Linking flood hazard to flood loss over large regions and multiple spatial scales: A new approach based on hillslope link flood simulation

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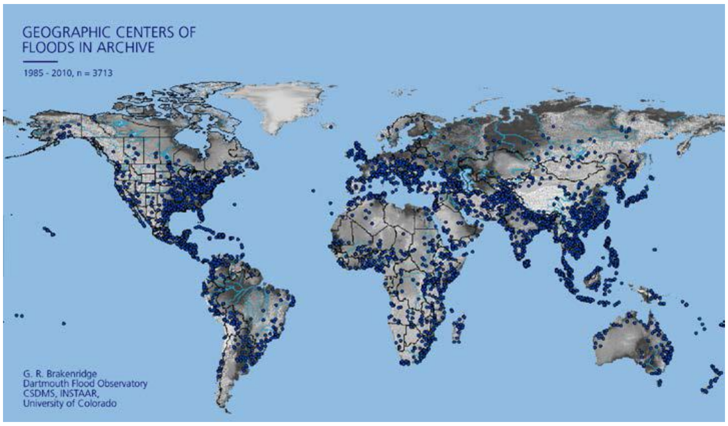
Flood losses worldwide are significant and expected to increase



- Compared with prior decade, worldwide flood events losses nearly doubled from 2000 to 2009
- Significant future impacts expected due to:
  - Likely increased heavy precipitation events; Sea-level rise and coastal flooding
  - Continued population growth, urbanization and economic development in hazard-prone areas

Sourced from "Enhancing community flood resilience: a way forward" (http://opim.wharton.upenn.edu/risk/library/zurichfloodresiliencealliance_ResilienceIssueBrief_2014.pdf)

Proper linking of flood hazard to flood losses

- Effective flood risk management, emergency response and recovery activities require a ***timely characterization of the hazard and its consequence (losses) at a given location***

= detailed maps of inundated areas and depths

- Methods that are able to accurately simulate or observe these properties over large areas, across multiple spatial scales, and in a timely manner are still unavailable:

  1) **Mathematical models** – operational limitations include high implementation costs, computational time, data requirements, and uncertainties

  2) **Observed steam-flow data** - many regions of the world are ungauged, and even gauged regions do not always have the required gauge density for a spatially explicit characterization of flood magnitudes

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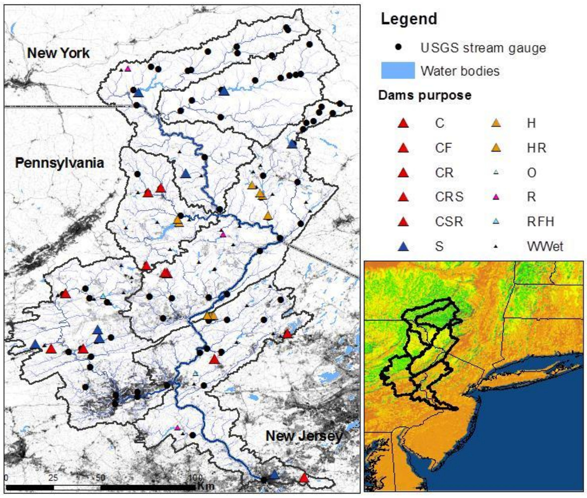
Our Integrated and Novel Approach

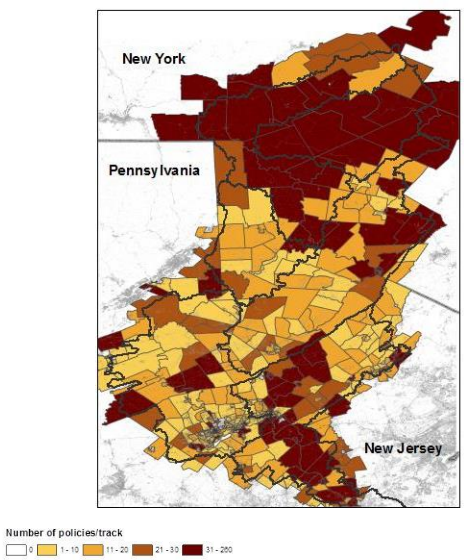
1) We quantify the flood hazard through a calibration-free multi-scale hydrological model that is able to **simulate stream-flow** across the entire river network represented by a **normalized flood index, i.e., flood peak ratio (FPR), used as a proxy for flood magnitude**
2) We benefit from an unique access to the entire portfolio of the federally run national flood insurance program (NFIP) that sells the vast majority of **flood insurance policies** across the U.S. and **empirically demonstrate that the FPR can be used to predict the number of insurance claims** in an impacted region
3) We apply this methodology in the Delaware River Basin which is also a highly gauged area of the U.S., allowing us to **compare to observed FPR results**

