

Valuing Ecosystem Services of Coastal Wetlands: Protection from Hurricane Storm Surge

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Resources for the Future

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Overview

Outline of talk:

- Ecosystem functions, services, values
- Storm surge and wetlands
- Reviewing the literature
- The Chesapeake Bay region
- Our methods:
  - Two approaches using ADCIRC+SWAN modeling, GIS, regressions, avoided damage calculations
- Results
- Next Steps

This work is related to our projects focused on properties of surge in the region, including field work (Ferreira team) and broader coastal resilience issues (Walls, Ferreira and other researchers).

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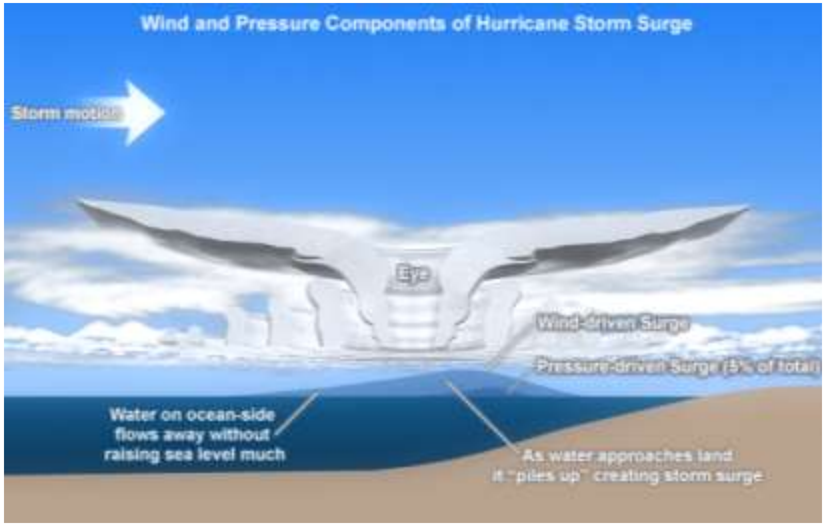
Ecosystem Functions & Services

- Natural lands in coastal areas perform a variety of ecosystem functions
  - e.g., carbon sequestration, habitat provision, fish nurseries, water purification, floodwater storage, storm surge attenuation
- These functions provide a set of services that has value to humans
- Protection from flooding associated with storm surge increasingly important
  - With climate change, these lands may increase in value
  - But at the same time, be under greater threat due to sea level rise

Storm Surge

- Surge is the abnormal rise of floodwaters generated by the wind and atmospheric pressure changes in a tropical storm



- Often responsible for largest damage and loss of life
- Several factors influence surge:
  - Storm intensity, size, forward speed
  - Width and slope of ocean bottom
  - Shape of coastline, topography
  - Land cover

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Storm Surge and Wetlands

- Wetlands attenuate surge by slowing its advance across the landscape and delaying arrival of water on the landward side

- USACE (1963) seminal study:
  - *Simple rule of thumb: surge heights reduced by, on average, 1m for every 14.5km of wetlands over which the surge travels*
- But range is large: 1m/5km – 1m/60km, depending on location and storm

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Storm Surge and Wetlands (cont.)

More recent studies:

- 1m/4km – 1m/25km (based on field measurements after Hurricane Rita, McGee et al. 2006)
- 1m/6km – 1m/25km (based on ADCIRC+SWAN modeling, coastal Louisiana, Wamsley *et al.* 2010)
- 5-40% reduction in surge depending on vegetation height, density and width (based on 3D modeling, Sheng *et al.* 2012)

These results mean that the value of the protective services of wetlands will vary by storm and by location

Value will also vary by the number & value of nearby properties

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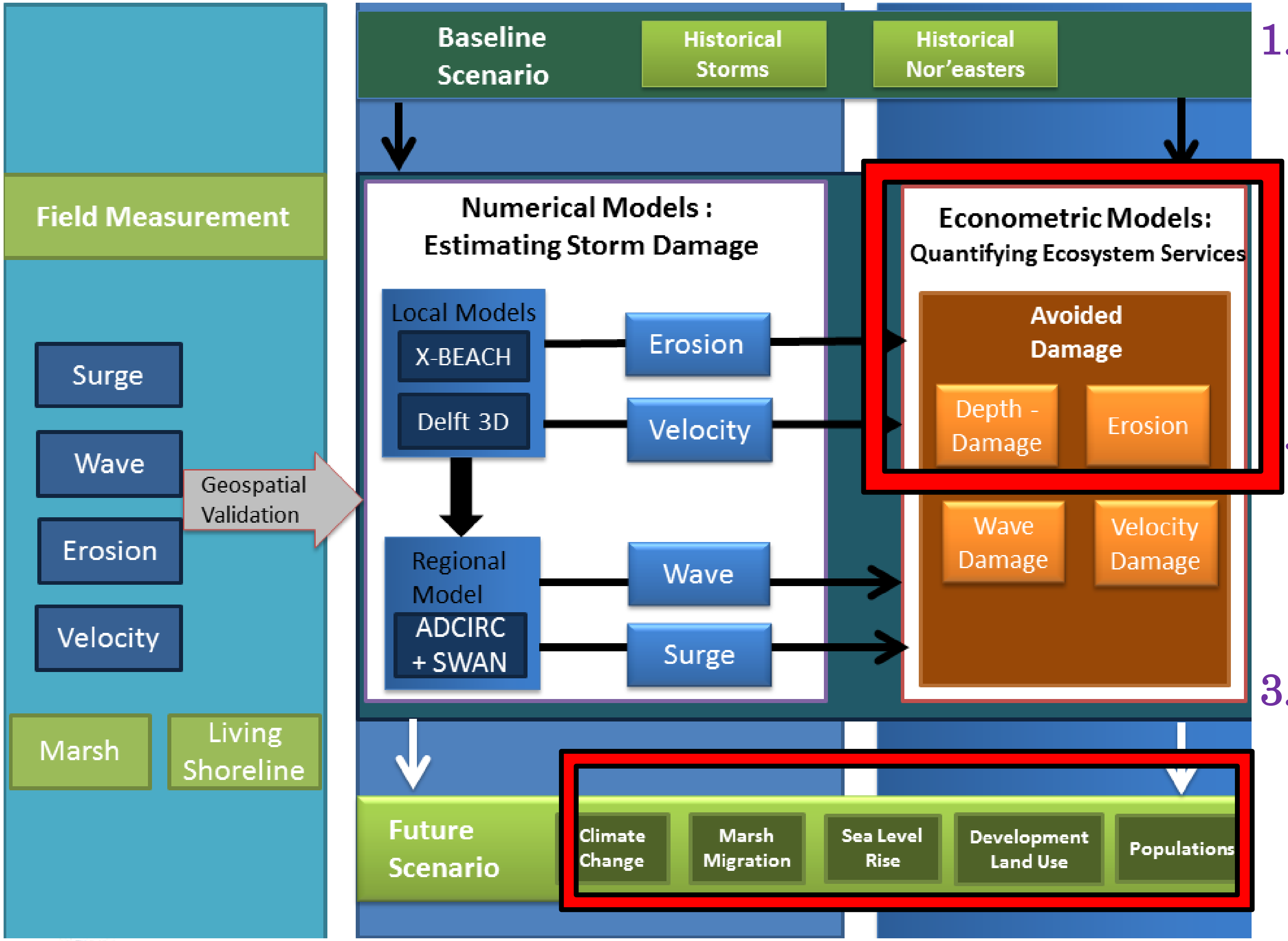
Overall Framework



1. **Field Measurement :** of water level, wave and current to improve defining geospatial parameters in the local and regional model
2. **Physical Modeling Approach :** Simulating surge and wave for a local and regional scale
3. **Econometric Models :** Incorporate simulated flood depth to calculate the avoided damage

Valuation Methodologies

Two methods:

1. Counter-factual modeling run—all wetlands replaced with open water
2. Regression analysis of modeling results—surge heights at a parcel level as a function of extent of surrounding wetlands
   - Estimated coefficient will measure how marginal change in nearby wetlands affects flooding on a parcel

Both methods use data for 5 hurricanes of varying intensity (Floyd, Dennis, Ernesto, Isabel, Irene)

Valuation Methodologies (cont.)

