Validation of Spire Radio Occultation Retrievals with SNPP ATMS Microwave and Radiosonde Measurements

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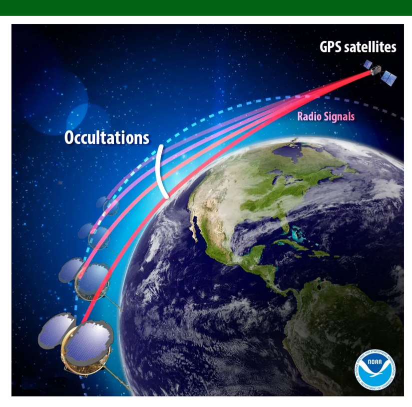
Abstract

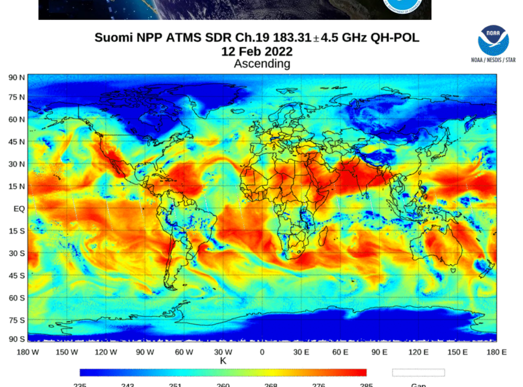
- Global Navigation Satellite System (GNSS) radio occultation (RO) data are collected by measuring the changes in a radio signal as it is refracted through the atmosphere, allowing derivation of temperatures and moisture in atmosphere's layers. The GNSS radio occultation RO data play an essential role in numerical weather prediction (NWP) and climate change monitoring.
- Spire RO data were provided to NOAA under the Commercial Weather Data for RO (CWD-RO) project to evaluate the commercial RO data quality. To ensure the data quality from Spire is consistent with other RO missions and is not significantly deviated from observations by NOAA's satellite, we need to quantify their accuracy and retrieval uncertainty carefully.
- In this work, the Spire Wet Profile (wet temperate and humidity profiles) data from 2021-09 to 2022-06 (Delivery Order-3 and -4) processed by the University Corporation for Atmospheric Research (UCAR) are evaluated through comparison with Suomi National Polar-orbiting Partnership (SNPP) Advanced Technology Microwave Sounder (ATMS) microwave sounder measurements and collocated radiosonde measurements.
- Observations from RO, microwave sounders such as ATMS, and radiosonde are all assimilated into NWP. The inter-consistency among Spire RO, SNPP ATMS, and radiosonde data is critical in improving the global weather forecasts and monitoring/predicting severe weather events, and still remains challenging to be quantitively characterized.

Datasets Used in This Study



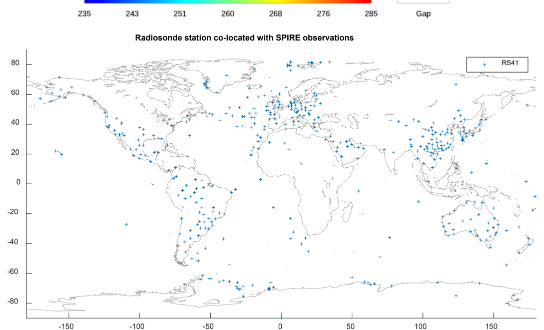
Spire RO Data under NOAA Commercial Weather Data (CWD) Project

- Under NOAA CWD program, Spire provides space-based radio occultation data to NOAA for the purpose of demonstrating data quality and potential value to NOAA's weather forecasts and warnings. (https://www.space.commerce.gov/noaa-awards-4th-delivery-order-for-commercial-radio-occultation-data/)
- GPS and GLONASS receiver
- Spire RO data evaluated in this study
  - Temperature and Humidity profile data processed by UCAR
  - 2021/09 to 2021/06



Advanced Technology Microwave Sounder (ATMS) Observations

- A cross-track scanner, 22 channels in bands from 23 GHz through 183 GHz.
- Provide sounding observations for retrieving profiles of atmospheric temperature and moisture for NWS as well for climate monitoring purposes.
- ATMS is onboard NPP and NOAA-20, and will be on the follow-on JPSS missions. ATMS is calibrated/Validated and monitored at NOAA/NESDIS/STAR.
- Collocated Spire RO and SNPP ATMS data over ocean are analysed.



