# Evaluation of Tropospheric Moisture Characteristics Among COSMIC-2, ERA5, and MERRA-2 in the Tropics and Subtropics

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## INTRODUCTION

- Accurate and consistent tropospheric water vapor measurements are essential for studying water vapor feedbacks on the global energy budget
- Many tools have been developed to observe water vapor distribution, each with their own strengths and limitations
- The radio occultation (RO) technique has many strengths, but low SNR in the lower troposphere can result in bending angle negative bias and derived moisture underrepresentation
- The COSMIC-2 (C2) satellite constellation, launched in July 2019, improves on this limitation by offering the highest SNR of any RO mission and increased tropical sampling density

**There are three main goals of this research:**

1) **Validate C2 specific humidity profiles through comparison with ERA5 and MERRA-2**
2) **Quantify tropical/subtropical moisture and its variability**
3) **Analyze when and why moisture differences can occur between the datasets**

## DATA

**COSMIC-2 GNSS Radio Occultation**

- Up to 5000 tropical and subtropical atmospheric profiles daily
- Horizontal resolution: ~200 km
- High vertical resolution (~200m in lower troposphere)
- All weather capabilities (insensitive to clouds/precipitation)

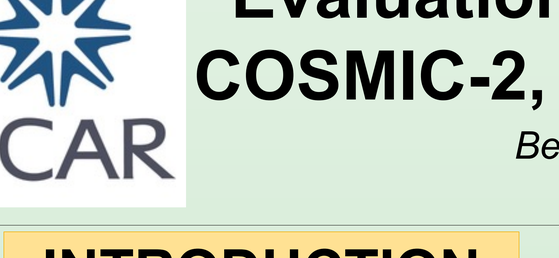


***Figure 1. C2 sampling using 5° × 5° grids (color contours) along with penetration percentage to at least 1 km above the surface (dashed contours).***

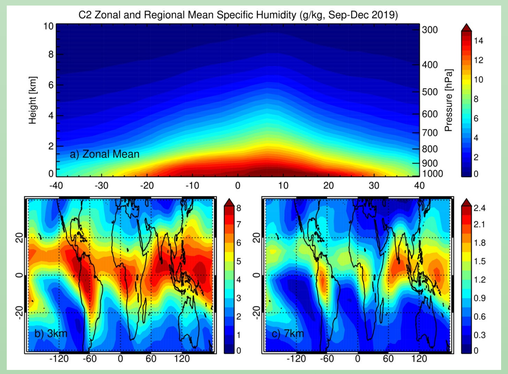


***Figure 2. (a) C2 zonal mean specific humidity (g/kg), along with the C2 specific humidity at (b) 3 km and (c) 7 km within 40° N–40° S.***

**ERA5 reanalysis**

- Temporal resolution: Hourly
- Horizontal resolution: ~31 km
- Vertical resolution: 137 levels

**MERRA-2 reanalysis**

- Temporal resolution: 3 hourly
- Horizontal resolution: ~50 km
- Vertical resolution: 72 levels

***Neither reanalysis had yet assimilated C2 data during the study period***

## METHODOLOGY

- Specific humidity (SH) profiles were obtained from the C2 wetPf2 retrievals from September-December 2019 between 40°N-40°S
- ERA5 and MERRA-2 reanalysis data were collocated to times and locations of RO profiles, including accounting for the tangent point drift of the profiles
- Profiles were interpolated to same uniform 50m vertical grid for ease of comparison
- Analyses were conducted zonally (2.5°) and by lat/lon (5°x5°) at two tropospheric altitudes
  - 3km is within the moist lower troposphere but above the boundary layer
  - 7km is within the middle troposphere
- Moisture differences were also studied in regions where large moisture differences and weaker correlations were observed to better understand why large SH differences can occur between profile pairs, including in regions that see frequent deep convection or strong moisture gradients

