Deltares
Enabling Delta Life

Introduction to technologies and modeling for providing objective risk-impact assessments

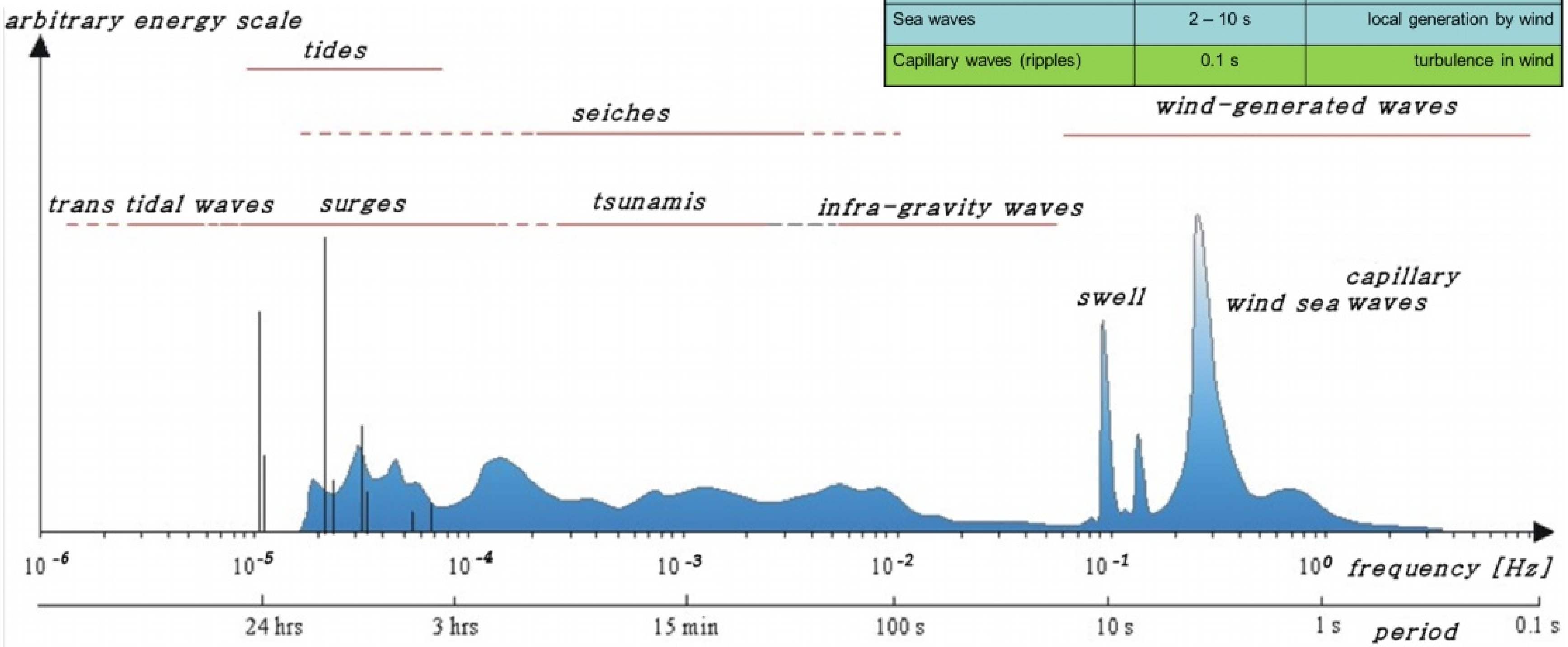
WORLD METEOROLOGICAL ORGANIZATION

STAKEHOLDERS WORKSHOP TO INITIATE THE IMPLEMENTATION OF IMPACT-BASED FORECASTING AND RISK-BASED WARNINGS

CURACAO, 10-13 OCTOBER 2015, Deepak Vatvani

Proper assessment of different hazards requires different models at different spatial and time scale

Wave type	Typical period	Generating mechanism
Storm surges	24 hours	wind
Tides	12 – 24 hours	moon, sun
Tsunami's	30 s to 1 hour	earthquake, landslide
Seiches	20 minutes	weather fronts, swell
(Bound) long waves	30 s – 2 minutes	wind waves (sea and swell)
Swell waves	15 – 20 s	distant storms (wind)
Sea waves	2 – 10 s	local generation by wind
Capillary waves (ripples)	0.1 s	turbulence in wind



Deltares

Multi Hazard – hazards to be considered / modeled for Impact forecasting

- Wind hazard, tornado / funnel clouds (land/waterspouts)
- Storm surge (regional and local) → flooding
- Wave / swell AND set-up (regional and local) → flooding
- (Infra Gravity wave setup) → flooding
- Riverine discharge (or dam break) → Fluvial flooding
- Flash flood — Pluvial flooding
- Landslide
- Tsunami → flooding

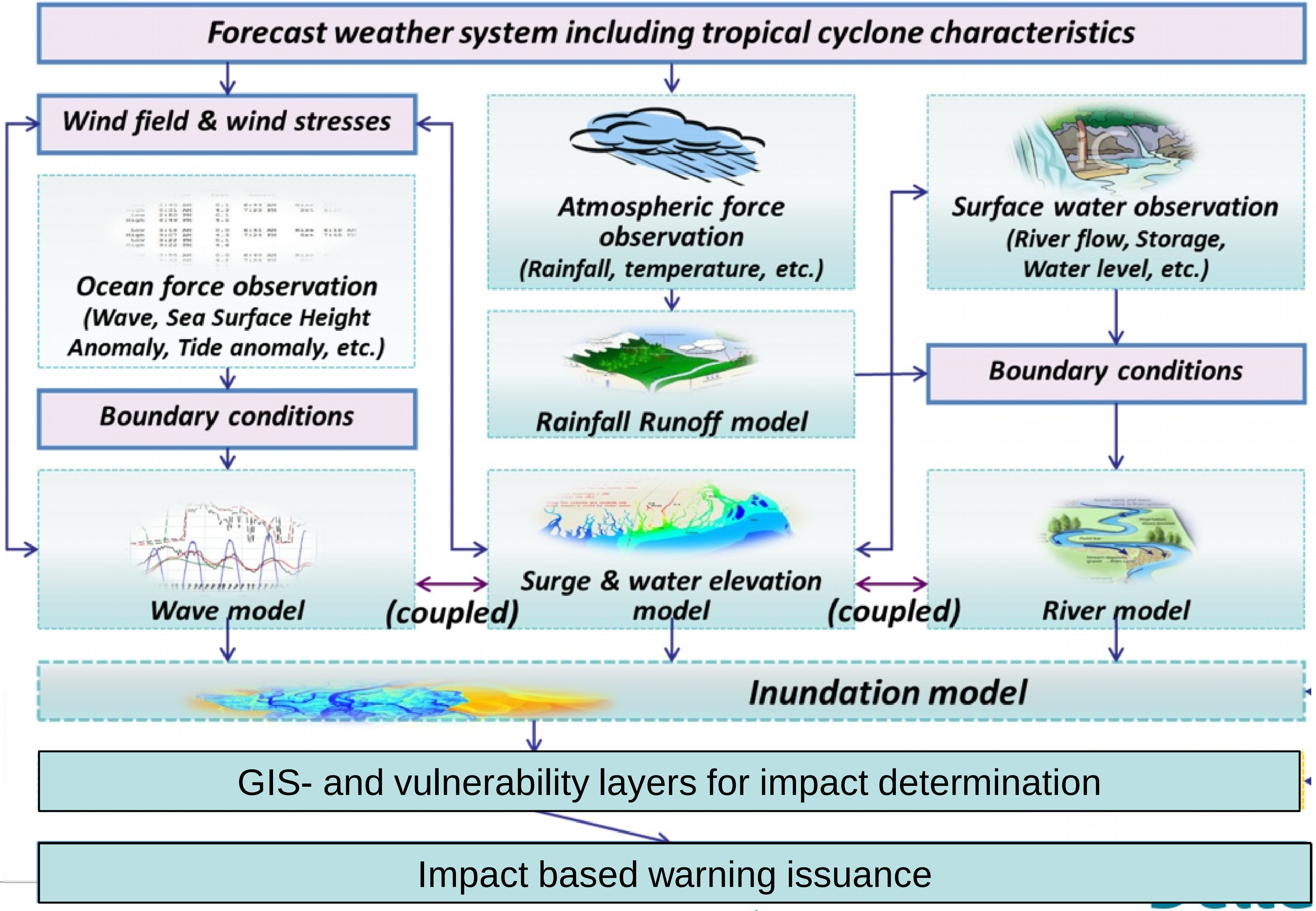
(Quality controlled) Input data

- Meteo forecast (regional scale)
- Tropical Cyclone track, wind and pressure forecast (local scale)
- Tide
- Precipitation; Radar and rain gauges data essential in real time
- Soil stability
- Earthquakes, Tsunami Sources

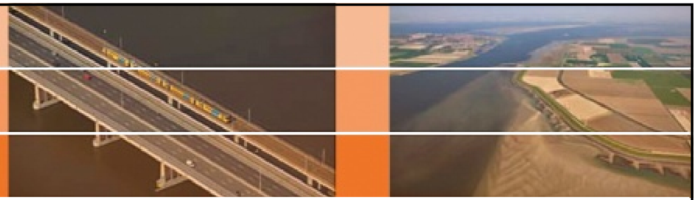
Deltares

Schematic representation; integrated system

(parts copied from CIFDP system design)

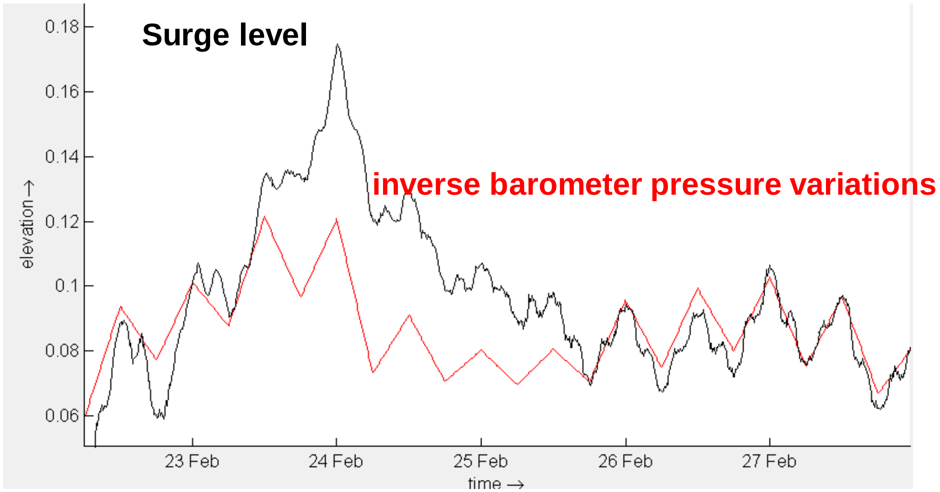


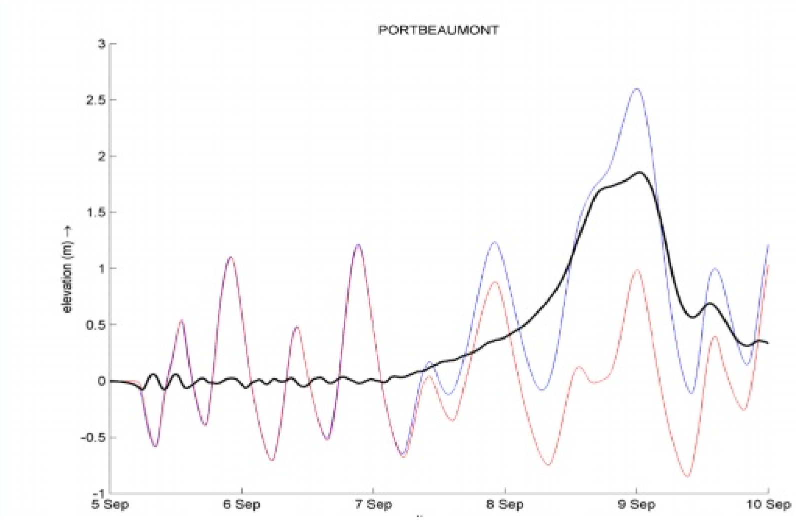
Storm surge

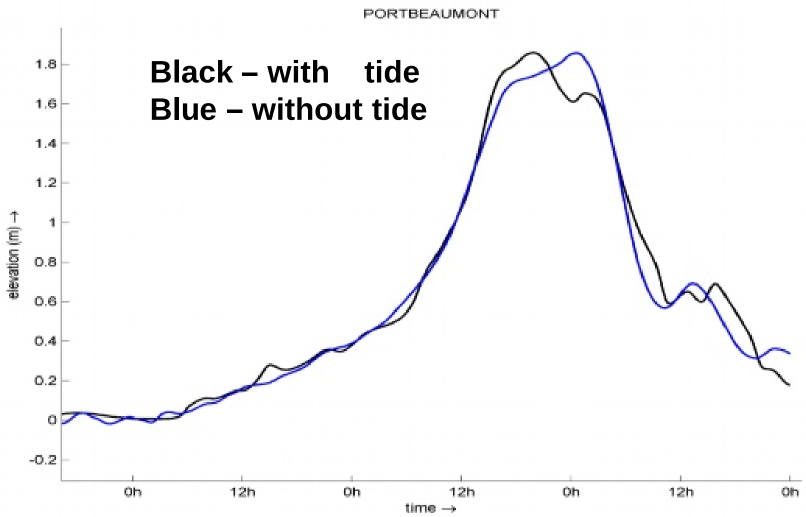


Any contributions to water level besides astronomical tide:

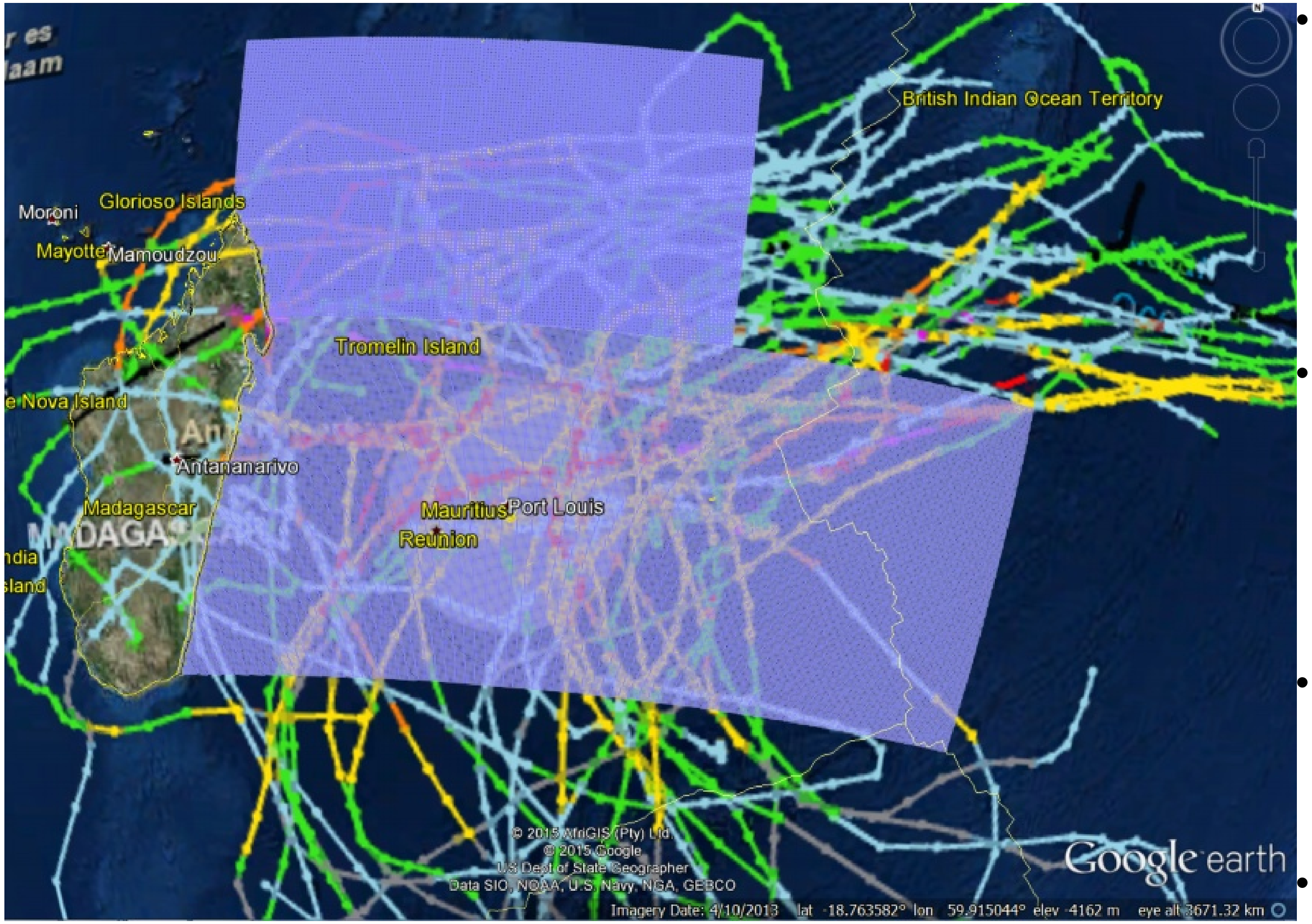
- Direct set-up caused by (extreme) wind
- Inverse barometric effect
- Mean Sea Level Anomaly
- Annual sea level variation
- Interaction with tide







