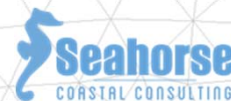# Enabling Distributed, Event-Based, High-Resolution Storm Surge Modeling

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USGS

Jason Fleming
Seahorse Coastal Consulting

68th Interdepartmental Hurricane Conference
4 March, 2014

Motivation

Resiliency of coastal areas a major concern

Extreme weather events

Sea level variability and rise

Critical need for detailed hazard and risk estimation information

Detailed → high spatial resolution

Real-time operational forecast products

Research → operations

Courtesy: J. Hanson, USACE/FRF/Duck

Photo by: Don McClosky

AdcircViz

Many Storm Surge Tools Used

- GIS
- Statistical models
- Numerical models (Dynamic)
  - SLOSH
    - Operational by NOAA, NHC
    - Curvilinear, orthogonal grid
    - Not parallel computing
    - Can run easily on a PC/laptop
    - Ideally suited for rapid ensembles
  - FVCOM, SELFE
  - ADCIRC
    - Research modes
    - Operational at NCEP
    - Finite element (triangular)
    - Very high spatial resolution
    - Concomitant high computational cost
    - Not suited (yet) for large dynamic ensembles

SLOSH NC basin

ADCIRC NC grid
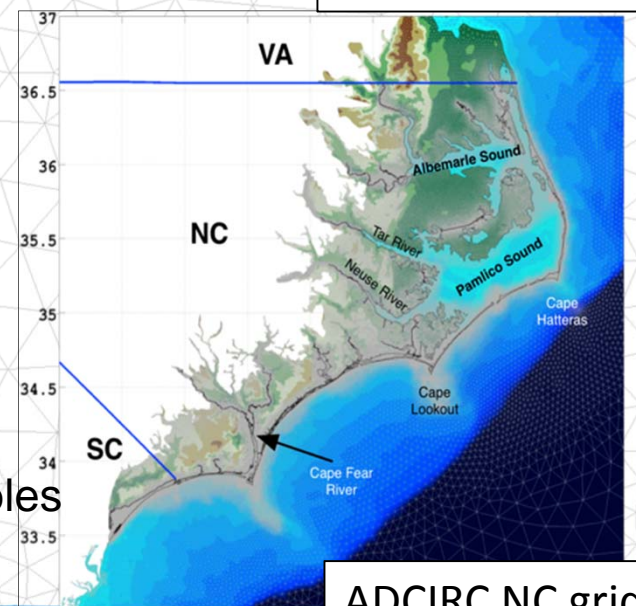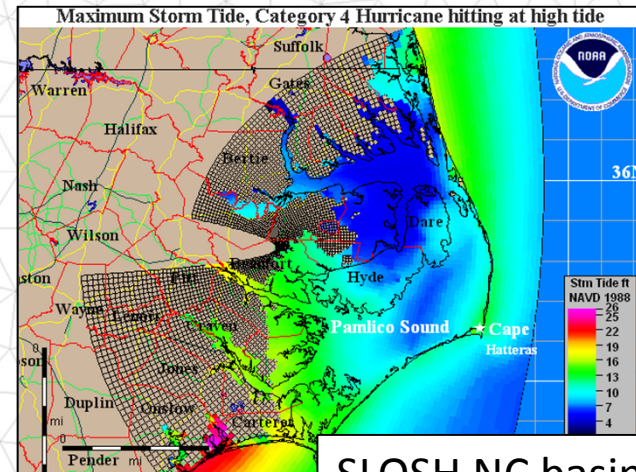
Main Point

Critical need for detailed hazard and risk estimation information

Unstructured grid models can provide very detailed assessments

Unstructured model spatial grids can greatly complicate information dissemination and end-user usage

Many non-federal/research modeling efforts can be leveraged

But NOT without community standards

ADCIRC Forecasting Systems

Distributed geographically:

- There are currently 5-6 ADCIRC-based forecast systems running for the US East and Gulf of Mexico coasts.

- Typically from Adcirc Surge Guidance System (ASGS, J. Fleming)

- Output files are large and distributed across academic and federal data centers

Event-based:

- Usually run for tropical cyclone events

How can we provide *uniform* access to
  - different ASGS system outputs
  - run by different groups
  - on different ADCIRC grids

