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# Observing GNSS-RO grazing reflection and its applications to characterize planetary boundary layer

K.-N. Wang[1], T. K. Meehan, C. O. Ao[1], P. Vergado[1]

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

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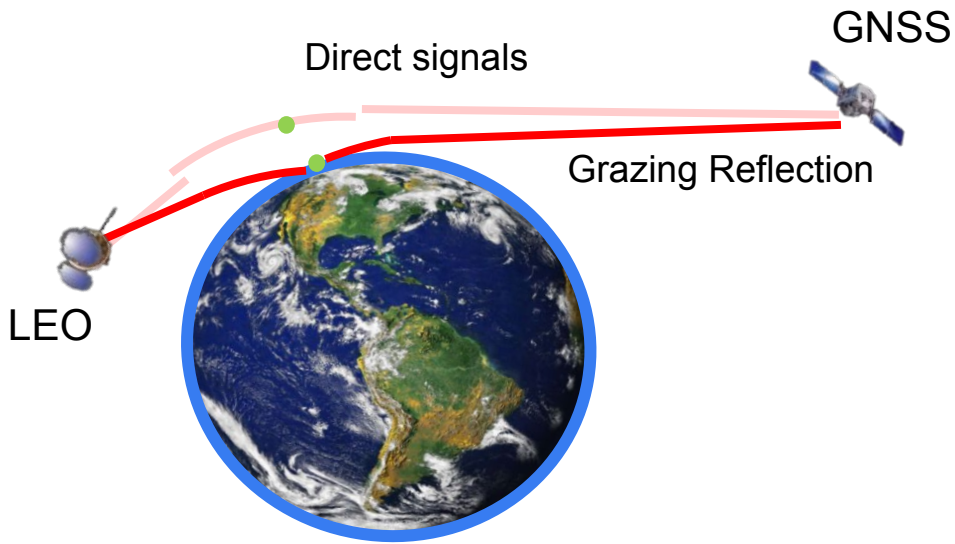
Jet Propulsion Laboratory
California Institute of Technology

# Outline

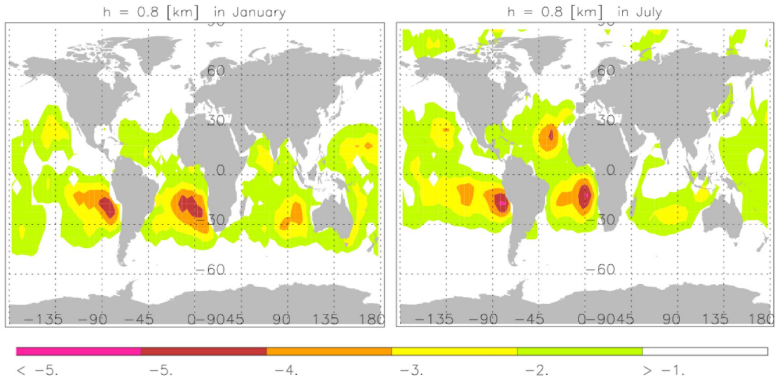
- **Motivation**
- **Ducting & Grazing reflection**
- **Grazing RO processing**
- **COSMIC-2 grazing RO**
- **OL tracking for grazing RO**
- **Conclusion**

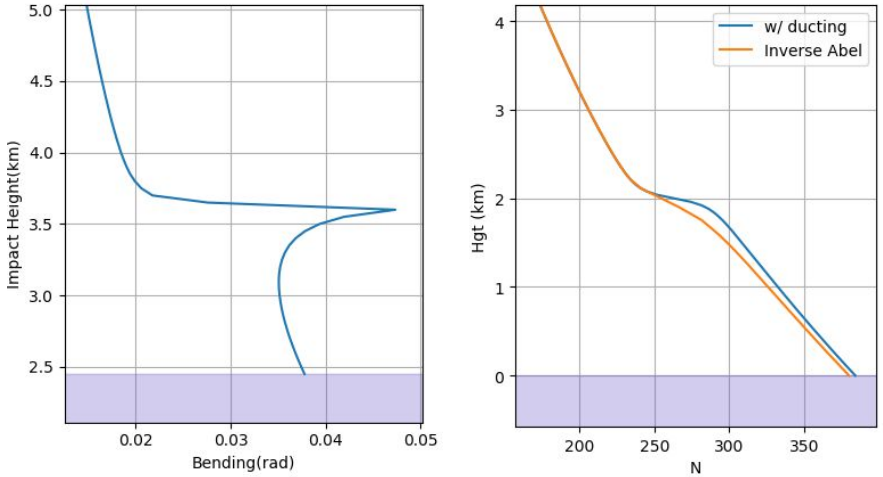


# Motivation

- **Abel inversion** assumes 1-to-1 relation between each bending angle and refractivity pair. However, this is not always the case.

- **Ducting** condition breaks the 1-to-1 relationship and causes negative bias in refractivity retrieval (*N*-bias)



