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

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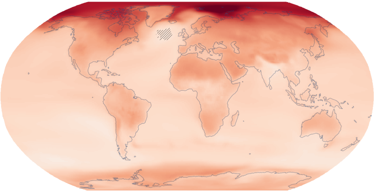
Aim and Motivation



(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?

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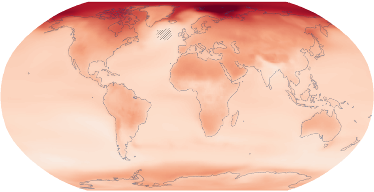

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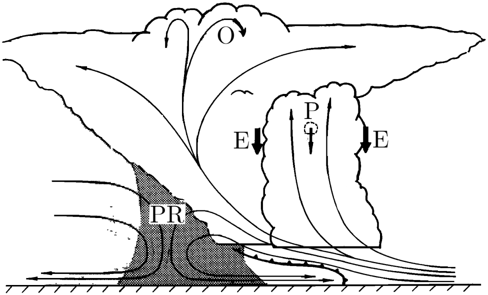
Literature

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

- Vertical motion under buoyant forces only:

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

- Descent is (dry or moist) adiabatic

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

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

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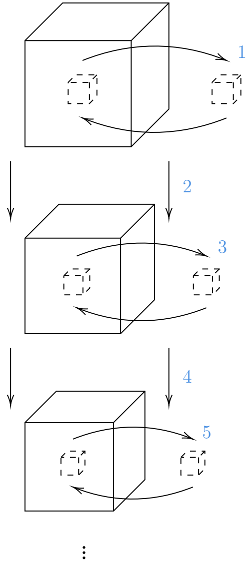

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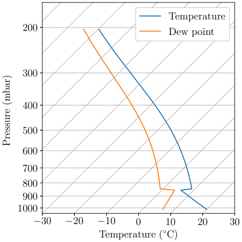
PRES hPa	HGHT m	TEMP C	DWPT C
1021.0	8	22.2	4.2
1018.0	34	21.0	4.5
1017.0	42	20.6	4.6



