Parameterized versus Explicit Convection in Global-Scale Simulations Using the WRF Model in Aquachannel and Aquapatch Configurations

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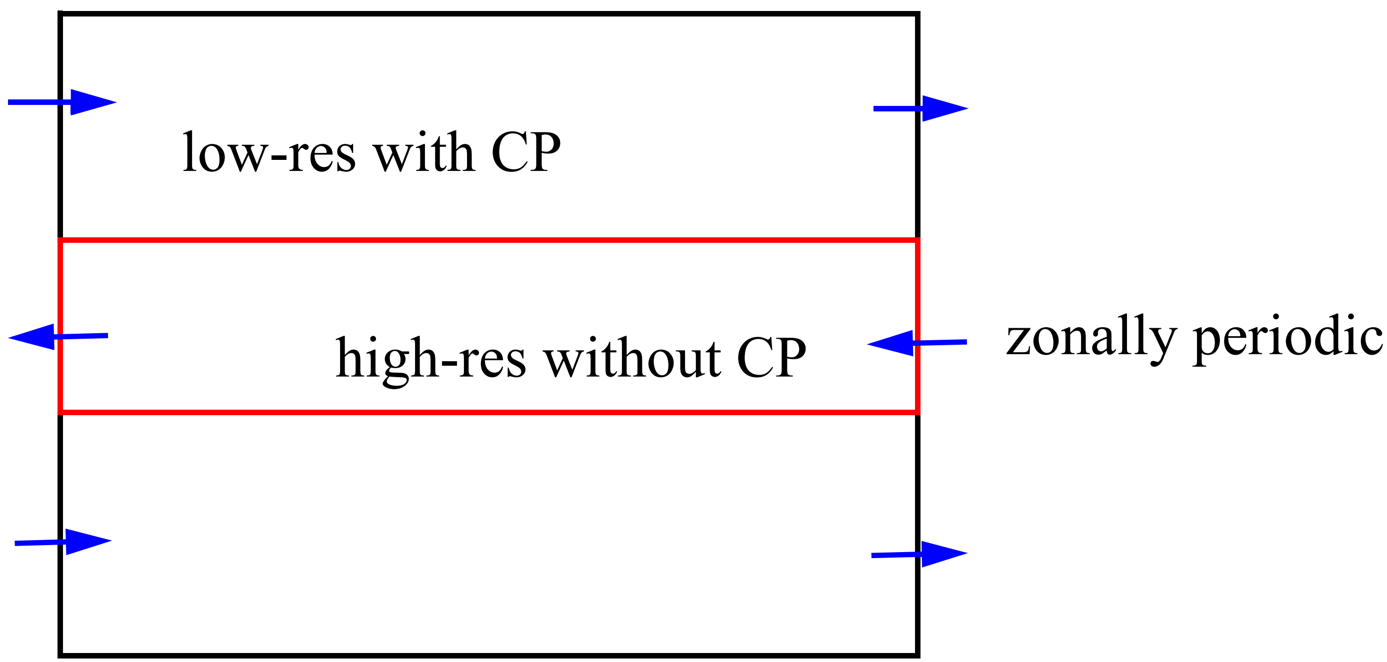
I. Objective

- To identify and understand the biases of tropical convection simulated with cumulus parameterization (CP) by side-by-side comparison to high-resolution simulations without CP.

  And to do so with tolerable computational cost.

- This will be achieved with a "nested channel" configuration of WRF, modified so nested grids can extend across periodic boundaries.



II. The Aquachannel and the Aquapatch

- Will a “tropical channel model” produce mean states and eddies similar to an aquaplanet?

  We compare to the “Aqua-Planet Experiment” simulations (Neale and Hoskins 2001).

- The Aquachannel:

  WRF 3.4.1

  Equatorial beta-plane configuration (no map factors)

  139.05 km grid spacing, 288 x 96 points --> 60S to 60N, length of real equator.

  50 vertical levels up to 26 km.

  Permanent equinox, with diurnal cycle.

