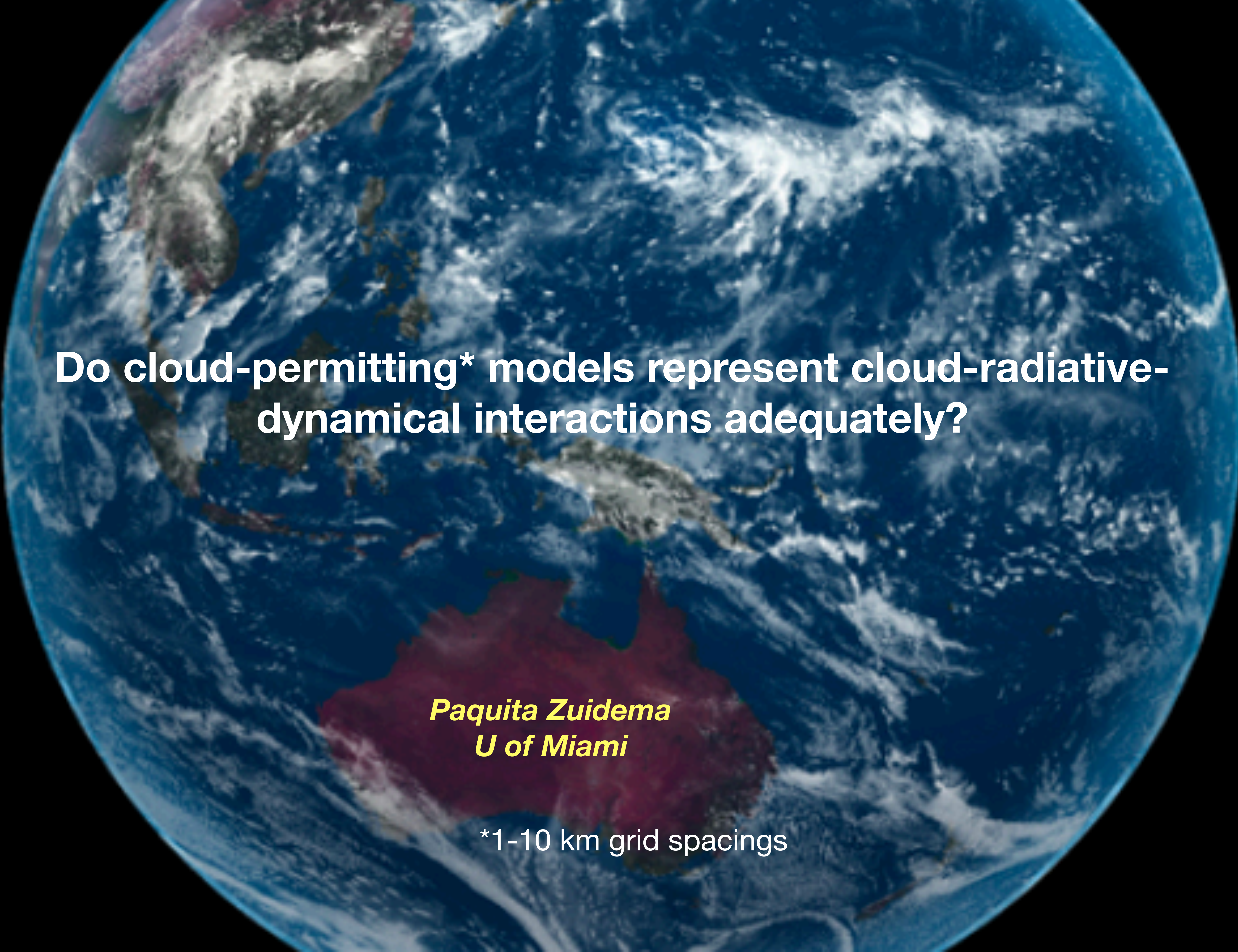
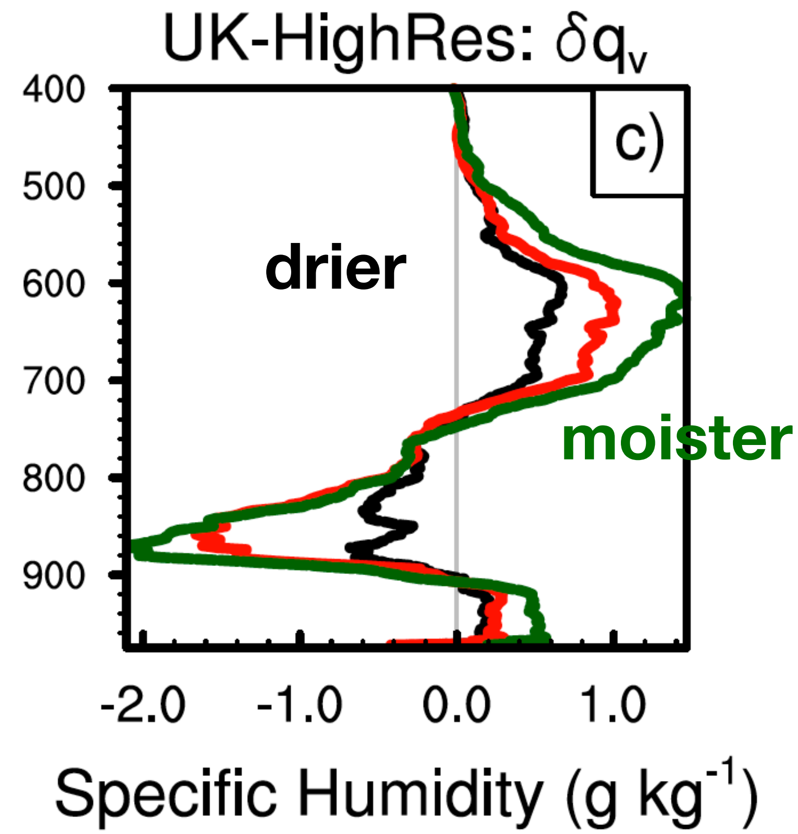


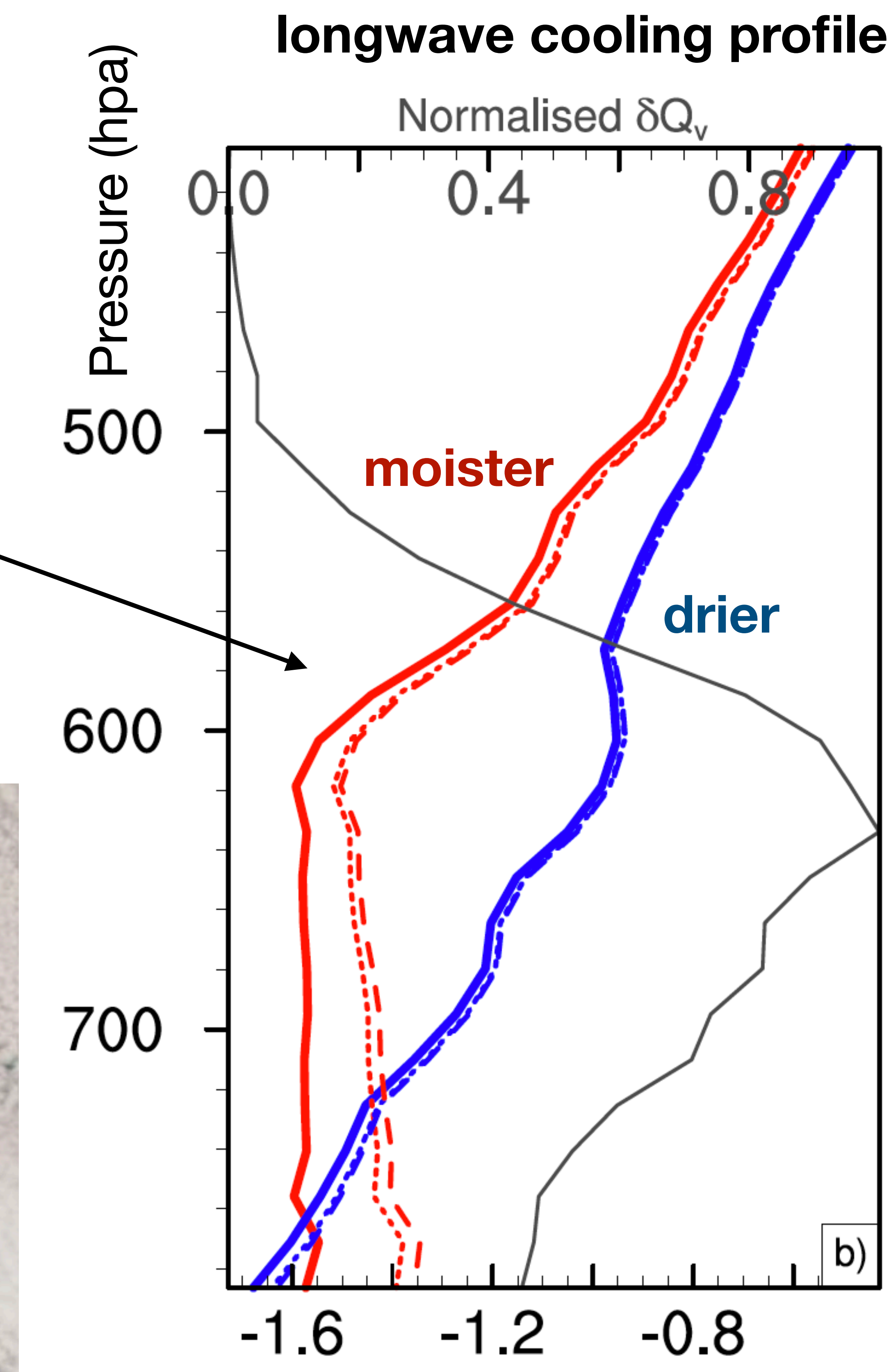
Do cloud-permitting* models represent cloud-radiative-dynamical interactions adequately?

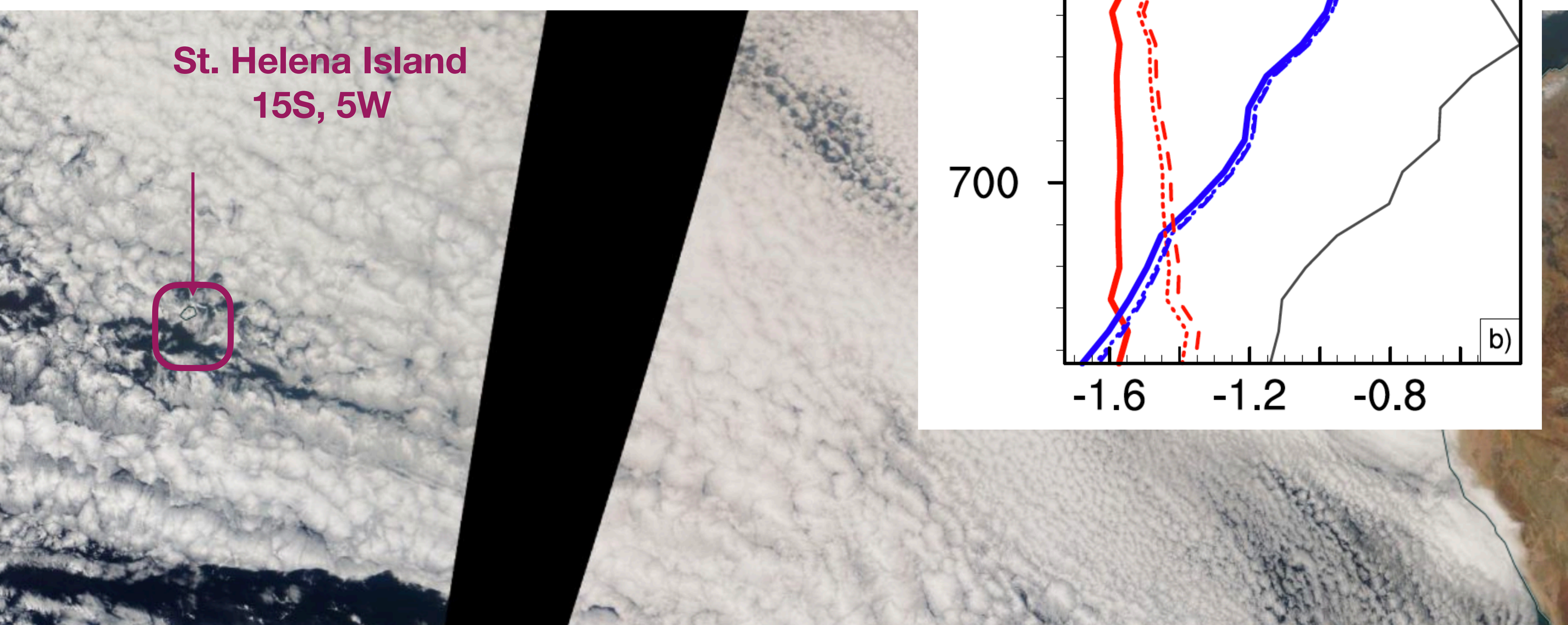
Paquita Zuidema
U of Miami

*1-10 km grid spacings



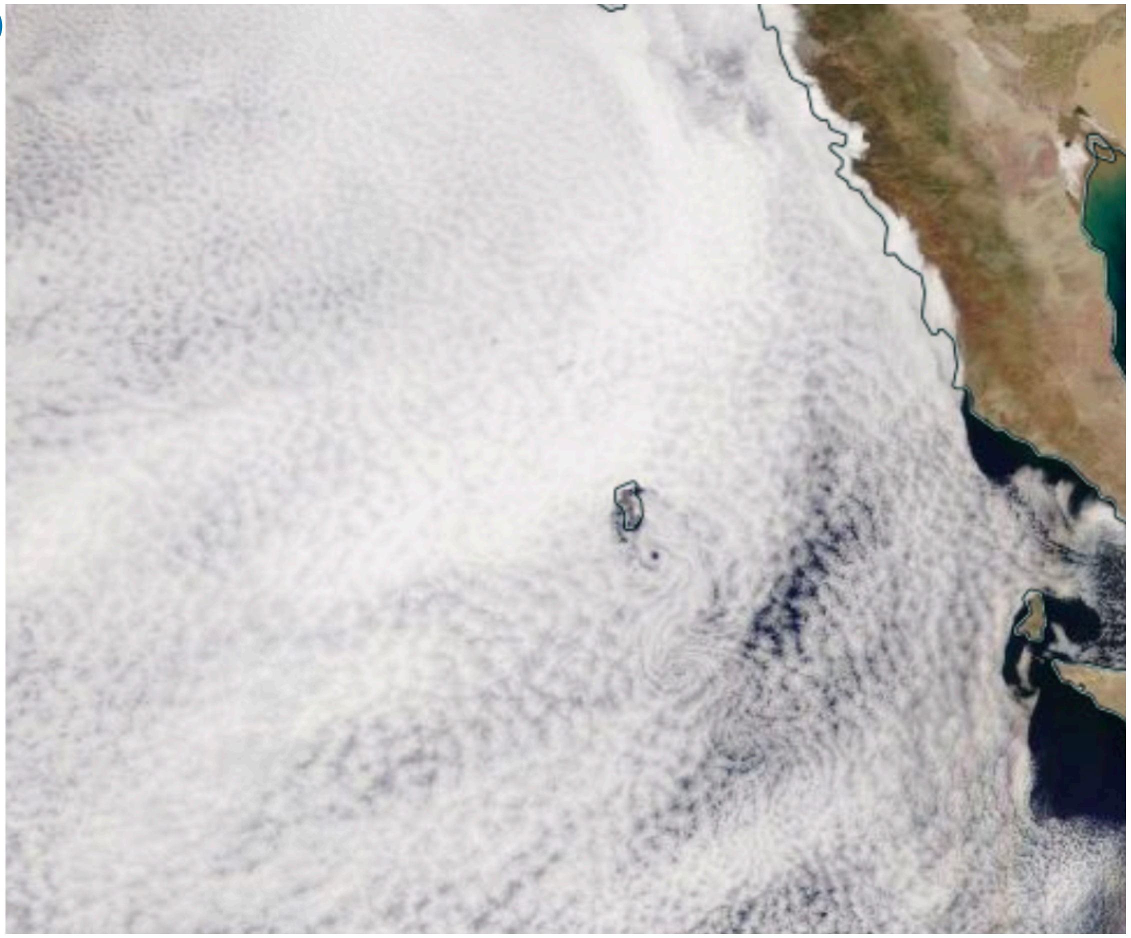
It doesn't take much of a moisture perturbation above the cloudy boundary layer to change the RT cooling profile





What are these 'radiatively-driven cold pools' of which we speak?

