CCRIF SPC
The Caribbean Catastrophe Risk Insurance Facility

Caribbean Regional Technical Workshop on CCRIF Models

The SPHERA TC risk model
A tropical cyclone wind and storm surge model for the Caribbean and Central America

With financial support from the European Union in the framework of the Caribbean Regional Resilience Building Facility, managed by the Global Facility for Disaster Reduction and Recovery (GFDRR)

CARIBBEAN REGIONAL RESILIENCE BUILDING FACILITY
A partnership funded by EUROPEAN UNION
GFDRR Global Facility for Disaster Reduction and Recovery
Administered by THE WORLD BANK IBRD • IDA | WORLD BANK GROUP

Outline

- Geographical area
- Introduction
- Exposure
- Hazard
- Vulnerability
- Loss computation and insurance scheme
- Real-time operation
- Updates 2023

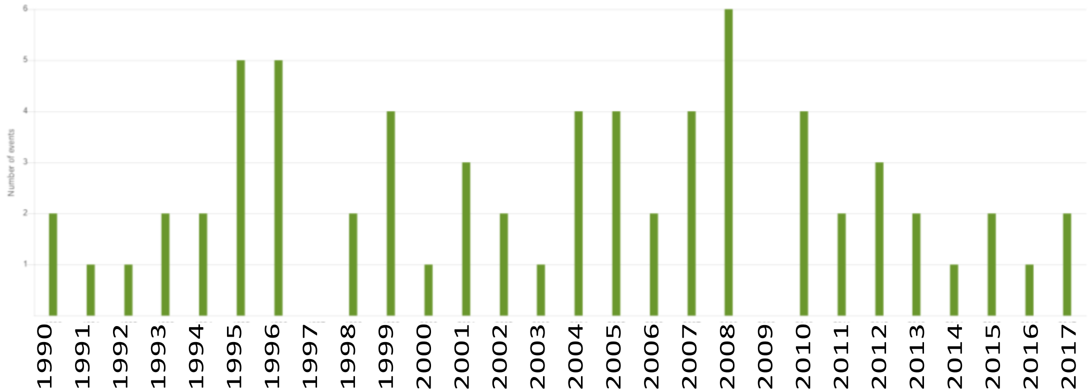
Geographical area

- Caribbean and Central America

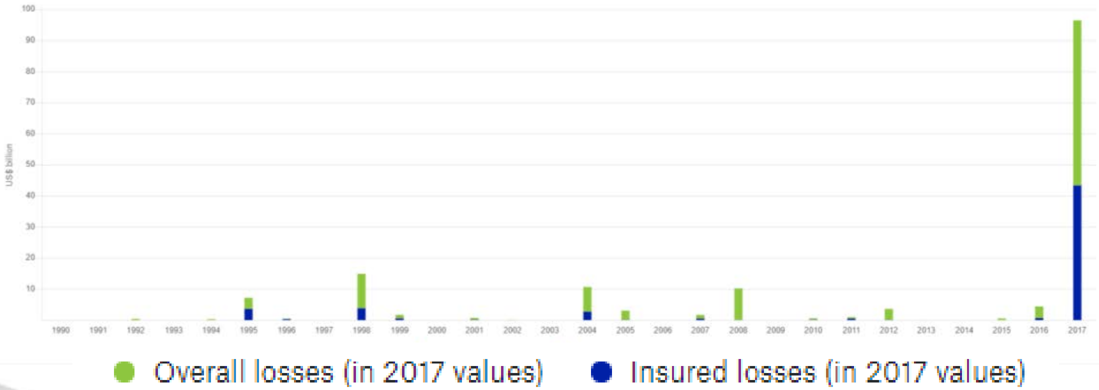
Introduction

- Tropical cyclones in the Caribbean

Number of tropical cyclones in the Caribbean (1990-2017)



Losses by TC in the Caribbean (1990-2017)

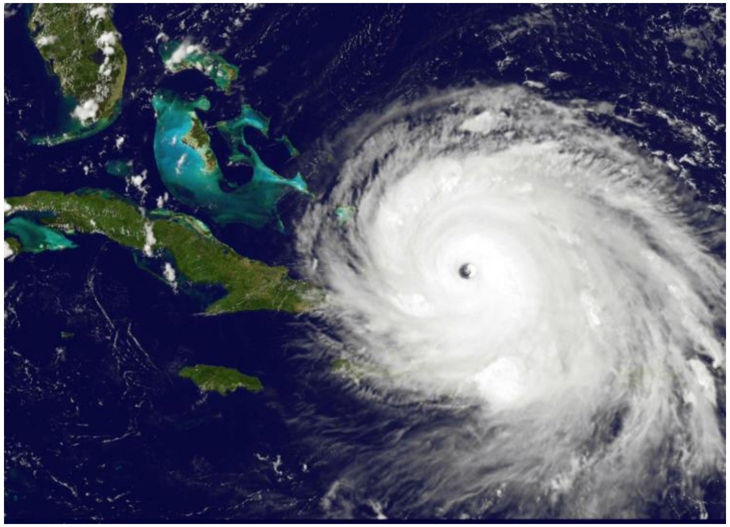


Geographical overview of tropical cyclones in the Caribbean (1990-2017)

Source: NatCatSERVICE Munich RE

Introduction

- Recent natural catastrophe have caused large damages in the Caribbean
  - 2019: TC Dorian
  - 2017: TC Irma and Maria
  - 2016: TC Earl, Matthew and Otto
  - 2015: TC Erika
  - 2014: TC Gonzalo
  - 2010: Haiti earthquake
  - ...
- Readily-available money is of paramount importance to start relief efforts and recovery operations



Hurricane Irma 2017

Earthquake Haiti 2010

Introduction

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- Parametric insurance can provide an additional income to catastrophe-hit countries
- CCRIF has pioneered the field of sovereign parametric insurance against tropical cyclone and earthquake losses

Introduction

- Caribbean and Central America TC model (SPHERA - System for Probabilistic Hazard Evaluation and Risk Assessment):
  - To be used by country-level institutions, e.g. governments
  - Provides payouts around two weeks after the event
  - Based on a physically-based wind and storm-surge models
  - Extensive and detailed asset exposure database (including buildings, infrastructure and crops)
  - Calibrated against reported losses of historical tropical cyclone events

Introduction

- SPHERA TC

EXPOSURE

HAZARD

VULNERABILITY

LOSS COMPUTATION

SPHERA exposure

System for Probabilistic Hazard Evaluation and Risk Assessment

SPHERA exposure

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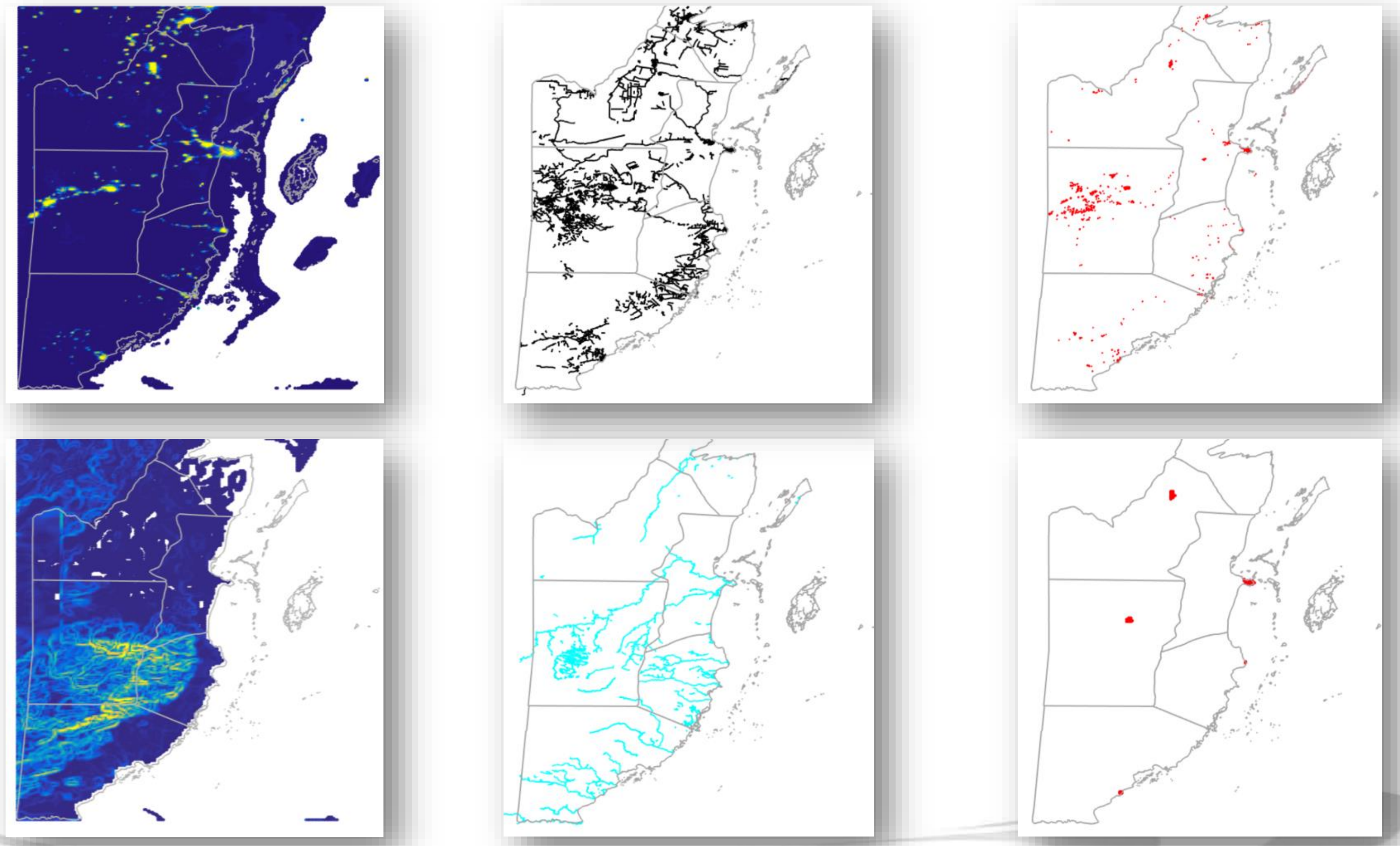
- The SPHERA exposure database is built and validated on country level census data, international pliterature, publicly available reports and databases and satellite images