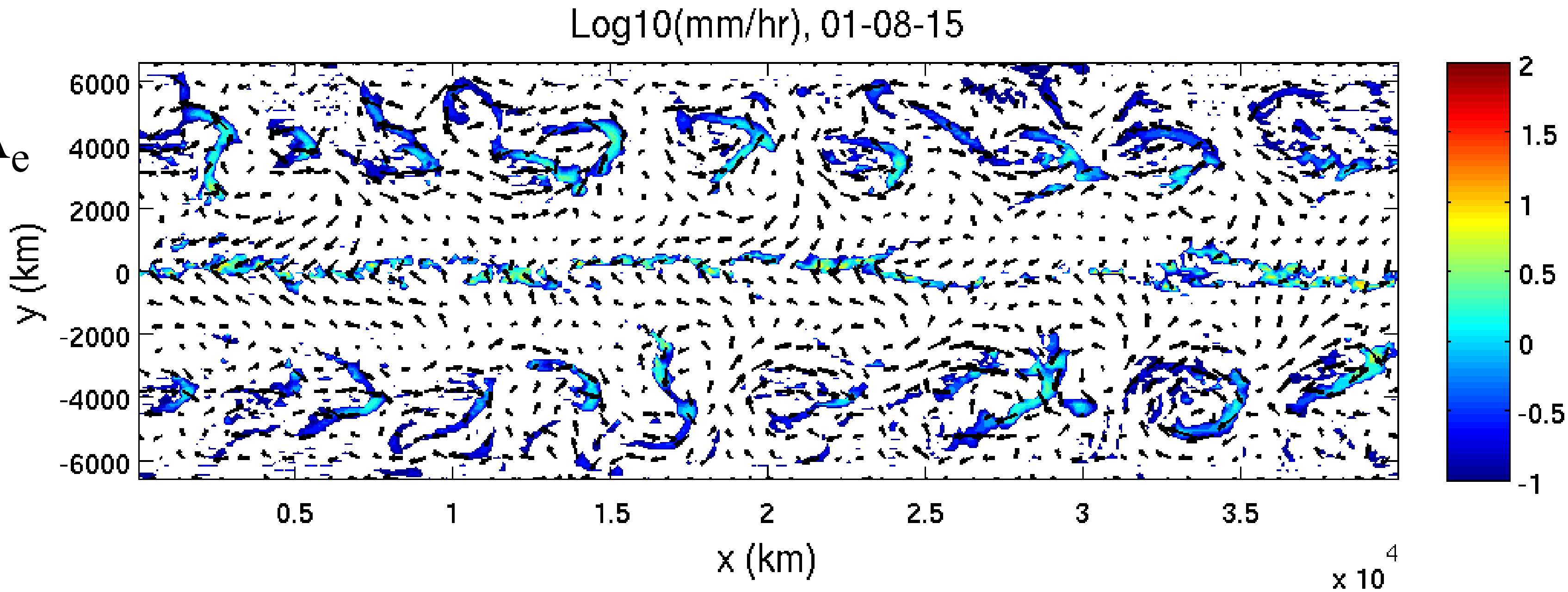
  Modified Tiedtke cumulus parameterization (WRF, Wang et al. 2003, 2007)

  APE “control” SST profile (narrow peak) and “observed” profile (broader).

  12 month spin-up, compute statistics over next 6-12 months.

