Title – NOAA PSL Thermodynamic profiles from microwave radiometers retrieved with TROPoe

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1.0 Data Set Description

This dataset contains daily files with thermodynamic profiles retrieved with the optimal estimation physical retrieval TROPoe (TROPoe, Turner and Löhnert 2014; Turner and Blumberg 2019; Turner and Löhnert 2021). The profiles are retrieved every 10 min from instantaneous brightness temperatures observed with a microwave radiometer (MWR). The MWR are MP-3000A Microwave Radiometers (Solheim, et al. 1998) and manufactured by Radiometrics. They were deployed during the Propagation, Evolution and Rotation in Linear Storms (PERiLS) experiment in Columbia, LA, and Courtland, AL. The MWR are operated continuously between the middle of February 2022 and the middle of May 2023.

Brightness temperature data at 35 frequencies in the microwave range from vertical stare and low-elevation scans are included in the retrieval. Additional input data in TROPoe are cloud base height from a collocated ceilometer, temperature, water vapor mixing ratio, and pressure from collocated near-surface measurements, from hourly virtual temperature profiles measured by collocated Radio Acoustic Sounding System (RASS), and from hourly analysis profiles from the operational Rapid Refresh (RAP, Benjamin et al. 2021) weather prediction model at the closest grid point. The latter are used only outside the atmospheric boundary layer (ABL) above 4 km above ground level (AGL) and provide information in the middle and upper troposphere where little to no information content is available from the infrared radiances. The RASS were associated with a 915 MHz radar wind profiler. The inclusion of RASS and RAP were both shown to improve the retrieval accuracy (Djalalova et al. 2022, Bianco et al. 2024).

In addition to these temporally resolved input data, TROPoe requires an a priori dataset (prior) which provides mean climatological estimates of thermodynamic profiles and specifies how temperature and humidity covary with height as an input (for details see e.g. Djalalova et al. 2022). The prior is a key component of the retrieval and provides a constraint on the ill-posed inversion problem. For this study, we computed the prior from operational radiosondes launched at Shreveport, LA, for the retrievals at Columbia and at Birmingham, AL, for the retrievals at Courtland.

- Data status: Final
- Time period:

Columbia, LA: 10 February 2022 – 19 May 2023
Courtland, AL: 12 February 2022 – 18 May 2023

- Physical location:
  Columbia, LA: 32.124322 N, 92.055569 W, 20 m above mean sea level
  Courtland, AL: 34.66 N, 87.35 W, 187 m above mean sea level
- Data Frequency: continuous every 10 min
- Data set restrictions: none

2.0 Instrument Description

The two MWRs observed brightness temperatures at 21 frequencies in the K-band (22 to 30 GHz) and at 14 frequencies in the V-band (51 to 59 GHz). It performed a combination of vertical stare and low elevation scans for an improved representation of the low-level temperature profile (Crewell and Löhnert, 2007). The MWR is equipped with a surface sensor measuring temperature, relative humidity, and barometric pressure and an upward pointing infrared thermometer. For details on the instrument specifics, see the manufacturer manual.

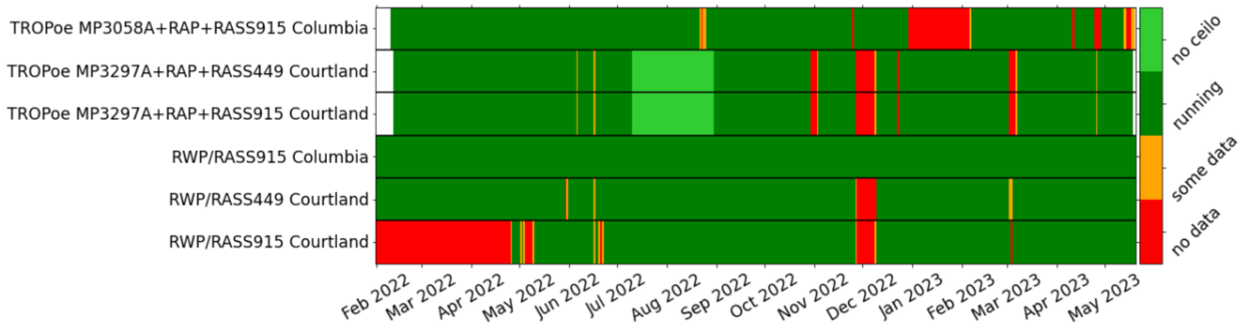
3.0 Data Collection and Processing

Data are collected continuously. We used the TROPoe version 0.13 (available from DockerHub as davidturner53/tropoe/v0.13).

