GNSS-RO Deep Refraction Signals from Moist Atmospheric Boundary Layer

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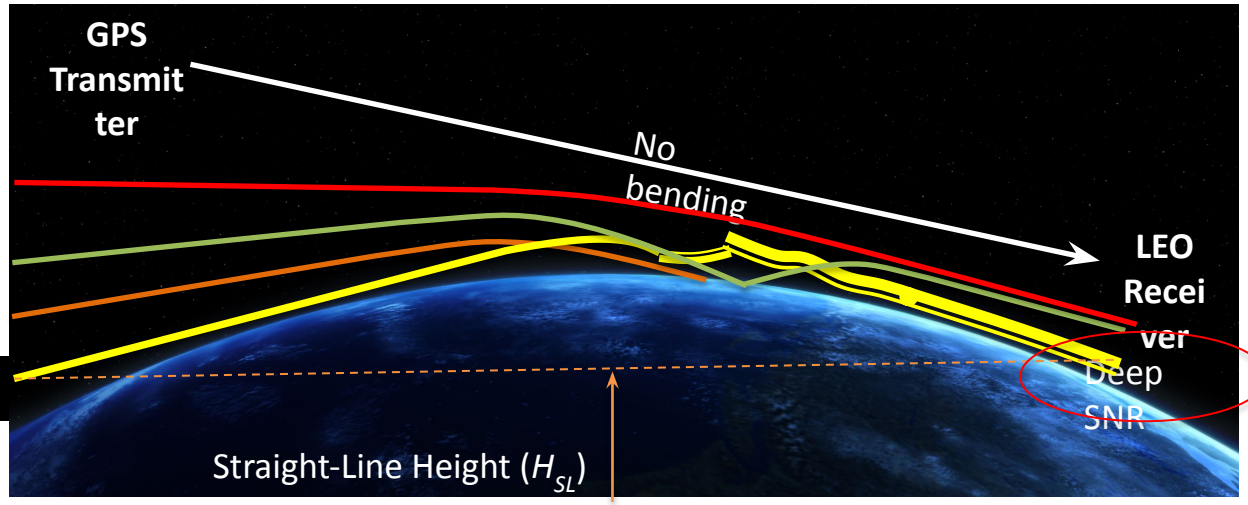
Atmospheric Refraction, Ducting and Diffraction in RO



