The role of the boundary layer when deep convection is very active: Forcing or response?

David Randall

Acknowledgments

Don Dazlich

Mark Branson

The “forcing and response” paradigm

“These prognostic equations involve terms of two types: ‘Cloud terms,’ which depend on the mass flux distribution function…; and ‘large-scale terms,’ such as large-scale advection, surface eddy fluxes, and radiational heating terms, which do not depend on the mass flux distribution function….We call the large-scale terms the large-scale forcing.”

—AS74

$$R + F \cong 0$$

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“The large-scale forcing can be divided into two parts: … the ‘cloud layer forcing’ and the ‘mixed layer forcing.’”

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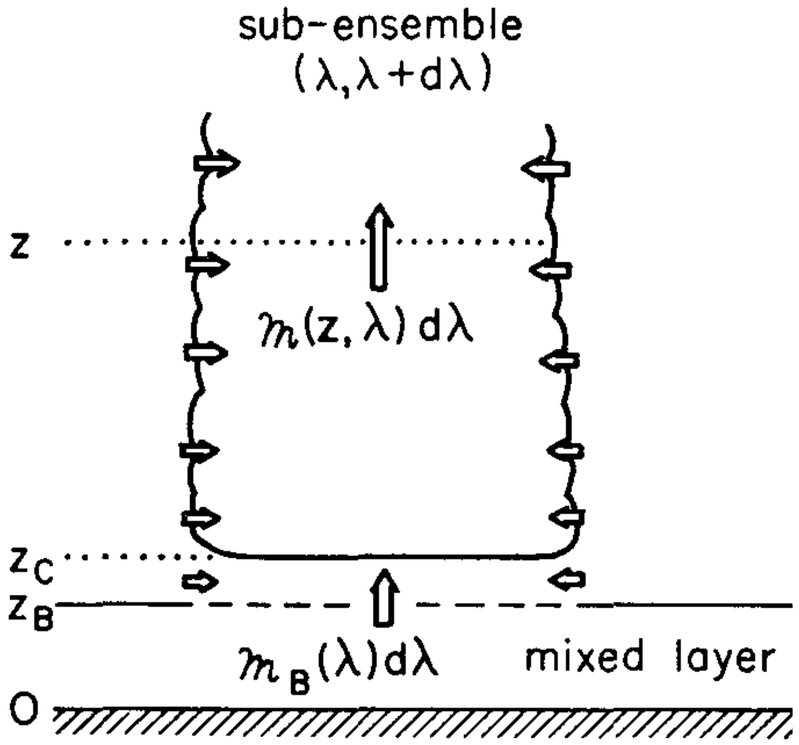
The mixed-layer forcing



The mixed-layer forcing exerts a powerful influence on the CAPE,
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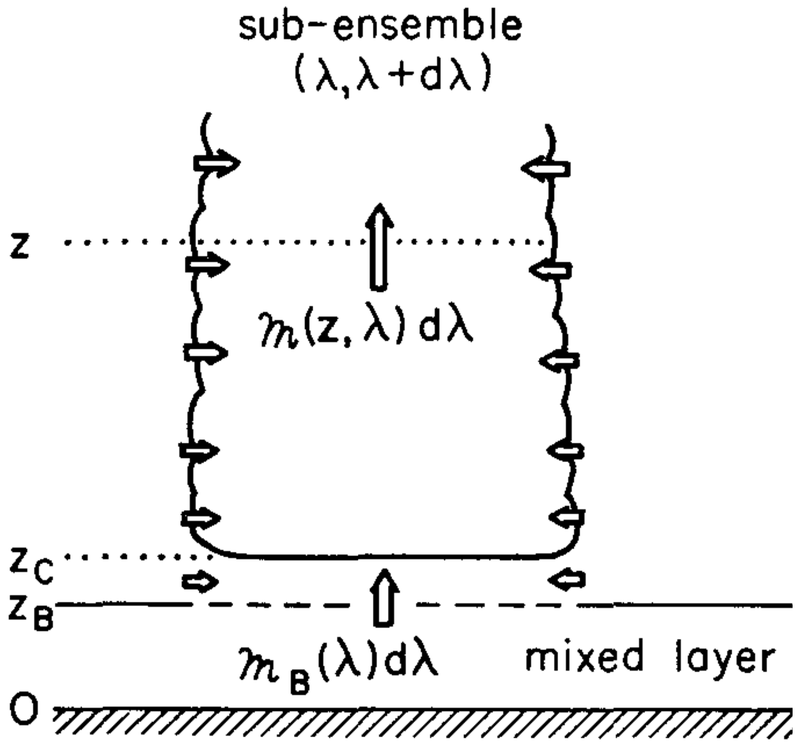
The mixed-layer forcing



Surface evaporation

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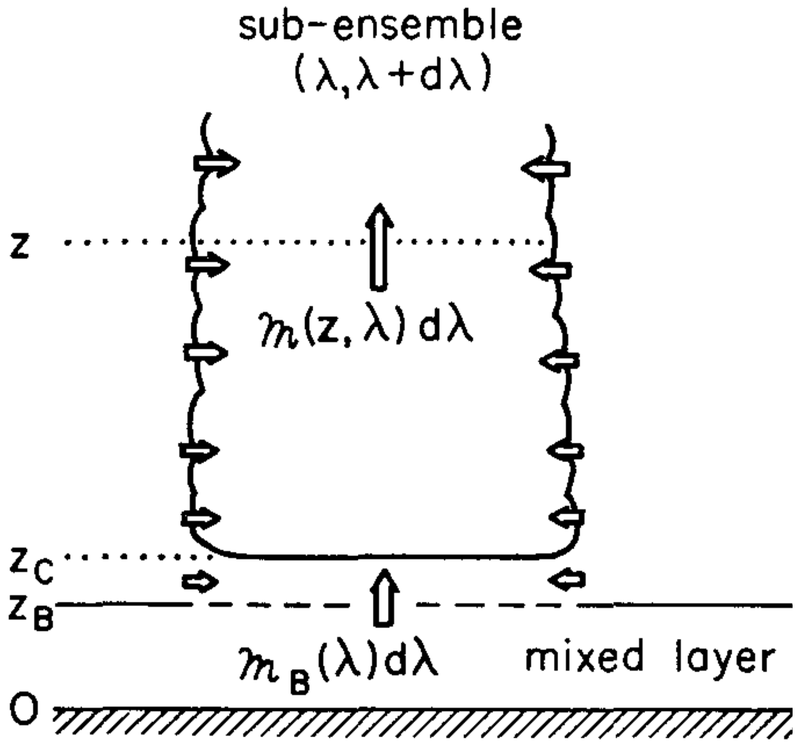

