Satellite Fusion Based Historical Inundation Estimates for Accurate Return Period Estimates in Bangladesh

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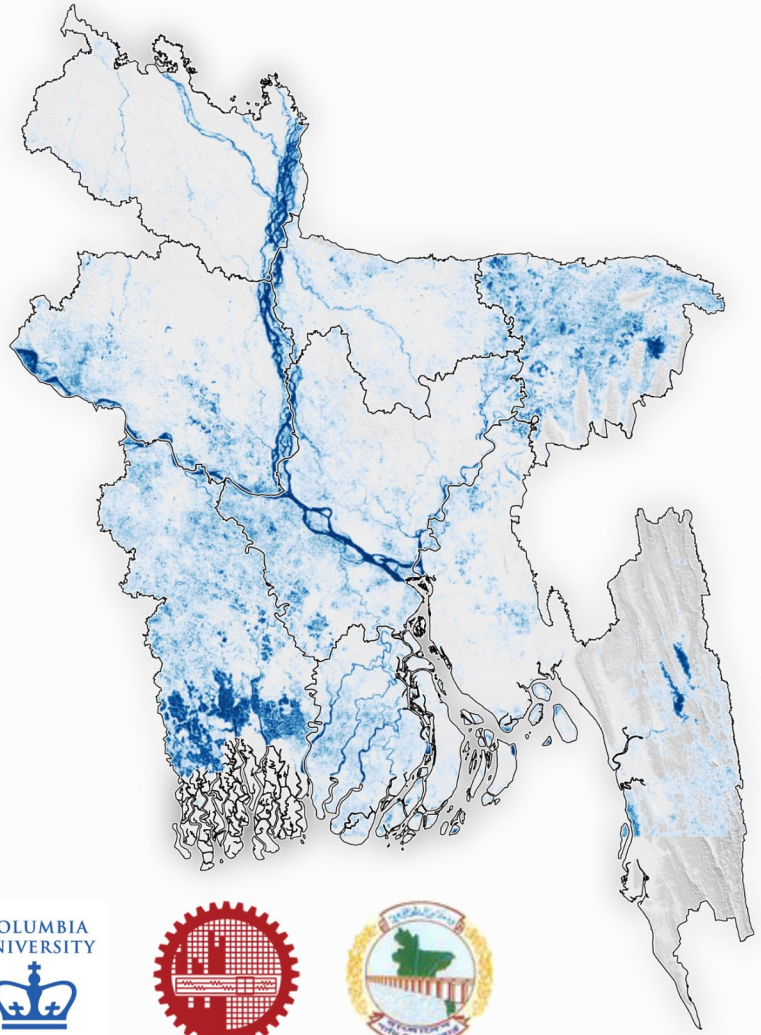

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Floods affect crops

15% of flood losses absorbed by the agricultural sector (FAO 2015)

Asia lost 48 billion USD in agricultural production from 1980-2013 (60% due to floods) (FAO 2015)

Insurance can support farmers' sustainable development Benami et al 2021

<1% insurance penetration in Bangladesh!

Bangladesh: world's first satellite based agricultural flood index insurance

Interpress News Service: Mintu Deshwara/ Sheikh Nasir

PREMIUM

Payout amount ($200M)

Transaction cost (15%)

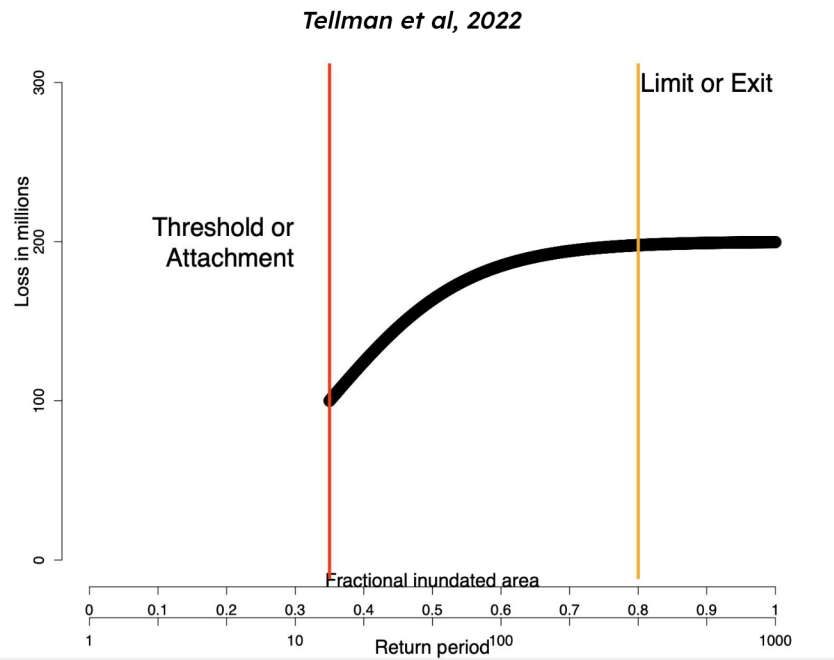
$$R_\theta = Pp_{exc} + kPsp_{exc} + f1 + f2P$$

