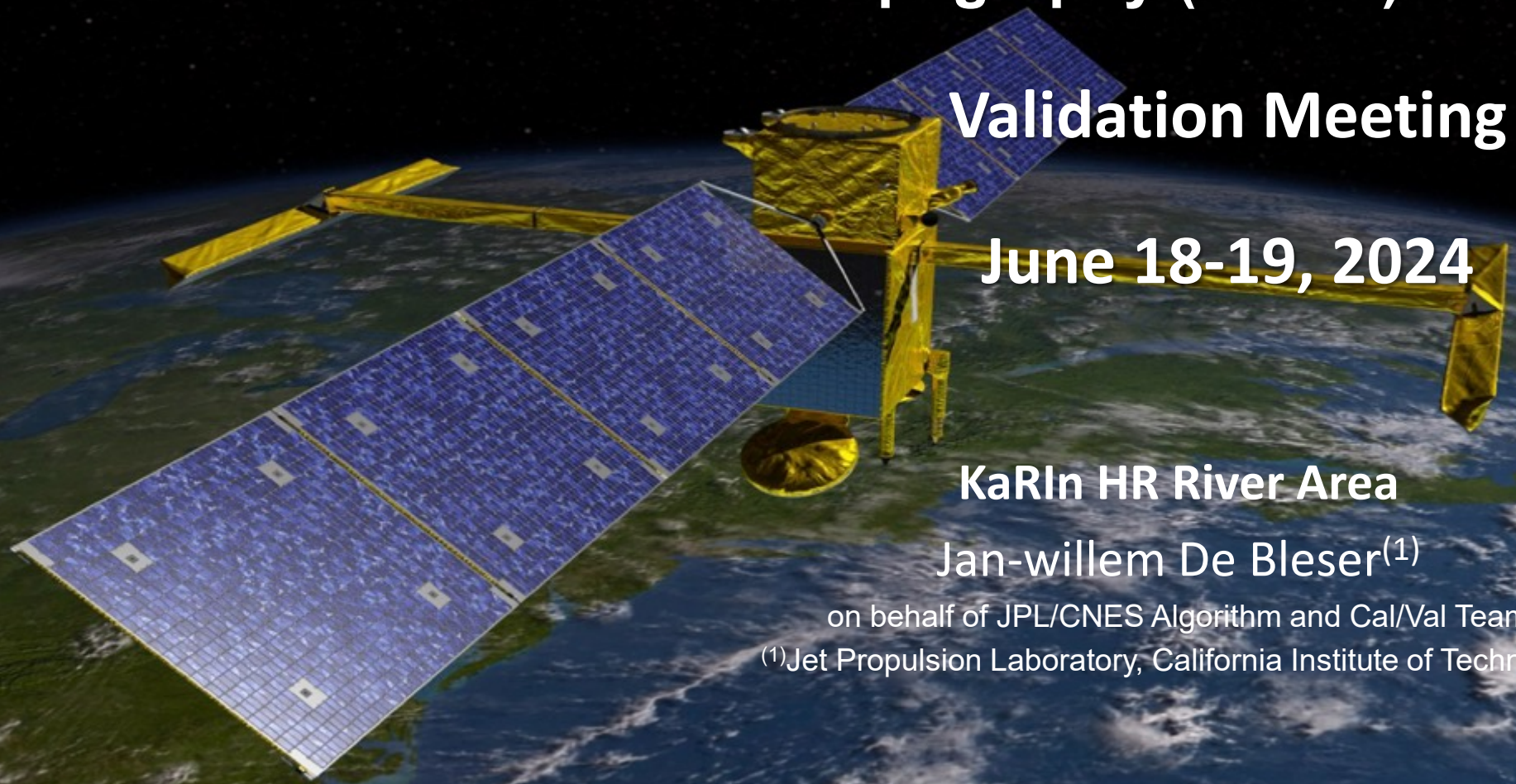
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Surface Water and Ocean Topography (SWOT) Mission

Validation Meeting

June 18-19, 2024



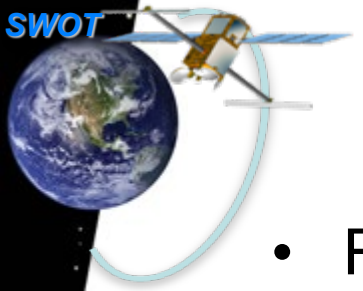
KaRIn HR River Area

Jan-willem De Bleser[1]

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

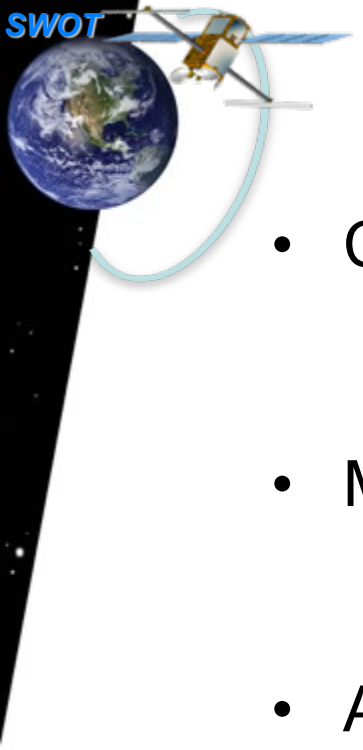
[1]Jet Propulsion Laboratory, California Institute of Technology

URS 326092/CL#24-3173



Outline

- River area validation approach
- Performance statistics by site
  - For Version C data and for offline run with development processing
  - Major issues affecting performance statistics
- Common features and issues affecting river area.

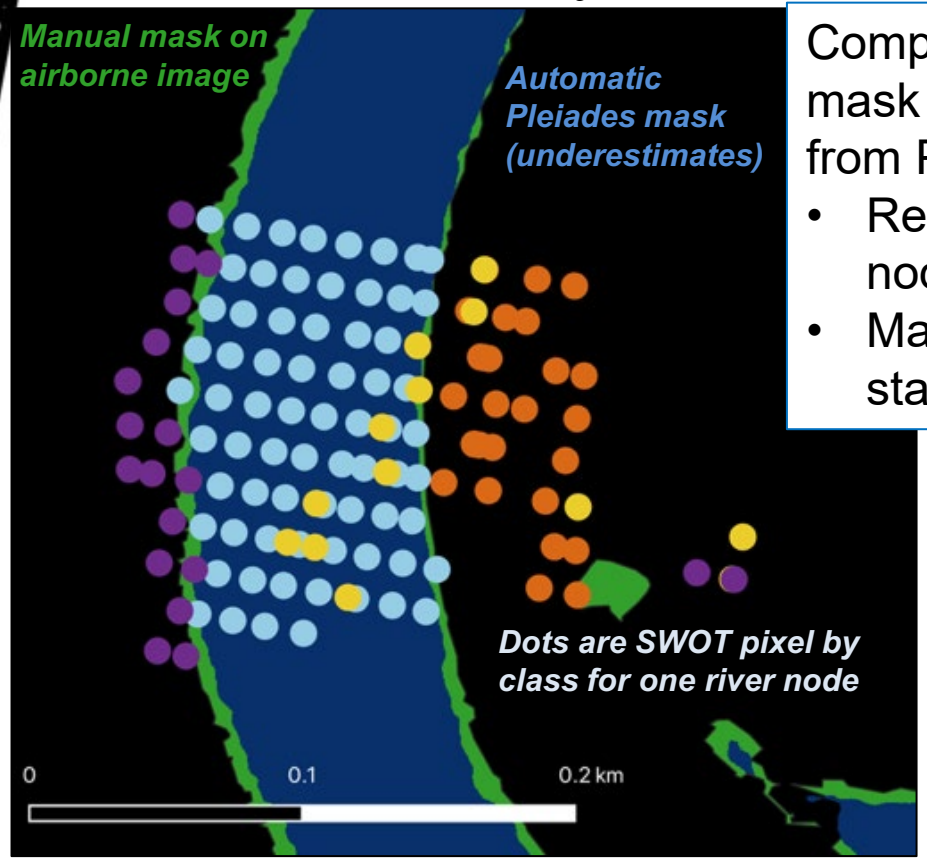


River Area Validation Approach

- Compare to water masks derived from optical imagery
  - Primarily 4-band aerial imagery (Pléiades, Planet imagery also considered)
  - One hand-drawn mask, others automatically classified.
- Map water masks to SWORD reaches and nodes with RiverObs
  - Consequence: Issues related to SWORD may affect widths from optical masks as well
- Assess performance for both SWOT Version C data and offline processing with development software and parameters
- For now, prioritize depth of analysis rather rather than breadth
  - We already know that classification and pixel assignment are challenging given highly varied river and radar phenomenology
  - Want to not only *characterize* SWOT performance but *improve* it by making algorithms more capable
  - Start by looking at limited number of sites with high-quality water masks to understand why SWOT performance is what it is and how to make it better

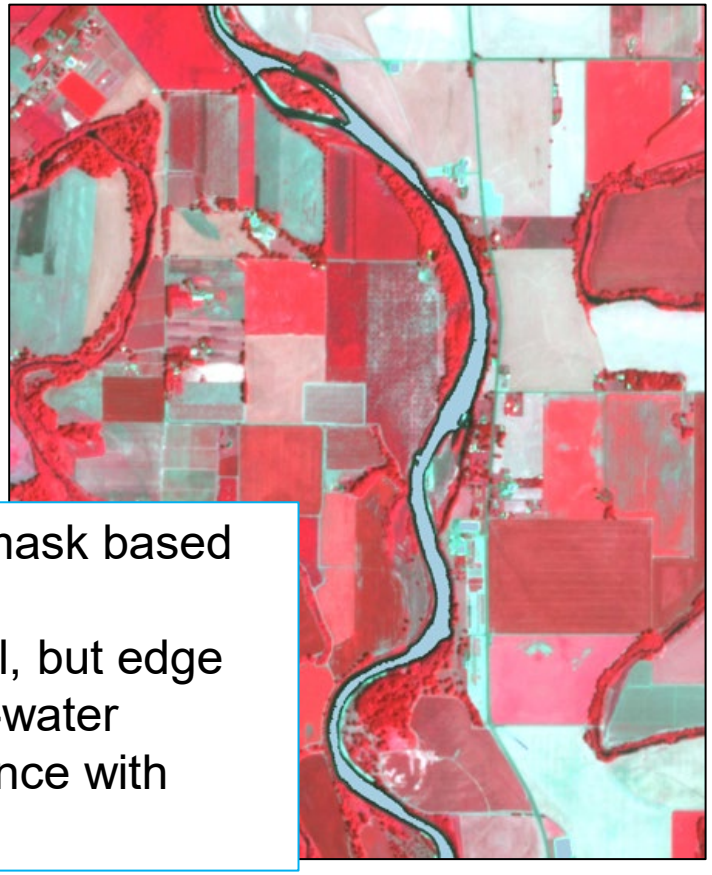
Water Mask Generation From Optical Imagery

- Classification accuracy of optical imagery can limit ability to validate SWOT
  - Hand-drawn mask is most reliable (but labor intensive)
  - Use neural-network classifier on airborne imagery, tuned to best match the manually drawn mask



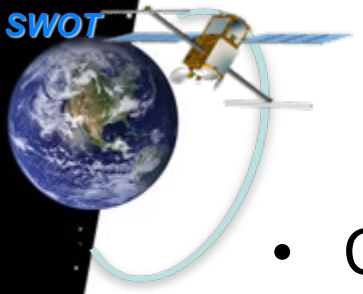
Comparison of manual Willamette mask versus automatic mask from Pléiades

- Relative area difference at node level is 9%
- Masks are < 1 day apart, river stage is stable



Light blue is automatic water mask based on Planet imagery

- Open water is identified well, but edge pixels are classified as non-water
- Resulting node-level difference with manual mask is ~10%



