Mission Configuration and Retrieval Technique for Profiling Water Vapor in the Marine Boundary Layer

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Abstract

Profiling water vapor in the marine boundary layer (MBL) is critical to marine weather prediction, maritime communications, and understanding feedbacks relevant to multi-decadal climate prediction, yet profiling the MBL remotely has proven extraordinarily difficult because of the spatial scales involved and the proximity of the ocean surface. Collocated radio occultation (RO) and nadir passive microwave (MW) soundings can be combined in retrieval to profile water vapor with the vertical resolution of RO and with super-refraction and the wet-dry ambiguity inherent to RO resolved by the MW. We have constructed a retrieval technique that considers collocated RO and MW soundings that yields profiles of water vapor in the MBL with unprecedented precision, accuracy, and vertical resolution. We have also performed RO and MW collocation studies that consider many current RO missions and MW instruments. The joint RO+MW retrieval technique mines the information in MW soundings for an inference of the microwave refractivity in the MBL surface air, removes the biasing effect of super-refraction following the approach of Xie et al. (2006, doi:10.1175/JTECH1996.1), and resolves the wet-dry ambiguity inherent to RO using the MW sounding as a constraint or a weather forecast as a prior in 1DVAR. We constructed a simulation-retrieval demonstration system that uses a multi-phase screen propagator to simulate RO amplitude and phase and the Optimal Spectral Sampler (OSS) to simulate AMSU-A radiances. In its current state, the retrieval technique is capable of producing MBL water vapor profiles with 2% accuracy and 100-meter vertical resolution. Our collocation study shows that existing RO satellites and orbiting MW instruments achieve approximately 1,300 collocations daily, defined with a temporal window of 10 minutes. To facilitate this study, we have formulated a time-dependent rotational transformation that is applied to RO geolocations. It is three orders of magnitude more efficient than a brute force approach to finding collocations and is valid to 4% precision. We have found that the greatest yield for collocations in low latitudes would come from RO satellites that would fly in tandem with the TROPICS MW CubeSats, potentially producing 1,500 daily RO+MW collocations in the Tropics and Subtropics.

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Background: Marine Boundary Layer

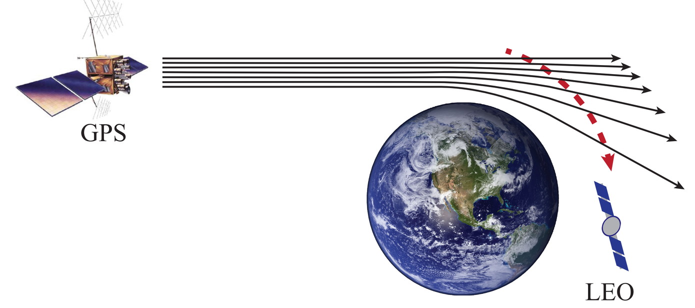
- The marine boundary layer (MBL) is key to constraining cloud feedbacks, forecasting maritime long-range communication
- High precision, accuracy and spatial resolution are nearly impossible from space, inhibiting global climatologies and forecasting
- Explore the fusion of two microwave data types, GNSS radio occultation (RO) and passive nadir sounding (MW)
  - Enable high precision and vertical resolution retrieval of water vapor in MBL
  - Insensitive to presence or absence of clouds

We attempt several approaches to retrieving water vapor in the MBL, two by combining RO and MW, one by combining RO and forecasts of a numerical weather prediction (NWP) system.

Data: GNSS RO and MW Sounders

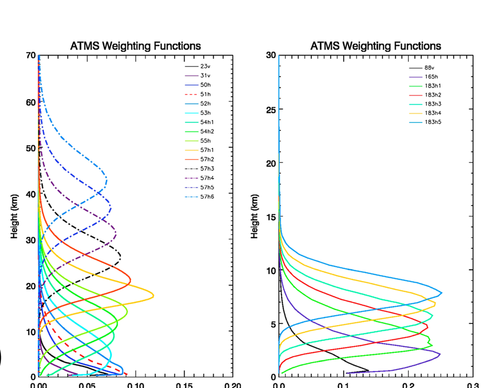
GNSS radio occultation

- High vertical resolution (~100m) and precision (0.3% refractivity), poor accuracy (4% refractivity) in MBL due largely to super-refraction, insensitive to clouds
- Currently ~6000 soundings daily (non-commercial)
- Simulation/retrieval tools: Abel integrals, multi-phase screen integrator, physical optics



Microwave Sounders

- Multiple channels probe MBL with little cloud contamination
- Currently two ATMS (Suomi-NPP, NOAA-20) and two AMSU-A operational sounders (Metop-B, Metop-C)
- Simulation/retrieval tools: Optimal Spectral Sampling (OSS), Optimal Estimation Testbed, both of which are AER utilities



Taken from Boukabara et al., *Journal of Geophysical Research*, 2017, doi:10.1002/2013JD020448, figure 1.

