FIER VIIRS Water Fraction Forecasting using GEOGloWS and National Water Model

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Session 2: Extreme Hydro-meteorological Forecasting and Flood Mapping

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Floods in 21st century

- Climate change, global warming, extreme events
- More water vapor in the Earth's atmosphere
- More frequent and intense extreme floods
  - Hurricane Katrina (2005): New Orleans
  - Hurricane Florence (2018): North/South Carolina
  - April floods: Alabama, Florida

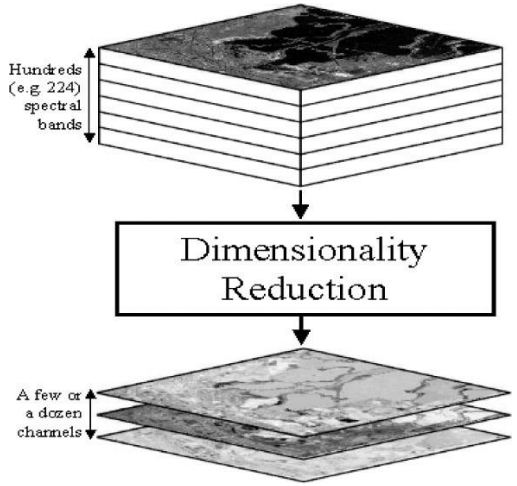
- ➢ Economic damages and life loss due to the floods
- ➢ Reliable flood forecasting systems are needed
- ➢ Accurate, scalable, fast, and operational methods
- ➢ Inundation maps are essentials for flood management

What is FIER?

- Forecasting Inundation Extents using Rotated Empirical Orthogonal Function (REOF) analysis (**FIER**) (Chang et al., 2020, 2023, 2024)

1. Historical Remote-sensing satellite images (Synthetic Aperture Radar (SAR), Optical imagery)
   - ❑ **VIIRS WF: Visible Infrared Imaging Radiometer Suite Water Fraction product (since 2012-present)**
   - ❑ Sentinel-1 SAR GRD images

2. Principle Component Analysis (PCA)
   - ❑ Capture the maximum information in the dataset
   - ❑ Reduce the number of dimensions of the dataset
   - ❑ Simpler visualization of the complex dataset



Adopted from Shen-En Qian (2011)

How PCA works?

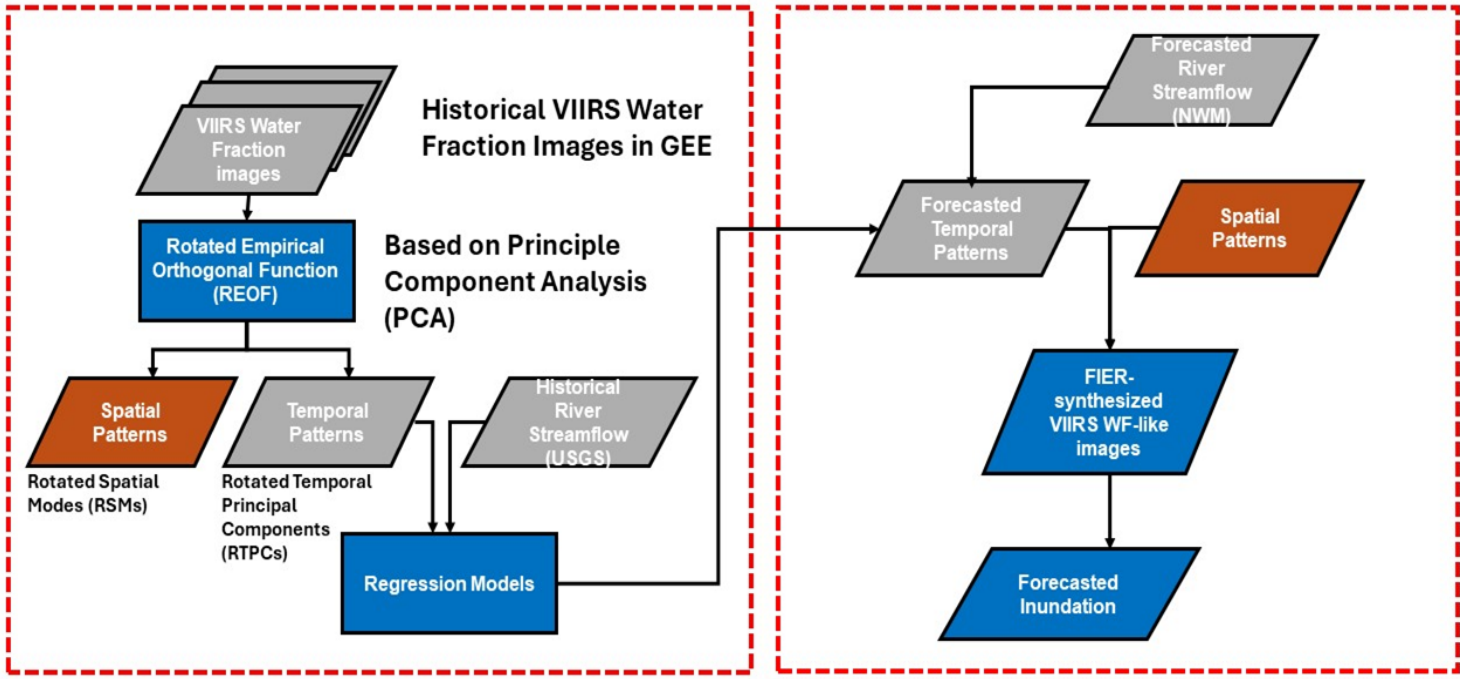
1. Covariance matrix of the RS cube data
2. Eigenvalues and associated eigenvectors (Singular Value **Decomposition**-SVD)
3. Sort eigenvectors based on the magnitude of eigenvalues (**max variance**)
4. Project the data points on those vectors (**synthesize**)

$$C = U\Sigma V^T$$

$$C_{n,n} = \begin{bmatrix} U_{i,j} \end{bmatrix}_{n,n} \begin{bmatrix} \sigma_1 & & \\ & \sigma_i & \\ & & \sigma_n \end{bmatrix}_{n,n} \begin{bmatrix} V_{i,j} \end{bmatrix}^T_{n,n}$$

How FIER Works?

- Meaningful relationship between hydrological variables (river water level/streamflow) and inundation extent
- Decomposition (SVD) of remote sensing imagery ➡ Temporal (eigenvalues) and Spatial (eigenvectors) pattern (modes). (Step2 in the previous slide)
- Build a regression model, hydrological data and temporal patterns of RS imagery
- Forecasted hydrological data ➡ how affect the RS images? ➡ Regression analysis ➡ synthesizing RS images (Step4 in the previous slide)

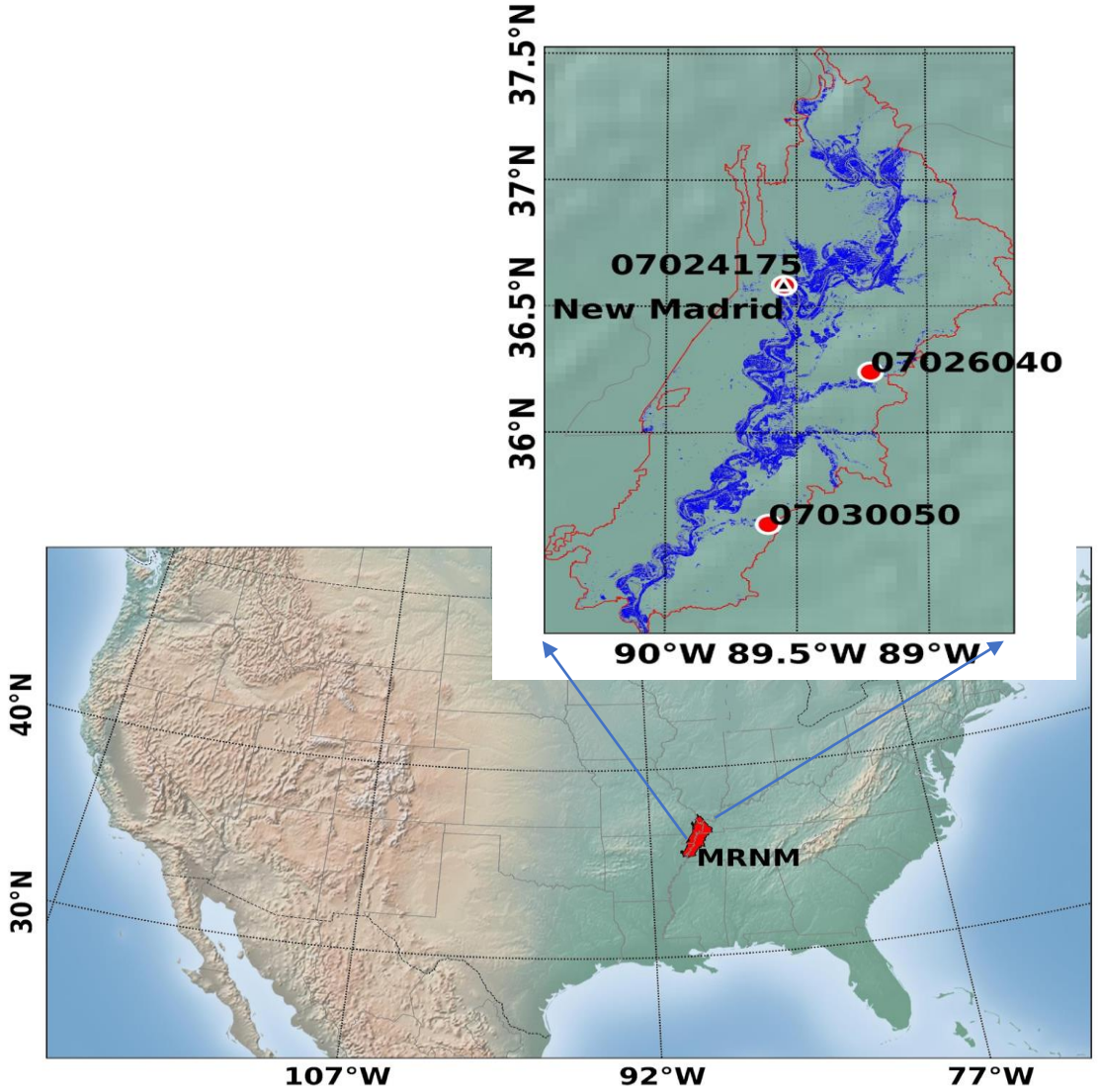


Study area and datasets

- **Mississippi River near New Madrid, MO**

✓ Model building
  - ✓ Historical Satellite images: VIIRS water fraction from 2012 – 2023
  - ✓ Historical Hydrological data:
  - ✓ USGS-07024175, 07030050