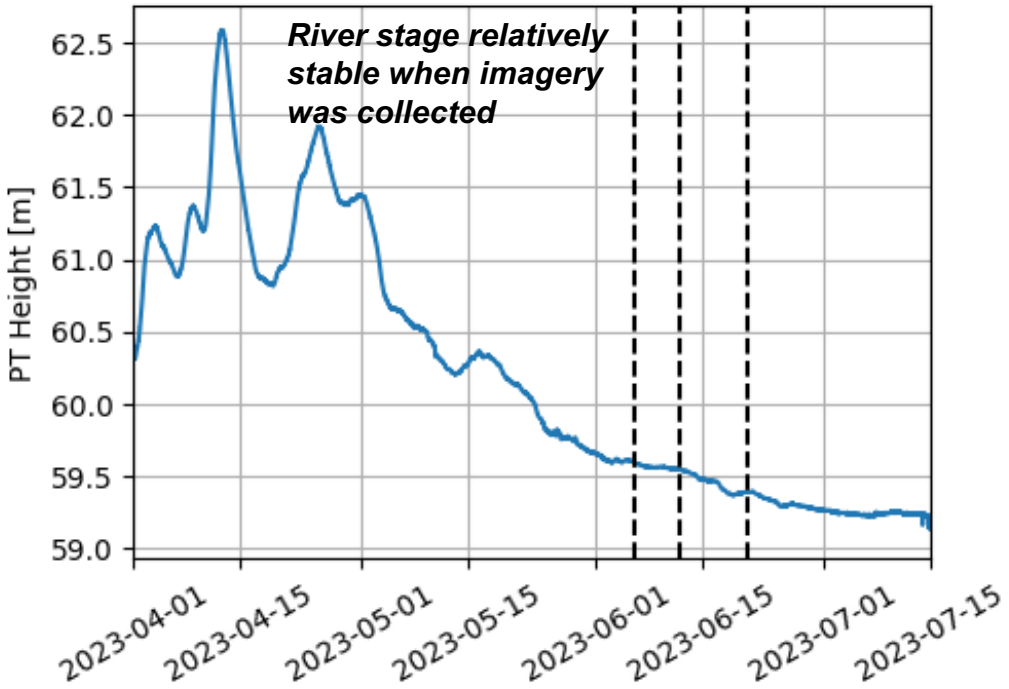
SWOT Data for Comparison

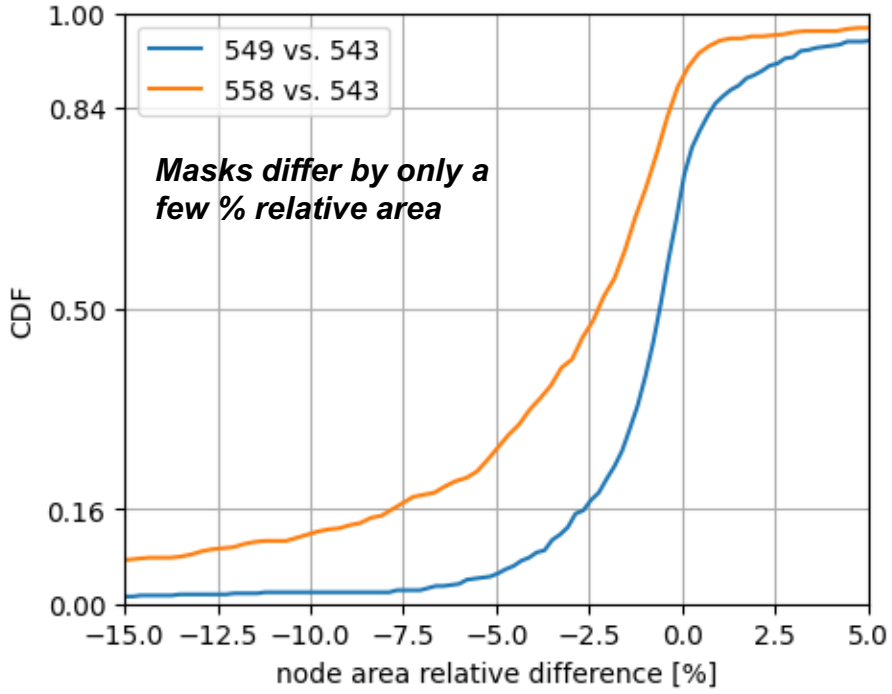
- Compare data at node level due to insufficient reach coverage for statistics
- Consider data only for:
  - Cross track from 10-60 km
  - River width >80 m
  - Quality flag does not indicate degraded or bad data
  - Reported fraction of dark water < 10%
    - Dark water is problematic for many reasons
    - When there is lots of dark water, area estimate is mostly coming from prior and not SWOT anyway
- Results for both Version C products and offline products generated with developmental software are shown in following slides

Willamette River

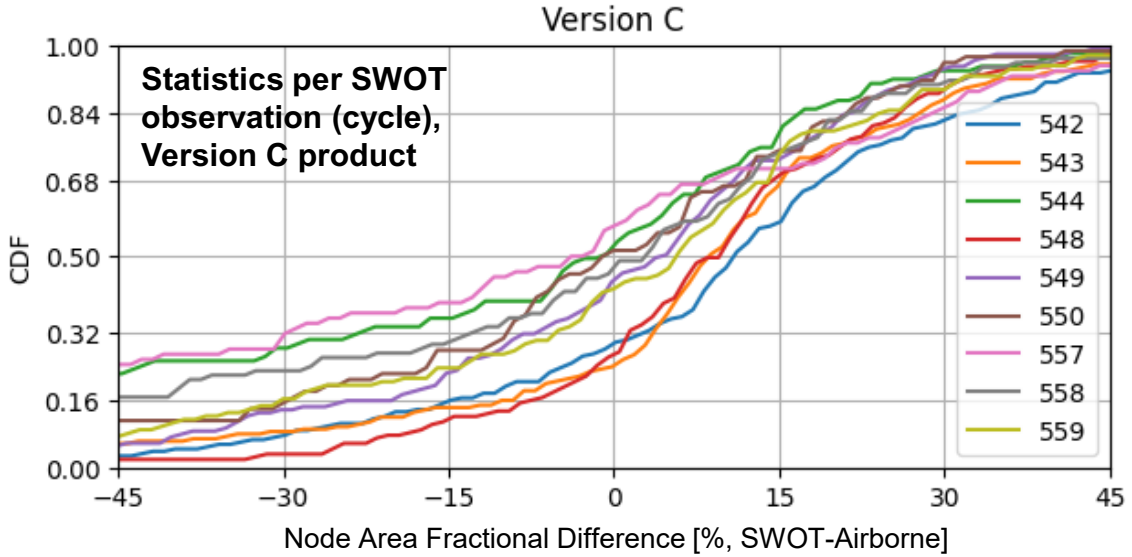
Three flights worth of airborne imagery collected for Willamette River

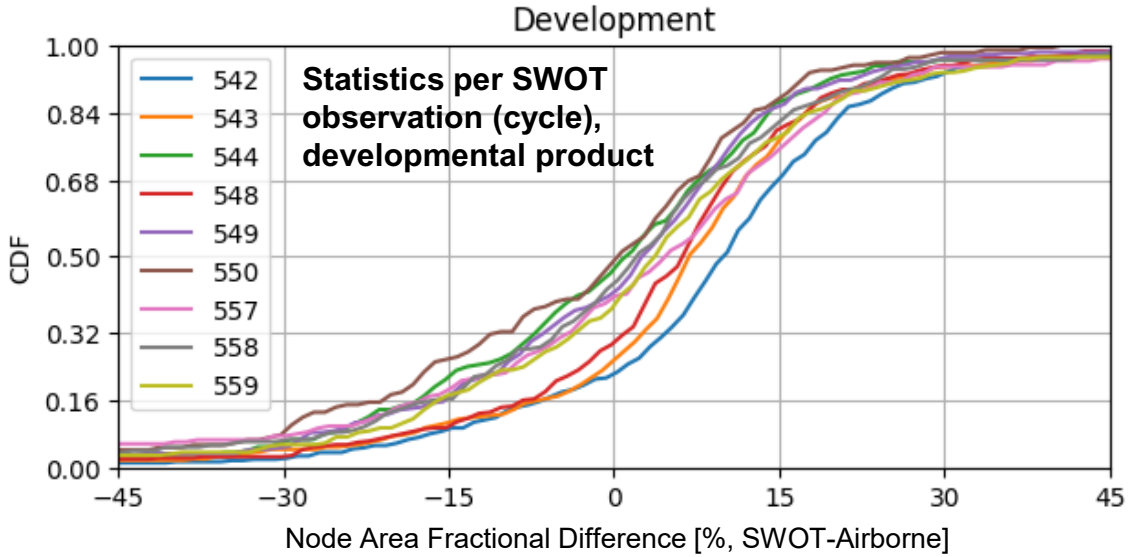
Imagery Date	SWOT Cycle	SWOT Pass/Tiles
2023-06-06	543 (cal orbit)	013_233L
2023-06-12	549 (cal orbit)	013_233L
2023-06-21	558 (cal orbit)	013_233L

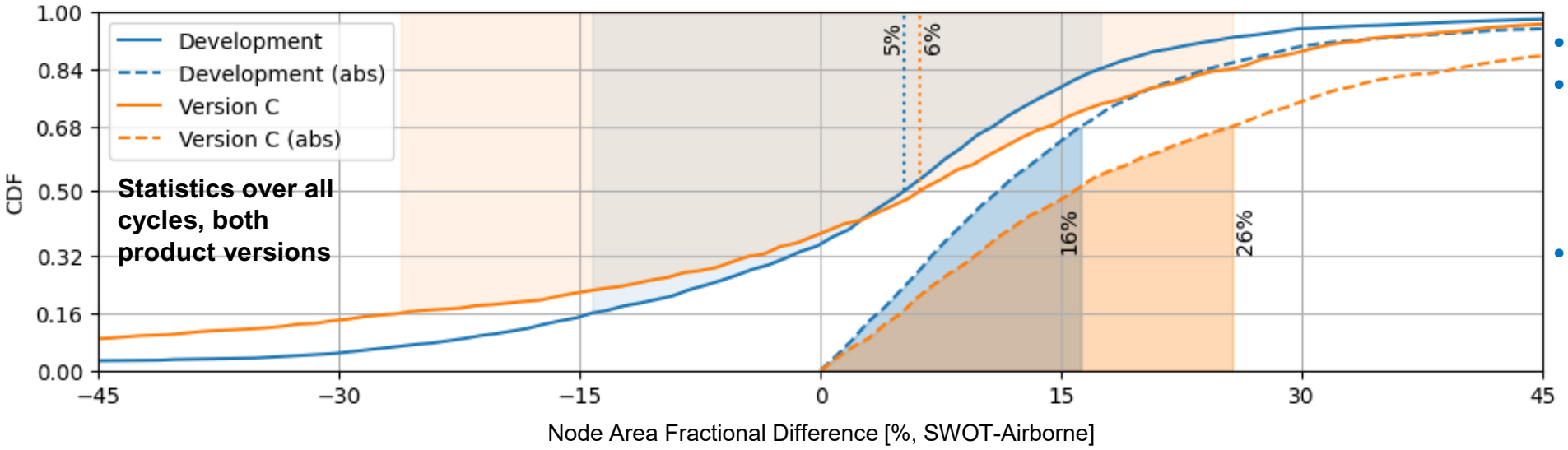




Willamette River Statistics



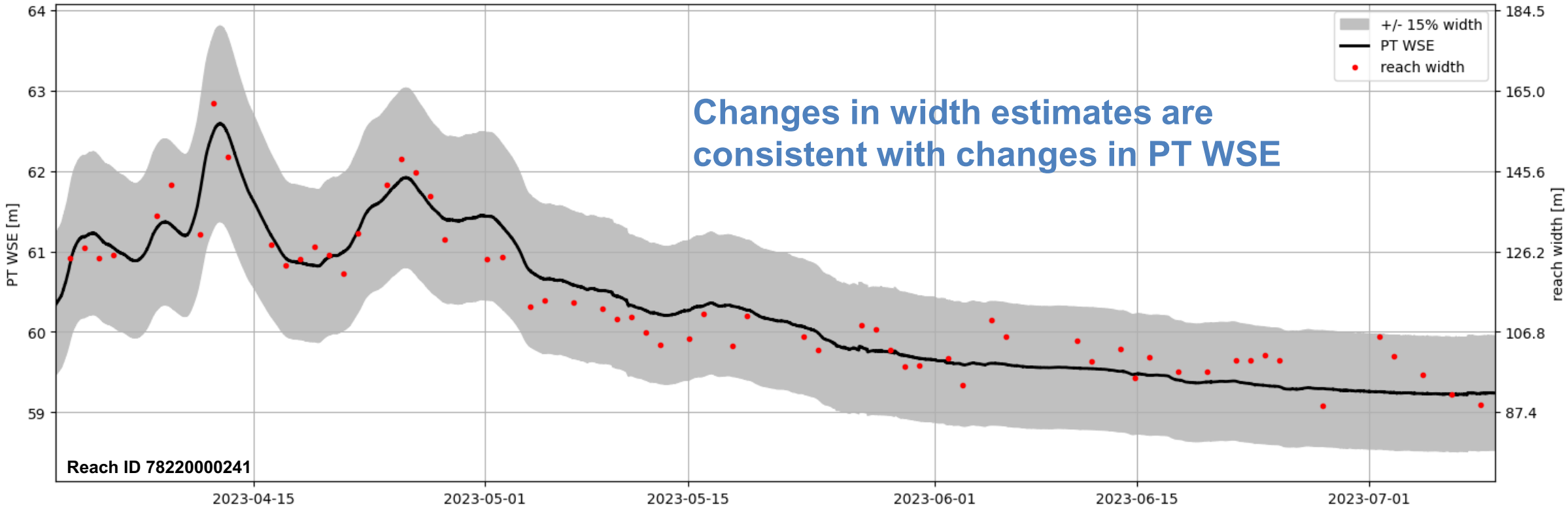




- Biases are relatively low
- Developmental version significantly reduces spread compared to Version C
- Moderate variability between different observations over ~1 month time span of data

