Planetary Boundary Layer (PBL) Height Estimation: Methodology and Case Study using NAST-I FIREX-AQ Field Campaign Data

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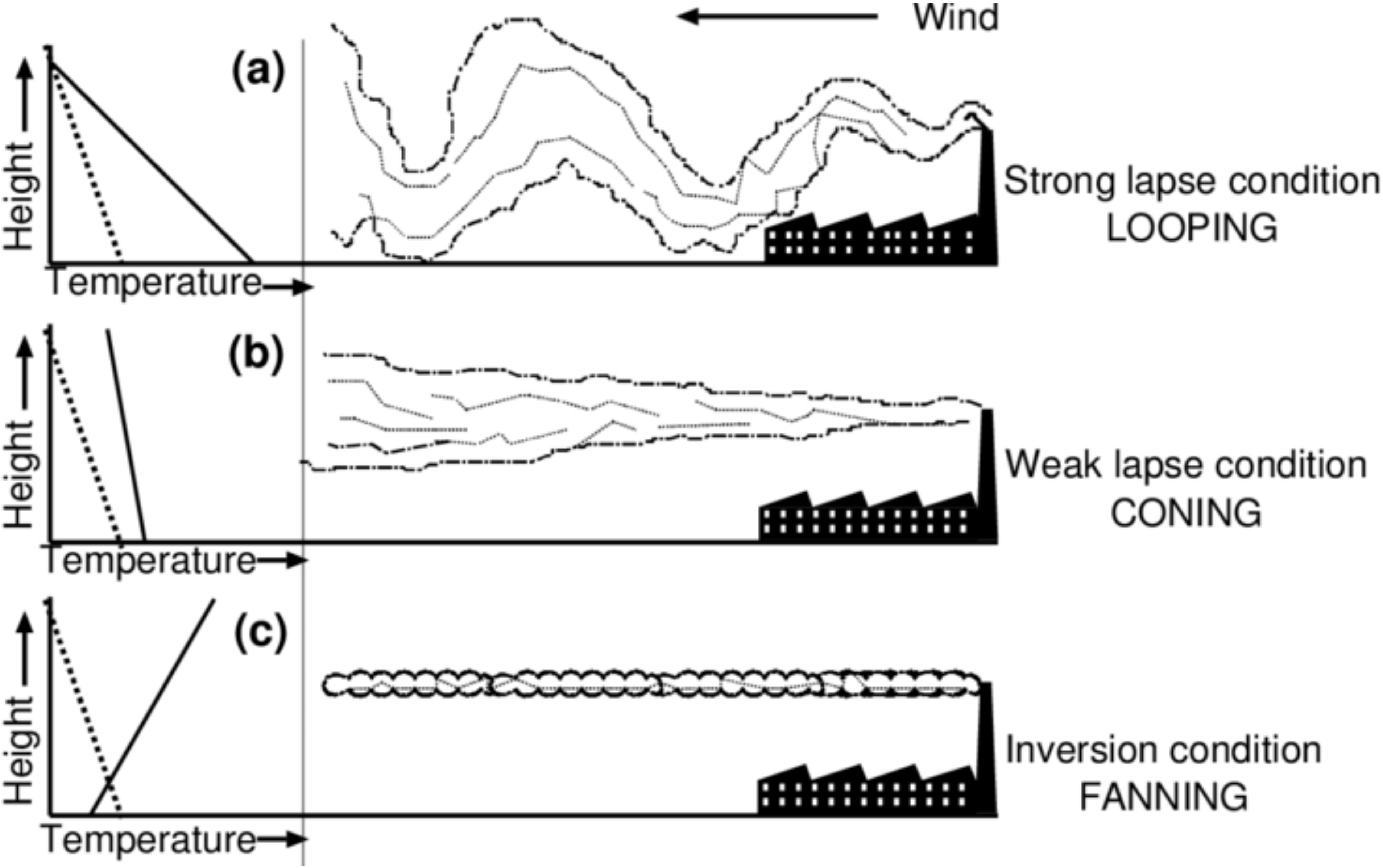


Reproduced with modifications from Geiger et al. 1995, pp.43,
Figure was generated by Prasanjit Dash, NOAA. doi: 10.13140/RG.2.1.2929.3282

Background

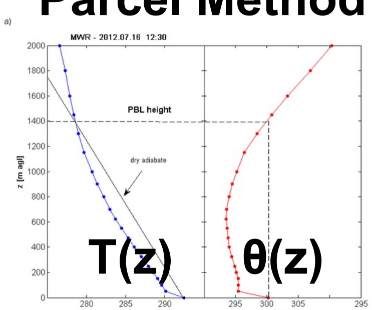
From NASA PBL incubation Study Team's PBL research overview,

"*Improved understanding and prediction accuracy of the atmospheric Planetary Boundary Layer (PBL) and the ability to make significant advances in several PBL application areas (e.g. air quality and human health, improved forecasting of severe storms, improved climate projections, renewable energies) are currently constrained by the lack of global PBL observations at sufficient spatial and temporal resolution and sampling. Current satellite observations from techniques such as radio occultation, microwave sounding and imaging, and **infrared sounding** are key for sampling PBL conditions over remote regions, such as the oceans and high latitudes. However, satellite capabilities to penetrate and resolve the vertical structure of the PBL are still limited*."

