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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Surface Water and Ocean Topography (SWOT) Mission

Validation Meeting

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PIXC Validation

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on behalf of JPL/CNES Algorithm and Cal/Val Team

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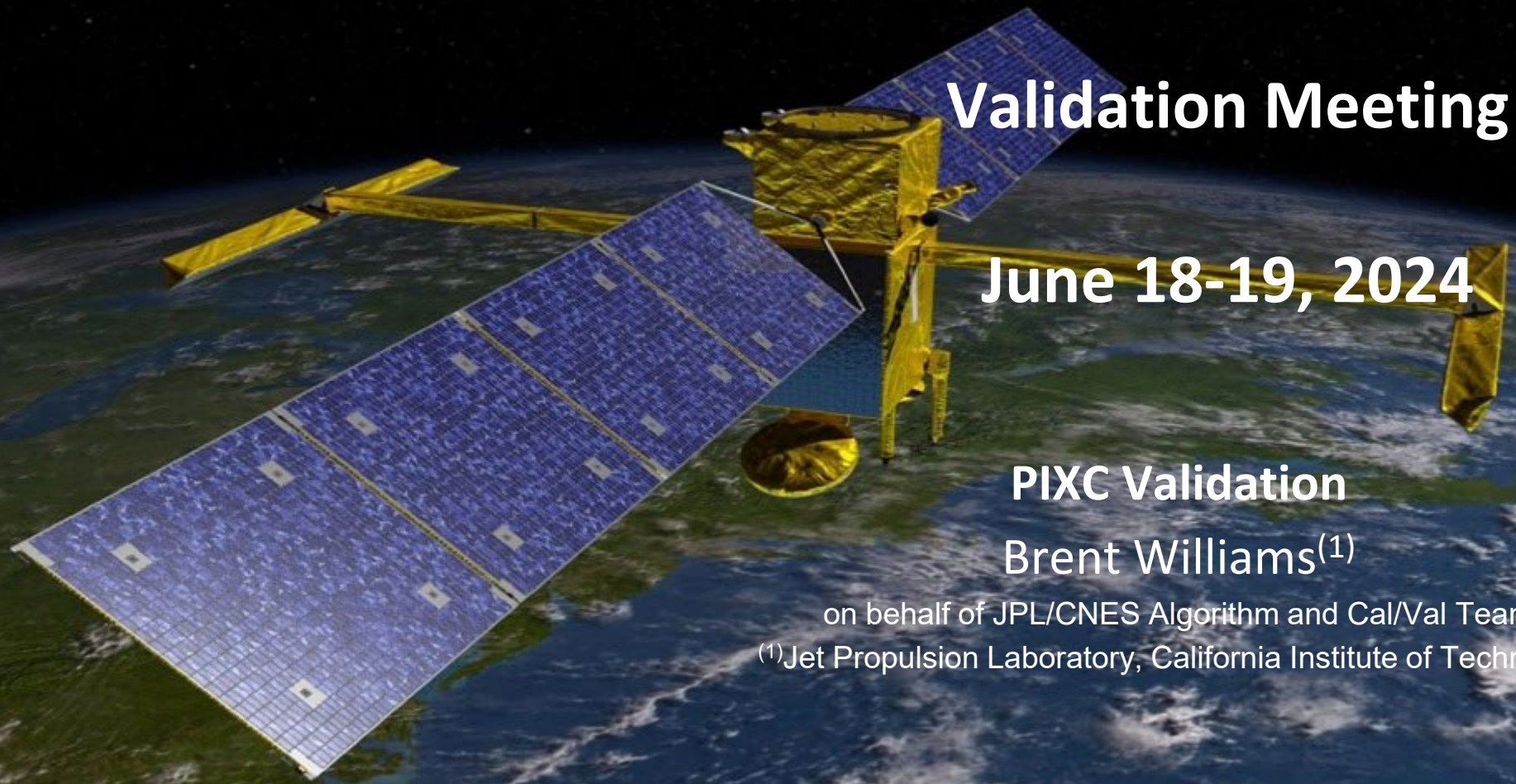
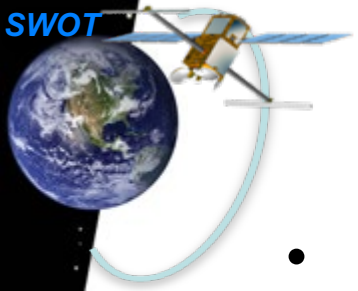


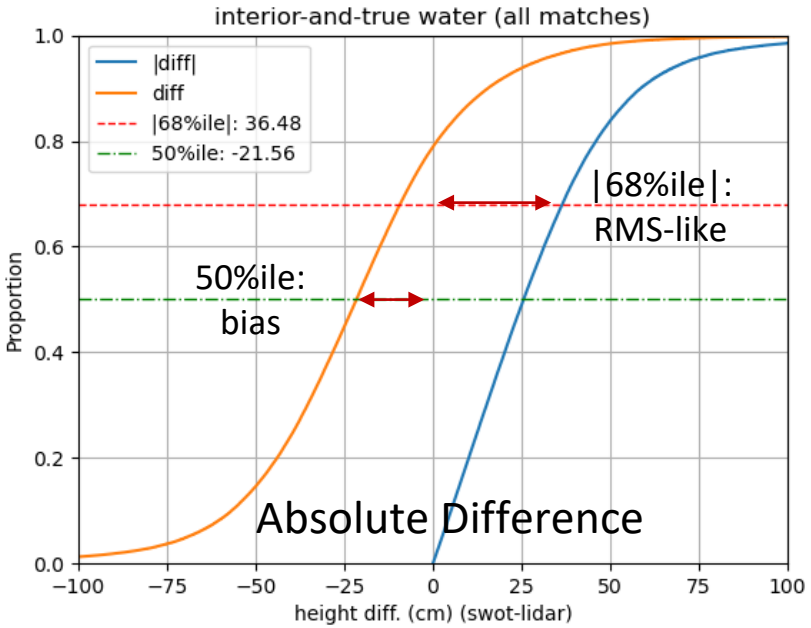


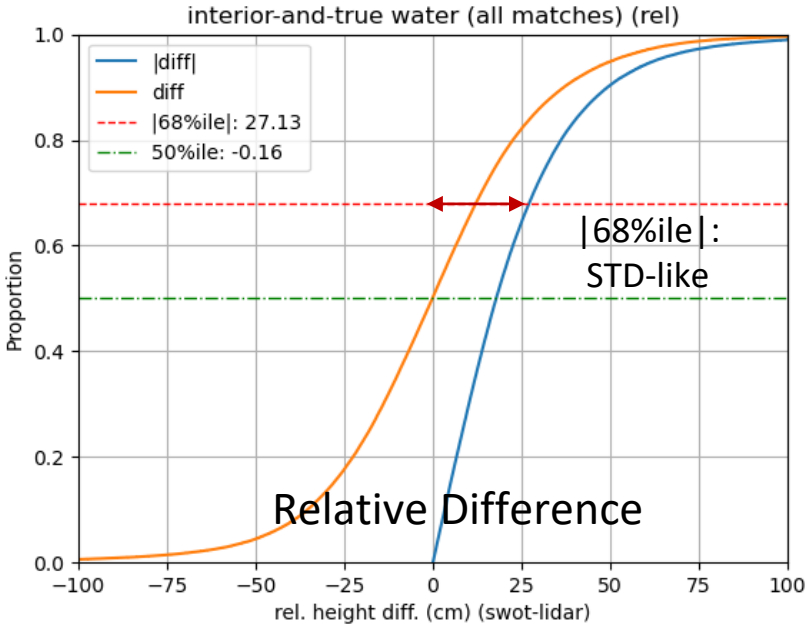
PIXC Validation Overview

- Metrics overview
- Pixel Cloud (PIXC) example
- Water Surface Elevation (WSE)/height validation
  - Pixel-wise comparisons with pressure transducers (PTs) (Tier 1 sites)
  - Pixel-wise comparisons with Lidar (several days of Waimakariri River data)
- WSE uncertainty characterization
  - Systematic/temporal undulation
  - Random/phase-noise
- Water-detection/water-fraction/aggregated-water-area estimates
  - Evaluated using Waimakariri lidar and water masks
- Quality flag recommendations

Metrics and Uncertainties

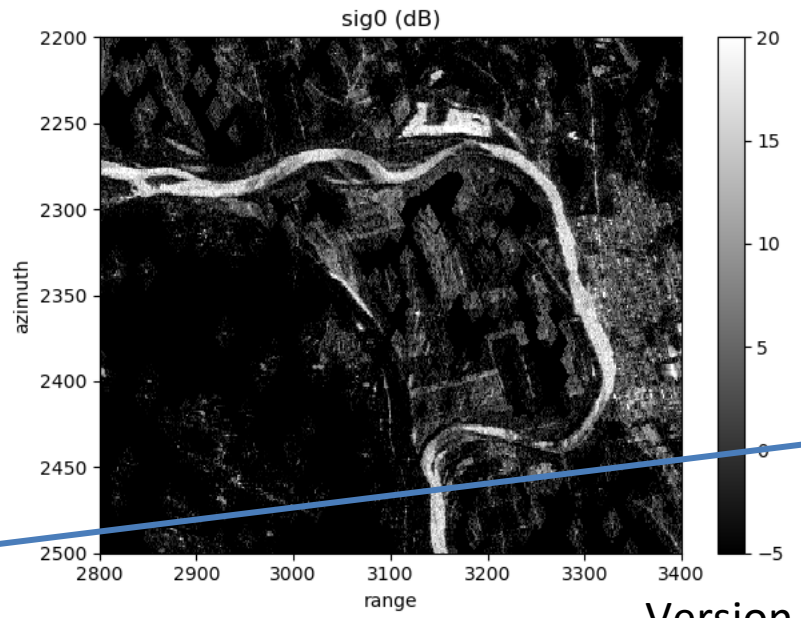
- Field data also has errors
  - Metrics used are differences not estimates of the SWOT errors themselves
- Metrics
  - STD diff
    - ~68% of data within +- 1-std for Gaussian distribution
    - Measure of the spread/dispersion around the mean (takes out bias)
  - RMS diff
    - Measure of the spread/dispersion and biases
  - 50%ile of signed diff (estimate of “bias”, less sensitive to outliers than mean)
  - |68|%ile of diff (68%ile of absolute value)
    - Similar to RMS, but less sensitive to outliers
  - |68|%ile of relative diff (68%ile of absolute value)
    - relative means taking out “bias”
    - Similar to STD, but less sensitive to outliers
- CDFs
  - Signed and unsigned (absolute value)
  - Shows all percentiles and describes entire distribution
- Uncertainties
  - Random (average down)
    - Estimate for water height is in products
  - Systematic (do not average down with coarser spatial scale)
    - May vary from cycle to cycle, but spatially smooth over single swath measurements
    - Not estimated/reported in products

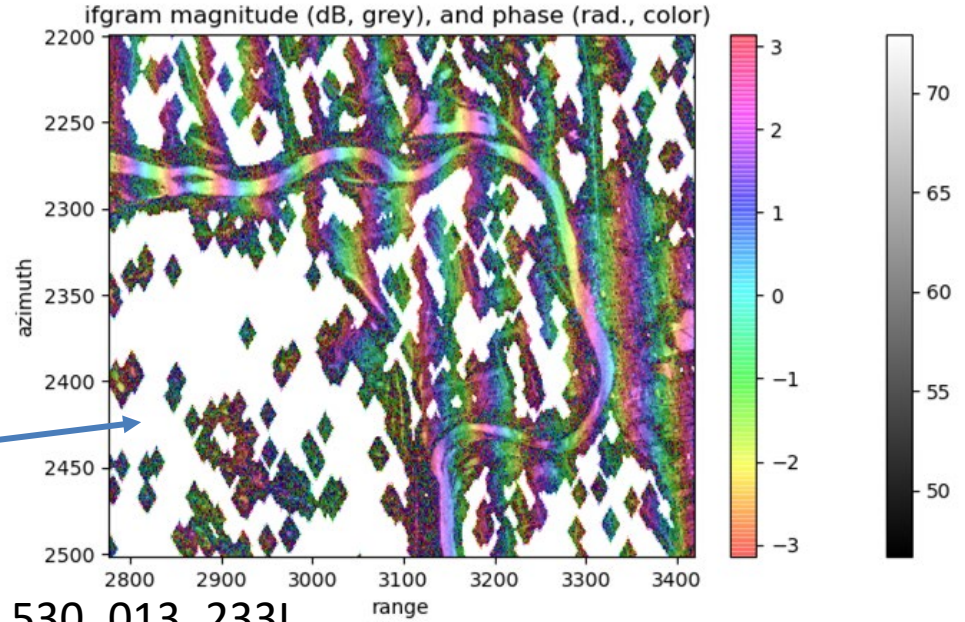




Pixel Cloud Example (Willamette River)

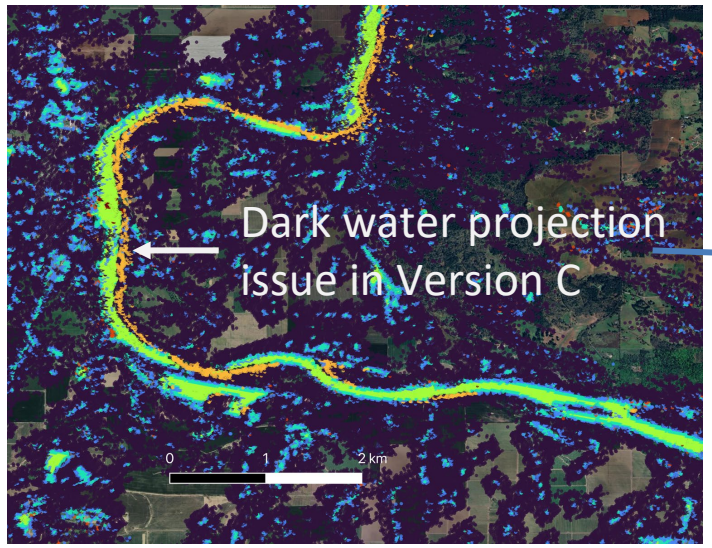
- Many PIXC variables
- Slant-plane/radar coordinates
  - Range and azimuth images on the right
- Many non-water pixels dropped/pruned from radar images

