GEOS 657 – MICROWAVE REMOTE SENSING

GRADUATE-LEVEL COURSE AT THE UNIVERSITY OF ALASKA FAIRBANKS

Lecturer:
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Lecture 17: Surface Water Mapping from SAR

UAF Course GEOS 657

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)

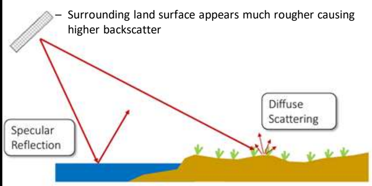
Modern SAR Sensors provide regularly-sampled, high-resolution & weather-independent earth observation data from Space

ESA Sentinel-1 SAR

SURFACE WATER SIGNATURES IN SAR

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



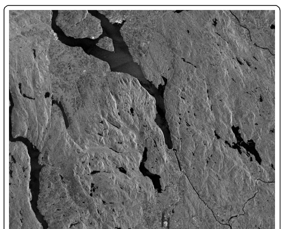
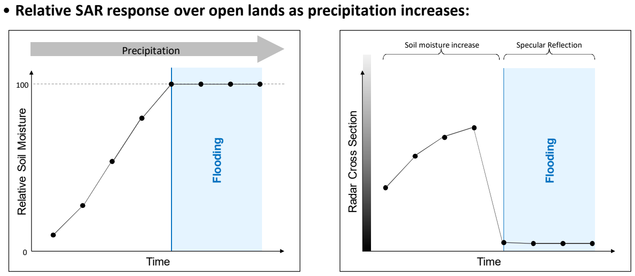


Fig.: Lake Mjosa, Norway, observed by ENVISAT ASAR Image Mode, 12 Dec 2003 (©ESA Multimedia Gallery)

Surface Water Signatures in SAR Amplitude Images

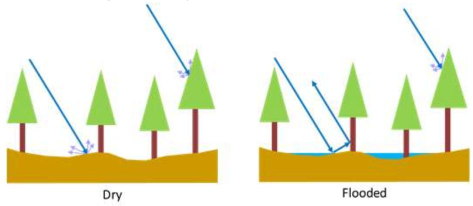
1. Open Lands – Areas with Low Vegetation Cover

- **Relative SAR response over open lands as precipitation increases:**



Surface Water Signatures in SAR Amplitude Images
2. Flooding under Vegetation Canopies

- **Mapping inundation under vegetation canopies:**

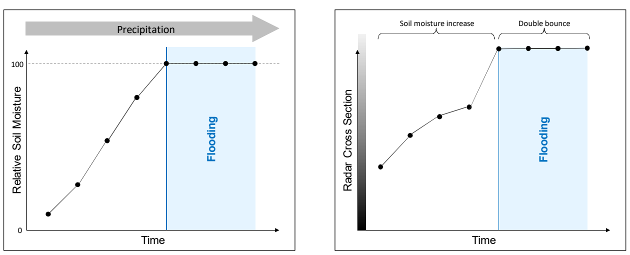


Enhanced return if tree cover underlain by water (double bounce effect – smooth water surface – vertical vegetation structures)

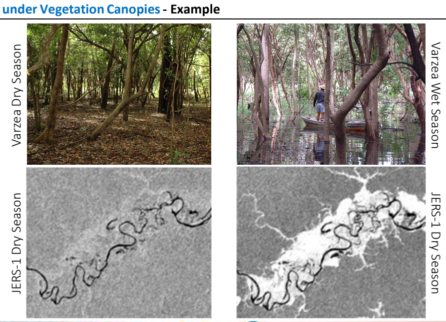
Fig.: Inundation effects on radar backscatter for forest stands (after Bourgeau-Chavez et al., 2009)

Surface Water Signatures in SAR Amplitude Images
2. Flooding under Vegetation Canopies

- **Relative SAR response in vegetated canopies as precipitation increases:**

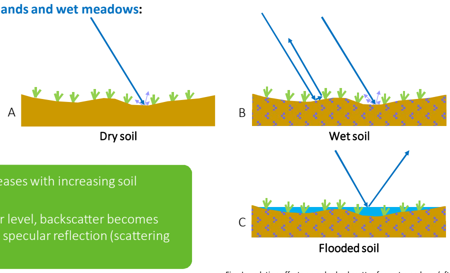


Surface Water Signatures in SAR Amplitude Images
2. Flooding under Vegetation Canopies - Example



