Severe storm research with thundeR package - improvements in calculation procedures of convective parameters

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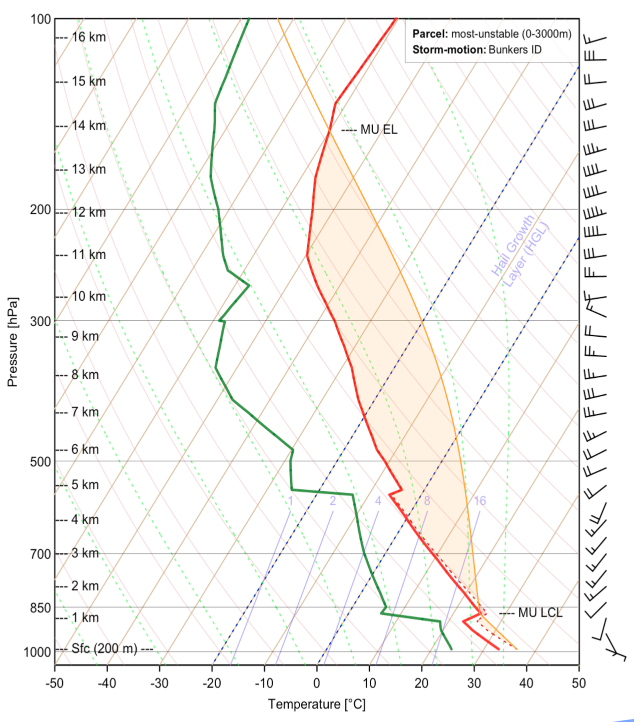
What is thundeR?

ThundeR is a free, open-source R package for Skew-T and hodograph visualization, and rapid computation of convective parameters used in research and operational severe storm forecasting. Developed since 2017, it is continuously updated with new features and parameters driven by community requests and the latest research results. The package computes over 300 parameters in ~1 centisecond (modern CPU), enabling fast processing of large climatological datasets and operationalnumerical weather prediction (NWP) models.

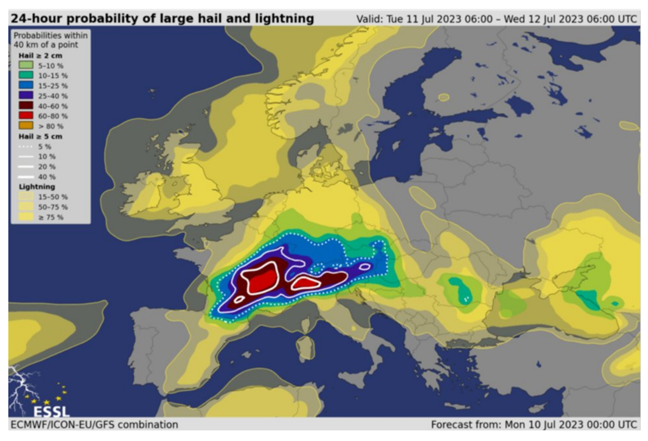


An online tool available at **www.rawinsonde.com** allows users to use thundeR in visualizing rawinsonde measurements and historical profiles from ERA5 reanalysis since 1950. It allows users to manually specify mixing and altitude of a convective parcel, input a manual storm-motion vector, control plotting of CAPE, CIN, DCAPE and SRH polygons, edit profiles online and download raw profile and parameters data in .csv.

Application in severe storm research

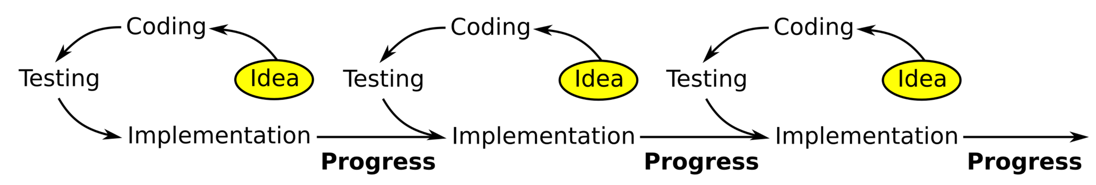
In recent years, thundeR has been applied to global reanalysis datasets, numerical weather prediction models, and rawinsonde observation visualization. As of November 2025, it has been used in more than 35 peer-reviewed studies (e.g., BAMS, Nature Geoscience) and has attracted interest from the insurance industry, national research laboratories, and hydrometeorological services worldwide. Among many projects, thundeR has contributed to development of ESSL's AR-CHaMo models, NOAA SPC's OMEGA project, NASA overshooting-top detection research, and the completion of three PhD theses.

During this process more than 1000 convective parameters including existing and new concepts were tested in the context of their skill and utility in representing environments associated with convective hazards. This experience allowed thundeR team to modify and develop new parameters that led to improvments in severe storm forecasting.



