Valuing Ecosystem Services of Coastal Wetlands: Protections from Surge

Margaret Walls[1], Ali M. Rezaie[2, 1], Ziyan Chu[1], Celso M. Ferreira[2]

[1]Civil Environmental and Infrastructure Engineering, George Mason University;
[2]Resources for the Future, Washington DC

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Overview

Outline of talk:

- ❑ Ecosystem functions, services, values
- ❑ Overall Framework
- ❑ Chesapeake Bay Region
- ❑ Methodology
  - Scenarios: w/o wetlands, sea level rise and marsh migration
  - Econometric regression
- ❑ Results
- ❑ Conclusions and Future Research

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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
- A service that is getting increasing attention is protection from flooding. Especially the flooding associated with hurricane storm surge.

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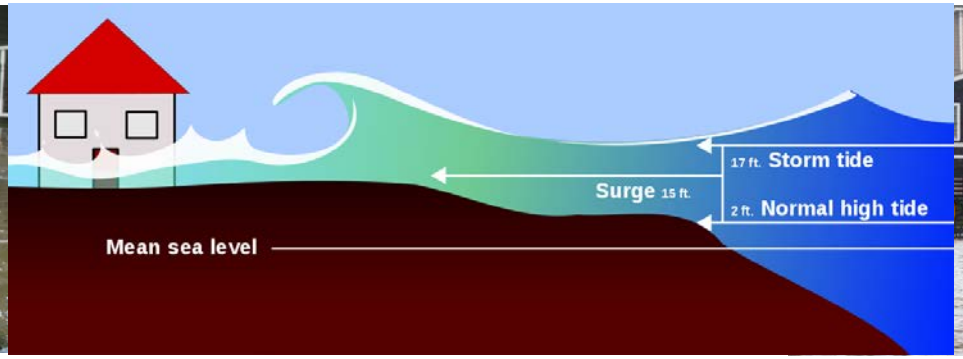
Hurricane Storm Surge Flooding

Hurricane Isabel flooding, Hampton Road and Virginia Beach, 2003



- **Storm surge is the abnormal rise in water level due to a presence of storm/hurricane**
- Hurricane Isabel (2003): Total Property damage $5.3 billion ~ 80% in VA & MD
- Insurance Information Institute ranked Virginia 9th and Maryland 18th state vulnerable to hurricane
- Recurrent flood risks on coastal areas are increasing with warmer climate, frequent storms, and increasing coastal population

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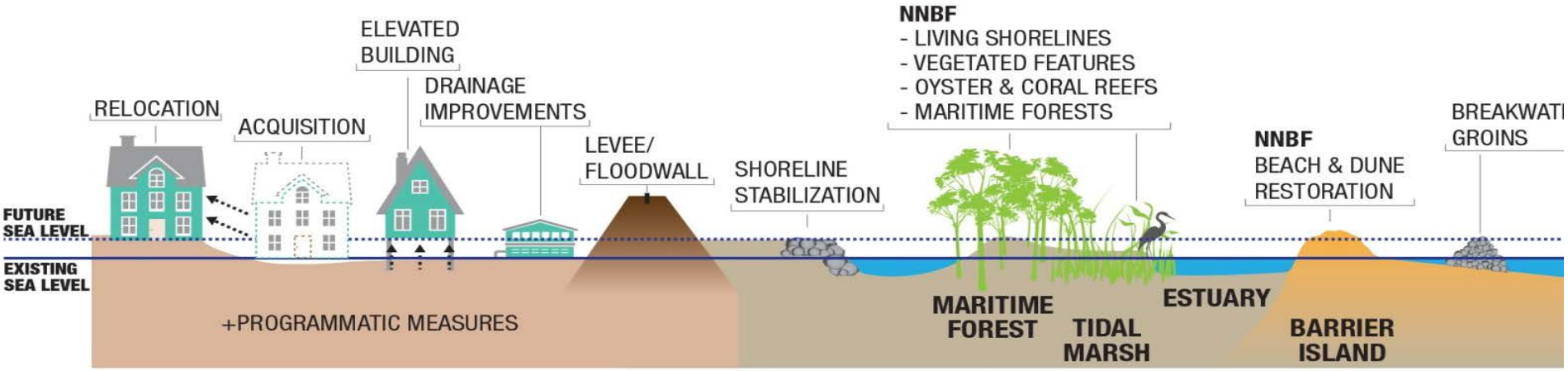
Wetlands: Nature Based Flood Defense

