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

PIXC Features and Issues

Brent Williams[1]

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

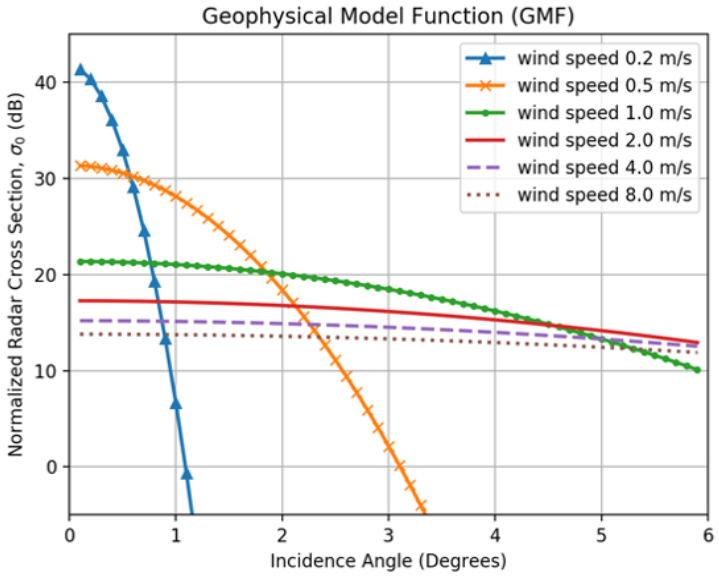
[1]Jet Propulsion Laboratory, California Institute of Technology

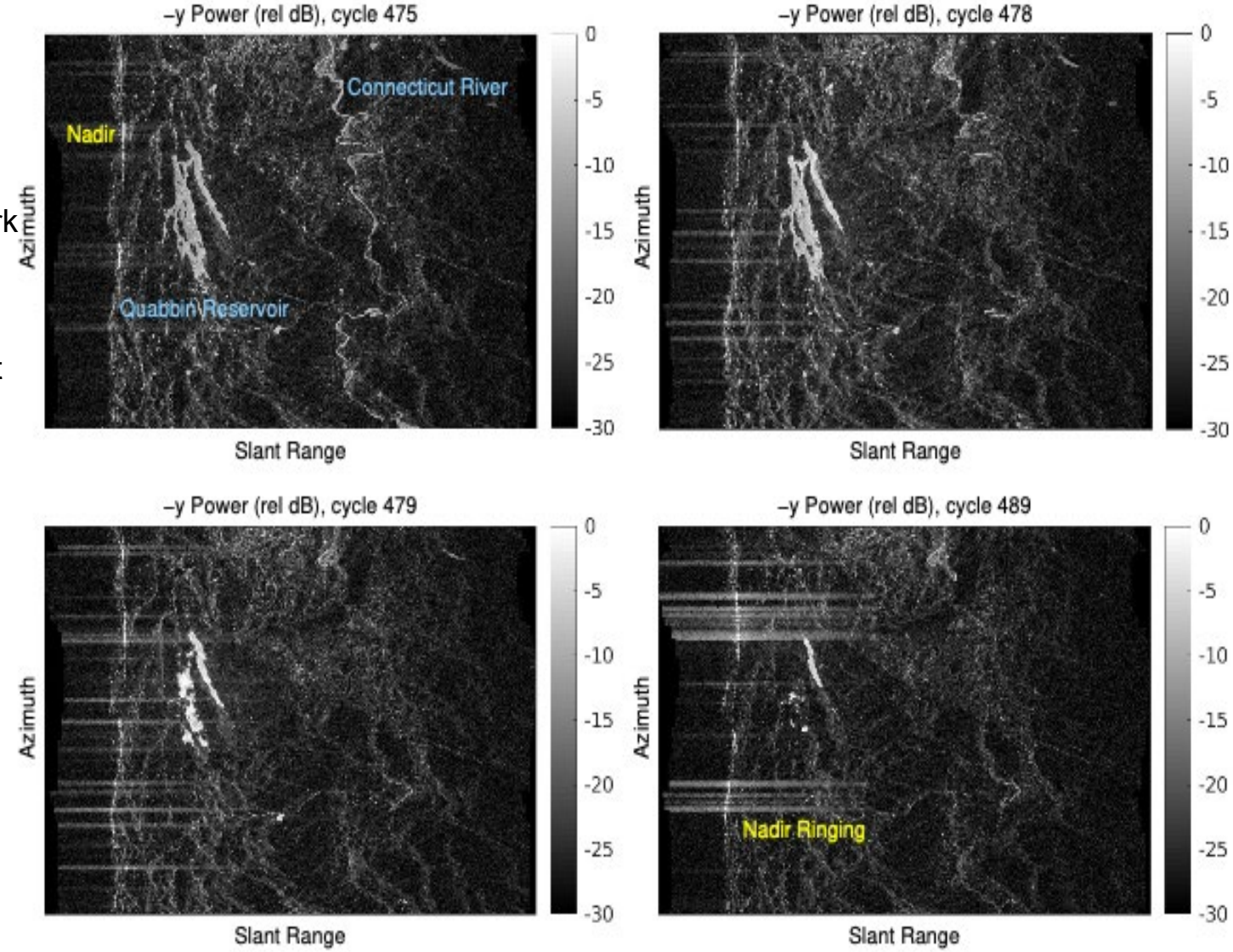
Features and Issues

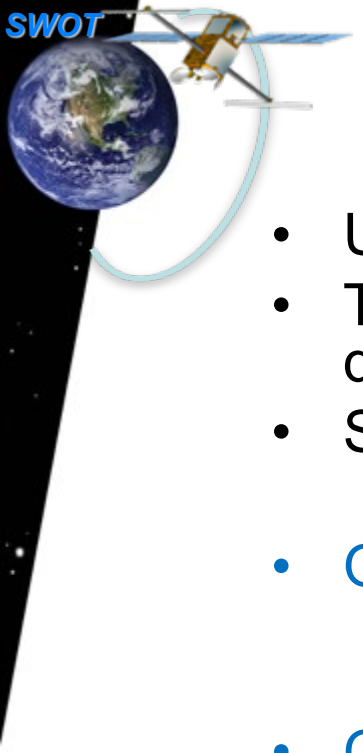
- Phenomenological Issues/features
  - Dark water
  - Specular ringing
  - Bright land
  - Low coherence
  - Coherence time smearing
- Algorithm/product issues/features
  - Water fraction features
  - Dark projection issues
  - Phase unwrapping errors
  - Crossover over flag status
  - Bug for phase/wse/geolocation of non-unwrapped pixels

Specular Scattering: Dark Water and Specular Ringing

- Low wind speed/roughness
  - Sigma0 low for much of swath
  - But very bright at nadir
- Dark Water
  - Chunks of lakes/rivers seem to intermittently disappear
  - Signal dropout in heavy rain also can result in dark water
  - Can significantly impact performance
- Specular Ringing
  - Bright nadir return couples with range point target response
  - Bright stripes extending ~half the swath
  - Flagged and reported in PIXC qual flags



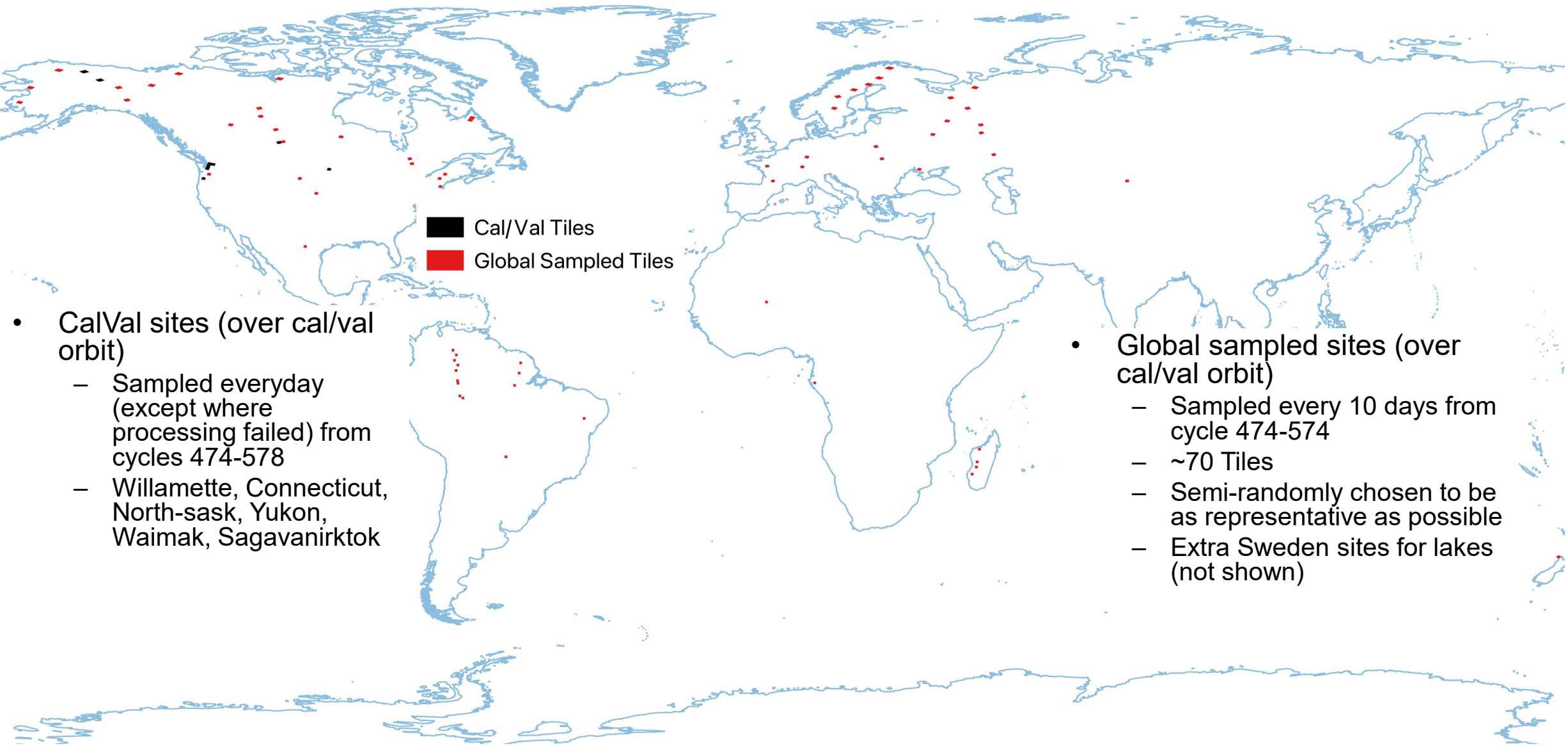




Dark Water Rates: Approach and Caveats

- Use dark water flagging results as truth for quantifying dark water occurrence
- The Version C SWOT data (as well as previous versions) is insufficiently accurate in dark water flagging for this purpose
- Special offline “developmental” run of PIXC processing
  - Better handling of projection of prior masks used for dark water flagging
- Offline river-tile processing (not RiverSP)
  - May have issues at tile boundaries where we don’t have the consecutive tiles processed through PIXC
- Offline lake processing
- Limitations:
  - Prior water probability itself is not perfect (especially in regions of dynamic river channel migration)
  - Projection can still be off in some cases (e.g., near bright cities projection errors can still have minor issues)
  - Estimated dark water occurrence rates are likely an over-estimate
  - Cannot actually do this globally, until a future reprocessing (with prior projection fix)
  - Here we focus on limited sites and cycles over cal/val orbit

River Dark Water Rates: Sites/Tiles



- CalVal sites (over cal/val orbit)
  - Sampled everyday (except where processing failed) from cycles 474-578
  - Willamette, Connecticut, North-sask, Yukon, Waimak, Sagavanirktok

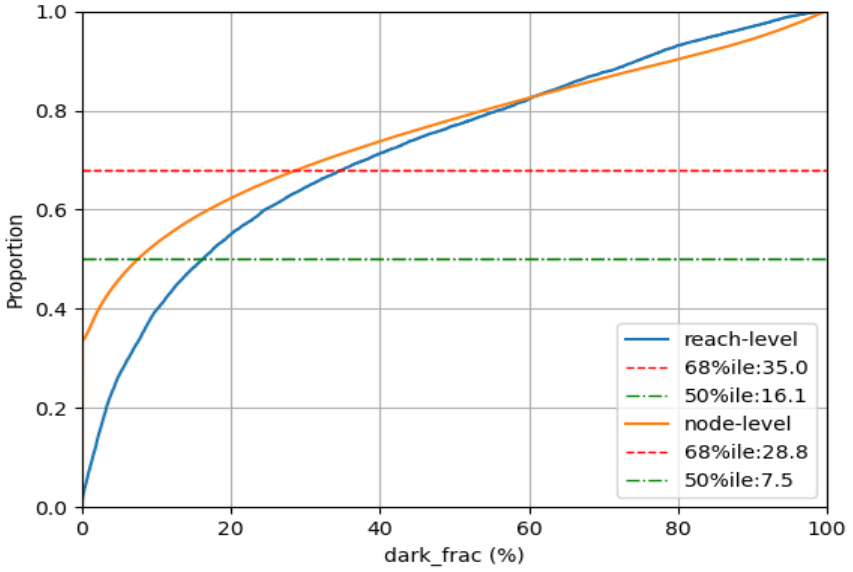
- Global sampled sites (over cal/val orbit)
  - Sampled every 10 days from cycle 474-574
  - ~70 Tiles
  - Semi-randomly chosen to be as representative as possible
  - Extra Sweden sites for lakes (not shown)