- For both methods, convert difference in surge heights to difference in property damages at individual property level
  - FEMA depth-damage functions
    - Residential parcels only
    - Functions vary by no. of stories & basement

Avoided damage is measure of value of protective service

Similar studies: Barbier et al. (2013); Narayan et al. (2016)

Chesapeake Bay Region

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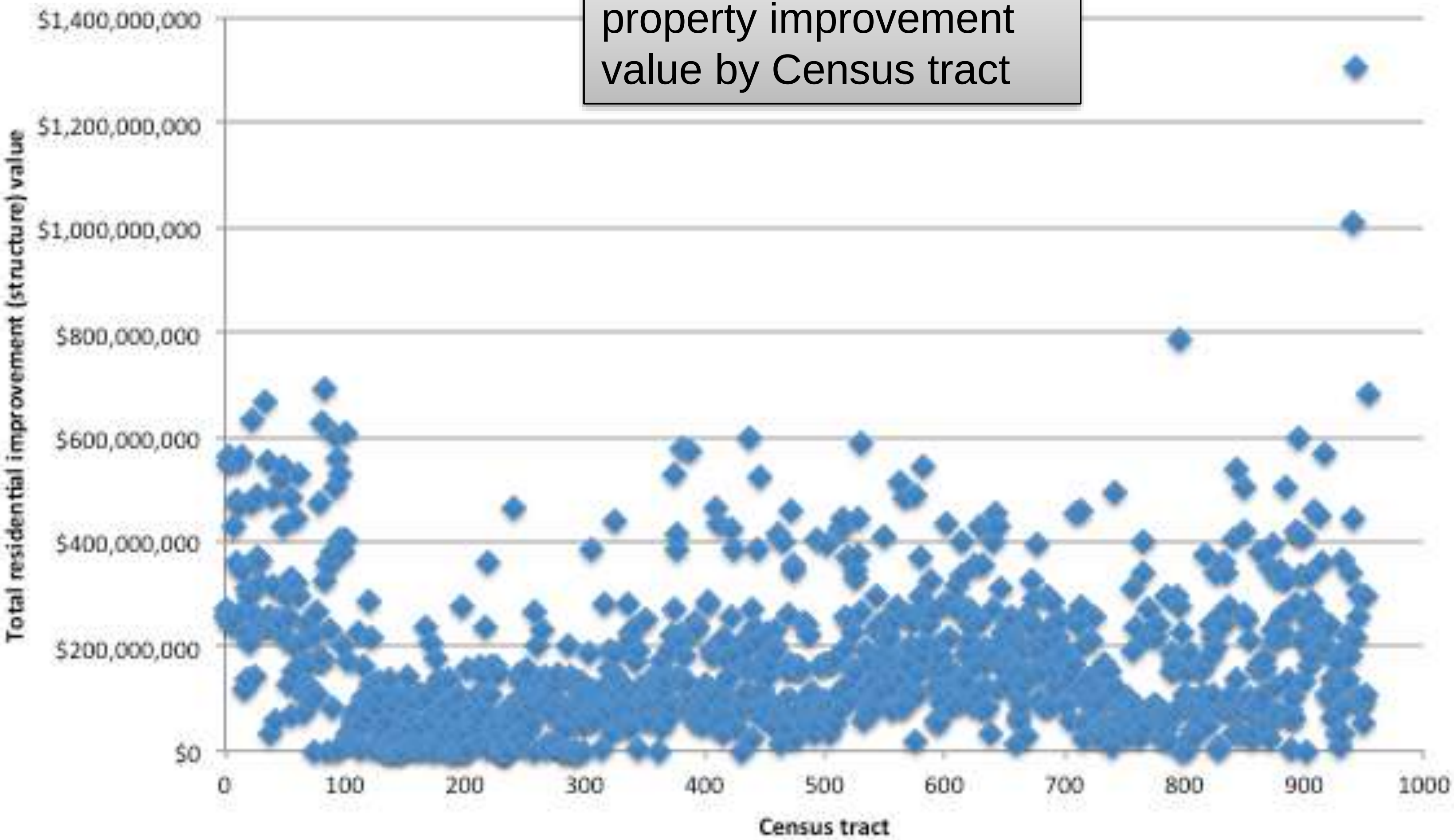
Exposure, by Census tract

Total residential property improvement value by Census tract



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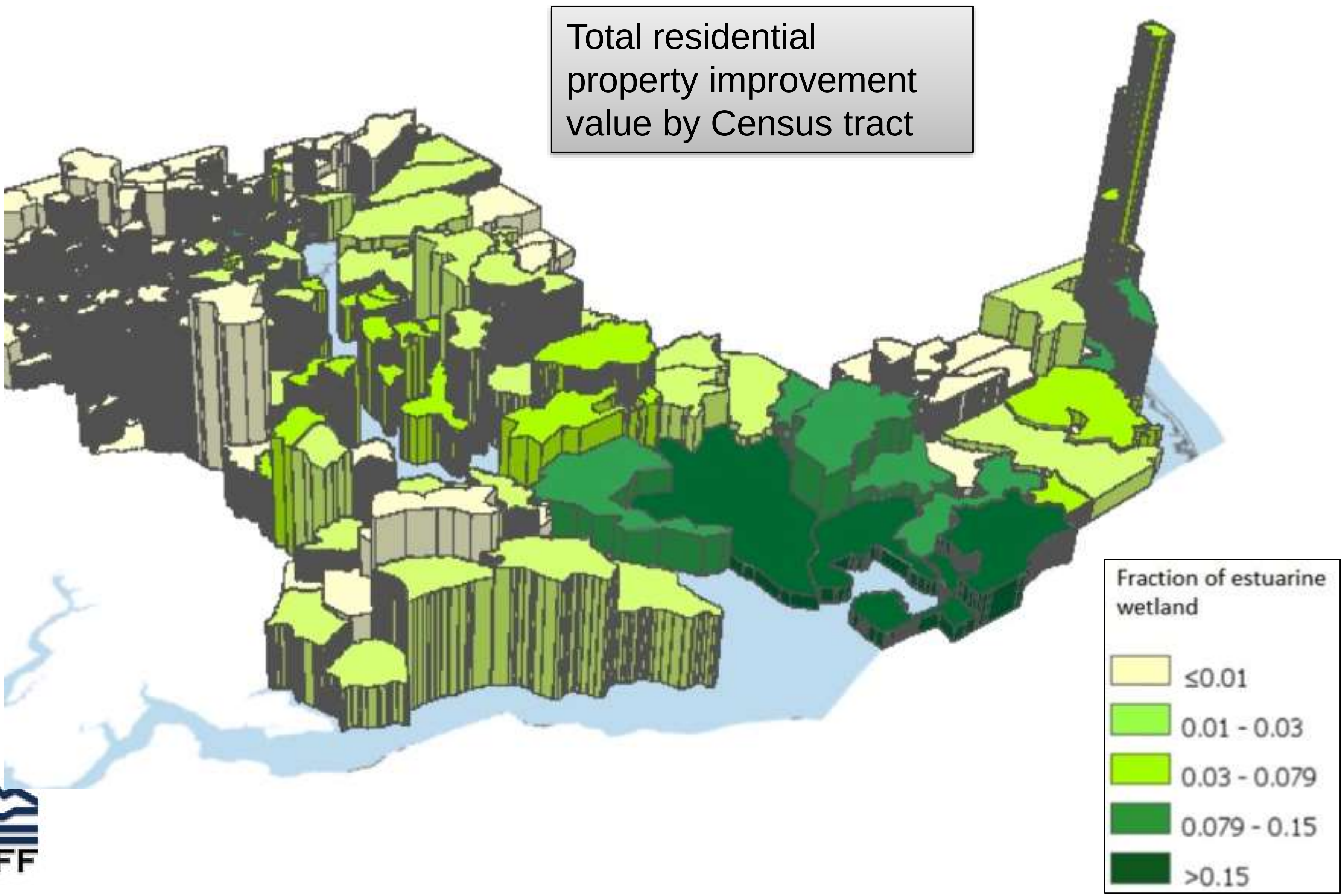
Exposure & Location of Wetlands