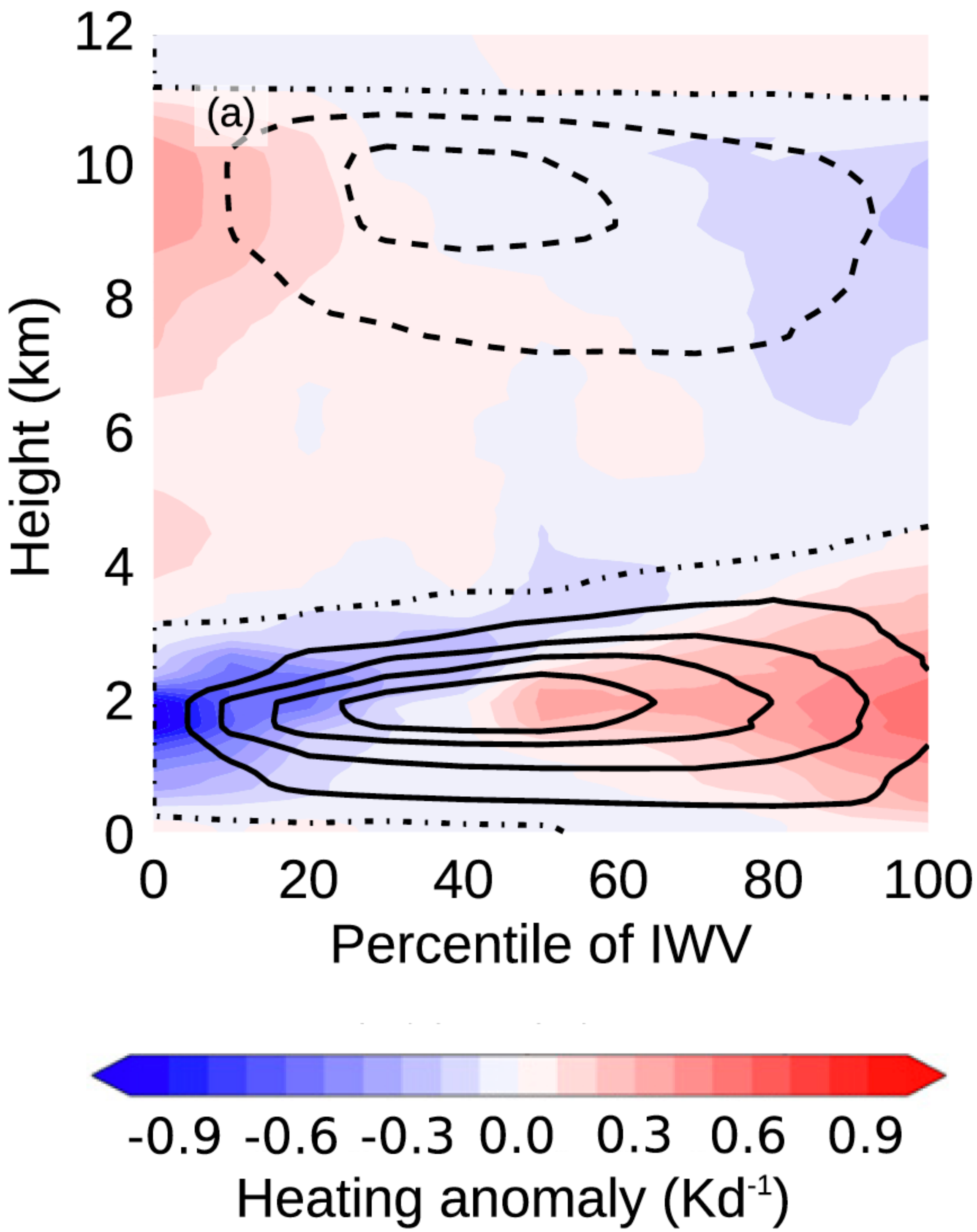
These quickly run into 'the low-cloud problem"
how often are low clouds represented, and if so
is it for the right reasons?



Shallow (<1km) boundary layers can
easily couple to the surface -
but stratocumulus isn't the intent

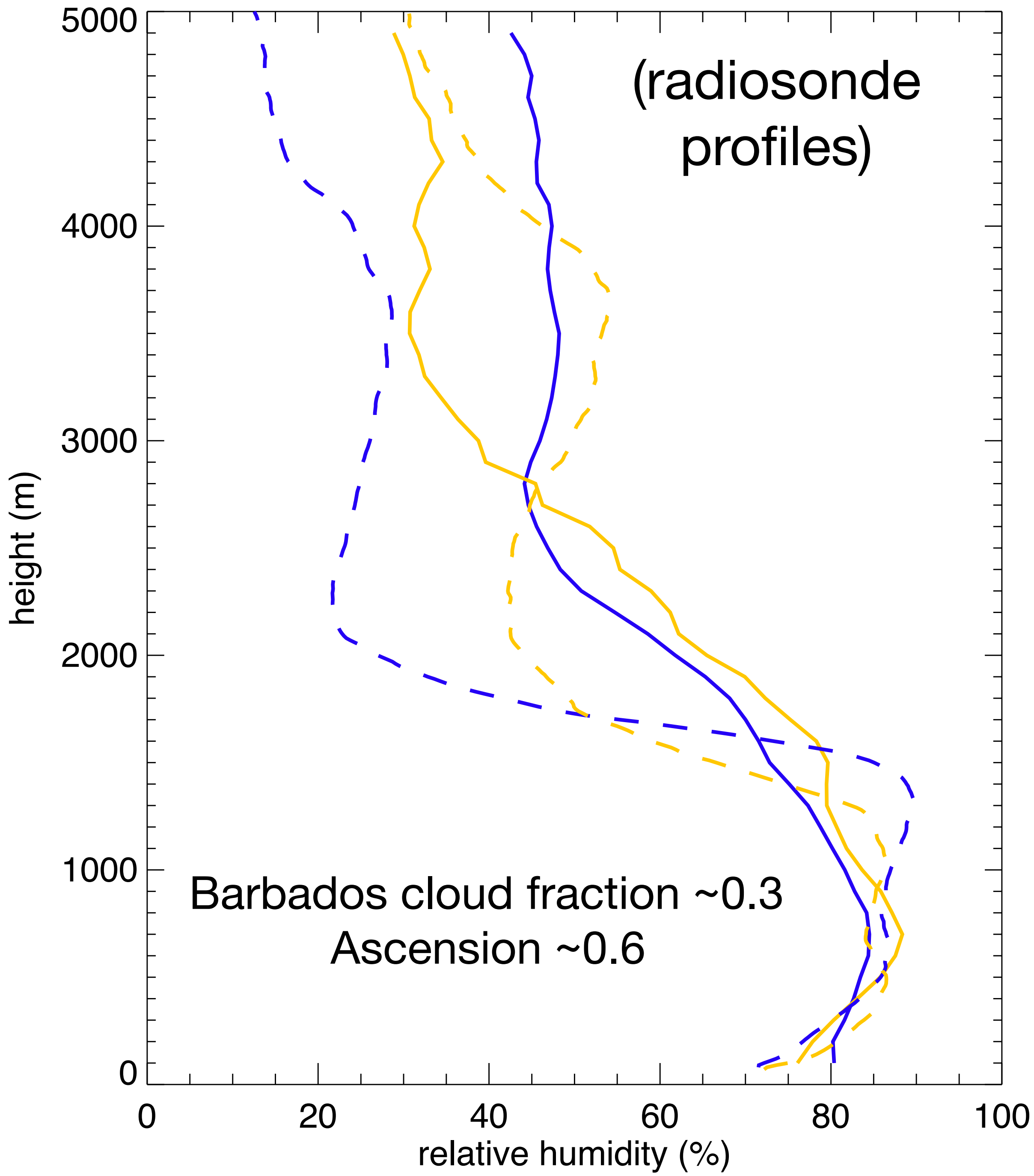
Deeper tropical boundary layers
with dry free-tropospheres
support shallow cumulus -
but such cloudy boundary layers
are intermittently coupled to the surface;
increased subsidence *should* increase
the low cloud fraction, but does it in models?

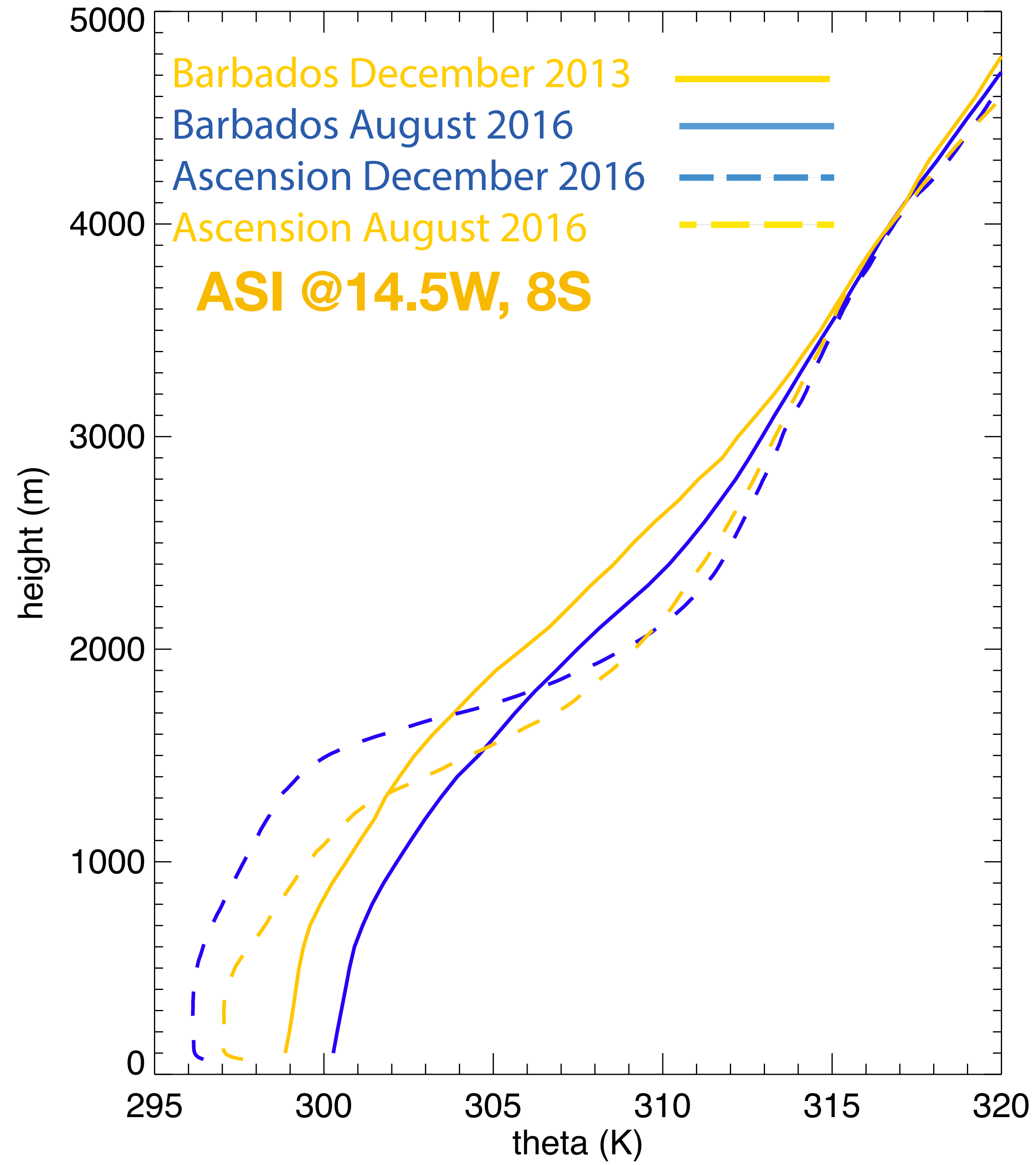
Does it matter?
Do we need low clouds for the radiation?



Net clear-sky radiative heating profiles based on Barbados soundings suggest clear-sky radiative heating differences can drive ~1/3 of shallow circulation (Schulz and Stevens, 2018)

Do details of the boundary layer in the 'radiatively-driven' dry regions matter?





I don't know


Do cloud-permitting* models represent cloud-~~radiative-~~
dynamical interactions adequately?
A qualified YES
*1-10 km grid spacings

What do we mean by cloud-permitting*?