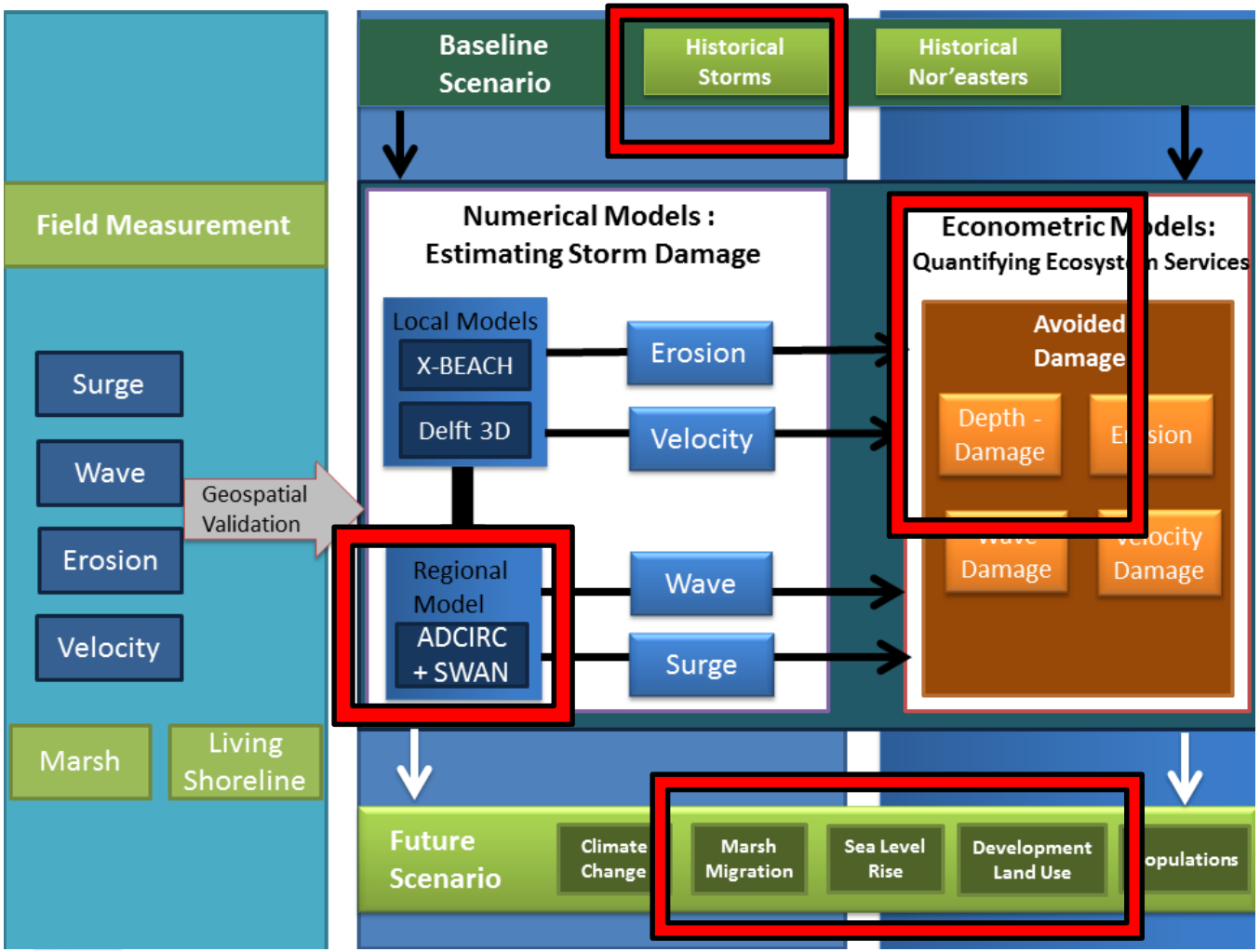
- Wetlands attenuate surge by slowing its advance across the landscape and delaying arrival of water on the landward side

- USACE (1963) seminal study in Louisiana:
  - *Simple rule of thumb: surge heights reduced by, on average,1m for every 14.5km of wetlands*

- Wamsley *et al*. (2010):
  - *5-60 km of wetland reduces 1m of surges based on storm intensity*



Overall Framework



1. Field Measurement : of water level, wave and current to improve defining geospatial parameters in local and regional models

2. Modeling Approach : Simulating surge and wave for local and regional scale

3. Economic Analysis: Incorporate simulated hydrodynamic parameters to calculate the avoided damage

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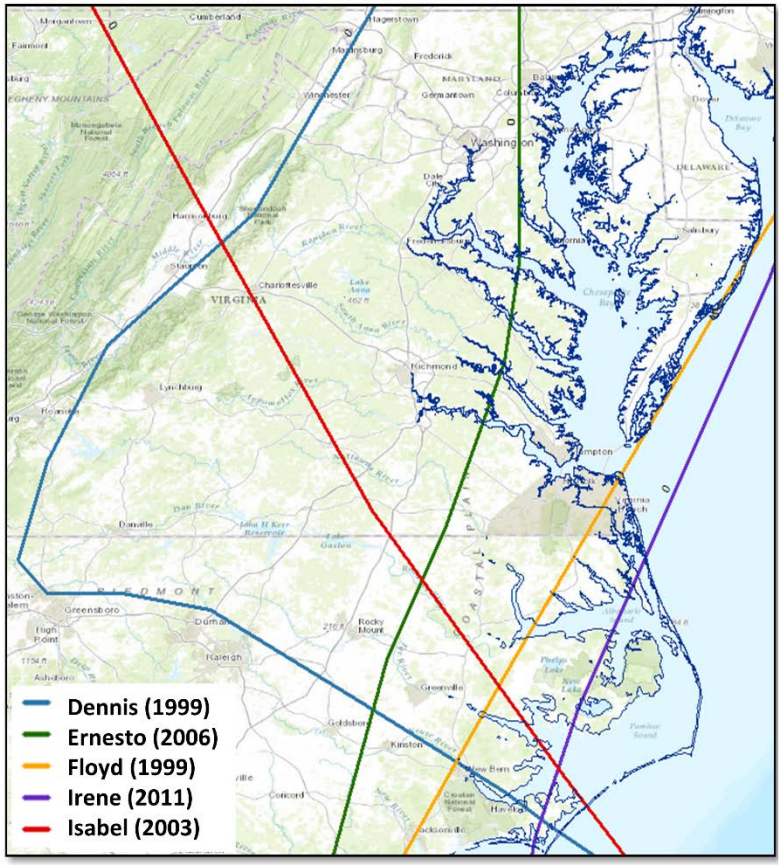
Storm Selection



Storm Name	Storm Year	Maximum Wind Speed (km/h)	Minimum Central Pressure (hPa)
Dennis	1999	167	962
Floyd	1999	250	921
Isabel	2003	269	915
Ernesto	2006	111	985
Irene	2011	167	942

A set of five storms with low to high intensity that hit or passed near the Chesapeake Bay regions in past 20 years.

