HYDROSAR – SURFACE WATER EXTENT MAPPING PRODUCTS AND WEB APPLICATION TRAINING

Contributors:

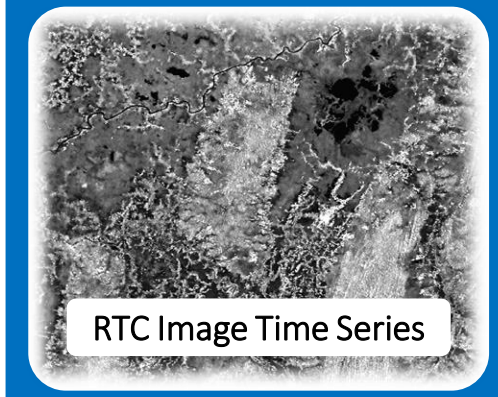
F.J Meyer[1)], A. Molthan[2)], L. Schultz[2)], J. Bell[2)], B. Osmanoglu[3)], M.J. Jo[3)], D.B. McAlpin[1)], T. Meyer[1)], B. Kubby[1)], A. Lewandowski[1)], B. Chapmann[4)], M. Matin[5)], R. Thapa[5)], B. Bajracharya[5)], K. Tsering[5)]

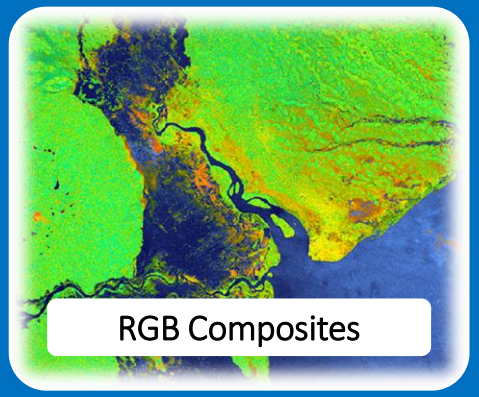
[1)]Geophysical Institute, University of Alaska Fairbanks, Fairbanks; [2)]NASA Marshall Space Flight Center, Huntsville, AL; [3)]Goddard Space Flight Center, Greenbelt, MD; [4)]Jet Propulsion Laboratory, Pasadena, CA; [5)]ICIMOD, Kathmandu, Nepal

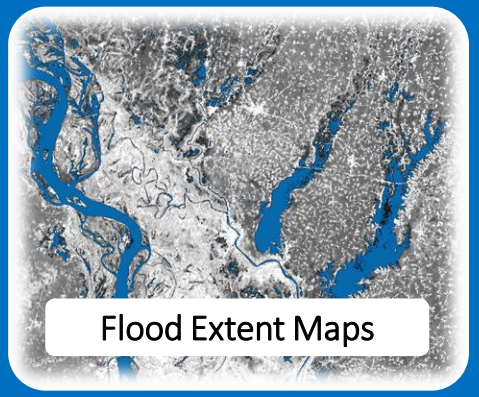
Overview of the HYDRO30 Surface Water Extent Product Including Capabilities and Limitations

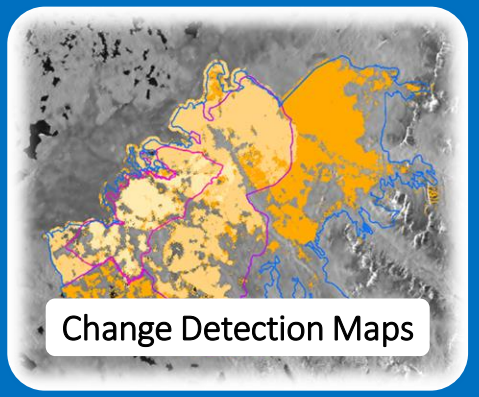
HydroSAR is an SERVIR-AST-Funded Project to Develop Products, Tools & Services to Support Monitoring Hydrological Hazards in the HKH Region

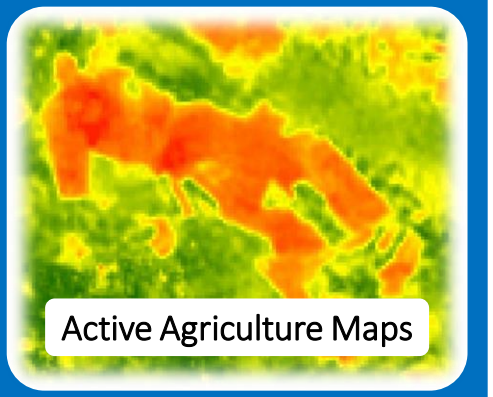
SAR-based value-added products







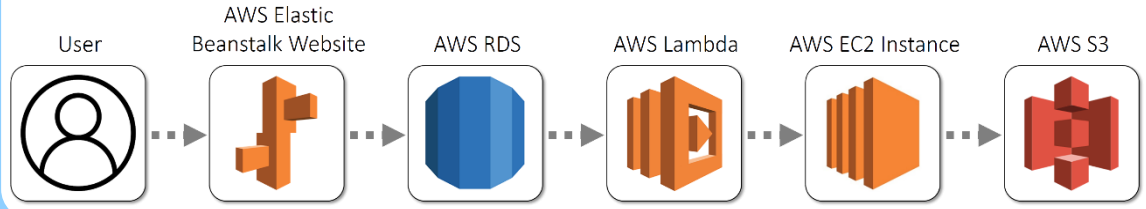




Cloud-based Computational Resources

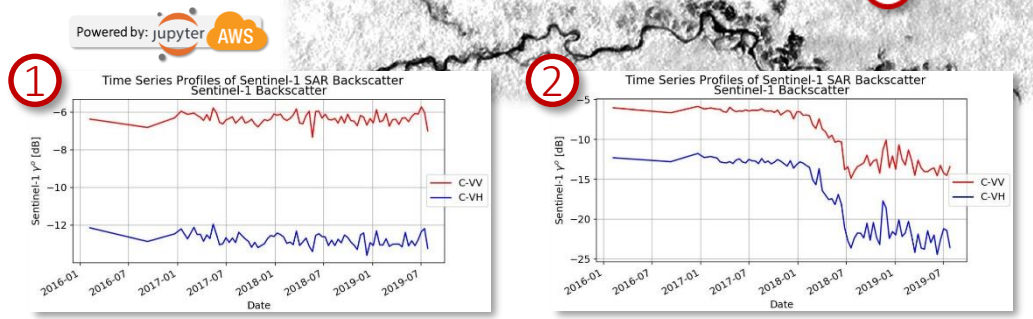
Automatic Cloud-based Production Pipelines

Exercising mature algorithm large scale
using cloud-based workflows



The OpenSARLab

Cloud-based Application
Development Platform



The HydroSAR Team

HydroSAR Development Team

University of Alaska Fairbanks / Alaska Satellite Facility

- Franz J Meyer
- Eric Lundell
- Alex Lewandowski
- Brooke Kubby
- Thomas Meyer

Marshall Space Flight Center

- Andrew Molthan
- Lori Schultz
- Jordan Bell
- Ronan Lucey

Goddard Space Flight Center

- Batuhan Osmanoglu
- MinJeong Jo
- Elodie Macorps

Jet Propulsion Laboratory

- Bruce Chapman

HydroSAR Partners

ICIMOD

HydroSAR Training Syllabus

- The Syllabus and all lecture materials can be found here:
  - https://drive.google.com/file/d/1abnXN4GyP6sKCTD8j_n-iGGvGzQ1tK4Y/view?usp=sharing

Orientation training on

Flood inundation mapping products and web application

August 12, 2021, 7:45 AM – 10:45 AM, Nepal Standard Time

About SERVIR

SERVIR connects space to village by helping developing countries use satellite data to address challenges in food security, water resources, weather and climate, land use, and natural disasters. A partnership of National Aeronautics and Space Administration (NASA), United States Agency for International Development (USAID), and leading technical organizations, SERVIR develops innovative solutions to improve livelihoods and foster self-reliance in Asia, Africa, and the Americas.

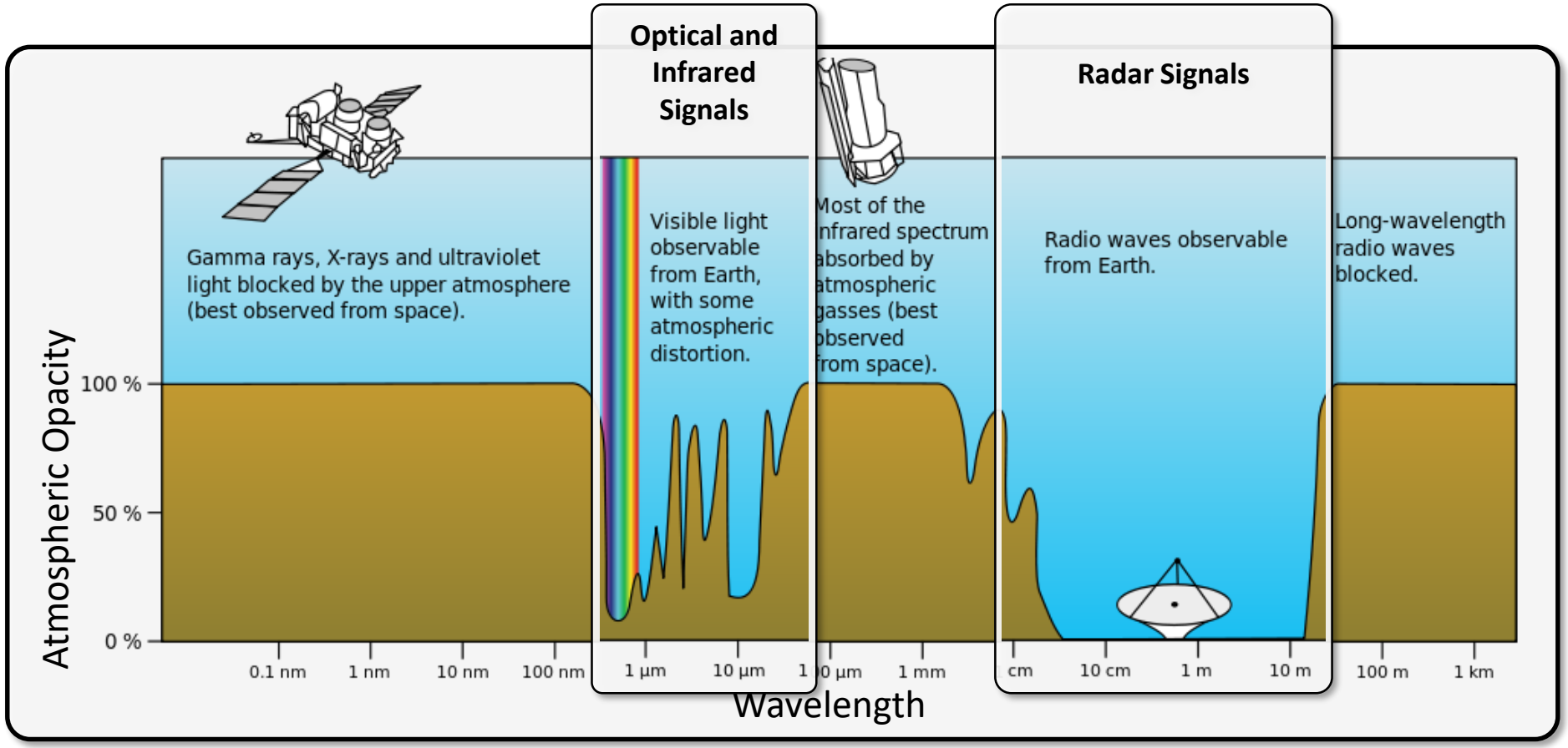
SERVIR Hindu Kush Himalaya

The International Centre for Integrated Mountain Development (ICIMOD) implements the SERVIR Hindu Kush Himalaya (SERVIR-HKH) Initiative – one of five regional hubs of the SERVIR network – in its regional member countries, prioritizing activities in Afghanistan, Bangladesh, Myanmar, Nepal, and Pakistan. SERVIR-HKH is an initiative under

A FEW WORDS ON THE DATASET WE ARE USING

Wavelength Discriminates Radar from Optical Data

- **Radar has excellent capabilities for routine global change monitoring**
  - **24/7 imaging capabilities:** due to weather and illumination independence
  - **Advanced change detection performance**: due to stable image geometry and own signal source
  - **Complementary to optical sensors**: provides independent information about surface



NASA Earth Observatory images by Robert Simmon, using Suomi NPP VIIRS data from Chris Elvidge (NOAA National Geophysical Data Center)

Weather Independence Provides Advantages Especially For Weather-Related Events such as Flooding and Rain-Triggered Landslide Activity

Animation of the use of SAR during Flooding events
(credit: DLR TerraSAR-X team)

Modern SAR Sensors provide regularly-sampled, high-resolution & weather-independent earth observation data from Space

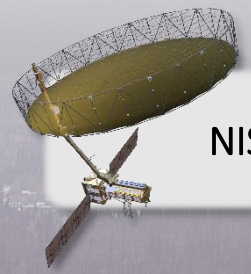
ESA Sentinel-1 SAR

The NASA Alaska Satellite Facility (ASF) DAAC

- **ASF is NASA Distributed Active Archive Center (DAAC) for SAR Data**
  - Established in 1991 as the prime U.S. downlink and processing center for SAR data
  - Operates 3 antennas for command uplink and data downlink of NASA and non-NASA remote sensing satellite systems
- **Currently, ASF is housing about 12PB of SAR data in its archives, most of which in the Amazon Web Service Cloud → all data available on spinning disks for immediate download**

SCAN ME

41 years of SAR data (since '78)
https://search.asf.alaska.edu



NISAR DAAC (all L0 – L2 data)

