AR Core Identification for Verification of West-WRF water vapor flux layer forecasts against CW3E radiosondes in Northern California

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Introduction

Background & Motivation

- Integrated Water Vapor Transport (IVT) is the primary metric used to identify and characterize atmospheric rivers (ARs).
- Accurate prediction of IVT magnitude, direction, and vertical structure is important for forecasting orographic precipitation.
- Previous forecast verification focuses primarily on IVT magnitude and precipitation, with less attention to errors in flow direction and the vertical distribution of moisture transport.

Study Objectives

- Evaluate a high-resolution, near-real-time AR forecast model using radiosonde observations.
- Assess model performance in predicting IVT magnitude, flow direction, and vertical extent of moisture transport, and other environmental characteristics respective of AR flow direction.
- Introduce a novel verification metric that evaluates the vertical location depth of the concentrated water vapor flux column to evaluate model to predictions.

AR Core Identification Methods

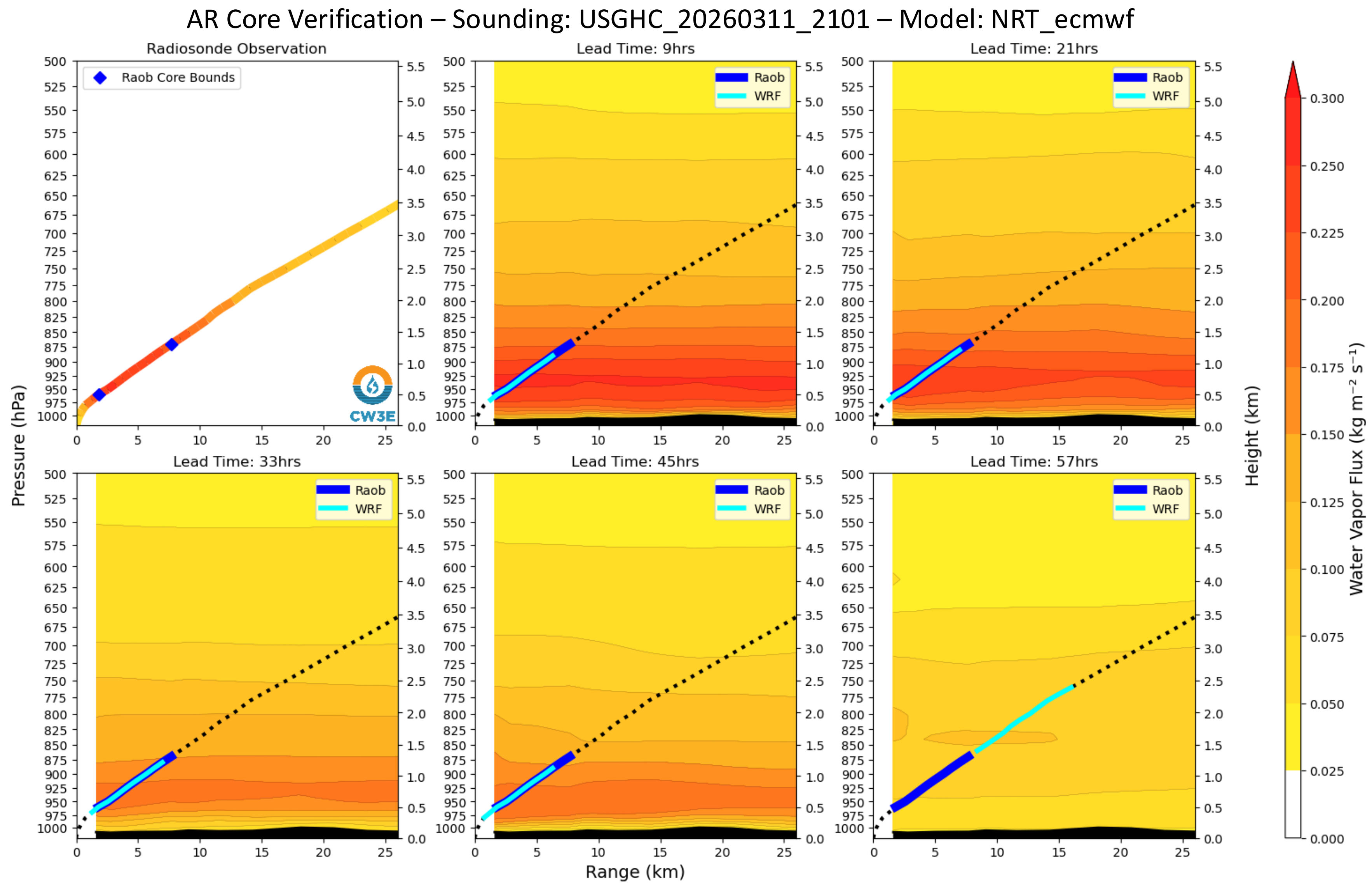

AR Core Verification – Sounding: USGHC_20260311_2101 – Model: NRT_ecmwf

Figure 1. Trajectory of individual radiosonde overlaid by water vapor flux of the atmospheric column. Identified AR Core highlighted in cyan (modelled) and blue (observational) with terrain blacked out on the x-axis. Each panel represents a different lead time from 9hrs to 57hrs lead time.

Observational Inputs

- Radiosonde observations from Bodega Bay (USBOD) and Marysville (USYUB) in northern California.
- 518 radiosonde launches collected between December 2021 and March 2024.
- Bodega Bay samples the coastal transition zone, while Marysville represents the windward Sierra Nevada environment.

Model Inputs

- Evaluated the West-WRF deterministic forecast model initialized with NCEP GFS analyses.
- Model output was interpolated to each radiosonde profile and matched to observations within ±30 minutes of the 800-hPa ascent time via a linear barycentric interpolation through 3-D space.

IVT Core Layer

- Interested in finding the most concentrated portion of vapor transport to determine most efficient layer of conveyance
- Defined an Integrated Vapor Flux (IVT) Core Layer as the thinnest vertical layer containing 25% of the total integrated water vapor flux through an iterative search over layer thickness and position.
- Used to evaluate the predicted vertical location and depth of concentrated moisture transport.

Climatology of IVT Core Layer

IVT Core Layer Climatology via USYUB and USBOD Radiosondes

- Represents the most concentrated portion of atmospheric water vapor transport. Identifying its vertical location helps isolate pressure levels where model biases occur.

Key Findings

- The most common core top & bottom: ~1000 hPa, ~900 hPa.
- Most IVT Core Layers have tops below 850 hPa, corresponding to a typical core depth of 100–150 hPa.
- Most frequent core top is slightly higher at Marysville (~880 hPa) than at Bodega Bay (~910 hPa).
- Few cases exhibit elevated IVT Core Layers (>800 hPa), demonstrating the need for a verification metric that evaluates moisture transport throughout the atmospheric column rather than only at lower levels.

