# Improving inland water altimetry retracking by incorporating spatial dependency of waveforms

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Continued, enhanced ocean altimetry and climate monitoring from space Conference

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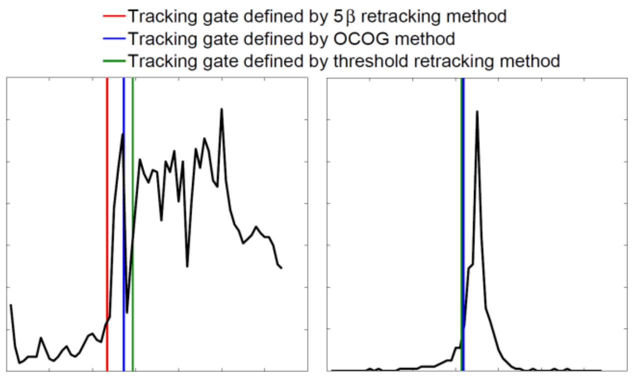
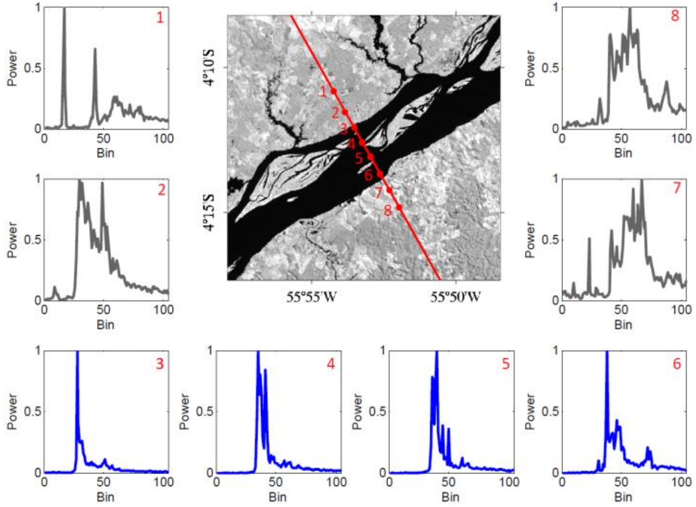
# Problem Statement

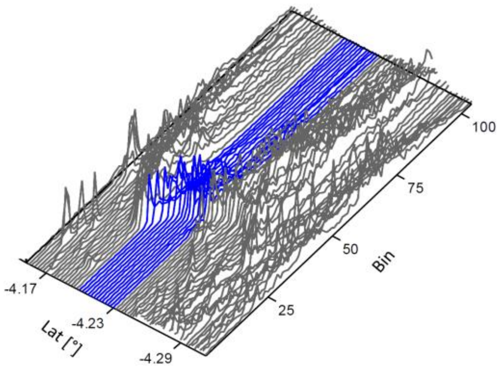
- Single-waveform retracking reached its limits, obtaining decimeter-level accuracy

- Conventional retracking algorithms cannot deal with the waveform complexities

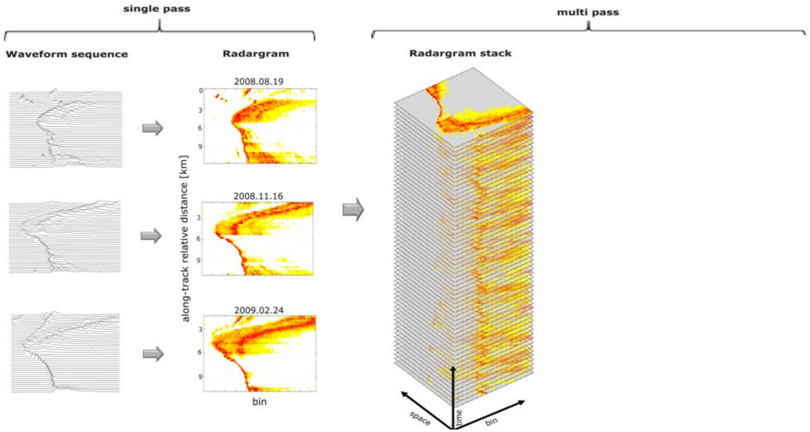
  - Dependency on waveform type and the preprocessing steps
  - Sensitivity to blunder
  - Sensitivity to noise
  - Ignoring the spatio-temporal evolutions of the waveforms



