Deutsches Geodätisches Forschungsinstitut
Ingenieurfakultät Bau Geo Umwelt
Technische Universität München

AWAX: A new Approach for Automated Extraction of Consistent Time-Variable Water Surfaces of Lakes and Reservoirs using Landsat and Sentinel-2

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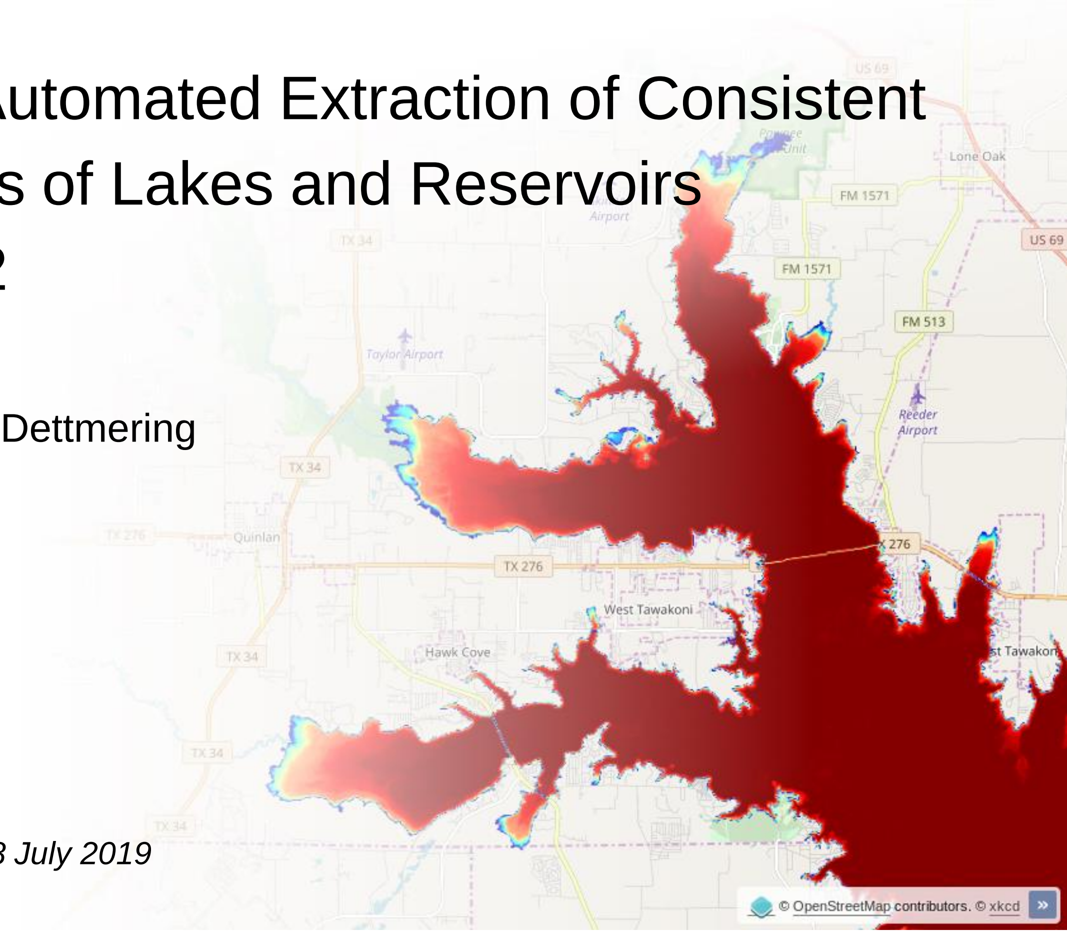

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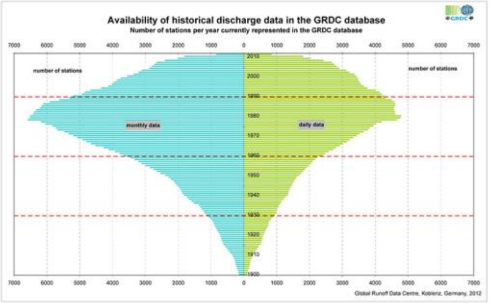
Motivation

- Monitoring and modeling of the Earth`s water cycle has become increasingly important in the last years, especially in the context of climate change.
- The number of in-situ stations has been decreasing since 1980 (see GRDC)
- The knowledge about storage changes (which cannot be measured directly) is of great importance for the development of hydrological models.
- Remote sensing has the potential to monitor **water levels** and **surface areas** in order to estimate **storage changes** also in remote areas



Credit: Global Runoff Data Center (GRDC)

- Water levels can be derived from satellite altimetry
- DGFI-TUM maintains the **"Database for Hydrological Time Series of Inland Waters" (DAHITI)** which provides more than 1700 water level time series from satellite altimetry for inland waters

- Radar or optical images can be used to retrieve surface information
- In this study, a new tool **"Automated Water Area Extraction Tool" (AWAX)** has been developed in order to extract monthly water masks and area extents using optical imagery from Landsat and Sentinel-2

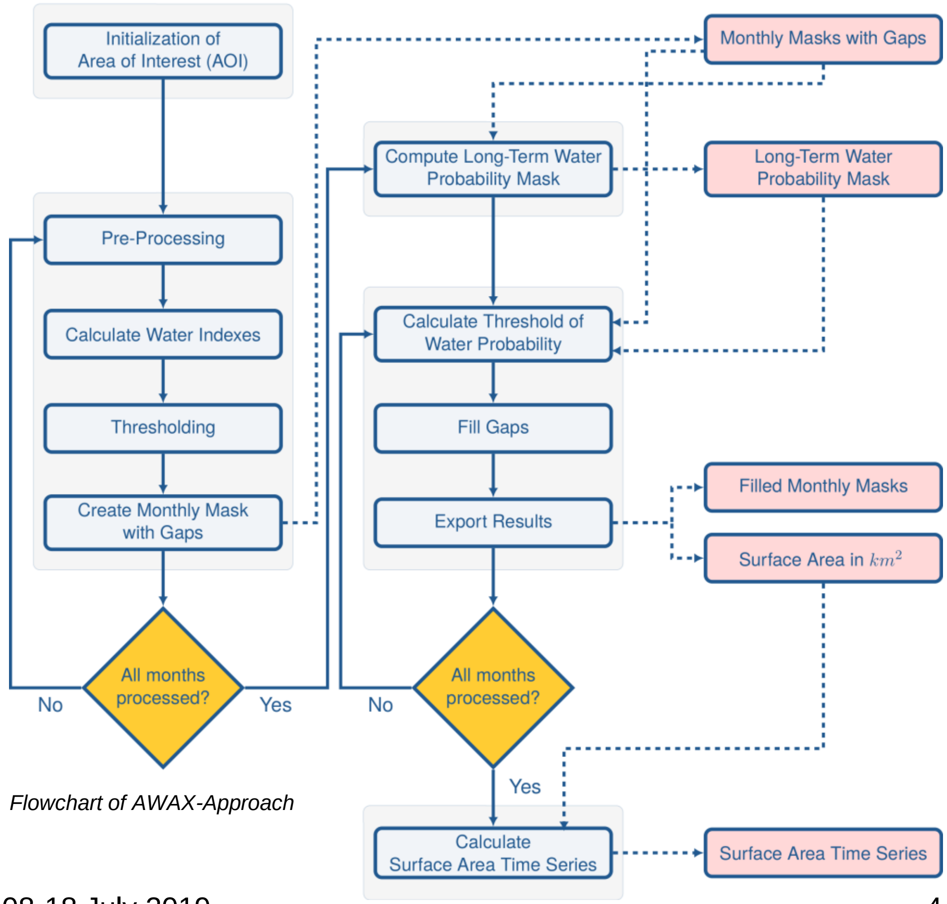
DAHITI - Website

Data

Mission	Repeat Cycle	Period	Resolutions (Bands)	Quality Band	Product
Landsat-4 (MSS,TM)	16 days	1982-08-24 – 1993-12-14	30m (R,G,B,N,S1,S2)	CFMASK	L2 (TOA)
Landsat-5 (MSS,TM)	16 days	1984-01-01 – 2012-05-05	30m (R,G,B,N,S1,S2)	CFMASK	L2 (TOA)
Landsat-7 (ETM+)	16 days	1999-01-01 – *active*	30m (R,G,B,N,S1,S2)	CFMASK	L2 (TOA)
Landsat-8 (OLI, TIRS)	16 days	2013-04-11 – *active*	30m (R,G,B,N,S1,S2)	CFMASK	L2 (TOA)
Sentinel-2A (MSI)	10 days	2015-06-23 – *active*	10m (R,G,B,N), 20m (S1,S2)	FMASK4	L1B (BOA)
Sentinel-2B (MSI)	10 days	2017-03-07 – *active*	10m (R,G,B,N), 20m (S1,S2)	FMASK4	L1B (BOA)

Methodology

Major processing steps:

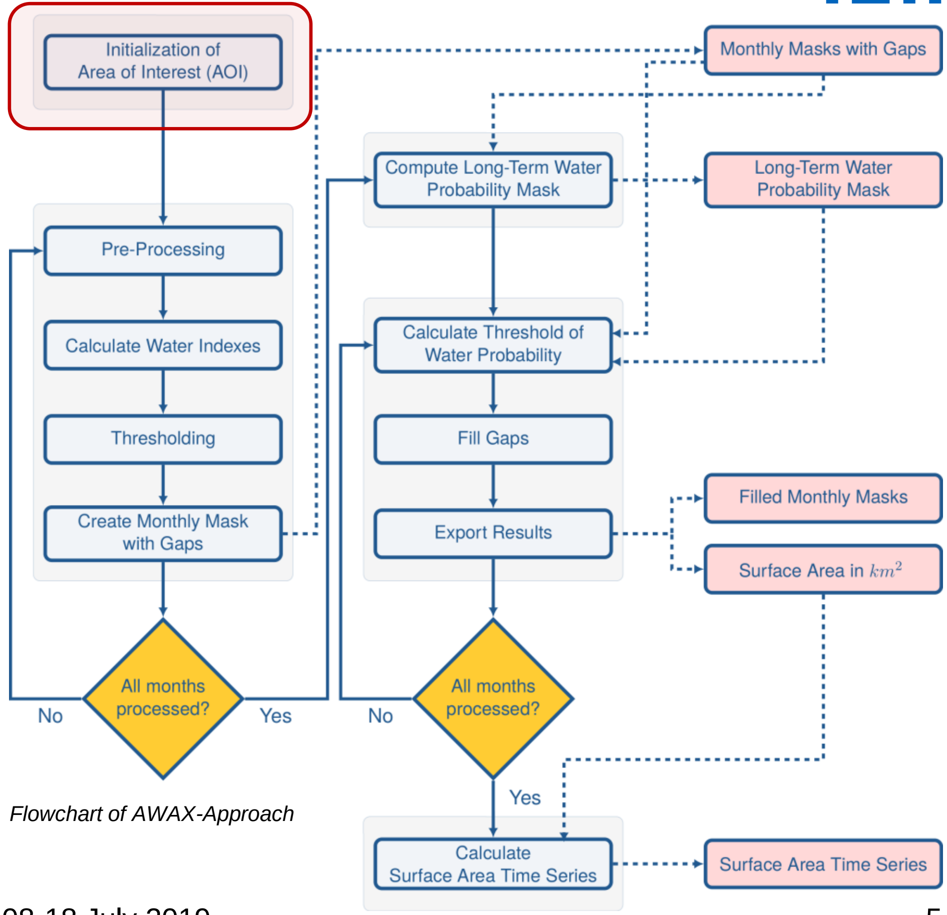


Flowchart of AWAX-Approach

Methodology

Major processing steps:

