Comparative Analysis of the Planetary Boundary Layer using COSMIC-2, ERA5 and Radiosondes in Houston, Texas

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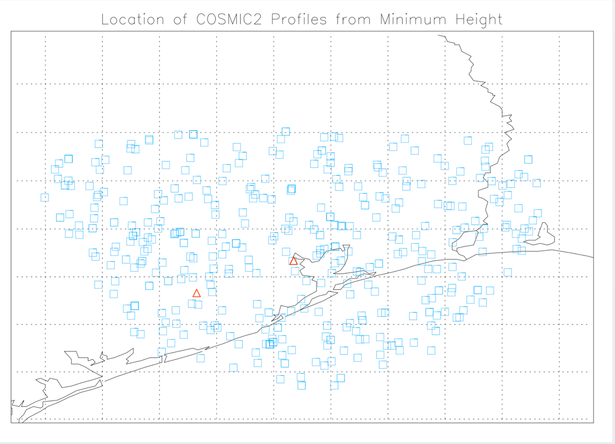
Introduction

The planetary boundary layer (PBL) significantly impacts weather and climate by affecting surface conditions, atmospheric turbulence, and the exchange of heat, moisture, and momentum between the Earth's surface and the atmosphere. Accurately representing the PBL and its heights is crucial for enhancing weather forecasts and climate models. This study offers an in-depth comparison of PBL structure and heights using high-resolution radiosonde data, COSMIC-2 radio occultation (RO) observations, and ERA5 reanalysis data collected in Houston, Texas, spanning from October 2021 to September 2022. The Houston area is located near the Gulf of Mexico providing an interesting testbed in coastal PBL study affected by the land-ocean contrast.

The quality of COSMIC-2 sounding was evaluated by the collocated radiosonde and ERA5. Each data set was run through the PBL height (PBLH) detection code and the frequency of multiple layers was noted. The seasonal and diurnal variation of the PBL was further investigated from the three datasets.

Data

- TRACER (Houston, TX) Radiosondes
  - October 1, 2021, to September 30, 2022
  - Sent up in 6-hour increments
  - High resolution and frequency radiosondes
  - Location (**29.670, -95.059**)
- ECMWF Reanalysis 5 (ERA5)
  - Collocated within closest grid and 3 hours of radiosonde launch time
  - Model Level information
- COSMIC-2
  - Collocated within 1.5 hours and 150 km of Houston radiosonde launch location
  - Level 2
    - Refractivity
    - Altitude



Location of the minimum height of every COSMIC2 profile used in the data set. 428 total profiles. Red triangles indicate the locations of radiosonde launch site.

- Range of minimum heights [0.00076 to 4.973 km]
- Mean min. height 0.525 km
- Median min. height 0.340 km