Delaware River Basin (DRB)



- Dense stream gauge network of 72 sites
- Total of 38 major dams which imposes difficulties for flood hazard characterization

NFIP Flood Insurance Penetration in the DRB



Insured Flood Losses from 4 Main Events

	Ivan 2004	ExTrop 2005	Convective 2006	Irene 2011	Total
Total DE River Basin Census Tracts (with simulated river data)	346	401	401	401	1549
DE River Basin Census Tracts with a residential flood claim	81	101	121	164	467
Percentage of total census tracts with a residential flood claim	**23%**	**25%**	**30%**	**41%**	**30%**
Total Residential Flood Claims Incurred	**636**	**1300**	**2133**	**850**	**4919**
Avg. claims per impacted tract	7.9	12.9	17.6	5.2	10.5
Total NFIP Policies-in-force (tracts with a claim)	2150	5583	6464	7087	21284
Total NFIP Policies-in-force (all DE river basin tracts)	5241	9729	9729	9729	34428

Flood Hazard Characterization Methodology

1) **Observed:** spatially interpolate (inverse distance weighted) observed streamflow point data provided by the stream gauge networks

2) **Simulated:** a physically based spatially explicit calibration-free hydrological model in DRB (Cunha et al, 2014 - lcunha@princeton.edu)

- ❑naturally discretizes ***(hillslope link vs. traditional grid)*** the terrain to obtain an accurate representation of the river network
- ❑methodology also applied in Iowa & Oklahoma (Cunha et al., 2013)
- ❑Datasets required to implement the model include:

"Available worldwide"

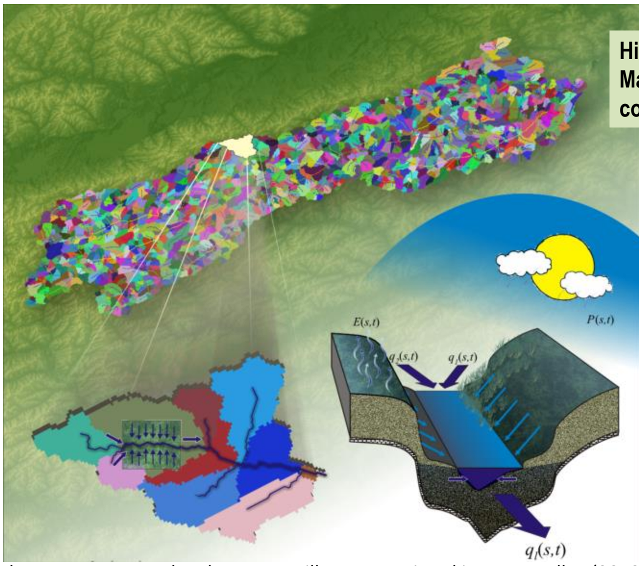
(1) Landscape and soil characterization: digital elevation model, land cover, soil properties;

(2) Hydrological forcings: rainfall and potential evapotranspiration

(3) Reservoirs: location, purpose and contributing area

Flood peak ratio – simulate or observed - is the event flood peak divided by the 10-year flood peak flow. **Used as a proxy for flood magnitude**

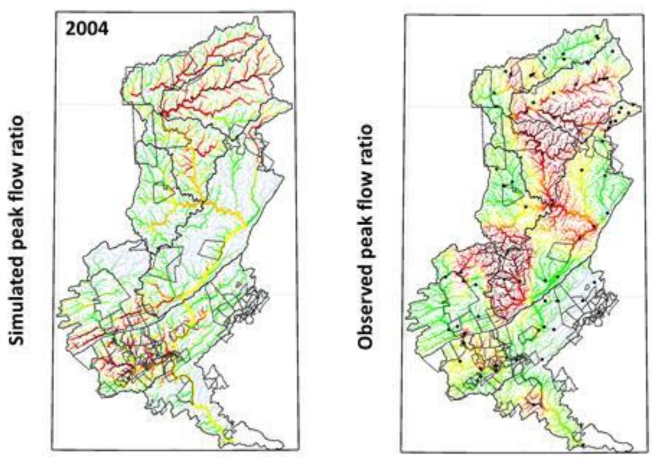
Hydrological model



Hillslope-Link Partitioning + Mass & Momentum conservations for each unit

Cunha, L. K., P. V. Mandapaka, R. Mantilla, W. F. Krajewski, A. B. Bradley (2013) Impact of radar-rainfall error structure on estimated flood magnitude across scales: An investigation based on a parsimonious distributed hydrological model, WRR, 48 (10).

