Assessment of COSMIC-2 Radio Occultation (RO) bending angle bias in the lower troposphere

Kuo-Nung (Eric) Wang[1], Chi O Ao[1], Shu-peng Ho[2], Lidia Cucurull[3]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

[2]NOAA/Center for Weather and Climate Prediction, College Park, Maryland, USA

[3]NOAA/Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, USA

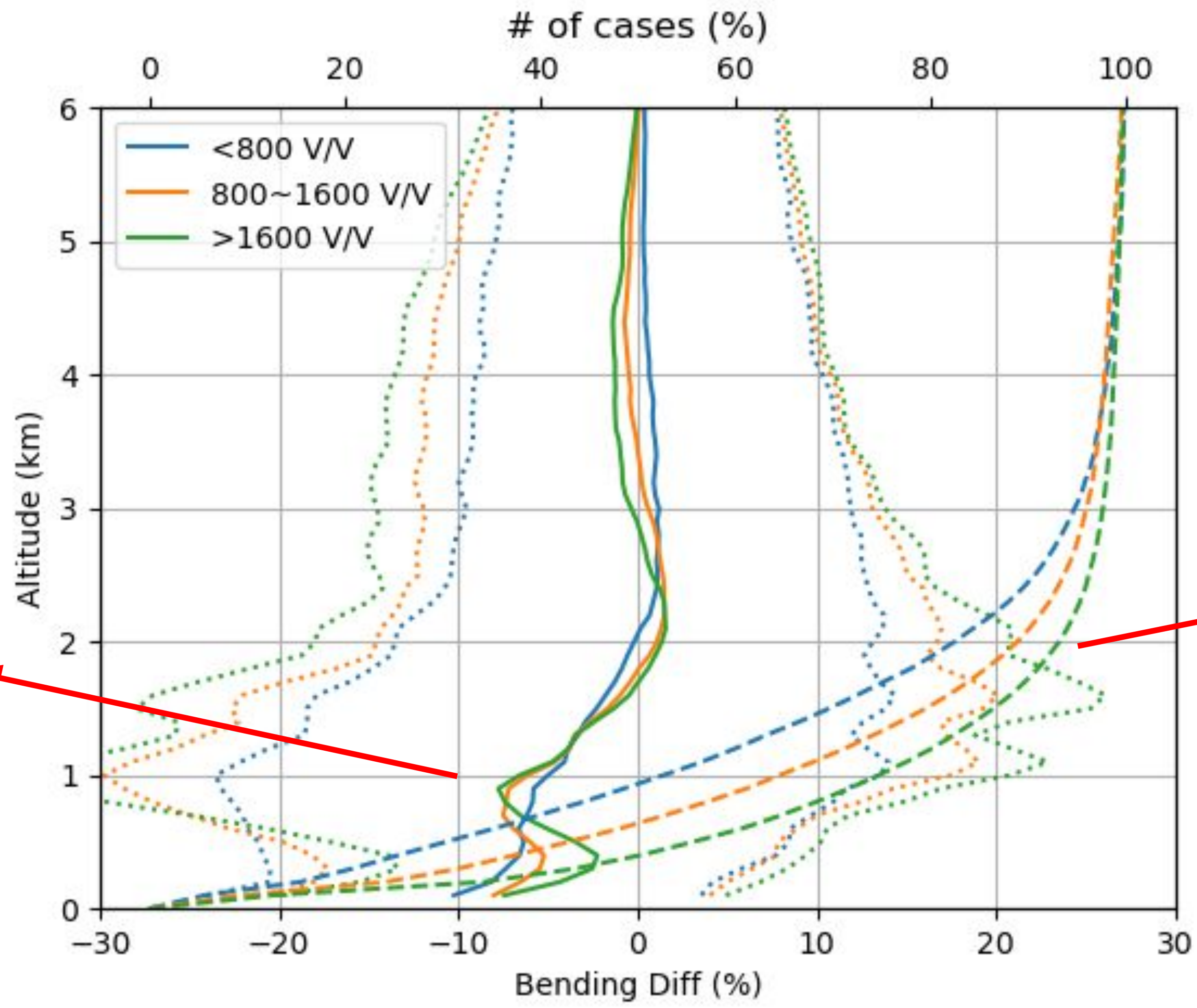
The NOAA NESDIS OPPA Technology Maturation Program (TMP)

Jet Propulsion Laboratory
California Institute of Technology

Introduction

- Bending angle bias: it has been shown that >80% of COSMIC-2 observations under 2km failed the quality control (QC) of the data assimilation (DA) process due to sizeable bending angle biases
- Higher SNR (>1000 V/V) of COSMIC-2 does not improve the biases below 2 km. Several possible error sources causing the negative biases are investigated
- Error source: Measurement
  - Smoothing
  - Noise
  - Sampling bandwidth
  - Receiver model

Bending O-A (COSMIC2 2020-04 ~ 2020-05)



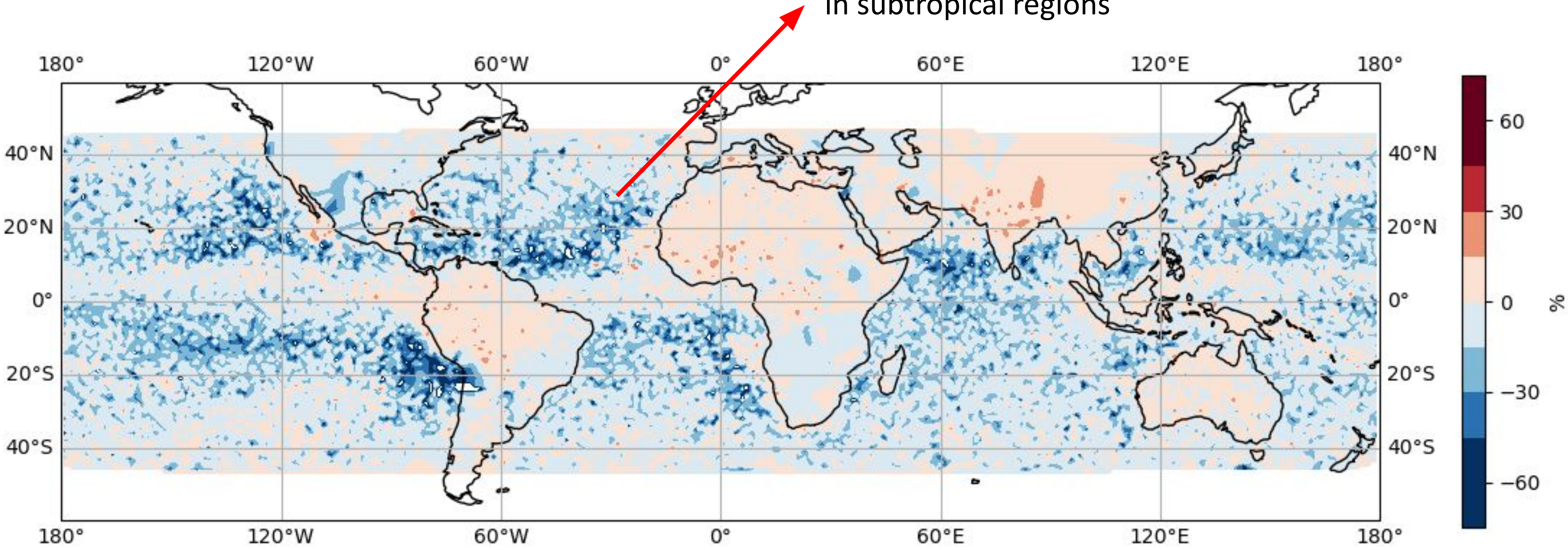
Negative bias > 8% at 1 km even in strong SNR cases

Penetration height improved when SNR is higher

Bending O-A (COSMIC2 2020-04 ~ 2020-05)

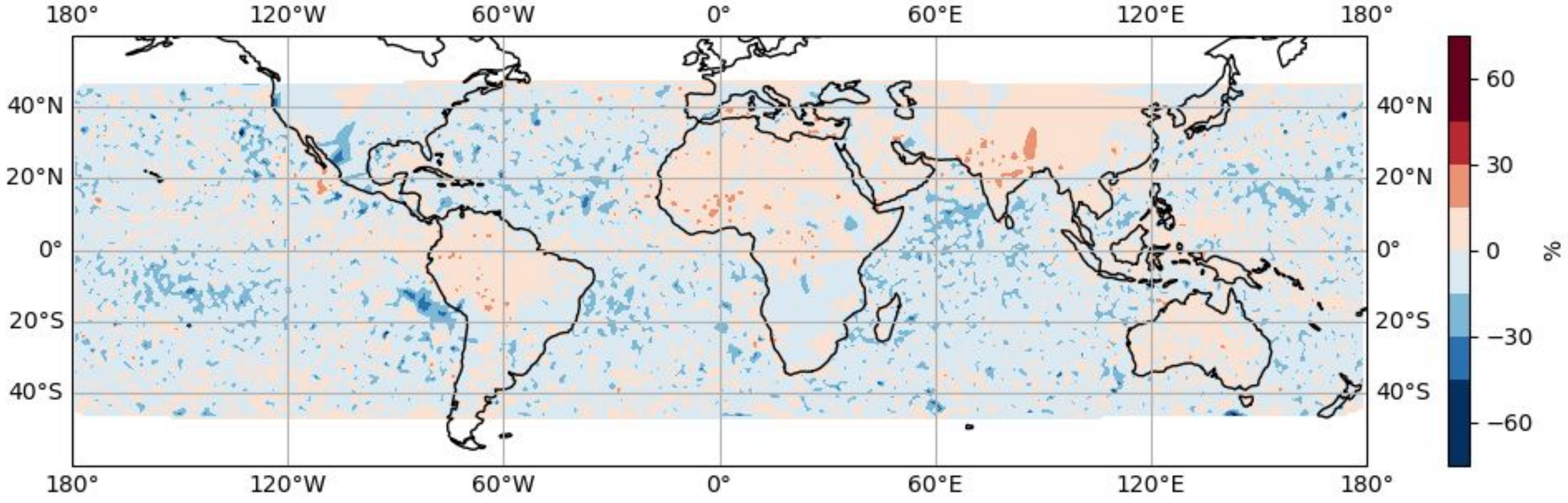
- COSMIC2 – NCEP: 1 km

Significant bending difference in subtropical regions



Bending O-A (COSMIC2 2020-04 ~ 2020-05)