(Teixeira et al., *NASA PBL Incubation Study Team*, 2021)

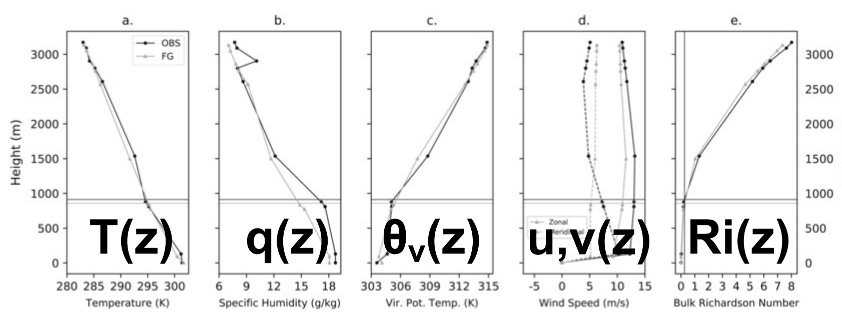
Straightforward definition but numerous existing methodologies (and continuing research)

Parcel Method



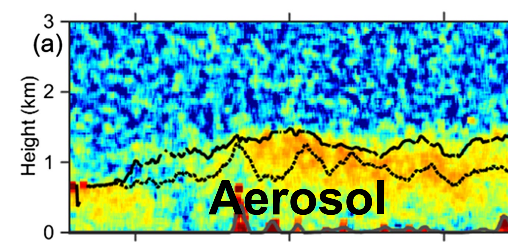
Collaud Coen et al. (*ACP*, 2014)

Bulk Richardson Number



Lavers et al. (*JGR: Atmos.*, 2019)

Max. Standard deviation Method



Tianning Su et al. (*JGR: Atmos.*, 2017)

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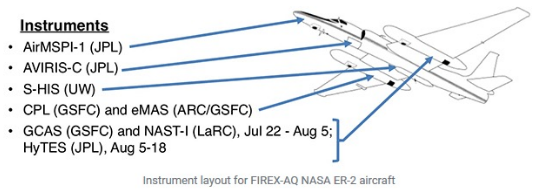
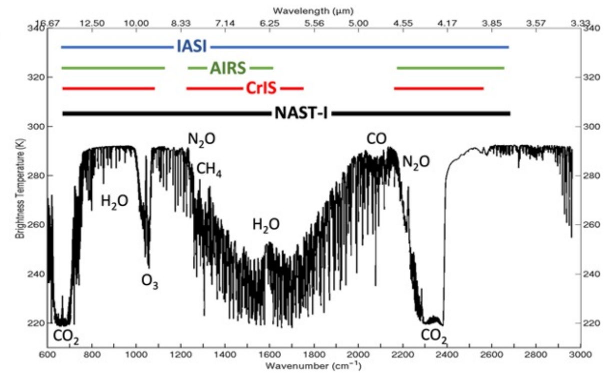
Instrument, Campaign, and Algorithm

NAST-I (National Airborne Sounder Testbed – Interferometer)





NAST-I spectral coverage encompasses all satellite IR sounders with a higher (or equivalent) spectral resolution and higher spatial resolution.

- 8632 channels (0.25 cm^{-1} spectral resolution)
- 2.5 km of spatial resolution

FIREX-AQ (Fire Influence on Regional to Global Environments and Air Quality)

- Summer in 2019 (NAST-I observations are mainly obtained during August)
- Western desert and mountain area of the United States

SiFSAP (Single Field-of-view Sounder Atmospheric Product)

- PCRTM (Principal Component-based radiative transfer model) based retrieval algorithm
- Physical retrieval method

Key Concept

Question:

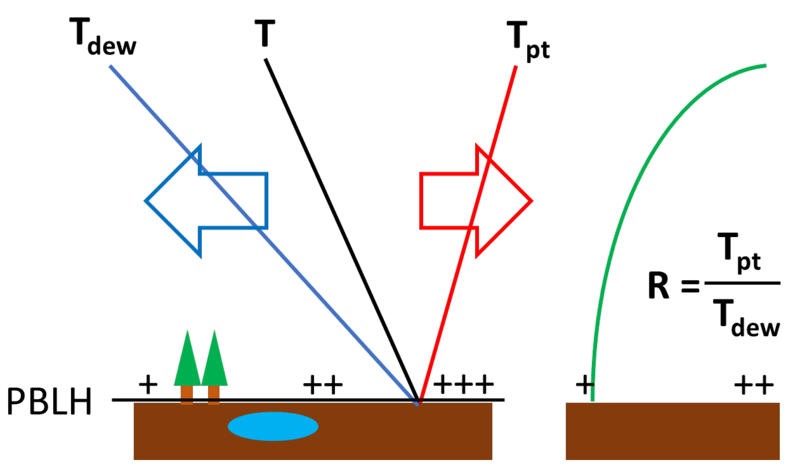
How can we improve vertical sensitivity for detecting PBLH using "given T/q information" from NAST-I? (i.e., Which form of T/q would be most effective for PBLH estimation?)