- Initialization of AOI

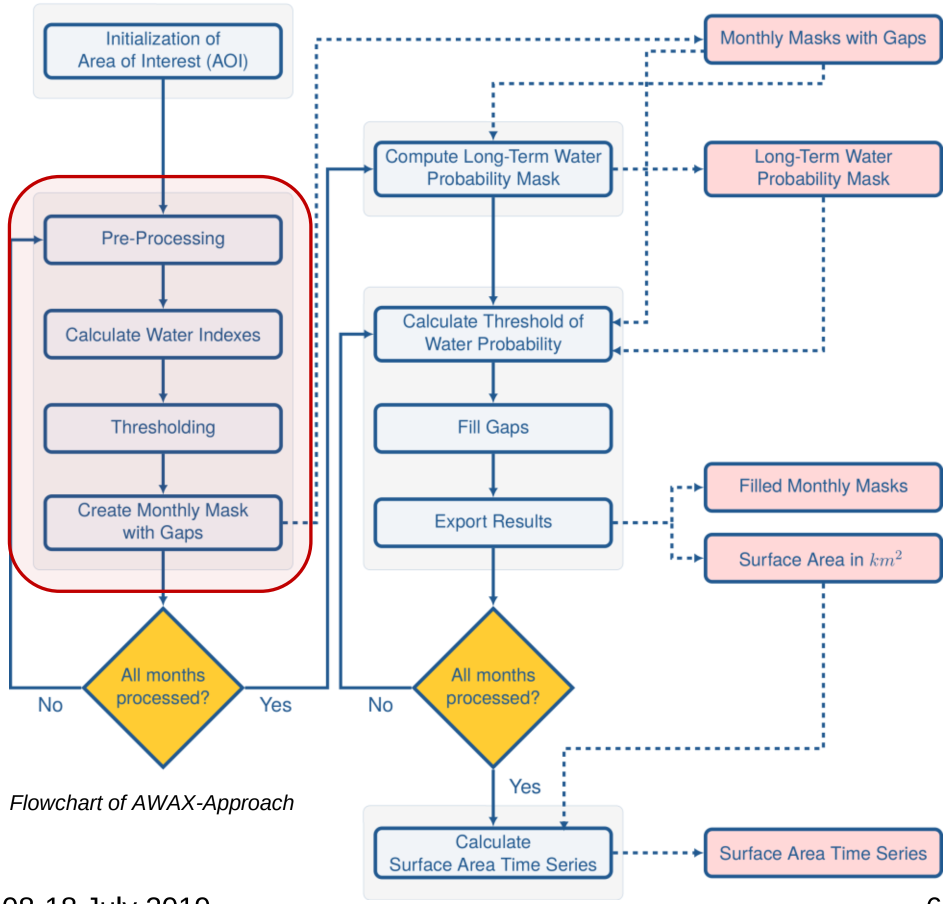


Flowchart of AWAX-Approach

Methodology

Major processing steps:

- Initialization of AOI
- Creation of monthly land-water masks (with data gaps)

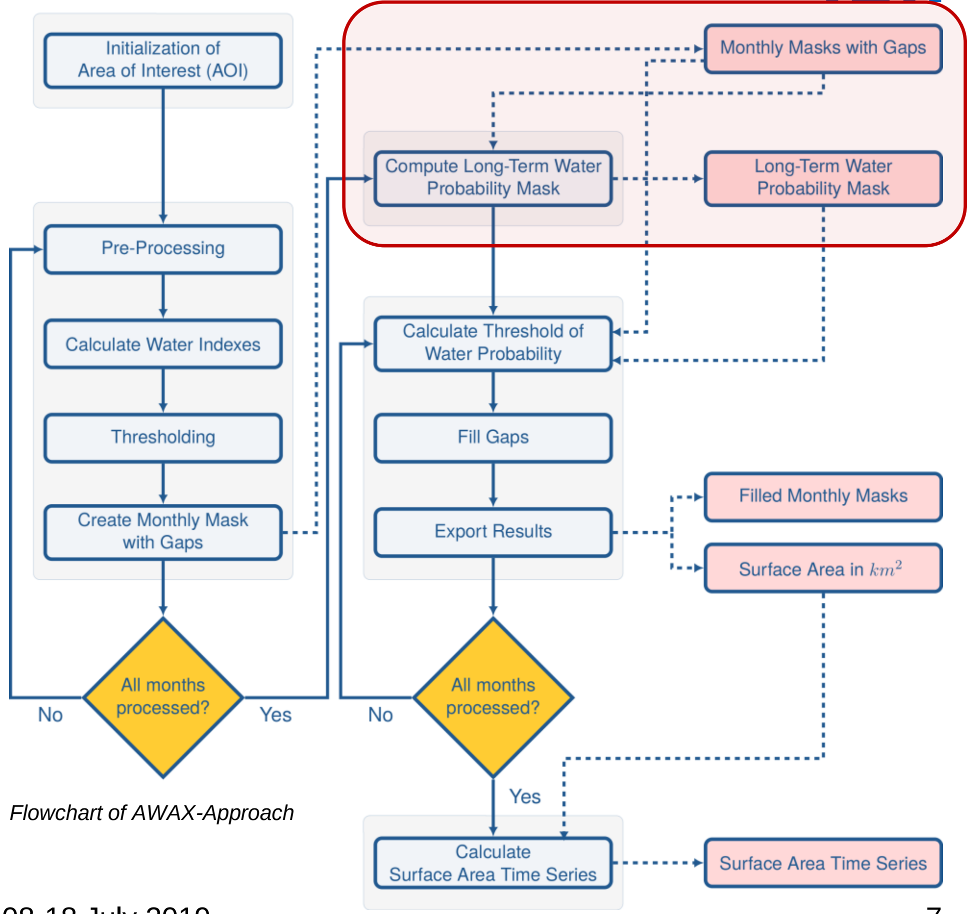


Flowchart of AWAX-Approach

Methodology

Major processing steps:

- Initialization of AOI
- Creation of monthly land-water masks (with data gaps)
- Computation of long-term water probability mask

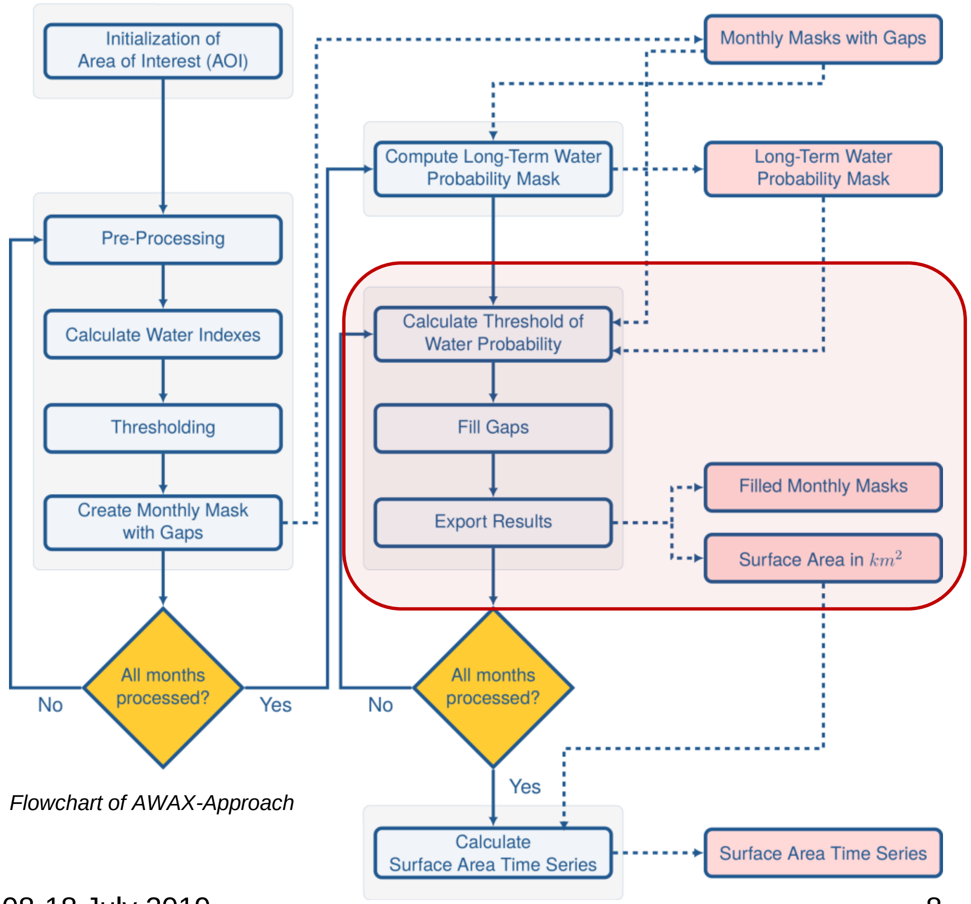


Flowchart of AWAX-Approach

Methodology

Major processing steps:

- Initialization of AOI
- Creation of monthly land-water masks (with data gaps)
- Computation of long-term water probability mask
- Filling data gaps

