Atmospheric Convection:

Known and unknowns

Cathy Hohenegger

Max-Planck-Institut
für Meteorologie

FESSTVaL

at least 6 km

Raining

Painting: Layne Johnson, https://laynejohnson.com/product/cumulonimbus/

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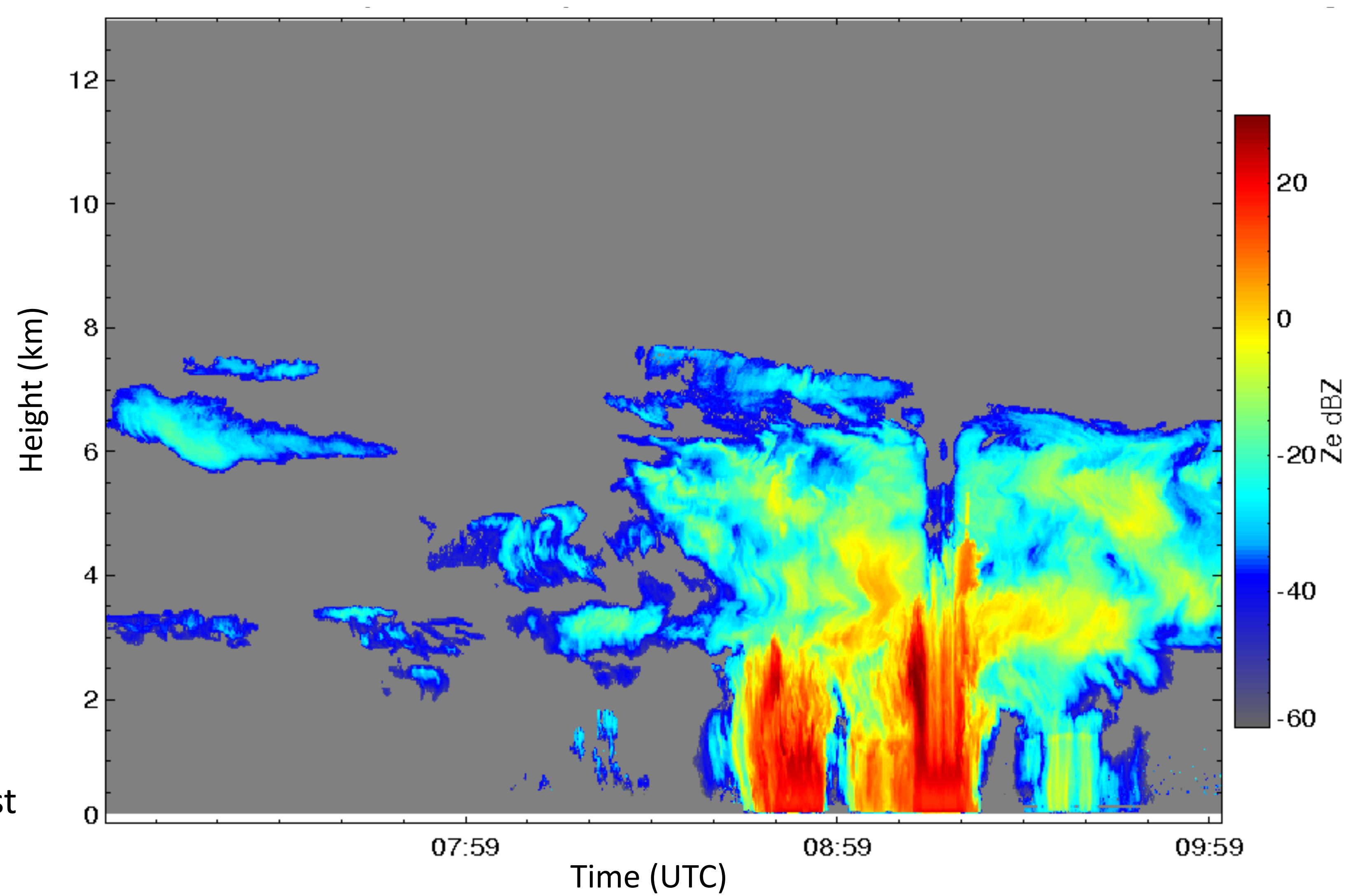

3 mm of rain
34 km/h wind gust

Cloud radar located in Lindenberg, picture provided by V. Lehmann (DWD)

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Under a deep convective cloud….

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Why fascination for deep convective clouds?

- Look nice

Painting: Layne Johnson, https://laynejohnson.com/product/cumulonimbus/

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Why fascination for deep convective clouds?

- Look nice
- Transport heat, momentum and moisture vertically

Painting: Layne Johnson, https://laynejohnson.com/product/cumulonimbus/

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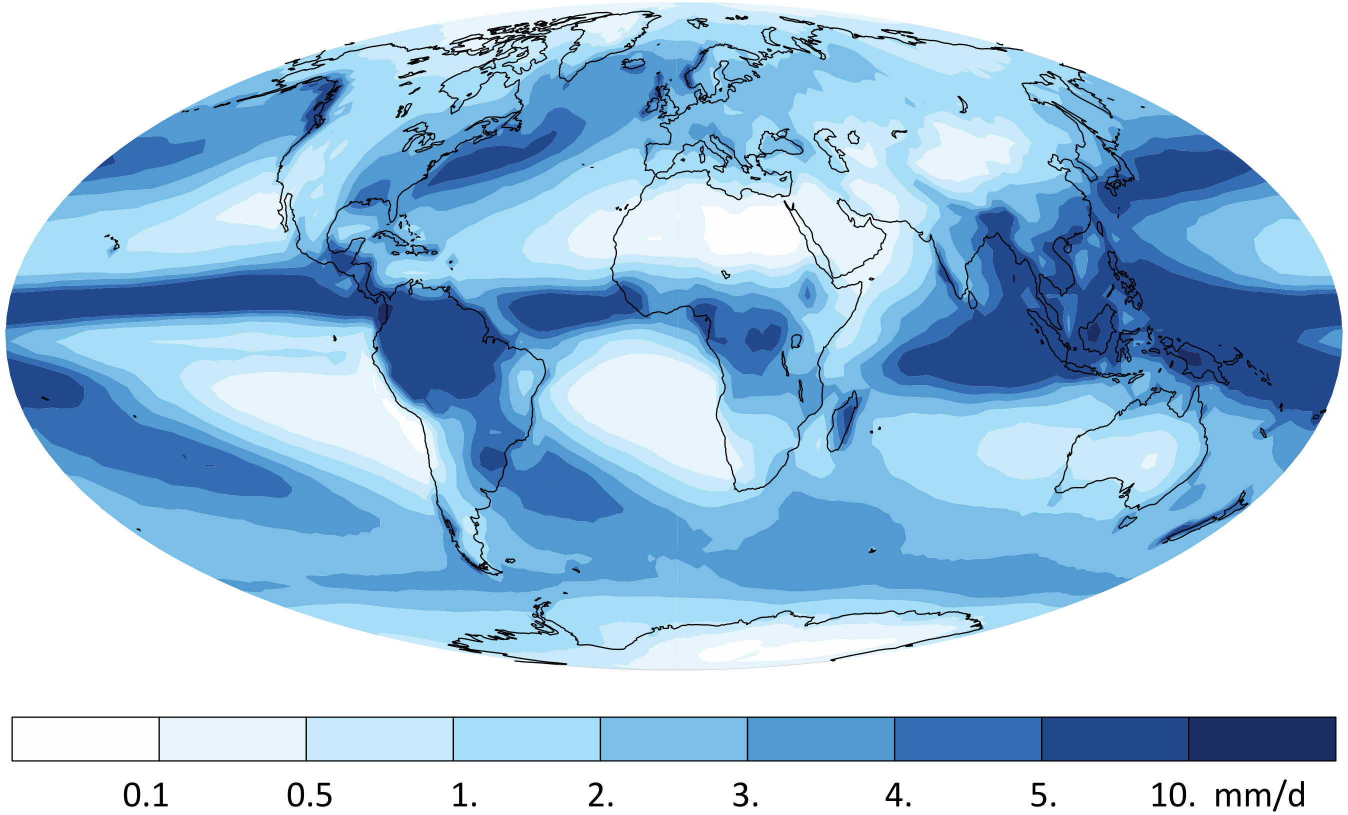
Why fascination for deep convective clouds?

- Look nice
- Transport heat, momentum and moisture vertically
- Produce precipitation



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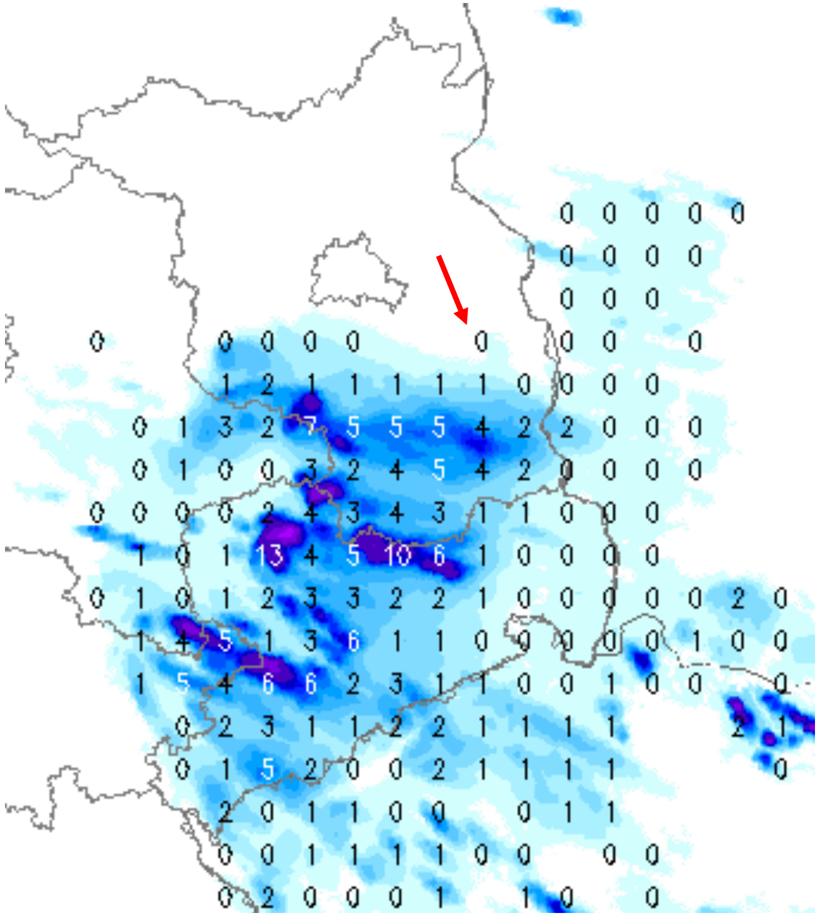
Why fascination for deep convective clouds?

- Look nice
- Transport heat, momentum and moisture vertically
- Produce precipitation
- Hard to forecast but can produce severe local damage

Accumulated precipitation, 7 h forecast



Weather forecast from DWD using the ICON model with a grid spacing of 2.2 km

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Outline

1. Some basics on convection

   a. The thermodynamical view

   b. The dynamical view

   c. The devil messes it up

2. The diurnal cycle of convection over land

3. Food for thoughts

FESSTVaL

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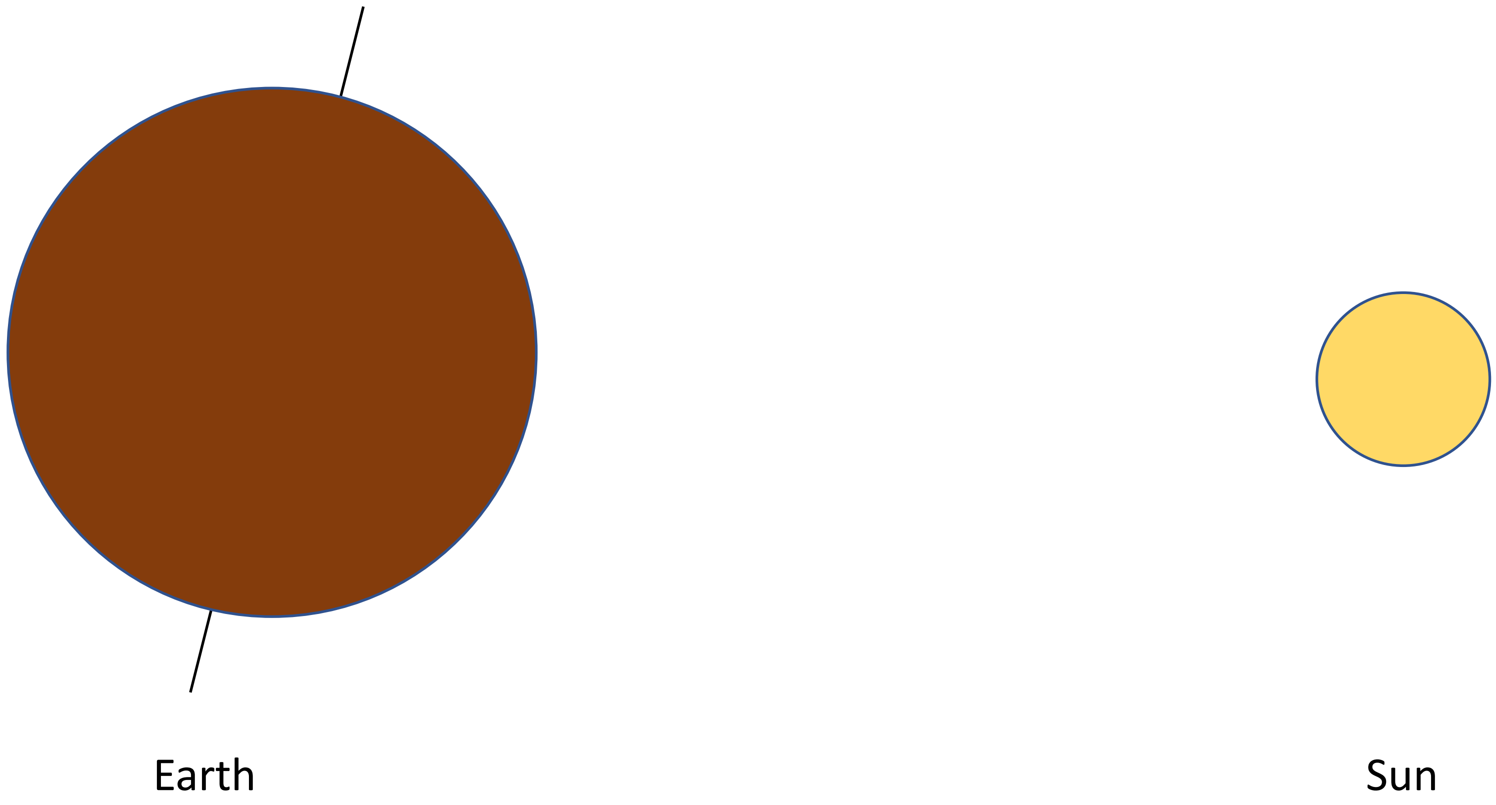
Imagine an Earth without convection….



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Imagine an Earth without convection….