Water Vapor Bending

Grazing Reflection

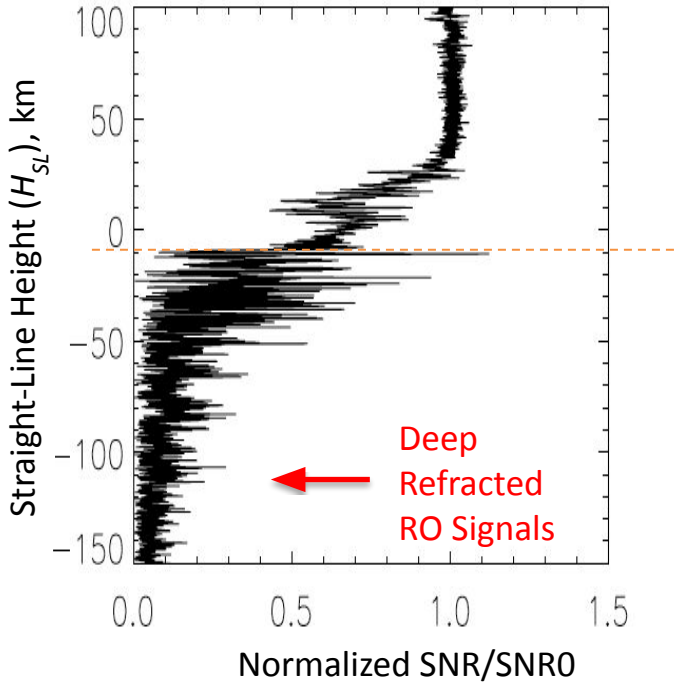
Super Refraction

Ducting/Diffraction

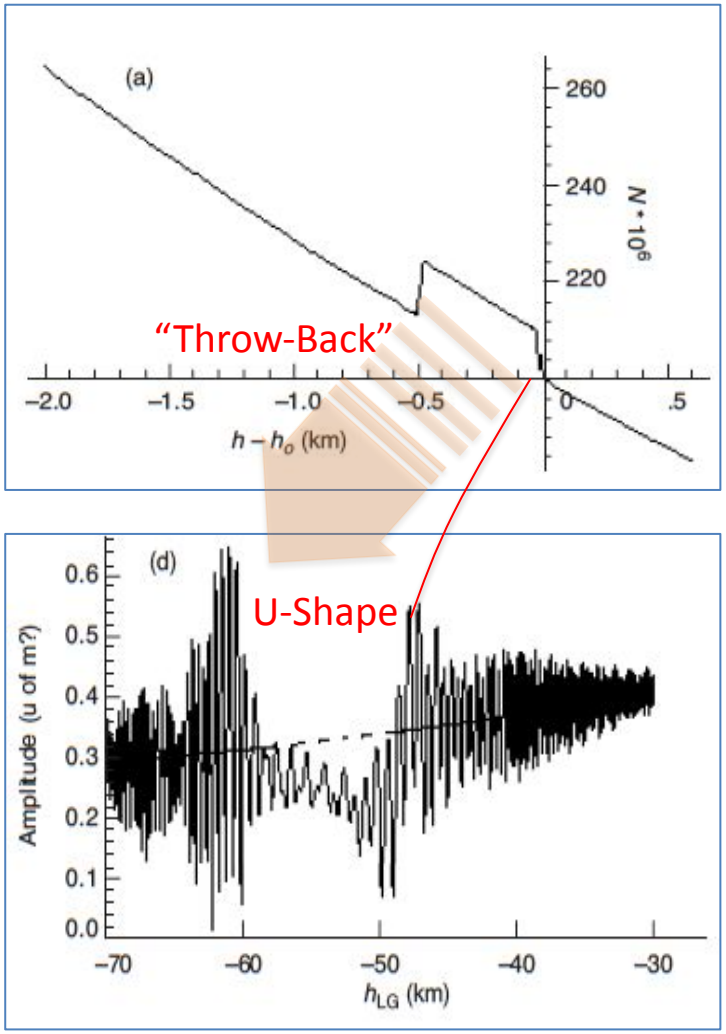
This Study

Atmospheric Optics: Fata Morgana

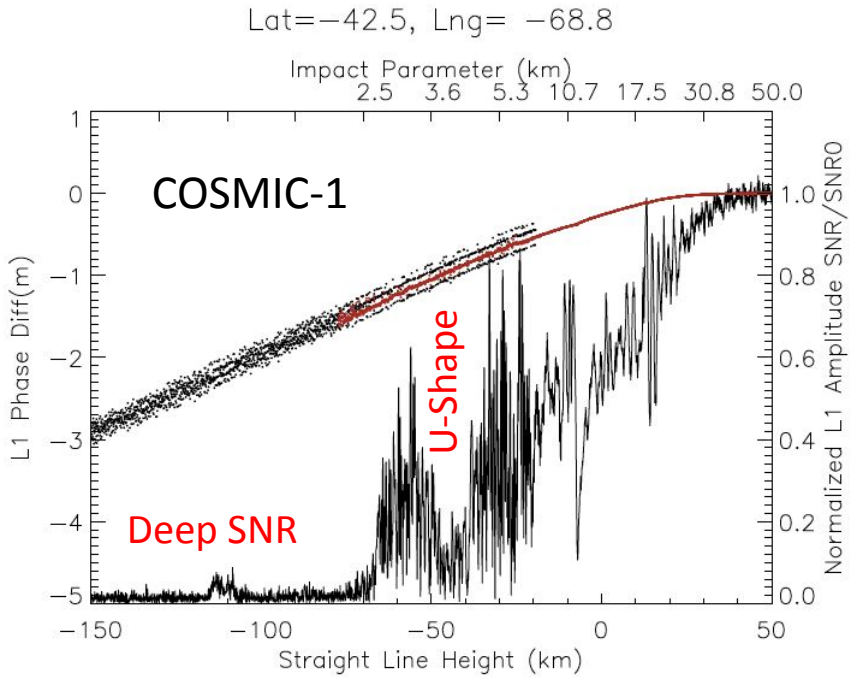
(Image Credit: Wikipedia)



Melbourne [2004]

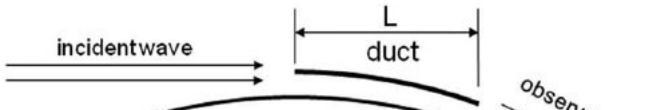


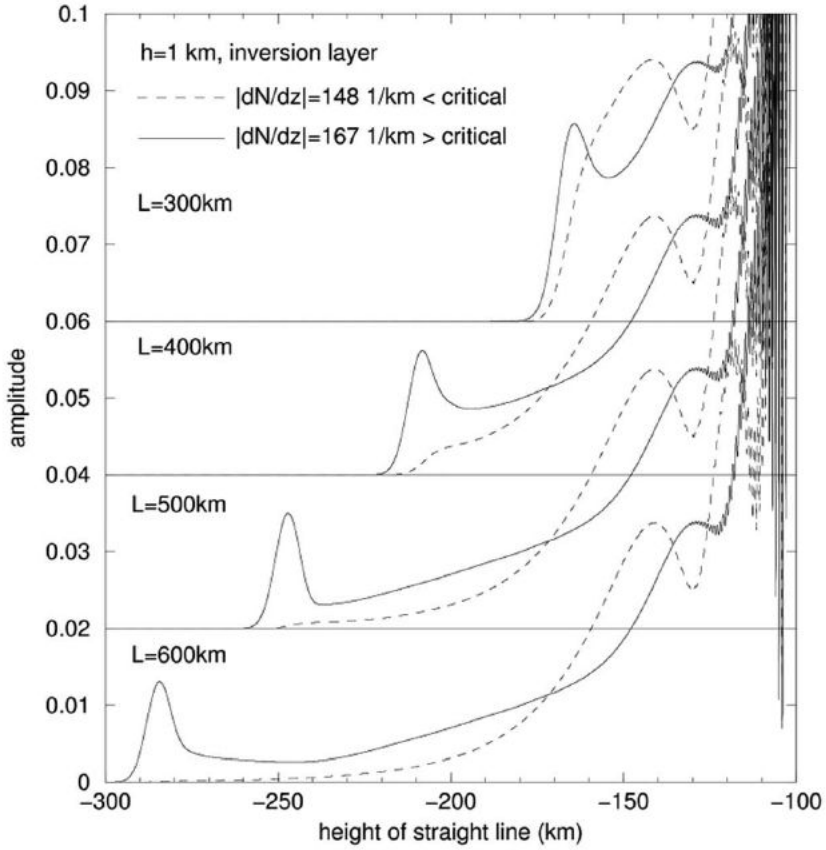
- Thin phase screen model for refractive + diffractive + multi-path RO signals
- Analytical calculation for a sharp 0.5-km atmospheric layer
- U-shape and deep-refraction SNR from 'shadow zone' filled by 'throw-back' rays

