Observations and simulations of planetary boundary layer in atmospheric rivers using airborne GNSS radio occultations

Pawel Hordyniec[1], Jennifer S. Haase[2], Bing Cao[2]

Wrocław University of Environmental and Life Sciences

(1) Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences, Wrocław, Poland
(2) Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, USA
contact: pawel.hordyniec@upwr.edu.pl

UC San Diego
Scripps Institution of Oceanography

Abstract

The Atmospheric River Reconnaissance (AR Recon) campaigns provide an unique opportunity for addressing science questions concerning winter storms developing over the northeast Pacific. Diverse dataset consisting of targeted dropsonde observations and complementary retrievals from airborne GNSS radio occultations (ARO) provide independent vertical soundings which can benefit improved forecasting of atmospheric rivers (ARs) and capturing associated inversion layers such as the planetary boundary layer (PBL). While the former has been recently made possible for ARO thanks to the development of the observation operator for the assimilation of bending angle retrievals, the latter remains challenging due to requirement of a deep atmospheric penetration, preferably down to the surface. Close inspection of ARO retrievals collected as a part of 2023 AR Recon during 9 intensive operation periods (IOPs) revealed 13 profiles with a penetration depth of 300 m or better motivating the exploration of ARO capability for sensing the PBL. The analysis is complemented with estimates of PBL height based on dropsonde and ECMWF reanalysis for over 400 collocated profiles. In order to provide independent and comparable PBL diagnostics, the observation operator for ARO has been further modified to enable forward modeling of bending angles from dropsonde observations. Except for significantly smaller data sample, PBL diagnostics based on ARO bending angle versus refractivity are shown to be in a good internal agreement. PBL from ARO typically develops at heights of 1 – 2 km which is supported in the inter-comparison with dropsonde estimates while the ECMWF suggests lower PBL than the other two. Very good internal agreement of PBL for bending angle versus refractivity is shown in both dropsonde and ECMWF diagnostics as well as in the humidity-based PBL. Analysis of PBL heights is complemented with the quality assessment of ARO retrievals in terms of "O minus B" statistics which can be now performed relative to dropsondes in the bending angle space. The assessment for the deep penetrating ARO profiles supports good quality of retrievals in the lower troposphere resulting in standard deviations on the order of 10 % and 2 % for bending angle and refractivity, respectively. Further analysis is focused on the relationship between PBL diagnostics and characteristics of ARs expressed in the integrated water vapor transport (IVT) and integrated water vapor (IWV) based on specific cross-sections.

Key Points

1) Forward modeling of dropsonde profiles to ARO geophysical parameters of bending angle and refractivity.
2) Quality assessment in terms of bending angle and refractivity between dropsonde, ECMWF and ARO.
3) RO-specific diagnostics of PBL in atmospheric rivers from three independent datasets.

1. Data and Methods

Input data:

(a) **ARO**: atmospheric profiles, AR Recon 2023, nine IOPs, **472 profiles** (52 profiles / daily)
(b) **dropsonde**: high-resolution (4 Hz), post QC'd
(c) **ECMWF**: ERA5 reanalysis, 137 model levels, 0.5×0.5 deg horizontal resolution, hourly

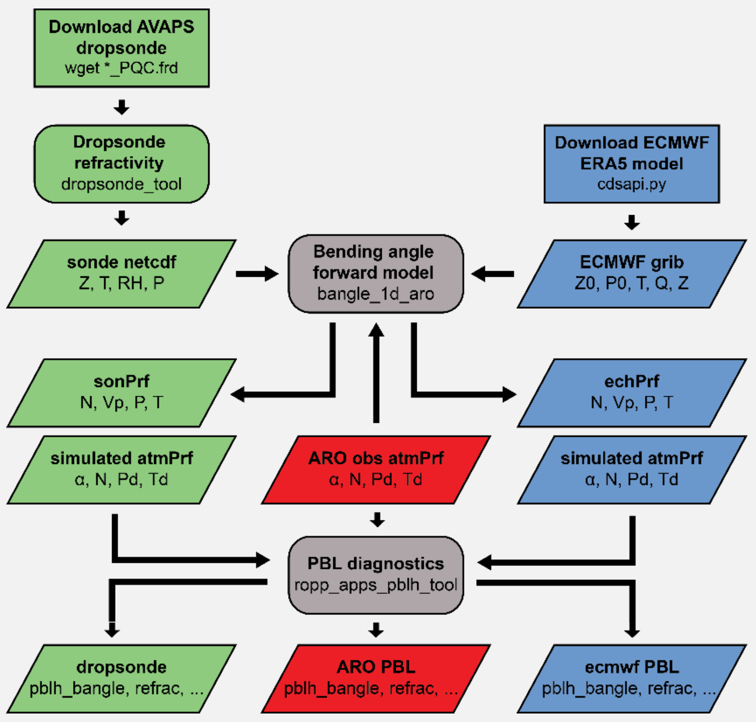

Fig 1. Flowchart utilizing three data types for PBL diagnostics

Core tools:

(a) **bangle_1d_aro**: bending angle forward model for ARO
(b) **dropsonde_tool**: pre-processing of dropsonde data
(c) **ropp_apps_pblh_tool**: ROPP planetary boundary layer height diagnostic tool from the kinks in RO profiles

PBLH parameter definitions

Element	Type(kind)	Definition
pblh_bangle	Real(4)	PBLH height (m)
pbla_bangle	Real(4)	PBLH bending angle (rad)
pblh_refrac	Real(4)	PBLH height (m)
pbln_refrac	Real(4)	PBLH refractivity (N-unit)
pblh_tdry	Real(4)	PBLH height (m)
pblt_tdry	Real(4)	PBLH dry temperature (K)
pblh_temp	Real(4)	PBLH height (m)
pblt_temp	Real(4)	PBLH temperature (K)
pblh_shum	Real(4)	PBLH height (m)
pblq_shum	Real(4)	PBLH specific humidity (g/kg)
pblh_rhum	Real(4)	PBLH height (m)
pblr_rhum	Real(4)	PBLH relative humidity (%)

Tab 1. PBL diagnostics (redacted from ROPP user guide)

2. Quality assessment

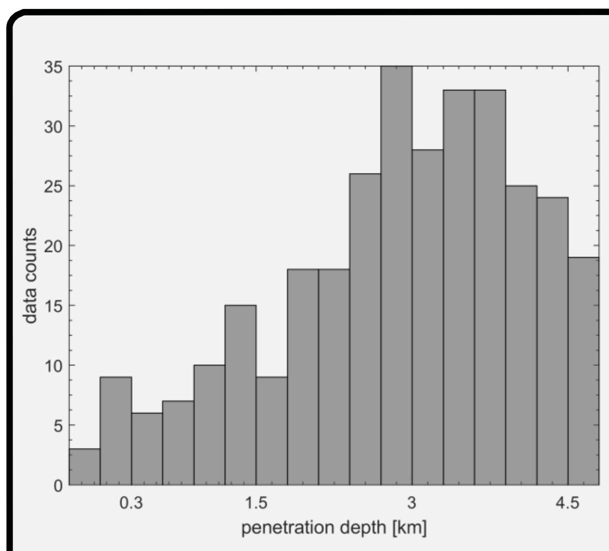

Fig 2. Penetration depth with ARO (300 m is a requirement for PBL detection)