SPHERA exposure

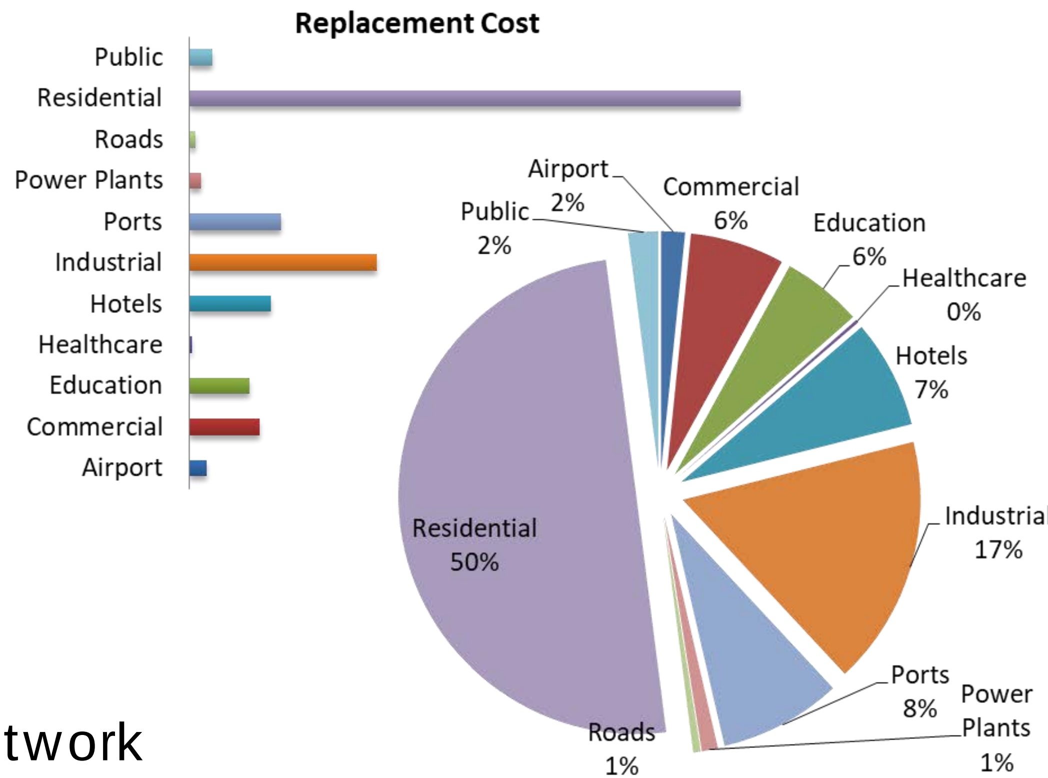
- The development of the model leveraged upon a large number of datasets such as:



SPHERA exposure

- Categories included:
  - Residential buildings
  - Commercial buildings
  - Public Buildings
  - Industrial facilities
  - Hotels and restaurants
  - Healthcare infrastructure
  - Energy Facilities
  - Education infrastructure
  - Airports and ports
  - Transportation (roads) network
  - Crops

Example: St Kitts and Nevis



SPHERA exposure

- Most common types of construction in each country
- Taxonomy defined to be used for different perils

Building Classes		
Code	Number of stories	Description
WL	1 - 2	Light wood members, low-rise
WS	1 - 2	Solid wood members, low-rise
WWD	1 - 2	Wattle and Daub, low-rise
A	1 - 2	Adobe construction, low-rise
UFM+LR	1 - 2	Unreinforced masonry, low-rise
SM	1 - 2	Stone masonry, low rise
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S+D+LR	1 - 2	Steel frame, ductile, low-rise
S+D+MR	3 - 6	Steel frame, ductile, mid-rise
S+INF+ND+LR	1 – 2	Steel frame, masonry infills, non-ductile, low rise
S+INF+D+LR	1 – 2	Steel frame, masonry infills, ductile, low rise
RC+INF+ND+LR	1 – 2	Reinforced concrete infilled frame, non-ductile, low-rise
RC+INF+ND+MR	3 – 6	Reinforced concrete infilled frame, non-ductile, mid-rise
RC+INF+ND+HR	> 7	Reinforced concrete infilled frame, non-ductile, high-rise
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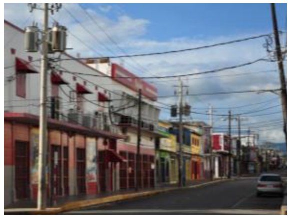
UNK	ND	Unknown and informal construction

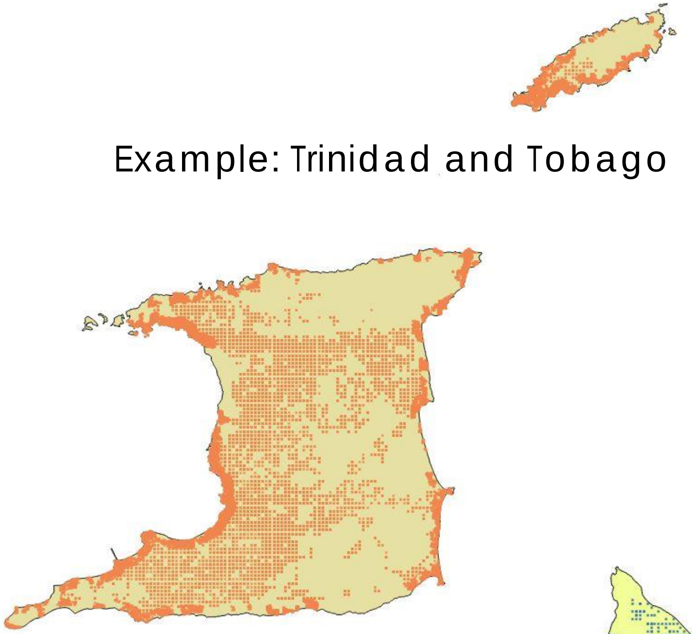




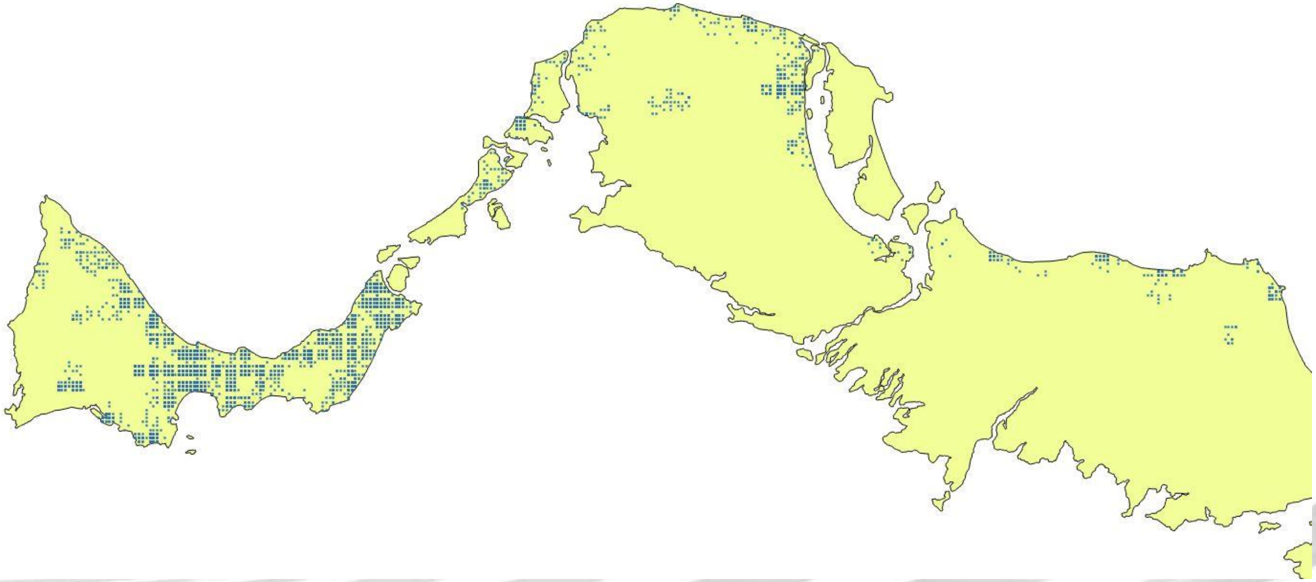
SPHERA exposure

- 1x1 km resolution for internal areas
- 100x100m or 200x200m (depending on the info available) for coastal areas



Example: Trinidad and Tobago

Example: Turks and Caicos



SPHERA exposure

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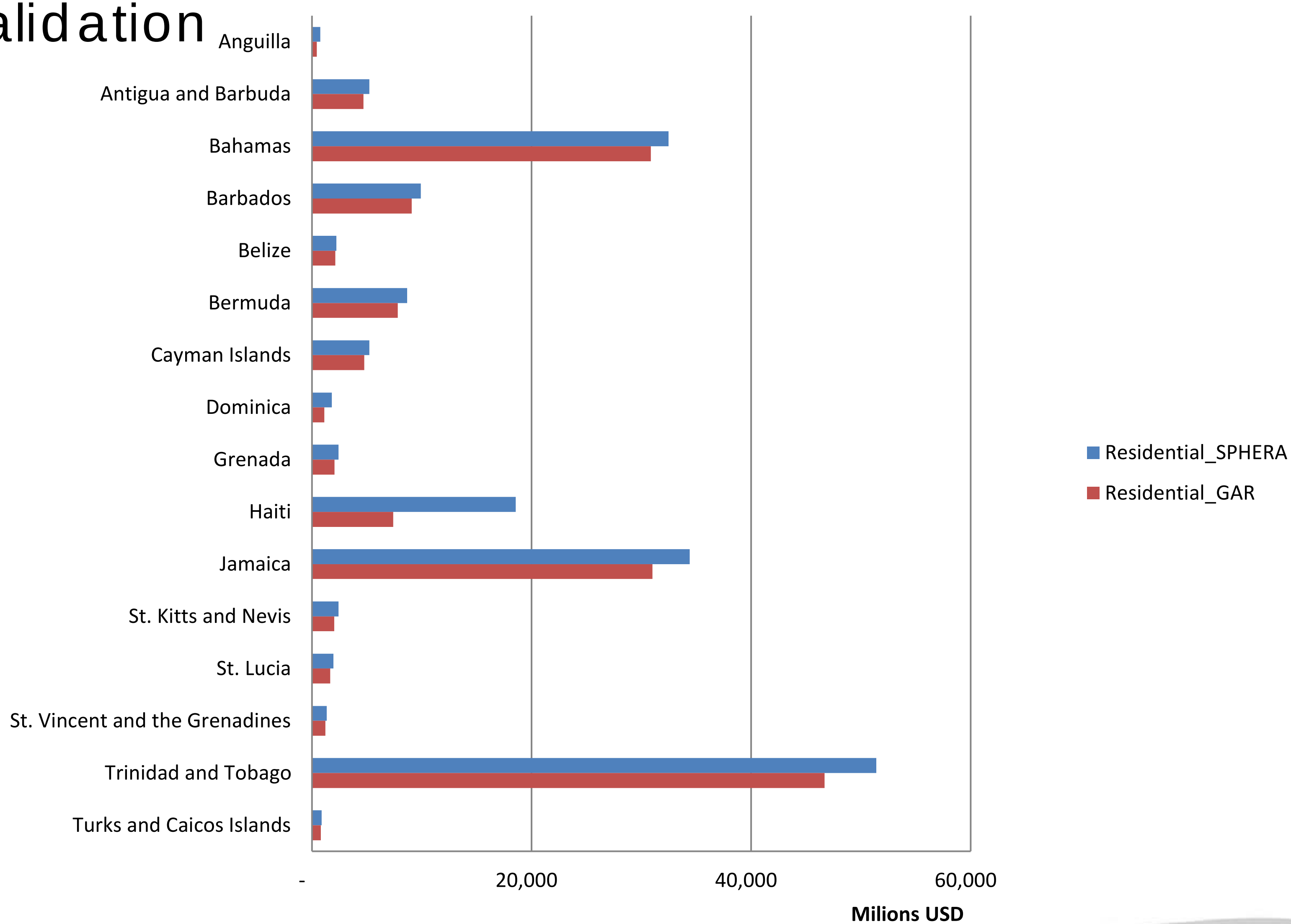
- Validation