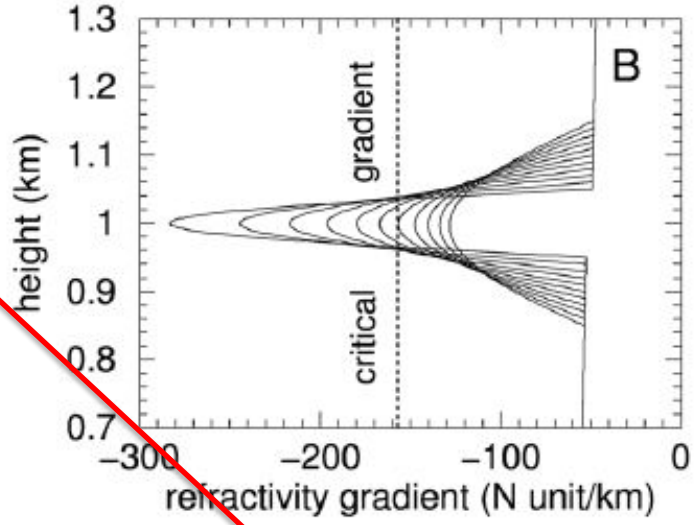


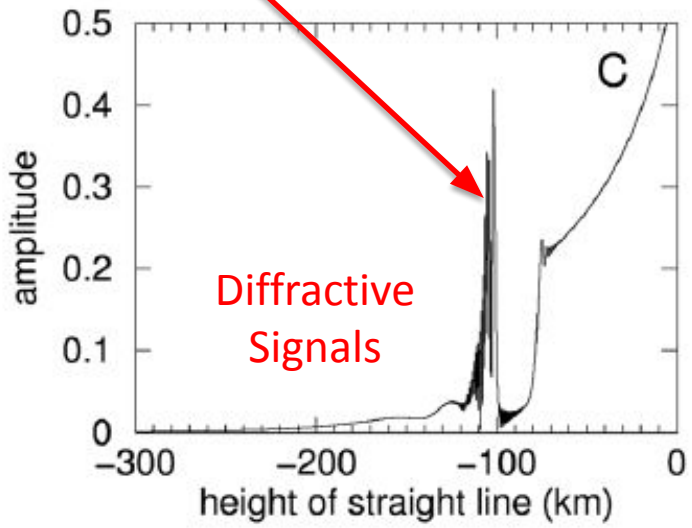
Sokolovskiy et al. [2014]

