Enabling Cloud Edge Measurements with Photon Counting

Grant Kirchhoff *[1], Matthew Hayman [2], Willem Marais [3], Jeffrey Thayer [1], Rory Barton-Grimley [4], Bryce Garby [1]

01.15.2025

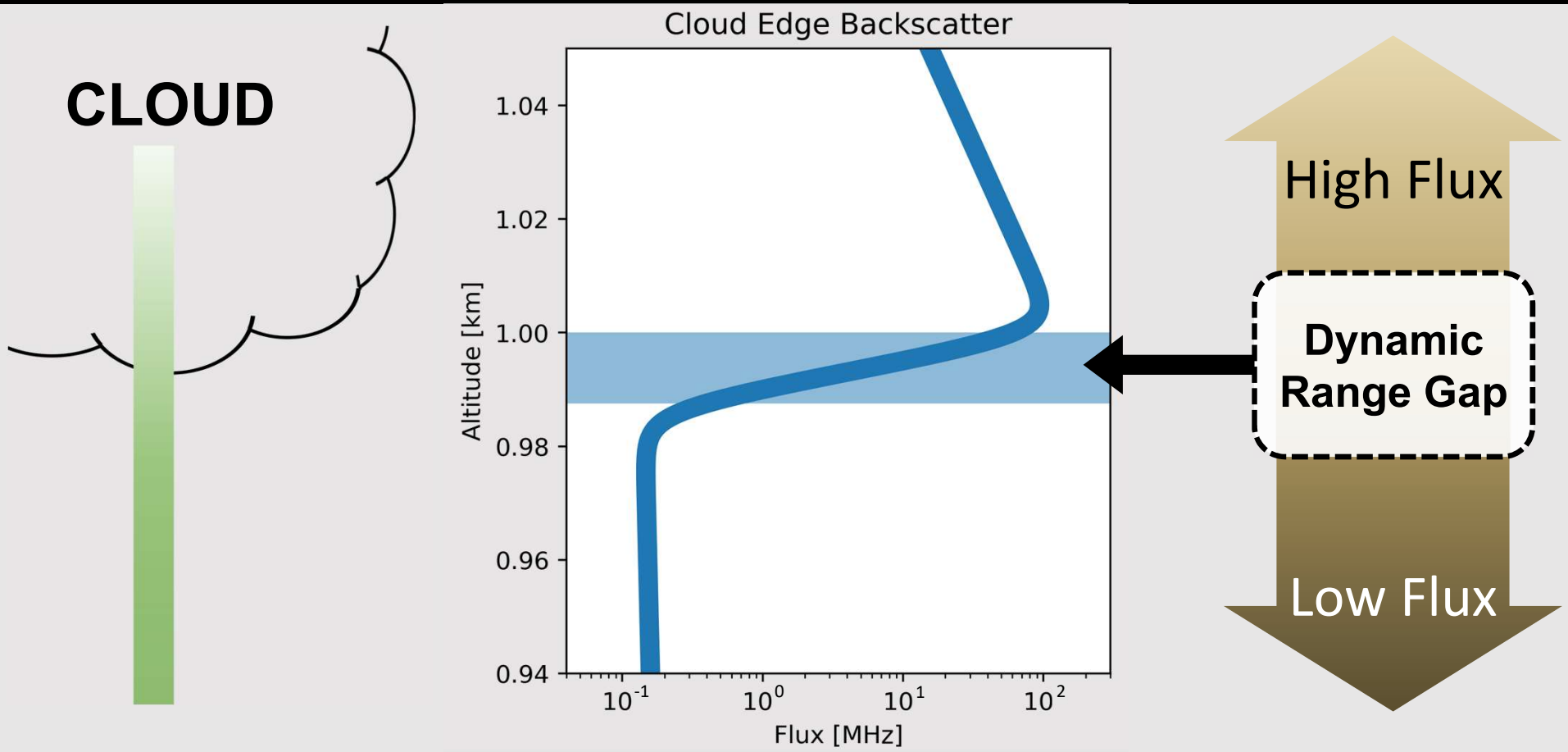
[1] University of Colorado Boulder, Aerospace Engineering Sciences