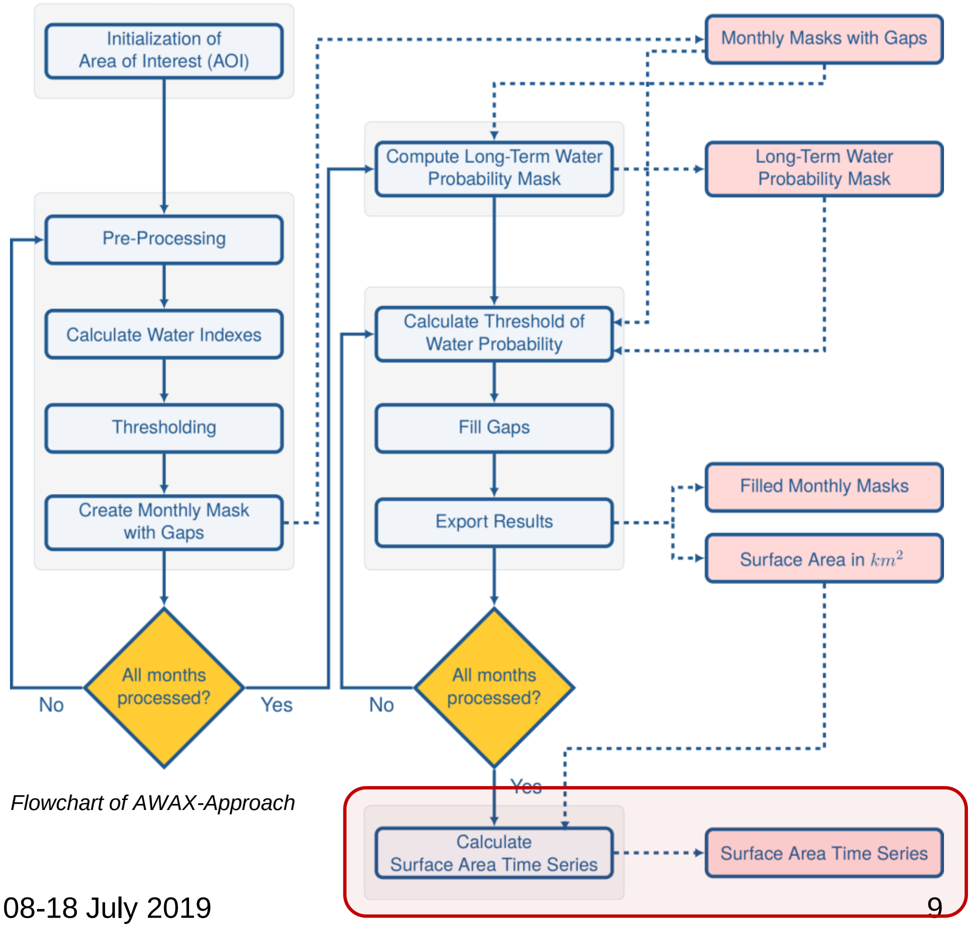


Flowchart of AWAX-Approach

Methodology

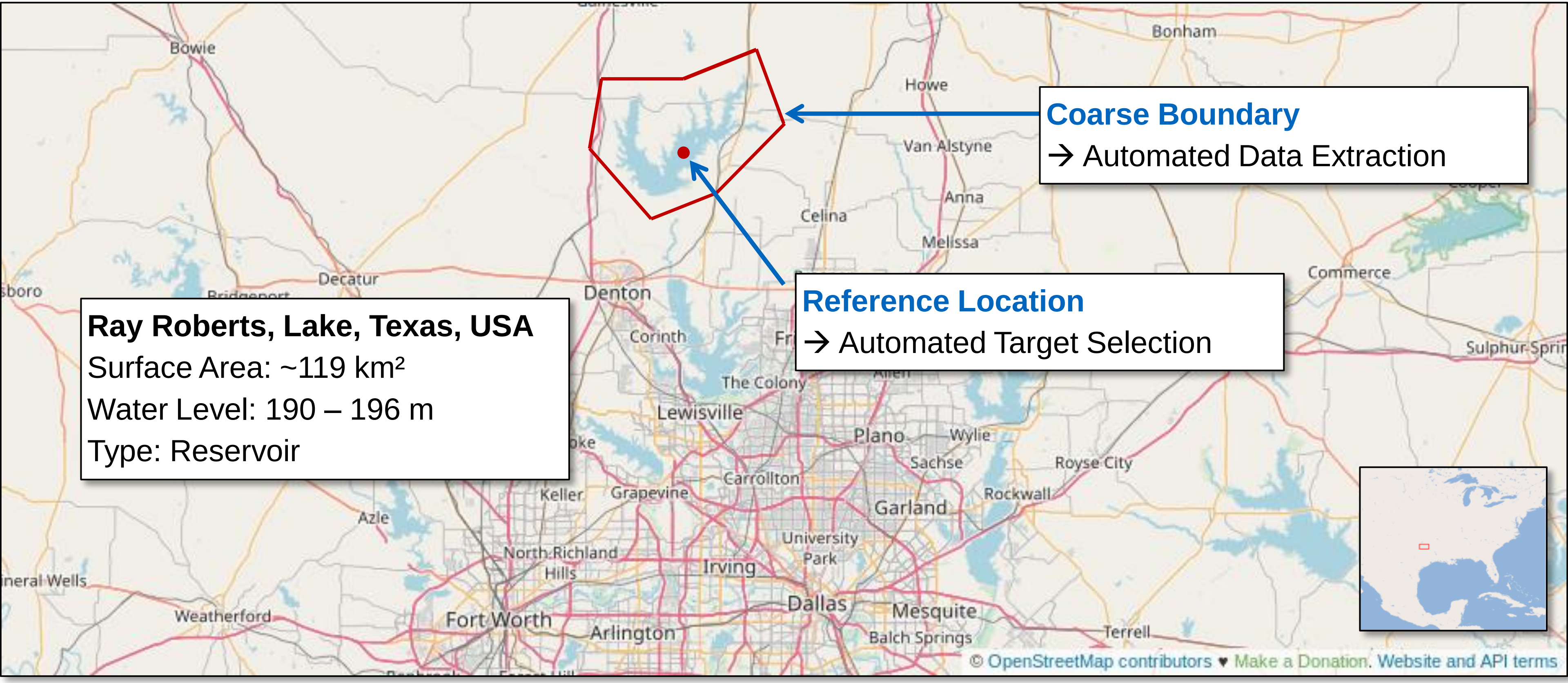
Major processing steps:

- Initialization of AOI
- Creation of monthly land-water masks (with data gaps)
- Computation of long-term water probability mask
- Filling data gaps
- Calculation of surface area time series



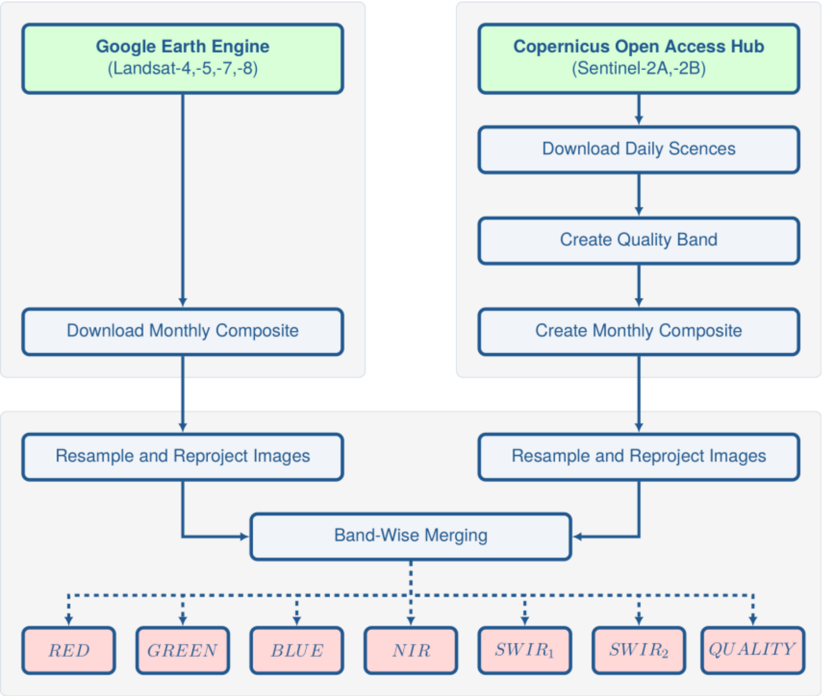
Flowchart of AWAX-Approach

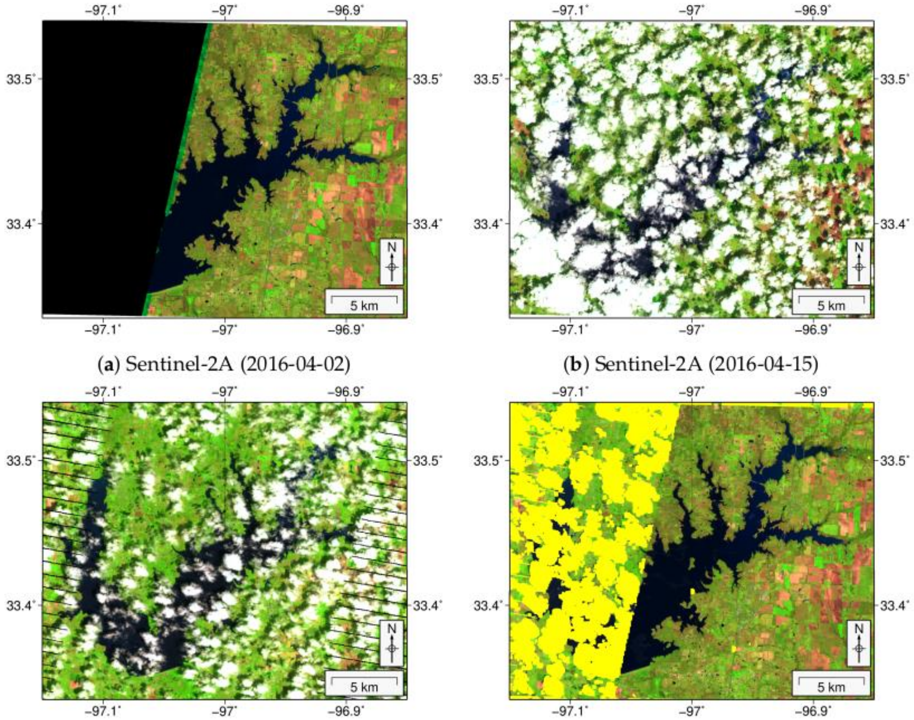
Initialization of Area of Interest (AOI)



Data Extraction

Creation of monthly composite images





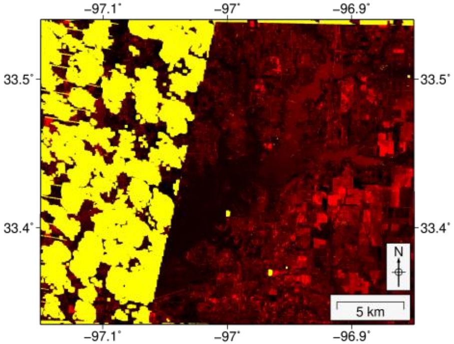
(a) Sentinel-2A (2016-04-02) (b) Sentinel-2A (2016-04-15)

(c) Landsat-7 (2016-04-25) (d) Composite (2016-04)

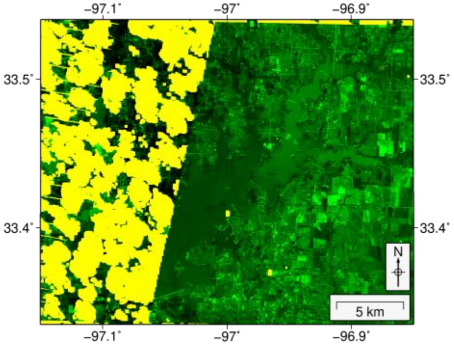
Figure 4. Used daily scenes from Landsat and Sentinel-2 and resulting composite image for Lake Ray Roberts in April 2016. Data gaps in the composite image are highlighted in yellow.

Data Extraction

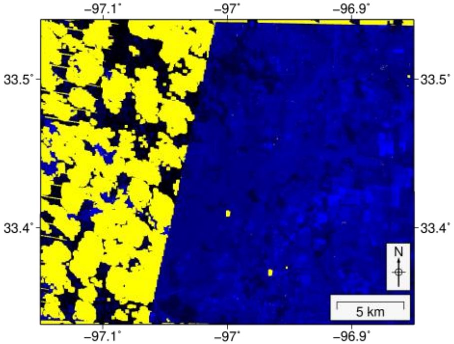
Used Bands …



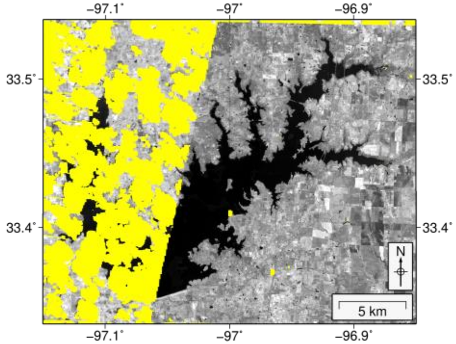
Red



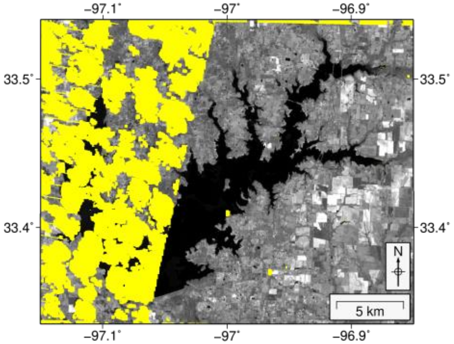
Green



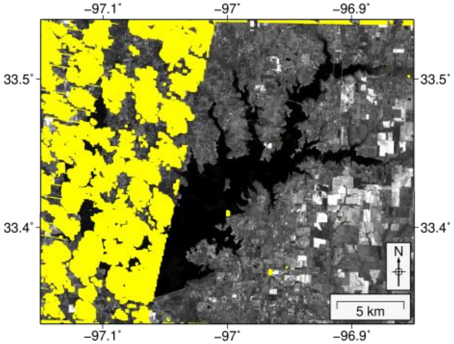
Blue



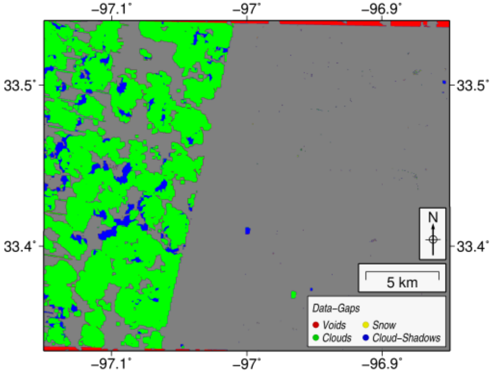
Near-Infrared (NIR)



Short Wave Infrared 1 (SWIR1)

