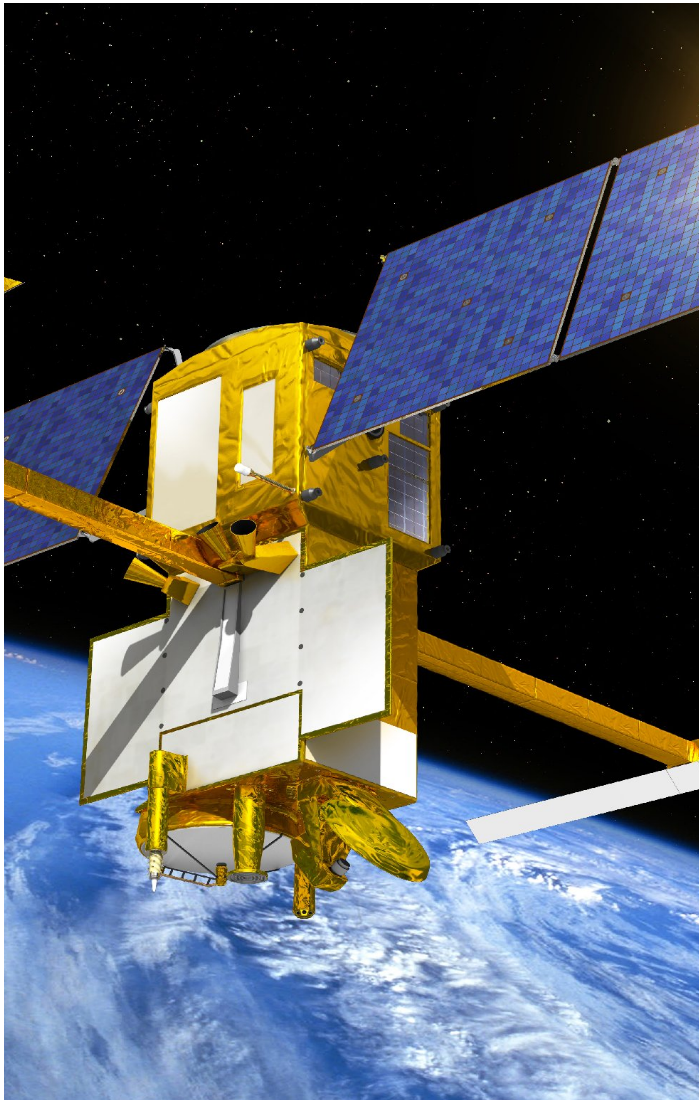
SWOT

Water Detection Algorithms and Prior Data

Roger Fjørtoft, Damien Desroches, Victor Poughon, Brent Williams, Lucie Labat-Allée, Emmanuelle Sarrazin, Nadine Pourthié, Denis Carbonne, Hervé Yesou

SWOT Science Team Meeting, Montreal, Canada
23 June 2018



OUTLINE

- Water detection in SWOT HR images
  - Phenomenology
  - Algorithms
  - Performance assessment
- Use of prior data
  - Objectives, applications
  - Dark water flagging: performance gain assessment
  - PIXC inclusion zones: assessment of prior water masks
- Status and way forward

SWOT water detection phenomenology

Water signal is assumed to be distinct from land signal

- Primarily by the power/brightness/σ_0
- May be some information in coherence or in height/phase flatness

Nominal σ_0: bright water, dark land

- Water is expected to be bright (σ_0 ~ 10 to 15 dB)
- Most land types are dark (σ_0 ~ -5 to 0 dB)

Water detection algorithm

σ_0 exceptions:

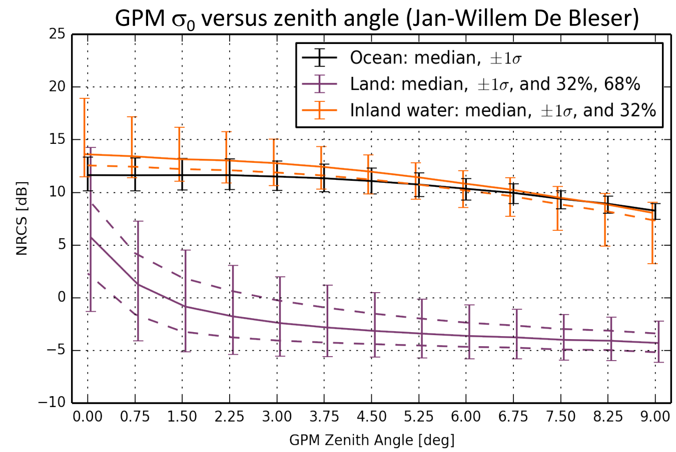
- Dark water: Weak water backscattering off-nadir for very low wind speeds (smooth surface)
- Rain and vegetation attenuate the surface signal
- Some bright land types (e.g., roads, urban areas, hills/mountains (layover), snow?)

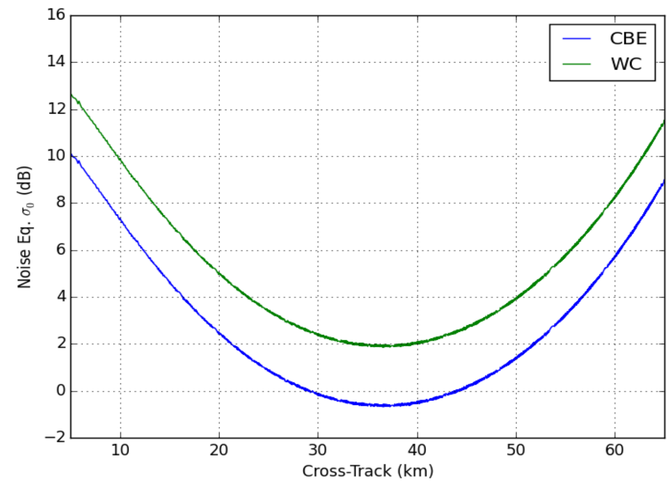
Use of prior data

SWOT has high thermal noise floor

- ~ 0 dB noise-equivalent- σ_0 in best part of swath for single channel (CBE)
- Most land signals dominated by noise
- Up to 3 dB SNR gain by combining two channels coherently, using a DEM to rotate phases

