Jet Propulsion Laboratory
California Institute of Technology

Benefits of Joint GNSS-RO and Passive MW Sounder Retrievals for PBL Remote Sensing

Chi O. Ao, Kuo-Nung Wang, Tanvir Islam, George Hajj, Joe Turk, Svetla Hristova-Veleeva, and David Morabito

Jet Propulsion Laboratory

California Institute of Technology, Pasadena, USA

October 16, 2020
NASA Sounder Science Team Meeting

Introduction

- Improved understanding/characterization of the PBL requires observations of temperature (T) and water vapor (q) with high horizontal and vertical resolutions.
- A combination of limb (RO) and nadir sounders (MW, IR) offers a possible solution.
- While such combination is done through NWP DA, there are advantages to explore joint retrievals independently (higher resolutions, better uncertainty estimates, less dependent on models, …)

GNSS-RO Overview

$\phi(t)$ Signal Phase

⬇ (GO or RH)

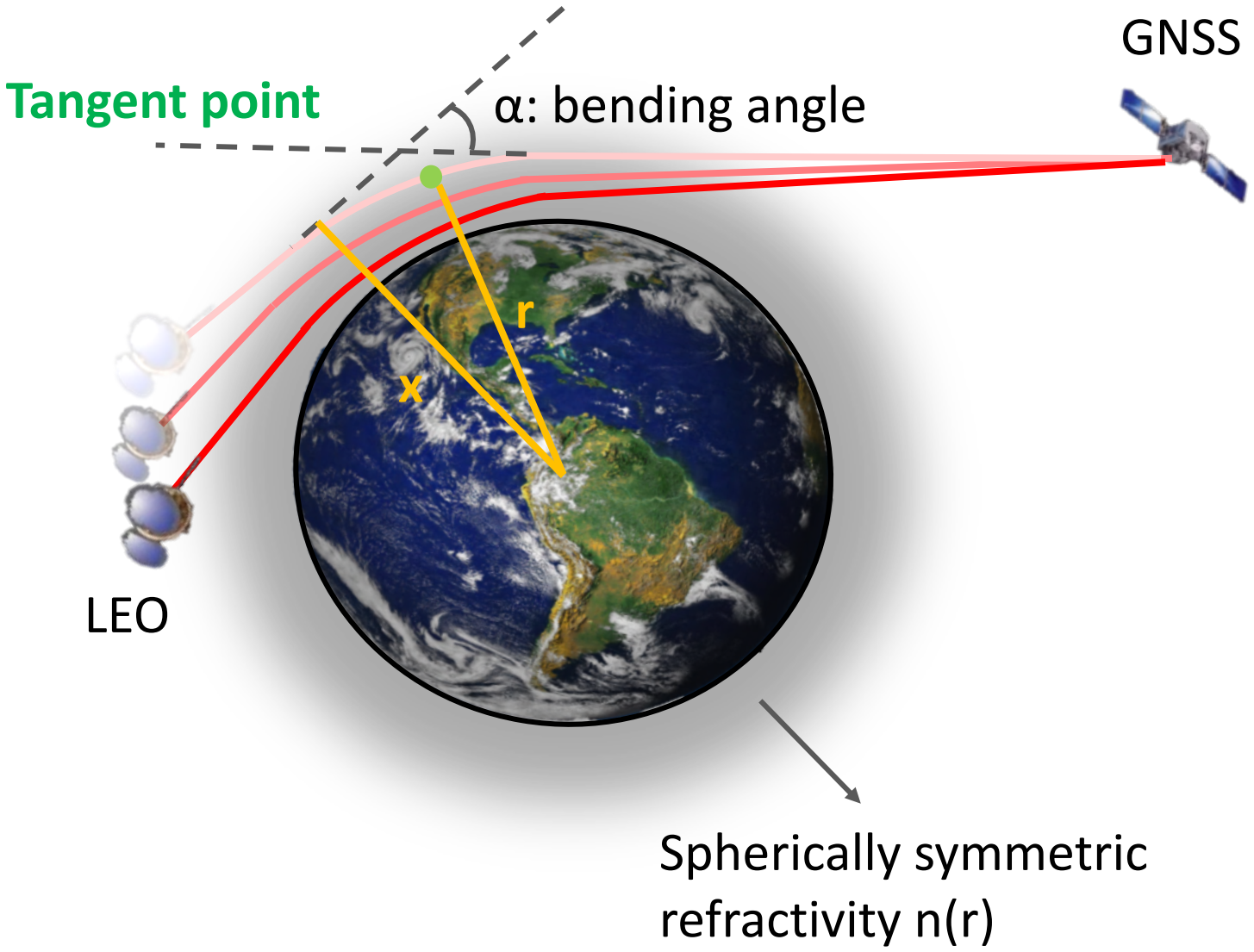
$\alpha(a)$ Bending angle

⬇ (Abel inversion)

