# Characterizing the Vertical Stratification of the Earth's Planetary Boundary Layer (PBL) with GNSS Radio Occultation

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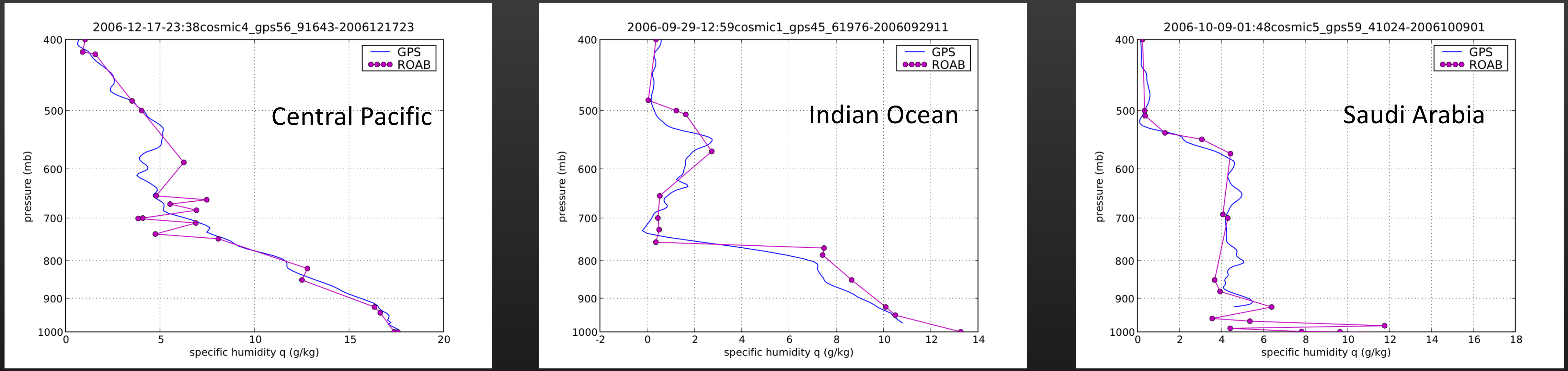
# Beyond PBL heights…



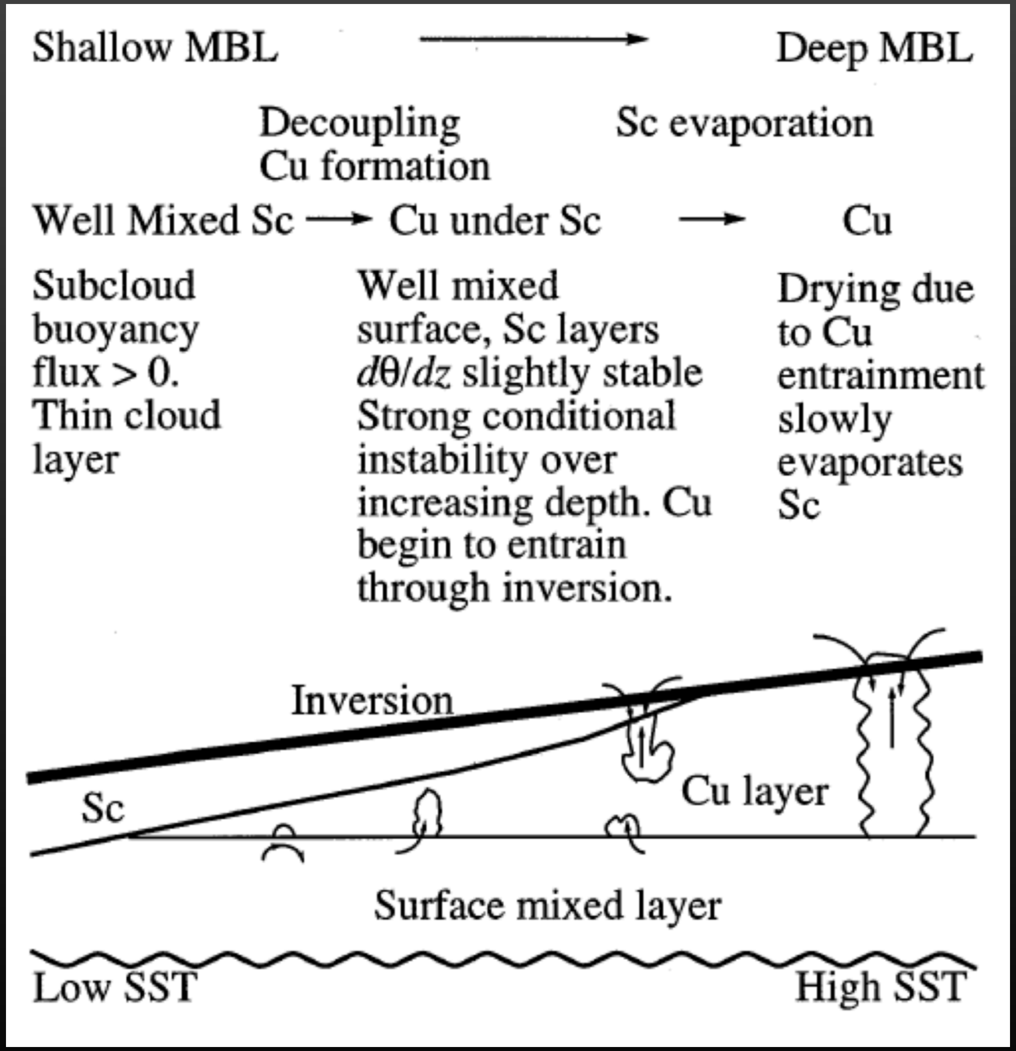

These examples of COSMIC humidity profiles collocated with ROABs show that RO provide ***<u>vertical structures within the PBL</u>***, which has been underutilized, partly due to retrieval uncertainty (N-bias, penetration depth)

