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Assessing extreme sea levels in the North Atlantic basin

Sanne Muis, Ning Lin, Martin Verlaan, Hessel Winsemius, Philip Ward & Jeroen Aerts

Areas around the world experience devastating impacts due to coastal flooding

Why assess coastal flood hazard at the global scale?

- Societal risks are increasing globally
  - Increasing number of people and assets located in the coastal zone
  - Increasing sea levels and changes in storminess due to climate change

- Global modelling can provide essential information for flood risk management
  - Global hazard and flood risk mapping
  - Project future flood risk
  - Impacts of ongoing events (anywhere)

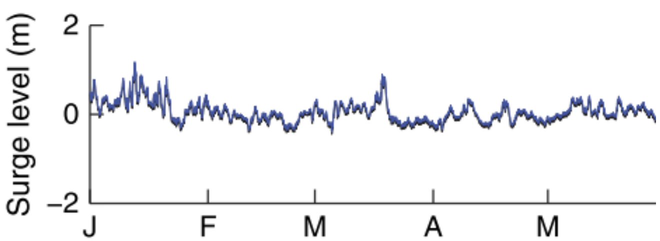
Global model framework to assess flood risk

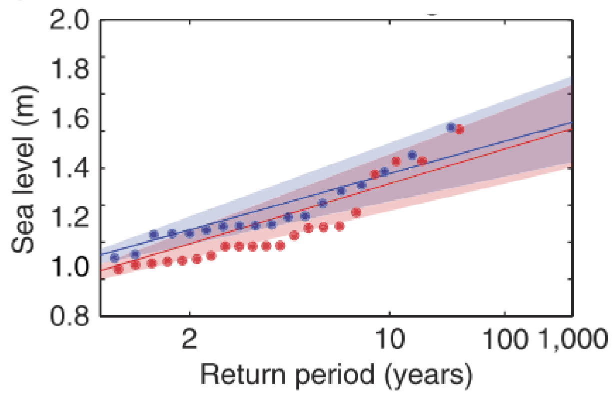
FES2012 → **Tides**

U10 and MSLP → **GTSM** → **Surges**

ERA-Interim, 1979-2014

Tides + Surges → **Total water levels** → **Annual maxima** → **GEV** → **Gumbel parameters** → **Inundation and impact model** → **Flood risk**





Flood risk

Number of people exposed, average annual damages etc.

Global modelling of storm surge

Global Tide and Surge Model (GTSM)

- Hydrodynamic model based on Delft3D-FM
- Computational power is used there where it is most needed..
  - Unstructured grid which is locally refined in shallow areas
  - Resolution ranges from 5 km in shallow areas to 50 km in deep ocean

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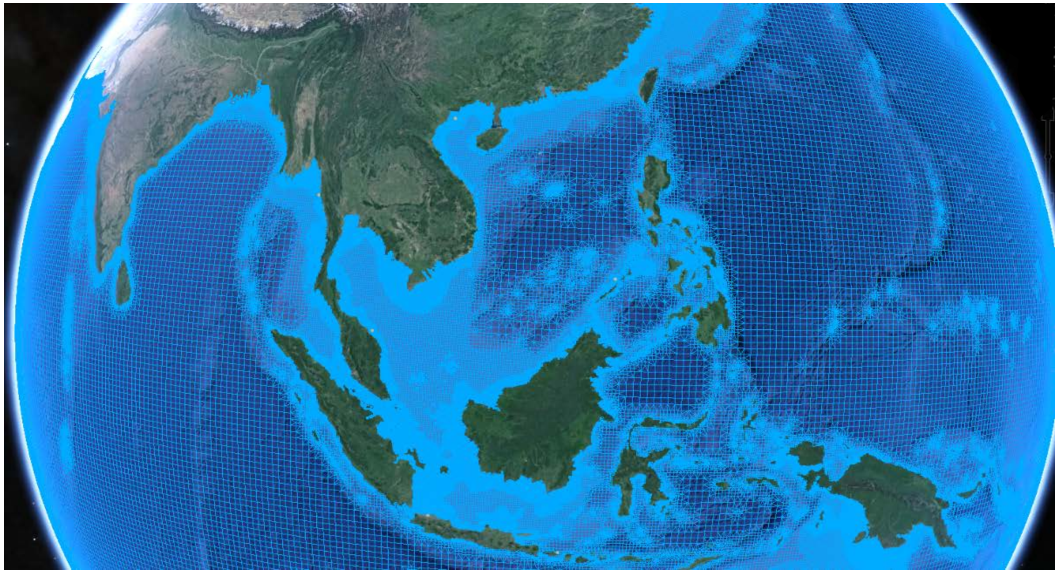