1. Example: storm surge model hindcast in Mauritius



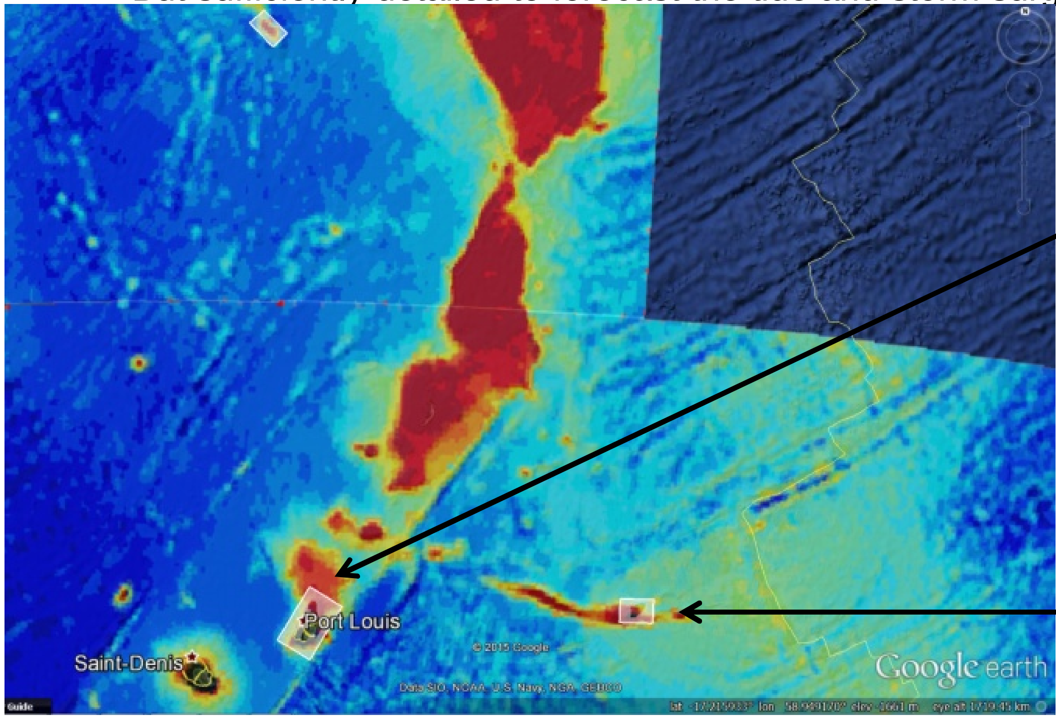
- **Models for storm surge for the Republic of Mauritius:**
  - **2 Regional models, covering Mauritius + Rodrigues and Agalega**
  - **3 Detailed models for the island's: Mauritius + Rodrigues and Agalega**
- **Not limited to surge generated by cyclones but also for surge generated by tropical storms and other severe weather conditions.**
- **Beside daily variation of tide, annual sea level variation has been calibrated**
- **Include import data in real time**

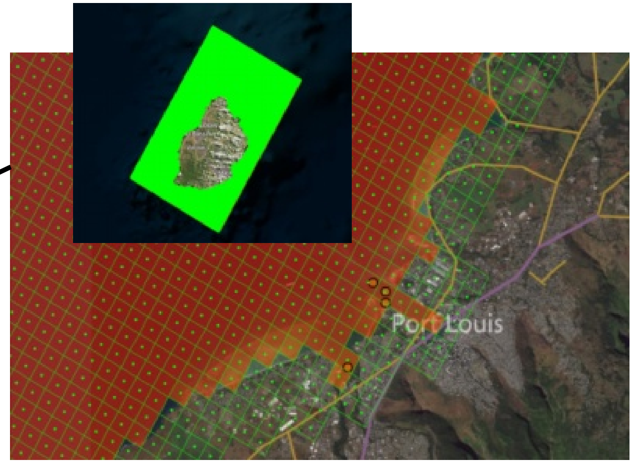
Deltares

2. Example: storm surge model hindcast in Mauritius

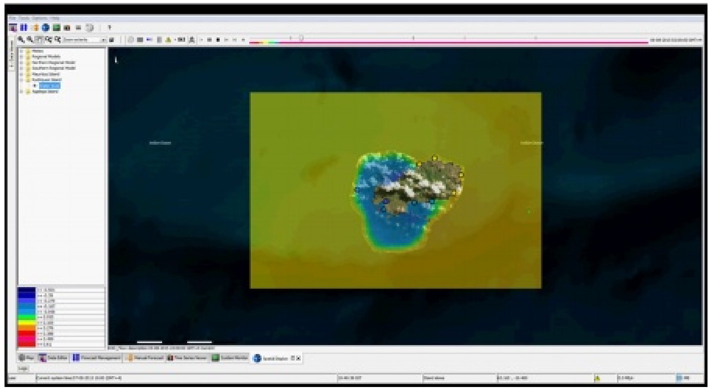
Model domain covers sufficient large area to allow 3-day forecasts

But sufficiently detailed to forecast the tide and storm surge locally





Detailed model (0.5 km resolution)

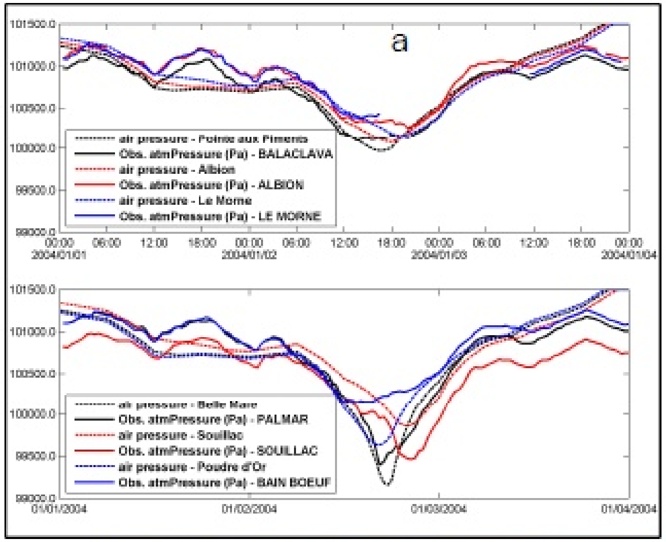


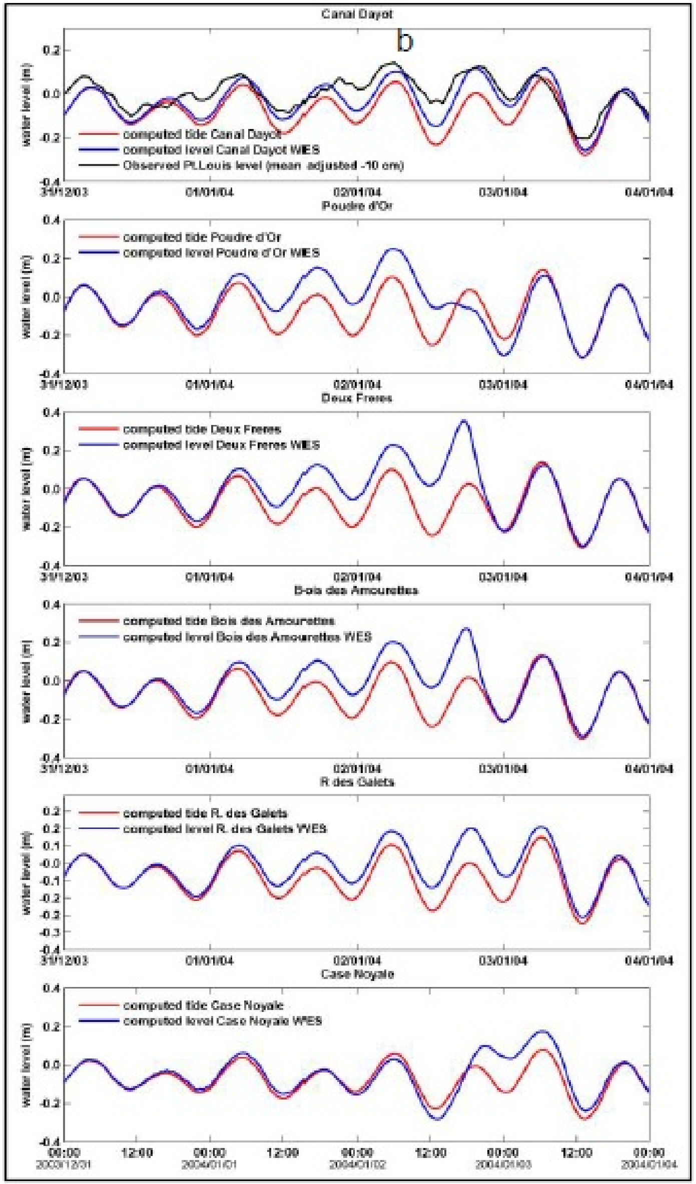
Detailed models nested in the coarser-grid models

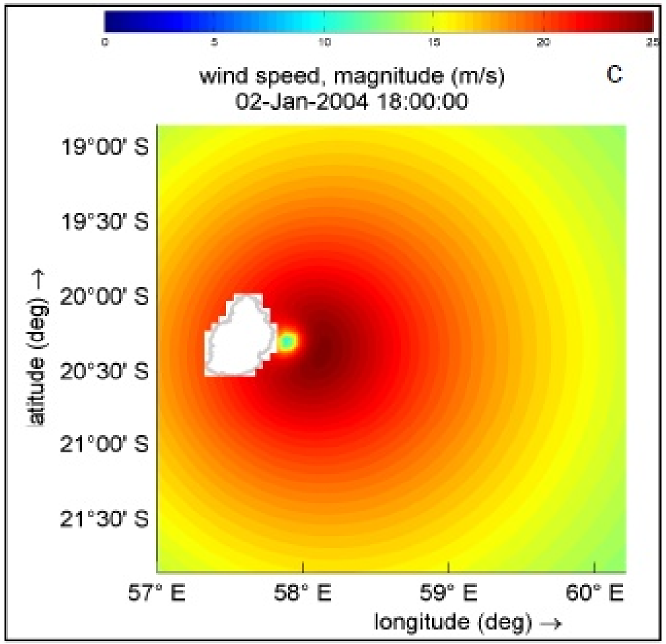
Model domain and resolution take into account future model application (wave effect)

Deltares

3. Example: storm surge model hindcast in Mauritius





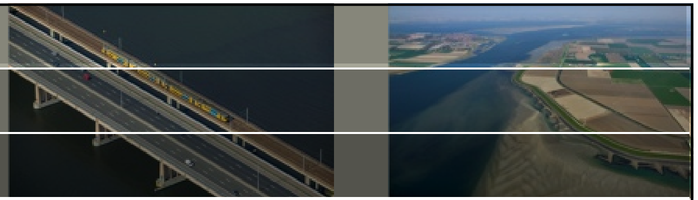


(a)Time series of computed and observed pressure levels at different coastal stations

(b) Simulated water levels at different coastal stations; Mauritius detailed model (blue) compared to tide-only (red)

Deltares

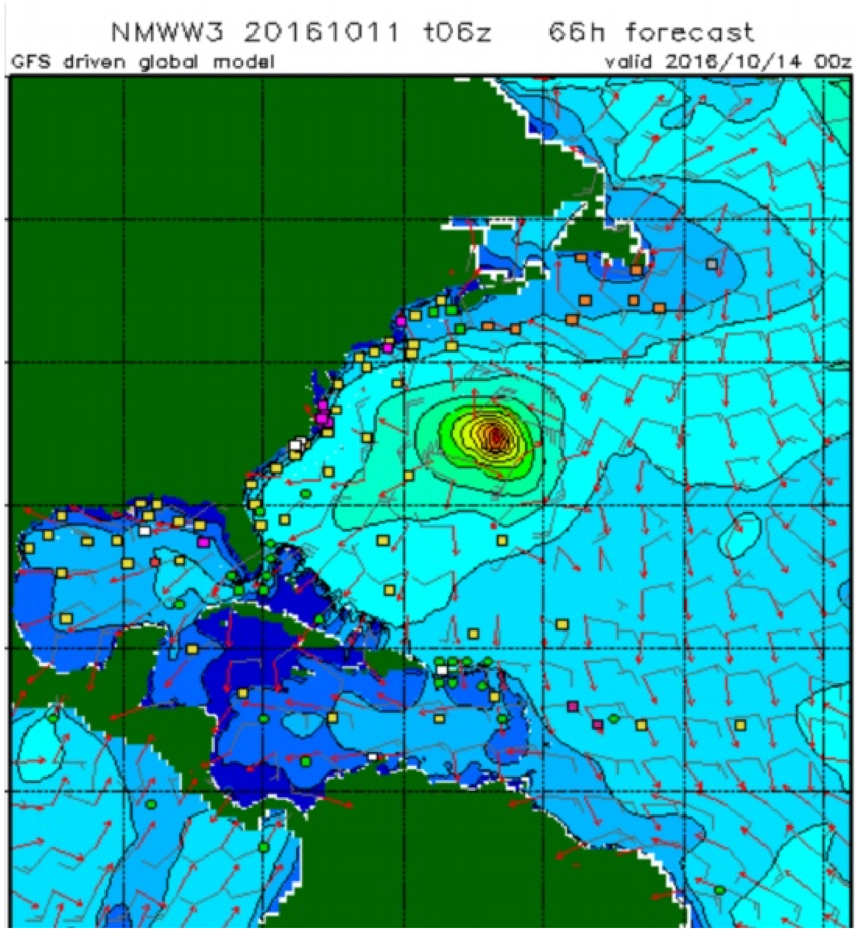
Short waves vs Swell waves



Short waves

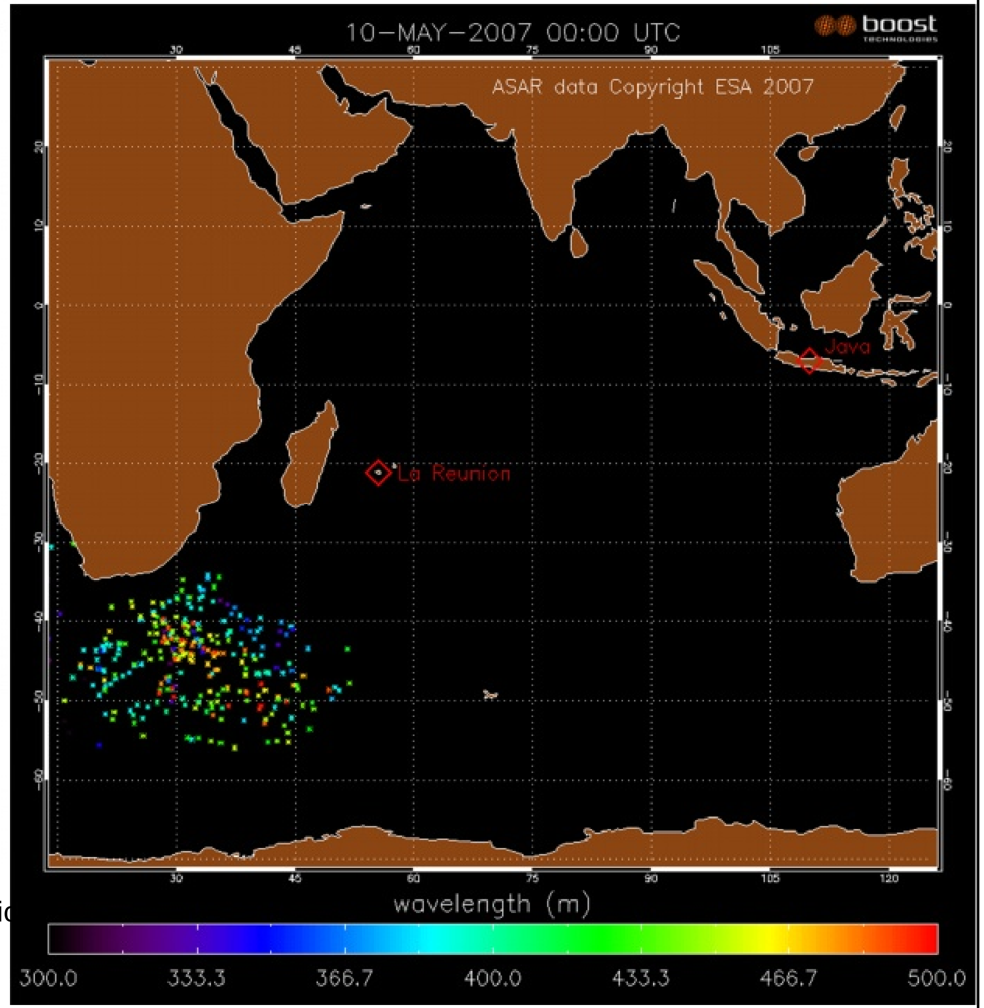
Swell waves

Wave modeling for wave/swell AND set-up forecast



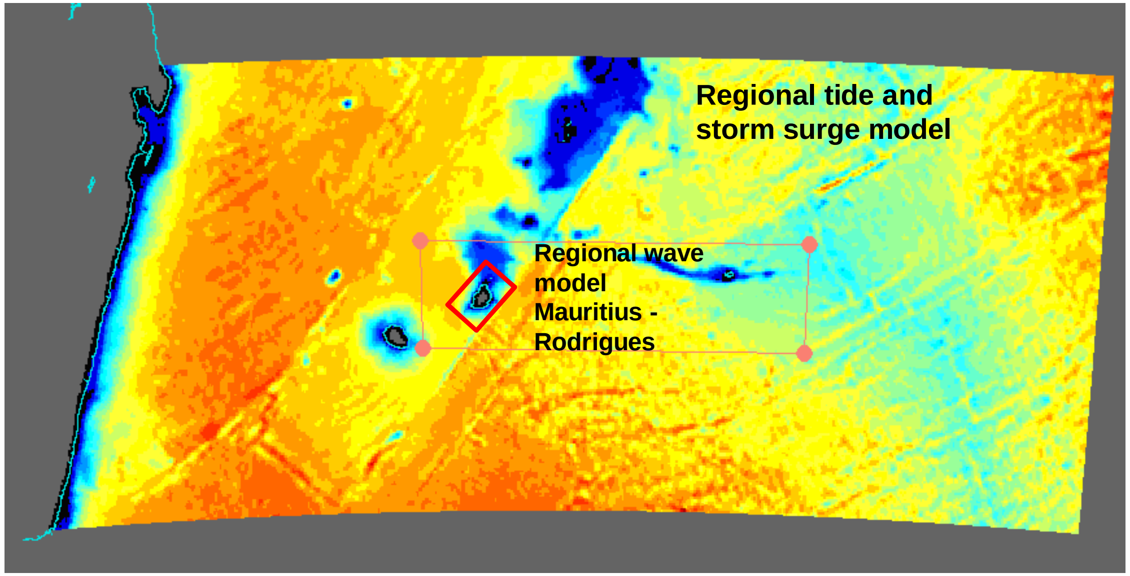
http://polar.ncep.noaa.gov/waves/viewer.shtml?-multi_1-NW_atlantic

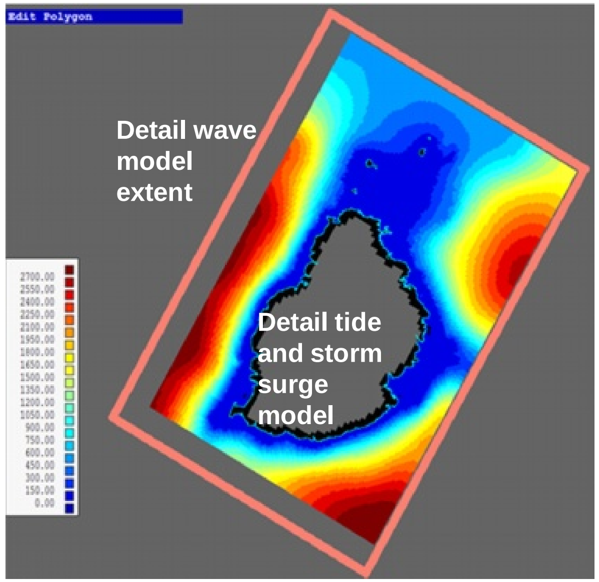
ifremer



Deltares

1. Example: storm surge and wave model hindcast in Mauritius





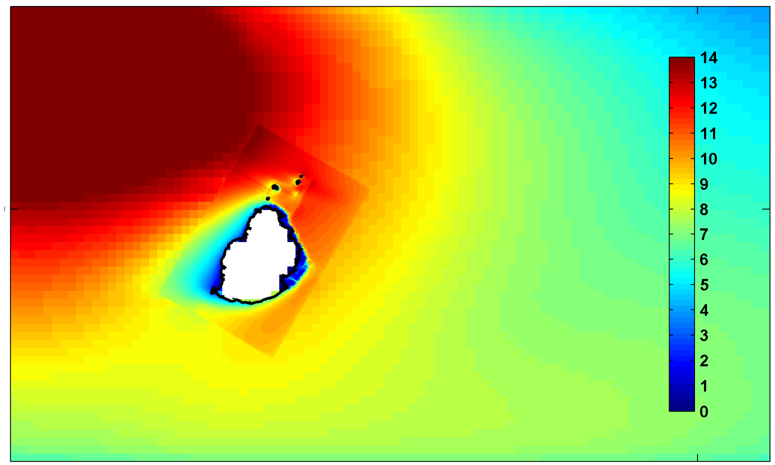
1. Models run on coupled mode in the area depicted
2. Boundary condition for the SWAN wave model later from WW3 model (now no open boundary condition)