River Dark Water Rates: Bulk Statistics

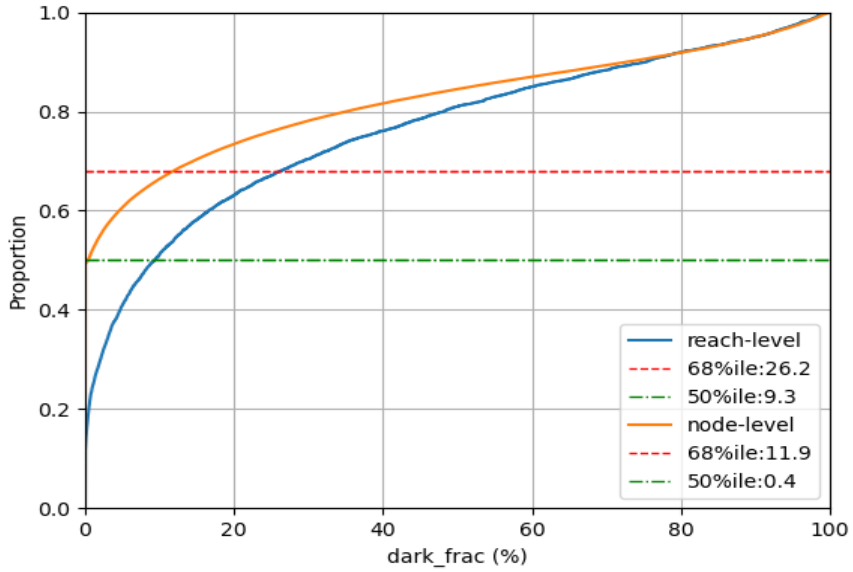
- dark_frac (%) is the percentage of water area in a node (or reach) that is flagged as dark water
- Dark water occurrence rates not negligible (impacts performance)
- Majority of time nodes and reaches have low dark frac (<~10-15% dark)
- ~quarter of the time nodes and reaches have significant dark frac (>50% dark)
- Cal/val sites more often darker than the global sites
  - ~50% of global nodes and ~35% of calval nodes have no dark water
  - ~20% of global reaches and ~ 5% of calval reaches have no dark water
  - Cal/Val sites sample more often at night over cal orbit (see next slide for impact of time-of-day sampling)

Node and reach curves differ because of scale of dark water patches (200m < dark_patch <10km)

CalVal Sites

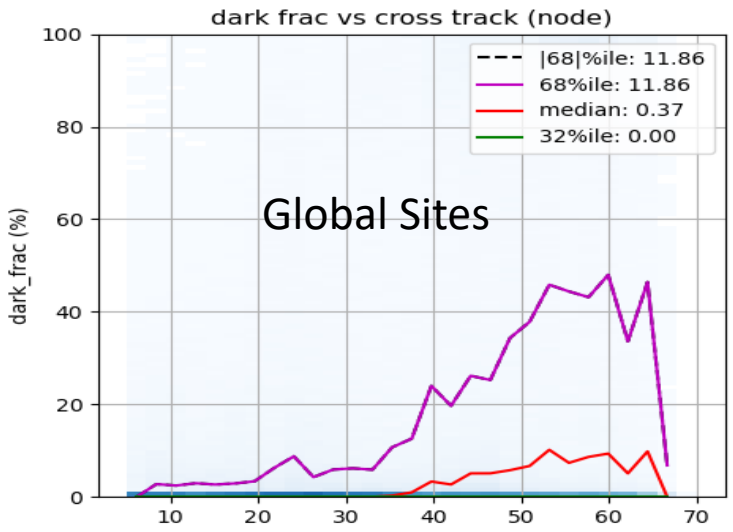


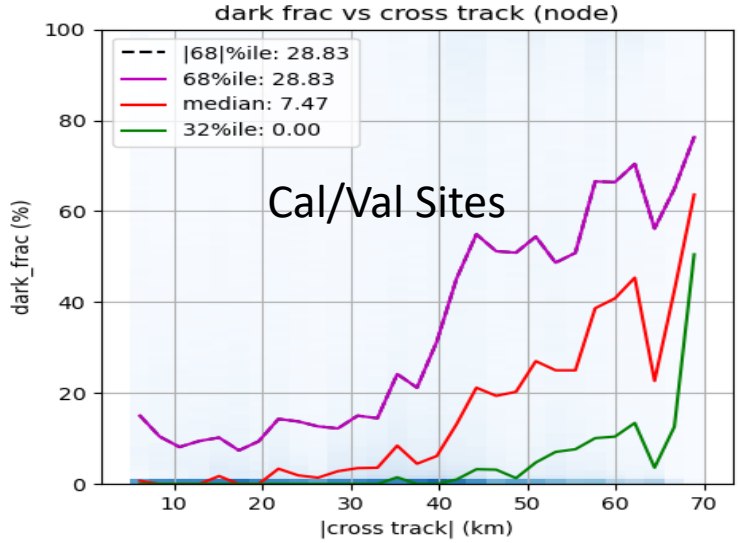
Global Sites



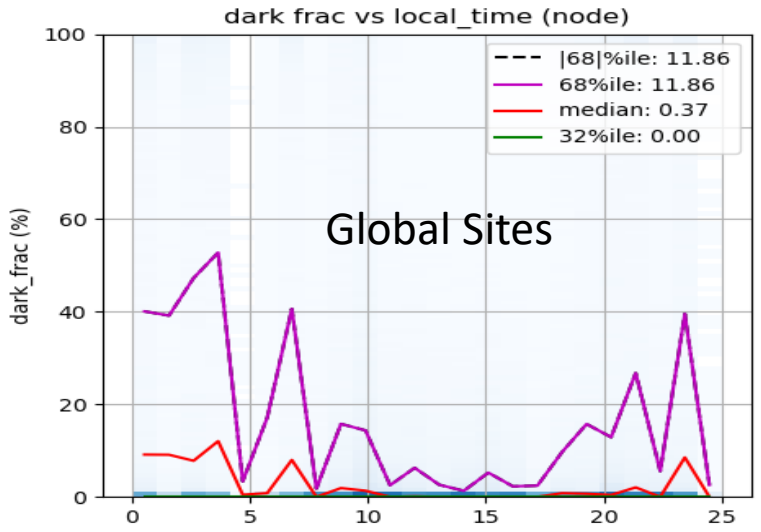
River Dark Water Rates: Most Significant Variables