$N(z)$ Refractivity

⬇ $N = k_1 \frac{p}{T} + k_2 \frac{e}{T^2}$

$T(z), p(z), e(z)$



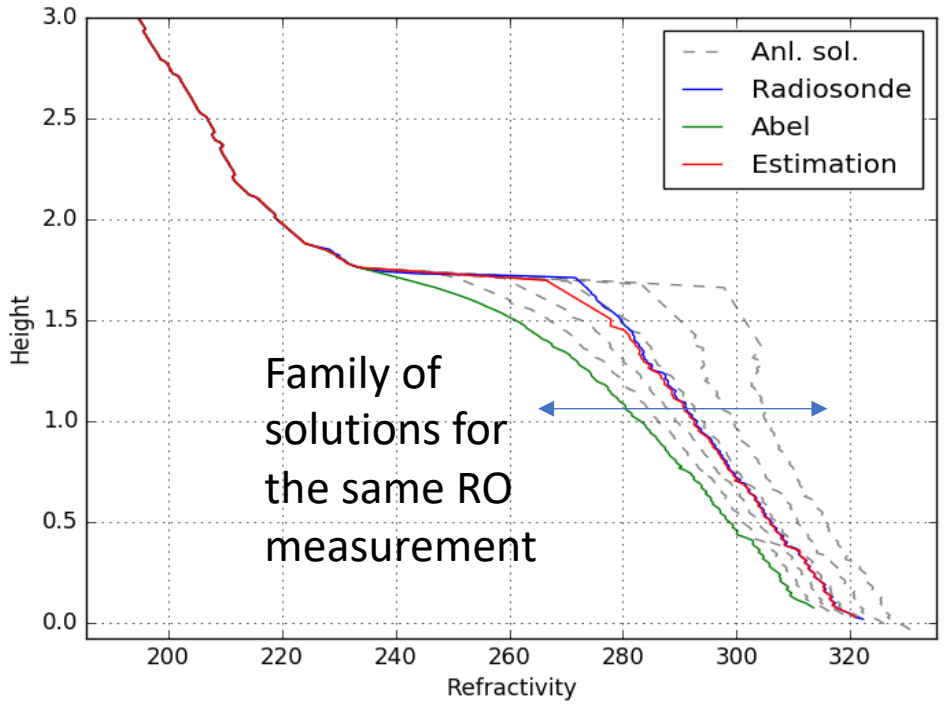
Benefits - 1D

Can we improve GNSS-RO temperature and water vapor profiles through a joint retrieval with both RO and MW measurements?

Simultaneous retrieval of temperature and water vapor from refractivity.

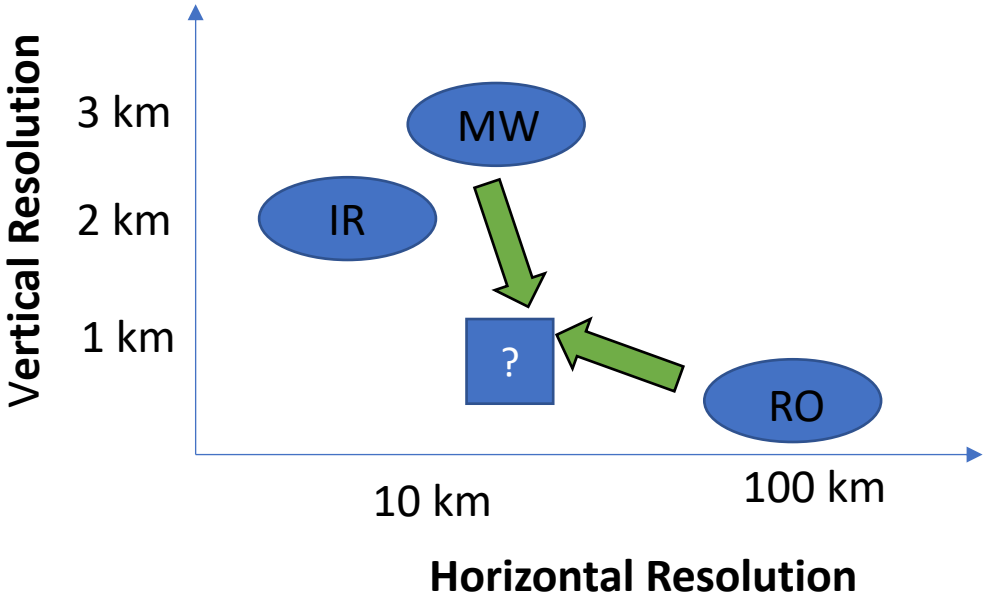
Refractivity solution is underdetermined in the presence of ducting.

Precipitable water (PW) from AMSR-E are used to constraint the refractivity solution below the duct [Wang et al. AMT, 2017].