July 1964 SYUKURO MANABE AND ROBERT F. STRICKLER 361

Thermal Equilibrium of the Atmosphere with a Convective Adjustment

Syukuro Manabe and Robert F. Strickler

General Circulation Research Laboratory, U. S. Weather Bureau, Washington, D. C.

(Manuscript received 19 December 1963, in revised form 13 April 1964)

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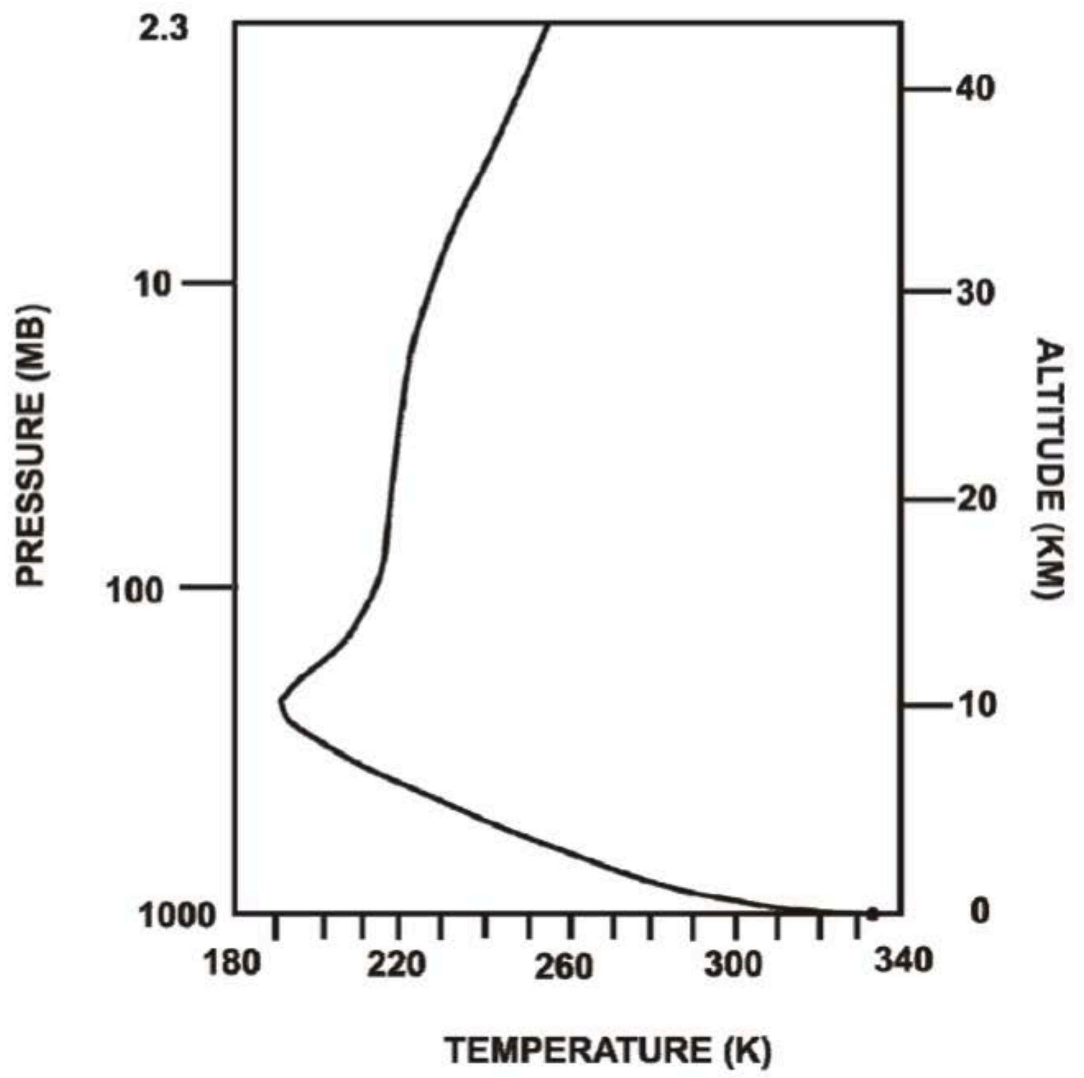
Imagine an Earth without convection….

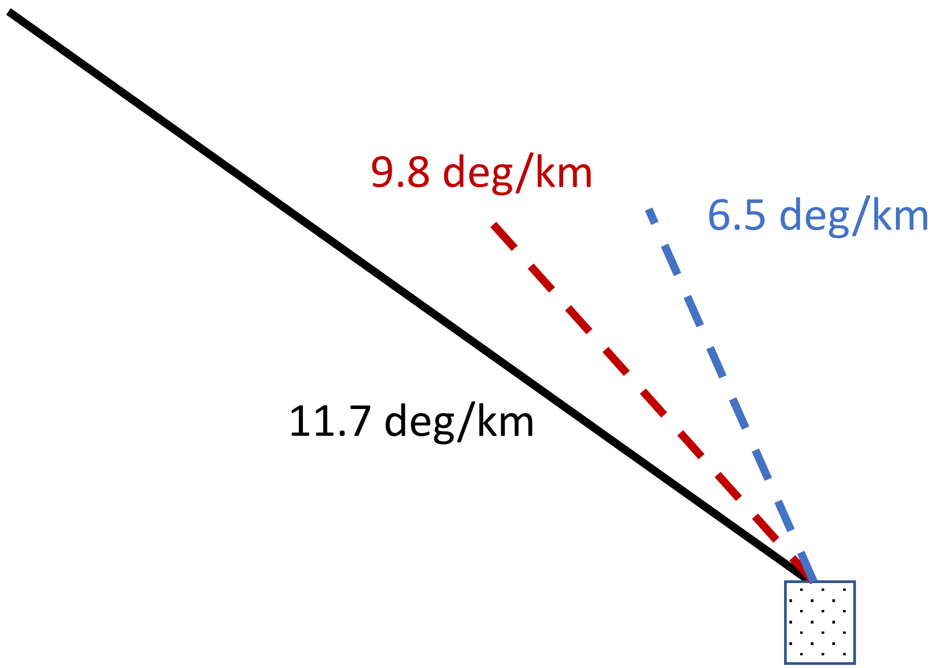
- Surface temperature too hot
- Tropopause temperature too cold
- Lapse rate: 11.7 deg/km



Manabe and Stickler (1964)

Imagine an Earth without convection….doesn‘t work physically!

- Parcel warmer than environment -> rises
- Atmosphere unstable and overturn
- Lapse rate cannot be larger than dry/moist adiabat lapse rate



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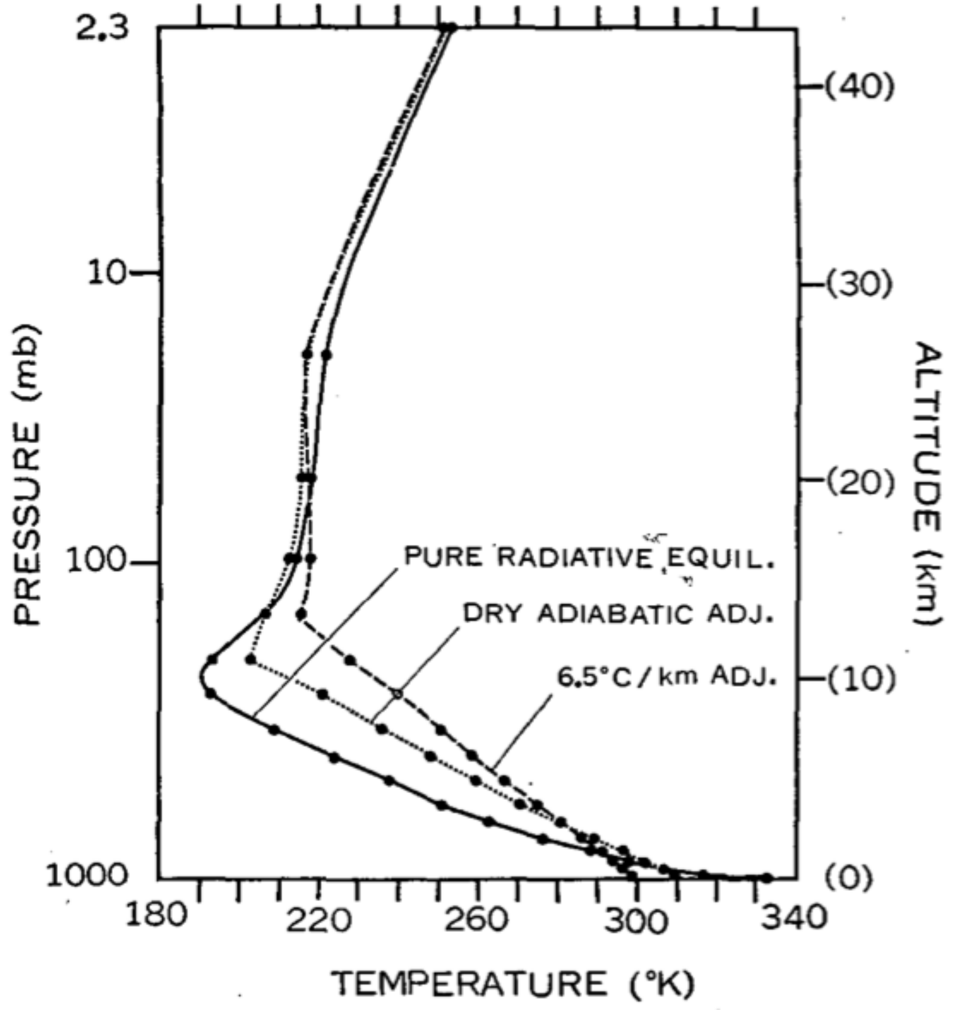
Radiative-convective equilibrium

- Radiation destabilizes the atmosphere
- Convection acts against it and stabilizes it
- Convection wins in the troposphere

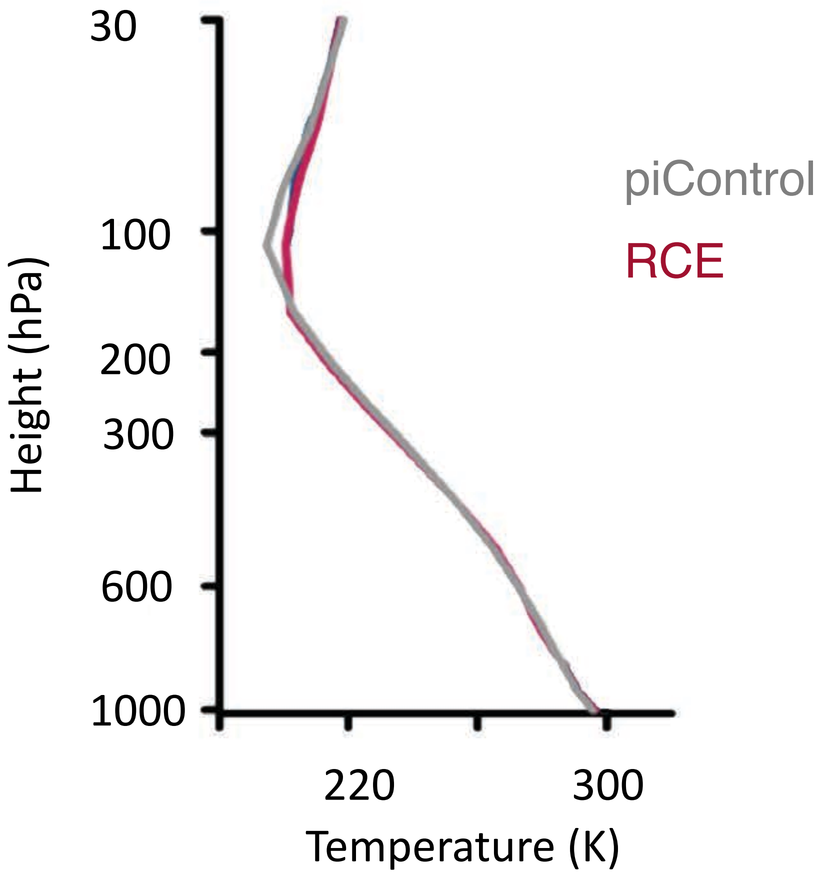


Manabe and Stickler (1964)

*Give **large-scale** constraints on convection*

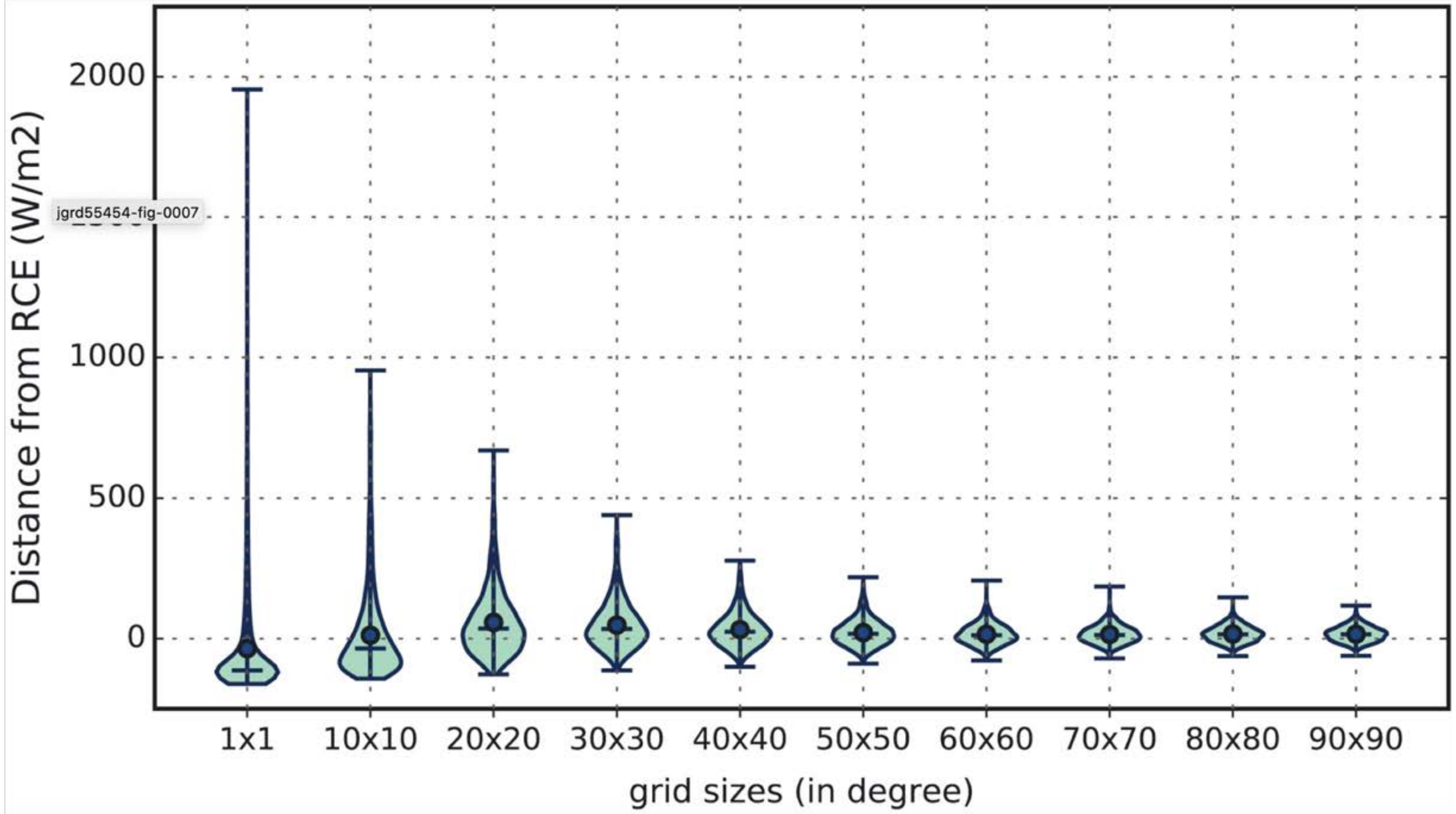
- Convection sets the mean temperature structure of the tropical atmosphere