Trigger: Probability of exceedance (0.4)

Risk price factor

5|95 spread of probability of exceedance (uncertainty)

Profit margin (6%)



Index Based Insurance

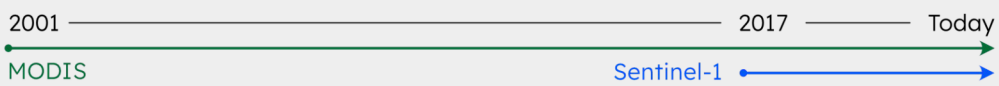
Payout based on **measurable proxy** for losses

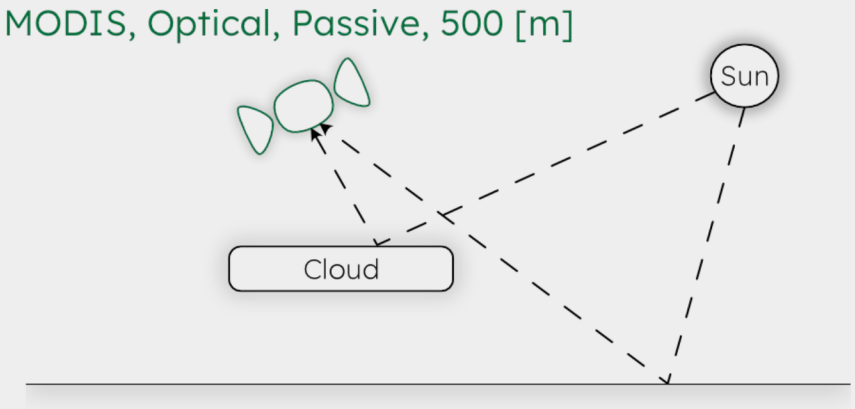
Payout issued when **pre-defined threshold** is reached

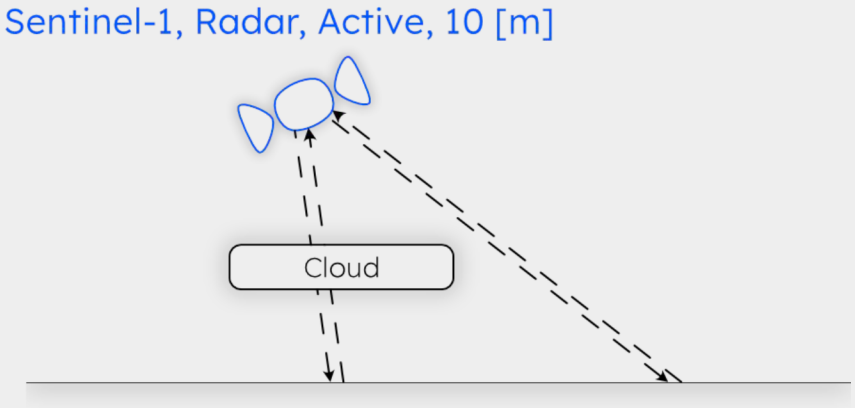
Interesting in remote areas, generates cheap premiums, less moral hazard

For Floods: based on **Return Period** vs **Fractional Flooded Area** estimates

Requires accurate **historical** estimate of **yearly maximum flood extent** (capture peaks)







Insurance requires >15 year time series to establish contracts, best satellites for flood mapping start ~2017

Longest Consistent Time Series: MODIS

MODIS: 500 m resolution, only Optical, can't see through clouds, difficult for floods

Sentinel-1: active imagery (radar, can see through clouds) at 10 meters resolution

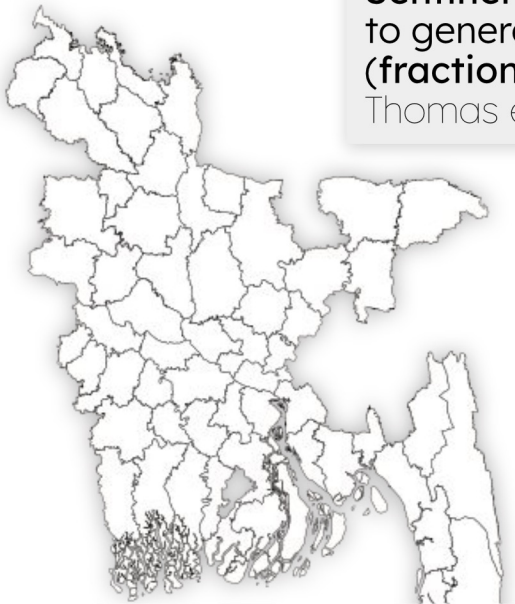
Higher spatial accuracy and temporal consistency, more correlated to damage

