A Simple Parcel Theory Model of Downdrafts in Convective Clouds

Thomas D. Schanzer

Taste of Research 2021

Supervisor: Prof. Steven Sherwood

School of Physics
Faculty of Science
University of New South Wales
Sydney, Australia

Abstract

Abstract

Acknowledgements

The author is most grateful to his supervisor, Prof. Steven Sherwood, for his patient guidance and mentorship during the ten-week research project whose outcomes are documented in this report. The author also thanks the members of Prof. Sherwood's research group at the UNSW Climate Change Research Centre for some useful suggestions and feedback.

The author would also like to thank the UNSW School of Physics for offering the Taste of Research program under which this project was conducted, and in particular the program coordinator, A. Prof. Sarah Martell. The program has proved to be a very valuable and enjoyable learning opportunity.

Notation for thermodynamic variables

Contents

1 Introduction and theory

Outline:

- Aim and key questions: what processes and conditions initiate and maintain/inhibit a downdraft?
- Motivation: improving the parametrisation of convection in global climate models and understanding of severe weather associated with downdrafts
- Overview of parcel theory and its assumptions (buoyant forces only, adiabatic processes, hydrostatically balanced environment, etc.)

2 Literature review

Possible items for discussion:

- Knupp and Cotton (1985): the downdraft types and their typical characteristics
- Thayer-Calder (2013): last chapter on the Lagrangian view of downdrafts
- Market et al. (2017): correlation between DCAPE and DCIN and downdraft strength
- Sumrall (2020): DCAPE, DCIN and severe surface winds
- Davies-Jones (2008): pseudoadiabatic wet bulb temperature approximations
- Bolton (1980): equivalent potential temperature and saturation vapour pressure approximations
- Saunders (1957): reversible moist adiabatic temperature approximation