Two-step Retrieval

Algorithm

Assume super-refracting level as known but layer properties as unknown.

1) Two-parameter retrieval by optimal estimation: retrieve MBL average humidity and surface air temperature assuming a well-mixed, moist, unsaturated adiabat.
2) Fix temperature profile, retrieve water vapor using RO.

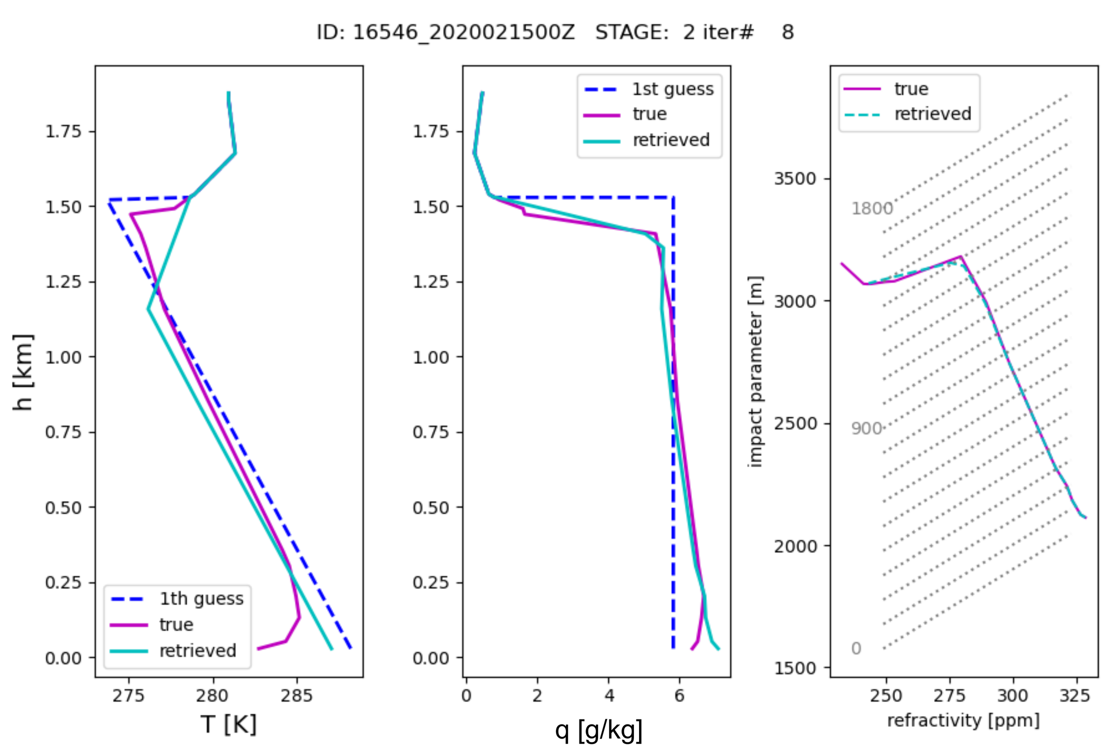


Figure 1. Illustration of two-step retrieval of water vapor (and temperature). RO bending angles and ATMS channel radiances are simulated from high-res ECMWF profiles. Blue dashed lines are first guess; aqua lines are result of first step; and purple lines are result of second step. The third plot shows refractivity vs. impact height and shows, in this case, a clear case of super-refraction.