# Outline

- Decoupling parameter (DCP) as bulk characterization of PBL stratification
- Uncertainty estimates
- Validation with radiosondes
- DCP climatology and model comparisons
- RO/PBL in US Decadal Survey

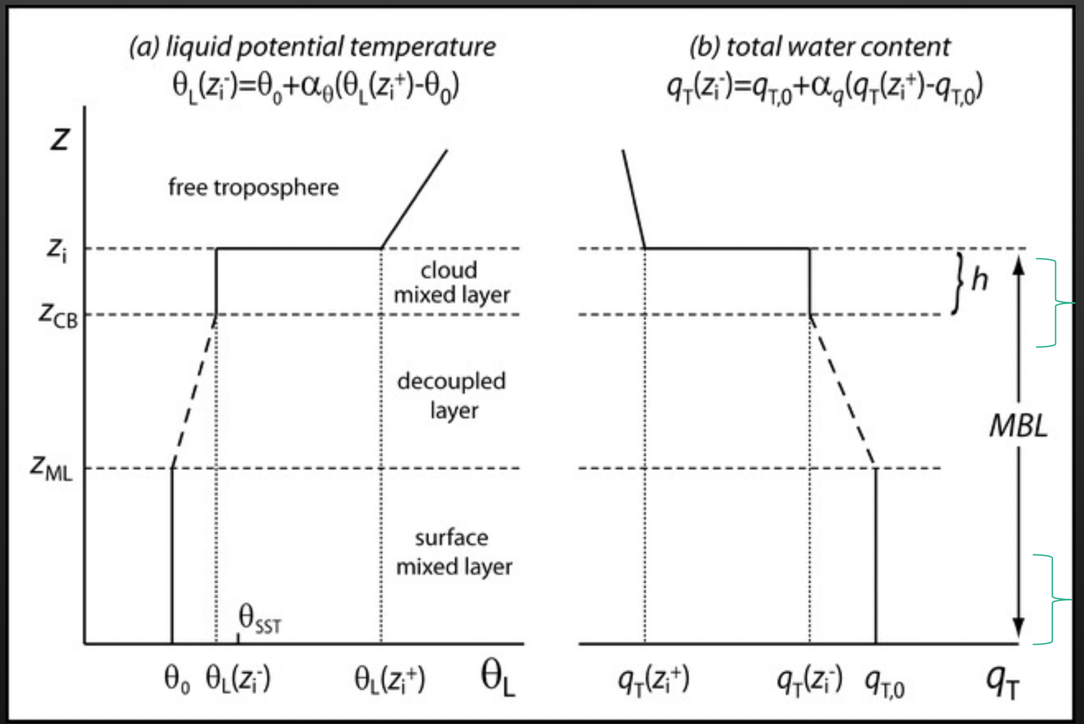
# PBL "Decoupling"

- The vertical structure of the PBL varies from a well-mixed layer where the specific humidity is relatively constant to a more complex structure with multiple layers.
- Decoupling: departure from the well-mixed state.
- Decoupling of the subtropical MBL leads to the breakup of stratocumulus clouds and transition to cumulus: difficult to simulate but important for climate feedback.
- Existing satellite estimates are indirect [Wood and Bretheron, 2004; Zheng et al. 2018]. **RO can provide a direct measure.**