3 Methods

3.1 General approach and code structure

Mention general capabilities of the code

3.2 Temperature as a function of pressure along a reversible moist adiabat

3.3 Temperature of an entraining, descending parcel

Mixing and phase equilibration

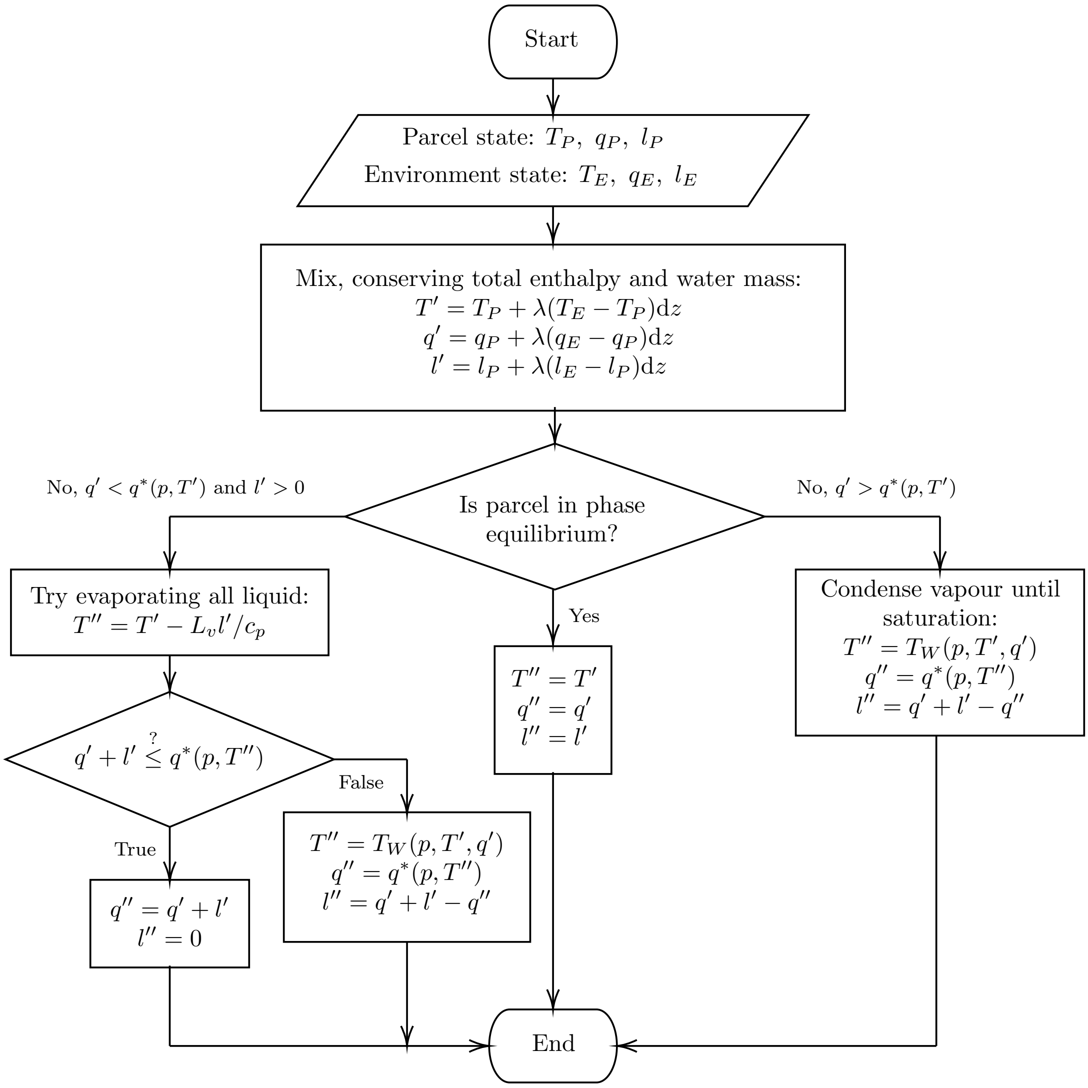

Figure 1: Flowchart for the mixing and phase equilibration calculation (functions `mix` and `equilibrate`) performed at each downward step for the entraining downdraft.