- Numerical wave-optics model simulations
- Longer duct => Deeper SNR





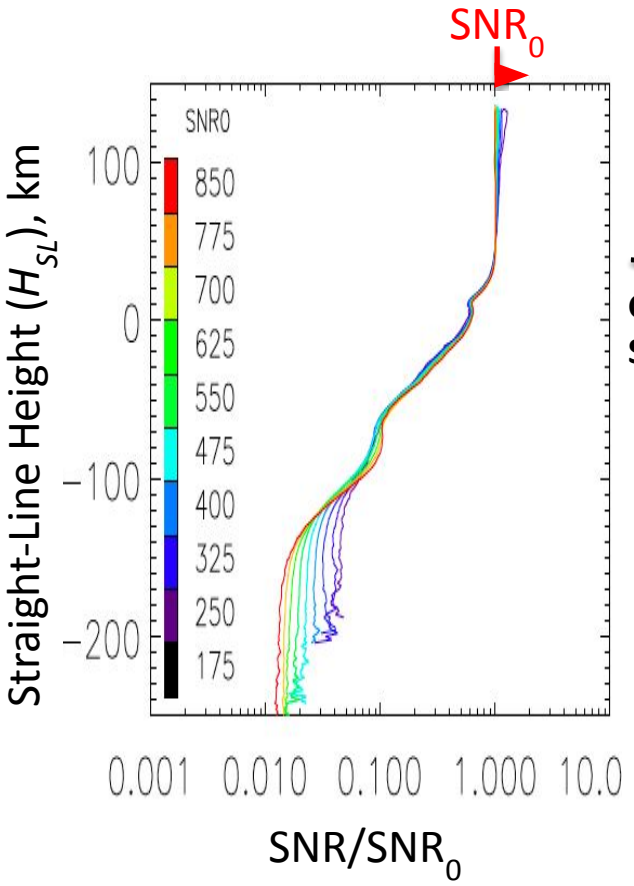




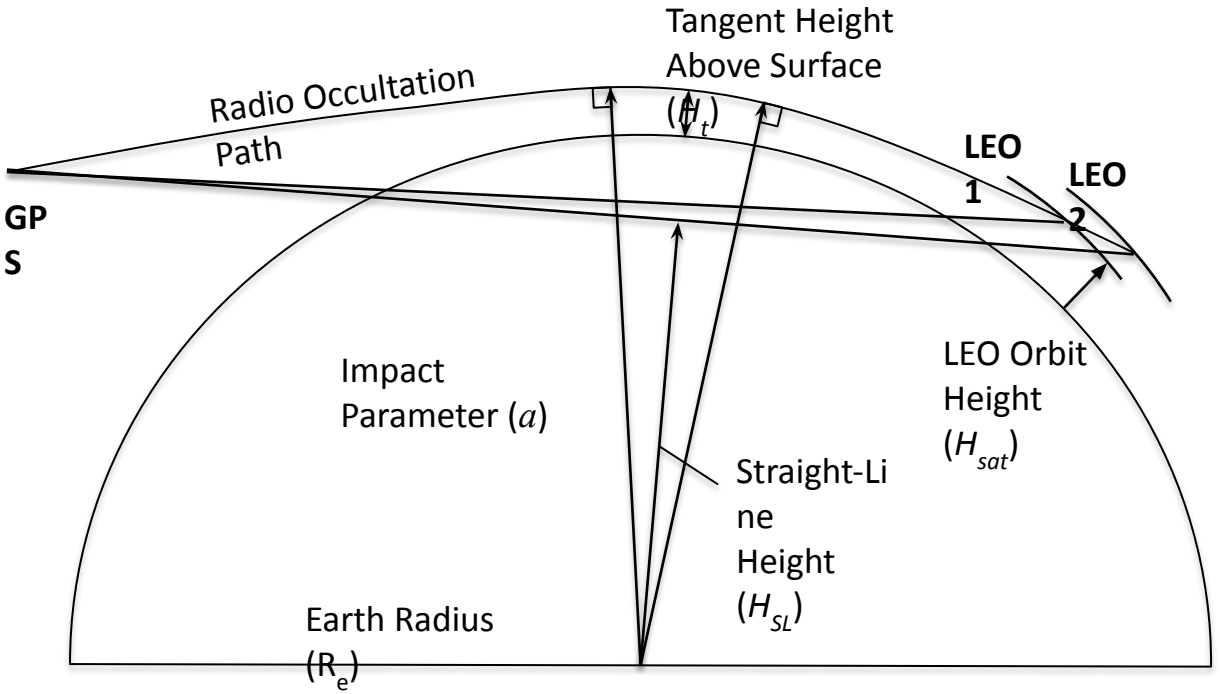
Analysis of RO SNR Data

Receiver noise (σ) effect

- Different σ in setting and rising RO
- Different σ from GPS and GLONASS ROs with same receiver (e.g., COSMIC-2)
- Similar σ in the same receiver set (e.g., COSMIC-1)
- Use of the data with strong signals (SNR0 > 600): still many samples