[2] NSF National Center for Atmospheric Research, Earth Observing Laboratory

[3] University of Wisconsin Madison, Space Science and Engineering Center

[4] NASA Langley Research Center

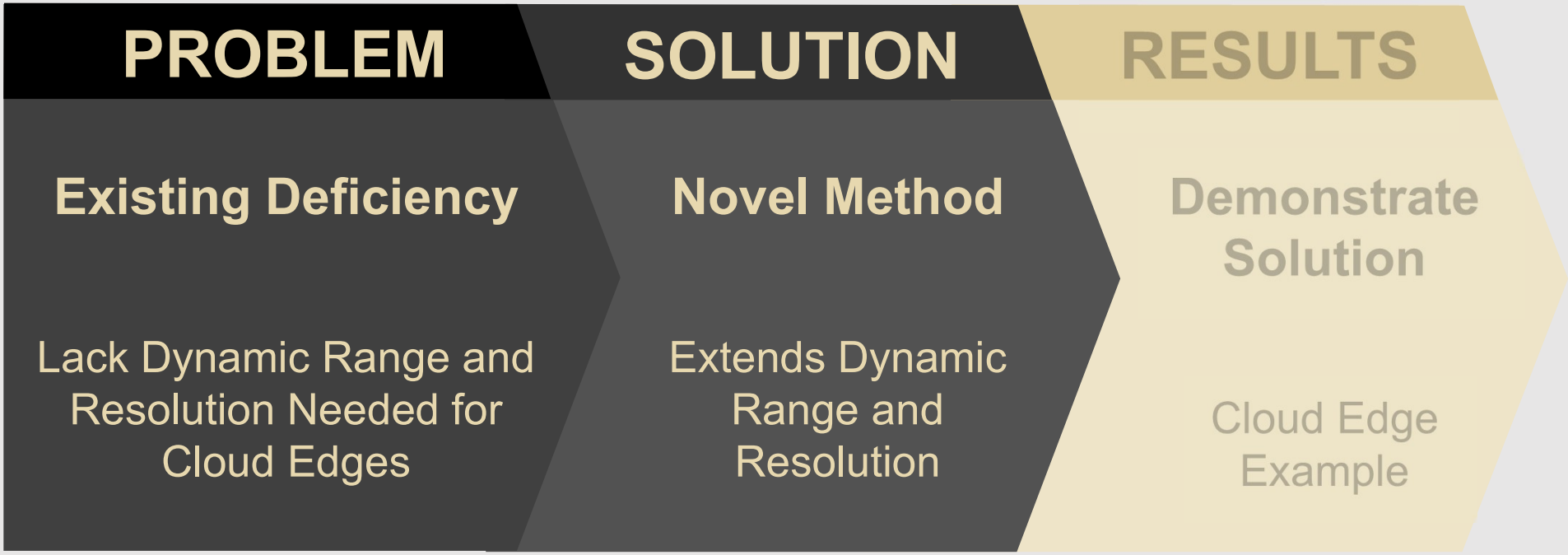
Measuring Cloud Edge



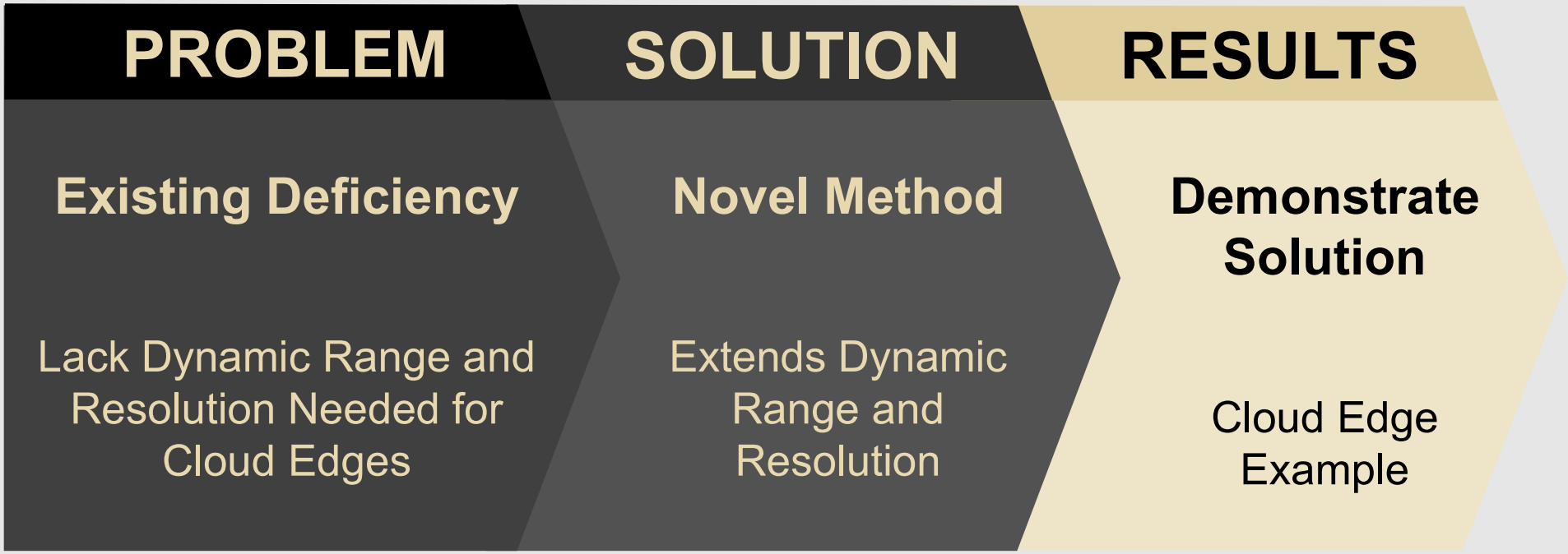
Outline


PROBLEM
SOLUTION
RESULTS
Existing Deficiency
Lack Dynamic Range and Resolution Needed for Cloud Edges
Novel Method
Extends Dynamic Range and Resolution
Demonstrate Solution
Cloud Edge Example

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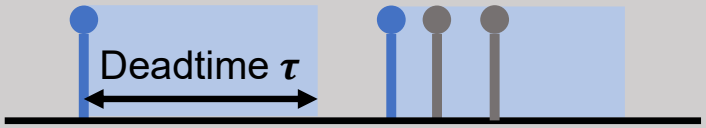

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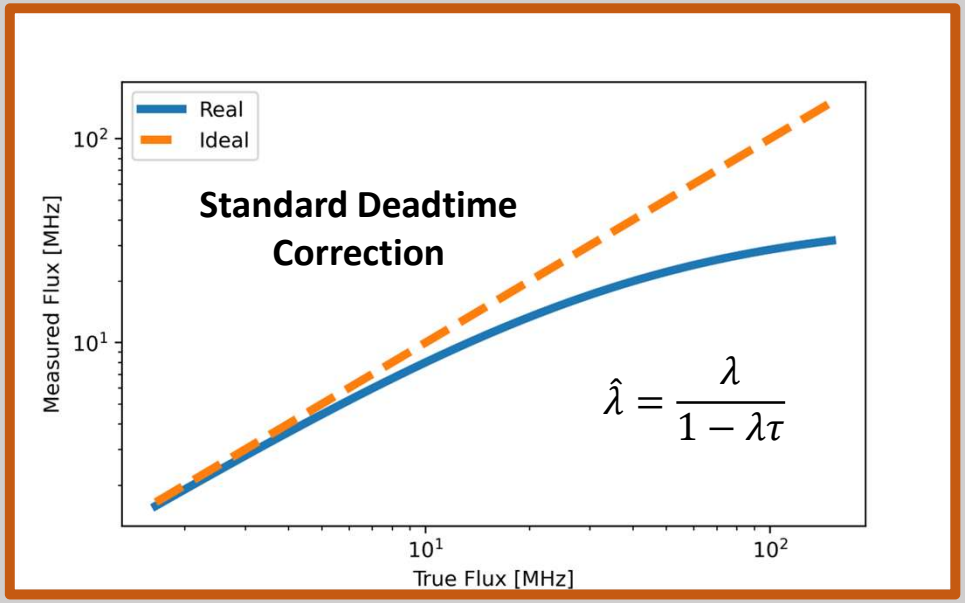

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Problem

Standard Deadtime Correction



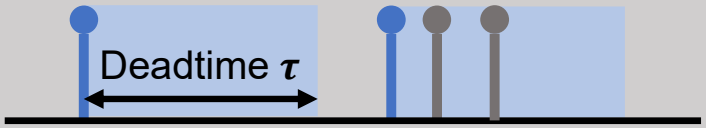
Time of flight



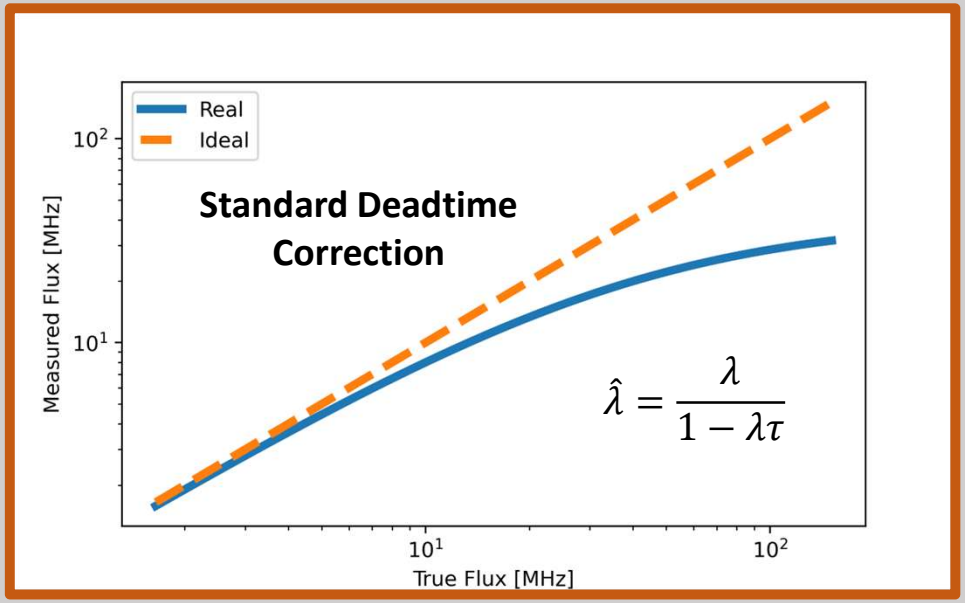
Problem

Sufficient Conditions to use Standard Deadtime Correction

1. **Constant Flux**
2. **Coarse Resolution** (> 10 meters)