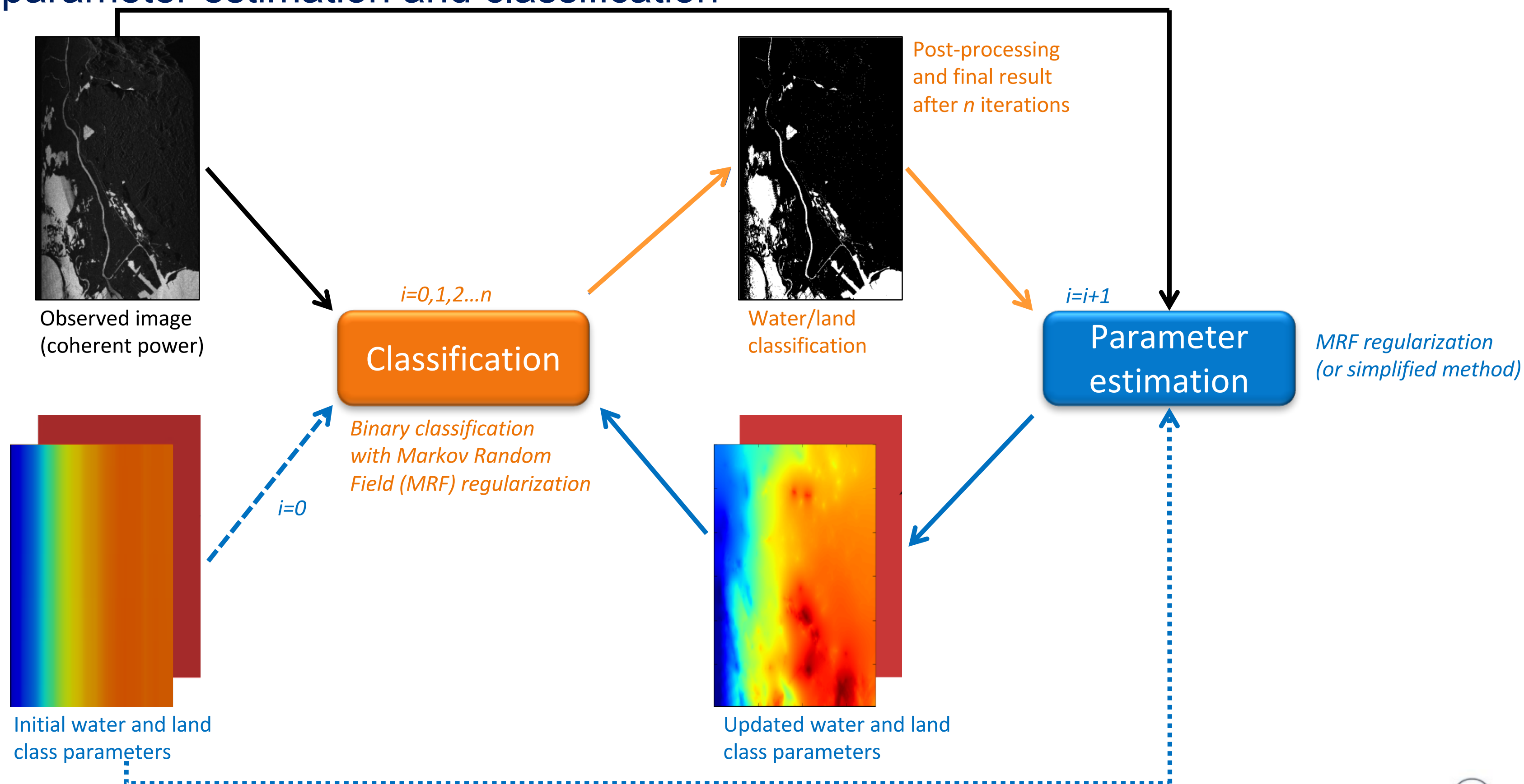
Coherence time of water limits azimuth focusing (widens azimuth PTR)





SWOT water detection baseline method

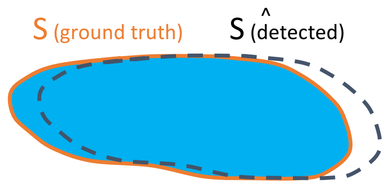
Iterative parameter estimation and classification



Water detection performance assessment

Assessment w.r.t science requirement: relative error in area [m^2]

	Relative Error	Lake size	River size
Req.	15% (1σ)	>(250m²)	>100m (x10km)
TSM Req.	15% (1σ)	>1km²	>170m (x10km)
Goal	25% (1σ)	(100m)² - (250m)²	[50 – 100]m (x10km)

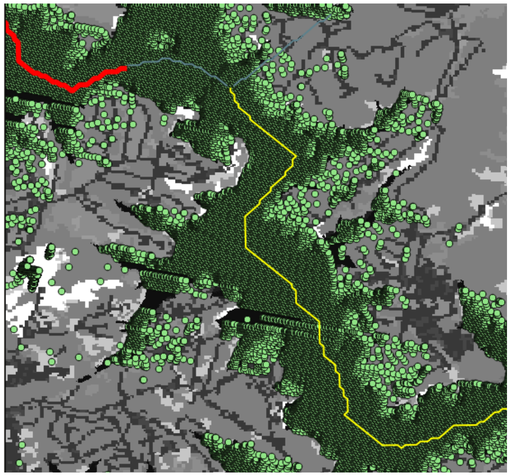


$e = (S-\hat{S})/S$

Principle: assessment at water body level (river reach or lake)

- Attribute detected and ground truth water pixels to known water bodies
- For each water body, compute relative error in surface area between detected water body and ground truth.
- Compute histogram of relative errors, 1σ value
- Compare with requirement: < 15% (1σ)

Example: attribution of pixels to reaches



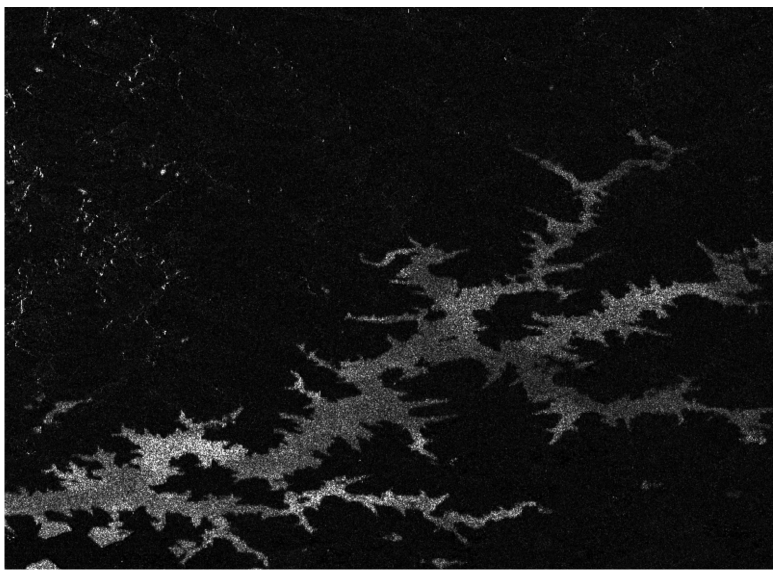
Remarks

- Science requirement is on area: perfect overlap not explicitly required
- Assessment on rivers only for Measurement Review 2 (using river DB, RiverObs)

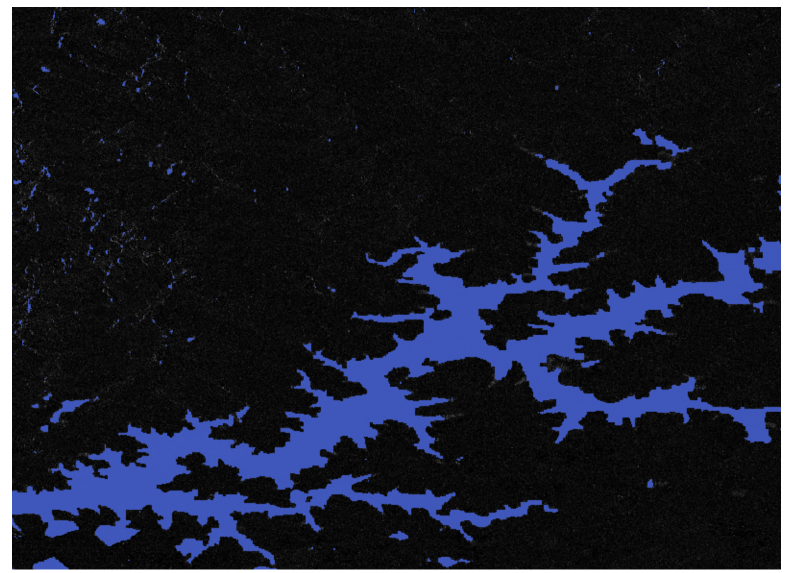
Water detection performance assessment

Performance assessment presented at Measurement Review 2 (5-6 Dec 2017)