Entrainment into the mixed layer

Surface evaporation

Surface sensible heat flux

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The mixed-layer forcing

A key missing ingredient:
Downdrafts

Surface evaporation

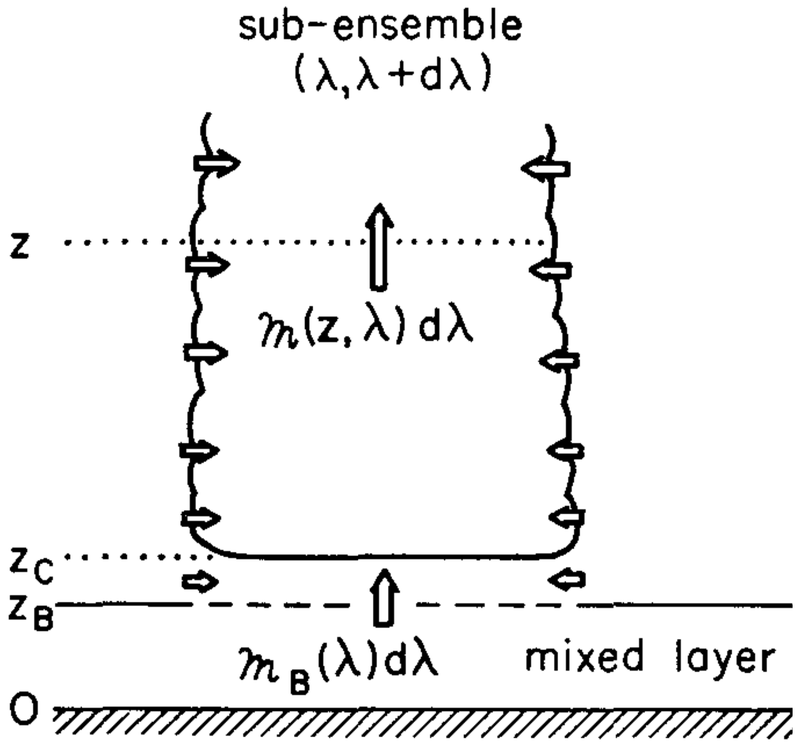

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Fig. 38 of Wayne Schubert's dissertation