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Hydrodynamic Model
ADCIRC
(Luettich & Westerink 1994)

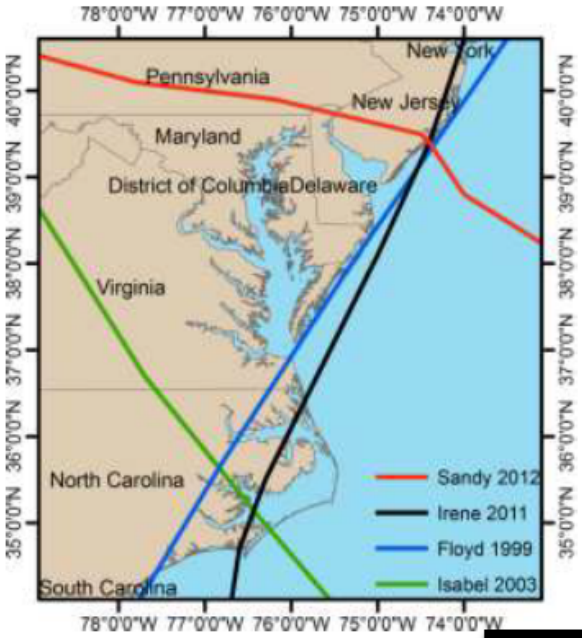
Wave Radiation Stress

Wave model
SWAN
(Booij 1999)

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

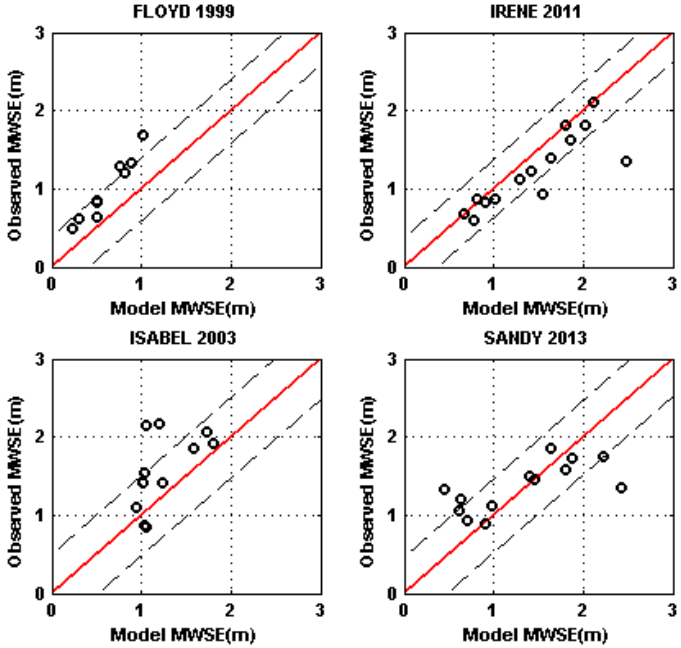
Meteorological Forcing

- **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:



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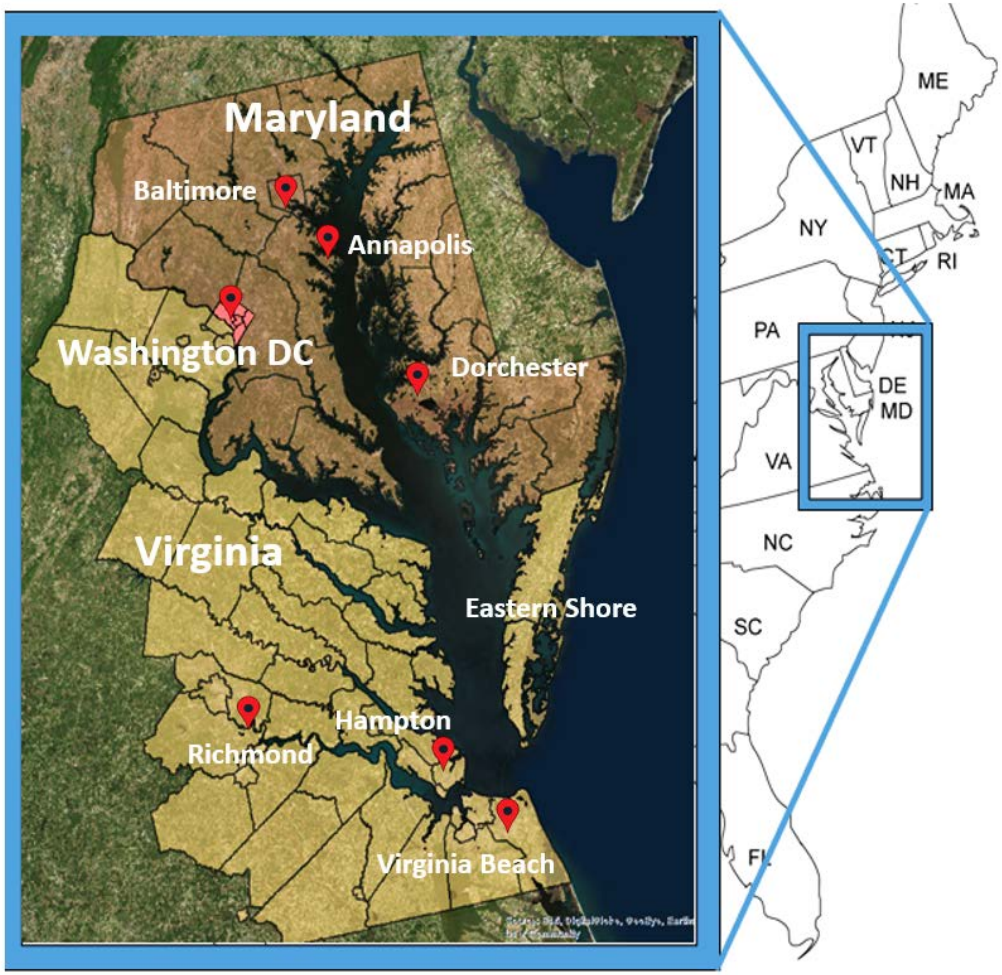
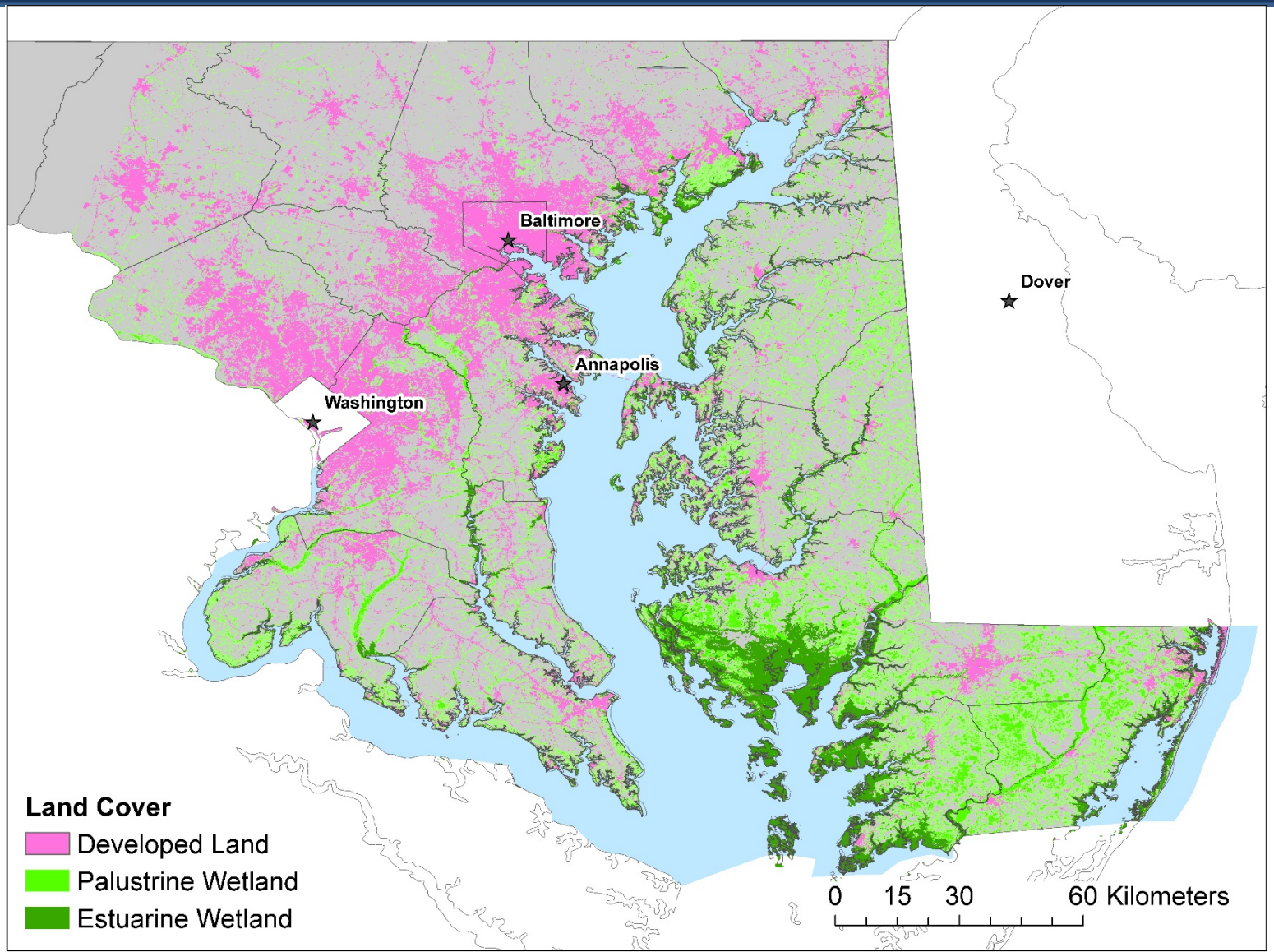
Arc StormSurge: input GIS data; output flood rasters (Ferreira et al. 2014)

