Frontal Modification of Atmospheric Boundary Layer Dynamics over Land in Mid-latitude

Nicholas Clark [1], Sandip Pal [1], and Temple R. Lee [2,3]

[1]Atmospheric Science Division , Department of Geosciences, Texas Tech University; [2] Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), Norman, OK, USA
[3] NOAA Air Resources Laboratory Atmospheric Turbulence and Diffusion Division, Oak Ridge, TN, USA

1. Introduction

Mid-latitude cyclones and associated passages of cold and warm fronts over the land-surface lead to high-impact weather events including deep moist convection and extreme precipitation. We hypothesize that during quasiperiodic passages of cyclonic and anti-cyclonic flows, the atmospheric boundary layer (ABL) encounters vigorous changes (both vertically and horizontally) due to three key competitive forcing: land-surface forcing via changes in soil moisture regimes due to precipitation, subsidence over the high-pressure-dominated cold sector, and convection, cloud coverage and frontal lifting. **We:**

- ✓ hypothesized that frontal passages help modify BLDs drastically so that BLD differences between pre- and post-frontal days can help understand the role of mid-latitude cyclones on ABL dynamics during all four seasons.
- ✓ strongly believe that the analyses presented here will advance our understanding of moist boundary-layer processes and single out potential sources that trigger drastic changes in ABL dynamics during, before, and after frontal passages.

2. Aims and Scopes

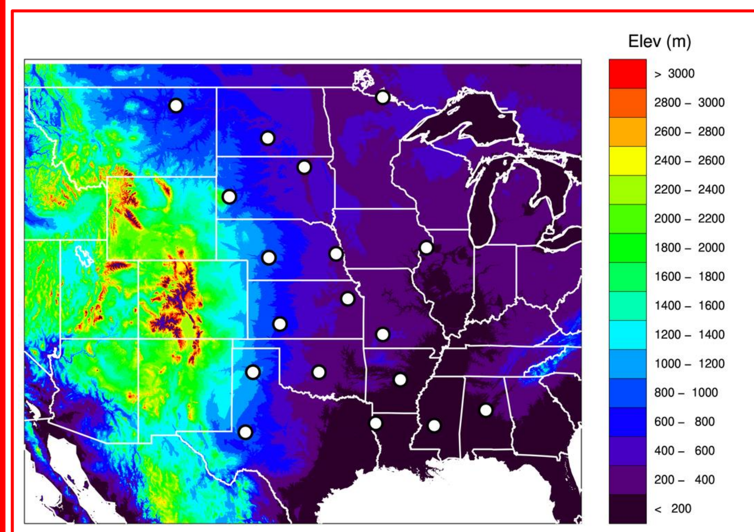
Within this work, we:

- ✓ explored regular 00-UTC rawinsonde-retrieved afternoon-BLDs over 18 sites located in the eastern US during one-year period (Dec 2013- Nov 2014);
- ✓ determined frontal passages using 3-hourly surface synoptic charts for the entire year.

We aim:

- ✓ to understand the frontal modification of daytime ABL depths (BLDs, i.e. z_i) during pre-to-post frontal conditions so that a comparison between BLDs in warm (pre-frontal) versus cold (post-frontal) sectors can be elucidated;
- ✓ investigate the BLD-contrasts (i.e. z_i^{Warm} - z_i^{Cold}) during four seasons to understand how the frontal impact on BLDs demarcate seasonally;
- ✓ determine how the BLD-contrasts change spatially over different regions;
- ✓ diagnose frontal-regimes and cyclone tracks when BLD-contrasts might be linked to the impact of contrasting meteorological processes taking place in the warm and cold sectors.

