Unforced Errors

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My mother taught me that in polite society, we do not talk about:

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My mother taught me that in polite society, we do not talk about:

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My mother taught me that in polite society, we do not talk about:

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Unforced Errors

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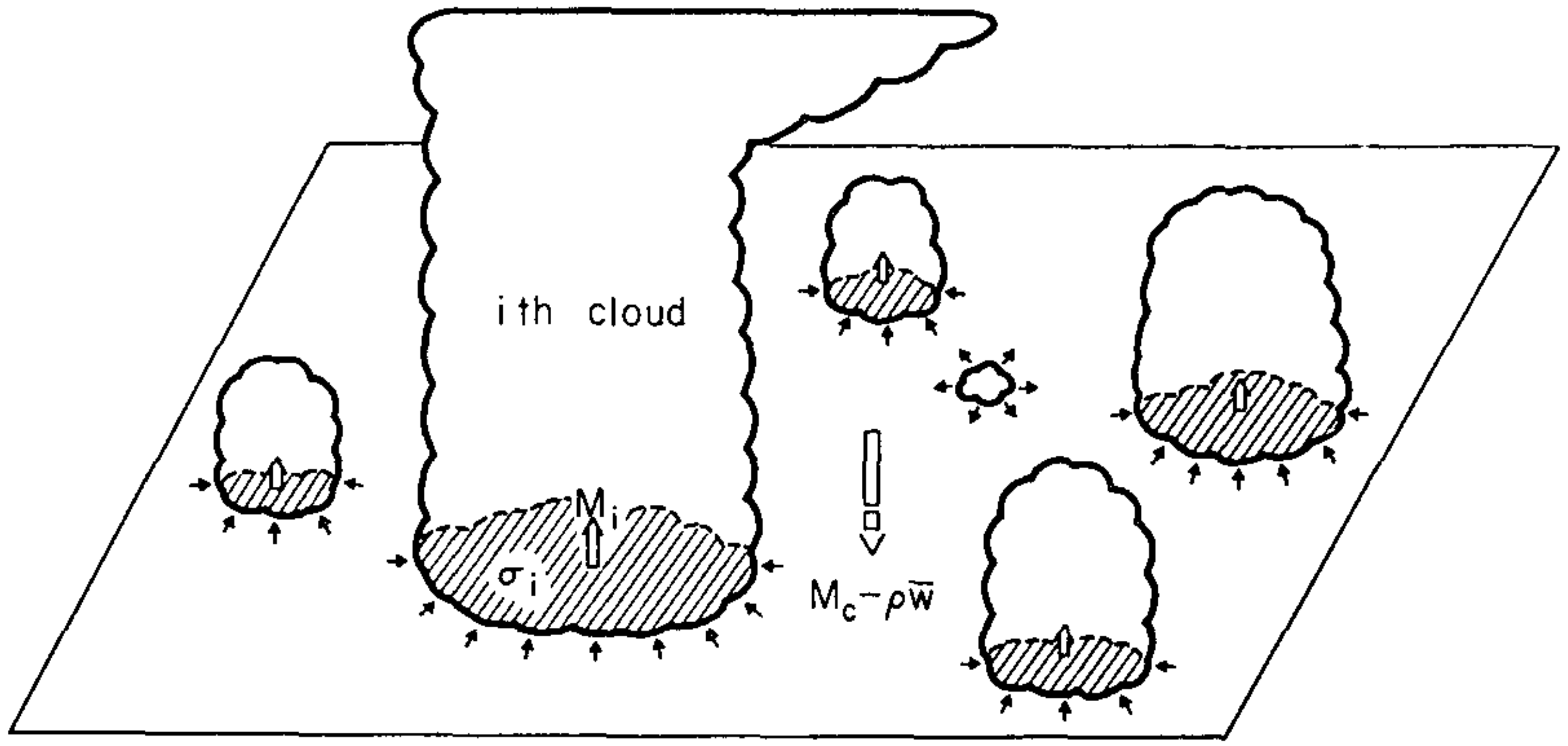
Going against her advice, today I'm going to talk about quasi-equilibrium, which is always a good way to start a lively discussion.

Acknowledgments

Don Dazlich

Mark Branson


i th cloud
M_i
σ_i
$M_c - \rho\bar{w}$

Sources and sinks of buoyancy

$$\frac{\partial}{\partial t} A(\lambda) = \int_0^{\lambda_{\max}} K(\lambda, \lambda') M_B(\lambda') \, d\lambda' + F(\lambda)$$

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$$\frac{\partial}{\partial t} A(\lambda) = \int_0^{\lambda_{\max}} K(\lambda,\lambda') M_B(\lambda') \, d\lambda' + F(\lambda)$$

Forcing

Sources and sinks of buoyancy

$$\frac{\partial}{\partial t}A(\lambda)=\int_0^{\lambda_{\max}}K(\lambda,\lambda')M_B(\lambda')\,d\lambda'+F(\lambda)$$

Response

Forcing


Forcing
Response

ASQE

$$\int_0^{\lambda_{\max}} K(\lambda,\lambda') M_B(\lambda')\, d\lambda' + F(\lambda) \cong 0$$

ASQE

$$\int_0^{\lambda_{\max}} K(\lambda,\lambda') M_B(\lambda') \, d\lambda' + F(\lambda) \cong 0$$

$$R + F \cong 0$$

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

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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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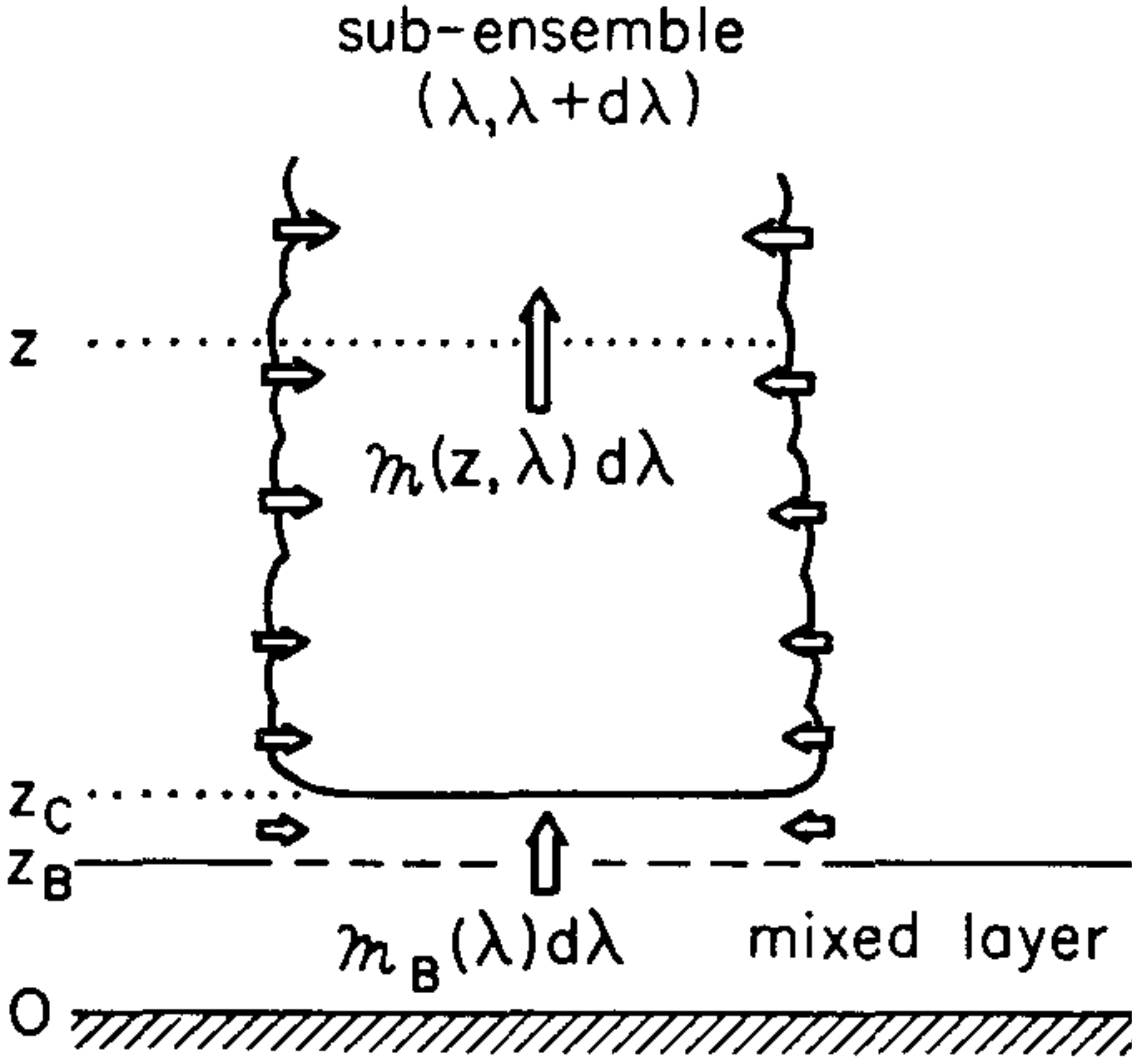
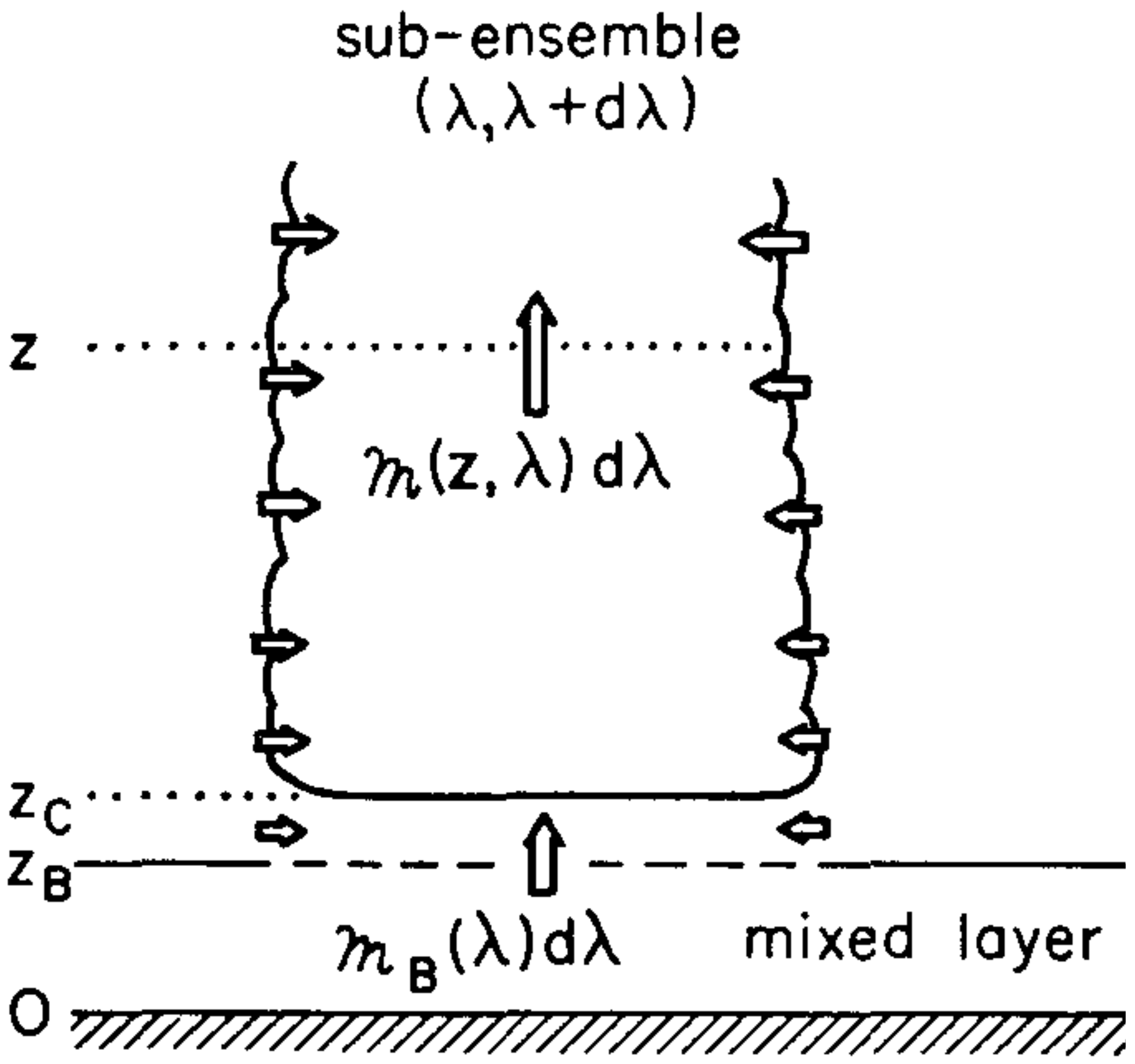
The mixed-layer forcing



The mixed-layer forcing exerts a powerful influence on the CAPE,
because what happens in the mixed layer affects an updraft's buoyancy *at all levels*.

The mixed-layer forcing



Surface evaporation

Surface sensible heat flux

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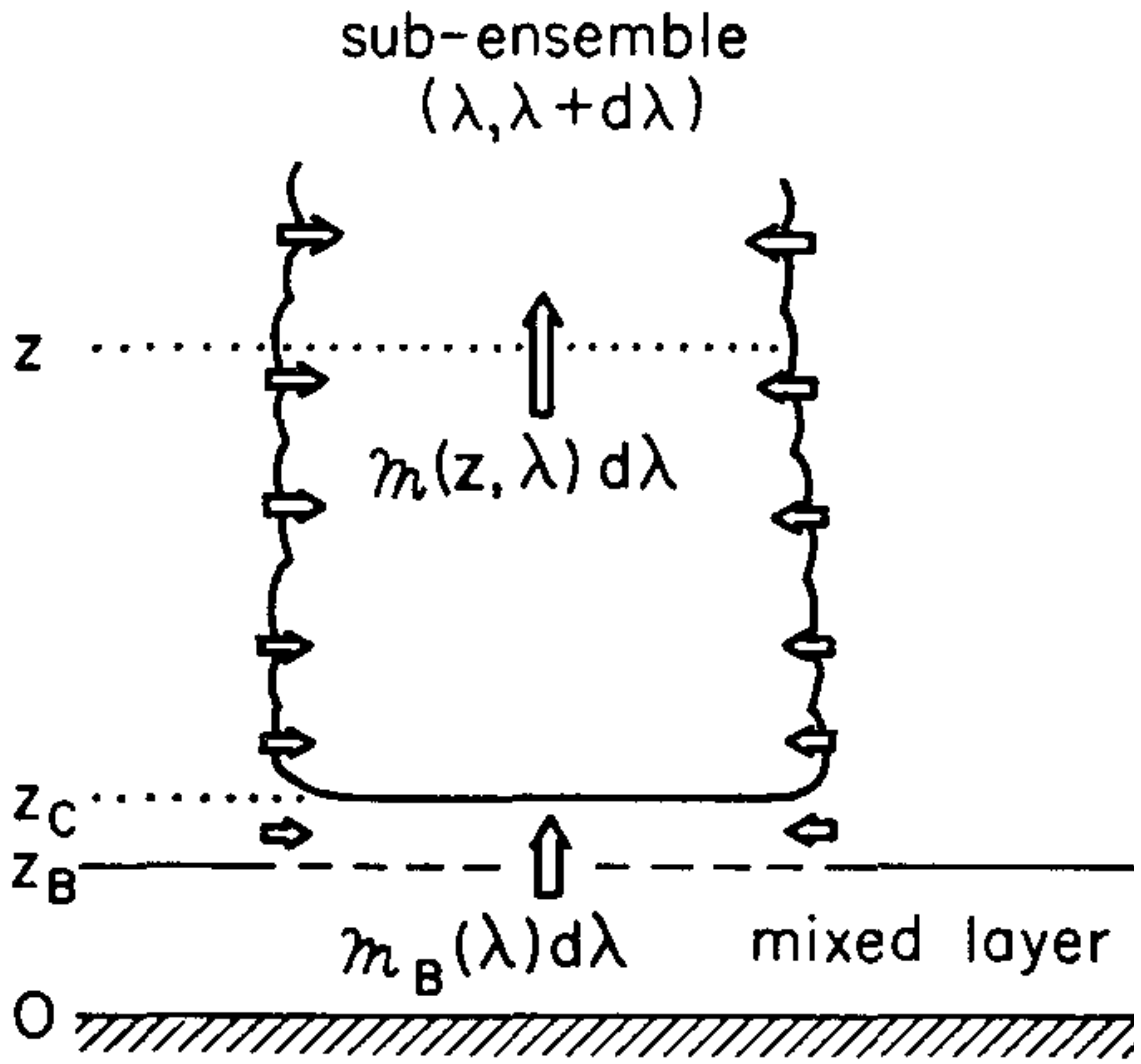

Entrainment into the mixed layer

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Surface sensible heat flux

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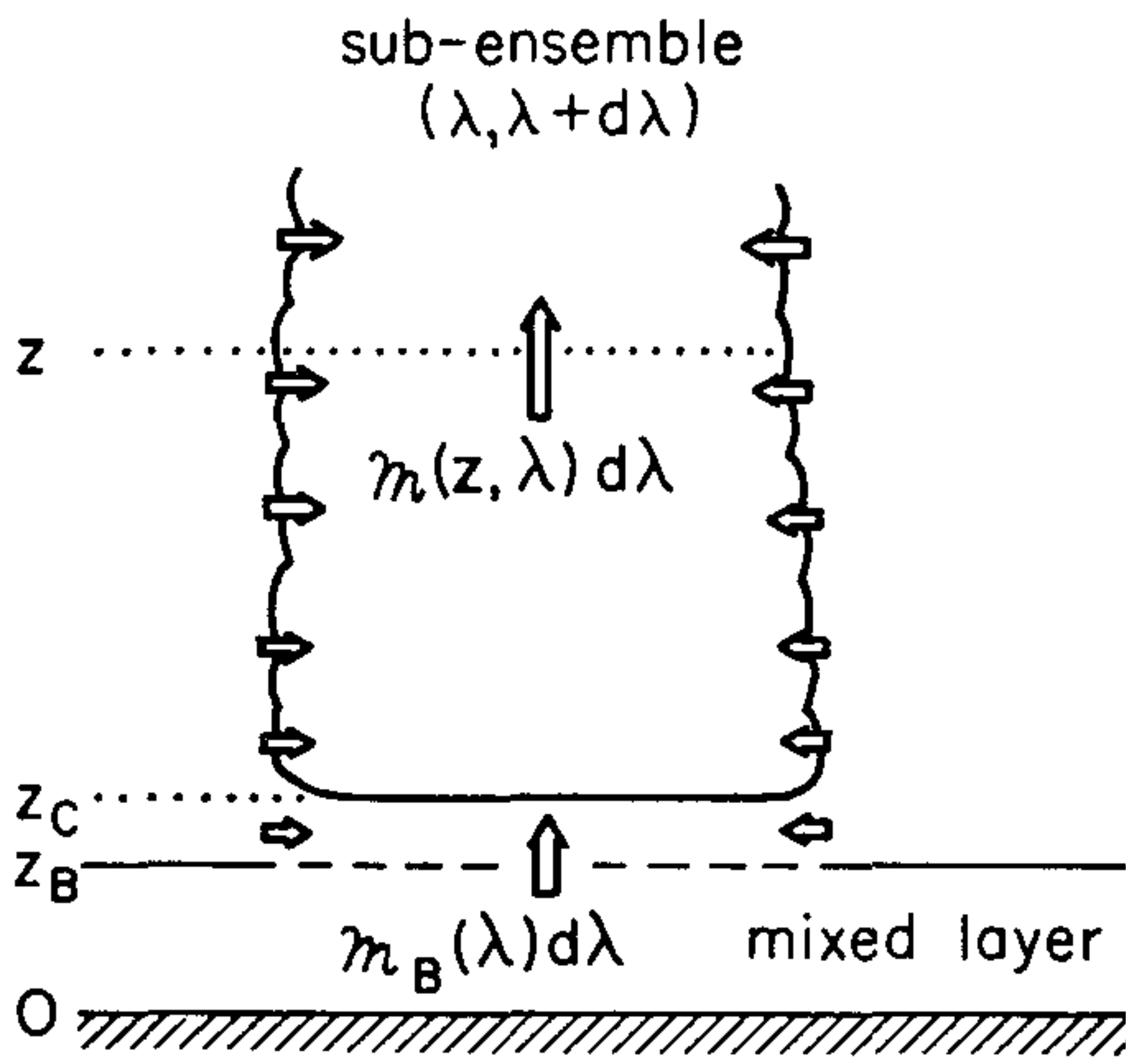
The mixed-layer forcing

