National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

# Surface Water and Ocean Topography Mission (SWOT) Mission

# River Product Water Surface Elevation (WSE) and Slope Validation, Features, and Issues

## SWOT Science Team Meeting
## June 2024

**Cassie Stuurman**[1]
on behalf of JPL/CNES Algorithm and Cal/Val Team

[1]Jet Propulsion Laboratory, California Institute of Technology

# Outline

## Part 1: River WSE/slope product validation

1. Review of data for comparisons
2. Mathematical definitions
3. Node-level WSE performance estimate
4. Reach-level slope & WSE performance estimate
5. Variability by river site
6. Comparisons against other independent estimates (Vortex.io, T3)
7. Relationships with quality; dark water; river width
8. Expected performance of future deliveries
9. Summary and conclusions

## Part 2: River Product WSE & slope features/issues

11. Symptoms of SWOT issues and their origins/occurrences
    11.1. Anomalies in river height profiles
    11.2. Other product symptoms
12. Summary and conclusions

# Part 1

## River slope & water surface elevation (WSE) product validation

# 1: Data for performance estimations

## 1a: Tier 1 In-situ data inclusion criteria

| | GNSS Drift Data | Pressure Transducer (PT) Data |
|---|---|---|
| **Temporally** | ≤8 hours OR matched to river stage by PT | ≤15 min |
| **Spatially** | Matched to SWORD; min. 80% reach coverage | Matched to SWORD; min 2 PT per reach |
| **Quality Flag** | N/A | **Good/suspect** quality only |
| **Bias-corrected** | ≥6 SWOT overpasses | ≥6 SWOT overpasses |

We compared SWOT WSE measurements to both GNSS drift data and PT (pressure transducer) in-situ data.

These data were **matched to the river stage** and **node/reach locations** of SWOT.

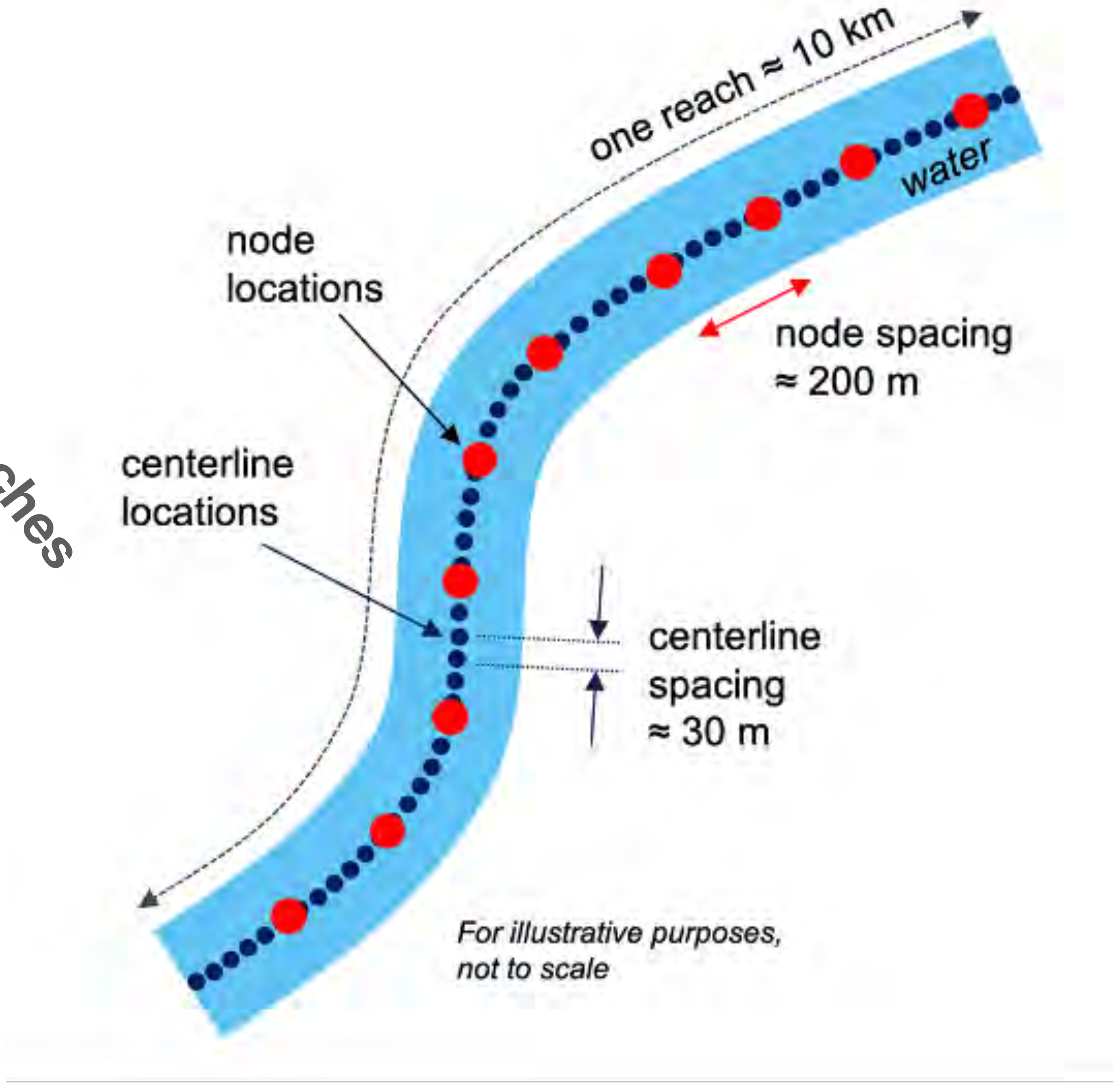
# 1: Data for performance estimations

## 1b: SWOT Data Inclusion Criteria

| | SWOT River Node | SWOT River Reach |
|---|---|---|
| **Cross-track** | 10-60 km | 10-60 km |
| **Prior channel width** | ≥ 80 m | ≥ 80 m |
| **Prior reach length** | N/A | ≥ 7 km |
| **Observed %** | N/A | ≥ 50% |
| **Quality Flag** | Good, suspect, & degraded | Good, suspect, & degraded |
| **Dark Fraction** | ≤ 50% | ≤ 50% |
| **Data versions** | Version C; dev* | Version C; dev* |

**60-70% of nodes**

**70-80% of reaches**



# 1: Data for performance estimations

## 1b: SWOT Data Inclusion Criteria

| | SWOT River Node | SWOT River Reach |
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60-70% of nodes

70-80% of reaches

Most results in this presentation apply these critera. The upper three are based on the science requirement bounds, and the lower are related to SWOT quality.

When we apply the quality filters, we maintain **70-80% of reach slope/WSE** and **55-70% of node WSE** values.

I will also share some data where these filters are modified or not applied, and explore the changes in our performance estimate with each variable.

# 1: Data for performance estimations

## 1b: SWOT Data Inclusion Criteria

| | SWOT River Node | SWOT River Reach |
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**60-70% of nodes**

**70-80% of reaches**

*In this presentation you will see both **public ("Version C") & developmental** SWOT river data.

"Developmental" RiverSP means the **latest software the algorithm team has developed** for next release.

The developmental results also use developmental upstream PIXC data with the dark water projection fix (which is not yet public).

# 1: Data for performance estimations

## 1c: US Tier 1 Field method pros & cons

In this slide deck I'll review reach and node performance using a variety of approaches, with an emphasis on the US Tier 1 dataset.

# 1: Data for performance estimations

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Each in-situ methodology has its pros & cons.

# 1: Data for performance estimations

## 1c: US Tier 1 Field method pros & cons

In this slide deck I'll review reach and node performance using a variety of approaches, with an emphasis on the US Tier 1 dataset.

Each in-situ methodology has its pros & cons.

GNSS Drift data provide our best estimate of the **WSE profile of the entire reach**, but may introduce temporal differences for river sites that change in stage rapidly (degrading slope performance).

# 1: Data for performance estimations

## 1c: US Tier 1 Field method pros & cons

In this slide deck I'll review reach and node performance using a variety of approaches, with an emphasis on the US Tier 1 dataset.

Each in-situ methodology has its pros & cons.

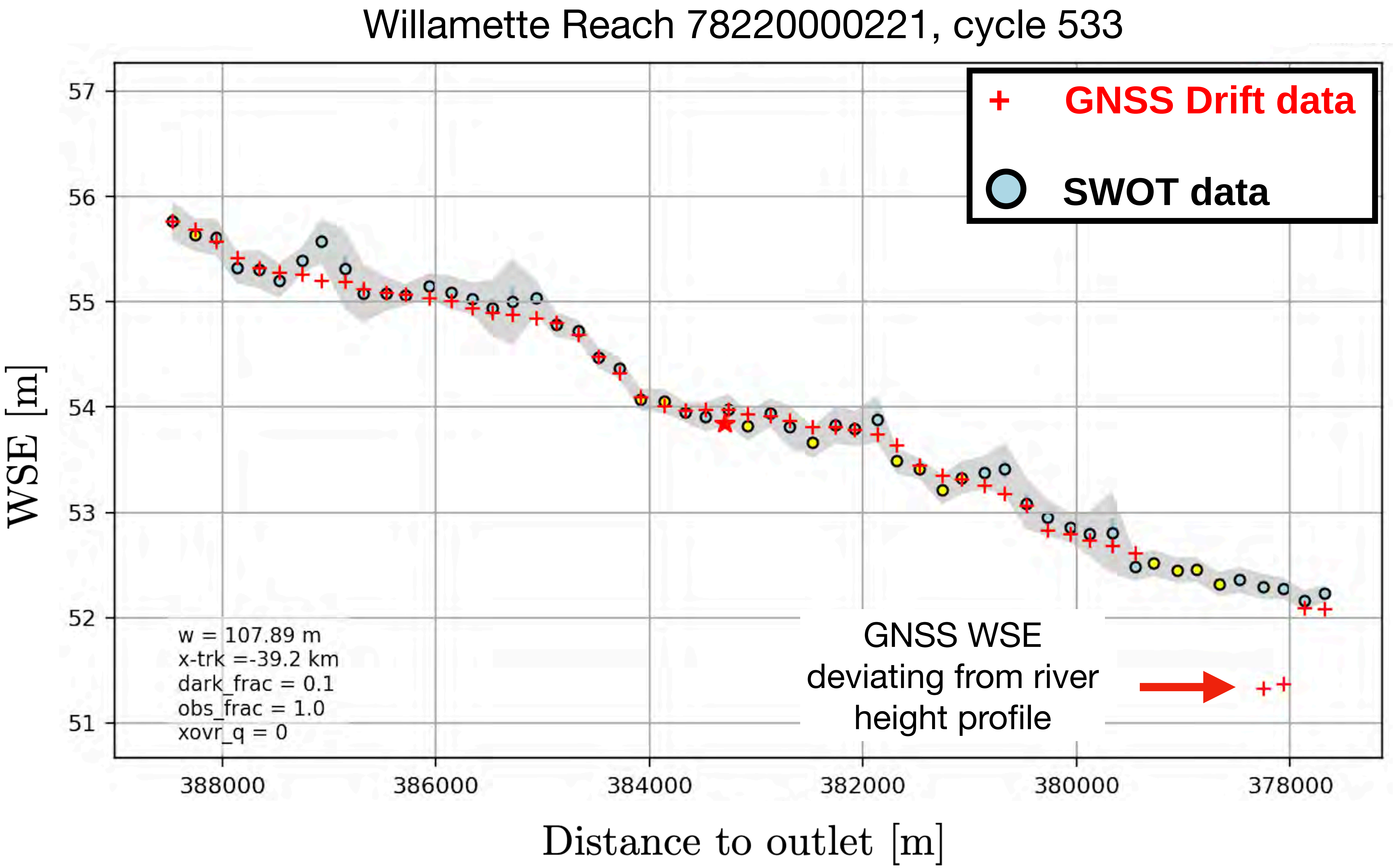
GNSS Drift data provide our best estimate of the WSE profile of the entire reach, but may introduce temporal differences for river sites that change in stage rapidly (degrading slope performance).

PT data have limited spatial sampling but excellent temporal sampling. **They are the gold standard for slopes and node-level WSE**, but have a lower fidelity reach WSE measurement compared to SWOT.

# 1: Data for performance estimations

## 1d: Example of GNSS Drift height profile

GNSS comparisons show SWOT does an **excellent job capturing small-scale features** in the WSE profile.

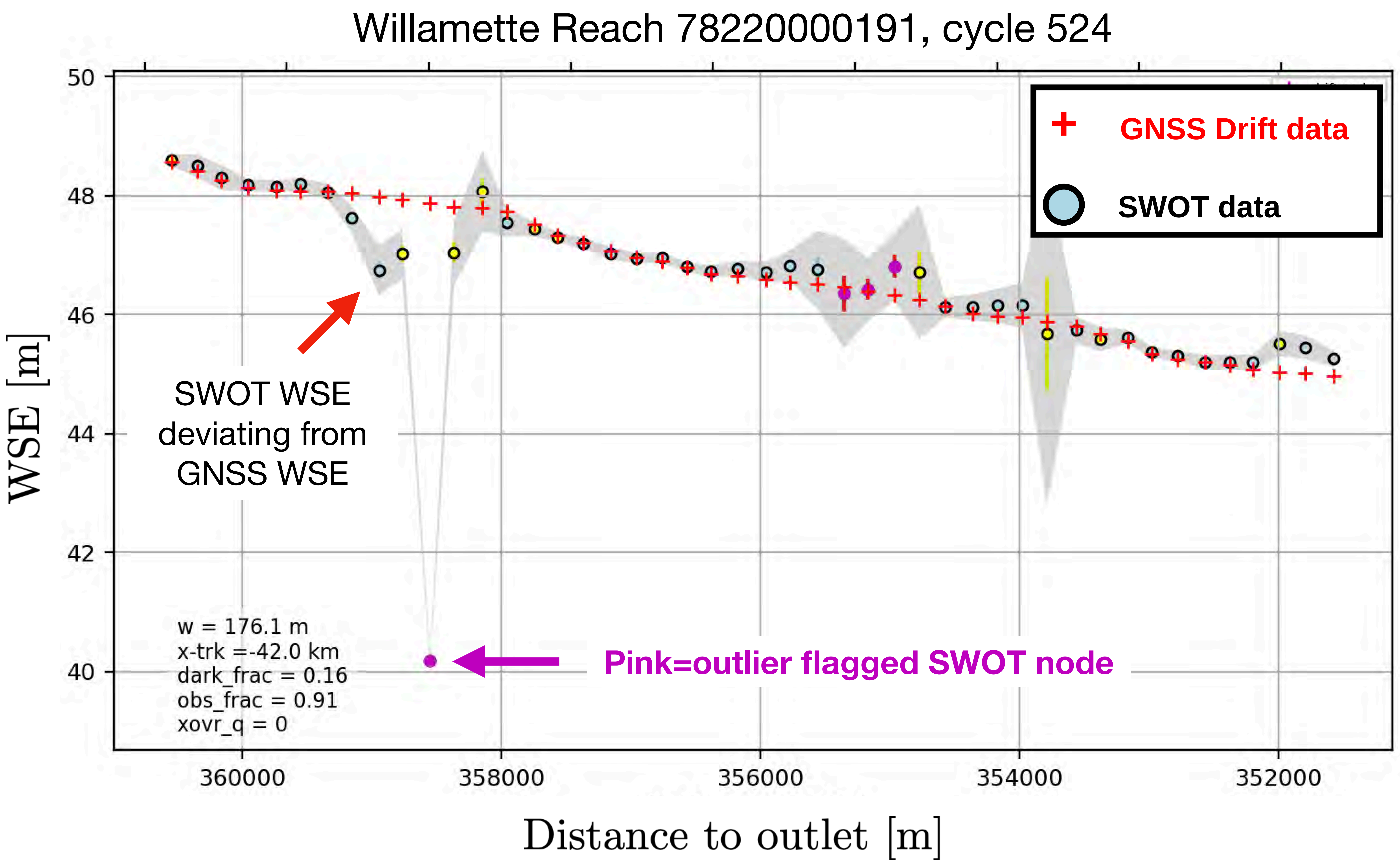


# 1: Data for performance estimations

## 1d: Example of GNSS Drift height profile

GNSS comparisons show SWOT does an **excellent job capturing small-scale features** in the WSE profile.

GNSS drift comparisons effectively capture absolute height differences across **all nodes** in a reach.



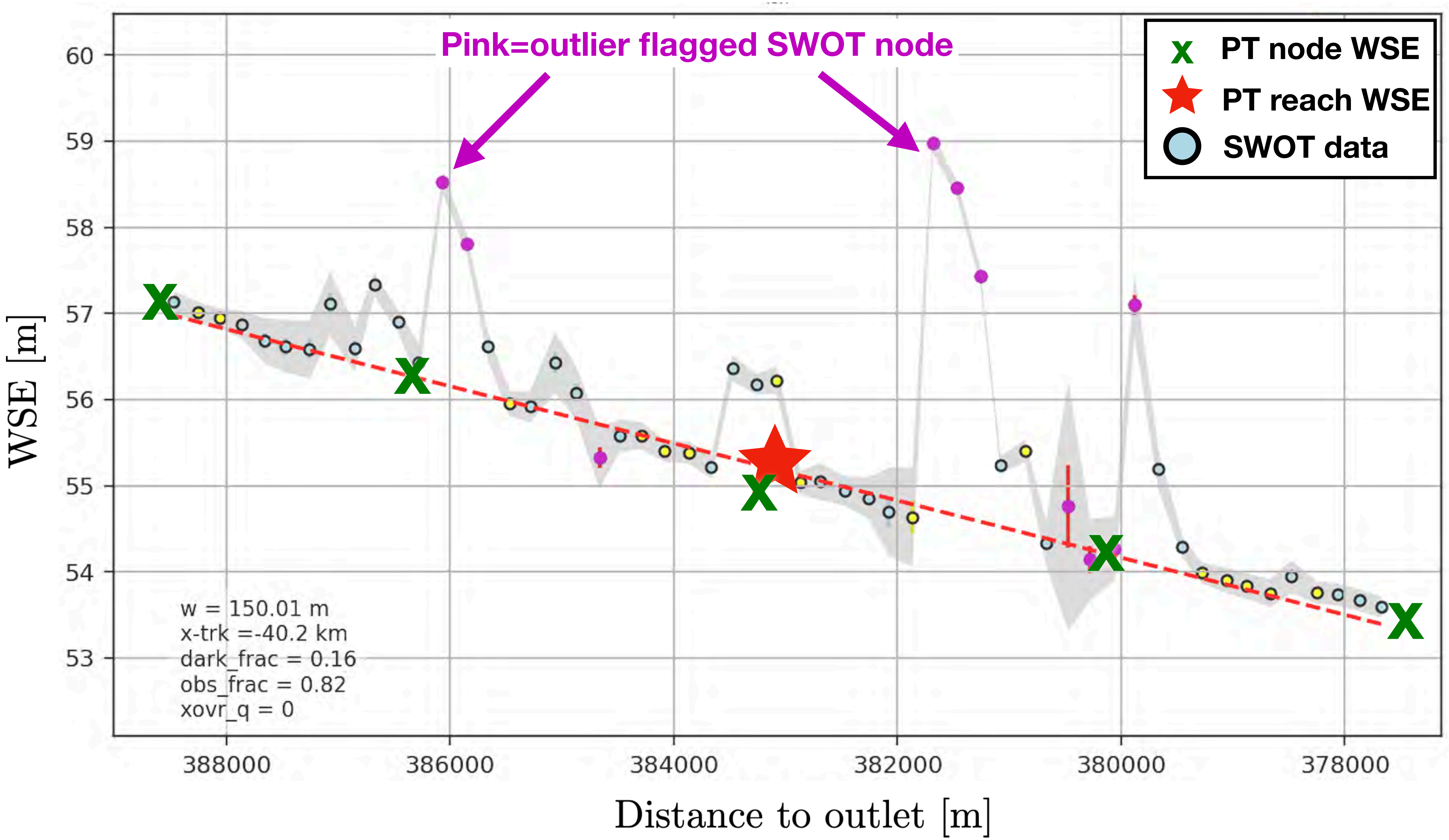
# 1: Data for performance estimations

## 1d: Example of PT height profile, Willamette 78220000221

In this example, **5 Pressure Transducers (PTs)** were placed along the reach

Each PT was used to estimate the node-level WSE.

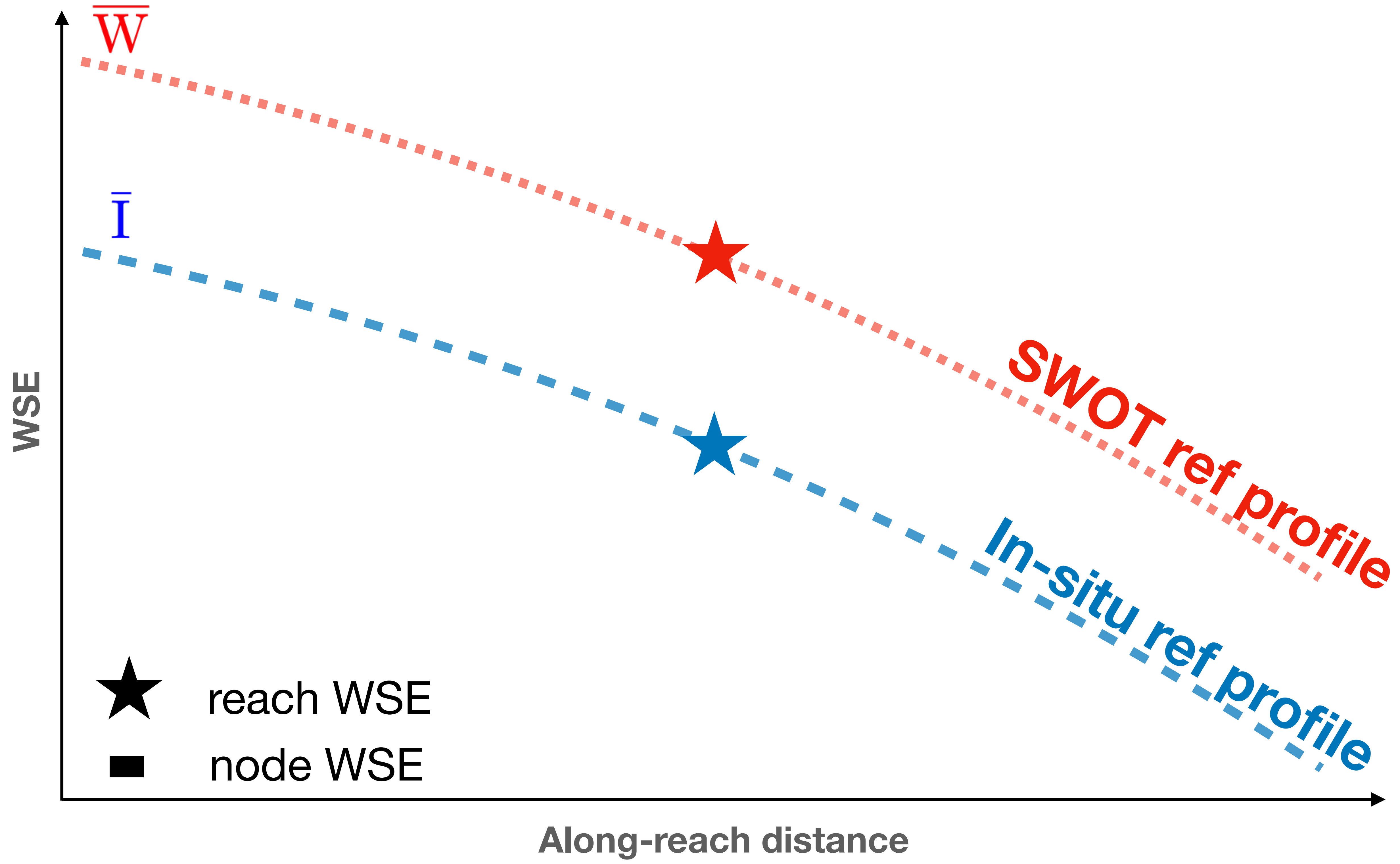
PT Nodes are then combined to estimate the in-situ, reach-level WSE and slope



# 2: Mathematical definitions

## 2a: “Reference” or “bias-corrected” reach/node WSE

Relative WSE is a measure of how well SWOT captures **changes** in river surface elevation through time.



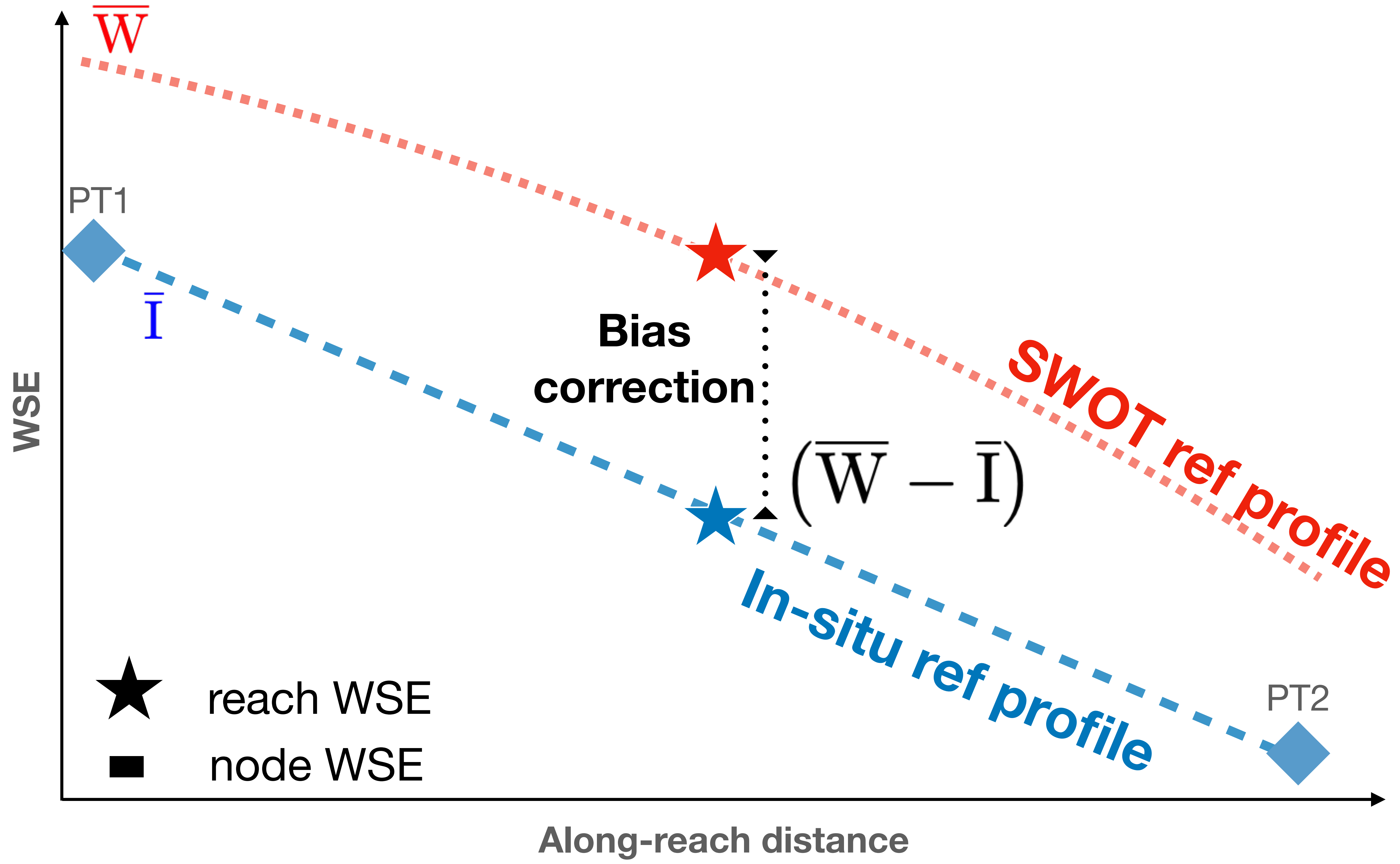

An example in-situ and SWOT averaged (or median) WSE profile. **The reach profiles are very similar, but have a WSE offset**.

This bias could be the result of **residual biases in SWOT or in-situ measurement, differences in referencing/levelling**, or **representation error** (such as PTs placed far from river nodes, or GNSS drifts in multi-channel rivers).

# 2: Mathematical definitions

## 2a: “Reference” or “bias-corrected” reach/node WSE

Differences in absolute WSE can result from residual biases in SWOT or in-situ measurement, differences in height referencing, or representation error.




For example, **all PT reach WSE measurements are expected to have a bias** due to differences in spatial sampling.

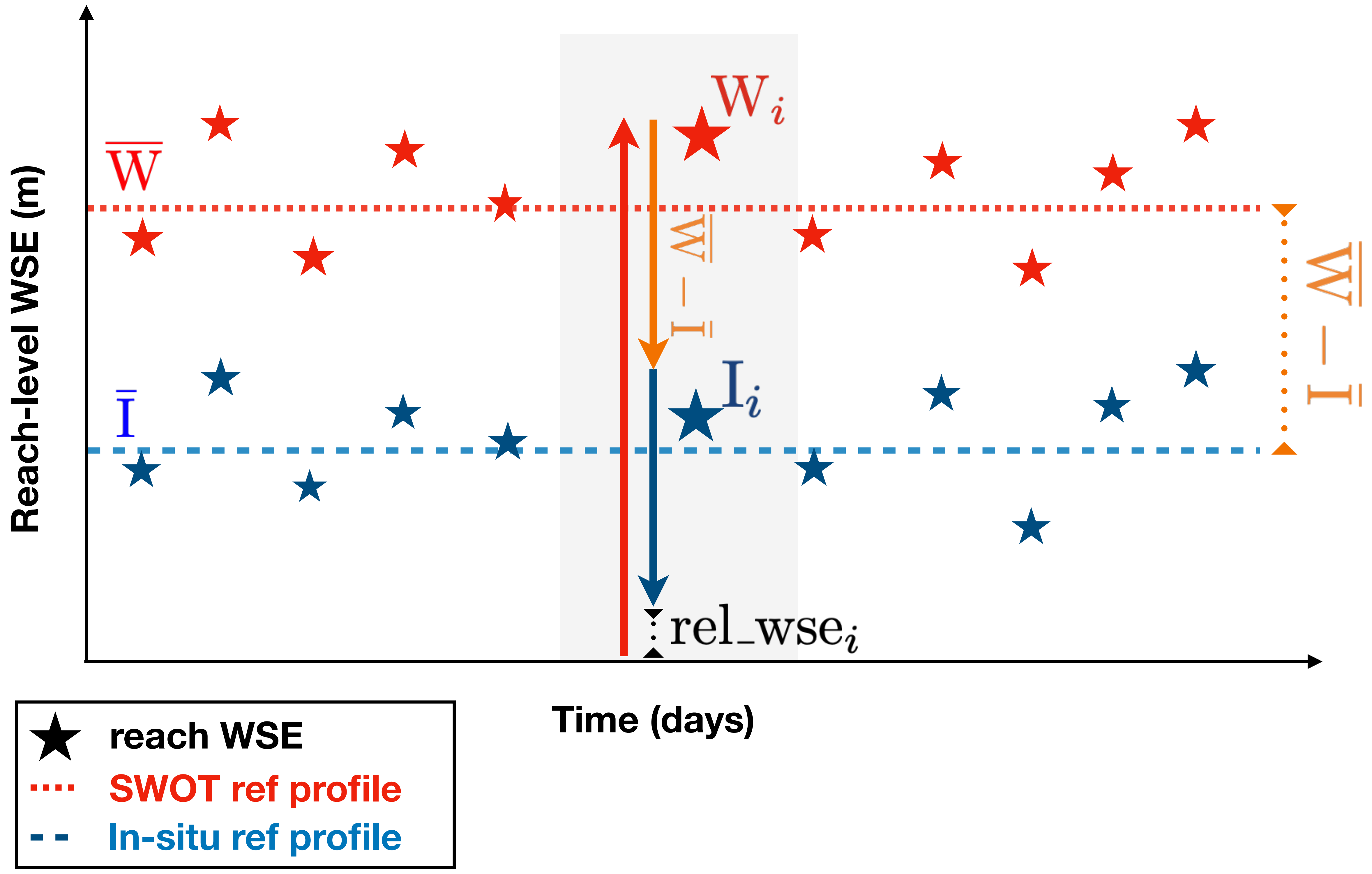
In this example we show a reach WSE computation created using only 2 nodes.

**We expect the PTs to effectively capture the changes in reach height through time, but it is not capturing the same absolute WSE measurement as SWOT**.

# 2: Mathematical definitions

## 2b: Time-series relative WSE

Each SWOT overpass has a WSE *and* relative WSE diff associated with it.




$$\text{rel\_wse}_i = W_i - I_i - (\overline{W} - \overline{I})$$

$$\text{rel\_wse}_i = W_i - I_i - \left( \frac{\sum_{j=1}^{n} w_j \cdot W_j}{\sum_{j=1}^{n} w_j} - \frac{\sum_{j=1}^{n} w_j \cdot I_j}{\sum_{j=1}^{n} w_j} \right)$$

where:

- $W_i$ is the water surface elevation (WSE) measured by SWOT for the $i$-th measurement.
- $I_i$ is the independent measurement of WSE for the $i$-th measurement.
- $w_j = \frac{1}{\text{wse\_r\_u}_j^2}$ is the weight assigned to the $j$-th measurement based on the SWOT random uncertainty.

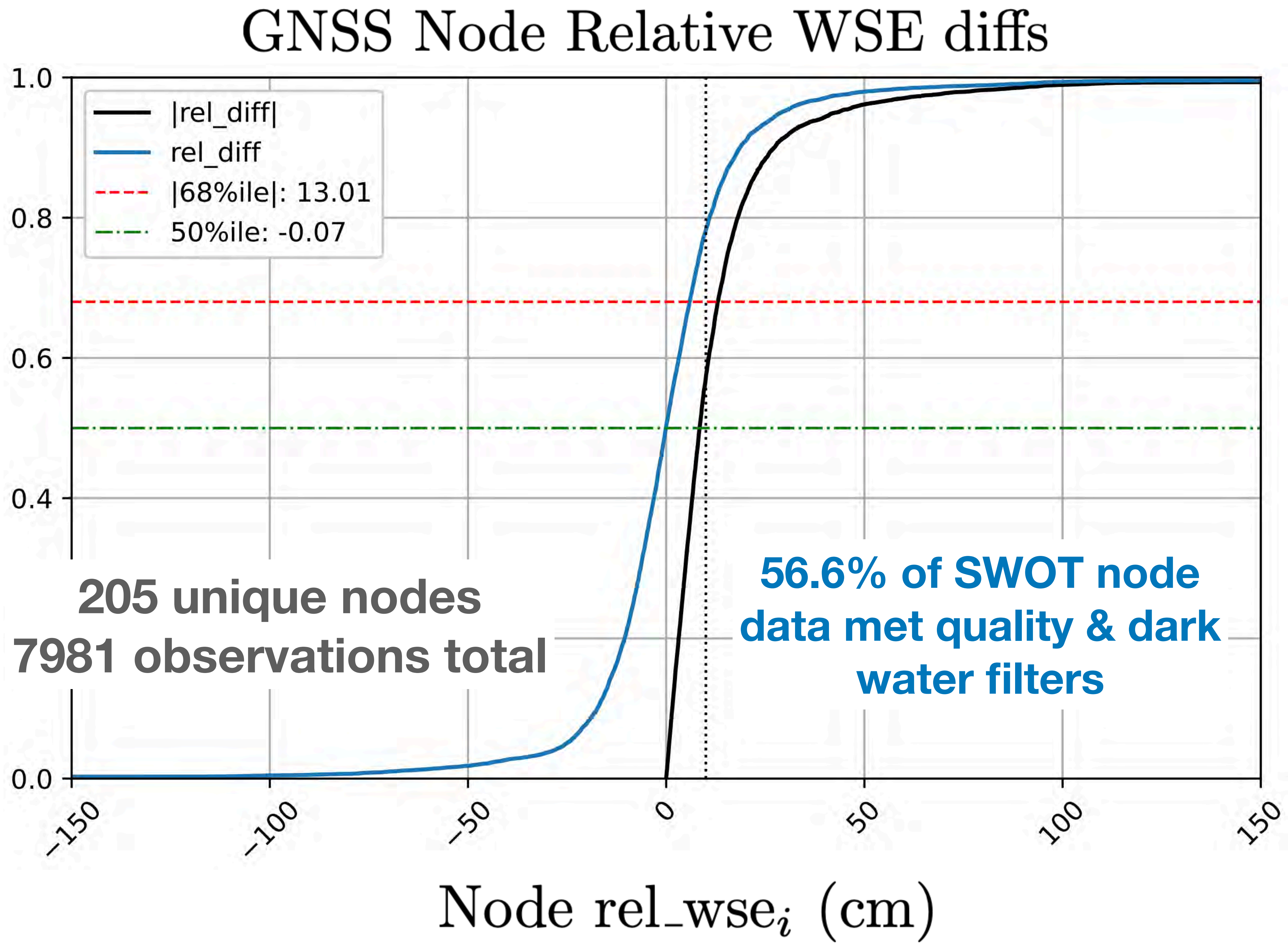
# Performance results

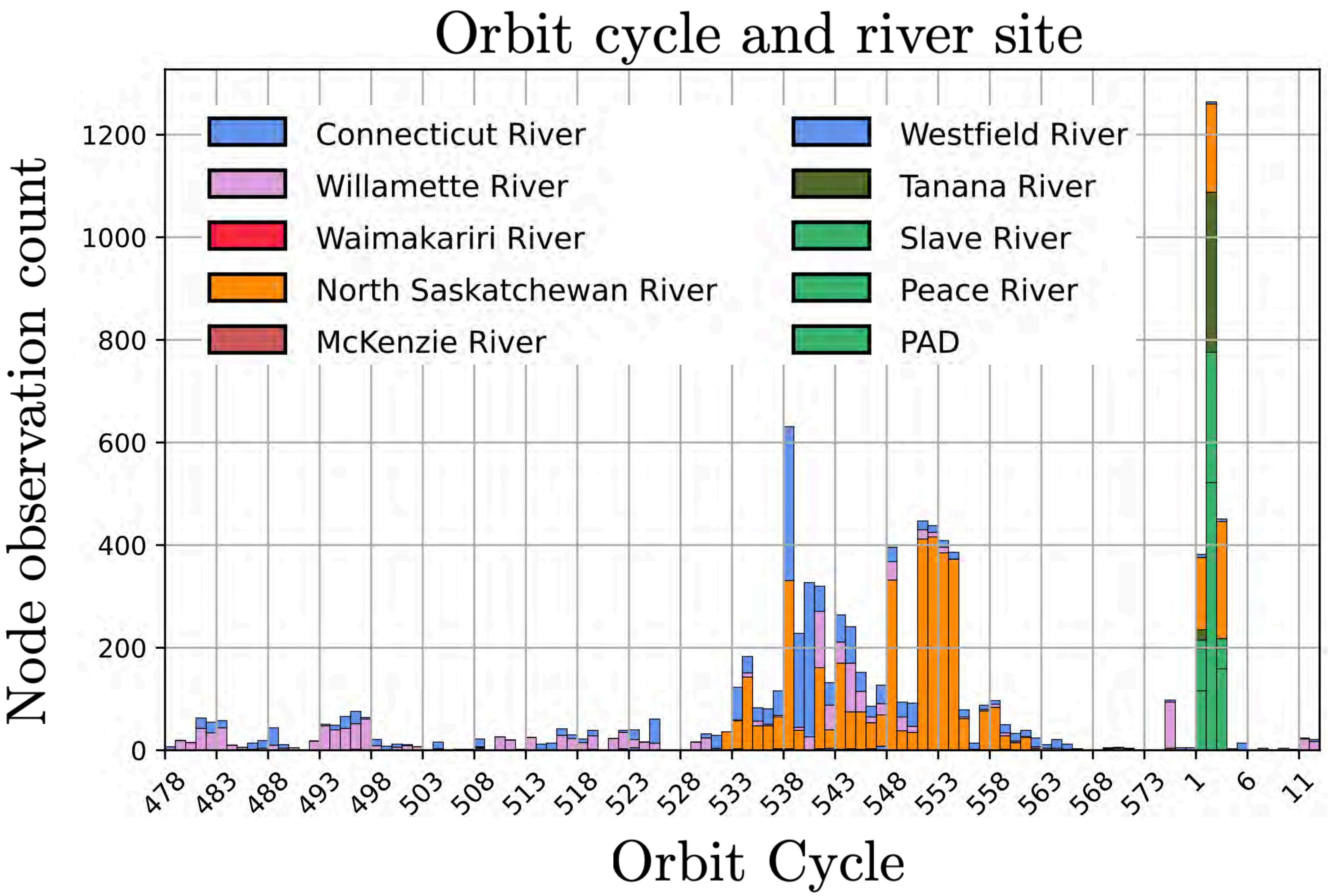
## River slope & water surface elevation (WSE) product validation

# 3: Node-level performance estimates

## Tier 1 "Version C" Water Surface Elevation & GNSS drift data

Relative WSE diff of **13.0 cm** for **GNSS node data** at |68%ile|



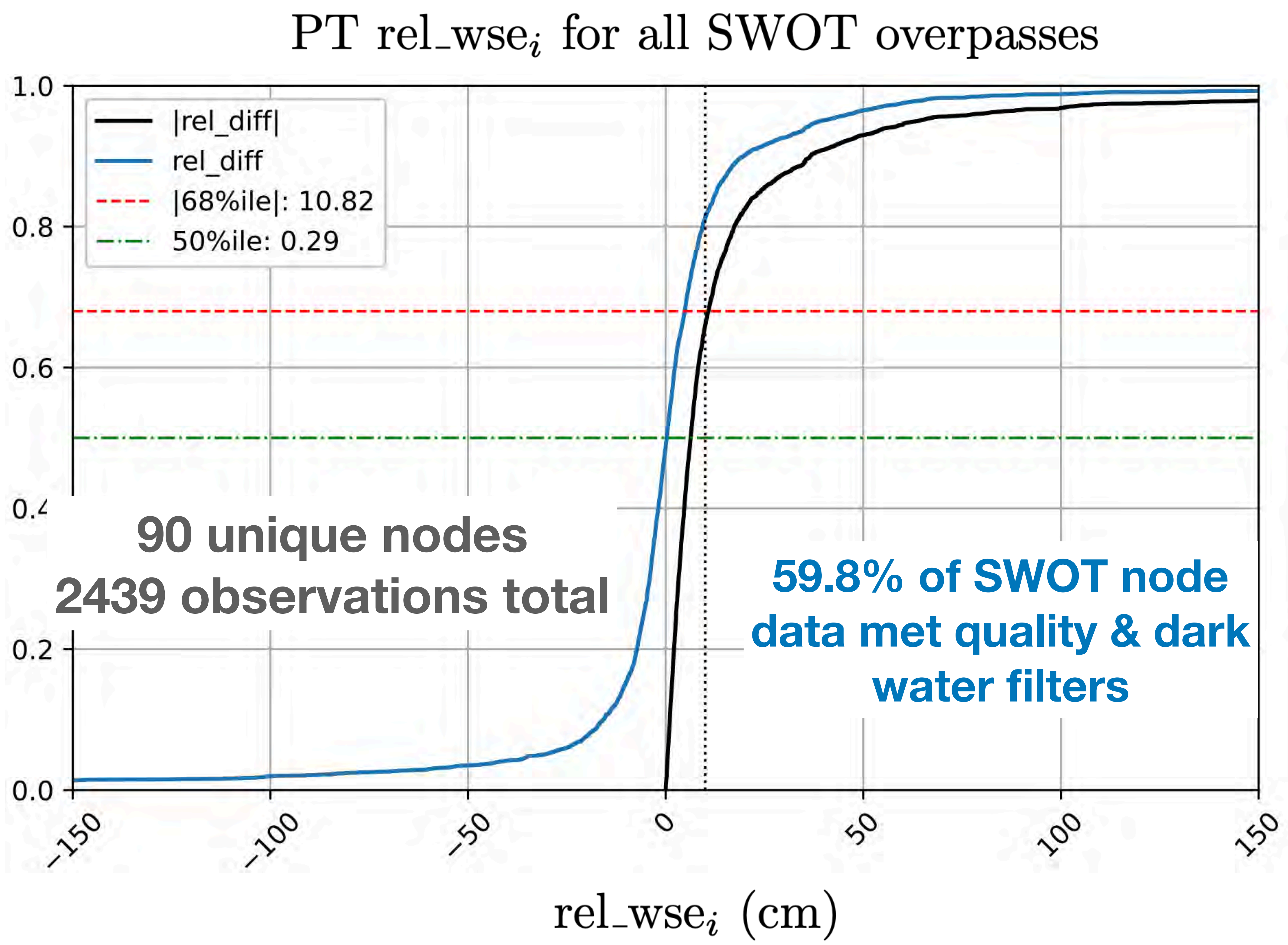



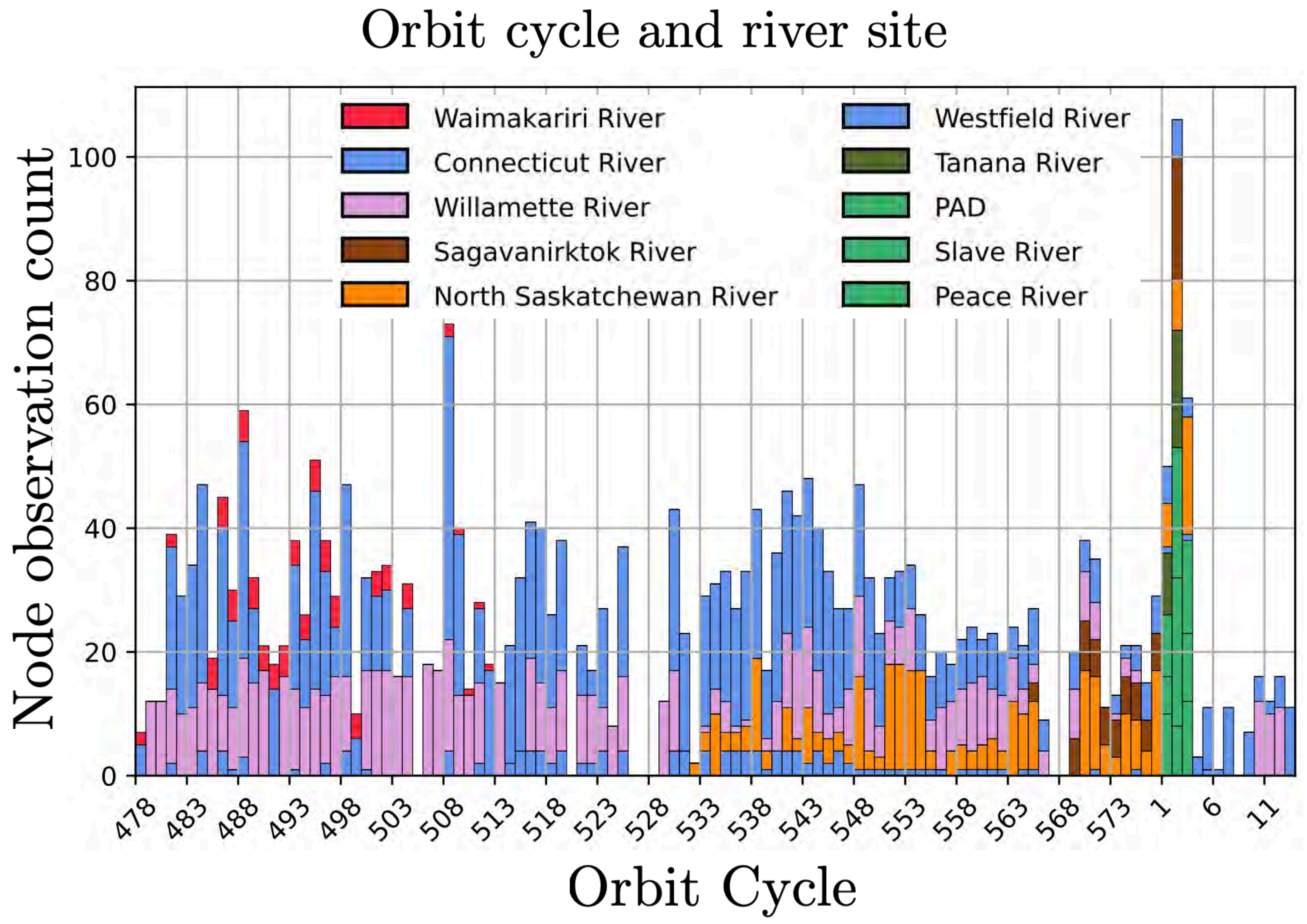
# 3: Node-level performance estimates

## Tier 1 Version C Water Surface Elevation & PT Node Data

**Relative WSE diff of 10.8 cm for PT node data at |68%ile|;** consistent with expectations vs. GNSS drift results.

We expect the PTs to produce a more accurate estimate of the node WSE during the SWOT overpass (vs. GNSS).