*Wyant et al., JAS, 1997*

# Decoupling Parameter (DCP)




*Wood and Bretherton, J. Clim., 2004*

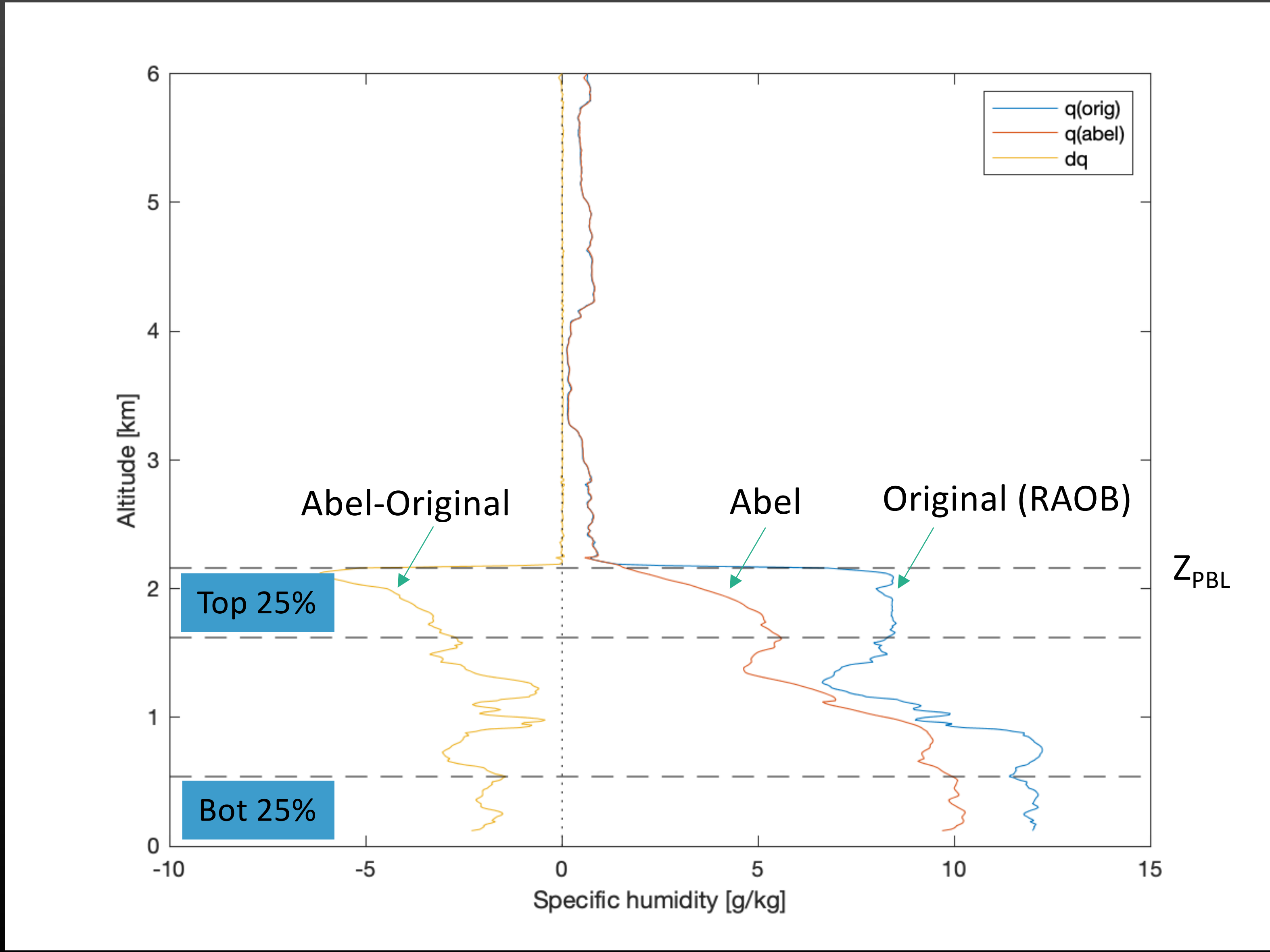
We define the decoupling parameter as [Jones et al., ACP, 2011]

DCP = q(bot)– q(top)

where bot, top = bottom (top) 25% of the PBL

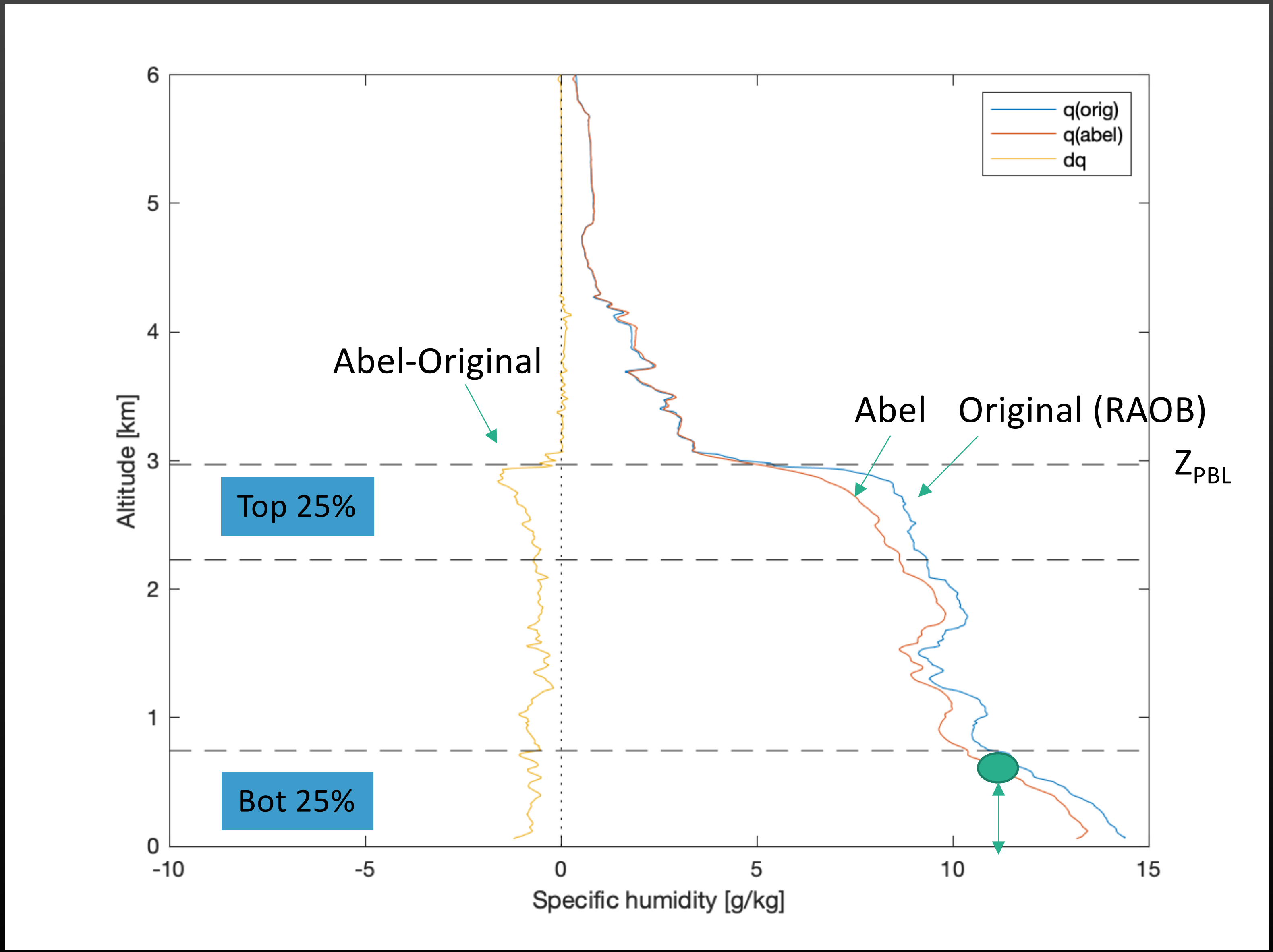
*Normalized decoupling parameter:*
*$DCP_N$ = DCP/<q(PBL)> (not shown here)*

