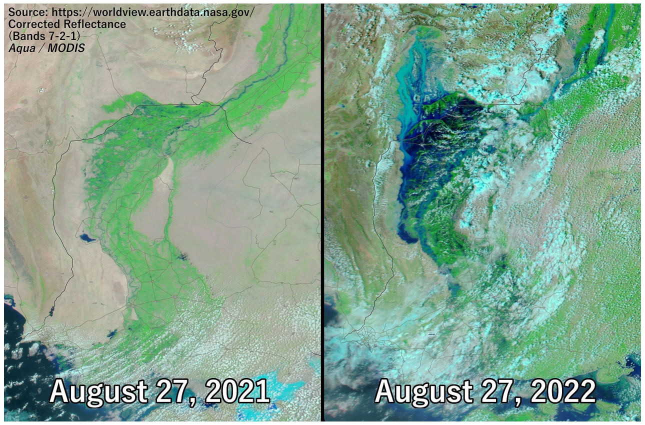
Budapest University of Technology and Economics*



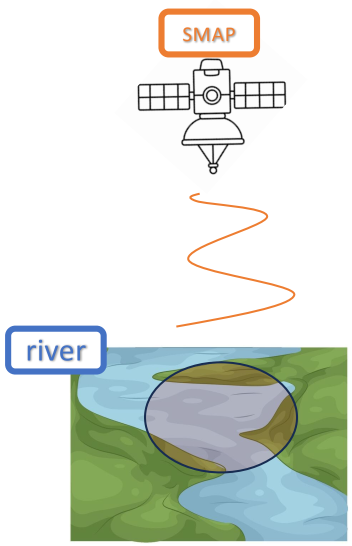
Zsófia KUGLER

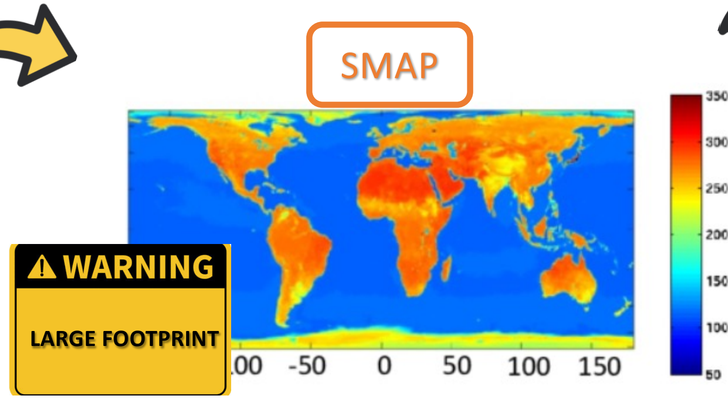
Passive microwave radiometry and OPERA DSWx for river gauge during 2022 Pakistan great flood

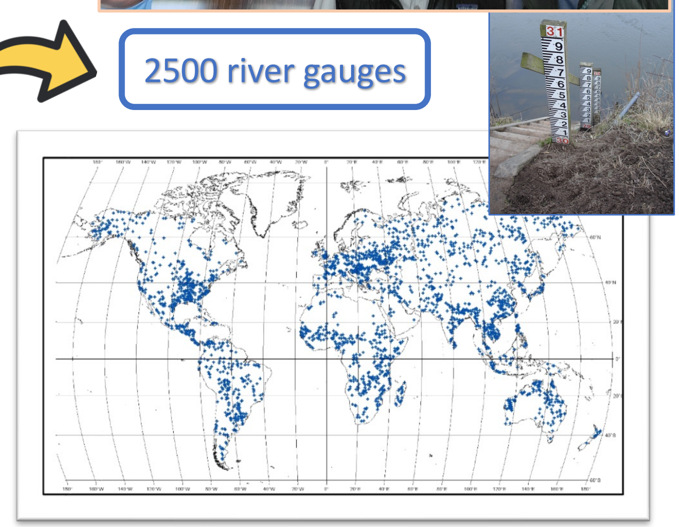
Flow data from PM satellite observations

Kugler Zsófia, BME
Son V. Nghiem NASA, JPL
Robert G. Brakenridge CU, Boulder

- Passive microwave radiometry (PMR): L-band SMAP and SMOS
- provide data for river discharge and lake water stage retrievals
- Daily, global river flow measurements around 2500 river reaches and lakes
- Decadal orbital time-series of river flow

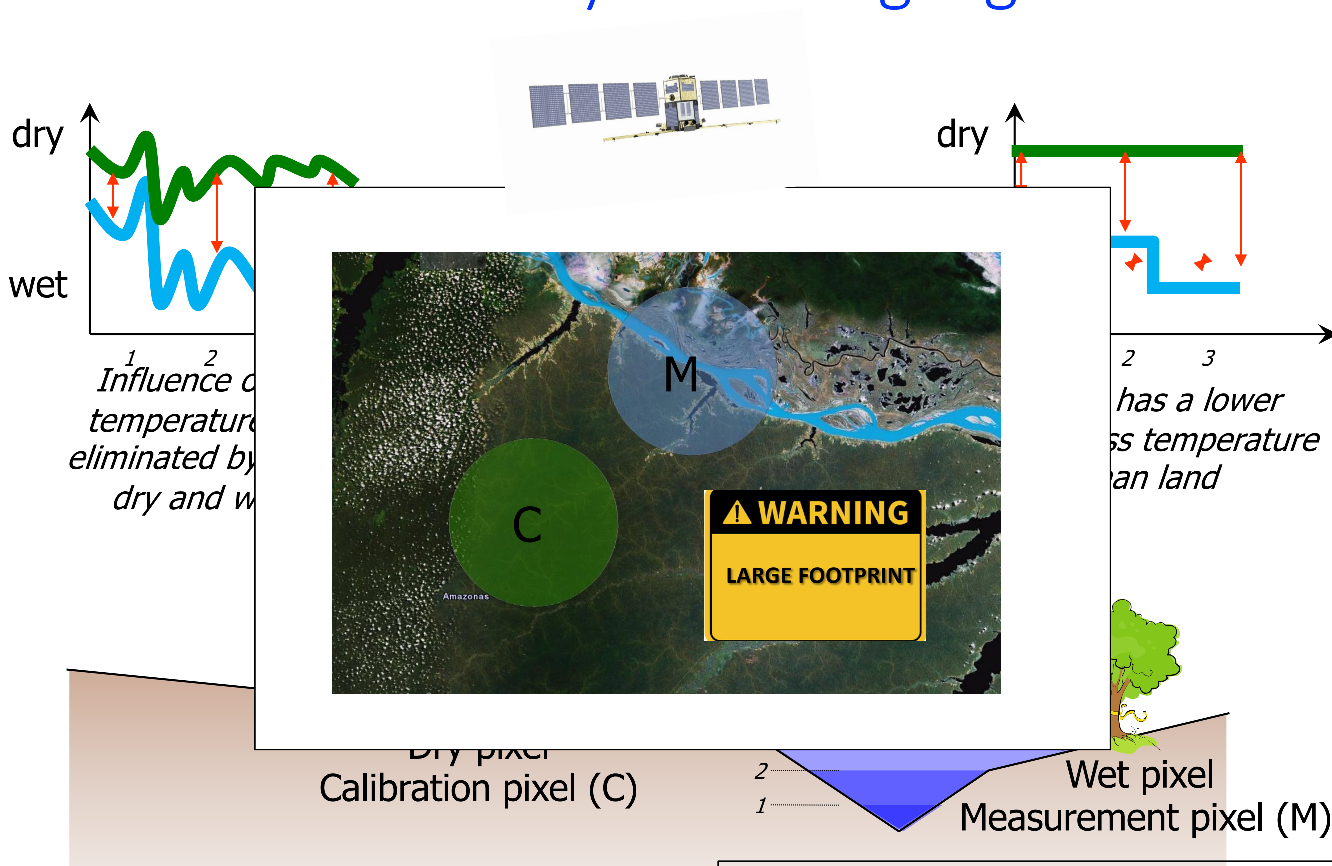






Z. Kugler, S. V. Nghiem and G. R. Brakenridge, "SMAP Passive Microwave Radiometer for Global River Flow Monitoring,“, IEEE Transactions on Geoscience and Remote Sensing, vol. 62, pp. 1-14, 2024, 10.1109/TGRS.2024.3359515

Passive microwave radiometry for river gauge? How?



Brakenridge, G. R., Nghiem, S. V., Anderson, E., & Mic, R. (2007), Orbital microwave measurement of river discharge and ice status. Water Resources Research. 43 (4). doi:10.1029/2006wr005238

Kugler, Z., De Groeve, T., Brakenridge, G. R., & Anderson. E. (2007). Towards Near-real Time Global Flood Detection System. The International Archives of Photogrammetry and Remote Sensing, XXXVI:(PART 7/C50), 1-8., ISSN 1682-1750

Mesurement Methods

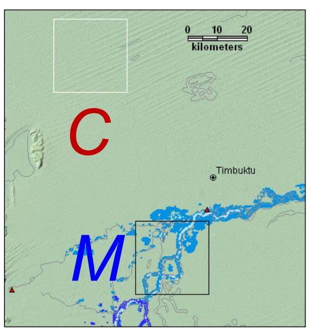
Traditional Method : Polarization Ratio

$$PR=(T_{bV}-T_{bH})/(T_{bV}+T_{bH})$$

New Method : Pair Ratio

$$HR=T_{bH}(C)/T_{bH}(M)$$

$$VR=T_{bV}(C)/T_{bV}(M)$$



M is the *M*easurement cell containing the river

C is the *C*alibration cell with no river

Brakenridge, G. R., Nghiem, S. V., Anderson, E., & Mic, R. (2007), Orbital microwave measurement of river discharge and ice status. Water Resources Research. 43 (4). doi:10.1029/2006wr005238

Emission Model Analysis for New Measurement Method

Pair Ratio H-pol: $HR = T_{bH}(C)/T_{bH}(M)$

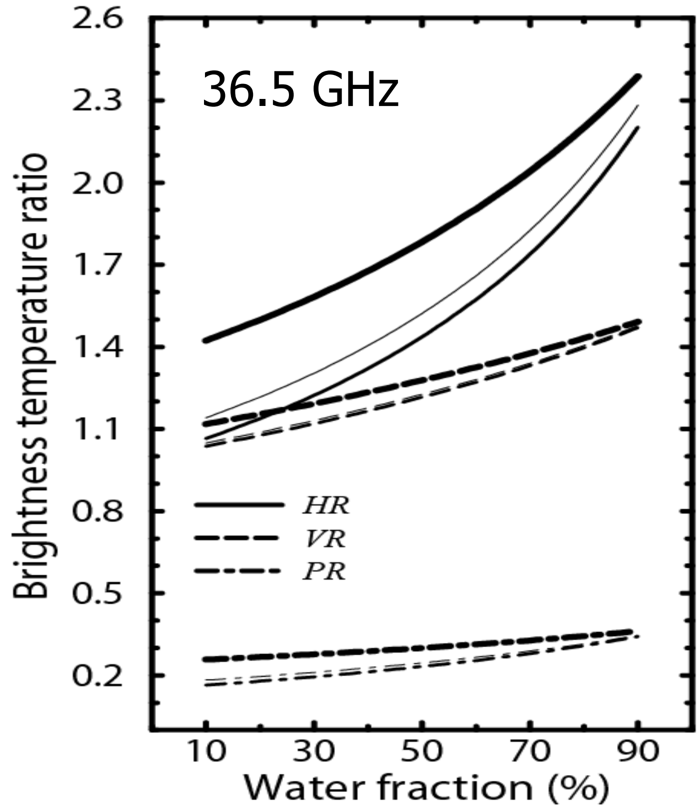
Silt-loam soil:
27% clay, 62% silt

Water fraction:
f_w=10-90%

Soil moisture%:

Rain in *M*, not *C*
m_v=10 *M*, 5 *C* (thin)
m_v=20 *M*, 5 *C* (**bold**)

