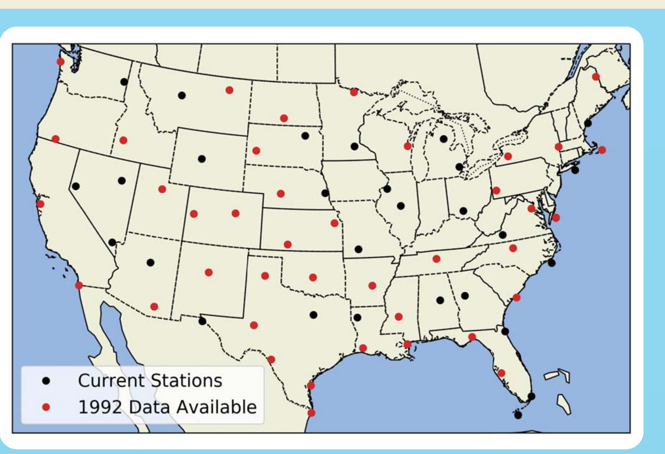
Meteorologists and their CAPEs

J.R. Leeman and R. May

Unidata - Boulder, CO

Introduction

The National Weather Service (NWS) launches weather balloons (also known as radiosondes or rawinsondes) twice daily at 92 sites. Balloon launches just before 00 Z and 12 Z provide measurements of temperature, dew point, wind speed, and wind direction at fixed mandatory heights, as well as at heights of significant change. These data are used by forecasters and in numerical weather prediction models to quantify and understand the state of the atmosphere.



US upper air sounding sites are distributed across the country and launch rawinsondes twice daily, at 00 and 12 UTC.

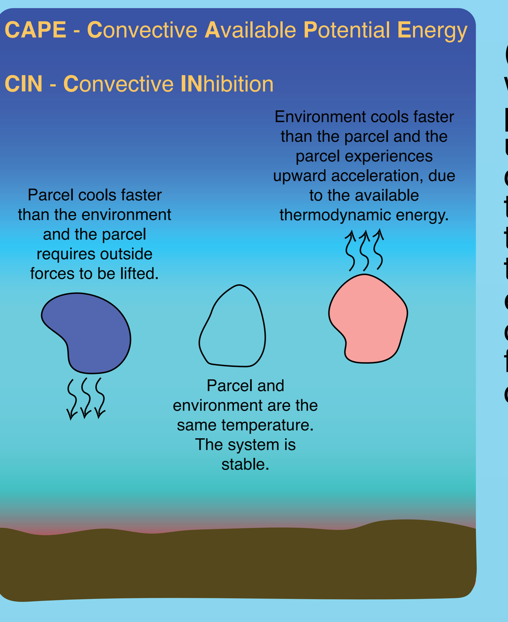
From the sounding data, a number of parameters are calculated, some empirically derived, others based on thermodynamics. The amount of energy available to air parcels in the atmosphere to convect, known as Convective Available Potential Energy (CAPE) and the energy barrier preventing convection, known as Convective INhibition (CIN) are of great interest in potential severe weather situations.

Students launch a rawinsonde at Valpariso University. Image: Teresa Bals-Elsholz

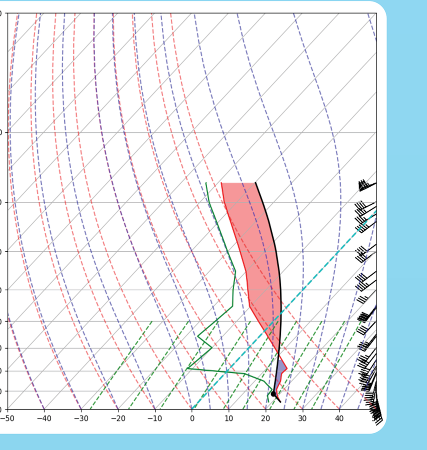
Here we present the process of implementing the seemingly simple calculations into MetPy, a community meteorological calculation and plotting package supported by Unidata. CAPE and CIN may be calculated with a number of minor corrections, use of different approximations, and different atmospheric parcels. The exact implementation used in many meteorological tools such as SharpPy, GEMPAK, and others is often poorly documented. We attempted to implement CAPE in the most versatile way possible to provide the maximum flexibility to users.

