clustering_portfolio

February 19, 2026

0.1 Motivation & Set-Up

0.1.1 My goal is to compare different selection processes for selecting an optimal number of k-means clusters over two different ecological regions.

```python
[63]: import os          # file paths
      import pickle       # for saving/loading data
      import re           # regular expressions
      import warnings     # for ignoring warnings


      import cartopy.crs as ccrs    # plotting maps
      import earthaccess             # accessing Earth data API
      import earthpy as et          # working with spatial data
      import geopandas as gpd       # working with geospatial data
      import geoviews as gv         # interactive geospatial visualizations
      import holoviews as hv        # interactive plotting
      import hvplot.pandas          # plotting with pandas dataframes
      import hvplot.xarray          # plotting with xarray datasets
      hv.extension('bokeh')
      import pyproj
      import pyogrio                     # working with geospatial vector data

      import numpy as np               # working with arrays
      import pandas as pd              # working with dataframes
      import rioxarray as rxr         # working with geospatial raster data
      import rioxarray.merge as rxrmerge   # merging geospatial raster data
      from tqdm.notebook import tqdm       # progress bars
      from ipywidgets import IntProgress   # progress bars
      from IPython.display import display      # displaying widgets
      import xarray as xr                     # working with multi-dimensional arrays
      from shapely.geometry import Polygon     # working with geometric shapes
      from sklearn.cluster import KMeans       # for clustering data
      from sklearn.preprocessing import StandardScaler     # scaling data
      from kneed import KneeLocator               # working with elbow test

      import requests
      import zipfile
```

```
### set GDAL parameters
os.environ["GDAL_HTTP_MAX_RETRY"] = "5"
os.environ["GDAL_HTTP_RETRY_DELAY"] = "1"

### skip non-critical warnings
warnings.simplefilter('ignore')
```

Set directory paths and caching decorator

```python
[2]: # modify cache directory for local file paths
     cache_dir = os.path.join(
         et.io.HOME,
         "Data",
         "Earth Analytics",
         "clustering-portfolio"
     )
```

```python
[3]: ### make the caching decorator
     def cached(func_key, override=False):
         """
         A decorator to cache function results

         Parameters
         ==========
         key: str
           File basename used to save pickled results
         override: bool
           When True, re-compute even if the results are already stored
         """
         def compute_and_cache_decorator(compute_function):
             """
             Wrap the caching function

             Parameters
             ==========
             compute_function: function
               The function to run and cache results
             """
             def compute_and_cache(*args, **kwargs):
                 """
                 Perform a computation and cache, or load cached result.

                 Parameters
                 ==========
                 args
                   Positional arguments for the compute function
                 kwargs
```

```python
    Keyword arguments for the compute function
    """
    ### Add an identifier from the particular function call
    if 'cache_key' in kwargs:
        key = '_'.join((func_key, kwargs['cache_key']))
    else:
        key = func_key

    ### define a file path based on the directory structure in earthpy
    path = os.path.join(

        ## established dir
        cache_dir,

        ### make a subdirectory called "jars"
        'jars',

        ### use f-string (formatted string) to create a string by
        ↪embedding the value
        ### of the variable "key" into the string
        ### use .pickle file extension (a pickle file is a serialized
        ↪python objecT)
        f'{key}.pickle')

    ### Check if the cache exists already or if we should override
    ↪caching
    if not os.path.exists(path) or override:

        ### Make jars directory if needed
        os.makedirs(os.path.dirname(path), exist_ok=True)

        ### Run the compute function as the user did
        result = compute_function(*args, **kwargs)

        ### Pickle the object (save to file)
        ### open the file at filename
        with open(path, 'wb') as file:

            ### save the result without needing to recompute when
            ↪loading
            ### it back into Python
            pickle.dump(result, file)

    ### if the file already exists/we are not overriding the cache
    else:

        ### Unpickle the object (load the cached result)
```

```
                with open(path, 'rb') as file:

                    ### use pickle.load to un-serialize the file back into a␣
 ↪python object
                    result = pickle.load(file)

            return result

        return compute_and_cache

    return compute_and_cache_decorator
```

