# Enhancing temporal and vertical resolution of Planetary Boundary Layer satellite temperature retrievals using in-situ aircraft observations and Deep Learning approaches

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## NASA Planetary Boundary Layer Decadal Survey Incubation Program

Accurate monitoring of the Planetary Boundary Layer (PBL) is essential for improving weather forecasting, climate understanding, and air quality assessment. However, the **global surface observational network remains sparse**, particularly over oceans and remote continental regions, which results in significant gaps in PBL characterization [1]. While **satellite remote sensing offers broad spatial coverage**, current retrievals often **lack the vertical and temporal resolution** needed to resolve key PBL processes [2]. Conversely, in-situ observations measured by commercial aircraft provide **high vertical and temporal resolution** thermodynamic profiles but are **geographically limited** to airports [3].

## Remote

### Microwave Integrated Retrieval System (MiRS) [4]

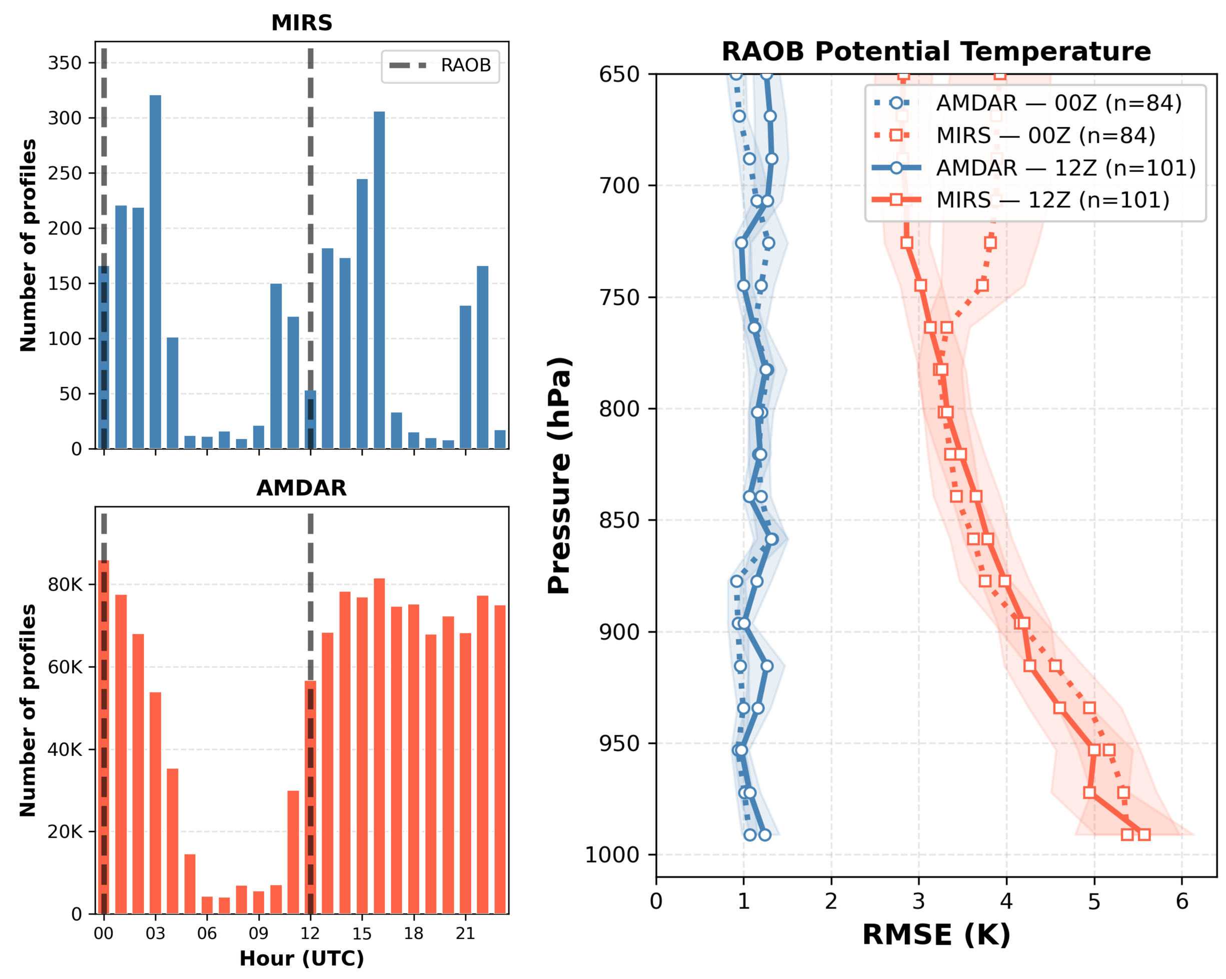
Physical retrieval algorithm applied to microwave products from various satellites (Metop-B and Metop-C, GPM, S-NPP, NOAA-20, and NOAA-21) with different instrumental configurations (AMSU-A, MHS, ATMS, GMI). The operational MiRS by NOAA produces advanced near-real-time surface, atmosphere and precipitation products in all-weather and over all-surface conditions.