- Po river (1 year) + US lidar scenes (altogether > 270 images x 2 configurations)
- Current Best Estimate (CBE) and Worst Case (WC) simulation configurations
- Example: US lidar scene (extract)



Coherent power

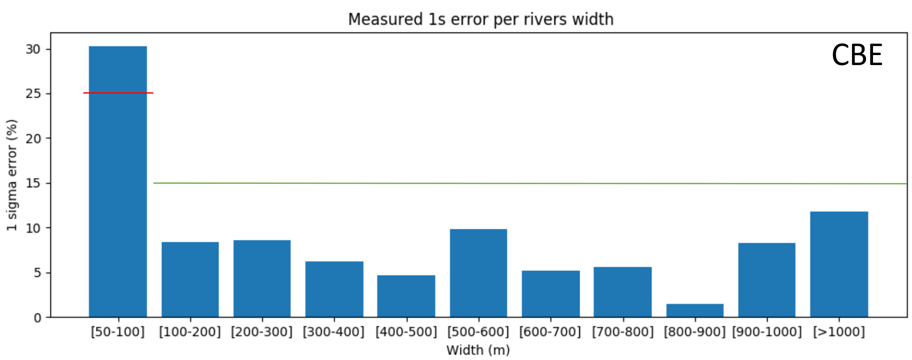


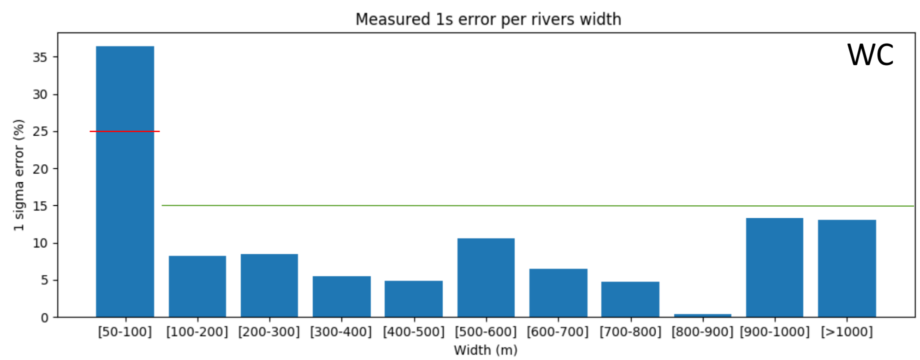
Detected water mask

Water detection performance assessment

Preliminary water detection results without dark water flagging

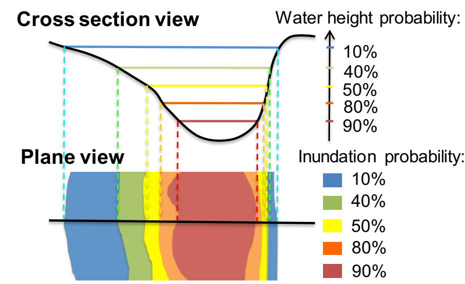
- Po river (1 year) + US lidar scenes (altogether > 270 images x 2 configurations)





- Within science requirements: <15% (1σ) for rivers >100m (CBE and WC)
- Errors mainly due to dark water (area underestimated)
- Slight overestimation of extent mainly due to azimuth smearing

Use of prior water masks in SWOT HR processing



Dark water flagging

- Extend detected water mask (compensate dark water, misclassification)
- GSWO (Pekel et al.): identify occurrence level (%) that fits detected water

Zones to always include in the HR L2 Pixel Cloud product (floodplain, wetlands…)

- Prior water probability > 0 for at least one water probability map (GSWO + ~ 2-3 others), or covered by the prior river and lake databases prepared for SWOT

Study: Identify a limited number of global water masks, ranked by accuracy and complementarity w.r.t. GWSO.

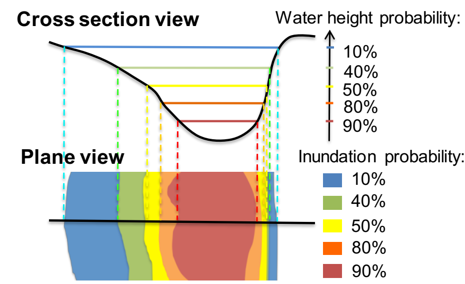
Zones to always exclude from the HR L2 Pixel Cloud product (water unlikely)

- Could be based on prior water masks, map information, DEM… (TBC)

Other potential applications (TBC)

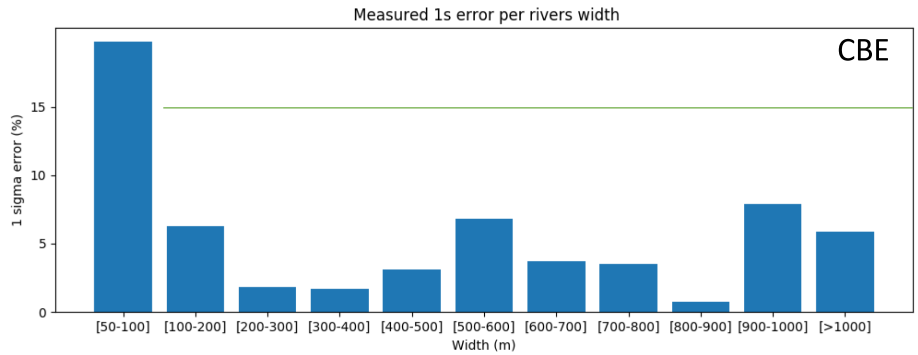
- Water detection(as training set or additional data layer)
- Land/water layover prediction?
- Phase unwrapping?

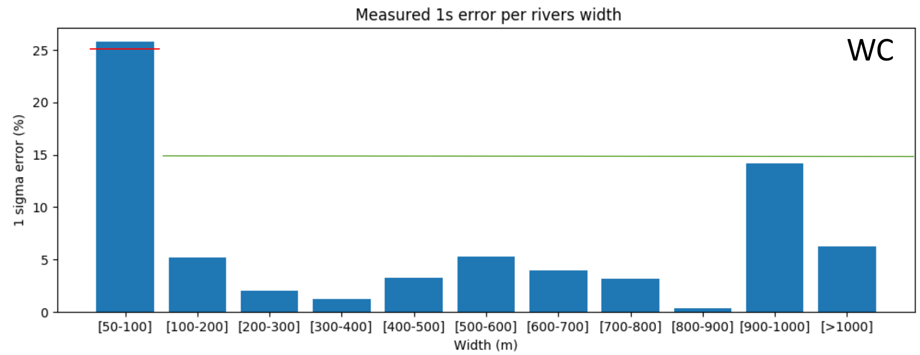
Water detection performance assessment



Preliminary water detection results with dark water flagging

- Po river (1 year) + US lidar scenes (altogether > 270 images)





- Well within science requirements: <15% (1σ) for rivers >100m (CBE and WC)
- On boarderline for meeting goal: <25% (1σ) for 50-100m rivers (CBE OK, WC NOK)

Approach for prior water mask assessment

Comparison of available and relevant global water masks on 5 different test sites

- List of water masks and test sites in backup slides
- Focus on maximum water extent (for PIXC inclusion zones)