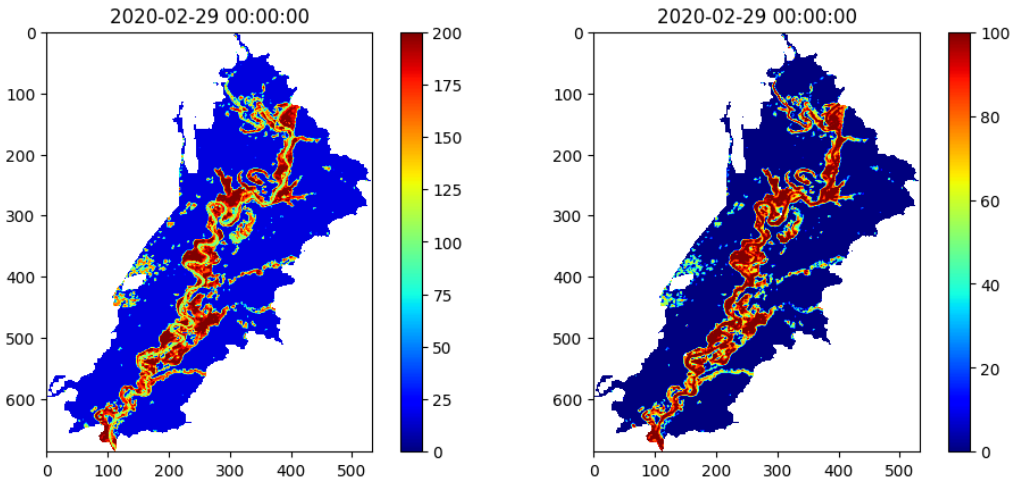
✓ Forecasting
  - ✓ Forecasting Hydrological data:
  - ✓ NWM-7469392, 14073444
  - ✓ GEOGloWS (retrospective)-760600230, 760660047



FIER-Step-by-Step

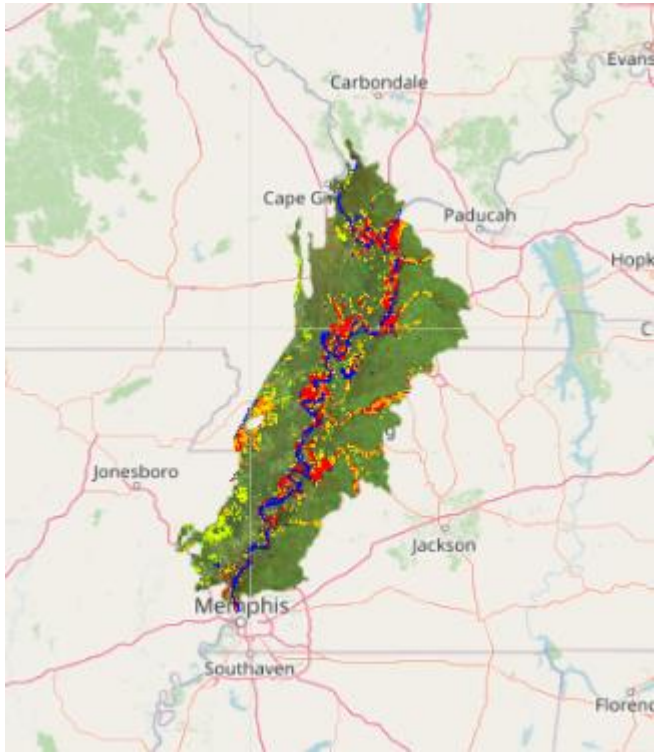
Step-1: Gathering and preprocessing datasets

- **VIIRS water fraction:**
  - Google Earth Engine: XEE package in python
    - An array extension for GEE
  - JPSS AWS portal
- **VIIRS preprocessing:**
  - Pertain VIIRS images with cloud coverage less than 5%
  - Crop images based on the Region of Interest (ROI) shapefile
  - Remove other classes (snow, ice, land,…) in the dataset



Before pre-processing

After pre-processing

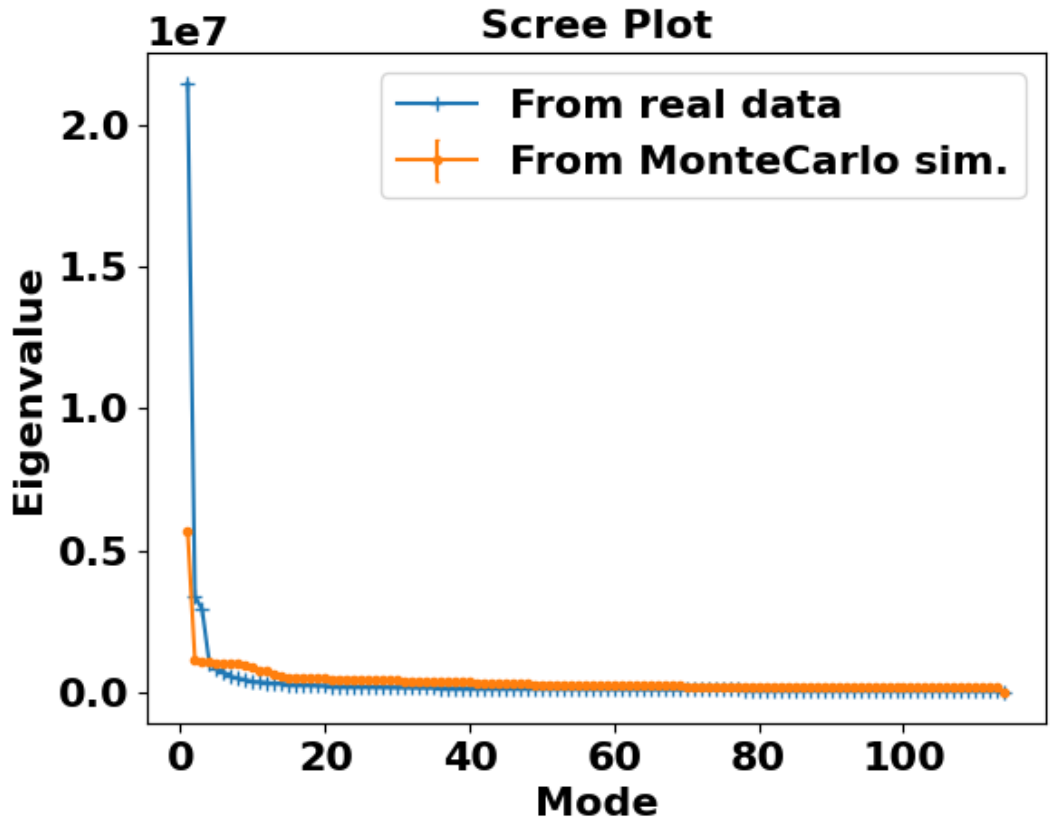


FIER-Step-by-Step

Step-2: Significant test

- **Which spatial mode(s) is (are) significant?**
- **Which spatial mode(s) represents the most dominant(s) changes over the ROI?**

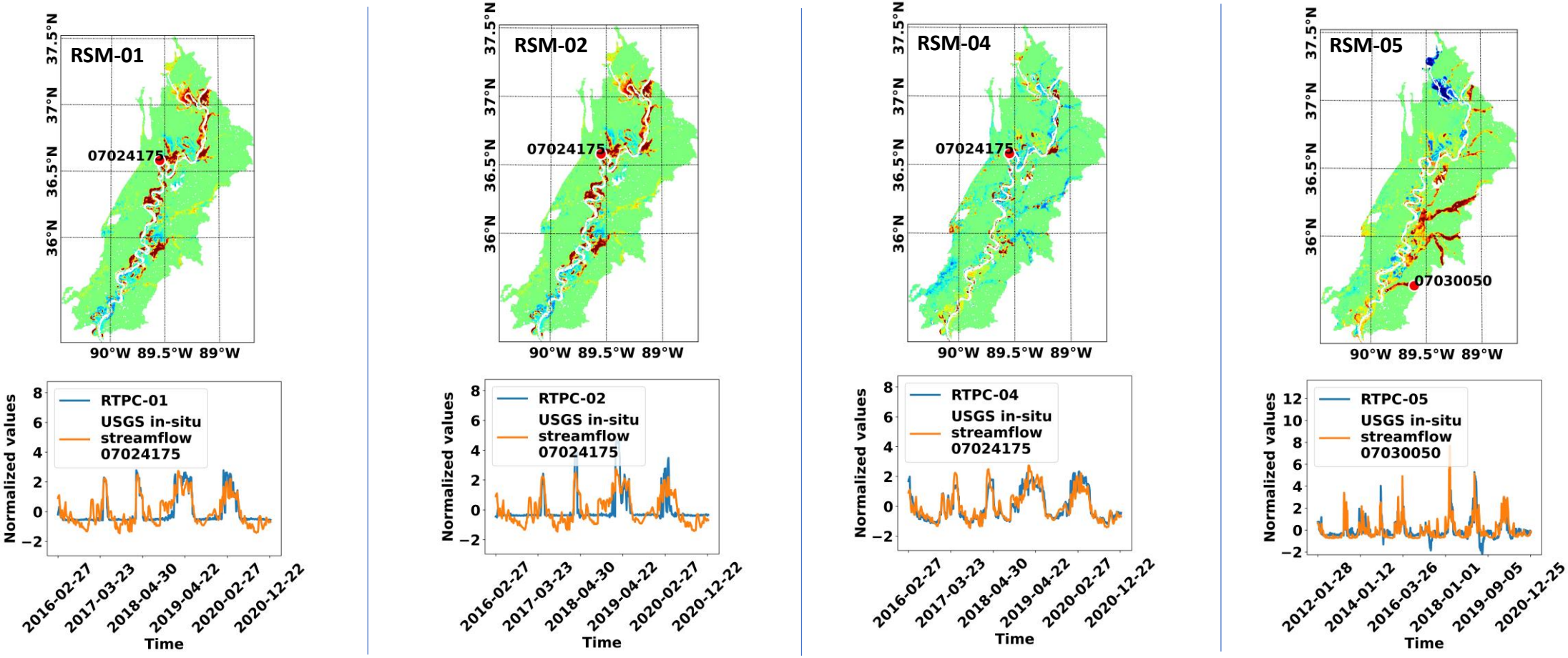
- ❑ Monte-Carlo Simulation
- ❑ Shuffle selection of VIIRS water fraction pixels
- ❑ Calculating Eigenvalues



FIER-Step-by-Step

Step-3: Rotated Empirical Orthogonal Function (REOF) analysis

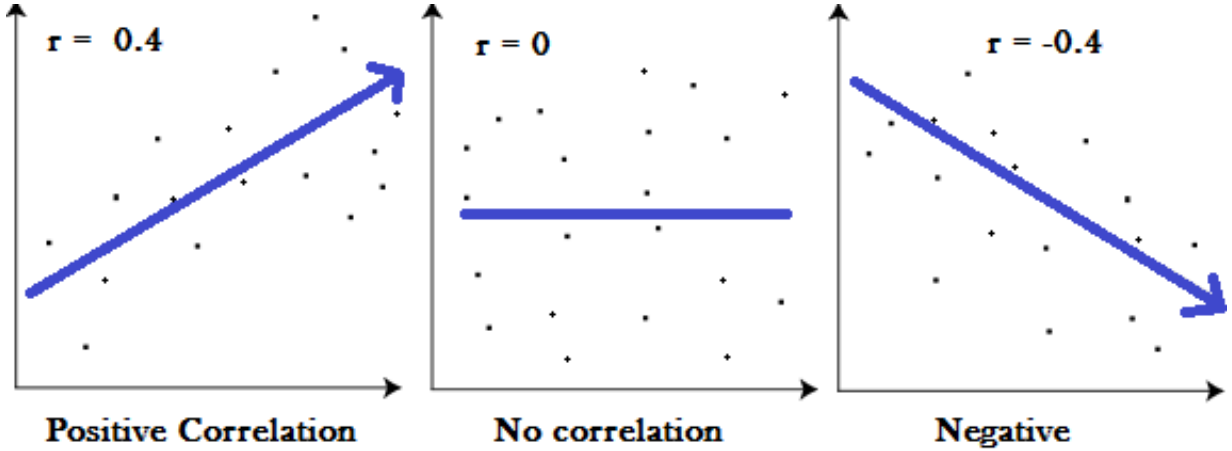
- **In which direction the dataset have the highest value of variance?**
- **In the other word, we are going to find the direction with most changes (spatial and temporal)**



