# Numerical simulations of orographic convection across multiple grey zones

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Cumulus congestus over Italian Alps, 30 Aug. 2019

# The “grey zone” problem

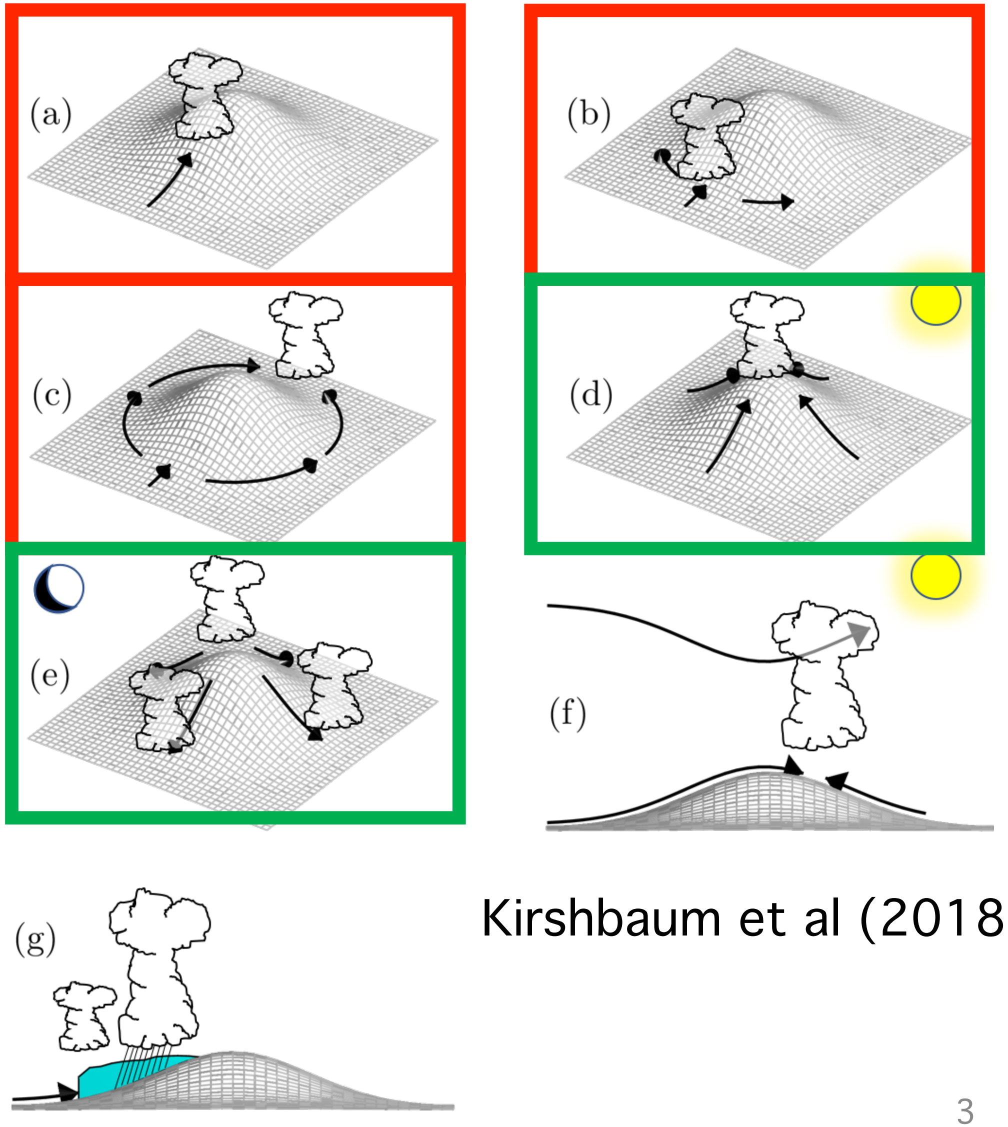
- Consider an atmospheric process of scale L
  - To numerically resolve, need grid spacing $\Delta < \sim 0.1L$
  - To parameterize, usually need $\Delta > L$ (given scale-separation assumptions)
  - Grey zone corresponds to $0.1L < \Delta < L$

- Two common grey zones
  - Deep convection (L~10 km)
  - Boundary-layer turbulence/shallow convection (L~1 km)

- How do atmospheric models represent orographic convection across these two grey zones?