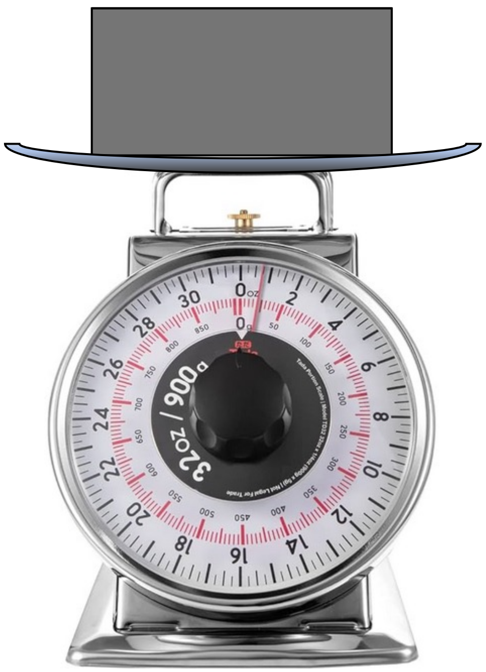
Rain in *M* and *C*
m_v=10-35 (**medium**)
in both M and C



Measurement Based on Sensitivity: The C&M Method

Objective: Measure weight of a total collection of pebbles

C: Box no pebble



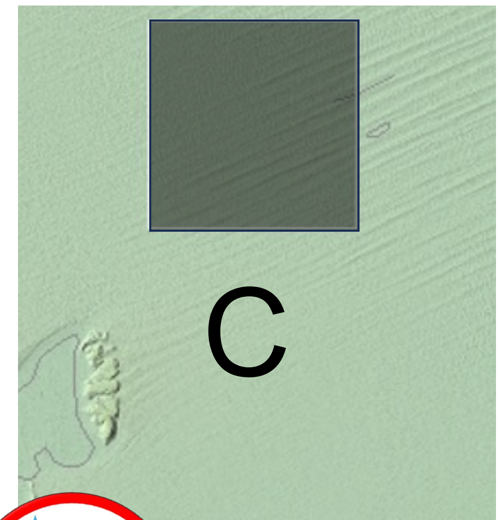
M: Box with pebbles

- C: Weight of empty box
- M: Weight of box and pebbles. M has to be large to contain one to many pebbles
- C & M: Cancel empty box to relate to pebble weight change
- Rating curve to make needle position to weight marking (oz or g); no need for recalibration routinely
- Can measure a single pebble to many pebbles depending on the sensitivity of the scale to the total weight change
- No need to see the pebbles in M. No need to know where the pebbles locate in M, how many pebbles, or how small or large the pebbles are.

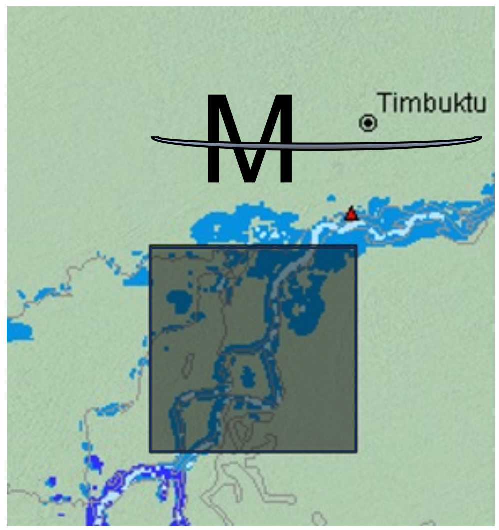
Measurement Based on Sensitivity: The C&M Method

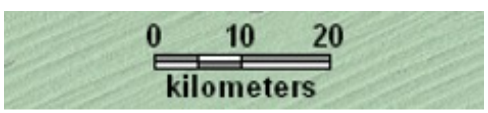
Objective: Measure river stage (or discharge)

C: Land no water



M: Land with river





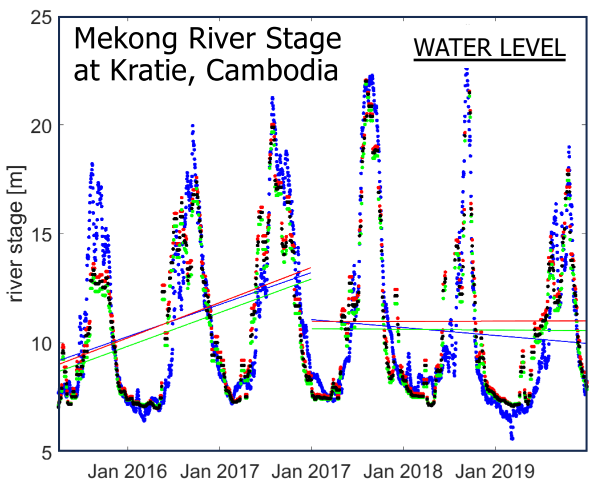
low resolution (10s km)

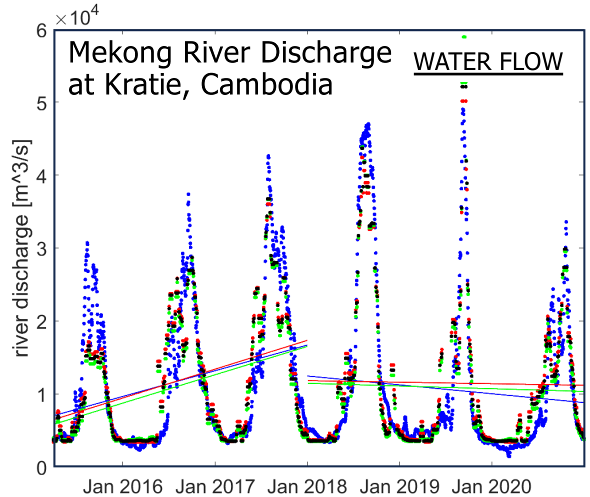
- C: Proportional to temperature without water
- M: Proportional to temperature with river water. M has low (coarse) resolution for all low to high flows
- C & M: Cancel temperature to get relation to river water change
- Rating curve to make PMR ratio to river stage (m) or discharge (m^3/s); no need for recalibration routinely
- Can measure small to large river depending on the sensitivity to total surface water change
- No need to see river water in M. No need to know where the river water in M, or surface water area, or how narrow or wide the river is.

PMR is passive microwave radiometry

SMAP Satellite Capability for River and Lake Measurements Demonstration and Validation in the Lower Mekong Basin

⚠ WARNING
IN REVIEW

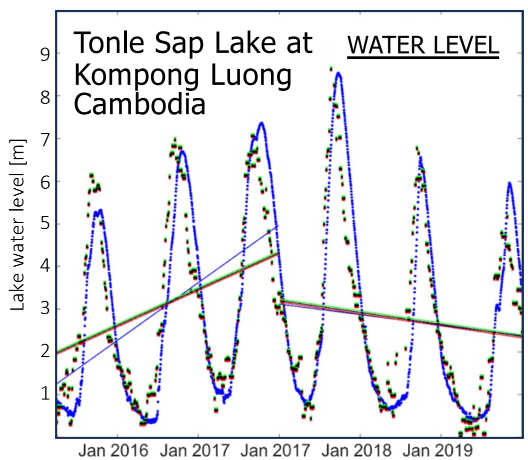




SMAP River Measurement

Accurate (ρ=0.91) for both river stage (water level) and river discharge (water flow) compared to in-situ river gauging data at Kratie.

- in-situ data
- forward-split validation
- backward-split validation
- full validation



SMAP Lake Measurement

Accurate (ρ=0.92) for lake water level compared to in-situ river gauging data at Kompong Luong.

PI: S. V. Nghiem (NASA/JPL), Co-I: G. R. Brakenridge (Univ. Colorado), Collaborators: Z. Kugler (Budapest Univ. in Hungary) and A. Podkowa (Warsaw Univ. in Poland). In coordination with Mekong River Commission Secretariat.

SMAP Capability for River and Lake Monitoring

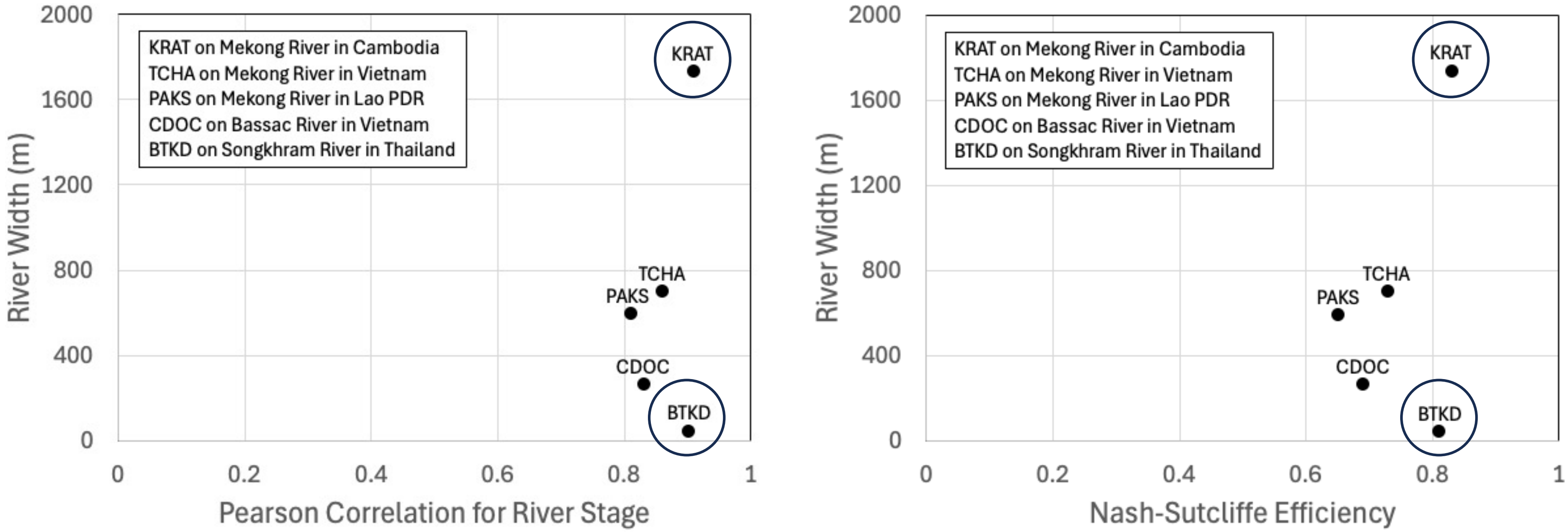
- New paradigm based on **sensitivity** to water aerial change, not surface level
- Do away with high resolution and use low resolution for all river/lake stages
- Global coverage with daily/near-daily observations
- Extensive decadal data record

SMAP Satellite Capability for River and Lake Measurements

WARNING
IN REVIEW

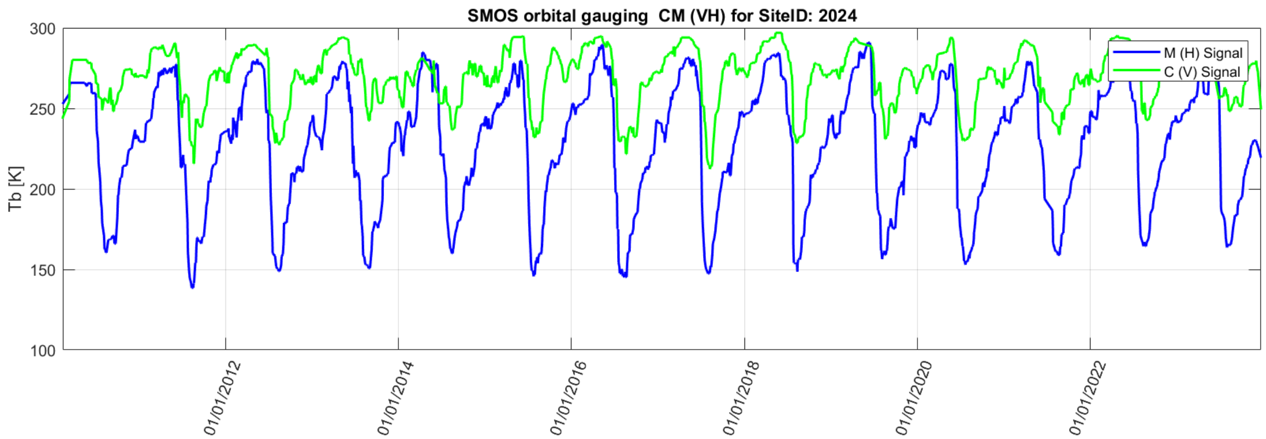
New Paradigm for both Narrow and Wide Rivers