Dry and/or reversible moist adiabatic descent

Finding temperature as a function of height

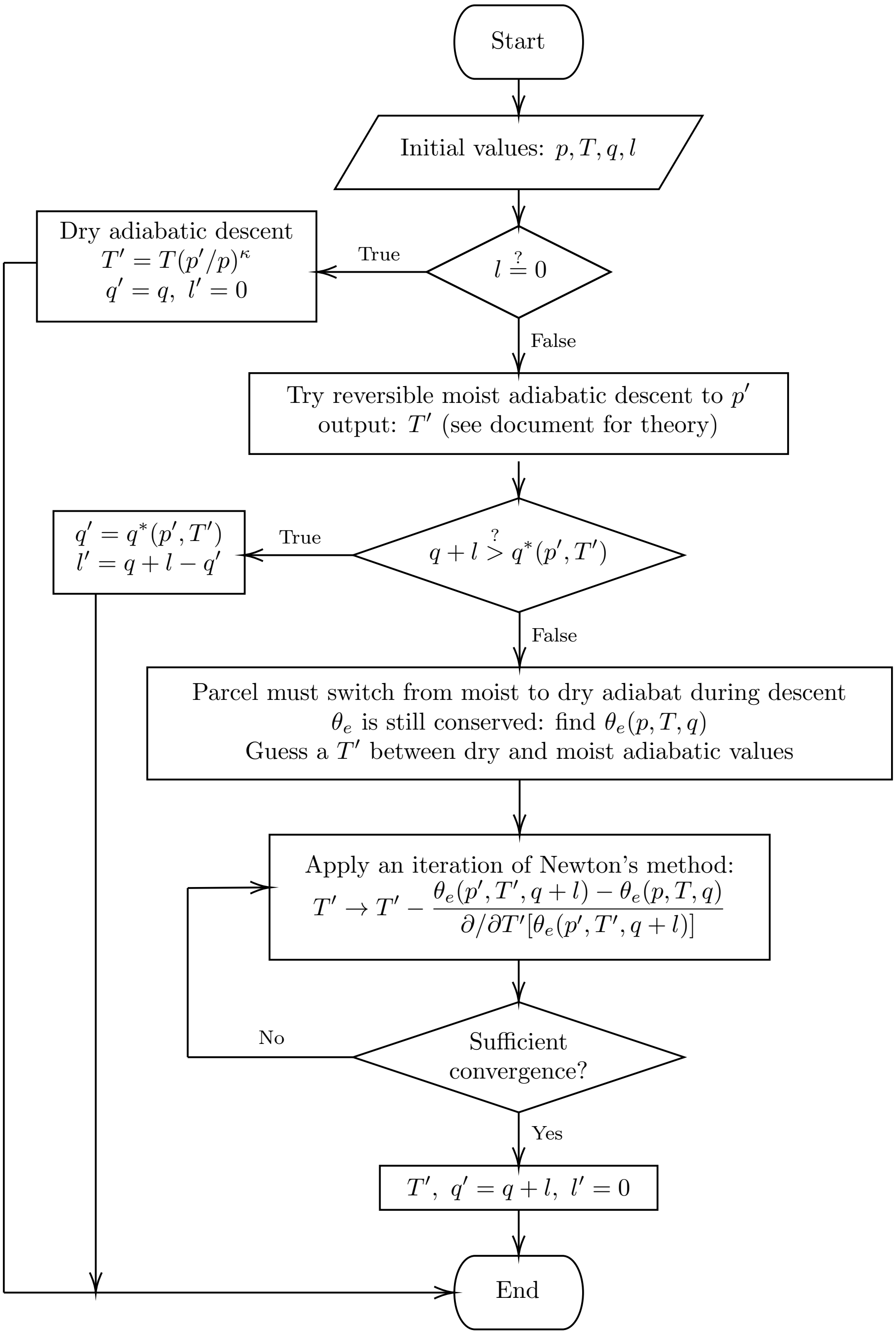

Figure 2: Flowchart for the descent calculation (`descend`) performed at each downward step for the entraining downdraft.

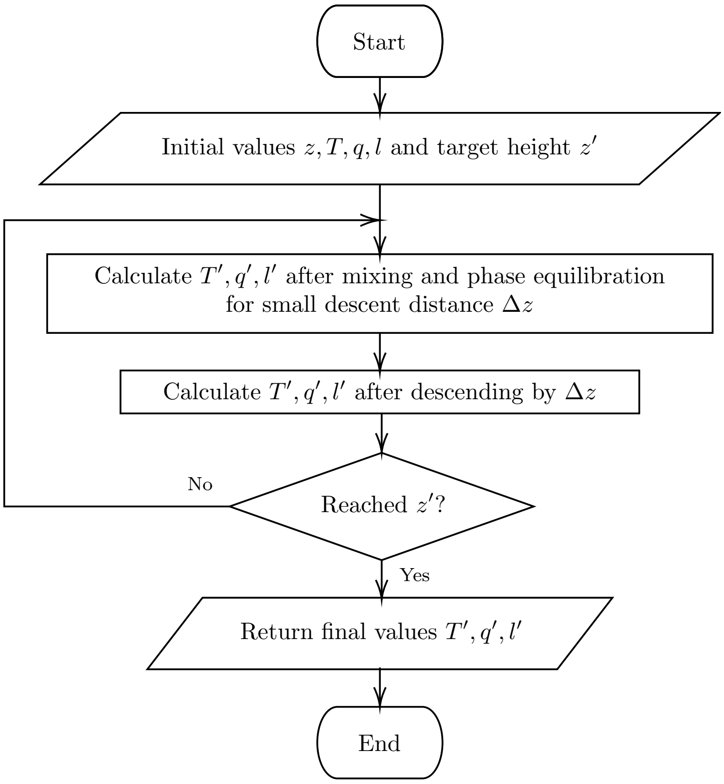

Figure 3: Flowchart for the calculation of parcel temperature as a function of height (`EntrainingParcel.profile`), assembling the routines shown in Figures 1 and 2.

3.4 Density, buoyancy and motion of a descending parcel

4 Results

4.1 Downdraft initiation and initial conditions

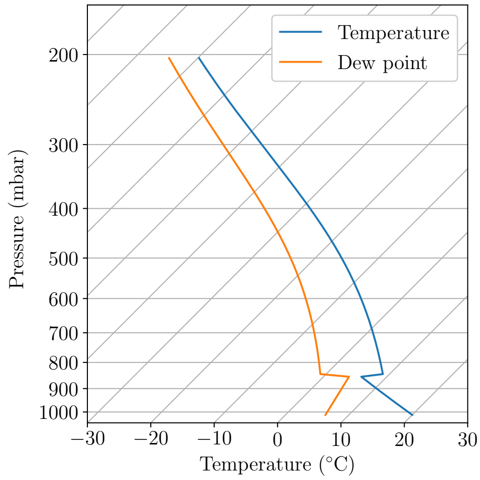

Figure 4: Skew T-$\log p$ plot of the idealised atmospheric sounding used in Section 4.1.