A key missing ingredient:
Downdrafts

Entrainment into the mixed layer



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Next, a few words about Wayne’s 1973 dissertation

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Late June, 1972

Fig. 38 of Wayne's dissertation

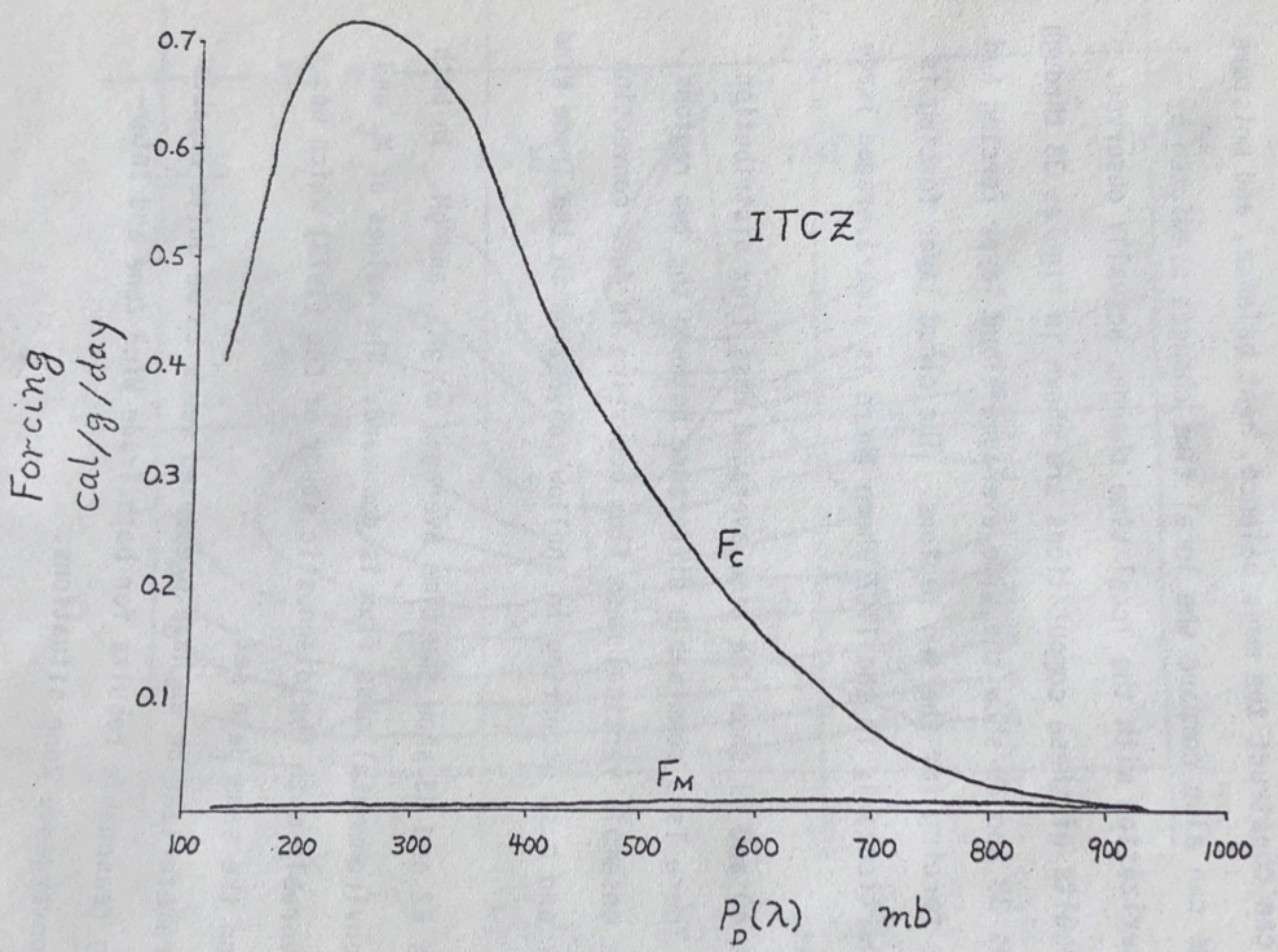
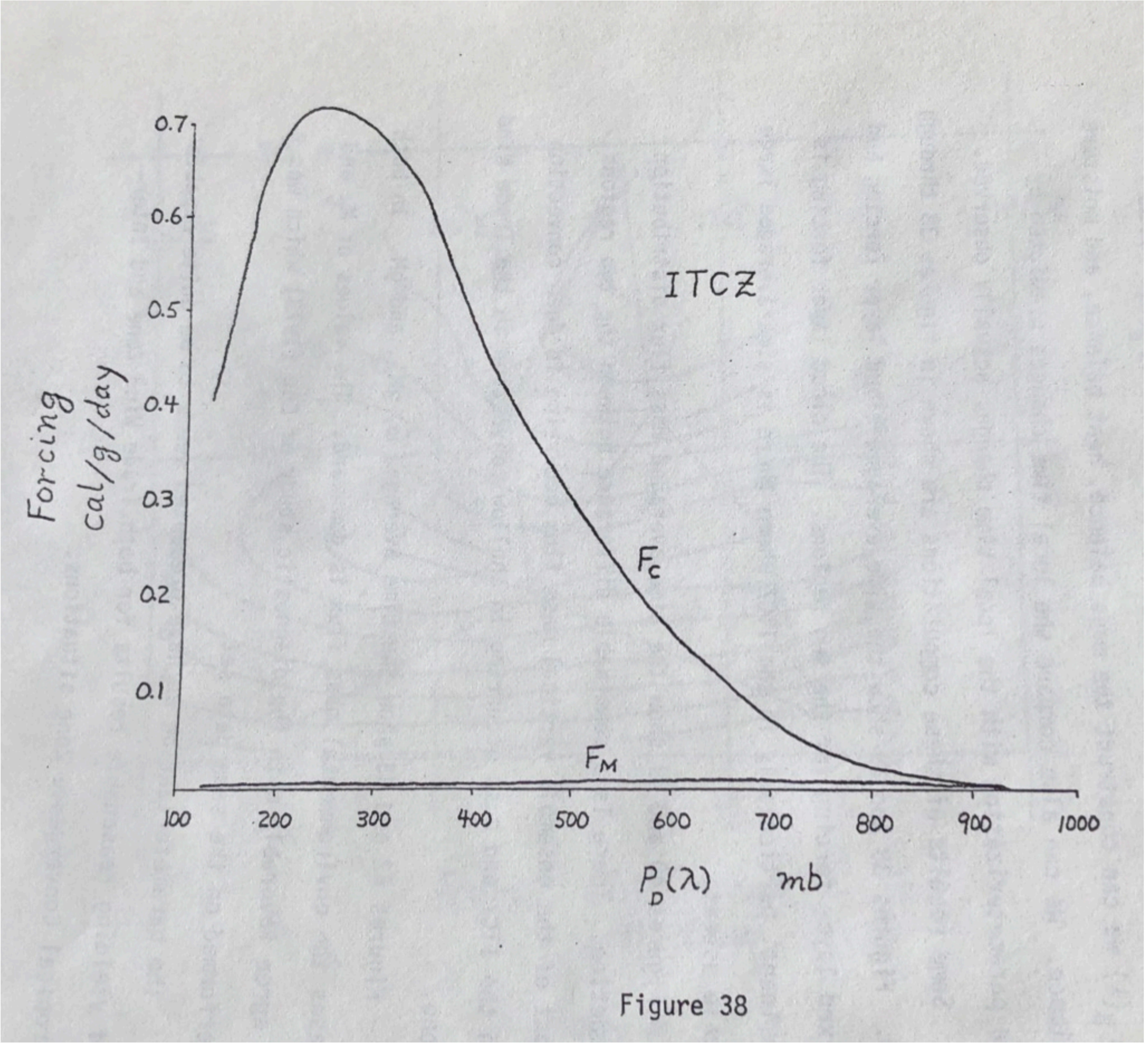


Figure 38

Fig. 38 of Wayne’s dissertation



“So, Wayne,” I said…

Fig. 38 of Wayne's dissertation

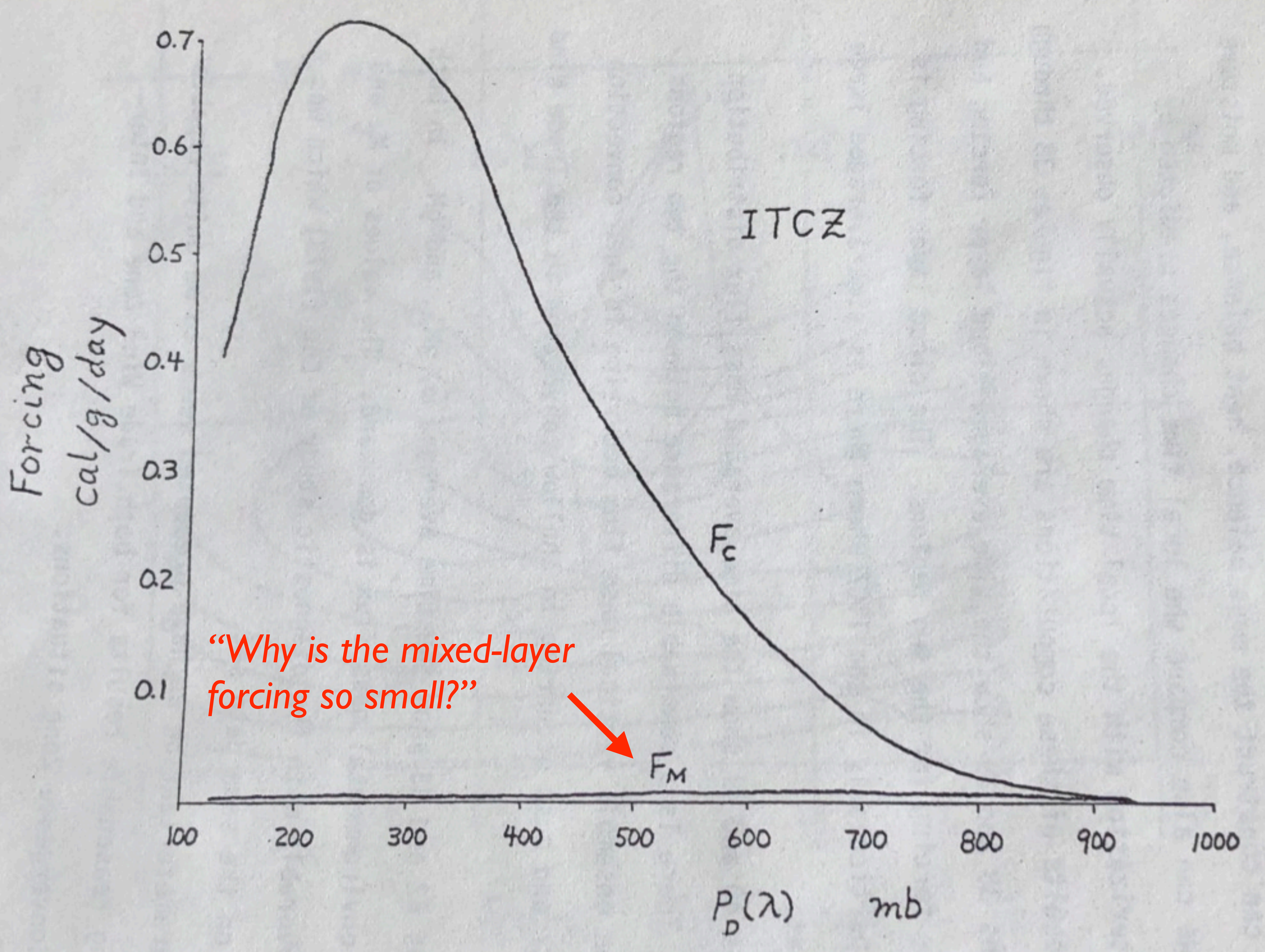


Figure 38

"So, Wayne," I said…

Marshall Islands Data

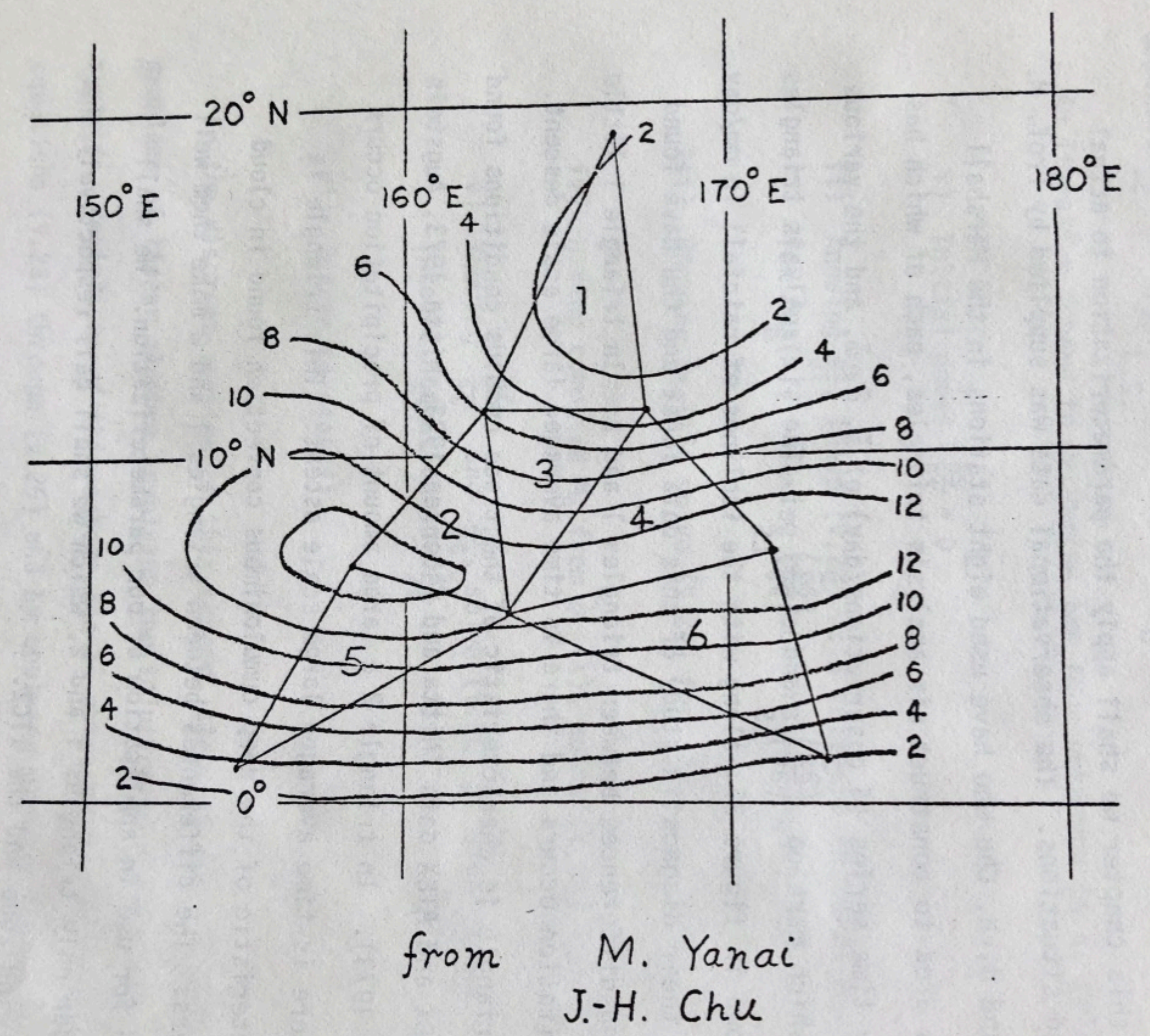


Figure 37

"Well," said Wayne…

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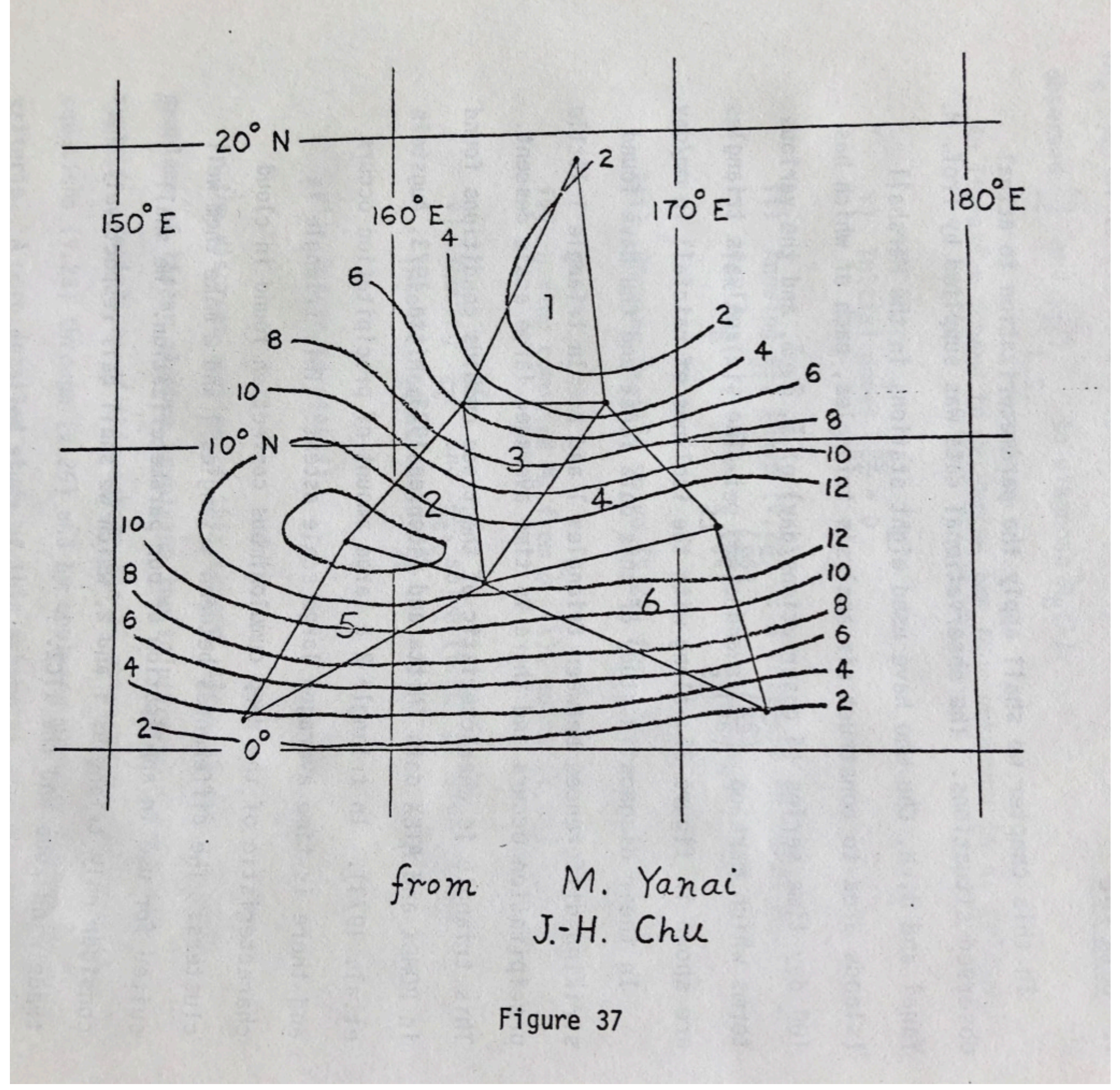
AS74 did not include downdrafts, so the moistening by surface evaporation has to be balanced by some combination of horizontal advection and the entrainment of dry air across the top of the mixed layer.