Surface Water Signatures in SAR Amplitude Images
3. Flooding in Crop Lands

- **Mapping inundation in crop lands and wet meadows:**

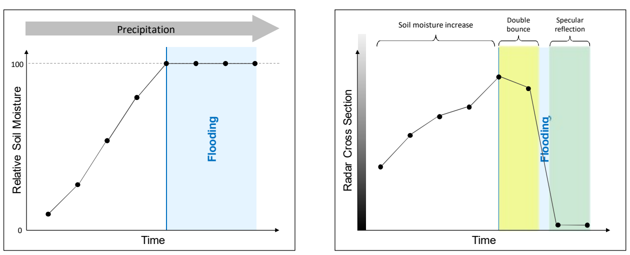


- A to B: First backscatter increases with increasing soil moisture
- C: then with increasing water level, backscatter becomes weaker with more and more specular reflection (scattering away from the sensor).

Fig.: Inundation effects on radar backscatter for wet meadows (after Bourgeau-Chavez et al., 2009)

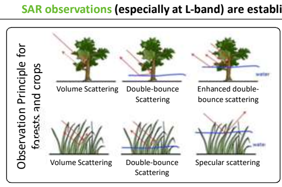
Surface Water Signatures in SAR Amplitude Images
3. Flooding in Crop Lands

- **Relative SAR response in crop lands as precipitation increases:**

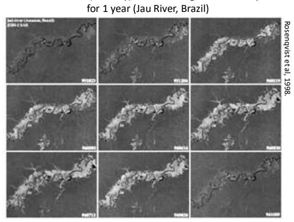


Vegetation Inundation Mapping using SAR

SAR observations (especially at L-band) are established as a reliable tool for mapping vegetation inundation



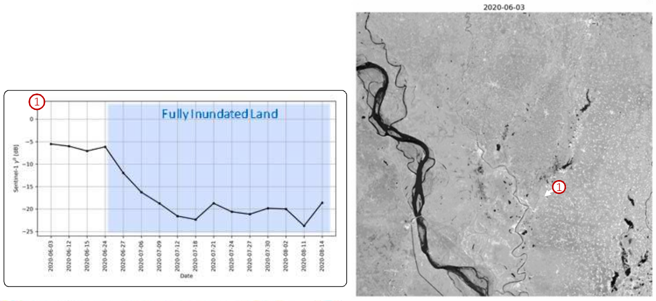
JERS-1 L-band SAR (HH only) data showing inundation dynamics for 1 year (Jau River, Brazil)



Rosenqvist et al. 1998.

- C-band sensors limited performance in densely vegetated areas
- Existing L-band SARs have limited coverage to accurately capture spatial extent and temporal variations of inundation over wetlands.
- Future sensors such as NISAR will acquire dual-pol data globally over all wetlands twice per 12 day orbit cycle → contribution to understanding wetland hydrology and the impacts of climate variations

Vegetation Signature Examples
2020 South Asia Monsoon Floods – West Bengal Region, India



Vegetation Signature Examples
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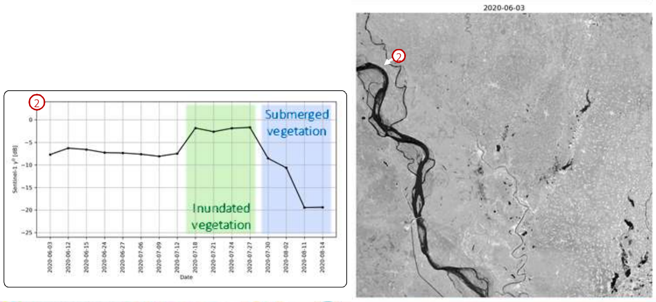
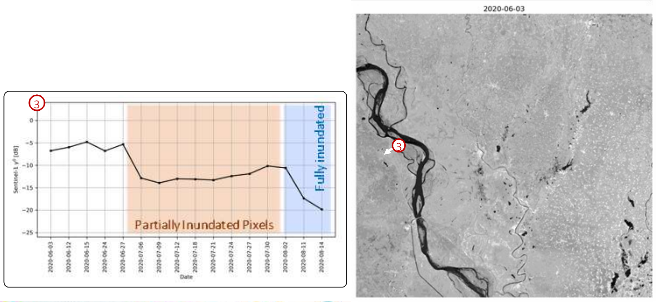
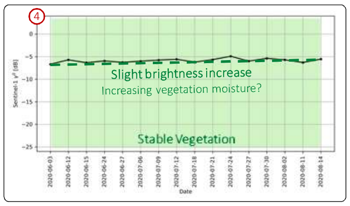


