A Simple Parcel Theory Model of Downdrafts in Atmospheric Convection

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

Supervisor: Prof. Steven Sherwood

UNSW School of Physics

Thursday 25 November 2021

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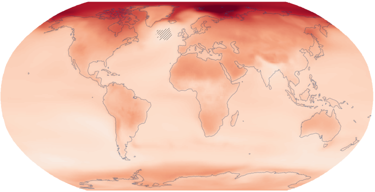
- Present a simple model...
- Firstly: thank Steve for his patient guidance
- Thank group for opportunity to speak

Aim and Motivation



(a) Convection parametrisation in global climate models

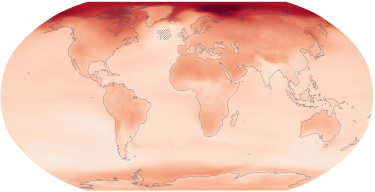
(b) Forecasting dangerous microbursts

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

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

1. Downdrafts play an important role (mass, momentum, heat and moisture)
2. Intergovernmental Panel on Climate Change #6, average temperature increase across 34 global climate models
3. Delta Flight 191, Dallas/Fort Worth 1985 (one of several)

Aim and Motivation



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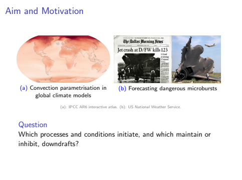
Question

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

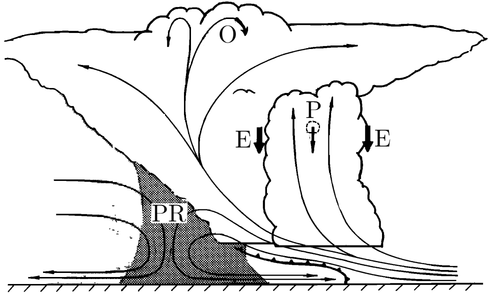


1. Both prompt us to ask...

Literature

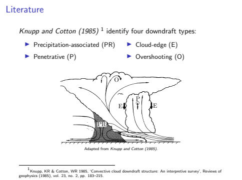
Knupp and Cotton (1985) [1] identify four downdraft types:

- 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.



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

Background: Parcel Theory

- Vertical motion under buoyant forces only:

$$b = \frac{\rho_{\text{env}} - \rho_{\text{parcel}}}{\rho_{\text{parcel}}} g.$$

- Descent is (dry or moist) adiabatic

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- Descent is (dry or moist) adiabatic

1. The basis of the model is...

Methods

Goal: calculate parcel temperature $\rightarrow$ density as functions of height

Complication: *entrainment*

Supply *any* environmental temperature and moisture profile

Choose initial conditions and numerically solve

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

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1. From scratch in Python, using parcel theory as basis, theoretical foundation
2. Buoyancy: need to know temperature vs. height

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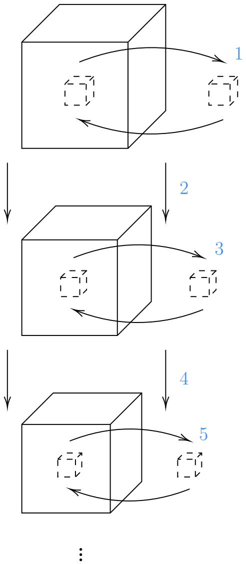

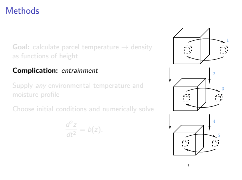

1. Not covered by traditional parcel theory
2. Relative amount dictated by entrainment rate (constant, linear)
3. Explain phase equilibration, competing factors

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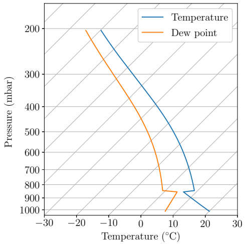
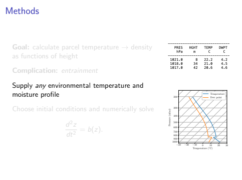
Supply *any* environmental temperature and moisture profile

Choose initial conditions and numerically solve

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

PRES hPa	HGHT m	TEMP C	DWPT C
1021.0	8	22.2	4.2
1018.0	34	21.0	4.5
1017.0	42	20.6	4.6





1. Need to know... (both for entrainment and buoyancy), Important capability: ..., (more later)
2. Real or idealised (used idealised, explain, constant relative humidity above boundary layer)

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Goal: calculate parcel temperature $\rightarrow$ density as functions of height

