# AdcircViz: A Visualization Application for Distributed ADCIRC-based Coastal Storm Surge, Inundation, and Wave Modeling

*A JHT 2013 Project*
*Final Report*

## Abstract

This final project report for AdcircViz provides a brief overview of the objectives and annual progress, as well as details of work performed during the no-cost extension period. The JHT-funded project delivers a user-driven application that allows easy access, visualization, and analysis of a collection of coastal models that generally run daily and/or during tropical cyclone events. The original ADCIRC-only approach was demonstrated in the first project year, with the second year devoted to generalizing the approach to encompass any model for which the output conforms to specified standards and conventions. The generalized version motivated a change in the application name to StormSurgeViz.

The approach was to create a graphical user interface (GUI) that was both easy to develop and easy to use. We chose MATLAB as the development and deployment environment, due to its GUI building functions and its prevalence in the research and federal modeling communities. The resulting project code is developed and maintained in the GitHub code repository environment, making development, dissemination, access, and contribution straightforward.

A no-cost extension was requested so that the entire 2015 Atlantic hurricane season could be used for testing. While the season turned out to be quiet, with only Hurricanes Erika and Joaquin providing some opportunity to exercise the application's capabilities, these storms did provide an opportunity to further improve the application. StormSurgeViz updates were provided to NHC shortly after each storm began to threaten the US coast and we continue to address small software/code issues as they arise. Additionally, we have included new models to the available catalog of storm surge data providers. This was straightforward, provided the models adhered to community standards and conventions. StormSurgeViz can easily access and display model output from ADCIRC, ROMS/TOMS, FVCOM, and SELFE. It can also handle PSurge model output when the grib2 files are converted to netCDF and augmented with NcML. StormSurgeViz is now in use by the project PIs and modelers at NOAA's CSDL and CO-OPS. The PIs and colleagues use the application to view and check the status of real-time model simulations as well as research simulations unrelated to quasi-operational systems.

# Overview of the AdcircViz/StormSurgeViz Project

StormSurgeViz, formerly AdcircViz, provides uniform and consistent access to a variety of coastal model simulation output when that output conforms to community standards and conventions and is posted to a THREDDS Data Server (TDS). It makes connections to a TDS using the OPeNDAP data transfer protocol through the MATLAB toolbox nctoolbox. This toolbox, which uses the Unidata netCDF java class as the data access layer, is used extensively to open netCDF data files and access metadata, without accessing the data components until they are needed (called *lazy loading*). Each graphic is generated using MATLAB functions and tools "on the fly". The color map, color limits and color increment are specified by the user with default values appropriate to the scalar field being rendered.

For the original proposal to the JHT program, we developed a prototype implementation to demonstrate the feasibility of the approach. This version (Figure 1) included the ability to visualize several scalar fields from ADCIRC (namely maximum water level, time-dependent water level, maximum significant wave height, time-dependent wind speed, and the maximum wind speed) for all ensemble members contained in an ASGS simulation directory. The data and metadata for populating the application are extracted from ADCIRC files posted on a THREDDs server (opendap.renci.org:1935). The files are in netCDF format with strict adherence to the CF-UGRID conventions and standards, and in a specific directory (folder) hierarchy that defines information such as storm name and advisory number. This prototype version was extensively tested during the 2012 Atlantic hurricane season, particularly during Hurricane Isaac. We have also tested the application with large Hurricane Katrina simulations in a hindcast mode, and this has proven to be a useful way to examine existing non-forecast simulations, as long as the files adhere to the CF-UGRID conventions and are put onto a THREDDs server.
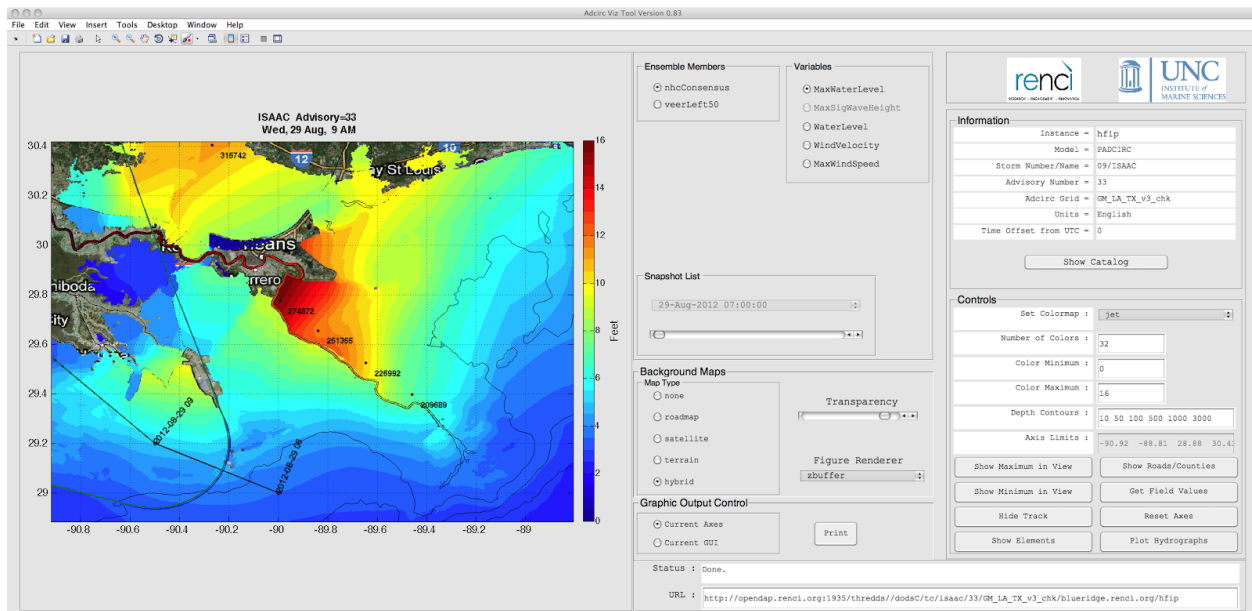


*Figure 1: Prototype application (AdcircViz) developed for the original proposal to JHT. This version was extensively tested during the 2012 Atlantic hurricane season and deployed to test/evaluation users in 2013.*

# Summary of the project outcomes (9/2013 - 8/2015)

**First project year (2014)**

The ADCIRC-only version (AdcircViz) was made available to the NHC Storm Surge Unit (SSU) for deployment and initial evaluation prior to the 2014 Atlantic hurricane season. A presentation describing the project was made at the 2014 Interdepartmental Hurricane Conference, and afterward the PI (Blanton) met with the SSU to discuss specific requirements for AdcircViz, including specific features, code access, machine/operating system dependencies, and how to optimally engage for bug fixes and feature requests.

