High-resolution simulations using CAM (4 and 5)

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With lots of help - *will try to cite at appropriate places*

Thanks to: Warren Washington, Jim Hack and DoE
for computer time at ORNL

AMWG Meeting February 16, 2011

Outline

1) Rough description of “quarter degree” configurations

2) CAM4 and CAM5 resolution sensitivity (2 vs ¼ degree)
   -CAM4 clouds are more sensitive

3) Means, variability and statistics
   -Mixed bag

4) Precipitation loading effects
   -Seem to be important

High resolution 0.23x0.31 configurations

CAM4: *out-of-the-box*

CAM4-ice: *Ice cloud radii dependence on T changed* * ,**
(with Cecile Hannay and Rich Neale)

CAM5 : *fully prognostic aerosols*

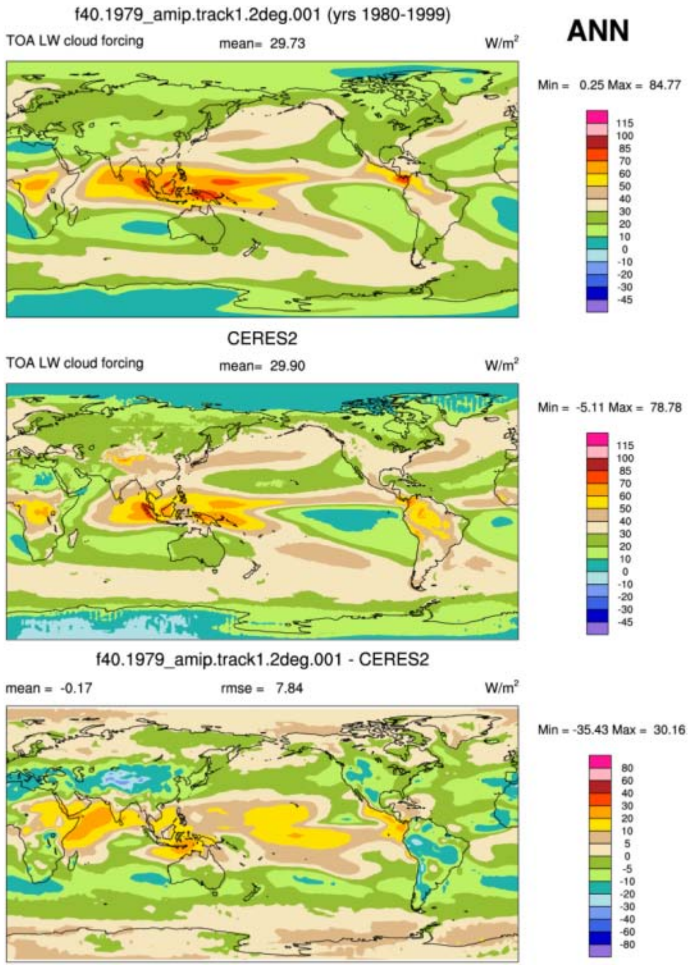
CAM5-BAM: *using prescribed bulk aerosols. (2x speed-up)*
(thanks to Andrew Gettelman)

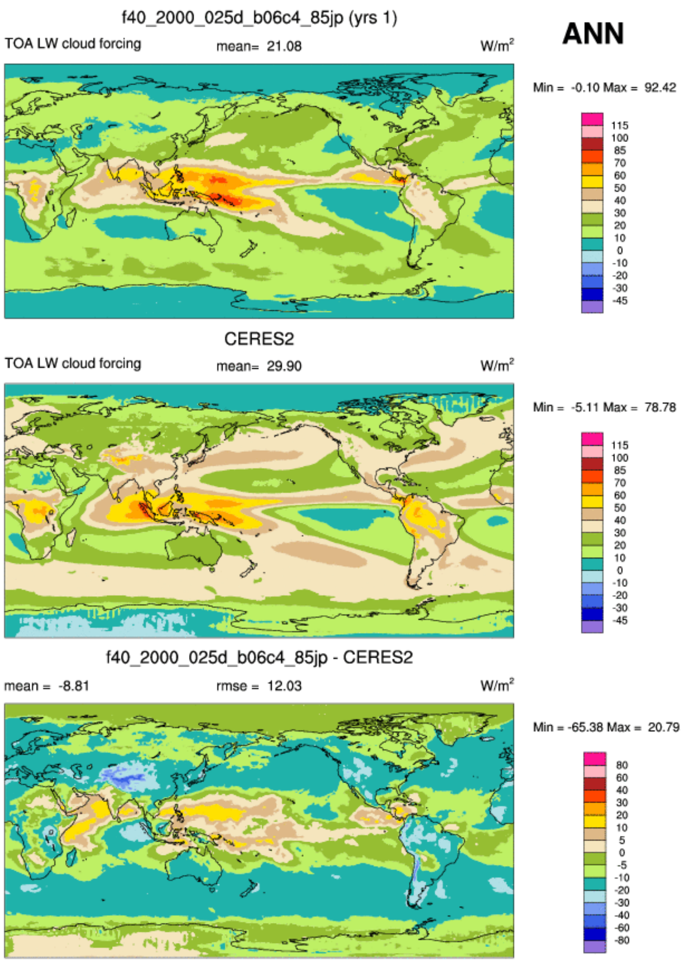
* $r_e=25\mu$ *for* $T<224K$ *linear decrease to* 10μ *at* $T=273K$

*** Used in 1989-2005 AMIP run and future time slice*

Sensitivity to horizontal resolution
(or time step?)

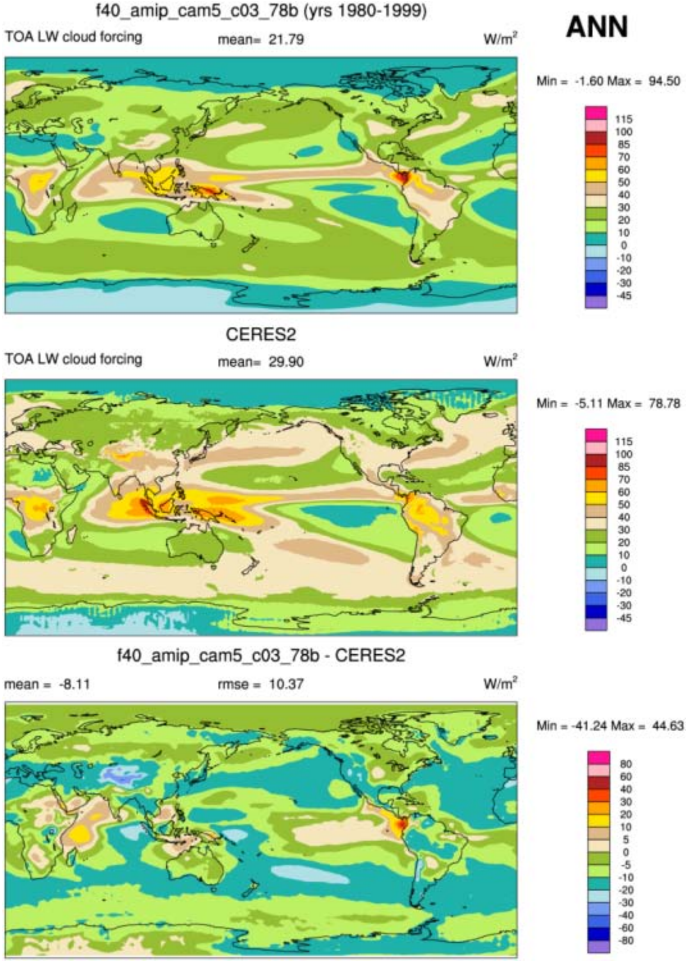
CAM 4 LWCF

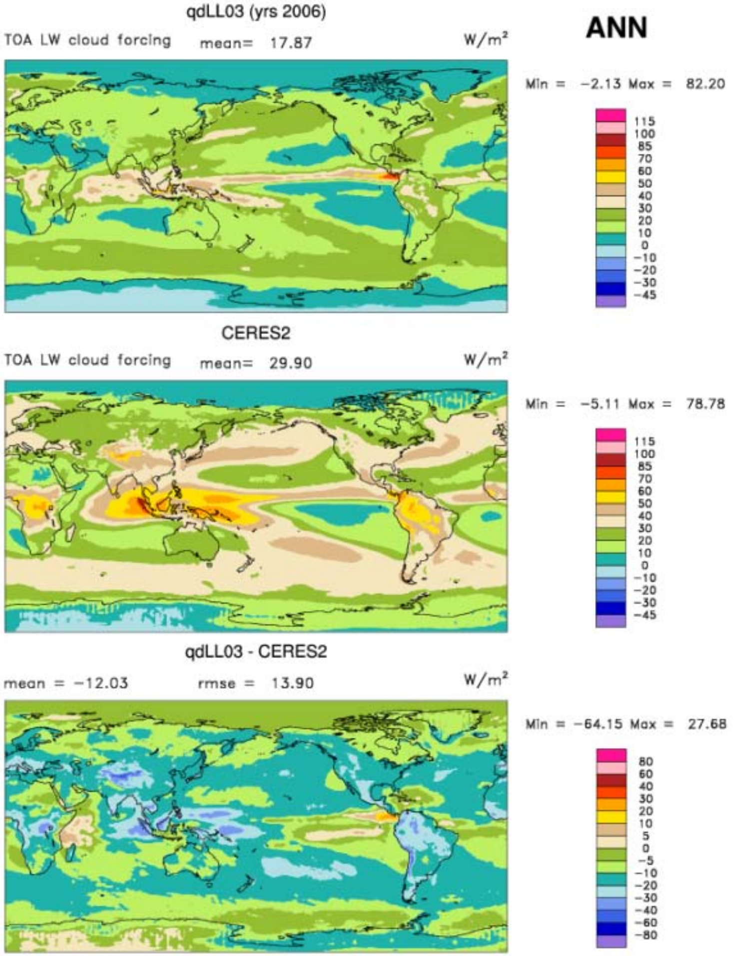




Well tuned at 2 degree resolution.
Drops sharply at 0.25 -- esp. in storm tracks
(30% global decrease, *factor of two in midlatitudes*)

CAM 5 LWCF

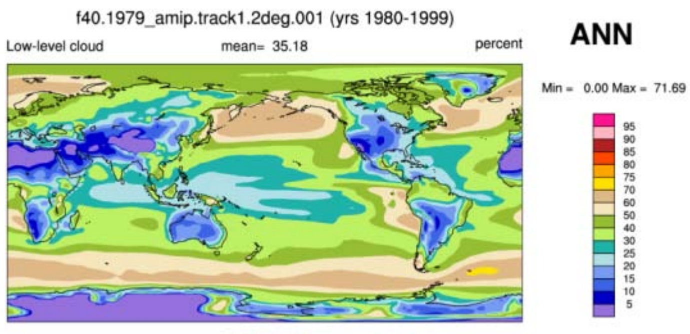


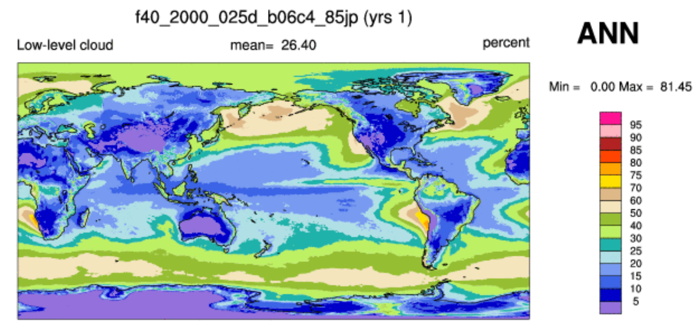


Starts with more bias at 2 degree but
Less sensitive to resolution in midlatitudes

CAM4 clouds tend to go away at high resolution.

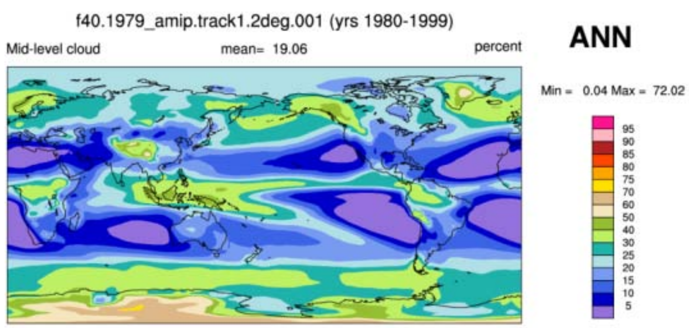
CLDLOW

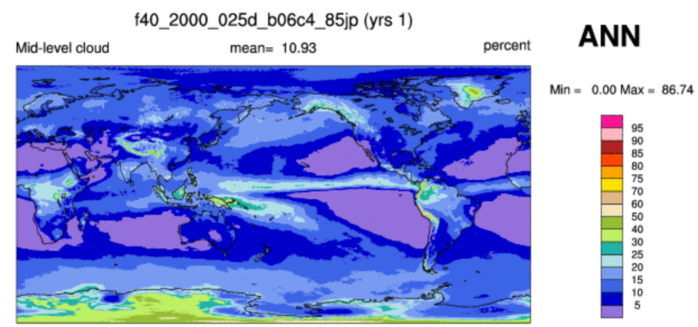




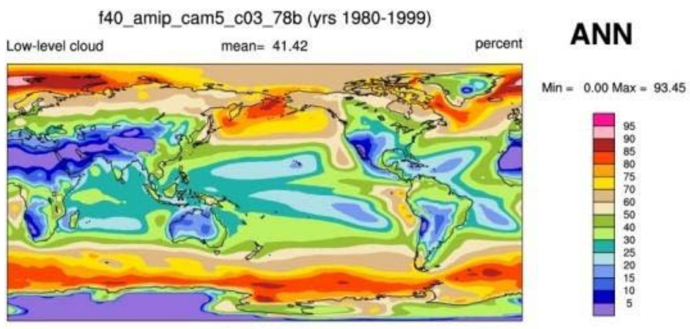
Mid and high-level clouds decrease by a factor of two

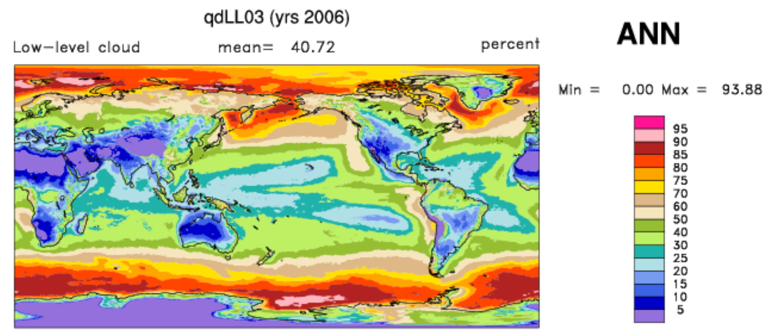
CLDMED



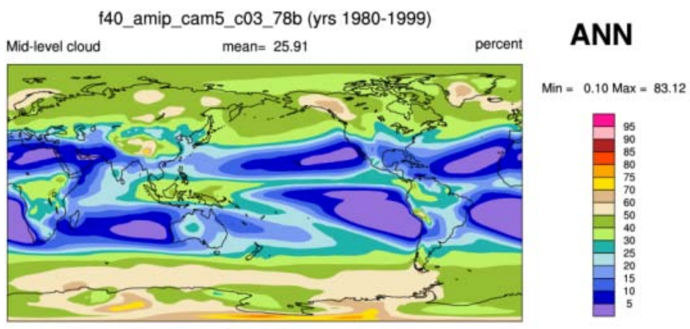


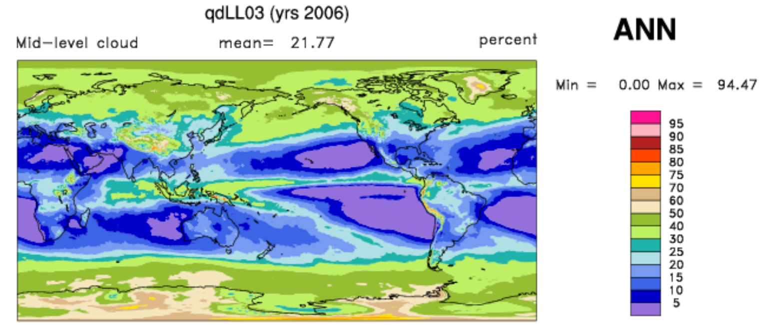
CAM5 clouds are nearly insensitive to resolution