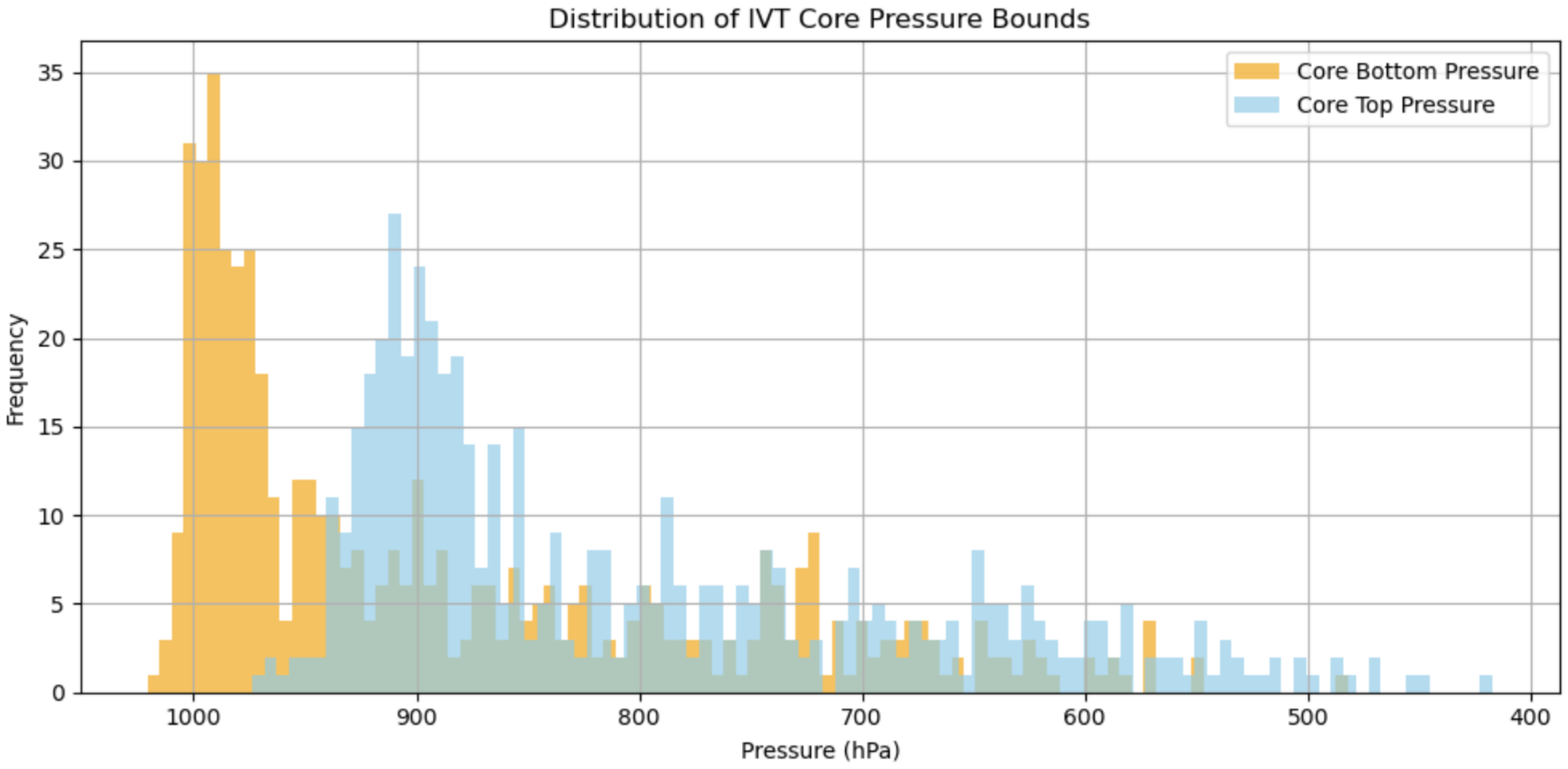