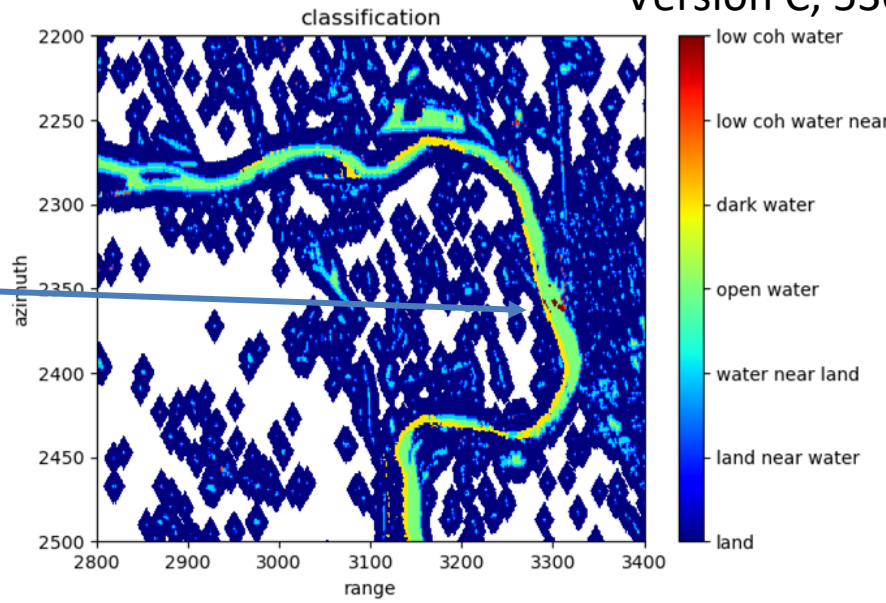


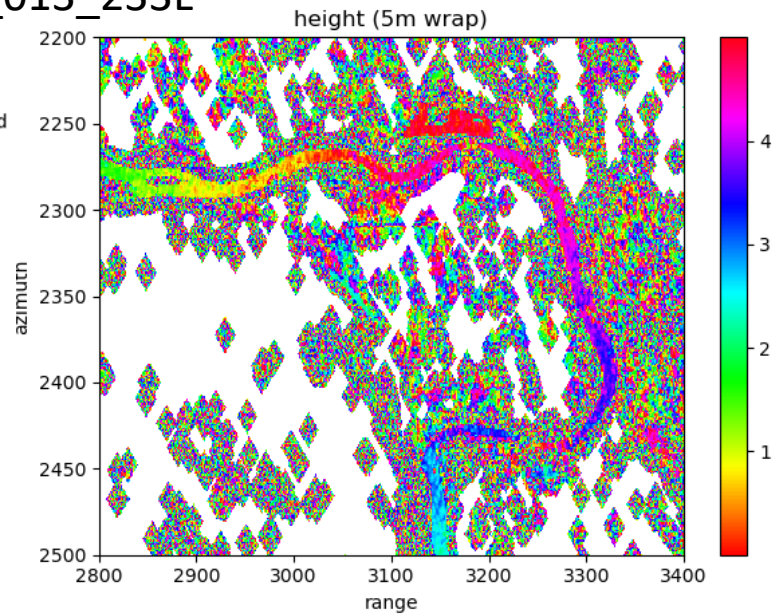


Version C, 530_013_233L

Classification

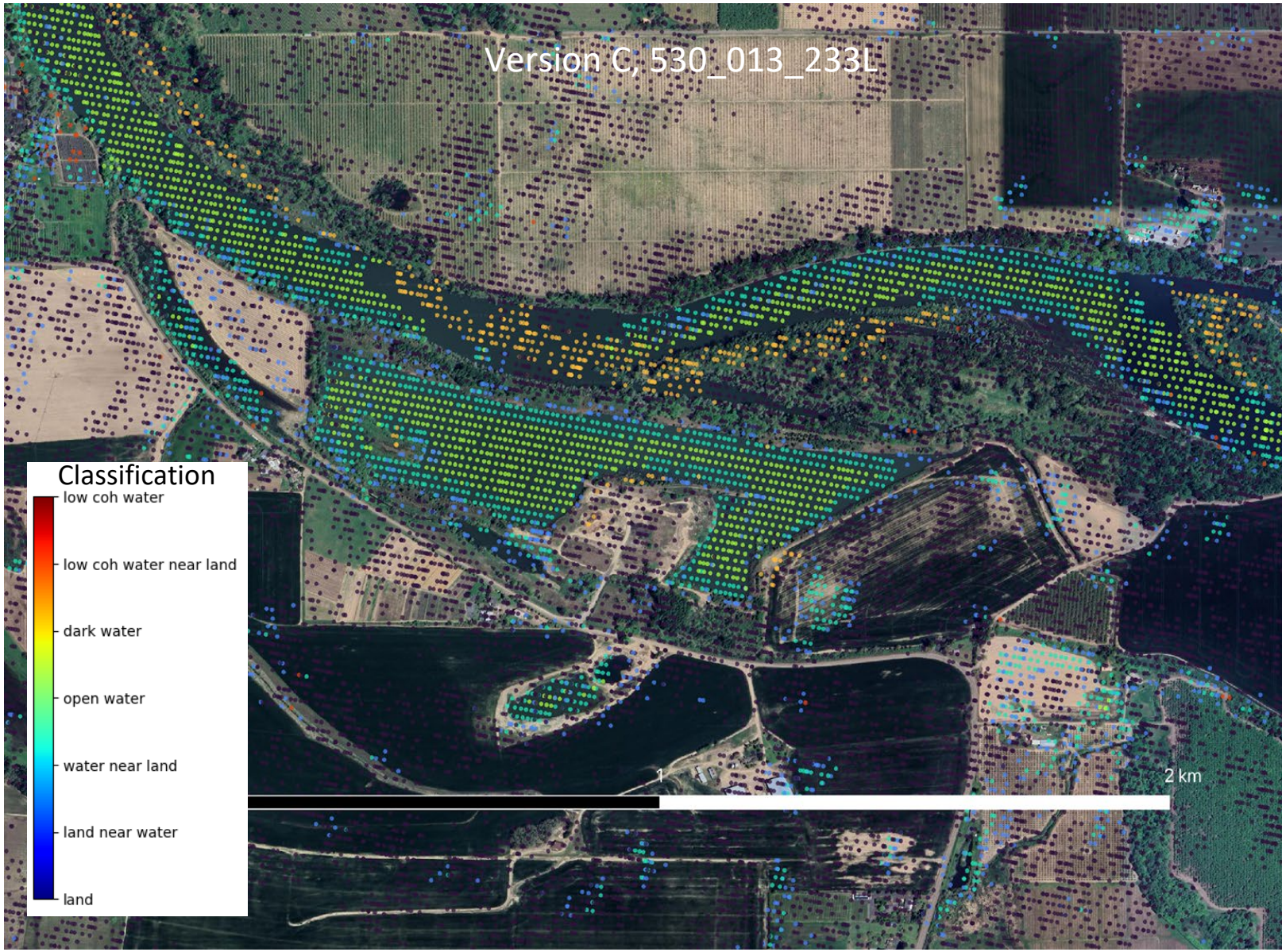






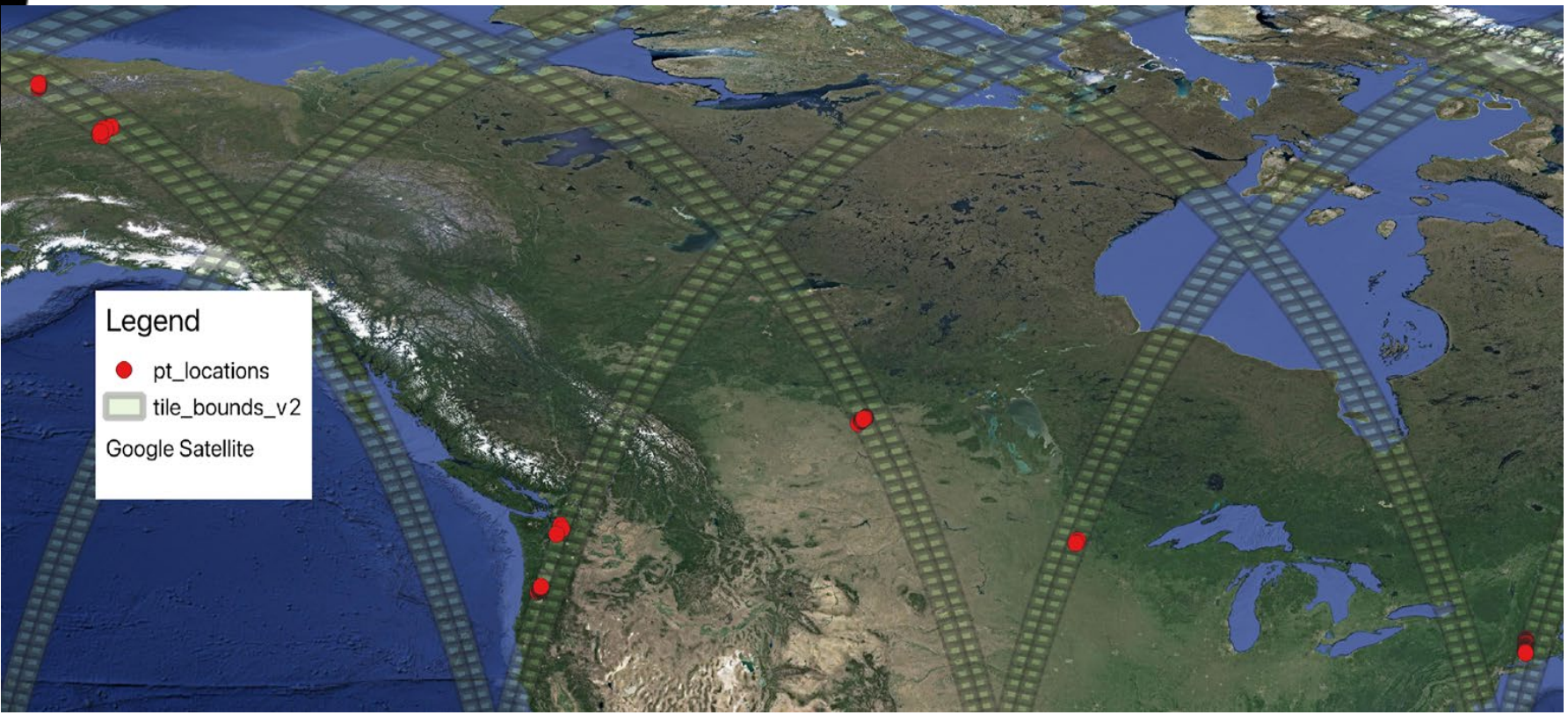
Pixel Cloud Example Zoom (Willamette River)

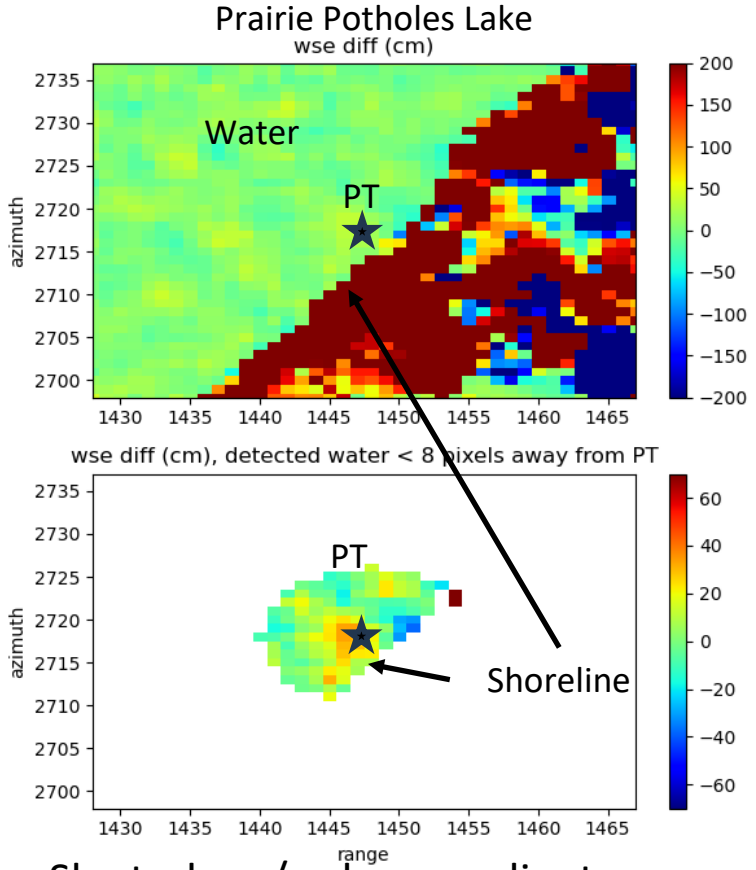
- Pixel geolocations (and heights) good for water pixels
  - Open/interior water
  - Water-near-land
- Geolocation (and height) show significant noise and artifacts for:
  - Land
  - Dark water
  - Low-coherence water
- Geolocation noise/errors can be larger than the pixel size (~20-60m)



WSE: Pressure Transducers (PTs)

- PT data
  - Tier 1 US site data
  - Absolutely leveled
  - Lakes and rivers
  - Spring/Summer 2023 (over Cal orbit)
  - Discard self-inconsistent field data (bad PT qual)
- SWOT data
  - Version C (PGC0) data (Cal orbit)
  - Only “good” geolocation pixels (geolocation_qual < 4)
  - Various detected water classes
  - Apply geoid and Earth tide corrections to get WSE from “height”
- Collocation process
  - Closest 15 min PT measurement to SWOT data
  - All pixels within a window in slant plane around PTs
    - Distance of 8 pixels around PT pixel (~200m radius)