0.2 WPD Boundaries

```
[9]: HUC_LEVEL = 12

     # folder where files should be saved
     download_dir = os.path.join(cache_dir,
                                 "downloads",
                                 "WBD_08_HU2_Shape")
     os.makedirs(download_dir, exist_ok=True)

     @cached(f'wpd_08_hu{HUC_LEVEL}_gdf', override=True)
     def read_wpd(wpd_filename, cache_key=None):
         """Download WBD shapefile directly to custom folder and return␣
      ↪GeoDataFrame"""

         # URL to zip file
         url = f"https://prd-tnm.s3.amazonaws.com/StagedProducts/Hydrography/WBD/HU2/
      ↪Shape/{wpd_filename}.zip"

         # local zip path
         zip_path = os.path.join(download_dir, f"{wpd_filename}.zip")

         # download if not already downloaded
         if not os.path.exists(zip_path):
             r = requests.get(url)
             r.raise_for_status()
             with open(zip_path, "wb") as f:
                 f.write(r.content)

         # unzip into download_dir
         with zipfile.ZipFile(zip_path, "r") as zip_ref:
             zip_ref.extractall(download_dir)

         # shapefile path inside the extracted folder
         shp_path = os.path.join(download_dir, "Shape", f"WBDHU{HUC_LEVEL}.shp")
```

```python
    # read shapefile
    gdf = gpd.read_file(shp_path, engine="pyogrio")
    return gdf
```

```python
# open and test the gdf
wpd_gdf = read_wpd("WBD_08_HU2_Shape")
wpd_gdf
```

```
                                      tnmid  \
0      {8AFB1AF9-7296-4303-89DE-14CD073B859A}
1      {916A17A6-B4A0-4FD7-9BB8-FFD1936B15B2}
2      {493C7EC1-2F1C-4B84-AFFB-6F6868A9868E}
3      {49A3C087-B460-4F97-9D99-78CBB675248B}
4      {0FB41498-11EA-4AB1-AF05-E2A8E5E2E274}
...                                       ...
2636   {9E524E78-2605-48CB-A41F-618AFCDF513D}
2637   {C11913D9-C534-4755-884C-4CAD470ED143}
2638   {3EEBF422-01AC-4322-A63C-24C0A34E1E4F}
2639   {4734715C-0F4A-4211-BBAE-86605B20B79A}
2640   {D3C1C8A9-C189-4E05-8E90-D093F28BB762}


                                 metasource  \
0      {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1      {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2      {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
3      {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
4      {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
...                                       ...
2636   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2637   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2638   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2639   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2640   {6A1A2621-3915-4BDD-BF49-57D80A2FF16C}


                              sourcedata  \
0      Watershed Boundary Dataset (WBD)
1      Watershed Boundary Dataset (WBD)
2      Watershed Boundary Dataset (WBD)
3      Watershed Boundary Dataset (WBD)
4      Watershed Boundary Dataset (WBD)
...                                  ...
2636   Watershed Boundary Dataset (WBD)
2637   Watershed Boundary Dataset (WBD)
2638   Watershed Boundary Dataset (WBD)
2639   Watershed Boundary Dataset (WBD)
2640   Watershed Boundary Dataset (WBD)
```

```
                                               sourceorig sourcefeat   loaddate  \
0     Natural Resources and Conservation Service and…       None 2024-08-15
1     Natural Resources and Conservation Service and…       None 2024-08-15
2     Natural Resources and Conservation Service and…       None 2024-08-15
3     Natural Resources and Conservation Service and…       None 2024-08-15
4     Natural Resources and Conservation Service and…       None 2024-08-15
…                                                      …          …        …
2636  Natural Resources and Conservation Service and…       None 2024-08-15
2637  Natural Resources and Conservation Service and…       None 2024-08-15
2638  Natural Resources and Conservation Service and…       None 2024-08-15
2639  Natural Resources and Conservation Service and…       None 2024-08-15
2640  Natural Resources and Conservation Service and…       None 2024-09-30

           referenceg  areaacres  areasqkm states  … \
0       535297,540579   29441.81    119.15     LA  …
1              535512   11406.67     46.16     LA  …
2       547190,559640   29138.21    117.92     LA  …
3         77417,78285   17759.39     71.87     AR  …
4             1628466   98564.62    398.88     LA  …
…                   …          …         …      …  …
2636    695171,692611    9132.46     36.96     MS  …
2637      77280,81842   20587.50     83.31     AR  …
2638           714675   21405.46     86.62     MO  …
2639    547104,553857   38848.09    157.21     LA  …
2640  1627973,1628339   29780.18    120.52     LA  …

                                              name hutype       humod  \
0                           Gourd Bayou-Youngs Bayou      S   LE,ID,DD
1                                        Hams Creek      S         ID
2                       Caney Creek-Bayou D'Arbonne      S         NM
3                         L'Aigle Creek-Saline River      S         NM
4                             West Cote Blanche Bay      W         NM
…                                                …      …          …
2636                  Widow Bayou-Big Sunflower River      S   AW,LE,TF
2637                   Lindermans Lake-Bayou Des Arc      S         LE
2638                                     Brewer Lake      S  LE,DD,IT,TF
2639                 Blounts Creek-Calcasieu River      S         ID
2640  Tchefuncte River-Frontal Lake Pontchartrain      F      LE,DD

            tohuc noncontrib  noncontr_1  shape_Leng  shape_Area  ObjectID  \
0     080500011308        0.0         0.0         NaN         NaN         1
1     080802050104        0.0         0.0         NaN         NaN         2
2     080402060503        0.0         0.0         NaN         NaN         3
3     080402020206        0.0         0.0         NaN         NaN         4
4     080801030800        0.0         0.0         NaN         NaN         5
…                …          …           …           …           …         …
```

```
2636   080302071707           0.0           0.0         NaN         NaN         2637
2637   080203010306           0.0           0.0         NaN         NaN         2638
2638   080103000102           0.0           0.0         NaN         NaN         2639
2639   080802030302           0.0           0.0         NaN         NaN         2640
2640   080902020100           0.0           0.0         NaN         NaN         2641

                                                    geometry
0      POLYGON ((-92.00021 32.53586, -91.99994 32.535…
1      POLYGON ((-93.37574 30.58982, -93.3747 30.5891…
2      POLYGON ((-93.07761 32.88752, -93.07784 32.887…
3      POLYGON ((-92.08947 33.29383, -92.0897 33.2938…
4      POLYGON ((-91.62408 29.73947, -91.62195 29.737…
…                                                        …
2636   POLYGON ((-90.76273 32.97428, -90.76209 32.973…
2637   POLYGON ((-91.73427 34.99197, -91.7342 34.9923…
2638   POLYGON ((-89.13715 36.97285, -89.13387 36.970…
2639   POLYGON ((-92.75965 31.12593, -92.75881 31.125…
2640   POLYGON ((-89.95187 30.45583, -89.95147 30.454…

[2641 rows x 21 columns]
```

[15]: `wpd_gdf.columns`

[15]:
```
Index(['tnmid', 'metasource', 'sourcedata', 'sourceorig', 'sourcefeat',
       'loaddate', 'referenceg', 'areaacres', 'areasqkm', 'states', 'huc12',
       'name', 'hutype', 'humod', 'tohuc', 'noncontrib', 'noncontr_1',
       'shape_Leng', 'shape_Area', 'ObjectID', 'geometry'],
      dtype='object')
```

The HUC 12 area we initially considered is 080902030506, just south of New Orleans. I plan to pick a close by region within the same larger HUC 8 area, 08090203 but need to add a huc8 column.

[16]: `wpd_gdf['huc8'] = wpd_gdf['huc12'].str[:8]`

[20]:
```python
# filter to the HUC 8 region we want

huc8_code = "08090203"
wpd_sub = wpd_gdf[wpd_gdf['huc8']==huc8_code]

wpd_sub
```

