Role of Storm Surge in COASTAL Act; Storm Surge Model Development at NOS

Nicole P. Kurkowski (NWS), Mike Bilder (NWS)
Sergey Vinogradov (NOS), Edward Myers (NOS), Saeed Moghimi (UCAR), Yuji Funakoshi (UCAR), Jaime Calzada (ERT)

Hurricane Forecast Improvement Program Annual Review Meeting
November 9 2017
Miami, FL
On July 6, 2012, the President signed the Federal highway conference bill, which included legislation known as the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act.

Intended to lower costs to the National Flood Insurance Program (NFIP) – managed by FEMA – by improving the determination of wind vs. water damage in cases of “indeterminate losses” (or “slab cases”).

A loss is indeterminate when little tangible evidence beyond a building’s foundation remains for the proper adjustment of insurance claims for homes totally destroyed by a tropical system (water damage is covered by NFIP; wind damage is covered by private insurers).

This will enable a more timely claims adjustment process, which has frequently faced excessive delays due to litigation between the Federal government and private insurers.
The COASTAL Act requires NOAA to produce detailed “post-storm assessments” following certain named tropical systems that impact the U.S. and its territories.

- The assessments will be produced using a new NOAA hindcast model that indicates the strength and timing of damaging winds and water at a given location in the impact area.
- The assessments must be submitted to FEMA within 90 days after DHS and NOAA deem a storm “reasonably constitutes a threat.”
- NOAA is required to make post-storm assessment results and obs from the storm available to the public via a new online database.

The post-storm assessment output (assuming it meets 90% accuracy at the location in question) will then be incorporated in the COASTAL Formula (managed by FEMA). The formula will consider other non-geophysical data (e.g. structure data) to determine the extent to which water vs. wind contributed to the destruction (thereby determining the cost responsibility between NFIP and private home insurers).
Agency Responsibilities

• NOAA Deliverables:
  – Data collection plan (the COASTAL Act Capabilities Development Plan or CACDP)
  – Data collection protocol
  – Coastal Wind and Water Event Database (CWWED)
  – Named Storm Event Model (NSEM)

• GAO must audit NOAA’s data collection efforts, including the cost-effectiveness of the approach

• FEMA must develop the COASTAL Formula and NAS will evaluate the formula’s effectiveness.
COASTAL Act Process

Observations (Wind, Water Level, Wave, Precip, etc)

Wind & Pressure Analysis (HWRF, URMA/RTMA, downscaling)

Water Level & Wave Analysis (WAVEWATCHIII / ADCIRC)

Validated NSEM Output (Post-storm Assessments)

CWWED

*N*Precip & Hydrological Products (NWM)

User (FEMA, industry, public, …)

*Note: FY17 funds enable hydrological component of NSEM to be addressed (new sub-project #10)*

FY16/17 funding activities
Summary

• Towards Integral Water Level Prediction
• Surge/Wave Coupling
  – NUOPC Layer
  – NEMS Infrastructure
  – ADCIRC modifications
  – COASTAL Act experiments
• Compound Flooding
• Assimilation of Coastal Water Levels
• Operational Forecast and Hindcast Model Skill Assessment
Requirements identified in NOAA’s Storm Surge Roadmap to provide coastal inundation model guidance for US Territories

- ESTOFS - Extra-Tropical: continuous forecasts
- HSOFS - Hurricane (Tropical): on-demand ensemble forecasts, post-event hindcasts
## Storm Surge Model Guidance Systems

<table>
<thead>
<tr>
<th>Component</th>
<th>ESTOFS-ATL</th>
<th>ESTOFS-PAC</th>
<th>ESTOFS-MIC</th>
<th>HSOFS-ATL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid resolution</td>
<td>160+ m (V2)</td>
<td>2+ km</td>
<td>500+ m</td>
<td>160+ m</td>
</tr>
<tr>
<td>Forcing</td>
<td>GFS</td>
<td>GFS</td>
<td>GFS</td>
<td>TRACK</td>
</tr>
<tr>
<td>Ensembles</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Forecast frequency/ Forecast horizon</td>
<td>4/day 180 hrs</td>
<td>4/day 180 hrs</td>
<td>4/day 180 hrs</td>
<td>On demand</td>
</tr>
<tr>
<td>Inland flooding</td>
<td>Yes (V2)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
ESTOFS – Atlantic

