Scale-aware and definition-aware evaluation of modeled near-surface precipitation frequency using CloudSat observations

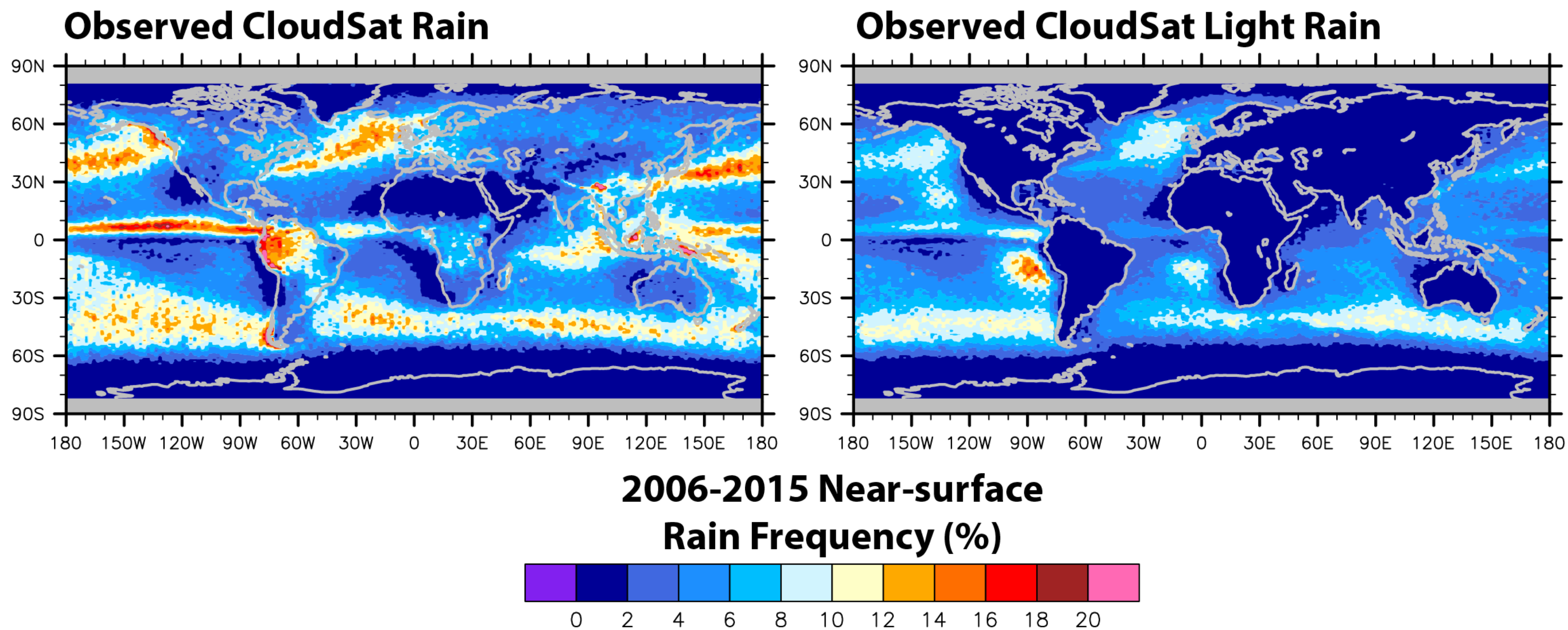
Jen Kay, University of Colorado (CU)

Tristan L'Ecuyer (UW-Madison), Dustin Swales (NOAA), Helene Chepfer/Rodrigo Guzman (LMD-Paris), Angie Pendergrass (NCAR) and Vineel Yettella (CU)

CESM | COMMUNITY EARTH SYSTEM MODEL

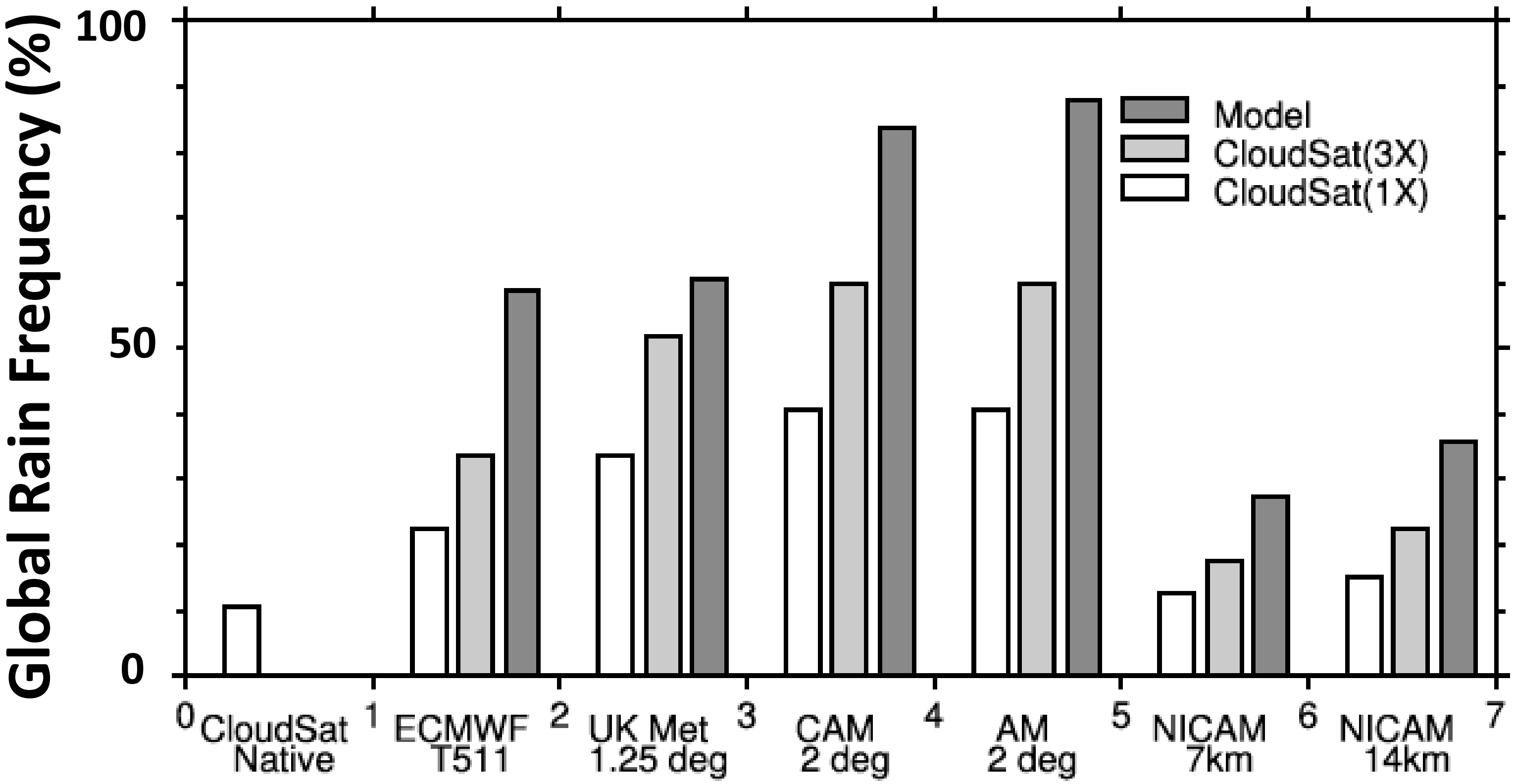
How often does it rain?

Use near-global CloudSat Observations!!