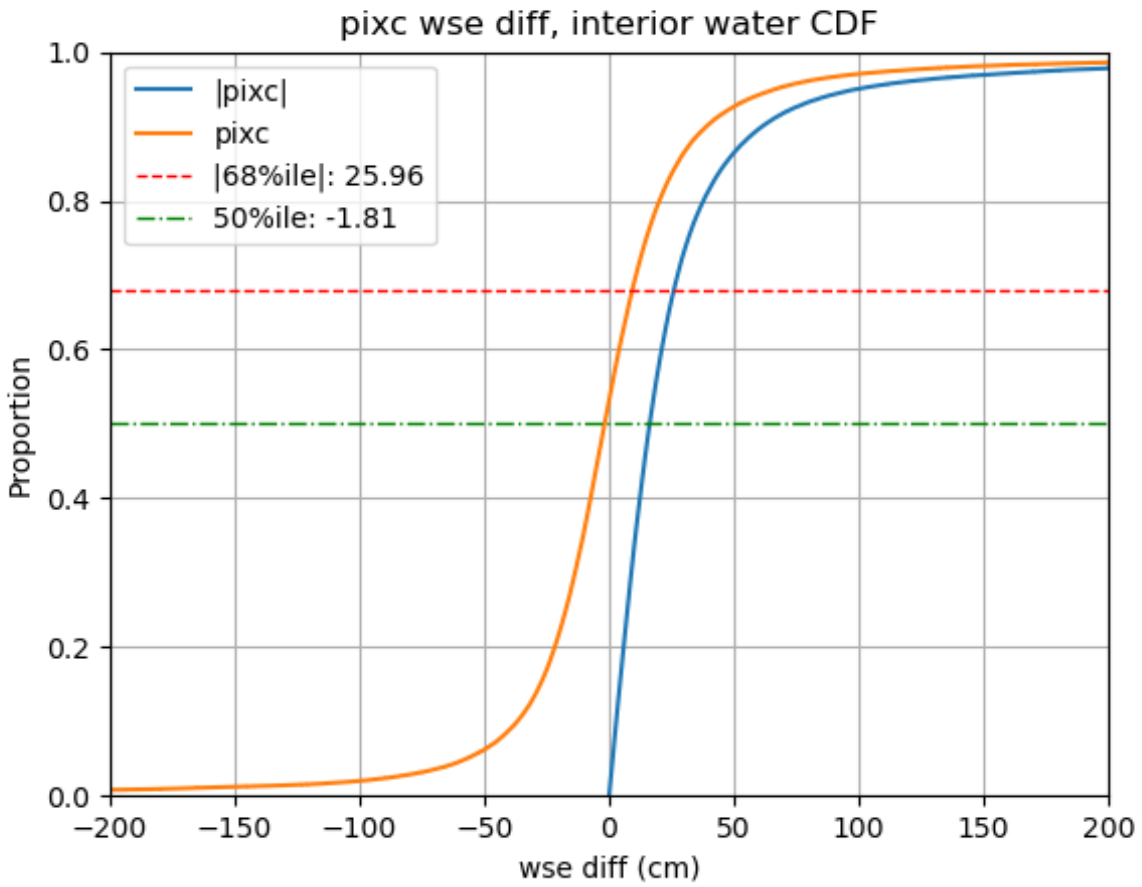


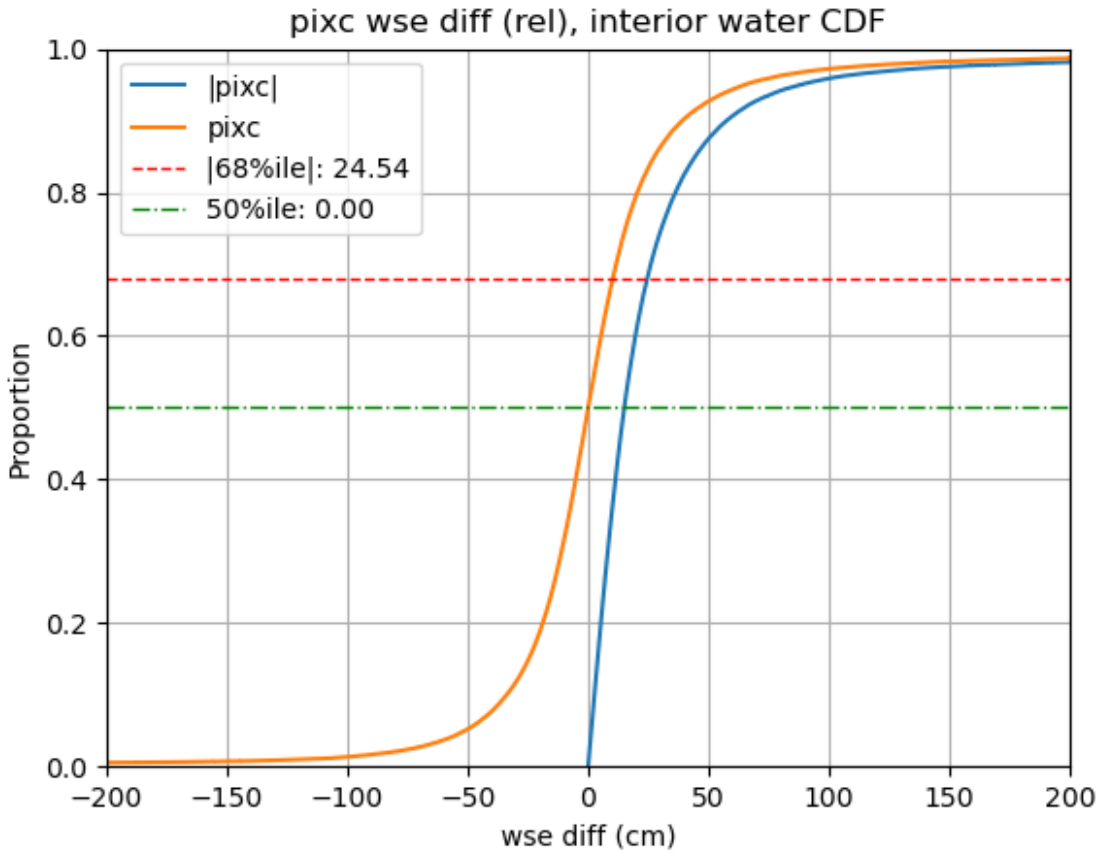


PT WSE Diff: Absolute and Relative are Excellent!

- SWOT agreement with PT WSE is excellent!
  - Pixel-wise comparison (~20-60m resolution)
  - Interior water: detected water, not land/water edge
  - Low bias (~-2 cm) overall, but can be significant from site to site
  - Relatively low RMS-like |68%ile| diff (~25 cm)

- PT relative water height diff similar to absolute
  - Relative is with median difference taken out per PT
  - Low STD-like |68%ile| relative diff (~25 cm)

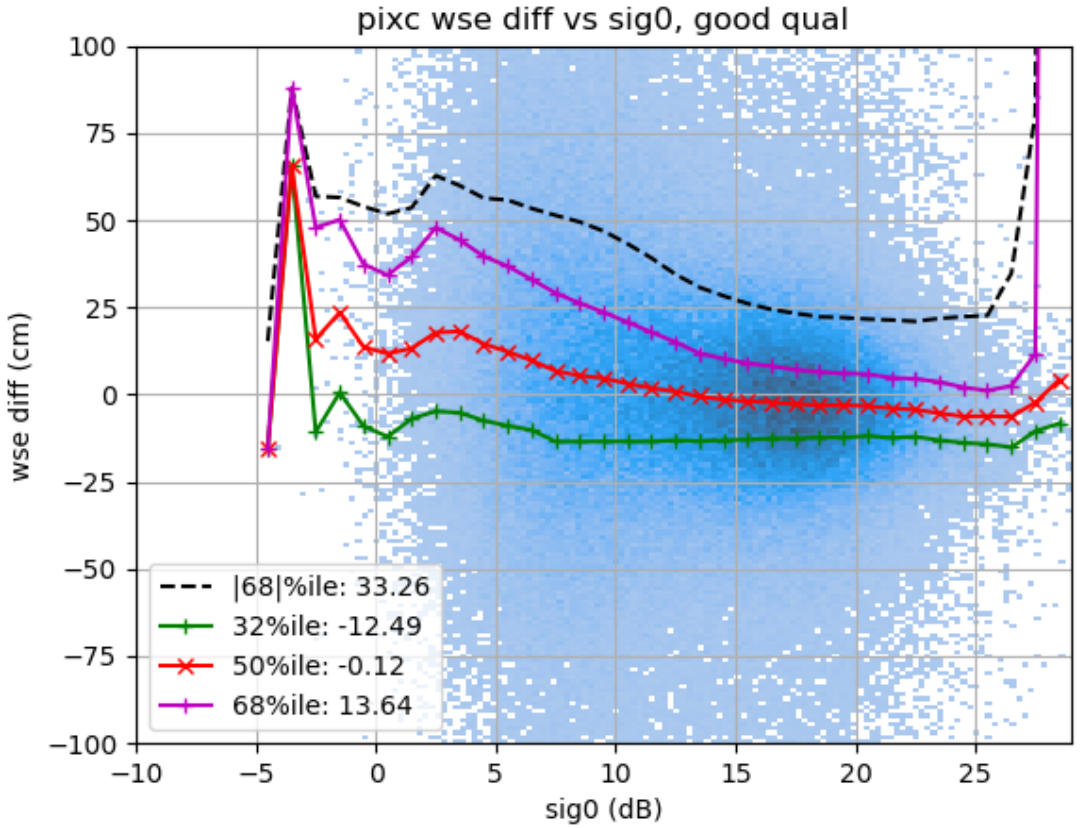


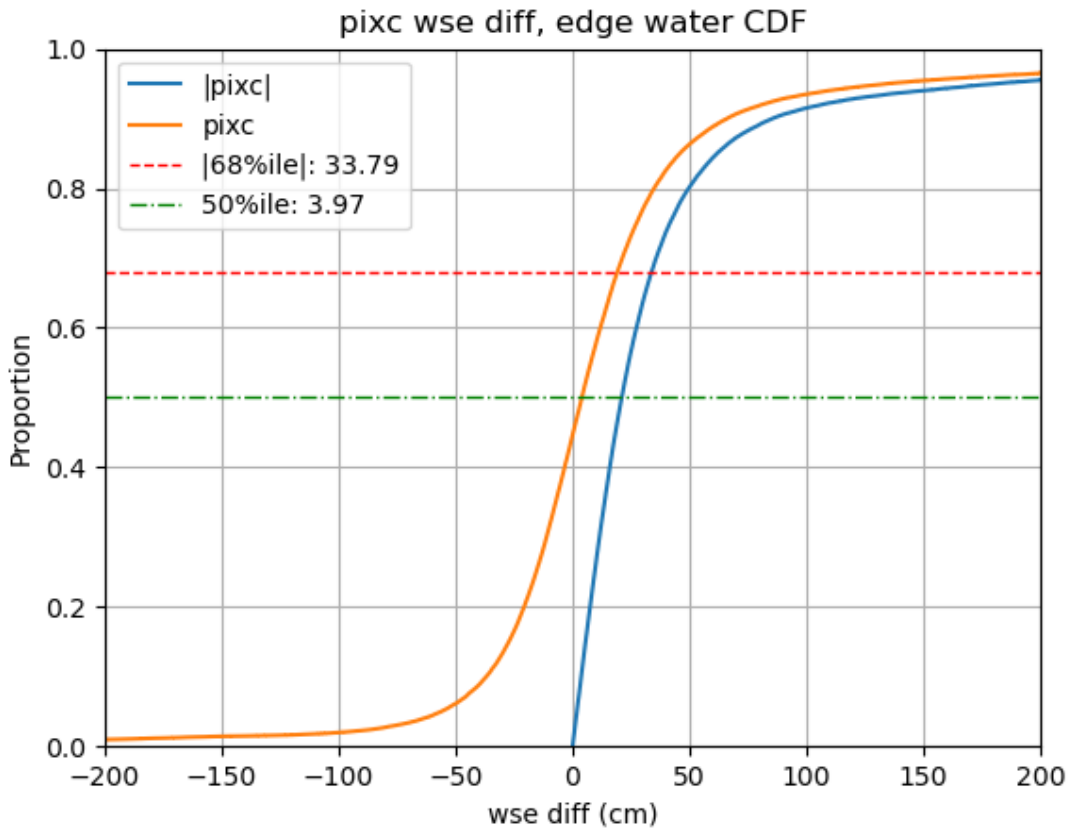


PT WSE Diff: vs Brightness and Edge Water Class

- Spread and bias is a function of water brightness
  - All water classes with “good” geoloc_qual
  - Higher spread with lower sigma0 is expected
  - Higher bias with lower sigma0 is curious
    - Layover impacting more?

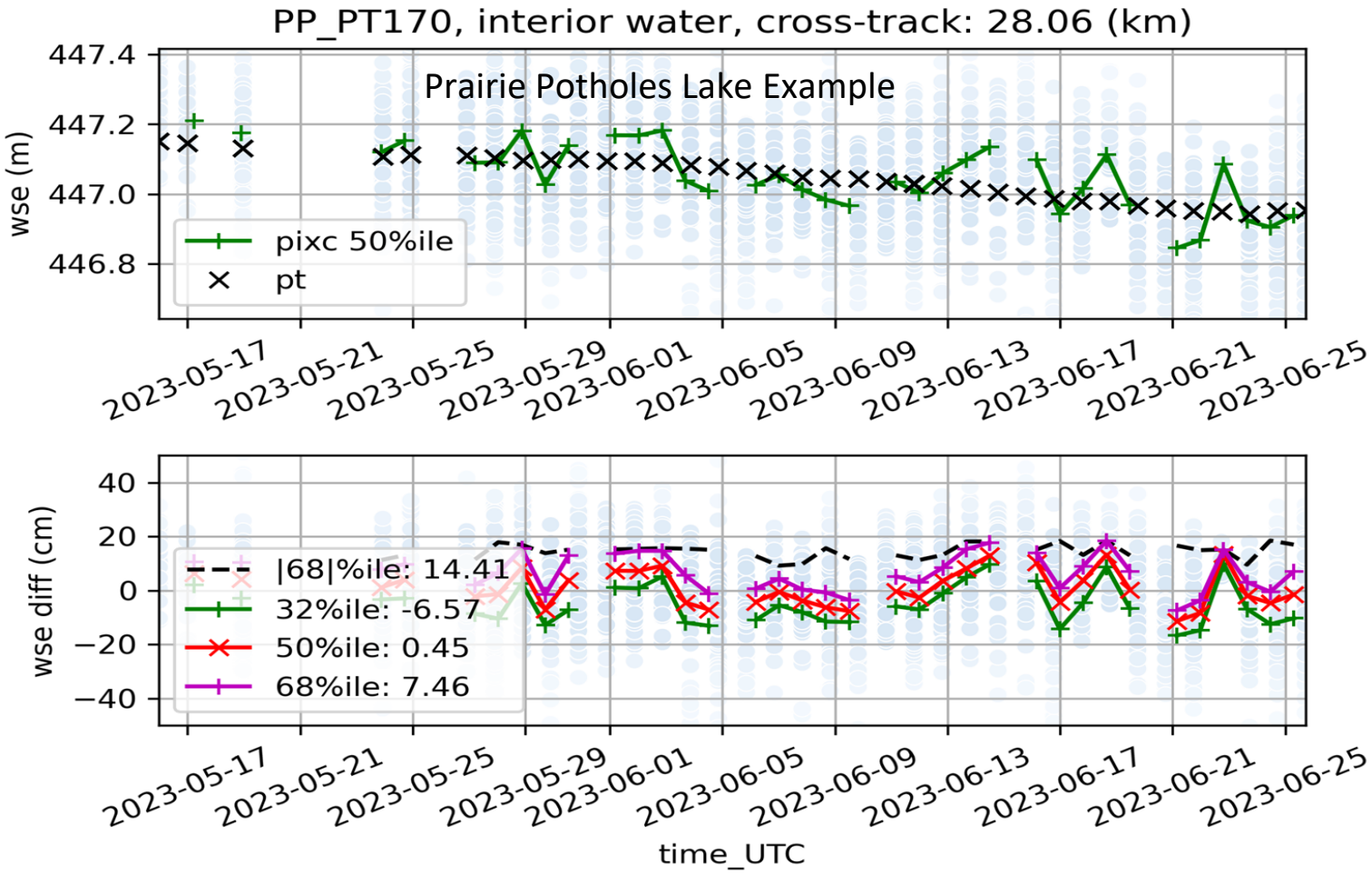
- WSE difference for edge water a little worse than interior water (~34 cm |68%ile|)
  - Expected as it is generally darker due to coherence time smearing
  - Narrow rivers and rivers with braided channels will have a slightly poorer WSE quality