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Supply any environmental temperature and moisture profile

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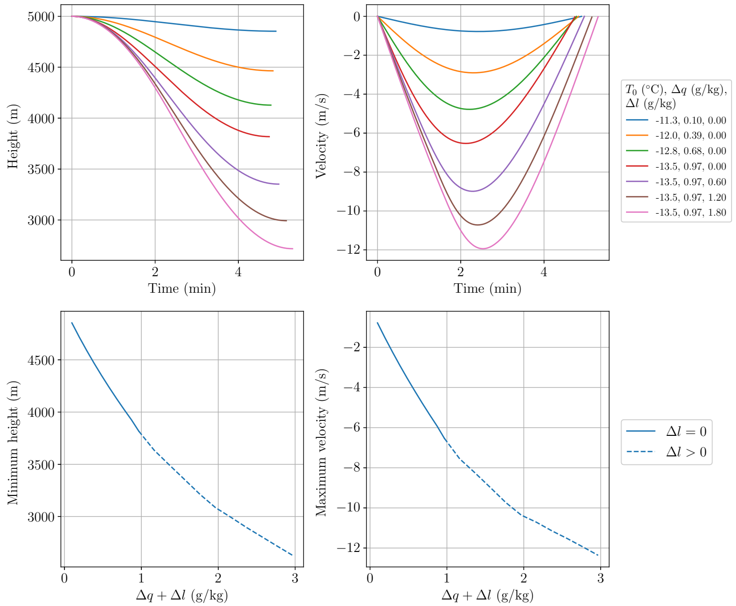
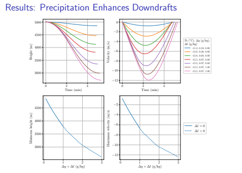
$$\frac{d^2z}{dt^2} = b(z).$$

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

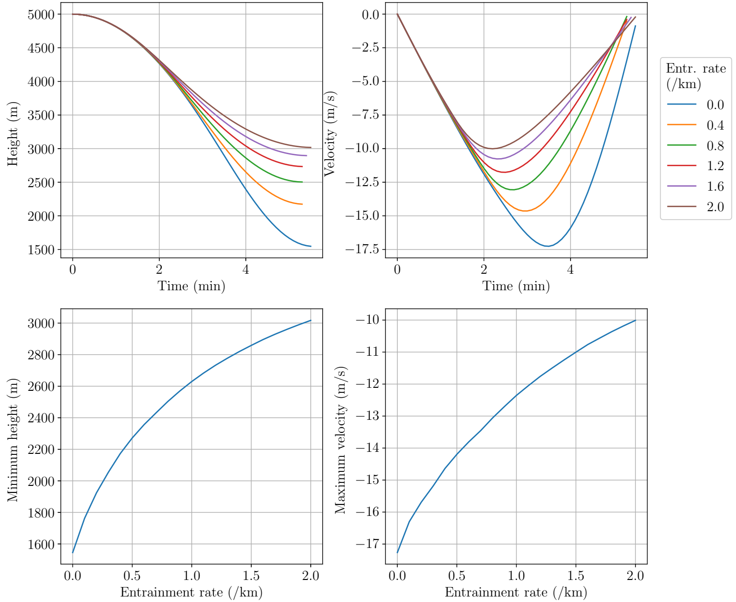
Results: Precipitation Enhances Downdrafts

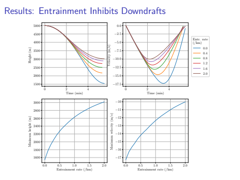




1. Imagine...
2. Bottom row: explain horizontal axis
3. Explain: why? (condensate loading, moist descent)

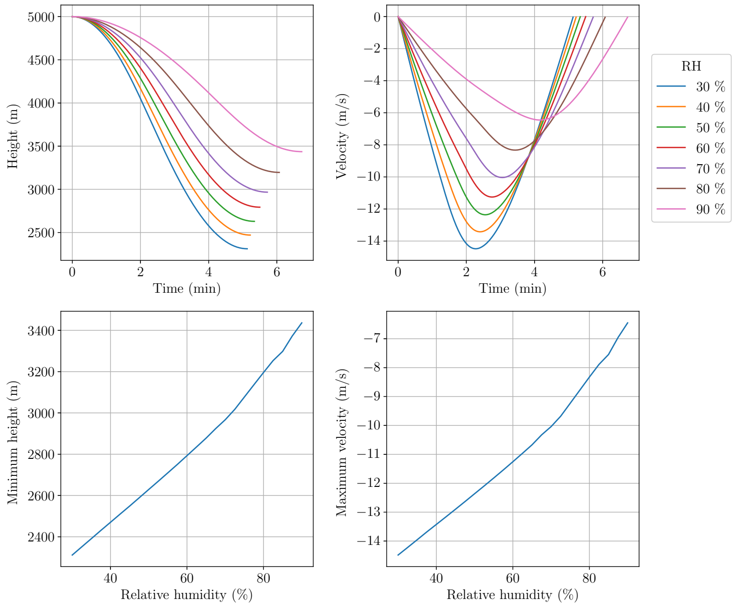
Results: Entrainment Inhibits Downdrafts