Hydrodynamic Model
ADCIRC
(Luettich & Westerink 1994)

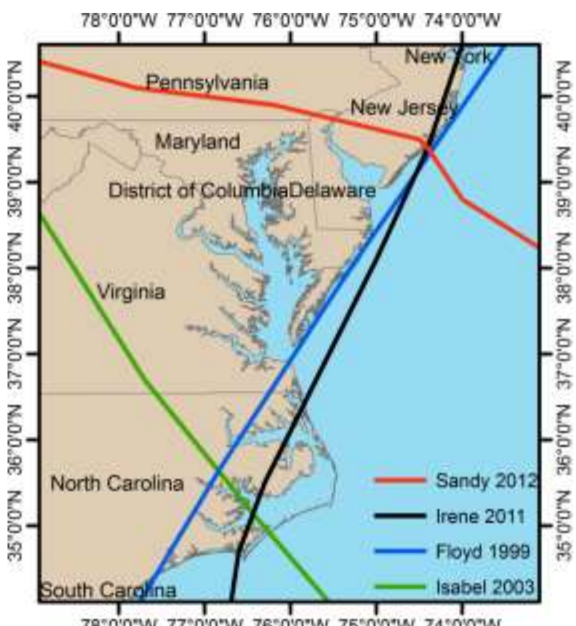
← *Wave Radiation Stress*

Wave model
SWAN
(Booij 1999)

Water Levels, Currents, Wind field, Bottom Friction, Roughness Length →

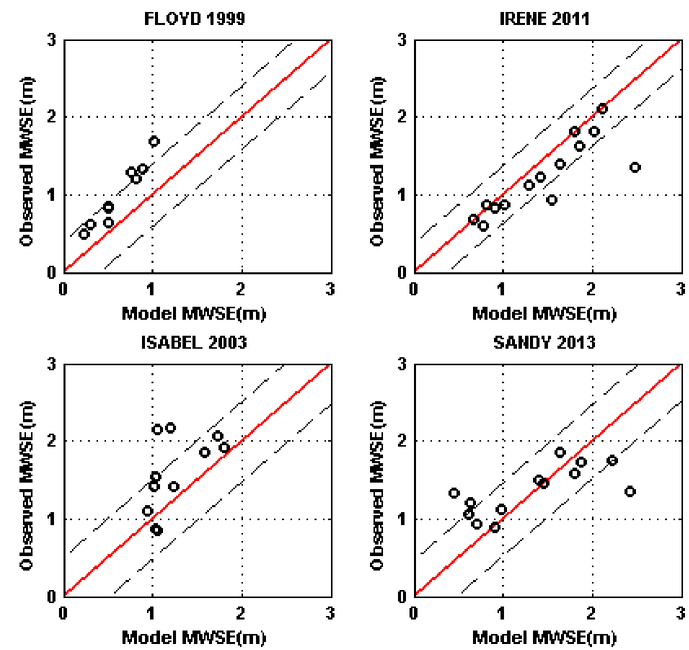
Meteorological Forcing

- **LeProvost Tidal Database**
- **National Hurricane Center (NHC) Best Track:**
    - Hurricane Track
    - Central Pressure (Cp)
    - Radius of storm (Rp)
    - Forward Speed (Vf)
    - Approach Angle (Θ)



Model Validation

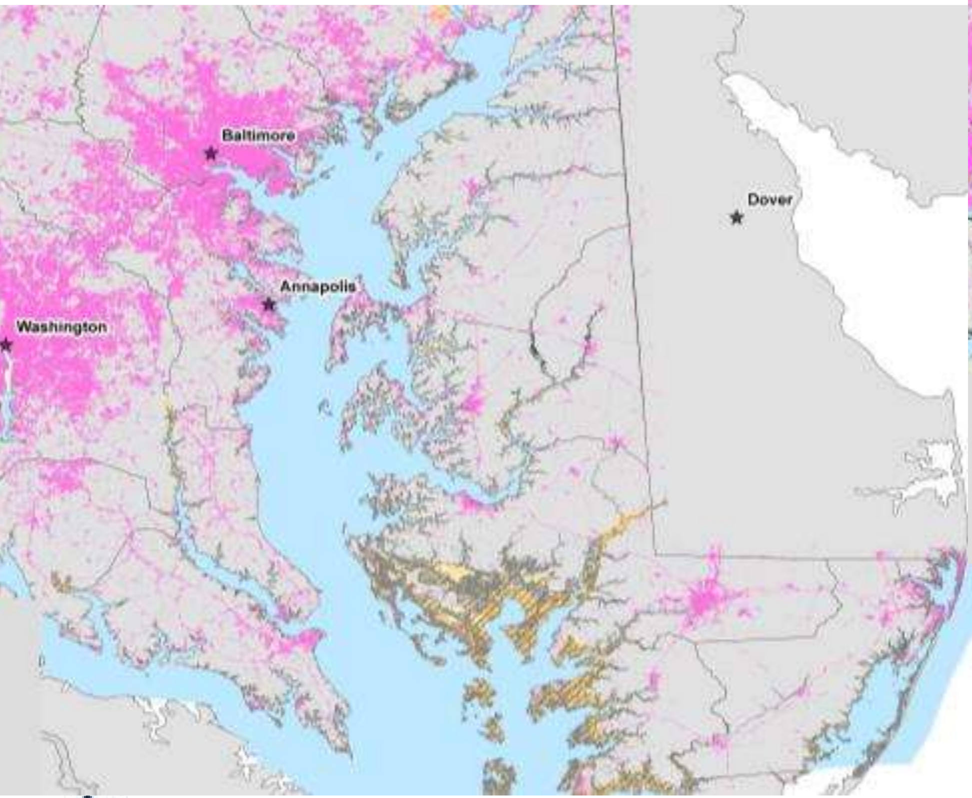
- Observed maximum water surface elevations (MWSE) at Chesapeake Bay NOAA stations for each storm compared with model MWSE
- 14 NOAA stations (data used as available)
- Root Mean Square Error (RMSE) computed for each storm:



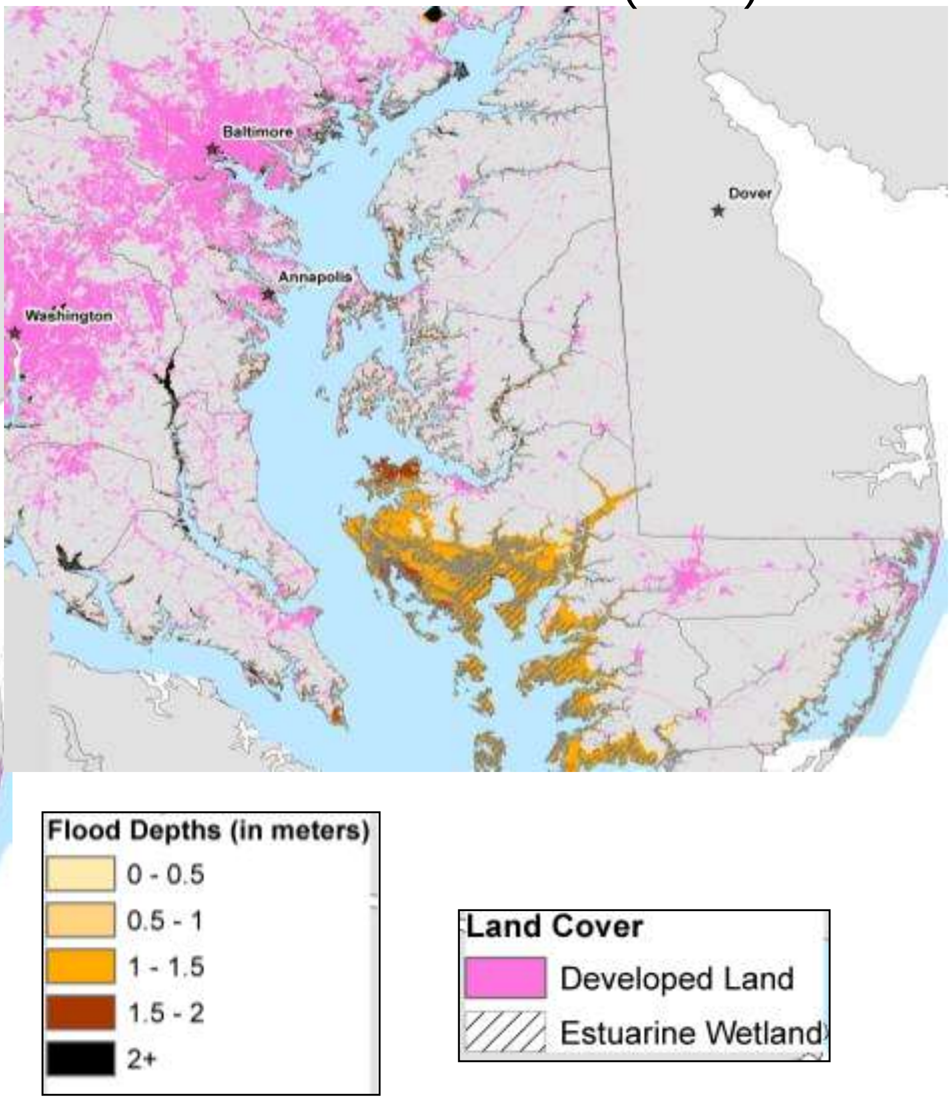
Arc StormSurge: input GIS data; output flood rasters (Ferreira et al. 2014)

Storm Surge Heights

Hurricane Floyd (1999)



Hurricane Isabel (2003)



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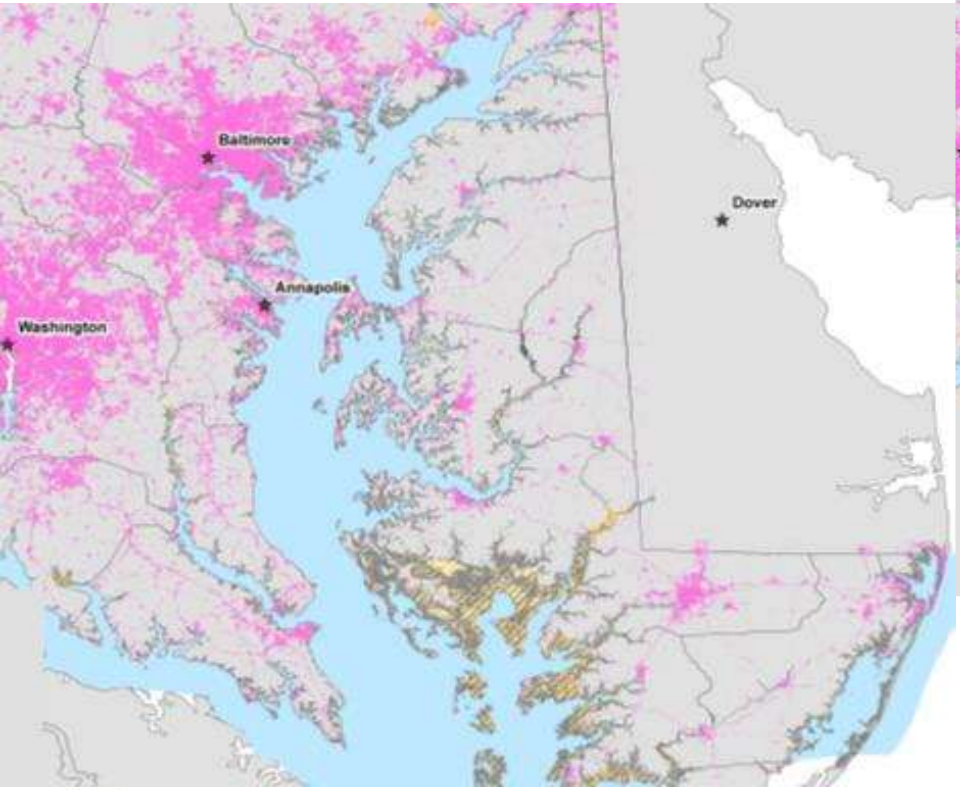
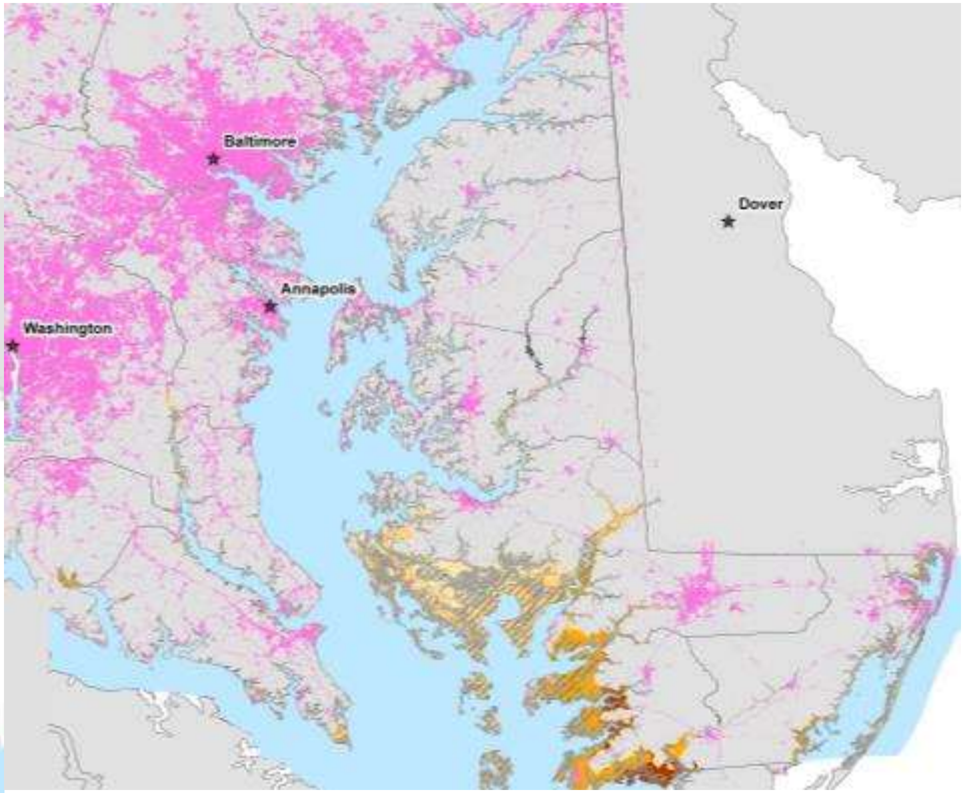
Storm Surge Heights (cont.)