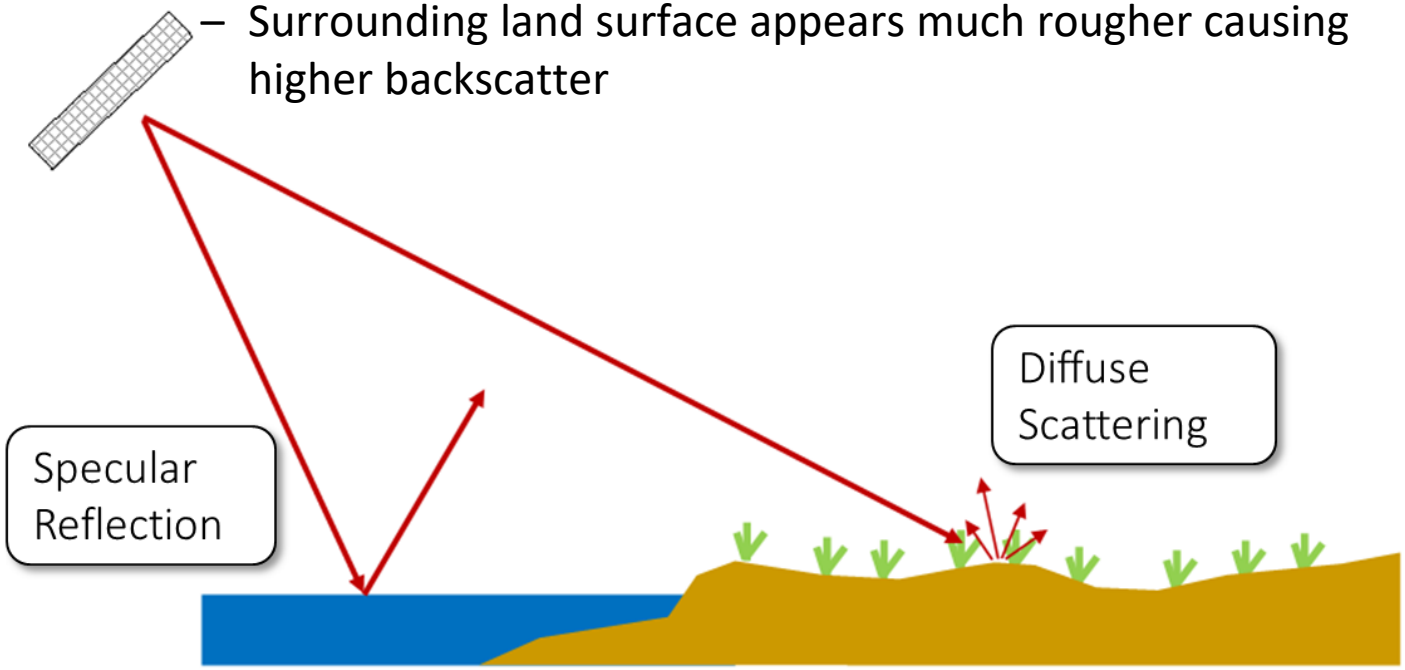
Host of
global Sentinel-1 archive

Visit ASF @ www.asf.alaska.edu

THE HYDROSAR HYDRO30 SURFACE WATER EXTENT MAPPING APPROACH

Surface Water Signatures in SAR Amplitude Images

- **Mapping of water surfaces (waterbodies, wetlands, flooded areas) based on different backscatter regimes of water surface and land surface**
  - Calm water surfaces appear smooth and cause specular reflection leading to low backscatter
  - Surrounding land surface appears much rougher causing higher backscatter



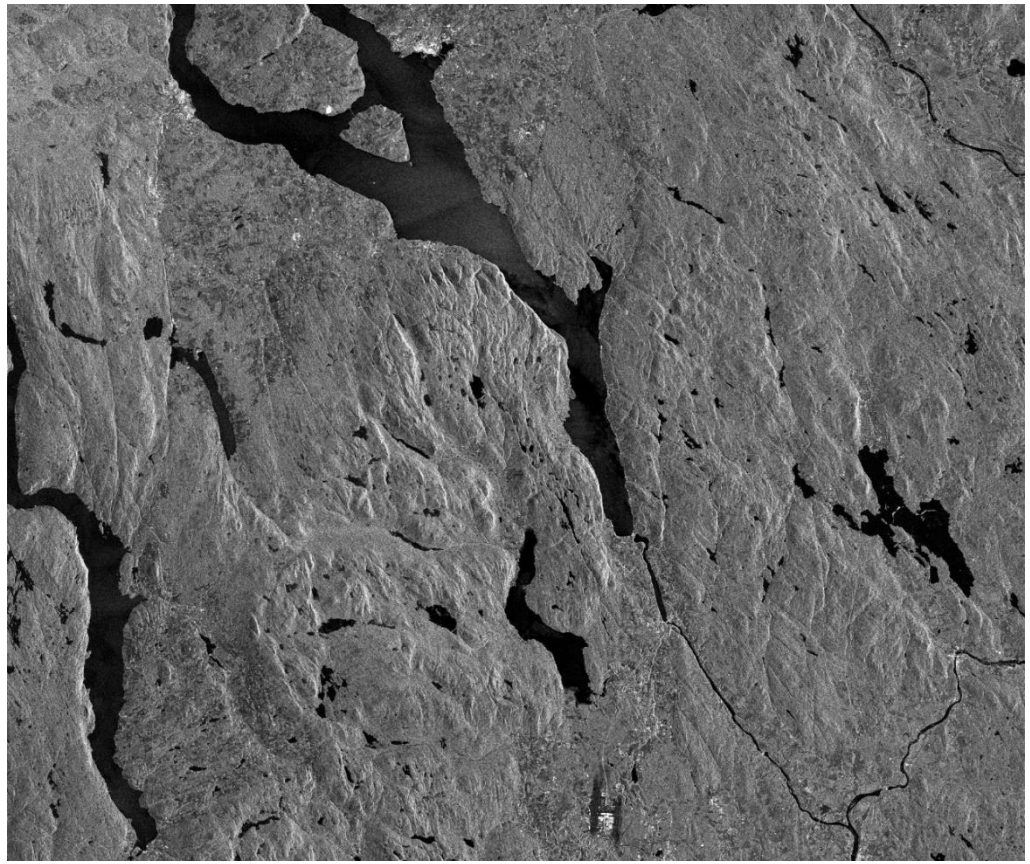


Fig.: Lake Mjosa, Norway, observed by ENVISAT ASAR Image Mode, 12 Dec 2003 (©ESA Multimedia Gallery)

The HydroSAR HYDRO30 Surface Water Extent Product

Surface Water Mapping Approaches from SAR Amplitude Images

- **One simple and common method for waterbody mapping is thresholding**
  - Contrast between land and open water surface increases with increasing incidence angle

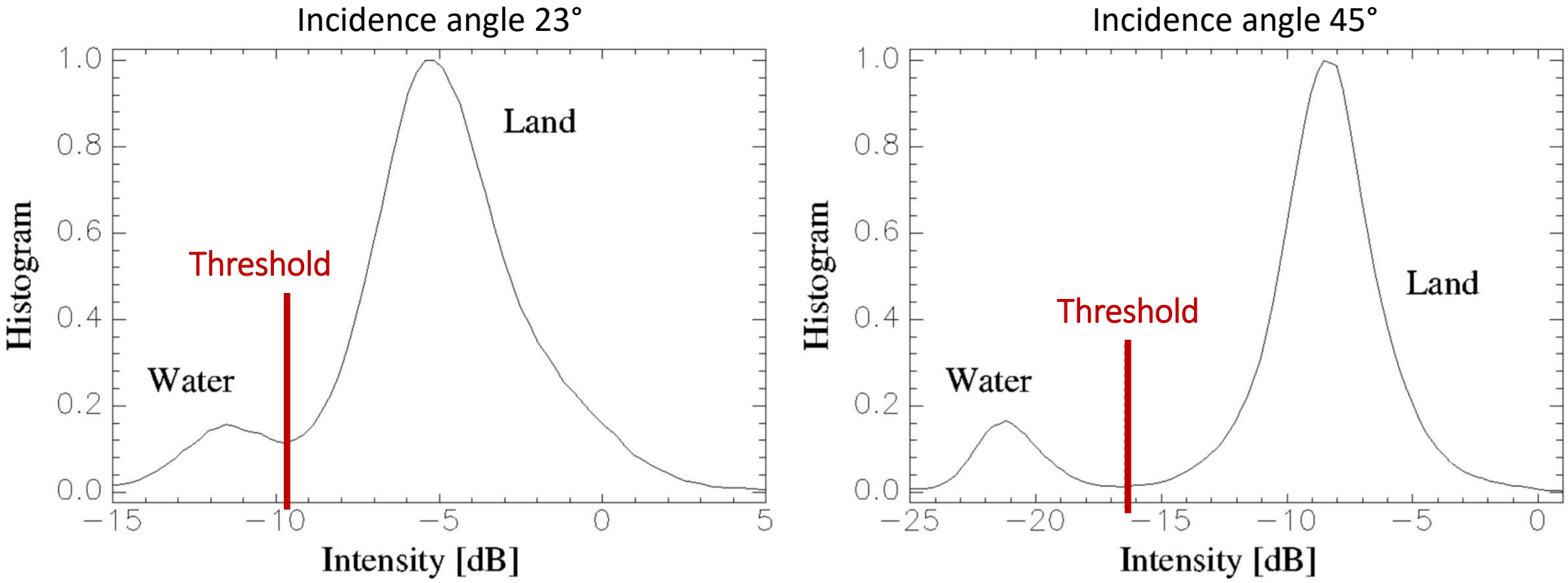


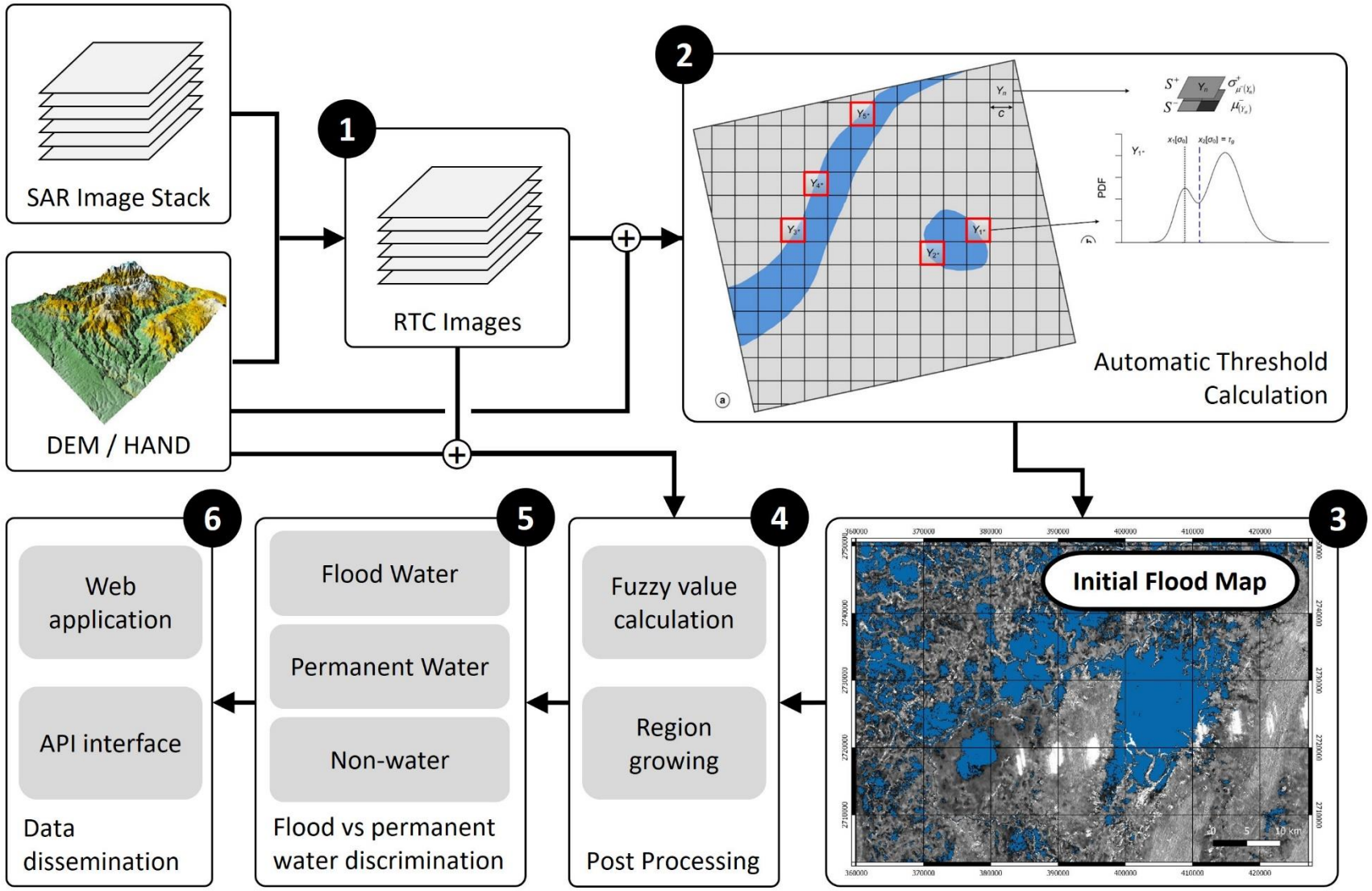
Fig.: Histogram of two Radarsat SAR images of the same region acquired under different incidence angles (Solbø & Solheim, 2004)

The HydroSAR HYDRO30 Surface Water Extent Product

Concept of Adaptive Threshold-based Surface Water Mapping Approach

HydroSAR water mapping approach composed of 6 steps:

1. Image Geocoding and Calibration (RTC Processing)
2. Automatic and adaptive threshold calculation
3. Initial flood map creating
4. Post-processing to remove false alarms
5. Discrimination of permanent and flood-related water
6. Data dissemination

