Why Do Climate Models Drizzle Too Much and What Impact Does This Have?

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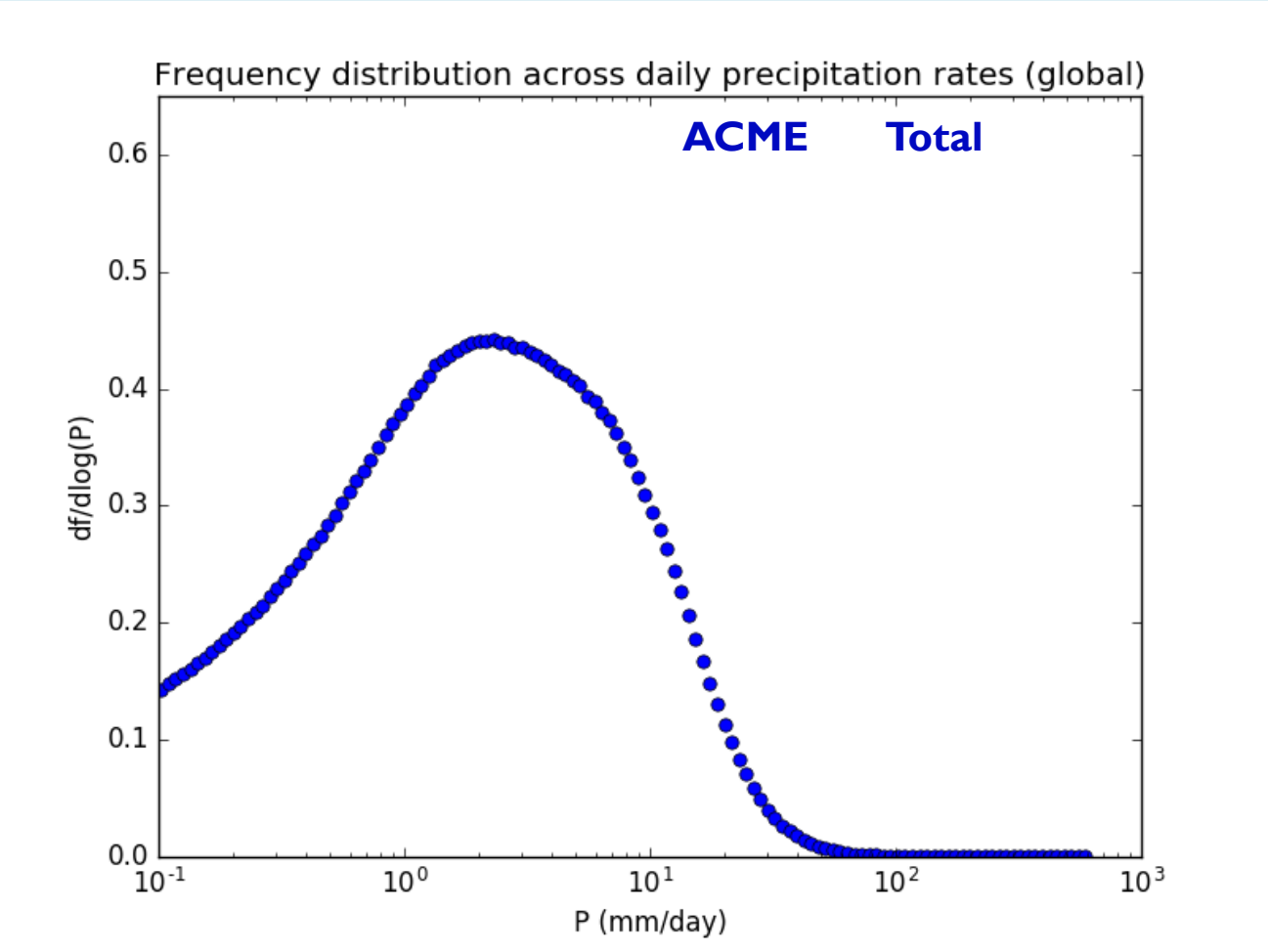
Models precipitate too lightly, too frequently



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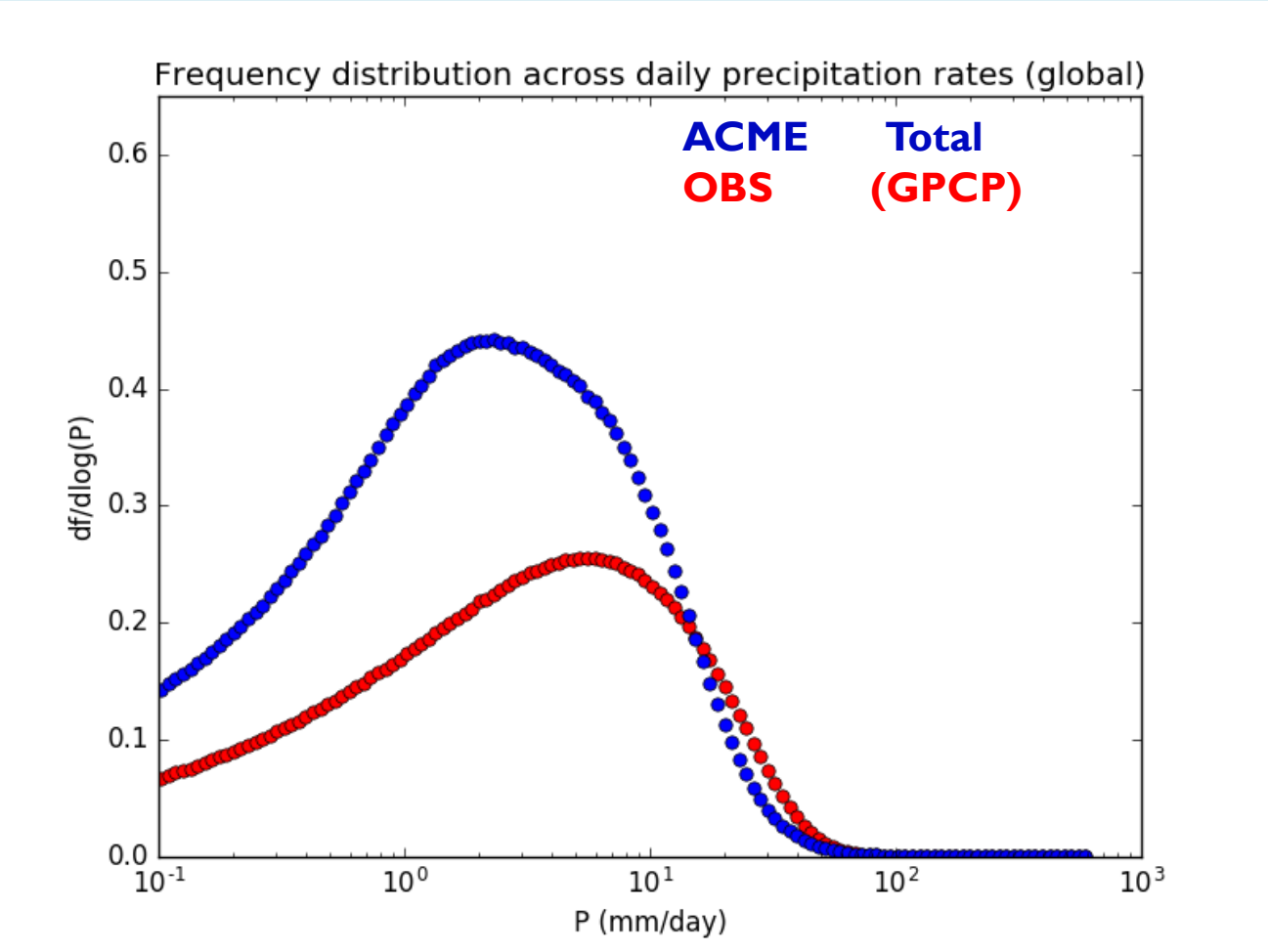

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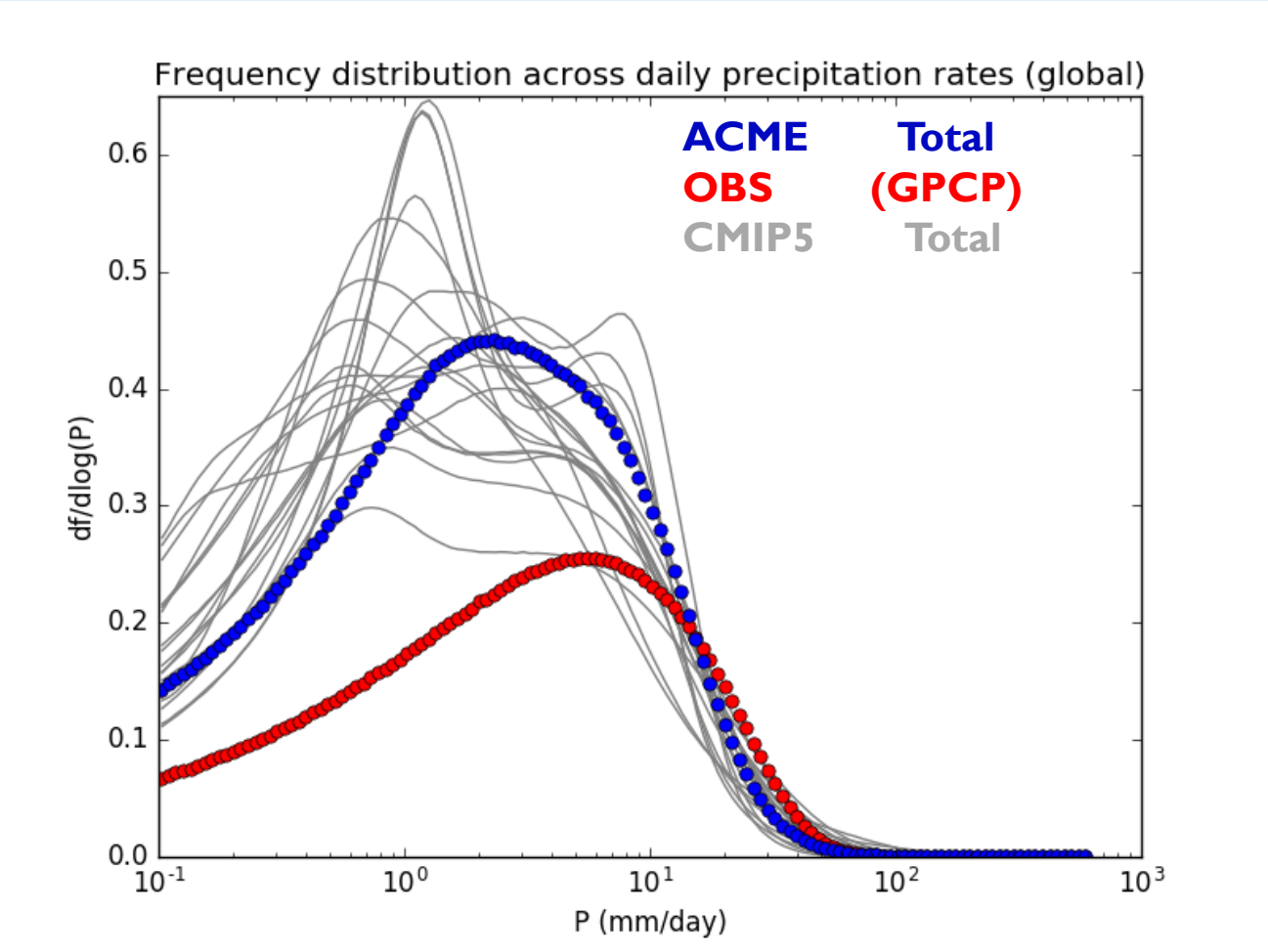

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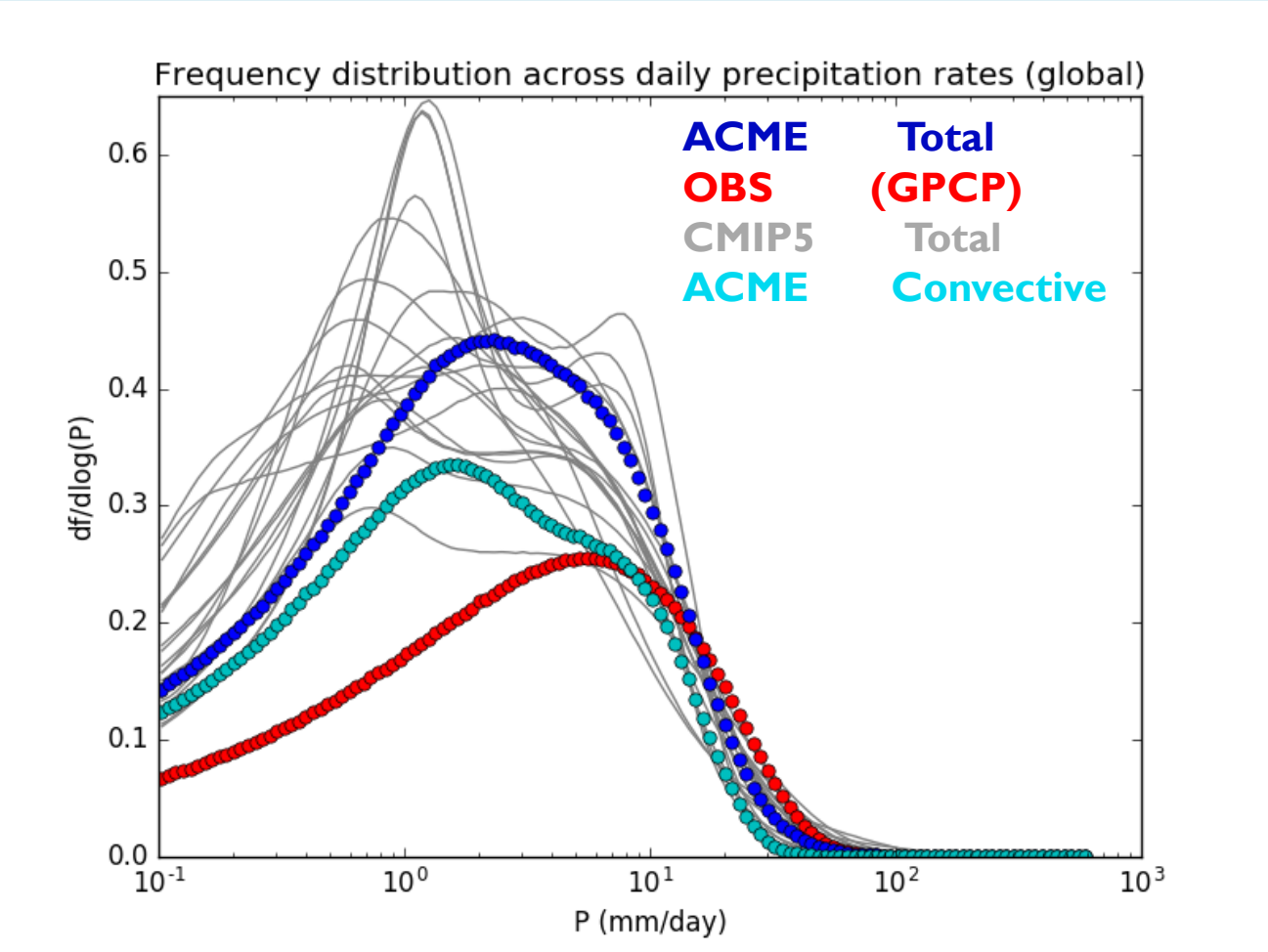

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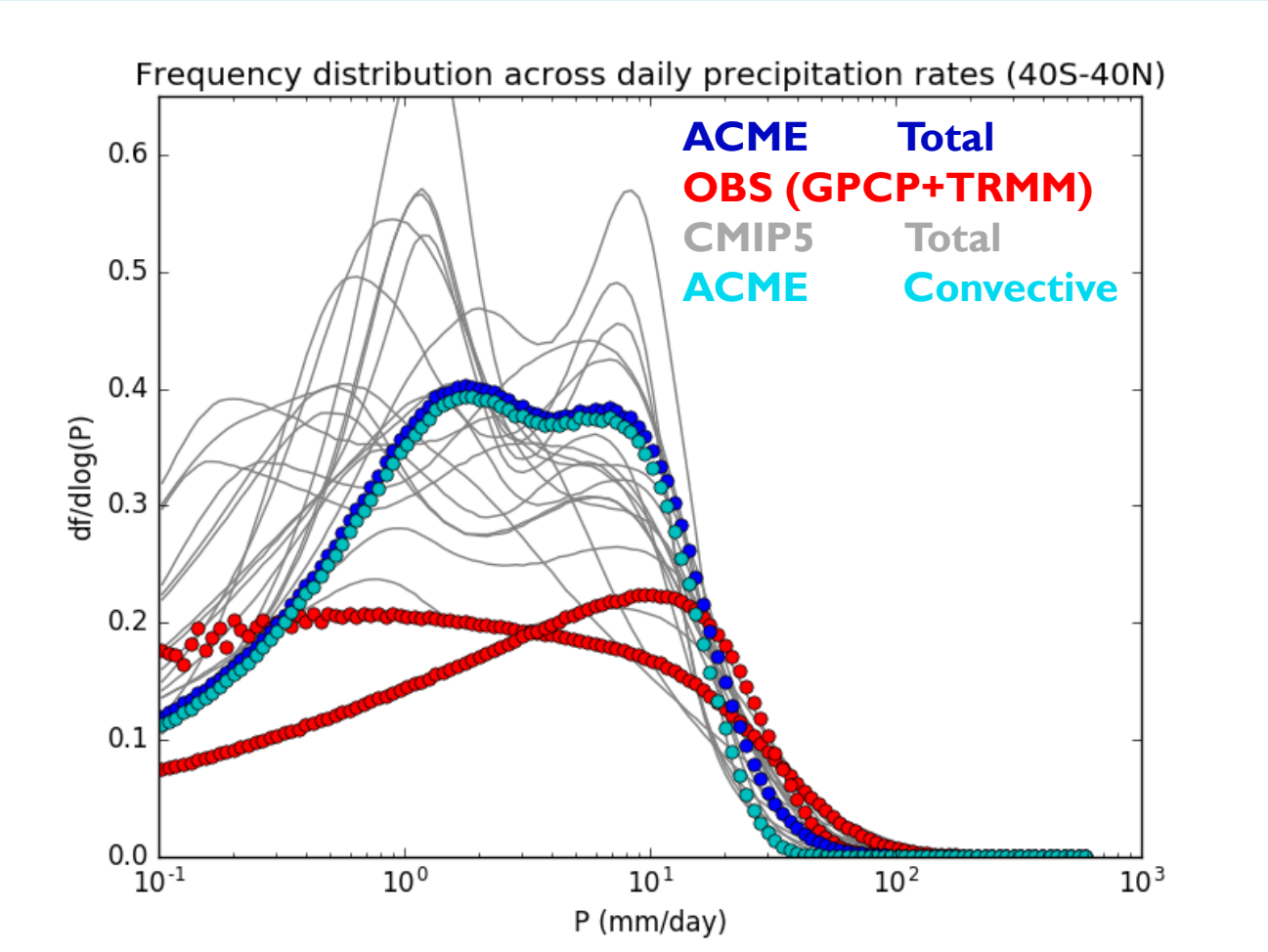