The Aquachannel

Area
=1.05A_e



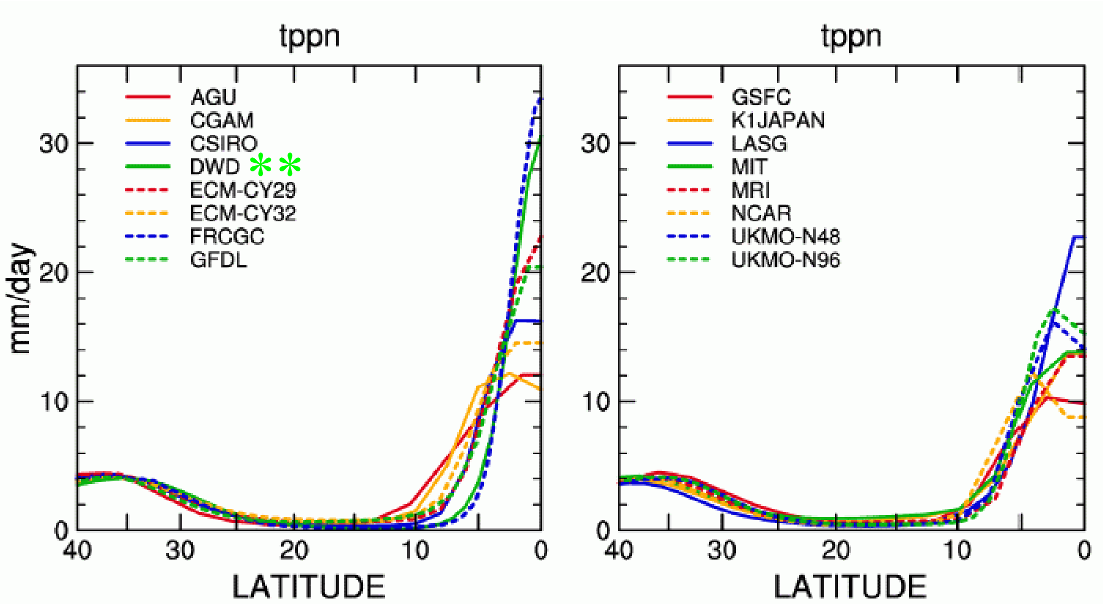