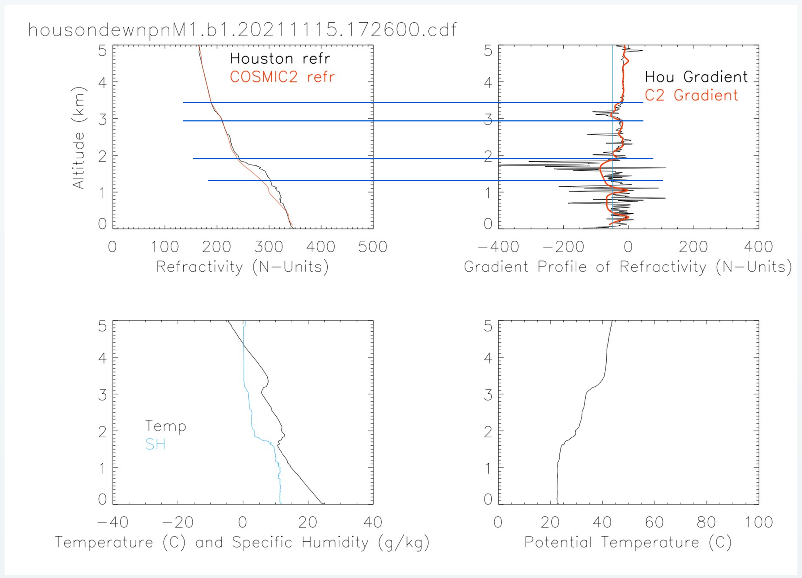
Acknowledgements

- Radiosonde from ARM Tracker Aerosol Convection Interactions Experiment (TRACER)
- ERA5 from ECMWF
- COSMIC-2 from UCAR CDAAC group
- NASA grant (NNH22ZDA001N-CNVOE)
- UCAR-COSMIC2 travel and housing assistance
- Lok Adhikari for his assistance with coding setbacks.

Methodology

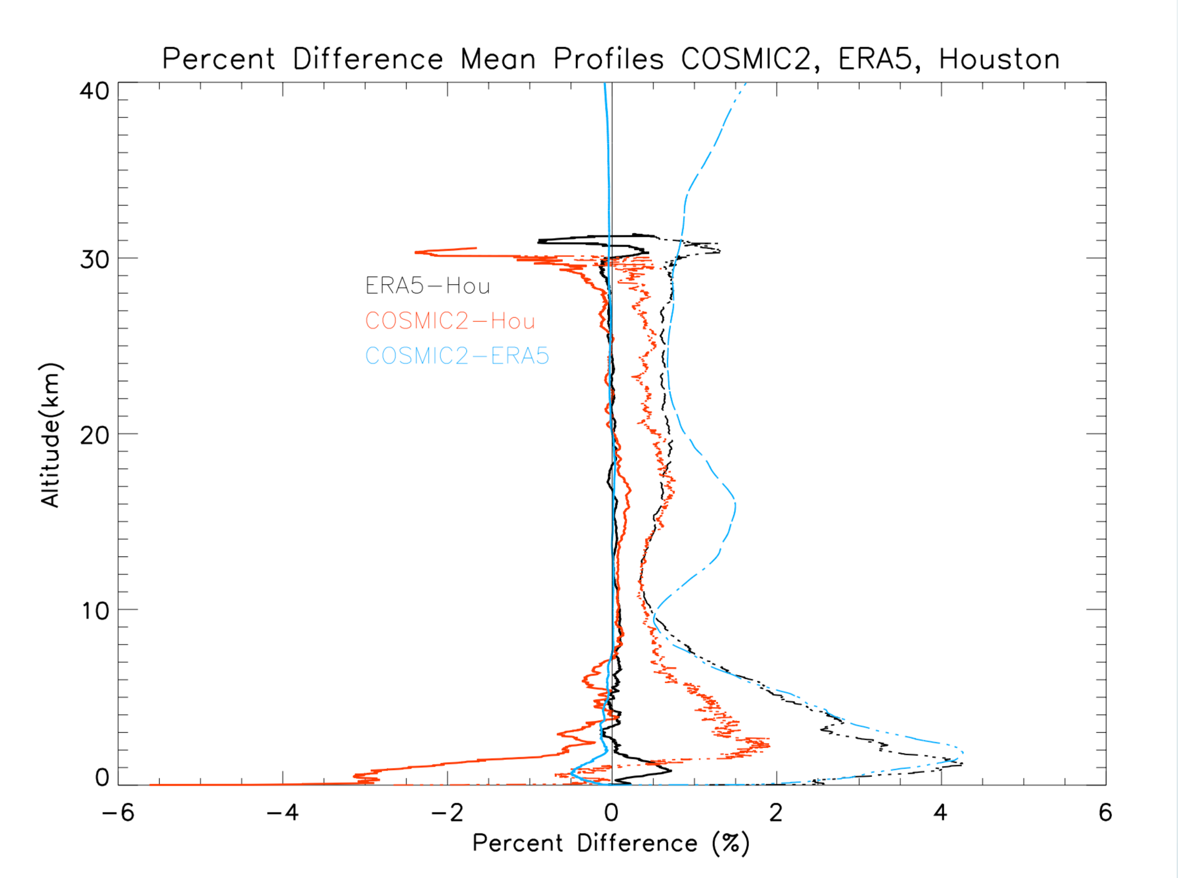
To further investigate the PBL and its structure, a procedure was created to determine multiple layers, if present, and ascertain the thickness of the respective layers.

