Detection of the diurnal Variation of the Planetary Boundary Layer Height over Oceans using COSMIC-2

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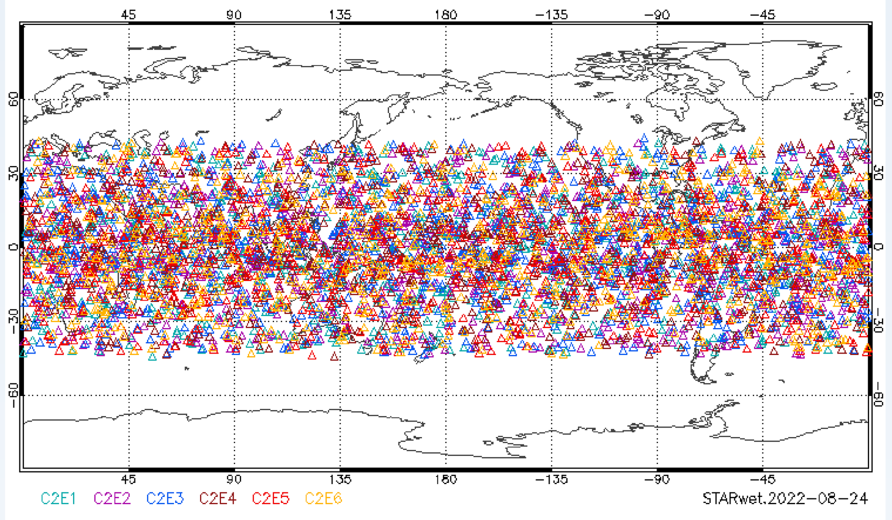
Abstract

- The planetary boundary layer (PBL) is an essential component of the troposphere. It controls rapid exchanges of heat, moisture, and chemical constituents between the surface and free atmosphere.
- A fundamental variable of the PBL is the top height (PBLH). The PBL structure is complicated, and the PBLH usually exhibits a robust diurnal cycle associated with the daily variation of solar radiation.
- The PBLH is often diagnosed from vertical profiles of temperature, humidity, and wind components. These profiles are conventionally measured with radiosondes only twice a day at 0000 and 1200 UTC, which cannot possibly capture the diurnal variations of the PBLH. In the meantime, most radiosonde profiles are reported only for the mandatory pressure levels with an insufficient vertical resolution to estimate PBLH with an acceptable uncertainty.
- Utilizing the strength of Global Navigation Satellite System (GNSS) Radio Occultation (RO) with the high vertical resolution (~ 200 meters), deeper penetration (75% of profiles penetrate to below 500 meters) and relative uniform geographic/local time distribution globally, the PBLH can be identified as the layer at the sharp atmospheric density changes near the surface.
- An objective and robust algorithm determining PBLH from GNSS RO bending angle (BA) profiles are developed and verified by available CALIPSO cloud top height retrievals. The diurnal cycle of PBLH and its temporal/spatial variability is also derived.

Datasets and approaches

- COSMIC-2, consisting of a six-satellite constellation in Low-Earth-Orbiting (LEO), tracks GPS and GLONASS transmittance signals, resulting in approximately 4000 quality-controlled occultation profiles per day in the provisional and initial operational phases from October 2019 to April 2021, then increased to over 5000 profiles per day in the complete operational phase from May 2021 till the present. COSMIC-2 provides an average of about three to five soundings per day in each 500 × 500 km^2 box latitude box in subtropics from 30^{o}N to 30^o, which is much denser than other RO missions. With the mission orbit inclination of 24^o, COSMIC-2 occultations distribute from 45^{o}N and 45^{o}S. Most (more than 75%) are within 30^{o}N and 30^{o}S.



- To remove strong vertical structures between layers resulting from local perturbations, we first apply a Locally Weighted Scatterplot Smoothing (LOWESS) approach with ±150 meters in width to eliminate high-frequency BA profiles. LOWESS and least-squares fitting, in general, are non-parametric strategies for fitting a smooth curve to data points. In the planet boundary layer, non-parametric smoother is a better choice than parametric smoother.
- Then we calculate the gradient to estimate the height of the PBL. We calculate the finite difference representation of the vertical gradient for each layer,

$$X'(Z_i) = \frac{X(Z_i) - X(Z_{i-1})}{Z_i - Z_{i-1}} \quad (1)$$

Where $X(Z_i)$ is BA. The PBLH is determined by the height of the minimum value of $X'(Z_i)$ between 0.5 to 3 km altitude. Only RO profiles penetrating lower than 0.5 km are included in this study.