Kay, L'Ecuyer et al. 2018 JGR
CloudSat's 2C-PRECIP-COLUMN
(Haynes et al. 2009 thresholds over ocean,
Smalley et al. 2014 thresholds over land)

How often does it rain in models?



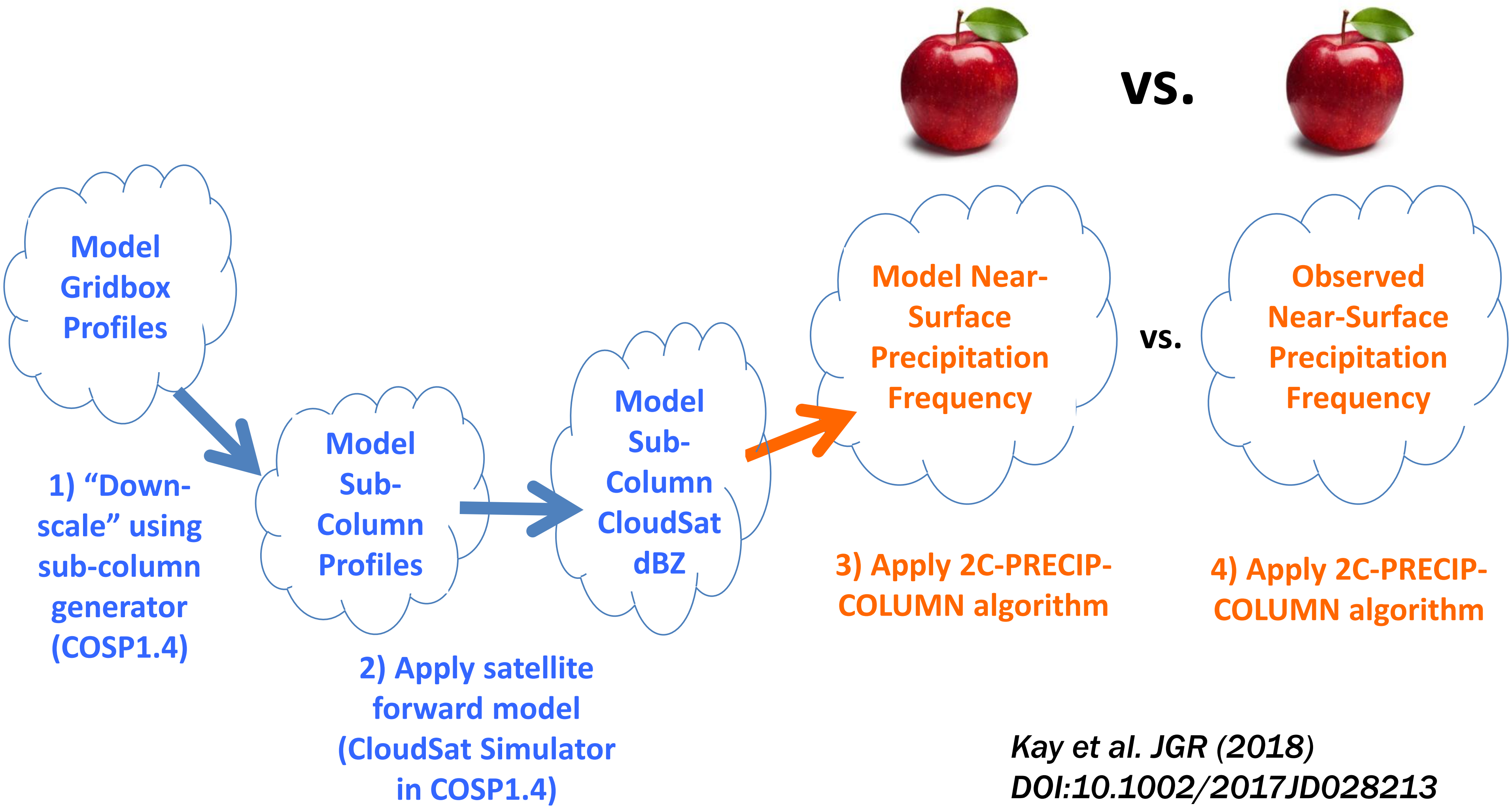
Stephens et al. 2010

CONCLUSION: models overestimate rain frequency, but underestimate rain intensity.

This evaluation "scale-aware" but not "definition-aware".

Goal: Use CloudSat to make definition-aware and scale-aware precipitation frequency comparisons

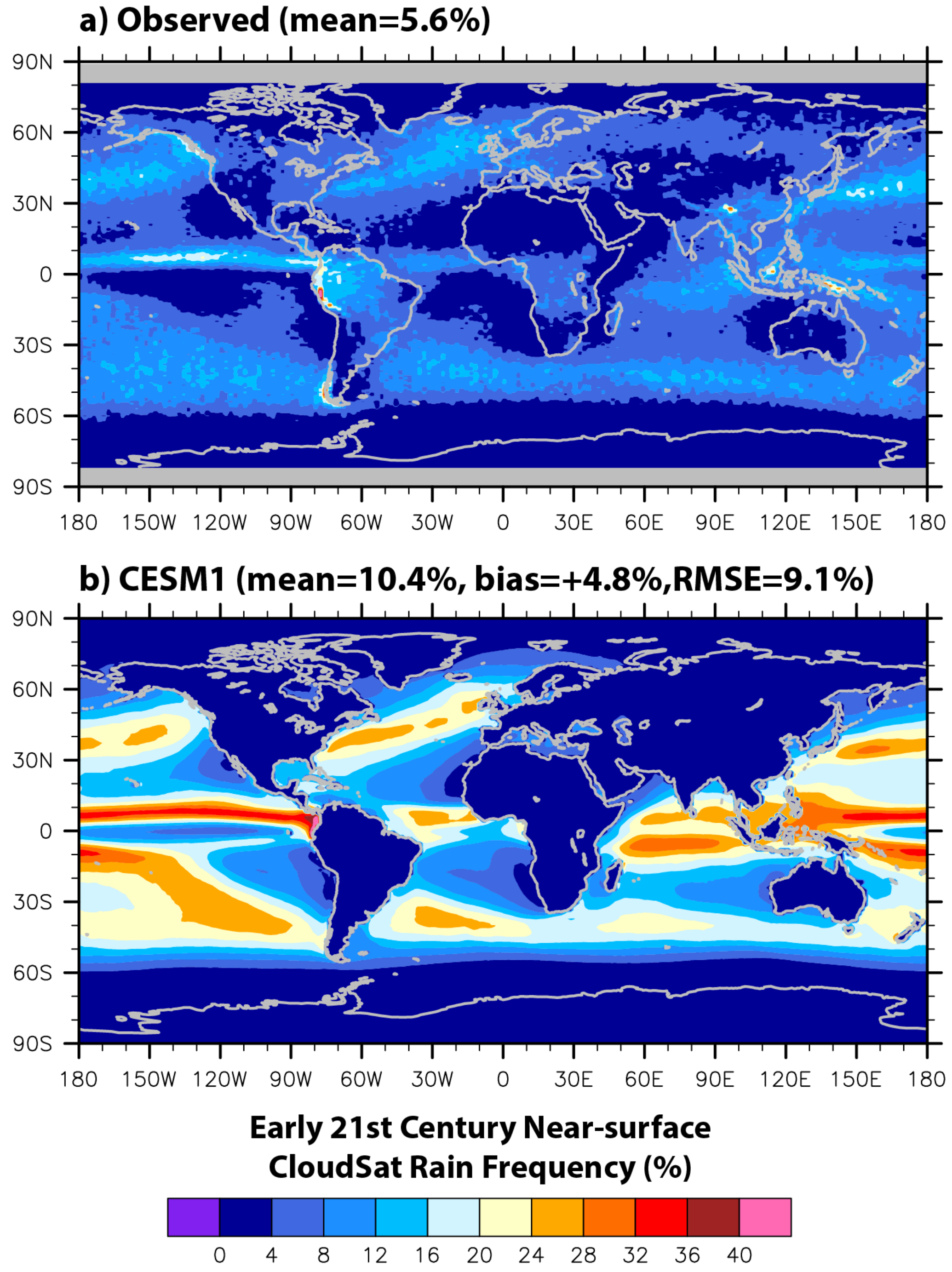
*But **how**? And what is **new**?*



Kay et al. JGR (2018)
DOI:10.1002/2017JD028213

Confirming the "dreary state of models"