- Ensure penetration threshold of at least 300 m
- Interpolate refractivity to every 10 m using quadratic interpolation
- Gradient Method used to discern minimums of refractivity profile (Seidel 2010)
- Find local minima that are below a gradient threshold.
  - -50 dN/dZ
- Group layers together based on sequential indices
- Determine the thickness of the layer, with a threshold of 100 m.
- Determine the largest sharpness parameter (Ao et al., 2012)
- If layer is greater than 100 m thick, that is the PBLH.
  - If there are multiple layers that are greater than 200 m thick, the taller height is determined as the PBLH.
  - 239/428 cases for COSMIC2 and 11/428 cases for collocated Houston radiosondes



11/15/2021: **Prominent case of Multi-layer PBL.** The gradient shows that COSMIC2 has a well-defined minimum at 1.64 km (730 m thick) but it also identifies the second layer a 3.0 km (120 m thick). The radiosonde PBLH was 1.73 km (180 m thick). There was not another layer thicker than the thickness threshold, but can still identify the gradient minimum around 3.1 km (70 m thick)

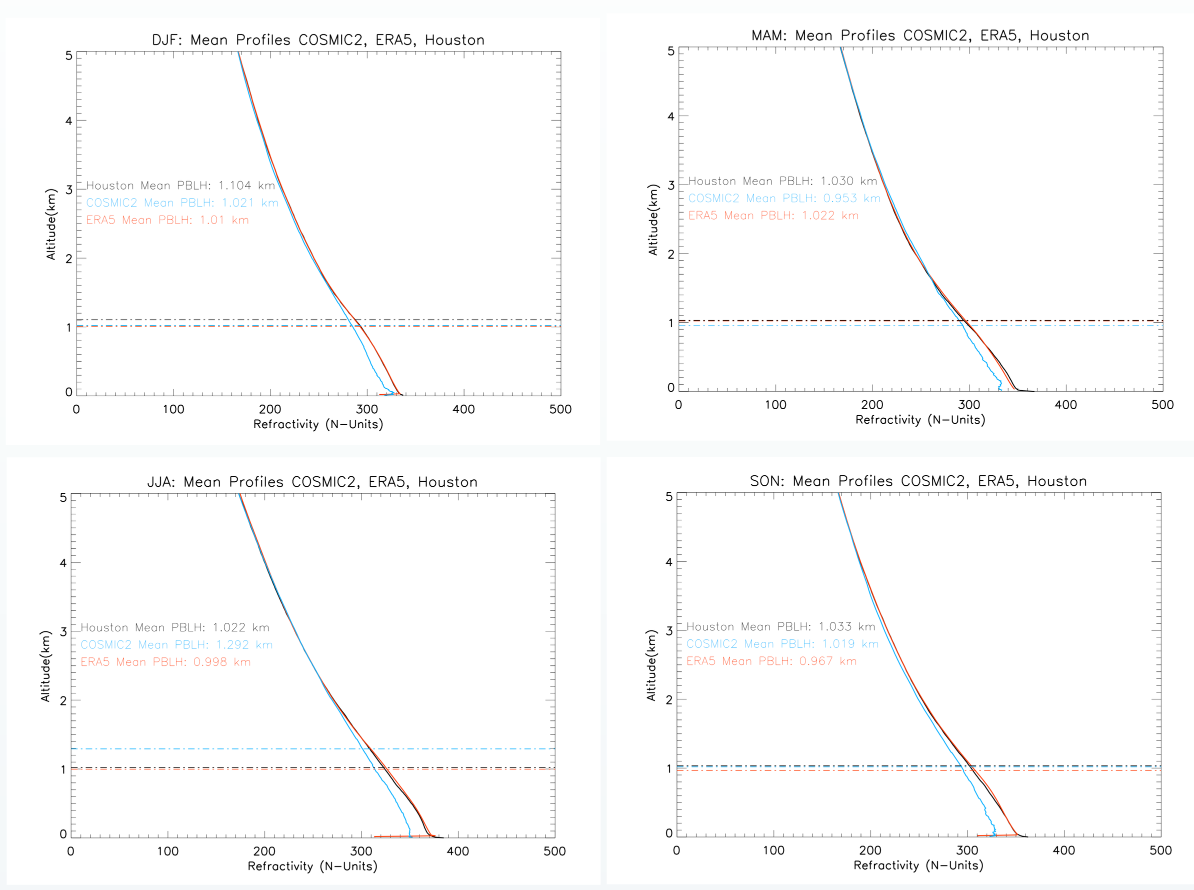
Intercomparison



Mean fractional refractivity difference (solid) and the standard deviation (dashed). Black is ERA5 minus Houston, red is COSMIC-2 minus Houston, and blue is COSMIC-2 minus ERA5

The mean biases are less than1% different with a bit more deviation below 8 km. COSMIC-2 differs close to 3% below 2 km which is expected due to the existing RO negative refractivity bias.

Seasonal Comparison



Seasonal mean refractivity profiles. Mean PBLH Houston radiosonde, ERA5 and COSMIC2 are the dashed lines of Black, Red, and Blue, respectively.

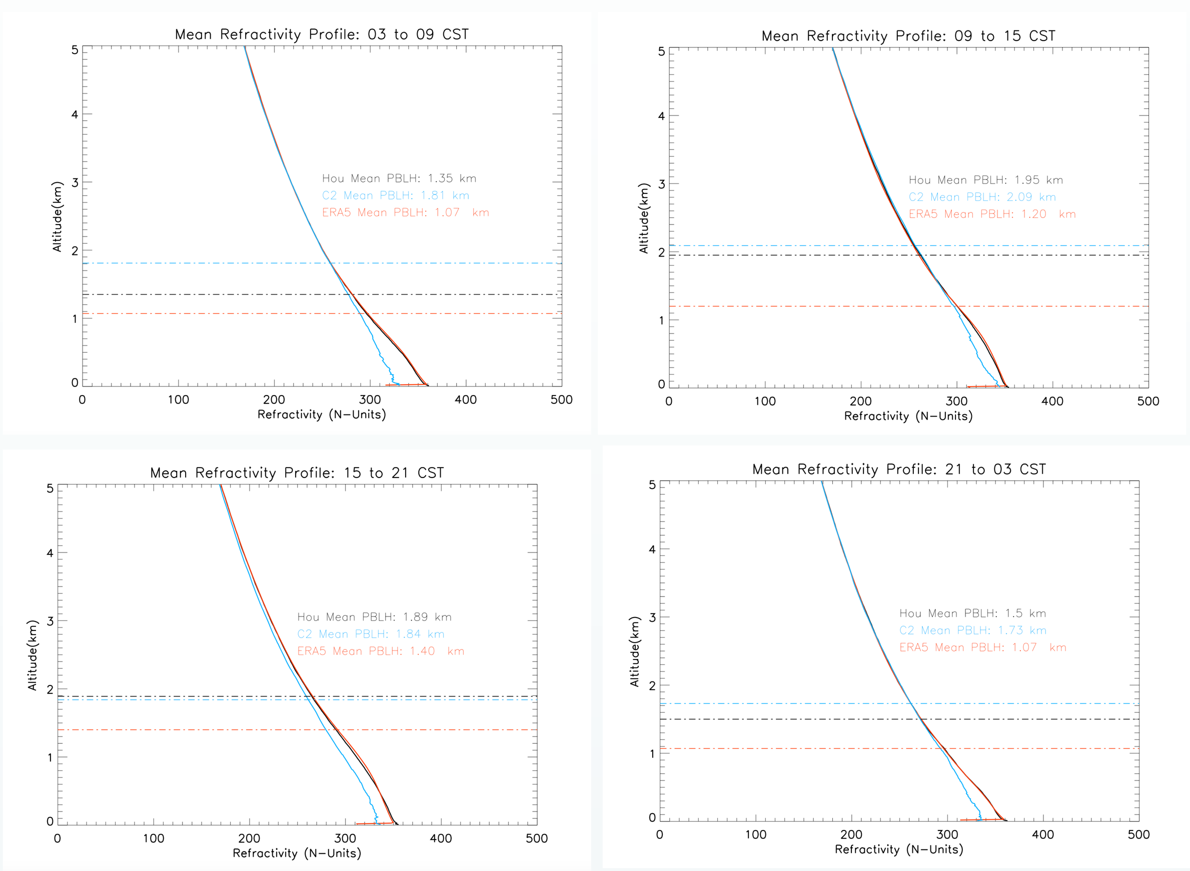
COSMIC2 seems to be consistently drier than ERA5 and radiosonde profiles. There is a larger discrepancy between COSMIC2 and the other two data set in the cooler months (SON & DJF). The large increase below 2 km in all data sets indicates an extremely moist environment. The mean PBLH are relatively the same across the data sets.