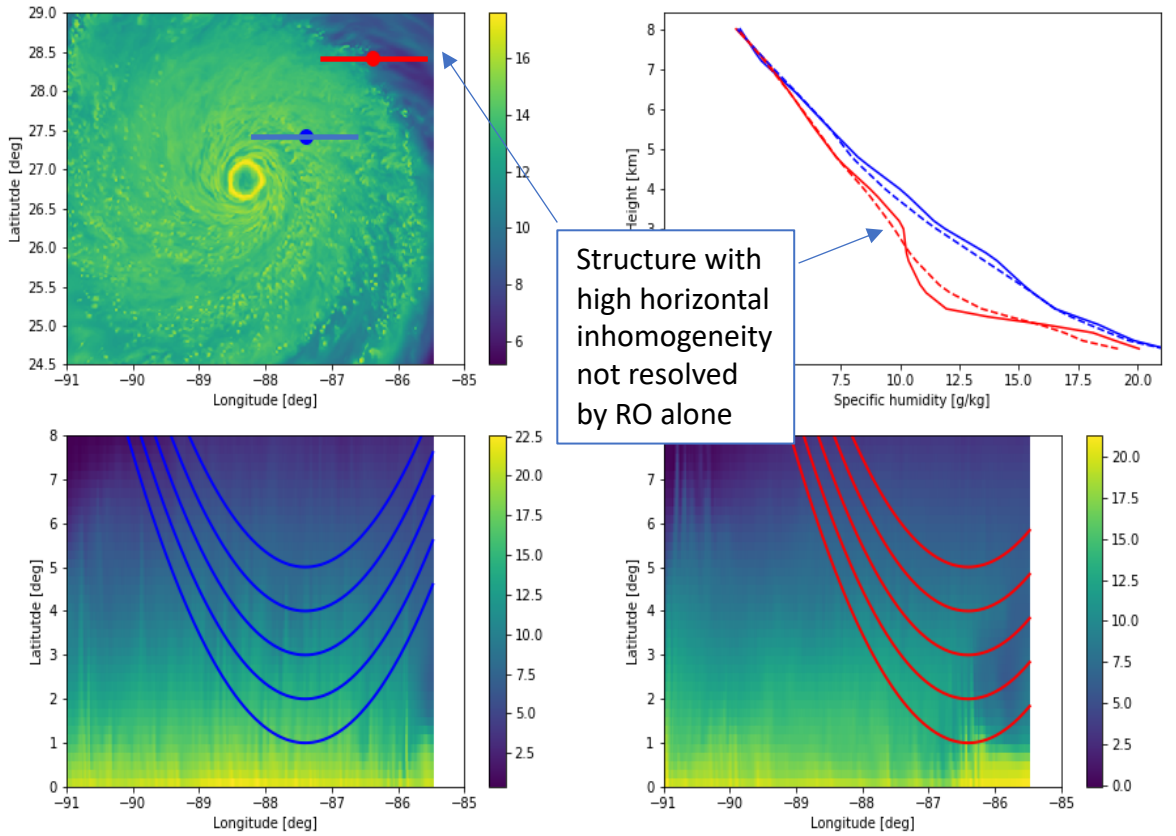


Benefits - 2D/3D

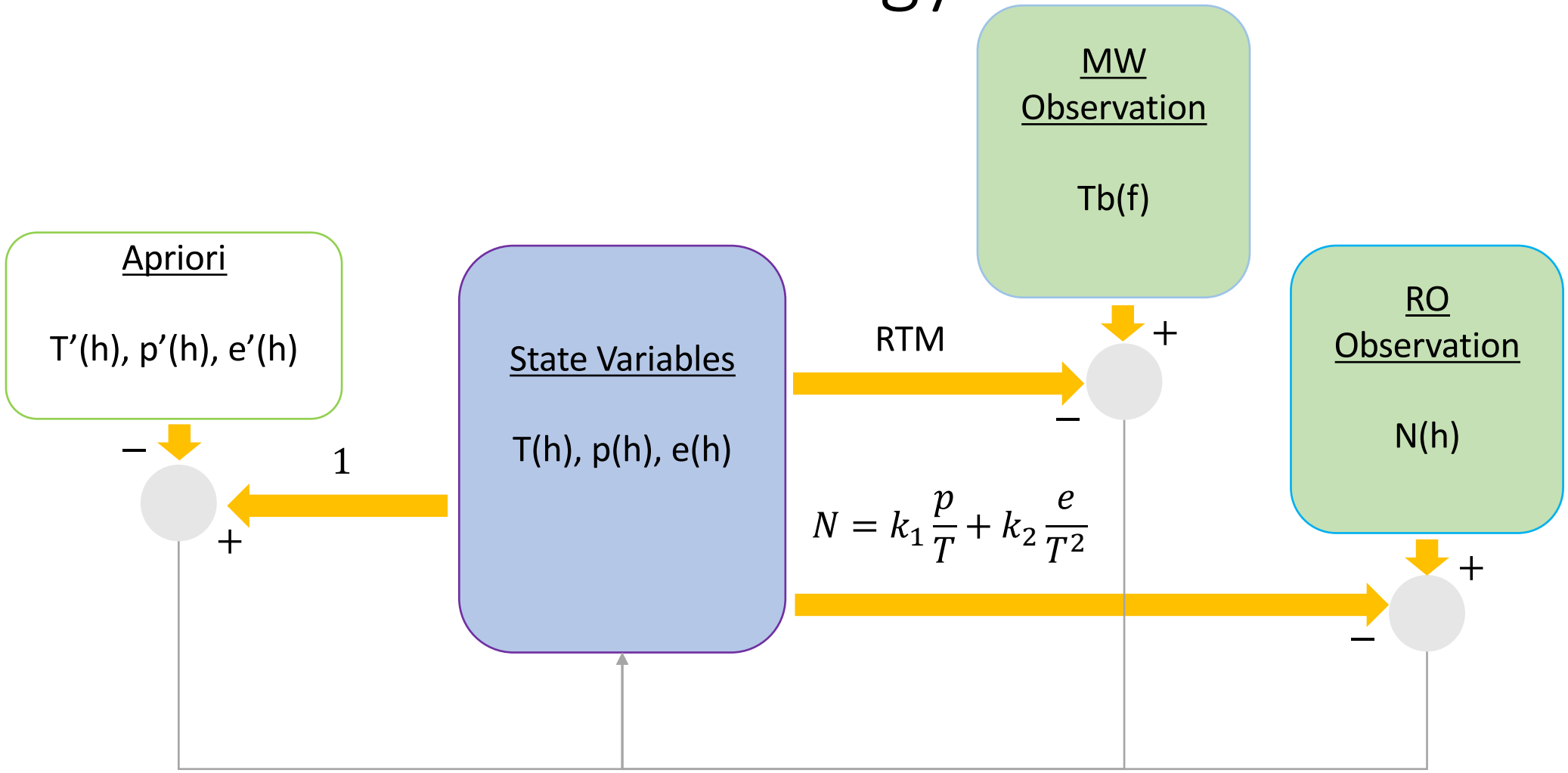
Can we obtain improved horizontal and vertical resolutions for temperature and water vapor retrievals by combining nadir and limb sounders?