Only consistently available since 2017

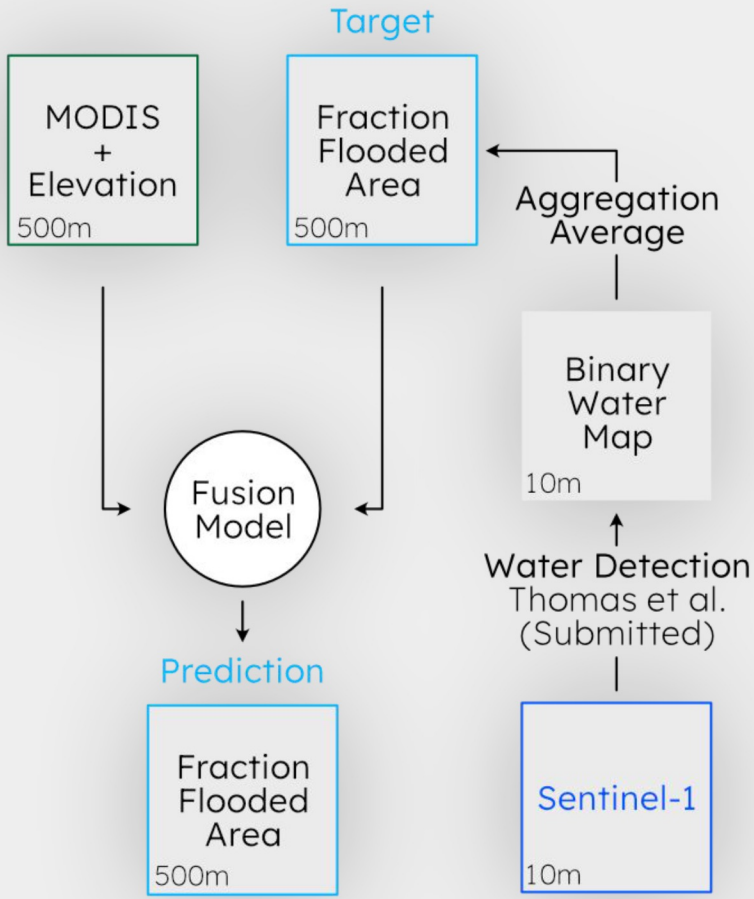
Goal: create historical (20+ years) time series of flooded areas over Bangladesh for return period estimates

Create a **Fusion** algorithm (**Deep Learning**) to estimate **fraction of flooded area** for each **MODIS** pixel

Sentinel-1 data (2017 - 2021) to generate weak labels (**fraction of flooded area**)
Thomas et al., submitted



Infer time series based on MODIS historical data (2001 – 2021) over all Bangladesh