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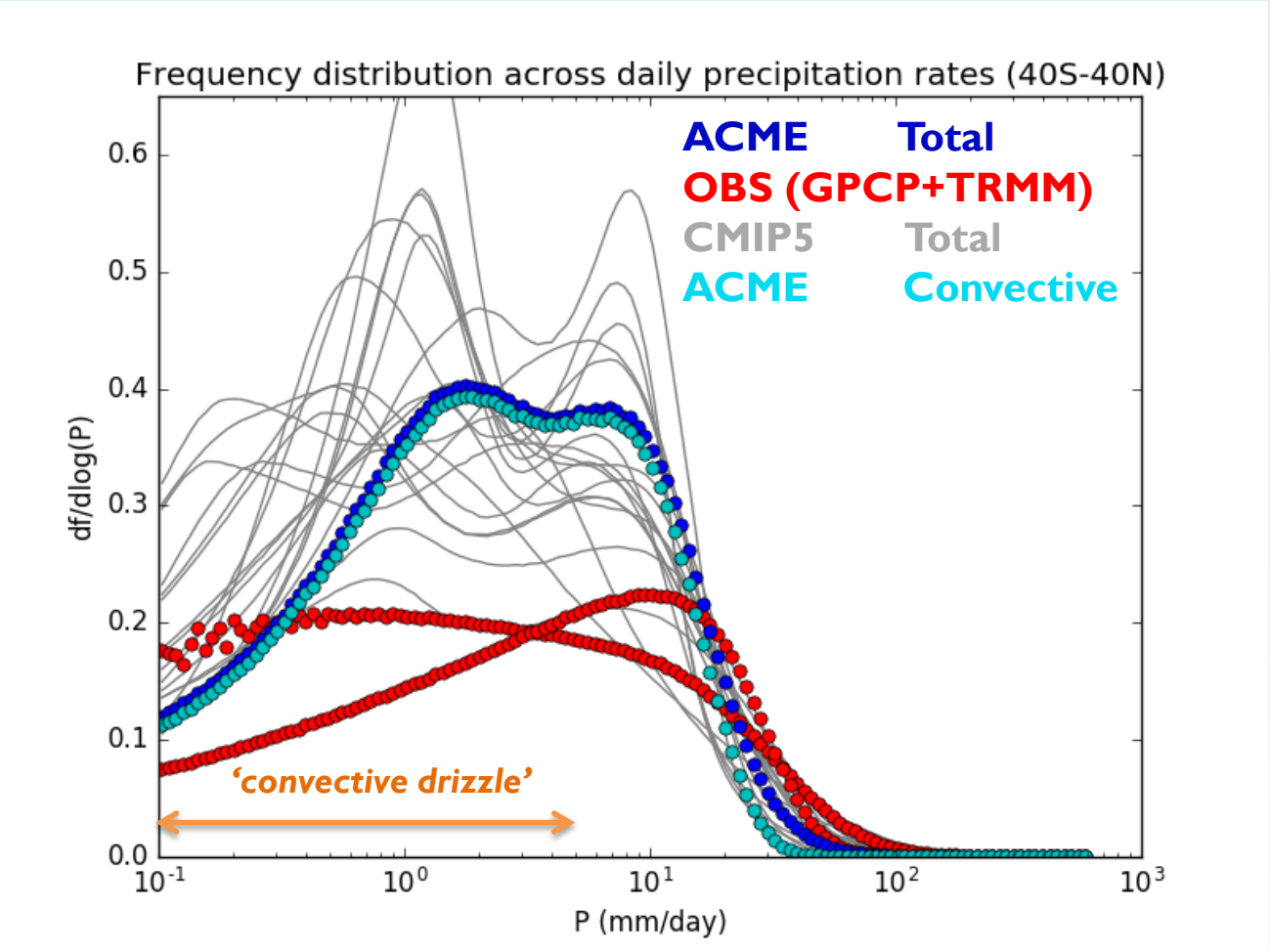

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Questions

1) What causes the light rain in the model?

Who?
What?
When?
Where?
Why?

2) How big is the model vs. observation discrepancy?

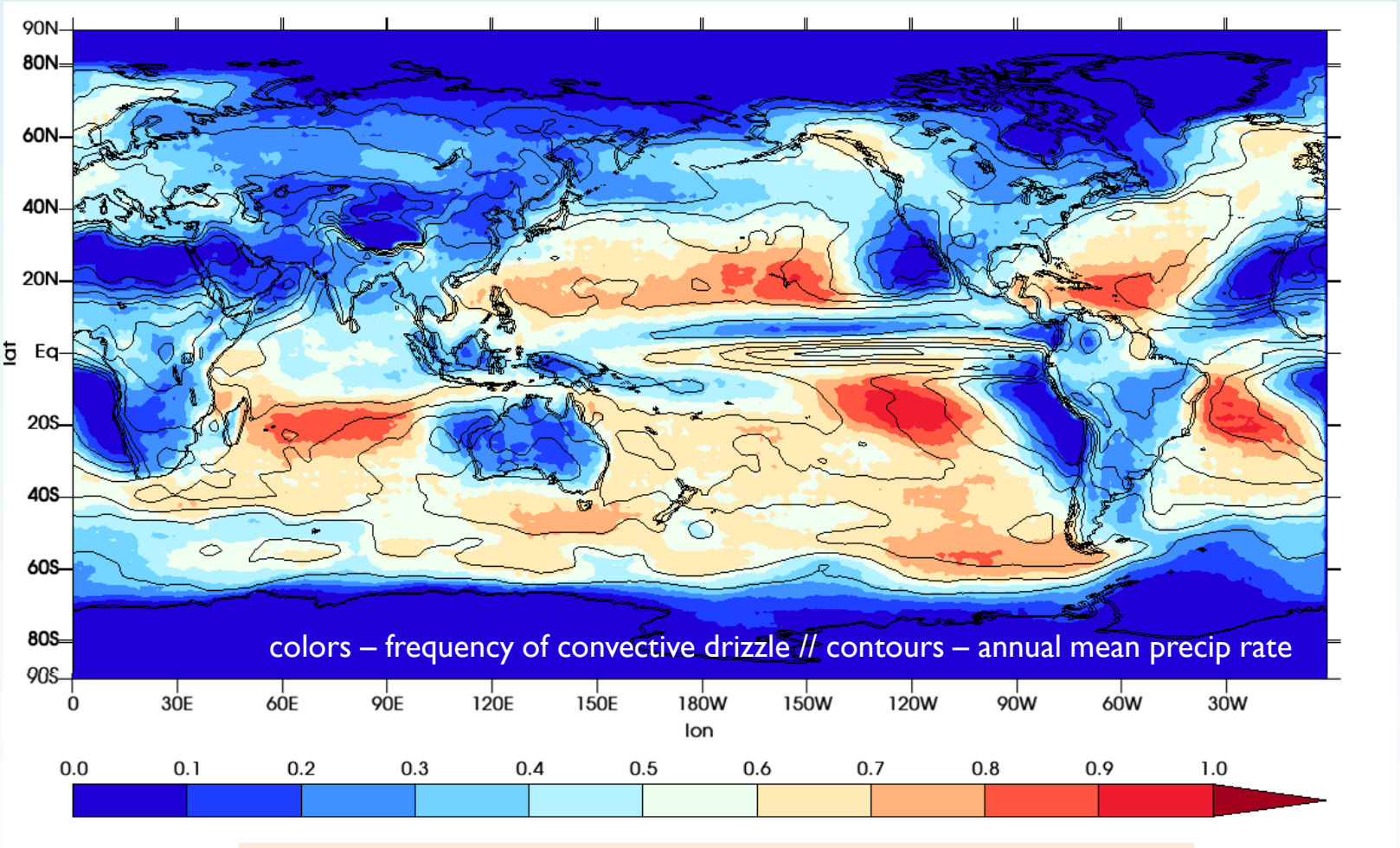
Comparisons with CloudSat

3) Does affect other parts of the current climate?

Model experiments where light rain is suppressed

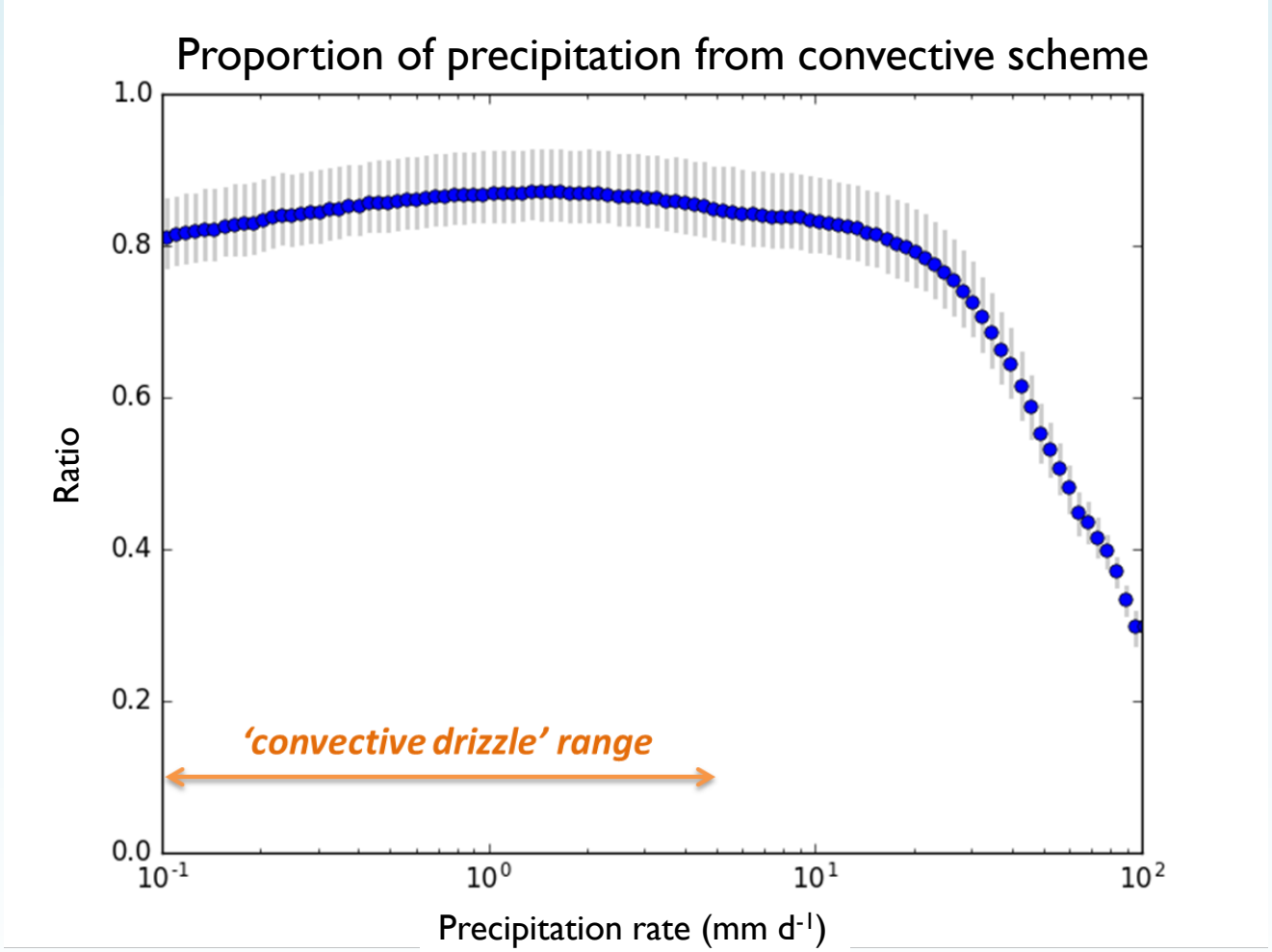
Where does it occur?

Frequency map of 0.1<P<5 mm d^{-1}



Occurs most frequently over ocean (Kooperman et al., 2015), in the transition to heavy precipitation

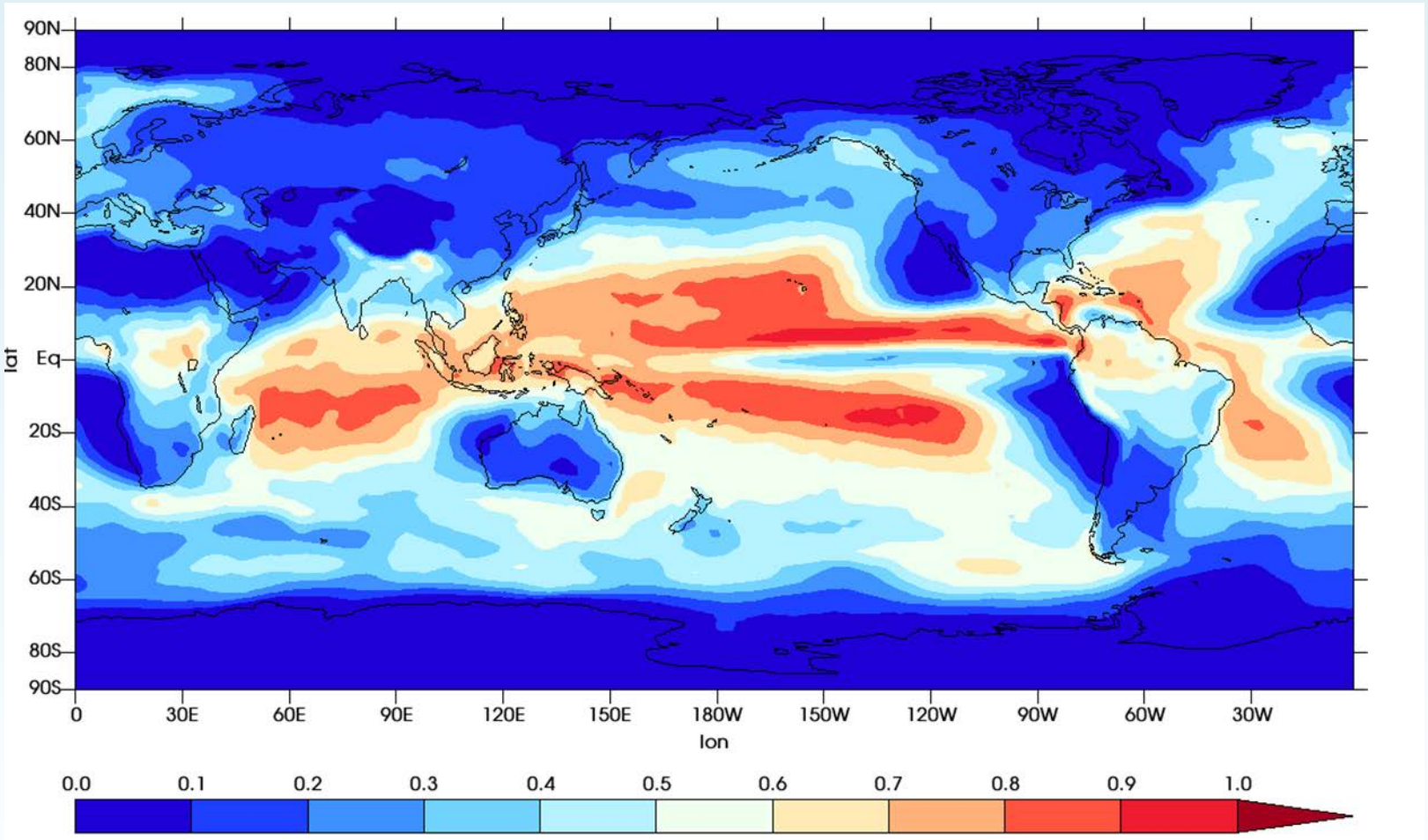
Who? – Convective precipitation contributes most to the light rain



Puzzle: Odd that the deep-convective scheme is producing light rainfall events (Zhang-MacFarlane scheme).