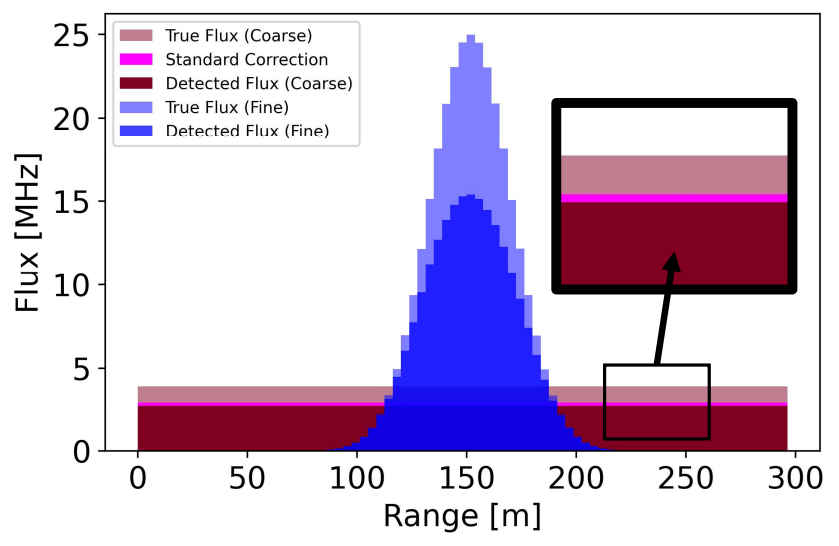
Time of flight



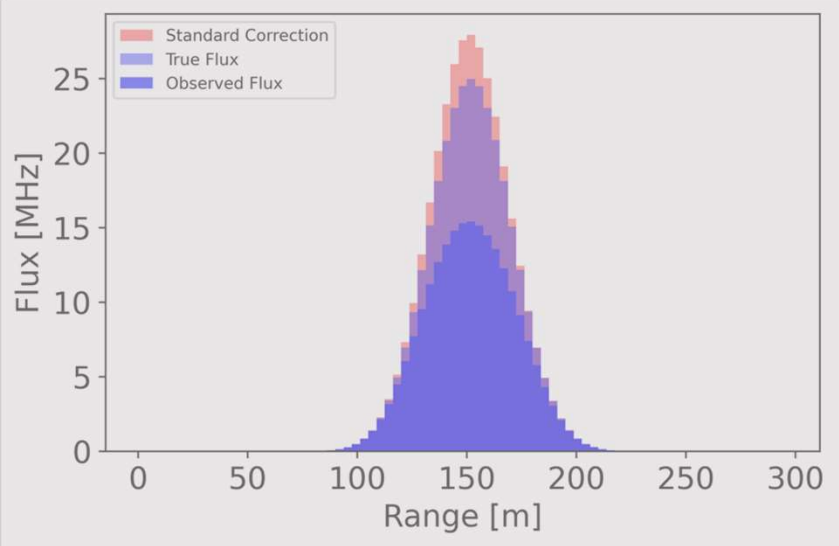
Problem

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Non-constant flux



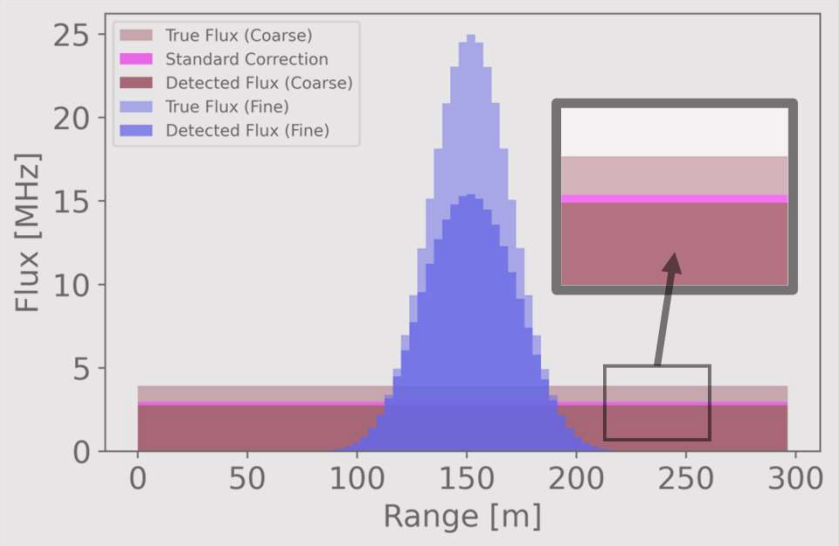
High Resolution



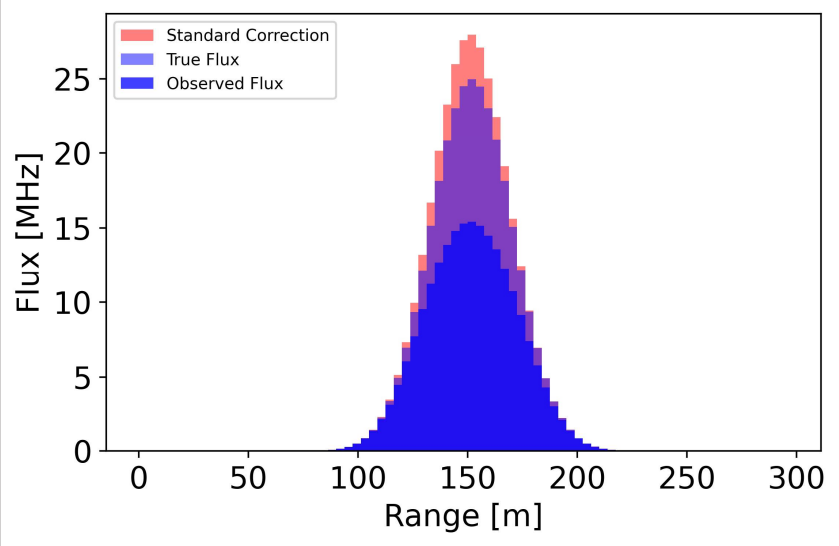
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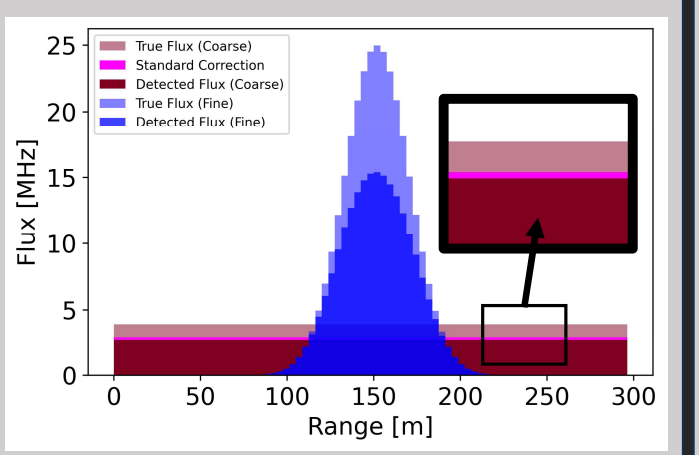
High Resolution



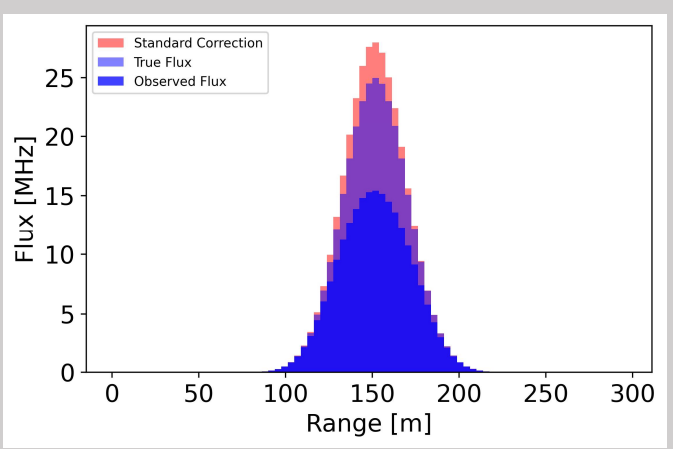
Problem

Variability at cloud edge is **incompatible** with Standard Correction

Non-constant flux

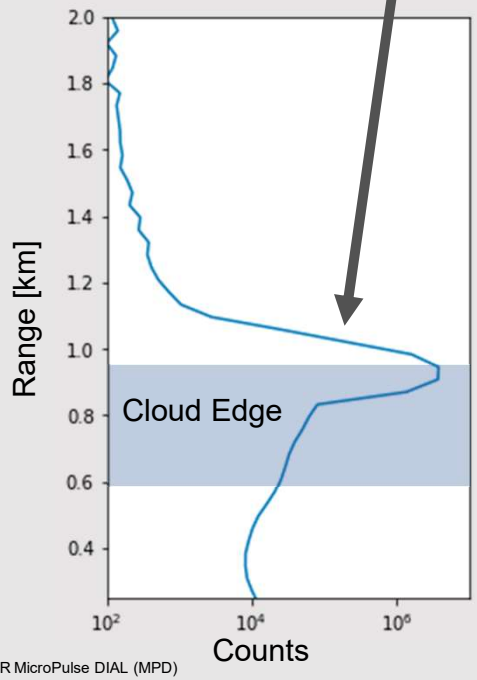


High Resolution



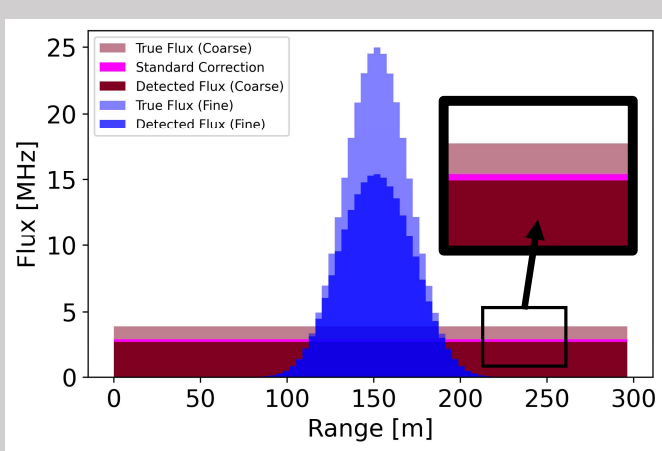
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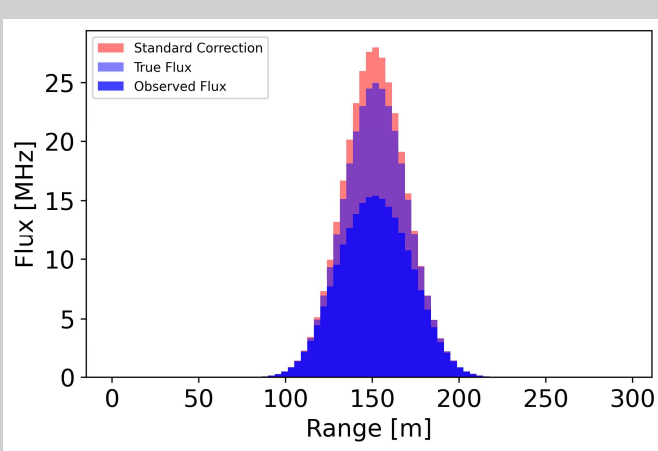