Due to a relatively quiescent 2014 Atlantic hurricane season, there were few "real time" opportunities to rigorously evaluate AdcircViz as a tool within the NHC's SSU. However, Hurricane Arthur, which made landfall on the North Carolina coast on July 3, provided an opportunity to exercise AdcircViz. We (RENCI) were able to monitor the status of our forecast system during the event. Each new advisory's simulation results were detected by AdcircViz and were immediately available to AdcircViz. Figure 2 shows the maximum water level [ft MSL] for Hurricane Arthur, Advisory 09.
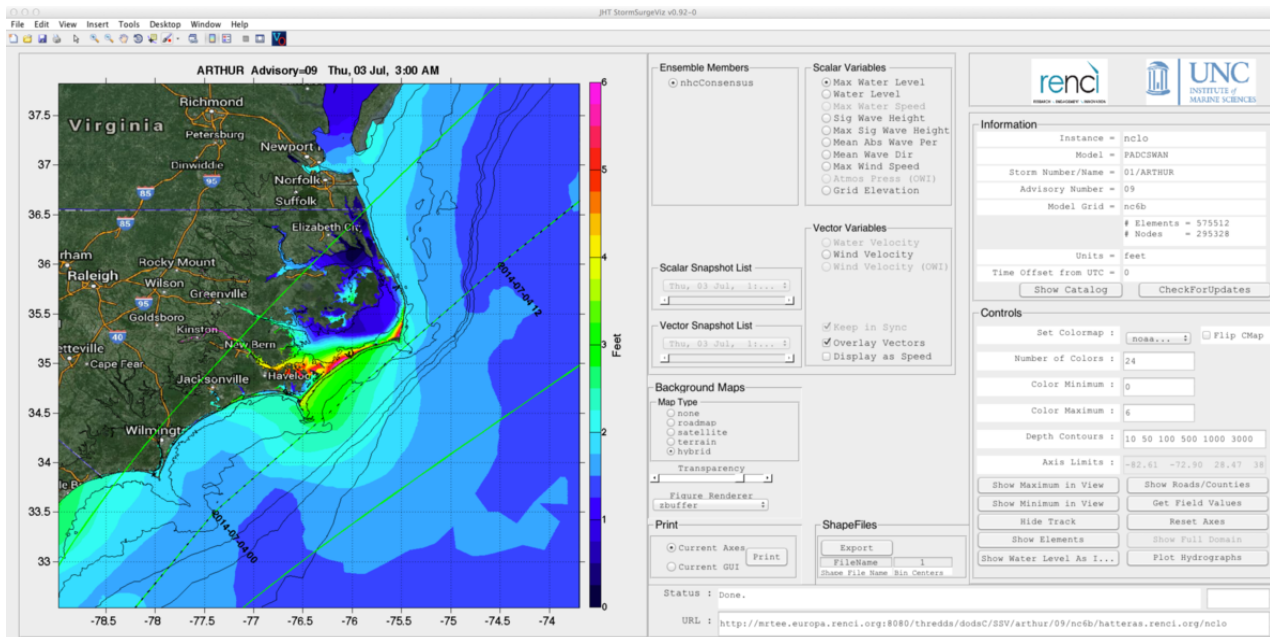


*Figure 2: AdcircViz showing the RENCI Adcirc Surge Guidance System forecast for Hurricane Arthur, Advisory 09. The colors are the maximum water level, including tides and wave setup, over the duration of the forecast simulation. The dashed line is the forecast storm track, with the uncertainty lines in green.*

Hurricane Gonzalo occurred in mid October 2014. This hurricane did not pose a threat to US coasts, instead veering north and east toward Bermuda. The ADCIRC grids used in most ASGS forecasting systems extend eastward to the 60-deg meridian, thus providing coverage of Bermuda, albeit not at substantial resolution. RENCI contacted NHC/SSU about using the Gonzalo ADCIRC-based forecasts on RENCI's THREDDS server as an opportunity to experiment with AdcircViz in a low-stress manner (NHC/SSU does not have operational responsibilities for Bermuda). During the Gonzalo event, the NHC/SSU reported substantial delays in the response of AdcircViz, noting that 10's of seconds elapsed when the application requested data slices from the THREDDS server. The perception was that AdcircViz would not be efficient

enough operational use. Subsequently, RENCI determined that the sluggishness was not due to the data servers, and in general the data transfer speeds between the servers and other remote sites (not NHC) were consistent with expected data speeds.

## Second project year (2015)

The PI (Blanton) attended the 2015 Interdepartmental Hurricane Conference (2-4 March 2015), with the JHT projects attending in Miami. During that meeting, we attempted to recreate the performance problems noted during the prior Gonzola test. We could not repeat the slow response. It was determined that network switching equipment had been upgraded in the intervening period, and the poor response of AdcircViz was due to a network equipment issue (either outdated/old or faulty equipment). During the IHC/JHT visit, the AdcircViz application performed as expected by both the PI and the SSU. The network transfer speeds were at least as fast as when AdcircViz is run at RENCI, where the data servers are located in close proximity to the workstations used by the PI for development and testing of the application.