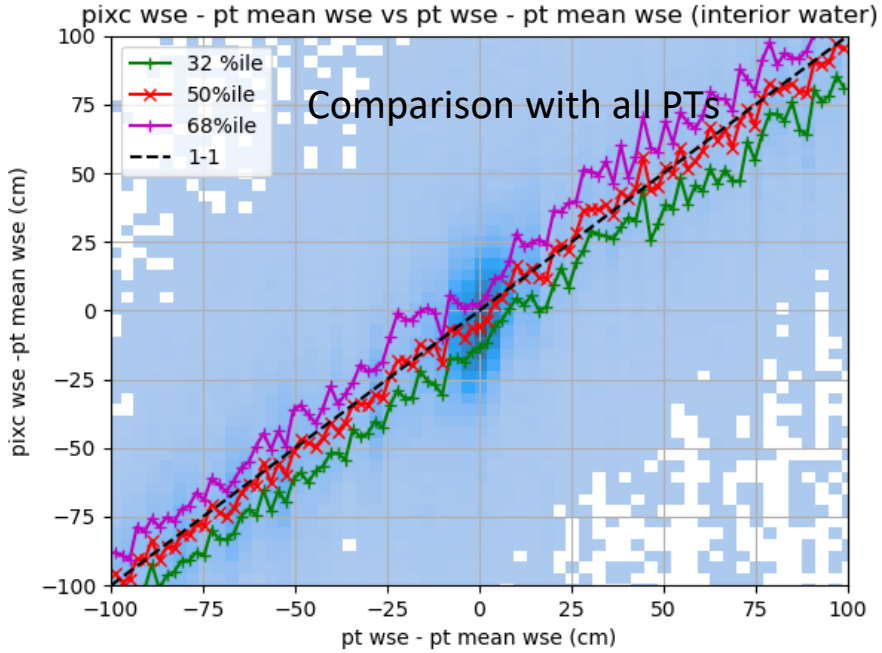


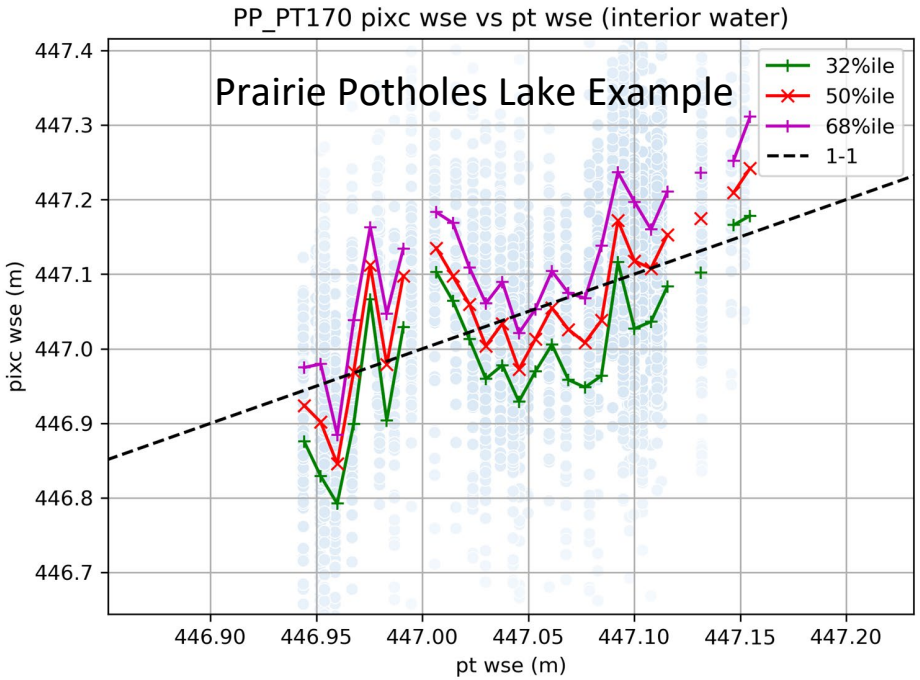


PT WSE Diff: SWOT Tracks PTs

- SWOT PIXC WSE tracks PT variations over time
  - Some residual undulations

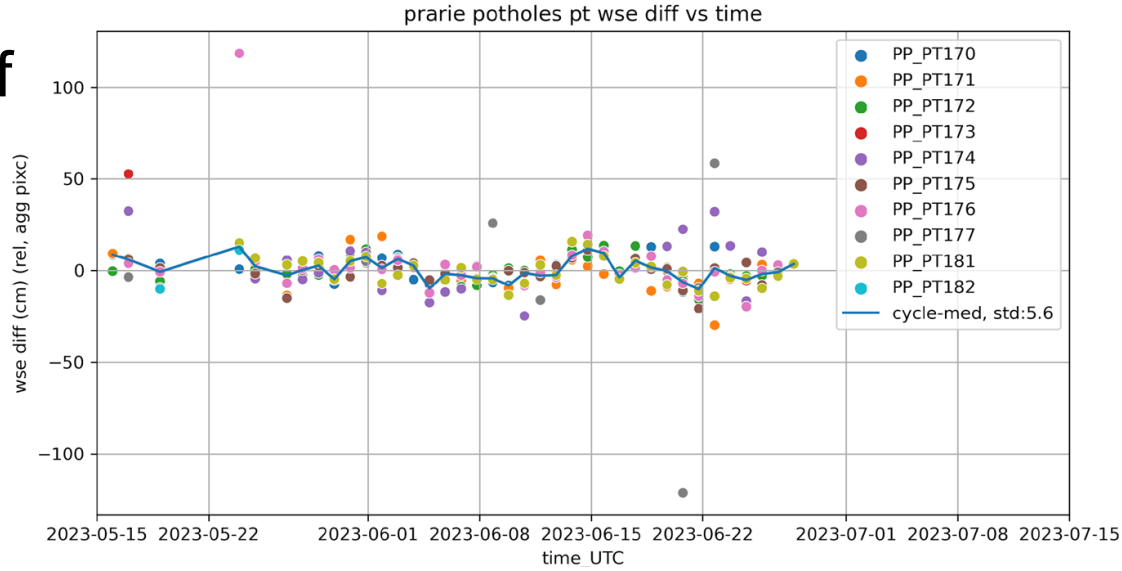


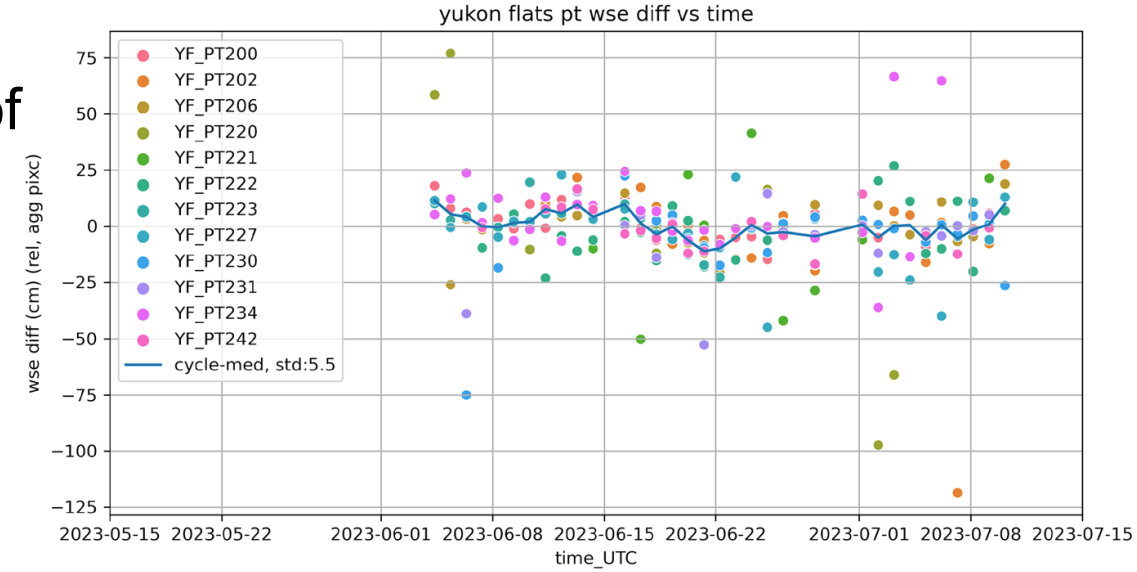




PT WSE Diff: Temporal Undulation O(5 cm)

- Apparent systematic error of relative WSE diff
  - Undulates over time
  - Seems consistent among all the PTs in a site
  - This signal is in SWOT but not the PT hydrographs
- Focus on Prairie Potholes (PP) and Yukon Flats (YF) Lakes (No slope)
  - PTs are widely distributed in cross-track
  - Details differ at the two sites, but magnitude of variation is similar (~5.5 cm std over time)
- This systematic error will not reduce with greater spatial aggregation (e.g., river node/reach or entire lake scales)



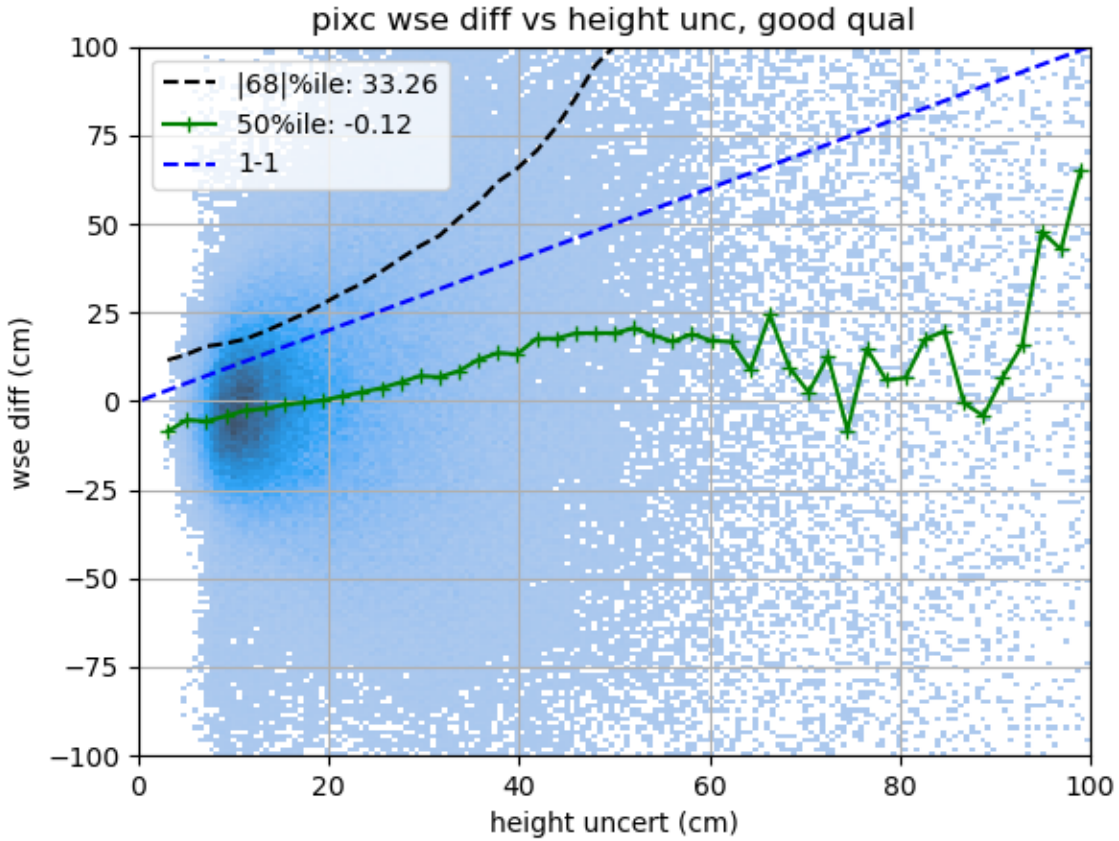


PT WSE Diff: Estimated Random Uncertainty

- Random height errors from phase
  - |68|%ile behaves as expected
    - ~Linear variation expected vs height uncertainty
    - Height uncert good characterization of the random errors
      - |68|%ile above the 1-1 line because of systematic errors not captured by the phase_noise_std
  - Bias a function of height uncert (or sig0) is curious
    - Could be partially due to layover systematic component
    - Potential for an empirical bias correction
    - Needs more investigation
  - Aggregates down
    - <1/sqrt(n) since pixels are slightly correlated due to adaptive multilooking

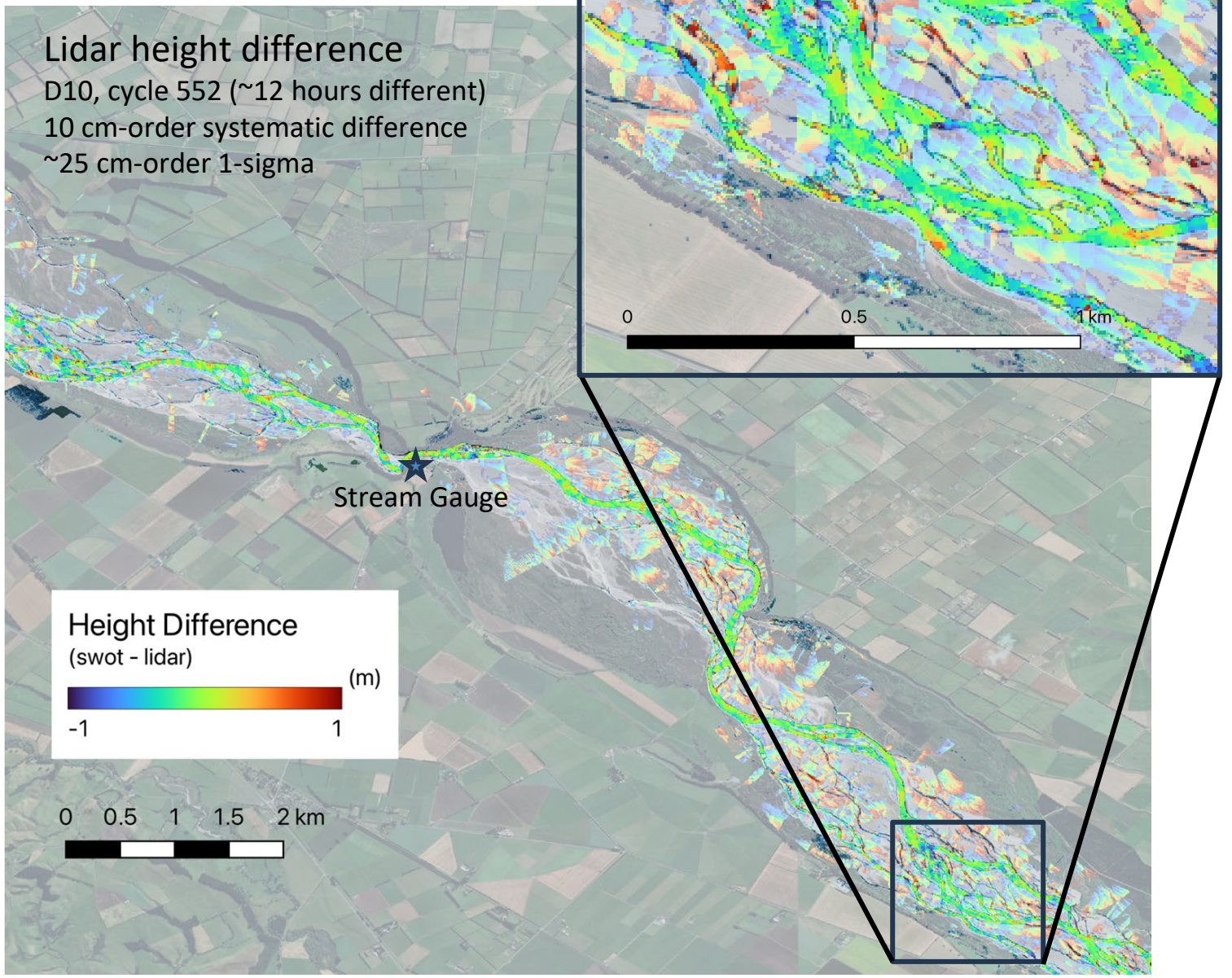
No systematic error terms

height uncert = phase_noise_std * dheight_dphase



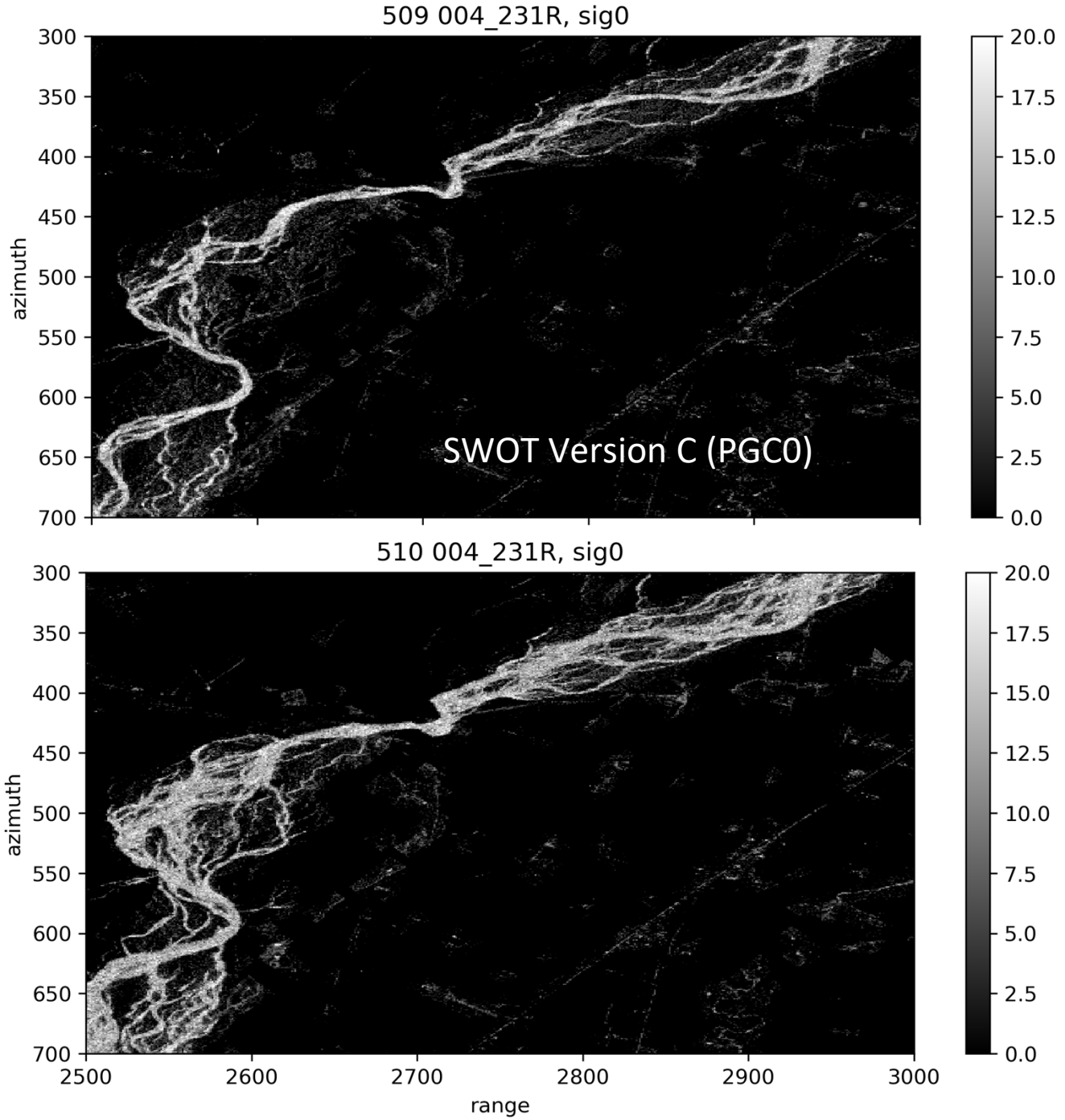
Lidar (Waimakariri)

