**Setting up the model for validation**

This study aims to use GeoClaw to model flood drivers’ influence in New York City. The model solves the three equations of the two-dimensional nonlinear shallow water equations using high-resolution finite-volume methods. There are a total of seven auxiliary variables initialized in the set run script of the model; three are related to the shallow water equations, one to friction, and the remaining three to storm fields. A large computational domain in Geoclaw was defined using longitude and latitude coordinates. The model had a spatial coverage of - 88° to -55° W and 15° to 45° N in the North Atlantic Ocean. The degree factor was set to 4, which is used to calculate the number of grid cells in each dimension. First, the time of the model simulation was converted from days to seconds. For the validation of Hurricane Sandy, the initial time was set to start three days before landfall. We set up a checkpoint file for the model in case of a restart. The output style was set to 1, indicating that output frames should be written at equally spaced time steps up to the final time. The number of output times was calculated based on the difference between the final and initial time, the recurrence, and the number of days. The initial time step was 0.010 days.

The time steps are based on desired CFL number. The model can also allow for very large time steps that are controlled by the CFL desired (0.75) and maximum number (1.0) function initialized in the set run script. The order accuracy was set to 2, which follows the Lax-Wendroff Flux limiter method. The dimension was left as unsplit as this is the only option currently allowed for AMRClaw. The transverse waves are also set to 2, which enables corner transport of second-order corrections. The number of waves was set to 3, indicating the number of waves in the Riemann solution. The Monotonized Central (MC) limiter was used for each wave family. The source split function was set up to advance the solution by solving the source term equations. Godunov (1st order) splitting was used, which is more accurate and can properly set ghost cells for boundary conditions, unlike Strang (2nd order) splitting. For the boundary conditions, we chose to extrapolate the values from the interior cells to the ghost cells.

Adaptive Mesh Refinement (AMR) parameters were used, and the maximum number of refinement levels was set to 8. The refinement ratios are set between successive levels in the x, and y directions, and time, respectively. Regions of refinement for the simulation were defined. Each region was specified by a list containing the minimum level, maximum level, start time, end time, lower x-coordinate, upper x-coordinate, lower y-coordinate, and upper y-coordinate. Also, the gauge locations for monitoring specific points in the domain during the simulation are defined. Each gauge is specified by a list containing the gauge number, longitude, latitude, start time, and end time. The gauges are appended to the list of the gauges. Geophysical parameters and settings were specified for the simulation. Parameters included gravity, coordinate system, Earth radius, the density of water and air, ambient pressure, Coriolis forcing, friction forcing, friction depth, sea level, and dry tolerance.

The scratch directory in the $CLAW folder is where the topography and storm files are stored and where they will be accessed during the model run. Data are downloaded from the [National Oceanic and Atmospheric Administration](https://ftp.nhc.noaa.gov/) archive (<https://ftp.nhc.noaa.gov/>). The files are converted from ATCF to GeoClaw format during the model run. The model ran in Python and some of its scripts are written in Fortran.

**Incorporating river discharge**

The subroutine “src2” script was used to integrate the river discharge into the model, fully written in Fortran. It is defined with several parameters specifying the number of equations, the size of the 2D grid on the x and y dimensions respectively, and the number of boundary cells, the auxiliary variables, the current time, and the time step relative to the simulation. There are arrays that contain the water levels and velocities at each grid cell for each time step and auxiliary data needed for the computations. The subroutine then imports several modules, including GeoClaw and storm modules, which provide functionalities related to geophysical computations and storm simulations respectively. Constants and functions from these modules are used in the code. Several local variables are then defined to assist with computations inside the subroutine. The river source conditions simulating a river's discharge into the system being modeled are defined. It sets certain geographical bounds for the river source, computes the river's discharge in cubic meters per second, and adds this to the q array (which represents the water level at each grid cell) for cells that fall within the river source area. Tidal forcing can be incorporated as a source term based on the desired eta and can be handled based on a list of tide times and associated tide heights. Eta is computed based on the sine function, representing some oscillatory behavior, like tides in an ocean. Also, multiple rivers’ conditions, each with its own geographical bounds and discharge rate can be incorporated.

**Synthetic storm modeling**

A few modifications were made to the set run script.

Long, lat, windspeed, radius, pressure, constant

| Storms | Date of Landfall | Date of impact in NYC | Hour of landfall | ATCF data |
| --- | --- | --- | --- | --- |
| Tropical Storm Barry | 2-Jun-2007 | 5-Jun-2007 | 14:00 | AL022007 |
| Hurricane Hanna | 6-Sep-2008 | 6-Sep-2008 | 7:20 | AL082008 |
| Hurricane Bill | 24-Aug-2009 | 22-Aug-2009 | 3:00 | AL032009 |
| Hurricane Irene | 28-Aug-2011 | 28-Aug-2011 | 13:00 | AL092011 |
| Hurricane Sandy | 29-Oct-2012 | 29-Oct-2012 | 23:30 | AL182012 |
| Tropical Storm Andrea | 6-Jun-2013 | 8-Jun-2013 | 22:00 | AL012013 |
| Hurricane Arthur | 4-Jul-2014 | 4-Jul-2014 | 8:00 | AL012014 |
| Tropical Storm Bill | 16-Jun-2015 | 22-Jun-2015 | 16:45 | AL022015 |
| Tropical Storm Bonnie | 29-May-2016 | 28-May-2016 | 12:30 | AL022016 |
| Hurricane Matthew | 8-Oct-2016 | 10-Oct-2016 | 15:00 | AL142016 |
| Tropical Storm Cindy | 22-Jun-2017 | 19-Jun-2017 | 7:00 | AL032017 |
| Hurricane Gert | 16-Aug-2017 | 18-Aug-2017 | 18:00 | AL082017 |
| Tropical Storm Jose\* | 19-Sep-2017 | 20-Sep-2017 | 0:00 | AL122017 |
| Hurricane Maria | 20-Sep-2017 | 27-Sep-2017 | 10:15 | AL152017 |
| Tropical Storm Philippe | 28-Oct-2017 | 30-Oct-2017 | 22:00 | AL182017 |
| Tropical Storm Gordon | 5-Sep-2018 | 9-Sep-2018 | 3:15 | AL072018 |
| Hurricane Michael | 10-Oct-2018 | 12-Oct-2018 | 17:30 | AL142018 |
| Hurricane Dorian | 6-Sep-2019 | 7-Sep-2019 | 12:30 | AL052019 |
| Tropical Storm Ogla | 27-Oct-2019 | 27-Oct-2019 | 3:00 | AL172019 |

\* Original landfall was on September 9, 2017

\* Original landfall was on September 9, 2017