Study Area: Chesapeake Bay Region



Study Area: Chesapeake Bay Region（cont.)



Methodology

- With and without wetland:
  - *(i) A baseline scenario*
  - *(ii) A counterfactual 'without wetland'*

- Sea Level Rise (SLR) and Marsh Migration (MM):
  - *(i) A baseline scenario*
  - *(ii) Highest SLR rise scenario (+7.6ft) and MM (+6ft)*
  - *(iii) Lowest SRL rise scenario (+1.6ft) and MM (+2ft)*

- Econometric analysis of modeling results – surge heights at parcel level as function of the extent of wetlands in surrounding land area

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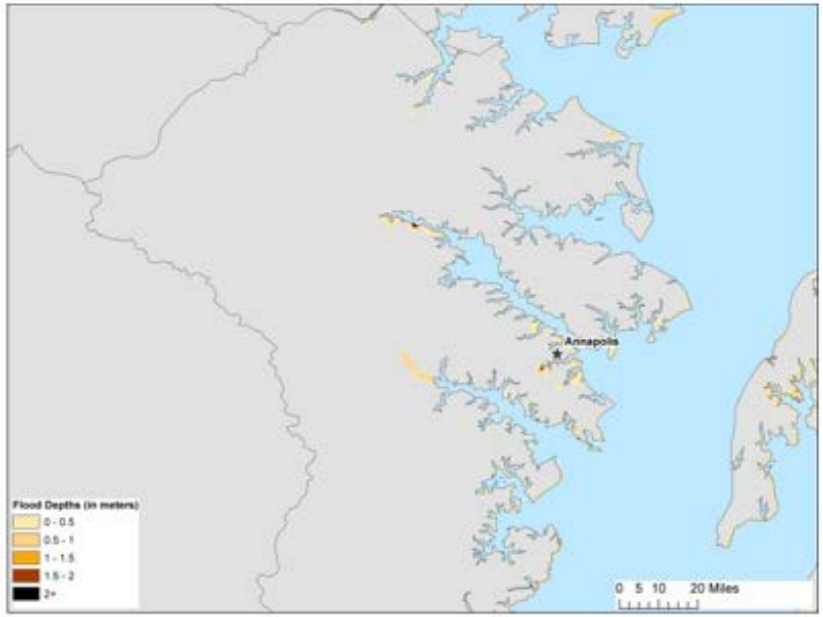
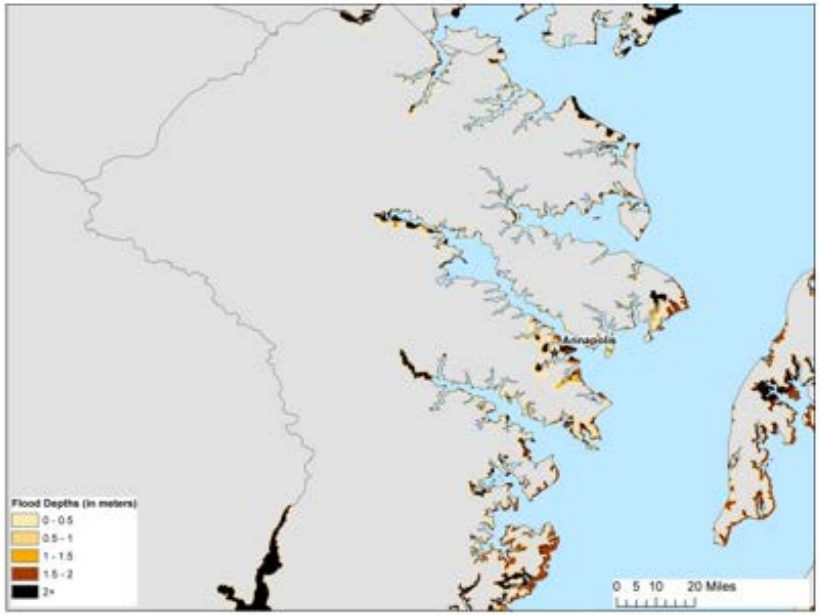