SPHERA TC hazard

System for Probabilistic Hazard Evaluation and Risk Assessment

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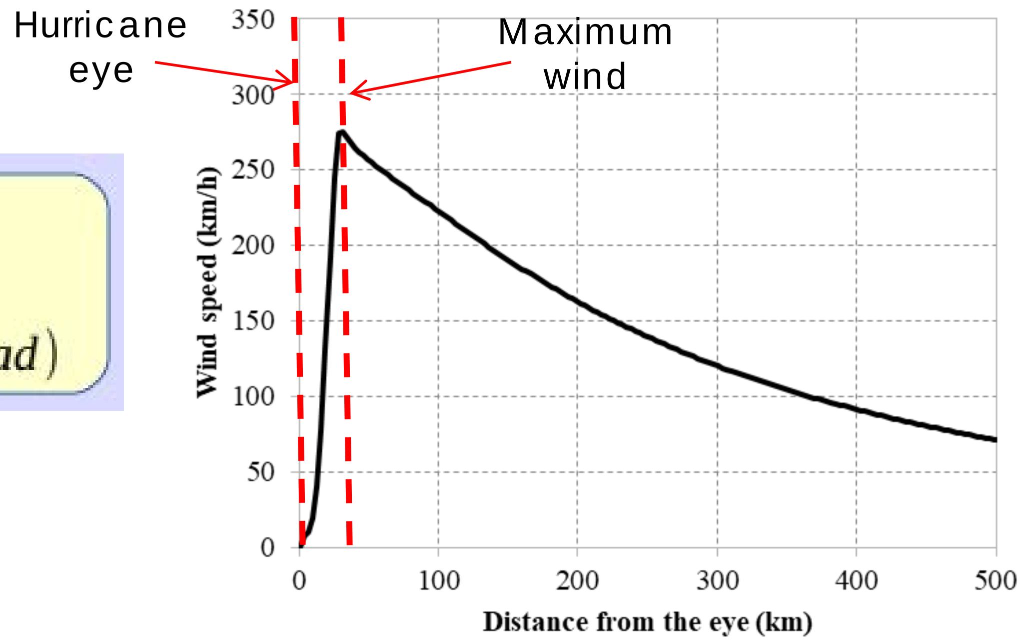
TC hazard

- Wind model:
  - Model selected: Silva et al. (2002):
    - Recent and state-of-the-art
    - Already developed and tested for Mexico
  - Parametric model, function of:
    - Cyclone position
    - Cyclone forward speed
    - Maximum wind speed/minimum atmospheric pressure
    - Radius of maximum wind

TC hazard

- Silva extreme wind model:
  - Wind profile function of pressure, radius of maximum wind and Coriolis force
  - Translational and rotational speed combined
  - Roughness effect considered

$$U_R = 21.8\sqrt{P_N - P_0} - 0.5 fR$$
$$P_N = 1013\,mb\,;\, f = 2\,w\sin(\varphi)\,;$$
$$w = 0.2618\,(rad/h)\,;\, \varphi = latitude\,(rad)$$

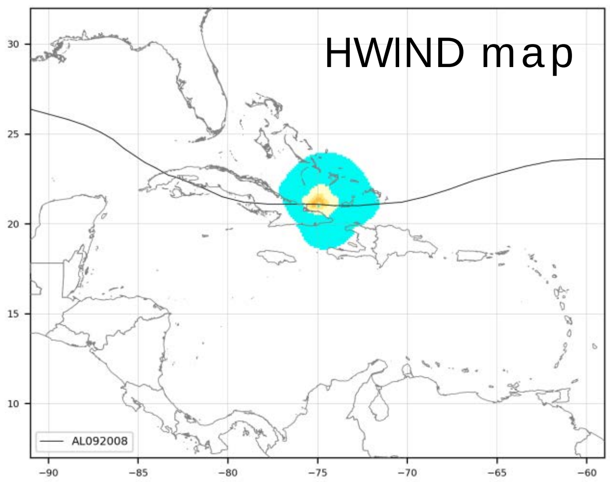


TC hazard

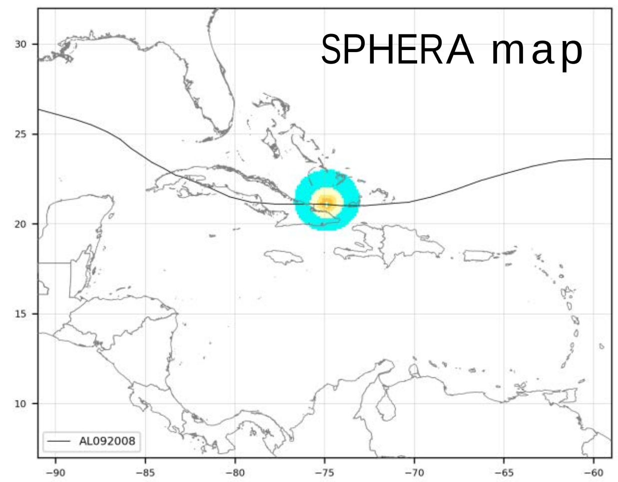
- Wind model validation (AL092008, 07/09/2008 22:30)

Ike

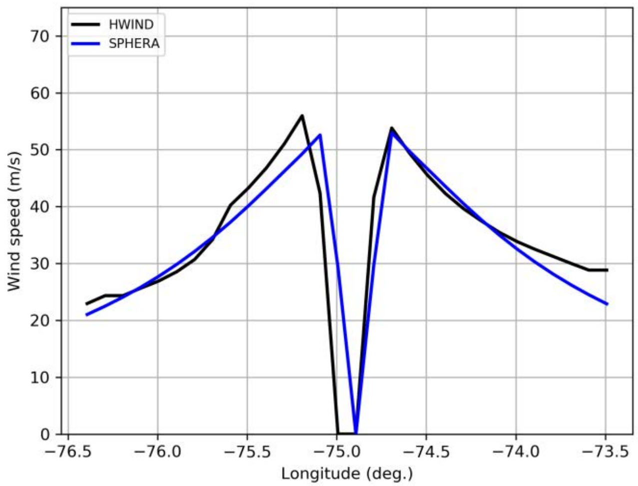
HWIND AL092008_0907_2230



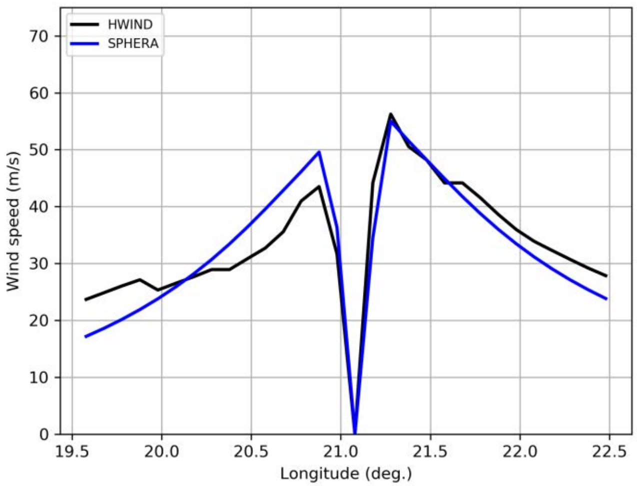
sphera_UR=f(Vmax)_f05_nozeroeye AL092008_0907_2230



AL092008_0907_2230 E-W cross-section



AL092008_0907_2230 N-S cross-section

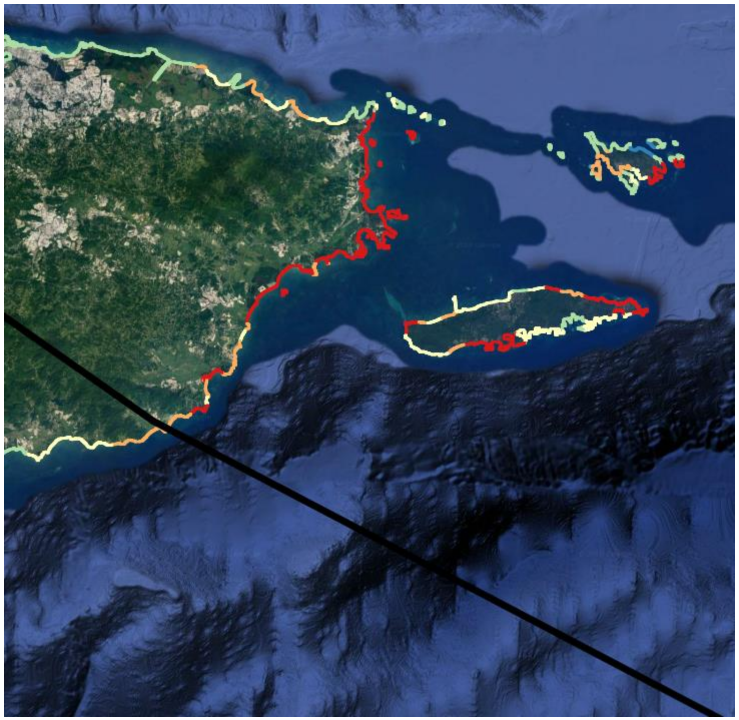


TC hazard

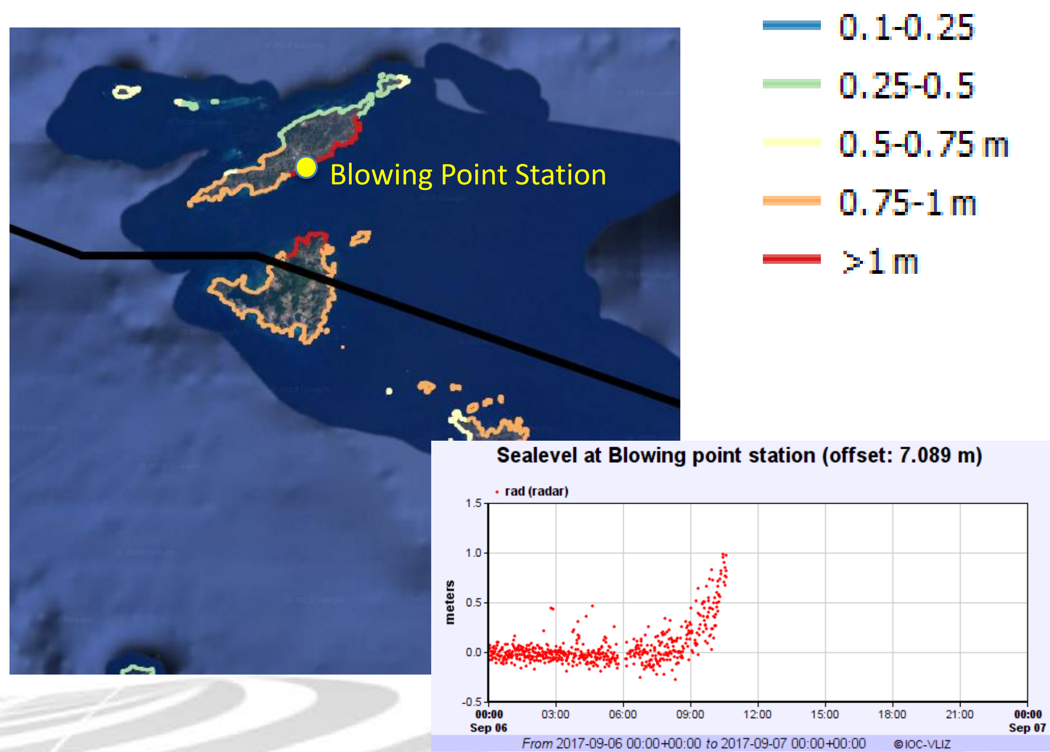
- Storm surge model: GEOCLAW
  - Based on ClawPack, a collection of state-of-the-art finite volume methods for resolving conservation laws
  - Well established model (by UniWashington/Columbia) for storm surge, tsunami, dam break and other geophysical flows
  - Completely free and open source
    - No licence limitations
    - It can be easily modified and adapted
  - Adaptive Mesh Refinement: the space and time resolution is automatically changed during the simulation
    - Much faster compared to other models
    - No need to run the model on several nested domains

