Please Note: The following presentation was given at the May 24, 2016 DRBC Flood Advisory Committee meeting. Contents should not be published or re-posted in whole or in part without the permission of DRBC.
Delaware

- Delaware is extremely vulnerable to the impacts of coastal hazards.
  - Tropical systems and Nor’easters
  - Rain, surge, waves, inland flooding
  - Extreme Wind
  - Shoreline erosion
  - Sea-level rise
  - Tsunamis
Decadal Frequency of Tropical Systems 1871-2009

Only about 10% of all coastal storms near Delaware are tropical!

http://climate.udel.edu/research/delaware-coastal-storm-climatology
### Risk Ranking of Hazards in Delaware

#### Table 4.2-47
Overall Risk Ranking for the State of Delaware by County and Statewide

<table>
<thead>
<tr>
<th>Hazard Ranking</th>
<th>New Castle County</th>
<th>Kent County</th>
<th>Sussex County</th>
<th>Statewide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flood</td>
<td>Flood</td>
<td>Flood</td>
<td>Flood</td>
</tr>
<tr>
<td>2</td>
<td>Hurricane Wind</td>
<td>Drought</td>
<td>Drought</td>
<td>Winter Storm</td>
</tr>
<tr>
<td>3</td>
<td>Winter Storm</td>
<td>Winter Storm</td>
<td>Winter Storm</td>
<td>Thunderstorm</td>
</tr>
<tr>
<td>4</td>
<td>Earthquake</td>
<td>Thunderstorm</td>
<td>Thunderstorm</td>
<td>Hurricane Wind</td>
</tr>
<tr>
<td>5</td>
<td>Drought</td>
<td>Extreme Heat/Cold</td>
<td>Extreme Heat/Cold</td>
<td>Extreme Heat/Cold</td>
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<tr>
<td>6</td>
<td>Thunderstorm</td>
<td>Earthquake</td>
<td>Earthquake</td>
<td>Drought</td>
</tr>
<tr>
<td>7</td>
<td>Extreme Temperature</td>
<td>Tornado</td>
<td>Tornado</td>
<td>Tornado</td>
</tr>
<tr>
<td>8</td>
<td>Tornado</td>
<td>Hurricane Wind</td>
<td>Hurricane Wind</td>
<td>Hail</td>
</tr>
<tr>
<td>9</td>
<td>None</td>
<td>Hail</td>
<td>Hail</td>
<td>Wildfire</td>
</tr>
<tr>
<td>10</td>
<td>Hail</td>
<td>Wildfire</td>
<td>Wildfire</td>
<td>Tsunami</td>
</tr>
<tr>
<td>11</td>
<td>Wildfire</td>
<td>Coastal Erosion</td>
<td>Coastal Erosion</td>
<td>Earthquake</td>
</tr>
<tr>
<td>Unranked</td>
<td>Coastal Erosion</td>
<td>Dam/Levee Failure</td>
<td>Dam/Levee Failure</td>
<td>Coastal Erosion</td>
</tr>
<tr>
<td>Unranked</td>
<td>Dam/Levee Failure</td>
<td>Tsunami</td>
<td>Tsunami</td>
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</tr>
<tr>
<td>Unranked</td>
<td>Tsunami</td>
<td>Volcano</td>
<td>Volcano</td>
<td>Volcano</td>
</tr>
<tr>
<td>Unranked</td>
<td>Volcano</td>
<td>Terrorism</td>
<td>Terrorism</td>
<td>Terrorism</td>
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<tr>
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<td>Terrorism</td>
<td>HazMat Incident</td>
<td>HazMat Incident</td>
<td>HazMat Incident</td>
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<tr>
<td>Unranked</td>
<td>HazMat Incident</td>
<td>Pipeline Failure</td>
<td>Pipeline Failure</td>
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</tr>
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<td>Pipeline Failure</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Delaware is very well monitored!
Satellites:
- GOES - East
- MODIS Terra & Aqua
- NPP/JPSS
- NOAA – 16, 18, 19
- MetOP

Products:
- Channel data
- SST/LST
- NDVI
- Chlorophyll
- CO2
- Cloud Pressure
- Cloudtop Temp
- Water Vapor
- Pressure/Heights

Products vary in…
- Resolution: 250m – 4km
- Frequency: 15 min – 4x daily
- Holdings: past week - 2010

http://udsrs.udel.edu
DGS, DEOS/Office of State Climatologist staff serve in the DEMA EOC during extreme events.