In operation since 2012

**Major Upgrade (April 24 2017)**
- Covers US East and Gulf Coast + Caribbean
- HSOFS grid + inland flooding
- 200 m coastal resolution
- 1.8M nodes
- GFS 13-km forcing

Cycles 00z, 06z, 12z and 18z
6-hr nowcast + 180-hr forecast

- Provides live boundary conditions for **Nearshore Wave Prediction System (NWPS)**
- 6-min water levels at 128 coastal tide gauges
- Hourly water levels for the whole domain
In operation since 2014

- Covers US West Coast + Hawaii
- 1-3 km coastal resolution
- 132K nodes
- No inland flooding
- GFS 55-km forcing

Cycles 00z, 06z, 12z and 18z
6-hr nowcast + 180-hr forecast

- Provides live boundary conditions for Nearshore Wave Prediction System (NWPS)
- 6-min water levels at 71 coastal tide gauges
- Hourly water levels for the whole domain

Future upgrades will include
- Increase forcing resolution to 13km
- Update model grid
Covers Palau, Mariana Islands, Fed State of Micronesia, Marshall Islands, Wake Island
- Up to 200 m coastal resolution
- Overland up to 10m elevation
- Implementation planned for September 2017

GFS 13-km forcing
- 24-hr nowcast + 180-hr forecast
- Will provide live boundary conditions for regional wave models
- Water levels at 4 CO-OPS tide gauges and 40+ populated islands and warning points
Hurricane Surge On-Demand Forecasting System (HSOFS)

- Implemented for ESTOFS-ATL domain
- 2-year testing phase with NWS National Hurricane Center
- Augments existing SLOSH/P-Surge capabilities with a high-fidelity estimates near landfall, or in post-event hindcasts
- Provides uncertainty estimates of NHC Best Track product

### 5 ensemble members
- NHC Track + 20% Higher Max Wind Speed + 20% Lower Overland Speed + 100% Shift Left of the Uncertainty Cone + 100% Shift Right of the Uncertainty Cone.

**2008 Ike: observed and modeled high water marks**

**2016 Hermine:**

**Ensemble Tracks + Ens. Max of Peak Flood**

**Ens. Water Levels Forecasts at Cedar Key, FL**
On-Demand Ensemble Modeling

@ 20170910 t00z experimental

HIWSPD
TRK
SLOWER

RIGHT

OBS: 1.66m MSL @23:06 GMT

GFS

Naples, Gulf of Mexico, FL

RIGHT

OBS
Total Water Level =

- Tides +
- Waves +
- Storm Surge +
- Freshwater Input +
- Steric Setup +
- Ocean Circulation +
- Sea Level Rise

- Wave setup, wave runup, wave breaking
- Wind-driven, pressure-driven setup
- River inflow, controlled release, precip, ...
- Local + remote seasonal density variations
- Mesoscale eddy intrusion, coastal jets
- Historical change in vertical datum

- Non-linear interactions between all major components
- Dynamical coupling required
- Model errors due to missing physics
- Model errors can be minimized by data assimilation
Surge/Wave Coupling

Framework

COASTAL (The Consumer Option for an Alternative System to Allocate Losses) Act
https://www.weather.gov/sti/coastalact

• Lower the cost to FEMA’s National Flood Insurance Program (NFIP)
• Better distinguish between wind- and water damage
• For every named storm, provide the best possible reanalysis/hindcast

Technology:

*In leu* of NOAA’s Unified Modeling Approach, utilize

– the National Unified Operational Prediction Capability (NUOPC)
– couple ADCIRC and WaveWatch III
– Flexible mechanism for adding/changing/upgrading the coupled models/modules
– Independent dev cycles for coupled components
– Allows easier transition of the coupled systems into operations in the future

COASTAL Act Modeling Partners:
Andre van der Westhuysen, Ali Abdolali, Jessica Meixner, Anil Kumar, Zaizong Ma, ...
NUOPC Layer interoperability rules are implemented using a set of **generic components** that represent the major structural pieces needed to build coupled models.