In an attempt to understand how a typical research meteorologist would use MetPy and the Unidata suite of tools, we chose to reproduce a famous paper that compares CAPE calculations with and without the virtual temperature correction by Doswell and Rasmussen in 1994.

CAPE and CIN



(Left) When an air parcel is warmer than the environment it is positively buoyant. The resulting upward acceleration produces convection and is a key ingredient to producing severe storms. On the other hand, parcels cooler than their surrounding environments have to be lifted via other means, such as topographic forcing, as they are experiencing a downward force.



(Above) On a Skew-T Log-P diagram, CAPE is proportional to the area between that measured temperature and projected parcel path curves when the parcel is warmer than the environment. CIN is the area where the parcel is cooler than the environment. While the integral to calculate these is simple, the various corrections, parcels, and assumptions made can make implementation complex.

Calculation Permutations

Profile Temperature

- No temperature Correction
- Virtual Temperature Correction

Source Parcel

- Surface Parcel
- Most Unstable (over depth)
- Mixed Layer (over depth)

Moist Adiabats

- Pseudoadiabatic (liquid only)
- Reversible (liquid only)
- Pseudoadiabatic (with ice)
- Reversible (with ice)

Getting Data

Data were obtained from the University of Wyoming sounding archive (http://weather.uwyo.edu/upperair/sounding.html). MetPy has a built-in utility to obtain sounding data from both the Wyoming and Iowa State archives.

```
from datetime import datetime
from metpy.io import get_upper_air_data

date = datetime(2010, 5, 10, 21)
ds = get_upper_air_data(data, 'OUN')
```

Data are returned in a netCDF-like format and can be easily manipulated for plotting or analysis. Units are pre-attached.

```
print(list(ds.variables))
```

```
['pressure', 'height', 'temperature', 'dewpoint',
 'u_wind', 'v_wind', 'speed', 'direction']
```

All data from 1992 were downloaded and stored in a CSV file written by Pandas.

	Date	Time	Station	Pressure	Temperature	Dewpoint	u wind	v wind	Speed	Direction
0	1992-05-01	12	UIL	1018.0	3.8	3.7	-5.638156	-2.052121	6.0	70.0
1	1992-05-01	12	UIL	1000.0	5.4	4.1	-4.698463	1.710101	5.0	110.0
2	1992-05-01	12	UIL	989.0	6.6	3.5	-3.078307	3.940054	5.0	142.0
3	1992-05-01	12	UIL	987.9	6.5	3.5	-2.867882	4.095760	5.0	145.0
4	1992-05-01	12	UIL	952.2	4.0	2.0	3.000000	5.196152	6.0	210.0

