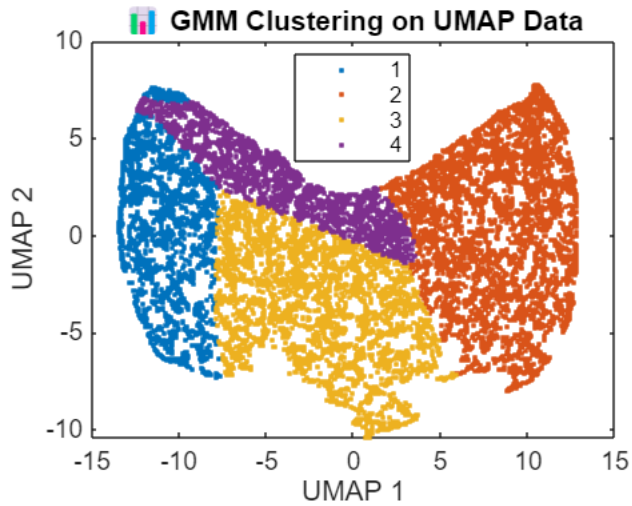
```
epsilon = 0.5;
minPts = 10;
idx_dbscan = dbscan(reducedData, epsilon, minPts);

figure;
gscatter(reducedData(:,1), reducedData(:,2), idx_dbscan);
title('� DBSCAN Clustering on UMAP Data');
xlabel('UMAP 1'); ylabel('UMAP 2');
```



Gaussian Mixture Model (GMM)

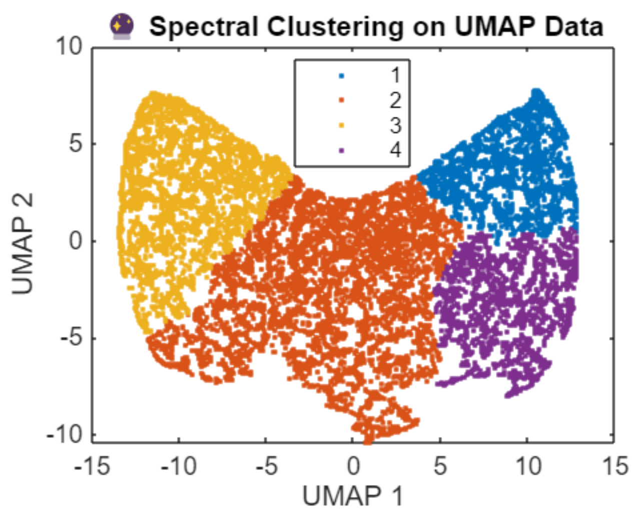
```
gmmModel = fitgmdist(reducedData, 4);
idx_gmm = cluster(gmmModel, reducedData);
```

```
figure;
gscatter(reducedData(:,1), reducedData(:,2), idx_gmm);
title('� GMM Clustering on UMAP Data');
xlabel('UMAP 1'); ylabel('UMAP 2');
```



Spectral Clustering (using built-in MATLAB Graph functions)

```
% Use similarity graph (you can tune neighbors)
[idx_spec, ~] = spectralcluster(reducedData, 4);

figure;
gscatter(reducedData(:,1), reducedData(:,2), idx_spec);
title('� Spectral Clustering on UMAP Data');
xlabel('UMAP 1'); ylabel('UMAP 2');
```



MATLAB script: K-Means, DBSCAN, GMM, Hierarchical, Spectral Clustering — all applied on your 2D