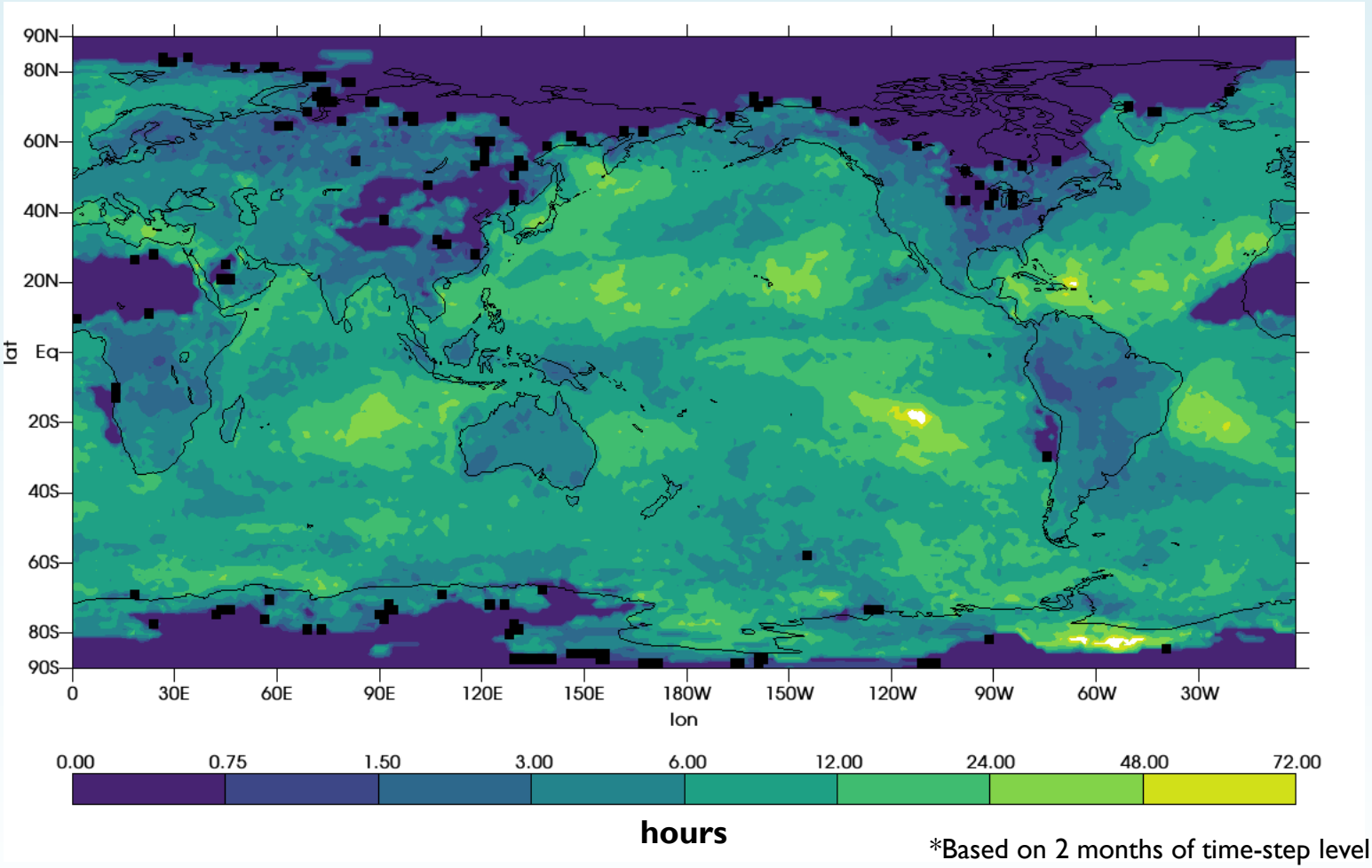
Deep-convection scheme triggers very frequently

Frequency map of ZM-scheme triggering



When? – how long do these convective drizzle events last?

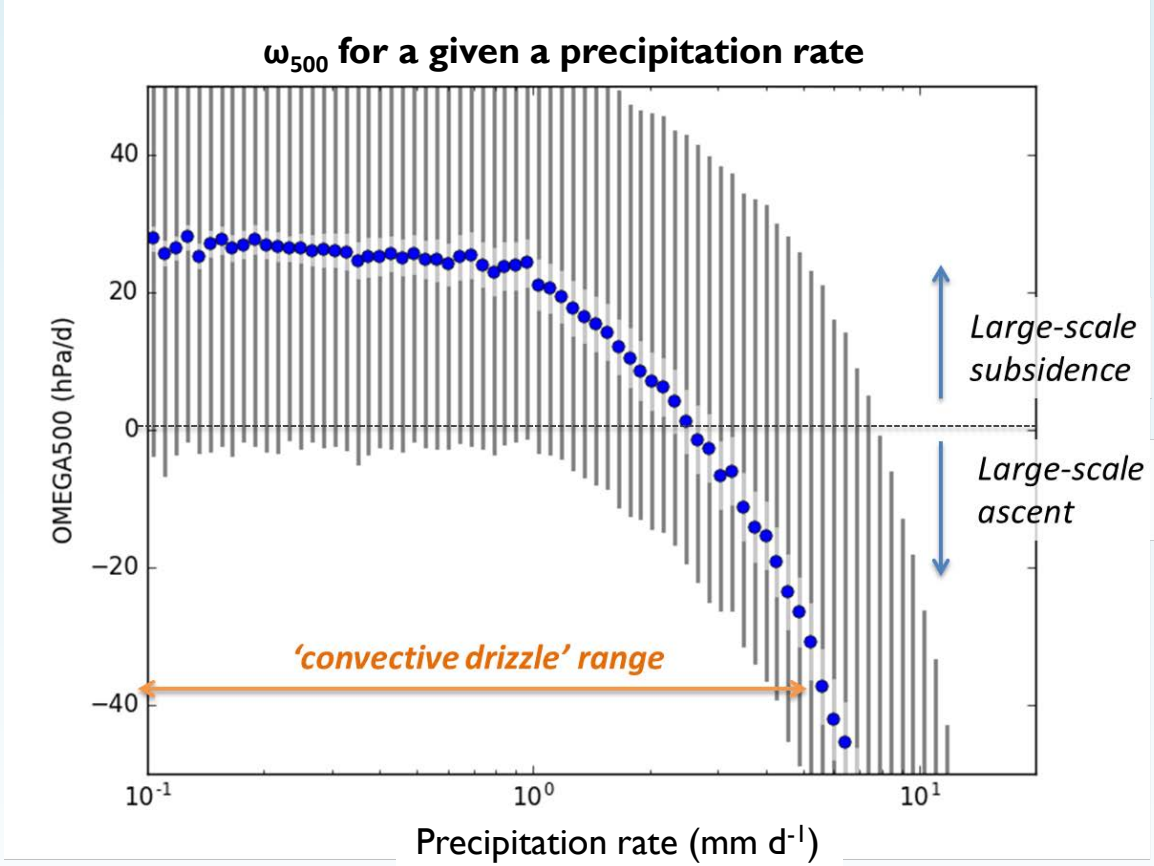
Average lifetime of a convective drizzle event



*Based on 2 months of time-step level output

The average lifetime is at least 6 hr over most regions, but can be as high as 48 hr (2 d) over some areas.

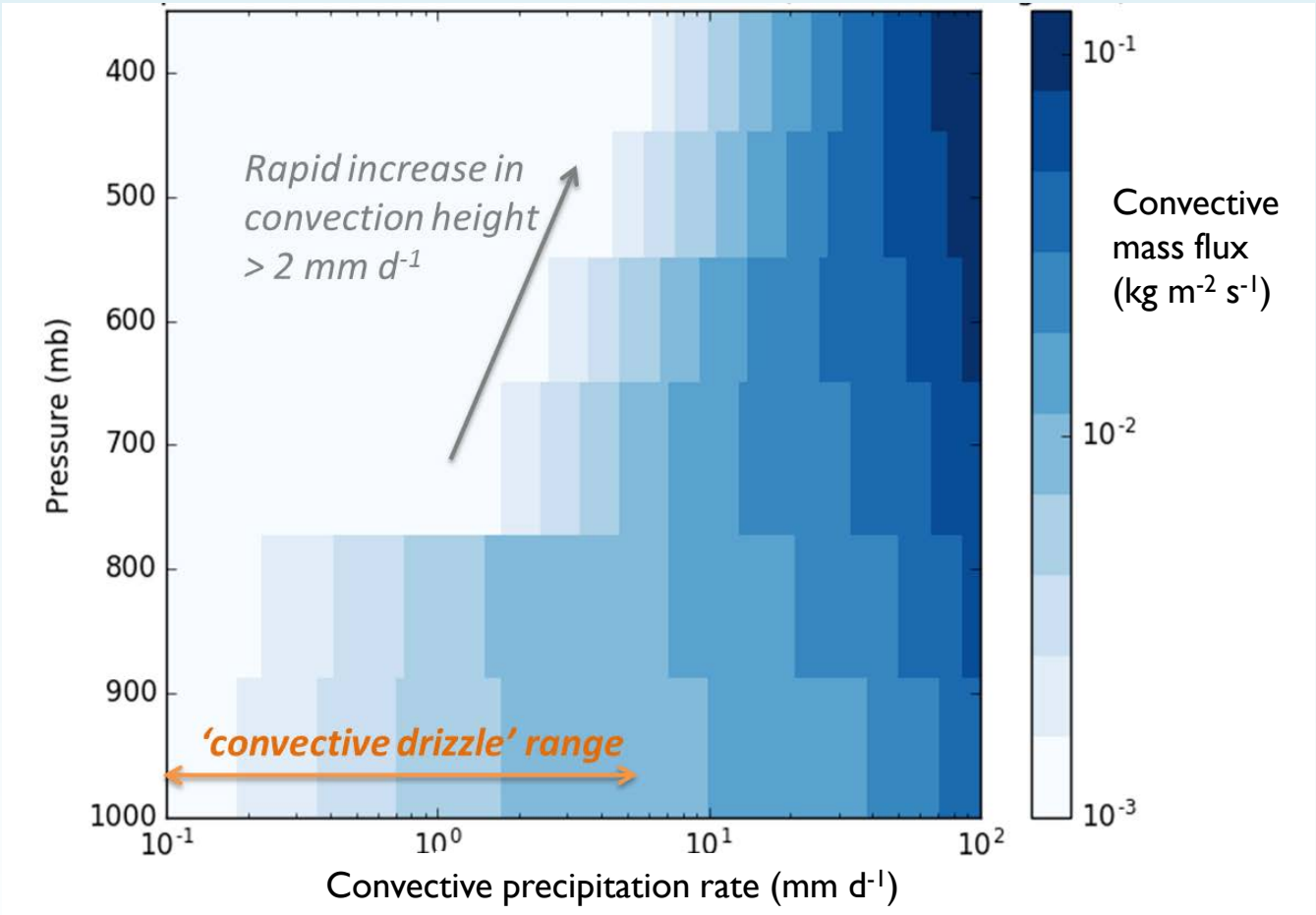
Why? – how does the deep convective scheme produce light rain?



Light rain mostly falls under large-scale subsidence

Why? – how does the deep convective scheme produce light rain? pt. 2

Convective mass flux between 925 and 400 mb

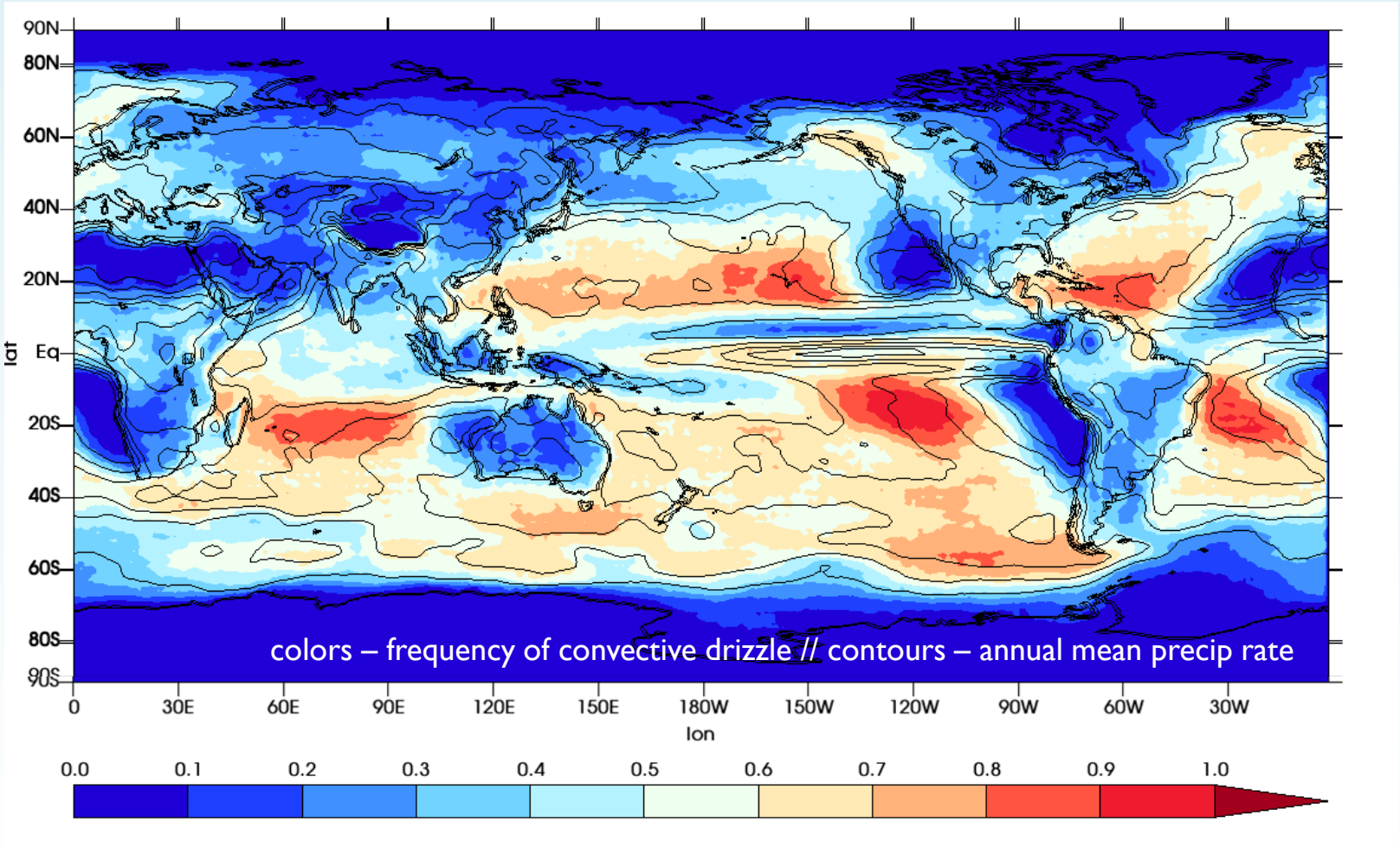


In light rain conditions, the deep-convective scheme only convects up to ~800mb.

- The ZM-scheme is doing *shallow mixing*.

But don't GPCP and TRMM miss light precipitation features?