TC hazard

- GeoClaw results example:



Hurricane Maria (2017)
in Eastern Puerto Rico

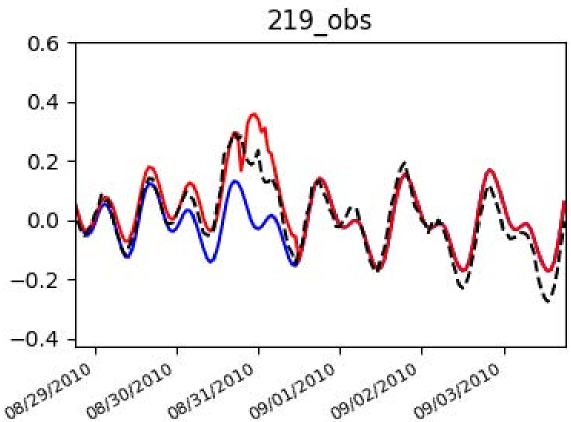


Hurricane Irma (2017)
in Anguilla and Saint-Martin/Sint Maarten

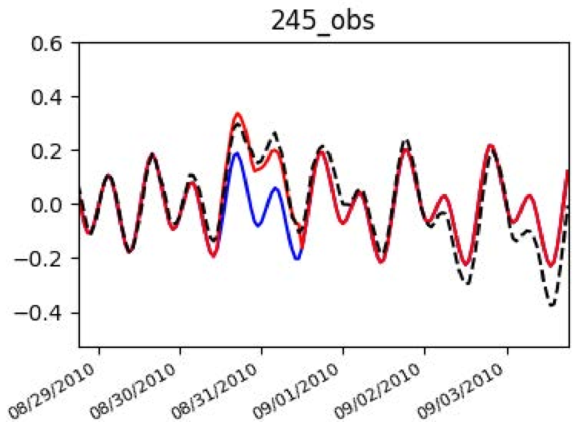
TC hazard

- Validation
  - Earl 2010

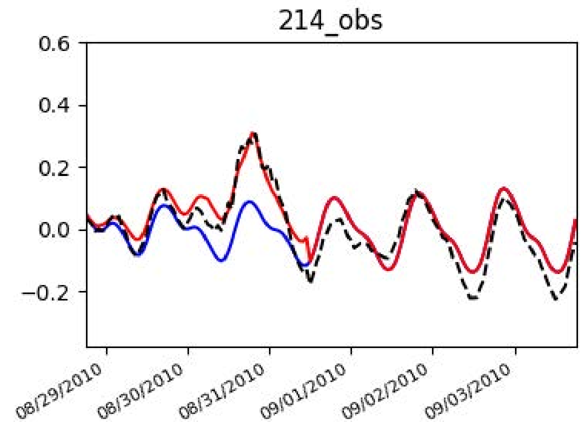
Observed level (m)
Simulated level (m)
Astronomical tide (m)



Culebra, PRI

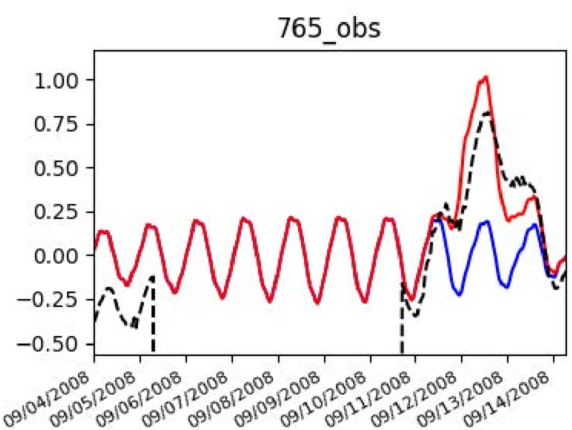


San Juan Puerto Rico, PRI

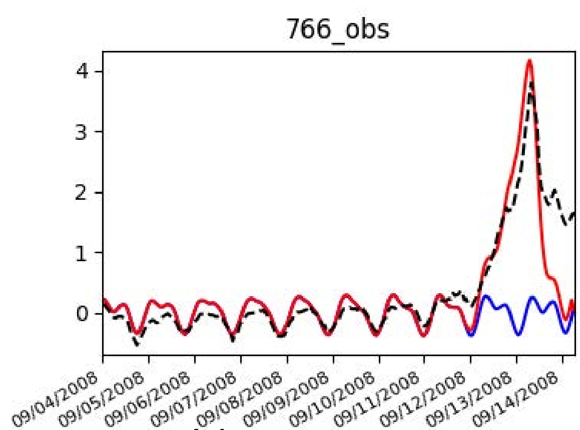


Lameshur Bay, USVI

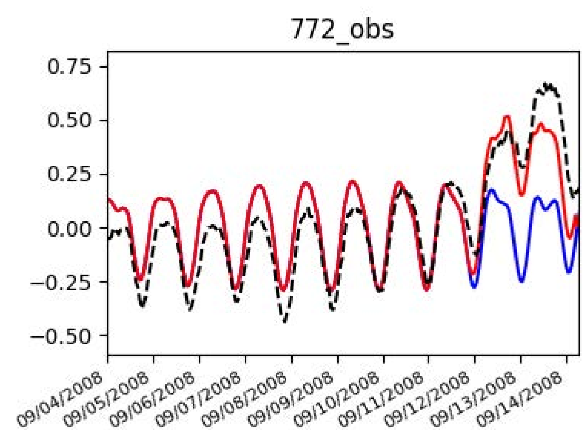
  - Ike 2008



Grand Isle, US



Sabine Pass, US



Port Isabel, US

TC hazard

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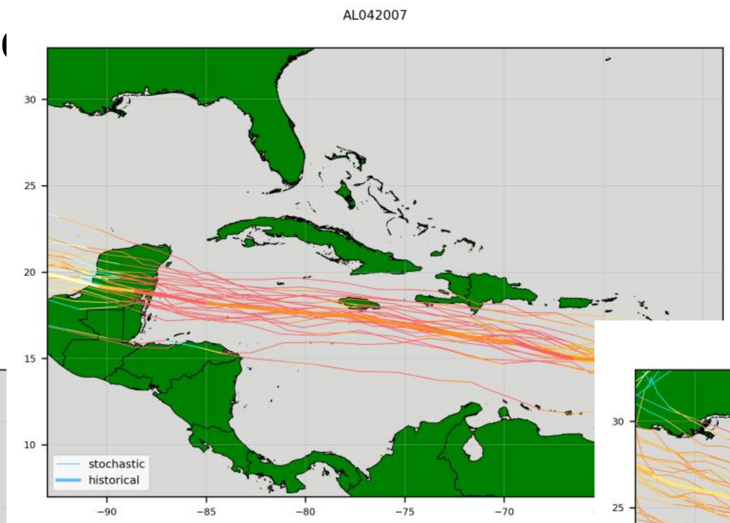
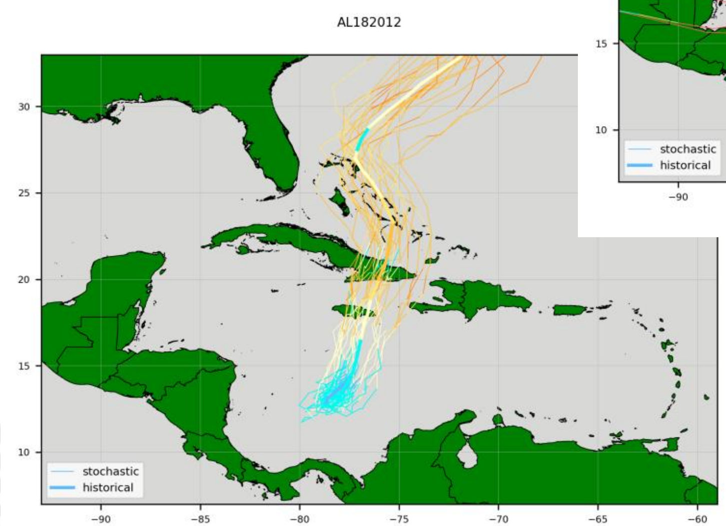
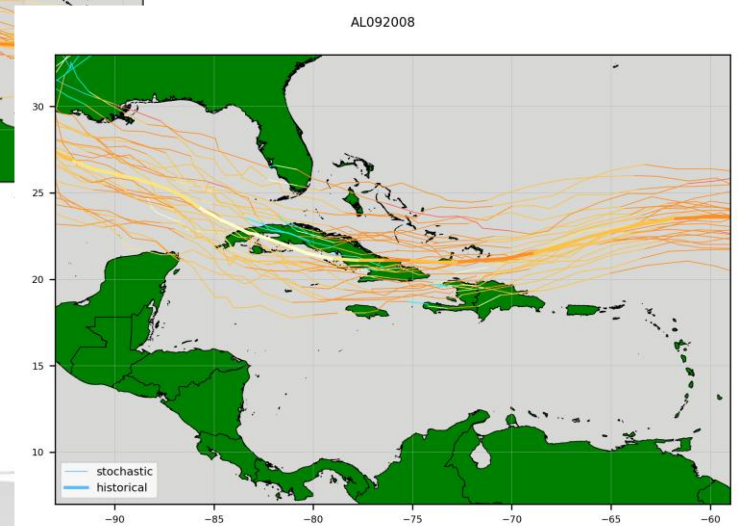
- Stochastic catalogue: very large number of theoretical events for risk assessment – UPDATED for 2023 policy cycle
  - The statistical properties of the stochastic cyclones are the same as the observed hurricanes (path, pressure variation, wind velocity, (







SPHERA TC vulnerability

System for Probabilistic Hazard Evaluation and Risk Assessment

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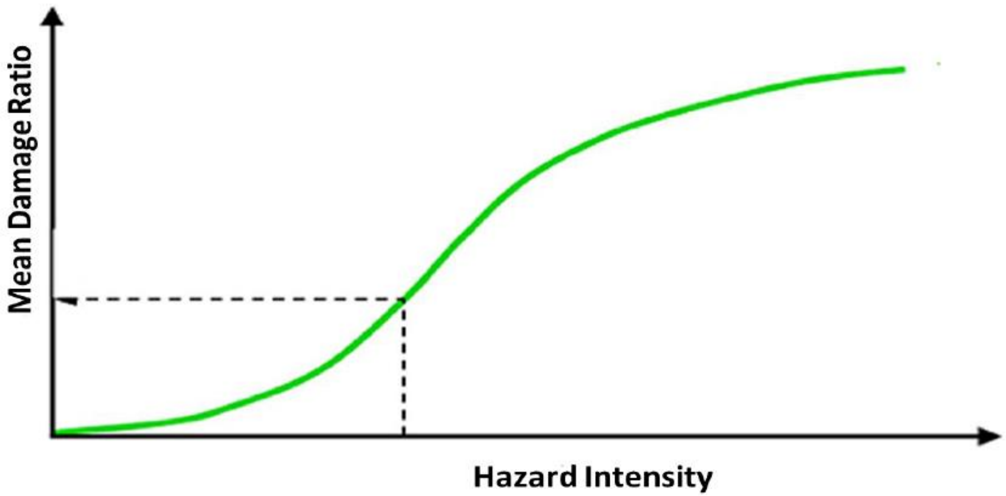
TC vulnerability