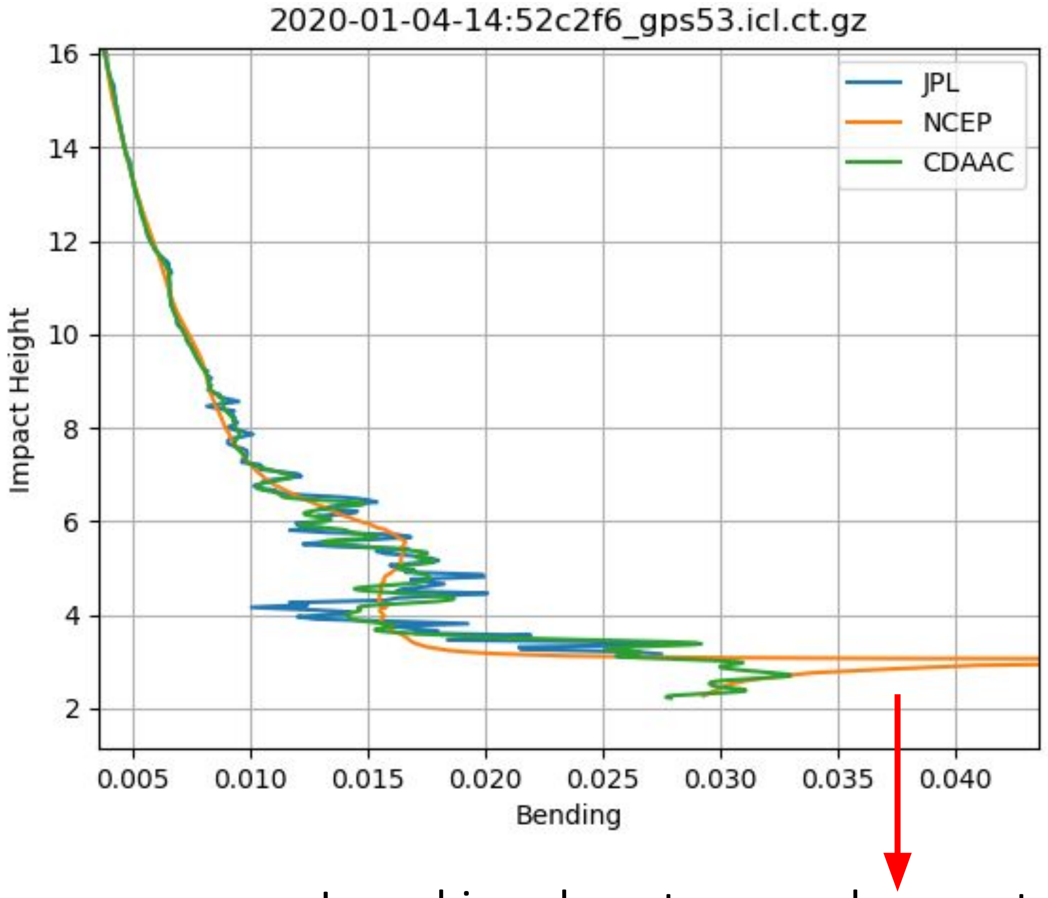
- COSMIC2 – NCEP: 1 km (max bending < 0.04 rad: 15% cases removed)

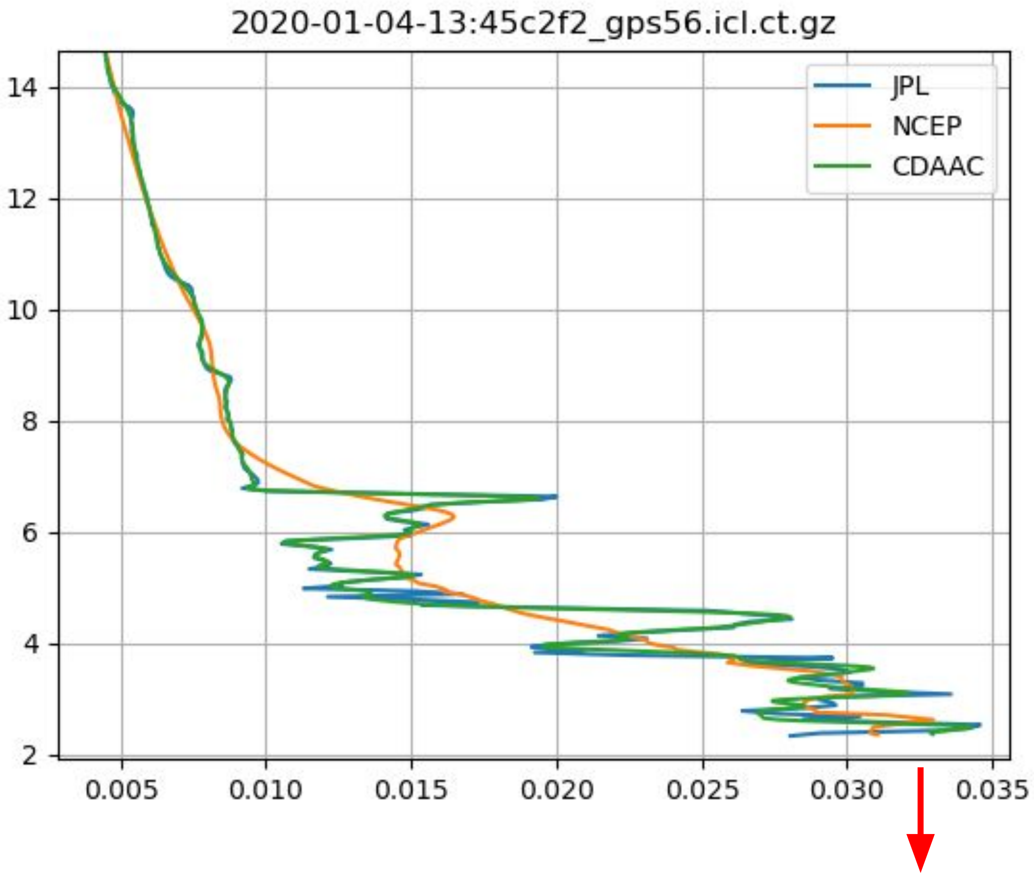


The negative bias at 1km mainly comes from the cases with strong N gradient!

Bending angle actual cases

- Individual cases (large peak BA vs small peak BA)