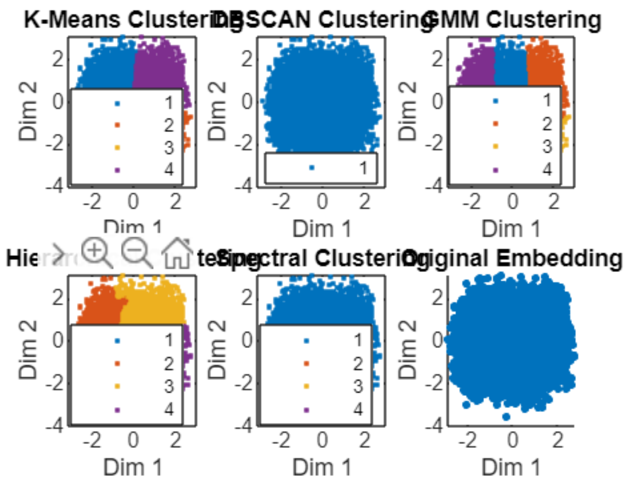
```
% � Make sure reducedData (from UMAP/t-SNE/PCA) is defined
% e.g., reducedData = embedding;

% Auto set seed for reproducibility
```

```
rng(42);

% Create figure
figure('Name','Clustering Results','NumberTitle','off');


%% � Load Data
data = readtable('climate_change_impact_on_agriculture_2024.csv');
data = rmmissing(data);

% � Select only numeric predictors
selectedColumns = {'Average_Temperature_C', 'Total_Precipitation_mm', ...
    'CO2_Emissions_MT', 'Crop_Yield_MT_per_HA', 'Extreme_Weather_Events', ...
    'Irrigation_Access_', 'Pesticide_Use_KG_per_HA', ...
    'Fertilizer_Use_KG_per_HA', 'Soil_Health_Index'};

X = table2array(data(:, selectedColumns));

% � Normalize
mu = mean(X);
sigma = std(X);
X_norm = (X - mu) ./ sigma;

% � PCA
[coeff, score] = pca(X_norm);
reducedData = score(:,1:2); % Top 2 PCs

% � KMeans
k = 5;
[idx_kmeans, C_kmeans] = kmeans(reducedData, k);

% � GMM
gmm = fitgmdist(reducedData, k, 'RegularizationValue', 0.1);


%% 1 K-Means
subplot(2,3,1)
k = 4; % You can change this
kIdx = kmeans(reducedData, k);
gscatter(reducedData(:,1), reducedData(:,2), kIdx);
title('K-Means Clustering')
xlabel('Dim 1'), ylabel('Dim 2')

%% 2 DBSCAN
subplot(2,3,2)
epsilon = 0.8;
minPts = 10;
dbIdx = dbscan(reducedData, epsilon, minPts);
gscatter(reducedData(:,1), reducedData(:,2), dbIdx);
title('DBSCAN Clustering')
```

```
xlabel('Dim 1'), ylabel('Dim 2')

%% 3 Gaussian Mixture Model (GMM)
subplot(2,3,3)
gmm = fitgmdist(reducedData, k);
```

```
Warning: Failed to converge in 100 iterations for gmdistribution with 4 components
```

```
gmmIdx = cluster(gmm, reducedData);
gscatter(reducedData(:,1), reducedData(:,2), gmmIdx);
title('GMM Clustering')
xlabel('Dim 1'), ylabel('Dim 2')

%% 4 Hierarchical Clustering
subplot(2,3,4)
linkTree = linkage(reducedData, 'ward');
hIdx = cluster(linkTree, 'maxclust', k);
gscatter(reducedData(:,1), reducedData(:,2), hIdx);
title('Hierarchical Clustering')
xlabel('Dim 1'), ylabel('Dim 2')

%% 5 Spectral Clustering
subplot(2,3,5)
W = pdist2(reducedData, reducedData);
sigma = 1;
S = exp(-W.^2 / (2*sigma^2));
D = diag(sum(S,2));
L = D - S;
[eigVecs, ~] = eigs(L, k, 'smallestabs');
specIdx = kmeans(eigVecs, k);
gscatter(reducedData(:,1), reducedData(:,2), specIdx);
title('Spectral Clustering')
xlabel('Dim 1'), ylabel('Dim 2')

%% 6 Ground Truth or Random Reference (Optional)
subplot(2,3,6)
scatter(reducedData(:,1), reducedData(:,2), 10, 'filled');
title('Original Embedding')
xlabel('Dim 1'), ylabel('Dim 2')
```




```
data = readtable('climate_change_impact_on_agriculture_2024.csv');
disp(data.Properties.VariableNames)
```