Hurricane Dennis (2005)



Hurricane Irene (2011)



Flood Depths (in meters)
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2+

Land Cover
Developed Land
Estuarine Wetland

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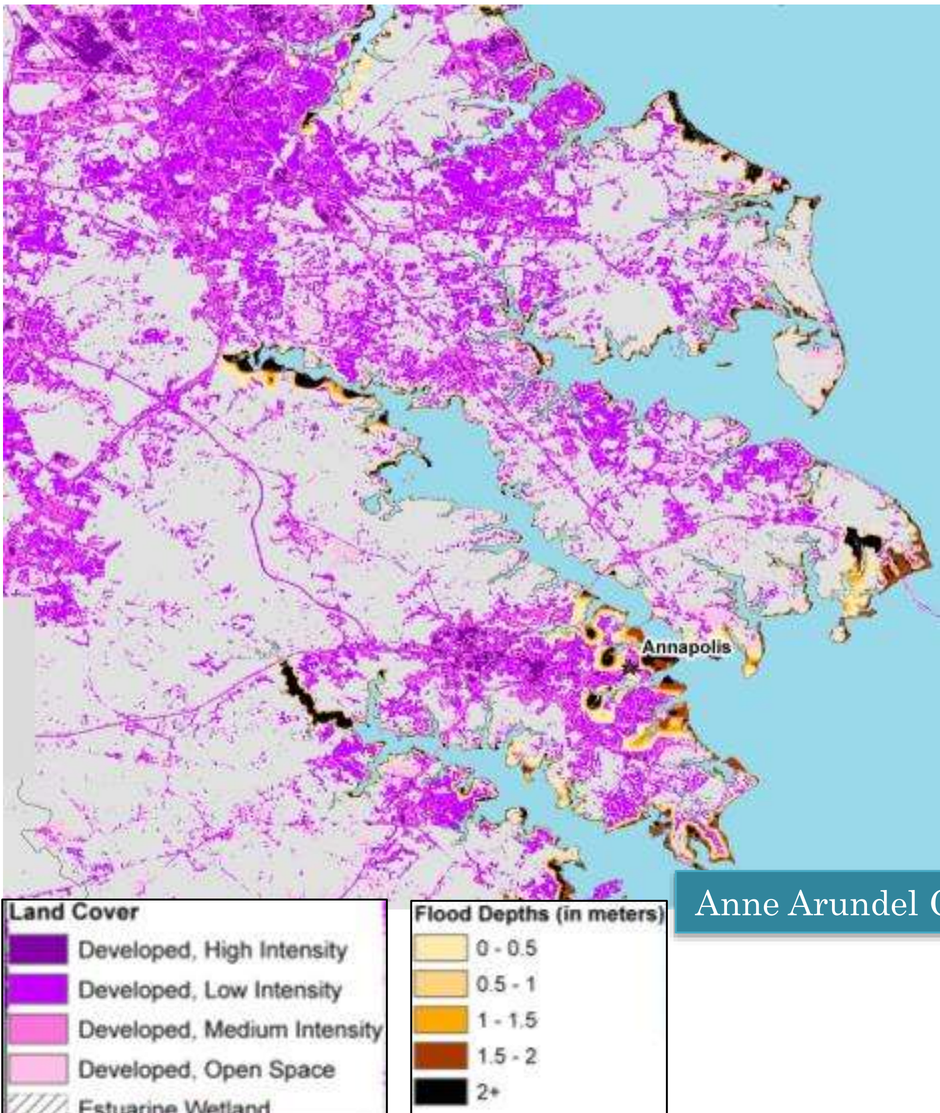
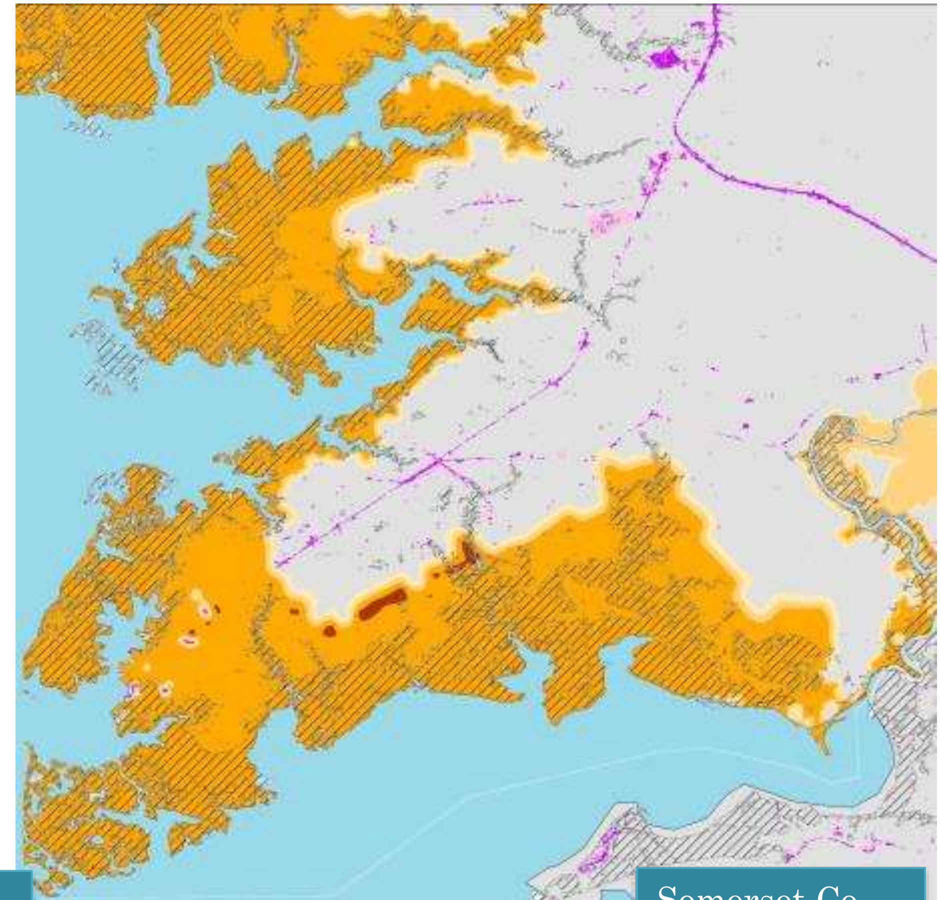
Surge Heights and Wetlands (cont.)

