From Relative Sea Level Rise to Coastal Risk: Estimating Contemporary and Future Flood Risk in Deltas

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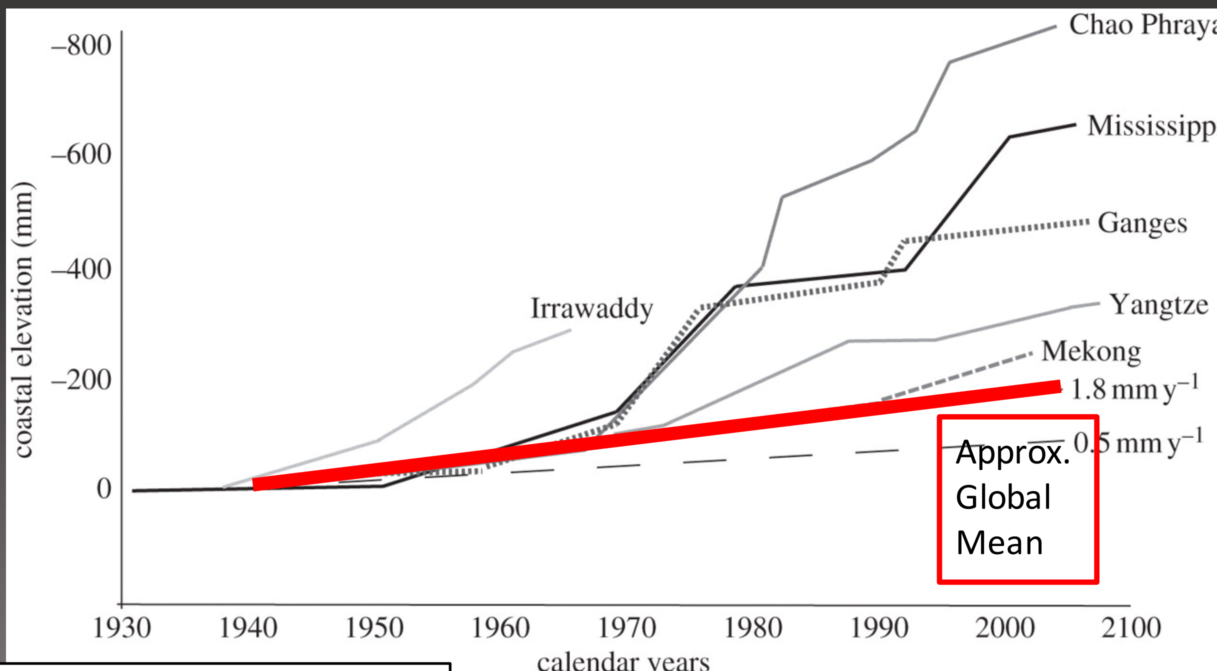
NASA; NSF; NASA Land-Cover / Land-Use Change Program; Belmont Forum

Relative Sea Level Rise is a major challenge in deltas



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

Phil. Trans. R. Soc. A (2011) **369**, 957–975
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Sediment flux and the Anthropocene

By James P. M. Syvitski* and Albert Kettner

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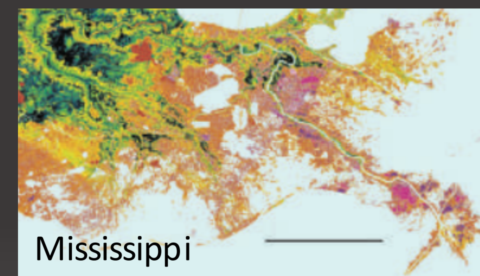
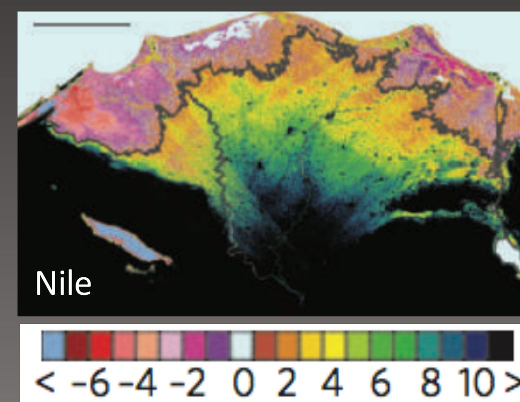
Newer estimates put rate of global mean SLR at 2.6-2.9+-0.4 mm/yr over satellite altimetry era (Watson et al. 2015)





Syvitski et al., 2009, Nature Geoscience

Z.

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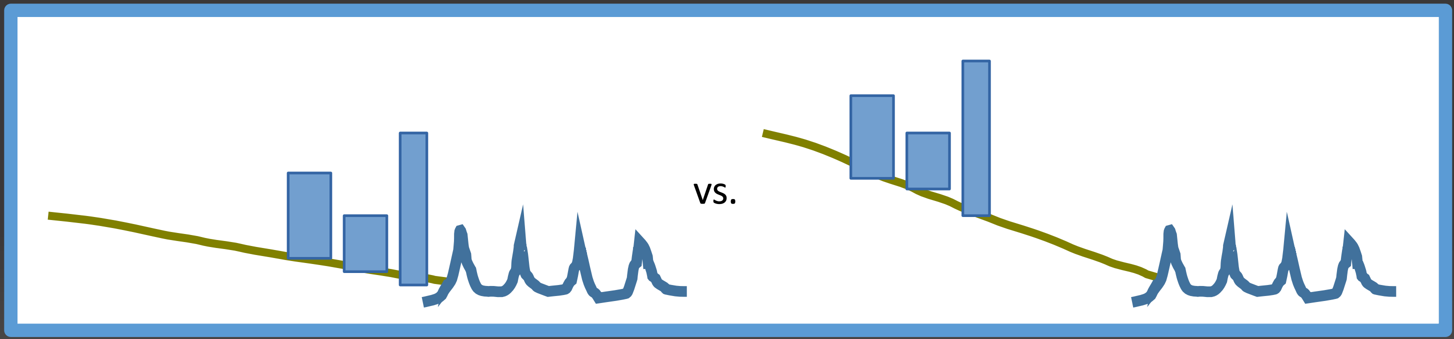
Drivers of RSLR

Fig. 6. Dominant factor in estimate of baseline ESLR for each of the 40 deltas. Sediment trapping is the dominant factor for 27 deltas, eustatic sea-level rise is the dominant factor for 8 deltas and accelerated subsidence is the dominant factor for 5 deltas. This represents the major forces at play under contemporary conditions.

But, consequences of RSLR are not equal across deltas

Coastal development:



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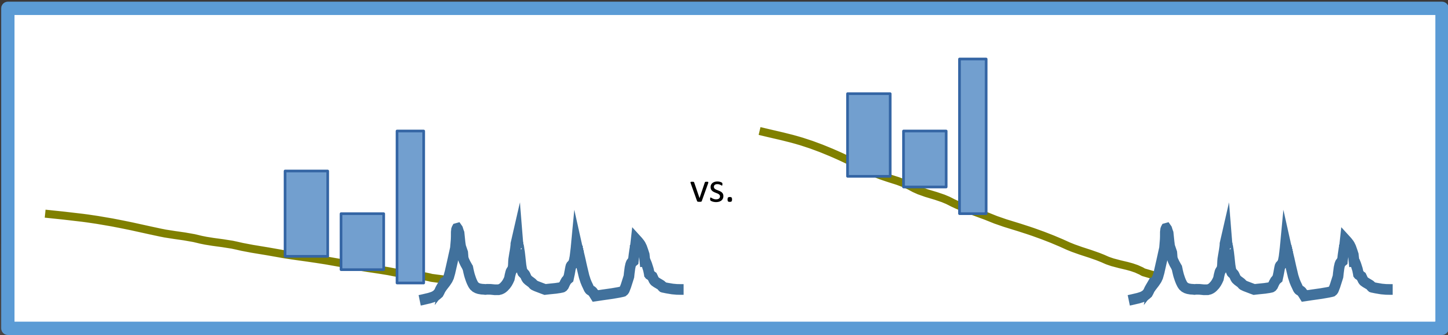
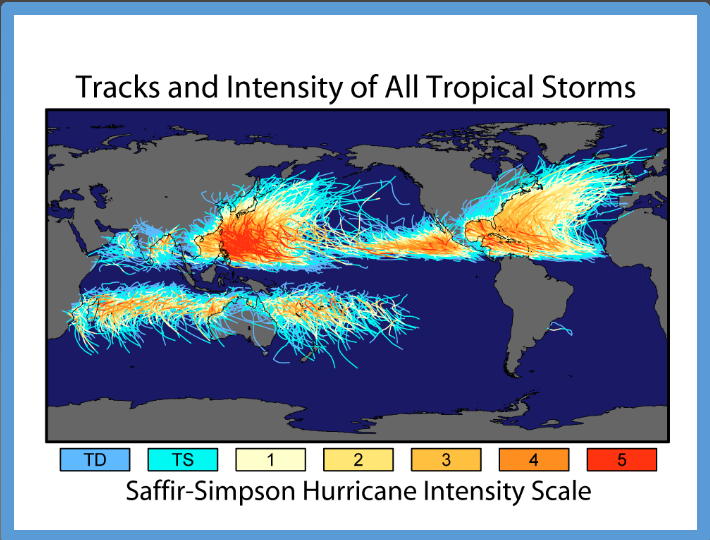


Different climo-meterologic conditions:



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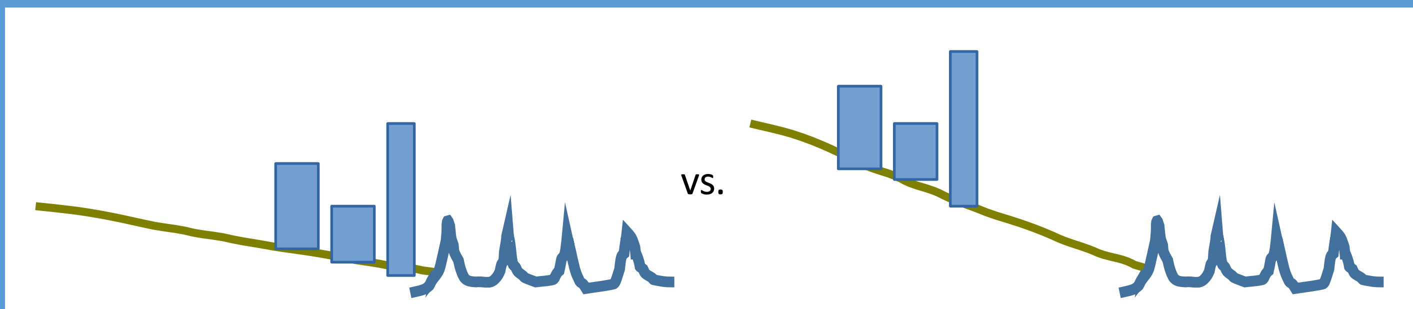
Coastal development



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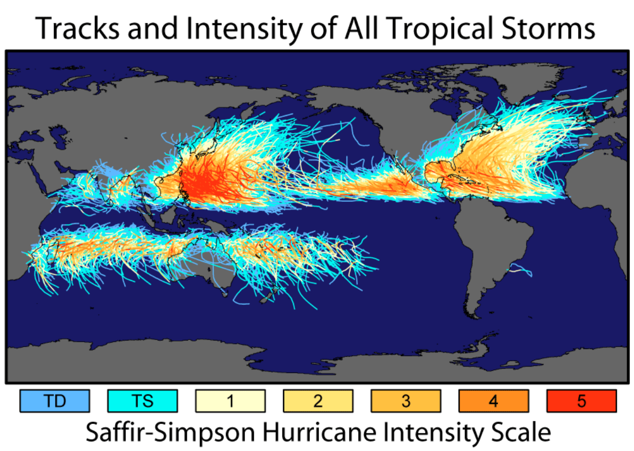
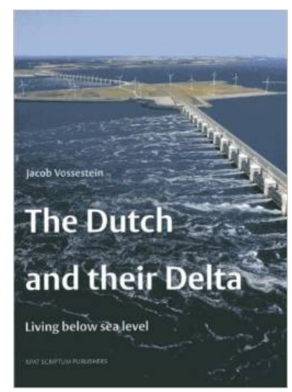


Coastal defense

Ganges Delta (photo: Irina Overeem)

vs.



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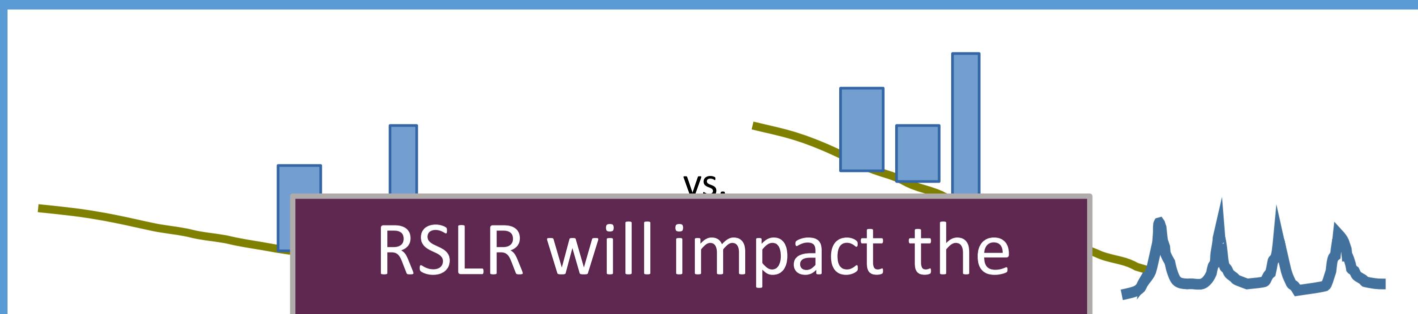
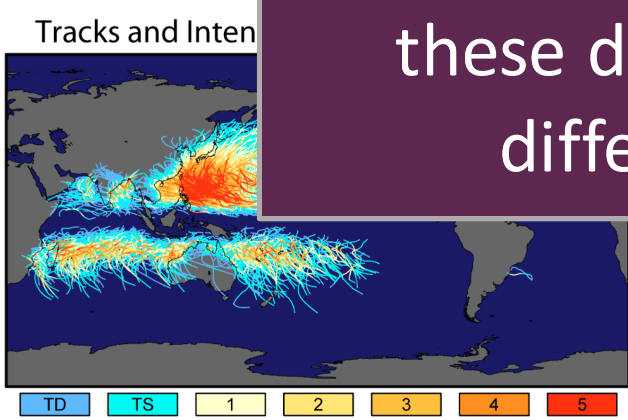
But, consequences of RSLR are not equal across deltas

Coastal development



RSLR will impact the communities living on these deltas very differently

Different climo-meterologic conditions



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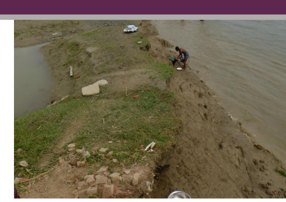

Ganges Delta (photo: Irina Overeem)

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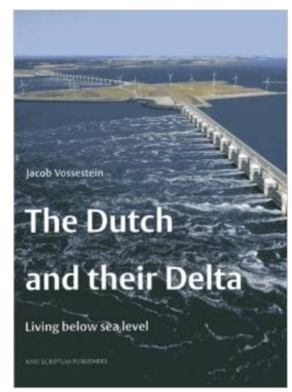

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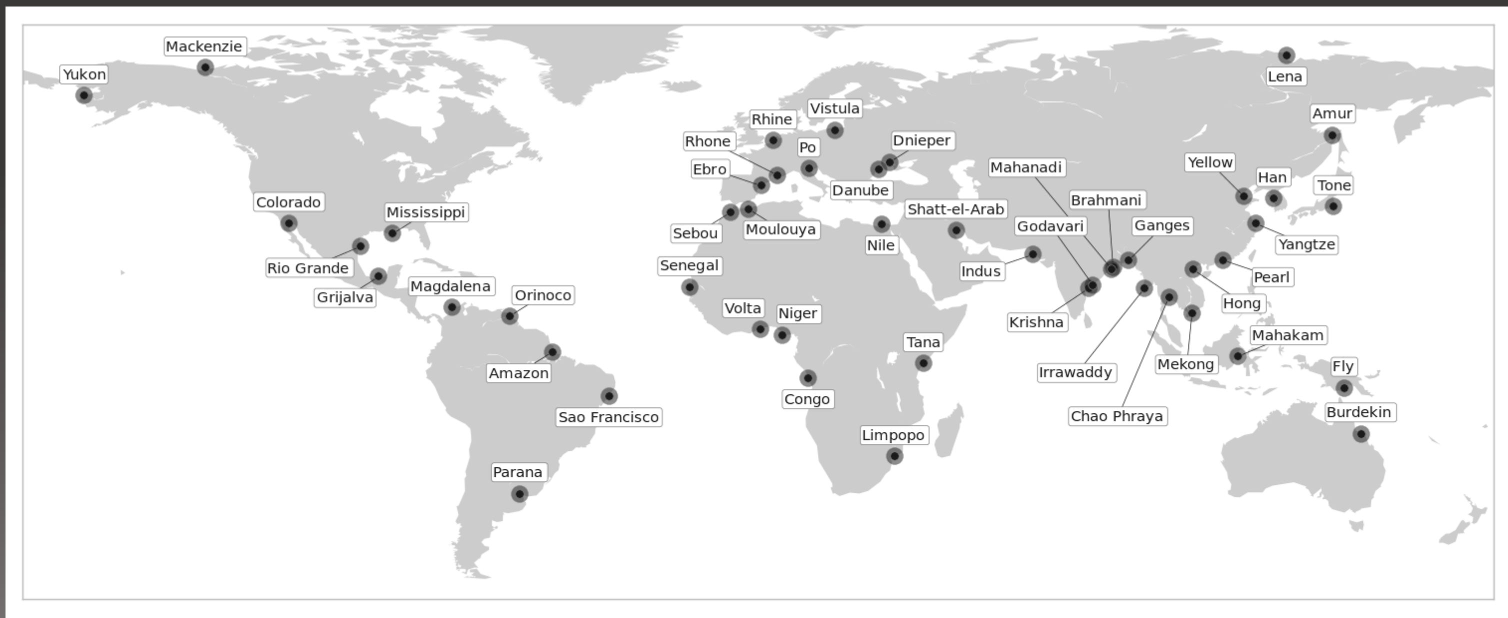
Goal: Estimate sensitivity of flood risk to RSLR across 48 major global deltas



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Risk and vulnerability modeling