Dashed lines: RO retrievals at ray TPs
Solid lines: WRF at ray TPs

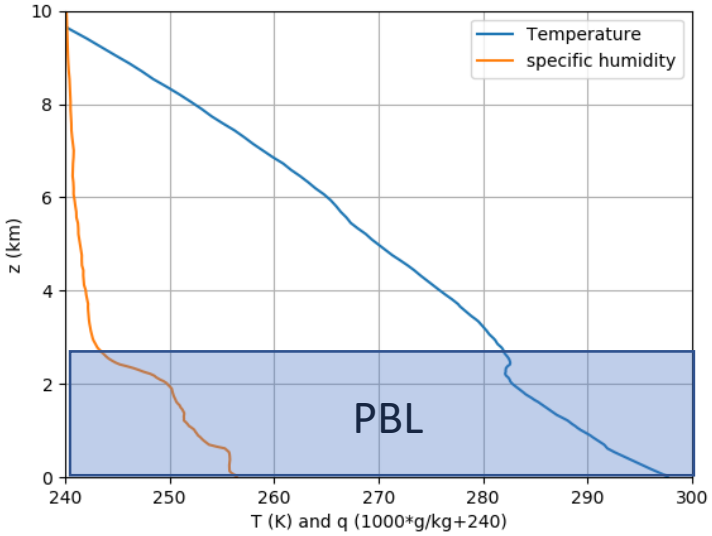


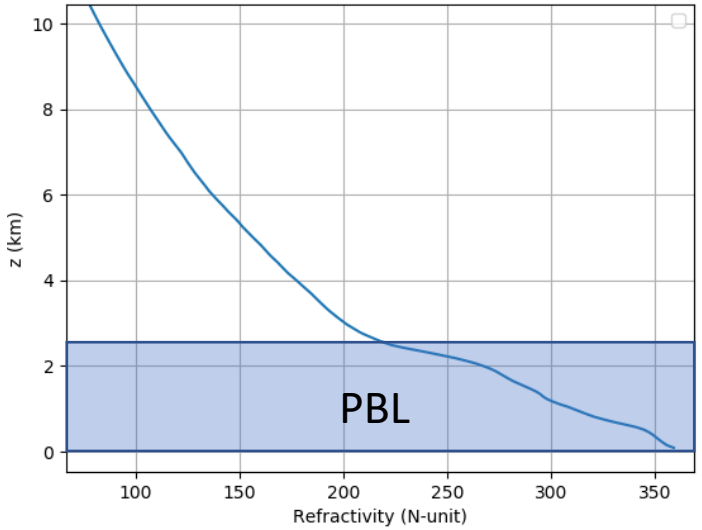
1D Joint Retrieval: Methodology



$$J = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}(y - H[x])^T O^{-1}(y - H[x])$$

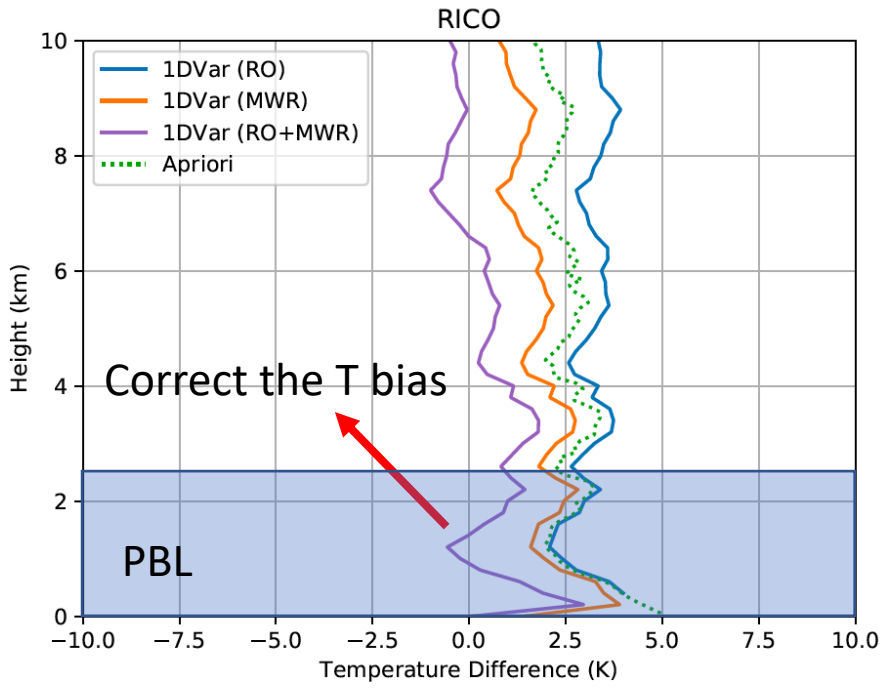
1D Joint Retrieval: Solution (1DVar)