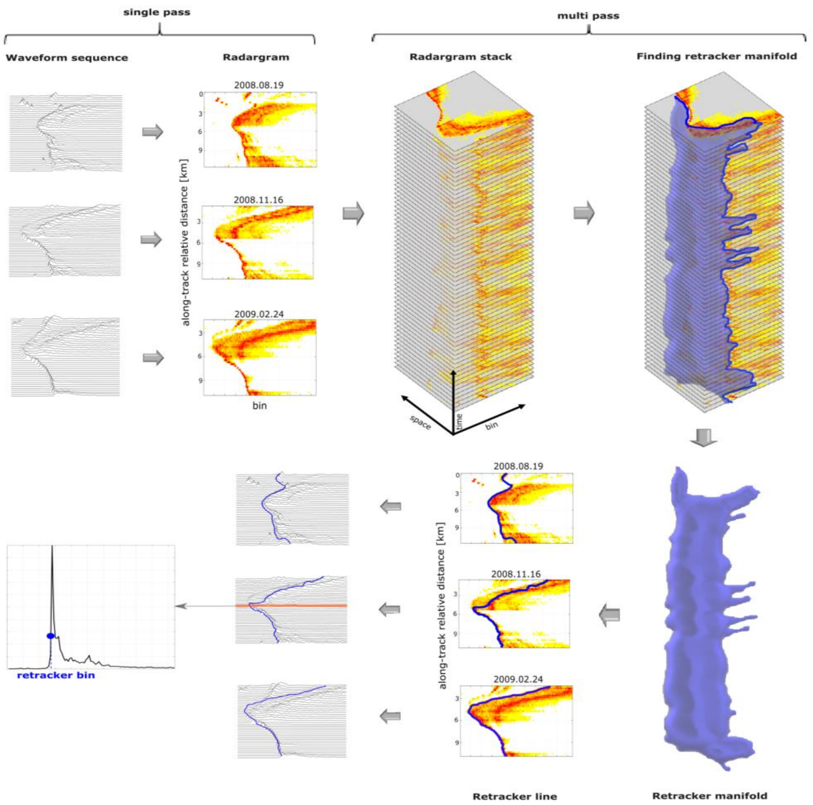

Bin-Space representation of the waveforms


single pass
multi pass
Waveform sequence
Radargram
Radargram stack
2008.08.19
2008.11.16
2009.02.24
along-track relative distance [km]
bin
space
time
bin

The retracker offset obtained from the radargram stack:

- benefits from the spatio-temporal correlation of recorded power
- less sensitive to noisy waveforms
- less influenced by blunders
- independent from a prescribed waveform type

**Objective:**
Developing a retracking method that benefits from the spatio-temporal variation of power in a radargram stack.



The retracker offset obtained from the radargram stack:

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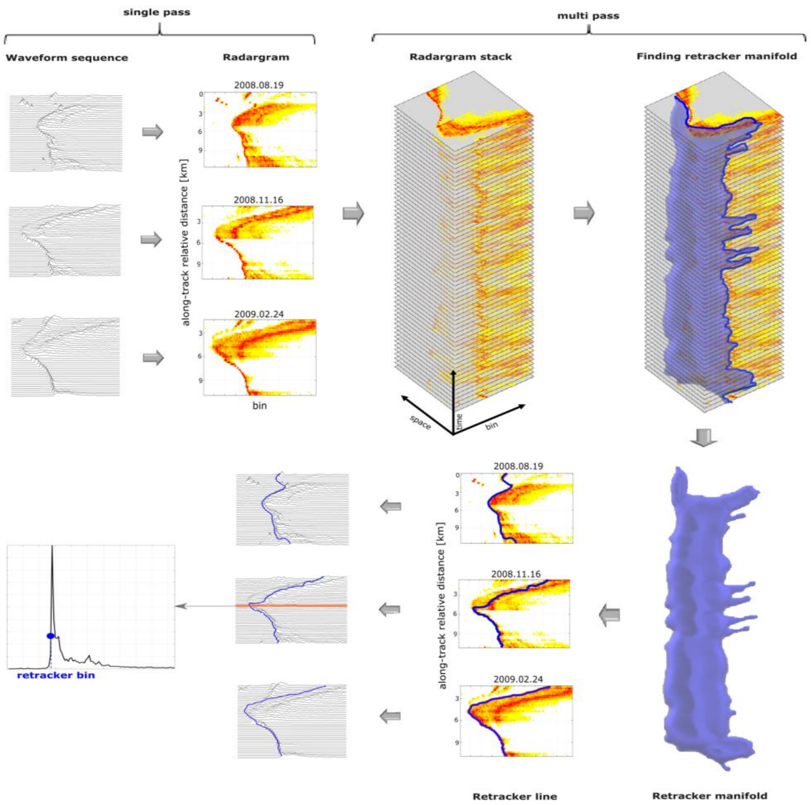
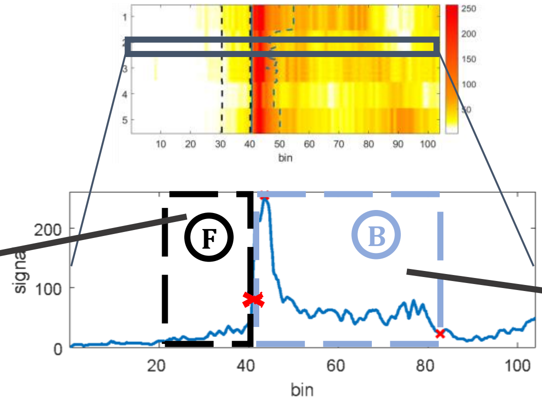



