ACM SIGSPATIAL Workshop on GeoAI

The Remote Sensing of Floods

Ronny Hänsch

Sustainable Development Goals (SDGs)

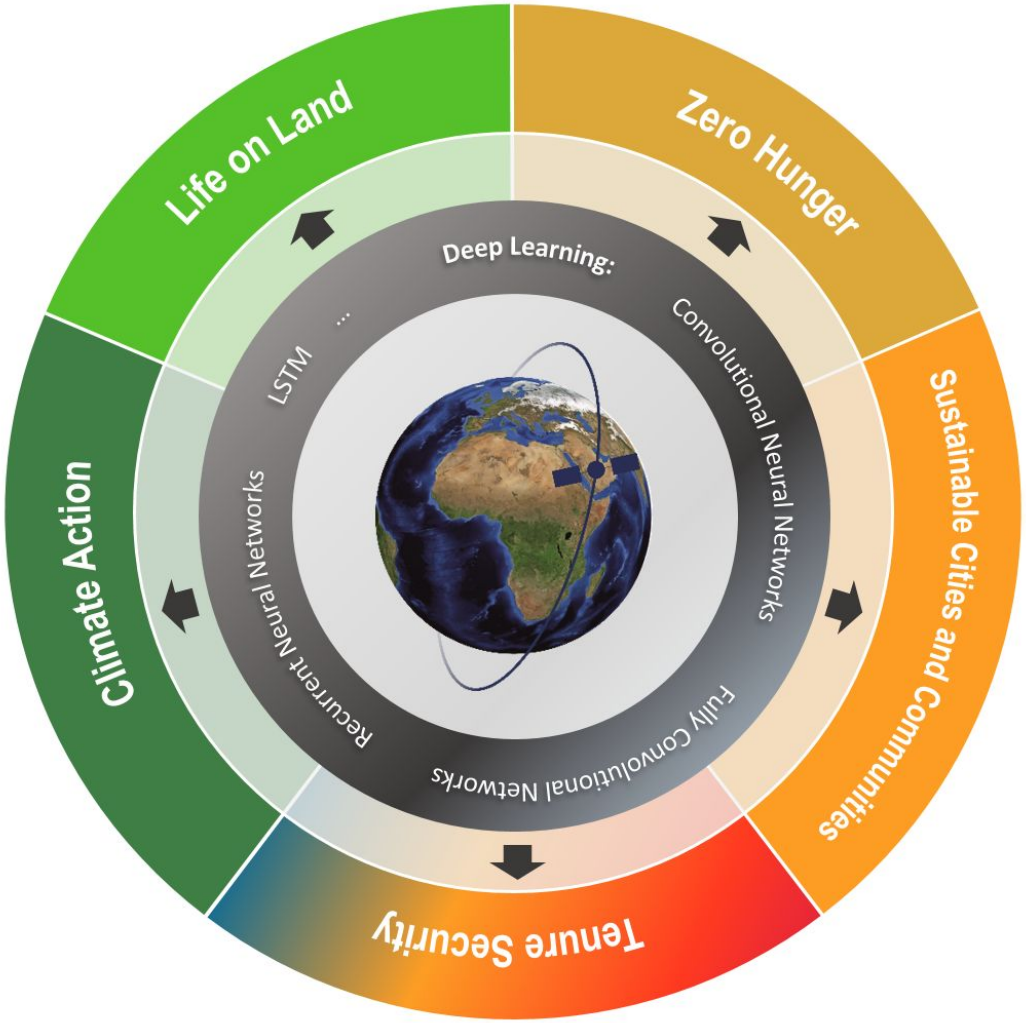
- Data-driven framework defined by the United Nations
- Set of seventeen goals representing actions to reach peace and prosperity for all people by 2030
  → Social, economic, and environmental challenges
- 169 targets and 232 indicators to measure, monitor, and report the progress

“If you can’t measure it, you can’t manage it!”

⇒ Need for objective, accurate and trustworthy information.

SDGs and EO

- Continuous temporal information over the globe
- Data at multiple scales
- Monitors the state of natural ecosystems, natural resources, oceans, coasts, land, built infrastructure and their change over time
- Spatially and temporally consistent
- Complementary with traditional statistical methods (e.g. household surveys and administrative data)



C. Persello et al., "Deep Learning and Earth Observation to Support the Sustainable Development Goals: Current approaches, open challenges, and future opportunities," in IEEE Geoscience and Remote Sensing Magazine, vol. 10, no. 2, pp. 172-200, June 2022

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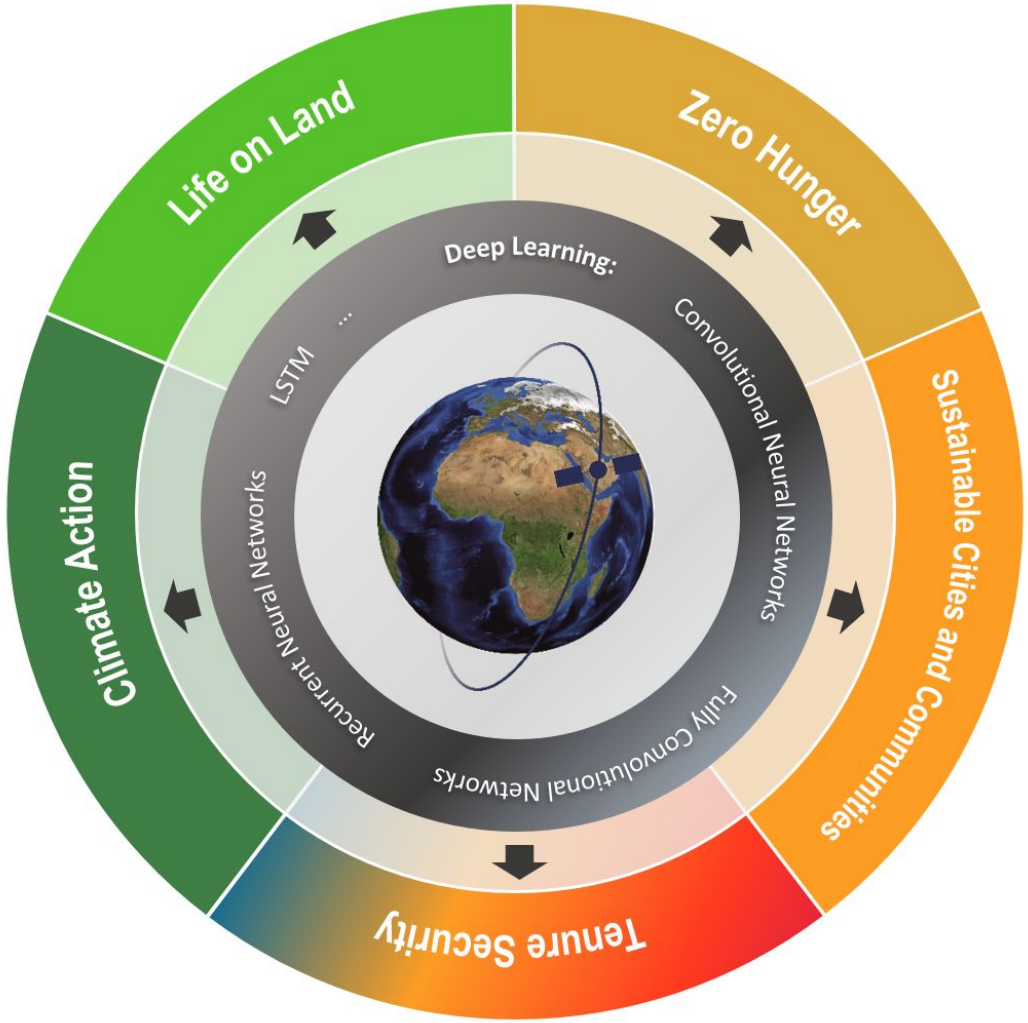
- 34 SDG indicators across 29 targets and 11 goals can be informed with EO data
- Effective comparison among different countries
- Reduce the cost of monitoring SDG targets



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SDGs and EO

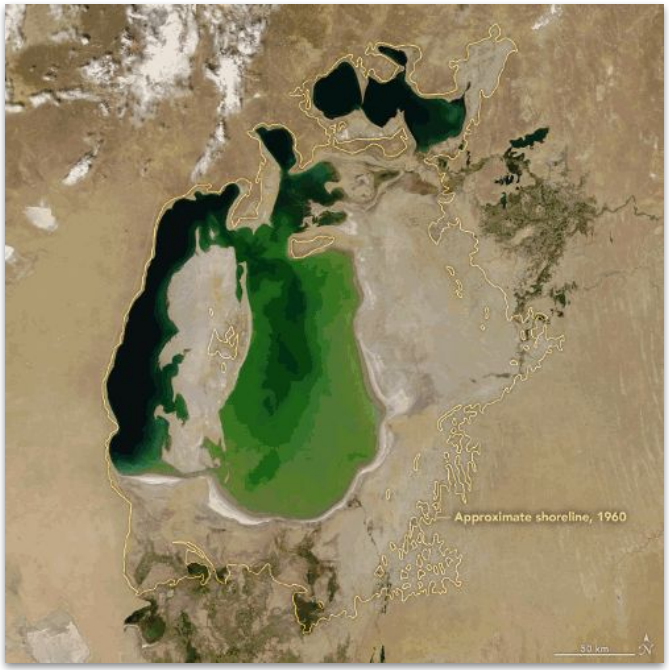
Monitoring of extreme events and quantifying their socioeconomic impacts

Urbanization
Shanghai 1984-2019

https://earthobservatory.nasa.gov/world-of-change/Shanghai

Deforestation
Amazon 2000-2012

https://earthobservatory.nasa.gov/world-of-change/Deforestation/



Drought
Aral Sea 2000-2018

https://earthobservatory.nasa.gov/world-of-change/AralSea/

SDGs and Floods

2.4.1: Adaptation to climate change, extreme weather, drought, flooding and other disasters

11.b.2: Disaster risk reduction
11.5.1: Reduced number of deaths related to disasters
11.5.3: Mitigate disaster damage to infrastructure

15.3.1: Maps of deserts and degraded land, prediction of drought and floods

Why floods?