## In-situ

### Aircraft Meteorological Data Relay (AMDAR)

Meteorological observations taken by commercial aircraft during landing and takeoff, offering both high vertical (25 - 150 meters) and temporal (1 min - 6 hours) [5] resolutions at 71 airports across CONUS.

**Dallas Fort-Worth Airport, USA**
**01/01/2018 to 31/12/2018**




## Objective

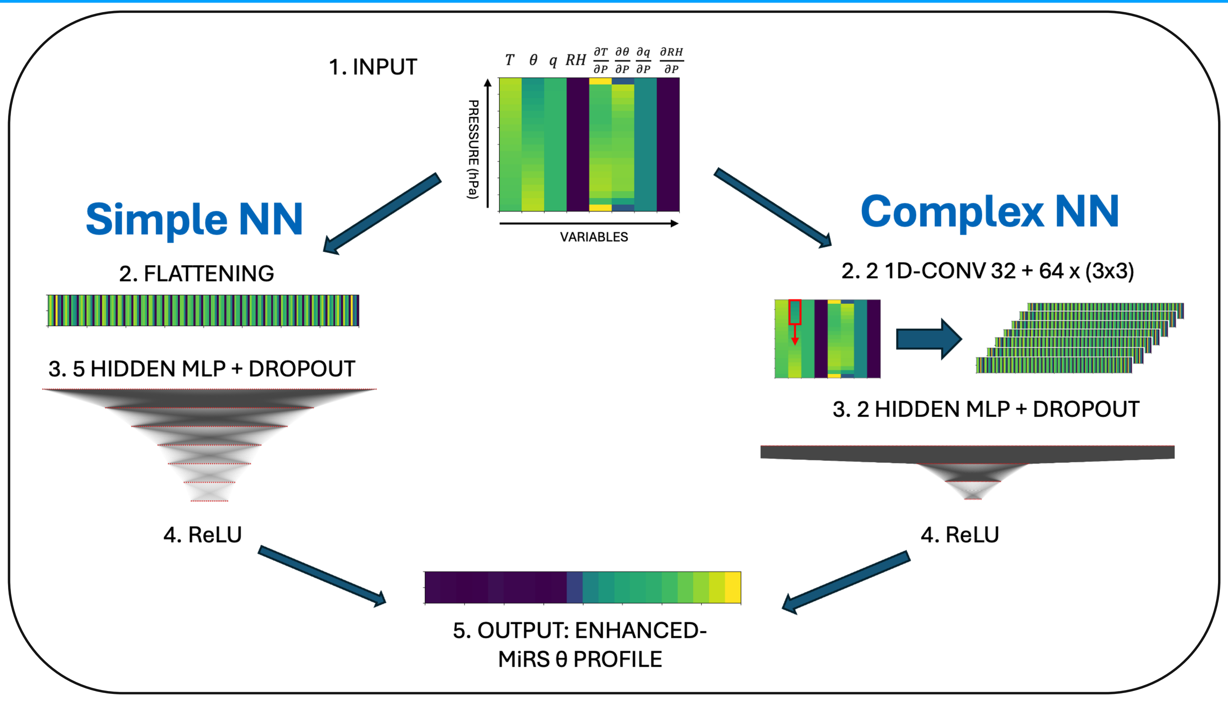
Evaluate the potential of deep learning to enhance satellite-derived PBL thermodynamic profiles by training a convolutional neural network (CNN) to **correct MIRS retrievals and capture the PBL diurnal cycle**, using high-resolution AMDAR observations as local training targets.