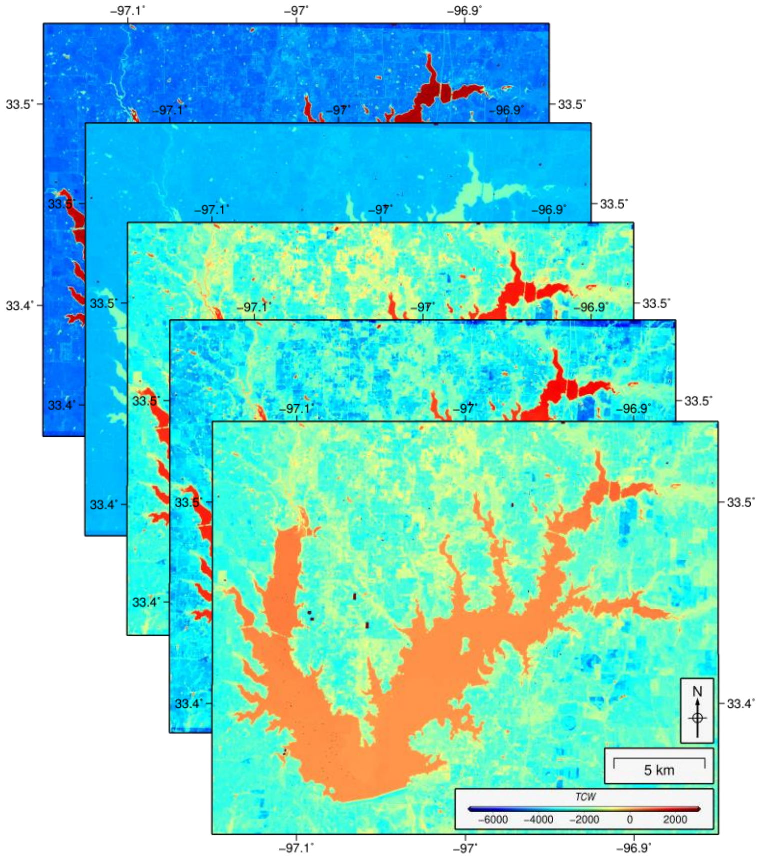


Short Wave Infrared 2 (SWIR2)



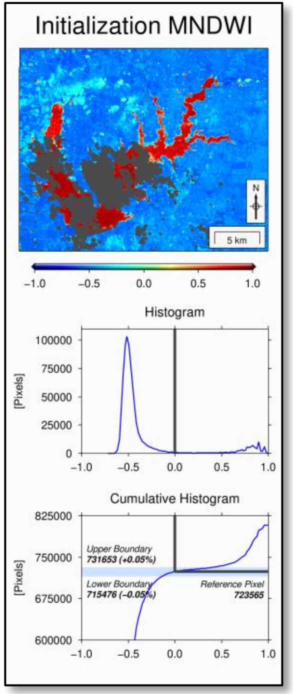
Quality-Band

Calculation of Water-Indexes

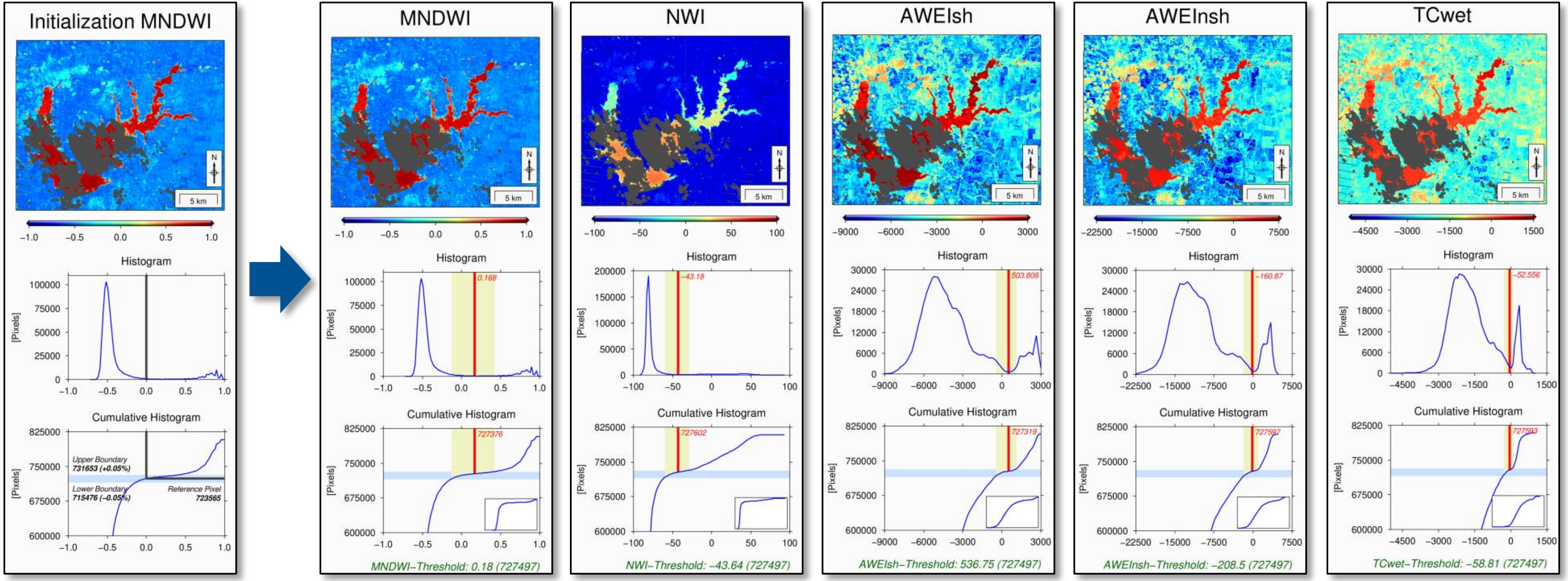


- **Modified Normalized Difference Water Index ($\mathbf{MNDWI}$)**
  (Xu, 2006)
- **New Water Index ($\mathbf{NWI}$)**
  (Li, 2016)
- **Automated Water Extraction Index for Non-Shadow Areas ($\mathbf{AWEI_{nsh}}$)**
  (Feyisa et al, 2014)
- **Automated Water Extraction Index for Shadow Areas ($\mathbf{AWEI_{sh}}$)**
  (Feyisa et al, 2014)
- **Tasseled Cap for Wetness ($\mathbf{TC_{wet}}$)**
  (Crest, 1985)

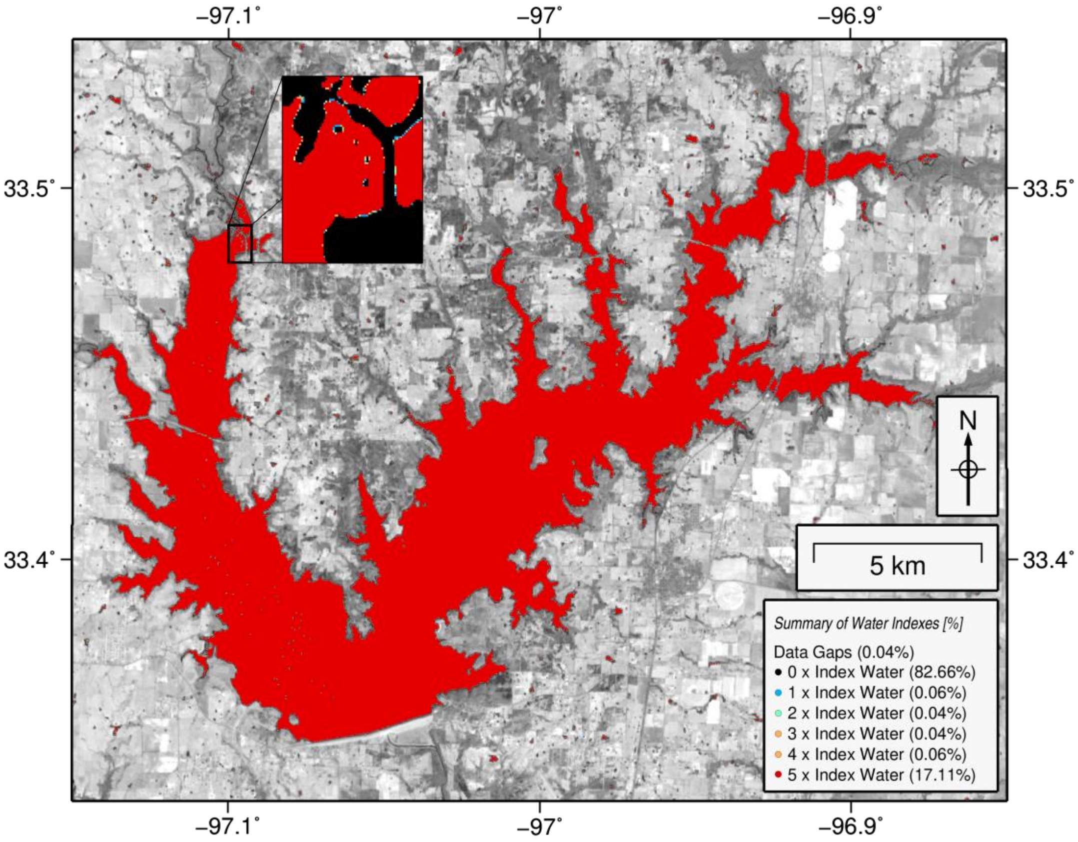
Land-Water Classification



Land-Water Classification



Masking

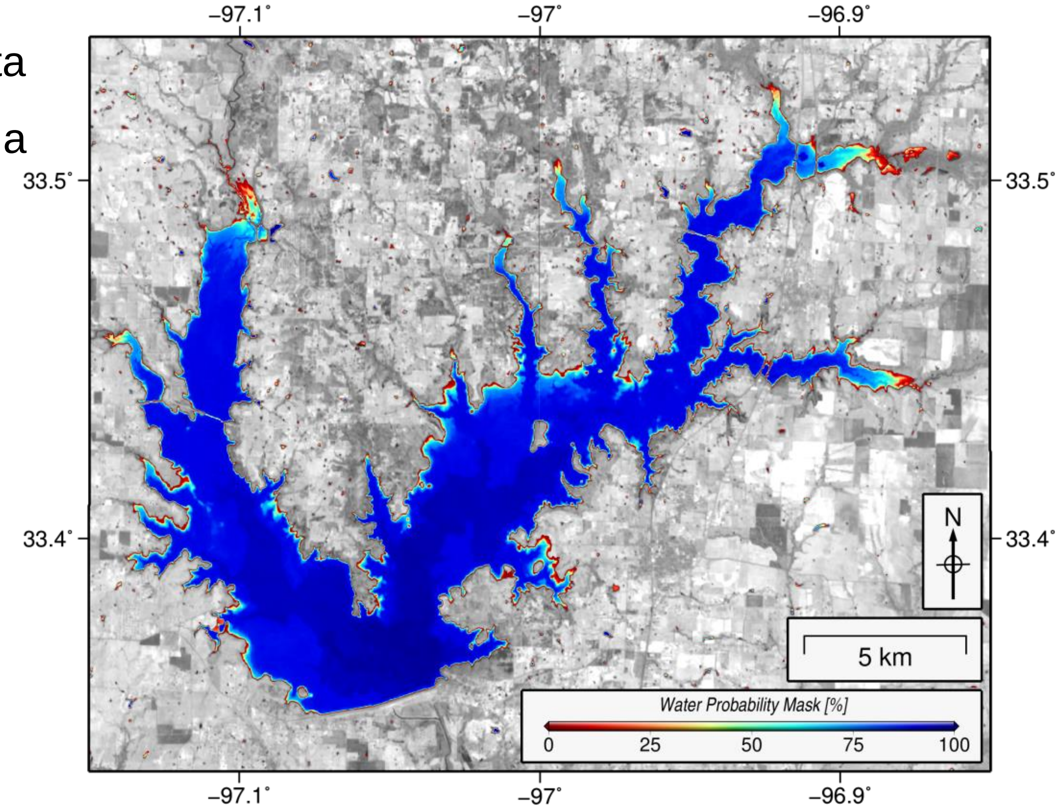


Creation of binary monthly land-water masks with data gaps

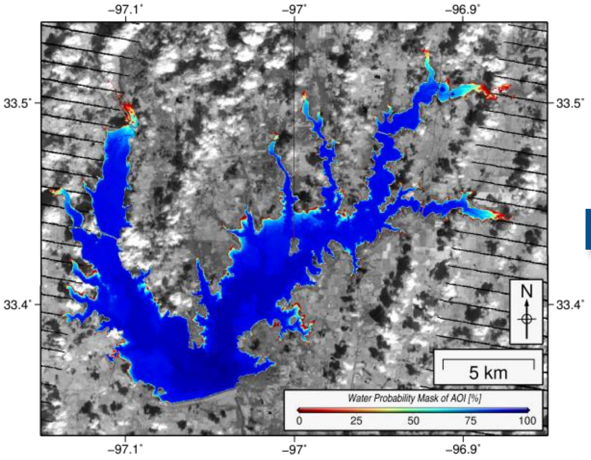
Input Value (based on 5 water indexes)	Monthly Land-water mask
5 Water Indexes	**Water (1)**
4 Water Indexes	**Water (1)**
3 Water Indexes	*Data Gap*
2 Water Indexes	*Data Gap*
1 Water Indexes	**Land (0)**
0 Water Indexes	**Land (0)**
Data Gap	*Data Gap*

