



Jet Propulsion Laboratory
California Institute of Technology



Hydrodynamic modeling using Anuga

Delta-X Workshop 2024
May 8th, Baton Rouge

Antoine Soloy
Post-doctoral researcher

URS Clearance CL#24-2353



Illustration generated by DALL-E

Part 1: Introduction



Why modeling hydrodynamics?

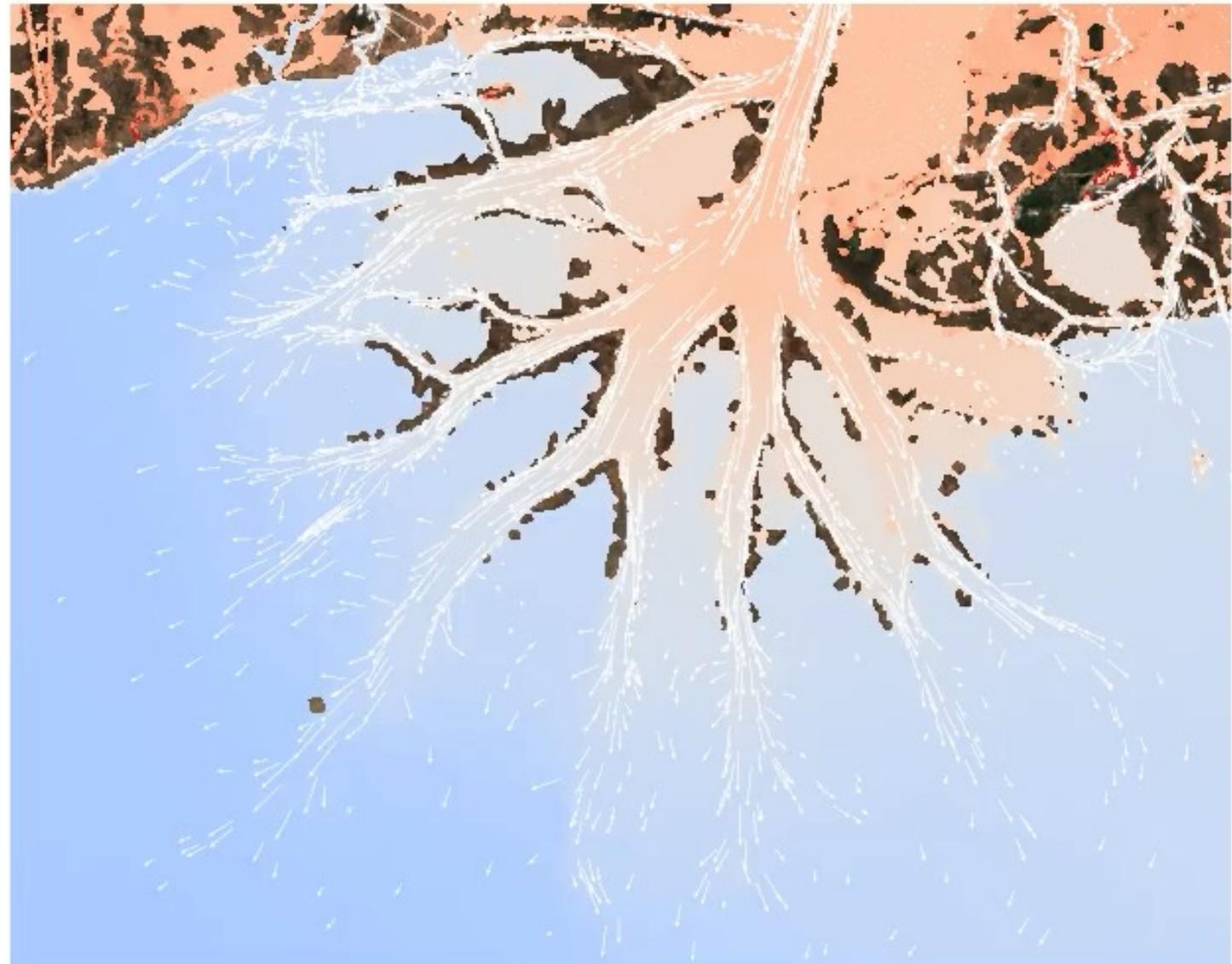
Due to their many levels of complexity, understanding the *dynamics of coastal environments* is crucial for a variety of applications :

- **Environmental Management**
- **Flood Risk Mitigation**
- **Navigation and Infrastructure**
- **Conservation Efforts**
- ...

The landscape of hydro-models

There exists a wide variety of models to simulate coastal dynamics:

- SWAN, Delft3D, XBeach
- Open Telemac Mascaret
- **Anuga**
- FVCOMS
- Mike 21/3
- ADCIRC
- ROMS
- SCHISM



Anuga: Strengths and limitations

Strengths

- Open Source
- Python
 - Executable on any OS able to run python code
- Lightweight
- Finite volumes
- Parallelizable
- QGIS supported (natively)

Limitations

- 2DH shallow waters only
- No waves
- No sediment transport
- No morpho-dynamics
- No chemistry

Delta-X hydro-model products

The screenshot shows the ORNL DAAC website interface. At the top, there's a navigation bar with links for 'About Us', 'Get Data', 'Submit Data', 'Tools', 'Resources', 'Help', and 'Sign out'. Below the navigation is a search bar with the placeholder 'Search ORNL DAAC' and a green 'Search' button. The main content area displays a welcome message for 'Antoine' and links to 'Cart', 'History', and 'Profile'. A breadcrumb navigation shows 'DAAC Home > Get Data > NASA Projects > Delta-X > Landing page'. The title of the dataset is 'Delta-X: ANUGA Hydrodynamic Outputs, Atchafalaya and Terrebonne, MRD, USA'. A note indicates it's in 'Final review' and should be considered provisional. The 'Overview' section contains a table with the following data:

DOI	https://doi.org/10.3334/ORNLDAAAC/2310
Version	1
Project	Delta-X
Published	0000-00-00
Updated	2024-03-20
Usage	3 downloads

Below the overview is a 'User Guide' button and a 'Resources' link. The 'Description' section provides a detailed explanation of the dataset, mentioning it covers the Atchafalaya and Terrebonne basins of the Mississippi River Delta in southern Louisiana, USA, using the ANUGA hydrodynamic model. It also includes a map of the region with a red box indicating the spatial coverage, and sections for 'Spatial Coverage' (bounding rectangle: N: 29.96, S: 28.71, E: -90.19, W: -91.86) and 'Temporal Coverage' (2012-03-20 to 2021-04-02).

