MODELING OF TSUNAMIS AND TROPICAL CYCLONES
CONTRIBUTIONS TO HAZARD ASSESSMENT AND
DISASTER MANAGEMENT

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HUMAN has always been interacted with the coast and the sea. Because water is the source of life. For thousands of years, a large portion of the world’s population has made their home along or near the coast.
HUMAN HAS ALWAYS BEEN INTERACTED WITH THE COAST AND THE SEA. 

BECAUSE WATER IS THE SOURCE of LIFE

FOR THOUSANDS OF YEARS, A LARGE PORTION OF THE WORLD’S POPULATION HAS MADE THEIR HOME ALONG OR NEAR THE COAST

SAFE COASTAL COMMUNITIES REQUIRE SAFE AND RESILIENT COASTAL DEFENSE
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Hydrological Hazards

• Earthquakes
• Tsunami
• Tropical Cyclones, Hurricanes, Typhoons
• Storm and Storm Surge, Tornadoes
• Tides
• Sea Level Rise
• Swell
• Seiches and Resonance
• Freak Waves
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The tsunami formed when energy from the earthquake vertically jolted the seabed by several metres, displacing hundreds of cubic kilometres of water.
In deep water the tsunami moved at up to 800km/h (500mph). When it reached shallow water near coastal areas, the tsunami slowed but increased in height.
Specific Terms (nearshore-inundation parameters):

**Run-up:** Vertical height a wave reaches above a reference sea level as it washes ashore.

**Wave height:** Vertical measurement of the wave before it reaches shore.

**Flow Depth:** Depth of the flow in inundation zone

**Current velocity:** Velocity of flow in inundation zone

**Inundation distance:** Horizontal distance a tsunami reaches landward from shoreline.

**Maximum negative Amplitude:** The maximum level of sea level subsidence.
CROSS SECTIONAL VIEW OF INUNDATION AND NEARSHORE TSUNAMI AND TROPICAL CYCLONE PARAMETERS
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NORTHERN SUMATRA (INDONESIA, INDIAN OCEAN)
EARTHQUAKE (Mw~9.0) OF DECEMBER 26, 2004:
SOURCE RUPTURE PROCESSES, SLIP DISTRIBUTION MODELING
AND TSUNAMI GENERATION

Preliminary Rupture Model Contributed by
Tuncay Taymaz, Onur Tan and Seda Yolçal
İstanbul Technical University, the Faculty of Mines
Department of Geophysics - Seismology Section, İstanbul
http://www.geop.itu.edu.tr/~taymaz/sumatra

DATE MARK
December 26, 2004
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UNESCO IOC POST TSUNAMI FIELD SURVEY SUMATRA
January 15-30, 2005 Medan, Simeulue and Meulaboh
http://yalciner.ce.metu.edu.tr/sumatra/survey
Meulaboh Port and Coastal Structures after tsunami

04° 07.740” N  96° 07.738” E
MEGA TSUNAMIS IN JAPAN

- 869 JOGAN TSUNAMI
- 1611 KEICHO TSUNAMI
- 1896 MEIJI TSUNAMI
- 1933 SHOWA TSUNAMI
- 1960 SHIZUKAWA TSUNAMI (CHILE EARTHQUAKE)
- 2011 GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI
KAMAISHI
GENERAL EVALUATION FROM THE PERSPECTIVE OF STRUCTURAL PERFORMANCE
2011 GREAT EAST JAPAN TSUNAMI

- Narrow long bays
- Along rivers
- Coastal Forestation
- Marine Vessels
- Tsunami Breakwaters
- Tsunami Walls along the Coastlines

- Wooden Structures
- Concrete Structures
- Bridges
- Scouring
- Berthing Places
HURRICANE IRMA AND MARIA
HURRICANE IRMA
The catastrophic hurricane made seven landfalls, four of which occurred as a category 5 hurricane across the northern Caribbean Islands.

Irma caused widespread devastation across the affected areas and was one of the strongest and costliest hurricanes on record in the Atlantic basin.


VIIRS satellite image of hurricane Irma when it was at its peak intensity and made landfall on Barbuda at 0535 UTC, 6 September.
Irma originated from a tropical wave that departed the west coast of Africa on 27 August 2017.
Irma’s estimated peak intensity of 155 kt from 5 September to 6 September is based on a blend of multiple SFMR surface wind estimates and flight-level winds observed by the Air Force Reserve and NOAA Hurricane Hunters during that time period.

a) Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Irma, 30 August–12 September 2017.

b) Selected pressure observations and best track minimum central pressure curve for Hurricane Irma, 30 August–12 September 2017.
Irma caused **47 direct deaths** as a result of its strong winds, heavy rains, and high surf **across the Caribbean Islands and the southeastern United States**. The majority of the causalities were in the Caribbean Islands, where Irma’s winds were the strongest.

