Notebook

October 16, 2024

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1 Preparation

1.1 Import library and set directory

```python
[1]: import os
     import xarray as xr
     import geopandas as gpd

     # Add the path to the designated folder containing custom modules.
     import sys
     sys.path.append('../src')

     # Import the custom module for benthic habitat mapping.
     # This module contains functions and utilities for tasks such as
     # correction and classification of benthic habitats.
     import benthic_mapping as bm

     import matplotlib.pyplot as plt
     # plt.style.use('dark_background')

     from datetime import datetime
```

```python
[2]: def construct_file_path(out_dir, user_year):
         # Ensure the year is a string
         user_year = str(user_year)
         # Construct the directory path
         year_folder = os.path.join(out_dir, 'atmospheric_correction', user_year)
         # Iterate through the files in the year folder
         for filename in os.listdir(year_folder):
             # Check if the file contains 'L2R' in its name
             if 'L2R' in filename:
                 # Construct the full file path
                 file_data_path = os.path.join(year_folder, filename)
                 return file_data_path
         # If no file is found, return None
         return
```

```
# Define folder path
base_dir =  os.path.abspath(os.path.join(os.getcwd(), '../..'))
data_dir = os.path.join(base_dir, 'data')
out_dir = os.path.join(base_dir, 'out')
raw_data_dir = os.path.join(data_dir, 'raw')

# Define file paths
user_year = "2016"
file_data_path = construct_file_path(out_dir, user_year)
shapefile_path_deepWater = os.path.join(out_dir, 'geom_def', 'geom_deepWater.
 ↪shp')
shapefile_path_sandObject = os.path.join(out_dir, 'geom_def', 'geom_sandObject.
 ↪shp')
shapefile_path_training_1 = os.path.join(out_dir, 'geom_def', 'geom_landWater.
 ↪shp')
shapefile_path_training_2 = os.path.join(out_dir, 'geom_def',␣
 ↪'geom_benthicObject.shp')

# Extract the base filename
base_filename = os.path.splitext(os.path.basename(file_data_path))[0]
base_filename = base_filename.rsplit('_', 1)[0]
```

1.2   Pre-processing dataset

1.2.1   Open and prepare the dataset

```
[3]: # Open dataset
     data = xr.open_dataset(file_data_path)

     # Determine if the dataset is from S2A or S2B based on the filename
     if 'S2A' in file_data_path:
         print('Detected dataset from Sentinel-2A')
         variables_to_keep = {
             'transverse_mercator': 'transverse_mercator',
             'lat': 'lat',
             'lon': 'lon',
             'rhos_492': 'blue',
             'rhos_560': 'green',
             'rhos_665': 'red',
             'rhos_704': 'red_edge',
             'rhos_833': 'nir',
             'rhos_1614': 'swir1',
             'rhos_2202': 'swir2'
         }
     elif 'S2B' in file_data_path:
         print('Detected dataset from Sentinel-2B')
```

```python
    variables_to_keep = {
        'transverse_mercator': 'transverse_mercator',
        'lat': 'lat',
        'lon': 'lon',
        'rhos_492': 'blue',
        'rhos_559': 'green',
        'rhos_665': 'red',
        'rhos_704': 'red_edge',
        'rhos_833': 'nir',
        'rhos_1610': 'swir1',
        'rhos_2186': 'swir2'
    }
else:
    raise ValueError("The dataset file path does not indicate whether it is S2A␣
 ↪or S2B.")

# Create the new dataset
new_vars = {}
for old_name, new_name in variables_to_keep.items():
    if old_name in data:
        # Select the variable and transpose if needed
        variable = data[old_name]
        new_vars[new_name] = variable

# Construct the new dataset
ds = xr.Dataset(new_vars)

# Preserve selected attributes
attributes_to_keep = [
    'generated_by', 'generated_on', 'contact', 'product_type',␣
 ↪'metadata_profile', 'Conventions',
    'sensor', 'isodate', 'global_dims', 'sza', 'vza', 'raa', 'scene_xrange',␣
 ↪'scene_yrange',
    'scene_dims', 'scene_pixel_size', 'data_dimensions', 'data_elements',␣
 ↪'acolite_version',
    'acolite_file_type', 'tile_code', 'proj4_string', 'pixel_size', 'uoz',␣
 ↪'uwv', 'wind',
    'pressure', 'oname'
]
ds.attrs = {key: data.attrs[key] for key in attributes_to_keep}

# Close the original dataset
data.close()
```