WMO OMM

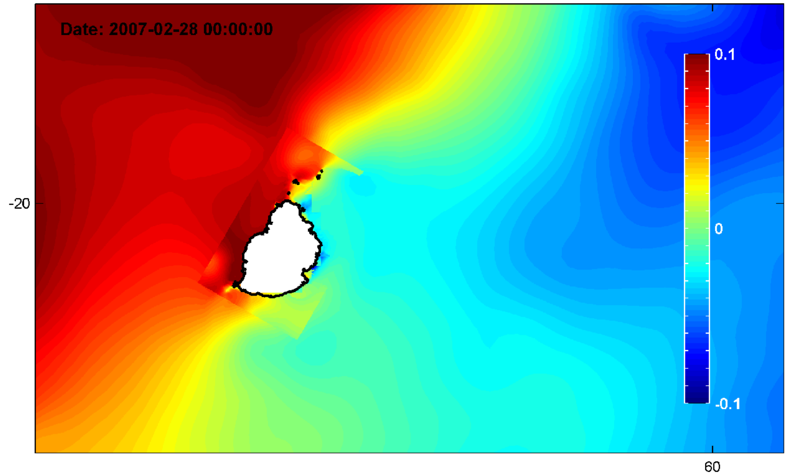
Deltares

2. Example: storm surge and wave model hindcast in Mauritius

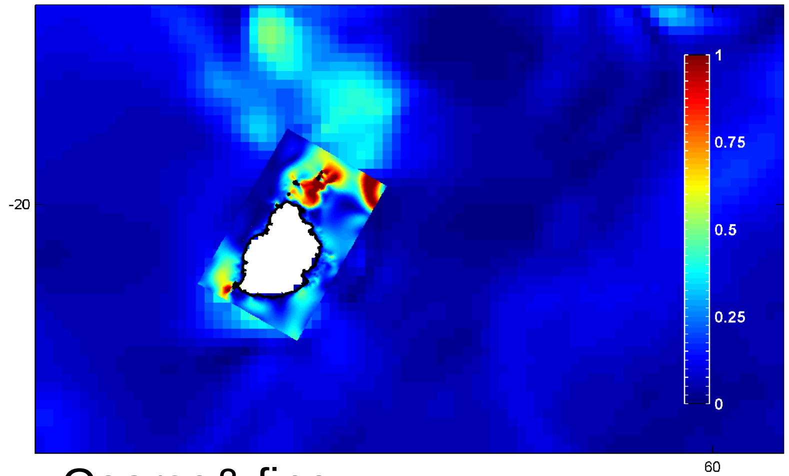
Hs (m)



Level (m)



Velocity (m/s)



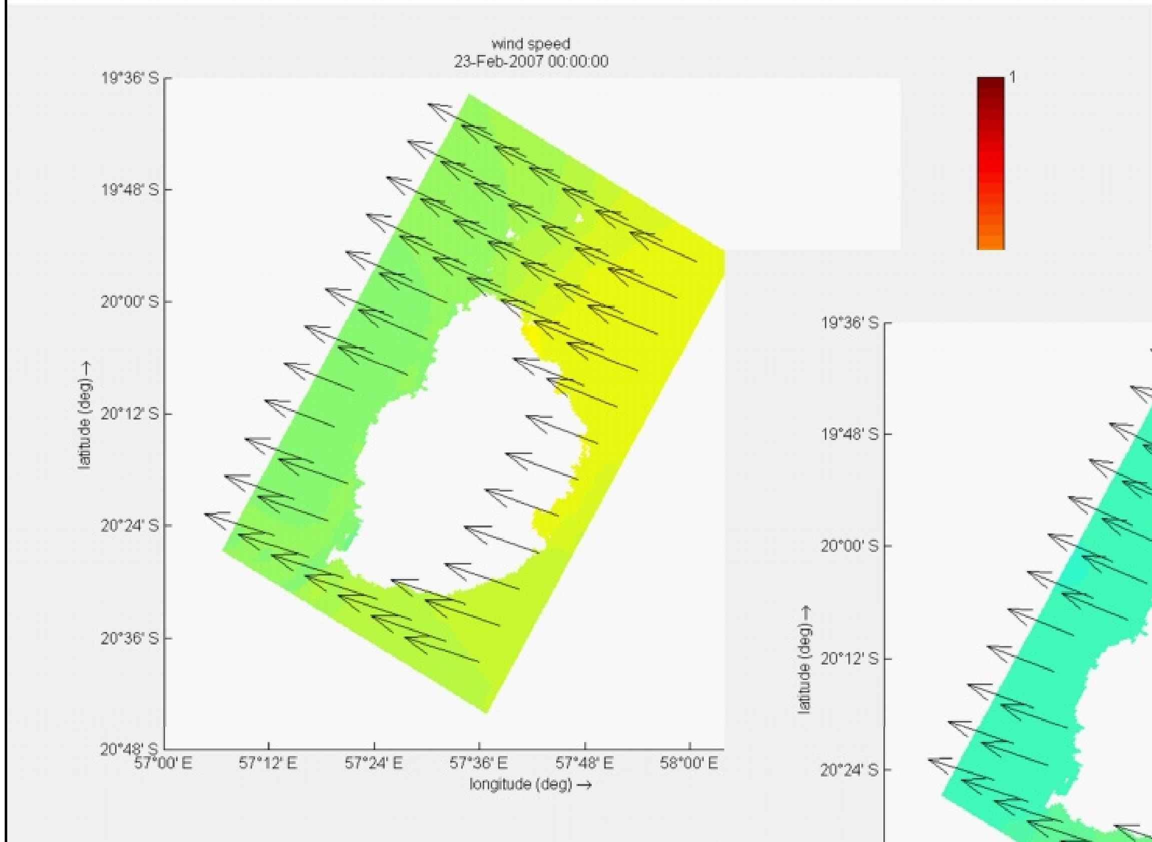
TC Gamede, 2004

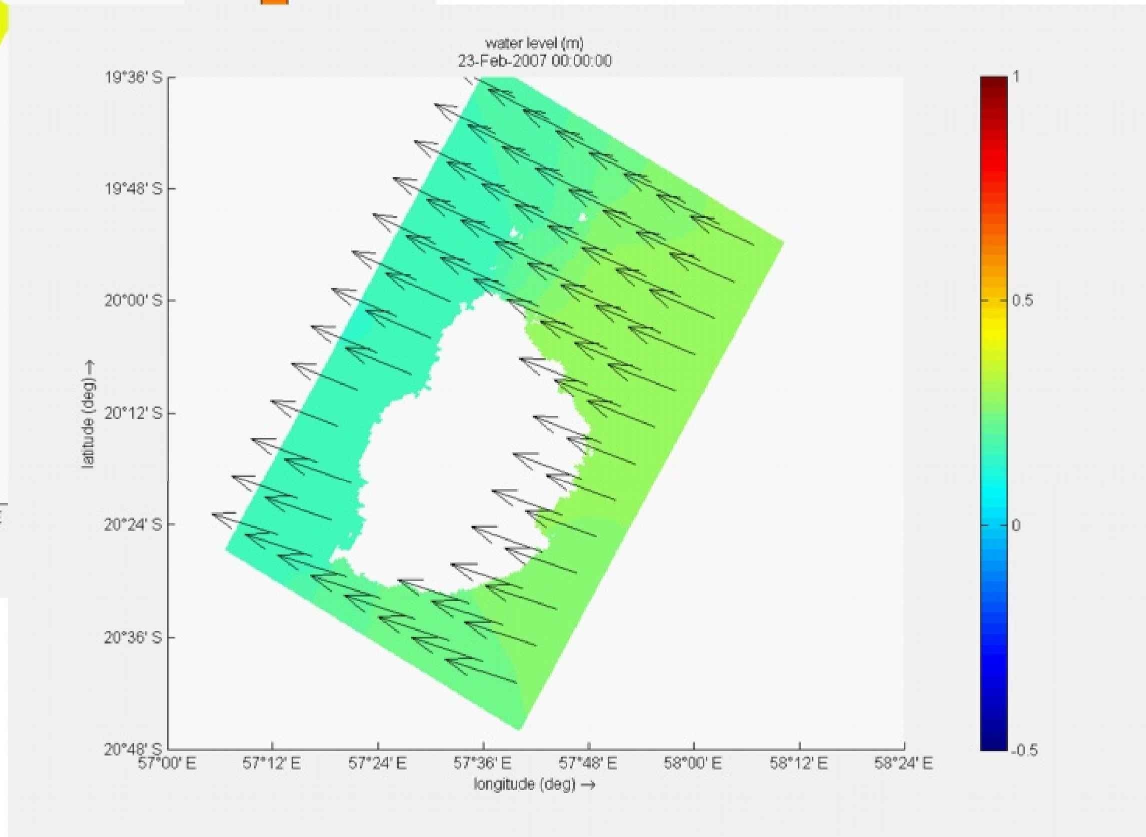
Coarse& fine

Deltares

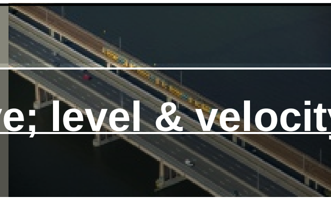
3. Example: storm surge and wave model hindcast in Mauritius

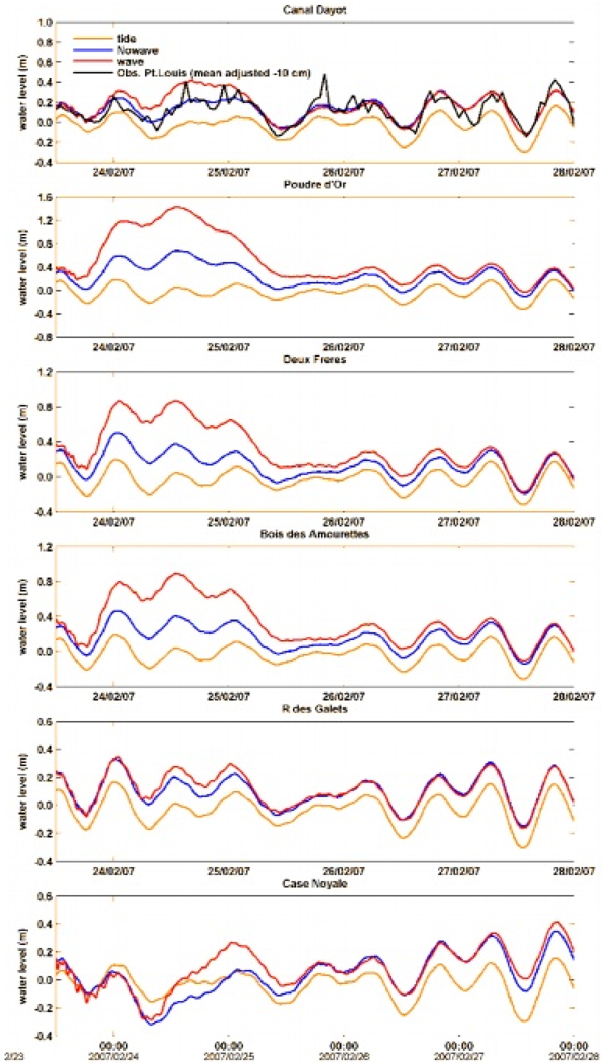
Gamede – with and without wave effects: level