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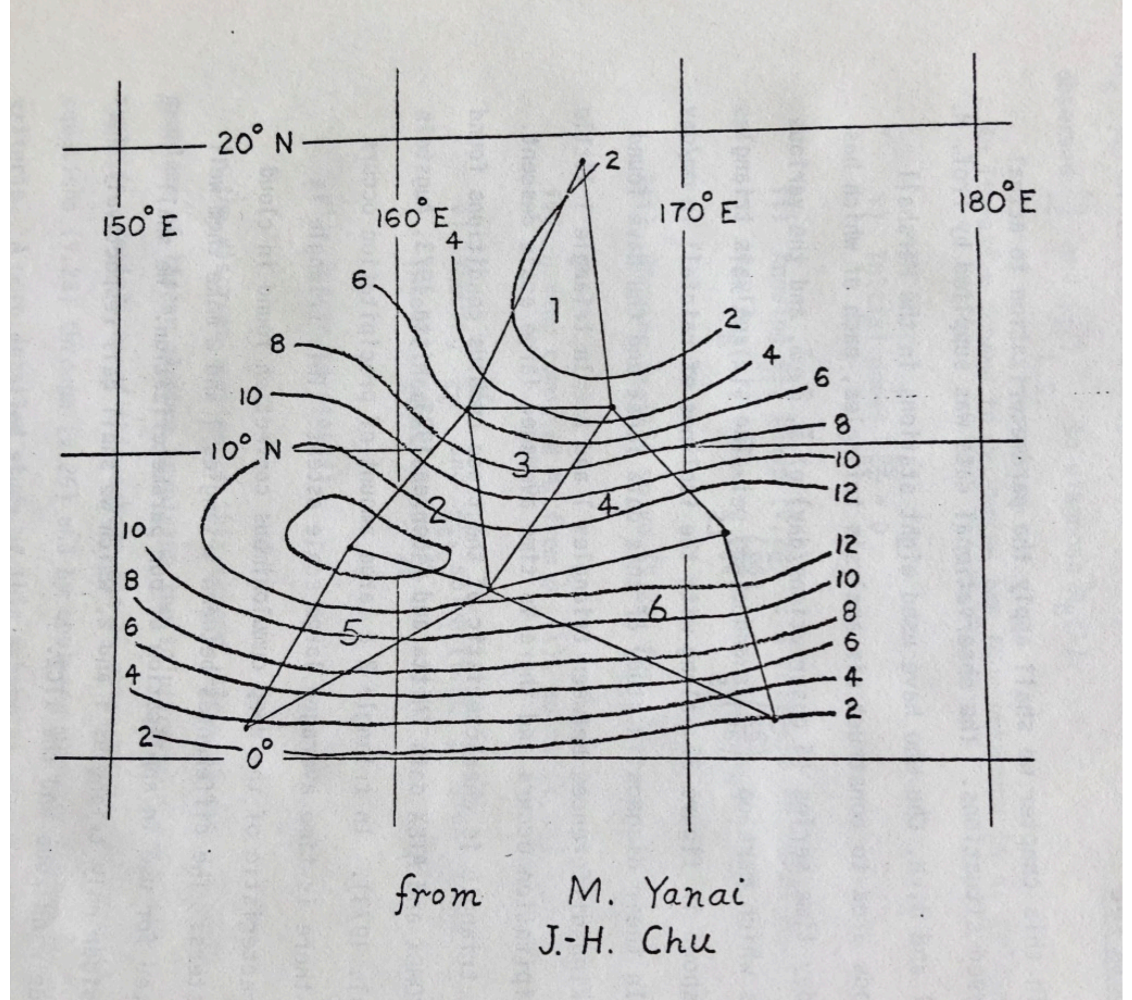

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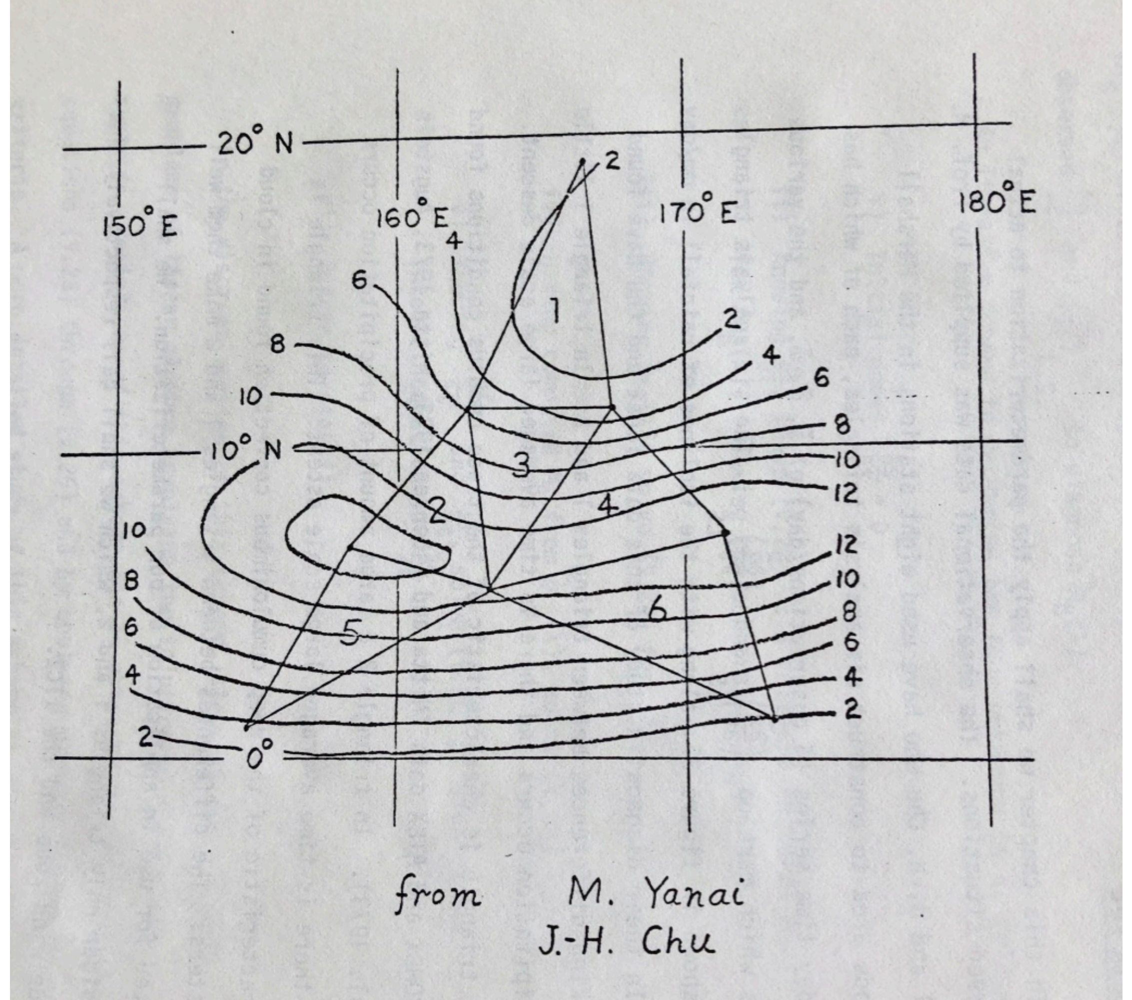
An assumption had to be made. Wayne's thesis doesn't say what was assumed, and Wayne doesn't remember.



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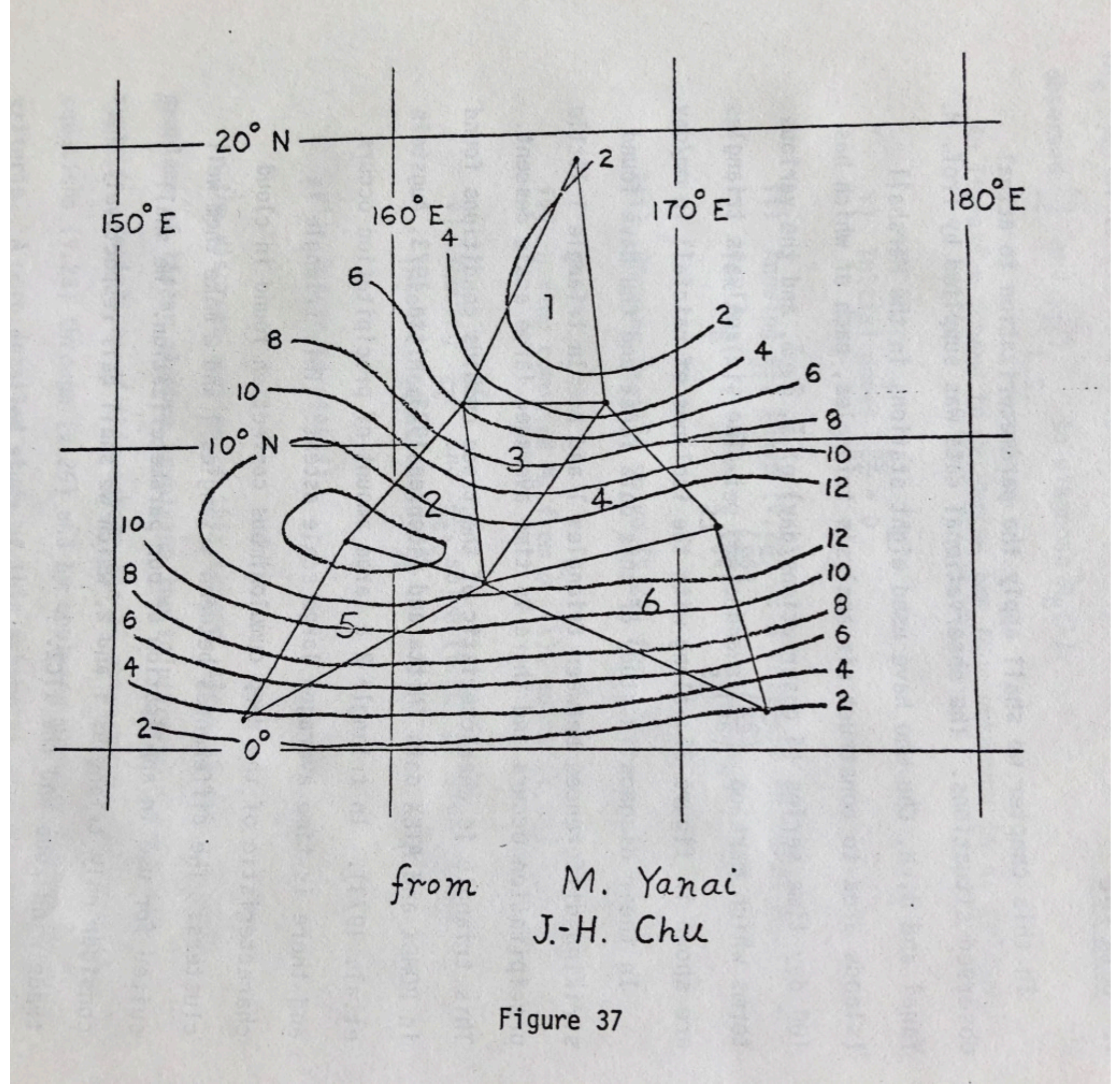
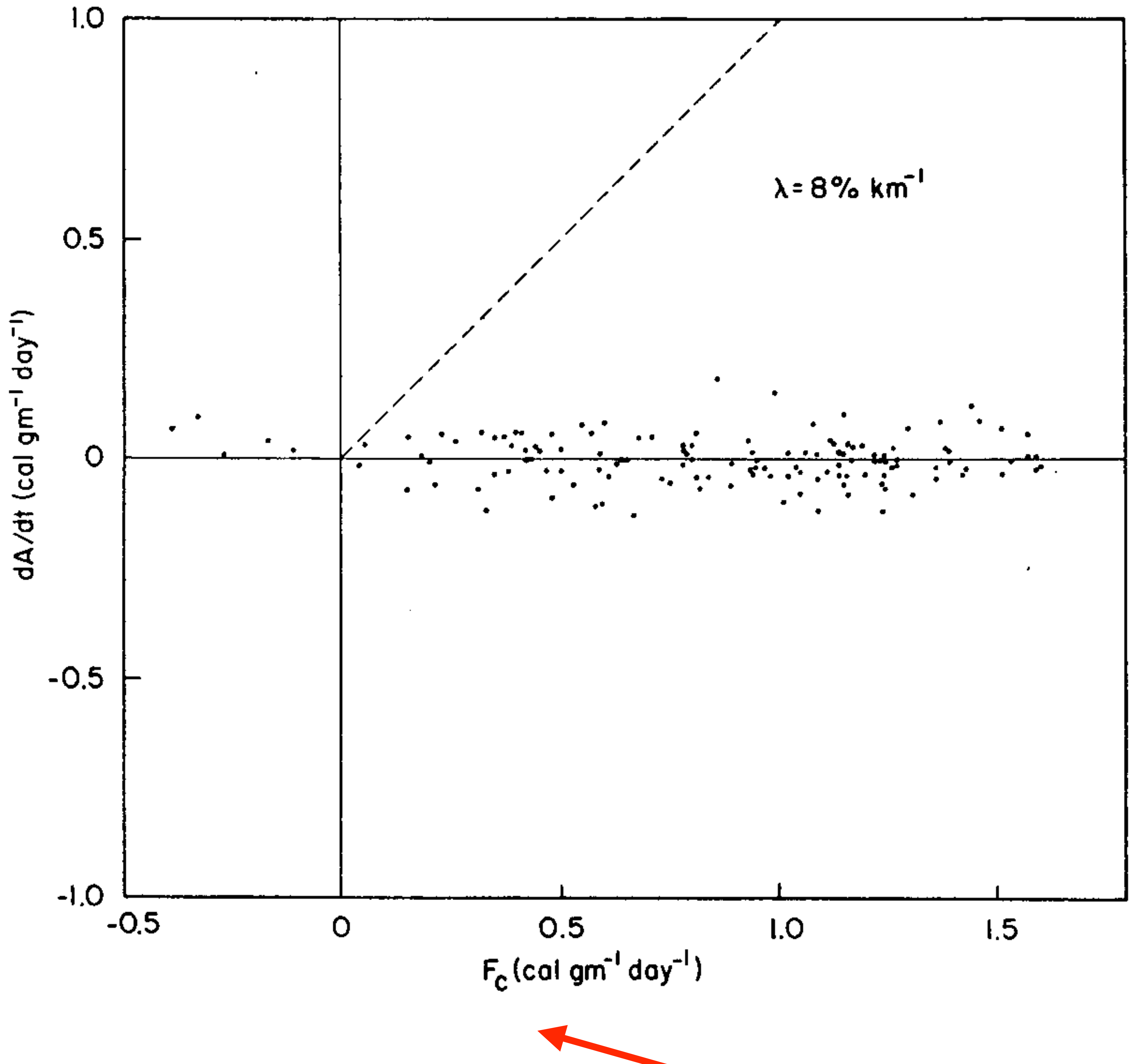


He may have assumed that the entrained air was dry enough to balance the surface evaporation.



"The large-scale forcing can be divided into two parts: … the 'cloud layer forcing' and the 'mixed layer forcing.'"

—AS74

Interaction of a Cumulus Cloud Ensemble with the Large-Scale Environment. Part III: Semi-Prognostic Test of the Arakawa-Schubert Cumulus Parameterization

STEPHEN J. LORD[1]

Department of Atmospheric Sciences, University of California, Los Angeles 90024

(Manuscript received 26 August 1980, in final form 14 September 1981)

In this study any possible changes in h_m and q_{vm} due to large-scale surface fluxes, entrainment at the SCL top, horizontal advection and radiation are neglected because the vertical resolution of the data is not sufficient to provide good estimates of these subcloud layer processes. Thus, $F(i)$ calculated by (5)–(6) corresponds to the cloud-layer forcing given by (B33) of Part I. Schubert (1973) using the mixed-layer model for the SCL discussed in Part I, has shown that the mixed-layer forcing is a small fraction of the cloud-layer forcing under most circumstances.

Our story so far...

- ASQE is based on a forcing-and-response paradigm in which the convection responds to "large-scale forcing."
- AS74 distinguished between the mixed-layer forcing and the cloud-layer forcing.
- Simple physical reasoning suggests that the mixed-layer forcing should be strong.
- Wayne's thesis includes a figure showing that the mixed-layer forcing is weak.
  This may have been based on an assumption that the surface evaporation is mostly cancelled by entrainment drying.
- The tests of QE reported by AS74 are based on the cloud-layer forcing alone.
- The semi-prognostic tests of Lord (1982) are also based on the cloud-layer forcing alone.

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

The Behavior of a Simple Hurricane Model Using a Convective Scheme Based on Subcloud-Layer Entropy Equilibrium

KERRY A. EMANUEL

Center for Meteorology and Physical Oceanography, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Manuscript received 11 August 1994, in final form 23 March 1995)

ABSTRACT

Recent work on the interaction of convection with large-scale flows suggests that a closure based on a presumed equilibrium between surface enthalpy fluxes and input of low-entropy air into the subcloud layer by convective downdrafts works well in models of the tropical atmosphere. Such a convective representation is here used in a simple numerical tropical cyclone model. This further simplifies the model, while in many respects improving its performance.

Mixed-layer forcing is key. Cumulus downdrafts balance it.

BLQE

15 NOVEMBER 1995 RAYMOND 3945

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."

BLQE

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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 cancel it out.