Eleven direct deaths were reported combined in Saint Martin and Saint Barthelemy, 9 in Cuba, 4 in Sint Maarten, 4 in the British Virgin Islands, 3 in the U.S. Virgin Islands, 3 in Barbuda, 1 in Barbados, 1 in Haiti, and 1 in Anguilla.
HURRICANE MARIA

16–30 September 2017

• Maria was a very severe Cape Verde Hurricane that ravaged the island of Dominica at category 5 (on the Saffir-Simpson Hurricane Wind Scale) intensity, and later devastated Puerto Rico as a high-end category 4 hurricane.

• It also inflicted serious damage on some of the other islands of the northeastern Caribbean Sea.

• Maria is the third costliest hurricane in United States history.

VIIRS satellite image of hurricane maria nearing peak intensity at 1942 UTC, 19 september 2017. Image Courtesy of UW-CIMSS.

Maria originated from a well-defined tropical wave that departed the west coast of Africa on 12 September.
a) Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Maria, 16–30 September 2017

b) Selected pressure observations and best track minimum central pressure curve for Hurricane Maria, 16–30 September 2017

Maria’s peak intensity of 150 kt is based on a blend of SFMR-observed surface winds of 152 kt and 700-mb flight-level winds of 157 kt.

Maria’s 65-kt intensity increase over 24 h on 18 September makes it tied for the sixth-fastest intensifying hurricane in the Atlantic basin record.
Damage by Cyclone Maria in Dominica. Photo credits, clockwise from upper left: WIC News, responsibletravel.com, AFP/Getty Images, Tomás Ayuso/IRIN.


Maria caused 31 direct deaths in Dominica with 34 missing. In Guadeloupe, two direct fatalities are attributed to Maria: one person died from a falling tree, and another was swept out to sea. In Puerto Rico, the death toll is highly uncertain and the official number stands at 65, which includes an unknown number of indirect deaths. It should be noted that hundreds of additional indirect deaths in Puerto Rico may eventually be attributed to Maria’s aftermath pending the results of an official government review.

• Tsunamis and Tropical Cyclones are two of the major important marine hazards, which may cause extensive loss of life and property.

• Numerical modeling is one of the most efficient tools for the assessment of these types of disasters, understanding the related risks and development of mitigation measures.
Forcing for Tsunamis and Cyclones

Phenomena causing long wave generation are transferring the energy gained by some outer forcing by;

• Tide
• Tsunami (earthquake, underwater landslides, volcanos)
• Atmospheric pressure disturbances (temporal-spatial)
• Wind Fields (temporal-spatial)
Seismic source model for tsunamis

- For a sub-sea earthquake, the rupture typically has durations less than a minute, which is considered instantaneous compared to tens of minutes period of tsunami wave, thus dynamic effect is neglected.

- Initial wave profile is assumed to be identical to the vertical static displacement of the sea floor given by Manshinha and Smylie’s (1971) model for inclined strike-slip and dip-slip faults.

- Typical fault parameters:
  - Epicenter location (lat., long.)
  - Rupture duration, $\tau$
  - Strike angle, $\theta$
  - Dip angle, $\lambda$
  - Rake angle (Slip), $\delta$
  - Focal Depth, $D$
  - Length, $L$
  - Width, $W$
  - Slip Displacement or Dislocation, $\Delta$

- Tsunami wave length $\sim 2W$
Source model for Tropical Cyclones

Atmospheric pressure
eastward wind
northward wind
wind data
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

PREPROCESSING

• STUDY AREA

According to
• Earthquake and tsunami potential
• Cyclone trajectory

• Coastal Communities
• Social and economic importance
• Superstructure and infrastructure
• Critical Structures
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

PREPROCESSING

DATA ACQUISITION AND PROCESSING

• the raw satellite data of the study area is collected from the available sources
• the collected data is analyzed and eliminated
• Digitize and process the available data

• BATHYMETRY and TOPOGRAPHY
  • the required resolution
  • bathymetric and topographic database
  • Numerical gauge points
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

PREPROCESSING

SOURCE (TSUNAMI)
• Possible tsunami sources (seismic or non-seismic)
the source file is created by implementing:
- Rupture parameters (fault length, fault width, dip angle, etc.)
- Mass movements (submarine or subaerial)
- Volcano activities

SOURCE (TROPICAL CYCLONE)
• Atmospheric Pressure
• Wind fields
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

PROCESSING

SIMULATION (TSUNAMI AND TROPICAL CYCLONE)