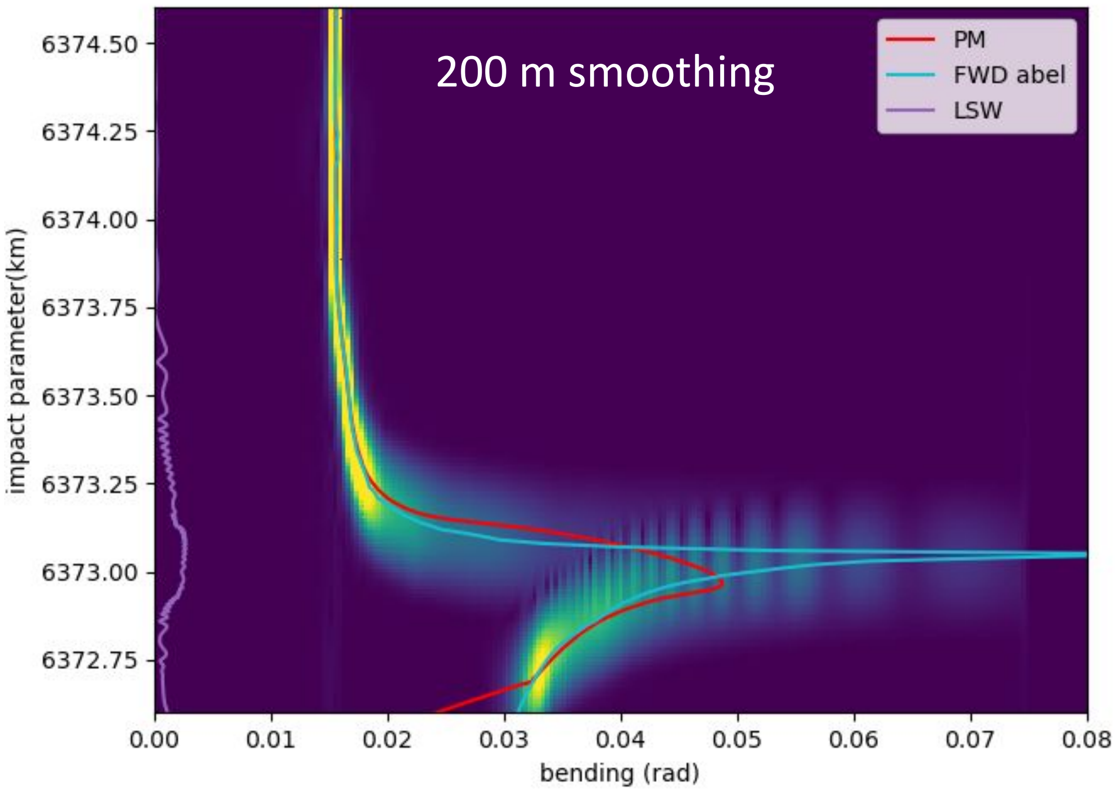


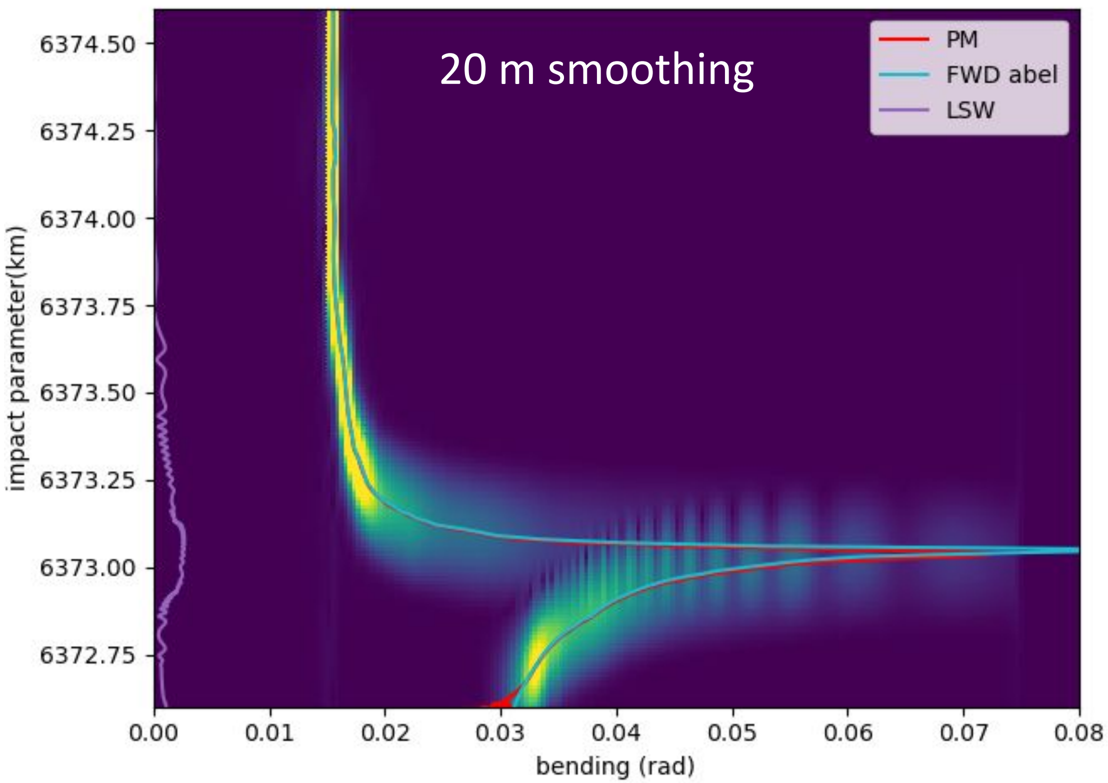
Large bias when strong peak presents

No clear bias if bending maximum < 0.04 rad

MPS simulation

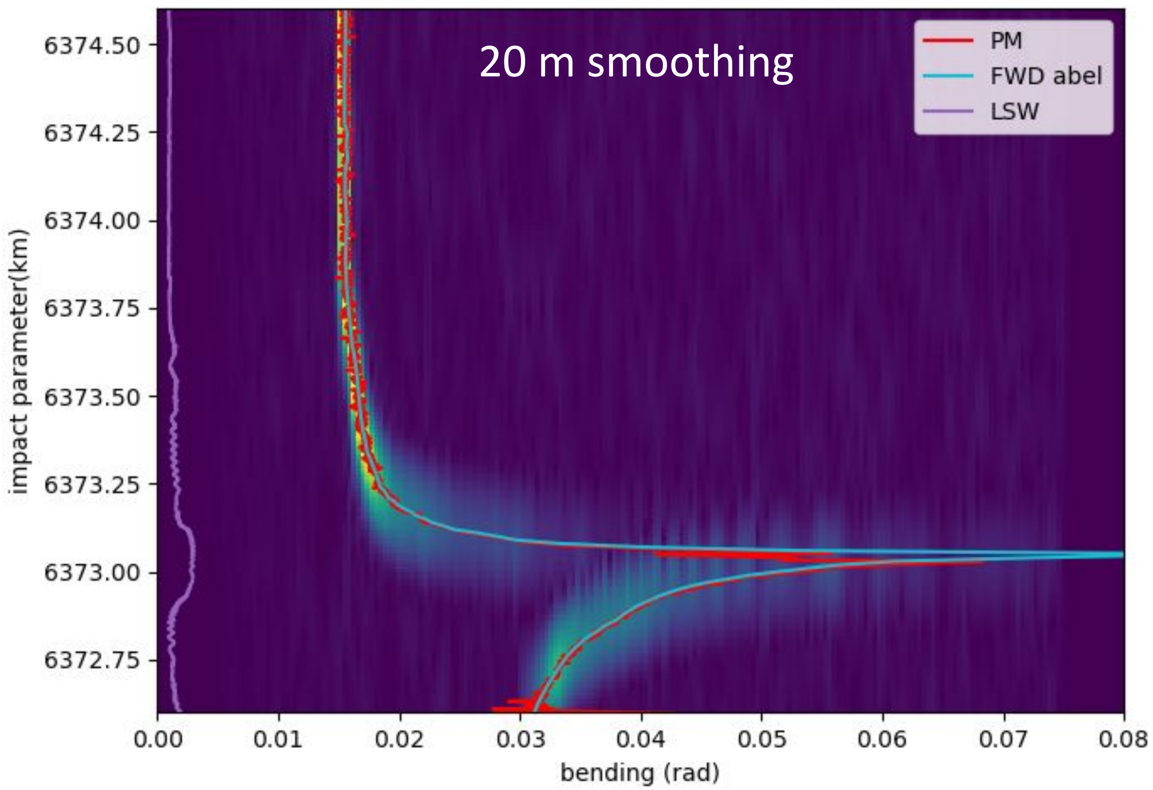
- Vertical smoothing (200m vs 20m)
  - Forward Abel
  - Multiple Phase Screen (MPS) + Phase Matching (PM)

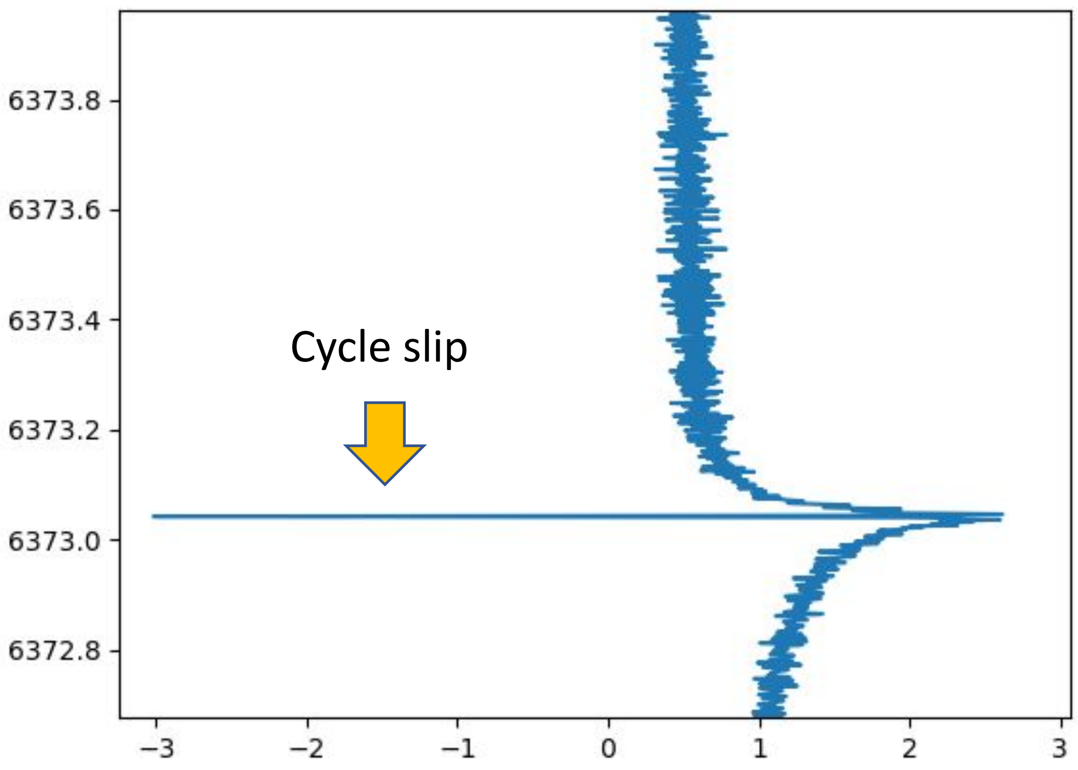




MPS simulation

- Noise (600 V/V w/ 20m smoothing)
  - Bending bias at the peak shows up when noise is applied
  - This is mainly due to noisy phase or cycle slip in the impact parameter domain