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

Inferences from Simple Models of Slow, Convectively Coupled Processes

KERRY EMANUEL

Lorenz Center, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Manuscript received 20 March 2018, in final form 28 October 2018)

Boundary layer quasi equilibrium may be thought of as the limit of (2) as the depth d of the boundary layer becomes vanishingly small. In that case, (2) may be approximated, after substituting (1) for the sum $M_d + w_e$, as

$$M_u = w + \frac{F_h}{h_b - h_m}. \qquad (3)$$

This is our simple way of dealing with deep moist convection. While relatively crude, it has been used with some success in a forecast model of tropical cyclones

BLQE is being used in simple models, but as far as I know it's not being used in any GCM.

If downdrafts are included in the cumulus parameterization, BLQE can be viewed as a limiting case of ASQE.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2014GL062649

A numerical investigation of boundary layer quasi-equilibrium

K. Thayer-Calder[1,2] and David Randall[3]

[1]Department of Applied Mathematics, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA, [2]National Center for Atmospheric Research, Boulder, Colorado, USA, [3]Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado, USA

Key Points:
- The tropical boundary layer is dried more by entrainment than by downdrafts
- Downdrafts sometimes inject high-energy air into the boundary layer
- Models need better parameterizations of entrainment at the boundary layer top

Correspondence to:
K. Thayer-Calder,
katec@ucar.edu

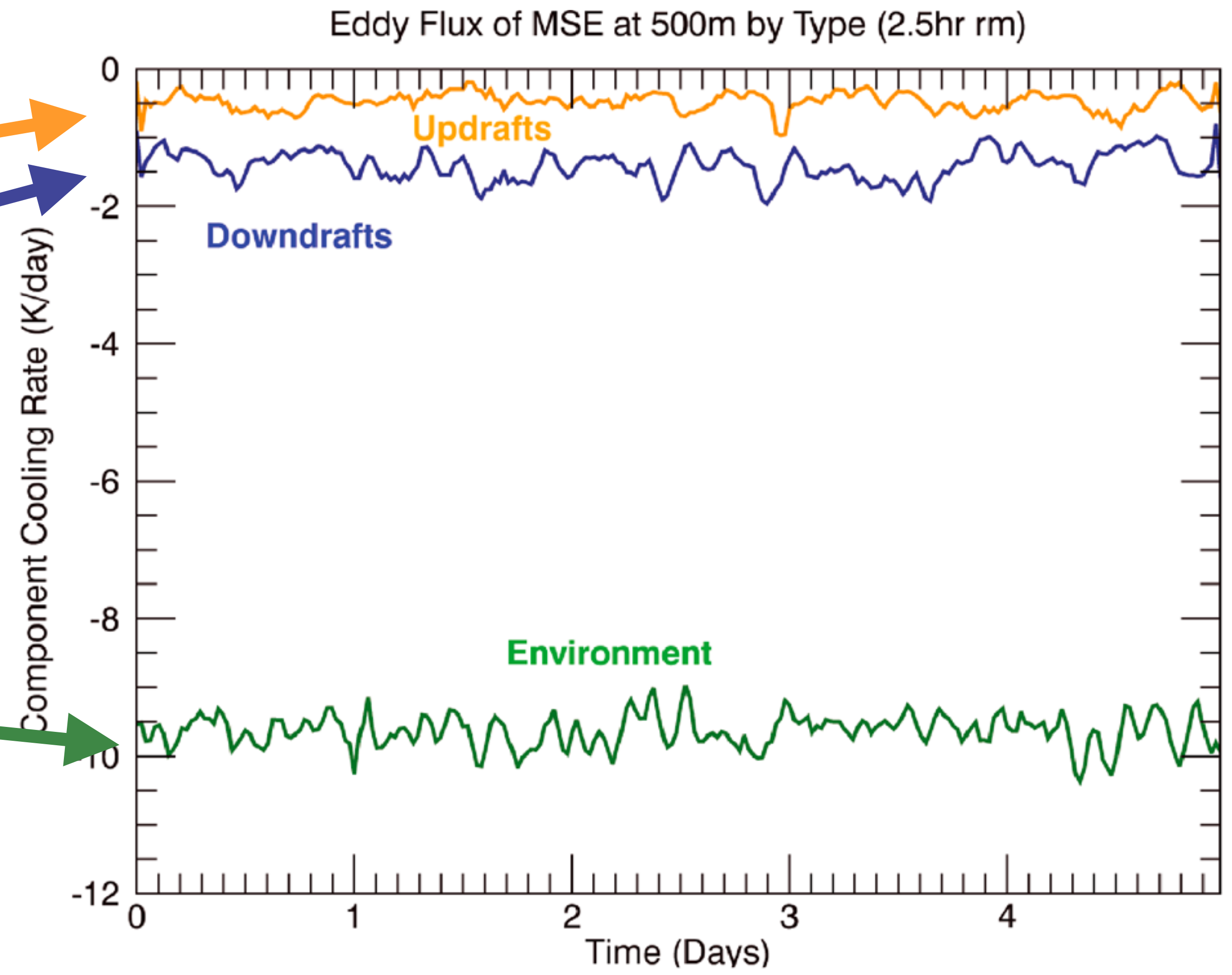
Abstract Despite the large energy input from surface evaporation, the moist static energy (MSE) of the tropical boundary layer remains relatively constant on large spatial and temporal scales due to lifting of vapor by cloudy updrafts and the addition of dry air from the layers above. Arakawa and Schubert (1974) suggested that drying is due mainly to clear-air turbulent entrainment between cloudy updrafts, while Raymond (1995) described drying due mainly to convective downdrafts. We used cloud-resolving numerical simulations to investigate the transport of MSE into the boundary layer and found turbulent entrainment between clouds to be the dominant process.

Drying of the mixed layer by:

updrafts

downdrafts

entrainment



Additional support for this conclusion comes from Torri & Kuang (2016) and deSzoeke et al. (2017).

Relevance to BLQE

The results of Thayer-Calder & Randall imply that downdrafts are not the primary regulator of boundary-layer entropy.

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It might be possible to rescue BLQE by modifying it to allow both downdrafts and entrainment to regulate the boundary-layer entropy.

Relevance to BLQE

The results of Thayer-Calder & Randall imply that downdrafts are not the primary regulator of boundary-layer entropy.

It might be possible to rescue BLQE by modifying it to allow both downdrafts and entrainment to regulate the boundary-layer entropy.

A problem with that idea is that cumulus convection does not strongly influence the rate of entrainment at the mixed-layer top (at least, as far as I can see), so it's not clear how a negative feedback loop would work.

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.

My first reaction:

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.

ADVANCING EARTH AND SPACE SCIENCE

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2017MS001191

Key Points:

- Improvements in convection scheme largely eliminate the double intertropical convergence zone (ITCZ) bias in all seasons in Community Earth System Model
- Analyses demonstrate that convection scheme is the primary contributor to the double ITCZ syndrome
- Impact of each modification to convection scheme on ITCZ simulation in the atmospheric model is identified and investigated

Supporting Information:

- Supporting Information S1

Correspondence to:
X. Song,
xisong@ucsd.edu

Citation:
Song, X., & Zhang, G. J. (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*, 842–866. https://doi.org/10.1002/2017MS001191

The Roles of Convection Parameterization in the Formation of Double ITCZ Syndrome in the NCAR CESM: I. Atmospheric Processes

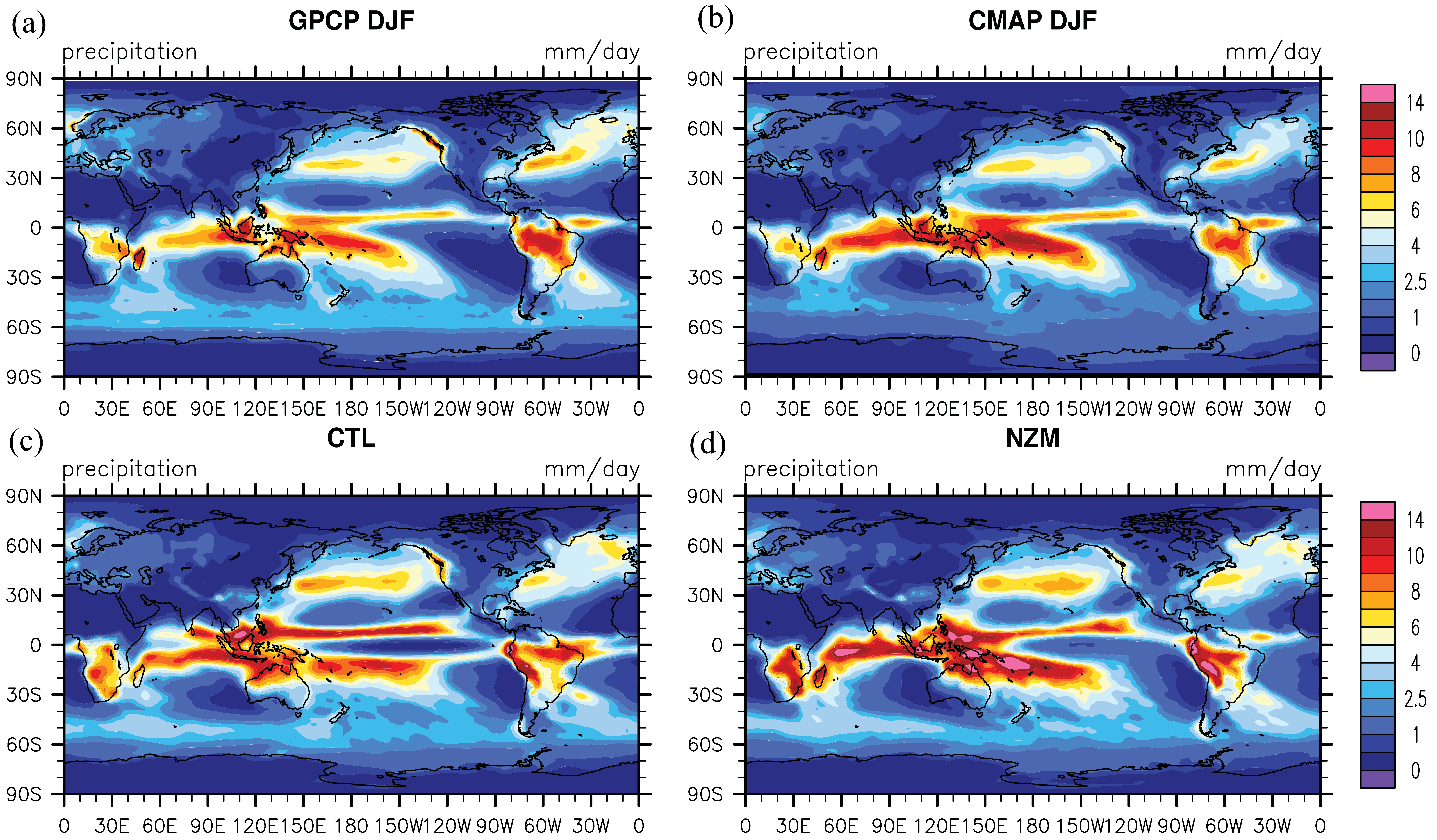
Xiaoliang Song[1] **and Guang J. Zhang**[1]

[1]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA

Abstract Several improvements are implemented in the Zhang-McFarlane (ZM) convection scheme to investigate the roles of convection parameterization in the formation of double intertropical convergence zone (ITCZ) bias in the NCAR CESM1.2.1. It is shown that the prominent double ITCZ biases of precipitation, sea surface temperature (SST), and wind stress in the standard CESM1.2.1 are largely eliminated in all seasons with the use of these improvements in convection scheme. This study for the first time demonstrates that the modifications of convection scheme can eliminate the double ITCZ biases in all seasons, including boreal winter and spring. Further analysis shows that the elimination of the double ITCZ bias is achieved not by improving other possible contributors, such as stratus cloud bias off the west coast of South America and cloud/radiation biases over the Southern Ocean, but by modifying the convection scheme itself. This study demonstrates that convection scheme is the primary contributor to the double ITCZ bias in the CESM1.2.1, and provides a possible solution to the long-standing double ITCZ problem. The atmospheric model simulations forced by observed SST show that the original ZM convection scheme tends to produce double ITCZ bias in high SST scenario, while the modified convection scheme does not. The impact of changes in each core component of convection scheme on the double ITCZ bias in atmospheric model is identified and further investigated.

1. Introduction

Results from CESM 1.2.1 (CAM 5.3)



From Song & Zhang 2018

We need to understand this.

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

We need to understand this.

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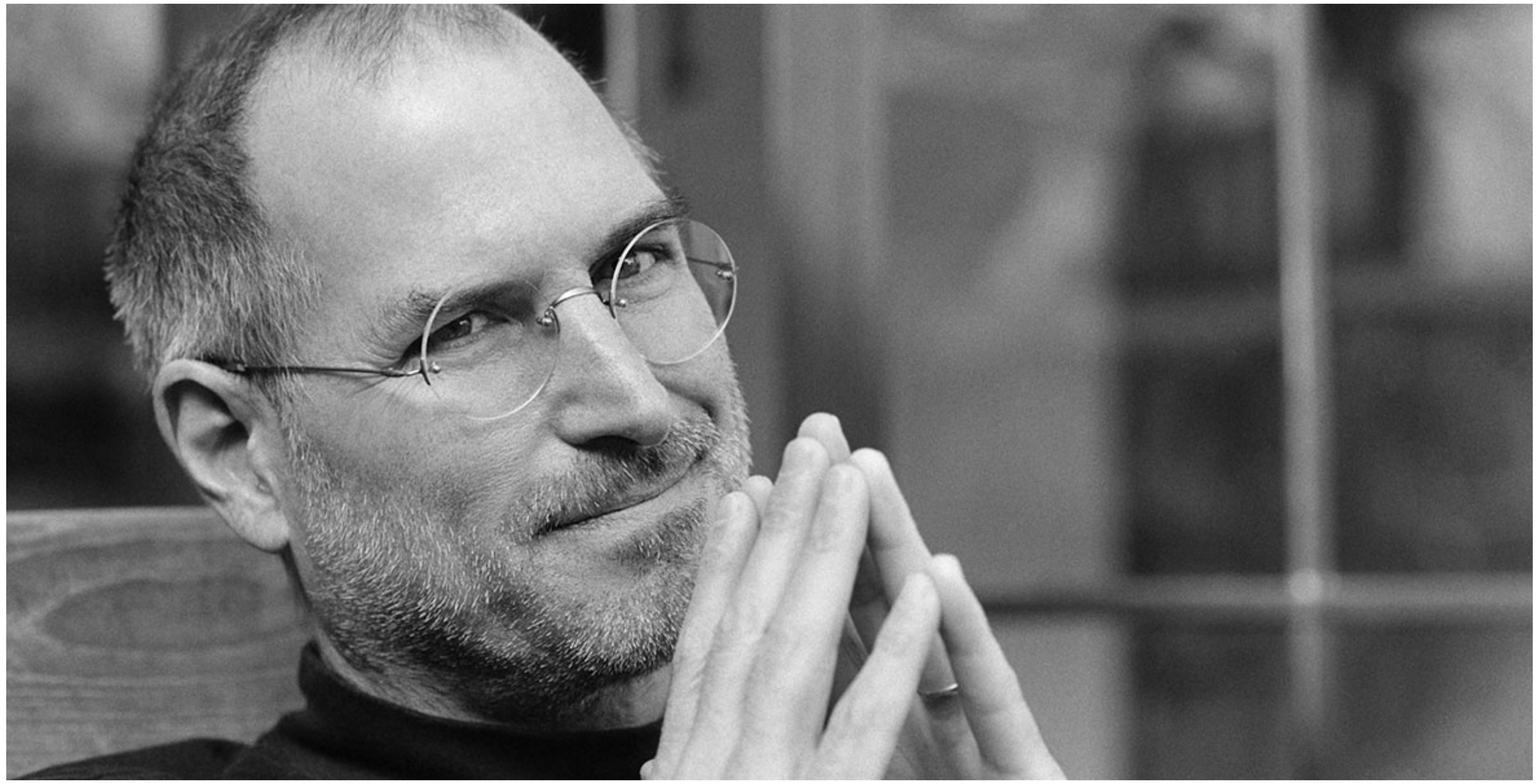

Why does it work?

Possible reasons:

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- Maybe the mixed-layer forcing really is small.
  It appears that some magic would be needed for this to be true.

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- If BLQE and ASQE were both true, FTQE would follow by subtraction.
  But that's impossible.

Why does it work?