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Global Reanalysis of Tide and Surges (GTSR)

First global coastal dataset that

- based on a hydrodynamic model approach
- has been extensively validated
- provides daily time series surge, tide and total sea levels
- provides Gumbel parameters to estimate return periods

Return periods are freely available

A global reanalysis of storm surges and extreme sea levels

Sanne Muis[1], Martin Verlaan[2,3], Hessel C. Winsemius[2], Jeroen C.J.H. Aerts[1] & Philip J. Ward[1]

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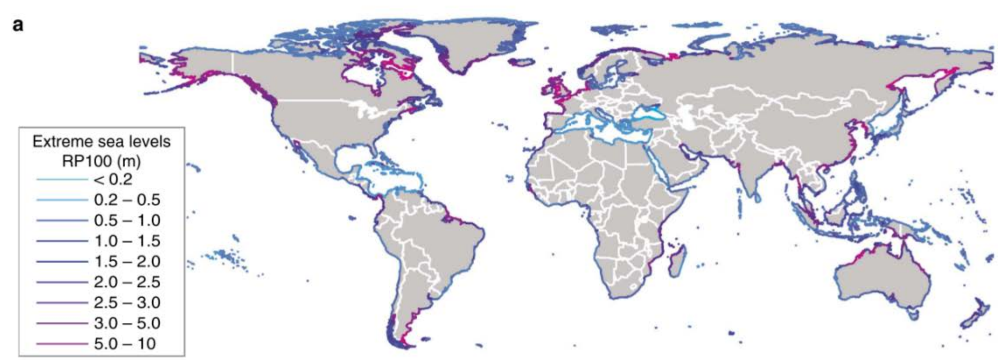
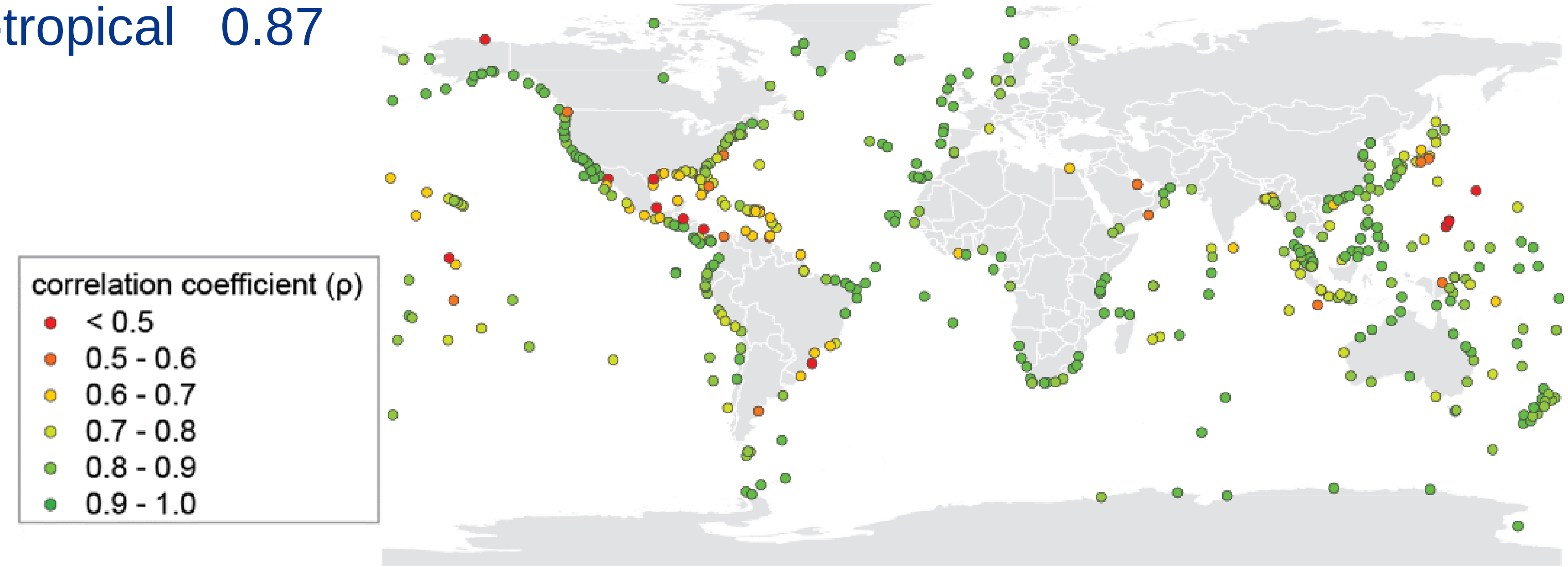