CESM1 rains too frequently



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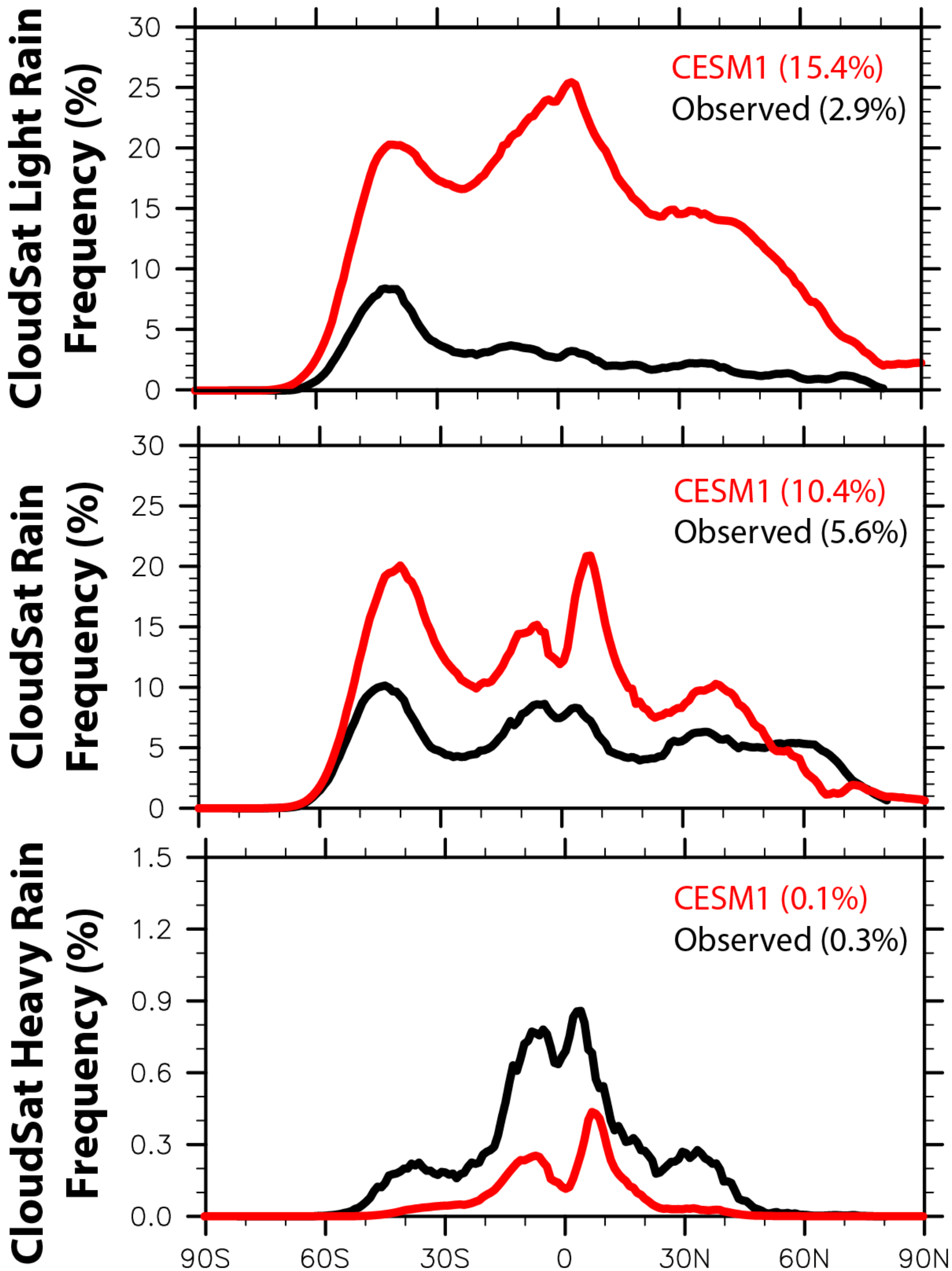
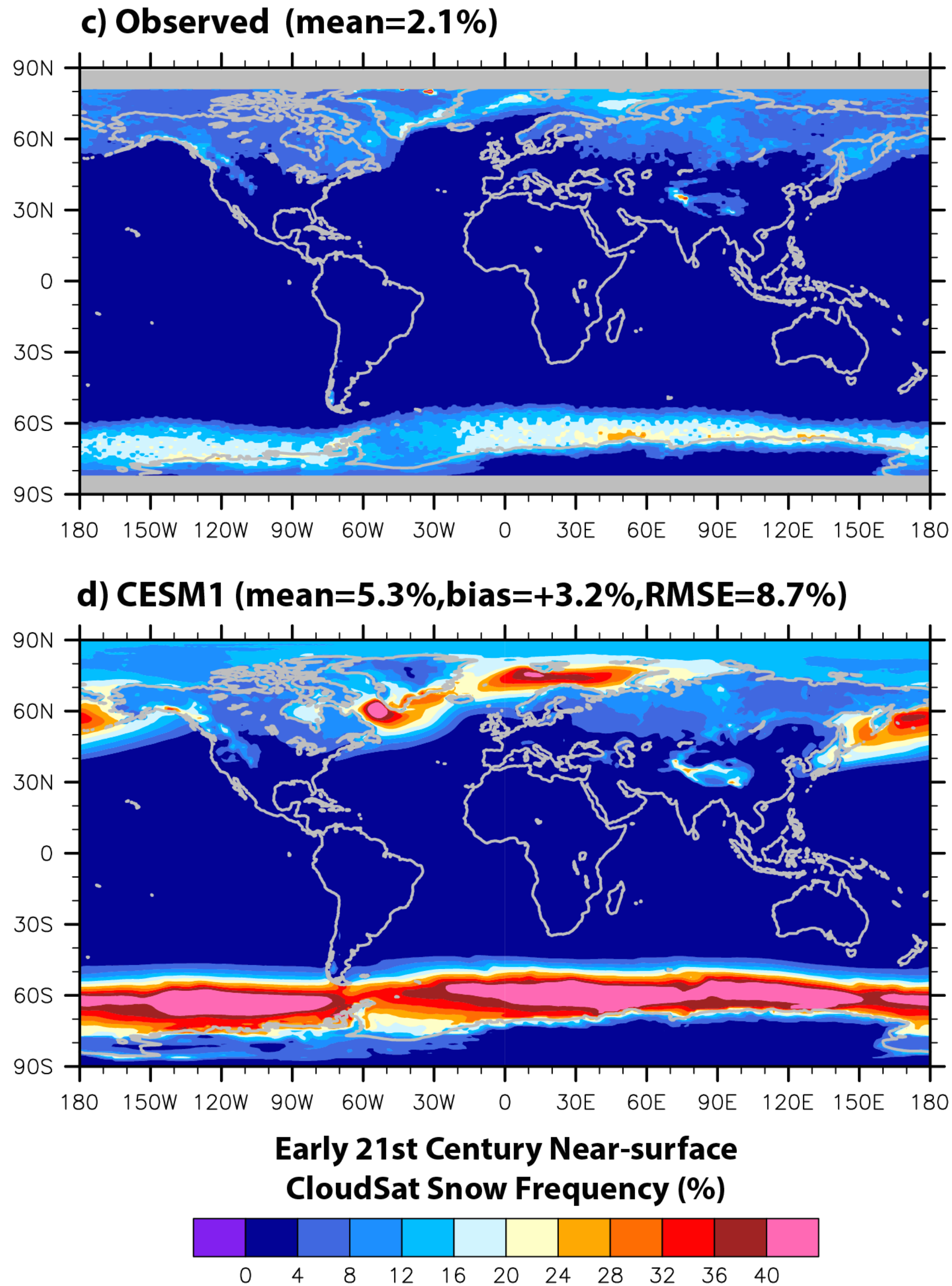