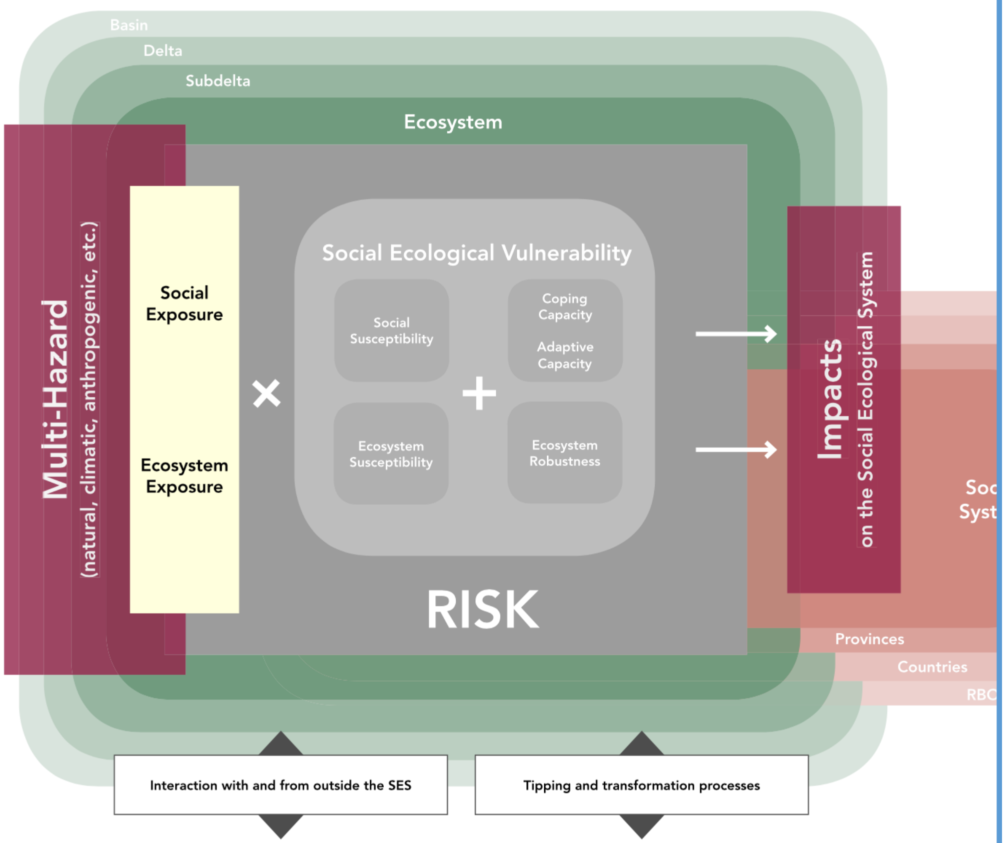


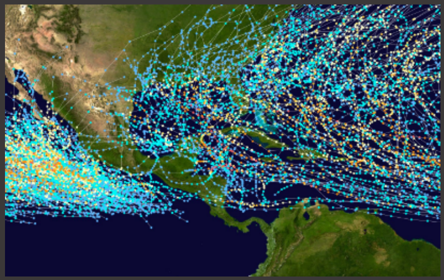
Fig. 1 Deltas-SES framework (source: authors based on Turner et al. 2003; Damm 2010; Garschagen 2014; Kloos et al. 201

Sustain Sci
DOI 10.1007/s11625-016-0366-4

Table 2 Illustrative example indicators used or suggested by the social vulnerability assessment

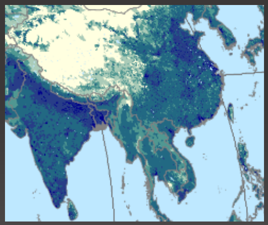
Social susceptibility	Indicator
Urban areas	
Urbanization, population density, and population growth	Population density (n/km2)
Key economic sectors and services	
Aggregate measures of public infrastructure	Density of public infrastructure (m/ha)
Water supply	Volume of water storage in the reservoir (m3)
Transportation infrastructure	Roads (km)
Housing/settlement characteristics	Quality of house (categorical)
Livelihoods	
Income	Income (amount of money/household/year)
Disability	Percentage of disabled persons (%)
Age	Age (years)
Gender	Percentage of male-headed household (%)
Household size	Homestead/household size (number of persons)
Assets	Landholdings (ha)
Dependency on climate-sensitive income sources	Percentage of population primarily living on fishing (%)
Human security	
Land conflicts	Land conflicts per year (n)
Human health	
Health impacts due to storms and floods	Percentage of population with access to cyclone shelter/ primary school (%)
Food and waterborne diseases	Percentage of households indicating ownership of a sanitary facility (%)
Arsenic- and salt-related health impacts	Arsenic consumption through drinking water (mg/L)
Coping and adaptive capacity	
Structural and physical options	
Engineered and built environment	Existence of structural measures such as dikes (binary)
Services (e.g., recovery relief, social networks, water management system, electricity, transportation, social capital index (–), medical services, access to market)	Percentage of households that received emergency recovery relief (%)
	Percentage of population using unsafe sources of drinking water (%)
	Percentage of population with no access to electricity (%)

Delta Flood Risk Model



- Model risk as an *expected loss*
- Loss from a single hazardous event, h_0:

$$L = E_{h_0} * V_{h_0}$$



- *E* is *exposure*, the number of people exposed to hazardous conditions by h_0
- *V* is *vulnerability*, is the average harm or loss endured by those exposed

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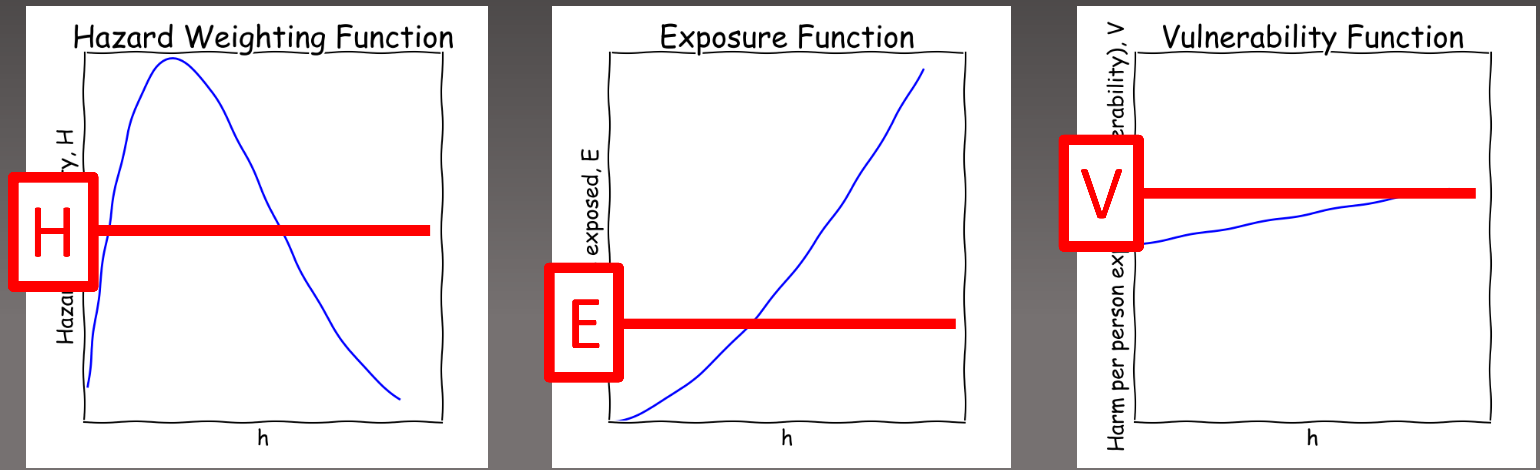
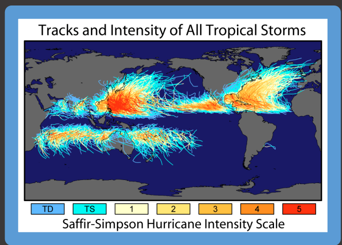
Delta Flood Risk Model

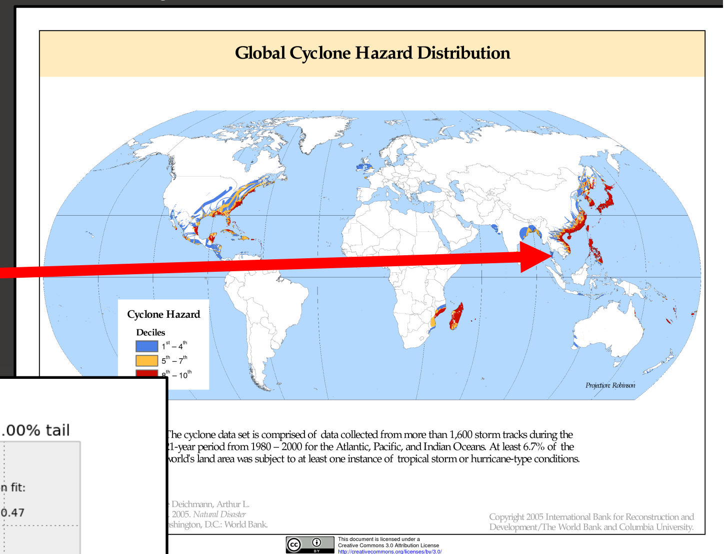
- Total risk or expected loss, *R*, is the sum of expected losses over all possible hazardous events, weighted by each event's probability *H(h)*:

$$R = \sum_h H(h)E(h)V(h)$$

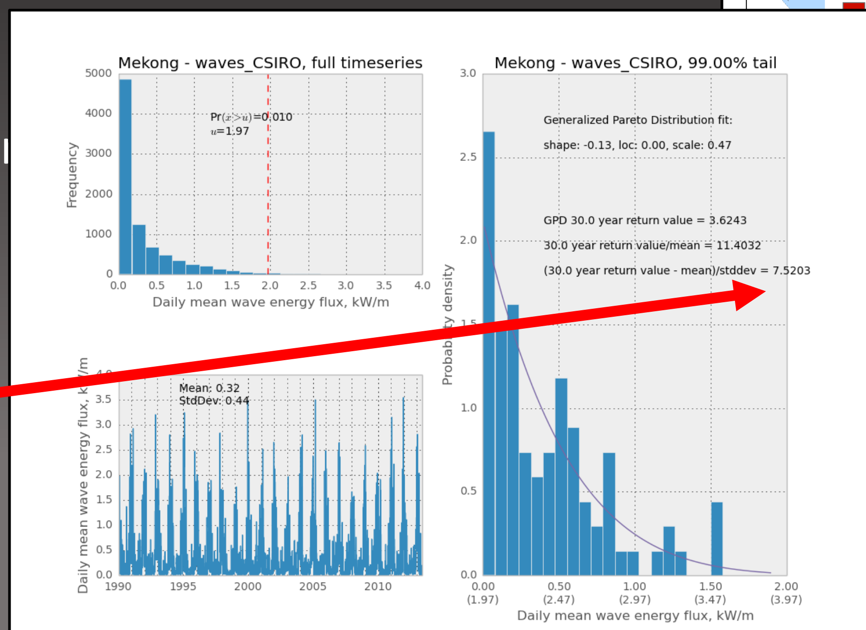




Hazard Frequency and Intensity (H)