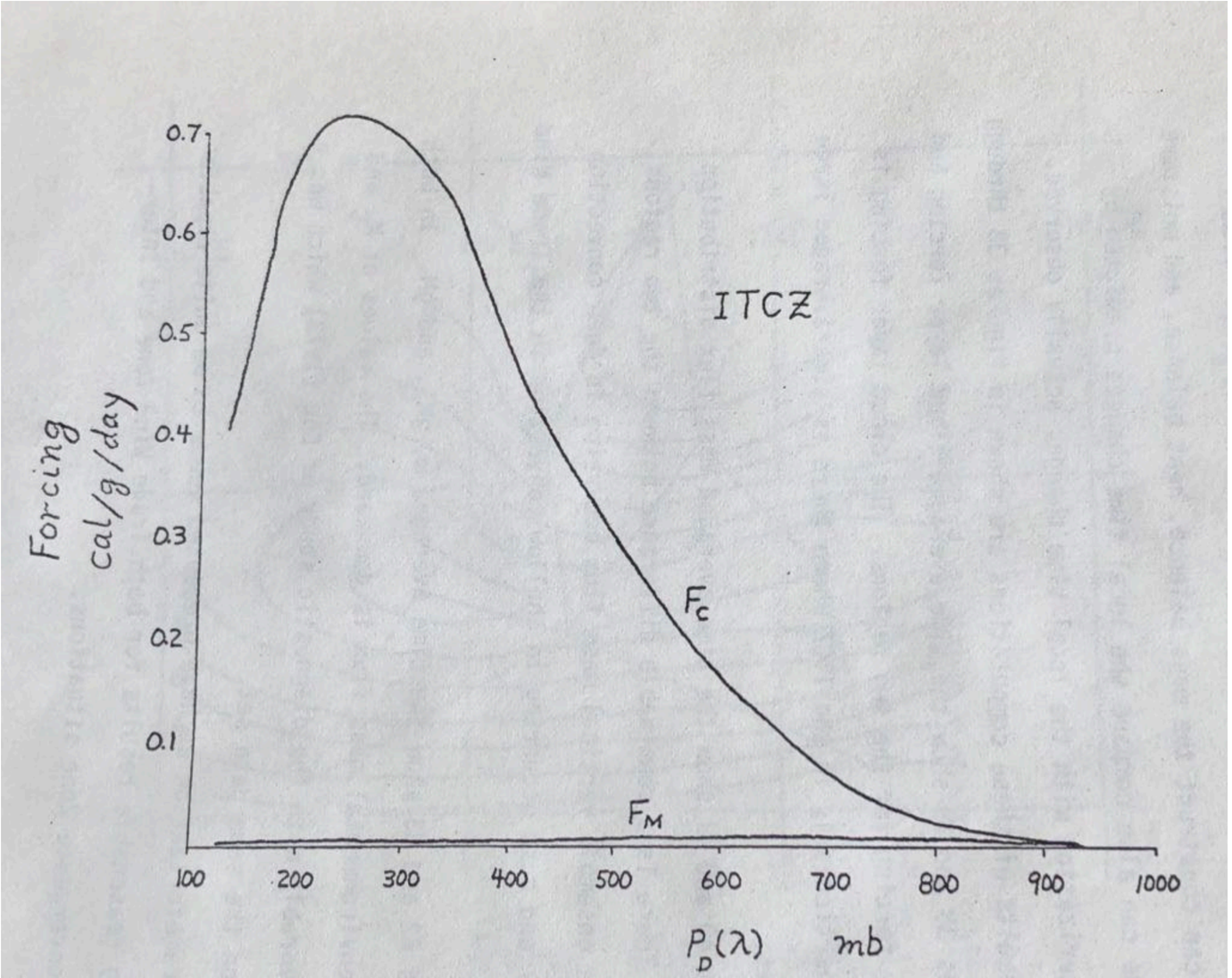


Figure 38

"So, Wayne," I said…

Fig. 38 of Wayne Schubert's dissertation

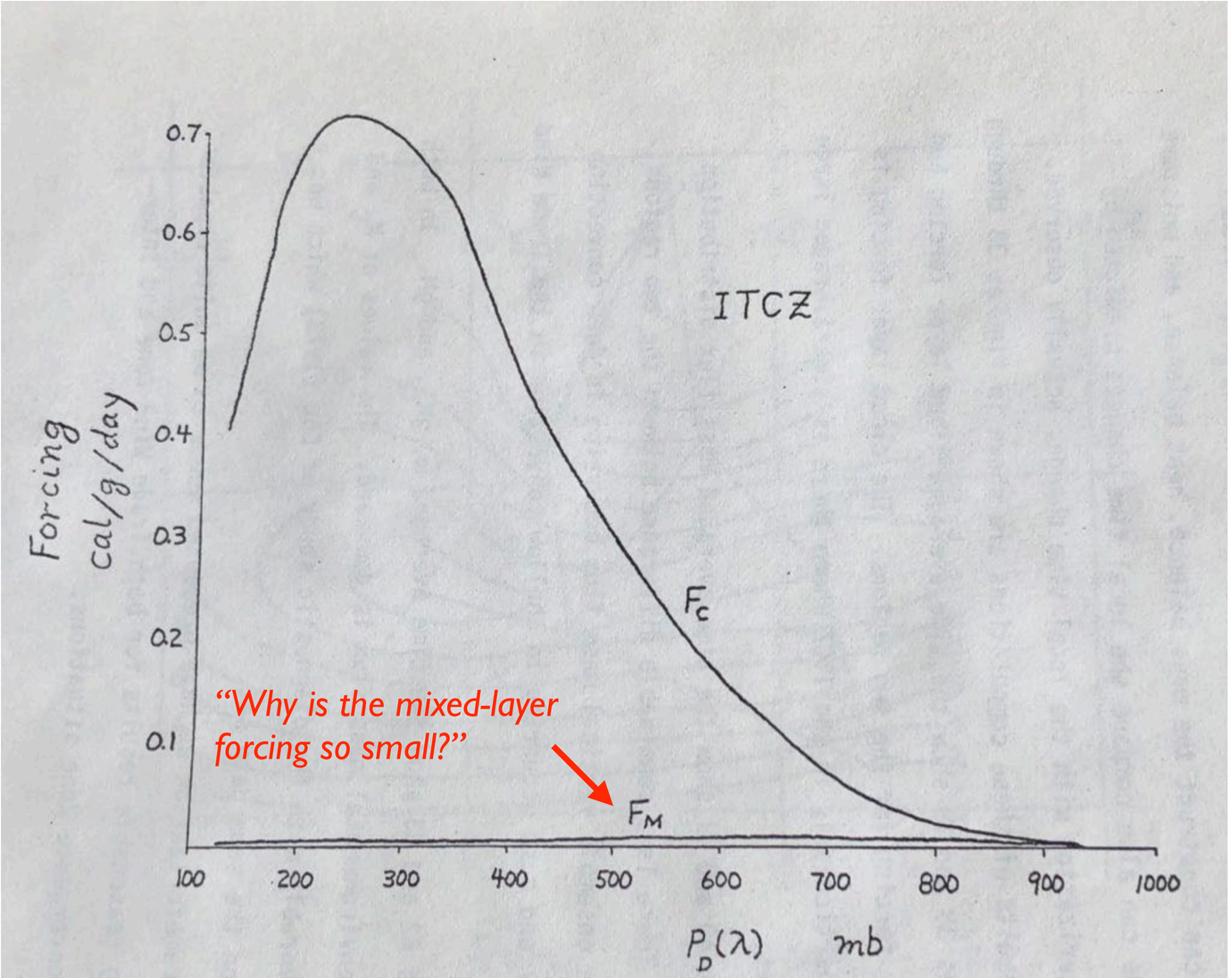
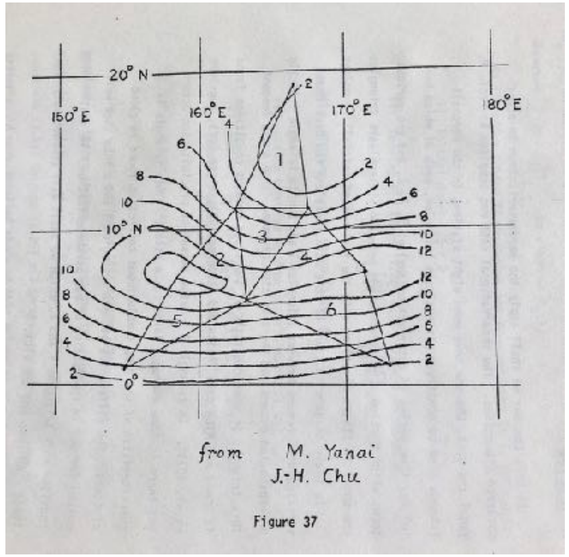


Figure 38

"So, Wayne," I said…

“Well,” said Wayne…

AS74 did not include downdrafts, so the moistening by surface evaporation has to be balanced by some combination of horizontal advection and the entrainment of dry air across the top of the mixed layer.