When compared to CloudSat observations, CESM1 raining too often but with insufficient intensity.

Kay et al. JGR (2018)
DOI:10.1002/2017JD028213

It also snows too frequently in CESM1…



Kay et al. JGR (2018)
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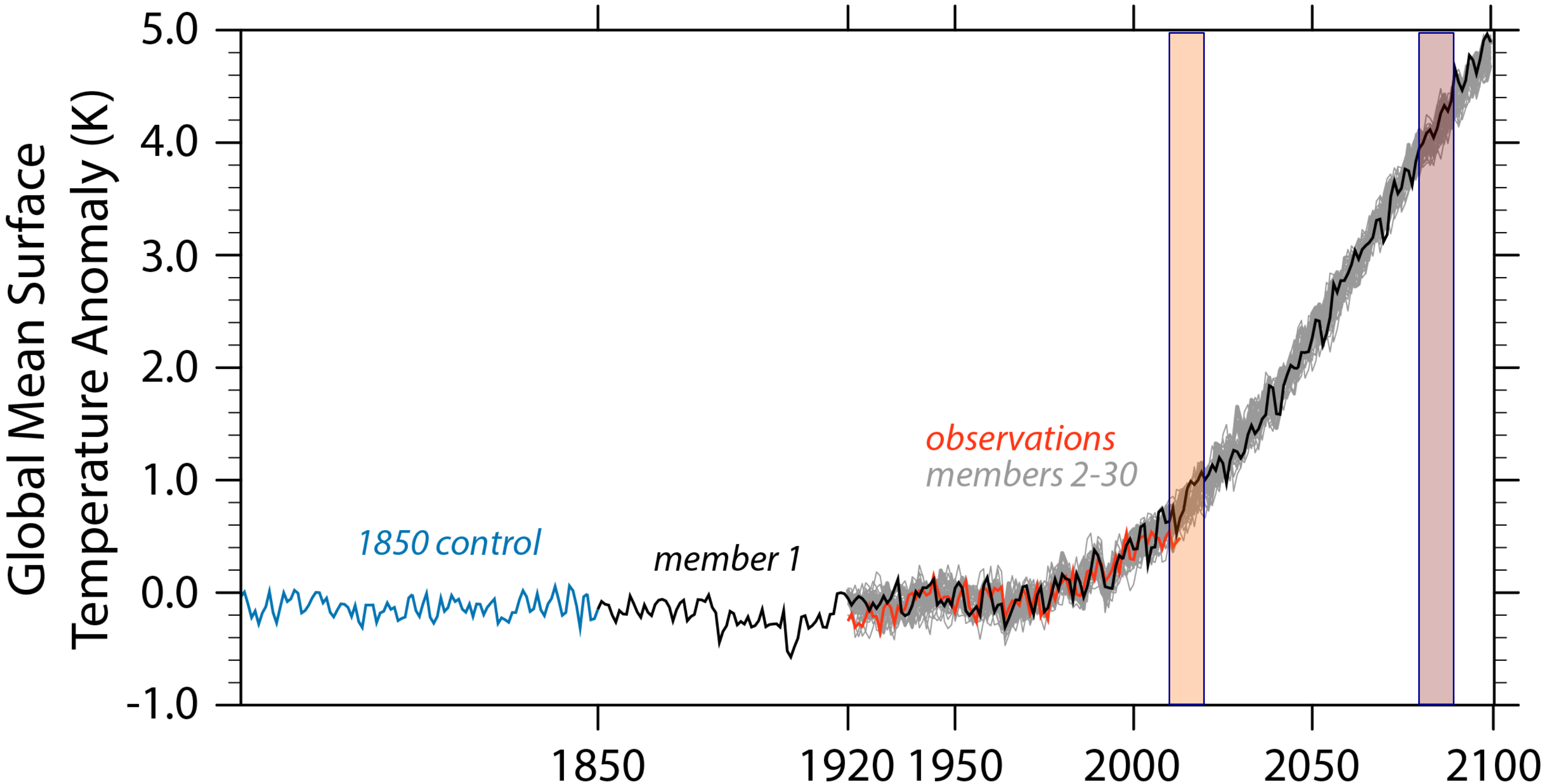
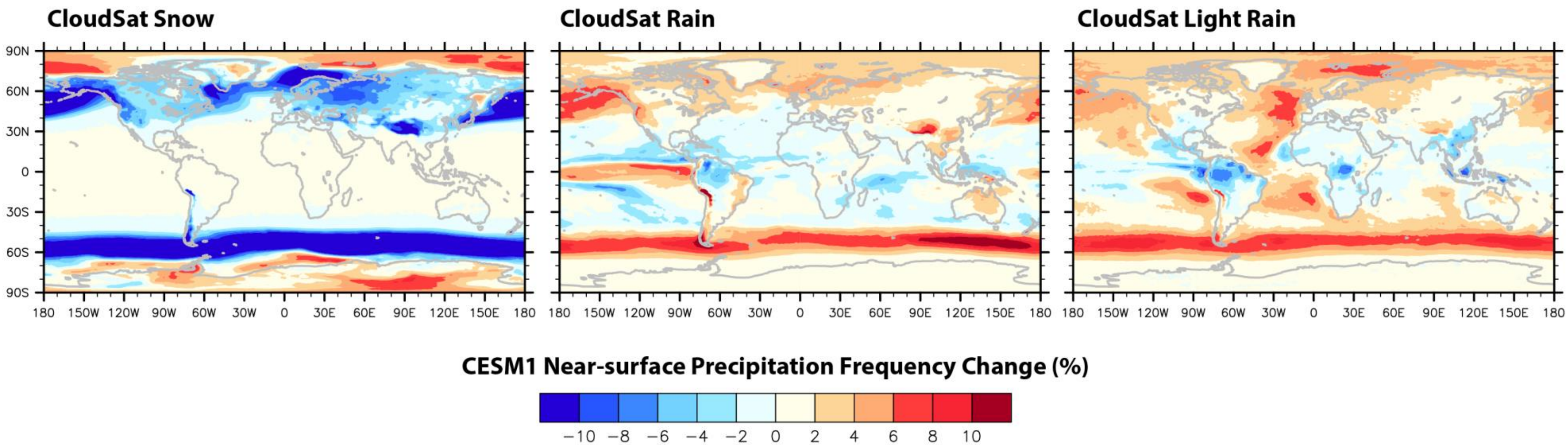
Would future near-surface precipitation changes be seen by CloudSat?