Validation of GSTR

Good agreement model and observations [1]

- Underestimation of extremes in tropical regions
- Better performance at mid-latitudes, indicated by higher correlation
  - Tropical 0.77
  - Extra-tropical 0.87



[1] Obtained from the archives of the University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu)

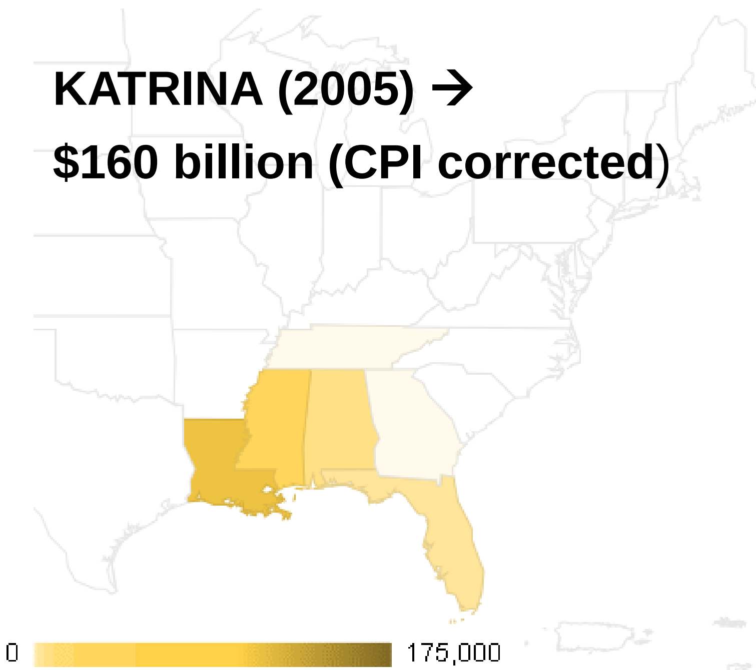
Limitations of GTSR

Underrepresentation of tropical cyclones (TCs)

- TCs are responsible for the most damaging storm surges
- Underestimation of risk in regions prone to TCs

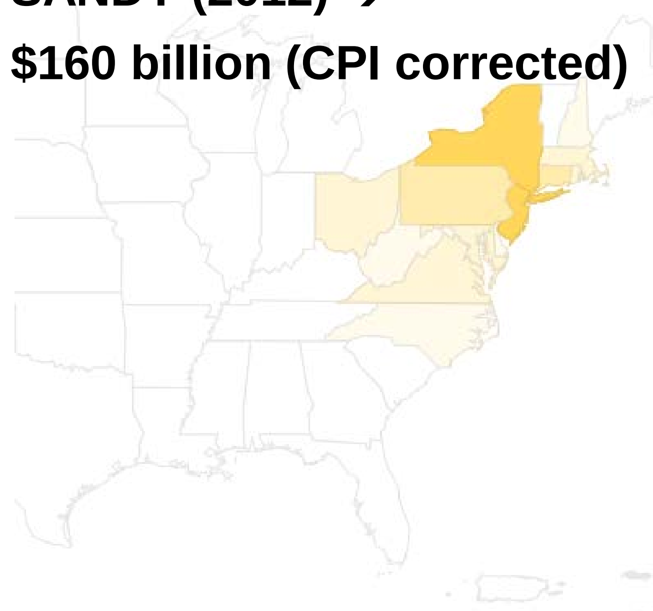
KATRINA (2005) →

$160 billion (CPI corrected)



SANDY (2012) →

$160 billion (CPI corrected)



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SOURCE: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2017).