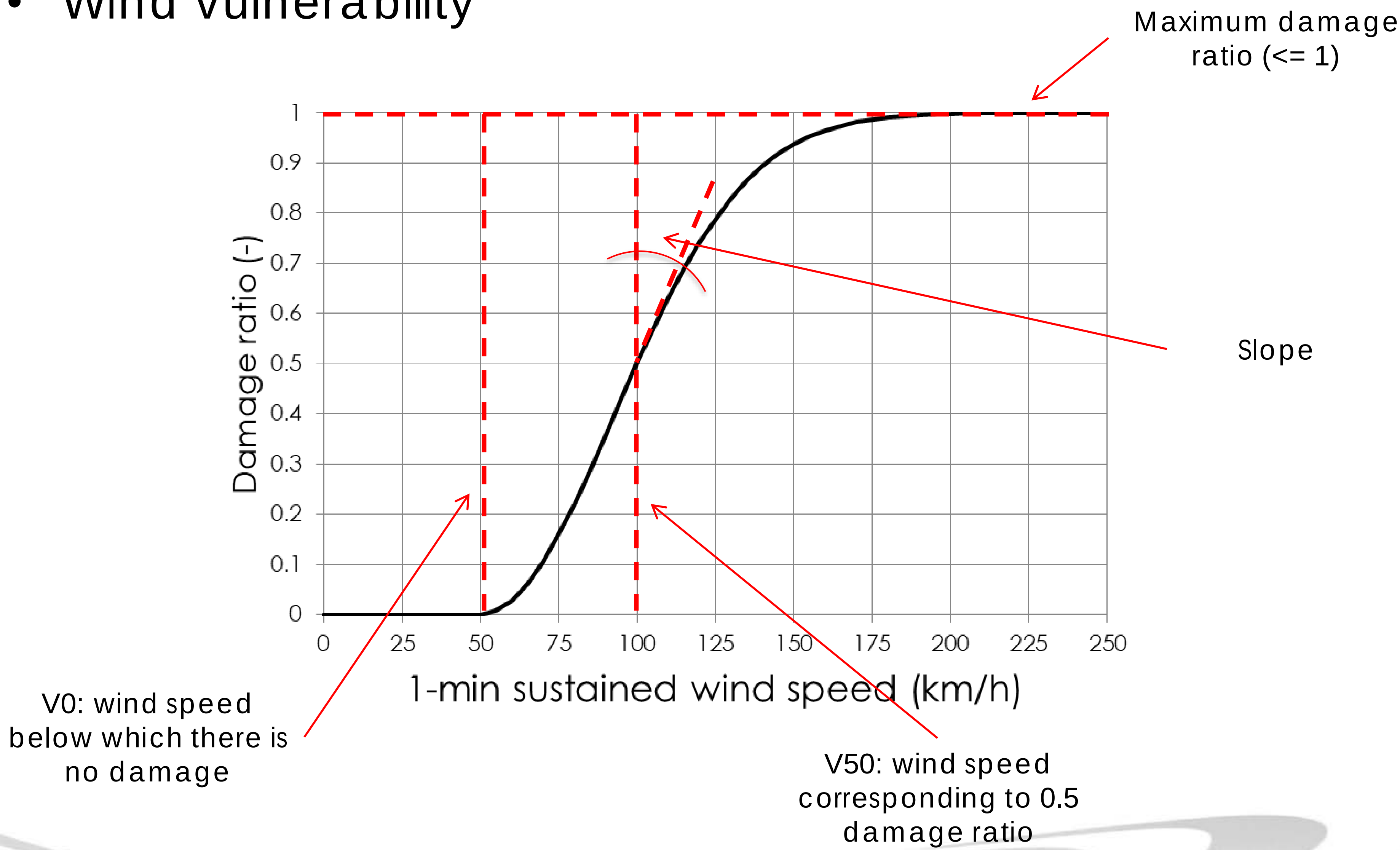
- Vulnerability:
  - Susceptibility of an asset (building, infrastructure, crop) to be damaged by a certain natural phenomenon
  - Usually expressed through damage curves



  - Mean damage ratio (MDR): repair cost divided by replacement cost of the structure

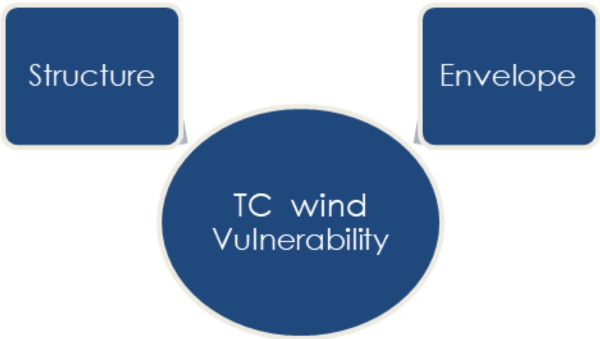
TC vulnerability

- Wind vulnerability



TC vulnerability

- Wind vulnerability



Types of envelope

Roof_shape	Arch
	Gable
	Hip
	Complex
	Flat/Monopitch
Roof_material	Sheet Metal/Eternite
	Shingle/Tiles
	Concrete
	Makeshift/Thatched
	Unknown
Shutter	None
	Present
Wall Opening	Windows <70% of walls
	Windows >70% of walls
	Walls without windows
	Open walls

Types of structure

Code	Number of stories	Description
WL	1 - 2	Light wood members, low-rise
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UNK	ND	Unknown and informal construction

TC vulnerability

- Storm vulnerability vulnerability
  - Dottori, F., et al., 2016. *INSYDE: a synthetic, probabilistic flood damage model based on explicit cost analysis*. Nat. Hazards Earth Syst. Sci. 16, 2577–2591
  - It takes into account:
    - hazard properties at the building locations (e.g., water depth)
    - characteristics of the exposed buildings (e.g., structural type)
    - replacement cost
  - Damage mechanisms of each building component described through a what-if analysis
  - Correction for coastal flood preparedness

SPHERA loss computation and insurance scheme

System for Probabilistic Hazard Evaluation and Risk Assessment

Risk assessment

- Losses for every asset *i*:

$$L_i = V_i(H_i) \times E_i$$

  - L_i: losses on asset *i* (USD)
  - H_i: hazard on asset *i*(USD)
  - $V_i(x)$: vulnerability curve of asset *i* (0-1)
  - E_i: exposure of asset *i*(USD)

- Problem: two concurrent perils (wind and storm surge
- Total losses ≠ losses by wind + losses by storm surge

Risk assessment

- Loss probability curves are generated from the results in the long-term loss event set

Event	Loss
1	Loss $_1$
2	Loss $_2$
3	Loss $_3$
⋮	⋮
n	Loss $_n$

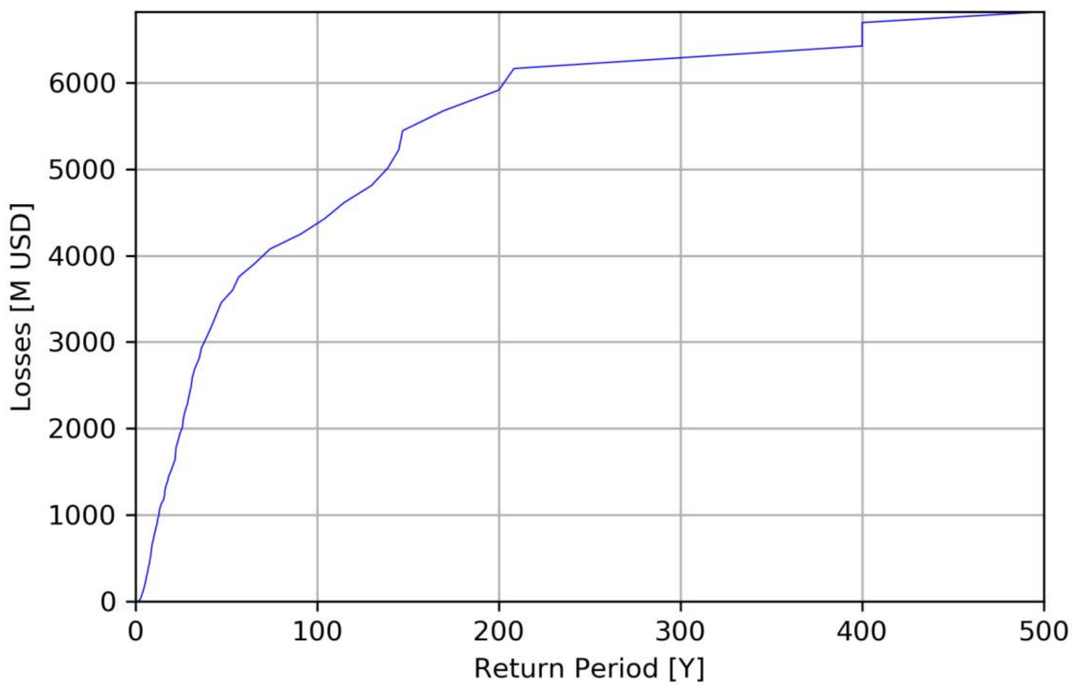
$$\textbf{Annual Probability of Exceedance of "Loss A"} = \frac{\text{Number of times Loss A has been exceeded}}{\text{Number of Years}}$$

$$\textbf{Return period of "Loss A"} = \frac{\text{Number of Years}}{\text{Number of times Loss A has been exceeded}}$$

Risk assessment

- Risk assessment:
  - Estimate the likelihood of losses exceeding a threshold
  - Example: exceedance probability curve