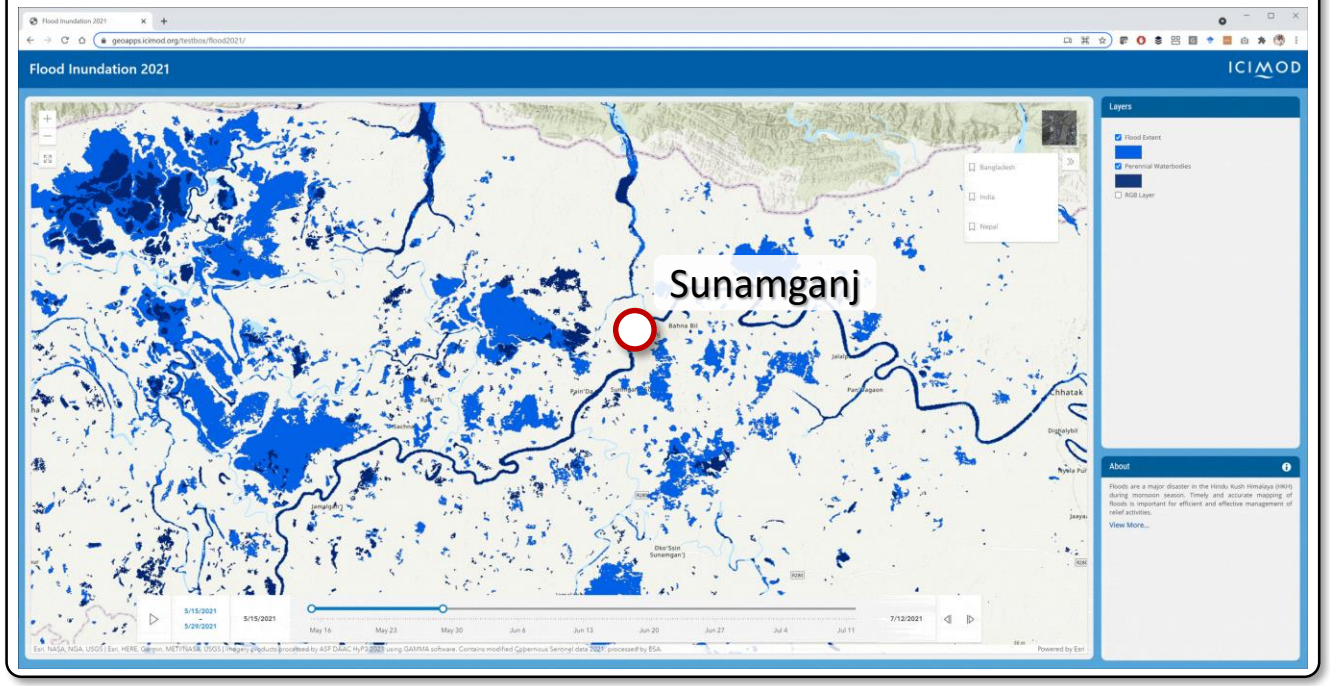


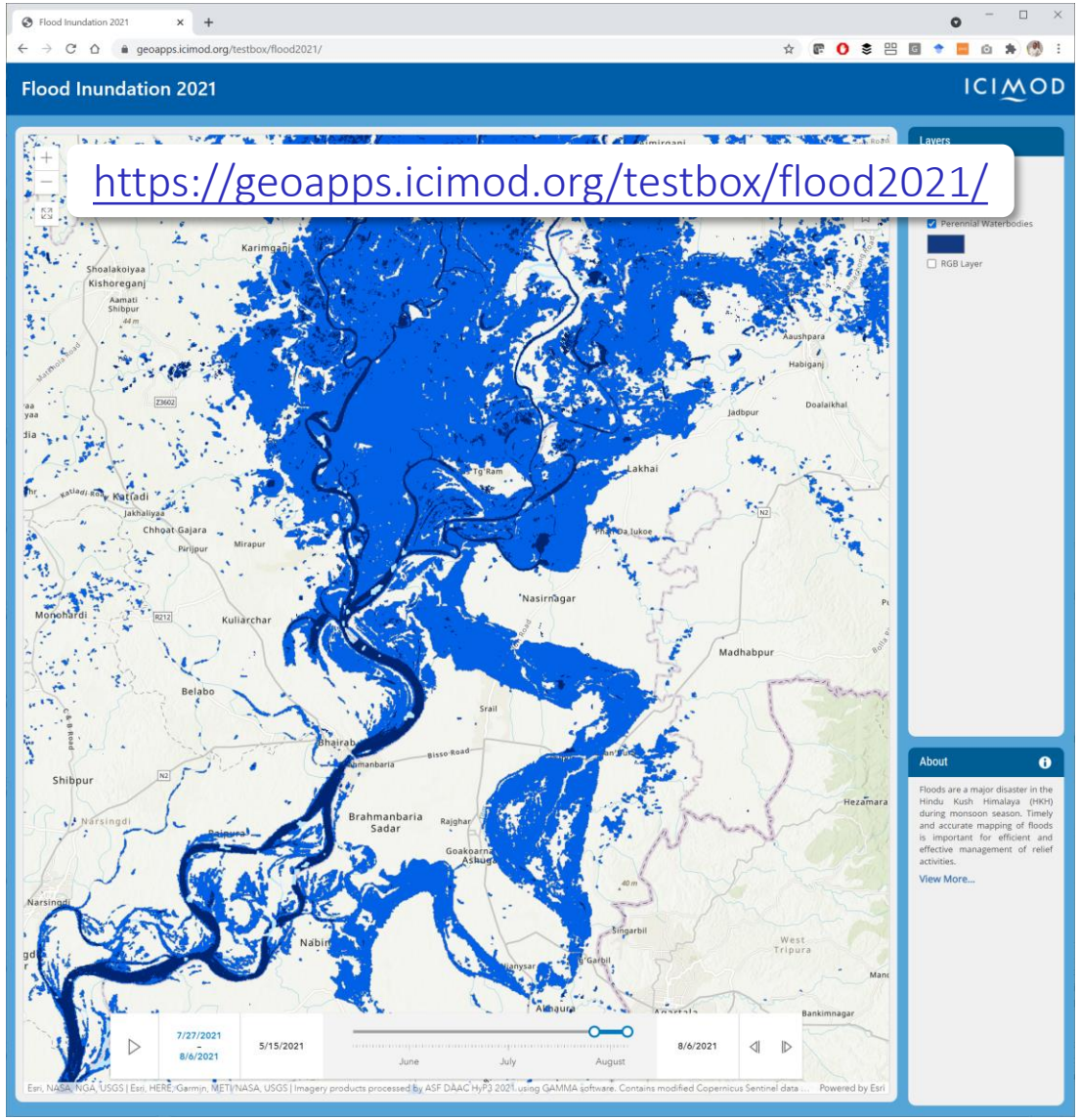
The HydroSAR / ICIMOD 2021 Flood Inundation Service

Coverage: Bangladesh, Northern India, Southern Nepal, Southern Bhutan

- Automatically updated **inundation information** with every new satellite pass
- **Permanent water layer** derived from water extent maps from mid March to mid April
- Optional: visualization of RGB-scaled SAR imagery

Example: Inundation Time Series near Sunamganj, Bangladesh



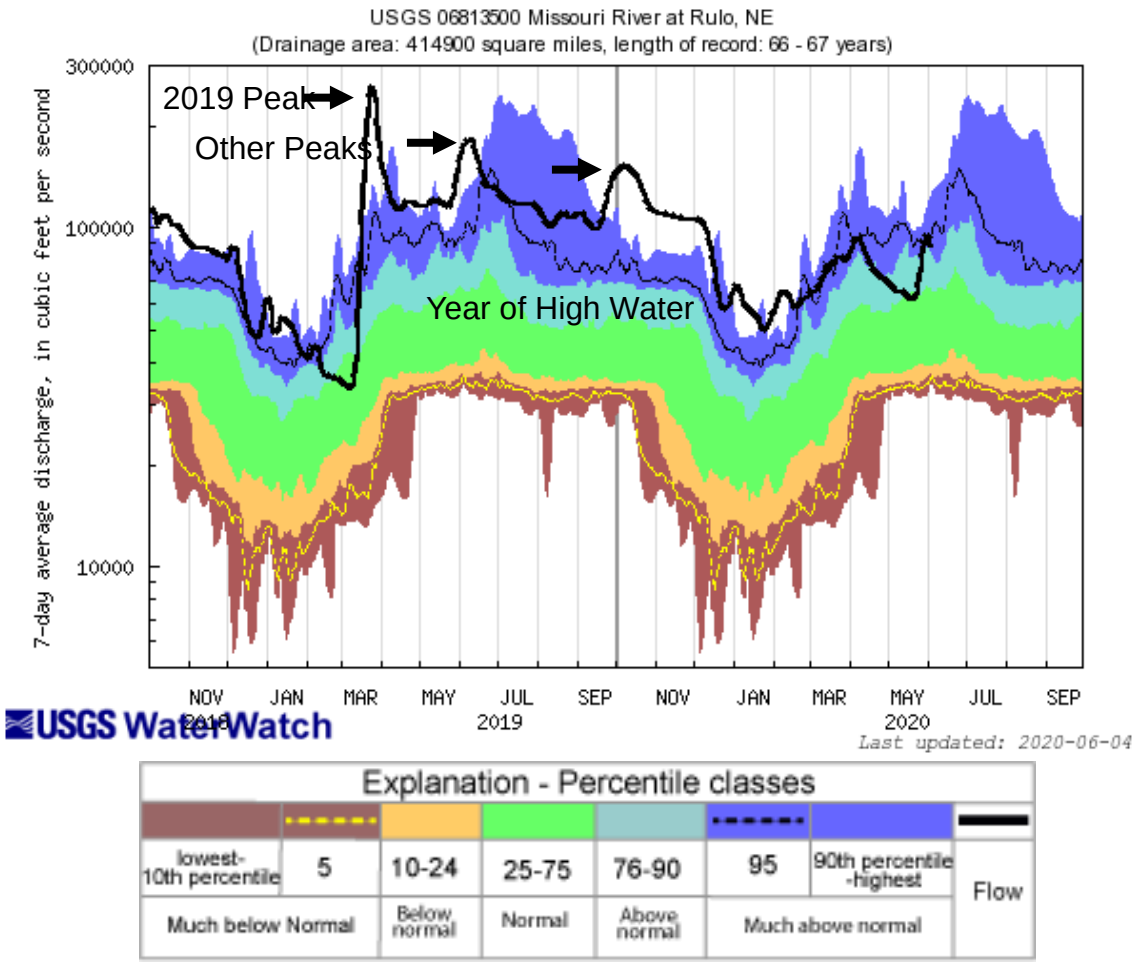


SOME HYDRO30 PERFORMANCE METRICS

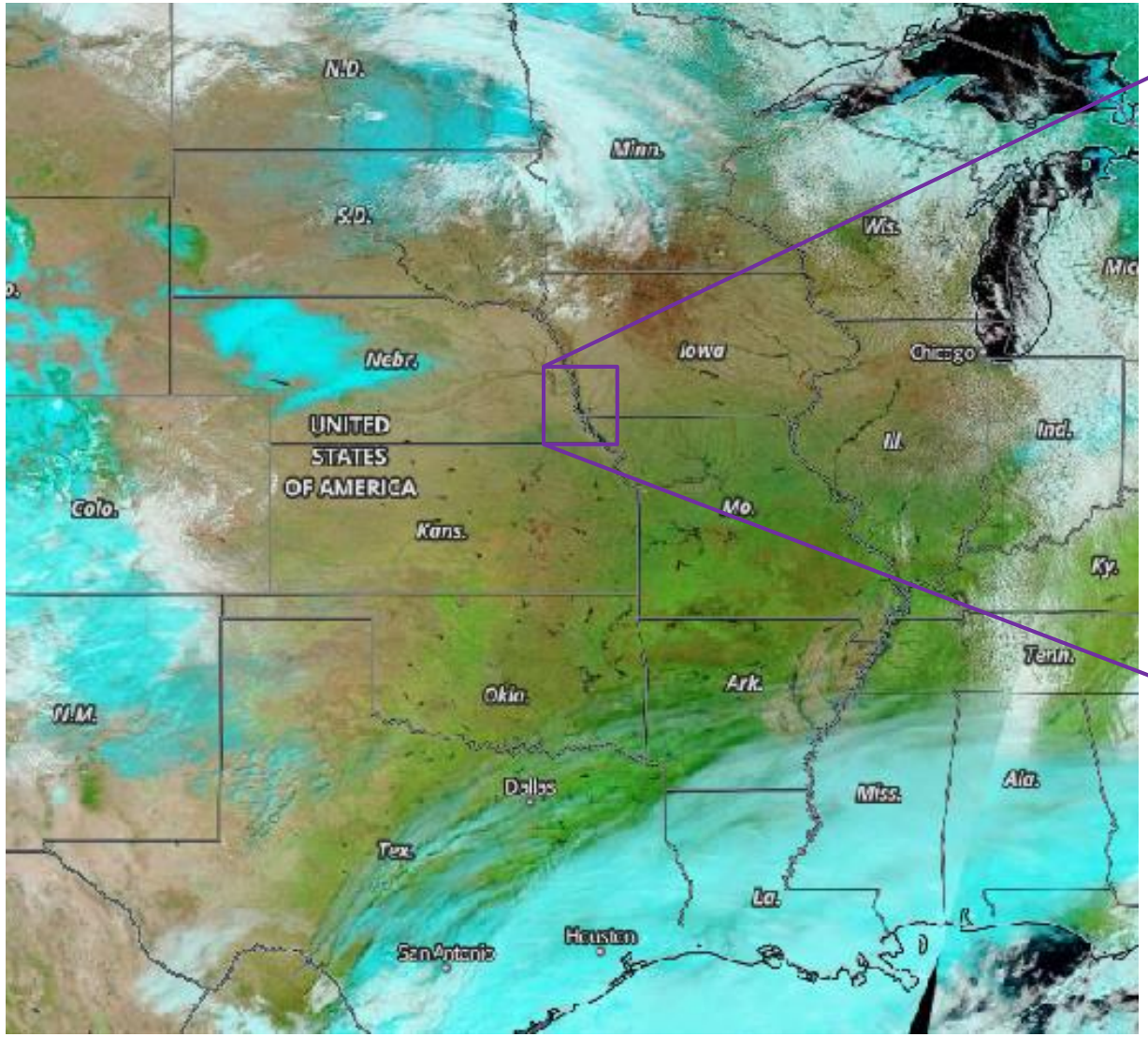
COMPARISON NEAR-SIMULTANEOUS OPTICAL IMAGERY – MISSOURI RIVER, NEBRASKA

Record-Setting Flood Event – Missouri River 2019

- Precursors
  - Below average temperatures in February
  - Significant snowfall, depth and coverage
  - Major winter storm leads to additional snowfall then rapid warming, rainfall, and snow melt across much of northeastern Nebraska
  - Cold winter weather and frozen ground limits infiltration, increases runoff and streamflow, develops ice jams, and extensive flooding
- Impacts
  - Extensive flooding begins in northeastern Nebraska, followed downstream with record-setting streamflows along the Missouri River
  - Record-setting damage in Nebraska and downstream states and continued seasonal and heavy rainfall events create a prolonged season of flooding with recurring events throughout 2019.