- Lidar DEMs and Water masks
  - 11 collections in April-June 2023
  - Used 10 of the 11 collection days
    - Day 11 (no SWOT data available at time of analysis)
  - Some days compared to multiple closest swot observations (a few are more than a day)
  - Comparison details
    - 5m water fraction masks projected into slant plane using corresponding 5m lidar DEMs
  - Each match has its own bias, but relatively consistent
- SWOT Data
  - Version C (PCG0)
  - Using only trusted SWOT quality pixels (geoloc_qual<4)
- Pixel-wise comparisons (no additional aggregation)



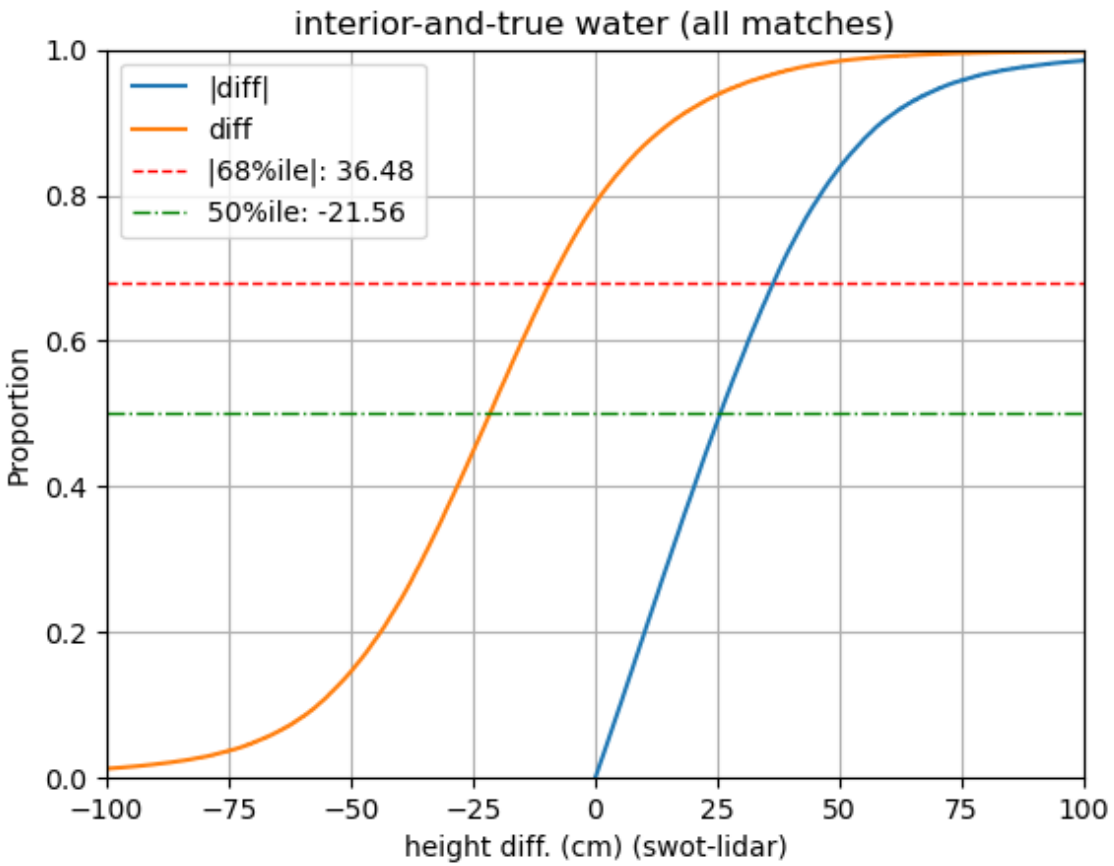
Waimakariri River

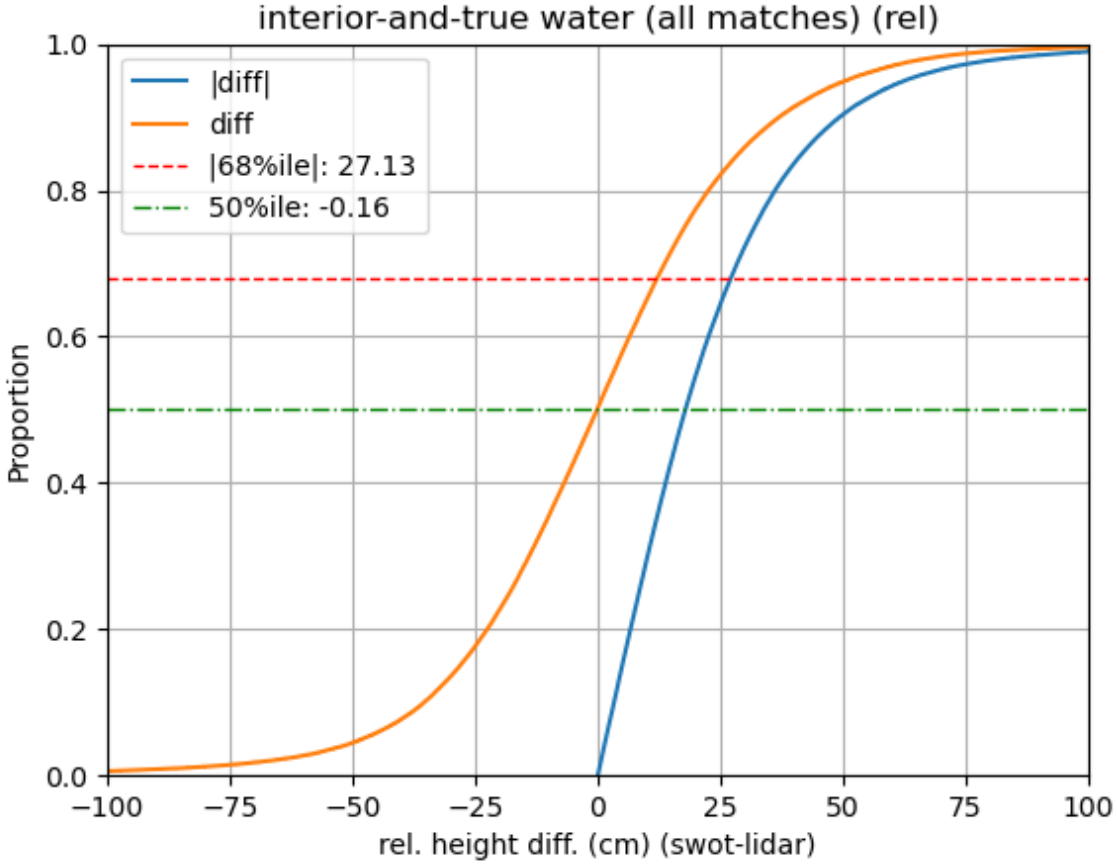
- Waimak is unique
- Detail even in narrow channels
- Several flow waves over Cal orbit
- Channels flood and move/migrate
  - Prior water occurrence mask is poor representation of water probability (smeared out)
- Steep, braided river
- Negligible dark water
- Negligible specular ringing



Lidar WSE Diff: Significant Bias but Rel. is Excellent

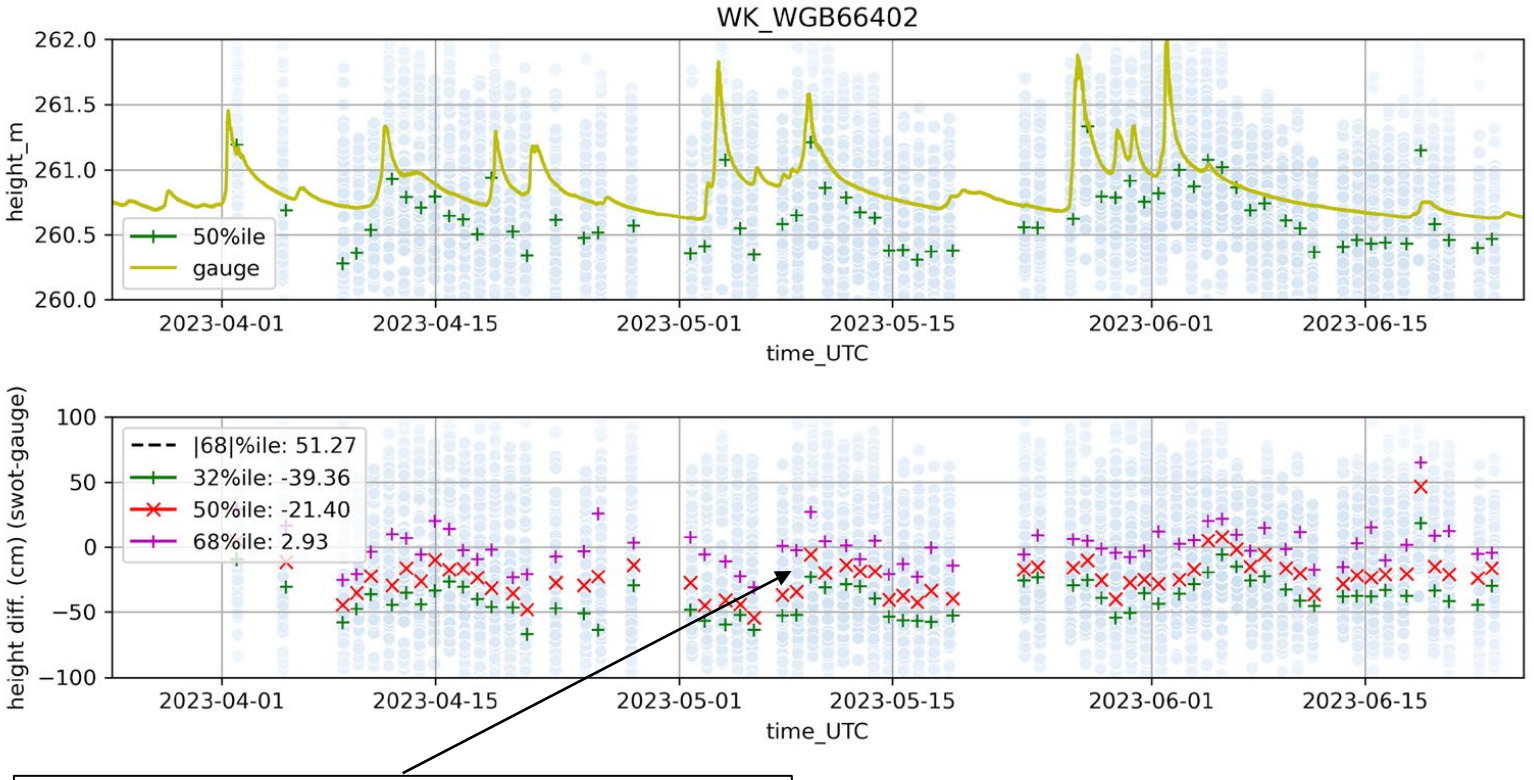
- SWOT agreement with Lidar water height data is good but has ~-20 cm bias
  - Possible reference mismatch, still investigating
- Lidar relative water height diff consistent with PTs
  - Relative is with taking out a -21.4 cm bias
    - estimated over many cycles using lidar-leveled-gauge data
  - Low STD-like |68%ile| relative diff (~27 cm)

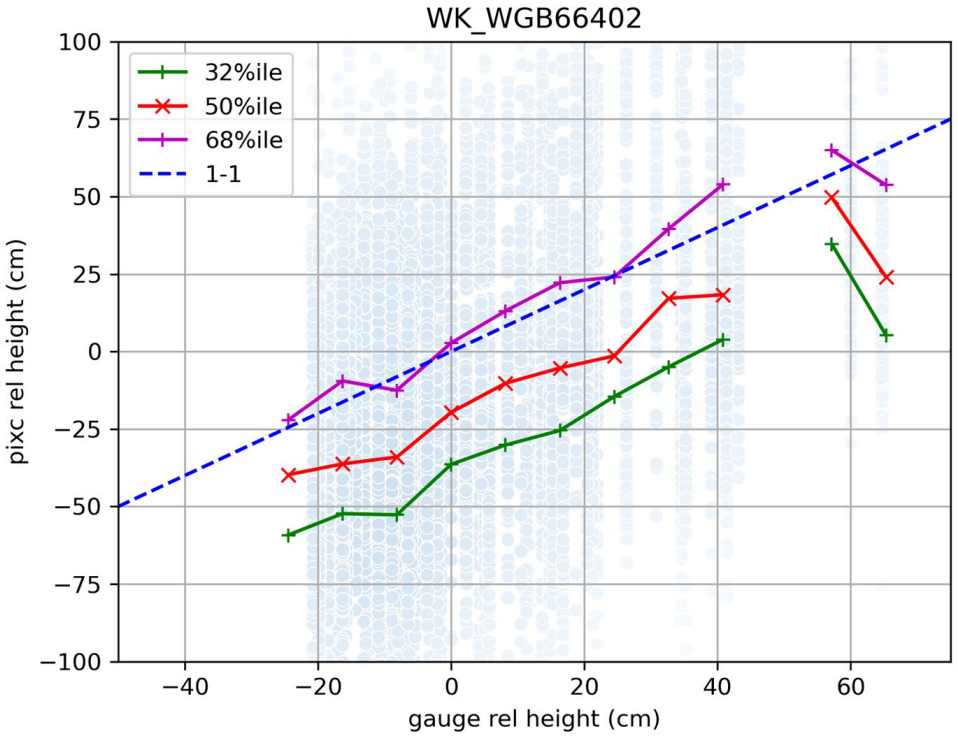




Waimak WSE Diff: SWOT Tracks Lidar/Gauge over Time

- Stream gauge leveled using lidar data (D10)
- Compared to SWOT data similar to the PT data
- Exhibits similar bias as lidar, but tracks the variations in stage over time