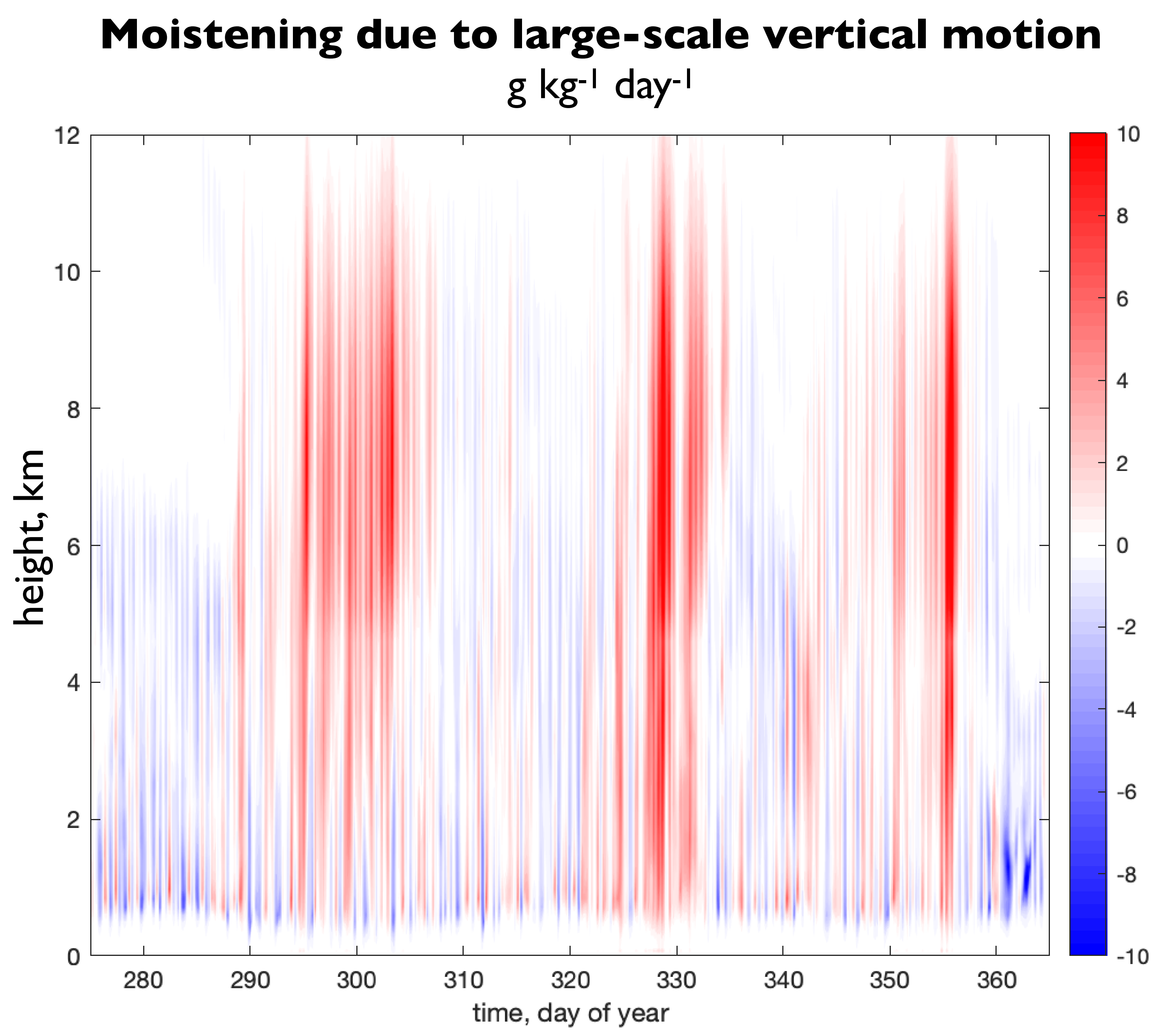
Possible reasons:

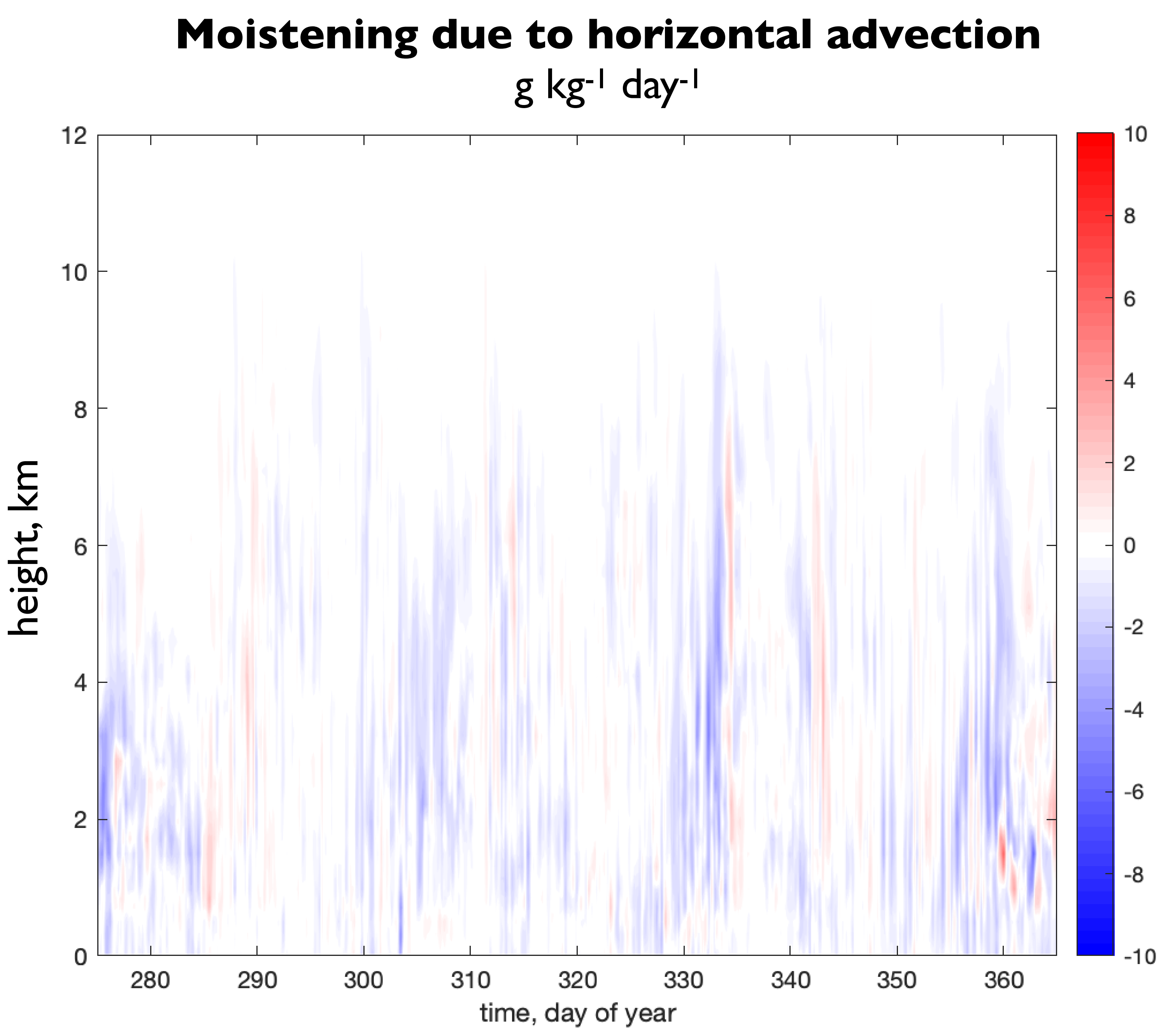
- Maybe the mixed-layer forcing really is small.
  It appears that some magic would be needed for this to be true.

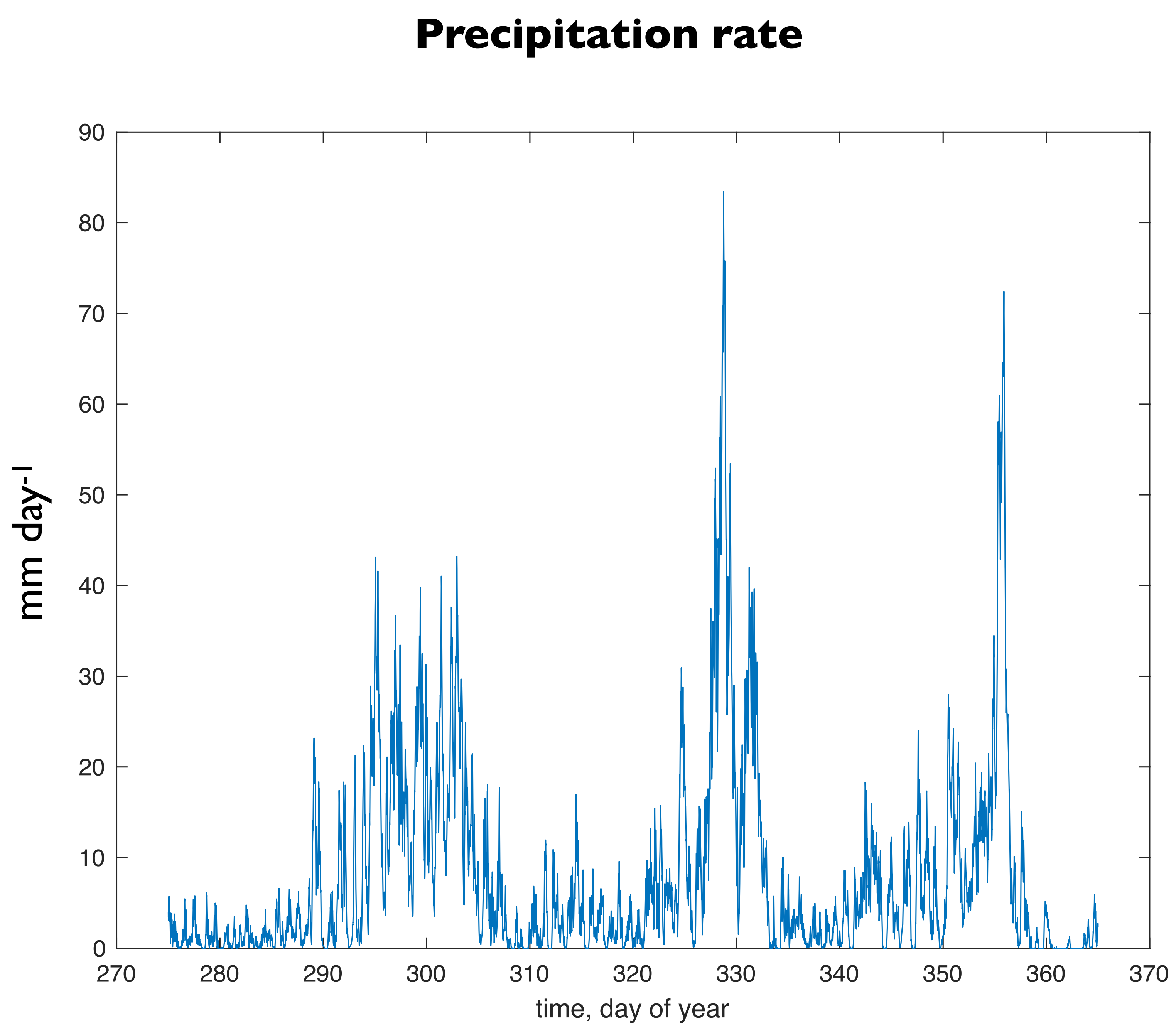
- If BLQE and ASQE were both true, FTQE would follow by subtraction.
  But that's impossible.

- Maybe the mixed-layer forcing does not exist when deep convection is intense, because under those conditions the surface fluxes do not converge inside the boundary layer.

DYNAMO simulation with SAM

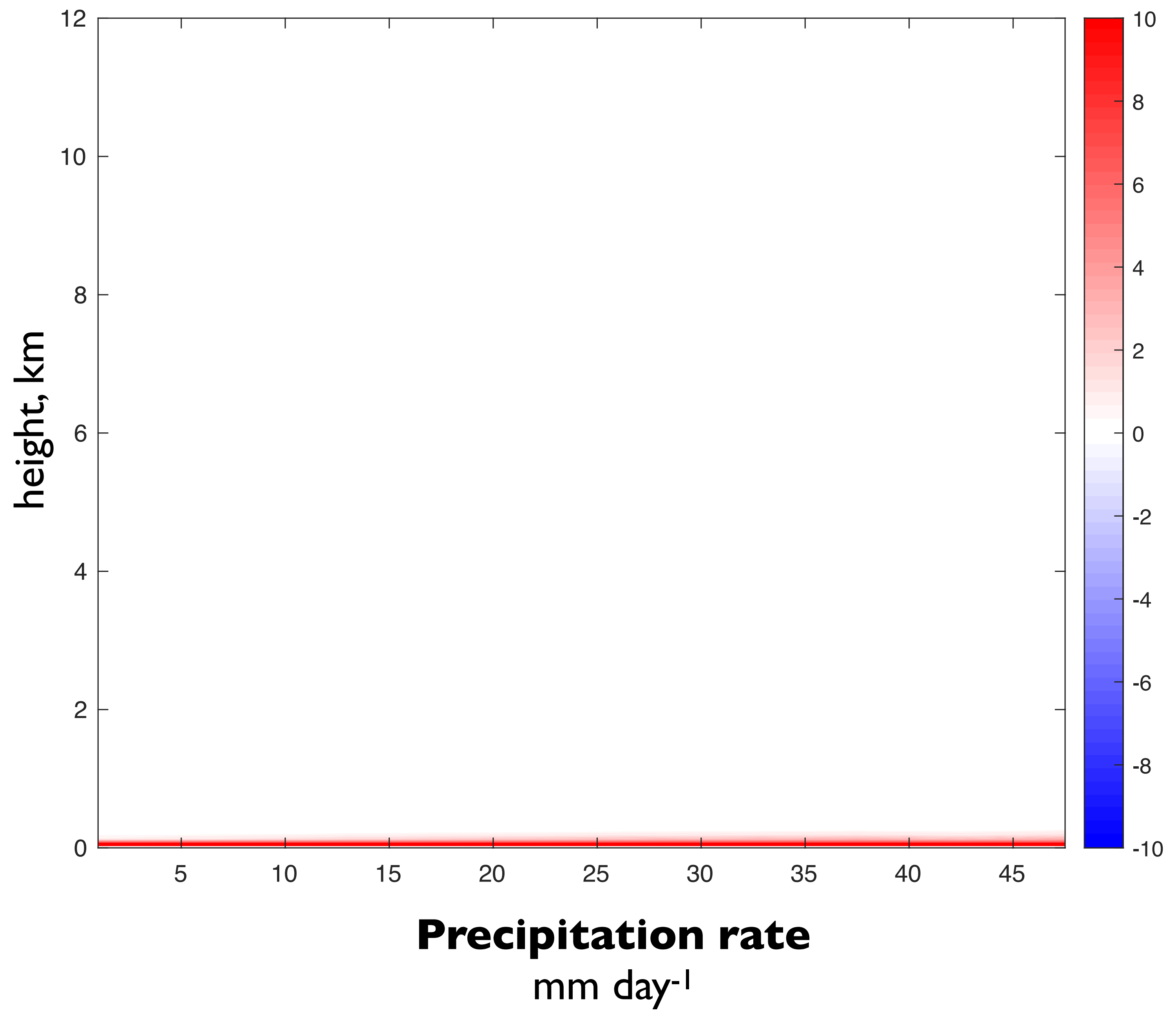




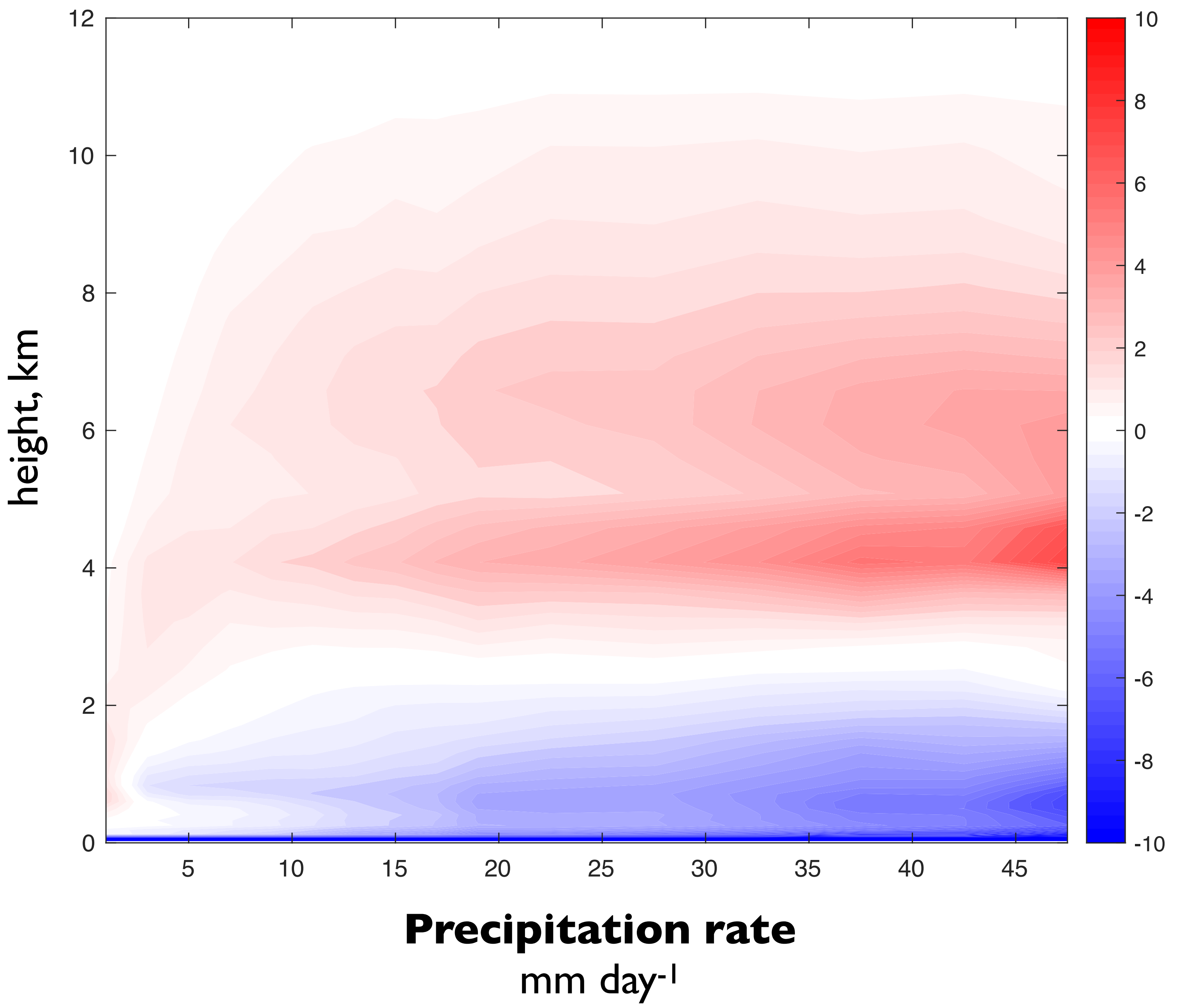


DYNAMO simulation results binned by precipitation rate

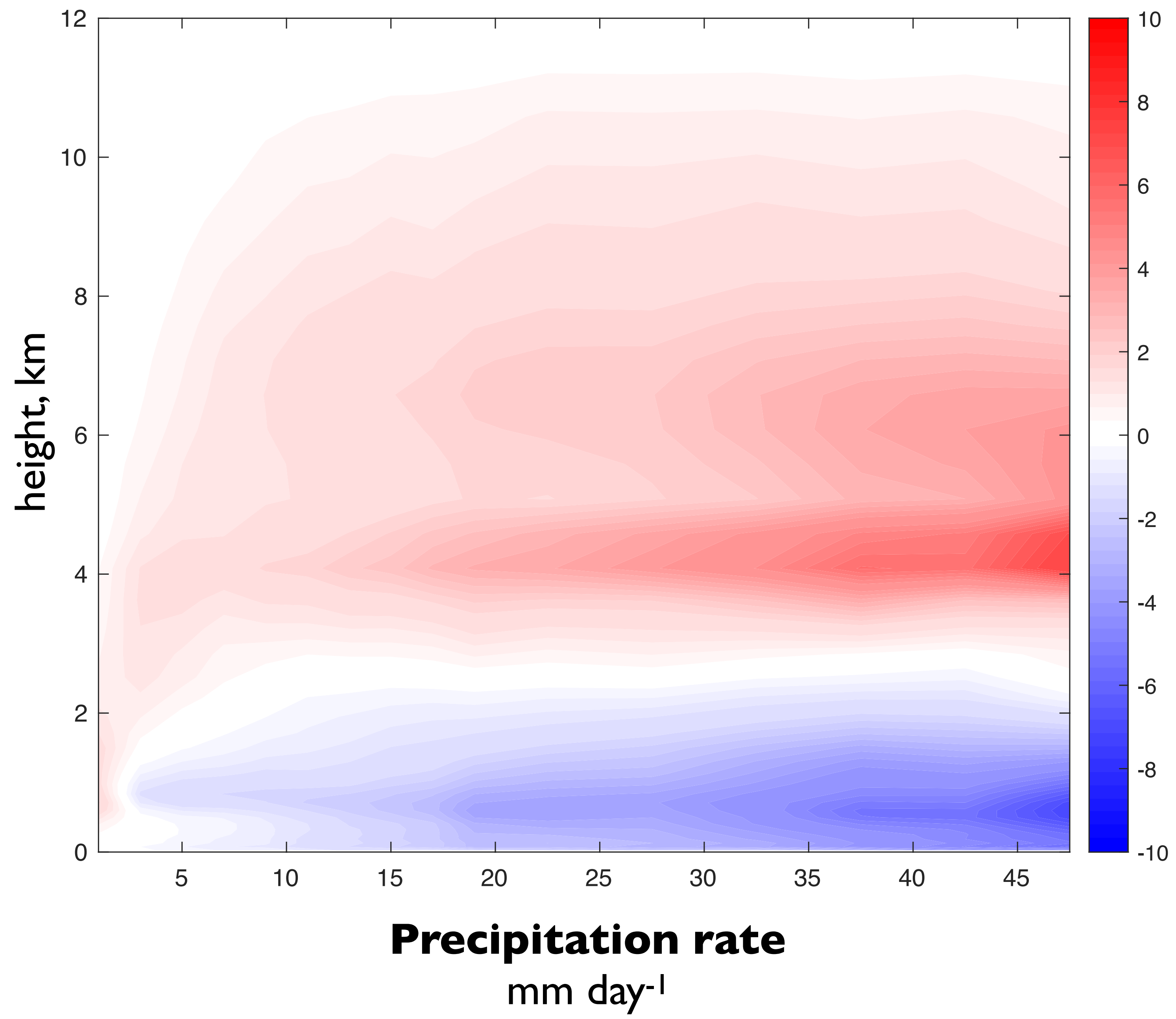
Moistening due to SGS fluxes
g kg^{-1} day^{-1}