Assessing historical sea levels in the North-Atlantic

Goal

- To develop a data set with historical extreme sea levels, including TC surges, for the North Atlantic basin

Approach

- Need for higher-resolution meteorological forcing
- Explicit modeling of TC winds to improve the simulation of TC surge

Improved model framework to assess water levels

FES2012 → **Tides**

U10 and MSLP → **GTSM** → **Surges**

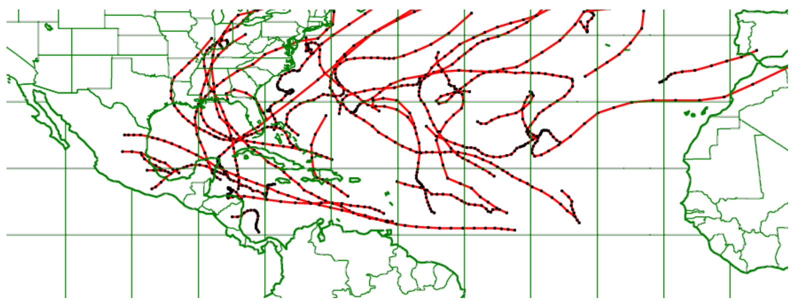
ERA-Interim, 1988-2016

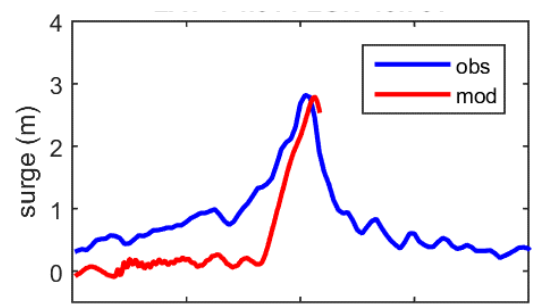
U10 and MSLP → **GTSM** → **TC Surges**

U10 and MSLP ↓ **Holland** ↓ **TC tracks**

EBTRCS, 1988-2016

Tides + **Surges** + **TC Surges** → **Total water levels**





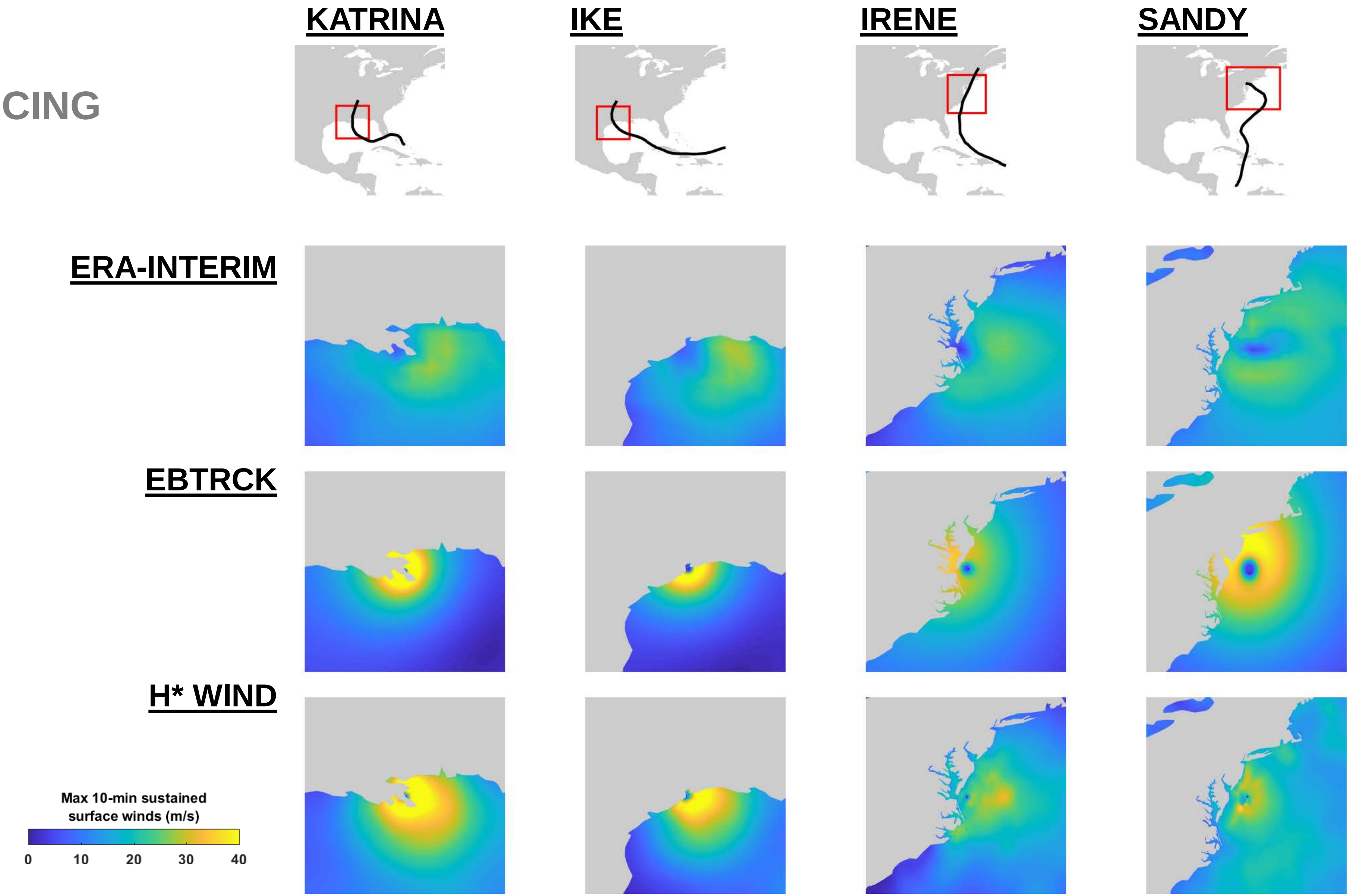
Data: Extended Best Track data (1988-2016)