Source: NCAR MicroPulse DIAL (MPD)

Non-constant flux

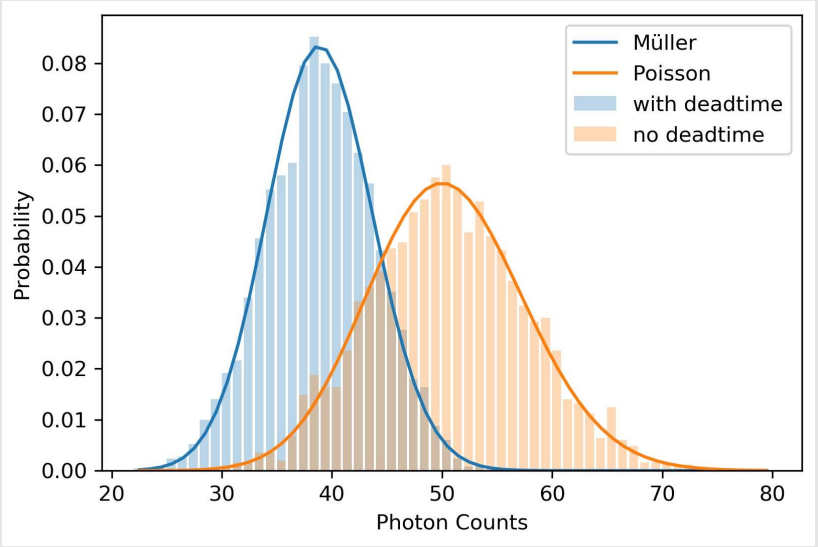


High Resolution



Solution

Developed a **“deadtime noise model”** [*]

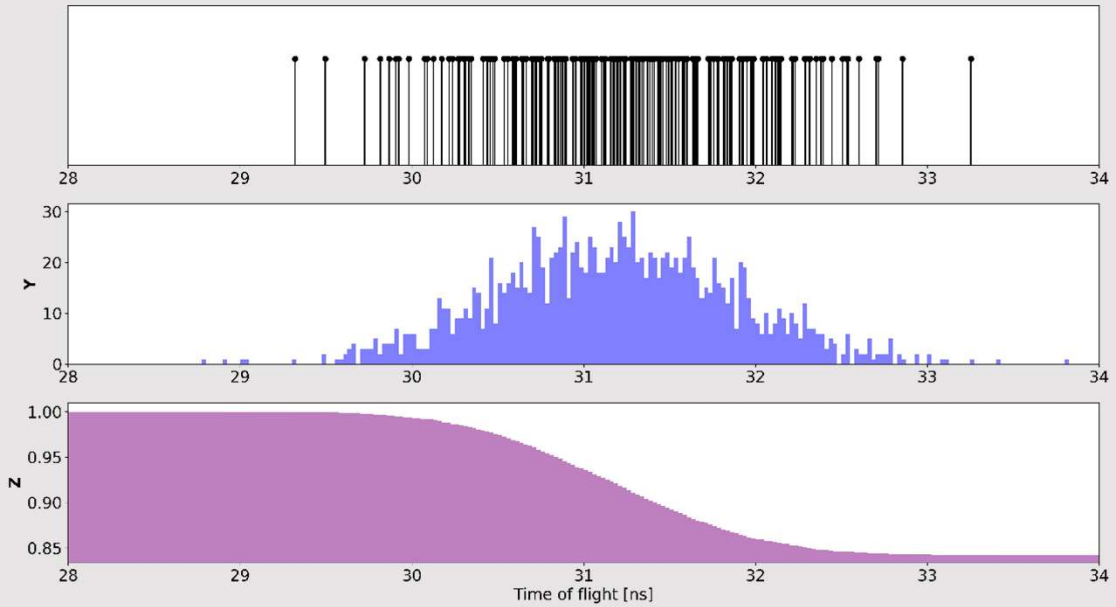


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Proposed Solution:

$$\hat{\lambda} = \frac{\boldsymbol{Y}}{N\Delta t}\frac{1}{\overline{Z}} = \lambda\frac{1}{\overline{Z}}$$