- Tropical systems
- Nor’easters
- Wind, precip, ice/snow
- Stream flooding
- Storm surge
- Evacuations
- Road and bridge closures

Participate on Statewide “bridge calls” and provide briefings.
Development of the Delaware Coastal Flood Monitoring System...

Delaware CFMS team:
John Callahan (DGS)

Kevin Brinson, Daniel Leathers (Delaware Environmental Observing System)

Tina Callahan (Delaware Environmental Monitoring and Analysis Center)
Mother’s Day Storm

- May 12th, 2008 Nor’easter and astronomically high tides caused significant coastal flooding
- Evacuations at Slaughter Beach, Kitts Hummock, Bowers Beach, and Woodland Beach
Can we give people more time?

Can we better predict and inform people on where the flooding might occur and how bad it might be?
The Delaware Coastal Flood Monitoring System (CFMS) is a web-based tool and alert system designed to provide emergency managers, planners, and others the information needed regarding upcoming coastal flood events. Lewes and serves three potential flood conditions, and to provide local tidal.

This project was funded, in part, through grants from the Office of Ocean and Coastal Management Program (OCCM) and the Delaware National Estuarine Research Reserve (DNERR) with funding from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration (NOAA) under award numbers NA06NOS4190172, NA10NOS4200185, and NA13NOS4190093.

http://coastal-flood.udel.edu
Bowers Beach - Water Level Forecast

Current model data:
-1.93 ft
Today, 4:00 pm

Maximum forecasted water level:
3.85 ft
05/23/2016 10:00 pm

MHHW: 2.75
MSL: 0.248
MLLW: -2.83

*All data relative to NAVD88
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Below are real-time observation stations for the two primary networks for real-time monitoring of tides: United States Geological Survey (USGS) and NOAA’s National Ocean Service (NOS). Click on a station map marker to display the latest weather and water level data.

**NOS: Lewes at Breakwater Harbor**

Nearest DEOS meteorological station:

- Humidity: 78%
- Wind: ENE at 3 mph
- Baro: Pressure: 1012.6 mbar
- Updated: 2016/09/23 12:25 UTC

Tidal station graph:

Source: [http://tidesandcurrents.noaa.gov/geo.shtml?location=8557380](http://tidesandcurrents.noaa.gov/geo.shtml?location=8557380)
Precipitation Forecasts

The NWS Mid-Atlantic River Forecast Center (MARFC) makes forecasts on total rain accumulation over the next few days. Below are the latest model runs for the next 72 hours in the Delaware region.

Day 1 Total | Day 2 Total | 3 Day Total Accumulation
---|---|---

More information on NWS MARFC: [http://www.weather.gov/marfc/Precipitation_Forecasts](http://www.weather.gov/marfc/Precipitation_Forecasts)

NWS Modeled Wind Forecasts

The NWS makes forecasts on winds and other meteorological variables available from the National Digital Forecast Database (NDFD). Below are the latest model runs for current wind gusts and sustained winds.
Input - DBOFS Forecast

- 48-hour forecast
- 4xdaily, hourly output
- 100m – 3km grid cells
- $119 \times 732 \times 10$
- ROMS hydro model
- Winds: NAM-12, then GFS
- Nowcast mode: CO-OPS and USGS observations
- Forecast mode: ET-Surge and Nowcast output for boundary/initial conditions
Coastal Community Coverage

- 15 communities between cities of New Castle and Lewes

- Each community has:
  - Configurable alerts
  - Inundation maps
  - Road profiles
  - Tidal parameters
Each subscriber sets a critical level to be notified. If that level is reached, at any time within the 48 hour forecast (adjustable), an alert is sent via text and email.

Intended use: Let emergency managers know they need to begin keeping an eye on tide gages and possibly begin preparations for any potential flooding.
Delaware CFMS

- Current site released in early 2013. Education and training workshops conducted as needed.

- Overall, very positive response from locals. In use during coastal events by numerous state and county agencies.

