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SWOT HR
LAKE PRODUCT VALIDATION

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on behalf of the HR Cal/Val Team

SWOT SCIENCE TEAM MEETING, ARCACHON, FRANCE
15 OCTOBER 2025

LAKE VALIDATION APPROACH

(as presented in more detail at the Validation Meeting)

- Validation on LakeSP_Prior products (now in version D, i.e. PID0/PGD0)
- Limited to principal variables: Water Surface Elevation (WSE) and area

- Dedicated in situ measurements and acquisitions of satellite images
  - Mainly during Cal/Val period (1-day orbit, March 30 – July 10, 2023)
- Extensive use of existing gauges and publicly available satellite data
- Additional levelling activities and preprocessing to make reference data directly comparable to LakeSP_Prior data
- Computation of error statistics on a large number of PLD lakes worldwide

- The reference data are targeted to be more accurate than SWOT requirements, but they are not perfect
  - The measured errors (differences) partially stem from inaccuracies in the reference data

SIGNIFICANT EVOLUTION IN FLAGS

in LakeSP version PIC2/PID0/PGD0 compared to PIC0/PGC0

- *quality_f* no longer binary: 0=good, 1=suspect, 2=degraded, 3=bad
- *qual_f_b* bitflag introduced, providing more detailed information
  - based on PIXC flags/bitflags, percentage of lake pixels concerned

➔ Filtering of data must be made with different flag values/thresholds

quality_f	Proportion of PXC0 pixels	Proportion of PXD0 pixels
0	65.8%	18,2%
1	34.2%	73,3%
2	-	4,8%
3	-	3,6%

➔ May use *qual_f_b* bitflag for finer tuning

Bit	Decimal	Hex	Flag meaning
0	1	1	classification_qual_suspect
1	2	2	geolocation_qual_suspect
2	4	4	
3	8	8	few_open_water_suspect
4	16	10	
5	32	20	wse_std_suspect
6	64	40	diff_from_pld_area_suspect
7	128	80	
8	256	100	xovr_cal_suspect
9	512	200	
10	1024	400	no_prior_suspect
11	2048	800	water_false_detection_rate_suspect
12	4096	1000	
13	8192	2000	
14	16384	4000	
15	32768	8000	classification_qual_degraded
16	65536	10000	geolocation_qual_degraded
17	131072	20000	
18	262144	40000	low_coh_degraded
19	524288	80000	specular_ringing_degraded
20	1048576	100000	
21	2097152	200000	
22	4194304	400000	
23	8388608	800000	low_coh_bad
24	16777216	1000000	xovr_cal_bad
25	33554432	2000000	
26	67108864	4000000	specular_ringing_bad
27	134217728	8000000	
28	268435456	10000000	

L2 HR WSE CONVENTIONS

A common set of representation conventions is necessary when comparing to other data

- PIXC products provide height (H) relative to the WGS84 ellipsoid referenced to the Earth's instantaneous center of mass ~ITRF2014.
- RiverSP, LakeSP and Raster products provide WSE.
- WSE has tidal corrections applied and is relative to the EGM2008 mean-tide geoid.
- Both height and WSE have corrections for media delays applied.

$$\begin{aligned} \text{WSE} = (&H \\ &- \text{geoid\_height} \\ &- \text{solid\_earth\_tide\_height} \\ &- \text{load\_tide\_height} \\ &- \text{pole\_tide\_height}). \end{aligned} \quad (3.5)$$

From Section 3.1.25 of User Handbook

Component	Description
Geoid Height	Height of EGM2008 geoid above WGS84 ellipsoid.
Solid Earth (Body) Tide Height	Direct response of solid Earth crust to luni-solar tide-generating forces.
Load Tide Height	Indirect response of the solid Earth crust to load of ocean tide mass.
Pole Tide Height	Response of the solid Earth crust and oceans to centrifugal potential force resulting from polar motion. Includes solid Earth, ocean, and load pole tides. Ocean pole tide = 0 over land.

- User Handbook has more information regarding conventions for LR and HR products.
- See Shailen's webinar talk for a more in-depth discussion of reference frames and representation conventions: http://podaac.jpl.nasa.gov/swot?tab=datasets-information&sections=about -> PDF, Webinar Recording

Courtesy: Alex Corben, Shailen Desai (JPL)

GEOGRAPHICAL DISTRIBUTION

PLD lakes with ground truth available for WSE validation (Cal/Val phase, leveled gauges only)

LAKE WSE ERROR

On PGD0 products (Cal/Val phase)