Simulated vs. Observed/Interpolated FPR



obtained correlation coefficients larger than 0.9 for all valid streamflow sites

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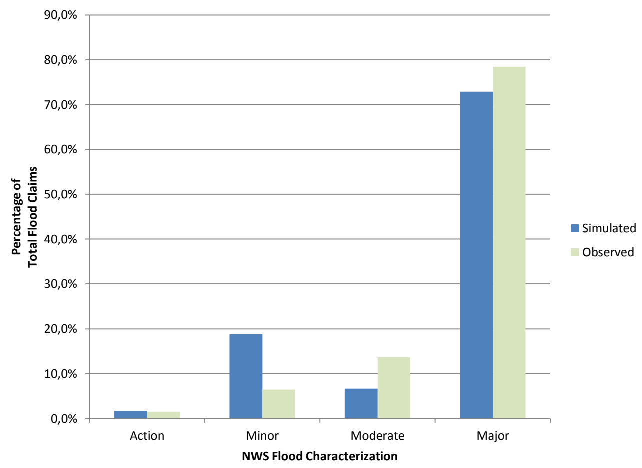
Quantification of Flood Ratio to Loss



The raw claims data illustrates an <u>upward trend</u> in the number of claims per census tract for NWS classified "major" flood ratio values

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Quantification of Flood Ratio to Loss – empirical estimation

NB model for the count of claims	(1)	(2)	(3)	(4)
Extra tropical 2005	-.77513474***	-0.02514849	-.67768324***	-0.09115
Convective 2006	-0.19481	0.1896516	-0.1553	0.114127
Ivan 2004	-0.01041	-0.13837904	-0.10882	0.016885
NJ	-0.07913	-0.26036572	-.34743311*	-.30426854*
NY	-.85007305***	-.5679641***	-.62828421***	-.54182333**
Housing Units	3.96E-05	0.00001058	5.16E-05	-1.2E-05
NFIP Policies	.02558216***	.02593212***	.02697008***	.02605888***
Number Pixels	-4.11E-06	5.56E-06	7.89E-06	8.28E-06
Percentage River	-.06736881***	-.08328866***	-.07191443***	-.07946214***
Horton One	-.88428488***	-0.52096827	-.92933599***	-0.43478
Horton Two	-0.05372	0.29732414	-0.13483	0.363211
Horton Three	0.002562	0.25939263	0.127363	0.237265
Horton Five	-0.30327	-.47715571**	-.4389749**	-.5064772**
Horton Six	1.2128648***	.86905146***	1.0815186***	.98517205***
Horton Seven	1.5302542***	1.2772333***	1.4255065***	1.2588885***
Observed Max FPR	.59413962***			
Simulated Max FPR		.56893882***		
ObsMax_Action			-0.33006	
ObsMax_Minor			-.41729565**	
ObsMax_Moderate			-.58314186***	
SimMax_Action				-.9109072***
SimMax_Minor				-0.33677
SimMax_Moderate				-.67560016***
constant	-.84920743***	-.88579022**	.09698159	.08501314

The empirical results indicate flood ratio – simulated and observed - is a <u>statistically significant and positive driver</u> of not only the probability of a claim occurring, but also the number of claims an average tract incurs

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Conclusion

- We demonstrate that our simulated FPR accurately captures the location and the spatial extent of floods/claims, and can be used alone to estimate expected flood losses.
- An important feature of our methodology is that the flood hazard model requires minimal calibration based on historical data, and can be implemented based on information that is available worldwide
- The proposed methodology can therefore be used to estimate flood hazard and losses in ungauged and poorly gauged regions of the globe
- These results also highlight the technological capabilities that can lead to a better integrated risk assessment of extreme riverine floods. This capacity will be of tremendous value to a number of public and private sector stakeholders dealing with flood disaster preparedness and loss indemnification in rich and poor countries alike.

Thank You – Questions?

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http://www.wharton.upenn.edu/riskcenter/