… small decrease in mid and high-levels





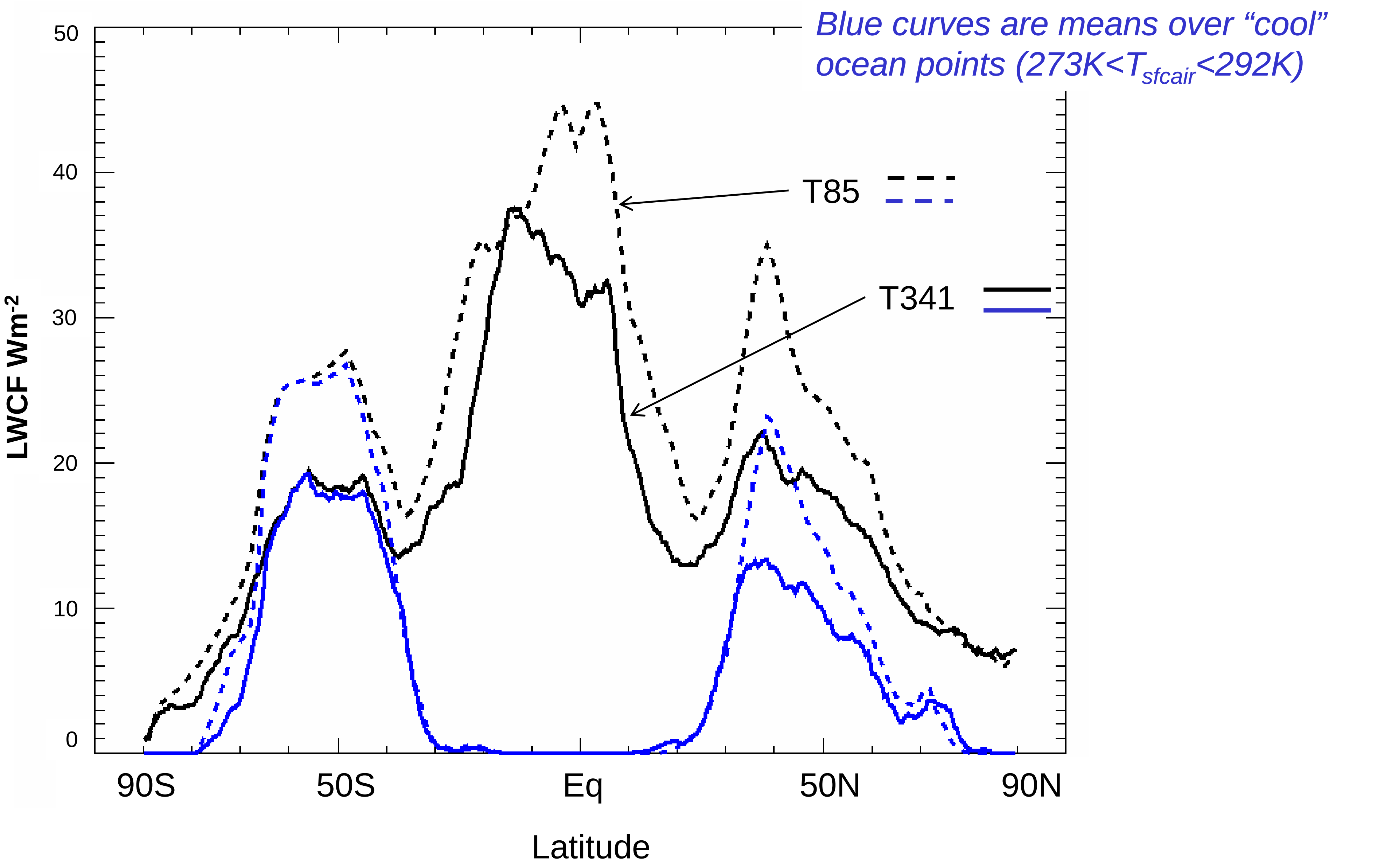
	LWCF (Wm-2)		SWCF (Wm-2)		CLDMED	
	2 deg	*¼ deg*	*2 deg*	*¼ deg*	*2 deg*	*¼ deg*
CAM4	30	21	-54	-43	19	11
CAM4-ice		29		-49		13
CAM5	22	18	-50	-50	26	22
CAM5-BAM		18		-52		25

Analysis of high frequency cloud output from CAM4 at T85 and T341

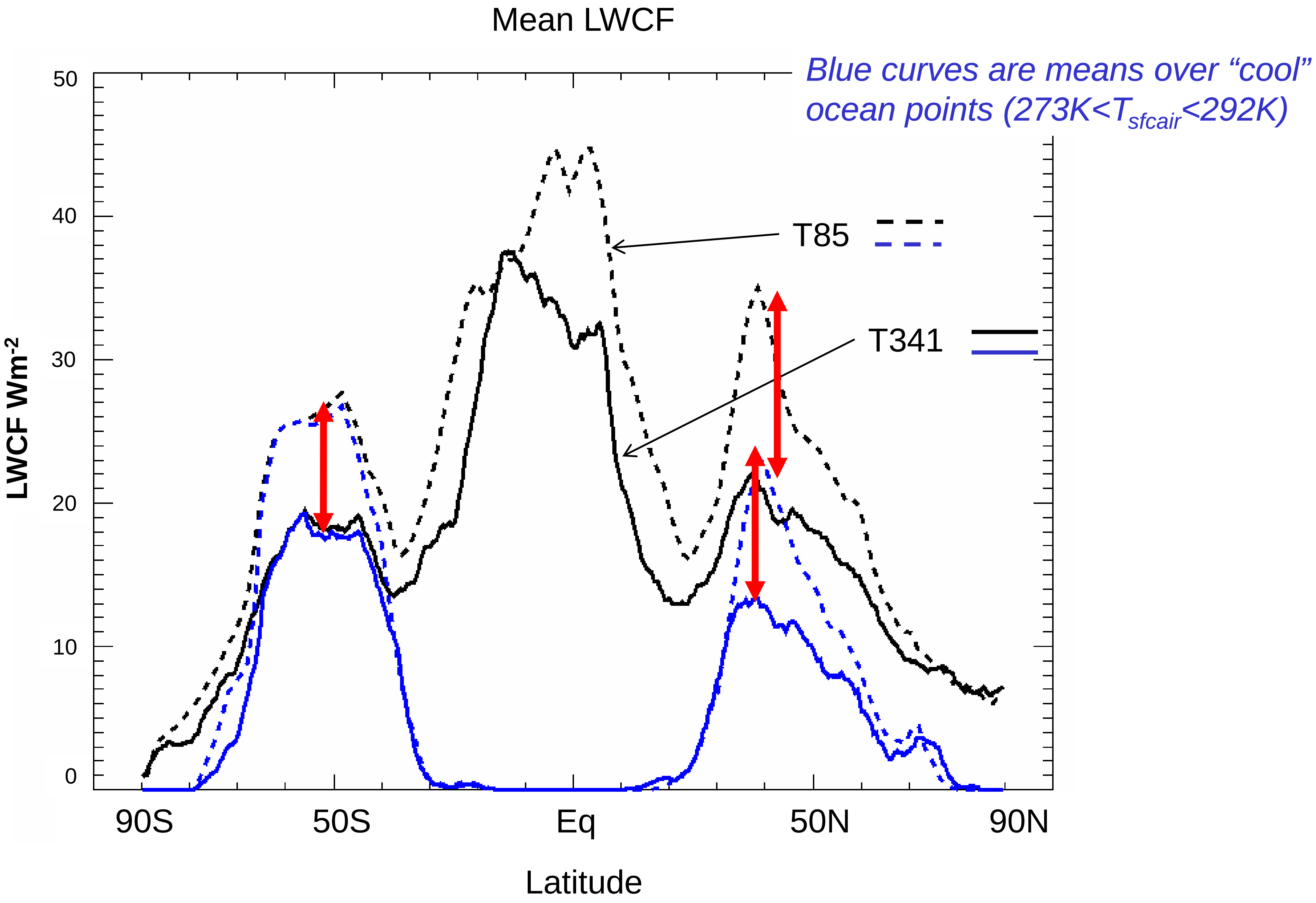
One month (January) of hourly instantaneous output

Thanks to John Truesdale and Julie Caron

Mean LWCF

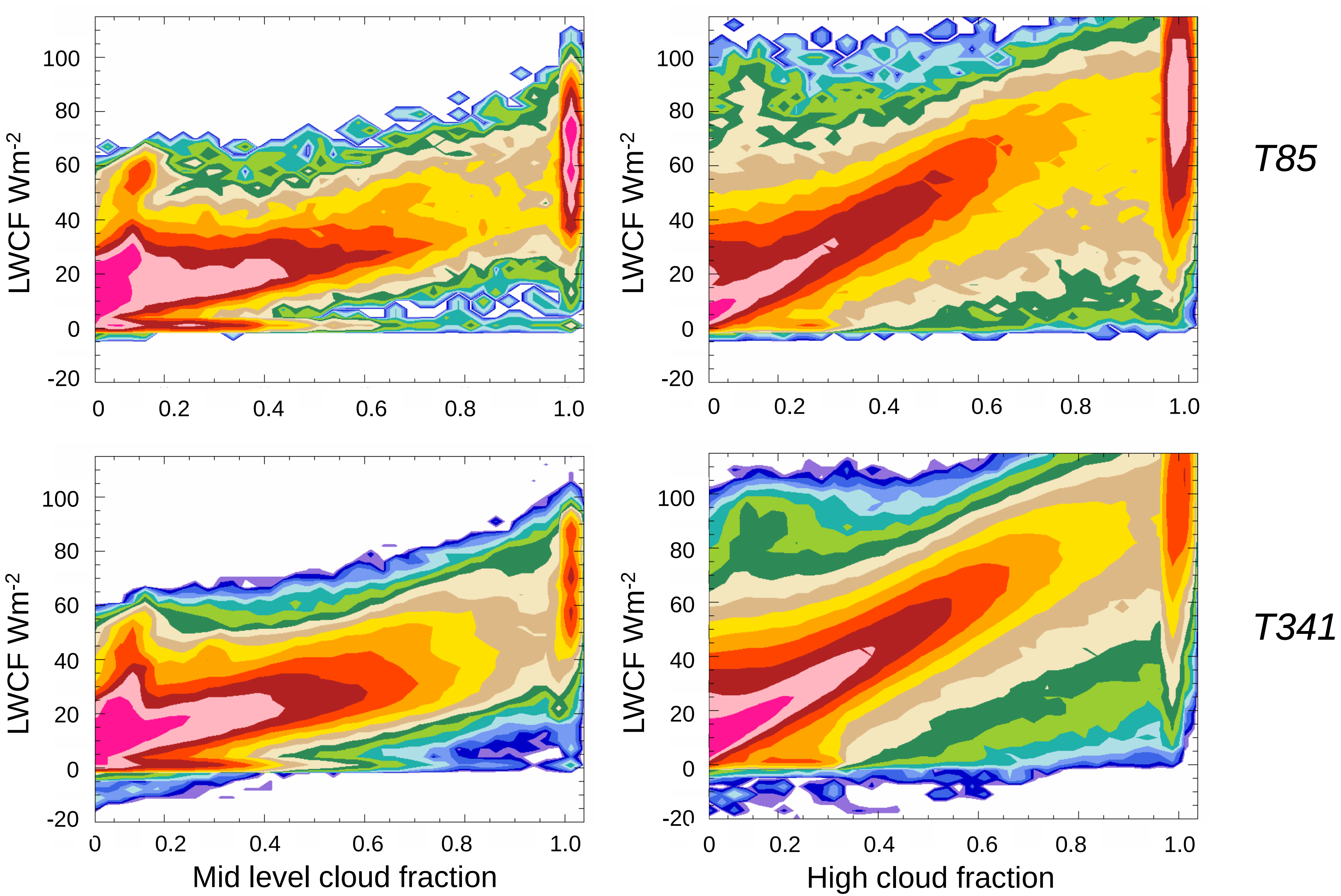


Blue curves are means over “cool” ocean points (273K<T$_{sfcair}$<292K)
LWCF Wm^{-2}
50
40
30
20
10
0
90S
50S
Eq
50N
90N
Latitude
T85
T341



Most of midlatitude decrease in LWCF takes place over cool oceans

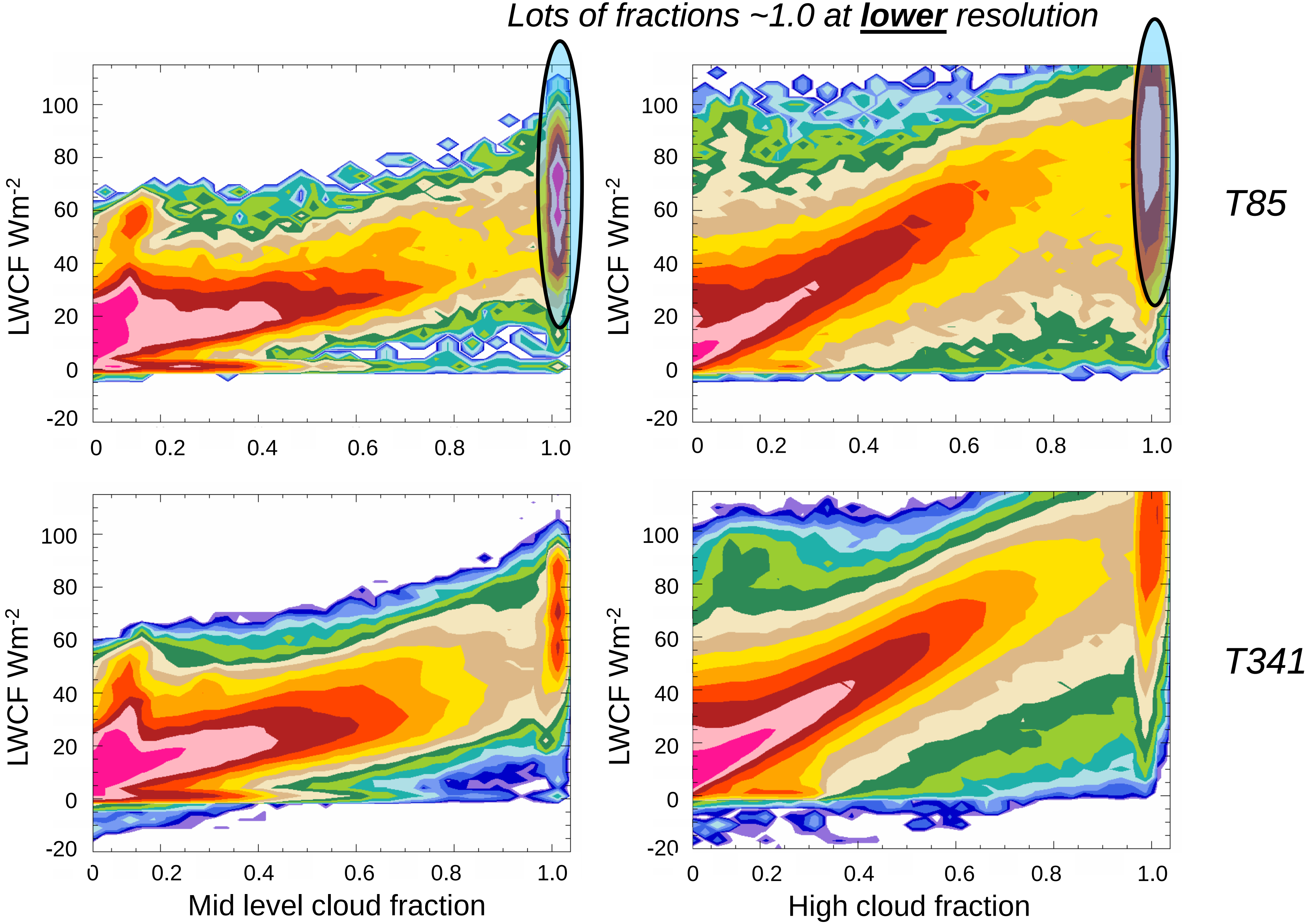
Joint PDFs of cloud fraction and LWCF over cool ocean



(overlying high cloud <0.1)

Joint PDFs of cloud fraction and LWCF over cool ocean

*Lots of fractions ~1.0 at **lower** resolution*

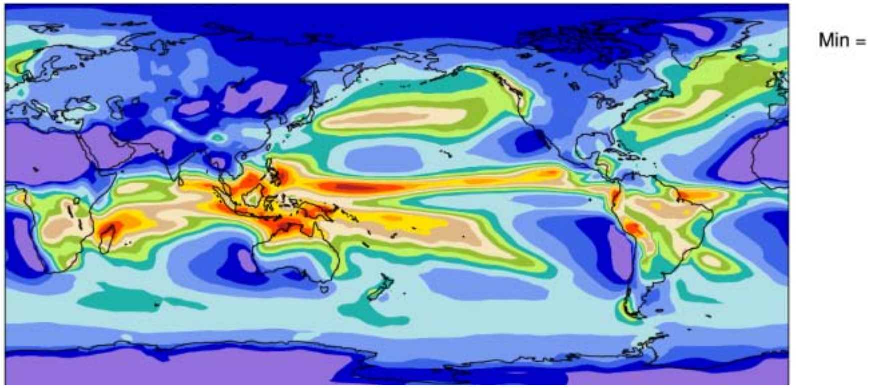


(overlying high cloud <0.1)