	Quality indicators	Value(s) allowed	Number of PLD lakes	Number of matchups	|WSE error| (1σ) for PLD lakes	
					> (250 m)², < 1 km²	> 1 km²
	No filtering	-	144	10 118	15 cm (-3 cm)	33 cm (-12 cm)
Outer	*ice_clim_f*	0, 1	135	8 214	14 cm (-3 cm)	19 cm (-10 cm)
Outer	*ice_clim_f*	**0**	134	6 250	14 cm (-3 cm)	12 cm (-5 cm)
Outer	*+ partial_f*	**0**	103	3 935	14 cm (-3 cm)	10 cm (-1 cm)
Inner	*+ quality_f*	0, 1, 2	103	3 777	14 cm	10 cm
Inner	*+ quality_f*	0, 1	103	3 551	14 cm	10 cm
Inner	*+ quality_f*	**0**	91	2 228	12 cm *(-2 cm)*	8 cm *(-2 cm)*

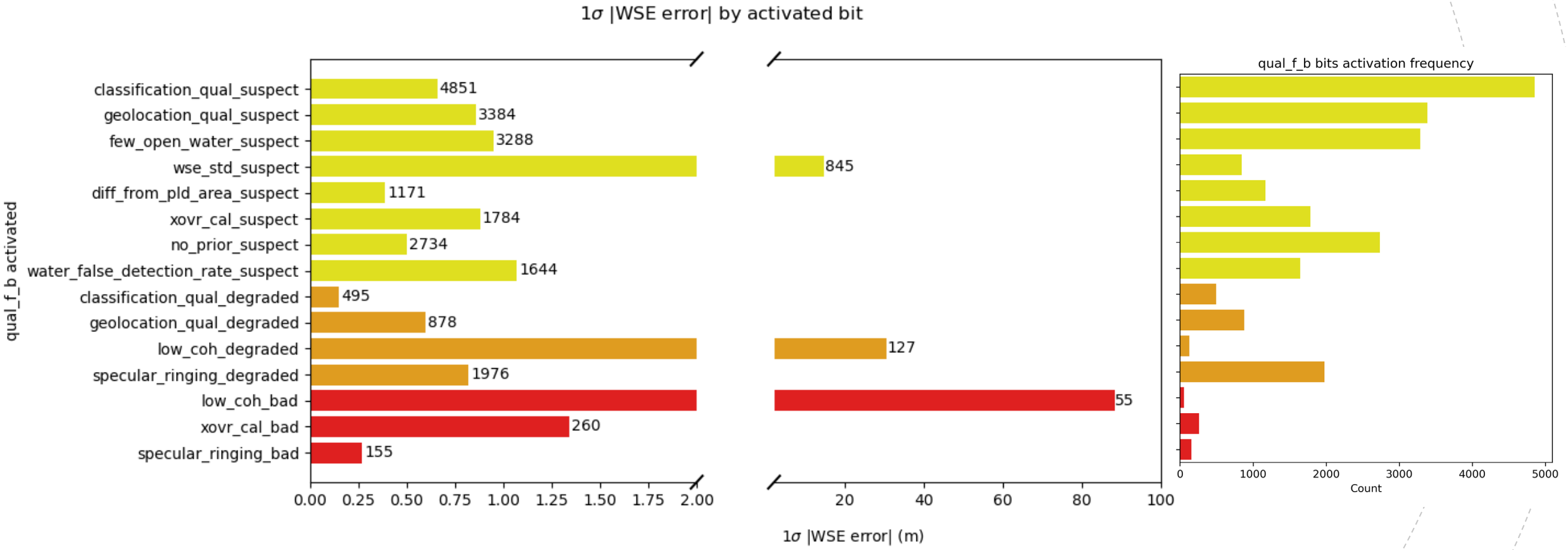
() = difference between version PGD0 and version PGC0, same matchups