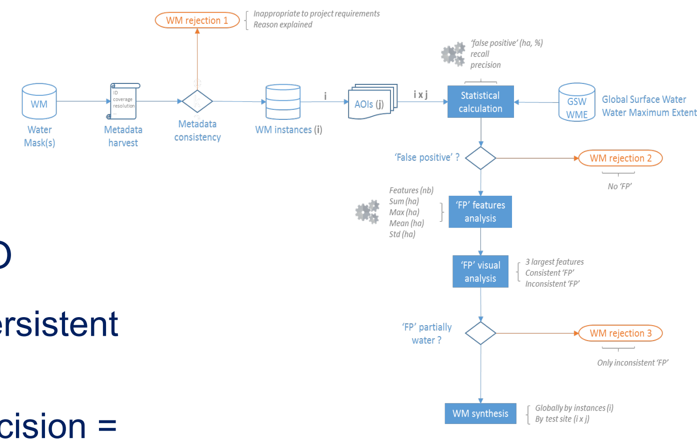
Quantitative analysis

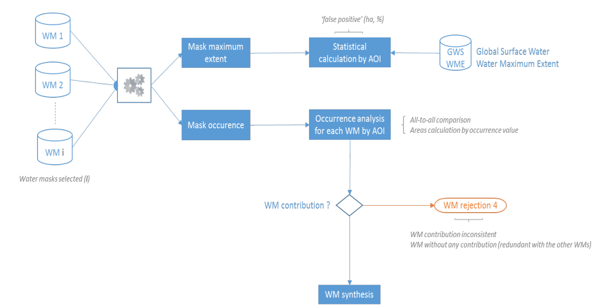
- Computation of statistical metrics relative to Pekel et al.'s GSWO
    - Knowing that GSWO is not perfect (water under vegetation, persistent cloud cover…)
    - False positives (FP) in ha and %, Recall = TP / (TP + FN), Precision = TP / (TP + FP)

Qualitative assessment

- Further analysis of false positives by visual interpretation
- Sentinel-2 and/or Sentinel-1 data (two dates in the hydrologic cycle)
- Other available ground truth

Ranking by site and overall





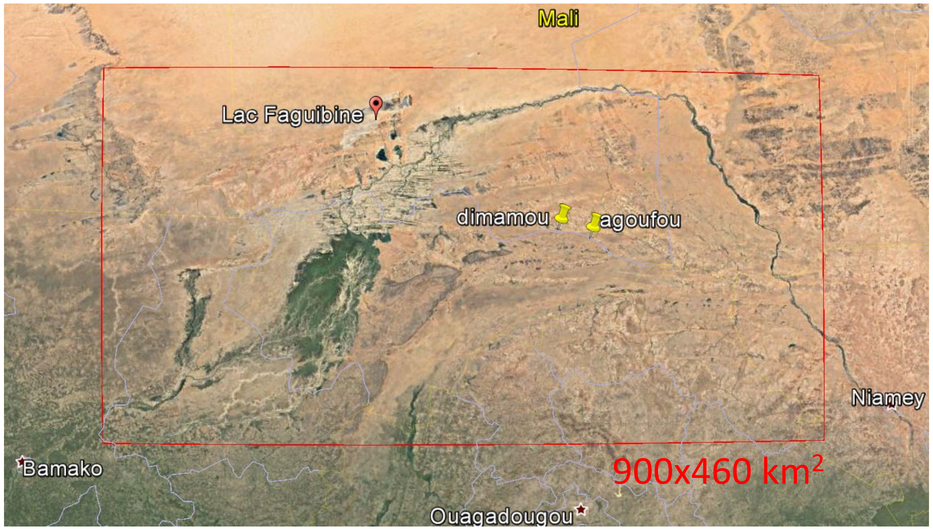
Prior water mask assessment

Example: Quantitative assessment on Inner Niger Delta (IND)

- Comparison with GSW maximum water extent

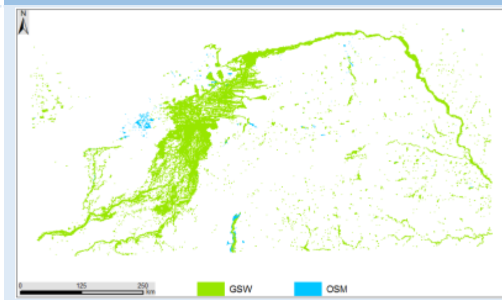
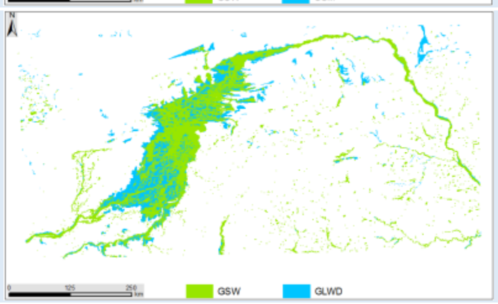
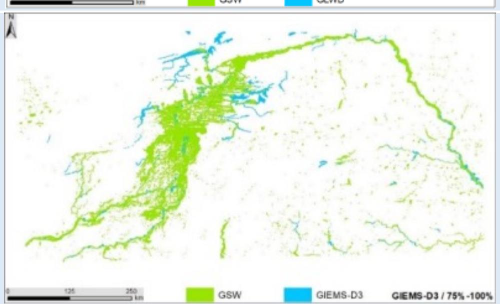
	FP (ha)	FPR (%)	Recall (%)	Precision (%)
GlobeLand30 Water	39194	3.49	19.49	84.37
GlobeLand30 Wetland	43281	3.83	2.33	36.85
GlobeLand30 Water & Wetland	82475	7.06	21.82	74.17
OSM	230461	17.51	31.97	60.1
From GLC Hierarchy	30406	2.72	19.96	87.69
GIEMS-D3 75-100%	381281	25.99	22.96	39.53
GIEMS-D3 50-100%	1896613	63.6	42.7	19.64
GIEMS-D3 25-100%	4136583	79.21	52.86	12.18
GIEMS-D3 0-100%	6047652	84,78	55,69	9,09
Global Water Pack				
GLWD	3677563	77.21	85.53	20.16
ESA CCI 300m	26799	2.41	16.8	87.19
ESA CCI 20m	58427	5.11	27.46	83.61

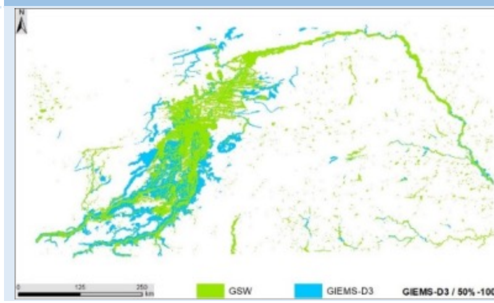
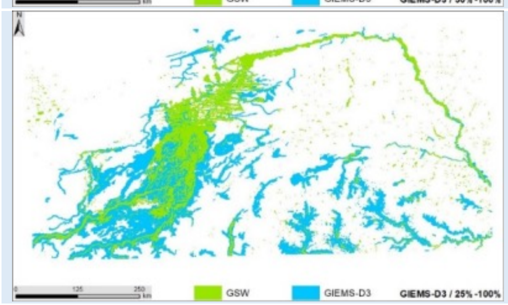
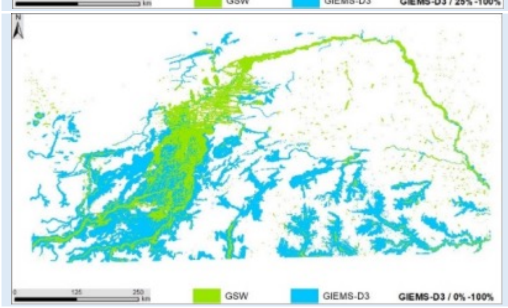
On the Inner Niger Delta test site we expect (want) a high FPR in order to cover the large delta not covered by GSW.