- Indicators:
  - Tropical cyclone intensity and frequency
  - M2 tidal amplitude
  - River discharge 30yr return value (standardized)
  - Wave energy 30yr return value (standardized)



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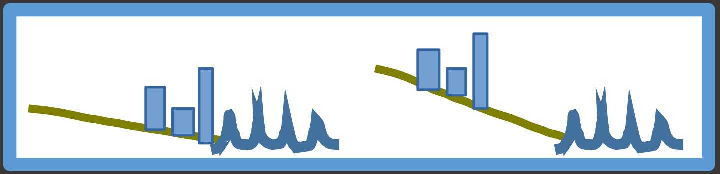
Vulnerability (V)

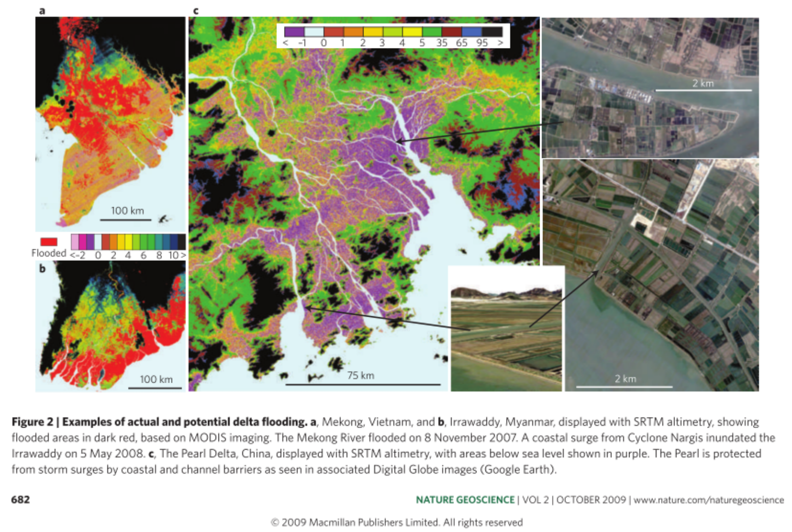
- Many variables have been used in local/regional studies to estimate social vulnerability
- Here, restricting ourselves to datasets available at the global scale
- Vulnerability of a delta varies at the household scale (strength/quality of housing) and the delta scale (coastal infrastructure)
- Indicators:
    - Per capita GDP (household vulnerability)
    - Aggregate GDP (Capacity for infrastructure investment)
    - Government effectiveness index (Capacity/will for preparedness, response)

Exposure (E)



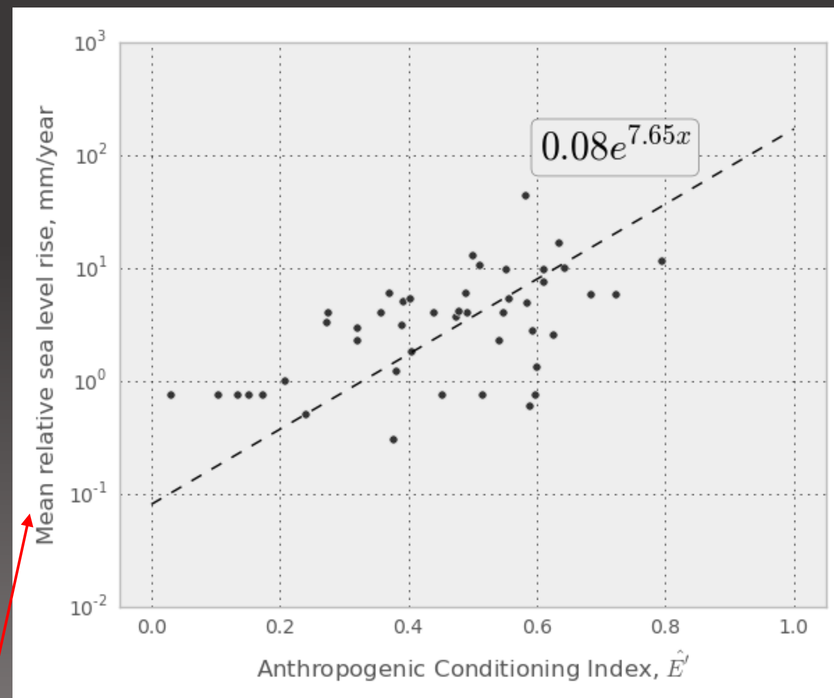
- RSLR results in lower elevation, increased population exposed (for a given hazard)
- Estimate RSLR from available indicators
- Obtain estimate for changing flood risk due to RSLR
- RSLR ~ E’

While low-lying areas in the Mekong and Irrawaddy are flooded, <0m elevation land in the Pearl is protected by coastal and channel barriers (From Syvitski 2009)



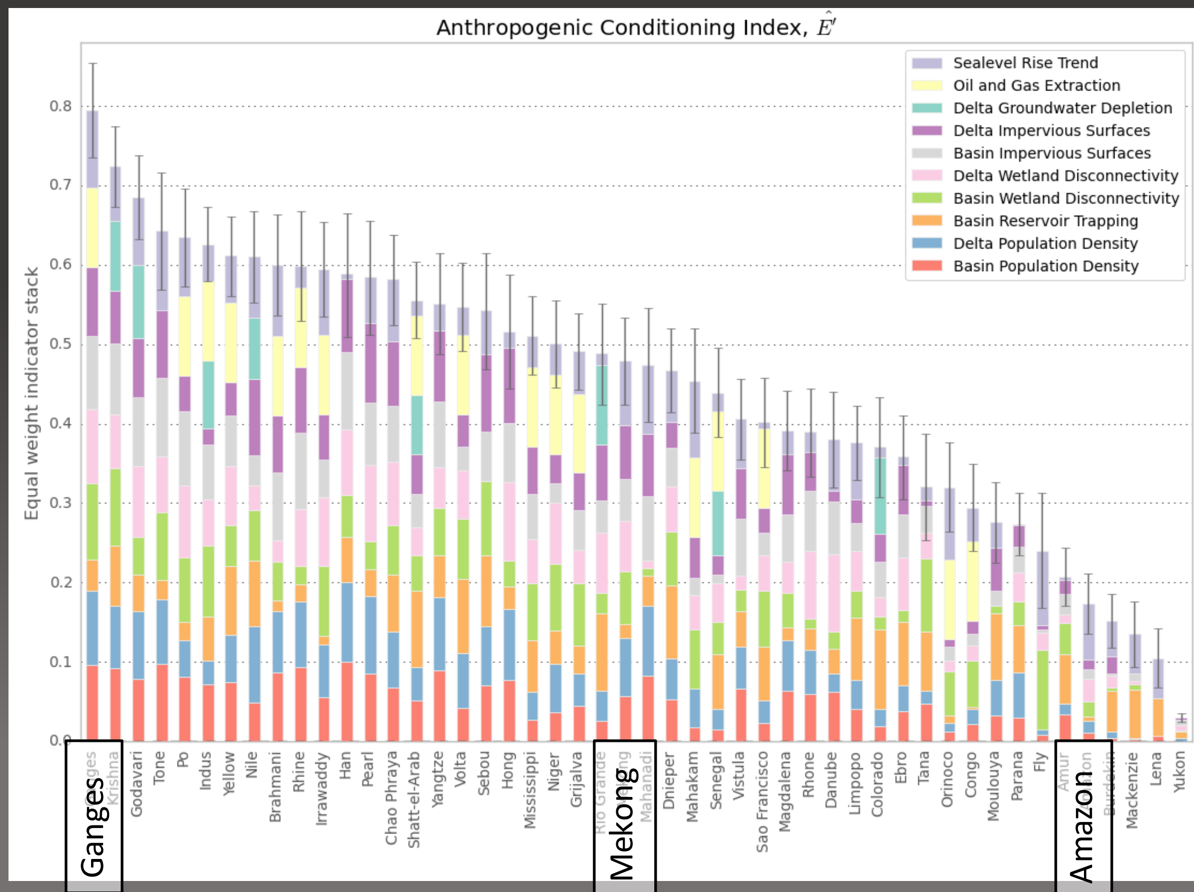
RSLR Indicators

- Delta:
  - Population Density
  - Wetland Disconnectivity
  - Impervious Surface Area
  - Groundwater Depletion
  - Hydrocarbon Extraction
- Upstream Basin:
  - Population Density
  - Wetland Disconnectivity
  - Impervious Surface Area
- Offshore:
  - Local sea level rise trend



Estimates from Ericson (2006) and Syvitski (2009)

Rate of Change of Exposure (E’)