Vaisala RS41 Radiosonde Observations

- Vaisala RS41 is equipped with advanced temperature and humidity sensor technologies
- Provide improvements in measurement accuracy for temperature, humidity, and pressure and wind parameters throughout the atmosphere.
- Collocated Spire RO and RS41 radiosonde observations (RAOB) data are analysed.

Inter-Comparison of Spire RO with SNPP ATMS Measurements over Ocean using Community Radiative-Transfer Model

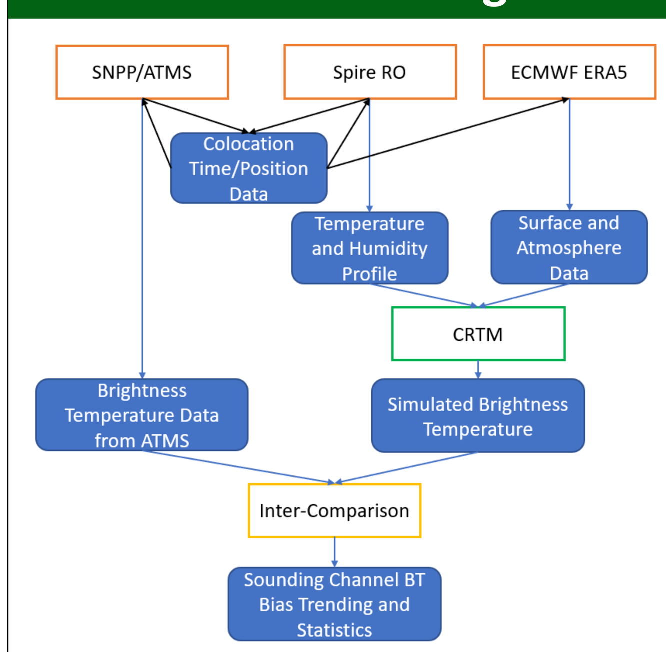


Figure 1: Radiative Transfer Modeling (RTM) simulation setup with CRTM as the simulator for inter-comparison between SNPP ATMS and Spire measurements.

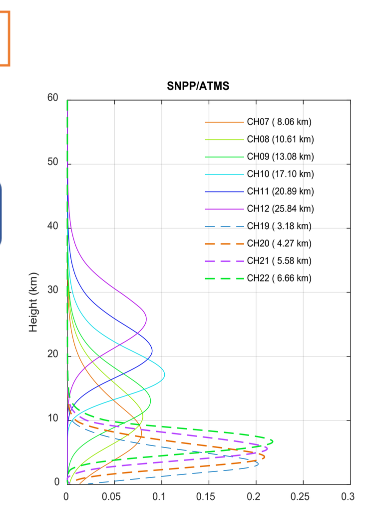


Figure 2: The weighting function and peak sounding heights for SNPP ATMS channels CH07–CH12 and CH19–22.

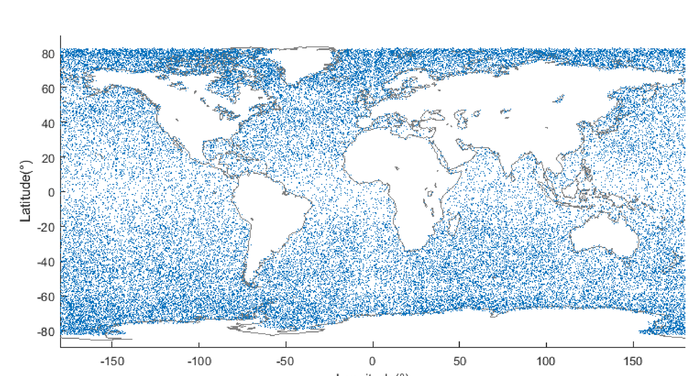


Figure 3: Global collocation distribution between Spire RO and SNPP ATMS measurements over the ocean.