• Use initial and boundary conditions, friction, tide etc.
• Compute all wave parameters (water elevations, current velocities, discharge fluxes, wave arrival times and max./min. free surface levels ...)
• Simulation duration, output file time interval and friction coefficient are all inputted in this step
SIMULATION (TSUNAMI AND TROPICAL CYCLONE)

- Evaluate the results of each simulation including inputs, and outputs (maximum positive amplitude of the wave, current, inundation, flow depth, arrival time, inundation distance, time histories of water level at selected locations) computed in the simulation

- Visualize the results, 1D, 2D Figures, inundation mapping, 3d animations, etc.
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

\[ \frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \] 
\[ \text{(Eq.1)} \]

\[ \frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left( \frac{MN}{D} \right) + gD \frac{\partial \eta}{\partial x} + \frac{\tau_x}{\rho_w} + \frac{D}{\rho_w} \frac{\partial P_{\text{atm}}}{\partial x} - \frac{\rho_{\text{air}} C_D}{\rho_w} U_{w10} \sqrt{U_{w10}^2 + V_{w10}^2} = 0 \] 
\[ \text{(Eq.2)} \]

\[ \frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left( \frac{MN}{D} \right) + \frac{\partial}{\partial y} \left( \frac{N^2}{D} \right) + gD \frac{\partial \eta}{\partial y} + \frac{\tau_y}{\rho_w} + \frac{D}{\rho_w} \frac{\partial P_{\text{atm}}}{\partial y} - \frac{\rho_{\text{air}} C_D}{\rho_w} V_{w10} \sqrt{U_{w10}^2 + V_{w10}^2} = 0 \] 
\[ \text{(Eq.3)} \]

\( P_{\text{atm}} \) in Pascal 
\( U_{w10}, V_{w10} \) are wind velocities at 10m elevation on the sea surface in W – E and S – N directions in m/sec

\( C_D = (0.75 + 0.067U_{w10}) \times 10^{-3} \) for \( U_{w10} \leq 26 \text{ m/sec} \) Garrat, 1977

\( C_D = 2.18 \times 10^{-3} \) for \( U_{w10} > 26 \text{ m/sec} \) Powell et al., 2003

Note: CD values depend on instantaneous wind velocity and are different in x and y directions at any time.
MODELING OF TSUNAMIS AND TROPICAL CYCLONES

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Note: \( C_D \) values depend on instantaneous wind velocity and are different in \( x \) and \( y \) directions at any time.
\[ \frac{\tau_x}{\rho} = \frac{n^2}{D^{7/3}} M \sqrt{M^2 + N^2} \]

\[ \frac{\tau_y}{\rho} = \frac{n^2}{D^{7/3}} N \sqrt{M^2 + N^2} \]

BM#4 – Bathymetry, Gauges

- For this benchmark, we will compare free surface, velocity, and momentum flux information recorded throughout the tank.

resolution: 0.1 m
Maximum Water Depth: 0.97 m
Simulation time step: 0.0005 sec
Manning Coeff: 0.01

BM#4 NTHMP Current Workshop (Lynett et al., 2017)
VALIDATION

Bathymetry: 2756x804
2500m grid size
1000m depth flat bathymetry
Pressure: 973 mbar at the center
Outside Pressure: 1013 mbar
VALIDATION

Bathymetry: 2756x804
2500m grid size
1000m depth flat bathymetry
Pressure: 1053 mbar at the center
Outside Pressure 1013 mbar

High Pressure

[Chart showing water elevation over time with pressure points 1053 mb and 1013 mb]
Irma originated from a tropical wave that departed the west coast of Africa on 27 August.

## Numerical Modeling of IRMA

<table>
<thead>
<tr>
<th>Bathymetry</th>
<th>Grid Size (m)</th>
<th>Corner Coordinates</th>
</tr>
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<tbody>
<tr>
<td>Coarse Bathymetry</td>
<td>900</td>
<td>292E 315E 9.8N 22N</td>
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<td>Nested Bathymetry</td>
<td>200</td>
<td>296.5E 299.5E 13.5N 18.7N</td>
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**Run Time:** 02.09.2017-11.09.2017
The atmospheric pressure, eastward wind and northward wind data of Hurricane Irma taken from CFSR on September 06, 2017 at 05:00 UTC.
Distribution of maximum water level due to atmospheric pressure and wind during IRMA
Distribution of maximum water level due to atmospheric pressure and wind during IRMA
Distribution of maximum water level due to atmospheric pressure and wind during IRMA
MODELING OF HURRICANE MARIA

Maria originated from a well-defined tropical wave that departed the west coast of Africa on 12 September.