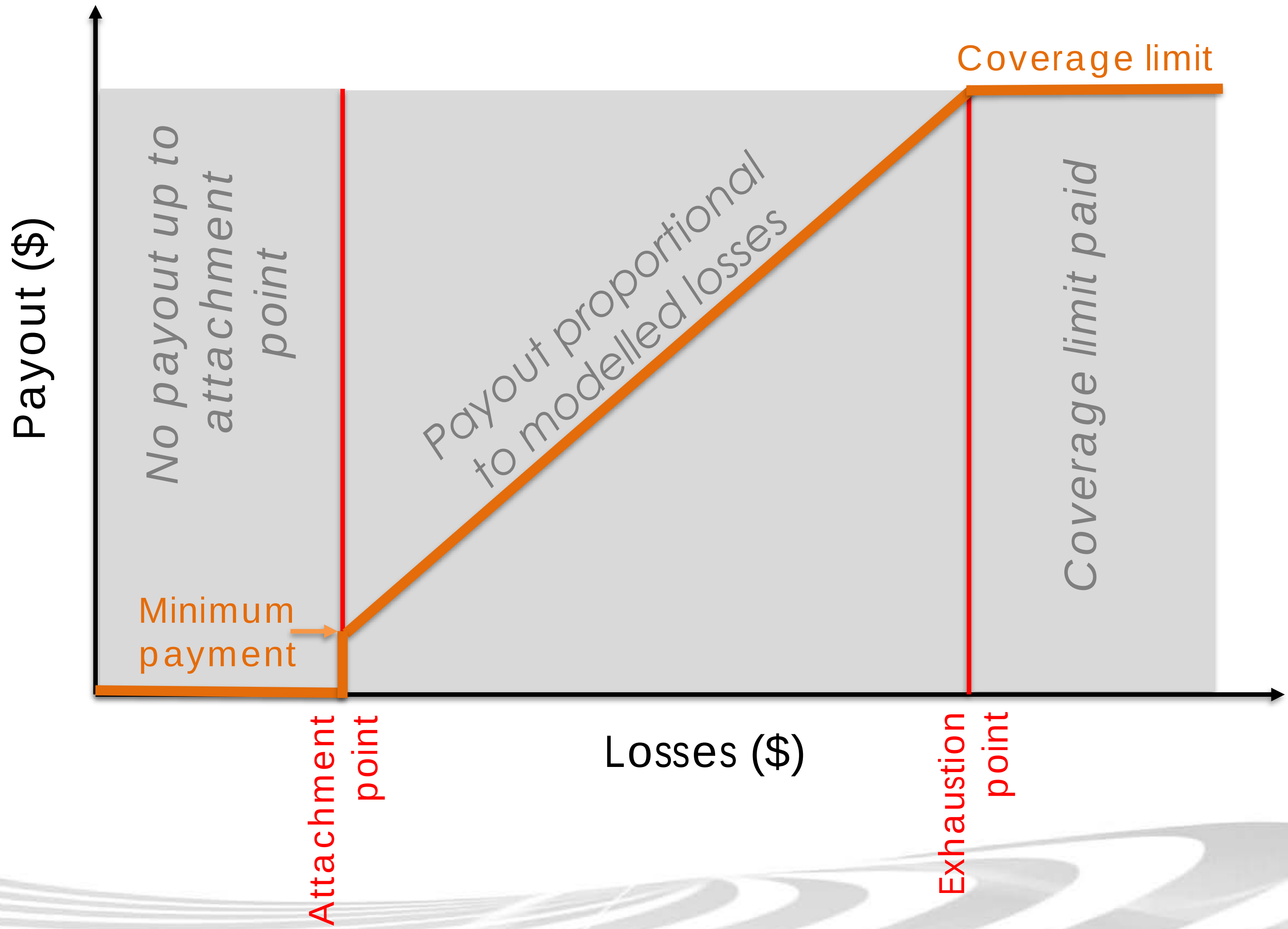
Losses: computed by the model, depending on hazard, vulnerability and exposure



Return period: estimated average time between events

Insurance scheme

- Insurance policy



SPHERA real-time operation

System for Probabilistic Hazard Evaluation and Risk Assessment

Real-time operation (TC)