- Through the Community Radiative Transfer Model (CRTM) simulation, the microwave sounder SNPP ATMS and Spire RO measurements are compared over the ATMS sounding channels CH07 to CH12 (temperature channels) with peak weighting function peak height from 8 to 25.8 km and CH19 to CH22 (water vapor channels) with weighting function peak heights ranging from 3.2 to 6.7 km.

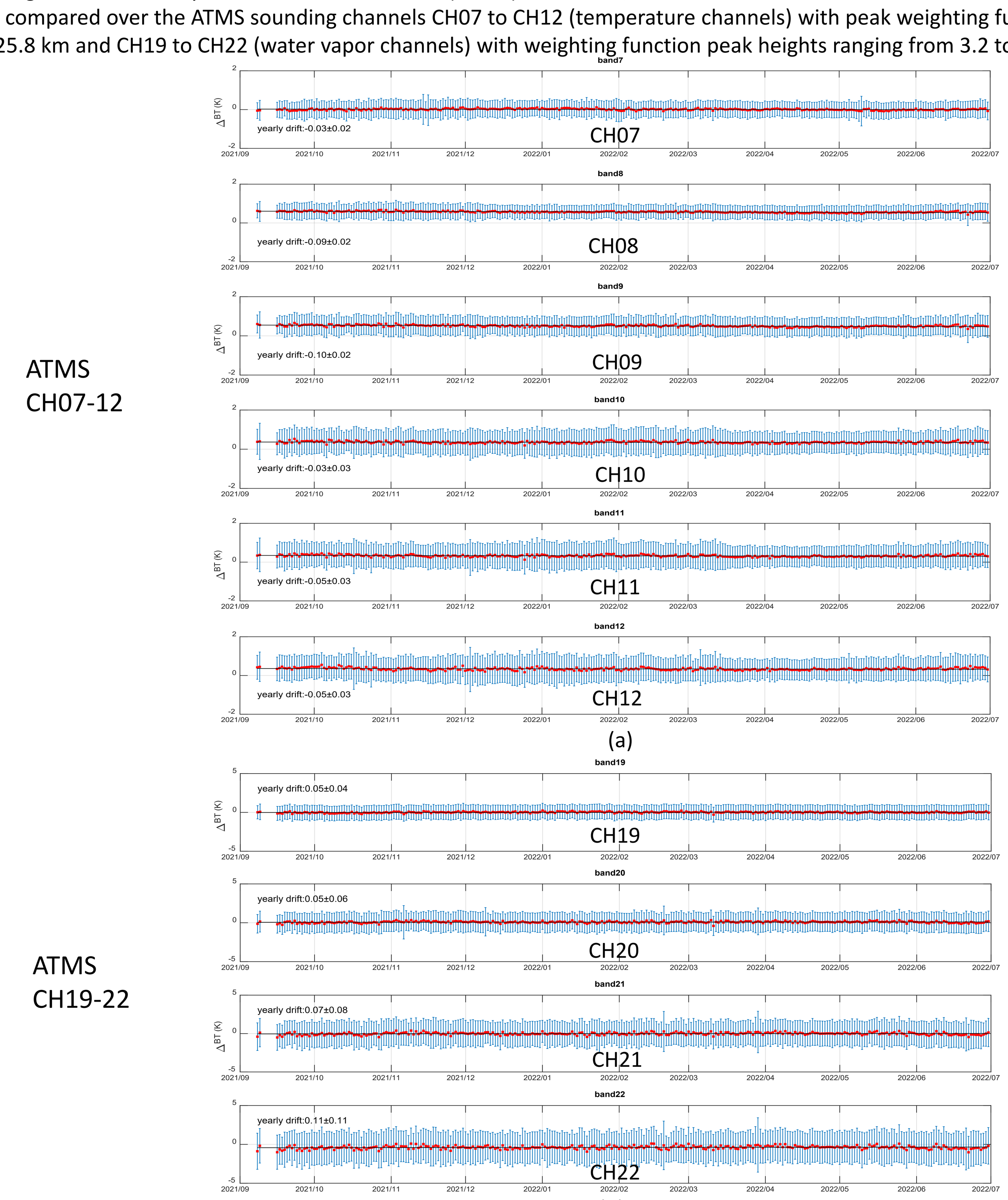


Figure 4: Trending of BT bias between CRTM-simulated Spire BT and SNPP ATMS measurements over 9 months from September 2021 to June 2022 for ATMS (a) CH07–12) and (b) CH19-22.

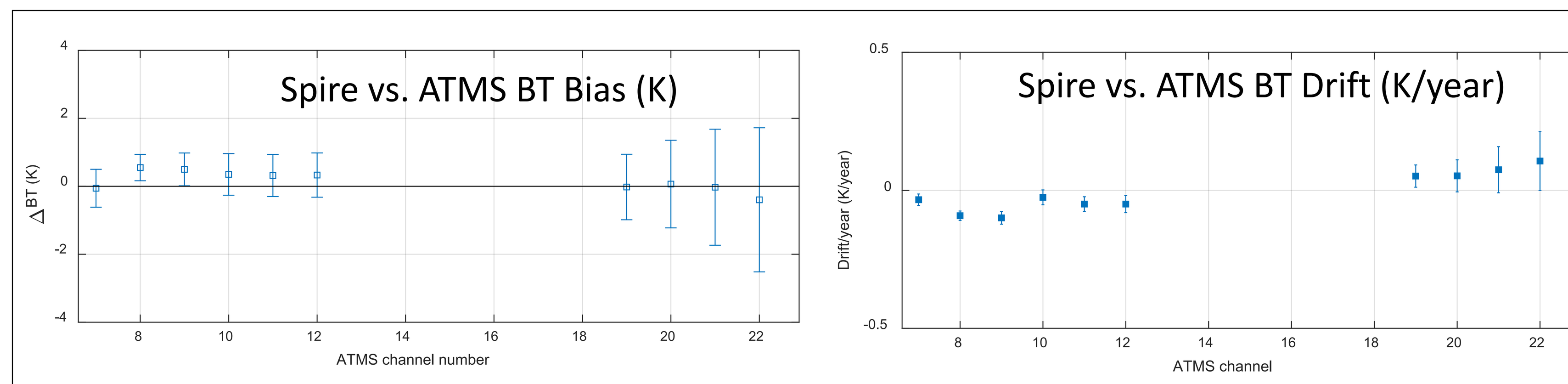


Figure 5: (Left) Mean BT biases (K) and (Right) BT bias trending slope ± 95% Confidence Interval (CI) (K/year) between CRTM-simulated BT data with UCAR Spire temperature/humidity data as inputs and SNPP ATMS measurements for ATMS CH7–CH12 and CH19–H22.

- For ATMS CH07, the Spire versus ATMS BT bias is within 0.1 K.
- For ATMS temperature sounding channels CH08-CH12, the Spire versus ATMS BT biases are within 0.6 K. The relatively large BT biases for these channels may come from CRTM simulation and are consistent with the results (within 0.15 K) from COSMIC-2 and ATMS comparison (Table 3 in Shao et al., 2021a) after applying double-difference method.
- For the ATMS moisture channels CH19-21, the Spire versus ATMS BT biases are consistent within 0.1 K.
- Preliminary stability analysis with ~9-month Spire data used in calculating Spire vs. ATMS BT drift.
  - The stability between modeled BT from Spire and ATMS measurements is consistent with the drift of BT bias < 0.05 K/year for ATMS CH07, CH10-CH12.
  - For ATMS CH19–CH20, the BT bias drifts are ~0.05 K/year, which shows the promising aspect of using Spire wet profiles for the calibration of these two ATMS water vapor channels.
  - The uncertainty of stability analysis is expected to be reduced with more extended time series of BT biases.