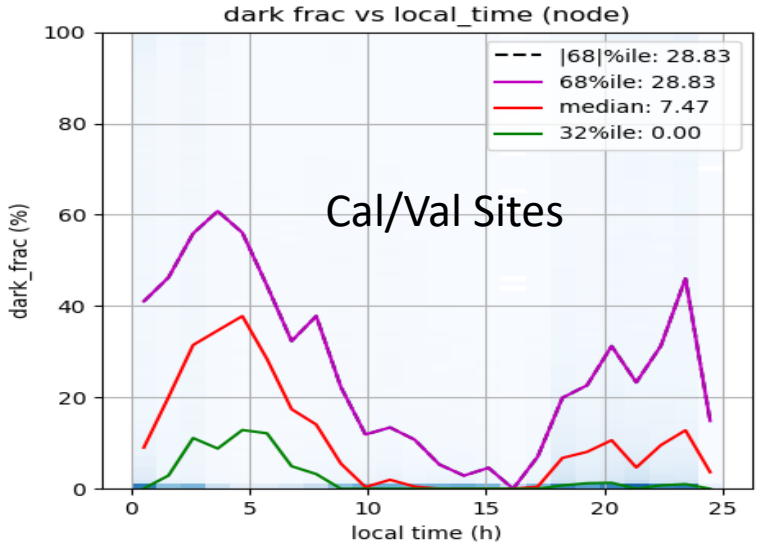
Darker at Higher Cross-track



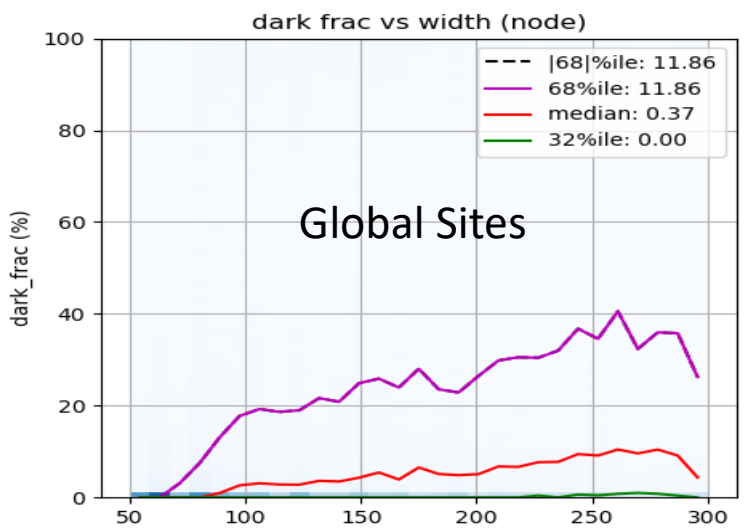


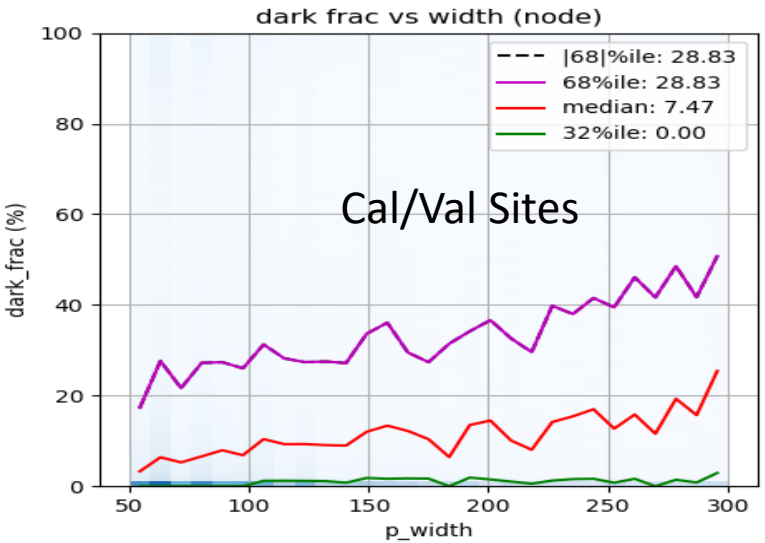
Darker at Night





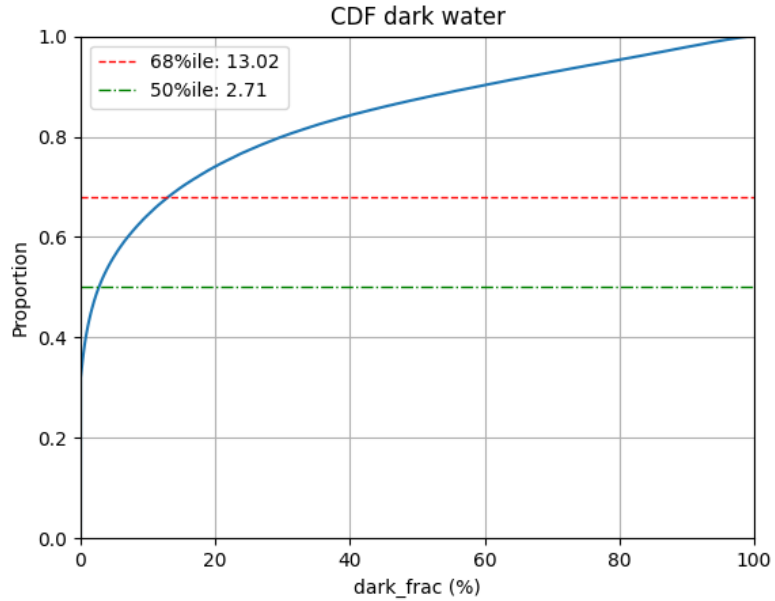
Darker for Wider Rivers

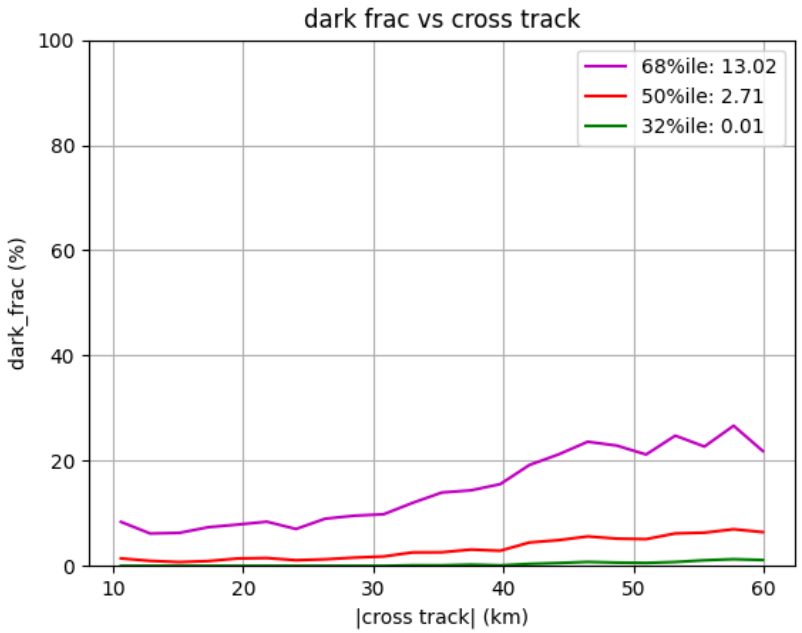


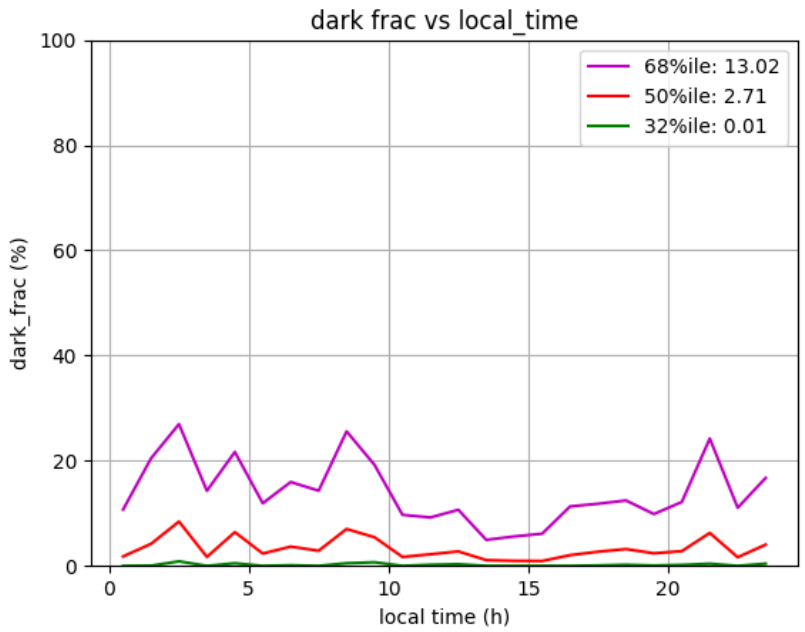


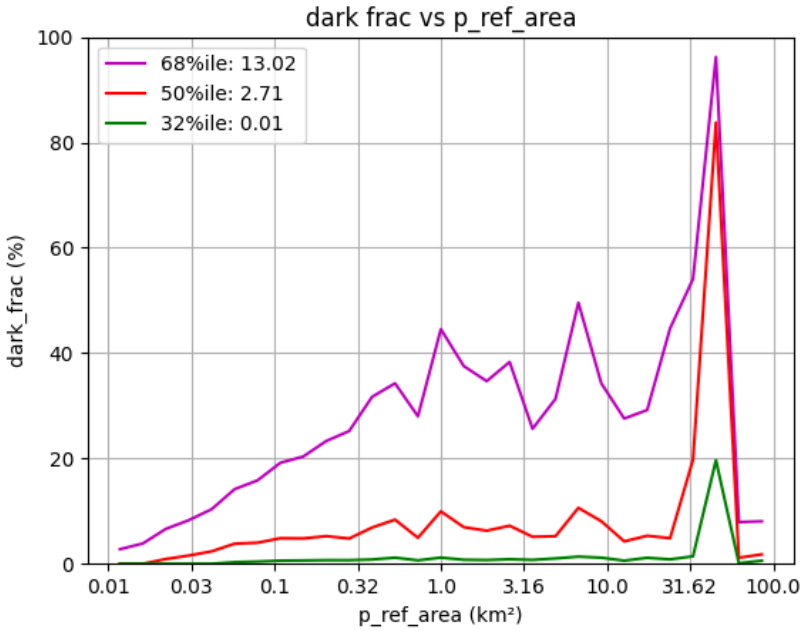
Lake Dark Water: Similar to Rivers

- Same cal/val and global tiles as rivers, with additional lakes over Sweden
- Lake dark water rates generally similar to rivers
  - Similar CDF, |68%ile| dark_frac of 13.0
  - Similar trends with cross-track and time but are less pronounced than rivers
  - Increasing trend with lake size is curious



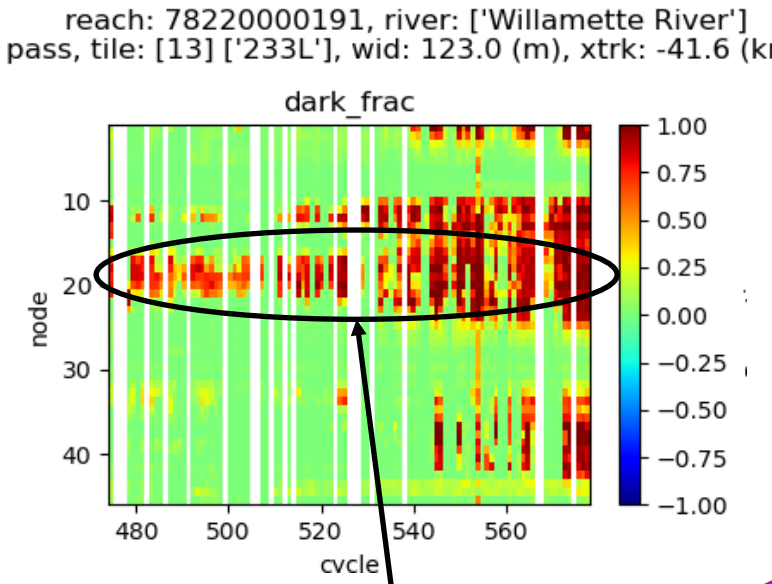


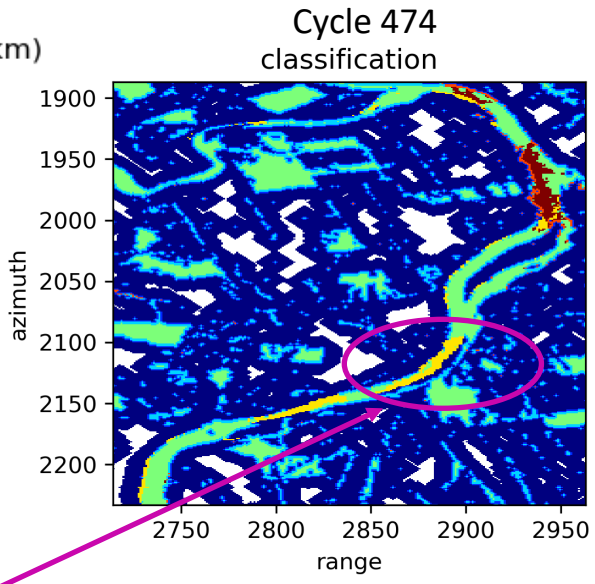


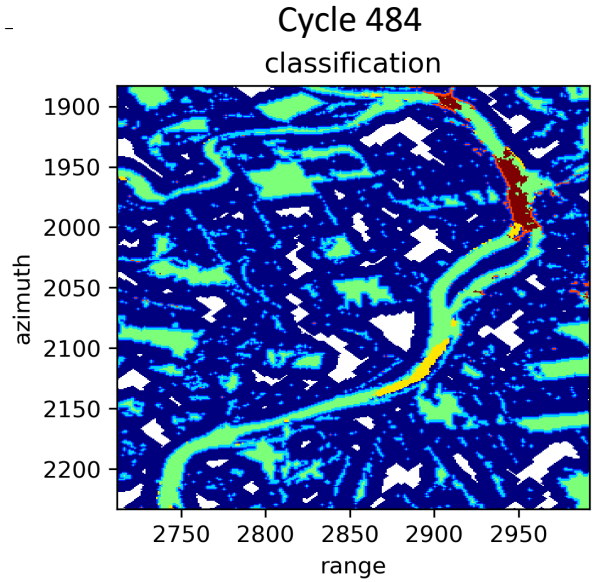


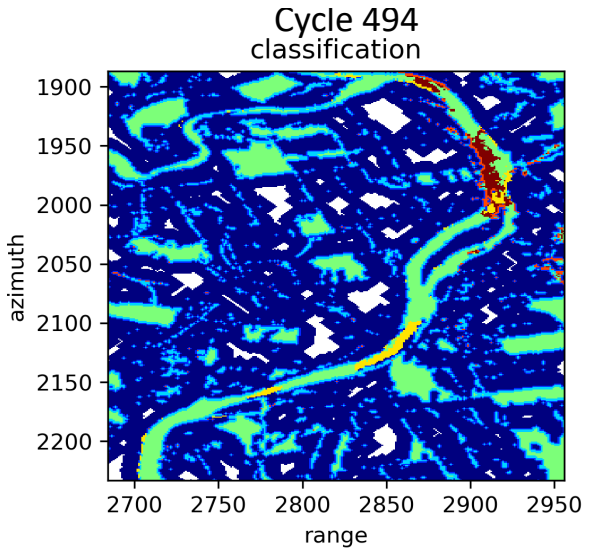
Dark Water Rates: Persistence

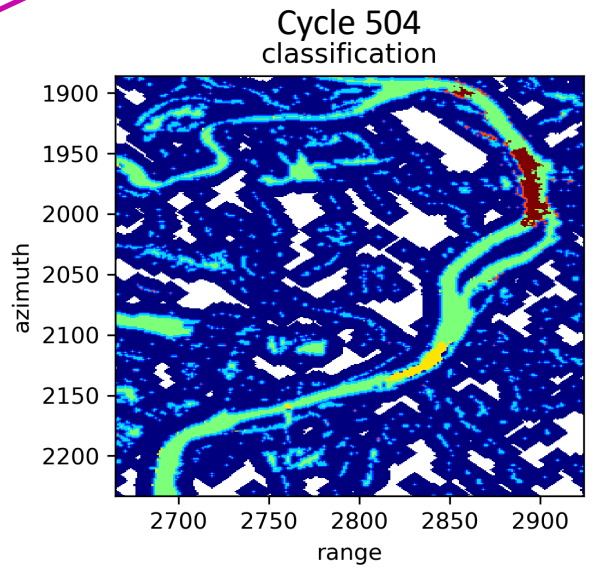
Yellow: dark water
Green: water
Red: low-coh water
Blue: land

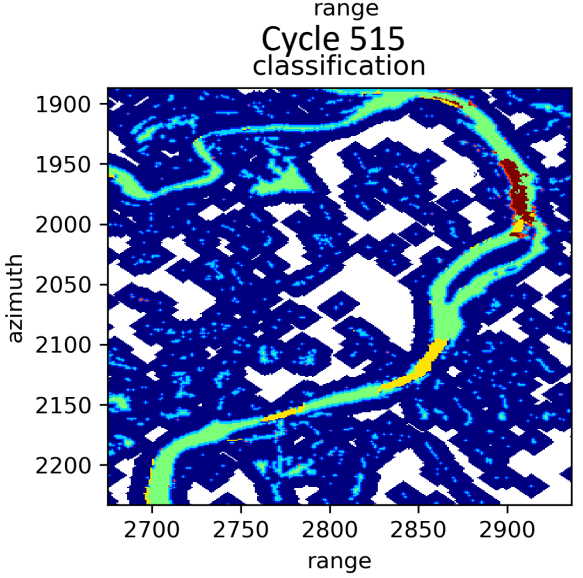


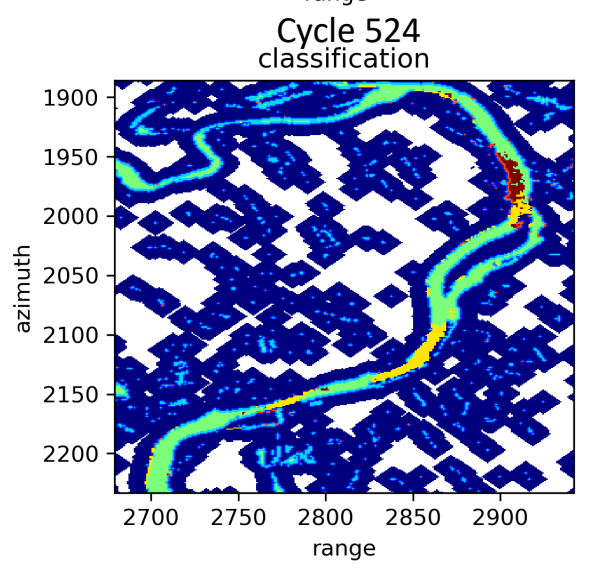










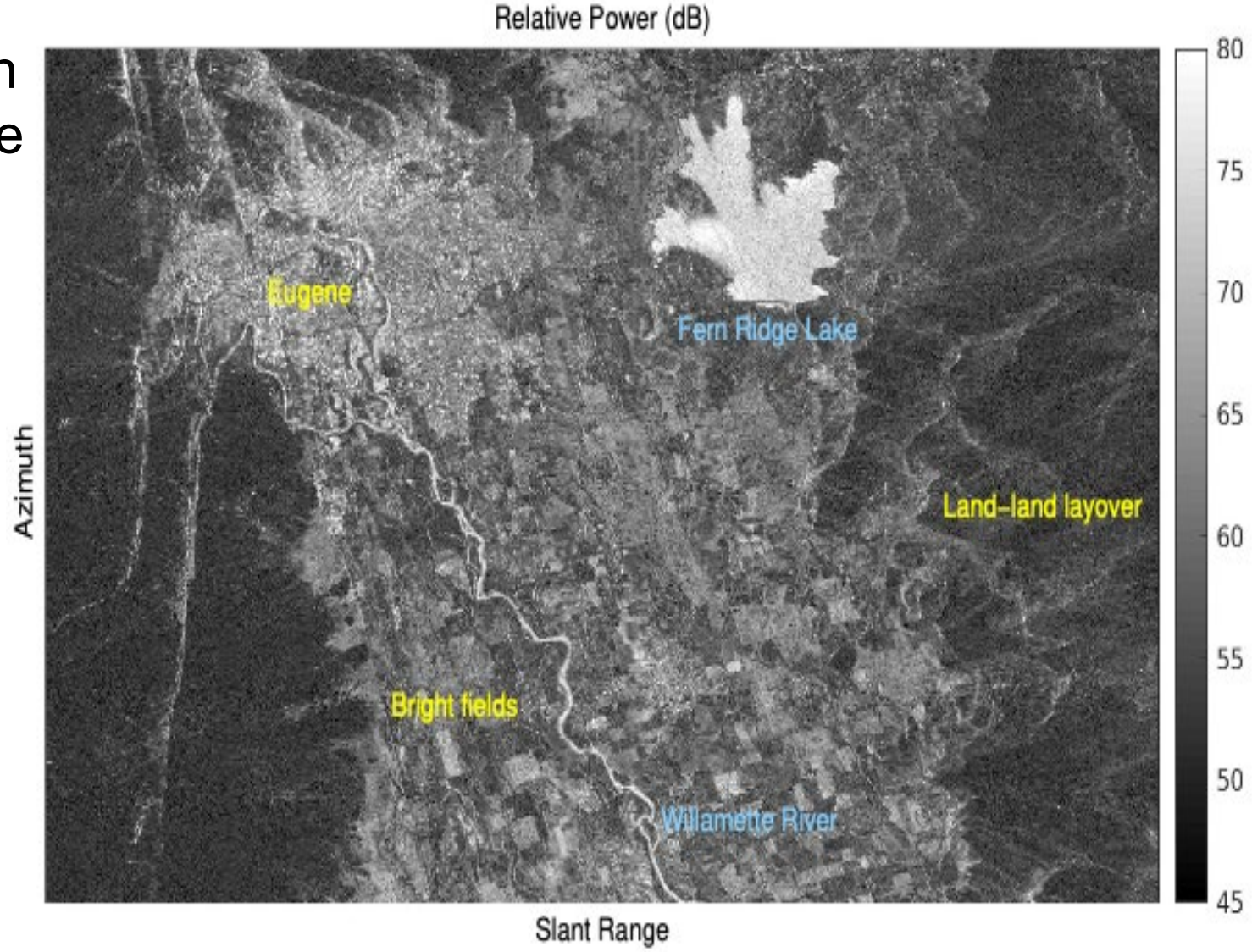


- Some areas (river nodes) are persistently dark over time
  - Calm/wind-sheltered sections of river?