Our Direction to Answer:

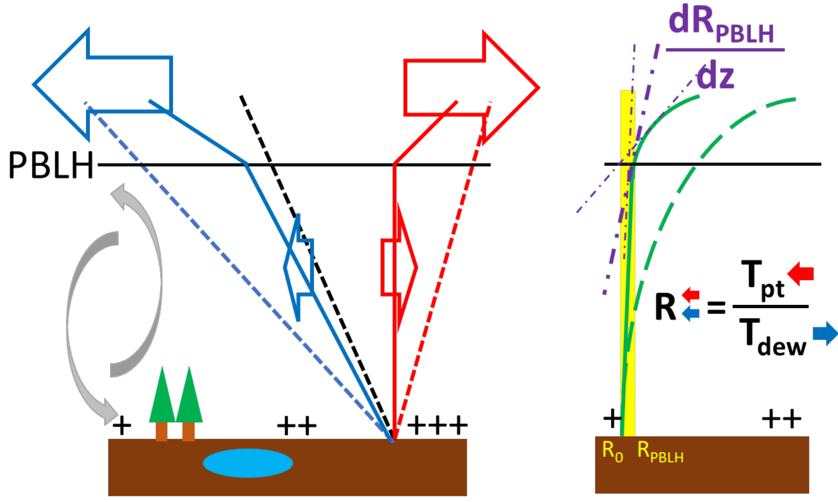
Zhou et al. (*AMS conference*, 2024) reported a possible linkage between **PBLH** and **the ratio (R) of potential temperature (T_p) to dewpoint temperature (T_d)**

Jang et al. (*NASA PBLH community meeting*, 2024) provided a qualitative explanation of why the ratio can be linked to PBLH and discussed potential benefits of using it

Atmosphere with shallow PBL (Baseline)



Atmosphere with well-developed PBL



Potential Benefits for Adopting Ratio

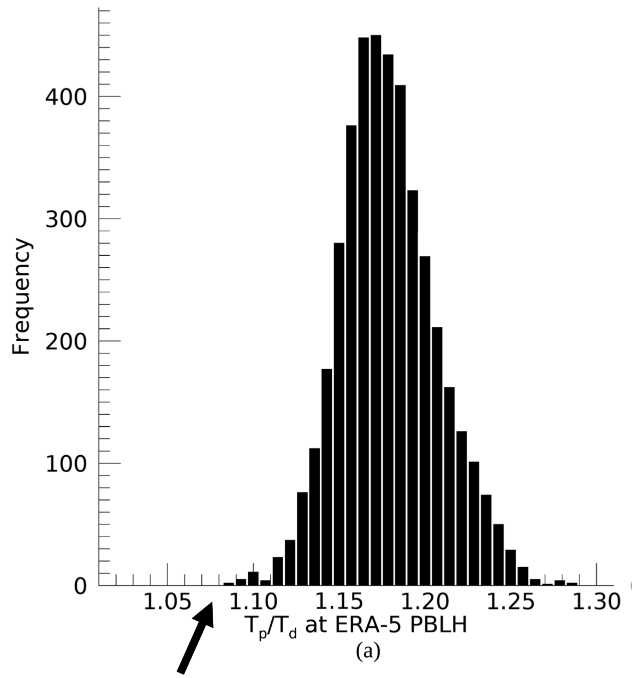
Also, we might expect:

1. **Possible cancellation of local temperature**

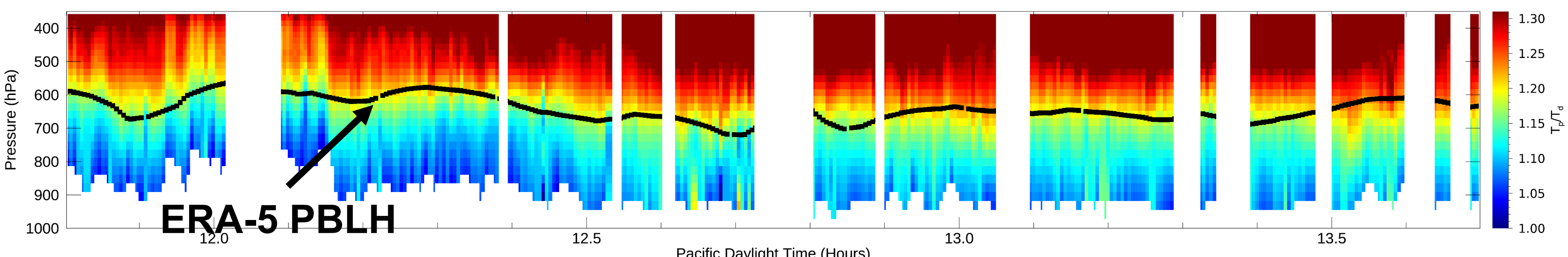
- T_p(temp., internal energy…) / T_d(temp., humidity …)
- A single peak histogram when stratifying R along with ERA-5 PBLH