Inter-Comparison of Spire RO Retrieval Products with Radiosonde Water Vapor and Temperature Measurements

- Collocated UCAR Spire temperature and humidity data are compared with in-situ RS41 Radiosonde data (mostly over land).
  - Collocated Spire retrievals and RS41 RAOB data within 150 km and 2 hours in locations and time.
  - The Spire geo-location is defined at the longitude/latitude of the perigee point at the occultation point.
- The temperature profile comparisons are focused on the upper troposphere and lower stratosphere regions, while the evaluation of humidity data quality is mainly in the mid and lower troposphere.

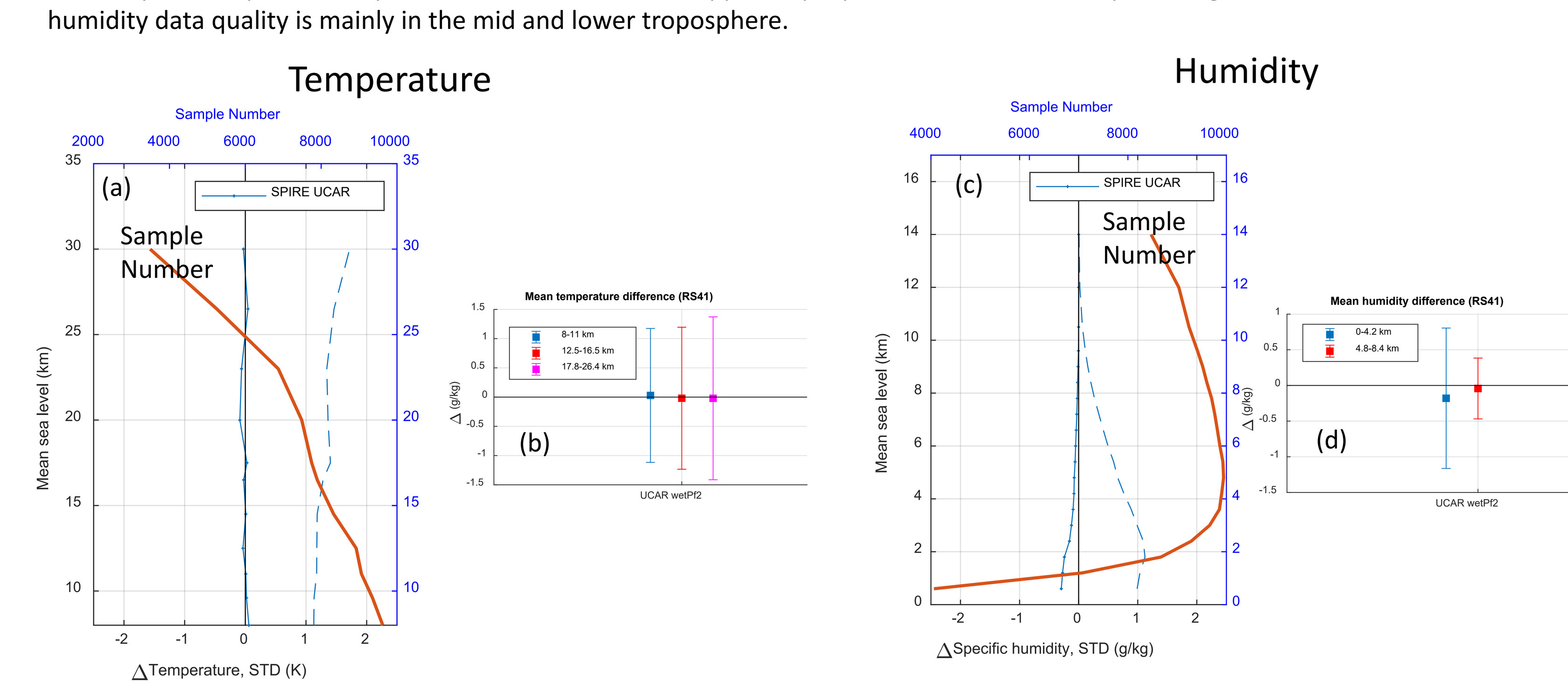


Figure 6: (a, c) Biases (dot lines) and uncertainties (dash lines) of (a) Spire temperature and (c) humidity profiles in comparison with RS41 RAOB data. The height variation of the number of samples used in the corresponding bias analysis is shown as red lines in each panel. (b) Mean temperature biases (K) of Spire versus RS41 RAOB observations over three height regions in the upper troposphere and lower stratosphere. (c) Mean humidity (g/kg) bias and uncertainty of Spire versus RS41 RAOB observations over two height regions in the lower troposphere.