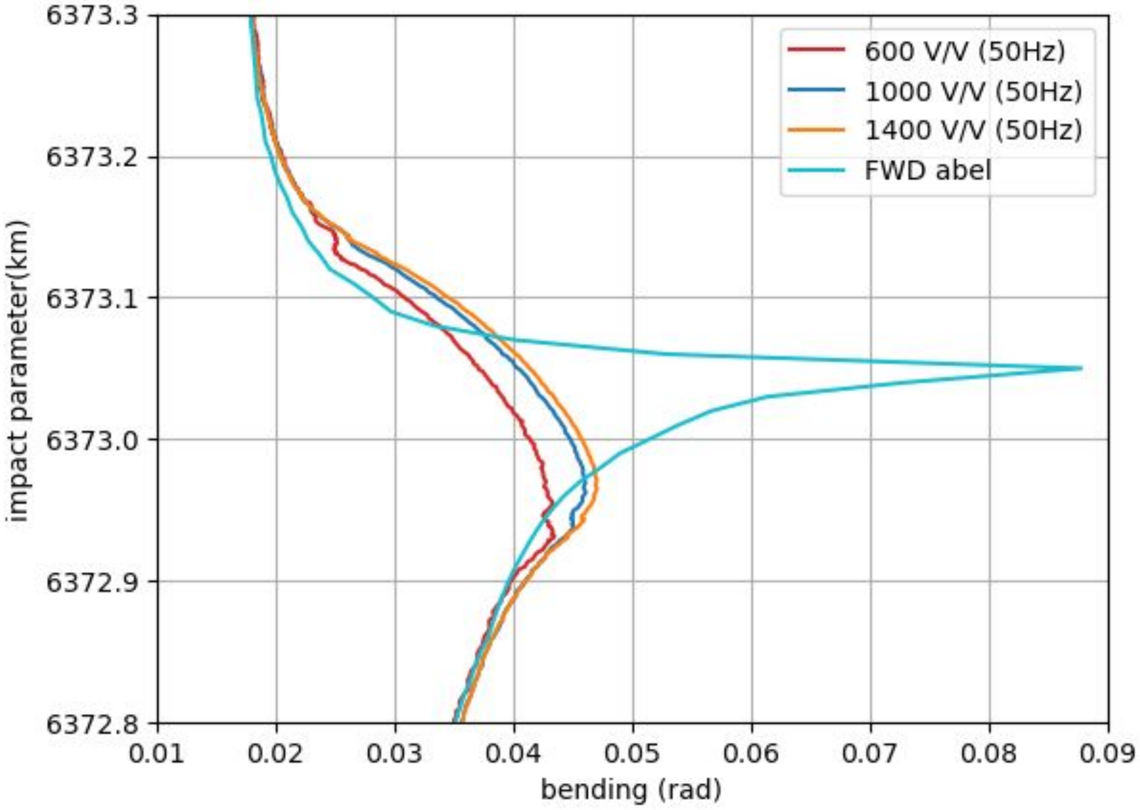


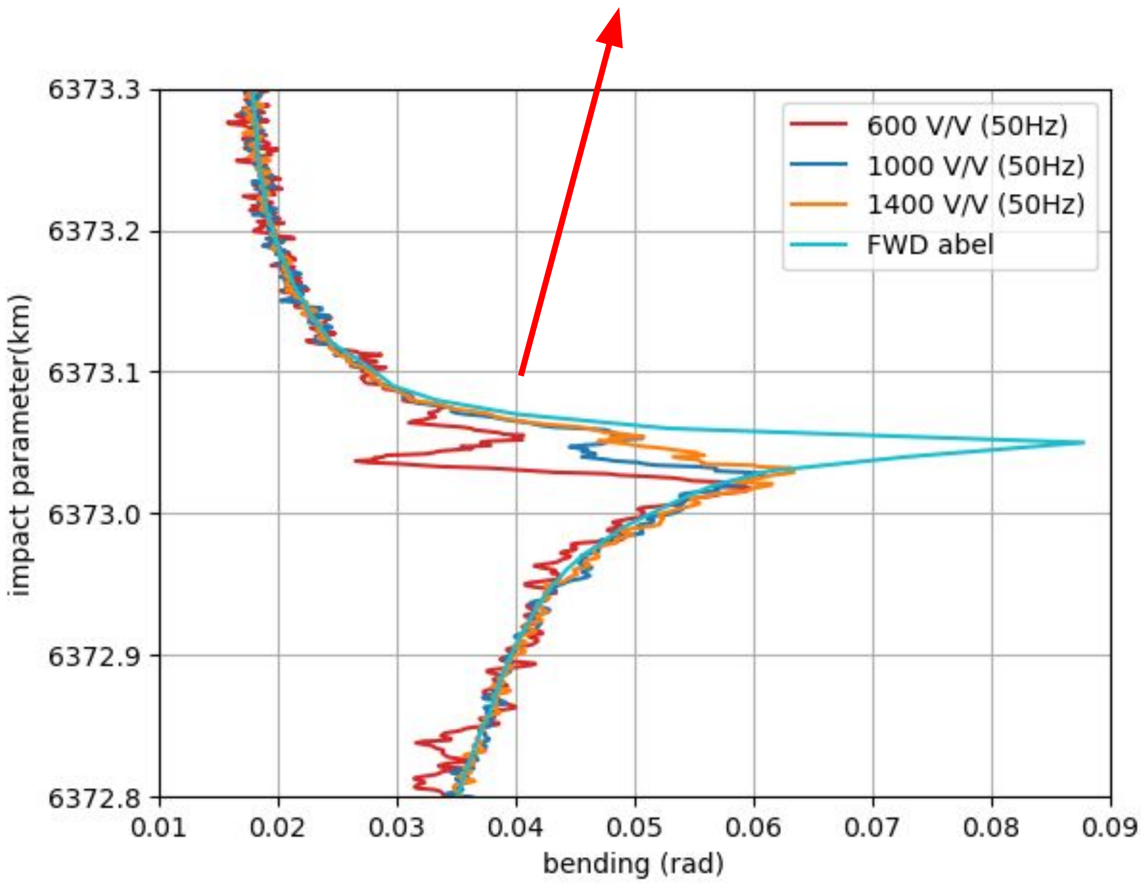


MPS simulation

- Noise - Sensitivity test (50Hz Sampling)
  - SNR scenario: 600 V/V, 1000 V/V, 1400 V/V
  - Monte Carlo analysis