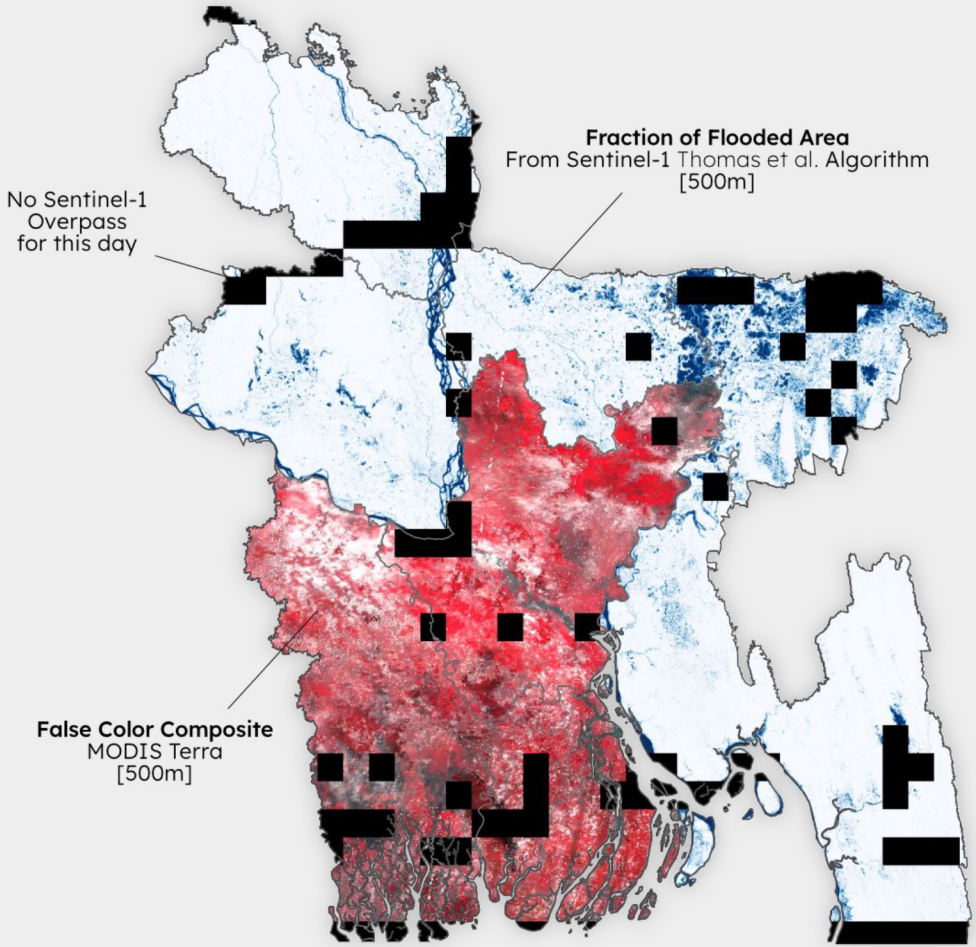
Data

Target: Fraction of Flooded Area at 500 meter resolution

- Based on Sentinel-1
- Dynamic thresholding algorithm creates a **binary** map at **10** [m] resolution Thomas et al., Submitted
- Calculate **fraction of inundated** area ($\in [0,1]$) for each **MODIS** pixel at **500** [m] resolution

Features:

- 8-Days MODIS Terra composite image at 500 [m] resolution
  - Daily imagery cloud cover is too dense during Monsoon
- Elevation (FABDEM)



Deep Learning Fusion Model

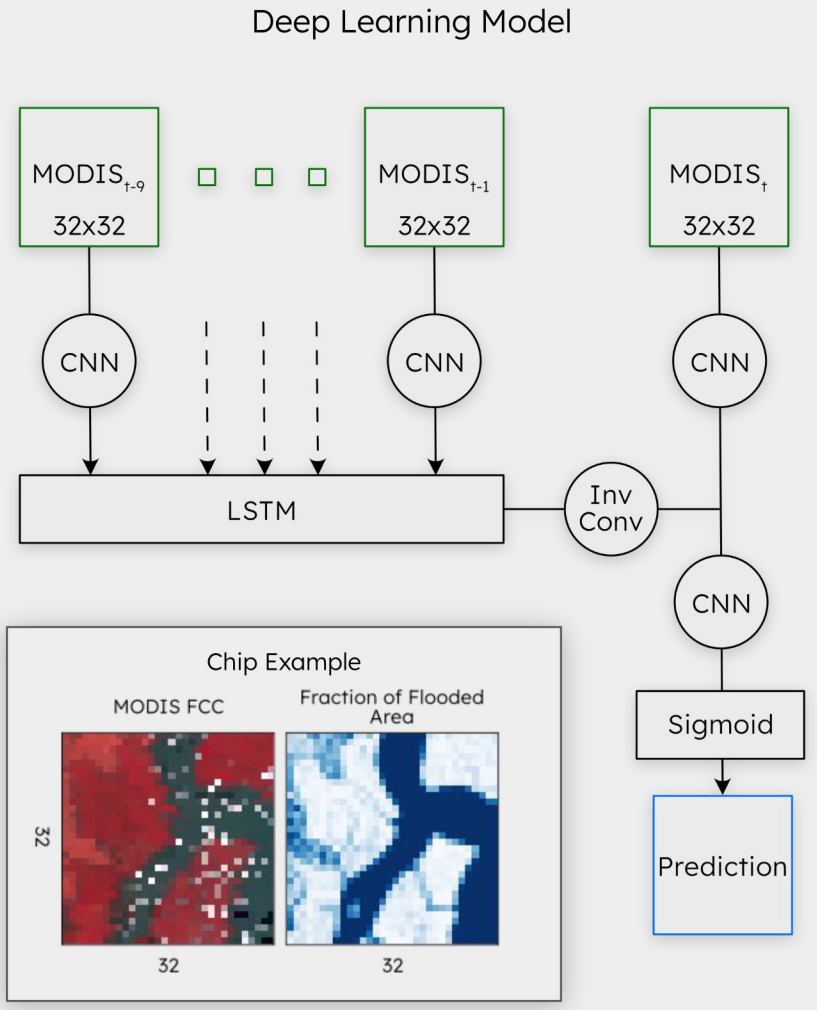
Long-Short-Term-Memory (LSTM) coupled with Convolutional Neural Networks (CNNS):

For each day:

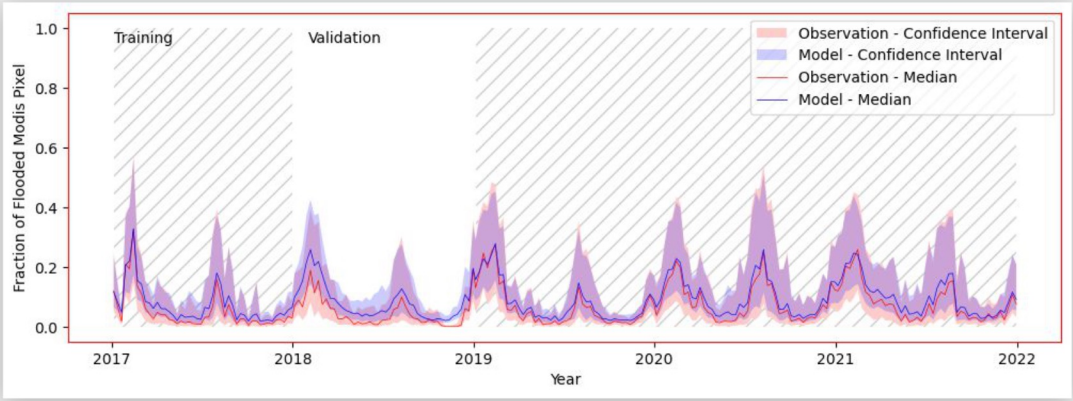
- The 10 MODIS images up to the event are run through a CNN (one network, same parameters)
  - Provides the **spatial context**
- The 9 previous CNN outputs are run through an LSTM
  - Provides the **temporal context**
- The LSTM output is combined with the CNN at time t and run through the last CNN to provide a prediction

Training and Testing:

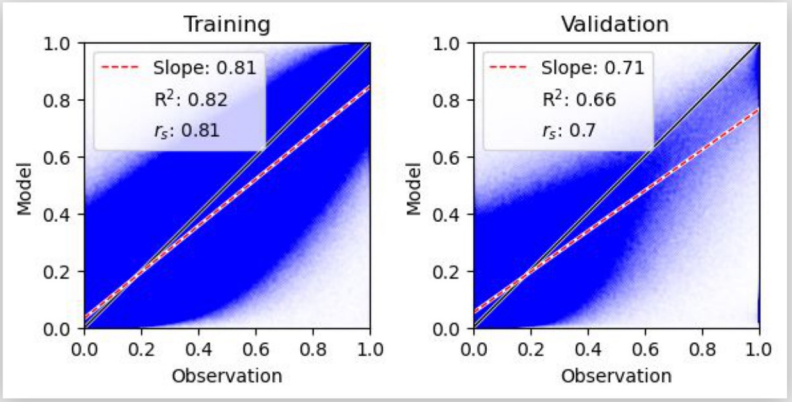
- Each Chip is **32x32** pixels at 500 [m]
- The total dataset contains **150'946** chips
- **Year 2018** is removed from the dataset for testing (21'487 chips)



Time Series for all Bangladesh



Observation vs Model



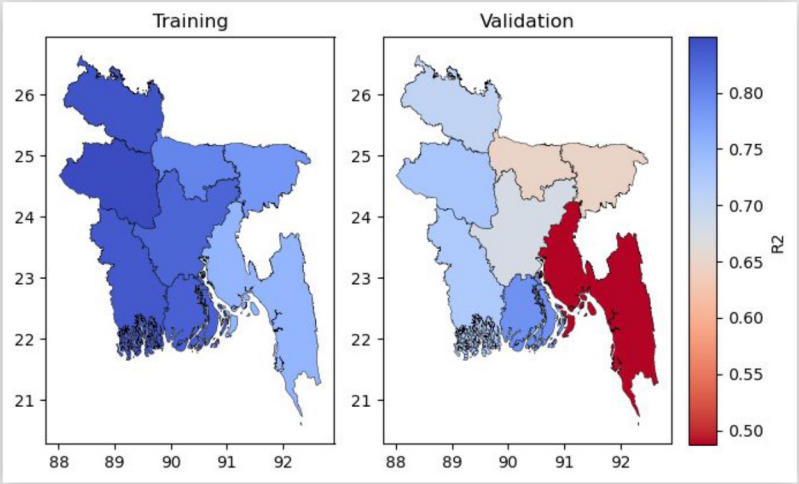
Results

Time series shows that the **flood peaks** and **valleys** are well reproduced

Overall R^2 of **.66** for the validation

Per region analysis shows that the model struggles with more **mountainous regions**