[20]:
```
                                   tnmid  \
13     {05D9DFD7-8B31-43D9-89E9-753B0BD0BF7E}
139    {A8E00DBB-488D-4A09-AB70-ACE37E07E7DD}
228    {ABA4F6E1-8607-47AD-9476-0431E5779706}
555    {FF72496C-9776-4025-B913-F3F0A6B808FD}
717    {FEC68B1D-76FD-4C80-816B-A70A7615DA41}
```

```
915    {FA42A3B0-3B37-48DA-9C60-F64A2455B809}
947    {910C4369-7D03-4B59-BB84-A53822D1489D}
1016   {57EE97C1-00EF-4288-BFCE-17FB7205BBD1}
1066   {C4358575-2325-4BCA-97F4-F8B894DD2FF6}
1472   {5D9D29E6-DCCB-49B4-9174-E3FDDA29E869}
1630   {B32BD6BC-5CAE-4E86-84C0-86BA836C14BD}
1700   {46C5917E-5CEC-4A97-9955-CA99FC0EACBC}
1726   {00614C6F-EB2C-4130-B9FF-2FE0D60CADFA}
1818   {41546F9C-F264-422B-B1DD-FF6E0E547A68}
1828   {3DF89D25-114E-4BEA-BDF7-21BF885FA635}
1843   {A39E07F9-ABB7-4D20-A891-DDFDAD223585}
1856   {31101660-B283-4D40-8AC3-62A1A2487FD4}
1858   {C3AA662E-F255-412A-B9F7-FA54CD0C8C70}
1895   {C8CC7033-9BD2-4CE3-A2F2-63521C3527ED}
1896   {473AEA32-5A1D-4BFF-B0BD-643E0A50B5E5}
1971   {426480B5-6471-416D-8779-78AB338D60F3}
1982   {ACD7EB96-13A7-483F-BC95-B80B10C6479C}
1983   {15381C7B-98A7-4D4A-92B0-7BA88BD2FE5C}
1988   {FCF62A04-82FC-4F51-B437-5E592E32BCDB}
2012   {66400CD9-4294-4DF2-9B97-88D00F6DB316}
2419   {39DE15E8-D08C-4F09-BA5A-711E9B2F92EF}
2428   {BCABF72E-8D3B-450B-A1F5-2014DA046621}
2437   {7F80A68B-D1EE-4DBD-BD70-F4C7CF09B2BD}
2449   {A8F819A2-9F31-4257-9806-084D0E223DB8}
2451   {FFC2B5AA-8966-4099-BAA3-94B192E0AD69}
2559   {E942B72E-599E-48F5-908A-EA5265701C14}
2586   {695567AD-7F18-4897-B516-8286B6F310FC}
2596   {1CCBB4F1-B778-4332-8321-CDB8C3F107E1}

                               metasource  \
13     {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
139    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
228    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
555    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
717    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
915    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
947    {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1016   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1066   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1472   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1630   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1700   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1726   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1818   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1828   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1843   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1856   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
```

```
1858   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1895   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1896   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1971   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1982   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1983   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
1988   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2012   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2419   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2428   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2437   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2449   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2451   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2559   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2586   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}
2596   {511D2AC8-11BA-45FC-AB98-F69D693D4C44}

                                 sourcedata   \
13     Watershed Boundary Dataset (WBD)
139    Watershed Boundary Dataset (WBD)
228    Watershed Boundary Dataset (WBD)
555    Watershed Boundary Dataset (WBD)
717    Watershed Boundary Dataset (WBD)
915    Watershed Boundary Dataset (WBD)
947    Watershed Boundary Dataset (WBD)
1016   Watershed Boundary Dataset (WBD)
1066   Watershed Boundary Dataset (WBD)
1472   Watershed Boundary Dataset (WBD)
1630   Watershed Boundary Dataset (WBD)
1700   Watershed Boundary Dataset (WBD)
1726   Watershed Boundary Dataset (WBD)
1818   Watershed Boundary Dataset (WBD)
1828   Watershed Boundary Dataset (WBD)
1843   Watershed Boundary Dataset (WBD)
1856   Watershed Boundary Dataset (WBD)
1858   Watershed Boundary Dataset (WBD)
1895   Watershed Boundary Dataset (WBD)
1896   Watershed Boundary Dataset (WBD)
1971   Watershed Boundary Dataset (WBD)
1982   Watershed Boundary Dataset (WBD)
1983   Watershed Boundary Dataset (WBD)
1988   Watershed Boundary Dataset (WBD)
2012   Watershed Boundary Dataset (WBD)
2419   Watershed Boundary Dataset (WBD)
2428   Watershed Boundary Dataset (WBD)
2437   Watershed Boundary Dataset (WBD)
2449   Watershed Boundary Dataset (WBD)
```

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2451  Watershed Boundary Dataset (WBD)
2559  Watershed Boundary Dataset (WBD)
2586  Watershed Boundary Dataset (WBD)
2596  Watershed Boundary Dataset (WBD)


                                              sourceorig sourcefeat   loaddate  \
13     Natural Resources and Conservation Service and…       None 2024-08-15
139    Natural Resources and Conservation Service and…       None 2024-08-15
228    Natural Resources and Conservation Service and…       None 2024-08-15
555    Natural Resources and Conservation Service and…       None 2024-08-15
717    Natural Resources and Conservation Service and…       None 2024-08-15
915    Natural Resources and Conservation Service and…       None 2024-08-15
947    Natural Resources and Conservation Service and…       None 2024-08-15
1016   Natural Resources and Conservation Service and…       None 2024-08-15
1066   Natural Resources and Conservation Service and…       None 2024-08-15
1472   Natural Resources and Conservation Service and…       None 2024-08-15
1630   Natural Resources and Conservation Service and…       None 2024-08-15
1700   Natural Resources and Conservation Service and…       None 2024-08-15
1726   Natural Resources and Conservation Service and…       None 2024-08-15
1818   Natural Resources and Conservation Service and…       None 2024-08-15
1828   Natural Resources and Conservation Service and…       None 2024-08-15
1843   Natural Resources and Conservation Service and…       None 2024-08-15
1856   Natural Resources and Conservation Service and…       None 2024-08-15
1858   Natural Resources and Conservation Service and…       None 2024-08-15
1895   Natural Resources and Conservation Service and…       None 2024-08-15
1896   Natural Resources and Conservation Service and…       None 2024-08-15
1971   Natural Resources and Conservation Service and…       None 2024-08-15
1982   Natural Resources and Conservation Service and…       None 2024-08-15
1983   Natural Resources and Conservation Service and…       None 2024-08-15
1988   Natural Resources and Conservation Service and…       None 2024-08-15
2012   Natural Resources and Conservation Service and…       None 2024-08-15
2419   Natural Resources and Conservation Service and…       None 2024-08-15
2428   Natural Resources and Conservation Service and…       None 2024-08-15
2437   Natural Resources and Conservation Service and…       None 2024-08-15
2449   Natural Resources and Conservation Service and…       None 2024-08-15
2451   Natural Resources and Conservation Service and…       None 2024-08-15
2559   Natural Resources and Conservation Service and…       None 2024-08-15
2586   Natural Resources and Conservation Service and…       None 2024-08-15
2596   Natural Resources and Conservation Service and…       None 2024-08-15


            referenceg  areaacres  areasqkm states  … hutype  \
13     1628039,559852   14549.47     58.88     LA  …      D
139    558306,1629919   32730.99    132.46     LA  …      F
228     558302,560269   24313.37     98.39     LA  …      F
555             558302   23652.90     95.72     LA  …      D
717    534652,533690   25536.55    103.34     LA  …      S
915             560223   23095.47     93.46     LA  …      D
```

947	554577,532674	39972.91	161.76	LA	…	D
1016	1627325,1628217	39165.11	158.50	LA	…	W
1066	532770,559668	27204.00	110.09	LA	…	F
1472	559872,560760	10652.63	43.11	LA	…	D
1630	560529	17903.81	72.45	LA	…	D
1700	1627674,1629919	33595.40	135.96	LA	…	F
1726	559837	29958.25	121.24	LA	…	W
1818	559655,533690	30202.03	122.22	LA	…	S
1828	532725,560269	34576.04	139.92	LA	…	F
1843	1627802	25153.50	101.79	LA	…	W
1856	560090	20037.95	81.09	LA	…	D
1858	560059,1627674	33785.51	136.73	LA	…	D
1895	560024,560725	24117.56	97.60	LA	…	F
1896	560716,560036	39860.61	161.31	LA	…	D
1971	537236	15127.51	61.22	LA	…	S
1982	1629514	1052466.96	4259.19	LA,MS	…	I
1983	1629514,558730	74920.05	303.19	LA	…	W
1988	532247,560269	19664.00	79.58	LA	…	F
2012	556476,560269	21498.20	87.00	LA	…	F
2419	559993,1627974	39707.30	160.69	LA	…	F
2428	559853	39931.62	161.60	LA	…	D
2437	536056	19072.51	77.18	LA	…	D
2449	1627475,560090	16270.27	65.84	LA	…	D
2451	559870	29326.82	118.68	LA	…	D
2559	536881,539539	37355.86	151.17	LA	…	D
2586	560090	39266.10	158.90	LA	…	D
2596	1629919	161837.25	654.93	LA	…	W

	humod	tohuc	noncontrib	noncontr_1	shape_Leng	\
13	GC,TF	080902030702	0.0	0.0	NaN	
139	NM	080902030400	0.0	0.0	NaN	
228	GC	080902030800	0.0	0.0	NaN	
555	LE,GC	080902030505	0.0	0.0	NaN	
717	LE,TF,UA	080902030103	0.0	0.0	NaN	
915	BC,GC	080902030800	0.0	0.0	NaN	
947	GC	080902030702	0.0	0.0	NaN	
1016	NM	080902030800	0.0	0.0	NaN	
1066	LE,BC,TF	080902030302	0.0	0.0	NaN	
1472	NM	080902030603	0.0	0.0	NaN	
1630	LE,TF,GC	080902030505	0.0	0.0	NaN	
1700	LE,BC	080902030400	0.0	0.0	NaN	
1726	NM	080902030606	0.0	0.0	NaN	
1818	LE,TF,UA,BC,OT	080902030302	0.0	0.0	NaN	
1828	GC,LE	080902030800	0.0	0.0	NaN	
1843	NM	080902030800	0.0	0.0	NaN	
1856	LE,TF	080902030502	0.0	0.0	NaN	
1858	BC	080902030800	0.0	0.0	NaN	