Hurricane modelling: Holland parametric model

Adjustments based on Lin & Chavas 2012

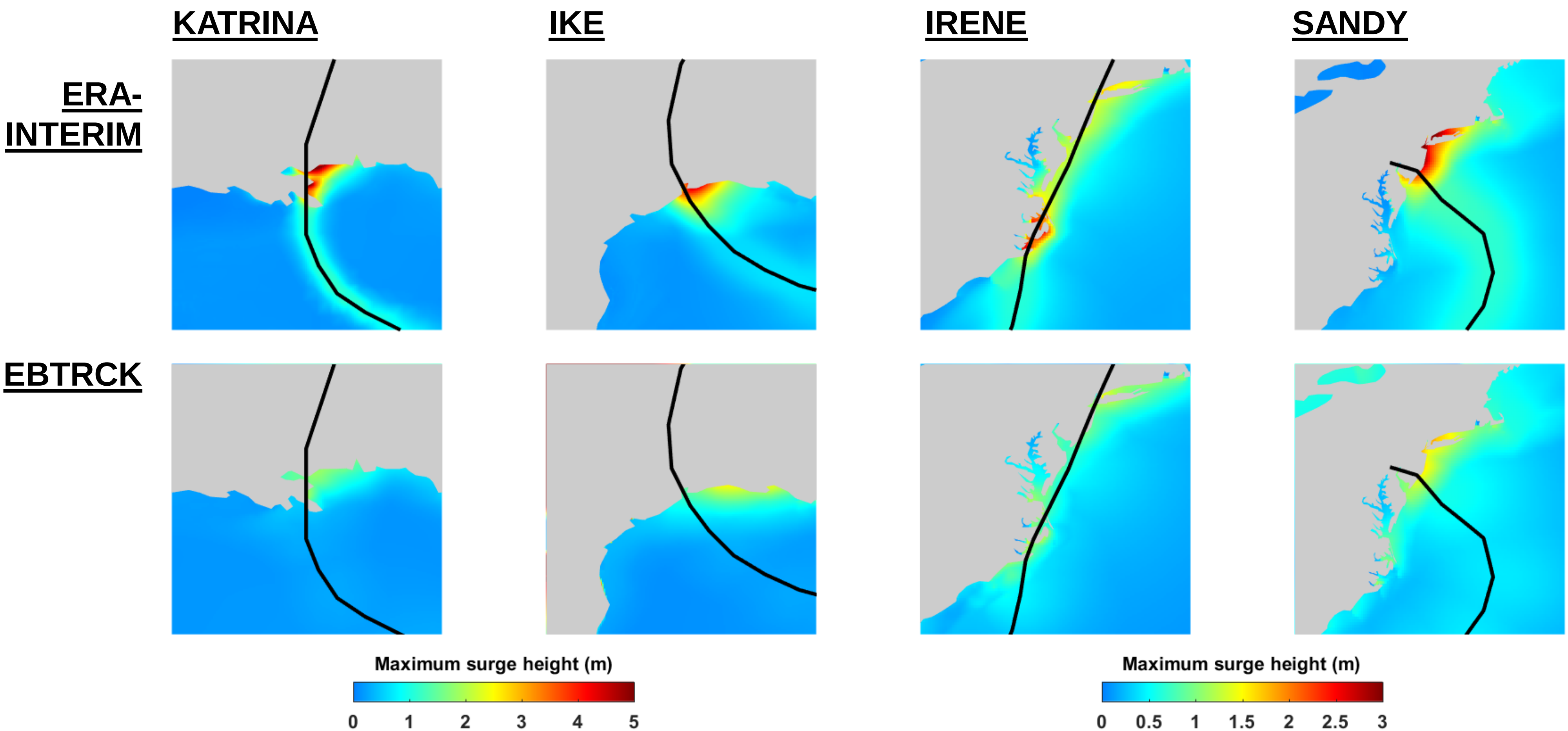
ERA-Interim vs. EBTRCK

WIND FORCING



ERA-Interim vs. EBTRCK

SURGE SIMULATIONS



Validation of major historical TC events

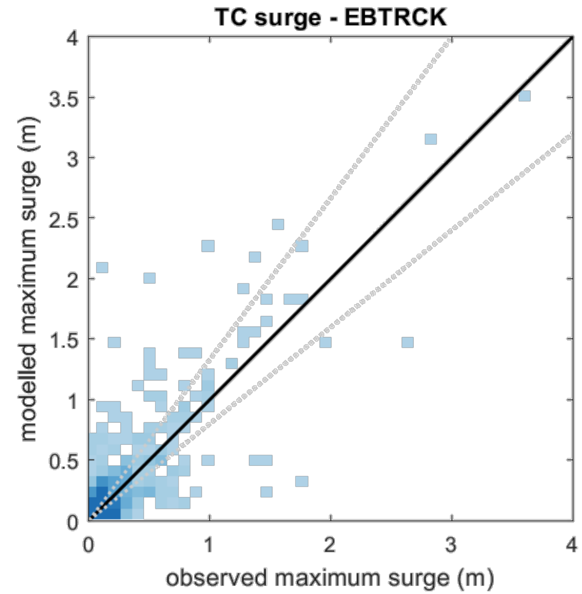
- Use of best track data performs much better than reanalysis data