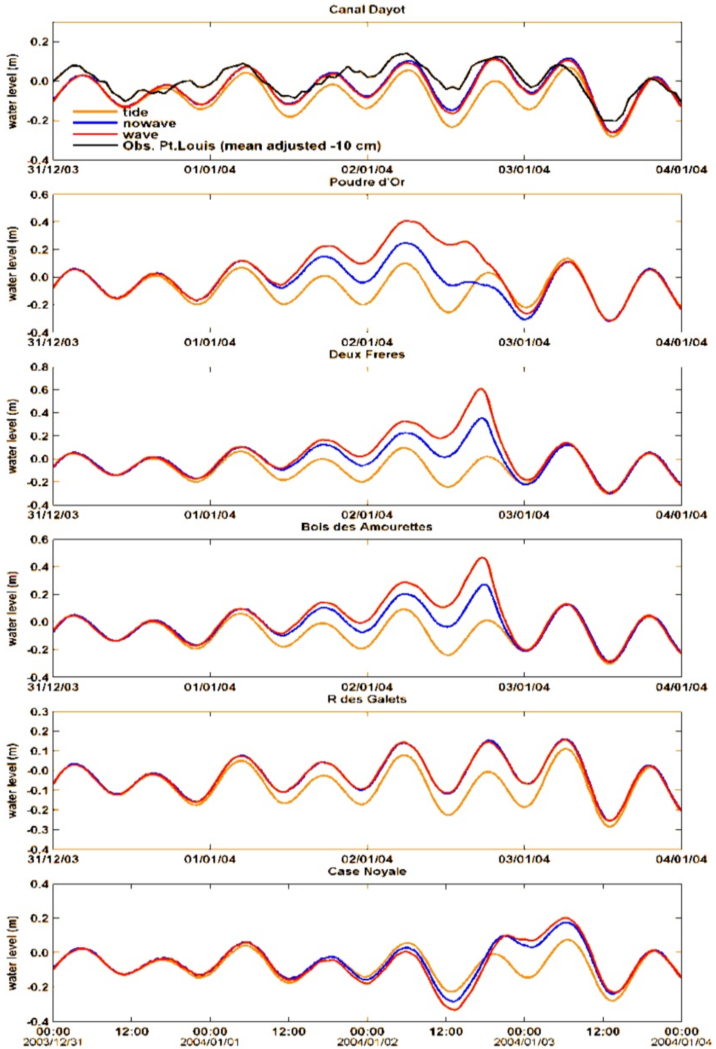




Overview of result Gamede – with wave; level & velocity



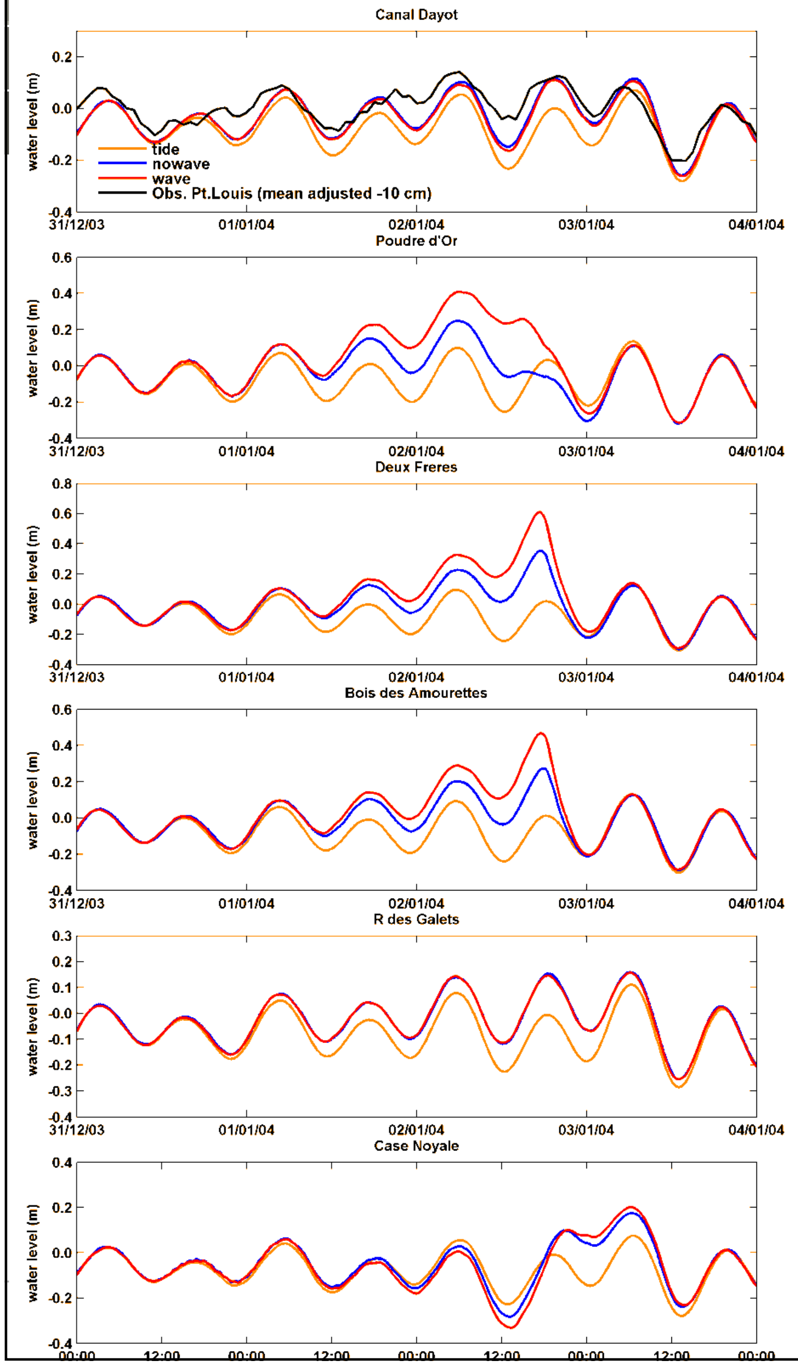


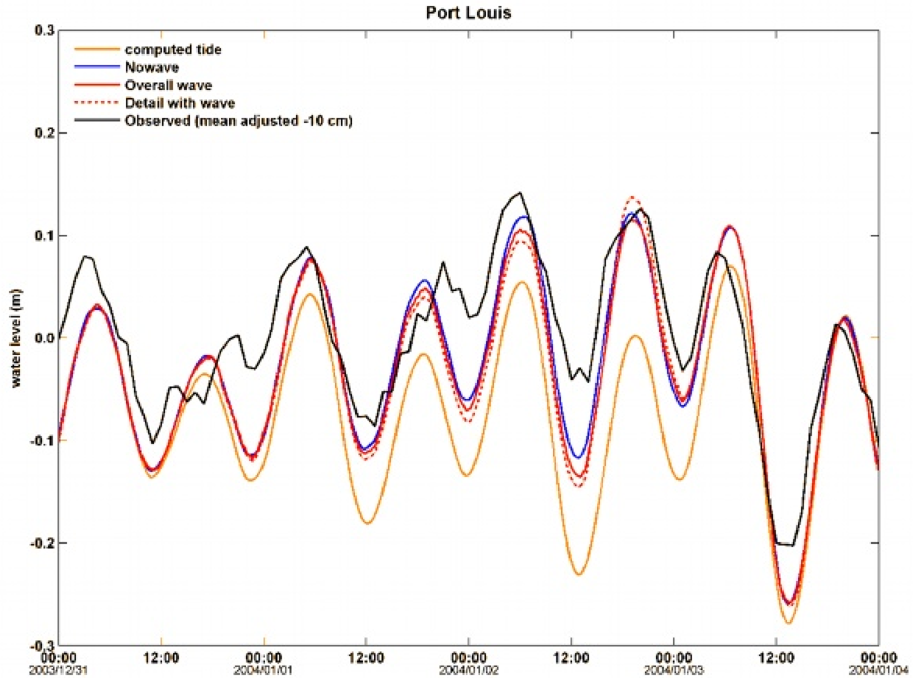


WMO OMM

Deltares

Result Darius – with wave; water levels

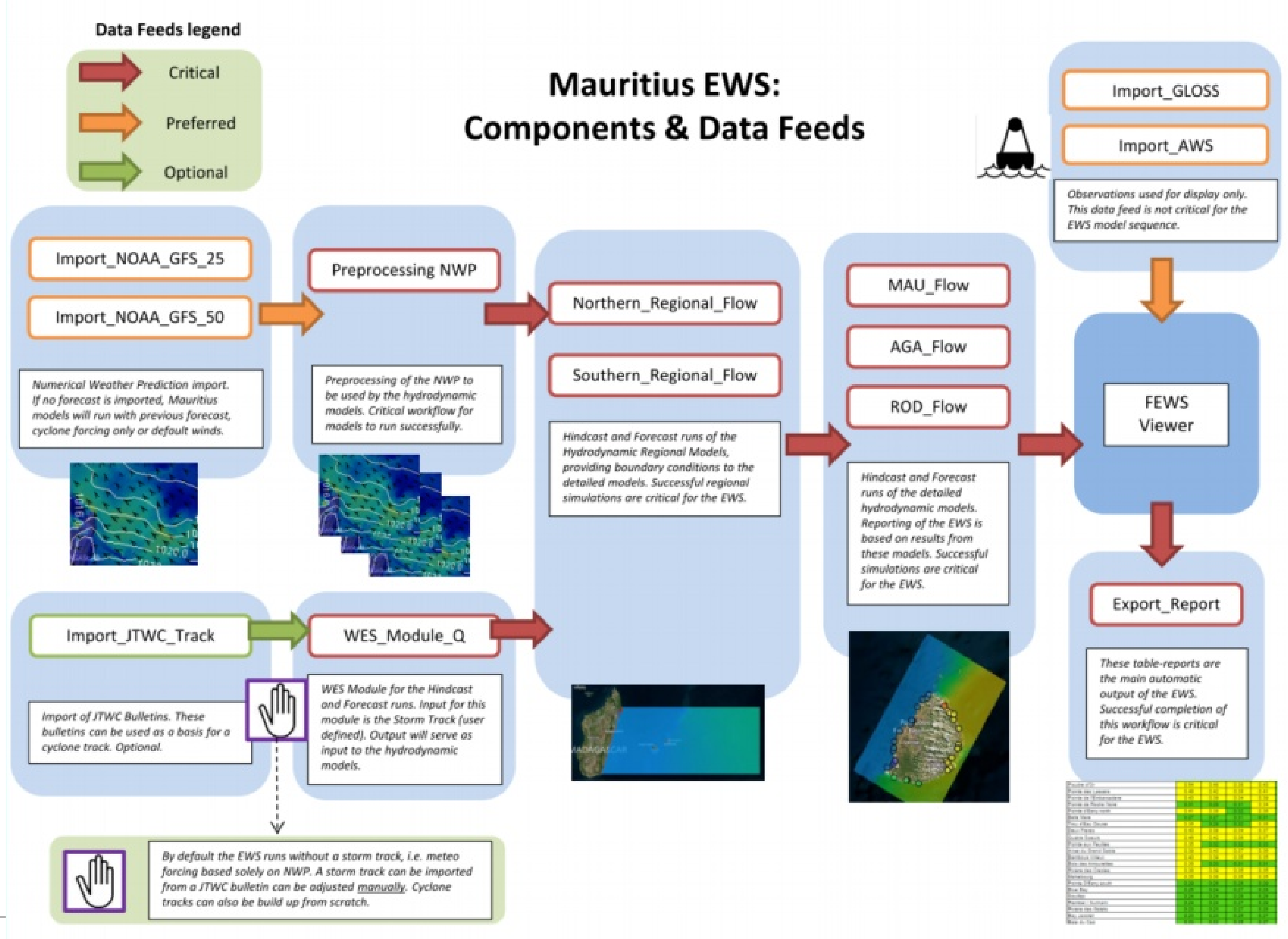




Deltares

System in Mauritius

The Early-Warning System for incoming storm surge and wave for the Mauritius, Rodrigues and Agalega islands was completed, installed and tested in August 2015. Implement in fully-automated, 24/7 mode. Forecast cycle: every 6 hours, 3 days ahead

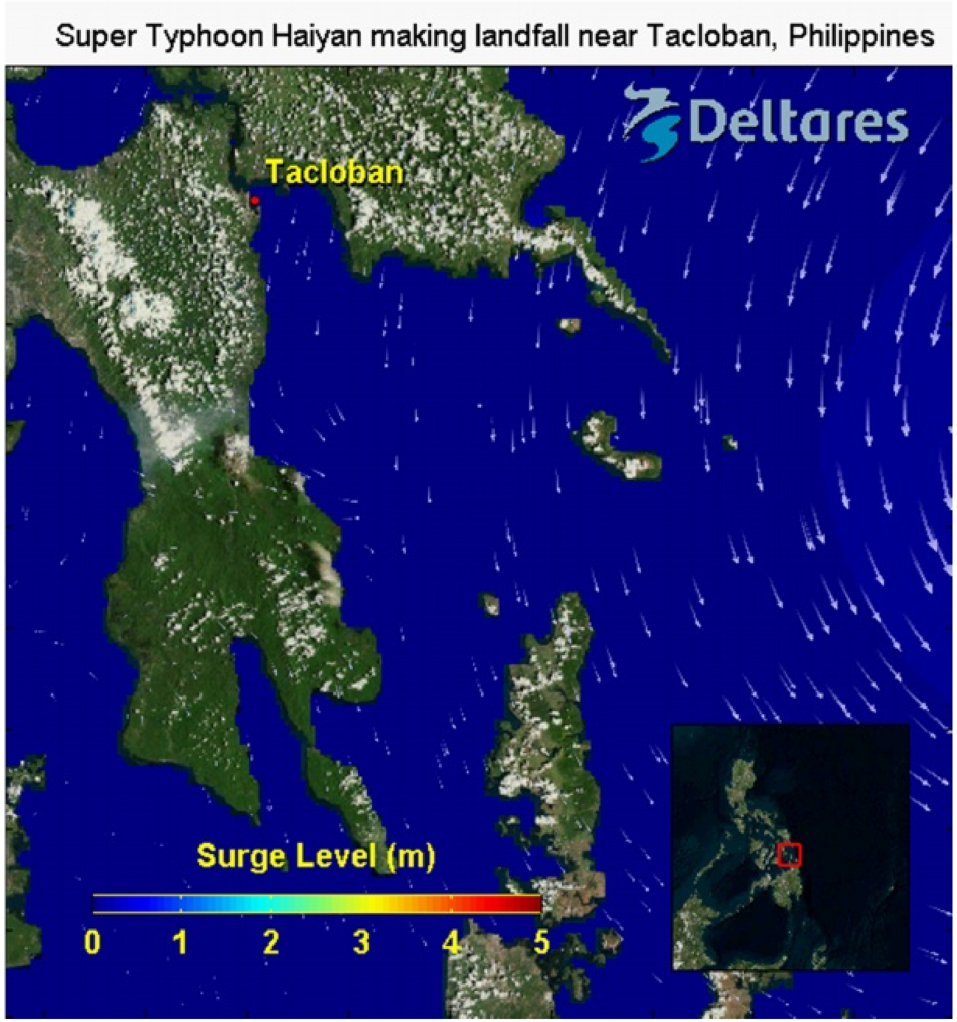


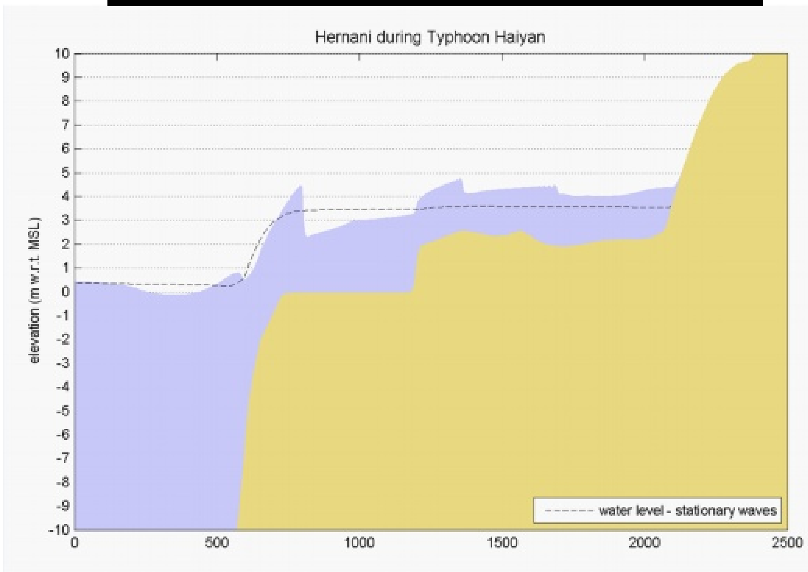
Deltares

Infra gravity waves (set-up)

Deltares

Infragravity waves during Haiyan

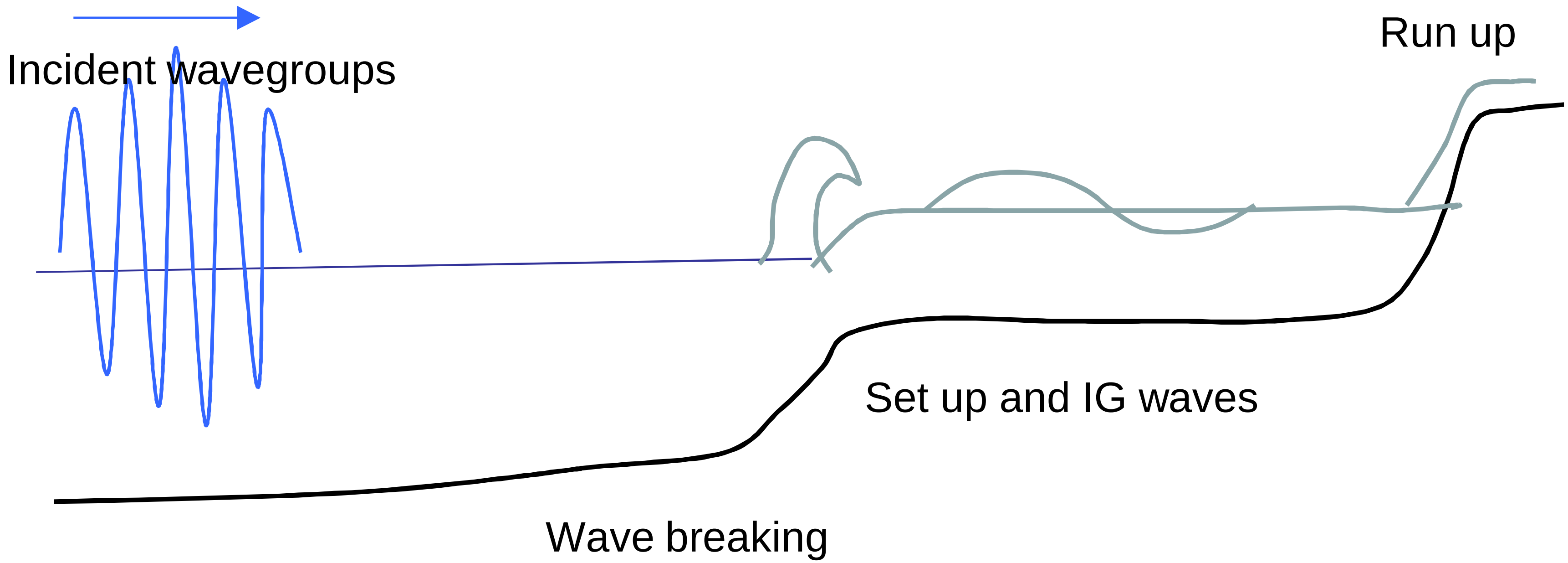




Effect of waves (on reefs)

Outgoing
free long wave
OFLW

- Incident ocean wave groups propagate from deep ocean to the reef
- Incident waves break on reef edge:
  - > Push water onto shore as "set up"
- Travel onto reef as longer waves ("infragravity waves")
- Waves are damped by friction due to coral roughness
- On shoreline, waves run up the shoreline causing damage



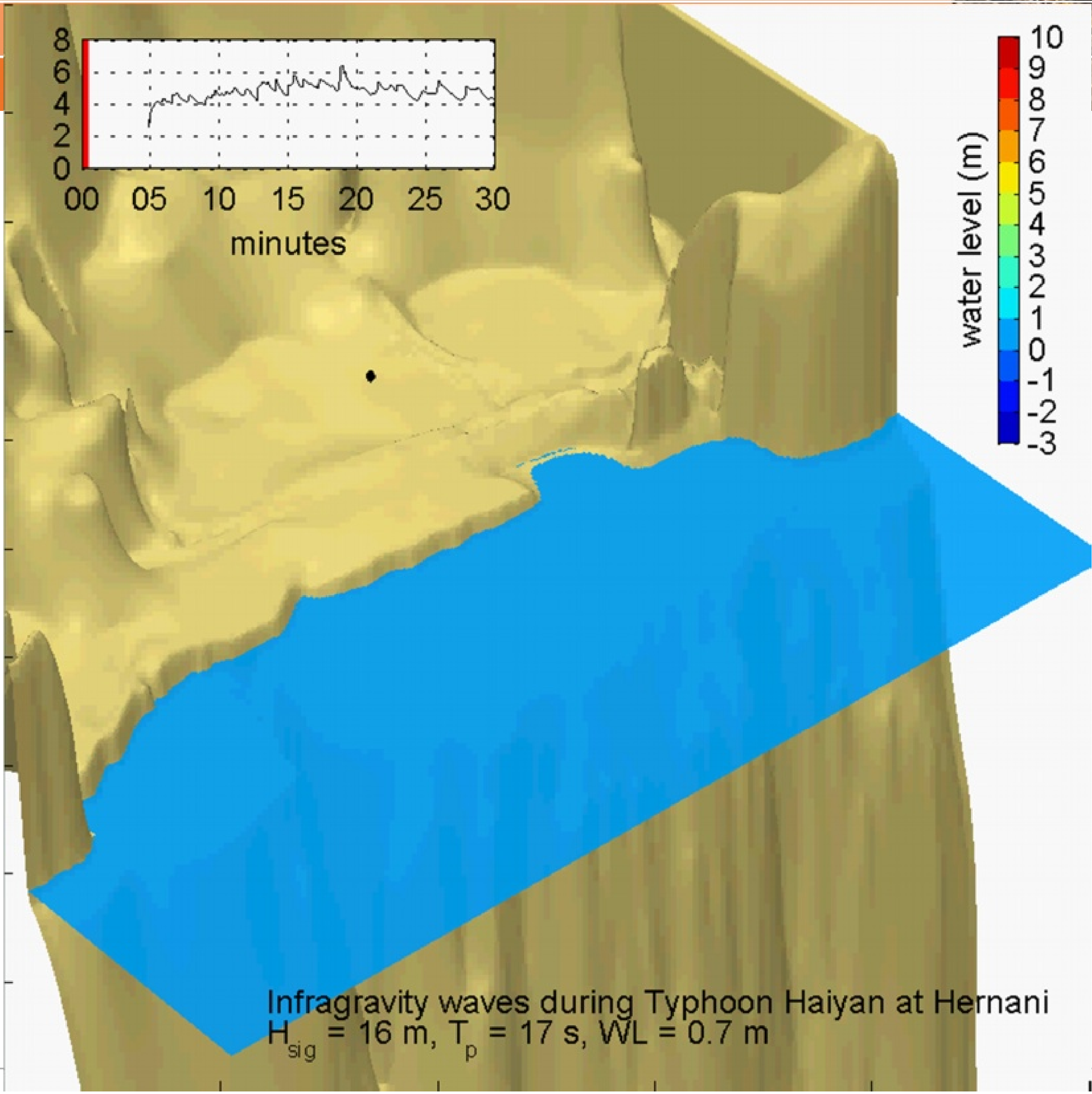
Deltares

Wave runup at Hernani for Haiyan Typhoon, Phillipines

- Total runup about 7 meters

- Offshore ocean surge (due to wind force) = 0.5 m
- Wave setup on reef = 3 m
- (Infra gravity) Wave runup on coast = 3.5 m

- Important: offshore surge as predicted by large scale ocean models is only very small part of total run up


8
6
4
2
0
00 05 10 15 20 25 30
minutes
water level (m)
10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3
Infragravity waves during Typhoon Haiyan at Hernani
H sig = 16 m, T p = 17 s, WL = 0.7 m

Deltares

Flash flood

Deltares

Enabling Delta Life

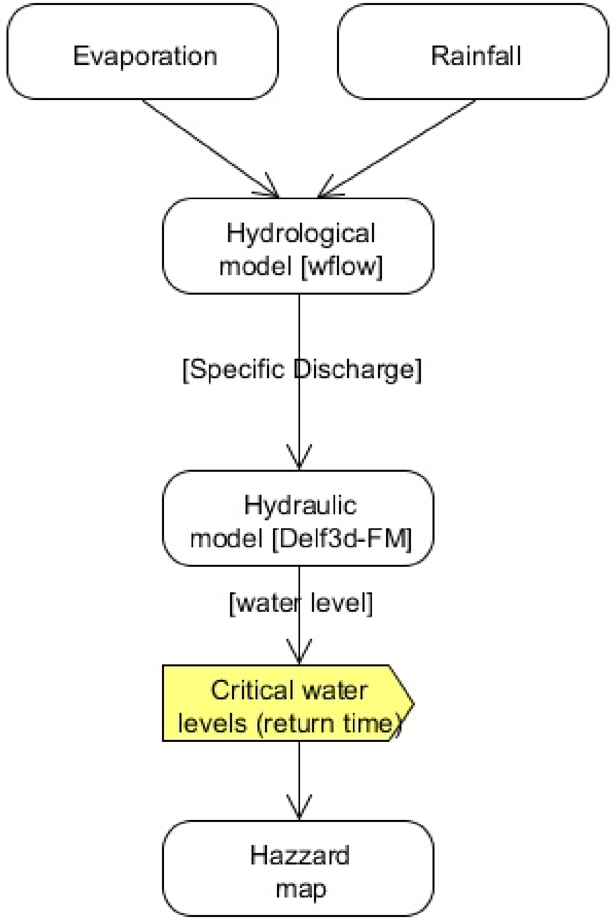
FEWS - Flash Flood Hazard Modeling (existing system and model infra structure available at MDC for forecast and analysis need to be further developed)

The models used to produce hazard maps that will provide a basis for a future Early warning System.