Since 2020, thundeR has played a key role in developing ESSL's flagship AR-CHaMo models used for operational forecasting and climate research of severe storms.

Key aspects of iteratively developing new convective parameters were (1) constructing global severe thunderstorm training datasets, (2) thundeR's high computational efficiency enabling frequent recalculations, and (3) collaboration with researchers thinking out-of-the-box!

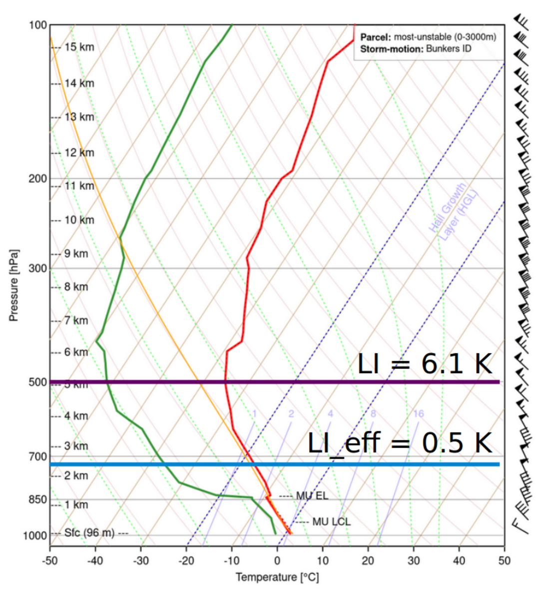


thundeR
rawinsonde package

thundeR v1.5: coming soon!

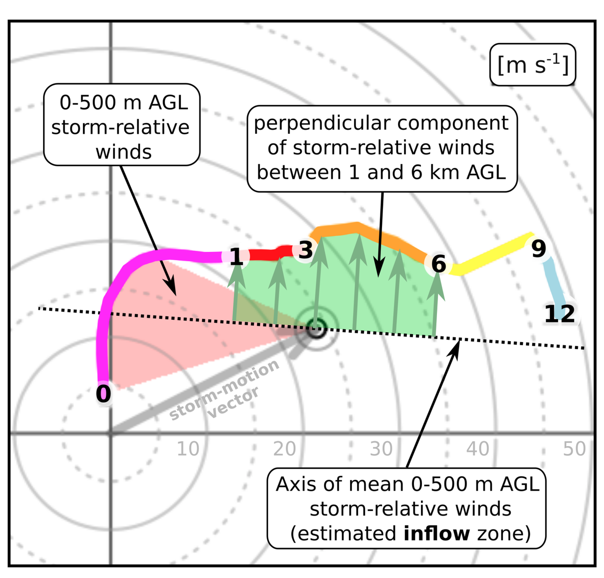
Selected new parameters that were tested across 4 continents (N. America, S. America, Europe, Australia) and showed skill in detecting severe storms are listed below:

- **Most-unstable-mean-layer (MUML) parcel** - calculated by mixing a moving window of 500 m, up to 3 km AGL. Layer with the largest theta-e is then selected to lift parcel. Improves hail and lightning prediction by more reliable identification of elevated storm environments.
- **Effective Lifted Index (LI_eff)** - the largest difference between lifted parcel and ambient temperature found in the entire profile assuming environmental temperature is below -10°C and the height is at least 2 km above lifted condensation level. Compared to classic LI formula, this parameter better accounts for low-topped and cool season thunderstorms, and high-elevation dry thunderstorm environments.



Comparison of classic LI with LI_eff for cool season severe storm outbreak in Poland on 7 Jan 2022.

- **Storm-relative moisture flux (MF_SR)** - mixing ratio multiplied by storm-relative wind, computed in both surface-based (0–500 m) and effective-layer versions. Serves as a proxy for convective severity, particularly hail size and tornado strength.
- **Inflow ventilation (VENT)** - perpendicular component of storm-relative wind relative to the axis of the mean inflow vector (surface-based or effective layer). Proves effective at identifying hazards from long-lived supercells, including significant tornadoes and very large hail.