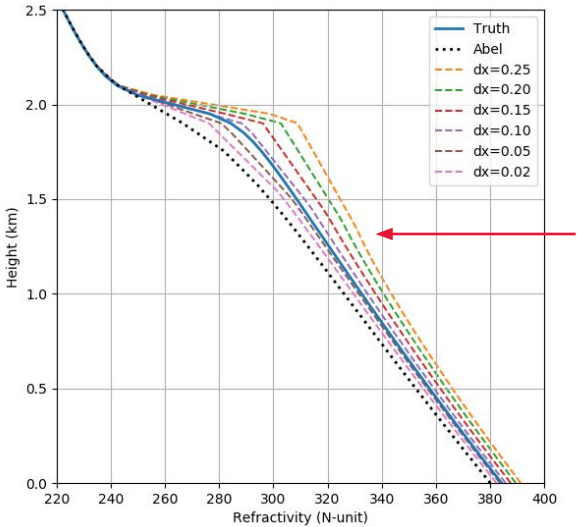

Bending Angle Profile → N Profile

**Abel Inversion**

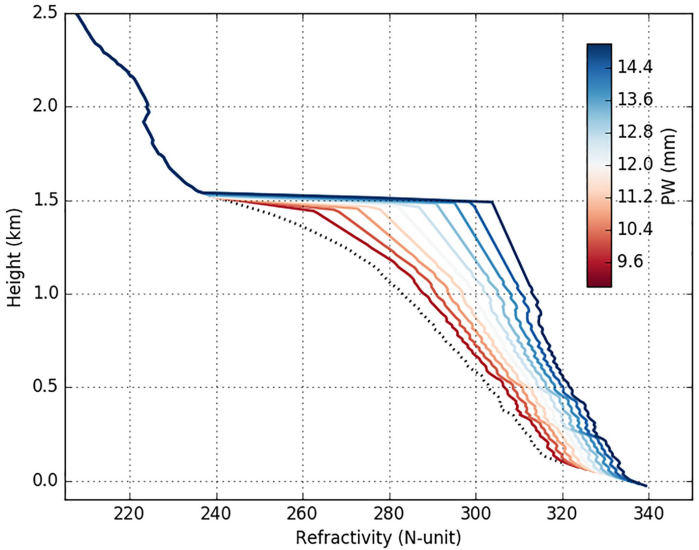
[Xie et al, GRL, Vol. 37, 2010]

# *N*-bias reduction

- **[Xie et al., 2006]** derived analytical refractivity solution family using Abel-inversed RO refractivity retrieval. However, an extra constraint is needed to identify the unbiased profile.




Refractivity profiles corresponding to the same direct bending angle profile under ducting condition

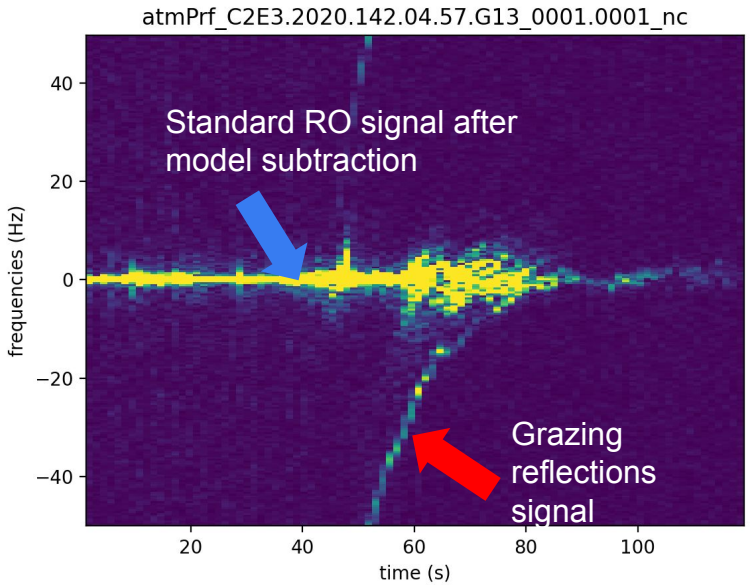


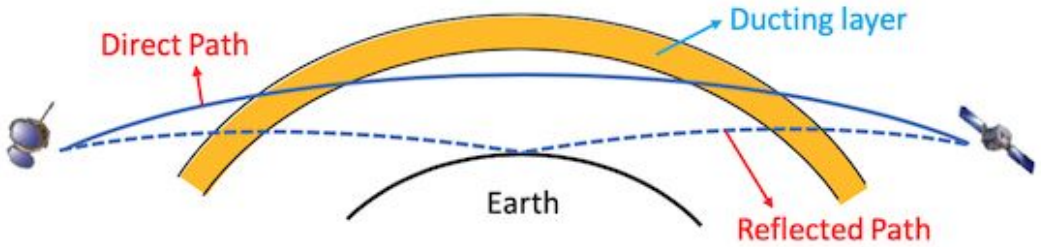

[Wang et al., 2017] proposed using PW from the collocated MWR measurements to identify the profile

# Grazing reflection

- The grazing reflection signals can be observed in the existing RO spectrum

Grazing reflections signal from COSMIC-2

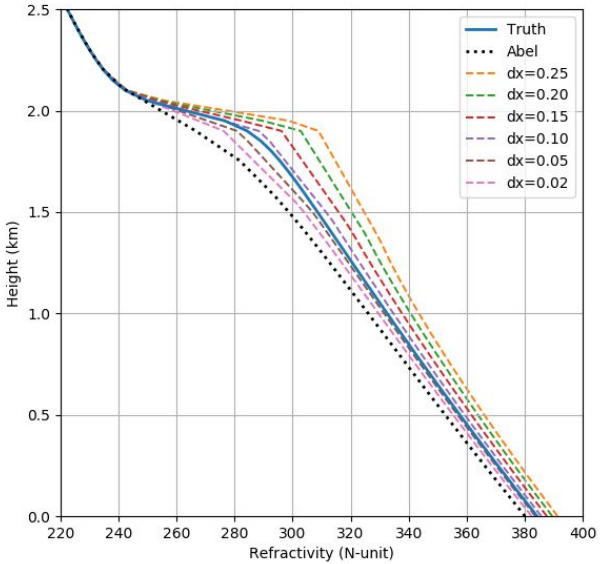


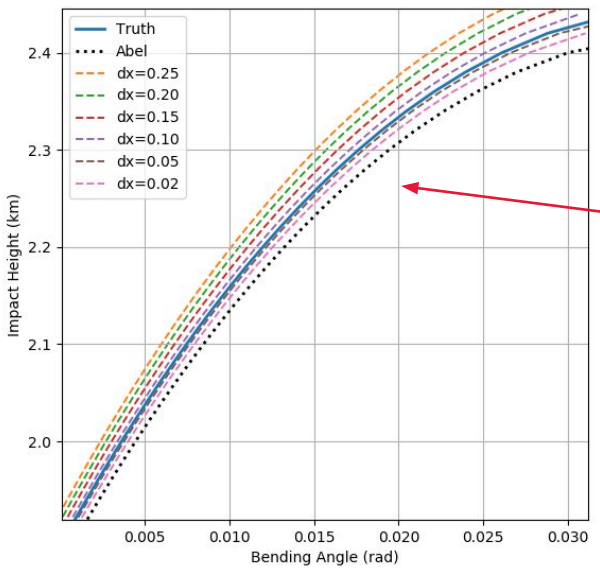




- Grazing reflection signals also contain atmospheric information which can be used as a constraint to select the unbiased profile.