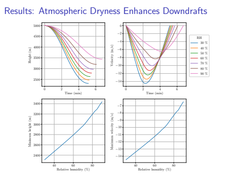




1. Similar to before, fix initial conditions: saturation, 2 g/kg liquid
2. Explain entrainment rate (legend)
3. Why?

Results: Atmospheric Dryness Enhances Downdrafts





1. Idealised profiles... vary humidity (constant above boundary layer)
2. Otherwise: initial conditions, entrainment rate constant
3. Why?

Results: DCAPE and DCIN

$$\text{DCAPE} = \int_{\text{surface}}^{\min T_W} \max\{b^*(z), 0\}\ dz \qquad \text{DCIN} = \int_{\text{surface}}^{\min T_W} \min\{b^*(z), 0\}\ dz$$

- No entrainment
- Moist descent only
- Pseudoadiabatic

- Fixed integration limits
- Fixed initial conditions

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- No entrainment
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- Fixed integration limits
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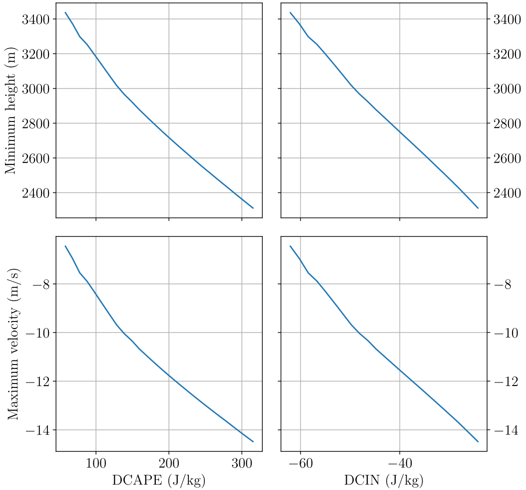
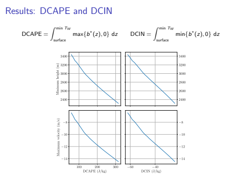
1. Thanks to Tim
2. DCAPE and DCIN measure...
3. Definitions
4. Just a fancy overcomplicated way of finding DCAPE? According to the conventional definitions...

Results: DCAPE and DCIN

$$\text{DCAPE} = \int_{\text{surface}}^{\min T_W} \max\{b^*(z), 0\}\ dz \qquad \text{DCIN} = \int_{\text{surface}}^{\min T_W} \min\{b^*(z), 0\}\ dz$$





Relate to previous plots

Conclusions

Conclusions: downdraft strength and penetration are

- Increased by precipitation evaporation and condensate loading,
- Reduced by entrainment of environmental air,
- Increased by atmospheric dryness,
- Strongly linked to DCAPE and DCIN.

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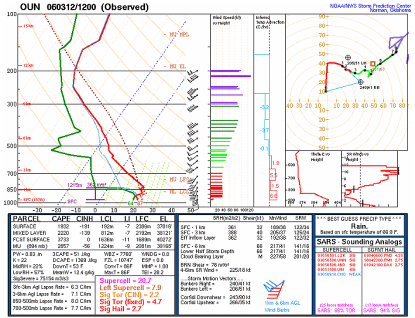
Strongly linked to DCAPE and DCIN.

To summarise...

Next Steps

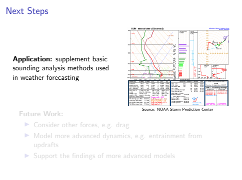
Application: supplement basic sounding analysis methods used in weather forecasting



Source: NOAA Storm Prediction Center

Future Work:

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



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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- Support the findings of more advanced models

1. Model is simple, with a few improvements: accurate numerical predictions... (mention momentum)
2. Steve + colleague at the Max Planck Institute for Meteorology, machine learning
3. Thank again