A Simple Parcel Theory Model of Downdrafts in Atmospheric Convection

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

Supervisor: Prof. Steven Sherwood

UNSW School of Physics

Monday 22 November 2021

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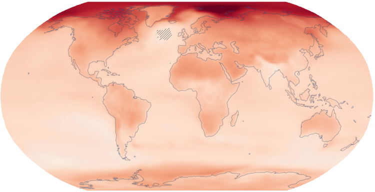
- Present a simple model...
- Downdraft: descending stream of air
- Firstly: thank Prof. Sherwood for his patient guidance

Aim and Motivation

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

Motivation



(a) Convection parametrisation in global climate models

(b) Forcasting dangerous microbursts

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

Question

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

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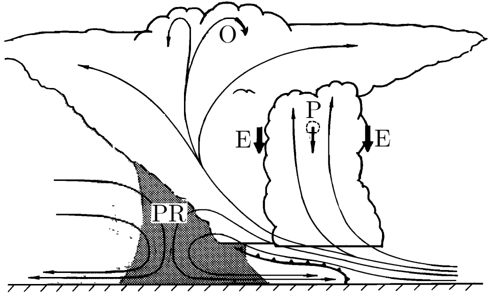
Which processes and conditions initiate, and which maintain or inhibit, downdrafts?

1. Mass, momentum, heat and moisture
2. Intergovernmental Panel on Climate Change #6, average temperature increase across 34 global climate models
   - Large spatial domain, long time scales (decades)
3. Delta Flight 191, Dallas/Fort Worth 1985 (one of several)
4. Both prompt us to ask...

Literature

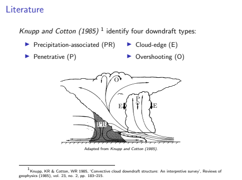
Knupp and Cotton (1985) [1] identify four downdraft types:

- Precipitation-associated (PR)
- Cloud-edge (E)
- Penetrative (P)
- 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.



1. Four qualitative answers identified in literature... (only PR, time constraints)
2. This work: primarily PR, but model is general – applicable to provided appropriate initial conditions

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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1. The basis of the model is...
2. Key assumptions...
   –
   – Pressure, work, internal energy/temperature

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Major driving force

- No liquid:... very similar to no water
- With liquid: saturation vapour pressure, evaporation, latent heat, cooling (considerably slower warming)

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

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

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1. From scratch, using parcel theory as basis, theoretical foundation
2. But... (explain entrainment), not covered by traditional parcel theory
3. Buoyancy: need to know temperature vs. height (explain method)

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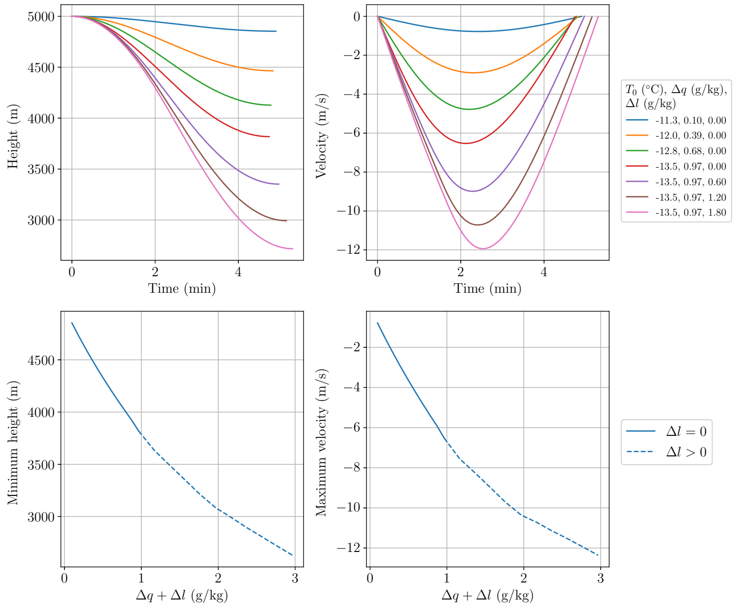
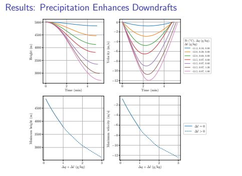
Now relatively simple (most work: finding $b(z)$)

Results: Precipitation Enhances Downdrafts





SLOW DOWN!Several results (time constraints)

1. Imagine...
2. Top left height vs. time: ..., relate to top right
3. Bottom row: explain horizontal axis
4. Why?

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

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To summarise...

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1. Mentioned earlier: any profile of environmental temperature, moisture (needed for...)
2. Measured 2x/day all over the world, forecasters calculate indices...
3. Sydney: assess downdraft potential without time, effort, expense...

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1. Model is simple, with a few improvements: accurate numerical predictions... (mention momentum)
2. Thank School of Physics