3. Datasets and Sites



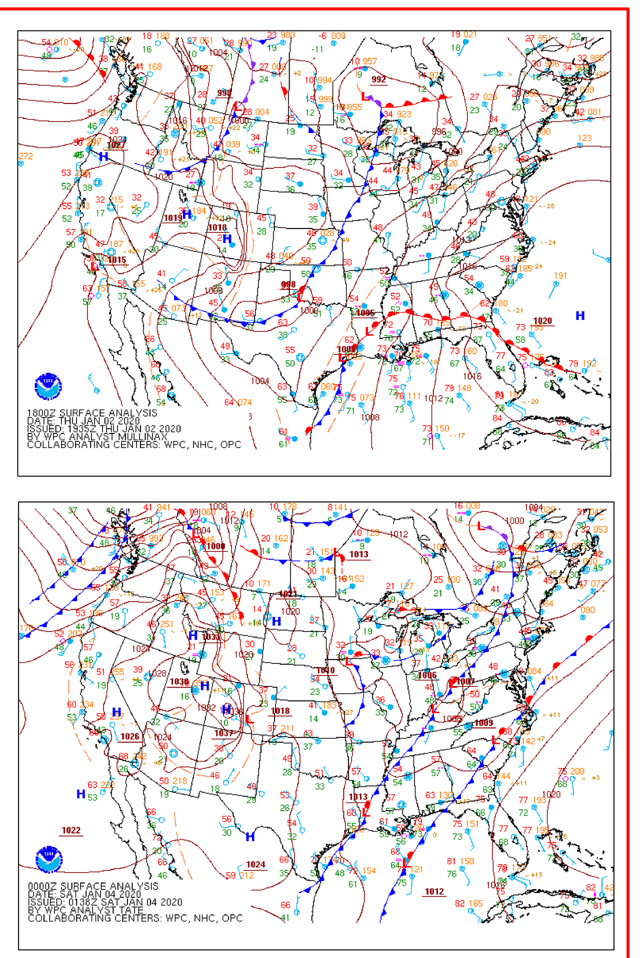


Figure 1: *(Left): Locations of 18 IGRA sites (white-filled-circles) overlaid on the topographical-maps (site-elevation in m MSL). (Right): Typical surface synoptic charts (e.g., 18 UTC on Jan 02, and 00-UTC on Jan 4, 2014) used in the analyses for detecting frontal passages over the IGRA sites. Surface-charts were obtained from NOAA's Weather Prediction Center.*

4. Method with an Example

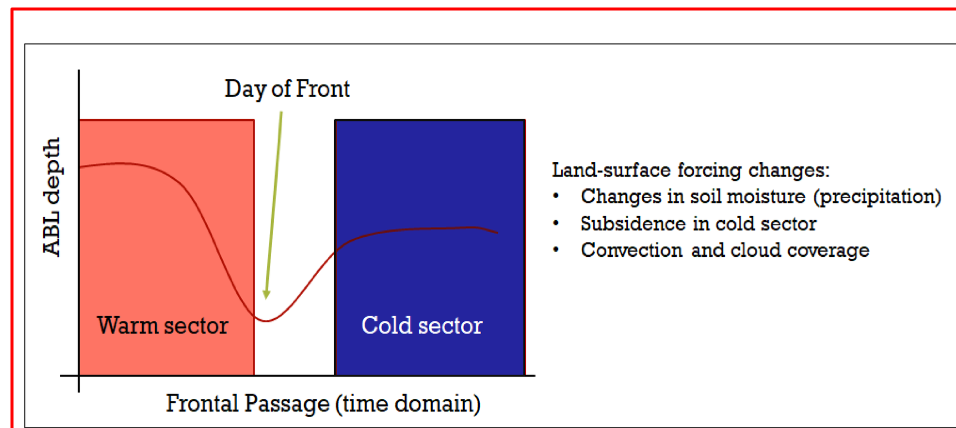


Figure 2: *Illustration of the method for determining frontal modification of atmospheric boundary layer depths over land via three competitive factors.*

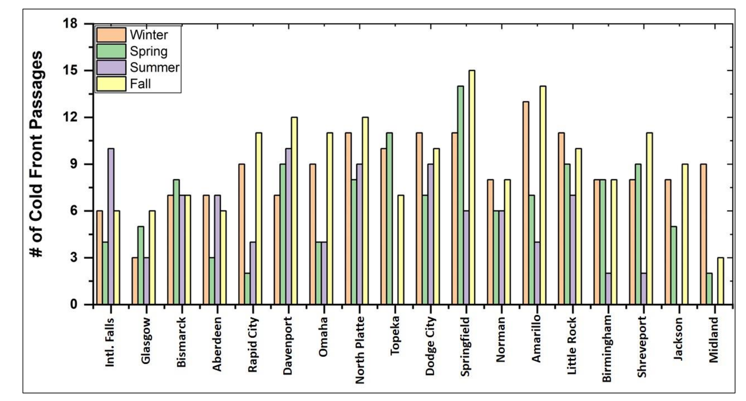


Figure 3: *Overview counts of cold front passages over the 18 IGRA sites. The cold front passages during which BLD measurements were available were only considered here.*

