2024 CIRES Rendezvous

EOMF

Creating a convenient PBL height dataset using aircraft data

Jason M. English[1,2], David D. Turner[1], Molly B. Smith[1,2], Daniel R. Adriaansen[3], Matthew S. Wandishin[1]

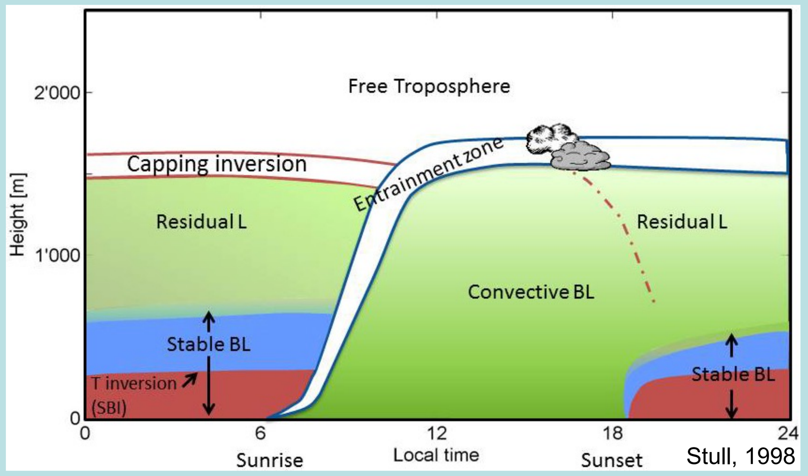
[1]NOAA Global Systems Laboratory, Boulder, CO *correspondence: jason.english@noaa.gov

[2]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO

[3]National Center for Atmospheric Research, Boulder, CO

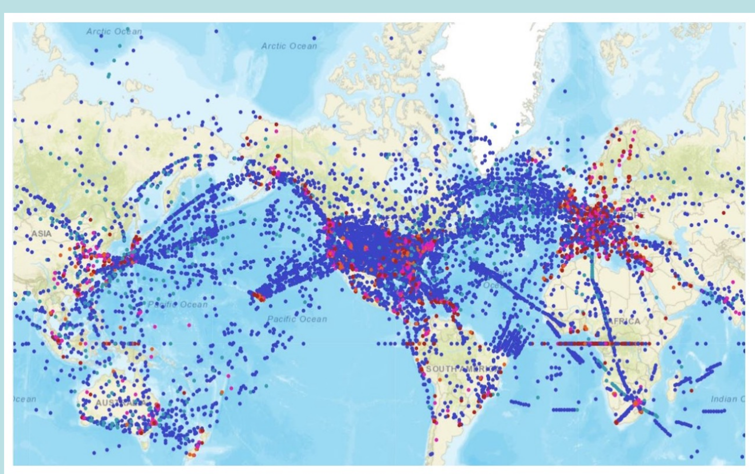
1. PBL Height as a Metric

- The Planetary Boundary Layer (PBL) is the well mixed, lowest layer of the atmosphere
- The PBL Height (PBLH) is a function of surface topography, surface radiation, wind speed/turbulence, air temperature, etc
- Getting PBLH correct is important for many applications (pollution, fog, severe weather/turbulence, wind energy, etc)
- Due to radiative heating, the PBL transitions from a nocturnal/stable (low) PBLH to a daytime/convective (high) PBLH each day
- PBLH is a simple metric that can effectively evaluate a model's ability to represent these lower atmosphere processes, which are often lacking in model verification



2. AMDAR Aircraft Data

- Aircraft data is the most important DA source (James et al. 2020), but is not well utilized for model verification
- Aircraft Meteorological DAta Relay (AMDAR) data is one of the only sources of lower atmosphere profiles with temporal frequency (which is needed to represent the PBL)
- AMDAR provides thousands of T, humidity, and wind measurements per hour [hourly netcdf files with 1-d fields]



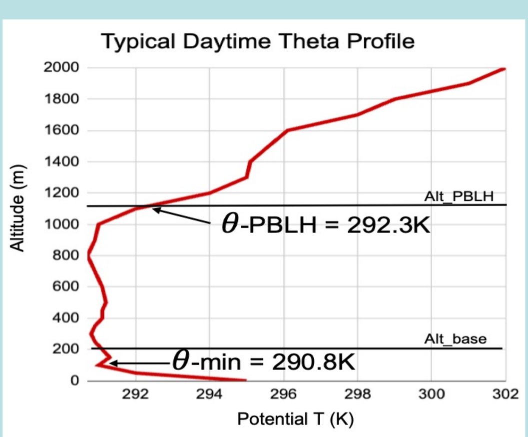
Indicative AMDAR data coverage map, 16 July, 2019.