Detected dataset from Sentinel-2A

1.2.2 Reset encoding and define projection

```python
[4]: # Reset encoding
     ds = ds.drop_encoding()

     # Set CRS
     wkt = ds.attrs['proj4_string']
     ds = ds.rio.write_crs(wkt, inplace=True)

     # Drop 'grid_mapping'
     for var in ds.data_vars:
         if 'grid_mapping' in ds[var].attrs:
             del ds[var].attrs['grid_mapping']

     # Print the current CRS
     print("Current CRS:", ds.rio.crs)
```

```
Current CRS: EPSG:32748
```

2 Image Processing

2.1 Sun Glint Correction (Hedley et al., 2005)

```python
[5]: # Subsetting sample area for the Sun Glint Correction
     # Read shapefile and desired year for the input
     var_select = ['blue', 'green', 'red', 'red_edge', 'nir']  # Variables to select␣
      ↪from the dataset
     gdf = gpd.read_file(shapefile_path_deepWater)  # Load shapefile containing the␣
      ↪region of interest
     desired_year = int(user_year)  # Convert user_year to integer

     # Mask the dataset based on the shapefile and desired year
     samples = bm.mask_dataset(
         ds[var_select], gdf, desired_year
     )

     # Compute sun glint correction using the 'sunglint_correction' function from␣
      ↪the module
     # Note: The 'vars_ignore' parameter excludes 'lat' and 'lon' from the␣
      ↪correction process. Default set to None
     sg_ds = bm.sunglint_correction(ds, samples, 'nir', vars_ignore=['lat', 'lon'])
```

```
Minimum NIR brightness (MinNir): 0.007346587721258402
Regression results for blue: slope=0.429002333999439,
r_value=0.34442138731347044, p_value=0.0
Regression results for green: slope=0.5875828082320755,
r_value=0.5324793265248939, p_value=0.0
Regression results for red: slope=0.710009467695083, r_value=0.6562007595809348,
```

```
p_value=0.0
Regression results for red_edge: slope=0.6016551434462336,
r_value=0.7125819095488927, p_value=0.0

Slope information not found for variable 'swir1'. Skipping correction.
Slope information not found for variable 'swir2'. Skipping correction.
```

2.2 Depth Invariant Index (Green et al., 2000)

```python
[6]: # Subsetting sample area for the DII calculation
     # Read the shapefile containing the region of interest
     gdf = gpd.read_file(shapefile_path_sandObject)  # Load shapefile for sand
      ↪object classification

     # Mask the dataset based on the shapefile and desired year
     samples = bm.mask_dataset(
         sg_ds, gdf, desired_year
     )

     # Define pairs of bands for which to calculate k-ratio and Depth Invariant
      ↪Index (DII)
     band_pairs = [
         ('blue_sg', 'green_sg'),
         ('blue_sg', 'red_sg'),
         ('blue_sg', 'red_edge_sg'),
         ('green_sg', 'red_sg'),
         ('green_sg', 'red_edge_sg'),
         ('red_sg', 'red_edge_sg')
     ]

     # Calculate the water column corrected dataset using the specified band pairs
     wc_ds = bm.water_column_correction(sg_ds, samples, band_pairs)
```

```
Calculating DII for bands blue_sg and green_sg with k-ratio: 0.8367575305984772

Calculating DII for bands blue_sg and red_sg with k-ratio: 0.6241960291568832

Calculating DII for bands blue_sg and red_edge_sg with k-ratio:
0.7050131725807025

Calculating DII for bands green_sg and red_sg with k-ratio: 0.832054342606476

Calculating DII for bands green_sg and red_edge_sg with k-ratio:
0.953031382976959

Calculating DII for bands red_sg and red_edge_sg with k-ratio:
1.1386719402708636
```