The hazard maps are associated with a certain historic event. The work is to be continued towards hazards with a certain return period (e.g. 1 in 10 years, 1 in 100 years, 1 in 1000 years).

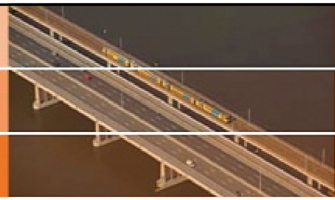
Flash flood models

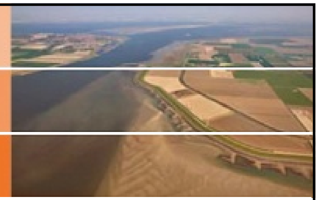
- Hydrological model (wflow): Open source distributed hydrological model developed by Deltares.
  - Input, **precipitation, evaporation**
  - Output: **specific discharge, discharge, soil moisture status**, etc
- Hydraulic model: Delft3D-FM
  - Input: specific discharge (discharge generated per cell)
  - Output: discharge and water levels on a high resolution (flexible) grid



Deltares

Other weather data



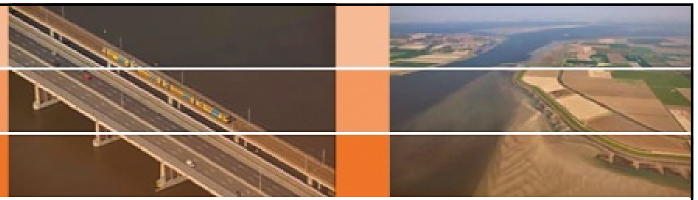


A lot of filtering and quality control required on

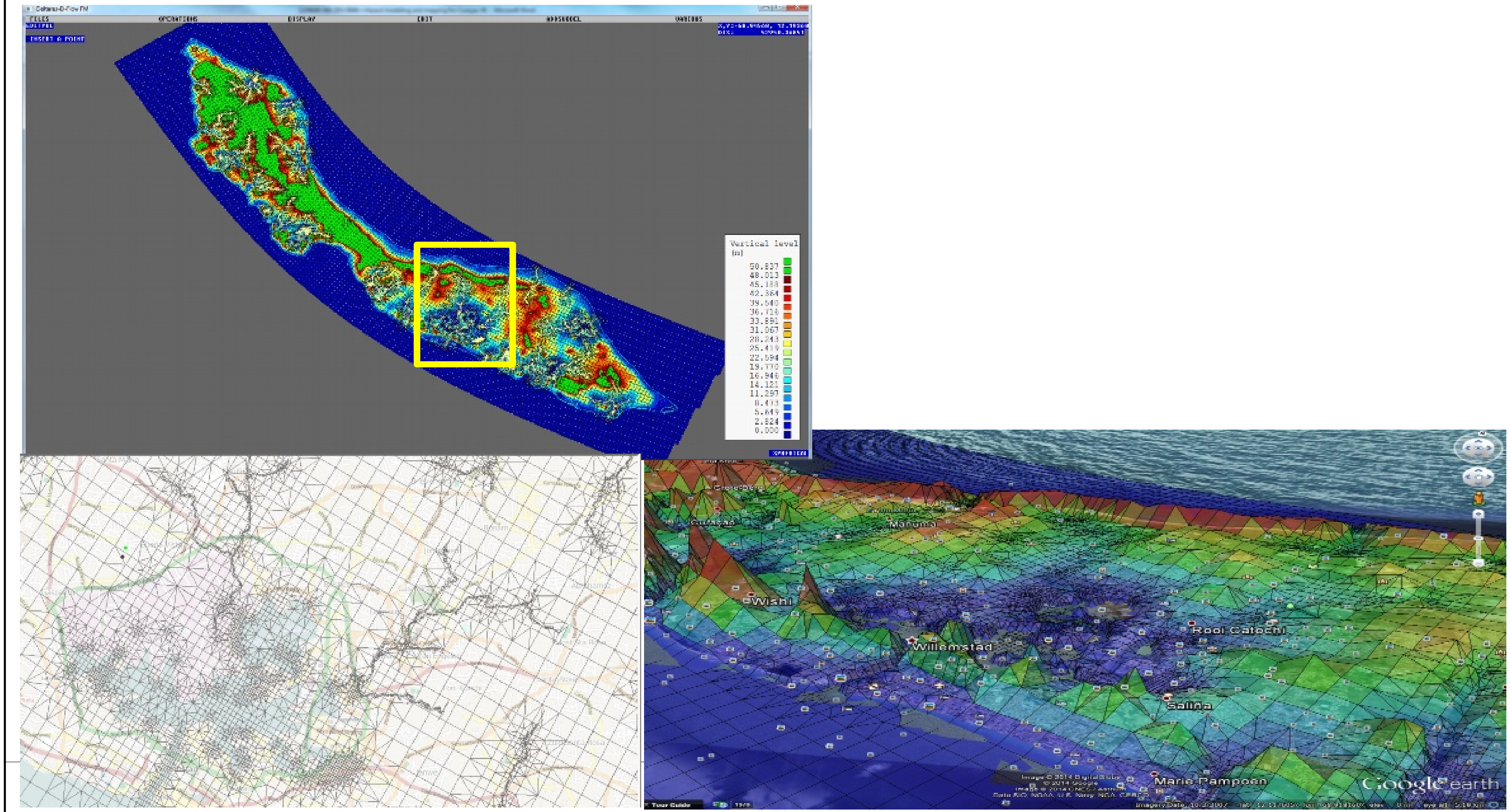
- Rainfall data
- Radar data
- Wind speed
- Relative humidity
- Solar radiation
- Temperature

- Based on quality and completeness of records, pan evaporation values were used in hydrological modeling

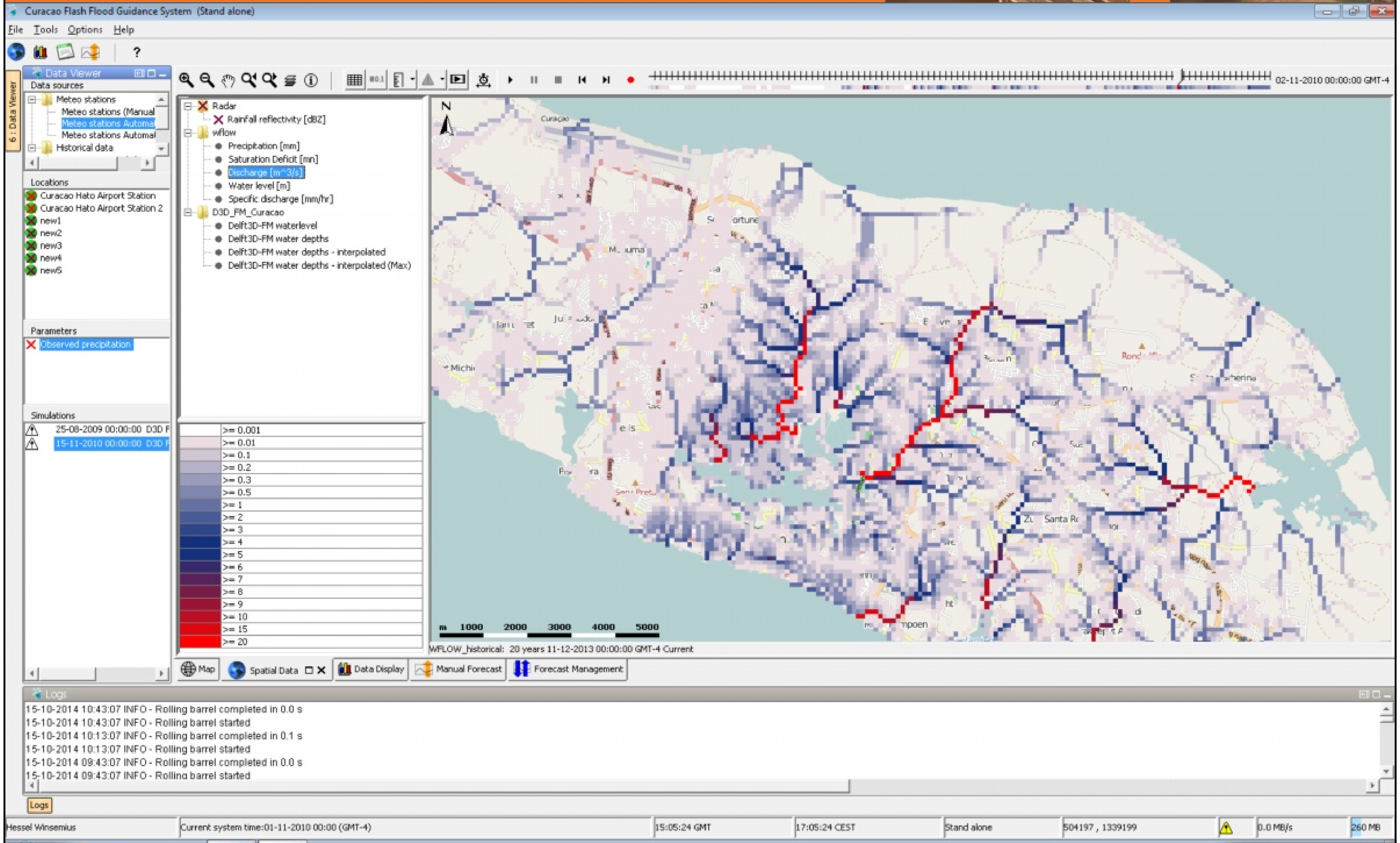
Hydrological model WFLOW



- Simulations of inland water level and discharge (in hindcast or operational purposes)
- Source maps needed: DEM, Land-use, Soil maps

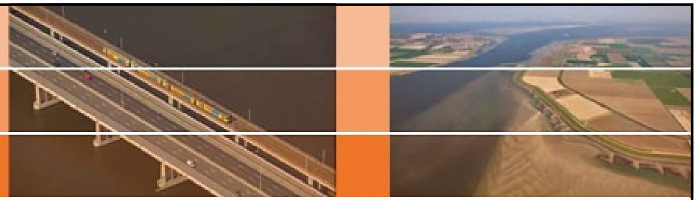


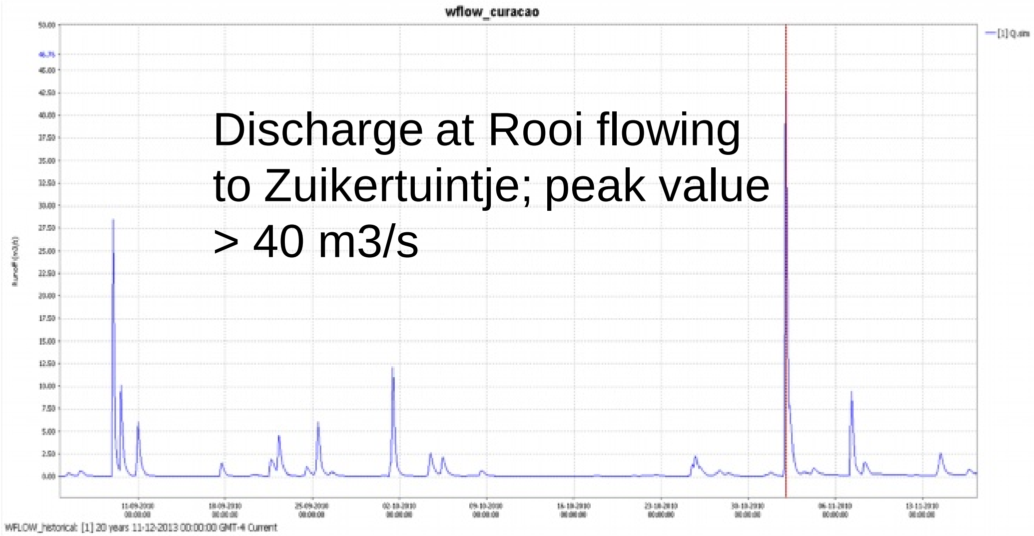
Route tracking



Deltares

Hindcast of Thomas

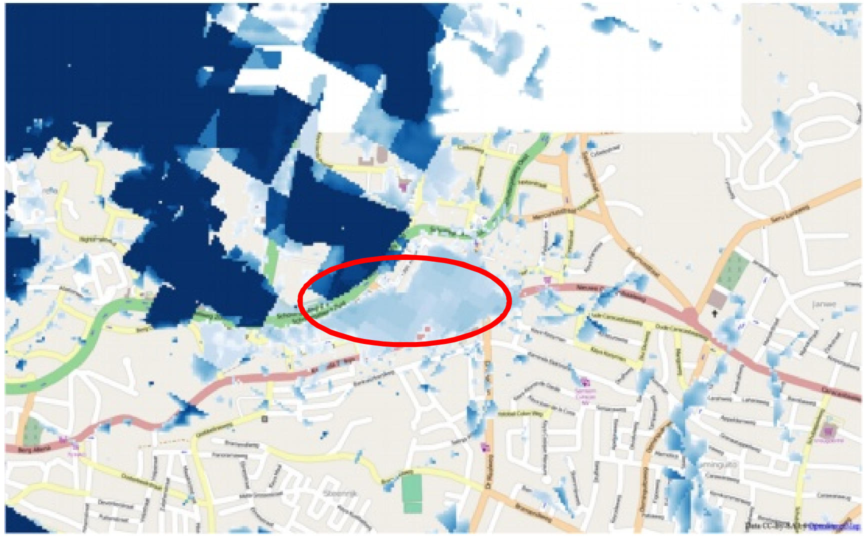


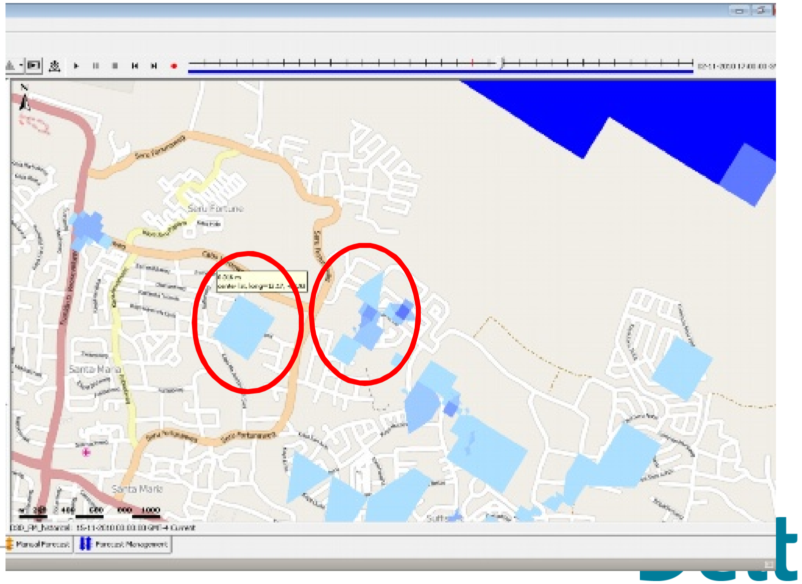


Discharge at Rooi flowing to Zuikertuintje; peak value > 40 m3/s

Deltares

Validation Tomas event – Salina; Seru Fortuna

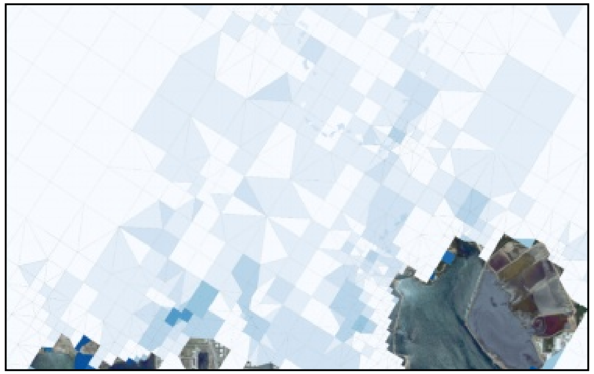




Deltares

Model output; at different scales

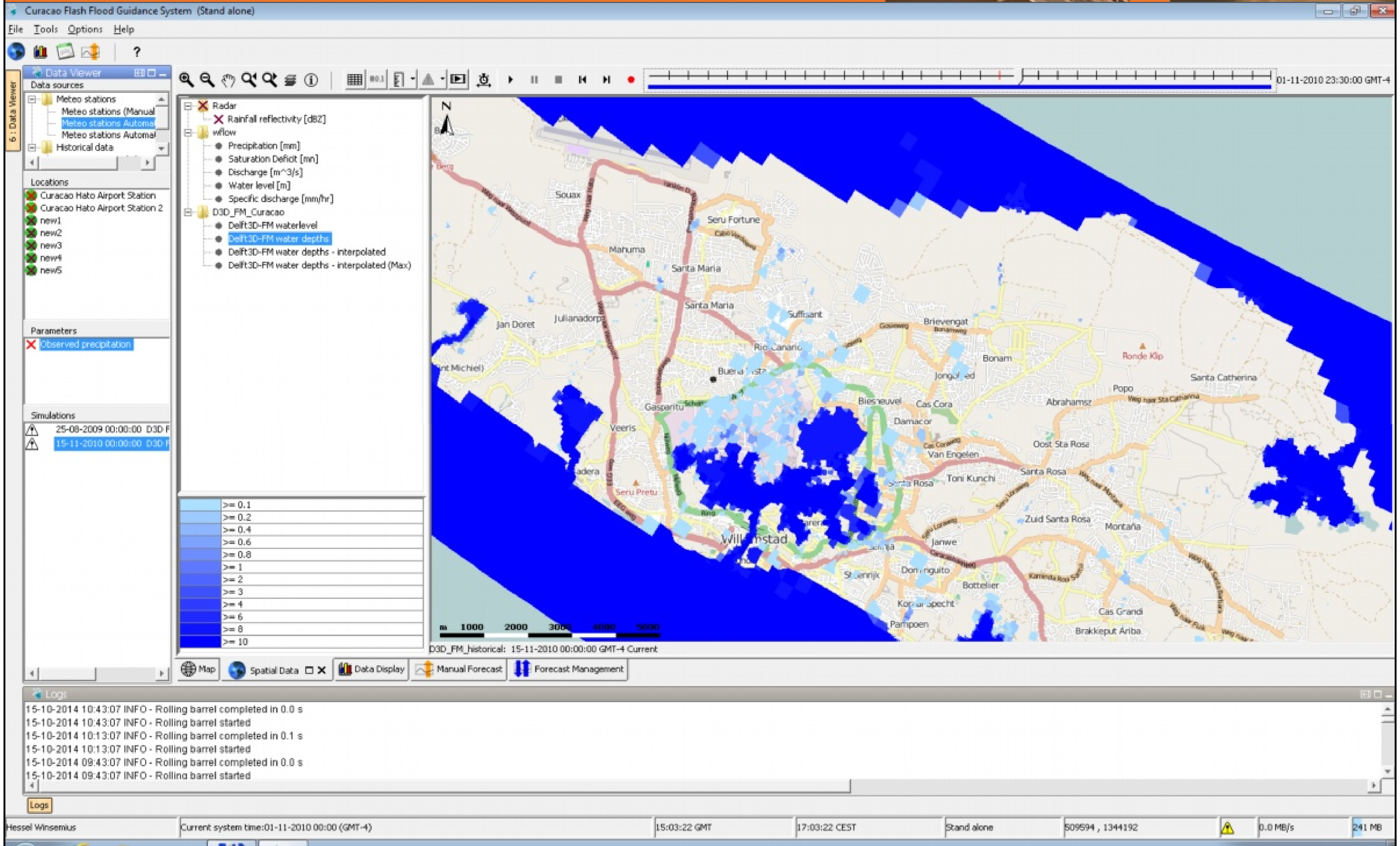
a) Model simulated values at variable mesh size (raw)