In conversations with the NHC and the JHT program, we decided that extending the original application's capabilities from ADCIRC-only to a model-neutral framework would best serve the SSU and the JHT program. Making this extension was the focus of the project's second year. This would enable the storm surge modeling community at large to provide storm surge hazard assessments to the NHC SSU during active tropical cyclone periods. We thus changed the name from AdcircViz to StormSurgeViz, and reorganized the application to harness and rely on model output described by NcML files, instead of directly accessing netCDF files.

As part of the community outreach activities, the NHC developed a letter inviting the community to participate in an experiment, whereby interested modelers would follow the on-boarding process to make their results available to StormSurgeViz. The letter directed interested participants to the project's on-boarding page: http://renci-unc.github.io/StormSurgeViz/participate.html (see Figure 3). This letter, sent on 7 April 2015 and included as Appendix 1 in this report, generated responses from two groups; the New York Harbor Operational Prediction System (NYHOPS) operated by Alan Blumberg and Nickitas Georgas of the Stevens Institute of Technology. The second response was from the Irish Marine Institute (IMI) in Galway, Ireland. While the latter is focused on the northeast Atlantic in the Ireland and England area, and not of direct relevance to the NHC, it provided a useful example of another "regular" grid model, and including it in the collection of data providers was straightforward. We note that there was some initial response from Florida International University regarding the CEST model, but follow-up emails did not generate useful model outputs for StormSurgeViz. We also note that while the on-boarding process is straightforward, we found it helpful to talk directly with NYHOPS and IMI to understand their model output structure and markup requirements.



*Figure 3: StormSurgeViz project GitHub page for the community onboarding process.*

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**Implementation of NcML version of StormSurgeViz**

The main activity in second year was to implement a modified version of StormSurgeViz capable of ingesting NcML files from THREDDS servers. NcML is an xml markup language for netCDF files. NcML acts as a simple intermediary file, between the native model output netCDF file on THREDDS servers and end-user clients such as StormSurgeViz. It "marks up" netCDF files with additional metadata, thus making the netCDF files conform to conventions and standards *without modification of either the model output routines or existing netCDF files.* NcML can be used on existing netCDF files to make the files appear to be CF compliant. It can also be used to aggregate multiple netCDF files so that they appear to be one, larger file. This is typically used to aggregate across time (if separate netCDF files are output for each output time) or if different dependent variables are output into separate files (as is the case for ADCIRC). NcML has proven to be essential to "marking up" the metadata for compliance without any changes to the underlying model output files.

For this extension, we "branched" the StormSurgeViz code in GitHub into an ncml-version. The "ncml-version" of StormSurgeViz can access and visualize multiple models, but does not yet process ensembles of models. It **_requires_** an NcML file as the access endpoint on a THREDDS server, even if the underlying netCDF file is fully CF compliant. In this case, the NcML file just passes the netCDF file to the client. If a model's output is split into separate files for each variable (as is the case for ADCIRC), then the data provider is responsible for including the aggregation definition in the NcML file. See Appendix 2 for examples. Currently, data providers host their own model output files, and the required NcML is hosted on RENCI's THREDDS server. This has simplified the NcML development phase. The current set of NcML files are posted at this URL, which StormSurgeViz uses to populate the Data Provider menu: http://opendap.renci.org:1935/thredds/dodsC/SSV-Ncml/. The long-term goal is to have the data providers create and host their own NcML, although that is beyond the scope of this project.

The first step in this extension was to determine the minimum level of metadata augmentation that was needed to adequately describe various model outputs. The two data providers, IMI and NYHOPS, already post their output in netCDF files on THREDDS servers, so we retrieved examples of these models to study. It was determined that the models were generally already CF-compliant, and little markup was needed. As a specific example, NYHOPS runs a version of the ECOMSED-3D model, which outputs the water level variable as "elev". The IMI system uses the Regional Ocean Model System (ROMs), and its water level variable is named sea_surface_height. The CF convention requires that this water level variable is named sea_surface_height_above_geoid, so NcML is used to map the native model variable names to this standard name. For the NYHOPS case, this looks as follows:

```
<variable name="elev" >
   <attribute name="standard_name" value="sea_surface_height_above_geoid" />
</variable>
```

For IMI:

```
<variable name="sea_surface_height" >
   <attribute name="standard_name" value="sea_surface_height_above_geoid" />
</variable>
```

ADCIRC's water level variable name is already `sea_surface_height_above_geoid`, so no markup is needed.

We also determined that a few other pieces of information, as expressed in NcML, would help better identify models to StormSurgeViz. This includes adding global attributes that define a title, institution, the

underlying model structure (ugrid for unstructured model output, cgrid for "regular" model output), and an advisory or cycle indicator.  The NcML requirements are included in Appendix 2.

In addition to the NYHOPS and IMI model output, we also incorporated the Coast Survey Development Laboratory (CSDL) ADCIRC-based output, from their tropical-ASGS and extratropical-NAM (ESTOFS) systems.  RENCI worked with CSDL to put NcML files on their THREDDS server, thus expanding the list of model output providers.