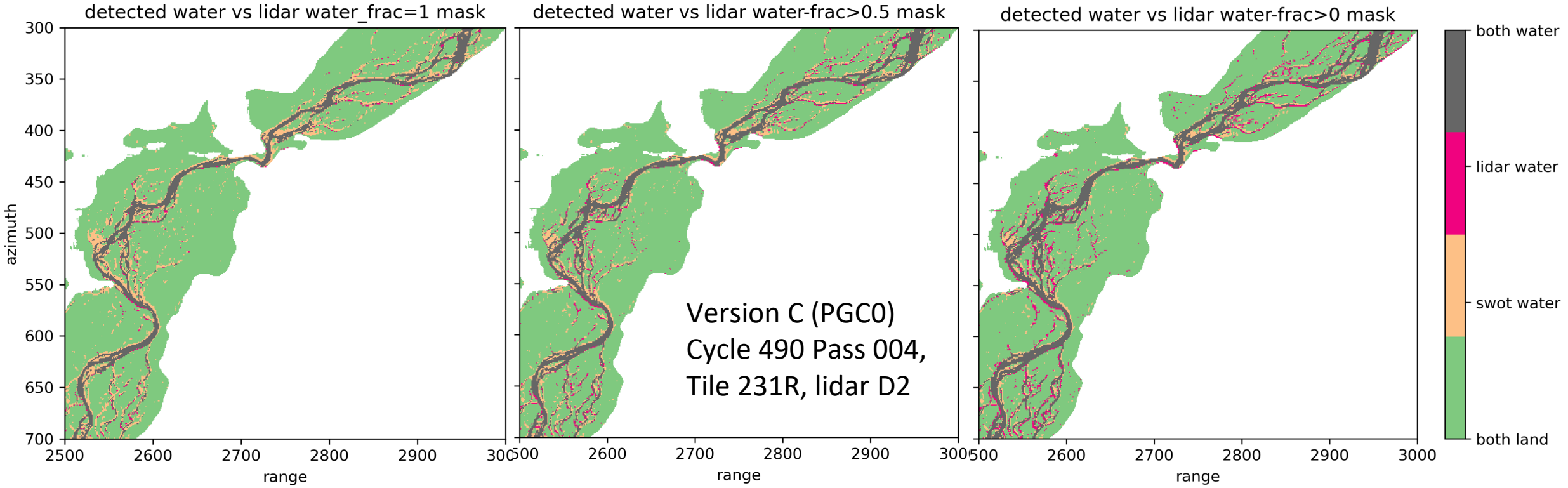




15.5 cm std of undulation of 50%ile

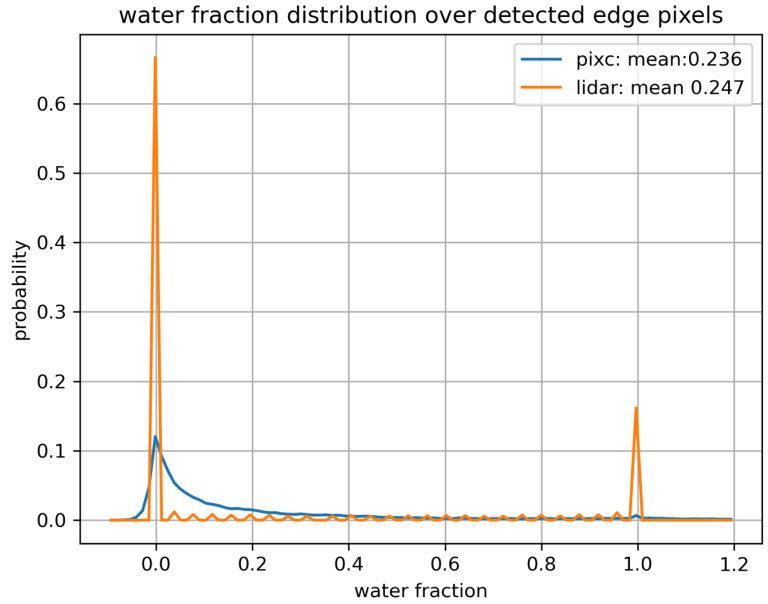
Water Detection: Behaves as Expected

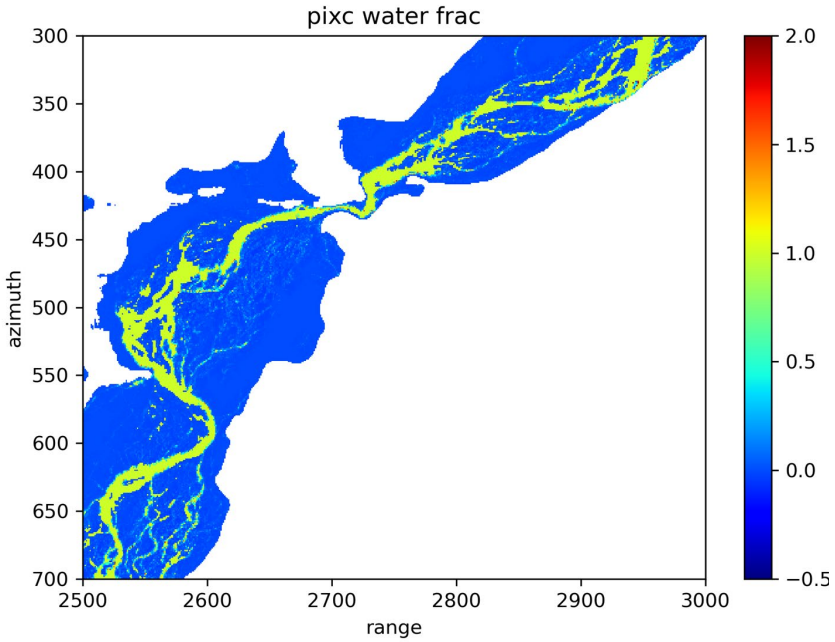
- Waimakariri water masks projected into slant plane
- Differences in lidar-water-mask depending on how partial-water pixels are handled
  - Lidar “water_frac” generated at 5m posting from the 1m water mask
  - Then projected into slant-plane/radar coordinates
- Detection rates (assuming no dark water) behave generally as expected
  - Tend to over-detect edges and narrow features
  - Missed detection rate p(l|w) is generally low
  - False detection rate p(w|l) decreases with cross-track, but significant in near-swath
  - Most differences occur on water edges
    - Detection errors on edges can be mitigated using PIXC water fraction estimate (see next slide)

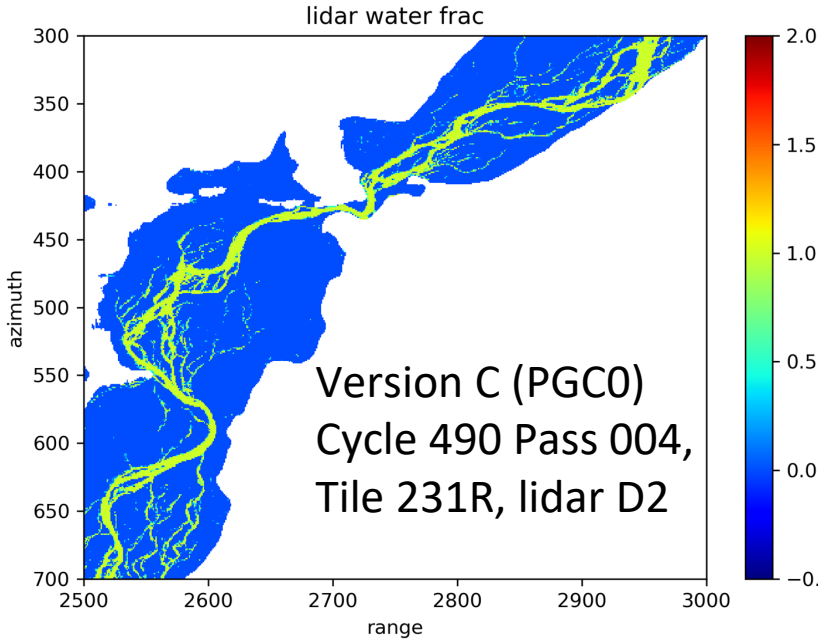


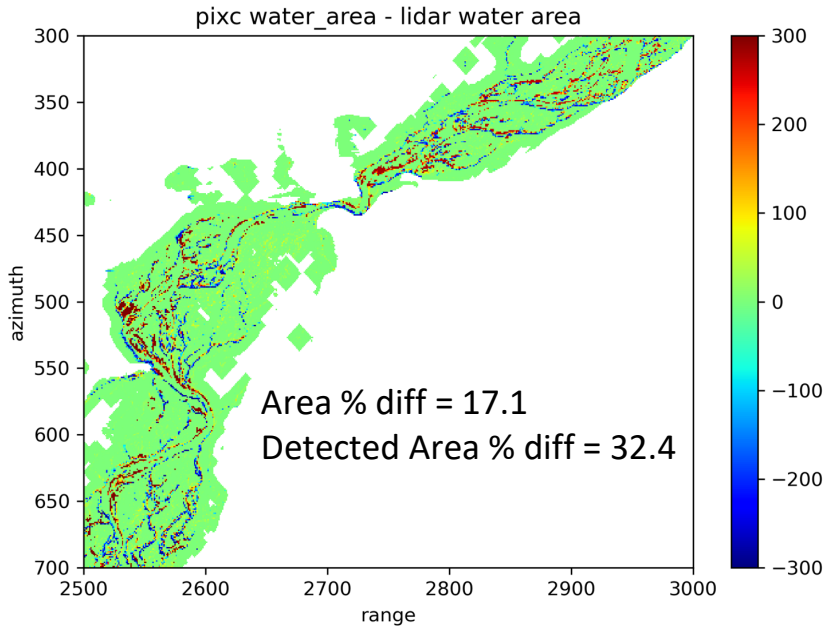
Water Fraction: Mitigates Overdetections with Caveats

- Waimakariri water frac projected into slant plane
- Neglecting dark water (re-estimating edge pixels)
- Water fraction
  - Noisy at the pixel level (can be negative or >1)
  - Helps mitigate over-detections due to coherence time smearing and partial inundation
- Water area after aggregation is what matters



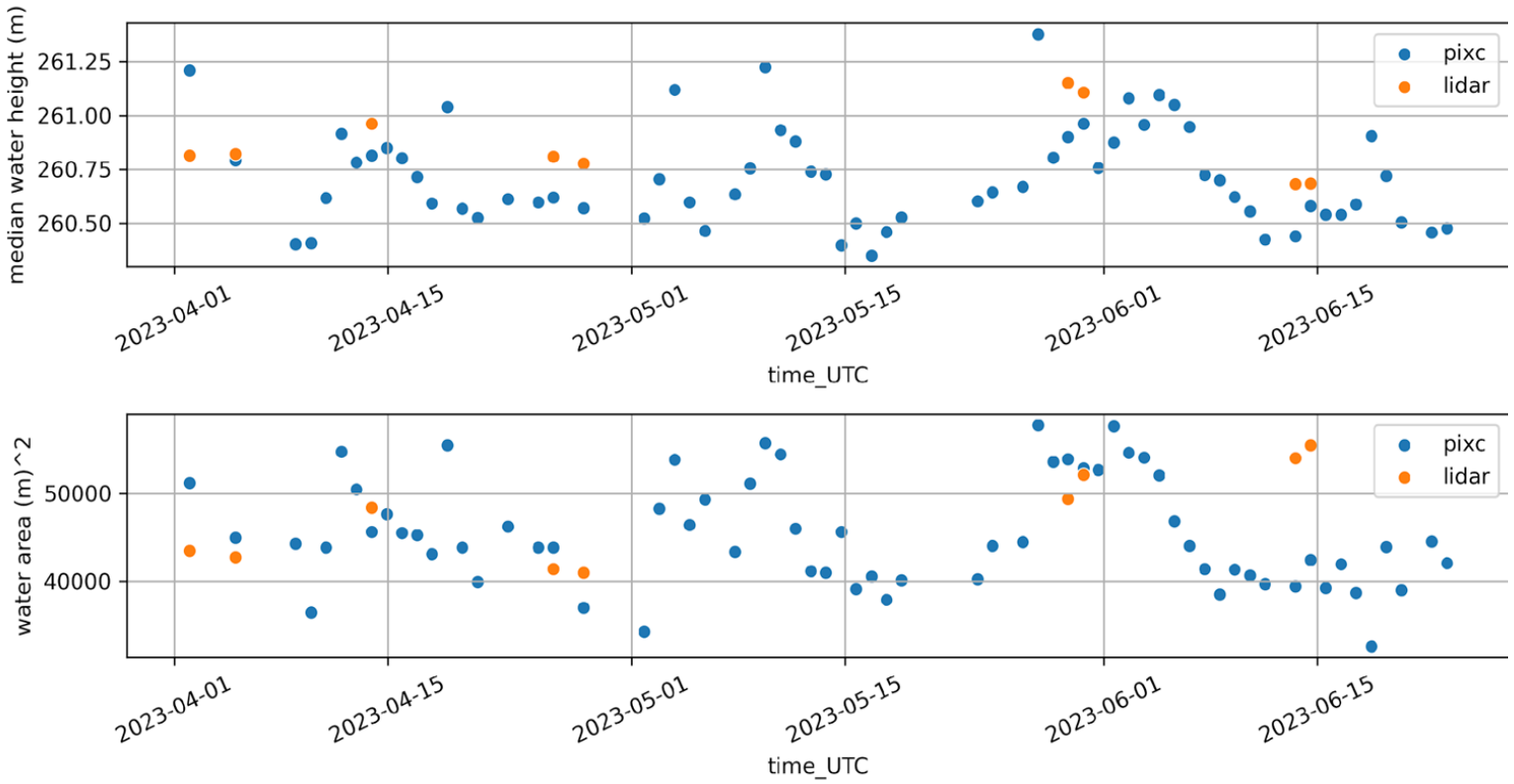


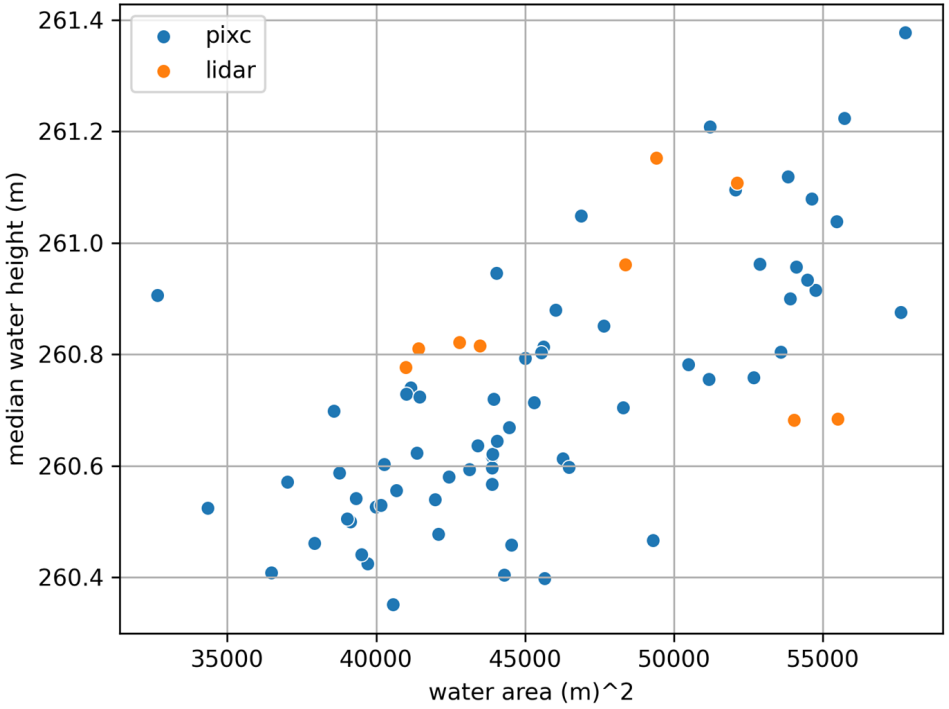


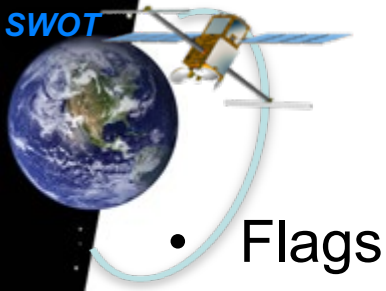


Waimak WSE and Area: Rating Curve Potential

- SWOT and lidar over larger PIXC window around gauge
  - Lidar projected into slant-plane
  - Compute median PIXC and total water area for both SWOT and Lidar
- WSE and area covary consistently
- SWOT consistent with lidar WSE/height vs area
  - Noisy with this method, node- and/or reach-level rating curves may be better