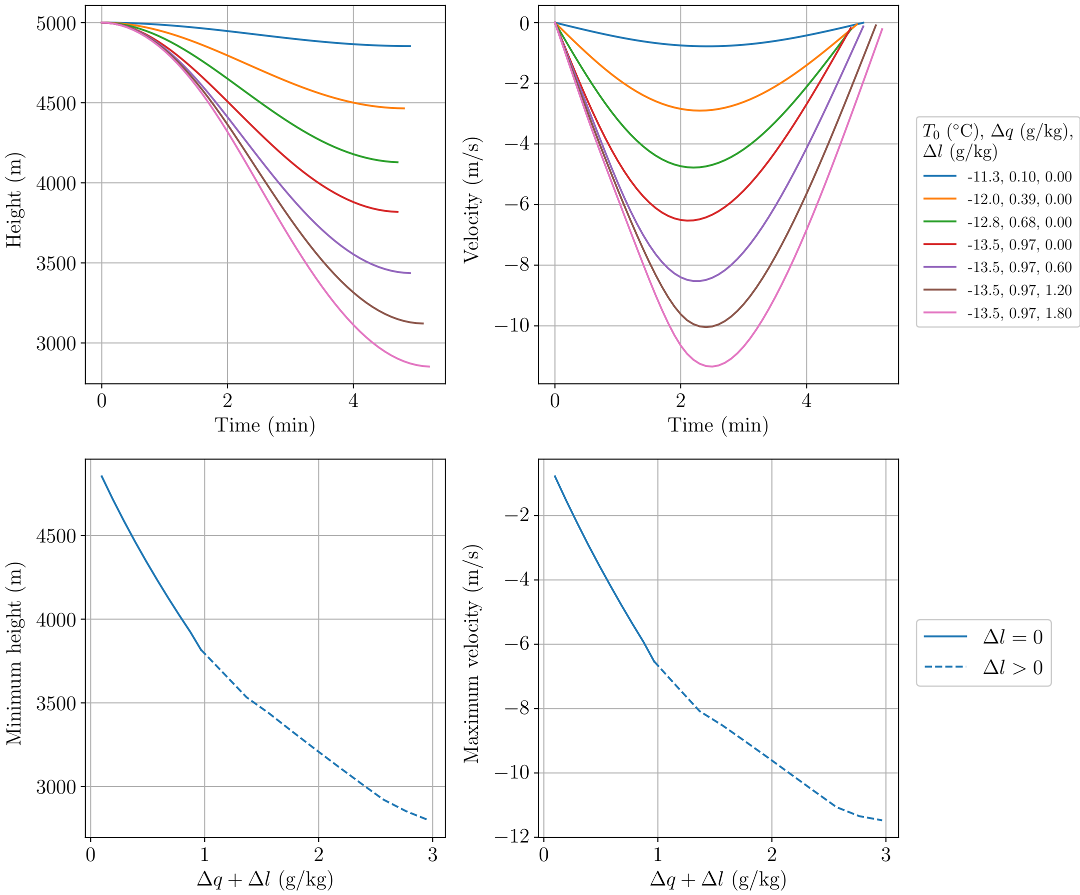

Figure 5: Properties of a downdraft parcel originating at height 5 km in an idealised atmospheric sounding with 50% relative humidity in the upper atmosphere and a fixed entrainment rate of $1\,\mathrm{km}^{-1}$. Top row: height (left) and velocity (right) as functions of time, for selected initial conditions. Bottom row: minimum height reached (left) and maximum downward velocity (right) as functions of the total amount of water initially added to the parcel (specific humidity change due to evaporation Δq plus additional liquid water per unit parcel mass Δl).