# Mechanisms of orographic convection

- Broadly speaking, there are two:
  - Mechanical: impinging air forced over or around a barrier [(a), (b), (c)]
  - Thermal: thermally direct circulations over sloping terrain [(d), (e)]

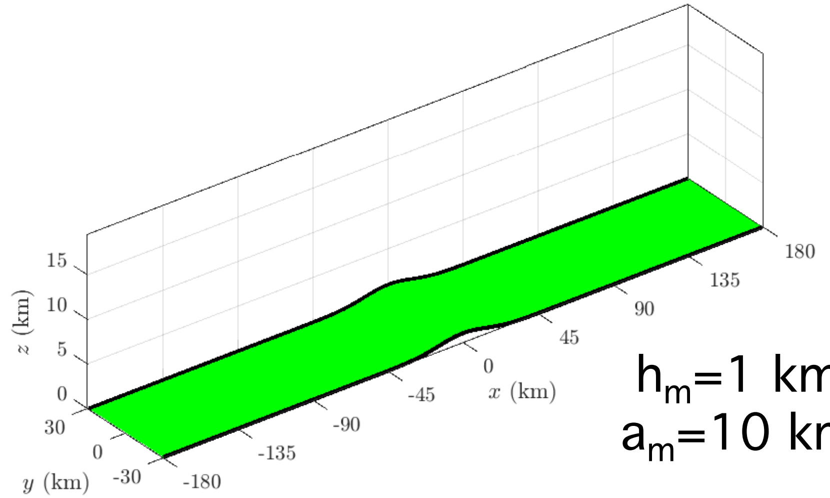



Kirshbaum et al (2018)

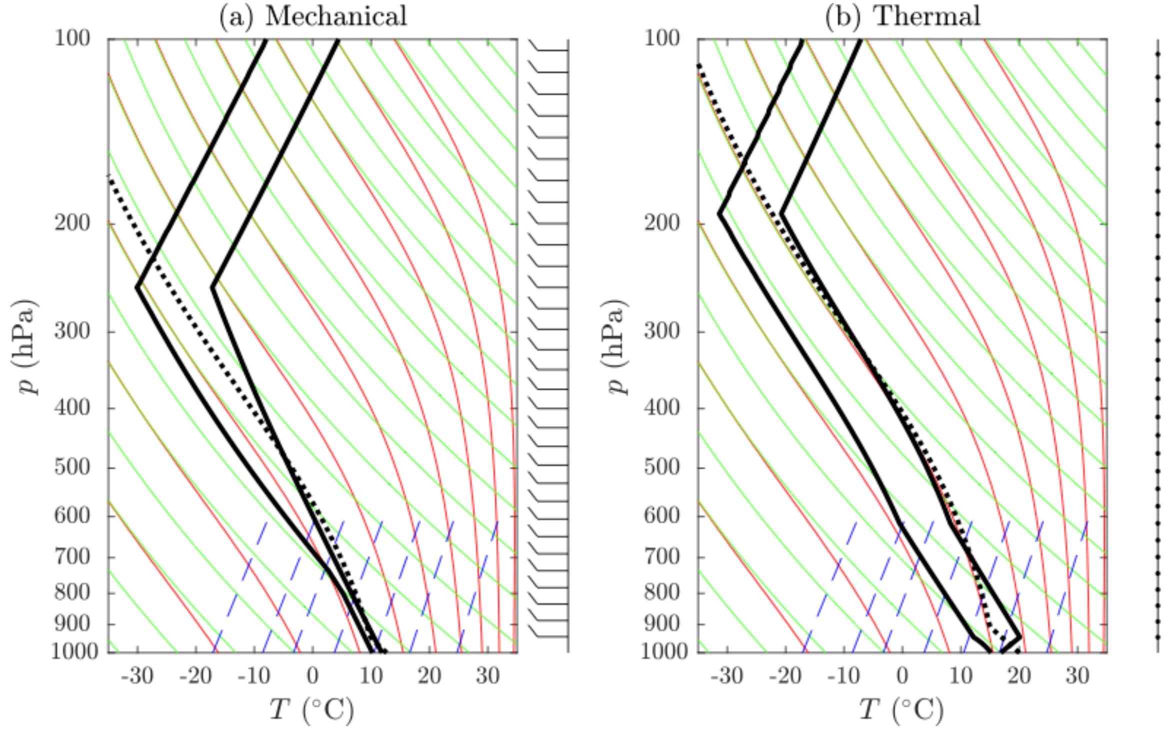
# Method

- Idealized simulations over a wide range of Δ (10 km → 62.5 m) with cm1 (Bryan and Fritsch 2002)
  - ➢ Quasi-2D configuration
  - ➢ Both mechanical (MECH) and thermal (THERM) forcing
  - ➢ 5-member ensemble for Δ=250 m

<u>Parameterizations:</u>
Cumulus: Kain-Fritsch (Δ ≥ 5km)
Turbulence: TKE (Deardorff 1980)
Cloud microphysics: Morrison et al (2005)