Can resolve mesoscale circulations and characteristics explicitly

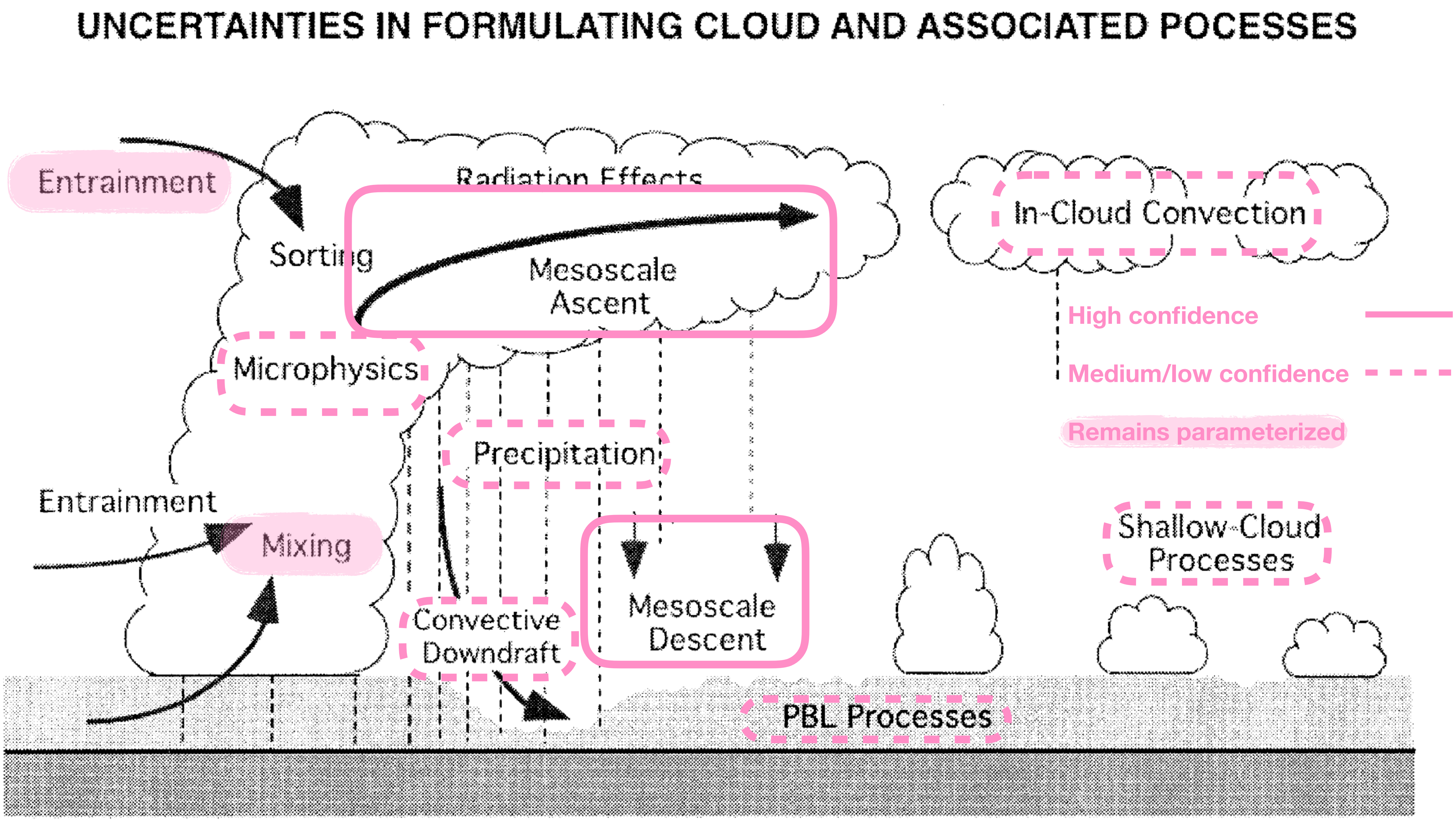


FIG. 2. Cloud and associated processes for which major uncertainties in formulation exist.

*1-10 km horizontal grid spacings

Arakawa, 2004: The Cumulus Parameterization Problem: Past, Present, and Future, J. Climate

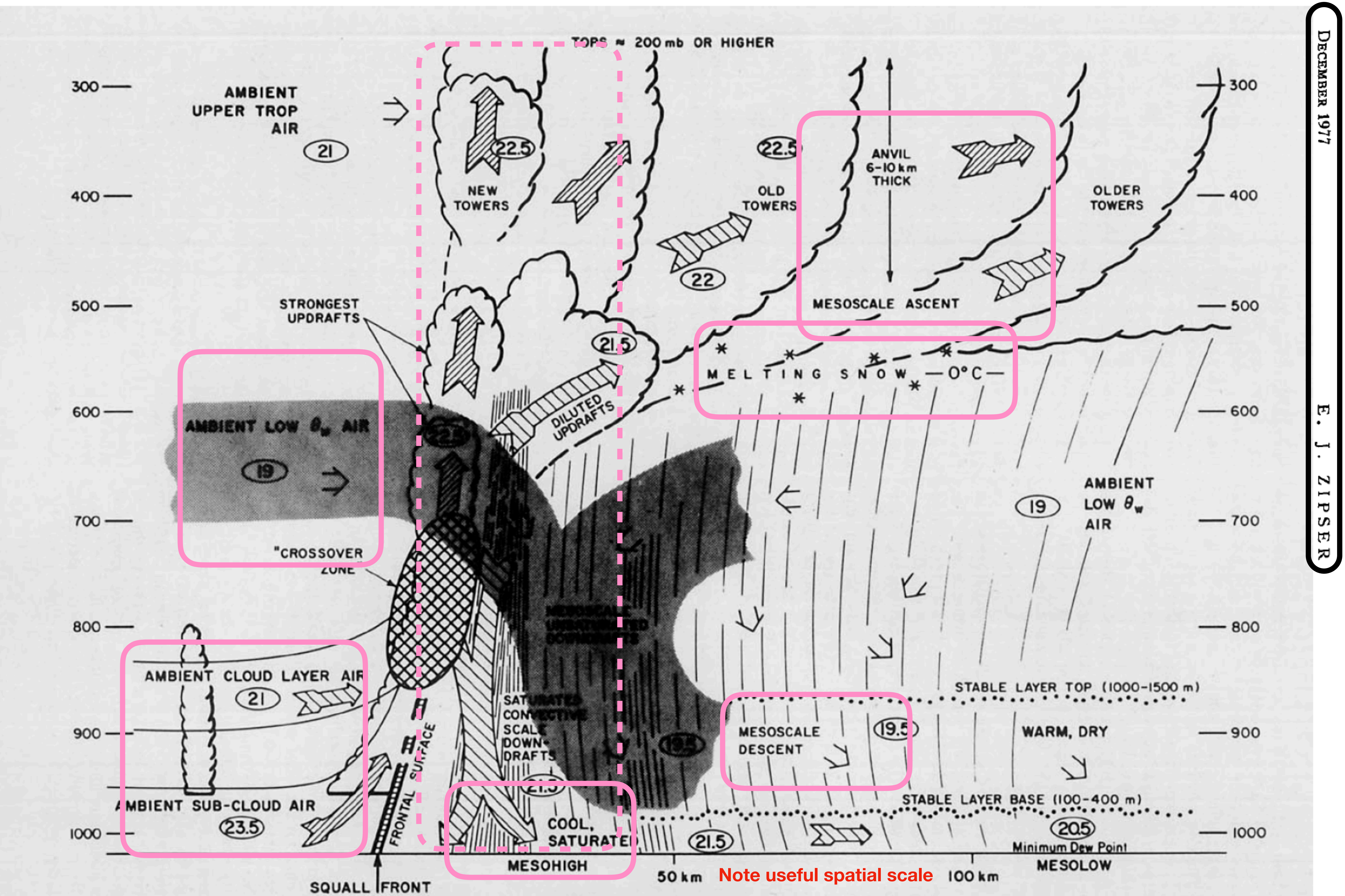


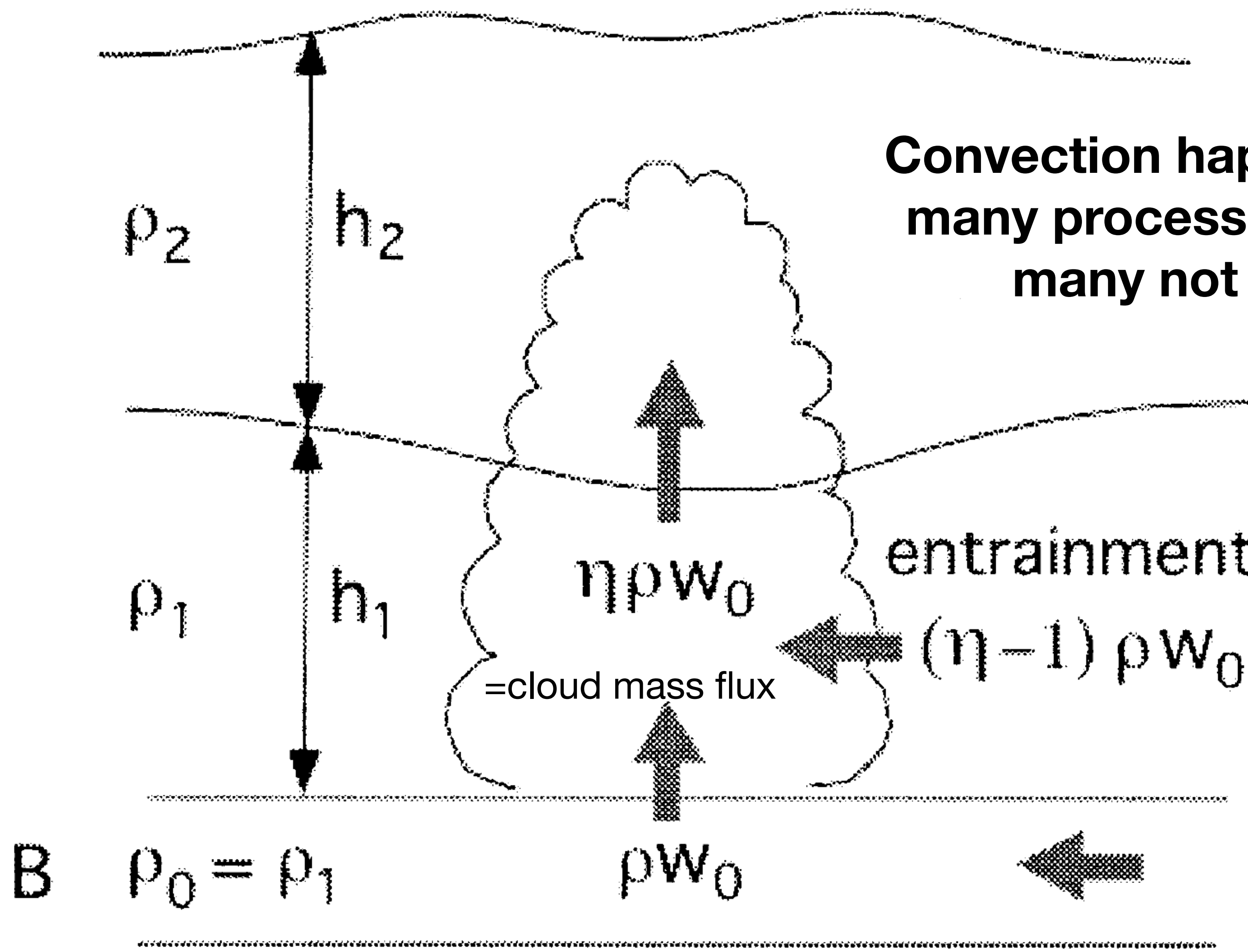
FIG. 13. Schematic cross section through a class of squall system. All flow is relative to the squall line which is moving from right to left. Circled numbers are typical values of θ_w in °C. See text for detailed discussion.

Zipser, 1977: Mon. Wea. Rev. "Mesoscale and convective-scale downdrafts as distinct components of squall-line structure"

“Just” by improving resolution - we experience a true paradigm shift: mesoscale interactions with the larger-scale circulation

This was the ‘before’….

Convection happens ‘in place’, so many processes parameterized, many not even defined!



How clunky !

FIG. 4. Structure of the model used by O69 for simulations of tropical cyclone development.

Arakawa, 2004: O69=Ooyama, 1969

A quick summary of some of the new understandings via CP simulations

- The MJO (e.g., ability to resolve the diurnal cycle more appropriately)
- Shallow circulations induced by soil moisture differentials
- Monsoonal-mesoscale interactions & their diurnal cycle
- Sea-breeze circulations
- Broadening of the ITCZ (and convecting regions in general)
- Resolution of non-convecting regions (“doldrums”) within the ITCZ
- Diurnal cycle of hurricanes
- Evaluation of the parameterized convection within large-scale coupled climate models

a better understanding of the MJO convection……

AGU PUBLICATIONS

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2016MS000725

The impact of the diurnal cycle on the propagation of Madden-Julian Oscillation convection across the Maritime Continent

Samson M. Hagos[1], Chidong Zhang[2], Zhe Feng[1], Casey D. Burleyson[1], Charlotte De Mott[3], Brandon Kerns[2], James J. Benedict[2], and Matus N. Martini[4]

Key Points:
- The diurnal cycle disrupts MJO propagation across the Maritime

of the November 2011 MJO episode are performed. In the CONTROL simulations, the MJO signal is weakened as it propagates across the MC, with much of the convection stalling over the large islands of Sumatra and Borneo. In the NODC simulations, where the incoming shortwave radiation at the top of the atmo-

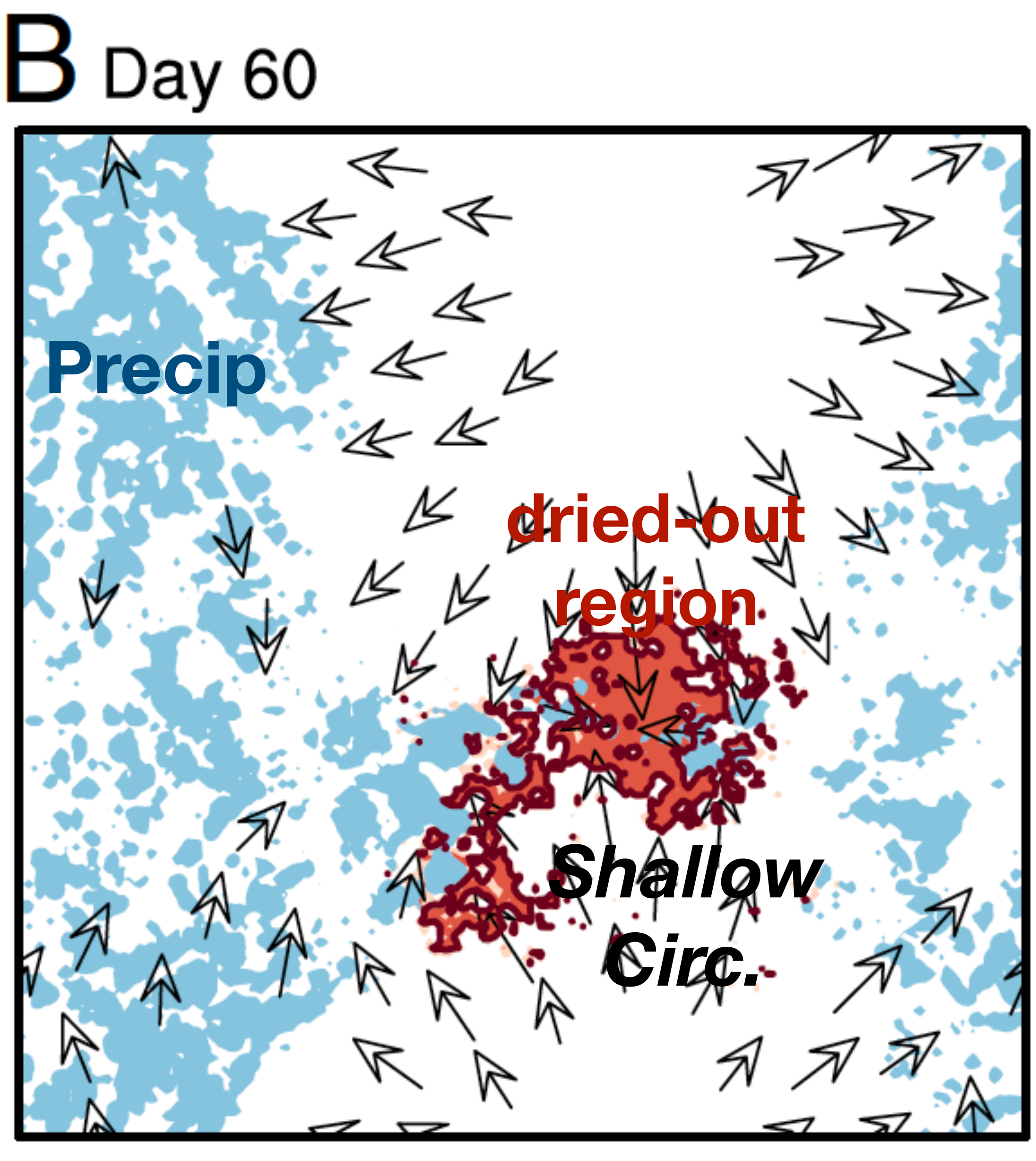
time. Furthermore, the diurnal covariability of surface wind speed and skin temperature results in a larger sensible heat flux and a cooler land surface in the CONTROL runs compared to NODC runs. An analysis of observations indicates that ahead of and behind the MJO active phase, the diurnal cycle of cloudiness enhances downwelling shortwave radiation and hence convection over the MC islands. This enhanced stationary convection competes with and disrupts the convective signal of MJO events that propagate over the waters surrounding the islands.