The larger the SNR the smaller the bias

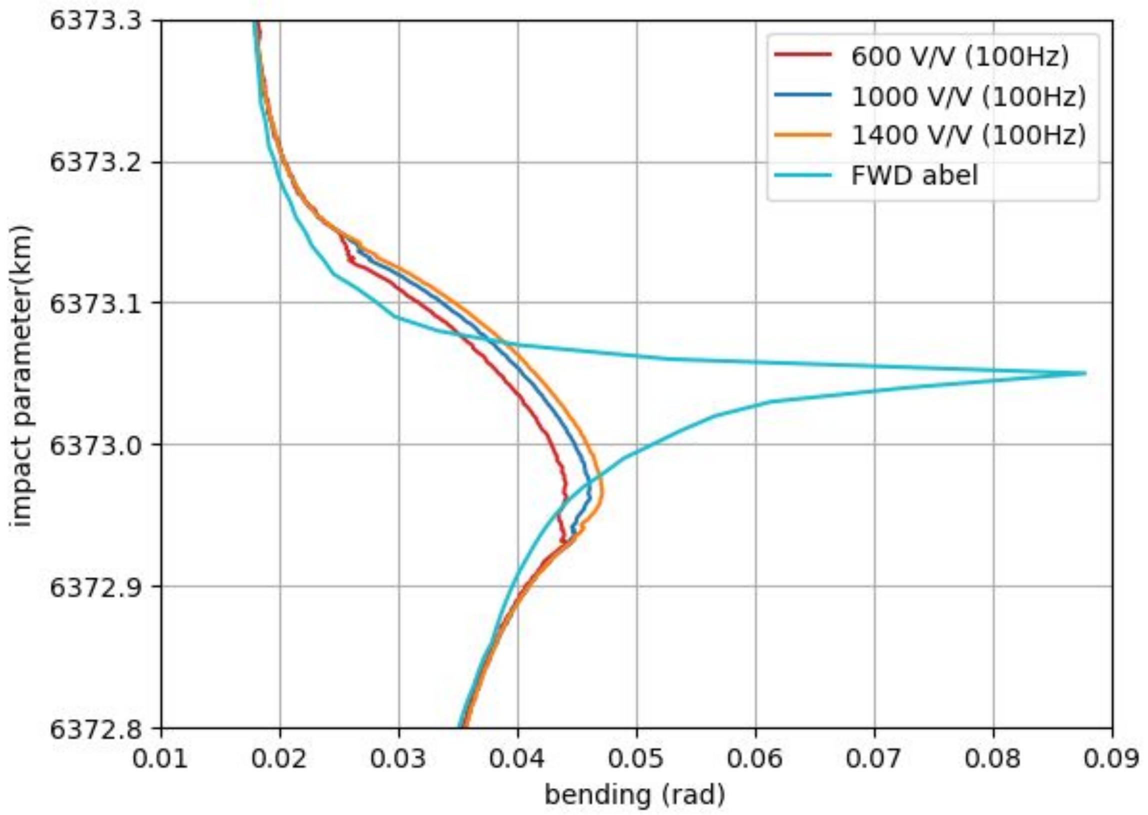


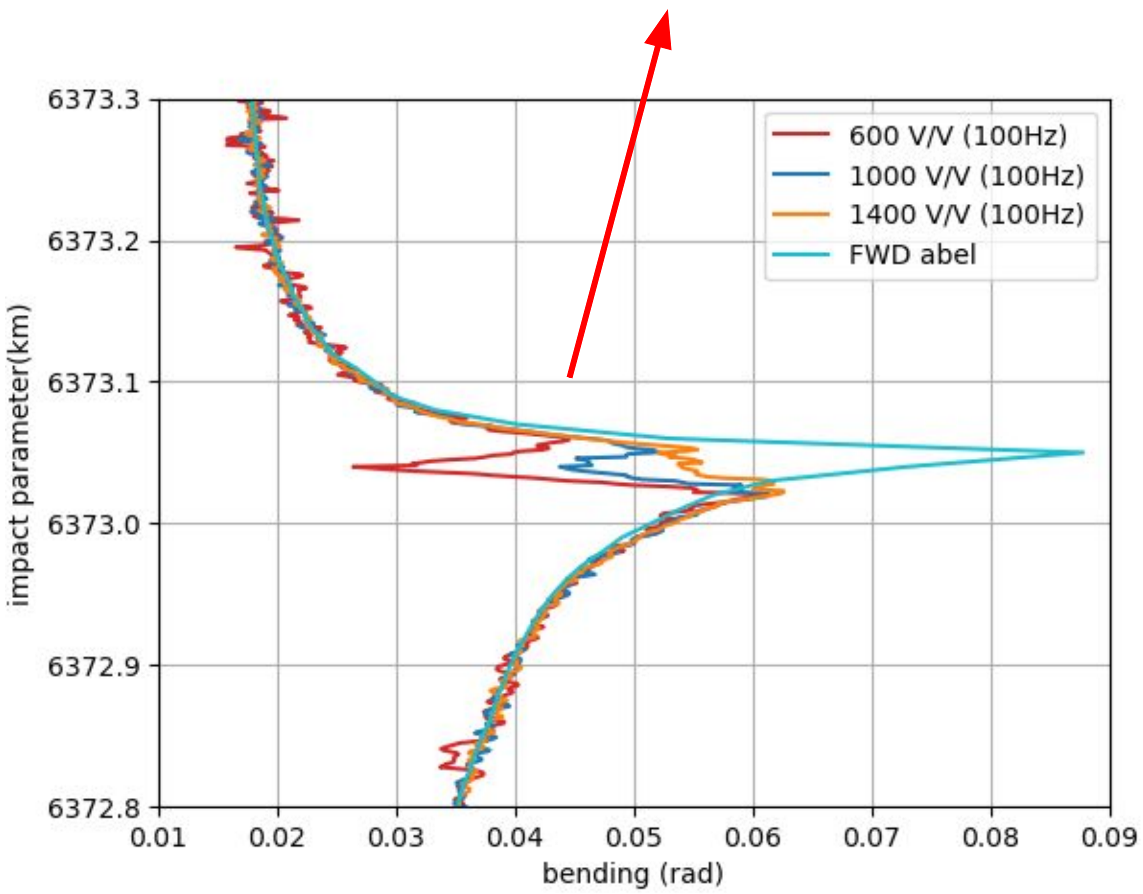


MPS simulation

- Noise - Sensitivity test (100Hz sampling)
  - SNR scenario: 600 V/V, 1000 V/V, 1400 V/V
  - Monte Carlo analysis

Larger sampling rate doesn't significantly reduce bias in all SNR scenarios

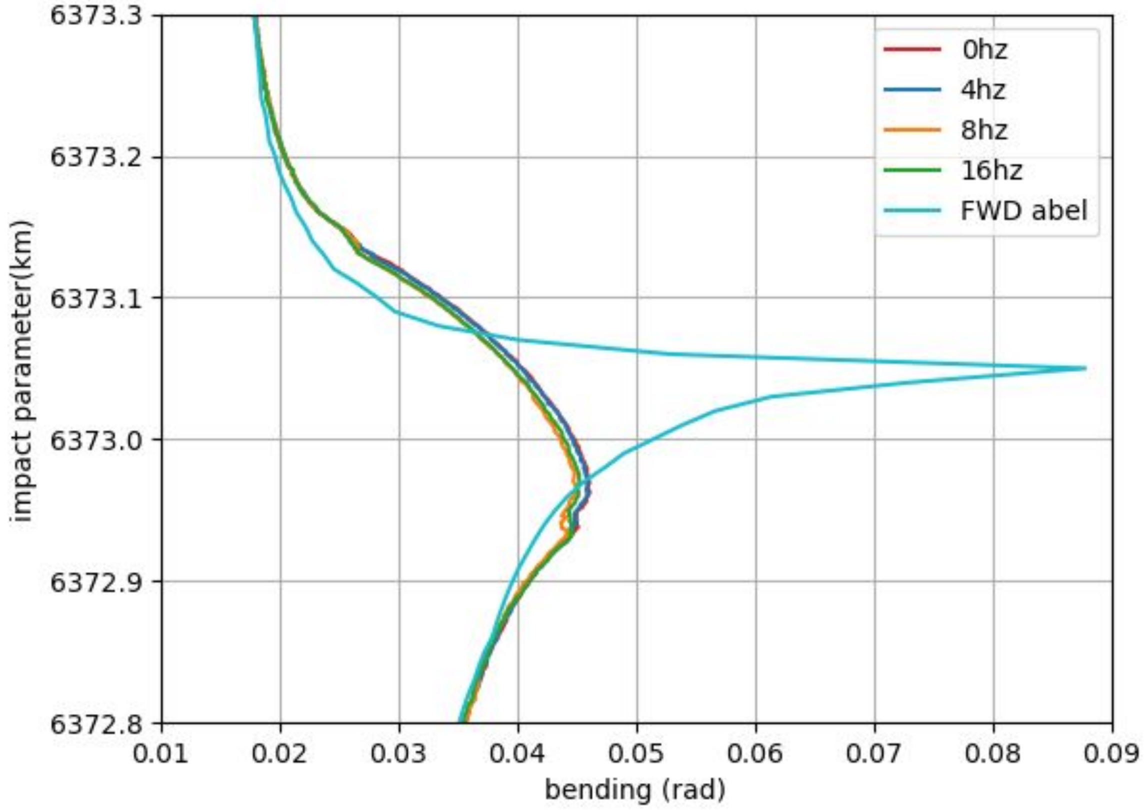


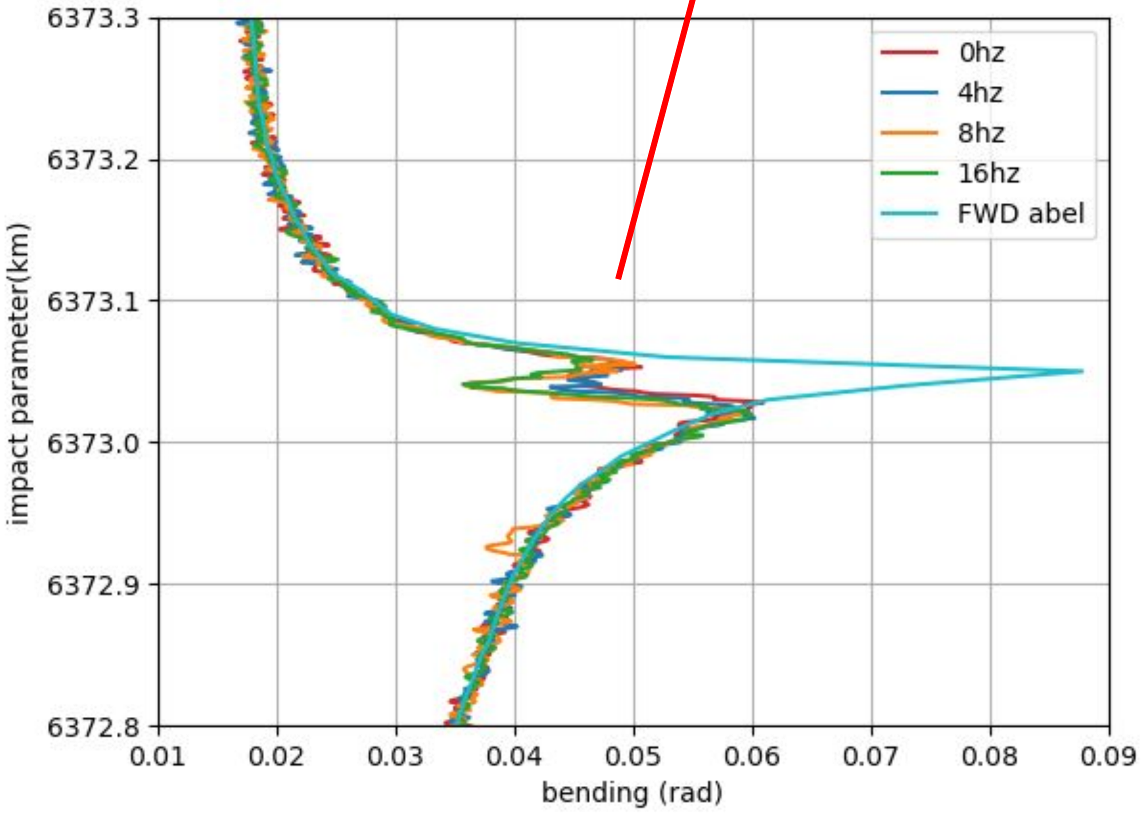


MPS simulation

- Receiver model (1000V/V and 50Hz sampling)
  - Model deviation scenario: 0Hz, 4Hz, 8Hz, 16Hz
  - Monte Carlo analysis