# Grazing reflection

- The bending of grazing reflection is sensitive to the refractivity within PBL, even when ducting occurs [Aparicio et al., 2018].



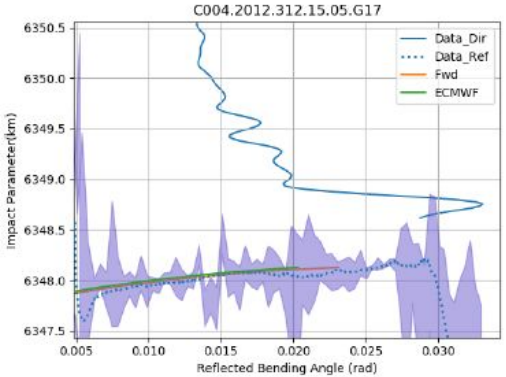



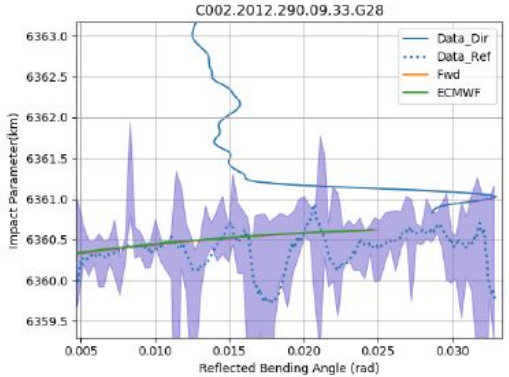

Each possible refractivity profile has its own **distinct reflected** bending angle

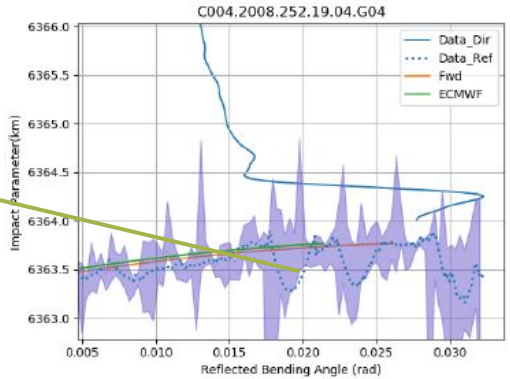
# Grazing RO retrieval

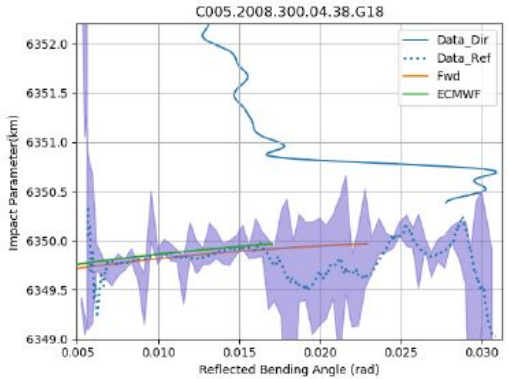
bending angle calculation

- Geometric optics
- Optimal estimation – search for the profile in the family that can best fit the observed bending angle