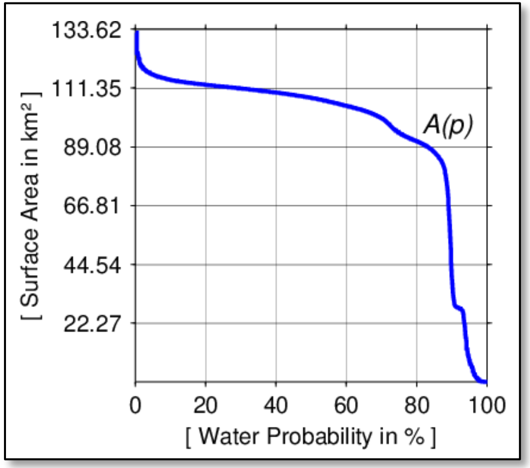
Long-Term Water Probability Mask

- All monthly land-water masks (with data gaps) are merged in order to compute a long-term water probability mask
- Finally, the reference point from the initialization step is used to select the area of interest (AOI)



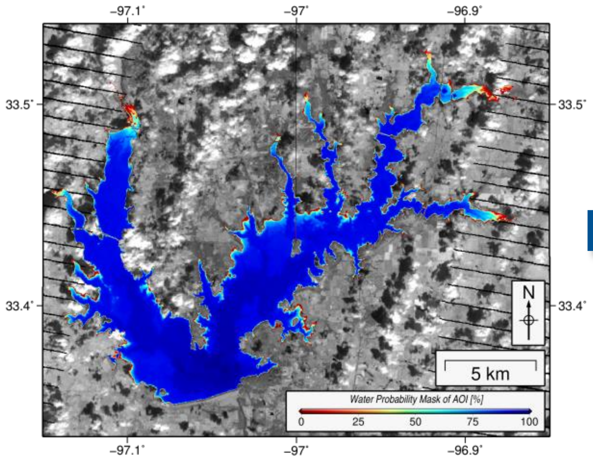
Fill Data Gaps

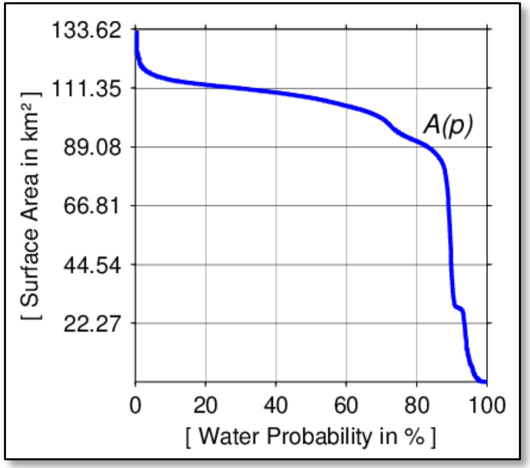


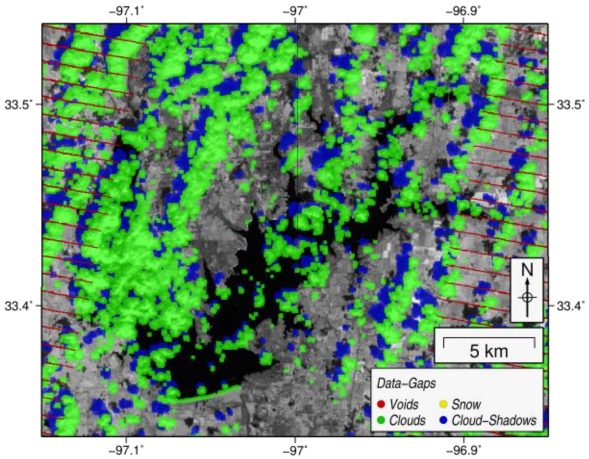


1. Create dependency between surface area and water probability mask

Fill Data Gaps

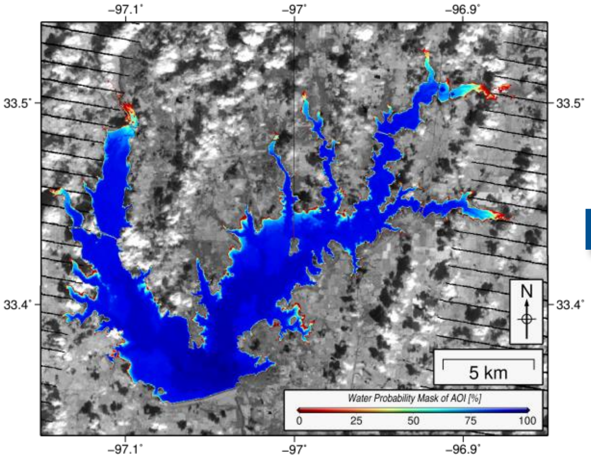


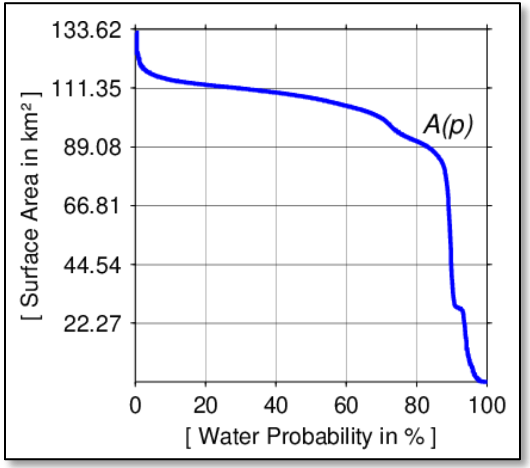


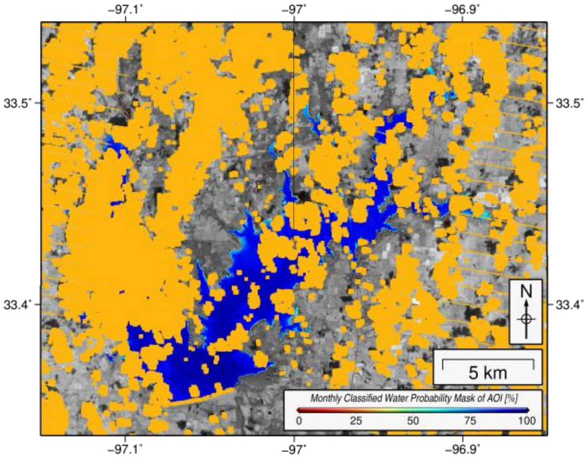


1. Create dependency between surface area and water probability mask
2. Merge land water mask (with gaps) and water probability mask

Fill Data Gaps







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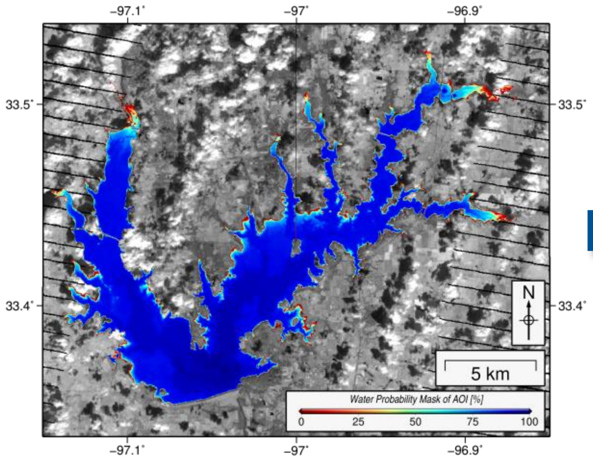
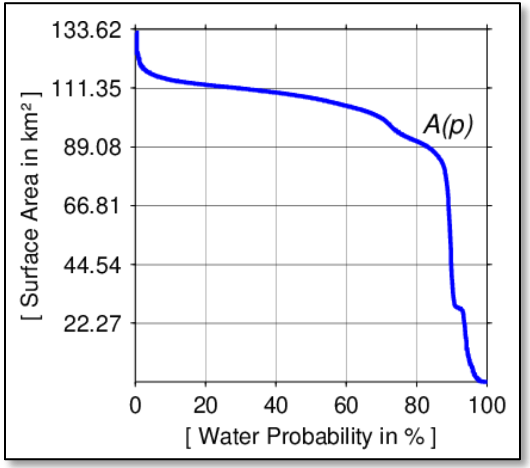
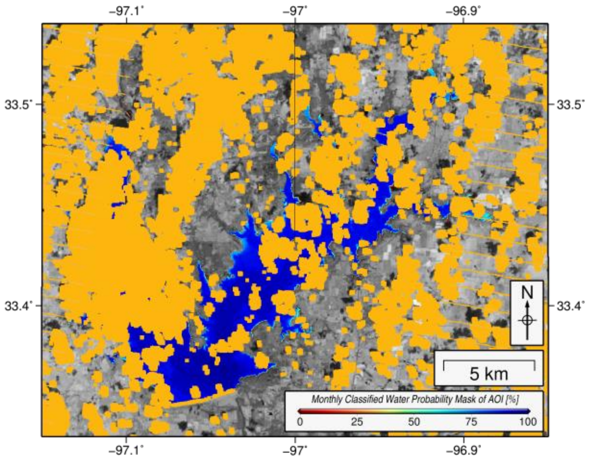
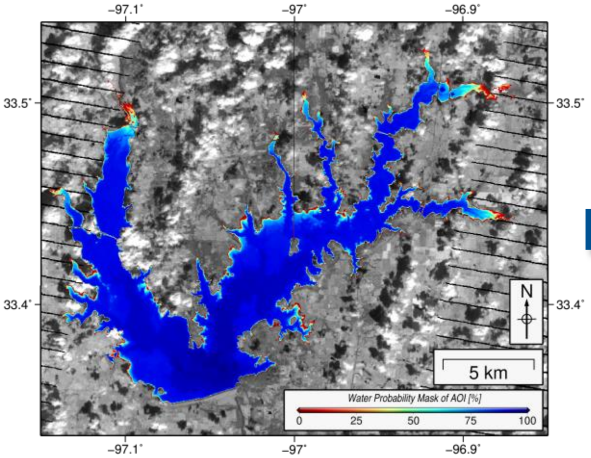


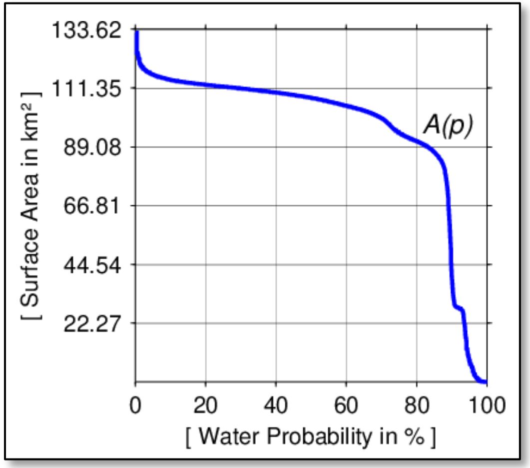


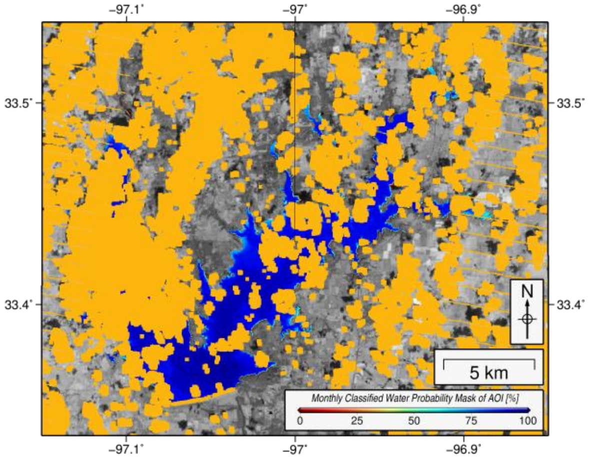


1. Create dependency between surface area and water probability mask
2. Merge land water mask (with gaps) and water probability mask
3. Calculate initial surface area $A_{initial}$ (46.85 km²)