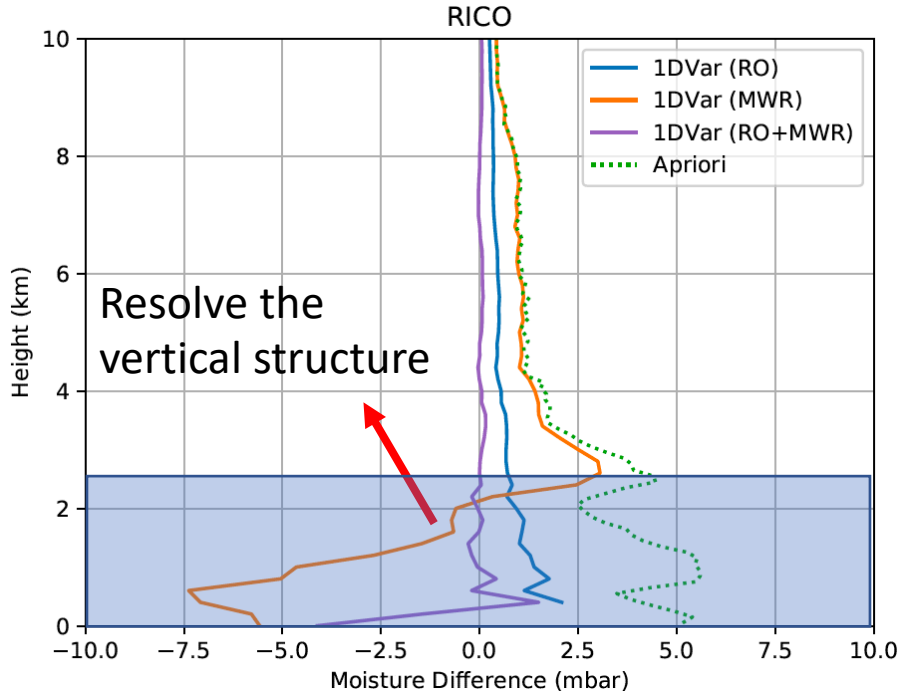




- Example from Large Eddy Simulation (RICO: Shallow Cumulus Marine Boundary Layer Condition)

LES provided by Marcin Kurowski (JPL)