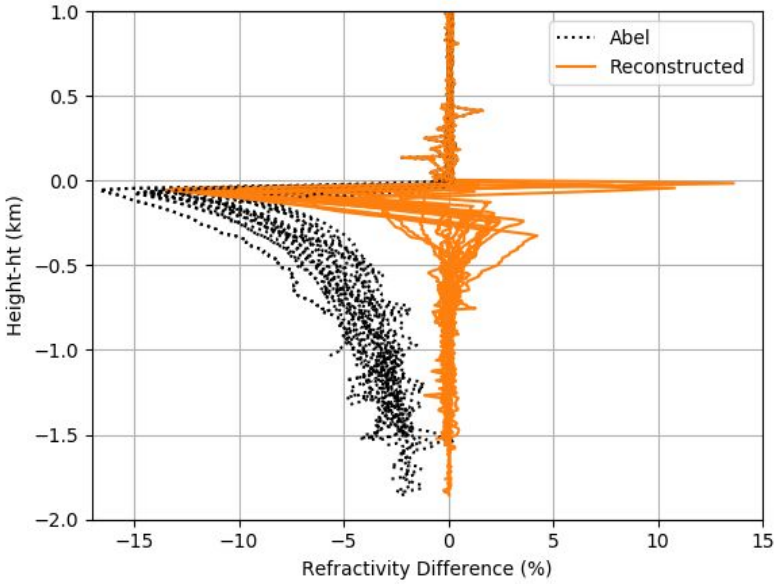



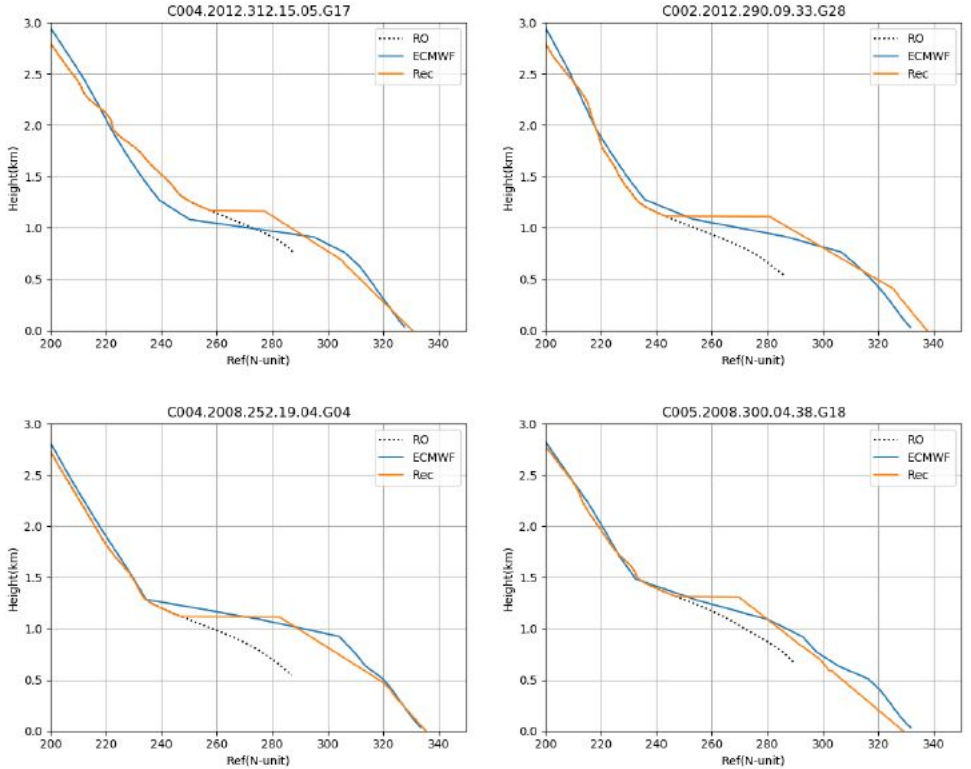




Large fluctuations due to low SNR

# Grazing RO retrieval

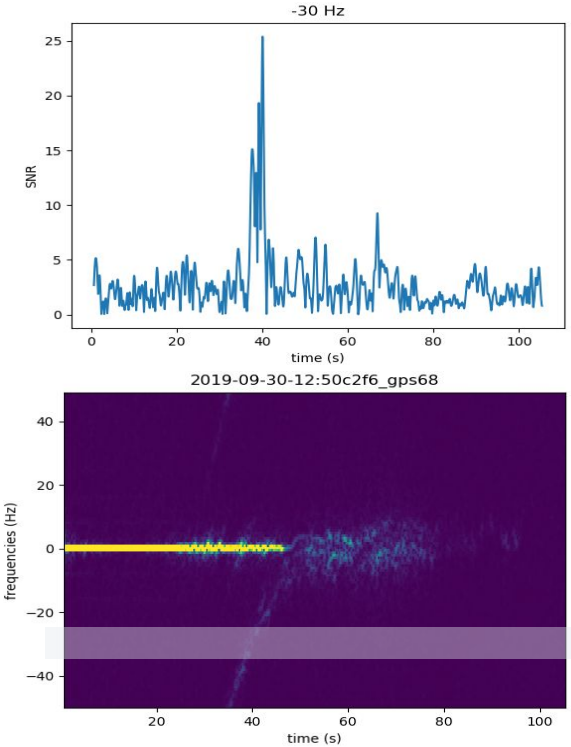
Ducting *N*-bias correction results [Wang et al., 2020]