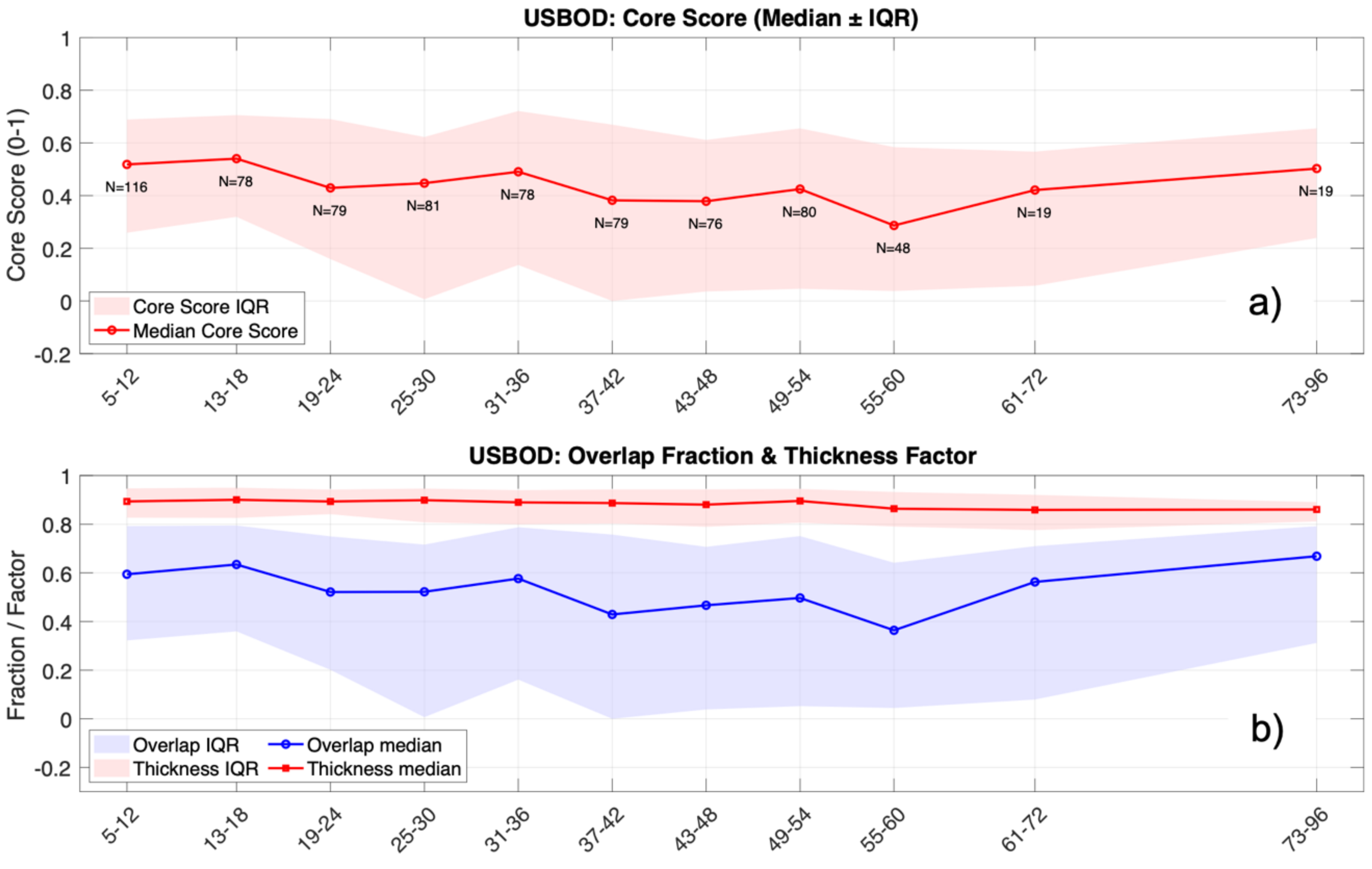