4.2 The impact of entrainment

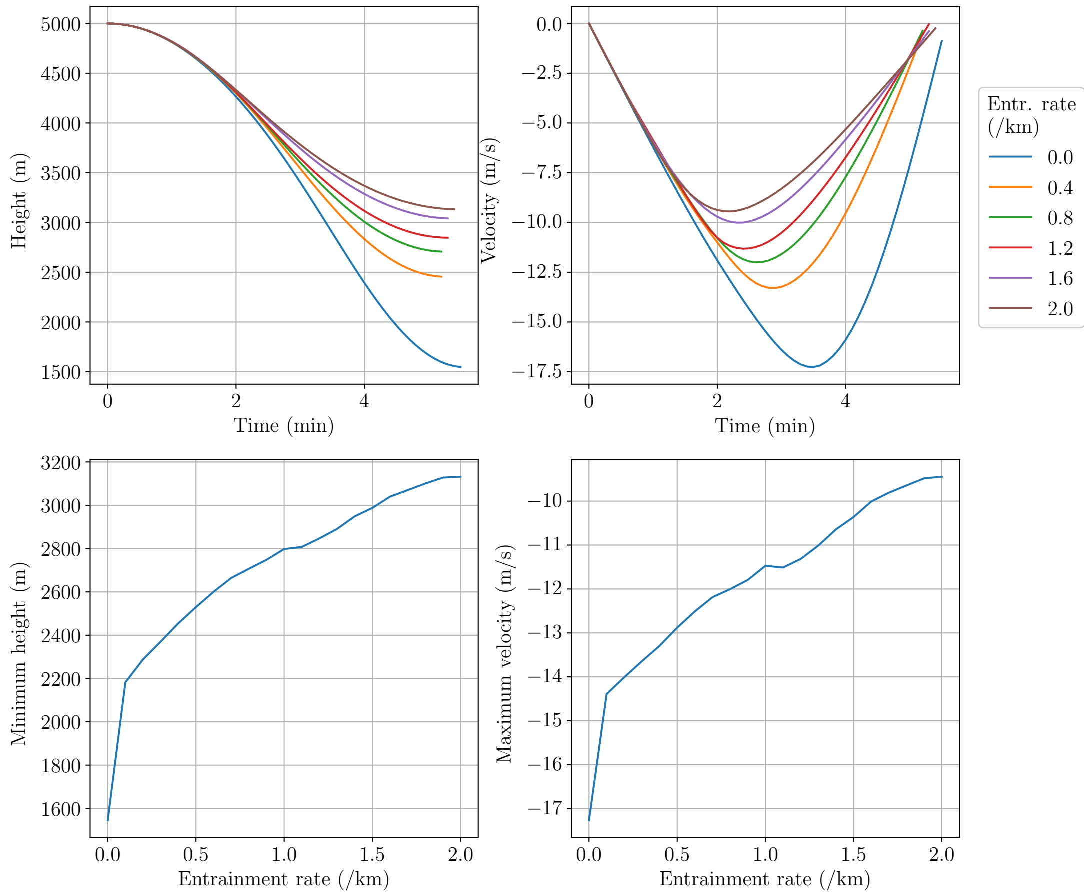

Figure 6: Properties of a downdraft parcel originating at height 5 km in an idealised atmospheric sounding with 50% relative humidity in the upper atmosphere. The initial conditions are fixed: an environmental parcel is brought to saturation by evaporation of liquid water, and $2\,\mathrm{g\,kg^{-1}}$ liquid water is additionally suspended in the parcel. Top row: height and velocity over time for selected entrainment rates. Bottom row: minimum height reached and maximum velocity as functions of entrainment rate.

4.3 The impact of environmental humidity

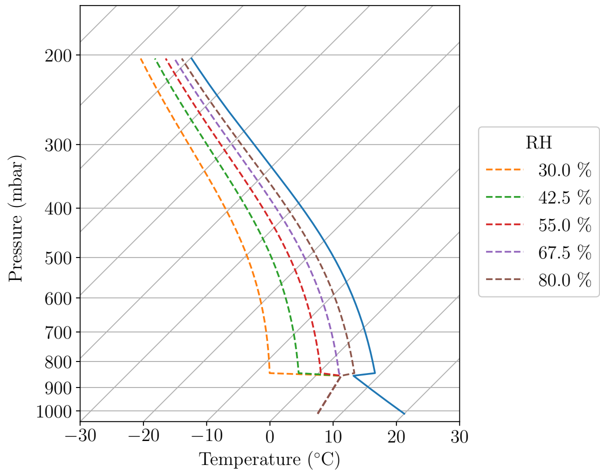

Figure 7: Skew T-$\log p$ plot of some selected idealised atmospheric soundings used in Section 4.3. The dashed lines on the left are the dewpoint profiles for the different soundings, and the solid blue line on the right is the common temperature profile.