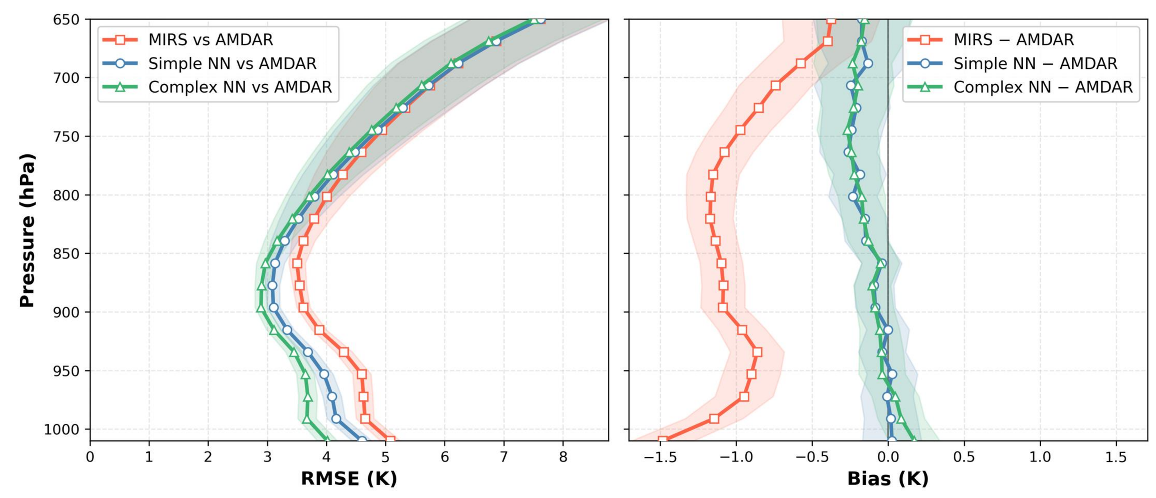
## Variables

Original variables: *Air temperature (T), specific humidity (q), pressure (p)*

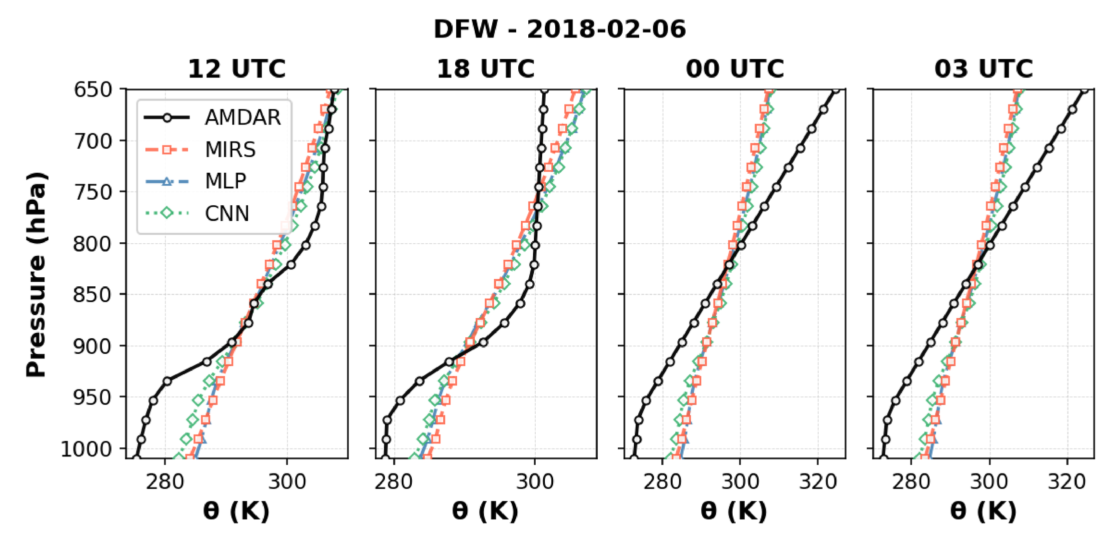
Derived variables: *Potential temperature (θ), relative humidity (RH),* $\frac{\partial T}{\partial p}, \frac{\partial q}{\partial p}, \frac{\partial RH}{\partial p}, \frac{\partial \theta}{\partial p}$.