Willamette River – Width vs Area Trends

- Plot below shows pressure transducer WSE with reach-level width estimate from SWOT overlaid
  - +/-15% width error band assumes that rating curve is linear for this range of WSEs
  - Plot spans ~3 months of data from calibration orbit (Spring 2023)

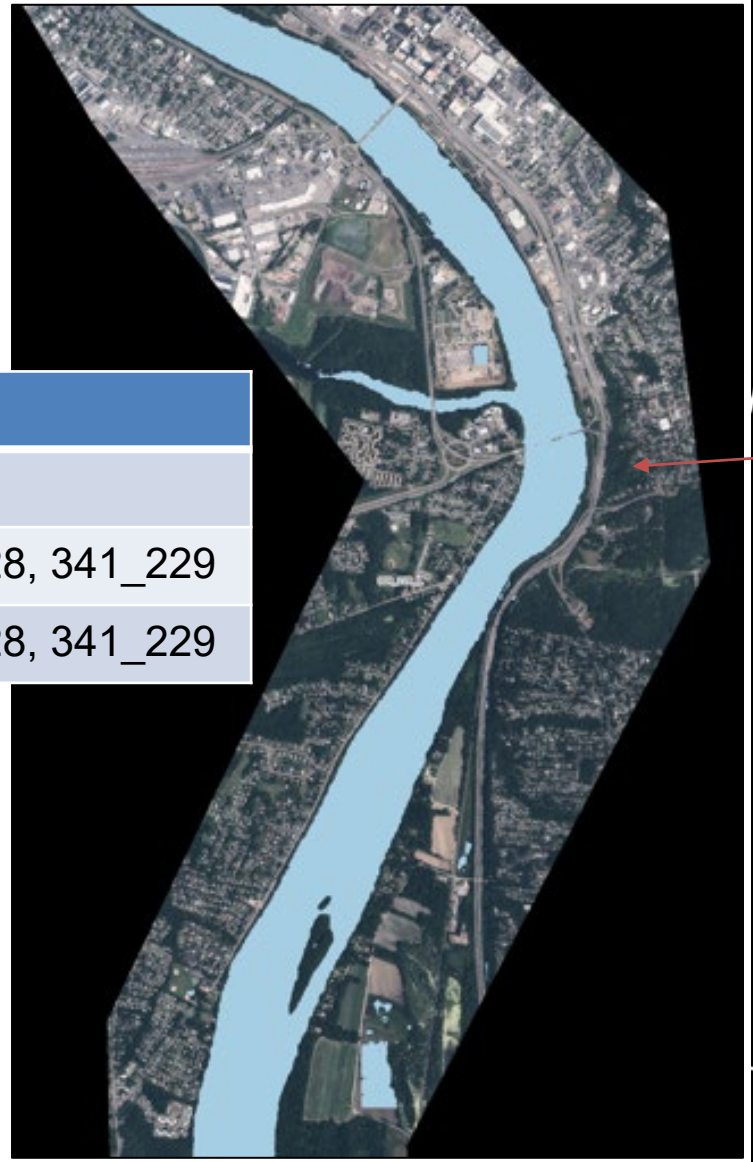


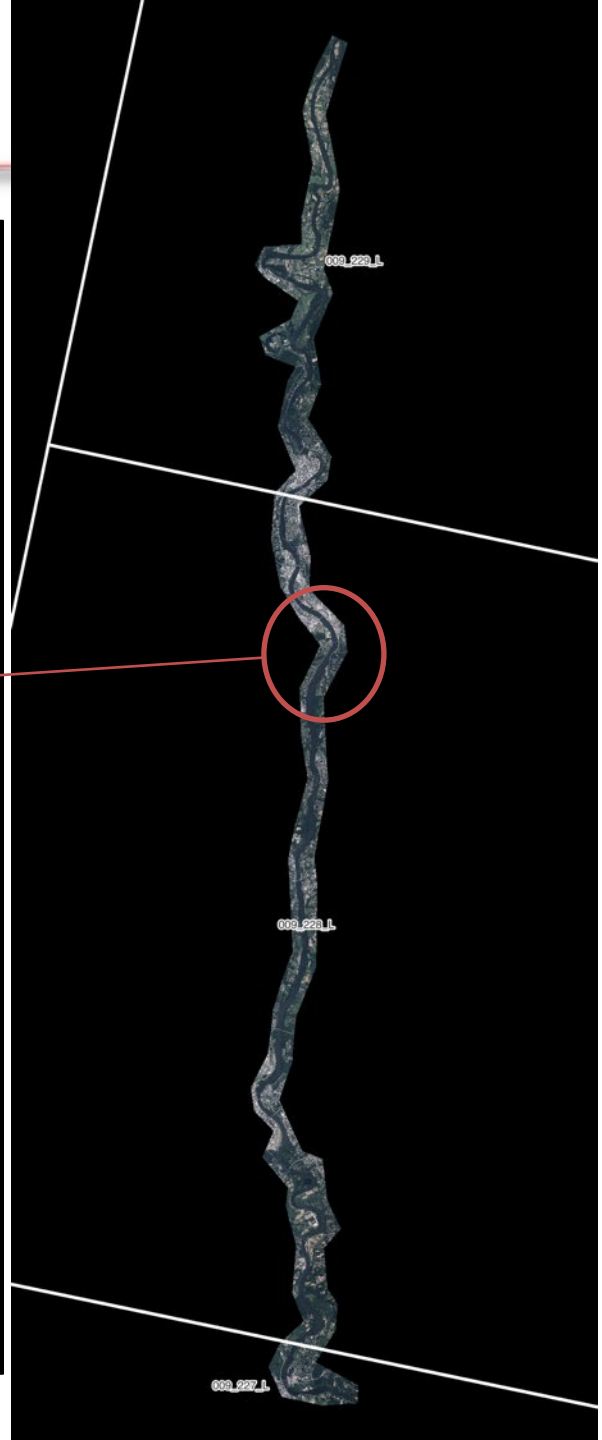
Connecticut River Masks

Three flights worth of airborne imagery collected for Connecticut River

Imagery Date	SWOT Cycle	SWOT Pass/Tiles
2023-07-06	574 (cal orbit)	009_227L to 009_229L
2024-01-15	009 (nom orbit)	298_080, 298_081, 341_228, 341_229
2024-02-05	010 (nom orbit)	298_080, 298_081, 341_228, 341_229

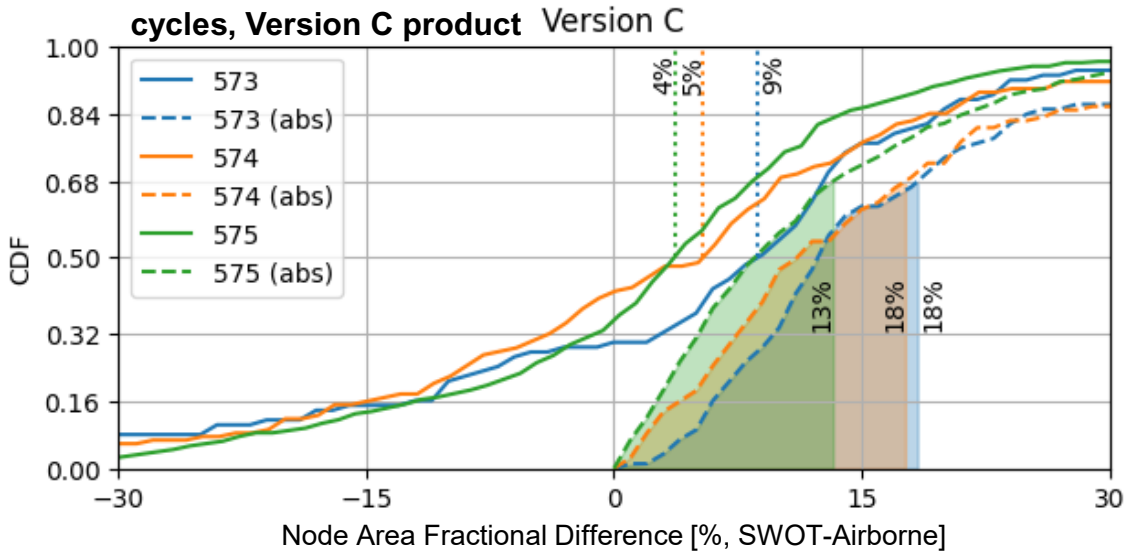
One image from summer, two images from winter