## RESULTS

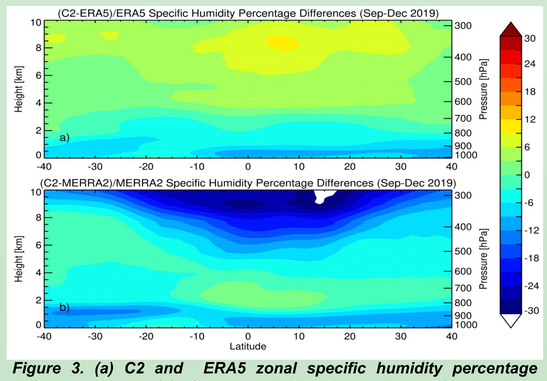


***Figure 3. (a) C2 and ERA5 zonal specific humidity percentage differences, and (b) C2 and MERRA-2 zonal specific humidity percentage differences within 40° N–40° S.***

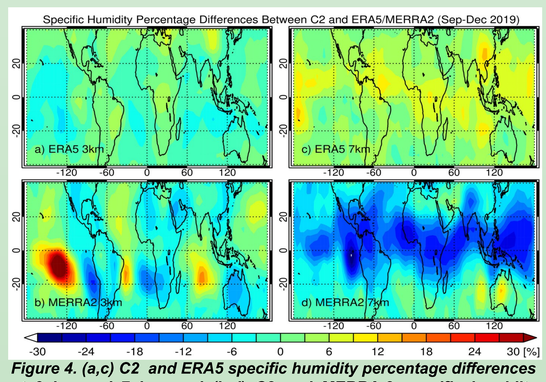


***Figure 4. (a,c) C2 and ERA5 specific humidity percentage differences at 3 km and 7 km, and (b,d) C2 and MERRA-2 specific humidity percentage differences at 3 km and 7 km within 40° N–40° S.***

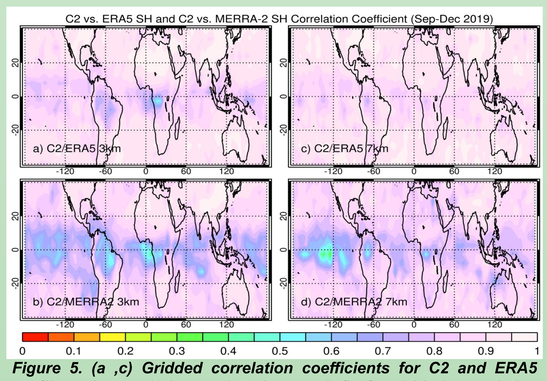


***Figure 5. (a ,c) Gridded correlation coefficients for C2 and ERA5 profile pairs at 3 km and 7 km, and (b,d) gridded correlation coefficients for C2 and MERRA-2 profile pairs at 3 km and 7 km.***

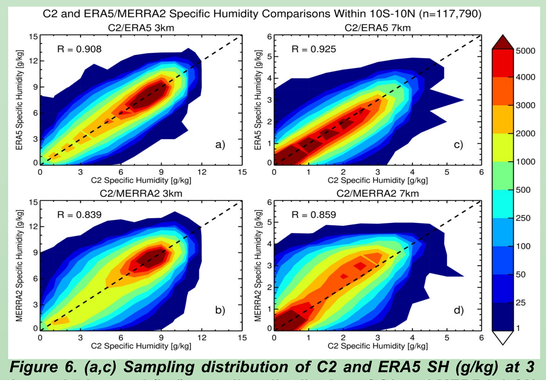


***Figure 6. (a,c) Sampling distribution of C2 and ERA5 SH (g/kg) at 3 km and 7 km, and (b,d) sampling distribution of C2 and MERRA-2 SH (g/kg) at 3 km and 7 km within 10° N–10° S.***

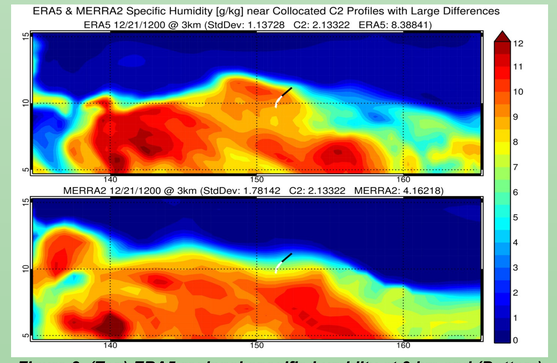


***Figure 8. (Top) ERA5 regional specific humidity at 3 km and (Bottom) MERRA-2 regional specific humidity at 3 km on 21 December 2019 at 12:00 UTC. Collocated C2 profile tangent points are indicated by the solid line, with the black line indicating tangent points below 5 km.***