```
1895                NM   080902030603        0.0        0.0        NaN
1896                NM   080902030606        0.0        0.0        NaN
1971          LE,BC,UA   080902030202        0.0        0.0        NaN
1982                NM   080902030900        0.0        0.0        NaN
1983                NM         OCEAN        0.0        0.0        NaN
1988       TF,OT,GC,LE   080902030800        0.0        0.0        NaN
2012             LE,GC   080902030800        0.0        0.0        NaN
2419             OC,LE   080902030102        0.0        0.0        NaN
2428                BC   080902030800        0.0        0.0        NaN
2437          LE,OT,GC   080902030505        0.0        0.0        NaN
2449             LE,GC   080902030702        0.0        0.0        NaN
2451                LE   080902030302        0.0        0.0        NaN
2559                GC   080902030508        0.0        0.0        NaN
2586             BC,GC   080902030800        0.0        0.0        NaN
2596                NM   031700091402        0.0        0.0        NaN

      shape_Area  ObjectID                                          geometry  \
13           NaN        14  POLYGON ((-89.75972 29.84024, -89.75749 29.840…
139          NaN       140  POLYGON ((-89.62701 30.14982, -89.62697 30.149…
228          NaN       229  POLYGON ((-89.70818 29.72359, -89.70676 29.723…
555          NaN       556  POLYGON ((-89.98997 29.77, -89.98945 29.76865,…
717          NaN       718  POLYGON ((-90.15505 30.01946, -90.15644 29.959…
915          NaN       916  POLYGON ((-89.60389 29.82618, -89.60091 29.824…
947          NaN       948  POLYGON ((-89.79177 29.7609, -89.78905 29.7594…
1016         NaN      1017  POLYGON ((-89.27418 30.02194, -89.27501 30.025…
1066         NaN      1067  POLYGON ((-89.94415 30.0758, -89.9409 30.07838…
1472         NaN      1473  POLYGON ((-89.45708 29.97146, -89.45493 29.970…
1630         NaN      1631  POLYGON ((-89.90424 29.85416, -89.87284 29.854…
1700         NaN      1701  POLYGON ((-89.81883 30.09693, -89.81869 30.096…
1726         NaN      1727  POLYGON ((-89.42295 30.03668, -89.41954 30.038…
1818         NaN      1819  POLYGON ((-90.15505 30.01946, -90.15166 30.018…
1828         NaN      1829  POLYGON ((-89.59436 29.43968, -89.59312 29.438…
1843         NaN      1844  POLYGON ((-89.21627 29.99331, -89.21855 29.993…
1856         NaN      1857  POLYGON ((-90.02668 29.9636, -90.02595 29.9663…
1858         NaN      1859  POLYGON ((-89.60091 29.82456, -89.59807 29.826…
1895         NaN      1896  POLYGON ((-89.45708 29.97146, -89.46783 29.969…
1896         NaN      1897  POLYGON ((-89.57102 29.96625, -89.56974 29.966…
1971         NaN      1972  POLYGON ((-89.90144 30.03694, -89.90194 30.036…
1982         NaN      1983  POLYGON ((-89.12941 30.18342, -89.125 30.18106…
1983         NaN      1984  POLYGON ((-89.09831 29.46341, -89.09929 29.463…
1988         NaN      1989  POLYGON ((-89.71636 29.5229, -89.71381 29.5241…
2012         NaN      2013  POLYGON ((-89.82401 29.60685, -89.82341 29.607…
2419         NaN      2420  POLYGON ((-90.39864 30.07264, -90.39591 30.070…
2428         NaN      2429  POLYGON ((-89.35232 29.87615, -89.35028 29.875…
2437         NaN      2438  POLYGON ((-89.98997 29.77, -89.99014 29.76963,…
2449         NaN      2450  POLYGON ((-89.91251 29.86185, -89.90943 29.863…
2451         NaN      2452  POLYGON ((-90.02078 29.98079, -90.01869 29.981…
```

```
2559         NaN      2560  POLYGON ((-89.97047 29.74687, -89.96593 29.750…
2586         NaN      2587  POLYGON ((-89.70058 29.84821, -89.69808 29.846…
2596         NaN      2597  POLYGON ((-89.54443 30.18165, -89.54419 30.181…

           huc8
13      08090203
139     08090203
228     08090203
555     08090203
717     08090203
915     08090203
947     08090203
1016    08090203
1066    08090203
1472    08090203
1630    08090203
1700    08090203
1726    08090203
1818    08090203
1828    08090203
1843    08090203
1856    08090203
1858    08090203
1895    08090203
1896    08090203
1971    08090203
1982    08090203
1983    08090203
1988    08090203
2012    08090203
2419    08090203
2428    08090203
2437    08090203
2449    08090203
2451    08090203
2559    08090203
2586    08090203
2596    08090203

[33 rows x 22 columns]
```

```python
# original huc12 code
past_huc_code = "080902030506"


# separate gdf for plotting to be safe
wpd_plot = wpd_sub.copy()
```

```python
# highlight original area of study
wpd_plot['color'] = wpd_plot['huc12'].apply(
    lambda x: 'grey' if x == '080902030506'
            else 'yellow' if x == '080902030502' or x == '080902030501'
            else 'lightgrey'
)


#
project = pyproj.Transformer.from_crs("EPSG:4326", "EPSG:3857", always_xy=True)

x0, y0 = project.transform(-90.1, 29.5)
x1, y1 = project.transform(-89.6, 30.0)

hv_map = wpd_plot.hvplot(
    geo=True,
    color='color',          # use the color column
    line_color='black',
    line_width=0.5,
    alpha = .4,
    width=600,
    height=600,
    tiles = 'EsriImagery',
    hover_cols=['huc12']

# lat and long bounds
).opts(
    xlim = (x0, x1),
    ylim = (y0, y1)
)

hv_map
```

```
[ ]: :Overlay
     .WMTS.I      :WMTS    [Longitude,Latitude]
     .Polygons.I :Polygons   [Longitude,Latitude]    (color,huc12)
```

The Huc12 regions north of our original area of study will be my focus. Region 080902030502 seems most similar but with likely a higher percentage of land cover. Region 080902030501 looks more urban which could be interesting as well once the workflow is established. I anticipate '01' will have the highest variability between clusters and between runs of K-means. '02' will be the primary focus for evaluating k-means selection since i believe it will have slightly more variability than the more water-dominated 06 region initially considered.