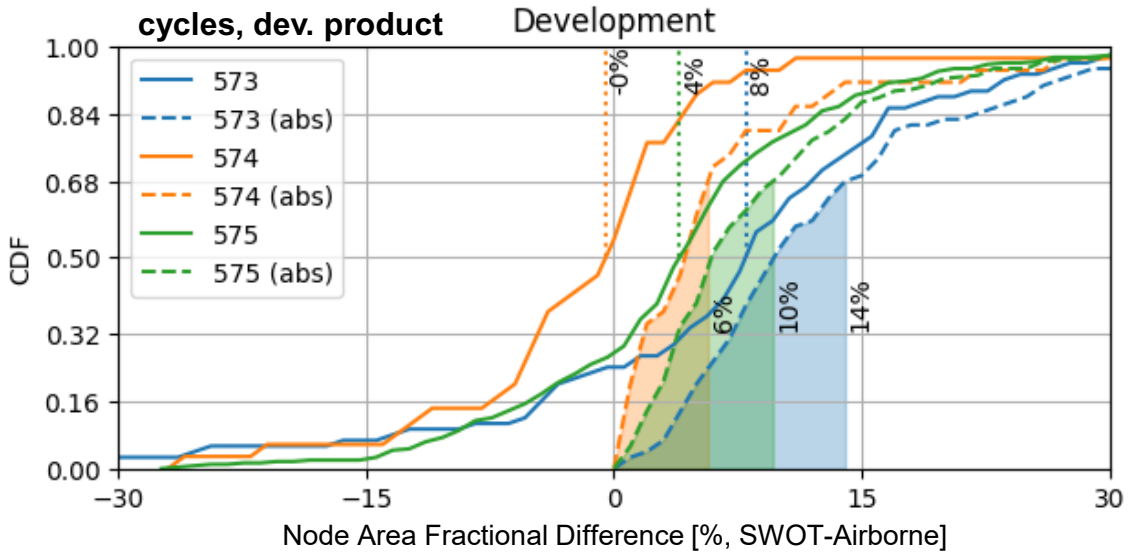


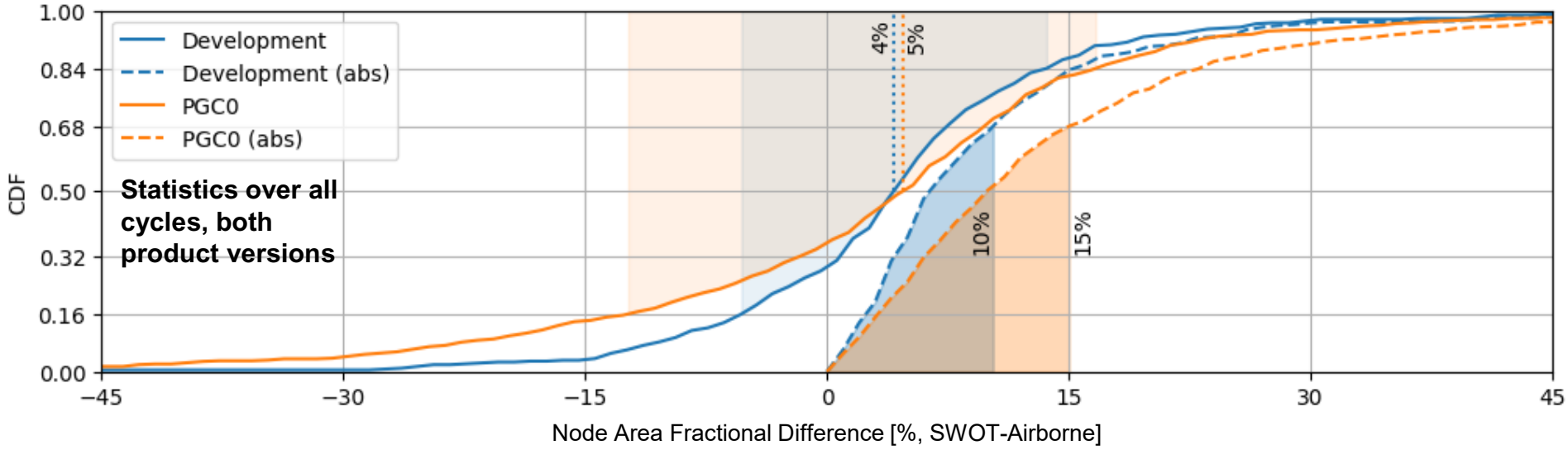
Connecticut River – Cycle 574 (Summer, Cal Orbit)

Statistics over three SWOT cycles, Version C product



Statistics over three SWOT cycles, dev. product

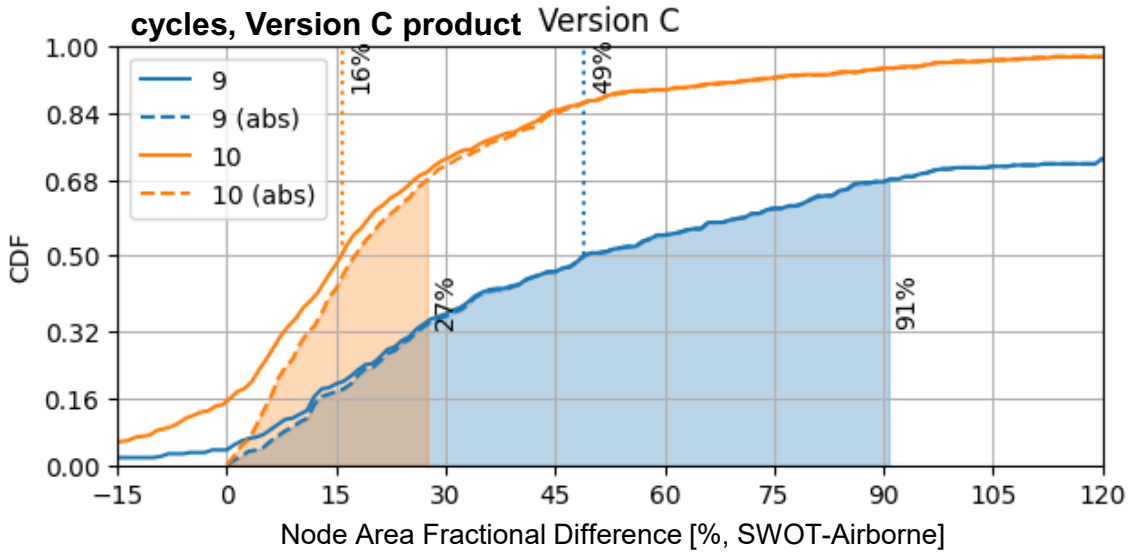




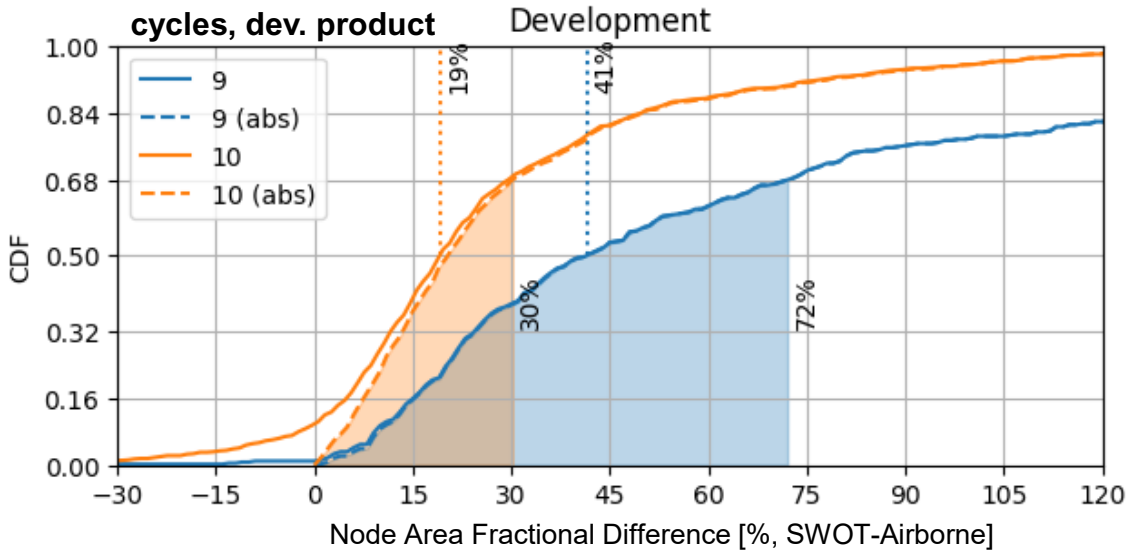
Biases are low; Spread (68th percentile) is larger for Version C than Dev, but not excessive.

Connecticut River – Cycles 009/010 (Winter, Nom Orbit)

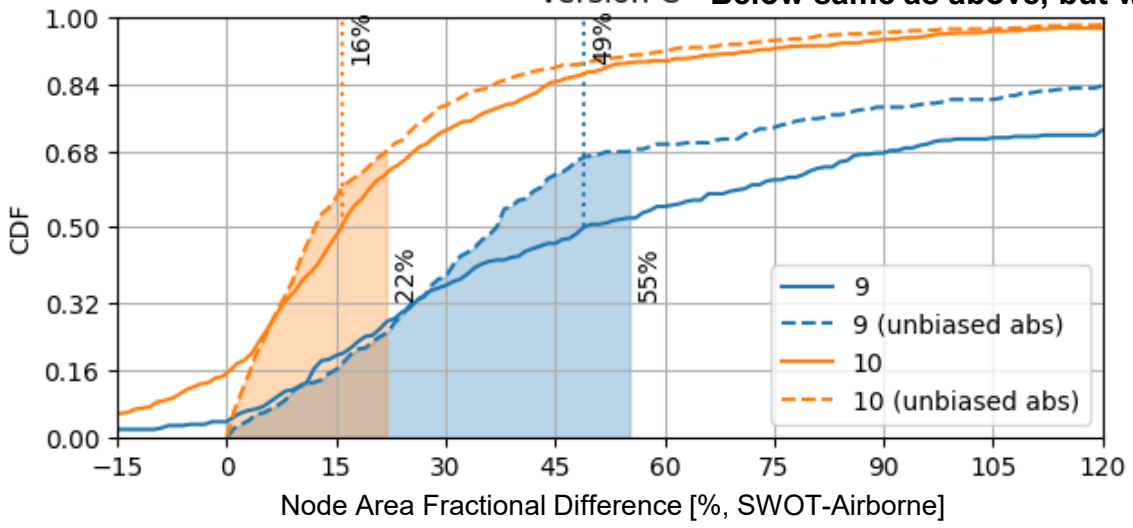
Statistics over two SWOT cycles, Version C product