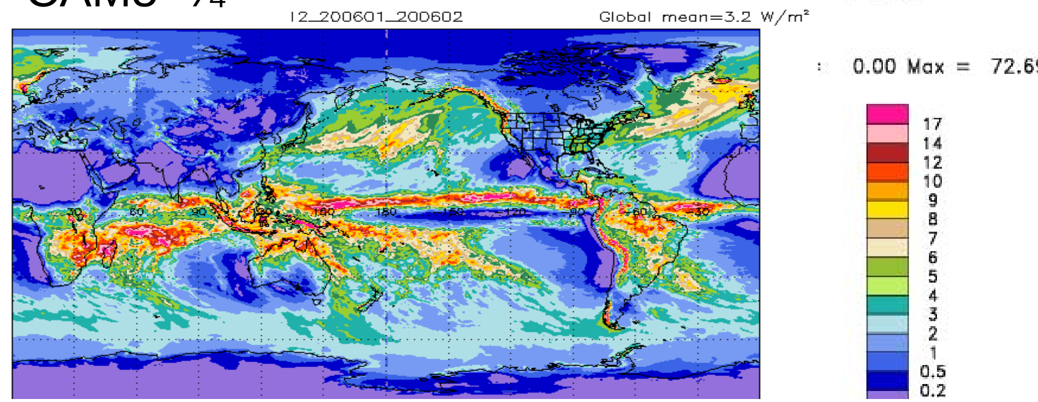
Means, diurnal cycle, TCs

Precipitation patterns are relatively insensitive to resolution

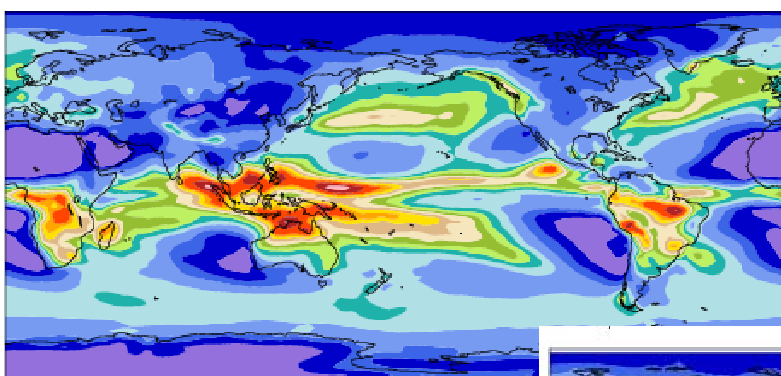
CAM5 2°



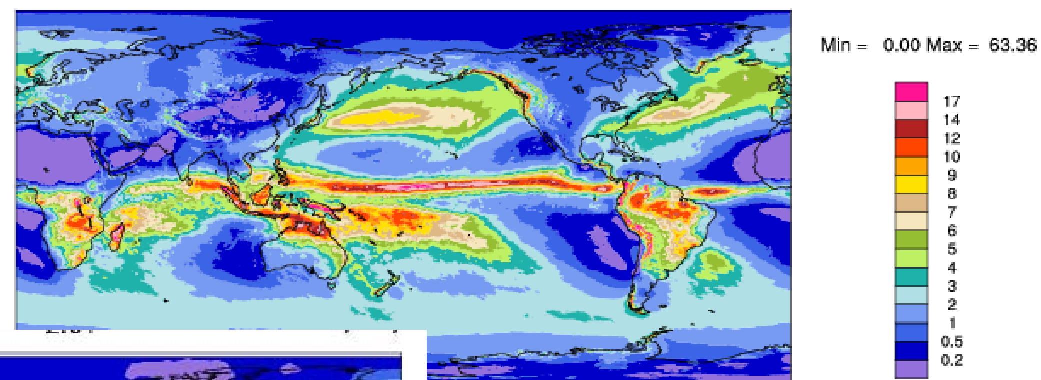
CAM5 ¼ °



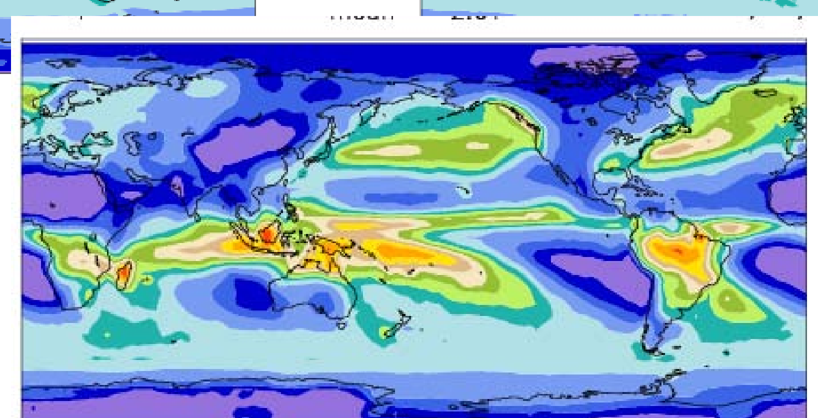
CAM4 2°



CAM4 ¼ °



GPCP

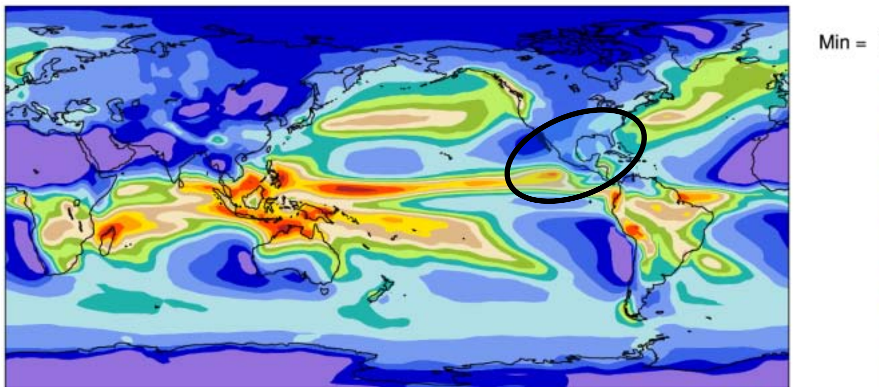


DJF

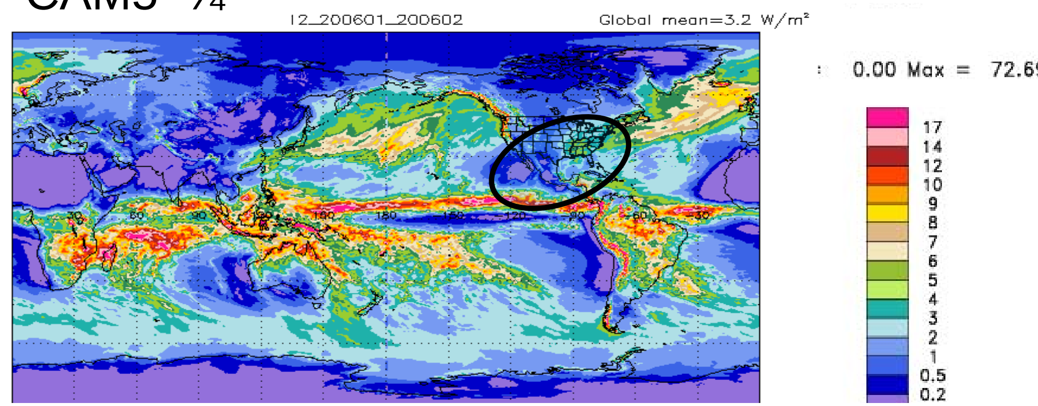
Precipitation patterns are relatively insensitive to resolution

Some improvement: *SE US winter precip up, NE tropical Pacific down. (Orography?)*

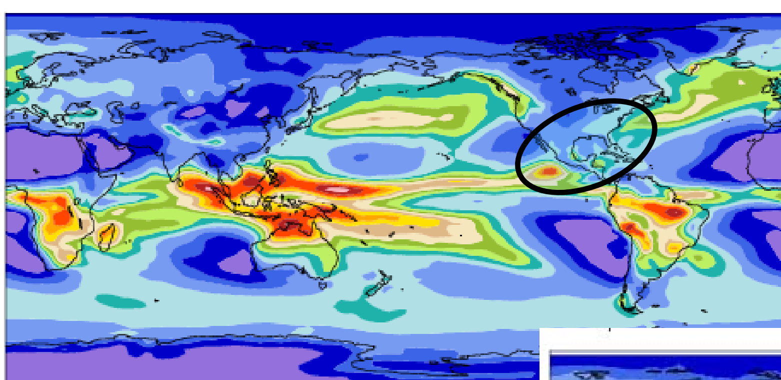
CAM5 2°



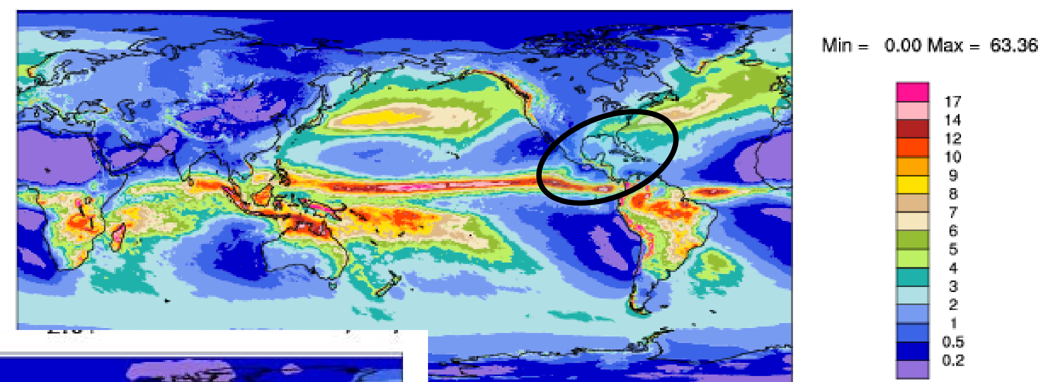
CAM5 ¼ °



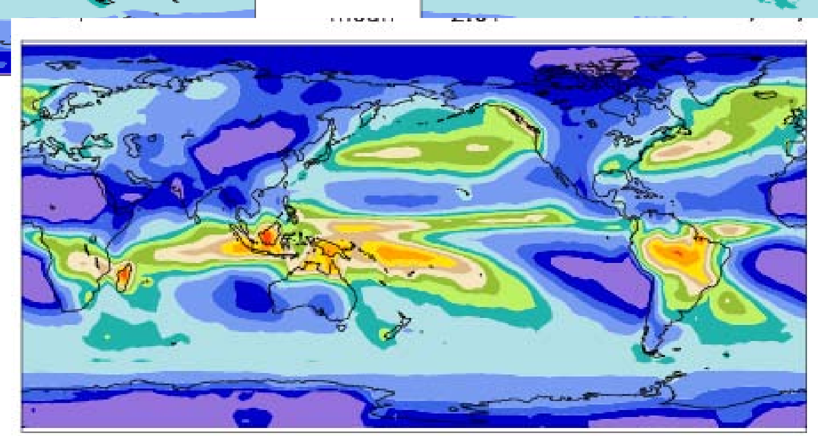
CAM4 2°



CAM4 ¼ °



GPCP

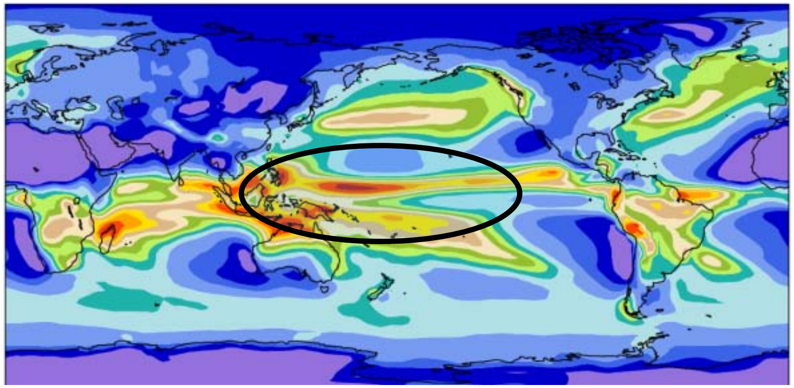


DJF

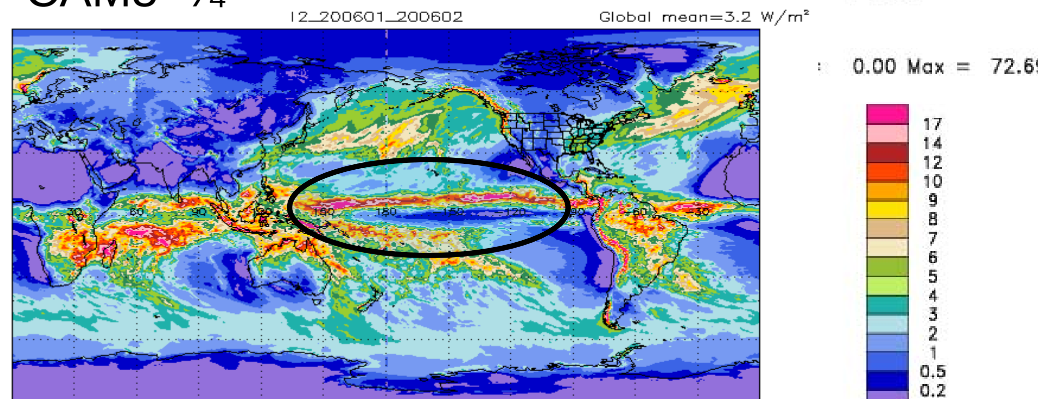
Precipitation patterns are relatively insensitive to resolution

Some degradation – *ITCZs intensified, more "doubled"*

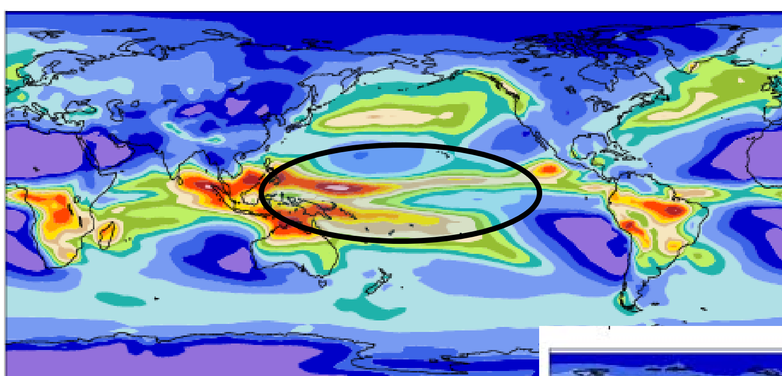
CAM5 2°



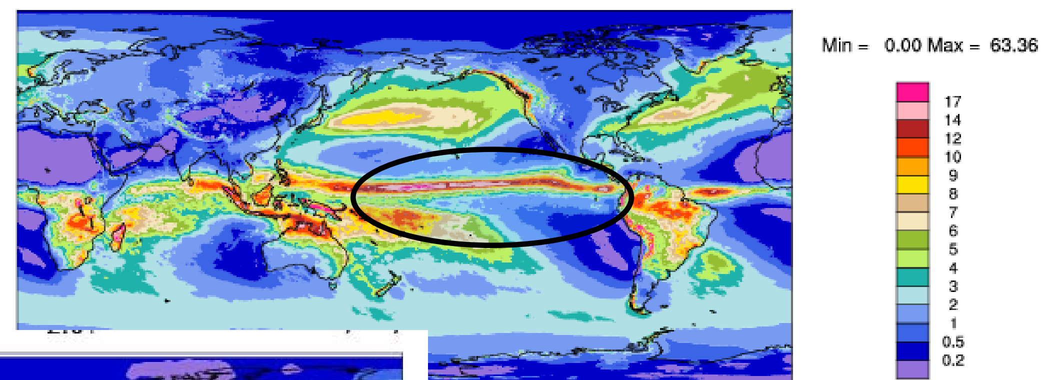
CAM5 ¼ °



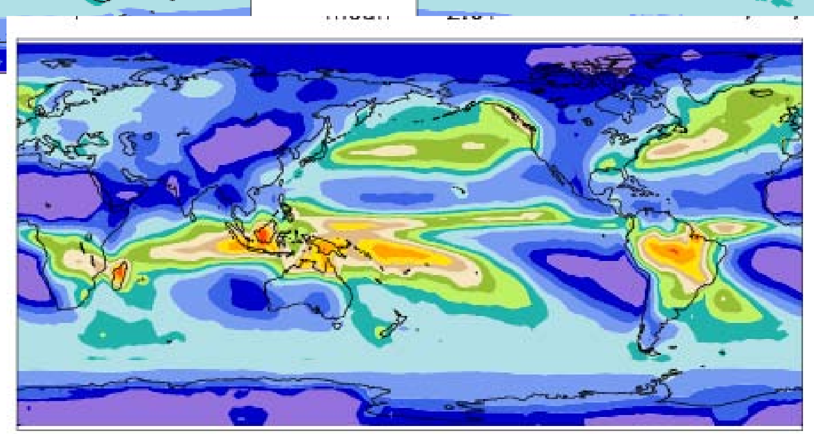
CAM4 2°



CAM4 ¼ °

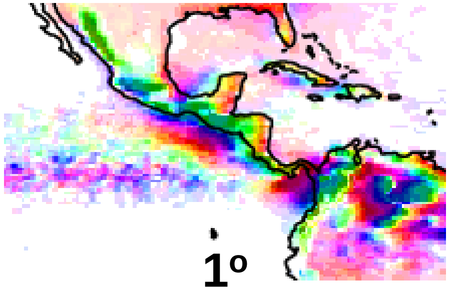


GPCP

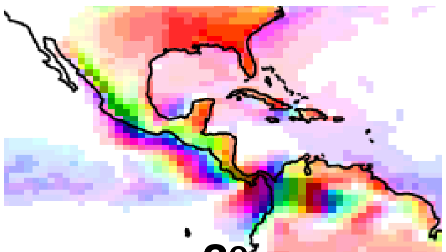


DJF

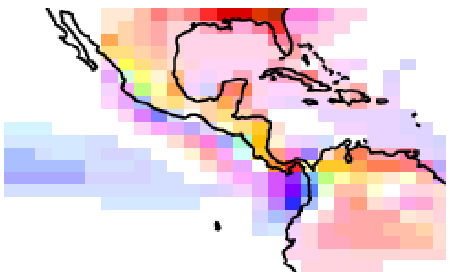
0.25°



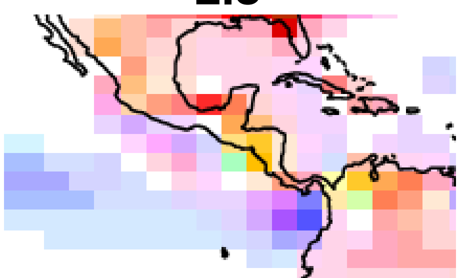
1°



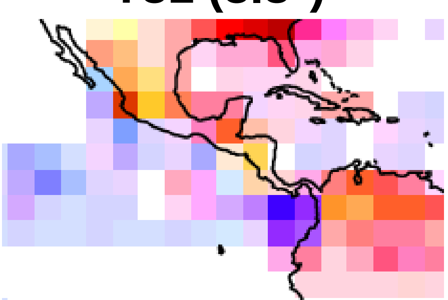
2°



2.5°

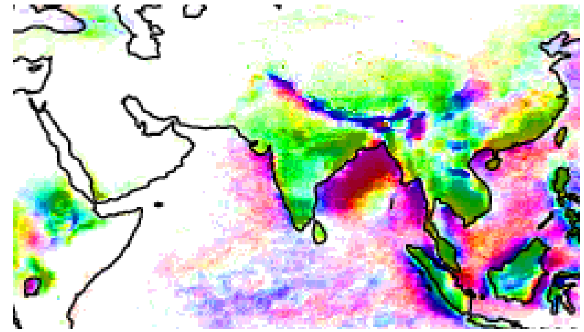


T31 (3.8°)