ASGS UND

ASGS CUNY

NOAA ADCIRC

ASGS NC

ASGS LSU

ASGS UTexas
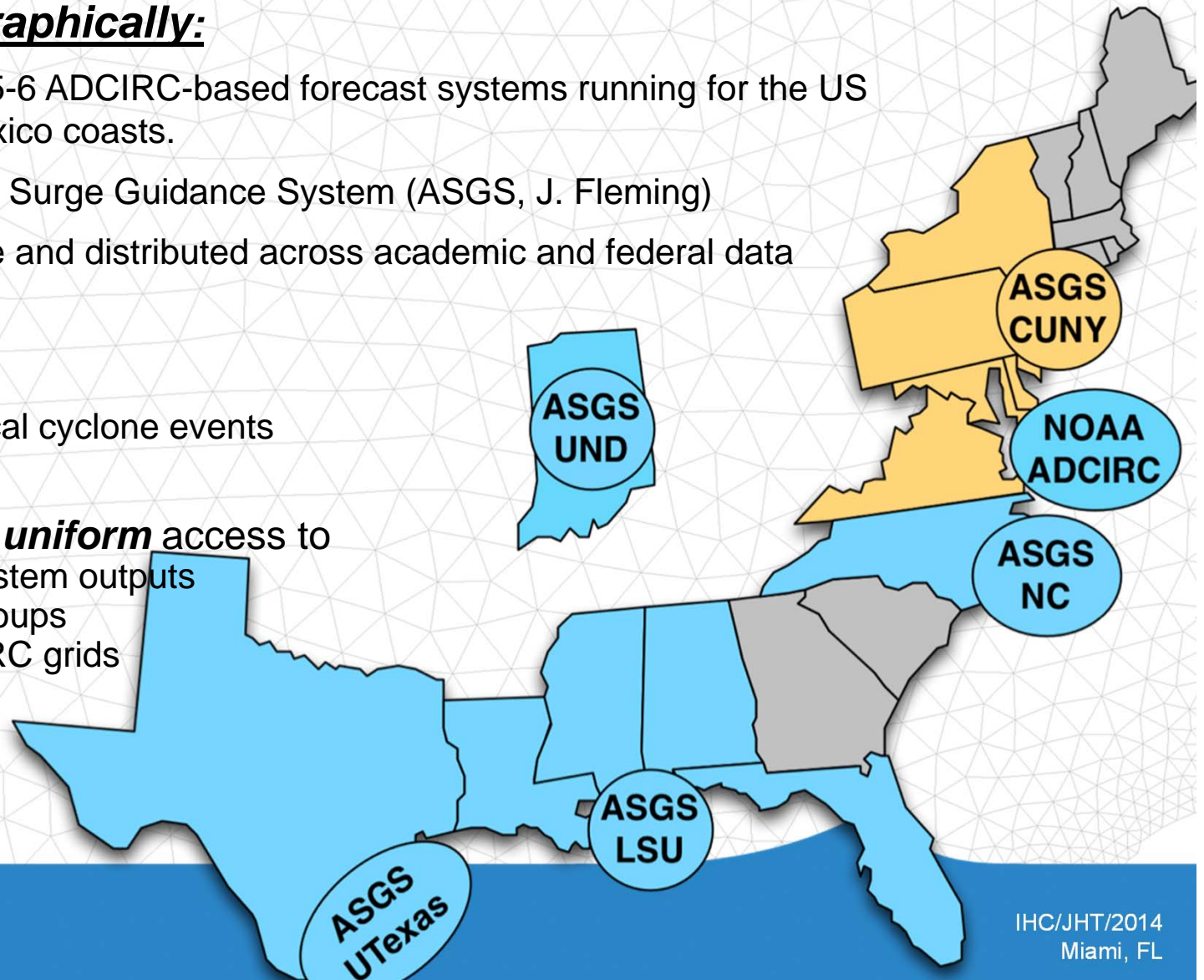
Use Case: Development Driver

What does ADCIRC say about this?

Is there a way to get ADCIRC results without dealing with the grid?

Forecaster

JHT-funded project to address this

- Develop methods that allow Operations to access Research results

- Methods must be robust, stable, and easy to use

- Minimal bandwidth usage

- R→O

- And

- O→ R

AdcircViz Development

- Application needs to:
  - Provide unified view of operating ADCIRC forecast system outputs
  - Allow user-driven data analysis
  - Allow user control of visualization
  - Keep data transfer to a minimum

- ***Embrace many models by requiring conformance to community standards and conventions***

- FVCOM, SELFE
- ADCIRC
- SLOSH
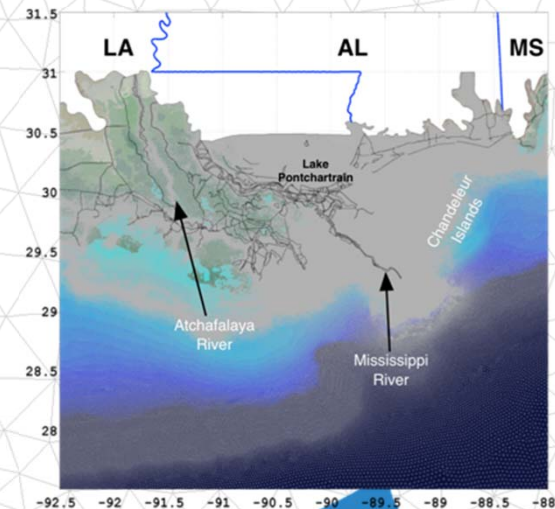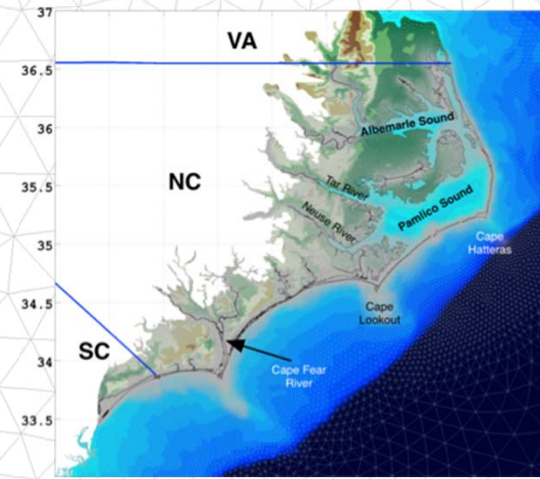
Standardization: a catalyst for innovation[*]

Need	Technology	Maintainer
Data and Metadata	netCDF4 files	Unidata
	CF with UGRID (0.9.0) extensions for non-rectangular grids	Community
Discovery	THREDDS Data Servers	Unidata
Access	OPeNDAP	OPeNDAP.org
	NCTOOLBOX in MATLAB	Community