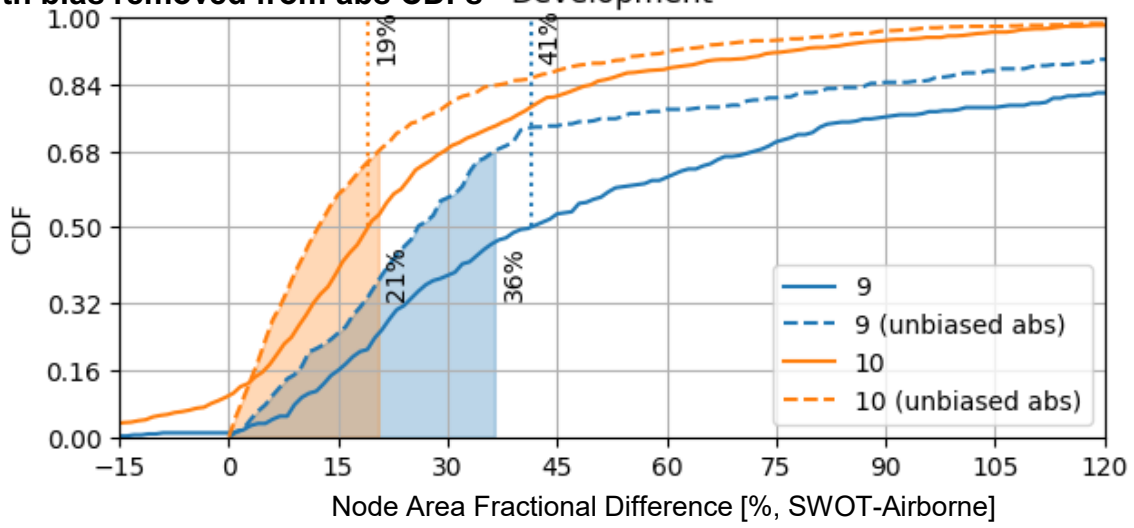


Statistics over two SWOT cycles, dev. product



Below same as above, but with bias removed from abs CDFs

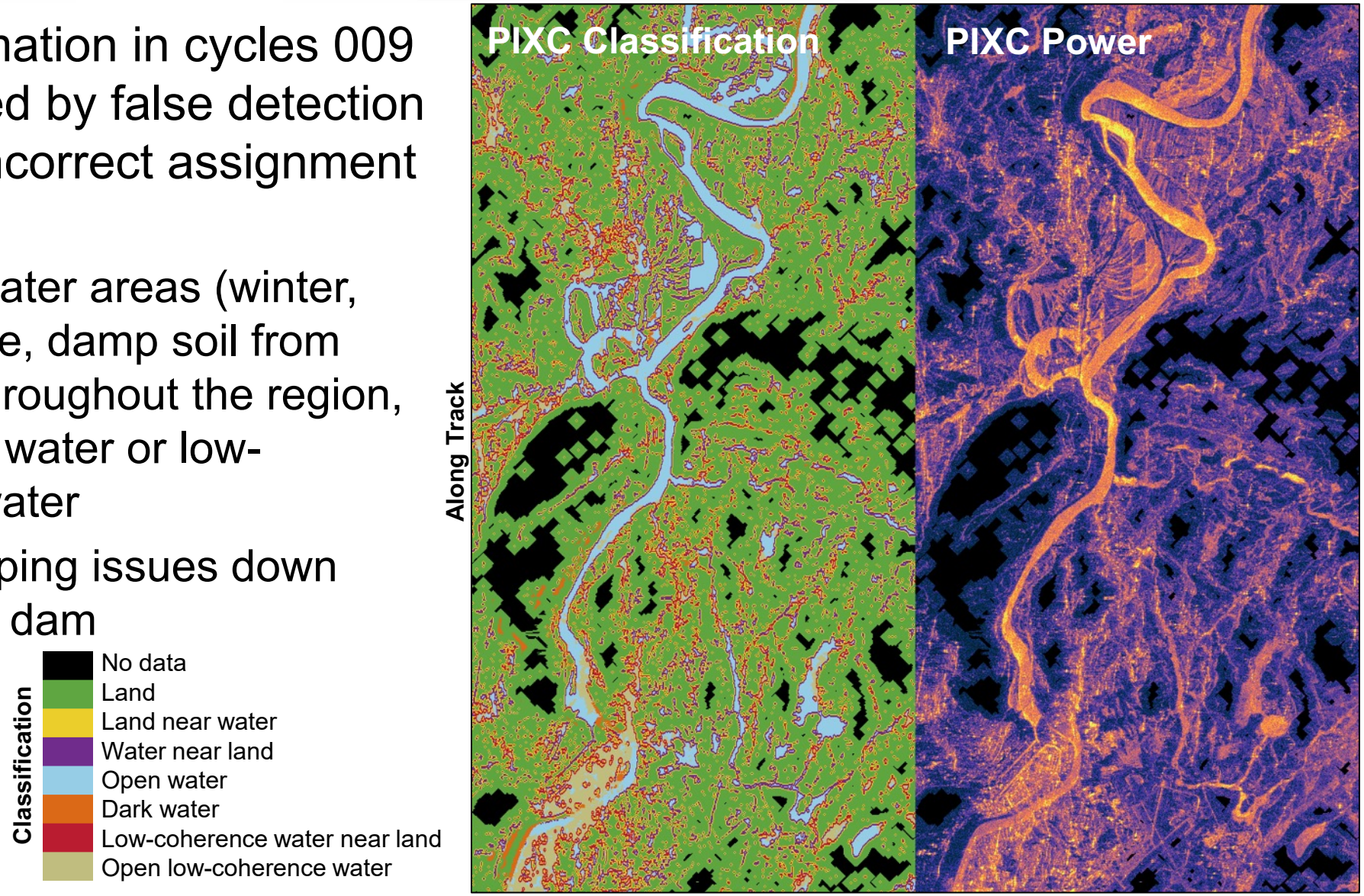




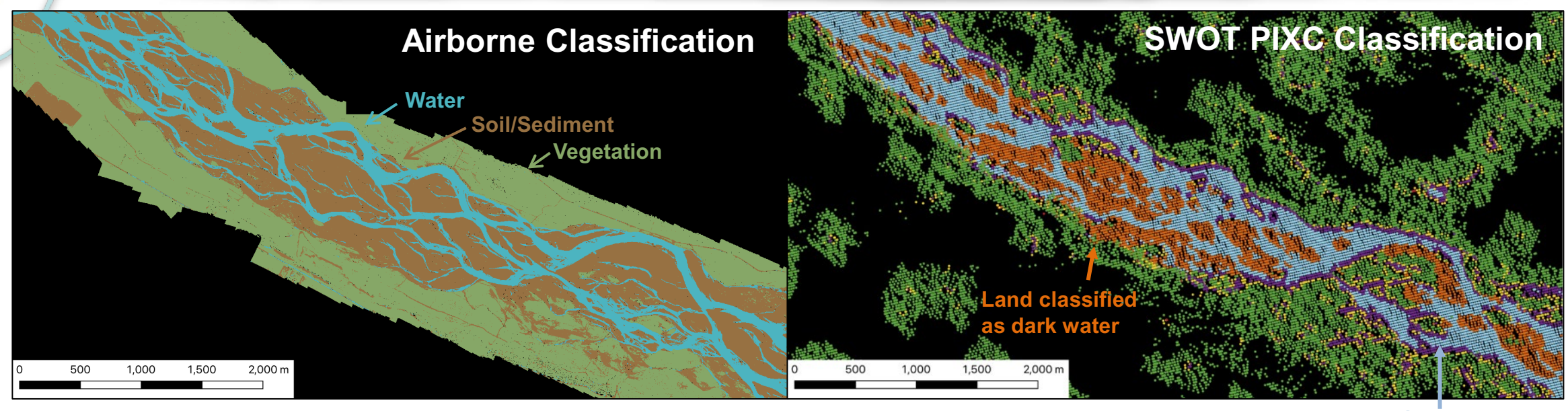
Significant bias (SWOT overestimates area) and larger spread compared to cycle 573

Connecticut River – Cycle 009/010 Details

- Area overestimation in cycles 009 and 010 caused by false detection of water and incorrect assignment to river
  - Bright non-water areas (winter, lack of foliage, damp soil from snowmelt) throughout the region, classified as water or low-coherence water
  - Also unwrapping issues down south near a dam

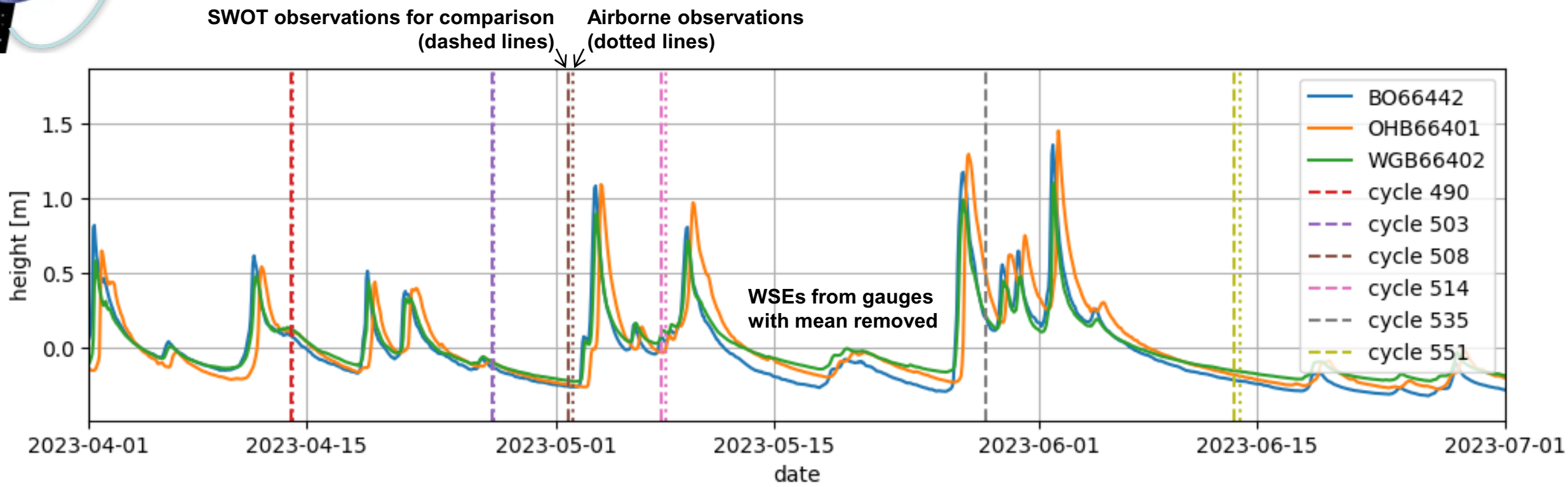


Waimakariri



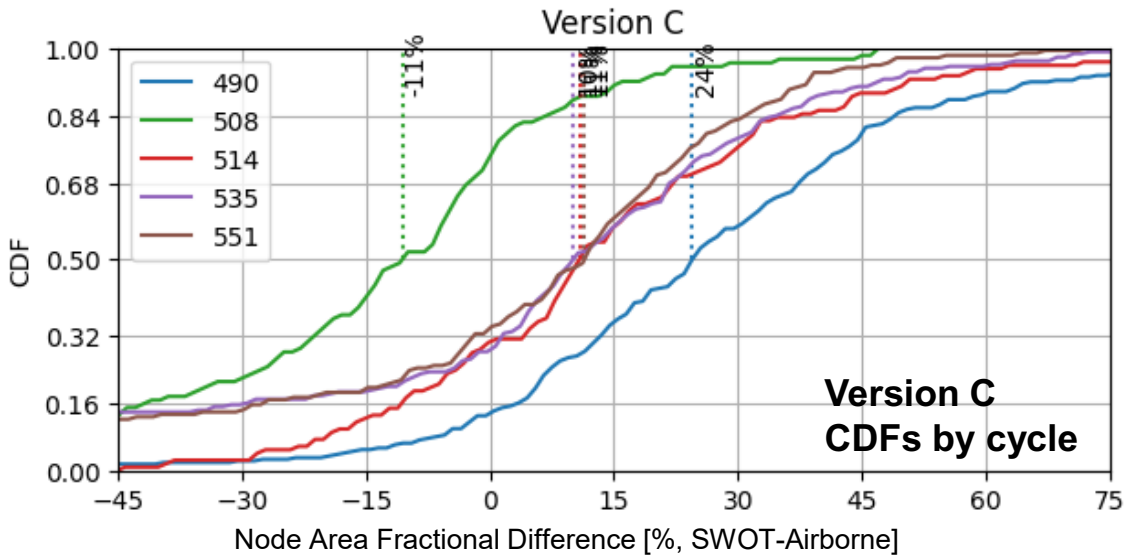
- Waimak is very challenging river for SWOT
  - Have useful water masks from five airborne flights
  - Analysis compares detected area rather than total area (i.e., special offline processing) because entire braidplain is classified as dark water
  - Because detected water is surrounded by dark water, fractional area of water-near-land pixels is not handled correctly in processing