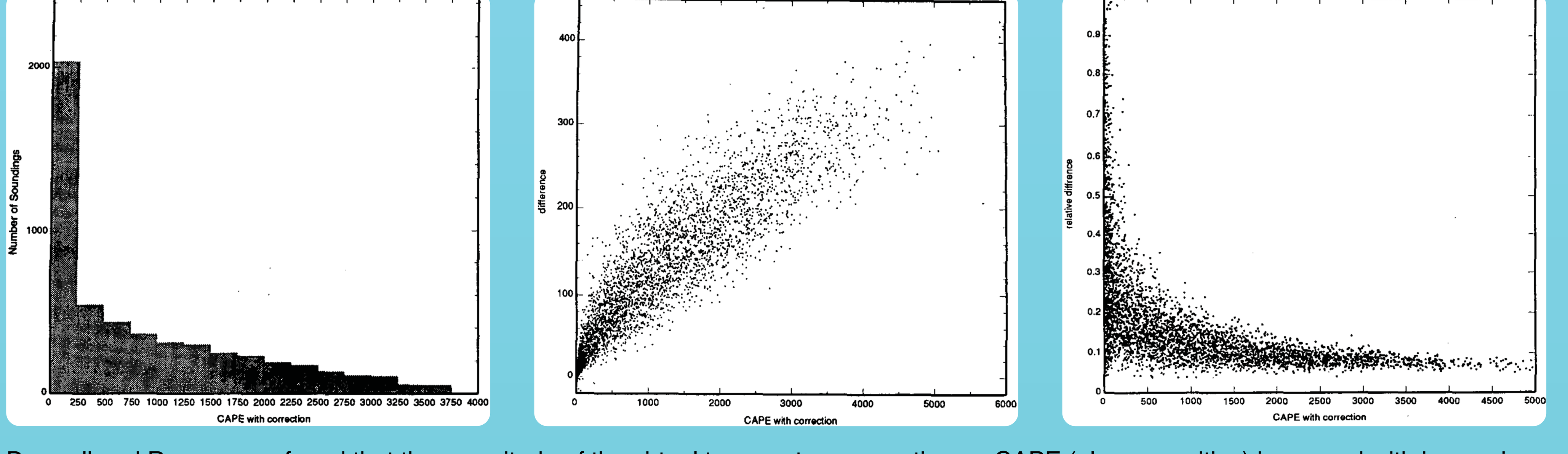
Results

The Effect of Neglecting the Virtual Temperature Correction on CAPE Calculations

CHARLES A. DOSWELL III AND ERIK N. RASMUSSEN*

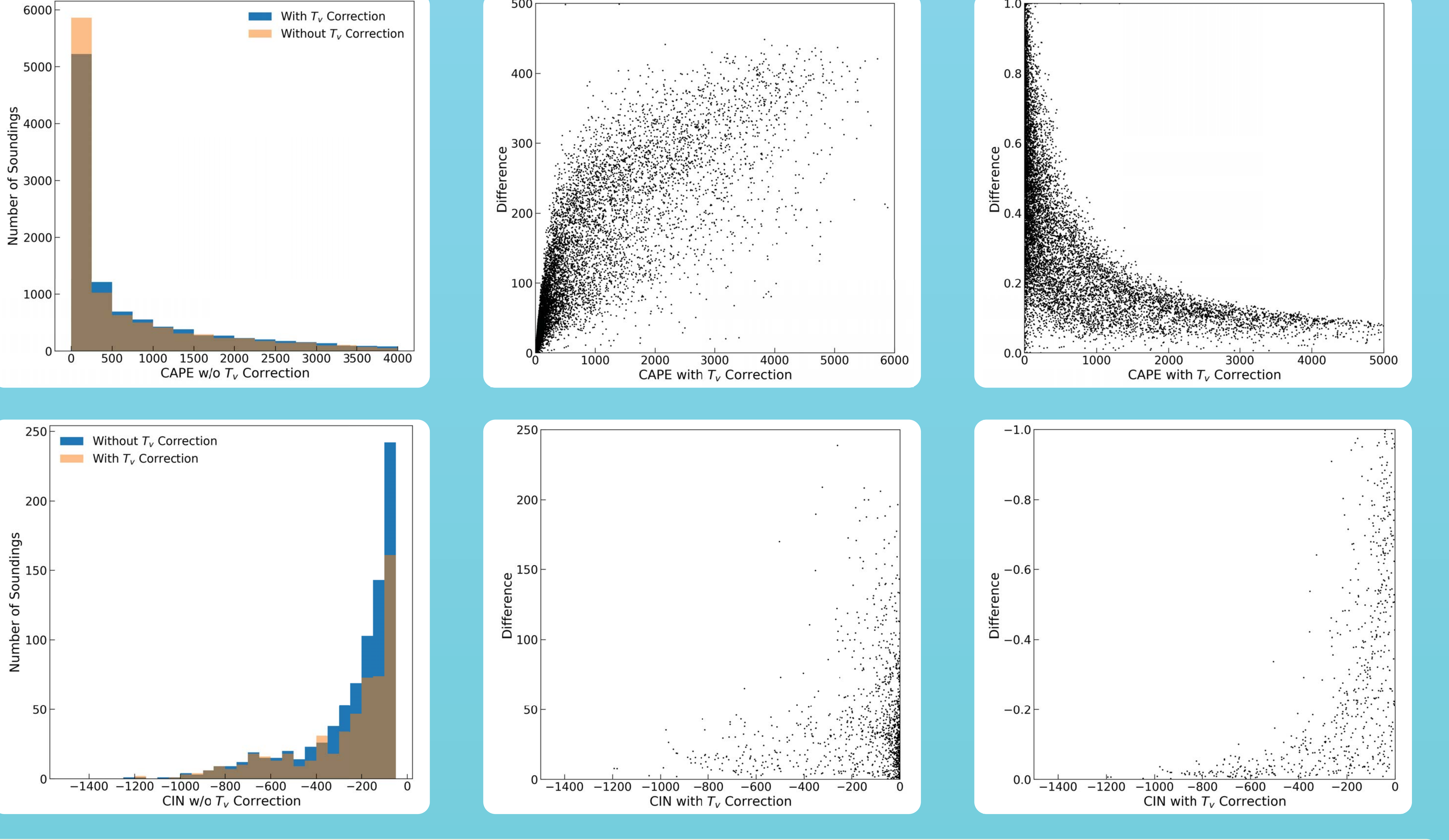
NOAA/Environmental Research Laboratories, National Severe Storms Laboratory, Norman, Oklahoma