- Spatial pattern coherent with NOAA tide gauges

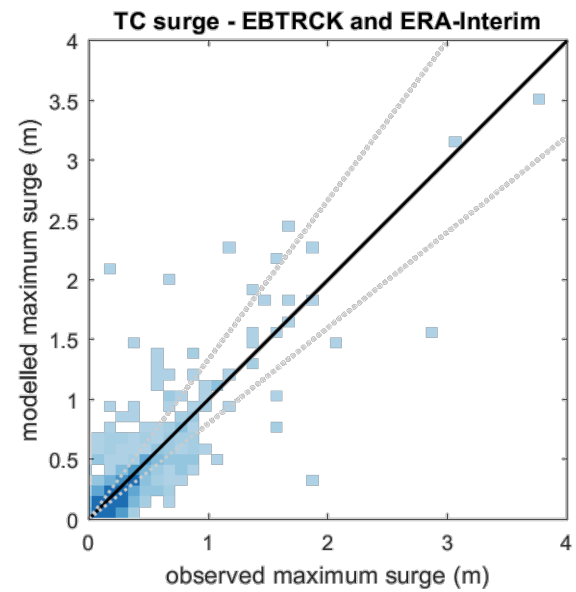
		Katrina	Ike	Irene	Sandy
EBTRCK	Mean bias (m)	-0.03	-0.25	0.19	0.06
	r^2	0.96	0.90	0.86	0.86
Era-Interim	Mean bias (m)	-0.12	-0.66	0.11	-0.18
	r^2	0.59	0.69	0.77	0.82
Number of tide gauges within 250 km radius of the TC track		10	12	44	24