The Caribbean Catastrophe Risk Insurance Facility

- Post-event (or quasi real-time) operational workflow

1 - NOAA activates a tropical cyclone alert

2 - NOAA produces a best track file

```
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AL, 11, 2017082806, 01, CARQ,   0, 120N,  195W,  25, 1009, DB,  50,
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AL, 11, 2017082806, 03, CLP5,  24, 128N,  224W,   0,     0,   ,   0,
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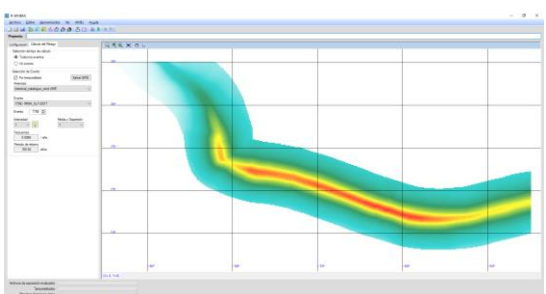
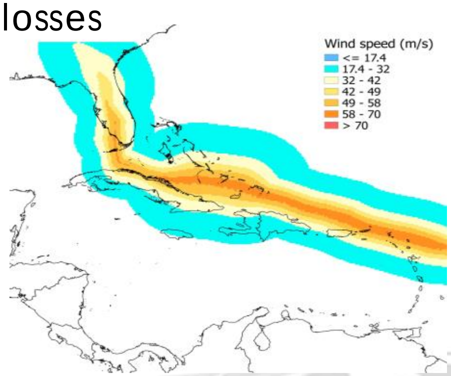
3 – CCRIF's calculation agent runs SPHERA using the best track file as input



4 - SPHERA produces estimates of wind speed, storm surge and economic losses



5 – Given the country's policy parameters, if the losses are above the attachment point, a payout is computed

Real-time operation (TC)

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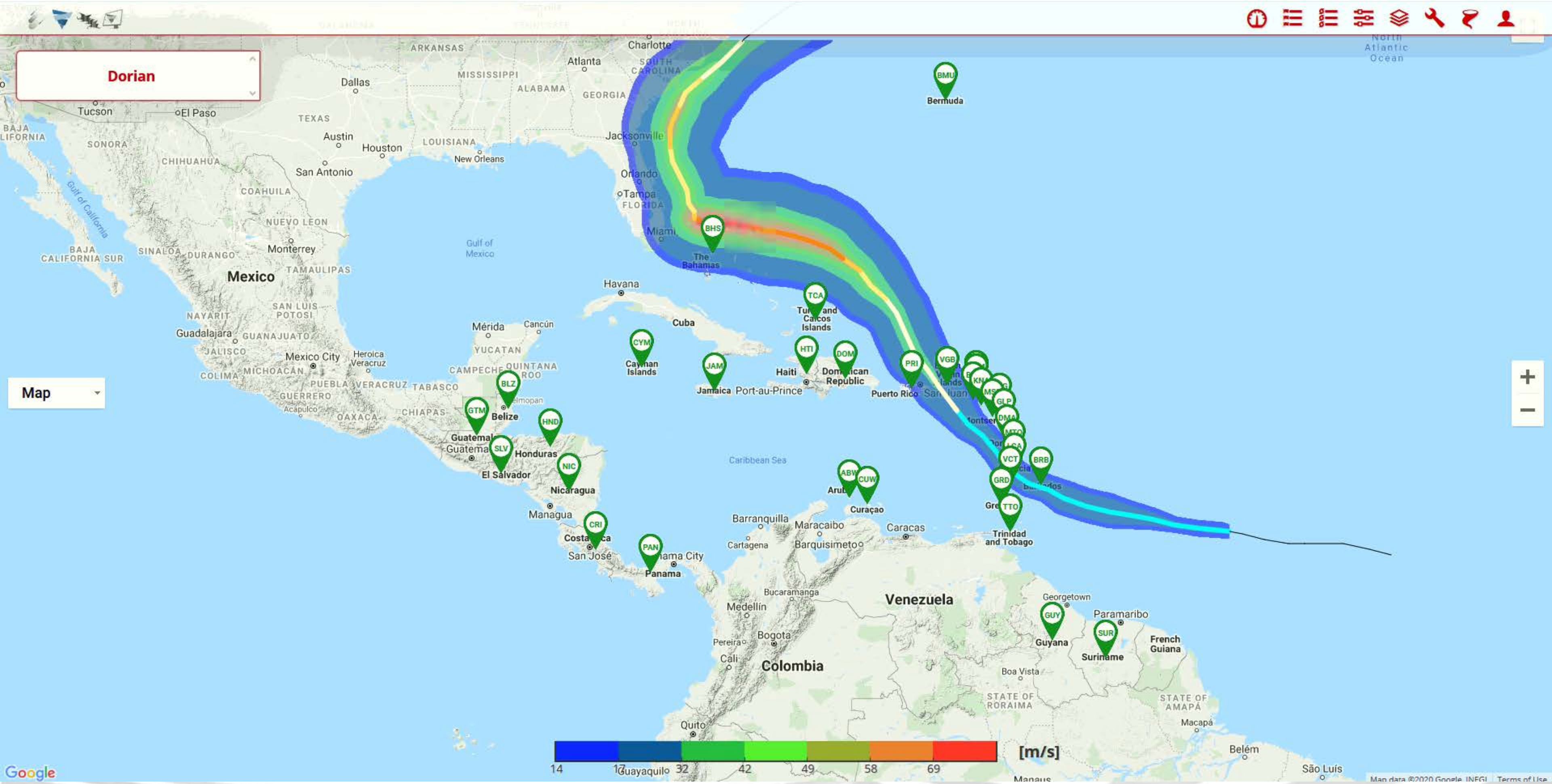
- WEMAP (specific session tomorrow)



Model updates 2023

System for Probabilistic Hazard Evaluation and Risk Assessment

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SPHERA TC – Updates 2023

Updates 2023

New stochastic catalogue

Additional trigger for localized events

SPHERA TC – Updates 2023

CCRIF SPC
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- New stochastic catalogue:
  - Developed and calibrated specifically for the Caribbean and Central America
  - Methodology more in line with other commercial TC models
    - TC movement based on autoregressions
    - Sea level pressure based on autoregressions and a spatially-variable limiting factor based on sea surface temperature (maximum potential intensity)
  - Longer catalogue: equivalent length 50,000 years
  - One catalogue for the Atlantic basin and one for the Pacific basin

SPHERA TC – Updates 2023

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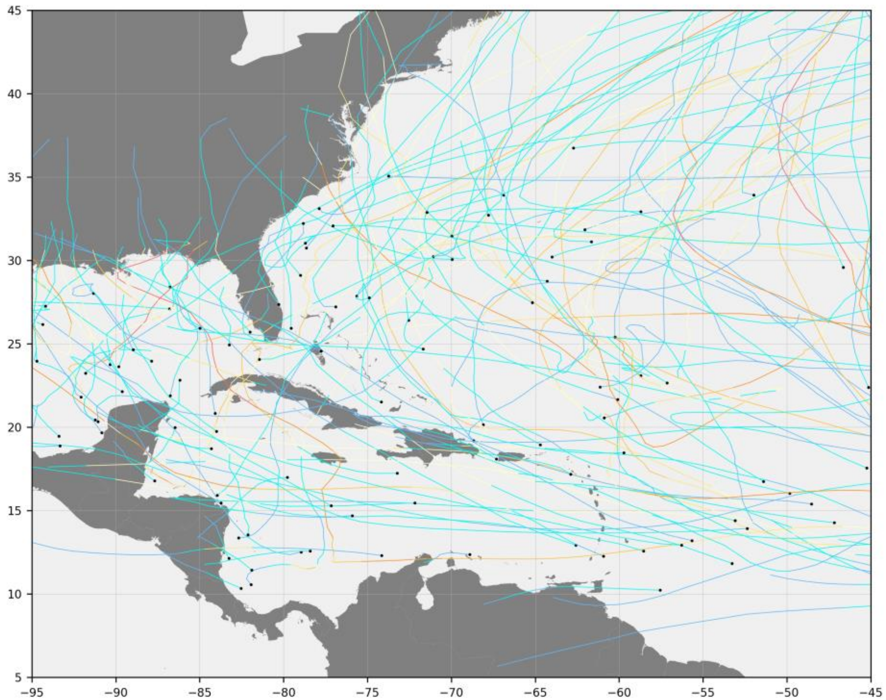
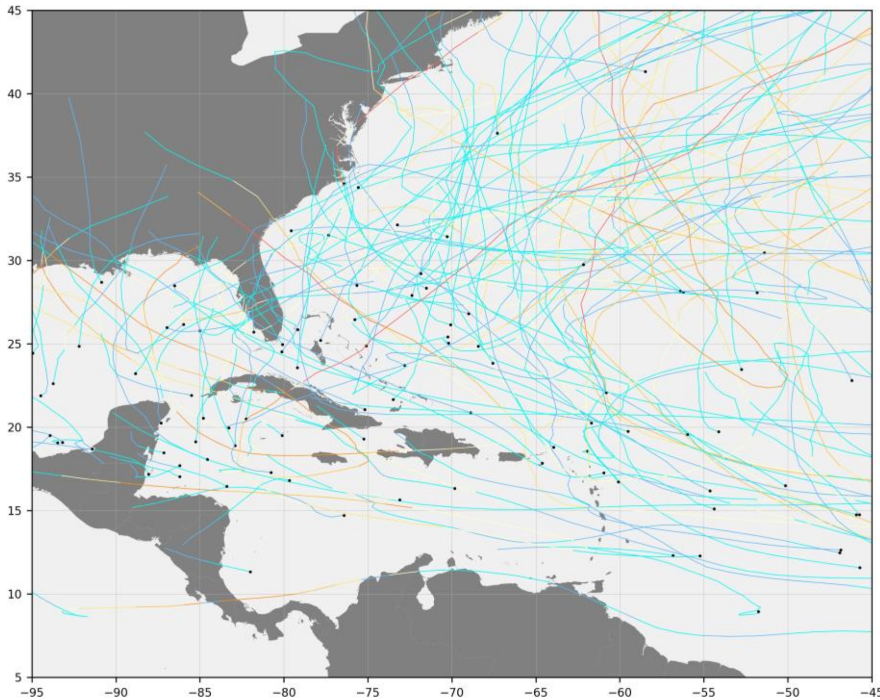
- New stochastic catalogue:
  - Some example of cyclone tracks





Saffir–Simpson scale

Category	Wind speeds m/s	knots (kn)	mph	km/h
Five	≥ 70 m/s	≥ 137 kn	≥ 157 mph	≥ 252 km/h
Four	58–70 m/s	113–136 kn	130–156 mph	209–251 km/h
Three	50–58 m/s	96–112 kn	111–129 mph	178–208 km/h
Two	43–49 m/s	83–95 kn	96–110 mph	154–177 km/h
One	33–42 m/s	64–82 kn	74–95 mph	119–153 km/h

Related classifications

Tropical storm	18–32 m/s	34–63 kn	39–73 mph	63–118 km/h
Tropical depression	≤ 17 m/s	≤ 33 kn	≤ 38 mph	≤ 62 km/h

SPHERA TC – Updates 2023

- New stochastic catalogue – main advantages:
  - A longer catalogue means a more stable and robust risk assessment, also for very small islands
  - The methodology used is aligned with recent literature and in line with other commercial models: it increases confidence of the market, the reinsurers and the community in **CCRIF's view** of tropical cyclone risk
  - Using spatially-variable autoregressions allows generating rare events that might not be covered using a track perturbation methodology
  - The use of a maximum potential intensity limit based on sea surface temperatures create more realistic events and, potentially, might allow including climate change effects in the future

Additional trigger: Purpose

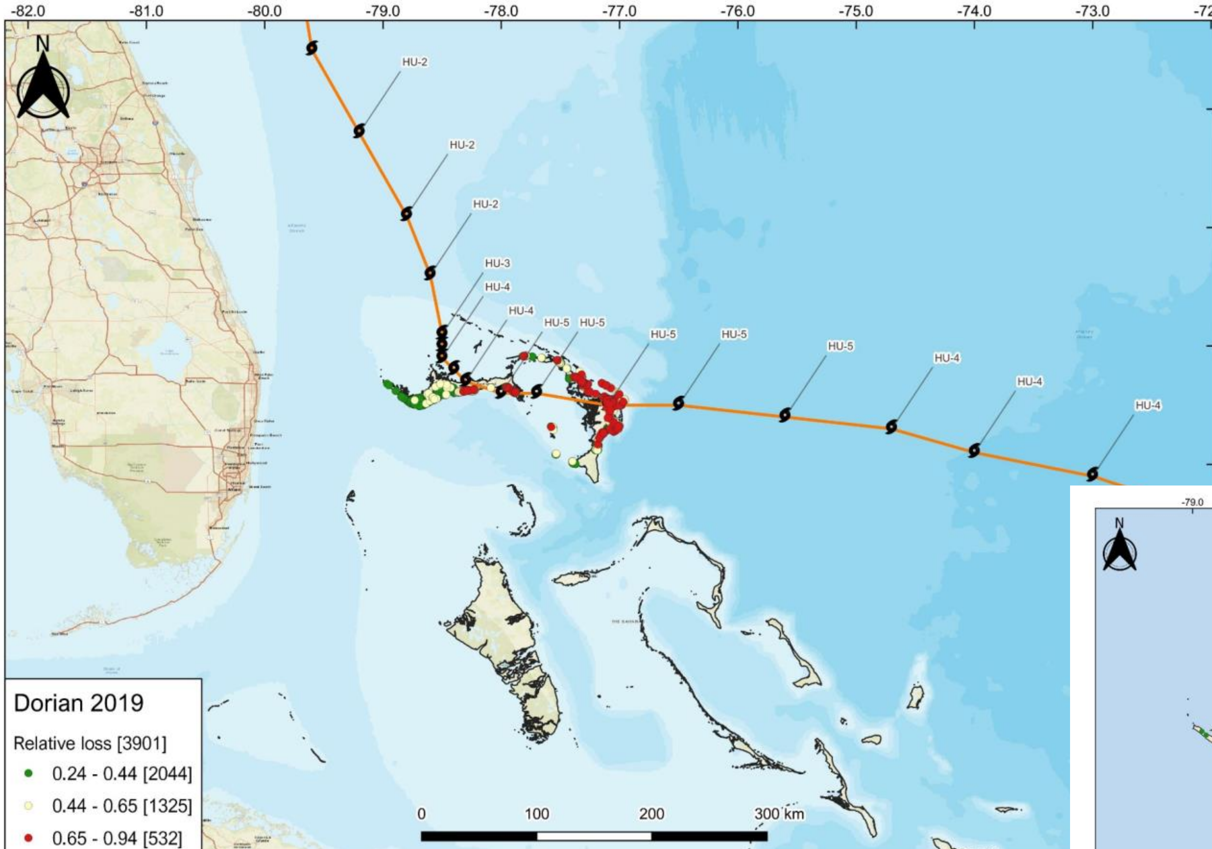
- To detect events in which losses are particularly concentrated and produce an adequate payout