Study Domain – SE Nebraska



https://go.nasa.gov/2LA13sk

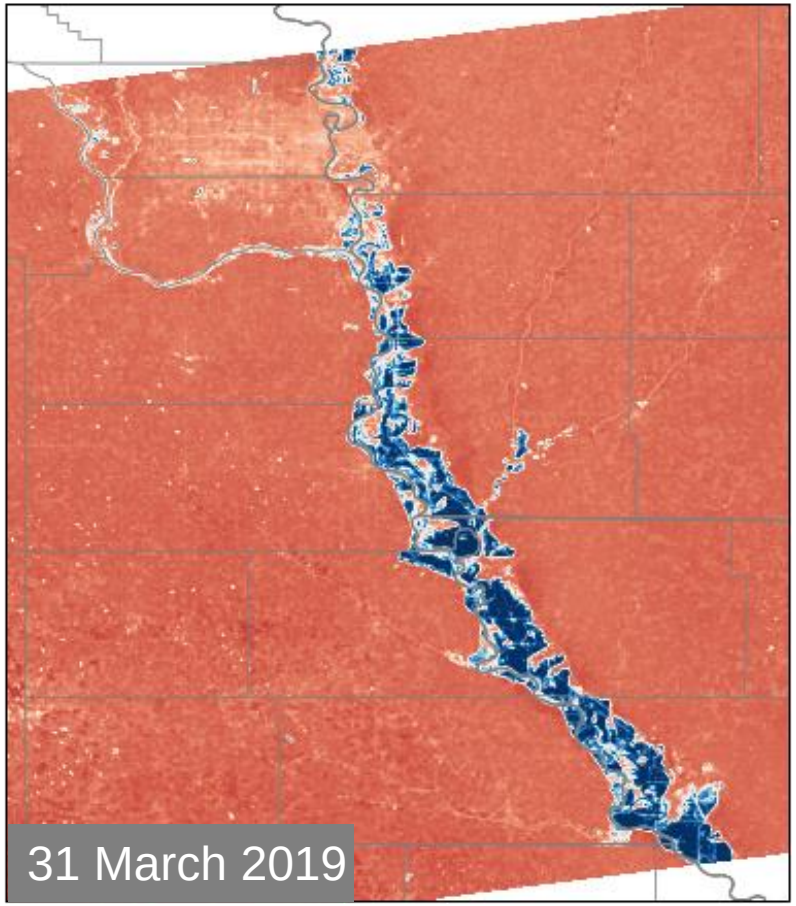
Study Period: 1 March – 1 Oct 2019

- Both Sentinel-1 and clear Sentinel-2 passes used

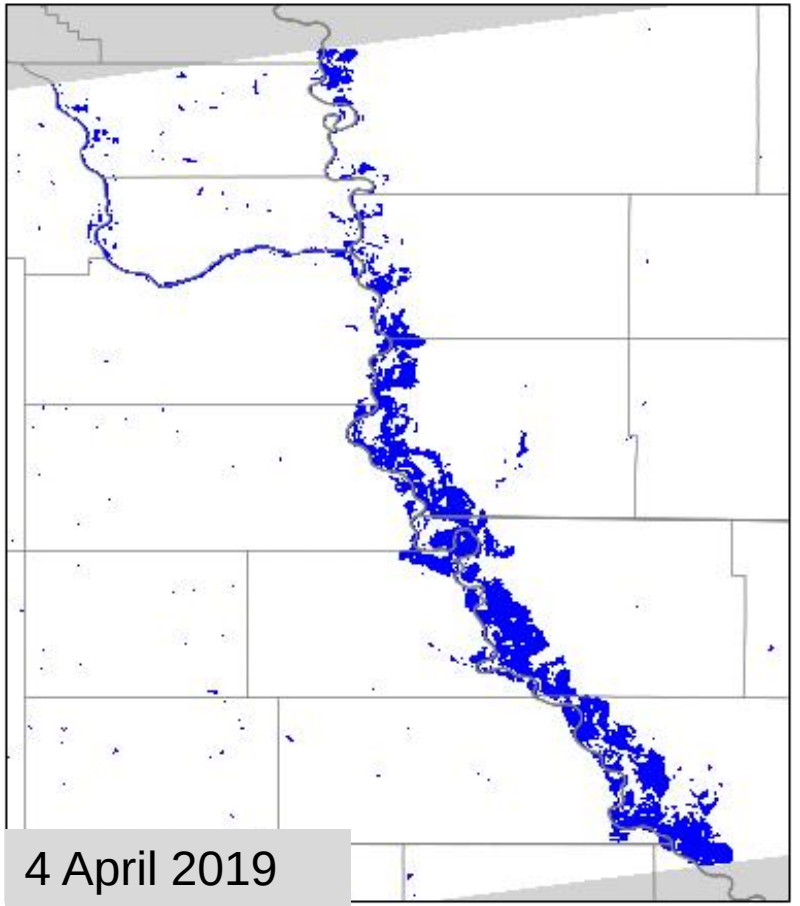
Comparing HYDRO30 to Water Maps from Sentinel-2

Sentinel-2 False Color 2019-03-31

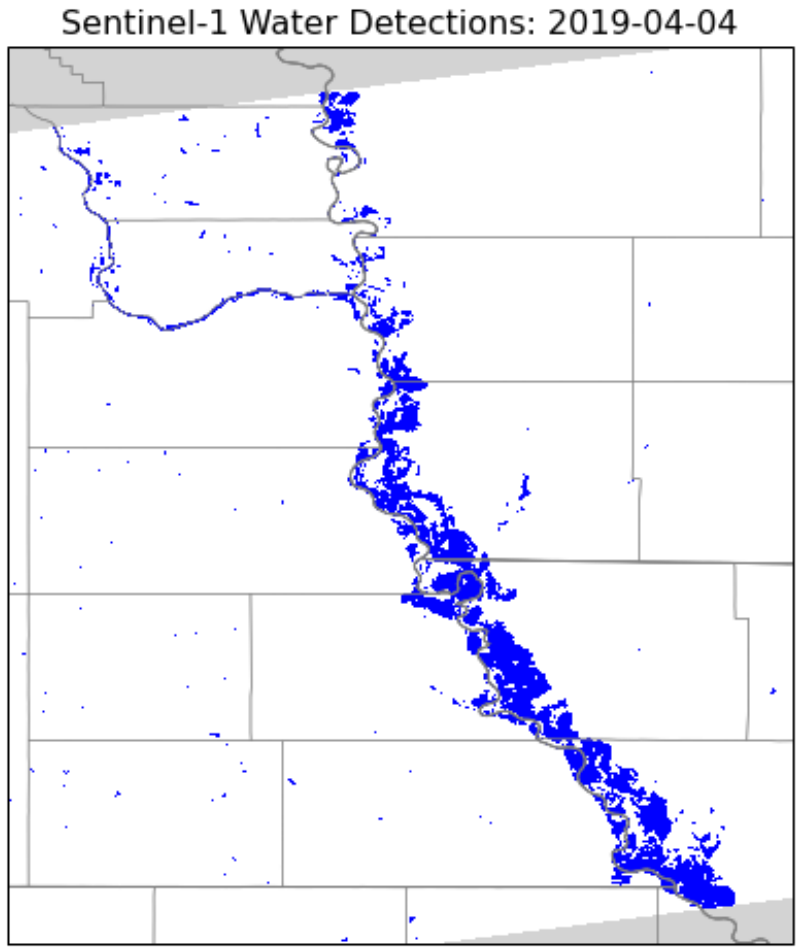
Sentinel-2 mNDWI



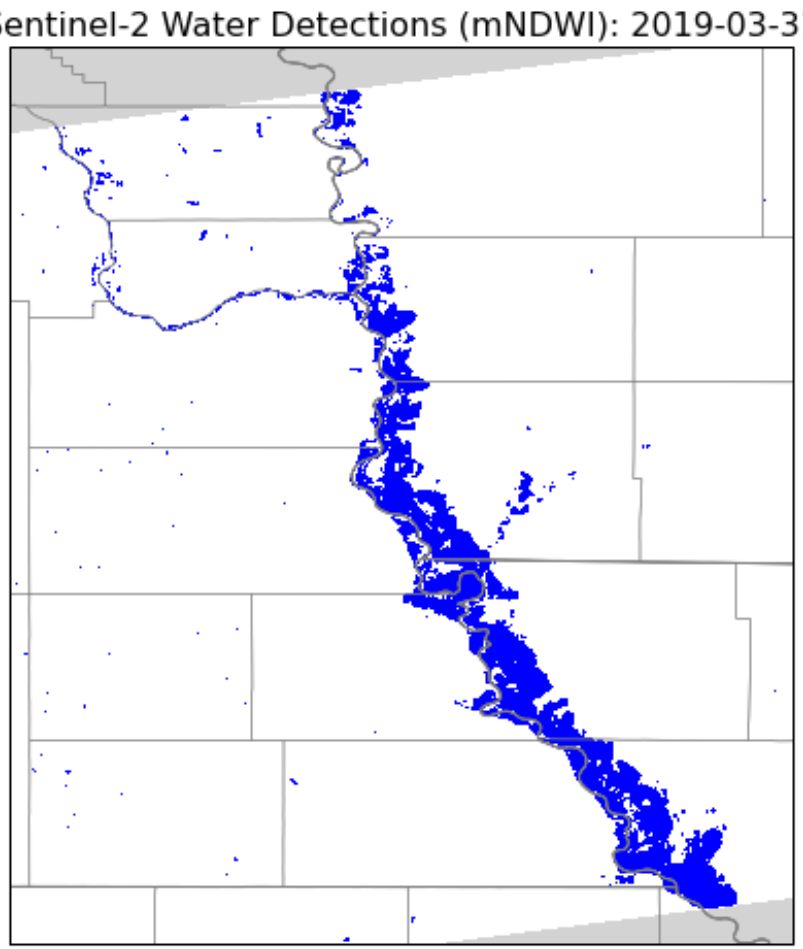
Sentinel-1 Water Detections: 2019-04-04



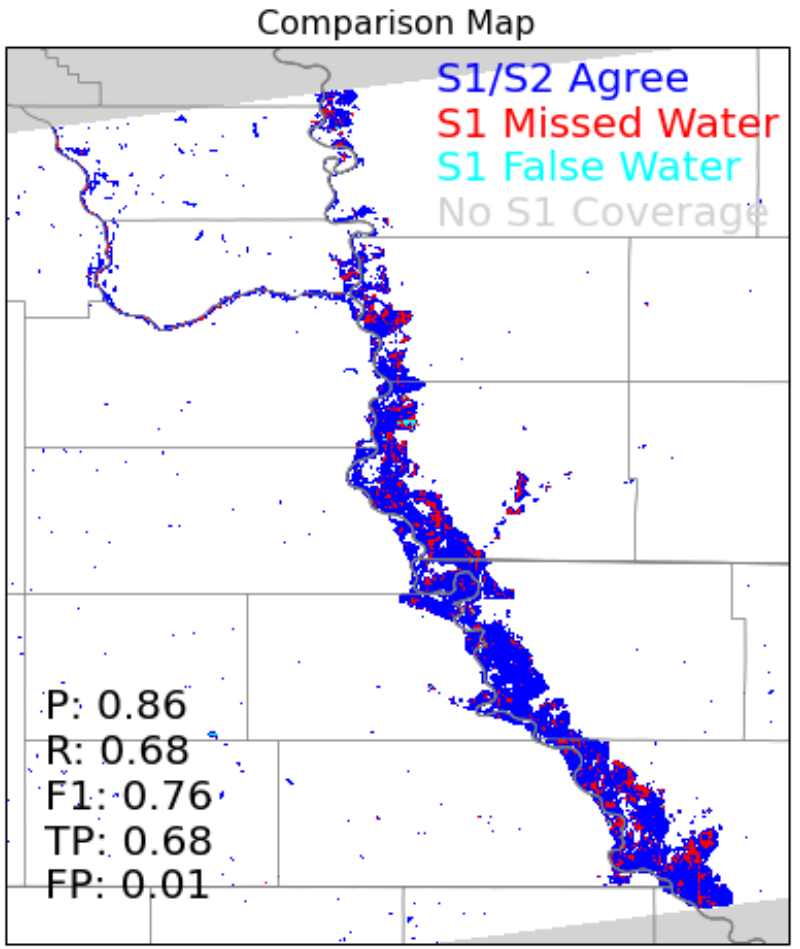
Comparing HYDRO30 to Water Maps from Sentinel-2



31 March 2019



31 March 2019

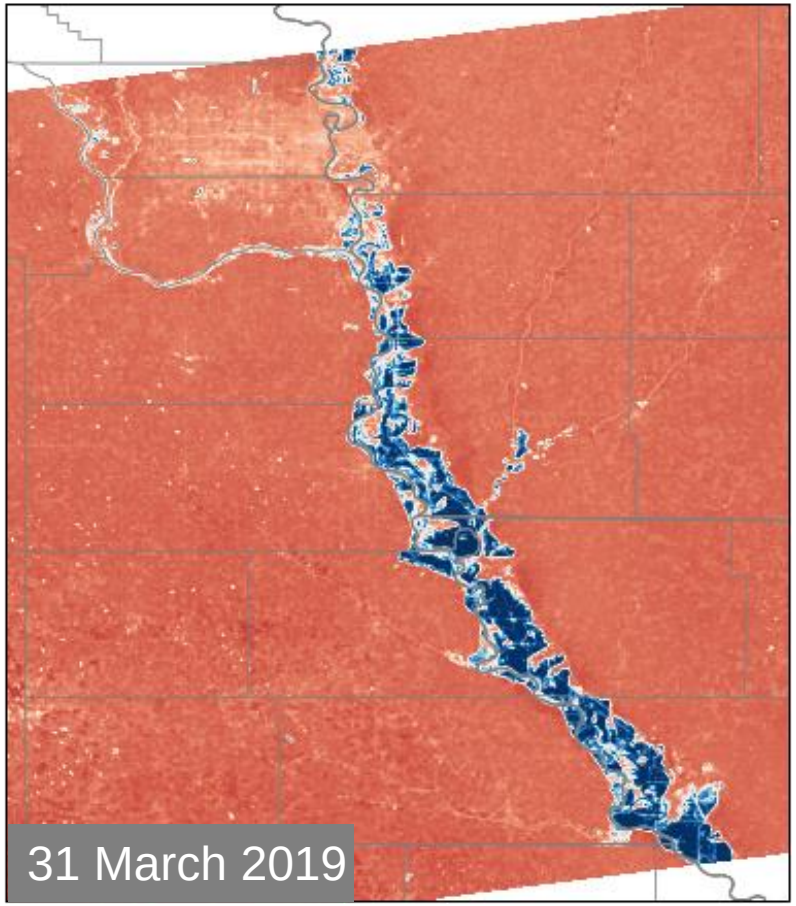


4 April 2019

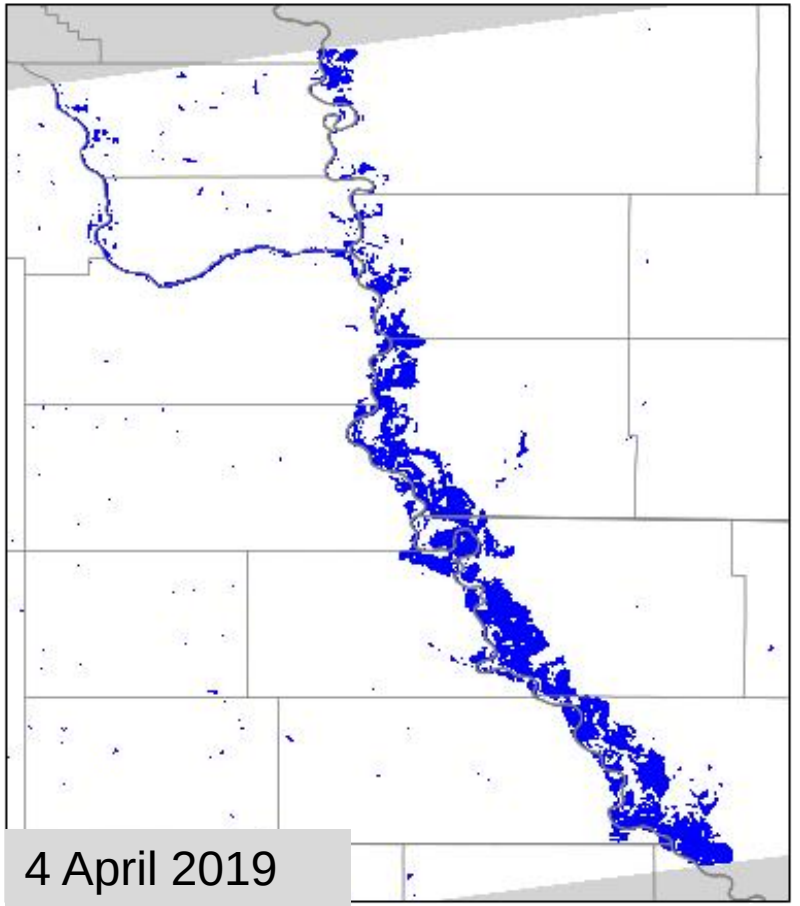
Comparing HYDRO30 to Water Maps from Sentinel-2