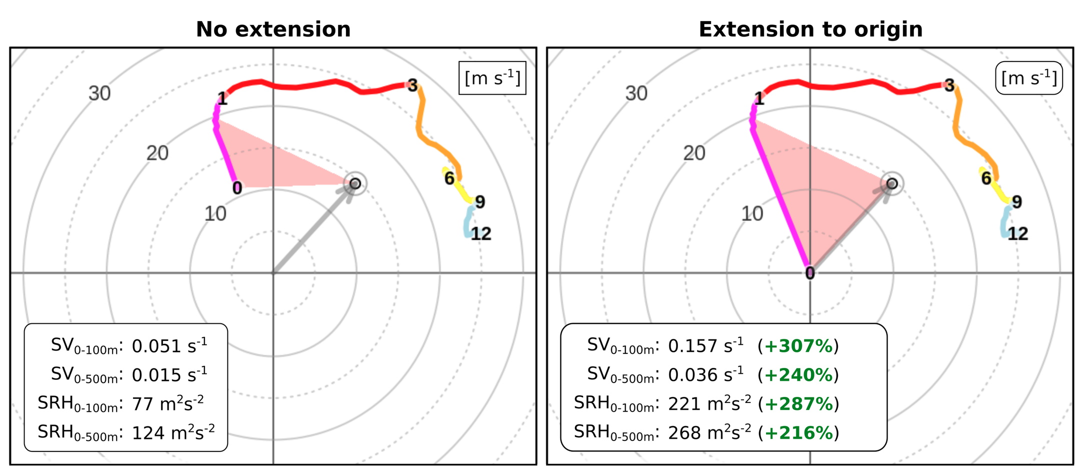


Calculation of inflow ventilation on the example of proximity profile associated with EF4 tornado on 10 December 2021 in Mayfield (United States).

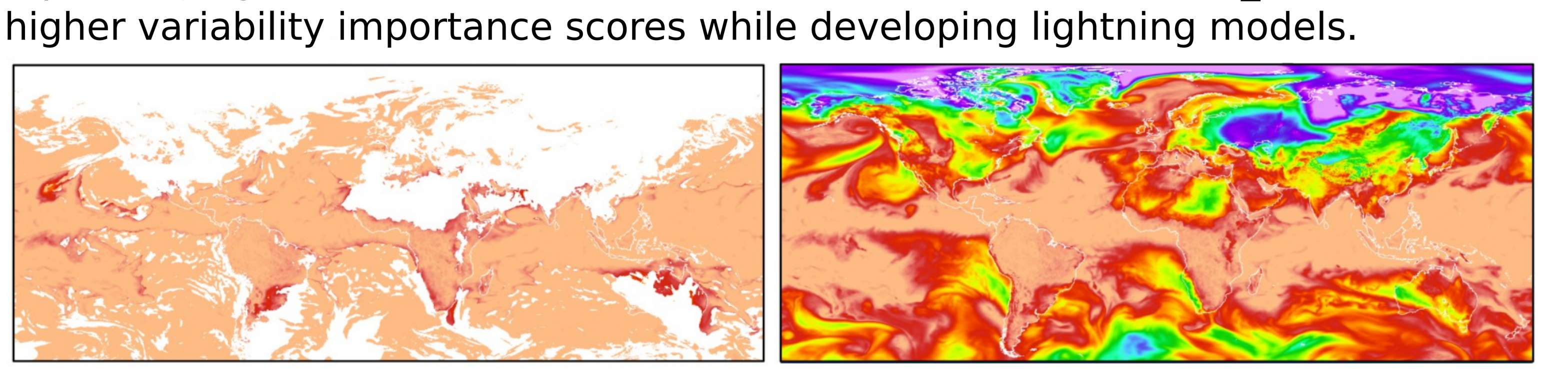
- **Effective RH (RH_eff)** - mean relative humidity in 3 km layer with the bottom of that layer at the lifted condensation level. Improves prediction of lightning development failure modes due to too dry portions of low-level trosposphere.
- **Bulk shear smoothness (BS_smooth)** - measures disproportion in vertical wind shear profile with value >1 indicating linear increase in shear and <1 uneven distribution of shear. Adds value in large hail prediction.

- **SRH with hodograph extension (SRH_HE)** - calculation of storm-relative helicity after extending hodograph to the origin (0 m s^{-1} at the surface). This extension proved to improve tornado prediction on each of the 4 evaluated continents. However, no added value was found for assesing tornado strength.

Comparison of SRH and SV calculation for wind profile with and without extension to origin on the example of hodograph for EF4 tornado in Pilger (Nebraska) on 16 Jun 20.



- **CIN over lowest 4 km (CIN_4km)** - integrated negative buoyancy in 4 km layer with the bottom of that layer at the parcel lifting height. This modification fixes biggest disadvantage of CIN being impossible to be computed when CAPE equals 0 J kg^{-1}. Such modification in CIN calculation allowed CIN_4km to obtain higher variability importance scores while developing lightning models.


Comparison of CIN calculation for global domain using classic CIN formula (left) and revised CIN_4km (right). Revised CIN allows to obtain continous fields without NA values (as on the left).

- **Calibrated Bunkers Vector (CBV)** - storm-motion vector with 7.5 m s^{-1} Bunkers constant scaled based on the value of 0-3 km SRH of mean wind vector. This modification is useful when processing data globally as the deviant motion vector is automatically assigned based on the shape of the hodograph.
- **Layer-based peak shear or peak wind speed** - measure of peak bulk wind shear or wind speed over an optimized depth identified using a moving-window technique or searching for a peak value within specific layer. Parameters calculated this way outperformed their fixed-layer equivalents.