WSE diff result varies with river site; node WSE issues tend to persist spatially over the Tier 1 validation set.

# 3: Node-level performance estimates

## Tier 1 "Version C" Water Surface Elevation Variability

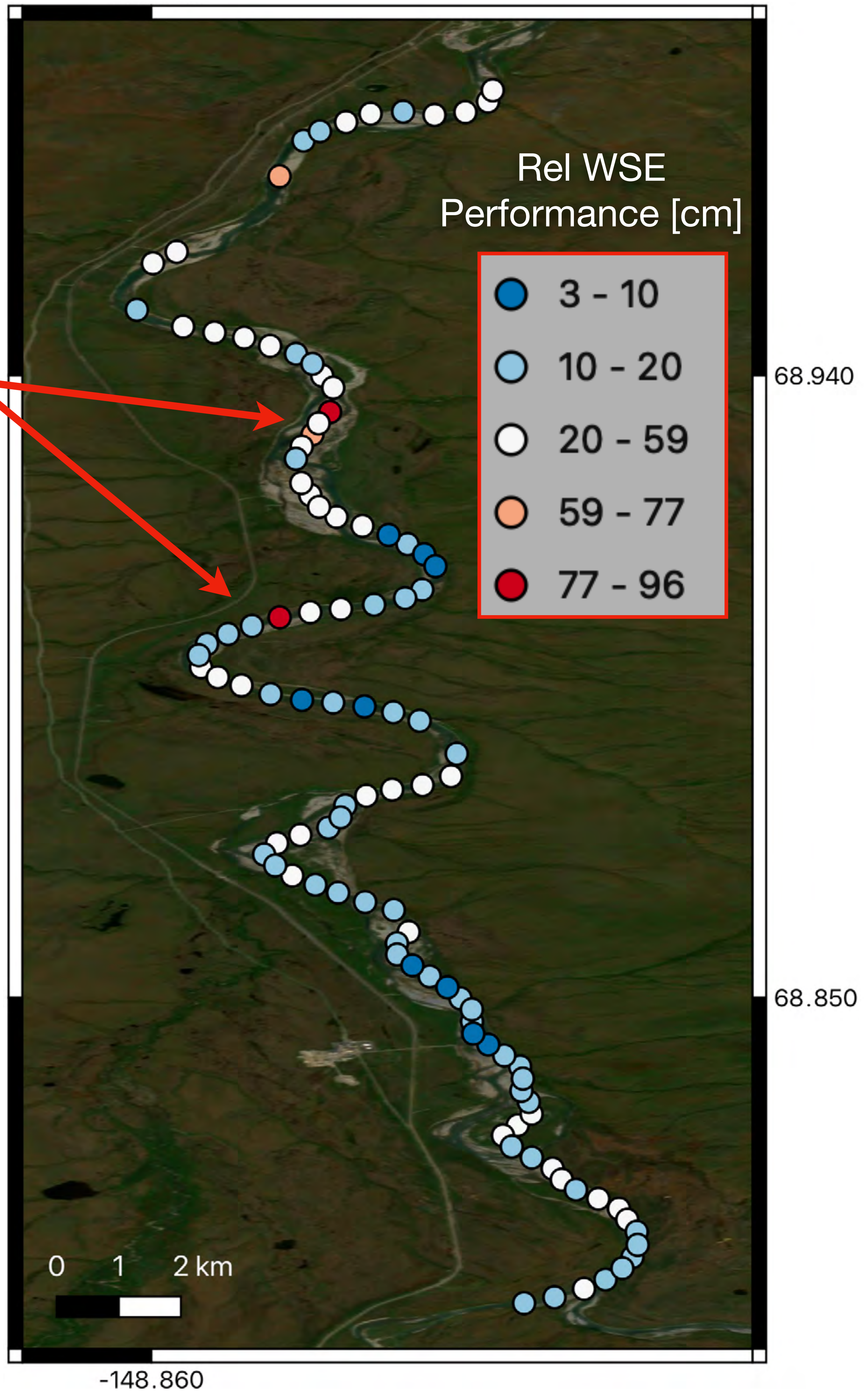
GNSS node |68%ile| wse_rel_diff_cm by river_name:

| river_name | \|68%ile\| | count |
|---|---|---|
| Willamette River | 17.3 | 1244 |
| North Saskatchewan River | 13.6 | 4200 |
| Connecticut River | 11.5 | 1777 |
| Westfield River | 10.4 | 66 |
| PAD | 9.4 | 386 |
| Peace River | 8.9 | 141 |
| Slave River | 8.7 | 92 |
| Tanana River | 5.9 | 69 |
| Waimakariri River | 5.2 | 6 |

PT node |68%ile| wse_rel_diff_cm by river_name:

| river_name | \|68%ile\| | count |
|---|---|---|
| Sagavanirktok River | 26.5 | 48 |
| North Saskatchewan River | 19.0 | 220 |
| Waimakariri River | 14.1 | 87 |
| Willamette River | 11.7 | 802 |
| Connecticut River | 8.5 | 1201 |
| PAD | 8.0 | 13 |
| Westfield River | 7.4 | 128 |

Performance of each Sagavanirktok node over all cycles observed. Most nodes perform generally well, but a minority are bad on all cycles.



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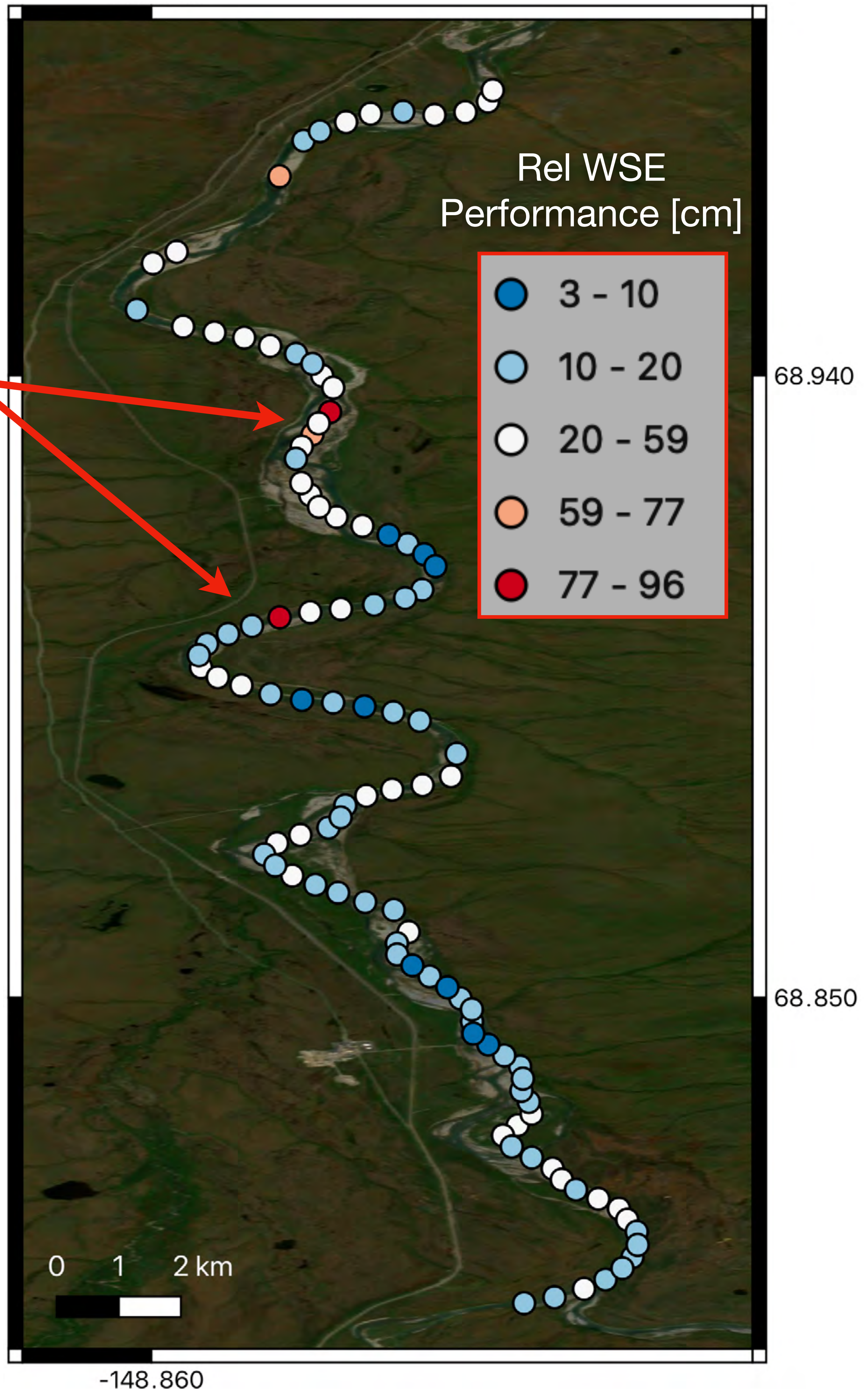
| Westfield River | 7.4 | 128 |

Performance of each Sagavanirktok node over all cycles observed. Most nodes perform generally well, but a minority are bad on all cycles.

This is consistent with the idea that most river issues are specific to target phenomenology — problems like layover, dark water, non-river waterbodies, cities, bright fields, etc are all spatially persistent.

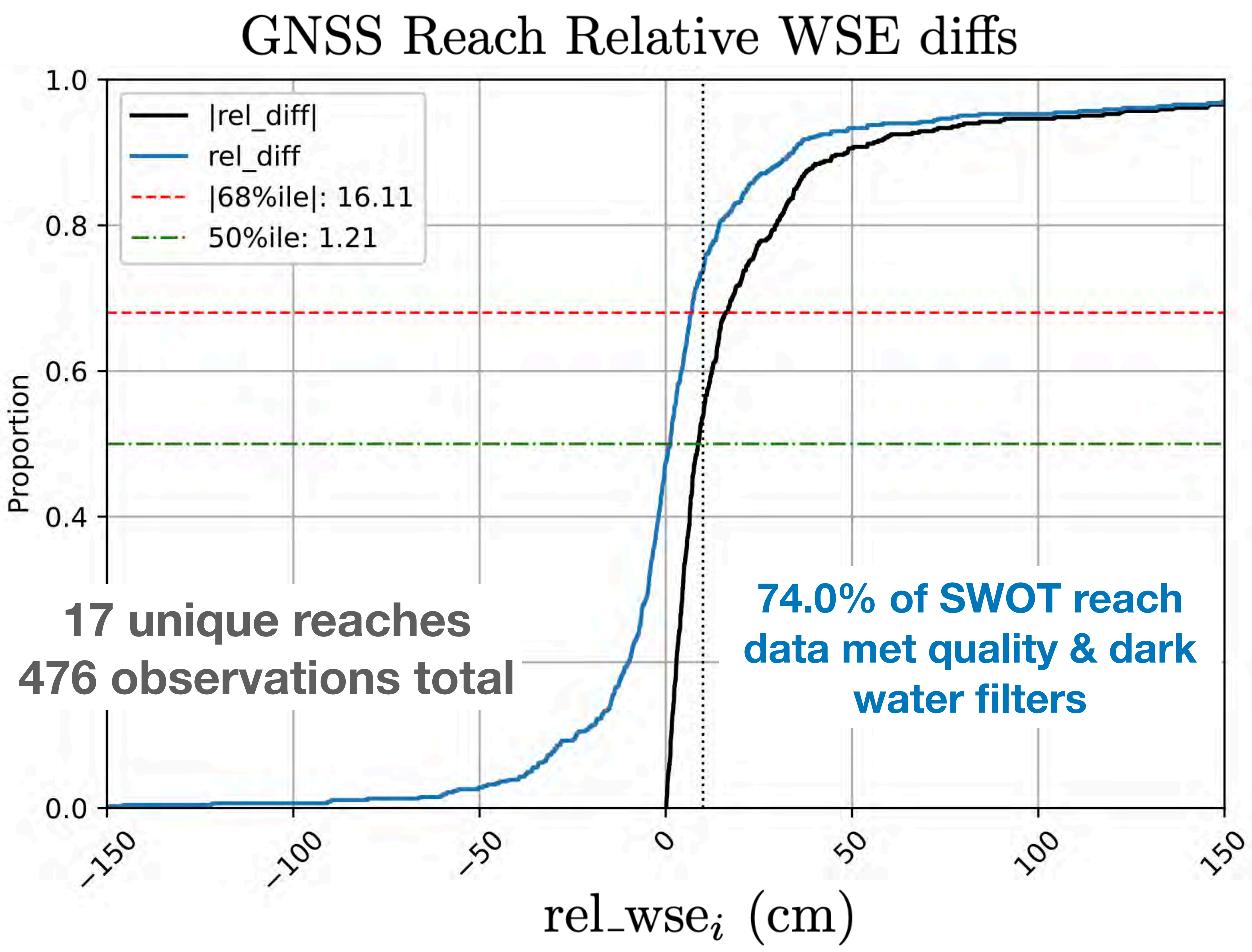
Bad in-situ measurements can also be driven by local river characteristics.

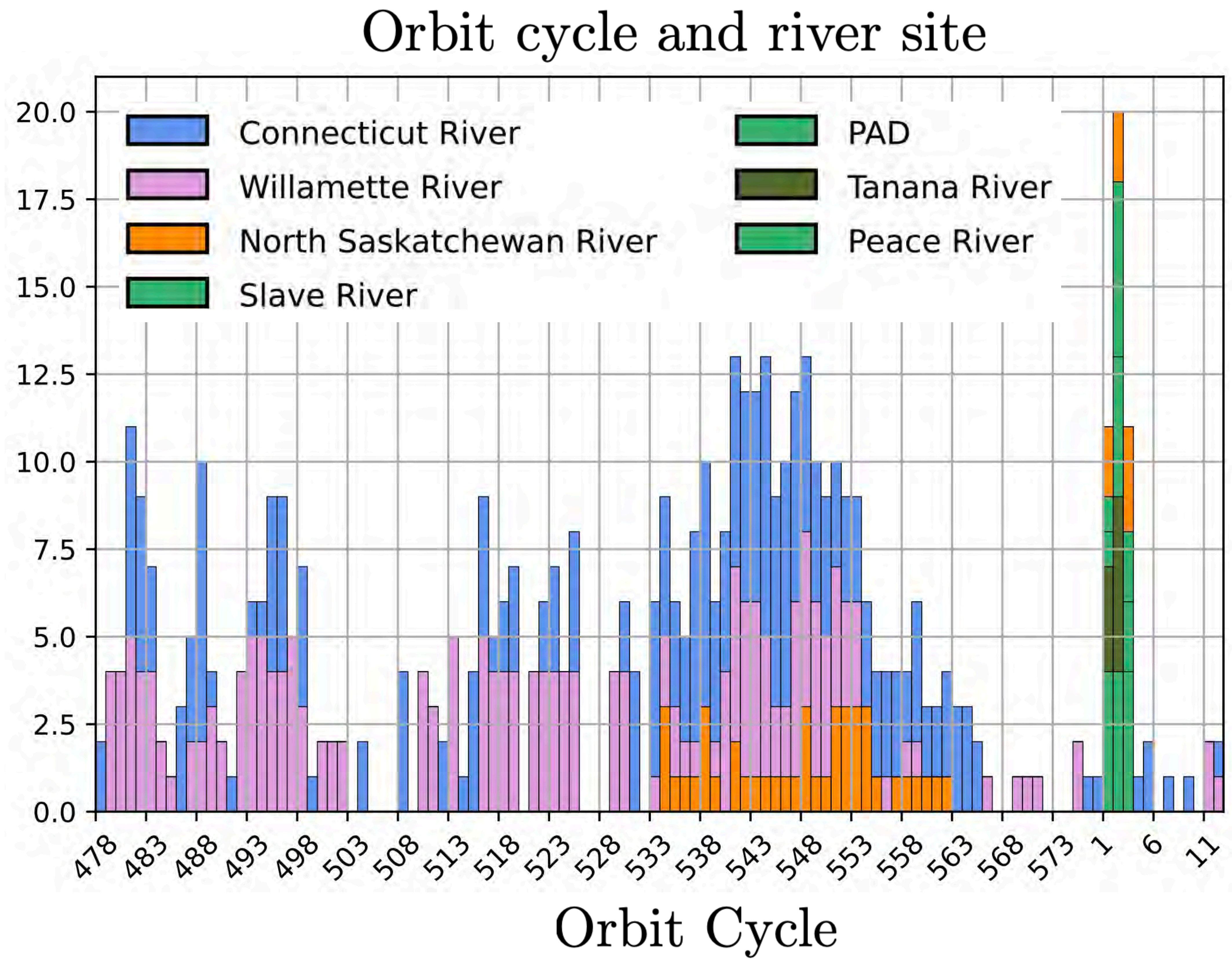


# 4: Reach-level performance estimations

## a. GNSS Drift Reach WSE data (Version C)

Relative WSE diff of **16.1 cm** for river stage matched **GNSS reach data** at |68%ile|. Notably, this is worse than the node-level GNSS performance estimate of 13.0 cm.

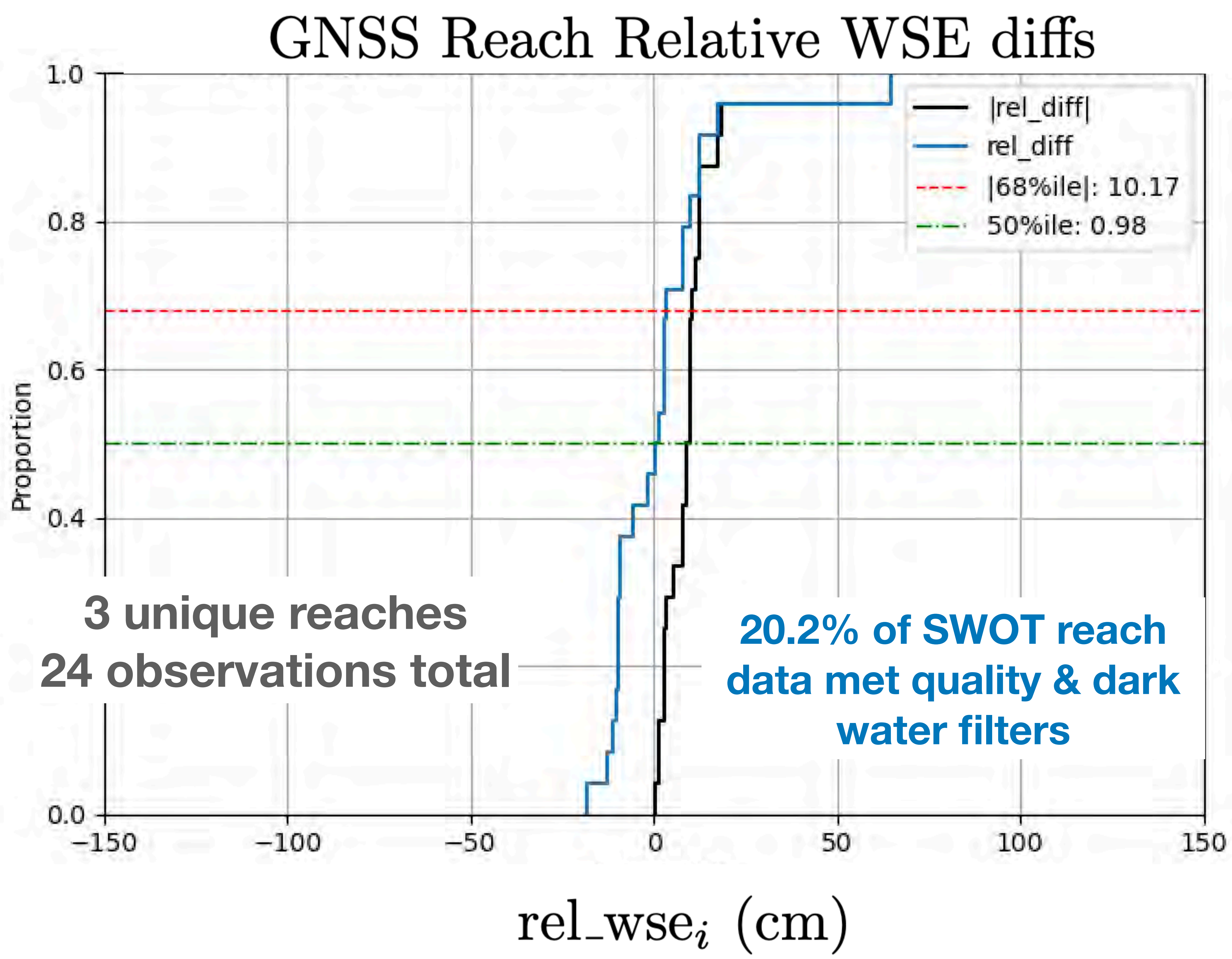


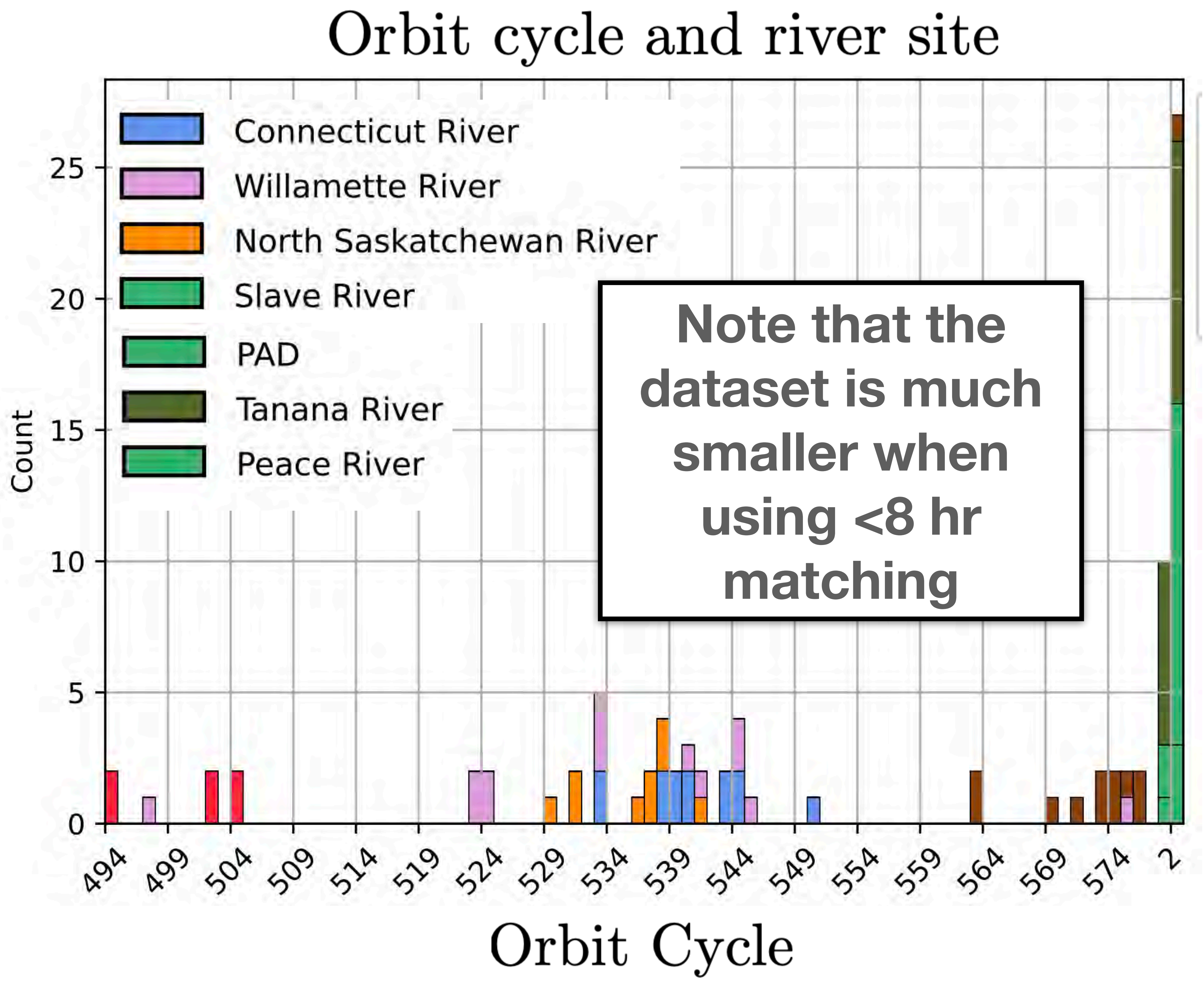



# 4: Reach-level performance estimations

## a. GNSS Drift Reach WSE data — strict matching (Version C)

If we use **only the best, most complete drifts** with **≤8 hr match to SWOT,** we see a **relative** WSE performance of **10.2 cm**

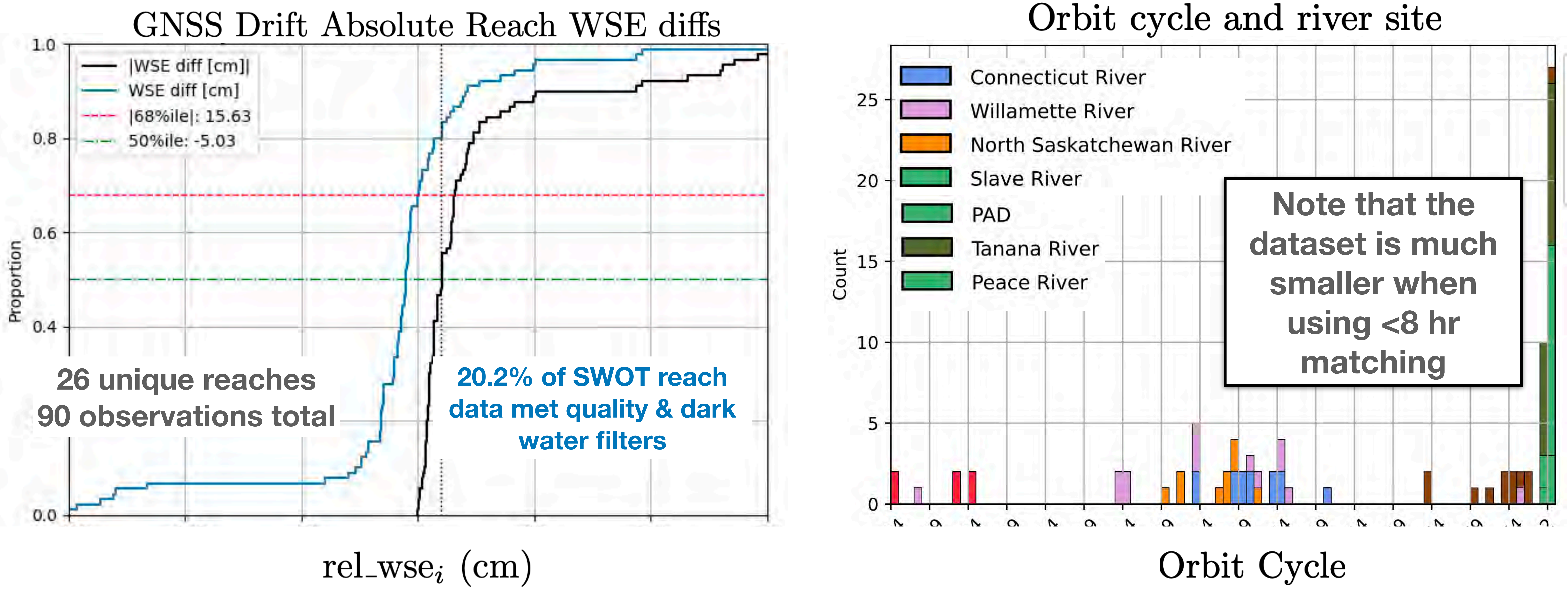


# 4: Reach-level performance estimations

## a. Absolute Reach WSE in GNSS Drift data (Version C)

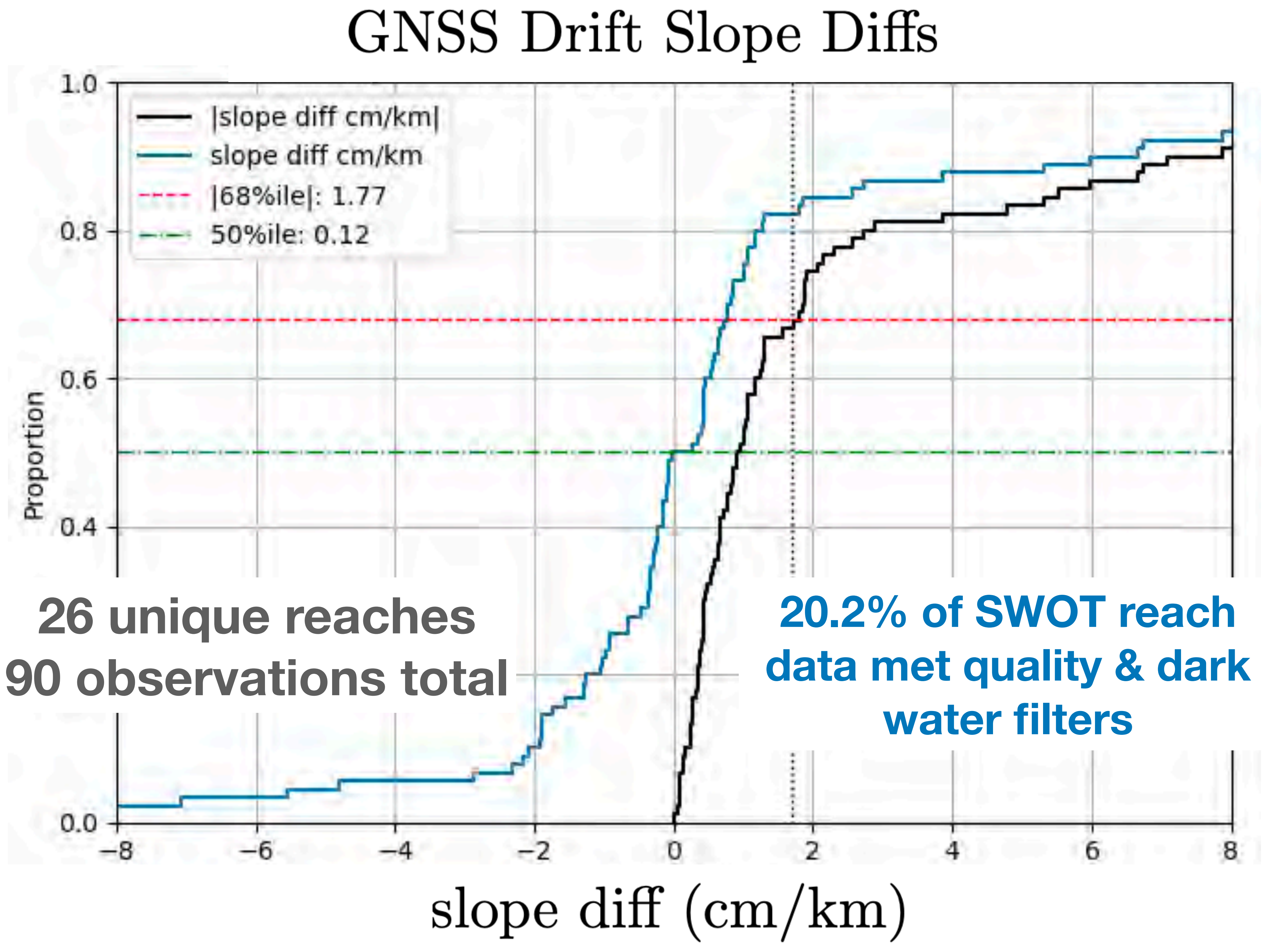
If we use **only the best, most complete drifts** with **≤8 hr match to SWOT,** we see an **absolute** reach WSE performance of **15.6 cm**



# 4: Reach-level performance estimations

## a. Absolute Reach WSE in GNSS Drift data (Version C)

If we use **only the best, most complete drifts with a ≤8 hr temporal match to SWOT,** we see a **reach slope performance** of **1.8 cm/km**




reach |68%ile| slp_error_cmkm by river_name:

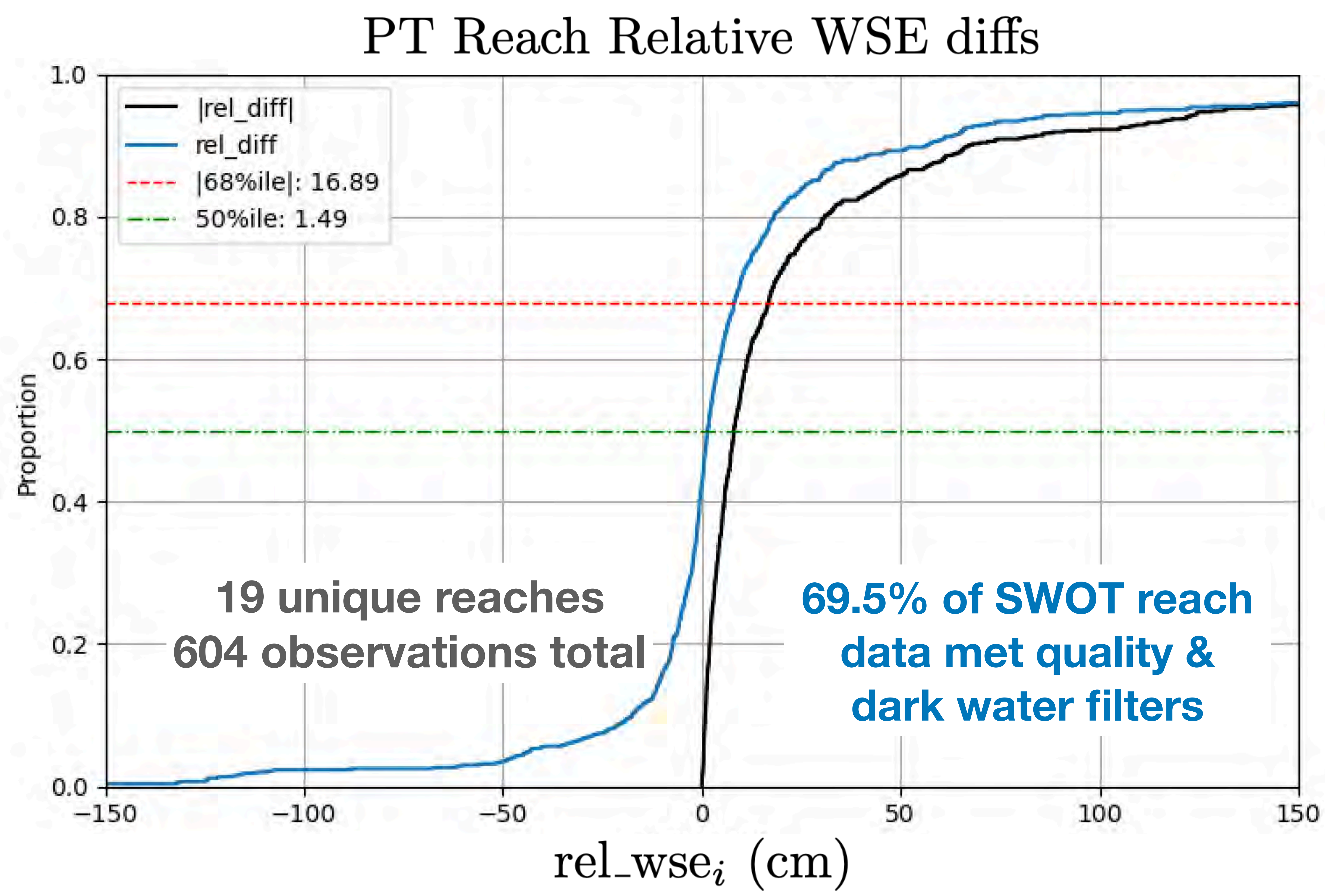
| river_name | \|68%ile\| slp diff | count |
|---|---|---|
| Sagavanirktok River | 8.209501 | 12 |
| Waimakariri River | 7.778603 | 6 |
| Willamette River | 2.697861 | 14 |
| Peace River | 1.174262 | 9 |
| North Saskatchewan River | 1.063274 | 9 |
| PAD | 1.012337 | 6 |
| Connecticut River | 0.858951 | 13 |
| Tanana River | 0.612493 | 17 |
| Slave River | 0.322358 | 4 |

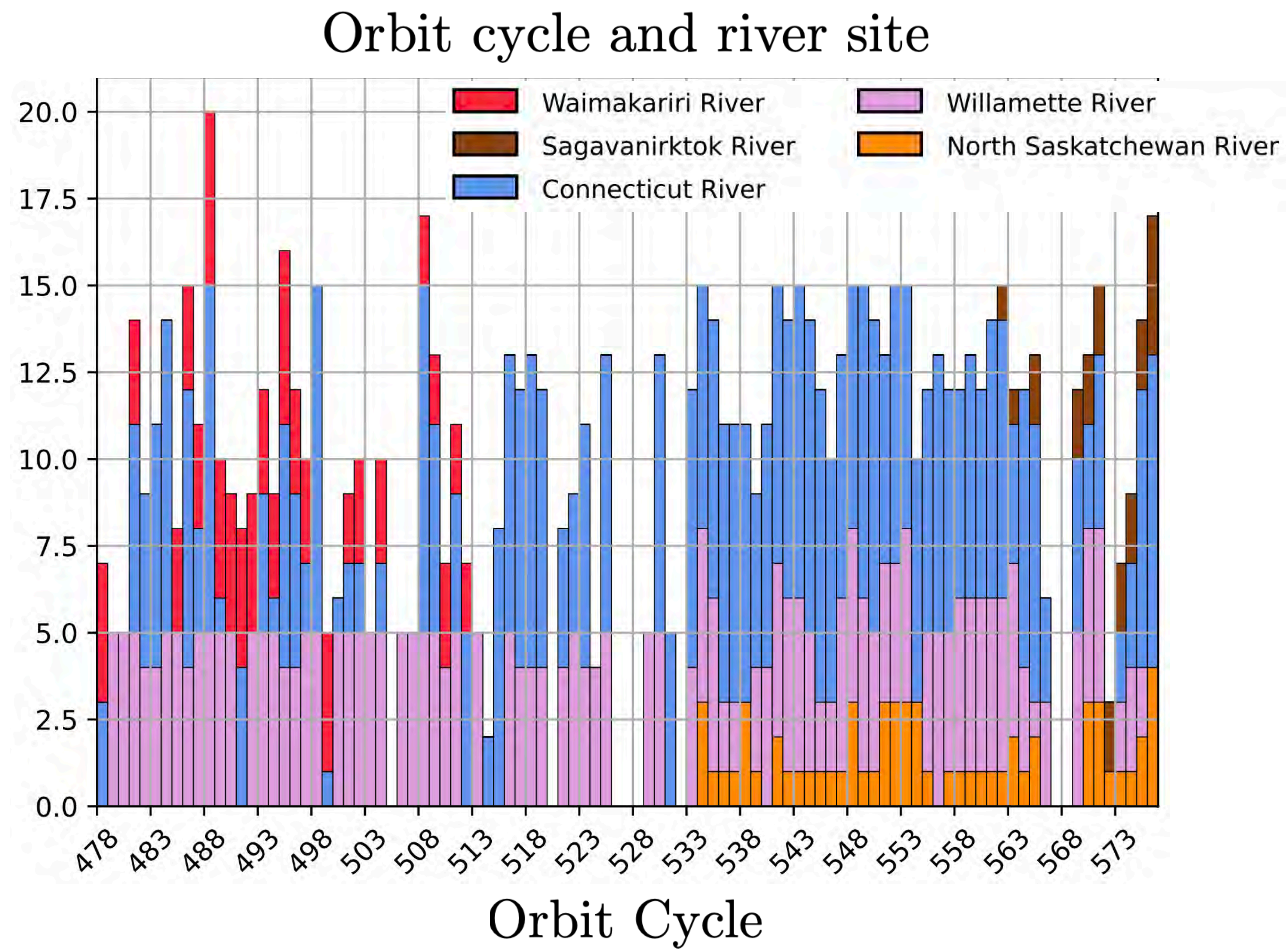
(If we use all stage-matched drifts the slope performance is 3.5 cm/km)

# 4: Reach-level performance estimations

## a. PT reach WSE (Version C)

**Relative WSE performance of 16.9 cm** for **PT cal orbit reach data** at **|68%ile|,** consistent with GNSS reach performance estimate of 16.1 cm.