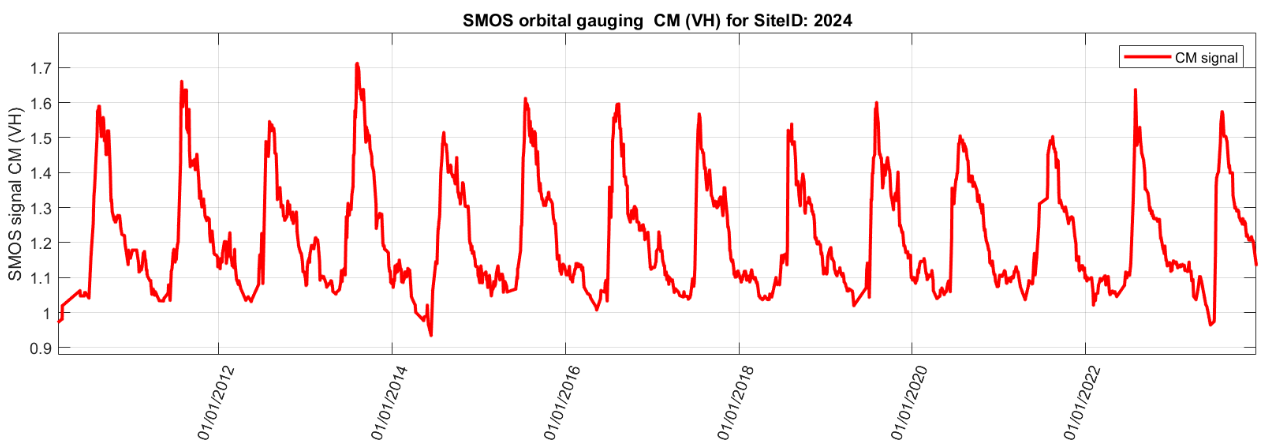
- New paradigm based on <u>sensitivity</u> to water aerial change, not surface level
- Do away with high resolution and use low resolution for all river/lake stages
- Global coverage with daily/near-daily observations
- Extensive decadal satellite data record for global river stage and discharge



Valid for small river (BTKD, 42-m width) and large river (KRAT, 1735-m width)

River gauge with SMOS C/M ratio 2010-2024



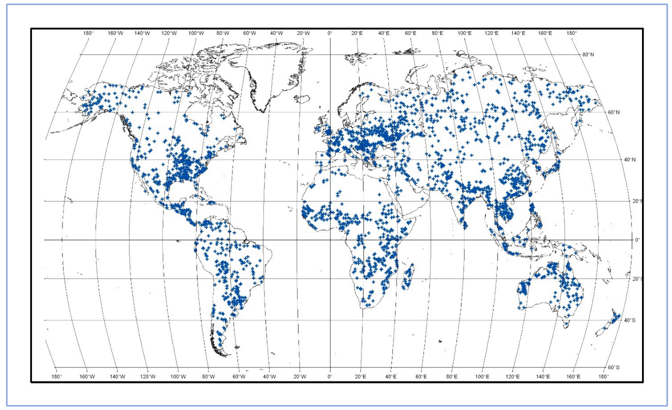


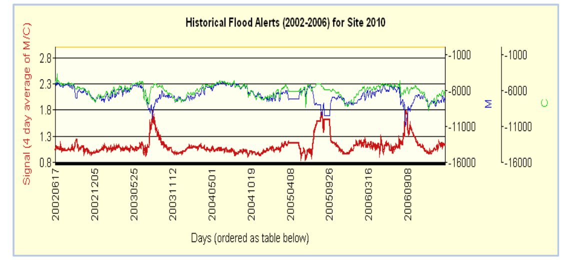
Son River, India
Tributary of Ganges

Dr. Son V. Nghiem

Implementation of methodology: Ka-band data repository

- AMSR-E, AMSR-2, GPM
- 2500 observation sites monitored
- sites showed a great sensibility of surface water area change to river discharge increase





Satellite river gauge database repository:

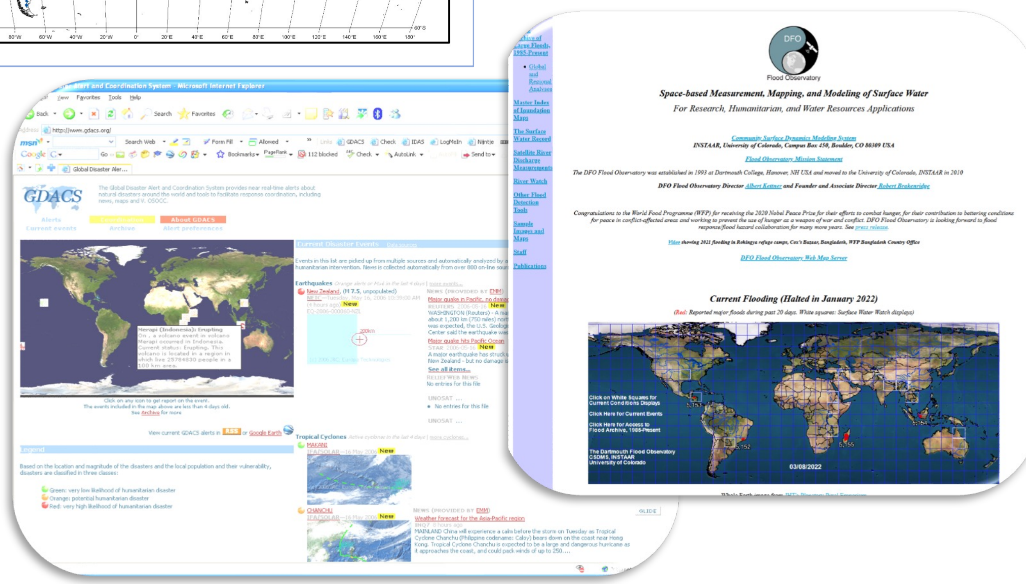
-European Commission JRC: GFDS
gdacs.org/flooddetection

- Dartmouth Flood Observatory: Flood Watch
floodobservatory.colorado.edu/

JRC
EUROPEAN COMMISSION

Scan QR code to go to DFO data portal

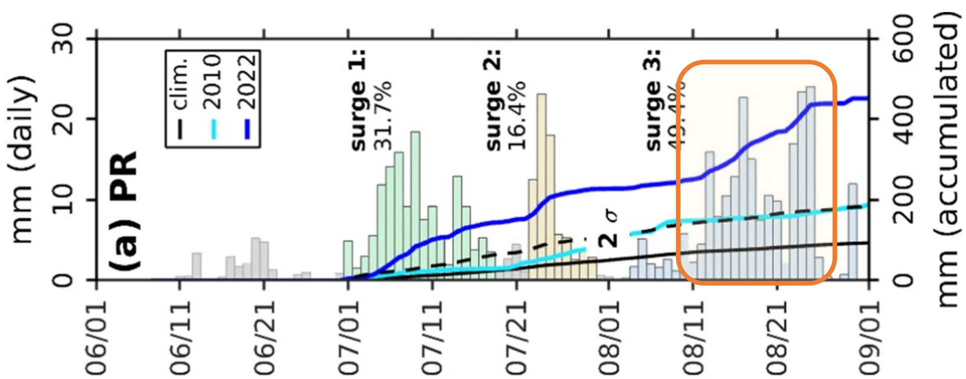
DFO
Flood Observatory



LIMIT: NOT INCLUDING SMAP AND SMOS DATA

Synergy between PMR river gauge and OPERA DSWx Case study - Indus River great flood in2022 Pakistan

- unusually intense monsoon rainfall surges that struck from early July to late August causing
- 30 million people homeless and resulted in 1000 deaths
- three **unusually strong monsoon** rainfall surged

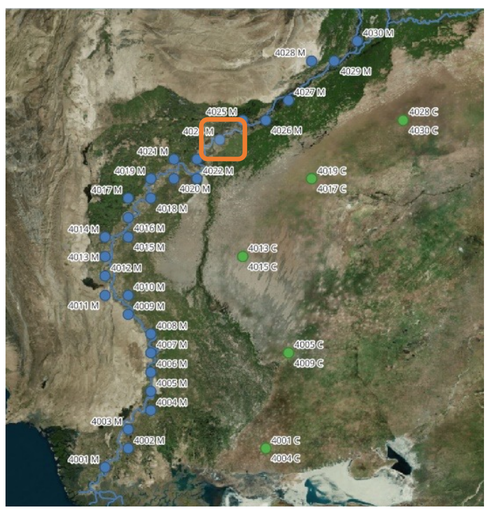


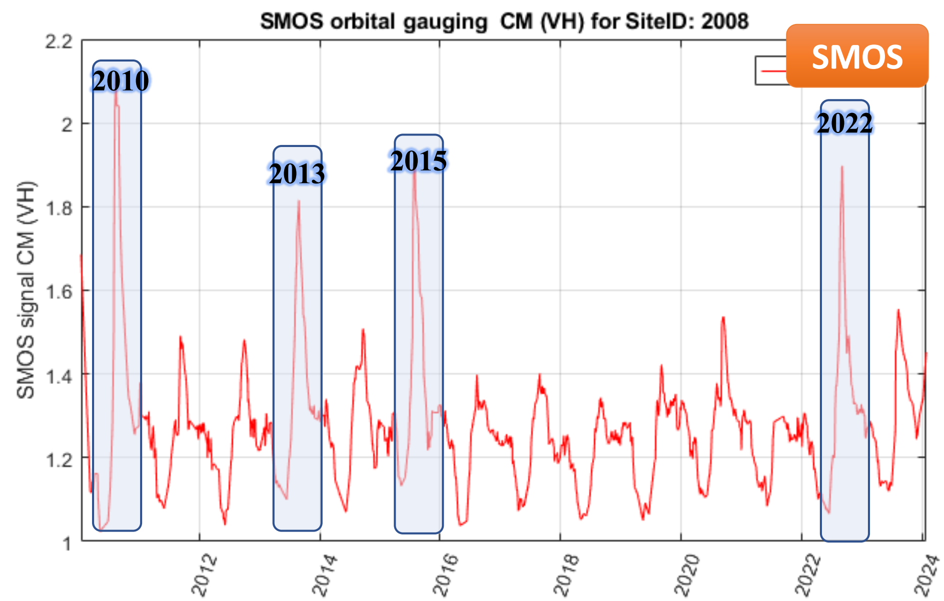
Study area – Indus watershed

- **30 pre-defined locations** that followed mainstem of the Indus River
- Obervations were spaced **every 25 km**, following the gridded product of L band PMR sensor of ESA SMOS (EASE – 25 km world grid)

SMOS river gauge product 2010 – 2024

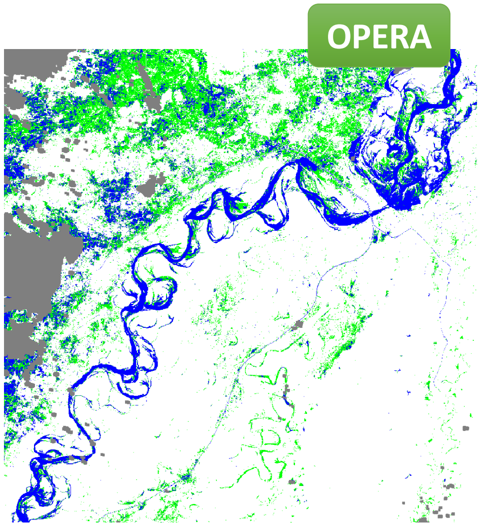
- Above average seasonal **flooding** occurred in 2010, 2013, 2015 and 2022
- **2010** and **2022** most devastating in the country's history