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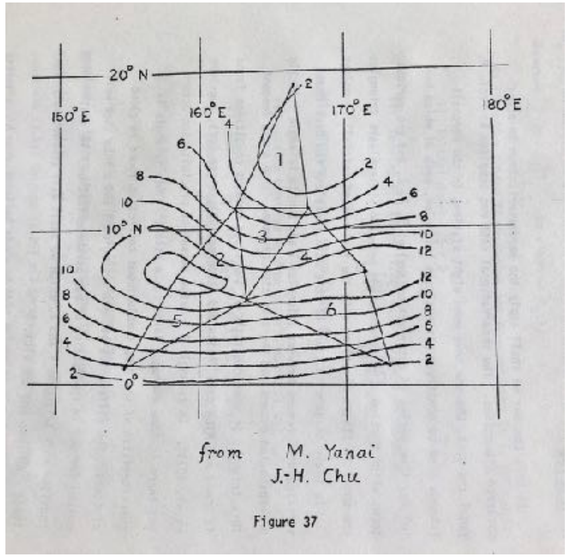

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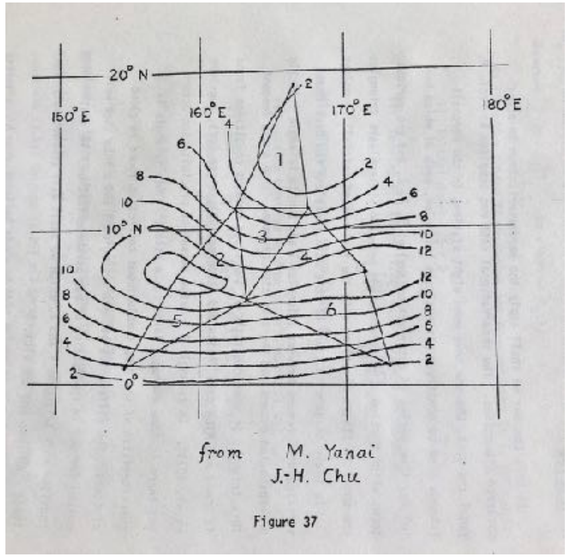

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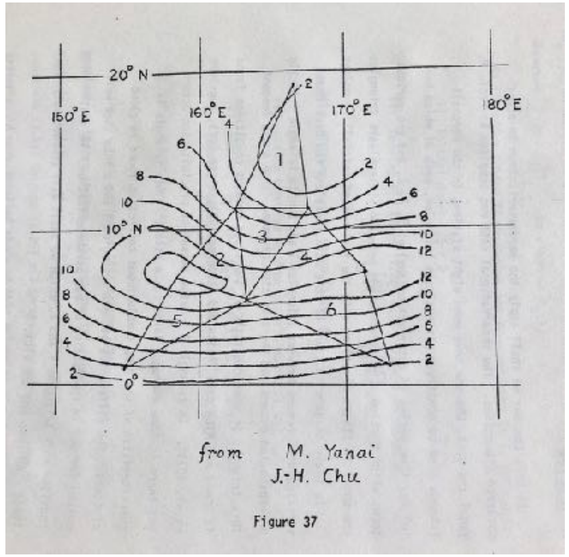

He may have assumed that the entrained air was dry enough to balance the surface evaporation.

According to one school of thought,
the mixed-layer forcing is dominant.

Boundary-Layer Quasi-Equilibrium (BLQE)

Regulation of Moist Convection over the West Pacific Warm Pool

DAVID J. RAYMOND

Physics Department and Geophysical Research Center, New Mexico Institute of Mining and Technology, Socorro, New Mexico

(Manuscript received 25 August 1994, in final form 24 May 1995)

"…convection is regulated by a balance between the respective tendencies of surface fluxes and convective downdrafts to increase and decrease boundary-layer equivalent potential temperature."

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15 NOVEMBER 1995 RAYMOND 3945

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The BLQE hypothesis asserts that the mixed-layer forcing is the primary driver for deep convection.

The physical argument is that the powerful mixed-layer forcing leads to cumulus downdrafts that efficiently cancel it out.

This is a hypothetical but explicit and plausible *negative feedback* of deep convection that regulates the mixed-layer's properties.

The plot thickens…

Free Tropospheric Quasi-Equilibrium (FTQE)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. D14, 10.1029/2001JD001005, 2002

Convective quasi-equilibrium in midlatitude continental environment and its effect on convective parameterization

Guang J. Zhang
Center for Atmospheric Sciences, Scripps Institution of Oceanography, La Jolla, California, USA

Received 28 June 2001; revised 10 December 2001; accepted 17 December 2001; published 31 July 2002.

Guang Zhang argues that the convective response is whatever is needed to cancel destabilization by the cloud-layer forcing.

He says that the mixed-layer forcing should be ignored.

FTQE is the antithesis of BLQE.

It is, however, consistent with Wayne's thesis.

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When I first heard about FTQE, I was very skeptical.

But there is now a body of work...

Zhang, G. J., 2002: Convective quasi-equilibrium in midlatitude continental environment and its effect on convective parameterization. *J. Geophys. Res.: Atmospheres*, **107**, 4220.

Zhang, G. J., 2003a: Convective quasi-equilibrium in the tropical western Pacific: Comparison with midlatitude continental environment. *J. Geophys. Res.: Atmospheres*, **108**, 4592.

Zhang, G.J., 2003b: Roles of tropospheric and boundary layer forcing in the diurnal cycle of convection in the US southern Great Plains. *Geophys. Res. Lett.*, **30**.

Zhang, G. J. and M. Mu., 2005a: Effects of modifications to the Zhang−McFarlane convection parameterization on the simulation of the tropical precipitation in the National Center for Atmospheric Research Community Climate Model, version 3. *J. Geophys. Res: Atmospheres*, **110**.