2. **Possible cancellation of correlated random errors in T_p and T_d retrievals**

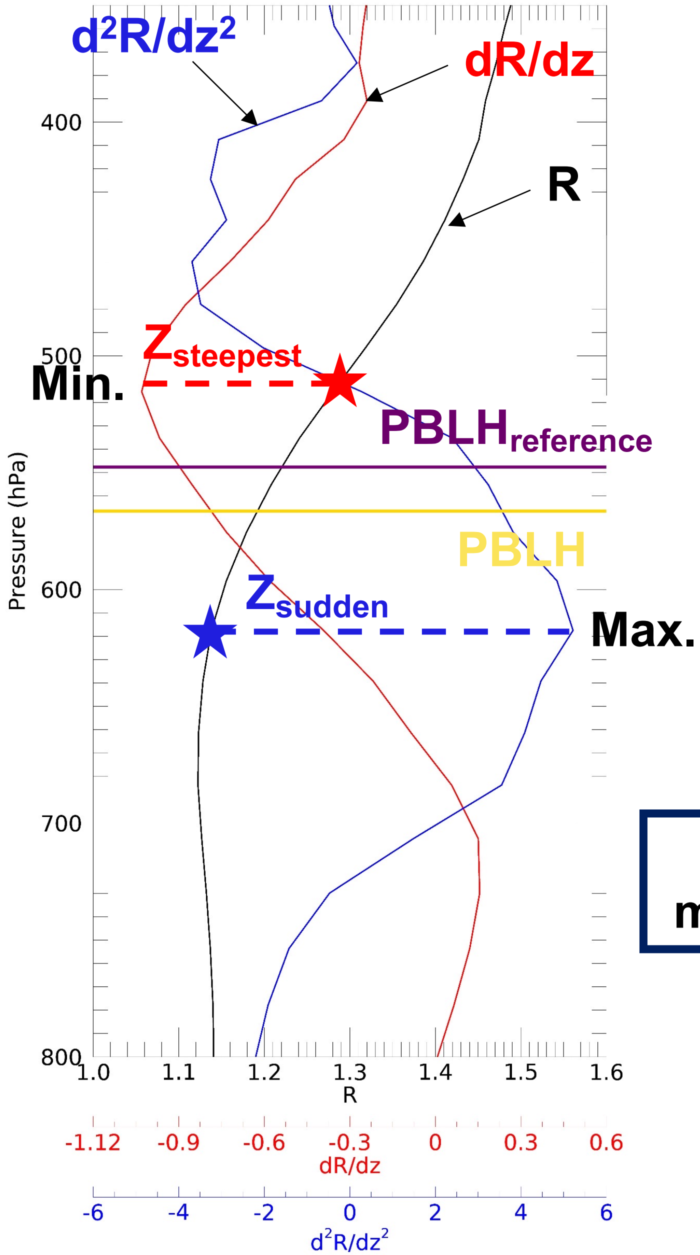
- Simultaneous estimation using the same NAST-I measurements from the SiFSAP algorithm