Prior water mask assessment

Example of visual/qualitative analysis (IND)

Mask	FPR	Illustration	Comments
OSM	18 %		- Delta vegetated areas still not covered + Polygons covering larger riverbeds - Dimamou lake not covered + Agoufou lake covered
GLWD	77 %		+ Large polygon including the global delta system + high recall (86 %) - Dimamou and Agoufou lakes not covered
GIEMS-D3 75-100%	26 %		- Delta vegetated areas still not covered - Dimamou and Agoufou lakes not covered

Mask	FPR	Illustration	Comments
GIEMS-D3 50-100%	64 %		+ Most of delta vegetated areas covered - Dimamou and Agoufou lakes not covered
GIEMS-D3 25-100%	79 %		+ Delta vegetated areas covered - Over-estimation out of the delta area - Dimamou and Agoufou lakes not covered
GIEMS-D3 0-100%	85 %		+ Delta vegetated areas covered - Over-estimation out of the delta area - Dimamou and Agoufou lakes not covered

Prior water mask assessment

Ranking based on quantitative results and qualitative analysis: highly dependent on test site!

Ranking	Inner Niger Delta	Ganges Brahmaputra Delta	Poyang Lake	Canadian Lakes	Alsace-Lorraine
1	GLWD	GIEMS-D3 75-100%	Global Water Pack	ESA CCI 300m	GIEMS-D3 0-100%
2	GIEMS-D3 50-100%	GlobeLand30 Water & Wetland	GlobeLand30 Water & Wetland	GlobeLand30 Water	HRL
3	OSM	GLWD	OSM	GLWD	OSM

- Preliminary overall top 3 ranking (i.e. for all sites, as a complement to GSWO)
  - GIEMS-D3 (provides considerable additional surface; the choice of occurrence range is delicate)
  - GLWD (excellent on Inner Niger Delta, very rough elsewhere (Poyang, Ganges-Brahmaputra…))
  - GlobeLand30 (provides limited additional surface, good overall precision)

Status and way forward

Water detection algorithms

- Baseline water detection method prototyped and integrated in PIXC SAS prototype
  - Iterative MRF classification and estimation (PhD of Sylvain Lobry, Télécom ParisTECH/CNES, Nov. 2017)
- Large-scale testing on simulated data in conjunction with Measurement Review 2 (Dec. 2017)
  - Science requirements w.r.t. water surface area met for rivers
  - Further improved by dark water flagging (based on GSWO)
- Ongoing and upcoming work
  - Further algorithm tuning, extension of performance assessment to lakes, larger data set
  - Writing of journal paper and ATBD section on baseline water detection method
  - Prototype evolving towards operational code (handling of degraded cases, computational efficiency…)
  - PhD of Nicolas Gasnier (Télécom ParisTECH/CNES/C-S), 2018-21
    - ✓ Further work on narrow river detection (supported by river database)
    - ✓ Multi-temporal and multi-sensor water detection (risk mitigation)

Status and way forward

Use of prior data related to water detection

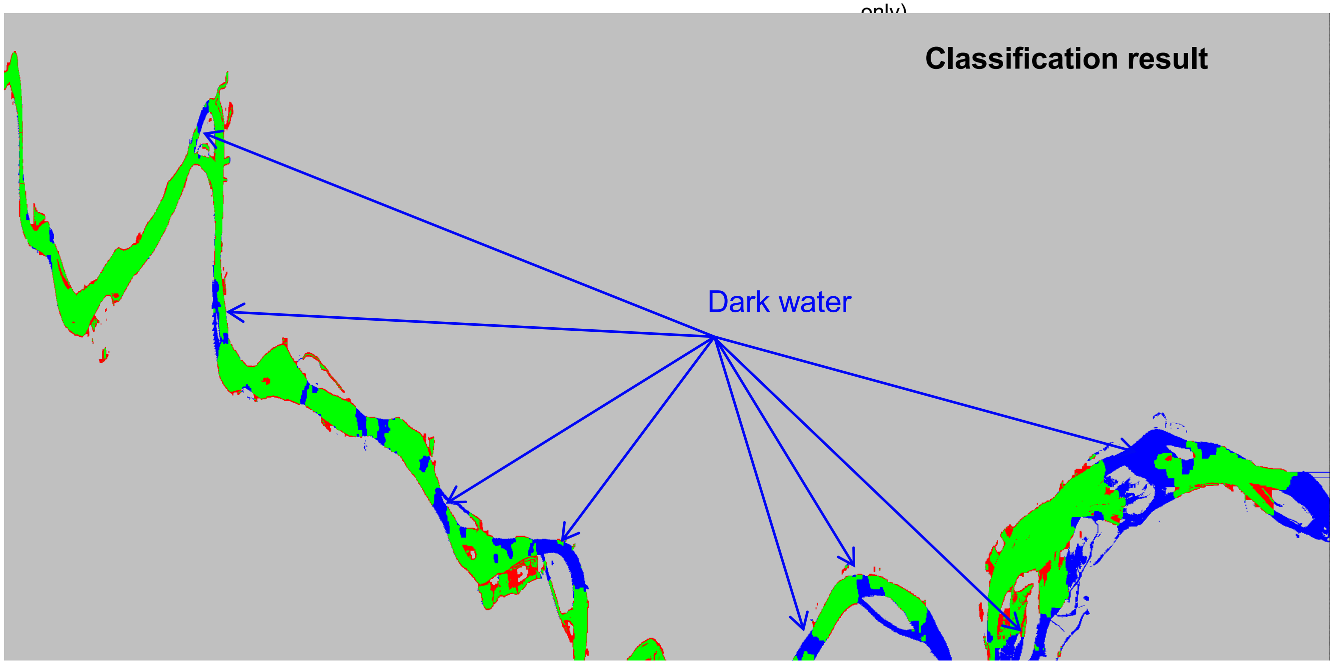
- Dark water flagging
  - Based on GSWO (Pekel et al.): identify occurrence level (%) that best fits detected water, expand
    - ✓ Shown to provide a gain in accuracy on simulated data
- Zones to always include in the HR L2 Pixel Cloud product (floodplain, wetlands…)
  - Prior water probability > 0 for at least one water probability map, or covered by the prior river and lake databases prepared for SWOT
    - ✓ Quantitative and qualitative assessment of water masks w.r.t. GSWO: accuracy highly dependent on test site
    - ✓ Preliminary overall top-3 ranking establish, but continue to follow new masks and meta-mask initiatives
- Ongoing and upcoming work
  - Assessment of DEM quality and coherence between DEMs and water masks
  - Study masks, DEMs and other data to define exclusion zones for SWOT HR L2 products
  - Prototyping of inclusion and exclusion zone processing steps

BACKUP

SWOT water detection phenomenology

Po river example

Courtesy of Sylvain Lobry, Télécom ParisTECH (preliminary result, for illustration purposes only)



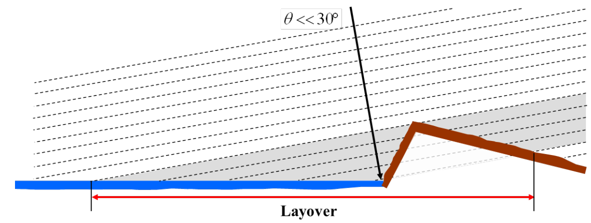
- True positive (TP)
- False positive (FP)
- False negative (FN)
- True negative (TN)

Maximization of TP (and TN), minimization of FP + FN in slant range radar geometry