FIER-Step-by-Step

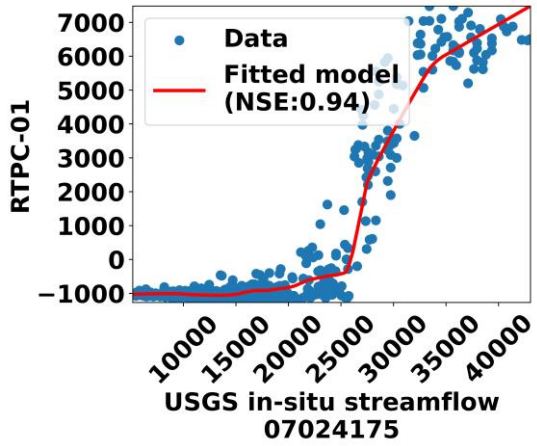
Step-4: Correlation analysis

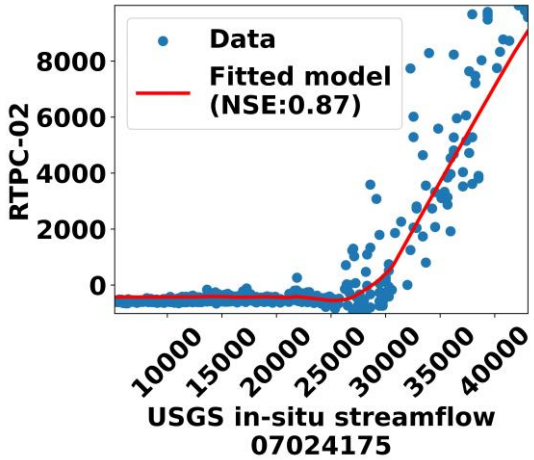
- **Which modes are the water-related signals?**
- **Which hydrologic stations should be used?**

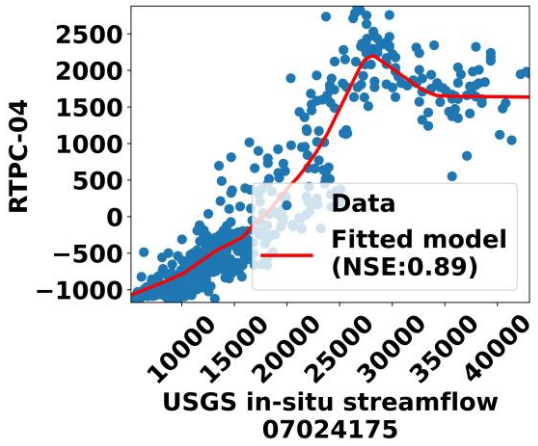


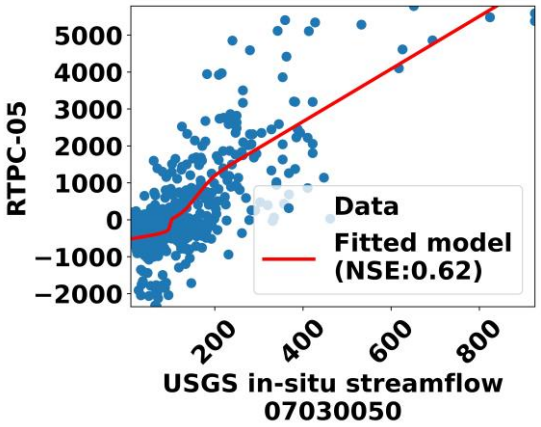
Step-5: Regression model

- Forecast hydrologic data → (?) Forecast RTPC
- ? = a regression model to create a relationship between them
- based on historical hydrologic variable (USGS) and RTPCs





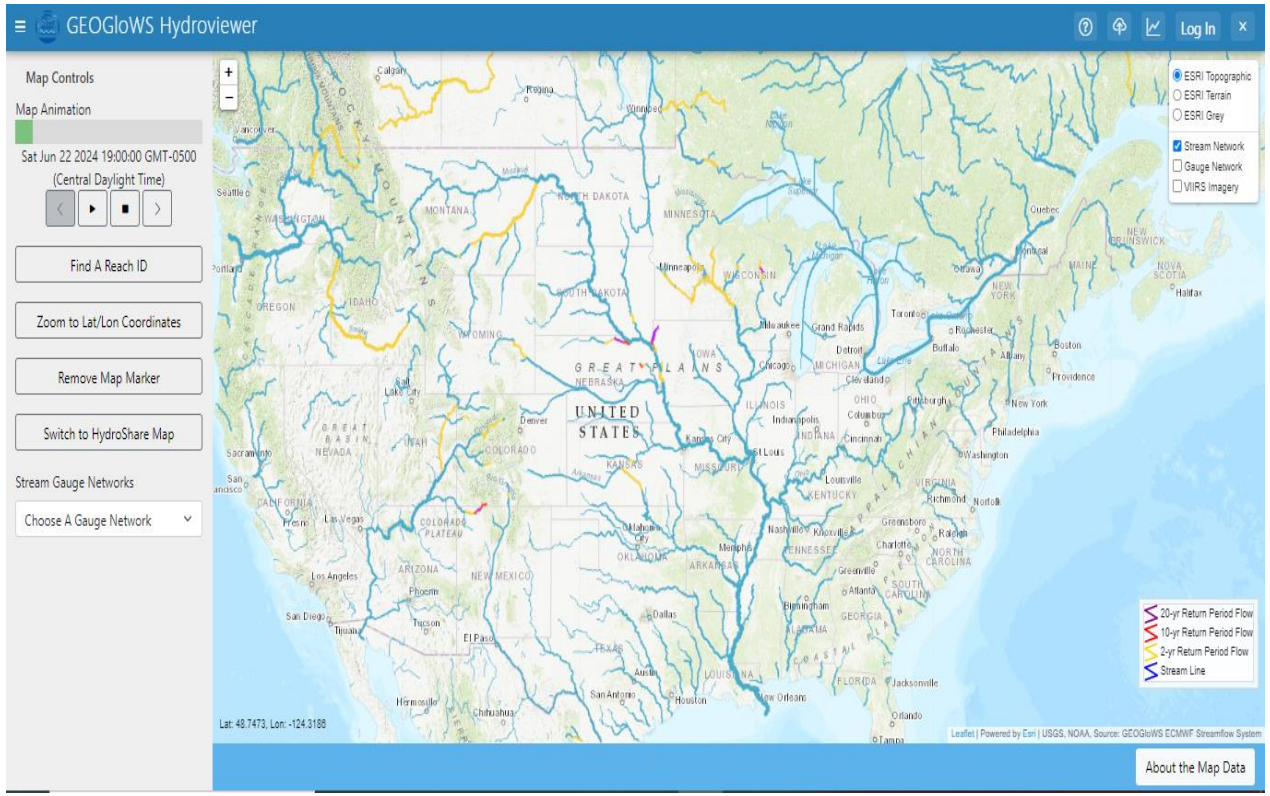




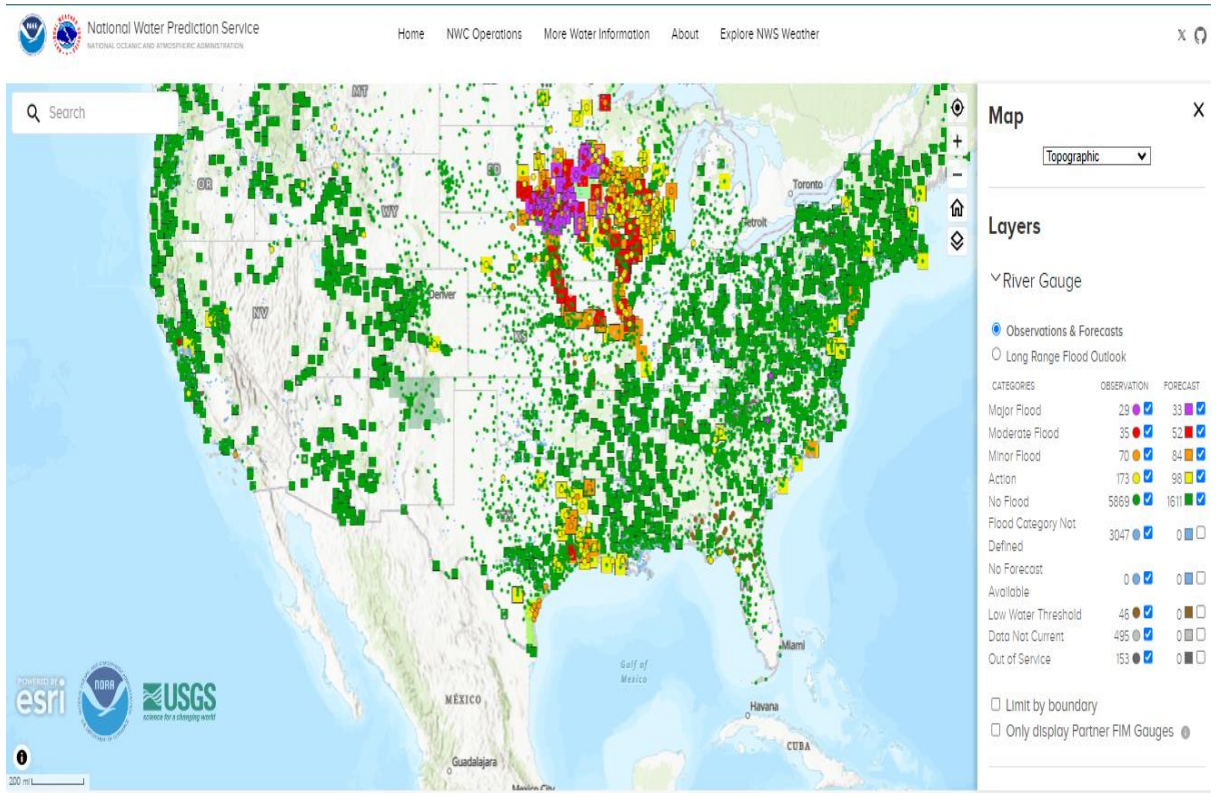
FIER-Step-by-Step

Forecast hydrologic data (streamflow):

