Using HPC to Inform Climate Change Policy Decisions

Paul Muzio  
paul/.muzio@csi.cuny.edu

Yauheni Dzedzits  
yauheni.dzedzits@csi.cuny.edu
ACKNOWLEDGEMENTS

The CUNY HPC Center acknowledges support from the following:

- NSF Grants 0855217, 0958379, 1126113
- City of New York
- New York State Regional Economic Development Grant
AGENDA

- Hurricane Sandy
  - Impact
  - Examples
- Bloomberg’s Special Initiative on Rebuilding and Resiliency (SIRR)
  - Key was not just rebuild, but to build to withstand future storms in an era of climate change (50 to 80 years out)
  - Update the FIRMs to include sea level rise “flood hazard analyses were conducted over NYC for future decades
    - Model storm surges using a hydrodynamic ocean model to simulate the dynamically-driven water flows
    - Closely reproduce FEMA flood hazard assessments for New York City (in Region 2) – 100-year, 500-year flood zone contours
    - Produce similar flood hazard assessments for future decades (2020s, 2050s, 2080s) with NPCC “high-end” (90th-percentile) estimates of sea level rise
    - Create contours of the 100- and 500-year flood zone boundary as GIS shape files for the future flood zones A and X
  - Planning document released – June 2013
  - Where to invest for the future
  - Additional studies
- Methodology
  - Model storm surges using a hydrodynamic ocean model
  - Validate by closely reproducing FEMA flood hazard assessments
  - Extend analyses by incorporating NPCC 90% percentile estimates of sea level rise for 2020, 2050, and 2080
- Computational issues
  - Grid modifications
  - Set-up (ramp-up time)
  - Number of runs
  - Computational resources required
  - Comparison of Cray XE6 (2.3 ghz magny-cours/Gemini interconnect vs 2.93 ghz nehalems/qdr
- Results
- Follow-on studies
  - Oyster beds off Staten Island
  - Jamaica Bay
The City University, the City, and the Environment
PlaNYC

- Community assessment

- New York City in 2030
  - Population growth from 8.3 million people to 9.5 million
  - Reduce carbon footprint to 30% below the 2007 level
  - Assess/minimize the impact of the City on the environment

- Recommendations/action plan to improve quality of life/economy

- Annual progress report

Hurricane Sandy

- Post-tropical cyclone
  - largest TC, 1800km
  - very low pressure

- Fatalities: 148 direct, 138 indirect

- 7,500,000 people without electric power

- Damage: $68 billion
  (2nd largest after Katrina)
Hurricane Sandy – New York City

• People and public safety
  – 44 people died in storm-related incidents

• Buildings
  – Nearly 20,000 buildings
  – Nearly 7,000 people occupied city shelters at peak occupancy

• Energy
  – 800,000+ customers lost power

• Telecommunications
  – Over 2 million telecom customers lost service
  – About 25,000 buildings in Sandy-inundation areas had damaged telecom equipment

• Waterfront and coastal
  – Over 2 million cubic yards of sand were lost from New York beaches, including 1.5 million cubic yards on the Rockaway peninsula alone
Hurricane Sandy – New York City

- **Public services**
  - More than 1,100 patients were evacuated from local hospitals
  - Schools closed for a week (1.1 million children)
  - Sewage treatment plants damaged/destroyed

- **Business and economic impact**
  - Direct/indirect losses amounted to $19 billion in damages
  - 94,000 businesses were inundated, lost power, or both
  - 890,000 employees worked at impacted businesses
  - Gasoline distribution disrupted

- **Transportation**
  - $10 billion in damage to transportation infrastructure
Hurricane Sandy

The subway line tracks to the Rockaways ($650 million in damage)
Hurricane Sandy

South Ferry Station ($800 million)
Hurricane Sandy

86th Street station
Hurricane Sandy

Over 80 homes were lost at Breezy Point to fires caused by downed power lines.
Hurricane Sandy

Manhattan blacked out (power plant explosion from salt water infiltration)
Flood Insurance Rate Maps (FIRMs)

- Federal Emergency Management Agency
- Pre-Sandy FIRM-R2 dated from 1983
- Updated FIRM-R2 released for comment in 2013
  - Did not include Sandy
  - Did not include projected impact of Sea Level Rise (SLR)
- Biggert-Waters Flood Insurance Reform Act (2012)
  - Required FEMA to develop recommendations on “future conditions mapping”

What could happen in the future?

Understanding the Risk: Prior to Sandy, FEMA’s maps had not been updated since 1983 and understated the risk in many areas

- Approximately 1/2 of all impacted residential units were outside 100-year floodplain
- More than 1/2 of all impacted buildings were outside 100-year floodplain

Source: FEMA and SIRR
Special Initiative on Rebuilding & Resiliency

- 2007 PlaNYC addressed (among other issues) the impact of the City on the environment

- SIRR adds the effect of the environment and climate change on the City
Special Initiative on Rebuilding and Resiliency (SIRR)

- Analyze what happened during and after Sandy and why
- What is the likely risk to NYC from climate change
  - In 2020, 2050, 2080
- Where to invest for the future:
  - Citywide infrastructure and buildings
  - Flood prone neighborhoods (including where to invest in de-investing)
- Produce “FIRM” equivalent maps to include SLR
  - One of the first studies to do so
SIRR

