Construction of the Planetary Boundary Layer Height Climatology in STAR using Multi-Mission GNSS Radio Occultation Profiles from 2007 to 2023: Examining their Spatiotemporal Variability

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Introduction:

- The planetary boundary layer (PBL) is the lowest part of the tropospheric atmosphere, controlling the exchange of heat, moisture, and chemical constituents between the Earth surface and free atmosphere;
- There is still a limited understanding of PBL including its top height (PBLH) especially over global oceans and in the remote land regions due to the lack of direct in situ observations;
- Compared to conventional (ground-based) and other spaceborne measurements of the atmosphere, the Global Navigation Satellite System (GNSS) Radio Occultation, for high vertical resolution (~0.2 km), deep penetration (75% below 0.5 km), and good spatial coverage, provides an excellent, unique opportunity for detecting/estimating the PBLH and its spatial distribution and temporal variations.

Objectives:

- Detect/estimate the PBLH by utilizing the GNSS RO bending angle (BA) profiles from multiple RO missions during 2007-present;
- Construct the PBLH climatology and temporally-consistent data record over global oceans (2007-2023) through combining the estimations from multiple RO missions;
- Assess and estimate the uncertainties/errors in combined PBLH products;
- Explore PBLH's spatial distributions and temporal variations at various time scales.

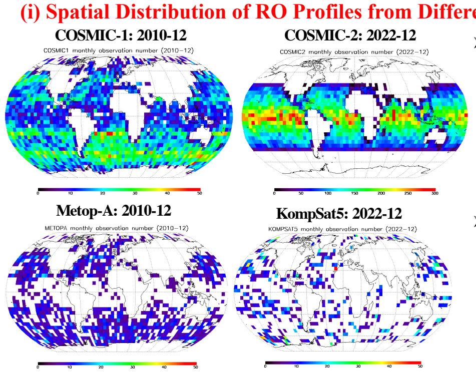
GNSS RO Data:

Bending angle (BA) profiles from nine GNSS RO missions are applied to generate the PBLH over global oceans, which include **COSMIC-1** (01/2007-12/2018), **COSMIC-2** (10/2019-12/2023), **KompSat5** (02/2015-12/2023), **Metop-A** (01/2007-11/2021), **Metop-B** (02/2013-12/2023), **Metop-C** (07/2019-12/2023), **TDX** (01/2016-12/2023), **TSX** (01/2012-12/2023), and **PAZ** (05/2018-12/2023).

PBLH Estimation Method (MGBA):

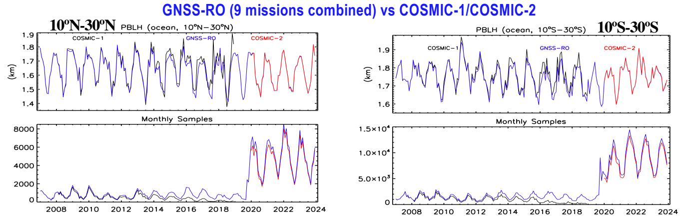
- Calculate the vertical gradient of GNSS RO BA profiles, and then identify/define the PBLH as the height with the minimum gradient (MG) value of BA between 0.5 to 3 km.

(i) Spatial Distribution of RO Profiles from Different GNSS RO Missions



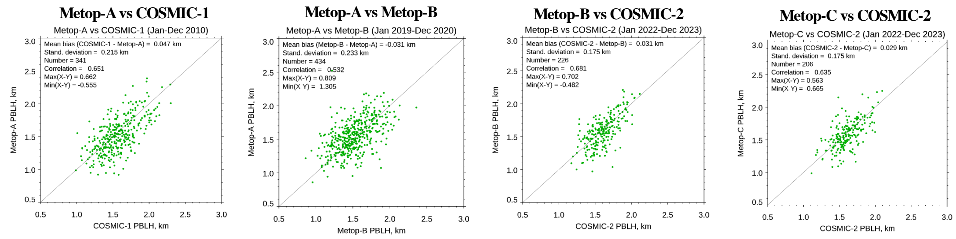
- Serious issues may exist for defining the RO-based PBLH climatology and constructing temporally-consistent data record of RO-based PBLH from any single RO mission for limited spatial sampling and time span;
- Issues may still exist for combining the estimates from multiple RO missions because of their different time spans and spatial sampling, resulting in spatially-inhomogeneous and time-varying data sampling.

(ii) Monthly Time Series of Domain-Mean PBLH and Data Samples



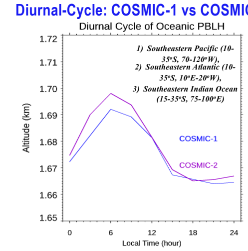
- Relatively large difference between COSMIC-1 and GNSS-RO (nine missions combined) after about 2013/2014 because of COSMIC-1's declining sampling;
- Including other GNSS RO missions such as Metop-A, Metop-B, KompSat5, etc. can greatly increase samples prior to the COSMIC-2 period and may hence reduce sampling errors in PBLH especially over large domains.

