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Atmospheric diurnal variations observed with GPS radio occultation soundings

F. Xie^{1,2}, D. L. Wu¹, C. O. Ao¹, and A. J. Mannucci¹

¹ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

² Joint Institute for Regional Earth System Science and Engineering, UCLA, CA

We thank all reviewers for the very insightful and detailed comments. Following the reviewers' suggestions, we made some major changes:

- (1) Remove the semi-diurnal variation component from the paper.
 - a. New title: "Atmospheric diurnal variations observed with GPS radio occultation soundings"
 - b. Remove Fig.2 showing semi-diurnal variations in tropics.
 - c. Remove Semi-diurnal amplitude plots in Fig.4

We agree with the reviewer#1 and review#3 that the phase of the semi-diurnal variations derived from COSMIC RO in the tropics is rather noisy and might not be statistically significant due to weak semidiurnal signal and possibly the lack of sampling. Although, we believe some significant semi-diurnal amplitude over high-latitude stratosphere and the lower troposphere could be realistic, we decide to leave it out, since it could be better supported with model simulations, which is currently not available.

- (2) Different colors are added into Fig-1a,c to distinguish different seasons in the diurnal tidal amplitude.
- (3) Fig.3 is changed to color version.
- (4) Change the title of Section 3 from "*Tropical Tidal Waves*" to "Tropical Diurnal Variations - the Tidal Waves". Also "Section 3.1" title is removed.
- (5) Remove the less relevant information in "Discussion" section related to the PBL retrieval in RO observations.

The reviewer's specific comments are addressed as follows.

Replies to Referee #3

Specific comments:

1. The authors state that “the six satellites, with a 30° orbital plane spacing, give a full diurnal cycle sampling ... within about one month for higher latitudes” (Page25413, Line5-7). For high latitudes, the COSMIC constellation seems not able to sample all local times uniformly within a month. The results over the high latitudes therefore might be questionable. Even though the authors tried to use RO data processed by different centers to investigate the reliability of their results in the discussion part, still under-sampling problem of COSMIC data itself won't be accounted. If possible, a simple simulation study using synthetic data might be helpful for testing the effects of this under-sampling problem.

We thank the reviewer for raising the important sampling issue. We look closely at the sampling rate at different latitudes including the high latitudes, and we believe that the sampling rate at high/polar latitudes should be adequate for diurnal variation study.

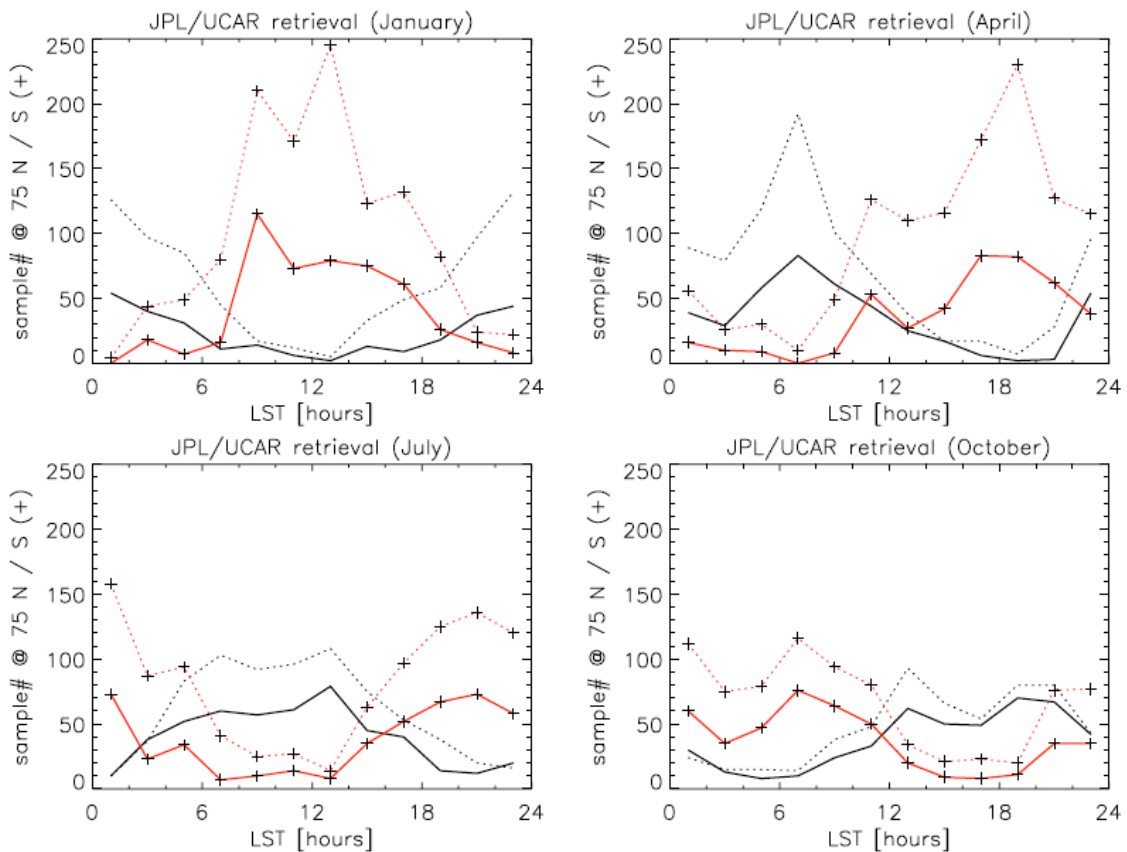


Figure A. COSMIC RO monthly (January, April, July and October) sample numbers within 2-hour LST bin, 5-deg latitude band (at 75°N and 75°S) from JPL (solid) and UCAR (dashed) retrievals in 2007. Note the sample numbers at 75°S are denoted by the

plus signs.