2.3 Spectral Indices

2.3.1 Normalized Difference

```
[7]: # Define pairs of variables for which to compute normalized difference indices
     variable_pairs = [
         ('nir', 'red'),
         ('green', 'swir1'),
         ('nir', 'green'),
         ('green', 'red'),
         ('green', 'red_edge')
     ]

     # Define names for the resulting normalized difference indices
     var_names = ['ndvi', 'mndwi', 'gndvi', 'ngrdi_red','ngrdi_red_edge']

     # Compute the normalized difference indices
     si_ds = bm.normalized_difference(ds, variable_pairs, var_names)
```

2.3.2 Non-Normalized Difference

```
[8]: # Calculate EVI
     evi = (ds['nir'] - ds['red']) / (ds['nir'] + 6 * ds['red'] - 7.5 * ds['blue'] +␣
      ↪1)

     # Calculate AWEI
     awei = 4 * (ds['green'] - ds['swir2']) - (0.25 * ds['nir'] + 2.75 * ds['swir1'])

     # Create DataArray for EVI with attributes
     si_ds['evi'] = xr.DataArray(
         data=evi,
         dims=ds['nir'].dims,
         coords=ds['nir'].coords,
         name='evi',
         attrs={
             'long_name': 'Enhanced Vegetation Index (EVI)',
             'formula': '(NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1)',
             'units': '1',
             'date_created': datetime.utcnow().isoformat(),
         }
     )

     # Create DataArray for AWEI with attributes
     si_ds['awei'] = xr.DataArray(
         data=awei,
         dims=ds['green'].dims,
         coords=ds['green'].coords,
         name='awei',
```

```
    attrs={
        'long_name': 'Automated Water Extraction Index (AWEI)',
        'formula': '4 * (GREEN - SWIR2) - (0.25 * NIR + 2.75 * SWIR1)',
        'units': '1',
        'date_created': datetime.utcnow().isoformat(),
    }
)
```

2.4 Merge Processed Dataset

```
[9]: # Merge dataset
     clf_ds = xr.merge([ds, sg_ds, wc_ds, si_ds])
```

3 Classification

```
[10]: import pandas as pd
      import numpy as np

      from sklearn.ensemble import RandomForestClassifier
      from sklearn.model_selection import train_test_split
      from sklearn.metrics import classification_report, confusion_matrix,␣
       ↪accuracy_score, cohen_kappa_score
```

3.1 Land-Water Classification

```
[11]: # Subsetting sample area for the classification
      # Read the shapefile containing the region of interest
      gdf = gpd.read_file(shapefile_path_training_1)

      # Extract labeled samples for the specified year
      samples = bm.labeled_samples(
          clf_ds,gdf, 'class', desired_year
      )

      # Define the list of features to be used in the classification model
      features = [
          'blue', 'green', 'red', 'red_edge', 'nir', 'swir1',
          'blue_sg', 'green_sg', 'red_sg', 'red_edge_sg',
          'dii_blue_sg_green_sg', 'dii_blue_sg_red_sg',
          'dii_blue_sg_red_edge_sg', 'dii_green_sg_red_sg',
          'dii_green_sg_red_edge_sg', 'dii_red_sg_red_edge_sg',
          'mndwi', 'awei',
      ]

      # Prepare the feature matrix (X) and target labels (y) from the given samples
      X, y = bm.prepare_samples(samples, features, 'label')
```

```python
[12]:  # Classification procedure
       # Split the samples into training and testing sets
       X_train, X_test, y_train, y_test = train_test_split(
           X, y, test_size=0.3, random_state=42
       )

       # Initialiaze a Random Forest classifier
       clf = RandomForestClassifier(
           n_estimators=80, random_state=42, max_depth=15,
           min_samples_leaf=1, min_samples_split=2
       )

       # Fit the classifier to the training data
       clf.fit(X_train, y_train)

       # Retrieve the features importance
       importances = clf.feature_importances_
       importance_df = pd.DataFrame({
           'Feature': features,
           'Importance': importances
       })
       importance_df = importance_df.sort_values(
           by='Importance', ascending=False
           ).reset_index(drop=True)

       # Print feature importances
       importance_df

       # Save the DataFrame to a CSV file
       export_file_path = os.path.join(out_dir, 'csv',␣
         ↪f"{'feature_importances_classification_1'}_{user_year}.csv")
       importance_df.to_csv(export_file_path)
```

```python
[13]:  # Accuracy assessment
       # Predict the labels for the test set using the trained classifier
       y_pred = clf.predict(X_test)

       # Print the reports
       print(classification_report(y_test, y_pred))
       print(f"{confusion_matrix(y_test, y_pred)}\n")
       print(f"accuracy score:{accuracy_score(y_test, y_pred)}")
       print(f"cohen's kappa:{cohen_kappa_score(y_test, y_pred)}")
```