Bright Land

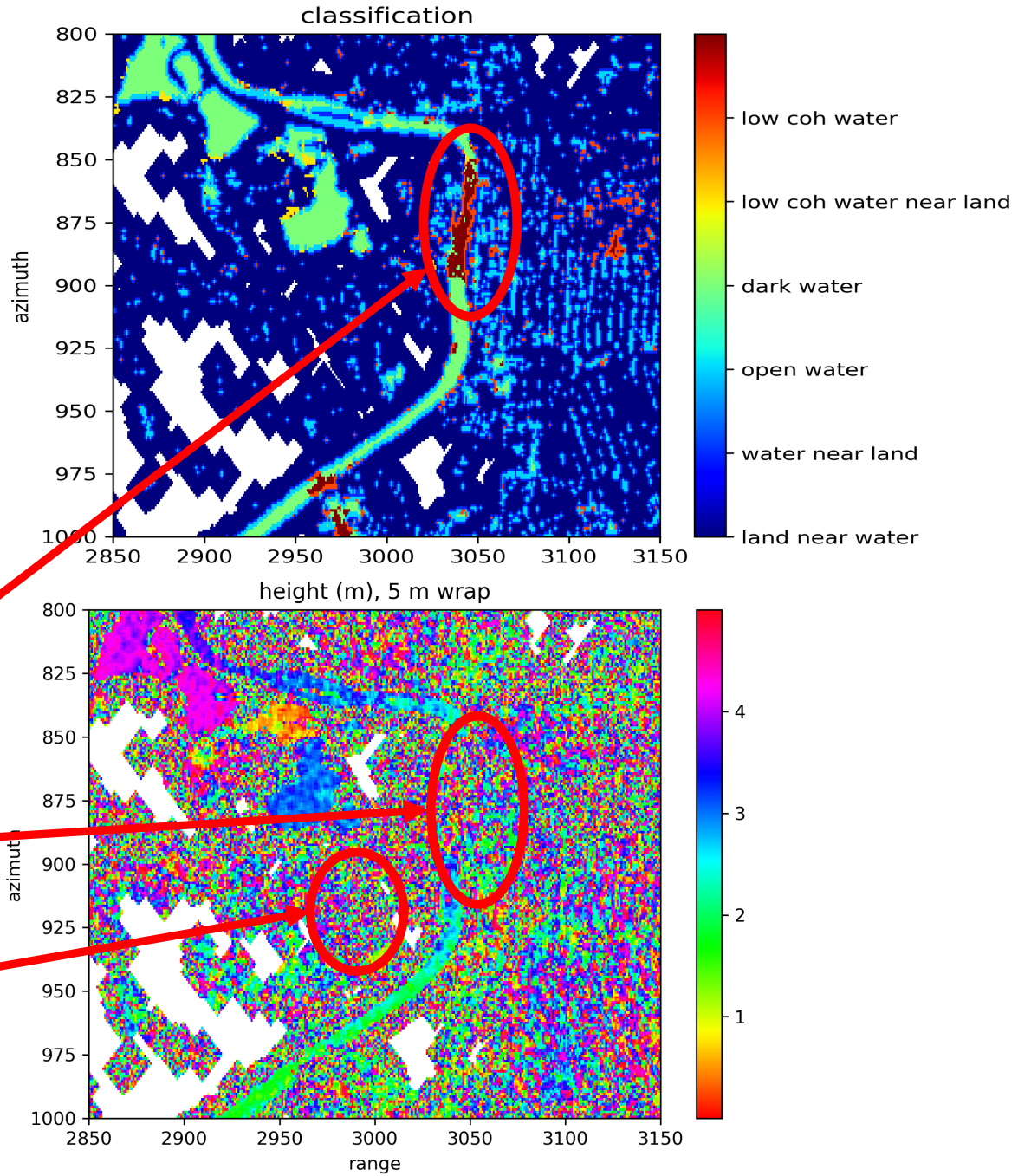
- Certain non-water surfaces can be comparatively bright (and be detected as water)
  - Urban scattering
  - Ice
  - Desert
  - Cropland
  - Layover
- Bright land mask can mitigate some of these, but not all

Version C (PGC0), Cycle 482, Pass, 013, Tile, 232L



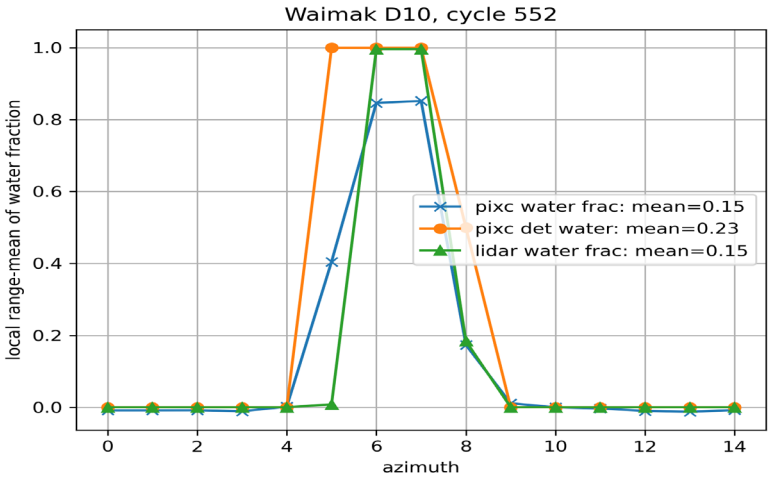
Low Coherence

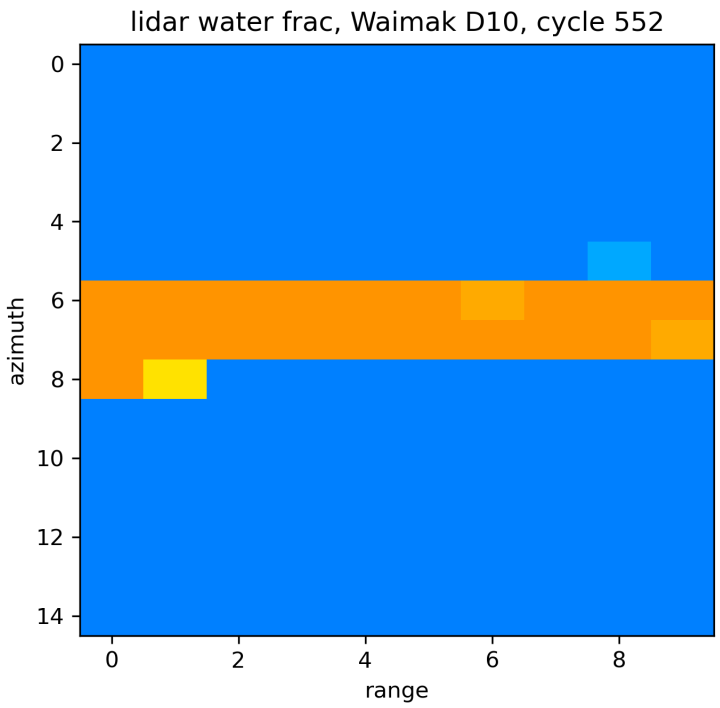
- Bright but low interferometric coherence generally indicates phase corruption
  - Bright layover
    - City/water layover
    - Water/water layover
    - Land/land layover (esp. bright land)
  - Specular ringing
- Classified as a separate class in PIXC “classification” variable
- Phase and heights are often degraded for these cases
- Dark areas (like most land) generally have low coherence and high phase noise
  - No explicit flag/class for this case

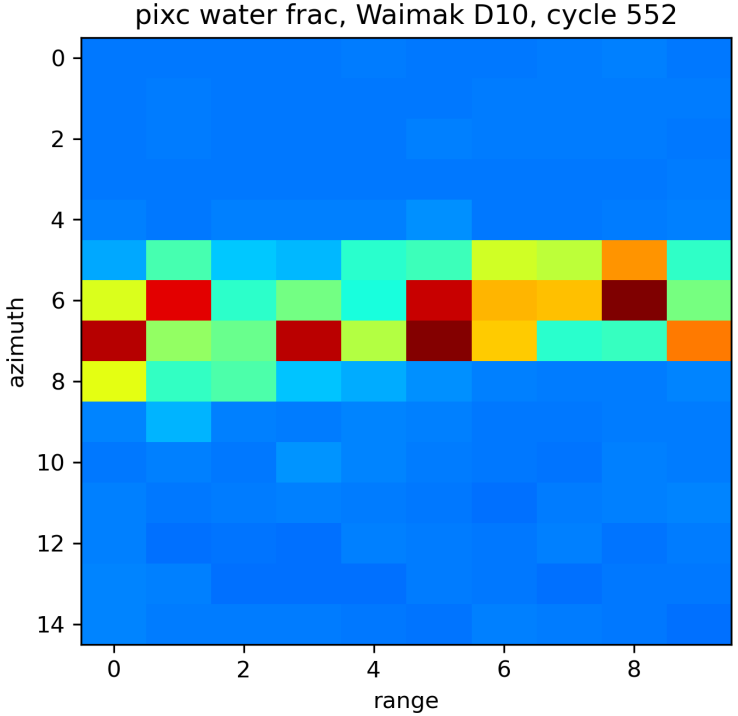


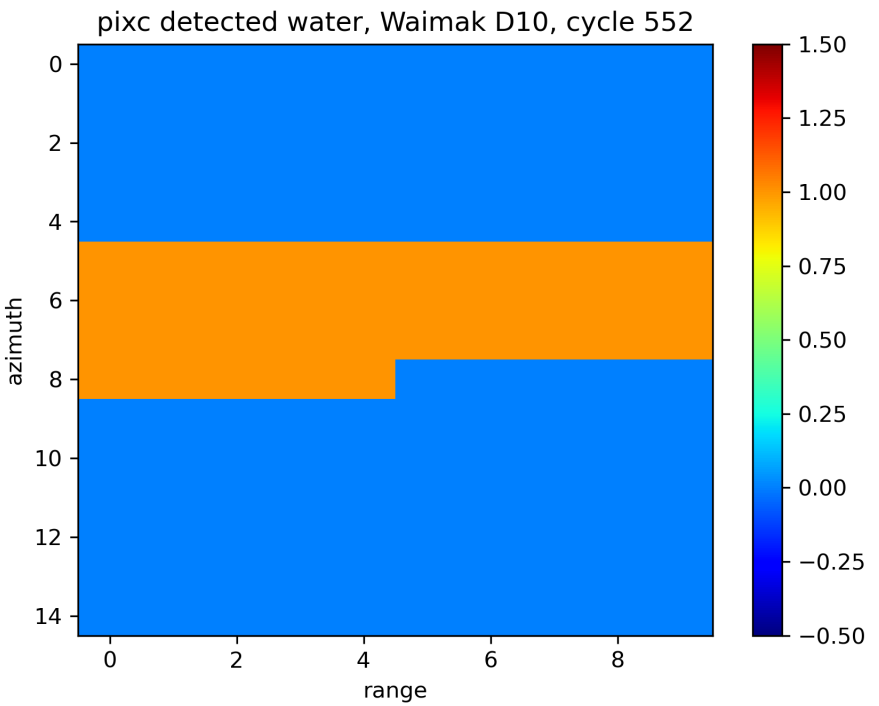
Coherence Time Smearing

- Water moves during synthetic aperture time
  - Coherence time not same as interferometric coherence
- Limits the azimuth resolution of water (but not land)
  - Water energy is smeared out in azimuth into neighboring cells
  - Smeared energy is still bright relative to land causing over-detection of water
  - Using water fraction helps mitigate coherence time smearing over-detection







