FLOOD MODELING: MAIN CONCEPTS AND IDEAS ON HOW TO DEVELOP FLOOD MODELS USING OPEN DATA

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TYPES OF FLOODING

Compound flooding: Interaction of multiple flood drivers (Zscheischler et al. 2018)
HAZARD INTERRELATION APPROACHES

I. Stochastic:
- Based on samples of different variables with random behavior evolving in time

II. Empirical:
- Based on measurements and are observation oriented

III. Mechanistic:
- Mathematically idealized representation of real phenomena

Source: Tilloy et al., 2019
TYPES OF FLOOD MODELS

1. **Hydrologic**: Characterization of hydrologic features and systems (i.e. HEC-HMS, EPA SWMM, SWAT, GSSHA, Vflo...)

2. **Hydraulic**: Simulate flood processes over unconfined flow surfaces and channels in 1D (i.e. HEC-RAS, IBER...) and 2D (i.e. FLO-2D, Infoworks ICM,ICPR4...)

3. **Storm surge**: Increase of surge levels due to storms, hurricanes and future coastal conditions (i.e. SLOSH, ADCIRC, SWAN...)

4. **Groundwater**: Surface-subsurface interactions from permeable soil strata (i.e. ModelMuse, MODFLOW)
MODEL LINKING TECHNIQUES

There are different techniques to combine numerical models:

- **One-way** (i.e. linking technique)
- **Two-way** (i.e. 1D + 2D models)
- **Tightly** (i.e. SWAN + ADCIRC)
- **Fully** (i.e. WASH123D)

*Grid nesting approaches* (can be one-way or two-way)

*Example on how to couple two numerical models.*

*Source: Santiago-Collazo et al., 2019*

*Nested model grid structure for multiple nesting*

*Source: Nash and Hartnett, 2019*
COMPOUND FLOODING EXAMPLES

CF can happen in coastal and inland areas

Likelihood in Europe (Paprotny et al., 2018)

- Storm surge + river discharges (Northern)
- Storm surge + precipitation (Southern)

Likelihood in USA (Wahl et al., 2015)

- Atlantic/Gulf > Pacific coast

Impacts all around the world, including the Danube basin, UK, Netherlands, Italy, US coastal cities (i.e. Hawaii, Miami, NY, NO, etc.)
COMPOUND FLOODING REVIEW

Research Findings

• CF models = Better estimation of current and future flood risk scenarios

• Most CF studies use physically based numerical models (hydrologic, ocean circulation or hydraulic models) to account extreme events:
  • Storm surge + precipitation in low-lying coastal watersheds
  • Storm surge + river discharges

Missing knowledge

• Lack of studies that incorporate storm drain systems and groundwater flooding interactions

• Limitations are still encountered:
  • Models’ inability to couple processes
  • Lack of data/measurements
  • Performance levels for calibration and validation
RESEARCH QUESTION:

What’s the role of climate and individual flood drivers in flood events?

• The response of urban catchments is influenced by:
  • Morphology
  • Hydrology
  • Hydraulic characteristics

• Climate change is increasing:
  • Global sea levels
  • Extreme precipitation events (Salas and Obeysekera, 2014)
  • Compound flooding (Vousdoukas et al., 2017)
MODEL (EPA SWMM)

- 1D dynamic rainfall-runoff model for urban drainage studies (Rossman et al., 2015):
  - Flood control design
  - Flood mapping
  - Mitigation strategies

Pipe system of Palermo. Source: Gabriele Freni

Source: Robert Dickinson (EPA SWMM)
MODEL (HEC-RAS)

- Developed by the US Army Corps of Engineers (USACE)
- 1D steady flow, 1D-2D unsteady flow, sediment transport and water quality modeling
- Open access software
- Most widely used tool worldwide for channel flow analysis and floodplain delineation

Flood insurance map. Source: FEMA

1D-2D unsteady flow simulation. Source: HECRAS
MODEL (FLO-2D)

- Grid-based volume conservation model that combines hydrology and hydraulics
- Compute superficial flow routing schemes, flow exchange between channel and floodplain, flood wave propagation and inundation dynamics in urban and rural environments
- Governing equations:

Continuity

\[
\frac{\partial h}{\partial t} + \frac{\partial h V}{\partial x} = i
\]

Dynamic wave momentum

\[
S_f = S_o - \frac{\partial h}{\partial x} + \frac{V}{g} \frac{\partial h V}{\partial x} - \frac{1}{g} \frac{\partial V}{\partial t}
\]

- \(i\) = EXCESS RAINFALL INTENSITY
- \(h\) = FLOW DEPTH
- \(V\) = DEPTH-AVERAGED VELOCITY IN 1 OF THE 8 FLOW DIRECTIONS
- \(S_f\) = FRICTION COMPONENT
- \(S_o\) = BED SLOPE GRADIENT
MODEL (MODFLOW-2005)

- Groundwater flow for confined or unconfined layers is simulated using a block-centered finite-difference approach.