- **GEOGloWS**



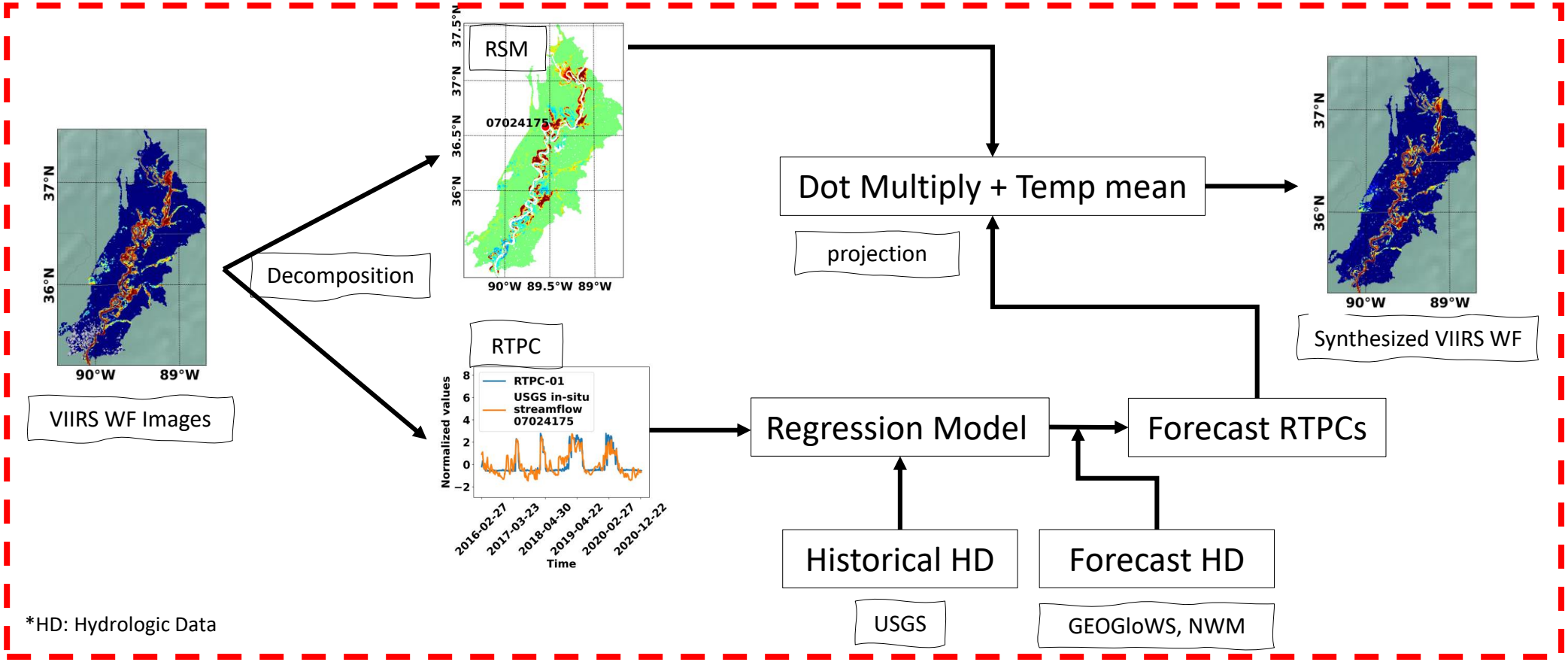
- **National Water Model**



FIER-Step-by-Step

Step-6: Synthesizing VIIRS WF images

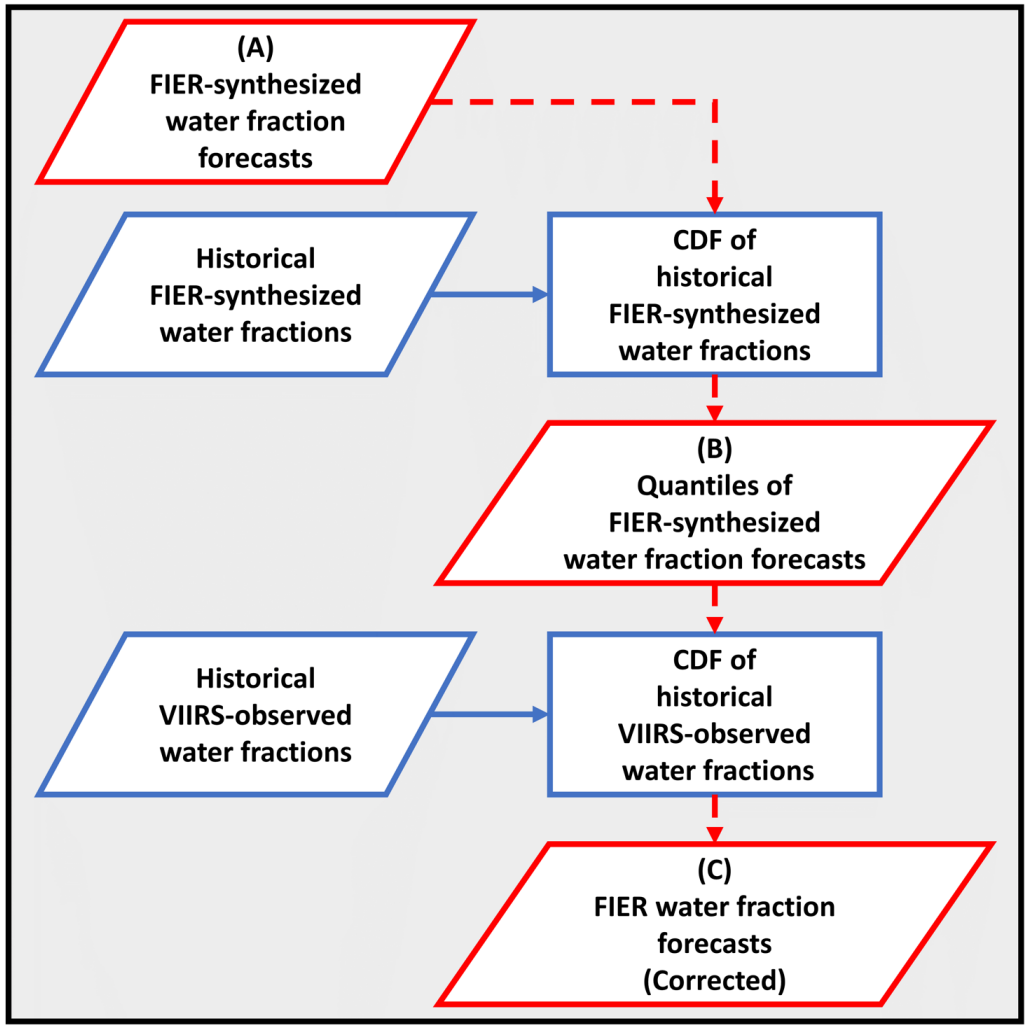
- **Backward procedure**

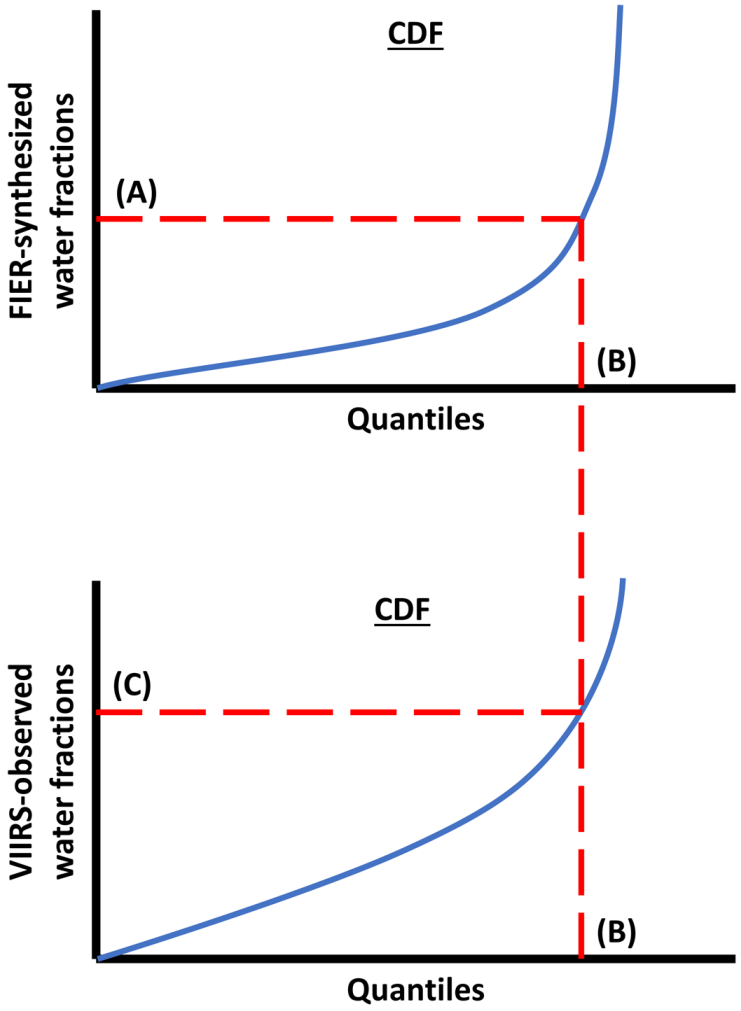


$$Syn\ img = \sum RSM_i\ .\ RTPC_i + Temp\_mean$$

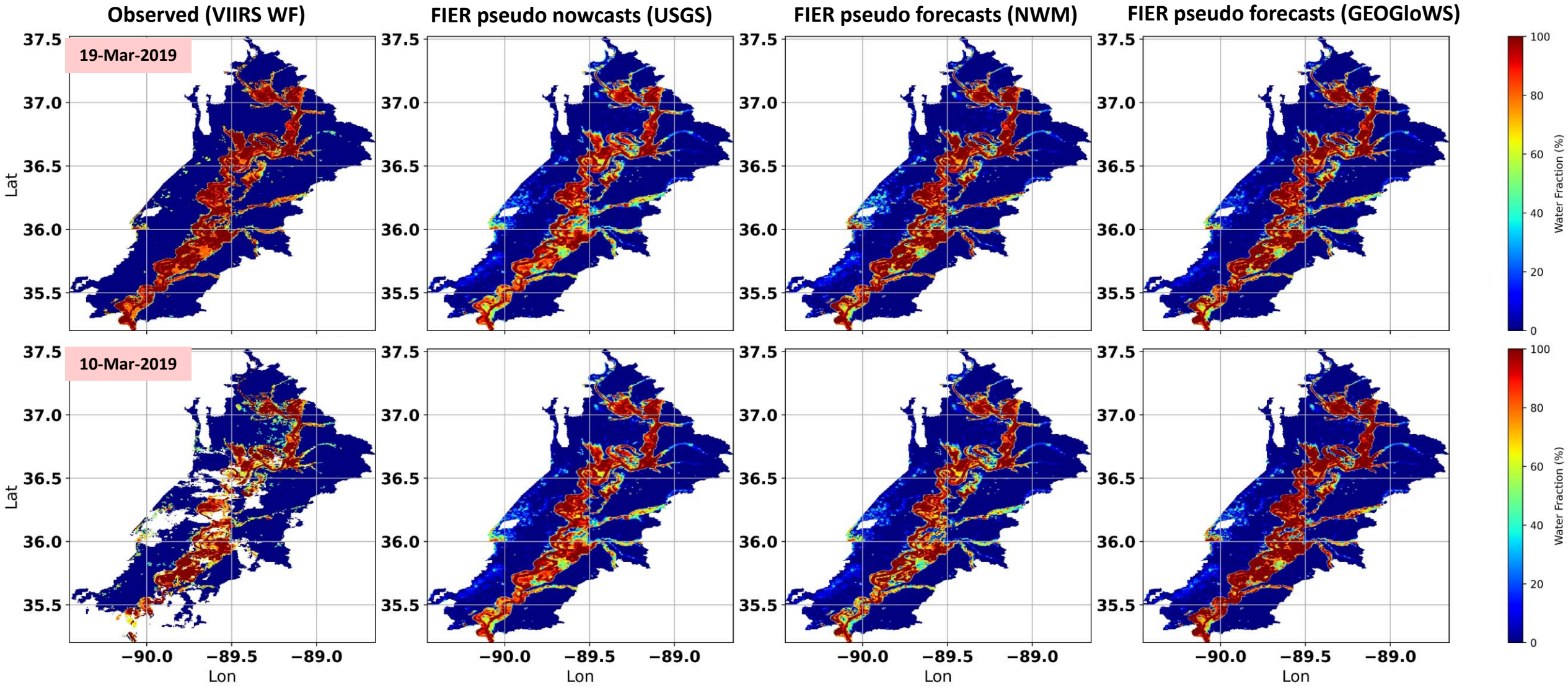
FIER-Step-by-Step