Version 1

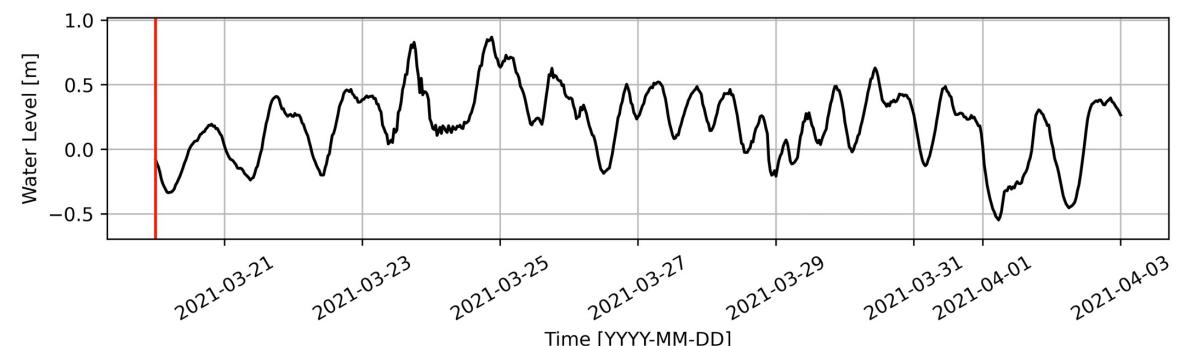
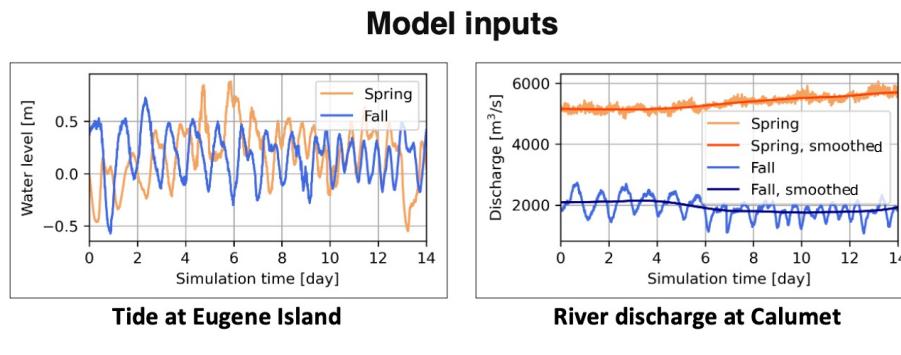
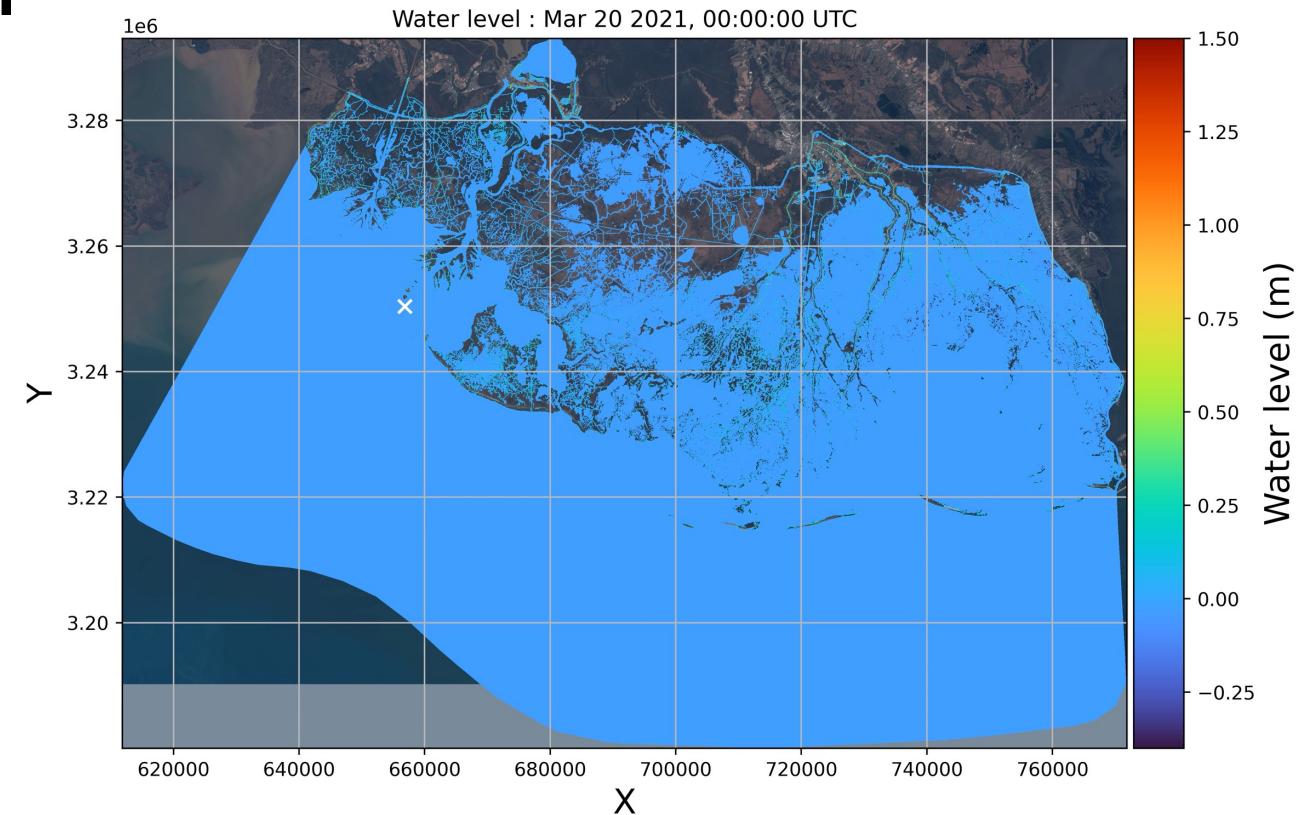
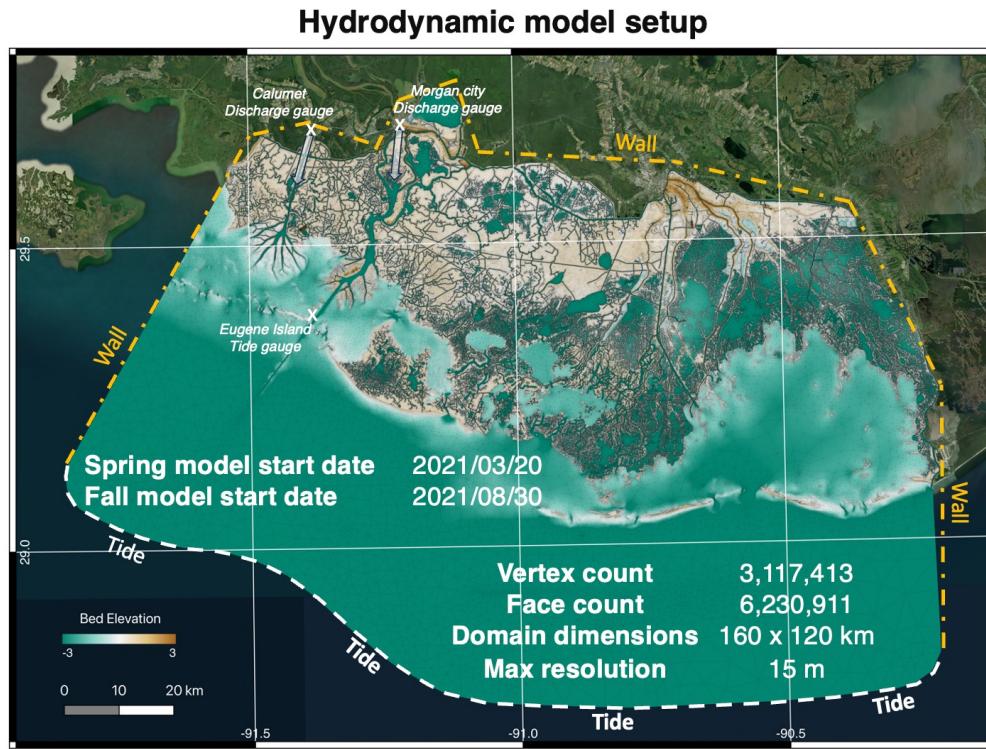
- Spring 2021