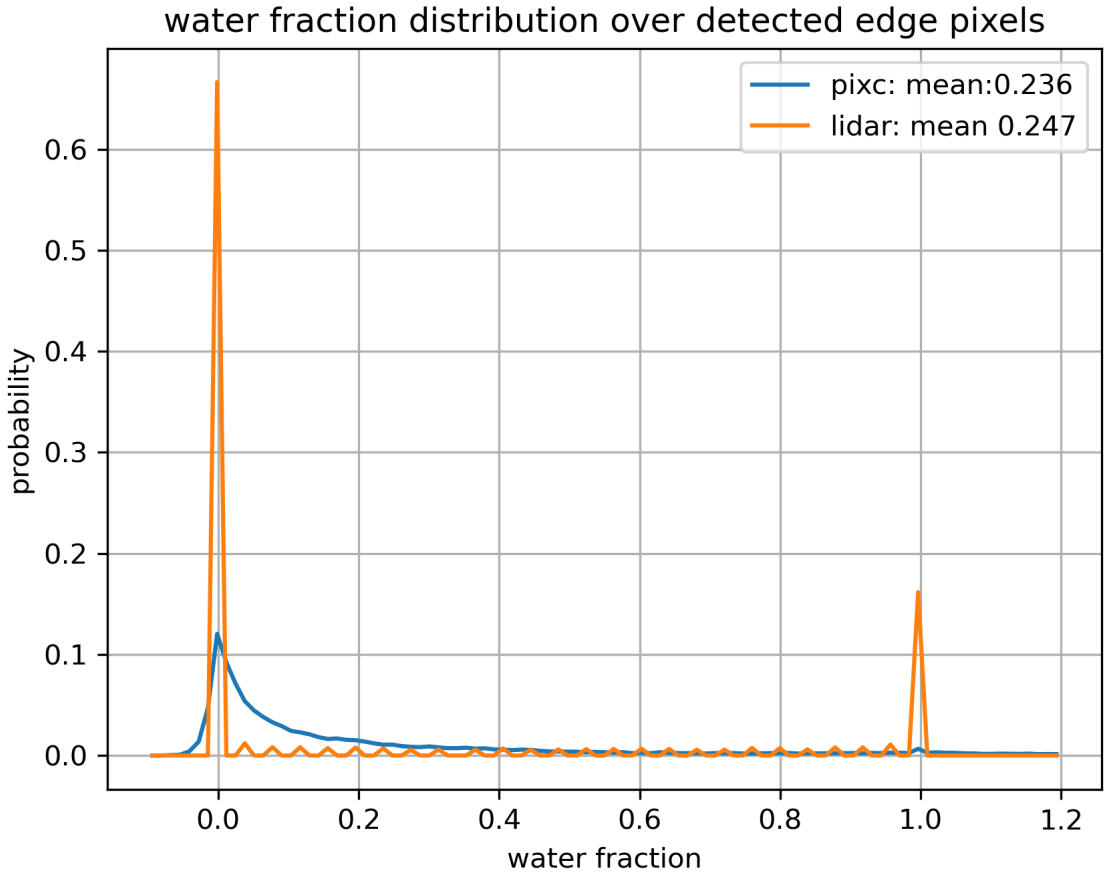


Water Fraction Features

- Water Fraction Characteristics
  - Noisy at the pixel cloud level
  - Can be less than zero
  - Can be greater than 1
- Used to handle coherence time smearing and over-detection effect on land/water boundary pixels
  - After aggregation to node/lakes
    - Distribution more well-behaved
    - Water area bias reduced

Users should compute/aggregate water-area over water features by scaling pixel-area by the water fraction on detected-land-edge and detected-water-edge pixels

Waimakariri River lidar comparison
Version C (PGC0), Cycle 490, Pass 004, Tile 231R,
Lidar D2

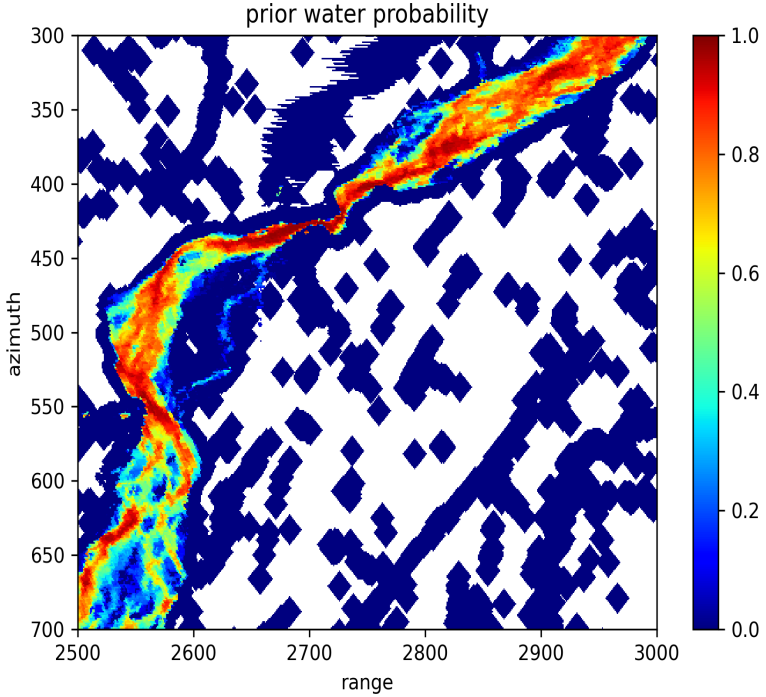


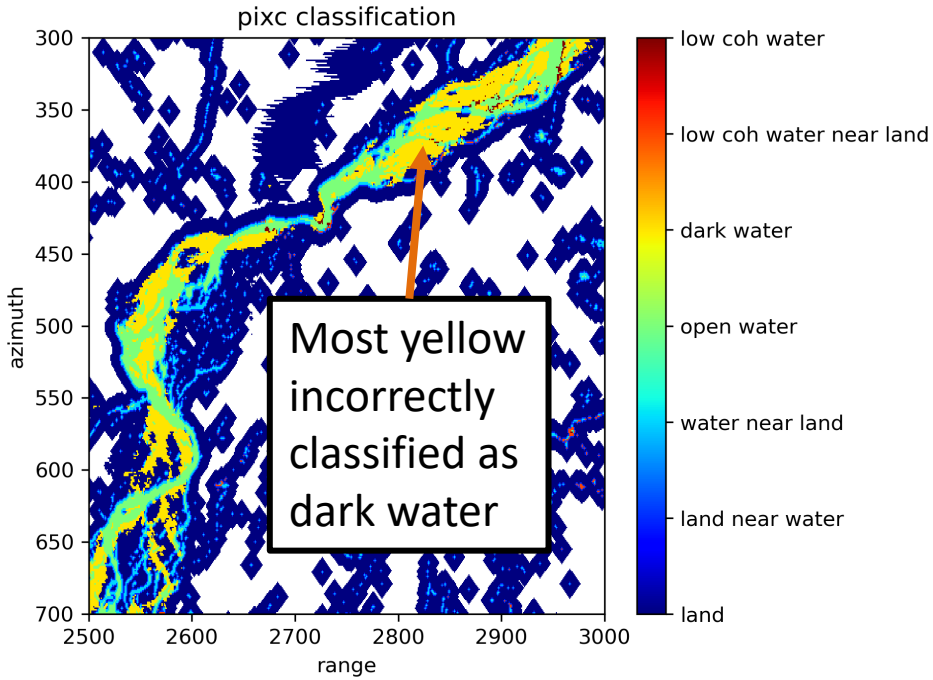
Dark Water Flagging: Prior Water Mask Errors

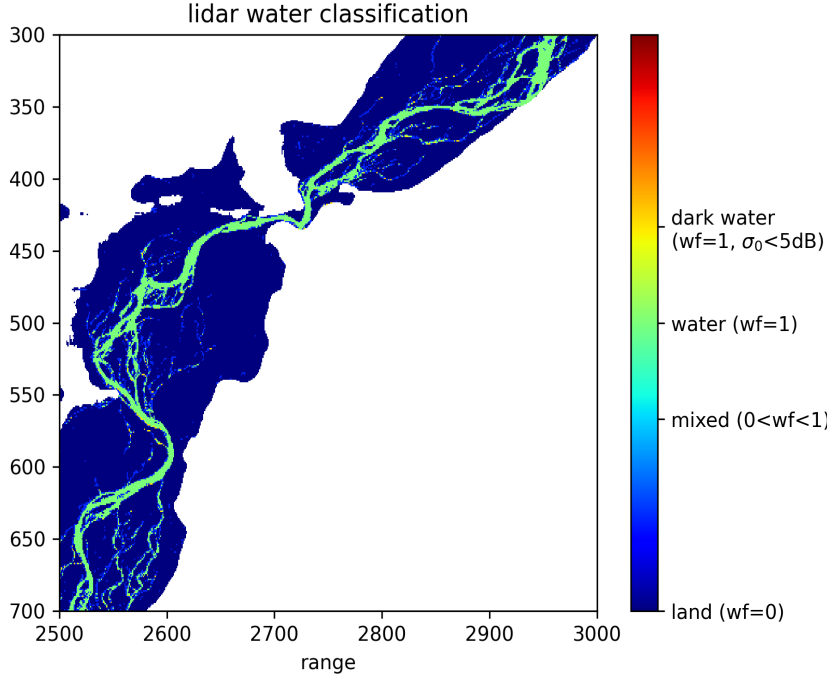
- Prior water mask errors
  - Prior occurrence mask can be a poor representation of water at a given time
    - River channels that migrate over time are smeared out in occurrence maps
    - Narrow channels limited in resolution
  - Dark water flagging is based on prior probability map (e.g., yellow in center plot is poorly flagged as dark water)
    - Over-estimate of water area/river width
  - Edge pixels flagged less often causing over-detection bias in area/width estimates even when neglecting the dark water pixels
    - Water frac not used to mitigate the over-detection if not detected edge pixel (area % diff of 17.1 vs 21.8 for this case)

Waimakariri River Example

Version C (PGC0) Cycle 490 Pass 004, Tile 231R, lidar D2

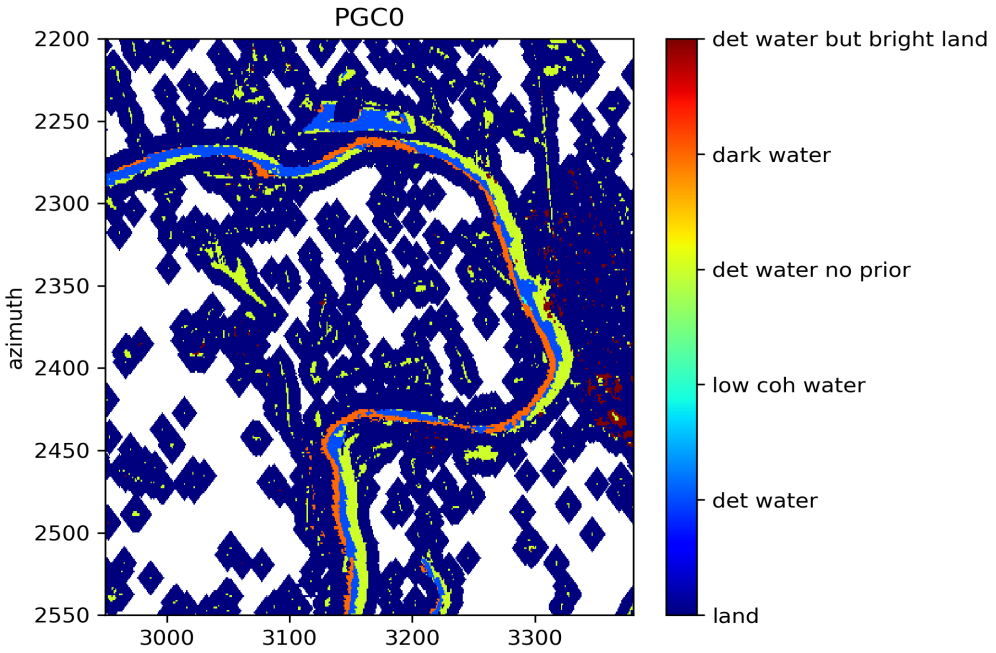


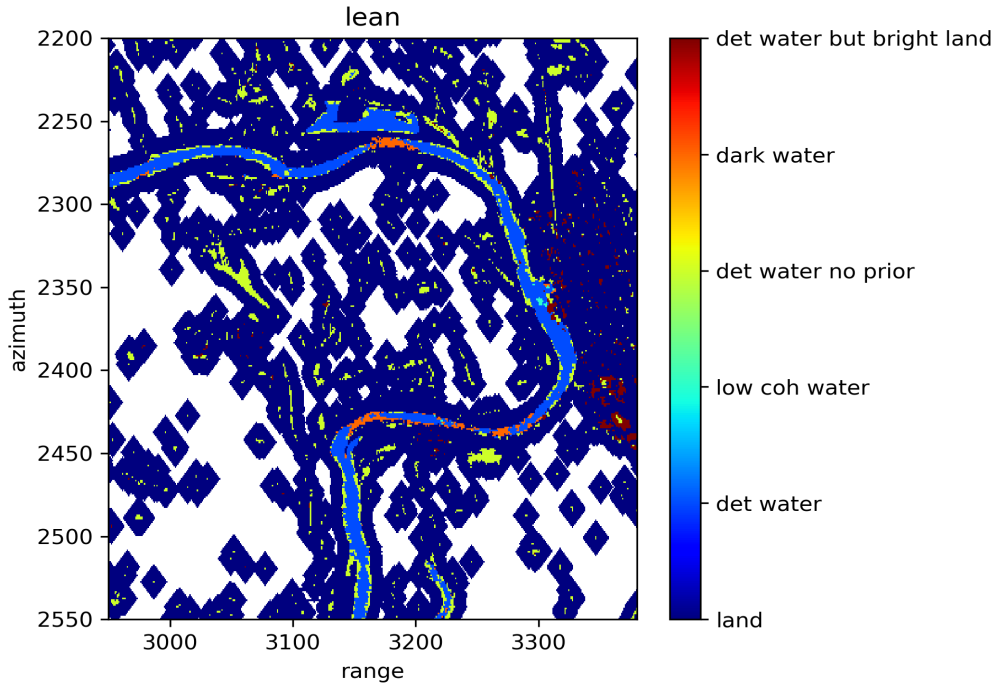




Dark Water Flagging: Projection Issue

- Issue in Version C (PxC0) data with projections into slant-plane
- Can cause significant area/width over-estimates
- Have a fix we have been evaluating with offline reprocessing (you will see in other presentations)
  - Uses estimated geolocations to help projections
  - Needs significantly more resources: runtime/CPU
- Have a newer implementation (“lean”)
  - Similar performance but can run efficiently enough for forward processing and future reprocessing(s)