- On the scale of the tropics, radiative cooling is compensating by latent heating from convection



Popke et al. (2013)

Give ***large-scale*** *constraints on convection*



Jakob, Singh and Jungandreas (2019)

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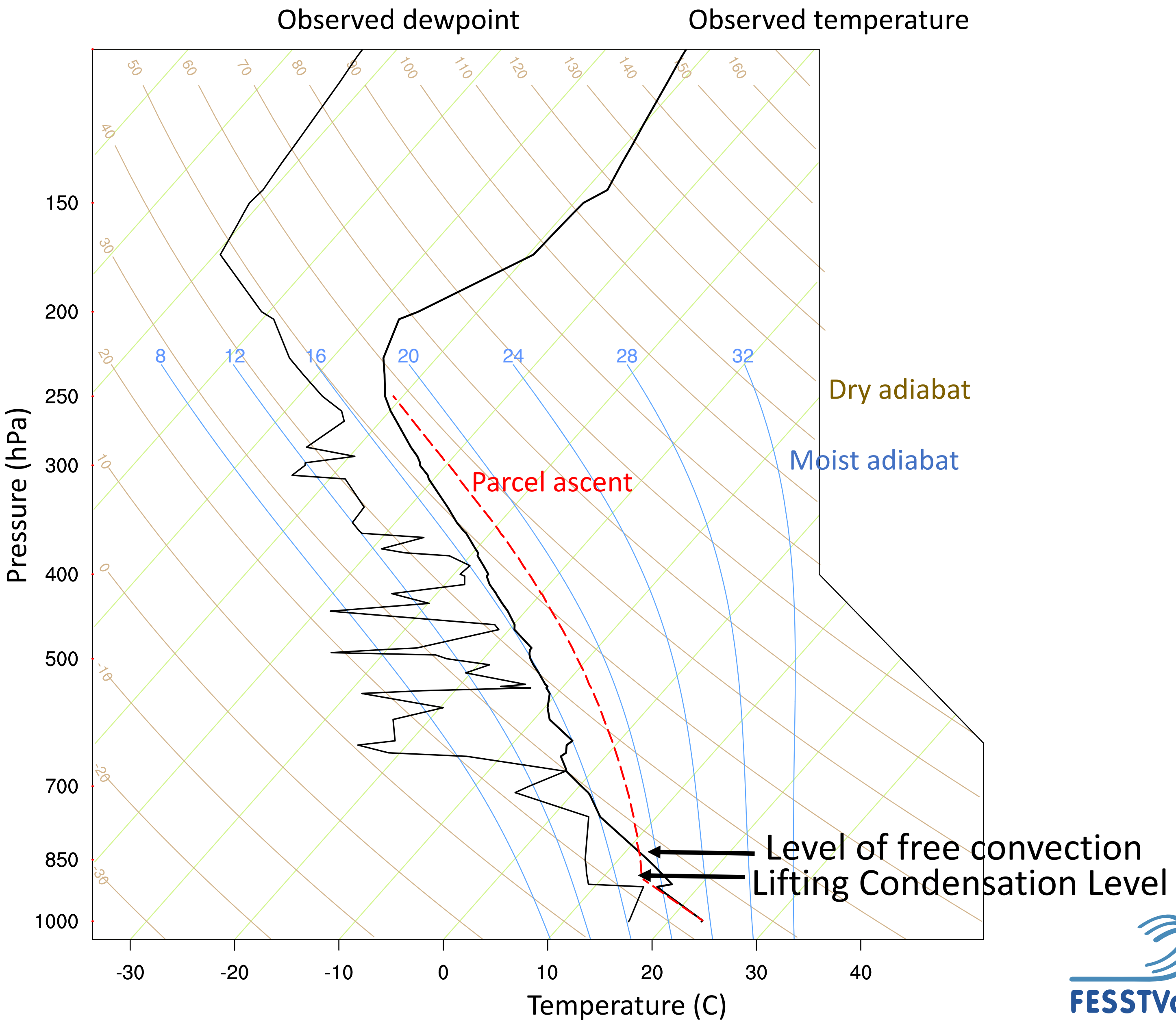
Convection arises because of instability caused by radiation

- As soon as unstable, convection
- Parcel view to check



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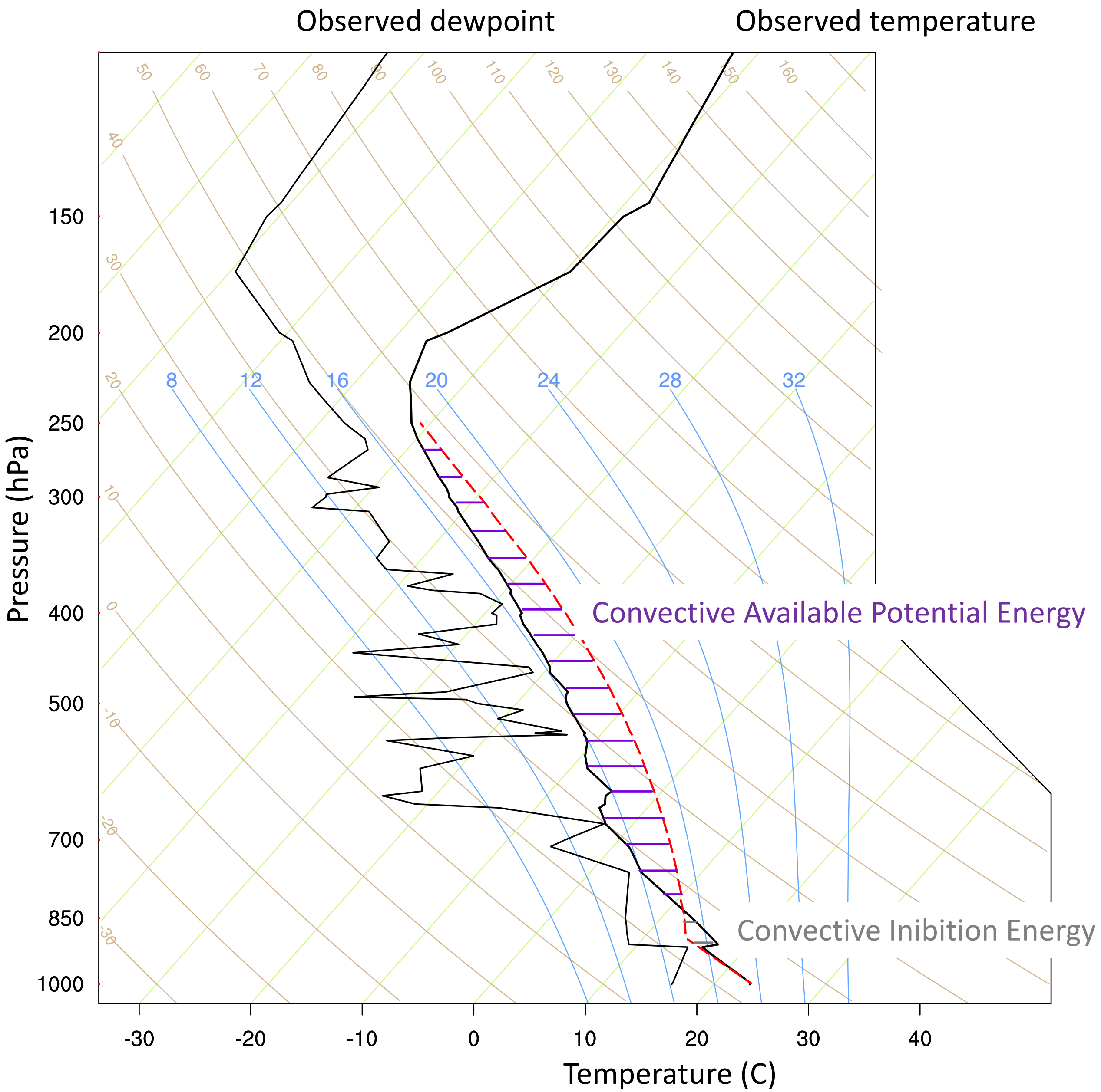
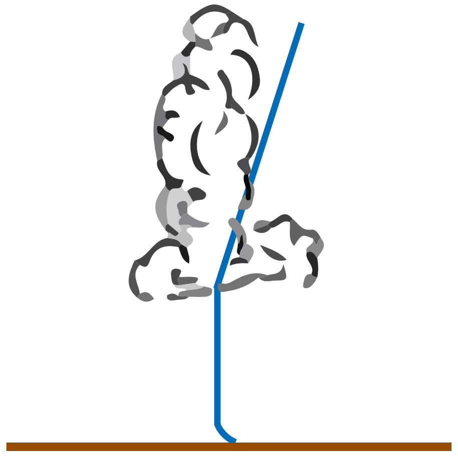
Convection arises because of instability caused by radiation

- As soon as unstable, convection
- Parcel view to check
- Instability indices

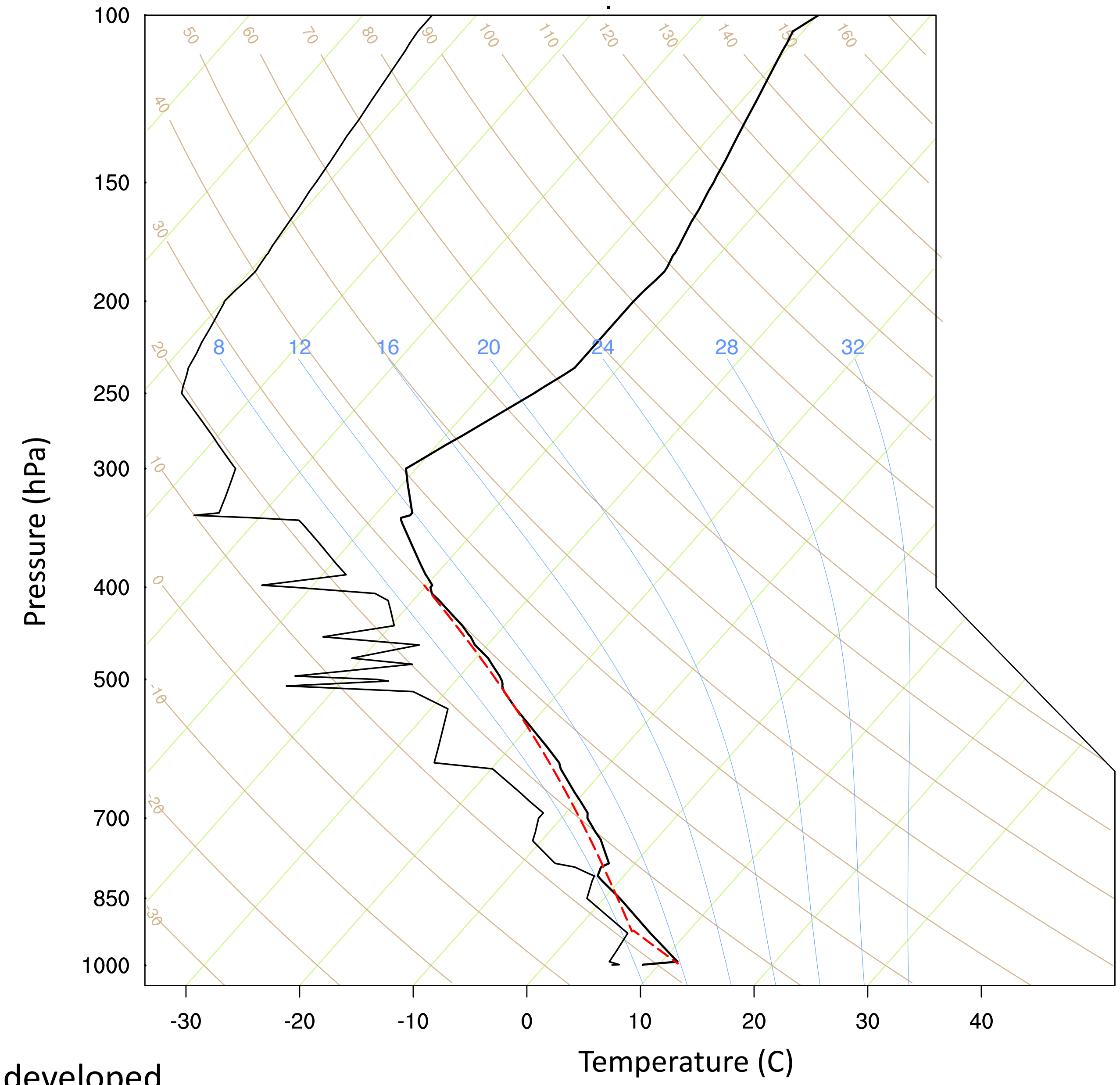


Summary thermodynamical view

- Convection triggered when profile unstable
- Column view
- Convection favored in unstable and moist atmospheres
- Large-scale constraint on precipitation amount