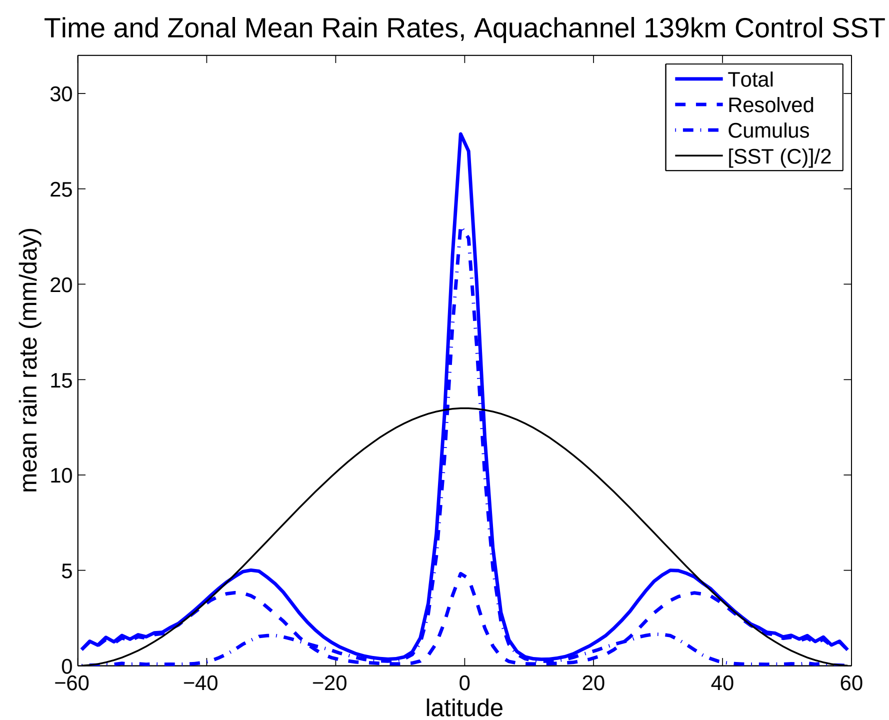
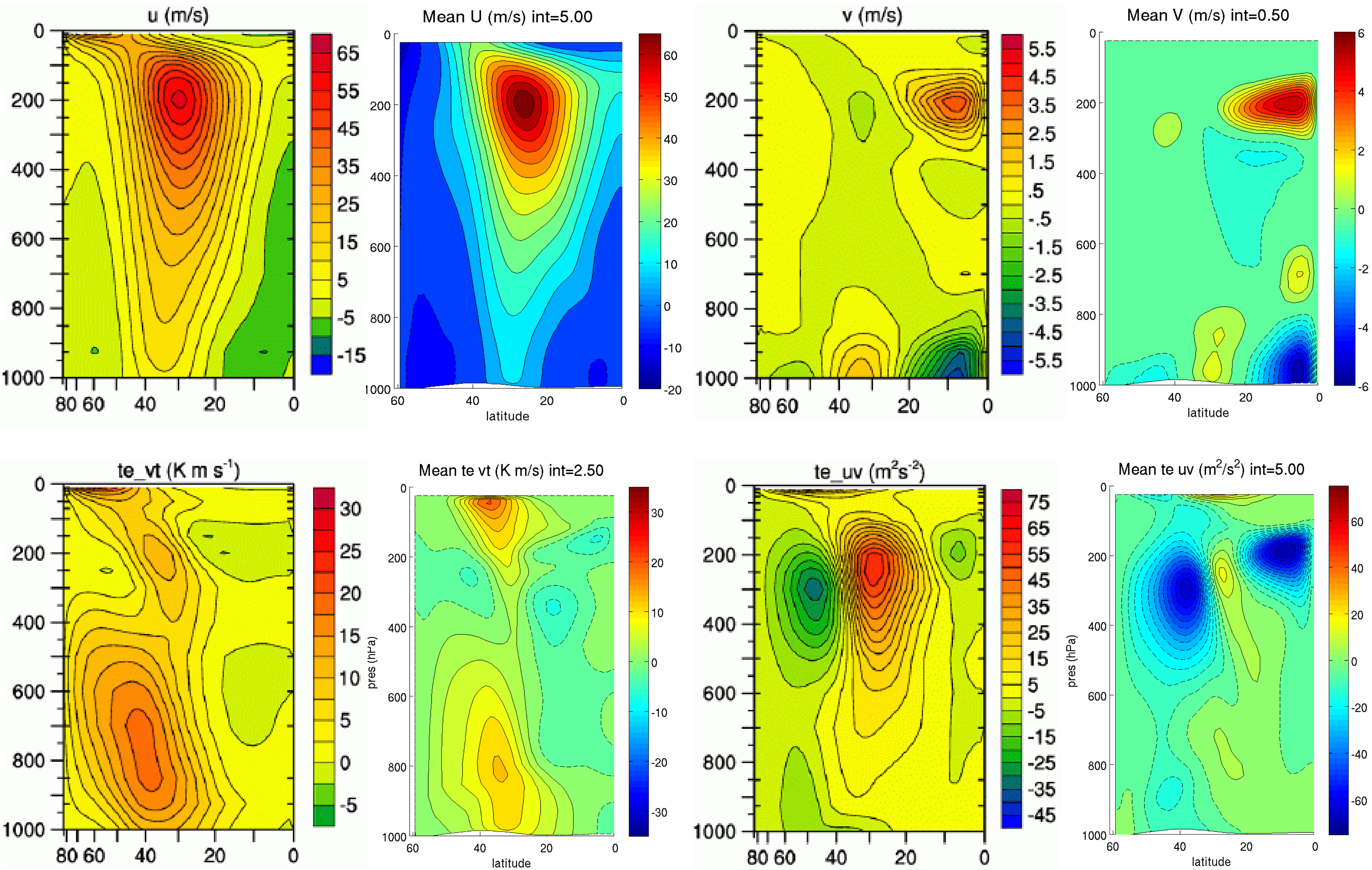