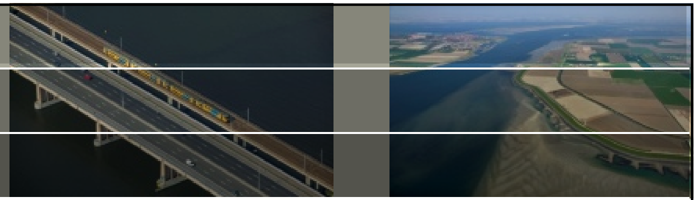
b) Interpolated 100x100 meter map (overall overview of flooding)

c) Downscaled 10x10 meter map for close-up

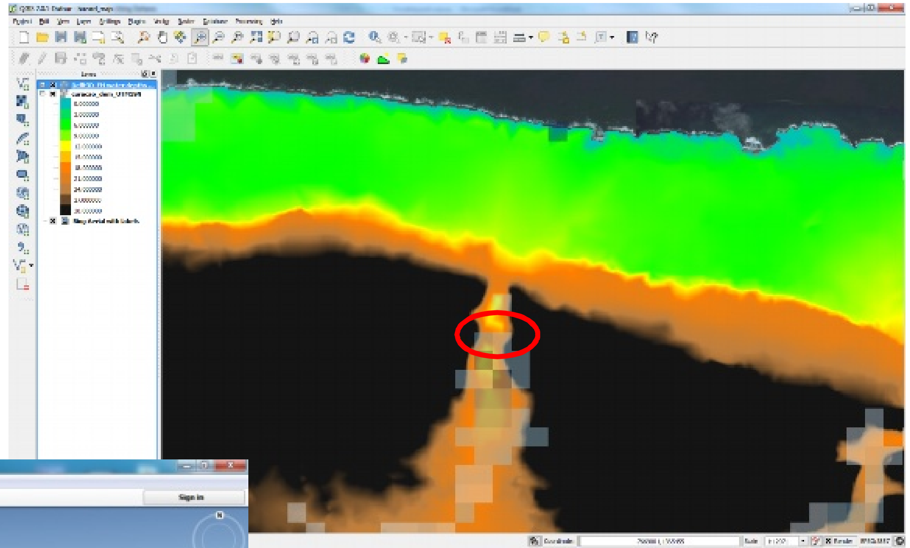
Spatial displays

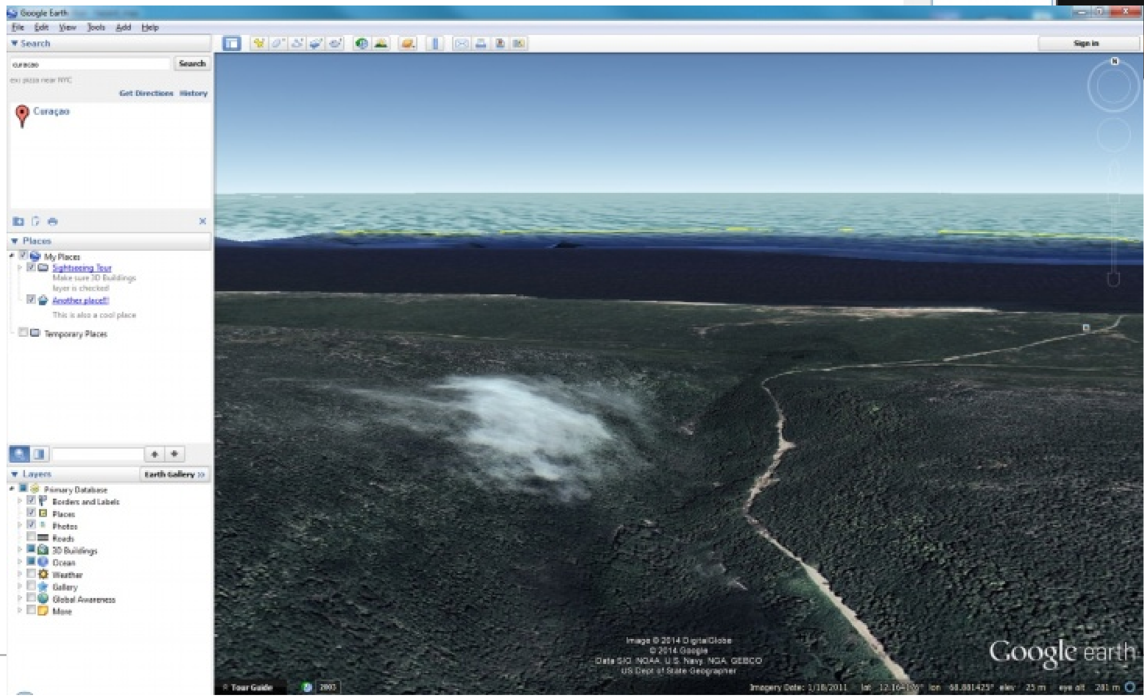


Model issues



Latitude -68.88, longitude 12.17, contains a ‘ridge’. Is this a real ridge where water is blocked? Or is there drainage?



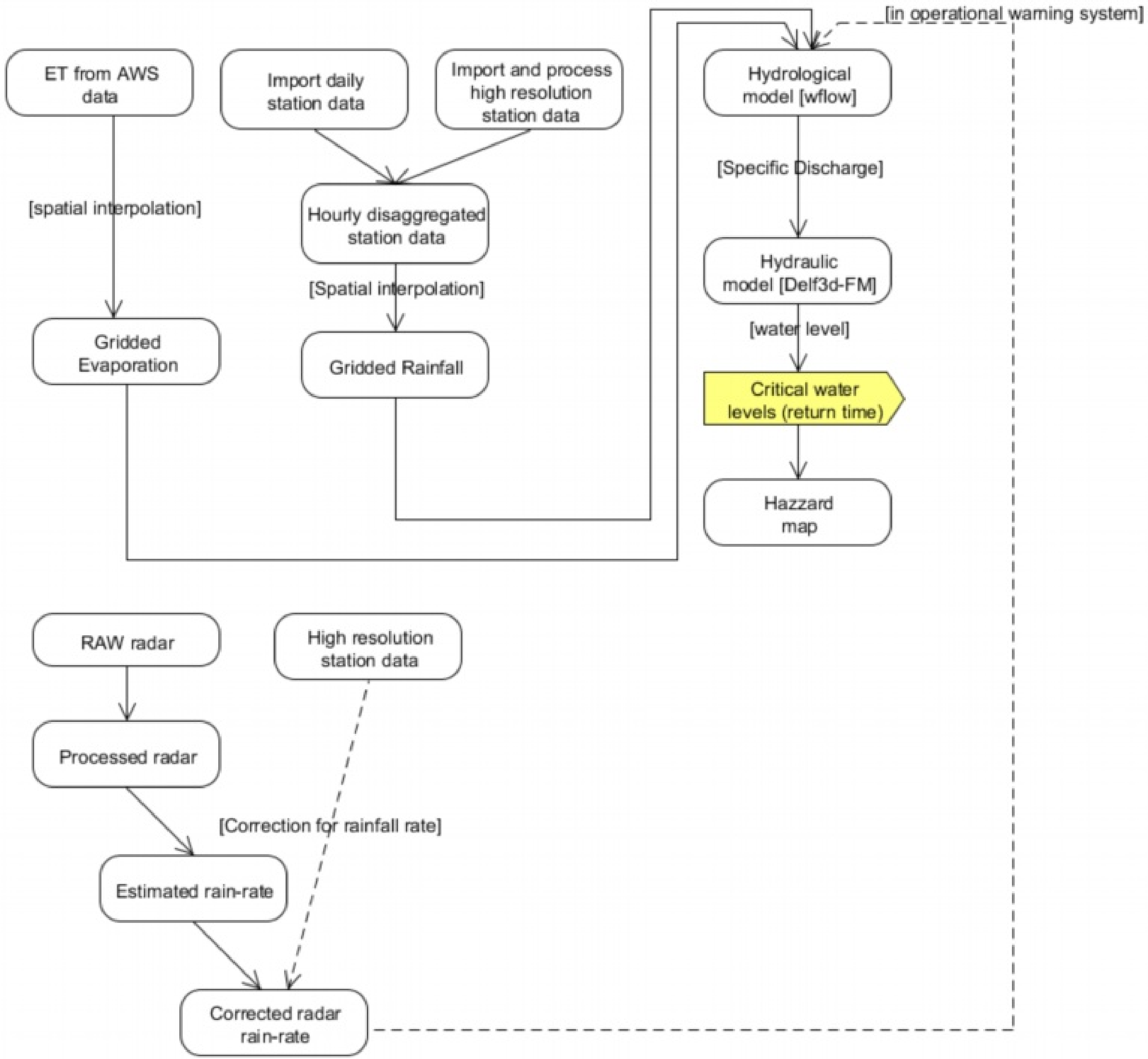


Caveats of modeled results

- Very near drainage channels, pixel results (10x10 meter maximum resolution) represent water in the drains

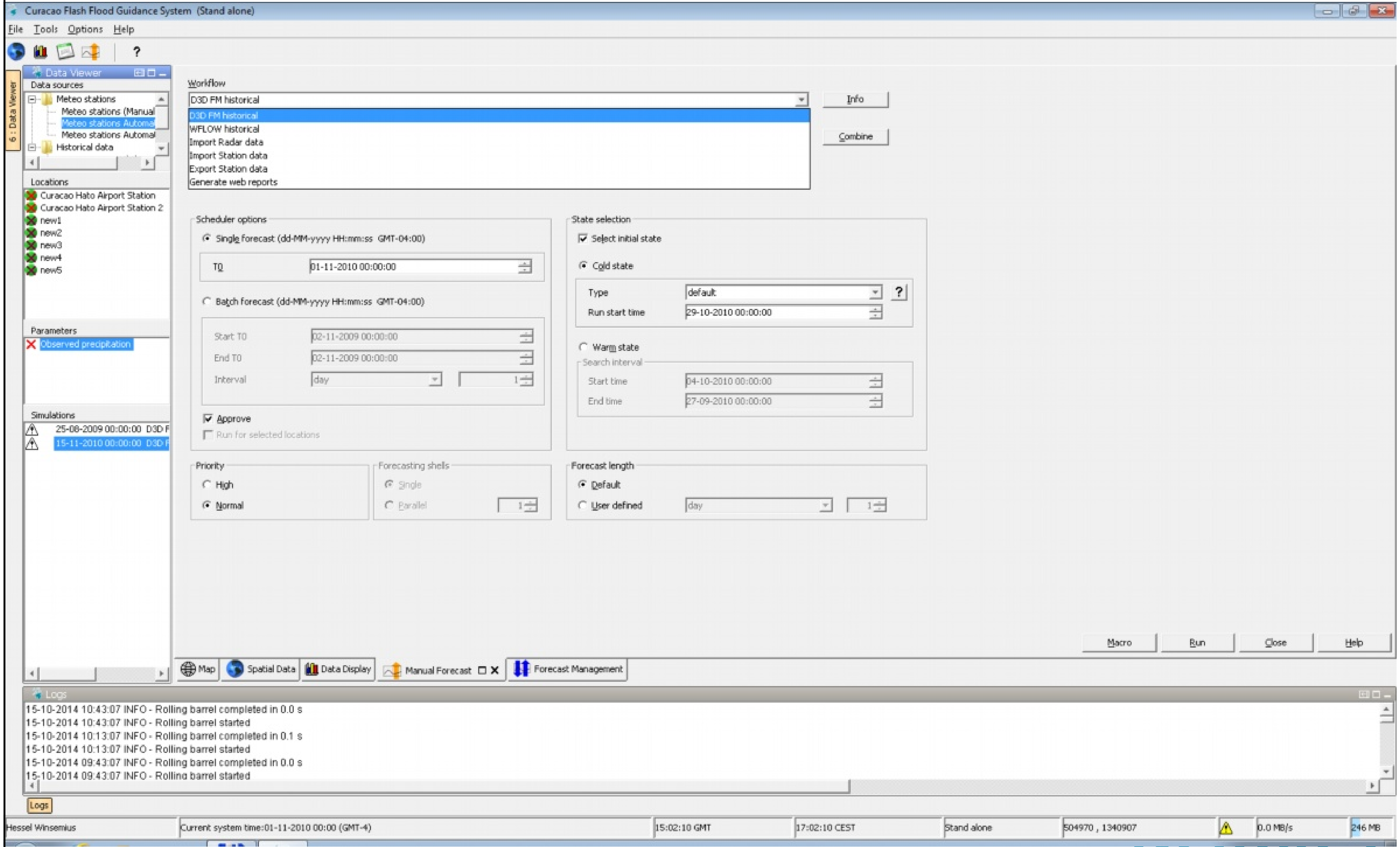
Deltares

Setup of the flash flood forecast system (Delft-FEWS)