Pitfall 1: need to know the temperature profile



Skew-T plot 9 hour before local thunderstorm developed

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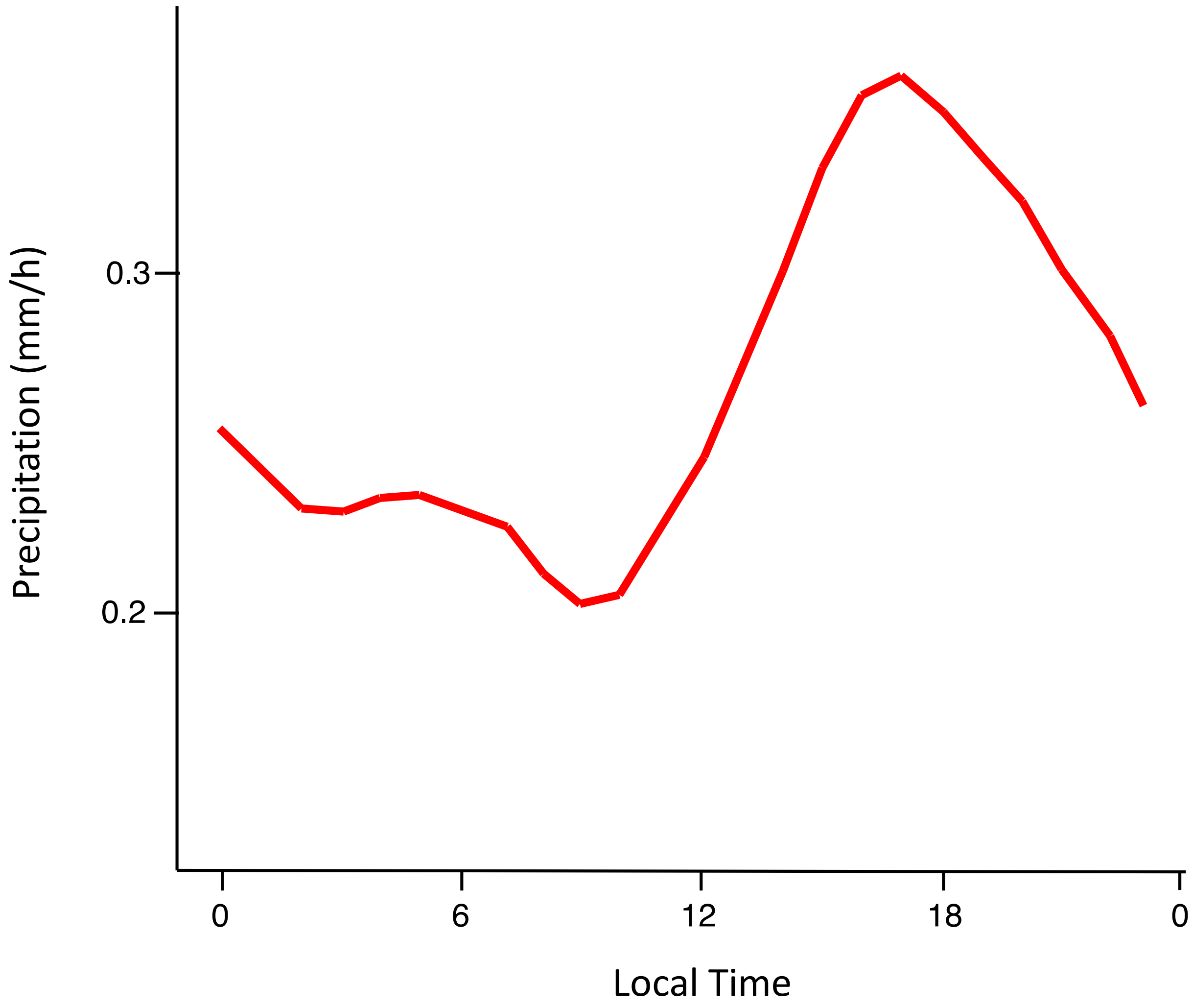
Pitfall 2: Diurnal cycle



After Ghada et al. (2019)

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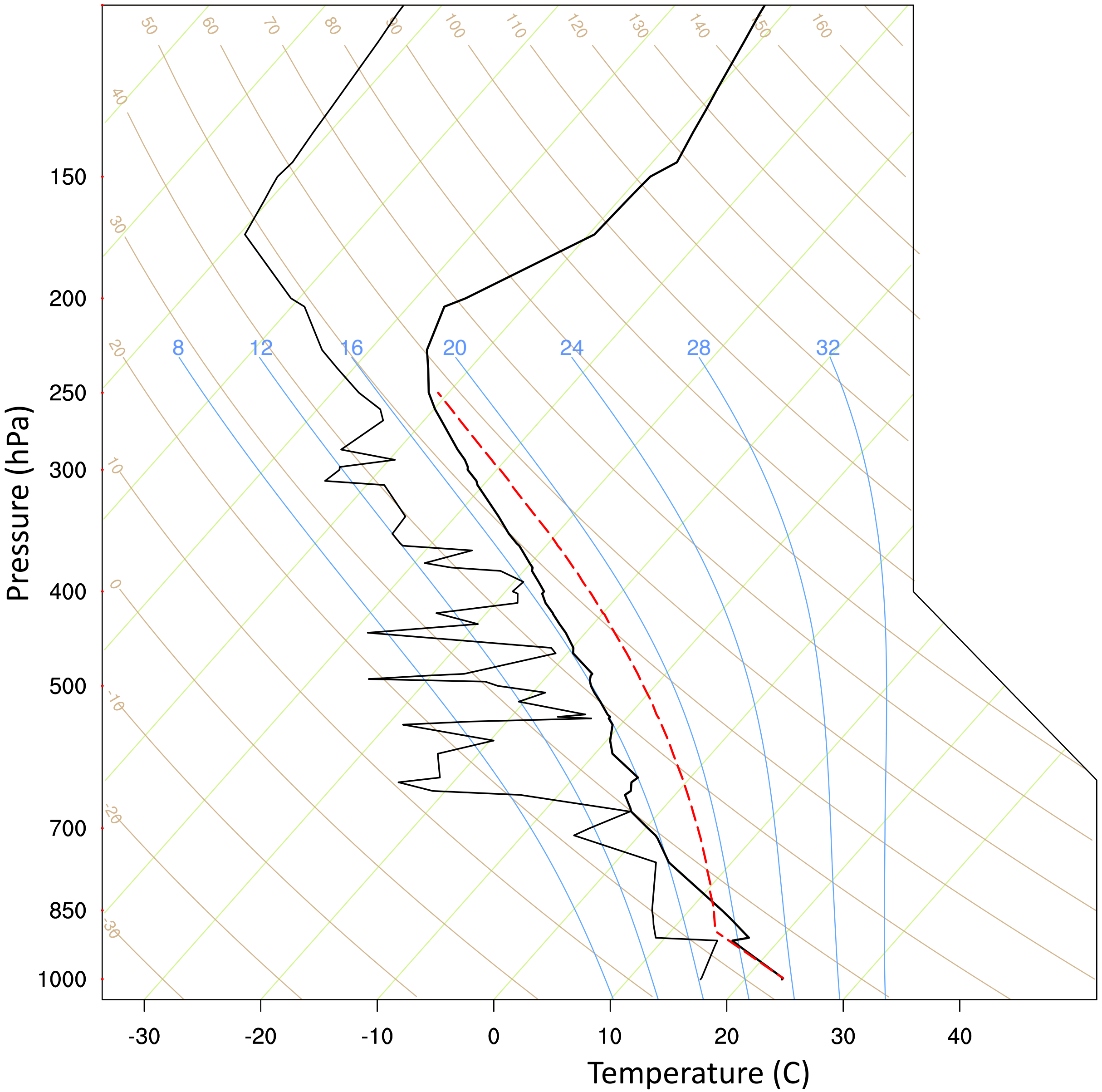
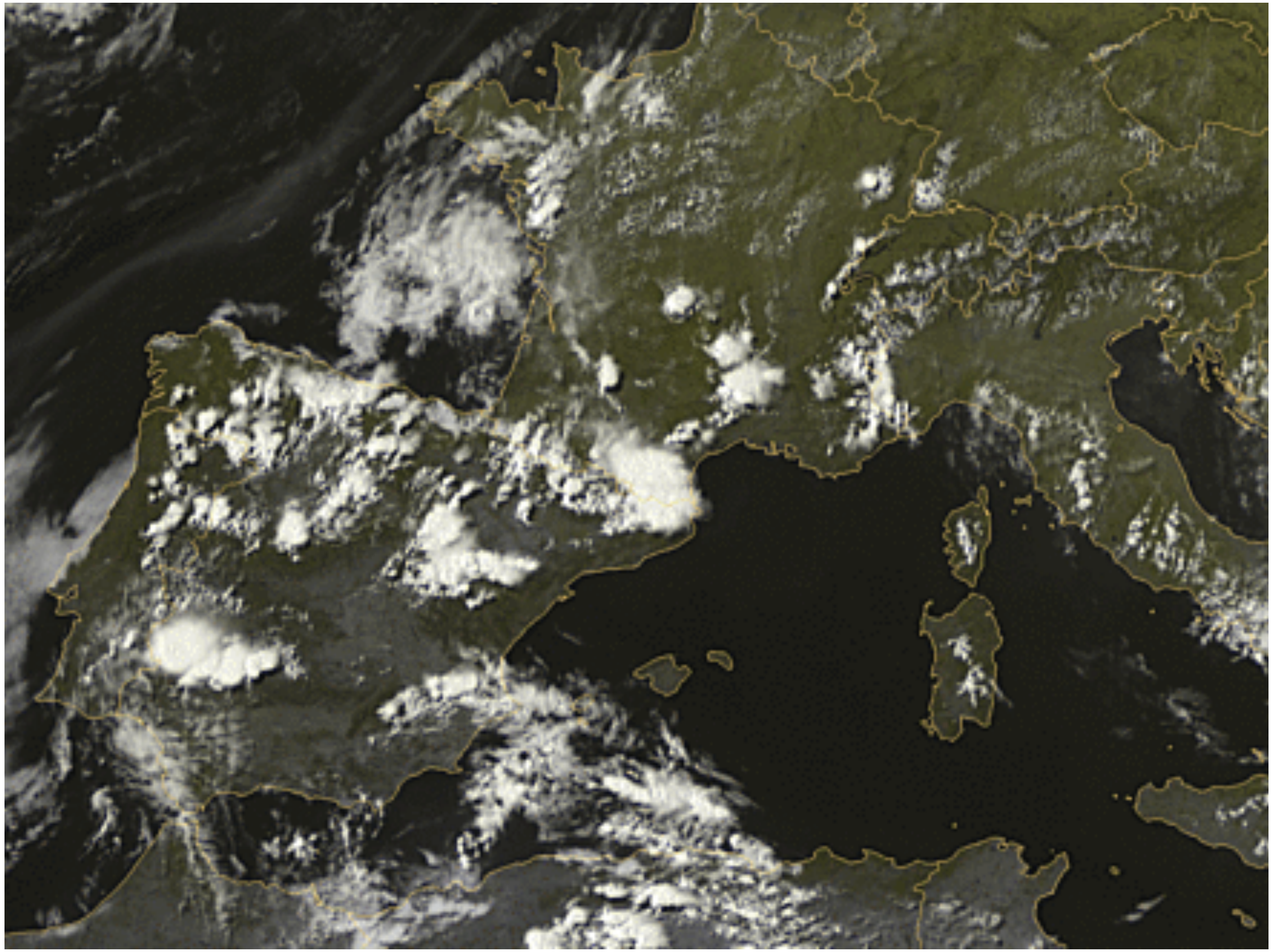
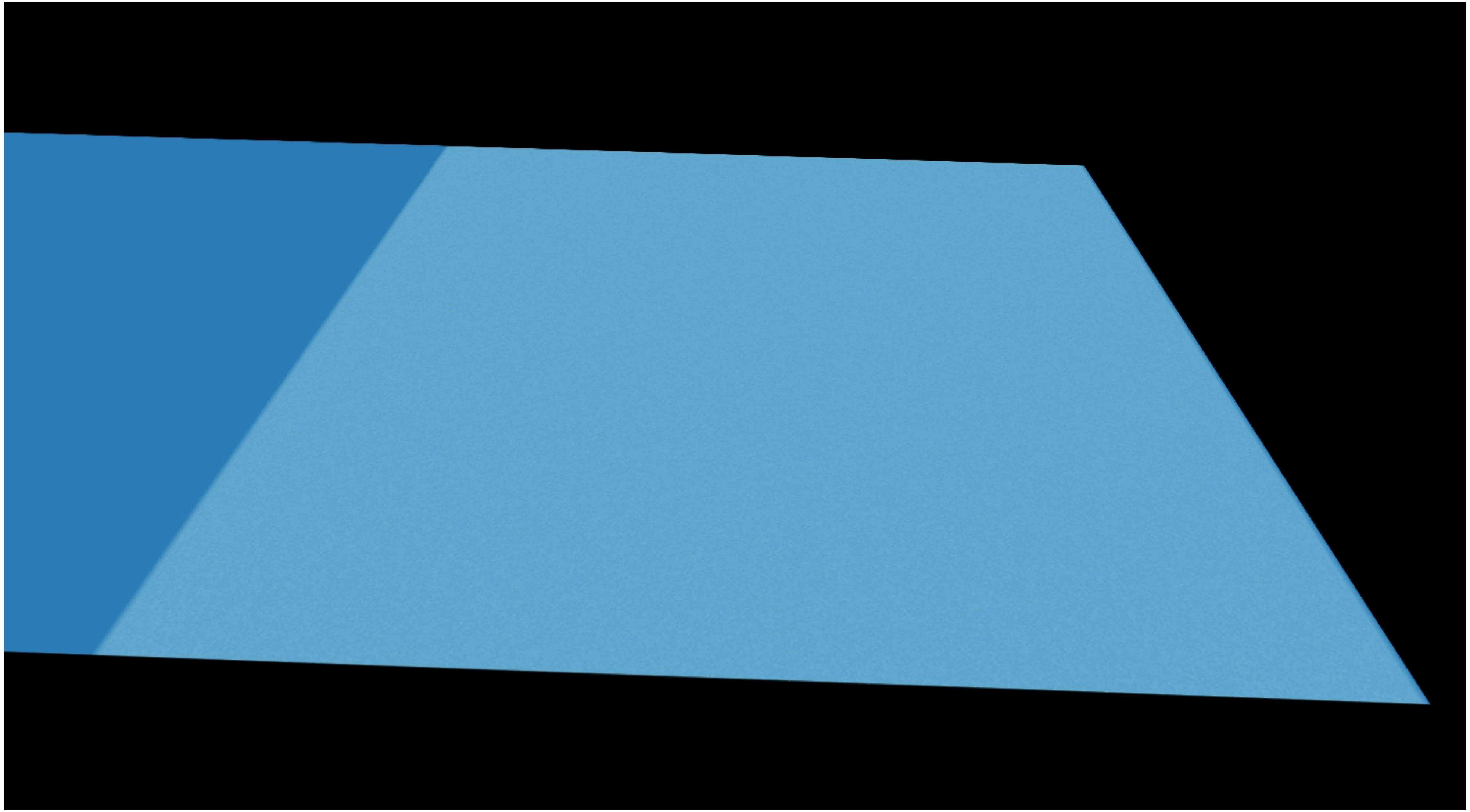
Forcing air to go up will also trigger convection



Forcing air to go up will also trigger convection: mountains



Forcing air to go up will also trigger convection: mesoscale circulation



Forcing air to go up will also trigger convection: large-scale circulation

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On the Relationship between SST Gradients, Boundary Layer Winds, and Convergence over the Tropical Oceans