- Danger to human lives
- Damage to buildings and infrastructure
- Costs for cleanup and rebuilding
- Power outages
- Disrupts transportation
- Landslides and erosion of arable land
- Environmental hazards

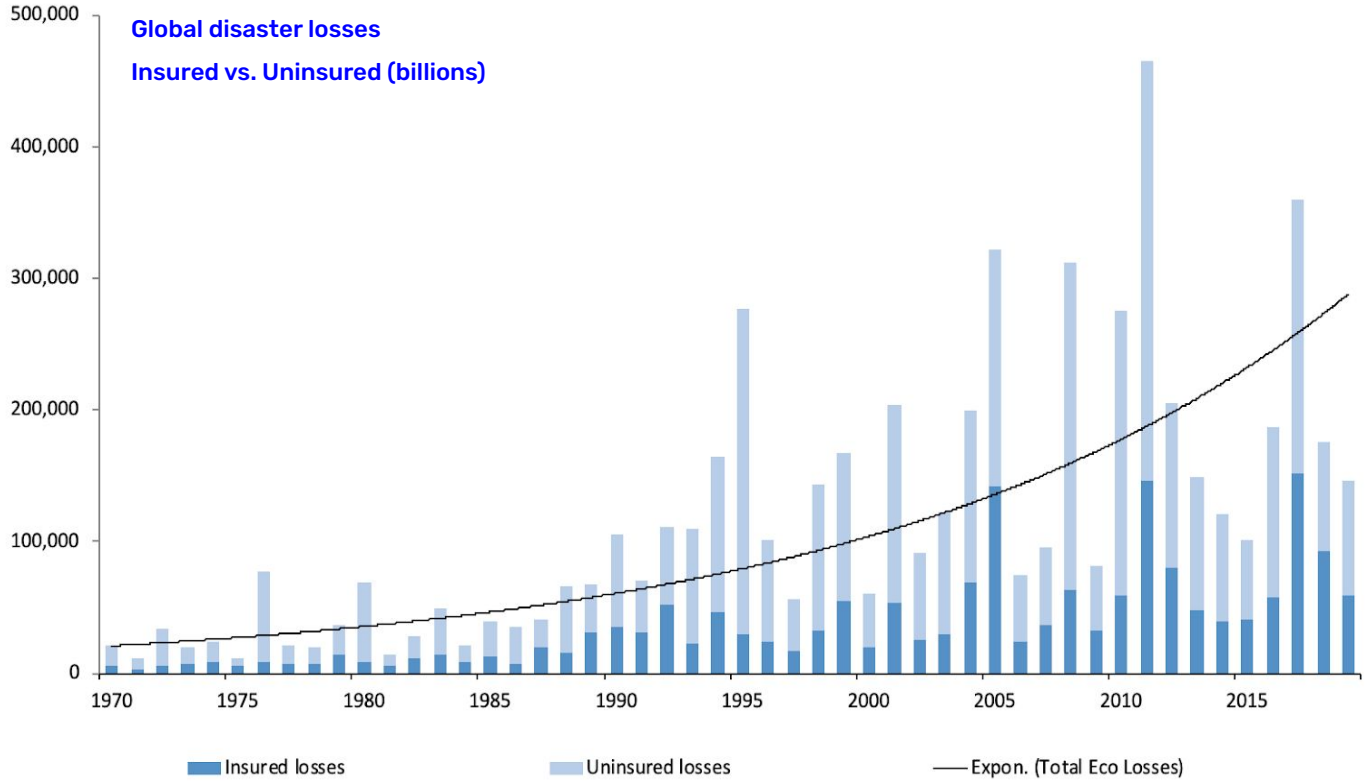
Why floods?

- Most common disaster
- Affect more people than all other natural disasters combined.

- 223 of 432 catastrophic events in 2021 were floods[1]
- 163 of 357 annual catastrophic events on average in 2000-2020

- 2.23 million km² flooded and 255-290 million people affected in the last 15 years

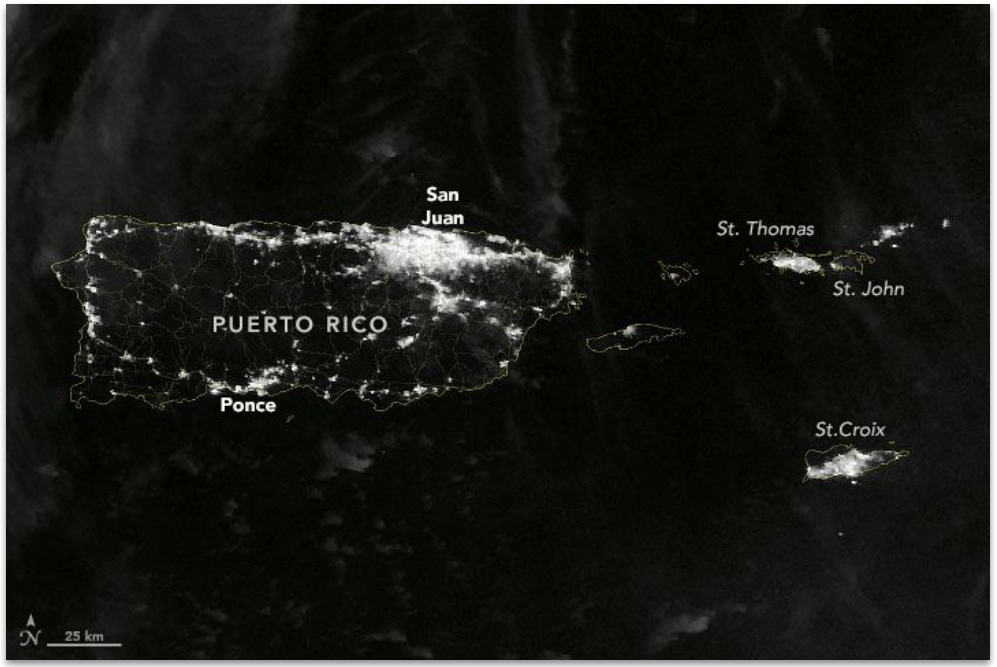
- $80 billion economic loss from floods in 2021[2]



1 https://reliefweb.int/report/world/2021-disasters-numbers
2 Source: The World Bank, Swiss Re Institute
3 Figure with courtesy S.Chakrabarti, Cloud2Street (Source: SwissRe Institute)

Satellites and Sensors

- Global Precipitation Measurement (GPM) Mission
- Soil Moisture Active Passive (SMAP)
- Terrain Data From Shuttle Radar Topography Mission (SRTM)
- Terra / Aqua and MODIS Sensor
- Suomi National Polar Partnership (SNPP); Visible Infrared Imaging Radiometer Suite (VIIRS)
  - 1-2 observations per day
  - 22 spectral bands
  - Spatial resolution: 375 – 750 m



Power outages in Puerto Rico after Hurricane Fiona mid-September 2022
(Imagery courtesy of W. Straka, SSEC/CIMSS)

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- Landsat 1-9

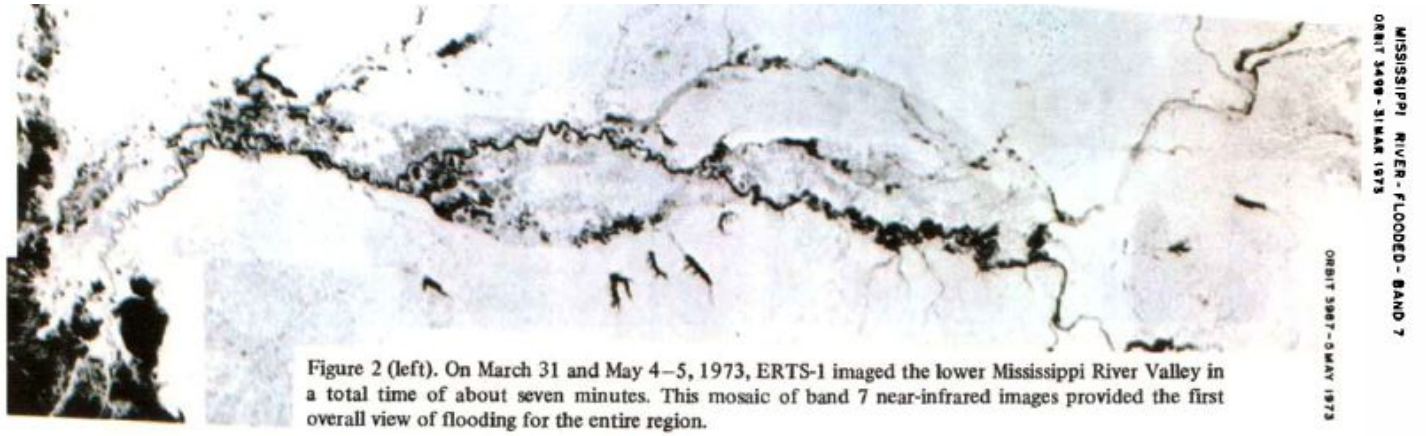

Figure 2 (left). On March 31 and May 4–5, 1973, ERTS-1 imaged the lower Mississippi River Valley in a total time of about seven minutes. This mosaic of band 7 near-infrared images provided the first overall view of flooding for the entire region.