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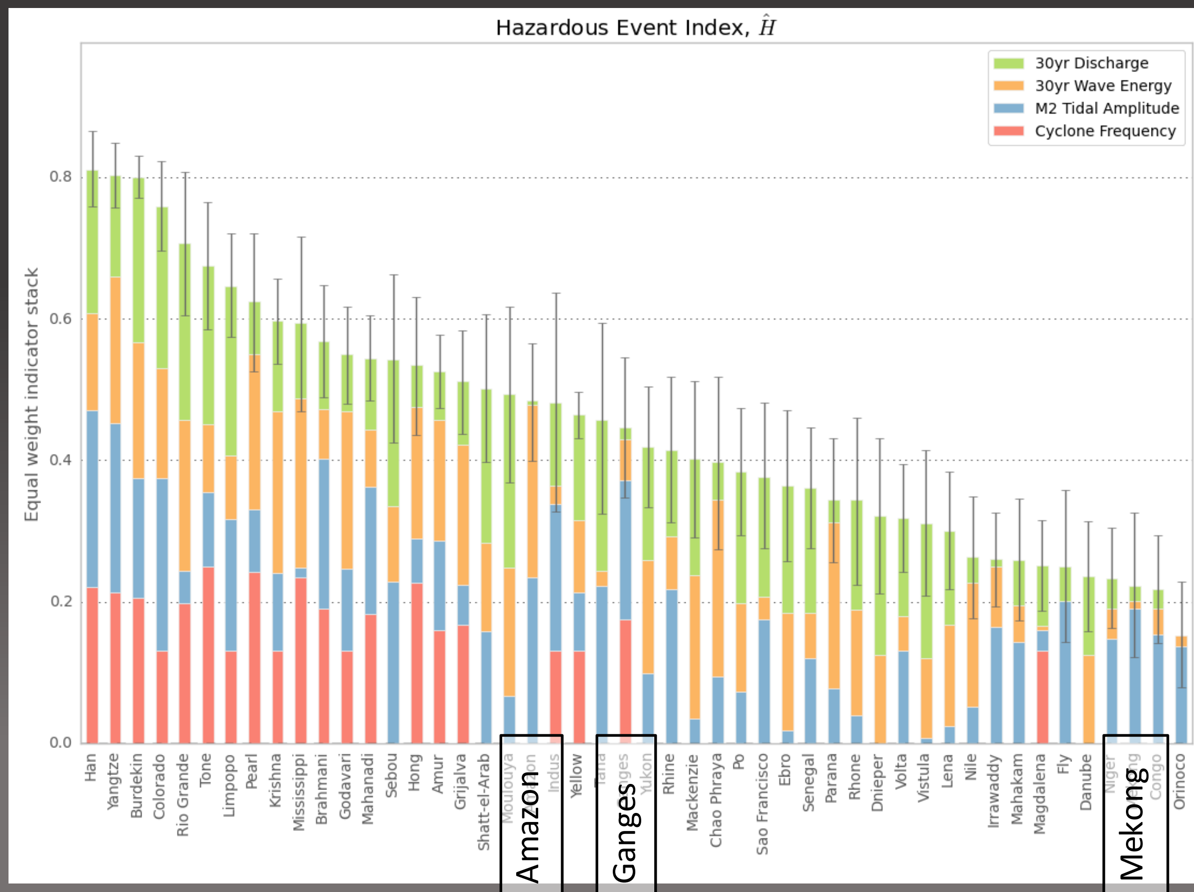
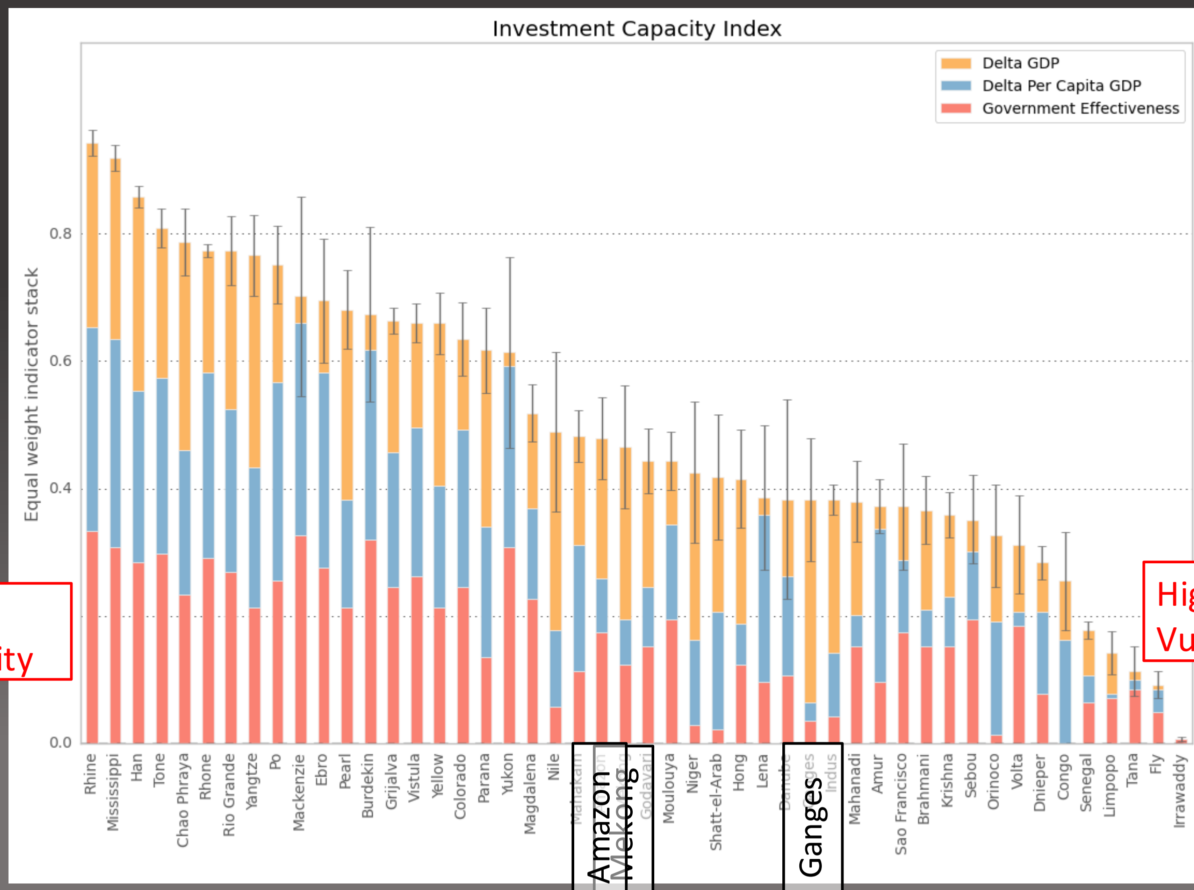
Hazard Frequency and Intensity (H)



Investment Capacity - inverse of Vulnerability (V)

Low Vulnerability



High Vulnerability

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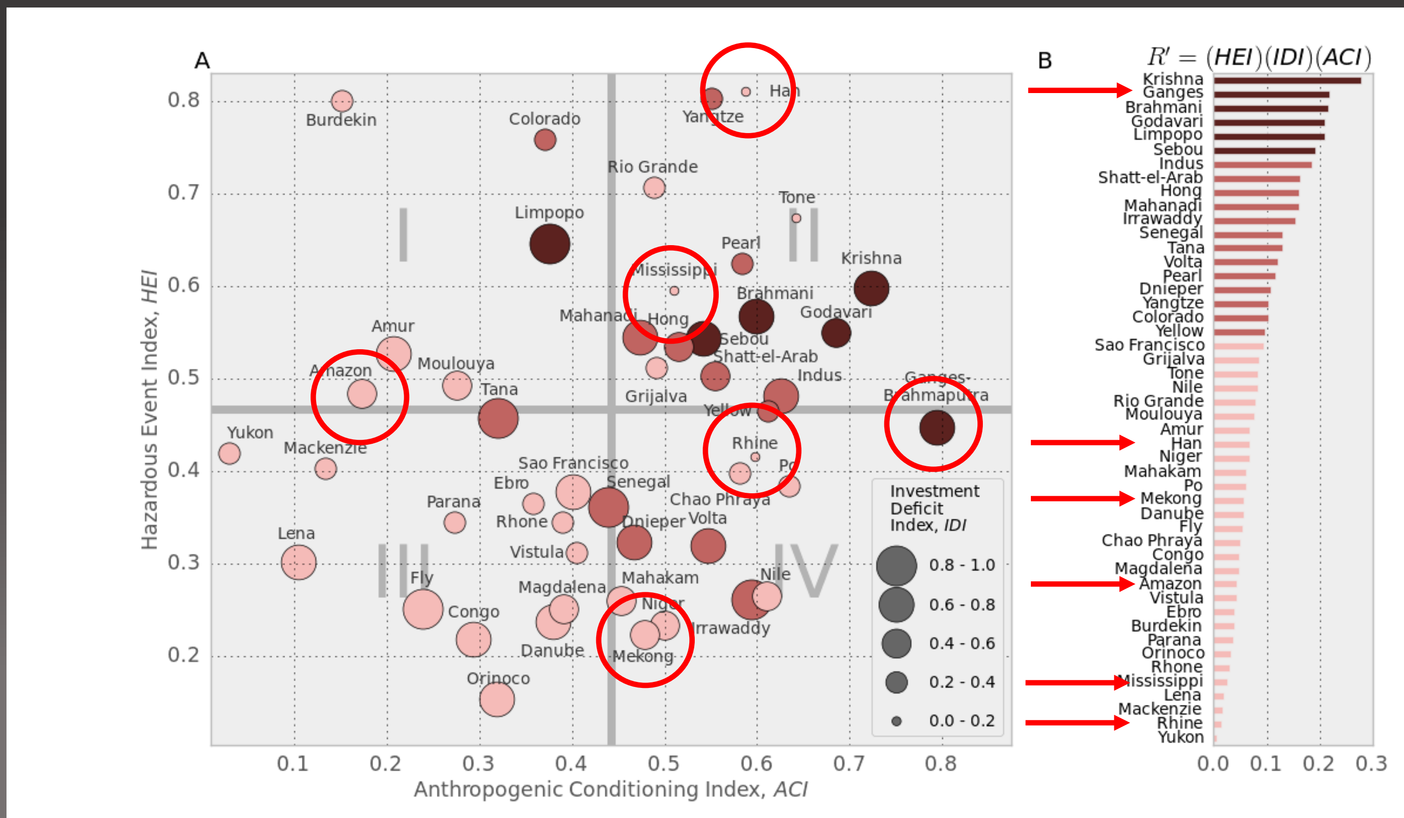
Delta R’ Space



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A thought experiment...