Let's compare 2010s with 2080s!



CESM1 Large Ensemble, (Kay et al. 2015)

CESM1-Projected 21st Century Change: What would CloudSat Observe?



Three CESM1-projected Changes:

1) Snow becoming Rain (esp. in mid-latitude storm tracks)
2) Less Off-Equatorial Rain, More Equatorial Rain (esp. in Pacific)
3) Increase in Sub-tropical Light Rain Frequency

Kay et al. JGR (2018)
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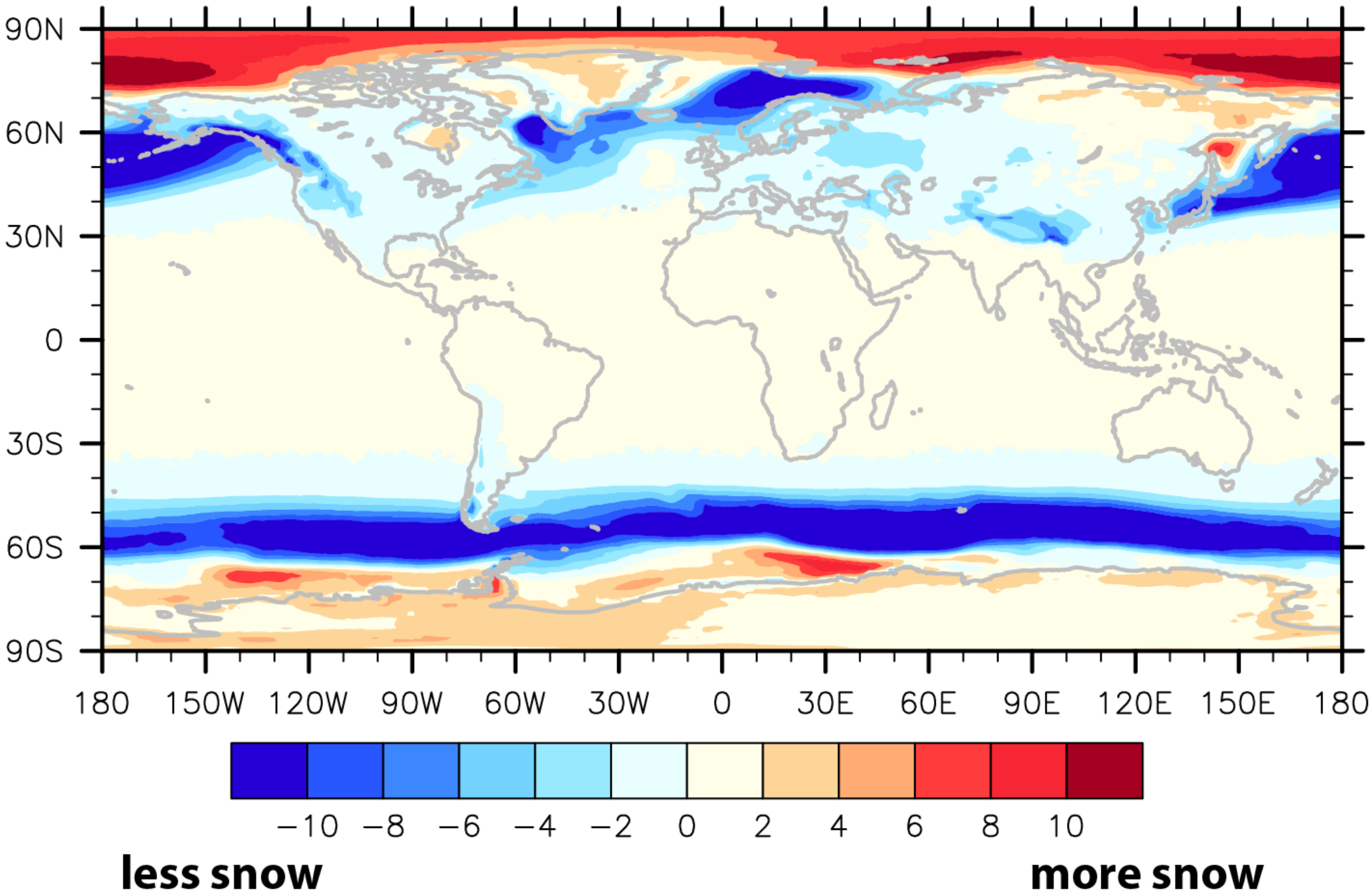
What is the future of snow?



Kay et al. JGR (2018)
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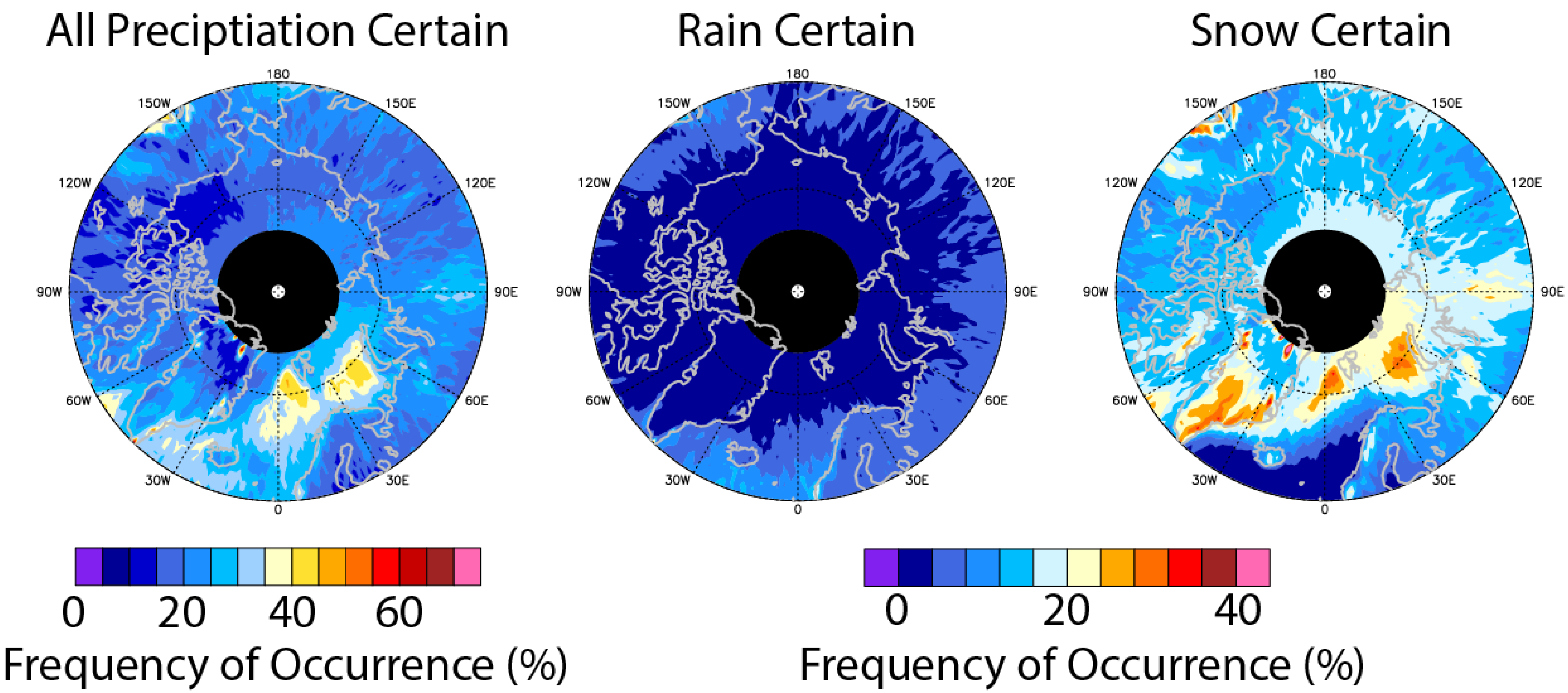
Arctic Precipitation is critical - CloudSat is the only satellite that measures it!!