AdcircViz

[*] Knut Blind, Rotterdam School of Management, Erasmus Univ., 2009

Essential CF-UGRID Components

NetCDF Climate and Forecast (CF) Metadata Conventions

UGRID = unstructured grid extension

Unstructured grids don't have simple parametric descriptions

Complete grid description contained in EACH netCDF file

```
dimensions:        // Triangles
    node = 185409
    nele = 369032
    nvertex = 3


variables:  // Mesh topology and node coordinates
    int adcirc_mesh(mesh)
        adcirc_mesh:long_name = "mesh_topology"
        ...

    int element(nele, nvertex)
        element:long_name = "element"
        ...

    double x(node)
        x:long_name = "longitude"
        x:units = "degrees_east"
        ...

    double y(node)
        y:long_name = "latitude"
        y:units = "degrees_north"
        ...
```
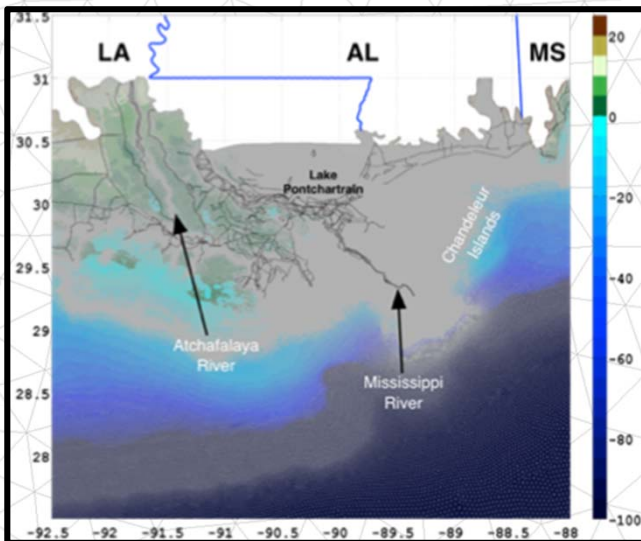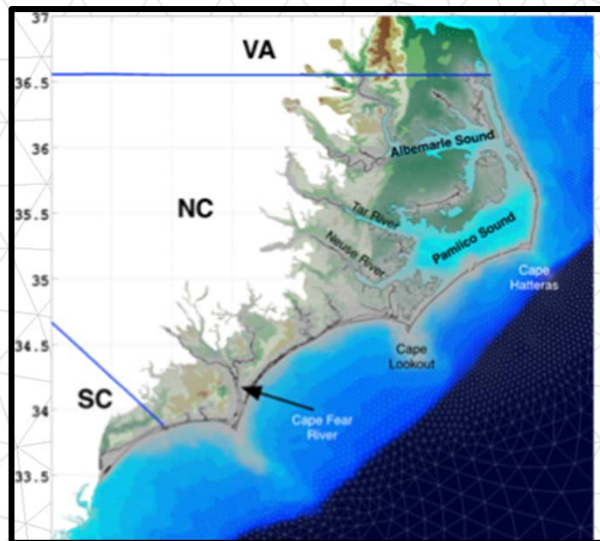
Which Grid?

Applications do not have to ask:

"Which ADCIRC grid was this solution
file computed on?"

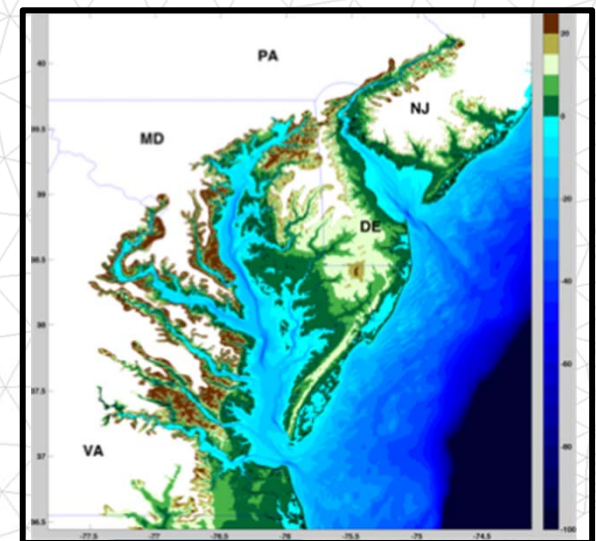Grid extracted from each solution file when needed.

Southern Louisiana (3M nodes)   North Carolina (NCFS) 600K nodes   FEMA Region 3 (1.8M nodes)
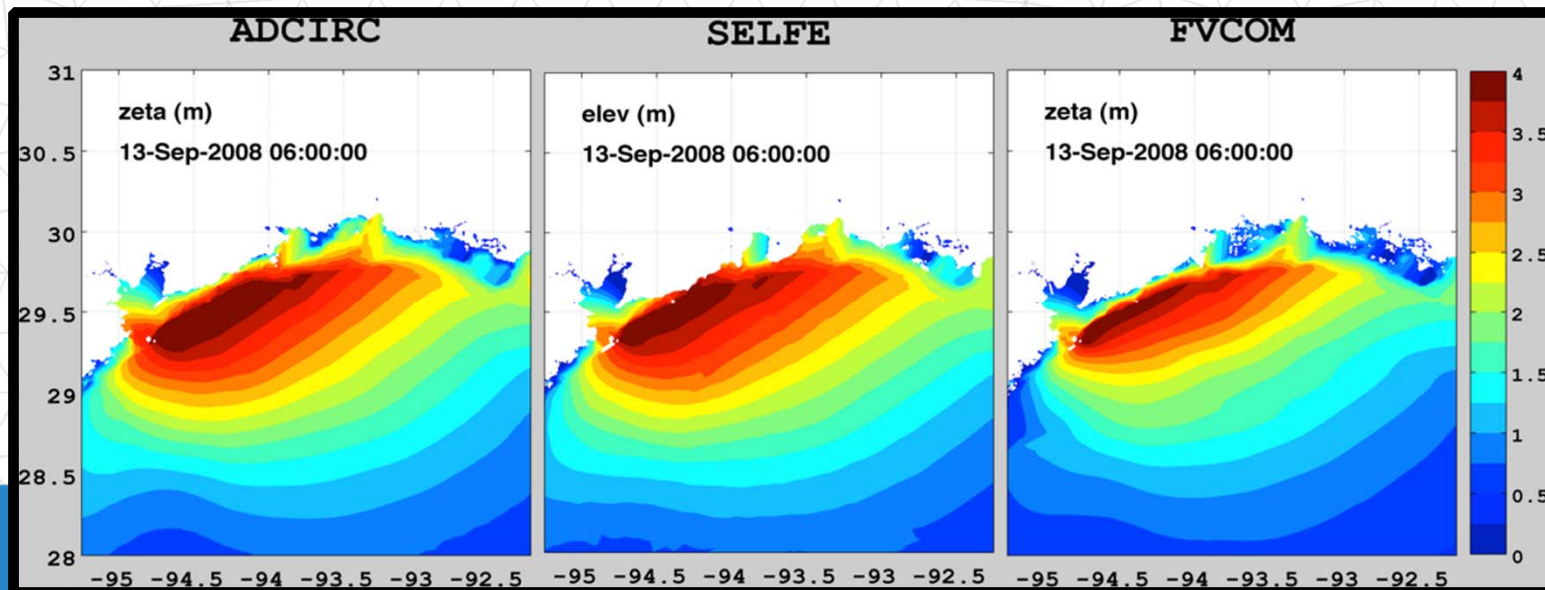
Essential Components