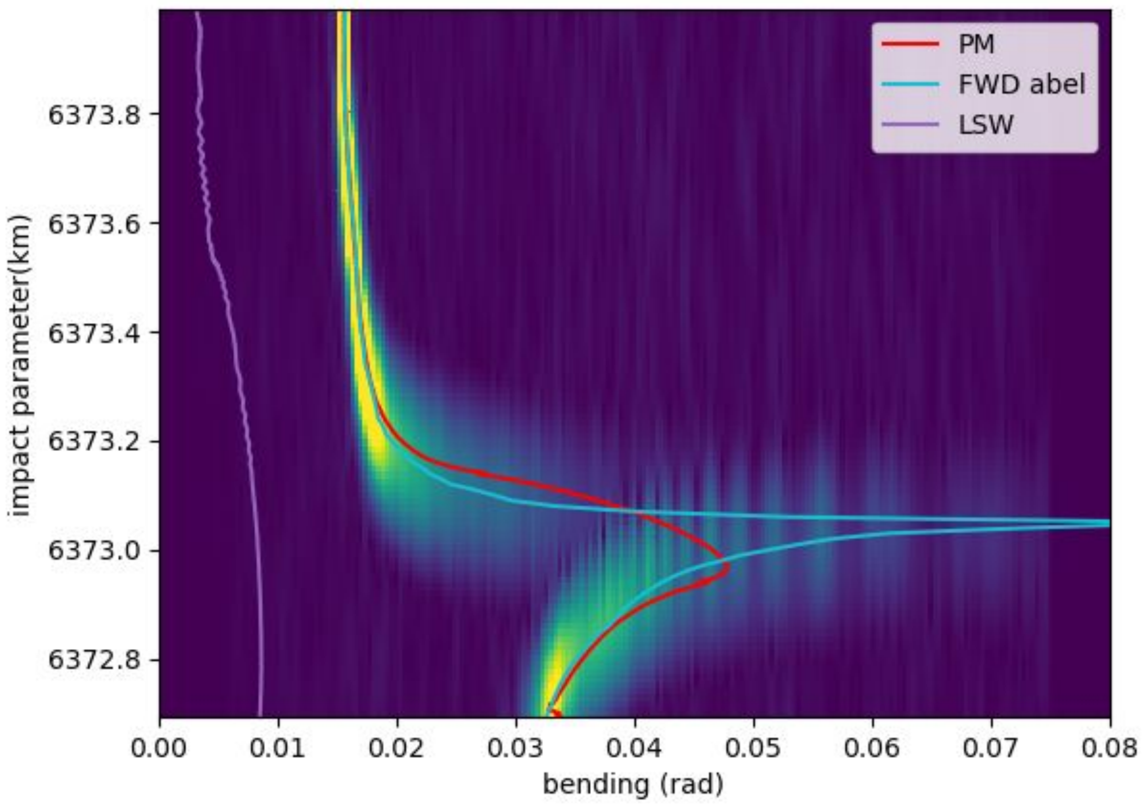
The receiver model has limited influence to the bending bias

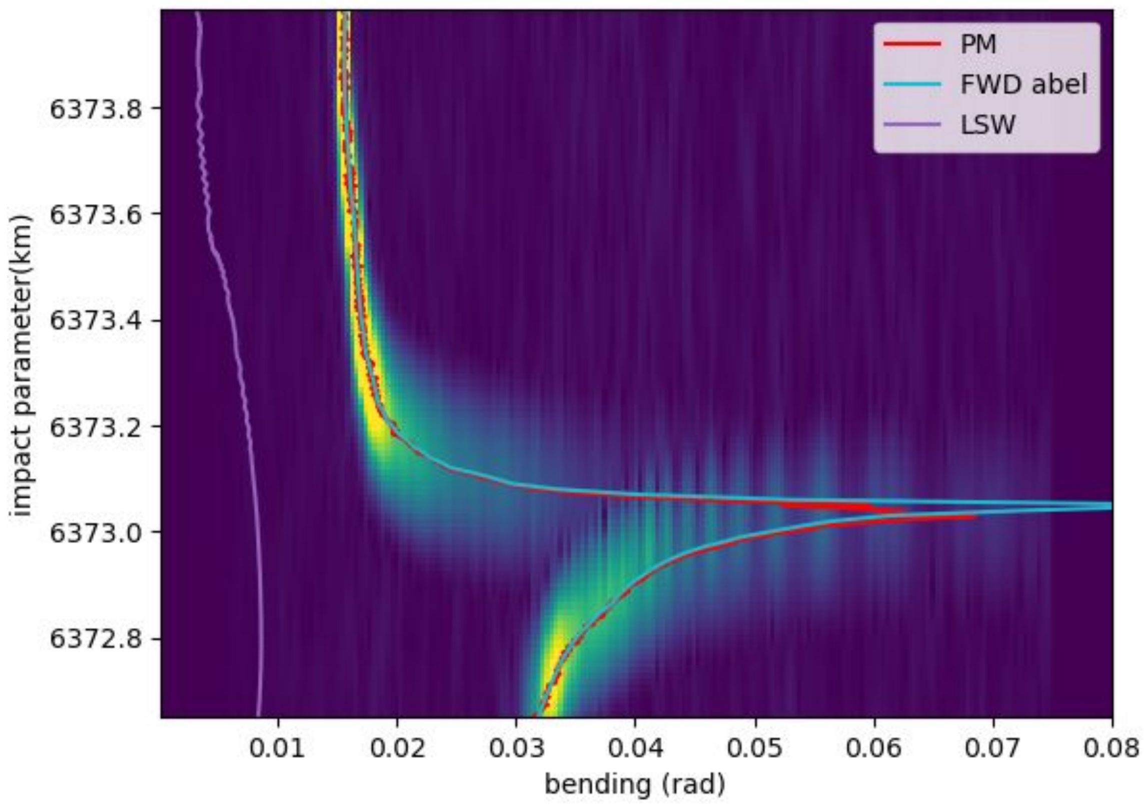




MPS simulation

- Receiver model (1000V/V and 50Hz sampling)
  - N=280*exp(-z/7)





Summary

- Negative RO bending angle bias w.r.t NCEP analysis can be found at ~1km, and is more significant in high refractivity gradient regions

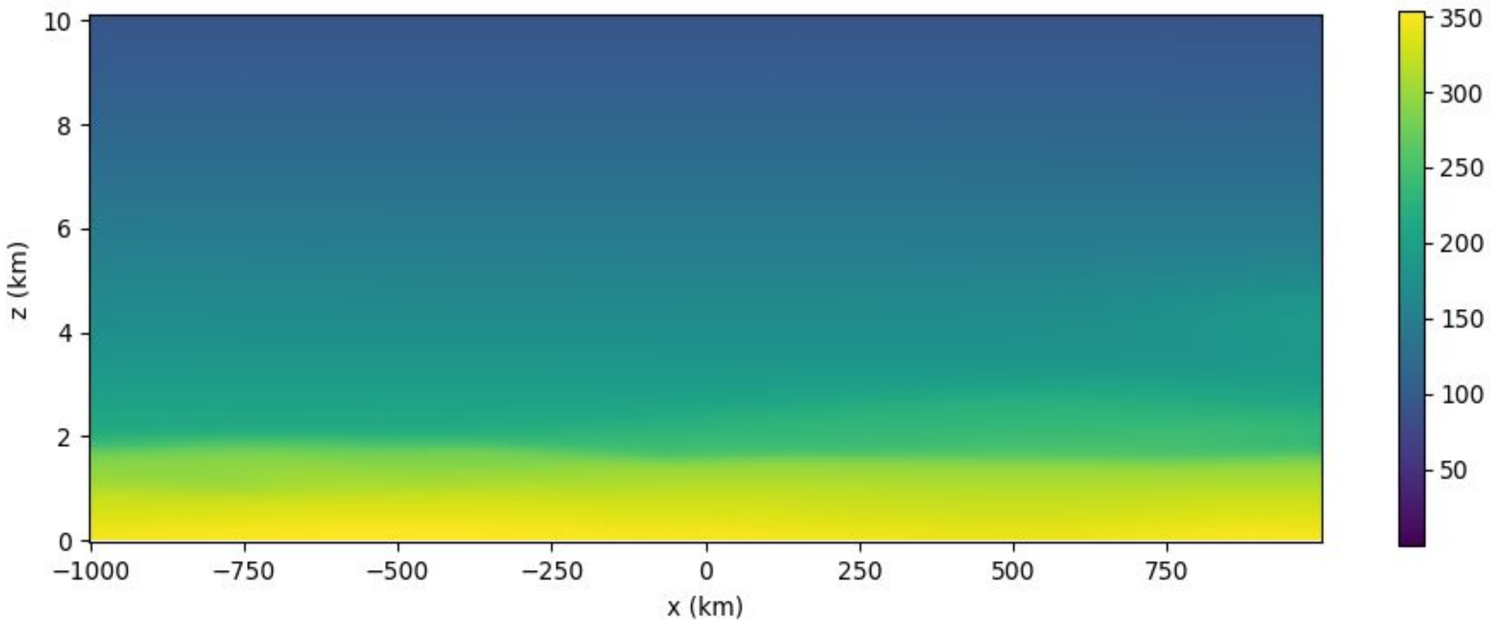
- Based on the MPS analysis the negative bias can be connected to the vertical smoothing, noise level, and the receiver model. The smoothing and noise contribute most of bending angle bias around the peak