## 1D approach – Single profiles



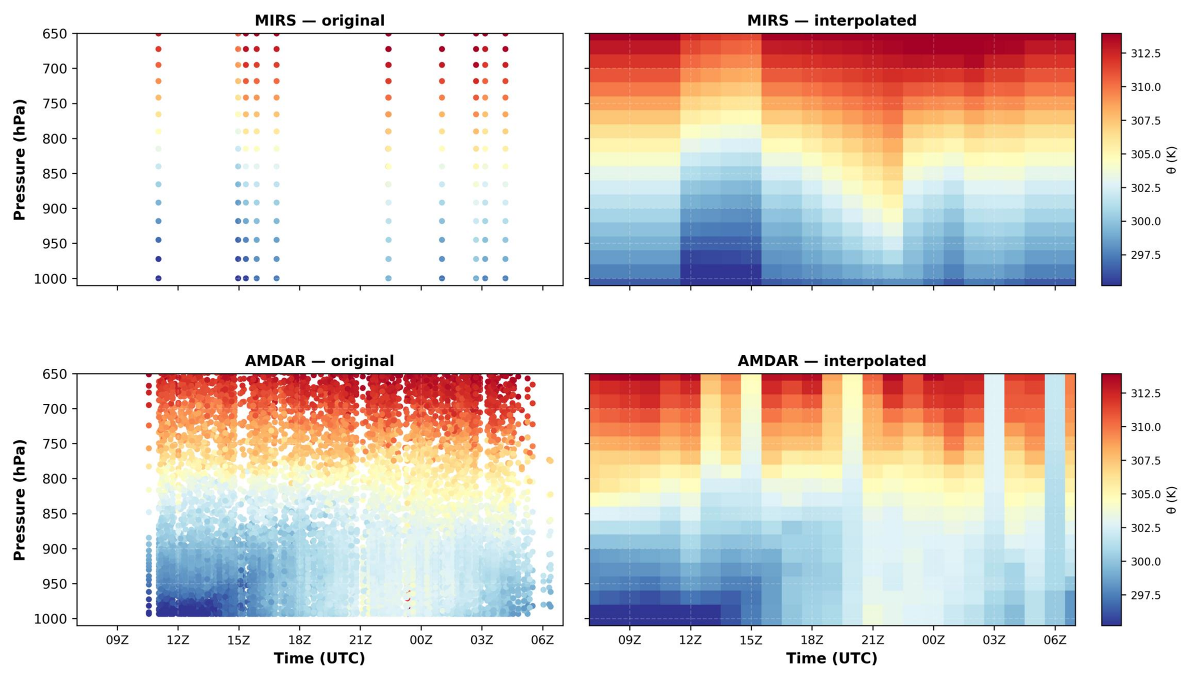




*Evaluation metrics using the testing dataset (30% - n = 564)*




*Models' performance for a specific date from the testing dataset.*