3. Project Goals/Approach

1. Develop & Implement two methods to compute PBLH from AMDAR data
   - Theta increase (TI) method *(Nielsen-Gammon et al. 2008)*
   - Critical Bulk Richardson number (CBRN) method *(Seidel et al. 2012)*
2. Provide AMDAR PBLH values for 50+ airports via three tools/datasets
   - Portable AMDAR netcdf files
   - METplus Use Case
   - METexpress [in GSL's Model Analysis Tools Suite (MATS)]

4. TI PBLH Method

- A potential temperature (PT/theta) profile is created from each flight ascent/descent
- PBLH is identified as the first instance where PT exceeds (PT_base + PT_delta)



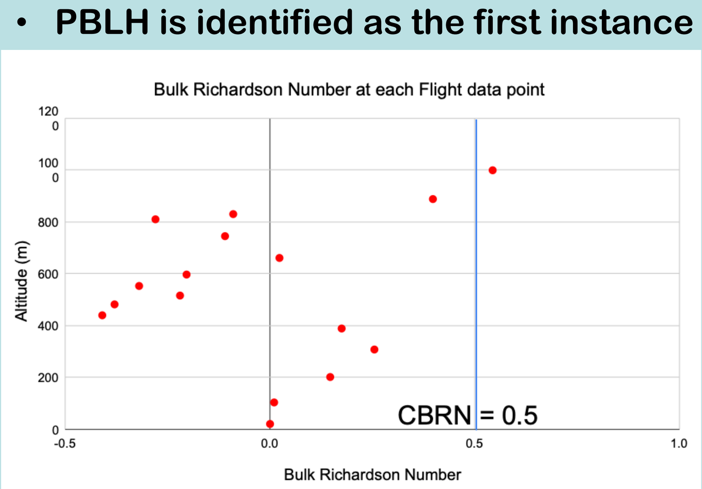
Theta-increase method example

- Step 1: Define alt_base (200 m)
- Step 2: Determine lowest theta value below alt_base (290.8 K)
- Step 3: Specify theta-increase (PT_delta) value (1.5 K)
- Step 4: Find first instance where theta exceeds theta-base + theta-increase (290.8 + 1.5 = 292.3 K)
- Step 5: PBLH is determined to be the altitude at this theta (1142 m)

The HRRR model also uses this method for daytime PBLH

5. CBRN PBLH Method

- Bulk Richardson (BR) numbers are computed for each flight ascent/descent data point
- PBLH is identified as the first instance where BR exceeds a specified CBR value



CBRN method example

- Step 1: Start with flight data point at lowest altitude; compute Richardson number

$$Ri_b = \frac{(g/\theta_{vs})(\theta_{vz} - \theta_{vs})(z - z_s)}{(u_z - u_s)^2 + (v_z - v_s)^2 + bu_*^2}$$

(20m; 0.3)

- Step 2: Recompute at the next higher data point
- Step 3: Stop when bulk Richardson number > CBRN (0.5)

This method is also used for ERA-5 and was found to be better for nocturnal PBLH (Zhang et al. 2020)