Version 2

- Spring 2016
- Spring 2021
- Fall 2021

<https://doi.org/10.3334/ORNLDAAAC/2310>

Delta-X hydro-model products

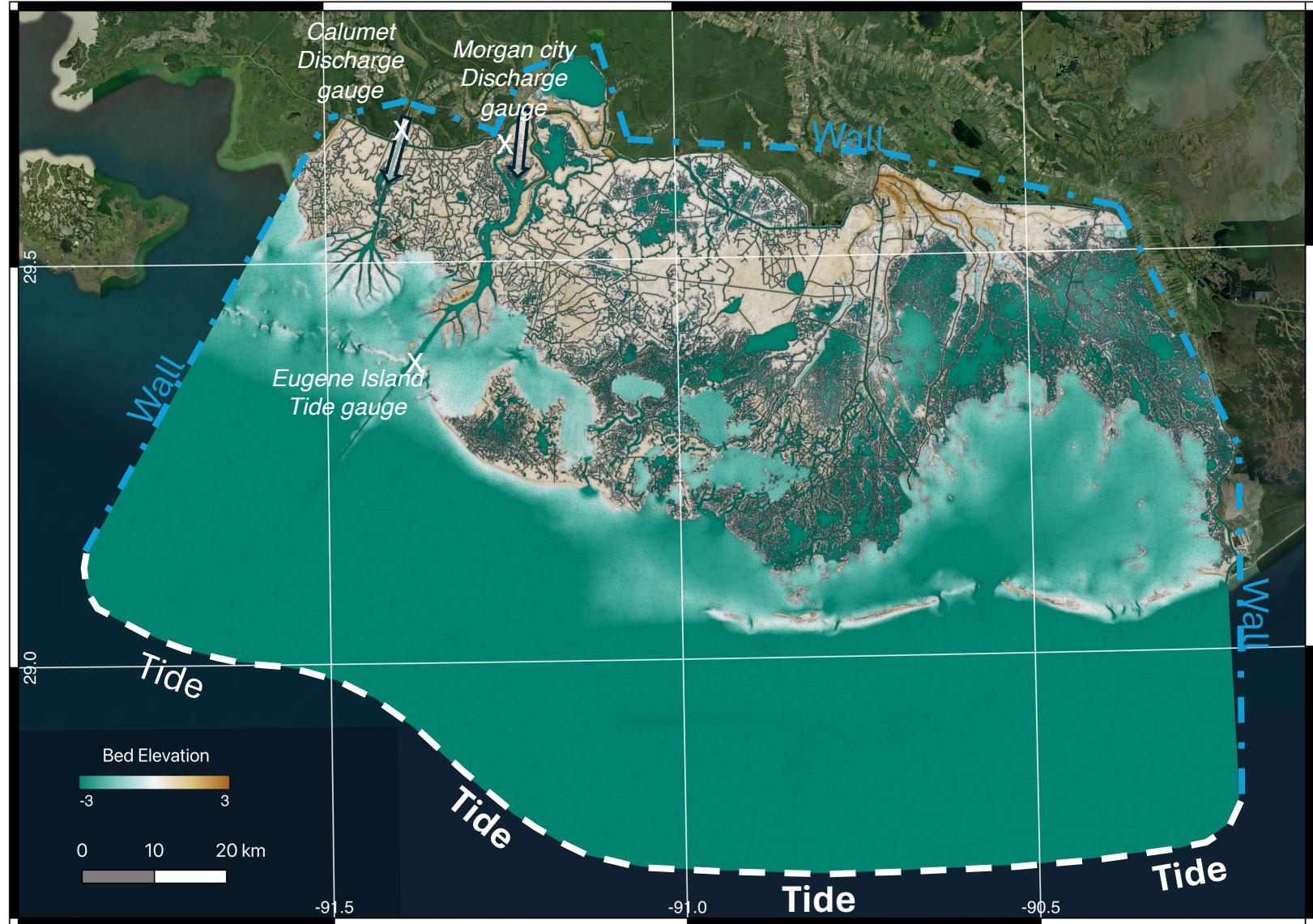


Part 2: Modeling Workflow

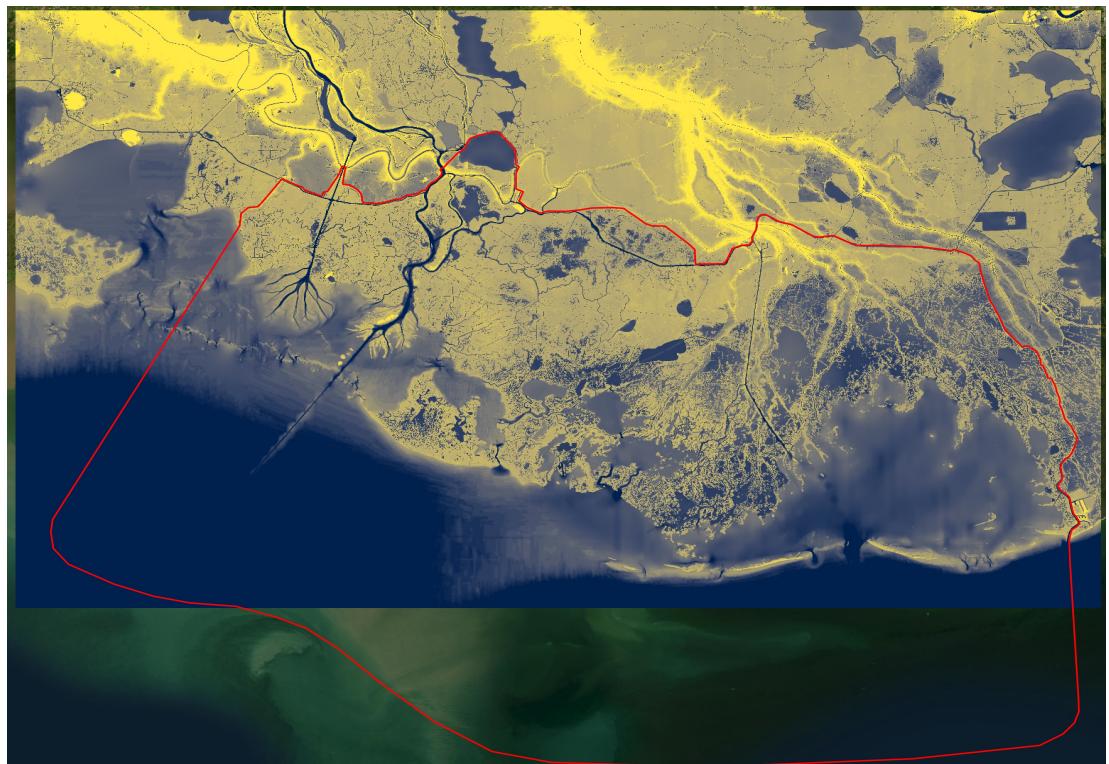
Domain Definition

Important Parameters:

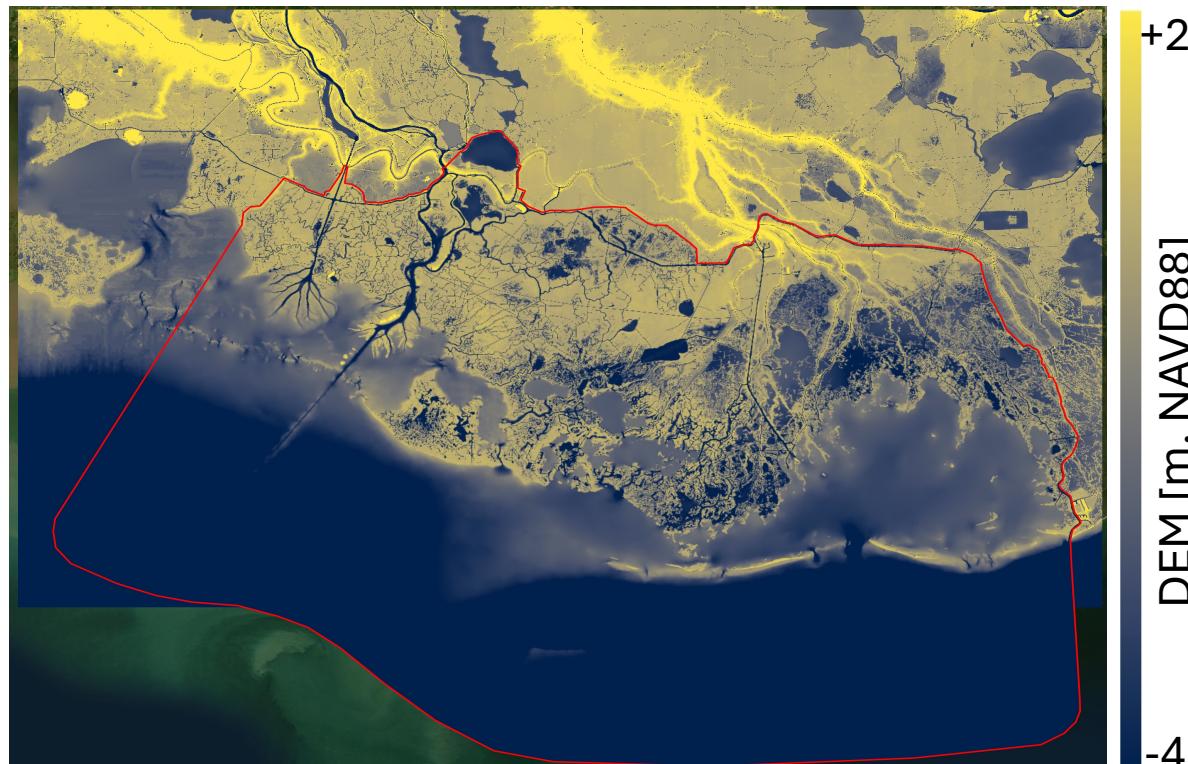
- Watershed isolation
- Data availability
- Geomorphological setting
- Size and computational constraints



DEM adjustments



Original DEM (Christensen et al., 2023)