## Objective:

Developing a retracking method that benefits from the spatio-temporal variation of power in a radargram stack.

## Our solution:

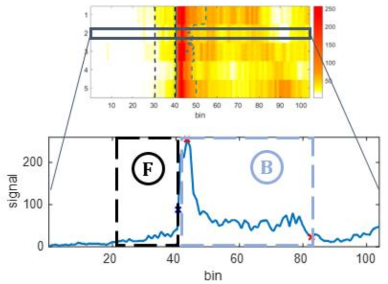
Determining the retracking offset by segmenting the radargram into two region: front and back of the regracking line




**Front region** represents the area spanned by the leading edge

**Back region** includes the peak and the portion of the trailing edge that still contains strong signal

**MRF-MAP problem → Energy-based optimization → Graph cuts technique**




$$E(f) = E_{\text{data}}(f) + \lambda\, E_{\text{smooth}}(f)$$

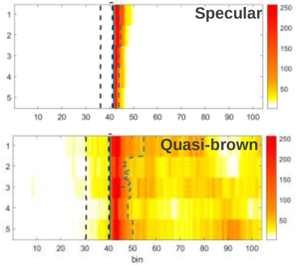
$$E_{\text{data}}(f) = \sum_{p} e_p^{\mathrm{F}}(I_p) + \sum_{p} e_p^{\mathrm{B}}(I_p)$$

represents the probability of pixel being segmented as front **F** and back **B** given its normalized power.

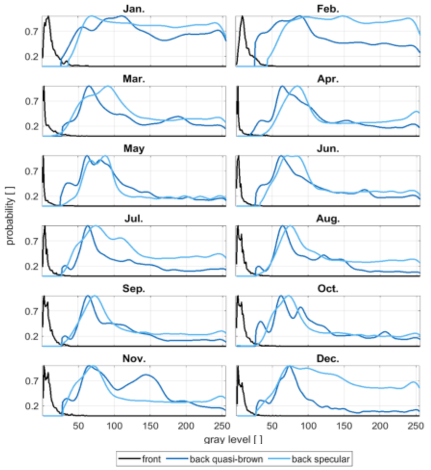
$$e_p^{\mathrm{F}} = -\log\left(\mathrm{P}_m^c\left(I_p \middle| p \epsilon \mathrm{F}\right)\right)$$

$$e_p^{\mathrm{B}} = -\log\left(\mathrm{P}_m^c\left(I_p \middle| p \epsilon \mathrm{B}\right)\right)$$

Waveform categories




Probability functions of the initial front and back regions for different months

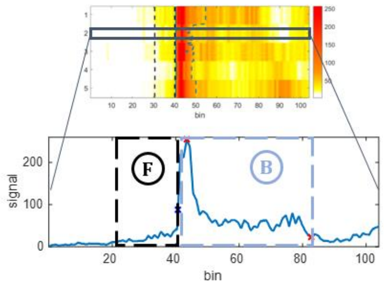



$$E_{\text{smooth}}(f) = \sum_{\{p,q\} \in \mathcal{N}} S_{\{p,q\}}(I_p, I_q)$$

measures the correspondence between two neighboring pixels with respect to their normalized power.