6/18/24

# 4: Reach-level performance estimations

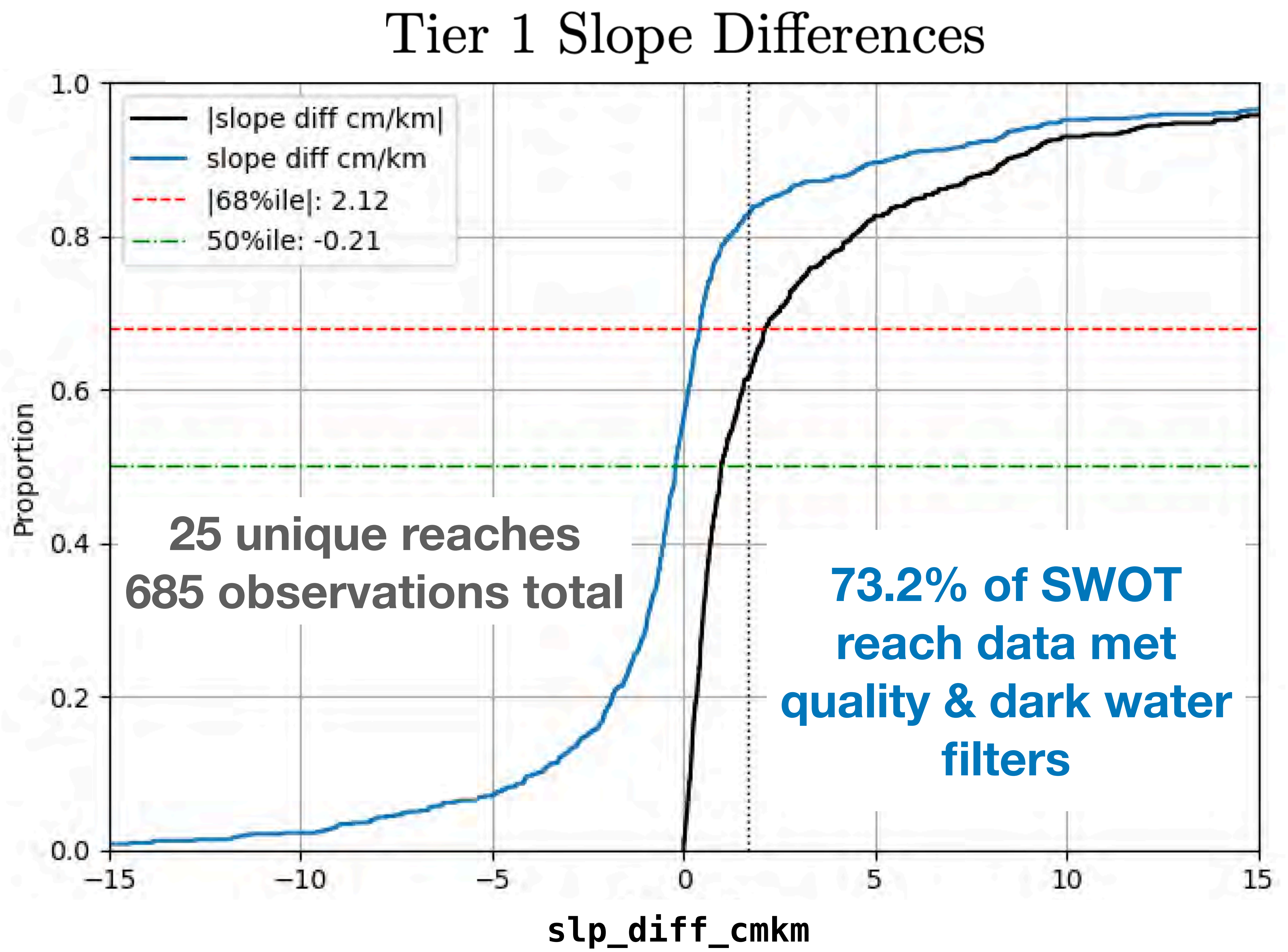
## a. PT slope (Version C)

Reach slope performance of **2.1 cm/km** in the Tier 1 US PT dataset.

Slope performance is generally very good when compared to the US Tier 1 PT dataset, but varies with each river.

```
reach |68%ile| slp_diff_cmkm by river_name:
```

| river_name | \|68%ile\| slp_diff | count |
|---|---|---|
| Tanana River | 6.652216 | 11 |
| Connecticut River | 3.469017 | 245 |
| Willamette River | 2.942534 | 334 |
| North Saskatchewan River | 1.418388 | 42 |
| Peace River | 1.161384 | 3 |
| PAD | 0.541289 | 3 |
| Slave River | 0.245065 | 3 |



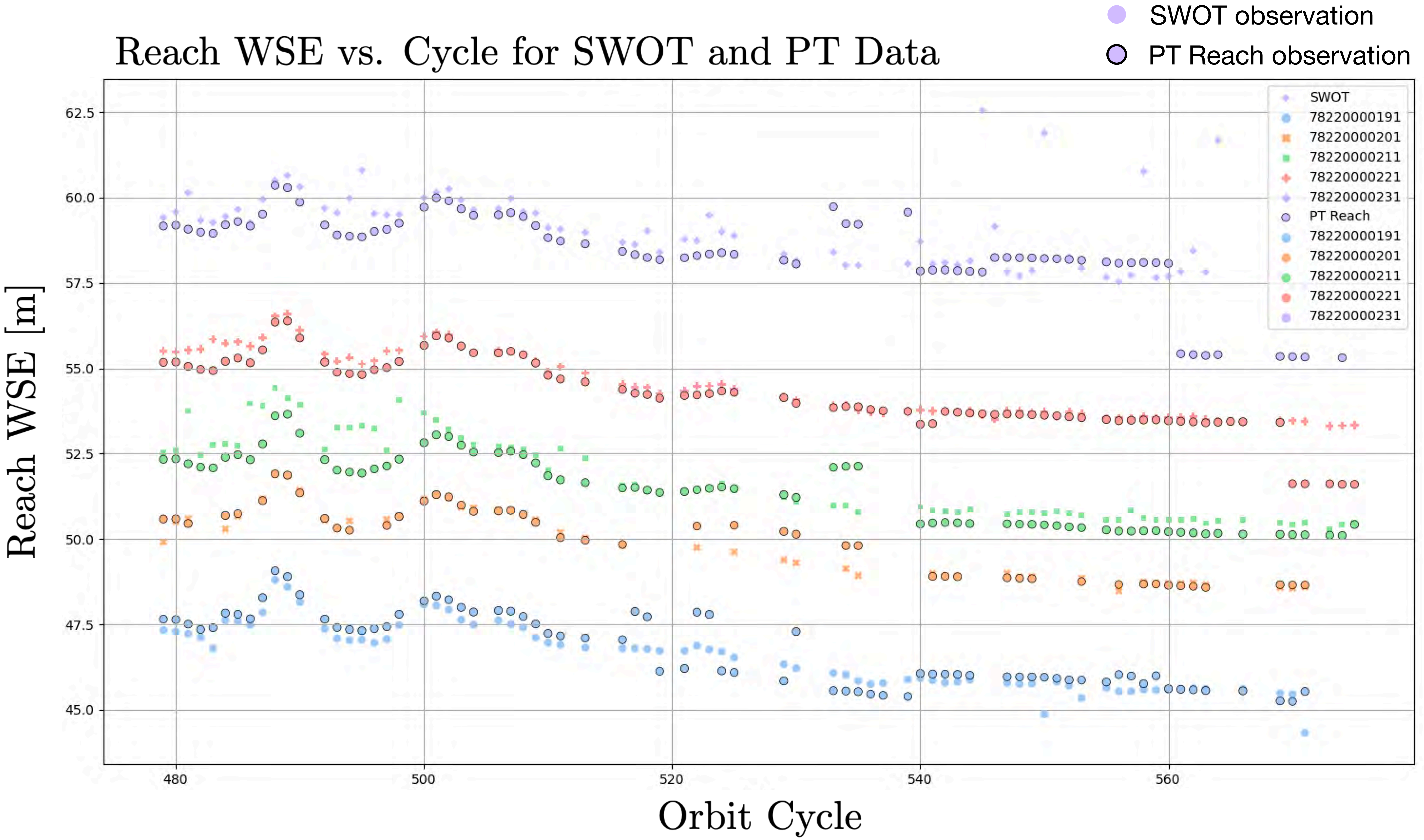

Note large discrepancy between GNSS & PT Tanana slopes suggest potential issue with Tanana PT comparison

# 5: Variability of performance by river site

## Reach-level WSE time series for Willamette

Performance varies significantly from place to place, where **some river sites consistently out-perform others**.

Most data are from one-day orbit; time-of-day or viewing geometry may be contributing factors.

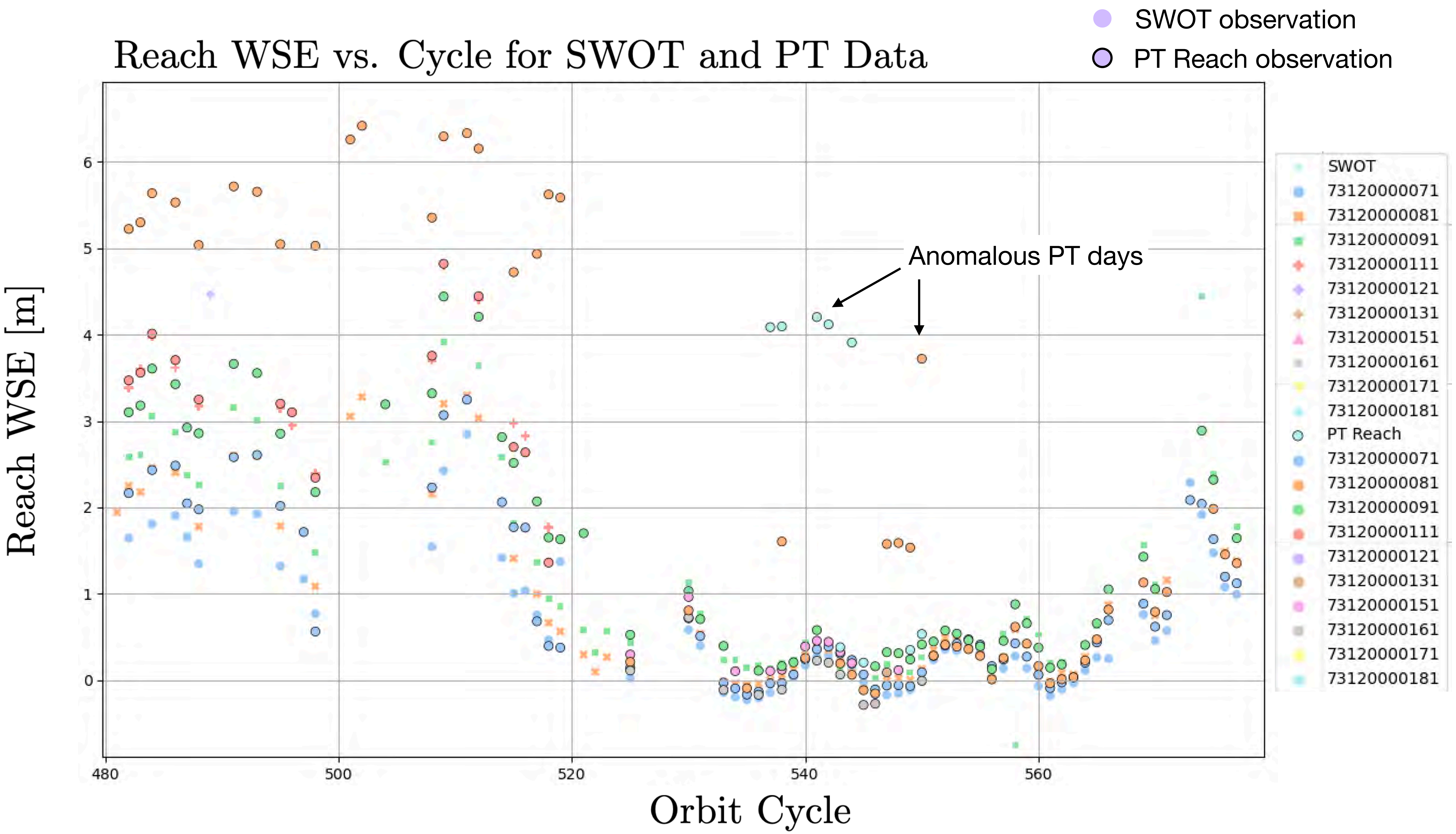


# 5: Variability of performance by river site

## Reach-level WSE time series for Connecticut

Performance varies significantly from place to place, where **some river sites consistently out-perform others**.

Most data are from one-day orbit; time-of-day or viewing geometry may be contributing factors.



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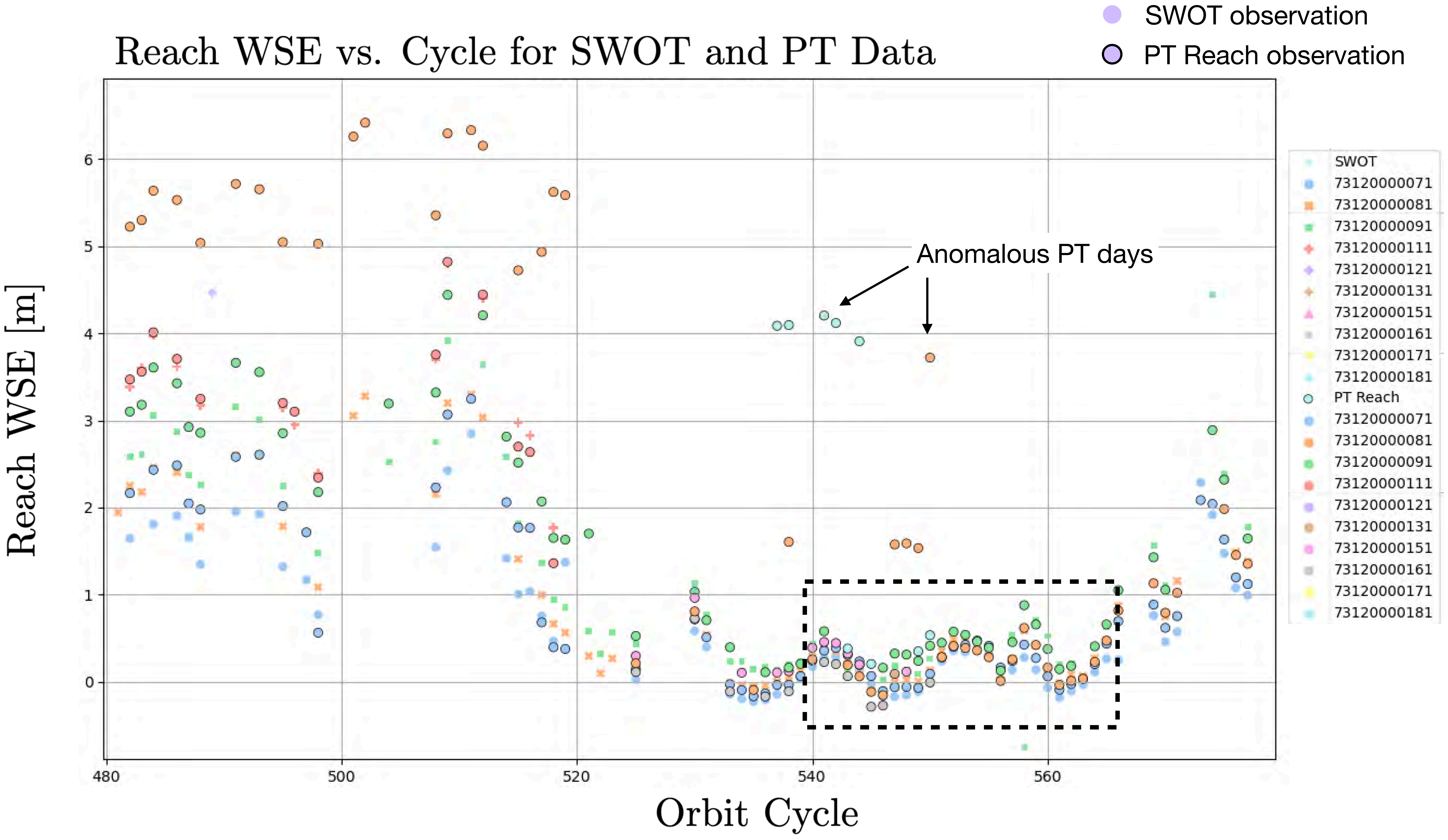

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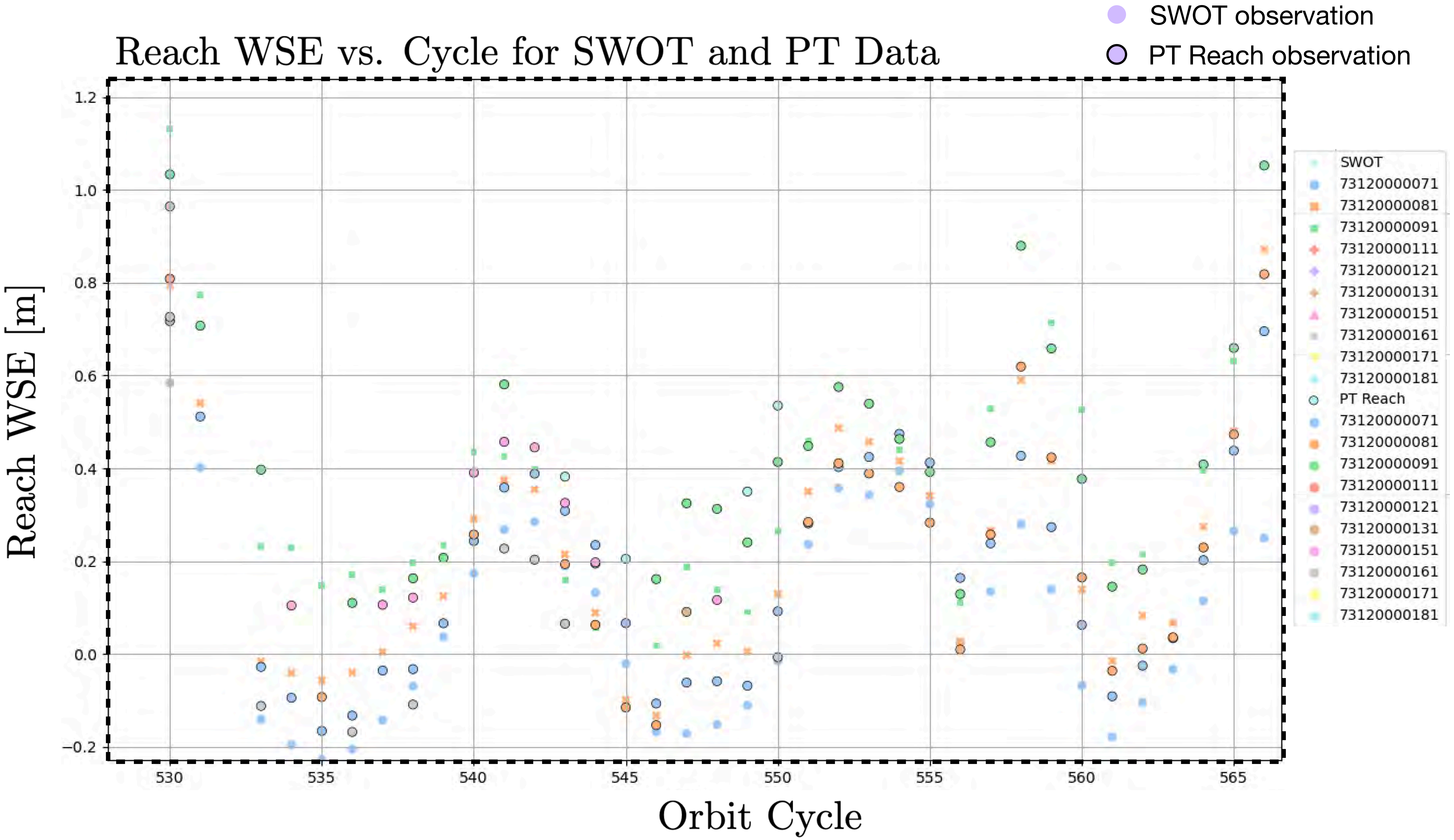
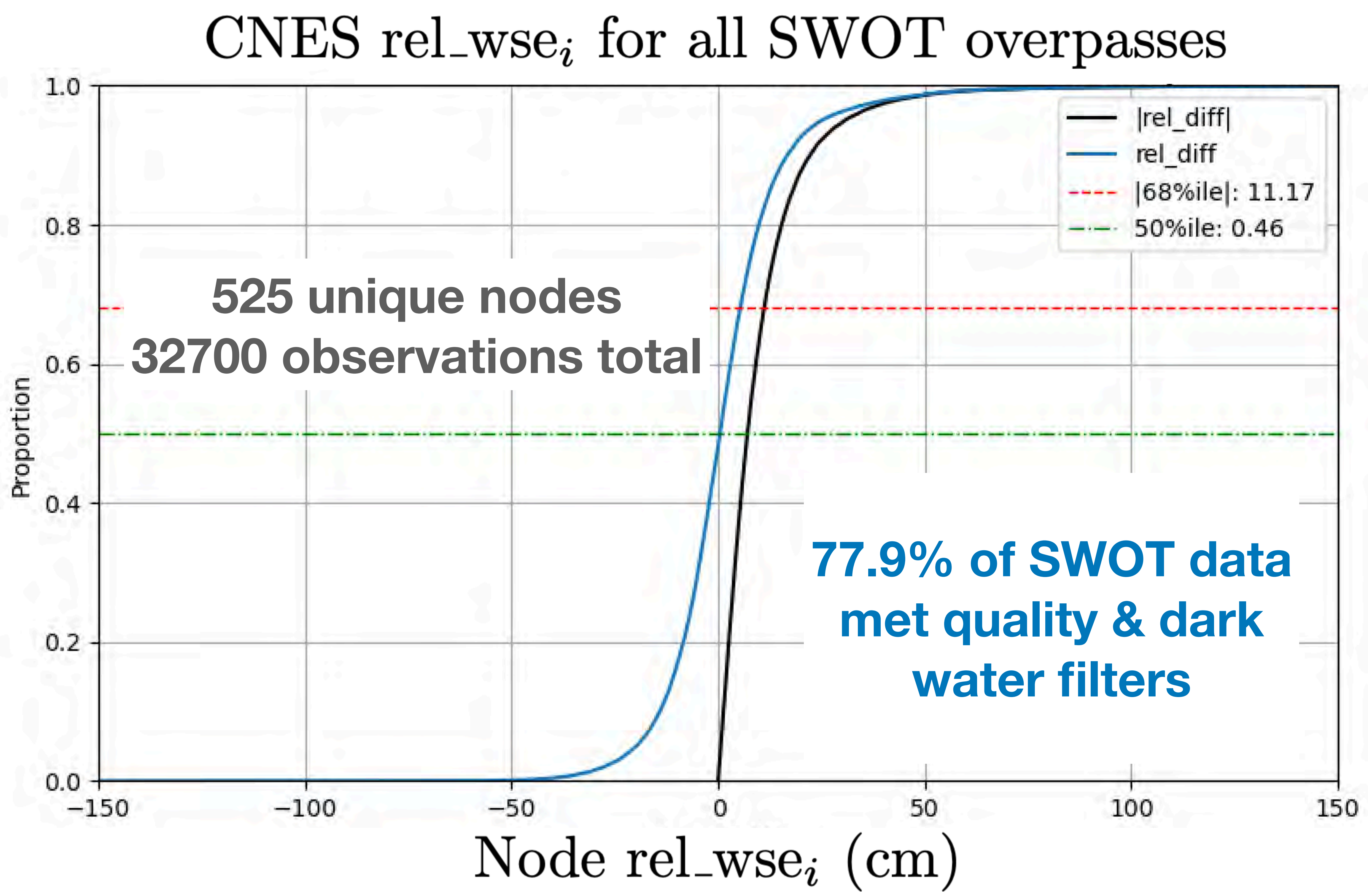
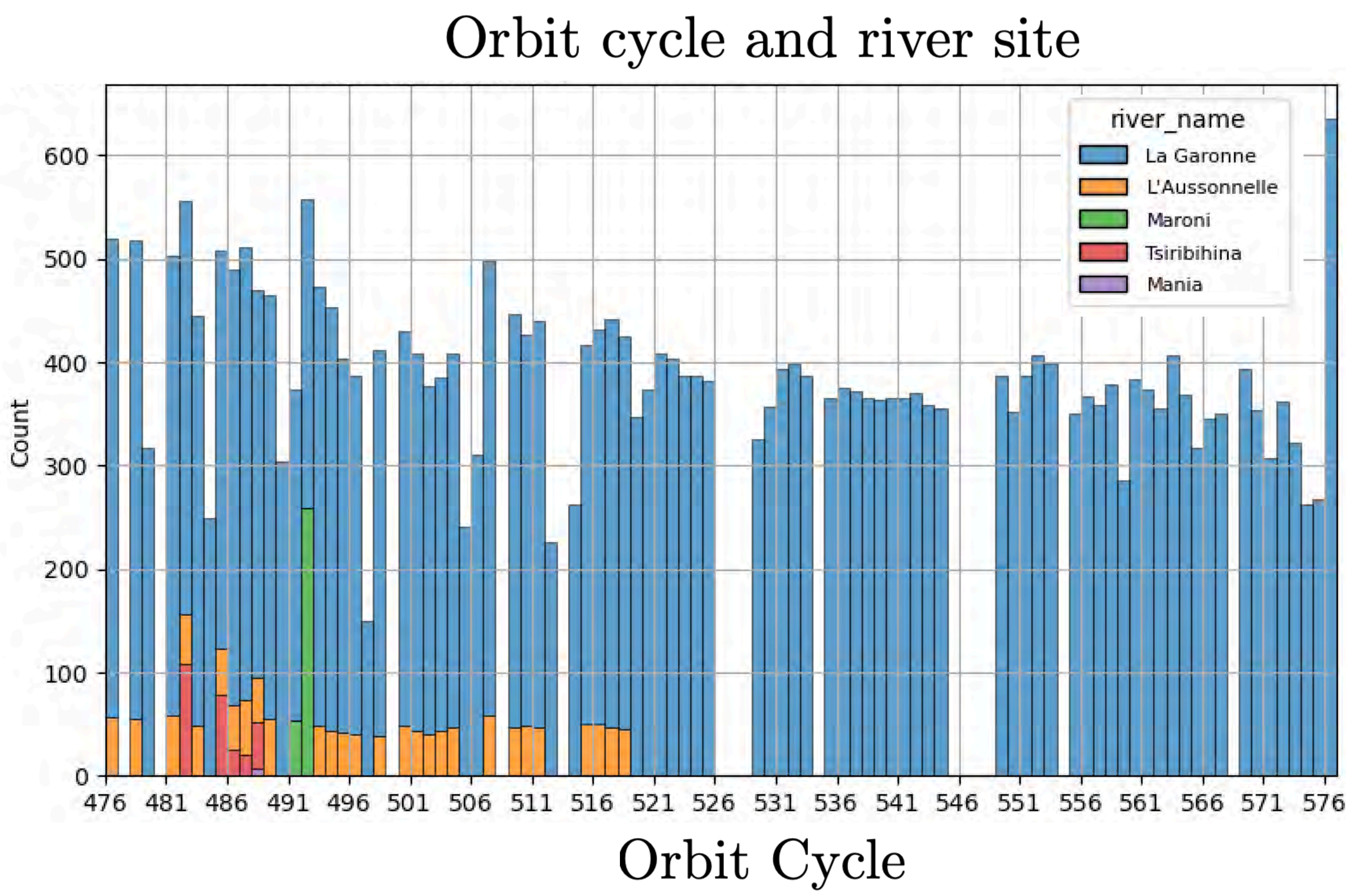


# 6: Comparisons to independent estimates

## vortex.io data; node-level relative WSE (Version C)

Results from field data from the Garonne **consistent** with US Tier 1 node WSE performance results (11.2 cm). These comparisons were kept separate from algorithm and quality tuning during the calval period and act as an **independent measure** of SWOT performance vs the US Tier 1 dataset.

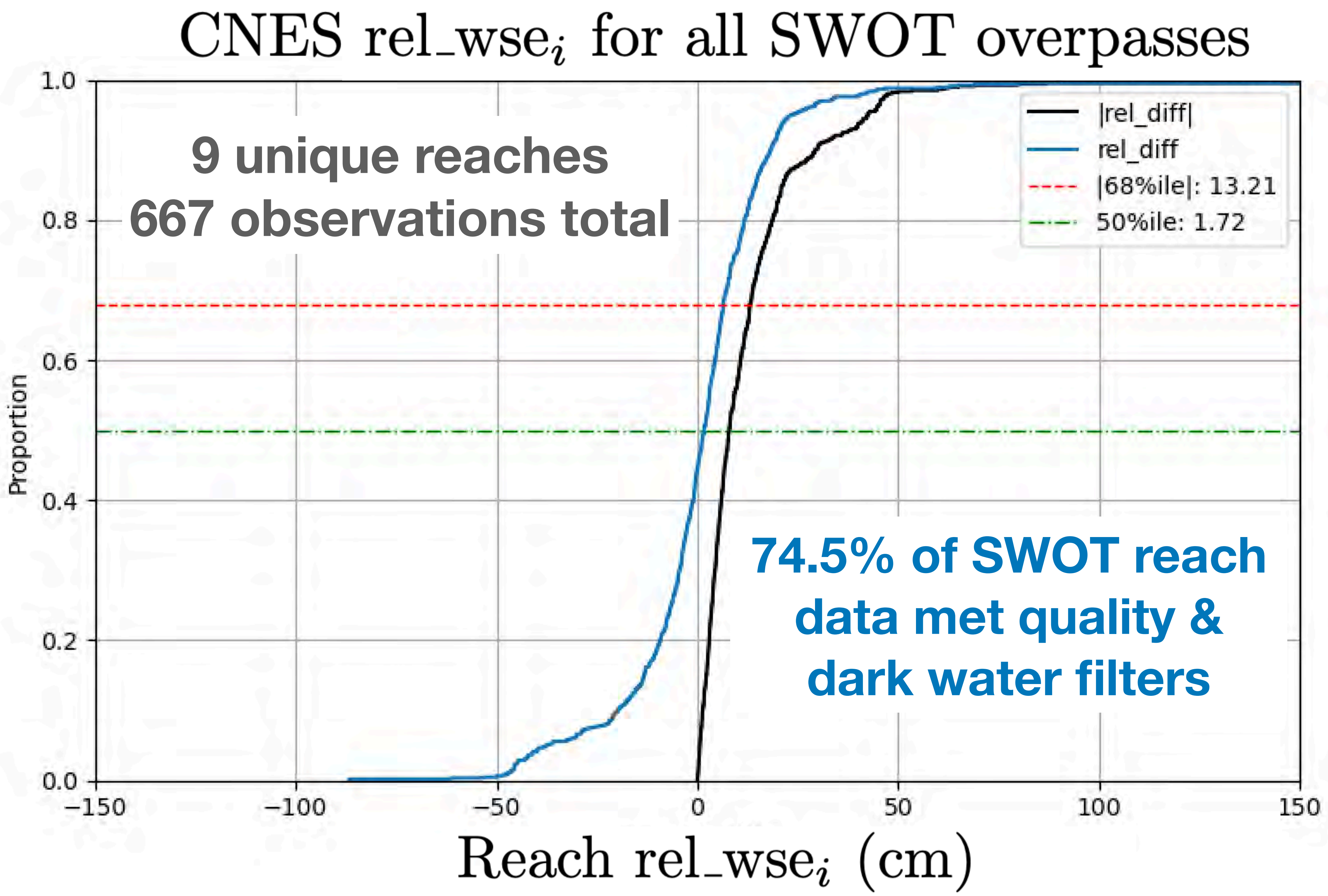


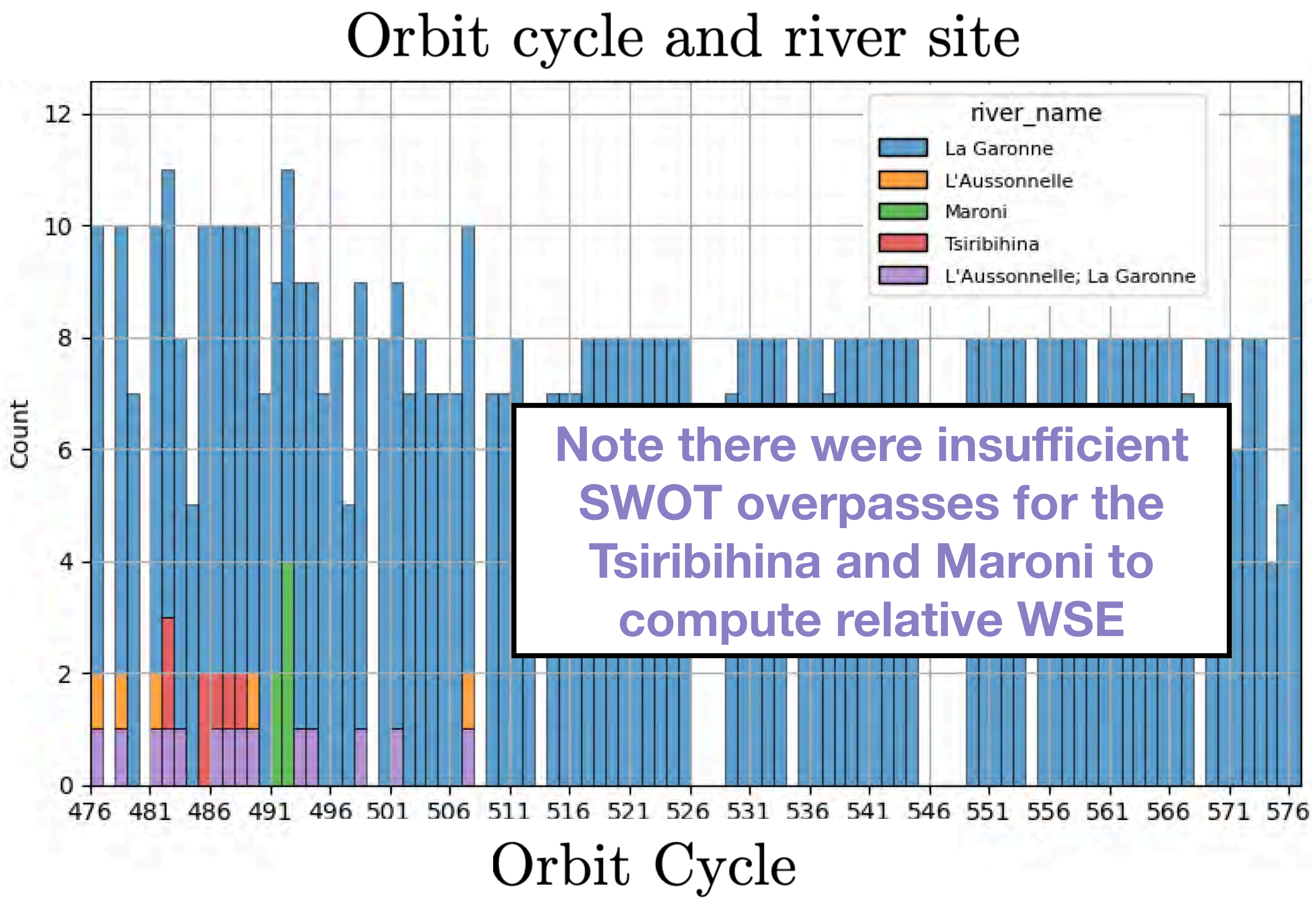



# 6: Comparisons to independent estimates

## Vortex.io data; reach-level relative WSE (Version C)

Reach-level WSE result ([13.2 cm]()) from Vortex.io data from the Garonne **consistent** with US Tier 1 Relative WSE performance of 10.2-16.9 cm.

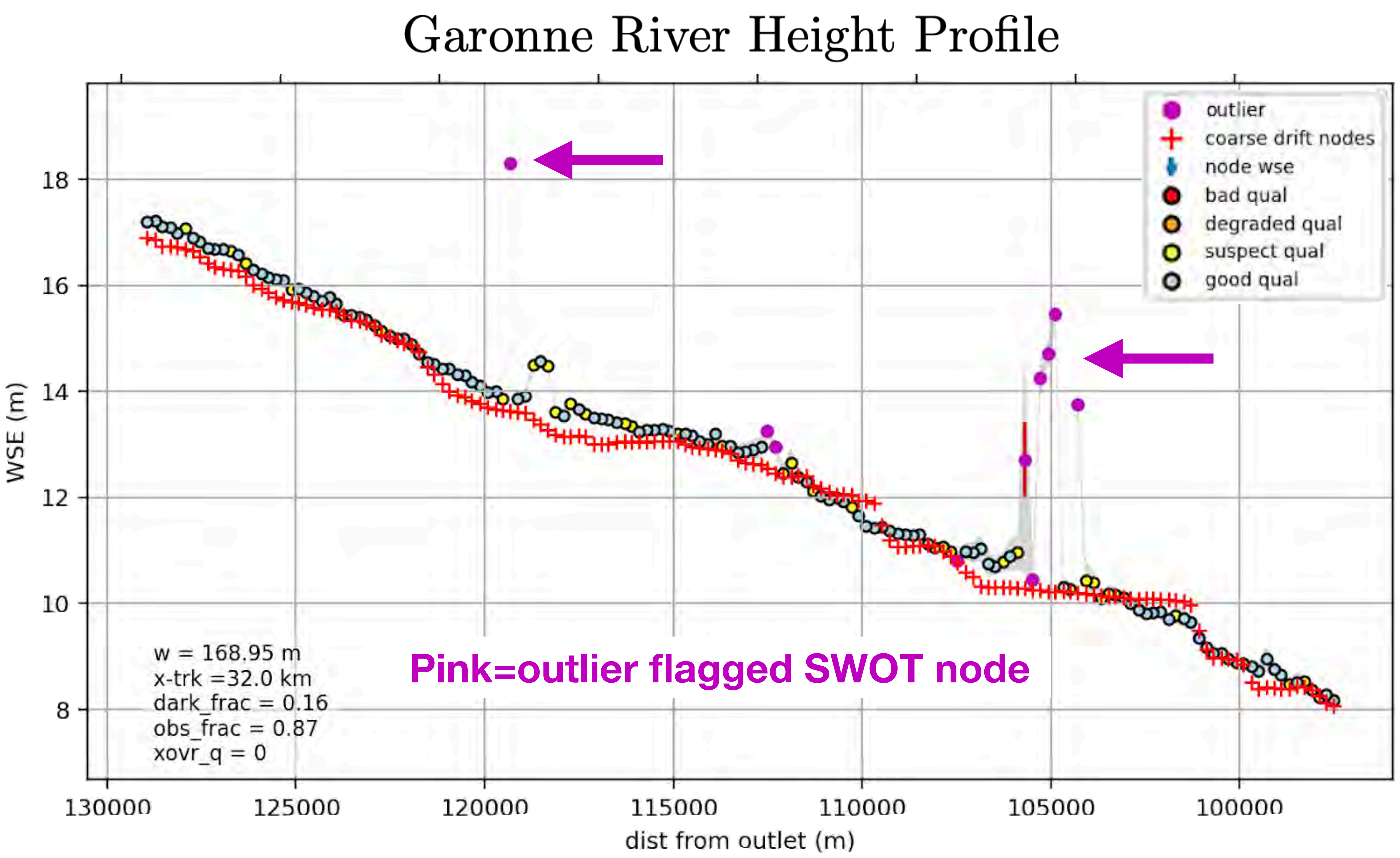


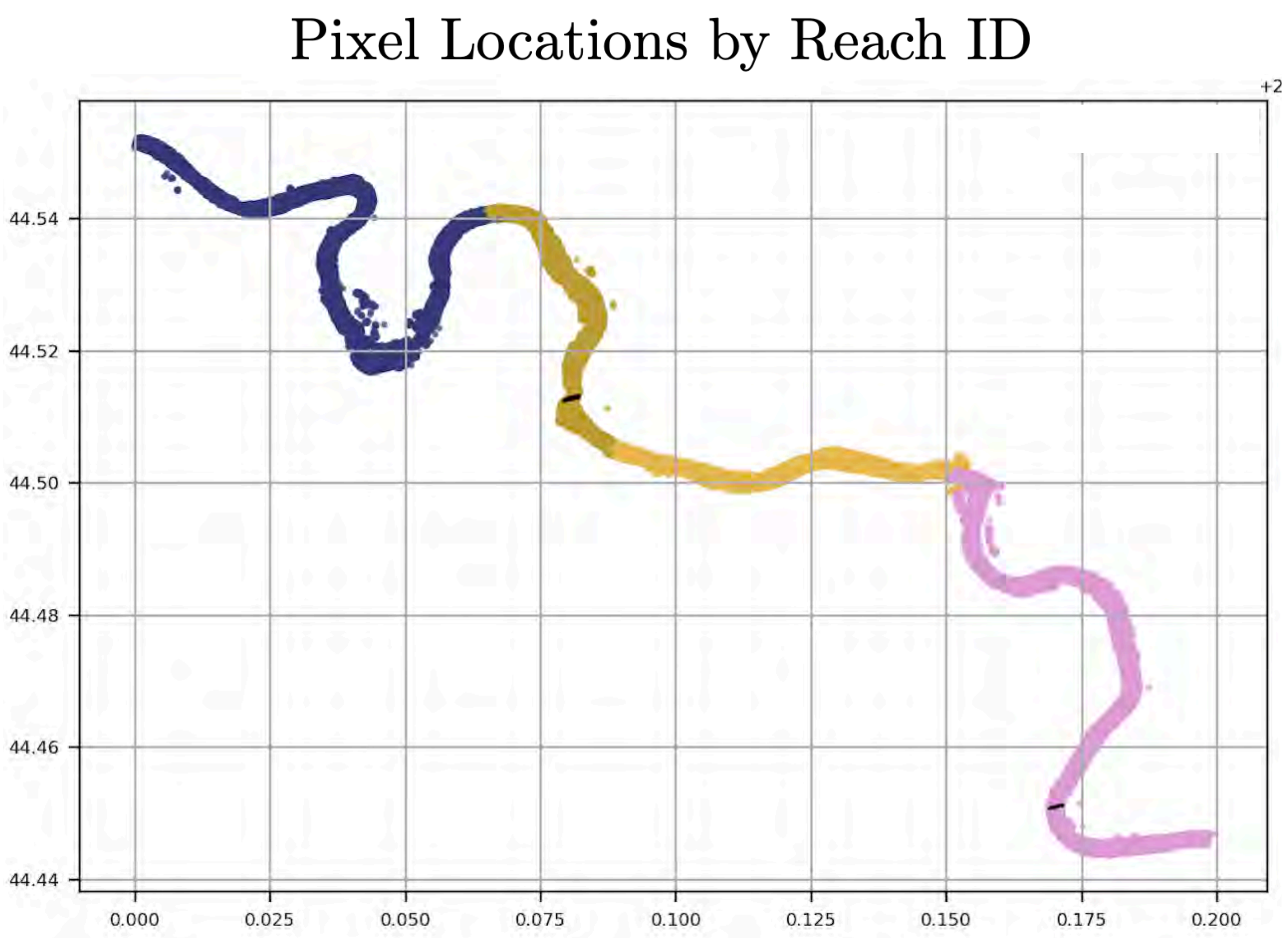



# 6: Comparisons to independent estimates

## Multi-reach Garonne River Height Profile

SWOT absolute node WSE generally agree with in-situ WSE's over Garonne River.