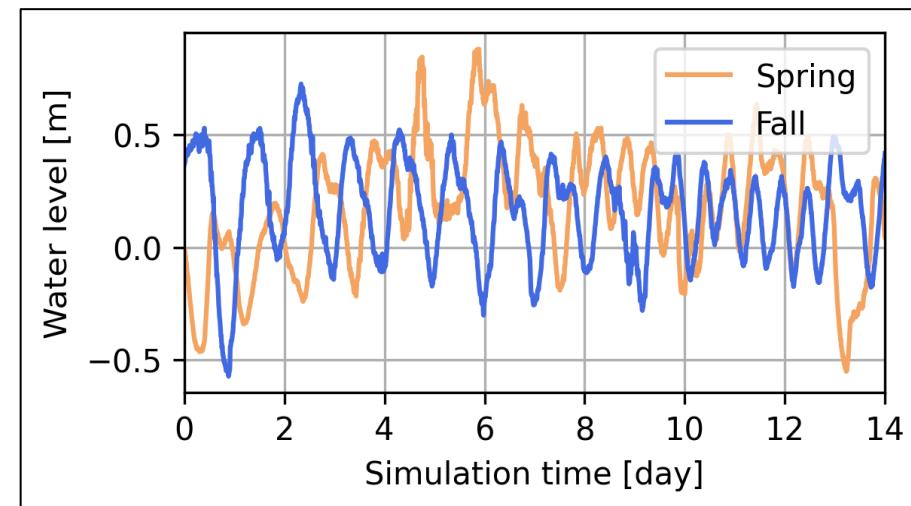
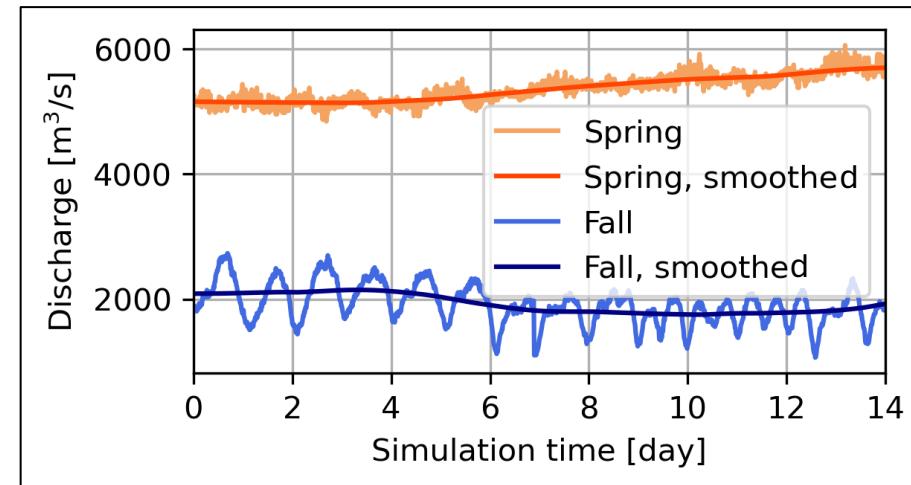
Modified DEM

+2
DEM [m, NAVD88]
-4

Input Data Selection

Common options:

- Digital Elevation Model (DEM)
 - Local model
 - Gebco
- Tides
 - NOAA
 - Global models: FES2014, ...
- River Discharges
 - Gauges
 - SWOT
- Waves
 - Buoys
 - Global models: WaveWatch3, ...
- Wind
 - NOAA

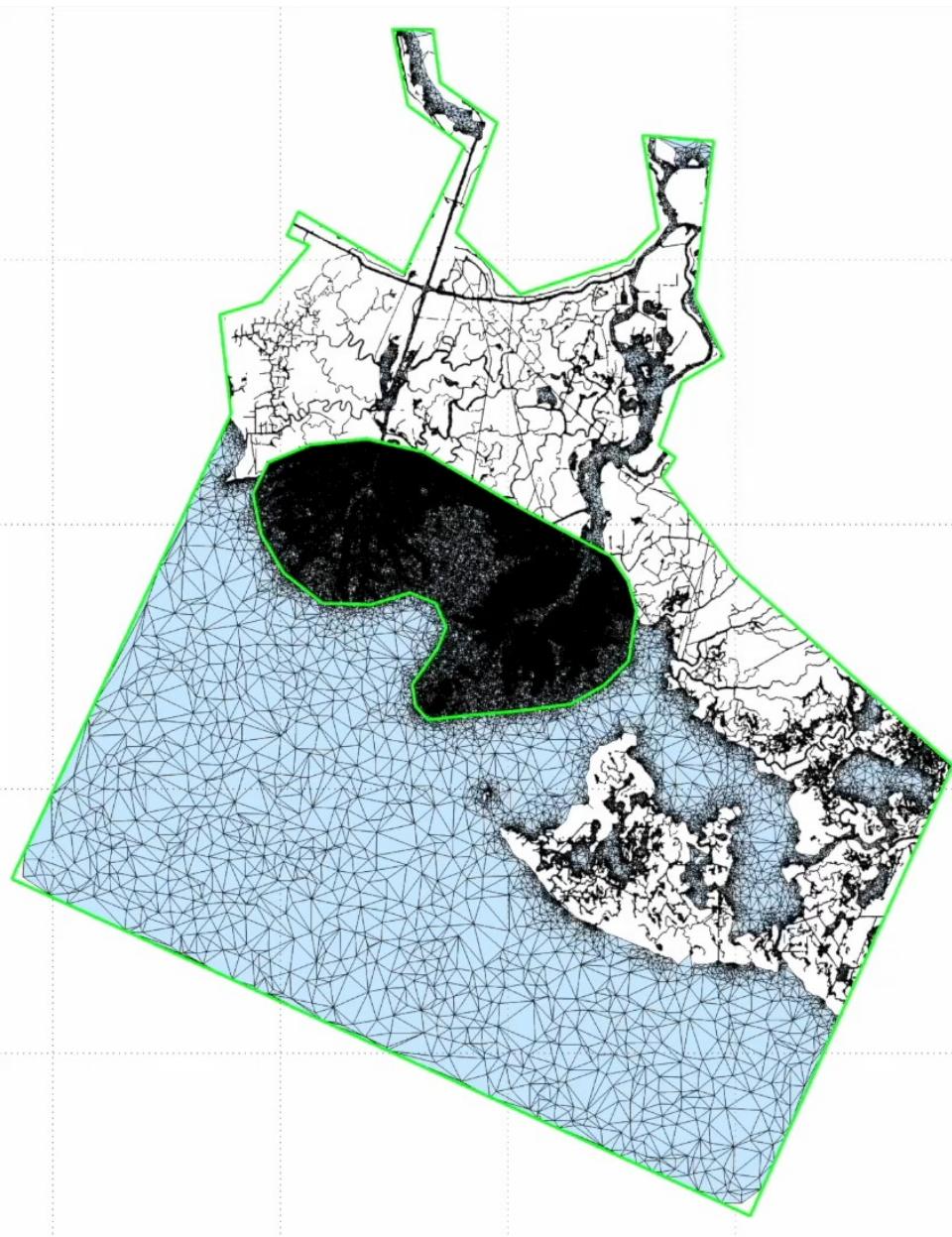


Input time series used in the Delta-X Anuga models

Domain Meshing

Common options:

- Structured
- Unstructured
 - Triangular (Anuga)
 - Model built in tools
 - OceanMesh2D (matlab)
 - Blue Kenue (windows only)
 - QGIS
 - Quadrilateral
- Hybrid