(iii) Comparison of PBLH estimations from Different GNSS RO missions



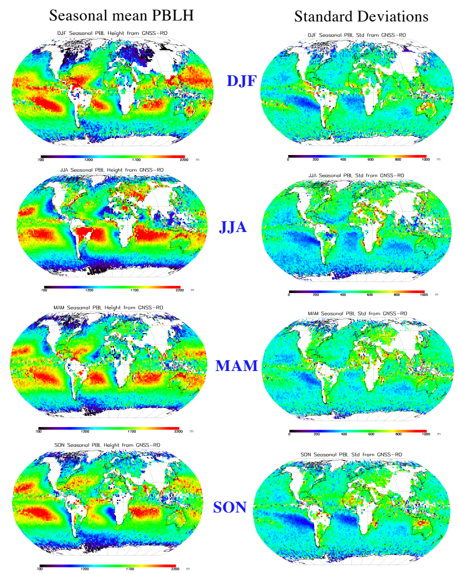
- Good consistency in PBLH estimation among different RO missions even though these matched pairs (binned to 2-deg grids) during the respective periods) may happen during different months.

Diurnal-Cycle: COSMIC-1 vs COSMIC-2



- Good consistency in the PBLH diurnal cycle between COSMIC-1 and COSMIC-2 even with different spatial sampling

(iv) Seasonal Climatology of GNSS RO PBLH Combined from Nine RO Missions



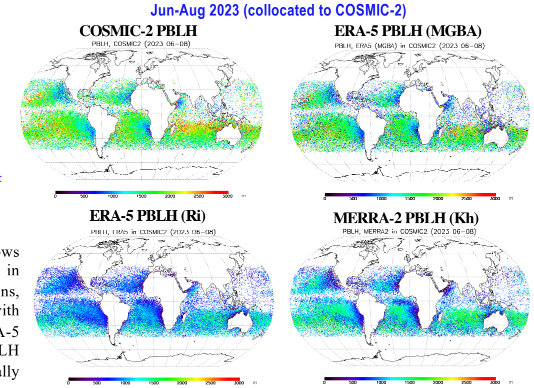
- Combining the PBLH estimations (binned to 2-deg grids) from nine RO missions provides a more accurate seasonal climatology of PBLH with global coverage than that from any single RO mission.

(v) Comparison between Reanalysis PBLHs and COSMIC-2 PBLH

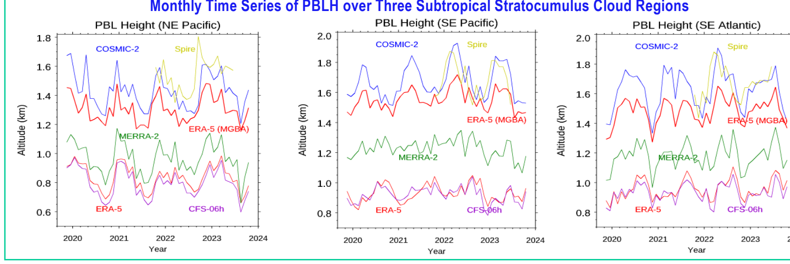
Reanalysis PBLHs:

1) **ERA-5 PBLH (MGBA)**: estimated by applying the MG method to ERA-5 simulated bending angles;
2) **ERA-5 PBLH (Ri)**: standard ERA-5 PBLH output estimated from the bulk Richardson (Ri) number method;
3) **MERRA-2 PBLH (Kh)**: standard MERRA-2 PBLH output estimated from the total eddy diffusion coefficient of heat (Kh) with a threshold equal to 10% of its column maximum.

- ERA-5 PBLH (MGBA) shows much higher consistency in magnitudes, spatial distributions, and temporal variations with COSMIC-2 PBLH than ERA-5 PBLH (Ri) and MERAA-2 PBLH (Kh), though it is still generally lower than COSMIC-2 PBLH.



Monthly Time Series of PBLH over Three Subtropical Stratocumulus Cloud Regions



Summary

- The bending angle (BA) profiles from nine GNSS RO missions are used to detect/estimate the PBLH over global oceans by means of the minimum gradient (MG) method, which are further combined to construct seasonal climatology and long-time data record of GNSS RO-based PBLH for the period of 2007-2023;
- A combination of nine RO missions can greatly improve data sampling especially for the pre-COSMIC-2 period when the total number of RO profiles from COSMIC-1 was declining significantly;
- High consistency between the PBLH estimations from different RO missions with regards to PBLH's monthly/seasonal mean values and temporal variation further confirms the feasibility of constructing the PBLH data record with climate data quality from various RO missions;
- Standard ERA-5/MERRA-2 PBLH outputs are consistently lower than RO-PBLH. However, the ERA-5 PBLH (MGBA) estimated from the ERA-5 simulated BA and using the same MG method as for RO-PBLH shows high consistency with (COSMIC-2) RO-based PBLH including spatial distribution and temporal variations. This consistency implies that the reanalysis-based PBLH such as ERA-5 PBLH (MGBA) could be eventually applied to estimate/remove sampling errors in the GNSS-RO PBLH data record constructed from various RO missions.

Acknowledgment: The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.