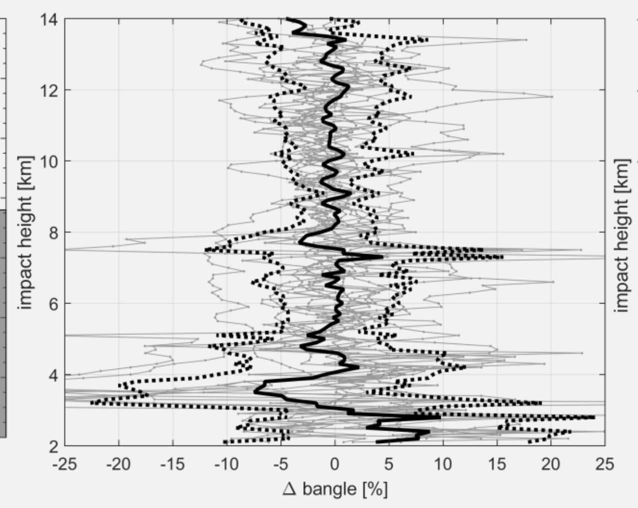

Fig 3. Bending angle: ARO minus dropsonde

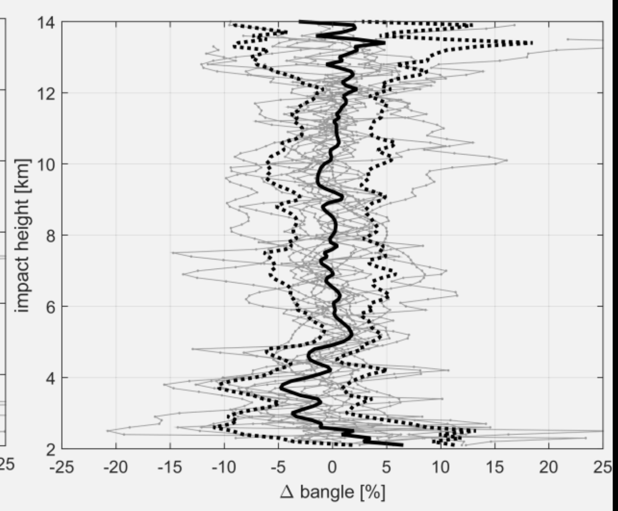

Fig 4. Bending angle: ARO minus ECMWF

3. PBL analysis

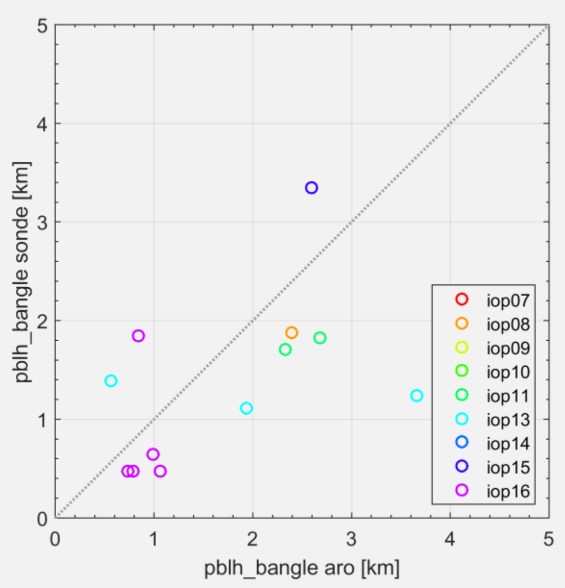

Fig 5. Bending angle PBL: ARO vs dropsonde

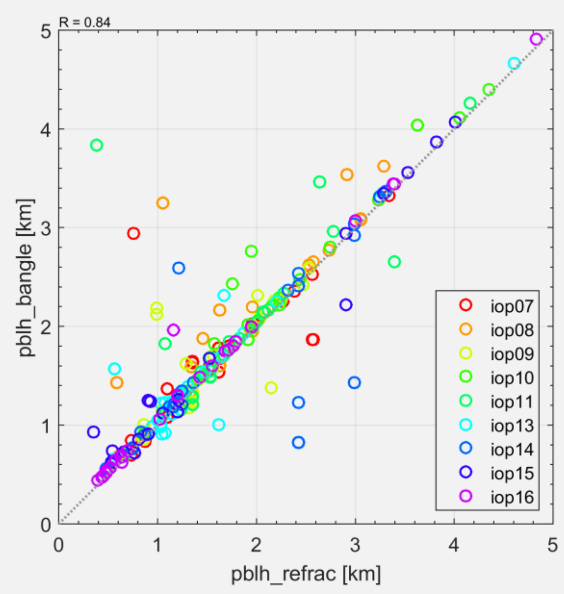

Fig 6. Dropsonde PBL: refractivity vs bending angle

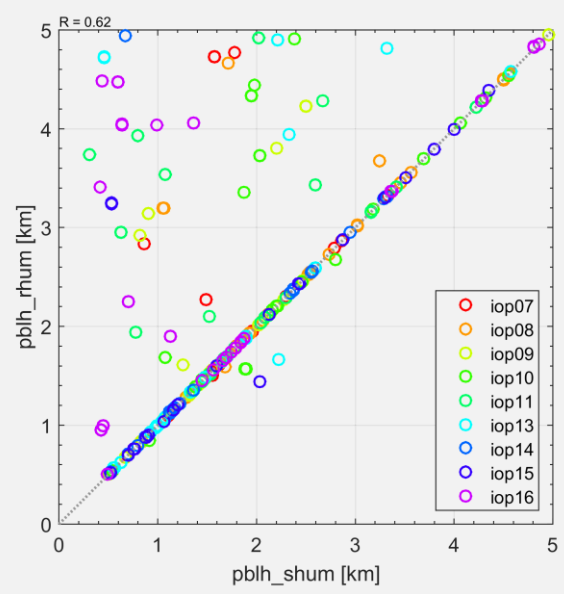

Fig 7. Dropsonde PBL: specific vs relative humidity

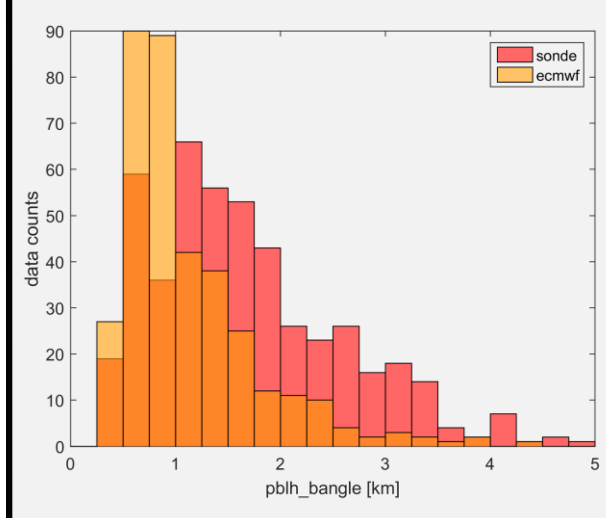

Fig 8. Histogram of PBL heights for dropsonde and ECMWF.

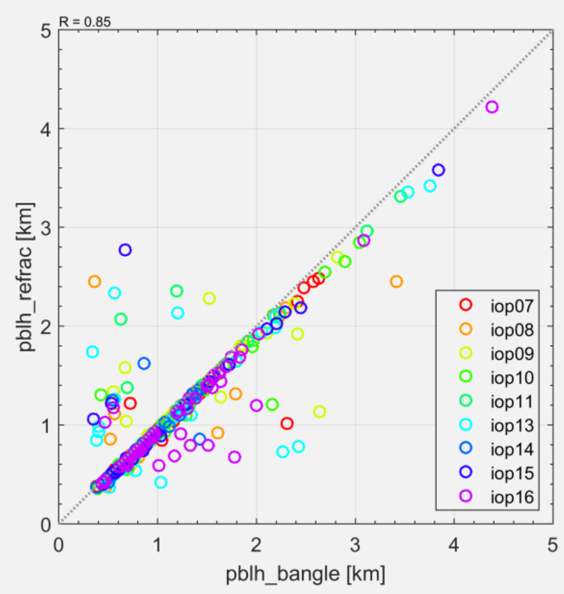

Fig 9. ECMWF PBL: refractivity vs bending angle

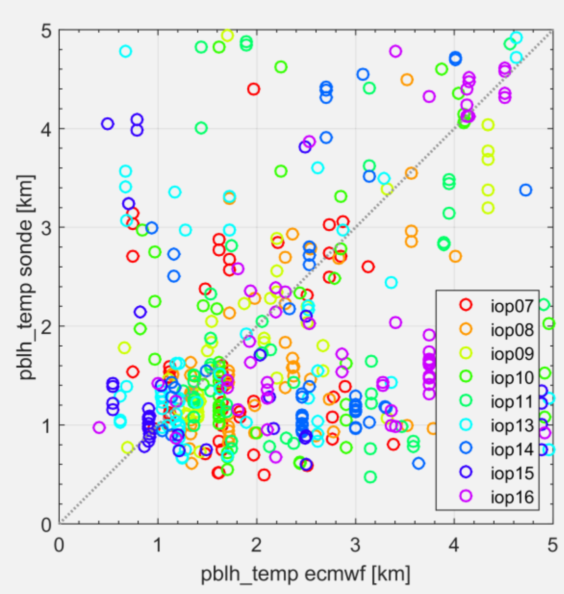

Fig 10. Temperature PBL: ECMWF vs dropsonde

Summary

First attempt to employ ARO retrievals for PBL diagnostics:

- limited capability due to penetration depth requirement (300 m or better) - used to be the case for spaceborne RO (Fig. 2),
- promising results (Fig. 5) with current "non-optimized" ARO data (not tailored for PBL, no strict QC),
- working towards improved ARO retrieval algorithm and GNSS receiver (wave optics and open loop tracking).

First application of dropsonde data to forward modeling of bending angle profiles for ARO:

- supports good quality of ARO retrievals, especially in the lower troposphere (Fig. 3), critical for PBL and data assimilation,
- independent reference for verification of numerical weather forecasts and reanalysis in atmospheric rivers (Fig. 4).

Common PBL definitions in atmospheric rivers for three datasets:

- very good internal agreement of PBL heights from refractivity and bending angle (Figs. 6,9),
- ECMWF suggests more shallow PBL than dropsonde in terms of bending angle (Fig. 8), supported in other diagnostics (not shown),
- larger spread in PBL heights based on conventional parameters, such as humidity (Fig. 7) and temperature (Fig. 10).

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