# Uncertainty from Retrieval Error (Example 1)




Ducting-induced negative N-bias tends to overestimate DCP because q(top) is reduced more than q(bot).

# Uncertainty from Retrieval Error (Example 2)




Insufficient penetration tends to underestimate DCP because near-surface q tends to be the same or slightly larger.

# Comparison with MAGIC RAOB

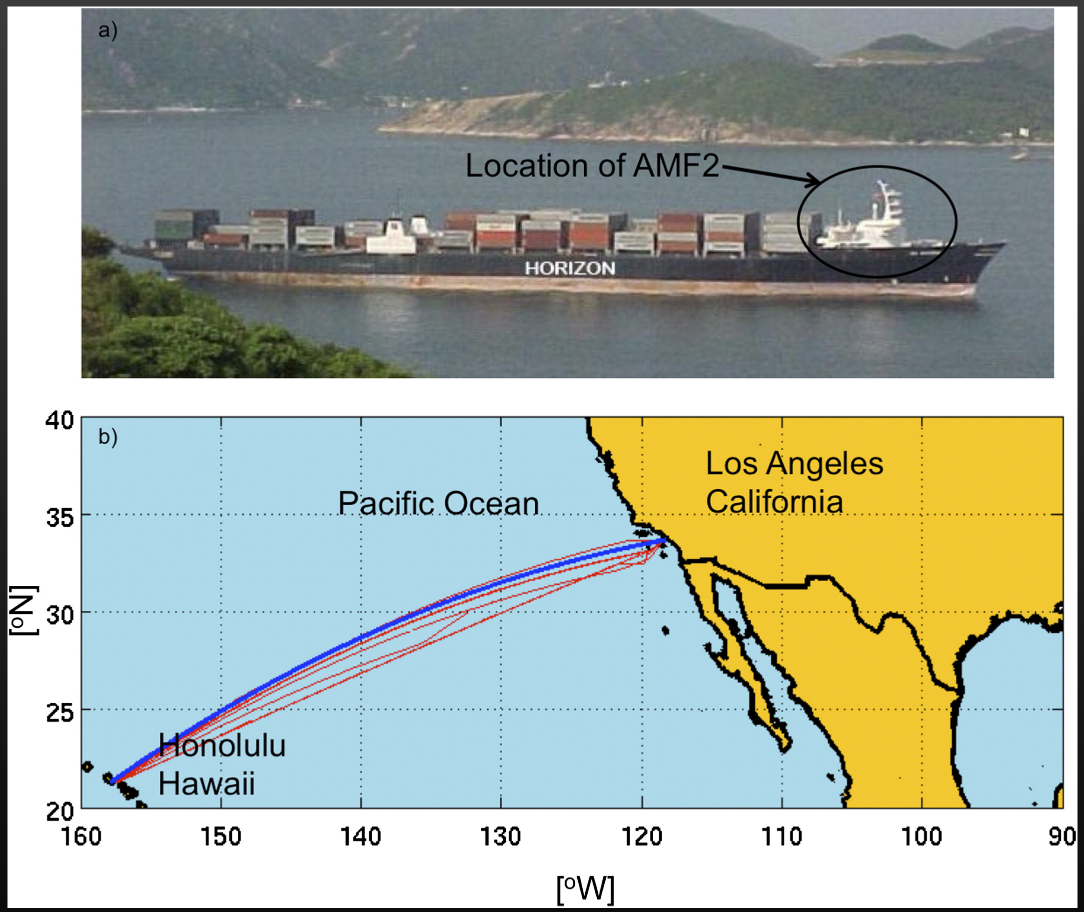
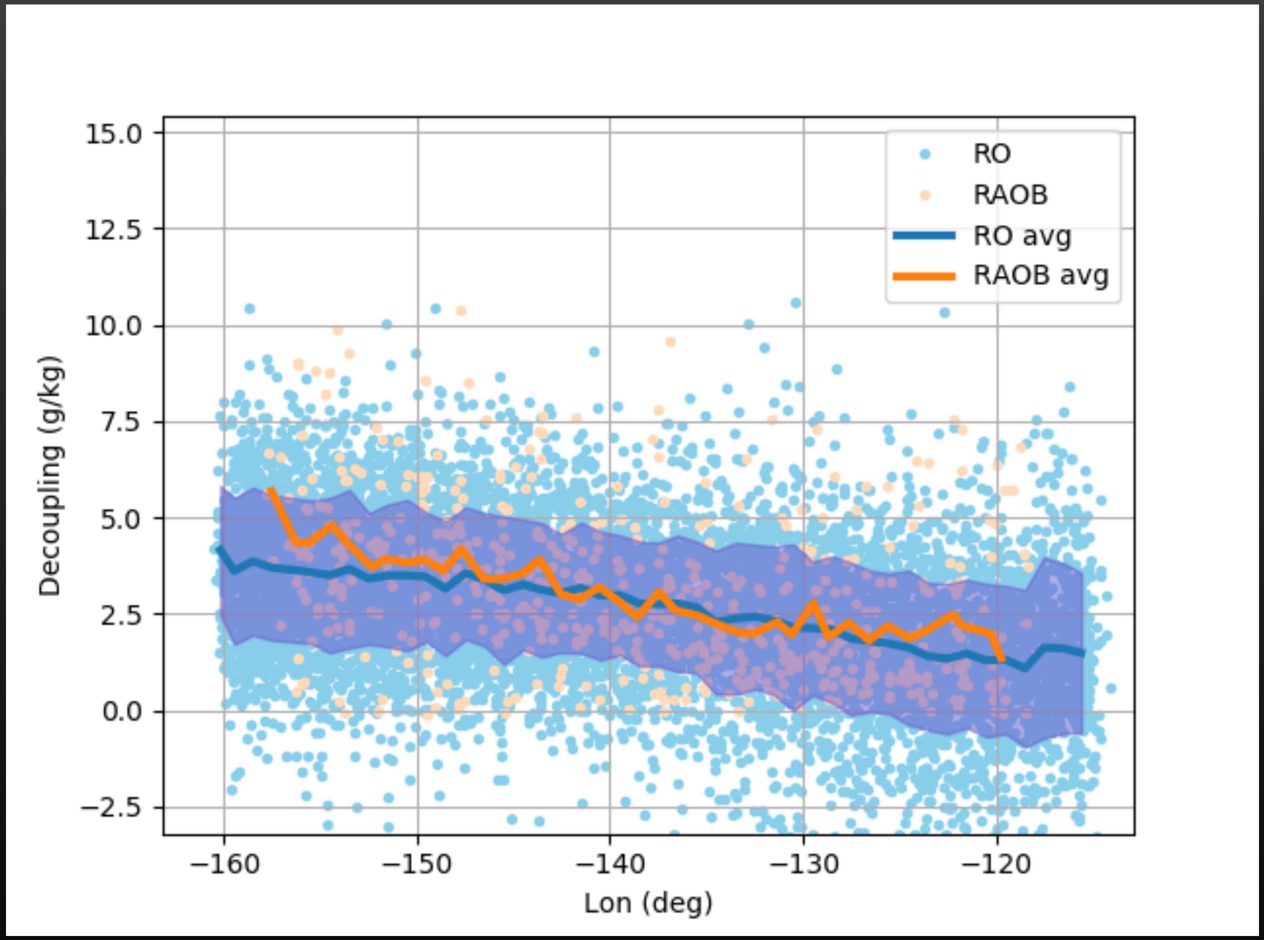
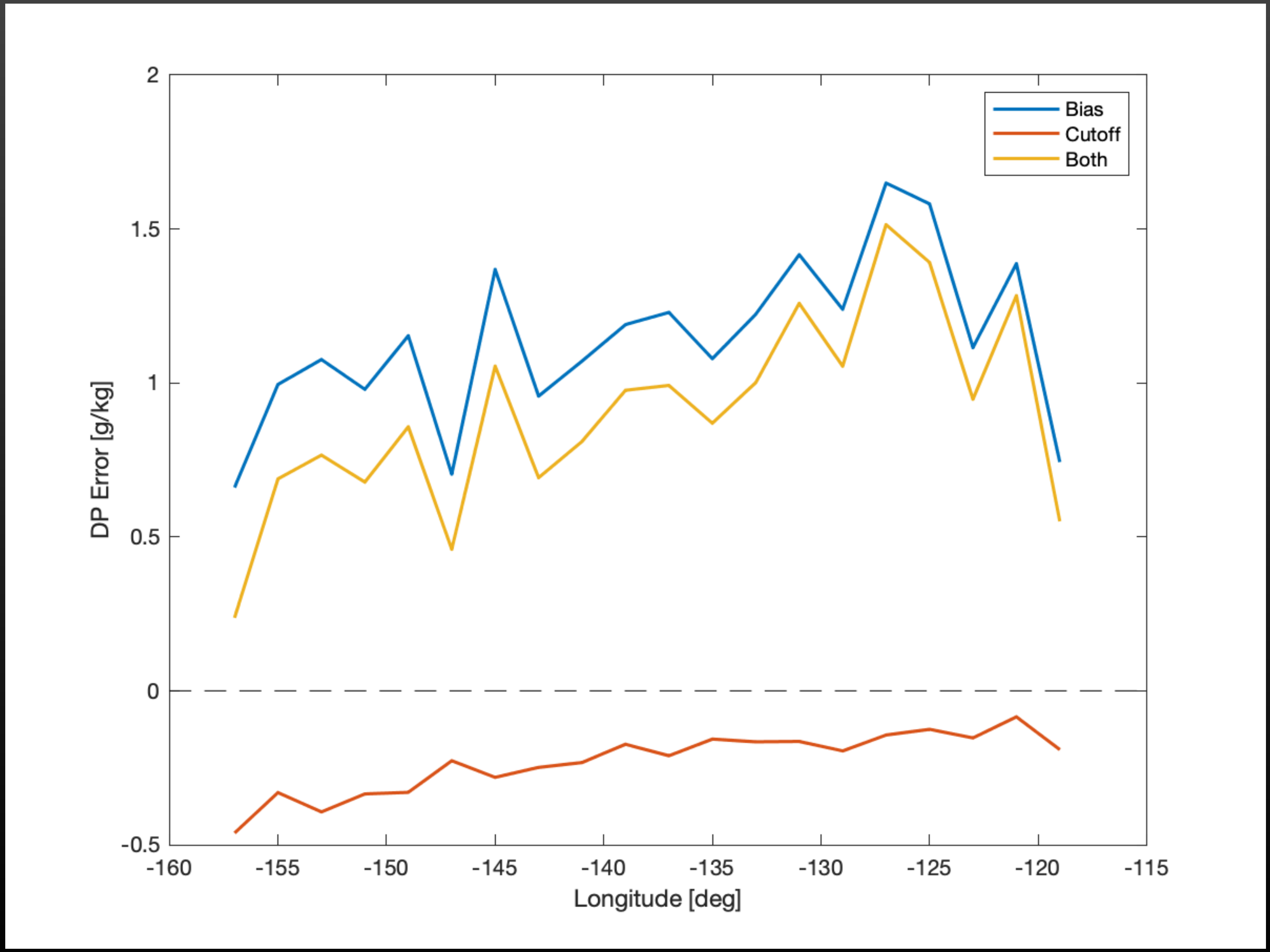