```python
[43]: delta6_gdf = wpd_gdf[wpd_gdf[

    ### filter the gdf to the row(s) with the watershed we want
```

```
    ### use "dissolve" to merge the geometries of all the rows matching the␣
    ↪target watershed

    f'huc{HUC_LEVEL}'].isin(['080902030506'])].dissolve()

delta6_gdf
```

[43]:   geometry \
     0 POLYGON ((-89.97047 29.74687, -89.96593 29.750…

                                          tnmid \
     0 {E942B72E-599E-48F5-908A-EA5265701C14}

                                     metasource   sourcedata \
     0 {511D2AC8-11BA-45FC-AB98-F69D693D4C44} Watershed Boundary Dataset (WBD)

                                         sourceorig sourcefeat   loaddate \
     0 Natural Resources and Conservation Service and…   None 2024-08-15

            referenceg areaacres areasqkm …   name hutype \
     0 536881,539539   37355.86   151.17 … Manuel Canal-Spanish Lake   D

       humod   tohuc noncontrib noncontr_1 shape_Leng shape_Area ObjectID \
     0   GC 080902030508   0.0   0.0   NaN   NaN   2560

           huc8
     0 08090203

     [1 rows x 22 columns]

[44]:
```
delta2_gdf = wpd_gdf[wpd_gdf[

    ### filter the gdf to the row(s) with the watershed we want
    ### use "dissolve" to merge the geometries of all the rows matching the␣
    ↪target watershed

    f'huc{HUC_LEVEL}'].isin(['080902030502'])].dissolve()

delta2_gdf
```

[44]:   geometry \
     0 POLYGON ((-89.90424 29.85416, -89.87284 29.854…

                                          tnmid \
     0 {B32BD6BC-5CAE-4E86-84C0-86BA836C14BD}

                                     metasource   sourcedata \

```
0  {511D2AC8-11BA-45FC-AB98-F69D693D4C44}  Watershed Boundary Dataset (WBD)

                                            sourceorig sourcefeat   loaddate  \
0  Natural Resources and Conservation Service and…        None 2024-08-15

   referenceg   areaacres   areasqkm  …                              name  \
0      560529    17903.81      72.45  …  Creedmore Canal-Fourty Arpent Canal

   hutype      humod            tohuc noncontrib noncontr_1   shape_Leng  \
0       D  LE,TF,GC   080902030505         0.0        0.0          NaN

     shape_Area  ObjectID       huc8
0          NaN      1631  08090203

[1 rows x 22 columns]
```

```python
urban_gdf = wpd_gdf[wpd_gdf[

    ### filter the gdf to the row(s) with the watershed we want
    ### use "dissolve" to merge the geometries of all the rows matching the
 ↪target watershed

    f'huc{HUC_LEVEL}'].isin(['080902030501']))].dissolve()

urban_gdf
```

```
                                            geometry  \
0  POLYGON ((-90.02668 29.9636, -90.02595 29.9663…

                                     tnmid  \
0  {31101660-B283-4D40-8AC3-62A1A2487FD4}

                                  metasource                      sourcedata  \
0  {511D2AC8-11BA-45FC-AB98-F69D693D4C44}  Watershed Boundary Dataset (WBD)

                                            sourceorig sourcefeat   loaddate  \
0  Natural Resources and Conservation Service and…        None 2024-08-15

   referenceg   areaacres   areasqkm  …  \
0      560090    20037.95      81.09  …

                                   name hutype   humod          tohuc  \
0  Bayou Terre aux Boeufs-Fourty Arpent Canal      D   LE,TF   080902030502

   noncontrib noncontr_1   shape_Leng   shape_Area  ObjectID       huc8
0         0.0        0.0          NaN          NaN      1857  08090203
```

```
[1 rows x 22 columns]
```

0.3 Multi-Spectral Data

```
[33]: ### Log in to earthaccess
      earthaccess.login(persist = True)
```

```
[33]: <earthaccess.auth.Auth at 0x1175f14d0>
```

```
[45]: ### Search for HLS granules we want
      results = earthaccess.search_data(