### NUOPC Generic Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driver</strong></td>
<td>Harness that initializes components according to an <em>Initialization Phase Definition</em>, and drives their Run() methods according to a customizable run sequence.</td>
</tr>
<tr>
<td><strong>Connector</strong></td>
<td>Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>Wraps model code so it is suitable to be plugged into a generic Driver component.</td>
</tr>
<tr>
<td><strong>Mediator</strong></td>
<td>Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.</td>
</tr>
</tbody>
</table>

*Theurich et al. 2016*
## NOAA Environmental Modeling System (NEMS) Infrastructure

<table>
<thead>
<tr>
<th>ATM</th>
<th>atmosphere</th>
<th>GSM (Global Spectral Model), NMMB (Non-hydrostatic multiscale model on the B-grid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCN</td>
<td>ocean</td>
<td>MOM5 (Modular Ocean Model), HYCOM (Hybrid Coordinate Ocean Model)</td>
</tr>
<tr>
<td>WAV</td>
<td>wave</td>
<td>WWIII (WAVEWATCH III)</td>
</tr>
<tr>
<td>ICE</td>
<td>sea ice</td>
<td>CICE (Los Alamos Sea Ice Model), KISS (Keeping Ice's Simplicity)</td>
</tr>
<tr>
<td>HYD</td>
<td>hydrology</td>
<td>WRF-Hydro (Weather Research and Forecast Model Hydrology)</td>
</tr>
<tr>
<td>LND</td>
<td>land</td>
<td>LIS (Land Information System)</td>
</tr>
<tr>
<td>AER</td>
<td>aerosol or chemistry</td>
<td>GOCART (Goddard Chemistry Aerosol Radiation and Transport)</td>
</tr>
<tr>
<td>IPM</td>
<td>ionosphere plasmasphere</td>
<td>IPE (Ionosphere-Plasmasphere Electrodynamics Model)</td>
</tr>
<tr>
<td>CST</td>
<td>coast</td>
<td>ADCIRC (Advanced Circulation)</td>
</tr>
<tr>
<td>Application</td>
<td>ATM</td>
<td>OCN</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>CMAQ Air Quality</td>
<td>NMMB</td>
<td></td>
</tr>
<tr>
<td>Coastal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYCOM-GSM-CICE</td>
<td>GSM</td>
<td>HYCOM</td>
</tr>
<tr>
<td>Regional Hydro</td>
<td>GSM</td>
<td>MOM5</td>
</tr>
<tr>
<td>Regional Nest</td>
<td>NMMB</td>
<td>HYCOM</td>
</tr>
<tr>
<td>UGCS-Seasonal</td>
<td>GSM</td>
<td>MOM5</td>
</tr>
<tr>
<td>UGCS-Weather</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAM-IPE</td>
<td>GSM</td>
<td></td>
</tr>
<tr>
<td>Wave</td>
<td>GSM</td>
<td></td>
</tr>
</tbody>
</table>
NSEModel Application

Model components
- HWRF-HYCOM-DA
- ADCIRC
- WW3

NUOPC components

Driver:
- Model: ADCIRC
- Model: WW3
- Model: HWRF (data)
ADCIRC Modifications

[Code Snippet]

Hurricane Surge On-Demand Forecast System (HSOFS) grid coverage

New fort.15 variables:
- HWRF coupling: NWS=17
- WW3 coupling: NRS=5
Atmospheric Forcing

- IKE_HWRF_GFS05d_HSOFS
- IKE_HWRF_GFS05d_OC_DA_HSOFS
- IKE_HWRF_GFS05d_OC_HSOFS
- IKE_HWRF_GFS1d_HSOFS
- IKE_HWRF_GFS25d_HSOFS