Example of resolution optimization of a triangular mesh using OM2D

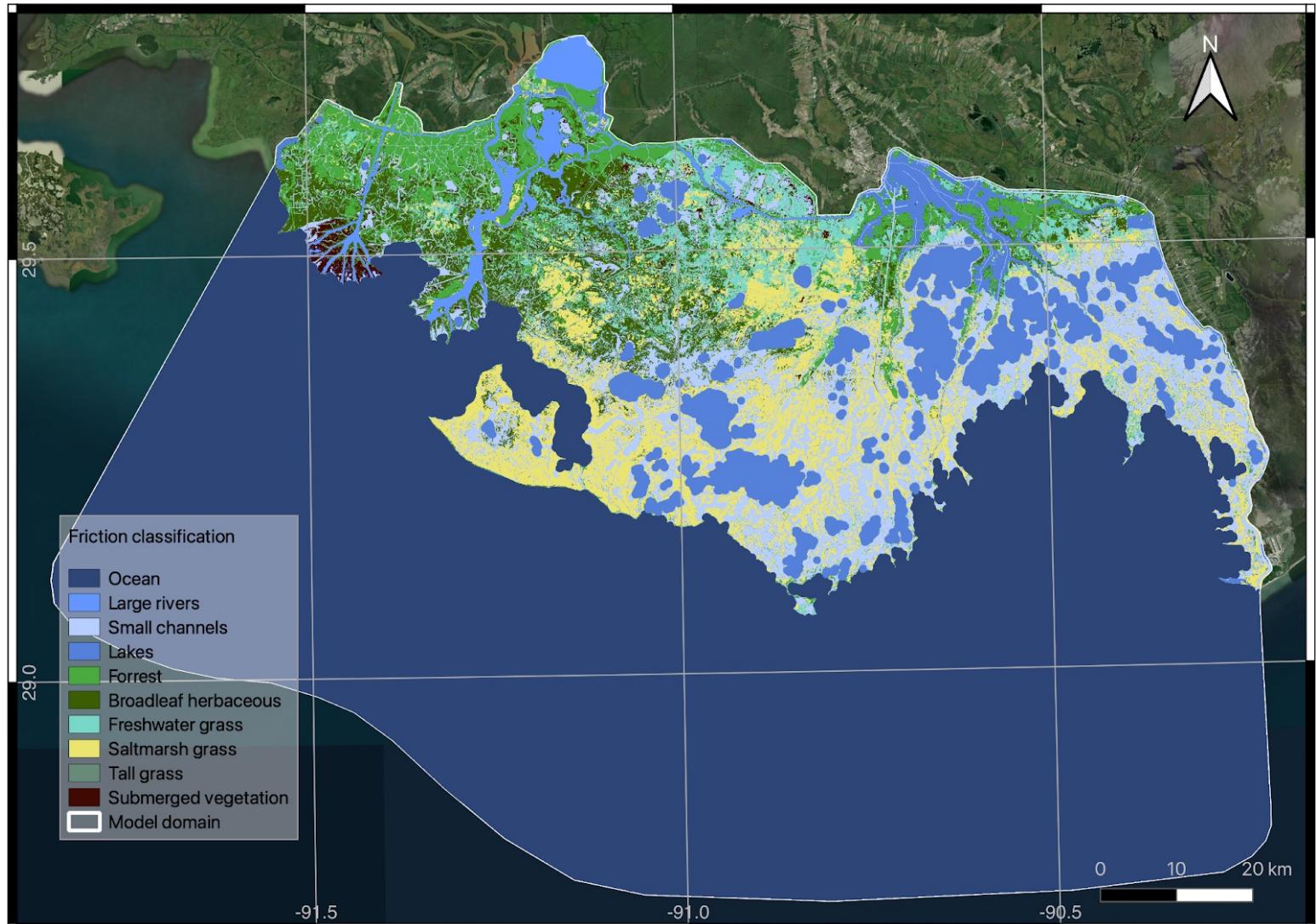
Step 4: Friction Calibration

Common options:

- Mapping Process
 - Water masks and land cover data
- Calibration process
 - Empirical tables
 - Try and Error approach

JPL Delta-X models:

- Mapping process
 - Vegetation classes
 - Aviris NG (Jensen et al. 2024)
 - Sentinel 2 (Christensen, pc)
 - Water classes
 - DEM dataset (Christensen et al. 2023)
- Calibration process
 - In situ biostatistics measurements (Castañeda-Moya and Solohin, 2021)
 - Weights to match with previous models from Wright et al. 2024
 - Try and error approach for finer calibration



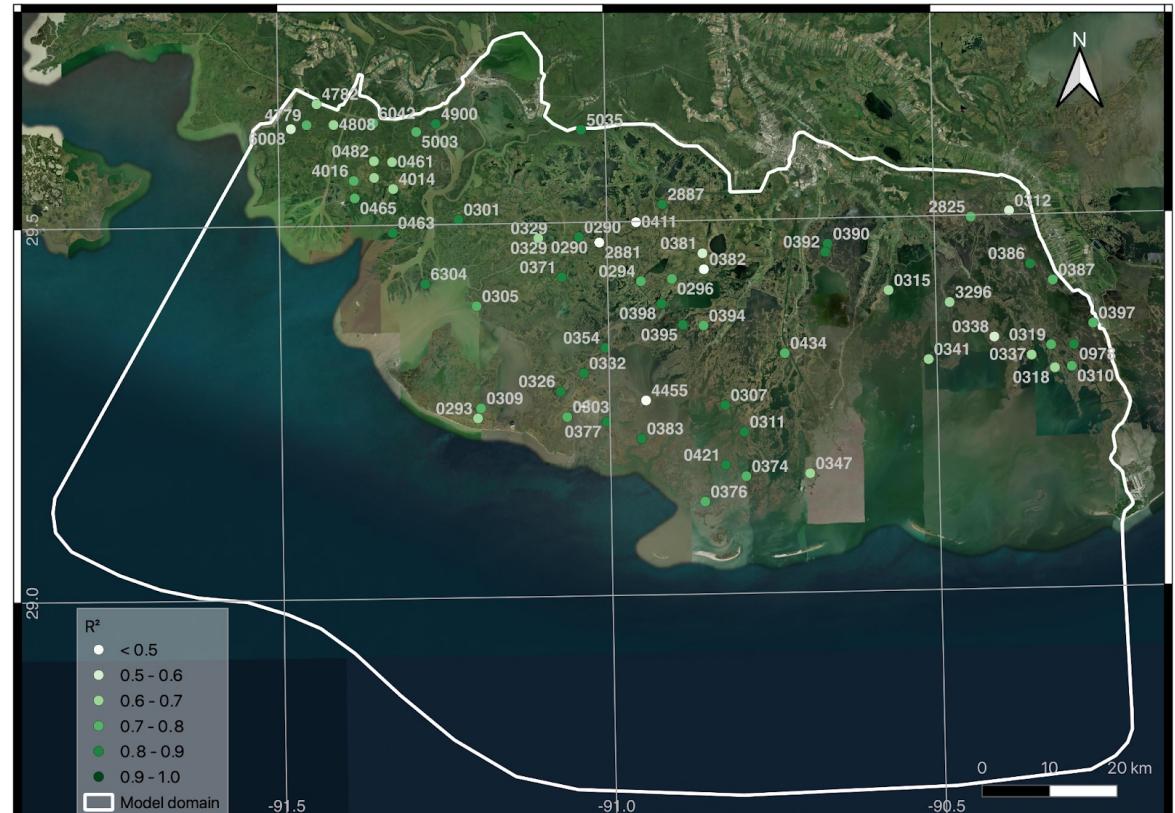
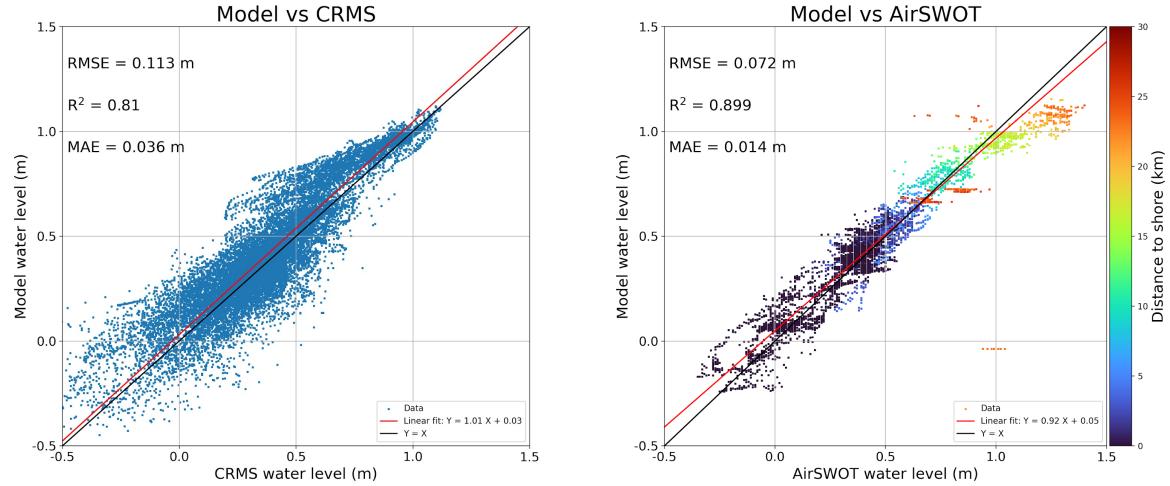
Model Validation

Common options:

- Local gauge stations
- Spaceborne radar altimetry data
- SWOT (since 2023)

JPL Delta-X models:

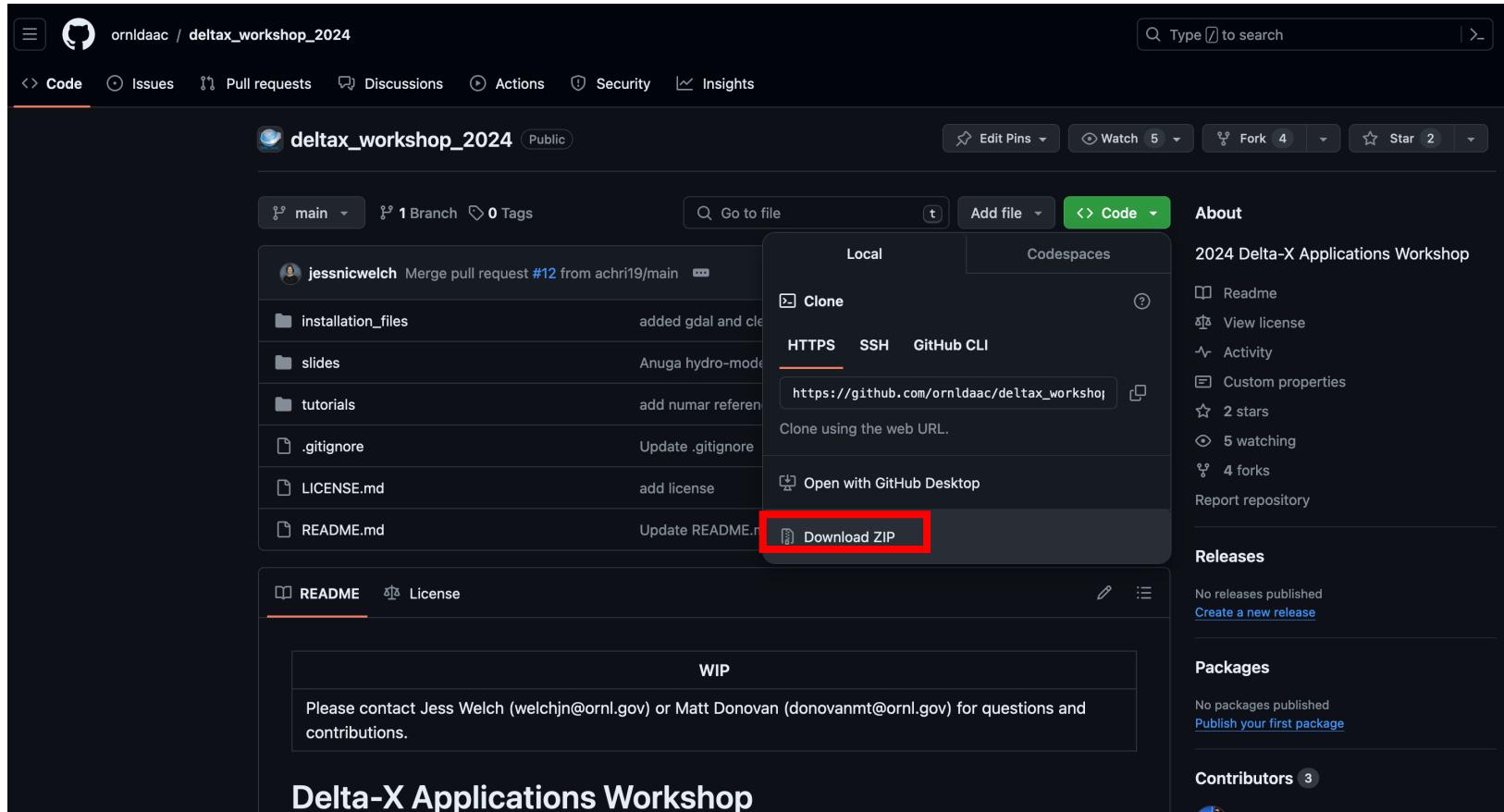
- AirSWOT data
- Delta-X JPL Gauges data
- CRMS Gauges data
- UAVSAR data



JPL Delta-X Model Validation using various datasets

Part 3: Hands On Exercises

Download the Workshop Material



1. Download the workshop archive
2. Unzip it on your computer at your preferred location

https://github.com/ornldaac/deltax_workshop_2024

Install the python environment

1. Download and install Anaconda
2. Open a command prompt / terminal window
3. ANUGA and DORADO conda environment

Download [*anuga_dorado.yml*](#) and navigate to the folder where it is saved and run the following commands

conda env create --name anuga_dx --file=anuga_dorado.yml

conda activate anuga_dx

python -m ipykernel install --user --name=anuga_dorado

Test the installation of ANUGA and DORADO by running the following command:

Python

Wait a few seconds while python initializes. When “>>>” appears on the left side of the window, copy-paste the following lines and hit return:

**import anuga
import dorado**

If for some reason something is not working, you will be prompted with an “Error” message (“Warnings” are not an issue). In such cases, please refer to [Section 4: ANUGA and DORADO - Manual Installation](#).

DEM download

EARTHDATA Other DAACs ▾

ORNL DAAC
DISTRIBUTED ACTIVE ARCHIVE CENTER
FOR BIOGEOCHEMICAL DYNAMICS

About Us Get Data Submit Data Tools Resources Help Sign out

Search ORNL DAAC

Welcome back, Antoine: Cart History Profile

DAAC Home > Get Data > NASA Projects > Delta-X > Landing page

Delta-X: Digital Elevation Model, MRD, LA, USA, 2021

Overview

DOI	https://doi.org/10.3334/ORNLDAAAC/2181
Version	1
Project	Delta-X
Published	2023-09-29
Updated	2023-09-29
Usage	38 downloads

[Download Data \(1.4 GB\)](#) [User Guide](#) [Resources](#)

Spatial Coverage

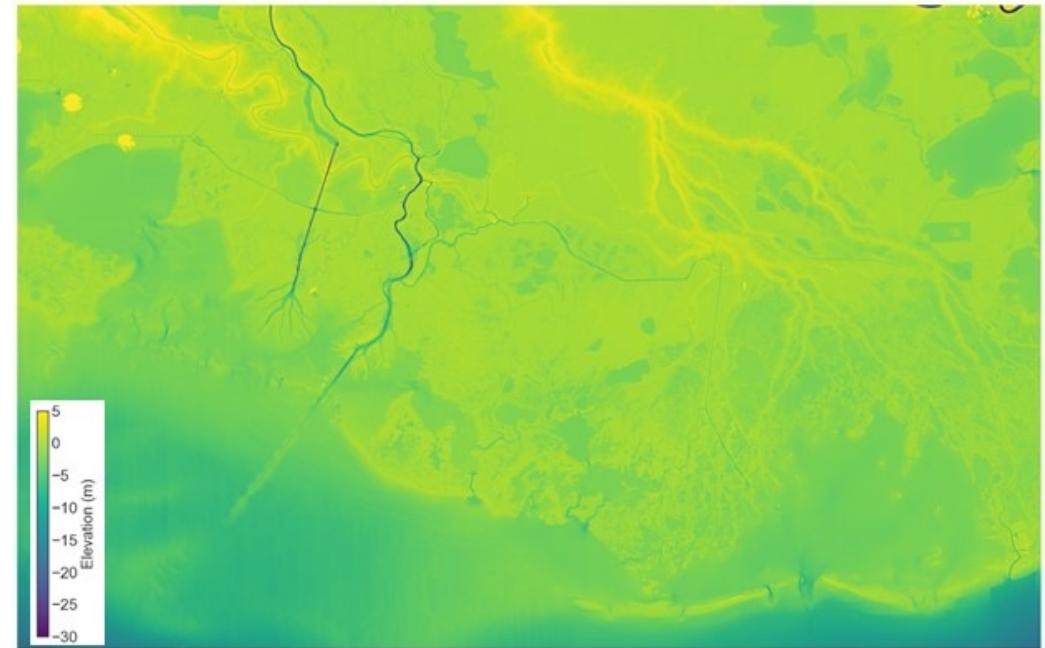
Bounding rectangle
N: 29.96 S: 28.97 E: -90.15 W: -91.91

Google Map Data Terms

Temporal Coverage

2012-01-01 to 2021-12-31

This dataset provides an updated digital elevation model (DEM) for the Atchafalaya and Terrebonne basins in coastal Louisiana, USA. The DEM is updated from the Pre-Delta-X DEM and extended to the full Delta-X study area. This DEM was developed from multiple data sources, including sonar data collected during Pre-Delta-X and Delta-X campaigns, bathymetric data from the Coastal Protection and Restoration Authority System-Wide Assessment and Monitoring System (CPRA SWAMP), and NOAA, and topography from the National Elevation Dataset and LiDAR from US Geological Survey (USGS). The provided data layers include the DEM, a binary water/land mask, data source flags, and eight layers with analysis weighting factors for each pixel. Elevation values are provided in meters with respect to the North American Vertical Datum of 1988 (NAVD88). The weighting factors indicate how each data source contributed to this multisource



Filename	Units	Description	Flag value
DeltaX_MultiSource_DEM_Atchafalaya-Terrebonne_Basin_2021_V1.tif	m	Interpolated elevation of bed (waterbodies) or land relative to the NAVD88 in meters.	-
DeltaX_MultiSource_DEM_Data_Source_Flag_V1.tif	-	Flags denoting data source for raster cells; see Table 2.	-
DeltaX_MultiSource_DEM_watermask_V1.tif	-	Binary mask denoting water (1) or land (0).	-
adh_weight_V1.tif	1	Analysis weight for ADH bathymetry.	1
atcha_weight_V1.tif	1	Analysis weight for lake bathymetry in Atchafalaya Basin	9

Download and place the tif files in the subfolder called **1_HydrodynamicModeling_ANUGA/data**

https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=2181

River Centerlines download

NASA Jet Propulsion Laboratory California Institute of Technology

Landscape

Home About Science **Data**

Data Search
Site data include available remote sensing products derived from lidar, field, radar, and optical products.

Global

NOTE: The 3D Global Vegetation Map does not align correctly in this map, but it does if you download it and open in Google Earth.