Model frequency map of $0.1<P<5$ mm d^{-1}



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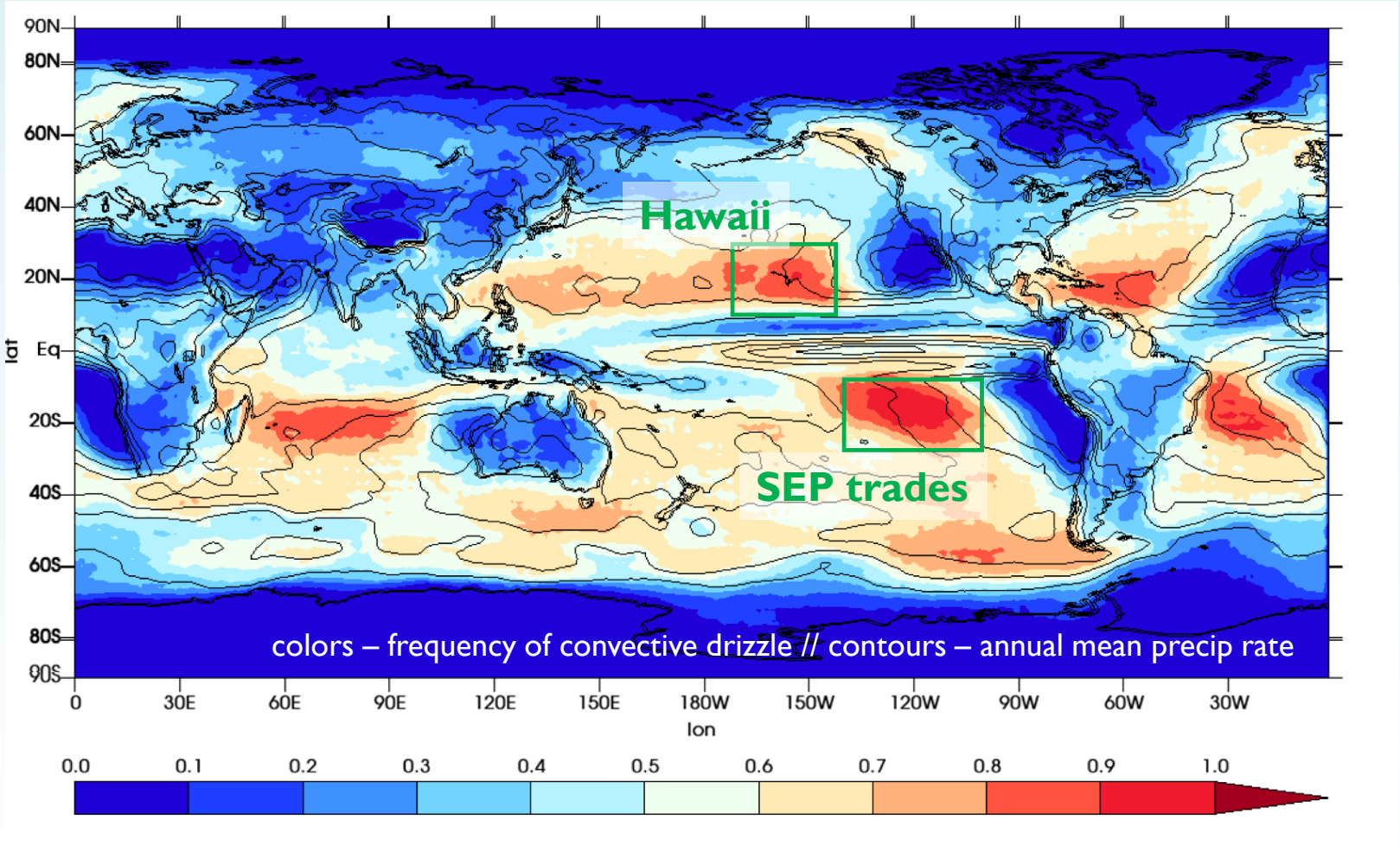
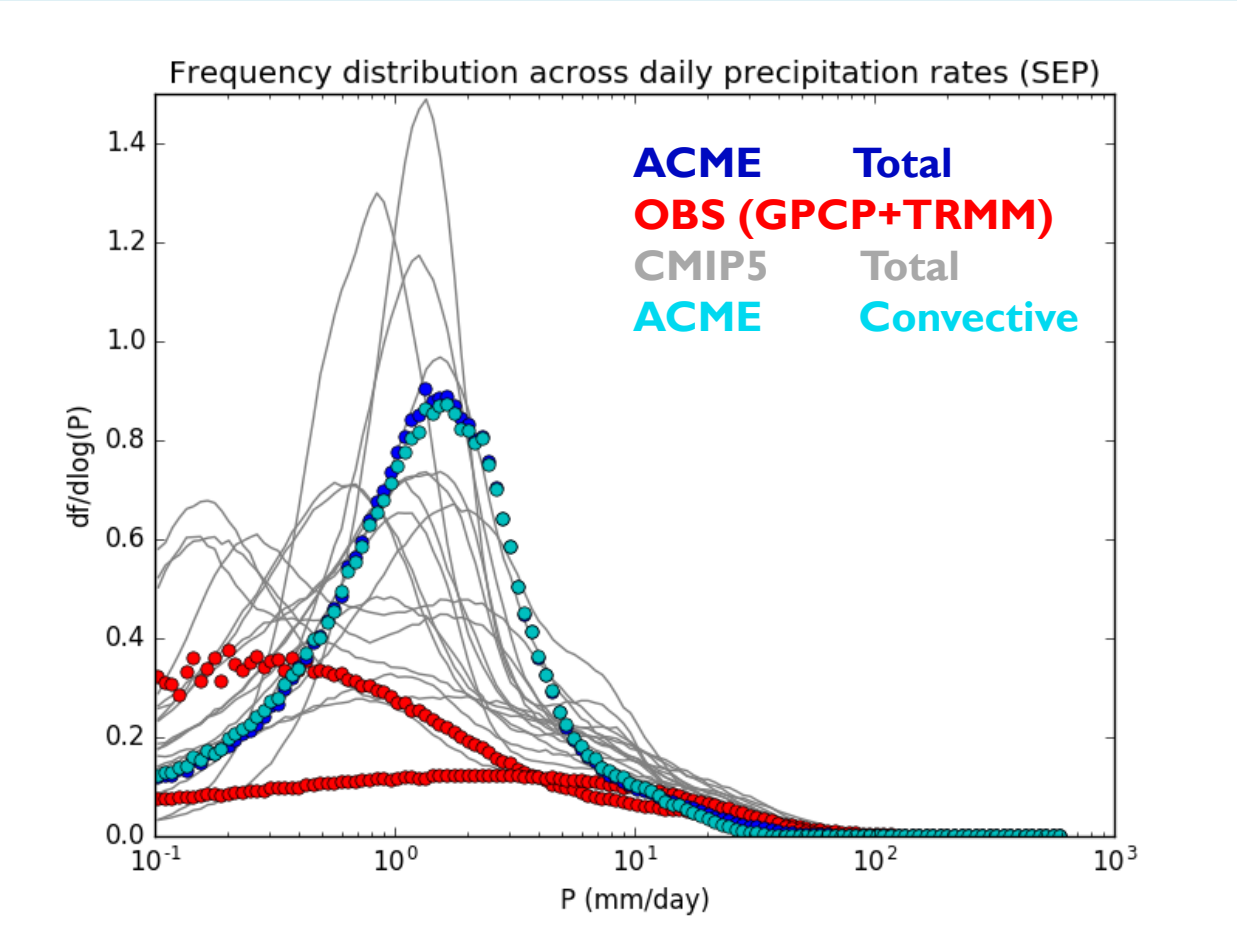


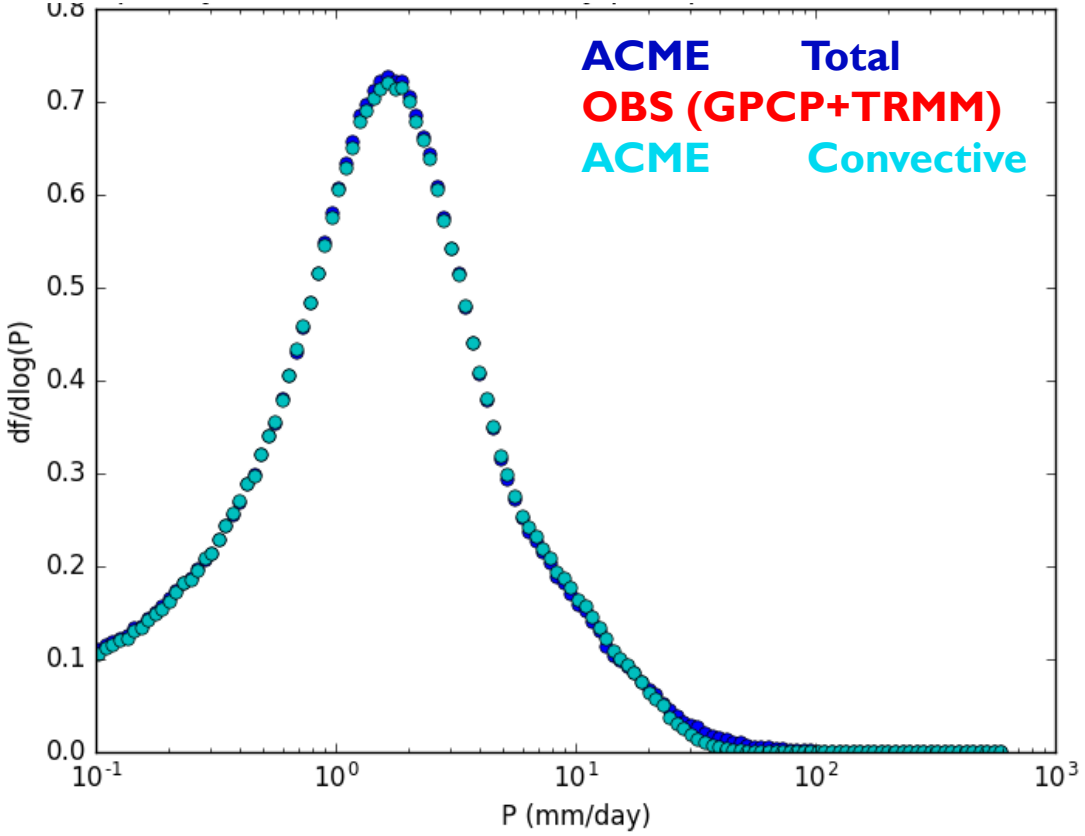
Daily precipitation frequency over SEP region

(lat: 7.5-27.5S lon:100-140W)



CloudSat snapshot data indicate more frequent light precipitation scenes than GPCP or TRMM

Frequency distribution with time-step level output (SEP trades)



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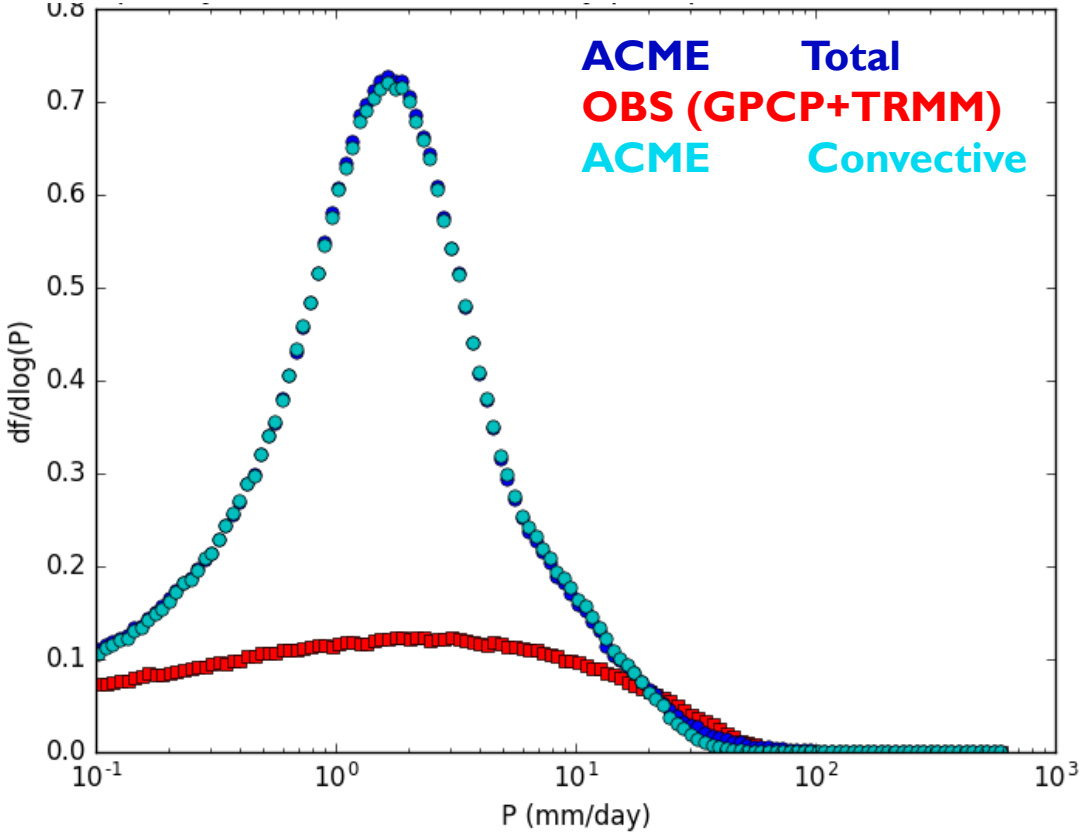

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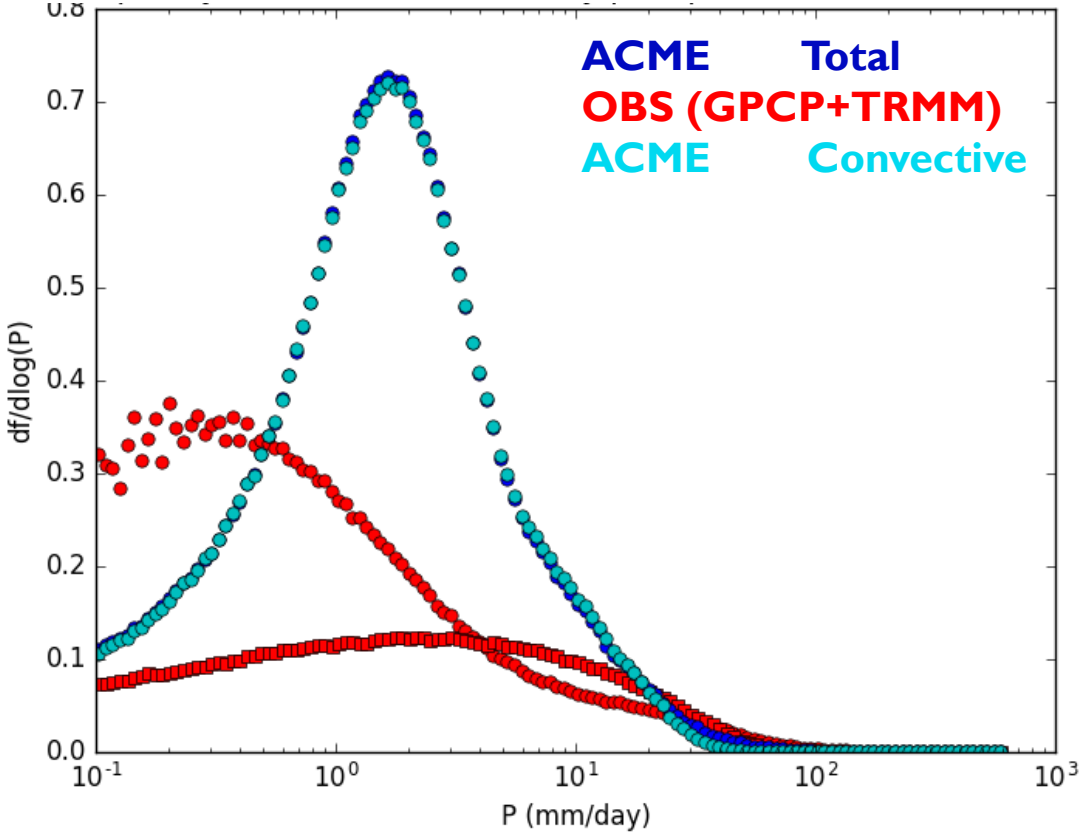

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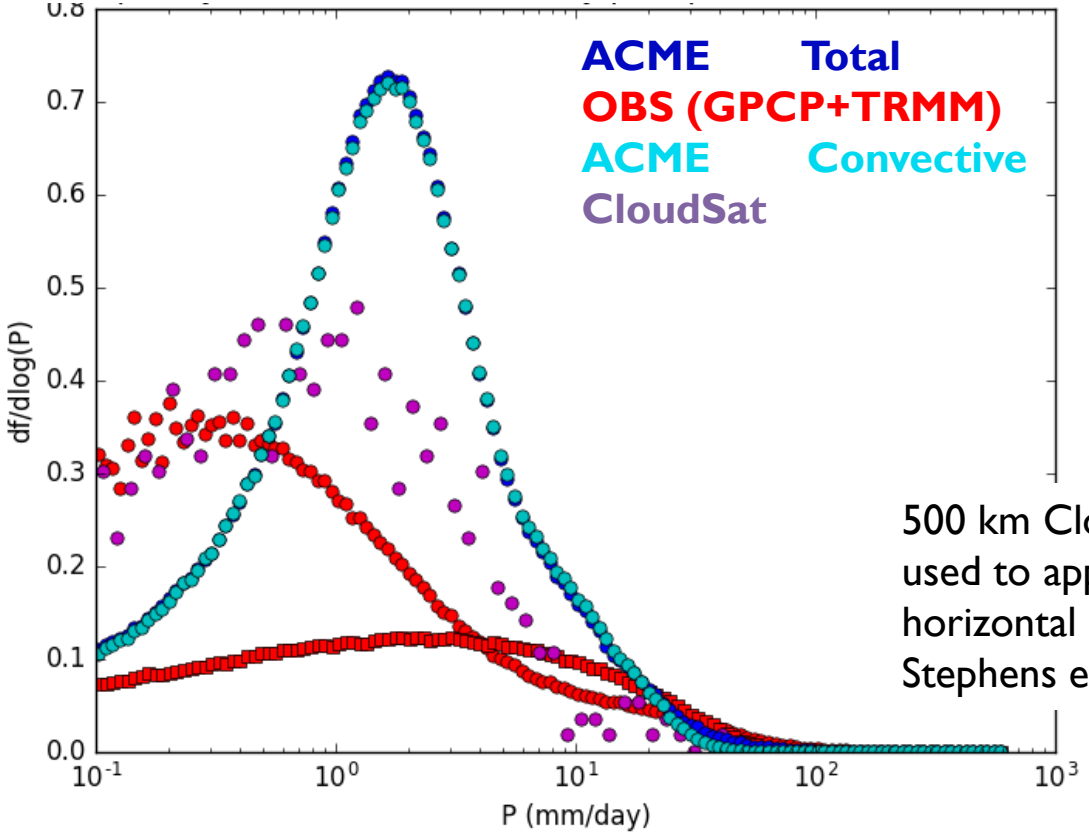

500 km CloudSat segments are used to approximate 1°x 1° horizontal gridding (following Stephens et al., 2010)