The Figure-A above shows the COSMIC RO samples from both JPL and UCAR retrievals in 2007. Note that the six COSMIC satellites were spread out but not in the final configuration in early 2007. Therefore, the COSMIC RO does show less uniform local time sampling in the polar region 75°N and 75°S. For example, there are fewer profiles in 75°N around noon in January and 19:00pm LST in April. However, there are still many samples for close-by local time.

Yes, the synthetic data could be helpful for addressing the sampling errors. However, over polar region, the diurnal variations and the planetary waves in the troposphere and stratosphere are not well known. The synthetic data set (e.g. model analysis) with normally 4 times a day, might not be able to simulate the diurnal variations and the red-spectrum like noises well. Therefore it could introduce challenge to quantify the realistic aliasing errors due to the spectrum leakage from the red-noise.

On the other hand, double sampling is another simple way of checking the aliasing error due to the spectrum leakage. The UCAR retrieval has double sampling over polar regions due to implementation of different calibration and quality control procedures. The double sampling reduces the amplitude by 10~20% overall, but resulting similar diurnal/semi-diurnal amplitude patterns. It is worthy to note that the diurnal amplitude is reduced by about 40% over north polar stratosphere between 100 hPa and 30 hPa around 75°N in January 2007. Another similar reduction of diurnal amplitude is found in south polar stratosphere at around 80°S in April 2008.

This suggests that to first order the diurnal amplitude extracted from the GPSRO (JPL retrieval) is statistically significant and the aliasing from under-sampling is non-negligible in some months but plays a secondary role. Quantitative evaluation of the aliasing errors due to the un-even and insufficient sampling would require further spectrum analysis (e.g., Wu et al., 1995).

2. Since the temperature and refractivity are one-one correspondences at specific pressure level in the upper troposphere and stratosphere, it is ideal that if the author can more clearly address the motivation and meaning of studying the diurnal refractivity variations over other height ranges.

Yes, it is certainly a challenge to directly interpret the refractivity in the lower moist troposphere. However, due to the relatively simple relation between the temperature and water vapor variation to the refractivity (Section 2.1). We think it is still very interesting to show the diurnal variations in terms of refractivity, which is better interpreted as air density

in the upper dry atmosphere, and the linear combination of dry air and water vapor in the lower troposphere. Also, it is rather straightforward to compute the diurnal refractivity amplitude from the model or analysis, which can be easily compared with the RO observations.

3. There's only one subsection 3.1 for Section 3. Also the term "migrating tides" is introduced suddenly in the beginning Section 3, which has no difference with "diurnal variations" widely used in the whole paper herein. I think it might be good to consistently use "diurnal variations" here unless the authors have other intention.

Change the title of Section 3 from "Tropical Tidal Waves" to "Tropical Diurnal Variations – the Tidal Waves". Also the title of Section 3.1 is removed.

The first two lines in Section 3 is modified as follows:

"The diurnal variation in the tropical region, investigated for decades, is one of the most well-observed and understood phenomena among tropical variabilities. The propagating (sun-synchronous) component of the diurnal variation is also called migrating atmospheric tide."

4. The semidiurnal amplitudes presented in this paper seem quite large for some seasons and altitudes, while their phases are rather irregular. The reader might question the reliability of these results. It might be useful if the authors can show the semidiurnal variations resolved from the models or global analysis data as references. Also since the presented seasonal variations of semidiurnal cycles are prominent (seen from Fig. 2), what would its seasonal variation look like (similar to Fig. 3)?

We have removed the semi-diurnal variation component from the paper (Fig.2 and part of Fig.5 in the former draft).

We agree with the reviewer that the phase of the semi-diurnal variations derived from COSMIC RO in the tropics is rather noisy and might not be statistically significant due to weak semidiurnal signal and possibly the lack of sampling. Although, we believe some significant semi-diurnal amplitude over high-latitude stratosphere and the lower troposphere could be realistic, we decide to leave it out, since it could be better supported with model simulations, which is currently not available. Also, it could be better to utilize all three plus years of COSMIC data together for the semi-diurnal variation analysis.

5. The authors mentioned several issues in the discussion section, some of them are not closely related (i.e. the last paragraph on Page 25428) or too general (i.e. ionospheric

residual effects on diurnal variations. How big is it? Any references?) to the topic of this paper.

Remove the discussion part of “PBL retrieval in RO observations” and adding the following sentences:

“However, the RO refractivity observations in the lower troposphere are likely to be contaminated by the negative bias in the presence of super-refraction (or ducting) near the PBL top (Sokolovskiy 2003; Xie et al., 2006; Ao, 2007). Such biased RO profiles would need to be corrected (e.g., Xie et al., 2006) before applying for diurnal analysis.”

Reference: (Kursinski et al., 1997) is added for ionospheric residual error discussion.

Technical corrections:

1. P25410, L18: “solor” -> “solar”
2. P25410, L20: “shows” -> “show”
3. P25411, L10: “Linzen” -> “Lindzen”
4. P25413, L11-17: “Sect.” -> “Section”
5. P25414, L9: “Shreiner” -> “Schreiner”
6. P25414, L13-16: Keep consistence with the unit of pressure, mbar or hPa
7. P25414, L20: “Kursinski, et al, 1997” -> “Kursinski et al., 1997”
8. P25418, L13: “some of the earlier studies” -> “some earlier studies”
9. P25420, L6: “Linzen” -> “Lindzen”
10. P25423, L29: “August~October” -> “August-October”

All the above suggestions are included in the new draft. Thanks.