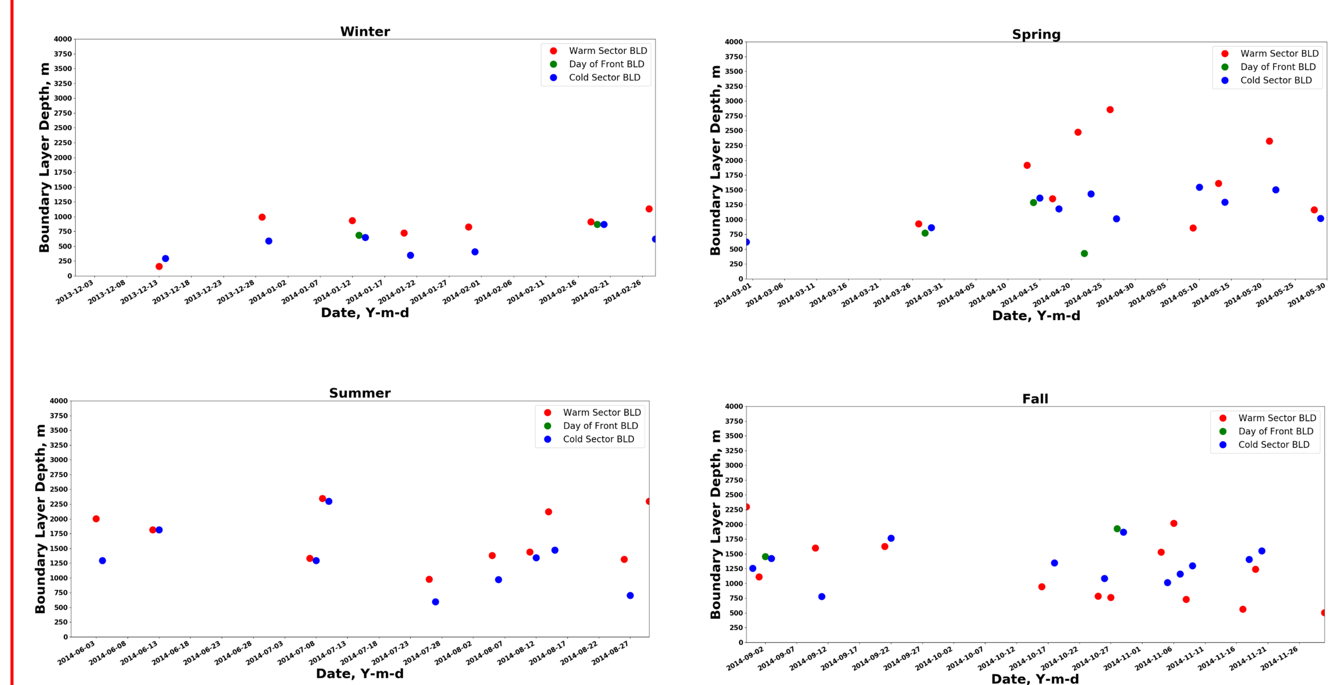


Figure 4: *BLD (z_i, m) variability on synoptic time scale during cold front passages over an example site Davenport, IA during four seasons (DJF, MAM, JJA, and SON) between Dec 2013 and Nov 2014. Red and blue filled-circles denote BLDs in warm and cold sectors, respectively. The BLDs measured on the day of frontal passages are also shown (green circle).*

5. BLDs over all the Sites (Warm vs. Cold)

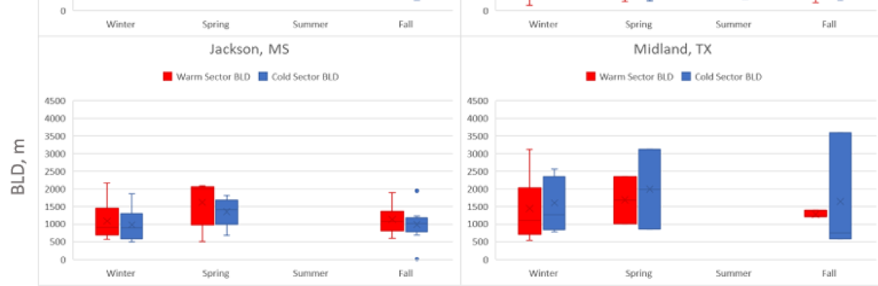


Figure 5: *Overview of rawinsonde-derived BLDs over 18 IGRA sites in all four seasons (Winter (DJF); Spring (MAM); Summer (JJA) and Fall (SON)) between Dec 2013 and Nov 2014 segregated by warm (red) and cold (blue) sector samples. Sites are arranged approximately from northern (top) to southern latitudes (bottom).*