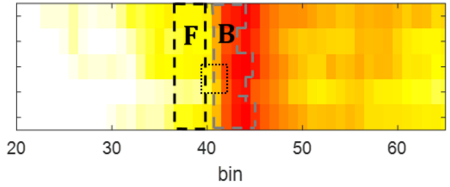
$$S_{\{p,q\}}(I_p, I_q) = c \exp\left(\frac{|I_p - I_q|}{2\sigma^2}\right)$$

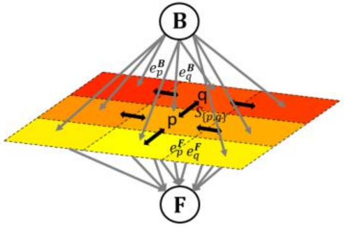
**MRF-MAP problem → Energy-based optimization → Graph cuts technique**

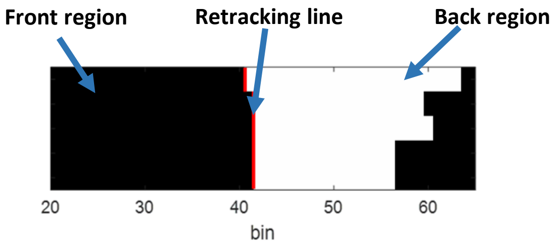



$$E(f) = E_{\mathrm{data}}(f) + \lambda\, E_{\mathrm{smooth}}(f)$$

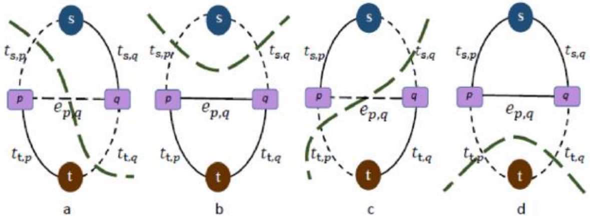
The most probable realization of back and front regions is found by applying the graph cuts optimization technique.




A cut in a graph is a subset of graph edges such that the terminals would be disconnected if they were removed from the graph