Brightness temperature data are corrected for spectral biases using the climatological prior. To account for temporal changes in bias, e.g. due to instrument drifts, power loss, and tip and liquid nitrogen calibrations, we computed a spectral bias for each day. To determine the biases, we used a multi-step approach. We ran TROPoe with no bias for the whole period and computed the spectral bias from the output for each clear sky profile. This procedure is described in Djalalova et al. (2022). Clear-sky periods were determined using the temporal standard deviation of the 30 GHz brightness temperature. We then concatenated all clear-sky biases in time and computed a 50-point rolling mean assigned at the end of the interval. We then re-assigned the so computed means to regular grid with 10 min temporal resolution by propagating the last valid mean value forward in time. From this 10-min timeseries we computed daily mean spectral biases. This method has the advantage that changes in bias are automatically determined and no manual time-consuming bias correction is needed. Due to the use of clear-sky profiles only and the 50-point window, some changes in biases, e.g. the ones that occur during cloudy periods are not immediately captured, but with a time delay depending on when the next clear sky profile becomes available.

The following schematic displays availability of TROPoe retrievals when MWR brightness temperatures were used at Courtland and Columbia. Dark green means that TROPoe retrievals were available during at least 50 % of the day. Data gaps are related to power failures and AC, instrument, and computer issues or to rainy periods when brightness temperatures where outside their physical limits. Red means that no data were available at all and yellow means that less than 50 % of data were available on a specific day. At Courtland, a weed vine was partially blocking the ceilometer window reducing the backscatter signal, between July 10 and August 30 2022 (light green). Because of this, the automatic cloud base height detection in CL-view hardly detected any cloud bases during this period. This means that the default cloud base height was used in the TROPoe retrievals. Note that this does not negatively impact the MWR retrievals, since clouds are

transparent in the microwave range. Suggestions for filtering are given below to assure the use of high-quality data only.
RASS data were included in the TROPoe retrieval when available. The availability of RASS data (RASS915 and RASS449 at Courtland and RASS915 at Columbia) is given in the last three rows of the schematic. For example, the RASS915 at Courtland was not operational until the end of April 2022. For the advanced user, information on data which are used in the observation vector as input to the retrieval are included in the variables obs_flag, obs_dimension, obs_vector, and obs_vector_uncertainty in the TROPoe netcdf output files.



4.0 Data Format

The daily files are in netcdf format and the file naming conventions for the files are as follows:
clbtropoeMP3058A_RAP_RASS915.final_v1.yyyymmdd.HHMMSS.cdf
ctdtropoeMP3297A_RAP_RASS915.final_v1.yyyymmdd.HHMMSS.cdf
ctdtropoeMP3297A_RAP_RASS449.final_v1.yyyymmdd.HHMMSS.cdf

with
yyyy: Year
mm: Month
dd: Day
HH: Hour
MM: Minute
SS: Second

The time stamp of all data is in UTC and HHMMSS indicate the time of the first retrieved profile of the day. The netcdf file contain a larger number of diagnostic variables that can be used by the experienced TROPoe user to assess details of the retrieved profiles. For most users the following variables are sufficient:

Name	Dimension	Unit
base_time	Single value	Seconds (since 00 UTC 1 Jan 1970)
time_offset	Time	Second (since base_time)
hour	Time	Hours since 00UTC this day
height	Height	km AGL
temperature	Time, Height	C, temperature
waterVapor	Time, Height	g/kg, water vapor mixing ratio
theta	Time, Height	K, potential temperature

lwp	Time	g/m^2, Liquid water path
pressure	Time, Height	hPa, pressure
rh	Time, Height	%, relative humidity
dewpt	Time, Height	C, dew point temperature
thetae	Time, Height	K, equivalent potential temperature
sigma_temperature	Time, Height	C, 1-sigma uncertainty temperature
sigma_waterVapor	Time, Height	g/kg, 1-sigma uncertainty water vapor
cdfs_temperature	Time, Height	cumulative degrees of freedom for temperature
cdfs_waterVapor	Time, Height	Cumulative degrees of freedom for water vapor
gamma	Time	Gamma parameter
rmsa	Time	Root mean square error between observation vector and the forward calculation
rmsr	Time	Root mean square error between IRS and MWR obs in the observation vector and the forward calculation

Bold variables are the main retrieved meteorological variables, from which the other variables are derived.