Sentinel-2 False Color 2019-03-31

Sentinel-2 mNDWI

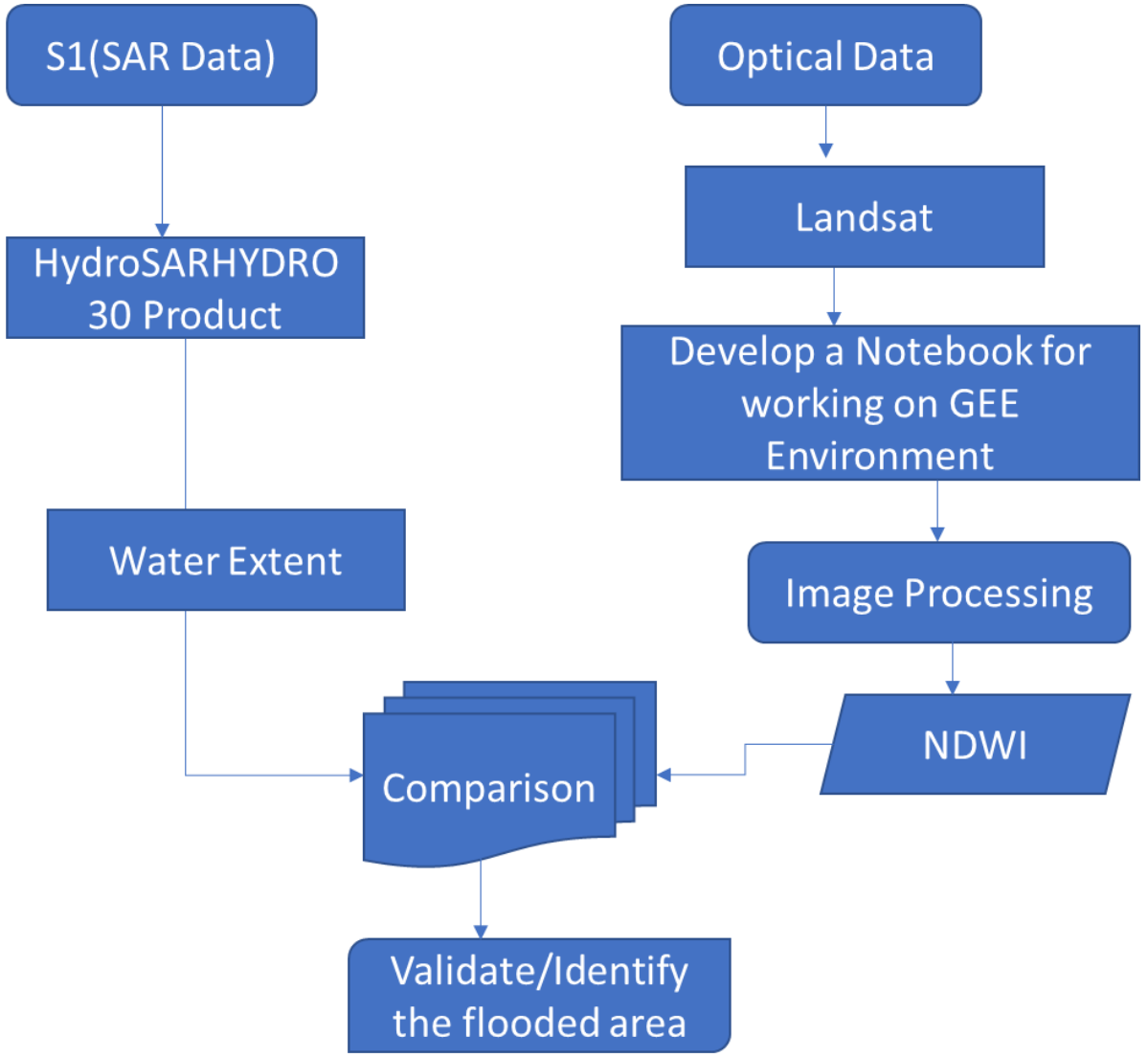


Sentinel-1 Water Detections: 2019-04-04



Preliminary Evaluation by ICIMOD

Comparison of HYDRO30 and Landsat



Preliminary Evaluation by ICIMOD

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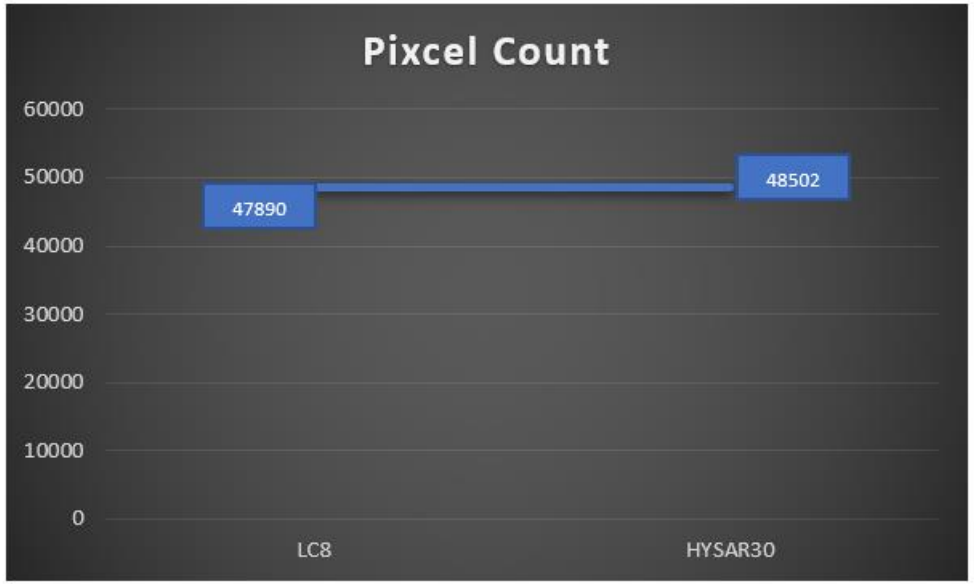
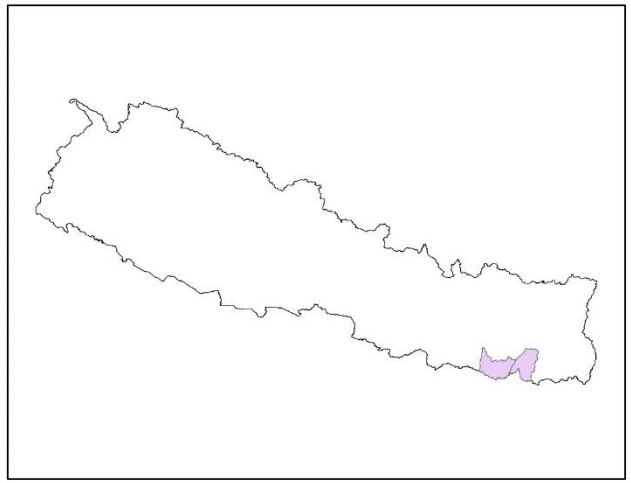
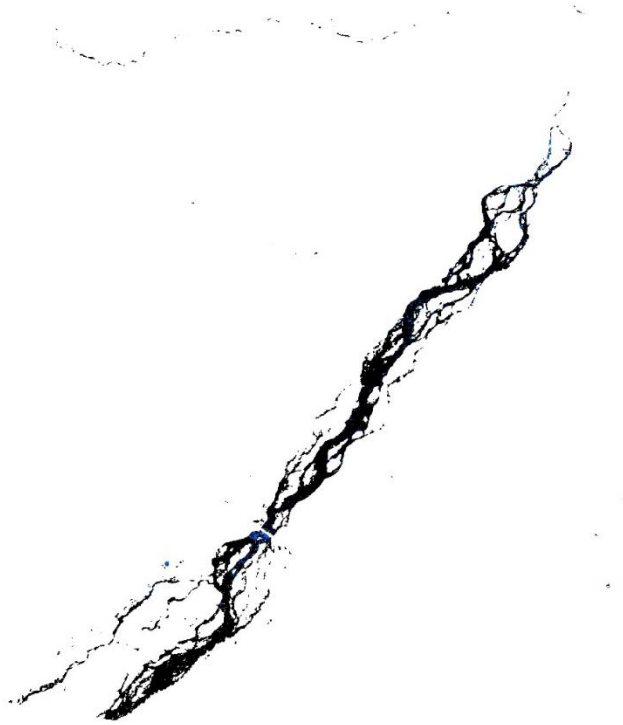






Legend

S_1_20200608_fcWM.tiff _Water Extent

L8_NDWI_20200607.tif_Water Extent

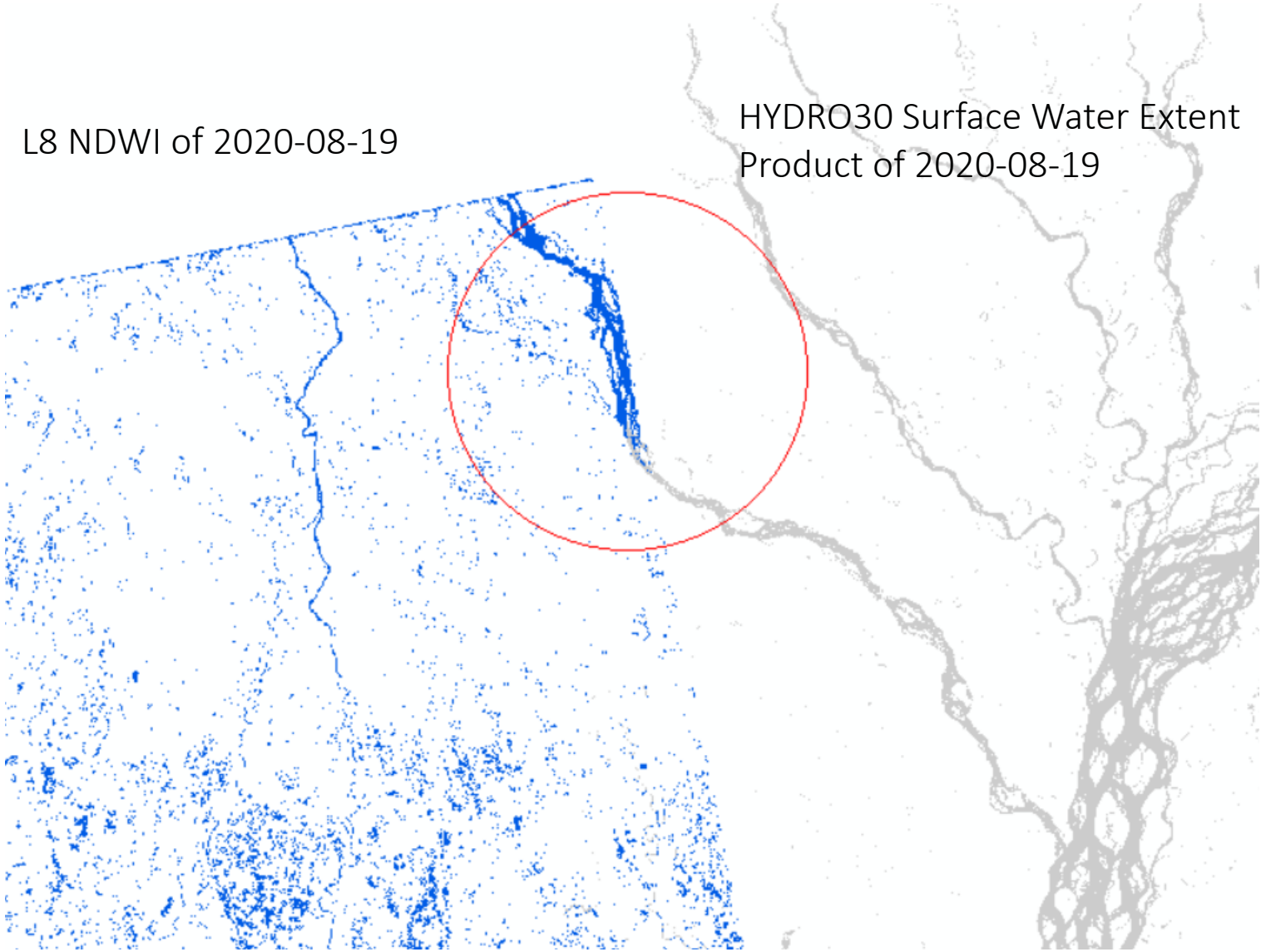
Preliminary Evaluation by ICIMOD

Comparison of HYDRO30 and Landsat

Figure shows both flood (water extent) masks in comparison. Apart from that and some river structures and adjoining area, there is an overall concordance between both flood masks.