Distribution of IVT Core Pressure Bounds

Figure 2. Histogram of pressure locations (hPa) for the top of the IVT core layer (blue) and bottom of the IVT core layer (orange) using data at both Bodega Bay and Marysville, CA.

Core Score Analyses


USBOD: Core Score (Median ± IQR)

USBOD: Overlap Fraction & Thickness Factor

Figure 3. (a) Core score and (b) overlap fraction (red) and thickness factor (blue). The solid line in each panel represents the median value and the shaded areas represent the interquartile range (IQR). The number of forecast-observations pairs in each lead time bin are given below the core score in panel a.

Core Score Verification Metric

To evaluate how well forecasted and observed IVT Core Layers agree, the study introduces a **Core Score** that combines:

- **Vertical overlap** between forecast and observed core layers (Overlap Fraction)
- **Agreement in core thickness** (Thickness Factor)

$$\textit{Core Score} = \textit{Overlap Fraction} * \textit{Thickness Factor}$$

This study evaluated IVT error with respect to:

- Along-flow and cross-flow IVT.
- Total and core-layer IVT magnitude.
- Core Score distribution and vertical bias.
- Temperature, dew point, and wind speed.

Key Findings

- West-WRF captures the overall vertical structure of ARs but systematically underestimates total and core IVT magnitude.
- IVT errors occur in a context of systematic temperature and moisture biases, variable wind errors, and cold and dry biases in the lower and mid-troposphere.
- Improving the representation of flow-aligned moisture transport and vertical core position has potential to improve forecast skill over complex terrain.
- Future work will extend this framework to ensemble forecasts to evaluate forecast uncertainty and probabilistic skill.

Acknowledgments

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