Per Region R^2



Historical Inference

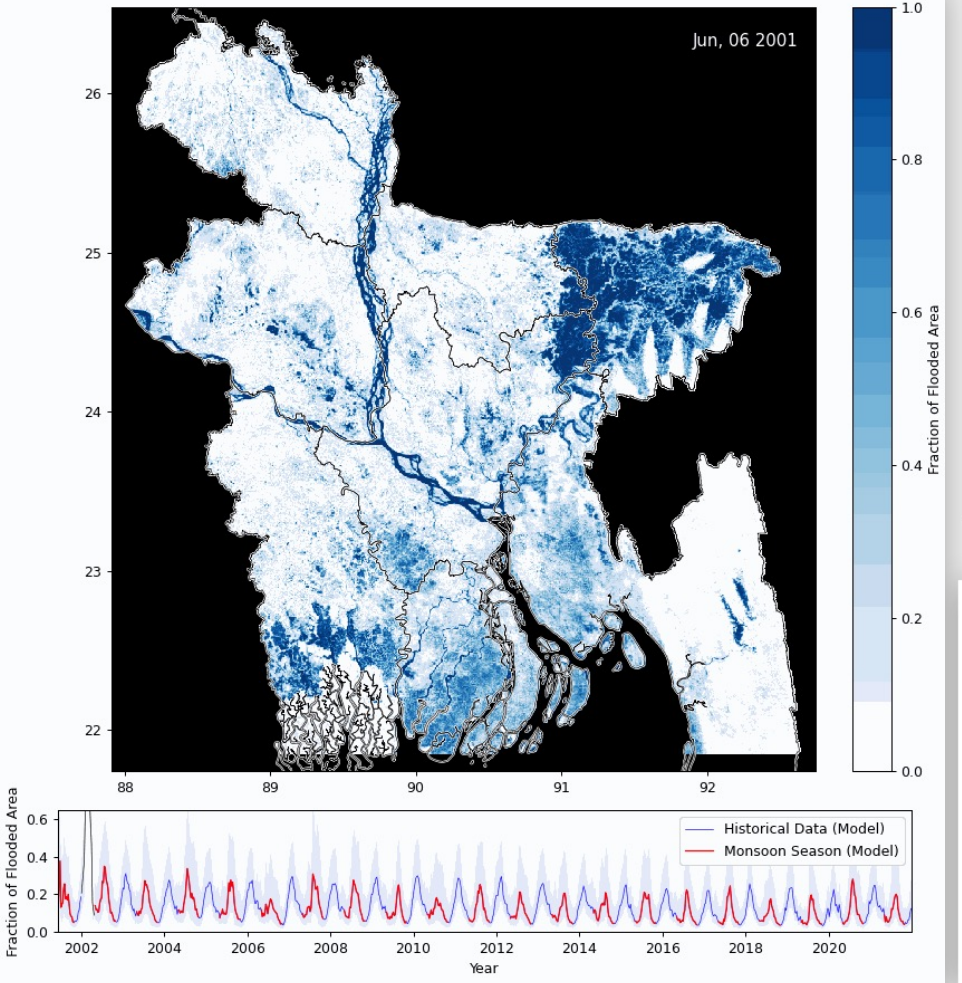
Infer time series of fraction of flooded area based on MODIS Fusion algorithm (20 years)

Extract yearly maximum extent

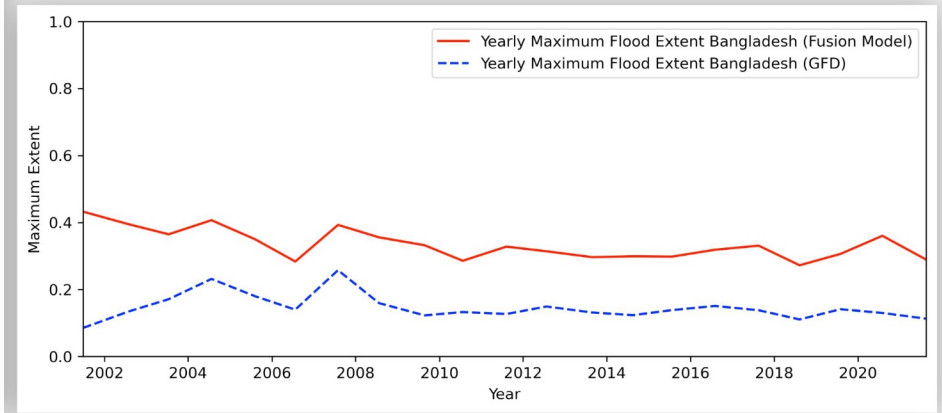
Compare to Global Flood Database Algorithm (GFD)

Inferred time series

Link to GIF



Yearly Maximum Extent



Return Period Estimates

Return period estimates for **Fractional Flooded Area** using **Beta-2 distribution**