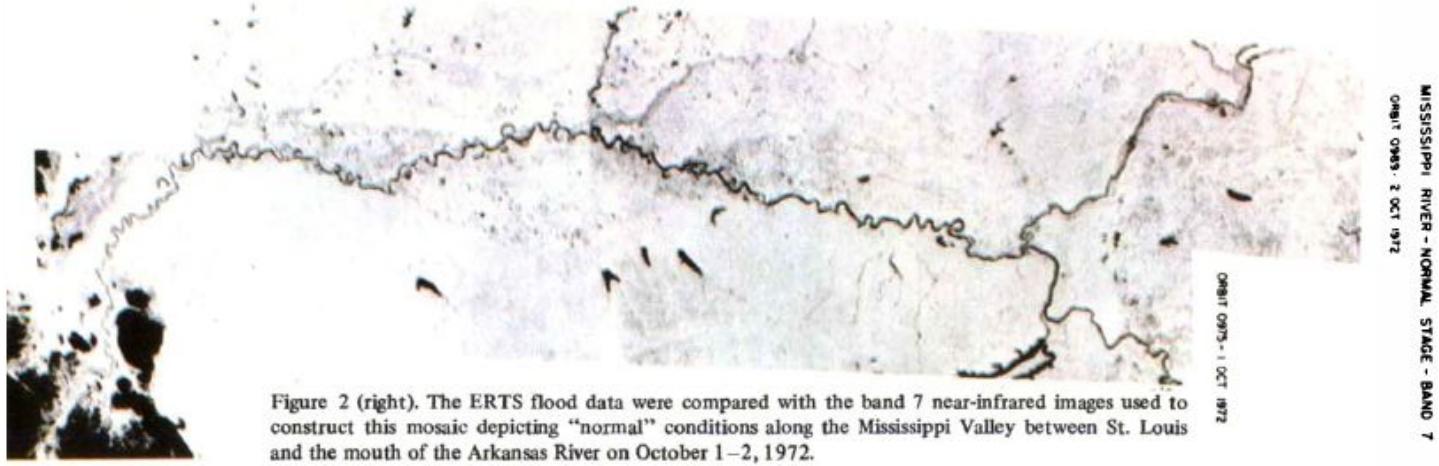

Figure 2 (right). The ERTS flood data were compared with the band 7 near-infrared images used to construct this mosaic depicting "normal" conditions along the Mississippi Valley between St. Louis and the mouth of the Arkansas River on October 1–2, 1972.

One of the first flood events captured from space (by Landsat 1 aka ERTS-1):
→ Mississippi floods, March / May 1973

Deutsch, M. and Ruggles, F. (1974), "Optical data processing and projected applications of the ERTS-1 imagery covering the 1973 Mississippi river valley floods", JAWRA Journal of the American Water Resources Association, 10: 1023-1039

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- Landsat 1-9
- Other optical satellites (e.g WorldView)

MAXAR

EVENTS FROM 2022

EVENT	DATE
Hurricane Fiona	Sept. 19, 2022
Sudan Flooding	Aug. 22, 2022
The Gambia Flooding	Aug. 09, 2022
Kentucky Flooding	July 29, 2022
Pakistan Flooding	July 26, 2022
Bangladesh Flooding	June 22, 2022
Afghanistan Earthquake	June 21, 2022
Yellowstone Flooding	June 15, 2022
South Africa Flooding	April 13, 2022
Tropical Storm Megi	April 10, 2022
Brazil Flooding	April 06, 2022
Louisiana Tornadoes	March 23, 2022

https://www.maxar.com/open-data

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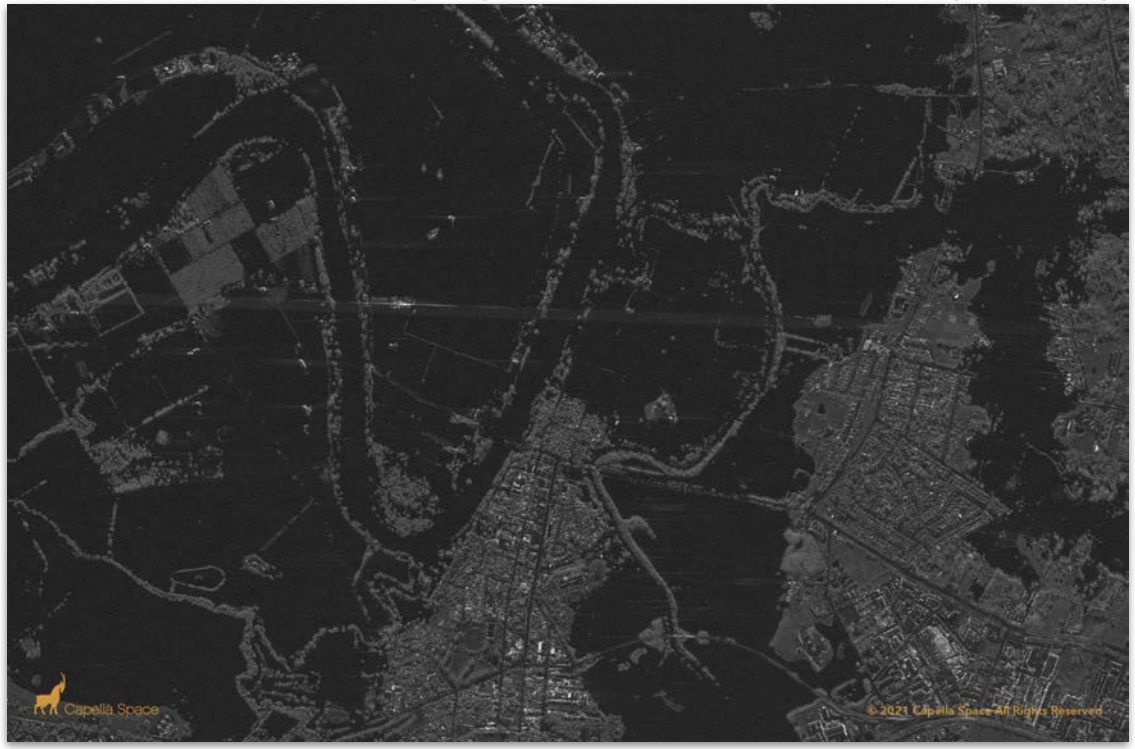
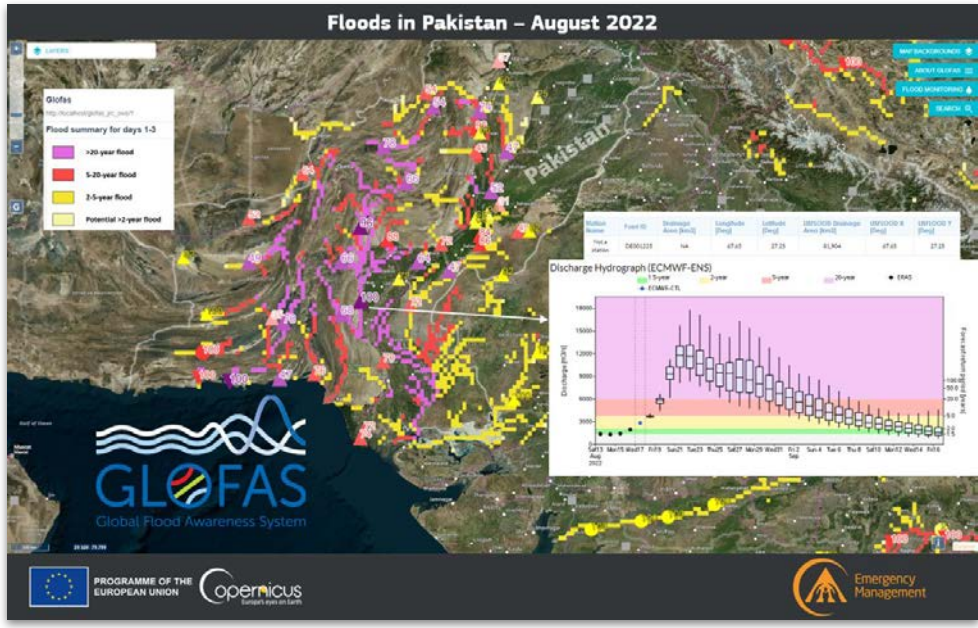
- Landsat 1-9
- Other optical satellites
- SAR (Sentinel 1, TSX/TDX, RadarSAT, Cosmo-SkyMed, Capella Space, Iceye, …)
  - Daylight independent
  - Penetrate clouds
  - Sensitive for surface roughness and permittivity (moisture)



2021 New South Wales Floods, Australia, https://www.capellaspace.com/gallery/

Services

- MODIS NRT Global Flood Mapping and NASA Worldview
- Dartmouth Flood Observatory (DFO River Watch)
- HYDrologic Remote Sensing Analysis for Floods (HYDRAFloods)
- European Flood Awareness Systems (EFAS)
- Global Flood Awareness System (GloFAS)
  - Operational global hydrological forecasting and monitoring
  - Acquisition of satellite images can be pre-tasked



Services

- Global Flood Monitoring
  - Operational, near real-time service
  - Continuous, global, automated satellite-based monitoring
  - All incoming Sentinel-1 images are analysed by 3 flood detection algorithms
  - Provides
    - Observed flood extent
    - Observed water extent
    - Reference water mask
    - Exclusion mask
    - Uncertainty values
    - Affected population
    - Affected land cover

Services (Industry): Floodbase (formerly Cloud to Street)