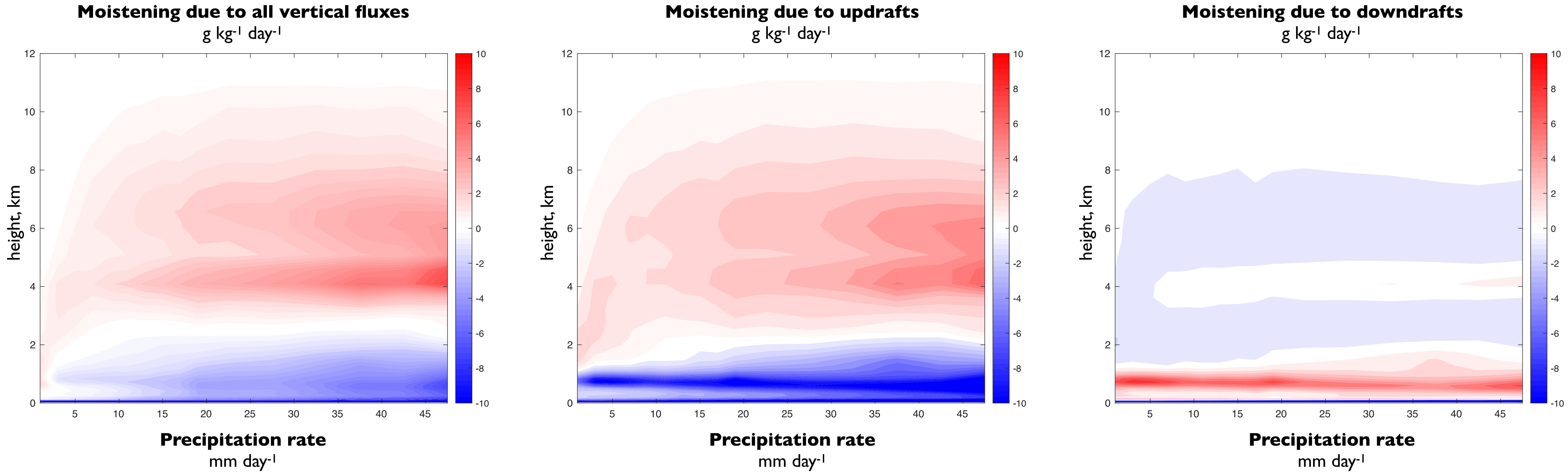
Moistening due to resolved fluxes
DYNAMO-1600m64L Qv+Qc tendency due to flux divergence, net, g kg^{-1} day^{-1}



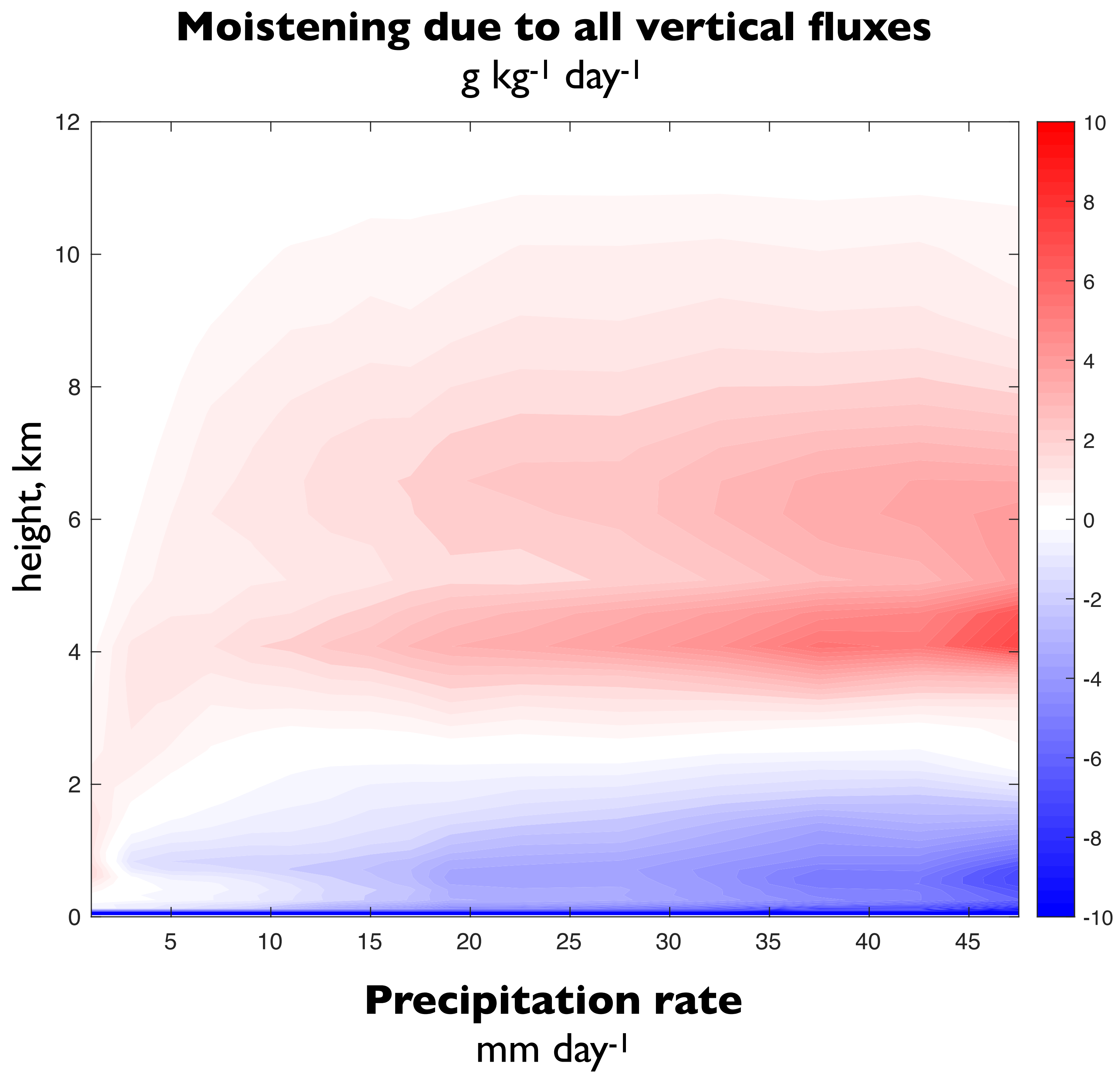
Moistening due to resolved and SGS fluxes
g kg^{-1} day^{-1}

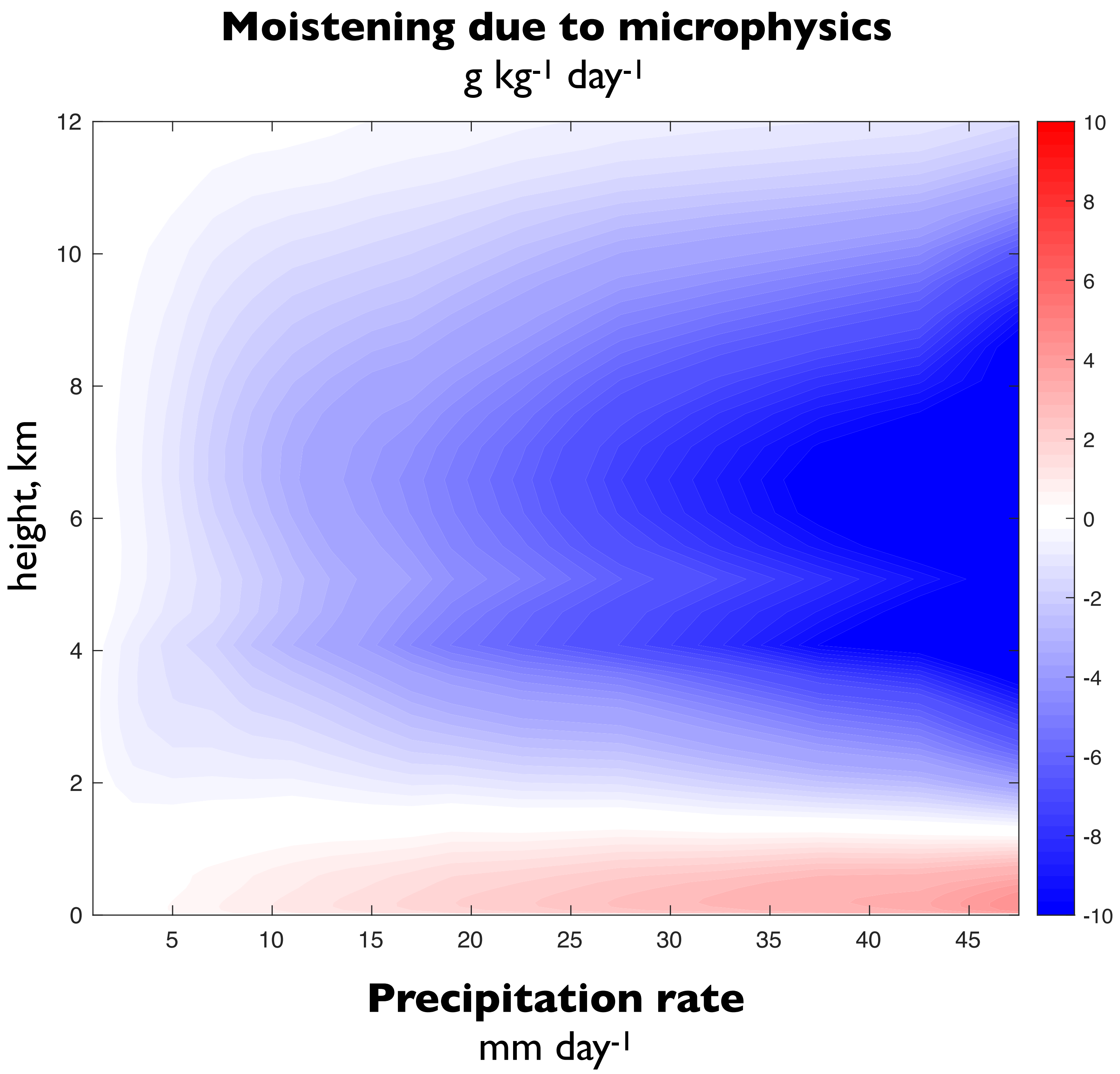


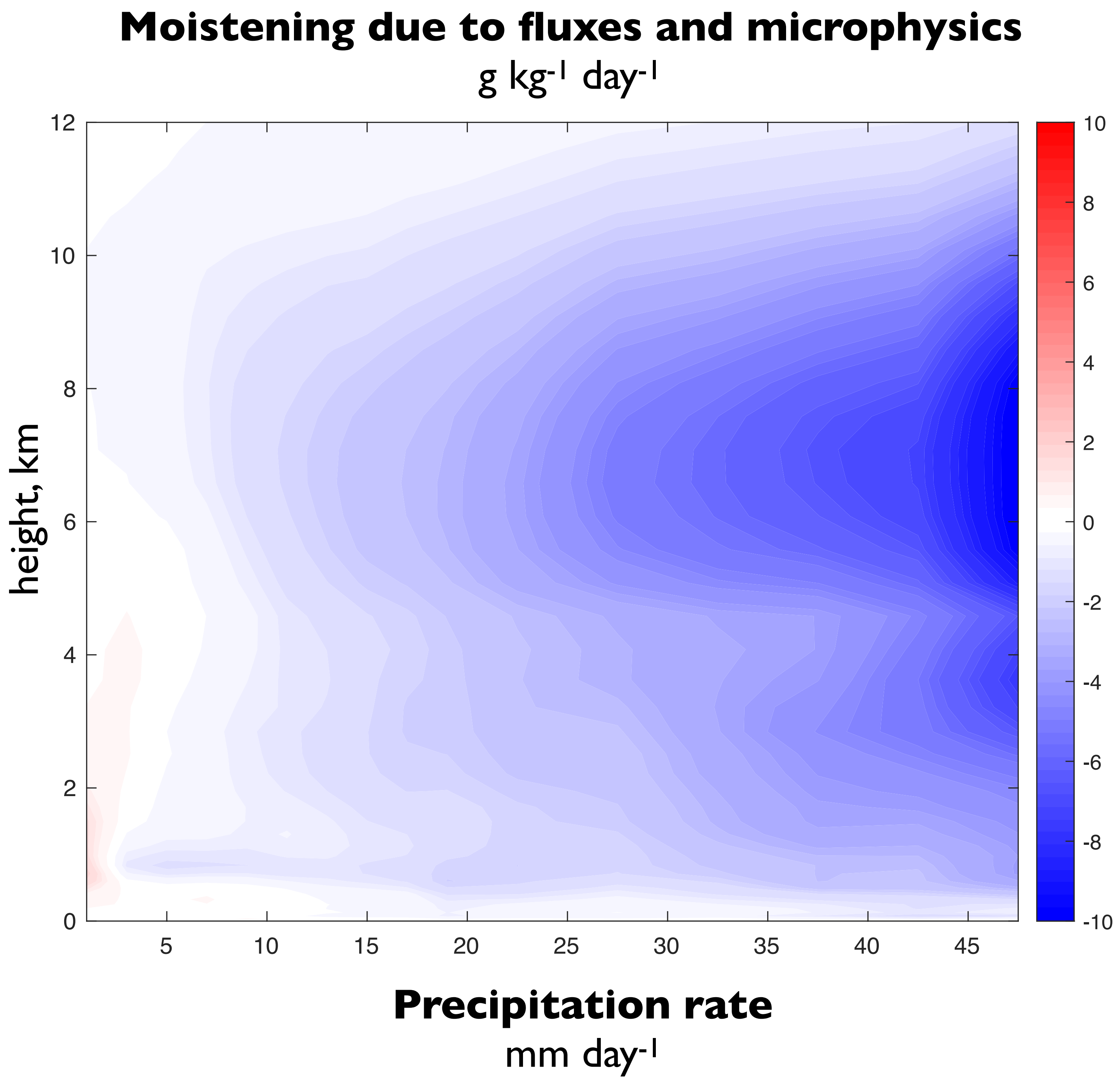
DYNAMO simulation binned by precipitation rate