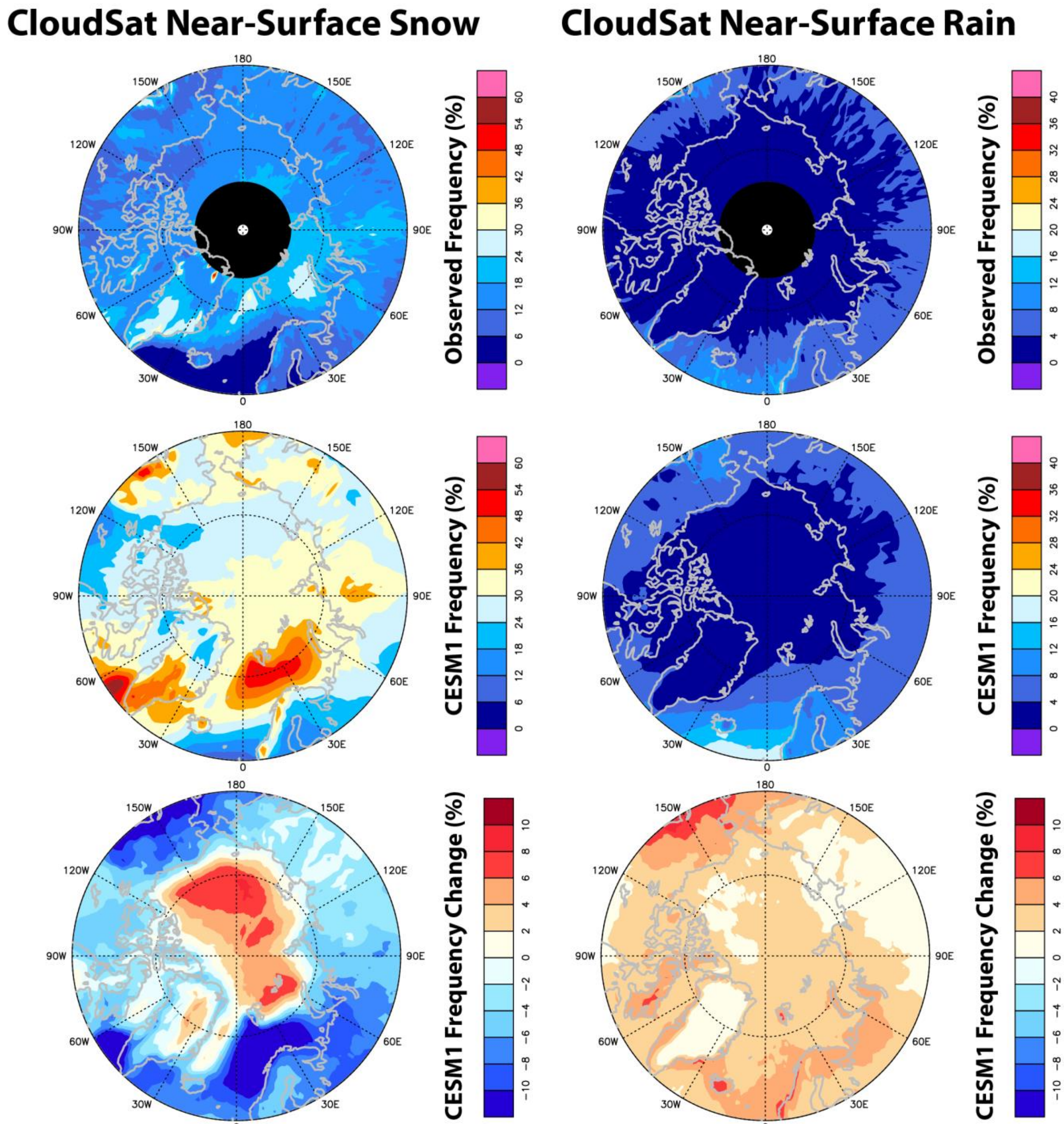


Arctic Snow and Rain Frequency Maps

CESM1-projected 21st century changes:

1) More Snow over Arctic Ocean and Greenland
2) More Rain Except over Greenland and Central Russia

Look for Camron et al. (in prep) for Greenland



Conclusions – Kay et al. 2018 JGR

1) Scale-aware and definition-aware diagnostics for CloudSat near-surface precipitation frequency available for model evaluation.
2) Diagnostics show CESM1 overestimates rain, light rain, and snow frequency, but underestimates heavy rain.
3) ***If CESM1 realistic*** – a future CloudSat launched in the 2080s would observe conversion of snow to rain, narrowing of the tropical rain belt, increased light rain in sub-tropics, more snow in high Arctic and over Greenland.
4) Happy to Share Code and Model Runs! Feedback Welcome!

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What if I want to use these diagnostics? Are they available?

1) CloudSat-based precipitation frequency diagnostics available in CESM2 and in COSP2 (publicly released on github, official release for satellite simulators of clouds and precipitation).
2) Plans for CESM2: PCWG Special Issue Paper by McIlhattan et al. to evaluate Arctic precipitation over sea ice. Synergy with PCWG CESM2 Special Issue Paper by Webster et al. to evaluate influence of snow on sea ice exciting!
3) Simply put: Could these be a part of your analysis? YES!