NCTOOLBOX: a MATLAB toolbox that provides access to common data model datasets

- NetCDF-Java as access layer
- NetCDF, OPeNDAP, HDF5, GRIB, GRIB2

Any UGRID-compliant model output can be handled by exactly the same method.

Example from NOAA IOOS Coastal Ocean Modeling Testbed

Hurricane Ike Hindcast
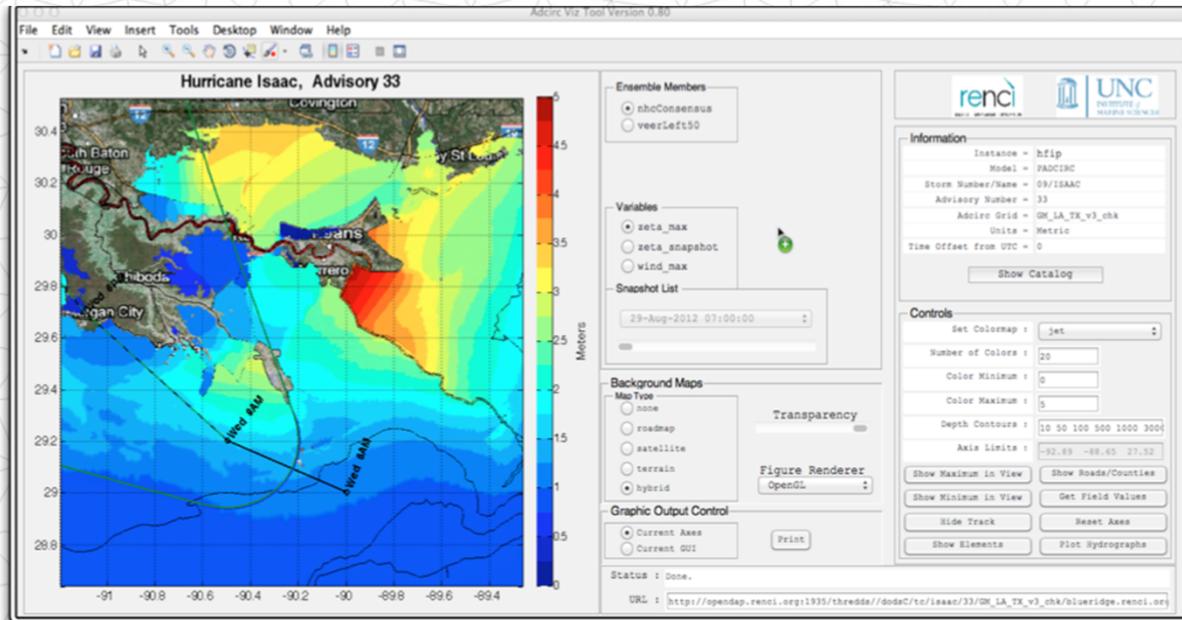
ADCIRC Data Collection

- Build a "data grid"
- Collection of THREDDS Data Servers

- Simple harvester aggregates THREDDS server content into master catalog
- Catalog replicated across sites