6. BLD Frontal-Contrasts in Four Seasons

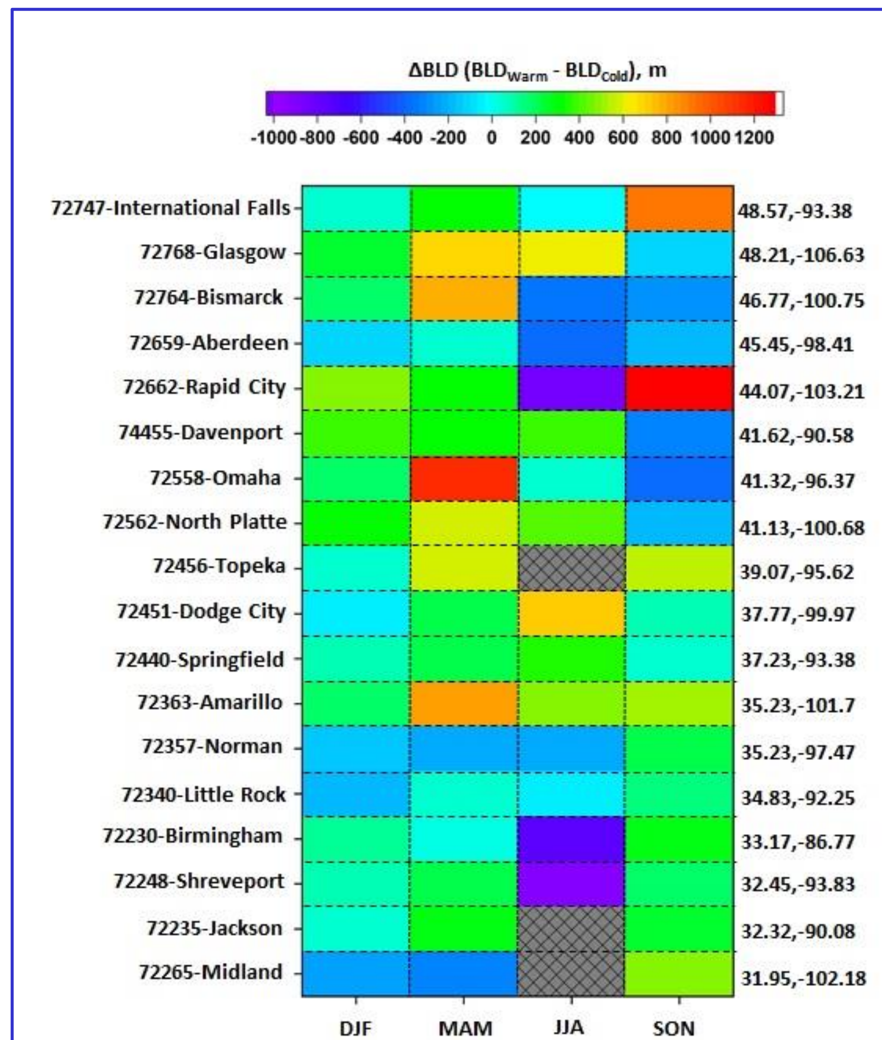


Figure 6: *Heat-map view of seasonal-cycle patterns of medians of ΔBLDs (i.e. z_i^{Warm} minus z_i^{Cold}) over the 10 IGRA sites illustrating the impact of frontal passages on BLDs. The sites are arranged from south to north in y-axis; latitude and longitude values are also kept on the right-y axis. Grey-boxes denote measurement gaps.*