- CALIPSO, launched on Apr 28, 2006, is a collaborative NASA/CNES project satellite science mission. In situ observations have intensively validated the accuracy of cloud-top height determined by CALIPSO within 100 meters. The global CALIPSO data provide a unique opportunity to validate the RO-derived PBLH in regions dominated by marine PBL clouds. The CALIPSO level 2 cloud 1-km layer products (V4.20 and V4.21) are used in this study.

Conclusions and Future Work

- A robust method using a minimum gradient of GNSS RO bending angle profile has been applied to COSMIC-2 data to derive PBL height over the ocean.
- CALIPSO cloud top height verified that the RO PBLH accuracy is within 100 m, and precision is within 200 m.
- The PBLH derived from the full COSMIC-2 dataset over the stratocumulus cloud-dominated regions from Oct 2019 to Jun 2022 demonstrates clear diurnal, seasonal PBLH variations.
- The relatively uniformly distributed COSMIC-2 data over the ocean provide high-quality PBLH information, which can be used with other satellites and in situ measurements to provide insights into the physics and chemistry of boundary layer processes in climate models.
- COSMIC-2 BA profiles can potentially infer the depths of the shallower PBLs which usually form at nighttime because of radiative cooling of the ground with a typical height within 200-500 m of the surface. We will attempt it in future work.