Step-7: Quantile-Scale Mapping

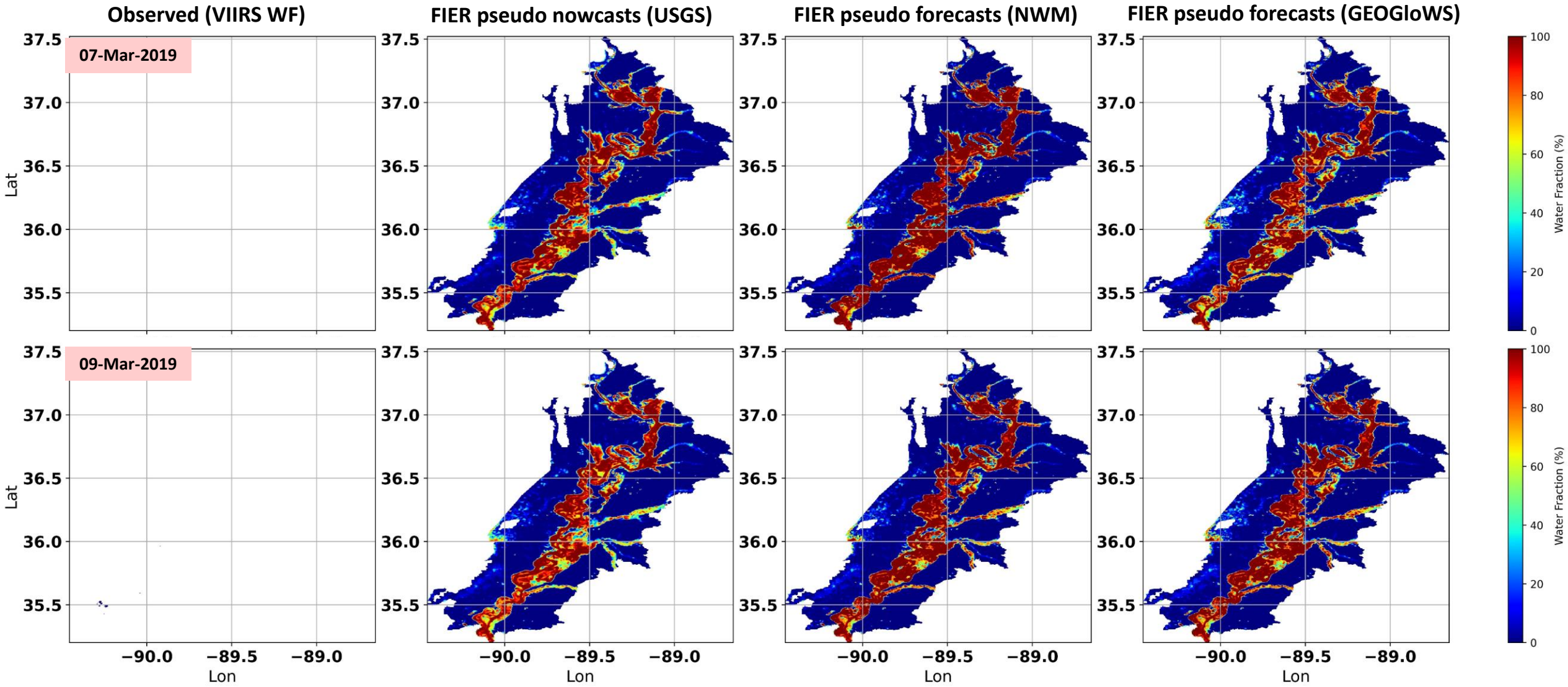




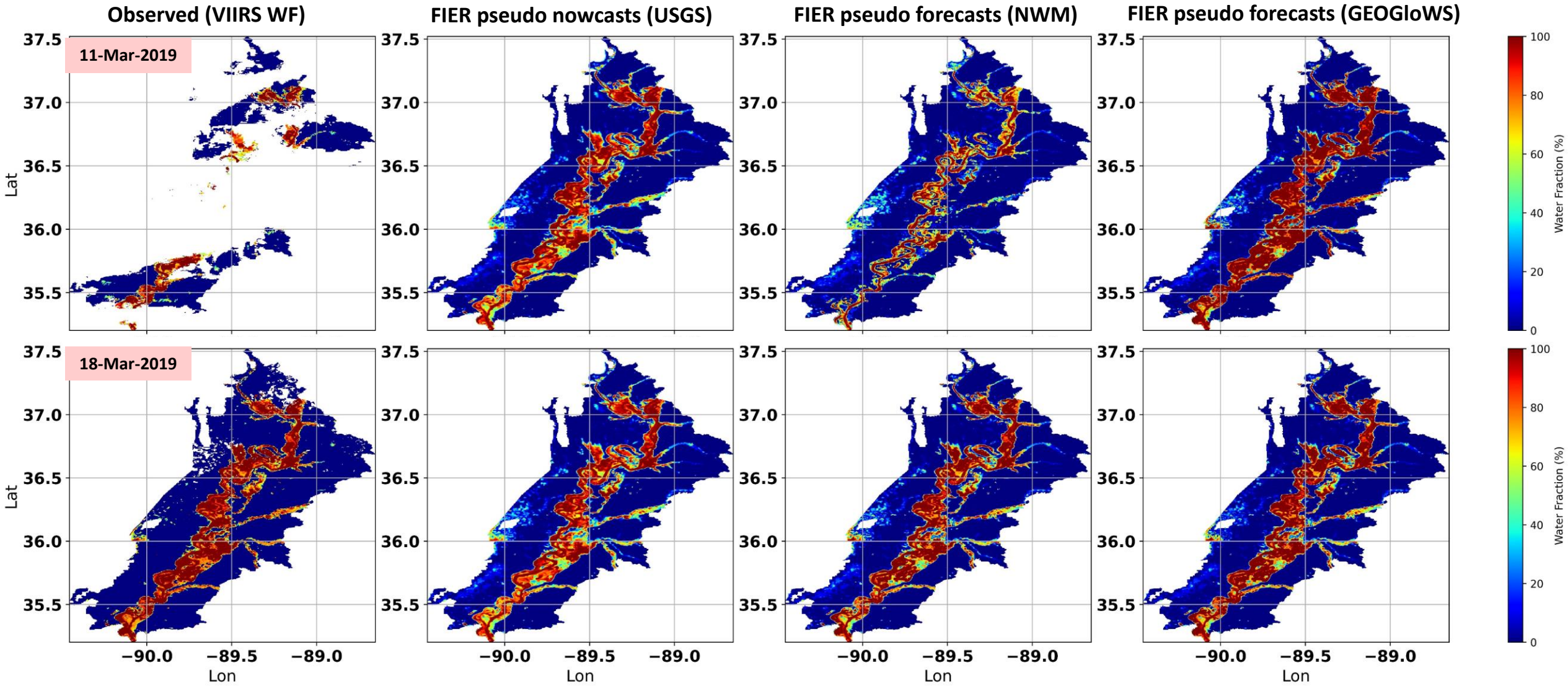
FIER water fraction forecasting results



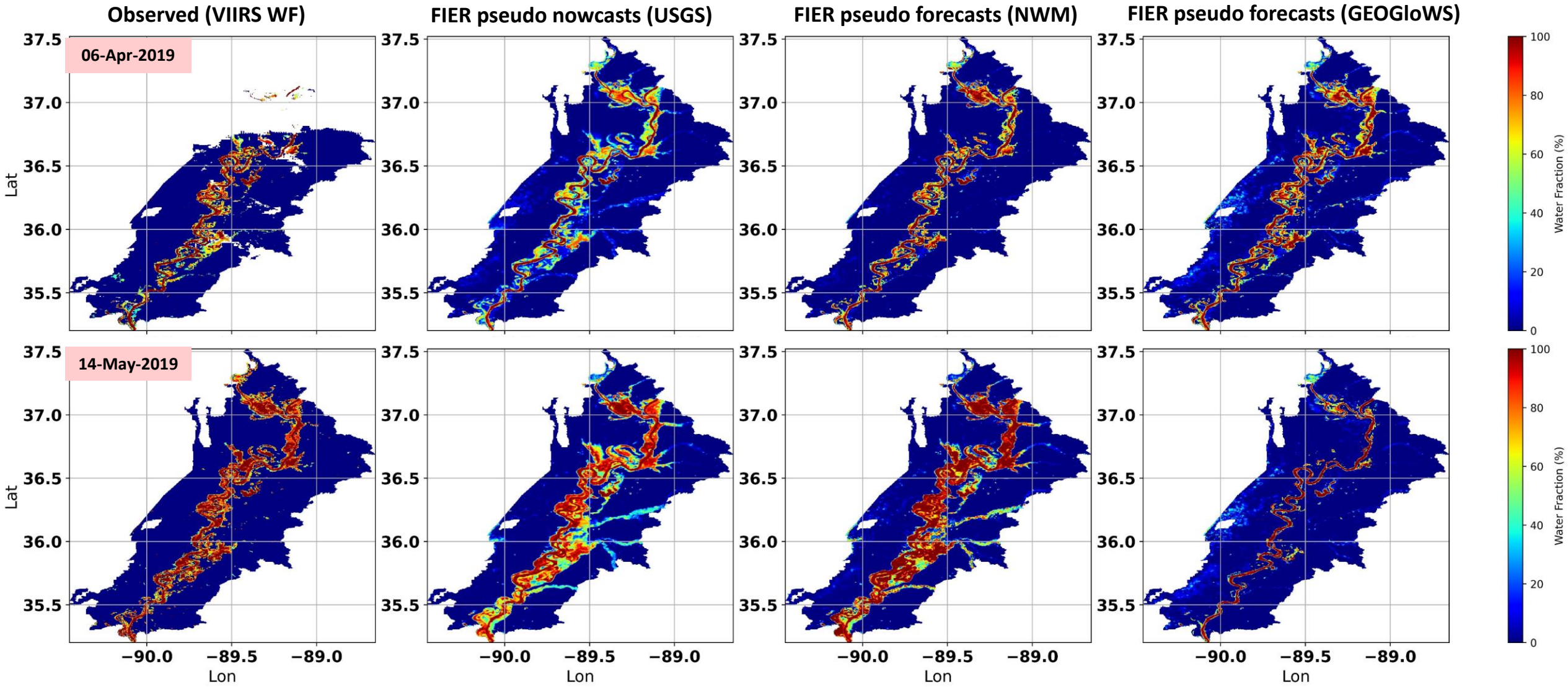
FIER water fraction forecasting results



FIER water fraction forecasting results

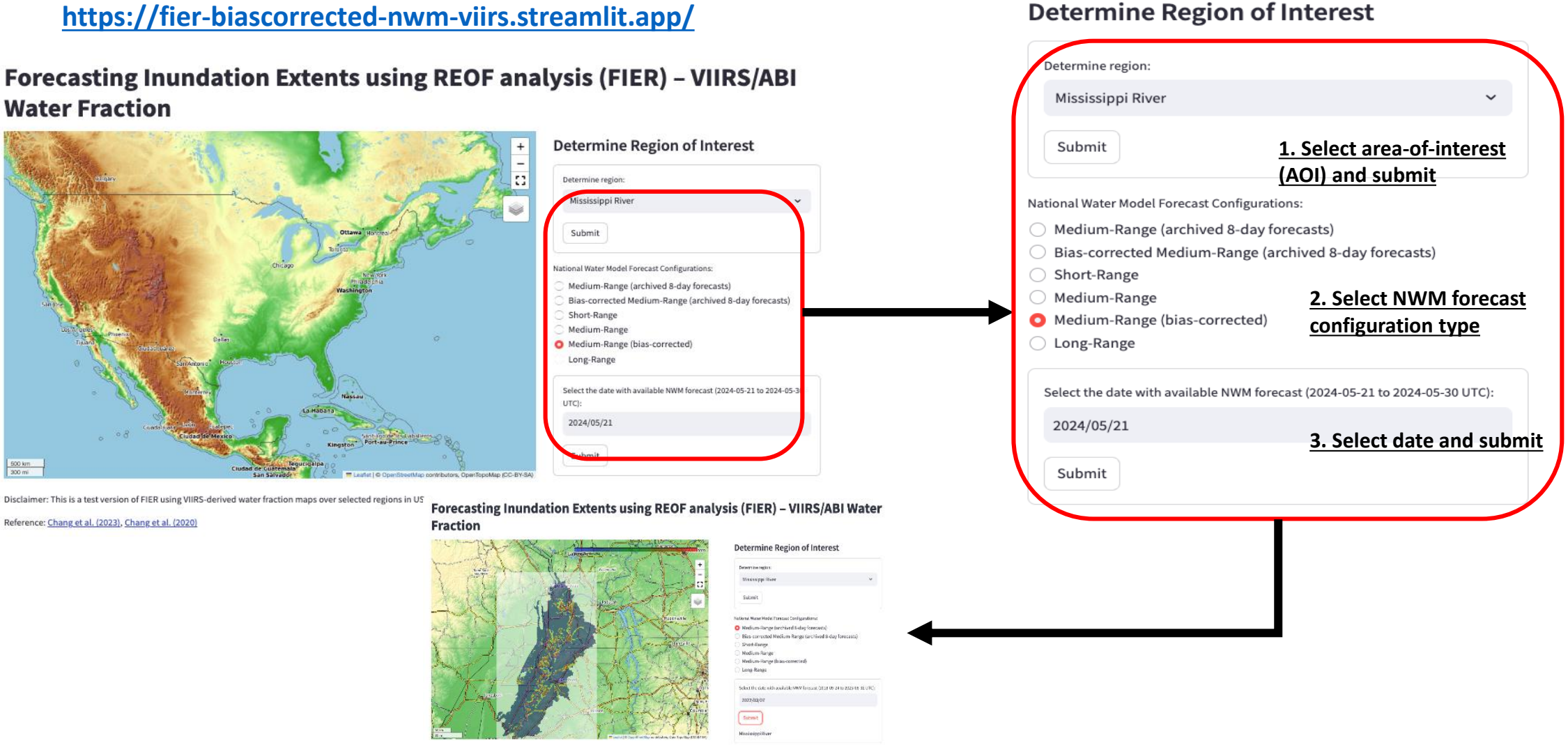


FIER water fraction forecasting results