PIXC Quality Indicators and Flags

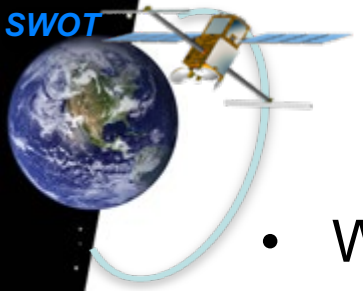
- Flags and class values can be a good source of information
  - To interpret the quality of the PIXC variables and river/lake/raster
  - Note these will also evolve and are not yet fully validated
- Some flags/variables more reliable than others
  - ADT has focused so far on validating:
    - WSE (“height” and “geolocation_qual”)
    - WSE random uncertainty (“phase_noise_std * dheight_dphase”)
    - Water detection and dark water flagging (“classification”)
    - Water-fraction estimation (“water_frac”)
  - Have not evaluated in detail (may be less-reliable):
    - Detection and water frac uncertainty (“false_detection_rate”, “missed_detection_rate”, and “water_frac_uncert”
    - Layover (“layover_impact”)
    - Phase unwrapping error rates and impact (“ambiguity_cost1/2”)
    - Specular ringing flagging error rates
    - “sig0” (except in radiometric calibration) and “sig0_uncert”

PIXC Quality Filtering Recommendations

- Version C height qual filtering recommendations
  - Use primarily the bright water classes (e.g., classification = 3 or 4). Use with the following caveats:
    - geolocation_qual variable is a bit flag, but ordered so higher values have increasing bad-ness
      - Good for geolocation_qual < 4
        - » i.e., ignore bits for layover_significant, and phase_noise_suspect
      - Suspect for 4 <= geolocation_qual < 2^16 (=65536)
      - Degraded for 2^16 <= geolocation_qual < 2^25 (=33554432)
      - Bad for geolocation_qual >= 2^25
    - Other considerations
      - May want to treat water pixels with bright land flag set as suspect or degraded (likely false detection of bright land as water)
  - Land, dark water, and low-coherence water classes (e.g., classification = 1,2,5,6,7) have significant height errors (meter- to decameter-level)
    - Use with caution

Ignore these bits

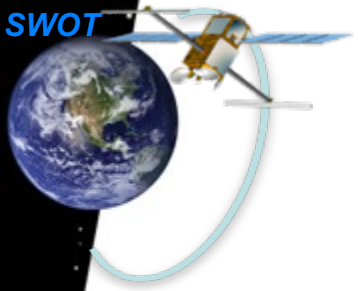
	Bit (from LSB)	Decimal	geolocation_qual
	0	1	layover_significant
	1	2	phase_noise_suspect
Suspect	2	4	phase_unwrapping_suspect
	3	8	model_dry_tropo_cor_suspect
	4	16	model_wet_tropo_cor_suspect
	5	32	iono_cor_gim_ka_suspect
	6	64	xovercal_suspect
	7	128	
	8	256	
	9	512	
	10	1024	
	11	2048	
	12	4096	medium_phase_suspect
	13	8192	tvp_suspect
	14	16384	sc_event_suspect
	15	32768	small_karin_gap
Degraded	16	65536	
	17	131072	
	18	262144	
	19	524288	specular_ringing_degraded
	20	1048576	model_dry_tropo_cor_missing
	21	2097152	model_wet_tropo_cor_missing
	22	4194304	iono_cor_gim_ka_missing
	23	8388608	xovercal_missing
	24	16777216	geolocation_is_from_refloc
Bad	25	33554432	
	26	67108864	
	27	134217728	no_geolocation_bad
	28	268435456	medium_phase_bad
	29	536870912	tvp_bad
	30	1073741824	sc_event_bad
	31	2147483648	large_karin_gap



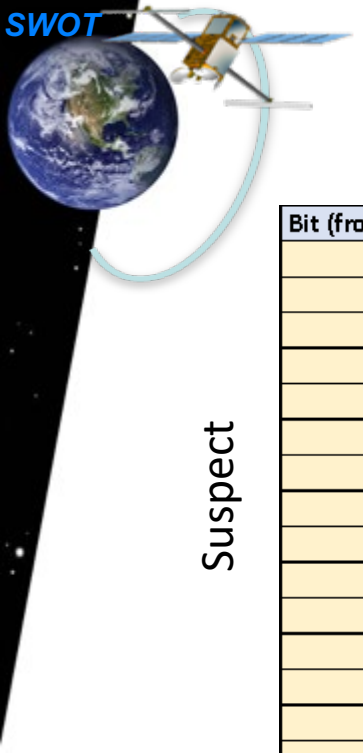
PIXC Validation Summary/Take-aways

- WSE/height
  - Excellent shape
    - WSE differences on the order of ~20-30cm (|68|%ile)
- Water-detection/water-fraction/aggregated-water-area estimates
  - Good shape, behaving as expected
- Dark water flagging (see PIXC Features and Issues slides)
  - OK shape
    - Version C (PGC0) data has issues with projections of prior, but have an offline fix
- Uncertainty estimates
  - OK shape, but still work to do
    - WSE random errors consistent with predictions
    - Predicted detection error rates difficult to assess with imperfect field data
- Quality flags
  - Useful for interpreting/filtering data, but still under development and subject to change
- PIXC ADT future work will continue
  - Algorithm improvements, quality flagging enhancements, bug fixes
  - General validation/characterization

Questions?

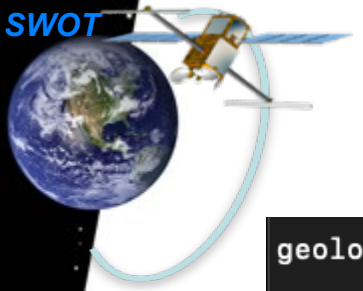


Backup



PIXC Quality Bit Flag Details

	Bit (from LSB)	Decimal	Hex	interferogram_qual	classification_qual	geolocation_qual	sig0_qual	pixc_line_qual
Suspect	0	1	1		no_coherent_gain	layover_significant	sig0_uncert_suspect	not_in_tile
	1	2	2		power_close_to_noise_floor	phase_noise_suspect	sig0_cor_atmos_suspect	
	2	4	4		detected_water_but_no_prior_water	phase_unwrapping_suspect	noise_power_suspect	
	3	8	8		detected_water_but_bright_land	model_dry_tropo_cor_suspect	xfactor_suspect	
	4	16	10		water_false_detection_rate_suspect	model_wet_tropo_cor_suspect		
	5	32	20			iono_cor_gim_ka_suspect		
	6	64	40			xovercal_suspect		
	7	128	80					
	8	256	100					
	9	512	200					
	10	1024	400					
	11	2048	800	rare_power_suspect	coherent_power_suspect		rare_power_suspect	
	12	4096	1000	rare_phase_suspect		medium_phase_suspect		
	13	8192	2000	tvp_suspect	tvp_suspect	tvp_suspect	tvp_suspect	tvp_suspect
	14	16384	4000	sc_event_suspect	sc_event_suspect	sc_event_suspect	sc_event_suspect	sc_event_suspect
	15	32768	8000	small_karin_gap	small_karin_gap	small_karin_gap	small_karin_gap	small_karin_gap
Degraded	16	65536	10000					
	17	131072	20000					
	18	262144	40000	in_air_pixel_degraded	in_air_pixel_degraded		in_air_pixel_degraded	
	19	524288	80000	specular_ringing_degraded	specular_ringing_degraded	specular_ringing_degraded	specular_ringing_degraded	
	20	1048576	100000			model_dry_tropo_cor_missing	sig0_cor_atmos_missing	
	21	2097152	200000			model_wet_tropo_cor_missing		
	22	4194304	400000			iono_cor_gim_ka_missing		
	23	8388608	800000			xovercal_missing		
	24	16777216	1000000			geolocation_is_from_refloc		
Bad	25	33554432	2000000				noise_power_bad	
	26	67108864	4000000				xfactor_bad	
	27	134217728	8000000	rare_power_bad	coherent_power_bad	no_geolocation_bad	rare_power_bad	
	28	268435456	10000000	rare_phase_bad		medium_phase_bad		
	29	536870912	20000000	tvp_bad	tvp_bad	tvp_bad	tvp_bad	tvp_bad
	30	1073741824	40000000	sc_event_bad	sc_event_bad	sc_event_bad	sc_event_bad	sc_event_bad
	31	2147483648	80000000	large_karin_gap	large_karin_gap	large_karin_gap	large_karin_gap	large_karin_gap



PIXC Quality Bit Flag Rates: geolocation_qual

geoloc_qual:

	ALL PIXELS	OPEN WATER	EDGE WATER	DARK WATER	EDGE LAND	LAND
p_good(%)	28.252806	86.835646	76.255881	0.000000	0.000000	0.000000
p_sus(%)	66.263820	7.434406	18.915089	93.948971	94.810313	94.569501
p_deg(%)	4.695898	4.738553	4.213129	5.847808	4.380040	4.589084
p_bad(%)	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
N_tot	953300.000000	188623.000000	107972.000000	120558.000000	93127.000000	404438.000000
p_0xeff8(%)	4.358859	4.161210	4.776238	5.355099	4.647417	3.939788
p_0xeffb(%)	8.175810	5.649364	7.990034	6.769356	10.367563	8.823602
layover_significant	3.942201	1.557074	3.370318	1.503011	5.986449	5.072965
phase_noise_suspect	0.041855	0.002121	0.003705	0.000000	0.000000	0.000000
phase_unwrapping_suspect	68.341550	3.467764	14.533398	100.000000	100.000000	100.000000
model_dry_tropo_cor_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
model_wet_tropo_cor_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
iono_cor_gim_ka_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
xovercal_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
medium_phase_suspect	0.544530	0.004241	0.012966	0.306077	3.415766	0.372369
tvp_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_suspect	4.358859	4.161210	4.776238	5.355099	4.647417	3.939788
small_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
specular_ringing_degraded	1.778978	1.833287	1.194754	3.278920	1.402386	1.578981
model_dry_tropo_cor_missing	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
model_wet_tropo_cor_missing	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
iono_cor_gim_ka_missing	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
xovercal_missing	3.796811	4.059420	3.728744	2.806948	3.897903	3.923222
geolocation_is_from_refloc	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
no_geolocation_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
medium_phase_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
tvp_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_bad	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
large_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

PIXC Quality Bit Flag Rates: classification_qual

class_qual:

	ALL PIXELS	OPEN WATER	EDGE WATER	DARK WATER	EDGE LAND	LAND
p_good(%)	56.408791	65.460734	23.279183	61.339770	80.549143	56.656892
p_sus(%)	41.273786	32.005641	75.137999	35.495778	17.457880	41.157112
p_deg(%)	1.529949	1.542230	0.966917	2.961230	1.183330	1.344582
p_bad(%)	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
N_tot	953300.000000	188623.000000	107972.000000	120558.000000	93127.000000	404438.000000
p_0xfff0(%)	11.023812	5.985484	7.709406	13.371987	11.478948	11.994916
p_0xfff1(%)	24.525753	7.960853	9.790501	29.801423	15.430541	35.349794
no_coherent_gain	21.224798	3.957100	5.364354	26.364074	11.519753	32.796621
power_close_to_noise_floor	8.271058	0.000000	0.000000	13.177060	2.686654	14.949139
detected_water_but_no_prior_water	15.981643	27.653043	74.778646	0.000000	0.000000	0.000000
detected_water_but_bright_land	0.786636	0.746463	3.120253	0.000000	0.000000	0.000000
water_false_detection_rate_suspect	0.010280	0.020146	0.055570	0.000000	0.000000	0.000000
coherent_power_suspect	7.241372	1.944620	3.198051	8.834752	7.371654	8.805305
tvp_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_suspect	4.358859	4.161210	4.776238	5.355099	4.647417	3.939788
small_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
in_air_pixel_degraded	0.000105	0.000000	0.000000	0.000000	0.000000	0.000247
specular_ringing_degraded	1.529844	1.542230	0.966917	2.961230	1.183330	1.344335
coherent_power_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
tvp_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_bad	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
large_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

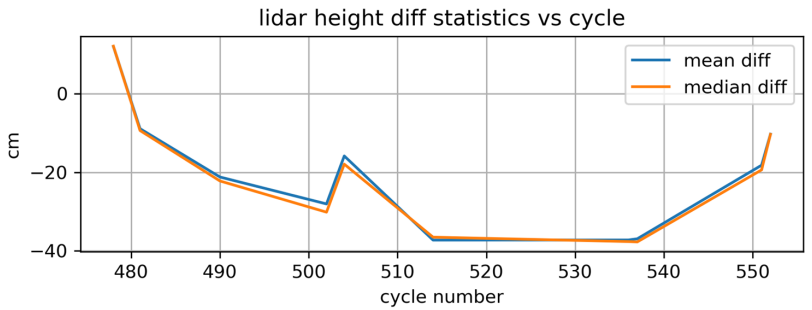
PIXC Quality Bit Flag Rates: sig0_qual

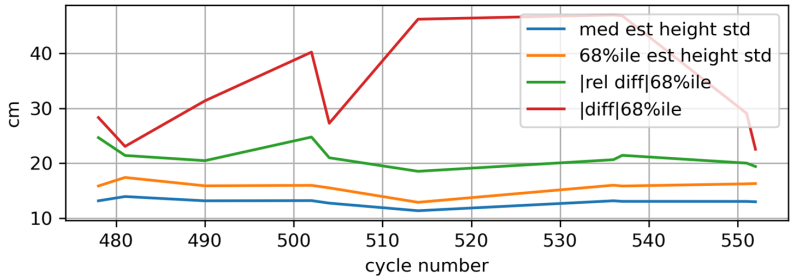
sig0_qual:

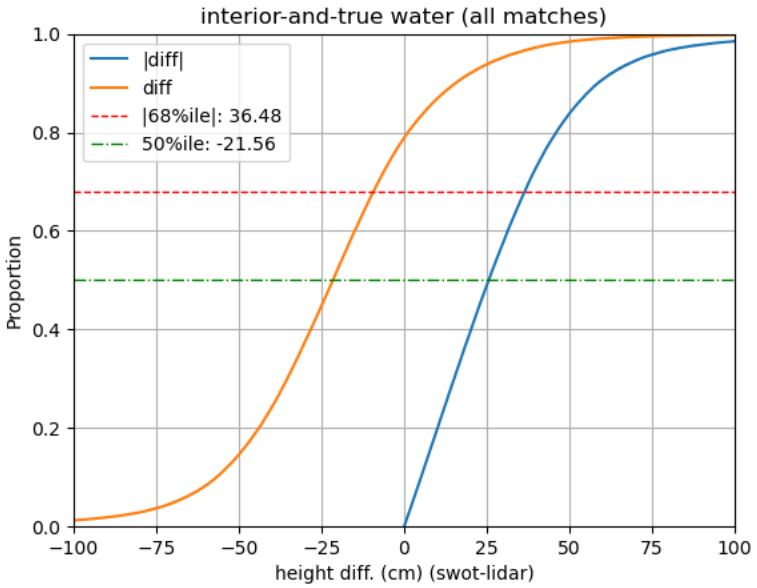
	ALL PIXELS	OPEN WATER	EDGE WATER	DARK WATER	EDGE LAND	LAND
p_good(%)	92.583342	93.400063	93.695588	90.281027	93.214642	92.452242
p_sus(%)	5.099234	4.066312	4.721594	6.554521	4.792380	5.361761
p_deg(%)	1.529949	1.542230	0.966917	2.961230	1.183330	1.344582
p_bad(%)	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
N_tot	953300.000000	188623.000000	107972.000000	120558.000000	93127.000000	404438.000000
p_0x1ffffff(%)	6.630022	5.608542	5.688512	9.515752	5.976784	6.708074
sig0_uncert_suspect	0.845589	0.000000	0.000000	1.471491	0.217982	1.504310
sig0_cor_atmos_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
noise_power_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
xfactor_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
rare_power_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
tvp_suspect	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_suspect	4.358859	4.161210	4.776238	5.355099	4.647417	3.939788
small_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
in_air_pixel_degraded	0.000105	0.000000	0.000000	0.000000	0.000000	0.000247
specular_ringing_degraded	1.529844	1.542230	0.966917	2.961230	1.183330	1.344335
sig0_cor_atmos_missing	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
noise_power_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
xfactor_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
rare_power_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
tvp_bad	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
sc_event_bad	0.787475	0.991396	0.615900	0.203222	0.809647	0.841415
large_karin_gap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

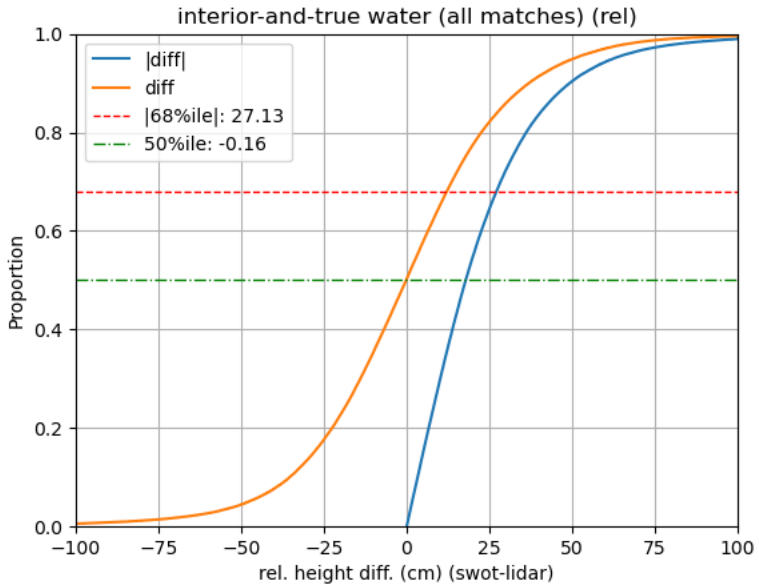
Waimakariri River

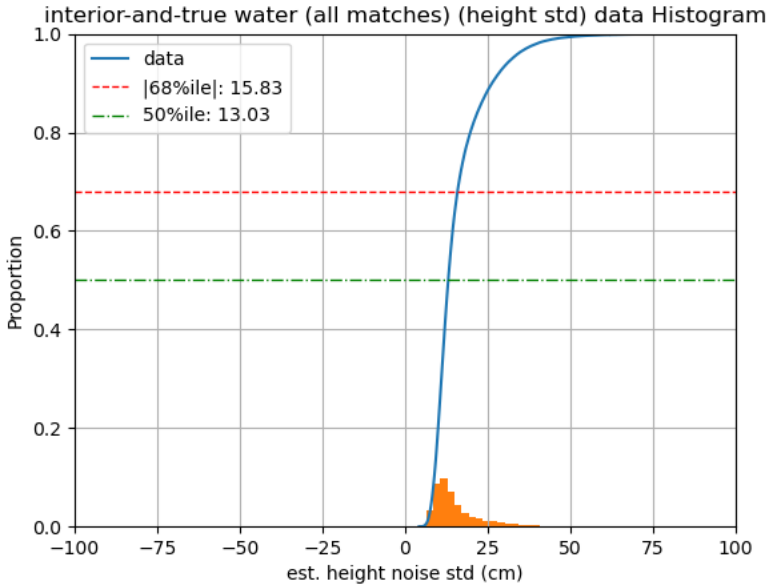
- Lidar comparison over time
  - 10 of the 11 collection days
    - data was not available, but probably is now
  - Some days compared to multiple closest swot observations (a few are more than a day)
  - Comparison details
    - 5m water fraction masks projected into slant plane using corresponding 5m lidar DEMs
    - Using only trusted SWOT quality pixels (geolocation_qual<=4)
    - Using only interior water class and projected water-frac=1
  - Each match has its own bias, but relatively consistent
  - “rel” is with taking out a -21.4 cm bias
  - pixel-wise differences of ~20-30cm are ~2x expectations for random noise







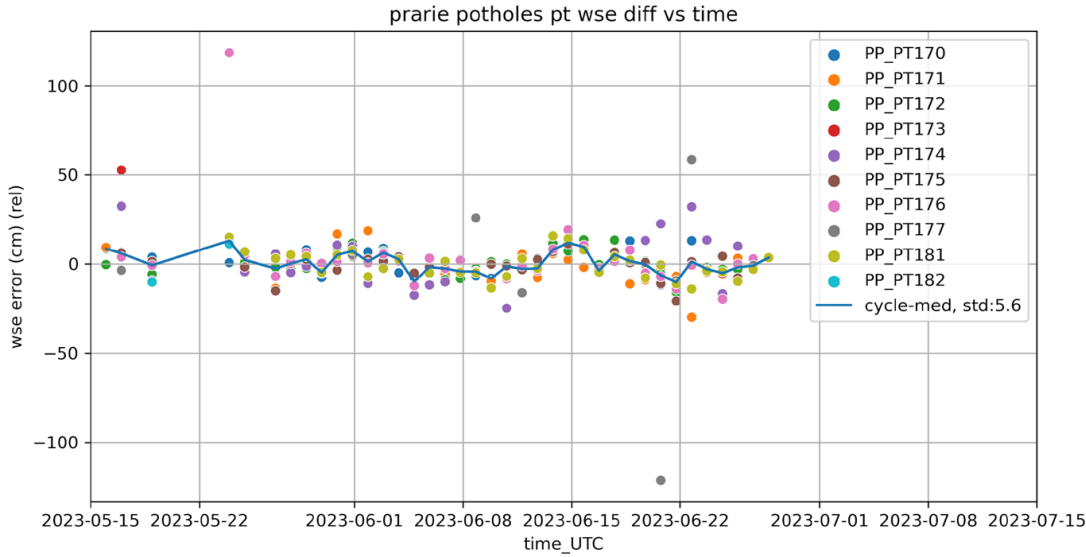


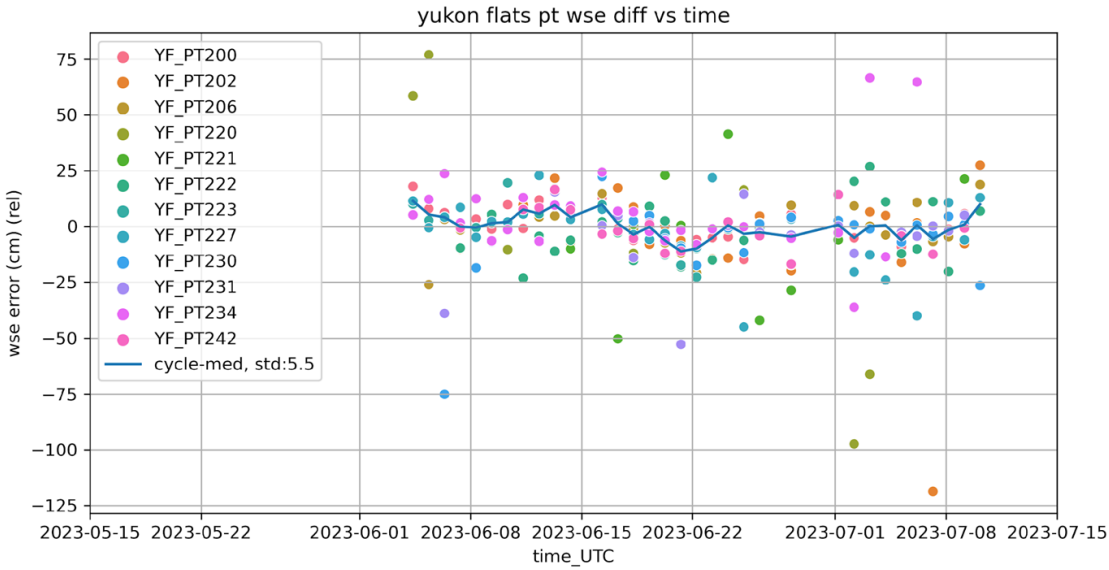


PT WSE Diff: Temporal Undulation O(5 cm)

- Apparent systematic error of relative WSE diff
  - Undulates over time
  - Seems consistent among all the PTs in a site
  - This signal is in SWOT but not the PT hydrographs
- Focus on Prairie Potholes (PP) and Yukon Flats (YF) Lakes (N slope)
  - PTs are widely distributed in cross-track
  - Details differ at the two sites, but magnitude of variation is similar (~5.5 cm std over time)
- This systematic error will not reduce with greater spatial aggregation (e.g., river node/reach or entire lake scales)
- Is there a potential to calibrate it out?
  - Using lakes or trusted gauge network data?
  - Possibly related the residual crossover signal?

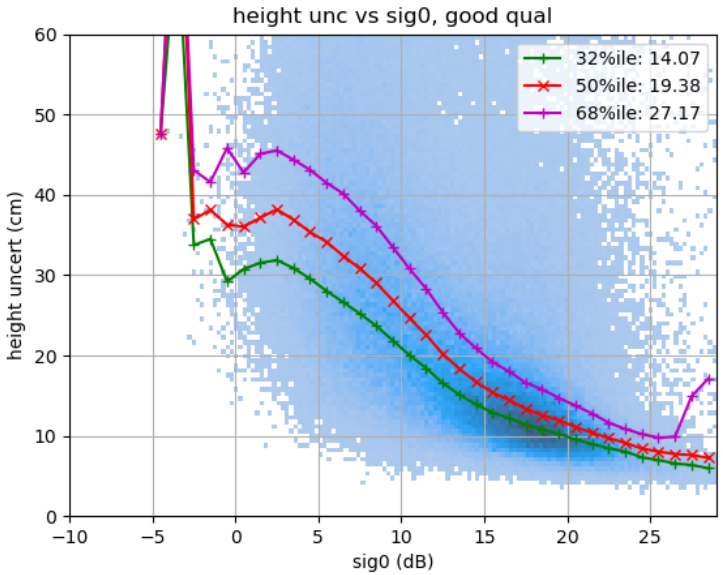
- Plots on the right are generated with the following logic:
  - For each SWOT/PT match
    - Take out median wse difference for each PT (e.g., rel.WSE diff)
    - Spatially aggregate the PIXC pixels around each PT for each cycle by taking the median (with 8 pixels of PT, ~400m resolution)
    - Plot vs cycle/time for each PT in the PP or YF sites (colored dots)
    - Take median over all PTs in a given site (blue line)
    - Take the std to get the 1-sigma spread of the undulation

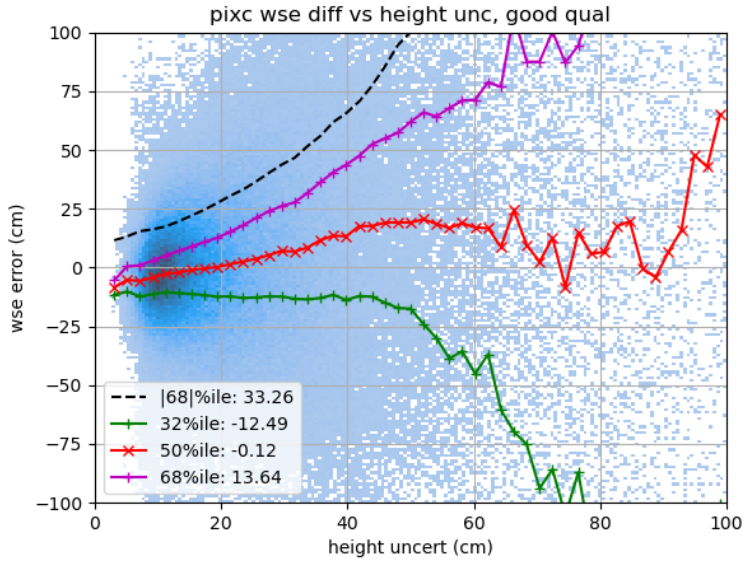


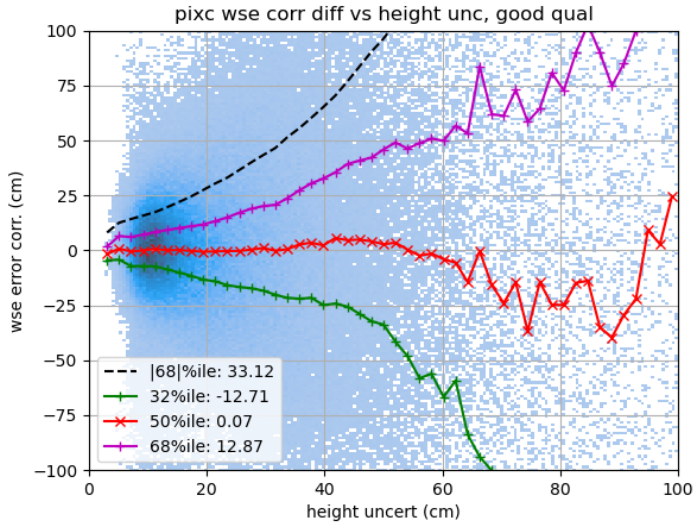


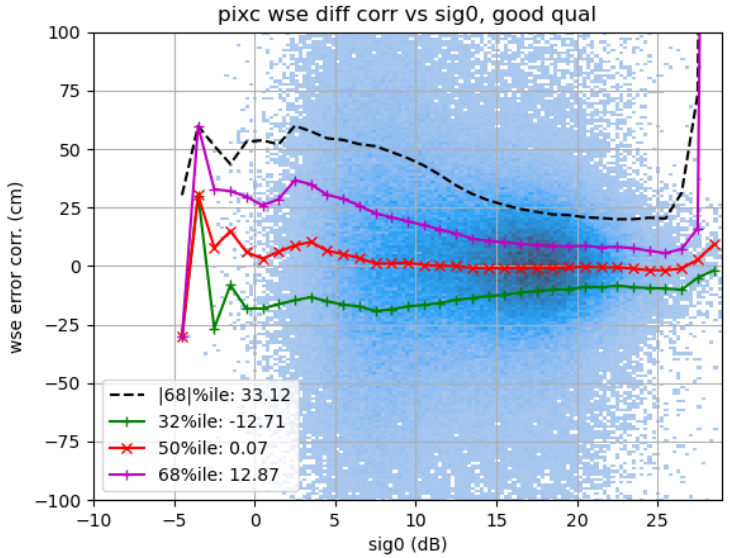
PT WSE Diff: Estimated Random Uncertainties

- Random height errors from phase
  - Partially-validated per-pixel estimate in product: “height_uncert”
  - Varies with brightness between ~(7 - 40cm)
  - Bias a function of height uncert (or sig0)?
    - Could be partially due to layover systematic component
    - Potential for an empirical bias correction (bottom right two plots)
    - Needs more investigation
  - Aggregates down
    - <1/sqrt(n) since pixels are slightly correlated due to adaptive multilooking









HR Algorithm Flow