- Three-dimensional transient groundwater flow equation combines the Darcy's and mass conservation laws:

\[
\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) + W = S_s \frac{\partial h}{\partial t}
\]

\( x, y, z \) = SPACE VARIABLES; \( t \) = TIME VARIABLE
\( h \) = HYDRAULIC HEAD
\( Kx, Ky, Kz \) = HYDRAULIC CONDUCTIVITY IN X-, Y-, Z-COORDINATE DIRECTION
\( W \) = TERM WHICH COMBINED ALL SOURCES AND SINKS
\( Ss \) = SPECIFIC STORAGE

Finite difference grid in MODFLOW-2005. Source: Harbaugh, 2005
## EXAMPLE: FLOOD RISK EVALUATION

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Arch Creek Basin (Miami)</th>
<th>Palermo (Italy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Tropical monsoon</td>
<td>Mediterranean</td>
</tr>
<tr>
<td>Topography</td>
<td>Flat topography</td>
<td>Steep slope floodplain</td>
</tr>
<tr>
<td>Precipitation</td>
<td>1570 mm</td>
<td>61.9 inches</td>
</tr>
<tr>
<td>Pluvial</td>
<td>High risk</td>
<td>High risk</td>
</tr>
<tr>
<td>Fluvial</td>
<td>Medium risk</td>
<td>Medium risk</td>
</tr>
<tr>
<td>Coastal surge</td>
<td>High risk</td>
<td>Low risk</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Unconfined aquifer</td>
<td>Confined aquifer</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>5-13 mm/year</td>
<td>10 mm/year</td>
</tr>
<tr>
<td>Flood risk</td>
<td>Very high</td>
<td>High</td>
</tr>
</tbody>
</table>
CASE STUDY: ADDIS ABABA

Characteristics:

• Avg. annual precipitation ≈ 1120 mm
• Upper part of the Awash River basin
• Drainage area ≈ 110,000 km²
• Sub-catchments:
  • Big Akaki (900 km²)
  • Little Akaki (500 km²)
• Mountains and floodplain valley
CASE STUDY: ADDIS ABABA

Why does it flood?

• Rapid urbanization
• Deforestation
• Impervious surfaces
• Inadequate urban planning
• Informal settlements
• Poor road design and urban drainage infrastructure
• Sewer and river blockages
CASE STUDY: ADDIS ABABA

Flood model

• 2D hydraulic model FLO-2D for open channel hydraulics
• DEM 30m (USGS website)
• 50m grid model resolution
• 200 year return period hydrograph (peak discharge 27m³/s)
• River geometry (Global database)
• Crowdsourced data and VGI
HOW TO BUILD A MODEL FROM SCRATCH

Data collection

• Digital Elevation Model (DEM)
• Hydrology
• Land use cover
• Urban features
• Channel bathymetry
• Storm drain data
• Volunteered Geographic Information (VGI)
HOW TO BUILD A MODEL FROM SCRATCH

Digital Elevation Model (DEM)

- USGS EARTH EXPLORER
- JAXA
- INGV (Italy)
- INEGI (Mexico)
- Regional Geoportals

Source: The Engineering Community and Francisco Peña
HOW TO BUILD A MODEL FROM SCRATCH

Hydrology

• NOAA Atlas 14
• NOAA Tides & Currents website
• USGS (Waterwatch or Waterdata)
• Scientific publications
• Regional Geoportals

Time plot to represent time series data. Source: ISPRA 2013

Inflow hydrograph. Source: Francisco Peña

Inflow hydrograph. Source: De Risi et al., 2020
HOW TO BUILD A MODEL FROM SCRATCH

Land Use Cover

• USGS
• International organizations
• National and Regional Geoportals
• Scientific publications
• GIS Hubs
• Open data repositories

Land cover map of Ethiopia for 2017. Source: Kamathi et al., 2020
HOW TO BUILD A MODEL FROM SCRATCH

Urban features

• National and Regional Geoportals
• GIS hubs and open data repositories
• Manual digitalization

Example of urban features in flood models. Source: ESRI and Francisco Peña
Channel Bathymetry

- National and Regional Geoportals (Bathymetric Data Viewer)
- Global river database:
  - HydroSHEDS (Andreadis et al., 2012)
  - HYDRO1K
  - Global Width Database of Large Rivers (GWD-LR)
- Geomorphological laws (Leopold and Maddock, 1953)
- Manual digitalization (GIS Software/GE)

MERIT Hydro river width map database.
Source: Yamazaki et al. 2019
Channel Bathymetry

A simple global river bankfull width & depth database (Andreadis et al., 2012)

ESRI Shapefiles as ZIP files per continent
http://gaia.geosci.unc.edu/rivers/
HOW TO BUILD A MODEL FROM SCRATCH

Storm Drain System

- Regional Geoportals
- Private entities

Types of storm drain inlets
Source: FLO-2D Storm Drain Manual

Elevation, land use, bathymetry and storm drain data.
Source: SFWMD (Miami)
HOW TO BUILD A MODEL FROM SCRATCH

Crowdsourcing and Volunteered Geographic Information (VGI)

• Multimedia content:
  • Web browser
  • Social media platforms
  • Newspaper

Citizens as sensors to calibrate and validate flood models

Location of crowdsourced images selected for a specific flood event. Source: Annis and Nardi 2019

Integrating VGI and 2D hydraulic models into a data assimilation framework for real time flood forecasting and mapping

Antonio Annis and Fernando Nardi

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EXPECTED OUTPUTS

Flood hazard mapping products
Source: FLO-2D and Francisco Peña
EXPECTED OUTPUTS

• Important to understand the impacts of flooding in cultural and historical sites
• Identification of relevant/negligible flooding mechanisms to develop simplified flood studies
• All models are wrong, but some are useful = Better estimation of flood risk = Better policy making = More resilient cities
REFERENCES

THANK YOU

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