soil moisture impact on mesoscale circulations:

The role of the permanent wilting point in controlling the spatial distribution of precipitation

Cathy Hohenegger[a,1] and Bjorn Stevens[a]

PNAS, 2019

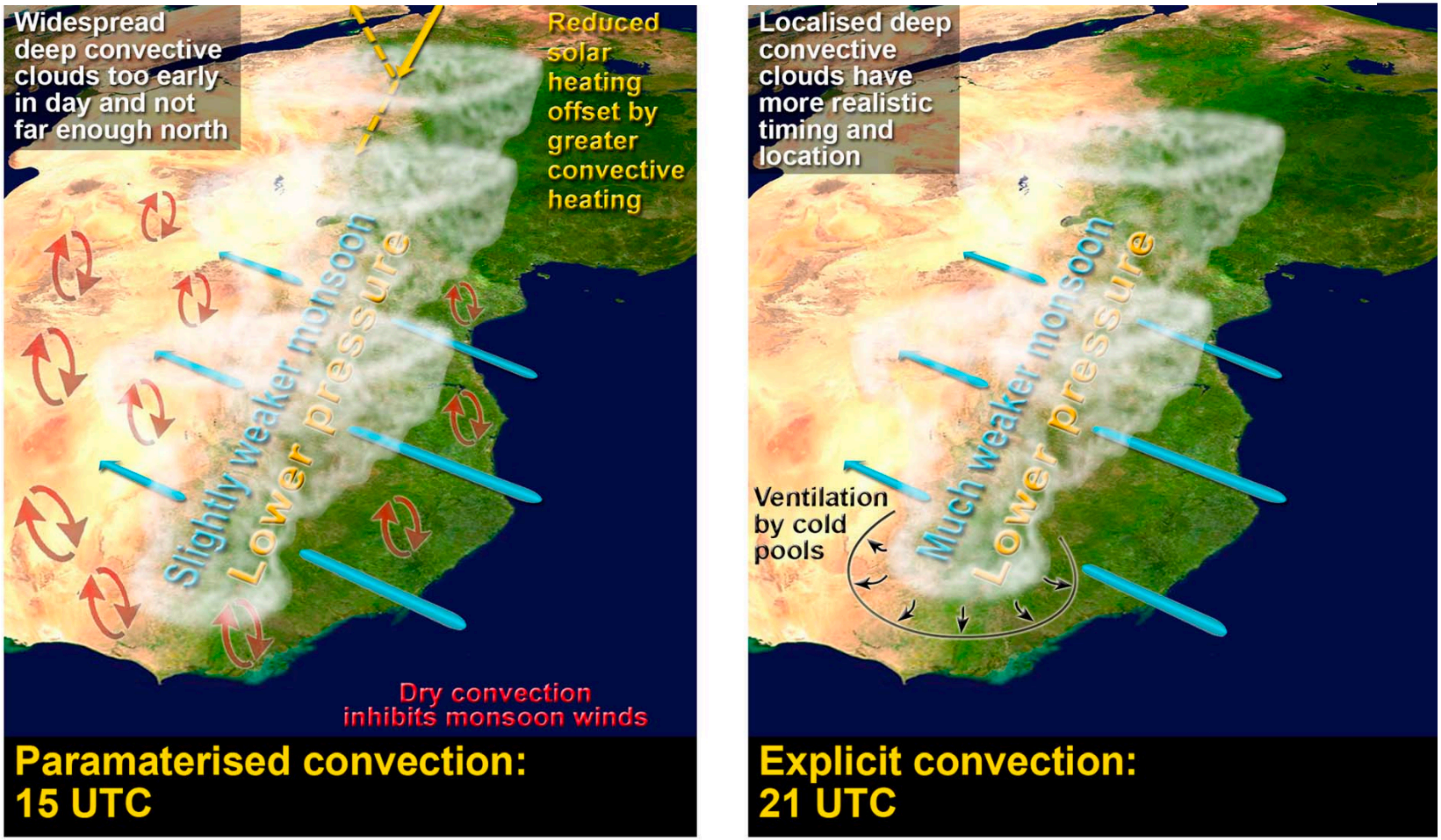


One basic distinction between land and ocean is that the land can dry out. We show that this is of fundamental importance for the precipitation distribution over land as it brings precipitation from the precipitating region to the nonprecipitating region. These findings help understand why tropical rain bands broaden poleward over land, the more so the drier the soils are.

The role of moist convection in the West African monsoon system: Insights from continental-scale convection-permitting simulations

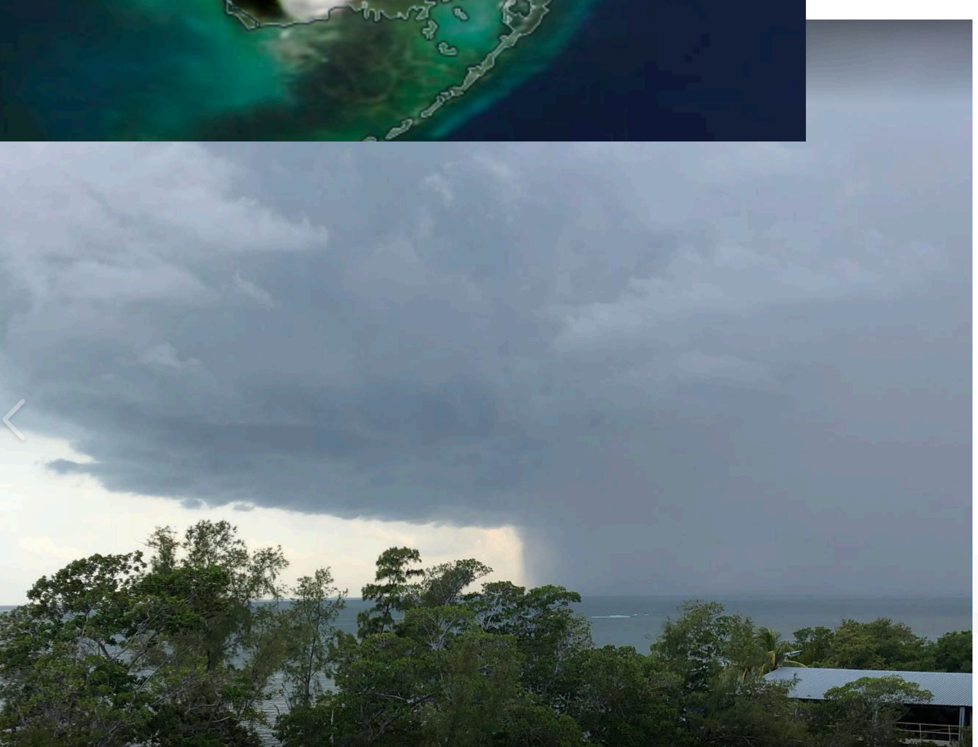
GRL, 2014

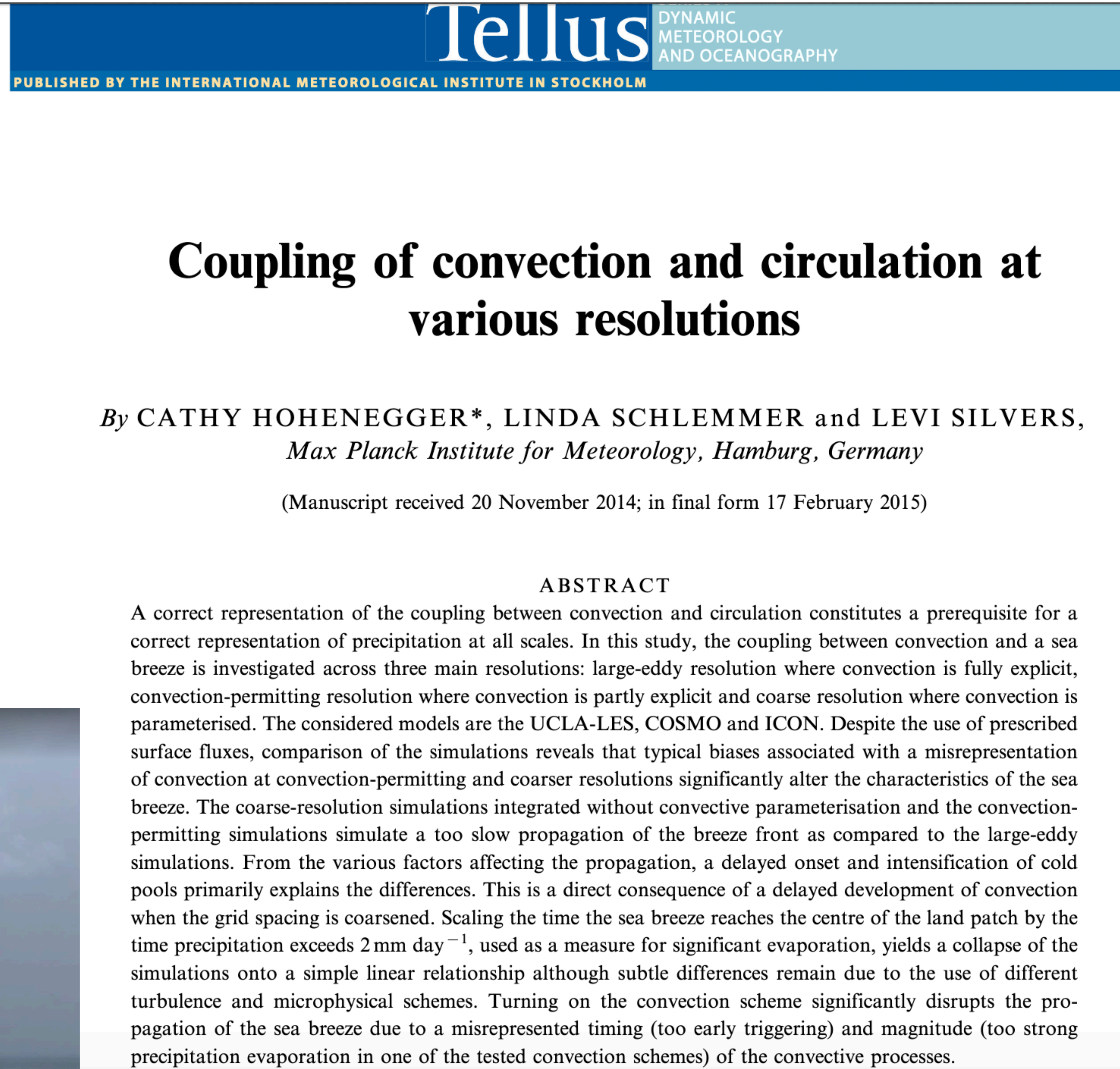
John H. Marsham,[1,2] Nick S. Dixon,[2] Luis Garcia-Carreras,[2] Grenville M. S. Lister,[1,3] Douglas J. Parker,[2] Peter Knippertz,[2] and Cathryn E. Birch[2]



The more realistic explicit convection increases latent and radiative heating farther north, with latent heating later in the day. This weakens the Sahel-Sahara pressure gradient, delaying monsoon's diurnal cycle and changing interactions between the monsoon and boundary layer convection. In explicit runs, cold storm outflows provide a significant component of the monsoon flux.

Sea-breeze convection - a big deal in south Florida





Tellus DYNAMIC METEOROLOGY AND OCEANOGRAPHY
PUBLISHED BY THE INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

Coupling of convection and circulation at various resolutions

By CATHY HOHENEGGER*, LINDA SCHLEMMER and LEVI SILVERS,
Max Planck Institute for Meteorology, Hamburg, Germany

(Manuscript received 20 November 2014; in final form 17 February 2015)

ABSTRACT

A correct representation of the coupling between convection and circulation constitutes a prerequisite for a correct representation of precipitation at all scales. In this study, the coupling between convection and a sea breeze is investigated across three main resolutions: large-eddy resolution where convection is fully explicit, convection-permitting resolution where convection is partly explicit and coarse resolution where convection is parameterised. The considered models are the UCLA-LES, COSMO and ICON. Despite the use of prescribed surface fluxes, comparison of the simulations reveals that typical biases associated with a misrepresentation of convection at convection-permitting and coarser resolutions significantly alter the characteristics of the sea breeze. The coarse-resolution simulations integrated without convective parameterisation and the convection-permitting simulations simulate a too slow propagation of the breeze front as compared to the large-eddy simulations. From the various factors affecting the propagation, a delayed onset and intensification of cold pools primarily explains the differences. This is a direct consequence of a delayed development of convection when the grid spacing is coarsened. Scaling the time the sea breeze reaches the centre of the land patch by the time precipitation exceeds 2 mm day^{-1}, used as a measure for significant evaporation, yields a collapse of the simulations onto a simple linear relationship although subtle differences remain due to the use of different turbulence and microphysical schemes. Turning on the convection scheme significantly disrupts the propagation of the sea breeze due to a misrepresented timing (too early triggering) and magnitude (too strong precipitation evaporation in one of the tested convection schemes) of the convective processes.

photo by Jianhao Zhang

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2015MS000560

ITCZ structure as determined by parameterized versus explicit convection in aquachannel and aquapatch simulations

David S. Nolan[1], Stefan N. Tulich[2], and Joaquin E. Blanco[1]

[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, USA, [2]Cooperative Institute for Research in the Environmental Sciences, University of Colorado, Boulder, Colorado, USA

Key Points:

- Aquachannel and aquapatch models can be used to simulate the general circulation on an aquaplanet
- Grid-nesting within an aquachannel can be used to achieve cloud-resolving grid spacings
- Cloud-resolving simulations produce broader rainfall because they have propagating squall lines

Abstract Numerous studies using both global and regional models of the atmosphere have found daunting sensitivities of the structure and dynamics of the intertropical convergence zone (ITCZ) to the rep-

the higher resolution allows for the representation of squall lines and associated coldpools that propagate meridionally, redistributing rainfall away from the ITCZ and broadening the rainfall distribution.

nature geoscience

PERSPECTIVE

https://doi.org/10.1038/s41561-017-0005-4

Rediscovery of the doldrums in storm-resolving simulations over the tropical Atlantic

Daniel Klocke[1,2]*, Matthias Brueck[3], Cathy Hohenegger[3] and Bjorn Stevens[3]

The doldrums — a zone of calm and variable winds in the deep tropics between the trades — were of key importance to nineteenth century maritime travel. As a result, the region was a focus in atmospheric science at that time. However, as sailing ships were replaced by steamboats, scientific interest shifted to the heavy precipitating storms within the doldrums: the deep convective systems of the intertropical convergence zone. Now, in storm-system-resolving simulations over a period of two months that cover a large part of the tropical Atlantic, the doldrums are one of the most prominent features. The doldrums are substantially less pronounced in coarser-resolution simulations that use a parameterization for convection, despite their large-scale extent. We conclude that explicitly representing the storm scale dynamics and their coupling to the surface wind on the storm-system scales helps to maintain the systems of winds that define the doldrums. We suggest that the lack of these wind systems could explain the persistent tropical precipitation biases in climate models.