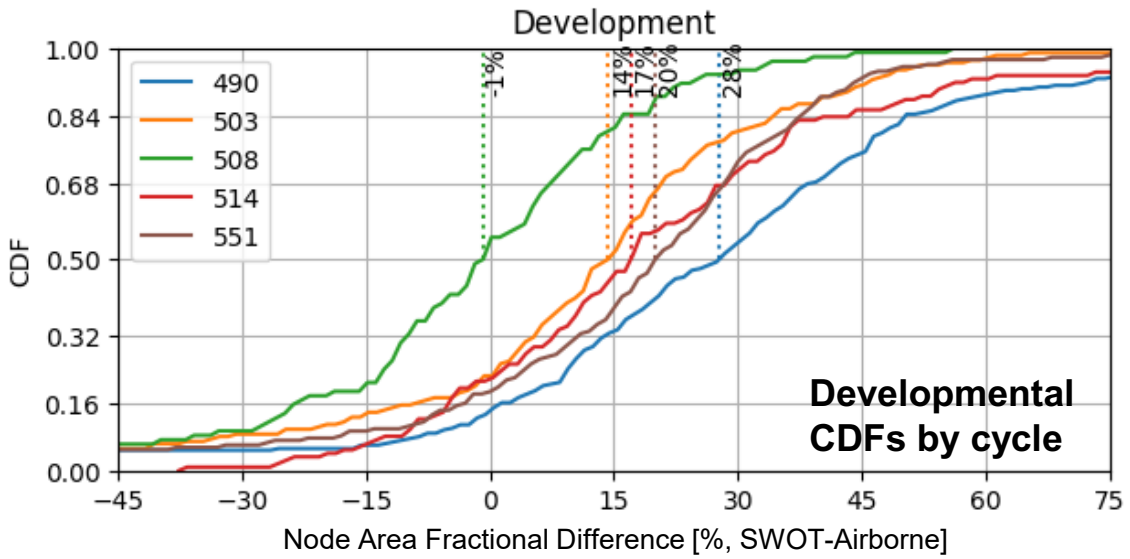
Waimakariri Data Comparison Times

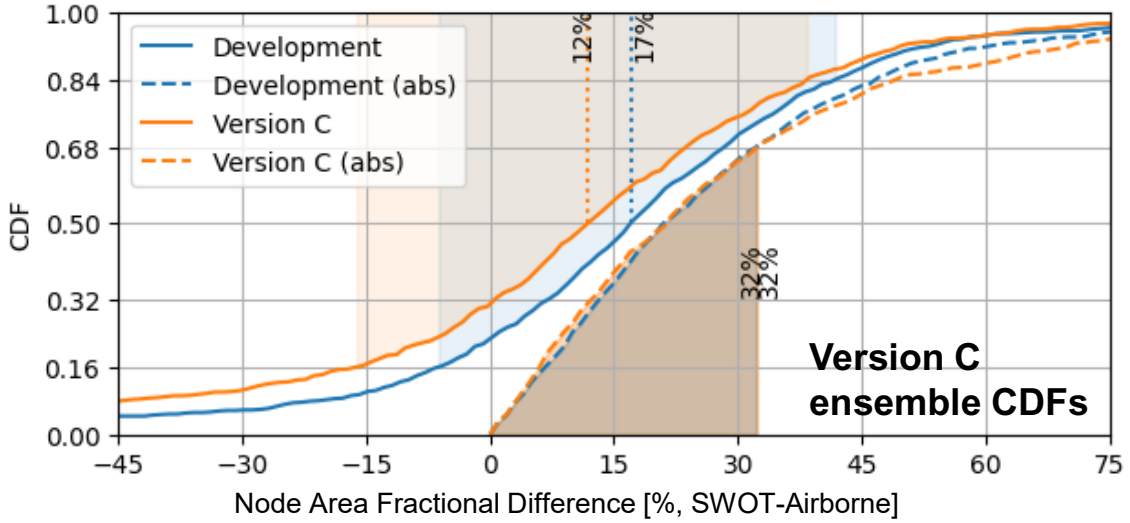


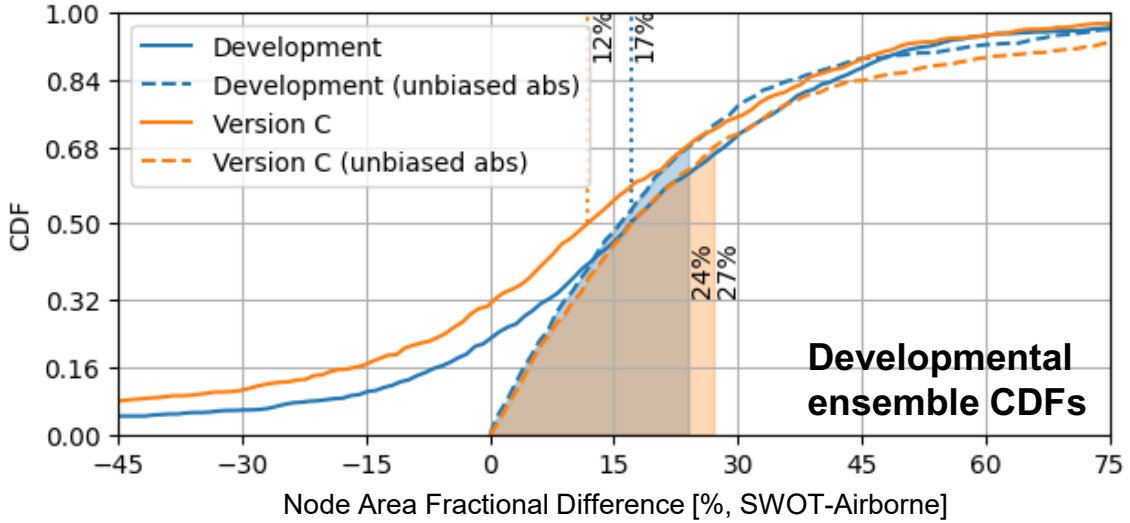
Airborne flights were within hours of SWOT observations and usually when stage was not changing *too* much

Waimakariri Area Statistics







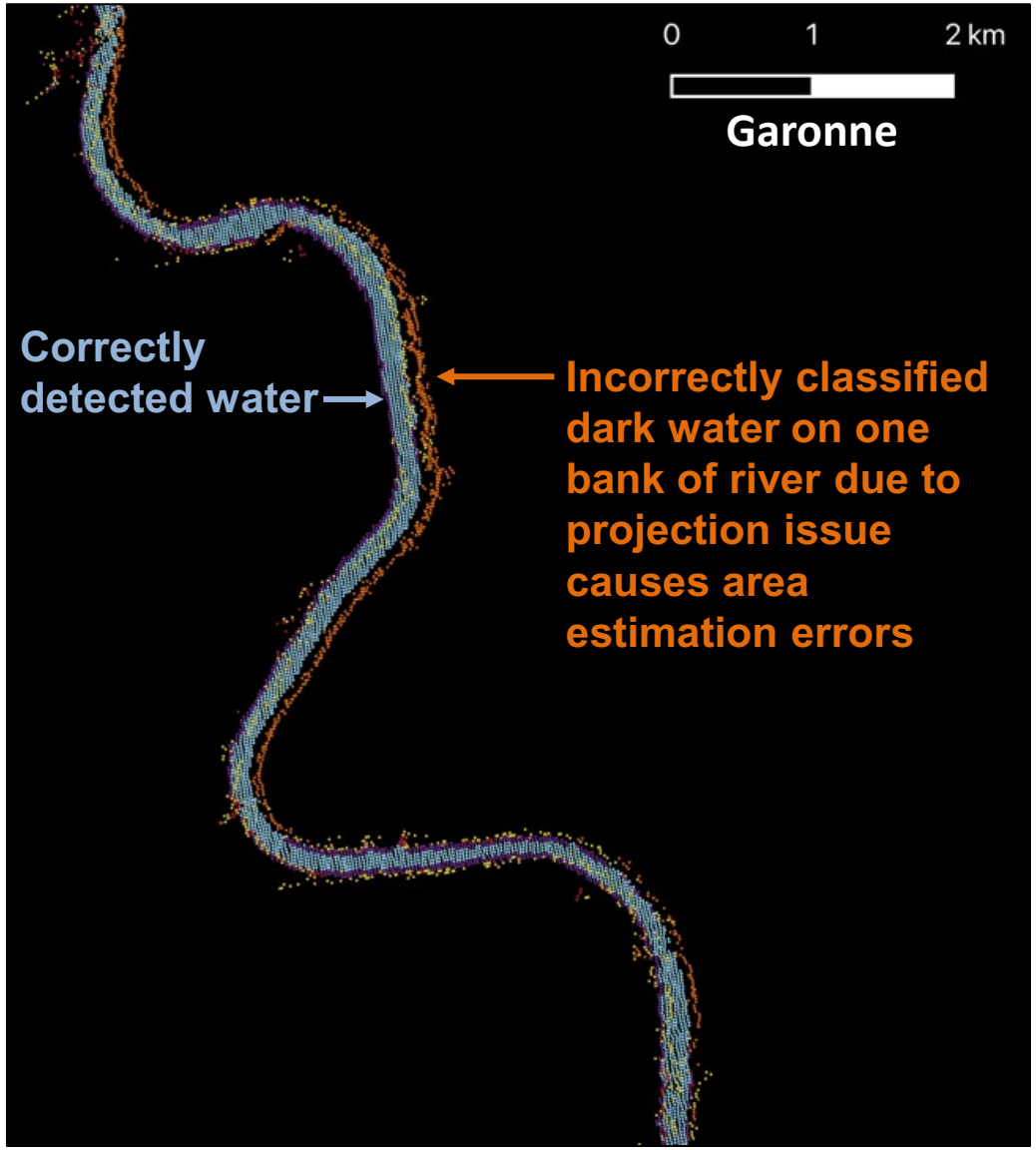


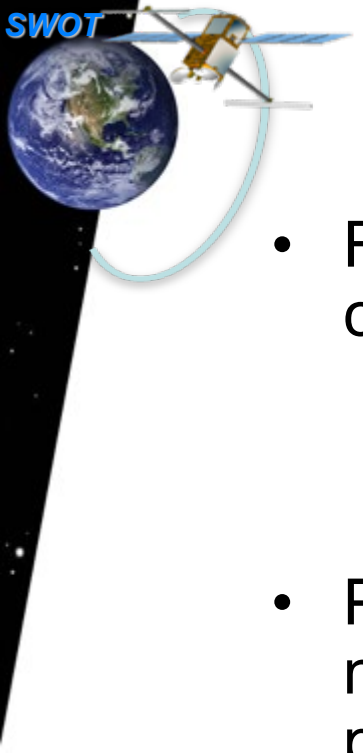
SWOT overestimates detected area, but spread is only somewhat higher than other good cases

Measurement contains plenty of useful information that could be exploited manually or with future algorithm improvements

Dark Water Projection Issue Causes Area Errors

- Dark water projection issue can cause significant area estimation errors for rivers
  - Misprojection causes land pixels to be falsely classified as dark water
  - If dark water pixels are used for area estimates (default for river processing), area is overestimated
  - If dark water pixels are not used for area estimates, area is underestimated if there are real dark water pixels that are correctly classified
- Area estimates are more reliable when estimated dark water fraction (variable *dark_frac*) is low
- **Classification errors due to dark water projection issue will be greatly reduced in PIXC processing for future product version**





River Segmentation Algorithm Improvement

- RiverObs identifies contiguous stretches of water based on pixel cloud classification and flags, referred to as segments.
  - Bridges, classified as non-water, and specular ringing flagged water will both cause the creation of additional segments. Low SNR on narrow rivers with poor prior water information can also result in segmentation.
- Pixels are assigned to nodes based on connectivity and on distance from the node (simplified explanation). This behaviour is affected by whether the pixels are part of the “dominant” segment.
  - Non-dominant segments are cropped more strictly. In the presence of centerline errors, this can cause open water pixels to be cropped from a node.
- Currently-deployed software treats the largest group of pixels of a reach as dominant.
  - Rivers with many interruptions and with centerline errors have area errors due to excessive cropping during the pixel assignment.
  - Recent algorithm changes better handle segmentation

Algorithm Segmentation Improvements

Geolocation Quality Flag

Reach ID

Segmentation Label (Version C)

Segmentation Label (Developmental)

Streaks of flagged pixels due to specular ringing break connectivity of river pixels

Connectivity may also be broken by bridges, missed water detection, etc.

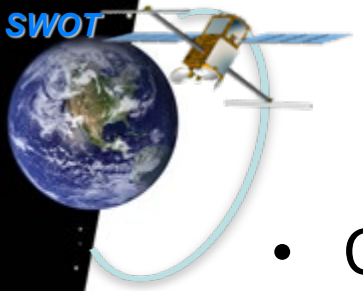
Version C vs. Dev Processing

Algorithm for Version C misses some water pixels (does not assign them to reach) because of the way specular-ringing breaks the connectivity of the pixels

Developmental algorithm correctly assigns pixels to reach even though the flagged pixels remain missing

Plots show rasterized PIXC, PIXCVec, and internal diagnostic river processing data