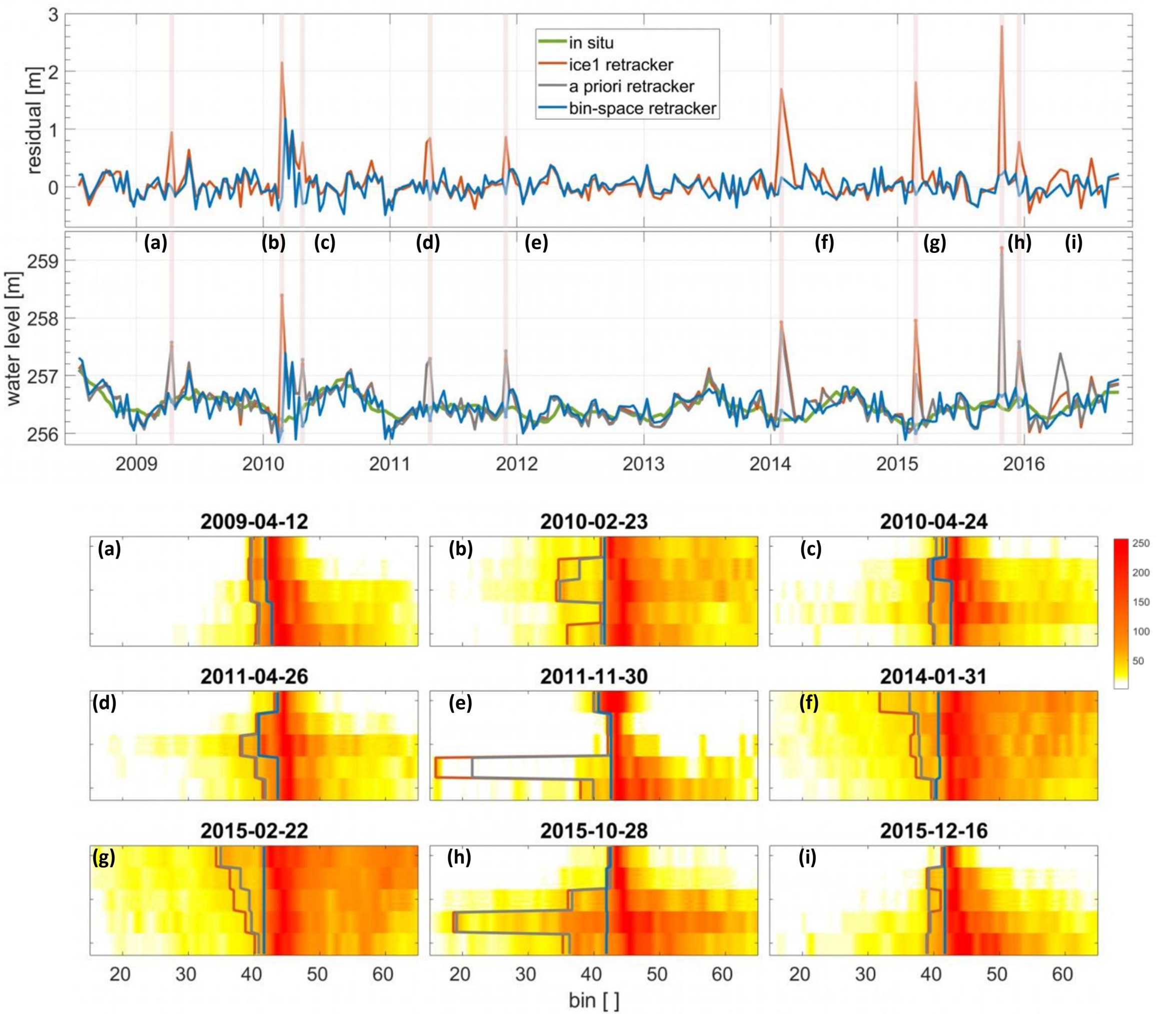


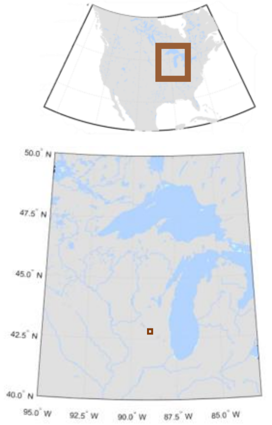

$$C_a = \{t_{s,p}, e_{p,q}, t_{t,q}\}$$

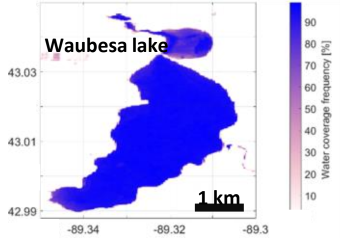
$$C_b = \{t_{s,p}, t_{s,q}\}$$

$$C_c = \{t_{t,p}, e_{p,q}, t_{s,q}\}$$

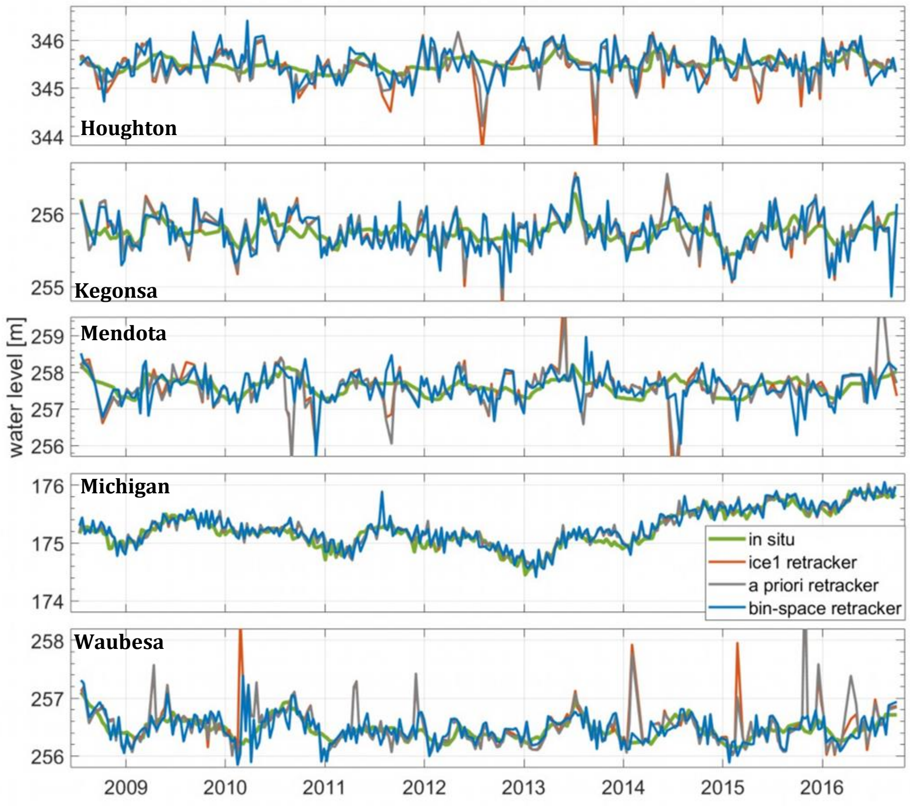
$$C_d = \{t_{t,p}, t_{t,q}\}$$

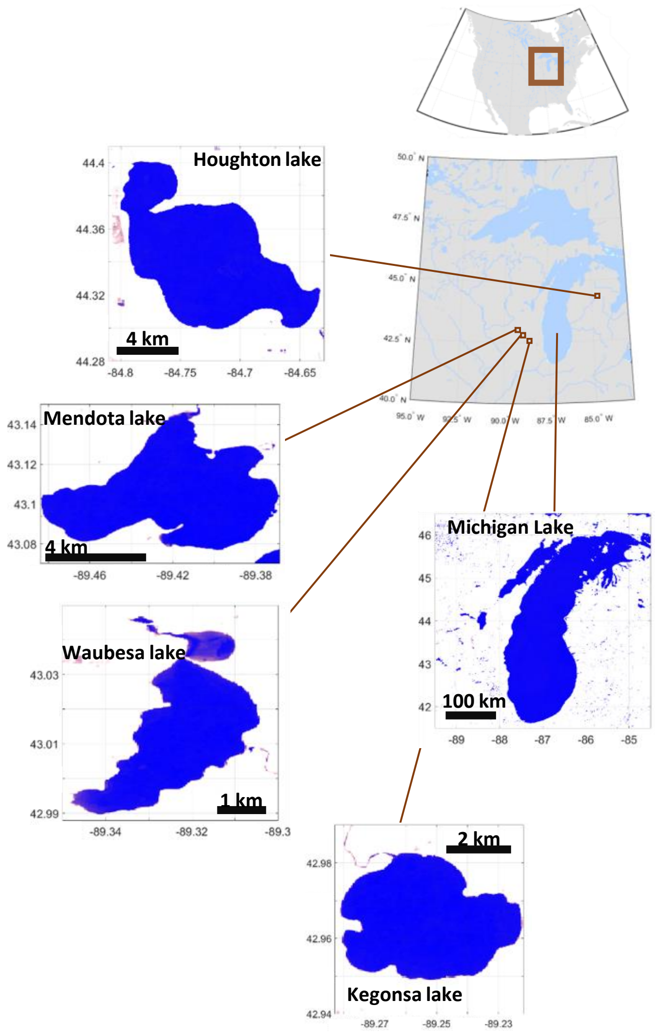





| Lake | ice1 retracker correlation | ice1 retracker RMSE [m] | bin-space retracker correlation | bin-space retracker RMSE [m] |
|---|---|---|---|---|
| Waubesa | 0.34 | 0.35 | 0.59 | 0.20 |




| Lake | ice1 retracker correlation | ice1 retracker RMSE [m] | bin-space retracker correlation | bin-space retracker RMSE [m] |
|---|---|---|---|---|
| Houghton | 0.27 | 0.35 | 0.37 | 0.28 |
| Kegonsa | 0.49 | 0.23 | 0.50 | 0.22 |
| Mendota | 0.19 | 0.56 | 0.40 | 0.38 |
| Michigan | 0.94 | 0.12 | 0.92 | 0.13 |
| Waubesa | 0.34 | 0.35 | 0.59 | 0.20 |

# Conclusion and Outlook

The bin-space retracker algorithm determines the retracker offset more accurately than the conventional retracker algorithm by

- Incorporating the spatio-temporal dependencies of the consecutive waveforms.
- Mitigating the error of the noisy waveforms
- Ignoring the blunders

The improvement over the small lakes was more significant since most of the waveforms are noisy.

The computational complexity is the main obstacle of the algorithm

Further improvements:

- Incorporating the temporal constraints more efficiently
- Expanding the graph to the higher orders neighboring structure.

# Thank you for your attention!!

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