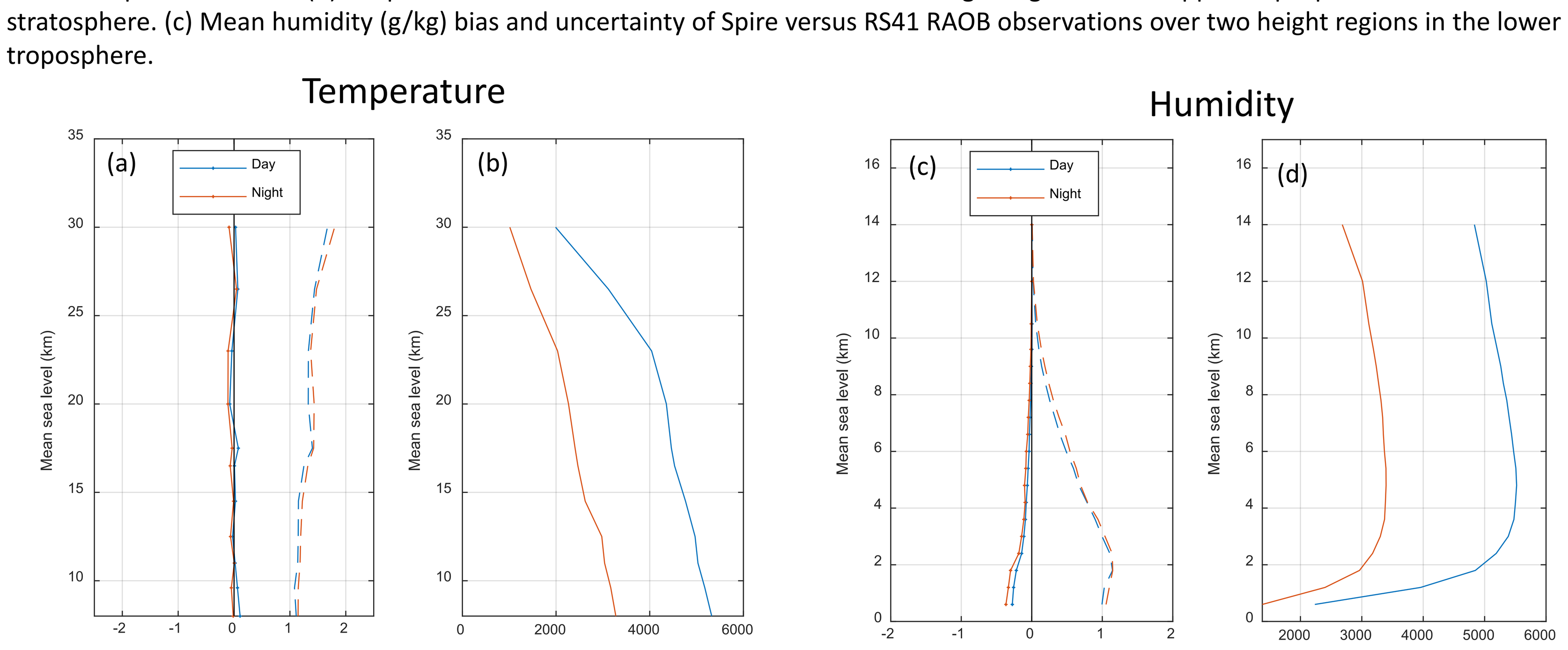


Figure 7: (a ,c) Height-dependent (a) temperature and (c) humidity biases and uncertainties of Spire wet profile versus RS41, observations in two SZA zones of daytime (SZA < 80°) and nighttime (SZA > 100°). (b, d) Height-varying sample number corresponding to the collocated cases in the two SZA zones shown in the (a) and (c), respectively.

- Overall temperature bias between Spire RO and RS41 RAOB is less than 0.05 K over height range from 8 to 30 km.
- Day-night temperature bias differences
  - Daytime bias is 0.06 K over 8-11 km and ~0 K over 12.5- 26.4 km; Mean night time bias is ~-0.05 K over 8-26.4 km.
  - 8-11 km: Day time bias is larger than night time bias by 0.1 K
  - 12.5- 26.4 km: Day time bias is larger than night time bias by ~0.05 K
- Below 4 km, the Spire humidity retrievals deviate from RS41 RAOBs with increasing negative humidity biases approaching the surface (Fig. 6c), which can be attributed to the negative refractivity biases due to the super-refraction conditions.
- Day-night humidity bias differences
  - Below 4.2 Km: Night time humidity bias is slightly lower (mean difference ~ 0.05 g/kg) than day time humidity bias
  - 4.8 to 8.4 Km: both night and day time humidity biases are small.
- Day-night difference between Spire RO and RS41 RAOB biases can be due to the radiation-induced error correction applied to RS41 sensor.

Summary

- Our evaluations show overall consistency between Spire data and SNPP ATMS data through CRTM simulation
  - For the ATMS CH07 and CH19-21, the Spire versus ATMS BT biases are consistent within 0.1 K. For ATM CH08 to CH12, Spire vs. ATMS BT biases are within 0.15 K in comparison with COSMIC-2 and ATMS comparison.