Fill Data Gaps



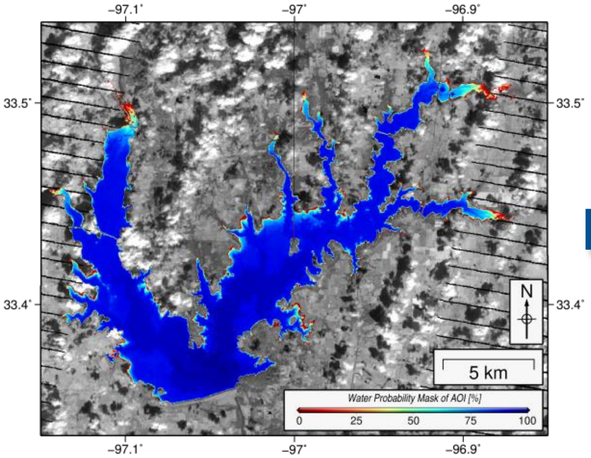


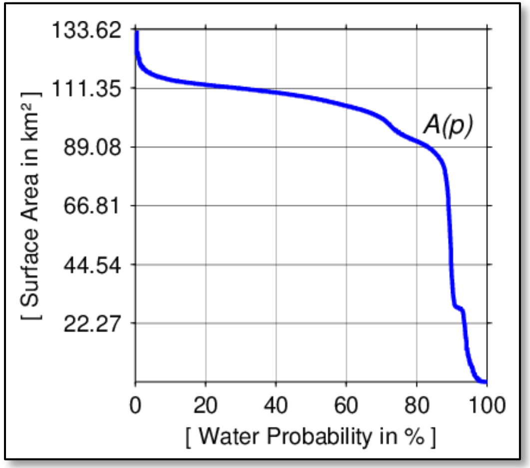


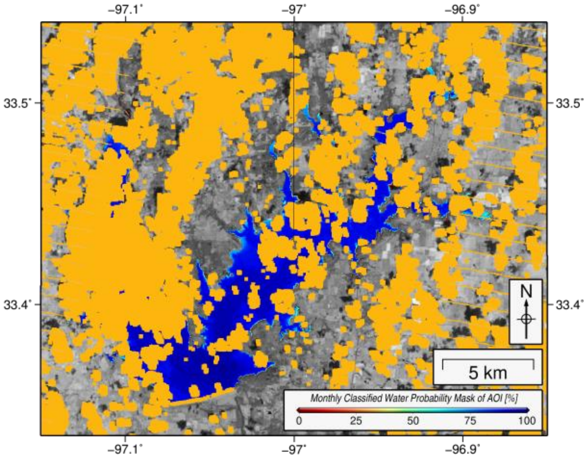
1. Create dependency between surface area and water probability mask
2. Merge land water mask (with gaps) and water probability mask
3. Calculate initial surface area $A_{initial}$ (46.85 km²)
4. Iterative filling of data gaps A_{fill} (p = 45% → 61.01 km²)

$$|(A_{initial} + A_{fill}(p)) - A(p)| \stackrel{!}{=} Min$$

Fill Data Gaps







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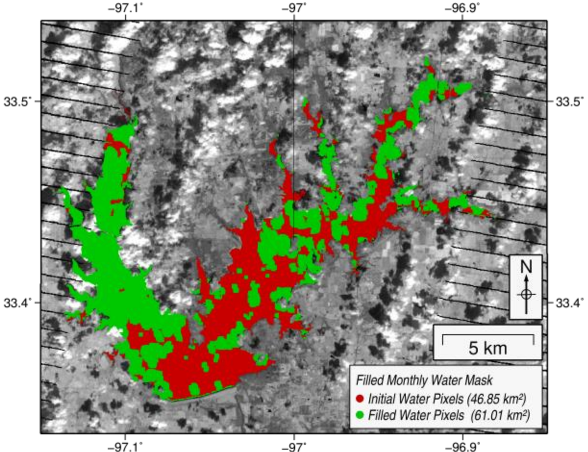
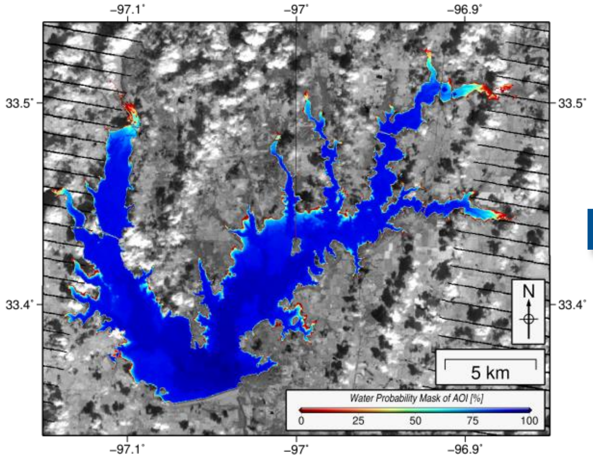
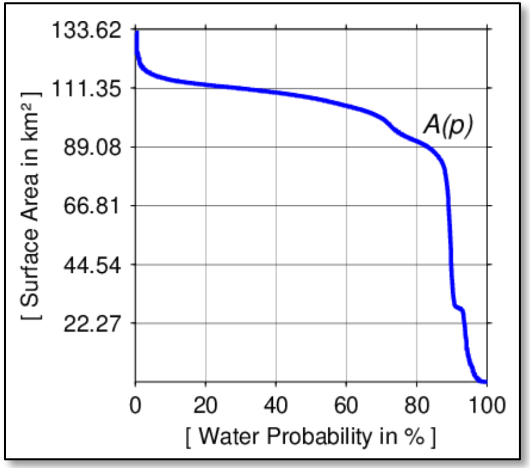
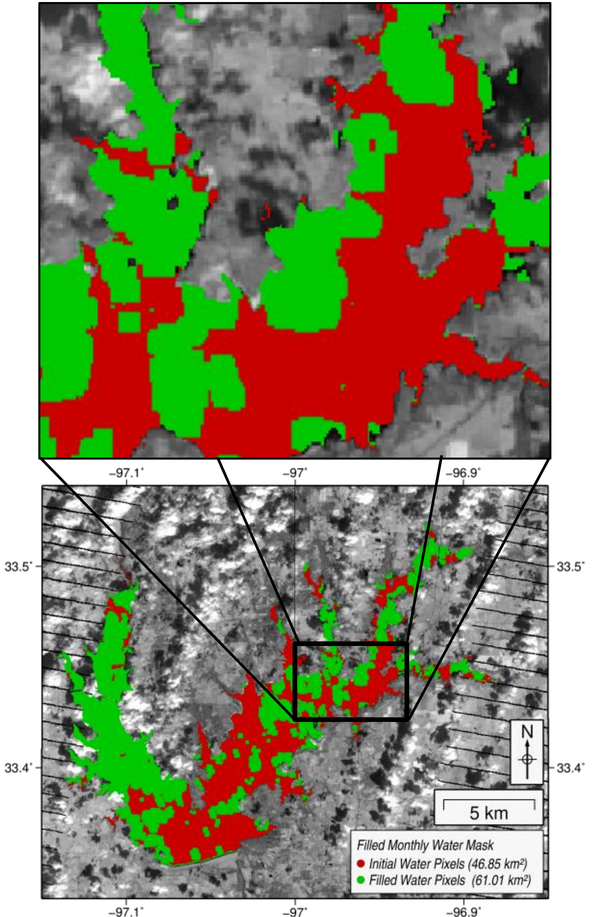
4. Iterative filling of data gaps A_{fill} (p = 45% → 61.01 km²)
5. Merge initial and fill masks to get gap-free mask $A(45\%) = 107.86$ km²



Fill Data Gaps







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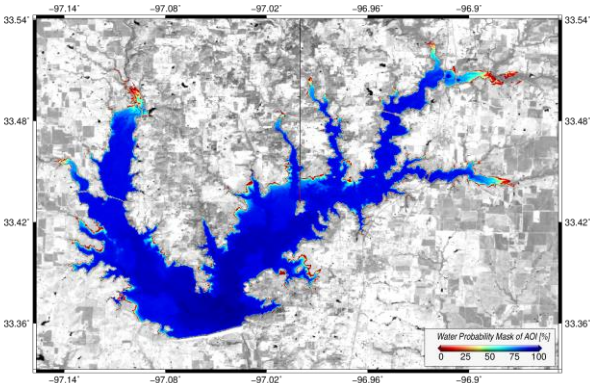
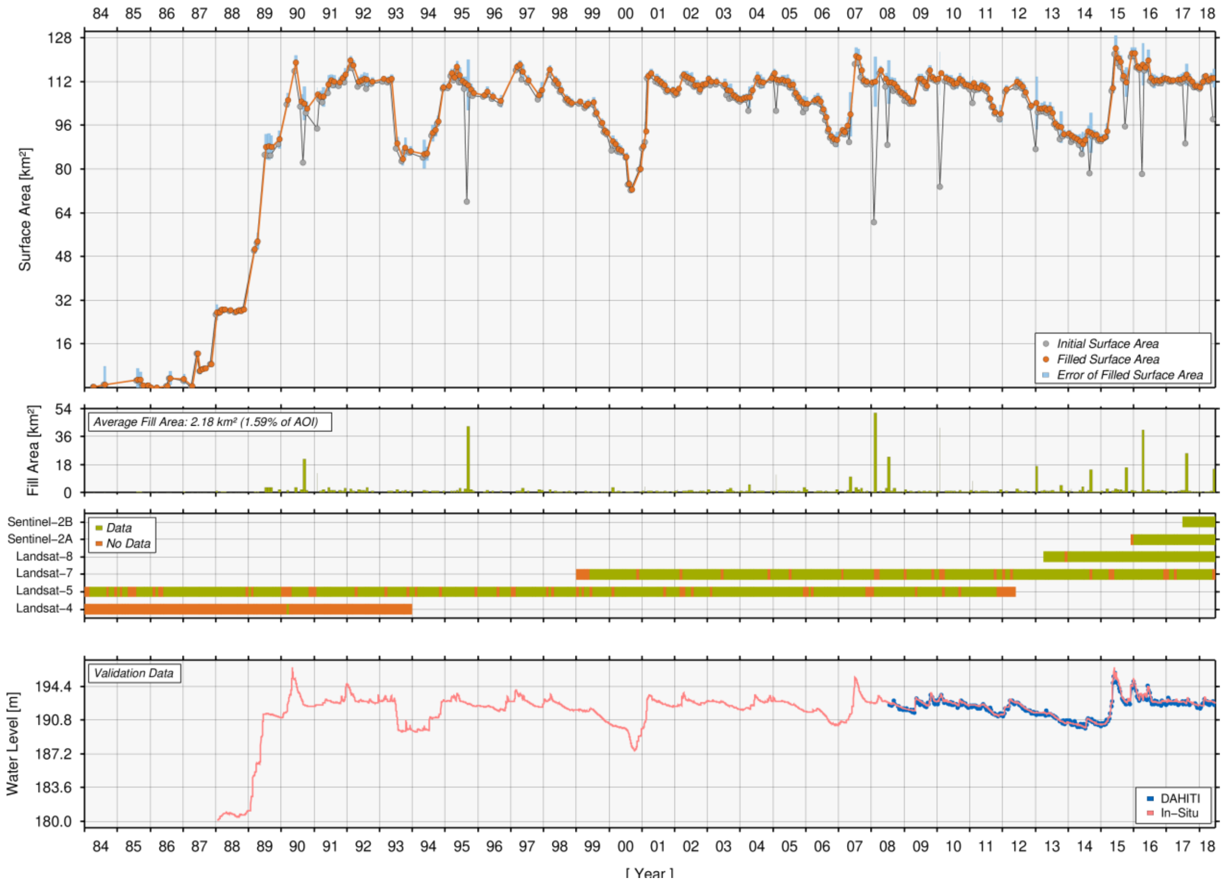
Results / Validation