FIER operational web app tool

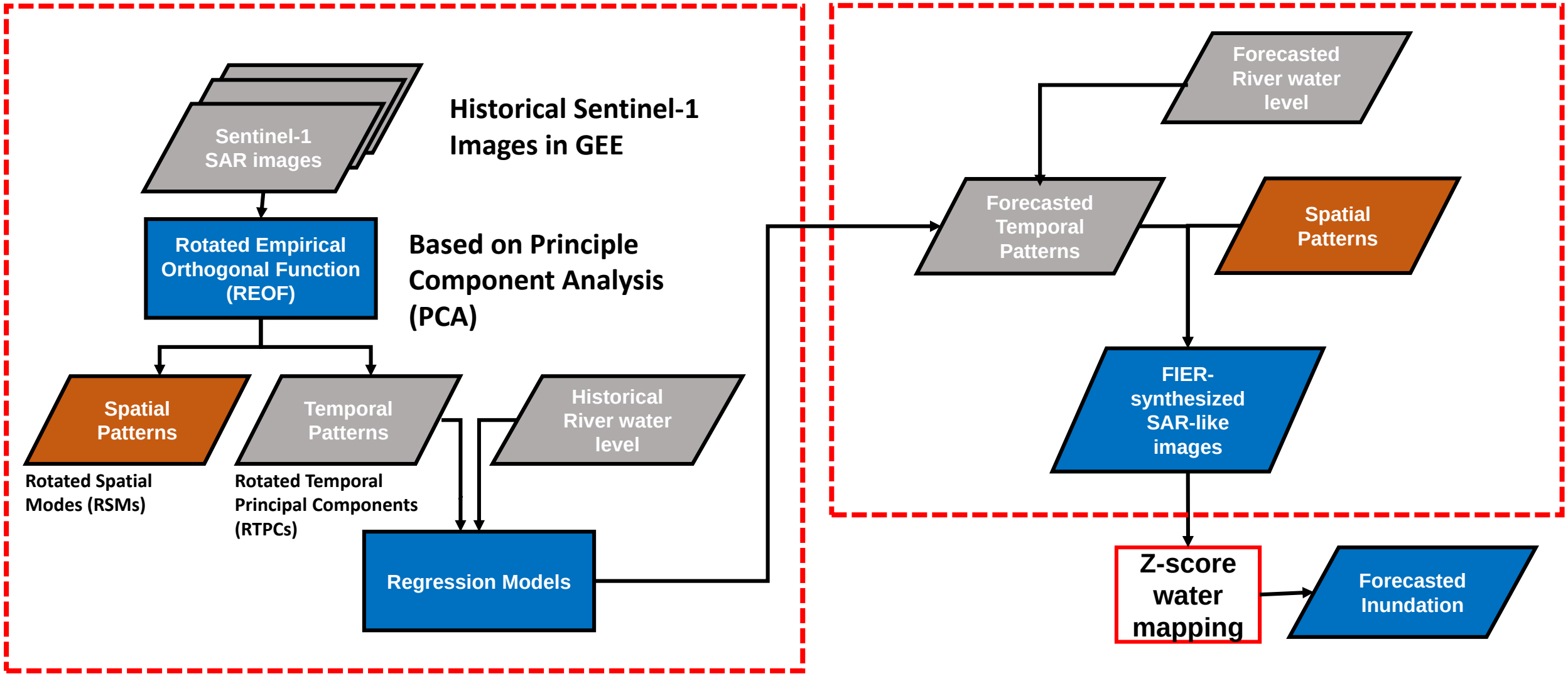
https://fier-biascorrected-nwm-viirs.streamlit.app/



Thanks for your attention!

Backup slides

FIER with SAR data

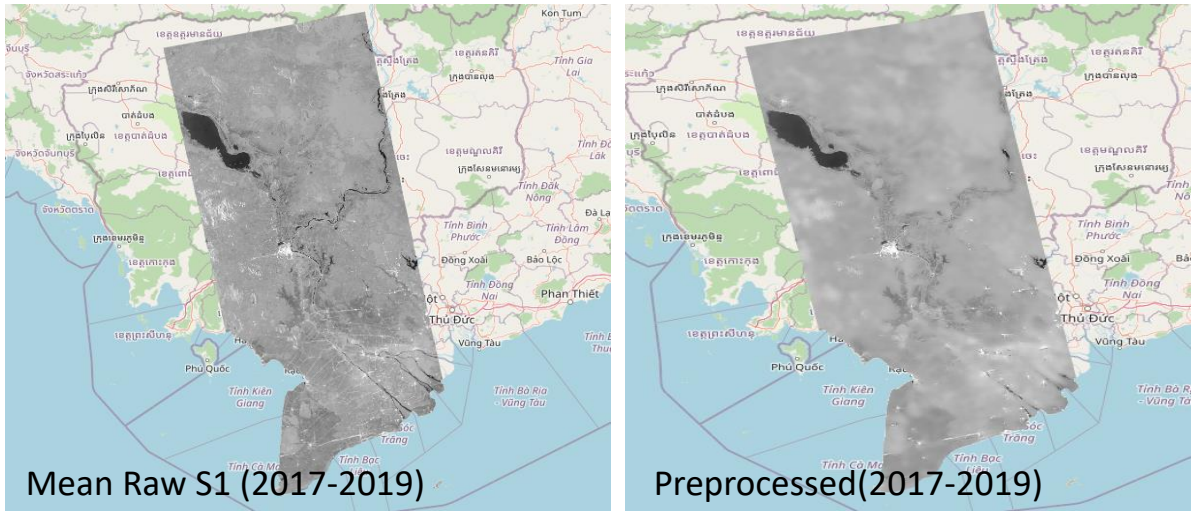


FIER with SAR data

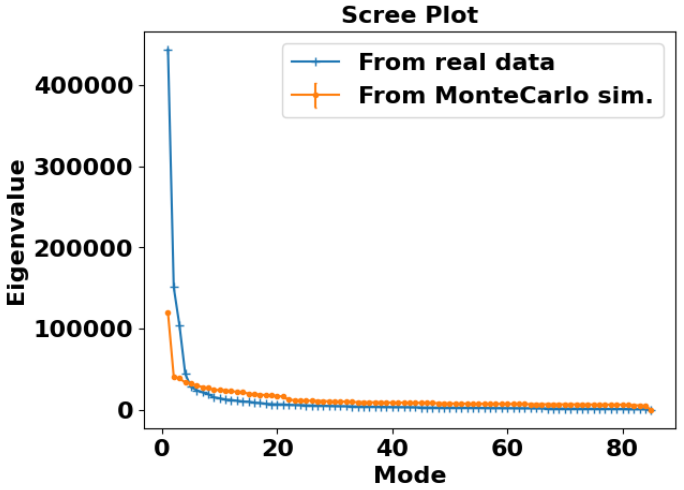
Step-1: Gathering and preprocessing Sentinel-1 data