	COSMIC-2		ERA		RADIOSONDE	
	Mean/SDEV	Median/MAD	Mean/SDEV	Median/MAD	Mean/SDEV	Median/MAD
All	1.241/0.45	1.249/0.38	1.064/0.444	1.041/0.369	1.132/0.46	1.116/0.34
DJF	1.021/0.53	0.959/0.44	1.01/0.439	1.009/0.36	1.104/0.42	1.099/0.35
MAM	0.953/0.56	0.999/0.48	1.022/0.460	0.959/0.377	1.030/0.43	1.009/0.35
JJA	1.292/0.53	1.269/0.47	0.998/0.431	0.969/0.367	1.022/0.45	0.969/0.38
SON	1.019/0.52	1.079/0.45	0.967/0.466	0.949/0.383	1.033/0.43	1.001/0.37

Mean and median PBL heights for each data set. The standard deviation and median absolute deviation are also included.

COSMIC2 has a slightly higher PBLH than ERA5 and Houston except for the MAM months. The ERA5 is generally lower suggesting a possible under-estimation of parameterized processes such as turbulence or convection. This could also be due to broad grid estimations whereas Houston data is an in-situ observation.

Diurnal Comparison



This time series shows how the mean refractivity profile changes during the different times of day. The time is centered around the Houston Radiosonde launch times [0600, 1200, 1800, and 2400 Central Standard Time] to get an easier idea of local time of day.

COSMIC2 has the smallest bias 15-21 Z in regard to PBLH but is does much worse during the overnight/early morning hours than Houston radiosondes (Nelson, 2021).

Conclusions

- COSMIC2 does reasonably well in detecting PBL in the Houston area. The multi-layer PBL is harder to discern, but a detection has been developed.
- COSMIC-2 is capable of detecting a multiple-layer PBL.
- COSMIC-2 is very comparative to Houston Radiosondes and ERA5 is good until below 2 km where there is a slight negative bias from COSMIC-2.
- Seasonal and Diurnal variation is clearly seen in the refractivity profile, although biased.
- ERA5 is extremely similar radiosonde data in all cases.

Future Work:

- Expanding the radiosonde and COSMIC2 datasets should help with the sampling issues to look deeper into the diurnal variation of PBL and the corresponding height levels.
- Expanding to other coastal areas such as Corpus Christi, TX, and Lake Charles, LA, to get a better grasp of the change that occurs along the coast.

References

Nelson, K. J. et al, 2021: Diurnal Variation of the Planetary Boundary Layer Height Observed from GNSS Radio Occultation and Radiosonde Soundings over the Southern Great Plains.

Seidel. D. J. et al, 2010: Estimating Climatological planetary boundary layer heights from radiosonde observations: Comparison of methods and uncertainty analysis