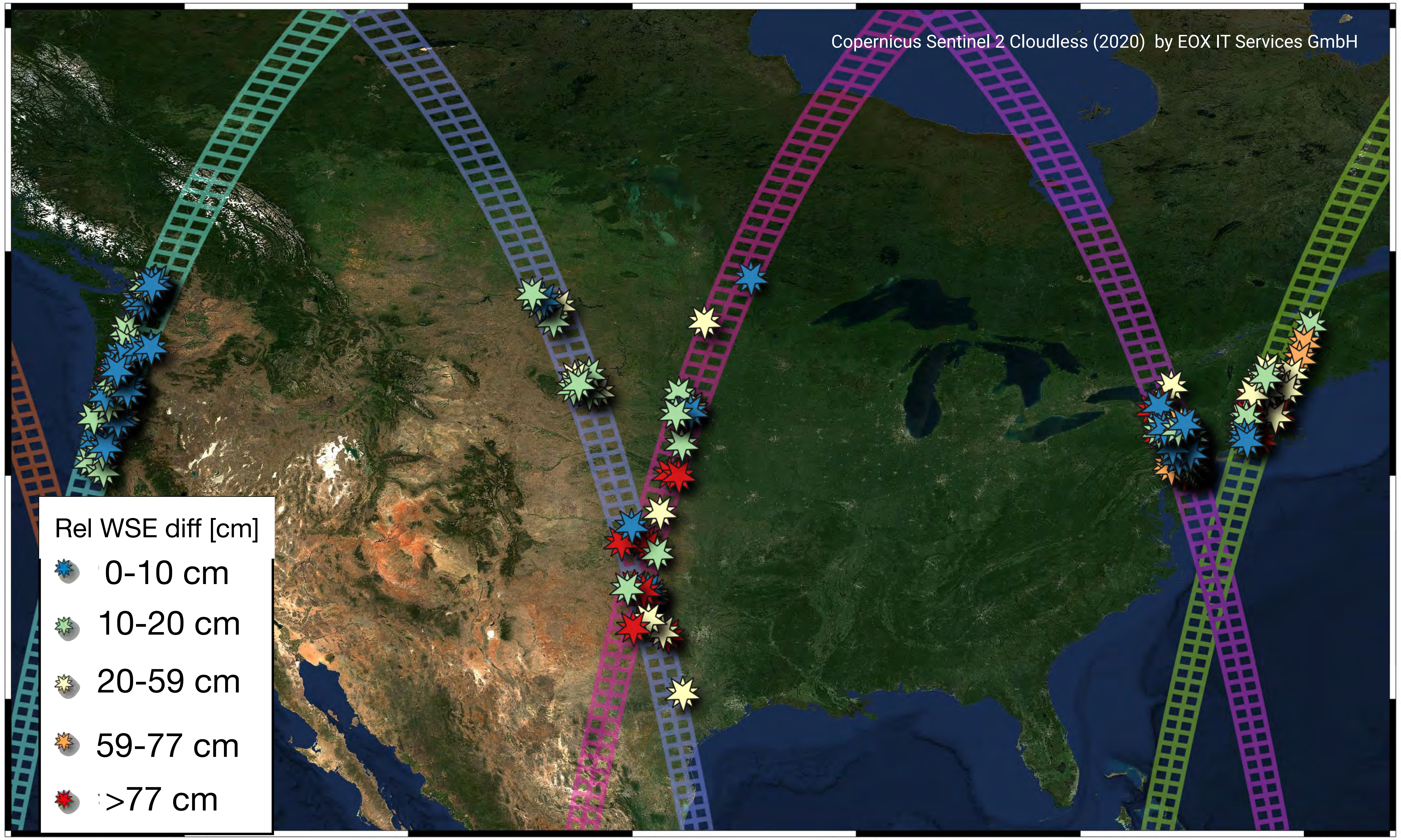



# 6: Comparisons to independent estimates

## Tier 3 Gauge Dataset

- Collection of **188 gauge sites** in the continental US spanning **72 unique river names** in SWORD
- Cycles **476 - 577** in calval orbit (96 observed days total)
- Cycles **1-8** in science orbit (8 observed days total)
- A total of **3375 usable node WSE comparisons**

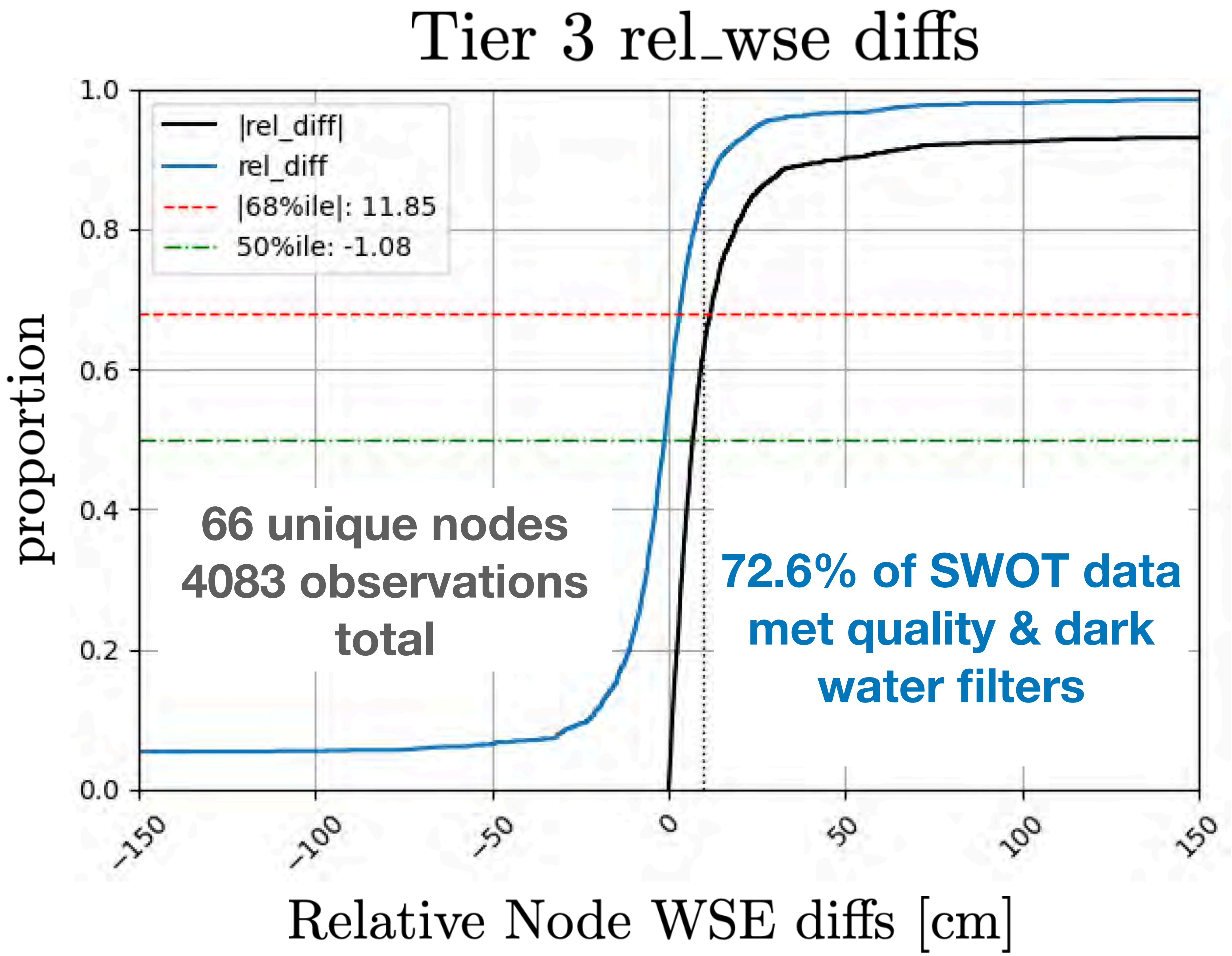
Relative WSE Performance by Tier 3 Gauge Site



# 6: Comparisons to independent estimates

## Sci & calval orbit Tier 3 gauge comparison

Tier 3 node-level performance of **11.85 cm** consistent with the US Tier 1 Site results of 10.9-13.0 cm.




Node |68%ile| wse_rel_diff_cm by river_name:

| river_name | |68%ile| | count |
|---|---|---|
| Colorado River | 634.091220 | 10 |
| Merrimack River | 212.171395 | 139 |
| Brazos River | 62.851184 | 17 |
| Willamette River | 52.836076 | 24 |
| Chenango River | 19.170056 | 14 |
| Connecticut River | 18.929777 | 52 |
| North Fork Red River | 17.489928 | 8 |
| Cimarron River | 17.228584 | 12 |
| Seneca River | 15.049776 | 110 |
| Oswego River | 14.991240 | 6 |
| Snohomish River | 12.001040 | 7 |
| Pohopoco Creek | 11.343680 | 44 |
| Delaware River | 11.138032 | 78 |
| Skagit River | 10.098016 | 45 |
| Saint John River | 9.076672 | 9 |
| Columbia River | 8.986866 | 111 |
| Missouri River | 8.743953 | 83 |
| Middle Fork Willamette River | 8.332417 | 84 |
| Yellowstone River | 8.169279 | 161 |
| Mormon Canal | 8.012860 | 14 |
| North Branch Susquehanna River | 7.798691 | 218 |
| Rainy River | 7.638384 | 65 |
| Lehigh River | 6.767948 | 85 |
| 742955 | 5.732384 | 14 |
| 731300 | 2.920982 | 9 |

**Most sites perform well, with a small number performing very badly.**

**Note results include some known non-SWOT (gauge/ analysis) errors.**

# 7: Quality flags and River Performance

## Overflagging Suspect & Degraded in Version C data

In Tier 3 **Version C RiverSP Node Products**:

- **~3% of nodes are "good"**
- **~60% are flagged "suspect"**
- **~20% are "degraded"**
- the rest are "bad" or unobserved.

In the Tier 1 Dataset of **Version C RiverSP Reach Products**:

- **~1% are flagged "good"**
- **~72% are flagged "suspect"**
- **~27% are "degraded"**
- And no reaches were "bad" or unobserved.

I will show that the **node-level degraded and bad flags are generally accurate**. The **suspect nodes and reaches are usually "good"**, and the **degraded reaches are also often "good" but may be bad.**

A future release will improve the accuracy and meaningfulness of the reach and node quality flags.

**Tier 3 Rel WSE performance by node quality**

| node_q | \|68%ile\| rel WSE | count | % |
|---|---|---|---|
| 3 (bad) | 631.9 cm | 249 | 17.5 |
| 2 (deg) | 173.7 cm | 342 | 19.6 |
| 1 (sus) | 16.9 cm | 1342 | 59.6 |
| 0 (good) | 13.9 cm | 98 | 3.3 |

← Most nodes are marked suspect

**Tier 1 Rel WSE performance by reach quality**

| reach_q | \|68%ile\| rel WSE | count | % |
|---|---|---|---|
| 2 (deg) | 48.1 cm | 196 | 27.1 |
| 1 (sus) | 12.0 cm | 518 | 71.7 |
| 0 (good) | 12.1 cm | 8 | 1.1 |

← Suspect reaches perform like "good" reaches in Tier 1 set

# 7a: Quality flags and River Performance

## US Tier 1 & Garonne Version C Node PT data

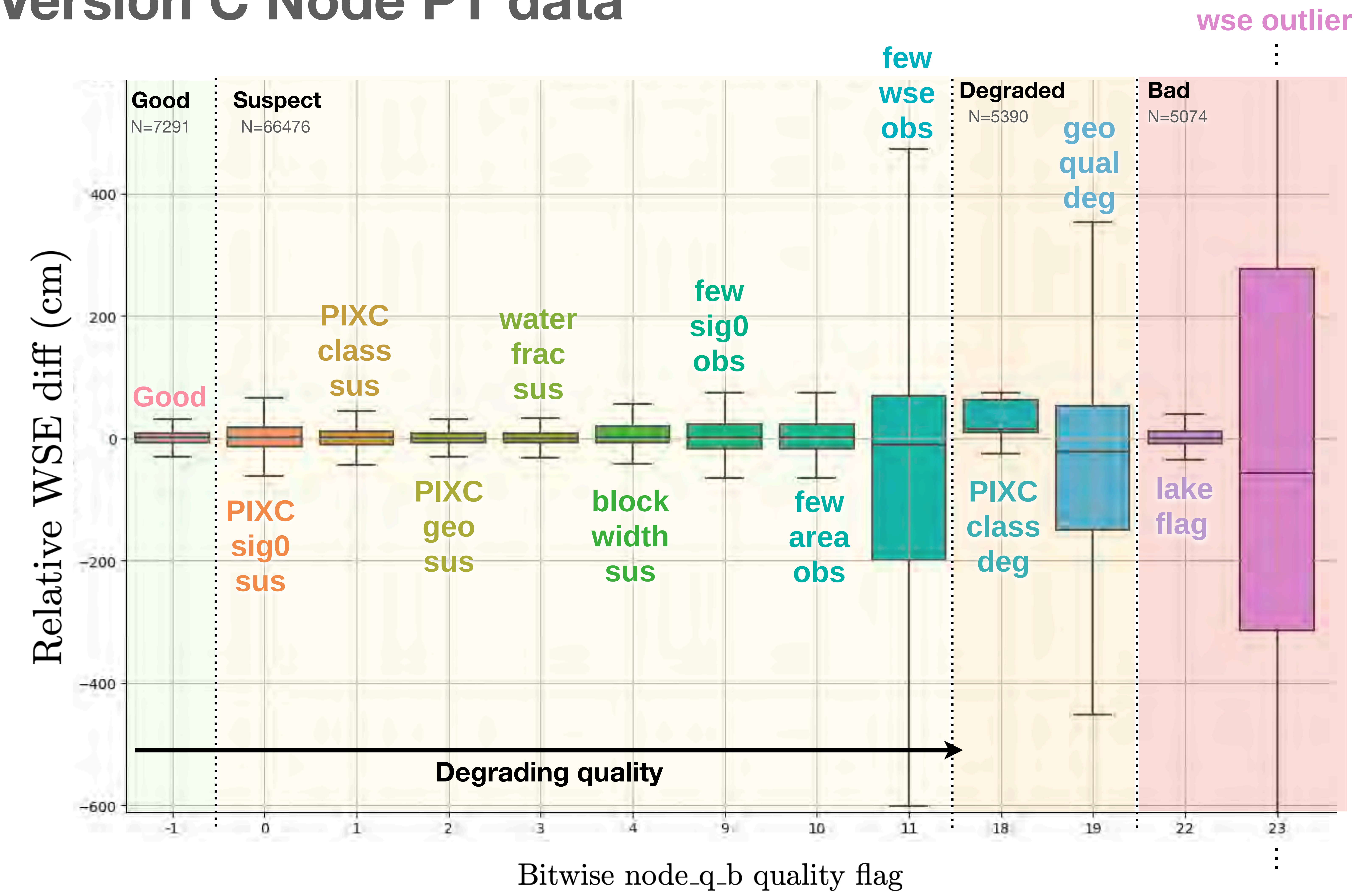
The **node-level summary quality flags (0, 1, 2, 3)** successfully capture bad WSE performance, **especially for degraded and bad nodes**.

A biwise analysis shows **low-value suspect nodes perform similarly as good nodes**.

Bits associated with bad WSE performance have worse WSE performance (as expected).

Bits associated with poor areas show weak relationship with bad WSE performance (as expected).

Note these results **do not filter** for SWOT quality or dark water.








6/18/24

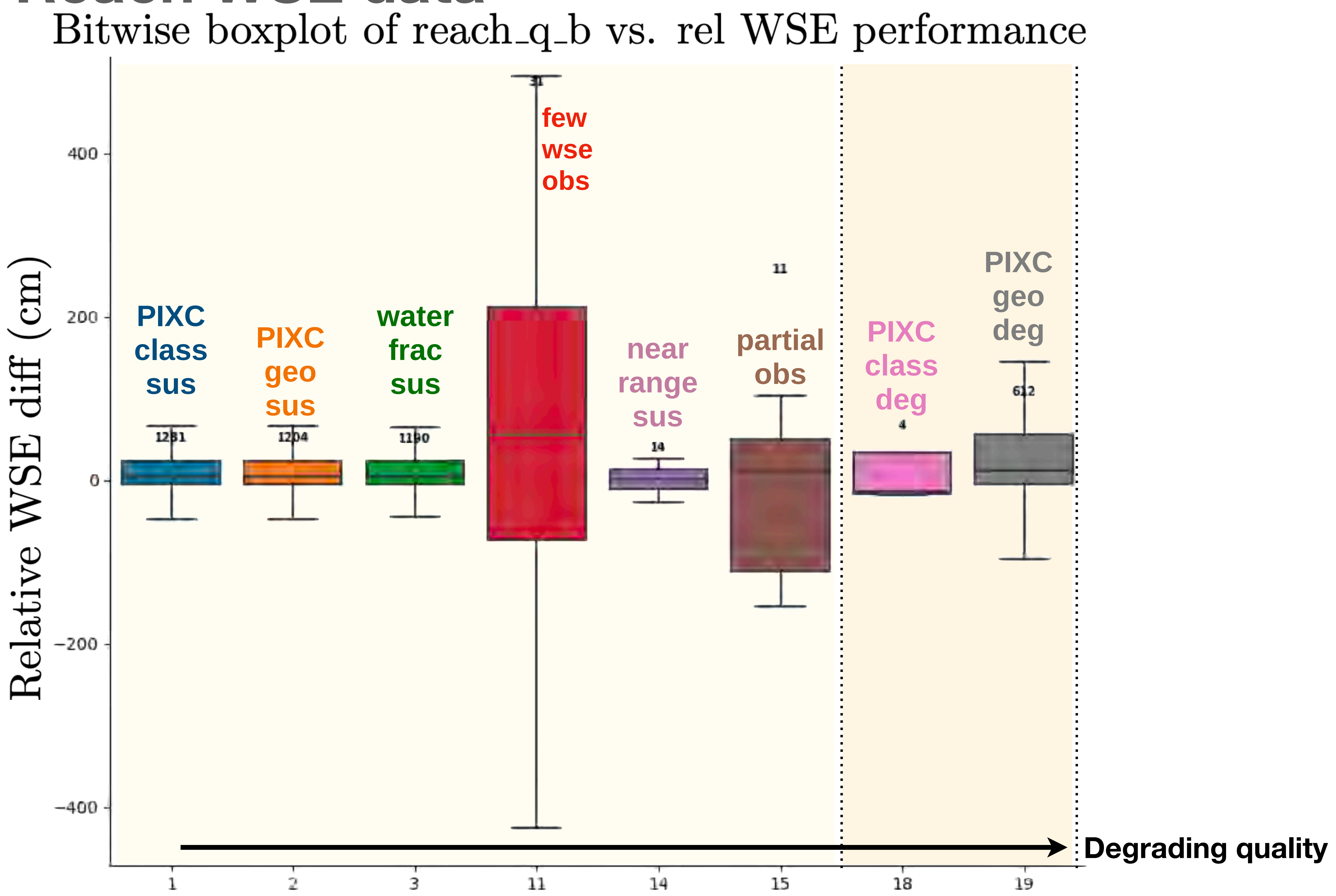
# 7a: Quality flags and River Performance

## Version C Tier 1 & vortex.io Reach WSE data

The "**Version C**" reach-level quality flags are **overflagging suspect and degraded reaches**.

reach_q_b is less meaningful as a result.

Note these results **do not filter** for SWOT quality or dark water.



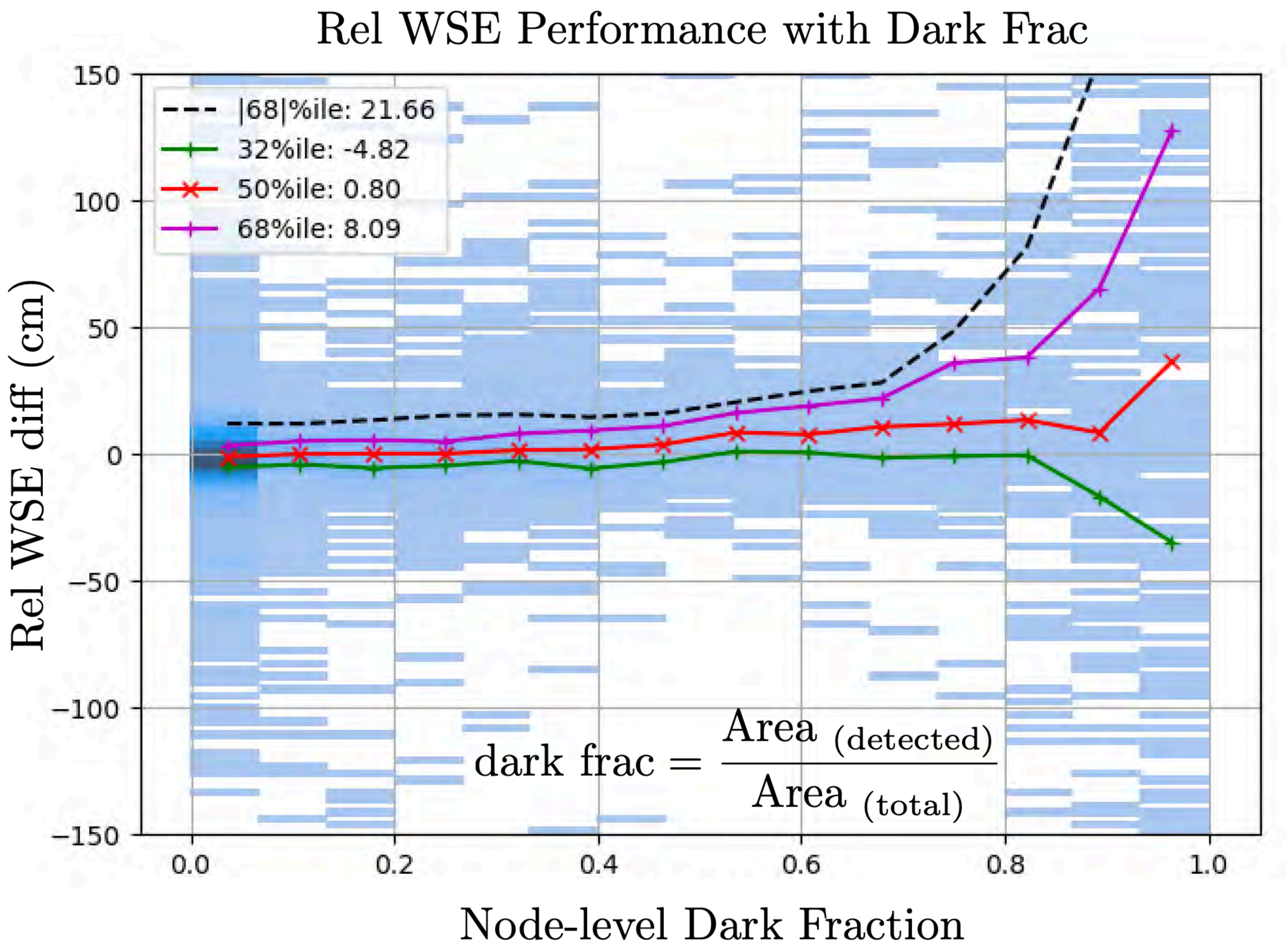
# 7b: Relationships with dark water

## PT Node Version C

**Node-level** diffs increase significantly when dark water fraction exceeds 60% over the Tier 1 sites.

This likely changes depending on river width (where wider rivers have more pixels to begin with).

Note these results **do filter** for SWOT quality flags. Users can find dark_frac info in RiverSP product.




83.5% of node data met quality filters

# 7b: Relationships with dark water

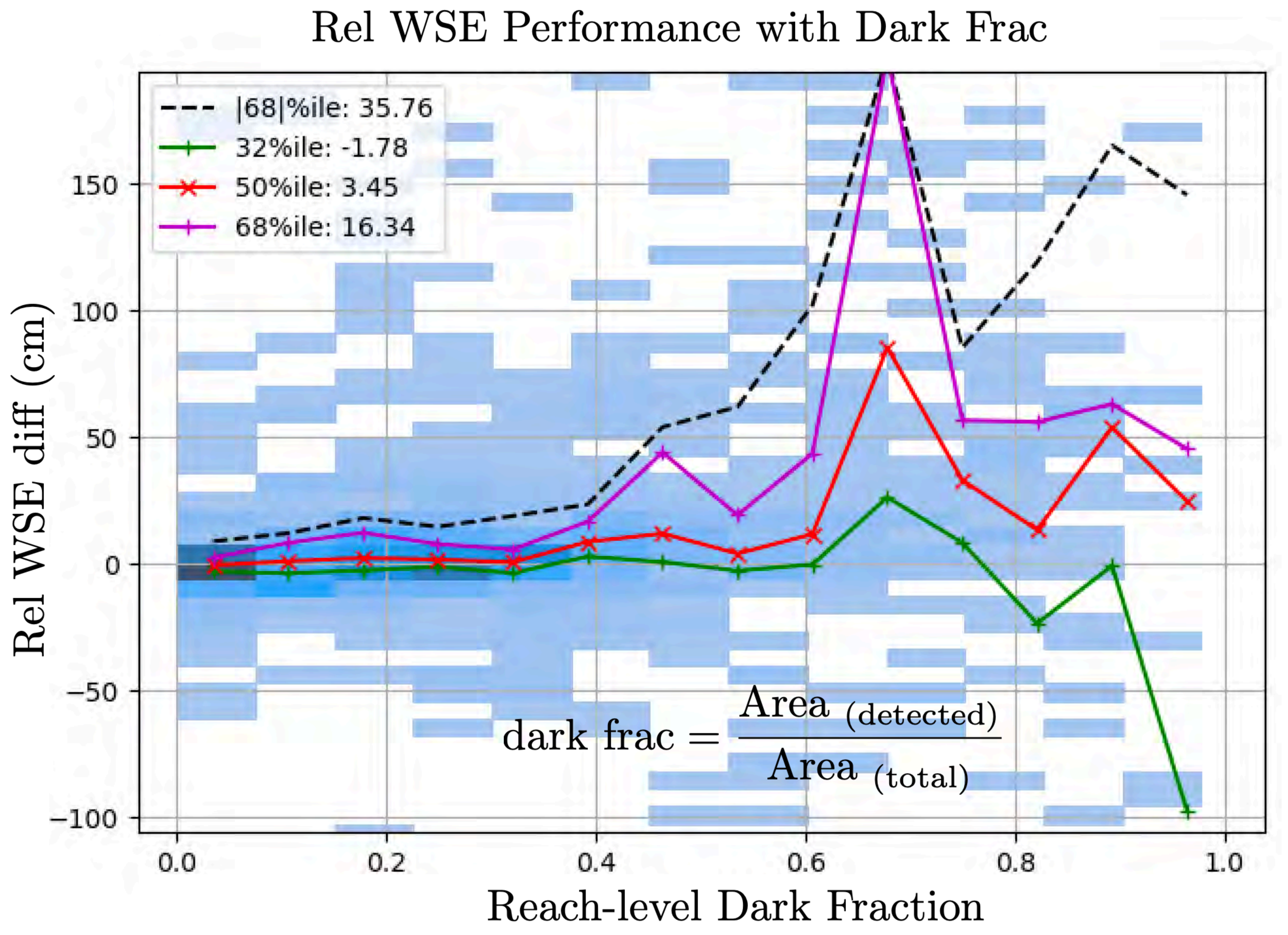
## PT Reach Version C

**Reach-level diffs** increase significantly when dark water fraction exceeds 40% over the Tier 1 sites.

This likely changes depending on river width (where wider rivers have more pixels to begin with).

Note these results **do filter** for SWOT quality flags. Users can find dark_frac info in RiverSP product.

95.0% of reach data met quality filters



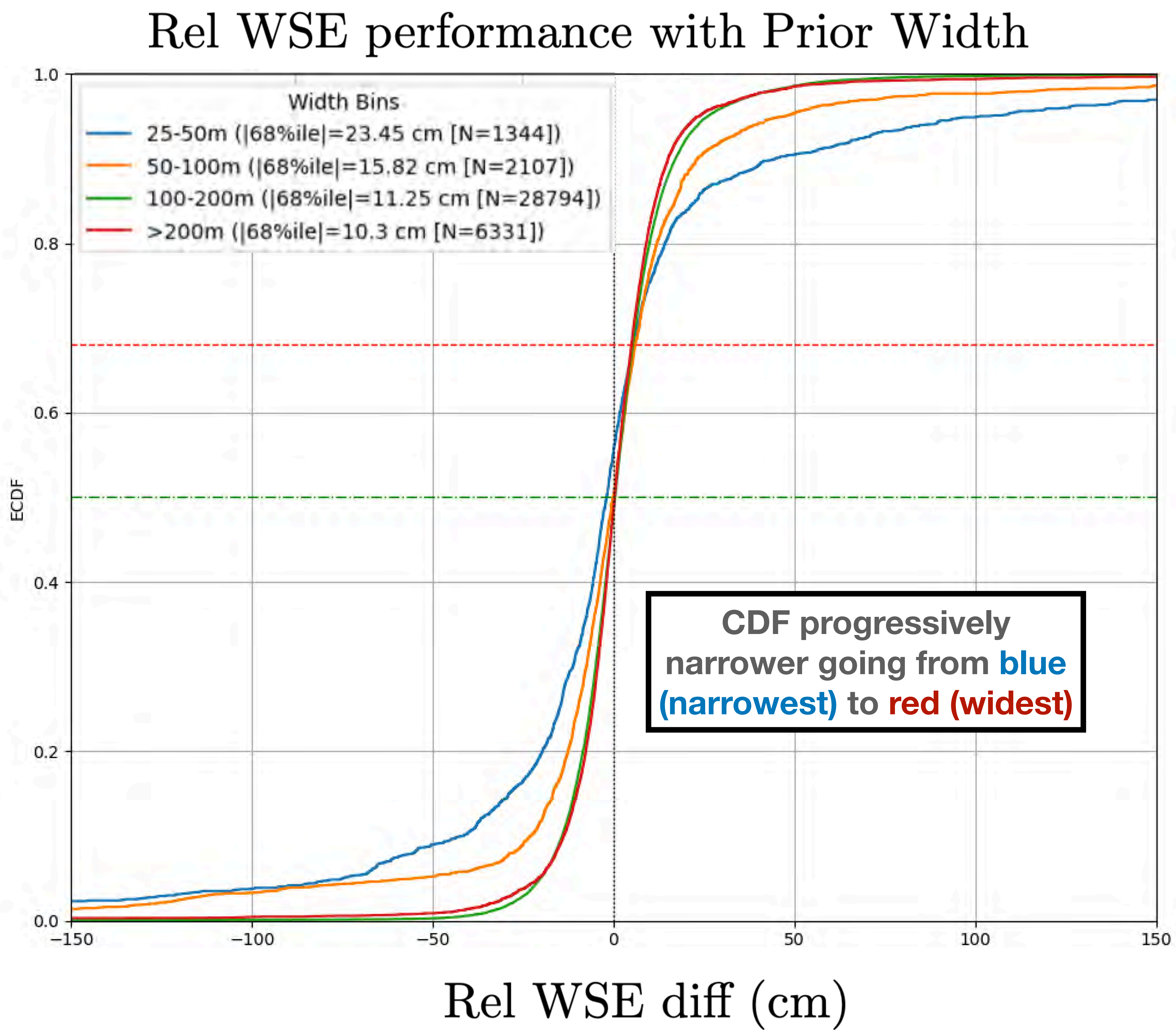
# 7c: Relationships with prior river width

## Node-level data; CNES/Tier 3/Tier 1 combined

This CDF **combines all relative WSE node data from all measurement approaches**, for a total of N=38 576 WSE comparisons.

We observe that **node-level performance degrades below 100 m.**

| River Width | \|68%ile\| Node WSE performance |
|---|---|
| 25-50 m | 23.5 cm |
| 50-80 m | 15.8 cm |
| 100-200 m | 11.3 cm |
| > 200 m | 10.3 cm |



# 7c: Relationships with prior river width

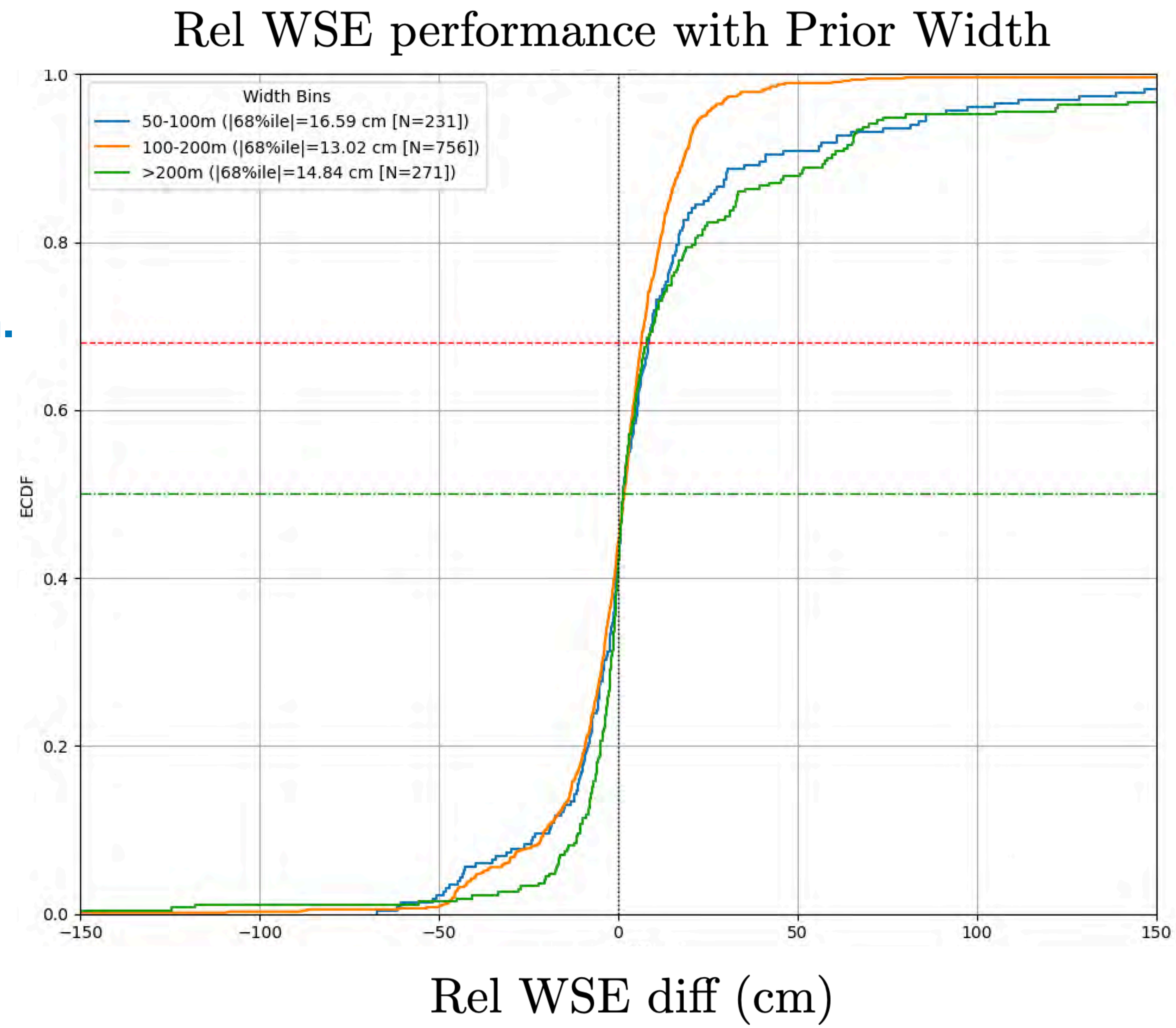
## Reach-level data; CNES/Tier 1 combined

This CDF **combines all relative WSE reach data from all measurement approaches**, for a total of N=1258 WSE comparisons.

We observe that **reach-level performance degrades below 100 m.**

Notably, wider reaches perform worse than 100-200 m reaches in this dataset. This is driven by Connecticut 73120000121 and 73120000151, which are very dark, have many observations, and are >300 m wide).

| River Width | \|68%ile\| Reach WSE performance |
|---|---|
| 50-100 m | 16.59 cm |
| 100-200 m | 13.02 cm |
| > 200 m | 14.84 cm |

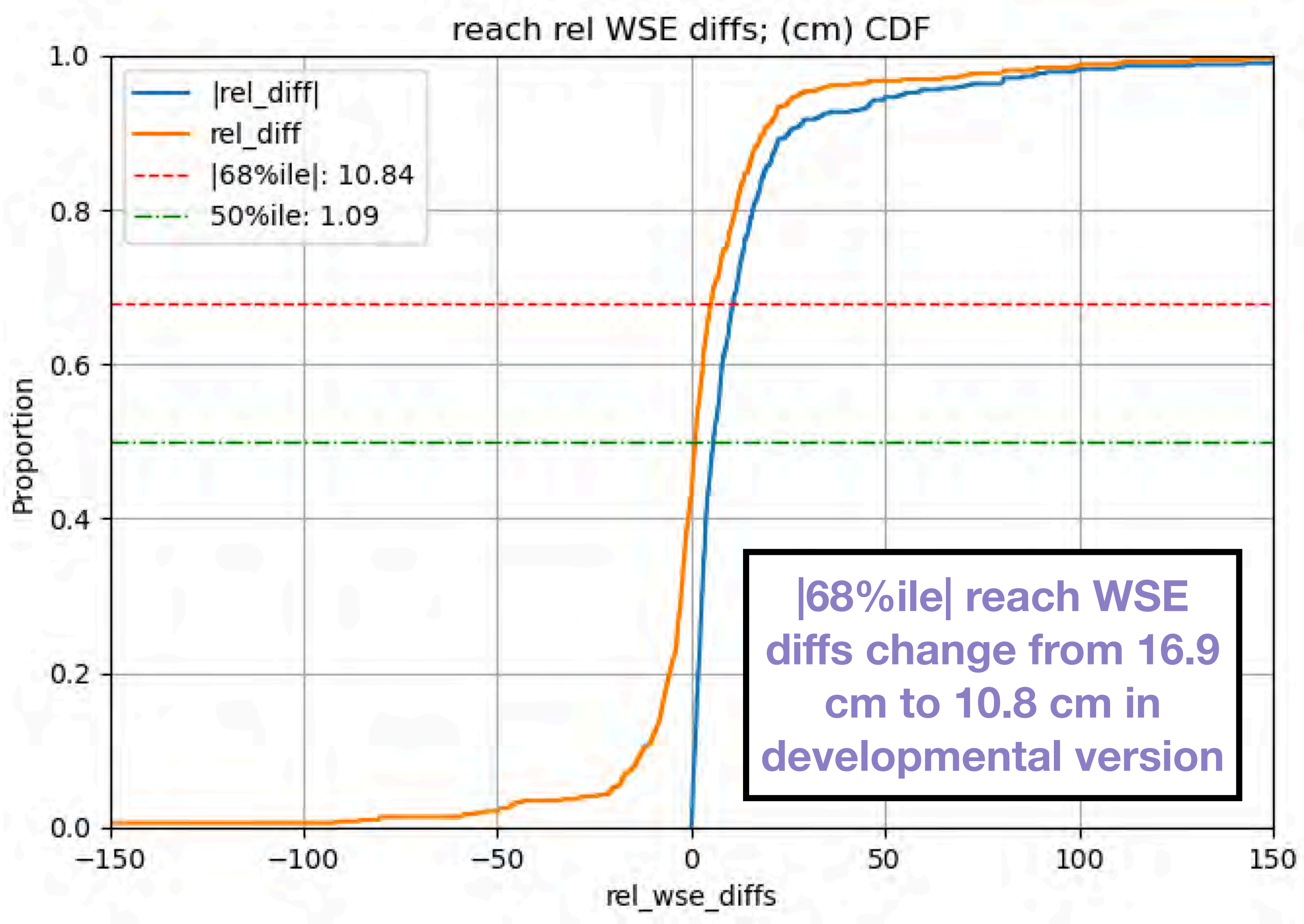


# 8: Developmental performance

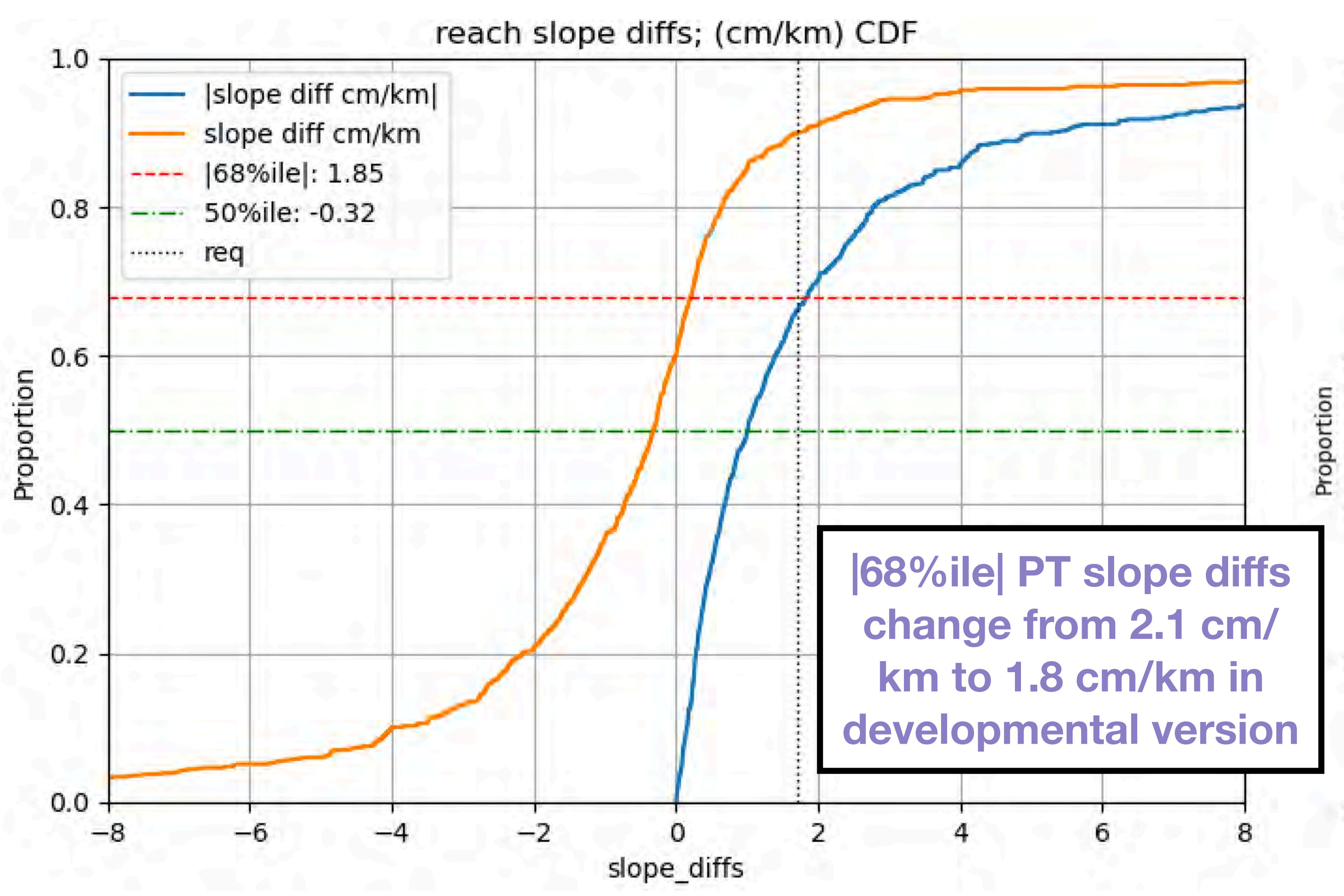
## Future deliveries will show improved WSE and slope performance

Our developmental dataset includes **improved pixel assignment, quality handling/propagation, outlier detection and flagging**, and miscellaneous bug/product fixes. It also includes upstream PIXC changes. We see significantly improved performance and more meaningful quality flags for users in the developmental data.