*Figure from Zhou et al., J Clim. 2015*

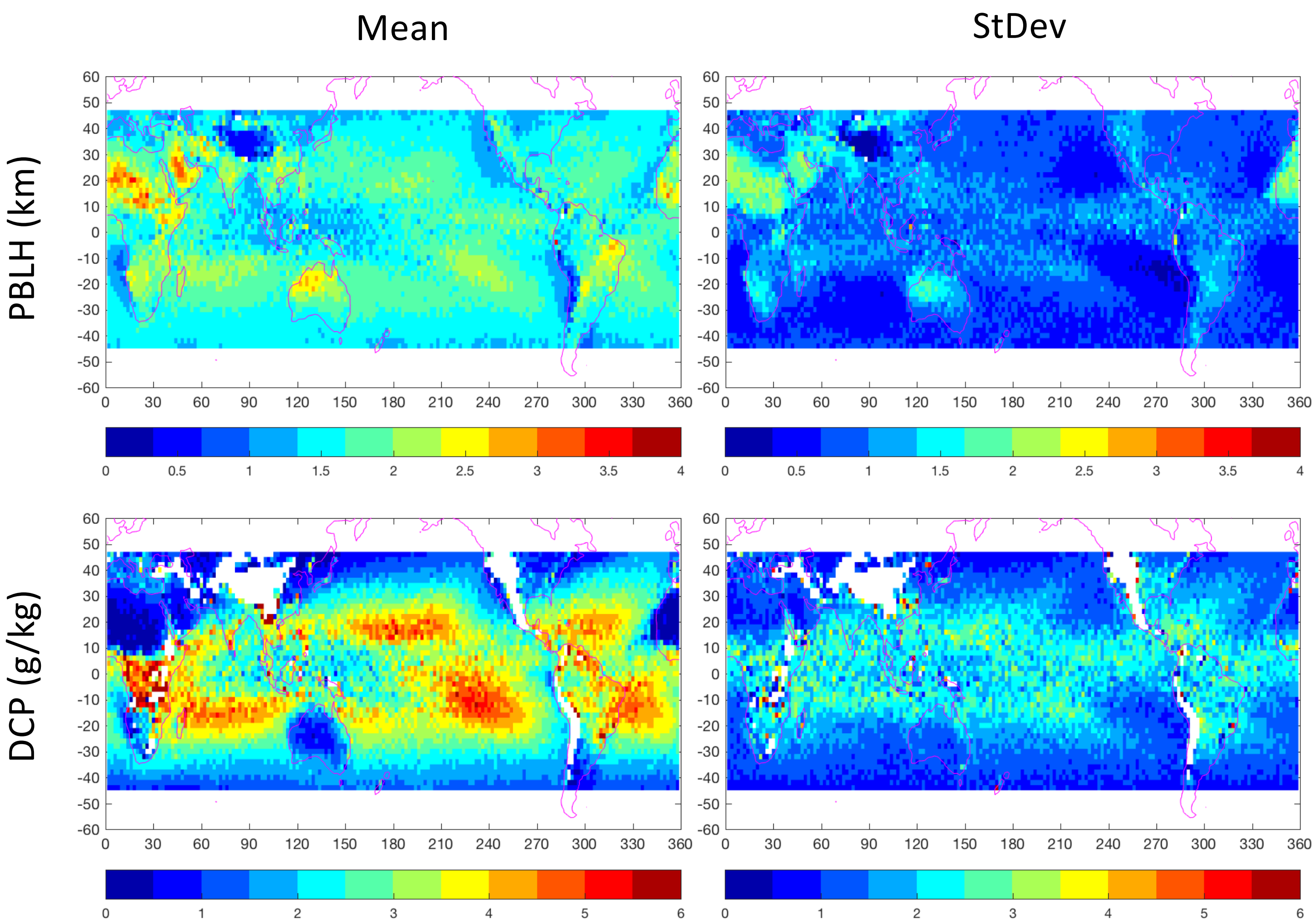



**Good agreement between RO and RAOB on average!**

# Uncertainty from Retrieval Error (MAGIC)




- Positive DCP error on the order of ~ 1 g/kg arises mainly from ducting-induced negative N-bias.