## 2D approach – Time-Height sections



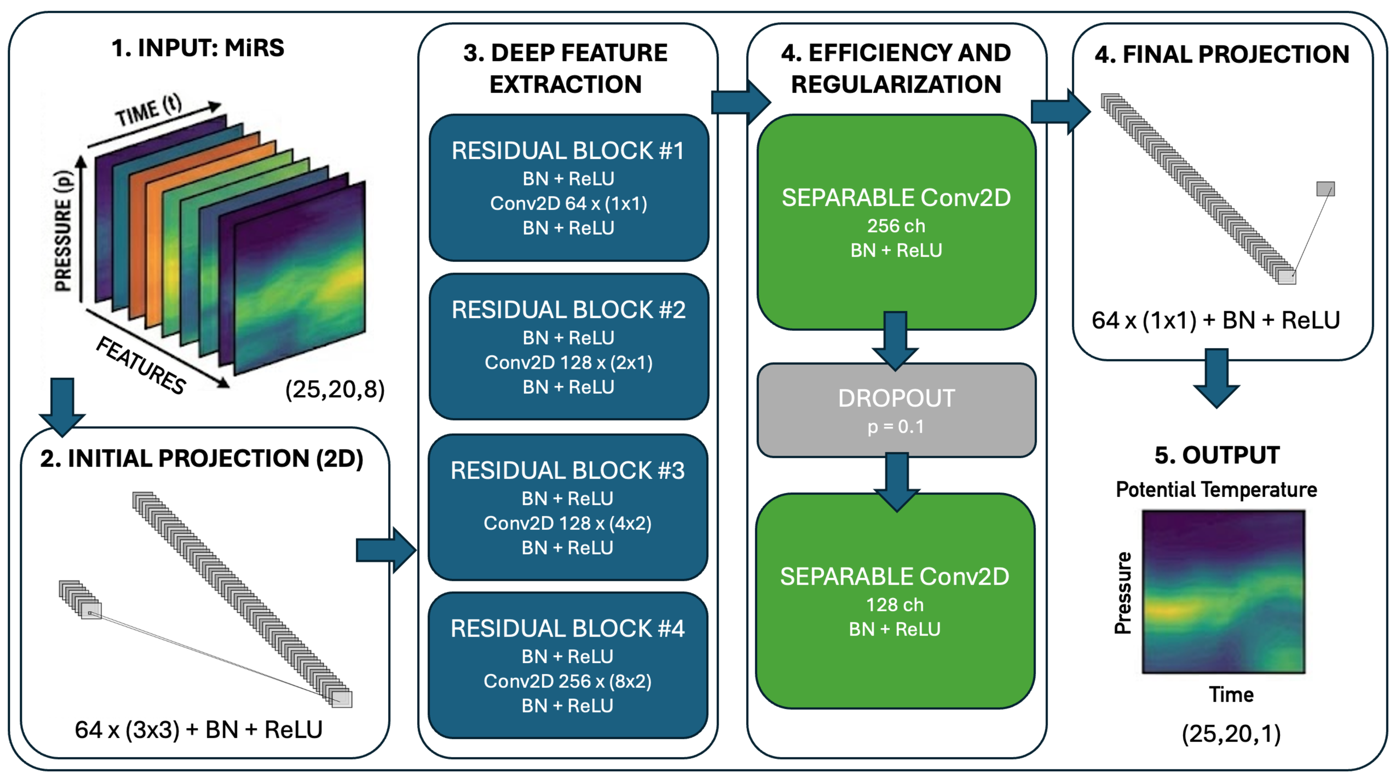

*Example of extrapolation strategy for θ on May 21, 2018*

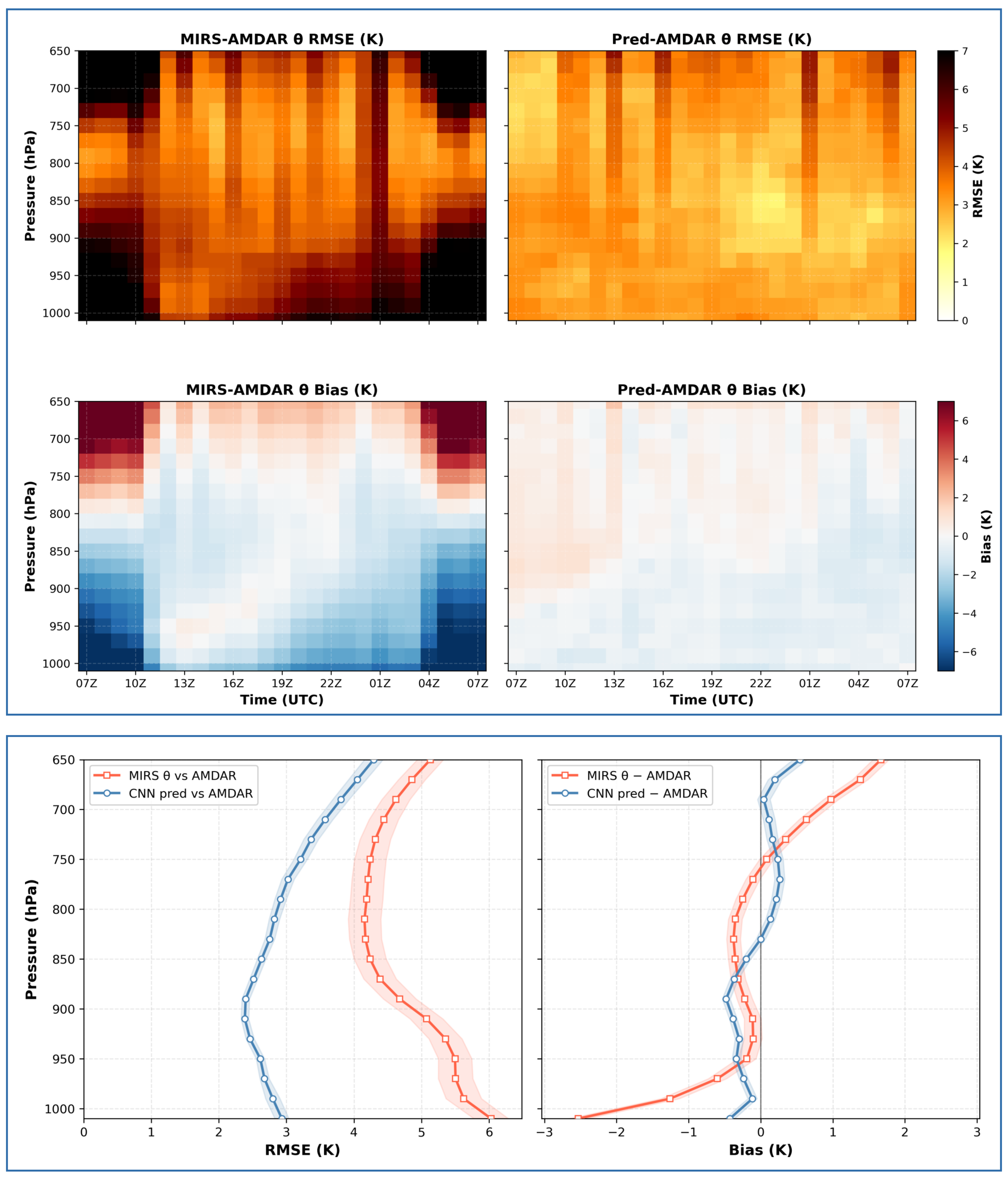
| Dataset | Original shape | After extrapolation shape |
|---|---|---|
| MIRS | 15 p-levels<br>1–14 time steps | 20 p-levels<br>25 time steps* |
| AMDAR | 1–50 h-levels<br>1–310 time steps | 20 p-levels<br>25 time steps* |

*24-hour periods are delimited at 07 UTC due to the low profile counts in both datasets around that hour.