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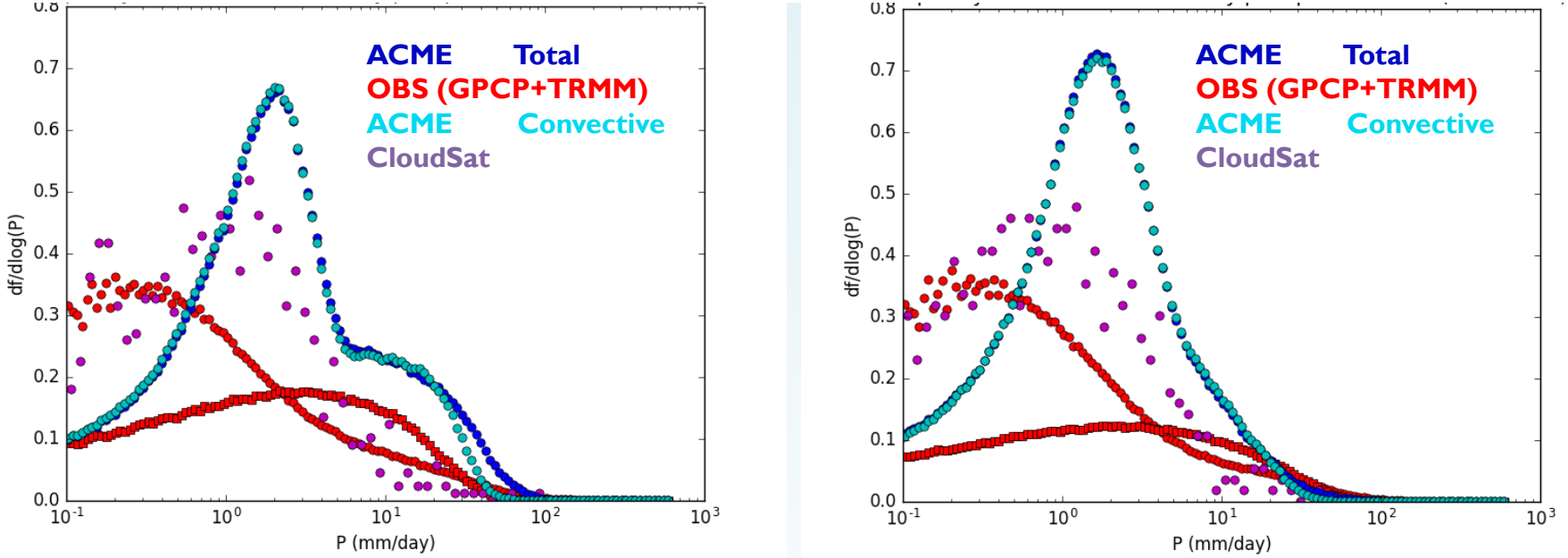
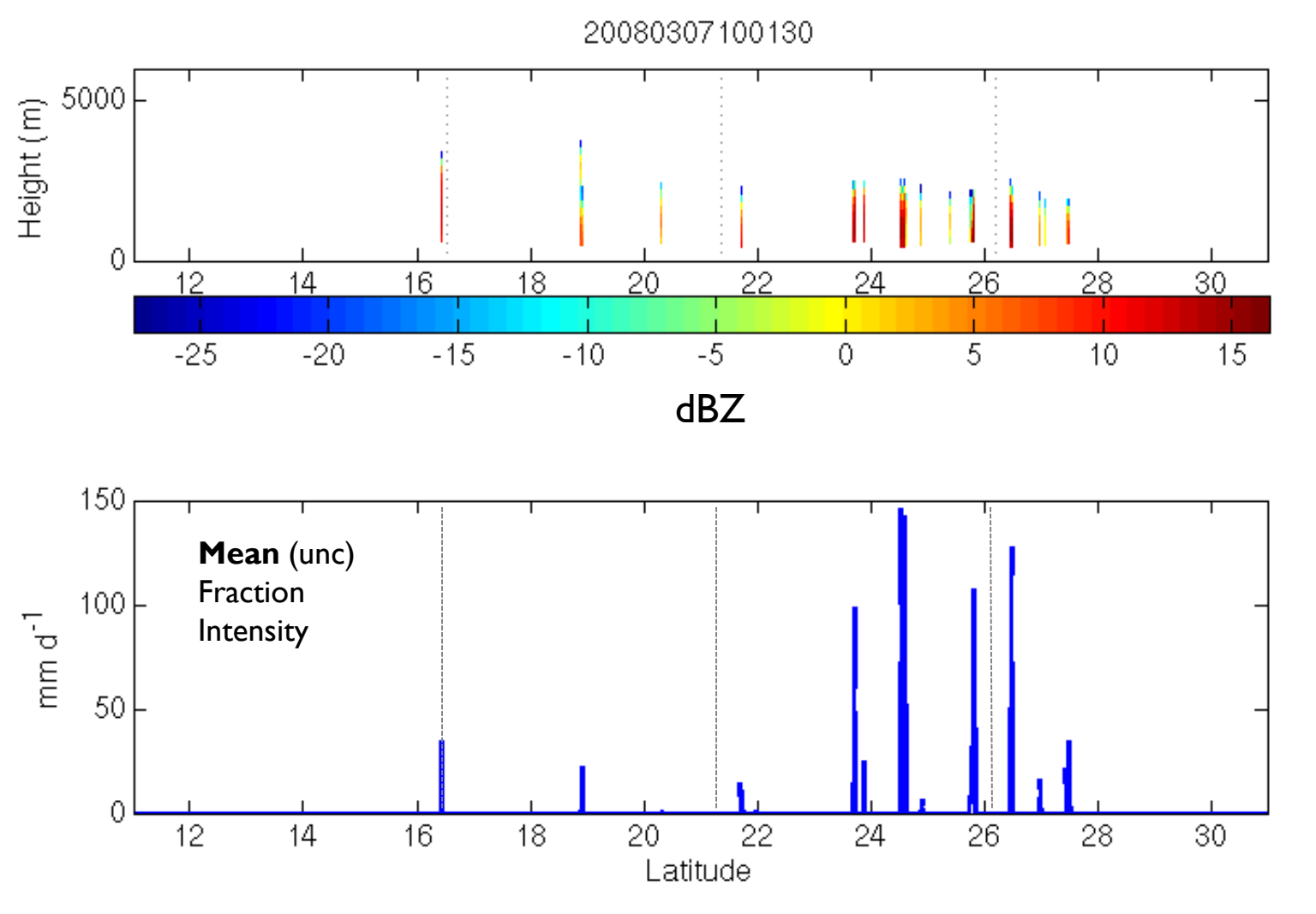
Hawaii **SEP**

Frequency distribution with time-step level output



Over the Hawaii and SEP regions, where frequent 'drizzle' is found in the model, CloudSat also indicates a high frequency of light precipitation rate.
However, light rain is still too frequent in the model.

What does the precipitation look like in CloudSat?



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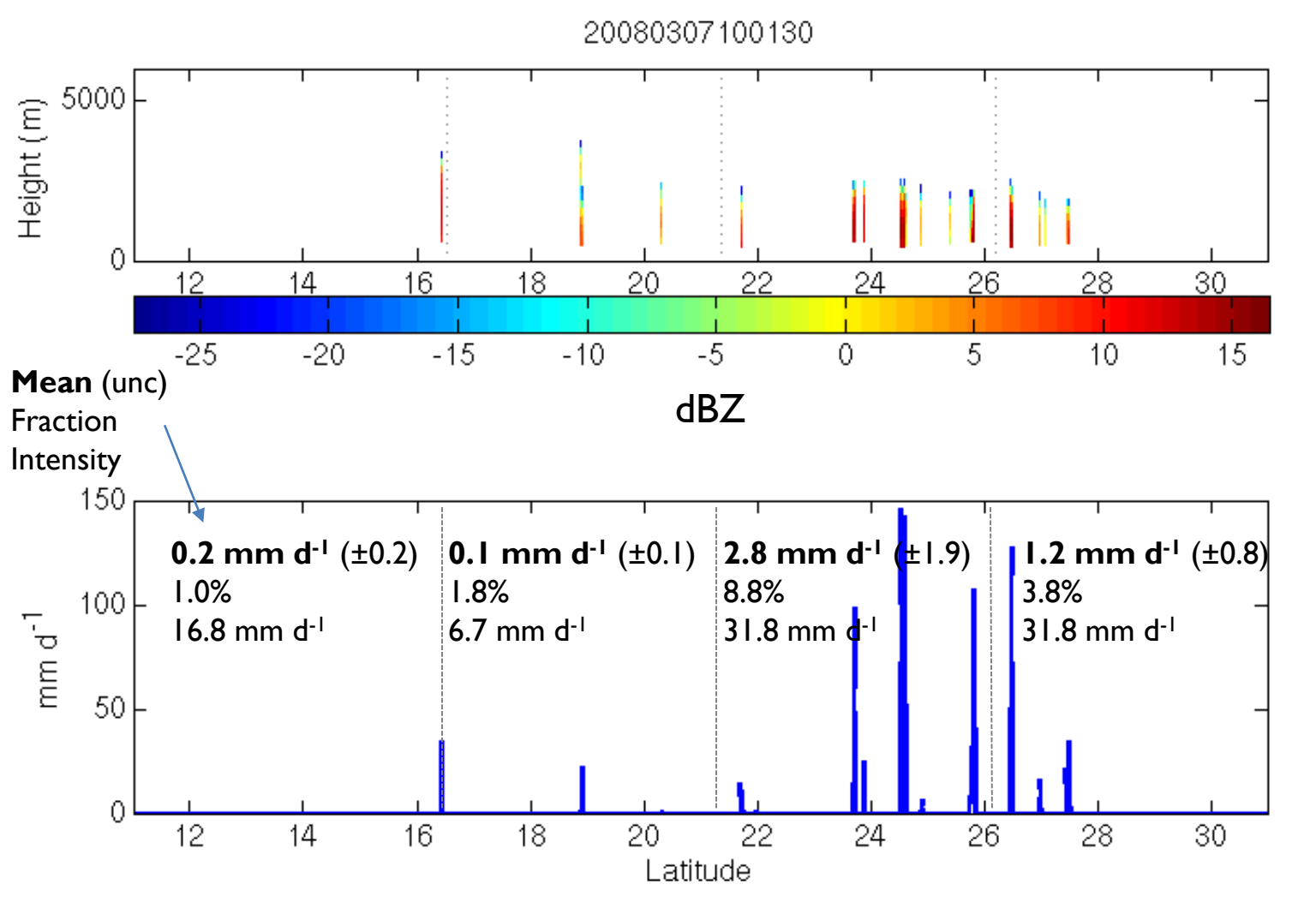

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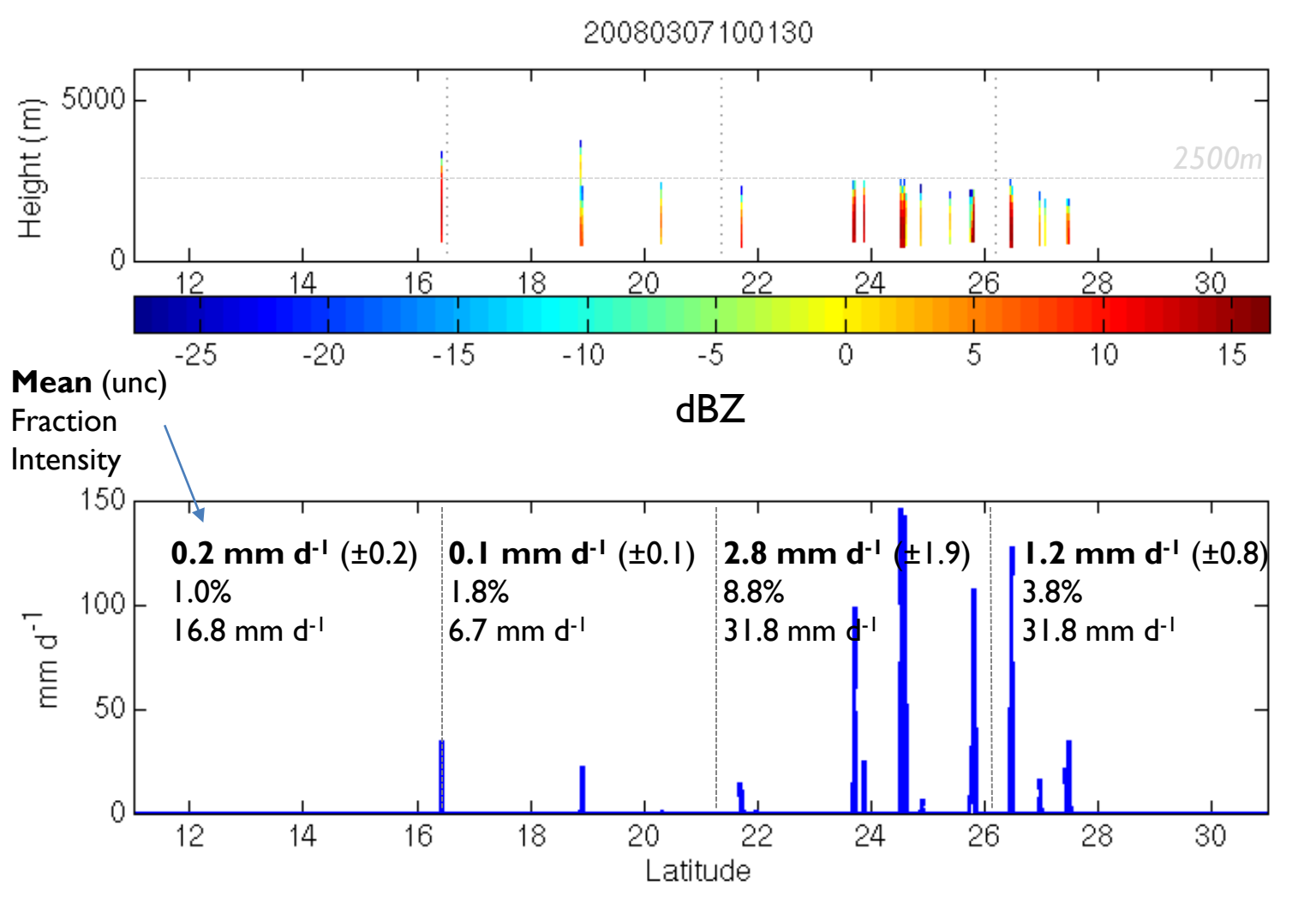

What are the climate implications?

What is the effect of the light rain on climate?

→ Does the simulated climate look different without the light rainfall?

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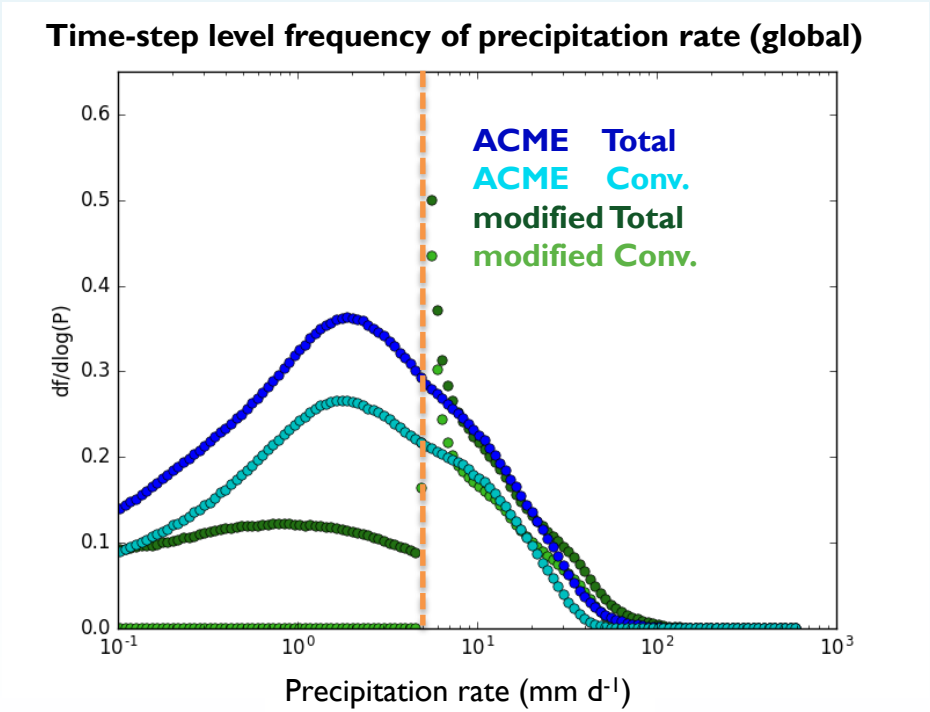
Conduct an experiment where we artificially zero all convective tendencies when the convective rain rate is < 5 mm d^{-1}.