Hurricane Isabel



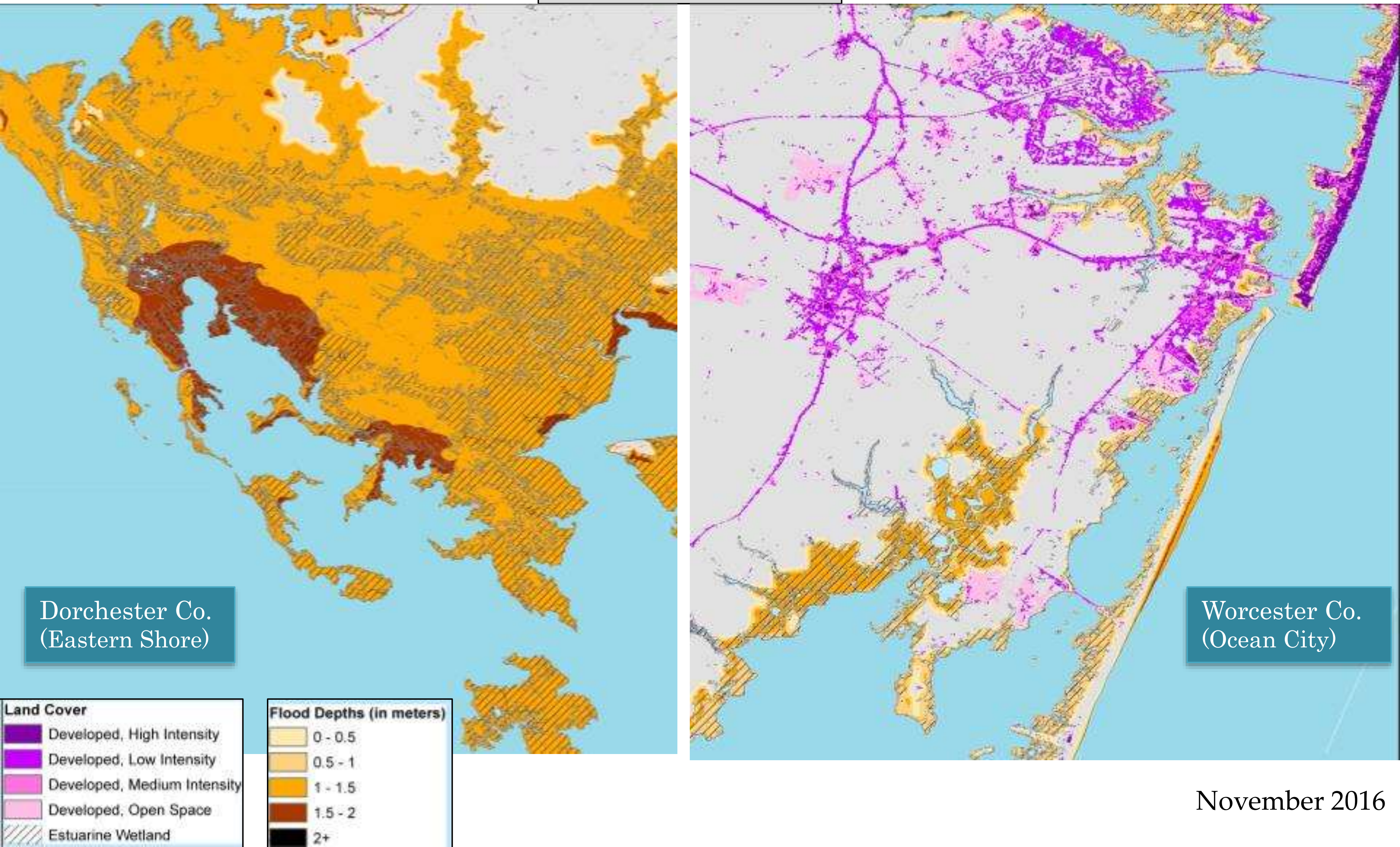
Anne Arundel Co.



Somerset Co.
(Eastern Shore)

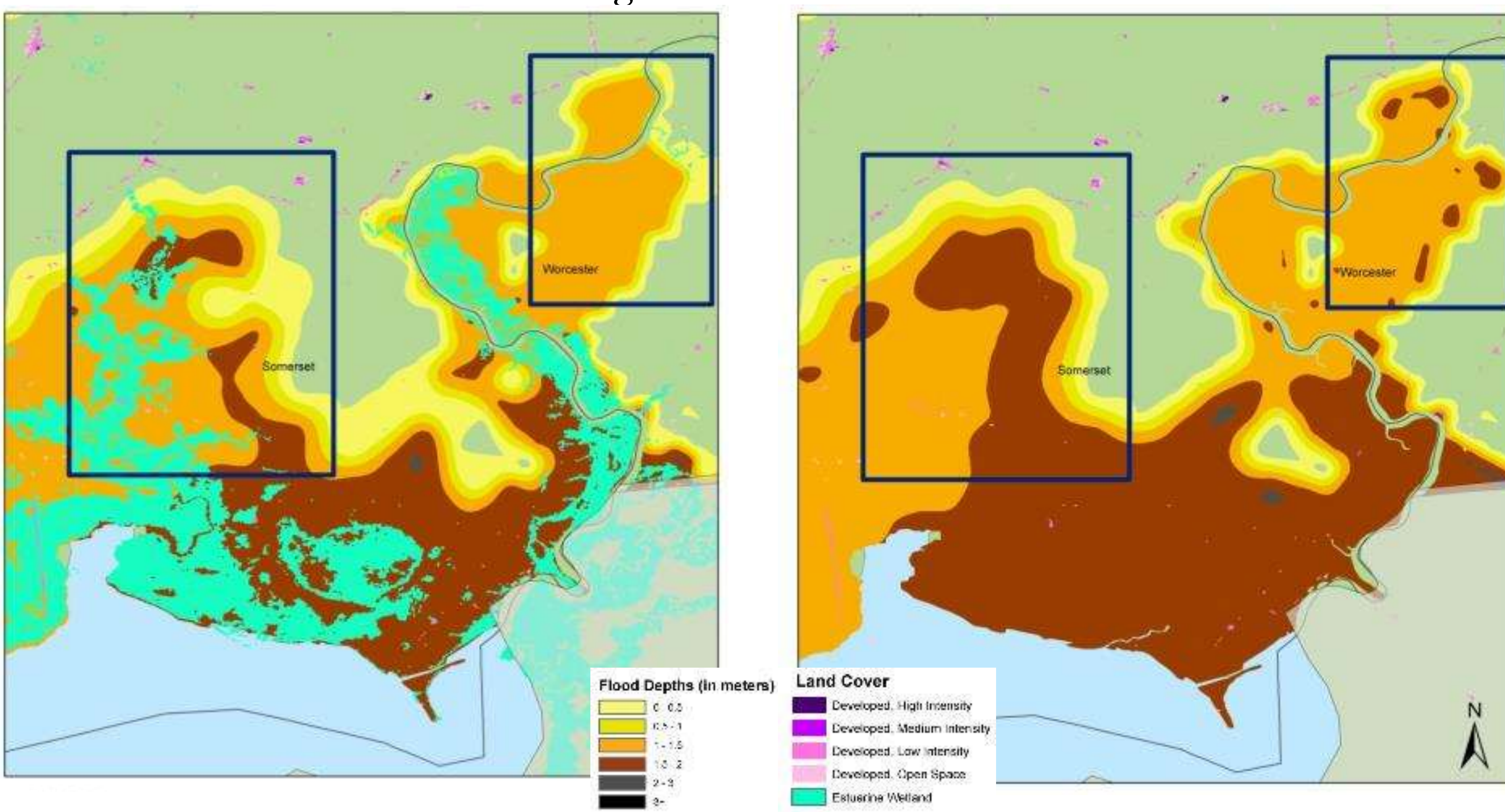
Surge Heights and Wetlands (cont.)

Hurricane Isabel



Valuation Method 1

Storm Surge Model Runs with Hypothetical Land Cover…all estuarine wetlands replaced with open water in ADCIRC + SWAN modeling



Method 1 Results (cont.)