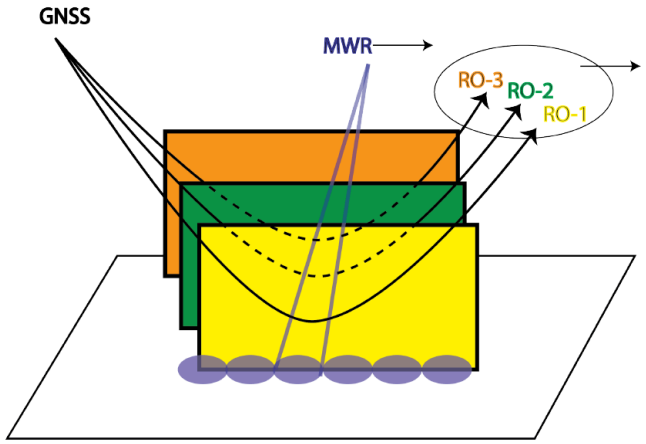


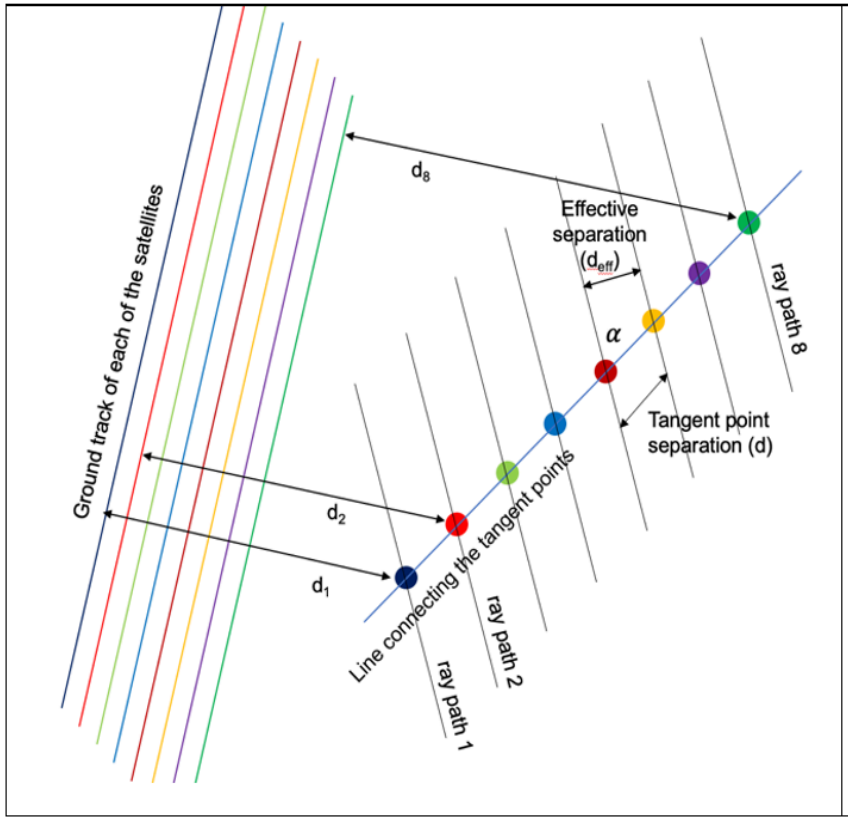


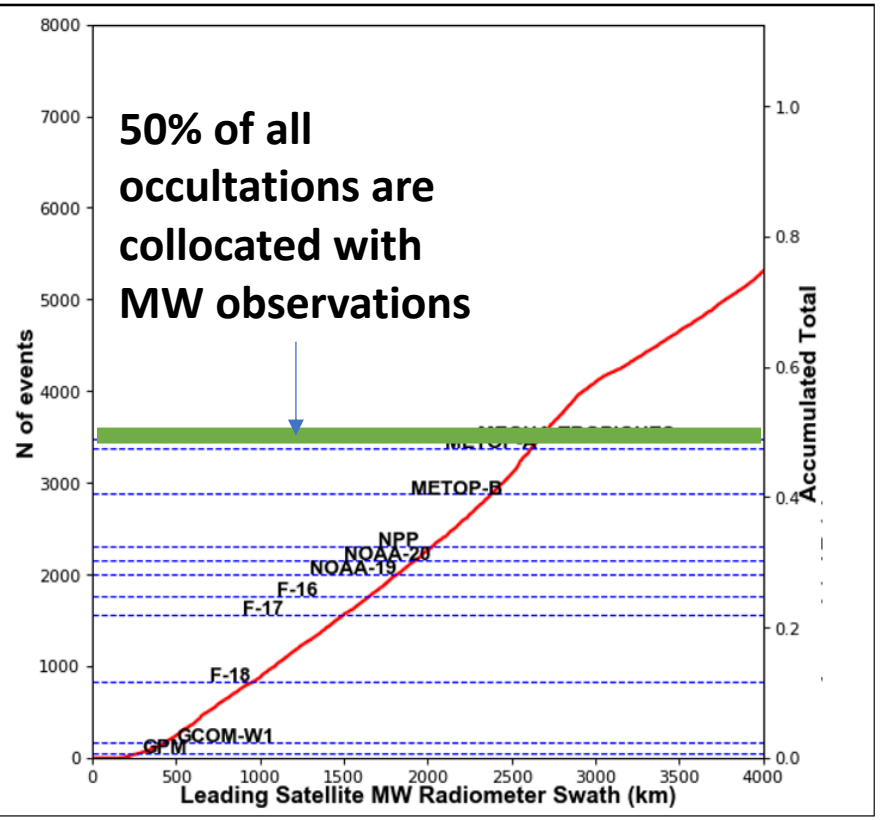
2D/3D (Tomographic) Retrieval

- We consider a number of RO soundings that occur within the swath of the MW radiometer.

Existing POR from current/future constellation of passive MW imagers and sounders provides excellent opportunities for such collocations.