FLOODBASE

https://www.floodbase.com/

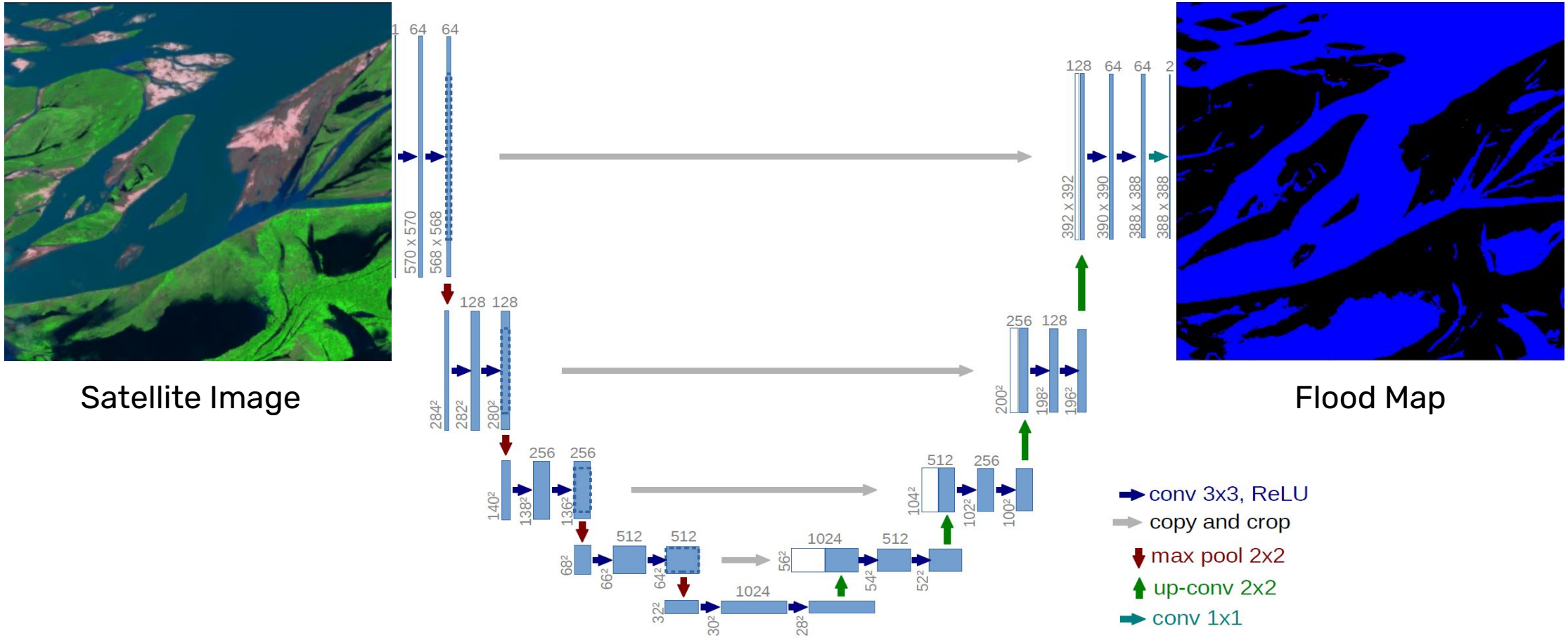
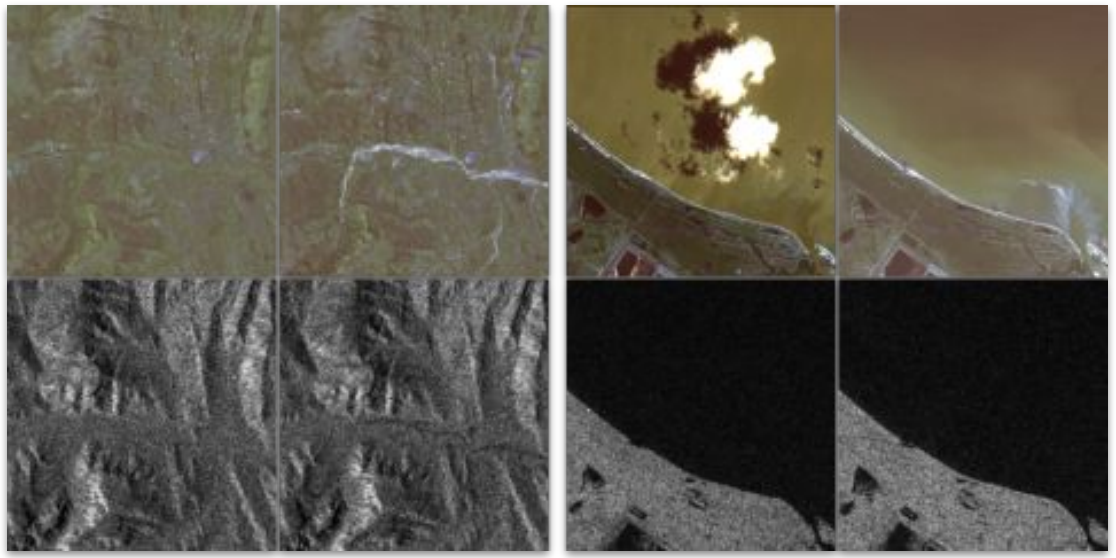


Figure courtesy S.Chakrabarti, Cloud2Street

Datasets

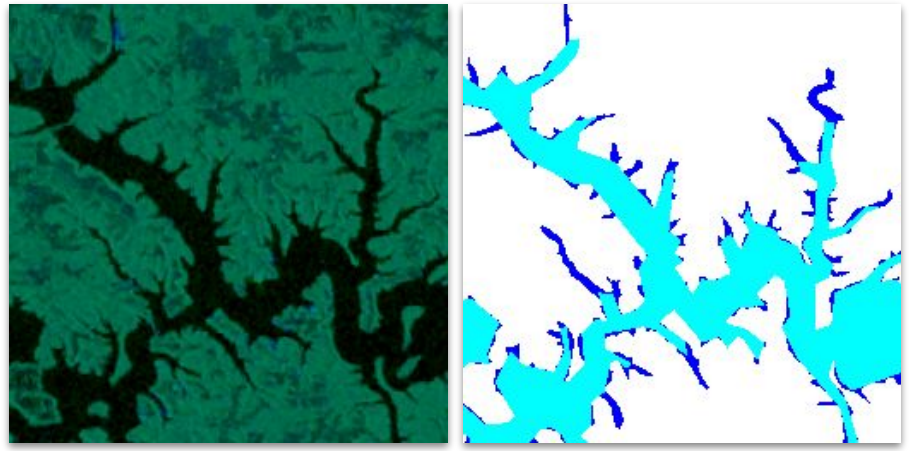
Sen12-FLOOD

- Sentinel 1&2 images
- 412 time series (~9 optical, ~14 SAR images)
- Flood event in ~45\% of the cases
- Flood label only on image level



Flood Extent Detection

- More than 30k Sentinel 1 image patches (256 x 256)
- https://nasa-impact.github.io/etci2021/



IMPACT
Interagency Implementation and Advanced Concepts Team

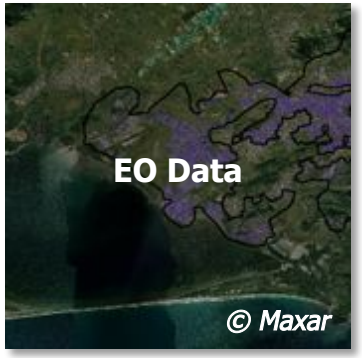
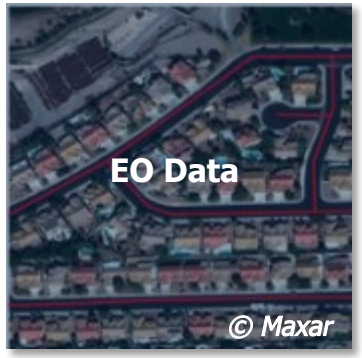
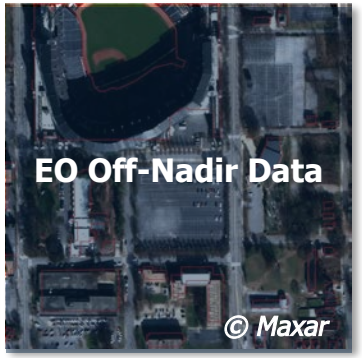
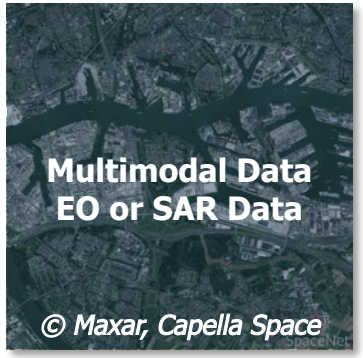
NASA

DLR

Datasets: SpaceNet

- Founded by In-Q-Tel Labs' CosmiQ Works and Maxar Technologies in August 2016
- Partners: Maxar, IEEE GRSS, AWS, Topcoder, and Oak Ridge National Laboratory
- Web: www.spacenet.ai Twitter: @Spacenet_AI
- AWS: registry.opendata.aws/spacenet

SpaceNet 8 – Motivation

SpaceNet 1 11/2016 – 1/2017	SpaceNet 2 6/2017 – 8/2017	SpaceNet 3 11/2017 – 2/2018	SpaceNet 4 10/2018 – 1/2019	SpaceNet 5 9/2019 – 10/2019	SpaceNet 6 3/2020 – 5/2020	SpaceNet 7 8/2020 – 10/2020
						
Building Footprint Detection	Building Footprint Detection	Road Extraction & Routing	Building Footprint Detection	Road Extraction, Routing & Times	Building Footprint Detection	Building Footprint Detection & Tracking

Build upon previous challenges …

… but go beyond pure foundation mapping

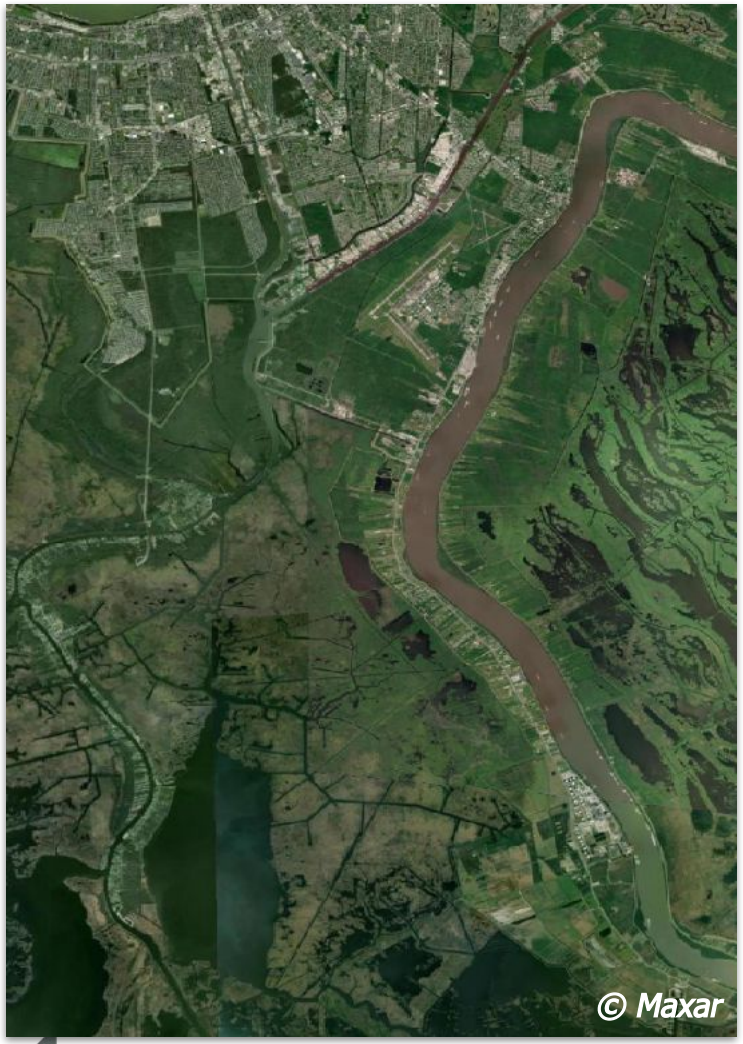
SpaceNet 8 – Task

- Detect the impact of floods on buildings and roads
  - Accurately map pre-event infrastructure and identify post-event flood attributes
  - New dataset released for three AOIs
  - Featured in the CVPR 2022 EarthVision Workshop