**No-cost extension period**

The previous section documented three different models available through StormSurgeViz at the end of project year 2. These included several ADCIRC-based systems,  a ROMS-based system in the United Kingdom area and a POM-based system in the New York Harbor area.  During the no-cost extension period, we added additional models to the available provider list, from the NOAA-COOPS operational forecast system suite.  This was suggested by Dr. Greg Dusek from NOAA/CO-OPS at the American Meteorological Society's 2016 Annual Meeting in New Orleans.  This suite of coastal ocean models provides operational forecast output to various NOAA groups, all of which is posted on a NOAA THREDDS server.  The model suite includes a variety of models, including SELFE, FVCOM, and ROMS/TOMS, that were easy to include; minimal NcML was needed.  The user is now able to select from the collection of providers through a pull-down menu at the top of the application (Figure 4).
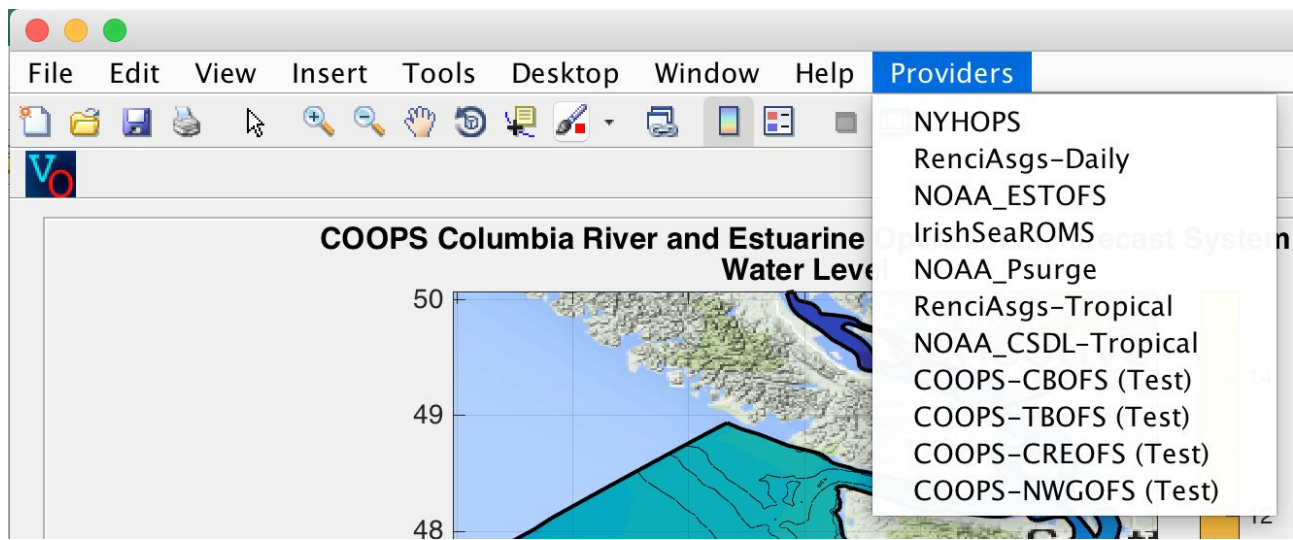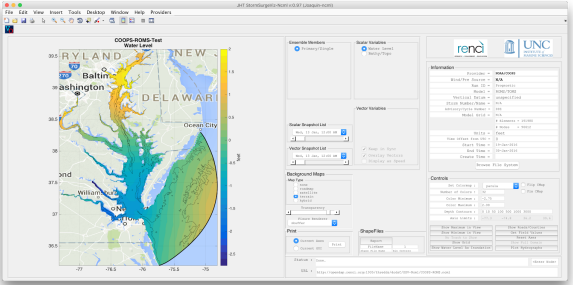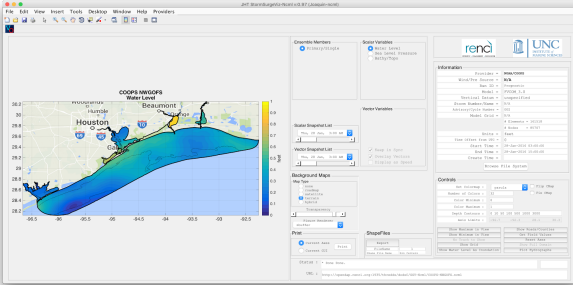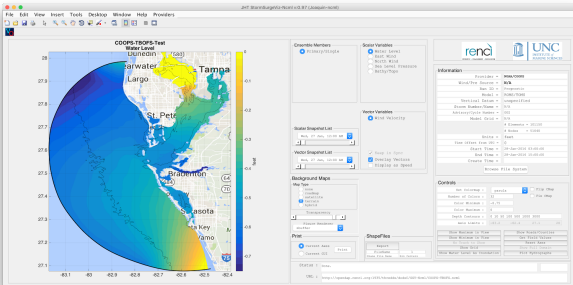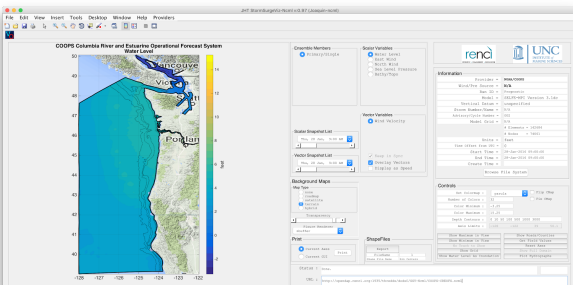


*Figure 4:  StormSurgeViz pulldown menu of model providers. The four CO-OPS models are additions made during the no-cost extension period.*

**Current  StormSurgeViz Data Providers:**

Here, we provide a summary of currently available models that are available in StormSurgeViz, with the additions made during the no-cost extension period first (marked NEW):

| | |
|---|---|
|  | **NEW**<br>**Provider: NOAA CO-OPS CBOFS**<br>Focus: Chesapeake Bay (CBOFS)<br>Frequency: Daily<br>Model: ROMS/TOMS<br>Wind: unknown<br>Grid: curvilinear (cgrid) |
|  | **NEW**<br>**Provider: NOAA CO-OPS NWGOFS**<br>Focus: Galveston area (NWGOFS)<br>Frequency: Daily<br>Model: FVCOM<br>Wind: unknown<br>Grid: triangular (ugrid) |
|  | **NEW**<br>**Provider: NOAA CO-OPS TBOFS**<br>Focus: Tampa Bay (TBOFS)<br>Frequency: Daily<br>Model: ROMS/TOMS<br>Wind: unknown<br>Grid: curvilinear (cgrid) |
|  | **NEW**<br>**Provider: NOAA CO-OPS CREOFS**<br>Focus: Columbia River/Oregon Coast (CREOFS)<br>Frequency: Daily<br>Model: SELFE<br>Wind: unknown<br>Grid: triangular (ugrid) |