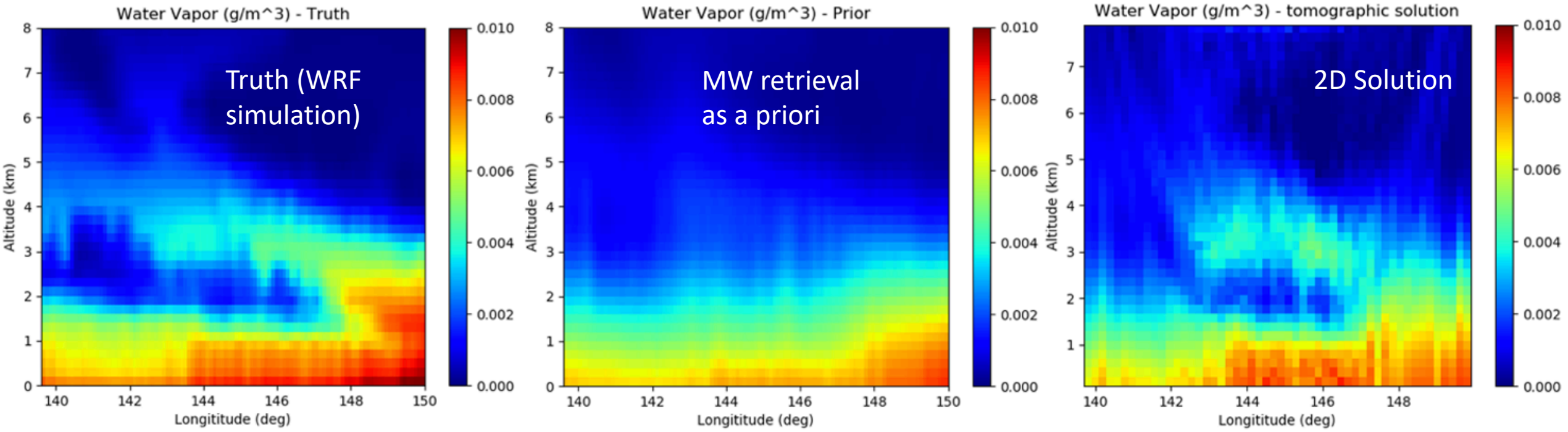






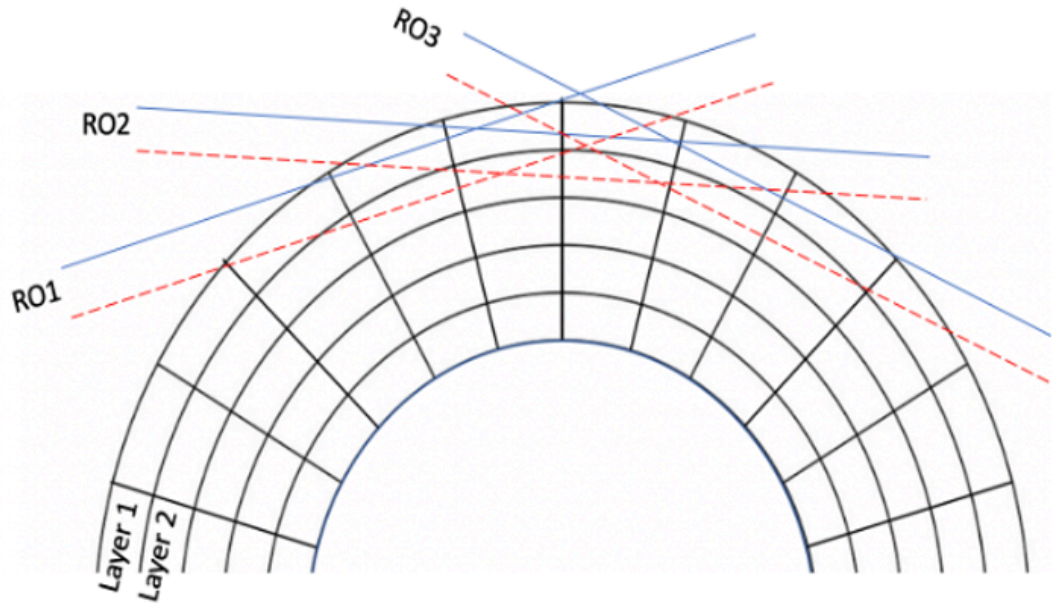
2D water vapor retrieval using Kalman filtering estimation

- Assuming all occultations occur within the same plane (8 occultations used)
- Simplified RO geometry (no bending), but account for raypath trajectories
- Known temperature