Note that the vertical resolution of the retrieved profiles decreases with height, because of the broadening of the weighting function as a function of height. Thus, there are relatively few independent pieces of information in the profiles, this is reflected in the cumulative degree of freedom variables. The majority of the information from the MWR is in the lowest 2-3 km, above that most information comes from the RAP model.

To assure that only high-quality thermodynamic profiles are used the following quality control steps are recommended. The thresholds given here are rather strict and it might be desirable for some case study to relax the thresholds for higher data availability, e.g. not all cloudy profiles with higher LWP are suspicious and data below cloud base may still be good.

1. RMSA filter: Large RMSA values indicate a large discrepancy between the solution and the observations even though the retrieval found a solution. We suggest to use profiles with rmsa < 3.
2. Gamma filter: The scalar γ is used to stabilize the retrieval when iteration number is small. It is a function of iteration number and cycles through a fixed sequence of integer values ranging from 1000 to 1. It decreases to unity for larger n and is used to change the relative weight between the prior information and the observation, where $\gamma > 1$ corresponds to less information from the observations relative to the prior (more details are provided in Turner and Löhnert, 2014). We suggest to use profiles with gamma =1.
3. LWP filter: Although clouds are transparent in the microwae range, we still suggest to exclude profiles when LWP > 200 g/m^2 to screen out cases when clouds are raining for which our assumption of being in the Rayleigh scattering regime is not correct. Note that the MWR is not very sensitive to thin clouds, unlike the infrared spectrometer (details in Turner 2007).

A very important note for the MWR-based TROPoe retrievals is that TROPoe creates a profile even if no brightness temperature observations from the MWR are available at a time stamp. In this case the retrieval only uses RASS, RAP, and surface meteorology. It is not recommended to use such profiles. They can easily be filtered by removing any profiles with rmsr =0.

5.0 Data Remarks

None

6.0 References

Bianco, L., Adler, B., Bariteau, L., Djalalova, I. V., Myers, T., Pezoa, S., Turner, D. D., and Wilczak, J. M., 2024: Sensitivity of thermodynamic profiles retrieved from ground-based microwave and infrared observations to additional input data from active remote sensing instruments and numerical weather prediction models, Atmos. Meas. Tech., 17, 3933–3948, https://doi.org/10.5194/amt-17-3933-2024.

S. Crewell and U. Löhnert, 2007: Accuracy of Boundary Layer Temperature Profiles Retrieved With Multifrequency Multiangle Microwave Radiometry, IEEE Transactions on Geoscience and Remote Sensing, 45, 7, 2195-220, doi: 10.1109/TGRS.2006.888434

Djalalova, I. V., Turner, D. D., Bianco, L., Wilczak, J. M., Duncan, J., Adler, B., and Gottas, D., 2022: Improving thermodynamic profile retrievals from microwave radiometers by including radio acoustic sounding system (RASS) observations, Atmos. Meas. Tech., 15, 521–537, https://doi.org/10.5194/amt-15-521-2022.

Solheim, F., J. R. Godwin, and R. Ware, 1998: Passive ground-based remote sensing of atmospheric temperature, water vapor, and cloud liquid profiles by a frequency synthesized microwave radiometer, Meteorol. Z., 7, 370–376, https://doi.org/10.1029/97RS0365

Turner, D. D., 2007, Improved ground-based liquid water path retrievals using a combined infrared and microwave approach, J. Geophys. Res., 112, D15204, doi:10.1029/2007JD008530.

Turner, D. D., and U. Löhnert, 2014: Information content and uncertainties in thermodynamic profiles and liquid cloud properties retrieved from the ground-based atmospheric emitted radiance interferometer (AERI). J. Appl. Meteor. Climatol., 53, 752–771, https://doi.org/10.1175/JAMC-D-13-0126.1.

Turner, D. D., and W. G. Blumberg, 2019: Improvements to the AERIoe thermodynamic profile retrieval algorithm. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 12, 1339–1354, https://doi.org/10.1109/JSTARS.2018.2874968.

Turner, D. D., and U. Löhnert, 2021: Ground-based temperature and humidity profiling: Combining active and passive remote sensors. Atmos. Meas. Tech., 14, 3033–3048, https://doi.org/10.5194/amt-14-3033-2021.

7.0 Appendix

GCMD keywords

EARTH SCIENCE	SPECTRAL/ENGINEERING	INFRARED WAVELENGTHS	INFRARED RADIANCE				69f475b6-42af-4822-ae57-6c8fd8ebad4a