- Challenge hosted on Topcoder
  - $50,000 in total prizes
  - Awards to top 5 overall teams
  - Plus, top undergrad & grad academic teams

Germany AOI
GeoEye-1 | July 18, 2021

SpaceNet 8 – Louisiana AOI



SpaceNet 8 – Challenges: High Level of Detail

SpaceNet 8 – Challenges: Significant Content Change

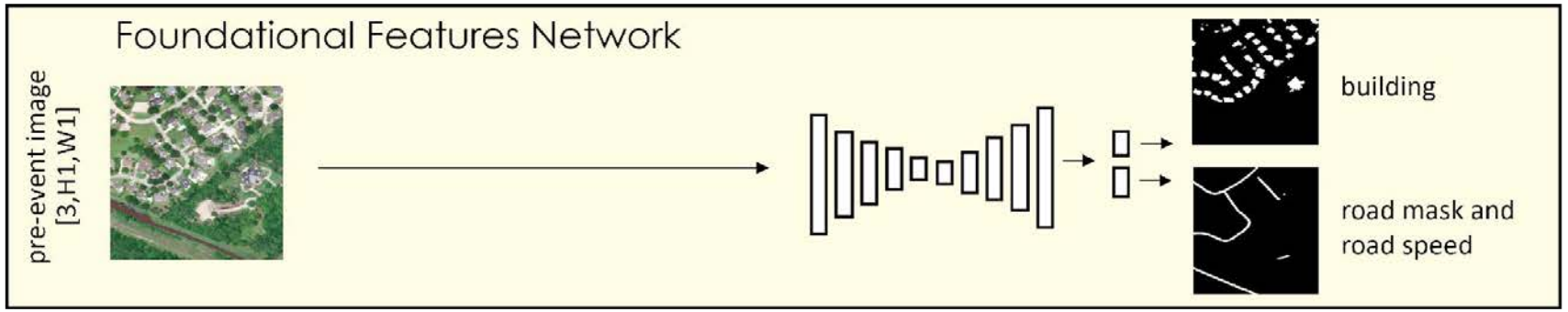
SpaceNet 8 – Challenges: Significant Content Change

SpaceNet 8 – Challenges: Significant Appearance Change

SpaceNet 8 – Challenges: Significant Appearance Change

SpaceNet 8 – Challenges: Cloud Cover

SpaceNet 8 – Baseline Algorithm



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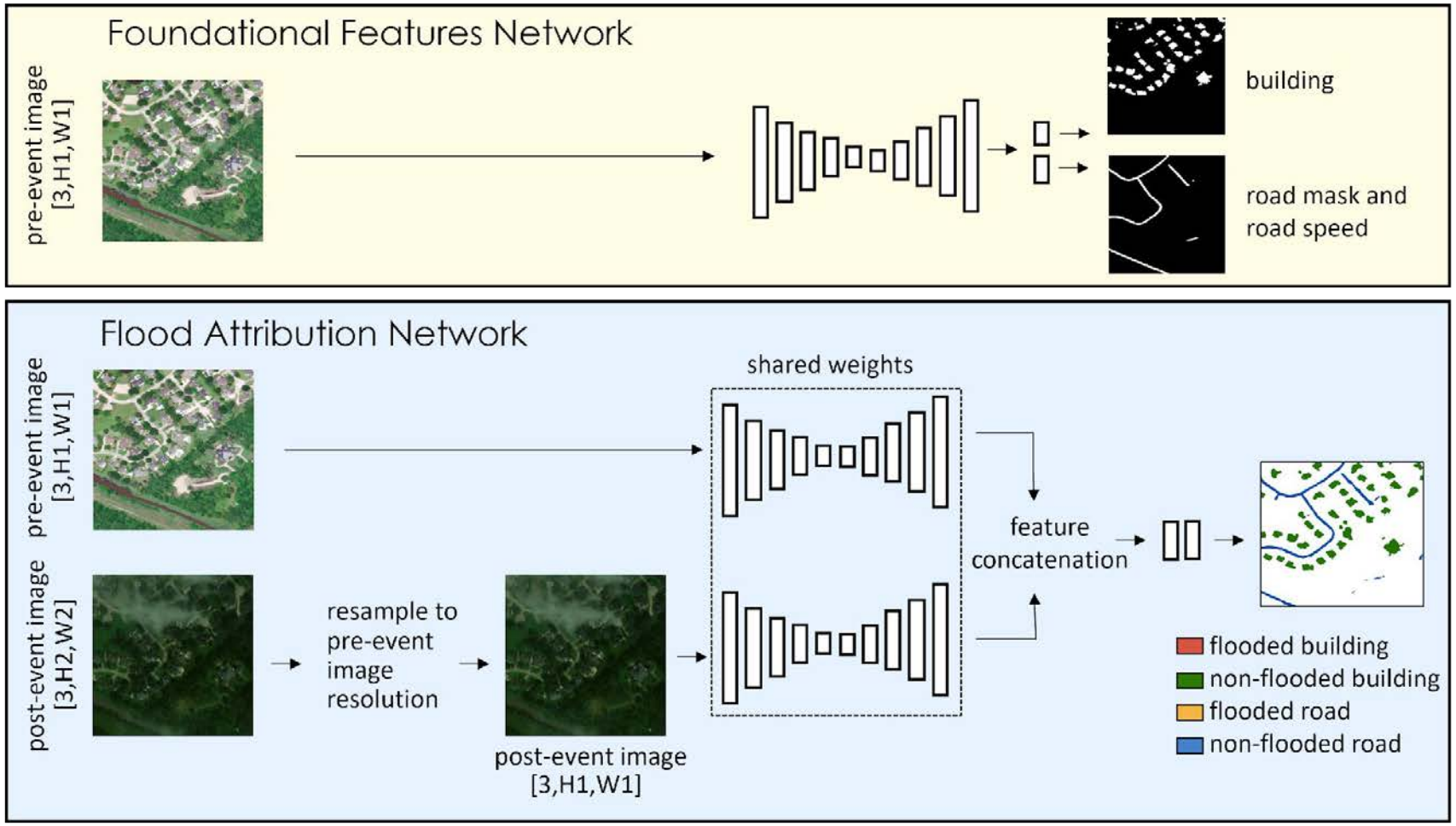

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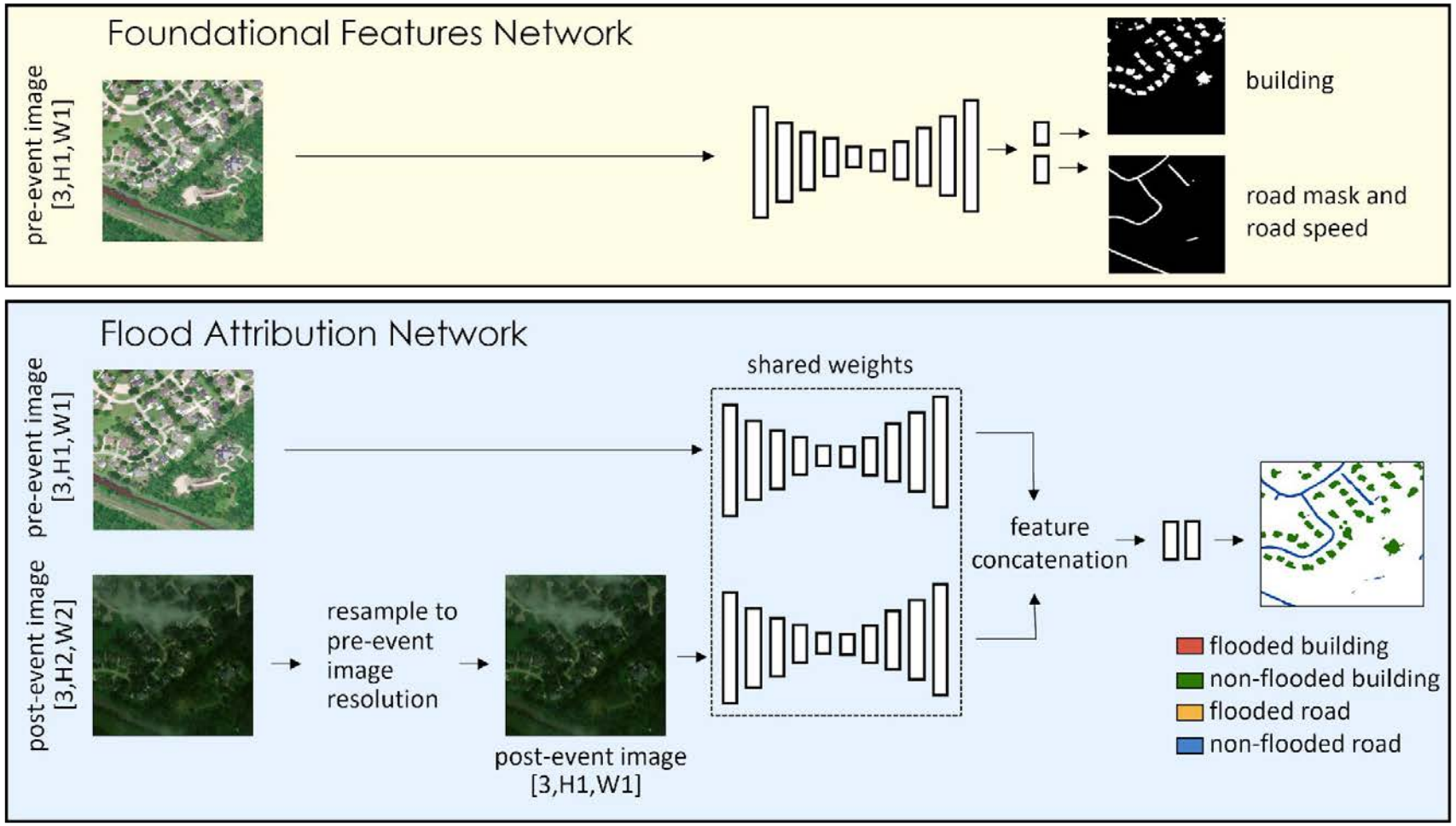
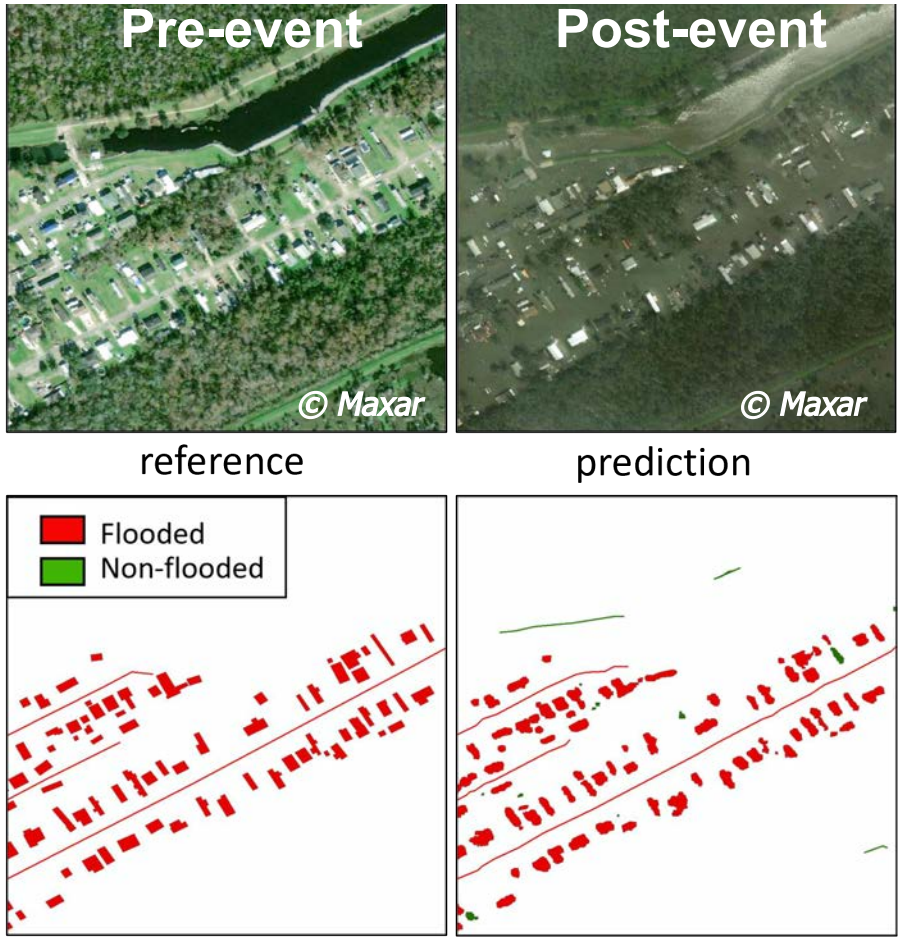