546_016_076R

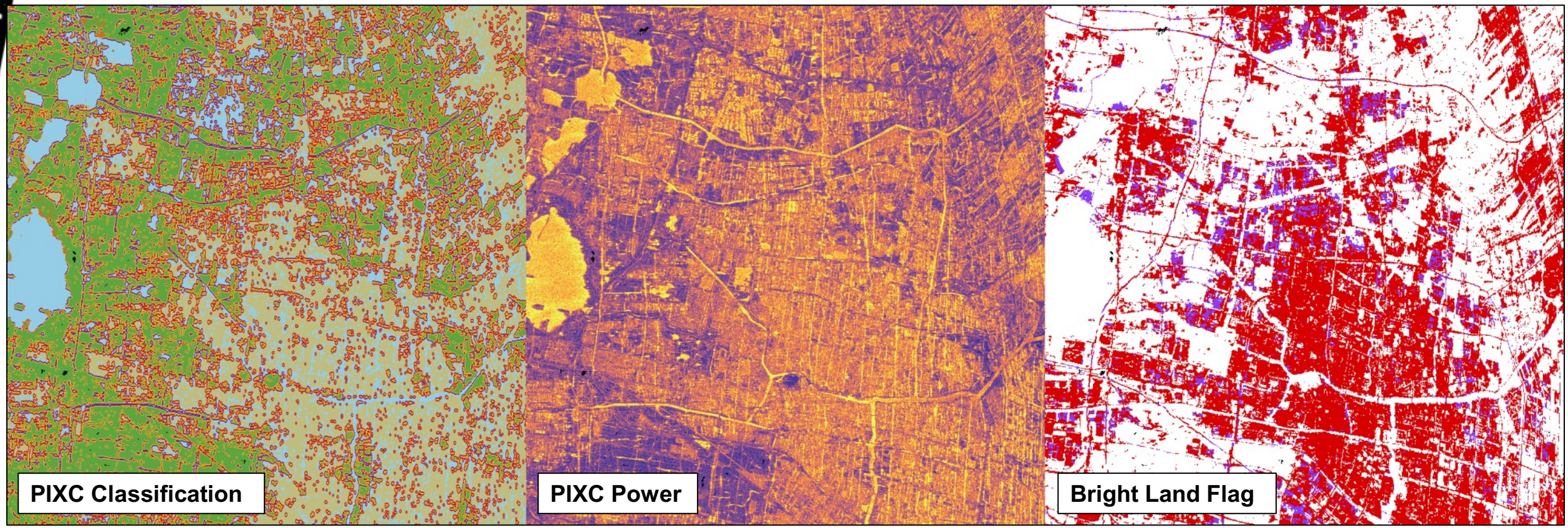


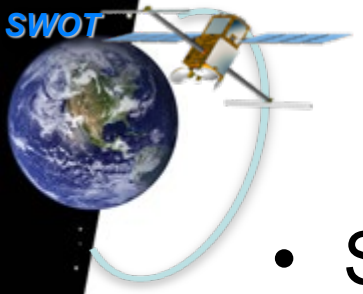
Other Symptoms Affecting Area Estimates

- Coherence-time smearing: Bright returns from water can cause overestimates at edges
- Bright returns from land can affect area estimates
- Imperfect prior knowledge can cause area overestimates and underestimates.
  - Prior water location (Pekel mask).
  - Prior river width (SWORD).
- PIXCVec product in conjunction with PIXC product gives most detailed information
  - PIXCVec product gives relationship between pixels in PIXC product and Reach/Node objects in RiverSP product

Area Errors Due to Bright Land

- Yushanzhen (玉山镇): Bright urban environment near water
- Bright land flag helps some, but extensive **bright land is nonetheless problematic for river area estimation**
  - Note: There are not actually SWORD reaches in these images as of SWORD v16, but there are channels that could in principle be in some future version of SWORD



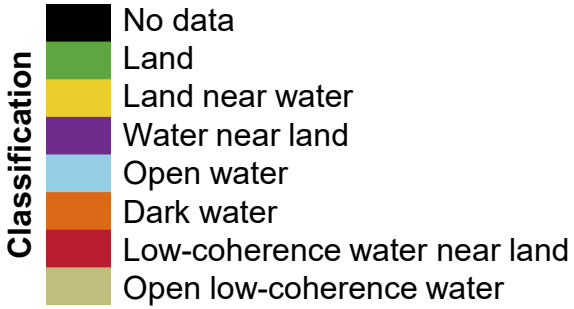


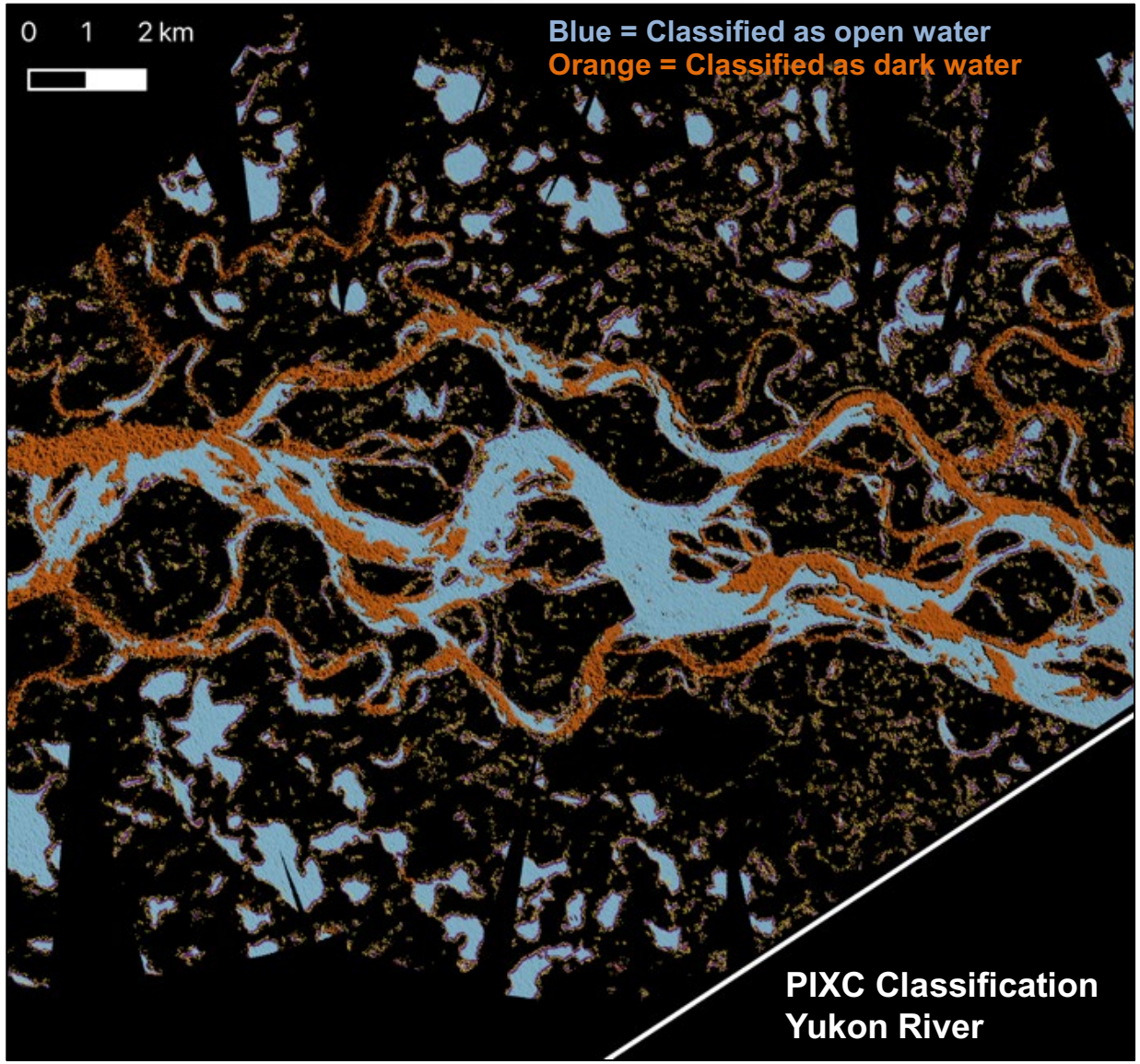
Erroneous Prior Width

- SWORD width is used to clip out non-river water bodies near desired SWORD rivers during river processing
  - If SWORD width is *greater than* true river width (at time of observation), river processing may include nearby water, biasing the SWOT area estimate high
  - If SWORD width is *less than* true river width (at time of observation), river processing may exclude true water pixels, biasing the SWOT area estimate low
- Interacts with segmentation issue (discussed previously)

Erroneous Prior Width – Yukon Overestimate Example

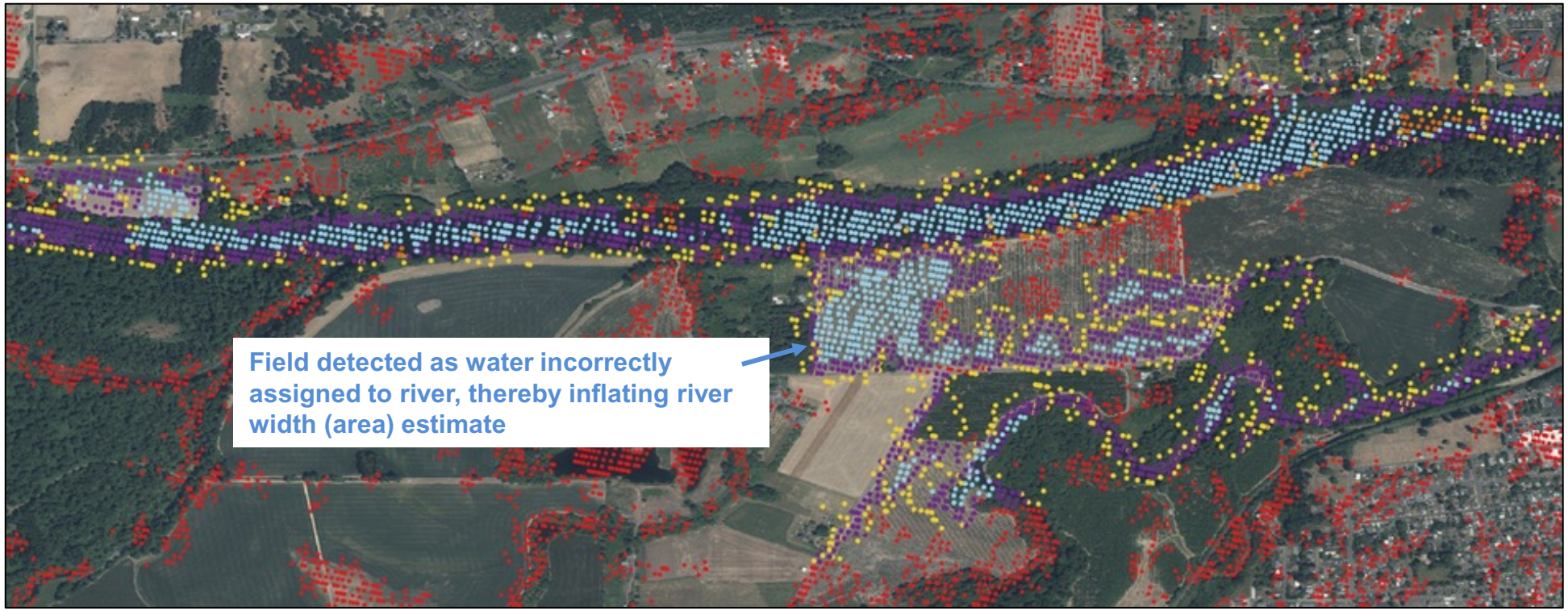
- Yukon River example
  - All pixels shown in graphic are assigned to river
  - Prior river width from SWORD is too large here, so surrounding lakes are included in the river nodes
  - Resulting area is overestimated by 100% versus Pléiades data