Not strictly comparable as quality_f has evolved between the two versions

Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase

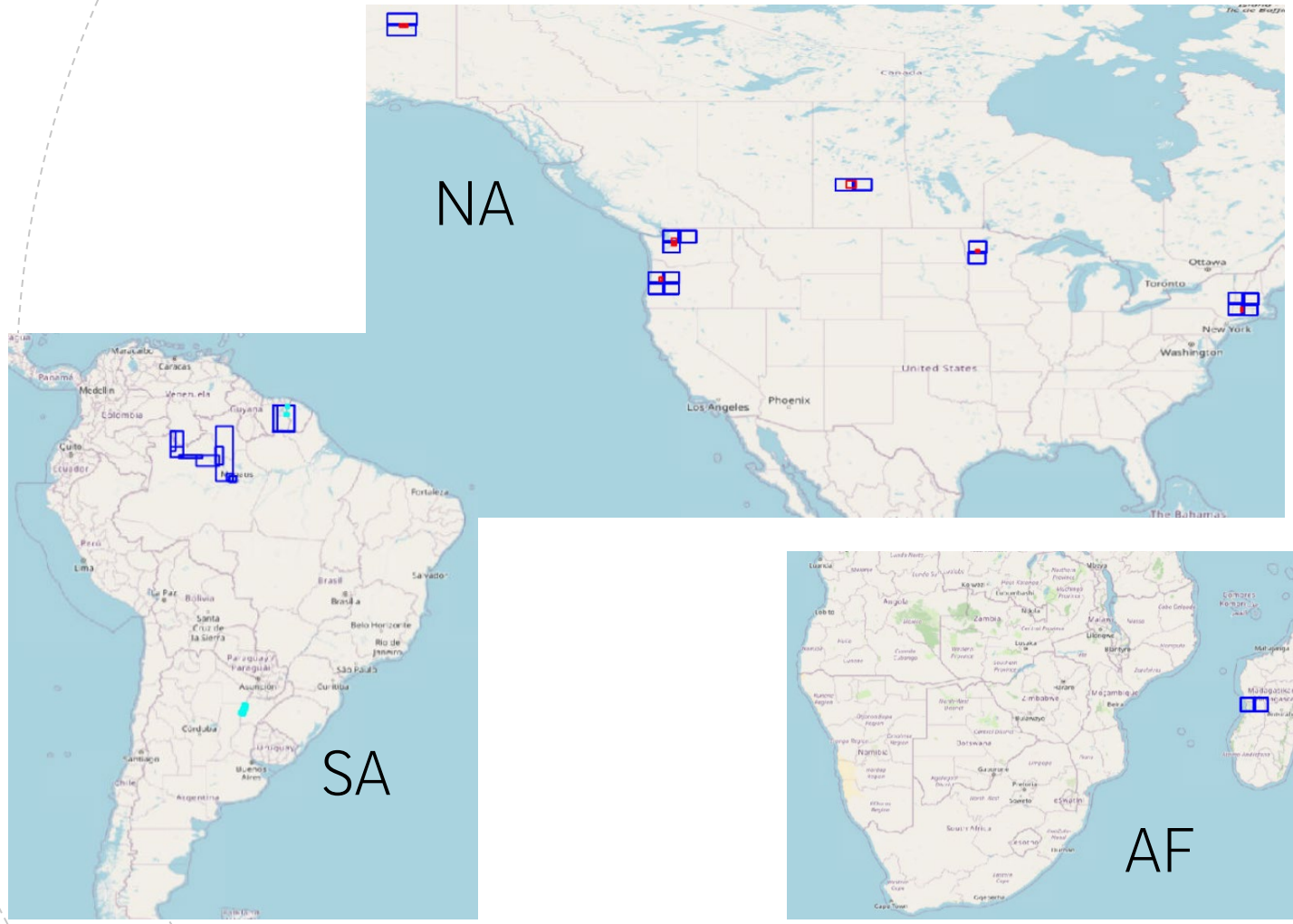
LAKE WSE ERROR

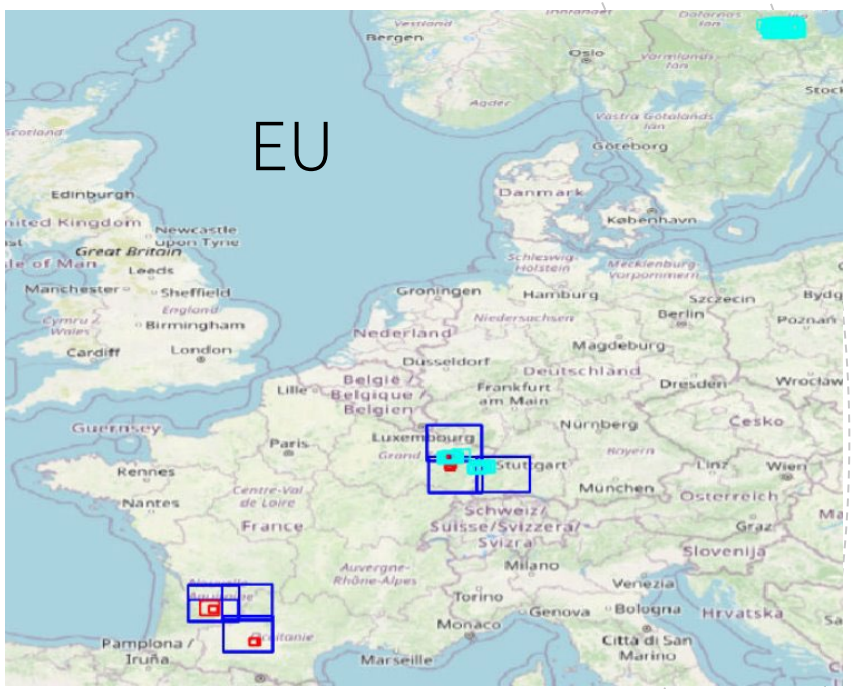
On PGD0 products (Cal/Val phase)



Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase

GEOGRAPHICAL DISTRIBUTION OF AREA REFERENCE DATA



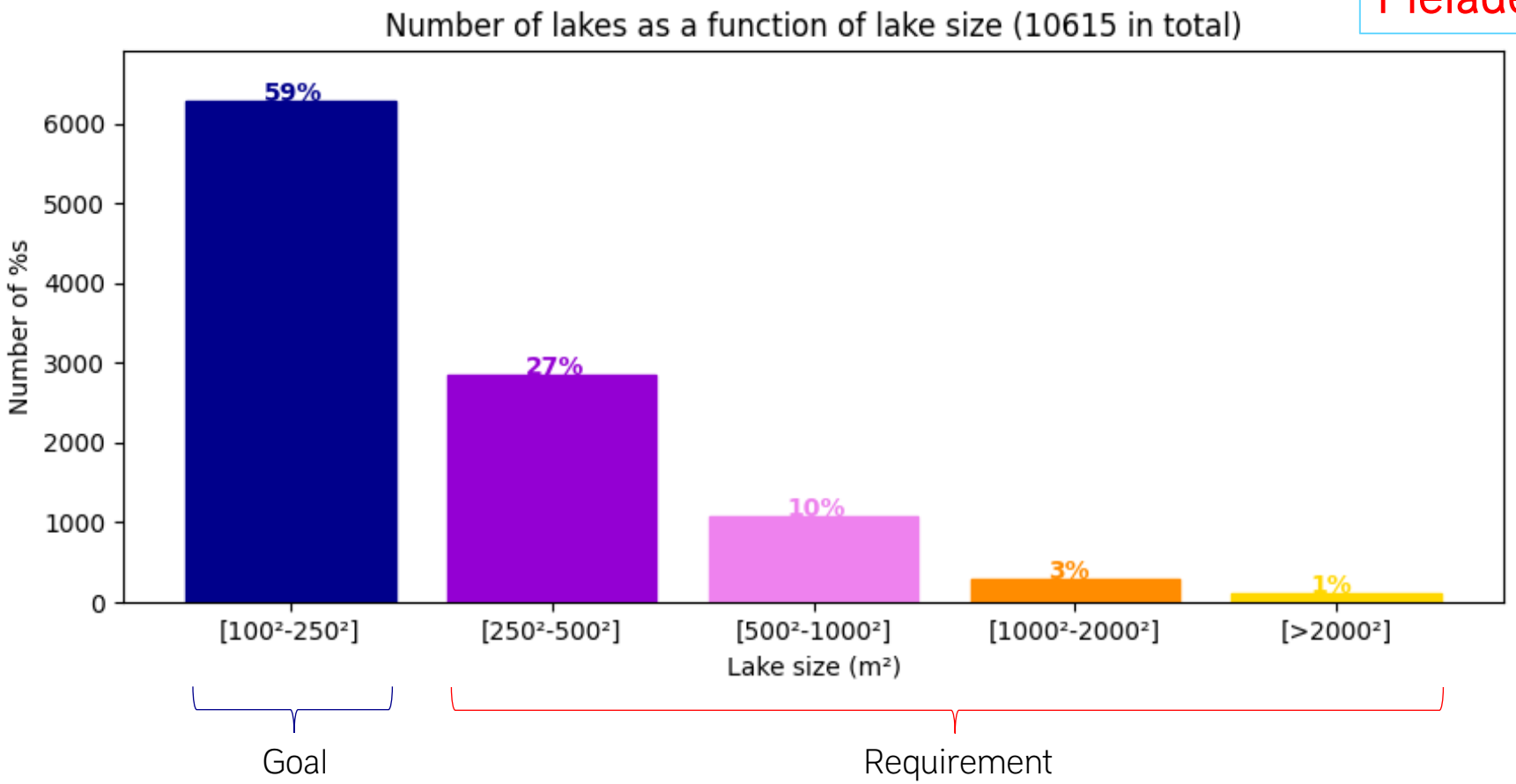


Reference water masks based on different kinds of satellite images:

- 283 x S2 [10 m]
- 204 x RCM [5 m]
- 34 x Pleiades [0.5 m]

SIZE DISTRIBUTION OF PLD LAKES WITH MATCHING AREA REFERENCE DATA

Pleiades + RCM + S2



- Corresponds roughly to expected global distribution: decreasing number of lakes with increasing size

Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase

RELATIVE LAKE AREA ERROR

On PGD0 products (Cal/Val phase)

Pleiades + RCM + S2

	Quality indicators	Value(s) allowed	Number of PLD lakes	Number of matchups	|relative area error| (1σ) for PLD lakes		
					> (100 m)², ≤ (250 m)²	> (250 m)²	> 1 km²
	No filtering	-	10615	189865	75 % (-15 %)	43 % (-6 %)	23 % (+1 %)
Outer	*partial_f*	**0**	10369	182956	74 % (-11 %)	41 % (-4 %)	19 % (+1 %)
Outer	*+ ice_clim_f*	**0**	10205	173239	72 % (-10 %)	41 % (-4 %)	19 % (0 %)
Inner	*+ quality_f*	0,1,2 0,1 **0**	10171 10082 3458	166372 160179 38341	72 % 71 % 28 % *(-15 %)*	41 % 41 % 22 % *(-11 %)*	19 % 19 % 15 % *(-1 %)*
Inner	*+ xovr_qual_q*	**0**	3458	38341	28 % *(-15 %)*	22 % *(-11 %)*	15 % *(-1 %)*
Inner	*+ dark_frac*	< 50%	3458	38341	28 % *(-16 %)*	22 % *(-11 %)*	15 % *(-1 %)*
Inner	*+ |area_truth – area_PLD| / area_PLD*	< 50%	3186	35163	26 % *(-13 %)*	19 % *(-8 %)*	14 % *(0 %)*