Wind Speed plot

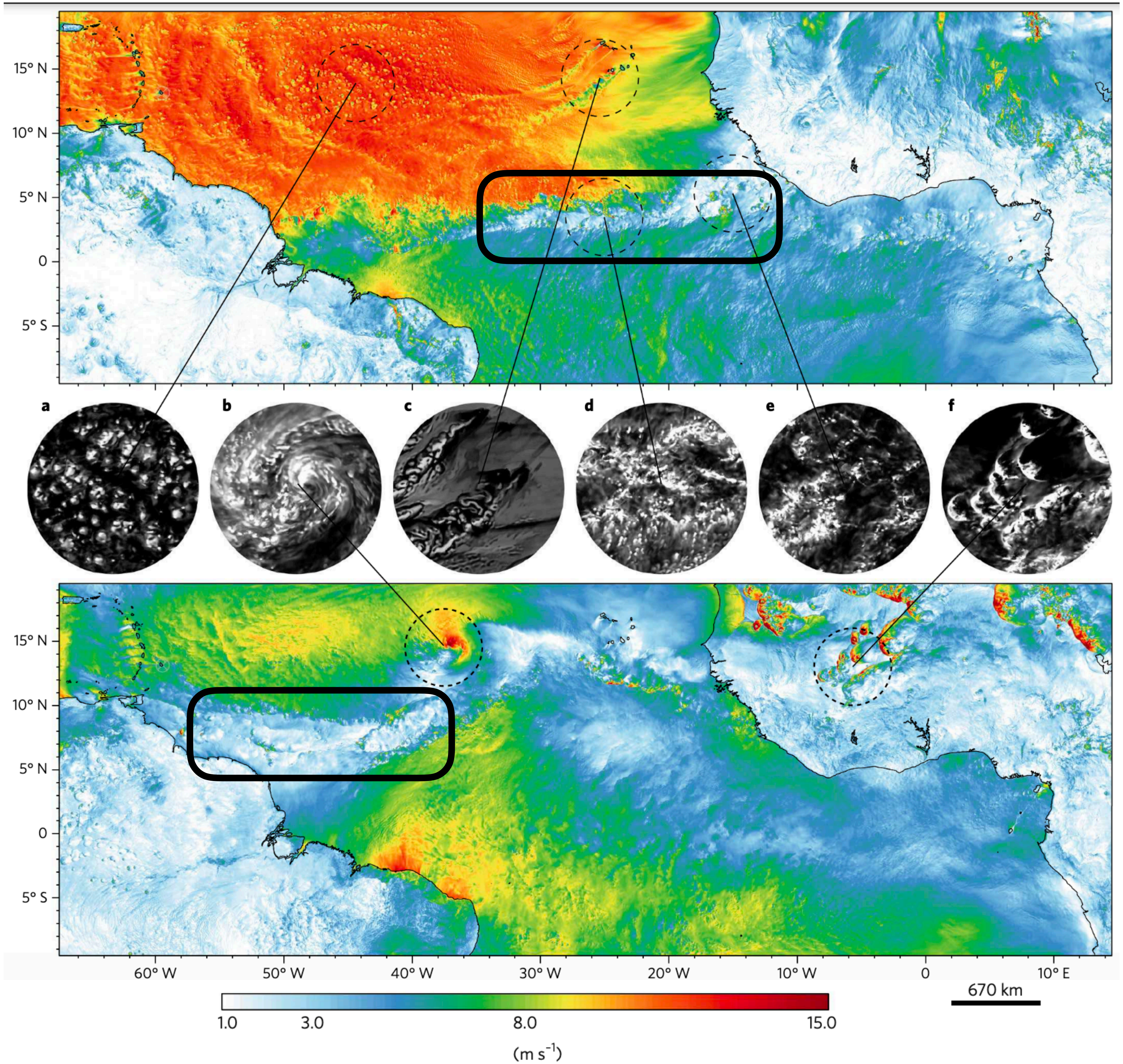


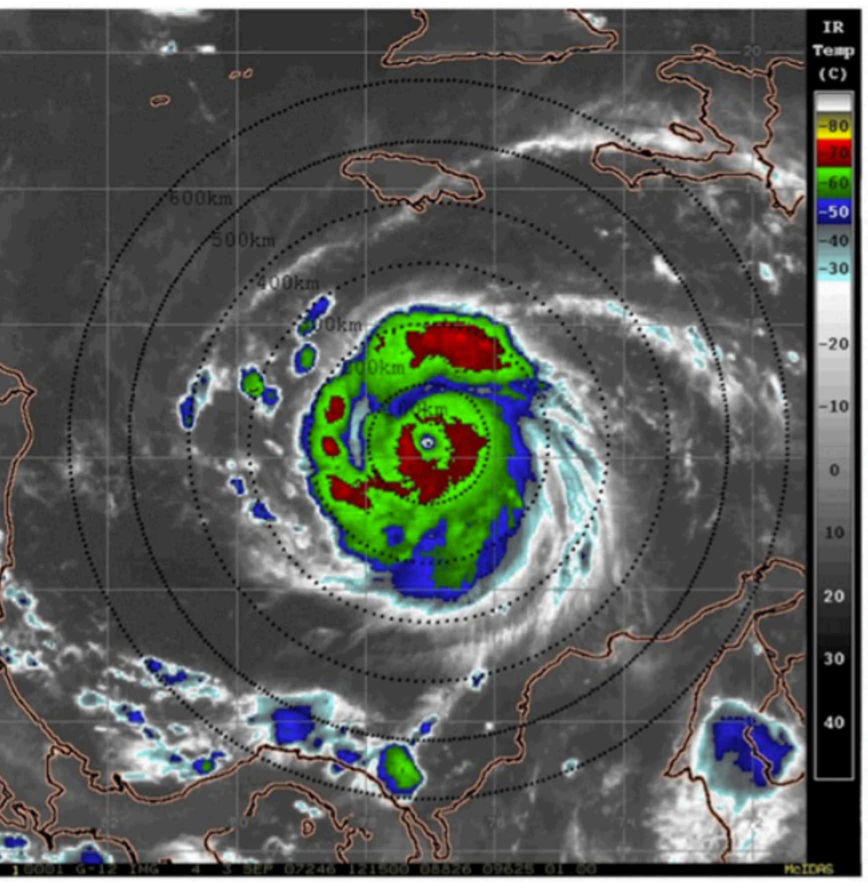
Fig. 1 | Snap-shot of wind speed at 10 m height in the storm-resolving simulations. An exemplary December (top) and August (bottom) day after 24 h of simulation time is shown. **a**–**f**, The bubble insets show liquid water path for some phenomena emerging from the simulations: shallow convective storms in the trades (**a**), hurricane Fiona (**b**), vortex streets (**c**), organized deep convective clusters (**d**), Calms and Tornados (**e**) and squall lines (**f**). The doldrums show up as a longitudinal band of low wind speeds (light-blue band with wind-speeds <3 m s^{-1}) over the ocean north of the Equator.

hurricanes….

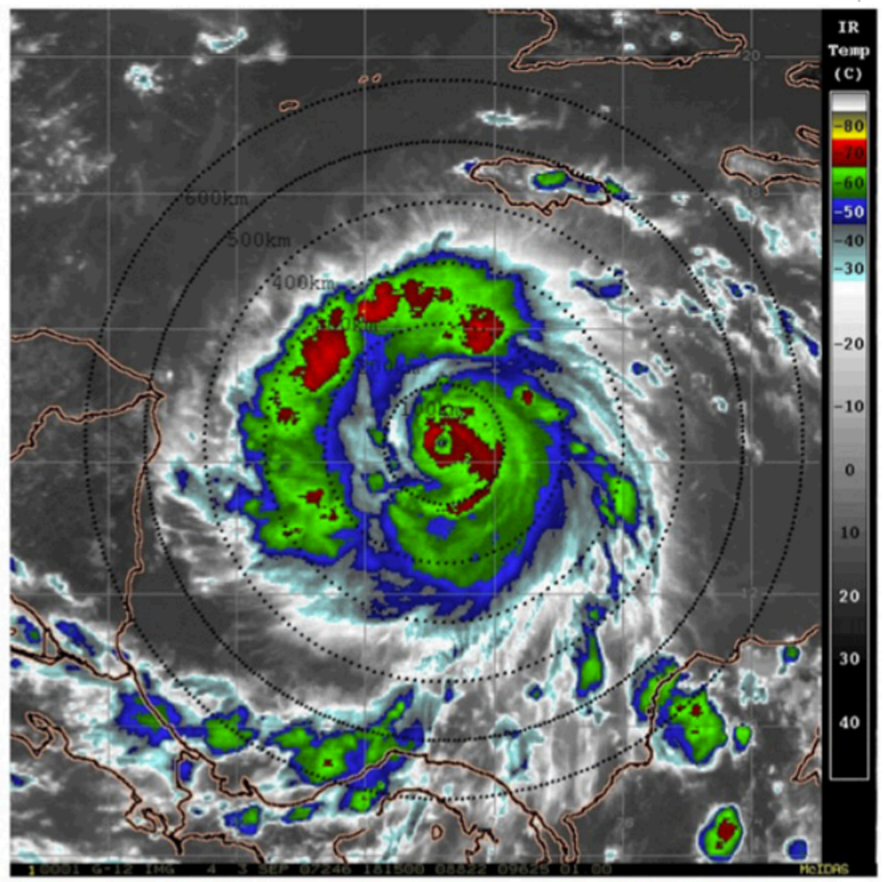
Tropical Cyclone Diurnal Cycle Signals in a Hurricane Nature Run

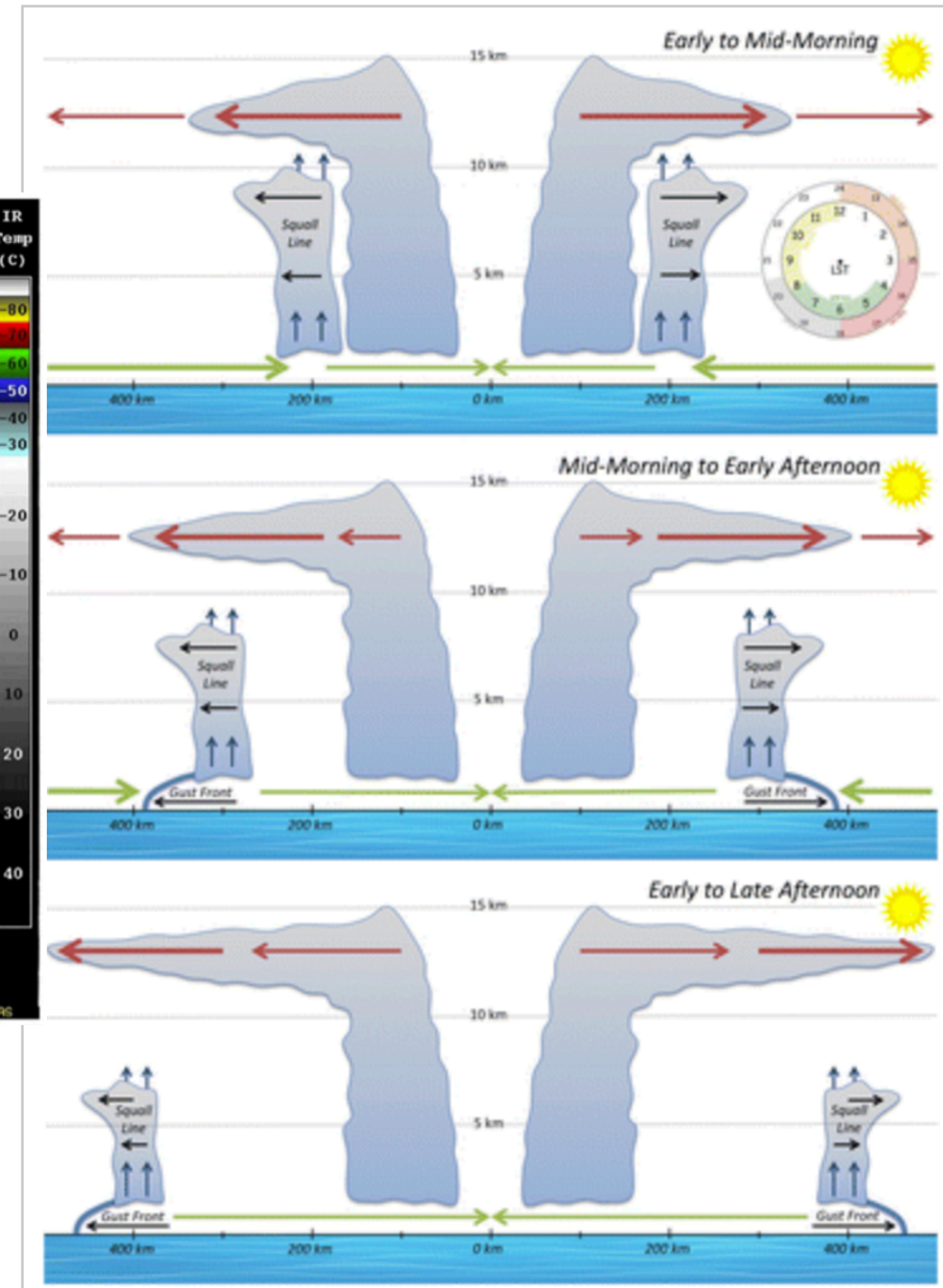
Jason P. Dunion
Cooperative Institute for Marine and Atmospheric Studies, University of Miami, and NOAA/Atlantic Oceanographic and Meteorological Laboratory/Hurricane Research Division, Miami, Florida

7am



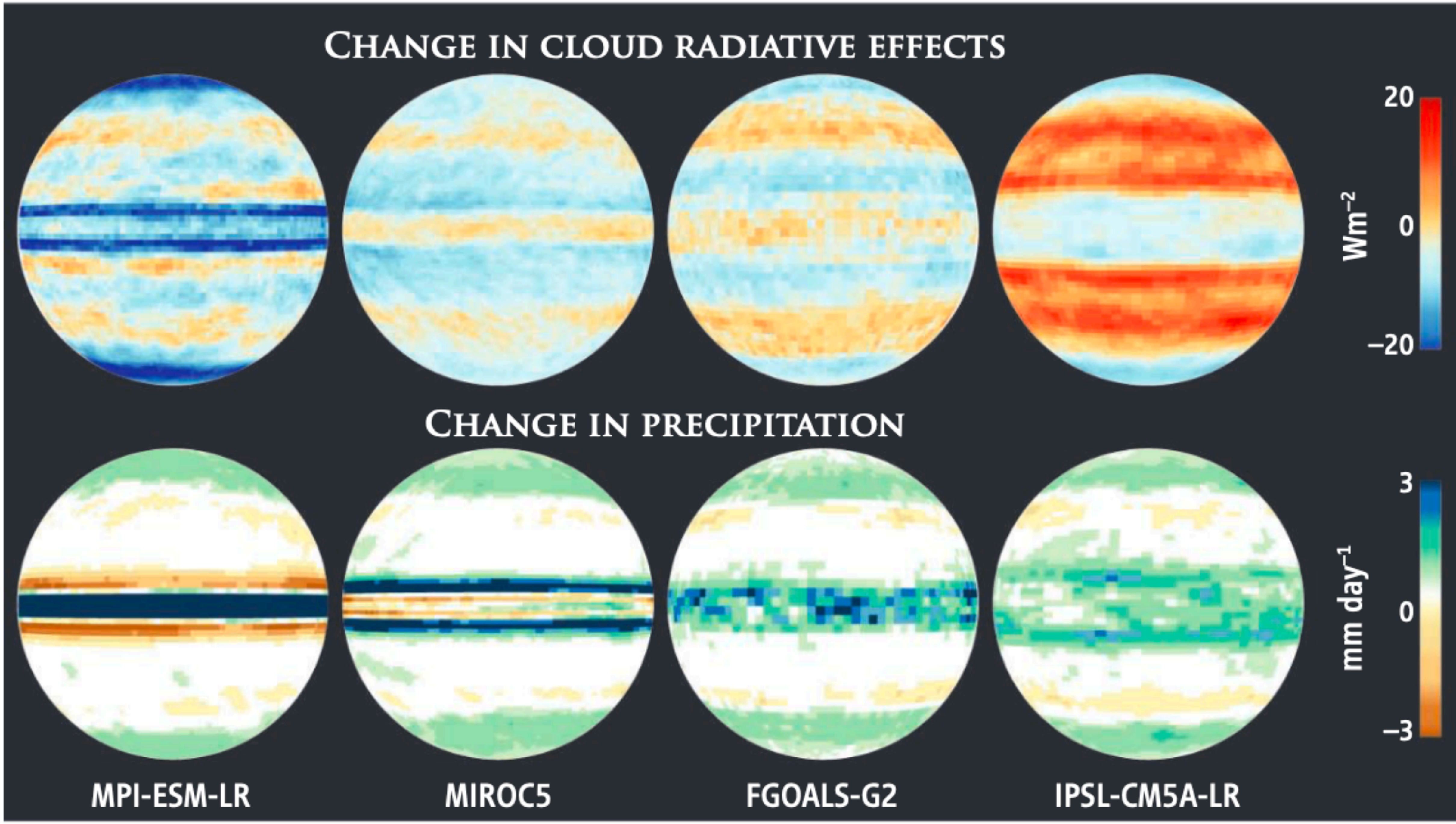
1pm





Dunion et al., 2014, MWR

And for course - evaluation of parameterized convection



Wide variation. The response patterns of clouds and precipitation to warming vary dramatically depending on the climate model, even in the simplest model configuration. Shown are changes in the radiative effects of clouds and in precipitation accompanying a uniform warming (4°C) predicted by four models from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for a water planet with prescribed surface temperatures.