- However, actual comparison between COSMIC and MAGIC shows better agreement than 1 g/kg
  - Sampling?
  - Other retrieval biases?




From ~ 10 years of COSMIC and TSX data

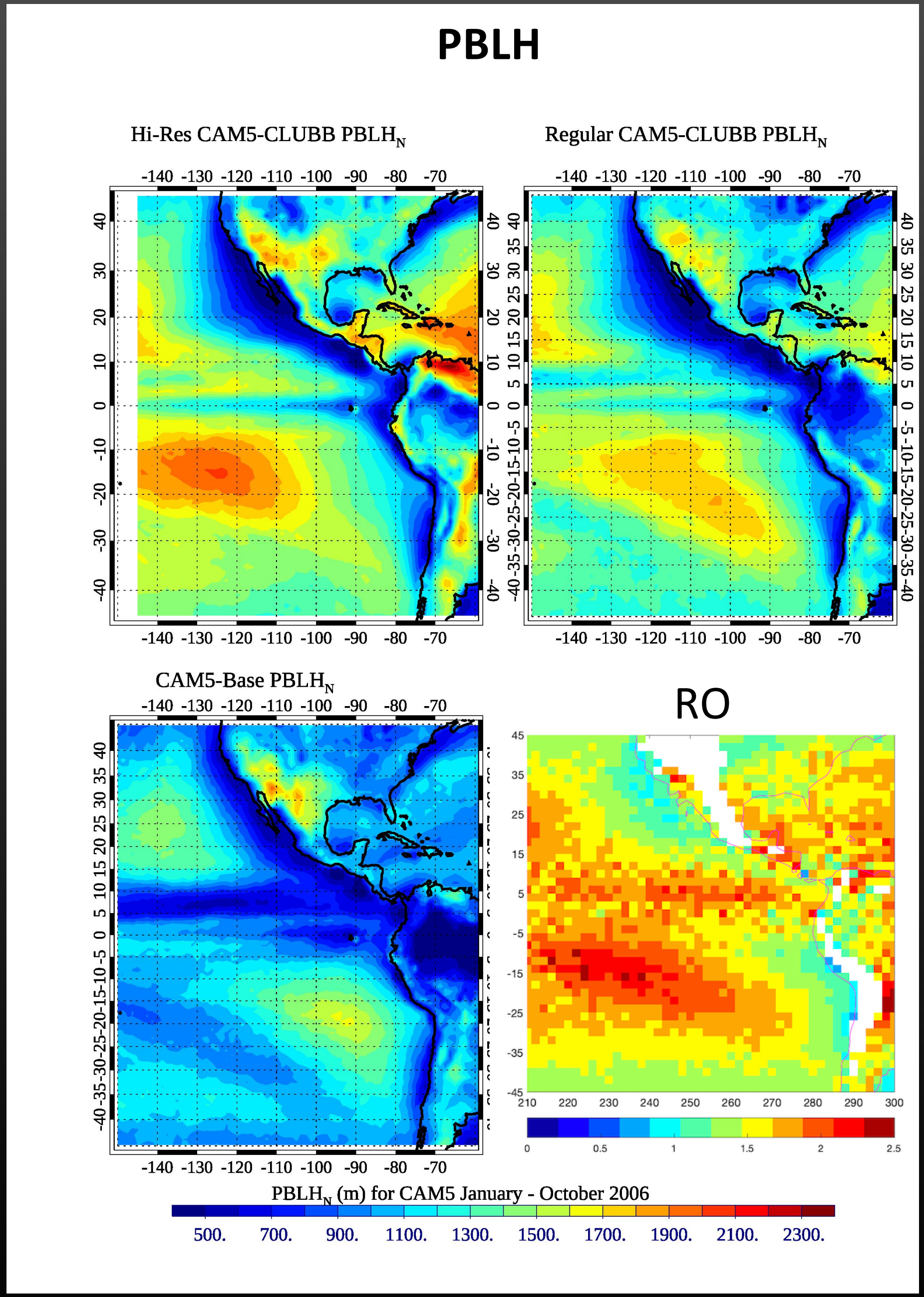
- Strong positive correlation between PBLH and DCP over the ocean.
- Distinct behavior over subtropical land (high PBLH and small DCP).