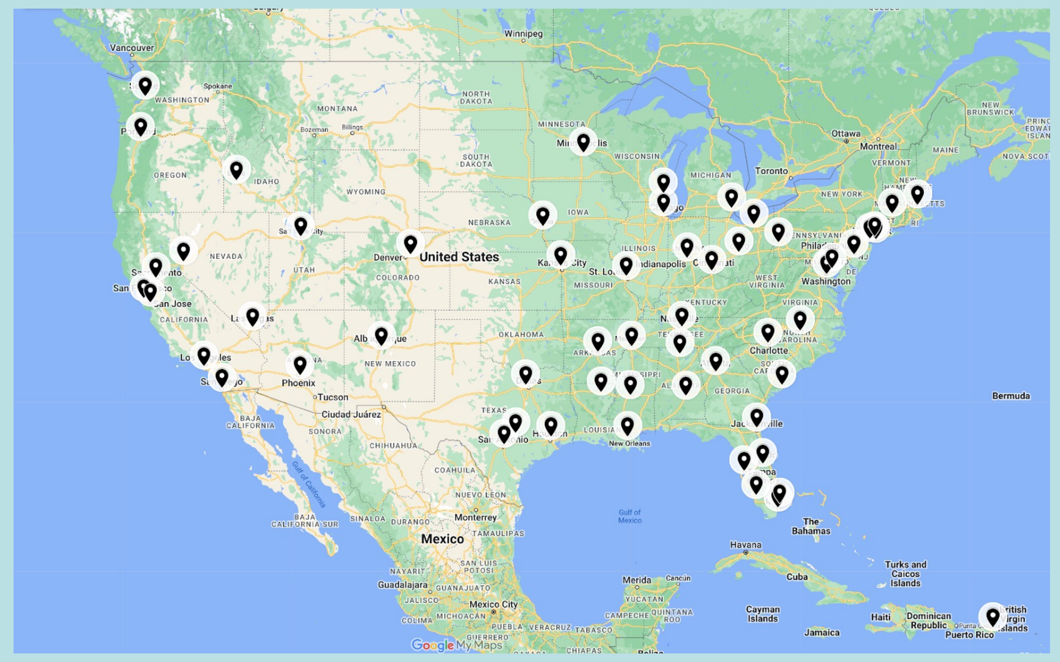
6. List of Airports Computed

- The PBLH tools read in a text file of airport information, loop through all airports, and compute PBLH for each flight at each airport

Airport Name	Code	Lat (deg N)	Lon (deg E)	Ground Ht (m)	Radius (deg)
Denver	DEN	39.86	-104.68	1615.4	0.7

Info in the text file (one row for each airport)

- The tools have the flexibility to read in different text files for different projects/purposes



We conducted development with an "amdar_airports_pblh_usa_60.txt" file that contains 60 airports

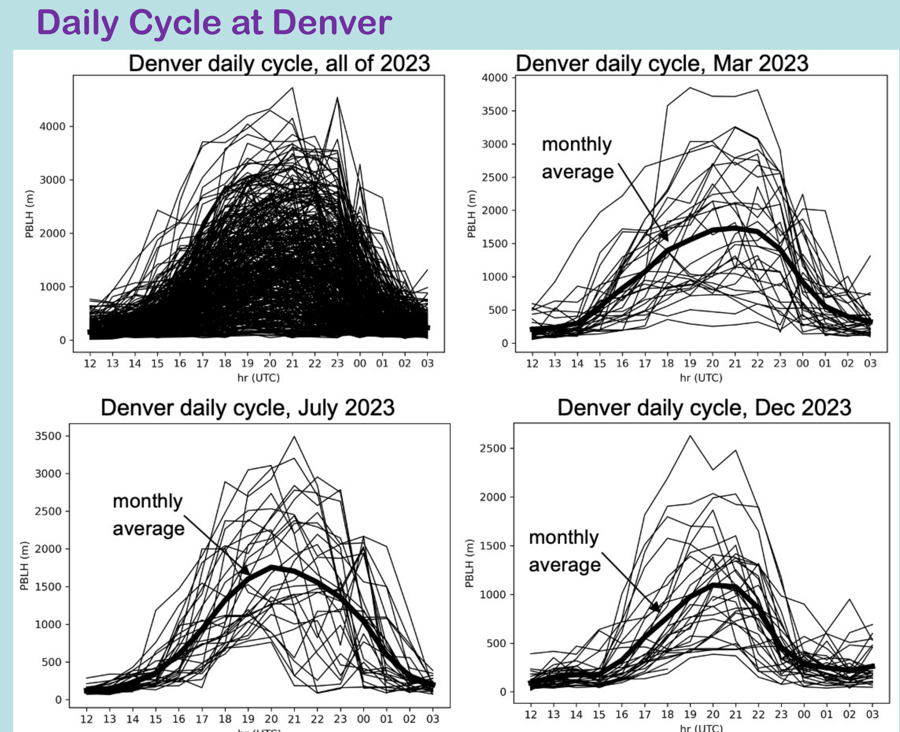
It includes the top 55 USA airports based on passenger traffic plus 5 additional airports in the southeast CONUS