L8 NDWI of 2020-08-19

HYDRO30 Surface Water Extent Product of 2020-08-19



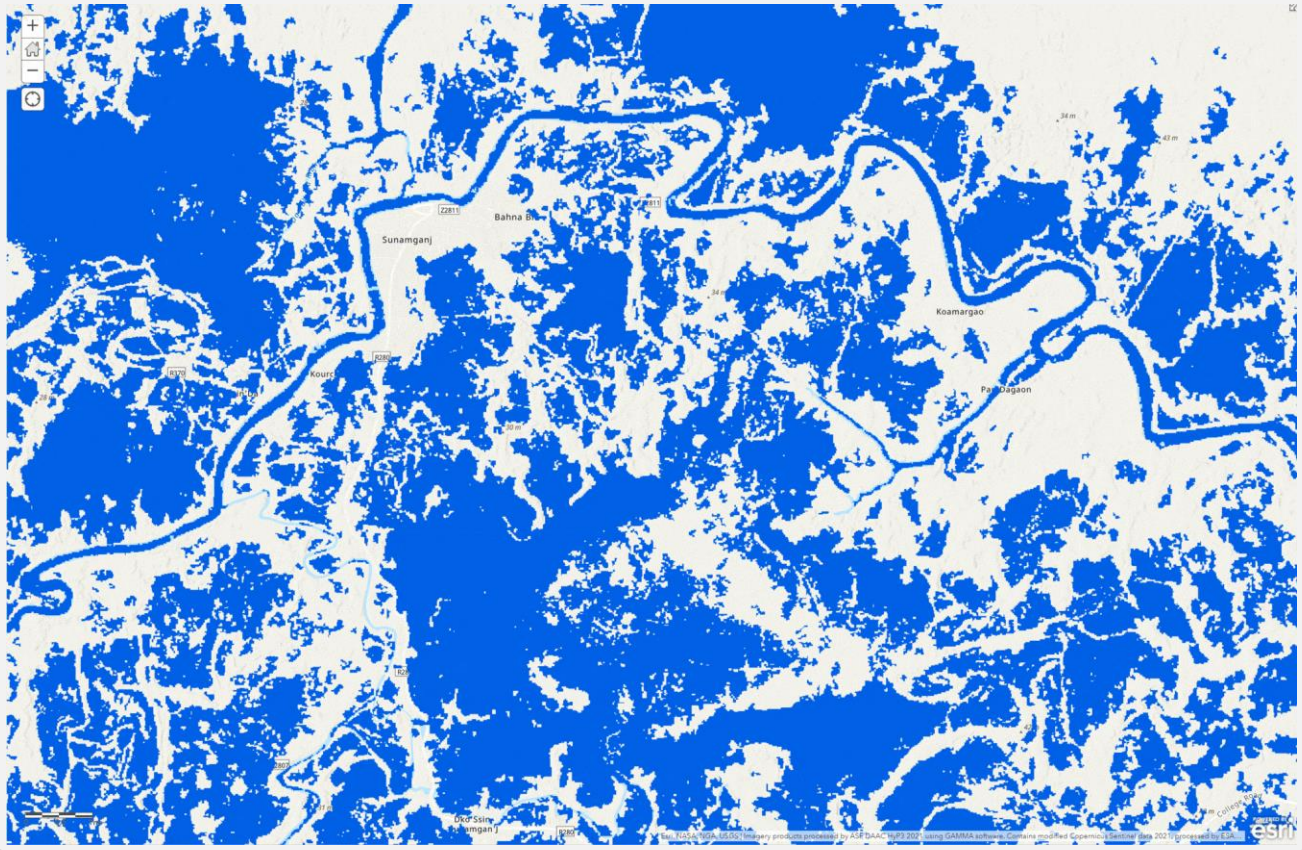
SOME HYDRO30 PERFORMANCE METRICS

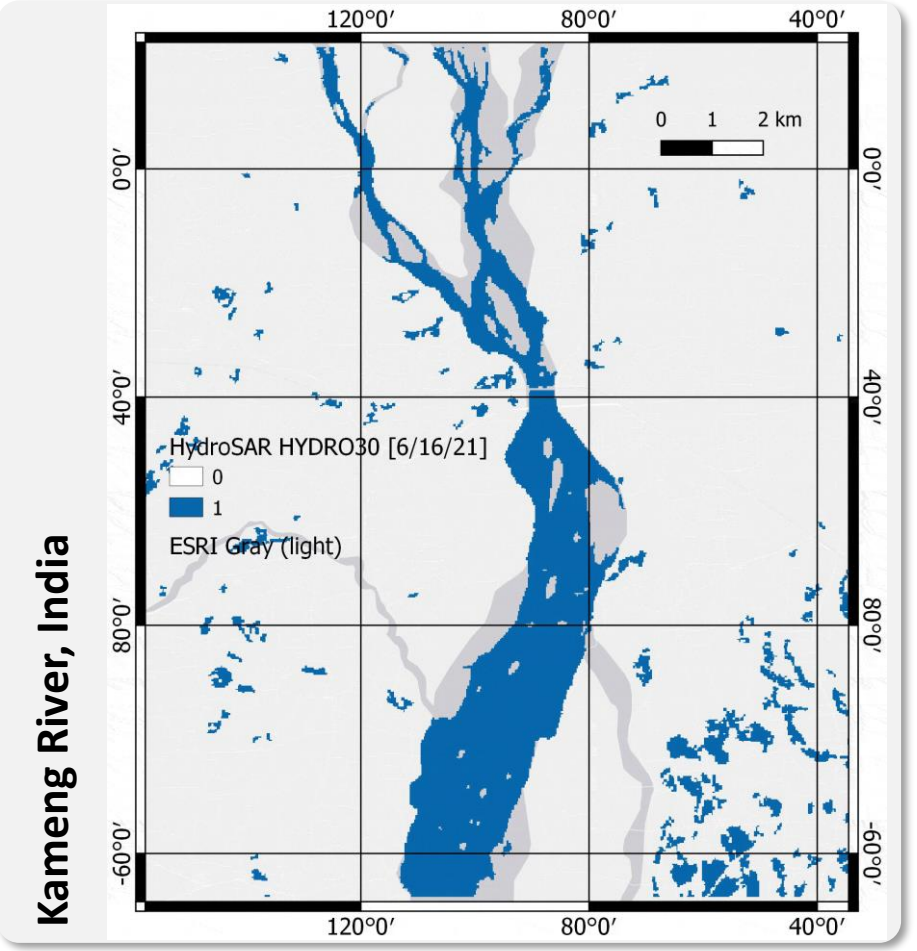
COMPARISON TO SHORT-TERM GOOGLE FLOOD FORECASTS

Comparing HYDRO30 Products to Google Flood Forecasts

Northern India & Bangladesh Example: Comparison of HYDRO30 Data to near-term Flood Forecasts

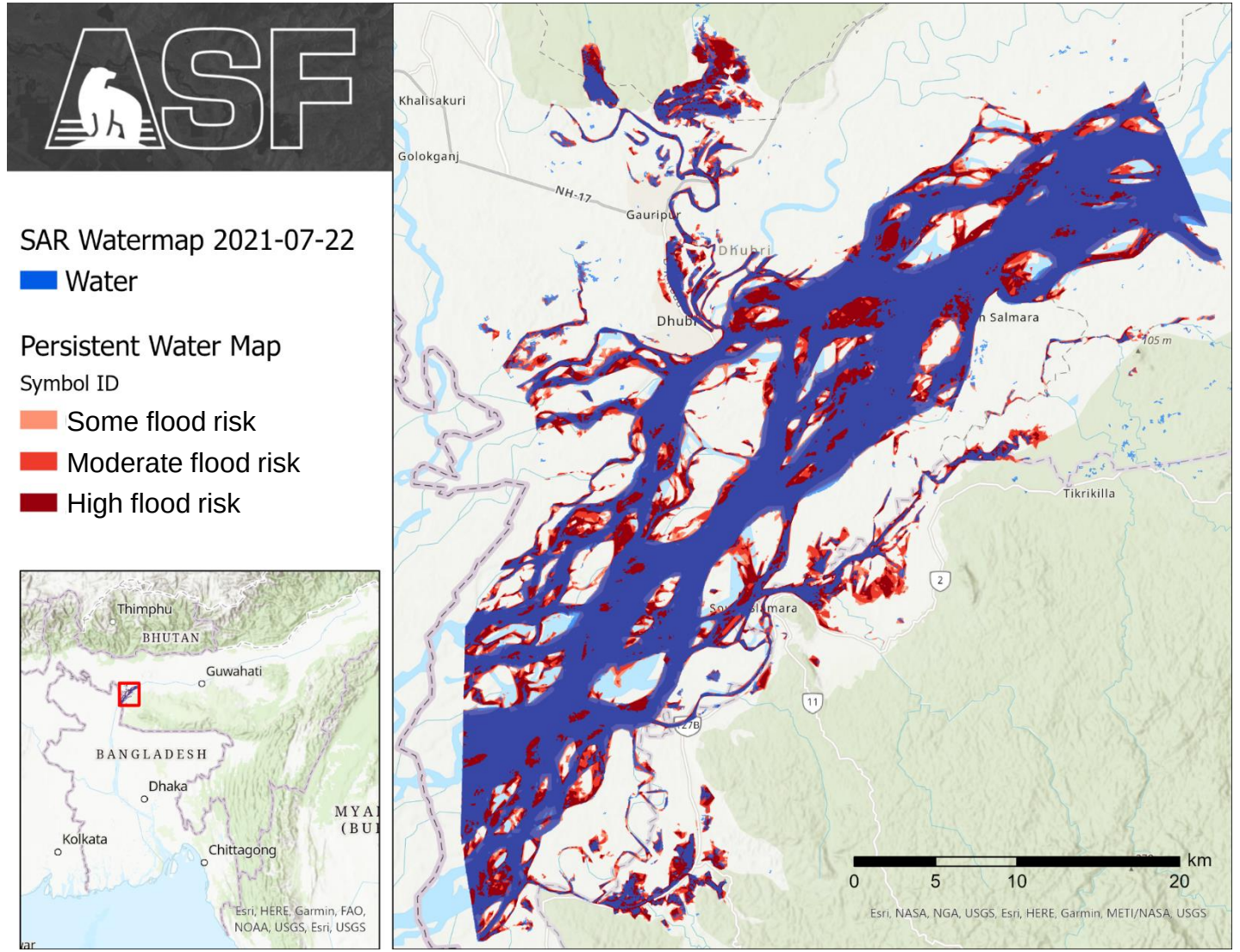
Surma River, Bangladesh HYDRO30 Google Flood Forecast





Comparing HYDRO30 Products to Google Flood Forecasts

- Comparison of HYDRO30 and Google Flood Forecast near Dhubri, Assam, India
  - Data later in the flood season
  - Comparison shows consistent features with forecasted flood extent slightly larger



KNOWN LIMITATIONS OF THE HYDRO30 PRODUCT

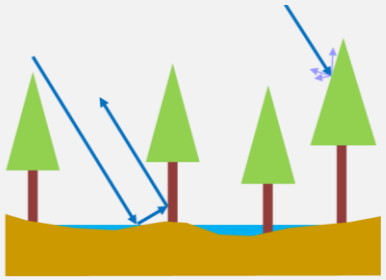
Limitations of Threshold-based Surface Water Mapping

Sensor-based limitations

Wind roughness on water

- **Problem**: Increases radar brightness and may prevent water detection
- **Mitigation**: use VH in addition to VV for water detection

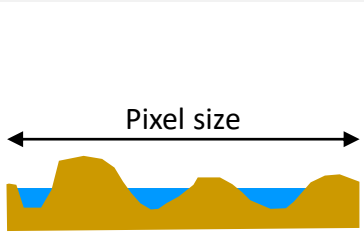
Water under dense vegetation



- **Problem**: Radar may not be able to penetrate vegetation
- **Mitigation**: Use longer wavelength radar (e.g., NISAR)

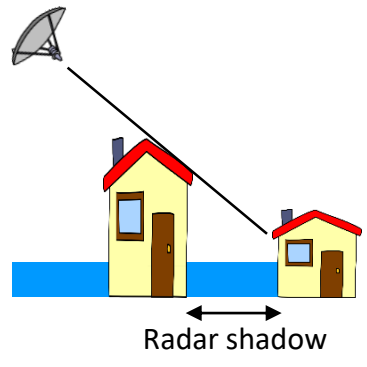
Environmental limitations

Partially inundated pixels



- **Problem**: Pixels are not dark enough for detection
- **Mitigation**: Higher-resolution radar or combine with change detection approach

Water in Urban environments

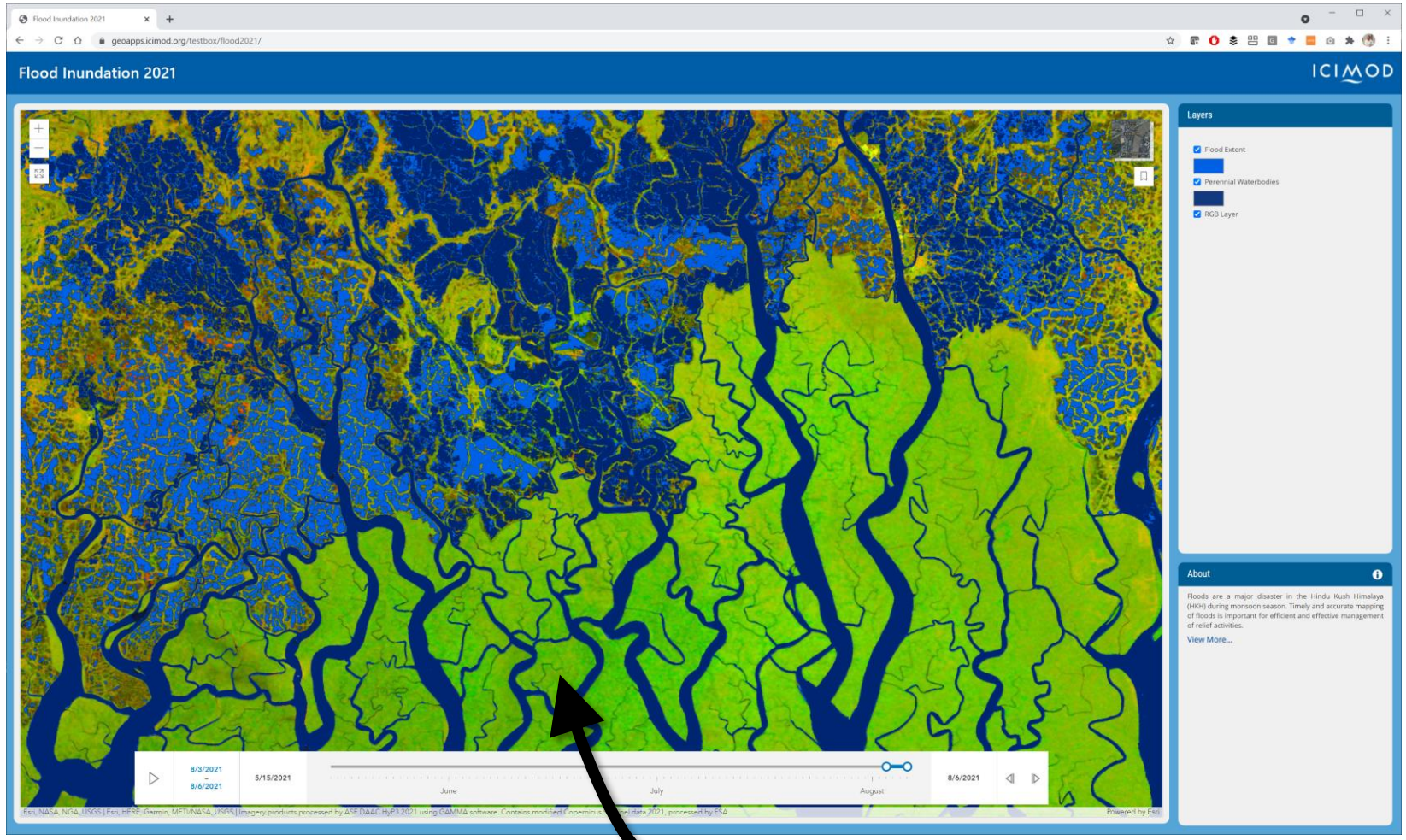


- **Problem**: Due to side-looking geometry, buildings obstruct surface water from view
- **Mitigation**: Use multiple viewing geometries – use optical data

Limitations of Threshold-based Surface Water Mapping

1. Missed Detections in “Water under Vegetation” Areas

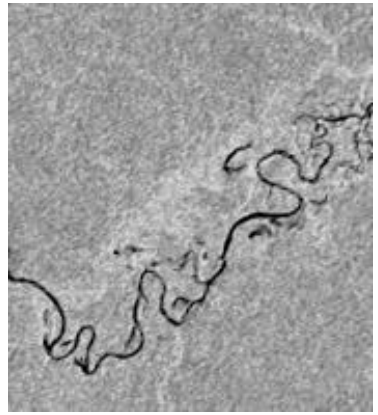
Flood Water Detections Permanent Water Map



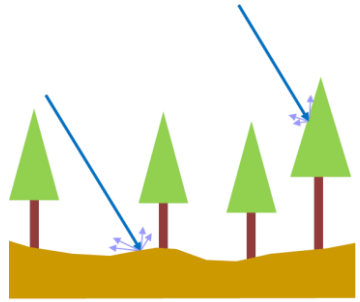
Missing Water Detections in Mangrove forest

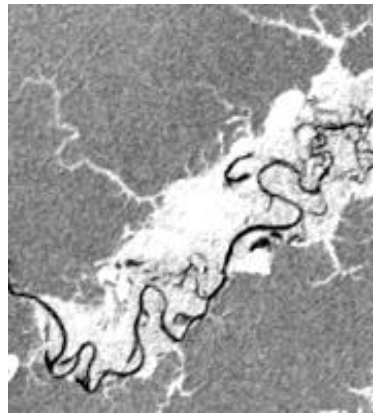
Additional Note:

At L-band (NISAR) water under vegetation shows up as bright areas in the image.