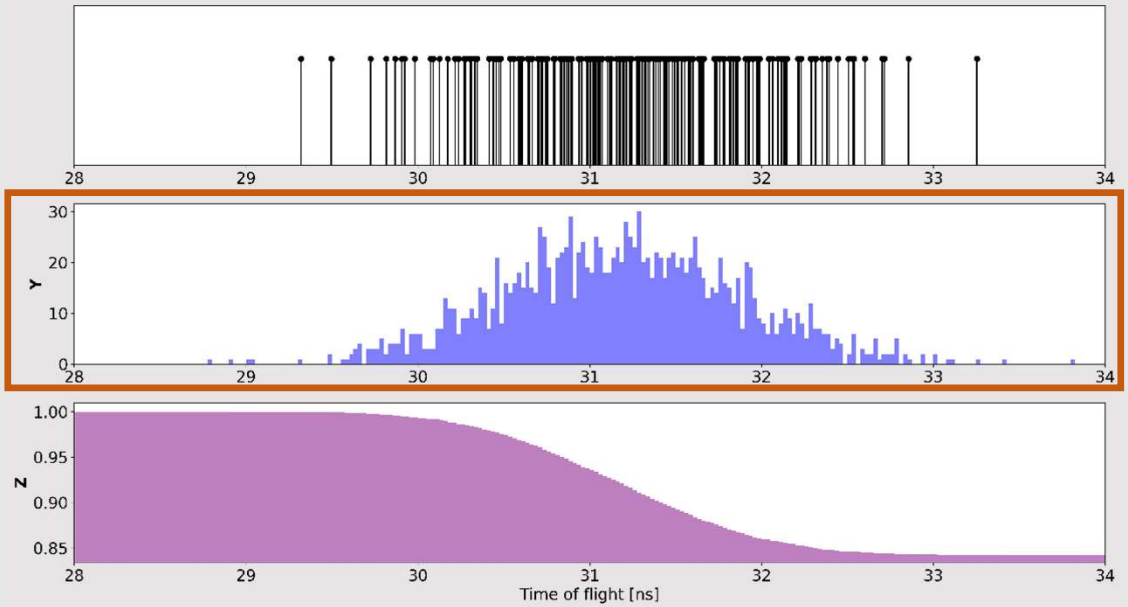
[*] Publication in review

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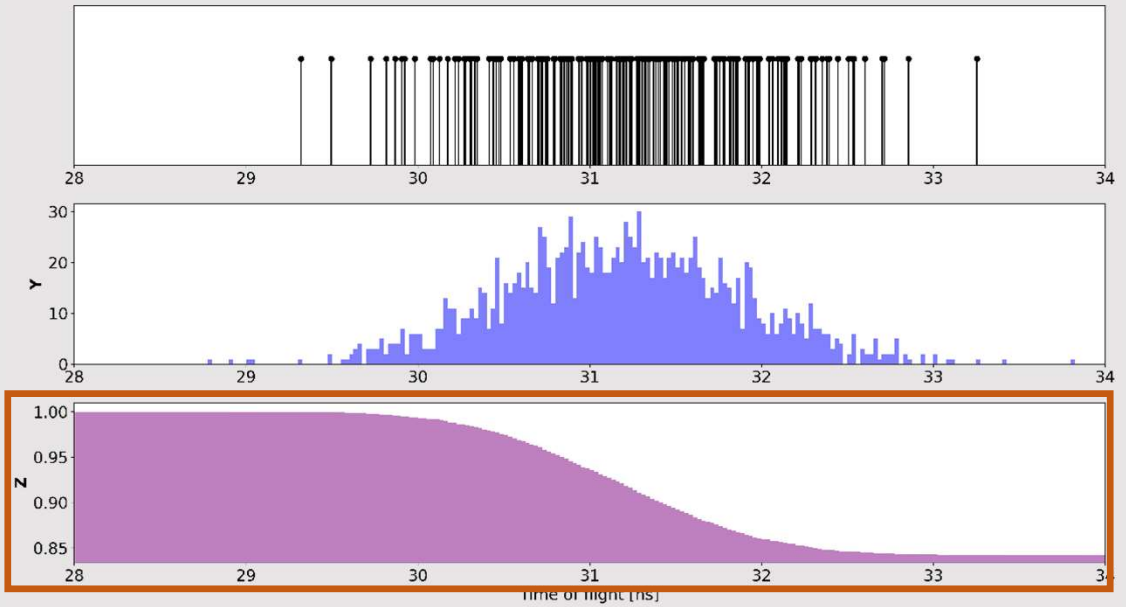
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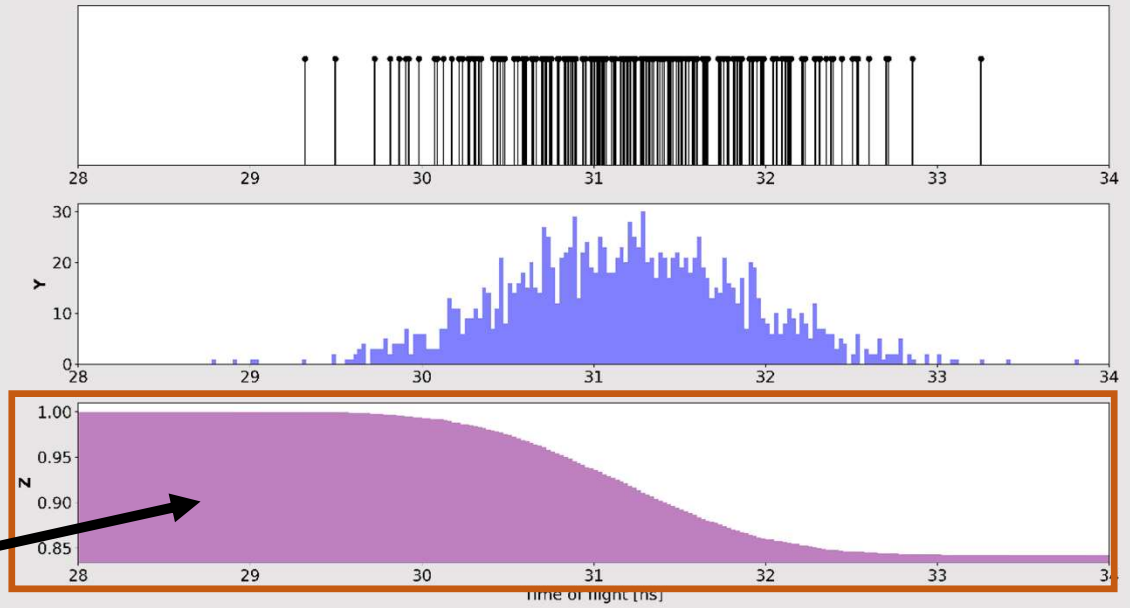
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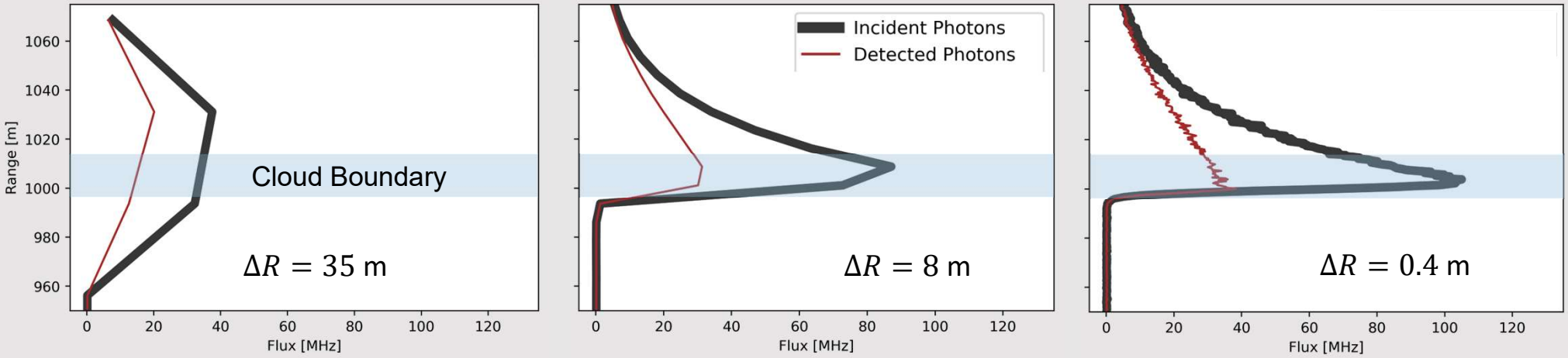


