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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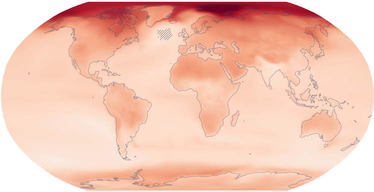
Aim and Motivation

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



(a) Convection parametrisation in global climate models

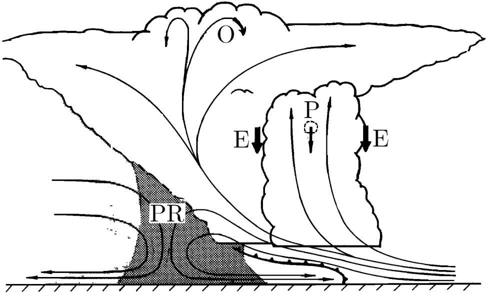
(b) Forcasting dangerous microbursts

(a): IPCC AR6 interactive atlas. (b): US National Weather Service.

Literature

Knupp and Cotton (1985) [1] identify four downdraft types:

- Precipitation-associated (PR)
- Penetrative (P)
- Cloud-edge (E)
- Overshooting (O)



Adapted from *Knupp and Cotton (1985)*.

[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 boundary.

- Motion is purely vertical and buoyancy is the only force involved:

$$b = (\text{force}/\text{mass}) = \frac{(\text{environment density}) - (\text{parcel density})}{(\text{parcel density})} g.$$

- Raising and lowering the parcel is an adiabatic process

Complication 1: the atmosphere contains water!

- Descent is either *dry adiabatic* (no phase changes) or *moist adiabatic* (with phase changes)

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Methods

Original model developed in Python.

Complication 2: finding the temperature of an *entraining* parcel

- Small steps: (non-adiabatic) mixing $\rightarrow$ adiabatic descent $\rightarrow$ mixing $\rightarrow$ ...

End goal: calculate parcel temperature $\rightarrow$ density $\rightarrow$ buoyancy as functions of height and numerically solve

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

We can use *any* real or idealised profiles of environmental temperature and moisture.

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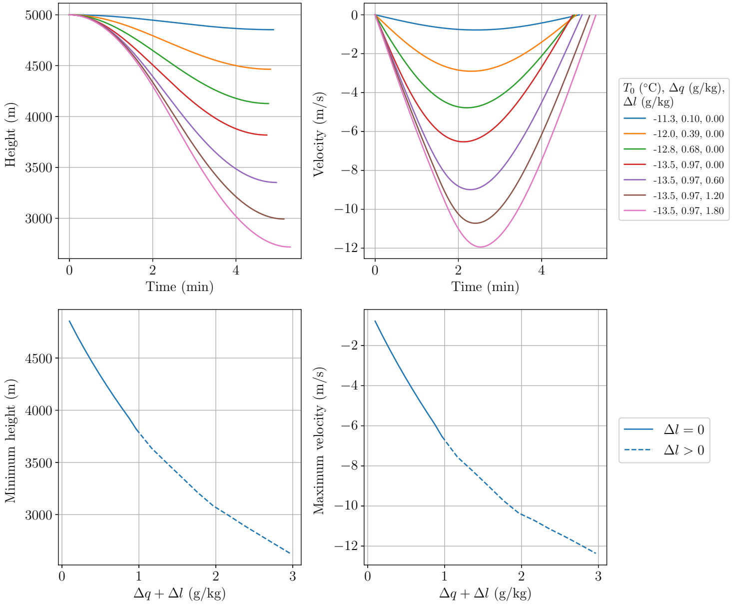
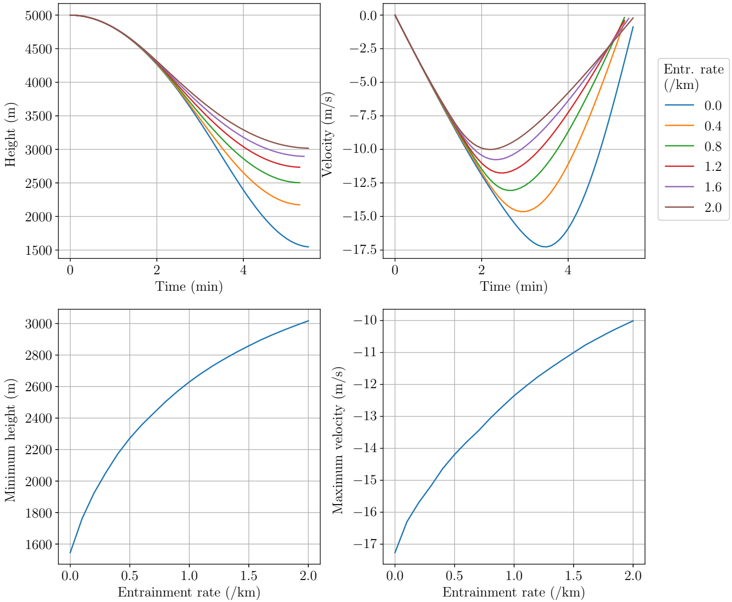
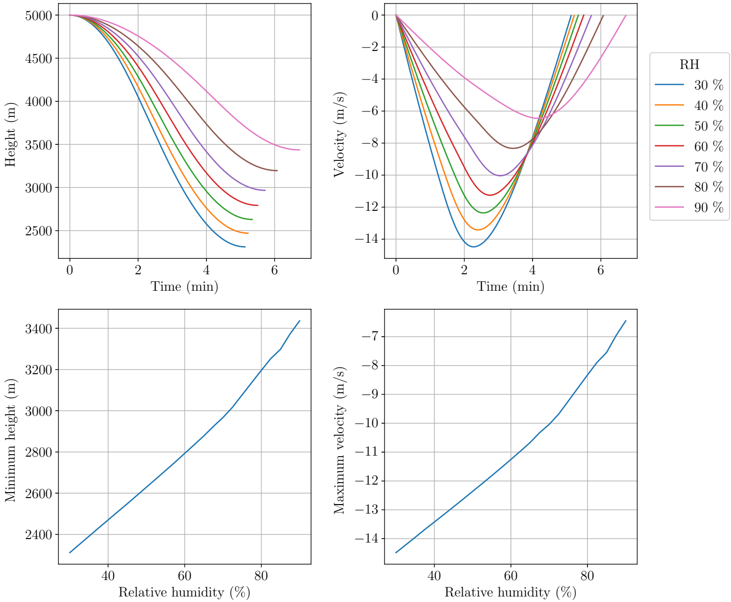
Results: Precipitation Enhances Downdrafts



Results: Entrainment Inhibits Downdrafts



Results: Atmospheric Dryness Enhances Downdrafts



Conclusions and Future Work

Conclusions: downdraft strength and penetration are

- Increased by precipitation evaporation and condensate loading,
- Reduced by entrainment of environmental air,
- Increased by atmospheric dryness.

Application: supplement basic sounding analysis methods used in weather forecasting

Future Work:

- Consider other forces, e.g. drag
- Model more advanced dynamics, e.g. entrainment from updrafts
- Support the findings of more advanced models

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