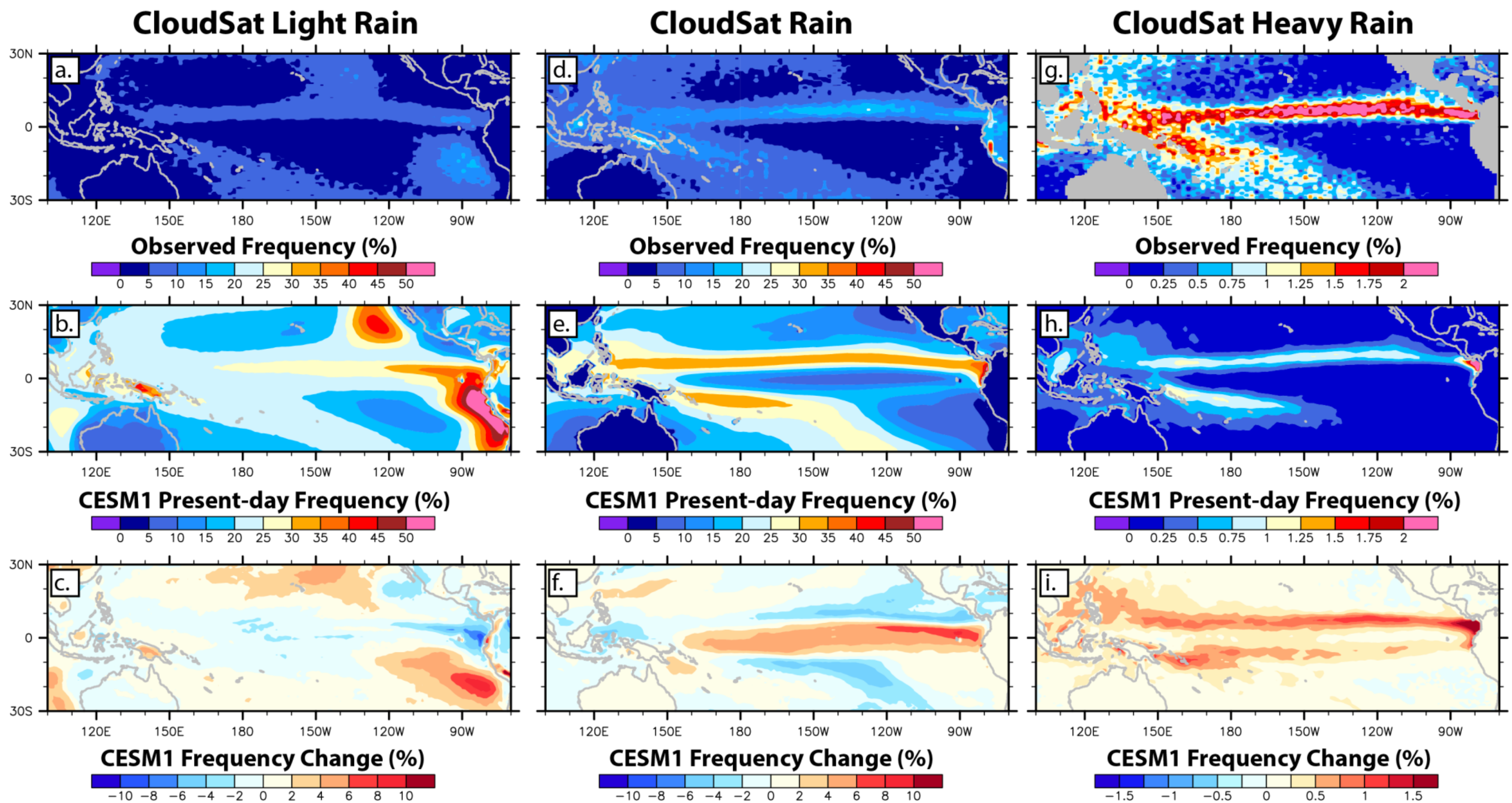
THRESHOLDS APPLIED

Table 2
CloudSat-Based Precipitation Classes Used in This Study

Name	Thresholds
CloudSat light rain	-15 dBZ $<$ dBZ $<$ 0 dBZ and $F_{ice} < 0.1$ over ocean; -15 dBZ $<$ dBZ $<$ 5 dBZ and $T_{air\text{-}surf} > 275$ over land
CloudSat rain	$>$ 0 dBZ and $F_{ice} < 0.1$ over ocean; $>$ 5 dBZ or heavy attenuated indicated by maximum dBZ in the profile $>$10 dBZ or two-way radar beam attenuation $>$30 dBZ and $T_{air\text{-}surf} > 275$ over land
CloudSat heavy rain	Two-way radar beam attenuation $>$40 dBZ and $F_{ice} < 0.1$ over ocean
CloudSat light snow	-15 dBZ $<$ dBZ $<$ -5 dBZ and $F_{ice} > 0.9$ over ocean; -15 dBZ $<$ dBZ $<$ -5 dBZ and $T_{air\text{-}surf} < 273$ K over land
CloudSat snow	$>$ -5 dBZ and $F_{ice} > 0.9$ over ocean; $>$ -5 dBZ and $T_{air\text{-}surf} < 273$ over land

Note. Over the ocean, precipitation classes are defined by applying thresholds to the near-surface (480–960 m) unattenuated radar reflectivity (dBZ) and the fraction of ice (F_{ice}), following the 2CPC algorithm (Haynes et al., 2009). The same thresholds are applied in both model simulations and in observations. Over the land, precipitation classes are defined by applying thresholds to the near-surface (960–1,440 m) attenuated radar reflectivity (dBZ) and the surface air temperature ($T_{air\text{-}surf}$) following Smalley et al. (2014).

Tropical Rain and Light Rain Maps



Kay et al. JGR (2018)
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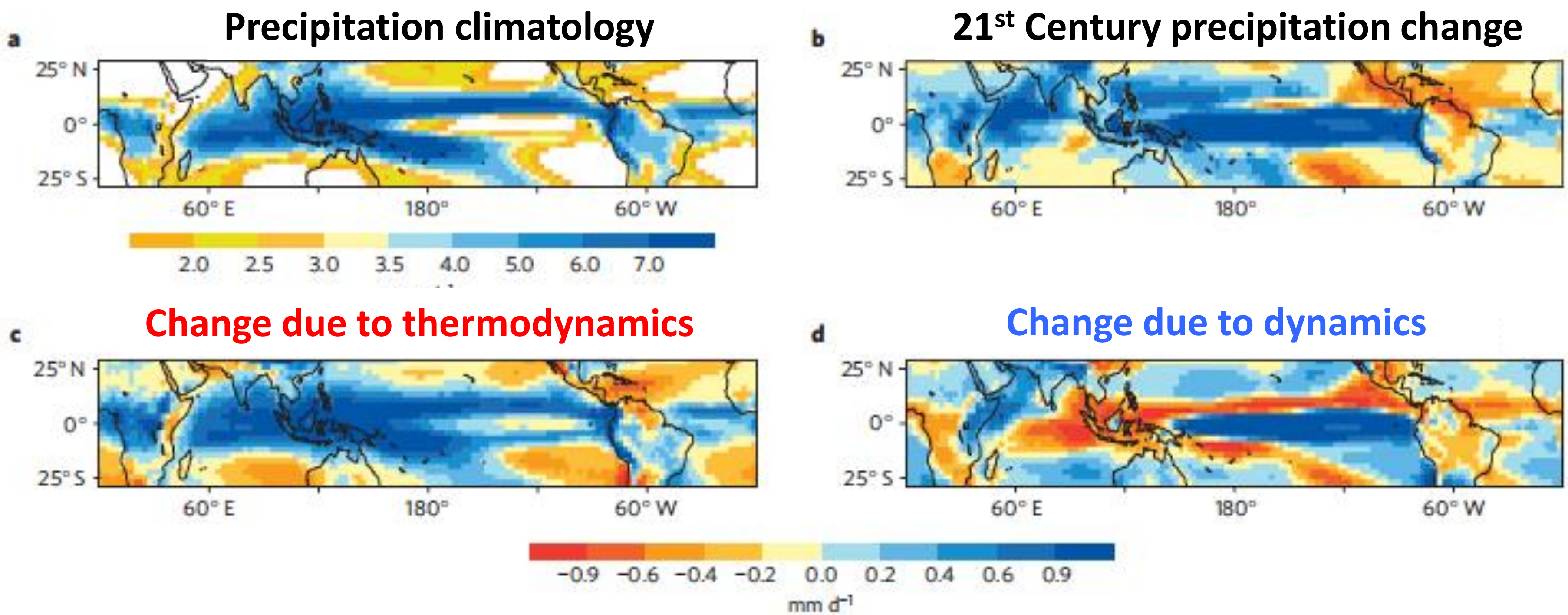
Tropical precipitation response to greenhouse warming (RCP8.5 2090 = 4xCO_2)