Ray Roberts, Lake *(USA)*

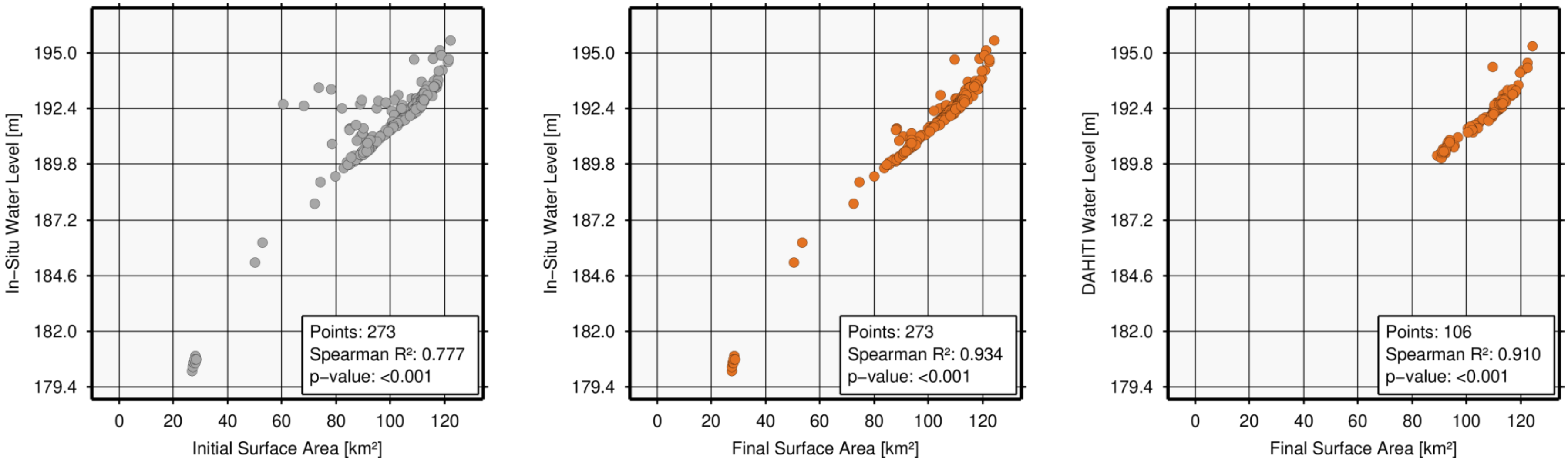




- AOI: 137.38 km²
- 290 valid masks (1984 - 2018)
- Fill Area:
  - Max: 51.58km² (37.5 % of AOI)
  - Avg: 2.18km² (1.6 % of AOI)

Results / Validation

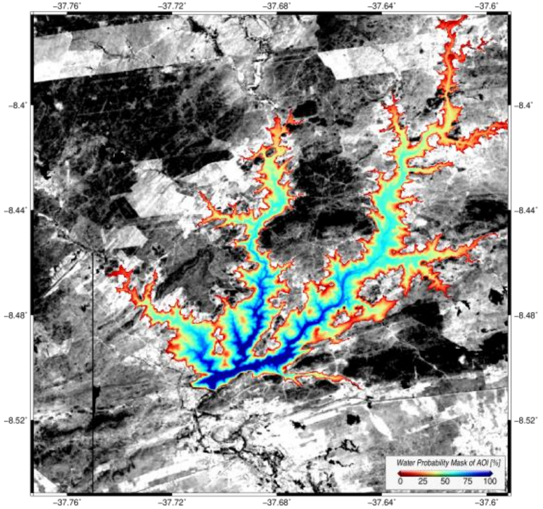
Ray Roberts, Lake *(USA)*



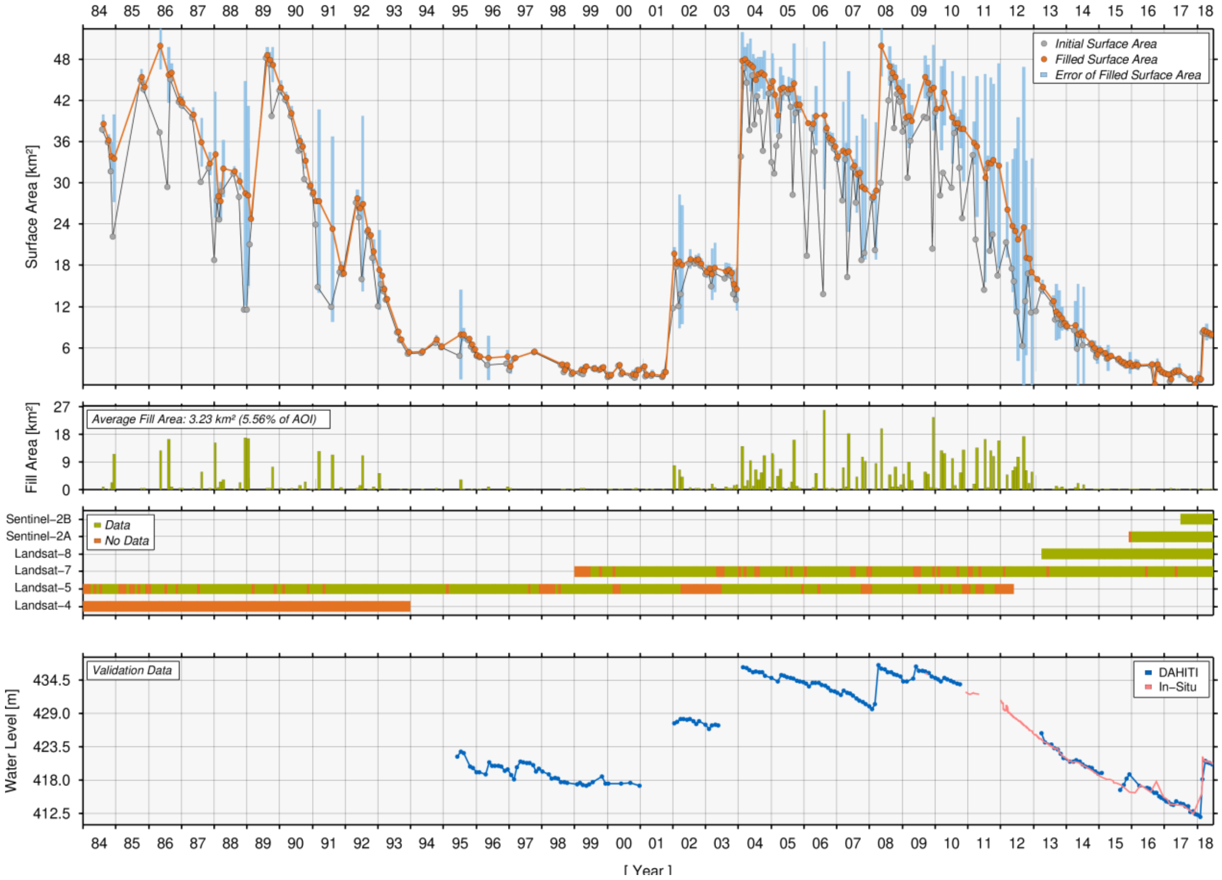
- Improvement of R^2 from 0.777 to 0.934 (in-situ), respectively 0.910 (altimetry)
- Cross-validation leads to a RMSE of 2.85 km² (2.07% of AOI)

Results / Validation

Poco da Cruz, Reservoir *(Brazil)*

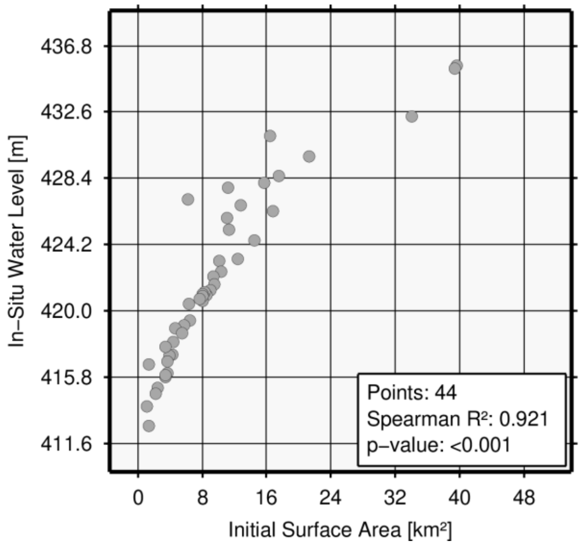


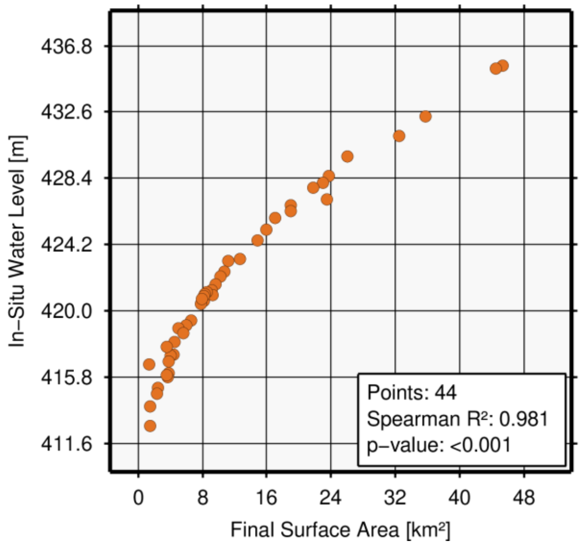
- AOI: 58.07 km²
- 228 valid masks (1984 - 2018)
- Fill Area:
  - Max: 25.95 km² (44.7 % of AOI)
  - Avg: 3.23 km² (5.6 % of AOI)