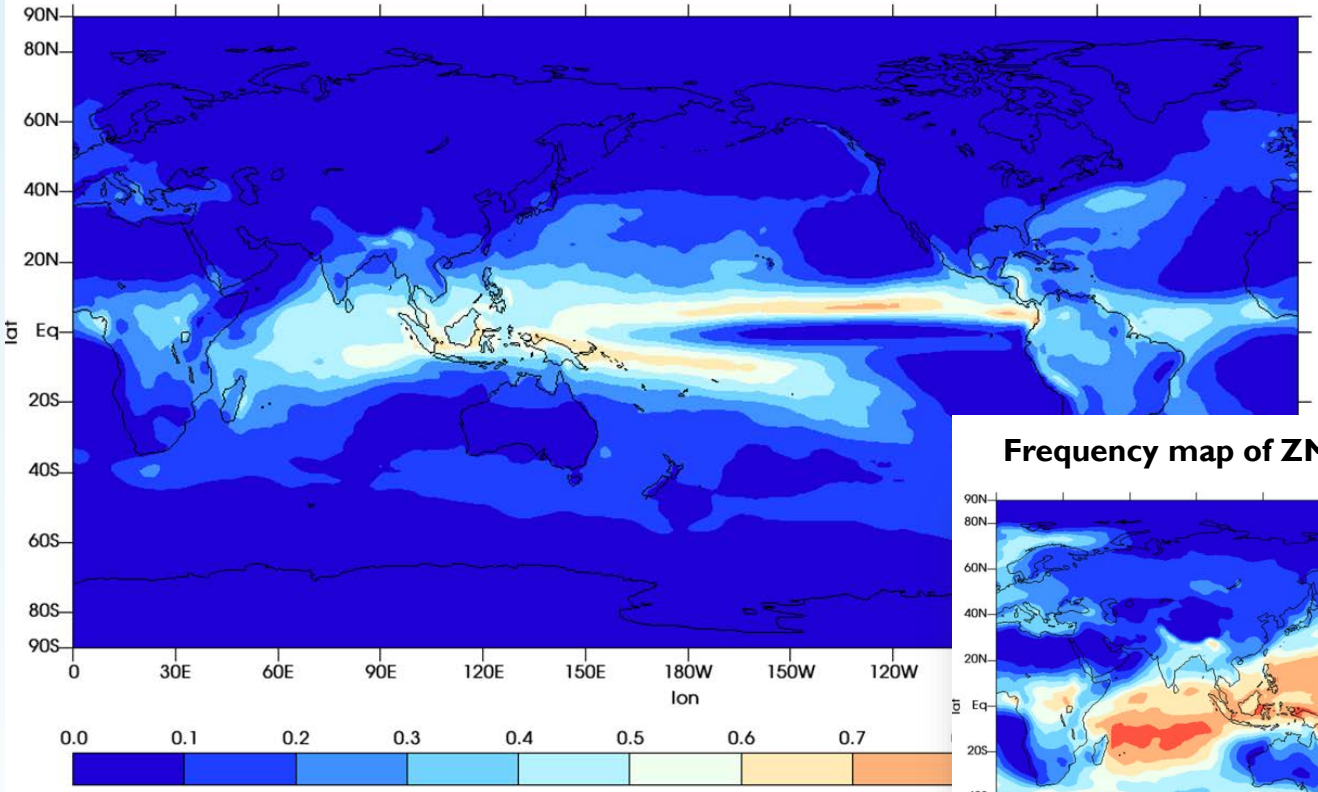
Experiment details

5-year simulations of control and experiment

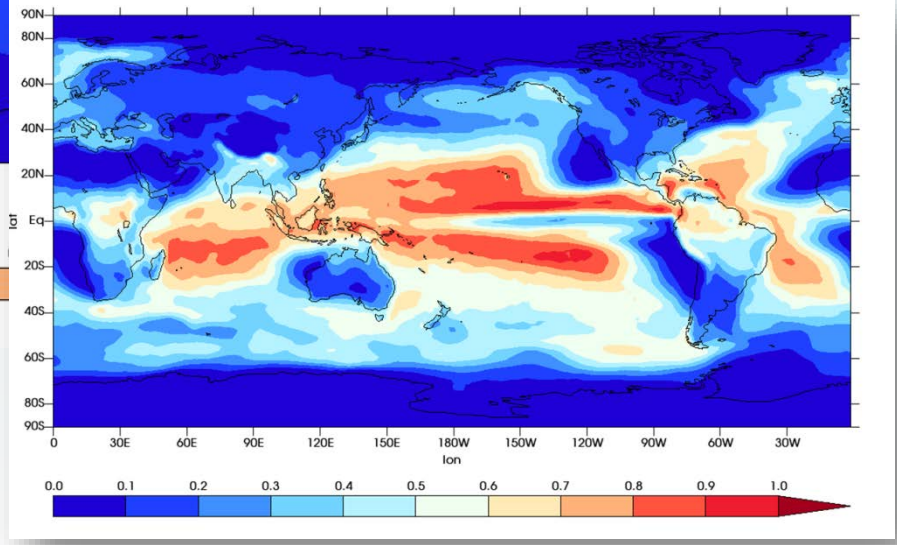
Perpetual year 2000 conditions

Result: Deep-convective scheme triggers substantially less often with modification

Frequency map of ZM-scheme triggering (modified run)

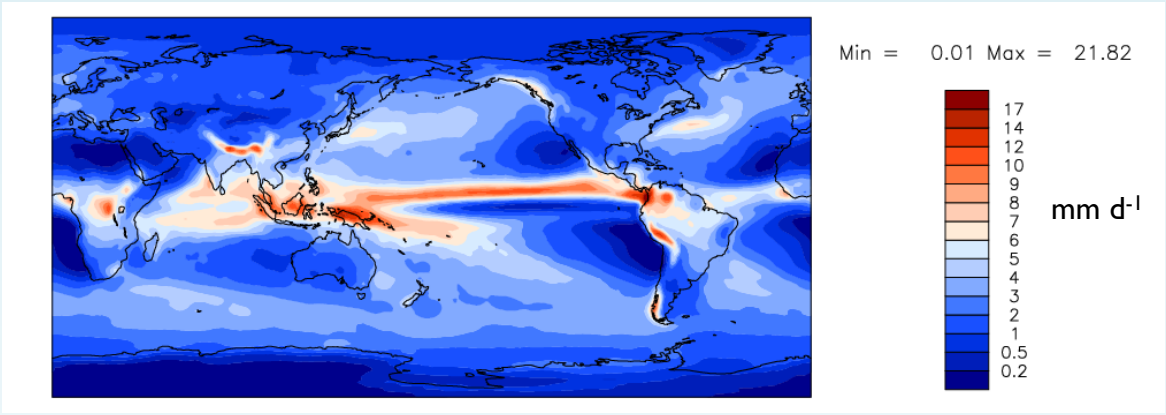


Frequency map of ZM-scheme triggering (original)

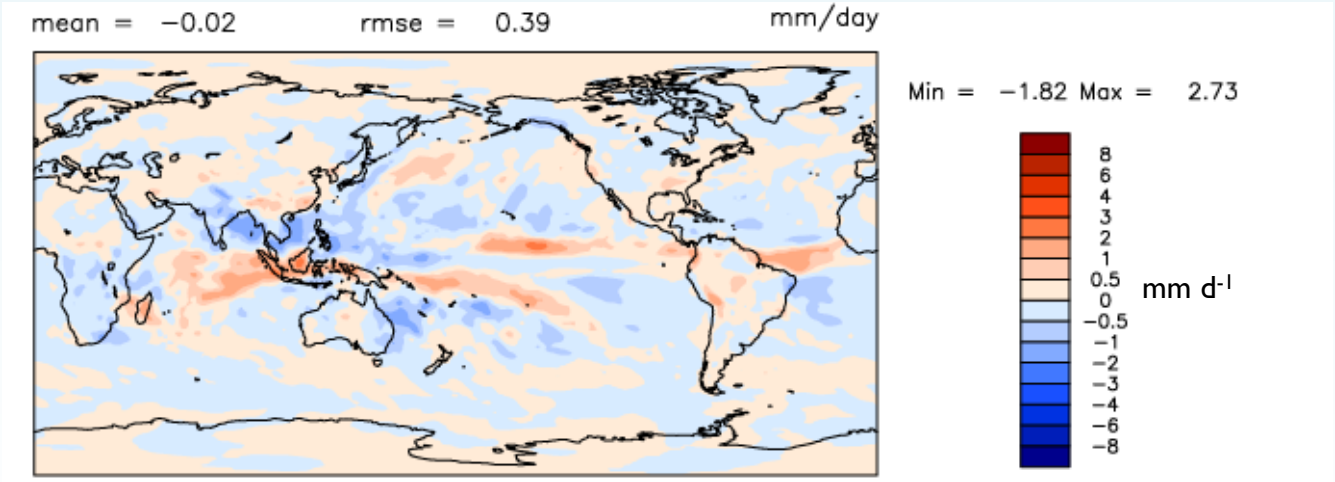


Slight shift of precipitation to heavier regions

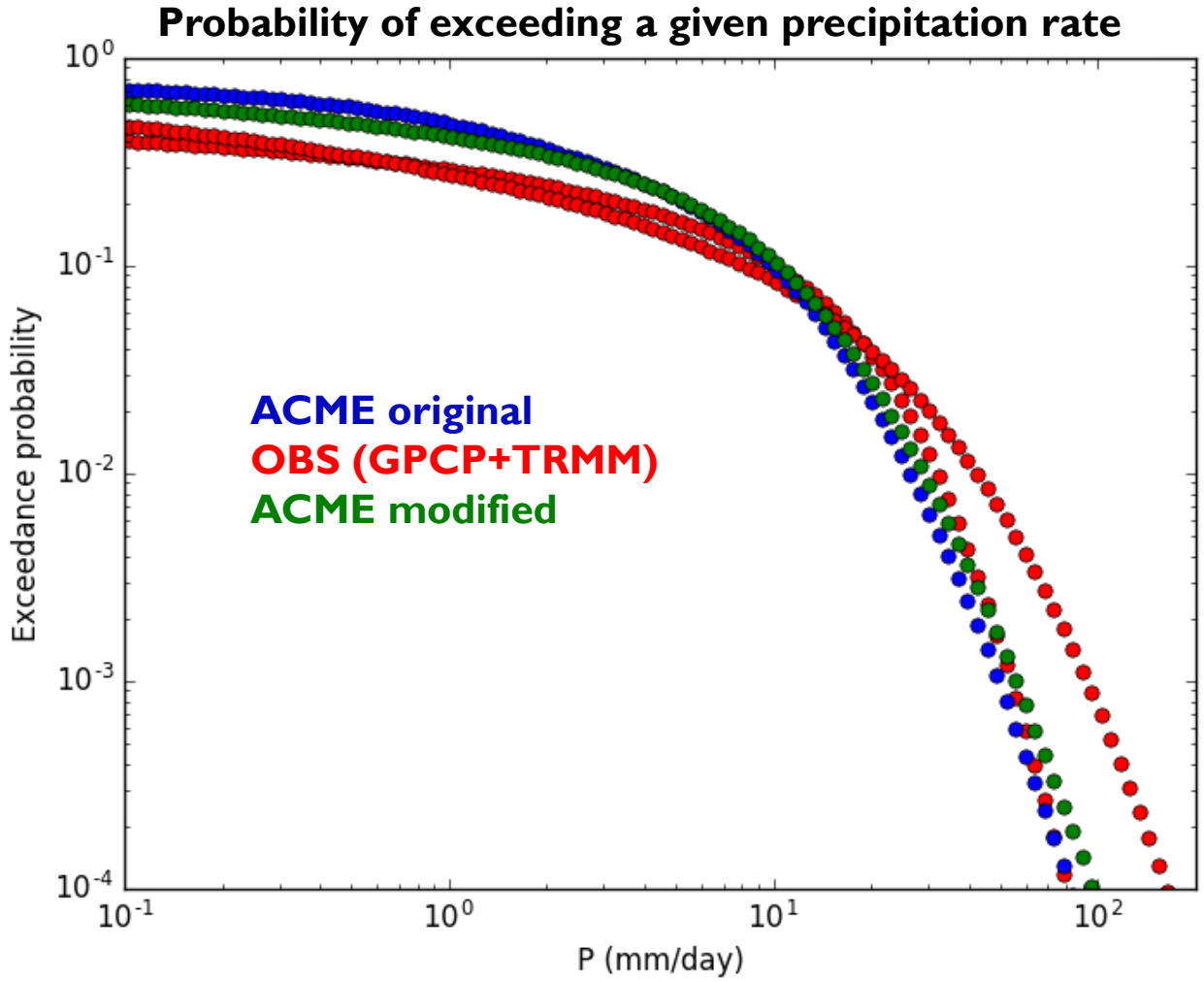
Annual-mean precipitation rate in original simulation



Modified simulation minus original simulation



Increase in the frequency of heavy events



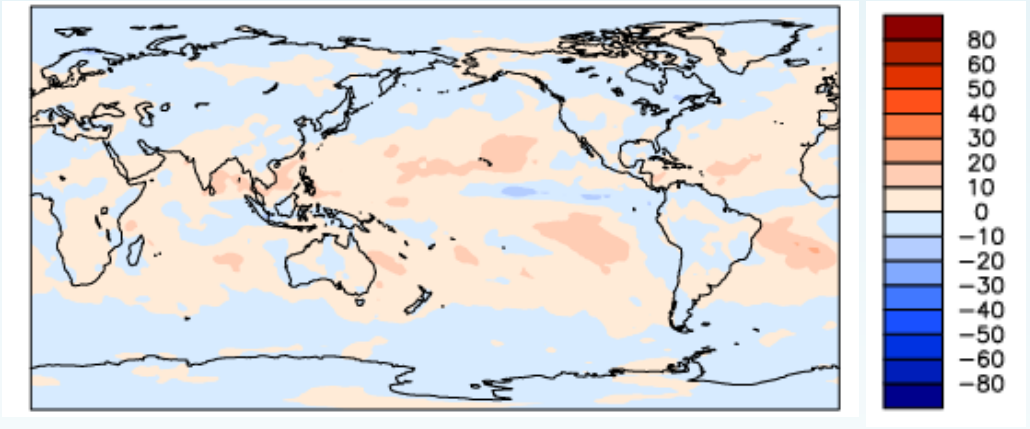
Although the modification increases extreme precipitation rates, the model still underestimates the frequency of heaviest precipitation events

Reduction of clouds leads to more absorbed solar radiation

Top of atmosphere radiation (Original → Modified):
0.59 W m^{-2} → 1.26 W m^{-2}

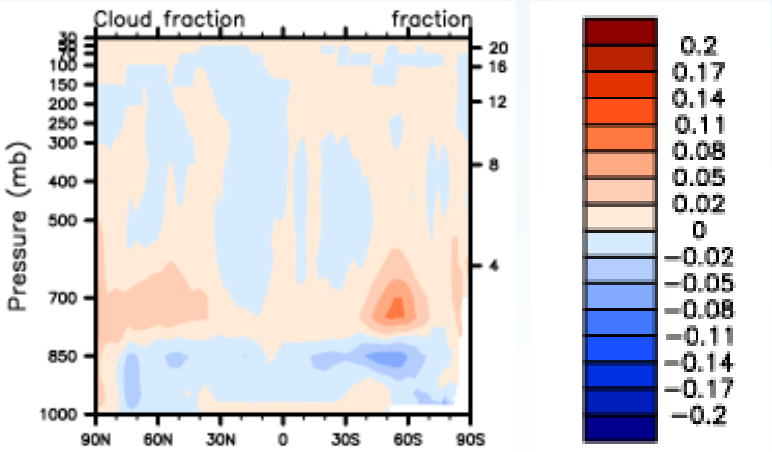
Difference in shortwave cloud forcing

mean =1.42 W m^{-2}



Reductions in low-level clouds lead to more absorbed radiation at the surface.

Difference in cloud fraction



Conclusions

Identified the conditions behind the too light and too frequent precipitation problem in a prototype of the ACME climate model

Who? - *Deep convective scheme*
What? - *Rains too lightly, too frequently*
When? - *Mostly under drier FT, large-scale subsidence*
Where? - *Over the trade cumulus regions*
Why? - *The deep convective scheme drives shallow mixing*

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When we keep the model from producing convective drizzle, then

1) the precipitation shifts to heavier regions
2) the frequency of heavier precipitation rates slightly increases
3) the amount of absorbed shortwave radiation increases due to fewer low-level clouds

Ongoing work

What are the implications to moisture and energy transport of the frequent light rain events?

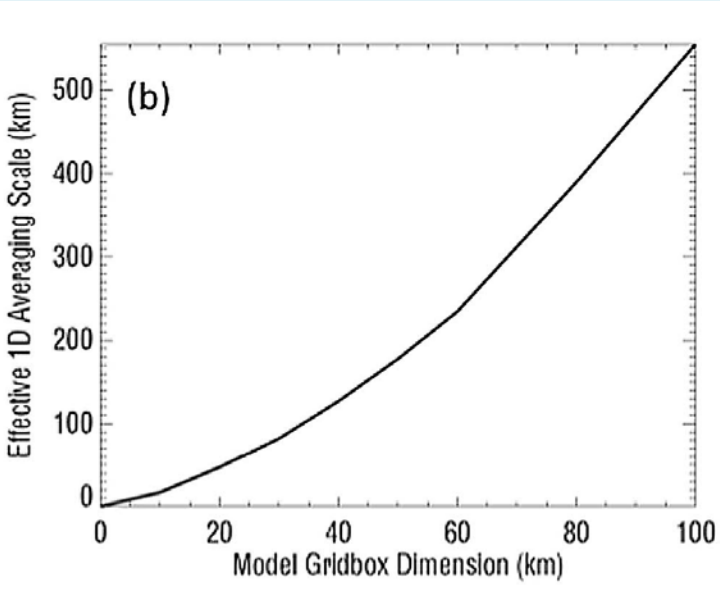
Can differences in between CloudSat, TRMM/GPCP, and the model be due to spatial or temporal scaling issues?

What are the implications of the light rain on future precipitation response?

How well can we generalize the mechanisms behind the too light, too frequent problem to other climate models?