- Strategy based on the Local Disaster Index (LDI) that will be described as follows

LDI

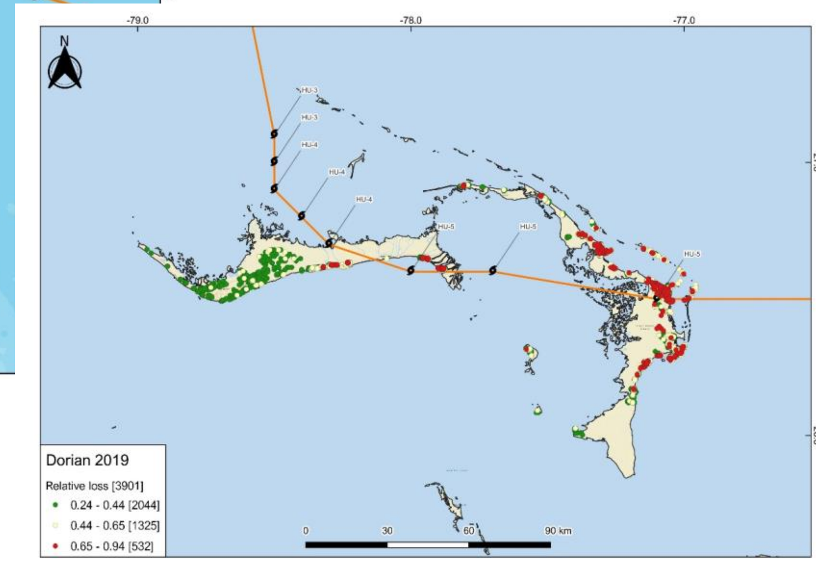
Step 1: Identify "red cells". Red cells are 5% of the cells with highest damage ratio, β_i:

1. For a given event, compute for each cell $\beta_i = \frac{Loss_i}{Exposed\ Value_i}$
2. Sort them from largest to smallest
3. Keep the 5% of the cells with highest

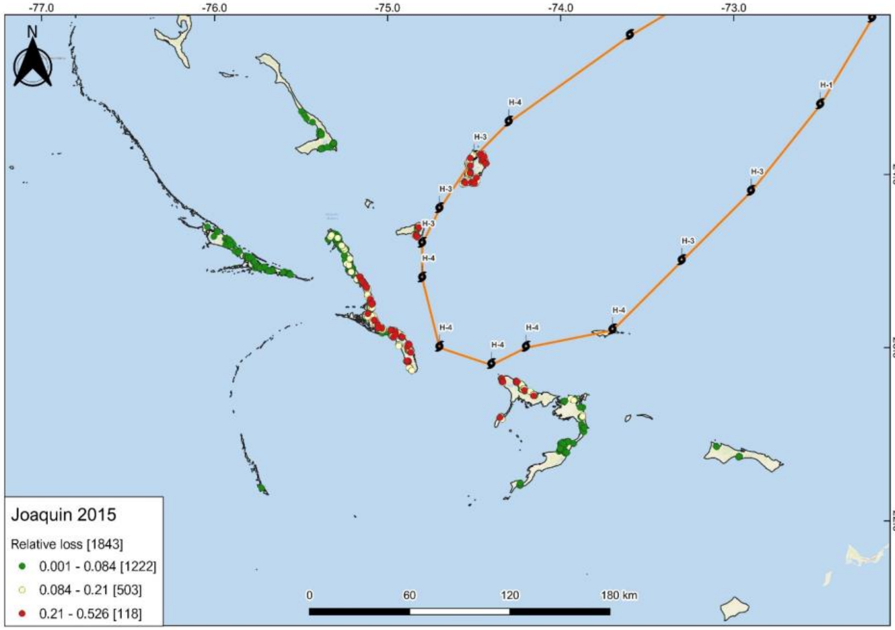
Dorian 2019



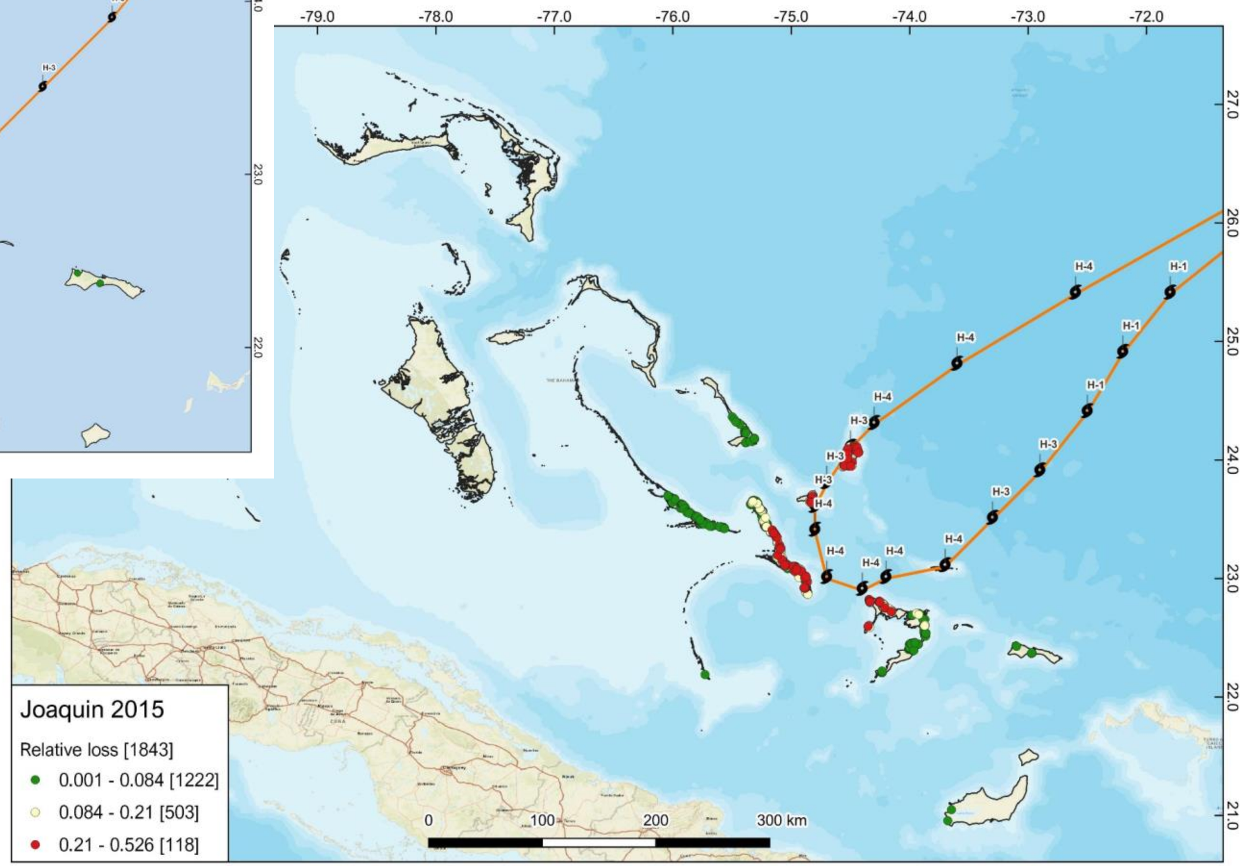
-82.0
-81.0
-80.0
-79.0
-78.0
-77.0
-76.0
-75.0
-74.0
-73.0
-72.0
29.0
28.0
27.0
26.0
N
HU-2
HU-2
HU-2
HU-3
HU-4
HU-4
HU-5
HU-5
HU-5
HU-5
HU-5
HU-4
HU-4
HU-4
Dorian 2019
Relative loss [3901]
0.24 - 0.44 [2044]
0.44 - 0.65 [1325]
0.65 - 0.94 [532]
0
100
200
300 km



-79.0
-78.0
-77.0
27.0
26.0
N
Dorian 2019
Relative loss [3901]
0.24 - 0.44 [2044]
0.44 - 0.65 [1325]
0.65 - 0.94 [532]
0
30
60
90 km



Joaquin 2015



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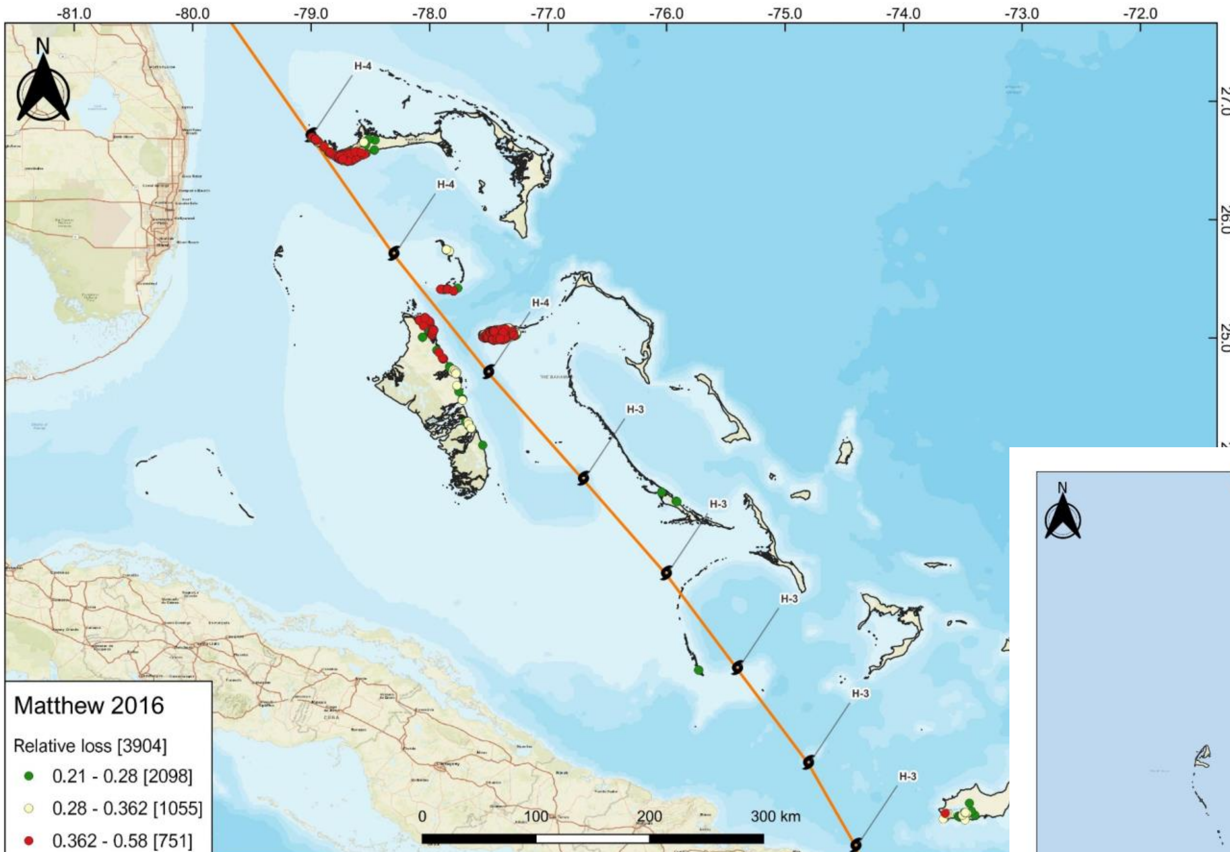
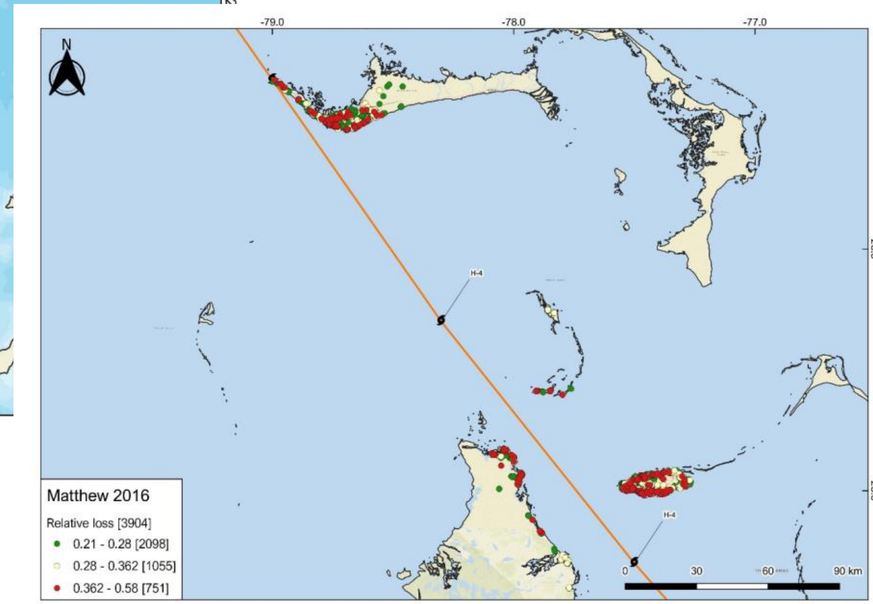


Matthew 2016



LDI

Step 2: Compute the average relative losses in the red cells, β_r:

1. For a given event, compute the losses experienced in the red cells and the exposed value comprised in the red cells:

$$Loss_r = \sum_{j=1}^{Nr} Loss_j$$

$$Exposed_r = \sum_{j=1}^{Nr} Exposed_j$$

where j comprises all red cells

2. Compute $\beta_r = {}^{Loss_r}/_{Exposed_r}$

Step 3: Compute the average damage ratio in all the cells, β_g:

1.

$$Loss_g = \sum_{k=1}^{N} Loss_k$$

$$Exposed_g = \sum_{k=1}^{N} Exposed_k$$

where *k* comprises all cells

2. Compute $\beta_g = {Loss_g}/{Exposed_g}$

LDI

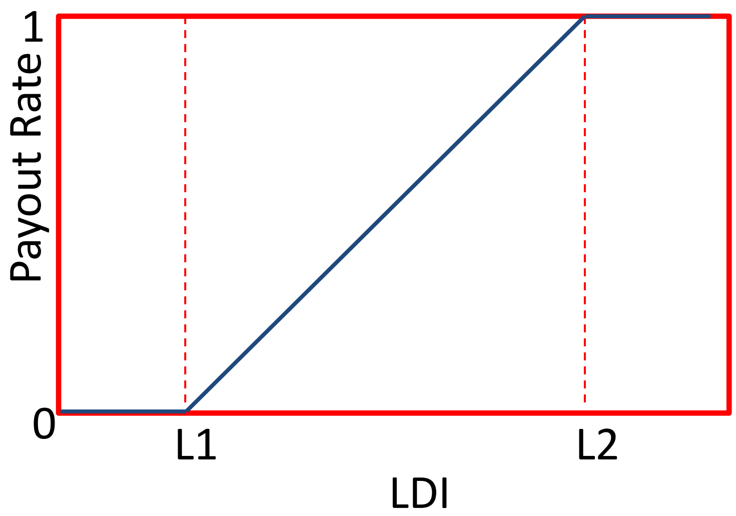
Step 4: Compute *LDI*:

$$LDI = \begin{cases} 0 & \beta_r < 1\% \; or \; \beta_g < 0.06\% \\ \dfrac{\beta_r}{\beta_g} & other\ cases \end{cases}$$

LDI is computed only when losses in the red cells are meaningful

How is *LDI* used?

- The country has a primary policy that is designed and operates in the same way as it operates now
- But there is a secondary policy whose payouts are indexed to LDI:



$$PayOut = Payout\ Rate * CL_2$$

- L1 and L2 are percentiles of LDI in the stochastic catalog (excluding null values)
- CL_2 is chosen based on the amount of premium that wants to be used in the secondary policy (20% in our calculations)

Conclusion

System for Probabilistic Hazard Evaluation and Risk Assessment

SPHERA TC Model - Conclusion

- ✓ The SPHERA TC model is a modern, state-of-the-art tropical cyclone model designed to support parametric insurance against infrequent and catastrophic events
- ✓ It has been reviewed and validated
- ✓ It runs near real time and allows making payments very quickly
- ✓ It has been successfully operating for a few years

SPHERA TC Model - Conclusion

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- ✓ The SPHERA TC model has become even more robust and reliable thanks to:
  - ✓ New stochastic catalogue, longer than the previous and based on a methodology in line with other commercial models
  - ✓ New trigger for localised events

- ✓ The new version of SPHERA TC will start operating from the beginning of next policy year, June 1st 2023

CCRIF Regional Workshop, Miami, USA

16th February 2023

Thanks for your attention!

CCRIF SPC

The Caribbean Catastrophe Risk Insurance Facility