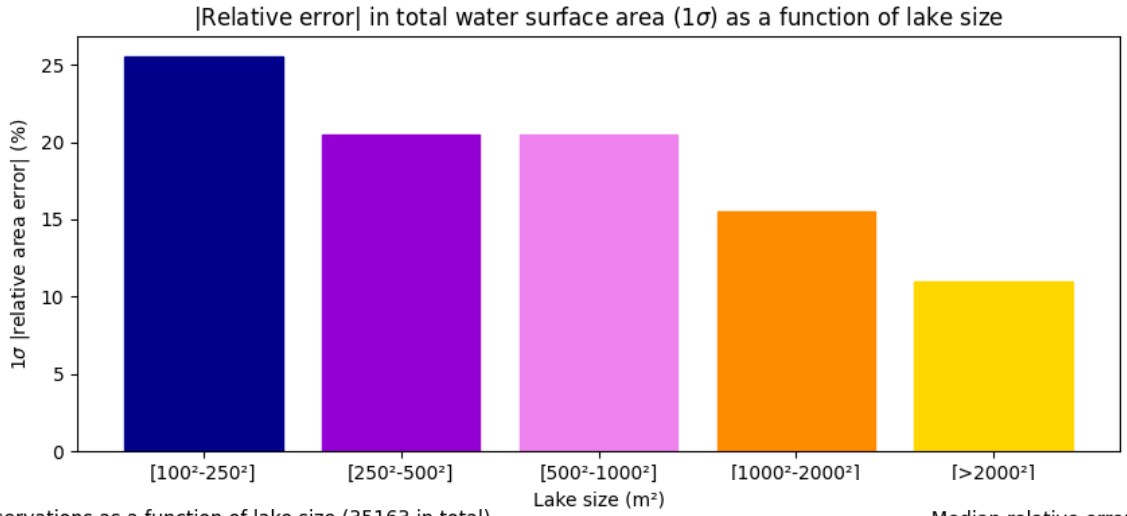
Not strictly comparable as quality_f has evolved between the two versions

Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase
(Comparison with version PGC0 data based on common subset of PLD lakes)

RELATIVE LAKE AREA ERROR

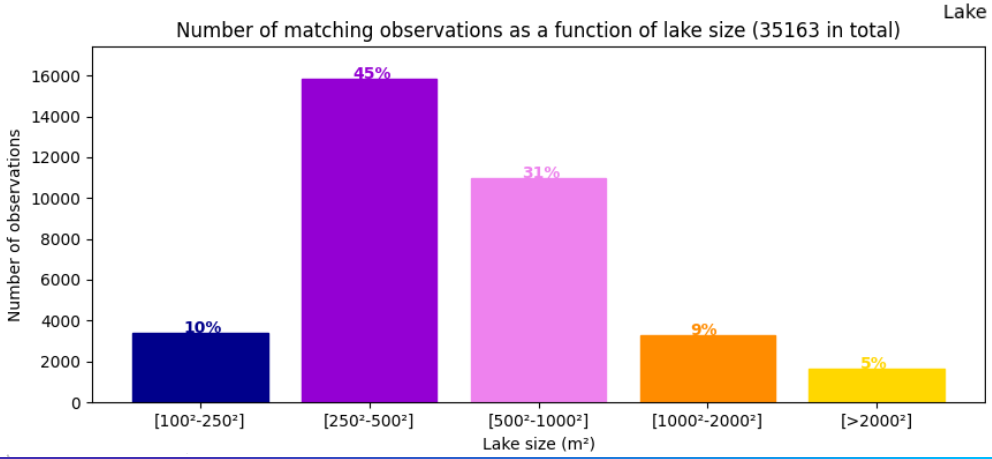
Filtering corresponding to last row in table on previous slide