$\boldsymbol{Z}$: **"Active Fraction Histogram"**

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Results

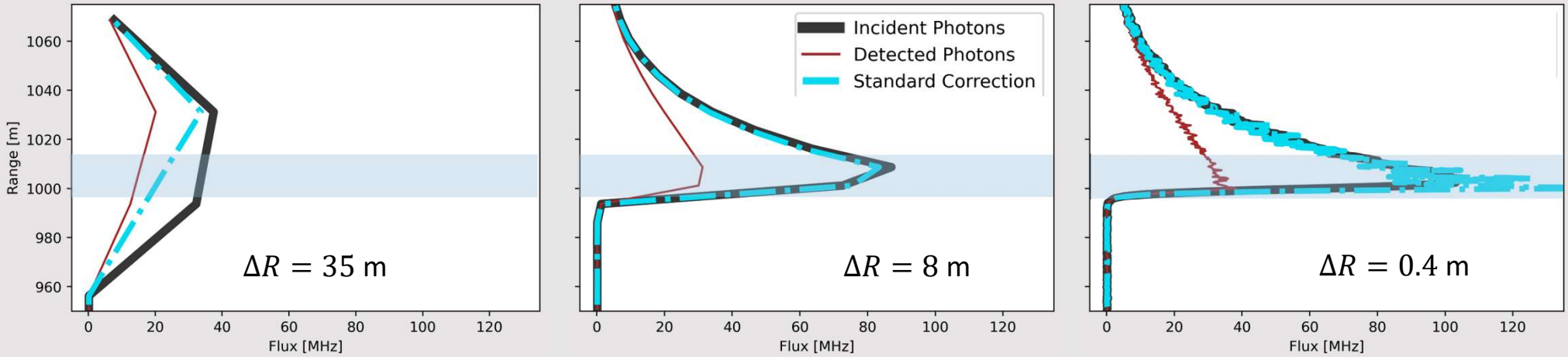
CLOUD-EDGE BACKSCATTER



Results

CLOUD-EDGE BACKSCATTER

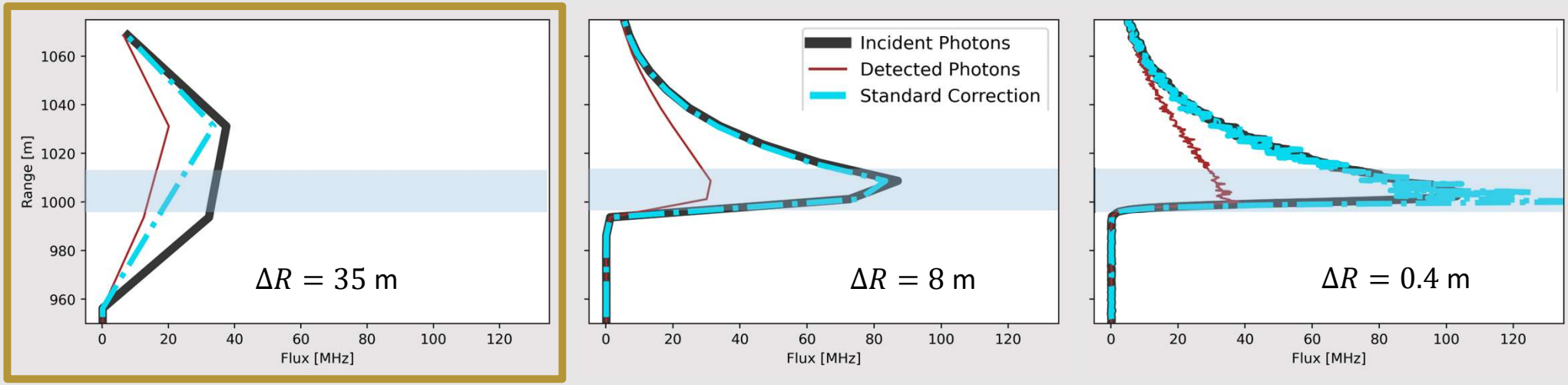
Standard Correction



Results

CLOUD-EDGE BACKSCATTER

Standard Correction

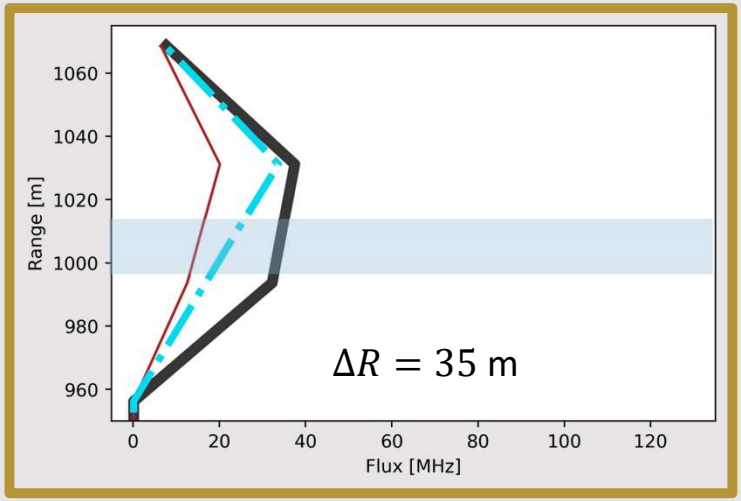


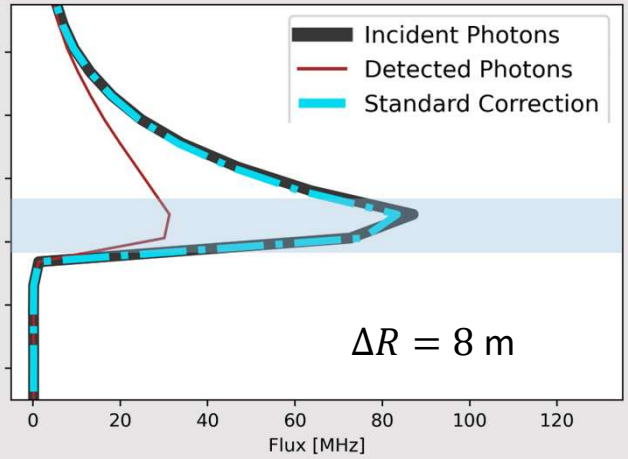
Standard Correction prone to bias when
averaging over structure and at **high resolution**

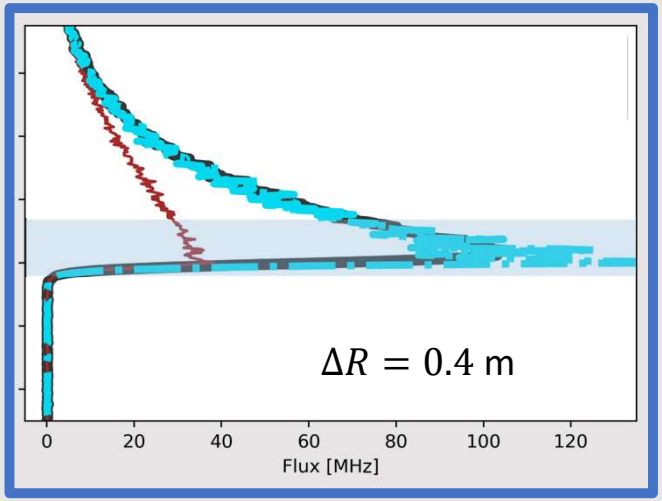
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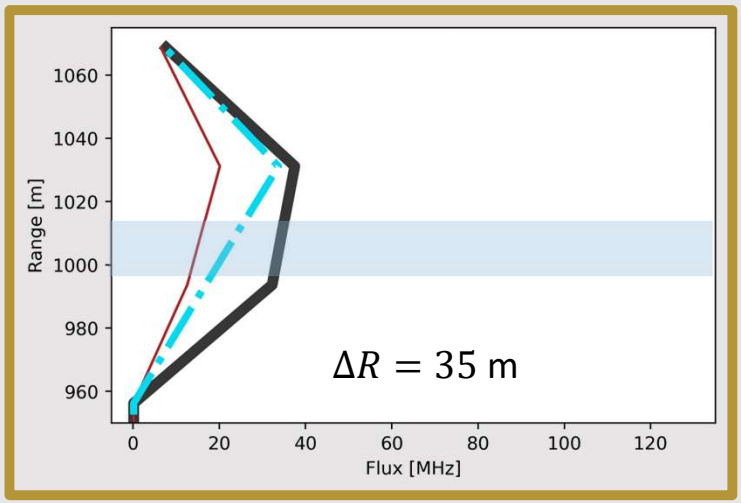


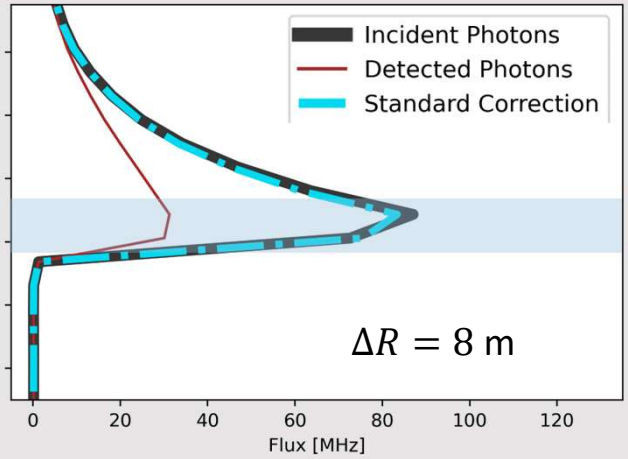
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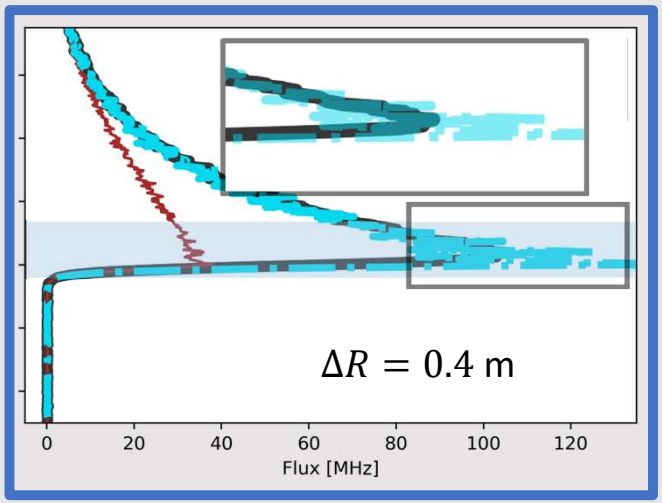
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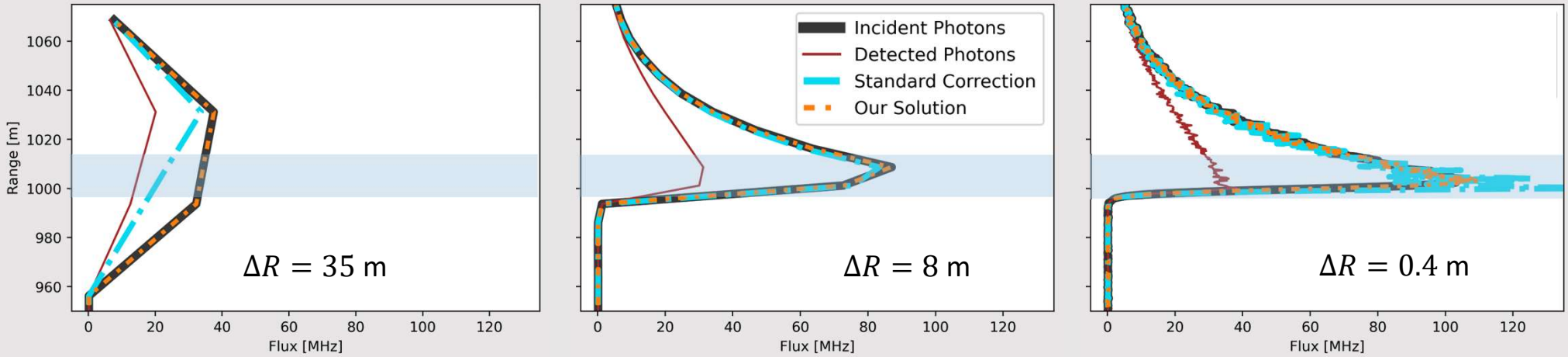