Zhang, G.J. and Mu, M., 2005b: Simulation of the Madden–Julian oscillation in the NCAR CCM3 using a revised Zhang–McFarlane convection parameterization scheme. *J. Climate*, **18**, 4046-4064.

Zhang, G. J. and H. Wang, 2006: Toward mitigating the double ITCZ problem in NCAR CCSM3. *Geophysical Research Letters*, **33**.

Bechtold, P., N. Semane, P. Lopez, J.-P. Chaboureau, A. Beljaars, and N. Bormann, 2014: Representing equilibrium and nonequilibrium convection in large-scale models. *J. Atmos. Sci.*, **71**, 734-753.

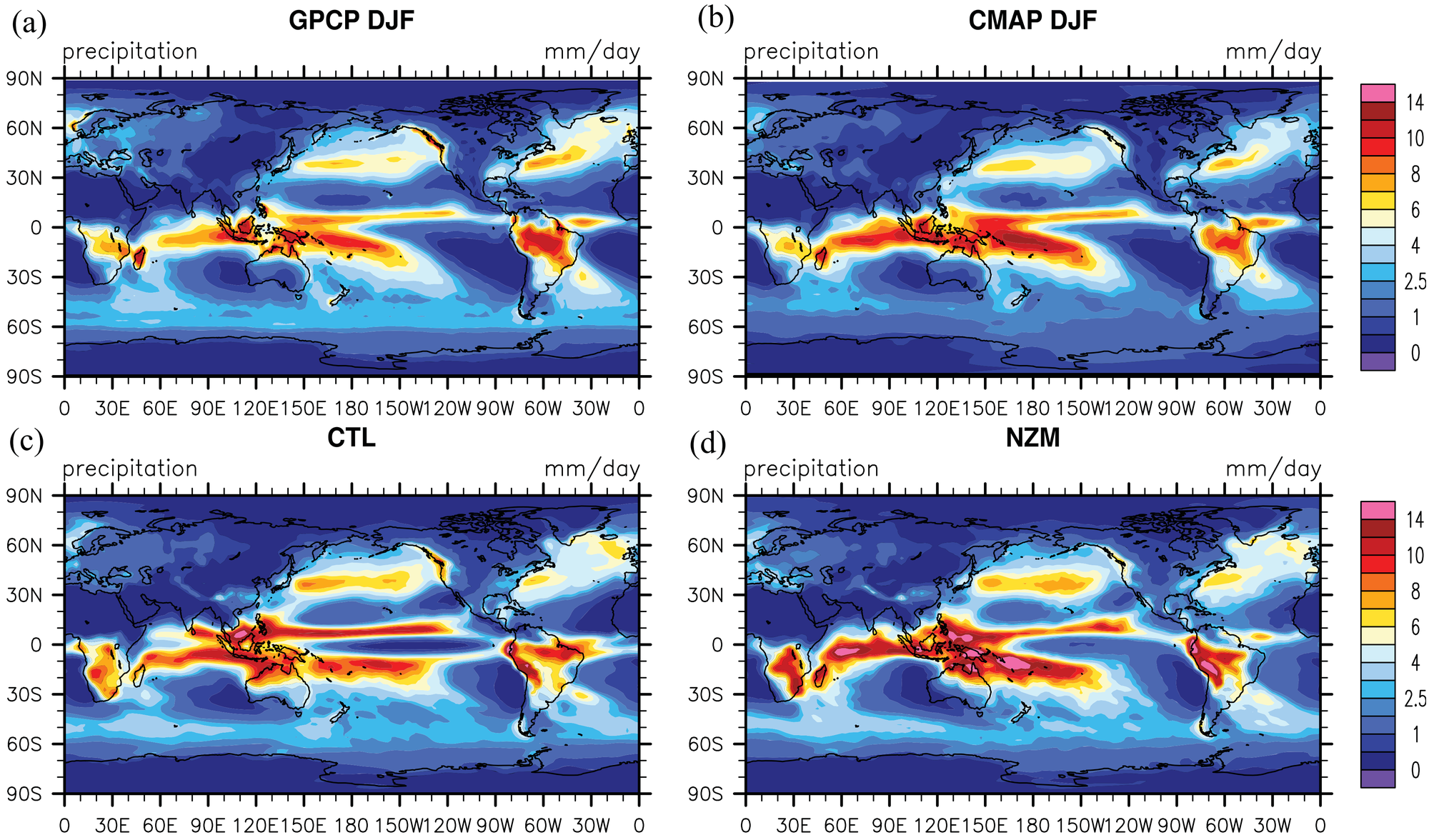
Song, F. and Zhang, G.J., 2016. Effects of southeastern Pacific sea surface temperature on the double-ITCZ bias in NCAR CESM1. *Journal of Climate*, **29**, 7417-7433.

Song, X. and G. J. Zhang, 2018: The roles of convection parameterization in the formation of double ITCZ syndrome in the NCAR CESM: I. Atmospheric processes. *J. Adv. Modeling Earth Syst.*, **10**, 842-866.

Song, X. and G. J. Zhang, 2009: Convection parameterization, tropical Pacific double ITCZ, and upper-ocean biases in the NCAR CCSM3. Part I: Climatology and atmospheric feedback. *J.Climate*, **22**, 4299-4315.

Song, X. and G. J. Zhang, 2018: The roles of convection parameterization in the formation of double ITCZ syndrome in the NCAR CESM: I. Atmospheric processes. *Journal of Advances in Modeling Earth Systems*, **10**, pp.842-866.

Results from CESM 1.2.1 (CAM 5.3)



From Song & Zhang 2018

We need to understand this.

We need to understand this.

Guang Zhang's tests show that FTQE works well in the CAM.

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I am not aware of any physical argument that purports to explain why FTQE should work.

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It just works.