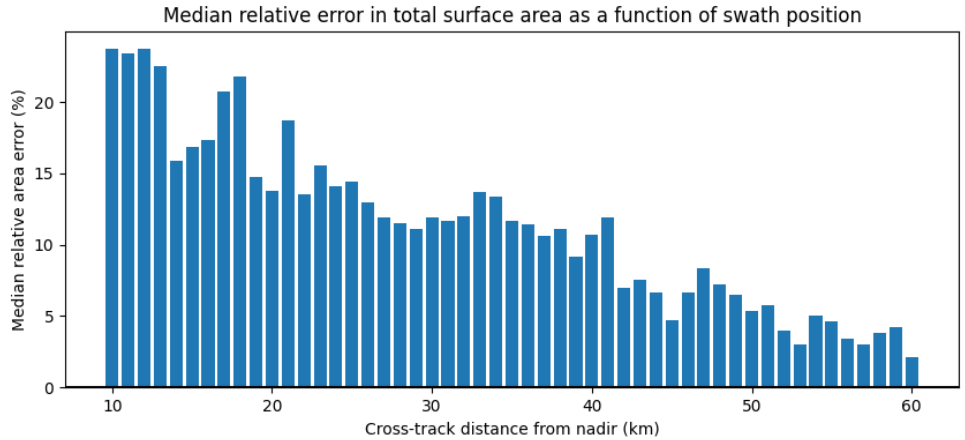
Pleiades + RCM + S2



> 250x250 m²: 19 % (1σ)
> 1 km²: 14 % (1σ)

3186 PLD lakes





Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase

RELATIVE LAKE AREA ERROR

On PGD0 products (Cal/Val phase)

Pleiades + RCM

	Quality indicators	Value(s) allowed	Number of PLD lakes	Number of matchups	|relative area error| (1σ) for PLD lakes		
					> (100 m)², ≤ (250 m)²	> (250 m)²	> 1 km²
	No filtering	-	1623	31961	42 % (-4 %)	31 % (-7 %)	14 % (0 %)
Outer	*partial_f*	**0**	1601	31099	41 % (-5 %)	30 % (-6 %)	12 % (0 %)
Outer	*+ ice_clim_f*	**0**	1599	31046	41 % (-5 %)	30 % (-6 %)	12 % (0 %)
Inner	*+ quality_f*	0,1,2	1588	29026	41 %	29 %	12 %
Inner		0,1	1580	28351	40 %	29 %	12 %
Inner		**0**	654	8814	19 % *(-14 %)*	14 % *(-9 %)*	9 % *(-1 %)*
Inner	*+ xovr_qual_q*	**0**	654	8814	19 % *(-13 %)*	14 % *(-8 %)*	9 % *(-1 %)*
Inner	*+ dark_frac*	< 50%	654	8814	19 % *(-13 %)*	14 % *(-8 %)*	9 % *(-1 %)*
Inner	*+ |area_truth − area_PLD| / area_PLD*	< 50%	542	7961	16 % *(-13 %)*	12 % *(-5 %)*	7 % *(+1 %)*

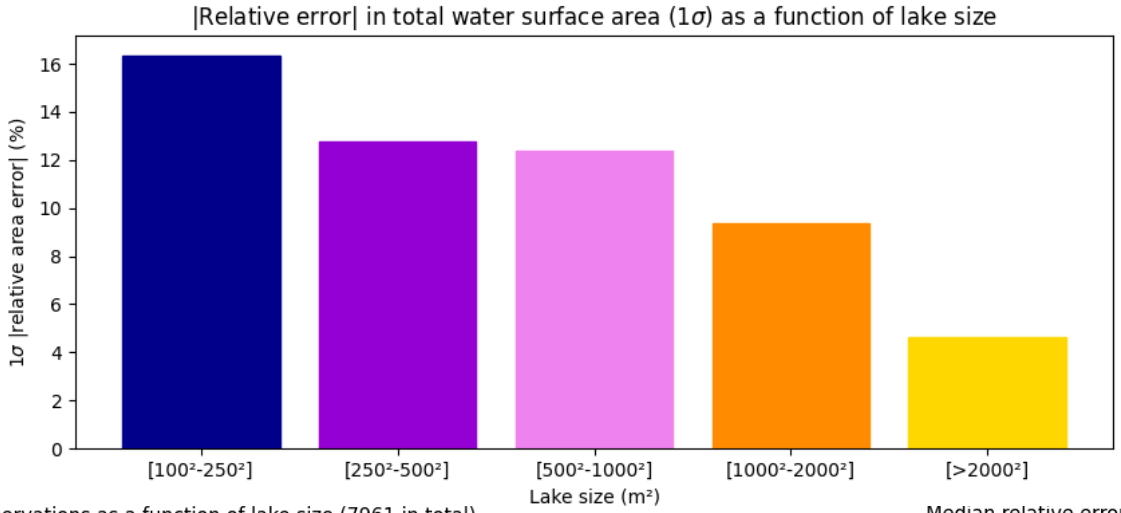
Not strictly comparable as quality_f has evolved between the two versions

Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase
(Comparison with version PGC0 data based on common subset of PLD lakes)