DYNAMO simulation binned by precipitation rate

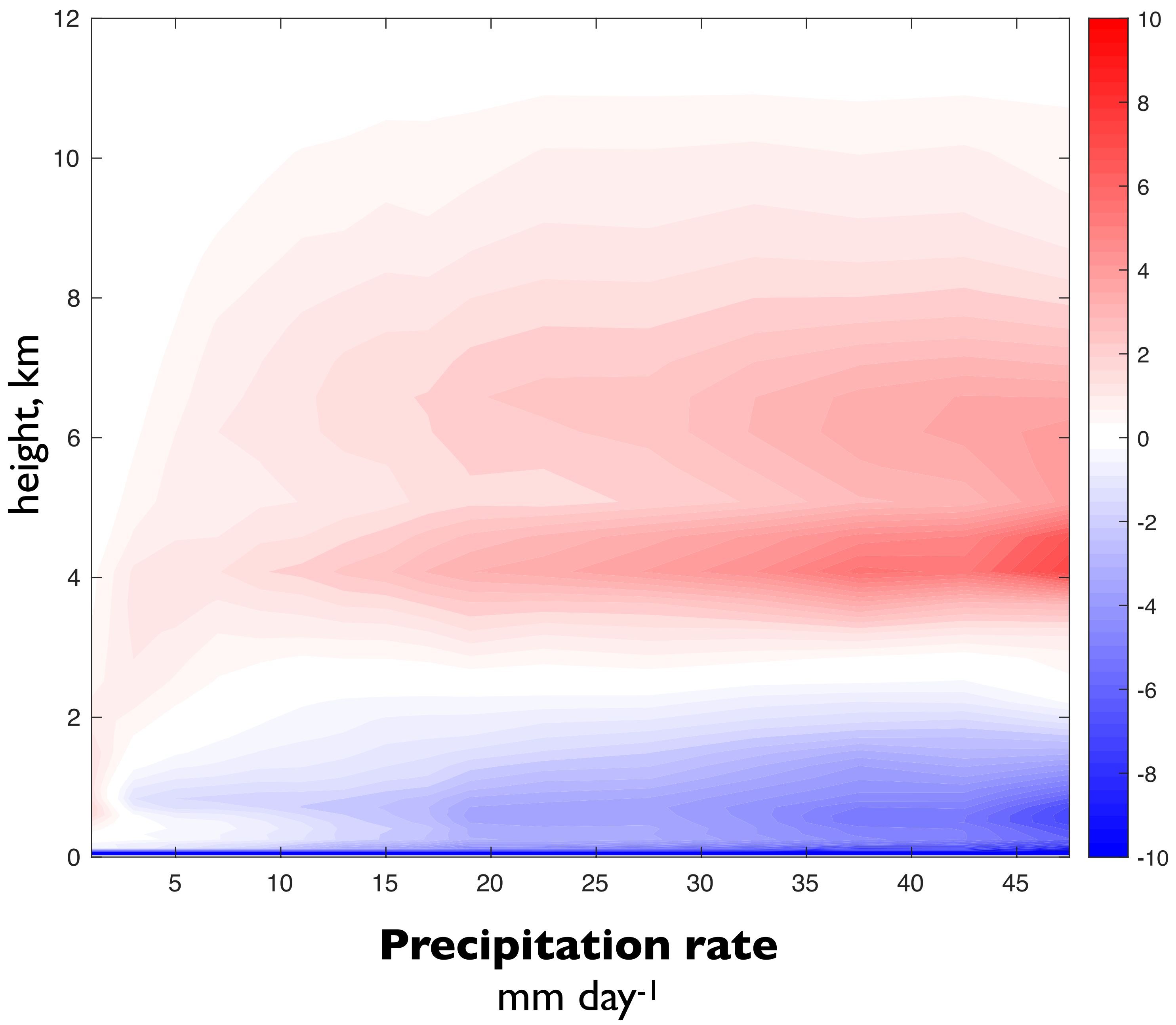




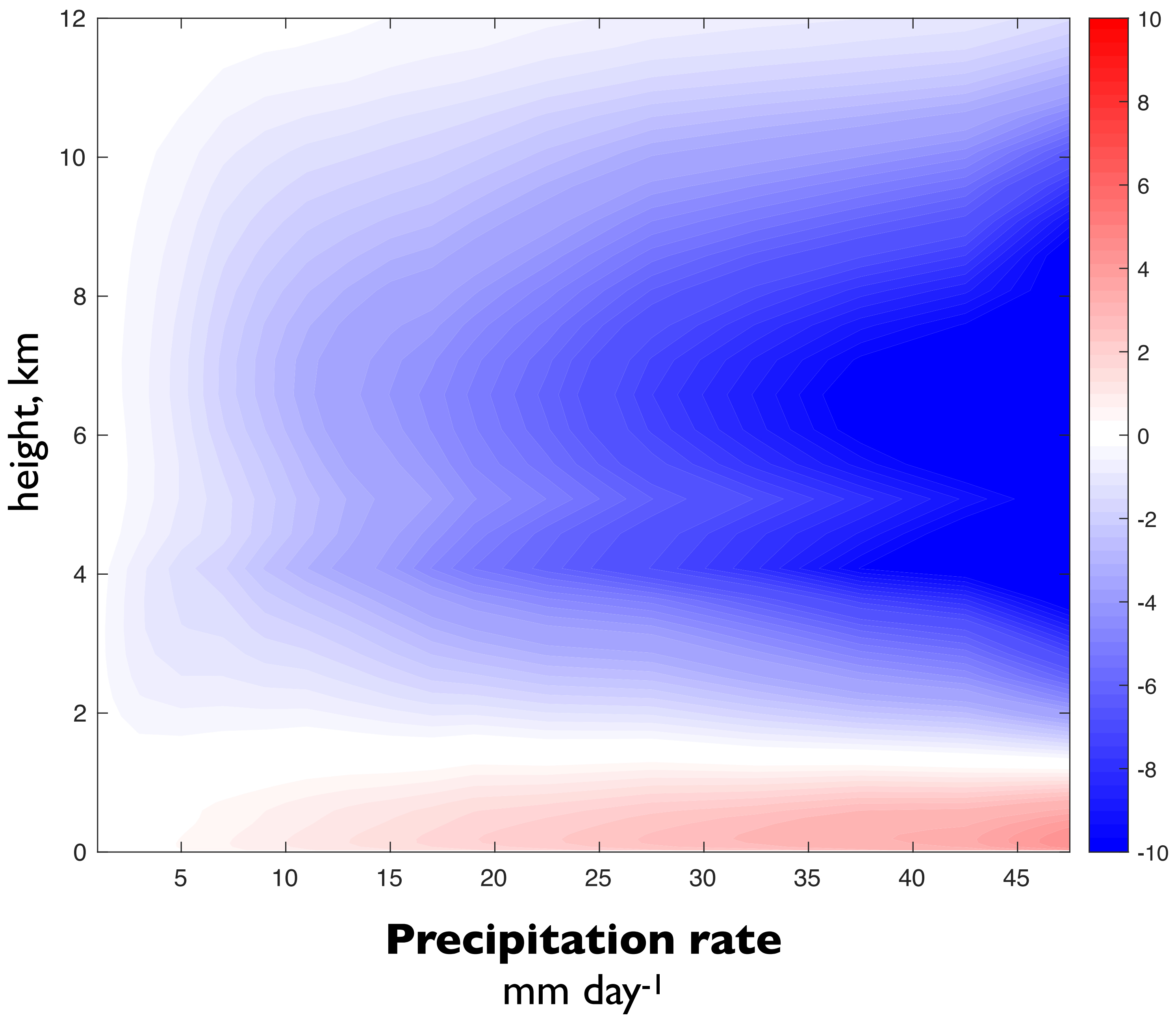


DYNAMO simulation binned by precipitation rate

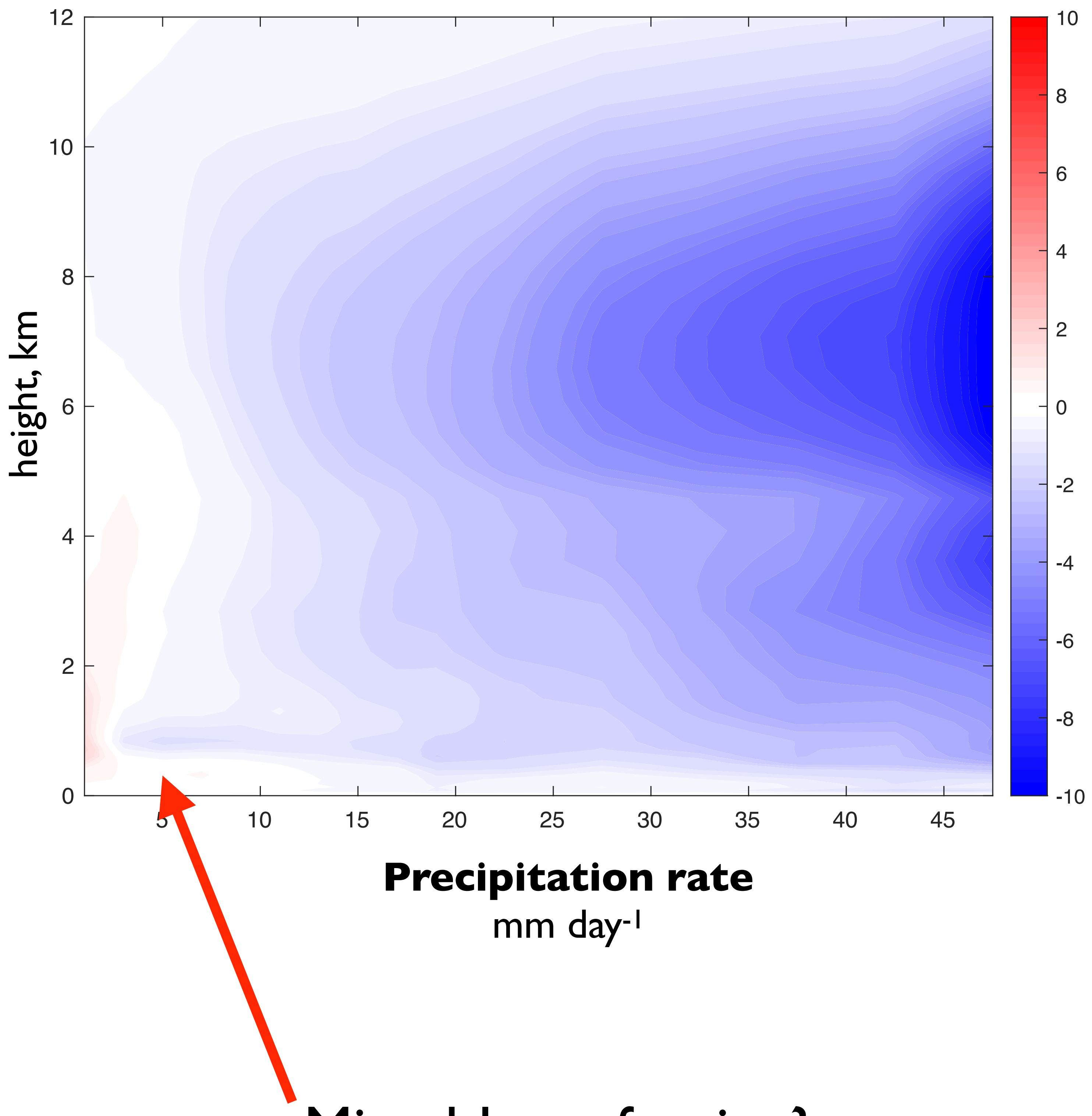
Moistening due to all vertical fluxes
g kg^{-1} day^{-1}



Moistening due to microphysics
g kg^{-1} day^{-1}

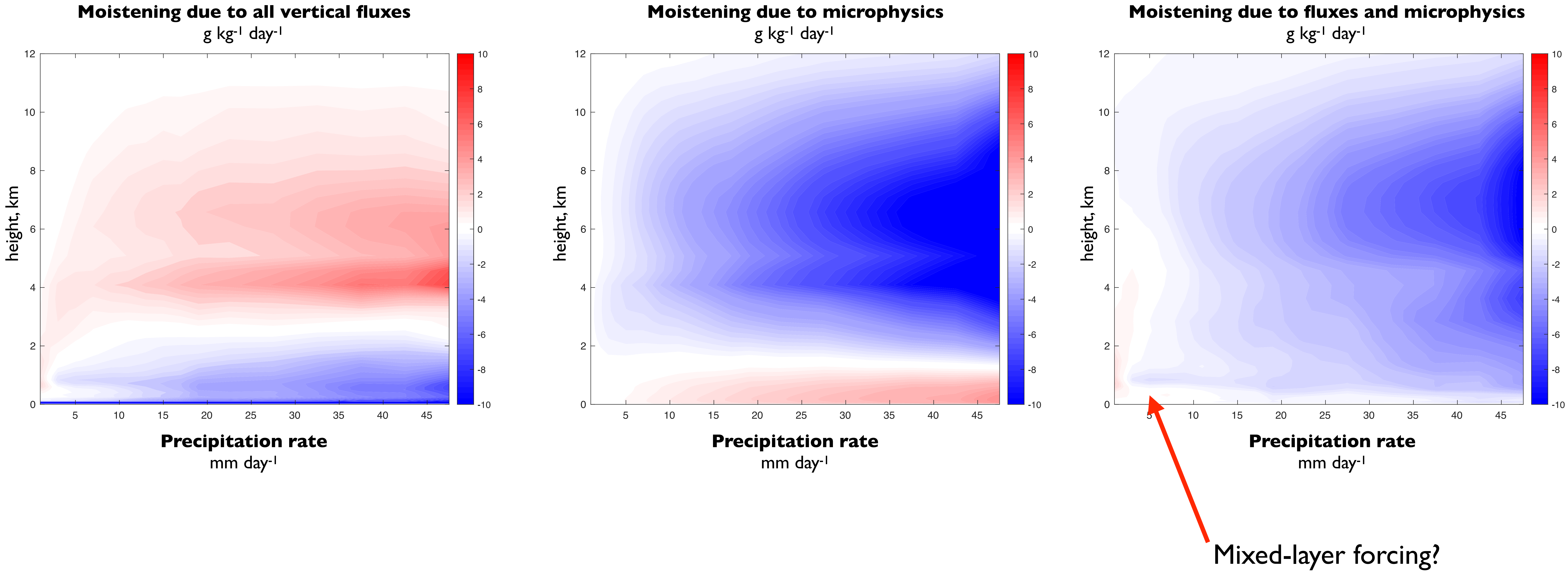


Moistening due to fluxes and microphysics
g kg^{-1} day^{-1}



Mixed-layer forcing?

DYNAMO simulation binned by precipitation rate

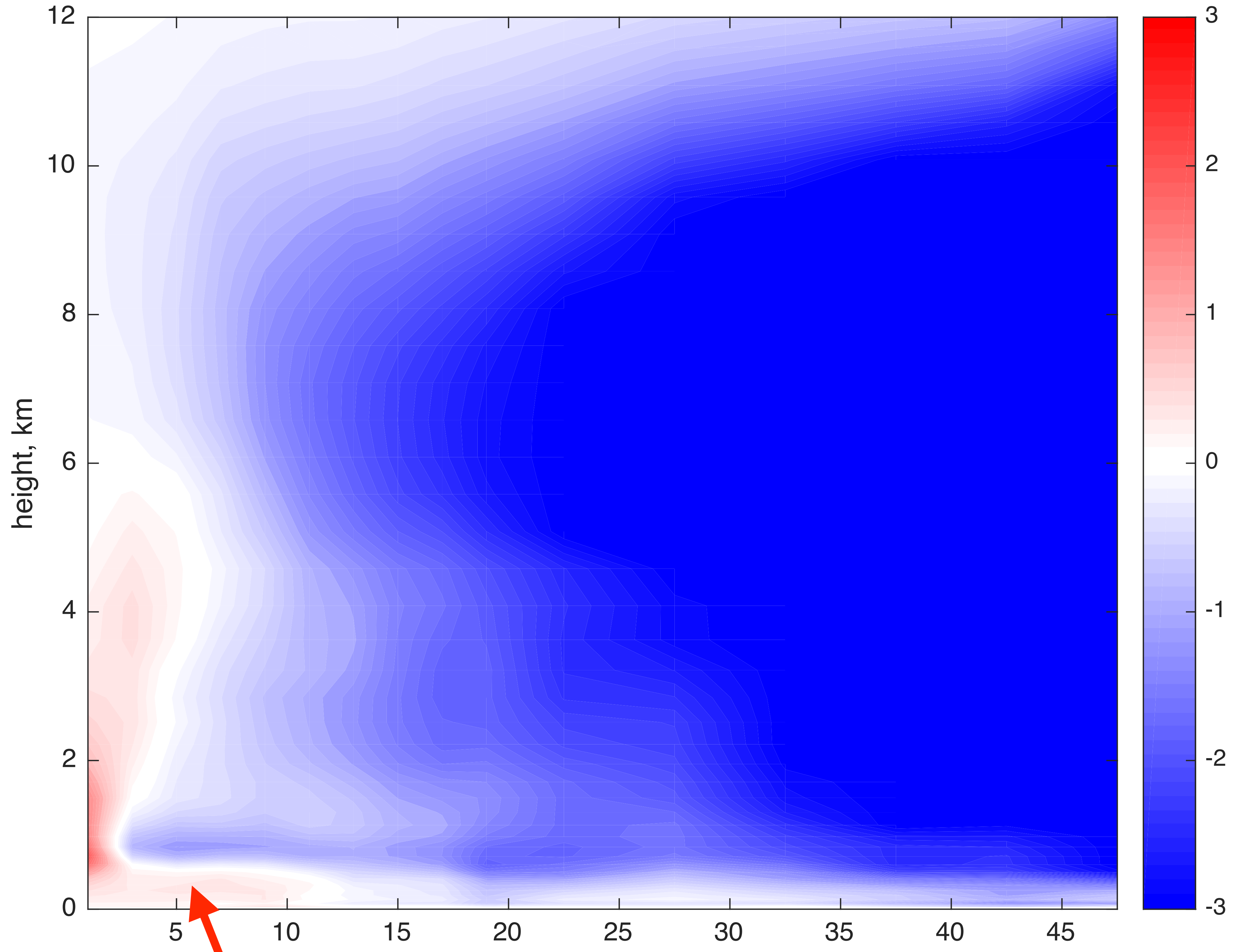


The mixed-layer forcing does not exist when deep convection is intense, because the moisture flux does not converge inside the mixed layer.

Same plot with a different color bar

Moistening due to fluxes and microphysics

g kg⁻¹ day⁻¹



Precipitation rate

mm day⁻¹

Mixed-layer forcing?

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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- Radiatively active stratiform clouds are influenced by deep convection.

Randall and Pan (1993, p. 143):

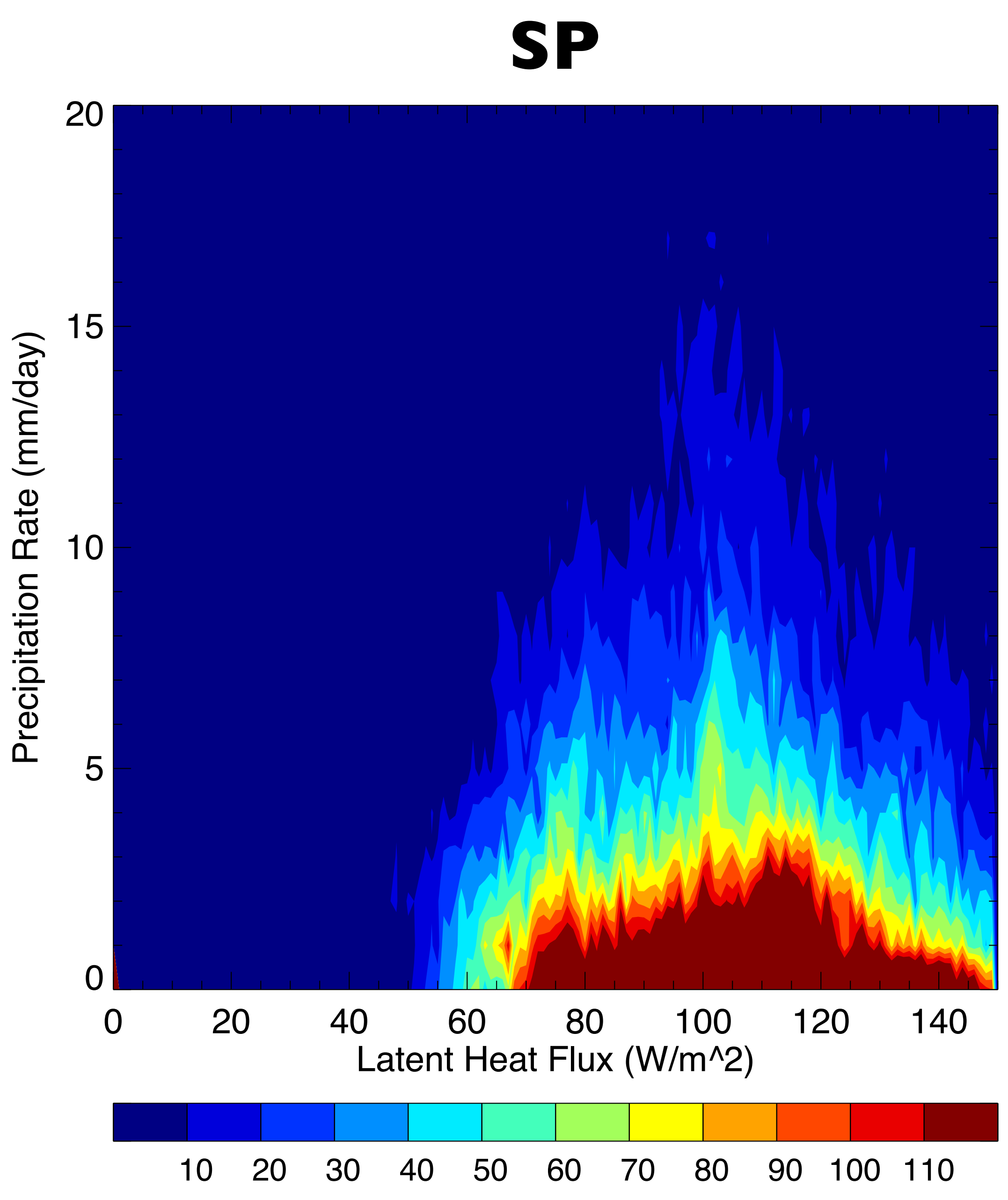
"… it is not always clear which processes are convective and which are not."