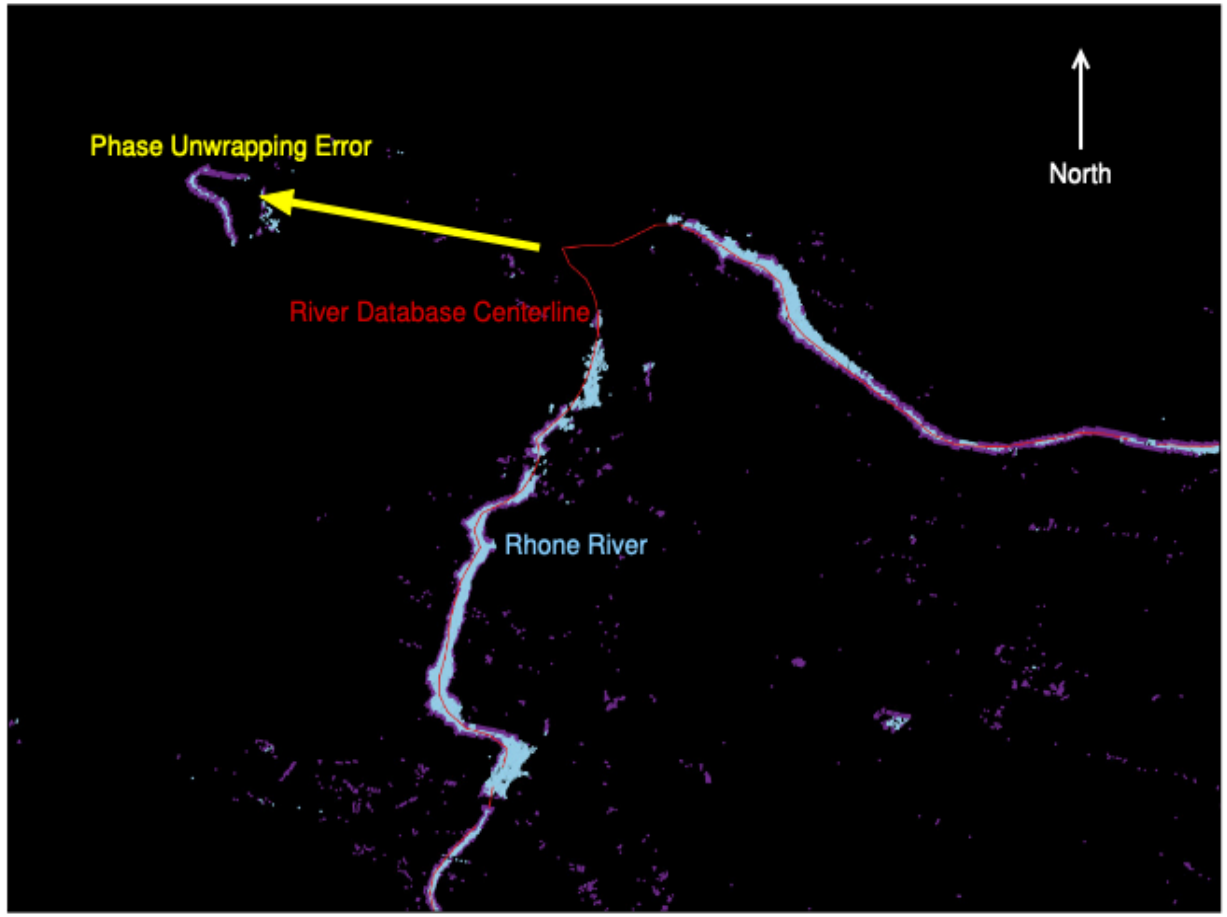




Features of Phase Unwrapping

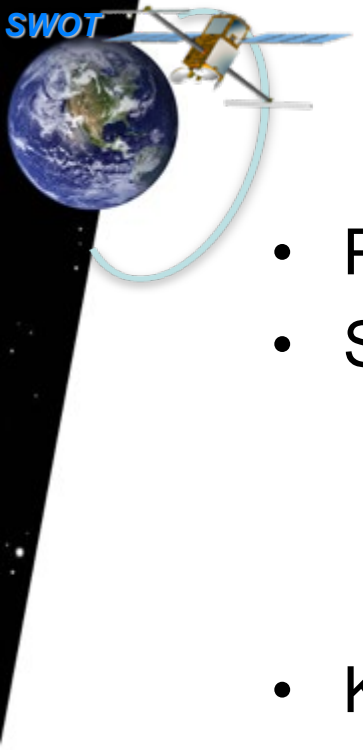
- Phase unwrapping signature
  - Regions shifted and offset in height
    - Ambiguity height ~10-60 m
    - ~750 m in cross-track direction
- Occurs infrequently, but when it does exhibits large errors
- Quality flags/indicators exist, but poorly validated on the real data

Version A (PIA1), Cycle 523, Pass003, Tile 235L



PIXC Version C (PxC0) Product Issues

- Crossover roll-phase flag = 2 treated as “bad” even though often the crossover estimates are decent when that flag is set
  - Only affects the Science Orbit data that uses the Level 2 Crossovers
  - Version C Cal orbit data (PGC0) is unaffected by this since it uses the Level 3 Crossover product
  - The development PIXC code has been updated to treat roll-phase flag = 2 as suspect
    - The fix will be delivered in future SDS delivery to forward processing (and future bulk reprocessing)
- Bug for non-unwrapped pixels (e.g., dark water, or low coherence regions etc.)
  - The phase was not being re-flattened properly before assigning absolute phase using the reference locations
  - Arbitrary offsets in heights for these areas (relative to properly unwrapped regions)
  - Detected water is rarely affected by this bug
  - The development PIXC code has been updated to fix this bug
    - The fix will be delivered in future SDS delivery to forward processing (and future bulk reprocessing)



Conclusions

- PIXC is a complicated product with many features and nuances
- Some phenomenological issues cannot be fully mitigated
  - E.g., dark water, specular ringing can be flagged, but may not be correctable
  - Impacts all hydrology products (not just PIXC)
  - Ongoing effort to characterize the impact
- Known fixable issues in Version C already fixed in development code
  - Dark water projection issue
  - Crossover flag handling
  - Bug on non-unwrapped pixels
- Algorithmic and product issues will continue to evolve and improve
- 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

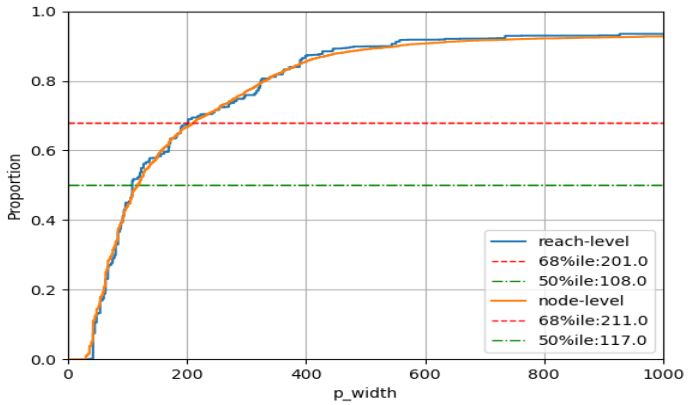
Questions?

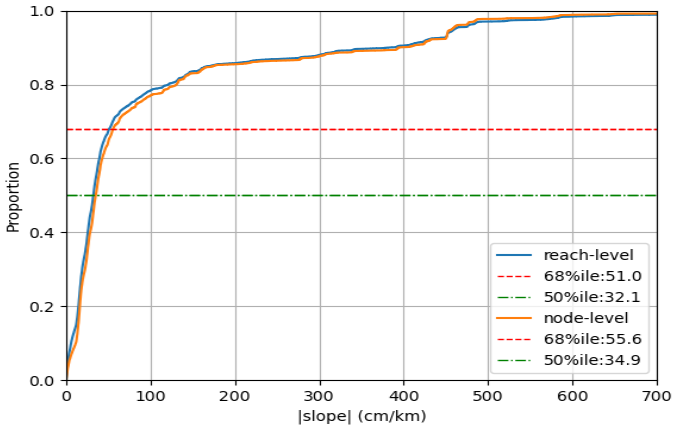
Backup

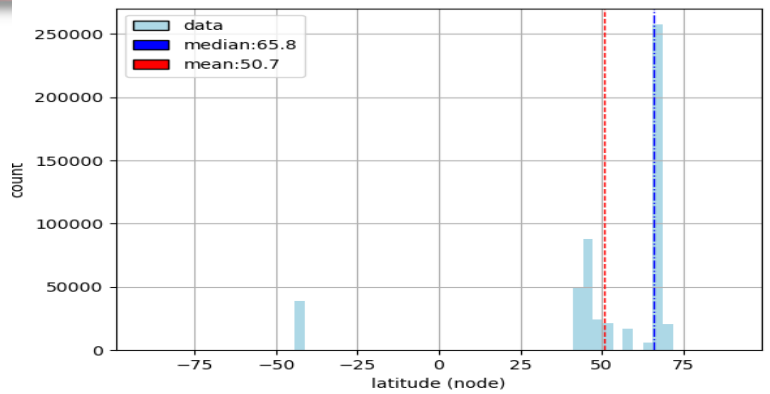
Cal/val Sites Distributions

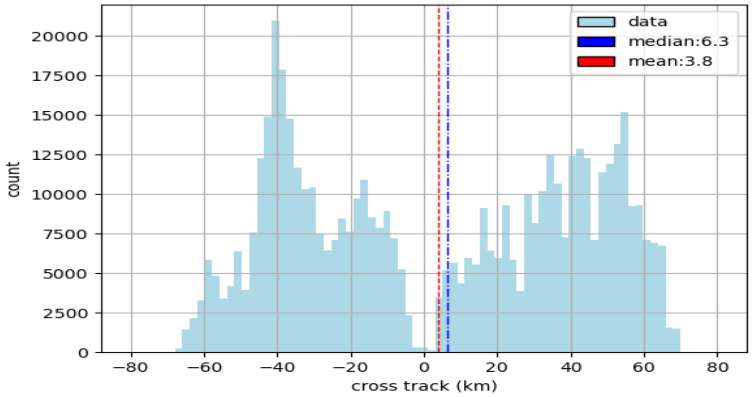
- Not exactly same as global distribution, but not unsimilar