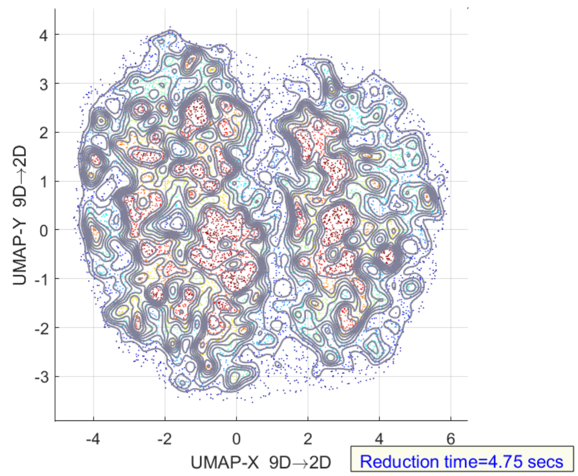
```
    {'Year'}    {'Country'}    {'Region'}    {'Crop_Type'}    {'Average_Temperature_C'}    {'Total_Precipitation_mm
```

GUI Code Block

```
%% � Climate Adaptation Cluster Predictor GUI
clc; clear; close all;

%% � Load and Normalize Data
data = readtable('climate_change_impact_on_agriculture_2024.csv');
data = rmmissing(data);

selectedColumns = {'Average_Temperature_C', 'Total_Precipitation_mm',
'CO2_Emissions_MT', ...
    'Crop_Yield_MT_per_HA', 'Extreme_Weather_Events', 'Irrigation_Access_', ...
    'Pesticide_Use_KG_per_HA', 'Fertilizer_Use_KG_per_HA', 'Soil_Health_Index'};

X = table2array(data(:, selectedColumns));
mu = mean(X);
sigma = std(X);
X_norm = (X - mu) ./ sigma;

%% � UMAP Dimensionality Reduction
[reduction, umapStruct] = run_umap(X_norm, 'n_components', 2);
```

```
UMAP & UST (v4.4), Herzenberg Lab, Stanford University,
    Original inventors: Leland McInnes, John Healy & James Melville
    MATLAB/C++/Java/Python implementors/evolvers: Connor Meehan, Jonathan Ebrahimian & Stephen Meehan


ans = 

    javahandle_withcallbacks.edu.stanford.facs.swing.ImageButton

Parallelizing UMAP with MATLAB's 12 assigned logical cores for nn_descent_tasks, sgd_tasks
```