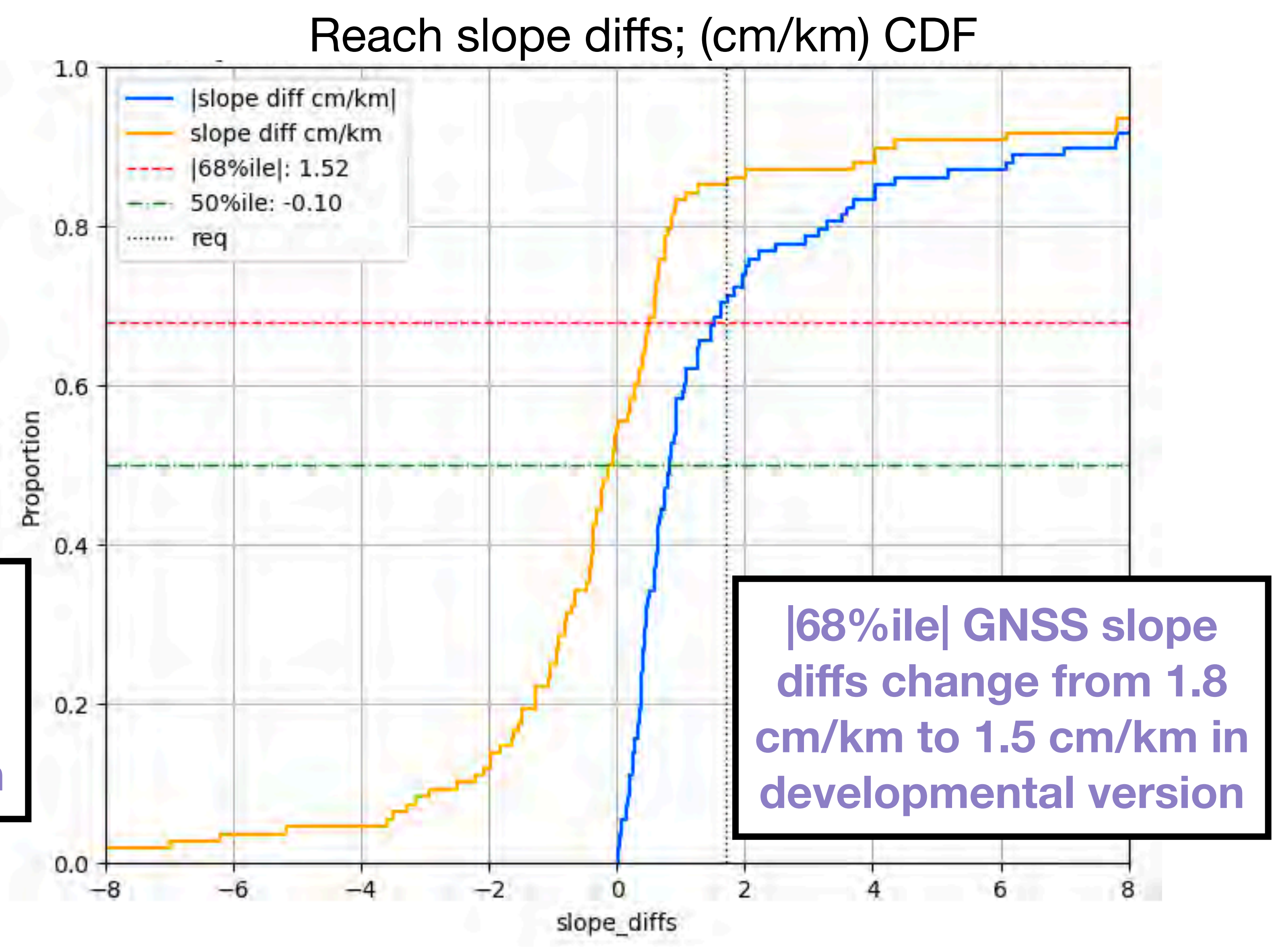
**Tier 1 PT Reach WSE diffs**




**Tier 1 PT slope diffs**




**Tier 1 GNSS slope diffs**




`dark_frac ≤ 0.5; reach_q ≤ 2`

# 9: Summary and conclusions

## Takeaways for science users

- SWOT river performance is generally good but varies significantly with site, overpass, and in-situ methodology
- **Filtering nodes/reaches for dark water, bad quality, river length/width, and crossover calibration quality is critical for hydrological science applications using "Version C" data**
- Version C reach-level WSE performance is variable; and reach quality flags may be overflagging
- Node-level quality flags are accurate and useful for filtering WSE results
- Future L2_HR_RiverSP release will be more robust to darkwater, outlier water bodies, and have improved quality flagging. Node- and reach-level WSE and slope performance will significantly improve.

RiverSP Performance Summary

| | Version | GNSS | PT | vortex.io | Tier 3 Gauge |
|---|---|---|---|---|---|
| Node WSE | C | 13.0 cm | 10.9 cm | 11.2 cm | 11.85 cm |
| Reach WSE | C | 16.1 cm | 16.9 cm | 13.2 cm | N/A |
| Slope | C | 1.8 cm/km | 2.1 cm/km | 15.6 cm/km | N/A |
| Node WSE | Dev | 12.6 cm | 9.8 cm | 10.3 cm | N/A |
| Reach WSE | Dev | 12.9 cm | 10.8 cm | 12.9 cm | N/A |
| Slope | Dev | 1.5 cm/km | 1.8 cm/km | 11.8 cm/km | N/A |

# 9: Summary and conclusions

## Takeaways for science users

- SWOT river performance is generally good but varies significantly with site, overpass, and in-situ methodology
- **Filtering nodes/reaches for dark water, bad quality, river length/width, and crossover calibration quality is critical for hydrological science applications using "Version C" data**
- Version C reach-level WSE performance is variable; and reach quality flags may be overflagging
- Node-level quality flags are accurate and useful for filtering WSE results
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RiverSP Performance Summary

| | Version | GNSS | PT | vortex.io | Tier 3 Gauge |
|---|---|---|---|---|---|
| Node WSE | C | 13.0 cm | **10.9 cm** | 11.2 cm | 11.85 cm |
| Reach WSE | C | **16.1 cm** | **16.9 cm** | 13.2 cm | N/A |
| Slope | C | 1.8 cm/km | **2.1 cm/km** | 15.6 cm/km | N/A |
| Node WSE | Dev | 12.6 cm | **9.8 cm** | 10.3 cm | N/A |
| Reach WSE | Dev | **12.9 cm** | **10.8 cm** | 12.9 cm | N/A |
| Slope | Dev | 1.5 cm/km | **1.8 cm/km** | 11.8 cm/km | N/A |

# Part 2

## River Slope and WSE Features & Issues

SWOT

# Outline

## Part 1: River WSE/slope product validation

1. Review of data for comparisons
2. Mathematical definitions of performance calculations
3. Node-level WSE performance estimate
4. Reach-level slope & WSE performance estimate
5. Variability by River Site
6. Comparisons against other independent estimates (Vortex.io, T3)
7. Relationships with quality; dark water; river width
8. Expected performance of future deliveries
9. Summary and conclusions

## Part 2: River Product WSE & slope features/issues

11. Symptoms of SWOT issues and their origins/occurrences
    11.1. Anomalies in river height profiles
    11.2. Other product symptoms
12. Summary and conclusions

# 11. Symptoms of SWOT issues

## Overview and roadmap

**From the user perspective, slope and WSE problems can look like:**

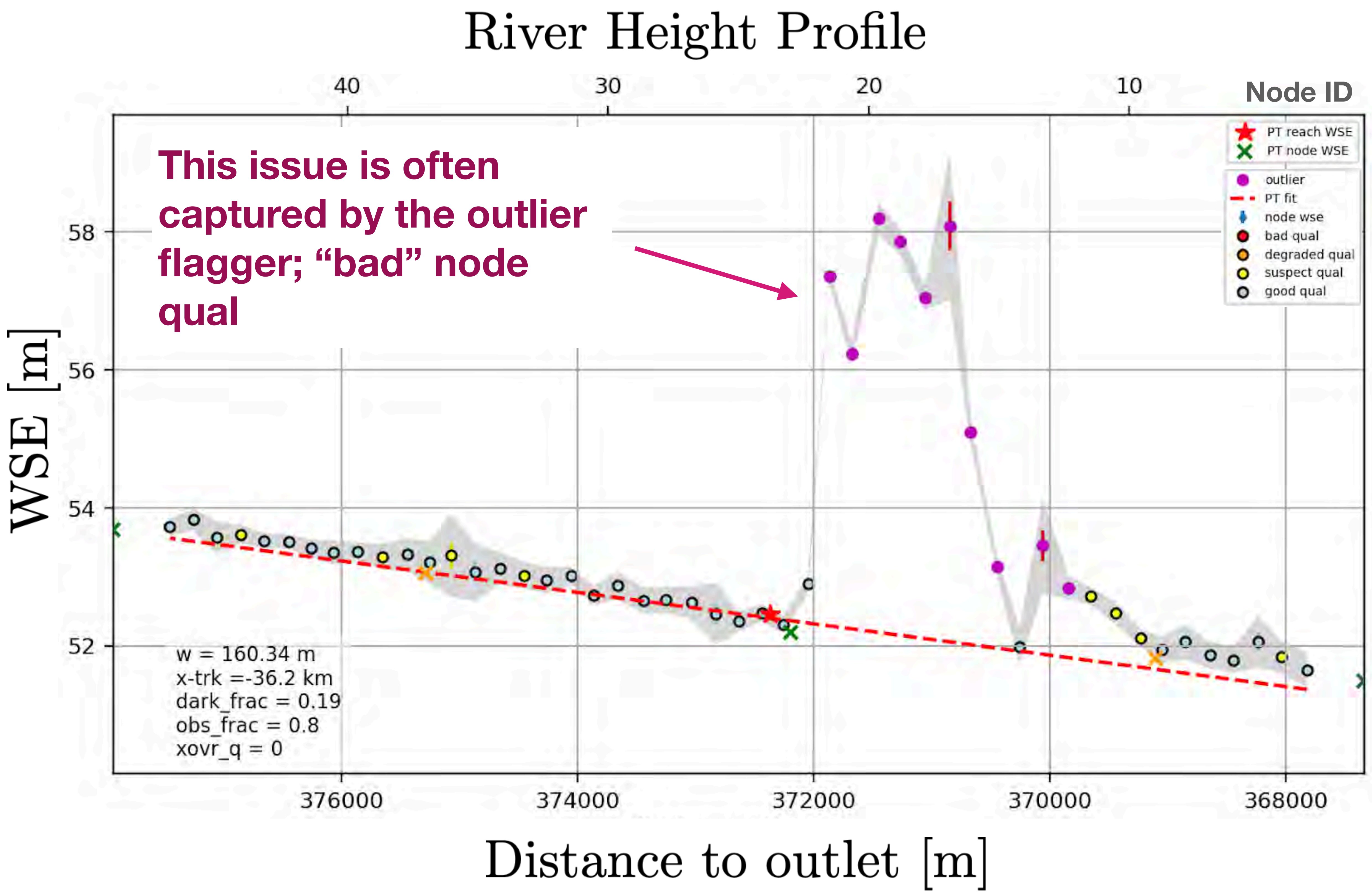
1. **Anomalies in River height profiles**
   - 1.1. Meter-scale WSE outliers
   - 1.2. Decameter-scale WSE outliers
   - 1.3. Noisy and jagged height profiles
   - 1.4. Widespread WSE Bias

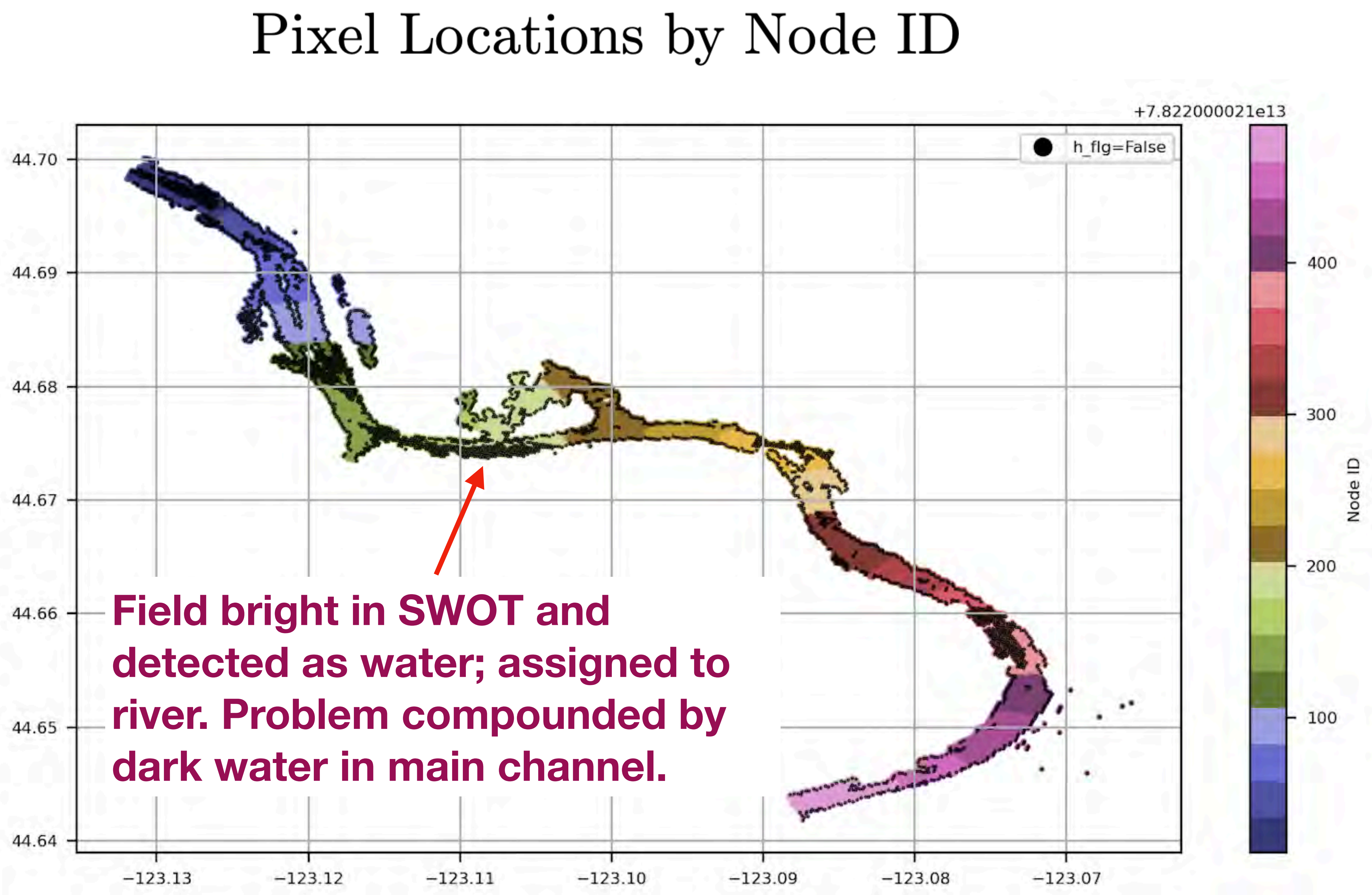
2. **Other product symptoms**
   - 2.1. Bit & Summary Quality flags
   - 2.2. Product qual indicators
     - 2.2.1. dark_frac
     - 2.2.2. obs_frac
     - 2.2.3. xovr_cal_q
     - 2.2.4. ice_clim_f

# 11: Symptoms of WSE issues

## 11.1.1 Metre-scale WSE outliers in River Height Profiles

**Positive, metre-to-decameter** WSE outliers with **low WSE random uncertainties** may indicate non-river waterbodies (e.g. fields, nearby lakes, cities) were aggregated to the river.




Pixel assignment info avaiable in PIXCVec product

SWOT

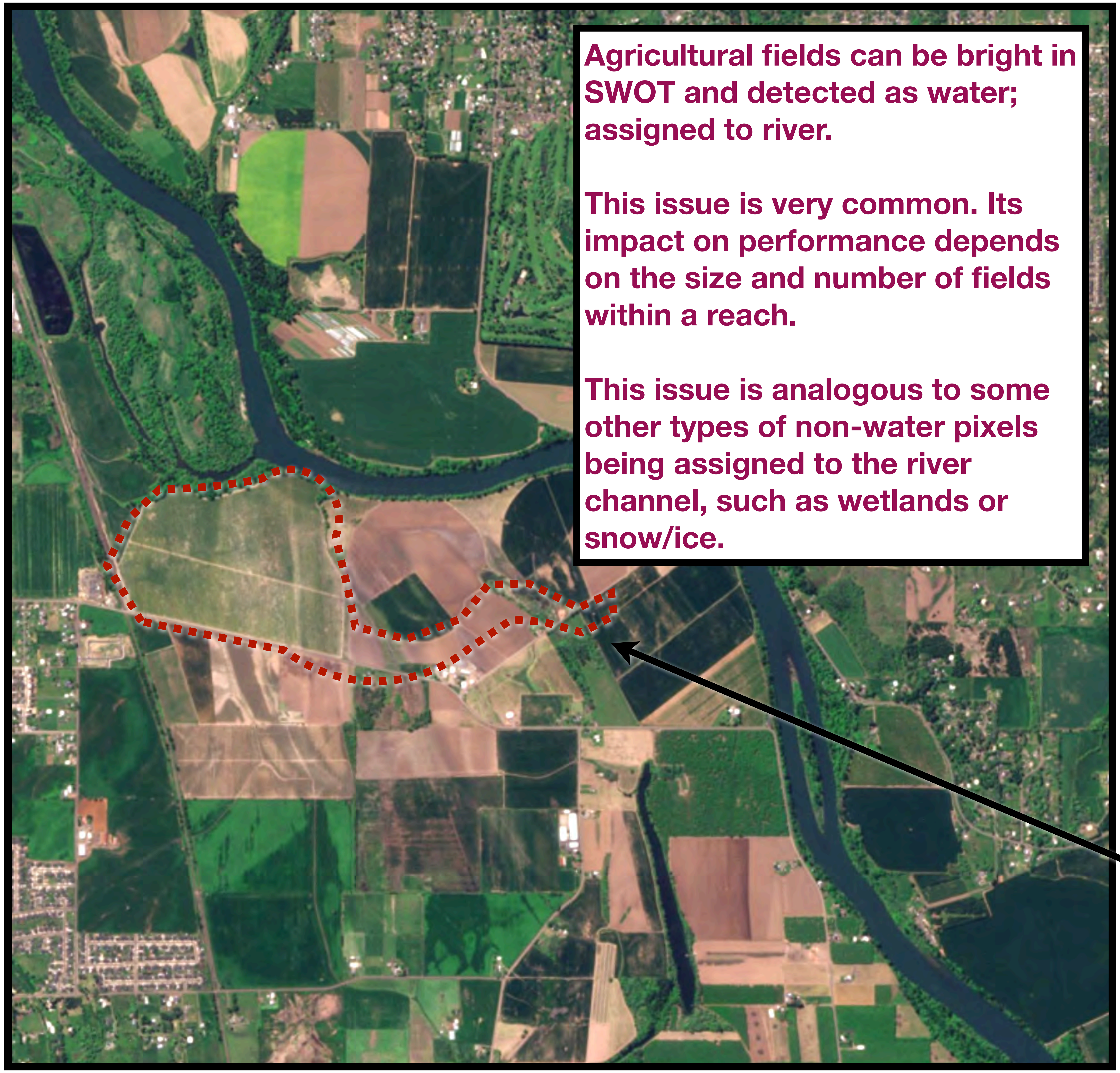
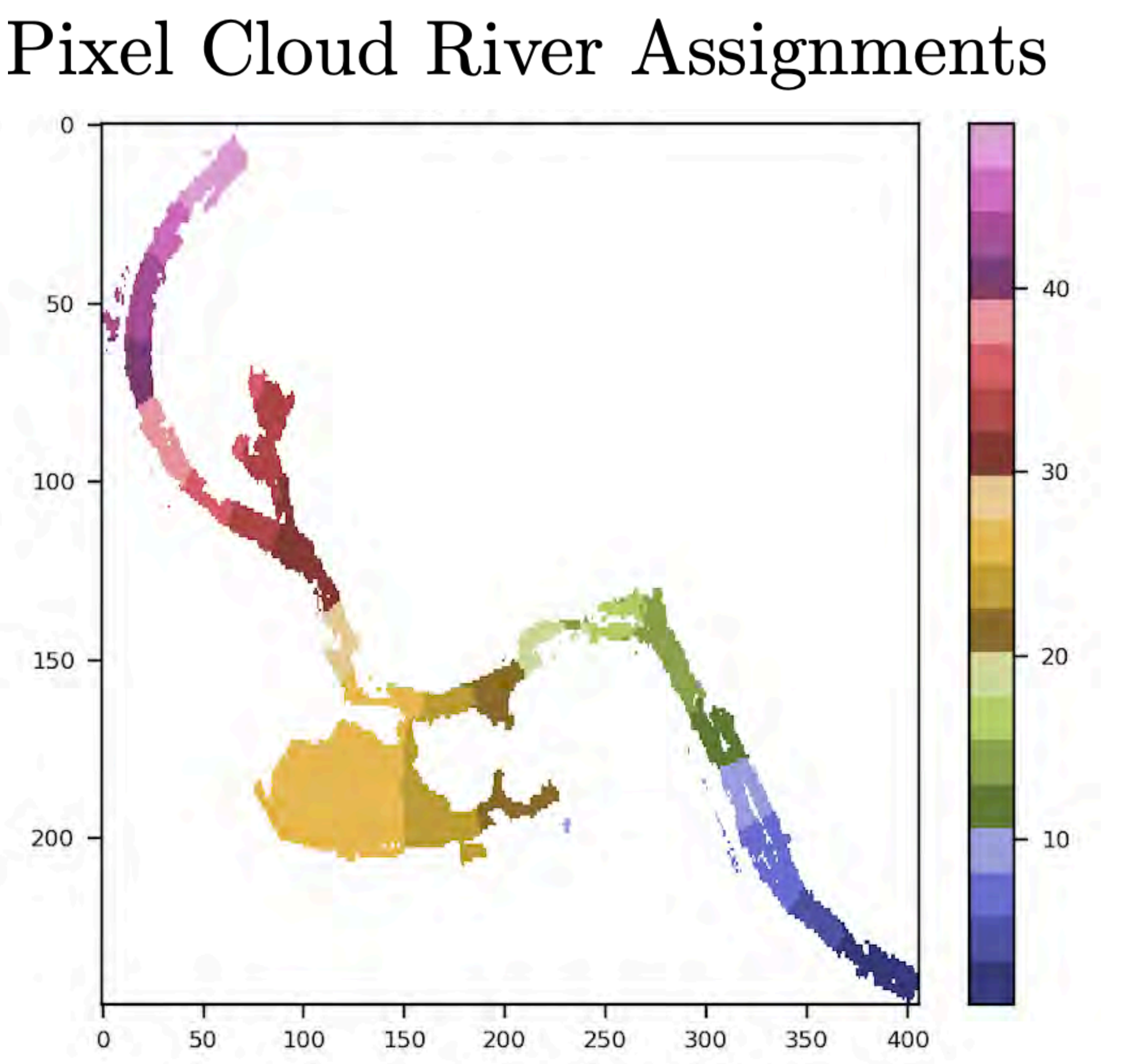
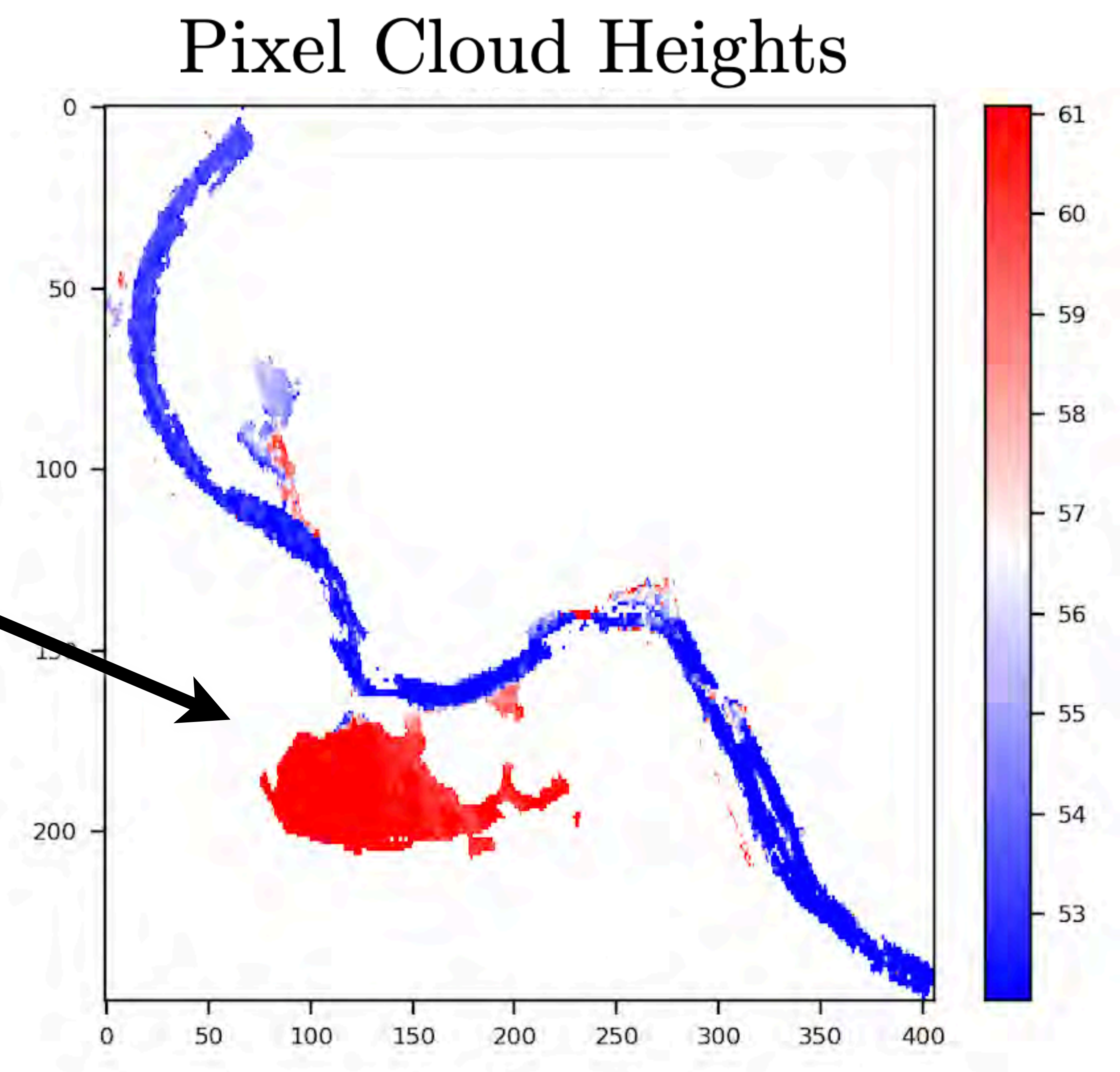



Image © 2023 Planet Labs PBC



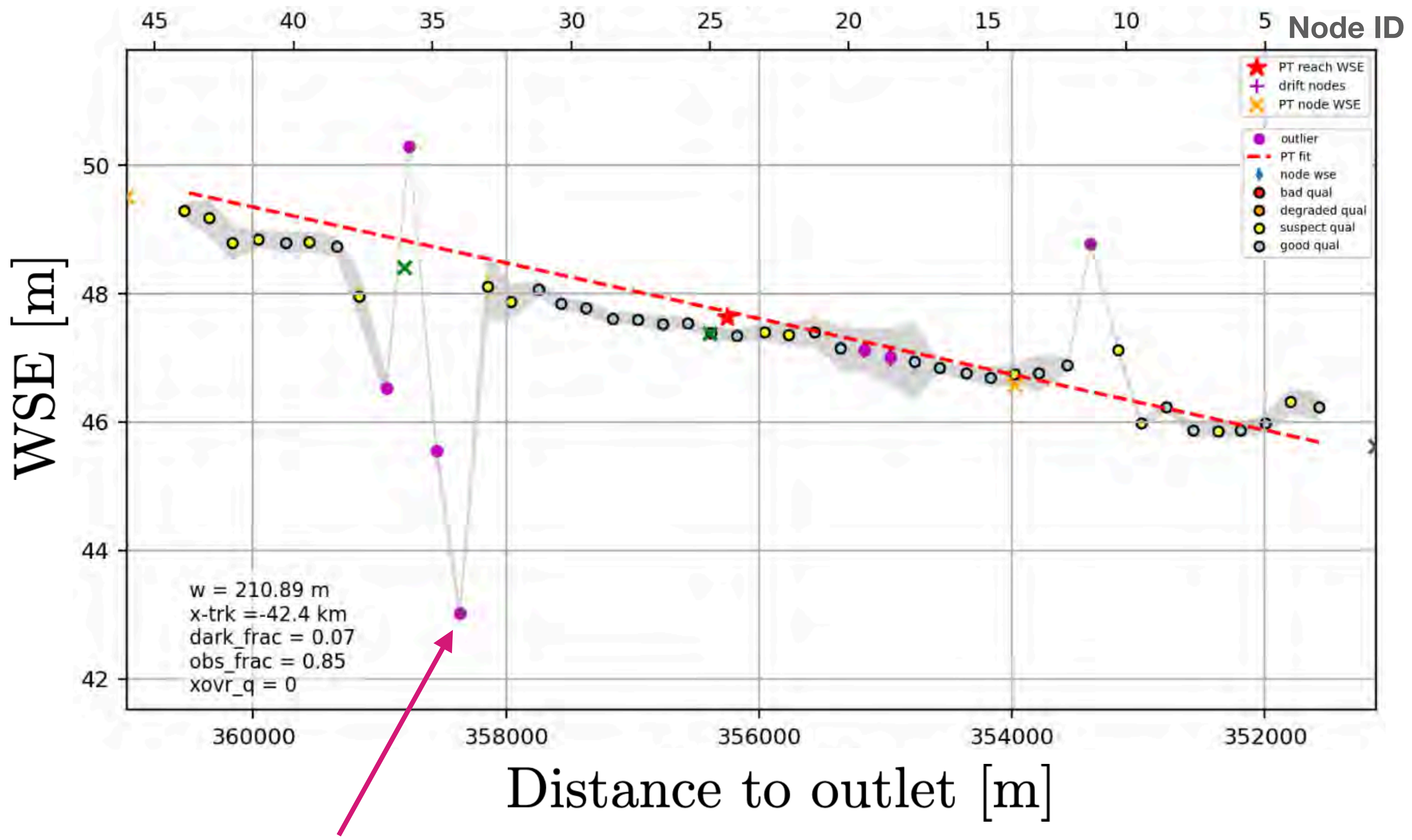



# 11: Symptoms of WSE issues

## 11.1.1: Meter-scale jumps with low wse_r_u

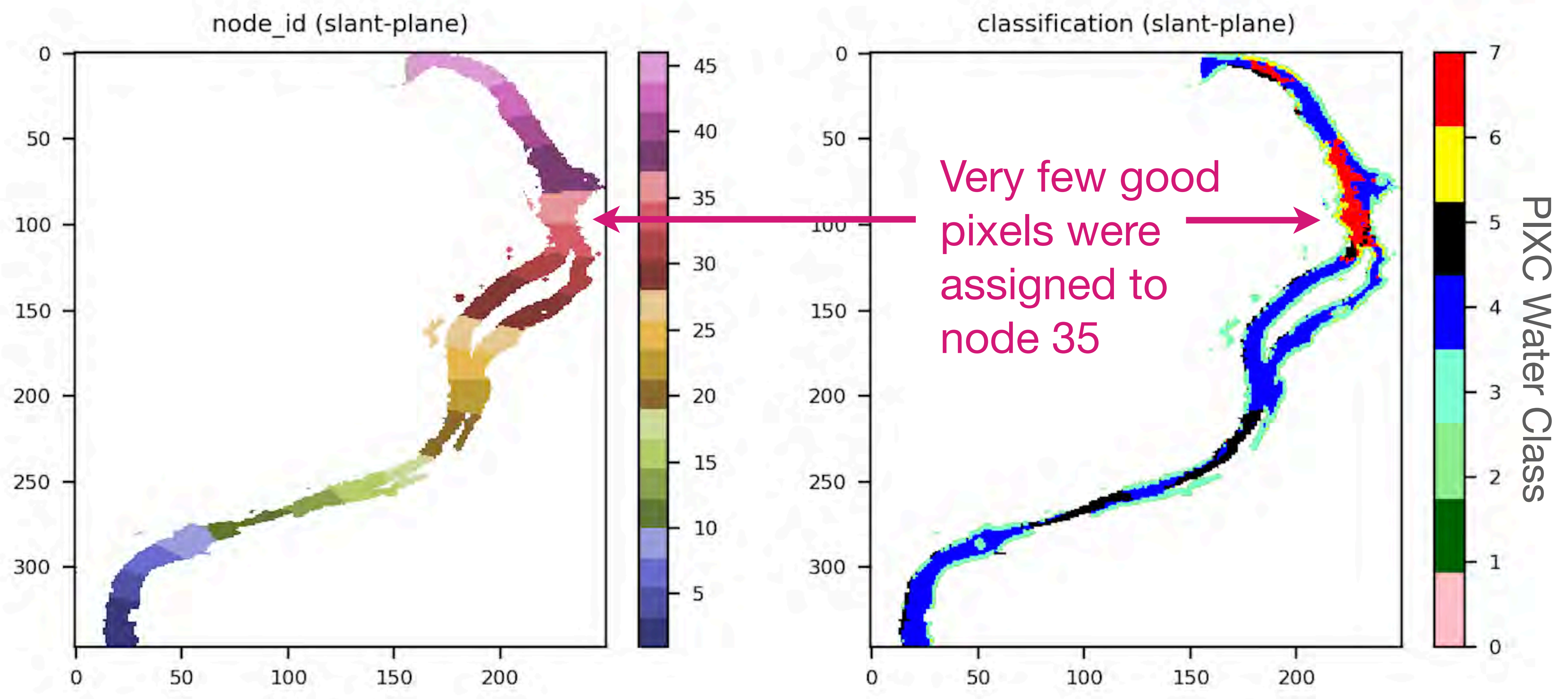
Meter-scale jumps with **low random uncertainties (wse_r_u)** can also indicate **layover**, especially where there are few good pixels assigned to node. In this example, very few pixels were assigned to node due to dark water and low-coherence pixels, increasing the node WSE's vulnerability to laid over pixels.

River Height Profile




**Node 35 n_good_pix = 9**

Pixel Cloud River Assignments

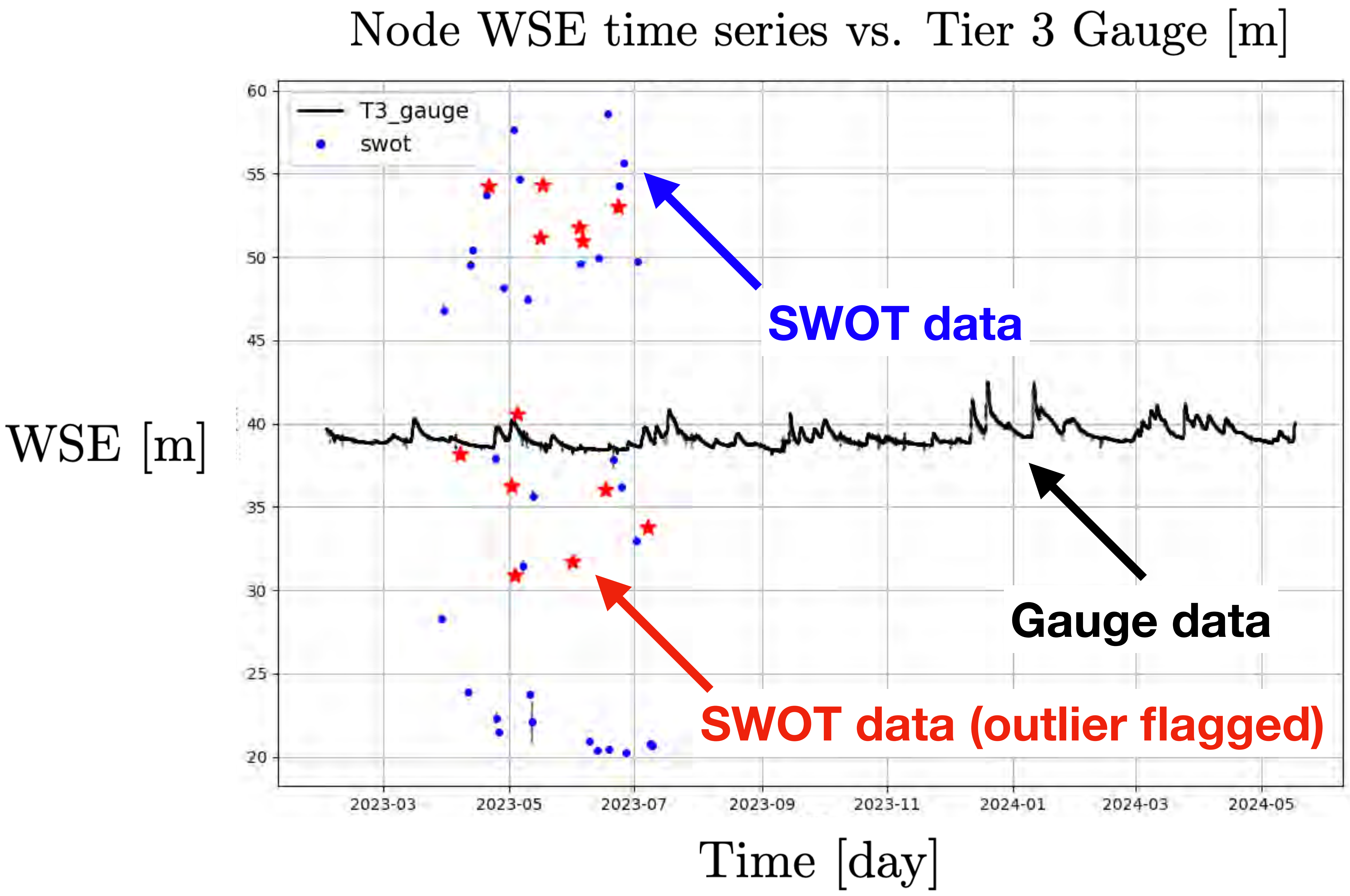


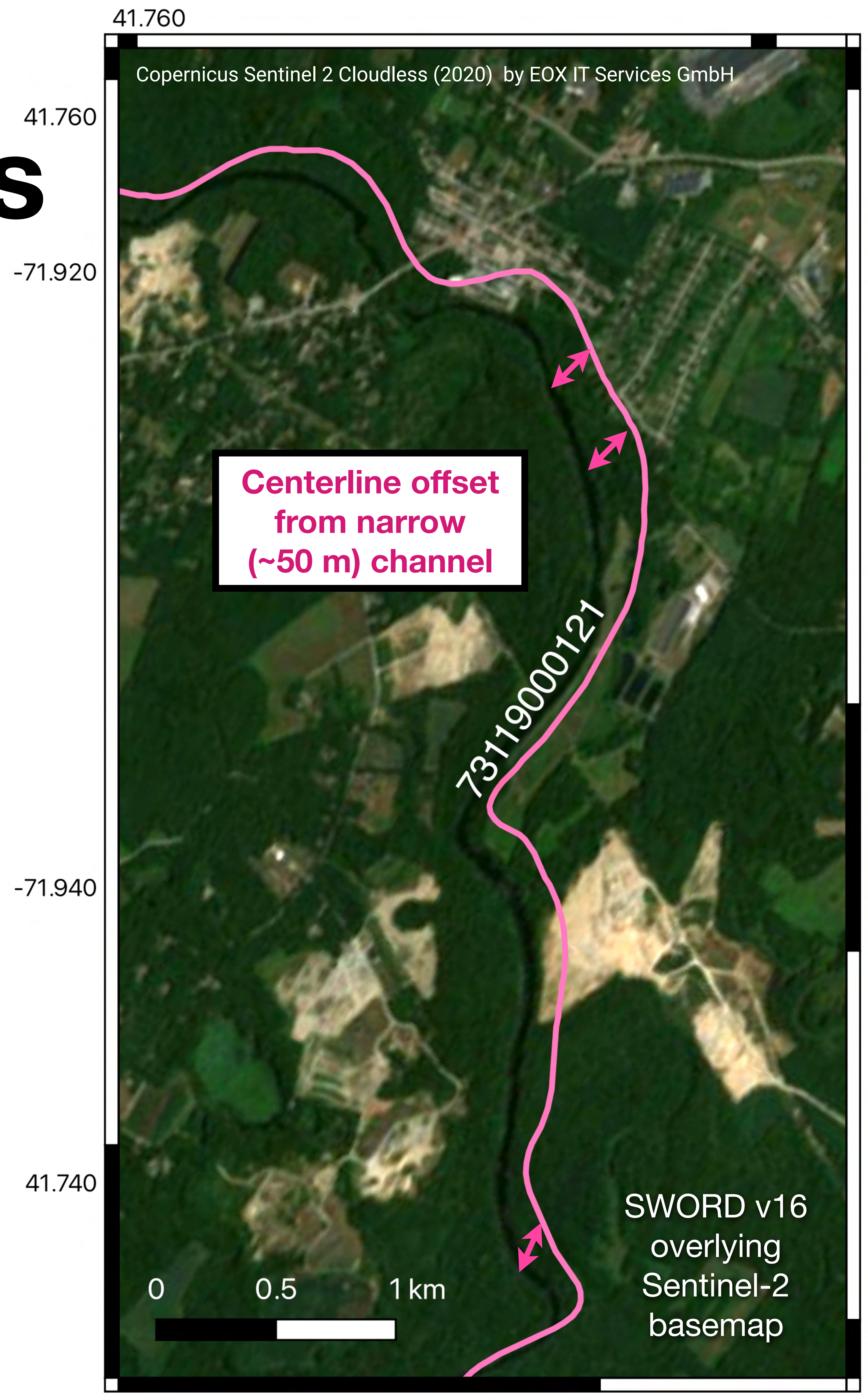

The red PIXC water class means low coherence and is associated with layover. Low coh WSE pixels are not used for node WSE computations.

# 11: Symptoms of WSE issues

## 11.1.2: Decameter-scale WSE jumps

Rarely, decameter jumps can relate to **SWORD centerline errors & pixel misassignment**. More often, centerline errors produce < 10 m errors or fill-value node WSE due to a lack of pixels.