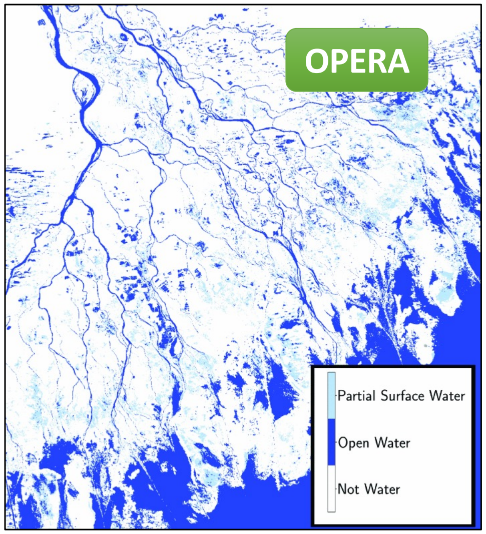


OPERA - Dynamic Surace Water Extent product (DSWx)

- Observational Products for End-Users from Remote Sensing Analysis (**OPERA**) project (https://www.jpl.nasa.gov/go/opera/)
- **DSWx** is a freely available, quasi-global, multi-sensor suite of products that maps **water surface extent** since April 2023.
- **DSWx-HLS**: Harmonized **Landsat 8** and **Sentinel 2** (HLS) imagery based product
- HLS repeat frequency (**median 2.9 days**)



Dynamic Surface Water Extent (DSWx) algorithm



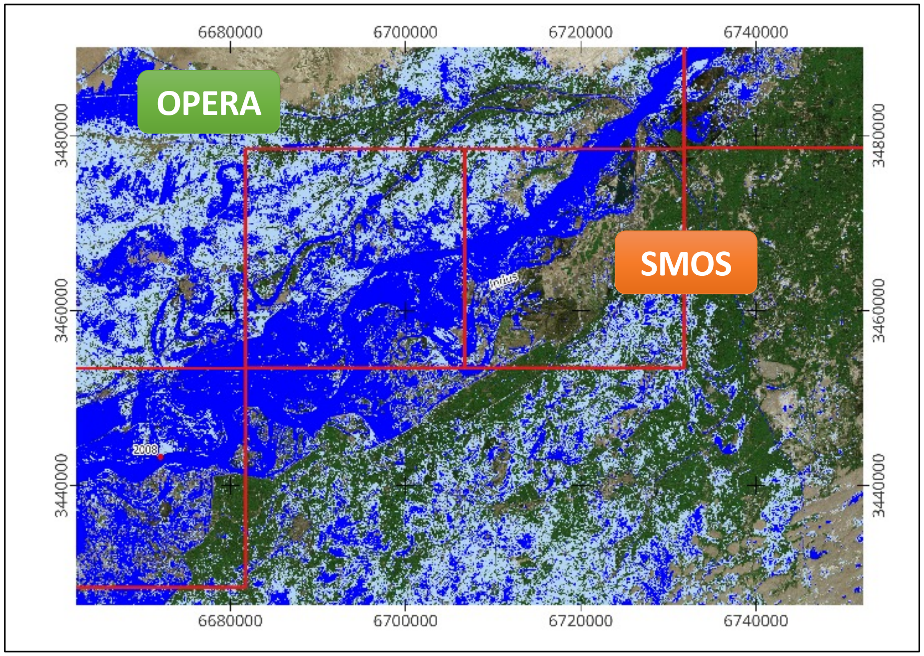
- **Decision tree approach** with a total of five tests:
  - MNDWI: Modified Normalized Difference Water Index
  - MBSRV: Multi-band Spectral Relationship Visible
  - MBSRN: Multi-band Spectral Relationship Near-Infrared
  - $AWEI_{SH}$: Automated Water Extraction Index Shadow
  - NDVI: Normalized Difference Vegetation Index

- **Five tests** are in the expressions:
  1. $\mathrm{MNDWI} > 0.124$
  2. $\mathrm{MBSRV} > \mathrm{MBSRN}$
  3. $\mathrm{AWEI_{SH}} > 0$
  4. $\mathrm{MNDWI} > -0.44$ and $\mathrm{SWIR1} < 900$ and $\mathrm{NIR} < 1500$ and $\mathrm{NDVI} < 0.7$
  5. $\mathrm{MNDWI} > -0.5$ and $\mathrm{Blue} < 1000$ and $\mathrm{SWIR1} < 3000$ and $\mathrm{SWIR2} < 1000$ and $NIR < 2500$

- **Classification** approach
  - If four or five of the conditions are met: **open water** high confidence
  - If three of the conditions are true, the pixel is classified as **open water** moderate confidence
  - If conditions in expressions 4 and 5 are met: **partial surface water** conservative
  - if any other combination of at least two conditions are true: **partial surface water** aggressive
  - if fewer than two conditions are met: **not water**.

Synergy between Opera DSWx-HLS and SMOS flow

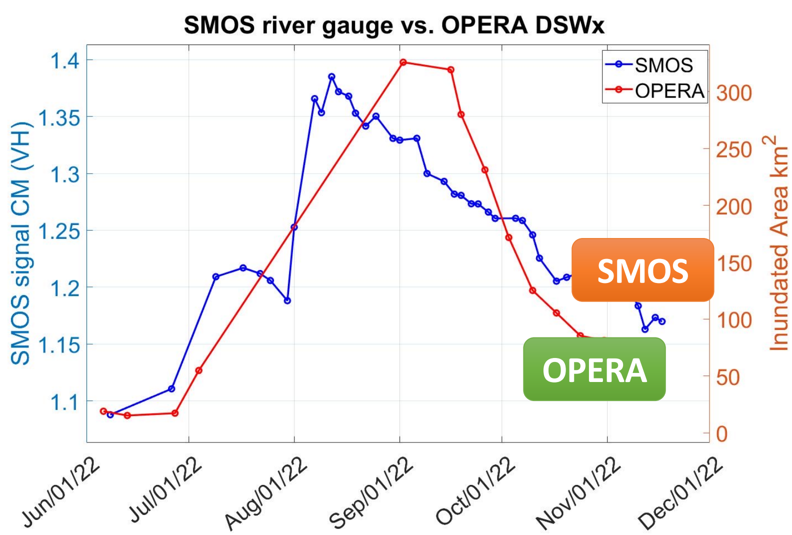
- **DSW** extent was divided into **segments** corresponding to **25 km gridded SMOS**
- both measuring **water surface extent variation** on the floodplain around the river channel
- Derived DSWx-HLS water **surface area calculation** at each footprint location
- **Agreement** was measured by **linear regression** and expressed by the coefficient of determination **R2** around each node

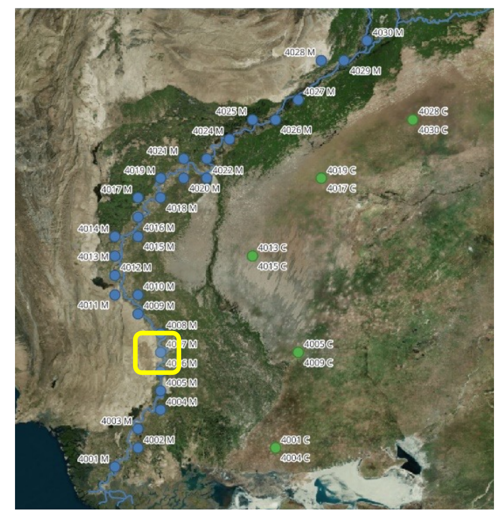


Correlation between SMOS based river gauge and OPERA water surface area measurements

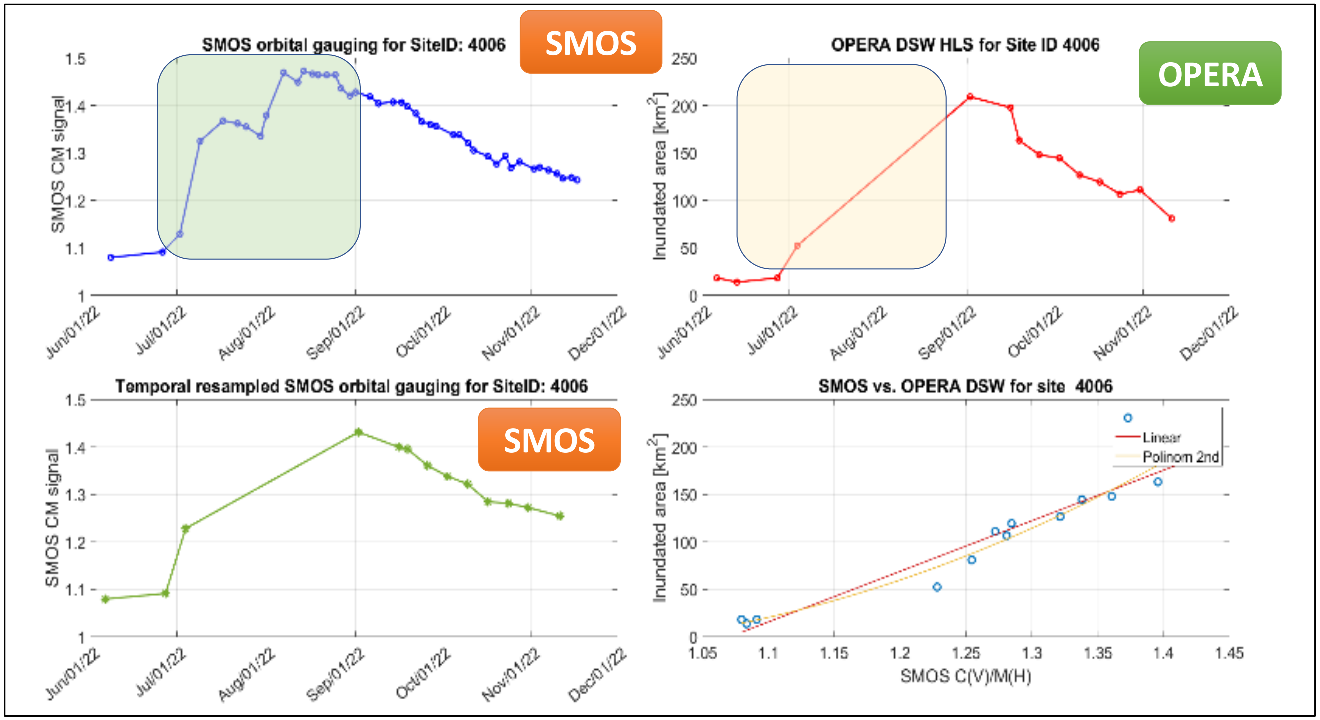
- Statistics of **R2** above **0.7** for all 25 river stations along the Indus river
- correlation was calculated for a **very short period** of 6 months the short temporal coverage may result in larger error.