3 March 1994 and 22 June 1994



Doswell and Rasmussen found that the magnitude of the virtual temperature correction on CAPE (always positive) increased with increasing CAPE values, but that the relative importance of the correction decreased with increasing CAPE values. The authors suggest a standardized CAPE calculation in which the simple pseudoadiabatic profile is used, the virtual temperature correction made, and the most unstable parcel in the lowest 300 hPa of the atmosphere used.

Our results are similar (right), but appear to contain many more soundings that the original paper. The original data used were not presented in tabular form, leaving the differences unexplained. In general, trends and magnitudes are preserved. Further comparison with other sounding analysis tools is in progress to further cross-compare results from different analysis tools.



Design Challenges

Assumptions Object

Most of the complexity in the calculation lies in the air parcel path determination. We have prototyped an assumptions object that holds assumptions about the calculation to be made. Future plans include adding assumptions onto other calculations and building a solver that automatically determines the best and valid path from one set of a parameters to another derived set of parameters.

This assumptions object avoids putting the data into an arbitrary "sounding object" or similar. This enables the user to easily work with their own data of any format, as long as it can be read into a Numpy array without needing to learn a custom MetPy data model.

```
class parcelPathAssumptions(object):
    """
    Holds assumptions made about the parcel path during calculations.
    """
    __slots__ = ('use_virtual_temperature', 'moist_adiabat')
    def __init__(self):
        self.use_virtual_temperature = True
        self.moist_adiabat = 'pseudoadiabatic'

prof = parcel_profile(pressure, temperature, dewpt,
assumptions=parcelPathAssumptions(moist_adiabat='reversible'))
```

Calculations that require parcel path information can either take a parcel path provided by the user (in a research situation with non-standard paths for example), calculate a default path, or calculate a path given an assumptions object. This allows easy standard use cases, but maximum flexibility for advanced users.

CAPE/CIN Wrappers

The core CAPE/CIN calculation is a simple integral, but depends upon calculation of a number of thermodynamically significant levels and the starting parcel and associated parcel path. This core calculation is available to the user wanting to do a complex or custom calculation, but we have provided wrappers for the most common types of CAPE/CIN calculated by research and operational meteorologists.

Surface Based CAPE

```
sbcape_cin(pressure, temperature, dewpt)
```

Surface temperature/dewpoint

Virtual temperature correction

Mixed Layer CAPE

```
mlcape_cin(pressure, temperature, dewpt,
           bottom=None, depth=300 * units.hPa)
```

Log mean parcel properties over a layer

Bottom and depth specified

Most Unstable CAPE

```
mucape_cin(pressure, temperature, dewpt,
           bottom=None, depth=300 * units.hPa)
```

Starting parcel at maximum θ_e

Depth bound for search

Conclusions

API/Library Design

During the course of developing this frequently requested feature, the MetPy team was able to crystallize some ideas about where complexity in calculations should lie in the package and how assumptions/different solutions to the same problem could be addressed. The team intends to continue adding a variety of meteorological calculations to the package as requested by the community and implement a solver to help automatically determine the calculations required to get from the input variables to the desired quantity.

- Complexity should be pushed to the lowest, most fundamental level.
- Assumptions should be integrated into a single method to calculate the desired quantity.
- Methods should accept arguments in any physically sensible unit and handle conversions internally with the appropriate assumption.

Reproducibility

In the course of reproducing the results of a classic paper, we encountered several challenges. The largest of which was finding the same data used as no table of data was included. The numerical results of the study were not included either, and poorly scanned PDFs of the paper prevented accurate reverse engineering of the data from the graphs. The vast majority of the same data were likely found, but this poses a challenge for true reproducibility.

- Finding data without data tables is difficult
- No numerical results were given in the paper
- No code was included with the paper

Our hope is that with the thoroughly documented and citeable MetPy and tools like GitHub LFS, that such a study done now could be made easily reproducible.

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