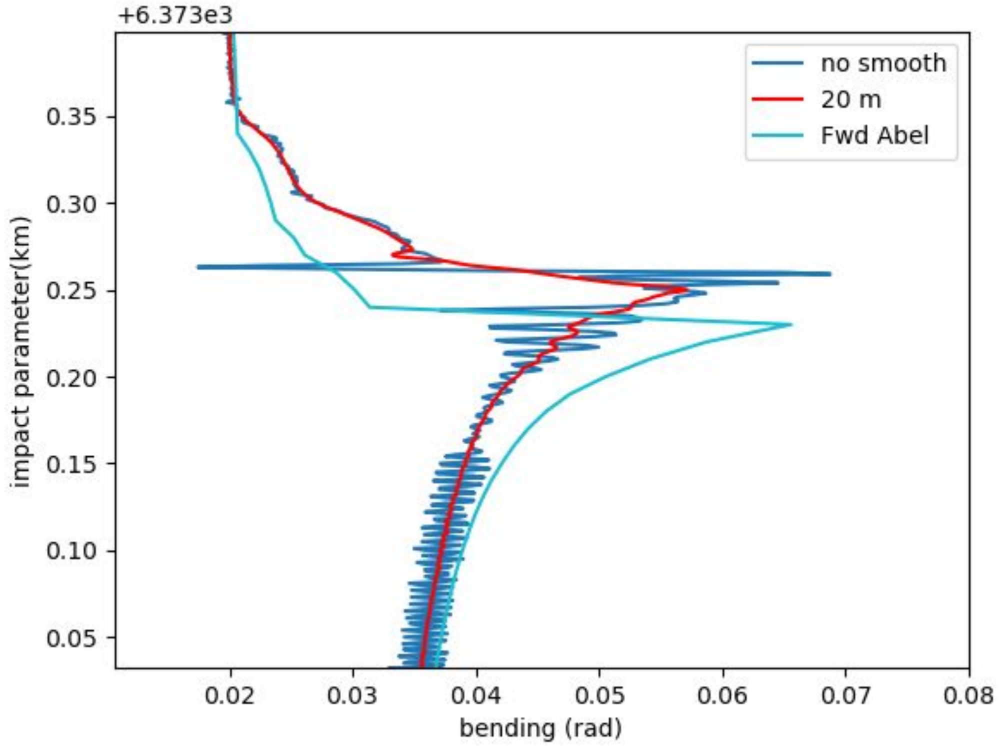
- The horizontal inhomogeneity in different scales could also influence the bending angle bias, which needs further studies.

Thank you for your attention!

MPS simulation

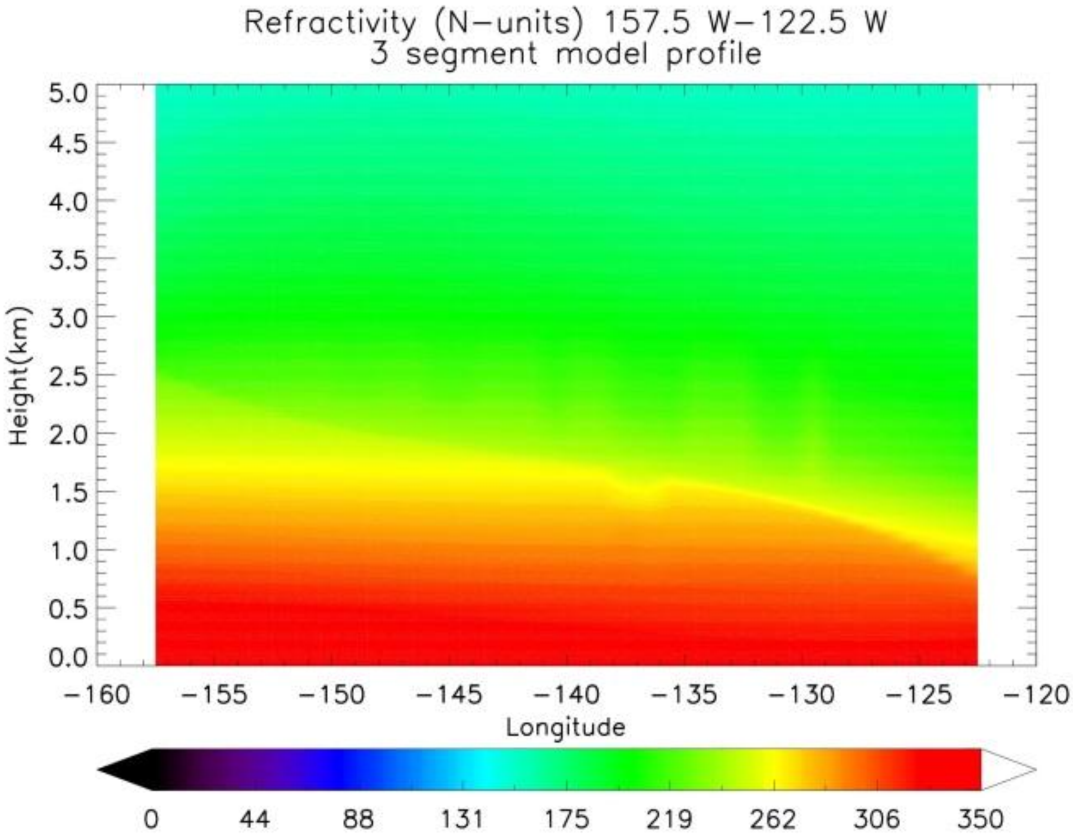
- Horizontal inhomogeneity

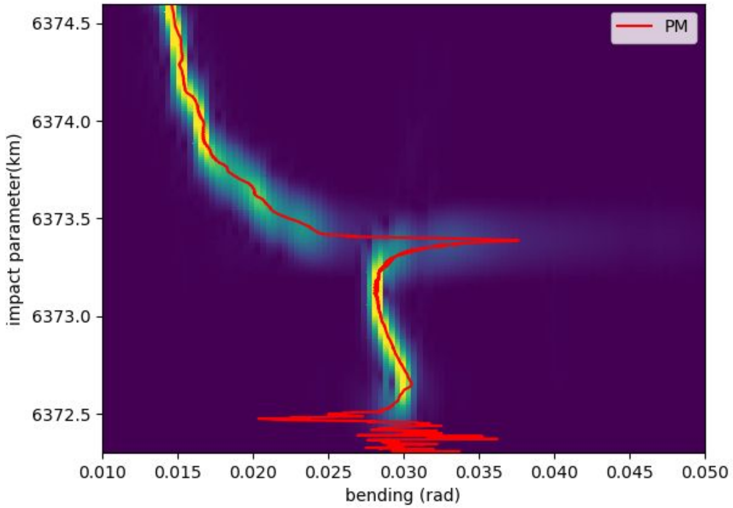




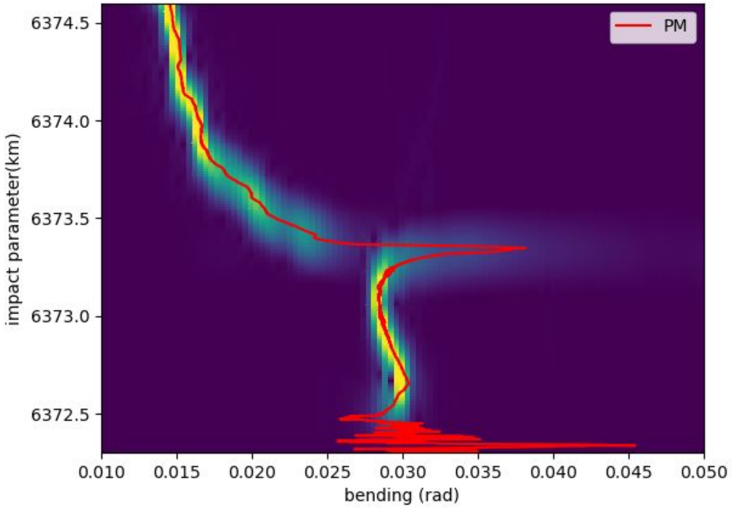
MPS simulation

- Horizontal inhomogeneity (20m smoothing) (Courtesy to Thomas Winning)