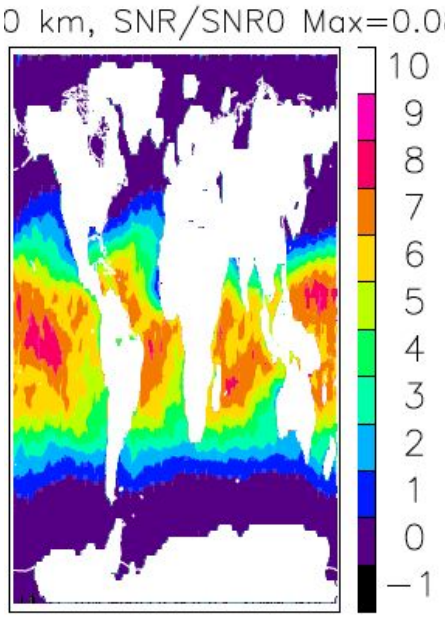


LEO altitude effect

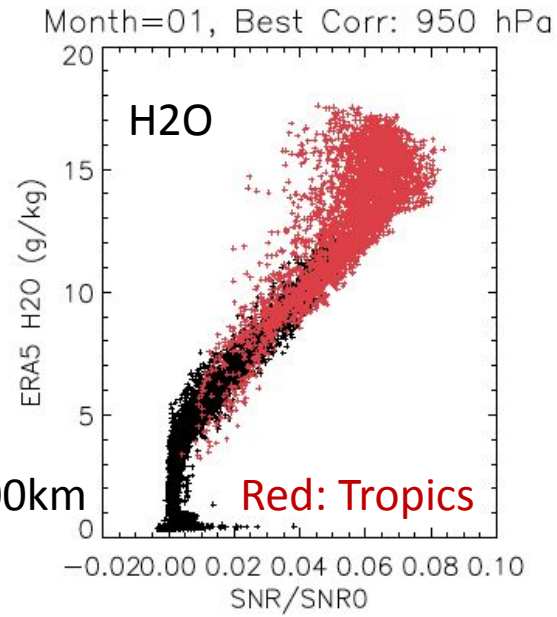


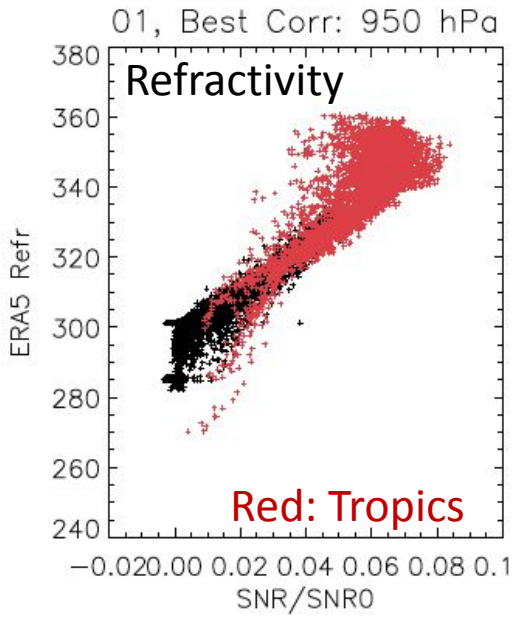
Correlation between Deep (H_{SL}=-100km) SNR/SNR0 (COSMIC 2008-2011) and ERA5 950-hPa H2O and Refractivity over Ocean