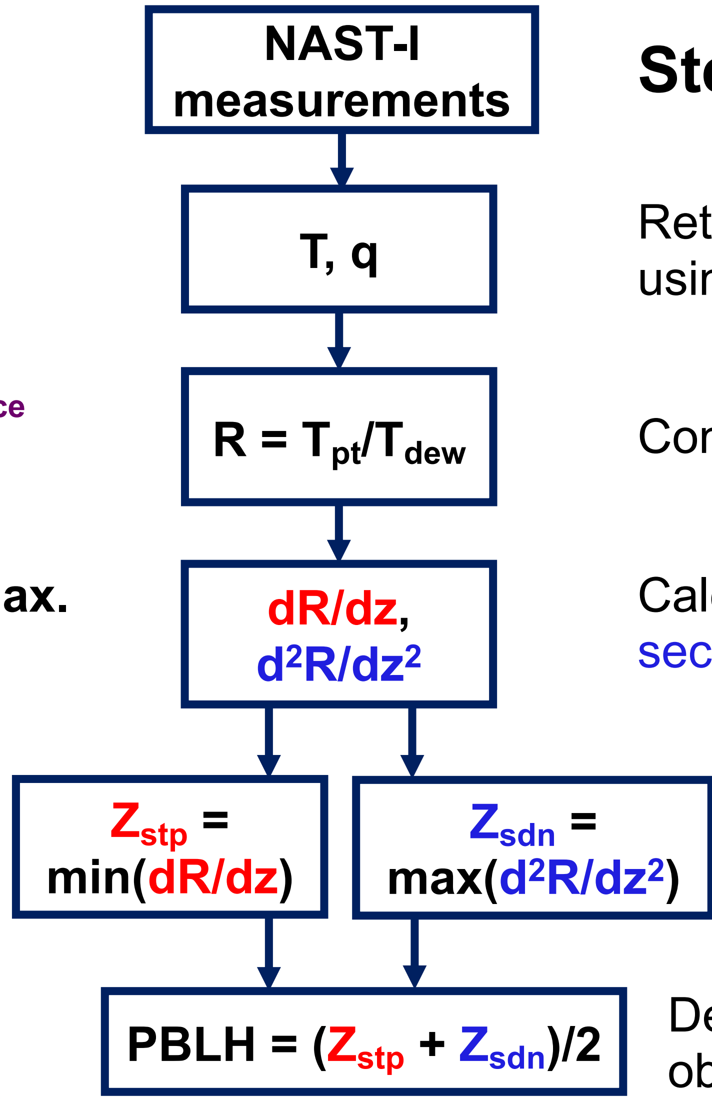


Histogram to determine which R value appears most frequently at PBLH



How to Define PBLH





Steps we followed:

Retrieve T and q using SiFSAP

Convert T and q into R

Calculate the first and the second derivatives of R

Identify levels of steepest and sudden change in R

Define PBLH based on observed variations

Quality Control

Case A. The level of steepest decrease in R is lower (closer to the surface) than the level of sudden change in R → Reject

Define PBLH using T_{pt} only ($PBLH_{pt}$) and T_{dew} only ($PBLH_{dew}$) instead of R:

Case B. PBLH located near $PBLH_{pt}$ and $PBLH_{dew}$ → Higher significance (QC=0)

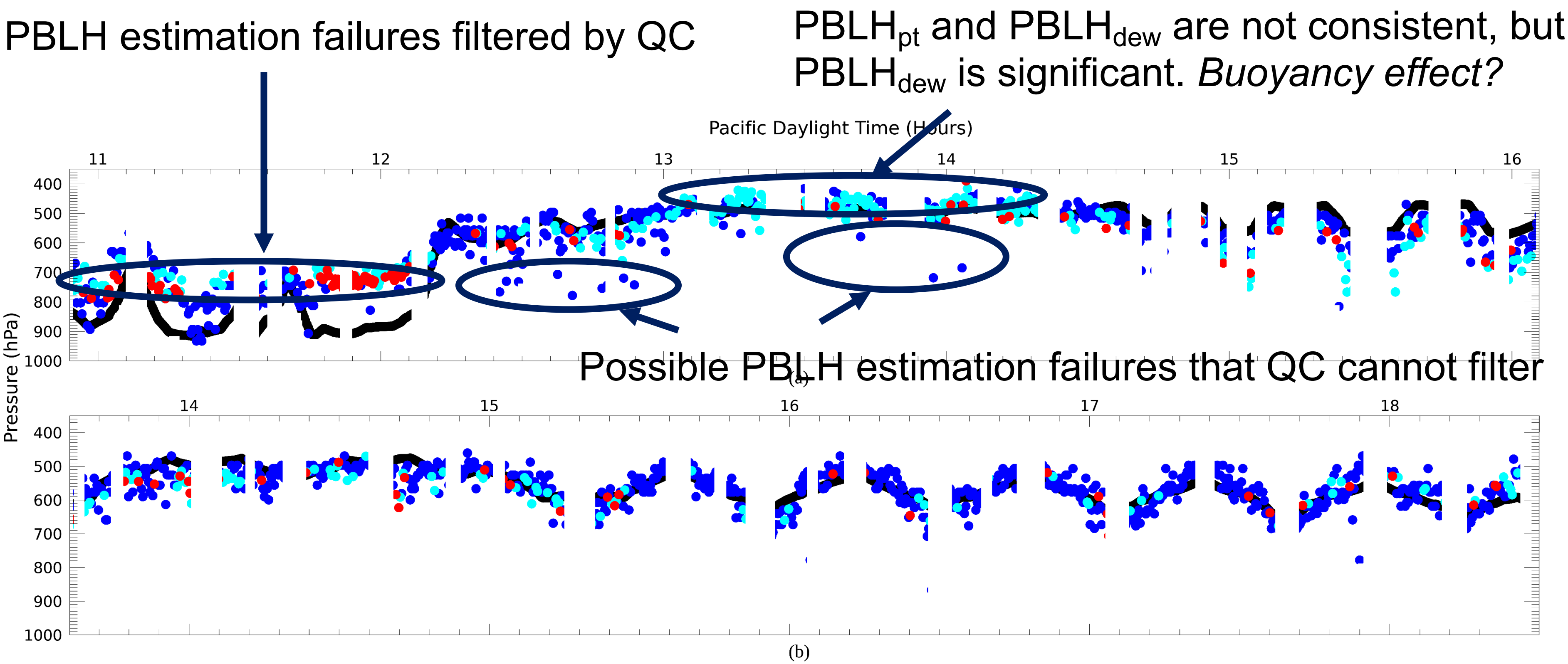
Case C. PBLH located away from $PBLH_{pt}$ or $PBLH_{dew}$ → Lower significance (QC=1 or 2)