Bony and Stevens

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2016MS000666

Coupled radiative convective equilibrium simulations with explicit and parameterized convection

Cathy Hohenegger[1] and Bjorn Stevens[1]

Key Points:

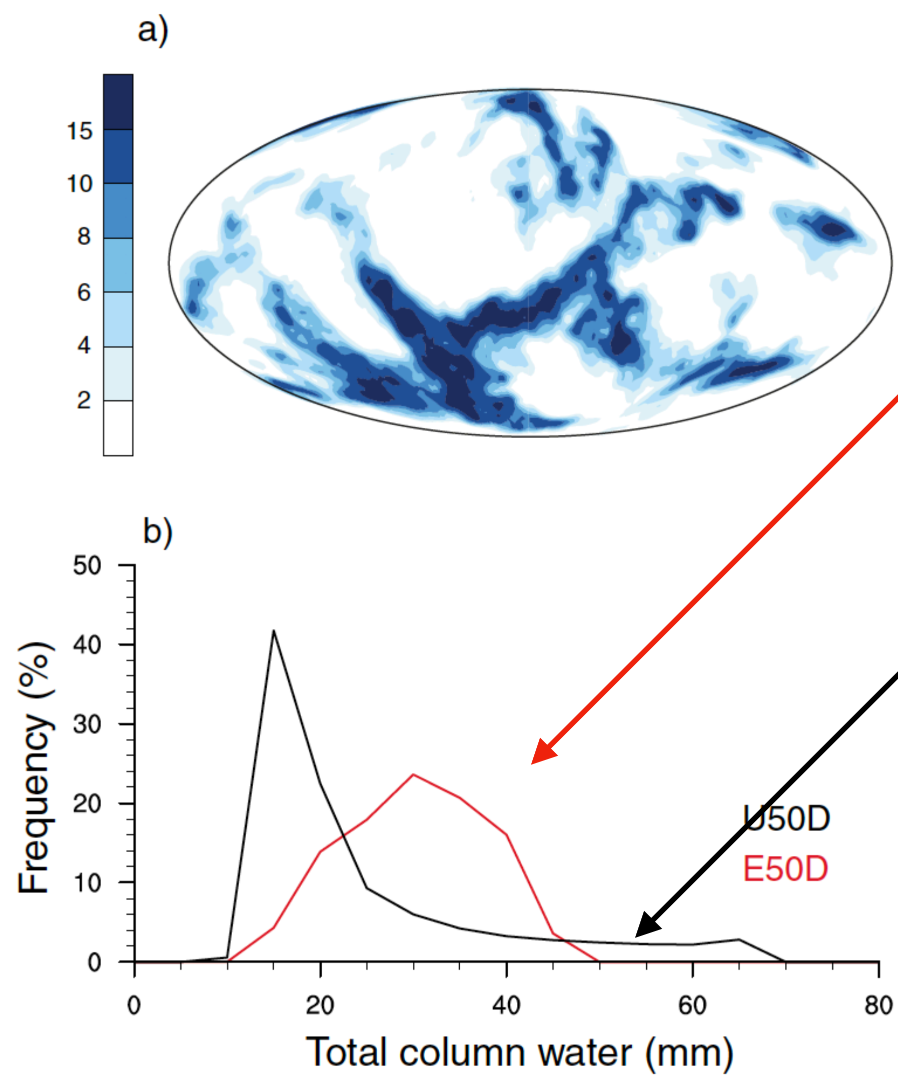
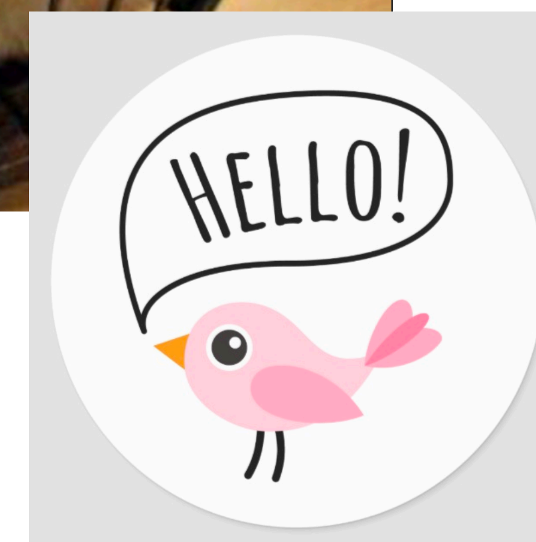
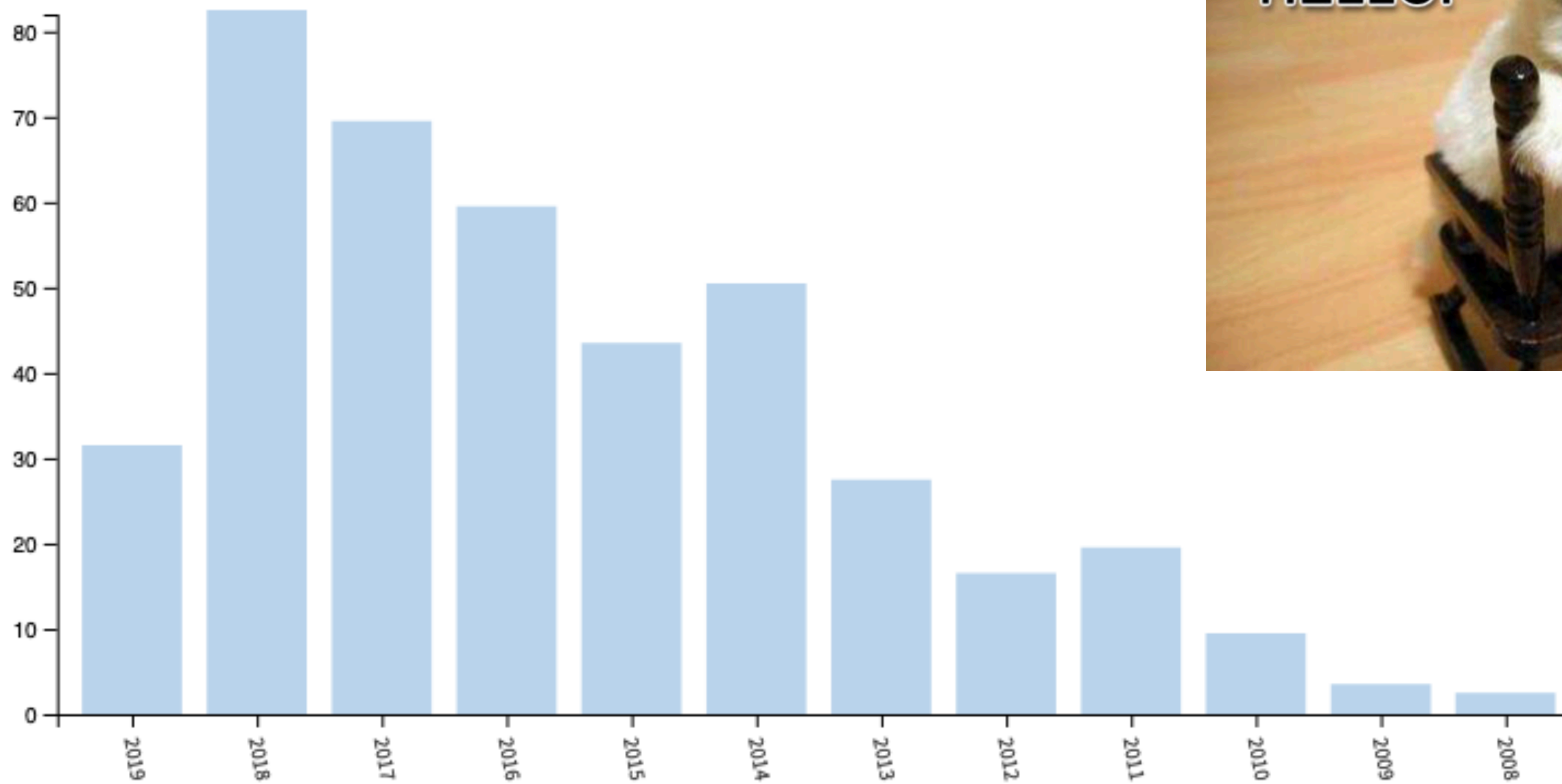


Figure 8. (a) Global map of the precipitation distribution (mm d^{-1}) drawn on a Mollweide projection for E50D and (b) histogram of total column water I_q (mm) in E50D (red) and U50D (black). All data averaged over 1 month taken from the equilibrium state.

"The convection-permitting simulations also suggest that cloud feedbacks, as arising when perturbing the equilibrium state, may be very different, and in our case less negative, than what emerges from general circulation models."

This seems like the right reason to be excited by the growing availability of CP model simulations





2019 1998

Web of science search on ‘convection-permitting model’

It’s all a matter of perspective….

but doesn’t replacing parameterized convection with resolved convection still leave you with a ‘they said vs they said’?

NO.

Now can do

to

comparisons

Convection-permitting Models

Observations

…of processes….

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD021371

This article is a companion to *Varble et al.* [2014] doi:10.1002/2013JD021372.

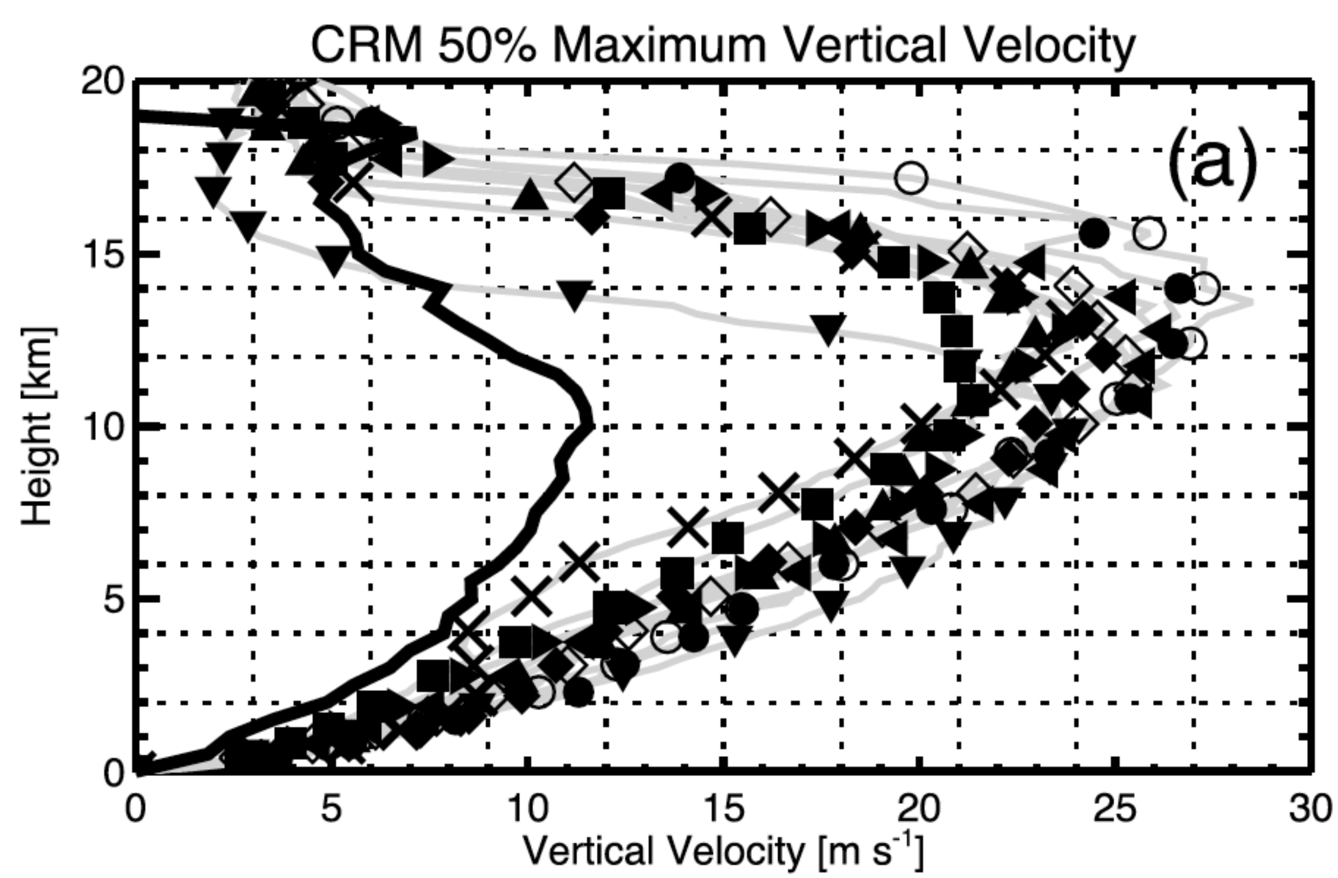
Evaluation of cloud-resolving and limited area model intercomparison simulations using TWP-ICE observations: 1. Deep convective updraft properties

Adam Varble[1], Edward J. Zipser[1], Ann M. Fridlind[2], Ping Zhu[3], Andrew S. Ackerman[2], Jean-Pierre Chaboureau[4], Scott Collis[5], Jiwen Fan[6], Adrian Hill[7], and Ben Shipway[7]