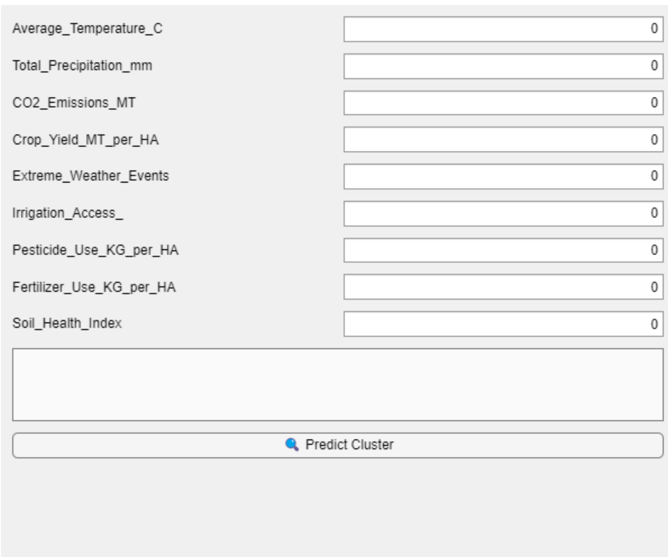
```
 Running basic (ub) reduction, v4.4
(ub=basic, us=supervised, ubt=template, ust=supervised template)
UMAP(method=MEX, n_neighbors=15, n_components=2, metric='euclidean', n_epochs=[], learning_rate=1, init=spectral, m
ans =
  Contour with properties:

    EdgeColor: [0.5000 0.5000 0.6000]
    LineStyle: '-'
    LineWidth: 1
    FaceColor: 'none'
    LevelList: [0.0103 0.0128 0.0145 0.0159 0.0174 0.0187 0.0198 0.0212 0.0230 0.0323]
        XData: [256×256 double]
        YData: [256×256 double]
        ZData: [256×256 double]

  Show all properties
```




```
UMAP reduction finished (cost 5.01 secs)
 Finished basic (ub) reduction
```

```
reducedData = reduction;

%% � KMeans Clustering
k = 5;
[idx_kmeans, C_kmeans] = kmeans(reducedData, k, 'Replicates', 10);

%% � GMM Clustering
gmm = fitgmdist(reducedData, k, 'RegularizationValue', 0.1);
idx_gmm = cluster(gmm, reducedData);

%% �� GUI Setup
f = uifigure('Name', 'Climate Adaptation Cluster Predictor', 'Position', [100 100
600 500]);
uigrid = uigridlayout(f, [length(selectedColumns)+2, 2]);
uigrid.RowHeight = repmat({'fit'}, 1, length(selectedColumns)+2);
uigrid.ColumnWidth = {'1x','1x'};

fields = cell(length(selectedColumns), 1);
for i = 1:length(selectedColumns)
    uilabel(uigrid, 'Text', selectedColumns{i});
    fields{i} = uieditfield(uigrid, 'numeric');
```

```
end

resultArea = uitextarea(uigrid, 'Editable', 'off');
resultArea.Layout.Row = length(selectedColumns)+1;
resultArea.Layout.Column = [1 2];

predictBtn = uibutton(uigrid, 'Text', '� Predict Cluster');
predictBtn.Layout.Row = length(selectedColumns)+2;
predictBtn.Layout.Column = [1 2];

% Assign fixed callback
predictBtn.ButtonPushedFcn = @(btn,event) predictClusterCallback(f, fields, mu,
sigma, selectedColumns, C_kmeans, gmm, resultArea);
```




```
%% □ Final Callback Function
function predictClusterCallback(f, fields, mu, sigma, selectedColumns, C_kmeans,
gmm, resultArea)
try
    % Extract and validate input
    userInput = zeros(1, length(fields));
    for i = 1:length(fields)
        val = fields{i}.Value;  % already numeric
        if isempty(val) || ~isnumeric(val)
            uialert(f, sprintf('Invalid input in %s', selectedColumns{i}), 'Input
Error');
            return;
        end
        userInput(i) = val;

    end

    % Normalize user input
    userInputNorm = (userInput - mu) ./ sigma;
```

```
    % Run UMAP without displaying figures (must have at least 2 rows)
    userUMAP = run_umap([userInputNorm; zeros(10, length(userInputNorm))], ...
        'n_components', 2, ...
        'display', 'none');
    X_new_2D = userUMAP(1,:);  % Only take the first row

    % Predict cluster from KMeans and GMM
    [~, pred_kmeans] = min(vecnorm(C_kmeans - X_new_2D, 2, 2));
    pred_gmm = cluster(gmm, X_new_2D);

    % Show results
    resultArea.Value = sprintf("� KMeans Cluster: %d\n� GMM Cluster: %d", ...
        pred_kmeans, pred_gmm);

catch ME
    if isvalid(resultArea)
        resultArea.Value = sprintf("⍰ Error: %s", ME.message);
    else
        disp("⚠ GUI was closed before prediction finished.");
    end
end
end
```