  - Preliminary Spire vs. ATMS BT stability analysis with ~9-month Spire data show the drift of BT bias ≤ 0.05 K/year for ATMS CH07, CH10-12 and CH19-20. Uncertainty of stability analysis is expected to be reduced with more extended time series of BT biases.
  - The stability of Spire RO data makes it well serves as the reference standard to detect and monitor the stability variation of sounding channels similar to ATMS CH7, CH10-12 and CH19–20 on other microwave-sounding sensors.
- Spire RO vs. RS41 RAOB temperature/humidity profile comparison
  - Over the height from 8 to 26 km, the RS41 RAOBs match Spire temperature profiles very well with temperature biases < 0.05 K.
  - Below 4 km, the Spire humidity retrievals have negative biases deviate from RS41 RAOBs with increasing negative humidity biases approaching the surface due to the super-refraction conditions.
  - The RAOB data quality can be affected by the solar illumination correction. Small day-night temperature and humidity bias differences can be detected with Spire data. Spire RO data provide an opportunity to serve as a reference to understand the day-night dependence of the temperature/humidity biases and uncertainties from the Vaisala RS41 RAOBs.

References:

Shao, X., Shu-Peng Ho, Bin Zhang, Changyong Cao, and Yong Chen, Consistency and Stability of SNPP ATMS Microwave Observations and COSMIC-2 Radio Occultation over Oceans, *Remote Sens.*, *13*, 3754, 2021a.

Shao, X., S.-P. Ho, B. Zhang, X. Zhou, S. Kireev, Y. Chen, and C. Cao, Comparison of COSMIC-2 radio occultation retrievals with RS41 and RS92 radiosonde humidity and temperature measurements. Terr. Atmos. Ocean. Sci., 32, 1015-1032, 2021b.

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