Jan

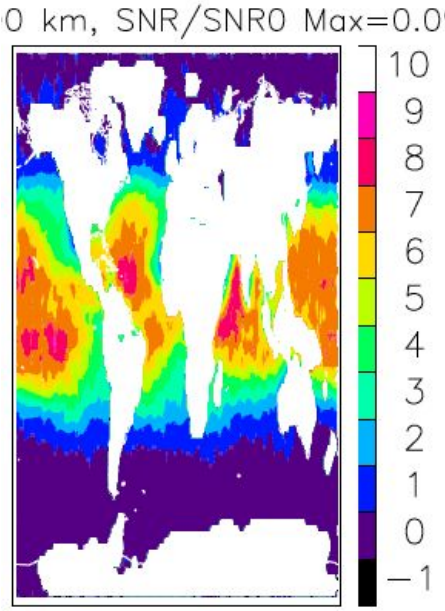


At -100km

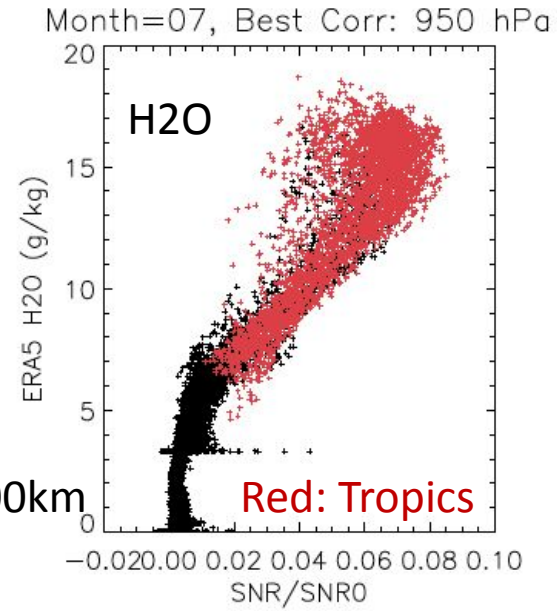


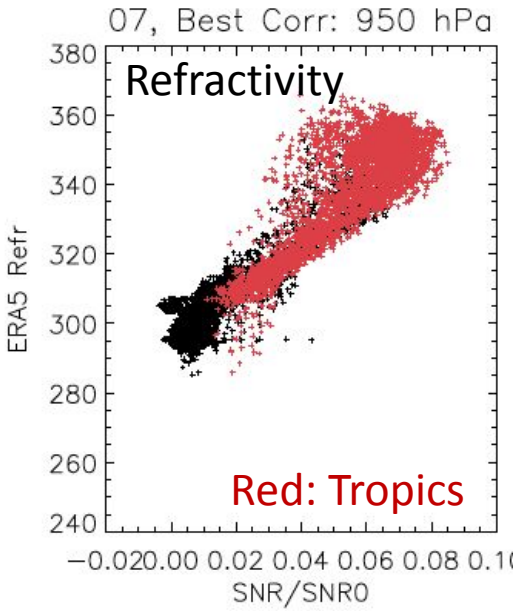


Jul

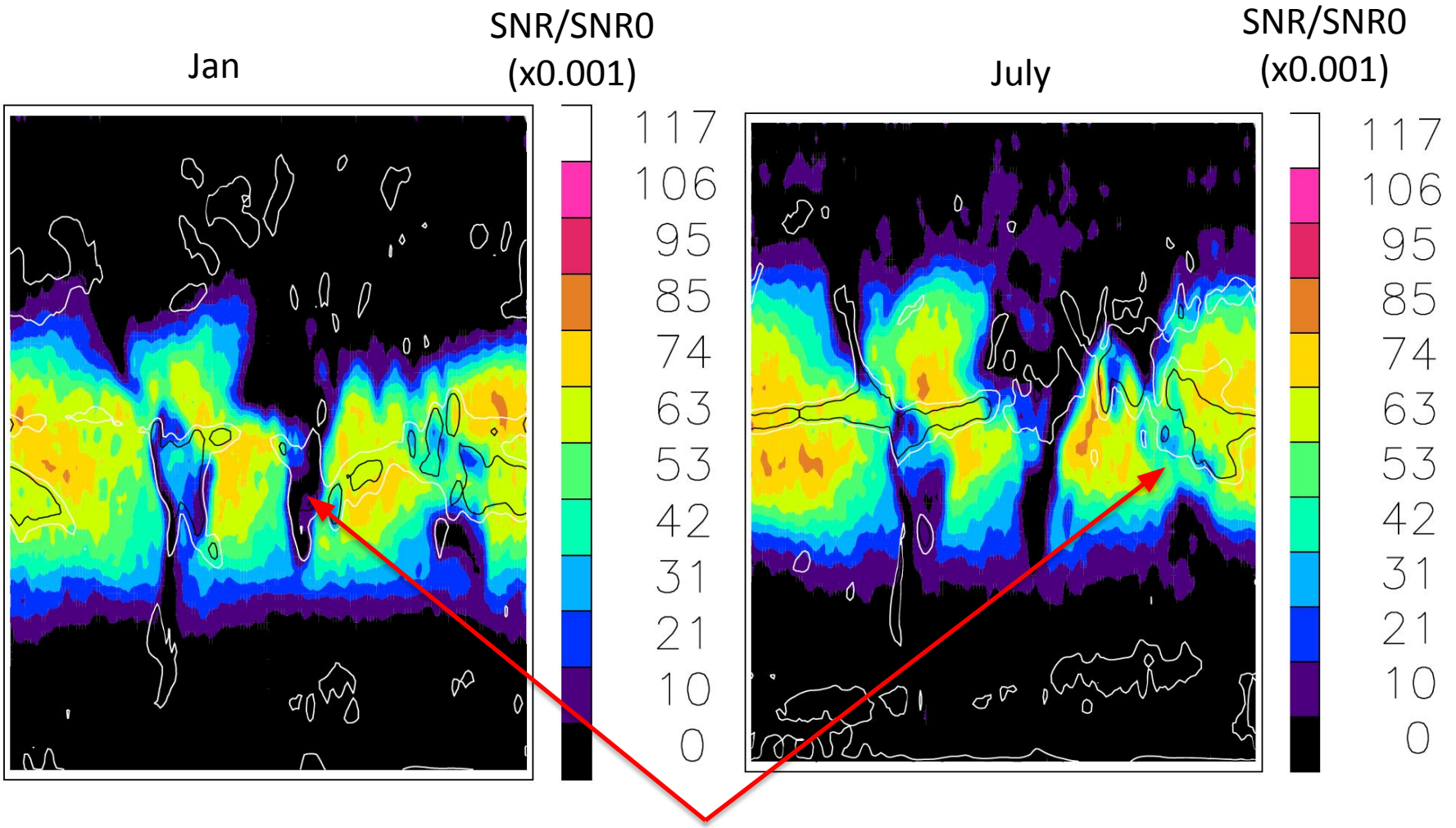


At -100km





Impacts of Vertical Motions and Terrain at H_{SL}=-100 km