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CLOUD-EDGE BACKSCATTER

Our Solution

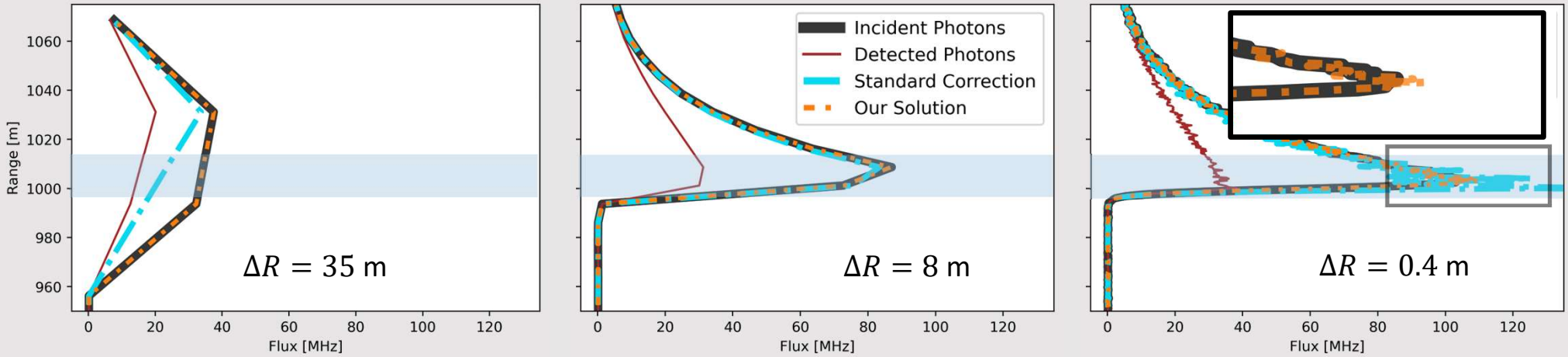


Our Solution Is Bias Free

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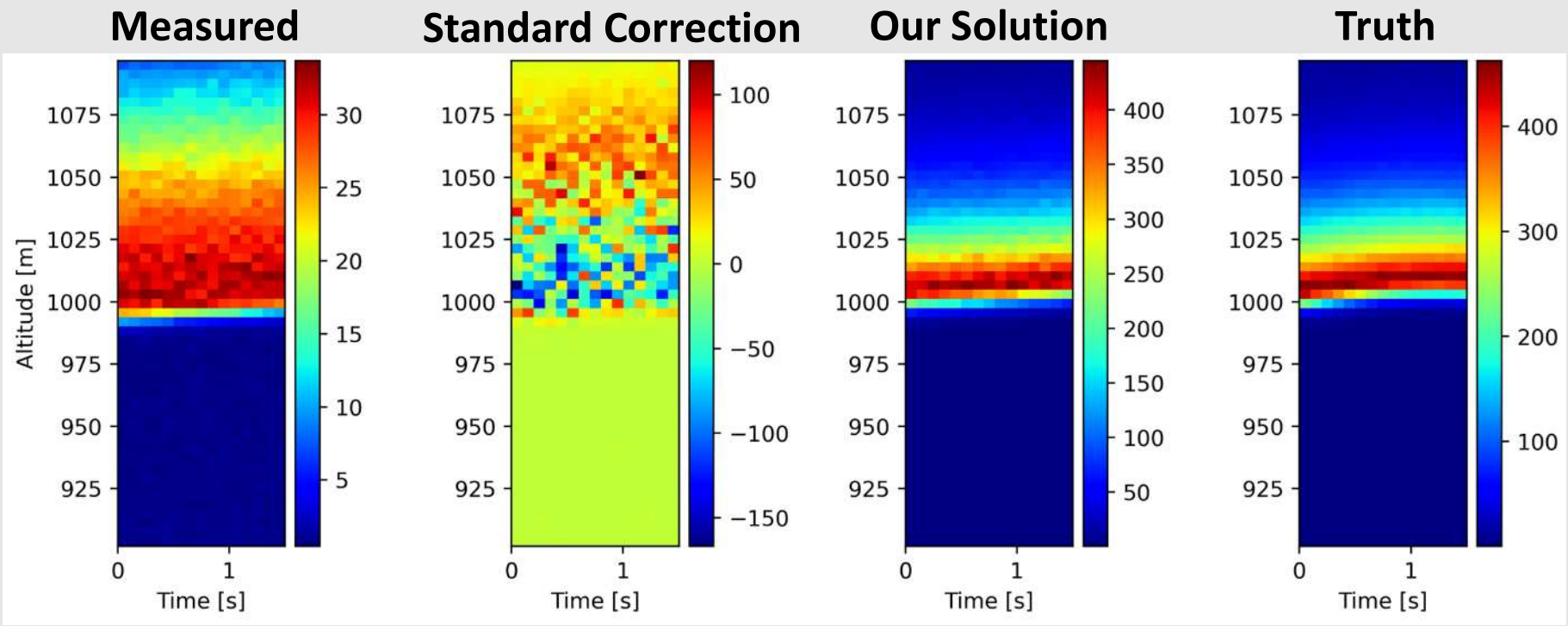
CLOUD-EDGE BACKSCATTER

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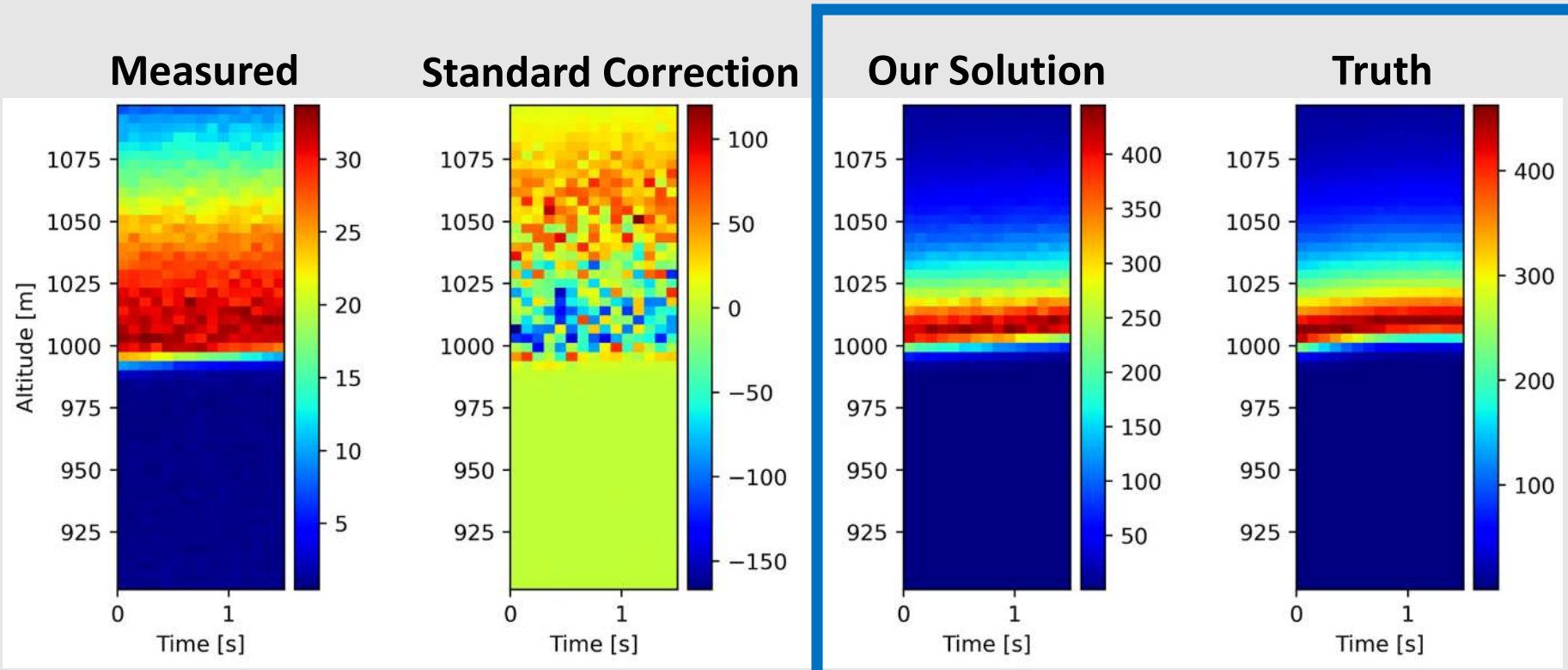