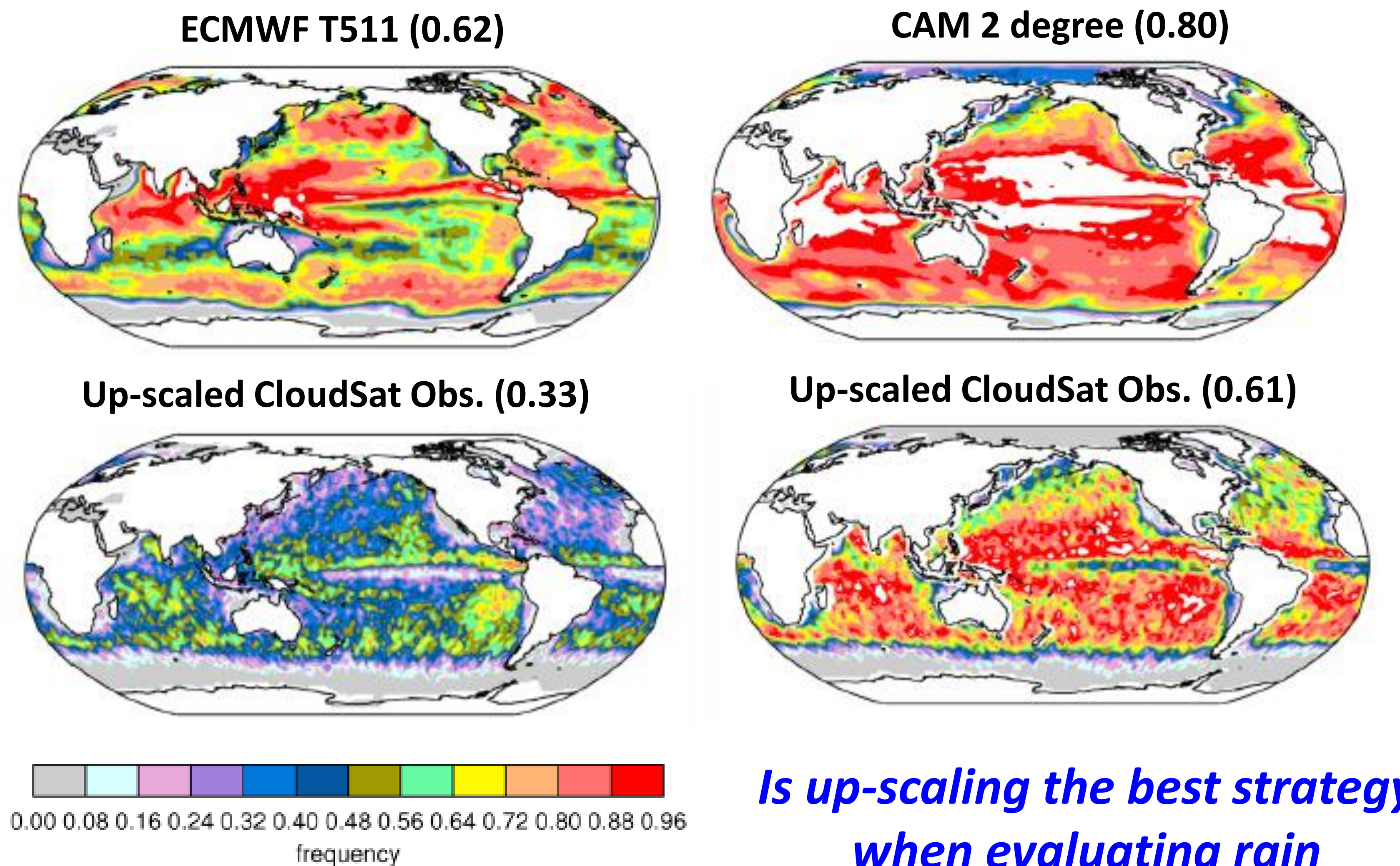


Panel shows the "thermodynamic response" resulting from "wet get wetter dry get drier"

Panel shows the "dynamic response" resulting from reduced overturning circulation

Figure 1 Bony et al. 2013

Upscaling CloudSat observations to evaluate the “dreary state of models!



Stephens et al. 2010

Is up-scaling the best strategy when evaluating rain frequency?

How often does it rain in climate models?

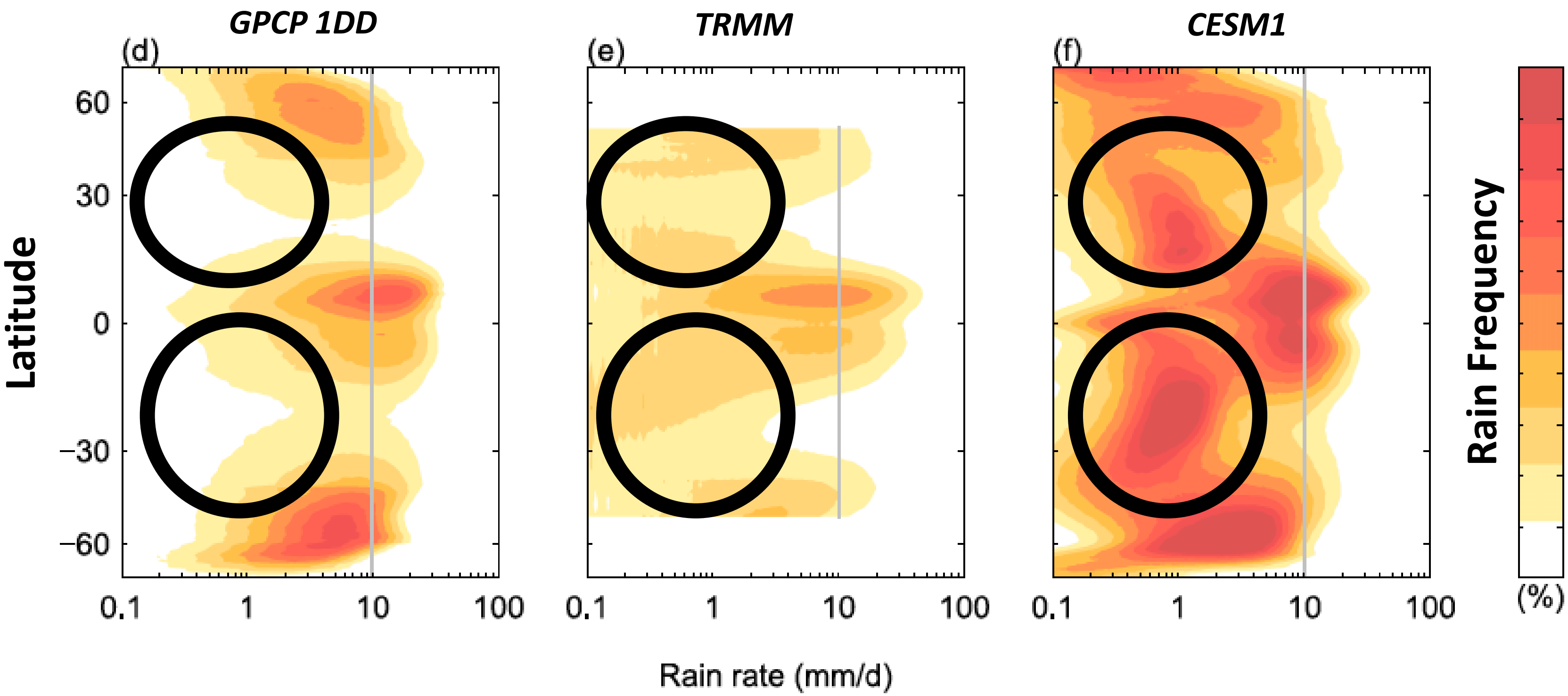


Figure adapted from Pendergrass and Deser (2017) J. Climate

Problem: This evaluation is not "definition-aware".

TRMM and GPCP <u>do not detect</u> "light rain" (< 1 mm/day) (Berg et al. 2010; Behrangi et al. 2014)