Fig. 4. Zonal-time average total precipitation (tppn) for individual models, mm day^{-1}. The 16 models are split between two panels for clarity.



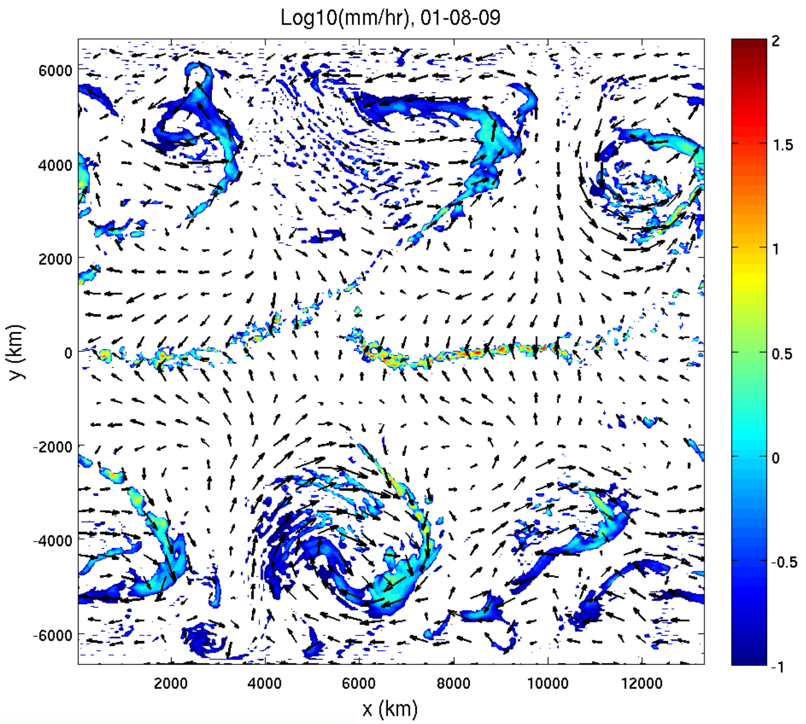
Blackburn et al. (2013) - APE control case.

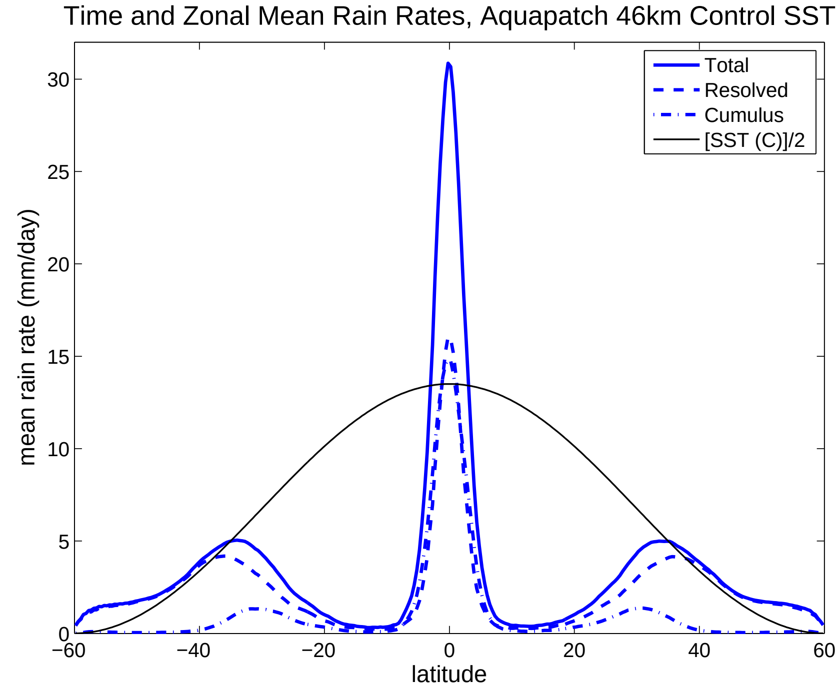
General Circulation: Aquaplanet vs. Aquachannel