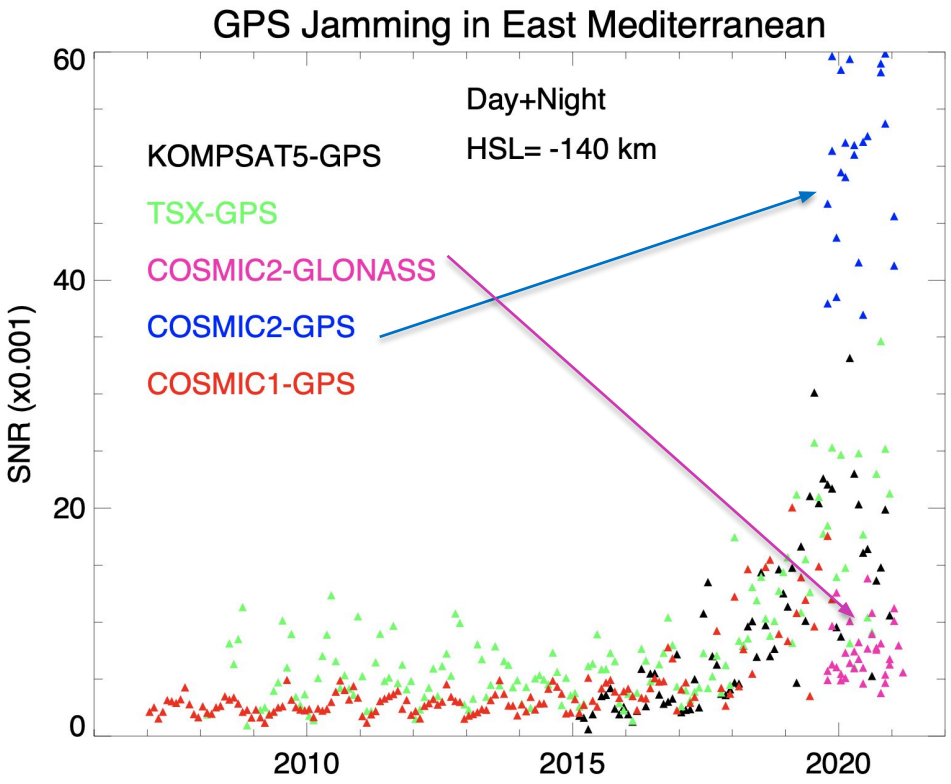


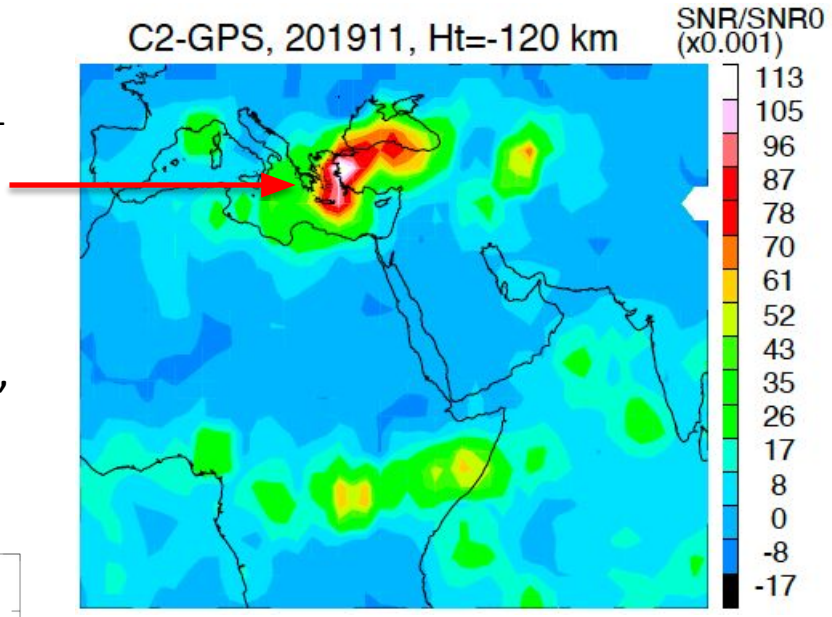
Contours = ERA5 vertical velocity (w)

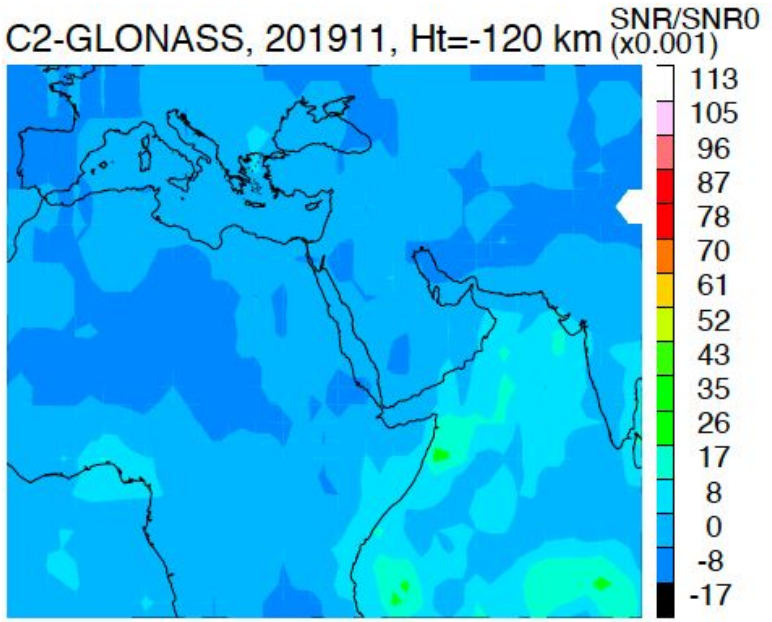
- Low SNR over terrain except flat forest lands (e.g., Amazon)
- Low SNR in the region of high w (e.g., ITCZ)