# 11: Symptoms of WSE issues

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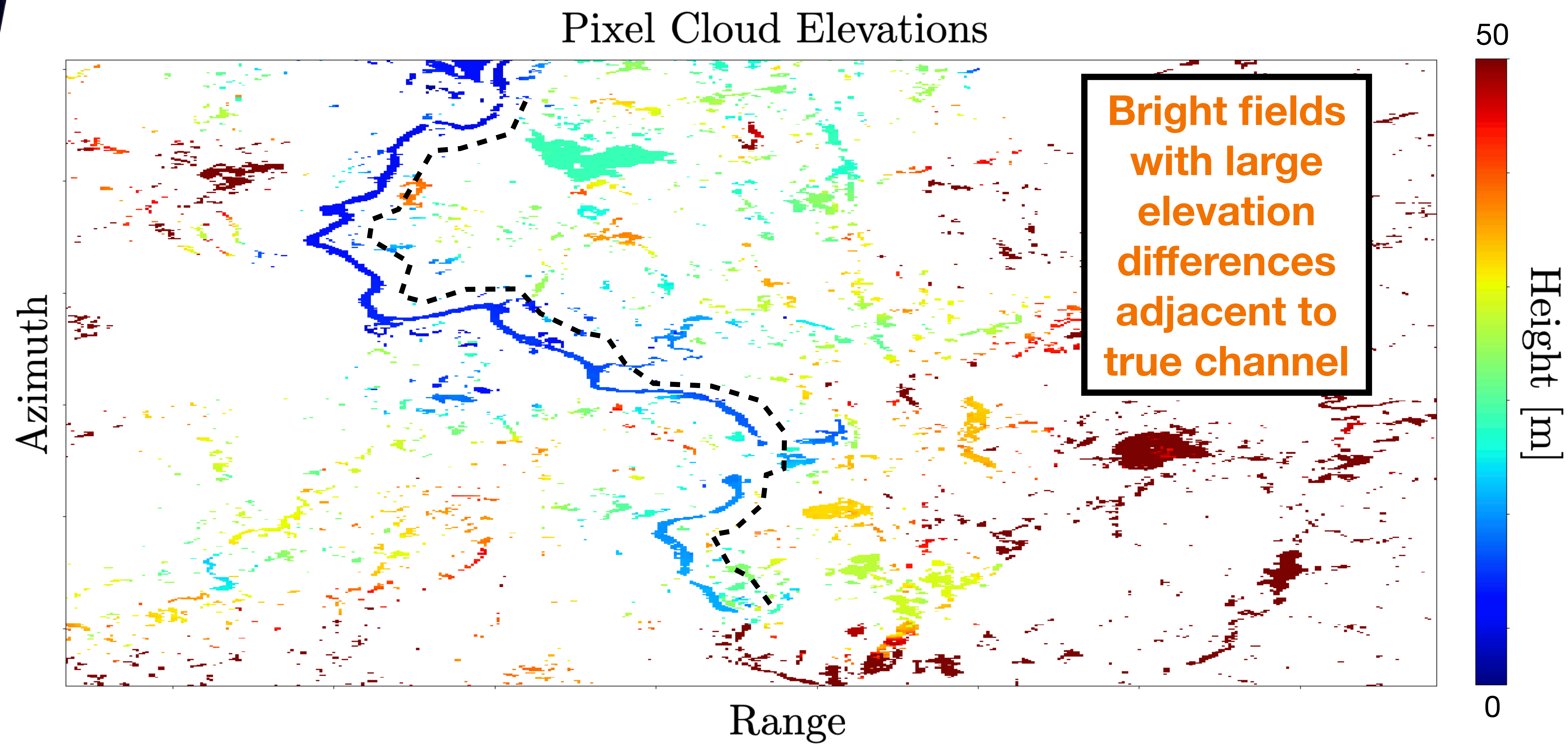
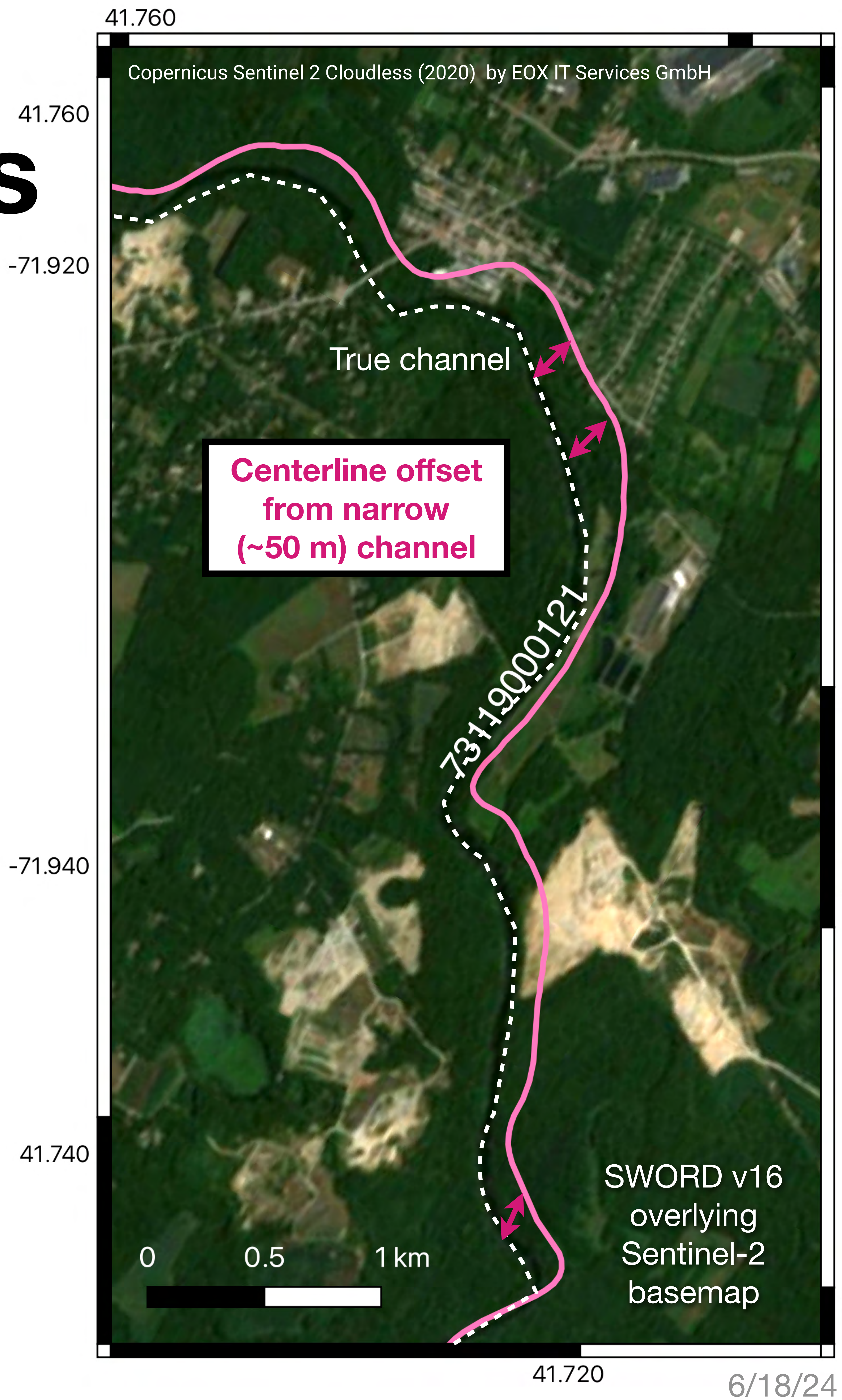


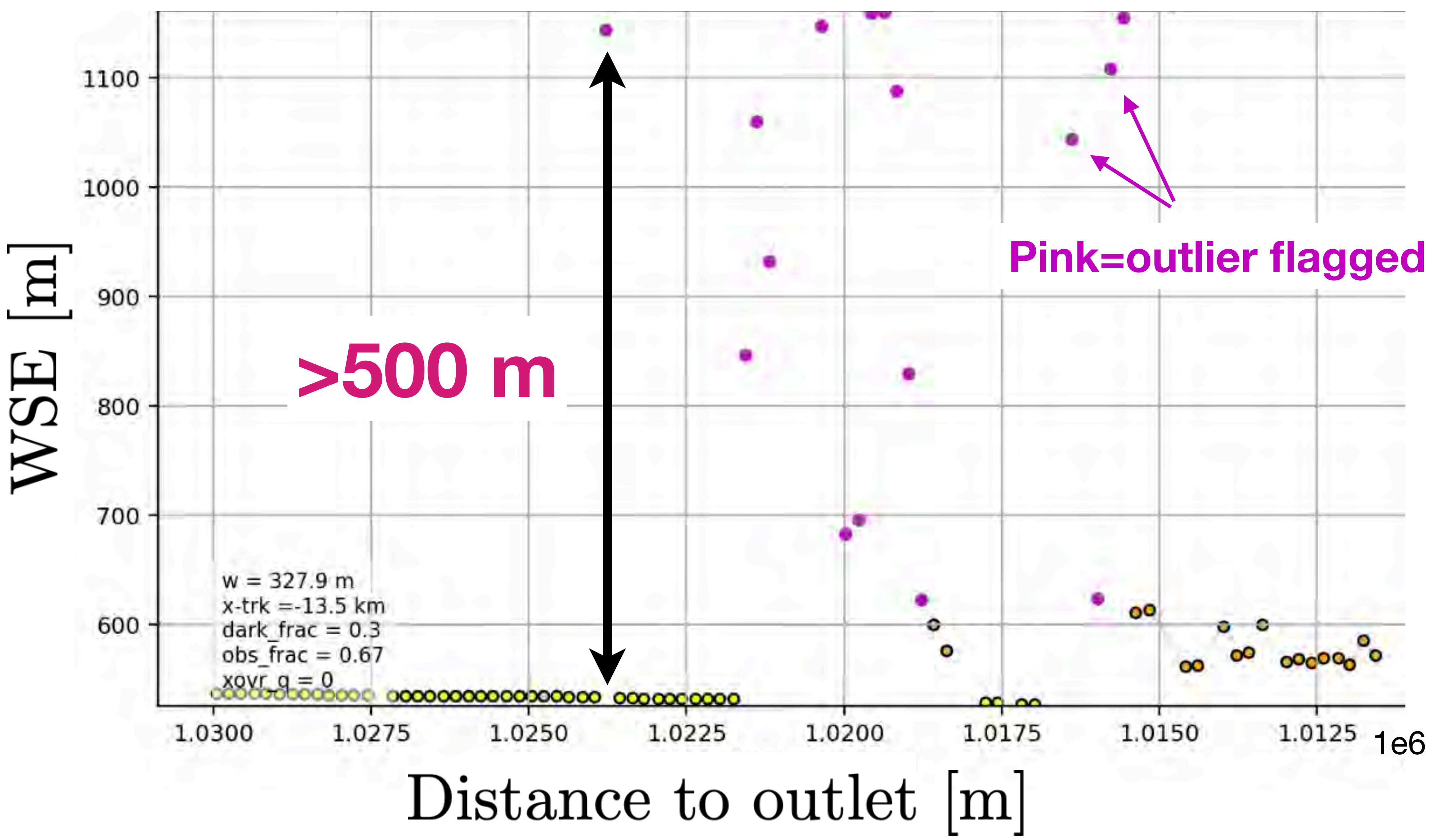



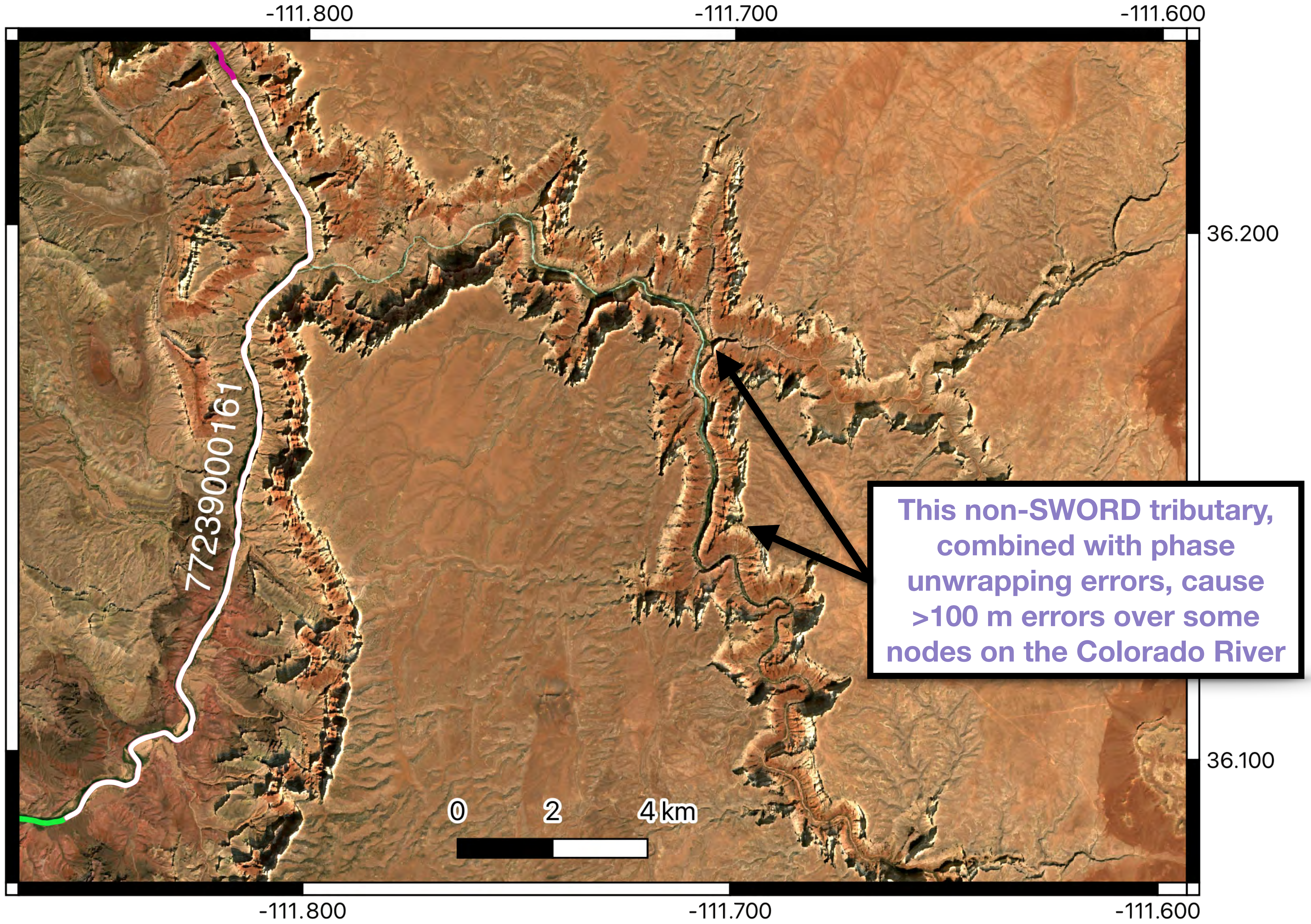
# 11: Symptoms of WSE issues

## 11.1.2: 100 m-scale WSE jumps

The Grand Canyon is prone to **large phase unwrapping errors** on the order of 100's of metres. Layover is uncommon. **Narrow tributaries (not in SWORD) are complicating factors**.

These nodes are usually flagged by the outlier detector and reach WSE are often good.

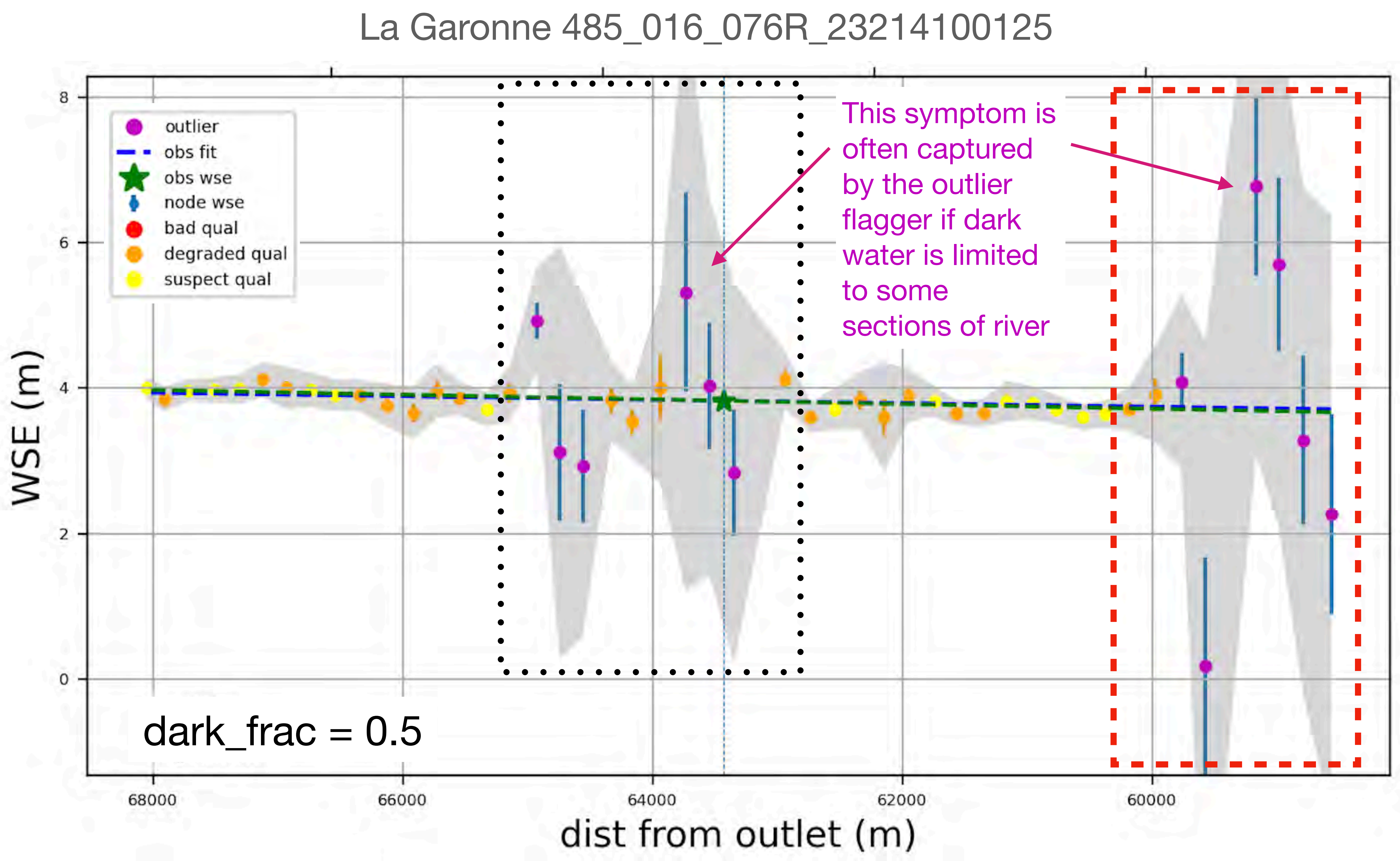


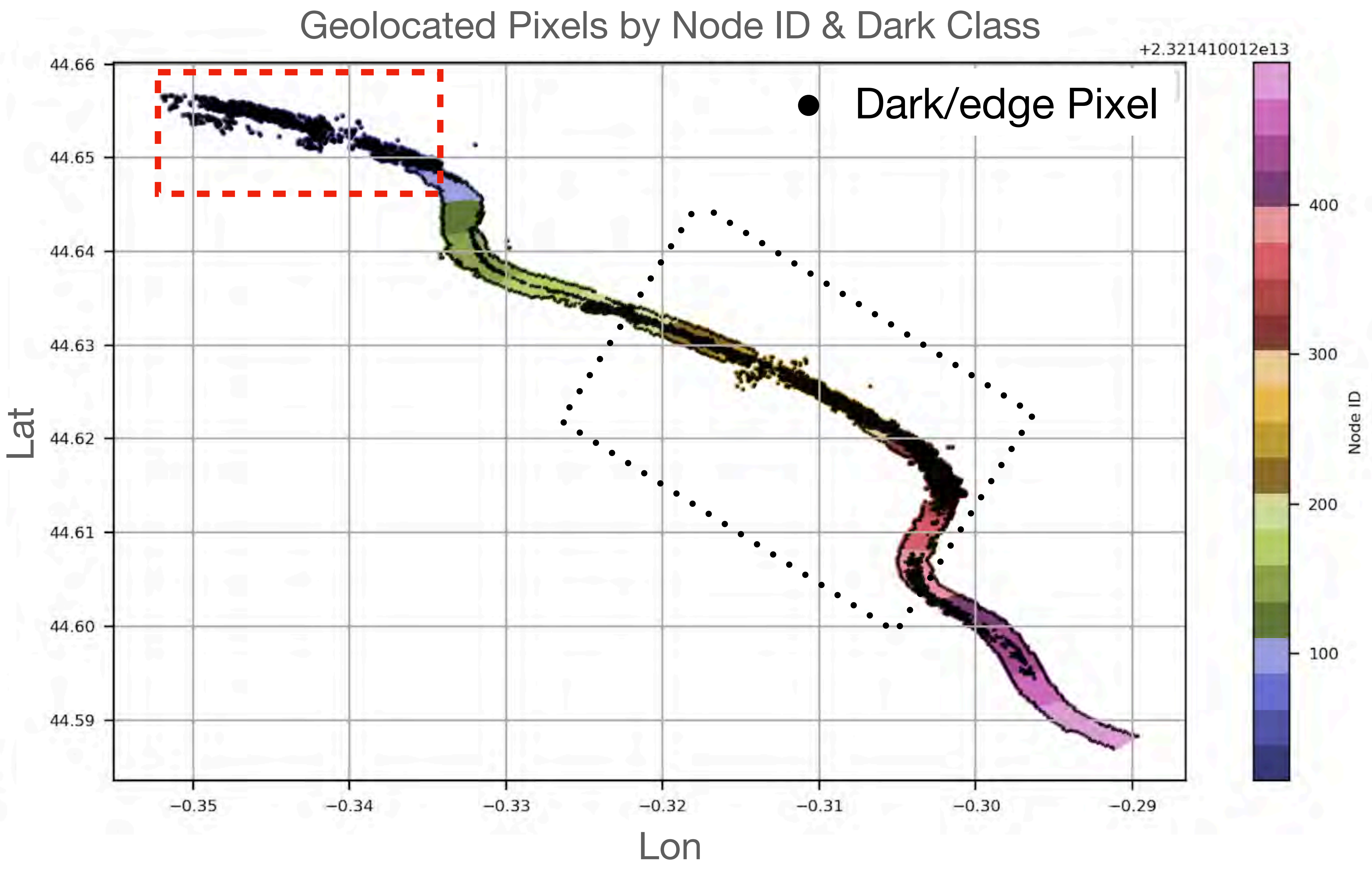



# 11: Symptoms of WSE issues

## 11.1.3: Noisy or Jagged River Height Profiles

Darkwater pixel heights are not used for computing node WSE. Thus, nodes with dark water have fewer aggregated pixels, resulting in **noisy, meter-scale variations in node WSE with large random uncertainties**



# 11: Symptoms of WSE issues

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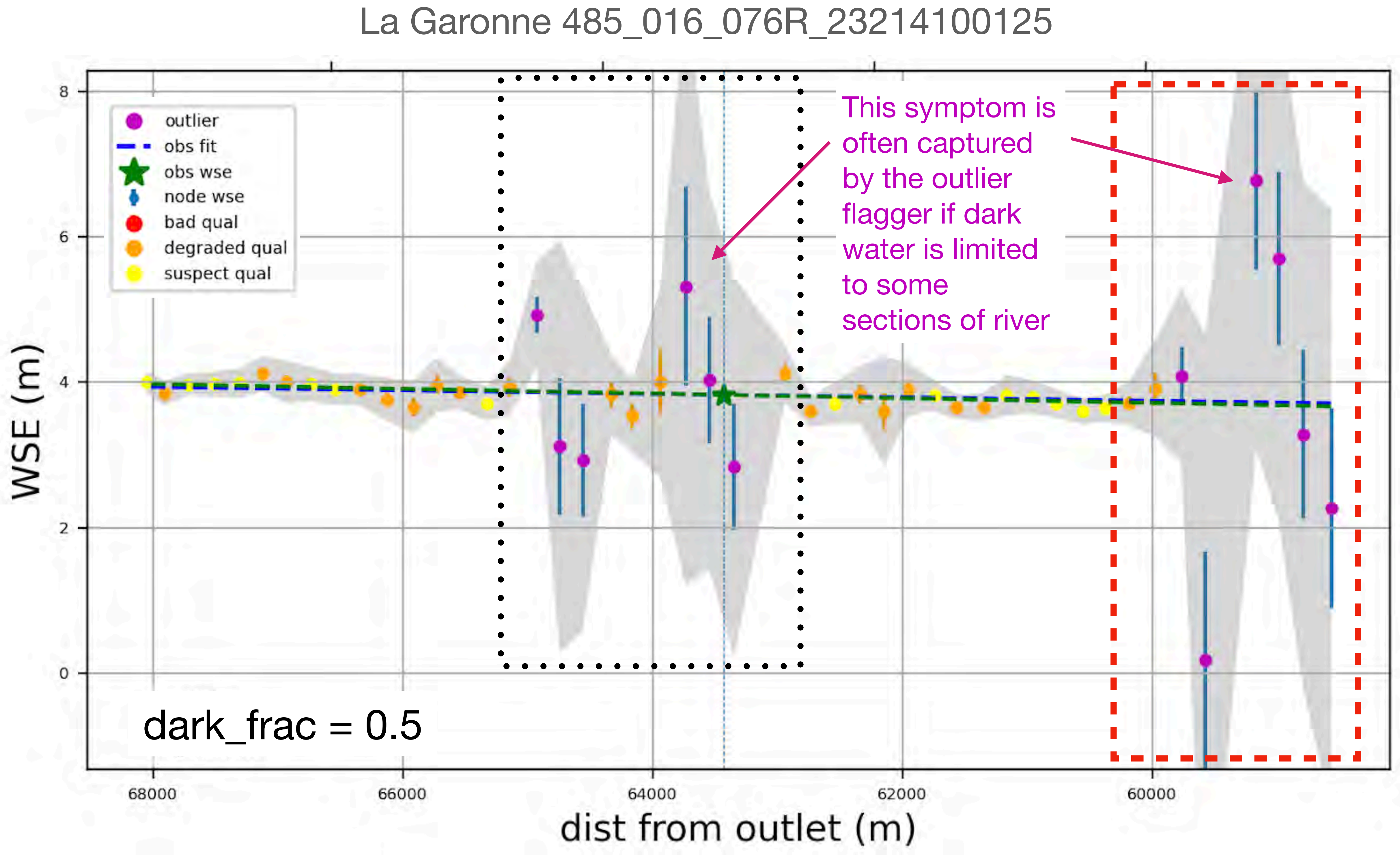
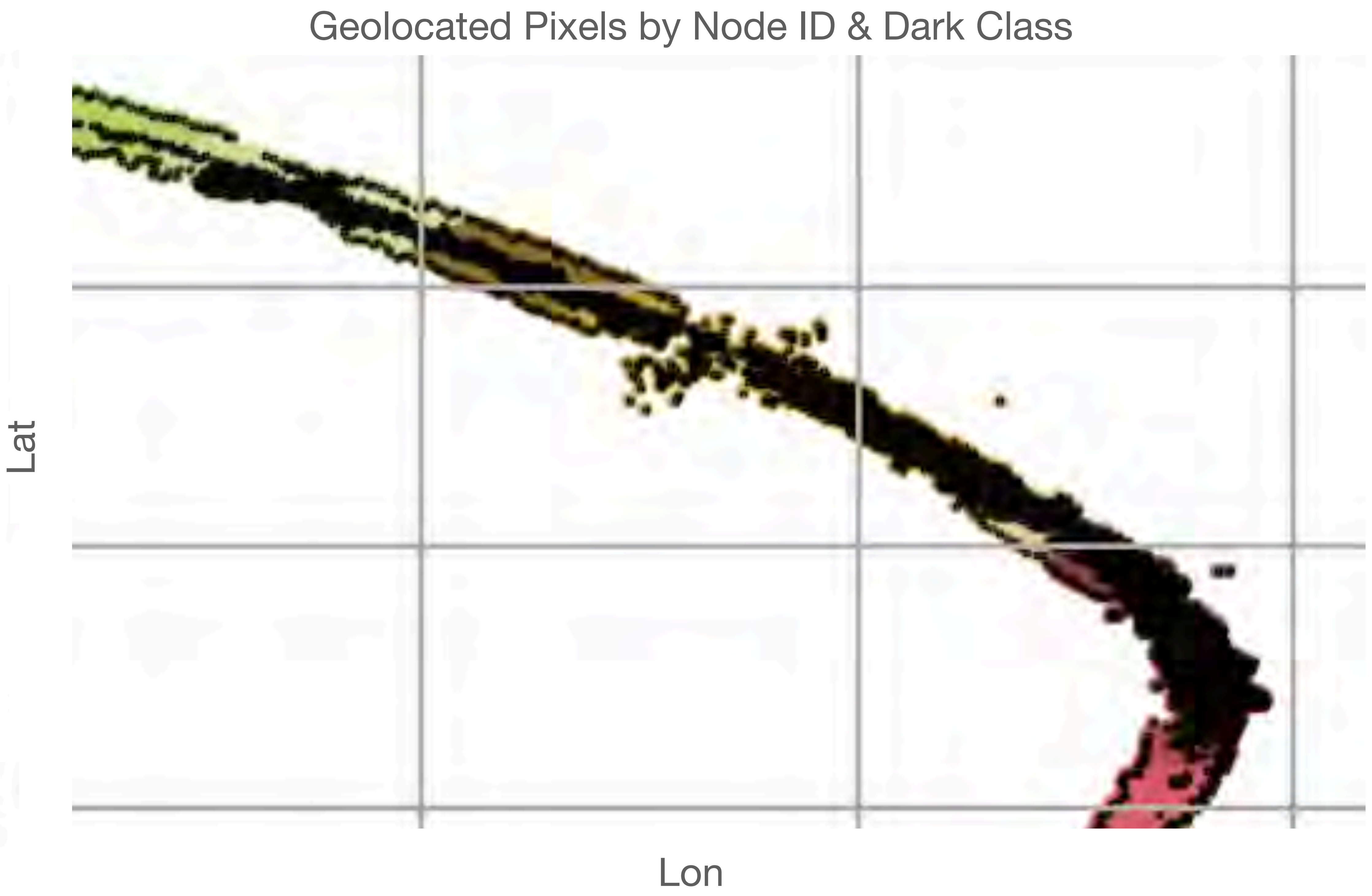


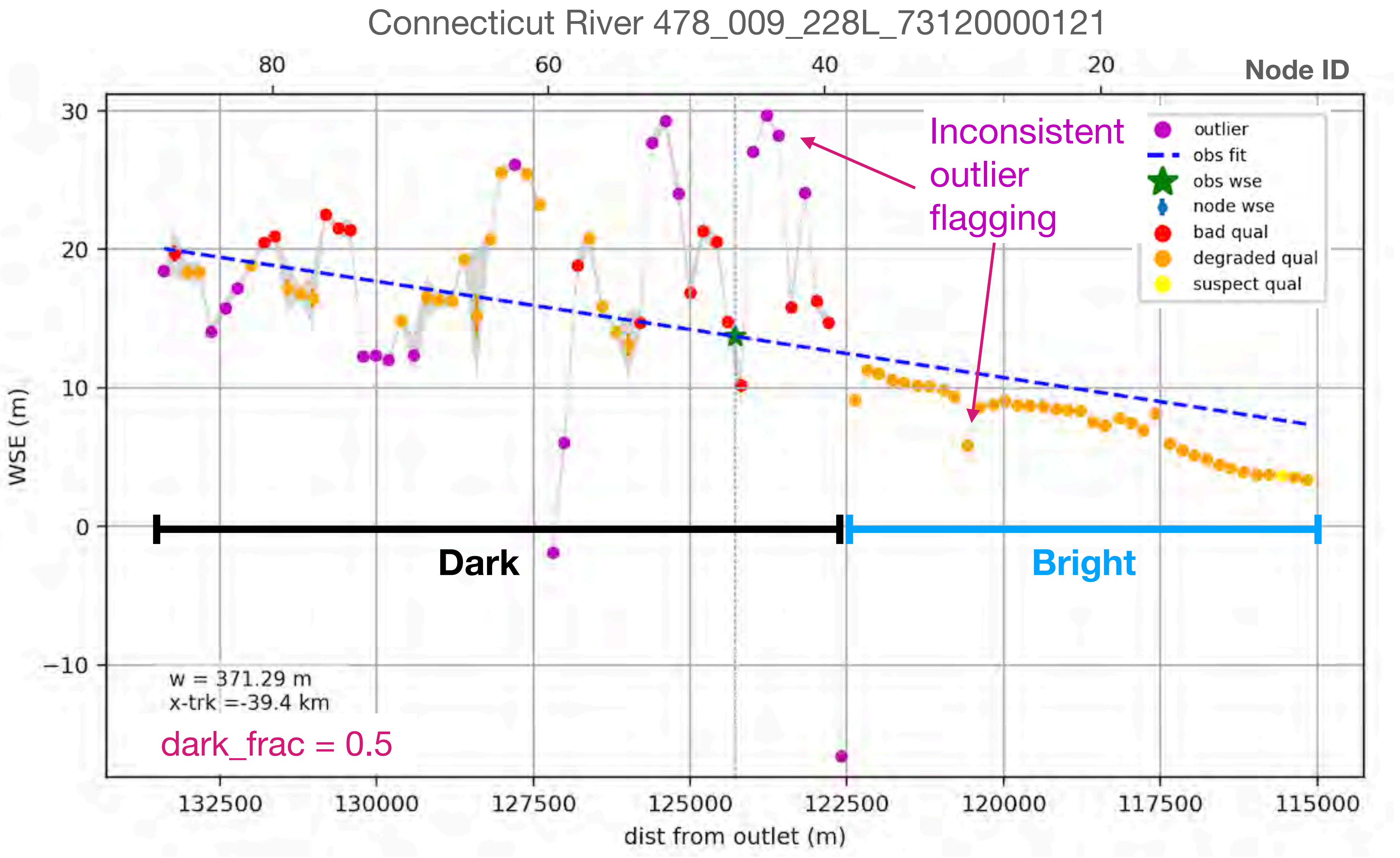



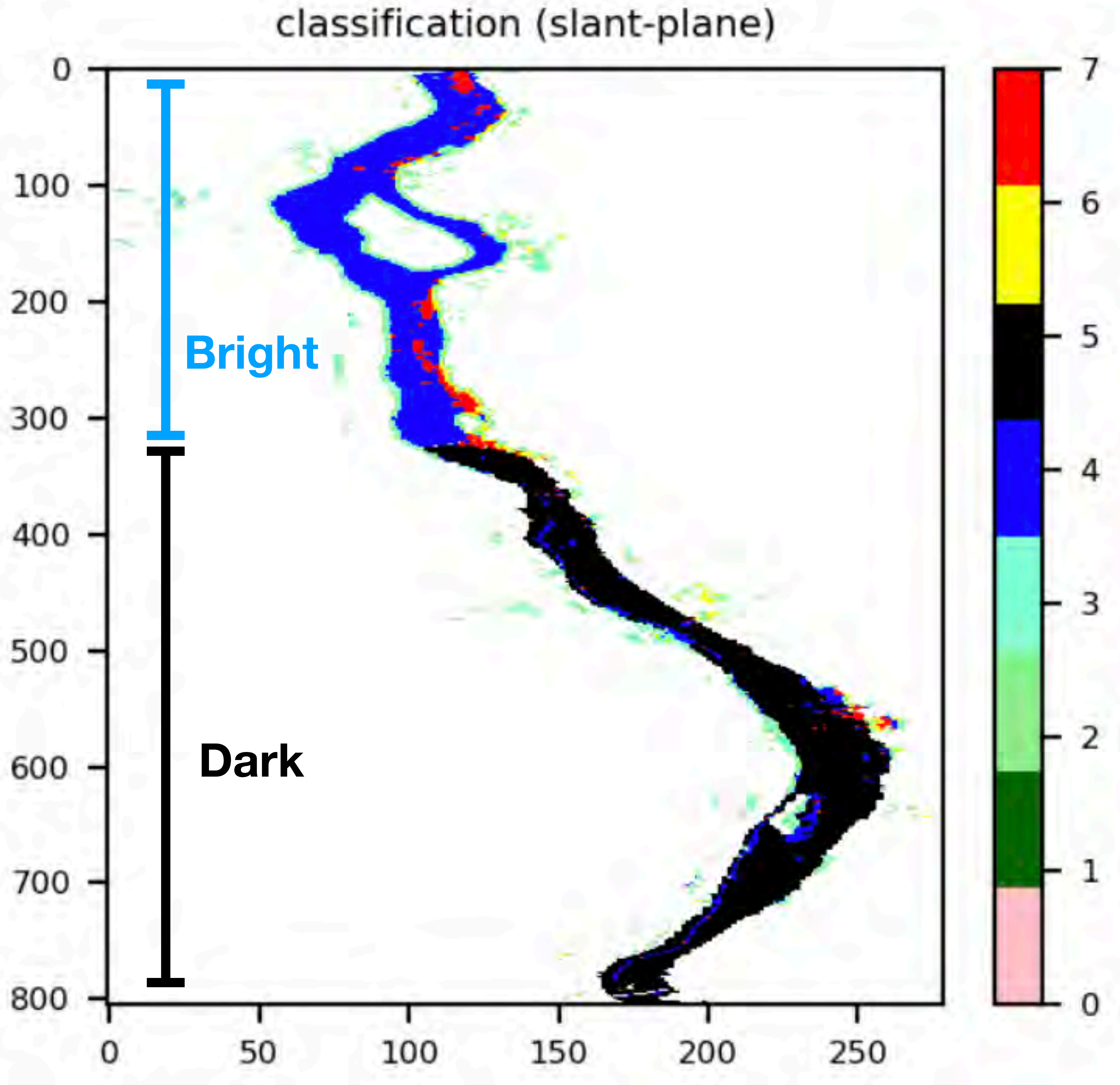
SWOT

# 11: Symptoms of WSE issues

## 11.1.3: Jagged WSE & Pervasive Darkwater in River Height Profiles

Where dark water is widespread, the node outlier flagging performance degrades. Node WSEs are more vulnerable to layover, causing sharp jumps in the river height profile. Reach-level heights and slopes may be untrustworthy.



# 11: Symptoms of WSE issues

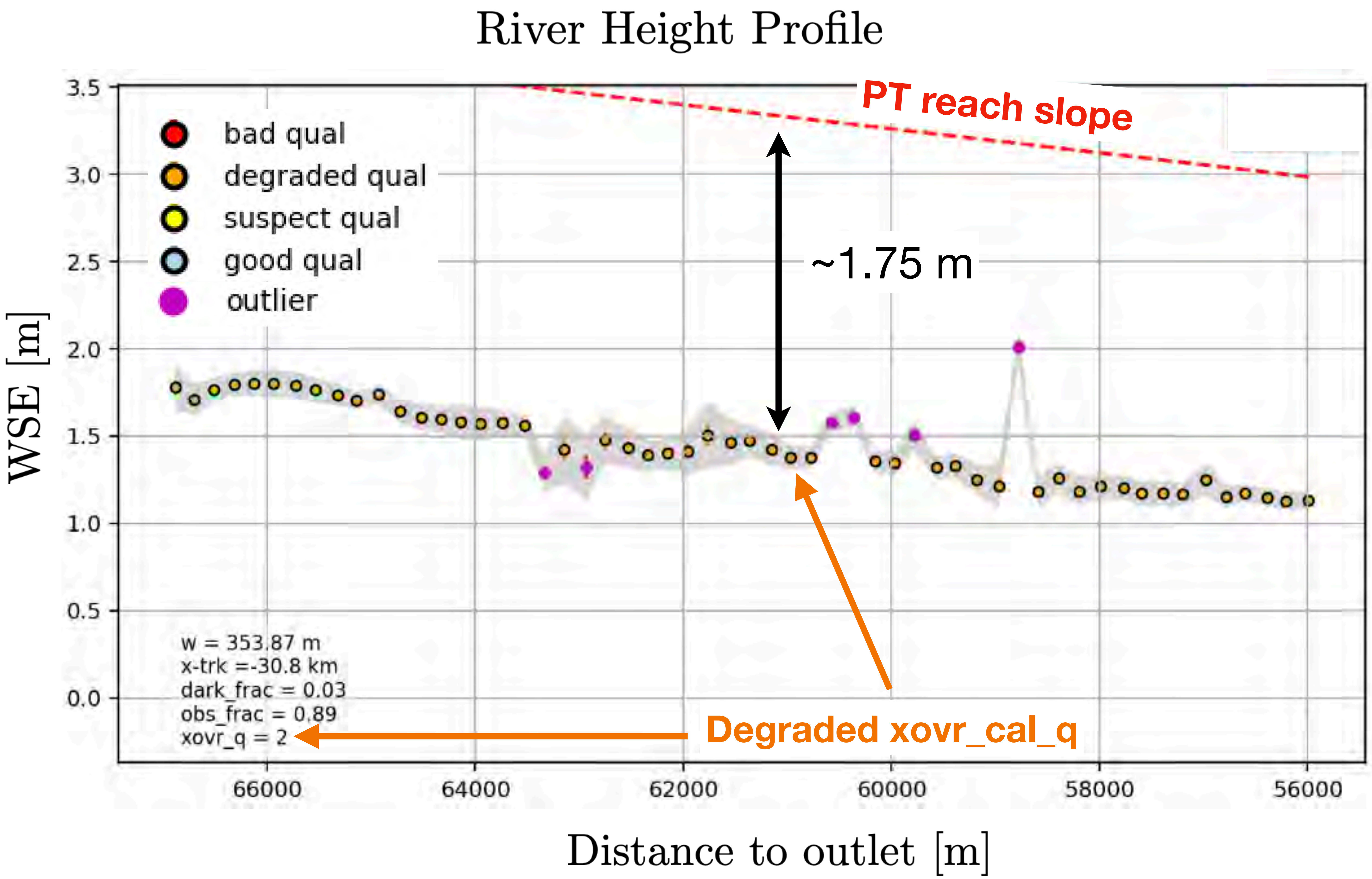
## 11.1.4: Widespread bias and Crossover issues in River Height Profiles

Crossover issues are characterized by:

1. Metre-scale WSE bias that is either **constant** or has a **slight slope** over a whole cycle-pass

2. Node and Reach qual **Degraded** (if xovr missing in PIXC) or **suspect** (if xovr suspect in PIXC) in RiverSP

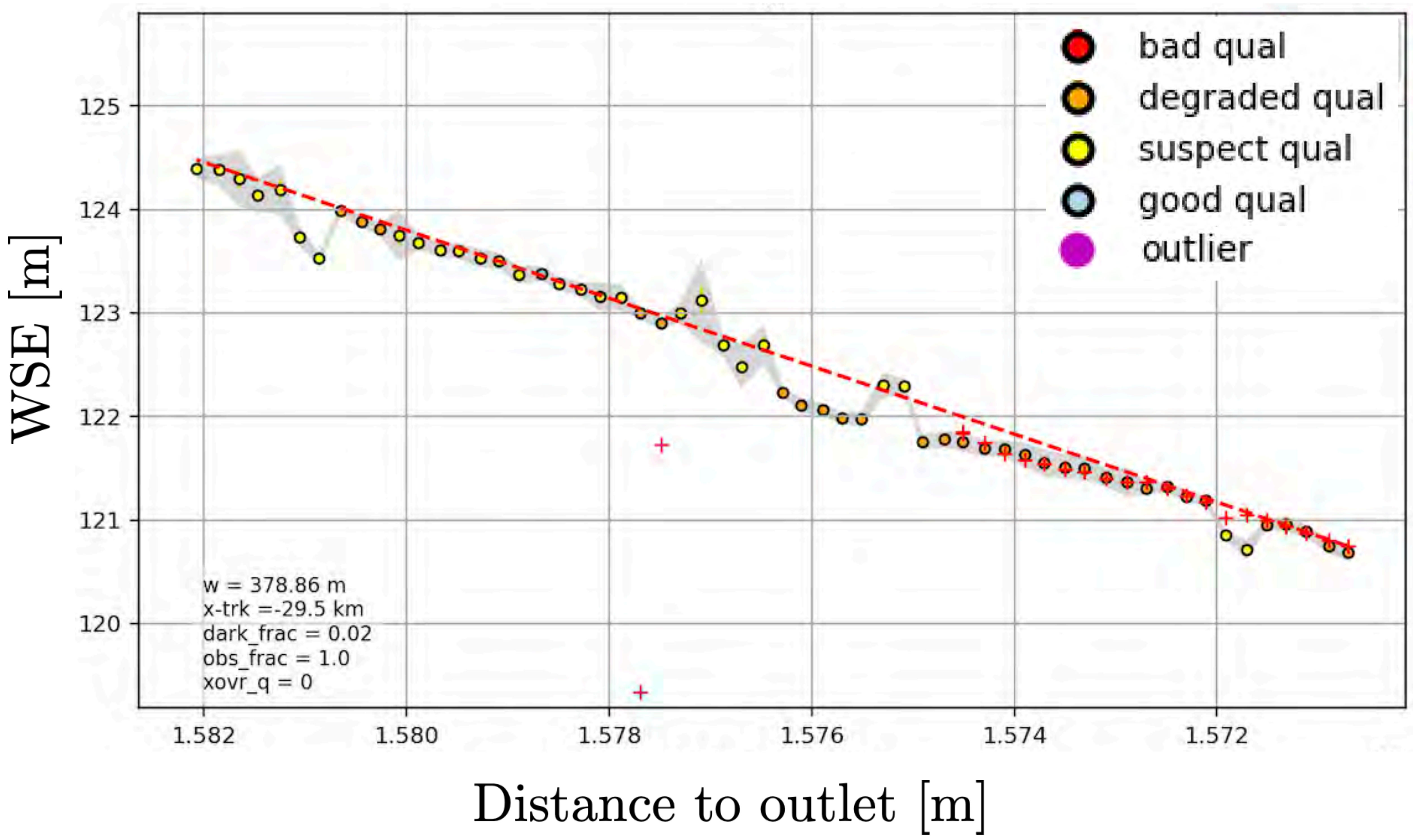
3. **xovr_cal_q = 2** (degraded) or **xovr_cal_q = 1** (suspect) in River Product

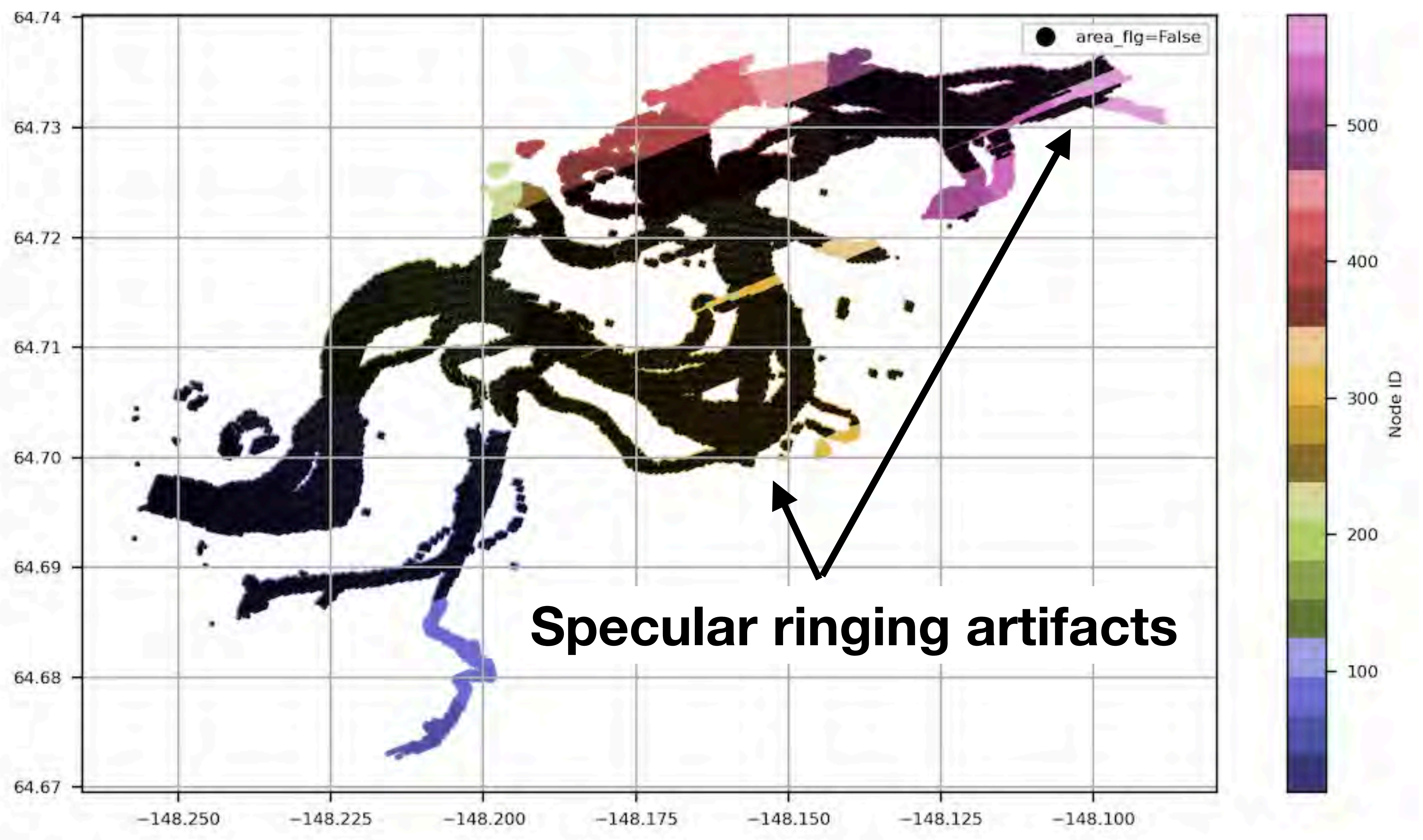


# Symptoms of WSE issues

## 11.2.1: Bit and Summary Quality flags

Reaches or nodes marked “Degraded” often have good WSE and slope. This is because a single specular ringing node will result in “degraded” reach qual. This will be fixed in a future RiverSP version.