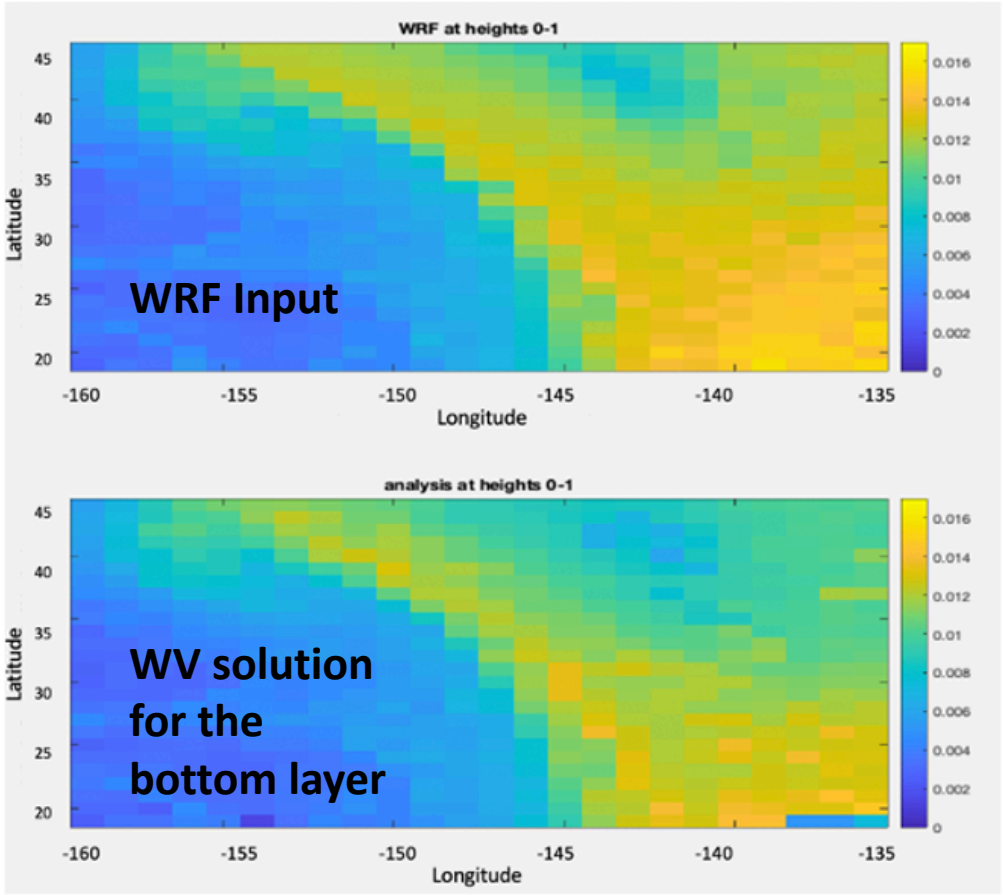


3D retrieval using Generalized Abel inversion approach

Layer-by-Layer approach allows fast computation time



100 occultations within domain



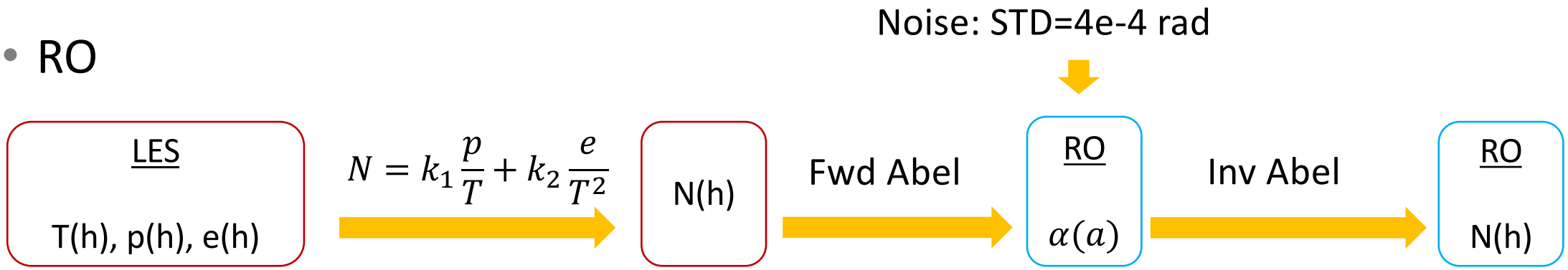
Summary

- PBL science/applications require high resolution PBL temperature and water vapor that a single remote sensing instrument cannot provide.
- Synergy between limb and nadir sounders should be exploited. We focus on joint retrievals of GNSS-RO and passive MW sounders here, but can be extended to RO and IR.
- 1D joint retrieval helps untangle wet/dry ambiguity inherent in GNSS-RO and can help constraint refractivity solution under strong PBL inversions.
- With multiple RO observations collocated with MW, tomographic retrievals can yield highly detailed 3D retrieval of water vapor.

backups

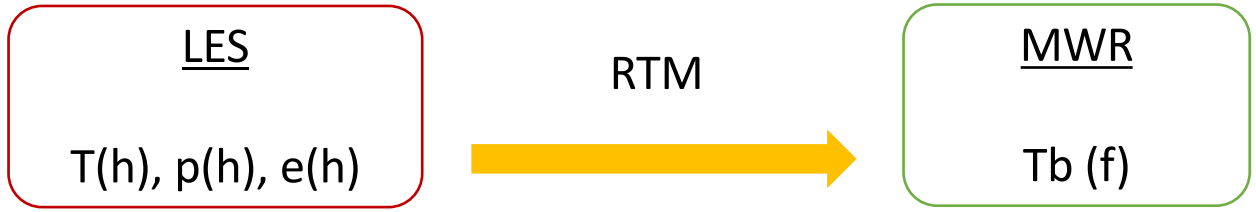
- RO and MWR Observation

  - RO



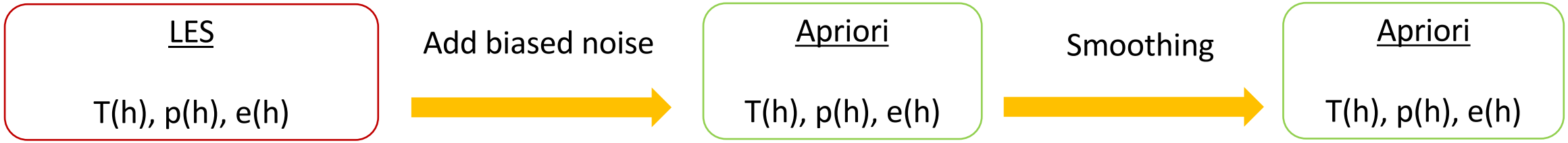
    - Covariance: N: 0.04 N-unit, α: 4e-4 rad

  - MWR



    - Covariance: Tb: 0.5K

- Apriori
  - Smoothing the true profile



  - T covariance: 2.5K (0~10km), 2.5K-10K (10~30km)
  - p covariance: 1%*p
  - e covariance:
    - RO: 40%*e
    - RO+MWR: 100%*e

T

Bayesian inversion

Forward model (systematic error) covariance matrix

Measurement (random error) covariance matrix

$$E(\mathbf{x}) = \sum_j \mathbf{x}_j A^{-1} \exp\left[-\frac{1}{2}\left(\mathbf{y}_{obs} - \mathbf{y}_{sim}(\mathbf{x}_j)\right)^T (O+S)^{-1} \left(\mathbf{y}_{obs} - \mathbf{y}_{sim}(\mathbf{x}_j)\right)\right]$$

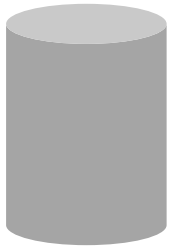
Observed TBs and refractivity

Simulated TBs and refractivity from forward model

Normalization factor

$$A = \sum_j \exp\left[-\frac{1}{2}\left(\mathbf{y}_{obs} - \mathbf{y}_{sim}(\mathbf{x}_j)\right)^T (O+S)^{-1} \left(\mathbf{y}_{obs} - \mathbf{y}_{sim}(\mathbf{x}_j)\right)\right]$$

- **Physically-based algorithm**
- **Fast-inversion processing**
- **Able to handle hyper spectral MW measurements**



Radiosonde sounding Profiles

MW Fwd Model

RO Fwd Model

TBs

Refractivity

1D Joint Retrieval: Solution (Bayesian Inversion)

Water Vapor Profiling

Temperature Profiling