[58 shown here, plus 1 Alaska, 1 Hawaii]

7. TI PBLH Method Evaluation

- July 2023 evaluation of daytime convective PBLH using the TI method

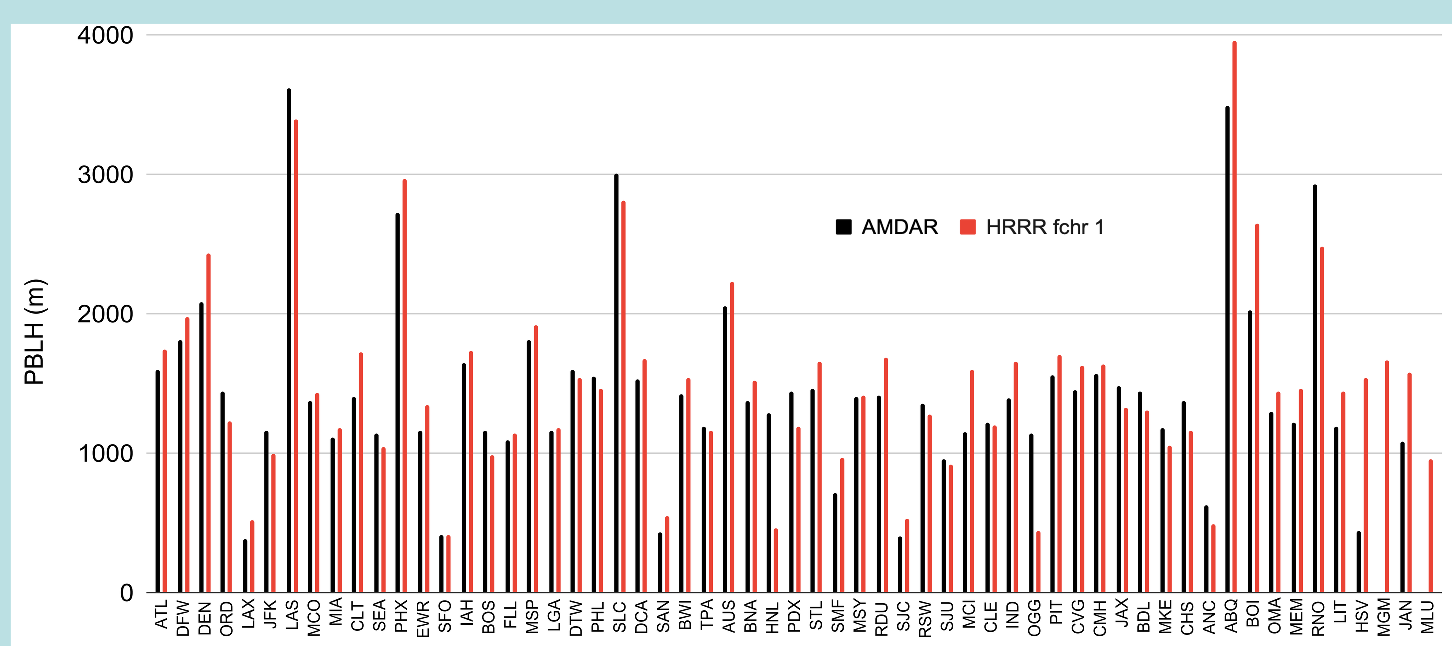
Daily Cycle at Denver



- Large daily variation in PBLH due to seasonal & daily meteorology
- PBLH evolution from stable/nighttime to convective/daytime is present most days
- Large variation in PBLH at the daytime peak (ranges from ~200 – 4500 m)
- Daytime peak time varies; generally occurs around 20-23 UTC each day
- Generally PBLH is higher in warmer months, as expected