3D Global Vegetation Map [info/download](#)

Sites

- Amazon Delta
- Amur Delta
- Brahmani Delta
- Burdekin Delta
- Chepko River

NASA | CALTECH | PRIVACY | IMAGE POLICY | FAQ | FEEDBACK



Mahanadi Delta

Mekong Delta

Mississippi Delta

Site boundary [download KML](#)

LandChange_Cropped [info/download](#)

Landcover_Uncropped [info/download](#)

NDVI_Trend_Masked [info/download](#)

River_Centerlines_V1 [info/download](#)

Moulouya Delta

Niger Delta

Nile Delta

Orinoco Delta



<https://landscape.jpl.nasa.gov/cgi-bin/data-search.pl>

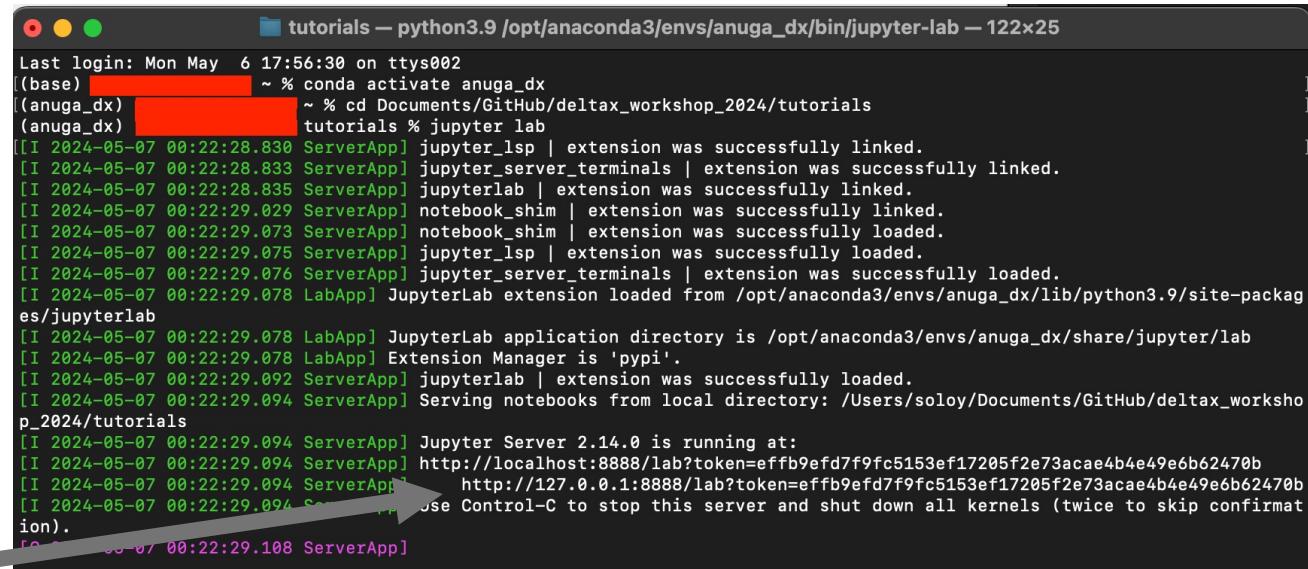
Download and place the unzipped centerlines folder in the subfolder called
1_HydrodynamicModeling_ANUGA/data

Other data download

- **Delta-X Vegetation Classification Map** 
 - Download link:
[https://drive.google.com/file/d/1OSyAWekAuXGFz3yLRz61PlLuQgj2FkGa/
view?usp=drive_link](https://drive.google.com/file/d/1OSyAWekAuXGFz3yLRz61PlLuQgj2FkGa/view?usp=drive_link)
- **Delta-X AirSWOT L3 Water Surface Elevations**
 - Download link: <https://doi.org/10.3334/ORNLDAAC/2349>
- **CRMS water level gauges**
 - Download link: [https://drive.google.com/file/d/1WjOSv8XcYZwkN_oPdsdXH_5Lg2zcp5x/
view?usp=drive_link](https://drive.google.com/file/d/1WjOSv8XcYZwkN_oPdsdXH_5Lg2zcp5x/view?usp=drive_link) (workshop sample)

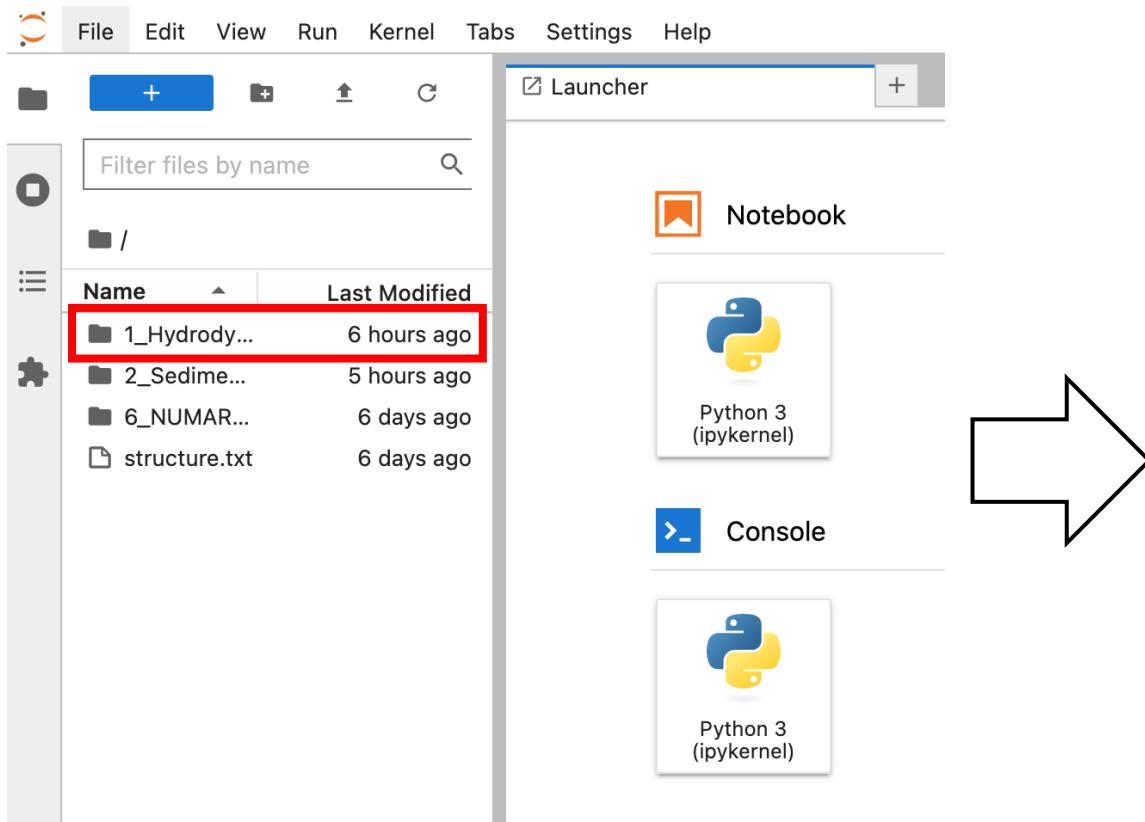
Jupyter Notebook / Lab (1)

- Open a command prompt / terminal window
- Activate the new environment using
conda activate anuga_dx
- Navigate to the unzipped archive
cd path/to/deltax_workshop_2024/tutorials
- Open Jupyter Lab (equivalent to Jupyter Notebook)
jupyter lab
- Wait for your web browser to open.
- **If nothing happens**, copy one of the url addresses from your command prompt/terminal window into a new browser page.