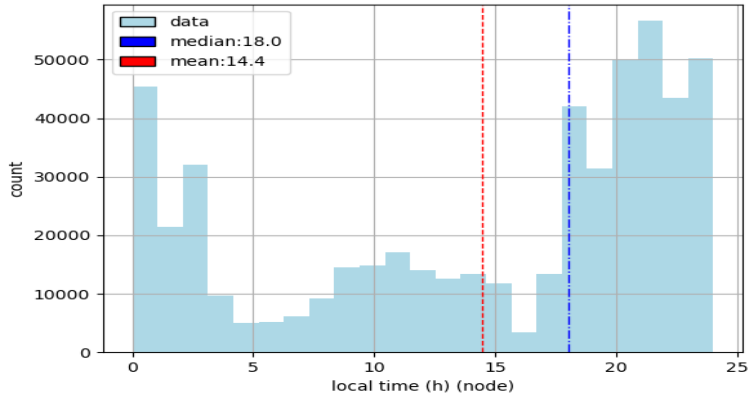
CDF







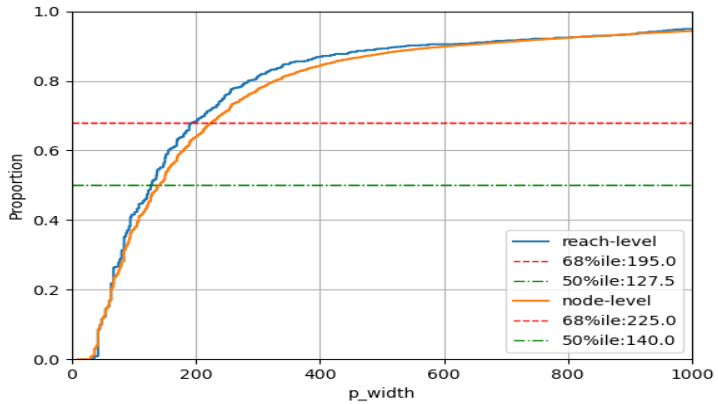


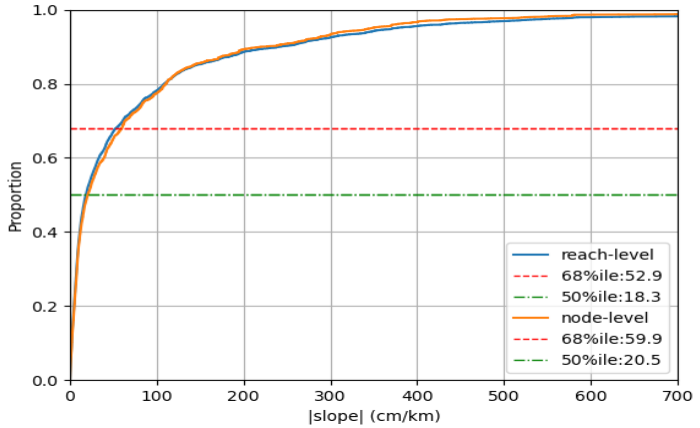


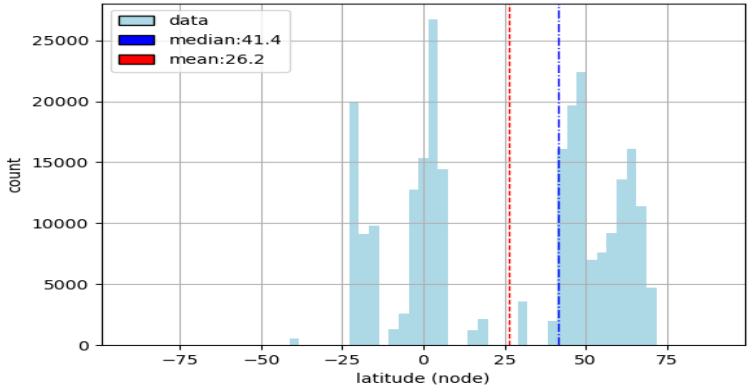
Global Sites Distributions

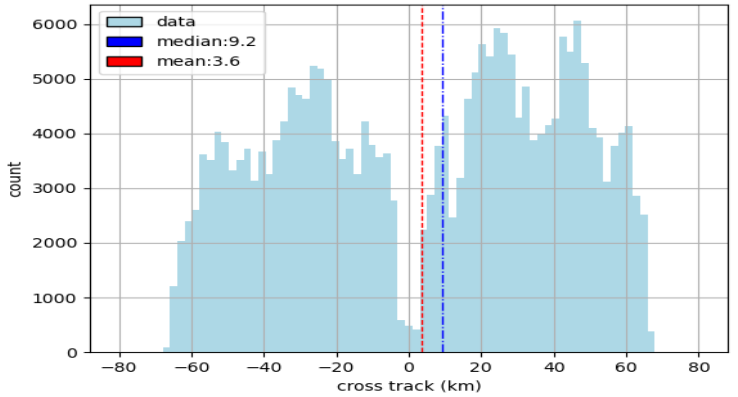
- Good sampling in cross-track
- More uniform sampling in time of day than cal/val sites