SpaceNet 8 – Evaluation

- Scoring is designed to be relevant for real-world applications
- Metrics:
  - Intersection over Union (IoU) for building footprints
  - Average Path Length Similarity (APLS) for roads
- Submitted solutions are assigned a single score composed of building damage and road networks



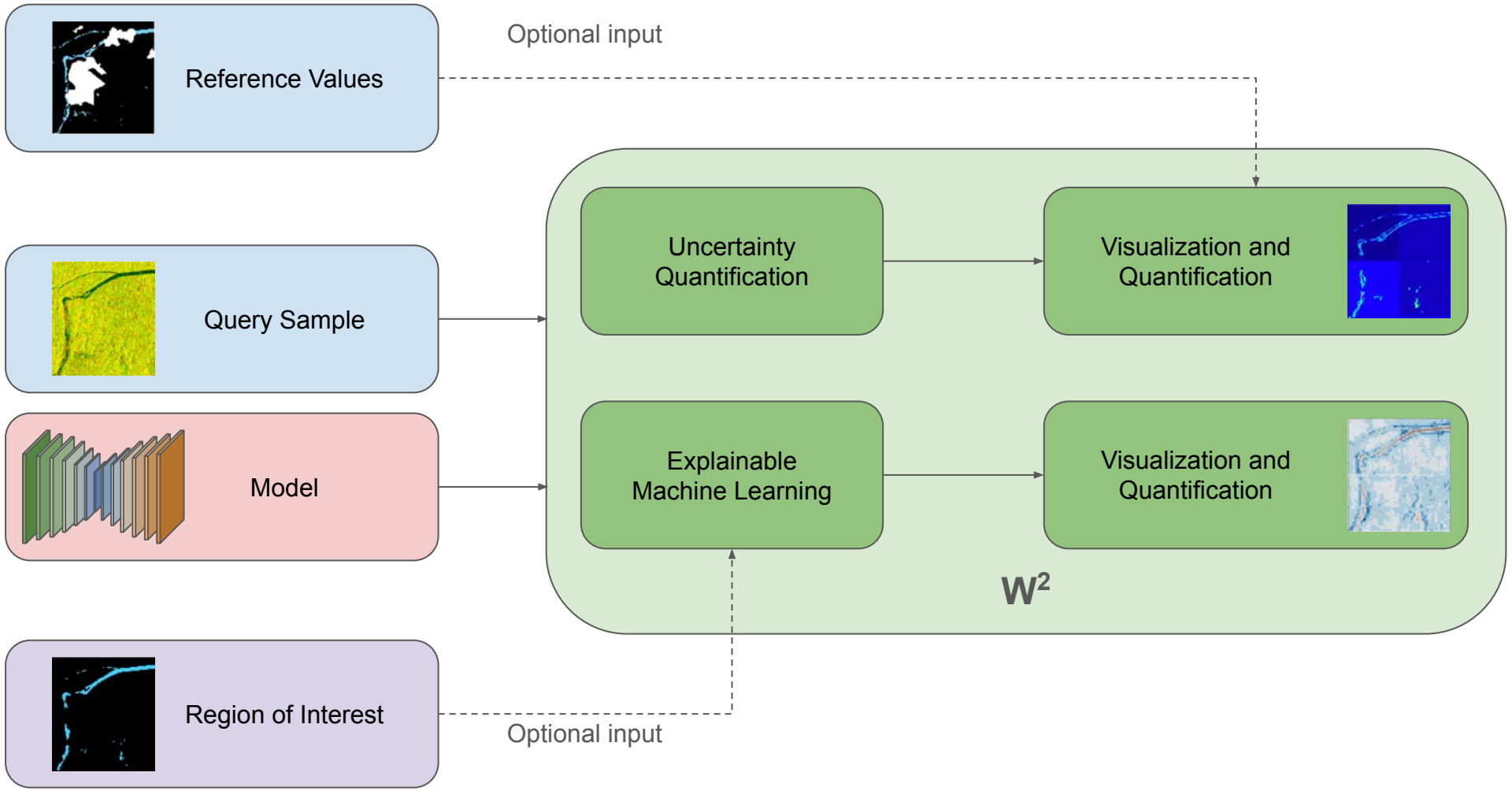
SpaceNet 8 – Results

- Run from July 12 to Aug 23 (292 registrations)

Place	Competitor	Score out of 100
1st	Ohhan777	66.998
2nd	Number13	66.242
3rd	SIAnalytics	65.852
4th	Zaburo	65.520
5th	Motokimura	64.828
Baseline	N/A	44.341

- Dominating factors were
  - data augmentation,
  - pre-training (incl. previous SN data),
  - neural network ensembles,
  - and U-Nets.