Check whether T_{dew} is significant for detecting PBLH:

Case C-1. Case C, but $PBLH_{dew}$ has high significance → Inconsistency between mixing height and PBLH, which can occur (QC=1)

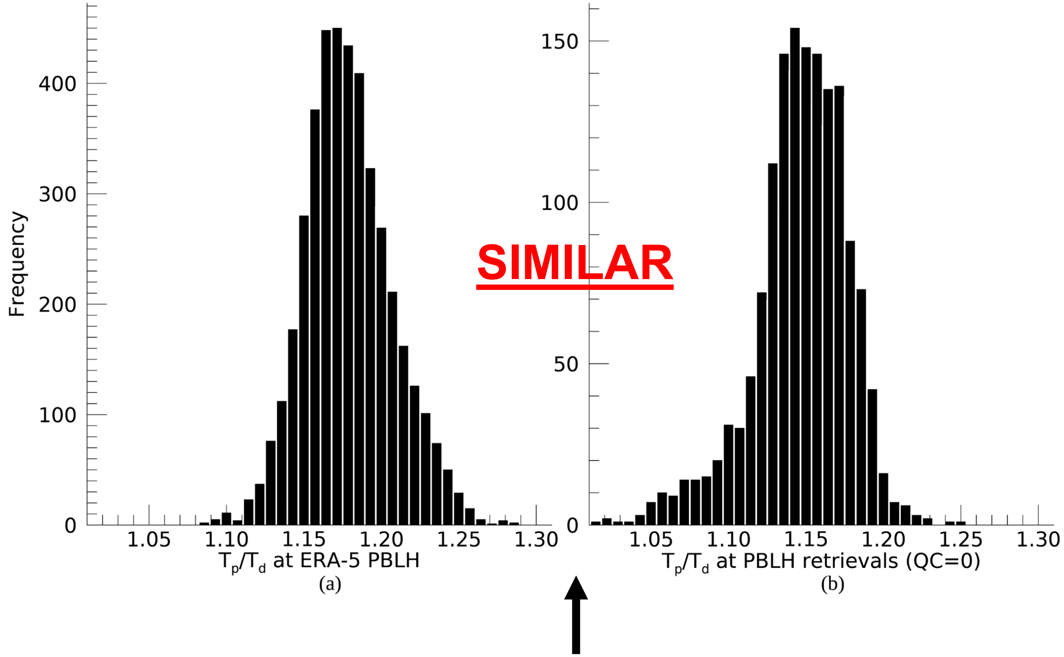
Case C-2. Case C, but $PBLH_{dew}$ has no physical consistency with PBLH → T/q does not provide significant information for detecting PBLH (QC = 2)

Examples of PBLH with QC



Cross-sections of NAST-I PBLH at nadir on August 15, 2019 (top), and August 16, 2019 (bottom), with collocated ERA-5 PBLH shown in black. Colors indicate quality control status: QC = 0 (blue), QC = 1(cyan), and QC = 2 (red).