	precision	recall	f1-score	support
1	1.00	1.00	1.00	157530
2	0.99	1.00	1.00	1527
3	0.99	0.99	0.99	1294

```
   accuracy                              1.00    160351
  macro avg          0.99        1.00    0.99    160351
weighted avg         1.00        1.00    1.00    160351

[[157517       3      10]
 [     1    1525       1]
 [     9       8    1277]]
```

accuracy score:0.999800437789599

cohen's kappa:0.9942552438209195

```python
[14]: # Predict full set and reshape into the original spatial dimensions
      # Get the dimensions (height and widht) of the dataset
      height = clf_ds.sizes['y']
      width = clf_ds.sizes['x']

      # Stack the feature data into a 2D array 'X_full'
      # Create a mask to identify rows with valid (non-NaN) feature values
      # Predict the labels for the entire dataset using the trained RandomForest model
      X_full = np.stack([clf_ds[var].values.flatten() for var in features], axis=1)
      mask = ~np.isnan(X_full).any(axis=1)
      y_full_pred = clf.predict(X_full)

      # Initialize an array filled with NaN values to store reshaped predictions
      y_full_pred_reshaped = np.full((height, width), np.nan)
      # Flatten the predicted labels and create a flattened array filled with NaN
       ↪values
      y_full_pred_flattened = y_full_pred.reshape(-1)
      y_full_pred_reshaped_flat = np.full(height * width, np.nan)
      # Apply the mask to place the predicted labels into the correct positions in
       ↪the flattened array
      y_full_pred_reshaped_flat[mask] = y_full_pred_flattened[mask]
      # Reshape the flattened array back into the original 2D shape (height, width)
      y_full_pred_reshaped = y_full_pred_reshaped_flat.reshape((height, width))

      # Create a new xarray.DataArray to store the predictions in the dataset
      clf_ds['predictions'] = xr.DataArray(
          y_full_pred_reshaped,
          dims=clf_ds[list(clf_ds.data_vars)[0]].dims,
          coords=clf_ds[list(clf_ds.data_vars)[0]].coords,
          name='predictions',
          attrs={
              'long_name': 'Predicted label',
              'model': 'RandomForestClassifier',
              'data_created': datetime.utcnow().isoformat(),
          }
```

```
)
```

[15]:
```python
# Store the data for export
clf_ds_export_1 = clf_ds
```

[16]:
```python
# Create a boolean mask where the predictions are equal to 2 (shallow water)
pred_equals_2 = clf_ds['predictions'] == 2

# Filter the dataset variables to include only those where the predictions␣
 ↪equal 2
# This retains only the values for which the condition (predictions == 2) is␣
 ↪true
filtered_ds = xr.Dataset({var_name: clf_ds[var_name].where(pred_equals_2) for␣
 ↪var_name in clf_ds.data_vars})

# Copy attributes from the original dataset to the new filtered dataset
for attr in clf_ds.attrs:
    filtered_ds.attrs[attr] = clf_ds.attrs[attr]

# Copy coordinates from the original dataset to the new filtered dataset
for coord in clf_ds.coords:
    filtered_ds[coord] = clf_ds[coord]

# Update the original dataset to the new filtered dataset
clf_ds = filtered_ds
```