Uncertainty Quantification and Explainability



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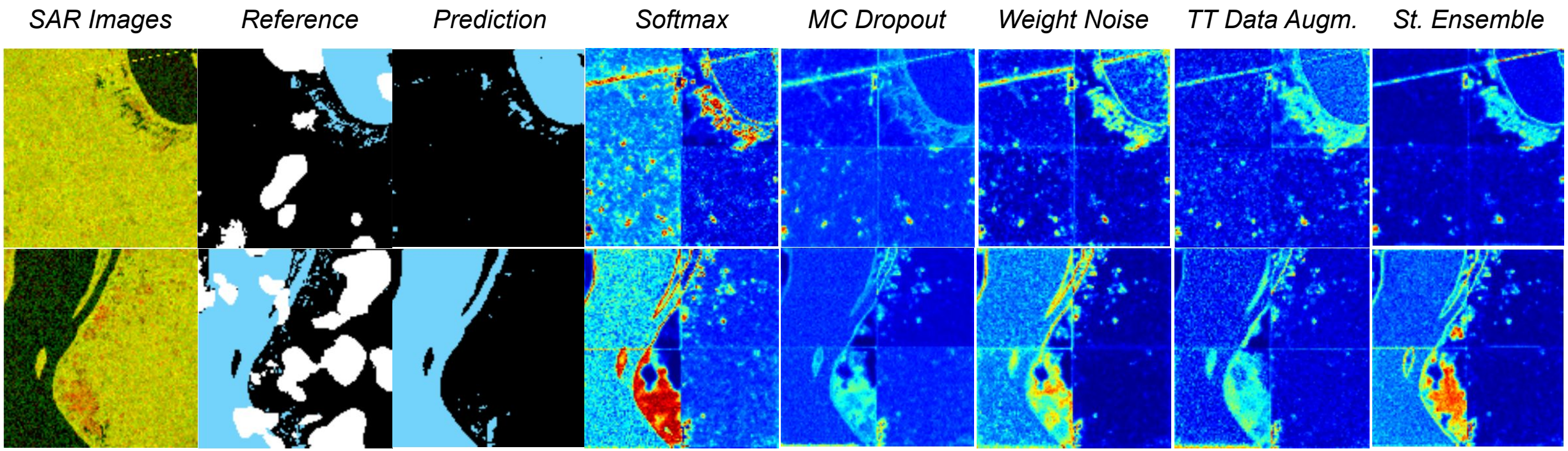
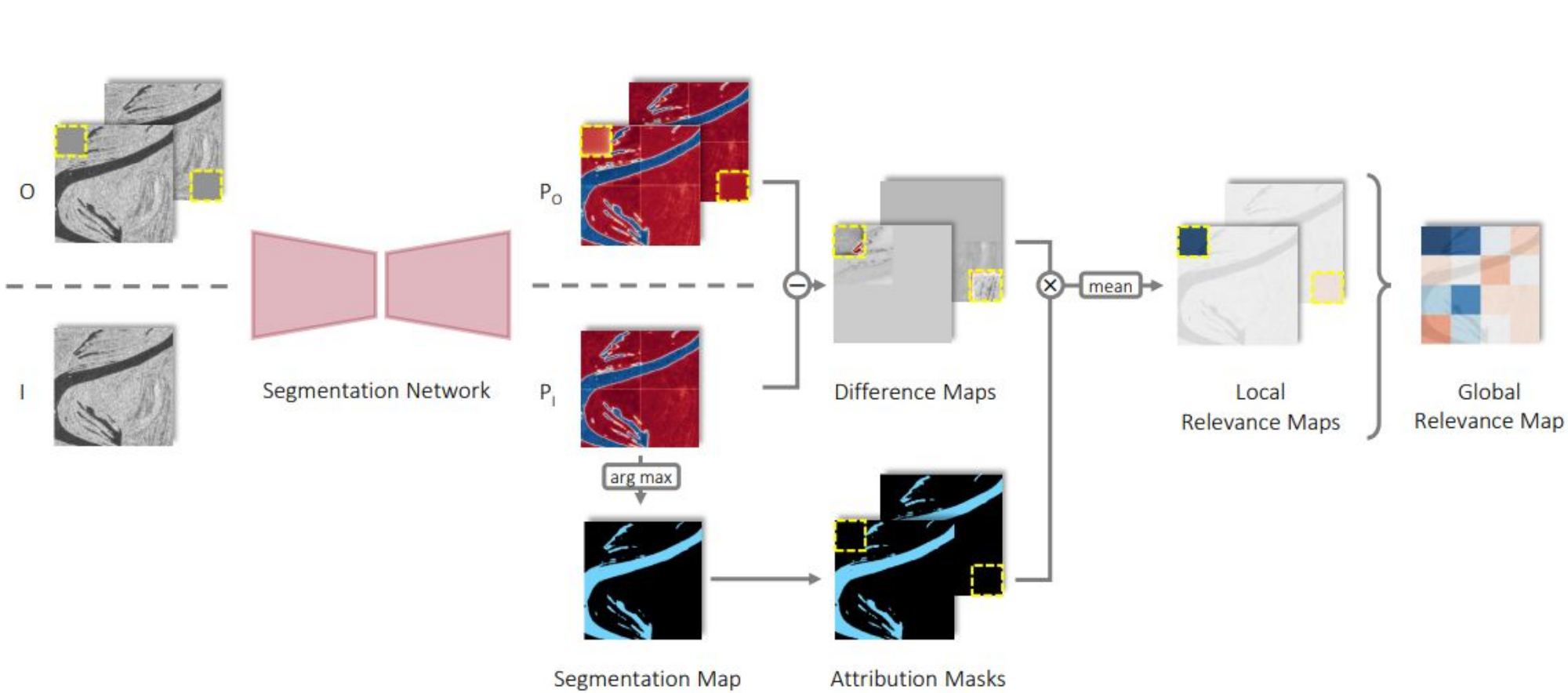
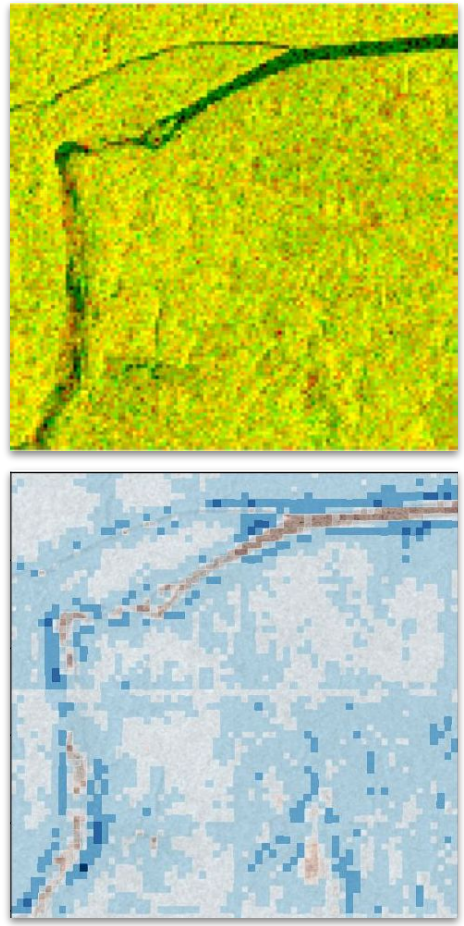


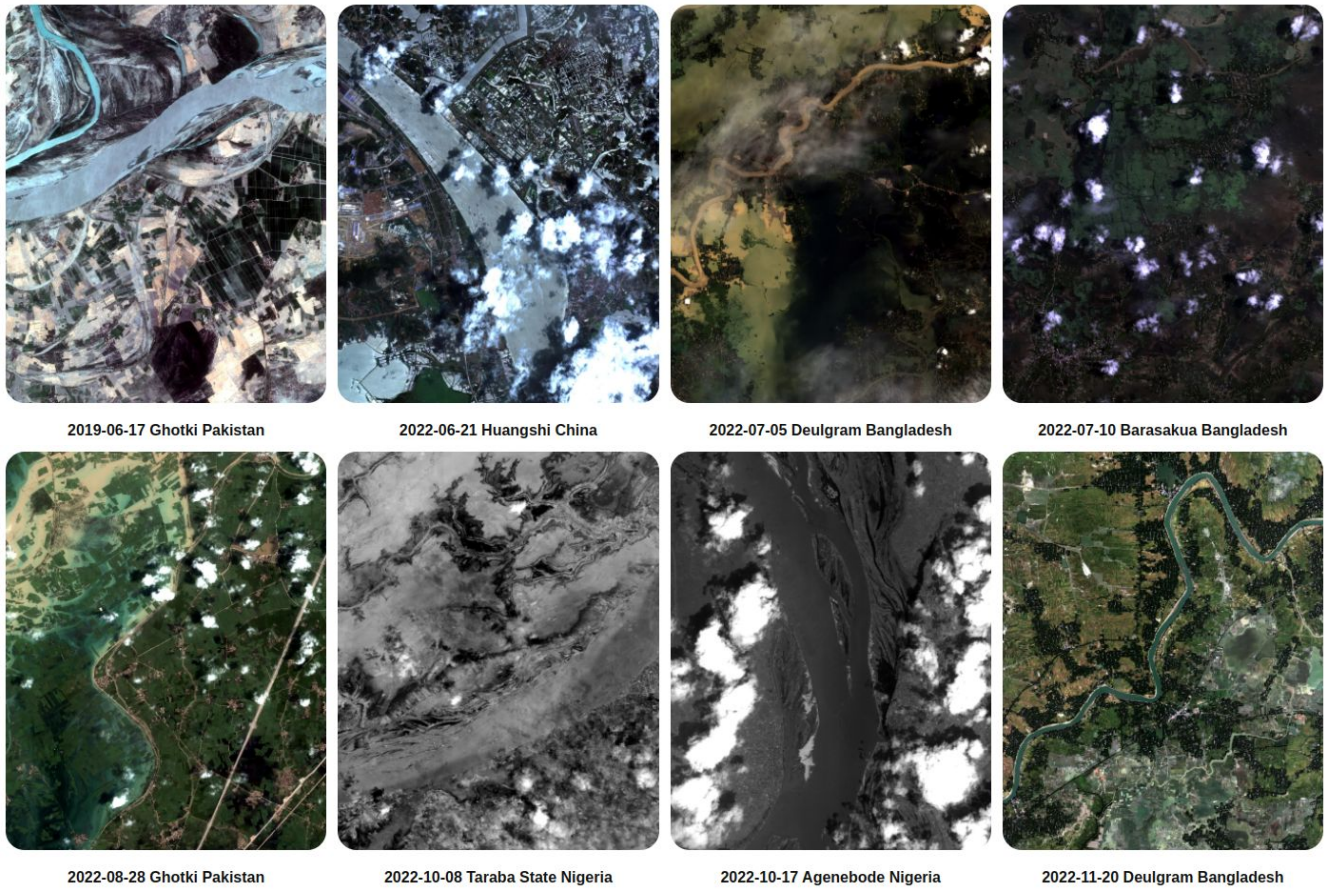
Explainability





AI Powered Flood Mapathon

- Eight different flood events with pre- and post-event (optical) imagery



www.grss-ieee.org/community/technical-committees/ai-powered-flood-mapathon/

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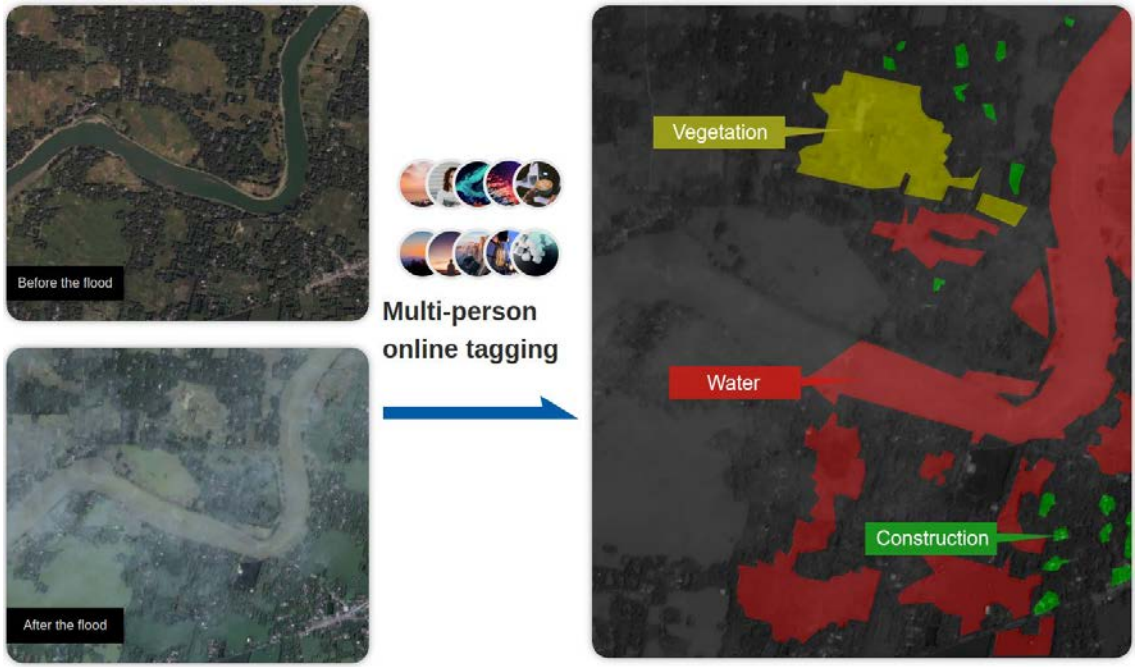
- Crowd-based ranking scheme