Average Daily PBLH Peak for 60 airports

- We compute the daily peak PBLH value for each airport and average across the month of July 2023
- We compared AMDAR PBLH to the High Resolution Rapid Refresh (HRRR) method (which also uses the TI method for daytime convective PBLH)

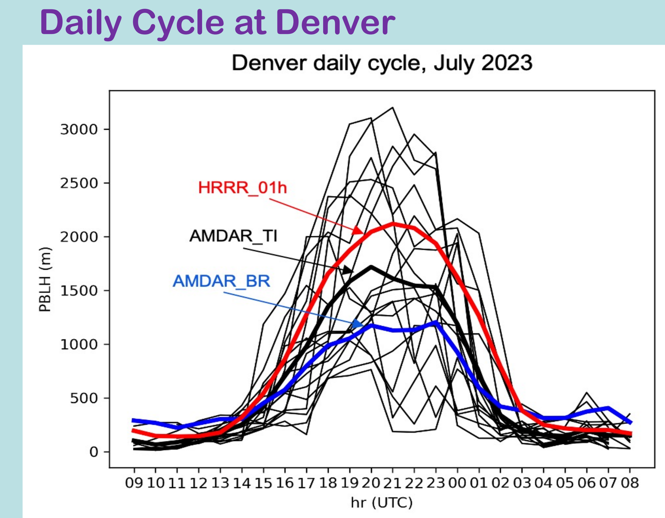


- Airports have a big range in daily peak PBLH (500 – 4000 m); locations that are warm and windy have higher PBLH (e.g. LAS, PHX, SLC, ABQ)
- PBLH from AMDAR data is generally possible, except for three smallest airports
- AMDAR & HRRR compare fairly well (imperfect HRRR grid box averaging will be more accurate in METplus/METexpress)

8. CBRN Method Evaluation

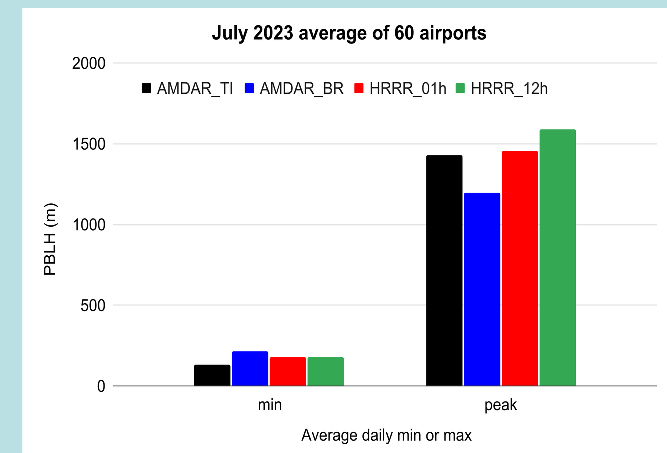
- CBRN Method preliminary results (the method is still being refined)

Daily Cycle at Denver



- Fairly large disagreement in Peak PBLH amongst the three datasets at Denver: HRRR is highest, then AMDAR_TI, with AMDAR_BR lowest
- Denver is a tough airport due to high PBLH and large topographical gradients; differences are smaller at most other airports
- Daily (nocturnal) PBLH minimum ranges from 100-300 m; AMDAR_BR method is higher

Average Daily PBLH Average across 60 airports



- PBLH peak are similar for AMDAR_TI and HRRR_01 while AMDAR_BR is ~200m lower (average 60 airports)
- HRRR 12h forecasts produce taller PBLH than 1h forecasts (this is a known issue)
- PBLH minimums agree better, with AMDAR_BR higher than AMDAR_TI, and HRRR in the middle

9. Portable AMDAR PBLH netcdf files

- Hourly netcdf files
  - File names pblh_*region*_*YYDOYHHMM*q.nc
  - Same suffix as source AMDAR files
  - Small size (~5 MB each)
- Key dimensions
  - flight_index=UNLIMITED (appended w/ each flight)
  - altitude=241 (25m bins from 0-6000m)
  - Airport=60 (list of individual airports)
- Logic/design
  - Read in airport text file & loop through all airports
  - Include all flights within a specified radius, reorder flight array to be ascending
  - Conduct PBLH algorithm(s)
  - Map each flight profile data point to altitude array
  - Save 1d and 2d fields to netcdf file
- So far, processed 1 year of AMDAR PBLH files (2023)