          ### specify which dataset and spatial resolution we want
          short_name = 'HLSL30',

          ### specify that we're using cloud data
          cloud_hosted = True,

          ### use the bounding box from our watershed boundary
          bounding_box = tuple(delta2_gdf.total_bounds),

          ### set the temporal range of the data
          temporal = ('2024-06', '2024-08')
      )
```

```
[46]: results
```

```
[46]: [Collection: {'EntryTitle': 'HLS Landsat Operational Land Imager Surface
      Reflectance and TOA Brightness Daily Global 30m v2.0'}
       Spatial coverage: {'HorizontalSpatialDomain': {'Geometry': {'GPolygons':
      [{'Boundary': {'Points': [{'Longitude': -89.79864173, 'Latitude': 29.70347853},
      {'Longitude': -89.76643746, 'Latitude': 30.69278312}, {'Longitude':
      -90.91181412, 'Latitude': 30.71627038}, {'Longitude': -90.93262544, 'Latitude':
      29.72659663}, {'Longitude': -89.79864173, 'Latitude': 29.70347853}]}}]}}}}
       Temporal coverage: {'RangeDateTime': {'BeginningDateTime':
      '2024-06-07T16:31:11.509Z', 'EndingDateTime': '2024-06-07T16:31:11.509Z'}}
       Size(MB): 169.50417041778564
       Data: ['https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.02
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      , 'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.
      L30.T15RYP.2024159T163111.v2.0/HLS.L30.T15RYP.2024159T163111.v2.0.SAA.tif',
      'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.L3
      0.T15RYP.2024159T163111.v2.0/HLS.L30.T15RYP.2024159T163111.v2.0.VZA.tif',
      'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.L3
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      'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.L3
      0.T15RYP.2024159T163111.v2.0/HLS.L30.T15RYP.2024159T163111.v2.0.B09.tif',
```

'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.L3
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-89.02503941, 'Latitude': 30.71727112}, {'Longitude': -90.13201749, 'Latitude':
30.69527405}, {'Longitude': -90.10082051, 'Latitude': 29.70587294}]}}]}}}
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, 'https://data.lpdaac.earthdatacloud.nasa.gov/lp-prod-protected/HLSL30.020/HLS.
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```
0.T15RYN.2024239T163151.v2.0/HLS.L30.T15RYN.2024239T163151.v2.0.B06.tif']]
```

```python
[39]:   ### make a function to process all the granules from the earthaccess search
        ### and extract information for each granule

        ### define the function
        def get_earthaccess_links(results):

            ### make and display a progress bar
            progress_bar = IntProgress(min=0, max = len(results), description='Open␣
         ↪granules:')
            display(progress_bar)

            ### use a regular expression to extract tile_id and bank from .tif files
            url_re = re.compile(
                r'\.(?P<tile_id>\w+)\.\d+T\d+\.v\d\.\d\.(?P<band>[A-Za-z0-9]+)\.tif')

            ### accumulate gdf rows from each granule
            link_rows = []

            ### loop over granules to extract info
            for granule in results:

                ### locate metadata (UMM = universal metadata model)
                info_dict = granule['umm']

                ### pull out unique identifier for the granule
                granule_id = info_dict['GranuleUR']

                ### extract date/time
                datetime = pd.to_datetime(
                    info_dict['TemporalExtent']['RangeDateTime']['BeginningDateTime']
                )

                ### extract boundary coordinates for granule
                points = (
                    info_dict

         ↪['SpatialExtent']['HorizontalSpatialDomain']['Geometry']['GPolygons'][0]
                    ['Boundary']['Points']
                )

                ### make polygon using coordinate points for granule
                geometry = Polygon(
                    [(point['Longitude'],
                      point['Latitude']) for point in points]
                )
```

```python
    ### get url and open granule
    files = earthaccess.open([granule])

    ### loop through each file in the granule
    for file in files:

        ### use url regular expression to get url
        match = url_re.search(file.full_name)

        ### if match is found, append data to link_rows gdf we initialized
        if match is not None:
            link_rows.append(

                ### makes a gdf with the granule's data and geometry
                gpd.GeoDataFrame(
                    dict(

                        # timestamp
                        datetime = [datetime],

                        # unique tile ID
                        tile_id = [match.group('tile_id')],

                        # band
                        band = [match.group('band')],

                        # url
                        url = [file],

                        # polygon
                        geometry = [geometry]
                    ),

                    crs = 'EPSG:4326'

                )
            )
    ### update progress bar after each granule is done
    progress_bar.value += 1

### combine into a single gdf
file_df = pd.concat(link_rows).reset_index(drop = True)

### return the final gdf file
return file_df
```

```python
[40]: # look at one granule
      test_granule = results[0]

      test_granule
```

[40]: Collection: {'EntryTitle': 'HLS Landsat Operational Land Imager Surface
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```python
# look at umm
info_dict = test_granule['umm']
info_dict
```

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    'Description': 'api endpoint to retrieve temporary credentials valid for
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```
        'IdentifierType': 'ProducerGranuleId'}],
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      'ArchiveAndDistributionInformation': [{'Name': 'Not provided',
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        'SizeUnit': 'MB'}]},
    'Platforms': [{'ShortName': 'LANDSAT-8',
      'Instruments': [{'ShortName': 'OLI'}]}],
    'MetadataSpecification': {'URL':
'https://cdn.earthdata.nasa.gov/umm/granule/v1.6.6',
      'Name': 'UMM-G',
      'Version': '1.6.6'}}
```

```python
# run the function to get granule search results

# set path to save file
links_path = os.path.join(
    cache_dir,
    "downloads",
    'links_file_df.gpkg'
)

if os.path.exists(links_path):
    links_file_df = gpd.read_file(links_path)
else:
    links_file_df = get_earthaccess_links(results)
    os.makedirs(os.path.dirname(links_path), exist_ok=True)
    links_file_df.to_file(links_path, driver = "GPKG")
```

```python
[48]: links_file_df.head()
```

```
[48]:                           datetime tile_id band  \
      0 2024-06-07 16:31:11.509000+00:00  T15RYP  B10
      1 2024-06-07 16:31:11.509000+00:00  T15RYP  SAA
      2 2024-06-07 16:31:11.509000+00:00  T15RYP  VZA
      3 2024-06-07 16:31:11.509000+00:00  T15RYP  B06
      4 2024-06-07 16:31:11.509000+00:00  T15RYP  B09


                                             url  \
      0  <File-like object HTTPFileSystem, https://data…
      1  <File-like object HTTPFileSystem, https://data…
      2  <File-like object HTTPFileSystem, https://data…
      3  <File-like object HTTPFileSystem, https://data…
      4  <File-like object HTTPFileSystem, https://data…


                                        geometry
      0  POLYGON ((-89.79864 29.70348, -89.76644 30.692…
      1  POLYGON ((-89.79864 29.70348, -89.76644 30.692…
```

```
2  POLYGON ((-89.79864 29.70348, -89.76644 30.692…
3  POLYGON ((-89.79864 29.70348, -89.76644 30.692…
4  POLYGON ((-89.79864 29.70348, -89.76644 30.692…
```