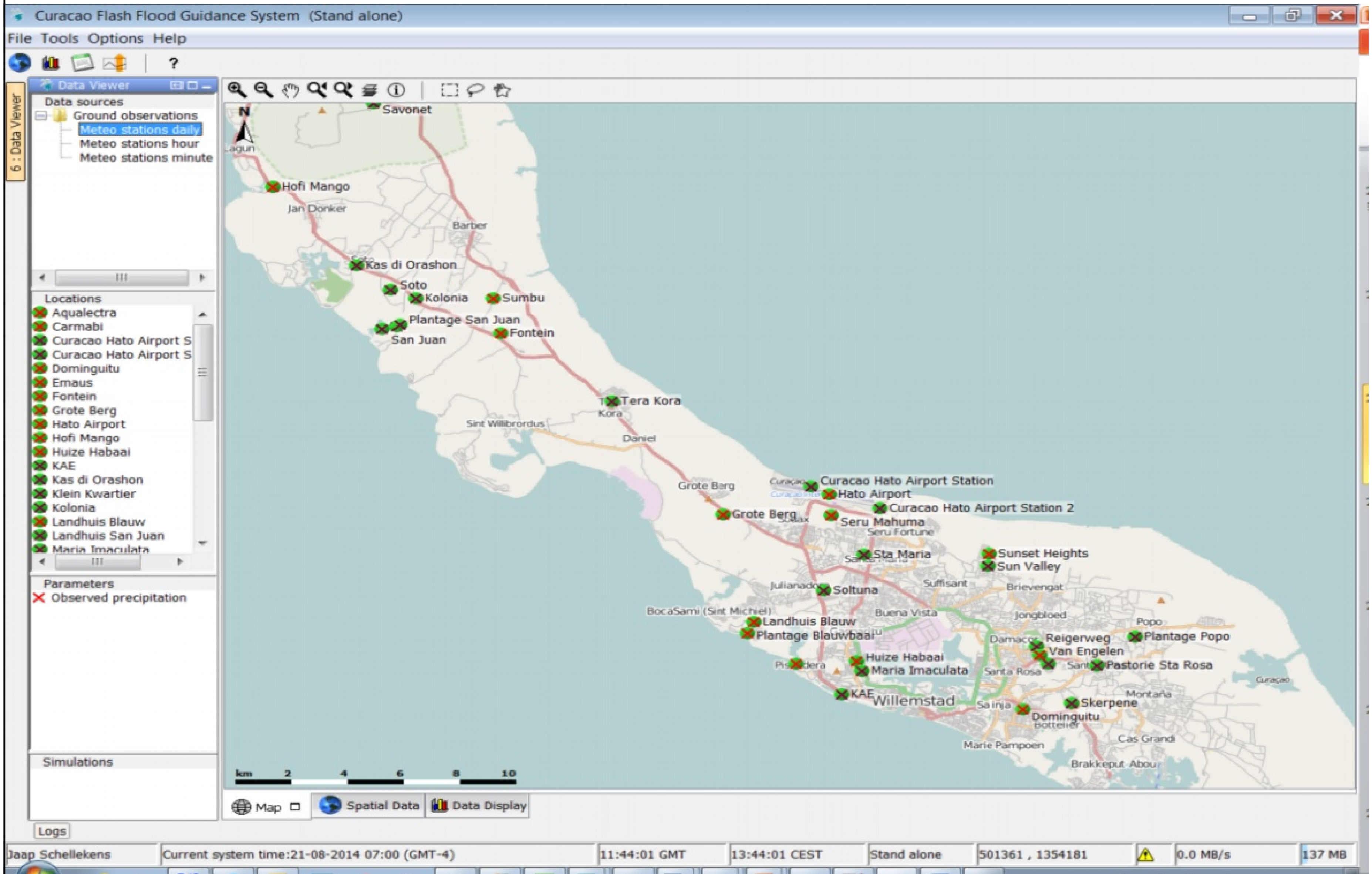


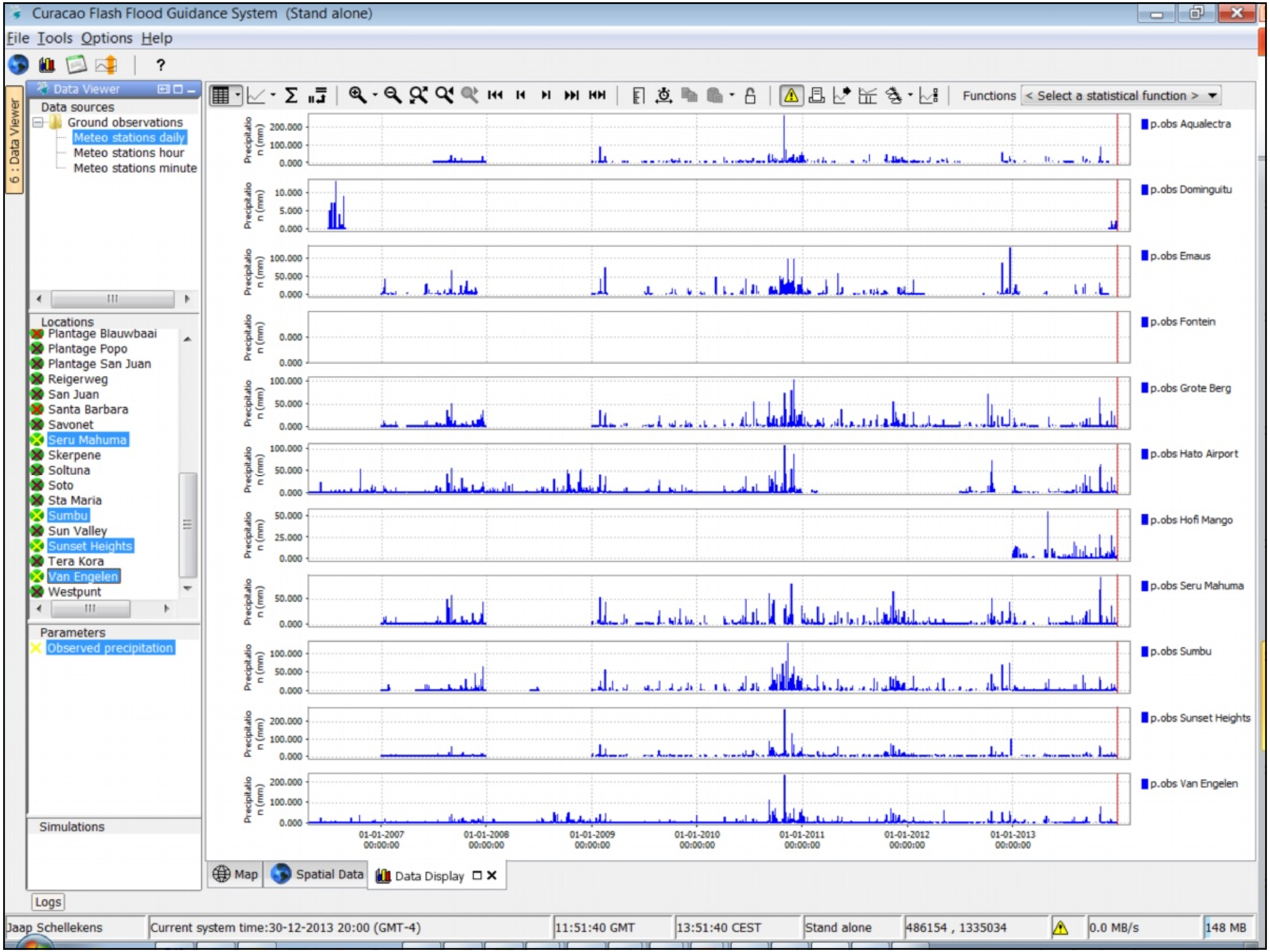
Deltares

Workflows

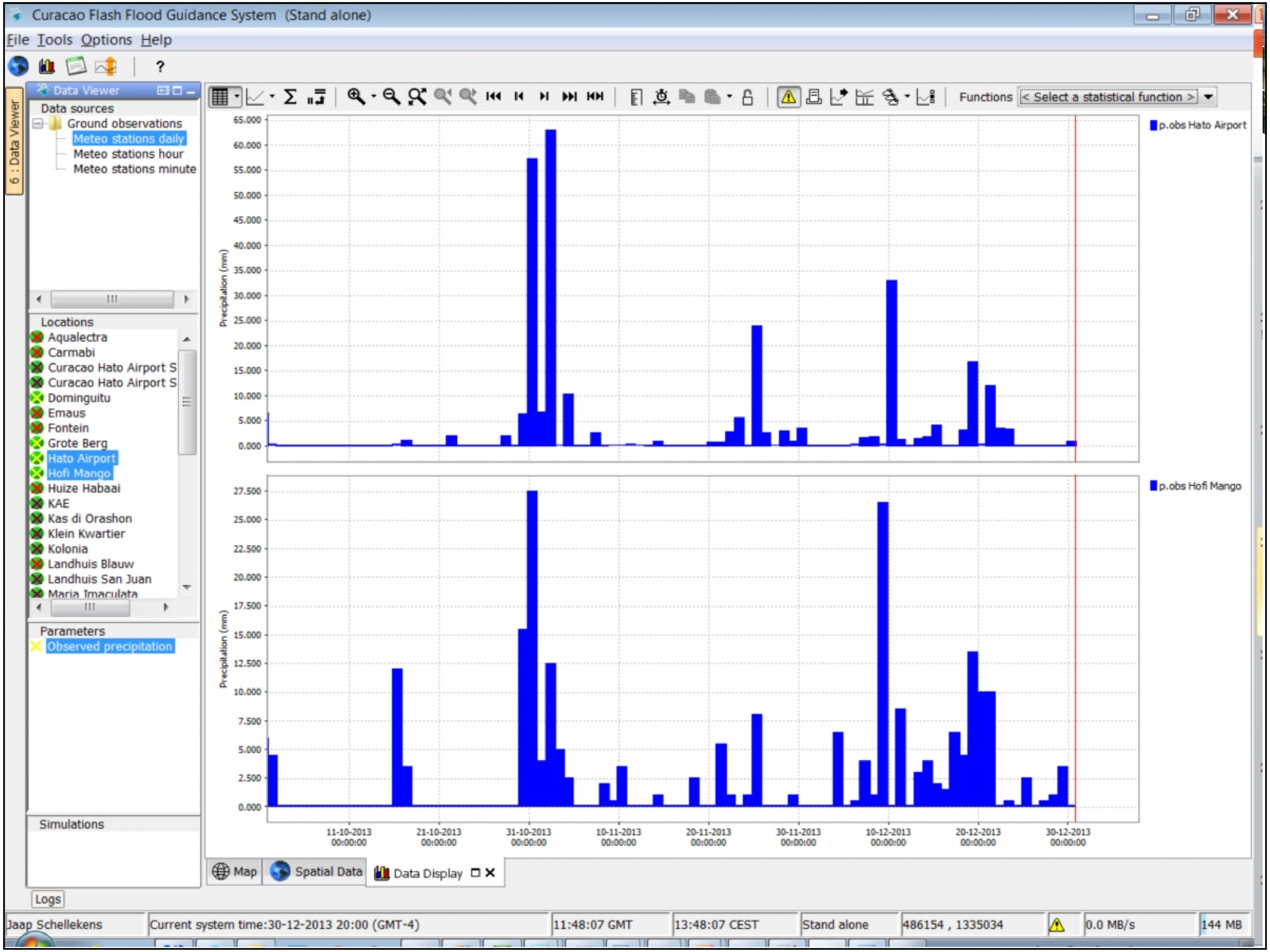

Curacao Flash Flood Guidance System (Stand alone)
File Tools Options Help
Data Viewer
Data sources
Meteo stations
Meteo stations (Manual
Meteo stations Automa
Meteo stations Automa
Historical data
Locations
Curacao Hato Airport Station
Curacao Hato Airport Station 2
new1
new2
new3
new4
new5
Parameters
Observed precipitation
Simulations
25-08-2009 00:00:00 D3D F
15-11-2010 00:00:00 D3D F
Workflow
D3D FM historical
D3D FM historical
WFLOW historical
Import Radar data
Import Station data
Export Station data
Generate web reports
Info
Combine
Scheduler options
Single forecast (dd-MM-yyyy HH:mm:ss GMT-04:00)
T0
01-11-2010 00:00:00
Batch forecast (dd-MM-yyyy HH:mm:ss GMT-04:00)
Start T0
02-11-2009 00:00:00
End T0
02-11-2009 00:00:00
Interval
day
Approve
Run for selected locations
State selection
Select initial state
Cold state
Type
default
Run start time
29-10-2010 00:00:00
Warm state
Search interval
Start time
04-10-2010 00:00:00
End time
27-09-2010 00:00:00
Priority
High
Normal
Forecasting shells
Single
Parallel
Forecast length
Default
User defined
day
Macro
Run
Close
Help
Map
Spatial Data
Data Display
Manual Forecast
Forecast Management
Logs
15-10-2014 10:43:07 INFO - Rolling barrel completed in 0.0 s
15-10-2014 10:43:07 INFO - Rolling barrel started
15-10-2014 10:13:07 INFO - Rolling barrel completed in 0.1 s
15-10-2014 10:13:07 INFO - Rolling barrel started
15-10-2014 09:43:07 INFO - Rolling barrel completed in 0.0 s
15-10-2014 09:43:07 INFO - Rolling barrel started
Logs
Hessel Winsemius
Current system time:01-11-2010 00:00 (GMT-4)
15:02:10 GMT
17:02:10 CEST
Stand alone
504970 , 1340907
0.0 MB/s
246 MB

Setup of the flash flood forecast system (Delft-FEWS)





Curacao Flash Flood Guidance System (Stand alone)
File Tools Options Help
Data Viewer
6 : Data Viewer
Data sources
Ground observations
Meteo stations daily
Meteo stations hour
Meteo stations minute
Locations
Plantage Blauwbaai
Plantage Popo
Plantage San Juan
Reigerweg
San Juan
Santa Barbara
Savonet
Seru Mahuma
Skerpene
Soltuna
Soto
Sta Maria
Sumbu
Sun Valley
Sunset Heights
Tera Kora
Van Engelen
Westpunt
Parameters
Observed precipitation
Simulations
Logs
Functions
< Select a statistical function >
p.obs Aqualectra
p.obs Dominguitu
p.obs Emaus
p.obs Fontein
p.obs Grote Berg
p.obs Hato Airport
p.obs Hofi Mango
p.obs Seru Mahuma
p.obs Sumbu
p.obs Sunset Heights
p.obs Van Engelen
Precipitation (mm)
01-01-2007 00:00:00
01-01-2008 00:00:00
01-01-2009 00:00:00
01-01-2010 00:00:00
01-01-2011 00:00:00
01-01-2012 00:00:00
01-01-2013 00:00:00
Map
Spatial Data
Data Display
Jaap Schellekens
Current system time:30-12-2013 20:00 (GMT-4)
11:51:40 GMT
13:51:40 CEST
Stand alone
486154 , 1335034
0.0 MB/s
148 MB


Curacao Flash Flood Guidance System (Stand alone)
File Tools Options Help
Data Viewer
6 : Data Viewer
Data sources
Ground observations
Meteo stations daily
Meteo stations hour
Meteo stations minute
Locations
Aqualectra
Carmabi
Curacao Hato Airport S
Curacao Hato Airport S
Dominguitu
Emaus
Fontein
Grote Berg
Hato Airport
Hofi Mango
Huize Habaai
KAE
Kas di Orashon
Klein Kwartier
Kolonia
Landhuis Blauw
Landhuis San Juan
Maria Imaculata
Parameters
Observed precipitation
Simulations
Logs
Functions
< Select a statistical function >
p.obs Hato Airport
p.obs Hofi Mango
Precipitation (mm)
65.000
60.000
55.000
50.000
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
27.500
25.000
22.500
20.000
17.500
15.000
12.500
10.000
7.500
5.000
2.500
0.000
11-10-2013 00:00:00
21-10-2013 00:00:00
31-10-2013 00:00:00
10-11-2013 00:00:00
20-11-2013 00:00:00
30-11-2013 00:00:00
10-12-2013 00:00:00
20-12-2013 00:00:00
30-12-2013 00:00:00
Map
Spatial Data
Data Display
Jaap Schellekens
Current system time:30-12-2013 20:00 (GMT-4)
11:48:07 GMT
13:48:07 CEST
Stand alone
486154 , 1335034
0.0 MB/s
144 MB

Most important findings of the FEWS – flash flood project for Curacao

- Sub-hourly rainfall is essential for flash flood simulation. The rainfall radar (if calibrated) will be valuable in tracking / forecasting of flash floods
- A Delft-FEWS system is established that integrates all models and data. Automatic imports of rainfall data are already established
- Two models are integrated in Delft-FEWS, such that they can simulate historic flash flood events
- A flood footprint (map) was generated for this event.

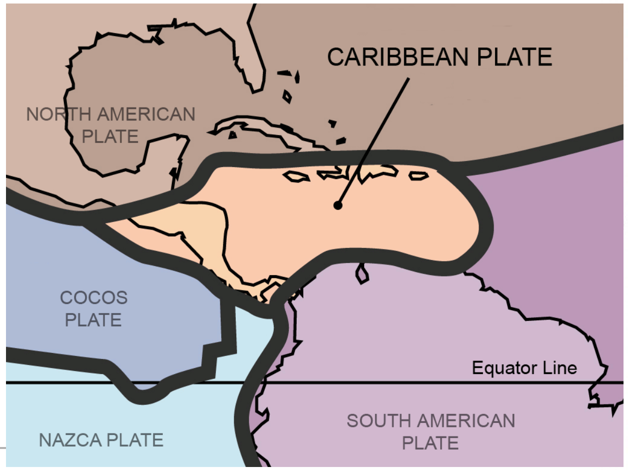
Recommendations of the project

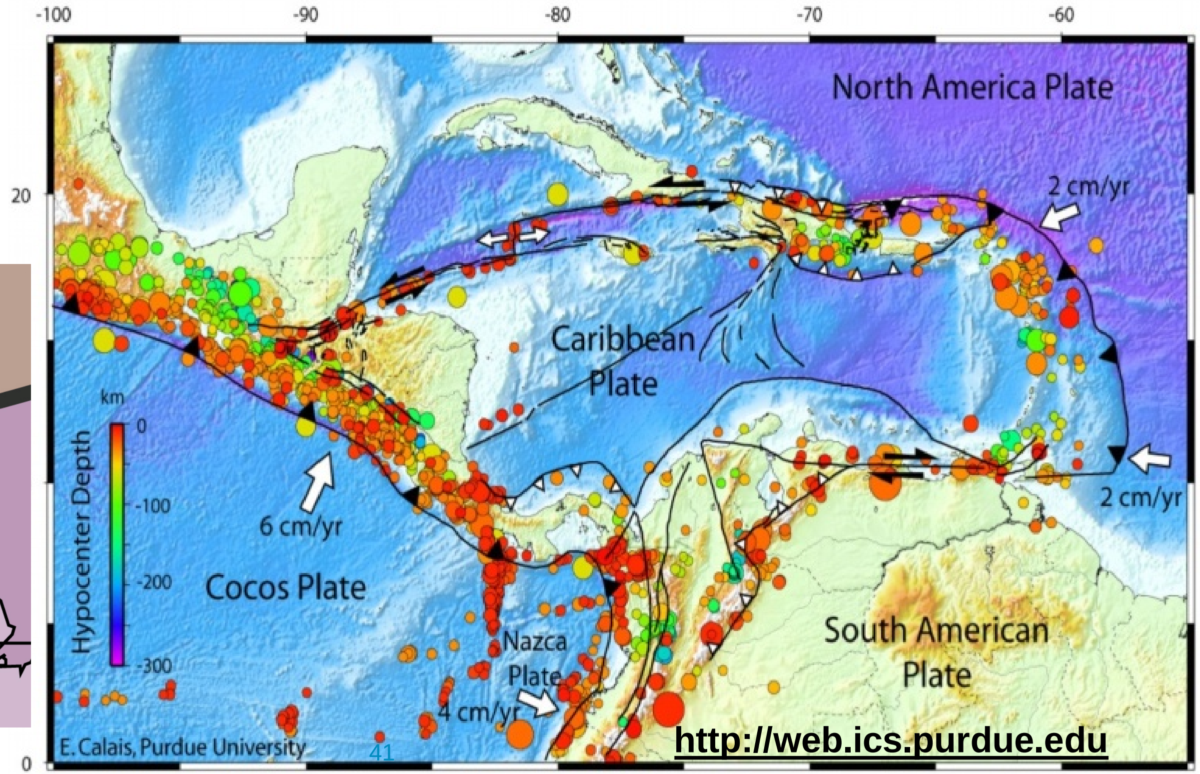
- Extend model with coast and include tide, surge and wave components and wind/pressure forcing
- Include import of forecast data of wind, pressure and wave from global model
- Investigate radar-based rainfall forecast (e.g. with STEPS approach)
- Extend workflows to forecast with lead time using the above
- Establish sound mitigation and warning procedures based on hazard maps (which areas are flood-prone?)

Tsunami

Caribian plate is bordered by the North-Americanse, Cocos-, Nazca en South-American plate. This plate formed from sediments ca. 70-60 million years ago. The vulcanic arc formed in the East is moving eastwards.
Through subduction and obduction the plate is raised (source: Wikipedia).