(A) Anne Arundel County, Floyd

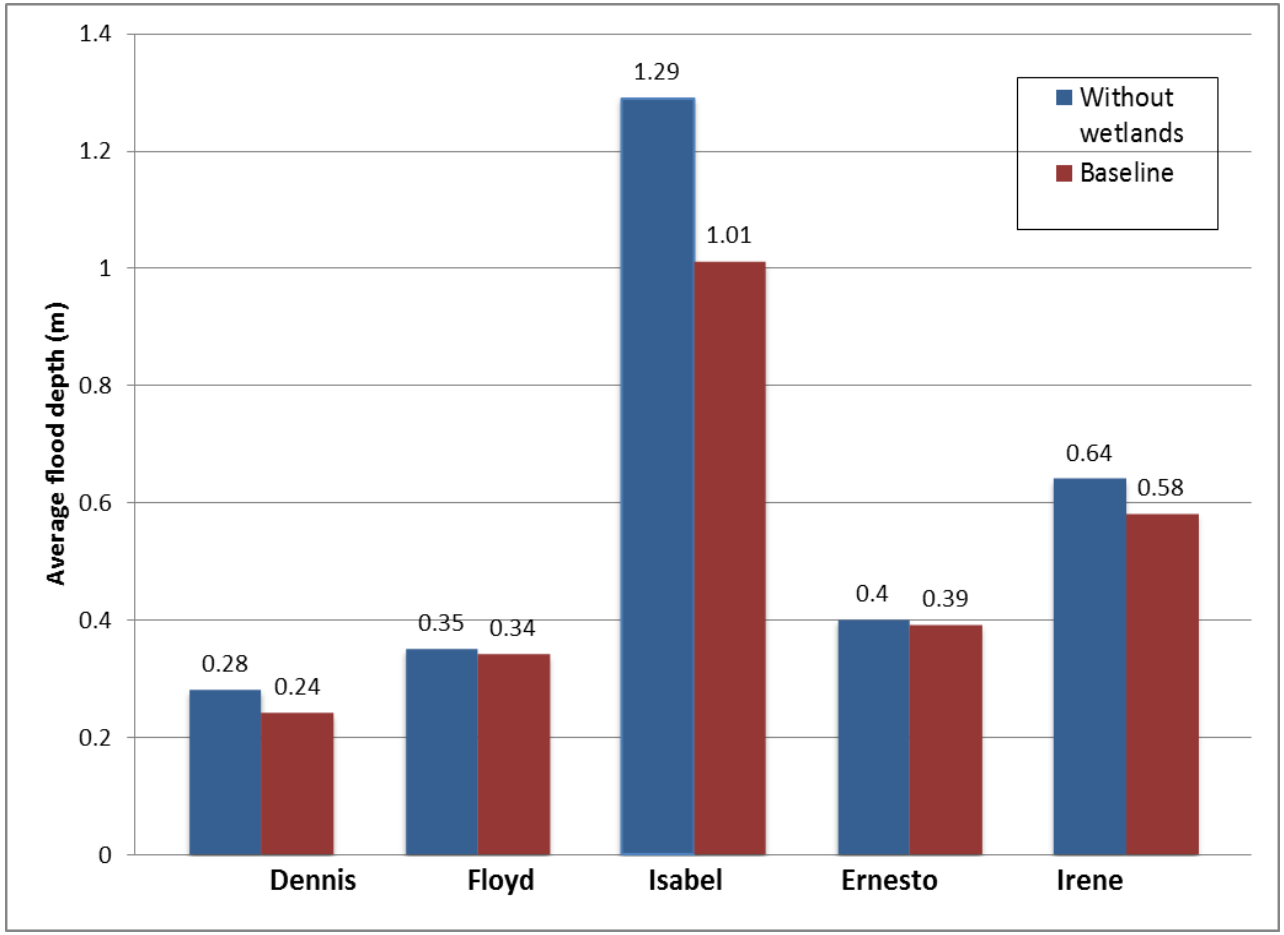


(C) Anne Arundel County, Isabel

(B) Somerset County, Floyd

(D) Somerset County, Isabel

Scenario: With and without wetland



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Scenario: With and without wetland（cont.)