LARISSA E. BACK

Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts

CHRISTOPHER S. BRETHERTON

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

Forcing air to go up will also trigger convection: large-scale circulation

Temperature gradient

↓

Pressure gradient

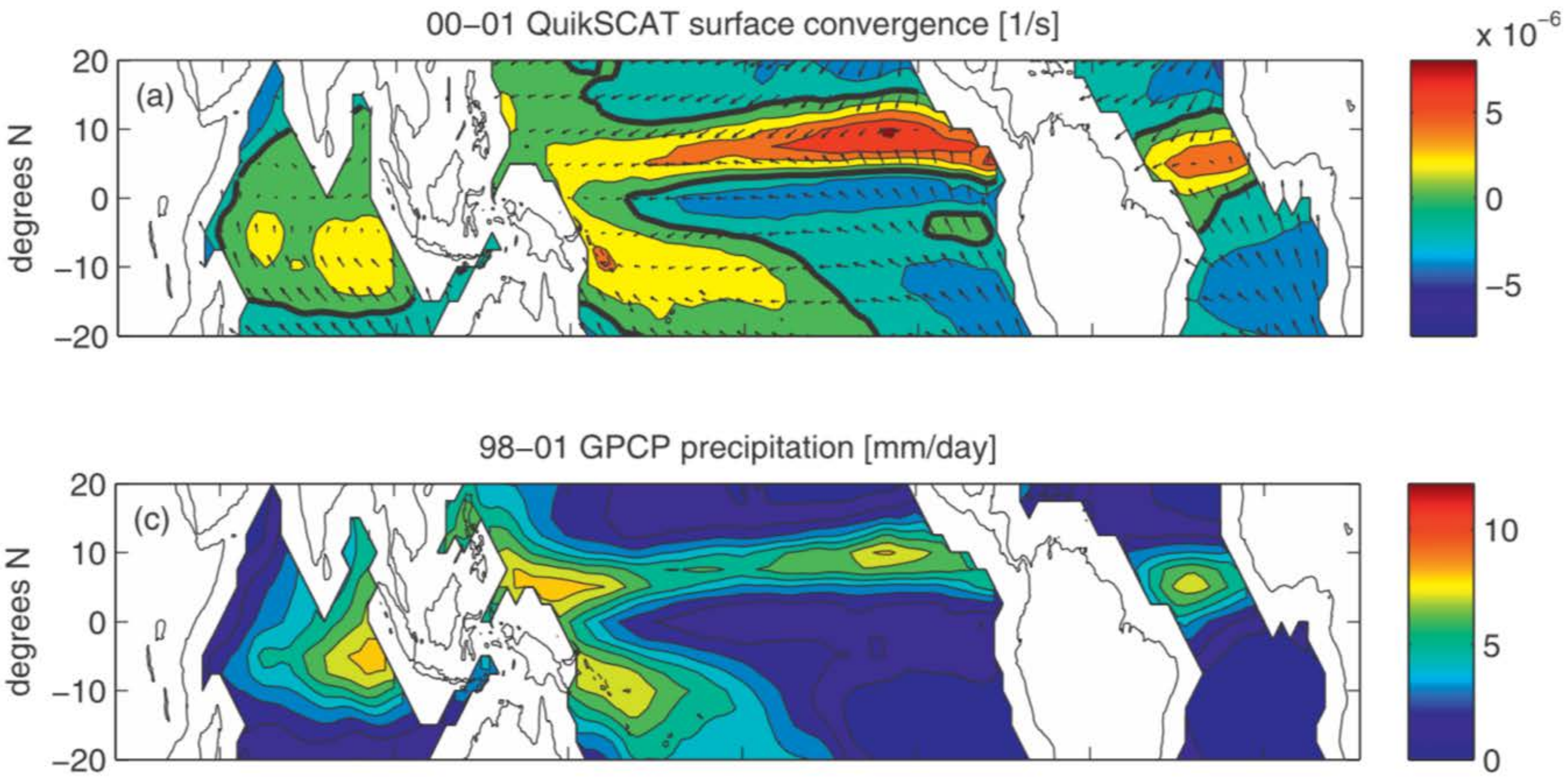
↓

Wind

Wind convergence

↓

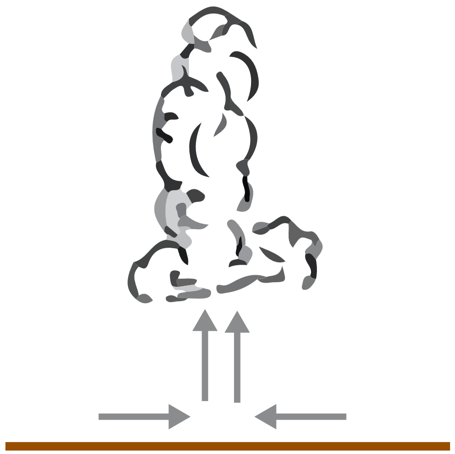
Ascent



Back and Bretherton (2009)

Summary dynamical view

- Convection triggered by forced vertical ascent
- Horizontal view
- Horizontal heterogeneity needed



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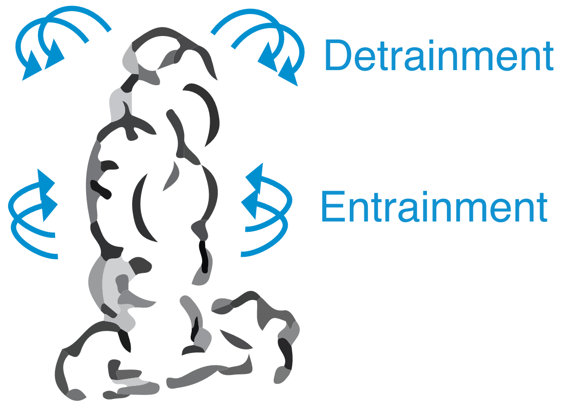
Who is the devil?

Who is the devil?

Convection!

Thermodynamic effect: Convective clouds moisten their near-by environment

- Convective clouds entrain cold and dry environmental air
- Leads to evaporation of cloud water
- Non-buoyant air is detrained in the environment and moistens it



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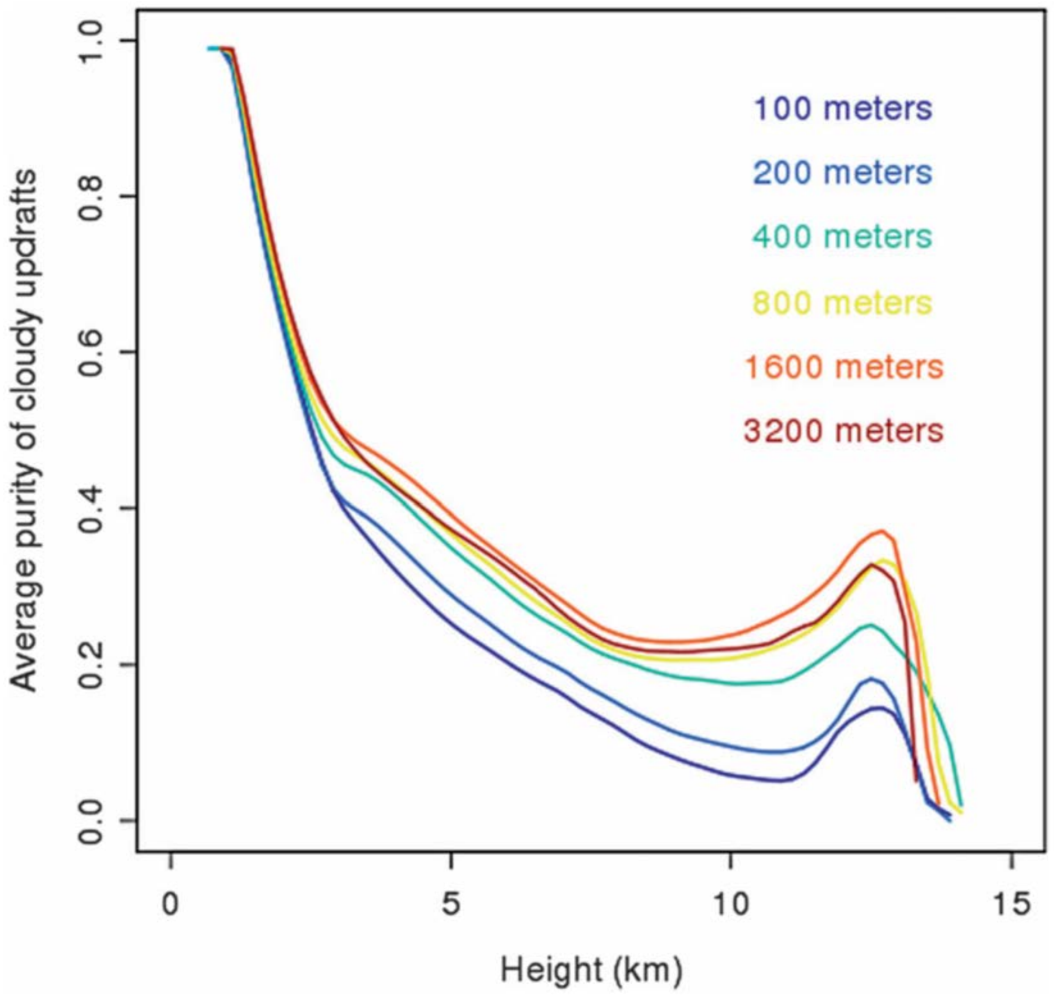
Do undiluted updrafts exist?

- Not over tropical ocean
- But observed in severe convective storms over land



Romps and Kuang (2009)

Convection and environmental humidity

Q. J. R. Meteorol. Soc. (2004), **130**, pp. 3055–3079 doi: 10.1256/qj.03.130

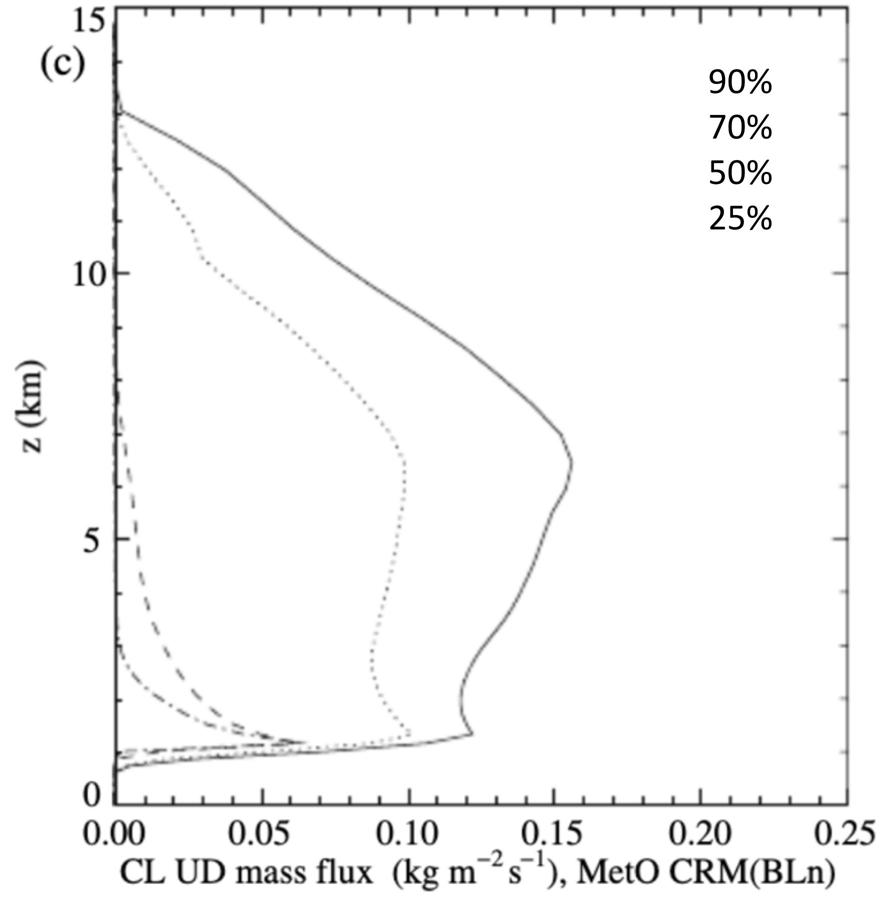
Sensitivity of moist convection to environmental humidity

By S. H. DERBYSHIRE[1]*, I. BEAU[2], P. BECHTOLD[3,4], J.-Y. GRANDPEIX[5], J.-M. PIRIOU[6], J.-L. REDELSPERGER[6] and P. M. M. SOARES[7,8]

[1] *Met Office, Exeter, UK*
[2] *Météo-France/ENM, Toulouse, France*
[3] *Observatoire Midi-Pyrénées, Toulouse, France*
[4] *European Centre for Medium-Range Weather Forecasts, Reading, UK*
[5] *Laboratoire de Météorologie Dynamique, Paris, France*
[6] *Météo-France/CNRM, Toulouse, France*
[7] *Instituto Superior de Engenharia de Lisboa, Portugal*
[8] *Centro de Geofisica da Universidade de Lisboa, Portugal*

Moisture-convection feedback

- Convection doesn‘t like dry atmosphere
- Convection moistens its nearby environment
- Moisture-convection feedback (see also Grabowsky and Moncrieff 2004)
- Chicken and egg problem….



Derbyshire et al. (2004)

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Dynamical effect: Convection induces its own circulation

Quart. J. R. Met. Soc. (1980), **106**, pp. 447–462

551.513.2:551.515.51

Some simple solutions for heat-induced tropical circulation

By A. E. GILL
Department of Applied Mathematics and Theoretical Physics,
University of Cambridge

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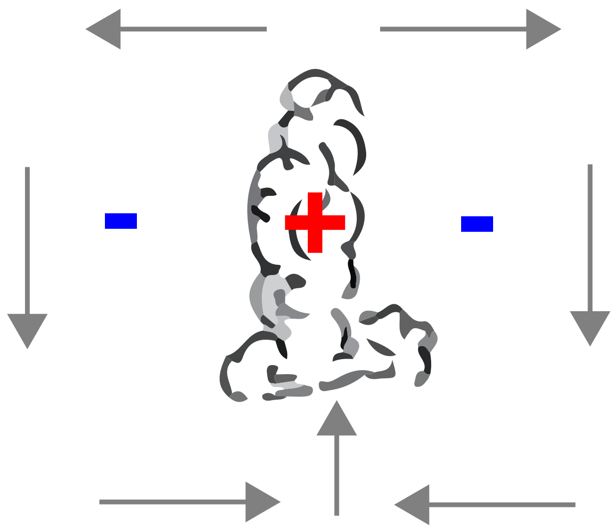
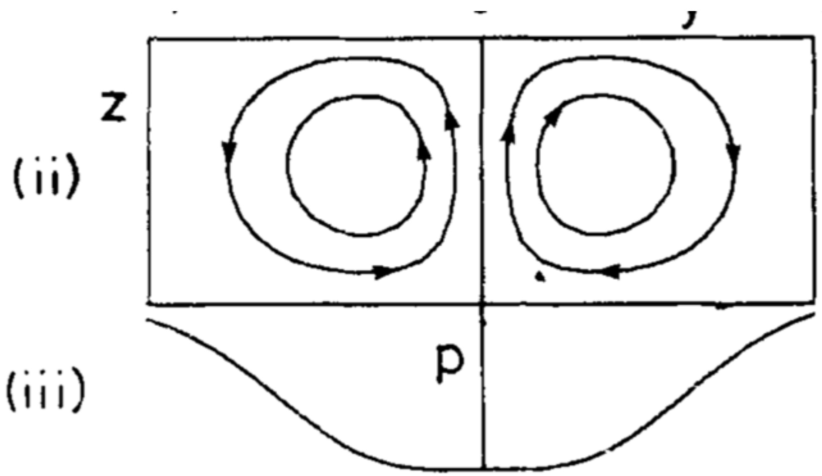
Dynamical effect: Convection induces its own circulation

- Latent heating from condensation generates deep heating
- Deep heating generates circulation
- Note: in deep convection, latent heating from condensation dominates over other heating sources
- Chicke and egg problem again….