	R^2
Mean	0.72
Minimum	0.52
Maximum	0.96
Standard dev	0.1318



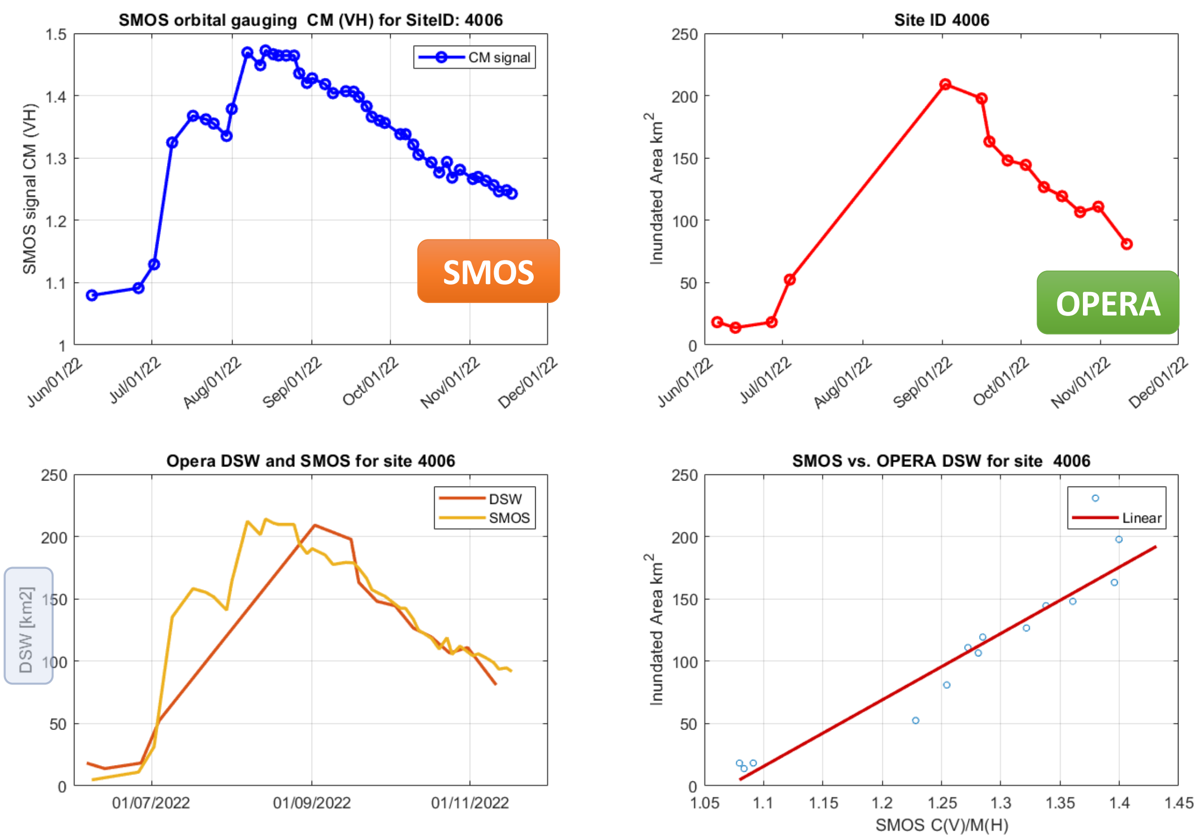


Temporal sampling of SMOS river gauge



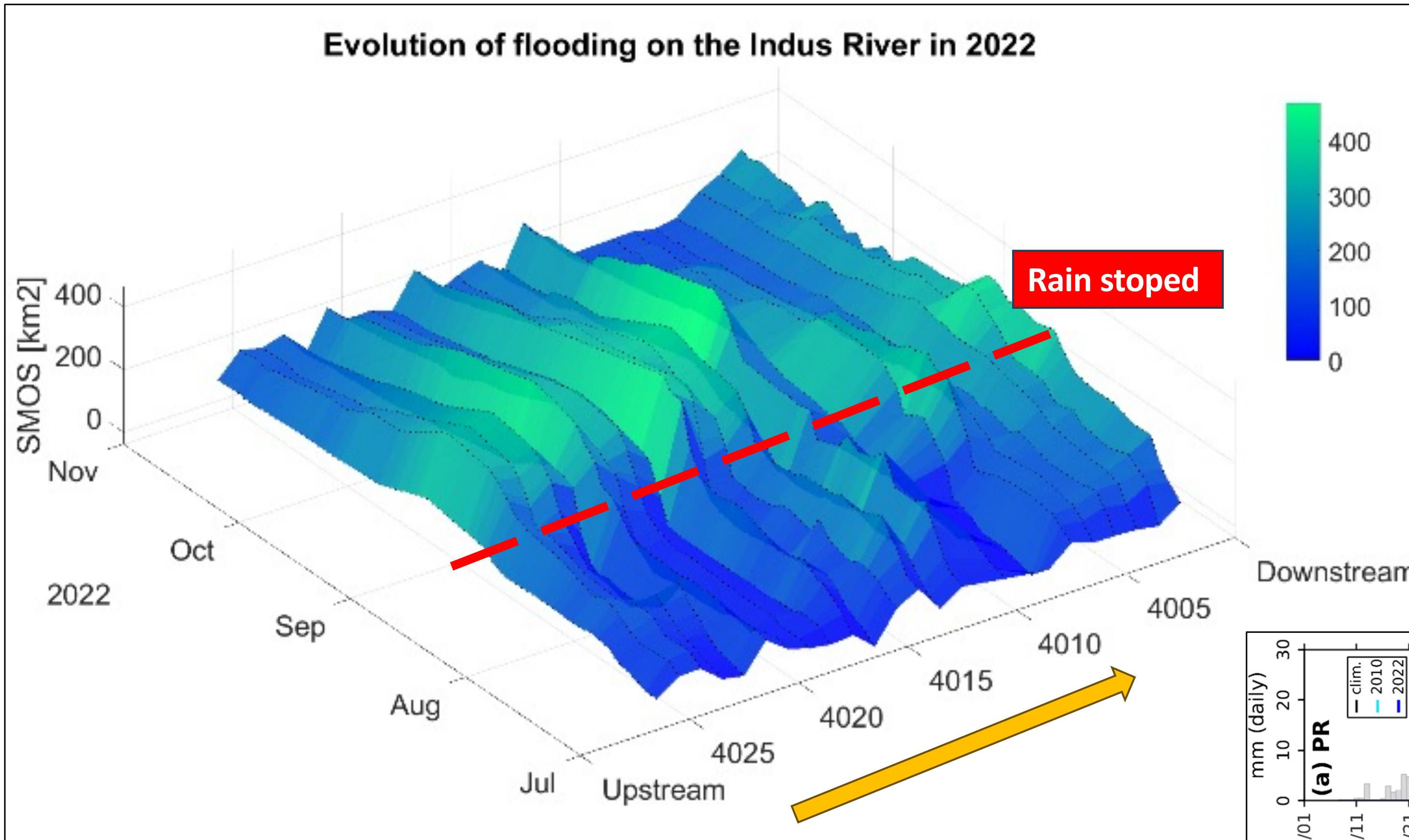
- **DSW** resulted in **14 observations** while **SMOS** yield **44** gauges
- DSW and PMR data had different **temporal resolutions**
- DSW large temporal **gap** between **July 4** and **September 2** (due to cloud cover)
- temporal frequency of SMOS was 4 days on average

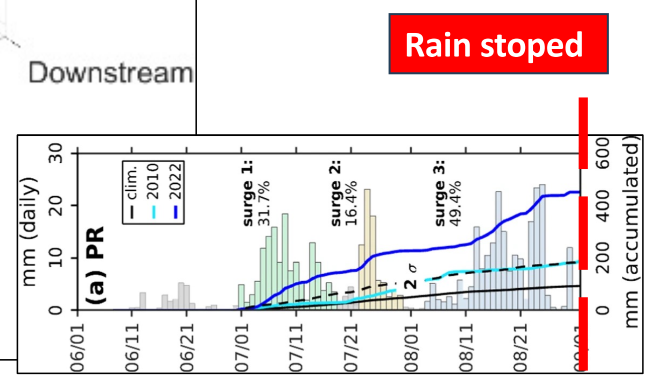
Calibration of SMOS river gauge to DSWx area

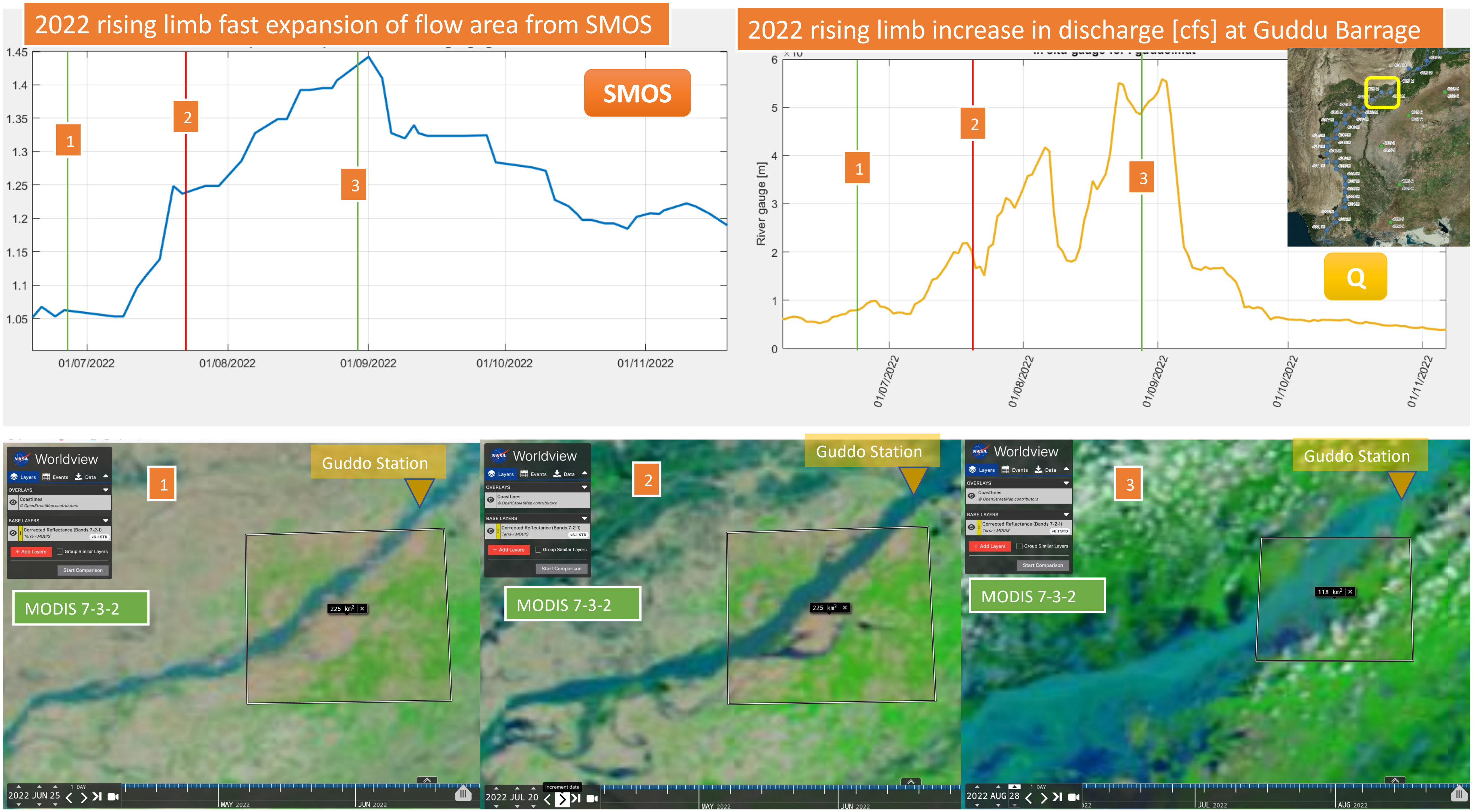


- **SMOS** river gauge retrieval returns a **relative value**
- needs **calibration** to metric values while DSW is retrieved in **km2 area** dimension.
- SMOS CM ratio to flow area using DSW measurements
- Calibration was carried out by **simple linear regression** method at each footprint