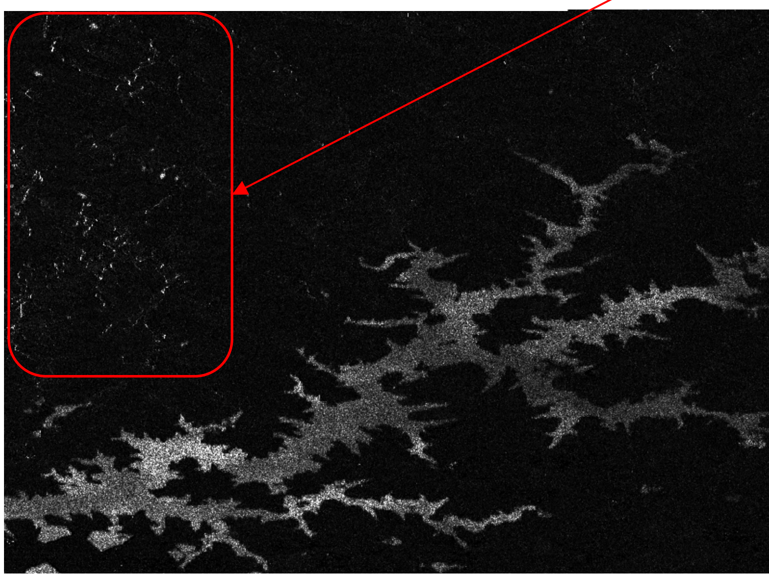
Relative error for water:
E = (FP+FN)/(TP+FN)

SWOT water detection phenomenology

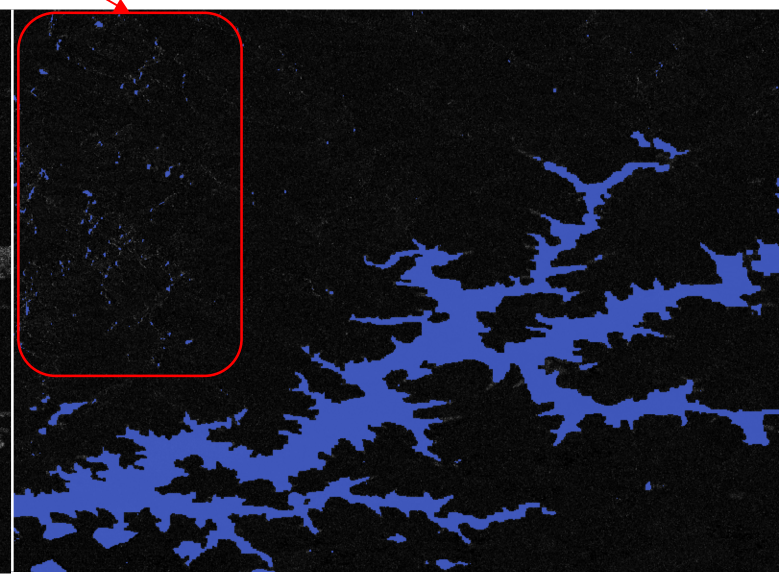
US lidar scene example



Bright land (layover)



Simulated coherent power

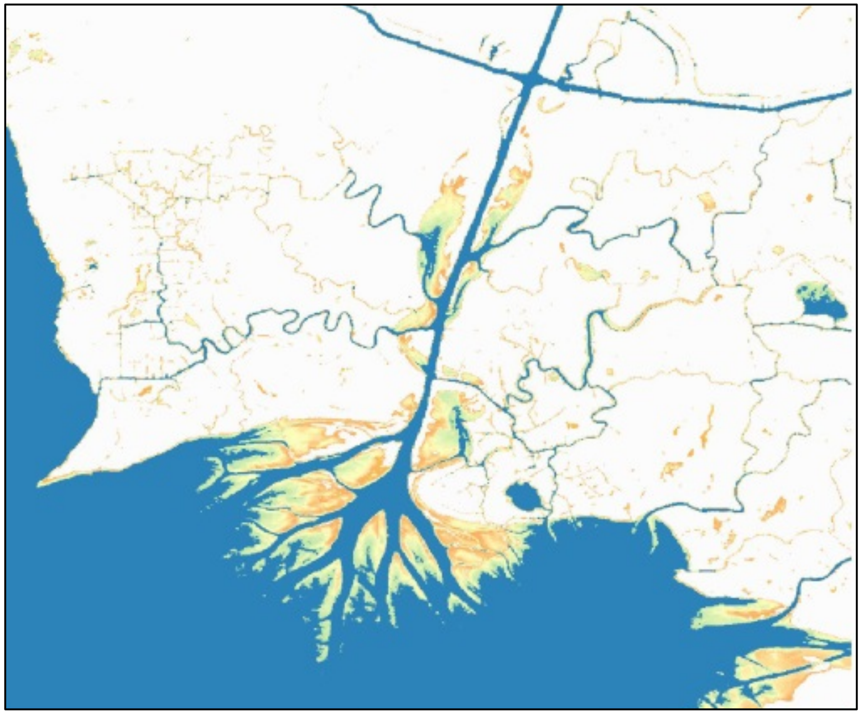


Detected water mask

Water probability maps of Pekel et al.

Global Water Surface (GWS) dataset

- Based on 32 years (1984-2015) of LandSat images at ~30 m resolution
- Available globally
  - GeoTiff files, WGS84, 10° x 10° tiles
- Several data layers (backup slides)
- Of particular interest for SWOT HR processing:
  - Global Surface Water Occurrence (GSWO) = water occurrence frequency between 1984 and 2015 (0-100%)
- Known weaknesses
  - Areas where water is covered by vegetation
  - Areas with persistent cloud cover
  - …



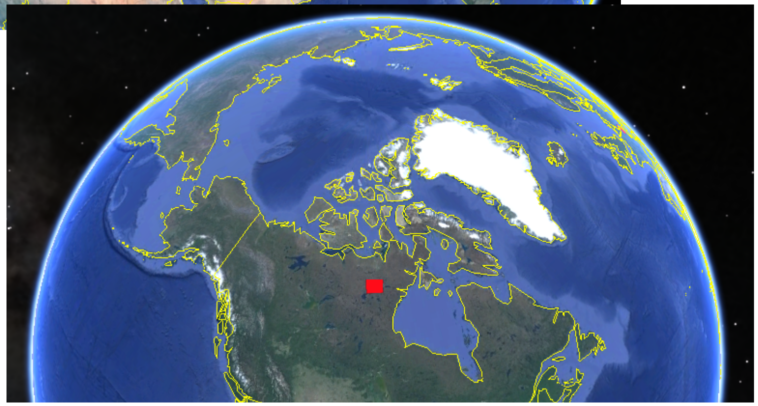
Example: Occurrence map over the Mississippi River (courtesy of J.-F. Pekel)