Diurnal cycle of precip shows some improvement with resolution

Thanks to Rich Neale



TRMM 3B42 (0.25°)

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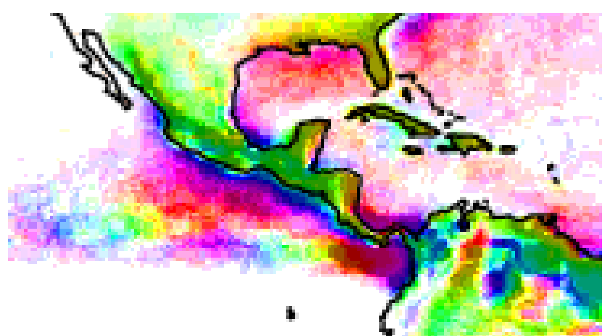
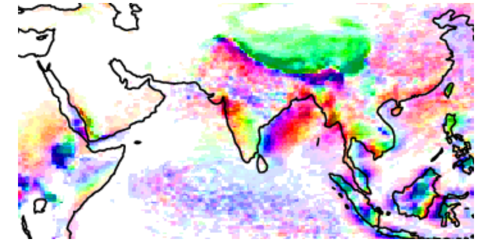
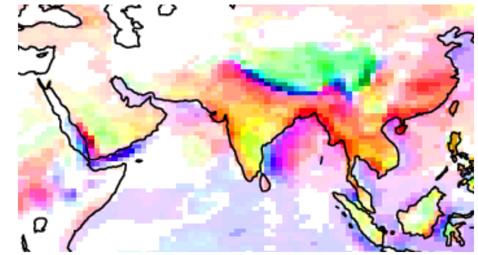


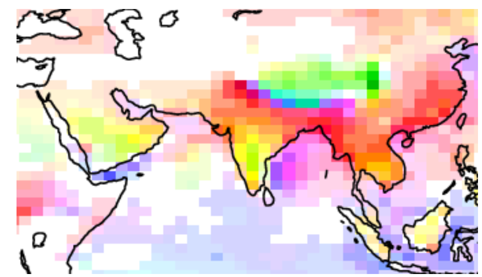
0.25°



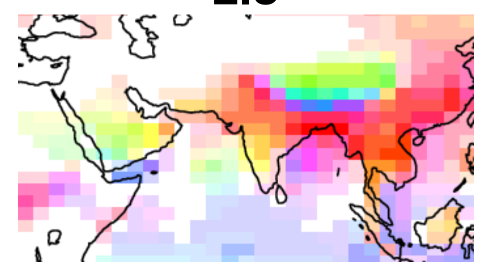
1°



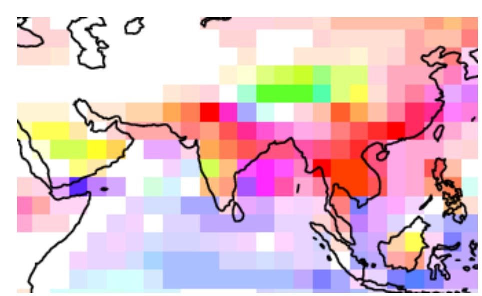
2°



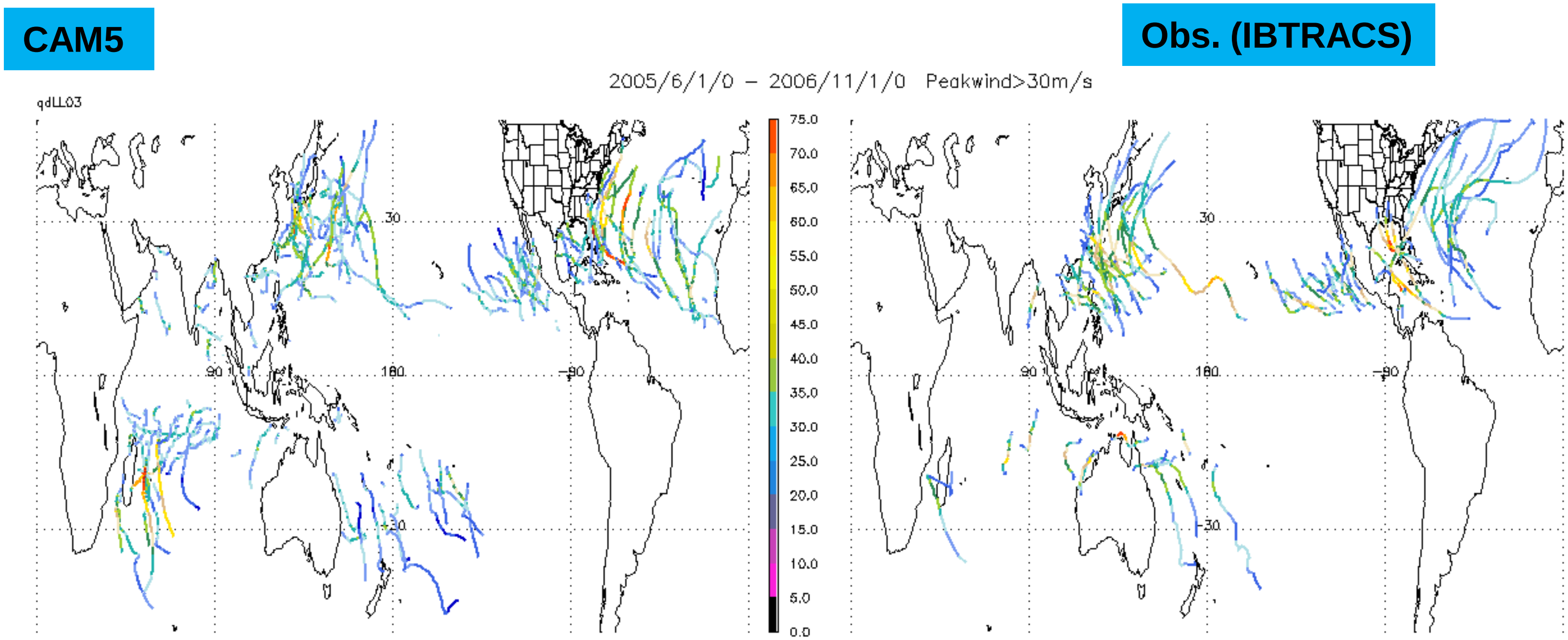
2.5°

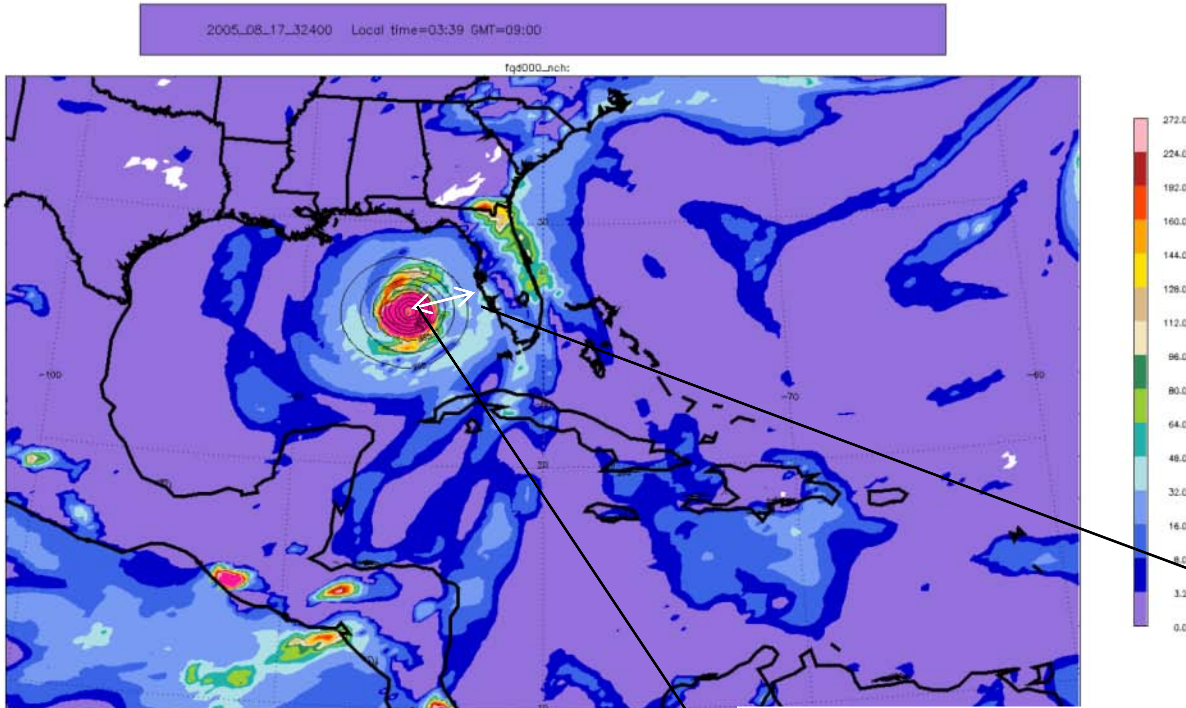


T31 (3.8°)



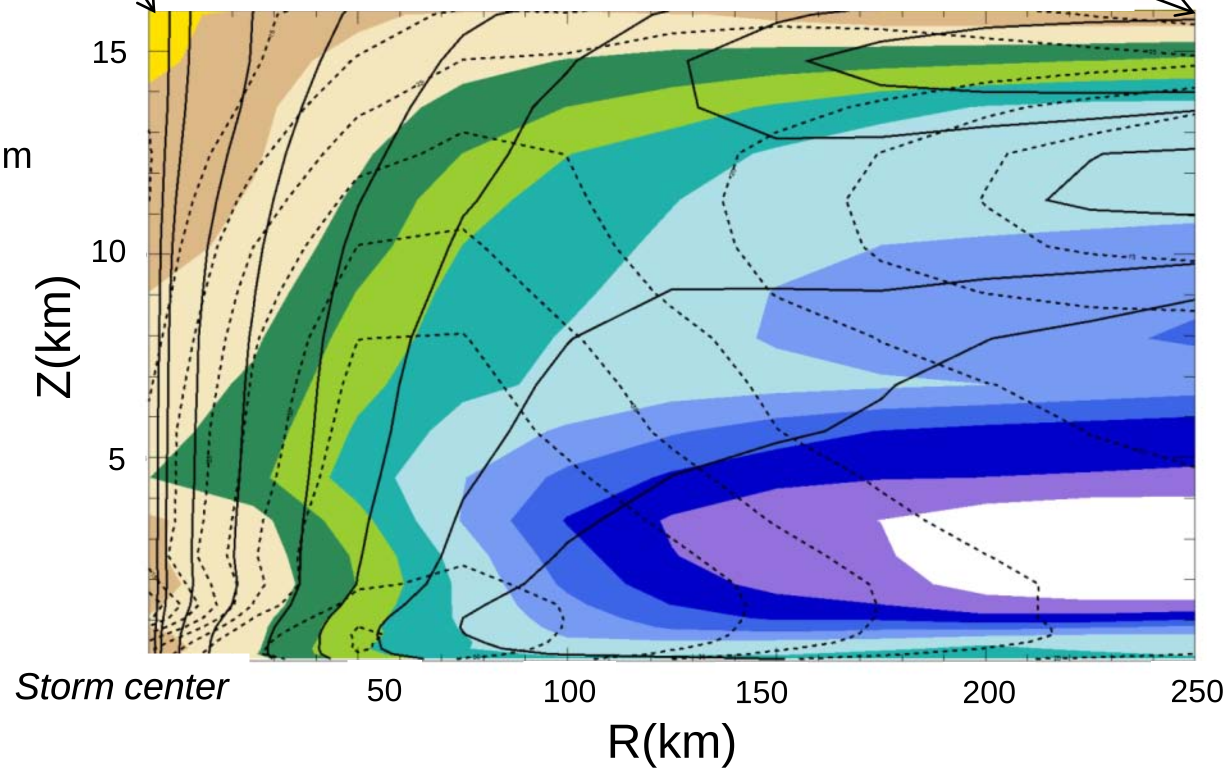
All storms June 1,2005 to November 1 2006





930 hPa, 60+ ms^{-1}

Azimuthal means of *s*, *V* and angular mom.



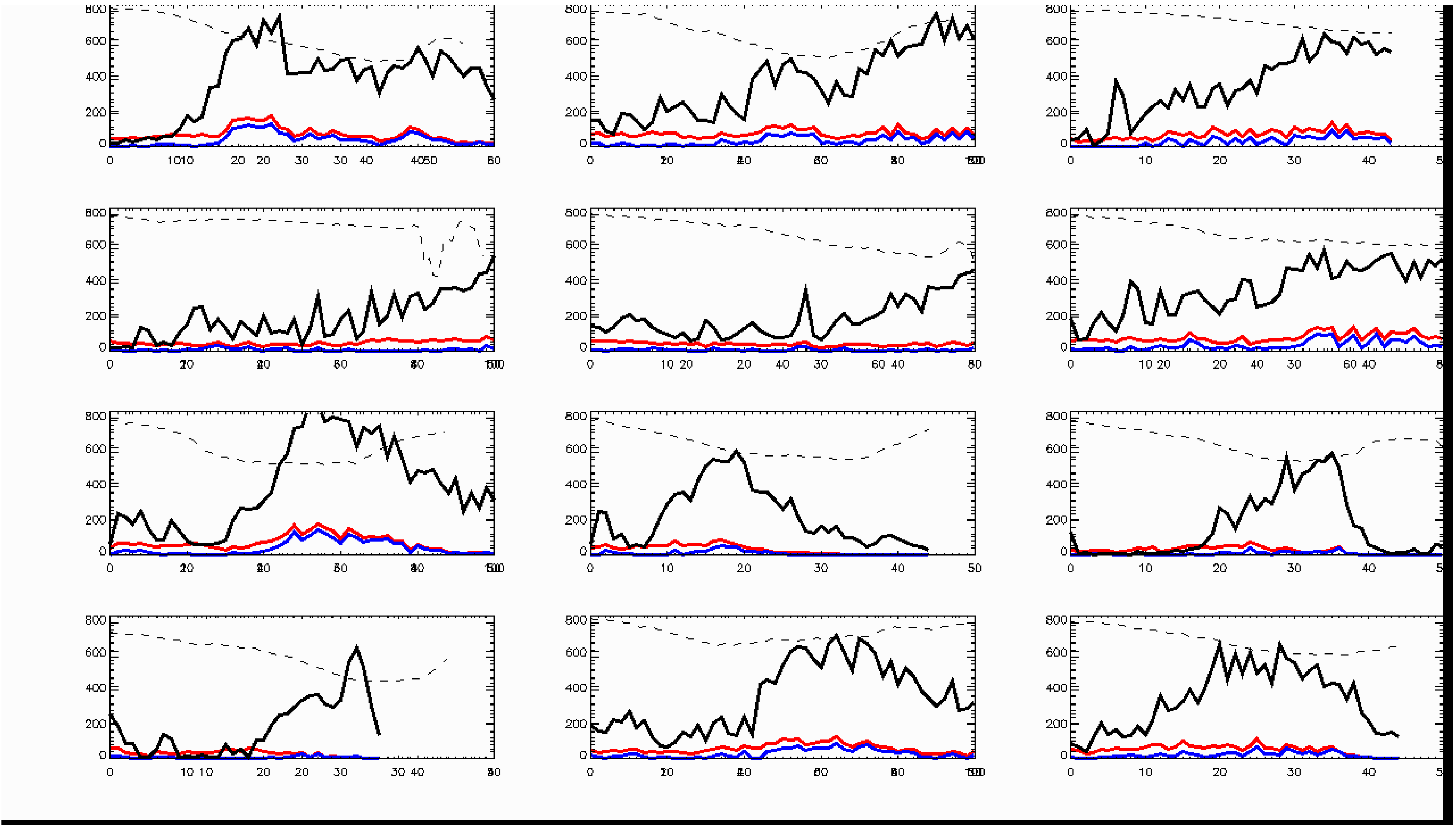
Shading - moist entropy *s;*
solid contours - angular momentum
dashed contours – wind speed *V*

$$s = c_p \log(T) - R\log(p) + \frac{Lq}{T}$$

(e.g. Emanuel, 2003)