- Applications retrieve catalog to get available simulations and metadata
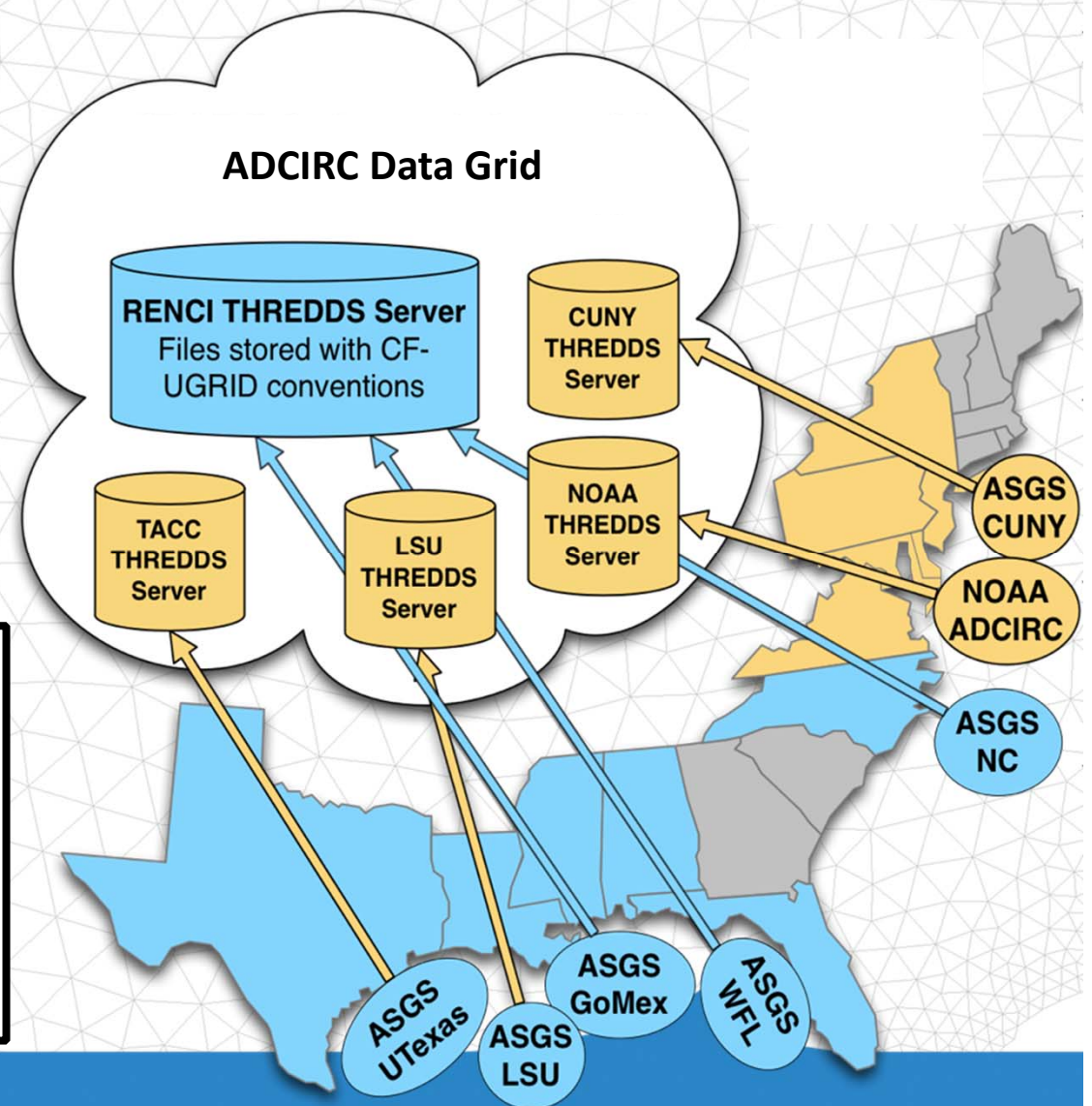
```
-------------------------------------------------------------------------------
Storms :  Advisories :        Grids         :      Machines       :  Instances
-------------------------------------------------------------------------------
   nam :  2013100100 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100112 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100200 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100212 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100200 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil : corpsbench
   nam :  2013100300 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100300 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil : corpsbench
   nam :  2013100318 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100400 :          nc6b         :   croatan.renci.org :    rentest
   nam :  2013100400 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil : corpsbench
 karen :          04 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          04 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          04 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          05 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          05 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          05 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          06 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          06 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          06 : sl15_2010_HSDRRS_2012_v9 : garnet.erdc.hpc.mil :  corpsmain
 karen :          07 : sl15_2010_HSDRRS_2012_v9 :   croatan.renci.org : corpsbackup2
 karen :          08 : sl15_2010_HSDRRS_2012_v9 :  hatteras.renci.org : corpsbackup3
 karen :          08 : sl15_2010_HSDRRS_2012_v9 :  hatteras.renci.org : corpsbackup3
```