- Centered on the following key areas:
  - Coastal Protection
  - Built Environment
  - Insurance
  - Energy
    - Utilities
    - Liquid Fuels
  - Healthcare
  - Telecommunications
  - Transportation
  - Water and Wastewater
  - Solid Waste
  - Food Supply
  - Parks
SIRR FIRM Re-analysis to include SLR

• Account for effects of predicted climate change
  – Model storm surges using a hydrodynamic ocean model (ADCIRC/SWAN)
  – Validate by closely reproducing existing FEMA flood hazard assessments
  – Produce similar flood hazard assessments for future decades (2020s, 2050s, 2080s) with NPCC “high-end” (90th-percentile) estimates of sea level rise
  – Create contours of the 100- and 500-year flood zone boundary as GIS shape files for the future flood zones A and X
SIRR FIRM Re-analysis to include SLR

- **SIRR “FIRMs”:**
  - Simulated only a subset of storms causing over-land flooding in the NYC
  - ADCIRC/SWAN v.49
  - Typical runs used 256 cores on Cray XE6m system
    - ~4.5 hours for typical TC storm
    - ~8 hours for typical ETC storm
    - ~1.5 days for full tidal spin-up for each scenario
  - 2D field of maximal elevations (peak sea level during an event) -- MAXELE dataset.
  - Post-processing using MATLAB and FigureGen tools on separate large-memory SMP Linux machine
  - Semi-automated process (crontab + python + bash) for submitting jobs, data movement and post-processing
  - > 1000 runs to cover all scenarios
Numerical Models

• ADCIRC
  • Circulation model
  • Solves shallow water equations
  • Unstructured finite element mesh
  • http://adcirc.org/

• SWAN
  • Spectral wave model
  • Solves action density equation for non-stationary waves
  • Unstructured, curvilinear, or structured mesh
METIS Decomposition

Courtesy: Zach Cobell, ARCADIS-US
Coupled Simulation Schematic

Note: This is a single model run

Courtesy: Zach Cobell, ARCADIS-US
Model Communication

Courtesy: Zach Cobell, ARCADIS-US
Model Efficiency

![Diagram showing simulation, receive, send, and output stages over two cycles.](image)

Courtesy: Zach Cobell, ARCADIS-US
Model Efficiency

Courtesy: Zach Cobell, ARCADIS-US
Model Efficiency
Model Efficiency
SIRR FIRM Re-analysis to include SLR

- FEMA FIRMs based on:
  - 159 tropical cyclones (TC) and 60 extra-tropical cyclones (ETC)
  - 2D coupled modeling system ADCIRC/SWAN
  - 604,790 nodes (minimum resolution 70m)
  - Compared simulation results to historical record

- SIRR FIRM Re-analysis
  - Excluded storms that did not have overland flooding
  - 1,016 model runs that include tide-only spin-up runs and storm runs
    - base set (0 cm SLR, 2000’s epoch)
    - 31 cm SLR scenario (2020’s epoch)
    - 150 cm SLR scenario (2080’s epoch)
      - along with all required tidal spinups
  - SLR estimates of 11, 31 and 58 inches (90 percentile SLR estimates)
ADCIRC Benchmark

Nehalem (Andy) (2.93 GHz)+QDR

MagnyCours (Salk)(2.3 GHz)+Gemini

<table>
<thead>
<tr>
<th># of cores</th>
<th>Wall Time (seconds)</th>
<th>Wall Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ANDY 2.93 GHz Nehalem QDR Interconnect</td>
<td>SALK 2.3 GHz Magny-Cours Gemini Interconnect</td>
</tr>
<tr>
<td>32</td>
<td>162,600</td>
<td>211,740</td>
</tr>
<tr>
<td>64</td>
<td>85,440</td>
<td>79,980</td>
</tr>
<tr>
<td>128</td>
<td>41,880</td>
<td>36,290</td>
</tr>
<tr>
<td>256</td>
<td>20,640</td>
<td>16,221</td>
</tr>
<tr>
<td>512</td>
<td>NA</td>
<td>7,982</td>
</tr>
</tbody>
</table>
Results

Stevens: Orton, Vinogradov, Georgas, Blumberg
• SIRR identified risk zones in future.
• Additional studies:
  – Buy-out or rebuild
  – Rebuild dunes
  – Create artificial reefs to protect rebuilt dunes from waves
  – Shallowing of the Jamaica Bay
  – Other possible protective structures
Analysis of quick dune repairs on Staten Island

- **LL:** Showing areas of flooding
- **UR:** Hindcast with quick dune fix except area adjacent to Federal property
- **LR:** Sandy hindcast with full dune restoration

CSI/CUNY: Kress, Benimoff
Oyster bed reefs

- Evaluate the potential benefit of oyster bed reefs on wave height reduction
- UL – No reefs
- UR – With reefs
- LR – Estimate of wave height reduction
- http://www.rebuildbydesign.org/project/scape-landscape-architecture-architecture-final-proposal/

Stevens: Orton, Vinogradov, Georgas, Blumberg
References

- “Hydrodynamic Mapping of Future Coastal Flood Hazards for New York City”, N. Georgas et al., NJIT, 2013
- New York City Panel on Climate Change 2015 Report Chapter 4: Dynamic Coastal Flood Modeling
- “Redefinition of the Coastal Flood Hazard Zones in FEMA Region II: Analysis of the Coastal Storm Surge Flood Frequencies”, FEMA, Fairfax, VA.
- “Modeling and Simulation of Storm Surge on Staten Island to Understand Inundation Mitigation Strategies”, M. Kress et al., Journal of Coastal Research, 2015