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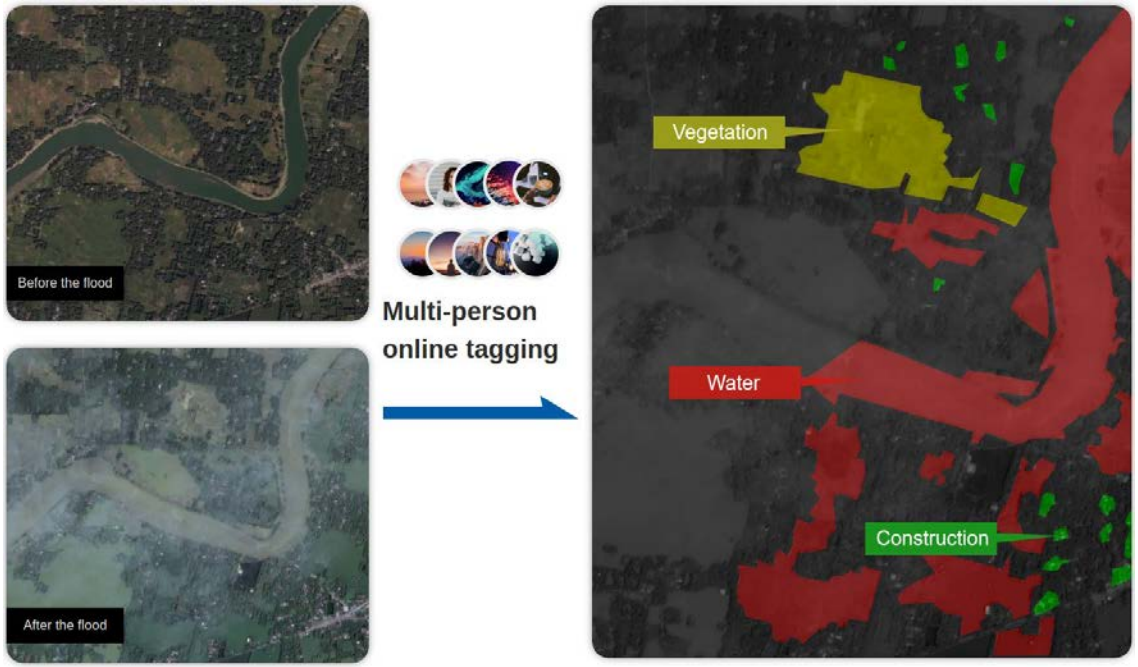
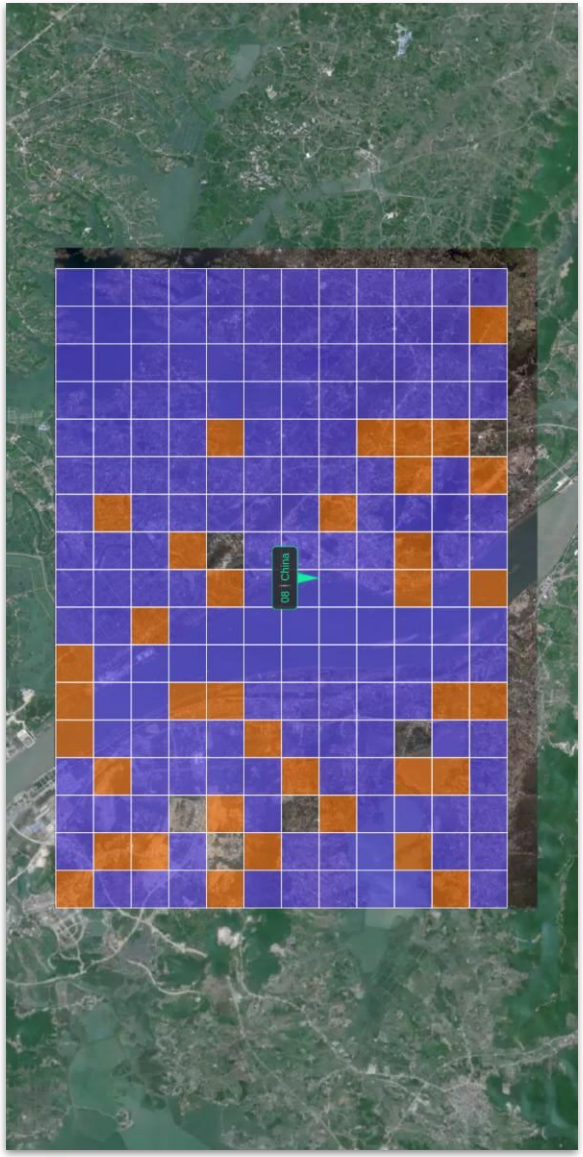
- October 16, 2023 – January 15, 2024





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- Eight different flood events
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- Crowd-based ranking scheme

- October 16, 2023 – January 15, 2024

- Best 200 participants get awarded

www.grss-ieee.org/community/technical-committees/ai-powered-flood-mapathon/

Summary

- Floods are one of the most common and severe disasters
- Cause loss of life, destruction of infrastructure, damage to buildings, environmental hazards
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- Detection, now- and forecasting, monitoring, response, damage assessment, etc. require a multitude of data
- Remote sensing plays a pivotal role
- Several public and private flood services heavily rely on EO data

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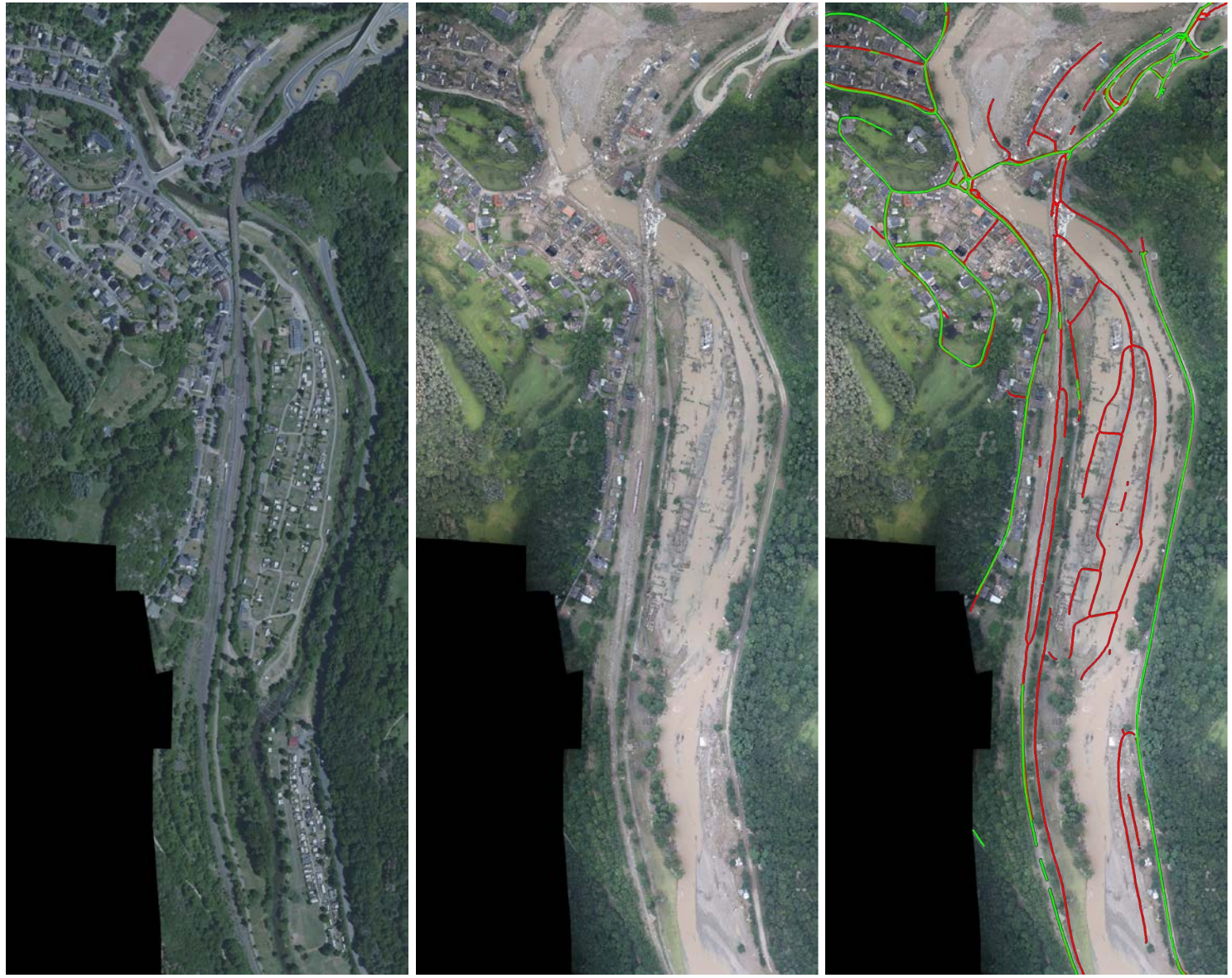
- Automatic analysis of RS imagery has not yet reached its potential
  - Fast (includes domain adaptation and cross-modal learning)
  - Reliable and accurate
  - Trustable and interpretable

Questions?



Ahr valley, Germany – 2021 – Flooding – Road segmentation
Credits: ZKI, DLR