Extra Slides

Scaling CloudSat curtains to model grid boxes



Stephens et al., 2010

Curtain selection

Curtain must pass within 500 km of the box center

Segment selection

Select section that exists within box

Hawaii - lat: 11-31N lon:140-170W

SEP - lat: 7.5-27.5S lon:100-140W

Time period

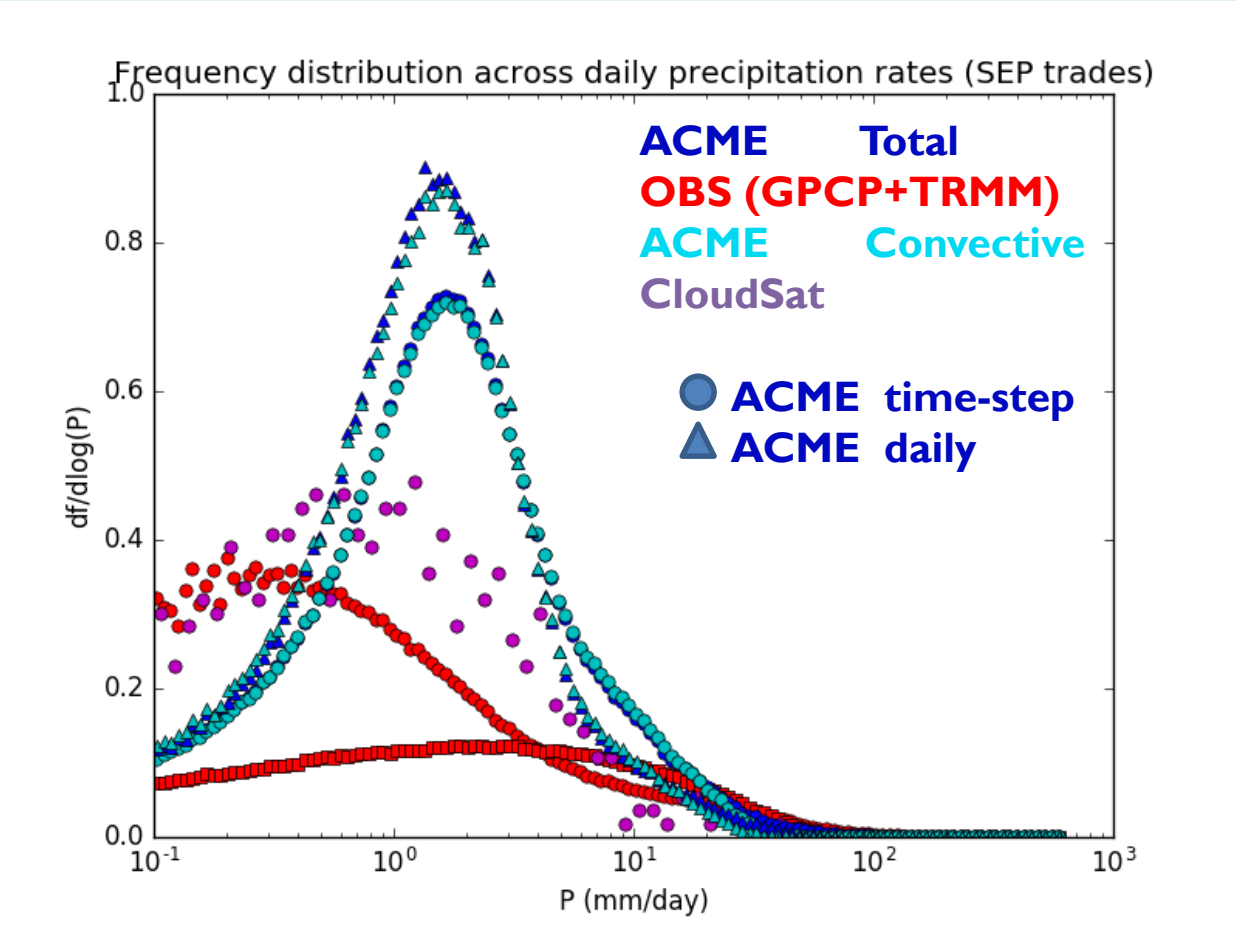
Hawaii – March 2008-June2009

SEP – July 2009-June2010

Averaging

500 km CloudSat segments are used to approximate 1°x 1° horizontal gridding (following Stephens et al., 2010)

Is the discrepancy due to time averaging?



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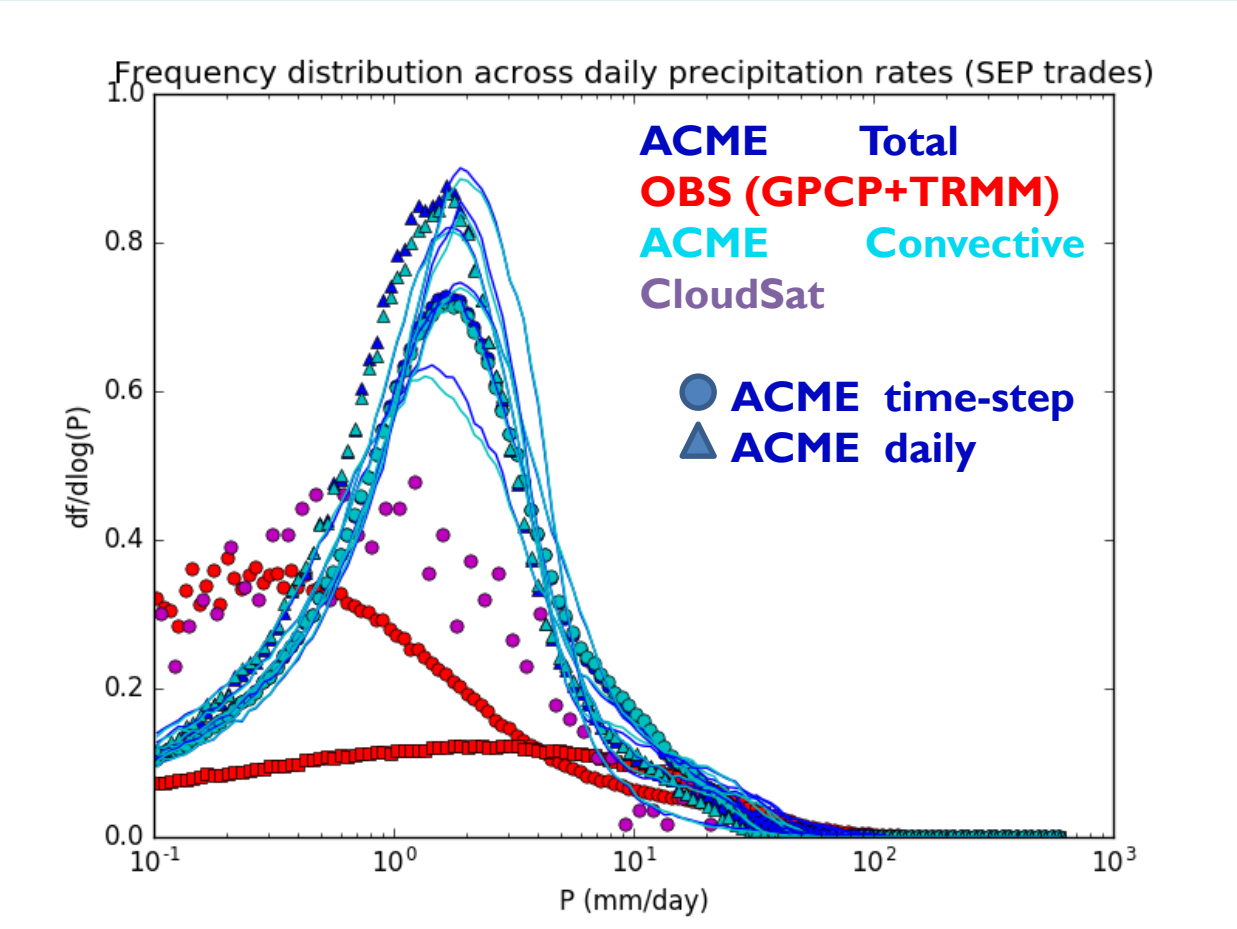

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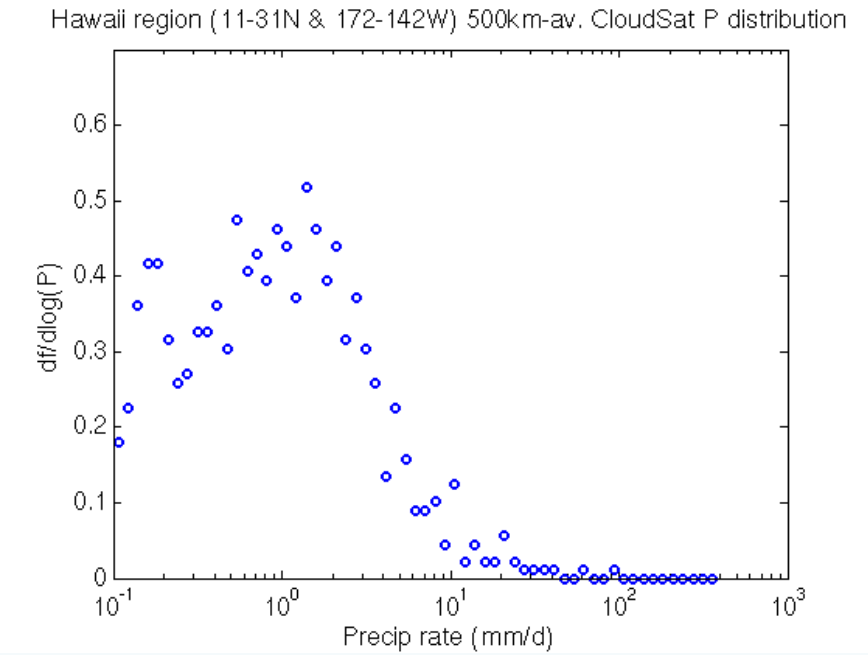

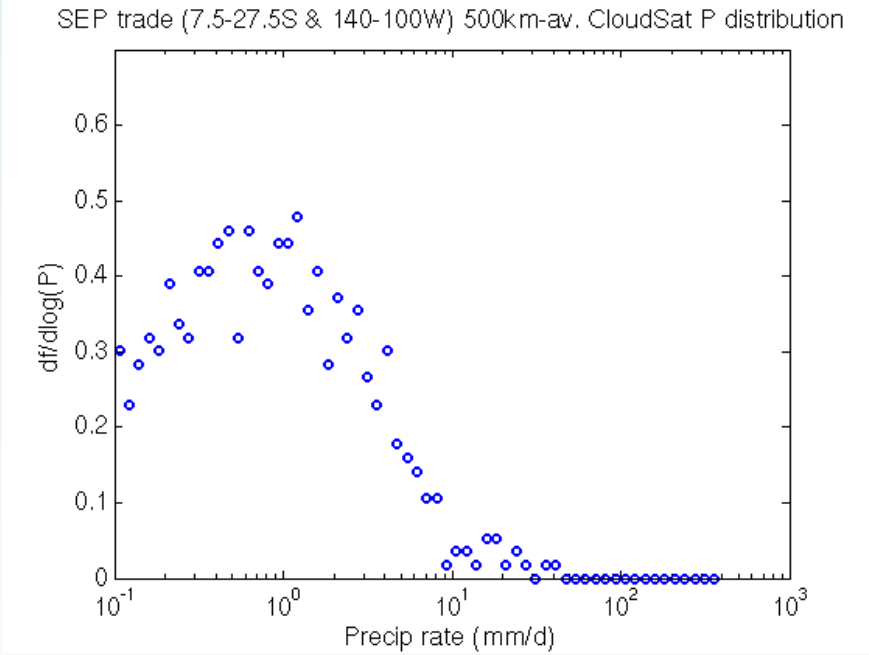

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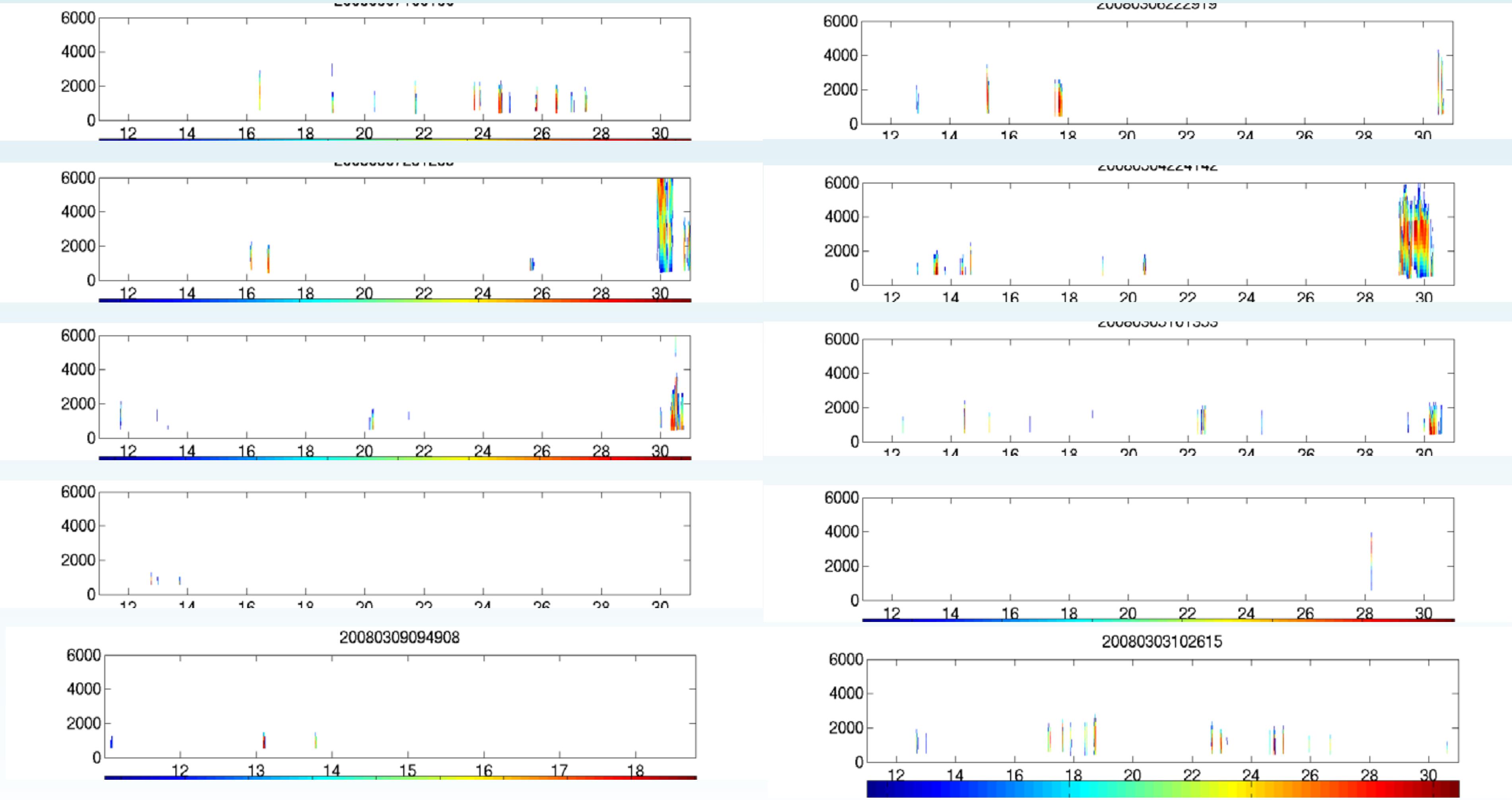