Area Flooded in Baseline and Counterfactual (No Wetlands) Scenarios, by Hurricane (in sq. km)

Storm	Baseline	Counterfactual, Without Wetlands	Difference (% difference)
Dennis	656	1,145	489 **(74.5%)**
Floyd	855	1,321	466 (54.5%)
Isabel	1,586	2,167	**581** (36.6%)
Ernesto	980	1415	436 (44.4%)
Irene	1,221	1,788	567 (46.5%)

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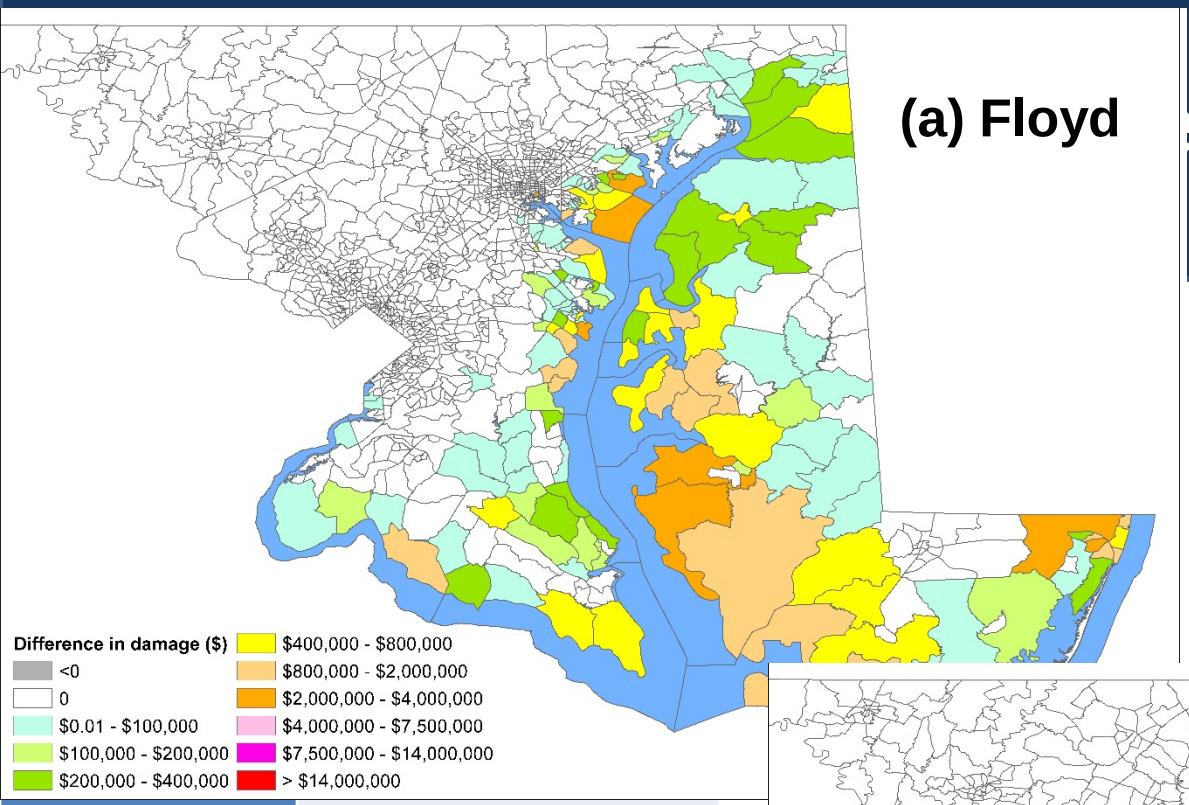
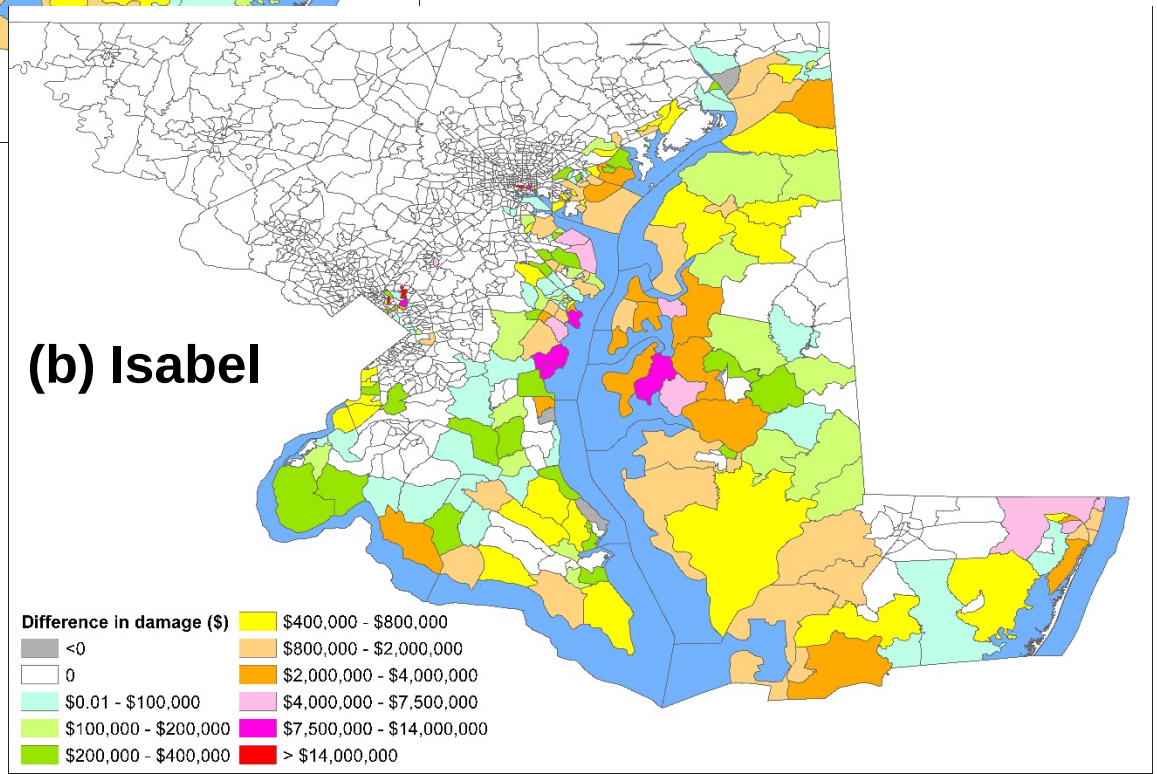
etland（cont.)