Validation of surge heights (1988-2015)

- Retrieving all observations within 250 km of the TC track results in 694 data points (~200 TCs)
- Good performance of EBTRCKS
- Merge EBTRCKS and ERA-Interim simulations by taking the highest surge height
- Slight improvement in performance

	EBTRCK	EBTRCK | EA-Interim
Mean bias (m)	0.04 S.D 0.17	0.06 S.D 0.13
r^2	0.84	0.84





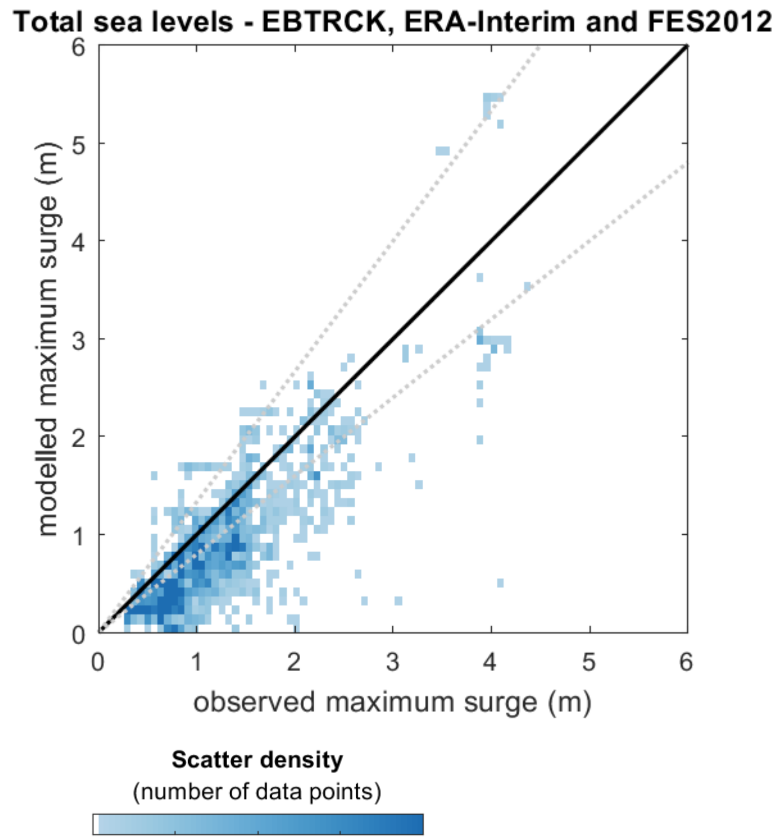
Scatter density
(number of data points)

Validation of total water levels (1988-2015)