- How might vulnerability change in an energy-constrained future?
  - Energy prices are expected to rise faster than GDP (US Energy Information Administration models)
  - Require stronger infrastructure to maintain constant level of protection due to future SLR
  - Overall, more expensive to reduce vulnerability
- Re-weight Vulnerability Index to reduce the relative importance of GDP
  - (more difficult to “buy your way out of trouble”)

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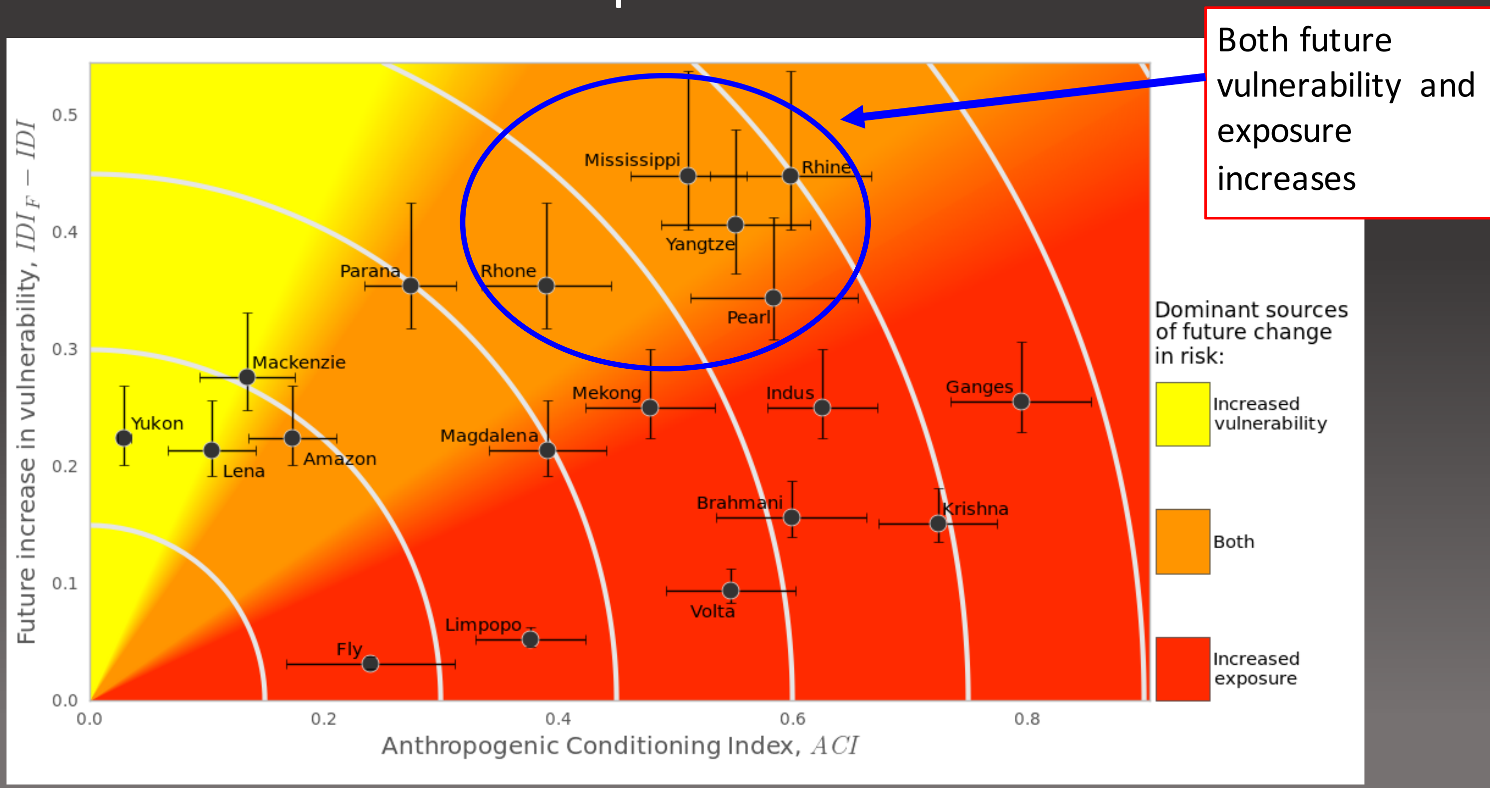
Future Changes in Vulnerability, and Exposure



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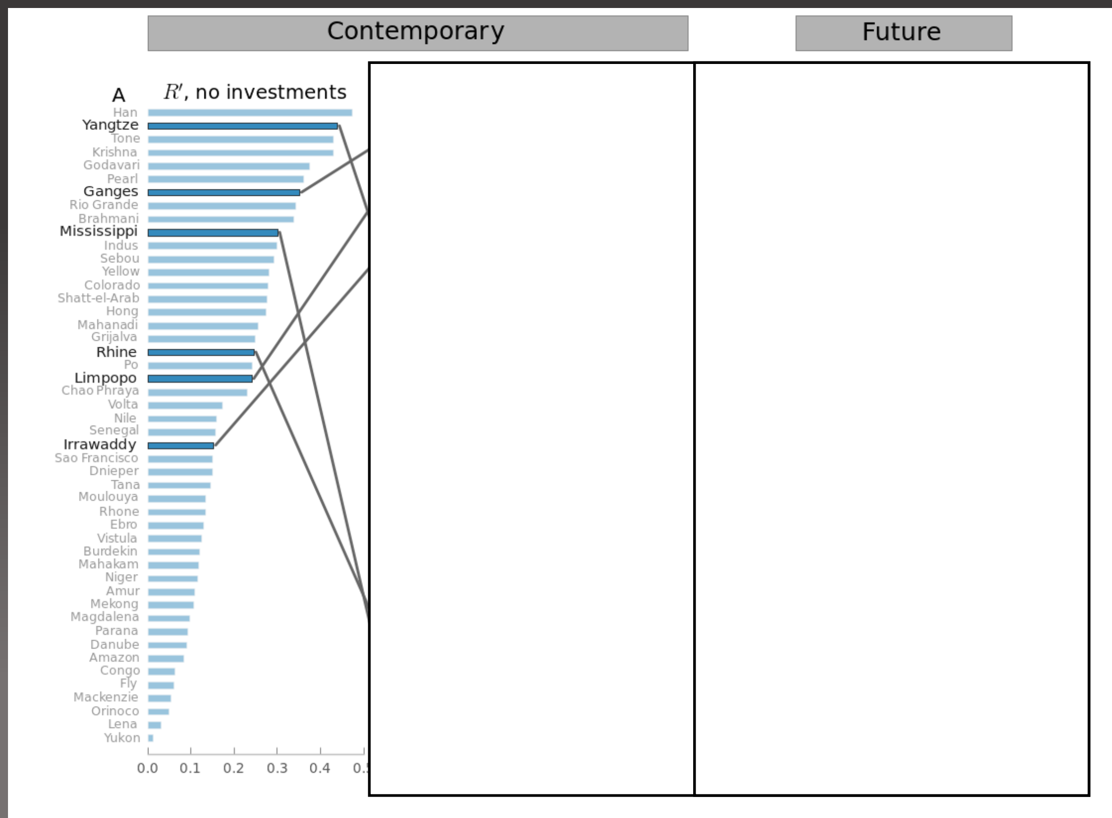
How do we expect R' to change in this future scenario?