ADCIRC Data Grid

RENCI THREDDS Server — Files stored with CF-UGRID conventions

CUNY THREDDS Server

NOAA THREDDS Server

TACC THREDDS Server

LSU THREDDS Server

ASGS CUNY

NOAA ADCIRC

ASGS NC

ASGS UTexas

ASGS LSU

ASGS GoMex

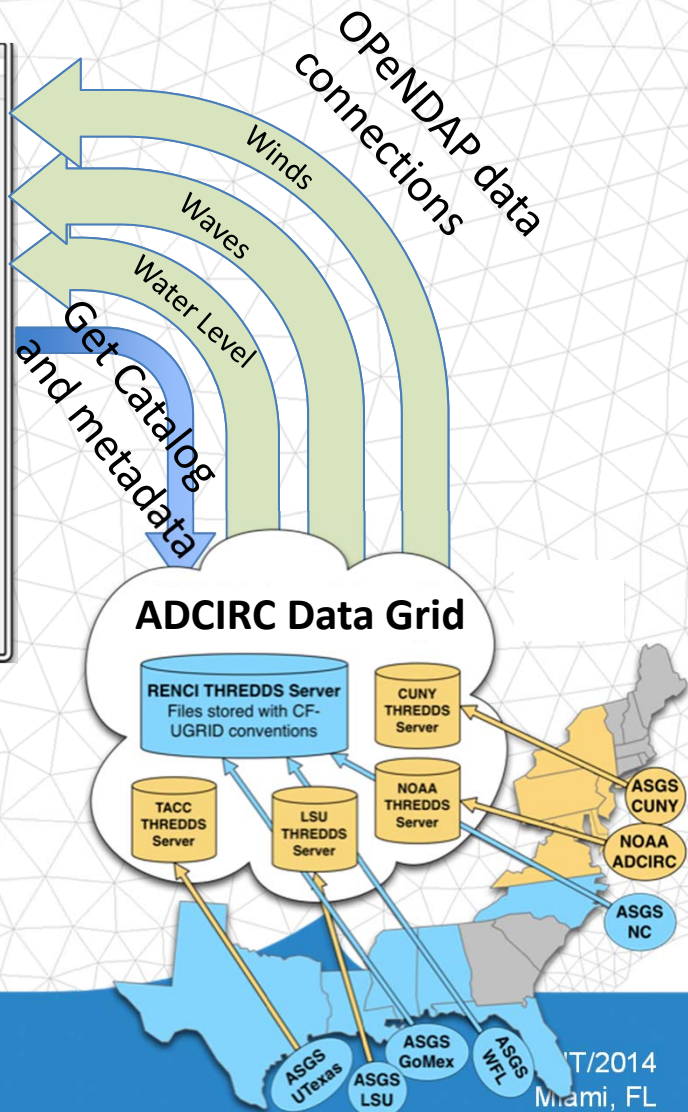ASGS WFL

AdcircViz App

Hurricane Isaac (2011)

MATLAB GUI populated by metadata in netCDF files

OPeNDAP, netCDF-Java
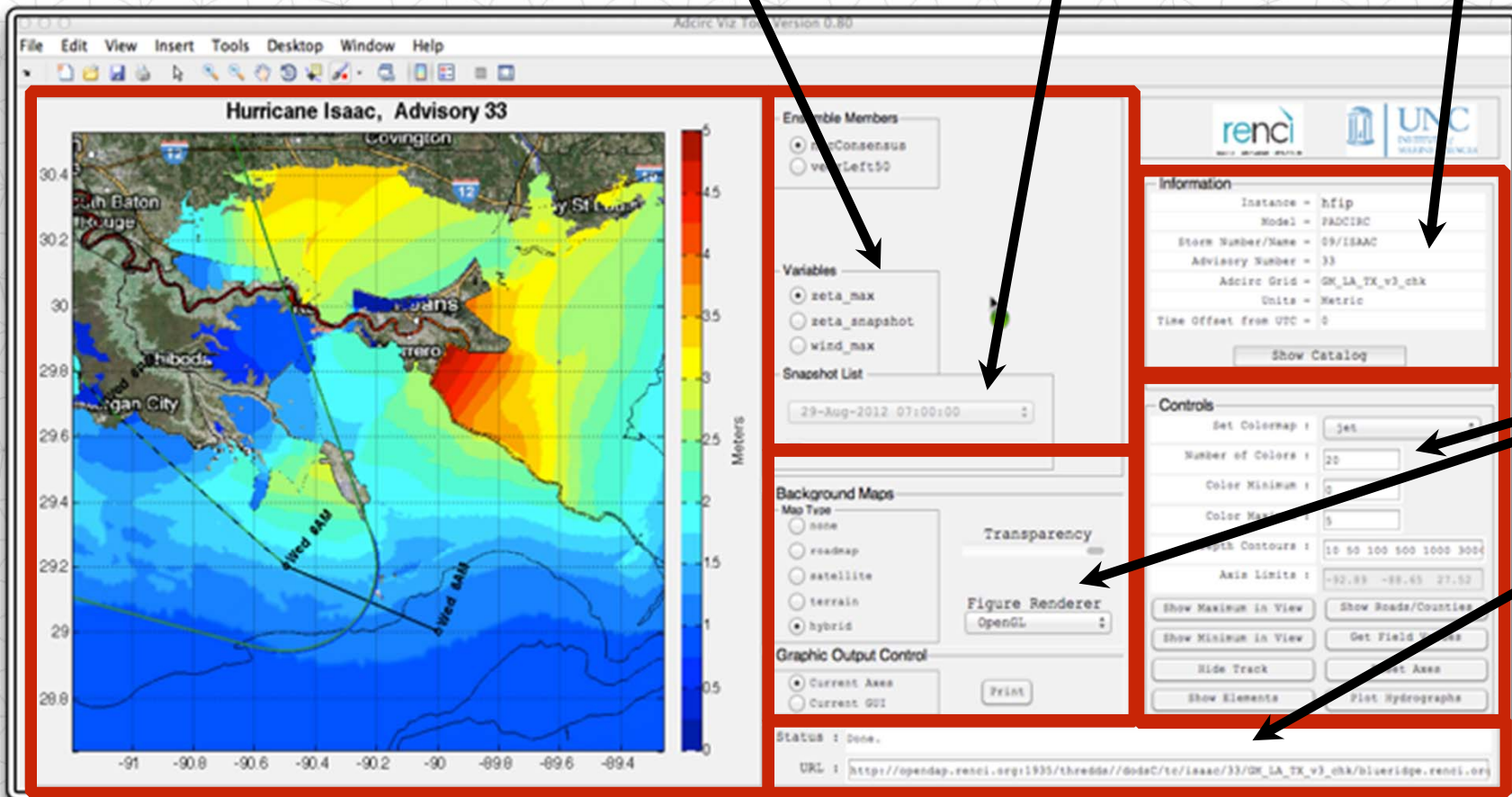
Only accesses data as it is needed