Key Points:
- High biased simulated convective dBZ partly results from overly intense updrafts

Key Points:

- High biased simulated convectiv
  dBZ partly results from overly
  intense updrafts
- Lofted large simulated rainwater
  contents produce excessive
  vertical velocities
- Increasing resolution does not
  completely solve simulation bias



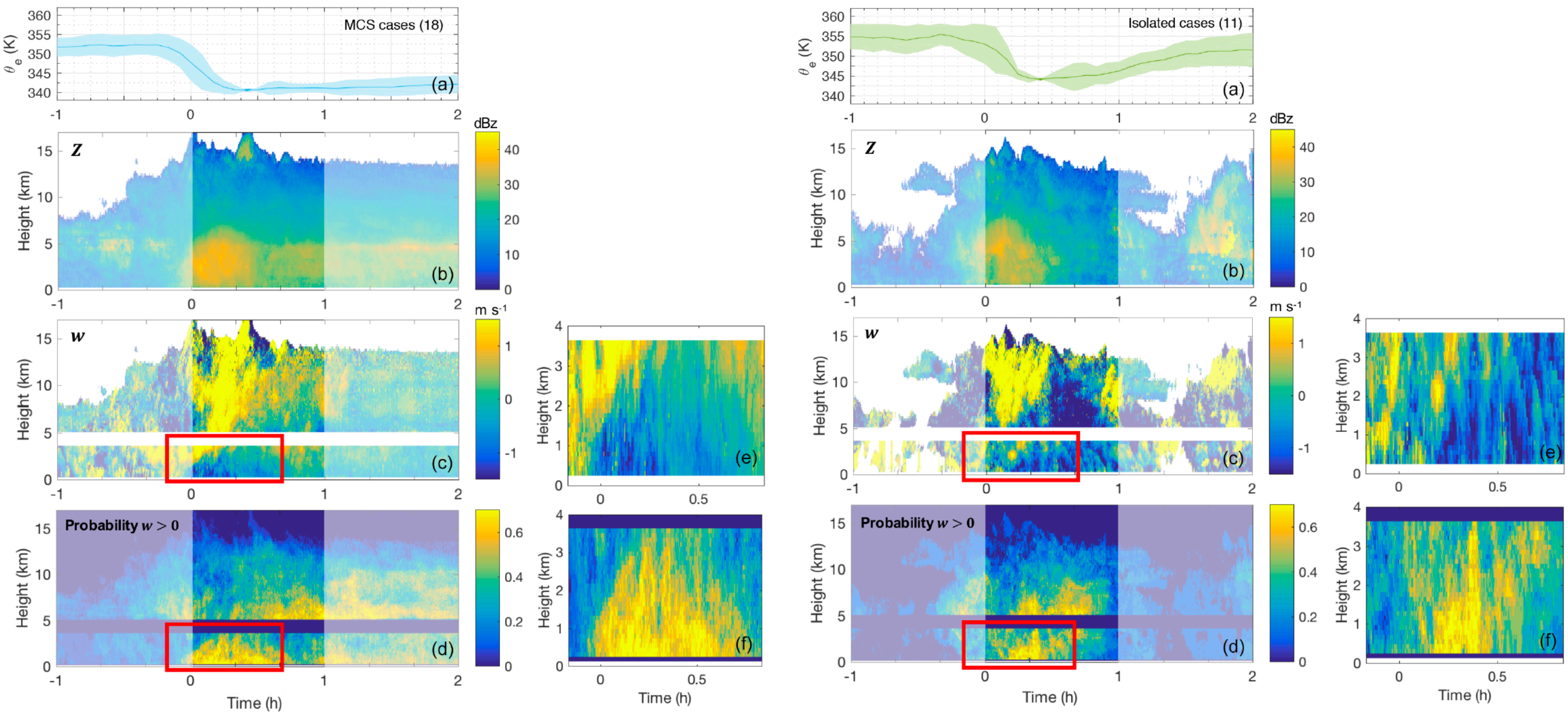
Black solid line= dual doppler vertical velocities, updraft cores only (obs. uncertainty of few m/s)

Tropical continental downdraft characteristics: mesoscale systems versus unorganized convection

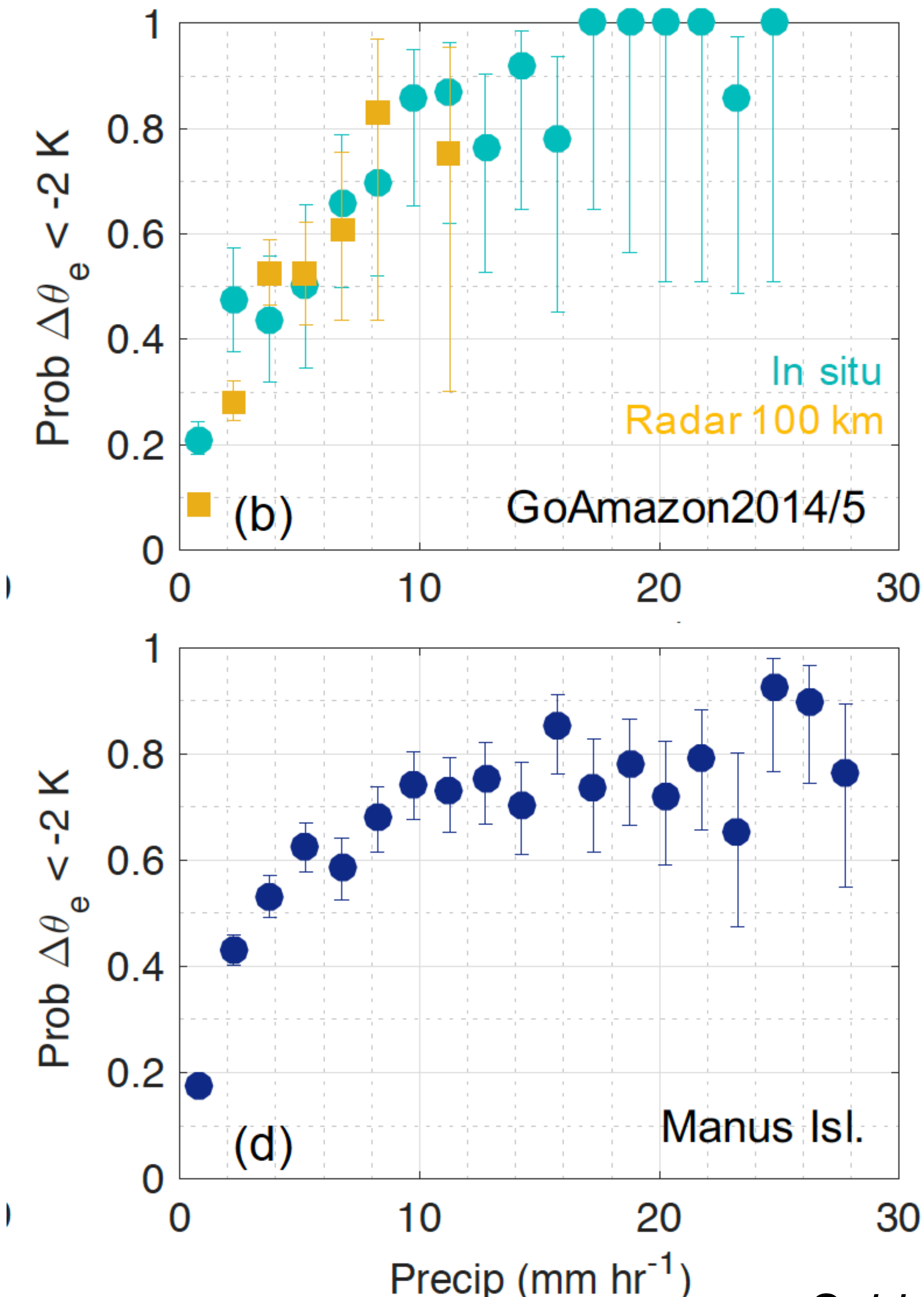
ACP, 2018

Kathleen A. Schiro and J. David Neelin

Department of Atmospheric and Oceanic Sciences, University of California Los Angeles, Los Angeles, CA, USA



Used radar wind profiler data to assess up/downdrafts

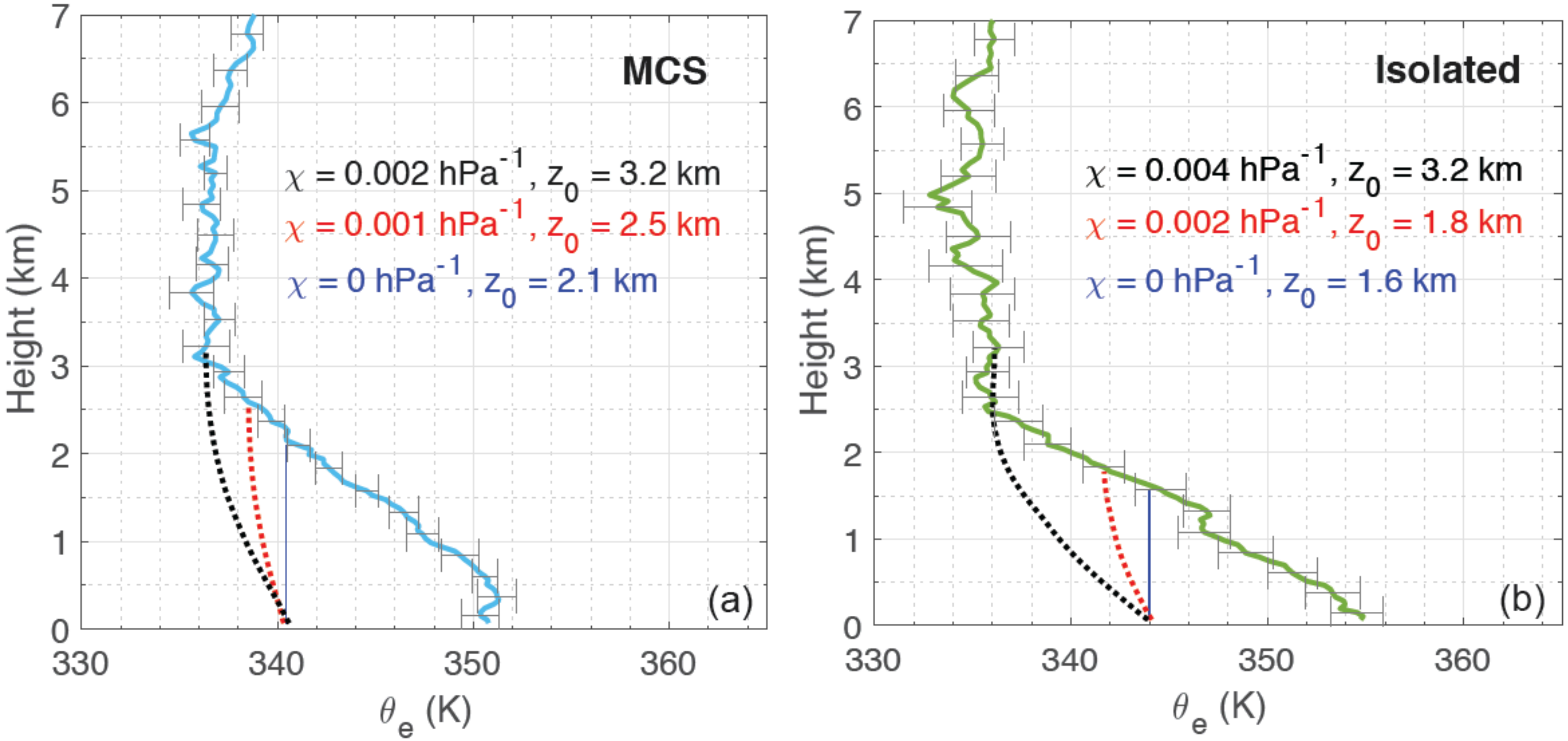


More rain -> increased likelihood of stronger downdrafts

(perhaps model downdrafts are typically too strong?)

Schiro and Neelin, 2018

Can be used to evaluate entrainment assumptions in models



(conclusion: models underentrain)

An arguably not-yet exploited opportunity for CP-model assessment of downdrafts:

RESEARCH LETTER
10.1002/2015GL063025

Key Points:
- The ASCAT scatterometer detects downdrafts from mesoscale convective systems
- Observations of OLR, rain, and surface temperature corroborate the downdrafts
- ASCAT-observed downdrafts lag the peak convection by 8–12 h

Correspondence to:
T. J. Kilpatrick,
tkilpatrick@ucsd.edu

Citation:
Kilpatrick, T. J., and S.-P. Xie (2015), ASCAT observations of downdrafts from mesoscale convective systems, *Geophys. Res. Lett.*, *42*, 1951–1958, doi:10.1002/2015GL063025.

ASCAT observations of downdrafts from mesoscale convective systems

Thomas J. Kilpatrick[1,2] and Shang-Ping Xie[1,2]

[1]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California, USA, [2]International Pacific Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, USA

Abstract Downdrafts of air cooled by evaporating raindrops are an essential component of mesoscale convective systems (MCSs). Here we use surface wind observations from the Advanced SCATterometer (ASCAT) to identify MCS downdrafts over the western equatorial Pacific Ocean as regions of horizontal wind divergence exceeding 10^{-4} s^{-1}. More than 1300 downdrafts are identified over the observation period (2009–2014). The downdraft signal in the surface winds is validated with satellite measurements of brightness temperature and rainfall rate, and surface buoy measurements of air temperature; composite analysis with these measurements indicates that ASCAT detects downdrafts that lag the peak convection by 8–12 h. While ASCAT resolves *mesoscale* downdrafts in regions of light rain, a composite against buoy air temperature indicates that ASCAT fails to resolve the stronger *convective-scale* downdrafts associated with heavy rainfall at squall fronts. Nevertheless, the global observations by the satellite scatterometer open a new avenue for studying MCSs.

What does this matter for convective aggregation?

RESEARCH ARTICLE
10.1002/2016MS000802

Organization of tropical convection in low vertical wind shears: Role of updraft entrainment

Adrian M. Tompkins[1] and **Addisu G. Semie**[1,2]

[1]Earth System Physics, Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, [2]Now at: Laboratoire de Météorologie Dynamique, Paris, France

Key Points:
- Updraft entrainment a critical process for spontaneous organization of deep convection
- With O(km) horizontal grid sizes, updraft entrainment represented by subgrid turbulence schemes, approaches vary by orders of magnitude
- Critical role of model assumptions highlights need for simulation ensembles and community organization model intercomparison project

Correspondence to:
A. Tompkins,
tompkins@ictp.it

Citation:
Tompkins, A. M., and A. G. Semie (2017), Organization of tropical convection in low vertical wind shears: Role of updraft entrainment, *J. Adv. Model. Earth Syst.*, *9*, 1046–1068,

Abstract Radiative-convective equilibrium simulations with a 2 km horizontal resolution are conducted to investigate the impact on convective organization of different parameterizations for horizontal and vertical subgrid turbulence mixing. Three standard approaches for representing horizontal diffusion produce starkly differing mixing rates, particularly for the entrainment mixing into updrafts, which differ by more than an order of magnitude between the schemes. The simulations demonstrate that the horizontal subgrid mixing of water vapor is key, with high mixing rates a necessary condition for organization of convection to occur, since entrainment of dry air into updrafts suppresses convection. It is argued that diabatic budgets, while demonstrating the role of spatially heterogeneous radiative heating rates in driving organization, can overlook the role of physical processes such as updraft entrainment. These results may partially explain previous studies that showed that organization is more likely to occur at coarser resolutions, when entrainment is solely represented by subgrid-scale turbulence schemes, highlighting the need for benchmark simulations of higher horizontal resolution. The recommendation is for the use of larger ensembles to ensure robustness of conclusions to subgrid-scale parameterization assumptions when numerically investigating convective organization, possibly through a coordinated community model intercomparison effort.