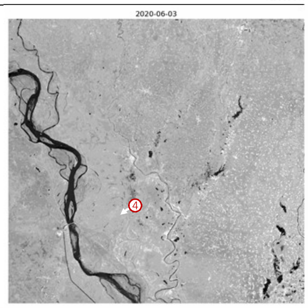
Vegetation Signature Examples
2020 South Asia Monsoon Floods – West Bengal Region, India



Vegetation Signature Examples

2020 South Asia Monsoon Floods – West Bengal Region, India





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A SINGLE-IMAGE THRESHOLDING APPROACH FOR SURFACE WATER MAPPING FROM SAR

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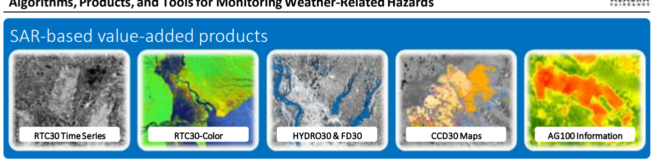
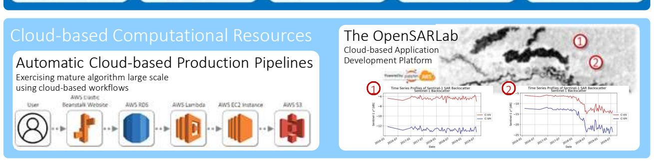
The HydroSAR Approach

Algorithms, Products, and Tools for Monitoring Weather-Related Hazards





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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

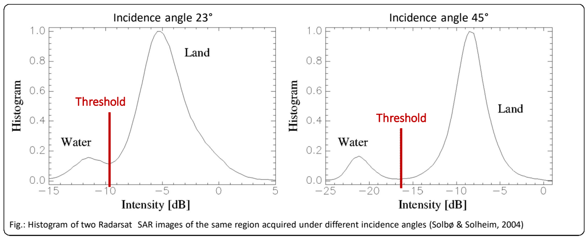
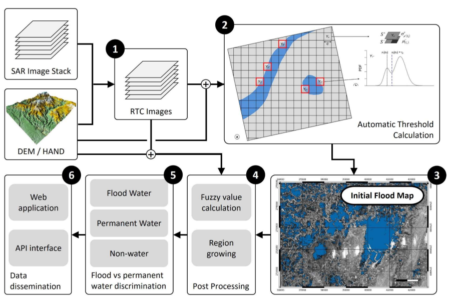


Fig.: Histogram of two Radarsat SAR images of the same region acquired under different incidence angles (Solbø & Solheim, 2004)

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 HYDRO30 Surface Water Extent Product
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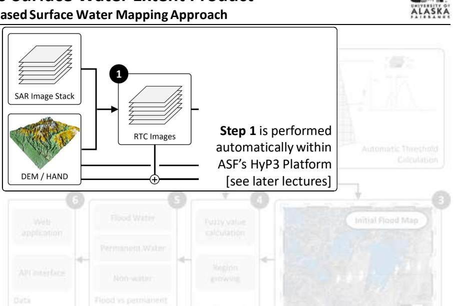
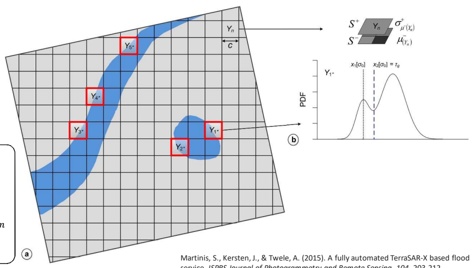