AdcircViz App

- Rapid development enabled by standards

Variable Selection   Animation Control   Simulation Details

Map/Viz
Controls

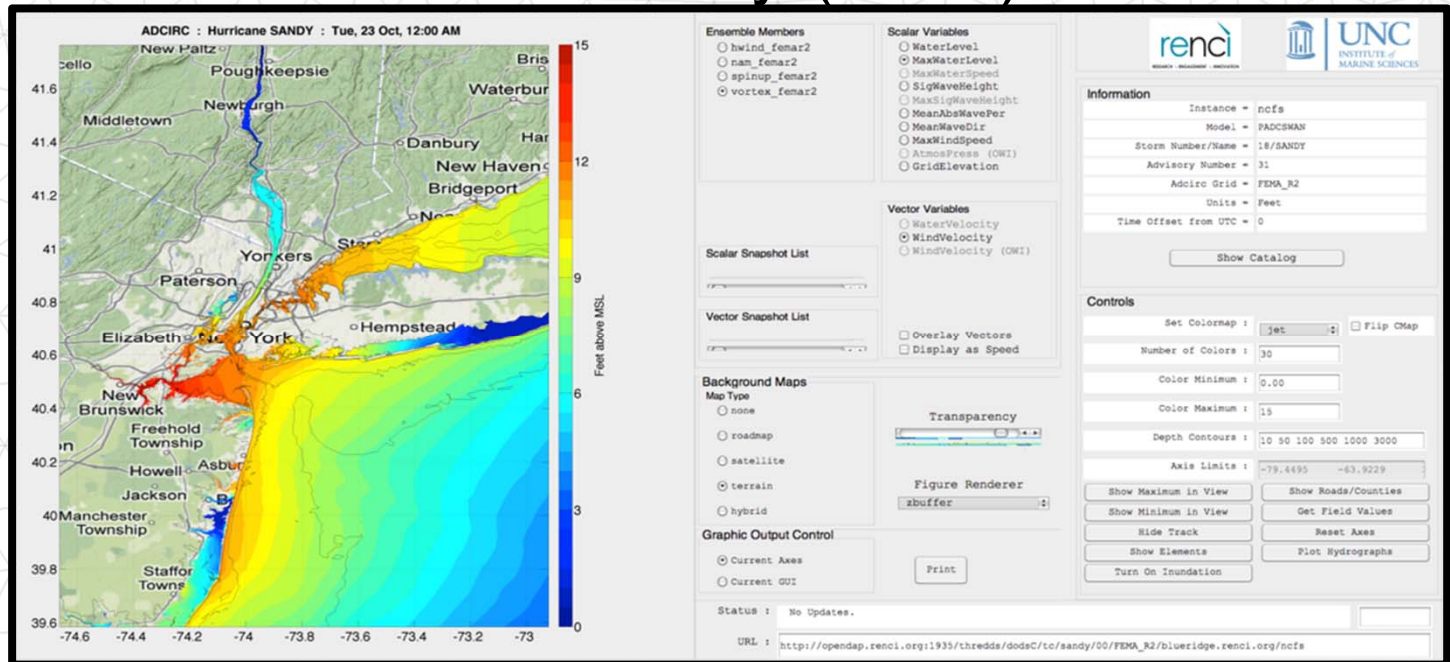OPeNDAP
URL

AdcircViz "Clients"
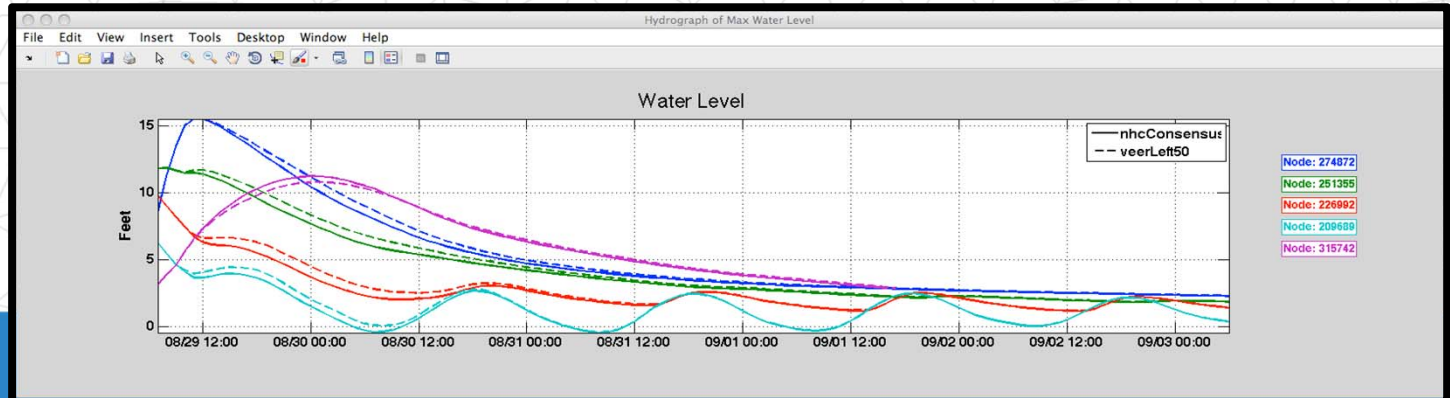
SS Sandy (2012)

Nat'l Hurr. Cen.