Sensitive to GNSS Signal Jamming

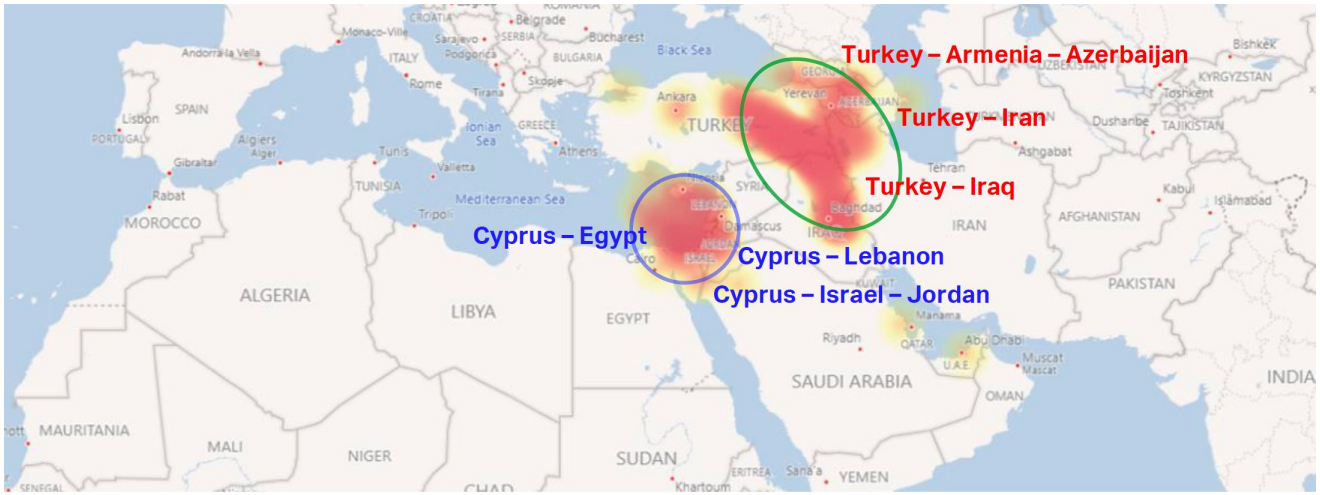
- Anomalous COSMIC-2 GPS signals at deep H_{SL} over the East Mediterranean and Turkey
- Slightly stronger in night than day
- Present in GPS but not in GLONASS signals
- Increased jamming on GPS signals since 2017, including the period of COVID-19 Pandemic

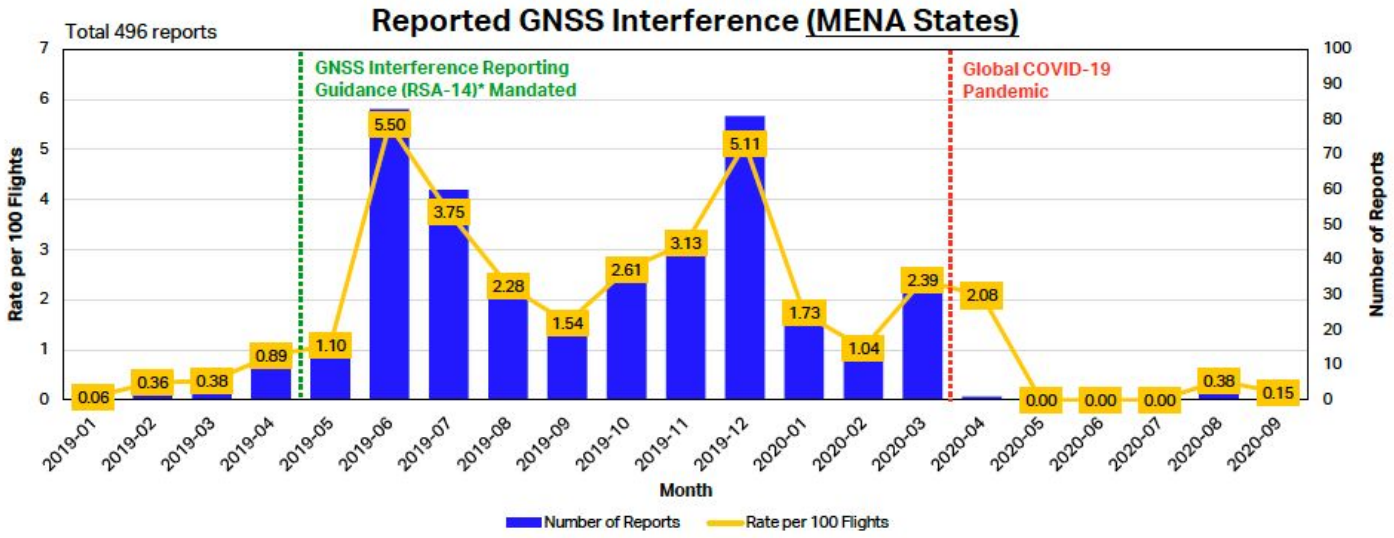






‘Hot Spots’ Reported by International Air Transport Association (IATA)





IATA (Nov, 2020)

- Major aviation safety concern
- 12-month study (Sep 2019 – Sep 2020)
- Based on pilot reports from cruise flights
- Insufficient flights for reporting due to COVID-19 Pandemic

Summary

- Deep refraction RO SNR signals were studied for the effects of refraction, ducting and diffraction in the lower troposphere.
- Strong correlation is found between deep SNR/SNR0 and marine ABL water vapor abundance.
- Algorithm for inferring marine ABL water vapor from RO SNR is under development.
- Deep RO SNR is sensitive to GNSS jamming, in which the jamming to GPS signals has significantly increased over the East Mediterranean since 2017.