[17]:
```python
# Create a boolean mask where the predictions are equal to 2 (shallow water)
# pred_equals_2 = clf_ds['predictions'] == 2
pred_equals_2 = clf_ds_export_1['predictions'] == 2

# Filter the dataset variables to include only those where the predictions␣
 ↪equal 2
# This retains only the values for which the condition (predictions == 2) is␣
 ↪true
filtered_ds = xr.Dataset({var_name: clf_ds_export_1[var_name].
 ↪where(pred_equals_2) for var_name in clf_ds_export_1.data_vars})

# Copy attributes from the original dataset to the new filtered dataset
for attr in clf_ds_export_1.attrs:
    filtered_ds.attrs[attr] = clf_ds_export_1.attrs[attr]

# Copy coordinates from the original dataset to the new filtered dataset
for coord in clf_ds_export_1.coords:
    filtered_ds[coord] = clf_ds_export_1[coord]

# Update the original dataset to the new filtered dataset
clf_ds = filtered_ds
```

3.2 Benthic Classification

```python
# Subsetting sample area for the classification
# Read the shapefile containing the region of interest
gdf = gpd.read_file(shapefile_path_training_2)

# Extract labeled samples for the specified year
samples = bm.labeled_samples(
    clf_ds,gdf, 'class', desired_year
)

# Define the list of features to be used in the classification model
features = [
    'blue', 'green', 'red', 'red_edge', 'nir', 'swir1',
    'swir2', 'blue_sg', 'green_sg', 'red_sg', 'red_edge_sg',
    'dii_blue_sg_green_sg', 'dii_blue_sg_red_sg',
    'dii_blue_sg_red_edge_sg', 'dii_green_sg_red_sg',
    'dii_green_sg_red_edge_sg', 'dii_red_sg_red_edge_sg',
    'ndvi', 'mndwi', 'gndvi', 'ngrdi_red', 'ngrdi_red_edge',
    'evi', 'awei',
]
# Prepare the feature matrix (X) and target labels (y) from the given samples
X, y = bm.prepare_samples(samples, features, 'label')
```

```python
# Classification procedure
# Split the samples into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(
    X, y, test_size=0.3, random_state=42
)

# Initialiaze a Random Forest classifier
clf = RandomForestClassifier(
    n_estimators=200, random_state=42, max_depth=15,
    min_samples_leaf=1, min_samples_split=2
)

# Fit the classifier to the training data
clf.fit(X_train, y_train)

# Retrieve the features importance
importances = clf.feature_importances_
importance_df = pd.DataFrame({
    'Feature': features,
    'Importance': importances
})
importance_df = importance_df.sort_values(
    by='Importance', ascending=False
    ).reset_index(drop=True)
```

```python
# Print feature importances
importance_df

# Save the DataFrame to a CSV file
export_file_path = os.path.join(out_dir, 'csv',
    f"{'feature_importances_classification_2'}_{user_year}.csv")
importance_df.to_csv(export_file_path)
```

```python
[20]: # Accuracy assessment
# Predict the labels for the test set using the trained classifier
y_pred = clf.predict(X_test)

# Print the reports
print(classification_report(y_test, y_pred))
print(f"{confusion_matrix(y_test, y_pred)}\n")
print(f"accuracy score:{accuracy_score(y_test, y_pred)}")
print(f"cohen's kappa:{cohen_kappa_score(y_test, y_pred)}")
```

```
              precision    recall  f1-score   support

           1       0.87      0.75      0.81       154
           2       0.89      0.96      0.92       338
           3       0.96      1.00      0.98       337
           4       0.96      0.92      0.94       437

    accuracy                           0.93      1266
   macro avg       0.92      0.91      0.91      1266
weighted avg       0.93      0.93      0.93      1266

[[116  20    1   17]
 [ 12 323    2    1]
 [  0   0  337    0]
 [  6  21   10  400]]

accuracy score:0.9289099526066351
cohen's kappa:0.9016463065140978
```

```python
[21]: # Predict full set and reshape into the original spatial dimensions
# Get the dimensions (height and widht) of the dataset
height = clf_ds.sizes['y']
width = clf_ds.sizes['x']

# Stack the feature data into a 2D array 'X_full'
# Create a mask to identify rows with valid (non-NaN) feature values
# Predict the labels for the entire dataset using the trained RandomForest model
X_full = np.stack([clf_ds[var].values.flatten() for var in features], axis=1)
```

```
mask = ~np.isnan(X_full).any(axis=1)
y_full_pred = clf.predict(X_full)

# Initialize an array filled with NaN values to store reshaped predictions
y_full_pred_reshaped = np.full((height, width), np.nan)
# Flatten the predicted labels and create a flattened array filled with NaN
 ↪values
y_full_pred_flattened = y_full_pred.reshape(-1)
y_full_pred_reshaped_flat = np.full(height * width, np.nan)
# Apply the mask to place the predicted labels into the correct positions in
 ↪the flattened array
y_full_pred_reshaped_flat[mask] = y_full_pred_flattened[mask]
# Reshape the flattened array back into the original 2D shape (height, width)
y_full_pred_reshaped = y_full_pred_reshaped_flat.reshape((height, width))

# Create a new xarray.DataArray to store the predictions in the dataset
clf_ds['predictions'] = xr.DataArray(
    y_full_pred_reshaped,
    dims=clf_ds[list(clf_ds.data_vars)[0]].dims,
    coords=clf_ds[list(clf_ds.data_vars)[0]].coords,
    name='predictions',
    attrs={
        'long_name': 'Predicted label',
        'model': 'RandomForestClassifier',
        'data_created': datetime.utcnow().isoformat(),
    }
)
```