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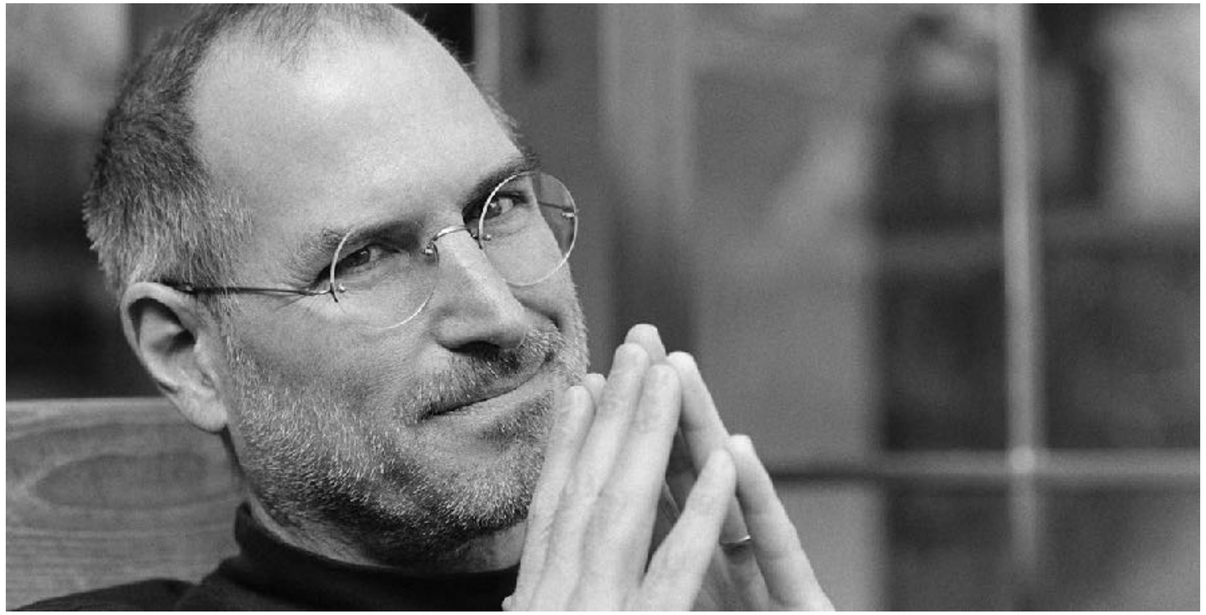
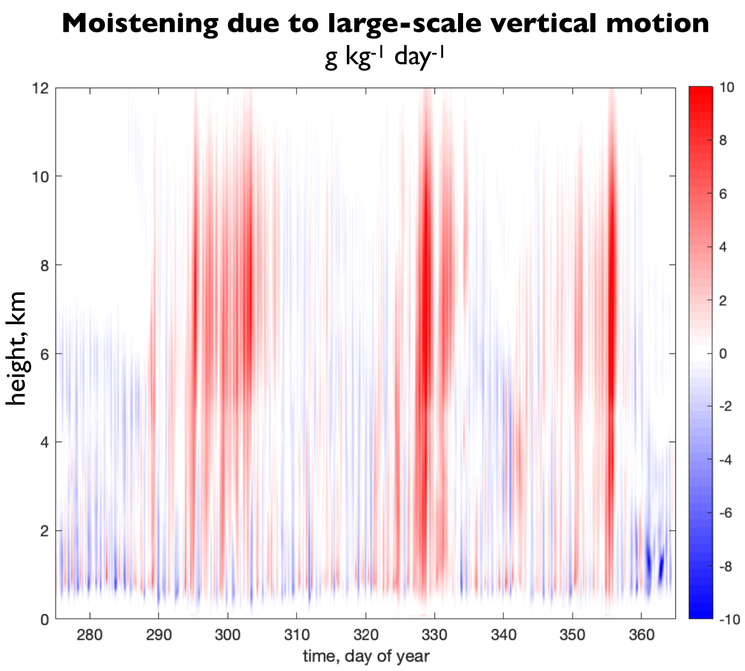
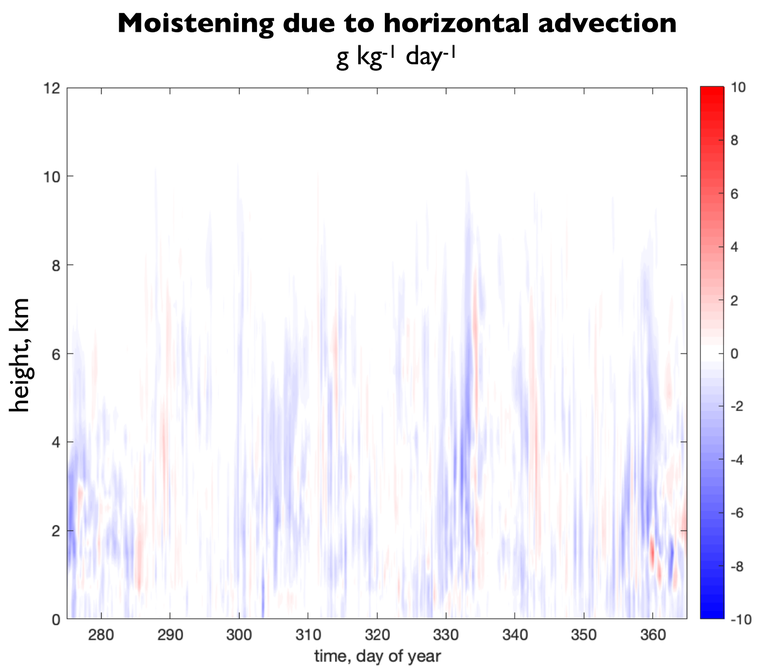
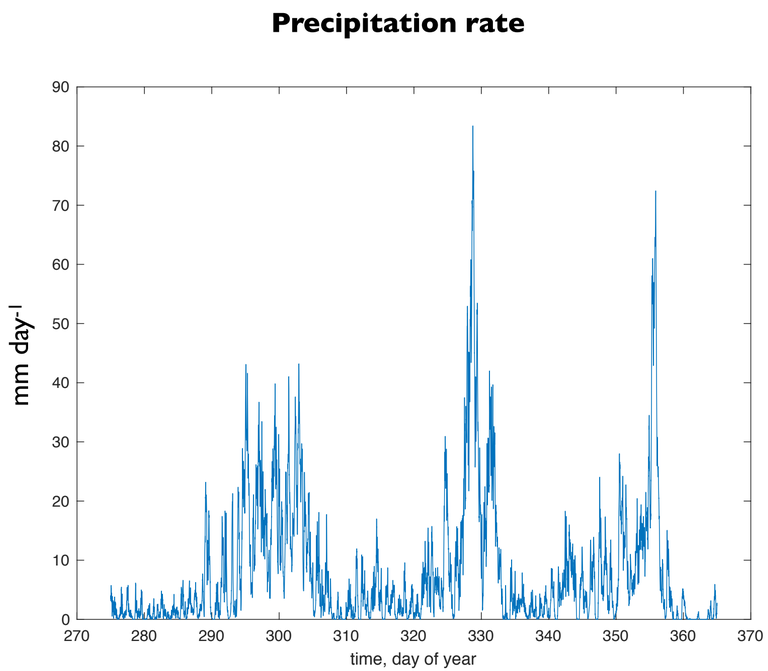