1d fields saved

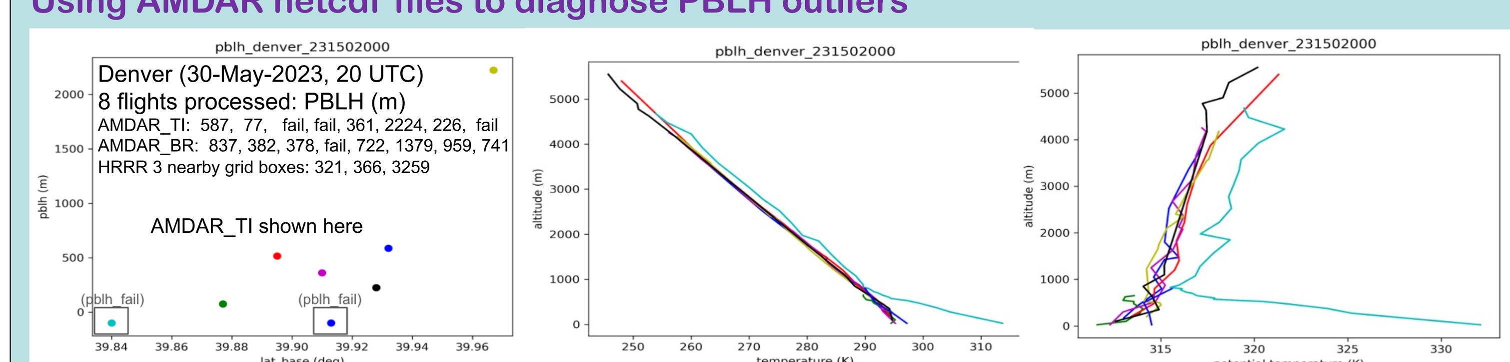
[flight_index] n=UNLIMITED: tail_number, airport_code, airport_name, sounding_flag, pblh, pblh_method, time_base, alt_base, lat_base, lon_base, time_pblh, lat_pblh, lon_pblh, alt_adj

[airport_list] n=60: pblh_avg, pblh_std

2d fields saved

[flight_index, altitude] n=[UNLIMITED, 241]: latitude, temperature, potential_temperature, pressure_altitude, dewpoint, windSpeed, windDir

Using AMDAR netcdf files to diagnose PBLH outliers



- Profiles can easily be plotted from the fields in the netcdf files
- In this example, the large range of PBLH values is partly due to stability (theta increase near the surface) (present with HRRR as well) plus one bad AMDAR profile

10. Summary / Next Steps

- Implemented two PBLH methods using AMDAR data (TI Method, CBRN Method) and processed 60 airports for the year 2023 (evaluating July 2023 here)
  - The AMDAR_TI method compares well with PBLH from the HRRR model
  - The AMDAR _BR method has lower PBLH peak, but is still being refined
- Created portable AMDAR PBLH netcdf datasets that include PBLH as well as key fields on a vertical coordinate grid
- Next Steps
  - Release new/improved METplus use case and METexpress tools
  - Further refine AMDAR_BR method, conduct more detailed seasonal evaluation, and submit a peer-reviewed manuscript

References

- Nielsen-Gammon J, Powell C, Mahoney M., Angevine W, et al (2008): Multisensor estimation of mixing heights over a coastal city. J. Appl. Meteorol. Climatol. 47: 27–43.
- Seidel, D. J., Zhang, Y., Beljaars, A., Golaz, J.-C., Jacobson, A. R., & Medeiros, B. (2012). Climatology of the planetary boundary layer over the continental United States and Europe. Journal of Geophysical Research, 117, D17106. https://doi.org/10.1029/2012JD018143
- Zhang, Y., Sun, K., Gao, Z., Pan, Z., Shook, M. A., & Li, D. (2020): Diurnal climatology of planetary boundary layer height over the contiguous United States derived from AMDAR and reanalysis data. JGR: Atmospheres, 125, e2020JD03280, https://doi.org/10.1029/2020JD032803.