l using depth-damage



Ernesto	$60.8
Irene	$248.3



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Methodology

- Sea Level Rise (SLR) and Marsh Migration (MM):
  (i) A baseline scenario
  (ii) Highest SLR rise scenario (+7.6ft) and MM (+6ft)
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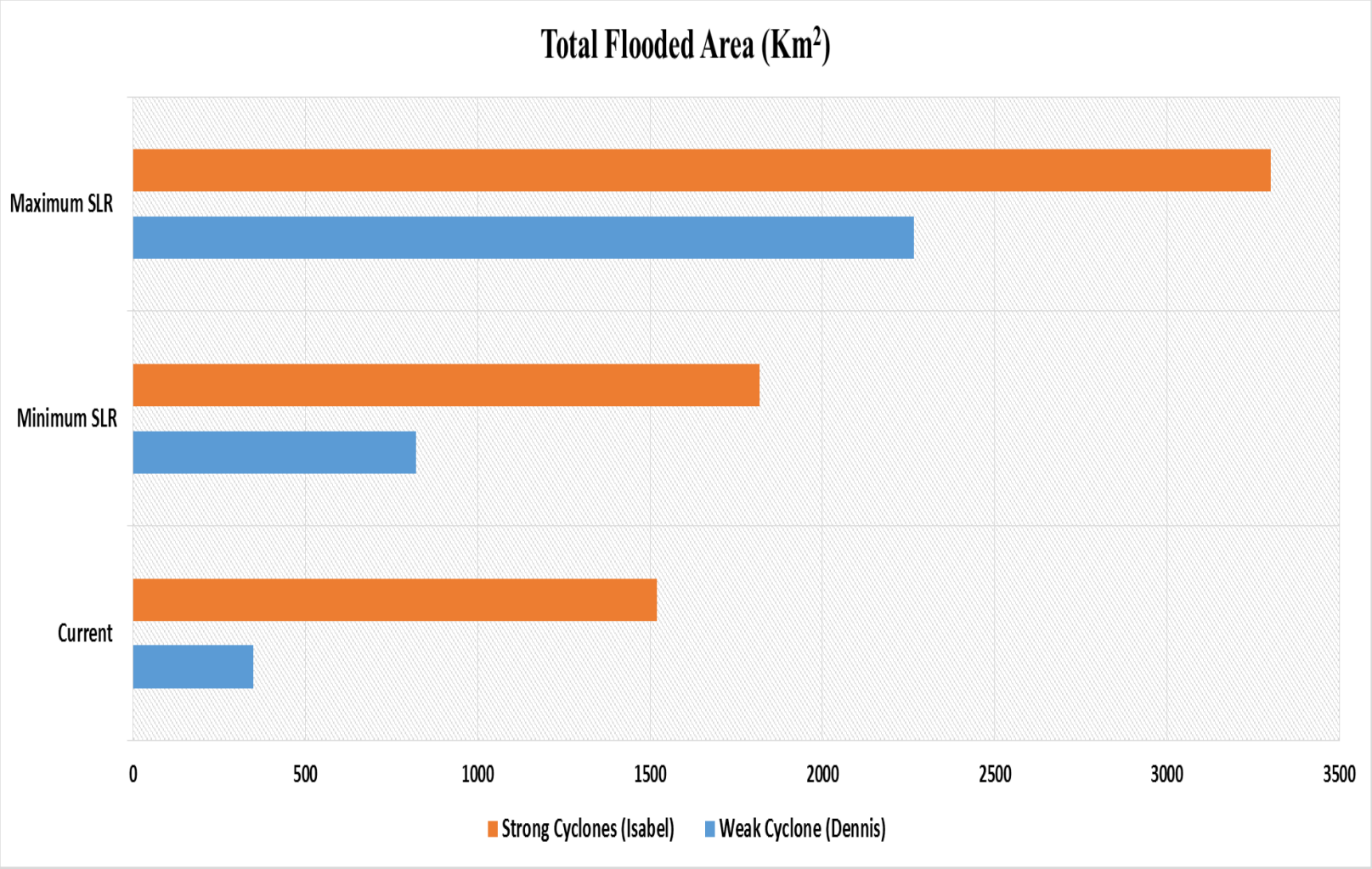
Scenario: SLR and MM



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Scenario: SLR and MM (cont.)

Impacts	Household Property Damage (Million USD) (Increase from Baseline)		Total No. of Flooded Household (% Increase from Baseline)	
Storms/ Scenarios	Dennis	Isabel	Dennis	Isabel
Baseline/ Current	$7.7	$264	3791	28694
Minimum SLR	$69.9 ($62.2)	$488 ($224)	16221 (327%)	42149 (47%)
Maximum SLR	$1,580 ($1572.3)	$2,310 ($2046)	90550 (2280%)	123195 (320%)

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Methodology

- Econometric analysis of modeling results – surge heights at parcel level as function of the extent of wetlands in surrounding land area

Regression analysis

- MDProperty View data on all parcels in Maryland
- Construct 500-m buffer around each flooded parcel
- Calculate % of flooded area of buffer that is wetlands
- Econometric model:
  - ❖ Use data for 8 tropical cyclones, 1996-2011
  - ❖ 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 meters)	Basic model	Hurricane-specific wetlands effects
Parcel elevation	0.0102	0.0102
	(0.00859)	(0.00862)
A zone	0.0855***	0.0858***
	(0.0232)	(0.0232)
V zone	0.0929***	0.0935***
	(0.0255)	(0.0256)
Buffer area flooded (as fraction of total buffer area)	1.008***	1.005***
	(0.172)	(0.174)
Open water in flooded area of buffer (as fraction of flooded area)	-0.255	-0.256
	(0.143)	(0.144)
Wetlands in flooded area of buffer (as fraction of flooded area)	-0.189	-0.368**
	(0.123)	(0.153)
*Wetlands in flooded area of buffer*Fran*		0.250***
		(0.0531)
*Wetlands in flooded area of buffer*Dennis*		0.119
		(0.0777)
*Wetlands in flooded area of buffer*Floyd*		0.104
		(0.0788)
*Wetlands in flooded area of buffer*Isabel*		0.289***
		(0.0535)
*Wetlands in flooded area of buffer*Ernesto*		0.0341
		(0.0191)
*Wetlands in flooded area of buffer*Hanna*		0.233***
		(0.0368)
*Wetlands in flooded area of buffer *Irene*		0.209***
		(0.0524)
Constant	-0.204*	-0.201**
	(0.0863)	(0.0830)
Hurricane FEs	yes	yes
Observations	292,622	292,622
R-squared	0.220	0.221