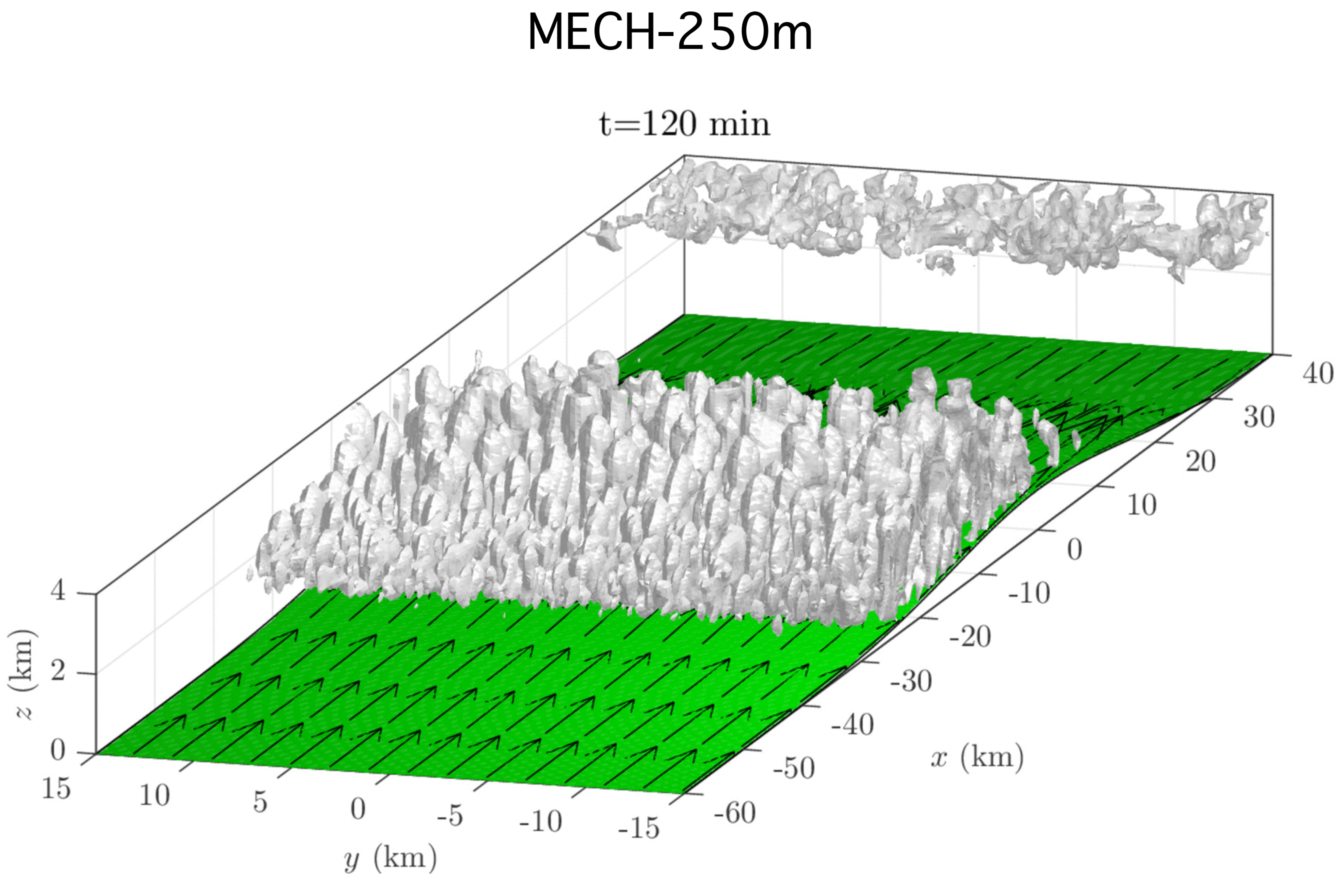

$h_m$=1 km
$a_m$=10 km

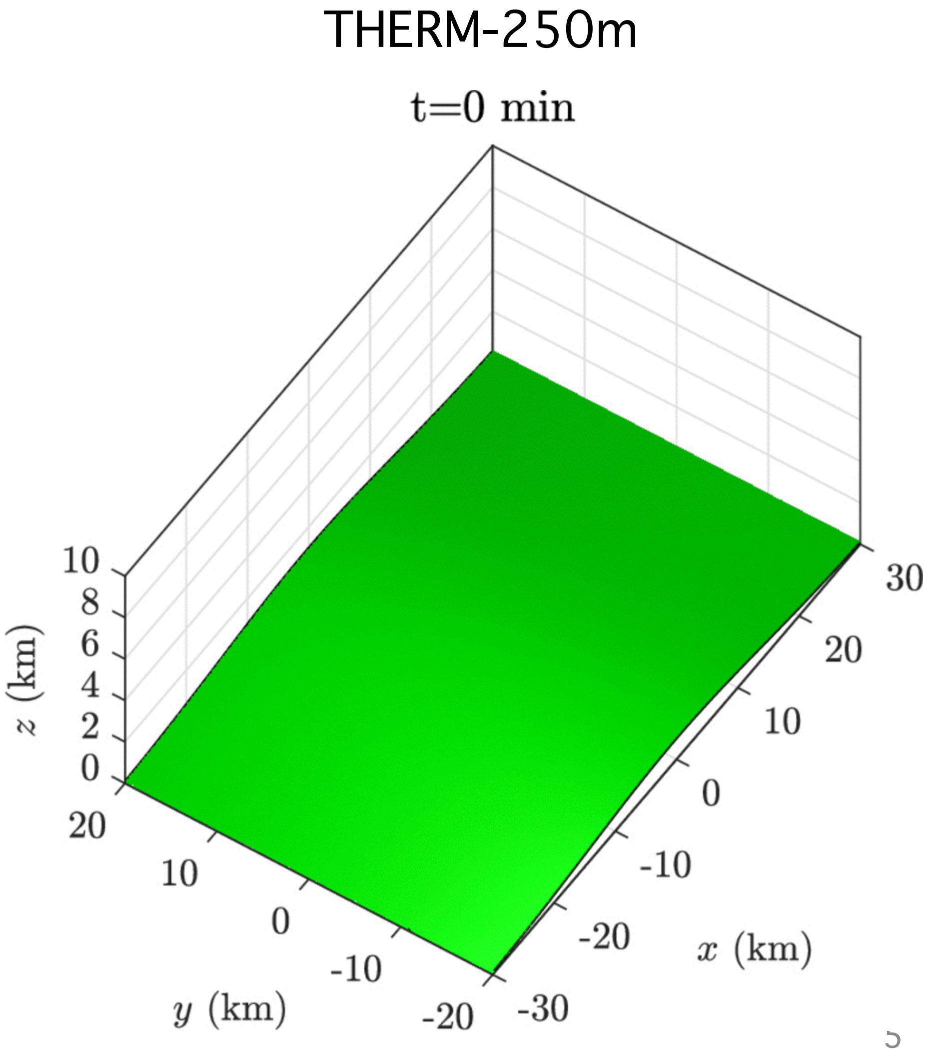



MECH:
freeslip, unheated

THERM:
semislip, diurnal heating

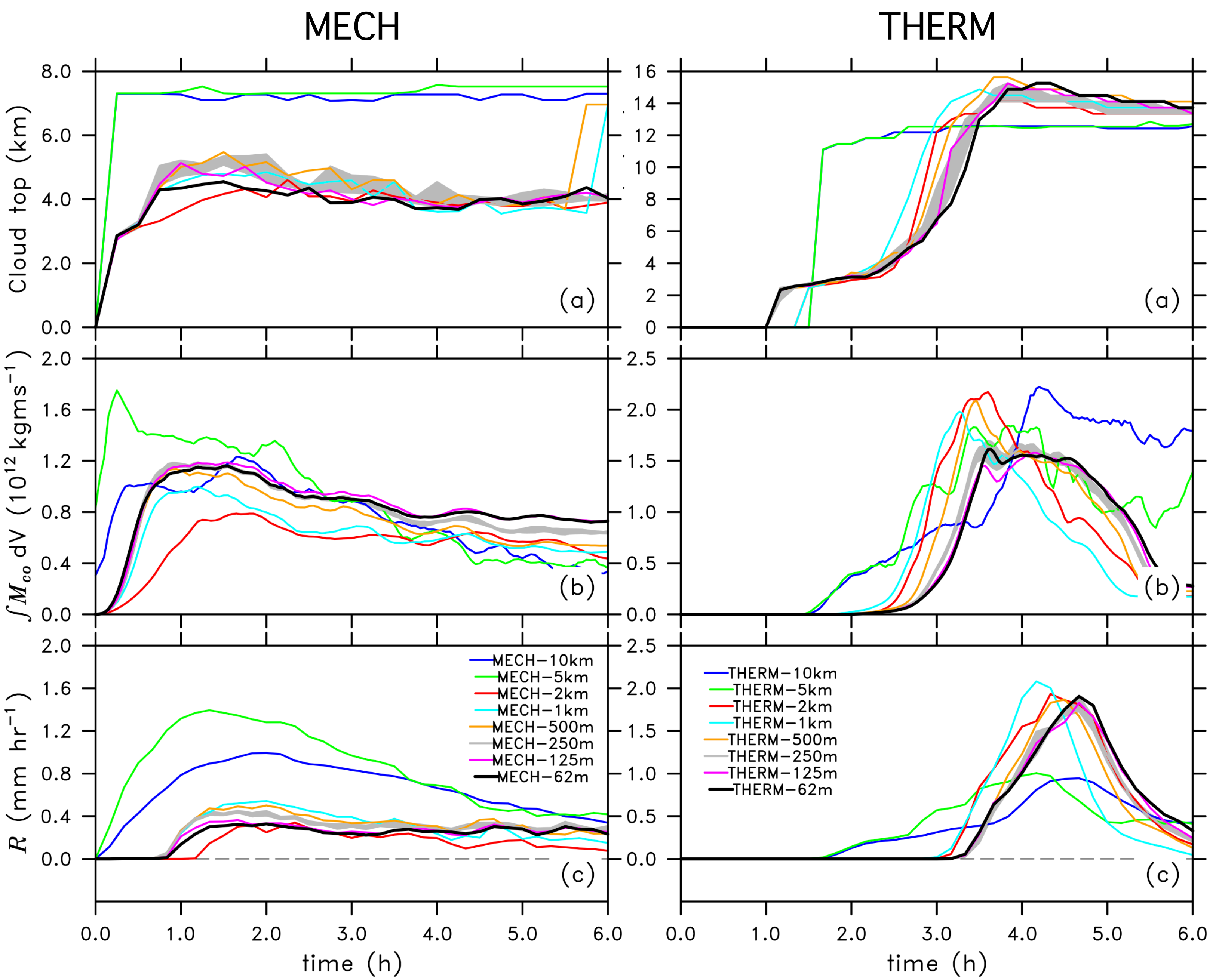
# Cloud animations



# Bulk convergence

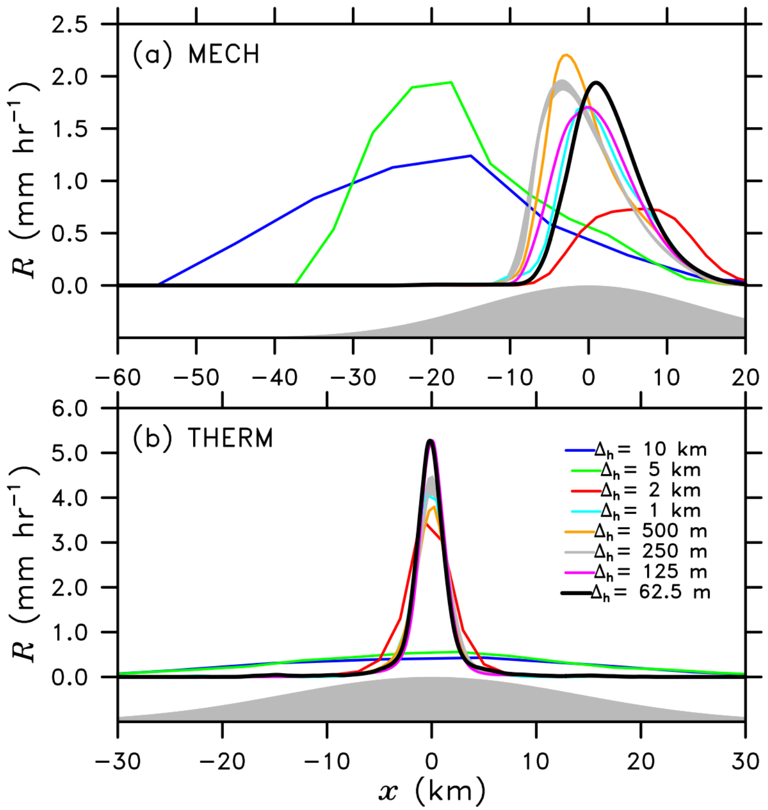
- Deep-convection grey zone: dominated by errors in cumulus scheme
- Turbulence grey zone: apparent convergence for Δ≤125 m