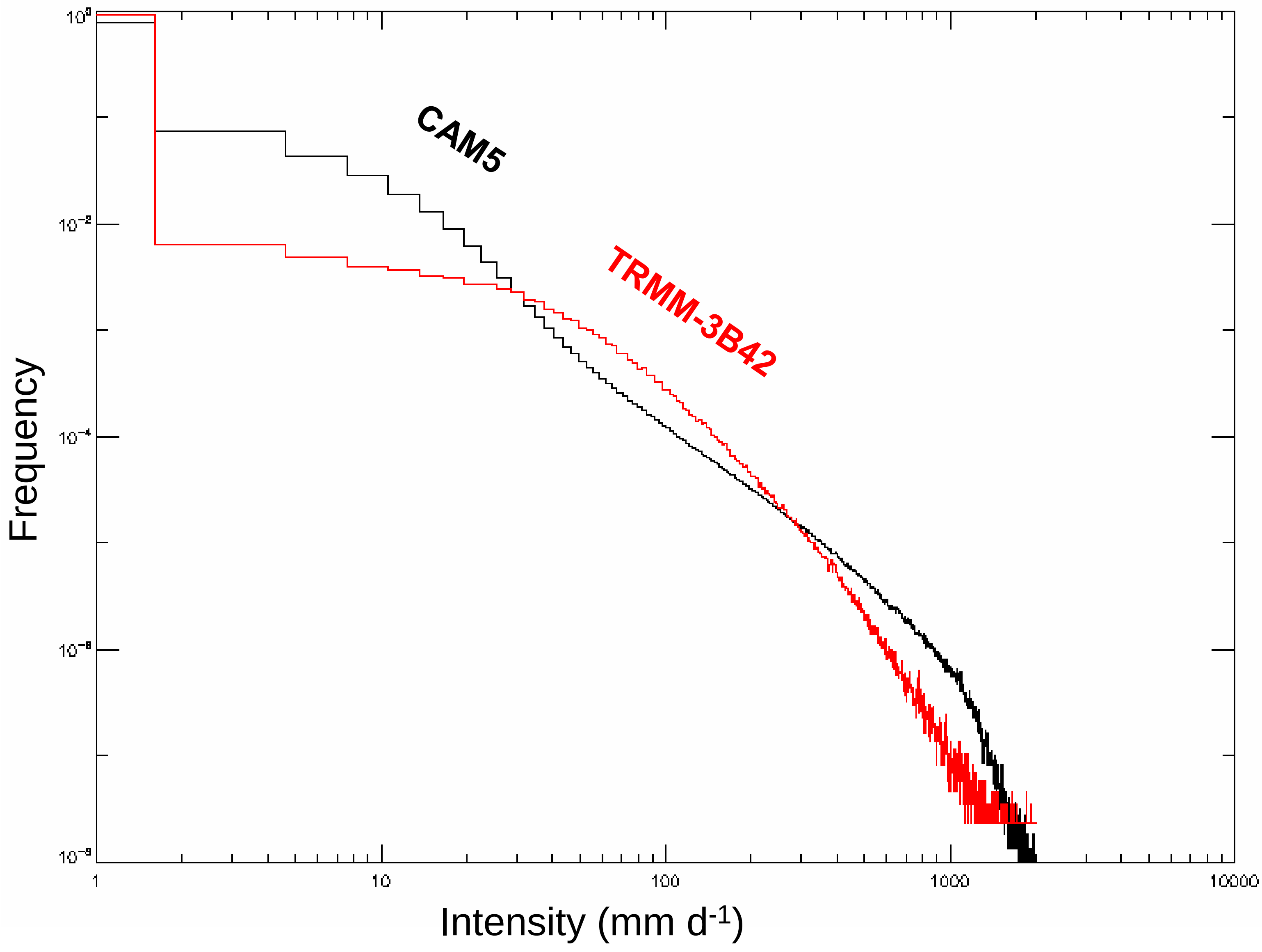
Large-scale rain dominates in cores of intense simulated cyclones

Large-scale, **total convective**, **shallow convective** rain
$(50km)^2$ average along tracks of top 12 storms from CAM5



Precipitation Intensity Distributions and Extremes

PDFs of tropical precipitation (30S-30N) rates Aug 2005



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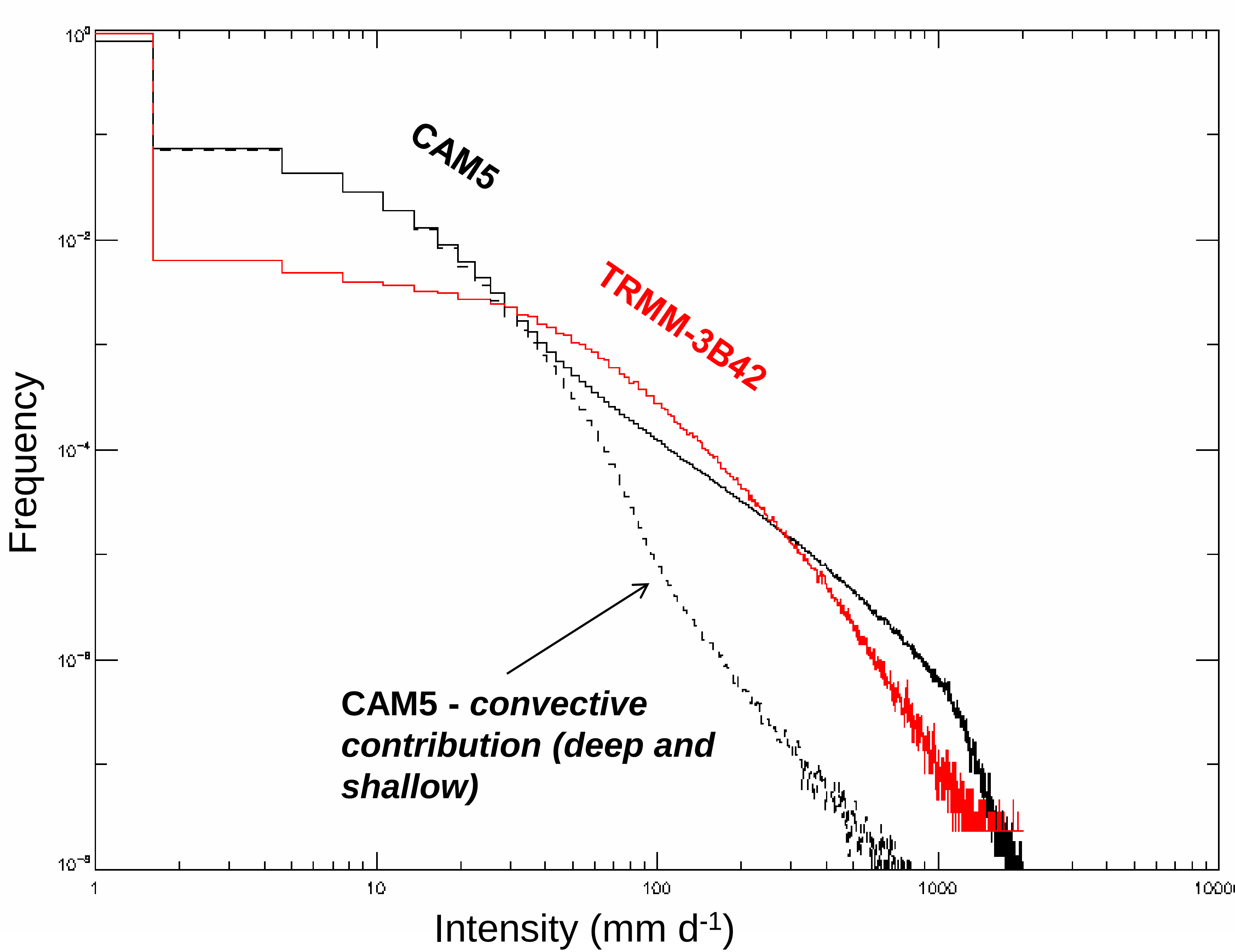

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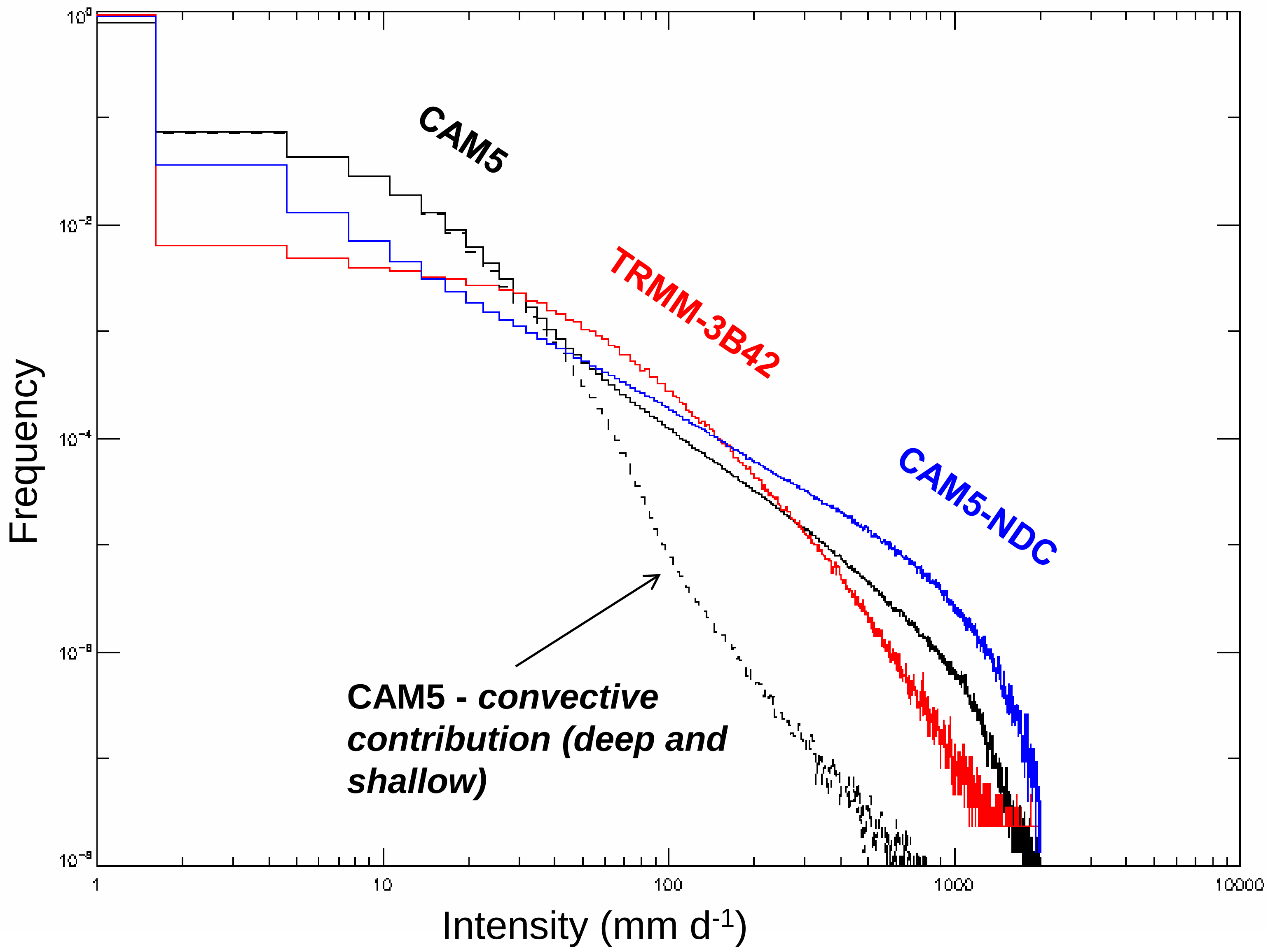

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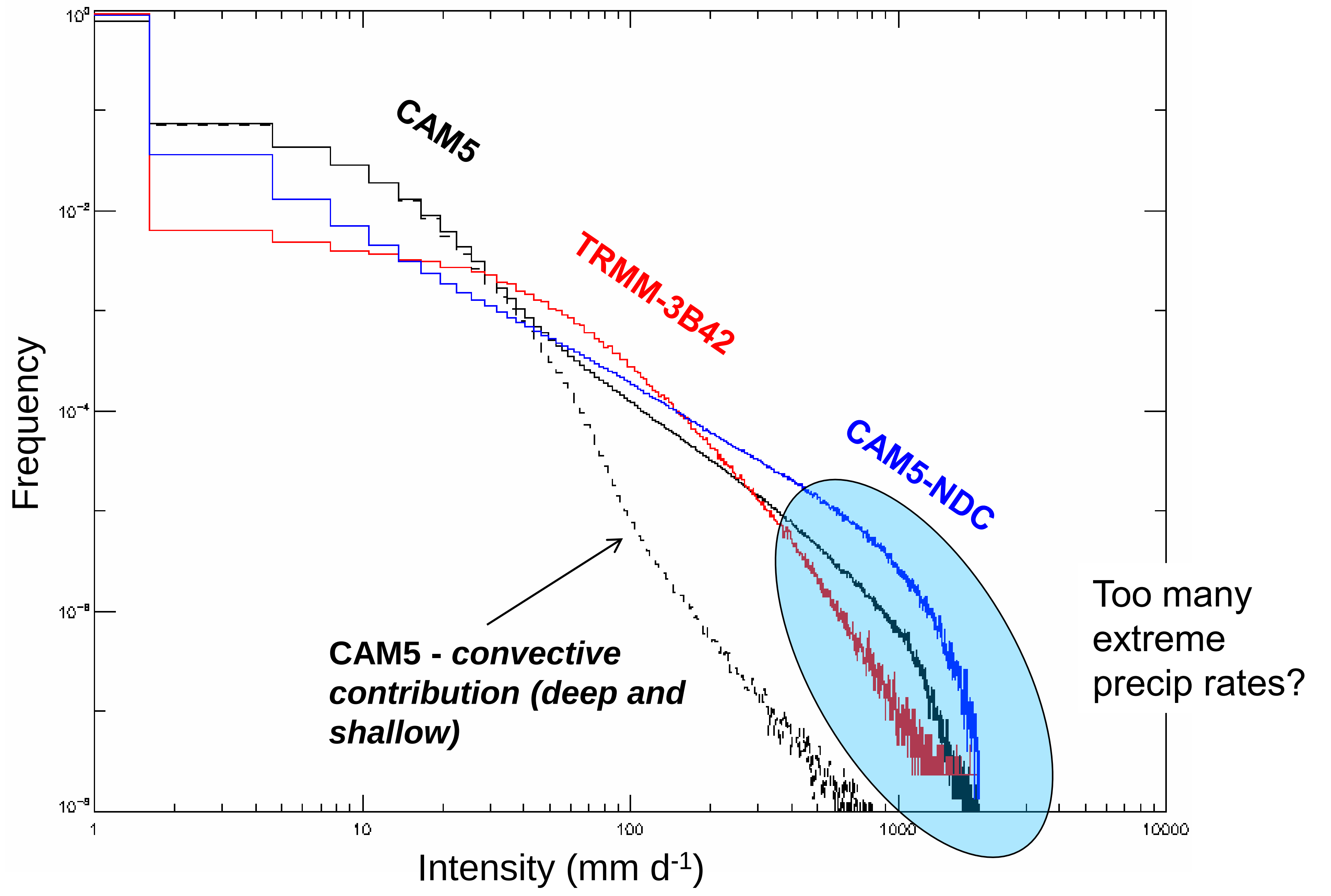
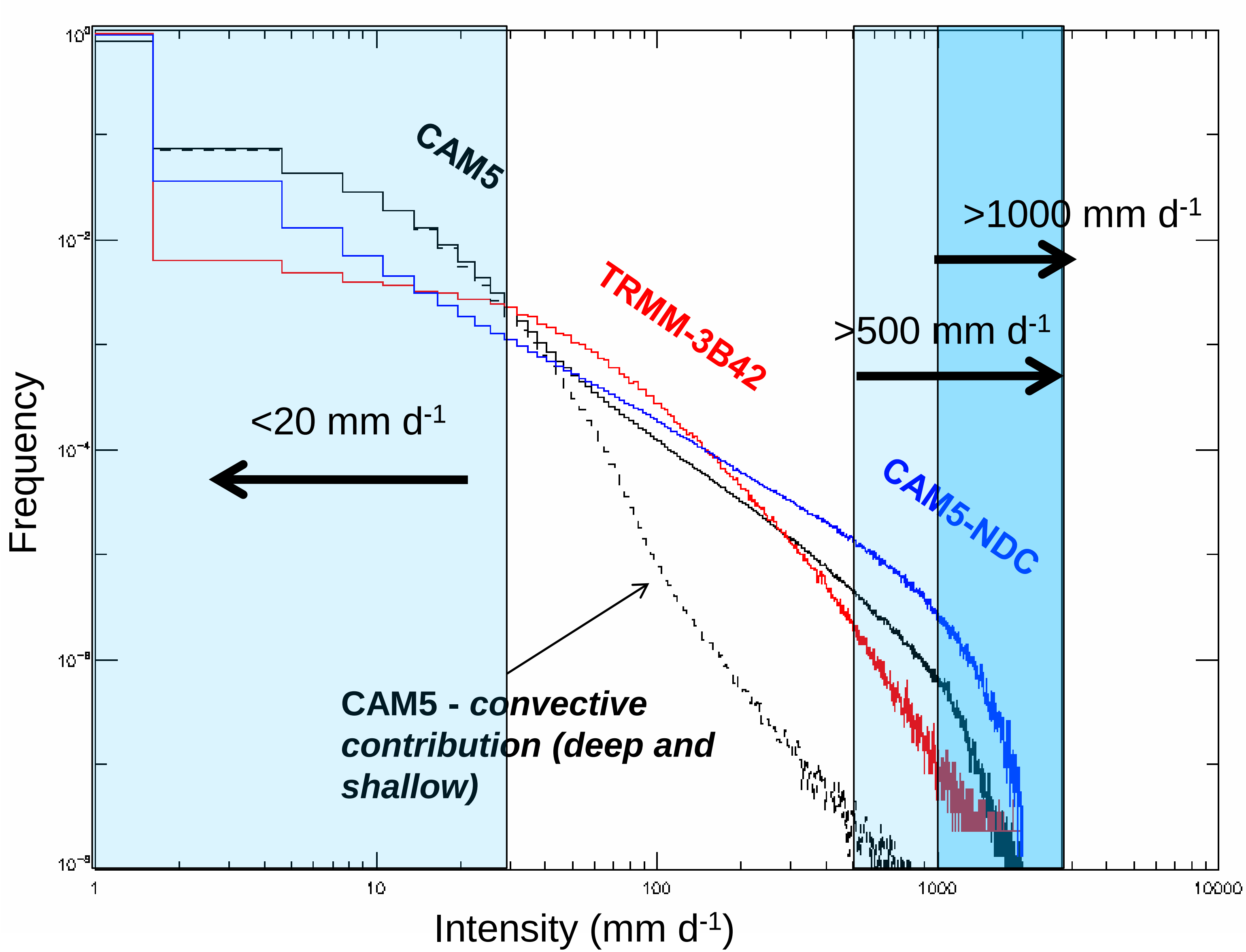
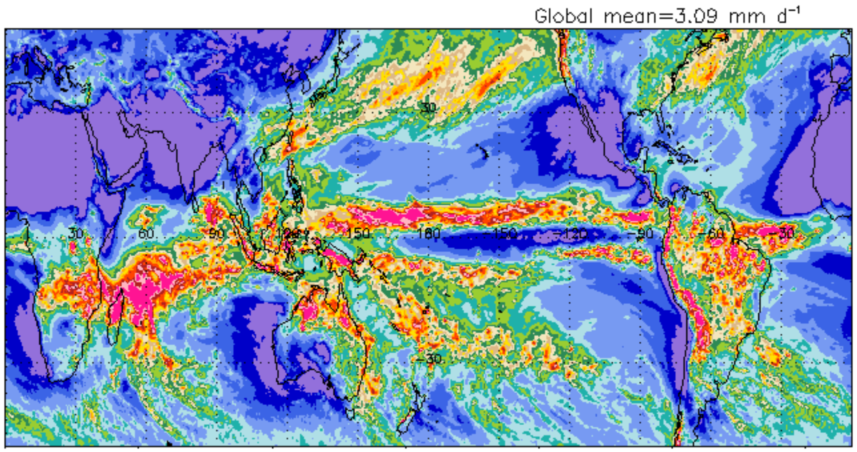