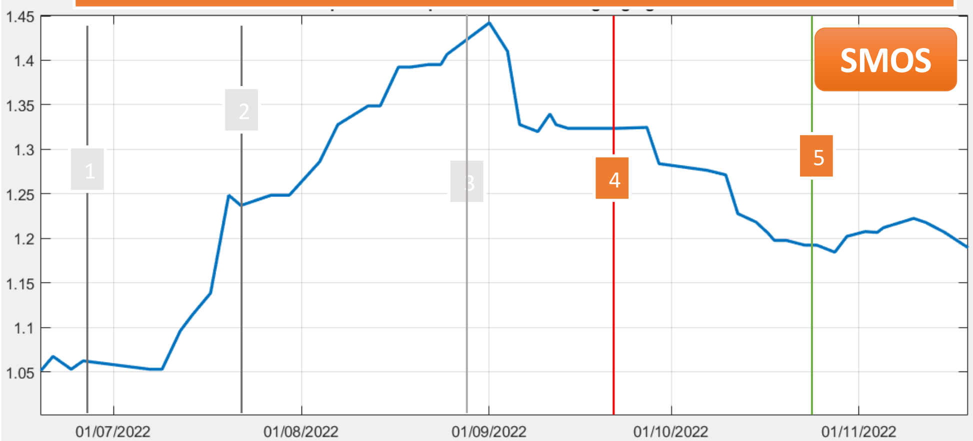
Near daily evolution of flood wave propagation from SMOS river gauge calibrated to water surface area from OPERA DSW



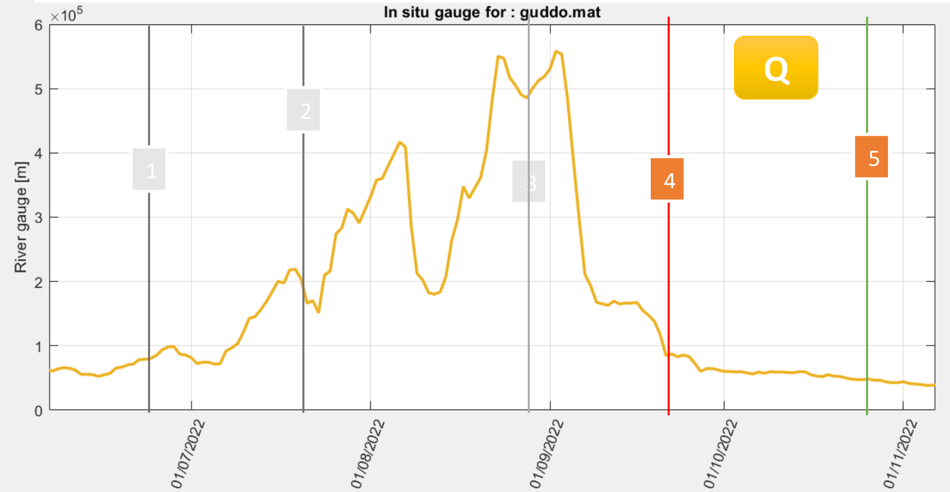


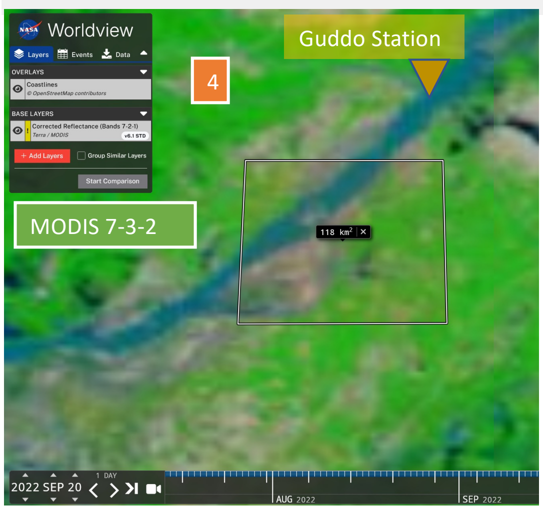

2022 rising limb fast expansion of flow area from SMOS
SMOS
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
2
3
01/07/2022
01/08/2022
01/09/2022
01/10/2022
01/11/2022
2022 rising limb increase in discharge [cfs] at Guddu Barrage
River gauge [m]
6
5
4
3
2
1
0
1
2
3
Q
01/07/2022
01/08/2022
01/09/2022
01/10/2022
01/11/2022
Worldview
Guddo Station
1
MODIS 7-3-2
225 km²
2022 JUN 25
MAY 2022
JUN 2022
Worldview
Guddo Station
2
MODIS 7-3-2
225 km²
2022 JUL 20
MAY 2022
JUN 2022
Worldview
Guddo Station
3
MODIS 7-3-2
118 km²
2022 AUG 28
JUL 2022
AUG 2022

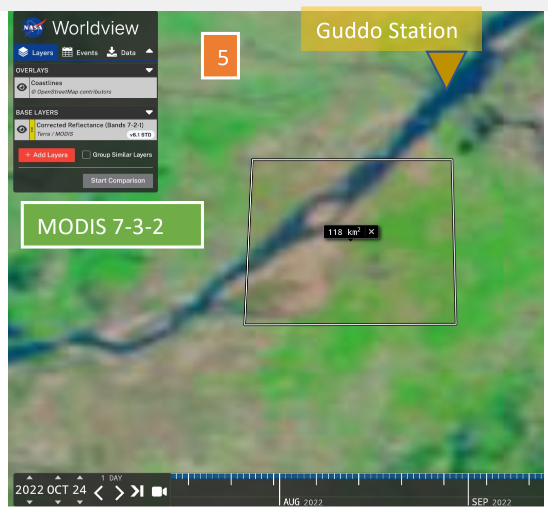
2022 falling limb lingering of floodplain inundation from SMOS

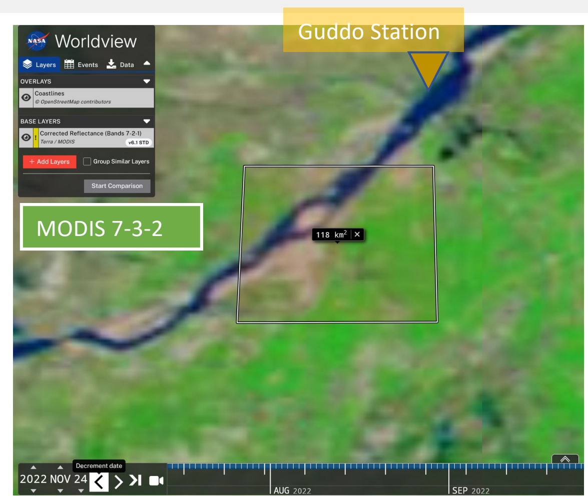


2022 falling limb fast decline of discharge [cfs] at Guddu Barrage



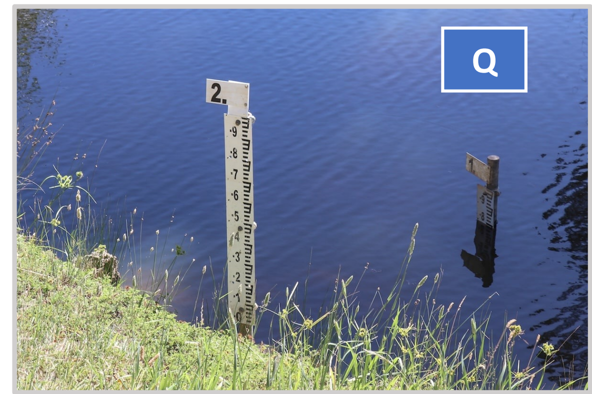






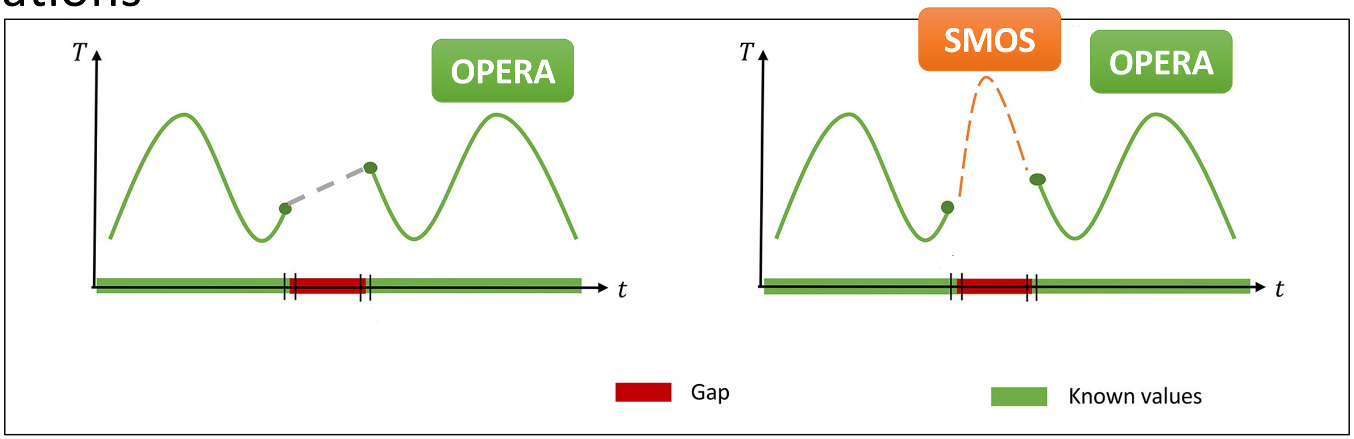
Flow area measurement vs. In-situ hydrometry?

- scale of **damage** highly depends on **how long water stays overbank**
- **caused** extended damage, delayed clean-up efforts, causing widespread interruption in water supply and agricultural production, further, to rising the risk of epidemic outbreaks and other health hazards.
- According to satellite observations water surface in the **Indus basin** was **lingering long** on the floodplain
- **Satellite** data collecting flow area or flood extent can deliver a particularly valuable information for **damage assessment**



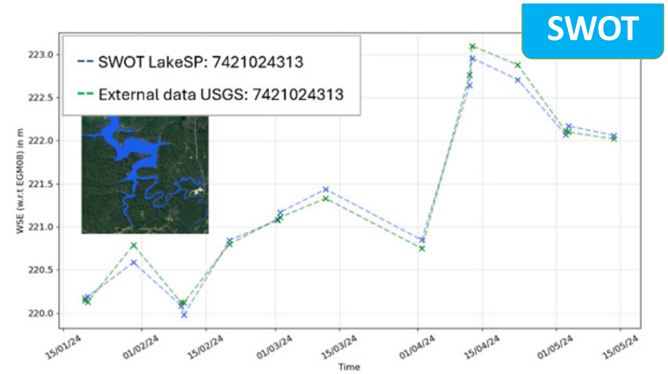
Take away: Fill the temporal gap with SMOS between OPERA observations

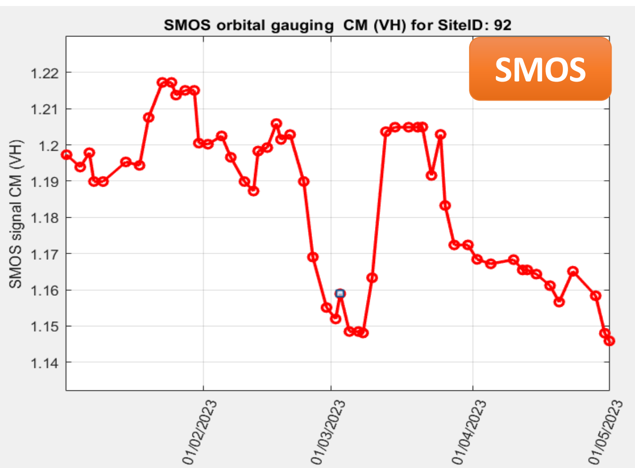
- **PMR** give time record **daily/near-daily** for **<u>decades</u>** from the past to the future continuously
- **PMR** retrieves a **relative value**
- **OPERA** delivers water extent in **metric area dimensions**
- PMR can (not only) fix the **temporal gap** between irregular observations with near-daily observations

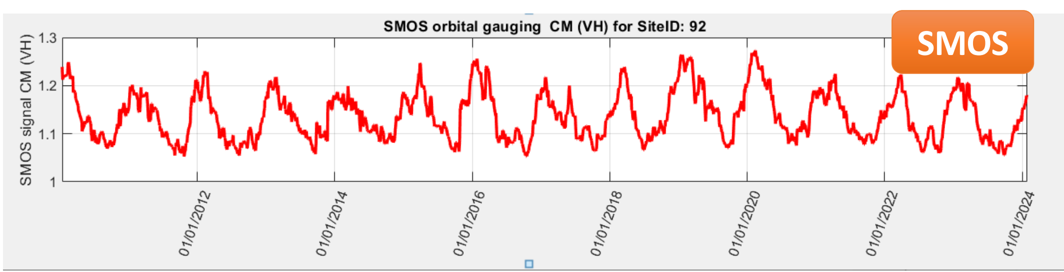


Potential synergy with SWOT

- SWOT launched in December 2022.
- Innovative Ka-band interferometric SAR (KaRIn sensor) to measure surface water elevations and slopes.
- **SWOT** measures river stage globally every **21 days** depending on latitude
- **PMR** data can be **cross-calibrated** with **SWOT** to fill in the time (~daily) over **decadal records**.
- Method to calibrate? To merge two time series? Leverage?