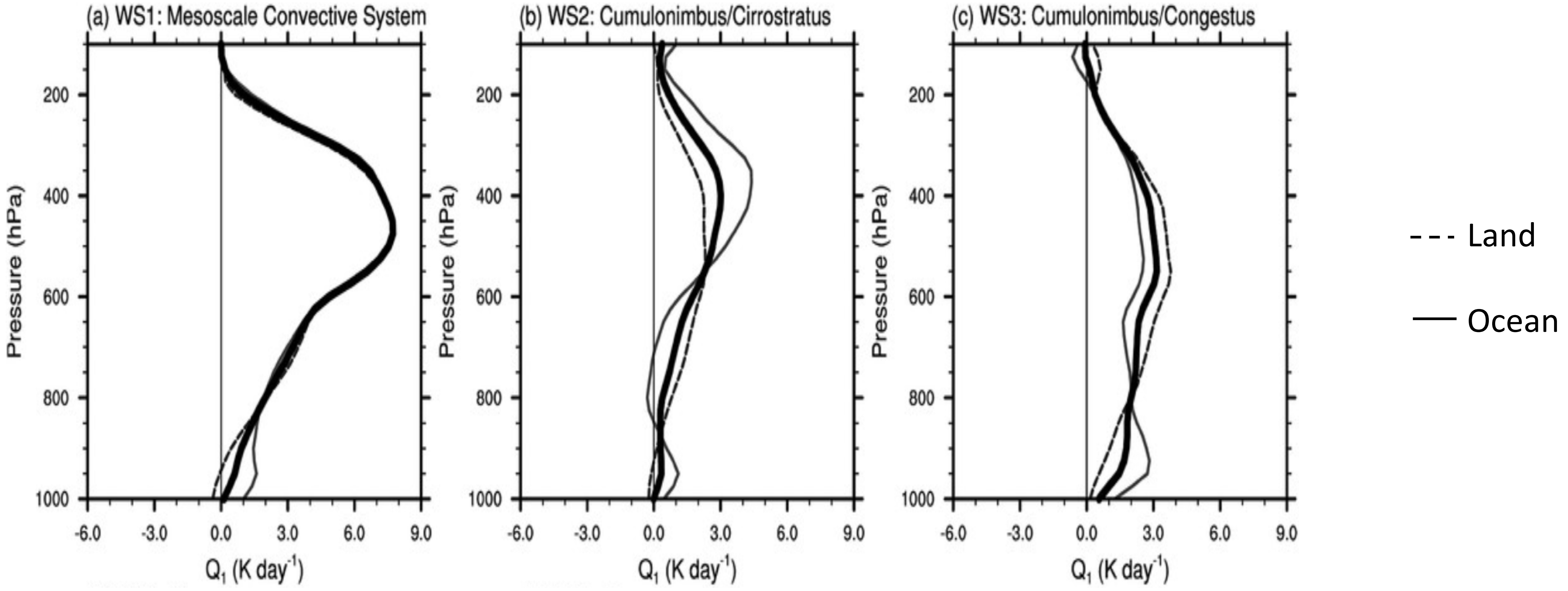




Gill (1980)

Zonally integrated solution

Observed heating profiles



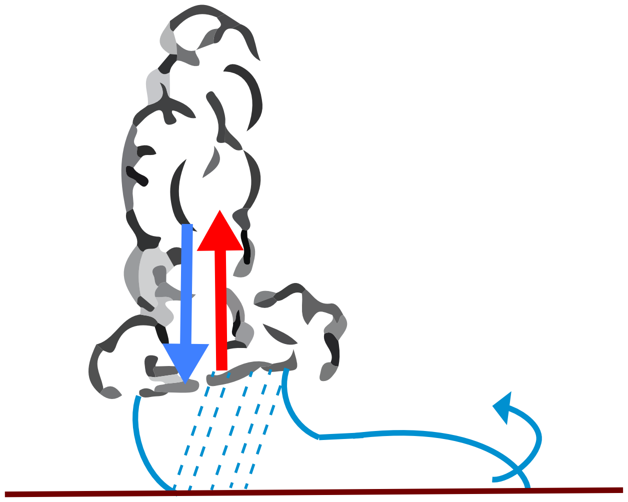
Stachnik et al. (2013)

Convection also induces convective outflows in the boundary layer

- Melting of ice and snow and evaporation of precipitation generate non-buoyant air that sinks through the cloud

- Drag from droplet

- Outflow spreads at the surface as a density current, called cold pool



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Processes happen on different scales!

Reviews of Geophysics

Free Access

Mesoscale convective systems

Robert A. Houze Jr.

First published: 31 December 2004 | https://doi.org/10.1029/2004RG000150 | Citations: 668

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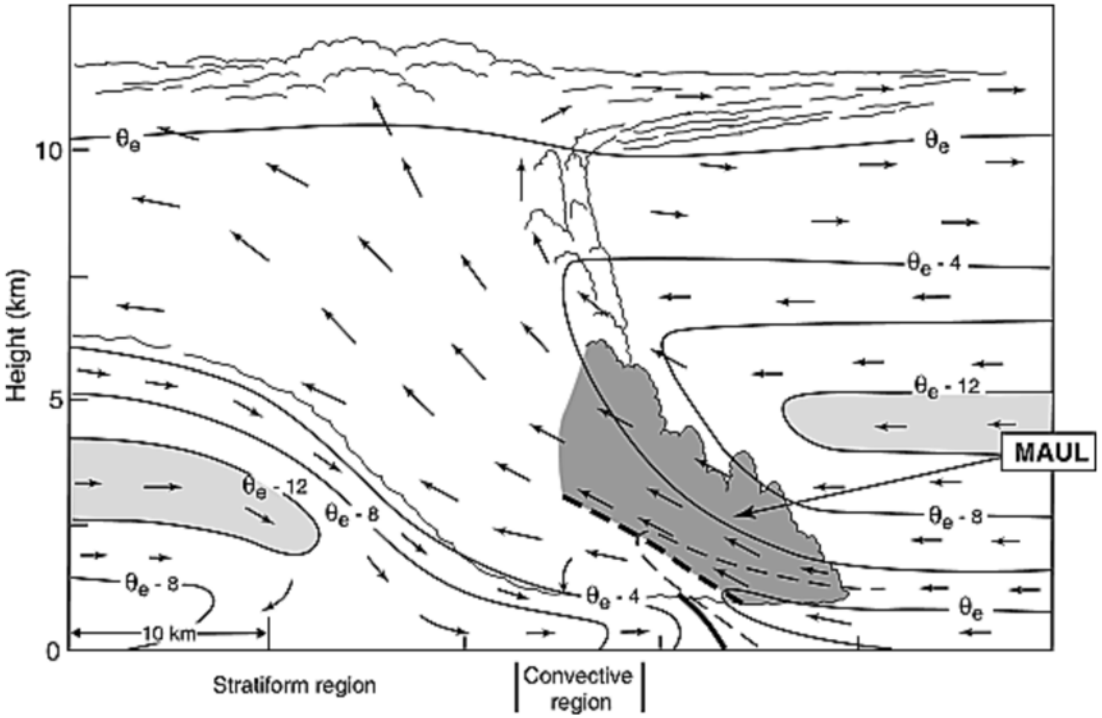
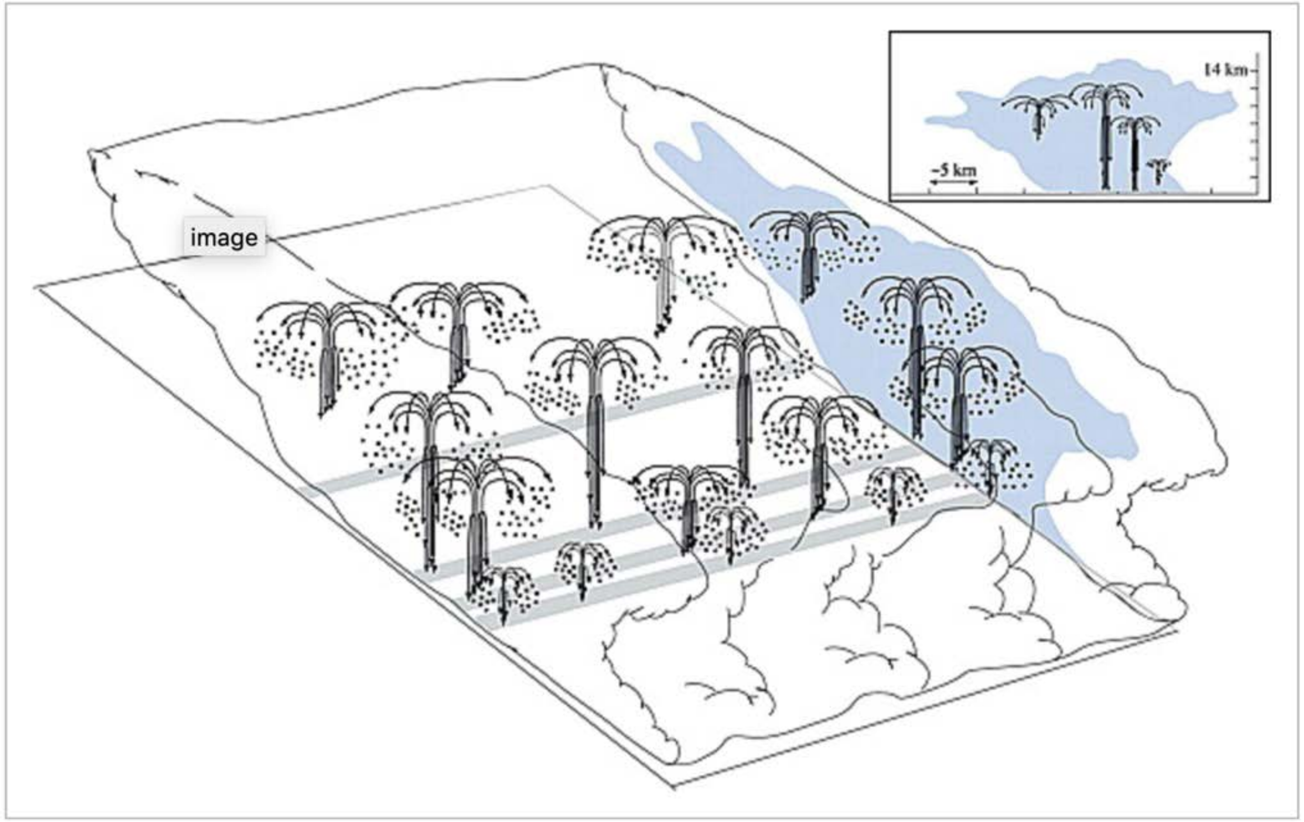
Processes happen on different scales!





Houze (2004)

Summary the devil messes it up

- Convection is the devil
- Thermodynamic: convection likes moist atmosphere but convection also moistens its near-by environment
- Dynamic: convection is triggered by circulation but convection generates its own circulation (deep heating + cold pools)

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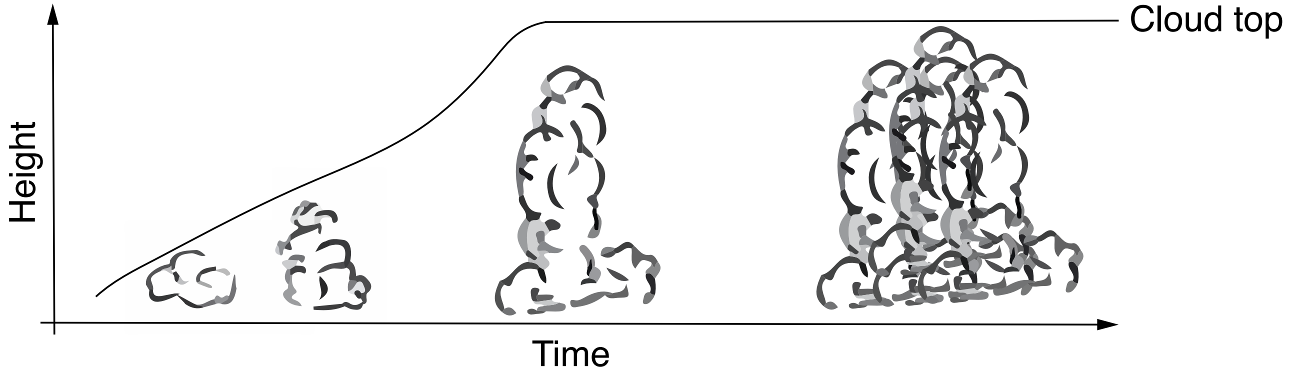
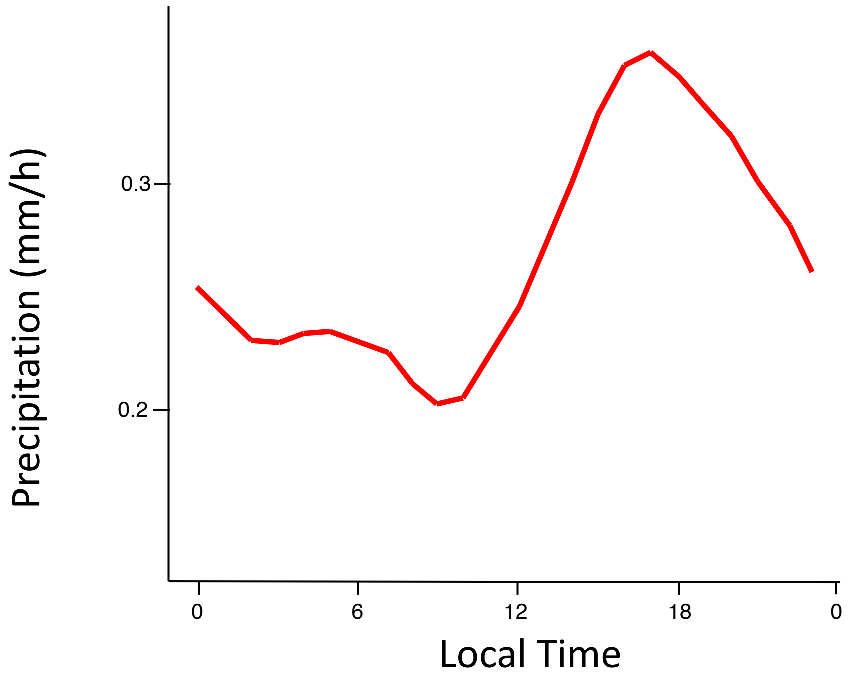
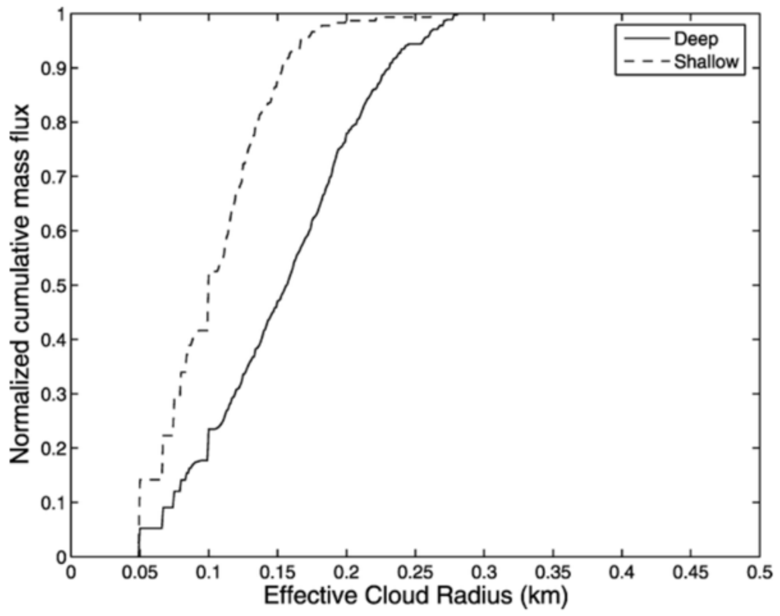
The diurnal cycle of convection over land