Might observations have a role in informing mixing representations?

Observations may also be able to shed light on dynamical vs thermodynamical Initiation of convection

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1029/2018JD028634

Moisture Distributions in Tropical Cold Pools From Equatorial Indian Ocean Observations and Cloud-Resolving Simulations

Arunchandra S. Chandra[1], Paquita Zuidema[1], Steven Krueger[2], Adam Kochanski[2], Simon P. de Szoeke[3], and Jianhao Zhang[1]

[1]Department of Atmospheric Sciences, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA, [2]Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT, USA, [3]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA

Key Points:

- Six of the eight strongest surface cold pools, from 300 total, occur during convectively suppressed conditions with a dry midtroposphere
- Cold pools help explain why cumulus congestus are common in the Tropics
- A constrained cloud-resolving model simulation has realistic rain rates but too much rain evaporation in the boundary layer

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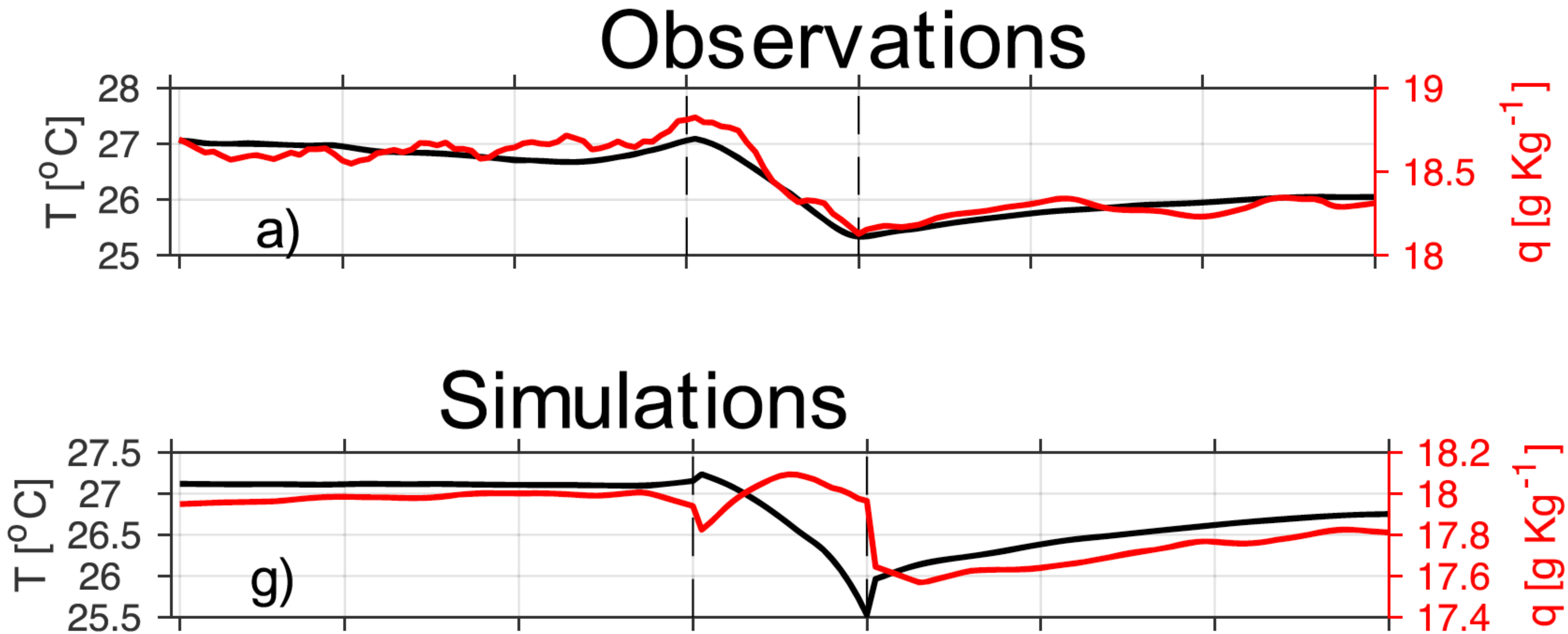
Citation:
Chandra, A. S., Zuidema, P., Krueger, S. K., Kochanski, A. K., de Szoeke, S. P., & Zhang, J. (2018). Moisture distributions in tropical cold pools from equatorial Indian Ocean observations and cloud-resolving simulations. *Journal of Geophysical Research: Atmospheres*, *123*. https://doi.org/10.1029/2018JD028634

Received 8 MAR 2018
Accepted 21 SEP 2018
Accepted article online 26 SEP 2018

Abstract The near-surface characteristics of approximately 300 convective cold pools over the equatorial Indian Ocean are studied using surface meteorological variables from two equatorial Indian Ocean sites, radar imagery, and constrained cloud-resolving simulations. The observed temperature drop at cold pool onset is typically accompanied by a drying and a decrease in moist static energy, signifying air transport from above the boundary layer through precipitation-induced downdrafts. The decrease in the surface water vapor mixing ratio is more pronounced for stronger temperature drops. Composites reveal a slight enhancement in moisture coincident with a slight enhancement in temperature prior to the cold pool frontal temperature drop. The slight enhancements occur prior to a gust of increased surface winds, suggesting that the immediate cause is wind convergence. A statistical analysis combined with a focus on selected case studies is consistent with a view that the strongest cold pools occur in intermediate column water vapor paths with drier midtropospheres. Such conditions are more likely to occur during convectively suppressed phases of the Madden-Julian Oscillation, when cold pool mesoscale organization facilitates the ability of cumulus congestus to reach the middle troposphere. Cold pools thus help explain why tropical cumulus congestus are common. Cloud-resolving simulations capture realistic rain rates and surface wind changes (and thereby surface fluxes). The evolution in the model near-surface moisture field is unrealistic, however, with an erroneous moisture enhancement inside the cold pool edge that is attributed to rain evaporation. This supports a further focus on the model representation of cold pool frontal dynamics and mixing.

Do models evaporate too much rain?



Chandra et al., 2018, JGR

Figure 12. (left) Gan Island observations. (right) Gan Island System for Atmospheric Modeling simulations. 8–16 October 2011 and 18–25 December 2011 only.

In observations, a bump up in surface water vapor mixing ratio at beginning of cold pool is consistent with a surface wind convergence

But what about the simulations?

Organization of Tropical Convection in Low Vertical Wind Shears: The Role of Cold Pools

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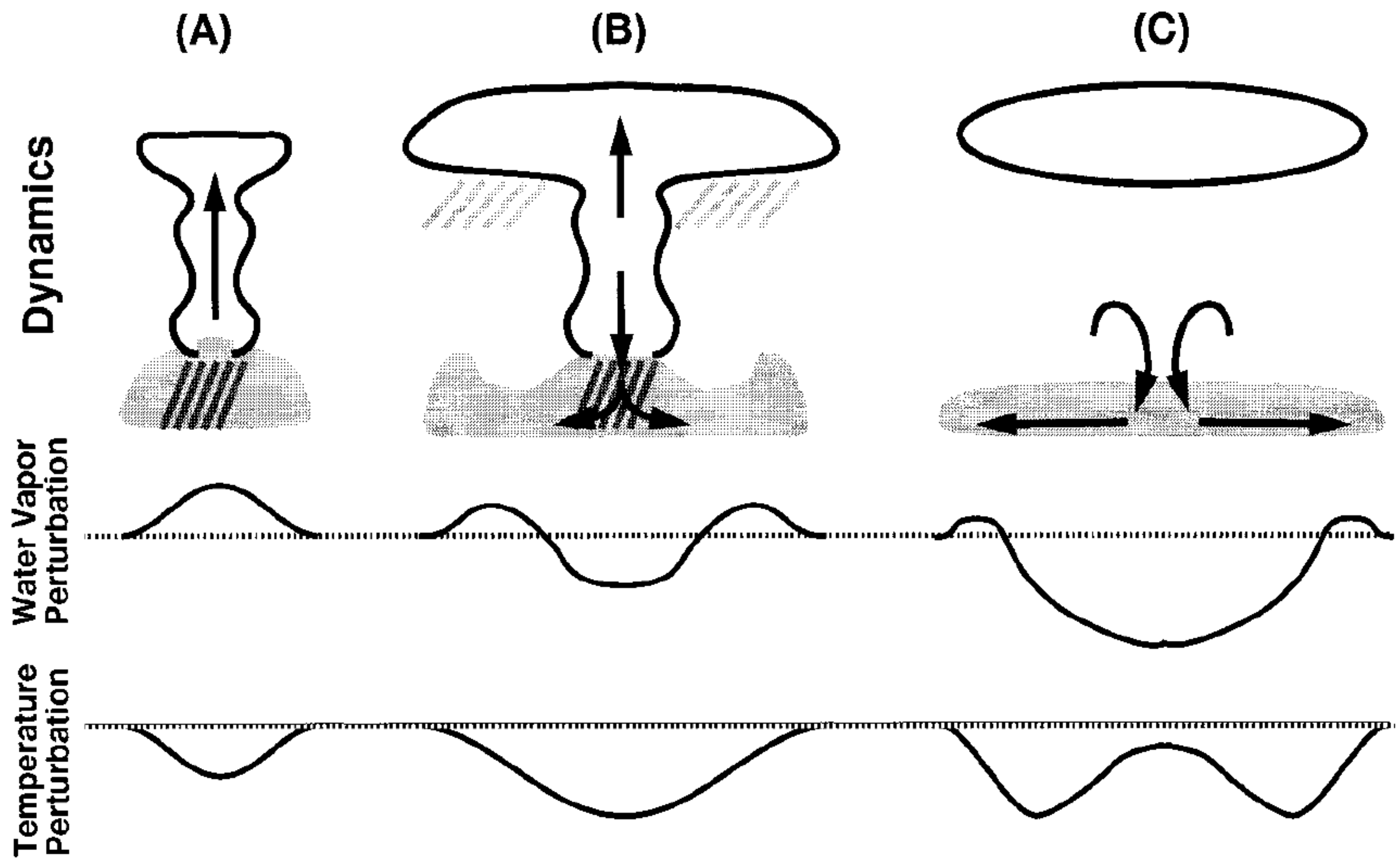


FIG. 14. Schematic diagram of cold pool development. (A) A deep convective tower develops, moistening and cooling the subcloud layer through the evaporation of rainfall, air that already had high θ_e values. (B) As convective tower matures, downdrafts introduce cold, dry air into the boundary layer, and the moist band is advected at the edges of the newly formed cold pool. (C) Convective system dissipates, leaving cirrus remnants. The edges of the cold pool have already recovered in temperature due to the action of surface fluxes, and are able to trigger new convection. In the wake of the downdraft, environmental air is entrained into the boundary layer, causing the fast recovery of the temperature to prewake conditions, but increasing the moisture perturbation.

Moisture clearly necessary
For cumulus development

But could it also be: Behind every great "isolated" cumulus cloud there's also a cold pool ?

Simple roll circulations enough to un-homogeneize the local thermodynamic environment

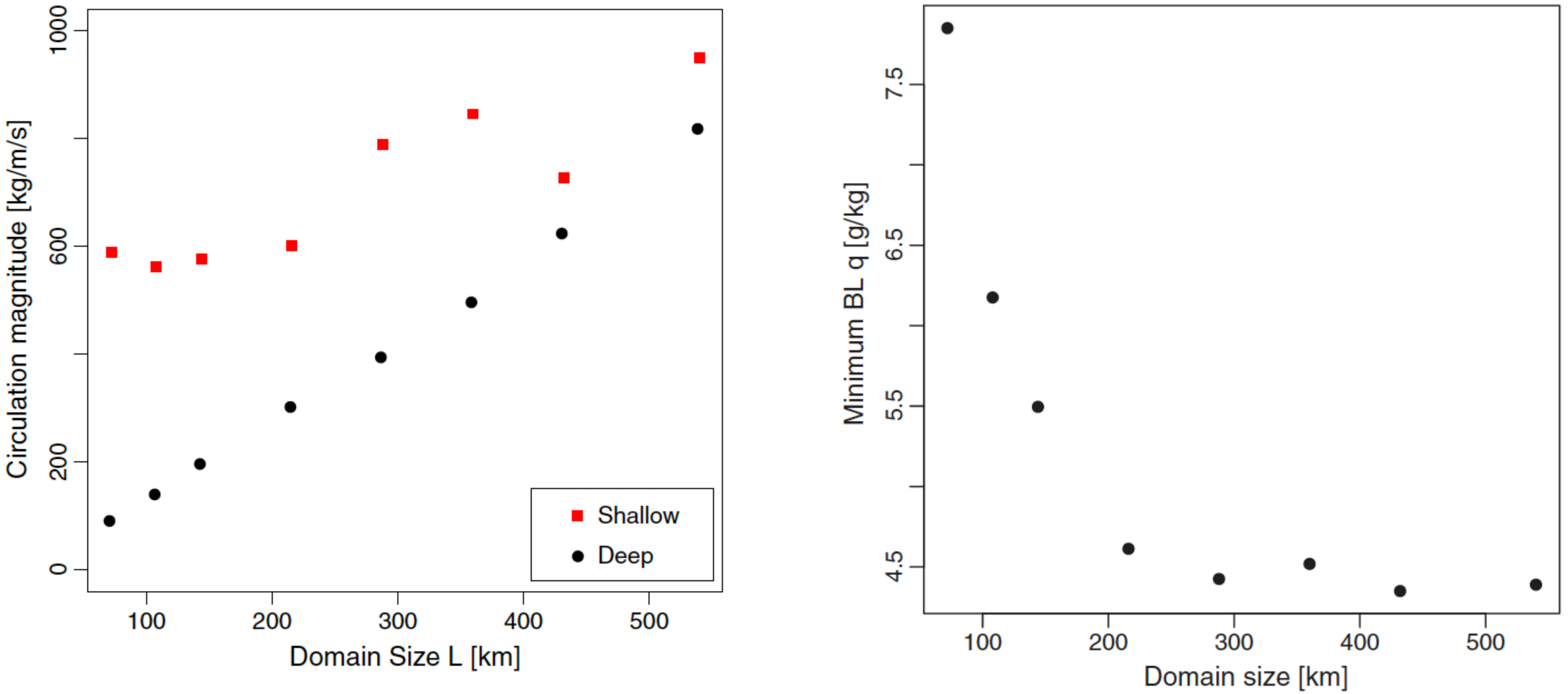
What does this have to do with climate?

As we resolve more model processes, we can better constrain how these processes will evolve within a warmer climate (mixing being key)

e.g. Sherwood et al., 2014: "*Spread in model climate sensitivity traced to atmospheric convective mixing*"

…and gain fundamental insights along the way….

Thayer-Calder and Randall, 2015: *entrainment drying dominates boundary layer budgets*
Raymond, 1995: *boundary layer mainly dries because of convective downdrafts*



Jeevanjee and Romps, 2013: deep convection dries BL through convective downdrafts,
Shallow convection moistens the boundary layer (no drying downdrafts)


Low clouds observations & their connection to models of all scales remain relevant
Looking for a student to work on the US component to the EUREC4A project….
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