PDFs of tropical precipitation (30S-30N) rates Aug 2005

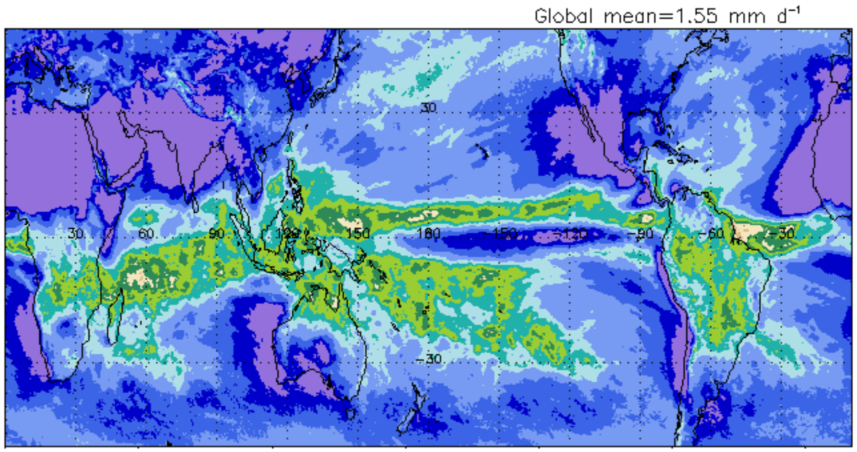


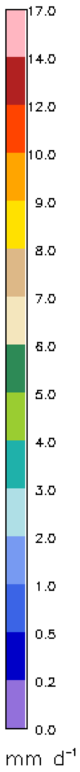
CAM5

ALL

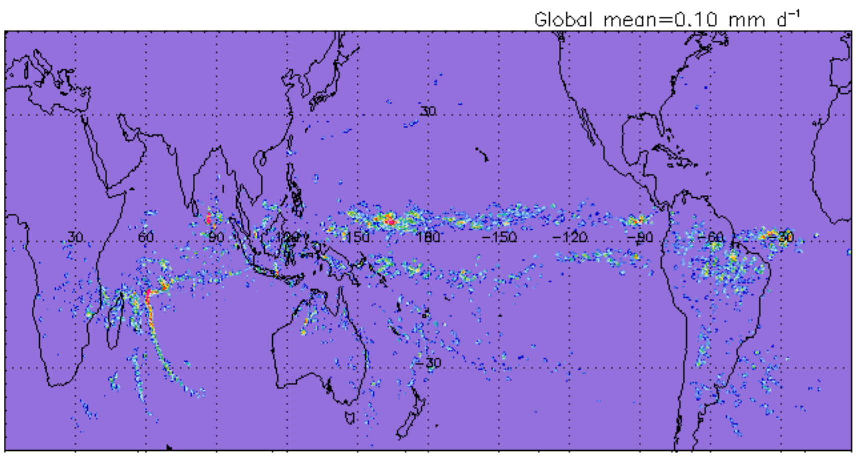


<20 mm d-1

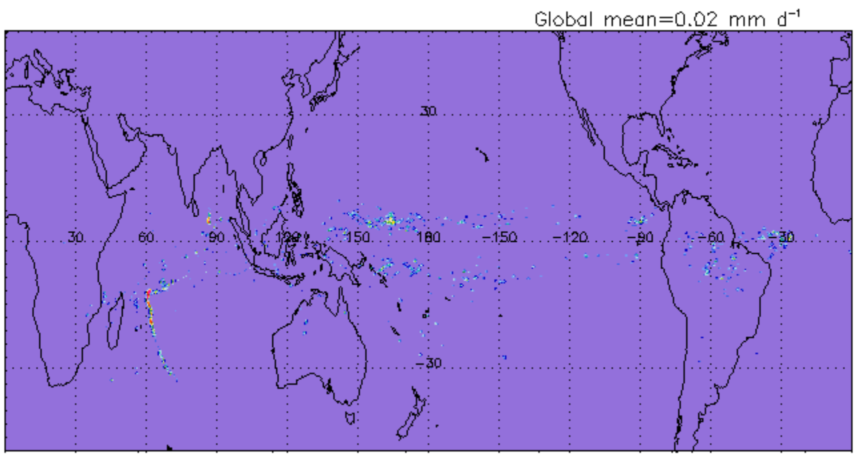




>500 mm d-1

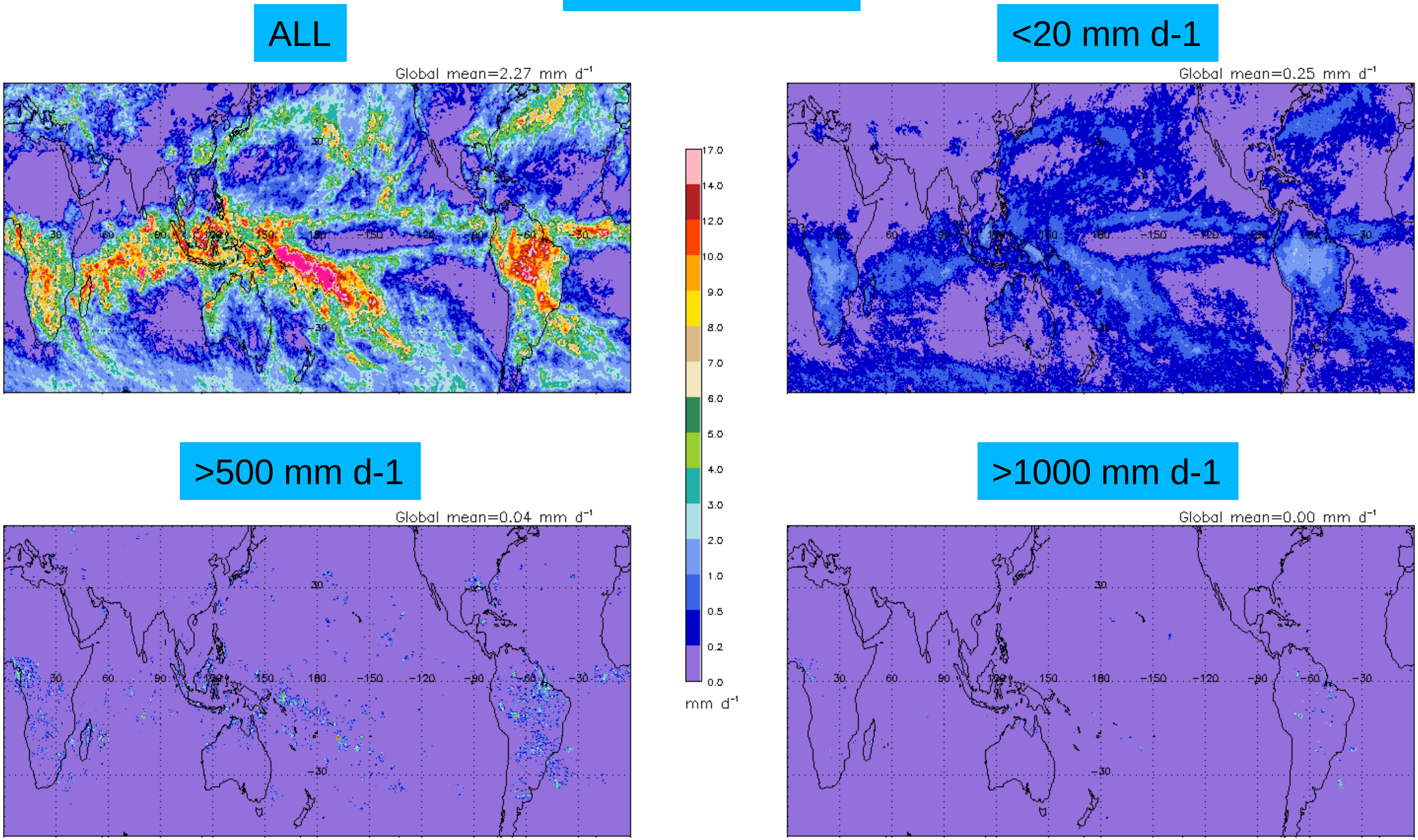


>1000 mm d-1



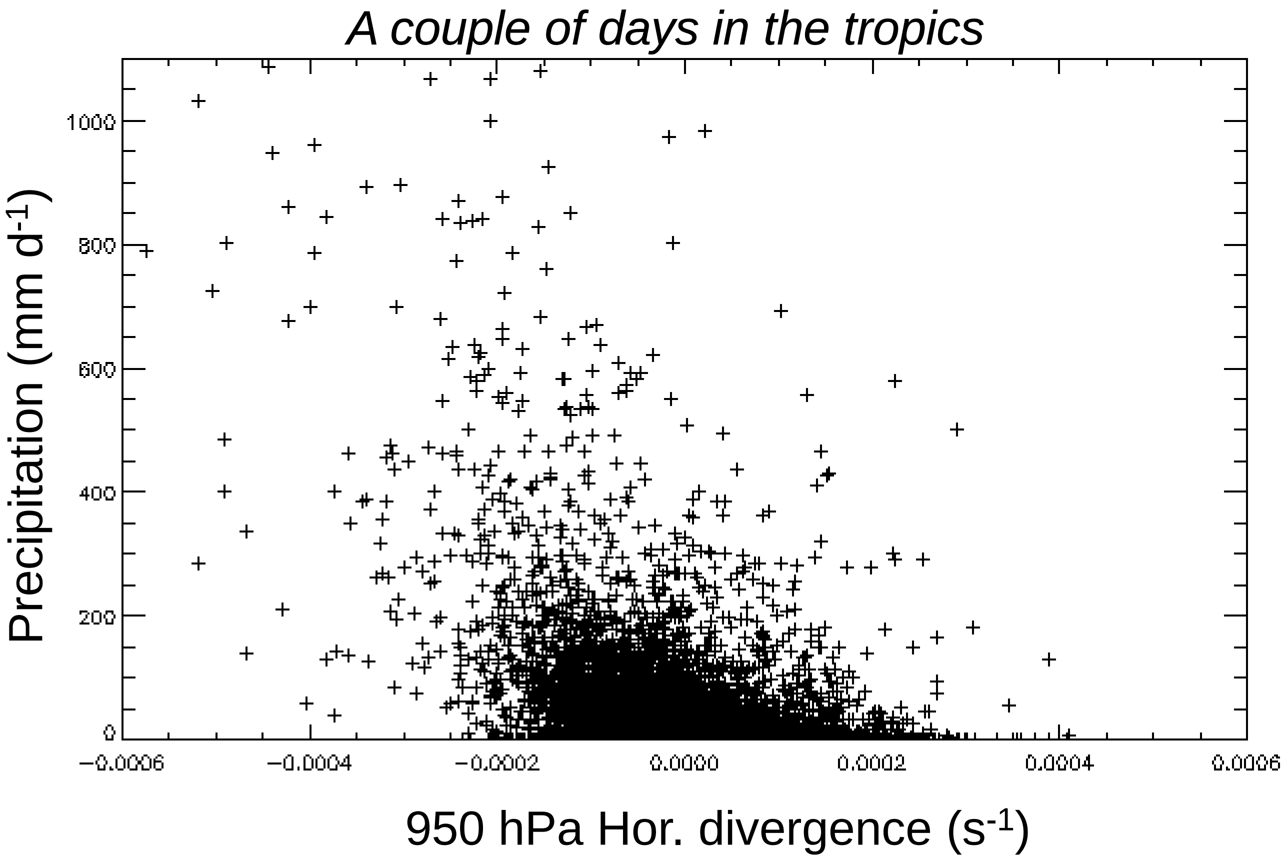
CAM5a February 2006

TRMM 3B42



TRMM 3B42 February 2006

Instantaneous precipitation rates are related to instantaneous convergence

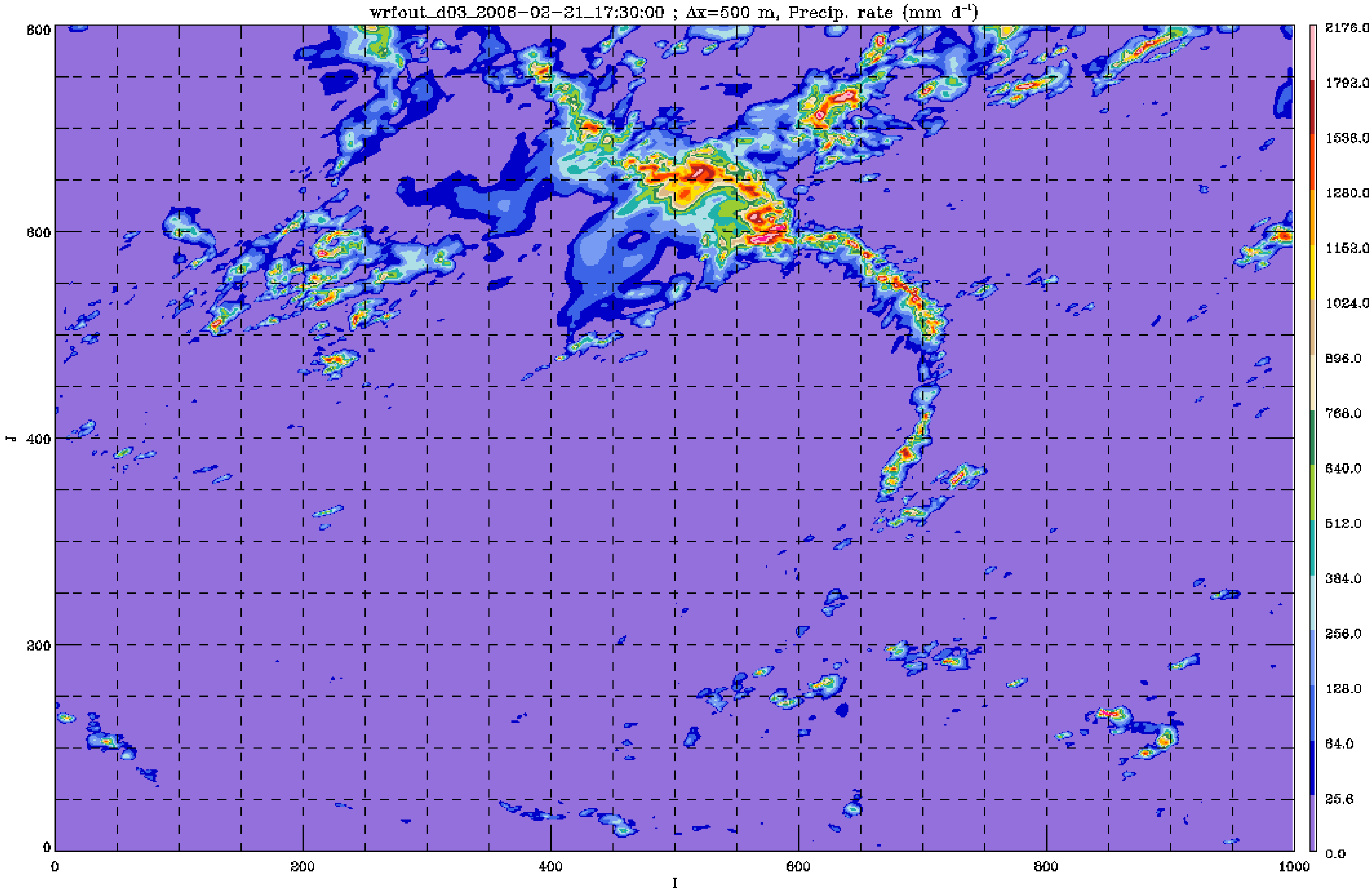


Pressure in a non-hydrostatic WRF experiment

Effects of condensate loading

(WRF results provided by Aiguo Dai)