| | |
|---|---|
|  | **Provider: NOAA CSDL**<br>Frequency: Tropical<br>Model: ADCIRC/ASGS<br>Wind: ATCF, ADCIRC vortex wind model<br>Grid: triangular (ugrid) |
|  | **Provider: NOAA ESTOFS**<br>Frequency: Daily<br>Model: ADCIRC/ASGS<br>Wind: NAM<br>Grid: triangular (ugrid) |
|  | **Provider: NYHOPS/Stevens Institute**<br>Frequency: Daily<br>Model: ECOMSED<br>Wind: NAM-driven<br>Grid: curvilinear (cgrid) |
|  | **Provider: Irish Marine Institute**<br>Frequency: Daily<br>Model: ROMS<br>Wind: ECMWF<br>Grid: regular (cgrid) |
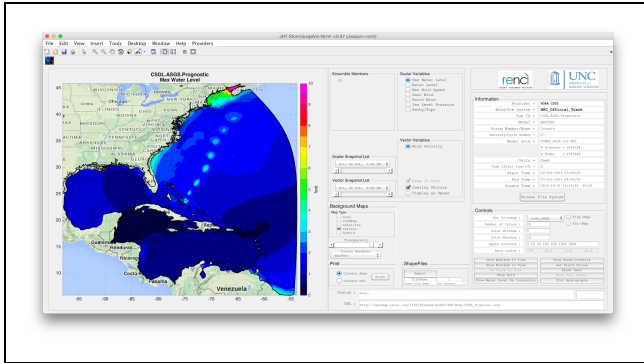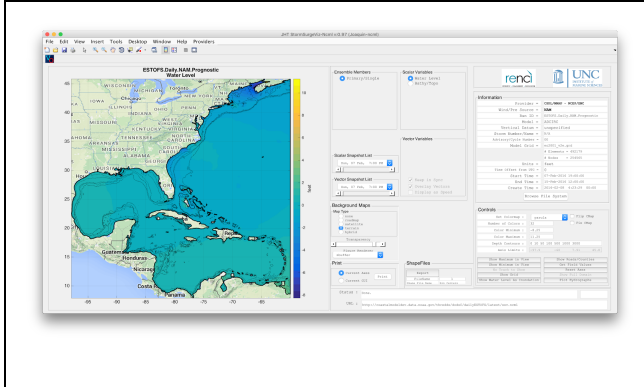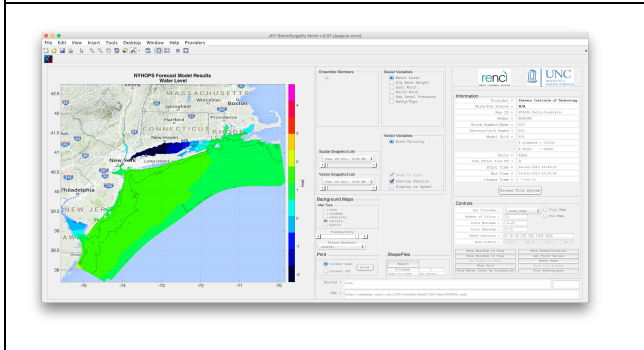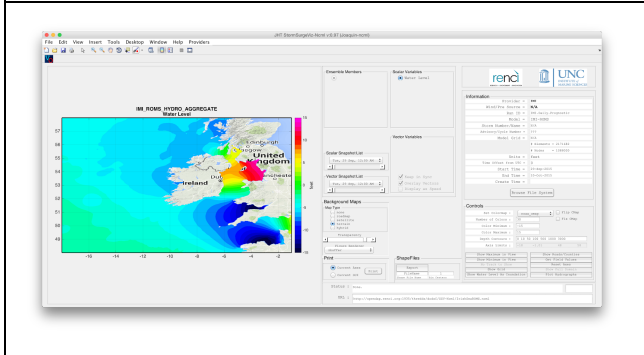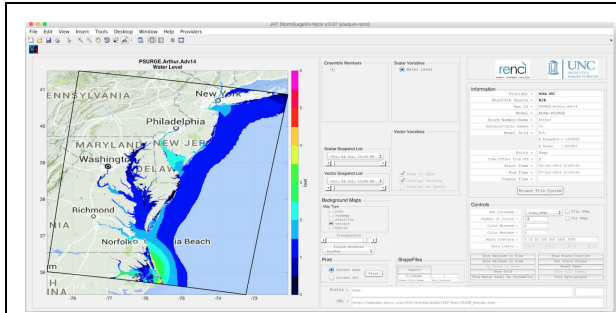
**Provider: NOAA P-Surge**
Frequency: Tropical
Model: Psurge/SLOSH
Wind: SLOSH winds, probabilistic tracks
Grid: mapped (cgrid)
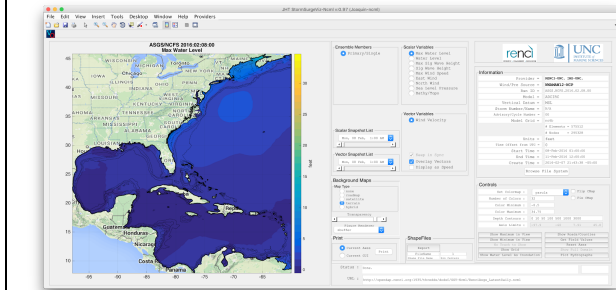