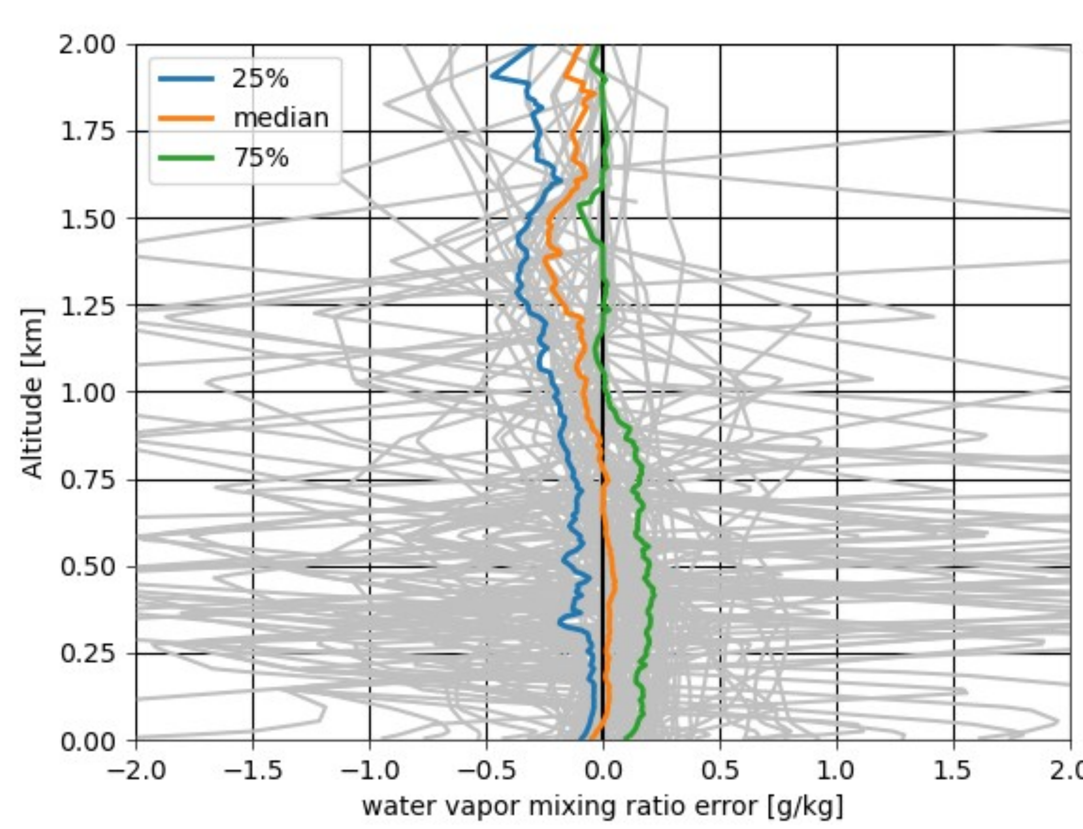


Figure 2. Statistics of simulation-retrieval demonstration of two-step approach. Errors in water vapor mixing ratio are plotted vs. altitude based on 53 ECMWF high-resolution profiles. Inter-quartile intervals are shown. While highly accurate and precise, this approach is computationally very expensive (~20 minutes) and prone to null-space instability, evident as outliers.

Super-refraction Parameterization

Algorithm

Assume super-refracting level as known and parameterize its structure (Xie et al. 2006).

1) Infer the super-refraction parameters by joint retrieval of RO and MW (RO+MW).
2) Alternatively, infer the super-refraction parameters by joint retrieval of RO and a 12-hr NWP forecast (RO+NWP).
3) Employ a simple 1DVAR approach to resolve the wet-dry ambiguity inherent to RO in lower troposphere.