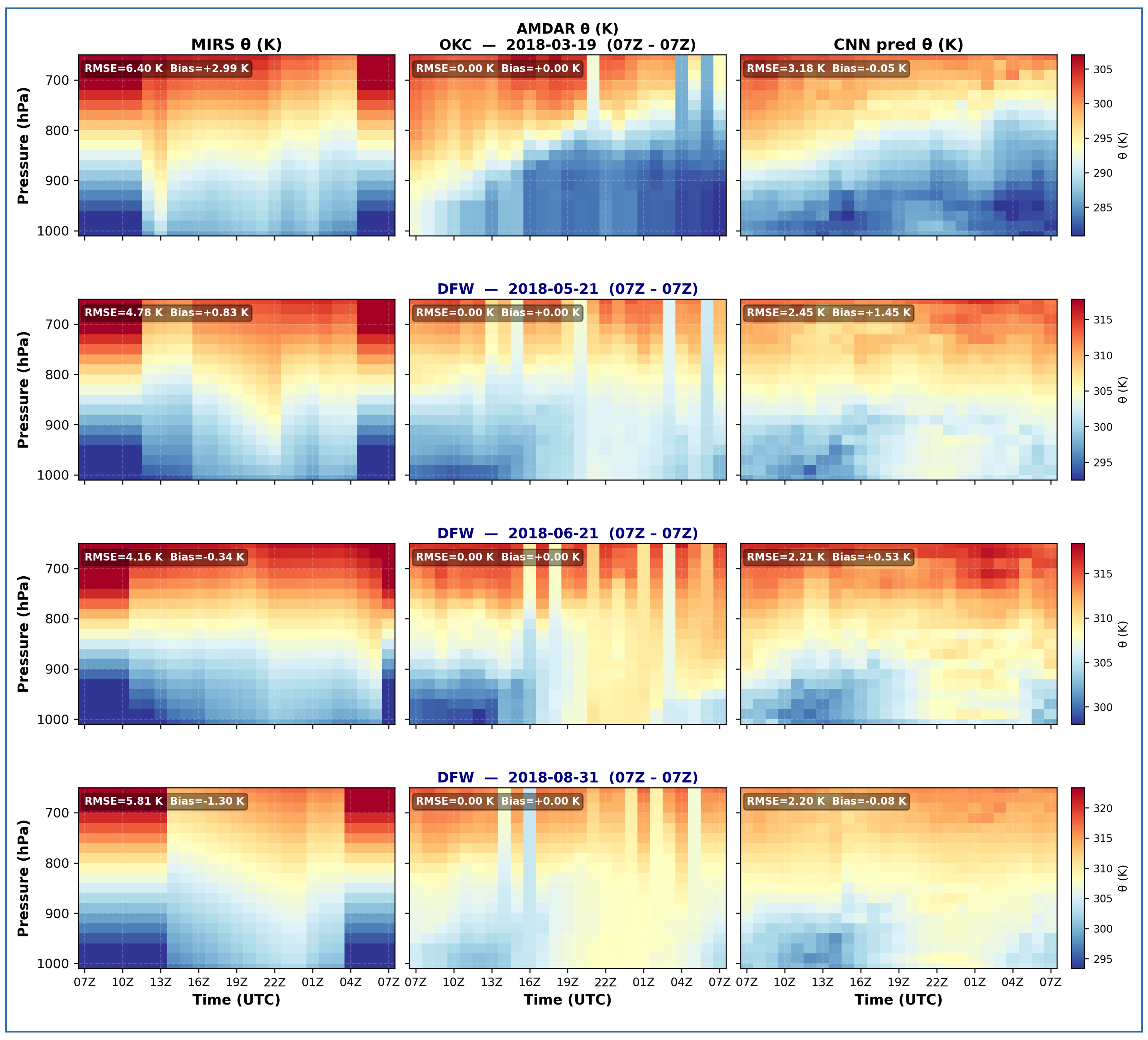
INPUT:

1. Min-Max Standardization
2. Train = 70%, Validation = 15%, Testing = 15%




*Evaluation metrics using the testing dataset (n = 116) with extrapolated sections (upper) and original profiles only (lower)*




*Model's performance for specific dates from the testing dataset.*

## Conclusions

Enhancement of single profiles is insufficient to characterize the diurnal evolution of PBL thermodynamics.

Temporal interpolation of MIRS profiles enables leveraging the high temporal resolution of AMDAR observations as training targets.

Deep learning effectively recognizes atmospheric patterns and enhance the representation of the PBL diurnal cycle, producing results consistent with the expected theoretical time-height thermodynamic evolution.

The fusion of satellite retrievals and in situ aircraft observations offers a promising and scalable solution for high-resolution global PBL monitoring.

## References

[1] NASEM, 2018, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space". [2] Teixeira et al, 2025, "Toward a Global Planetary Boundary Layer Observing System: A Summary". [3] Teixeira et al, 2021, "Toward a global planetary boundary layer observing system: The NASA PBL incubation study team report". [4] Boukabara et al, 2011, "MiRS: An all-weather 1DVAR satellite data assimilation and retrieval system.". [5] Moninger et al, 2009, "Evaluation of Regional Aircraft Observations Using TAMDAR".

## Acknowledgements

This research was supported by the Oak Ridge Associated Universities NASA Postdoctoral Program fellowship to M. Yabra. We thank J. English (CIRES-NOAA) for providing the AMDAR dataset, NOAA CLASS for the MiRS dataset, and J. A. Caraballo-Vega (NASA GSFC) and A. Kotsakis (NASA GSFC-UMCP) for valuable insights on AI approaches and strategies.

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