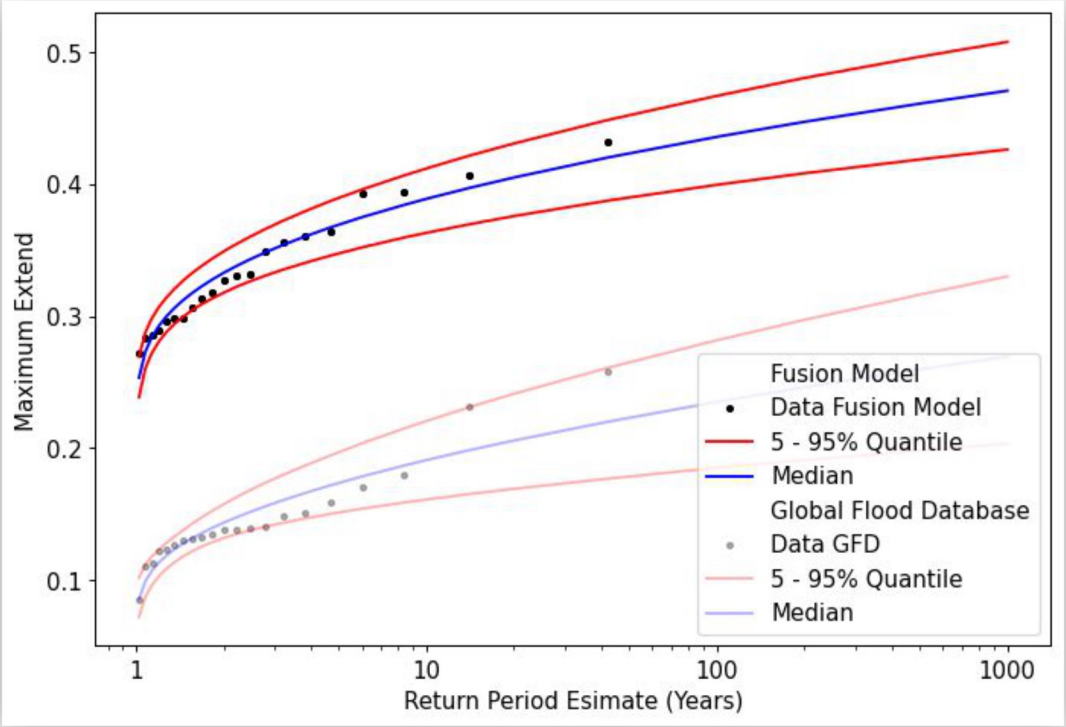
Tellman et al., 2022

Less uncertainty in the Fusion Model

GFD seems to underestimate flood extents compared to Fusion model

Reduced uncertainty and more accurate flood estimate could reduce base risk

Calculated Return Periods



Conclusions and Outlook

Fusion Algorithm seems to provide an accurate historical time series for return period estimates

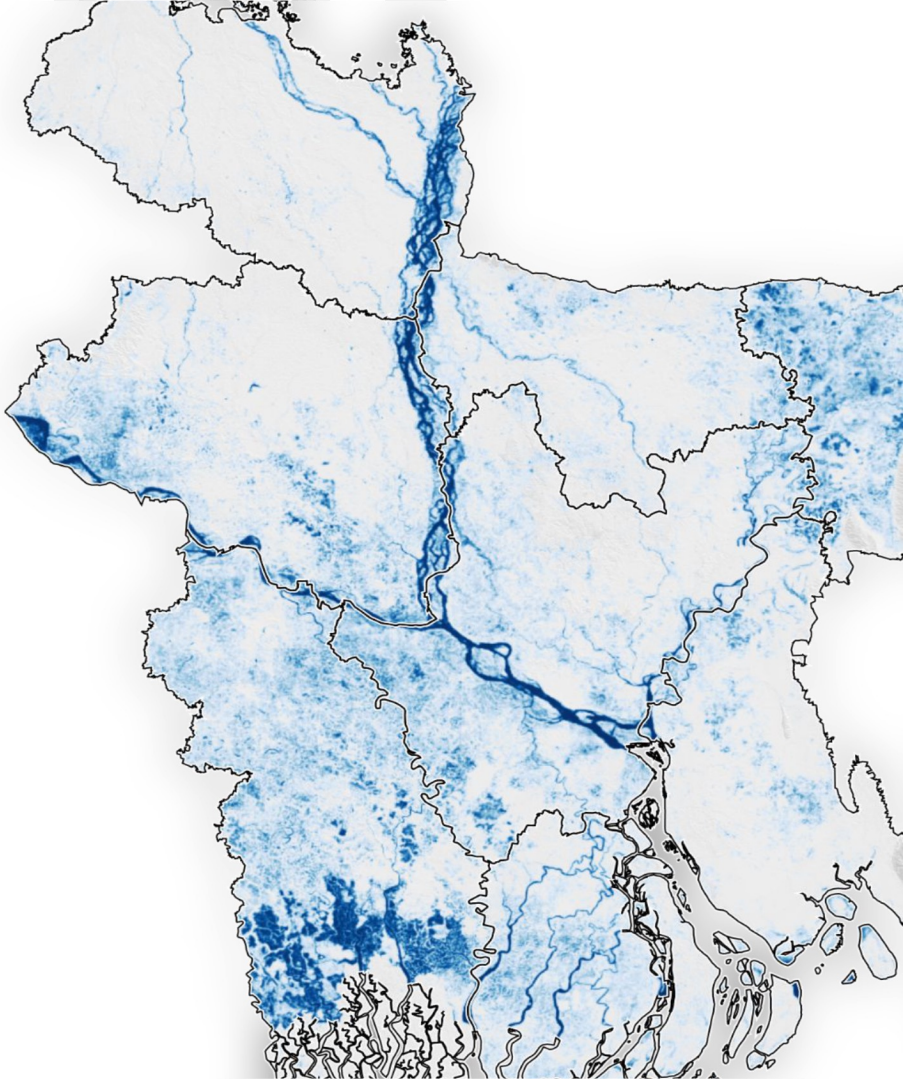
Algorithm needs further work to improve estimates in mountainous regions