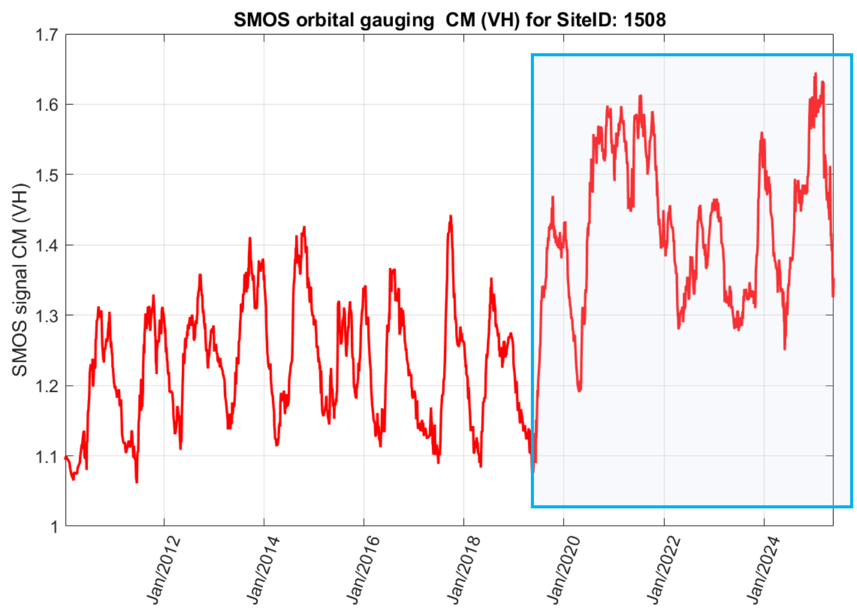




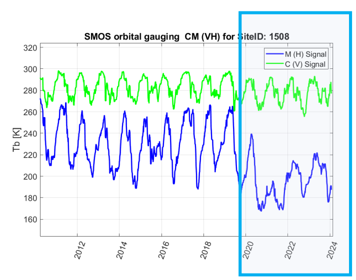


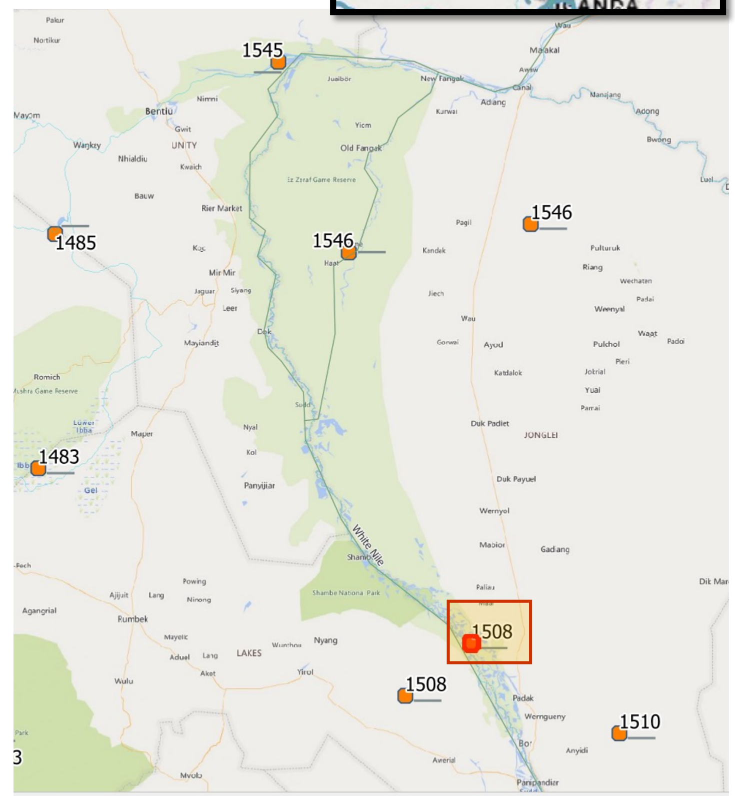
KEY POINT: Calibrated with SWOT, PMR serves as a **“time machine”** to monitor river flow ~daily over multiple decades to examine long-term river changes.

South Sudan: White Nile from SMOS



- Significant jump to higher flow rates during 2020 dry season
- Engineering intervention upstream?
- Jump is not related to any orbital drift as calibration footprint faces no notable change





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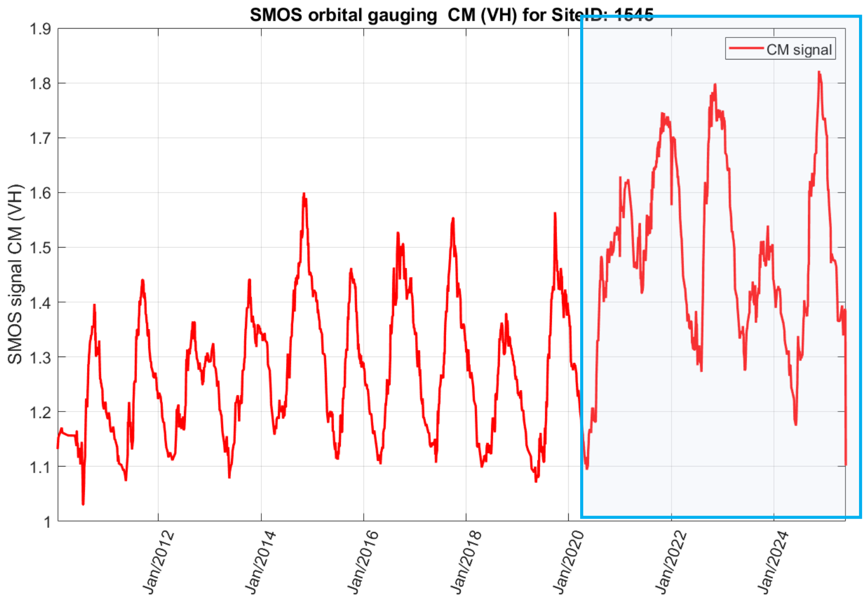
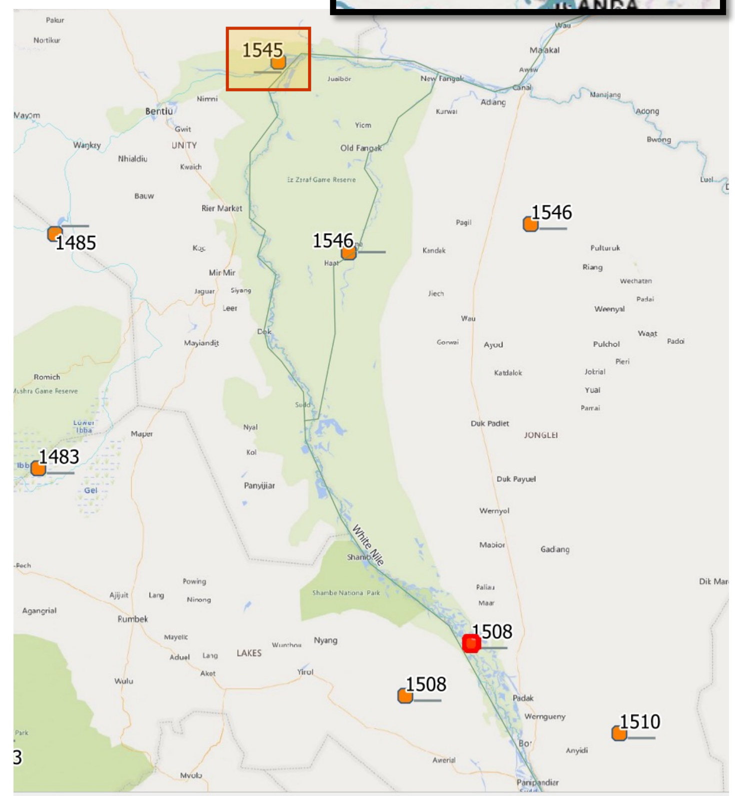
South Sudan: White Nile from SMOS





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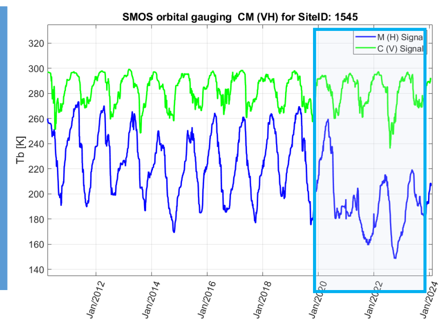

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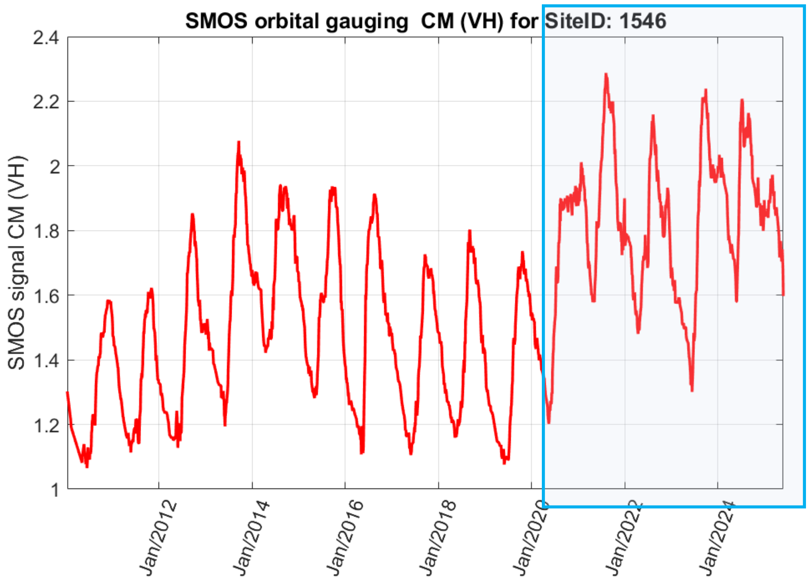
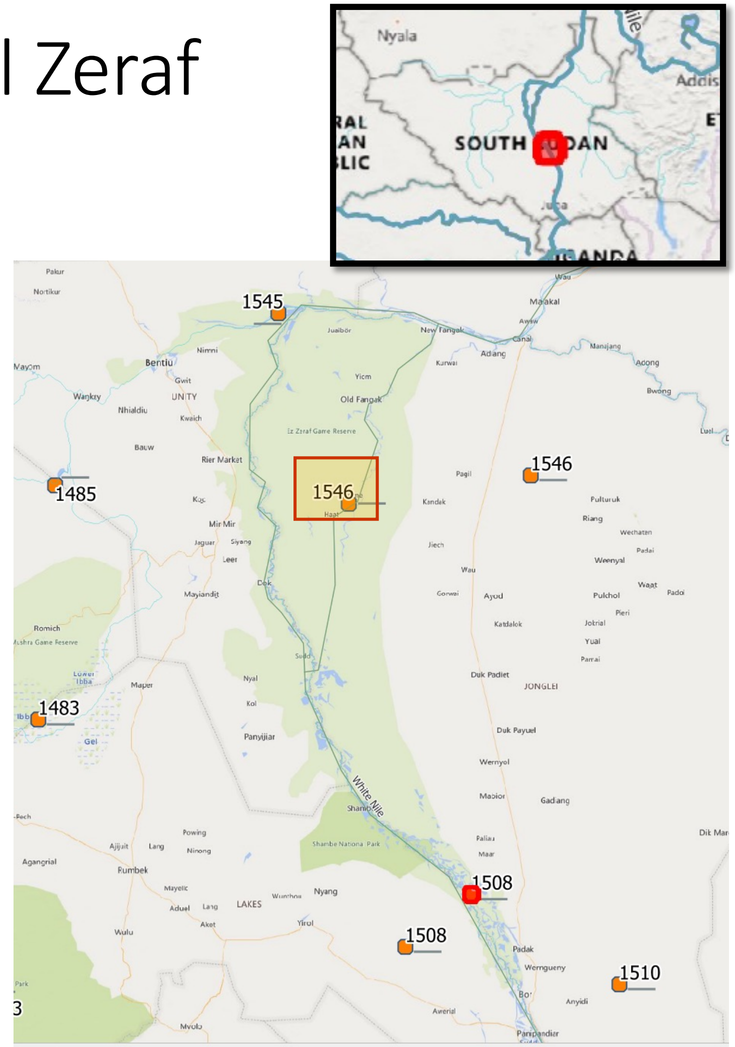
South Sudan: White Nile trib. Bahr el Zeraf