- Additional acres of land flooded with open water instead of wetlands: 126,000 - 153,000, depending on hurricane (7-8% increase)
- Average surge height increases by 0.01 – 0.12m, depending on hurricane (1-14% increase)
  - But wide range across the landscape
- Add'l $53 - $245 million damage (based on MDProperty View data and depth-damage functions)
  - In other words, the wetlands are providing between $53 and $245 million worth of protective services

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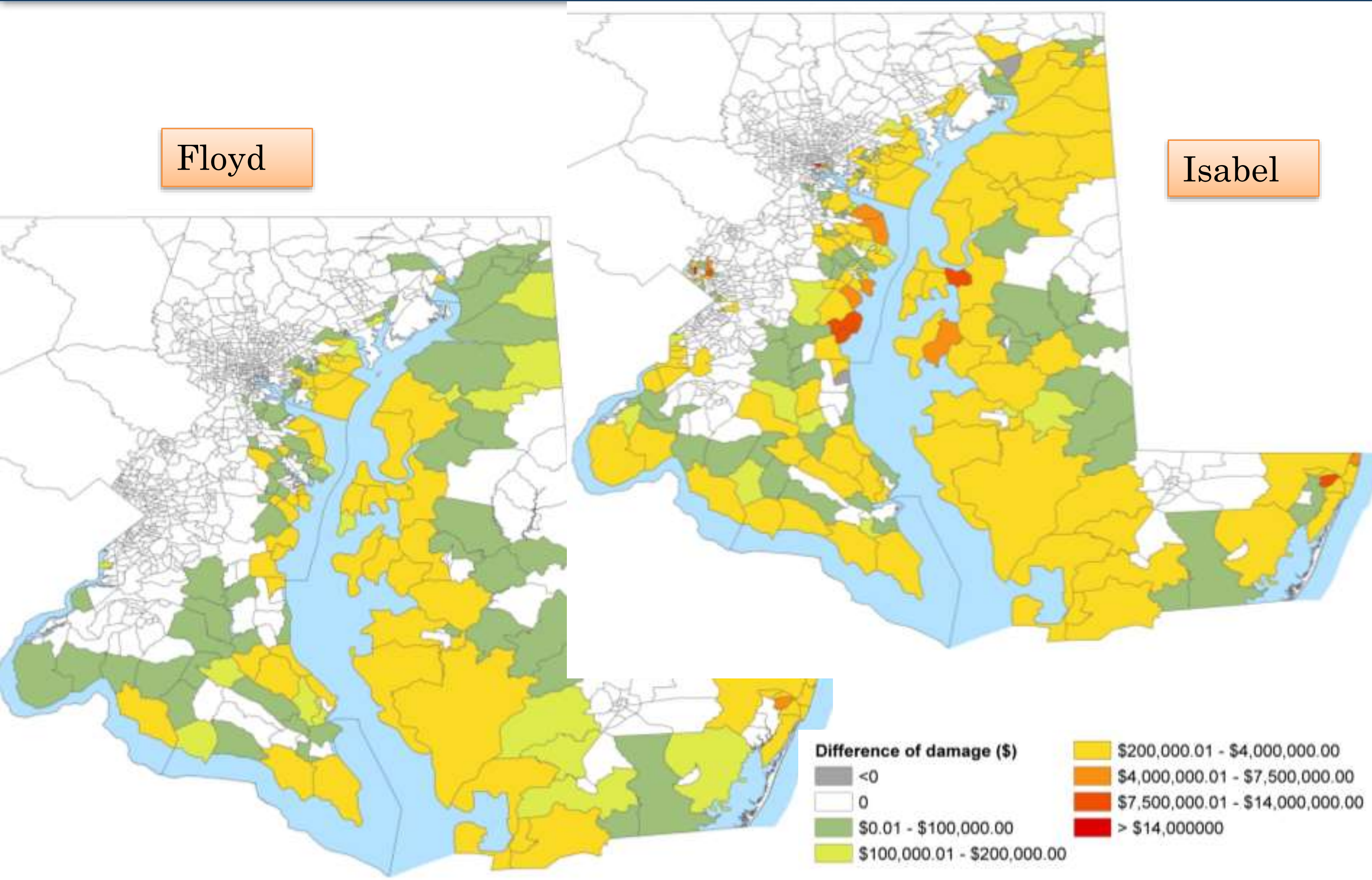
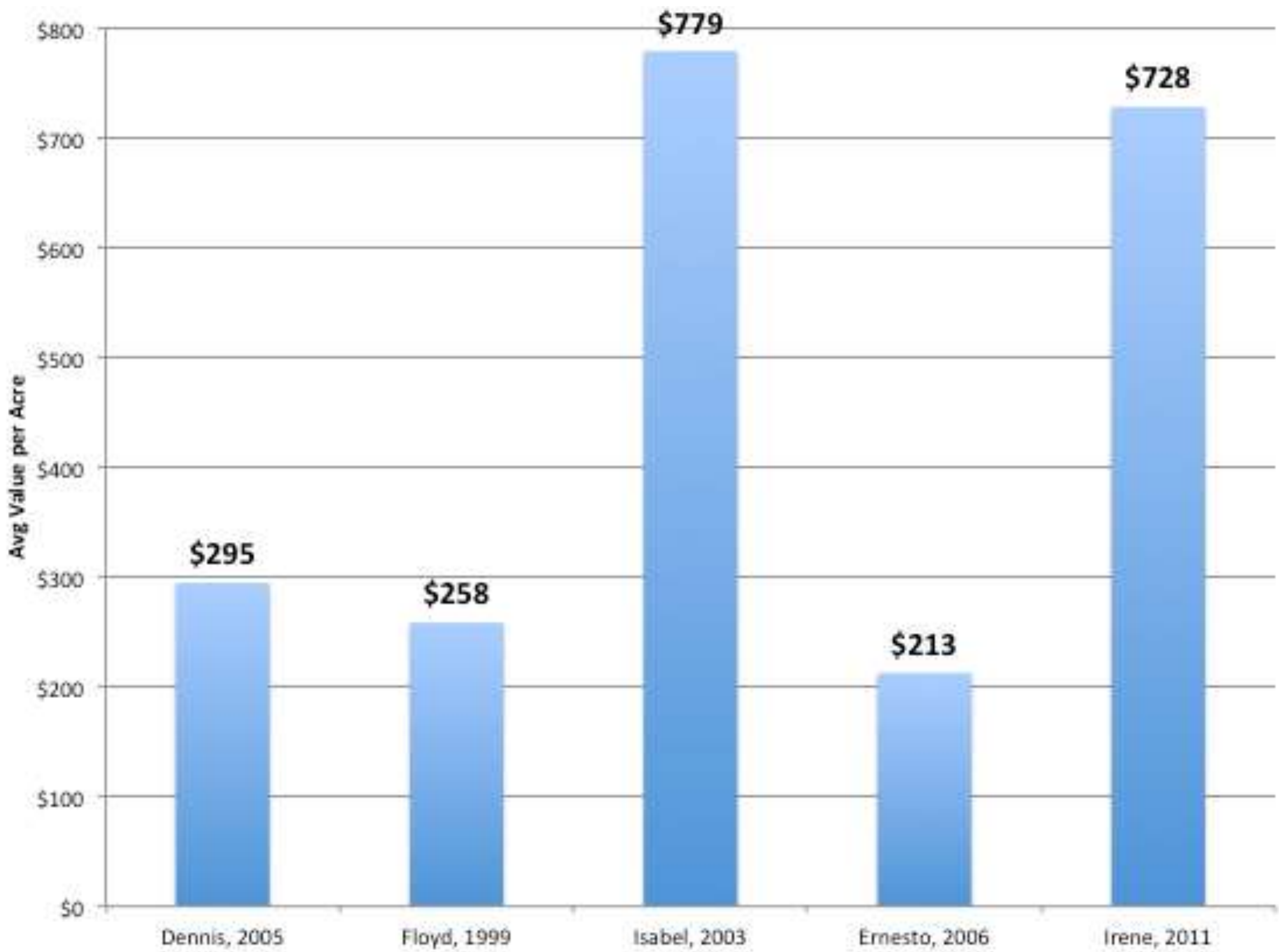
Value of Protective Services, by Census Tract



Value of Protective Services per Acre



Wetlands provided the biggest benefit in the worst hurricanes

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Valuation Method 2: Regression Analysis

- MD Property View data on all parcels in Maryland
- Construct buffer around each flooded parcel
    - 500-m (base case); 100-m; 1000-m
- Calculate % of flooded area of buffer that is wetlands
- Regressions:
    - Estimate surge heights as a function of %wetlands, and several control variables
    - Allow effects to vary by hurricane

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Regression Results

Dep. Variable = flood height on parcel (in m)	
All wetlands in buffer flooded area (as fraction of total flooded area)	-0.820*
	(0.342)
All wetlands in buffer flooded area*Floyd	-0.0460
	(0.0765)
All wetlands in buffer flooded area*Isabel	-0.636***
	(0.0958)
All wetlands in buffer flooded area*Ernesto	0.00426
	(0.0794)
All wetlands in buffer flooded area*Irene	0.245***
	(0.0456)
Constant	0.435***
	(0.0642)
Control vars: elevation, A/V zone, %water in buffer, %flooded area in buffer	yes
Hurricane fixed effects	yes
Observations	195,767
R-squared	0.137
* $p < .10$; ** $p < .05$; *** $p < .01$. Standard errors in parentheses.	