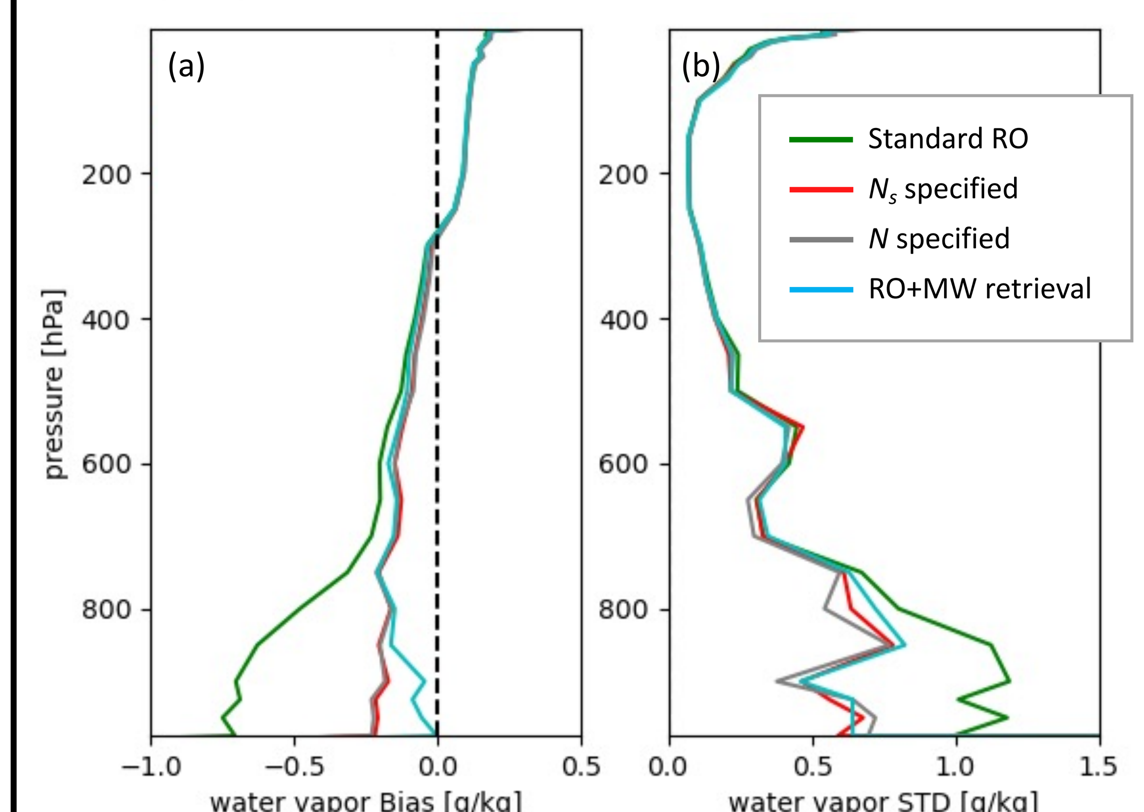


Figure 3. Statistics of RO+MW simulation-retrieval demonstration. High vertical-resolution radiosondes are used as input; RO amplitude and phase vs. time and ATMS channel radiances are simulated; temperature and water vapor are retrieved. Bias in the retrieval of water vapor mixing ratio shown on left, standard deviation on right. The results of standard RO retrieval shown as green; the (research-only) Xie et al. (2006) approach as red; perfect refractivity results as gray; and the RO+MW approach as aqua. (The MBL spans pressure from ~1000 to ~700 hPa.)

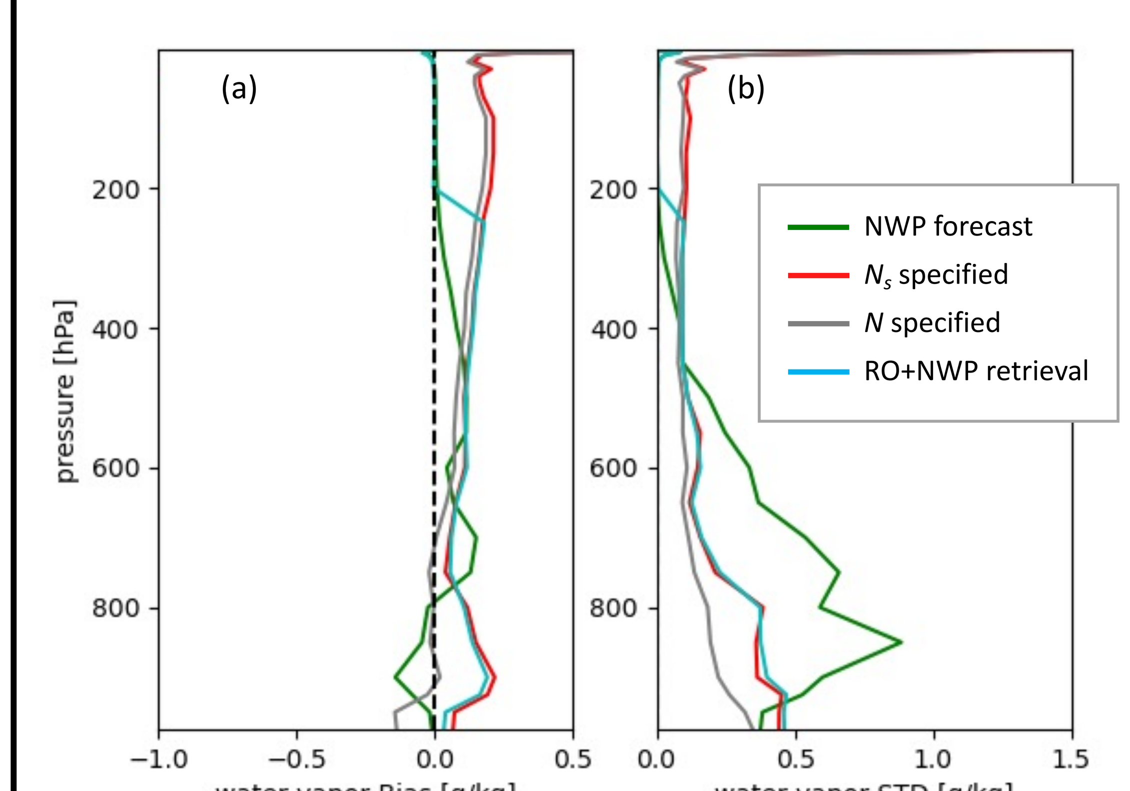


Figure 4. Same as figure 3 but for RO+NWP retrieval. The green is the error in the NWP forecast. The 12-hr forecasts of the NOAA GFS are used as priors.