Comparison of RO PBLH and CALIPSO cloud top height

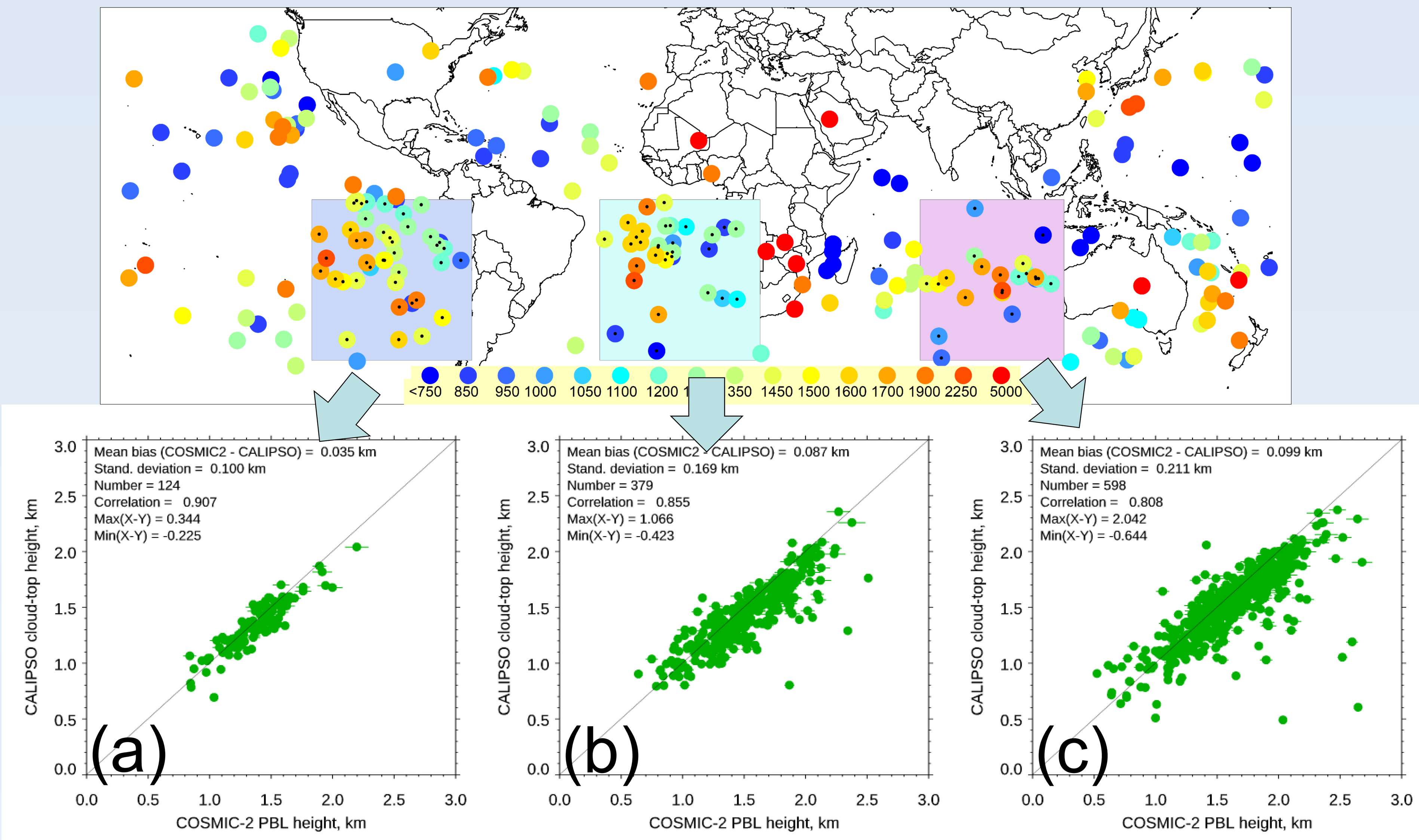


FIG. Scatterplots for all the RO-CALIPSO pairs of COSMIC-2 PBL height with the corresponding CALIPSO cloud-top height. (a) in east south Pacific Ocean (25^{o}S to 15^{o}S and 85^{o}W to 70^{o}W) (b) in east south Atlantic Ocean (25^{o}S to 5^{o}S and 20^{o}W to 0^o) (c) in east south Indian Ocean (35^{o}S to 15^{o}S and 70^{o}E to 112^{o}E)

The PBLH from COSMIC-2 tends to be somewhat higher, mainly because the bending angle gradient method detects the immediate top of the well-mixed layer, excluding the entrainment zone. This zone may extend 5%–100% of the underlying mixed layer (Cohn and Angevine 2000). Our comparison results are consistent with Ho and Liang (2015). They found that the mean difference of PBLH based on COSMIC-1 bending angle gradient and CALIPSO cloud-top height is 57 m, standard deviation of 144 m in the east and south Pacific Oceans. The two heights are in excellent agreement, with a mean difference of fewer than 100 m, standard deviation less than 210 m, and correlation coefficient larger than 0.8. We found an obvious outlier with a 1~2km difference (b and c). The significant difference in outliers is related to the multi-peak of the gradient profile, which generates a relative smaller sharpness parameter.