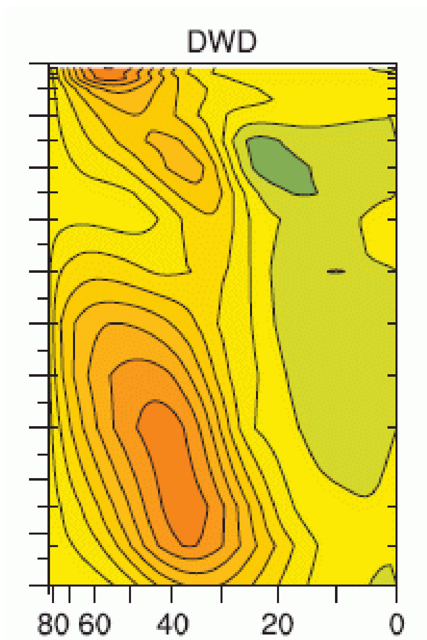


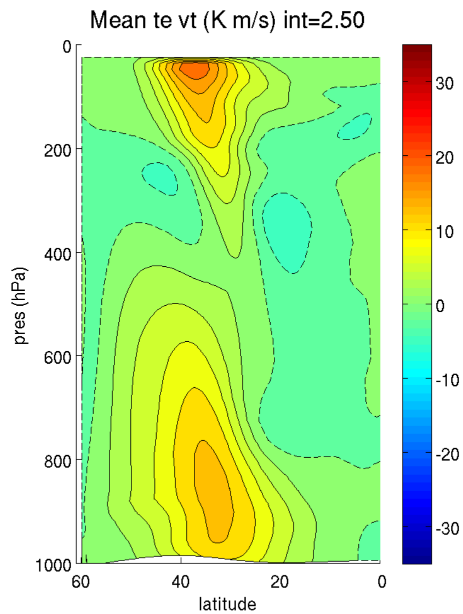
Left plots are *multimodel means* from Blackburn et al. (2013) - APE control case.

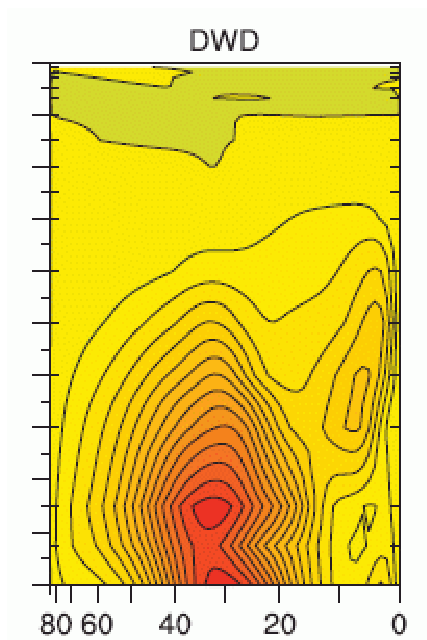
- Now...let’s shorten the domain to 1/3 the circumference.
  And, decrease grid spacing by 1/3: 288x288 points at 46.35km, ~ 120x120 degrees.