Robust SEs in parentheses.
****p<0.01, **p,0.05, *p<0.10*

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Value of Protective Service, by storms

Hurricane	Marginal Value of Wetlands, per acre
Bertha	$48
Fran	$105
Dennis	$106
Floyd	$138
Isabel	$90
Ernesto	$118
Hanna	$35
Irene	$204

Differences across hurricanes due to:

- Hurricane intensity & track
- Estimated relationship between wetland area and surge heights, by parcel
- Property values

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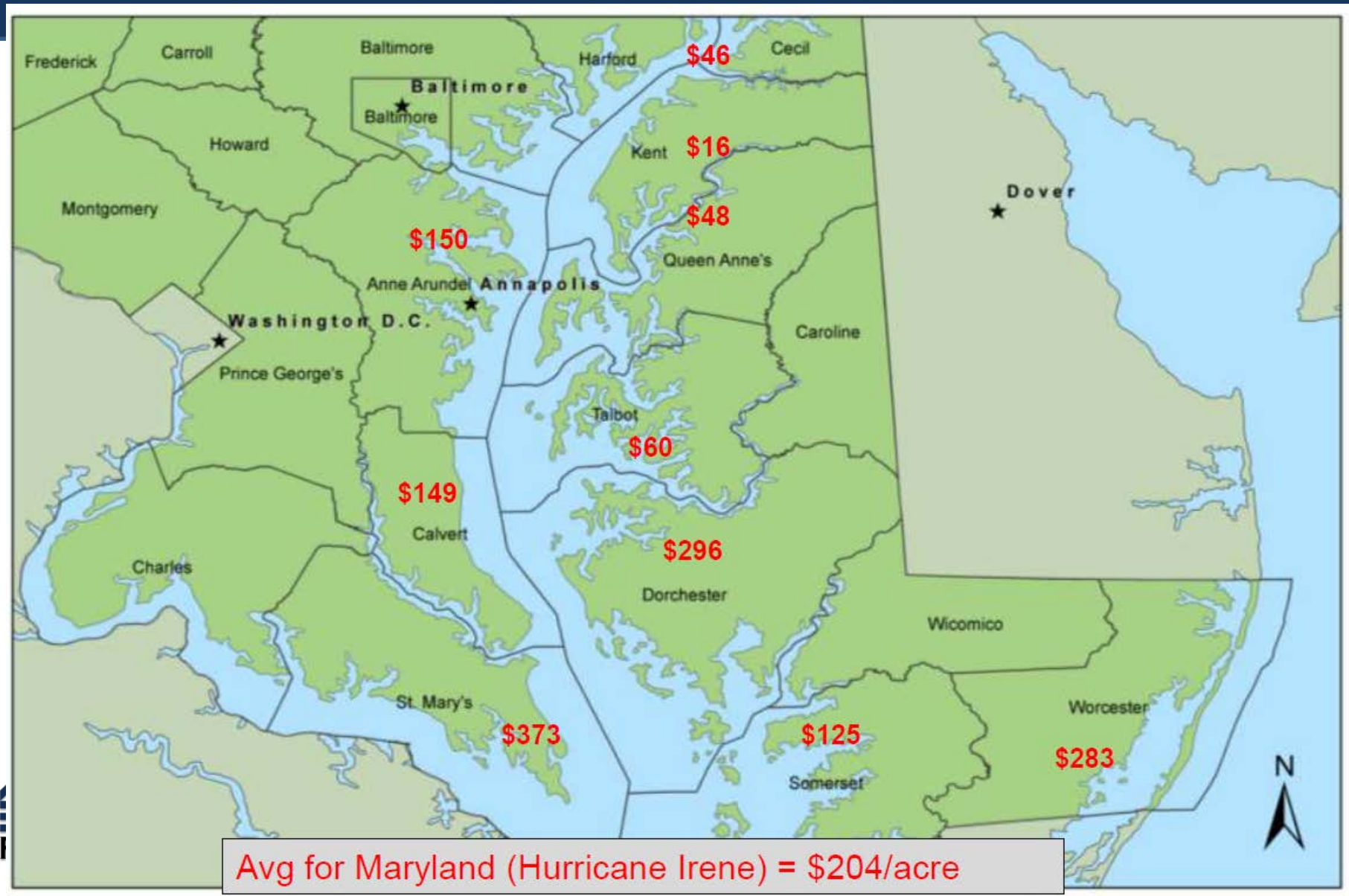
Value of Protective Services, by County



Avg for Maryland (Hurricane Irene) = $204/acre

Conclusions

(1) Wetlands in the Chesapeake Bay region provided protective services ranging in value from $55 to $454 million;

(2) The value is highest in the worst hurricanes; this means that wetlands may become increasingly valuable with climate change;

(3) The value also varies significantly across the landscape; zero to values as high as $14 million per census tract in Hurricane Isabel.

(4) Higher rate of SLR and marsh migration will cause a rapid increase in flood damage.

(5) Value of lost wetlands = $132/acre

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Future steps…

- Short Run:
  - Economic regressions: Alternative buffer sizes (1000-m)
  - Sensitivity of results to depth-damage functions
  - Valuation of protective services for future scenarios

- Longer Run:
  - Incorporation of erosion based damage due to hurricane
  - Targeting new wetlands conservation areas: i.e. Virginia

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Thank you!

Email: chu@rff.org

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