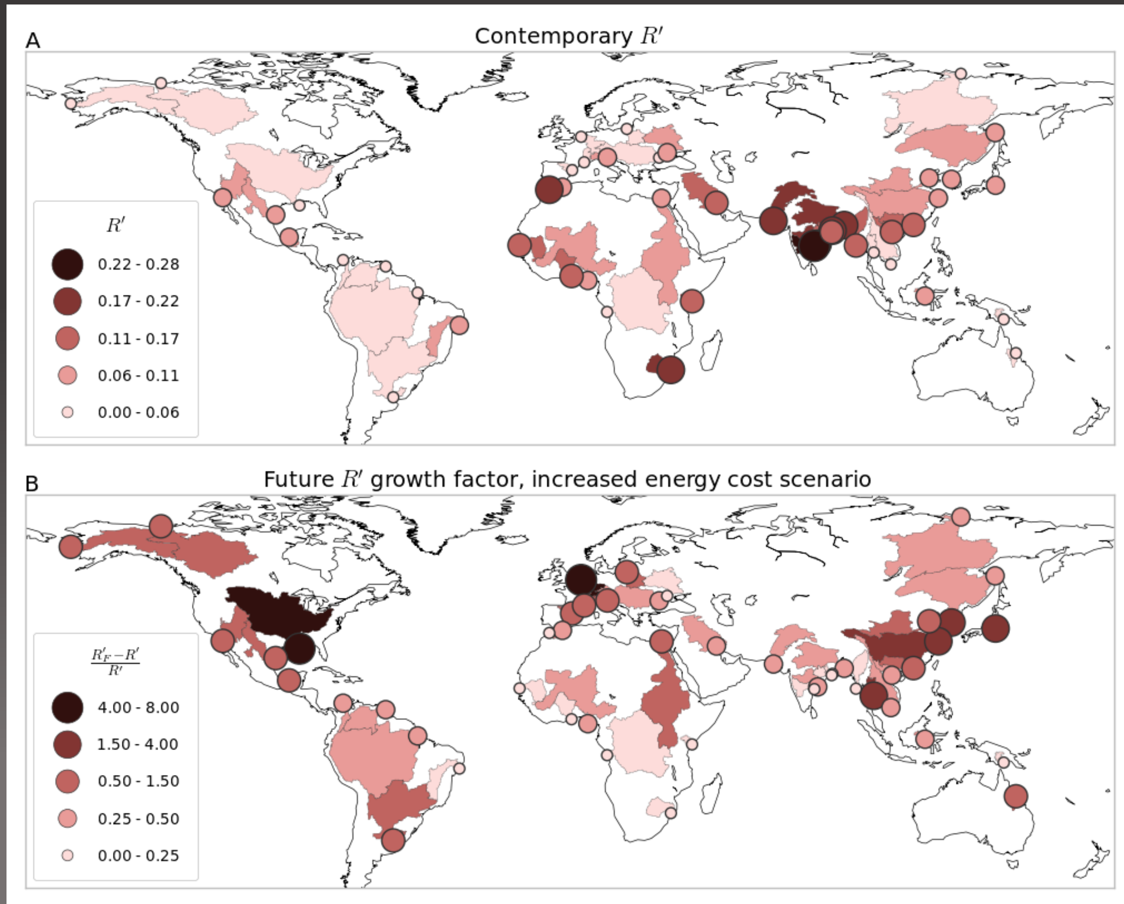
Wealthy deltas currently invest in protective infrastructure, reducing risk from increasing RSLR despite geophysical setting



If this is not an option in the future, risk "rebounds" and approaches the risk state with no investment.

Seen most dramatically in wealthy deltas in hazardous locations – Mississippi, Rhine, Han, Yangzte…

Risk', now and future scenario change



Future Scenarios

- Current methodology utilizes coarse scale indicators to build a heuristic model of coastal risk
- Lack of physical process modeling makes incorporating future change difficult.
- We considered future global macroeconomic trends – can we extend this to include other processes:
  - Accelerating SLR
  - Increased dam construction
  - Population growth, migration
- Can we quantify the effect of mitigation strategies on coastal risk?

Environmental change -> RSLR

- Following Ericson 2006 model of RSLR, with Syvitski and Milliman 2007 BQART model of mean fluvial sediment flux:

$$N_{eslr} = G_{slr} + G_{sub} - G_{cfluv}$$

N_{eslr} = Net effective sea-level rise

G_{slr} = Gross accelerated eustatic sea-level rise

G_{sub} = Gross total subsidence (= G_{ns} + G_{cs})
G_{cs} = Gross human-induced subsidence, approximated from drawdown estimates

G_{cfluv} = Gross contemporary accretion of fluvial sediment corrected for upstream trapping and decreased discharge

$$G_{cfluv} = G_{nfluv} * (1 - TE_{bas})$$

$$Q_s = \omega B Q^{0.31} A^{0.5} R T \quad \text{for } T \geq 2°\text{C},$$
$$Q_s = 2\omega B Q^{0.31} A^{0.5} R \quad \text{for } T < 2°\text{C},$$

Estimate long-term mean RSLR across global deltas based on global available remote sensing, modeling, and other data

Ericson, 2006

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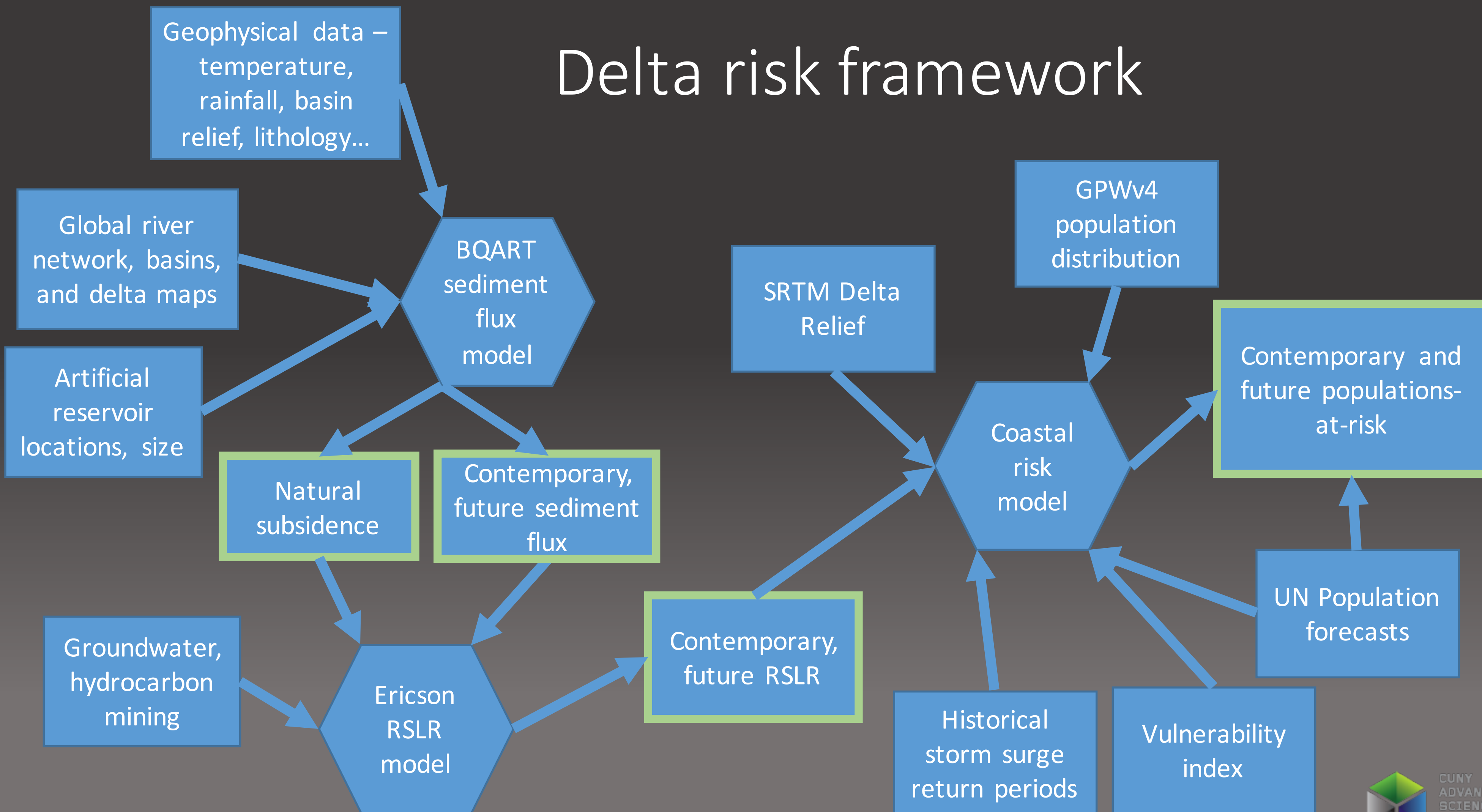
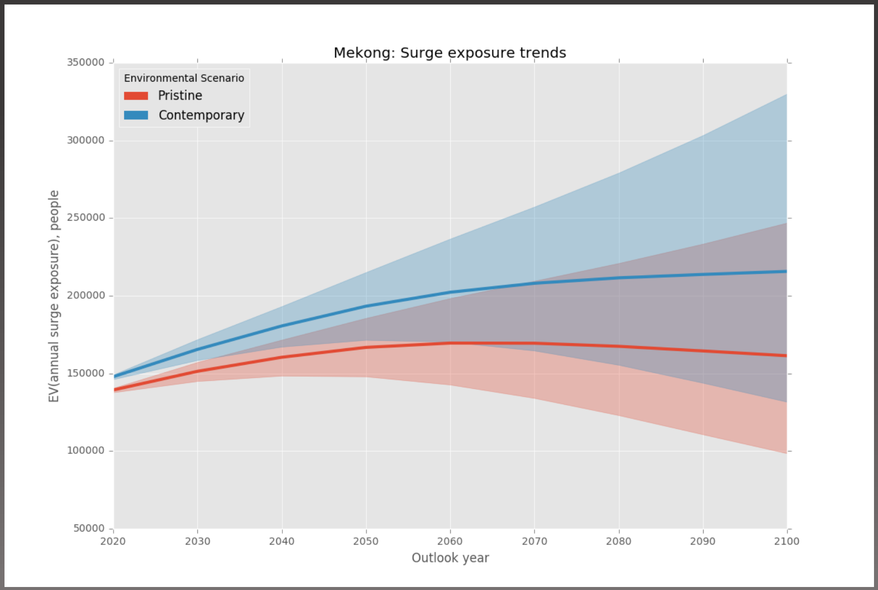
Delta risk framework