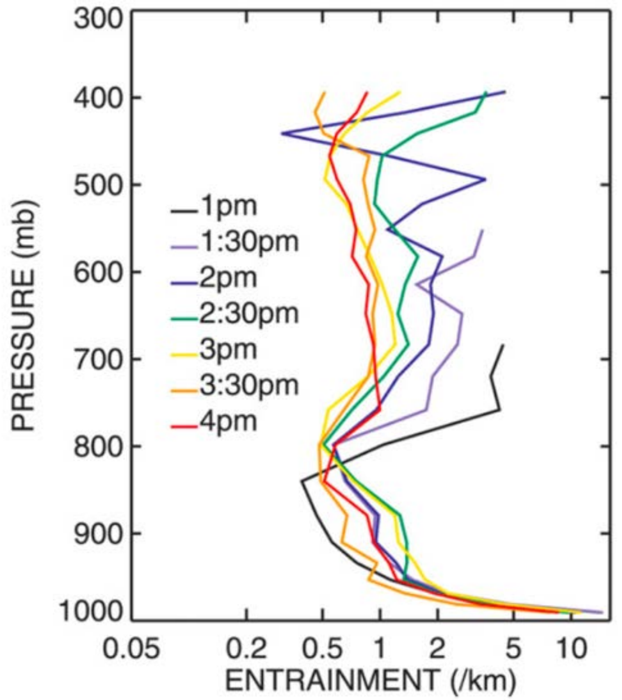
Idea 1: Changes in cloud morphology during the transition

- Grow wider



Kuang and Bretherton (2009)

- Entrain less



Del Genio and Wu (2010)

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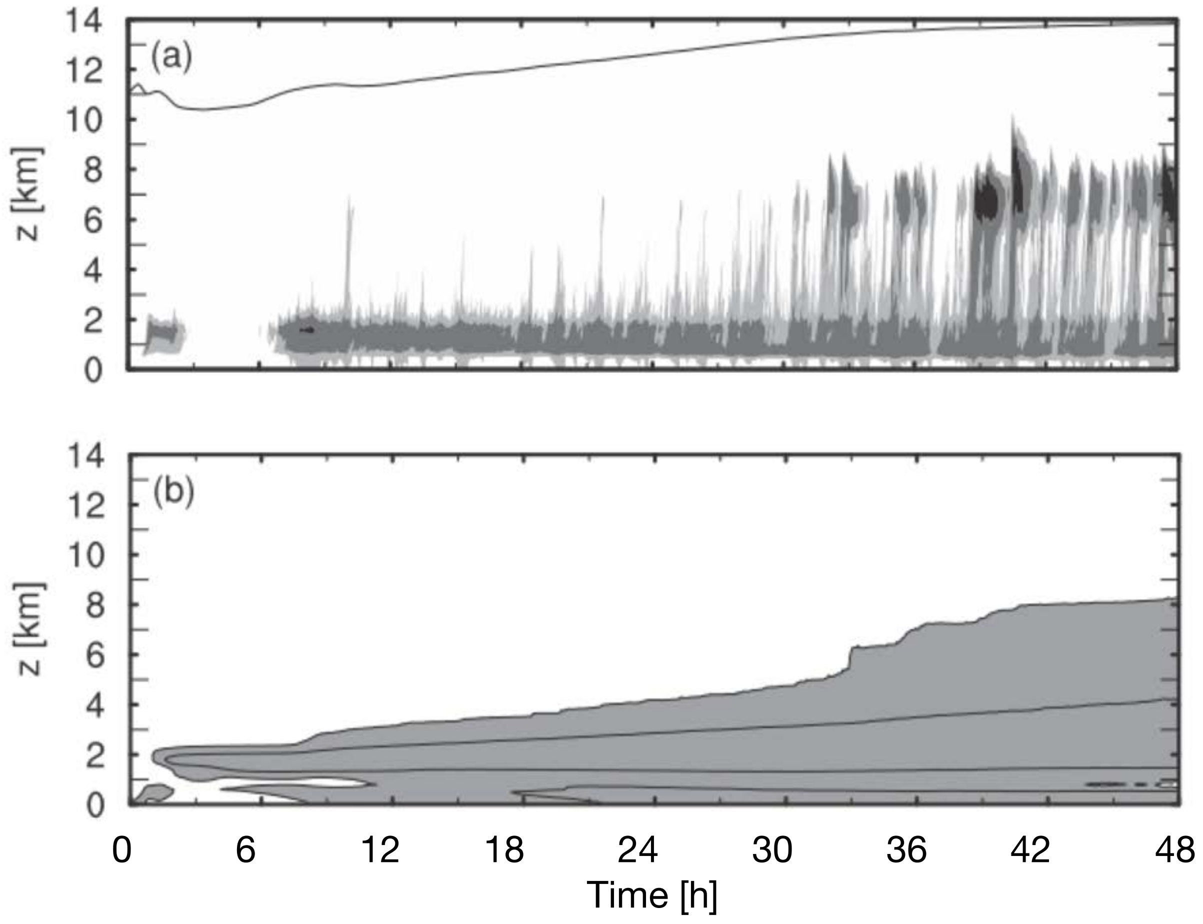
Idea 2: Preconditioning: thermodynamical view

- When the moistening by previous clouds has moistened the atmosphere enough



Condensates

Humidity deviation

Waite and Khouider (2010)

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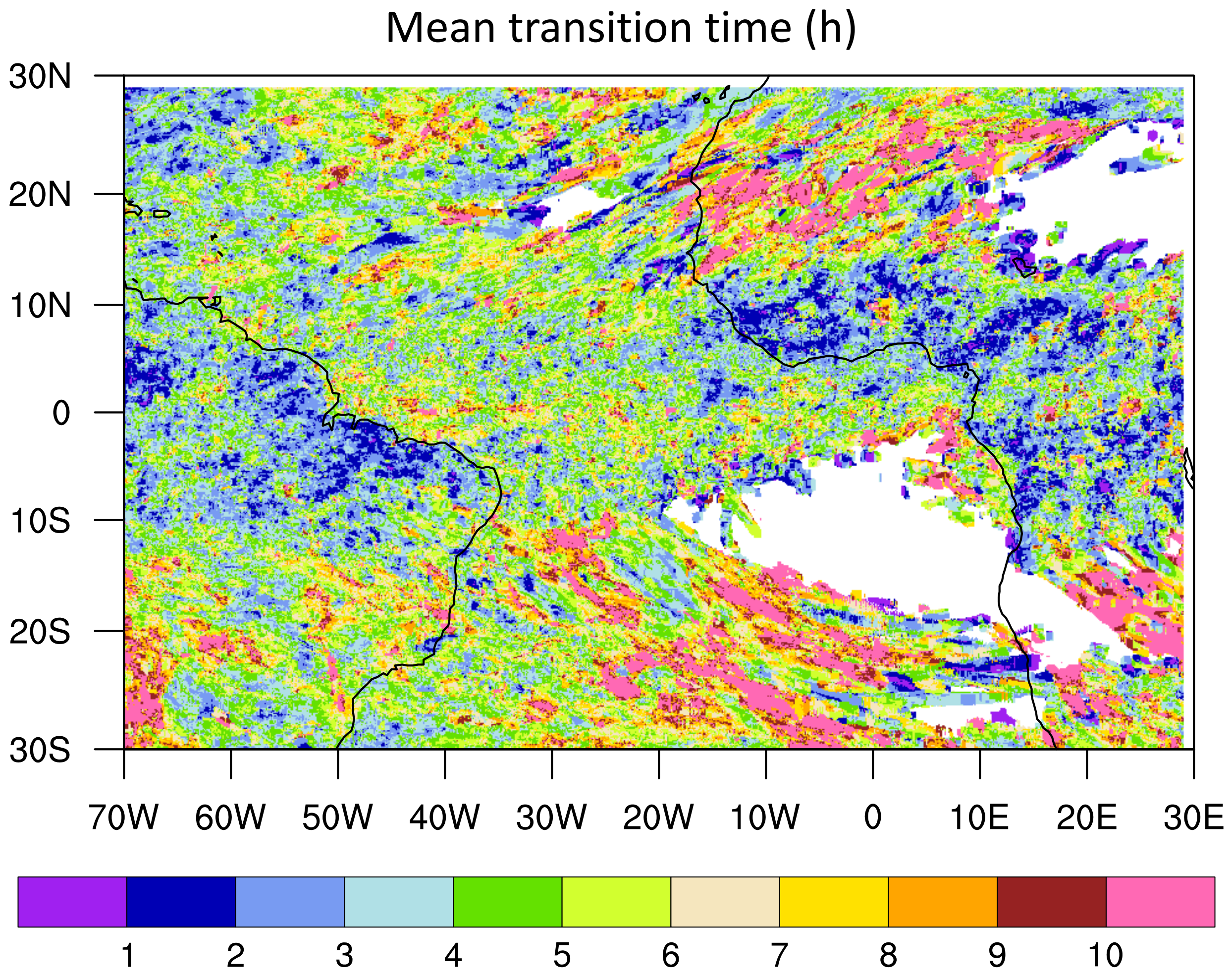
Idea 3: Preconditioning: thermodynamical view

- Mean transition time is 2 h over land
- Preconditioning likely too slow, needs dynamical forcing



Hohenegger and Stevens (2013)

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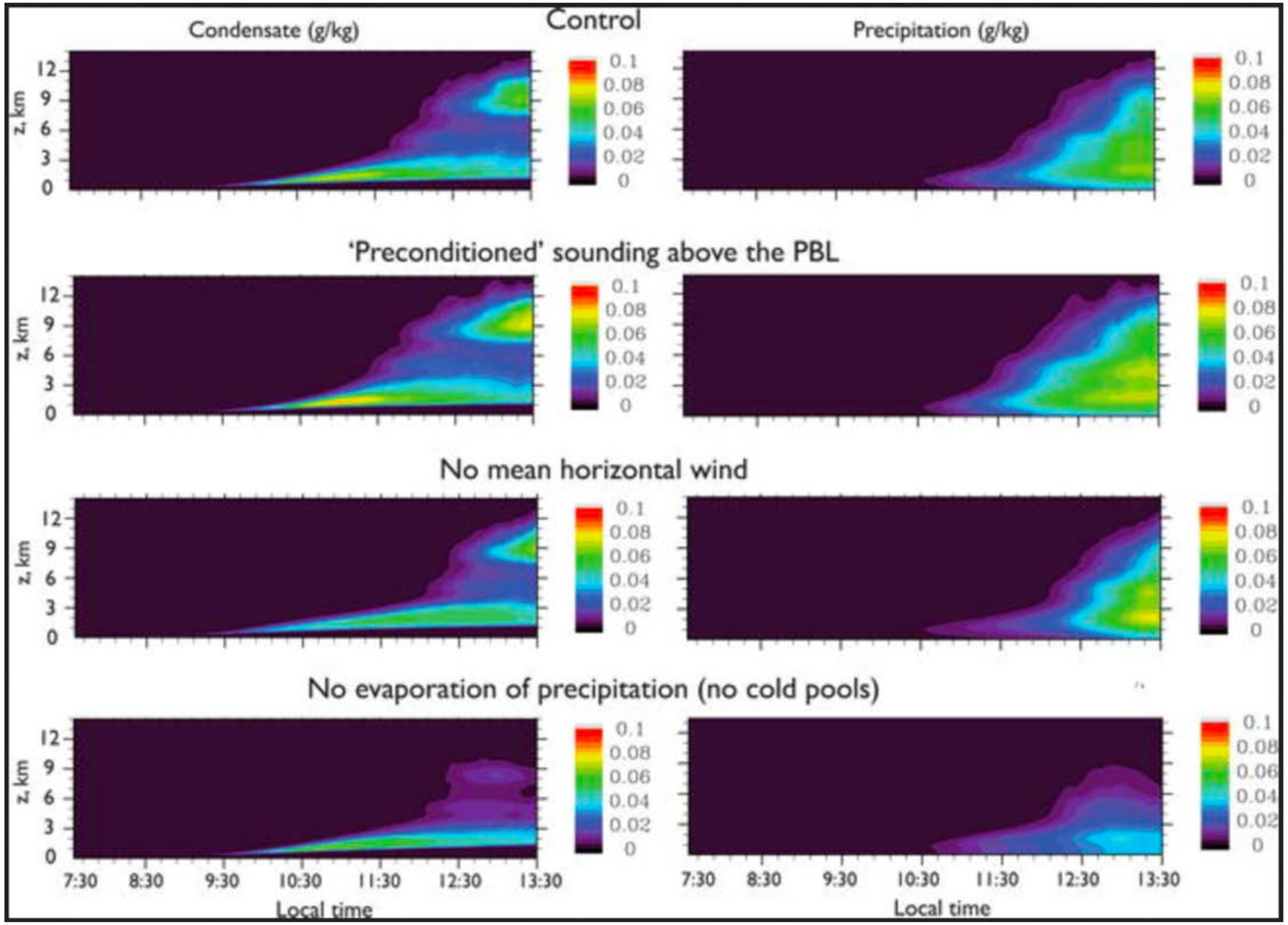
Idea 3: Cold pools: dynamical view

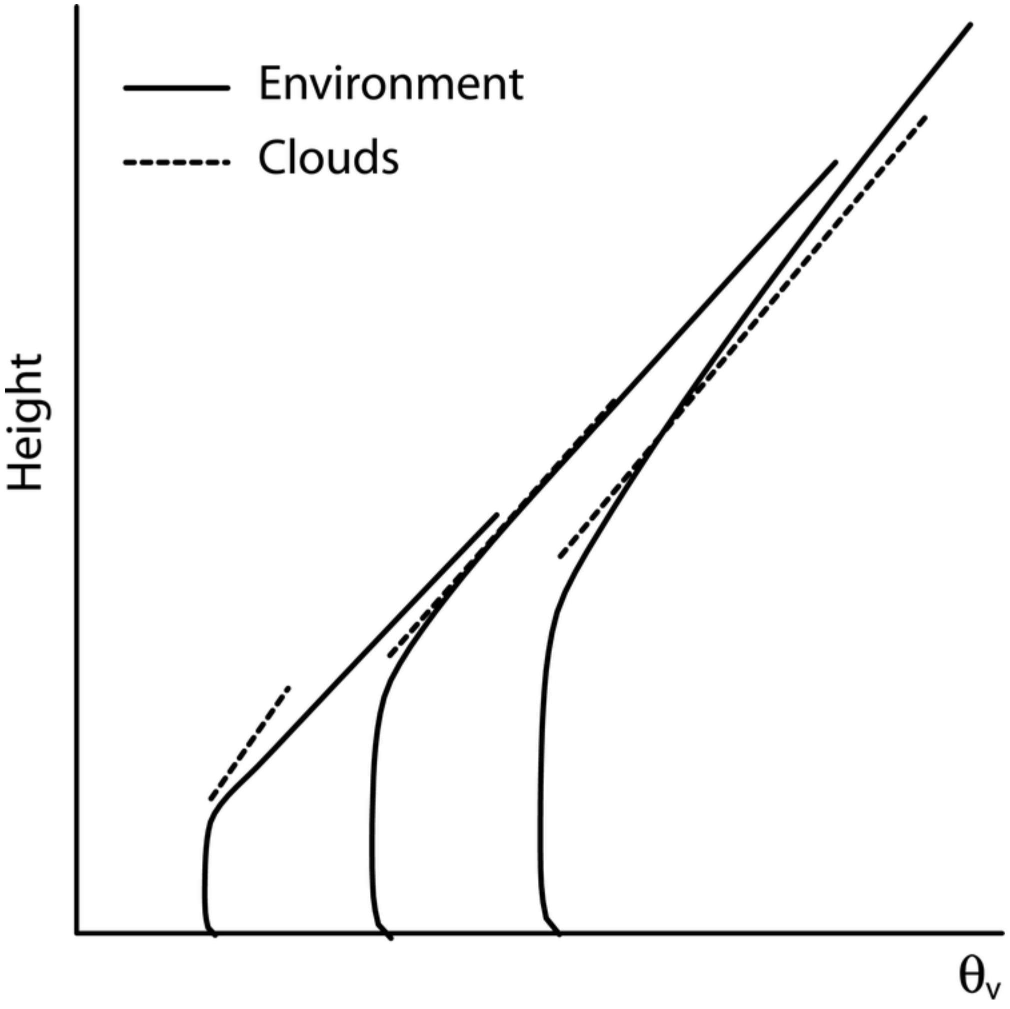
- When cold pools form



Khairoutdinov and Randall (2006)