**Provider: RENCI/ASGS  Daily**
Frequency: Daily
Model: ADCIRC
Wind: NAM
Grid: triangular (ugrid)
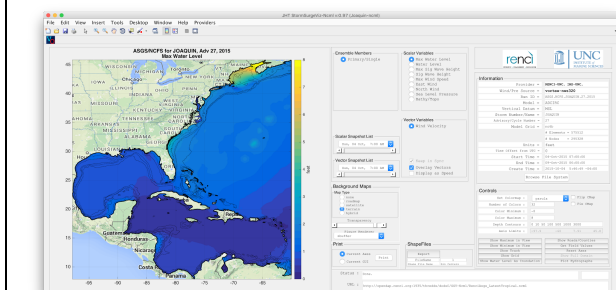


**Provider: RENCI/ASGS  Tropical (NCFS)**
Frequency: Tropical
Model: ADCIRC
Wind: ATCF, ADCIRC vortex wind model
Grid: triangular (ugrid)

**Appendix 1: Community on-boarding invitational letter from NHC**

Subject: [Coastal_list] Invitation to provide experimental, real-time storm surge model output to NHC
Date: 04/07/2015 7:46 AM
From: Christopher Landsea - NOAA Federal
To: coastal_list@UDel.Edu

Dear Storm Surge Expert,

The National Hurricane Center is able to test new observational and modeling capabilities experimentally through the Joint Hurricane Testbed. (For more information about the JHT: http://www.nhc.noaa.gov/jht/ [1].) As part of the JHT, a storm surge visualization tool - StormSurge Viz - is being tested at NHC. StormSurge Viz project's goal is to provide a community-based method for visualizing real-time storm surge model output from a variety of sources, possibly from academia, government agencies, and the private sector, for real-time consideration by the Storm Surge Unit at NHC. StormSurgeViz is capable of displaying storm surge model output from a variety of systems, as long as the output is provided in CF-compliant NetCDF format delivered via OPeNDAP/THREDDS servers. If you desire to provide real-time storm surge model output for consideration by NHC during the 2015 hurricane seasons, please follow the specifications listed. NHC relies heavily on operational storm surge model output from P-Surge (http://www.nhc.noaa.gov/surge/psurge.php [2]) as its primary source of guidance and will continue to do so going forward. Furthermore, participating in this project is not a proxy or substitute for operational transition of any modeling system. Rather, StormSurge Viz provides an experimental environment for the operational and research storm surge modeling communities to engage in improving understanding of operational needs and surge modeling techniques with the ultimate goal of improving forecasts for the public. (Please see below for details about specifications needed for providing storm surge model output.)

It is necessary to point out that volunteering to participate in this project does not constitute operational transition of any modeling system. Rather, it is a means for the operational and research community to engage and gain a better understanding of operational needs, which is ultimately in providing improved storm surge predictions for the public.

The community onboarding process is described as part of the StormSurgeViz code repository:

http://renci-unc.github.io/StormSurgeViz/participate.html [3]

Let me know if you have any questions about this invitation.

Sincerely,
Chris Landsea
*********************************************************************

**Appendix 2: NcML for Data Providers**

Due to differences in the ways individual models output their solutions, it is necessary to enable conformance to the CF and CF-UGRID conventions by marking up the netCDF files with the NcML language. This greatly simplifies the normalization of different model output variable names and provides additional metadata covering global run descriptions and variable attributes.

We also found it necessary to augment the metadata in the NcML files, beyond merely enforcing CF compliance, to better distinguish the different models and to provide non-CF information to the end-user. For example, there is not a CF standard way of describing the wind forcing for a model, but this is essential information for end-users to know. We thus defined the `wind_source` global attribute to allow the data provider to indicate the wind forcing. Similarly, the `title`, `model`, and `institution` are intended to inform the end-users of data sources. Note that StormSurgeViz does not care about the *values* of these attributes, only that the attributes are defined in the metadata (either natively in the netCDF files or augmented with NcML).

We have defined the following global attributes to be added to the NcML, if the attributes are NOT already defined in the netCDF files (metadata and data pass through the NcML files if not altered or edited by the NcML). Optional attributes would be filled with "N/A" or "unknown" if not supplied by the NcML.

| REQUIRED:<br>cdm_data_type<br>Conventions<br>institution<br>model<br>wind_source | OPTIONAL<br>(BUT HIGHLY RECOMMENDED):<br>advisory_or_cycle<br>grid<br>stormname<br>stormtype<br>stormyear | OPTIONAL:<br>id<br>title |
|---|---|---|

The basic and abbreviated NcML for two **NEW** data providers is as follows. Please see the previous project report (AdcircViz End of Year 2 Progress report, date: 9 October 2015) for NcML details for ADCIRC, NYHOPS, and IMI. The complete NcML can be seen from within the StormSurgeViz application.


**NOAA COOPS CREOFS**

```
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2" >

  <attribute name="title" type="string" value="COOPS Columbia River"/>
  <attribute name="institution" type="string" value="NOAA/COOPS"/>
  <attribute name="Conventions" value="CF-1.6" />
  <attribute name="cdm_data_type" value="ugrid" />
  <attribute name="model" value="SELFE-MPI Version 3.1dc" />
  <attribute name="advisory_or_cycle" value="00Z" />
  <attribute name="id" value="Prognostic" />

  <dimension name="mesh" length="1" />

  <variable name="selfe_mesh" shape="mesh" type="int">
    <attribute name="long_name"              value="mesh_topology" />
    <attribute name="node_coordinates"       value="x y" />
    <attribute name="face_node_connectivity" value="element" />
    <attribute name="cf_role"                value="mesh_topology" />
    <attribute name="topology_dimension"     value="2" type="int" />
  </variable>
```

```xml
  <variable name="element" orgName="ele" />

  <variable name="uwind_speed" >
     <attribute name="standard_name" value="eastward_wind" type="String"/>
     <attribute name="_FillValue" value="-9999.0" type="Float"/>
  </variable>

  <variable name="vwind_speed" >
     <attribute name="standard_name" value="northward_wind" type="String"/>
     <attribute name="_FillValue" value="-9999.0" type="Float"/>
  </variable>

  <variable name="Pair" >
     <attribute name="standard_name" value="air_pressure_at_sea_level" />
     <attribute name="_FillValue" value="-9999.0" type="Float"/>
  </variable>

  <variable name="lon" >
     <attribute name="standard_name" value="longitude" type="String"/>
  </variable>

  <variable name="lat" >
     <attribute name="standard_name" value="latitude" type="String"/>
  </variable>

  <variable name="zeta" >
     <attribute name="standard_name"
              value="sea_surface_height_above_geoid"/>
     <attribute name="_FillValue" value="-9999.0" type="Float"/>
  </variable>

  <variable name="h" >
     <attribute name="standard_name" value="depth_below_geoid"/>
  </variable>

  <aggregation type="joinExisting" dimName="time">

    <netcdf
      location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/CREOFS/MODELS/201601/nos.c
reofs.fields.n000.20160128.t03z.nc"/>
    <netcdf
      location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/CREOFS/MODELS/201601/nos.c
reofs.fields.n000.20160128.t09z.nc"/>
    <netcdf
      location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/CREOFS/MODELS/201601/nos.c
reofs.fields.n000.20160128.t15z.nc"/>

  </aggregation>
</netcdf>
```