4 Export dataset

```
[22]: def add_time_coordinate(dataset, base_filename):

          # Split the base filename to extract date and time components
          parts = base_filename.split('_')

          # Extract year, month, day, hour, and minute from the filename
          year = int(parts[2])
          month = int(parts[3])
          day = int(parts[4])
          hour = int(parts[5])
          minute = int(parts[6])

          # Create a datetime object for the time coordinate
          time_coord = [datetime(year, month, day, hour, minute)]

          # Assign the time coordinate to the dataset's coordinates
```

```python
        dataset = dataset.assign_coords(time=('time', time_coord))

        # Set attributes for the 'time' coordinate
        dataset['time'].attrs = {
            'standard_name': 'time',
            'long_name': 'time',
        }

        # Expand dimensions for all data variables to include the 'time' dimension
        for var in dataset.data_vars:
            dataset[var] = dataset[var].expand_dims('time', axis=0)

        return dataset
```

```python
[23]: def generate_encoding(dataset):
          encoding = {}

          for var_name in dataset.data_vars:
              var = dataset[var_name]
              encoding[var_name] = {
                  "dtype": "float32",
                  'zlib': False,
                  'shuffle': False,
                  'complevel': 0,
                  'fletcher32': False,
                  'contiguous': True,
                  'chunksizes': None,
                  'original_shape': (2343, 2530),
                  'grid_mapping': 'transverse_mercator'
              }

          return encoding
```

```python
[24]: # Save the data to a new NetCDF file
      encoding = generate_encoding(clf_ds_export_1)
      clf_ds_export_1 = add_time_coordinate(clf_ds_export_1, base_filename)
      export_file_path = os.path.join(out_dir, 'processed', f"{base_filename}_{'L2F'}.
        ↪nc")
      clf_ds_export_1.to_netcdf(export_file_path, encoding=encoding)
```

```python
[25]: # Save the data to a new NetCDF file
      encoding = generate_encoding(clf_ds)
      clf_ds = add_time_coordinate(clf_ds, base_filename)
      export_file_path = os.path.join(out_dir, 'classification',␣
        ↪f"{base_filename}_{'L3W'}.nc")
      clf_ds.to_netcdf(export_file_path, encoding=encoding )
```