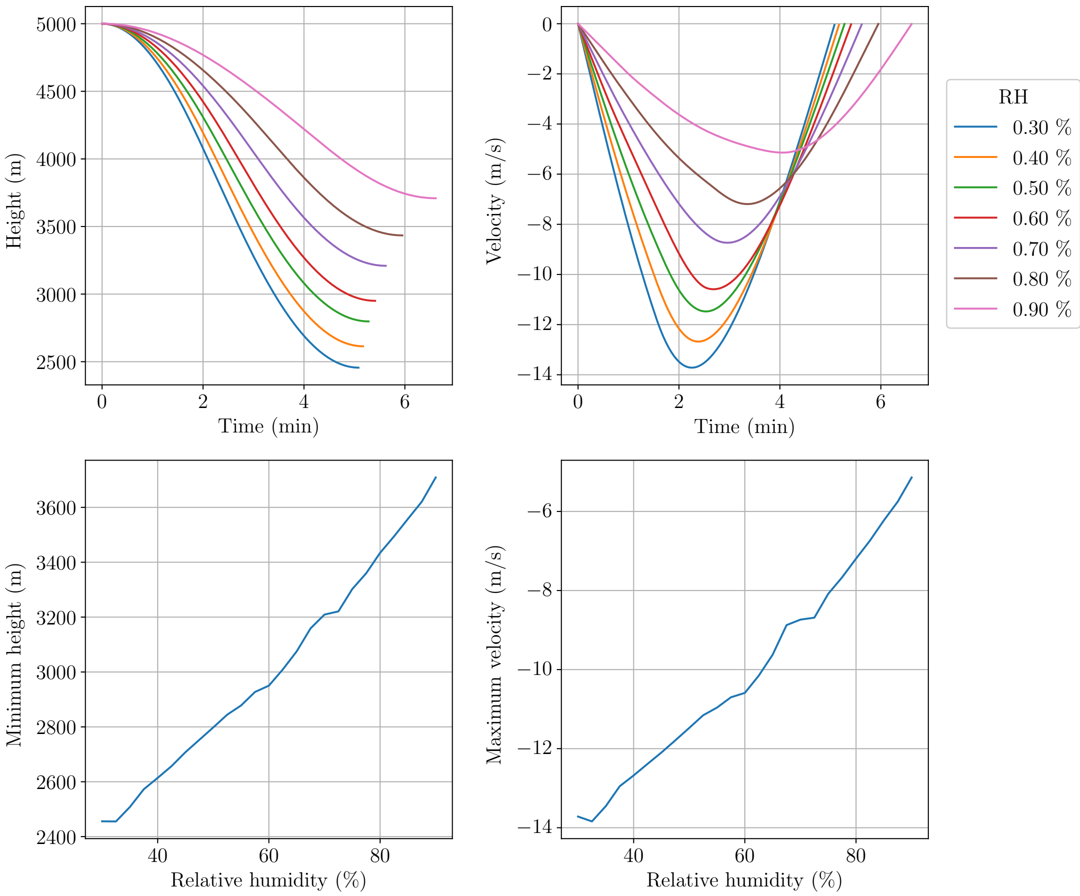

Figure 8: Properties of a downdraft parcel originating at height 5 km in idealised atmospheric soundings whose upper atmosphere relative humidities vary between 30% and 90%. The initial conditions are generated by bringing an environmental parcel to saturation by evaporation of liquid water (note that the resulting temperatures differ since more humid environmental parcels are closer to their wet bulb temperatures), and $2\,\mathrm{g\,kg^{-1}}$ liquid water is additionally suspended in the parcel. Top row: height and velocity of the parcel over time for selected soundings. Bottom row: minimum height reached and maximum downward velocity as functions of relative humidity in the upper atmosphere.