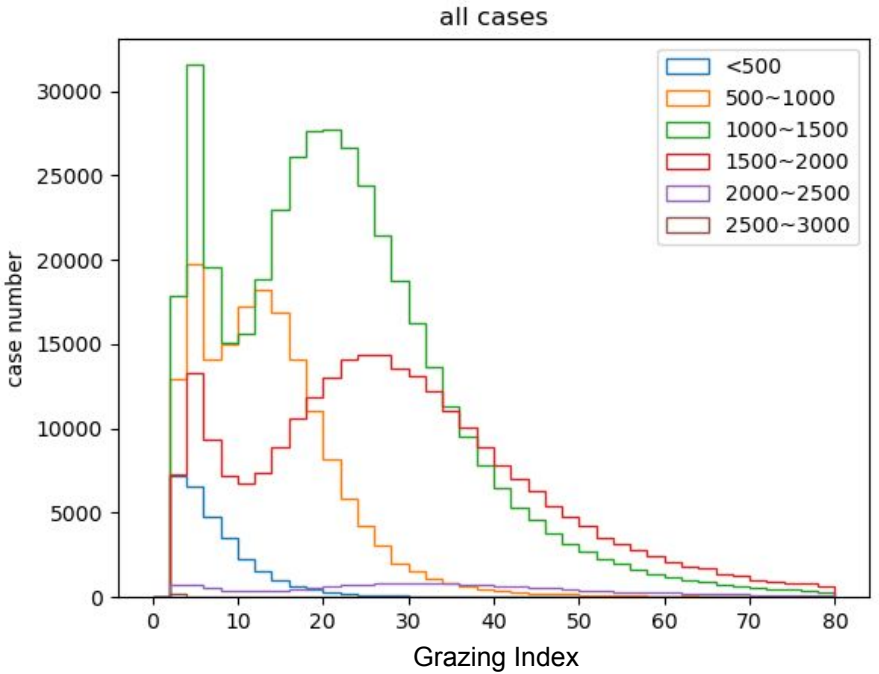


# COSMIC-2 grazing statistics

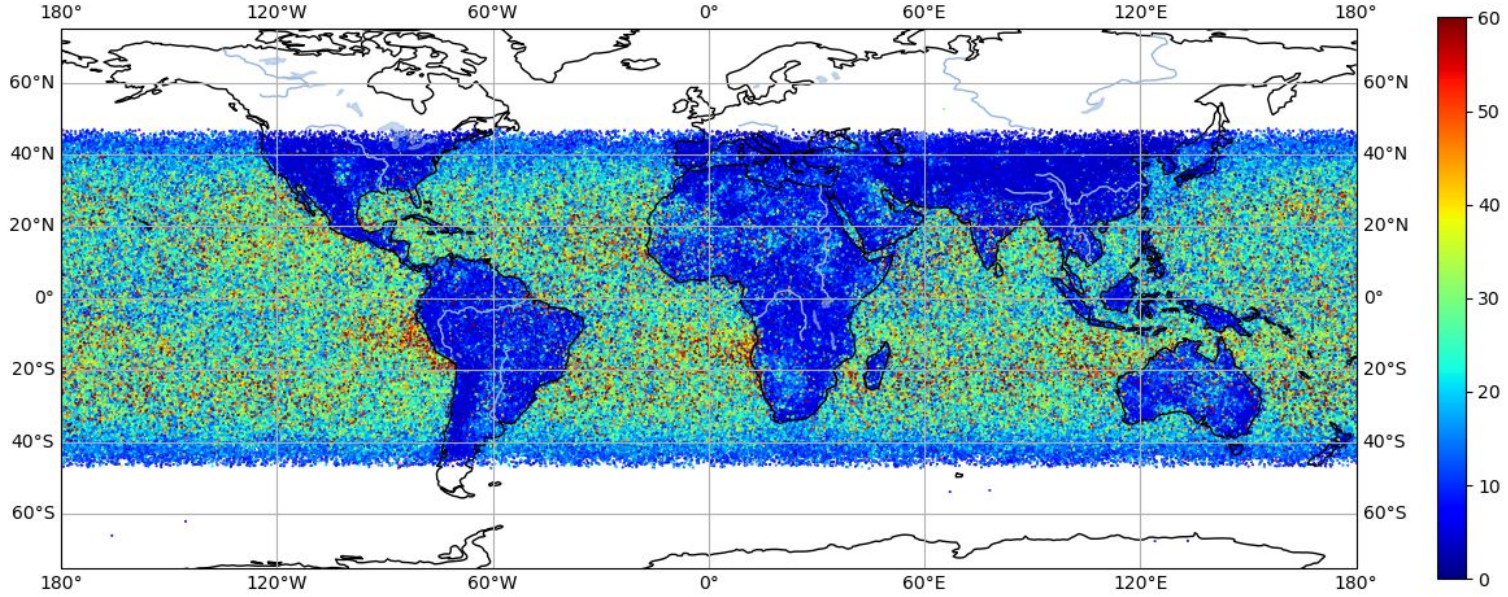
- Grazing signal detection grazing index $\left(\overline{SNR}_{p,25\sim35}\right)/SNR_N$



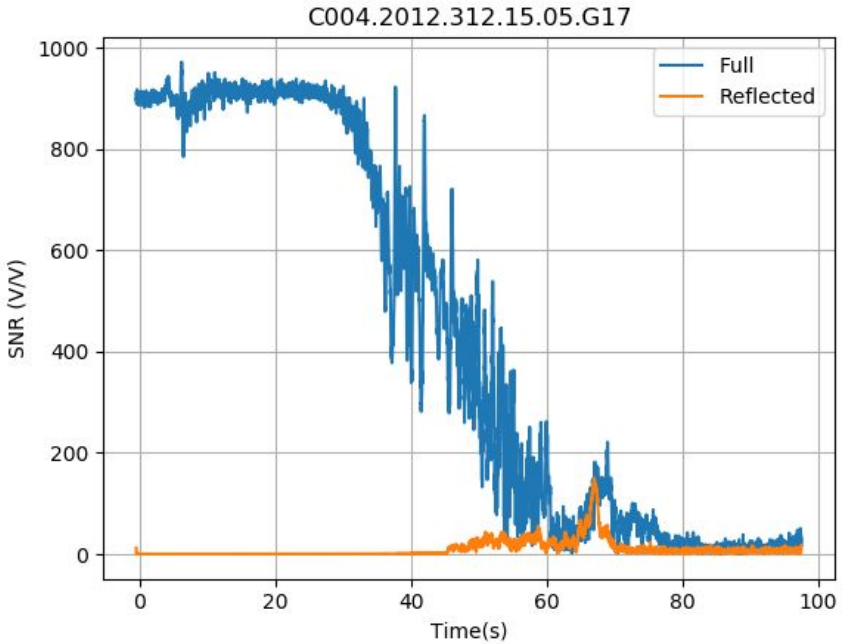
# COSMIC-2 grazing statistics

- Grazing signal strength using COSMIC-2
- Signal strength => Ocean: SST/atmospheric stability
  Land: Reflectivity/surface roughness



# Grazing reflection open-loop (OL) tracking

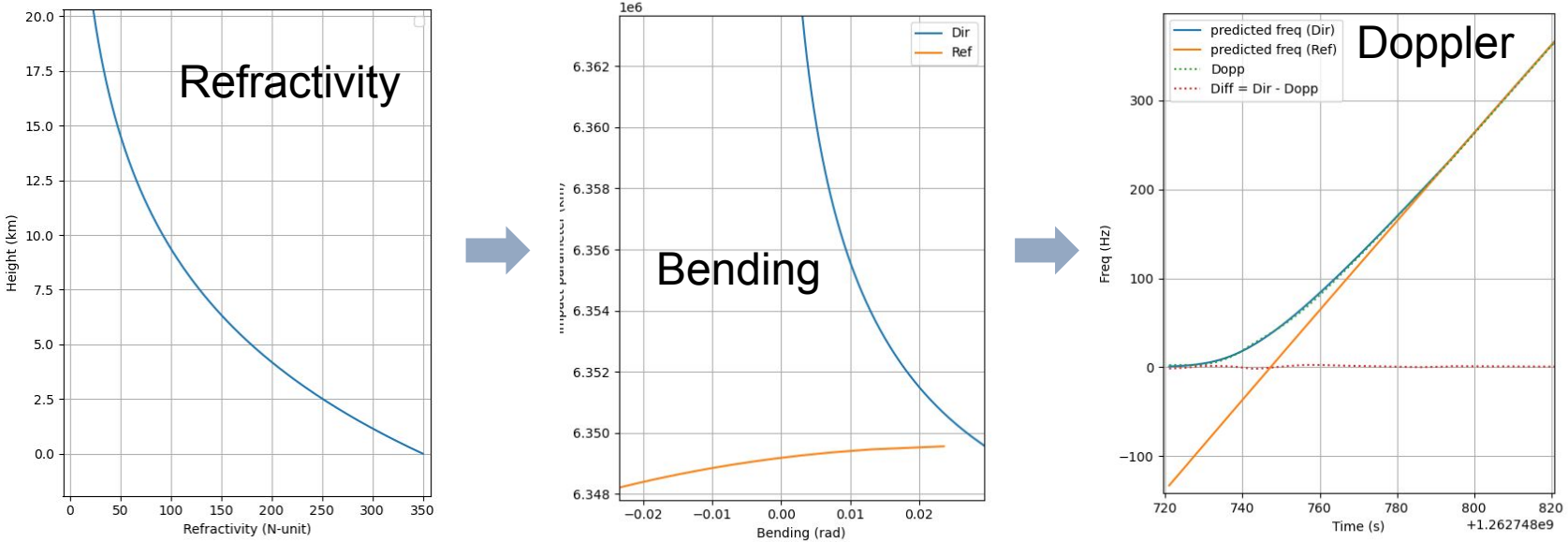
- Current grazing RO retrieval difficulties:
  - SNR is low (<100 V/V)
  - Suffer from multipath
  - Elevation angle range is low (< 2$^{o}$ )
- Can we do OL tracking on reflected signals?
  - HW: no change
  - SW: OL model needs to be calculated