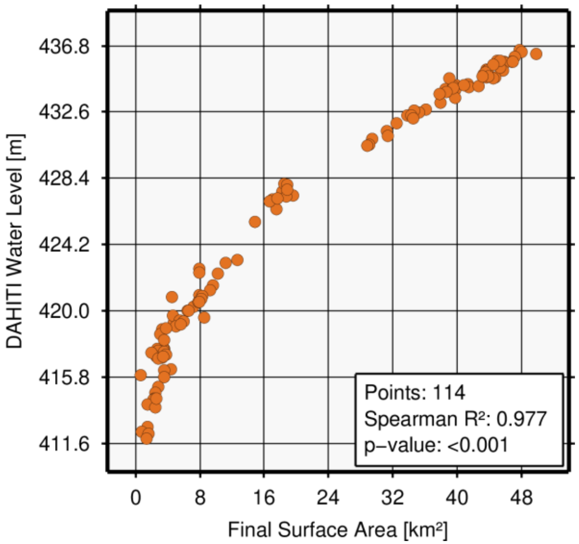


Results / Validation

- **Poco da Cruz, Reservoir** *(Brazil)*



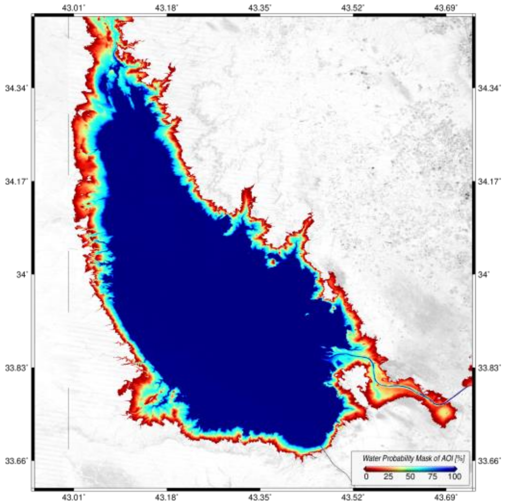




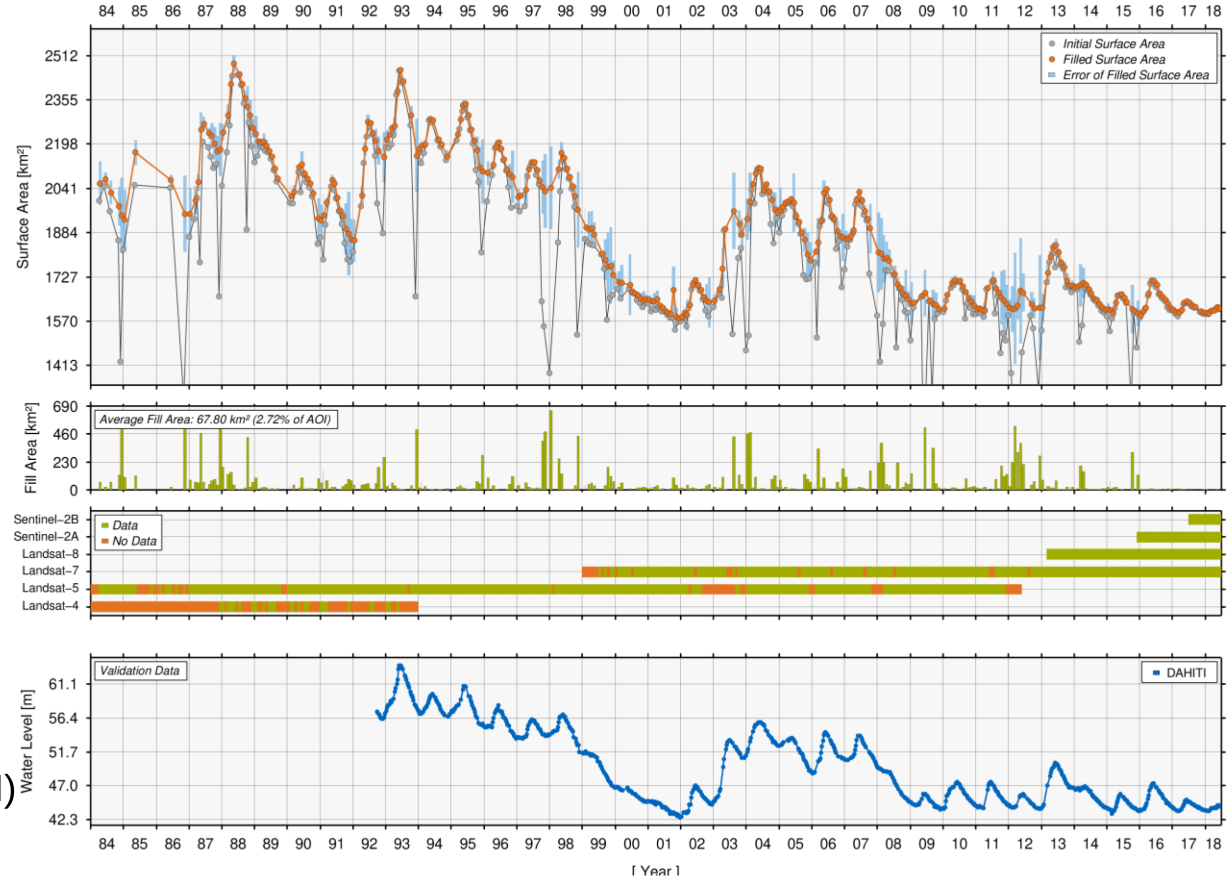
- Improvement of R^2 from 0.921 to 0.981 (in-situ), respectively 0.977 (altimetry)
- Cross-validation leads to a RMSE of 1.10 km² (1.9 % of AOI)

Results / Validation

Tharthar, Lake *(Iraq)*

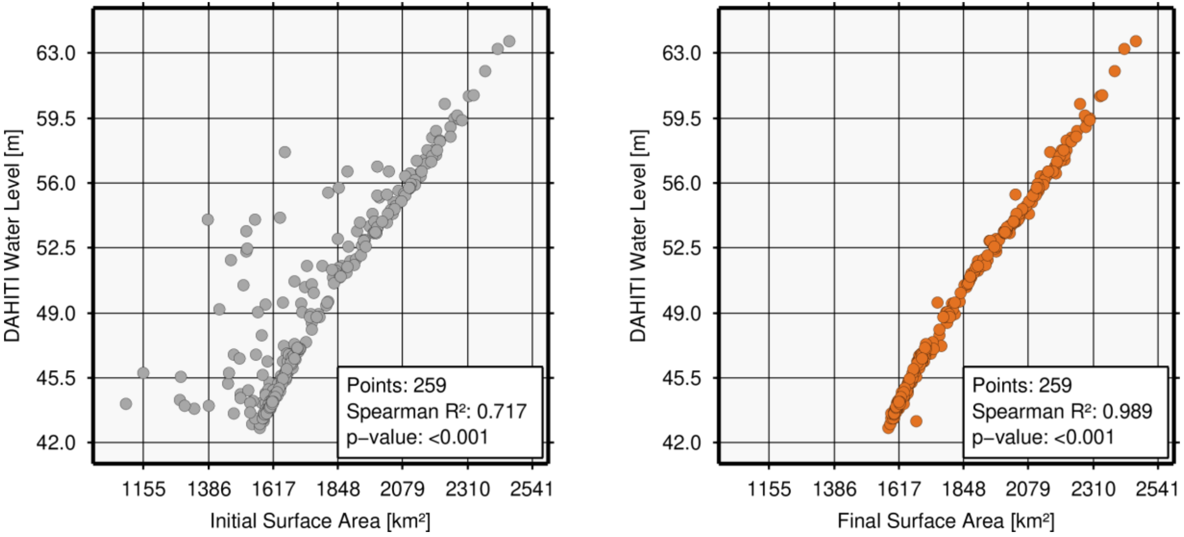


- AOI: 2491.37 km²
- 327 valid masks (1984 - 2018)
- Fill Area:
  - Max: 657.92 km² (44.7 % of AOI)
  - Avg: 67.80 km² (2.7 % of AOI)



Results / Validation

Tharthar, Lake *(Iraq)*

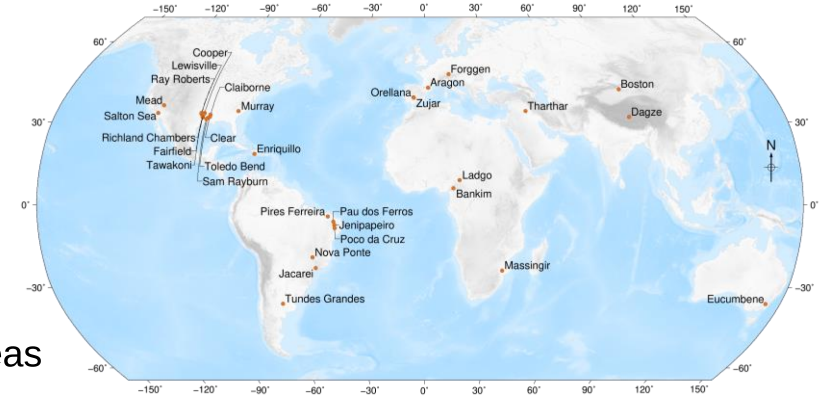


- Improvement of R^2 from 0.717 to 0.989 (altimetry)
- Cross-validation leads to a RMSE of 16.71 km² (0.7 % of AOI)

Quality Assessment

In this study, 32 globally distributed lakes and reservoirs have been investigated

- Surface area: 9.84 – 2491.37 km^2
- Water level variations: 2.26 – 43.56 m
- Annual cloud coverage: 22 – 65 %
- Annual rainfall: 71 – 1749 mm/y



Quality Assessment

- Improvements of R^2 between initial and filled surface areas
  - 0.037 – 0.441 using in-situ data
  - 0.014 – 0.734 using satellite altimetry (DAHITI)
  - → Final correlations R^2 have been increased to more than 0.8 or even 0.9 for almost all study areas.
- Average surface area errors from cross-validation
  - 0.30 km^2 - 67.80 km^2 (0.89 % - 9.68 % of AOI)

Conclusion / Outlook

- Optical images from Landsat-4/-5/-7/-8 and Sentinel-2A/2B are used for creation of monthly composites
- A new approach for the estimation of monthly land-water masks based on the combination of five water indexes (MNDWI, NWI, $\mathrm{AWEI_{sh}}$, $\mathrm{AWEI_{nsh}}$, TC_{wet}) and a new threshold computation has been demonstrated
- More than 30 years of monthly masks are merged in order to calculate a long-term water probability mask.
- Remaining data gaps are filled successfully by using the long-term water probability mask.
- **The average correlation coefficients R^2 between surface areas and water levels increased from 0.611 to 0.862 after filling data gaps which is an improvement of about 41%**

- This new product has the potential for new applications:
  - Densification of water level time series in combination with land water masks (talk today morning)
  - Volume storage variations of lakes and reservoirs in combination with satellite altimetry
  - Estimation of river discharge by remote sensing (optical imagery and satellite altimetry)

Register Login Password Forgotten?

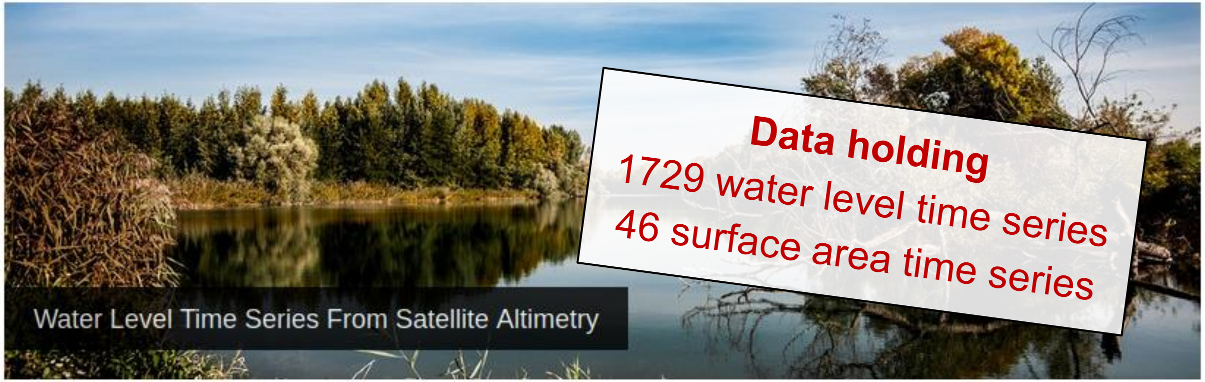
Database for Hydrological Time Series of Inland Waters (DAHITI)
Deutsches Geodätisches Forschungsinstitut
Technische Universität München

Free Data Access on http://dahiti.dgfi.tum.de

- DAHITI
- Virtual Stations +
- Map
- Lake/River not found?
- Publications
- DAHITI-API (Beta)

Search ...

Database for Hydrological Time Series of Inland Waters (DAHITI)



Data holding
1729 water level time series
46 surface area time series

WELCOME TO DAHITI ...

The **Database for Hydrological Time Series of Inland Waters** (DAHITI) was developed by the Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM) in 2013. DAHITI provides water level time series of lakes, ...ellite altimetry for hydrological applications. All water level time ...egistration process.

...el time series distributed over all continents, except Antarctica. In Africa (396 time series), Asia (282), Australia (17), Europe (51), North America (173), and South America (808) water level time

Schwatke C., Scherer D., Dettmering D.:
Automated Extraction of Consistent Time-Variable Water Surfaces of Lakes and Reservoirs Based on Landsat and Sentinel-2.
Remote Sensing, 11(9), 1010, 10.3390/rs11091010, 2019 *(Open Access)*

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DAHITI-Flyer