0.000000
0.1
0.250000
0.500000
0.750000
1.000000

Test sites

Objective: Cover highly different hydrological environments

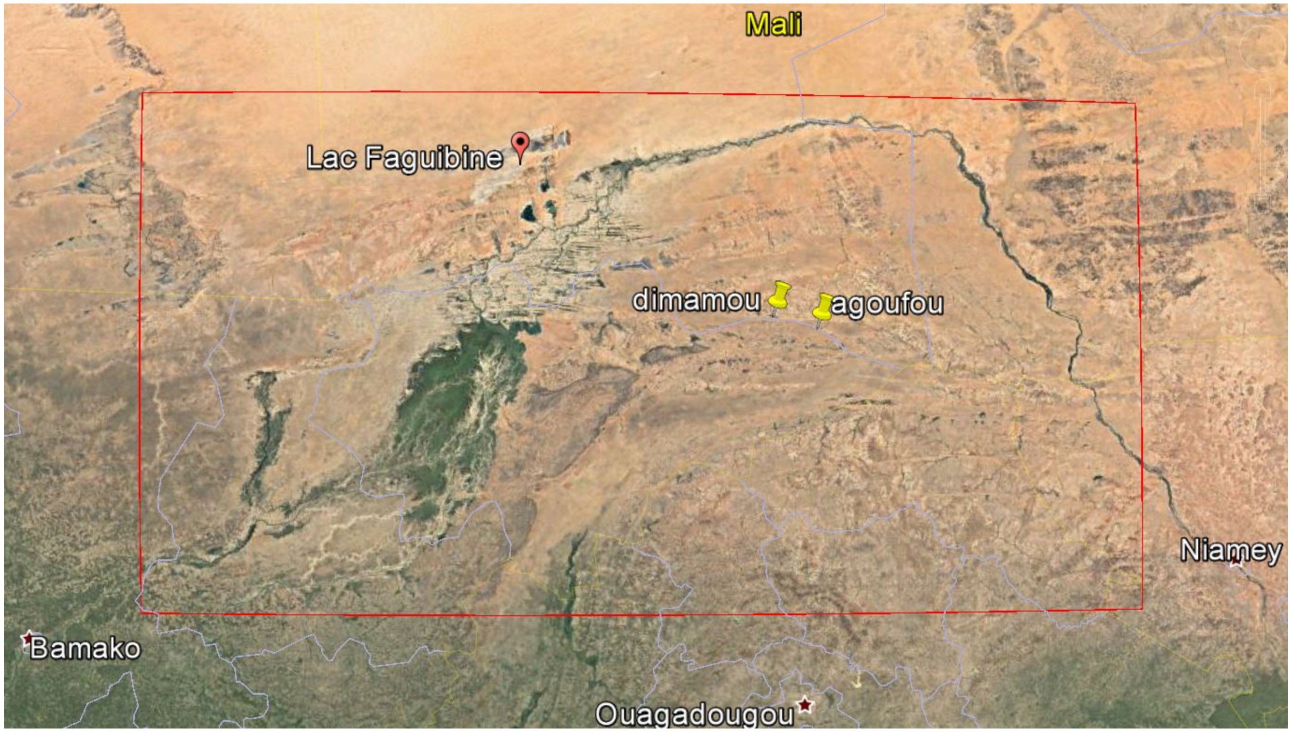
- Poyang Lake, Yangtze, China
- Alsatian flood plain and Lorraine lakes, France
- Ganges Brahmaputra Delta, Bangladesh/India
- Northern Lakes, Nunavut Province, Canada
- Inner Niger Delta and Niger Loop, Mali



Test sites

Inner Niger Delta & Niger Loop

- Sahel
- Semi-arid to semi-desert environment
- Yearly flood period start in September, peak in November, and end in April/May.
- Moderate slopes, braided river channels, wetlands, marshes and lakes
- A series of lakes, such as Debo Lake, Oro Lake, Korientze Lake, Faguibine Lake (590 km^2)

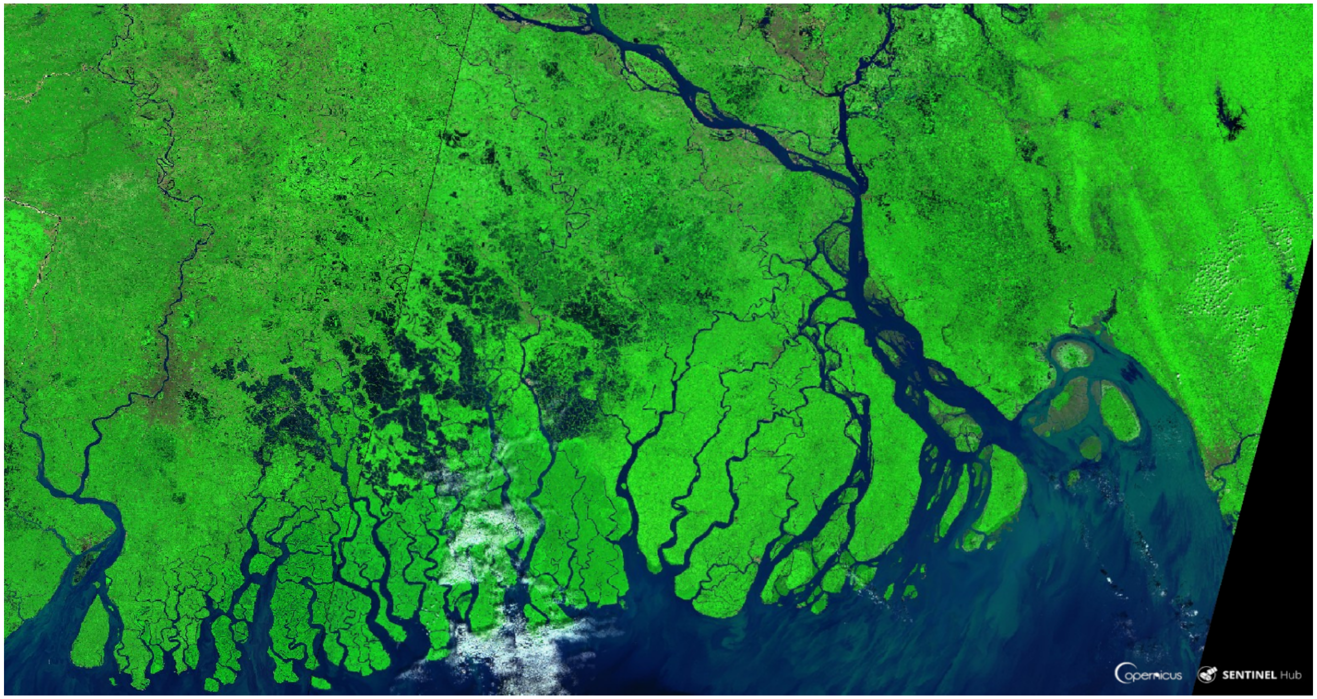


900x460 km^2

Test sites

Ganges Brahmaputra Delta

- Third and tenth biggest rivers in the world by discharge
- Mangrove wetland ecosystems and agricultural and aquaculture activities
- Strong influence of vegetation
- Monsoon climate: heavy rainfall June to September and dry period October to March



380*280 km^2

Test sites

Canadian lakes

- Nunavut Province
- 63°30-65°N
- Aberdeen, Wharton, Princess Mary, Mallery, Tebesjuak lakes (Upstream Baker Lake)
- Rivers: Dubawnt, Thelon…
- Ice/snow cover in winter
- Permafrost
- AirSWOT Mission July 2017
- Access to ground truth through Canadian Environmental Ministry
- 200 x160 km^2

Water masks

Global masks

- GWSO (Pekel et al.): Landsat optical data, 30 m
- GIEMS-D3 (Aires et al.): optical and passive/active microwave data, downscaled to 90 m
- Copernicus Global Land Service – Water bodies (Vito): PROBA-V, 333 m
- GLOBELAND30 Water & Wetlands (National Geomatics Center of China): Landsat 30 m
- Global Water Pack (DLR): Terra/Aqua, 250 m
- FROM-GLC-Hierarchy (Tsinghua University): MODIS, Landsat, 30 m
- ESA CCI 300/20m (ESA/Univ. Louvain): MERIS 250 m, S2 10 m (Africa)
- GLWD = Global Lakes and Wetlands Database (Lehner et al.): various maps and data
- OSM = Open Street Map (collaborative project)