Possibly longer LSTM to capture annual trends

Cross-validation for each year needs to be implemented

Spatial validation with district hold-outs

Bayesian return period estimation based on region or district grouping



Thank you for your attention!

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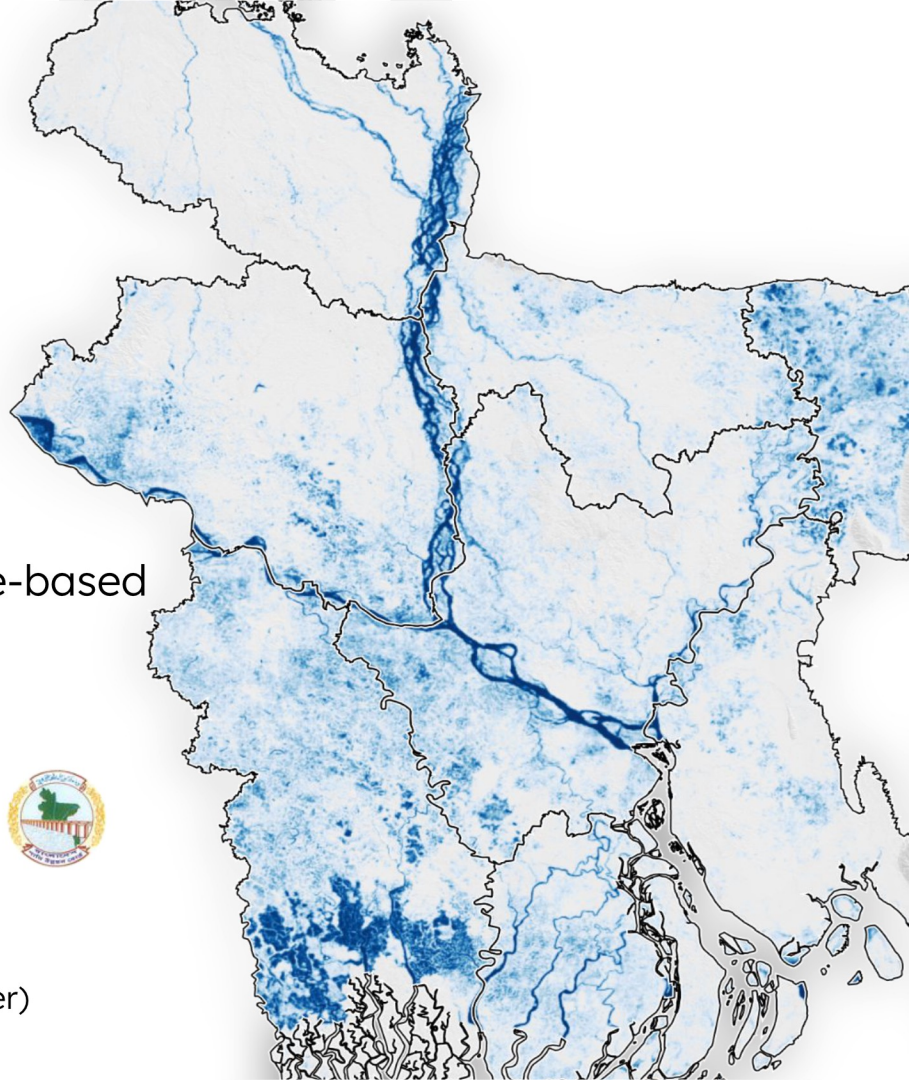

Reference: **Tellman et al**, *Earth's Future*, Regional Index Insurance using Satellite-based Fractional Flooded Area, 2022

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