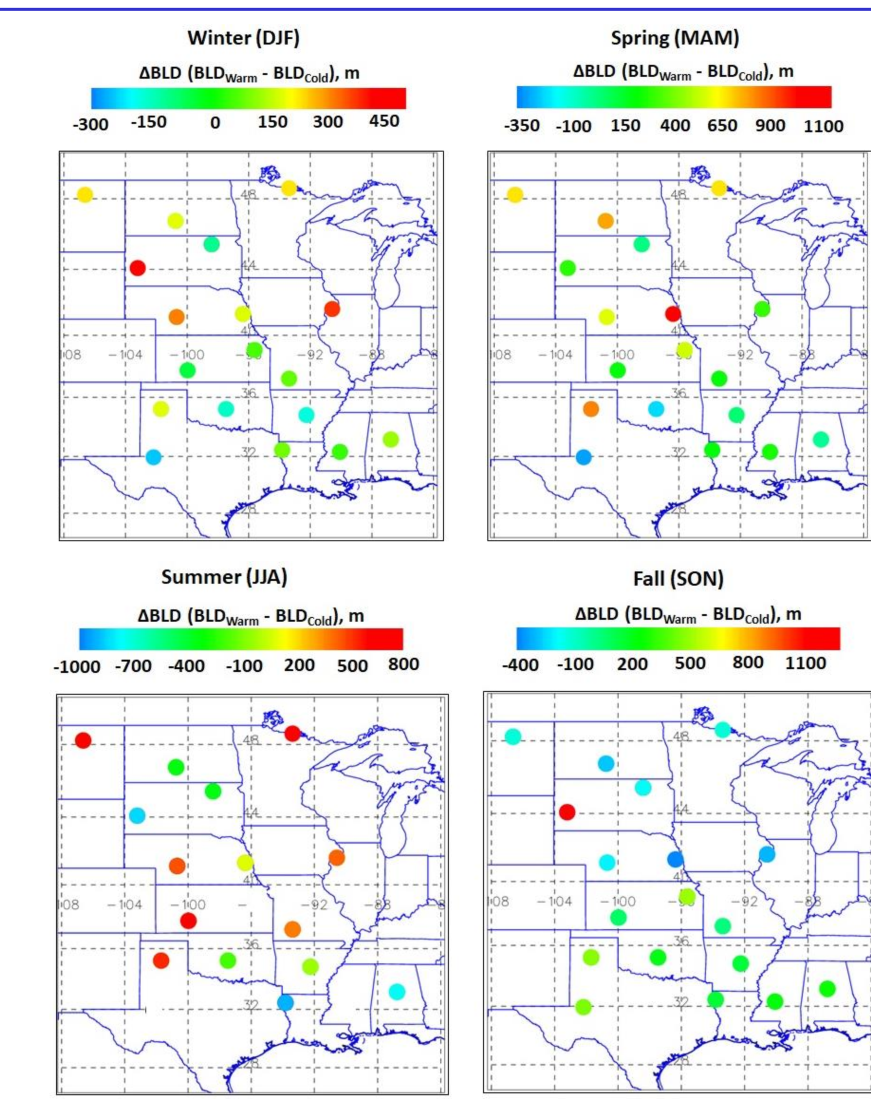


Figure 7: *Spatial variability in ΔBLDs during four seasons (DJF, MAM, JJA, and SON) illustrating the diverse impact of frontal passages on BLDs during 2014. Color bar scale limits are kept different to compare ΔBLDs among the sites within a season not among the seasons.*

7. Summary and Outlook

Within this first-of-its-kind empirical study, we investigated changes in ABL processes, before, during and after frontal passages and explored BLD spatiotemporal variability as a function of weather patterns which largely remained unexplored to the scientific community. **We found that:**

- due to the passages of cold fronts, BLDs become drastically modified so that we found significant differences between BLDs in the warm versus cold sectors
- pattern and magnitude of ΔBLDs (i.e. warm versus cold sectors) vary substantially among seasons and across space (e.g., different sites over the northern and southern Great Plains)
- there exist striking contrasts in BLDs under the impact of frontal passages in winter and spring
- southern sites show some anomalous features in BLD frontal-contrasts most likely due to internal boundary layer development within the Gulf inflow.

In future, we will compare these observational findings with the WRF and NARR simulations to investigate the performance of state-of-the-art high-resolution models whether these models can capture the frontal modifications of BLDs during four seasons. Our analyses will help build observational constrains for validating numerical models and to improve boundary layer parameterizations so that the observed ΔBLDs during four seasons, during spring and summer, could be replicated to obtain a better understanding of the frontal modifications of ABL dynamics

Acknowledgment: *This work was sponsored by an internal start-up research-grant at Texas Tech University, and the lead author Nicholas Clark was funded by the Texas Tech Pi²-scholarship and a Travel Grant from the Center for Transformative Undergraduate Experiences (TrUE) at TTU. The results and conclusions, and any views expressed herein, are those of the authors and do not reflect those of NOAA or the Department of Commerce. The IGRA rawinsonde-data and surface charts were obtained from ftp://ftp.ncdc.noaa.gov/, and from https://www.wpc.ncep.noaa.gov/#page=ovw, respectively.*