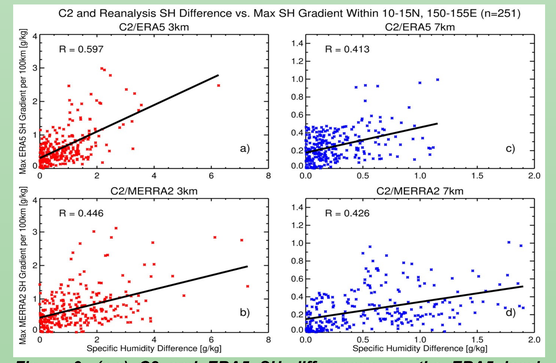


***Figure 9. (a,c) C2 and ERA5 SH differences vs. the ERA5 local moisture gradient per 100 km at 3 km and 7 km, and (b,d) C2 and MERRA-2 SH differences vs. the MERRA-2 local moisture gradient per 100 km at 3 km and 7 km within 10° N–15° N, 150° E–155° E.***

## RESULTS

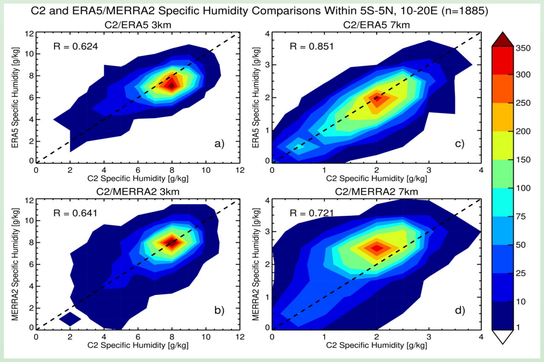


***Figure 10. (a,c) Sampling distribution of C2 and ERA5 specific humidity at 3 km and 7 km, and (b,d) sampling distribution of C2 and MERRA-2 specific humidity at 3 km and 7 km within 5° S–5° N, 10° E–20° E.***

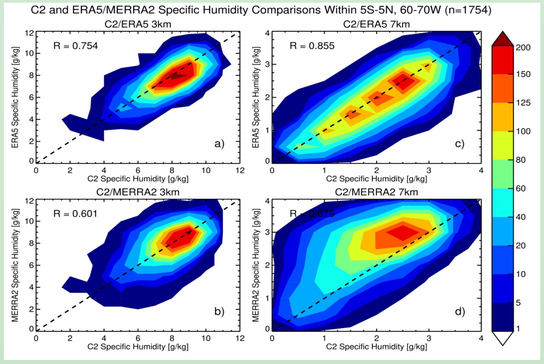


***Figure 11. (a,c) Sampling distribution of C2 and ERA5 specific humidity at 3 km and 7 km, and (b,d) sampling distribution of C2 and MERRA-2 specific humidity at 3 km and 7 km within 5° S–5° N, 60° W–70° W.***

## CONCLUSIONS

- Good agreement is generally seen between C2 and each reanalysis, with larger differences observed for the C2/MERRA-2 time-means
- Zonal analysis showed negative bias within boundary layer, likely due to receiver tracking errors and super-refraction
- At 7km, C2 displayed slightly more moisture than ERA5 (6–12%) and much less moisture than MERRA2 (15–30%) attributed to the underlying MERRA-2 AGCM that produces too much evaporation of tropical middle and upper tropospheric cloud ice crystals
- High correlation coefficients observed in the subtropics (>0.9) with lower coefficients within the tropics (0.5-0.8)
- Deep tropics – At 3km, excellent agreement between C2 and ERA5/MERRA-2; At 7km, C2 showed larger SH values than ERA5 and much smaller SH values than MERRA-2 when moisture amounts increased
- Large moisture differences were observed in locations with strong moisture gradients and these differences increased as humidity gradients increased, which highlights the importance of dataset resolution differences
- In regions with frequent deep convection, ERA5 has a negative SH bias at 3 km in higher moisture environments while at 7 km, MERRA-2 displayed large positive bias and C2 agreed well with ERA5

## ACKNOWLEDGEMENTS

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