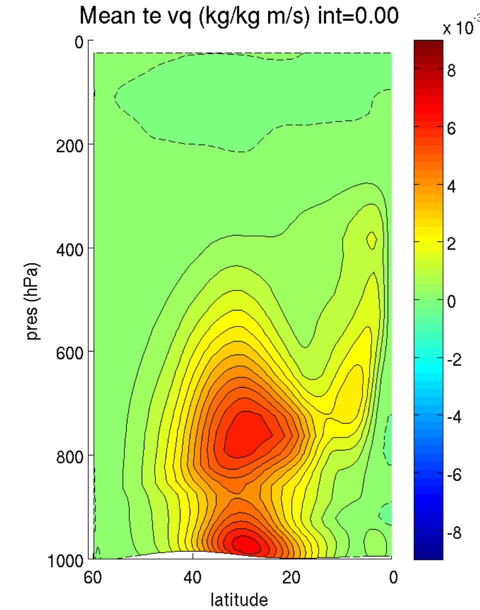




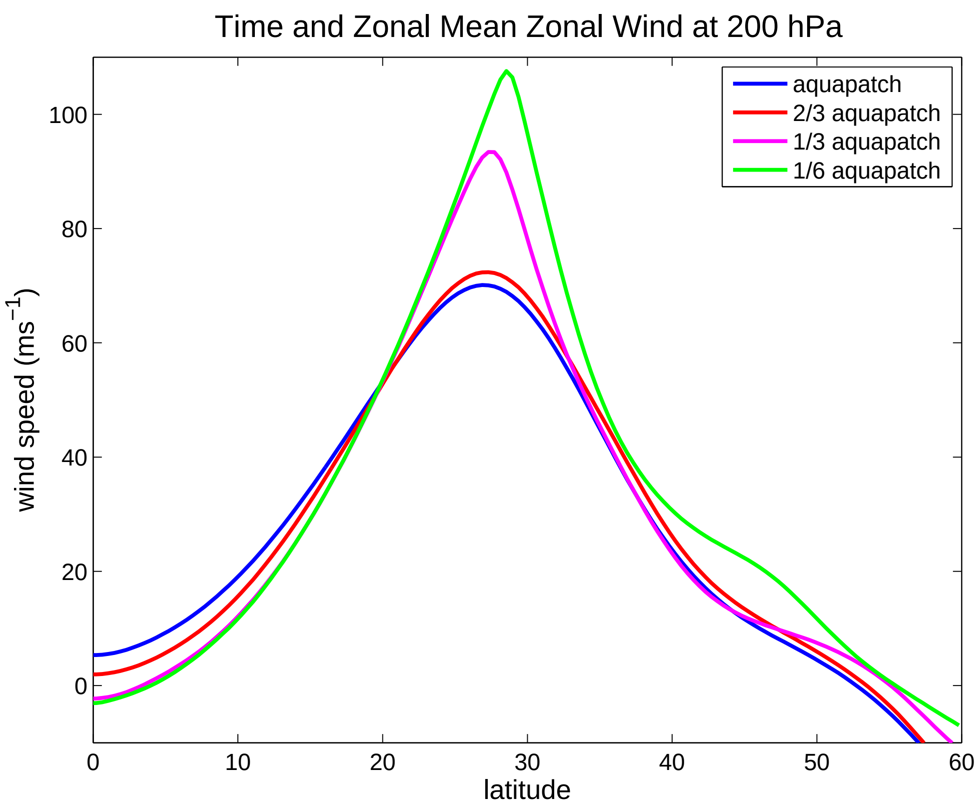


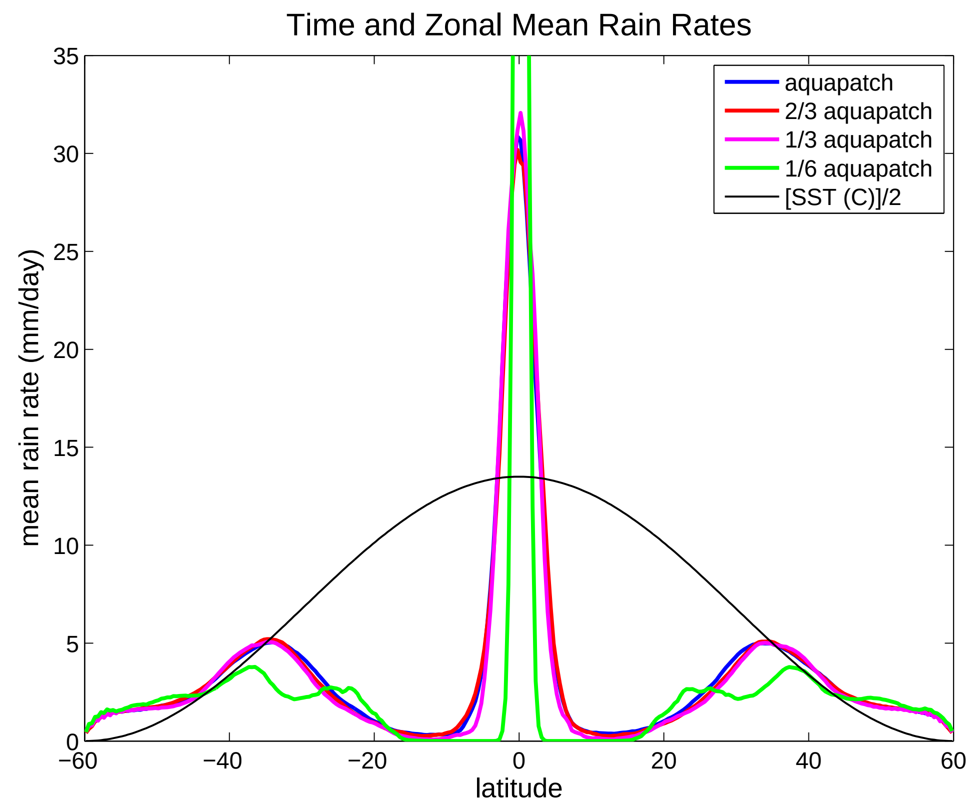






How short can the aquapatch be and make a reasonable climate?