- Downscaling
Hurricane 2008 Ike

Total surge + wave setup (detided)

IKE GFS05d_OC_Wav - Only tide
Surge [m]
Max. Val. = 4.9[m]
Hurricane 2008 Ike

Station: 8771510 at Galveston Pleasure Pier, TX

Station: 8770570 at Sabine Pass North, TX

Station: 8768094 at Calcasieu Pass, LA

Office of Coast Survey
Hurricane 2008 Ike

Total surge

Wave-setup
Hurricane 1992 Andrew

Total surge and wave setup (detided)

AND ATM&WAV2OCN HWRF - Only tide
Surge [m]
Max. Val. = 9.3[m]
Hurricane 2017 Irma

Total surge and wave setup (detided)

IRM ATM&WAV2OCN HWRF - Only tide
Surge [m]
Max. Val. = 5.7[m]
Compound Flooding

2017 Harvey:
- Freshwater flooding

Integrate with National Water Model to provide two-way coupling
- Precipitation + river inflow + surge upstream propagation
- Office of Water Prediction coordinating the effort
- Several solutions exist, need a feasibility study, e.g. model testbed
Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

- Modeled water levels are biased w.r.t observations
- Unresolved physics include seasonal steric signal, wind setup, HF weather events...
- Post-corrections do not properly reflect changes in inland flooding
- Initial water level offsets for a dynamically-consistent correction can be computed from the coastal observations

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![Graph showing water levels comparison](image-url)
Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

Start of the model hindcast/forecast

Time-mean setup = (WL OBS – Tides) = Initial correction wrt MSL
Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

Time mean WL setup at coastal tide gauges over the last 3 days.

polar.ncep.noaa.gov/estofs
Assimilation of Coastal Water Levels

Improving the Forecast – Linear biases and Data Assimilation

- ADCIRC v52 can now introduce spatially-varying WL offsets that are persistent throughout the whole period of model run
- This option is implemented as an additional ‘pseudo-pressure load’ term
- Offsets can vary with time
- Offsets need to be specified at each grid node
- User can manually add/remove/edit data points to improve the offset regionally
- Sparse data interpolation to unstructured grid
- Tapering offshore values to zero \( \sim f(\text{depth}) \)
- Tapering wrt data location
- Data assimilation of coastal WL observations
  - Can be applied to other kinds of data as well
- Will consider this option for all NOS OFS

Observed biases and interpolated surface Pre-2012 Sandy
**Assimilation of Coastal Water Levels**

**Improving the Forecast – Linear biases and Data Assimilation**

**RMSE improvement in hindcast water levels due to bias correction.**
Selected CO-OPS tide gauges Observed (green), predicted (blue) and modeled (black) water levels, meters MSL.
Operational Forecast and Hindcast Model Skill Assessment

Values of RMS errors, in meters, plotted at locations of CO-OPS tide gauges.

Values of variance in data that is explained by the model (a measure of coherence), in %, plotted at locations of CO-OPS tide gauges.
Operational Forecast and Hindcast Model Skill Assessment

Modeled peak surge vs HWM data, feet NAVD88. Dashed line is 1:1 fit. Shades of gray show areas of 0-10%, 10-20%, 20-30%, 30%+ errors.

Four areas corresponding to HWM data clusters have been selected and analyzed separately.
Operational Forecast and Hindcast Model Skill Assessment

Window of comparison

24 hrs OBS WL
-6 days forecast

-5 days forecast

nowcast model

model

model

model

model

model

model

model

model

data

Compute basic time series stats:

rmse, bias, peak, plag, rval, skill, varexp
Operational Forecast and Hindcast Model Skill Assessment

Skill of atm. forcing → Skill of ocean response

- Quantitative forcing inter-comparison
- Quantitative surge model inter-comparison
- Determining the applicability
- Determining the best lead times for on-demand applications

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