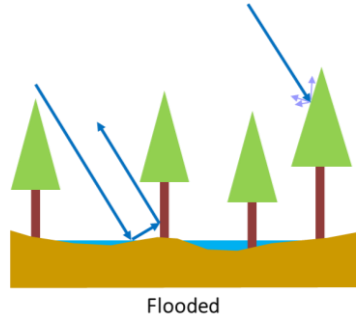


JERS-1 Dry Season





JERS-1 Wet Season

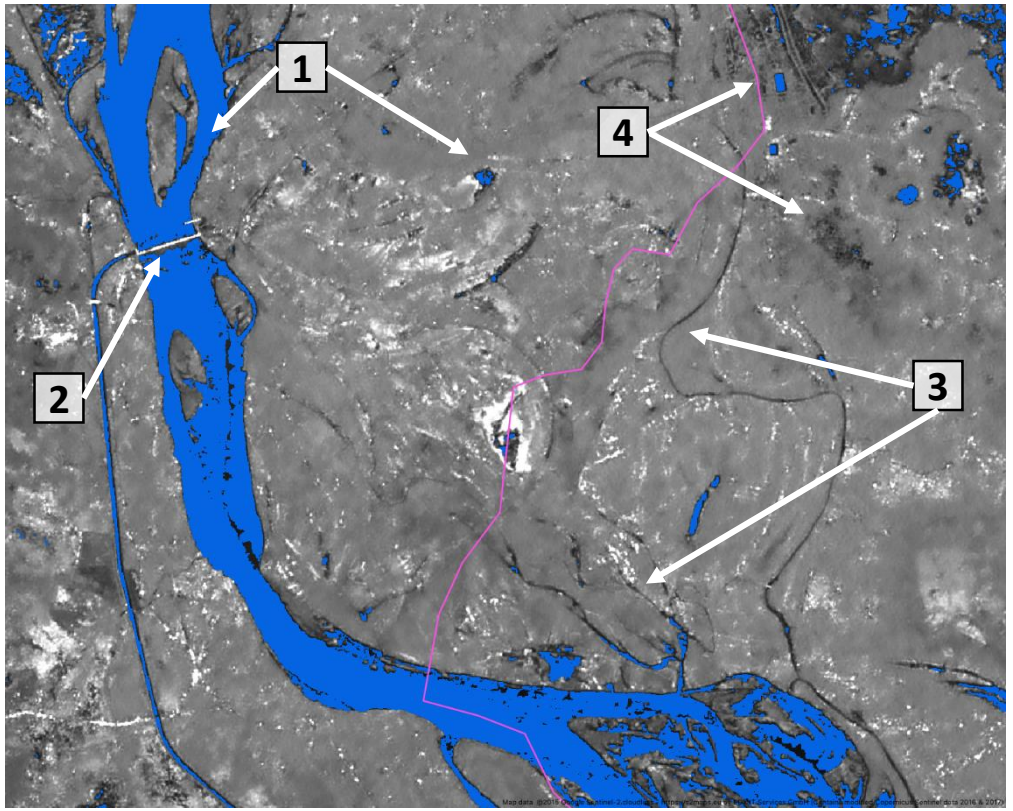


Limitations of Threshold-based Surface Water Mapping

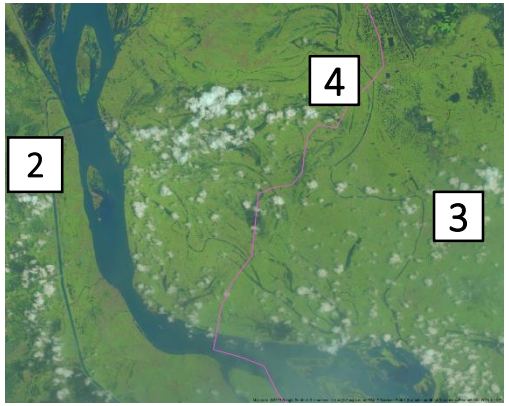
2. Mixed Pixels and Obstructions

- This example shows HYDRO30 detections over Sentinel-1 Co-pol (VV) from Aug 2, 2020:

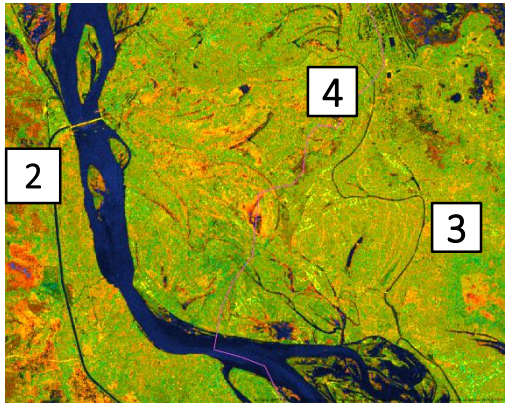
1. Correct HYDRO30 water extent
2. Object (bridge) obstructing the water extent detection
3. Mixed Pixels along narrow rivers: Resolution cannot detect water either due to vegetation or size of waterbody
4. Mixed Pixels in Cropland: Flooding in undulating terrain or cropland can lead to partially inundated pixels that appear darkened but are not dark enough to be detected as water



Comparison to other products



ESA Sentinel-2 SWIR - False Color RGB
2 August 2020 – 082354 UTC

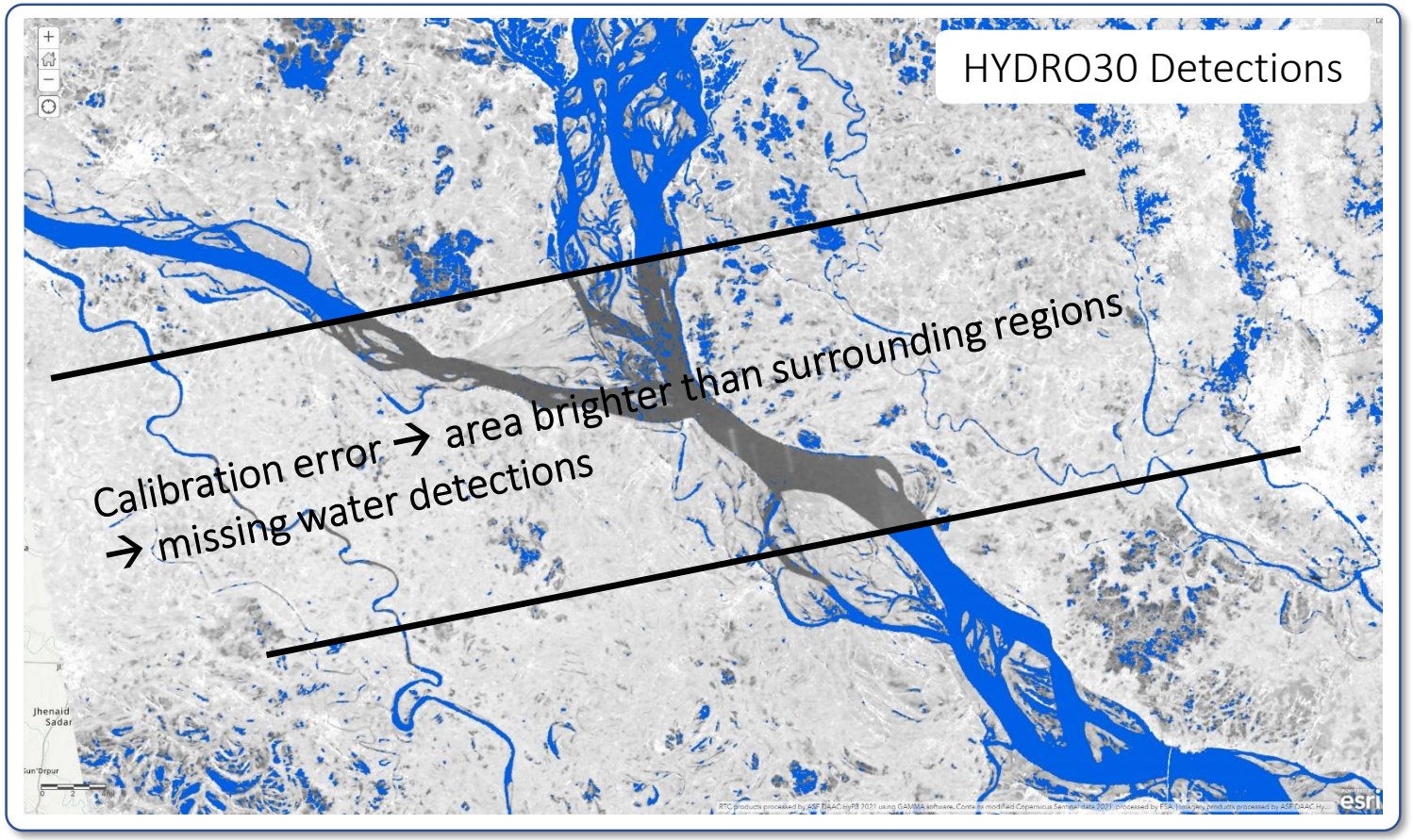


ESA Sentinel-1 - ASF SAR RGB
2 August 2020 – 000333 UTC

Limitations of Threshold-based Surface Water Mapping

3. Occasional "Bad Data" Issues

- **While SAR is a very stable instrument, "bad data" issues can occur that affect flood mapping performance**:
  - Calibration issues (see right)
  - Occasional cloud scattering
  - Radio Frequency Interference



SUPPLEMENTAL SLIDES

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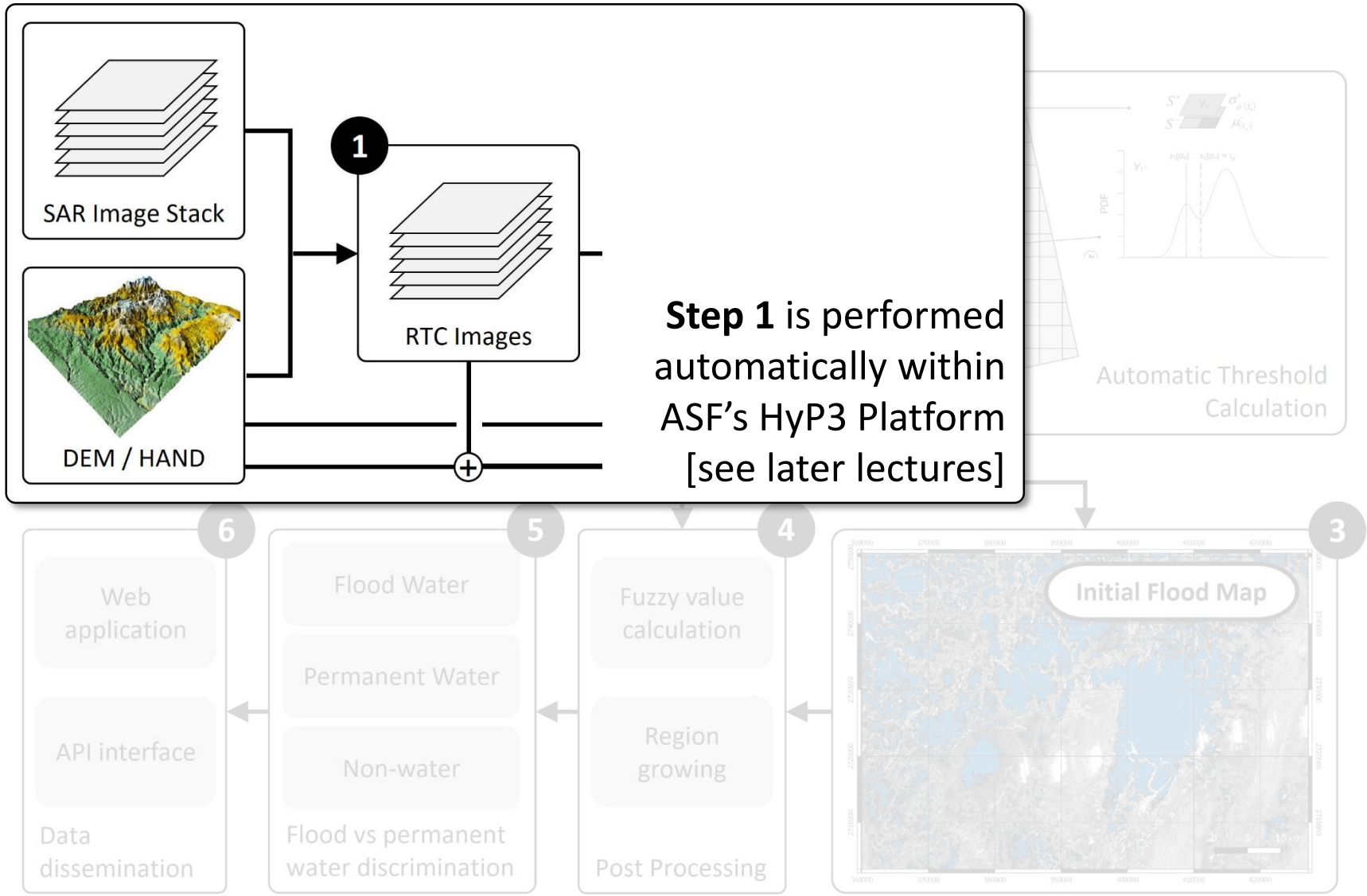
Concept of Adaptive Threshold-based Surface Water Mapping Approach