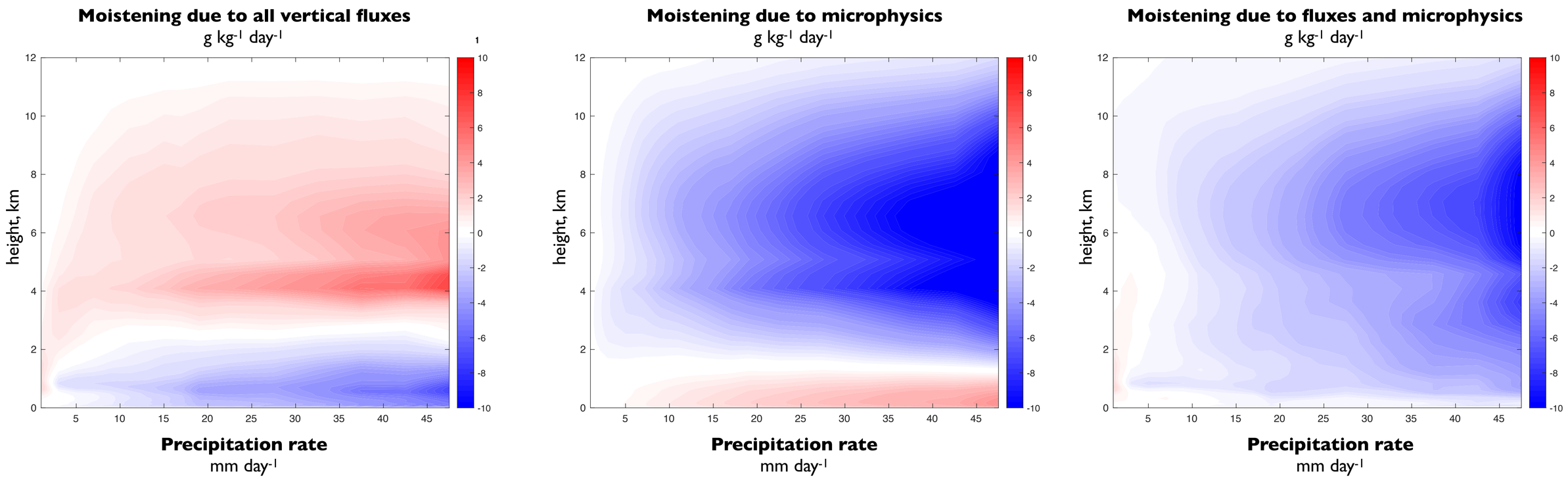
DYNAMO simulation with SAM







DYNAMO simulation binned by precipitation rate



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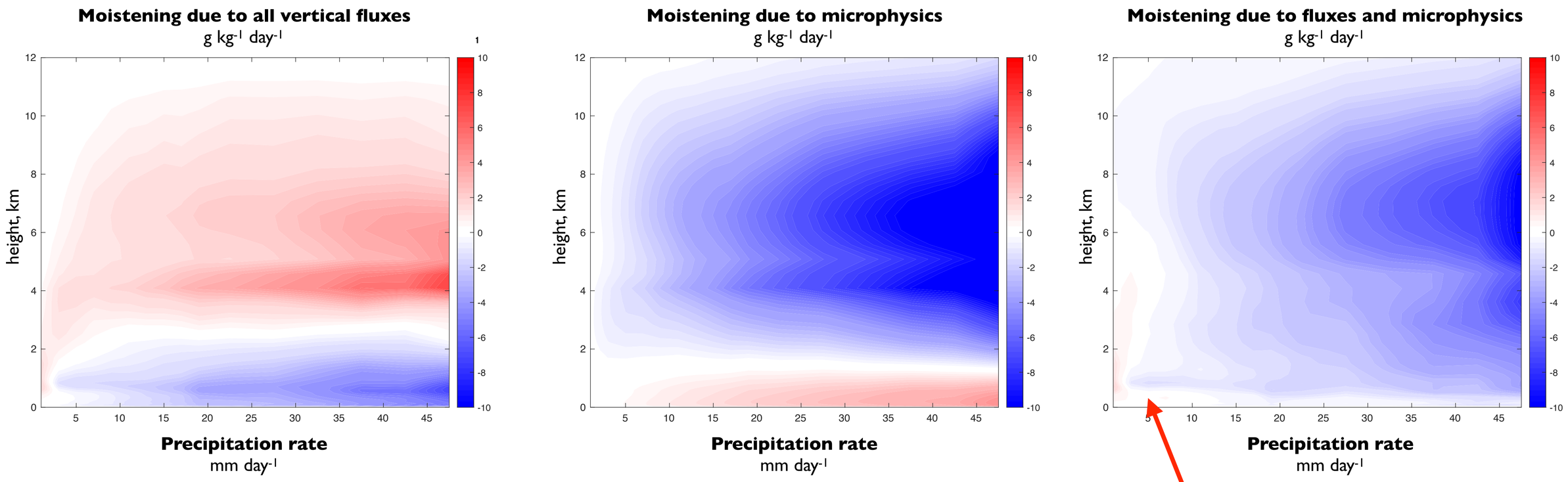
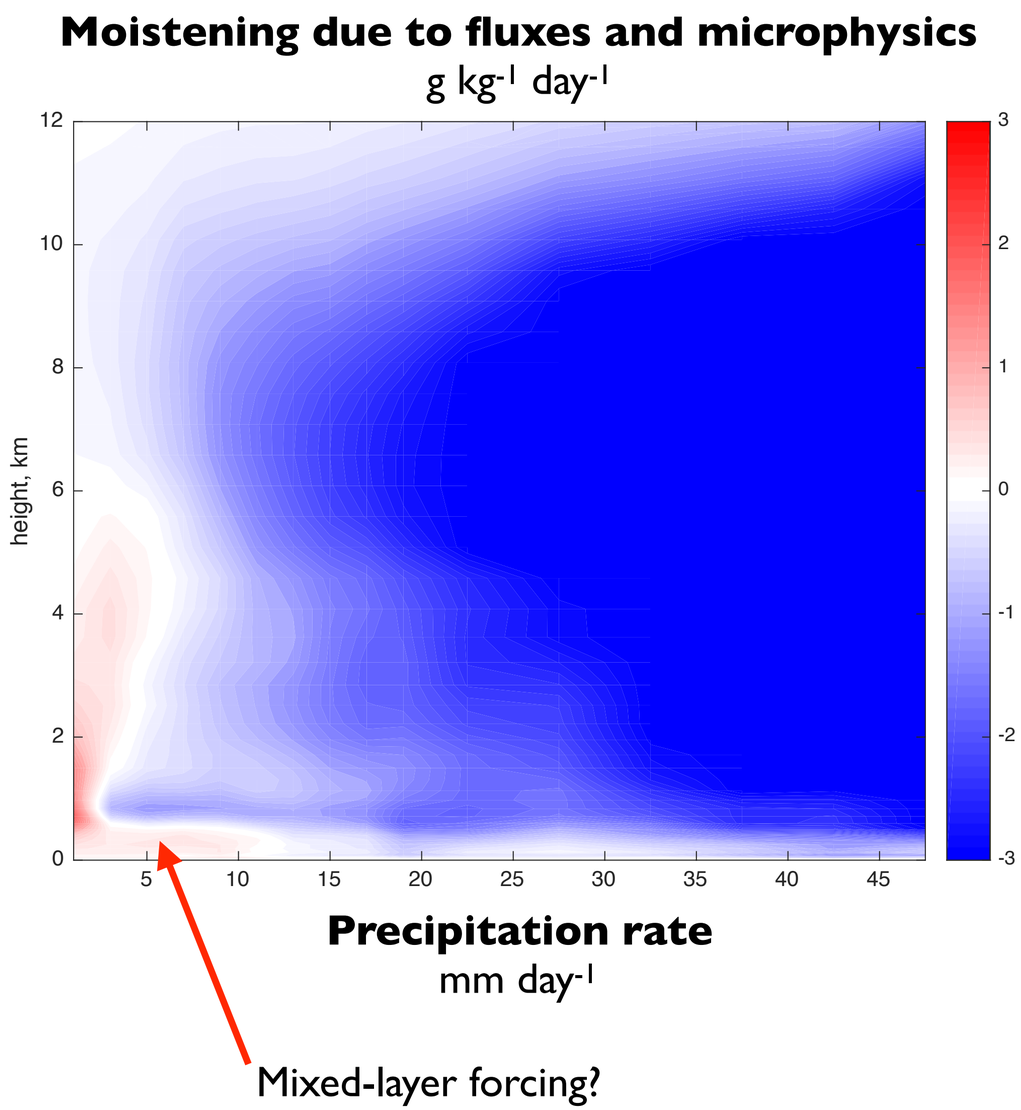


Mixed-layer forcing?

Same plot with a different color bar



The mixed-layer forcing does not exist when deep convection is intense, because the moisture flux does not converge inside the mixed layer.

A more basic issue:

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Can we really separate the forcing from the response?

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- Surface fluxes are influenced by deep convection.

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Randall and Pan (1993, p. 143):

"… it is not always clear which processes are convective and which are not."

Randall, D. A., and D.-M. Pan, 1993: Implementation of the Arakawa-Schubert cumulus parameterization with a prognostic closure. In *The Representation of Cumulus Convection in Numerical Models,* a Meteorological Monograph published by the American Meteorological Society, K. Emanuel and D. Raymond, Eds., pp. 137-144.

Two alternatives to forcing-and-response

Q. J. R. Meteorol. Soc. (1998), **124**, pp. 949–981

A cumulus parametrization with a prognostic closure

By DZONG-MING PAN* and DAVID. A. RANDALL
Colorado State University, USA

(Received 5 September 1996; revised 5 June 1997)

Predict the some measure of cumulus intensity.

GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 18, PAGES 3617-3620, SEPTEMBER 15, 2001

A Cloud Resolving Model as a Cloud Parameterization in the NCAR Community Climate System Model: Preliminary Results

Marat F. Khairoutdinov and David A. Randall
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

Use a super-parameterization.

Reasons to use prognostic closure

- There is no need to distinguish between forcing and response.
- The convection has memory.
- Prognostic closure is simpler and computationally faster.

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Conclusions

- We need to understand success of FTQE. In the process we will learn something.
- The mixed-layer forcing is not well defined when deep convection is intense.
- It's best to avoid the forcing-and-response paradigm.
  Prognostic closure and super-parameterization make that possible.


Thanks