- Retrieving all observations using POT → 980 data points
- Good agreement

Mean bias (m)	-0.19 S.D 0.30
r^2	0.89

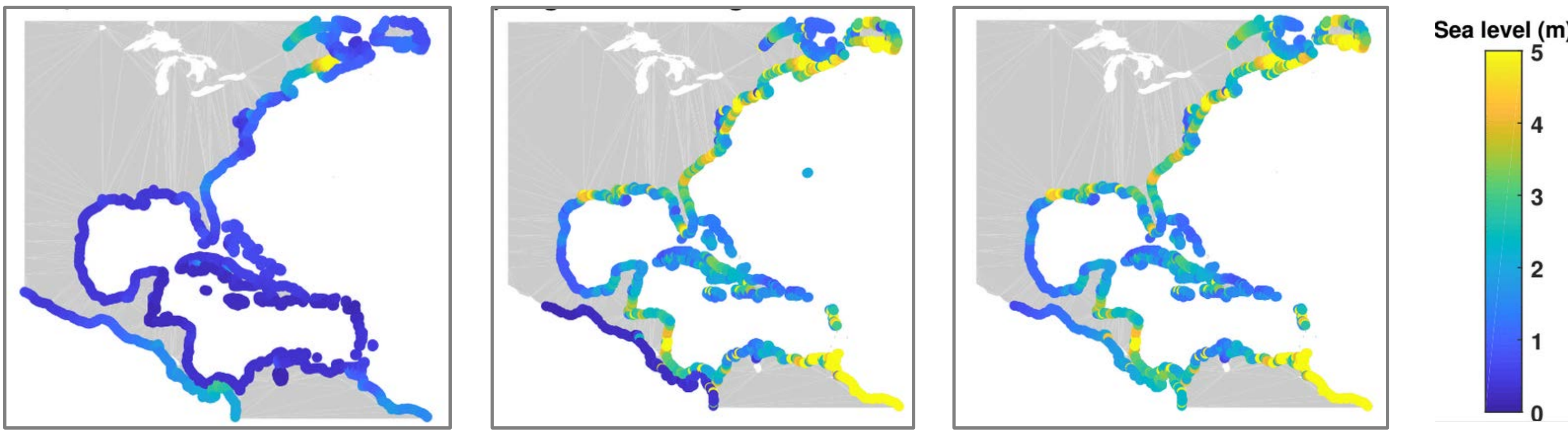
- Some of the observed maxima or not being reproduced by the model
  - Poorest model agreement in shallow and topographically more complex regions
  - Underestimation may be caused by exclusion of waves or problems with TC tracks



Understanding drivers of extreme sea levels

- Reanalysis of historical may help to improve understanding of extreme events
- Approach allows to differentiate between tides, ETC and TC surge as drivers of extreme sea levels

TIDES **SURGE** **TOTAL SEA LEVELS**

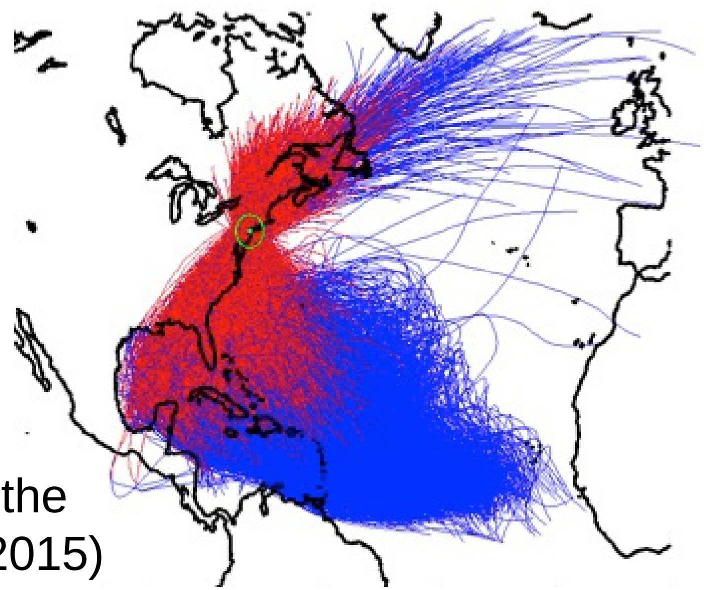


Towards assesing TC risk

- Modelling historical extreme sea show good performance
- Records are too short to reliably assess the probabilities of the most extreme events

Next steps

- Apply the model framework to synthetic TC tracks to assess probabilities of extremes sea levels



Synthetic tracks for the NYC region (Ning, 2015)

Summary

Global GTSR dataset

- 36-year reanalysis of extreme sea-levels for the coast
- Gumbel parameters from the GTSR dataset are freely available
- Good performance, but underestimation of TC surges

Improvements for the North-Atlantic

- Apply parametric wind model to TC track data
- Validation shows good performance of TC surge
- Approach combines the TCs and ETCs surges and tides
- Next step is to use synthetic tracks to assess exceedance probabilities for TCs and go towards a full risk assessment