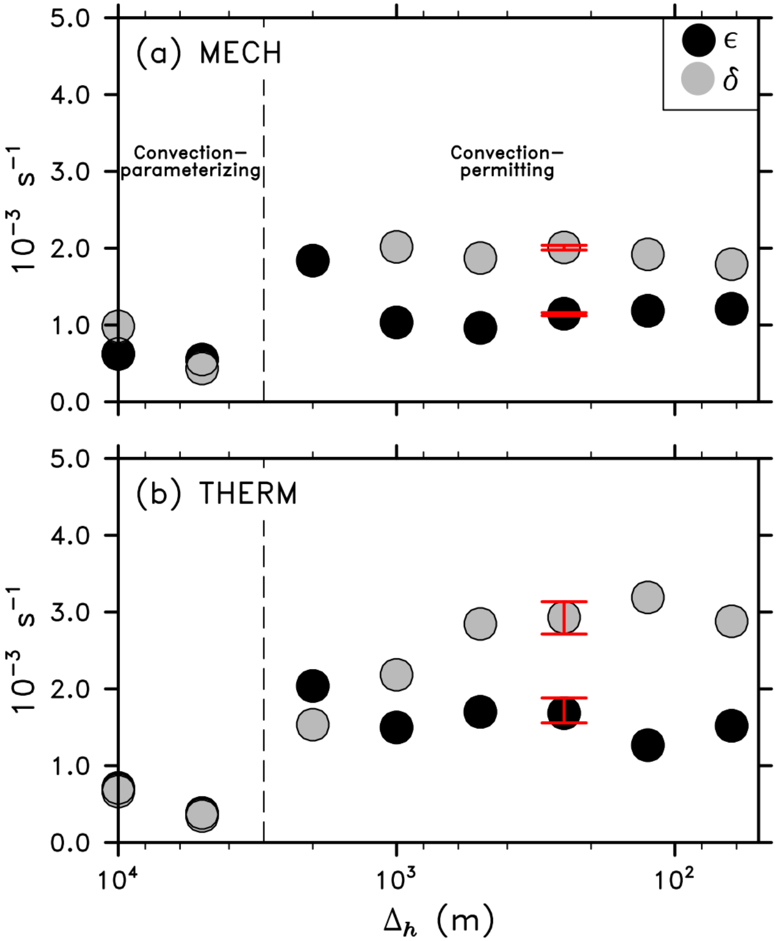
# Alternate perspectives

- MECH
  - Param: “windward-lee” bias
  - No convergence down to Δ=62.5 m
- THERM
  - Param: minimal rain
  - Onset of convergence at Δ=2 km, robustness at Δ=125 m.
- Parameterized ent/det way too small
  - Favors upstream (MECH) and early (THERM) convective initiation

Mean precipitation rate

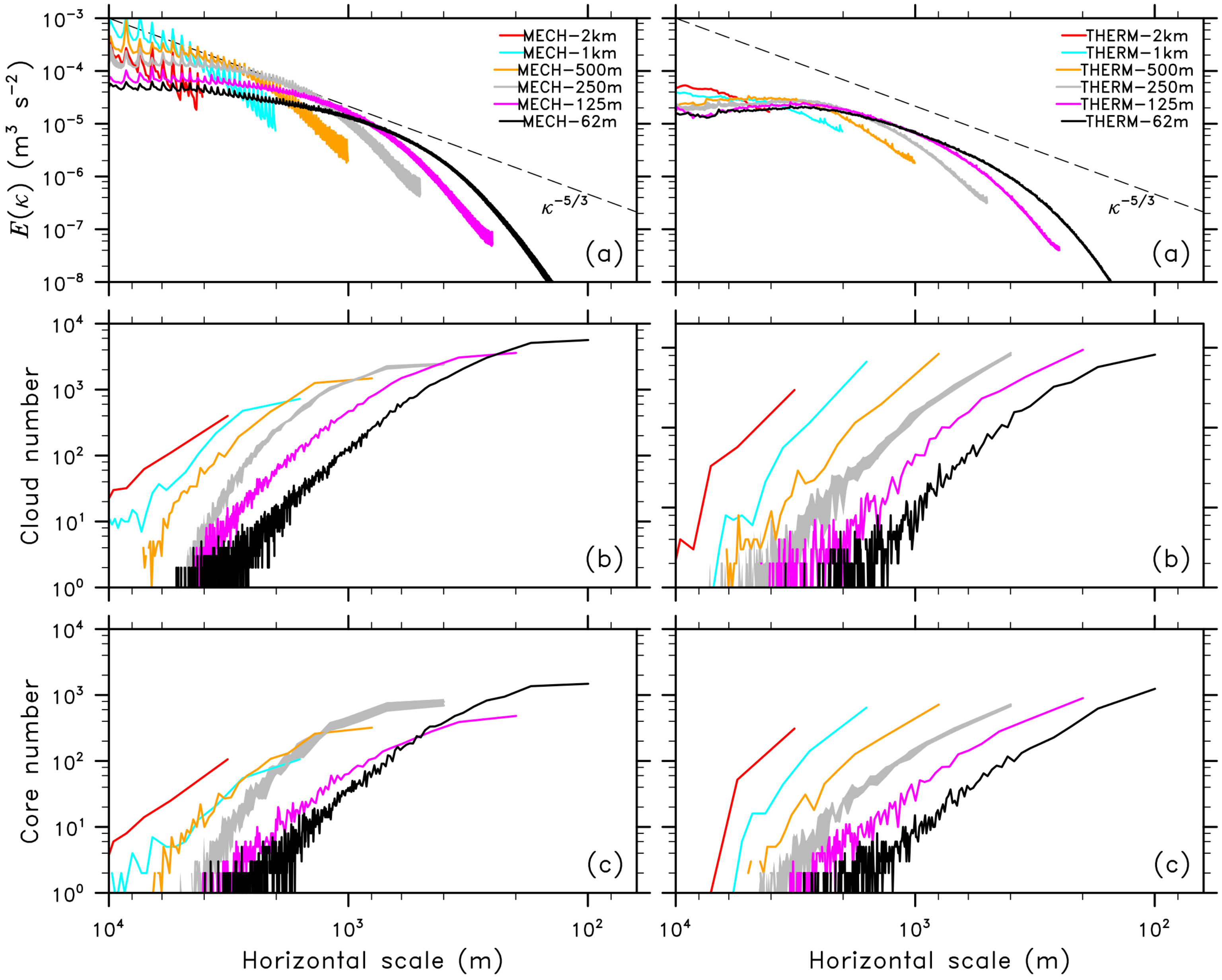



Entrainment/detrainment



# Structural convergence

- MECH
  - ➢ No convergence in horiz. energy spectrum, cloud or core sizes
- THERM
  - ➢ Power spectra converge in mesoscale for Δ ≤ 500 m
  - ➢ Still no convergence in cloud/core sizes