The HydroSAR HYDRO30 Surface Water Extent Product
Step 2: Automatic and Adaptive Threshold Calculation

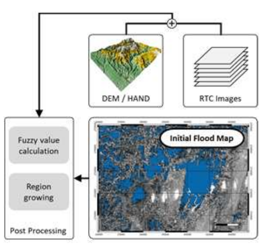


Tile image and select pivotal tiles (best tiles for threshold calculation) using
- Tile mean μ_n
- The tile standard deviation σ_n
- Height above nearest drainage $\mathrm{HAND} < 15\mathrm{m}$

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.

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**: $\begin{cases} x_{u,RCS} = \tau_g \\ x_{l,RCS} = \mu_{\sigma^0_{\tau_g}} \end{cases}$ 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.

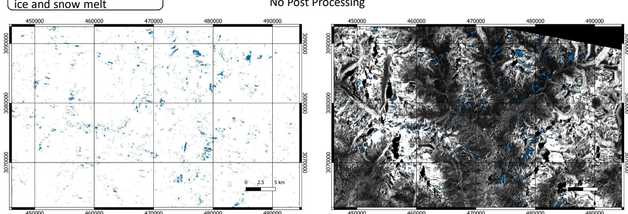


The HydroSAR HYDRO30 Surface Water Extent Product
Benefit of Post Processing Steps – Case 1: Mountainous Terrain

- **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

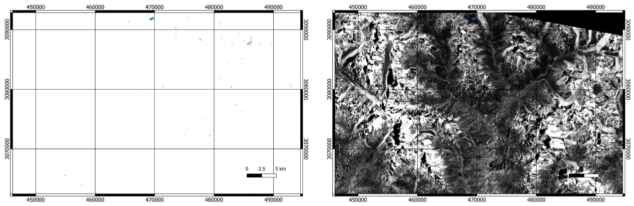


The HydroSAR HYDRO30 Surface Water Extent Product
Benefit of Post Processing Steps – Case 1: Mountainous Terrain

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

False alarms removed by Fuzzy logic post processing

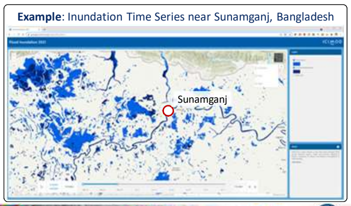
HYDRO30 Product Nepal
After Post Processing



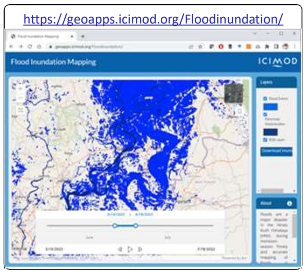
The HydroSAR / ICIMOD Flood Inundation Service
Coverage: Bangladesh, Northern India, Southern Nepal, Southern Bhutan

- 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

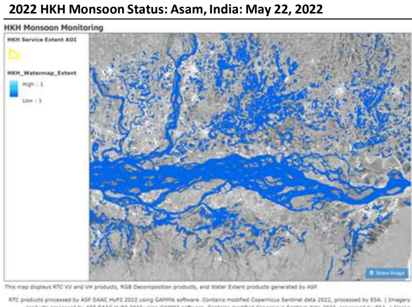
Example: Inundation Time Series near Sunamganj, Bangladesh



https://geoapps.icimod.org/Floodinundation/



Recent HYDRO30 Examples
2022 HKH Monsoon Status: Asam, India: May 22, 2022



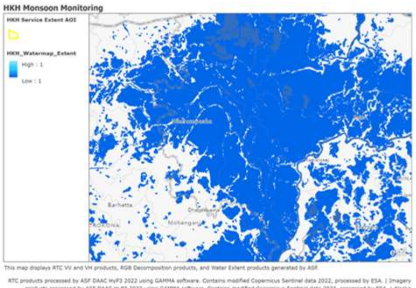
This map displays RTC VV and VH products, RGB Decomposition products, and Water Extent products generated by ASF.