- **Sentinel-1 GRD data:**
  - Google Earth Engine
  - Copernicus portal
- **Sentinel-1 data preprocessing:**
  - Mosaic
  - Slope correction
  - Speckle filtering

Mekong River Basin, Southeast Asia



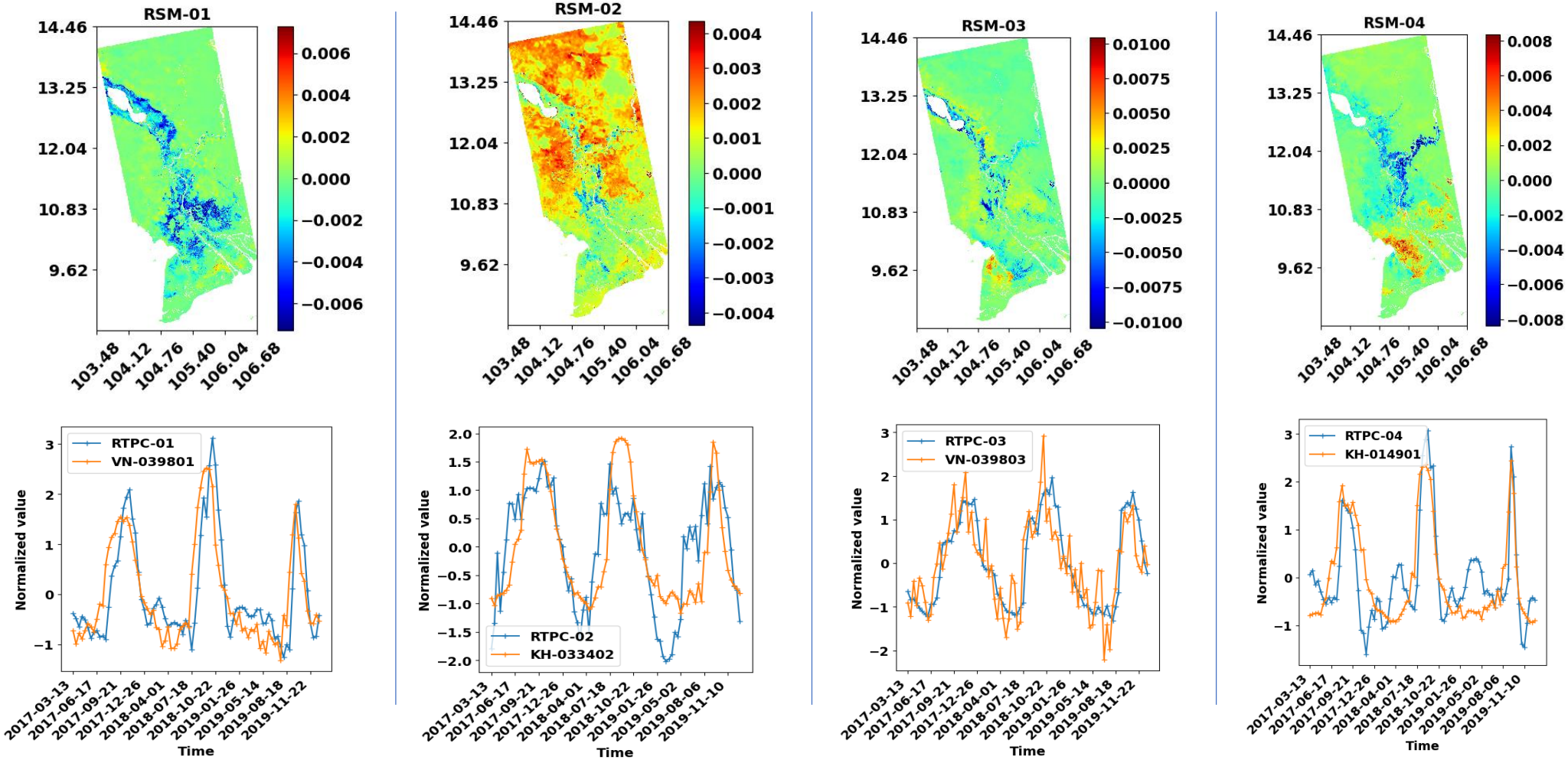
Step-2: Significant test



Step-3: Correlation analysis

FIER with SAR data

Step-4: REOF analysis



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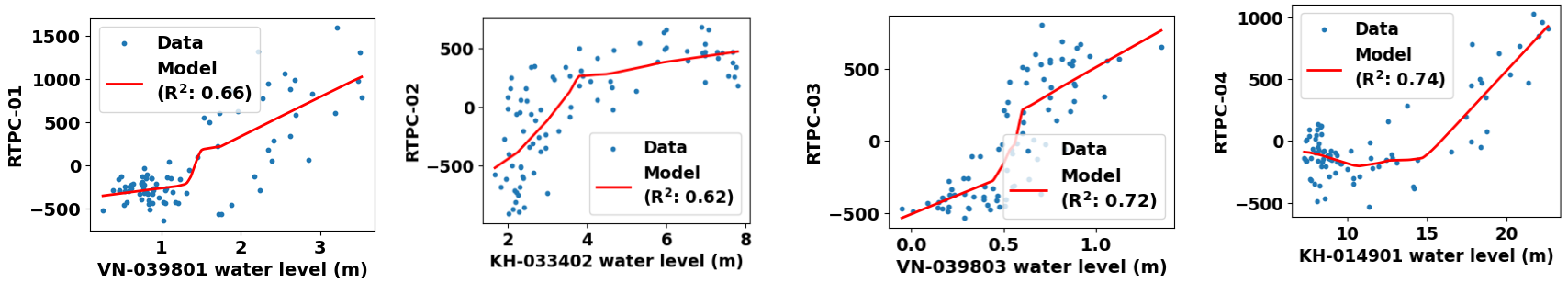
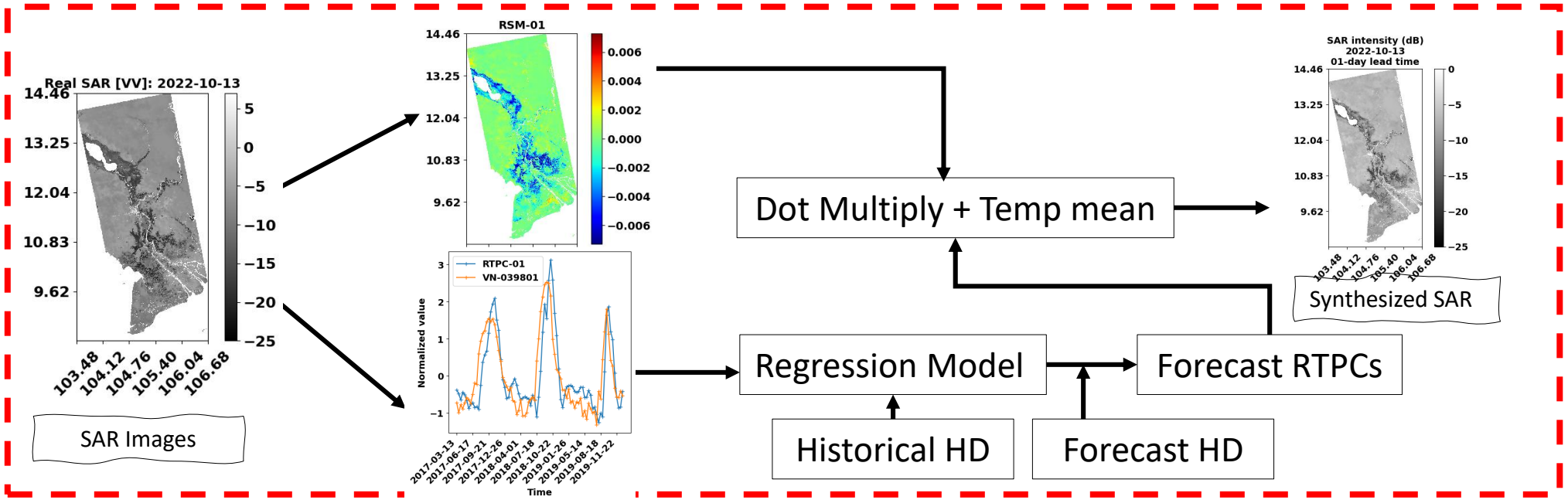
Step-5: Regression model

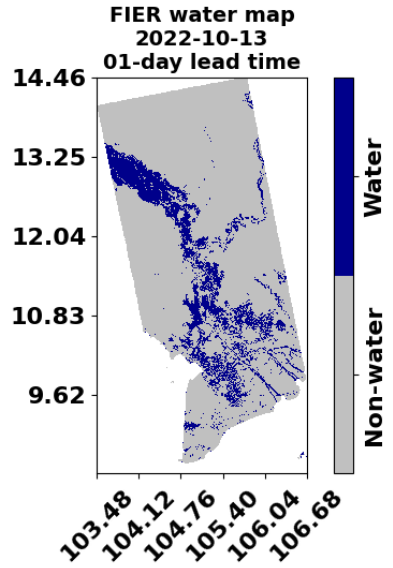


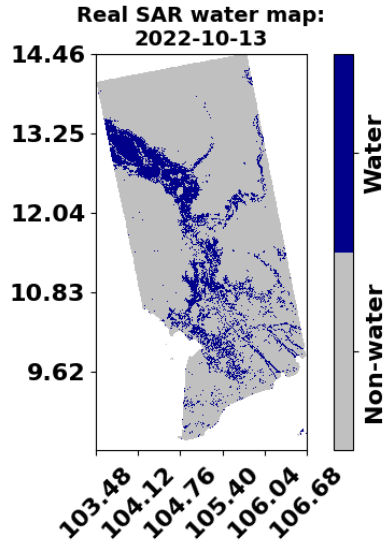
Step-6: Synthesizing Sentinel-1 SAR images