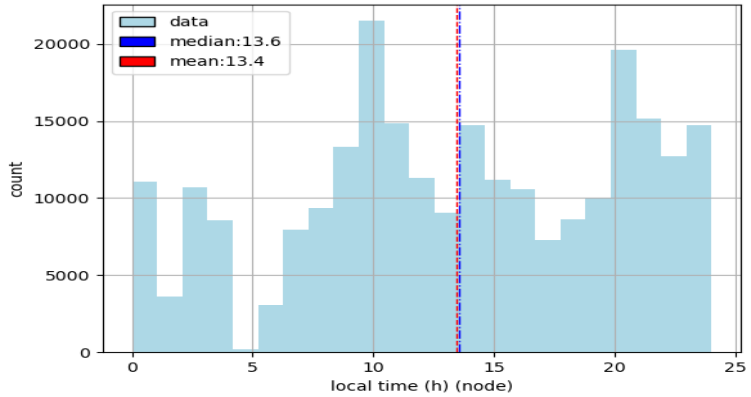
CDF





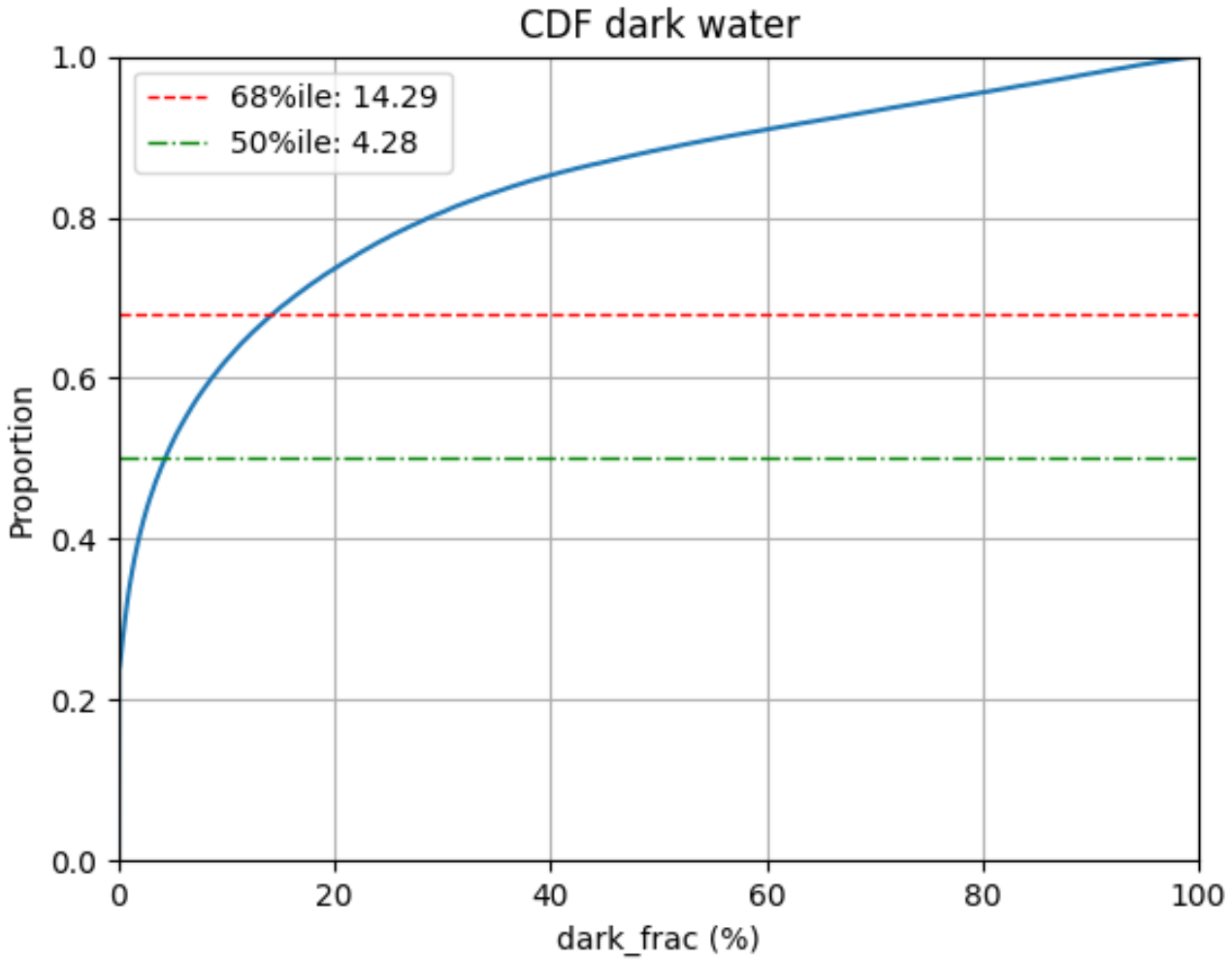






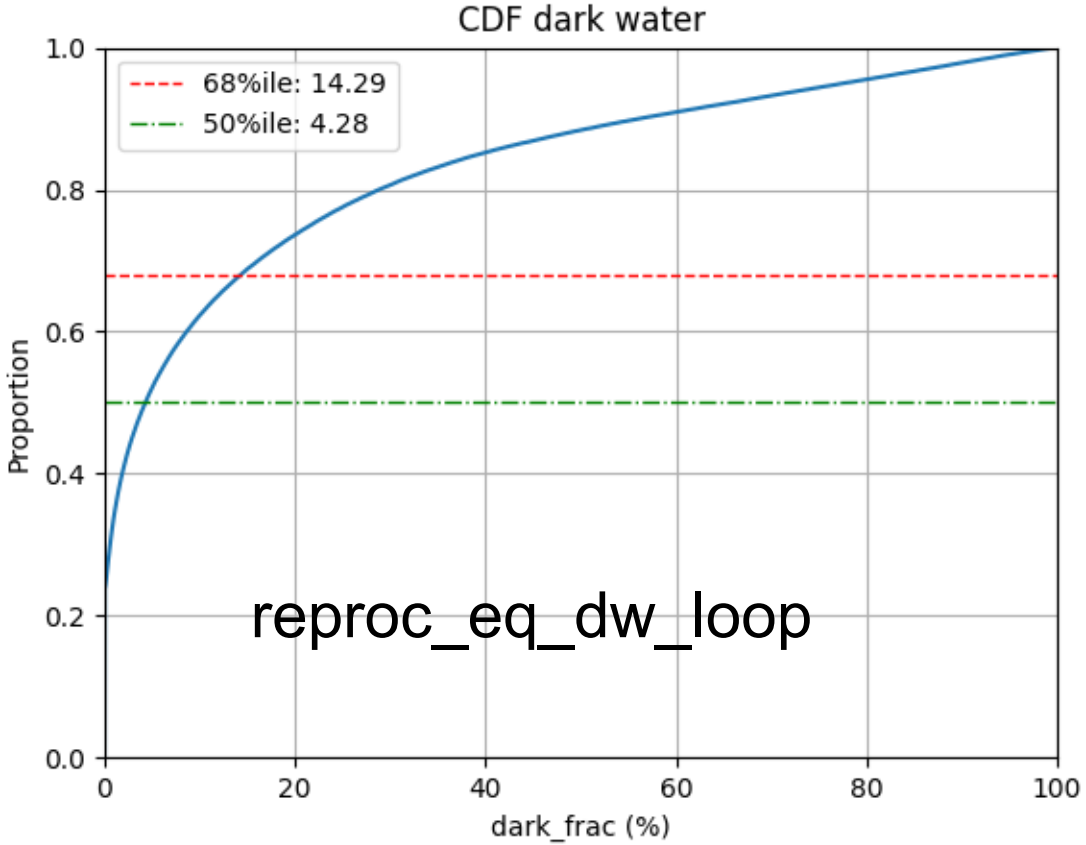
Dark Water: Lake size distributiion

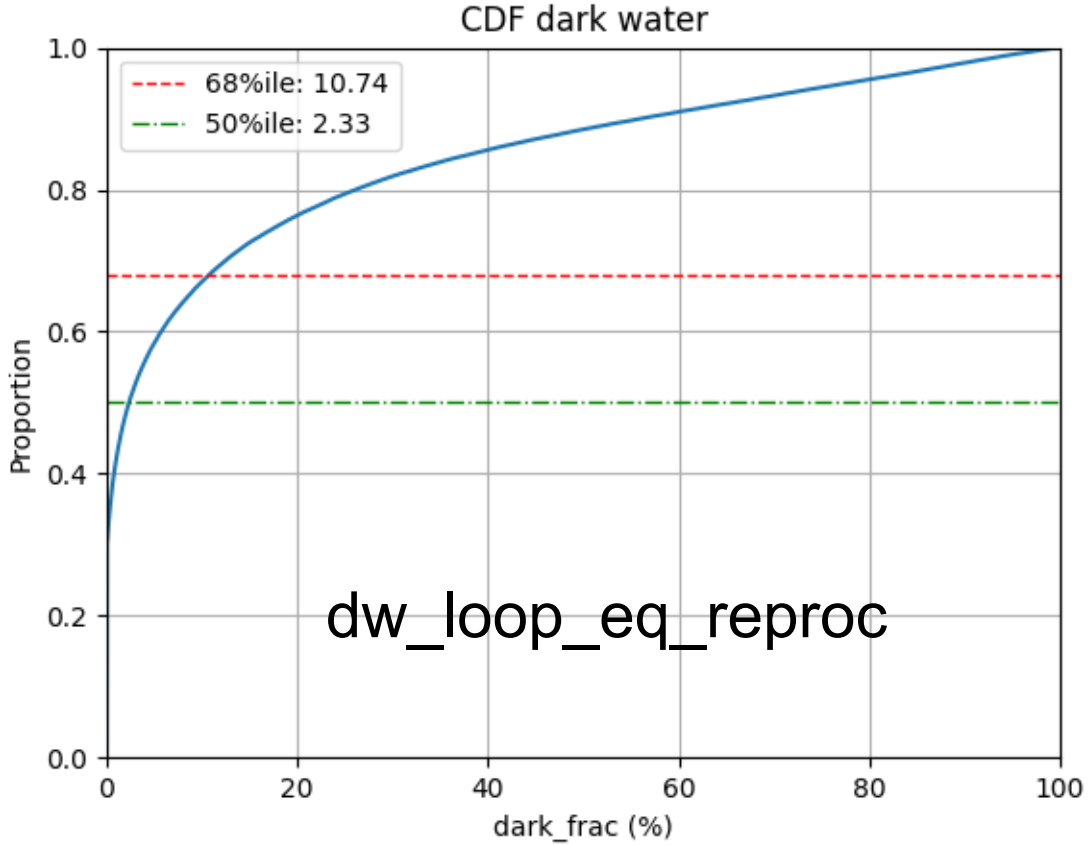
- DW_LOOP_ALL



Dark Water: Lake Version C vs Development

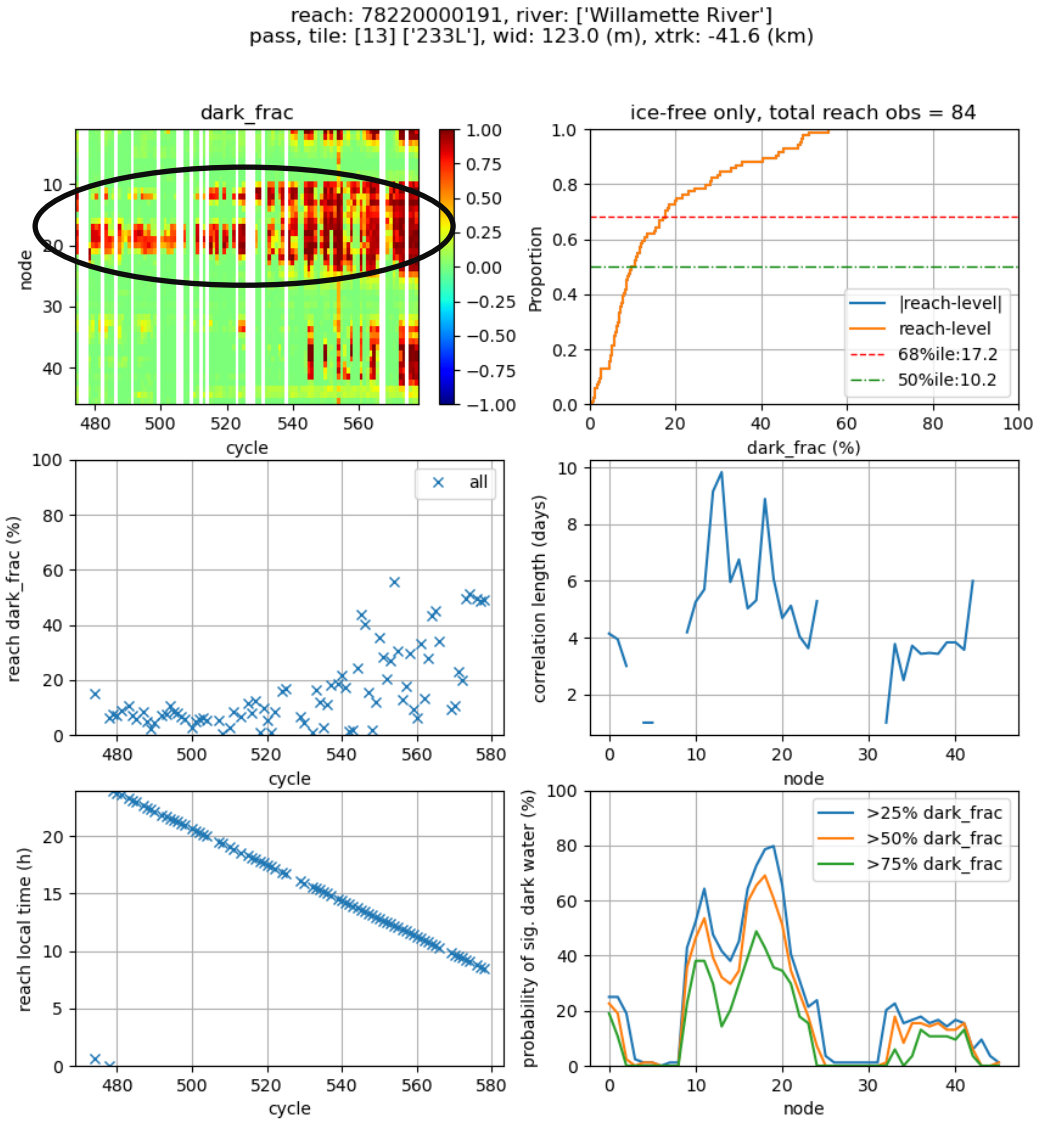
- Smaller dataset compared, consistent lakes/tiles between the two
- Development version is generally better
- Version C has additional bias
- Version C still shows general trends vs cross-track, time, and size still (not shown)





Per-reach Metrics (Willamette)

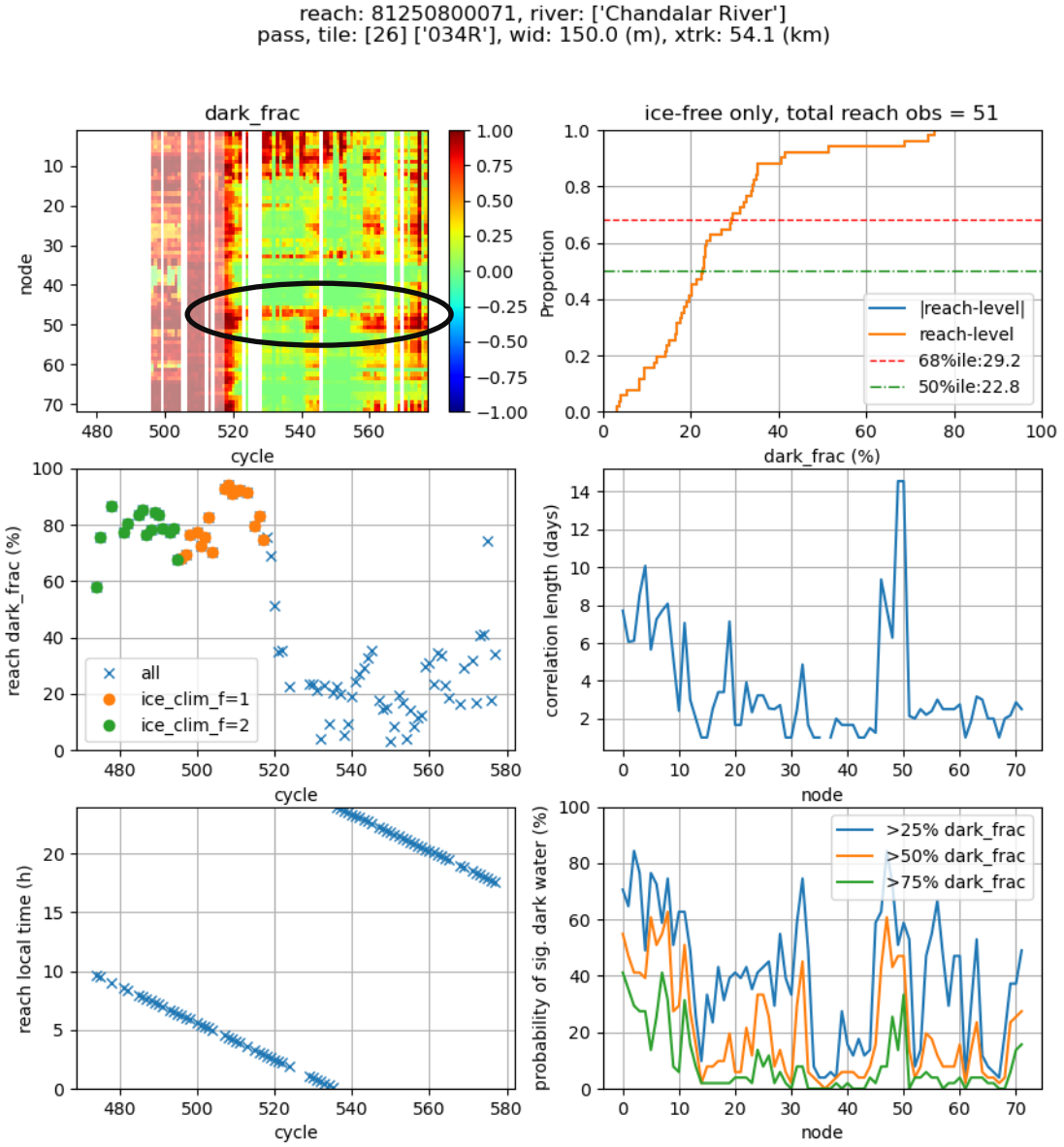
- Cal/Val Site Example
- Some nodes are persistently dark through time
  - Sometimes issue with prior mask, but sometimes real
  - May also be tied to sampling at a similar time of day over many consecutive passes
- Local time sweeps almost through whole day over the cal orbit
- Per node metrics can be mapped to river shapefiles to create maps of dark water occurrence rates and temporal persistence through time
- Dark water may also correlate with flow state
  - Higher flow in Willamette in the earlier cycles
  - Next steps: investigate dark water vs wse anomaly?



Per-reach Metrics (Yukon)

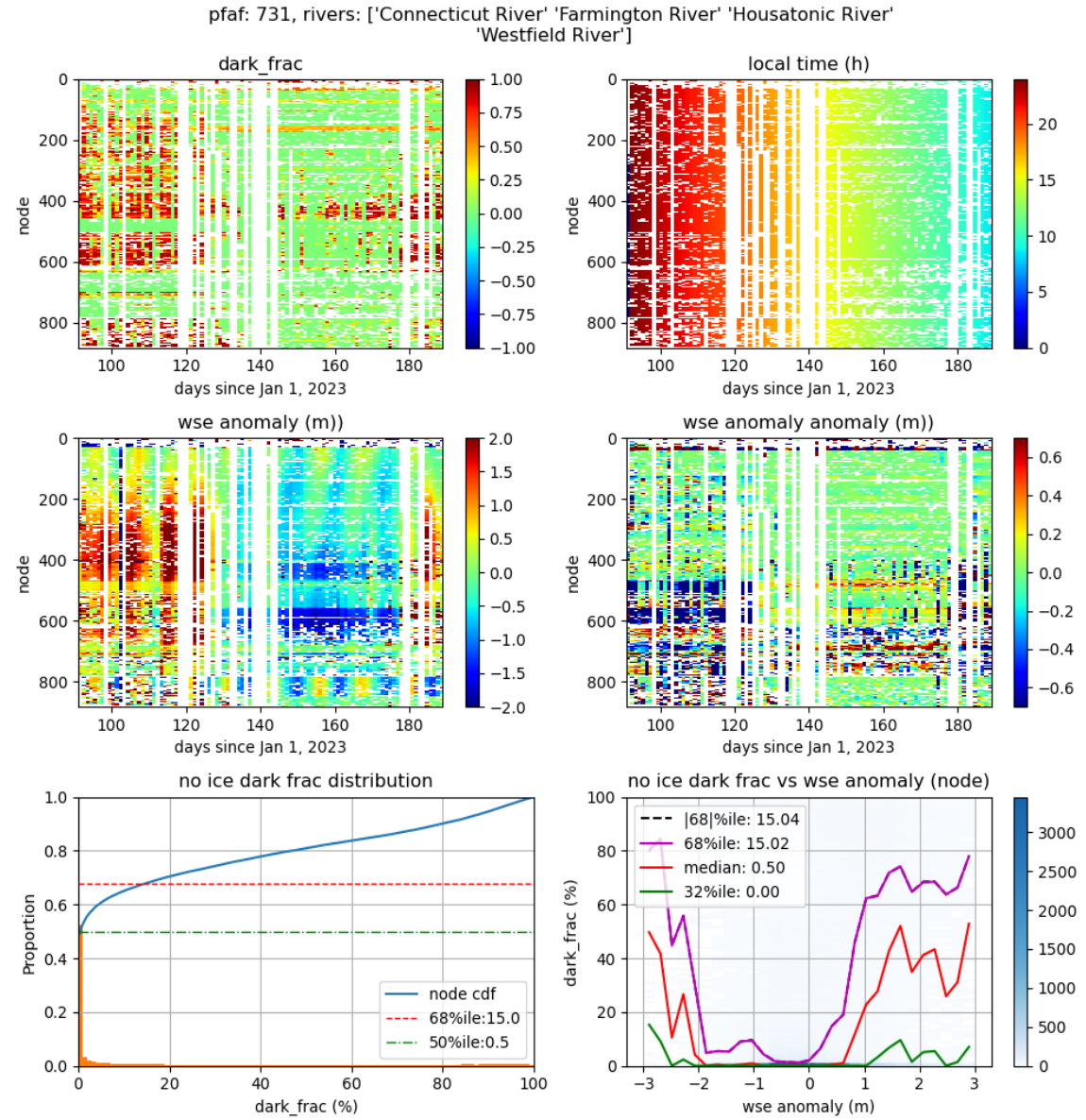
- Cal/Val Site Example

- This case ice covered up until cycle ~520
- Some nodes are persistently dark through time
  - Sometimes issue with prior mask, but sometimes real
  - May also be tied to sampling at a similar time of day over many consecutive passes
- Local time sweeps almost through whole day over the cal orbit
- Per node metrics can be mapped to river shapefiles to create maps of dark water occurrence rates and temporal persistence through time



Pfafstetter Plots

- Wse anomaly (flow state) is wse minus estimate of mean profile (aggregating over time)
  - Shows flow waves propagating through river network (because of hydropeaking)
- Wse anomaly anomaly is wse minus the reach wse at each time minus time averaged version of wse-reach wse
  - Should show how the average profile distorts at different flow states
  - Doesn't seem to have obvious structure related to the hydropeaking
- Dark water may have a relationship with flow state
  - Hard to tell if high dark rates at extreme flow states is real (e.g., less data there)
  - Trend is not common among different basins



Pfafstetter Plots

- Wse anomaly (flow state) is wse minus estimate of mean profile (aggregating over time)
  - Shows flow waves propagating through river network (because of spring melt)
- Wse anomaly anomaly is wse minus the reach wse at each time minus time averaged version of wse-reach wse
  - Should show how the average profile distorts at different flow states
  - Doesn't seem to have obvious structure related to changes in flow state
- Dark water may have a relationship with flow state
  - Possibly lower dark rates at higher flow?
  - Hard to tell if high dark rates at extreme flow states is real (e.g., less data there)
  - Trend is not common among different basins