15-min average precipitation rate (*Hong and Lim 2006 microphysics*)



Dashed lines show 50x50 gp (25km x 25km) squares used to coarse grain WRF fields to produce “high-res AGCM” fields

Hydrostatic Balance w/ and w/out condensate loading

$$\pi_{hyd} = \int_{z}^{z_{top}} \frac{g}{c_p \Theta_{\{v,cond\}}} dz' + \pi_{top}$$

$$p_{hyd} = p_{00}\, \pi_{hyd}^{\;1/\kappa}$$

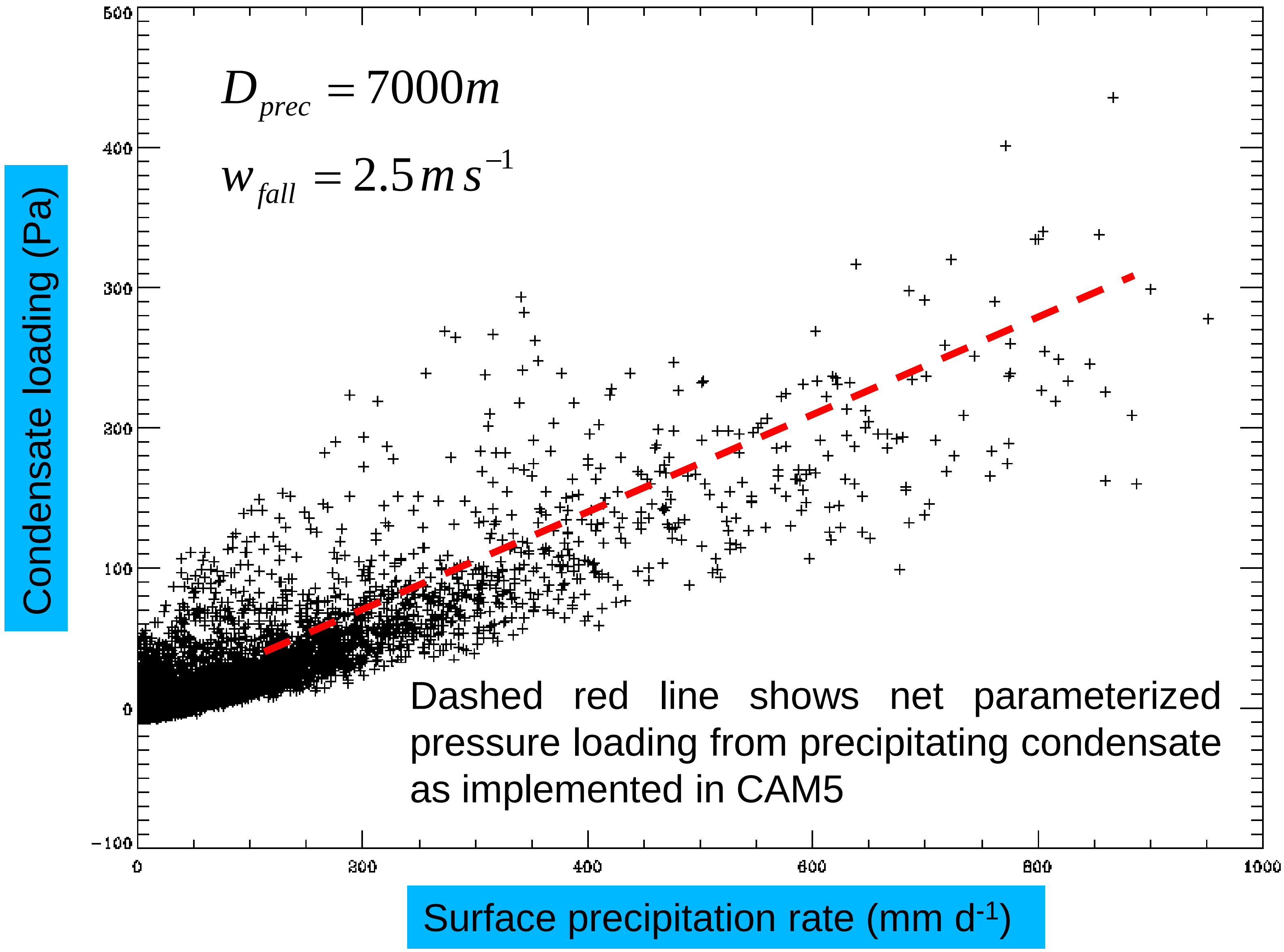
w/out loading:

$$\Theta_v = \Theta(1. + 0.61q)$$

with loading:

$$\Theta_{cond} = \Theta(1. + 0.61q - q_{liq} - q_{ice} - q_{rain} - q_{graup} - q_{snow})$$

Net loading at surface (in Pa) as a function of surface precipitation rate



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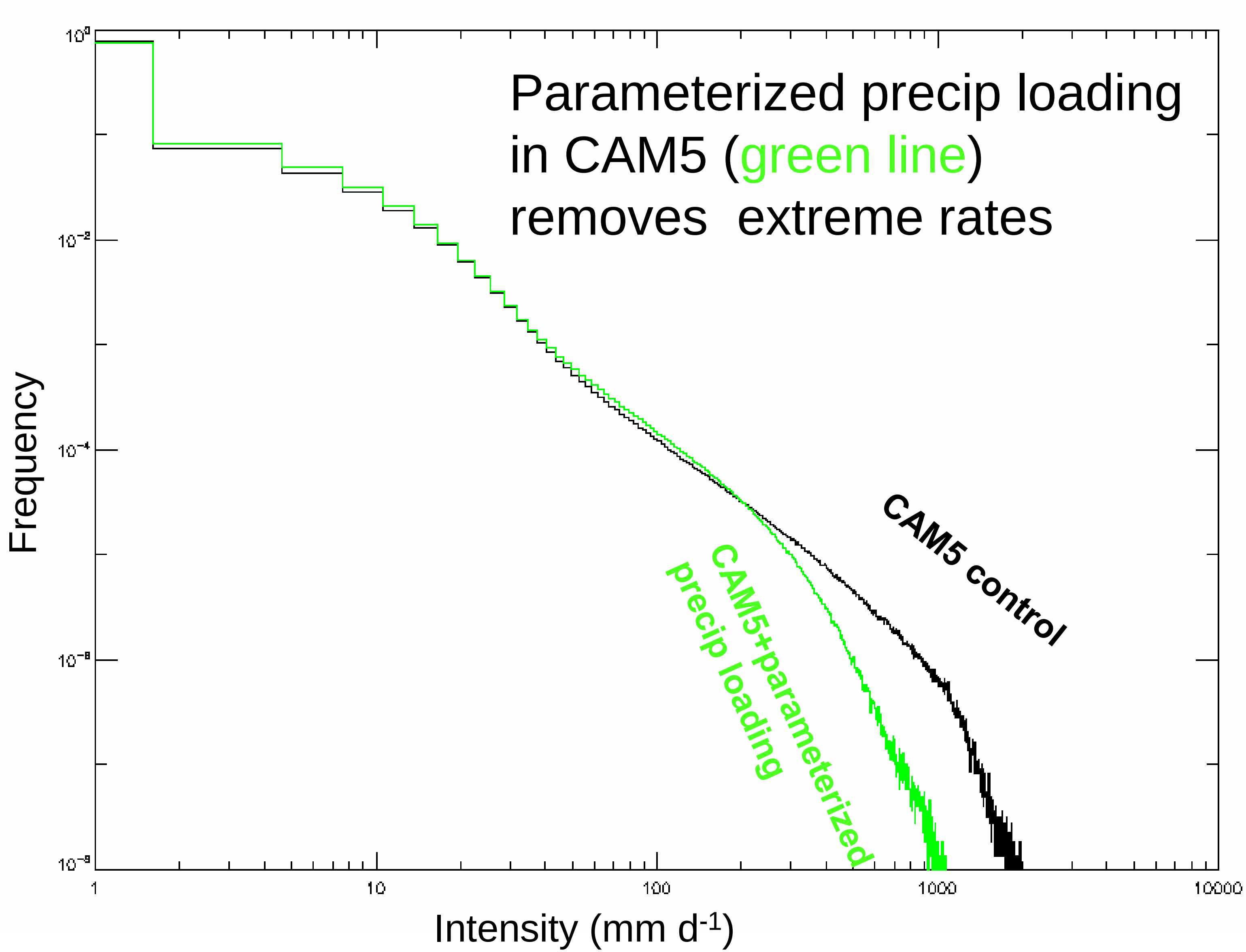
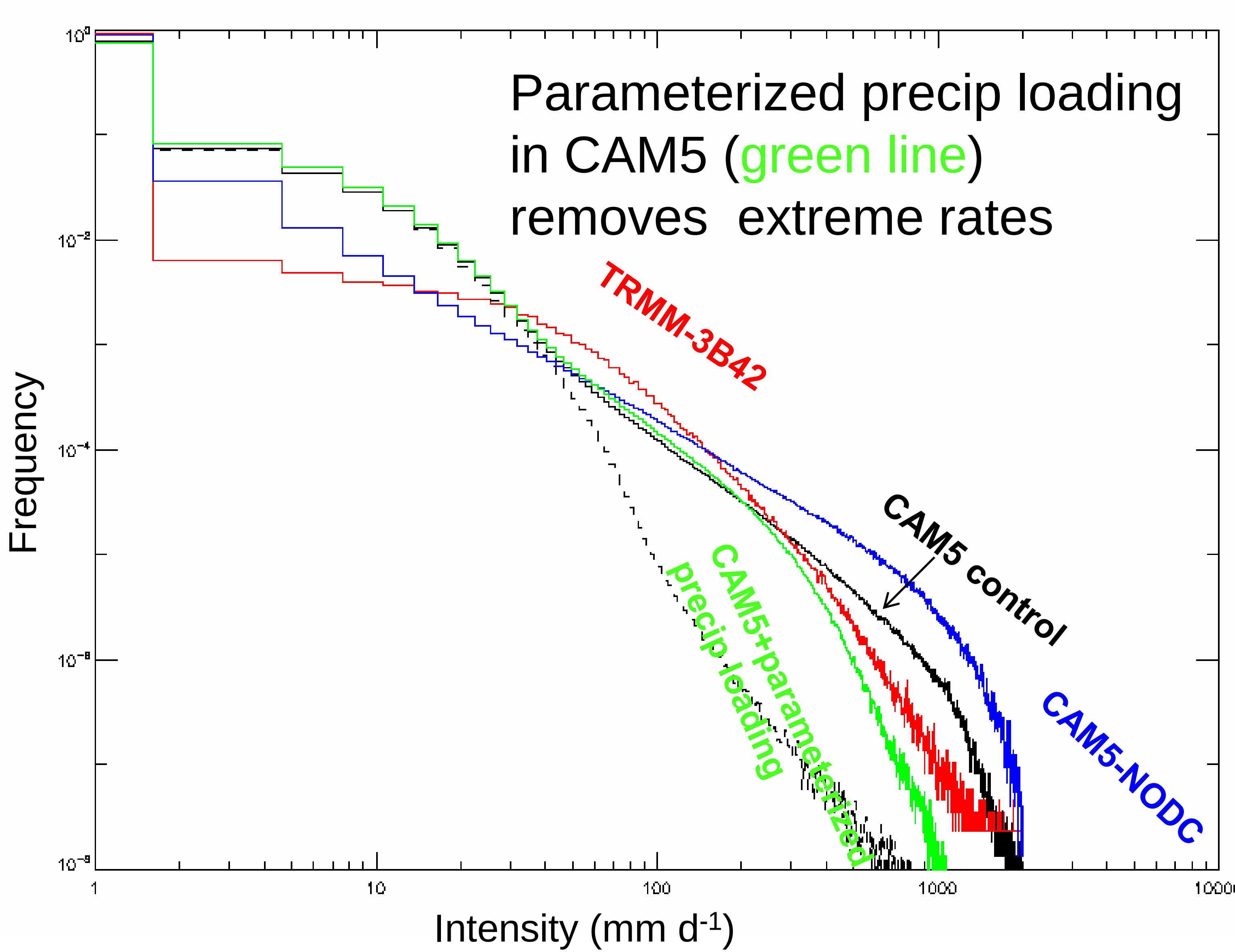
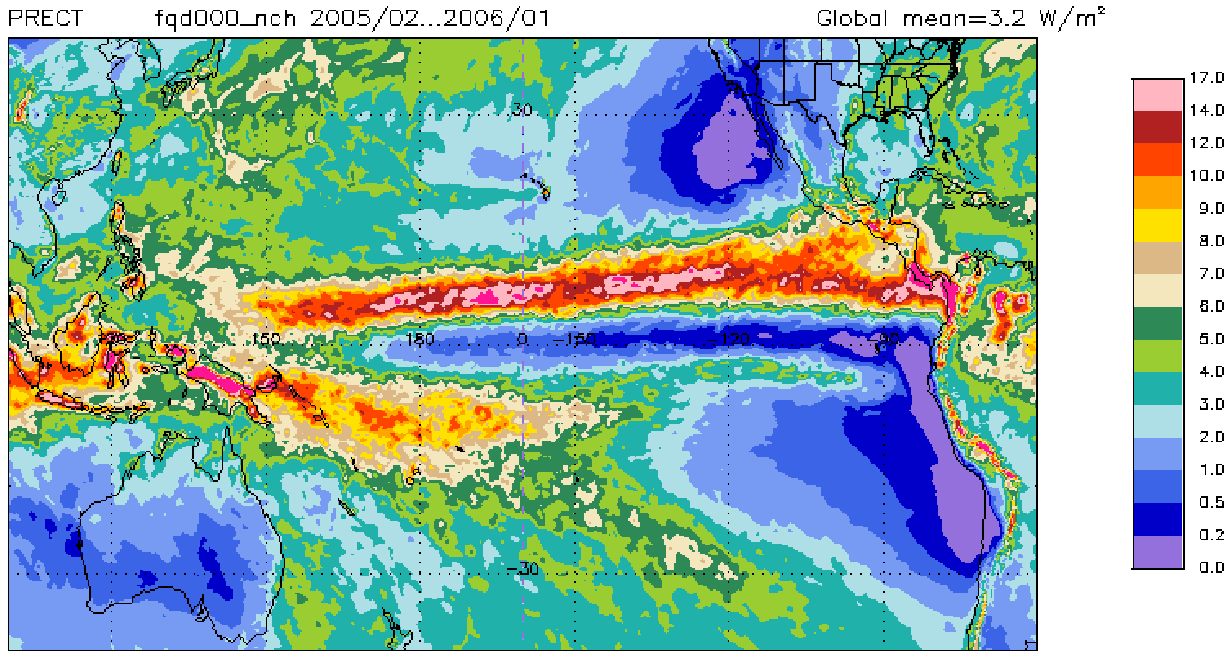


PDFs of tropical precipitation (30S-30N) rates Aug 2005

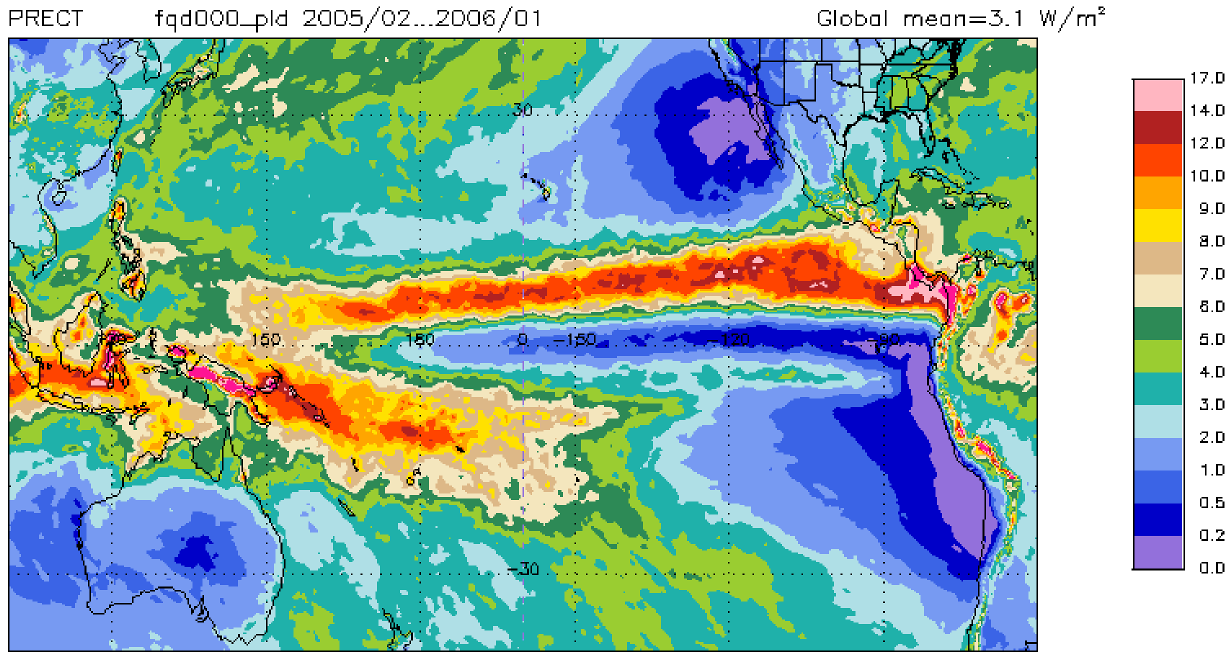


Annual mean precipitation

CAM5 control



w/ parameterized precipitation loading



Bad news: TC number also decreases

Summary

CAM5 clouds somewhat less sensitive to resolution. CAM4 counterintuitively produces more fractions ~1 at low resolution than at high resolution.