RELATIVE LAKE AREA ERROR

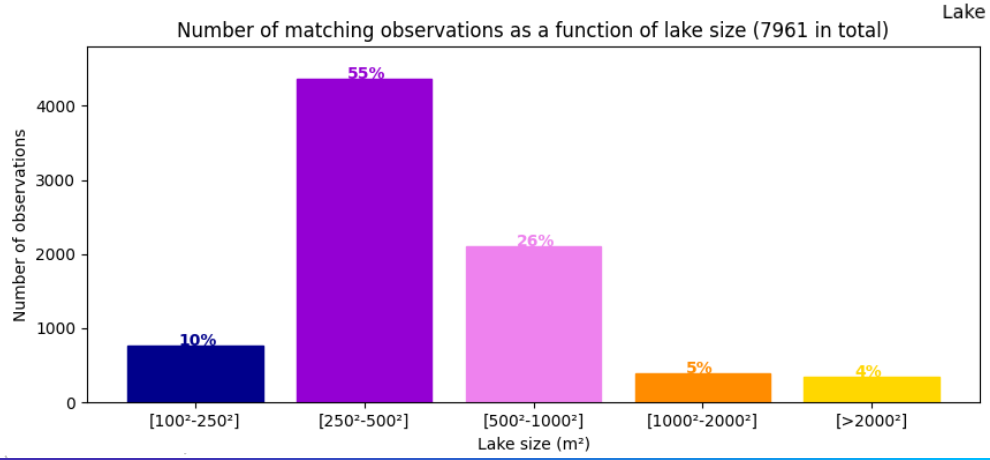
Filtering corresponding to last row in table on previous slide

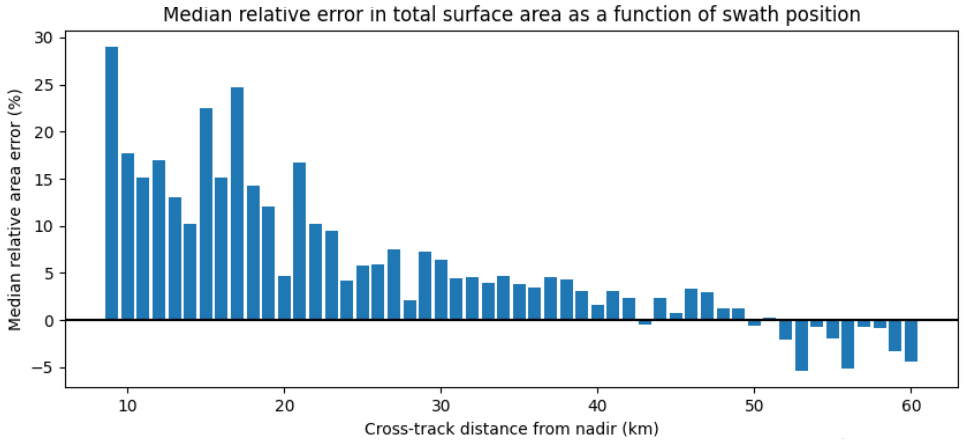
Pleiades + RCM



> 250x250 m^2: 12 % (1σ)
> 1 km^2: 7 % (1σ)

542 PLD lakes





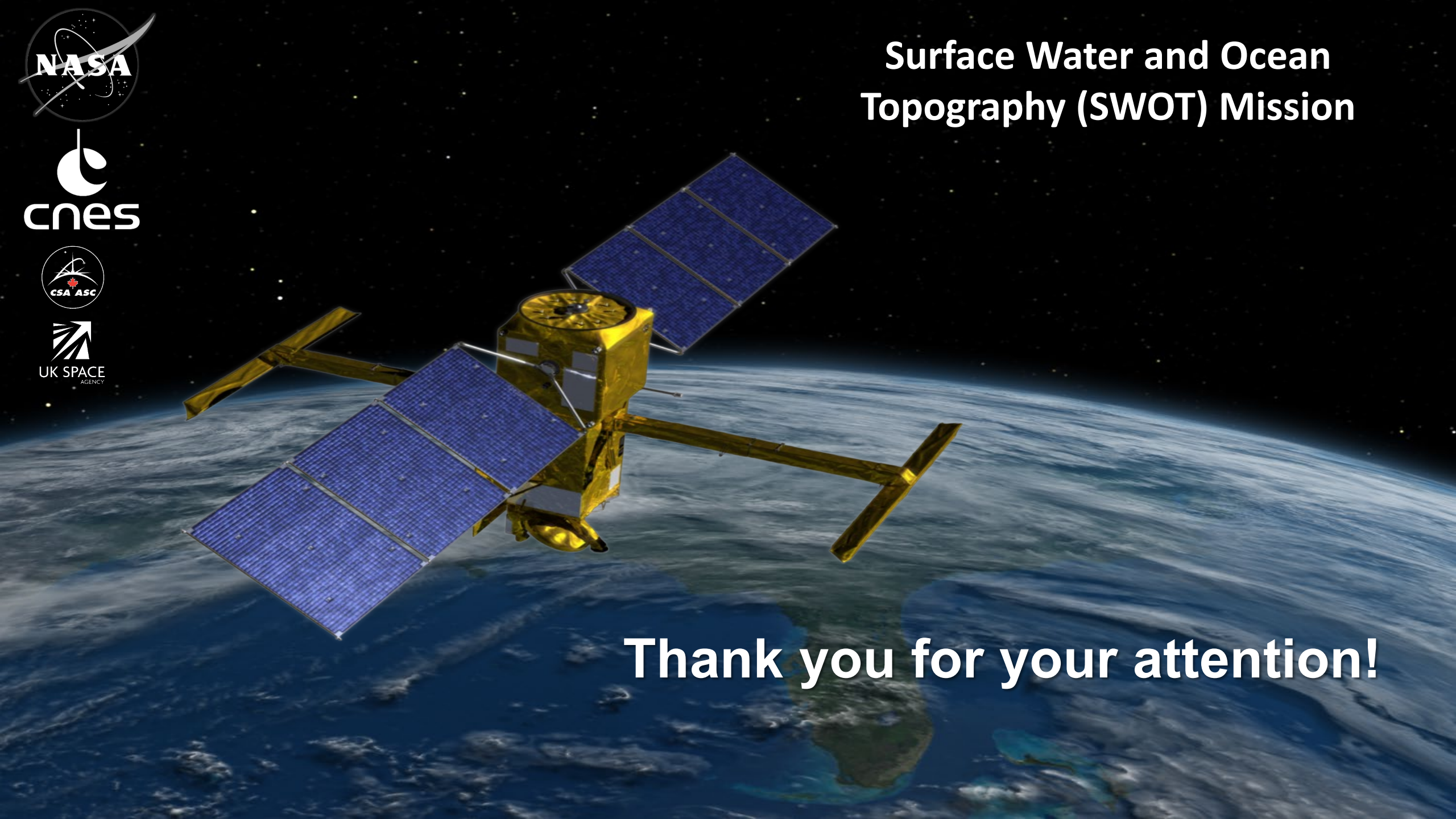
Preliminary figures based on ~4/5 of version PGD0 LakeSP data of the Cal/Val phase