[49]:
```python
### apply cached decorator to function
@cached('delta_reflectance_da_df')



### write function that computes reflectance data using
### search results (df of urls) and watershed boundary
def compute_reflectance_da(search_results, boundary_gdf):

    """
    Connect to files using VSI, crop the, apply a cloud mask, and wrangle the
 ↪data.

    Return a single reflectance DF with bands as columns and centroid coords &
 ↪datetime as index

    Parameters
    ==========
    search_results_list: list
        Search result links to the files (urls)
    boundary_gdf: gpd.GeoDataFrame
        Boundary used to crop the data
    """

    ### write a function to open raster from url, apply scale factor, crop, and
 ↪mask data
    def open_dataaray(url, boundary_proj_gdf, scale = 1, masked = True):

        # open raster data
        da = rxr.open_rasterio(url, masked = masked).squeeze() * scale

        # reproject boundary if needed to match raster crs
        if boundary_proj_gdf is None:
            boundary_proj_gdf = boundary_gdf.to_crs(da.rio.crs)

        # crop raster to bounding box
        cropped = da.rio.clip_box(*boundary_proj_gdf.total_bounds)

        return cropped

    ### write function to apply a cloud mask
    def compute_quality_mask(da, mask_bits = [1, 2, 3]):

        """Mask out low quality data by bit"""
```

```python
    # unpack the bits to a new axis
    bits = (

        # unpack each number into individual bits
        np.unpackbits(

            # convert to 8-bit unsigned int format
            da.astype(np.uint8),

            # set order of bits
            bitorder = 'little'

        # reshape to match original data with extra dim for bits
        ).reshape(da.shape + (-1,))
    )

    # select desired bits
    selected_bits = bits[..., mask_bits]

    # check they are all zero
    mask = np.all(selected_bits == 0, axis=-1)


    ### return the mask
    return mask


### grab metadata
file_df = get_earthaccess_links(search_results)

# store results for each granule
granule_da_rows = []

# store projected boundary
boundary_proj_gdf = None

# group the data by granule
group_iter = file_df.groupby(

    # datetime and tile_id
    ['datetime', 'tile_id']
)

## loop through each image and its metadata
for (datetime, tile_id), granule_df in tqdm(group_iter):
```

```python
        # print status bar
        print(f'Processing granule {tile_id} {datetime}')

        # find each granule's cloud mask file (fmask) url
        cloud_mask_url = (
            granule_df.loc[granule_df.band == 'Fmask', 'url']
            .values[0])

        # open granule cloud mask
        cloud_masked_cropped_da = open_dataaray(cloud_mask_url,
 ⌴boundary_proj_gdf, masked = False)

        ### compute cloud mask
        cloud_mask = compute_quality_mask(cloud_masked_cropped_da)

        ### loop through each spectral band to open, crop, and mask the band
        da_list = []
        df_list = []

        # loop through each band in granule
        for i, row in granule_df.iterrows():

            # only loop through spectral bands
            if row.band.startswith('B'):

                # open band's raster and scale to reflectance data
                band_cropped = open_dataaray(
                    row.url, boundary_proj_gdf, scale = .0001)

                # name the raster by the band
                band_cropped.name = row.band

                # apply the cloud mask to the raster
                row['da'] = band_cropped.where(cloud_mask)

                ### append the row to granule_da_rows
                granule_da_rows.append(row.to_frame().T)

    ### reassemble the metadata df
    return pd.concat(granule_da_rows)
```

```python
[50]: reflectance_da_df = compute_reflectance_da(results, delta2_gdf)
```

```
IntProgress(value=0, description='Open granules:', max=44)

QUEUEING TASKS |  :    0%|              | 0/15 [00:00<?, ?it/s]

PROCESSING TASKS |  :    0%|              | 0/15 [00:00<?, ?it/s]
```

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PROCESSING TASKS | :    0%|               | 0/15 [00:00<?, ?it/s]
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COLLECTING RESULTS | :    0%|              | 0/15 [00:00<?, ?it/s]
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PROCESSING TASKS | :    0%|             | 0/15 [00:00<?, ?it/s]
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COLLECTING RESULTS | :    0%|              | 0/15 [00:00<?, ?it/s]
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```
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Processing granule T15RYP 2024-06-07 16:31:11.509000+00:00
Processing granule T16RBT 2024-06-07 16:31:11.509000+00:00
Processing granule T16RBU 2024-06-07 16:31:11.509000+00:00
Processing granule T15RYN 2024-06-15 16:31:19.154000+00:00
Processing granule T15RYP 2024-06-15 16:31:19.154000+00:00
Processing granule T16RBT 2024-06-15 16:31:19.154000+00:00
Processing granule T16RBU 2024-06-15 16:31:19.154000+00:00
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Processing granule T15RYP 2024-06-23 16:31:21.277000+00:00
Processing granule T16RBT 2024-06-23 16:31:21.277000+00:00
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Processing granule T16RBU 2024-07-01 16:31:17.338000+00:00
Processing granule T15RYN 2024-07-09 16:31:29.187000+00:00
Processing granule T15RYP 2024-07-09 16:31:29.187000+00:00
Processing granule T16RBT 2024-07-09 16:31:29.187000+00:00
Processing granule T16RBU 2024-07-09 16:31:29.187000+00:00
Processing granule T15RYN 2024-07-17 16:31:33.271000+00:00
Processing granule T15RYP 2024-07-17 16:31:33.271000+00:00
Processing granule T16RBT 2024-07-17 16:31:33.271000+00:00
Processing granule T16RBU 2024-07-17 16:31:33.271000+00:00
Processing granule T15RYN 2024-07-25 16:31:43.265000+00:00
Processing granule T15RYP 2024-07-25 16:31:43.265000+00:00
Processing granule T16RBT 2024-07-25 16:31:43.265000+00:00
Processing granule T16RBU 2024-07-25 16:31:43.265000+00:00
Processing granule T15RYN 2024-08-02 16:31:36.413000+00:00
Processing granule T15RYP 2024-08-02 16:31:36.413000+00:00
Processing granule T16RBT 2024-08-02 16:31:36.413000+00:00
Processing granule T16RBU 2024-08-02 16:31:36.413000+00:00
Processing granule T15RYN 2024-08-10 16:31:42.335000+00:00
Processing granule T15RYP 2024-08-10 16:31:42.335000+00:00
Processing granule T16RBT 2024-08-10 16:31:42.335000+00:00
Processing granule T16RBU 2024-08-10 16:31:42.335000+00:00
Processing granule T15RYN 2024-08-18 16:31:46.256000+00:00
Processing granule T15RYP 2024-08-18 16:31:46.256000+00:00
Processing granule T16RBT 2024-08-18 16:31:46.256000+00:00
Processing granule T16RBU 2024-08-18 16:31:46.256000+00:00
Processing granule T15RYN 2024-08-26 16:31:51.172000+00:00
Processing granule T15RYP 2024-08-26 16:31:51.172000+00:00
Processing granule T16RBT 2024-08-26 16:31:51.172000+00:00
```

```
Processing granule T16RBU 2024-08-26 16:31:51.172000+00:00
```

```
[52]: reflectance_da_df.head()
```

```
[52]:                         datetime tile_id band  \
      45  2024-06-07 16:31:11.509000+00:00  T15RYN  B04
      48  2024-06-07 16:31:11.509000+00:00  T15RYN  B06
      49  2024-06-07 16:31:11.509000+00:00  T15RYN  B03
      50  2024-06-07 16:31:11.509000+00:00  T15RYN  B07
      51  2024-06-07 16:31:11.509000+00:00  T15RYN  B02


                                                    url  \
      45  <File-like object HTTPFileSystem, https://data…
      48  <File-like object HTTPFileSystem, https://data…
      49  <File-like object HTTPFileSystem, https://data…
      50  <File-like object HTTPFileSystem, https://data…
      51  <File-like object HTTPFileSystem, https://data…


                                               geometry  \
      45  POLYGON ((-89.82661214 28.80213717, -89.795837…
      48  POLYGON ((-89.82661214 28.80213717, -89.795837…
      49  POLYGON ((-89.82661214 28.80213717, -89.795837…
      50  POLYGON ((-89.82661214 28.80213717, -89.795837…
      51  POLYGON ((-89.82661214 28.80213717, -89.795837…


                                                     da
      45  [[<xarray.DataArray 'B04' ()> Size: 4B\narray(…
      48  [[<xarray.DataArray 'B06' ()> Size: 4B\narray(…
      49  [[<xarray.DataArray 'B03' ()> Size: 4B\narray(…
      50  [[<xarray.DataArray 'B07' ()> Size: 4B\narray(…
      51  [[<xarray.DataArray 'B02' ()> Size: 4B\narray(…
```

0.4 Merge Temporal Data

```python
[53]: ### apply cache decorator
      @cached('delta_reflectance_da')