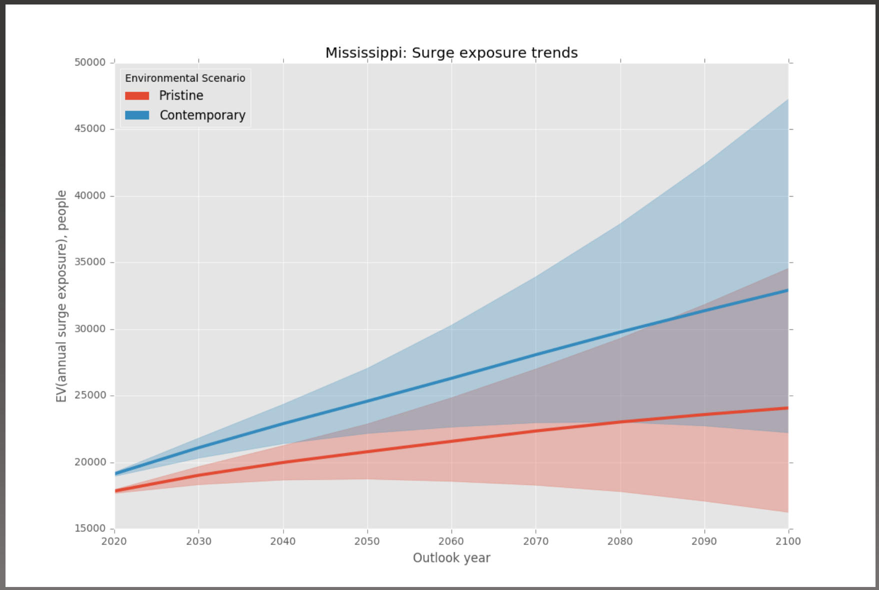


"Pristine" vs "Contemporary" conditions

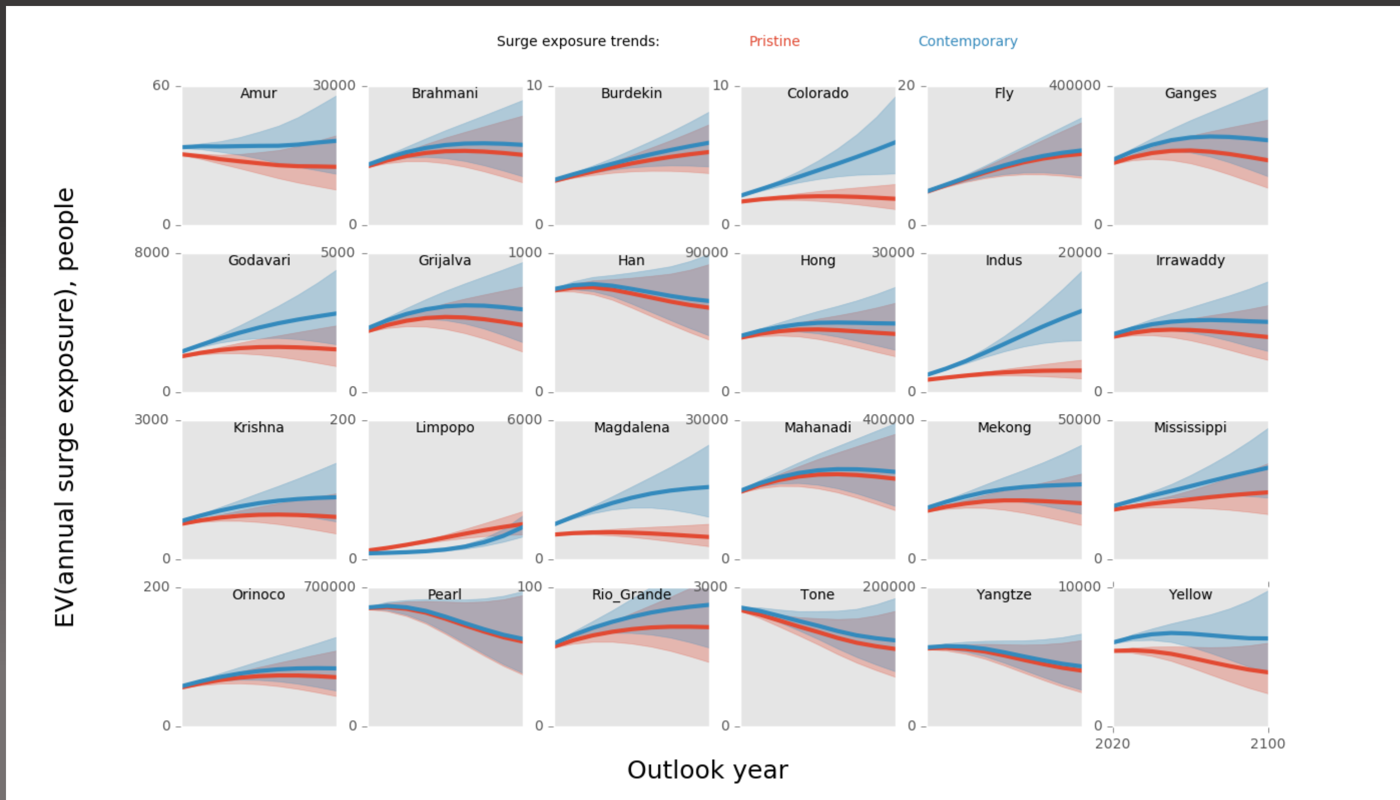
No humans, no reservoirs, no groundwater/hydrocarbon mining, 1.5mm/yr SLR

Modern conditions based on globally-available datasets, 3mm/yr SLR





"Pristine" vs "Contemporary"

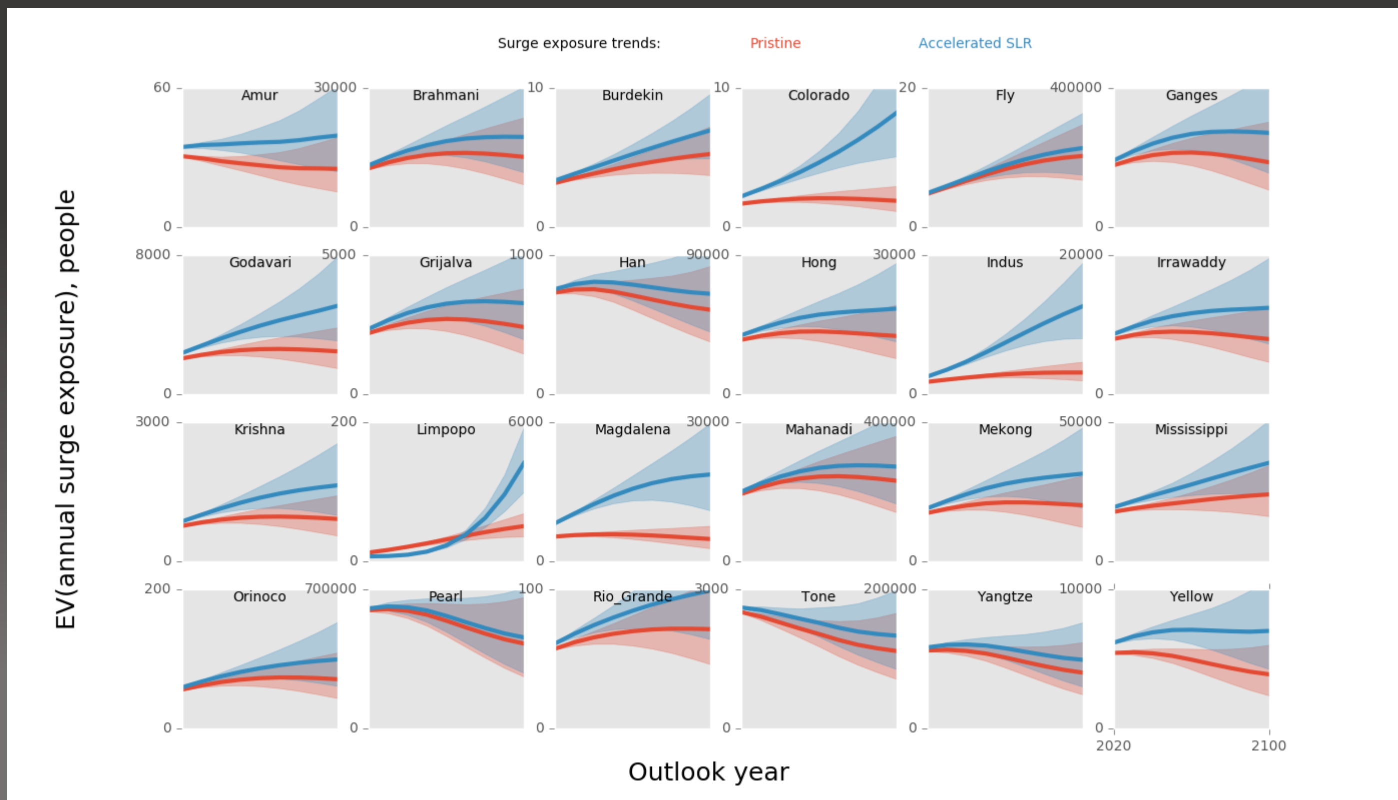


“Pristine” vs “Accelerated SLR (5mm/yr)”

Potential for a wide range of “What if” questions.

Compare relative scale of impact from different drivers?

Which deltas are more sensitive to specific environmental changes?



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Delta Risk Profiling Conclusions

- Krishna, Ganges, Brahmani, Godavari deltas are most sensitive to increased RSLR (per capita risk basis)
- Several wealthy deltas (Mississippi, Rhine) have low R’ despite high hazard and high RSLR estimates due to low vulnerability
- Future changes to vulnerability due to changing economics of coastal protection will have outsized effects on these systems. These particular systems are highly sensitive to changing vulnerability.
- Starting to investigate how anthropogenic changes to the upstream and coastal environments propagate through to affect long-term coastal risk.
- Population growth/contraction is a critical factor in future risk–collaborations with social scientists are very important!

www.globaldeltarisk.net

- Overview of research, plus all **data indices**, and all **delta maps** are available for download
- More details in Tessler et al., 2015, Science 349