RTC products processed by ASF DAAC HyP3 2022 using GAMMA software. Contains modified Copernicus Sentinel data 2022, processed by ESA. | Imagery products processed by ASF DAAC HyP3 2022 using GAMMA software. Contains modified Copernicus Sentinel data 2022, processed by ESA. | Alaska Satellite Facility | Esri, © OpenStreetMap contributors, HERE, Garmin, METI/NASA, USGS

Nearly 90,000 people have been moved to state-run relief shelters as water levels in rivers run high and large swaths of land remain submerged in most districts in Assam, India. [Anuwar Hazarika/Reuters]

Recent HYDRO30 Examples

2022 HKH Monsoon Status: Northern Bangladesh, May 22, 2022



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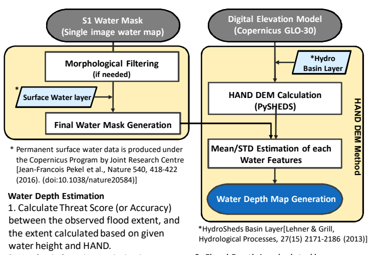
RTC products processed by ASF DAAC HyP3 2022 using GAMMA software. Contains modified Copernicus Sentinel data 2022, processed by ESA. | Imagery products processed by ASF DAAC HyP3 2022 using GAMMA software. Contains modified Copernicus Sentinel data 2022, processed by ESA. | Alaska Satellite Facility | Esri, HERE, Garmin, METI/NASA, USGS | Esri, HERE, Garmin, METI/NASA, USGS | Esri, HERE, Garmin, METI/NASA, USGS

An aerial photograph shows a large flooded area following heavy rains in Companiganj, Bangladesh. [AFP]

The HydroSAR FD30 Flood Water Depth Product

Flood Water Depth Mapping using Water Extent and HAND Information



* Permanent surface water data is produced under the Copernicus Program by Joint Research Centre [Jean-Francois Pekel et al., Nature 540, 418-422 (2016). (doi:10.1038/nature20584)]

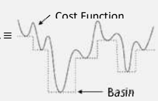
*HydroSheds Basin Layer[Lehner & Grill, Hydrological Processes, 27(15) 2171-2186 (2013)].

Water Depth Estimation

1. Calculate Threat Score (or Accuracy) between the observed flood extent, and the extent calculated based on given water height and HAND.
2. Use basin hopping optimization to find highest Threat Score (best matching height to the observed extent)
3. Flood Depth is calculated by subtracting HAND elevation from estimated water height.

Water Height Estimation

Iterative: $W.H. \equiv$



Critical Success Index (Threat Score) $\frac{TP}{TP+FP+FN}$

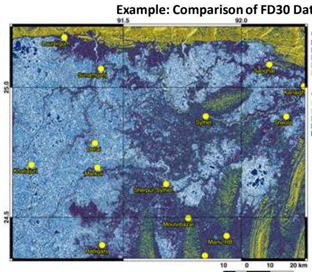
Accuracy $\frac{TP+TN}{TP+TN+FP+FN}$

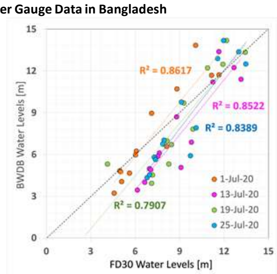
Basin Hopping [Olson et al., Advances in Artificial Intelligence, 2012, DOI:10.1155/2012/674832]

Calibration & Validation Activities

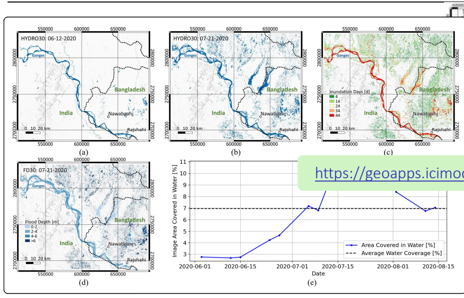
FD30 Product

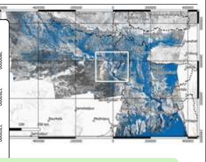
Example: Comparison of FD30 Data to River Gauge Data in Bangladesh





HydroSAR Example: 2020 South Asia Monsoon Flooding





https://geoapps.icimod.org/Floodinundation/

Figure: Examples of HydroSAR products for the 2020 South Asia monsoon floods subset shown in Figure 2: (a) minimum surface water extent (06/12/20); (b) maximum surface water extent (07/21/20); (c) number of inundation days; (d) flood depth estimate for 07/21/20; (e) change of surface water area.