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Results


Measured
Standard Correction
Our Solution
Truth
Altitude [m]
1075
1050
1025
1000
975
950
925
0
1
Time [s]
30
25
20
15
10
5
100
50
0
−50
−100
−150
400
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Conclusion

Problem: Standard Correction incompatible for cloud edges

Deficiencies

Dynamic Range: 1 kHz – 100 MHz
Resolution: <1 m range, < 1 sec time

Solution: Novel deadtime correction method to **enable this dynamic range and resolution**

Ongoing Work

- Build system to leverage this for cloud-edge measurements
- Publication demonstrating this concept in lab (in review)

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Acknowledgements

Funding: This work was supported by a NASA's Space Technology Research Grants Program

Resources: University of Colorado Boulder, NSF National Center for Atmospheric Research

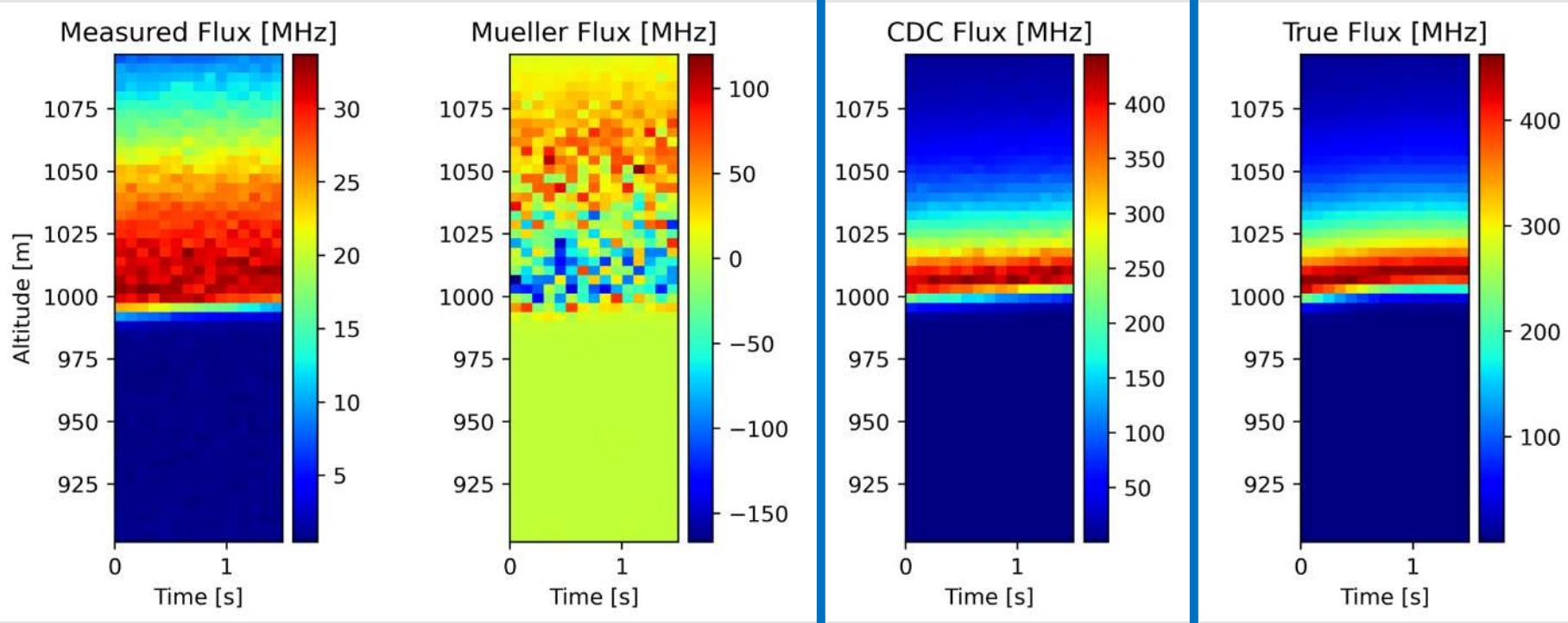


References

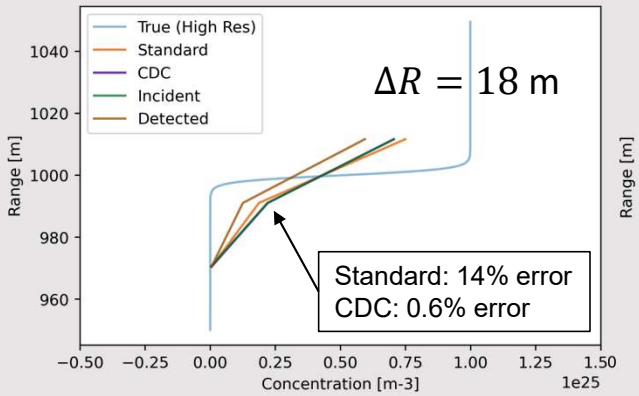
- **W. J. Marais** and M. Hayman, “Extending water vapor measurement capability of photon-limited differential absorption lidars through simultaneous denoising and inversion,” Atmos. Meas. Tech. (2022)
- **M. Hayman**, W. J. Marais, R. A. Stillwell et al., “Interrogation of heterogeneous atmospheric structure through statistical signal processing,” in 103rd Annual Meeting American Meteorological Society (2023)
- **R. A. Barton-Grimley**, R. A. Stillwell, and J. P. Thayer, “High resolution photon time-tagging lidar for atmospheric point cloud generation,” Opt. Express 26 (2018)
- **G. Kirchhoff**, M. Hayman, W. Marais, *et al.*, “Development of a photon counting deadtime noise model that extends dynamic range and resolution in atmospheric lidar,” (submitted).

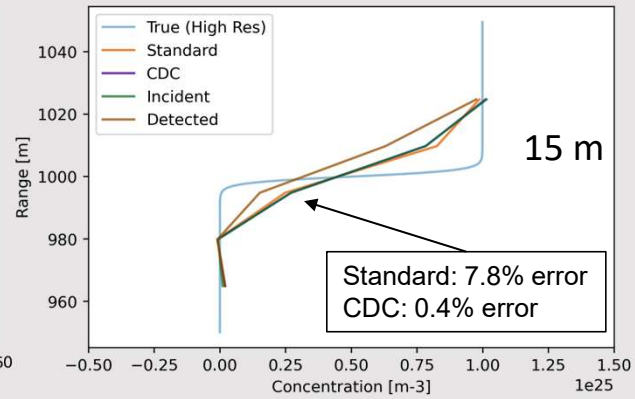
Backup Slides

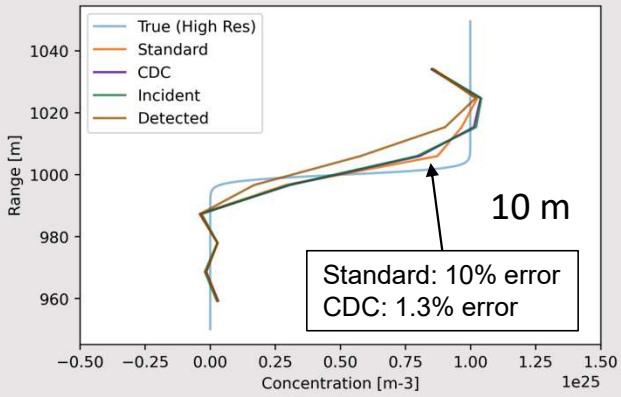
Temporal Variability

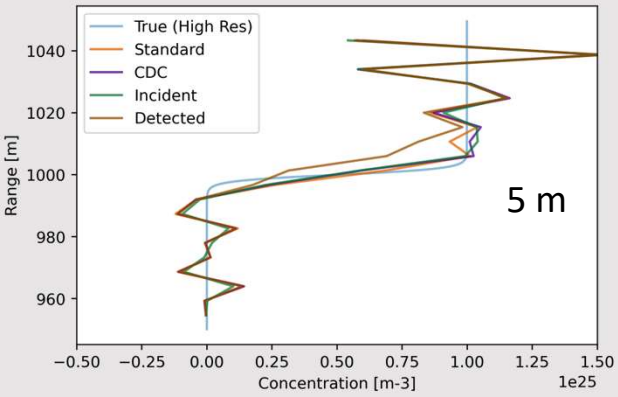


Results: Water Vapor









Spatially averaging variability

Non-physical water vapor concentrations a result of heterogeneity