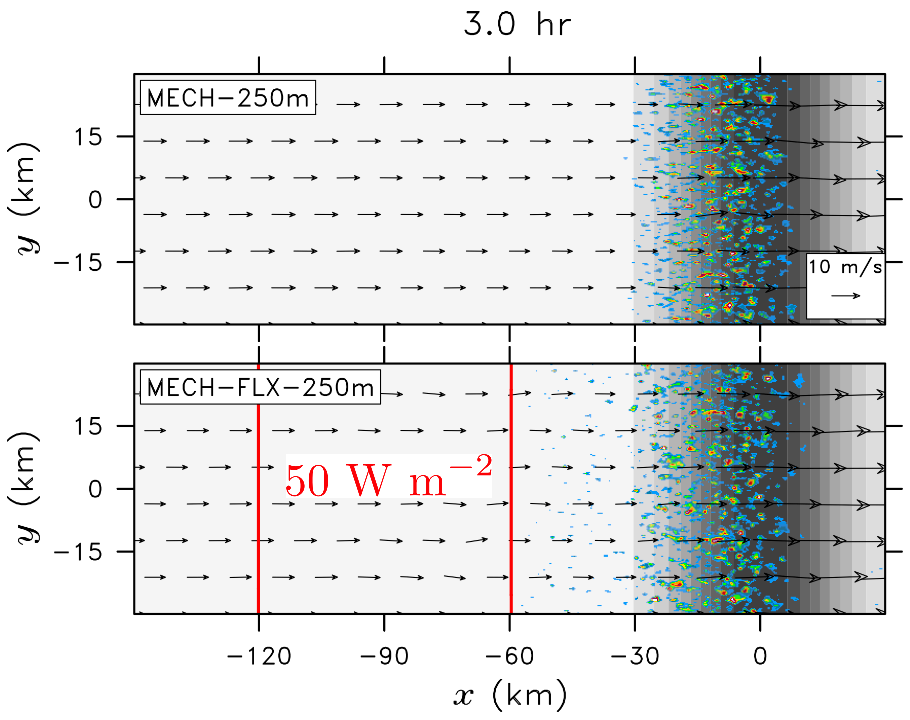


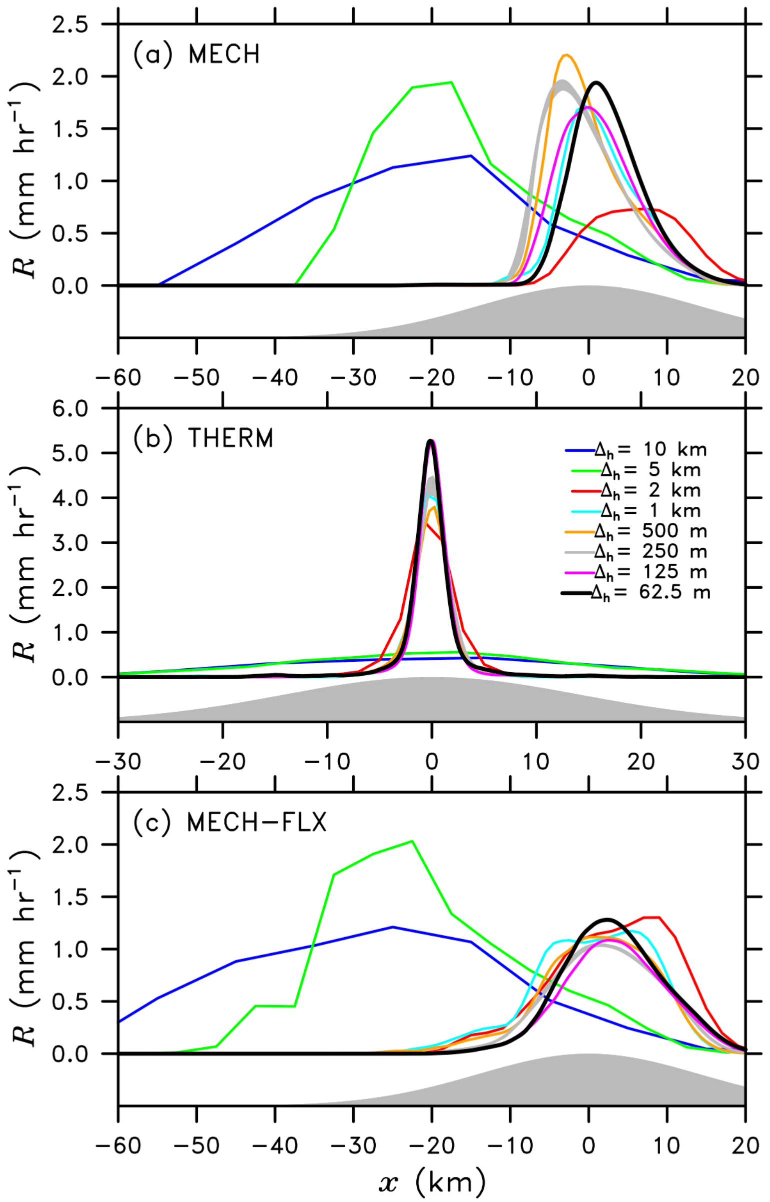
# Hypothesis

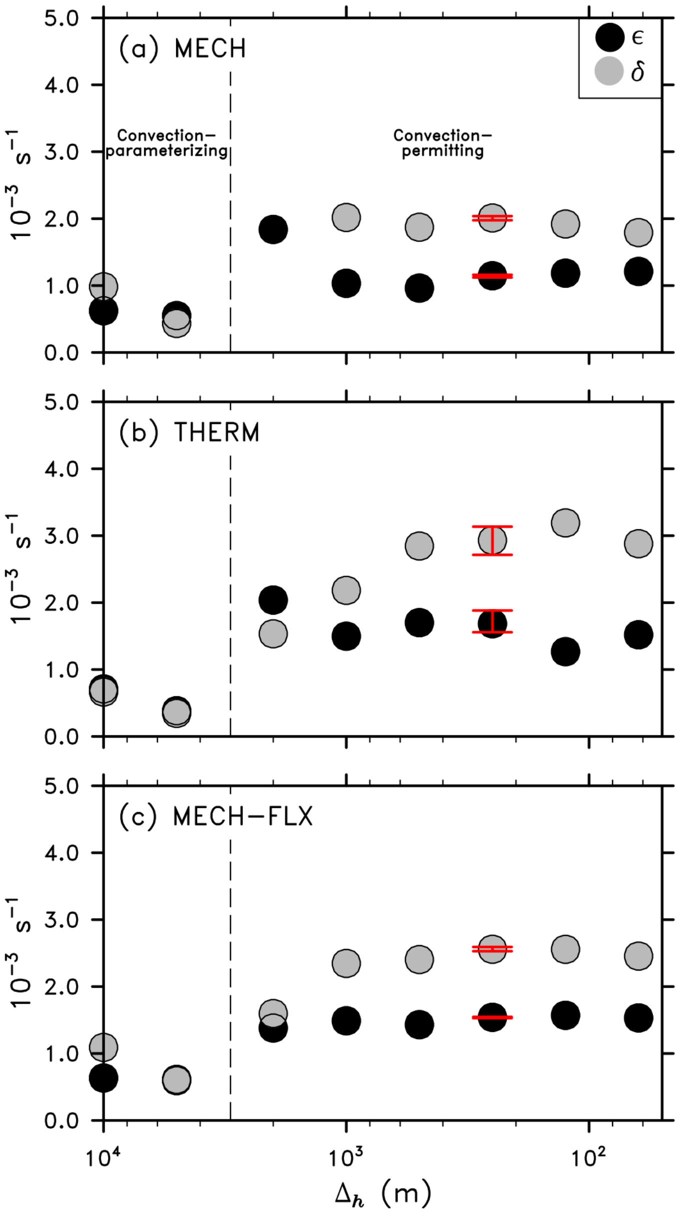
- For numerical convergence to occur, flow must satisfy the requirements of LES
  - $\Delta$ << large eddy scale (~ 1 km)
  - Resolved inertial subrange
- THERM, with a turbulent convective boundary layer, satisfies both requirements *prior to cloud formation*
- MECH, with no boundary layer, undergoes turbulent transition within orographic cloud
  - Process sensitive to $\Delta$ (finer grid resolution → faster transition)

# Testing the hypothesis

- MECH-FLX: MECH with upstream heat patch
  - ➢ Seeds turbulence in orographic cloud




Upstream heating facilitates numerical convergence!

# Conclusions

- In deep-convection grey zone, errors in cumulus parameterization dominate Δ sensitivity
  - Unrealistically small entrainment/detrainment promotes convection initiation too readily
- In turbulence grey zone, numerical convergence requires resolved turbulence in cloud inflow
  - MECH: laminar inflow, cloud undergoes turbulent transition (×)
  - THERM: domain-wide convective PBL (✓)
  - MECH-FLX: upstream heat patch energizes impinging flow (✓)