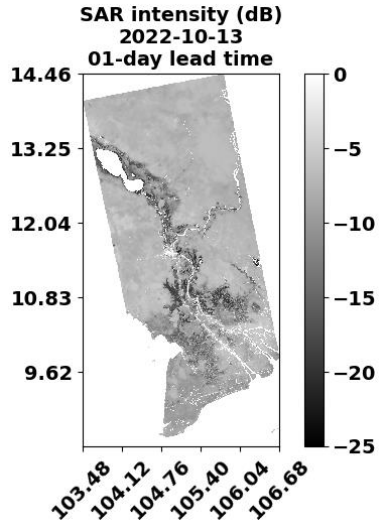


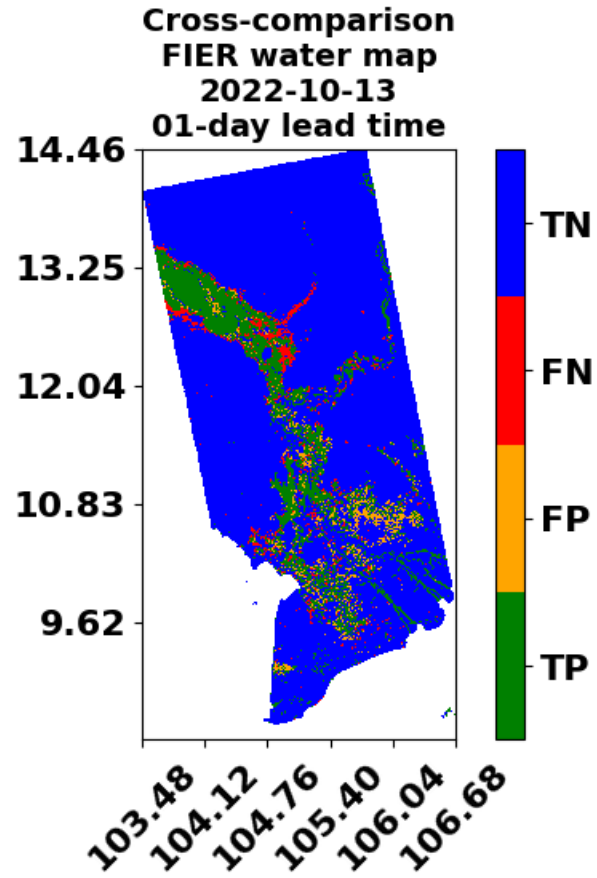
FIER with SAR data

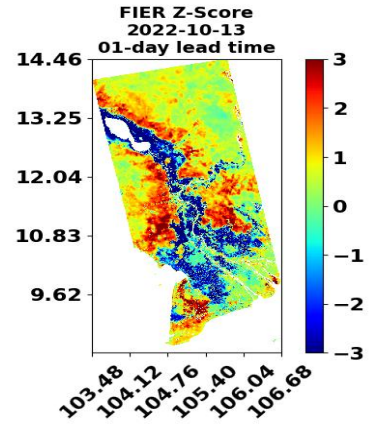
Step-7: Z-score water mapping

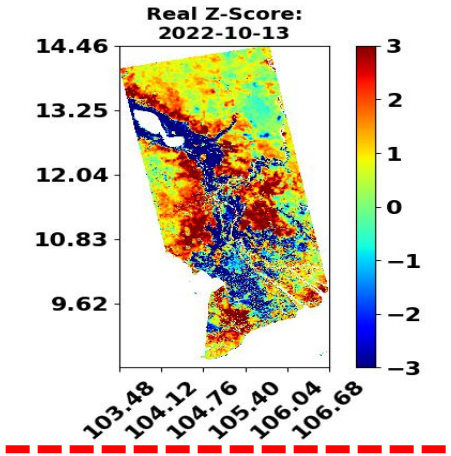


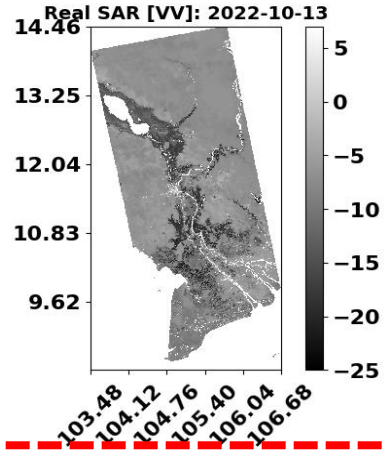






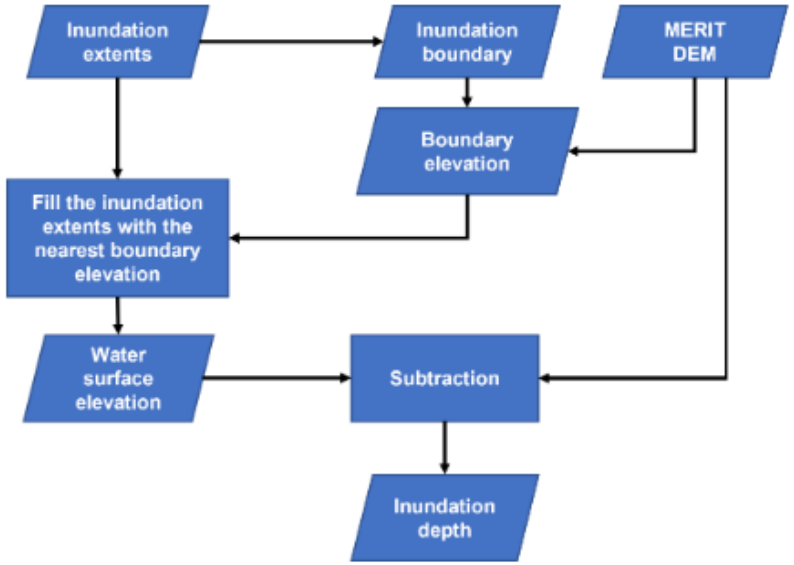


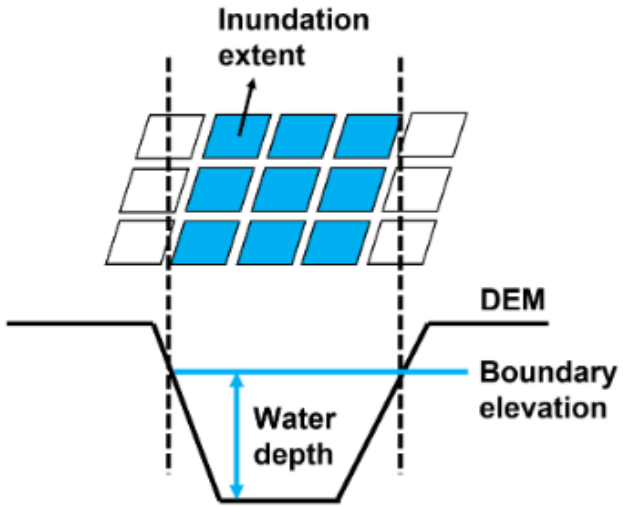


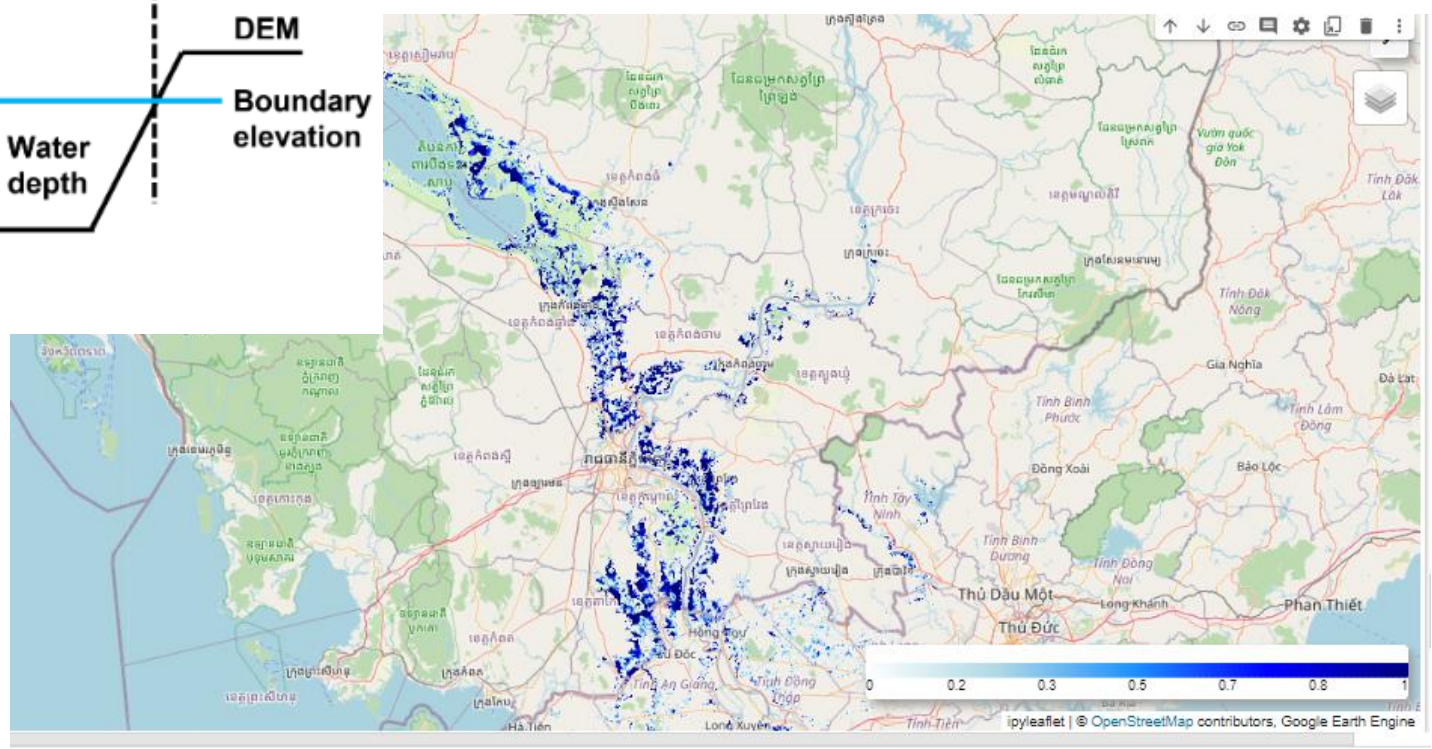


FIER with SAR data

Step-8: Flood depth estimation





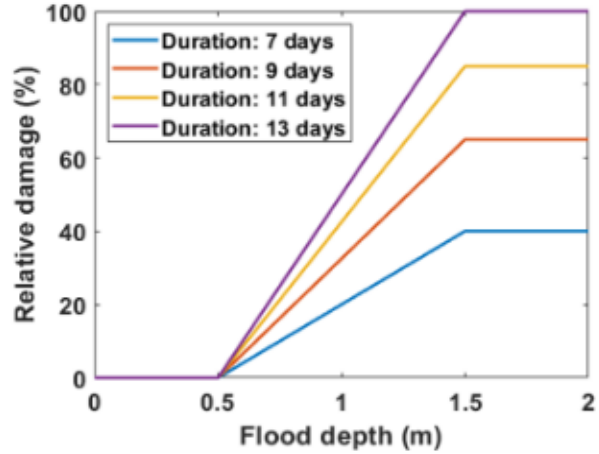


FIER with SAR data

Step-9: Rice damage assessment

$$D = MP \times Y \times A \times \sum_{i=1}^{N} RD$$

- MP: Rice market price (FAO: https://www.fao.org/markets-and-trade/commodities/rice/fao-rice-price-update/en/)
- Y: Rice yield (USDA: https://ipad.fas.usda.gov/countrysummary)
- RD: Pixel-wise rice relative damage (%) derived from damage curve (MRC, 2009)
- A: Pixel area
- N: Total number of pixels that are under flood risk based on definition of MRC (2009) (> 5 days of flood with depth > 0.5 m) in a country



Reconstructed from MRC (2009)