Also some masks with continental or regional coverage (backup slide)

Water masks

WORLDWIDE COVERAGE						
	n°	Alsace-Lorraine (France)	Poyang-Yangtze (Chine)	Inner Niger Delta	Canadian lakes	Gange-Brahmaputra (Bangladesh-Inde)
GSW (Pekel-JRC)	1	✓	✓	✓	✓	✓
GIEMS-D3 (Aires)	2	✔	✔	✔	✔	✔
Water bodies (Copernicus/Vito)	3	✓	✓	✓	✓	✓
GLC-30 (Chen)	4	✔	✔	✔	✔	✔
Global Water Pack (DLR)	5	✗	✔	✔	✔	✔
From GLC Hierarchy	6	✔	✔	✔	✔	✔
OSM	7	✔	✔	✔	✔	✔
GLWD (Lehner)	8	✓	✓	✓	✓	✓
ESA LCCS 2010	9	✓	✓	✓	✓	✓

CONTINENTAL COVERAGE						
	n°	Alsace-Lorraine (France)	Poyang-Yangtze (Chine)	Inner Niger Delta	Canadian lakes	Gange-Brahmaputra (Bangladesh-Inde)
ESA CCI LC 2016 (Africa)	10	✗	✗	✓	✗	✗
HR layers (Europe)	11	✓	✗	✗	✗	✗

LOCAL COVERAGE						
	n°	Alsace-Lorraine (France)	Poyang-Yangtze (Chine)	Inner Niger Delta	Canadian lakes	Gange-Brahmaputra (Bangladesh-Inde)
CES OSO (Cesbio France)	12	✓	✗	✗	✗	

Database dowloaded totally	✓
Database dowloaded partially (subset)	✔
Not available or not distributed	✗

Water masks

Description sheets for all the masks (13)

FROM-GLC-Hierarchy

ID 09	FROM-GLC-HIERARCHY

Abstract / Lineage

"Recent developments of 30 m global land characterization datasets (e.g., land cover, vegetation continues field) represent the finest spatial resolution inputs for global scale studies. Here, we present results from further improvement to land cover mapping and impact analysis of spatial resolution on area estimation for different land cover types. We proposed a set of methods to aggregate two existing 30 m resolution circa 2010 global land cover maps, namely FROM-GLC (Finer Resolution Observation and Monitoring-Global Land Cover) and FROM-GLC-seg (Segmentation), with two coarser resolution global maps on development, i.e., Night time Light Impervious Surface Area (NL-ISA) and MODIS urban extent (MODIS-urban), to produce an improved 30 m global land cover map—FROM-GLC-agg (Aggregation). It was post-processed using additional coarse resolution datasets (i.e., MCD12Q1, GlobCover2009, MOD44W etc.) to reduce land cover type confusion. Around 98.9% pixels remain 30 m resolution after some post-processing to this dataset. Based on this map, majority aggregation and proportion aggregation approaches were employed to create a multi-resolution hierarchy (i.e., 250 m, 500 m, 1 km, 5 km, 10 km, 25 km, 50 km, 100 km) of land cover maps to meet requirements for different resolutions from different applications. Through accuracy assessment, we found that the best overall accuracies for the post-processed base map (at 30 m) and the three maps subsequently aggregated at 250 m, 500 m, 1 km resolutions are 69.50%, 76.65%, 74.65%, and 73.47%, respectively. Our analysis of area-estimation biases for different land cover types at different resolutions suggests that maps at coarser than 5 km resolution contain at least 5% area estimation error for most land cover types. Proportion layers, which contain precise information on land cover percentage, are suggested for use when coarser resolution land cover data are required."

Resource locator

http://data.ess.tsinghua.edu.cn

Topic category

Land Cover

Geographic bounding box

Global
Longitude : -180, +180
Latitude : -60, +80

Coordinate system

EPSG 4326 (WGS84)

Temporal reference

2010

Spatial resolution

250 m, 500 m, 1 km, 5 km, 10 km, 25 km, 50 km, 100 km

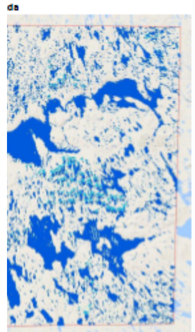
Conditions for access and use

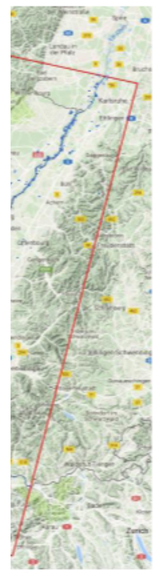
"The FROM-GLC, FROMGLC-seg, FROM-GLC-agg, and FROM-GLC-Hierarchy products are all freely available online at http://data.ess.tsinghua.edu.cn"

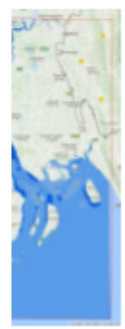
Credits

YU Le, WANG Jie, LI XueCao, LI CongCong, ZHAO YuanYuan and GONG Peng
"This work was supported by the National High-tech R&D Program of China (Grant No. 2009AA12200101), the National Natural Science Foundation of China (Grant No. 41301445), an Open Fund from the State Key Laboratory of Remote Sensing Science (Grant No. OFSLRSS201202), and a research grant from Tsinghua University (Grant No. 2012Z02287). We also thank Dr. Mark Broich at the University of New South Wales for valuable discussions on some result analysis in this paper."

SERTIT 2017 ID 09 - 1







HIGH RESOLUTION LAYER – WETLANDS

ID 10	HIGH RESOLUTION LAYER – WETLANDS

Abstract / Lineage

« The products maps the occurrence of permanent wetland, as a binary product (wetland/non-wetland), with no MMU (Minimum Mapping Unit) and a 20m MMW (Minimum Mapping Width). To map permanent wetlands, multi-temporal imagery from 2006, 2009 and 2012, as well as a seasonal time series of medium-resolution (MR) images, areused in production. Wetlands and water (see chapter 3.4) are produced using the same workflow. Basically the spectral information contained in the multi-temporal input imagery is, as part of a highly automated workflow, transferred into statistical frequency indices for water and wetland presence. These are used in a last step for the final classification. A pixel cannot be classified as wetland and water at the same time. »

Wetlands include the following landscape types:
- Wetlands associated with permanent water bodies;
- Wetlands not associated with permanent water bodies;
- Wetlands with vegetation (macrophyte) cover or without vegetation;
- Peatlands (having presence of surface water), and
- Coastal wetlands (salt marshes, salines, intertidal flats).

Land cover not to be considered as wetlands:
- Temporary water-logging because of snow melt or heavy rains;
- Permanent water surfaces (rivers, lakes, lagoons, estuaries, fish ponds), and
- Wet agricultural fields, including rice fields.

Resource locator

http://land.copernicus.eu/pan-european/high-resolution-layers/wetlands

Topic category

Wetlands

Geographic bounding box

Europe
Longitude : -56.37667, +71.38615
Latitude : -23.689528, +72.014094
Coverage : Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia the former Yugoslavian Republic of, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom

Coordinate system

EPSG:3035 (ETRS89, LAEA)

Temporal reference

2006 – 2012
Date of publication : 23 Mar 2016

Spatial resolution

20 m

Conditions for access and use

Access to data is based on a principle of full, open and free access as established by the Copernicus data and information policy Regulation (EU) No 1159/2013 of 12 July 2013.

SERTIT 2017 ID 10 - 1