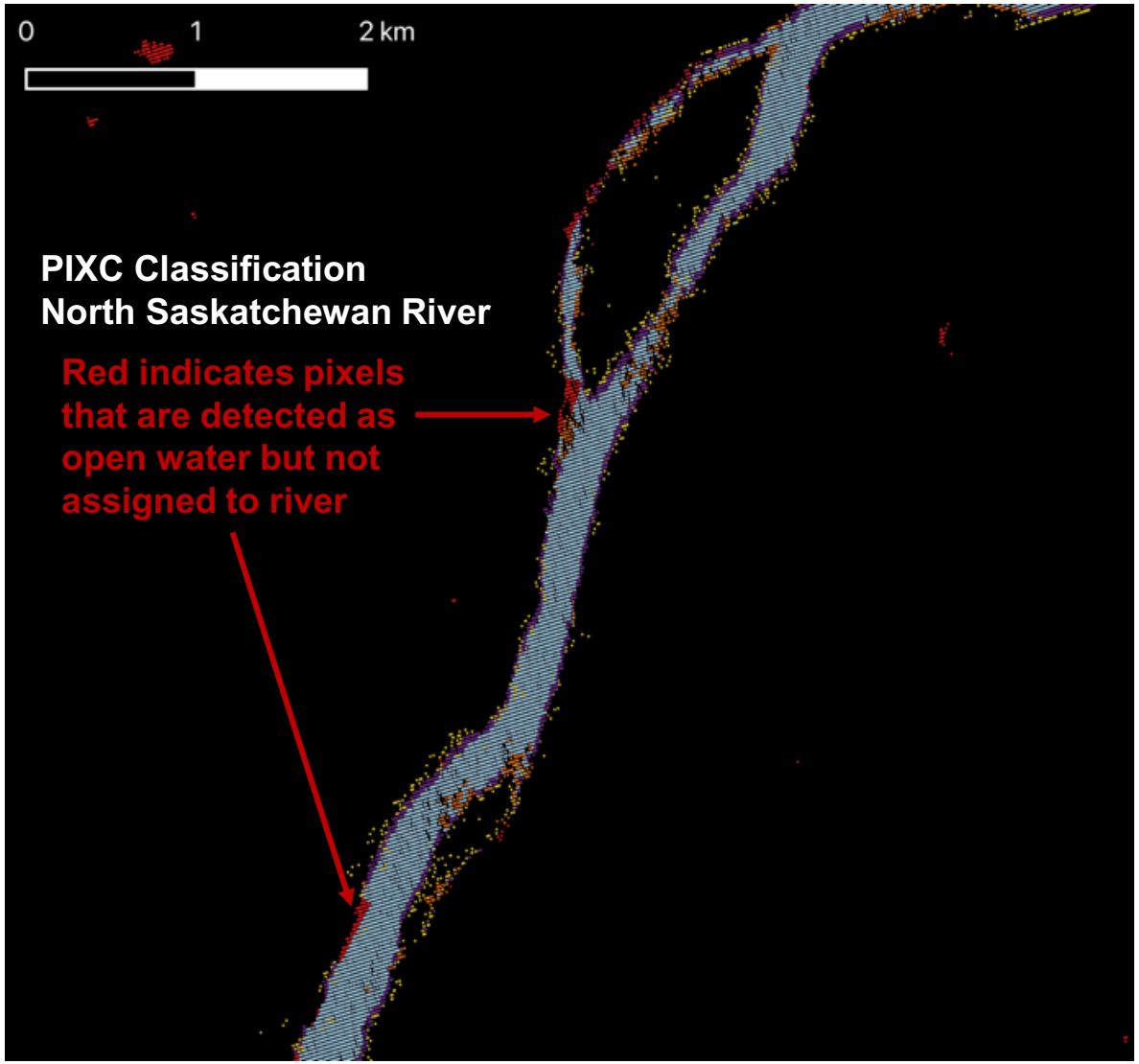
Erroneous Prior Width – Willamette Overestimate Example

- On a smaller scale: for ~ 10 days a field adjacent to the Willamette river (44.63°, -123.13°) was detected as open water.
  - Unknown if due to river flooding, actions by the farmer, or just false detection.
  - Causes large (> 50%) error in area estimate for affected node.



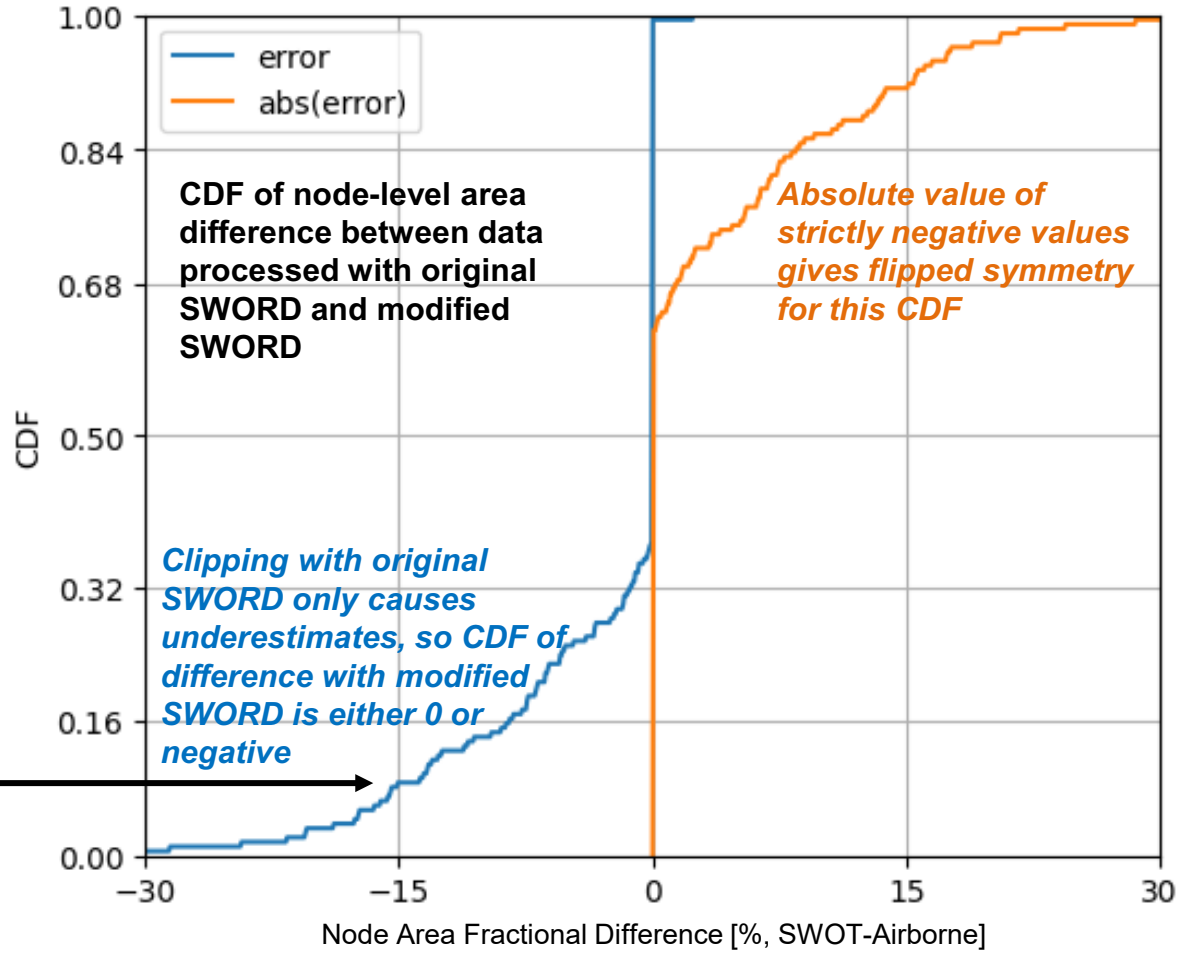
Erroneous Prior Width – Underestimate

- Area underestimate example due to SWORD width too small
  - Causes pixels that were correctly detected as water to be excluded from the river
  - May not show up in statistics in previous slides because both SWOT and external masks are clipped in the same way



Erroneous Prior Width – Magnitude of Underestimate

- To characterize impact of clipping due to SWORD width:
  - Manually modify SWORD to increase maximum width of North Sask (previous slide) for offline analysis
  - Compare runs with original and modified SWORD versions



Clipping is not negligible for this reach, but is worse than -15% relative area error for only 10% of nodes

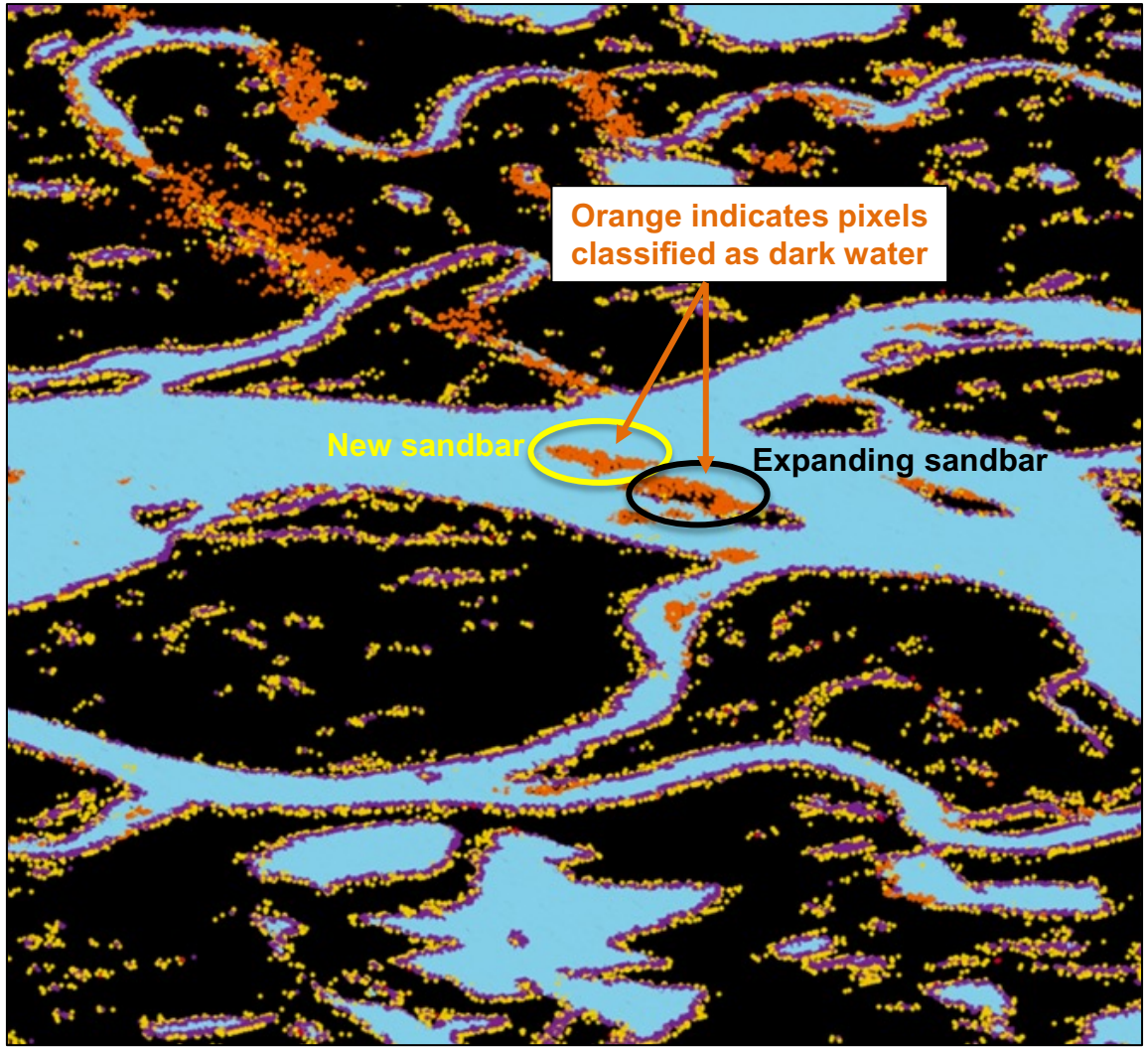
$$\frac{\text{area}(SWORD) - \text{area}(mod\ SWORD)}{\text{area}(mod\ SWORD)}$$

Imperfect Dark Water Prior Info

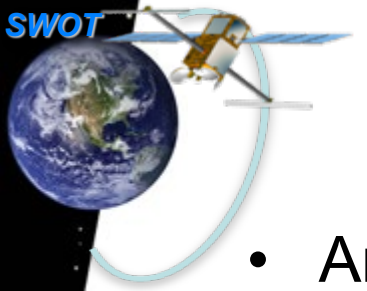
- Dark water is flagged based on prior water probability maps based on historical observations (Pekel)
- If river changes significantly from historical data, dark water flags may be incorrect

New Sandbars Classified as Dark Water

- Image shows sandbars that are incorrectly classified as dark water
  - Sandbars do not exist in dark water prior info
  - Confirmed with same-day Planet imagery
  - Similar to effect seen on Waimak



Yukon River 556_026_034R (66.5954˚, -145.7837˚)



Summary

- Area performance varies a lot
  - Area estimates are good for simple cases
  - Rivers that are dark, changing, and/or surrounded by bright land or other disconnected water features are much more challenging
  - Product contains information (dark fraction, quality flags, etc.) that may help distinguish between good cases and bad cases
- Measurement contains lots of information that might be exploitable by custom analysis and/or by future algorithms even when river area estimates are worse than desired
  - PIXC and PIXCVec products may be best suited to custom analysis
- Next RiverSP product version should have some significant improvements in river area performance