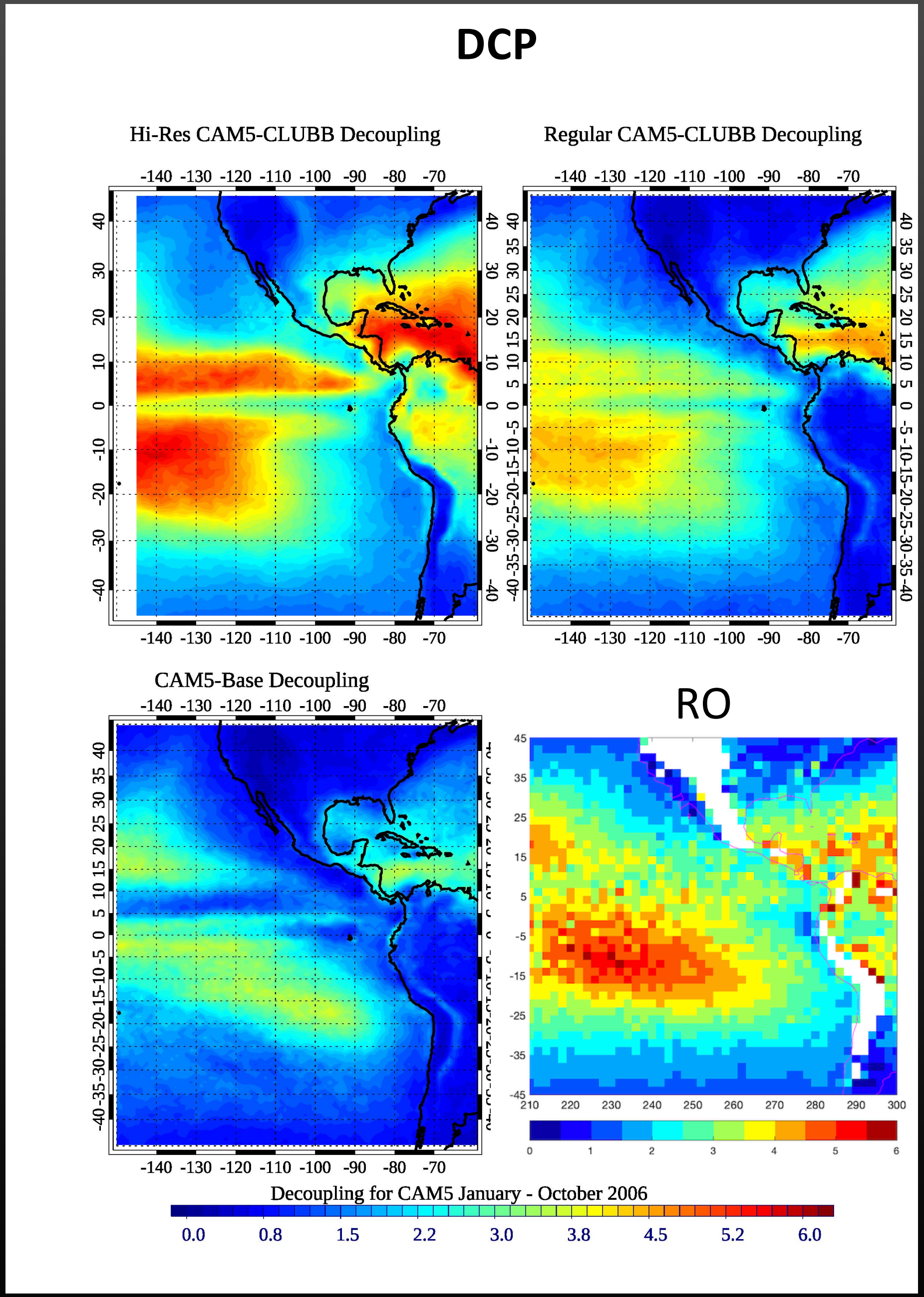
# Model Results

CAM5-Base
CAM5-CLUBB
CAM5-CLUBB High Res

**CAM5-CLIBB High Res yields PBLH and DCP that are most consistent with RO.**

(The PBLH comparison is discussed in details in Kubar et al., GRL, 2019.)



# The PBL is identified as a "Targeted Observable" in the *2017–2027 National Academy of Sciences Decadal Survey for Earth Science and Applications*

*"The planetary boundary layer (PBL) has broad importance to a number of Earth science priorities…. Accurate and high-resolution measurements and better understanding of boundary layer processes are of key importance for improving weather and climate models and predictions."*

TABLE S.2 Observing System Priorities

| Targeted Observable | Science/Applications Summary | Candidate Measurement Approach | Designated | Explorer | Incubation |
|---|---|---|---|---|---|
| **Planetary Boundary Layer** | **Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights | Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height | | | **X** |

*Incubation: "A new program element, focused on investment for priority observation capabilities needing advancement prior to cost-effective implementation,…"*

# Summary

- GNSS-RO profiles provide unique information on the vertical structures of the PBL characterized by the decoupling parameter.
- Comparison with radiosondes showed very good agreement.
- The primary uncertainty comes from refractivity bias and depth penetration, which may be improved with COSMIC-2 and use of non-Abel estimation technique when ducting is present [Wang et al. 2017].
- RO has been identified as a candidate measurement for PBL, which is a Decadal Survey targeted observable in need of “incubation” in the next decade.
  - *What are the remaining uncertainties and limitations from RO?*
  - *What technological advances in RO will further improve its ability to sense the PBL?*
  - *What would a PBL mission based primarily on GNSS-RO look like?*