# Grazing reflection open-loop (OL) tracking

## Grazing OL model

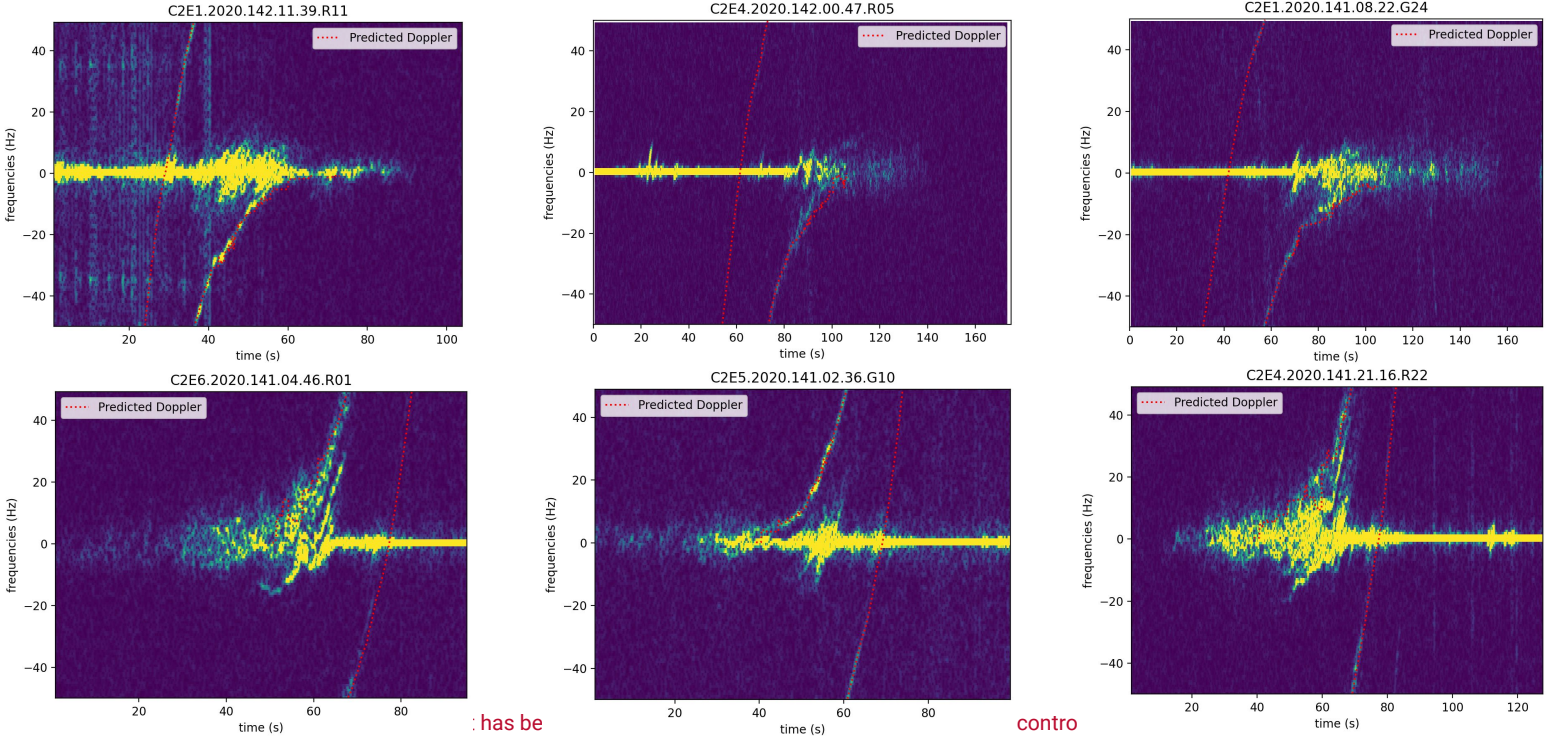
- Doppler/Range model based on the known profile



# Grazing reflection open-loop (OL) tracking

## Grazing OL model

- Validation



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# Conclusion

GNSS-RO grazing reflection

- In this research **the grazing reflection** is explored to constrain GNSS-RO observations within PBL under ducting condition
- The results show that the grazing reflection observations contain the atmospheric information needed for PBL characterization when SNR is sufficient.
- OL tracking for grazing reflection observations is developed for better quality signals, and hopefully will be tested in the near future


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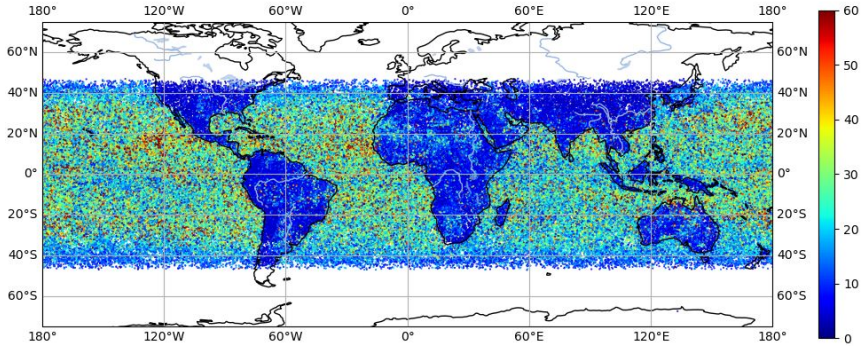
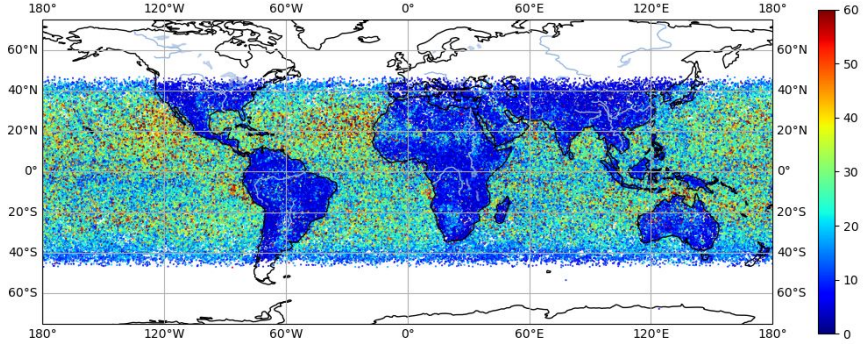
# Backup