Mission Configuration

RO and Passive Nadir Microwave Collocation

RO+MW retrieval requires collocated RO and MW soundings whereas RO+NWP retrieval does not. Mission architecture studies will require an efficient and accurate collocation tool, as brute force algorithms are extremely expensive computationally.

Rotation-collocation algorithm

Rotate RO soundings in space and time into the reference frame of the MW sounder's scan pattern and track the position of the RO sounding within a time window.

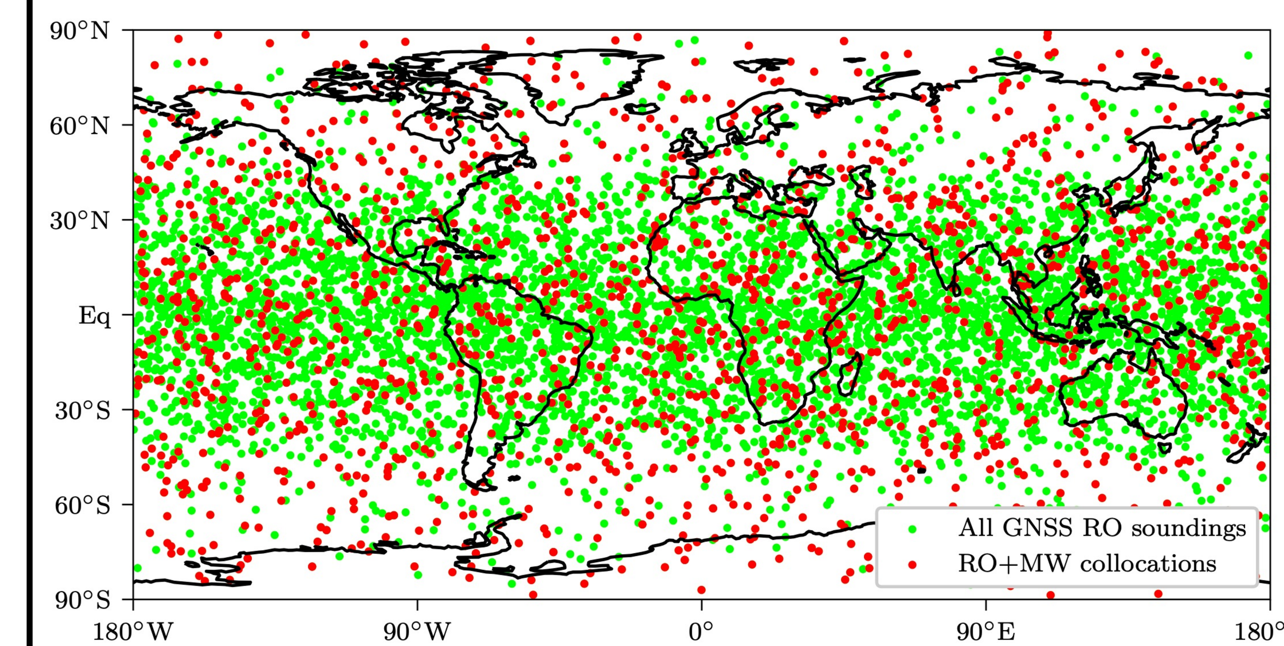


Figure 5. Daily GNSS RO soundings and RO+MW matchups. One day of RO soundings (COSMIC 2, Metop-A,B,C) are shown in green. The rotation-collocation method was used to find RO+MW collocations (~1,200) given Suomi-NPP, NOAA-20, and Metop-A,B,C MW instruments. The rotation-collocation algorithm is ~30 times faster than brute force searches and accurate to 99%.

Conclusions

RO+MW and RO+NWP retrieval algorithms for MBL water vapor have the potential for precision of ~1% and 100-m vertical resolution. The Xie et al. (2006) super-refraction parameterization is key.

The algorithms will be applied to actual RO, MW and NWP with further support.

RO+MW collocations are obtained at ~1,200 per day. Future RO collocation constellations can harvest ~30% of RO soundings with tandem RO+MW satellite configurations. If RO+NWP proves viable, however, collocation becomes unnecessary.

References

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Acknowledgements

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