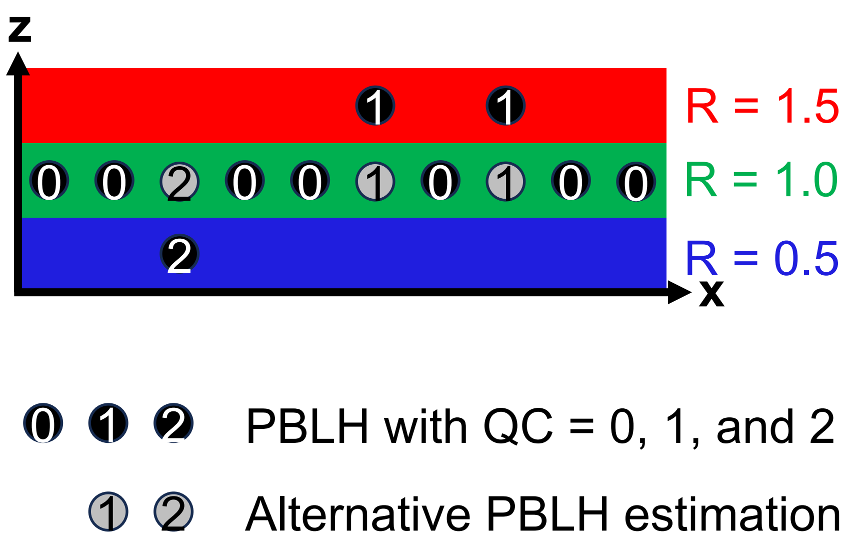
Alternative PBLH Estimation



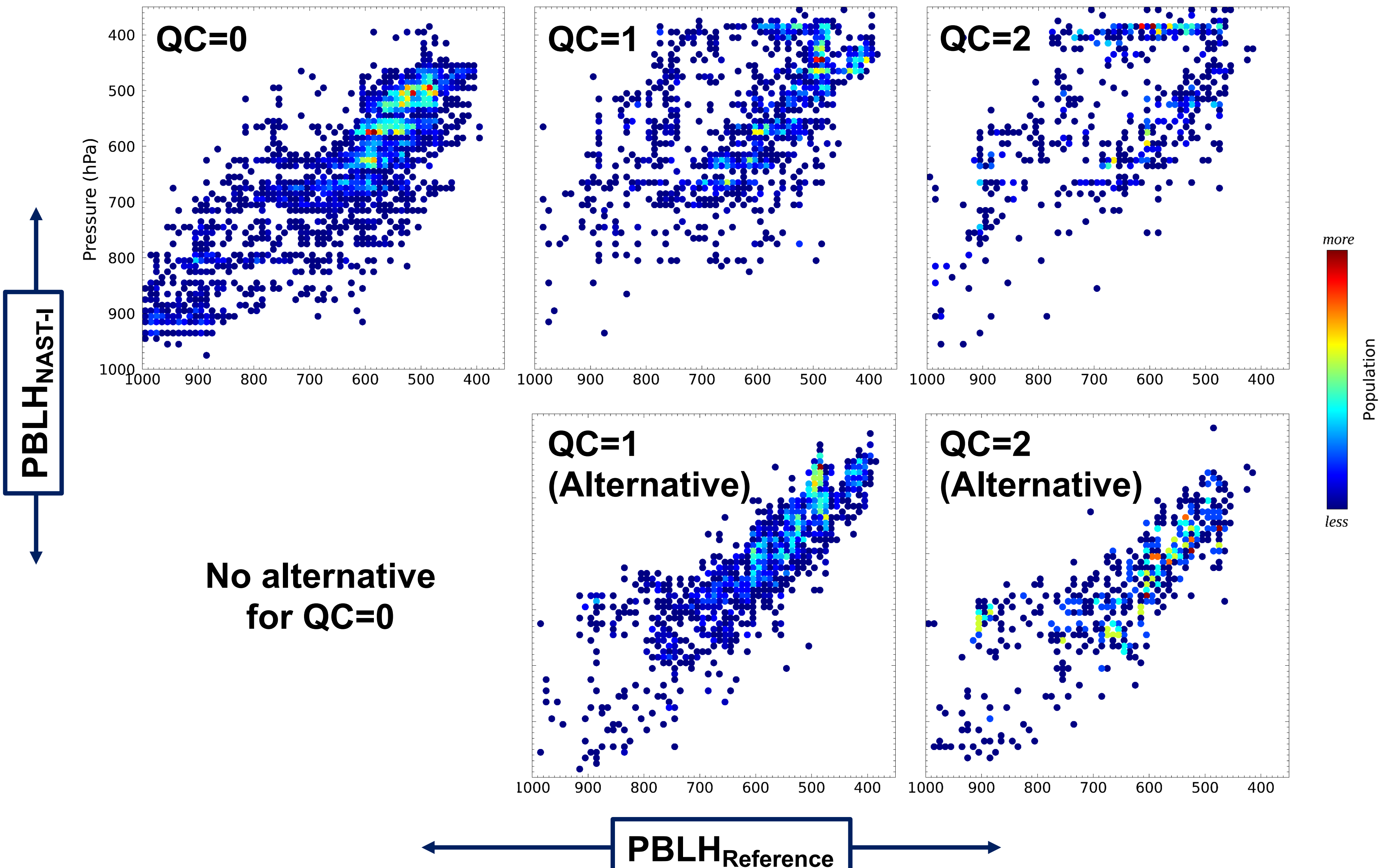
Left: which R is the most frequently shown at PBLH$_{ref}$?
Right: which R is the most frequently shown at PBLH (QC = 0)?