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Relevant Literature

- Twele, André, Wenxi Cao, Simon Plank, and Sandro Martinis. "Sentinel-1-based flood mapping: a fully automated processing chain." International Journal of Remote Sensing 37, no. 13 (2016): 2990-3004.
- Uddin, Kabir, Mir A. Matin, and Franz J. Meyer. "Operational flood mapping using multi-temporal sentinel-1 SAR images: a case study from Bangladesh." *Remote Sensing* 11, no. 13 (2019): 1581.
- Li, Yu, Sandro Martinis, Simon Plank, and Ralf Ludwig. "An automatic change detection approach for rapid flood mapping in Sentinel-1 SAR data." *International journal of applied earth observation and geoinformation* 73 (2018): 123-135.
- Martinis, Sandro, Jens Kersten, and André Twele. "A fully automated TerraSAR-X based flood service." *ISPRS Journal of Photogrammetry and Remote Sensing* 104 (2015): 203-212.
- Amitrano, Donato, Gerardo Di Martino, Antonio Iodice, Daniele Riccio, and Giuseppe Ruello. "Unsupervised rapid flood mapping using Sentinel-1 GRD SAR images." *IEEE Transactions on Geoscience and Remote Sensing* 56, no. 6 (2018): 3290-3299.
- Tay, Cheryl WJ, Sang-Ho Yun, Shi Tong Chin, Alok Bhardwaj, Jungkyo Jung, and Emma M. Hill. "Rapid flood and damage mapping using synthetic aperture radar in response to Typhoon Hagibis, Japan." *Scientific Data* 7, no. 1 (2020): 1-9.
- Ulloa, Noel Ivan, Shou-Hao Chiang, and Sang-Ho Yun. "Flood Proxy Mapping with Normalized Difference Sigma-Naught Index and Shannon's Entropy." *Remote Sensing* 12, no. 9 (2020): 1384.
- Grimaldi, Stefania, Jin Xu, Yuan Li, Valentijn RN Pauwels, and Jeffrey P. Walker. "Flood mapping under vegetation using single SAR acquisitions." Remote Sensing of Environment 237 (2020): 111582.
- Chang, Chi-Hung, Hyongki Lee, Faisal Hossain, Senaka Basnayake, Susantha Jayasinghe, Farrukh Chishtie, David Saah, Hanwen Yu, Khem Sothea, and Duong Du Bui. "A model-aided satellite-altimetry-based flood forecasting system for the Mekong River." Environmental modelling & software 112 (2019): 112-127.
- Chang, Chi-Hung, Hyongki Lee, Donghwan Kim, Euiho Hwang, Faisal Hossain, Farrukh Chishtie, Susantha Jayasinghe, and Senaka Basnayake. "Hindcast and forecast of daily inundation extents using satellite SAR and altimetry data with rotated empirical orthogonal function analysis: Case study in Tonle Sap Lake Floodplain." Remote Sensing of Environment 241 (2020): 111732.

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Launch Flood Mapping Notebook

- **Want to Try this on OpenSARLab?**
  - **Staged Data set**: *notebooks/SAR_Training/English/HydroSAR/Lab2-SurfaceWaterExtentMapping.ipynb*
  - **Your own data**: Look for Resources in folder *notebooks/SAR_Training/English/HydroSAR/ProcessOwnData/*
- **Try Outside OpenSARLab**: https://mybinder.org/v2/gh/asfadmin/asf-jupyter-notebooks/binder_SARHazards_Lab_Floods?filepath=SARHazards_Lab_Floods.ipynb

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