## Statistics (seasons)

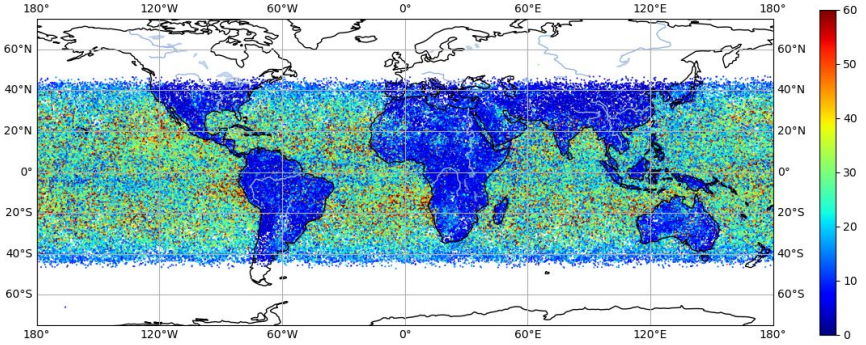
MAM



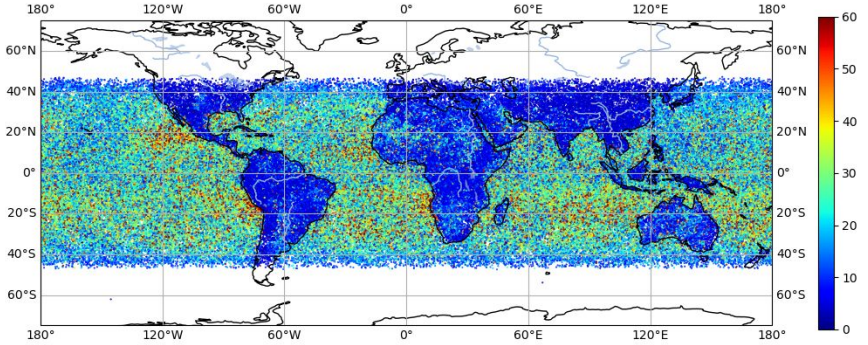

JJA




SON

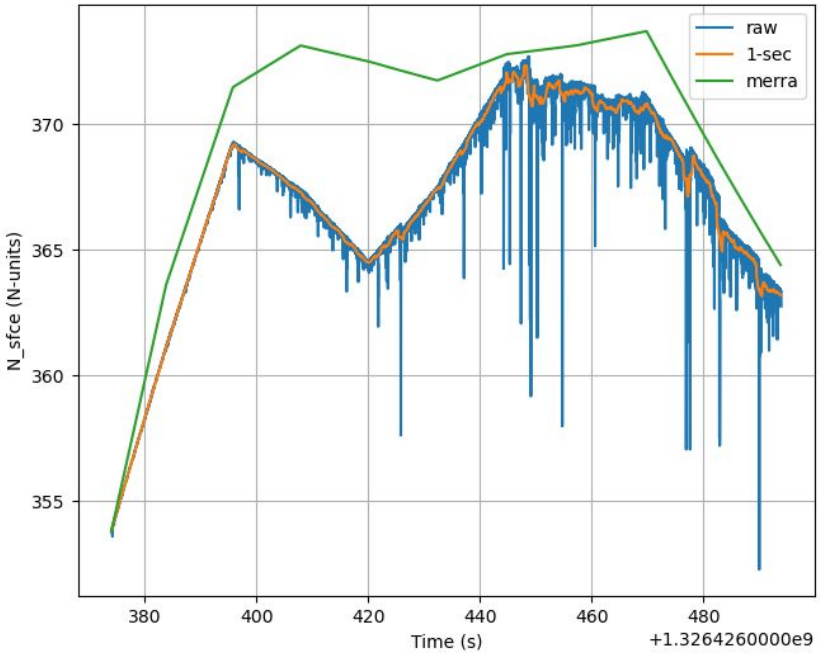


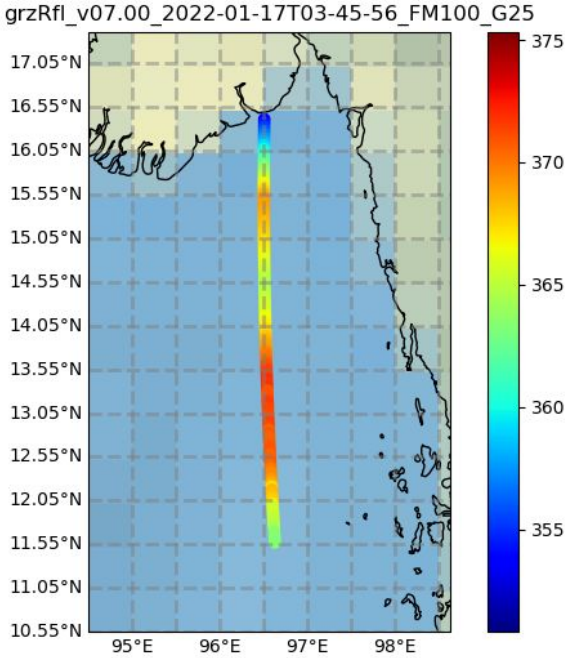

DJF



# Backup

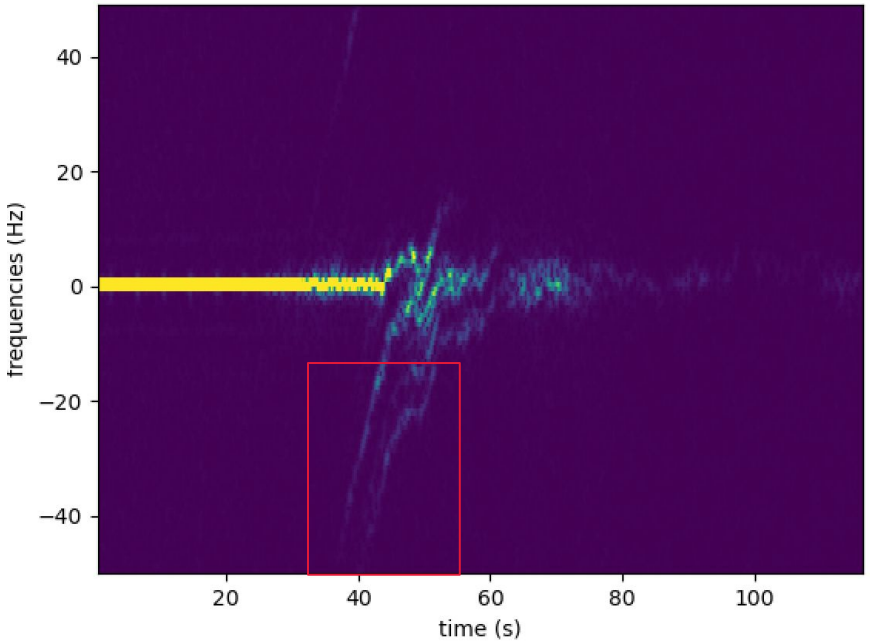
CSDA – near-surface refractivity retrieved from Spire data



# Backup

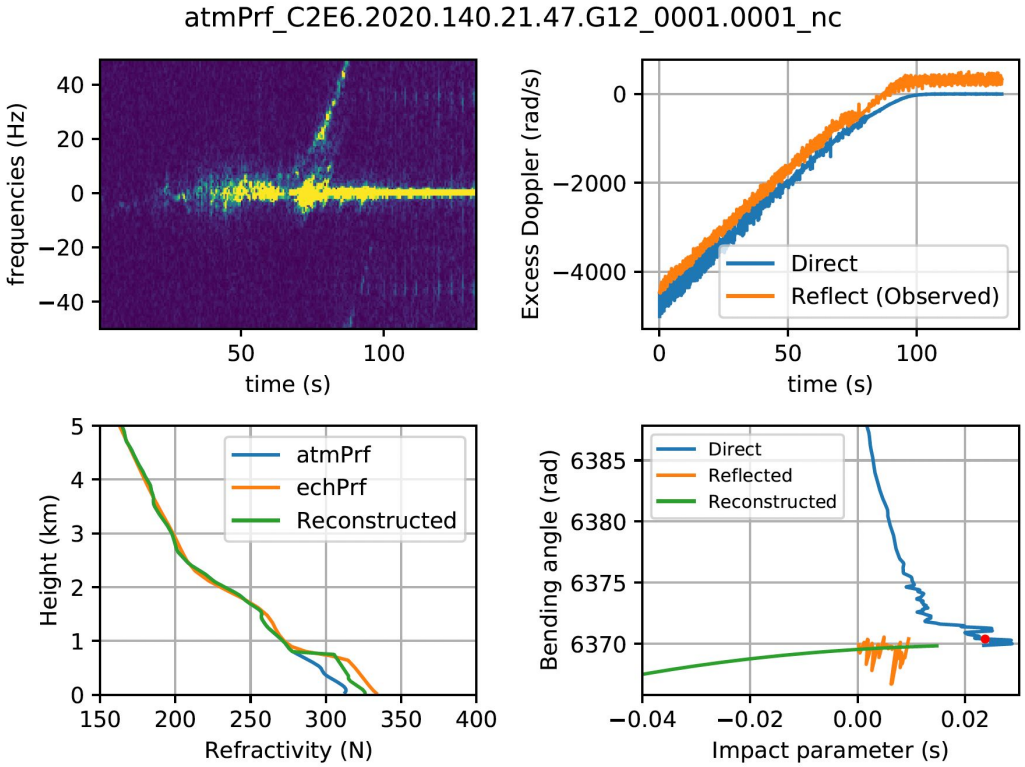
## Multipath




- Multipath from different reflection altitudes
  - Signal are received at the same time
  - Violates the RH assumption: each impact parameter shows only once during RO period.

# Backup

## COSMIC-2 single case reconstruction



# Backup

How does it connect to the atmosphere?

- Abel transform (Forward)
  - Direct signal (RO)

$$\alpha_D(a) = -2a \int_a^{\infty} \frac{1}{n(x)} \frac{dn(x)}{dx} \frac{dx}{\sqrt{x^2 - a^2}}$$

  - Reflected signal (Grazing reflection) [*Aparicio et al, 2018*]

$$\alpha_R(a) = -2a \int_{a_s}^{\infty} \frac{1}{n(x)} \frac{dn(x)}{dx} \frac{dx}{\sqrt{x^2 - a^2}} - 2cos^{-1}\left(\frac{a}{n_s r_s}\right)$$

Near surface refractivity

Refraction

Reflection

# Backup

## GNSS-RO **grazing reflections**

- Why do we care about grazing reflections?
  - Scientifically – Sensitive to the surface properties, near surface atm., and PBL
  - Technically – No HW change is needed from RO!

| | Deep Grazing | Grazing | GNSS-R |
|---|---|---|---|
| Elevation | < 2º (RHCP) | 5º~20º (RHCP) | > 40º (LHCP) |
| Obs. | Coherent phase | Coherent phase | DDM |
| Sen. - rough | Low | Medium | High |
| Sen. - Atmos. | High | Medium | Low |
| Applications | PBL/low Tropos. | Ice altimetry | Wind, Soil moisture |
| Mission | *COSMIC etc.* | *Spire* | *CYGNSS, HydroGNSS* |

# Backup

- **Ducting** condition breaks the 1-to-1 relationship and causes multiple refractivity solutions corresponding to the same measured bending angle profile