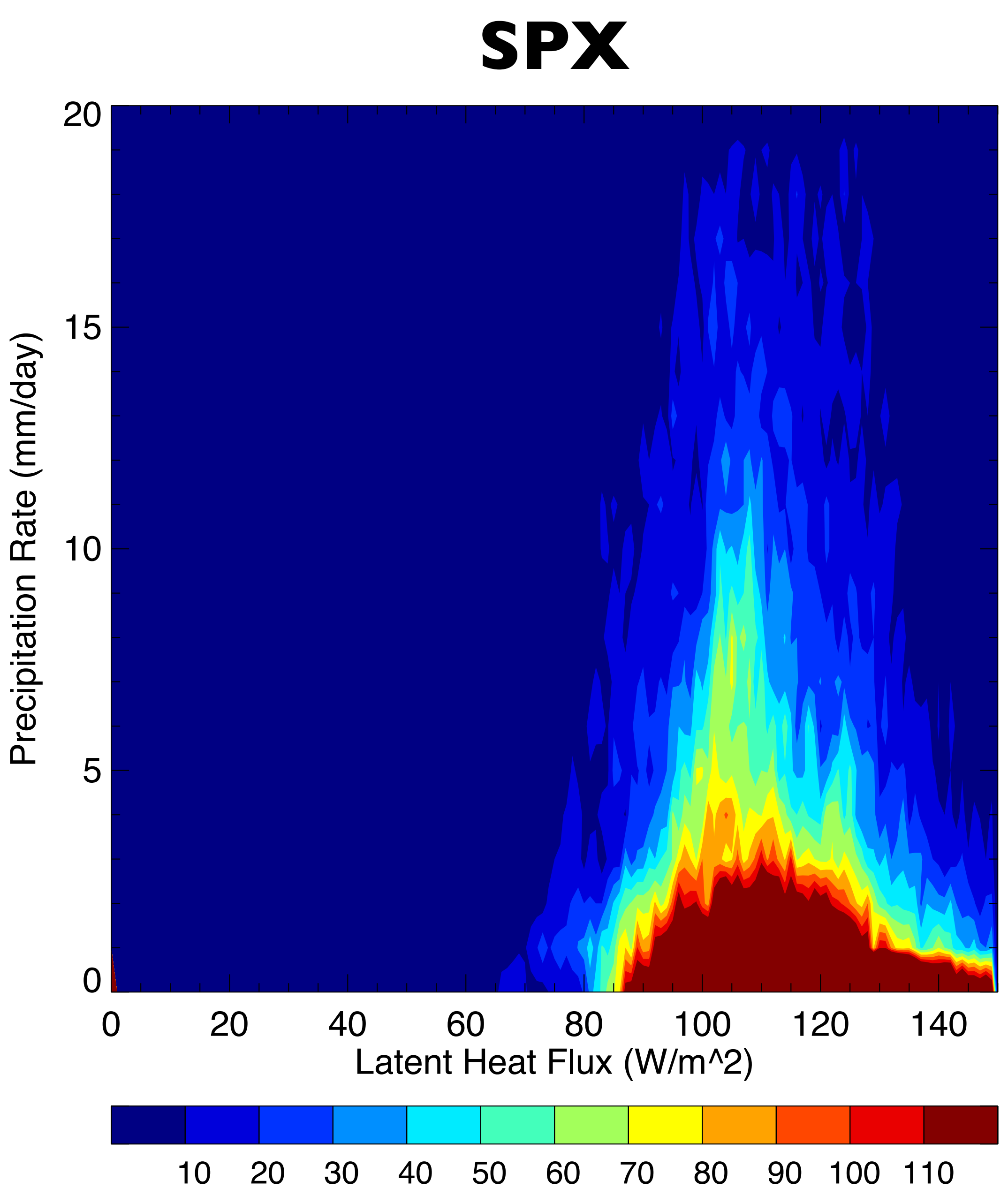
Randall, D. A., and D.-M. Pan, 1993: Implementation of the Arakawa-Schubert cumulus parameterization with a prognostic closure. In *The Representation of Cumulus Convection in Numerical Models,* a Meteorological Monograph published by the American Meteorological Society, K. Emanuel and D. Raymond, Eds.,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

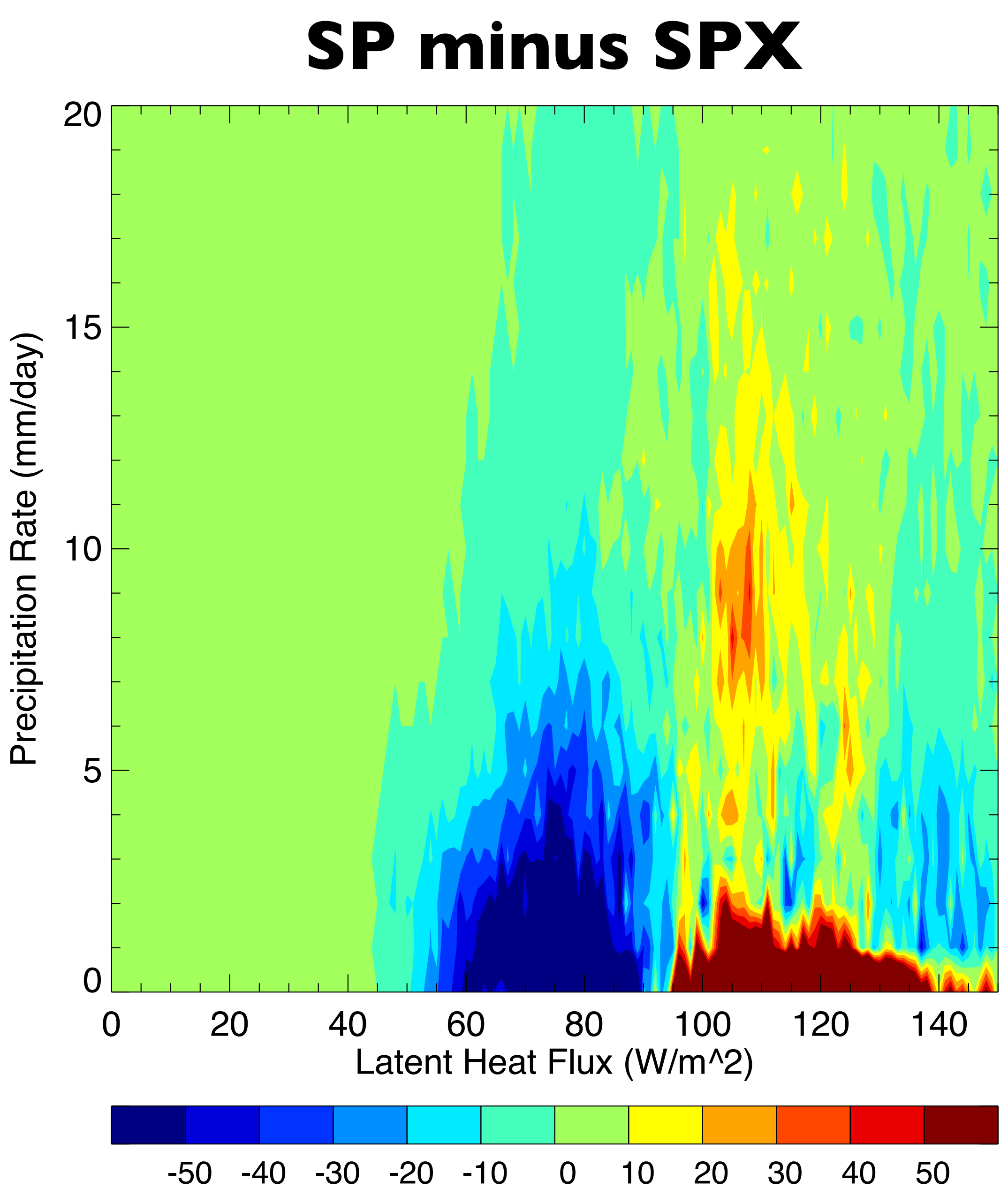
An example: SP vs. SPX

In SP, the surface fluxes are computed on the GCM grid and passed to the CRM, which uses the same fluxes for all grid columns of its fine grid.

In SPX, the surface fluxes are computed on the CRM's grid.
Averages over the CRM's grid are sent back to the GCM for use as diagnostics.







Is there an alternative to forcing and response?

Is there an alternative to forcing and response?

Sure!

Two alternatives

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)

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

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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If we avoid defining forcing and response, can we still talk about QE?

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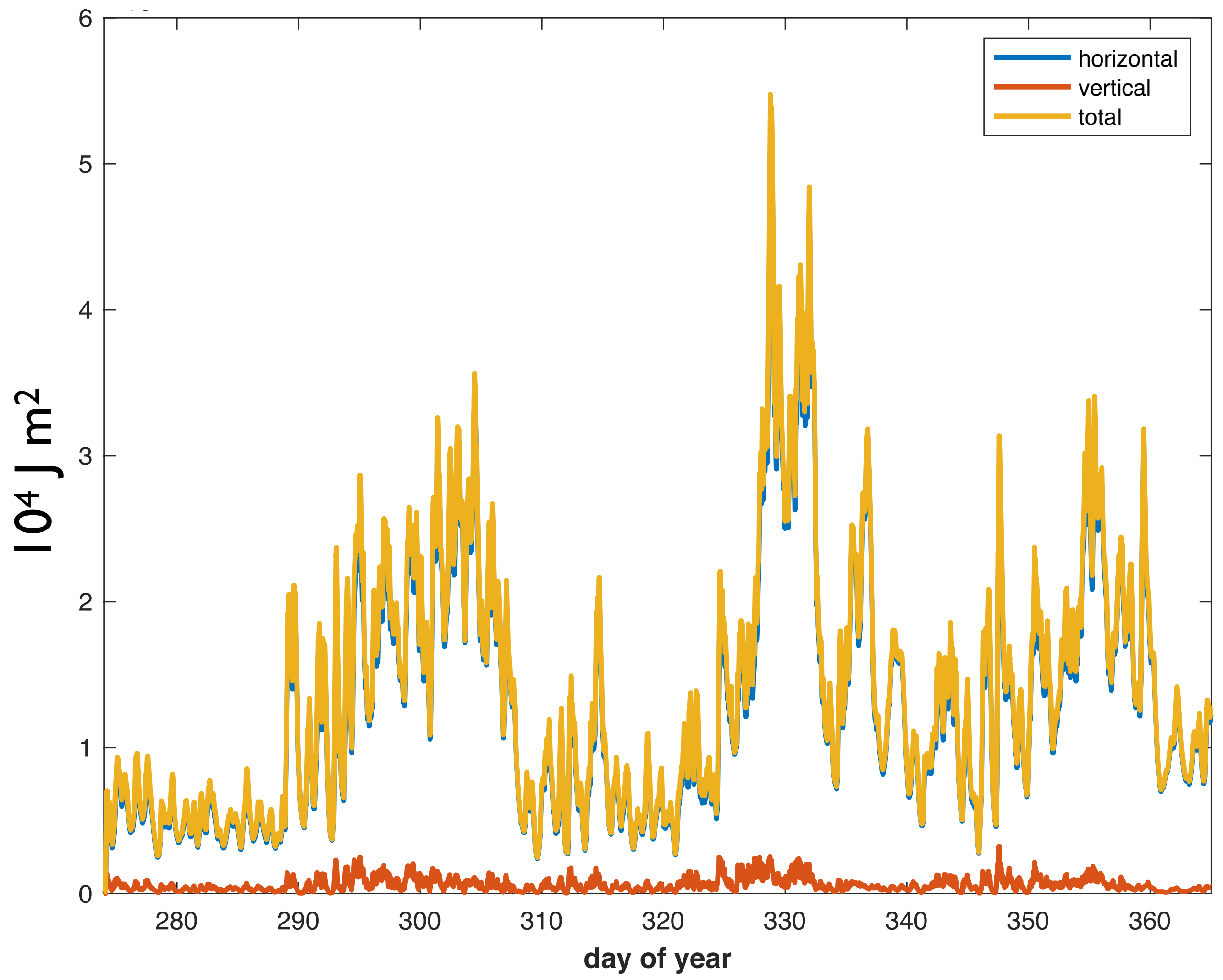
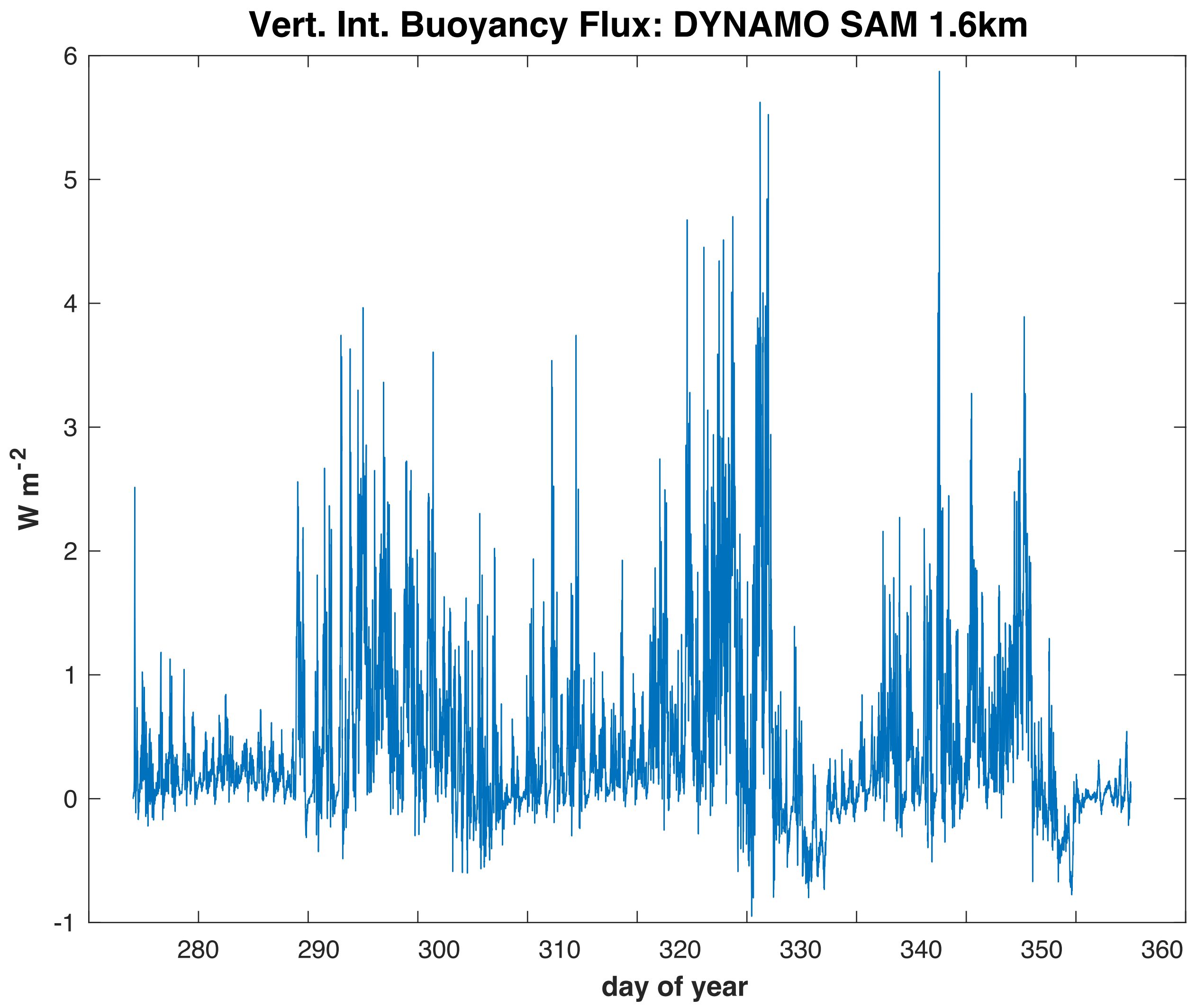
Sure!

Kinetic energy QE

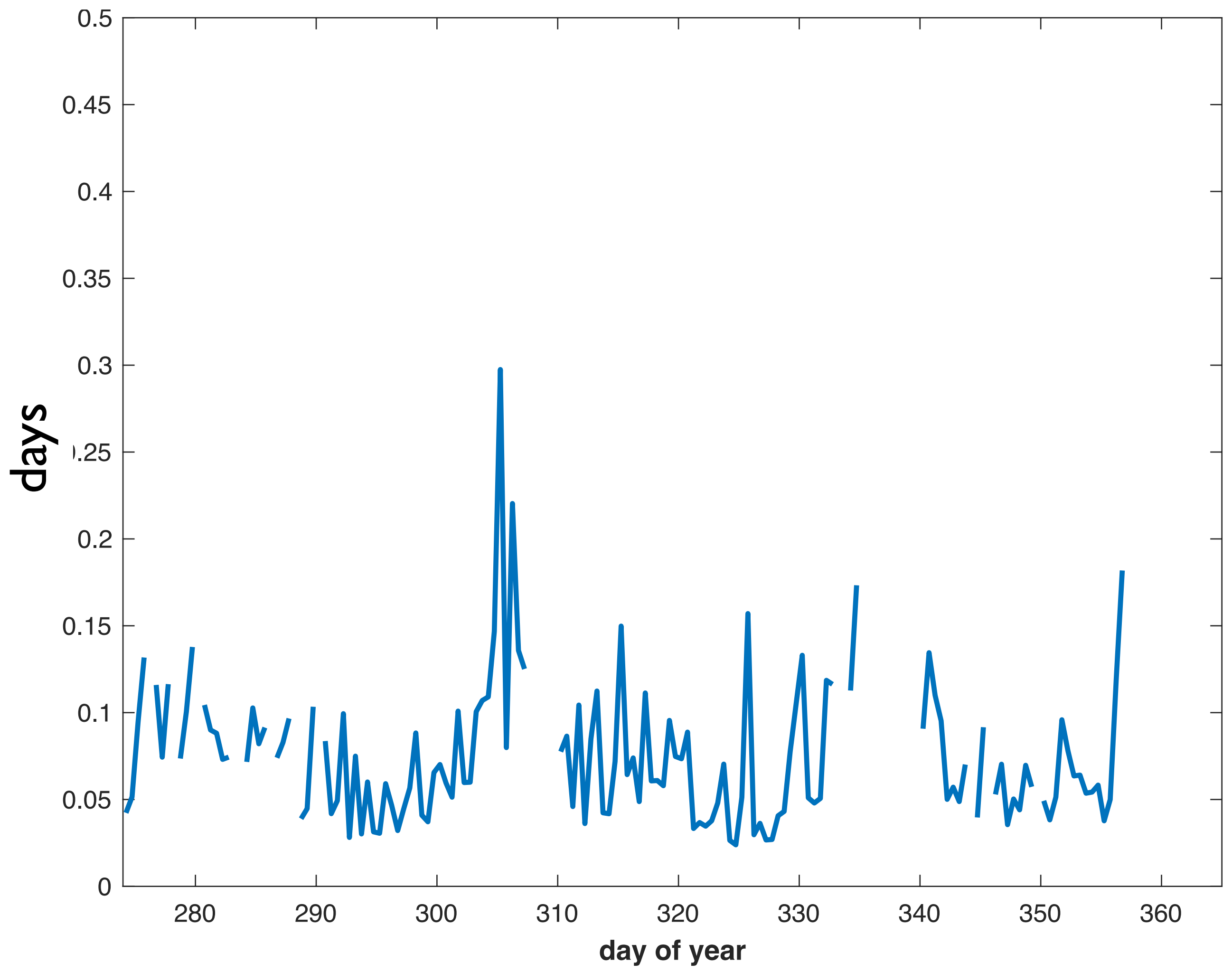
Vertically integrated CKE



Vertically integrated buoyancy flux



The ratio, which is a time scale



See Lord & Arakawa (1980, "Part II")

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 do that.
- Even without the forcing-and-response paradigm, quasi-equilibrium can still be discussed in terms of the cumulus kinetic energy.


Thanks