Pixel assignment info avaiable in PIXCVec product

# Symptoms of WSE issues

## 11.2.2: Other Product Quality Indicators

- Users should be aware of all river quality flags when cleaning SWOT data for their own analyses.
- We expect the below quality parameters to be accurate and useful for filtering data:
  - X_ovr_cal_q: Use good or suspect only for best results
  - node_q: Node-level summary quality flags perform well in Version C data
  - node_q_b: Some user applications may benefit from expert-level node quality flags
  - reach_q_b: Some user applications may benefit from expert-level reach quality flags
  - dark_frac: 50% or less is generally good; 40% or less for best reaches only
  - obs_frac/partial_f: 50% or better
  - wse_r_u: Useful for interpreting and troubleshooting results
  - ice_clim_f: 0 indicates no expected ice cover
- Users should reference the product documents for a full explanation of all RiverSP quality attributes.

# 12: Summary and conclusions

## Takeaways for science users on SWOT river features & issues

- SWOT WSE/slope anomalies can vary in vertical scale and horizontal extent
- The most common issues for SWOT node heights are:
  - **Pixel misassignment** due to bright pixels near the river channel
  - **Layover or low coherence pixels** contaminating node aggregations
  - **Dark water**, possibly compounded by one of the above factors
- These anomalies are **not always caught by the Version C quality flags**,  leading to spurious reach WSEs and slopes over some reaches
- Specular ringing, dark water over-flagging, and centerline errors have low to moderate effect on WSE performance for most reaches
- More issues may occur that were not covered here, e.g. flipped slope reaches, darkwater projection impacts, missing node WSEs due to qual flag settings, etc
- Future L2_HR_RiverSP release will be more robust to darkwater, outlier water bodies, and have improved quality flagging. Node- and reach-level WSE and slope performance will significantly improve.

Jet Propulsion Laboratory
California Institute of Technology

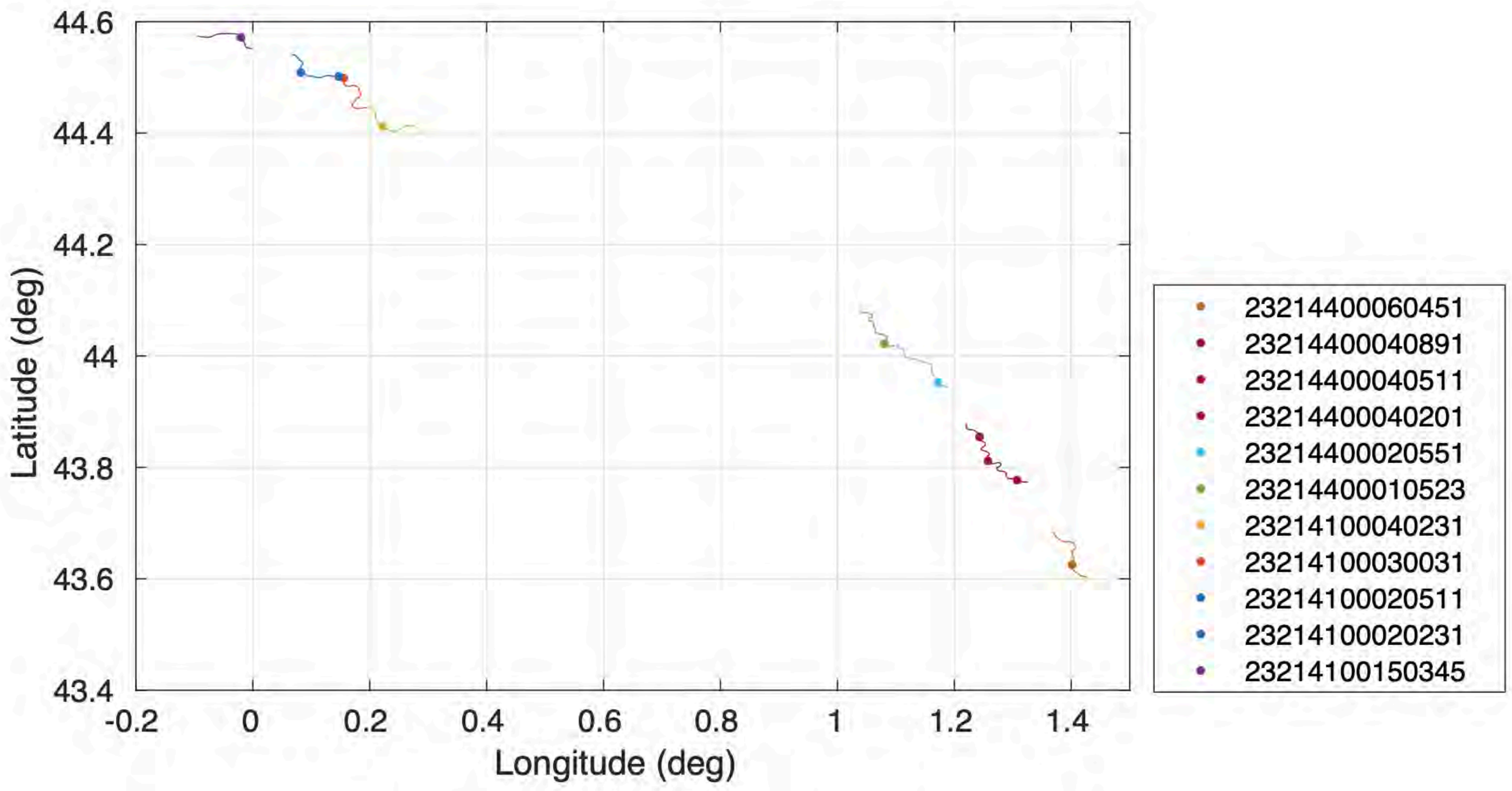
jpl.nasa.gov

# Bonus Slides

## Questions & Comments

# Garonne Slopes results

**Microstations on Garonne may not be placed very close to reach boundaries**

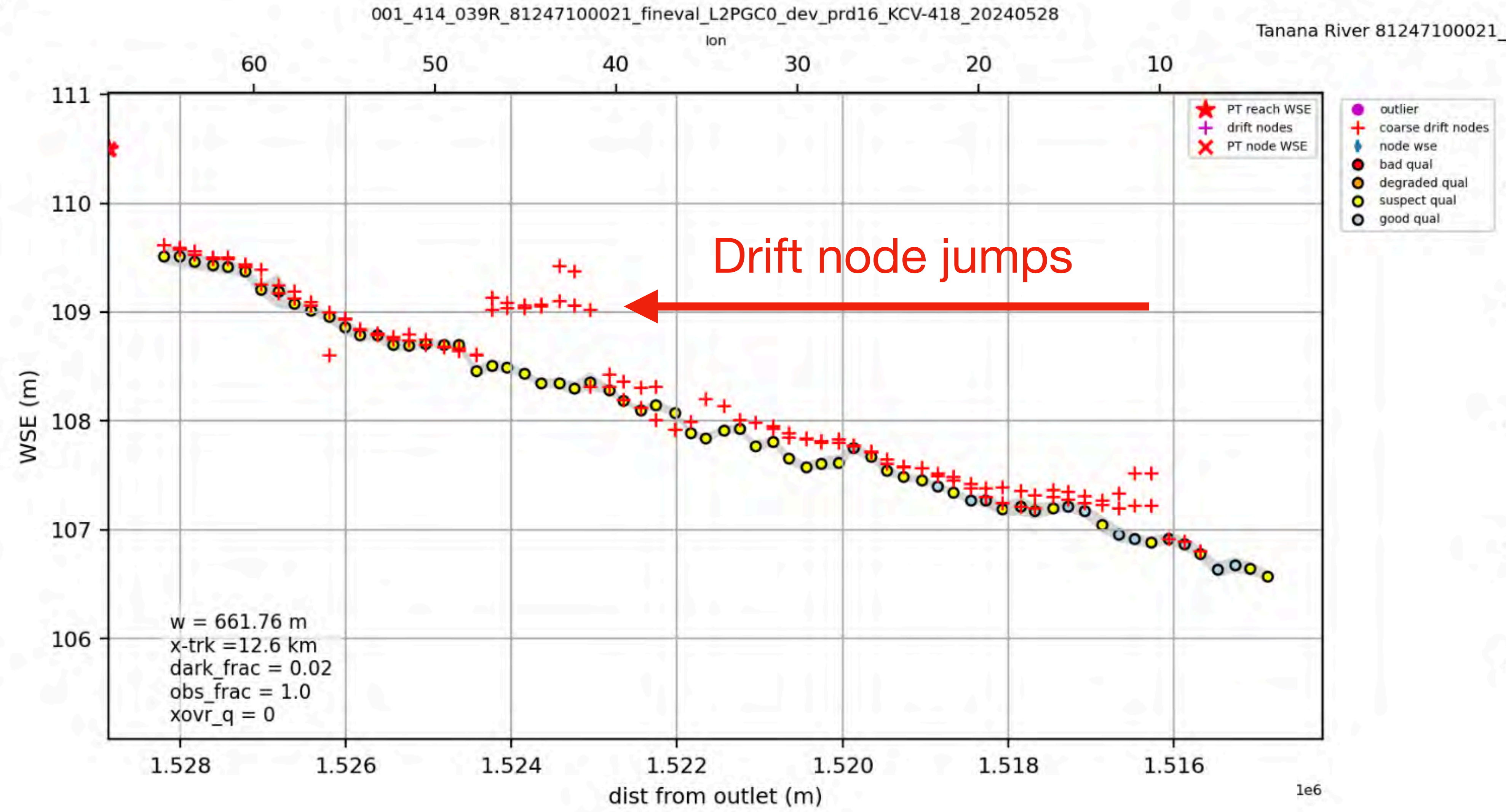


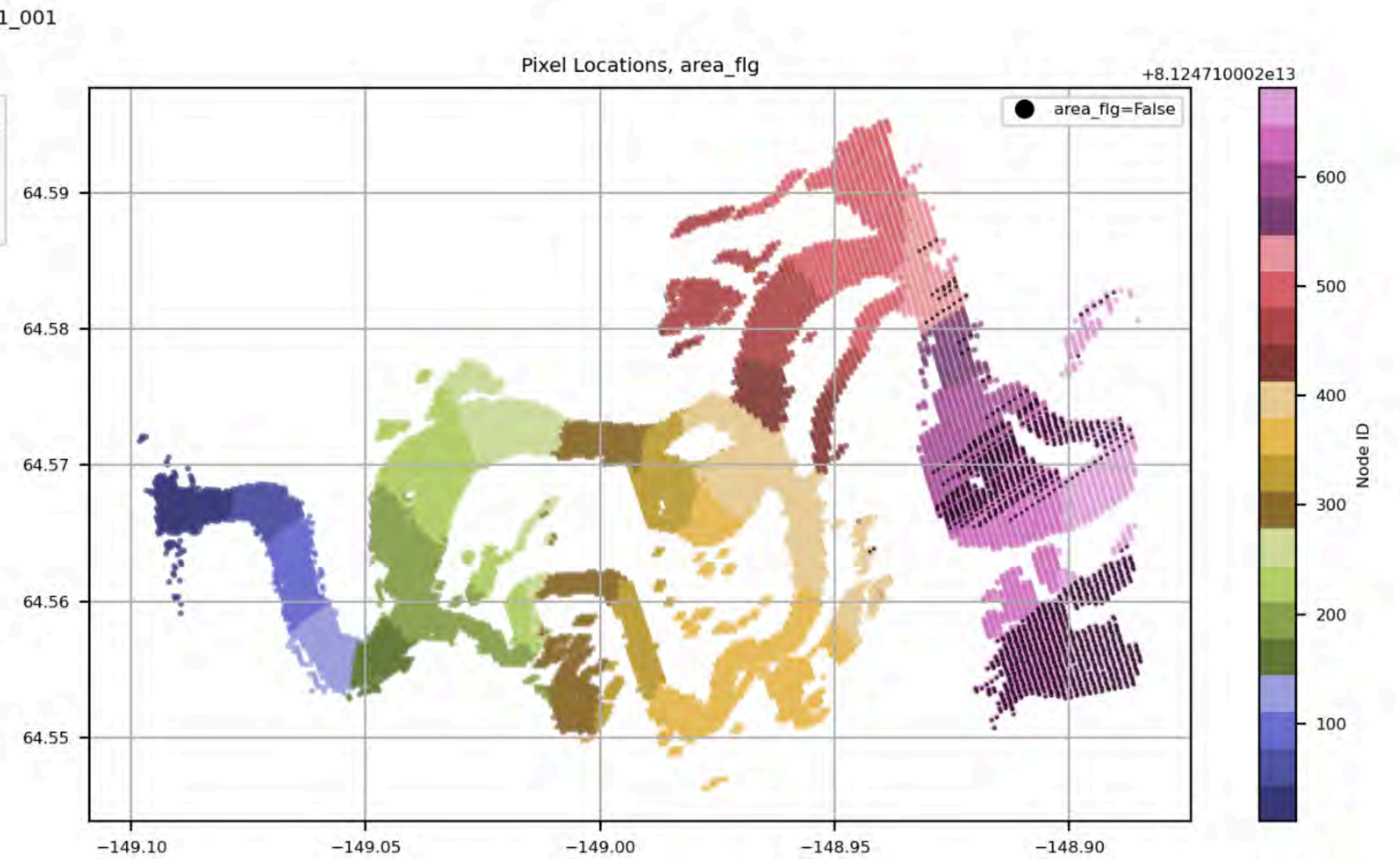

reach |68%ile| slp_error_cmkm by ['reach_id', 'river_name']:

| reach_id | river_name | \|68%ile\| | count |
|---|---|---|---|
| 61660400081 | Lawa | 204.623504 | 1 |
| 23214400021 | La Garonne | 177.233233 | 7 |
| 61660400101 | Lawa | 43.088349 | 2 |
| 23214100041 | La Garonne | 26.179508 | 62 |
| 23214100155 | La Garonne | 16.521732 | 71 |
| 23214400031 | La Garonne | 10.727368 | 7 |
| 23214400061 | L'Aussonnelle | 9.514372 | 5 |
| 18160100111 | Tsiribihina | 9.468694 | 2 |
| 23214400051 | L'Aussonnelle; La Garonne | 7.774067 | 14 |
| 18160100121 | Tsiribihina | 4.268321 | 2 |
| 61660400131 | Lawa | 3.560748 | 1 |
| 23214400041 | La Garonne | 3.309956 | 44 |
| 23214100021 | La Garonne | 3.108831 | 64 |
| 23214100031 | La Garonne | 2.206427 | 72 |
| 18160100081 | Tsiribihina | 1.096983 | 1 |
| 23214100011 | 232141 | 1.065345 | 72 |
| 18160100041 | Tsiribihina | 1.041353 | 1 |
| 61660400061 | Lawa | 0.779198 | 1 |
| 61660400051 | Lawa | 0.717589 | 1 |
| 18160100051 | Tsiribihina | 0.007253 | 1 |

# Tanana In-situ issues still being investigated

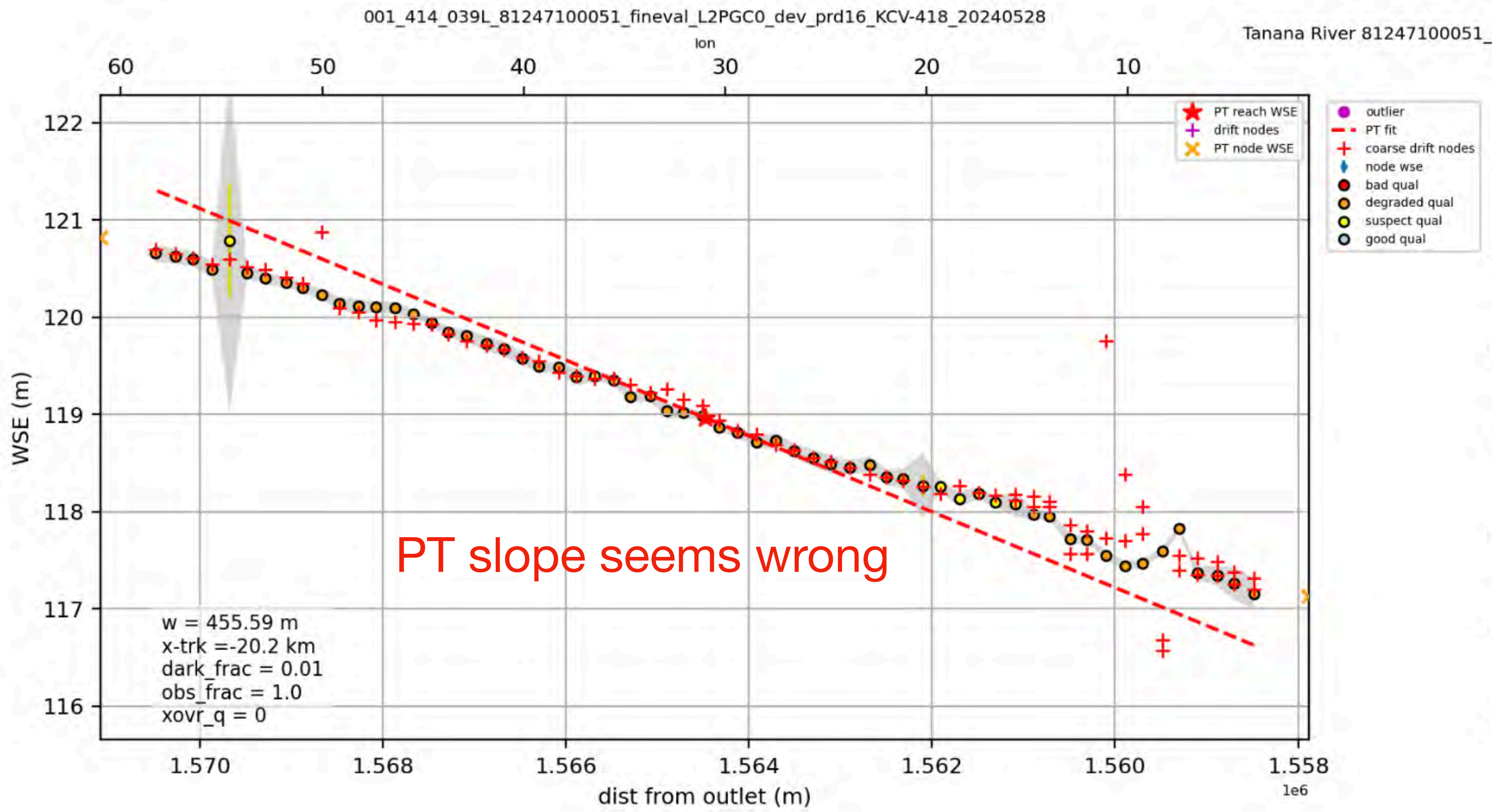
## GNSS and PTs seem to have issues that aren't fully resolved yet

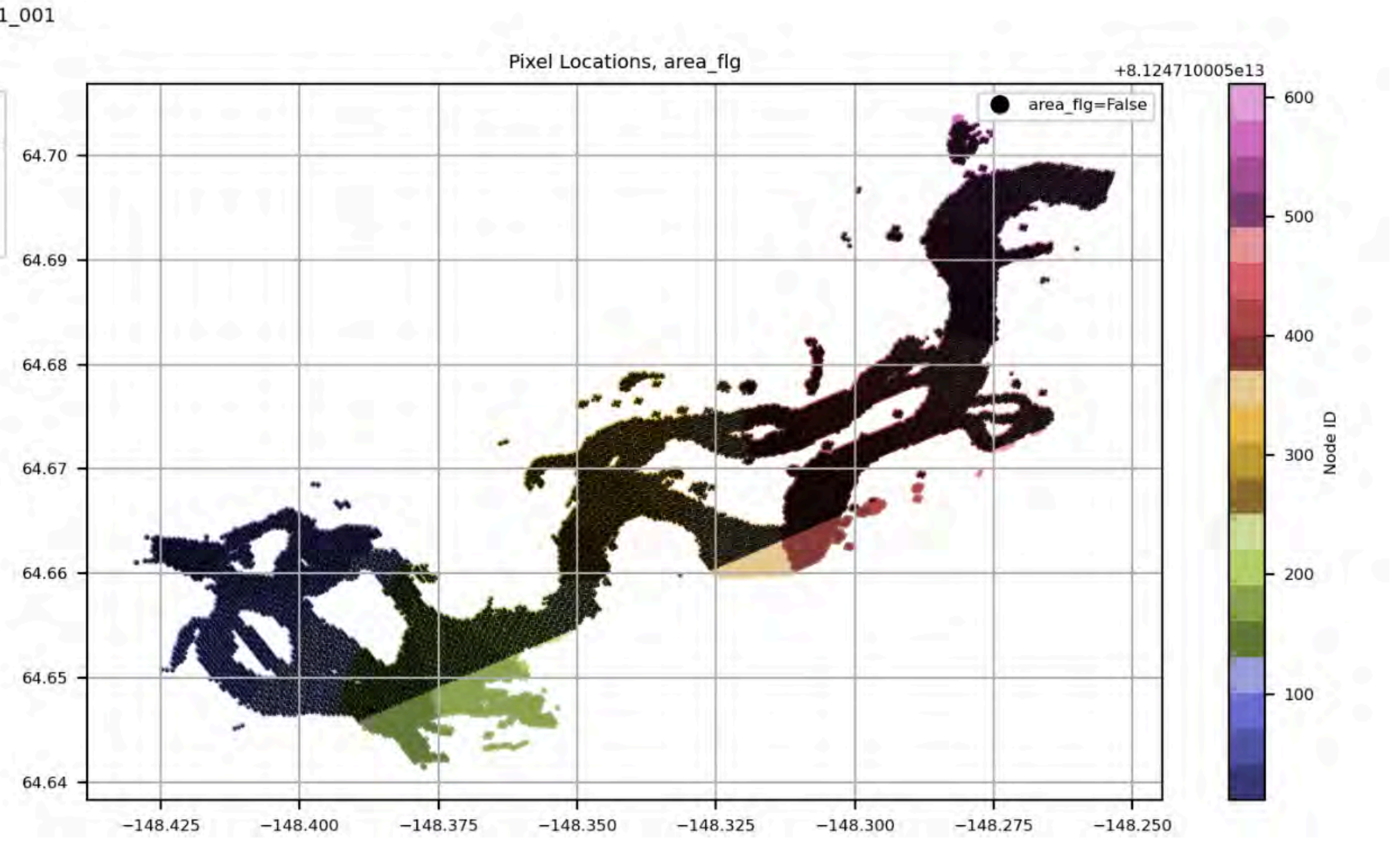



Tanana SWOT data look excellent. It is the brightest calval site in the Tier 1 dataset.

The in-situ data may need further validation.

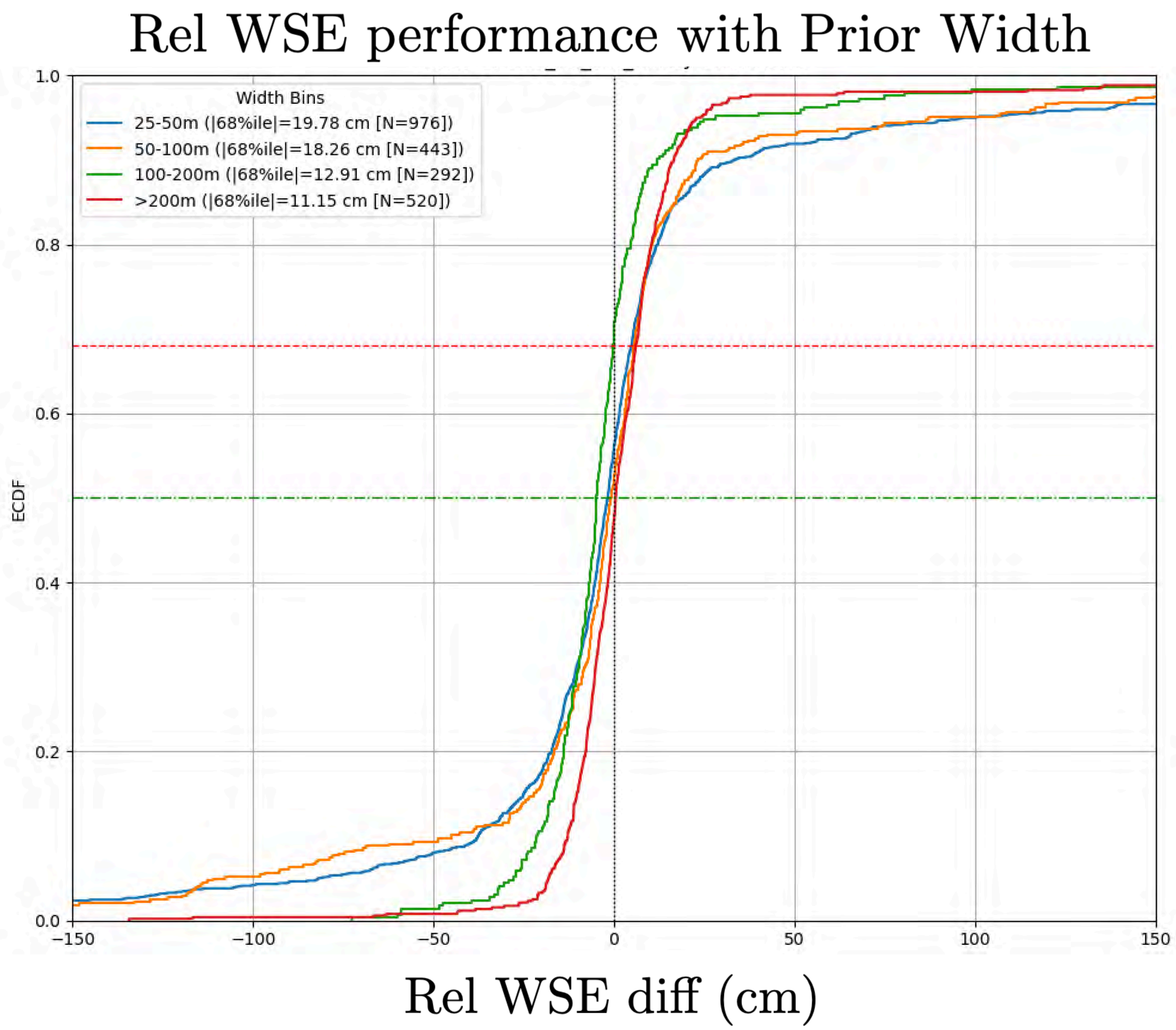


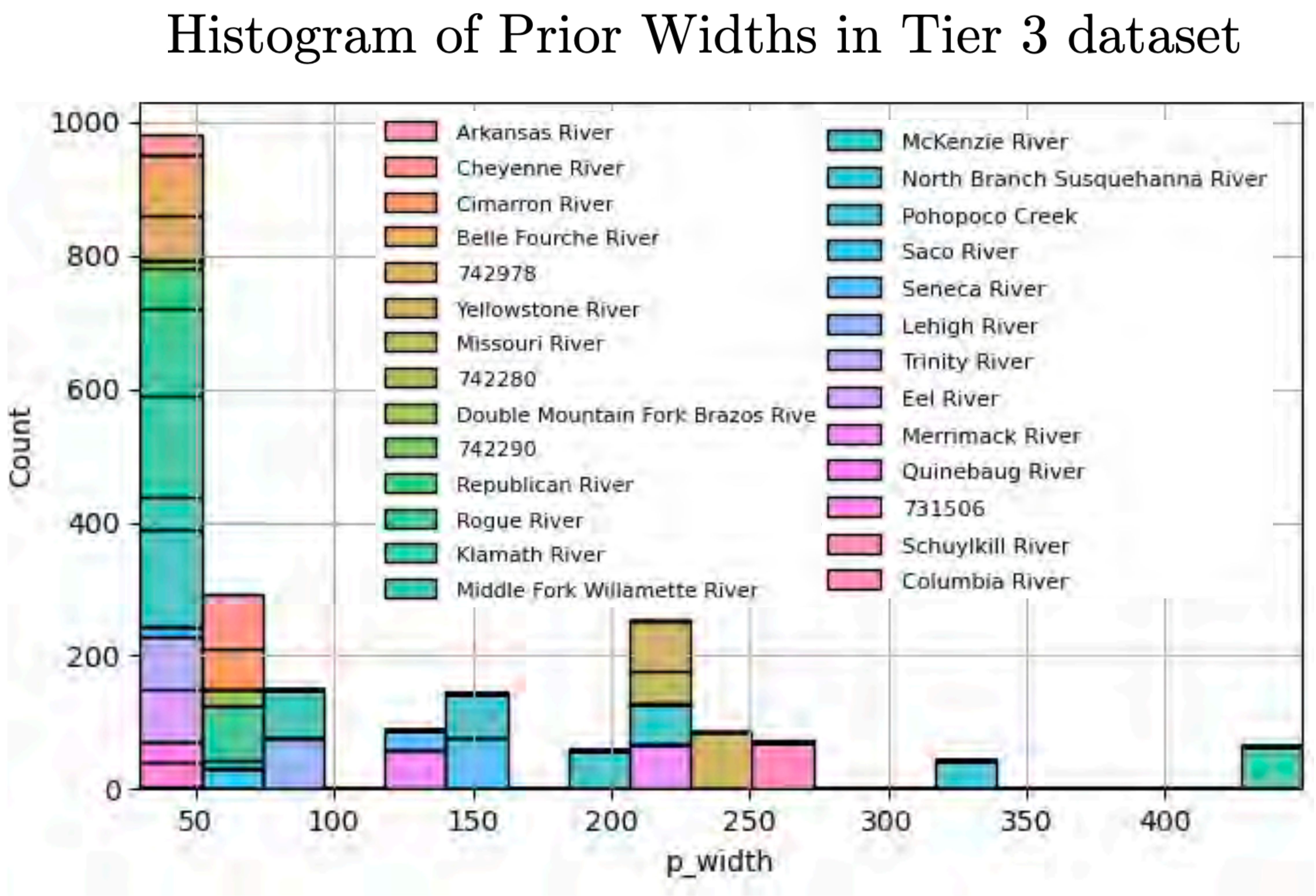



# Relationships with prior river width; xtrk

## PT Node Version C

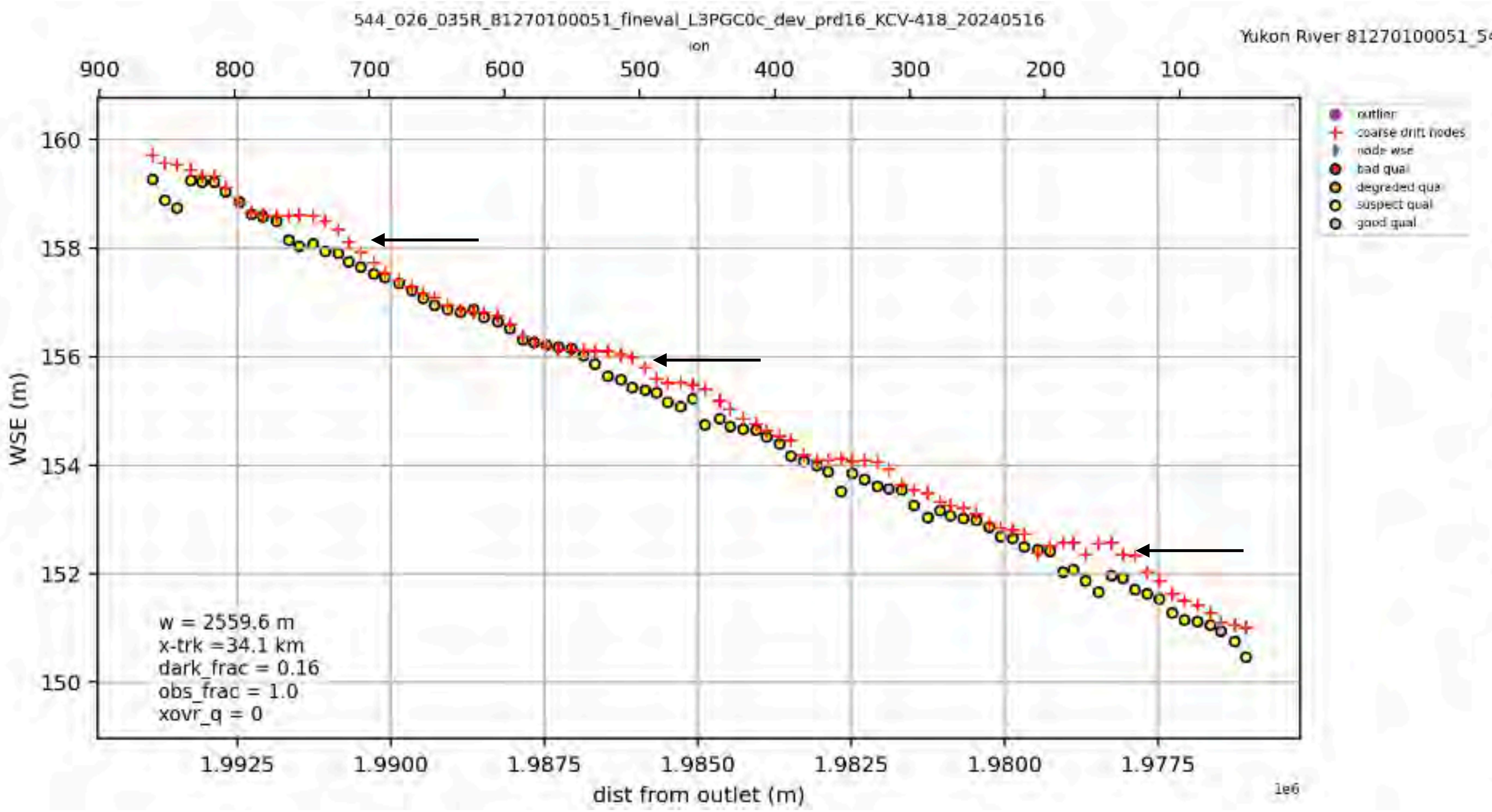
**Tier 3 dataset** includes more narrow nodes and near-range reaches.