      ### create a function to merge and composite reflectance data from multiple␣
       ↪granules
      ### end result: single, composite reflectance image for each spectral band
      def merge_and_composite_arrays(granule_da_df):

          ### initialize a list to store composites after processing
          da_list = []

          ### loop over each spectral band
          for band, band_df in granule_da_df.groupby('band'):
```

```python
        # list for storing merged data arrays (one per date)
        merged_das = []

        ### loop over date/time of image acquisition and merge granules for
 ↪each date
        for datetime, date_df in band_df.groupby('datetime'):

            # merge granules for each date
            merged_da = rxrmerge.merge_arrays(list(date_df.da))

            ### mask negative values (could be no data or invalid data)
            merged_da = merged_da.where(merged_da > 0)

            ### append to merged_das list we initialized
            merged_das.append(merged_da)

        ### composite images across dates
        composite_da = xr.concat(merged_das,
                                 # make a datetime dim
                                 # calculate median value across datetimes for
 ↪pixel
                                 dim = 'datetime').median('datetime')

        # assign band number to attribute of composite data array
        composite_da['band'] = int(band[1:])

        # name the composite data array
        composite_da.name = 'reflectance'

        ### add processed and composite data array to list
        da_list.append(composite_da)


    ### concatenates composite data arrays for each band along band dimension
    return xr.concat(da_list, dim = 'band')
```

```python
[54]: reflectance_da = merge_and_composite_arrays(reflectance_da_df)
```

```python
[55]: reflectance_da
```

```
[55]: <xarray.DataArray 'reflectance' (band: 10, y: 344, x: 497)> Size: 7MB
      array([[[nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              …,
              [nan, nan, nan, …, nan, nan, nan],
```

73

```
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan]],

             [[nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              …,
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan]],

             [[nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              …,
    …
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan]],

             [[nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              …,
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan]],

             [[nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              …,
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan],
              [nan, nan, nan, …, nan, nan, nan]]],
        shape=(10, 344, 497), dtype=float32)
Coordinates:
  * x            (x) float64 4kB 7.991e+05 7.991e+05 … 8.139e+05 8.14e+05
  * y            (y) float64 3kB 3.308e+06 3.308e+06 … 3.297e+06 3.297e+06
  * band         (band) int64 80B 1 2 3 4 5 6 7 9 10 11
    spatial_ref  int64 8B 0
```

0.5 K-Means Clustering

```
[59]: # establish model df and confirm correct formatting
      model_df = (reflectance_da

                  # flatten da into long df
                  .to_dataframe()

                  # select reflectance column
                  .reflectance

                  # make the table wide: each row will be a pixel location
                  # each column is a spectral band with reflectance value
                  .unstack('band')
                  )

      ### filter out rows with no data
      model_df = model_df.drop(columns = [10, 11]).dropna()
      model_df
```

```
[59]: band                              1        2        3        4        5  \
      y            x
      3.307669e+06 813185.60451  0.00990  0.01710  0.04060  0.03450  0.13160
                   813215.60451  0.00870  0.01550  0.03100  0.02740  0.07870
                   813245.60451  0.00795  0.01440  0.02890  0.02380  0.06700
                   813275.60451  0.00830  0.01180  0.02170  0.01870  0.04830
                   813305.60451  0.01420  0.02075  0.03495  0.03350  0.05825
      ...                            ...      ...      ...      ...      ...
      3.297439e+06 800165.60451  0.01805  0.02475  0.04320  0.03590  0.06010
                   800195.60451  0.01780  0.02400  0.04310  0.03850  0.05365
                   800225.60451  0.01840  0.02320  0.04015  0.03315  0.05390
      3.297409e+06 799595.60451  0.02630  0.03300  0.05740  0.05440  0.14260
                   799625.60451  0.02290  0.03010  0.05990  0.05000  0.22730

      band                              6        7        9
      y            x
      3.307669e+06 813185.60451  0.05700  0.03160  0.00080
                   813215.60451  0.03700  0.02210  0.00100
                   813245.60451  0.02890  0.01630  0.00100
                   813275.60451  0.02200  0.01410  0.00090
                   813305.60451  0.03675  0.02405  0.00070
      ...                            ...      ...      ...
      3.297439e+06 800165.60451  0.04285  0.02365  0.00090
                   800195.60451  0.02650  0.01885  0.00085
                   800225.60451  0.02730  0.01900  0.00075
      3.297409e+06 799595.60451  0.10370  0.05620  0.00080
                   799625.60451  0.14020  0.06460  0.00070
```

`[159214 rows x 8 columns]`

Now we can start to evaluate the optimal k-means clustering by the elbow method, which plots 'inertia' vs the number of clusters. Inertia is the sum of squared distances from each point to the assigned cluster center. Inertia is a measure of cluster 'quality' but if we increase k to equal our data points we can theoretically over-fit to every datapoint, but by looking for the 'elbow' where adding more clusters starts to decrease inertia more slowly.

```python
[75]: # select only feature columns
feature_cols = model_df.columns.difference(['x','y'])
Kmodel_unscaled = model_df[feature_cols]

# scale features to impact clustering equally
scaler = StandardScaler()
Kmodel = scaler.fit_transform(Kmodel_unscaled)


# set random sample size to avoid running k-means on full data for each k
sample_size = 20000
if Kmodel.shape[0] > sample_size:
    Ksample = Kmodel[np.random.choice(Kmodel.shape[0], sample_size,␣
 ↪replace=False)]
else:
    Ksample = Kmodel

# elbow test
# initialize inertia and k range
inertia = []
k_range = range(1, 15)

for k in k_range:
    kmeans = KMeans(n_clusters=k, random_state=123, n_init=10)
    kmeans.fit(Ksample)
    inertia.append(kmeans.inertia_)

# df for plot
inertia_df = pd.DataFrame({
    'k': list(k_range),
    'inertia': inertia
})

knee = KneeLocator(k_range, inertia, curve='convex', direction='decreasing')
optimal_k = knee.knee
print(f"Optimal number of clusters suggested by elbow method: {optimal_k}")
```

```
line = inertia_df.hvplot.line(
    x='k',
    y='inertia',
    title='Elbow Method for Optimal k',
    xlabel='Number of clusters (k)',
    ylabel='Inertia (Within-cluster sum of squares)'
)

points = inertia_df.hvplot.scatter(
    x='k',
    y='inertia',
    size=8
)

k_val = optimal_k
inertia_val = inertia_df.loc[inertia_df['k'] == k_val, 'inertia'].values[0]
highlight = hv.Points([(k_val, inertia_val)]).opts(color='red', size=10)

elbow_plot = line * points * highlight
elbow_plot
```

Optimal number of clusters suggested by elbow method: 4

[75]: :Overlay
       .Curve.I   :Curve   [k]   (inertia)
       .Scatter.I :Scatter   [k]   (inertia)
       .Points.I   :Points   [x,y]

[76]: `hv.save(elbow_plot, "img/elbow_output.html")`