HYDROSAR – SURFACE WATER EXTENT MAPPING PRODUCTS AND WEB APPLICATION TRAINING

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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

- RTC Image Time Series
- RGB Composites
- Flood Extent Maps
- Change Detection Maps
- Active Agriculture Maps

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

1. Time Series Profiles of Sentinel-1 SAR Backscatter
2. Time Series Profiles of Sentinel-2 NDVI Backscatter
The HydroSAR Team

HydroSAR Development Team

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HydroSAR Partners

SERVIR
Connecting Space to Village

ICIMOD

Franz J Meyer, UAF
HydroSAR Training, 08/2021
HydroSAR Training Syllabus

- The Syllabus and all lecture materials can be found here:
  - [https://drive.google.com/file/d/1abnXN4GyP6sKCTD8j_niGGvGzQ1tK4Y/view?usp=sharing](https://drive.google.com/file/d/1abnXN4GyP6sKCTD8j_niGGvGzQ1tK4Y/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

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Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).

Visible light observable from Earth, with some atmospheric distortion.

Most of the infrared spectrum absorbed by atmospheric gases (best observed from space).

Radio waves observable from Earth.

Long-wavelength radio waves blocked.

**Optical and Infrared Signals**

**Radar Signals**

**Atmospheric Opacity**

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

Visit ASF @ [www.asf.alaska.edu](http://www.asf.alaska.edu)

41 years of SAR data (since ‘78)

[https://search.asf.alaska.edu](https://search.asf.alaska.edu)

NISAR DAAC (all L0 – L2 data)

Host of global Sentinel-1 archive
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

![Histogram of two Radarsat SAR images of the same region acquired under different incidence angles (Solbø & Solheim, 2004)](image)
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

[https://geoapps.icimod.org/testbox/flood2021/](https://geoapps.icimod.org/testbox/flood2021/)
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

Study Period: 1 March – 1 Oct 2019
- Both Sentinel-1 and clear Sentinel-2 passes used

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

31 March 2019

31 March 2019

4 April 2019
Comparing HYDRO30 to Water Maps from Sentinel-2

Sentinel-1 Water Detections: 2019-04-04

Sentinel-2 Water Detections (mNDWI): 2019-03-31

Comparison Map

S1/S2 Agree
S1 Missed Water
S1 False Water
No S1 Coverage

P: 0.86
R: 0.68
F1: 0.76
TP: 0.68
FP: 0.01

31 March 2019

31 March 2019

4 April 2019
Comparing HYDRO30 to Water Maps from Sentinel-2

Sentinel-2 False Color
31 March 2019

Sentinel-2 mNDWI
31 March 2019

Sentinel-1 Water Detections: 2019-04-04
4 April 2019
Preliminary Evaluation by ICIMOD

Comparison of HYDRO30 and Landsat

S1(SAR Data) → HydroSARHYDRO 30 Product → Water Extent → Comparison → Validate/Identify the flooded area

Optical Data → Landsat → Develop a Notebook for working on GEE Environment → Image Processing → NDWI
Preliminary Evaluation by ICIMOD

Comparison of HYDRO30 and Landsat
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.
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

Kameng River, India
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

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
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
The HydroSAR HYDRO30 Surface Water Extent Product

Concept of Adaptive Threshold-based Surface Water Mapping Approach

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Step 1 is performed automatically within ASF’s HyP3 Platform [see later lectures]
The HydroSAR HYDRO30 Surface Water Extent Product

Step 2: Automatic and Adaptive Threshold Calculation

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

- Tile mean $\mu_n$
- The tile standard deviation $\sigma_n$
- Height above nearest drainage HAND $< 15m$

The HydroSAR HYDRO30 Surface Water Extent Product

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: \[ \begin{align*}
  x_{u,RCS} &= \tau_g \\
  x_{l,RCS} &= \mu_{\sigma_{tg}^0}
  \end{align*} \]
  \[ \sigma_{tg}^0 \] = initial flood classification and flood mapping threshold \( \tau_g \)

  - HAND elevation rule:
    \[ \begin{align*}
    x_{u,HAND} &= \mu_{\text{HAND(water)}} + 3 \cdot \sigma_{\text{HAND(water)}} \\
    x_{l,HAND} &= \mu_{\sigma_{tg}^0}
    \end{align*} \]

  - Surface slope \( \alpha \) rule:
    \[ \begin{align*}
    x_{u,\alpha} &= 15^\circ \\
    x_{l,\alpha} &= 0^\circ
    \end{align*} \]

  - Flood patch size \( A \) rule:
    \[ \begin{align*}
    x_{u,A} &= 10\text{px} \\
    x_{l,A} &= 3\text{px}
    \end{align*} \]

- Fuzzy membership functions calculated using a Z-shaped activation function.

- Membership functions are averaged and thresholded using a fuzzy threshold of 0.45.
The HydroSAR HYDRO30 Surface Water Extent Product

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
The HydroSAR HYDRO30 Surface Water Extent Product

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