For far source tsunami, earthquake from Portugal is the main threat (1755 Lisbon Tsunami)

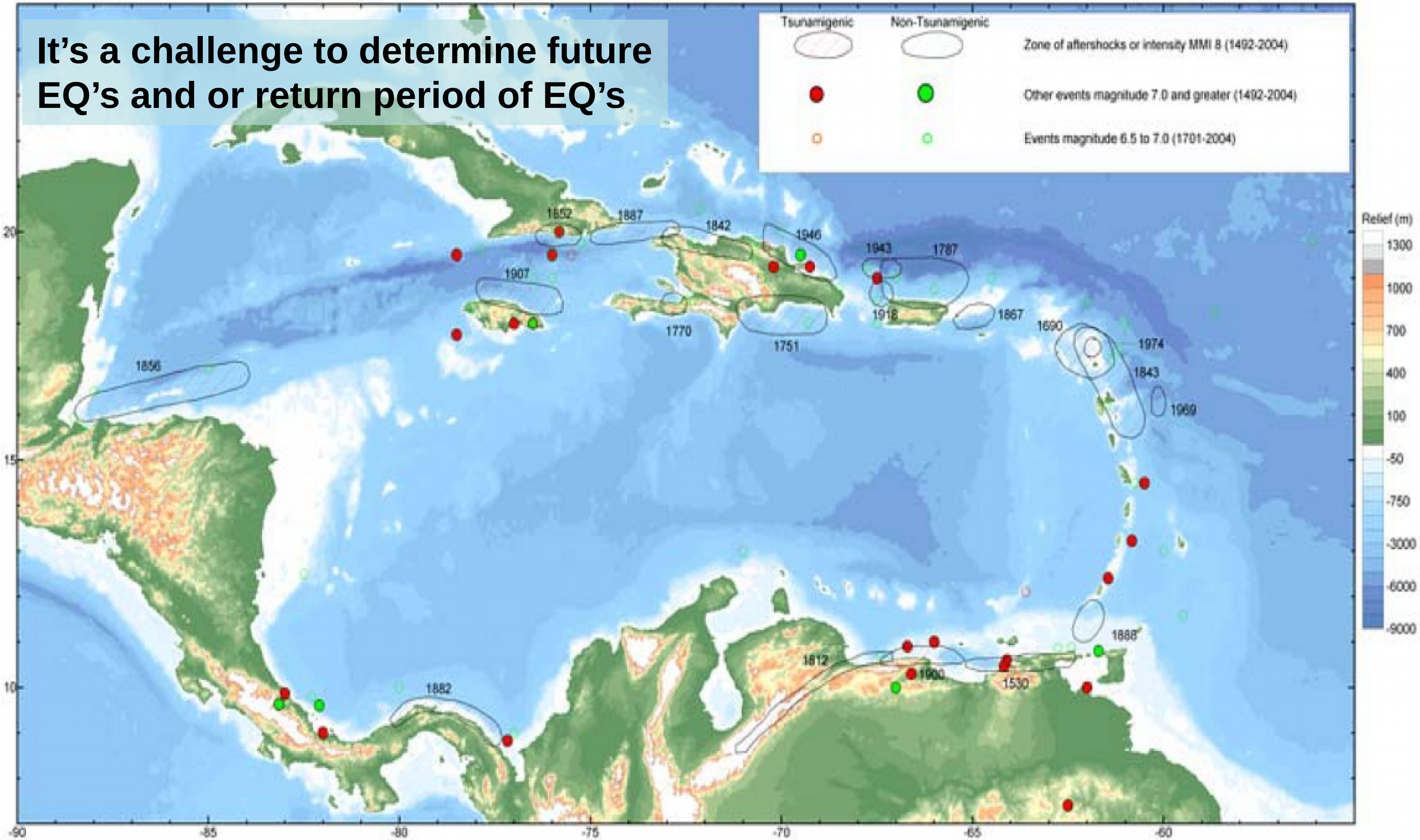




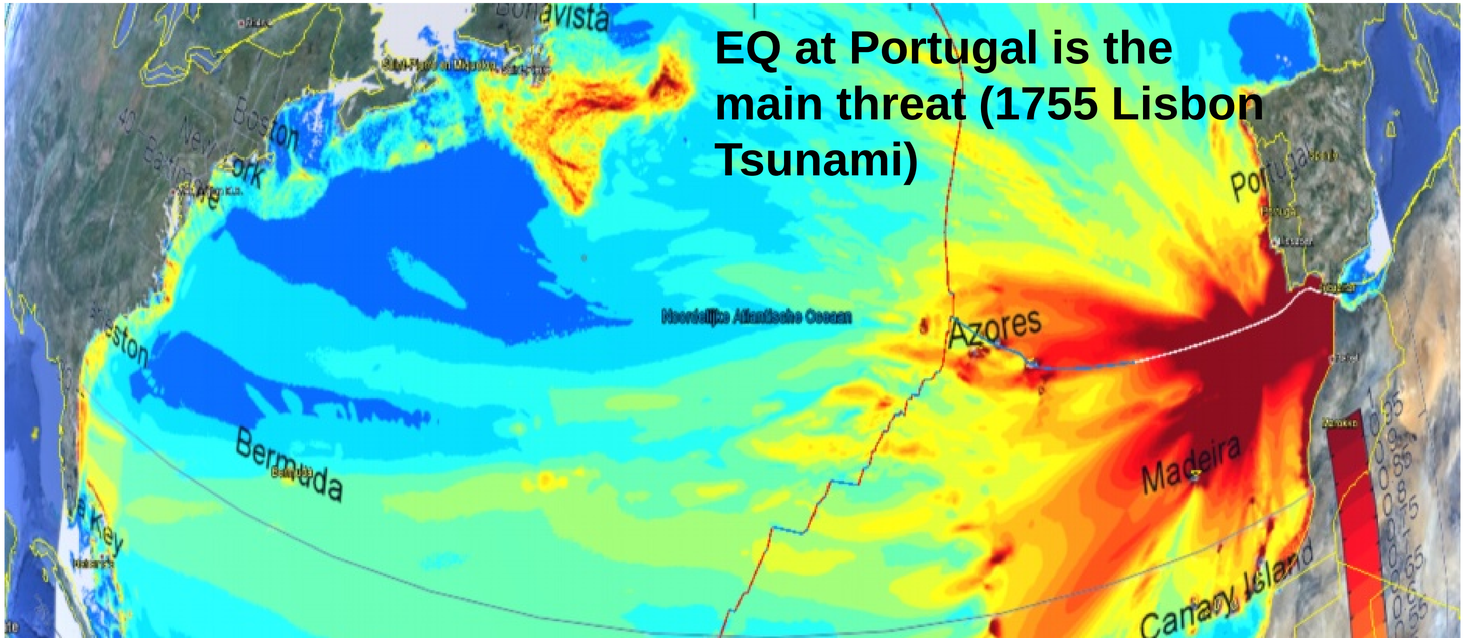
http://web.ics.purdue.edu

Tsunamigenic earthquake in the past (source: McCann, 2004).

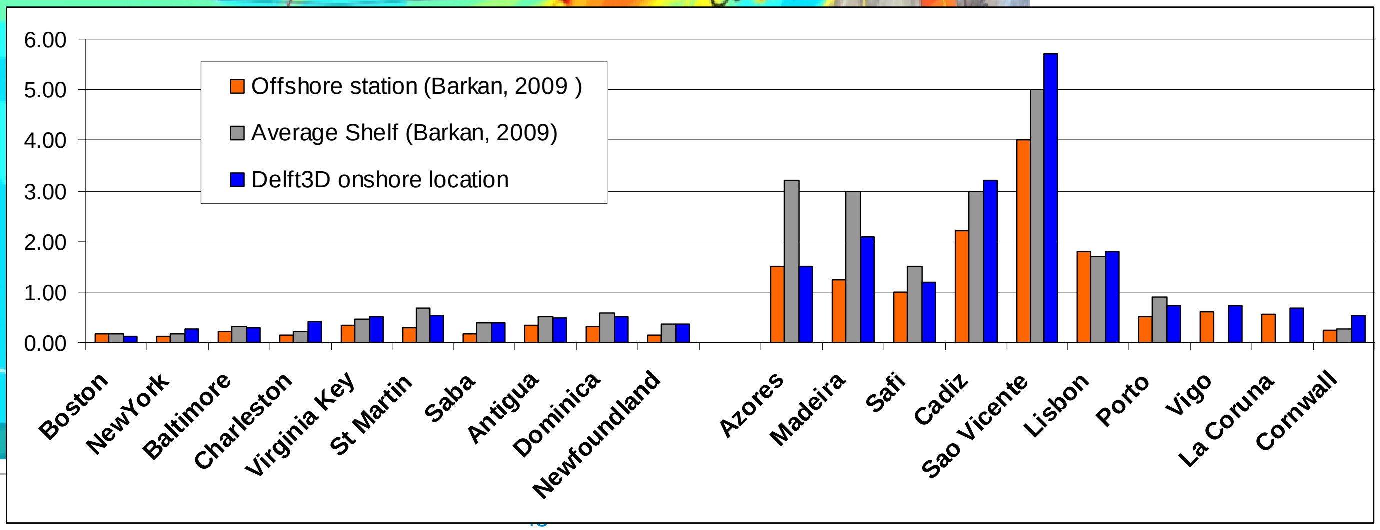
Historic Earthquakes and Tsunami 1492-2004



Far Source Tsunami (Deltares)

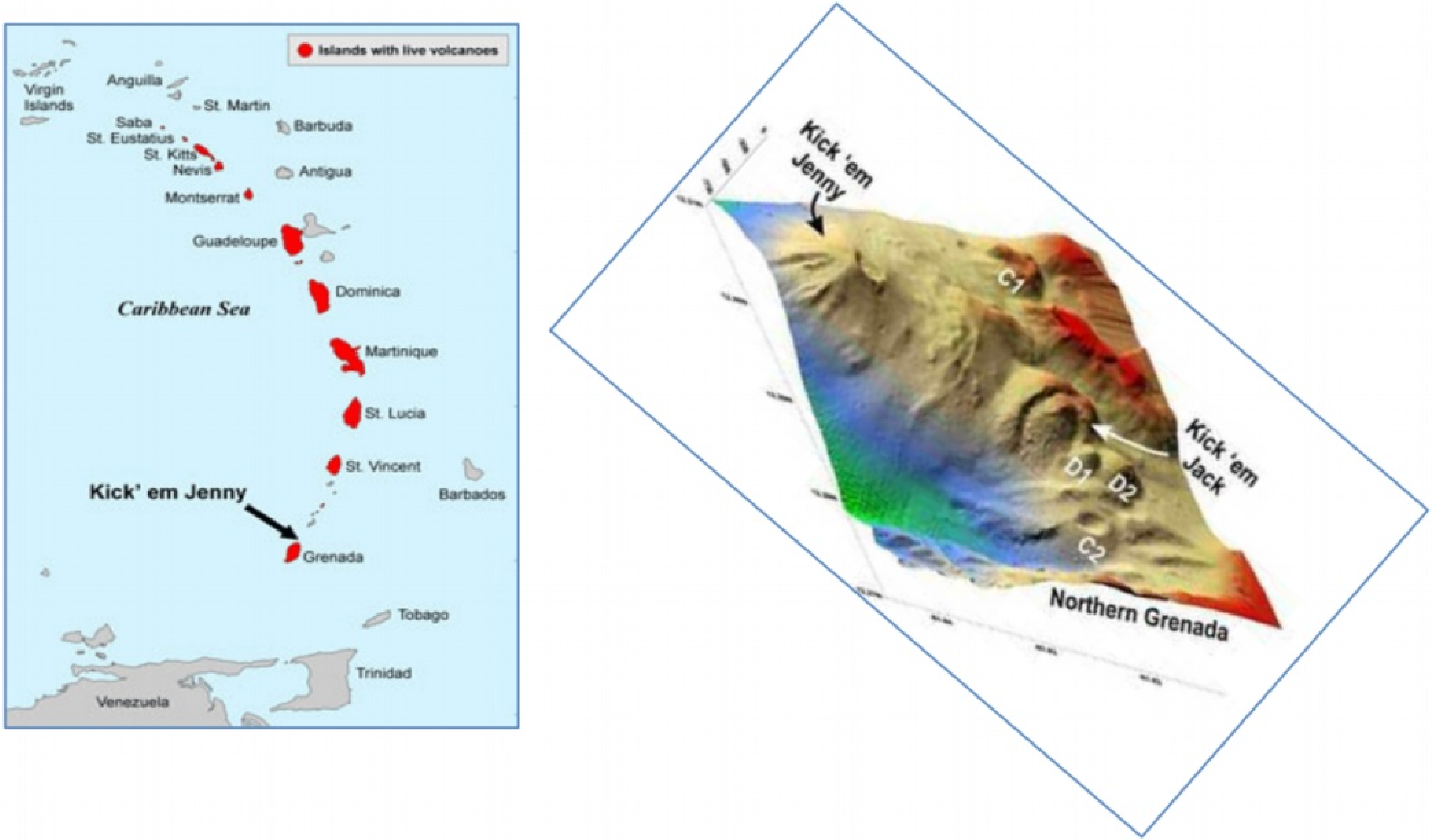


EQ at Portugal is the main threat (1755 Lisbon Tsunami)

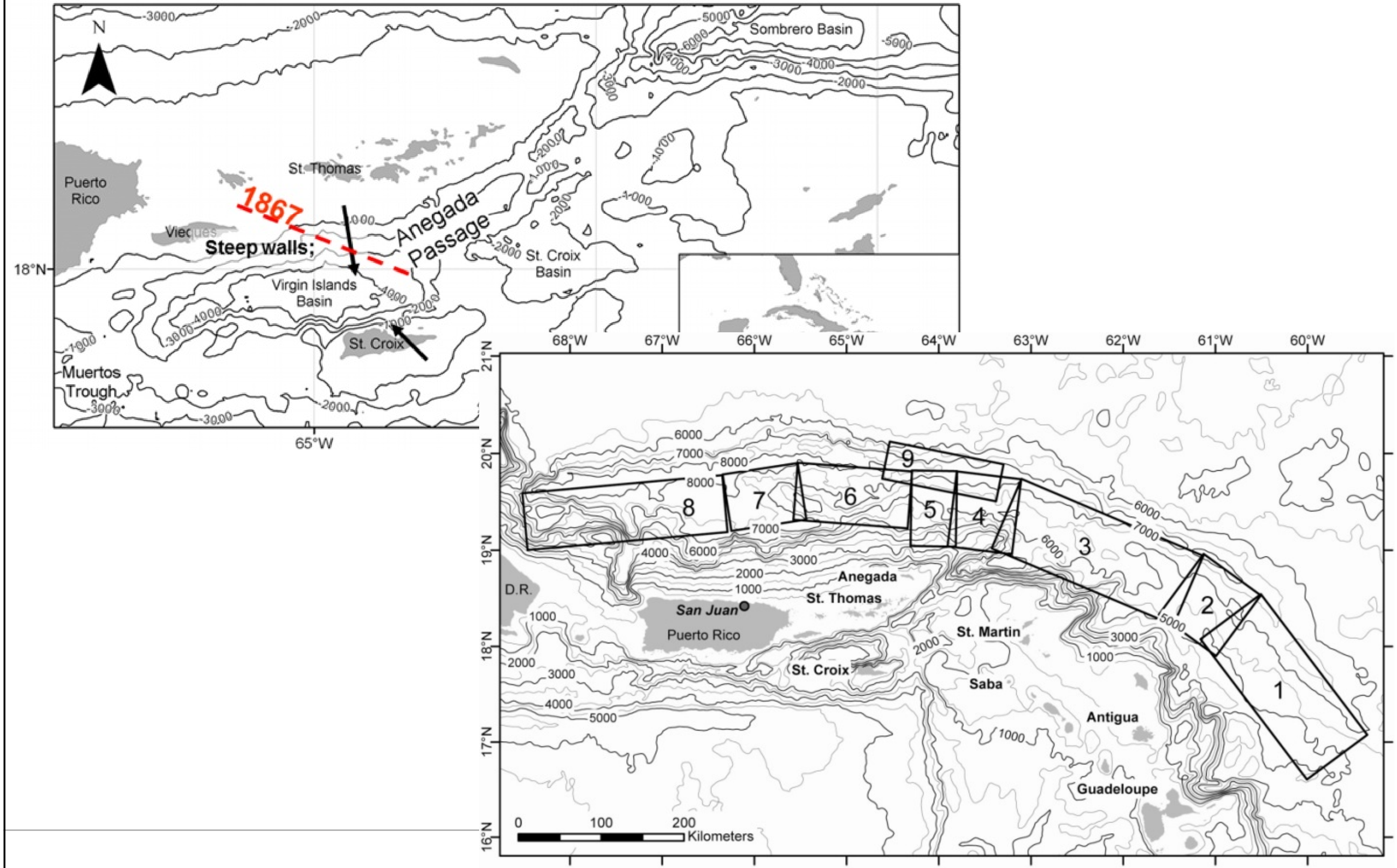


Kick em Jenny volcano

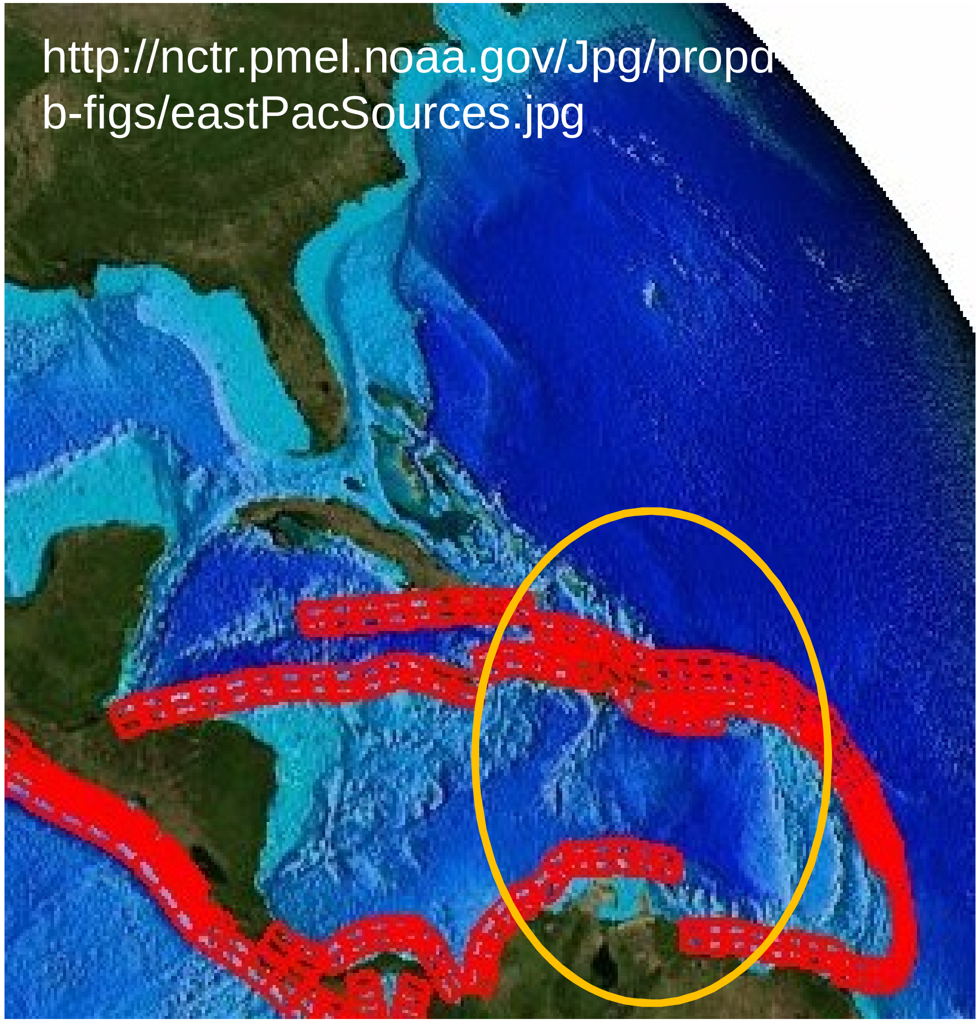
Figure 3 Locaties van de vulkanen Kick 'em Jenny en Kick 'em Jack (bron: www.uwiseismic.com/general.aspx?id=27)



Possible future large EQ sources identified by USGS



Approach for Curacao



Use unit source at each of the rectangle as defined by PMEL. This rectangle (by selective combination) forms possible EQ source along the fault lines. Pre-calculate response of each of the rectangle. Store the results.

When actual EQ occurs, through linear superposition of selected unit source, using appropriate weights, to match the reported EQ magnitude and produce the tsunami wave height for this EQ.

This can be done in real time and will take very short time.

Deltares