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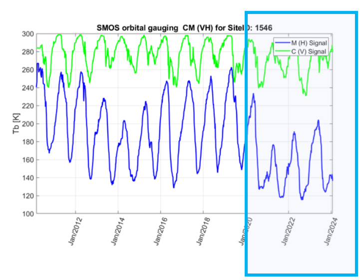
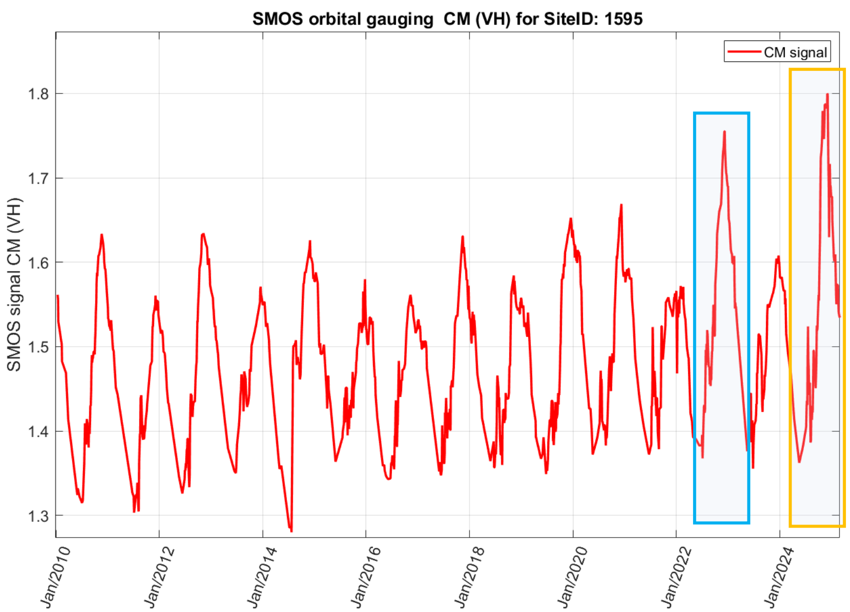
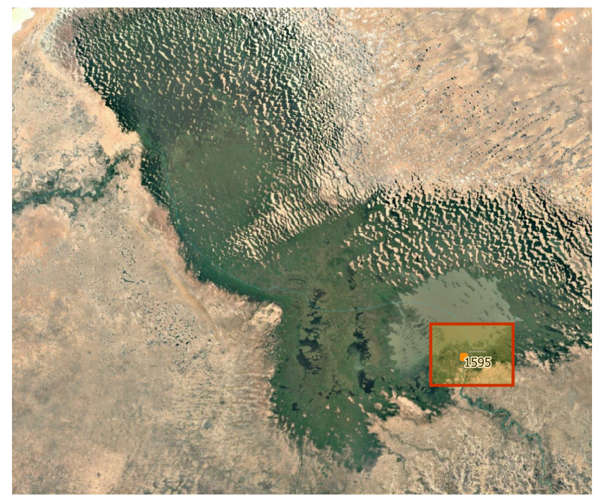


Lake Chad from SMOS





- High lake level values are measured in late 2022 caused by devastating floods
- Record flooding was measured in 2025

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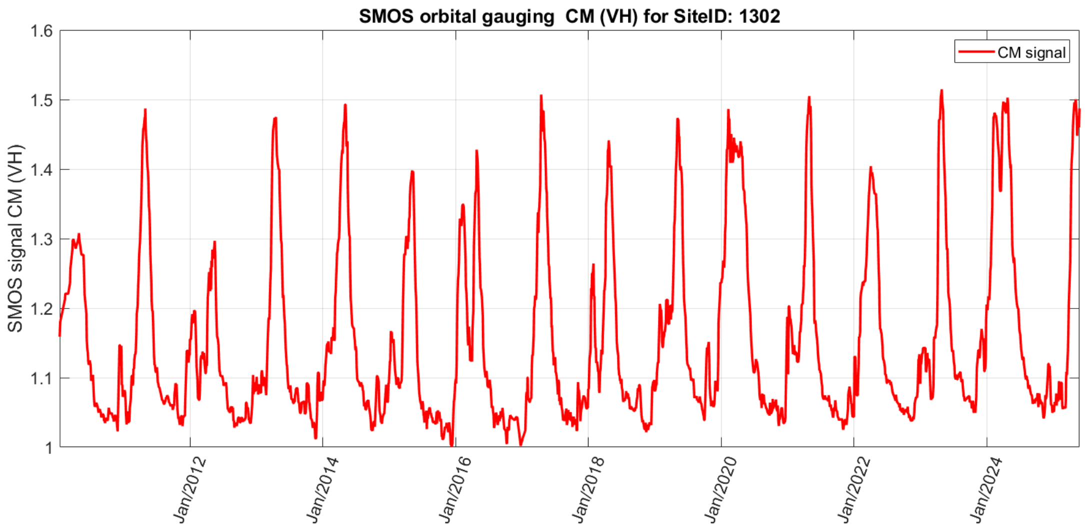
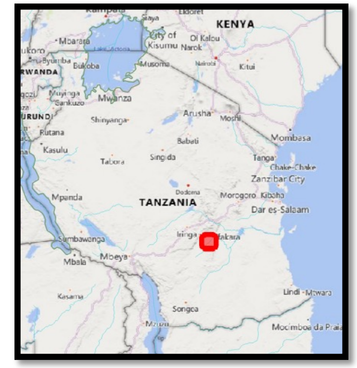
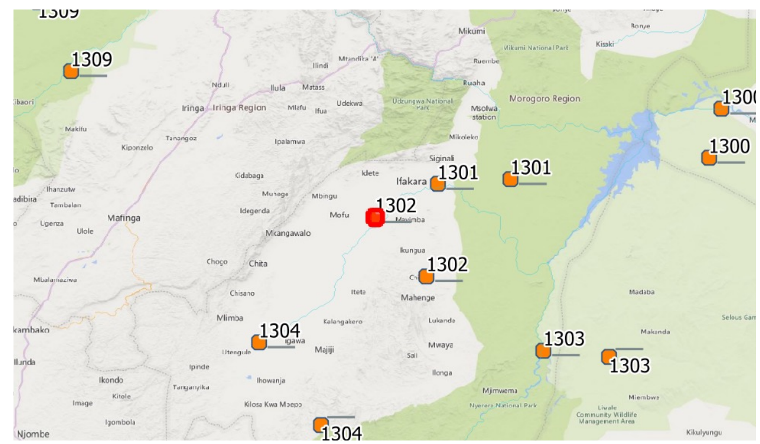
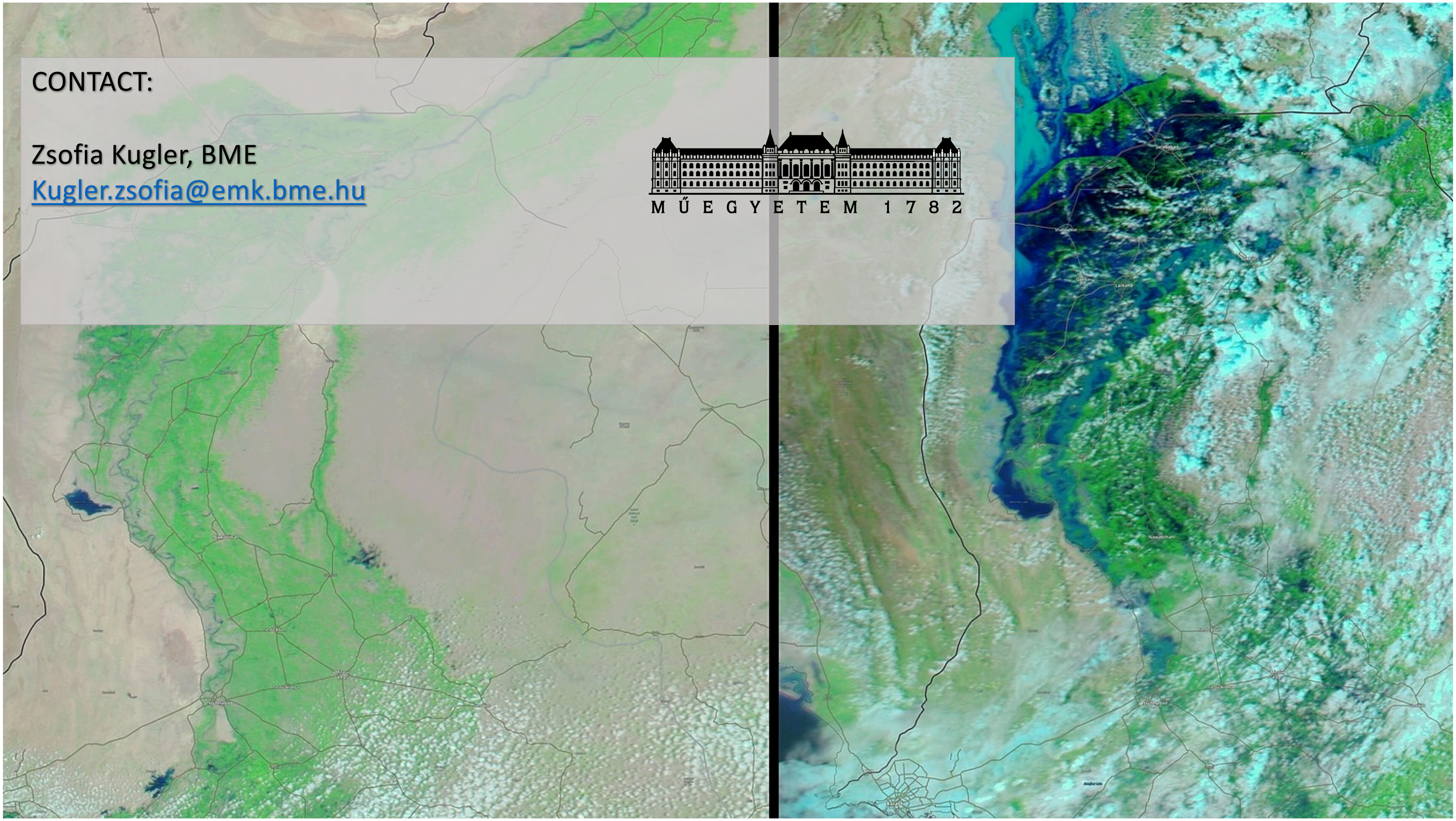
Kilombero River in Tanzania from SMOS









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