In terms of climate means and statistics, impact of high resolution is mixed.

-some biases worsen, *e.g., Pacific ITCZs*

-some improve*: SE US precip, diurnal cycles in some regions*

Summary (cont.)

-Encouraging tropical cyclone climatologies and structures with CAM5 at 0.23x0.31 *(Note: large-scale rain rather than convective appears to dominate tropical cyclone dynamics)*

-Extreme precipitation (>500 mm d^{-1} at 25^2 km^2) events are probably too common. Parameterized condensate loading seems to help

➔ Climate models at high-resolution may not be able to postpone adding consistent prognostic precipitation, including pressure effects

More important than adding non-hydrostatic effects.

"Middling" precip (5-20 mm d^{-1}) is also too common – *directly produced by convective parameterization(s)*

Future Work

Add correct condensate loading along with prognostic precipitation to CAM *(might need extra convective treatment)*

Longer CAM5 integrations (with prescribed MAM?)

Compare CAM4 and CAM5 TC climatologies

THANK YOU

The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

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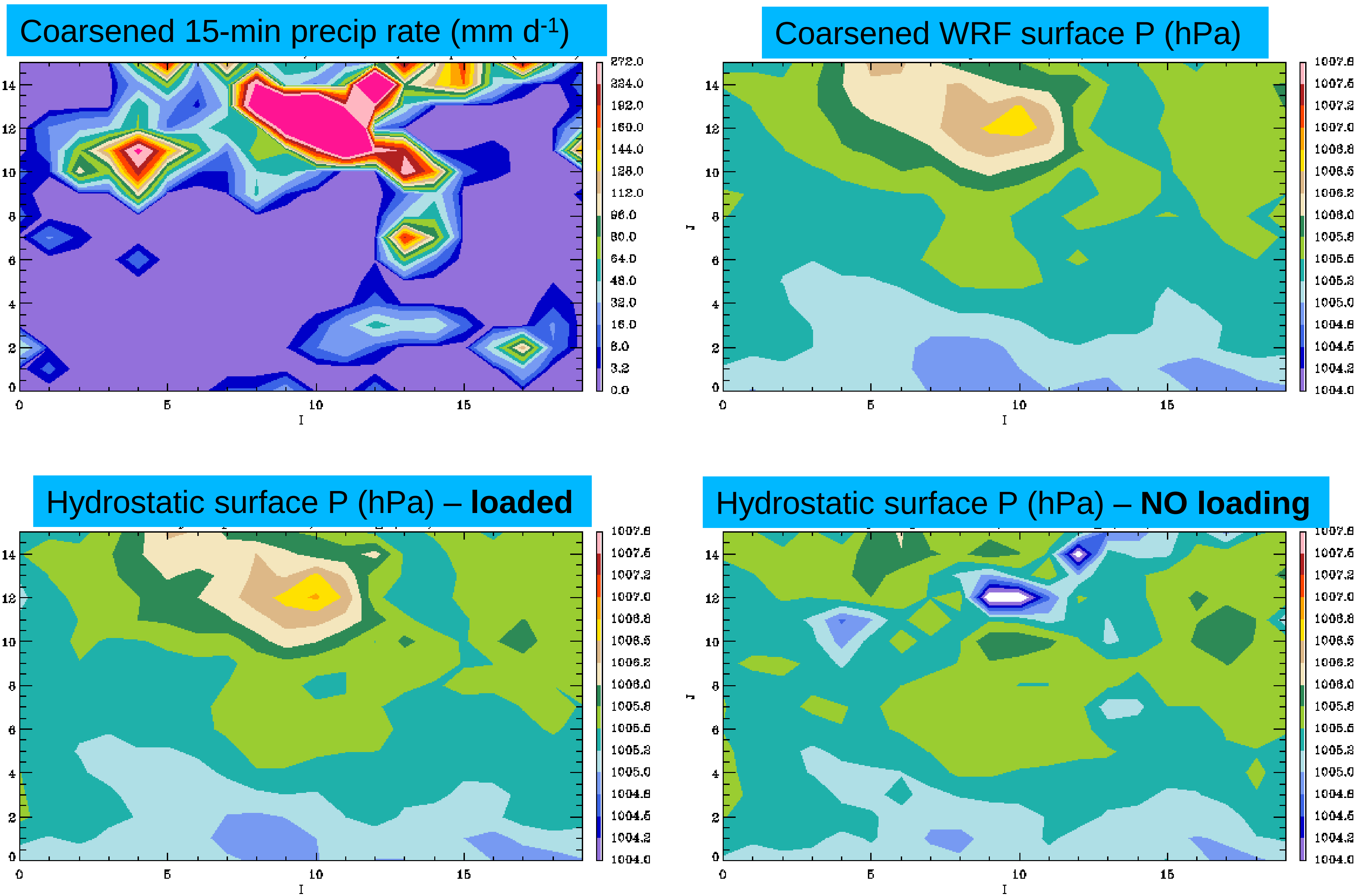
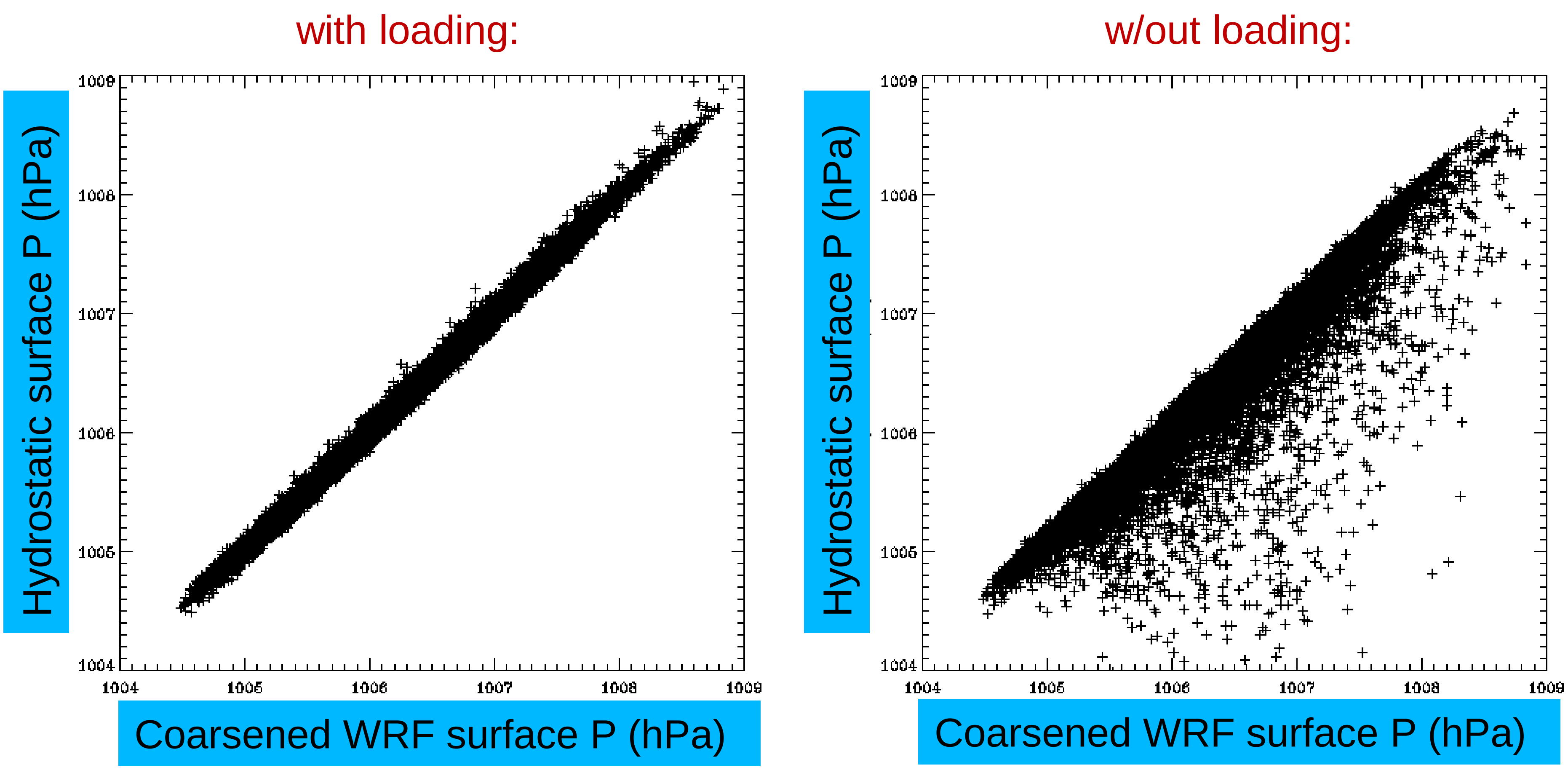


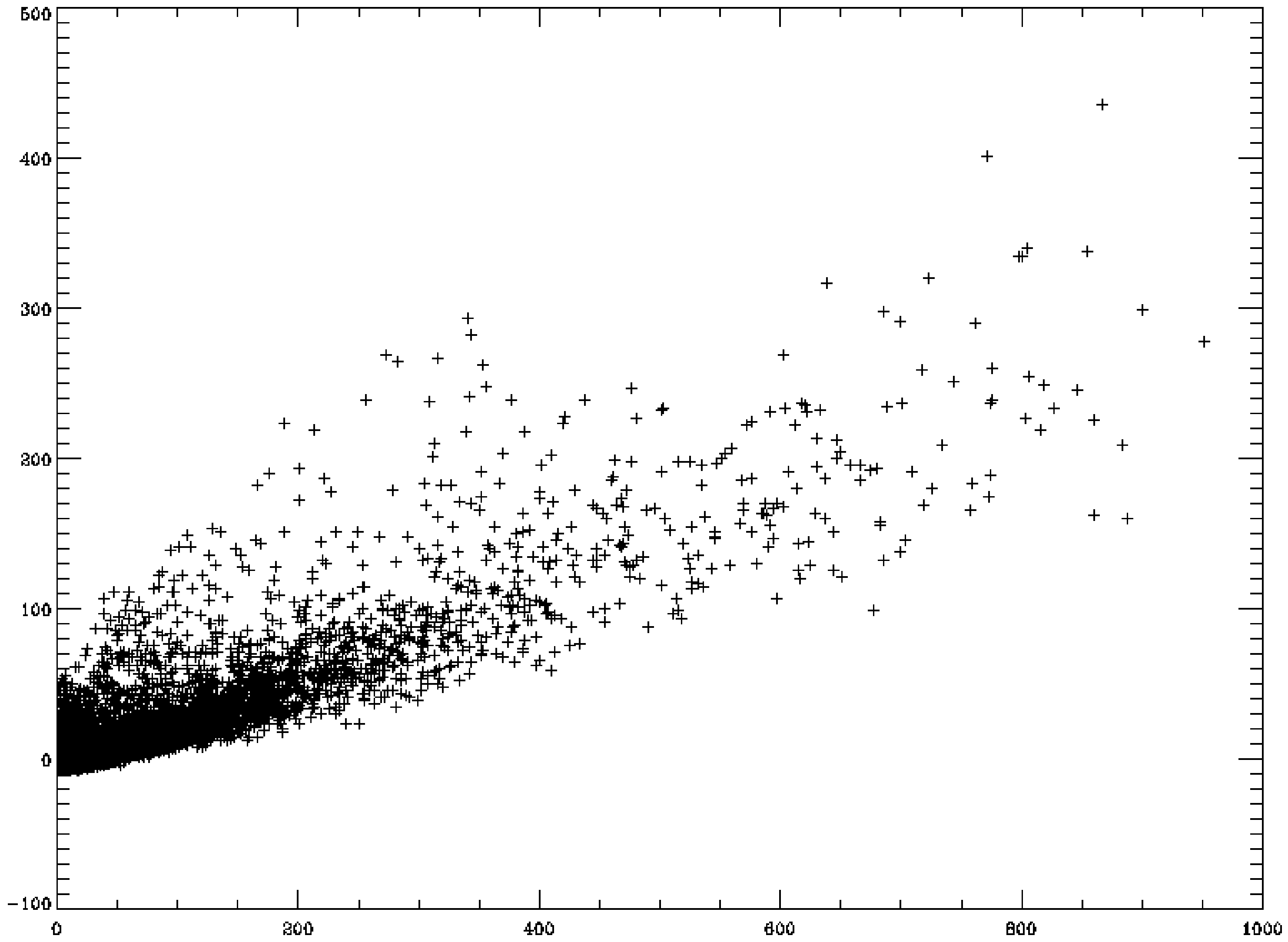
Coarsened 15-min precip rate (mm d^{-1})
272.0
224.0
192.0
160.0
144.0
128.0
112.0
96.0
80.0
64.0
48.0
32.0
16.0
8.0
3.2
0.0
Coarsened WRF surface P (hPa)
Hydrostatic surface P (hPa) – **loaded**
Hydrostatic surface P (hPa) – **NO loading**
1007.8
1007.5
1007.2
1007.0
1006.8
1006.5
1006.2
1006.0
1005.8
1005.5
1005.2
1005.0
1004.8
1004.5
1004.2
1004.0
I
J

Diagnosed hydrostatic surface pressure with and without condensate loading vs. coarse grained WRF surface pressure



Condensate loading matters – even in (25 km)^2 grid boxes

Net loading at surface (in Pa) as a function of surface precipitation rate



Condensate loading (Pa)

Surface precipitation rate (mm d^{-1})

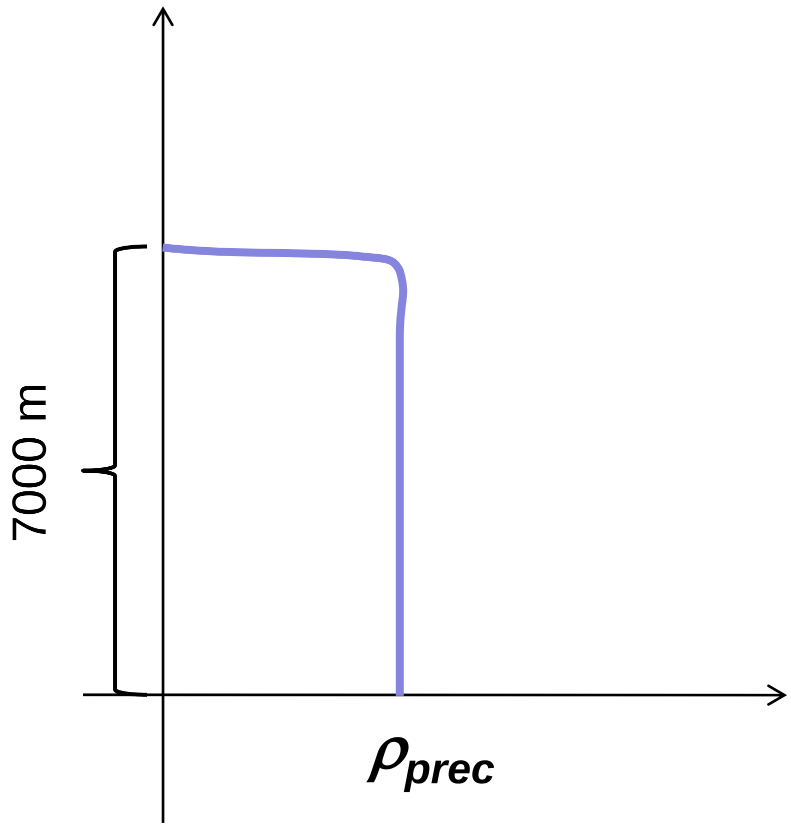
Parameterized precipitation loading

surface precip rate $\Re_{surf}$ *used to diagnose precipitating condensate density* ρ_{prec}

$$for \quad z < 7000m$$

$$\rho_{prec}(x,y,z,t) = \frac{\Re_{surf}(x,y,t)}{w_{fall}}$$

$$p_{prec}(x,y,z,t) = \int_{z}^{7000m} g\rho_{prec}\, dz'$$



Extra condensate pressure is added to “real” model pressure right before horizontal gradients are calculated, then removed