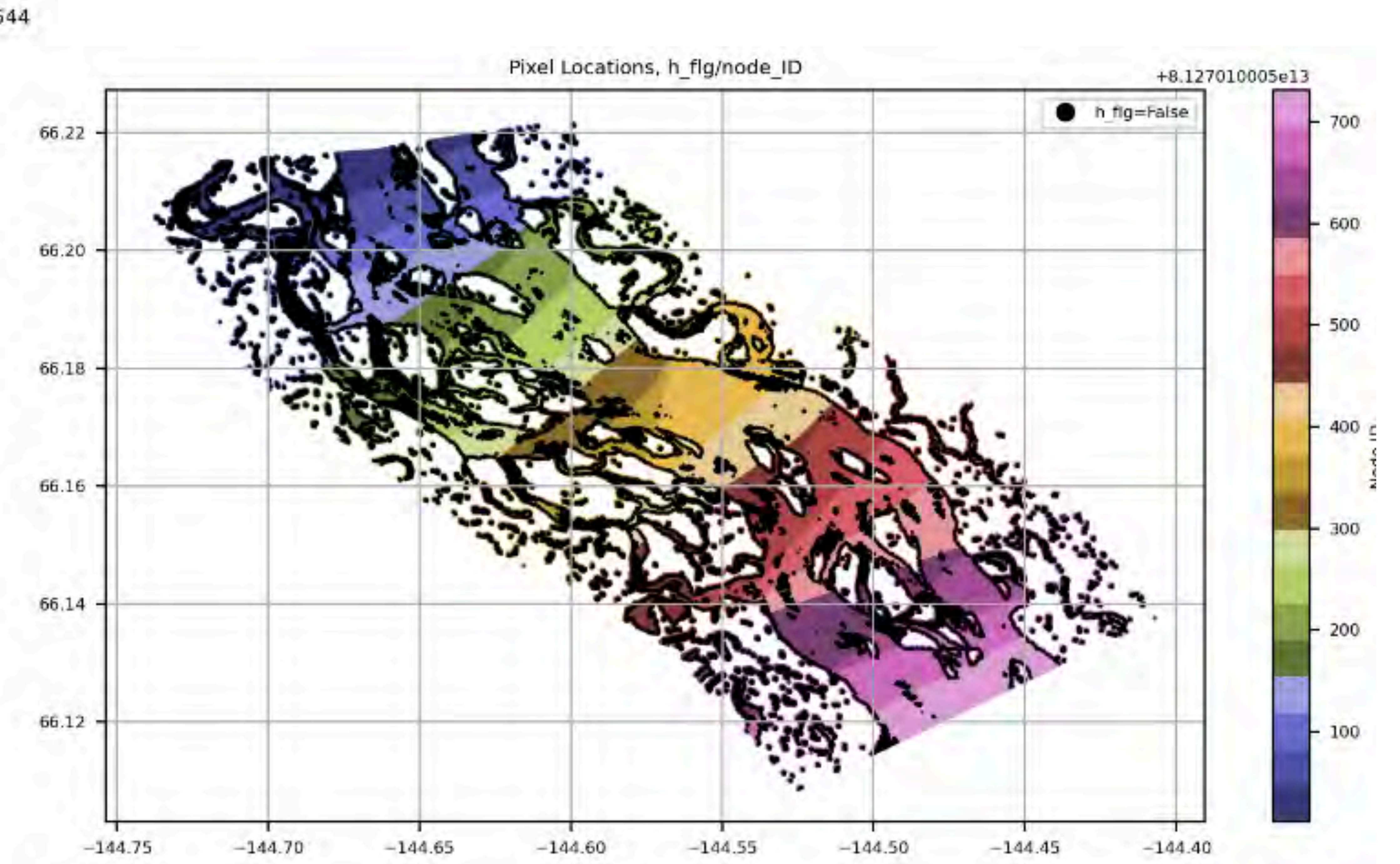


# Multichannel drift capture

## GNSS Drifts sample a single path down multi-channel rivers

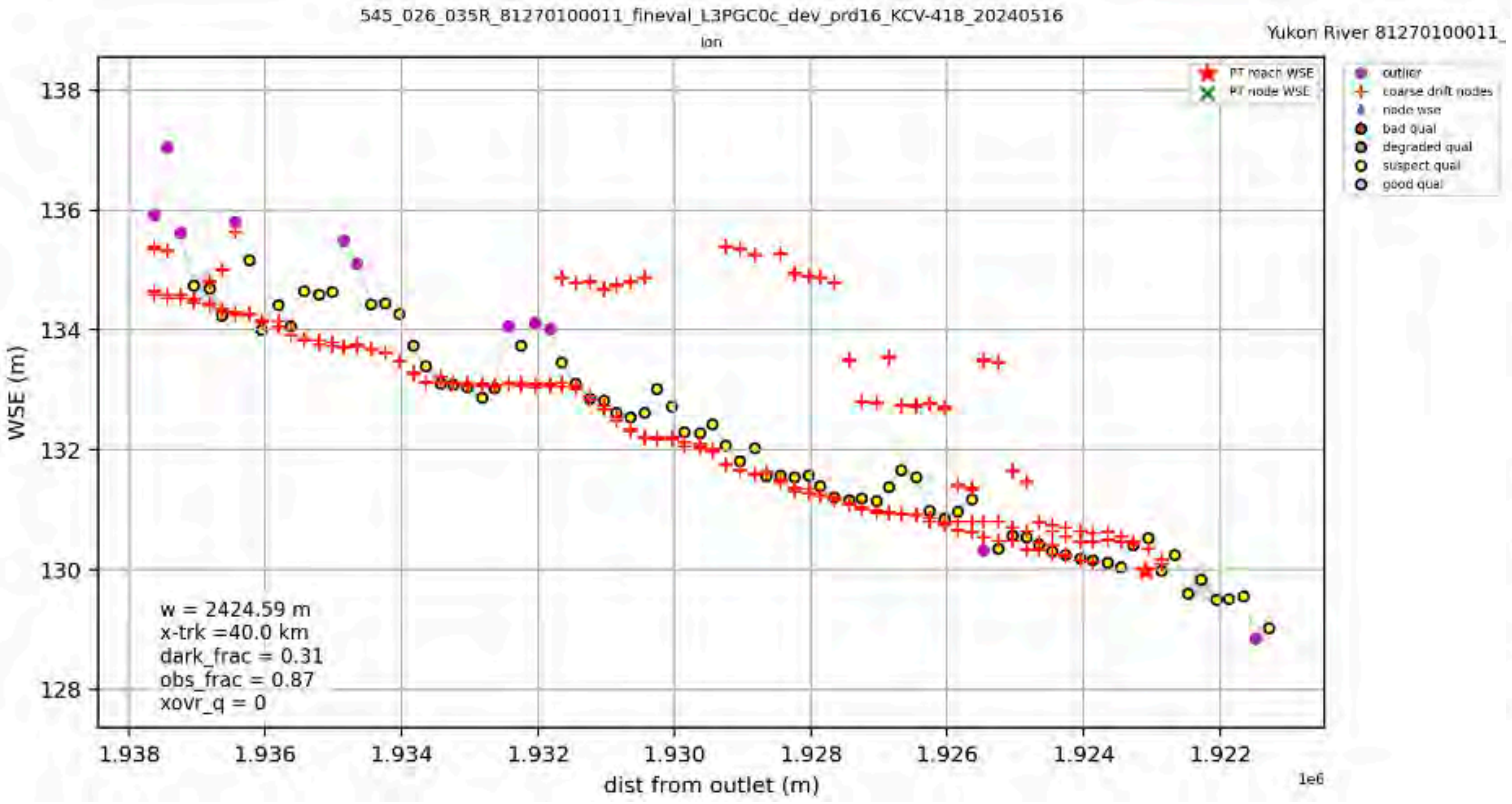


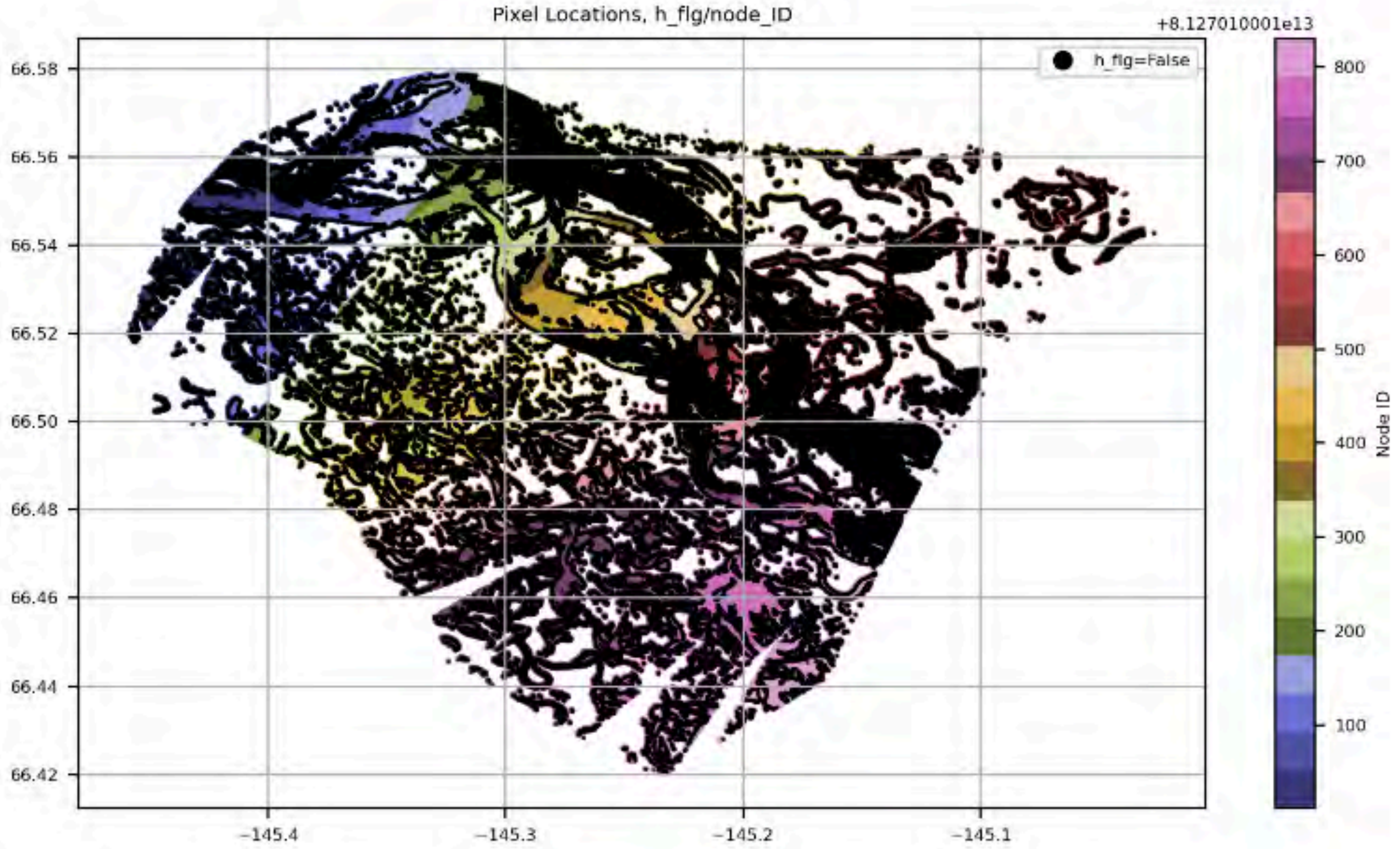




Water over-detection on Yukon River has minimal impact on slope/WSE performance

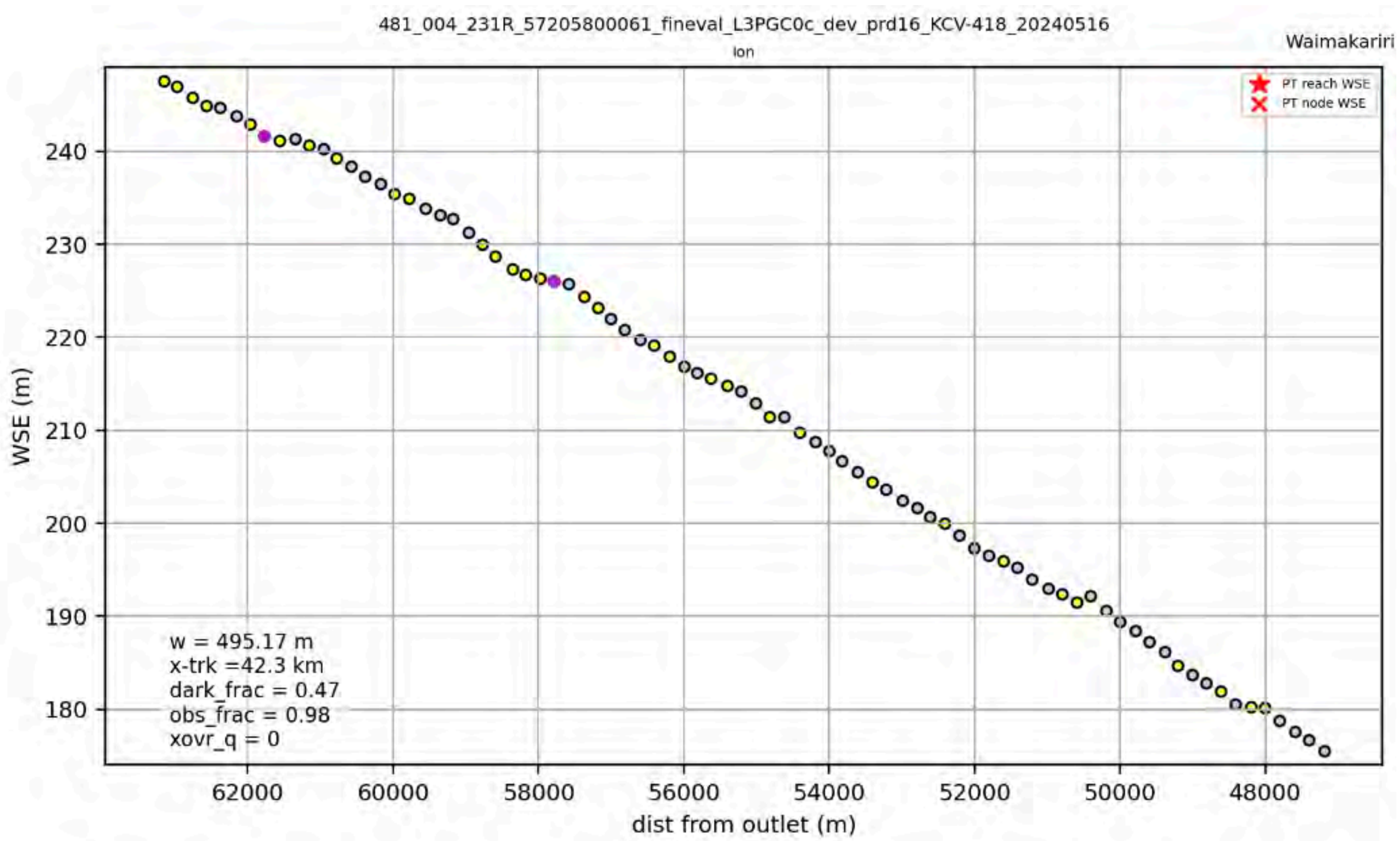
# Issues with toolbox reach drifts

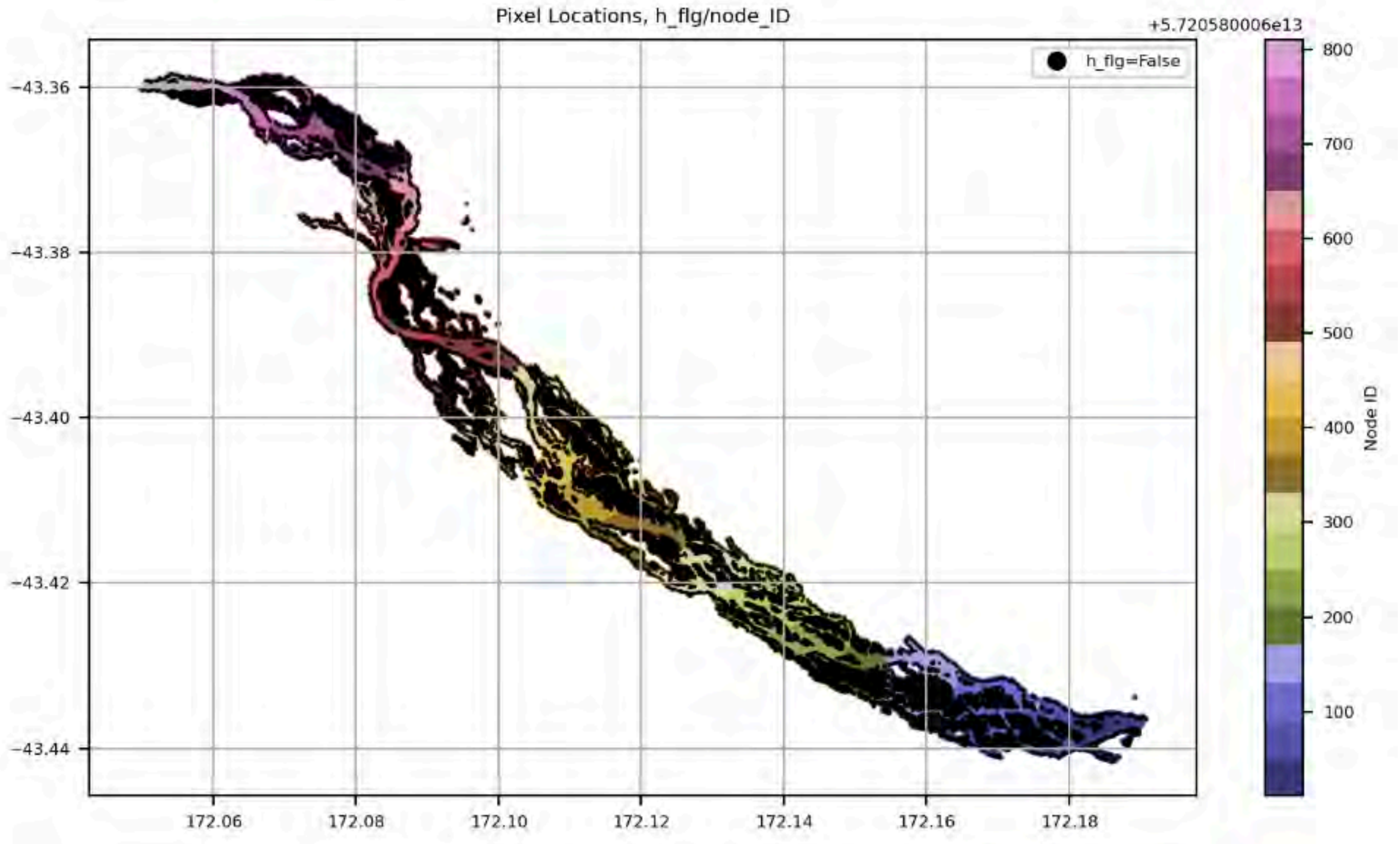
## Many-to-one GNSS matching leads to some complexities



# Waimak WSE not affected by dark water over flagging



# GNSS drift performance by river

## Version C

reach |68%ile| wse_rel_diff_cm

| reach_id | river_name | p_width | \|68%ile\| | count |
|---|---|---|---|---|
| 73120000121 | Connecticut River | 399.000000 | 244.974167 | 25 |
| 78220000231 | Willamette River | 80.000000 | 39.201548 | 45 |
| 73120000131 | Connecticut River | 283.000000 | 38.961691 | 26 |
| 78220000201 | Willamette River | 94.000000 | 27.325089 | 22 |
| 78220000211 | Willamette River | 84.000000 | 23.270772 | 38 |
| 78220000221 | Willamette River | 80.000000 | 20.087834 | 44 |
| 71241000121 | North Saskatchewan River | 314.000000 | 13.889396 | 7 |
| 73120000091 | Connecticut River | 363.000000 | 12.516135 | 23 |
| 71241000101 | North Saskatchewan River | 322.000000 | 12.397704 | 31 |
| 73120000151 | Connecticut River | 313.000000 | 11.652705 | 28 |
| 71241000111 | North Saskatchewan River | 296.000000 | 10.414210 | 11 |
| 78220000191 | Willamette River | 123.000000 | 9.597376 | 53 |
| 73120000171 | Connecticut River | 248.000000 | 8.942028 | 7 |
| 73120000071 | Connecticut River | 324.000000 | 7.807736 | 43 |
| 73120000161 | Connecticut River | 277.000000 | 7.745973 | 27 |
| 73120000081 | Connecticut River | 246.000000 | 6.040054 | 43 |
| 82282000321 | Peace River | 101.000000 | 4.821848 | 7 |

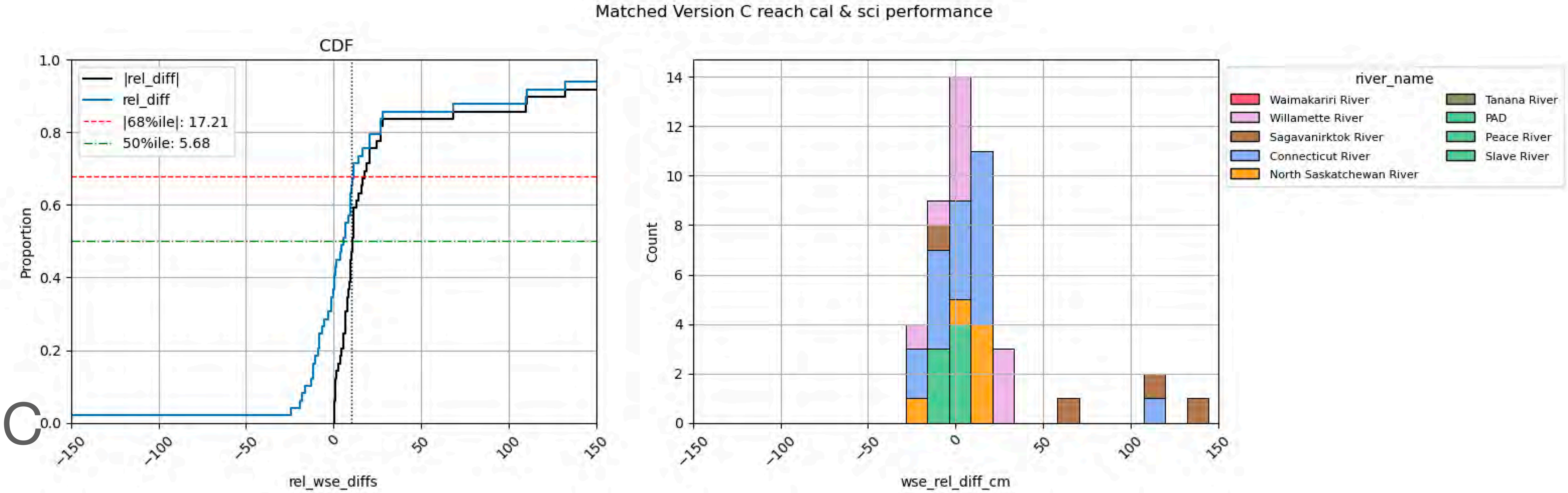
## Dev

reach |68%ile| wse_rel_diff_cm

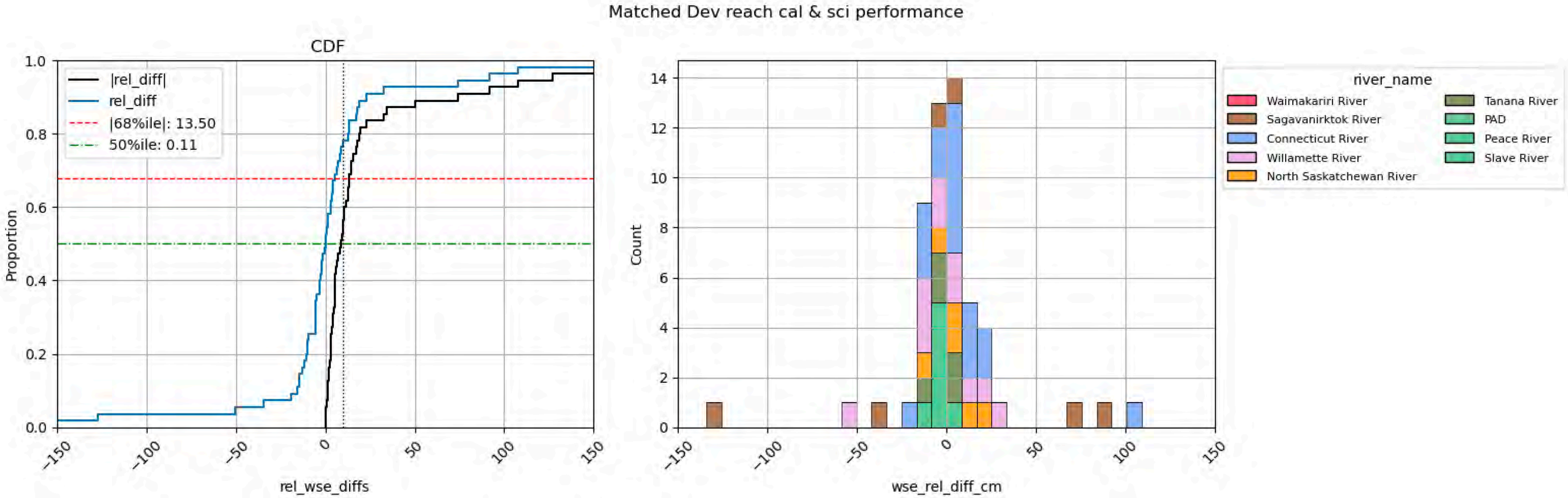
| reach_id | river_name | p_width | \|68%ile\| | count |
|---|---|---|---|---|
| 73120000121 | Connecticut River | 399.000000 | 232.486185 | 26 |
| 73120000131 | Connecticut River | 283.000000 | 41.379211 | 20 |
| 78220000201 | Willamette River | 94.000000 | 18.549114 | 27 |
| 78220000211 | Willamette River | 84.000000 | 15.733212 | 37 |
| 78220000231 | Willamette River | 80.000000 | 14.072053 | 44 |
| 71241000121 | North Saskatchewan River | 314.000000 | 12.729999 | 8 |
| 73120000091 | Connecticut River | 363.000000 | 11.435200 | 20 |
| 78220000221 | Willamette River | 80.000000 | 11.284369 | 40 |
| 78220000191 | Willamette River | 123.000000 | 9.802436 | 55 |
| 71241000101 | North Saskatchewan River | 322.000000 | 8.131862 | 27 |
| 71241000111 | North Saskatchewan River | 296.000000 | 7.560140 | 9 |
| 73120000081 | Connecticut River | 246.000000 | 5.902830 | 40 |
| 73120000071 | Connecticut River | 324.000000 | 5.854940 | 39 |
| 82282000321 | Peace River | 101.000000 | 4.830265 | 7 |

# GNSS drift performance by version (cal & sci)

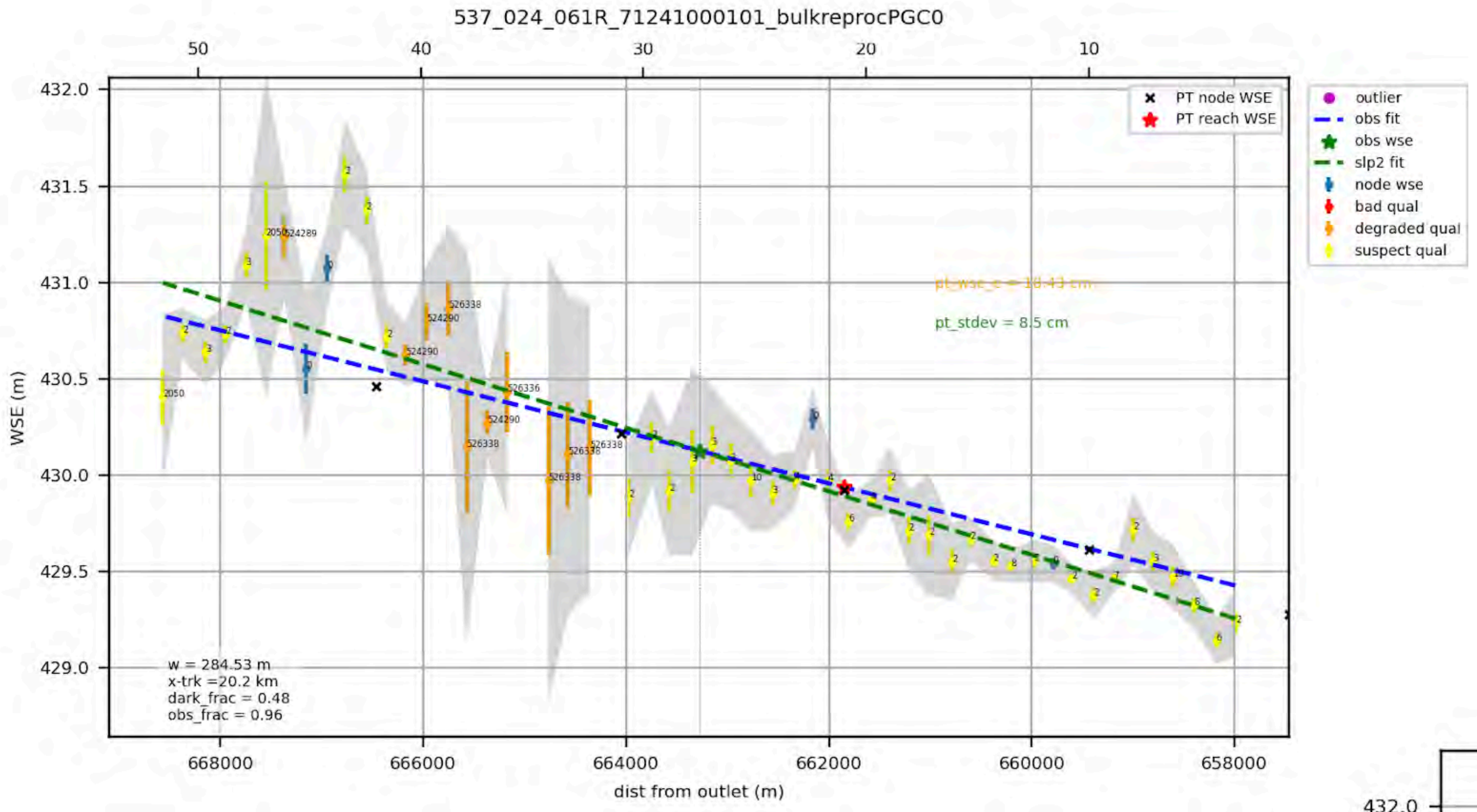
Version C

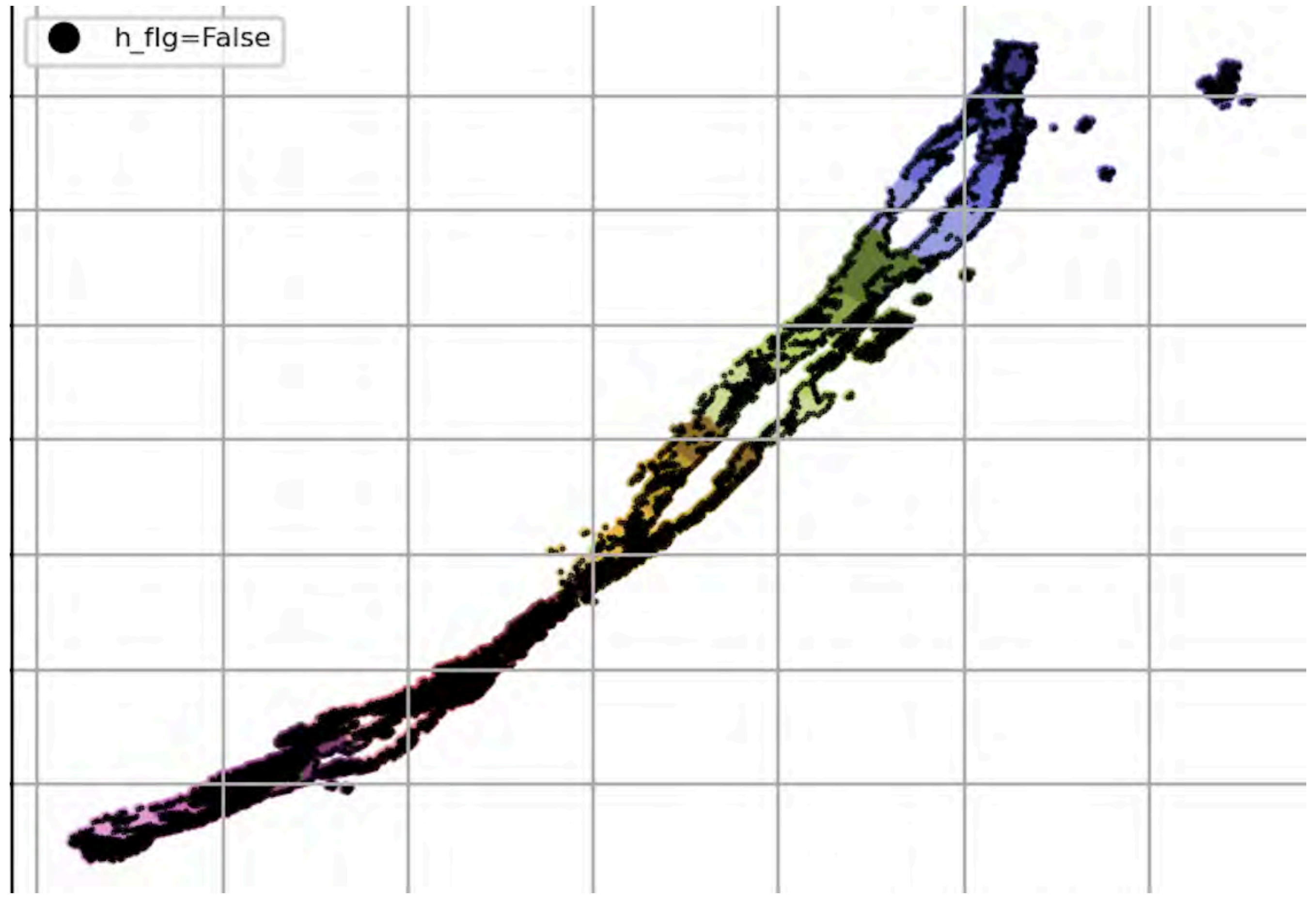


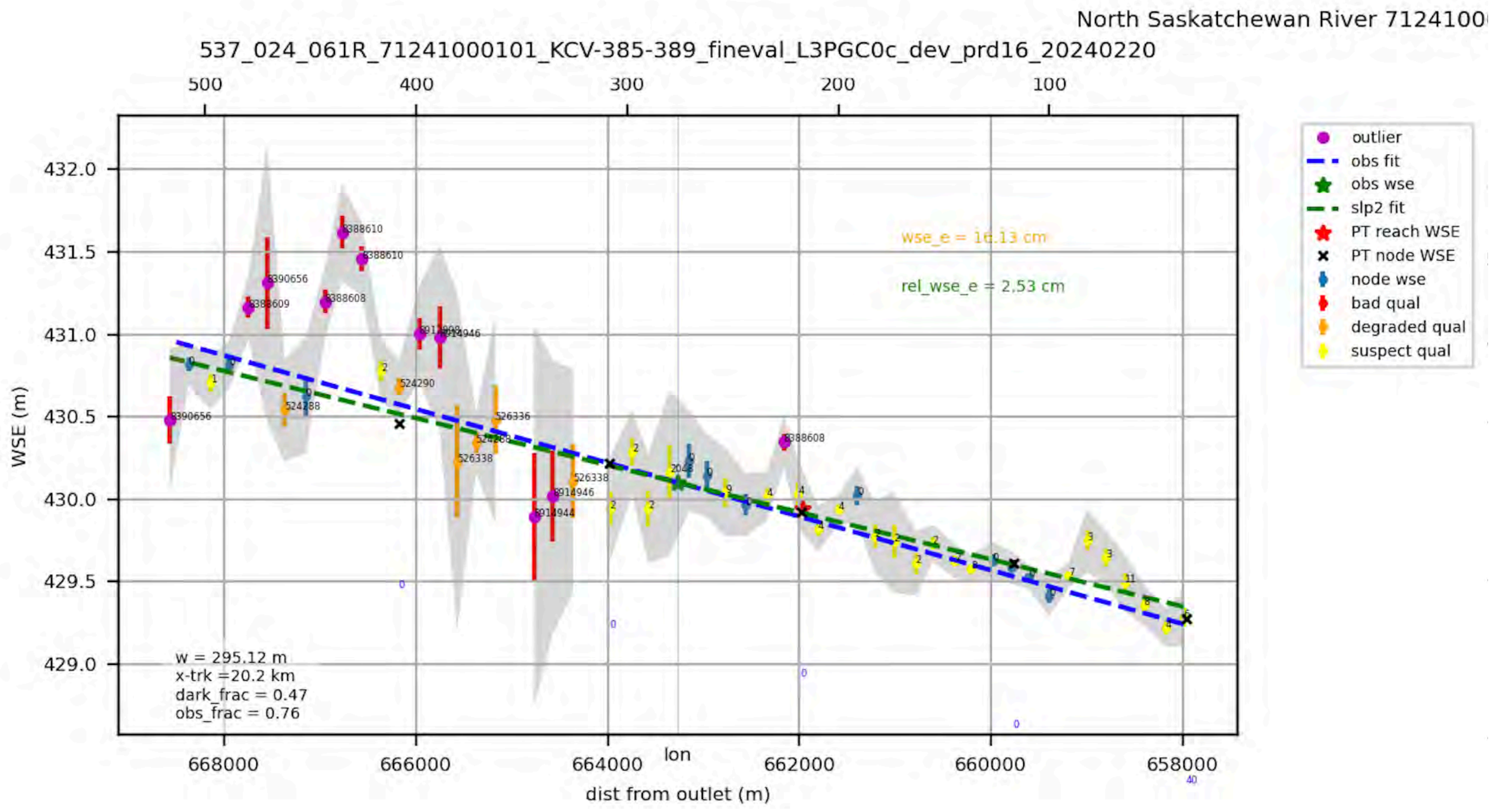

Dev



# Example performance change in Dev

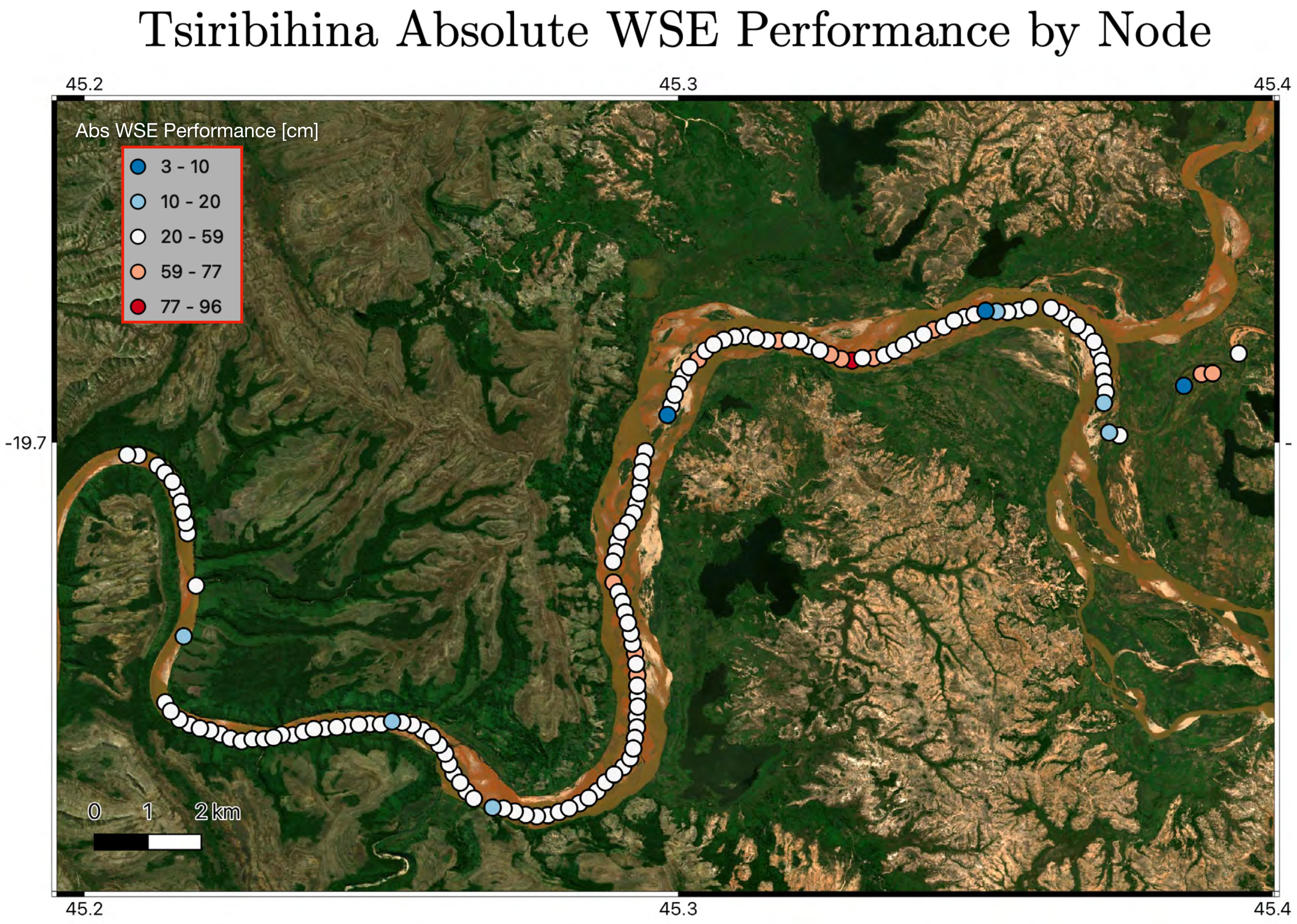


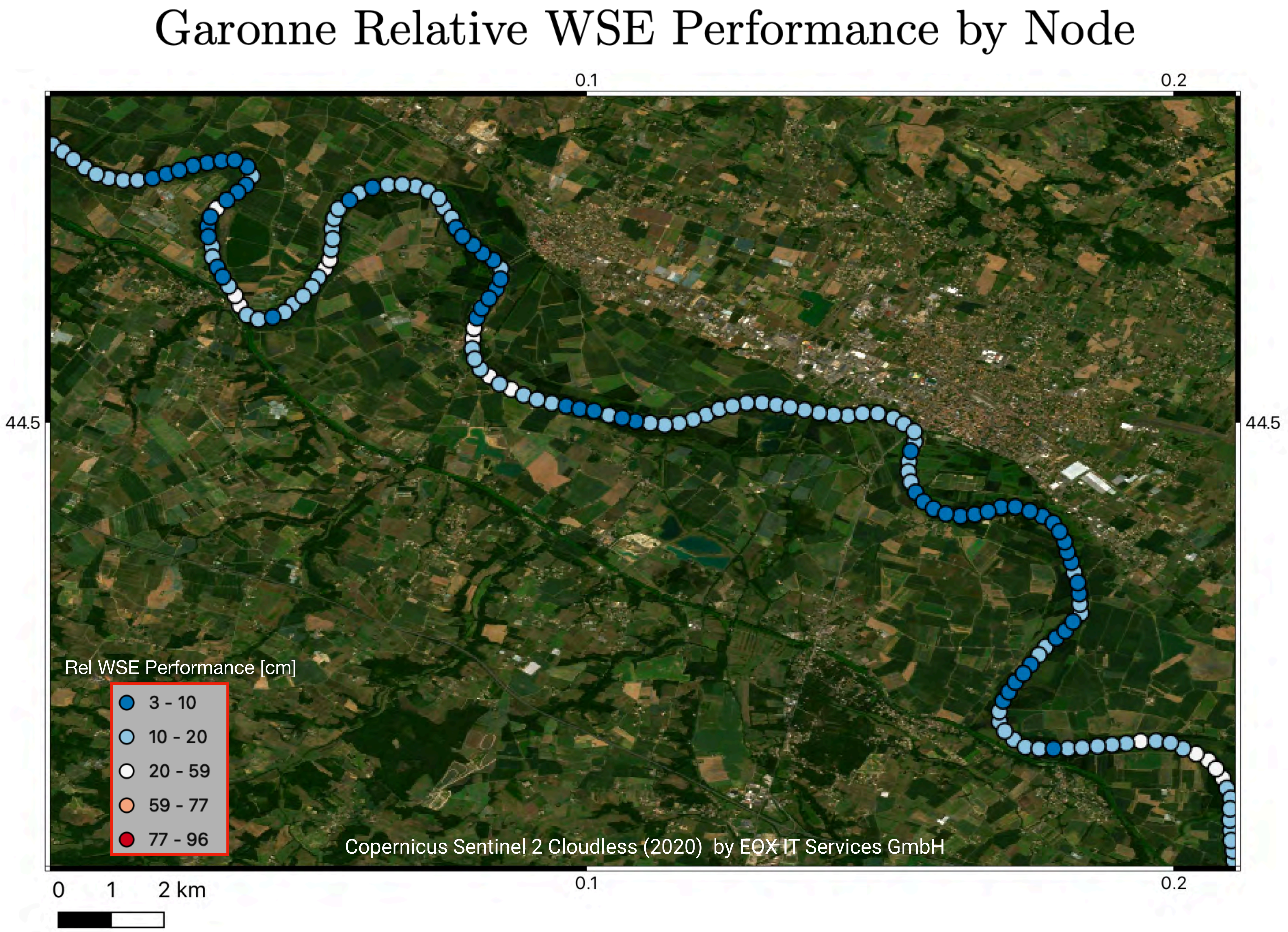



# 6: Comparisons to independent estimates

## Typical performance at each Node in CNES Dataset



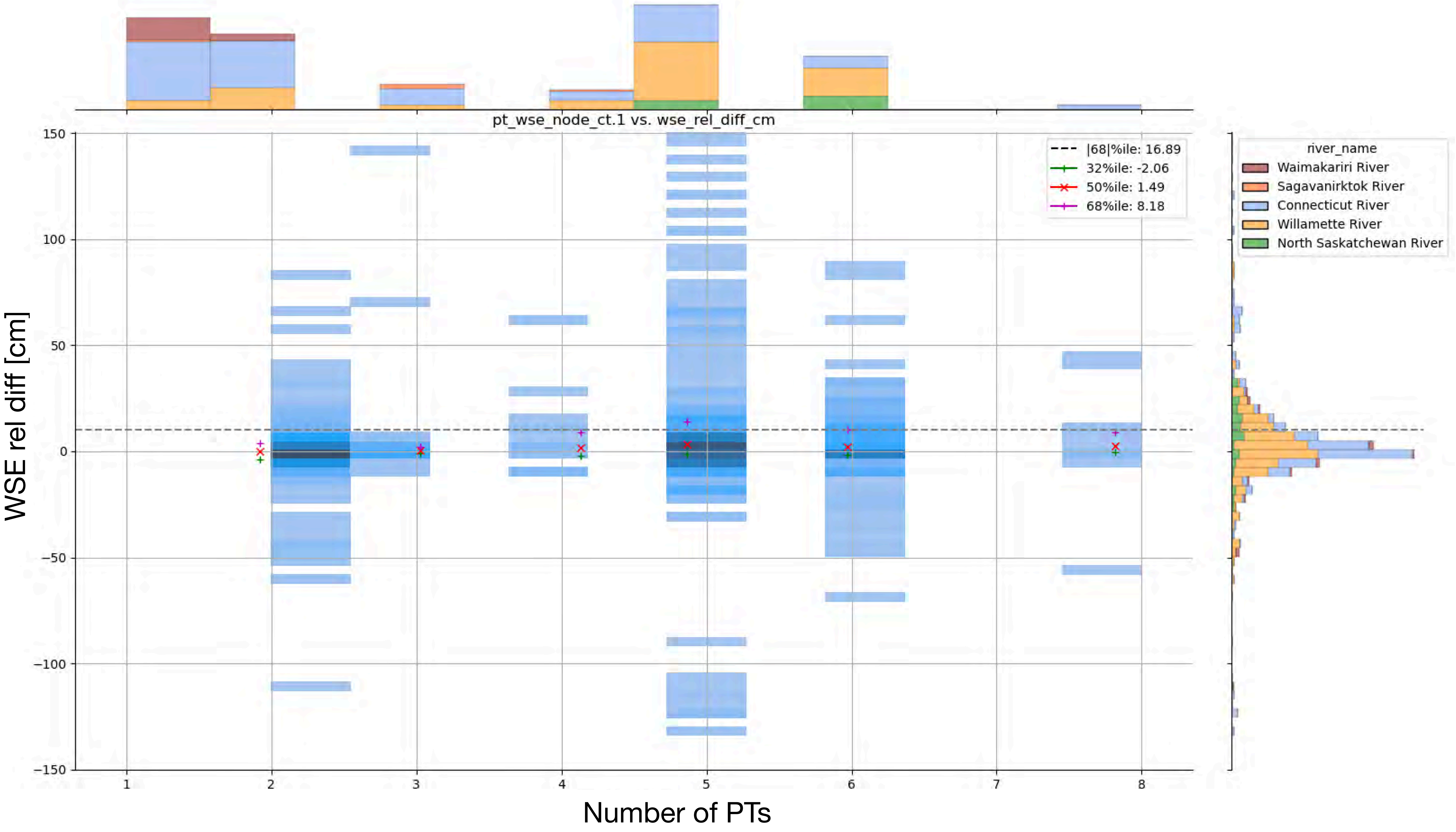



# Reach PT Performance vs. # of PT's

## Relative WSE performance doesn't seem to depend on PT #

```
reach |68%ile| wse_rel_diff_cm by river_name:
```

| river_name | \|68%ile\| rel WSE | count |
|---|---|---|
| Waimakariri River | 22.742364 | 16 |
| North Saskatchewan River | 18.096506 | 55 |
| Connecticut River | 16.848232 | 236 |
| Willamette River | 15.293897 | 297 |
| Sagavanirktok River | NaN | 0 |



# “ALL” results

## Version C Node level

```
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_cal_20240611/stats
/ALL/pt_matched_node_ALL.txt
                 metric     |68%ile|      50%ile        mean       count      uni_ct         rm%
----------------------- ---------- ---------- ---------- ---------- ---------- ----------
            wse_error_cm      33.13      0.6673       89.22       4936.       118.0       0.000
wse_error_no_outlier_cm      23.21      0.8879       88.00       4253.       118.0       13.84
  relative_wse_error_cm      46.85       2.399       15.10       4723.       114.0       4.320
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_sci_20240611/stats
/ALL/pt_matched_node_ALL.txt
                 metric     |68%ile|      50%ile        mean       count      uni_ct         rm%
----------------------- ---------- ---------- ---------- ---------- ---------- ----------
            wse_error_cm      27.74      -5.356       83.67       723.0       107.0       0.000
wse_error_no_outlier_cm      21.55      -5.582       44.30       588.0       106.0       18.67
  relative_wse_error_cm      79.72     -0.8257       37.89       355.0       42.00       50.90
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_sci_20240611/stats
/ALL/coarse_matched_node_ALL.txt
                 metric     |68%ile|      50%ile        mean       count      uni_ct         rm%
----------------------- ---------- ---------- ---------- ---------- ---------- ----------
            wse_error_cm      18.86      -8.970      0.8189       5097.       1065.       0.000
wse_error_no_outlier_cm      18.11      -9.035      -2.106       4386.       1049.       13.95
  relative_wse_error_cm      15.83      0.6895       23.92       2076.       268.0       59.27
```

# “ALL” results

## Version C reach level

```
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_sci_20240611/stats
/ALL/coarse_matched_reach_ALL.txt
         metric    |68%ile|      50%ile        mean       count      uni_ct         rm%
-------------- ---------- ---------- ---------- ---------- ---------- ----------
      wse (cm)      17.44      -4.126       19.04       84.00       18.00       0.000
  rel wse (cm)      19.94       1.071       36.17       62.00       8.000       26.19
 slope (cm/km)      3.533     -0.1540 -1.190e+15       84.00       18.00       0.000
slope2 (cm/km)      2.333     -0.2054 -1.190e+15       84.00       18.00       0.000
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_sci_20240611/stats
/ALL/pt_matched_reach_ALL.txt
         metric    |68%ile|      50%ile        mean       count      uni_ct    rm%
-------------- ---------- ---------- ---------- ---------- ---------- -----
      wse (cm)      143.2       11.47       80.06       330.0       36.00     0
  rel wse (cm)      76.55       14.00       160.2       274.0       23.00 16.97
 slope (cm/km)      10.09     -0.6168      -4.474       230.0       26.00     0
slope2 (cm/km)      7.806     -0.2240     -0.9431       230.0       26.00     0
[stuurman@swot-fn ~]$ cat /u/franz-r0/swot/calval-site-data/metrics/plot_field_stats/20240611/node_w80/bu
lkreprocPGC0_fwdPIC0/bulkreprocPGC0_PIC0_prd16_v20240514_field_data_temporal6_spatial2_sci_20240611/stats
/ALL/offline_coarse_matched_reach_ALL.txt
         metric    |68%ile|      50%ile        mean       count      uni_ct         rm%
-------------- ---------- ---------- ---------- ---------- ---------- ----------
      wse (cm)      15.55      -5.159       36.26       57.00       15.00       0.000
  rel wse (cm)      11.27       2.183       66.10       16.00       2.000       71.93
 slope (cm/km)      1.884     -0.1536      -1.331       57.00       15.00       0.000
slope2 (cm/km)      1.767    -0.06595      -2.192       57.00       15.00       0.000
```