- Maps do well with highlighting problem areas and with magnitude.
  - Not so well in DE Inland Bays

- 48 hour lead time seems to be sufficient.
Demonstration

http://coastal-flood.udel.edu
Related Ongoing Work...

- Historical Analysis
  - Coastal Storm Climatology
  - Stream and Tide “Storm Books”
  - High Water Mark database and website
  - Changes in Nuisance and Extreme flooding

- Predictive (to be integrated into the CFMS)
  - Delaware Bay Model Validation Analysis
  - Inland Bays Tidal and Storm Surge Prediction
  - Coastal Storm Severity Index (CSSI)
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1. Tidal and Storm Surge Relationships in Delaware Inland Bays

- Important to Delaware’s economy (recreation, fishing, tourism), natural habitat (white cedar swamp, fish, waterfowl), migratory birds, ecosystem services (filtering nutrients)...

- However, they are poorly flushed (slight changes can upset the balance), heavily developed, extremely vulnerable to coastal flooding
# Top Observed Storm Tides - DE Inland Bays

<table>
<thead>
<tr>
<th>Lewes</th>
<th>WL (ft)</th>
<th>IRB Inlet</th>
<th>WL (ft)</th>
<th>Rosedale</th>
<th>WL (ft)</th>
<th>Rehoboth</th>
<th>WL (ft)</th>
<th>S.Bethany</th>
<th>WL (ft)</th>
<th>FenwickIsl</th>
<th>WL (ft)</th>
<th>OceanCity</th>
<th>WL (ft)</th>
</tr>
</thead>
</table>

**Notable Storms**
- 10/29/2012 – Sandy
- 11/13/2009 – Nor’Ida
- 5/12/2008 – Mother’s Day
- 1/28/1998 – Nor’easter
- 2/5/1998 – Nor’easter
- 9/19/2003 – Isabel
Inland Bays Tidal Datums (NAVD88)

Based over 14 year period, 5/1/2000 - 4/30/2014 (John Callahan, DGS/UD, unpublished)
Storm Tide Prediction

- Prediction (using multiple regression) at four inland USGS gauges (as pilot project)
- High tides only for 2013
- Statistical relationship of ocean-side tides/surge to Inland Bays coastal regions
  - Input: WL at Inlet, Lewes, and Ocean City
  - Input: Precip (1, 3, 6, 12 hrs) and Wind (1, 3, 6 hrs)
- Correlations: R² from ~ 0.83 - 0.98
- 3-9 predictors, different for each wind direction and tide gauge
- Installed new water level sensors, each sensor near a flood-prone community
- Analysis of storm tides and storm surge (i.e., non-tidal residuals) ongoing
- Real-time application of early warning system (integrated into CFMS) in near future
2. Coastal Storm Severity Index (CSSI)

- Storm severity is usually classified based on a storm-centric view
  - Saffir-Simpson Hurricane Scale, 1-5
  - Enhanced Fujita Tornado Scale, 0-5
  - Numeric values of peak wind, precip, surge, etc...

- However, how about we take an impact-centric or community-centric approach?
Forecasts of meteorological parameters, combined with high resolution GIS data to determine local impact ratings for at least four storm effects...

Model forecasts of precipitation, winds, surge, and stream flow.

Hi-res GIS data... land-use, elevation, population, distance to waterway

Coastal Storm (Date) 
????? RISK Storm For Location

<table>
<thead>
<tr>
<th>Surge</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Flooding</td>
</tr>
</tbody>
</table>
Example: Consider a coastal location, no streams, sub-urban with a coastal storm with moderate winds, large surge and moderate precipitation.
Nor’easter
Feb 4-6, 1998
Hurricane Irene
Aug 24-30, 2011
Status of CSSI


- Working with Office of New Jersey State Climatologist

- Development of the CSSI is ongoing. Currently investigating intensity measures/ranking systems for each category

- Ultimately to be integrated into Delaware CFMS
Thank You!

John Callahan
Delaware Geological Survey
john.callahan@udel.edu

Kevin Brinson, Daniel Leathers, and Tina Callahan
DEOS/DEMAC/ODSC

http://coastal-flood.udel.edu

Special Thanks!