Baseline results: 500-m buffer around parcel

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Robustness checks: alternative buffers

1000-m buffer

Dep. Variable = flood height on parcel (in m)	
All wetlands in buffer flooded area (as fraction of total flooded area)	-1.305*
	(0.524)
All wetlands in buffer flooded area*Floyd	-0.0813
	(0.0827)
All wetlands in buffer flooded area*Isabel	-0.742***
	(0.0532)
All wetlands in buffer flooded area*Ernesto	-0.0375
	(0.0962)
All wetlands in buffer flooded area*Irene	0.203*
	(0.0853)
Constant	1.271**
	(0.312)
Control vars: elevation, A/V zone, %water in buffer, %flooded area in buffer	yes
Hurricane fixed effects	yes
Observations	195,767
R-squared	0.125

* $p < .10$; ** $p < .05$; *** $p < .01$. Standard errors in parentheses.

100-m buffer

Dep. Variable = flood height on parcel (in m)	
All wetlands in buffer flooded area (as fraction of total flooded area)	-0.0487
	(0.0356)
All wetlands in buffer flooded area*Floyd	0.0169
	(0.0337)
All wetlands in buffer flooded area*Isabel	-0.431***
	(0.0146)
All wetlands in buffer flooded area*Ernesto	0.0351
	(0.0390)
All wetlands in buffer flooded area*Irene	0.103**
	(0.0246)
Constant	-0.906
	(0.520)
Control vars: elevation, A/V zone, %water in buffer, %flooded area in buffer	yes
Hurricane fixed effects	yes
Observations	195,745
R-squared	0.161

* $p < .10$; ** $p < .05$; *** $p < .01$. Standard errors in parentheses.

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Interpreting Regression Results

- Doubling wetlands in the flooded portion of a 500-m buffer around a parcel reduces average surge heights by
  - 0.82 meters in Hurricanes Dennis, Floyd & Ernesto
  - 1.46 meters in Hurricane Isabel
  - 0.39 meters in Hurricane Irene

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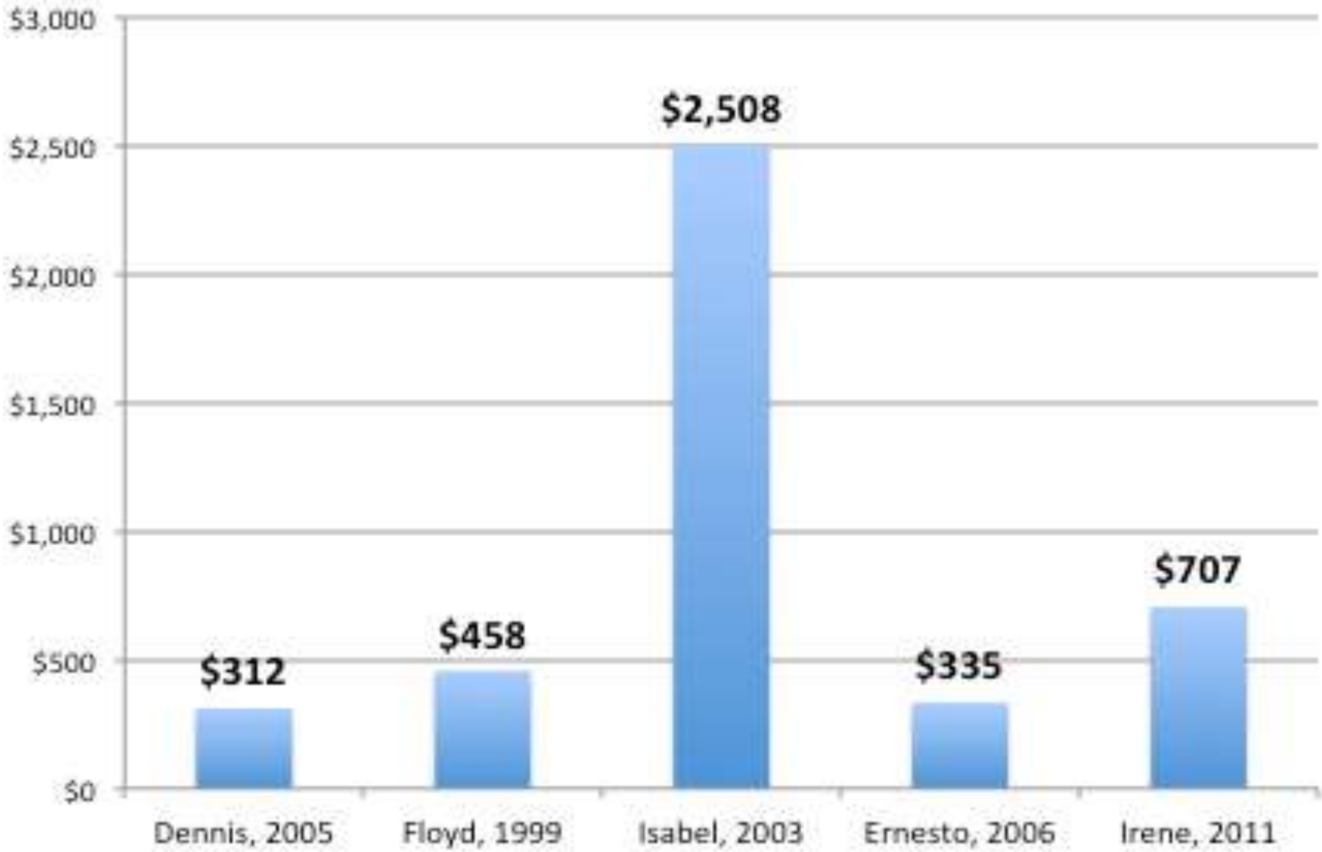
Value of Protective Services per Acre



Wetlands provided the biggest benefit in the worst hurricanes (consistent w/method 1)

Values in line with method 1 for some hurricanes but Isabel value much larger

Further thinking needed about comparison of methods

Some Comments, Thoughts, Conclusions

Strengths of the approach(es):

- Linking change in ecosystem functions (surge attenuation) to ecosystem services (reduced flood heights on residential parcels) & values (damage avoided)
- Spatially detailed, disaggregated data

Both valuation methods look only at difference in flooding on developed properties

- If nothing to damage, value of protective services = $0
- How to think about undeveloped parcels… "option value"?
  - Wetlands protect some lands that could be developed in future
- Calculations based on five hurricanes; other properties could flood in other hurricanes

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Next Steps

Short Run:

- Method 1:
  - Improve regression model with add'l control variables &/or hurricane characteristics
  - Sensitivity of results to depth-damage functions
- Method 2:
  - Sea level rise scenario, with marsh migration (underway)

Longer Run:

- Method 1: use suite of 500-1000 synthetic hurricanes; create and analyze distribution of values (need to figure out how to deal with computational issues)
  - Calculate expected annual value, not per-hurricane
- More economics: efficient targeting of new wetlands conservation areas?

Thank you!

Comments/questions: walls@rff.org

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