Idea 4: Instability: thermodynamical view

- When the lapse rate temperature of the clouds become larger than the environment



Wu, Stevens and Arakawa (2009)

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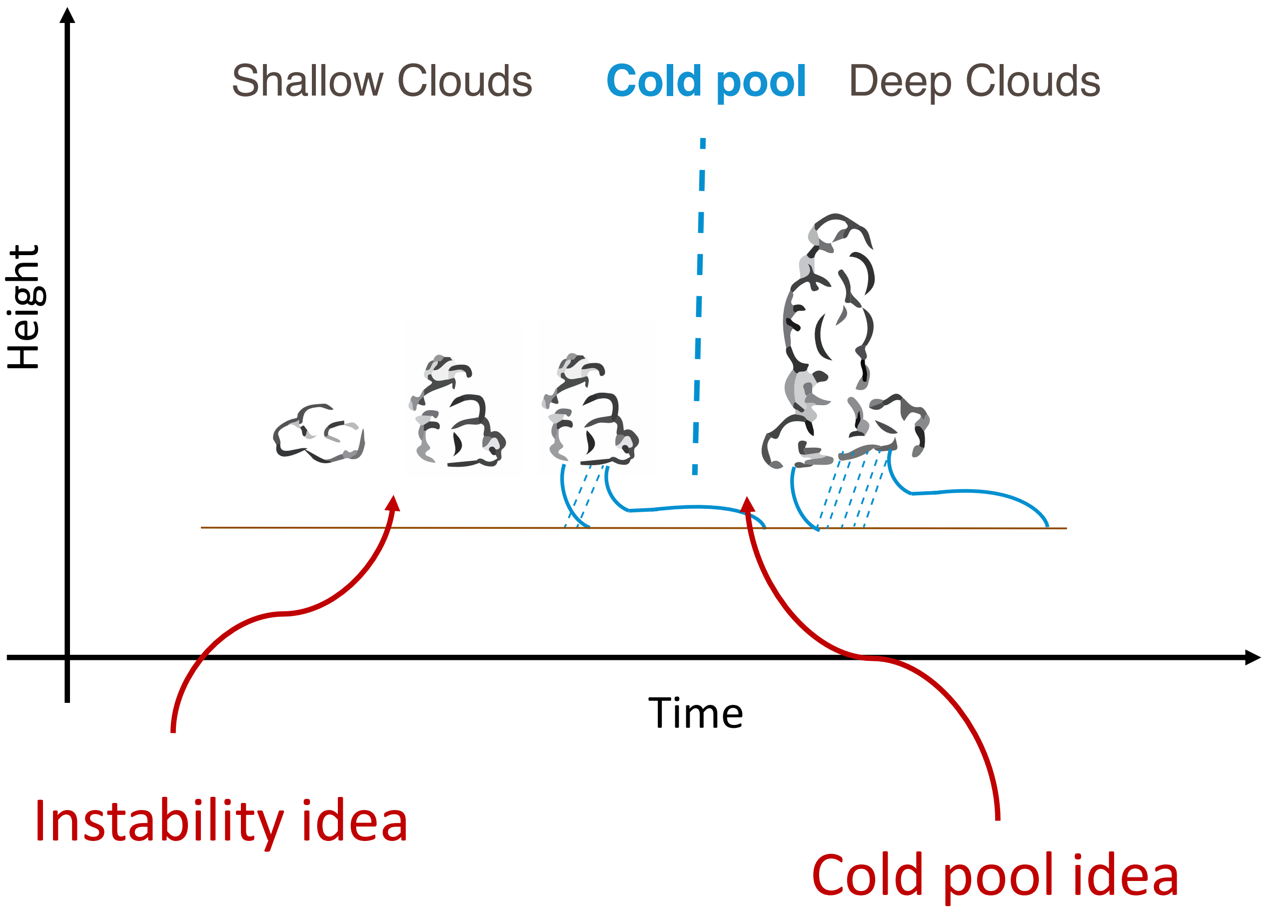
So what control the transition?



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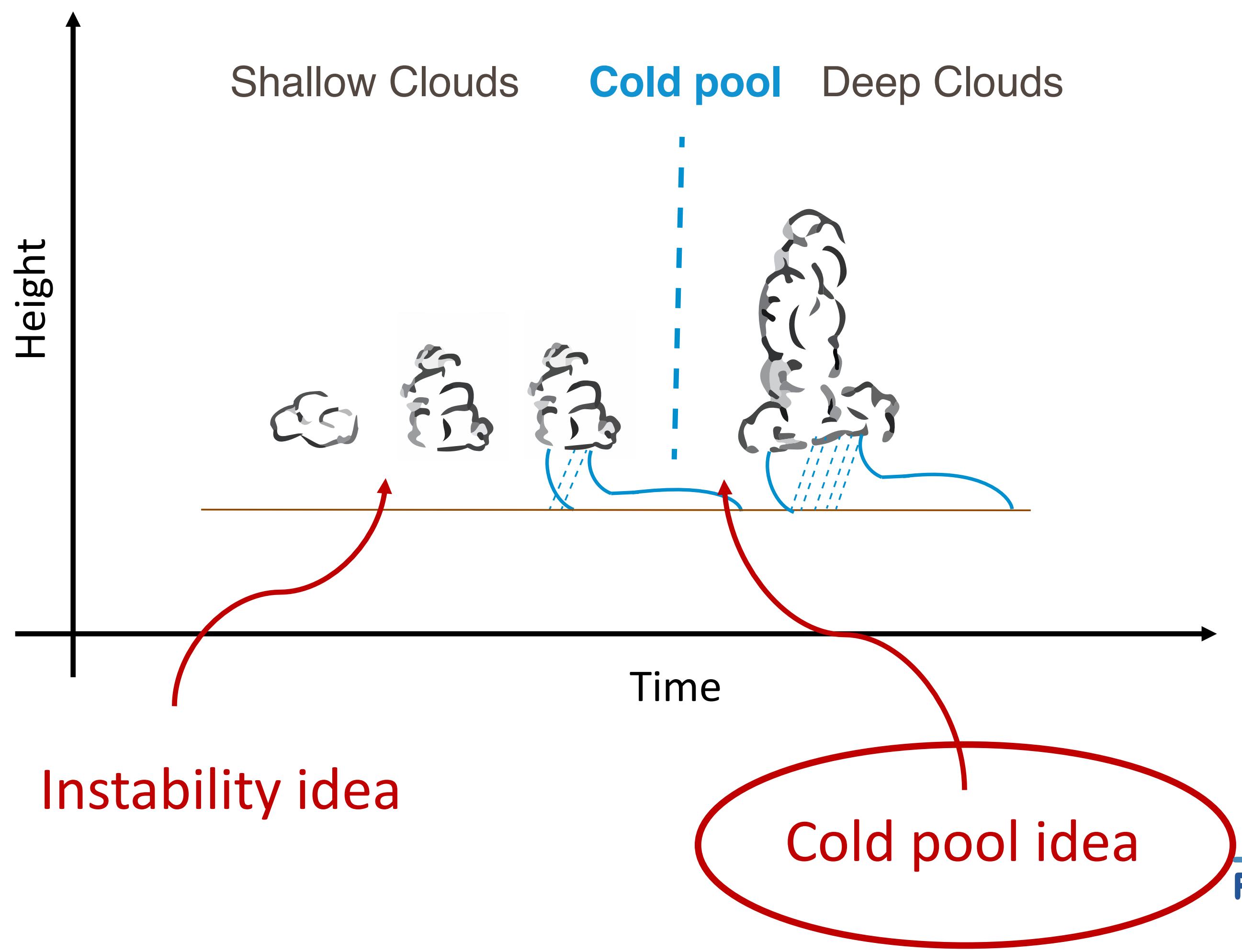
So what control the transition?



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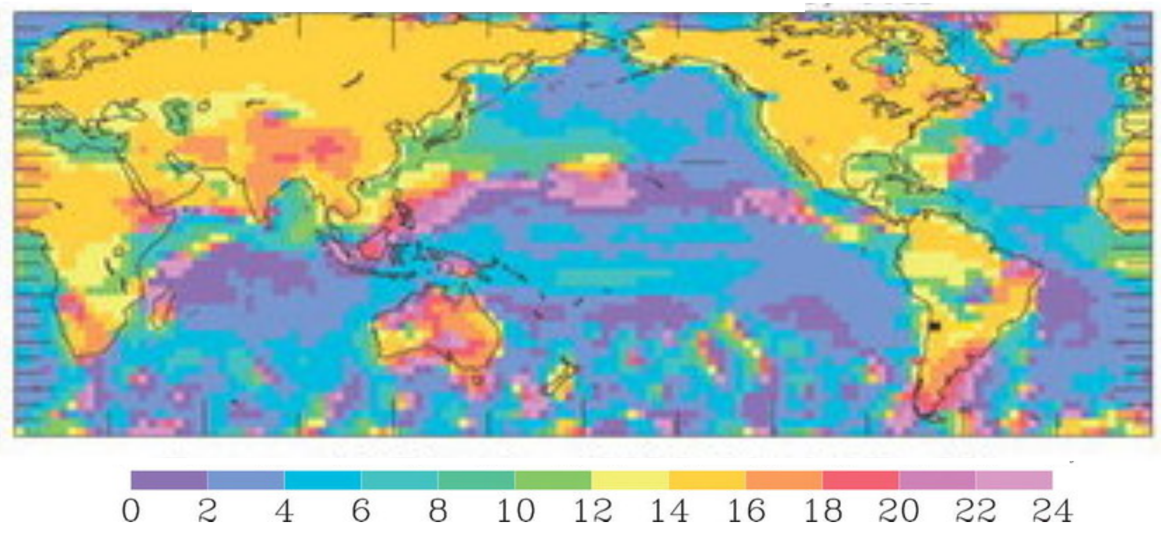
Is the timing of convection important ?

- The timing likely depends on processes happening on scales O(<10 km)

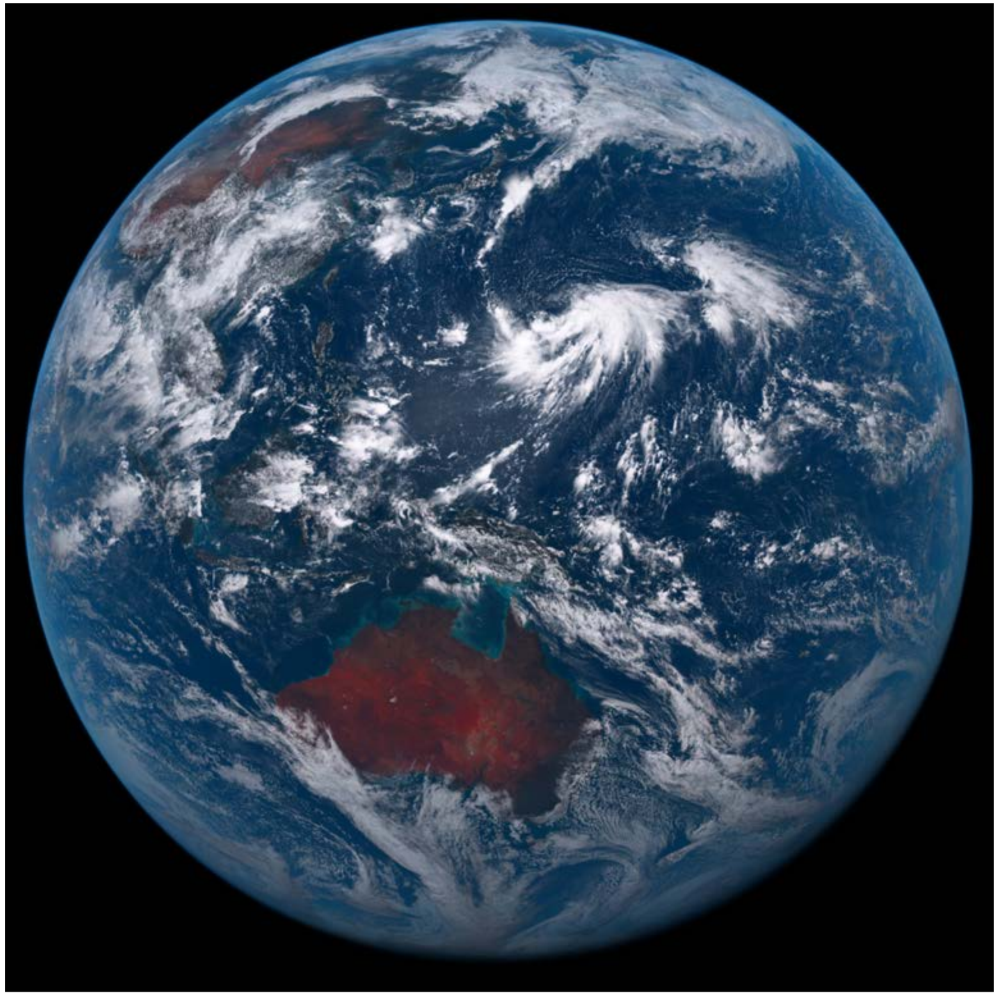
- Climate models have been run with a wrong timing of convection for decades

Time of max JJA precipitation



Dai (2006)

Global simulations at storm-resolving resolution



Cloud rendering as seen from a satellite point of view

Stevens et al. (2019)

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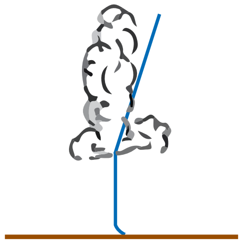
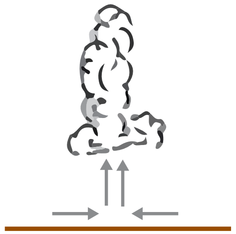
Summary

1. Some basics on convection

Thermodynamical view



Dynamical view



The devil messes it up

2. The diurnal cycle of convection over land

Entrainment
Preconiditioning
Instability
Cold Pool