Best track positions for Hurricane Maria, 16–30 September 2017. Track during the extratropical stage is partially based on analyses from the NOAA Ocean Prediction Center National Hurricane Center, Hurricane Irma Report, 2017.
### Numerical Modeling of MARIA

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**Run Time:** 16.09.2017-21.09.2017
The atmospheric pressure, eastward wind and northward wind data of Hurricane Irma taken from CFSR on September 20, 2017 at 03:00 UTC.
Distribution of maximum water level due to atmospheric pressure and wind during MARIA
Distribution of maximum water level due to atmospheric pressure and wind during MARIA
Distribution of maximum water level due to atmospheric pressure and wind during MARIA
(Heidarzadeh et. al., 2018)
(a) The original tide gauge records
(b) The de-tided tide gauge waveforms
(c) The one-hour averaged waveforms representing the storm surge amplitudes
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A CASE STUDY FOR TSUNAMI MODELING AND HAZARD ASSESSMENT
Complete Tsunami Hazard Assessment, Vulnerability and Risk Analysis for the Marmara Coast of Istanbul Metropolitan Area and Istanbul Metropolitan Municipality Tsunami Action Planning
“Updating of Istanbul’s Tsunami Hazard and Vulnerability Analyses”

PHASE 1:

STAGE 1) Development of high resolution Digital Elevation Model (DEM) data enhanced by including buildings.

STAGE 2) Computation of hazard levels for each 17 coastal districts w.r.t NAF sourced 14 different co-seismic and 3 submarine landslide areas with the use of NAMI DANCE GPU software.

STAGE 3) Vulnerability analysis by using the MeTHuVA (METU Metropolitan Tsunami Human Vulnerability Assessment) Method (Tufekci et al., 2018) that covers human vulnerability assessment with GIS-based multi criteria decision analysis (MCDA).

PHASE 2:

Tsunami Action Plan
39 districts of Istanbul Metropolitan Municipality
17 of 39 are along Marmara or Bosphorus Coast

Structural measures

Nonstructural Measures
STAGE 1: Development of high resolution Digital Elevation Model (DEM) data

1m resolution LIDAR based DEM data

High resolution bathymetrical data for 7-8 km offshore

Roads database

Buildings database
Example Application Area: Bakırköy district, İstanbul
➢ Tsunami Source LSBC
➢ Maximum flow 13.80 meters
➢ Maximum inundation distance reached 1200 meters.

Complete Tsunami Hazard Assessment, Vulnerability and Risk Analysis for the Marmara Coast of Istanbul Metropolitan Area
➢ Tsunami Source PIN/YAN
➢ Maximum flow depth 6.40 meters
➢ Maximum inundation distance reached 360 meters.
Seismic tsunami sources: PIN/YAN

Landslide tsunami source: LSBC

Complete Tsunami Hazard Assessment, Vulnerability and Risk Analysis for the Marmara Coast of Istanbul Metropolitan Area
Şekil 10.6 Marmara Uzaklar İstasyonu Su Baskını

Şekil 10.7 Marmara Ayazık Ççeşmesi İstasyonu Su Baskını
Structural Measures
Structural Measures

- Yenikapi Coastal Reclamation
- Tube Tunnel Kumkapı Entrance
- Marmaray Metro Station
- Breakwater at Haydarpasa port
- Coastal reclamation
Structural Measures
• Conducting educational activities to increase tsunami awareness and preparedness
• By increasing tsunami awareness at personal level, increase of «n» parameter in MeTHuVA
• Evaluation of risk by change of parameter «n» MeTHuVA
• Planning and organization of regular Tsunami Drills with participation of stakeholders
• Preparation of «Tsunami Evacuation Guide»
Hazard Zone Maps, Warning Signs and Evacuation Routes for 17 Districts of Istanbul
ISTANBUL METROPOLITAN MUNICIPALITY
TSUNAMI ACTION PLAN – BUYUKCEKMECE DISTRICT EXAMPLE
EVACUATION SIGNS
Achievements in Istanbul

<table>
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<th>DISTRICT</th>
<th>NUMBER OF EVACUATION ROUTES</th>
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<th>NUMBER OF SECURE AREA SIGNS</th>
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ICG/NEAMTWS-XVII

Dr. Öcal NECMİOĞLU
Progress in Istanbul

Dr. Öcal NECMİOĞLU
Curtesy Istanbul Metropolitan Municipality
REMARKS

- Marine Extreme Events Coastal Disasters
- Tsunamis and Tropical Cyclones
- Hazard Assessment and Disaster Management
- Structural and Societal Preparedness
- Awareness
- Preparedness
- Resilience
- Mitigation
THANKS FOR YOUR ATTENTION

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Bora Yalciner
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