PBLH geographic, diurnal and seasonal variations

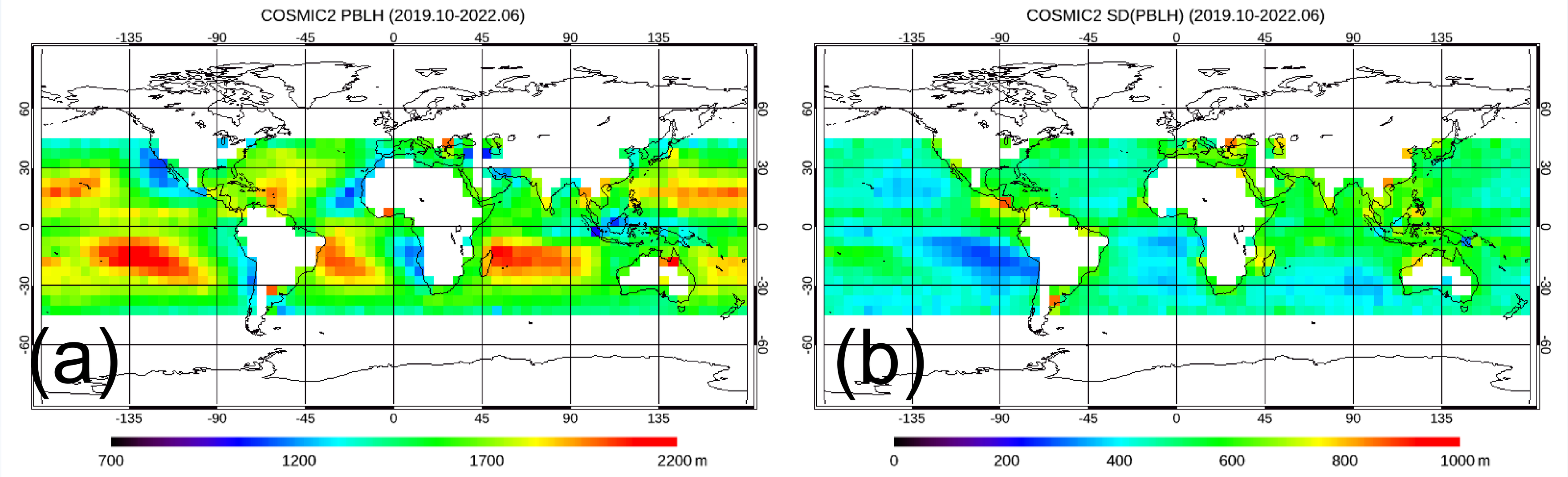


FIG. Global map of COSMIC-2 bending angle (BA) derived PBLH (a) and standard deviation (b) in 5^{o}x5 ^{o} box

The bending angle-based PBL heights (a) are lowest in the subtropical Eastern Pacific and Atlantic oceans at approximately 1–1.5 km. They are highest over the subtropical mid-Pacific, Atlantic and the Indian oceans at 2–2.5 km. The standard deviation (b) is the largest over many of the tropical oceans. The lowest standard deviation can be found in the subtropical Eastern Pacific Ocean and the Atlantic Ocean. The standard deviation measure the temporal (diurnal and seasonal) variability of the PBL heights and the sensitivity of the PBL height definitions to varying meteorological conditions.

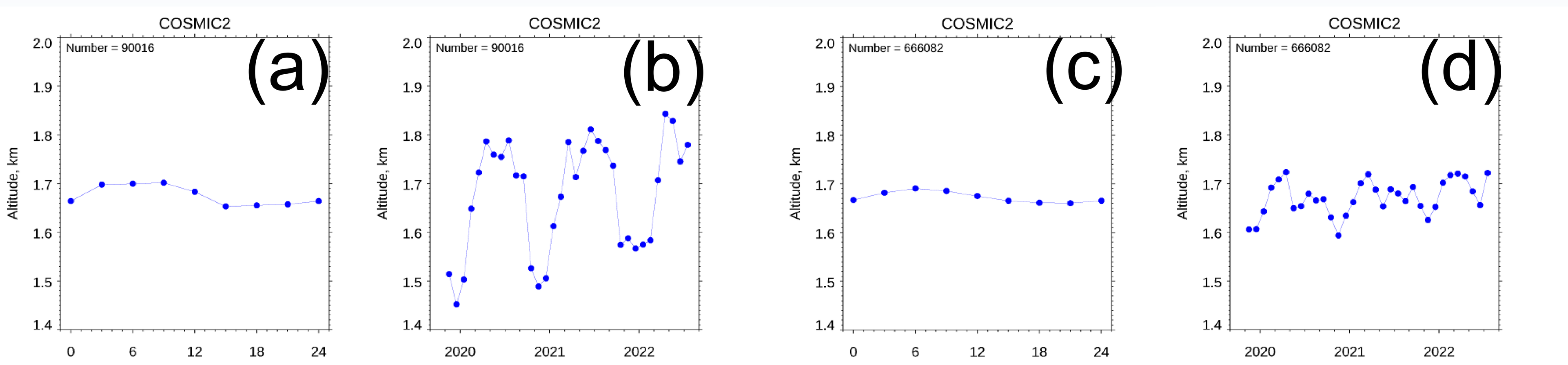


FIG. Diurnal and seasonal variation in 3 stratocumulus cloud-dominated regions combined (a and b) and in global oceans (c and d)

The climatological PBLH diurnal cycle is strong over stratocumulus cloud-dominated and general oceans, with a peak at 0600 LT. In the south hemisphere wintertime, PBLH is higher in the low cloud regions than in the summertime, indicating winter has colder surface temperatures and smaller sensible heat fluxes than other seasons, comparing to those over oceans near the equator.

References:

- Cohn, S. A., and W. M. Angevine, 2000: Boundary layer height and entrainment zone thickness measured by lidars and wind profiling radars. J. Appl. Meteor., 39, 1233–1247.
- Ho, S.-p., Peng, L., Anthes, R. A., Kuo, Y.-H., and Lin, H.-C.: Marine Boundary Layer Heights and Their Longitudinal, Diurnal, and Interseasonal Variability in the Southeastern Pacific Using COSMIC, CALIOP, and Radiosonde Data, J. Climate, 28, 2856–2872, https://doi.org/10.1175/JCLI-D-14-00238.1, 2015.

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