HydroSAR water mapping approach composed of 6 steps:

1. Image Geocoding and Calibration (RTC Processing)
2. Automatic and adaptive threshold calculation
3. Initial flood map creating
4. Post-processing to remove false alarms
5. Discrimination of permanent and flood-related water
6. Data dissemination



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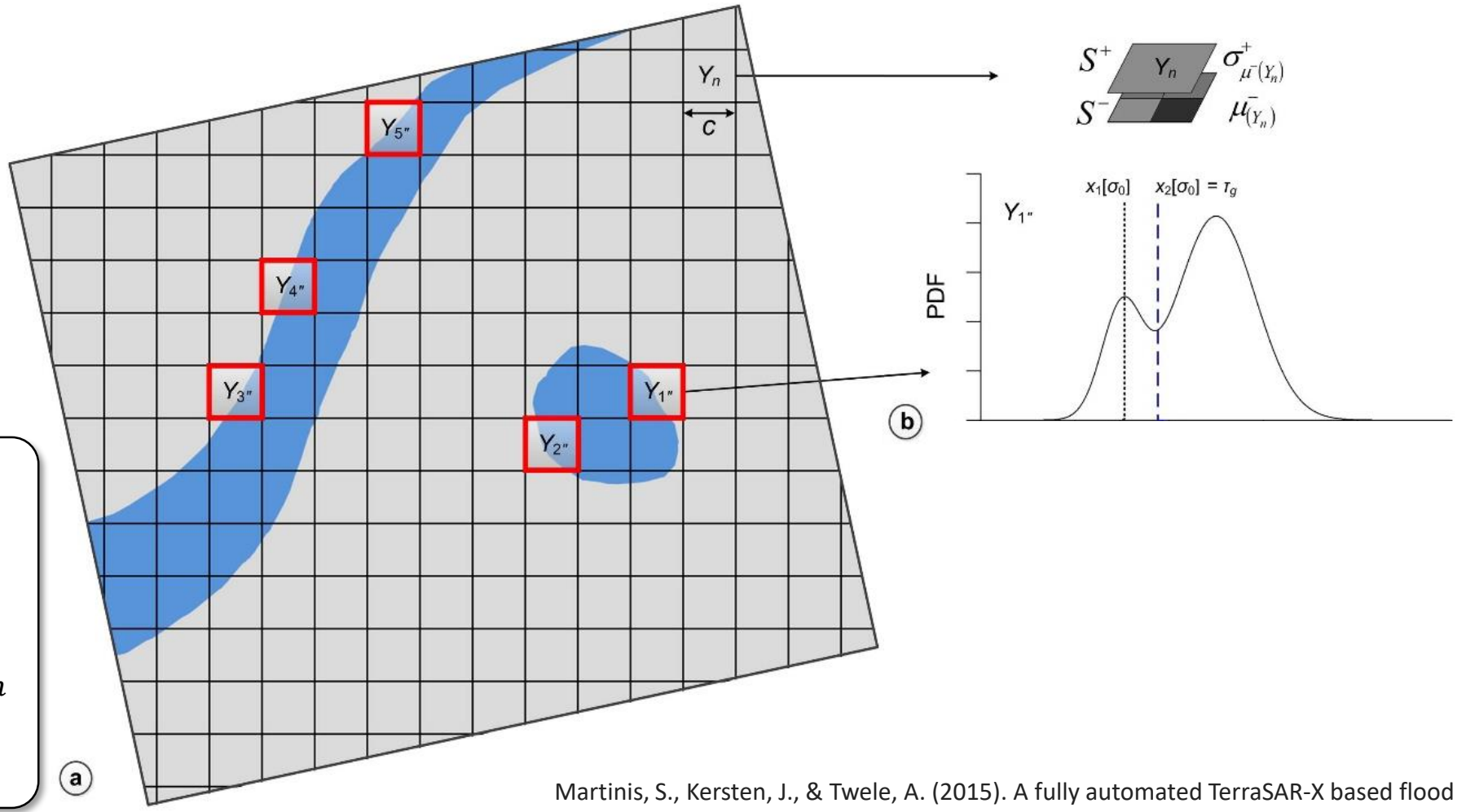
Step 2: Automatic and Adaptive Threshold Calculation

Tile image and select pivotal tiles (best tiles for threshold calculation) using

- Tile mean μ_n
- The tile standard deviation σ_n
- Height above nearest drainage $\mathrm{HAND} < 15\mathrm{m}$



Martinis, S., Kersten, J., & Twele, A. (2015). A fully automated TerraSAR-X based flood service. *ISPRS Journal of Photogrammetry and Remote Sensing*, *104*, 203-212.

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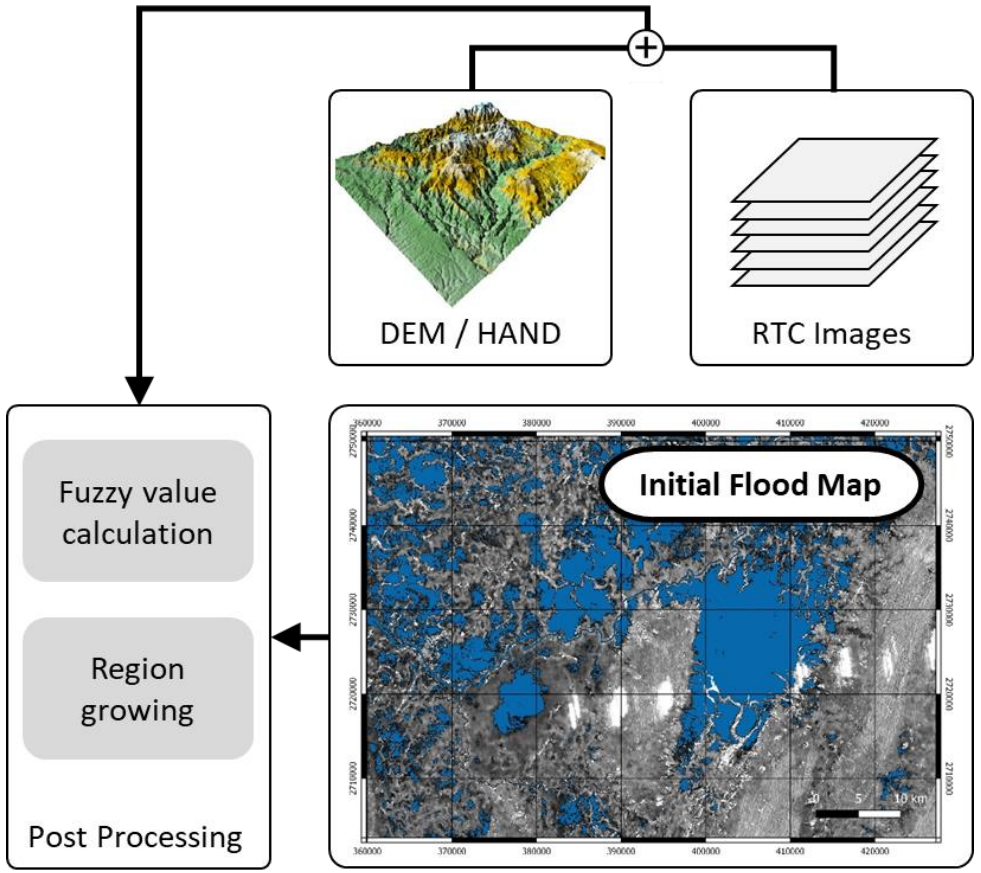
Step 4: Post-Processing to Remove False Alarms

- **Fuzzy logic rules to remove spurious false detection and improve upon the initial flood mapping product:**
  - **Radar Cross Section (RCS) rule**: $\begin{cases} x_{u,RCS} = \tau_g \\ x_{l,RCS} = \mu_{\sigma^0_{\tau_g}} \end{cases}$ with

    $\sigma^0_{\tau_g}$ = initial flood classification and flood mapping threshold τ_g
  - **HAND elevation rule**: $\begin{cases} x_{u,HAND} = \mu_{HAND(water)} + 3 \cdot \sigma_{HAND(water)} \\ x_{l,HAND} = \mu_{\sigma^0_{\tau_g}} \end{cases}$
  - **Surface slope α rule**: $\begin{cases} x_{u,\alpha} = 15^\circ \\ x_{l,\alpha} = 0^\circ \end{cases}$
  - **Flood patch size A rule**: $\begin{cases} x_{u,A} = 10px \\ x_{l,A} = 3px \end{cases}$



- Fuzzy membership functions calculated using a Z-shaped activation function.
- Membership functions are averaged and thresholded using a fuzzy threshold of 0.45.

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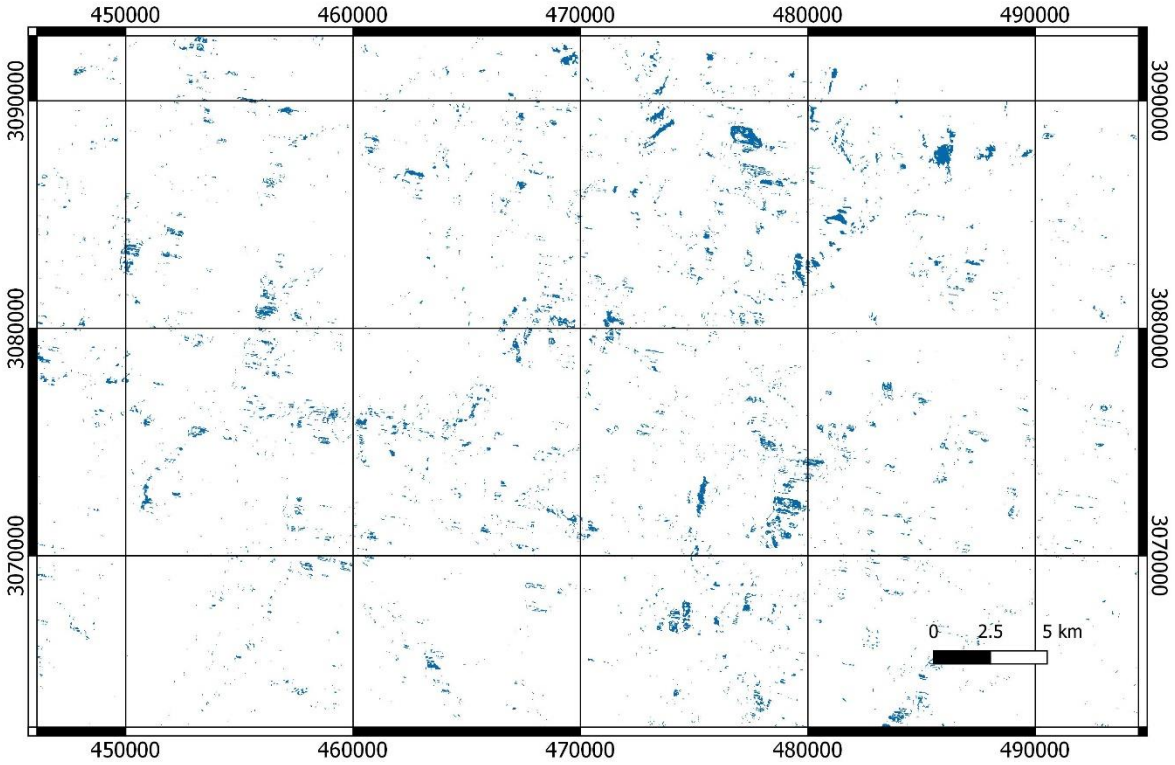
Benefit of Post Processing Steps – Case 1: Mountainous Terrain

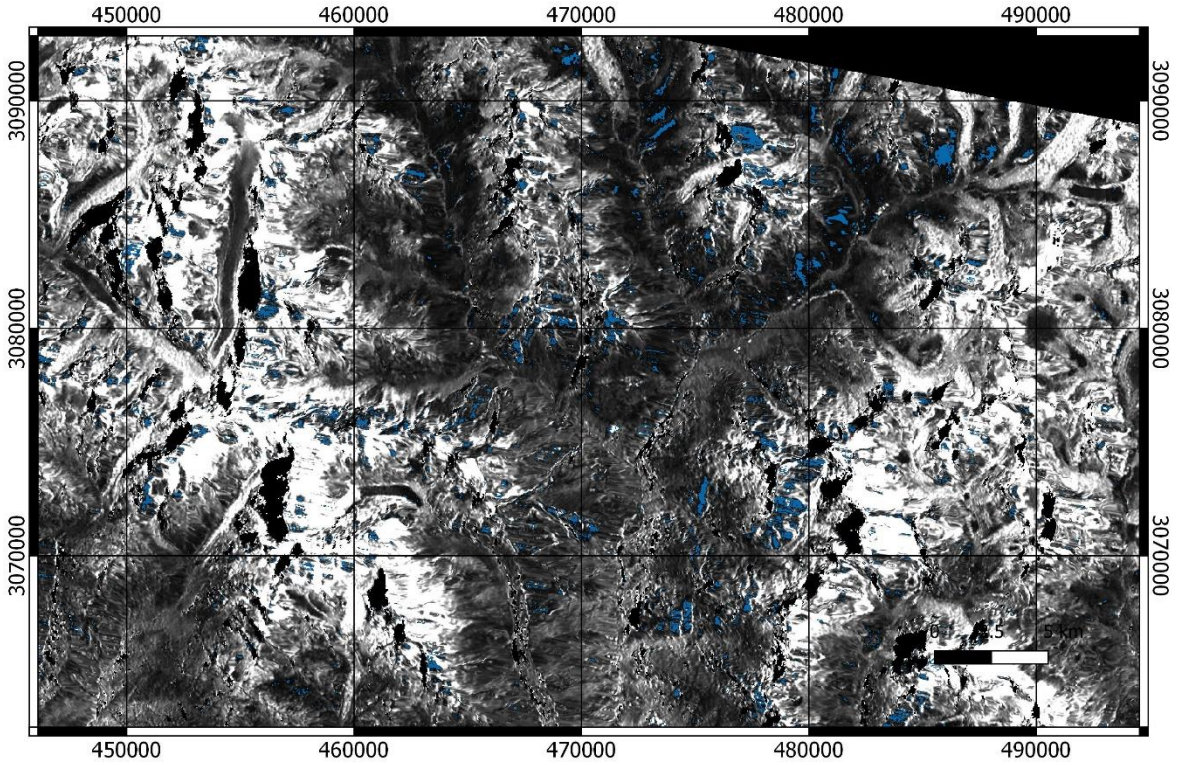
- **Mountainous terrain → flood look-alikes from layover, shadow, snow, and ice**

False alarms due to shadow ice and snow melt

HYDRO30 Product Nepal

No Post Processing





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Benefit of Post Processing Steps – Case 1: Mountainous Terrain

- **Mountainous terrain → flood look-alikes from layover, shadow, snow, and ice**

False alarms removed by
Fuzzy logic post processing

HYDRO30 Product Nepal

After Post Processing