## NOAA COOPS NWGOFS

```xml
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2" >

  <attribute name="title" type="string" value="COOPS NWGOFS"/>
  <attribute name="institution" type="string" value="NOAA/COOPS"/>
  <attribute name="Conventions" value="CF-1.6" />
  <attribute name="cdm_data_type" value="ugrid" />
  <attribute name="model" value="FVCOM_3.0" />
  <attribute name="advisory_or_cycle" value="00Z" />
  <attribute name="id" value="Prognostic" />

  <dimension name="mesh" length="1" />
```

```xml
<variable name="fvcom_mesh" shape="mesh" type="int">
  <attribute name="long_name"              value="mesh_topology" />
  <attribute name="node_coordinates"       value="x y" />
  <attribute name="face_node_connectivity" value="element" />
  <attribute name="cf_role"                value="mesh_topology" />
  <attribute name="topology_dimension"     value="2" type="int" />
</variable>

<variable name="element" orgName="nv" />

<variable name="h" >
   <attribute name="standard_name" value="depth_below_geoid"/>
 </variable>

 <variable name="time" >
   <attribute name="standard_name" value="time" type="String"/>
 </variable>

<aggregation type="joinExisting" dimName="time">

   <netcdf
location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/NWGOFS/MODELS/201601/nos.nwgofs.f
ields.f000.20160128.t03z.nc"/>
   <netcdf
location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/NWGOFS/MODELS/201601/nos.nwgofs.f
ields.f000.20160128.t09z.nc"/>
   <netcdf
location="http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/NWGOFS/MODELS/201601/nos.nwgofs.f
ields.f000.20160128.t15z.nc"/>

 </aggregation>


</netcdf>
```

**Appendix 3: PSurge access and visualization in StormSurgeViz**

Even though the PSurge output is not in netCDF, it is still possible to ingest PSurge output into StormSurgeViz (Figure 5 below) with a few pre-processing steps. It would be straightforward to create an automated process that detects new PSurge files on the NOAA servers and creates and posts the netCDF and NcML files in a standardized location. The basic process is detailed in this iPython notebook:

http://nbviewer.ipython.org/github/BrianOBlanton/DLobServatory/blob/master/SLOSH_PSurge_Example.ipynb

1) **Retrieve a GRIB2 file**: http://www.nws.noaa.gov/mdl/psurge2.0/

   Example: `Arthur_Adv14_2014070406_e10_cum_agl.grb`

2) **Convert from GRIB2 to netCDF:**

```
fgrib=Arthur_Adv14_2014070406_e10_cum_agl.grb
fnc=Arthur_Adv14_2014070406_e10_cum_agl.nc
wgrib2 $fgrib -netcdf $fnc
```

3) **Subset using NCO's ncea:** The GRIB2 footprint for PSurge covers the entire US. Use the NetCDF Operators command **ncea** to reduce the footprint and thus file size. In this example, subsetting is done along the x,y coordinate dimensions, such that 2500:3500 and 6700:7500 carve out an area for the middle Atlantic Bight.

```
ncea -d y,2500,3500 -d x,6700,7500 $fnc $fnc.reduced
```

4) **Mark up resulting netCDF file with NcML**: The result of converting the grib2 file into netCDF requires NcML to rename variables and define the location of the netCDF file, shown here:

```
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2"
        location="Arthur_Adv14_2014070406_e10_cum_agl_reduced.nc">

  <attribute name="cdm_data_type" value="cgrid" />
  <attribute name="model" value="NOAA-PSURGE" />
  <attribute name="id" value="PSURGE.Arthur.Adv14" />
  <attribute name="stormname" value="Arthur" />
  <attribute name="advisory_or_cycle" value="14" />
  <attribute name="institution" value="NOAA NHC" />

  <variable name="SURGE_0maboveground" >
      <attribute name="standard_name"
             value="sea_surface_height_above_geoid" />
  </variable>

  <variable name="longitude" >
      <attribute name="standard_name" value="longitude"/>
  </variable>

  <variable name="latitude" >
    <attribute name="standard_name" value="latitude" />
   </variable>

  </netcdf>
```