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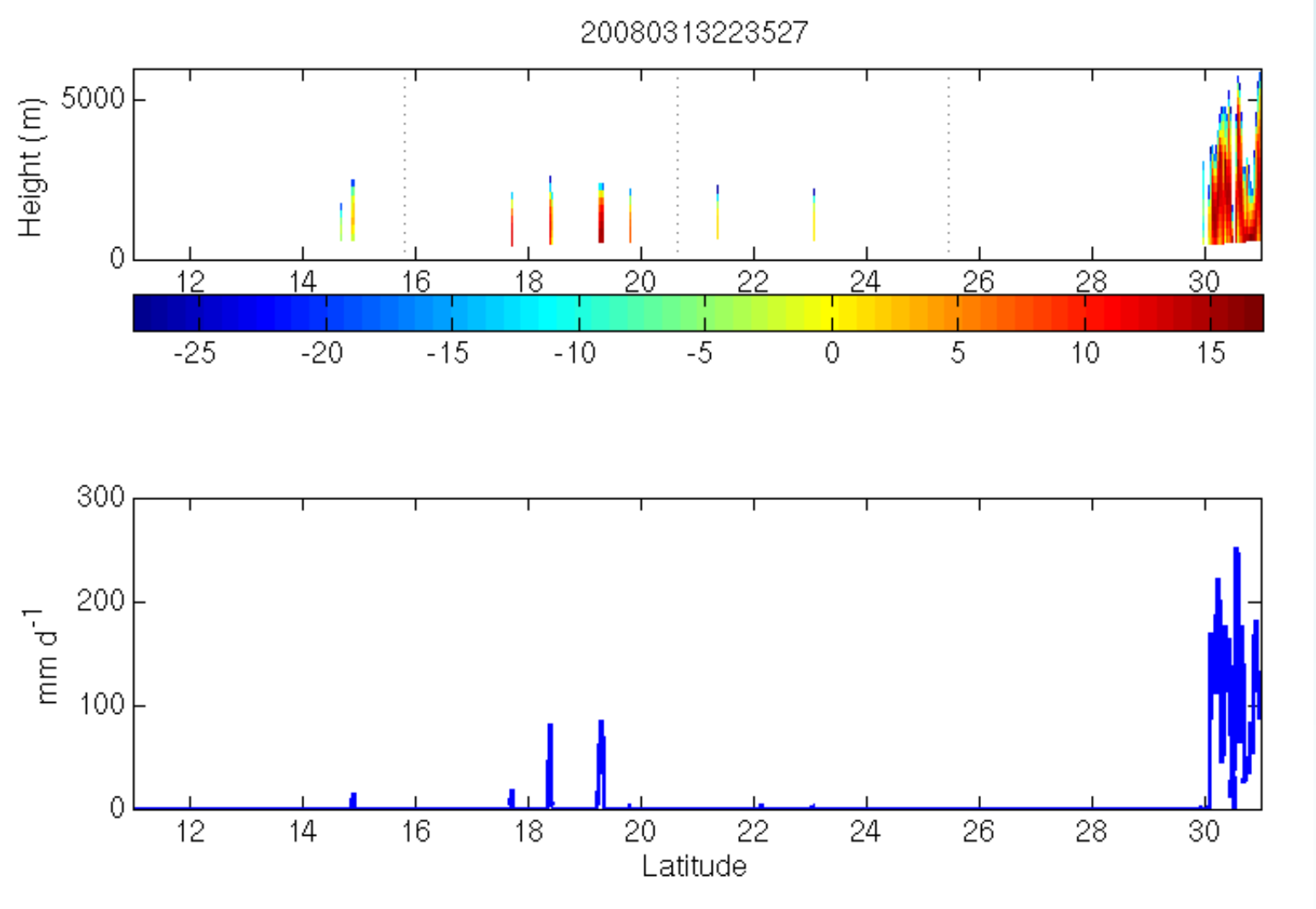
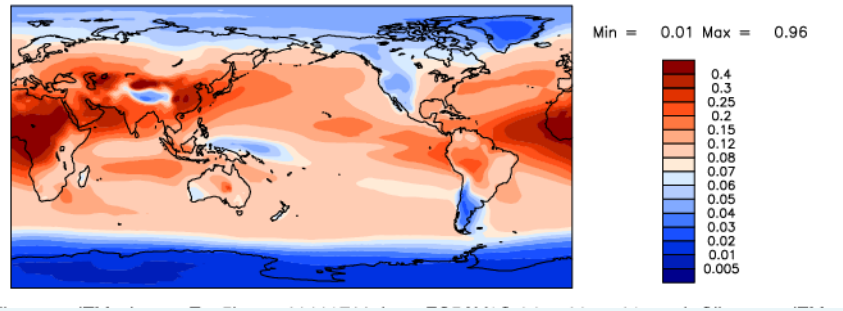


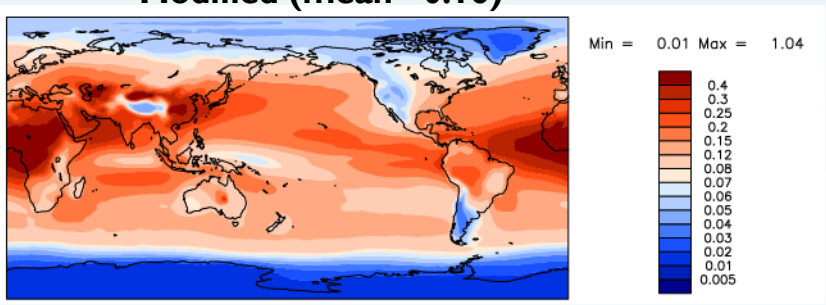
Substantial changes to the aerosol concentration and to cloud phase partitioning

Difference in Aerosol Optical Depth

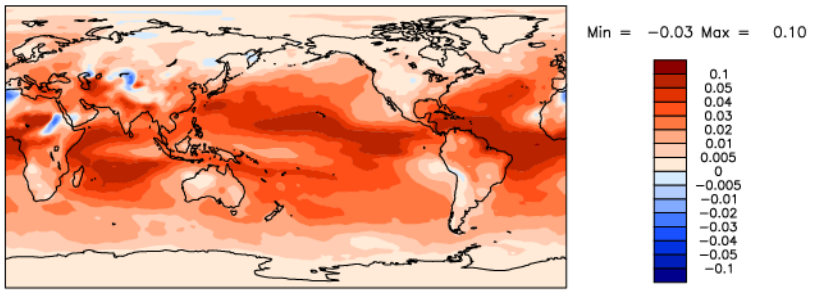
Original (mean =0.14)



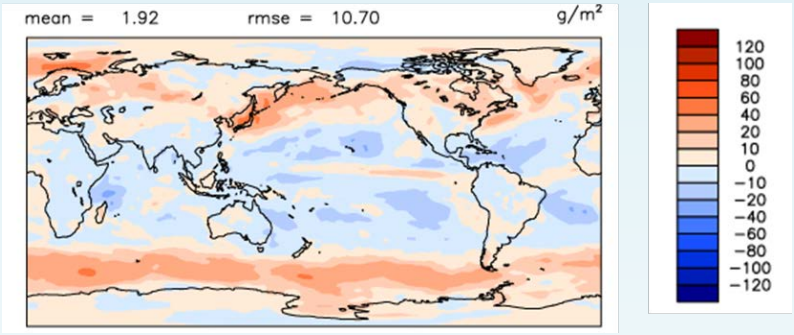
Modified (mean =0.16)



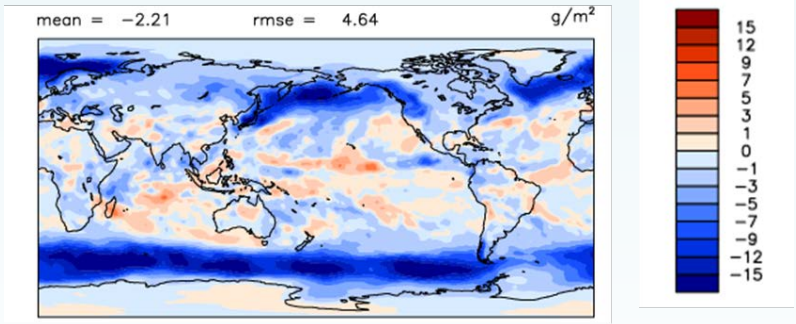
Difference (mean =0.02)



Difference in cloud LWP

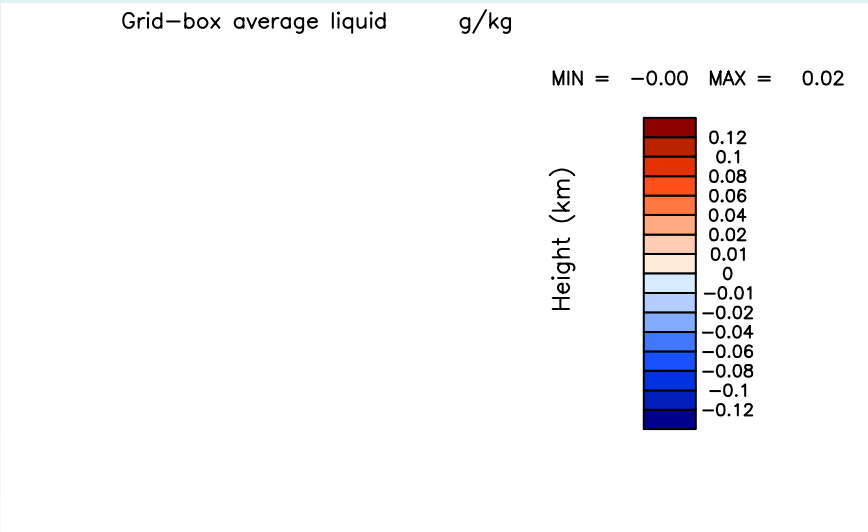


Difference in cloud IWP

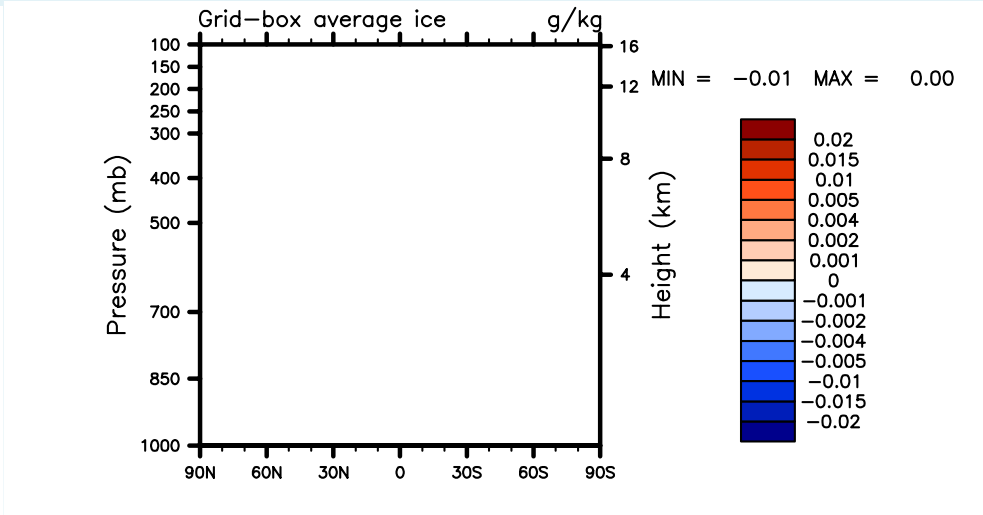


More details on cloud liquid and ice partitioning

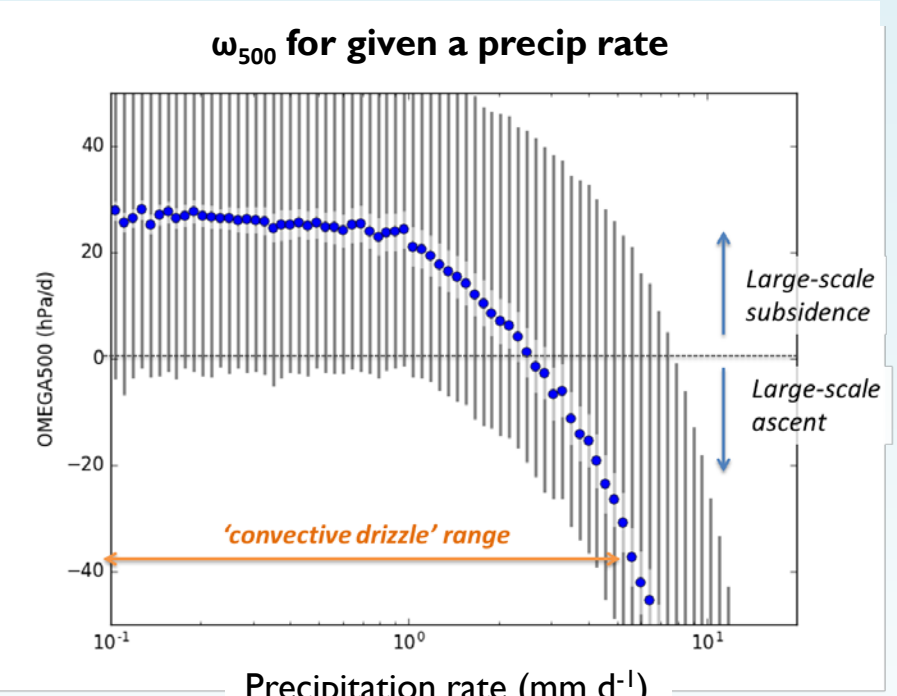
Difference in cloud liquid



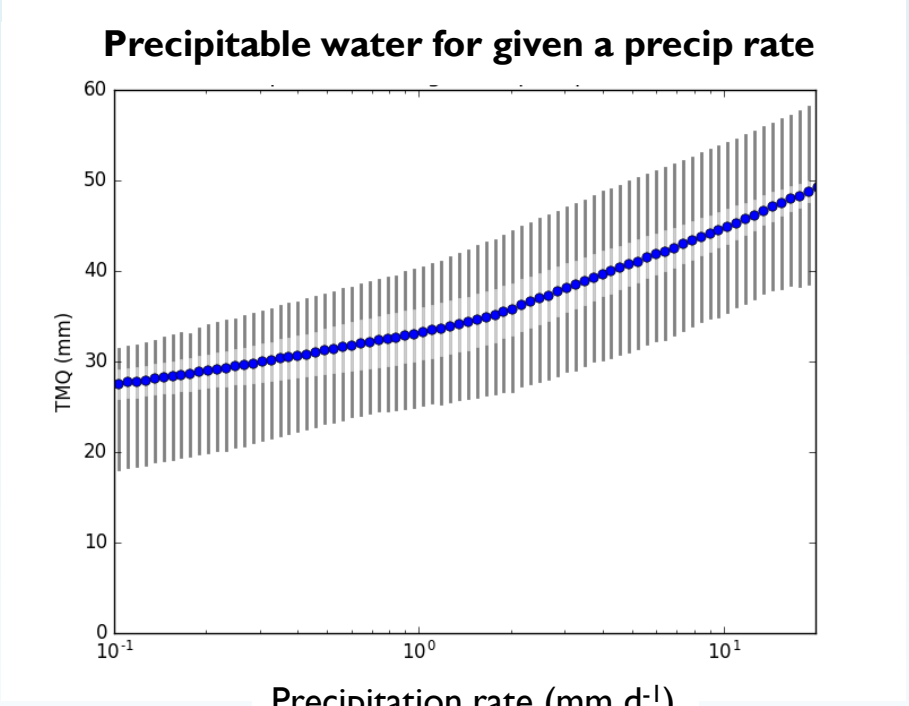
Difference in cloud ice



Why? – how does the deep convective scheme produce light rain?

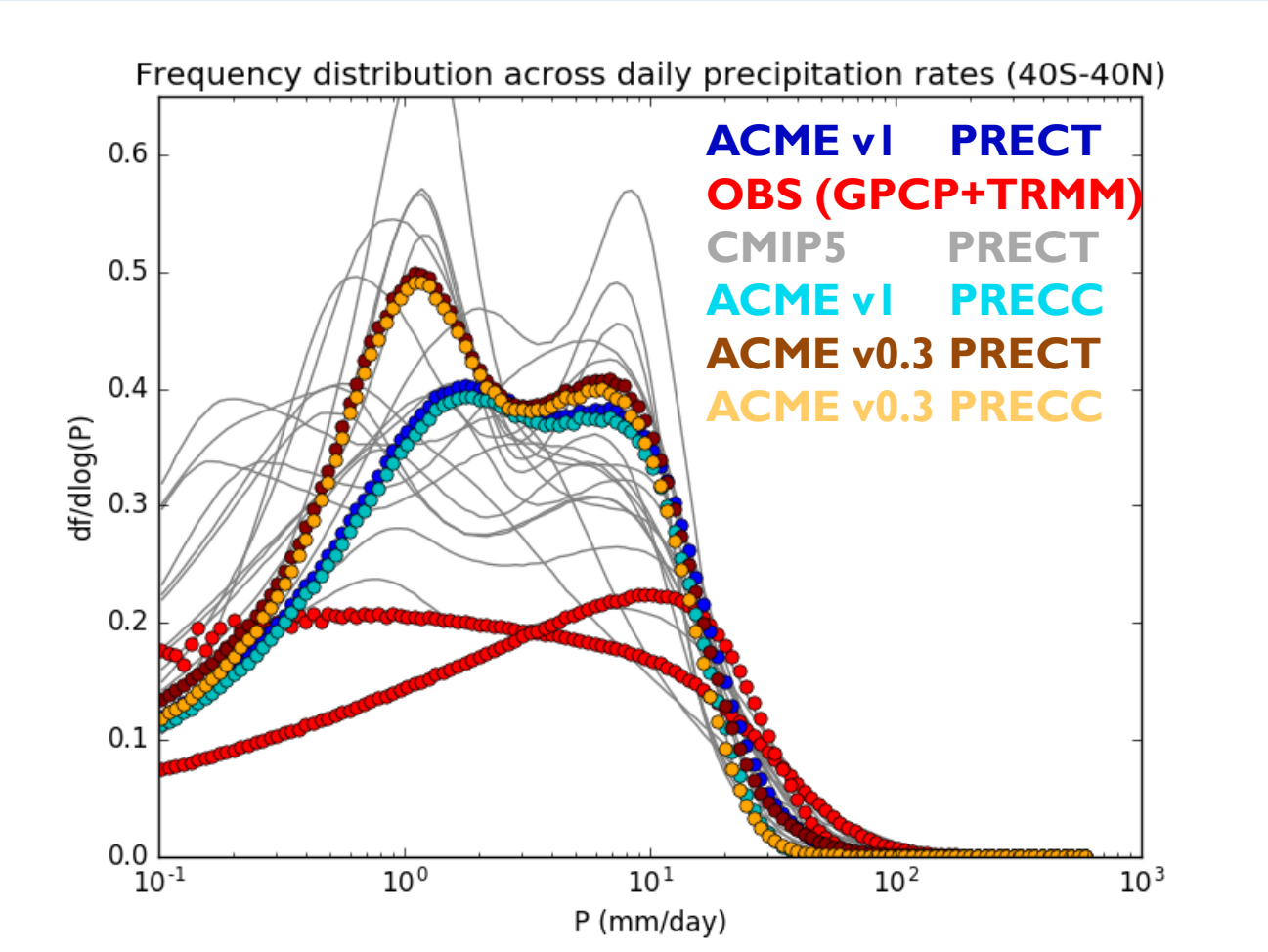


Light rain mostly falls under large-scale subsidence



Light rain mostly falls in 'dry' conditions

Models precipitate too lightly, too frequently



- Previous studies have found that many climate models rain too lightly and too frequently (Stephens et al., 2010; Pendergrass and Hartmann, 2014)
- Going to higher resolution does not improve issue (Terai et al., submitted)