SUMMARY AND OUTLOOK

Preliminary WSE and area performance for PXD0 LakeSP products

- It is essential to use quality flags to filter out bad (or degraded, or suspect) LakeSP data:
  - *quality_f* has substantially evolved from version PIC0/PGC0 to PIC2/PID0/PGD0
  - The corresponding bitflag *qual_f_b* permits finer tuning
  - Filtering based on *ice_f* and *partial_f* is generally necessary
- Improved performance of version PXD0 w.r.t. version PXC0:
  - Especially for big lakes for WSE
  - Especially for small lakes for area
- Ongoing and future work related to validation:
  - Make the reference datasets larger and more representative (gauge data, water masks)
  - Analyze a larger sample of the PID0/PGD0 dataset for lake validation paper
  - Test filtering based on bitflag to provide better trade-offs between performance and number of remaining observations
  - Analyze computed uncertainties w.r.t. actual performance
- Reconsider LakeSP product structure, further constrain water extent (next presentation)

The filtering need to be tailored to the product version and application!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Surface Water and Ocean Topography (SWOT) Mission
Thank you for your attention!

BACK-UP

MAIN LAKE AREA ERROR SOURCES

- Azimuth smearing
  - Lake extent systematically over-estimated
  - Larger impact on relative area error of small lakes
    - Can be improved through algorithm modifications (better handling of edge pixels, water fraction estimates…)
- Dark water
  - Area errors because of imperfect dark water flagging (estimation of extent or projection)
    - Can be improved through improved prior water occurrence masks , reference DEM and projection algorithm
- Bright land (humid soil, urban areas…)
  - Bright land detected as water adjacent to PLD lakes may cause important overestimation of lake area
    - Can be partially mitigated through active use of bright land flag
- Specular ringing
  - Specular ringing may seriously deteriorate lake polygon and degrade lake area and wse
    - Handling of specular ringing will be improved in future versions
- Assignment errors
  - Missing connected rivers in SWORD and missing nearby lakes in PLD may cause assignment and area errors
    - Improved versions of SWORD and PLD will reduce the assignments errors, likewise improved assignment algorithms

MAIN SCIENCE REQUIREMENTS FOR LAKES

- Global inventory of lakes, reservoirs and wetlands > 250x250 m^2 (Goal: >100x100 m^2)

- Water surface elevation (WSE) error
  - Requirement: < 10 cm (1σ) for lakes > 1 km^2
  - Goal: < 25 cm (1σ) for lakes > 250x250 m^2 and < 1 km^2
  - Threshold requirement: < 11 cm (1σ) for lakes > 1 km^2

- Relative surface area error
  - Requirement: < 15% (1σ) for lakes > 250x250 m^2
  - Goal: < 25% (1σ) for lakes > 100x100 m^2 and < 250x250 m^2
  - Threshold requirement: < 15% (1σ) for lakes > 1 km^2

(1σ) means that

68%

of the |errors| are smaller, and

32%

are bigger.