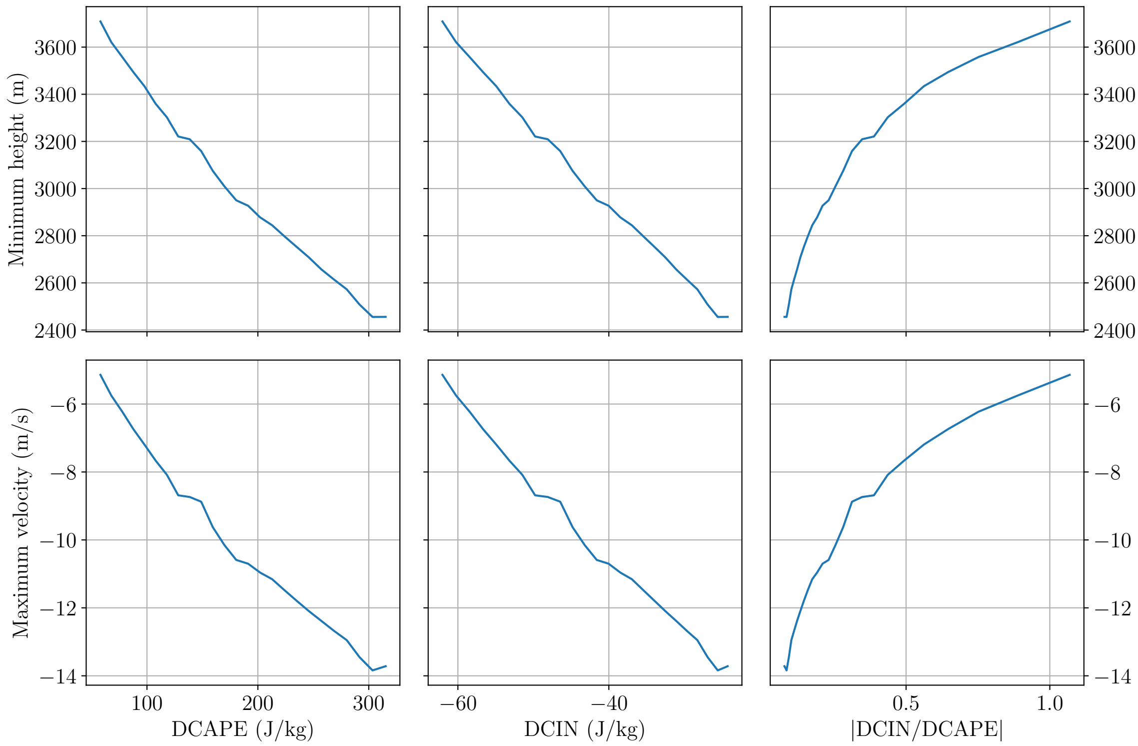

Figure 9: Plots of the minimum height (top row) and maximum downward velocity (bottom row) reached by the parcel of Figure 8 as functions of the downdraft convective available potential energy (DCAPE, left column), downdraft convective inhibition (DCIN, centre column) and the ratio |DCIN/DCAPE| (right column).

5 Conclusions

References

Bolton, David (1980). "The computation of equivalent potential temperature". In: *Mon. Weather Rev.* 108.7, pp. 1046–1053. ISSN: 0027-0644.

Davies-Jones, Robert (2008). "An efficient and accurate method for computing the wet-bulb temperature along pseudoadiabats". In: *Mon. Weather Rev.* 136.7, pp. 2764–2785. ISSN: 0027-0644. DOI: 10.1175/2007MWR2224.1.

Knupp, Kevin R and William R Cotton (1985). "Convective cloud downdraft structure: An interpretive survey". In: *Rev. Geophys.* 23.2, pp. 183–215. ISSN: 8755-1209. DOI: 10.1029/RG023i002p00183.

Market, P. S, S. M Rochette, J Shewchuk, R Difani, J. S Kastman, C. B Henson, and N. I Fox (2017). "Evaluating elevated convection with the downdraft convective inhibition". In: *Atmos. Sci. Lett.* 18.2, pp. 76–81. ISSN: 1530-261X. DOI: 10.1002/asl.727.

Saunders, P. M (1957). "The thermodynamics of saturated air: A contribution to the classical theory". In: *Q. J. Roy. Meteror. Soc.* 83.357, pp. 342–350. ISSN: 0035-9009.

Sumrall, Paula (2020). "Using DCIN and DCAPE to evaluate severe surface winds in the case of elevated convection". masters thesis. University of Missouri.

Thayer-Calder, Katherine (2013). "Downdraft impacts on tropical convection". PhD thesis. Colorado State University.