5) **Post NcML on a THREDDS server:** The NcML file above can then be posted on a THREDDS server. In this example, the file was posted on RENCI's server (opendap.renci.org:1935/thredds), and the reduced netCDF file is placed in the same location. StormSurgeViz was made aware of the NcML location, and was able to access and display the surge field, as shown on Figure 5. It would be up to the data provider to include the appropriate "storm dependent" metadata when the NcML is generated, and to identify which probability or water level field is being provided. It would also be possible to have the NcML present several PSurge outputs (multiple probability and water level surfaces) as a set of ensemble members.
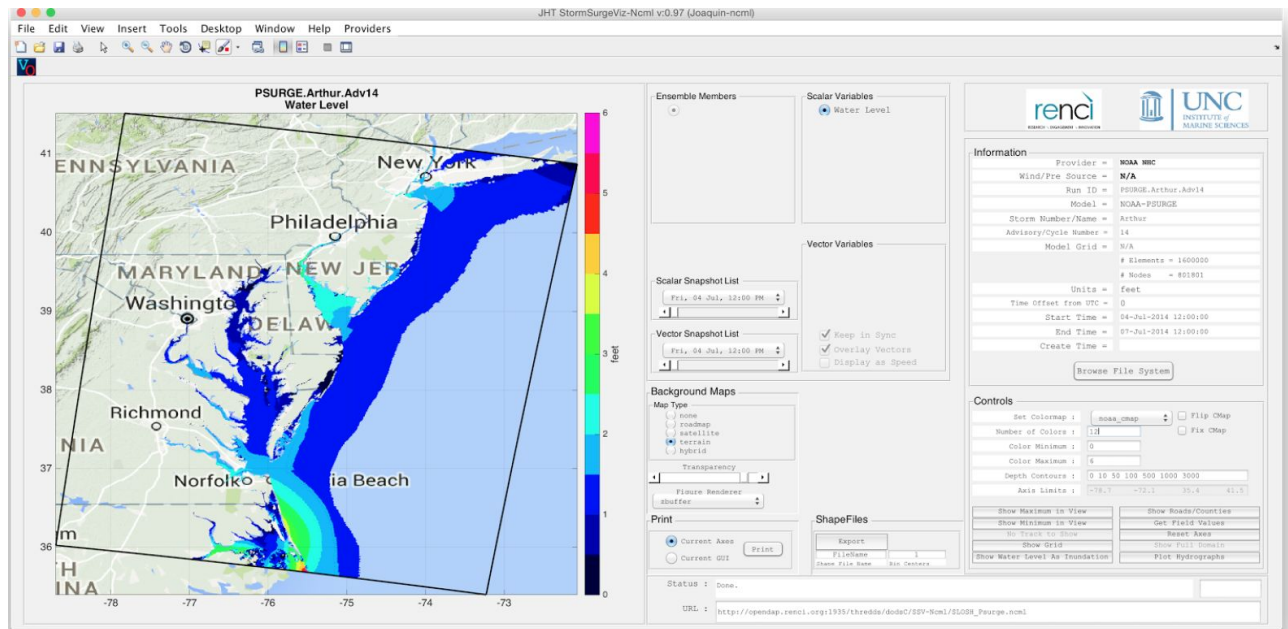


*Figure 5: NOAA's PSurge for Hurricane Arthur (2014) in StormSurgeViz. The original grib2 file was converted to netCDF, marked up with NcML, and posted on RENCI's THREDDS server for demonstration purposes. The outlined area is the bounding box of the reduced-extent PSurge output. The 10% exceedence water level is shown.*

## Appendix 4:  Current Data Providers for StormSurgeViz

- **RenciAsgs-Tropical**
  - Operator: RENCI, UNC, Seahorse Coastal Consulting
  - THREDDS Host:  http://opendap.renci.org:1935/thredds/catalog/LatestTropical/catalog.html
  - Model: ADCIRC
  - Reference: http://nc-cera.renci.org, http://adcirc.org
- **RenciAsgs-Daily**
  - Operator:  RENCI, UNC, Seahorse Coastal Consulting
  - THREDDS Host:  http://opendap.renci.org:1935/thredds/asgs.html
  - Model: ADCIRC
  - Reference:  http://nc-cera.renci.org, http://adcirc.org
- **NOAA_CSDL-Tropical**
  - Operator: NOAA/CSDL
  - THREDDS Host: http://coastalmodeldev.data.noaa.gov/thredds/dodsC/ASGS/latest/catalog.html
  - Model: ADCIRC
  - Reference: http://adcirc.org
- **NOAA_ESTOFS**
  - Operator: NOAA/CSDL
  - THREDDS Host:  http://coastalmodeldev.data.noaa.gov/thredds/catalog/dailyESTOFS/latest/catalog.html
  - Model: ADCIRC
  - Reference: http://adcirc.org
- **NYHOPS**
  - Operator: Stevens Institute of Technology
  - THREDDS Host: http://colossus.dl.stevens-tech.edu/thredds/complete_latest.html
  - Model: ECOMSED-3D (via POM)
  - Reference: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.4574&rep=rep1&type=pdf
- **IrishSeaROMS**
  - Operator: Marine Institute, Galway Ireland
  - THREDDS Host: http://milas.marine.ie/thredds/dodsC/IMI_ROMS_HYDRO/AGGREGATE
  - Model: ROMS
  - Reference: http://data.marine.ie/
- **NOAA_Psurge**
  - Operator: NOAA
  - THREDDS Host: N/A
  - Model: SLOSH + Probabilities
  - Reference: http://slosh.nws.noaa.gov/psurge2.0
- **NOAA CO-OPS CBOFS**
  - Operator: NOAA
  - THREDDS Host: http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/CBOFS
  - Model: ROMS/TOMS
  - Reference: https://www.myroms.org/documentation/docs.php
- **NOAA CO-OPS NWGOFS**
  - Operator: NOAA
  - THREDDS Host: http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/NWGOFS/
  - Model: FVCOM
  - Reference: http://fvcom.smast.umassd.edu
- **NOAA CO-OPS TBOFS**
  - Operator: NOAA
  - THREDDS Host: http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/TBOFS
  - Model: ROMS/TOMS
  - Reference: https://www.myroms.org/documentation/docs.php
- **NOAA CO-OPS CREOFS**
  - Operator: NOAA
  - THREDDS Host: http://opendap.co-ops.nos.noaa.gov/thredds/dodsC/NOAA/CREOFS
  - Model: SELFE
  - Reference: http://www.stccmop.org/knowledge_transfer/software/selfe