NOAA/CSDL

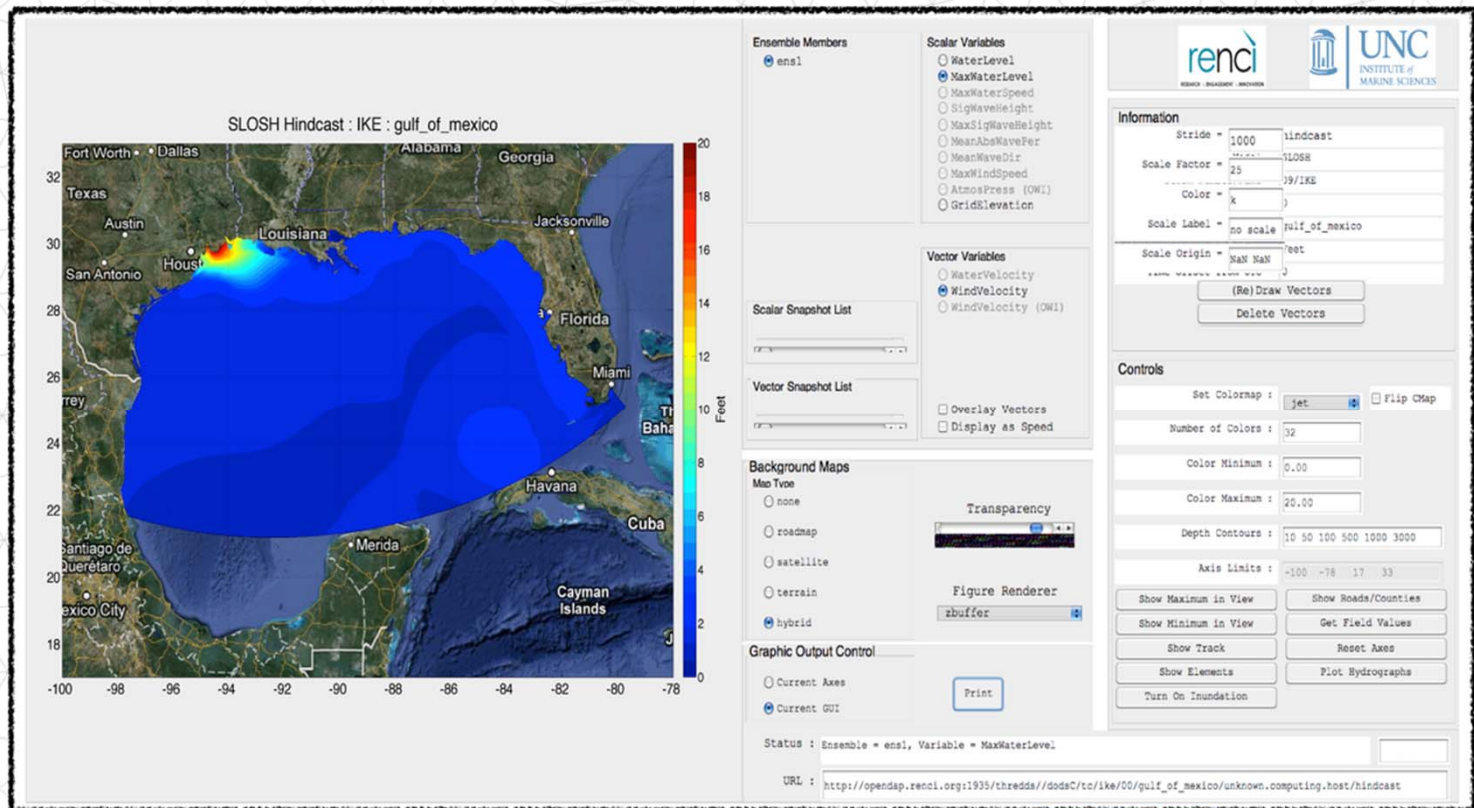US Coast Guard

USACE

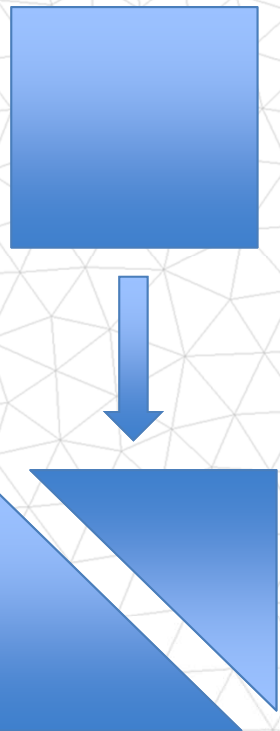Time Series for several locations

Mini-ensemble from ADCIRC

AdcircViz

Miami, FL

SLOSH in AdcircViz

- Any regular-grid can be trivially mapped to CF-UGRID.
- Makes available all of the existing finite element analysis tools

Data from NOAA IOOS Coastal Ocean Modeling Testbed

Tools being leveraged

unidata

- netCDF4
  - https://www.unidata.ucar.edu/software/netcdf/
- CF Conventions
  - https://www.unidata.ucar.edu/software/netcdf/workshops/2012/cf/index.html
- THREDDS Data Server
  - https://www.unidata.ucar.edu/software/thredds/current/tds/

Other Sources

- OPeNDAP
  - http://www.opendap.org/
- CF-UGRID Conventions
  - https://github.com/ugrid-conventions/ugrid-conventions
- NCTOOLBOX
  - https://github.com/nctoolbox/nctoolbox
- NOAA IOOS Coastal Ocean Modeling Testbed
  - http://www.ioos.noaa.gov/modeling/testbed.html

Final Thoughts

- ***Standards enable innovation***
  - ***Community standards and conventions are essential for "unifying" distributed efforts***
  - ***Rapid*** development of this application not possible without standards and conventions for data formats, metadata, and the community need for such "cyber-infrastructure"

- ***Community standards exist***
  - in coastal ocean modeling
    - NOAA IOOS Coastal Ocean Modeling Testbed
  - ... So USE them!
  - Leveraging Prior and Ongoing efforts, NCTOOLBOX, CF-UGRID, etc...

- Incorporation of rapid ***statistical simulations and ensemble methods*** into AdicrcViz
  - Rick Luettich's talk on Thursday

- **Funded by NOAA's Joint Hurricane Testbed (2013) Program**

Thank you very much

AdcircViz Code Management

http://brianoblanton.github.io/AdcircViz/

Code in GitHub
- Public repository
- Easy retrieval and updating of code
- Documentation will be available here

AdcircViz