Step 1. Identify the most frequent R at PBLH when QC = 0

Step 2. Set the height where R equals the R value found in Step 1 as PBLH for QC = 1 or 2

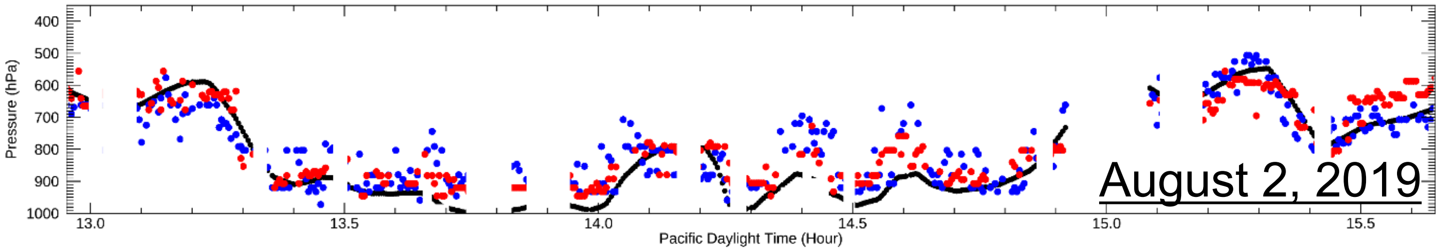


Error Statistics (All Cases, Nadir)



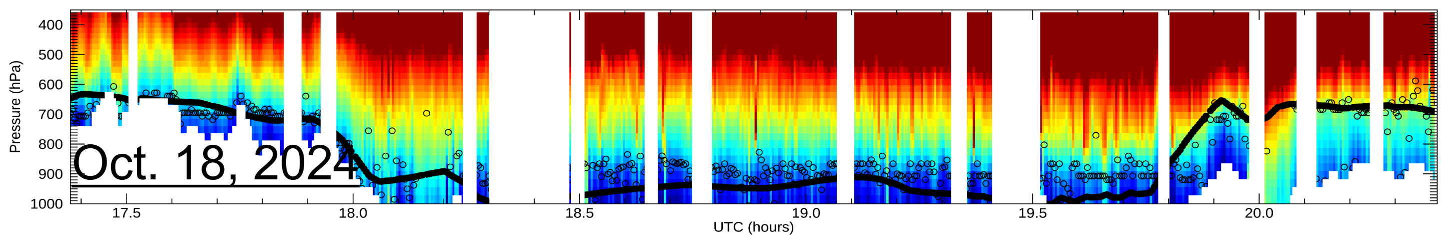
Apply the Methodology to Another Location

- NASA Langley's Channel-base Retrieval Algorithm



Red: Channel-base
Blue: SiFSAP
Black: ERA-5

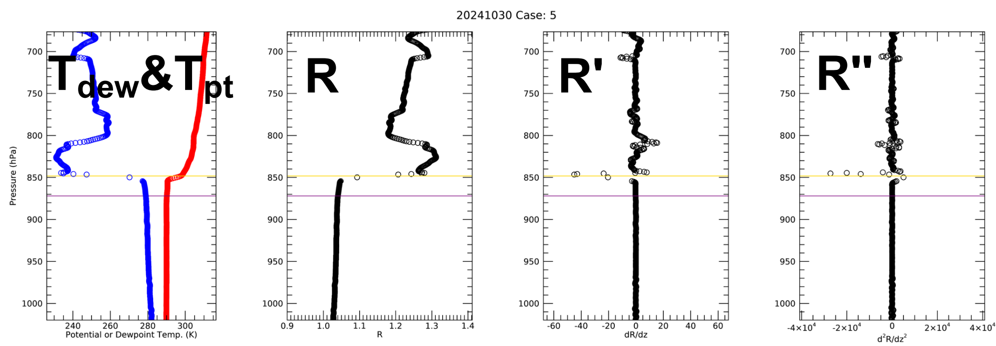
- WHyMSIE Field Campaign (Mostly Over Ocean)



Color: R
Blk line: ERA-5
Blk circle: NAST-I

- Dropsonde from WHyMSIE

Oct. 30, 2024
5th launch



- Yellow: Estimated PBLH
- Purple: ERA-5

Summary

- A method for estimating the PBLH using atmospheric temperature and moisture profile retrievals from NAST-I measurements with SiFSAP is presented
- The ratio of T_p and T_d provides enhanced sensitivity in the vertical direction against a regime change around the PBLH
- A quality control process, which primarily ensures consistency within a vertical changes of temperature or water vapor, improves the reliability of PBLH estimation
- Positive agreement between NAST-I measurement-derived PBLH and ERA-5 reanalysis supports the significance of this estimation method, at least for the area and season of the FIREX-AQ field campaign, which has favorable conditions for active atmospheric circulation
- It is believed that efforts to develop an improved PBLH estimation method using limited available variables will contribute to a deeper understanding of the atmospheric phenomena related to the PBLH

Error Table for Slide 11

	QC	Cor.	Bias	RMSD	#
PBLH retrievals	0	0.86	5.34	71.67	3584
	1	0.58	-55.89	107.80	1527
	2	0.60	-119.52	118.77	642
Alternative retrievals	0	0.90	8.10	62.19	3552
	1	0.86	20.74	62.81	1513
	2	0.82	14.90	80.11	641

Triple Collocation