Quantification of Horizontal Inhomogeneity in the Planetary Boundary Layer and its Impact on GNSS Radio Occultation Measurements

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Motivation – Horizontal Inhomogeneity

• The GNSS Radio Occultation (RO) retrieval assumes local spherical symmetric atmosphere, which could be violated in the lower troposphere especially near PBL.
• How will the horizontal inhomogeneity (HI) affect the GNSS RO refractivity retrieval?
• What steps are needed to create a 2D atmospheric model to represent various levels of HI?

PBL height (km) climatology for JJA (2007-2012) using refractivity minimum gradient derived from COSMIC RO.
Objectives

- Build a 2D refractivity model to accommodate various levels of horizontal inhomogeneity (HI)
  - Create a simple 1D 3-segment N model
  - Validate with the MAGIC radiosonde observation over northeastern Pacific
  - Quantify the inhomogeneity (inhomogeneity index)
- Use multiple-phase-screen (MPS) simulator to mimic RO observations in the presence of 2D horizontal inhomogeneity
- Evaluate the impact of various levels of horizontal inhomogeneity on RO retrievals
Transect over NE Pacific

- Marine ARM GPCI investigation of Clouds-MAGIC
  - Los Angeles, California to Honolulu, Hawaii
  - October 2012-September 2013
  - Zhou et al., 2015

https://www.arm.gov/sites/amf/mag

- Top: MAGIC transect with location of radiosonde profiles
- Bottom left: Single profile showing temperature, dewpoint temperature, water vapor partial pressure and refractivity (N/10).
- Bottom right: gradient w.r.t. height of temperature, pressure, water vapor partial pressure and refractivity
2D refractivity climatology over NE Pacific

- 2D refractivity field derived from MAGIC radiosonde soundings from 122°W to 157°W
- PBLH (height of minimum refractivity gradient) highlighted by black dotted line
1D 3-segment model profile

Model is a modified version of the parameterized equation from Sokolovskiy (2001)

\[ N_3(h) = N_f \exp \left( \frac{-(h-h_f)}{H_3(h)} \right) \]

\[ N_2(h) = N_0 \exp \left( \frac{-h}{H_2} \right) \left[ 1 - A \cdot \arctan \left( \frac{-(h-h_{pbl})}{B} \right) \right] \]

\[ N_1(h) = N_{sfc} \exp \left( \frac{-h}{H_1} \right) \]
Key variables for 1D refractivity model derived from MAGIC radiosondes

Scalar variables along NE Pacific transect. Each variable is calculated from the median value of a 5° longitude and then interpolated to 1° horizontal resolution. Data is then fit to a 3rd degree polynomial so each variable is a function of longitude and height.

Median scale height (solid red) ± 1 absolute deviation, calculated from 36 1° median profiles
N-model vs. climatology

Left Figure: Surface to 30 km plot of N-model, radiosonde (solid blue) and Nm(dashed red).
Right figure: Fractional difference between Nrds and Nm((Nm-Nrds)/Nrds)*100%.

Fractional difference (%) between 2D Model and the radiosonde climatology for 0-5km (left) and 0-30km (right). Black dotted line (left) shows the PBLH.
Quantifying inhomogeneity

- Asymmetry over analysis region
  - Refractivity at constant height over analysis region
  - Height intervals of 200 m from surface to 2 km increase to every 250 m from 2 km to 5 km
  - Black connected circles represent the refractivity value at PBL
  - Highlights the greatest asymmetry along the entire transect exists at the height of the PBL.

- Asymmetry index at $-140^\circ \pm 3^\circ$
  - Cross section total refractivity (CSTR)
    \[ CSTR = \int_{LB}^{RB} N (h_i) ds = \int_{LB}^{MPT} N (h_i) ds + \int_{MPT}^{RB} N (h_i) ds \]
  - Cross section asymmetry (CSA)
    \[ CSA = \left| \int_{LB}^{MPT} N (h_i) ds - \int_{MPT}^{RB} N (h_i) ds \right| \]
  - Cross section asymmetry index (CSAI)
    \[ CSAI = \left( \frac{CSA}{CSTR} \right) 10^2, \text{ where: } 0 \leq CSAI \leq 10 \]
Multiple Phase Screen Simulator

• Fourier split step solution of the parabolic wave equation
• Atmosphere approximated by a series of phase screens
• Full-wave diffraction effects with no required special treatment for multipath
• Key parameters for MPS
  – Center longitude: -140°
  – Longitude range: x=-1000 to x=1000 corresponding to x= -150° to x= -130°
  – Screen interval (\( \Delta x \)): 1 km
  – Total number of screens: 2000
  – Vertical range: -250 m to 60 km

Modified from Beyerle et al., 2003
Retrieval vs. input

- Calculation of percentage difference between N retrieval (N_ret) and profile from center of domain (N_-140).
  - \( \left( \frac{N_{\text{ret}} - N_{-140}}{N_{-140}} \right) \times 100\% \)

- Comparison at center of domain (-140°)
  - Bending could cause drift which is a reasonable explanation for the difference within the PBL.

*Figure courtesy of K.- N. Wang*
Conclusions and future work

• Work to date
  • A 2D refractivity model is created and validated by radiosonde data over NE Pacific. The 2D model can accommodate variation of inhomogeneity levels.
  • Inhomogeneity is quantified over the NE Pacific along the transect between South California and Hawaii using the asymmetry index.
  • MPS simulation is carried out to simulate the RO event in the presence of 2D horizontal inhomogeneity.

• Future work
  • Alter MPS simulation within the analysis region and evaluate the differences between simulation results.
  • Consider other variables that factor into the difference between the retrieval and model profile and how to isolate their contribution (ex. representative error, ducting-induced bias etc.)
  • Evaluate scenarios with varying inhomogeneity levels
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QUESTIONS?
Input: 2-D refractivity profiles with Horizontal Inhomogeneity

MPS simulation

Simulated GPS Radio Occultation (Phase, Amplitude)

Standard radio holographic retrieval (CT, PM, FSI)

Abel inversion

Bending angle

Output: 1-D Simulated RO refractivity profile

The End-to-end Simulation
References


Kursinski et al., 1997 Observing Earth’s atmosphere with radio occultation measurements using the Global Positioning System. JGR, vol. 102, D19, pgs. 23,459-23,465