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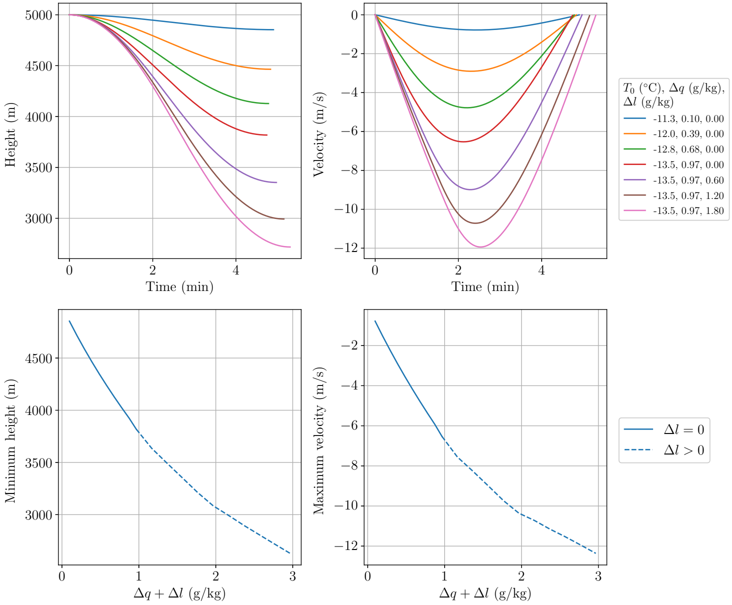
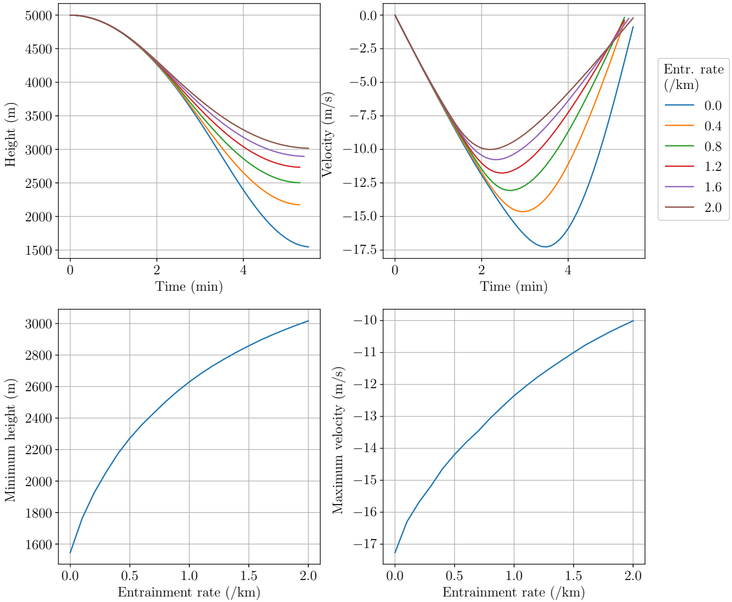
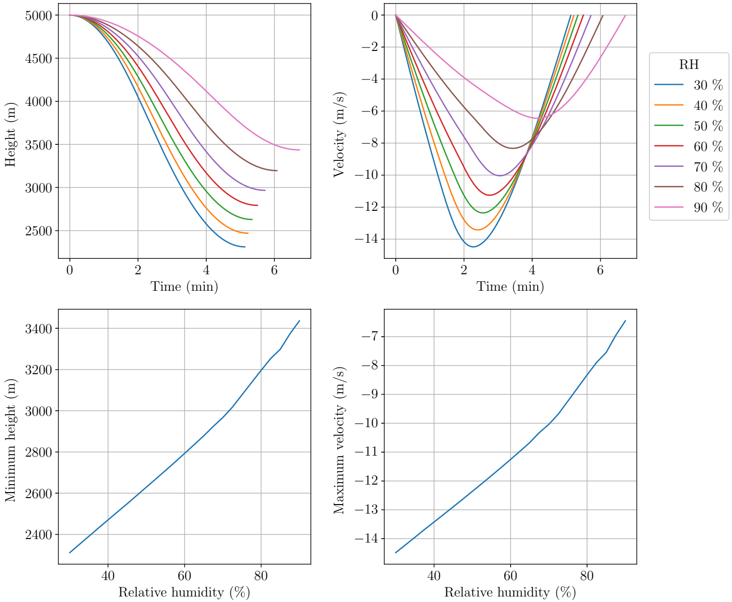
Results: Precipitation Enhances Downdrafts



Results: Entrainment Inhibits Downdrafts



Results: Atmospheric Dryness Enhances Downdrafts



Results: DCAPE and DCIN

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

- No entrainment
- Moist descent only
- Pseudoadiabatic

- Fixed integration limits
- Fixed initial conditions

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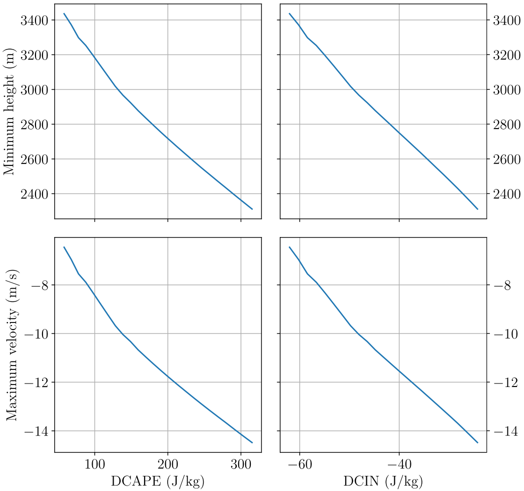


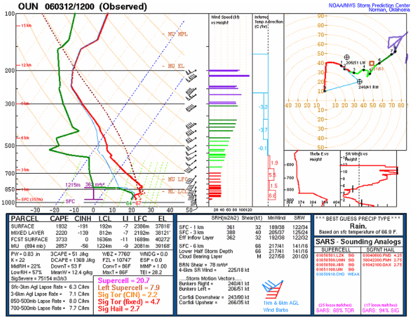
Conclusions

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.

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

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