A Simple Parcel Theory Model of Downdrafts in Atmospheric Convection

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https://github.com/tschanzer/taste-of-research-21T3

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Aim and Motivation

Downdrafts play an important role in the dynamics of the Earth's atmosphere and climate.

Question

Which processes and conditions initiate, and which maintain or inhibit, downdrafts?

Motivation

- Convection parametrisation in global climate models
- Forcasting dangerous downbursts

Literature

Knupp and Cotton (1985) [1] identify four downdraft types from a review of observational and modelling research:

- Precipitation-associated,
- Penetrative,
- Cloud-edge,
- Overshooting.

In this work: precipitation-associated and penetrative downdrafts.

[1] Knupp, KR & Cotton, WR 1985, 'Convective cloud downdraft structure: An interpretive survey', Reviews of geophysics (1985), vol. 23, no. 2, pp. 183–215.

Background: Parcel Theory

Parcel: small air mass with an imaginary, flexible but closed boundary.

Key assumptions:

- Motion is purely vertical and buoyancy is the only force involved:
$$b = \frac{\rho_E - \rho_P}{\rho_P} g.$$
- Raising and lowering the parcel is a reversible adiabatic process

Major complication: the atmosphere contains water!

- Descent is either *dry* adiabatic (no phase changes) or *moist* adiabatic (with phase changes)
- Phase equilibrium is maintained
- Air/vapour mixture is an ideal gas

Methods

Original model developed from first principles in Python.

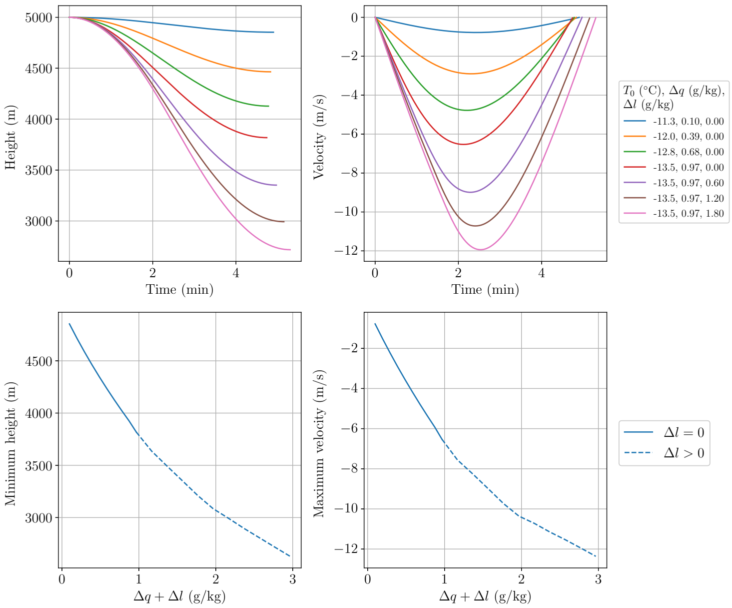
- The `Environment` class interpolates real atmospheric temperature and moisture profiles to calculate derived quantities:

```
>>> sydney.density(5*units.km)
0.7206758681891053 kilogram/meter^3
```

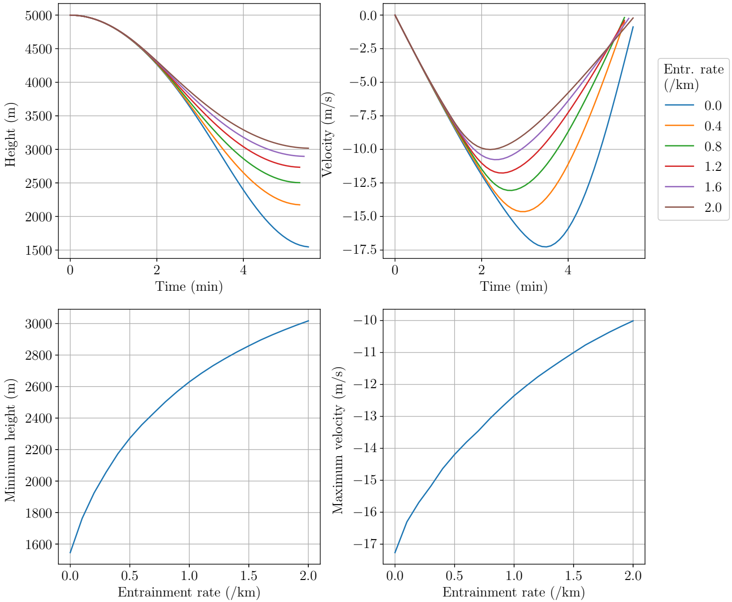
- Various thermodynamic calculations (approximate and exact) are implemented from literature
- End goal: calculate parcel temperature $\rightarrow$ density $\rightarrow$ buoyancy as functions of height and numerically solve

$$\frac{d^2 z}{dt^2} = b(z).$$

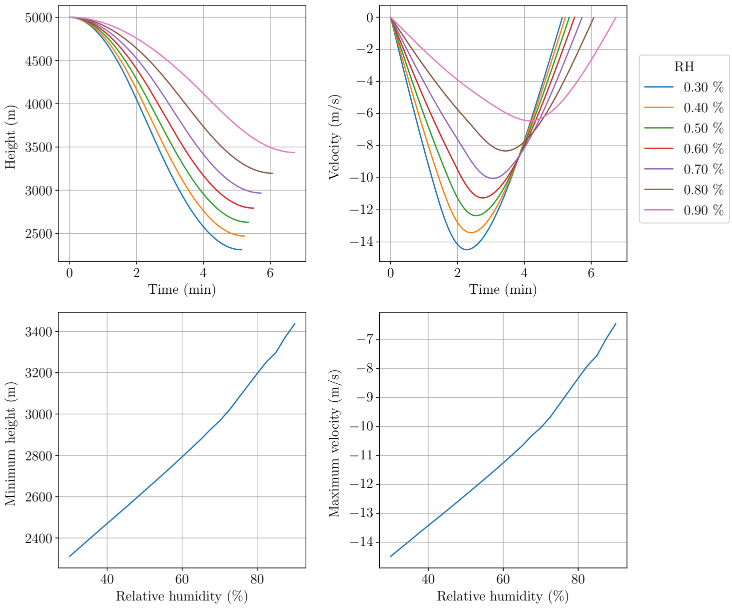
Results: Precipitation Enhances Downdrafts



Results: Entrainment Inhibits Downdrafts



Results: Atmospheric Dryness Enhances Downdrafts



Conclusions and Future Work

Conclusions:

- Precipitation evaporation increases strength and penetration
- Entrainment reduces them
- Atmospheric dryness increases them

Application: supplement basic sounding analysis methods used in weather forecasting

Future Work:

- Consider other forces at play, e.g. drag
- Model more advanced dynamics, e.g. entrainment from updrafts