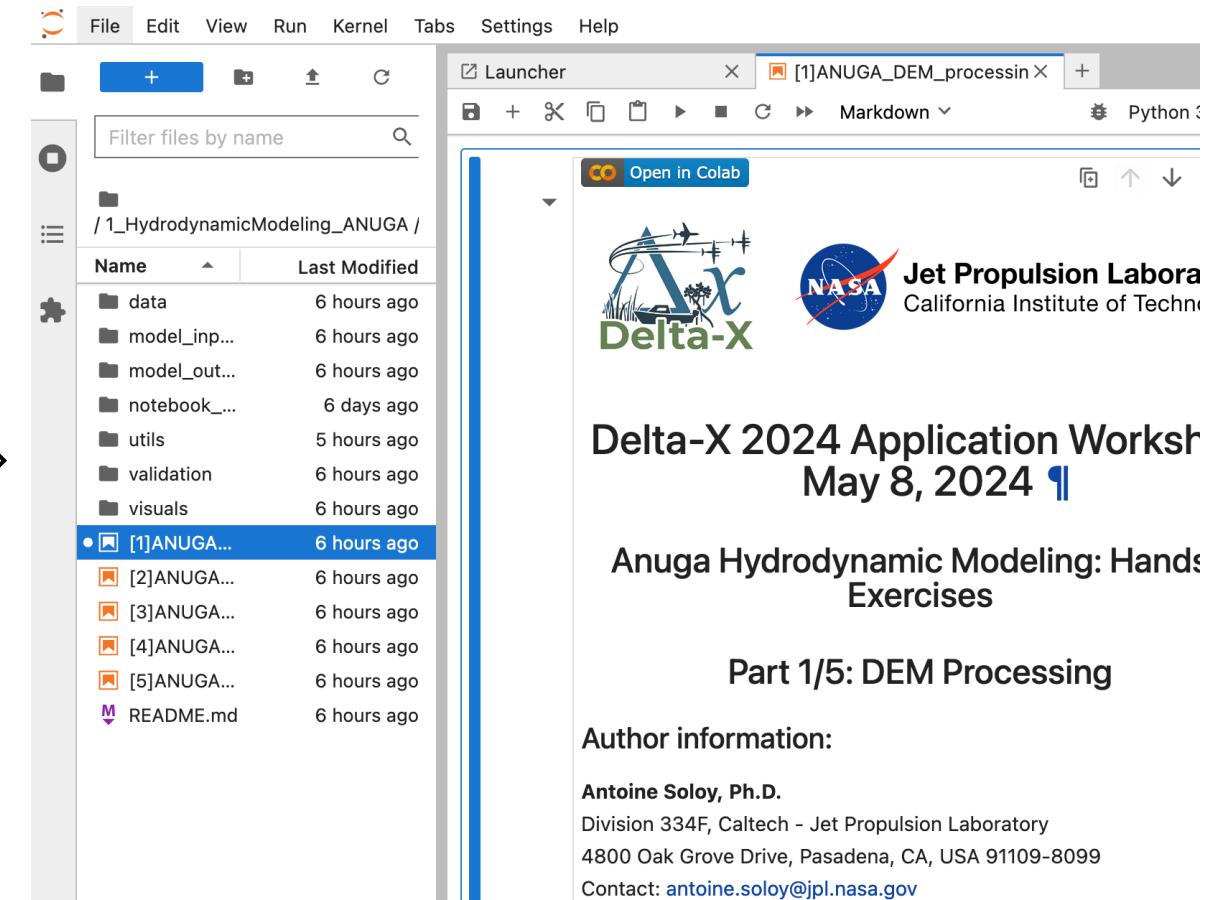


```
Last login: Mon May  6 17:56:30 on ttys002
[(base) [REDACTED] ~ % conda activate anuga_dx
([anuga_dx) [REDACTED] ~ % cd Documents/GitHub/deltax_workshop_2024/tutorials
(anuga_dx) [REDACTED] tutorials % jupyter lab
[I 2024-05-07 00:22:28.830 ServerApp] jupyter_lsp | extension was successfully linked.
[I 2024-05-07 00:22:28.833 ServerApp] jupyter_server_terminals | extension was successfully linked.
[I 2024-05-07 00:22:28.835 ServerApp] jupyterlab | extension was successfully linked.
[I 2024-05-07 00:22:29.029 ServerApp] notebook_shim | extension was successfully linked.
[I 2024-05-07 00:22:29.073 ServerApp] notebook_shim | extension was successfully loaded.
[I 2024-05-07 00:22:29.075 ServerApp] jupyter_lsp | extension was successfully loaded.
[I 2024-05-07 00:22:29.076 ServerApp] jupyter_server_terminals | extension was successfully loaded.
[I 2024-05-07 00:22:29.078 LabApp] JupyterLab extension loaded from /opt/anaconda3/envs/anuga_dx/lib/python3.9/site-packages/jupyterlab
[I 2024-05-07 00:22:29.078 LabApp] JupyterLab application directory is /opt/anaconda3/envs/anuga_dx/share/jupyter/lab
[I 2024-05-07 00:22:29.078 LabApp] Extension Manager is 'pypi'.
[I 2024-05-07 00:22:29.092 ServerApp] jupyterlab | extension was successfully loaded.
[I 2024-05-07 00:22:29.094 ServerApp] Serving notebooks from local directory: /Users/soloy/Documents/GitHub/deltax_workshop_2024/tutorials
[I 2024-05-07 00:22:29.094 ServerApp] Jupyter Server 2.14.0 is running at:
[I 2024-05-07 00:22:29.094 ServerApp] http://localhost:8888/lab?token=effb9efd7f9fc5153ef17205f2e73acae4b4e49e6b62470b
[I 2024-05-07 00:22:29.094 ServerApp] or http://127.0.0.1:8888/lab?token=effb9efd7f9fc5153ef17205f2e73acae4b4e49e6b62470b
[I 2024-05-07 00:22:29.094 ServerApp] Use Control-C to stop this server and shut down all kernels (twice to skip confirmation).
[O 2024-05-07 00:22:29.108 ServerApp]
```

Jupyter Notebook / Lab (2)



When Jupyter Lab opens, navigate in the first subdirectory



Then open the first Notebook

Jupyter Notebook / Lab (3)

How does it work ?

- Jupyter works in sequences of code cells.
- The content of one cell is read all at once, but cells can be read one by one.
- Reading a cell is done by using the “play” button at the top of the page.
- Most changes initiated by previously read instructions (i.e. created variables, imported packages, etc.) remain effective until the kernel is killed
- The script of the first workshop segment is a sequence of instructions to modify the Digital Elevation Model. Some parameters can be modified at will to customize the type/magnitude of changes
- The outputs of notebook 1 are the inputs of notebook 2, etc.

The screenshot shows a Jupyter Notebook interface with a file explorer on the left and a code editor on the right.

File Explorer: Shows the directory structure of the notebook. It includes a search bar, a list of files and folders, and a table showing the name and last modified time for each item. The table includes columns for Name and Last Modified.

Name	Last Modified
data	7 hours ago
model_inp...	6 hours ago
model_out...	6 hours ago
notebook_...	6 days ago
utils	6 hours ago
validation	6 hours ago
visuals	6 hours ago
[1]ANUGA...	6 hours ago
[2]ANUGA...	6 hours ago
[3]ANUGA...	6 hours ago
[4]ANUGA...	6 hours ago
[5]ANUGA...	6 hours ago
README.md	6 hours ago

Code Editor: Displays two code cells. Cell [1] contains code to handle Google Colab environments and set up working directories. Cell [2] contains code to import various Python libraries and define paths for workshop data.

```
[1]: import sys
if 'google.colab' in sys.modules:
    # In case the notebook is opened in google colab, here we download/install all
    try:
        import os
        os.chdir('/content')
        # Grab workbook files into colab directory
        !git clone https://github.com/soloyant/deltax_workshop_2024.git
        # Install everything using some bash scripts
        !/bin/bash /content/deltax_workshop_2024/tutorials/1_HydrodynamicModeling_ANUGA.sh
        os.chdir('/content/deltax_workshop_2024/tutorials/1_HydrodynamicModeling_ANUGA')
    except:
        pass

[2]: import pandas as pd
import geopandas as gpd
import rasterio as rio
import numpy as np
import os
from scipy import ndimage
import matplotlib.pyplot as plt
import cmcean
import shutil
from pathlib import Path
from tqdm import notebook
from utils import data_processing_tools as dpt

# Define the path to scripts and data
workshop_dir = os.getcwd()
# # Alternatively:
# workshop_dir = '/path/to/1_HydrodynamicModeling_ANUGA'
data_dir = os.path.join(workshop_dir, 'data')
model_inputs_dir = os.path.join(workshop_dir, 'model_inputs')
model_outputs_dir = os.path.join(workshop_dir, 'model_outputs')
if 'google.colab' in sys.modules:
    data_dir = os.path.join(data_dir, 'collab')
    model_inputs_dir = os.path.join(model_inputs_dir, 'collab')
    model_outputs_dir = os.path.join(model_outputs_dir, 'collab')
model_visuals_dir = os.path.join(workshop_dir, 'visuals')
```

At the bottom, status bars show "Simple" mode, line 0, column 0, "Python 3 (ipykernel) | Idle", "Mode: Edit", "Ln 5, Col 7", "[1]ANUGA_DEM_processing.ipynb", and a page number of 1.

Google Collab

Alternatively, one can run the notebooks in a Collab environment:

1. On the workshop's github page, navigate to tutorials, then to
[1_HydrodynamicModeling_ANUGA](#)
2. Locate the list of 5 “Open in Collab” buttons, and hit the first one
3. Run cells as if it was a local Jupyter Notebook
 - Nb: Google Colab is an online service, it is less easy to customize the script and save results, and all modifications are erased once the page is closed.

We recommend the use a local environment with Jupyter Lab or Notebook to follow this workshop, if possible.