1D

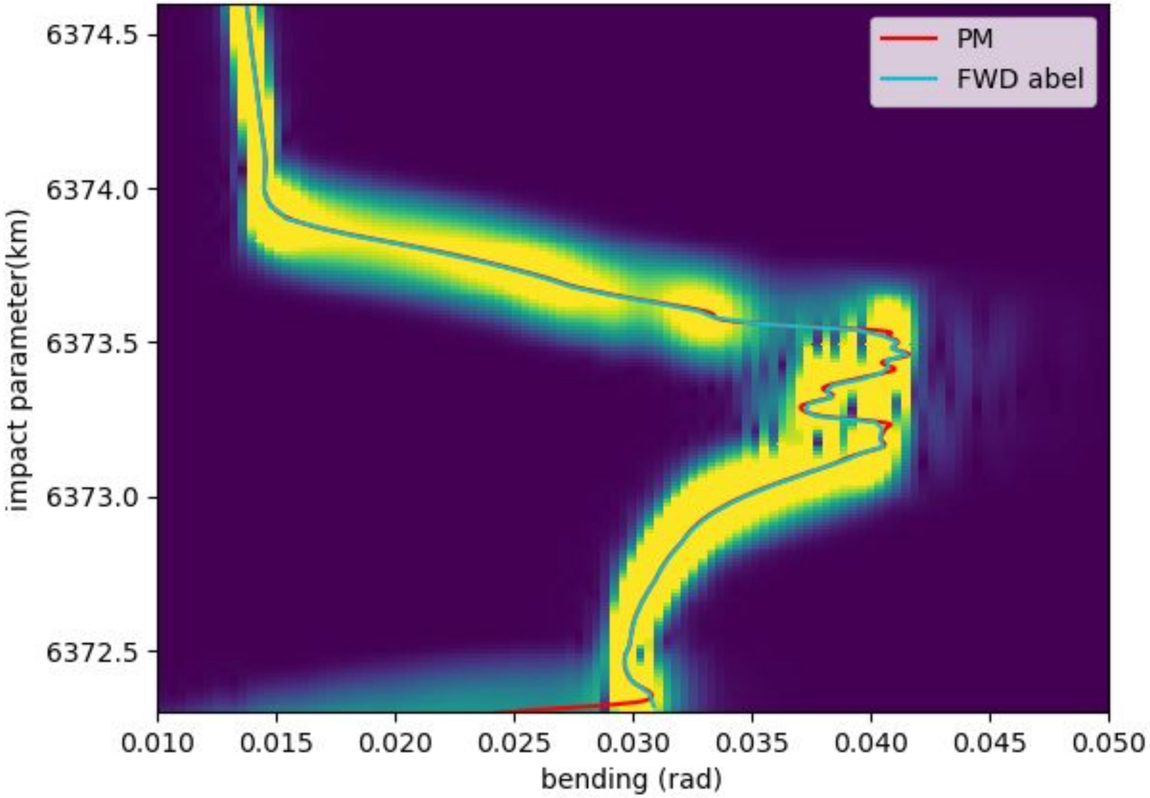


2D

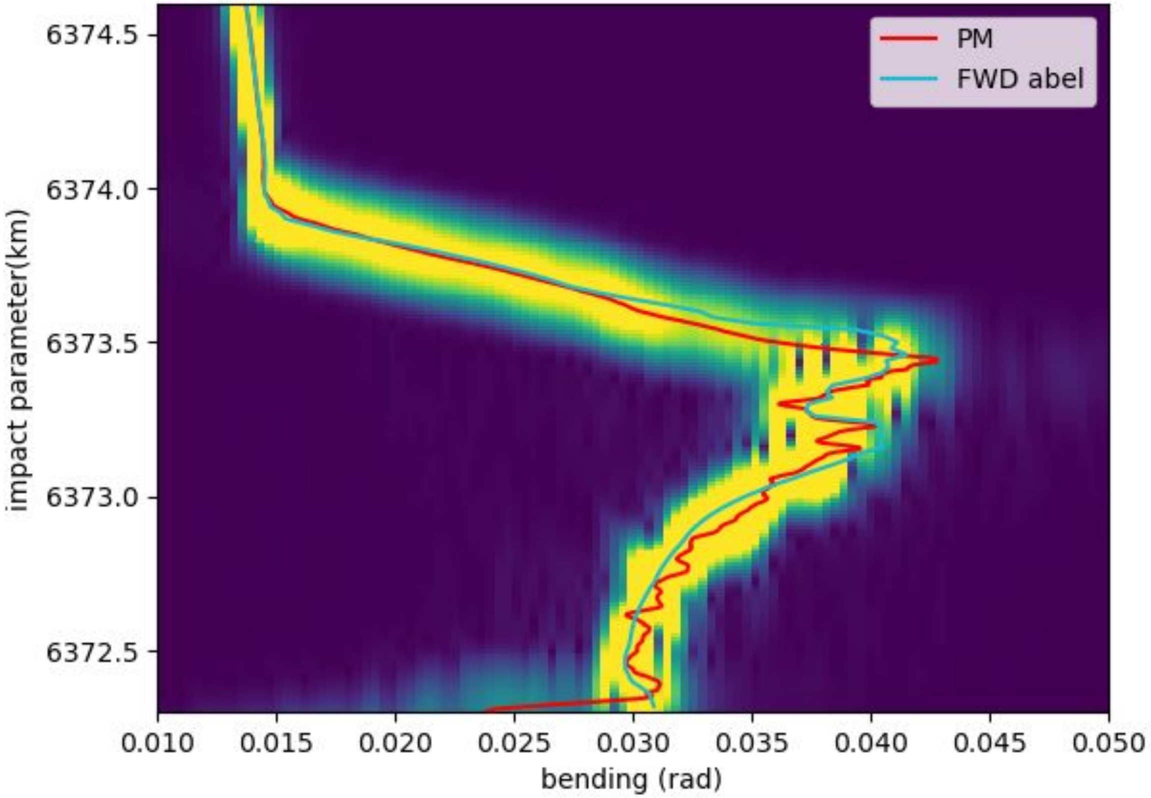
MPS simulation

- Turbulence (20m smoothing) (LES)

1D



2D



Forward Operator

- ROPP approach [Healy and Thepaut, 2006]
  - When the N decreases with height: Assuming the refractivity profile is exponential between each levels

$$\Delta\alpha = 10^{-6}\sqrt{2\pi a k_i} N_i \exp\left(k_i(x_i - a)\right)\left[erf\left(\sqrt{k_i(x-a)}\right)\right]\Big|_{x_i}^{x_{i+1}}$$

$$k_i = \frac{ln(N_i/N_{i+1})}{(x_{i+1} - x_i)} > 0$$

  - When the N increases with height: Assuming the refractivity gradient is constant between each levels

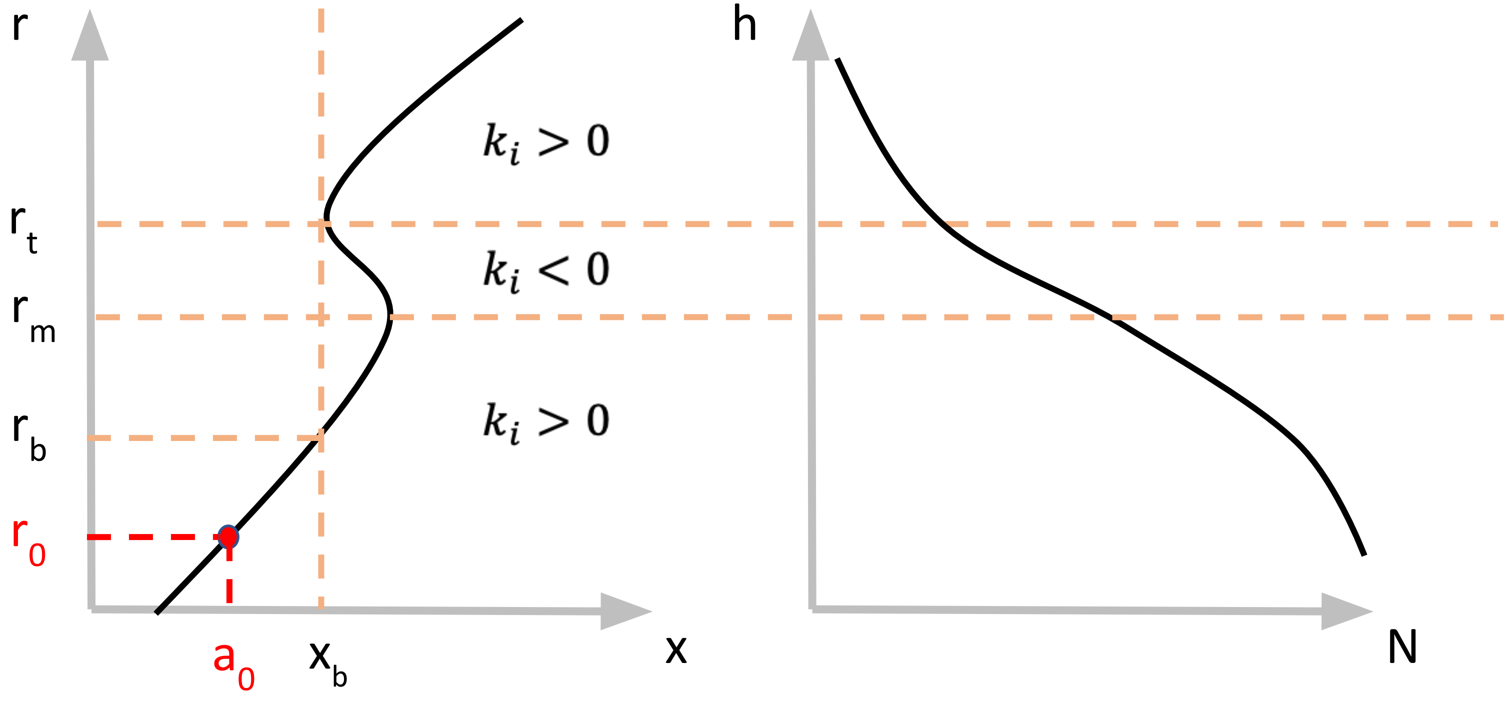
$$\Delta\alpha = -2\sqrt{2a}10^{-6}\frac{(N_{i+1} - N_i)}{(x_{i+1} - x_i)}\left[\sqrt{(x-a)}\right]\Big|_{x_i}^{x_{i+1}}$$

Forward Operator for Ducting

- Separate the Abel integral

$$\alpha(a_0) = -2a\left[\int_{r_0}^{r_m} + \int_{r_m}^{r_t} + \int_{r_t}^{\infty}\right]\frac{dr}{\sqrt{x^2 - a_0^2}}\frac{d\ln n}{dr}$$

[Ao et al, 2007] [Xie et al, 2006]



$$k_i = \frac{ln(N_i/N_{i+1})}{(x_{i+1} - x_i)}$$