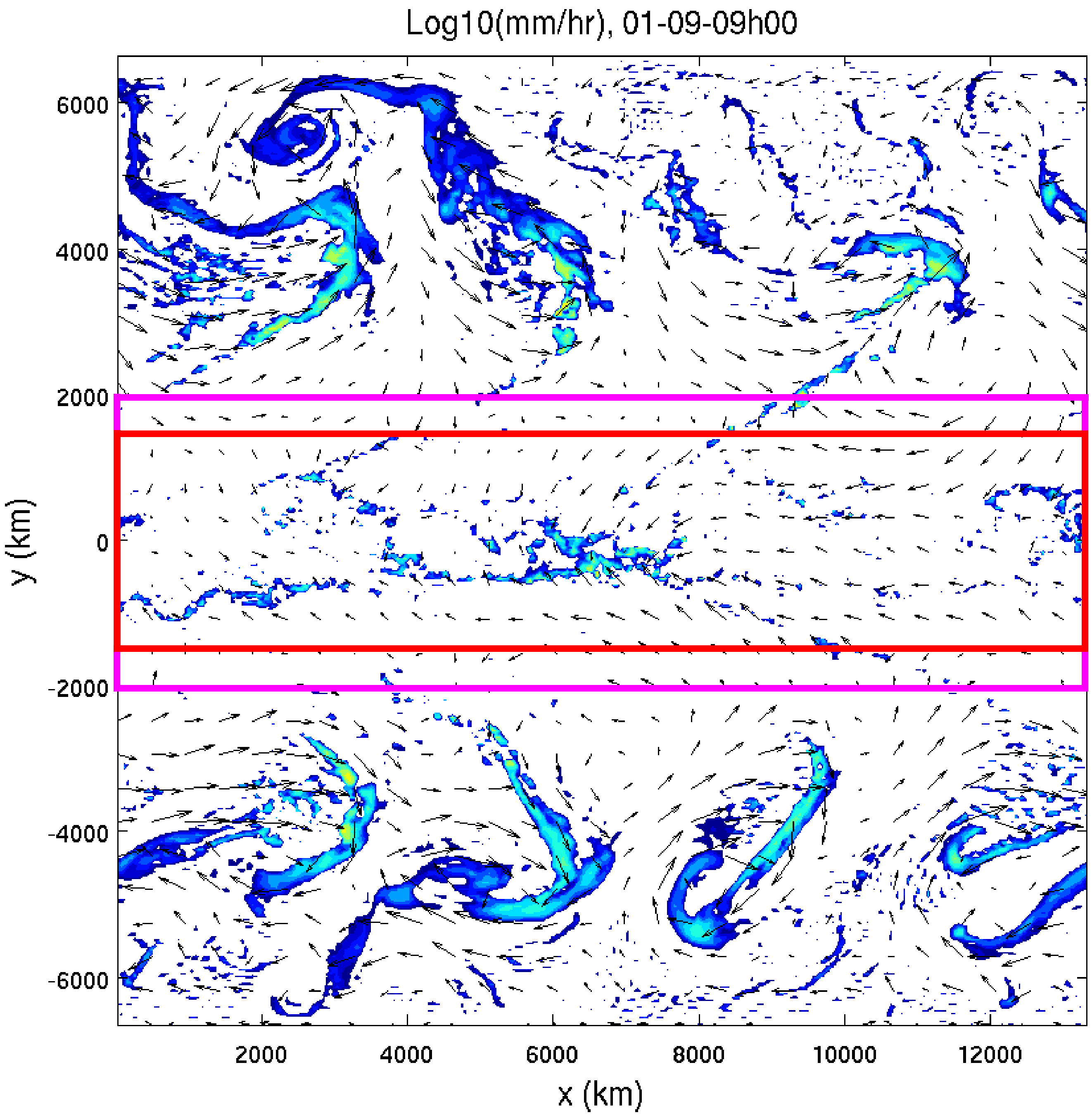




2/3 aquapatch = 2/3 x 1/3 length of equator

--> channel that is 2/9 length of equator makes a pretty good tropical climate

• And finally...let's nest down to 5.15 km resolution in the tropics:

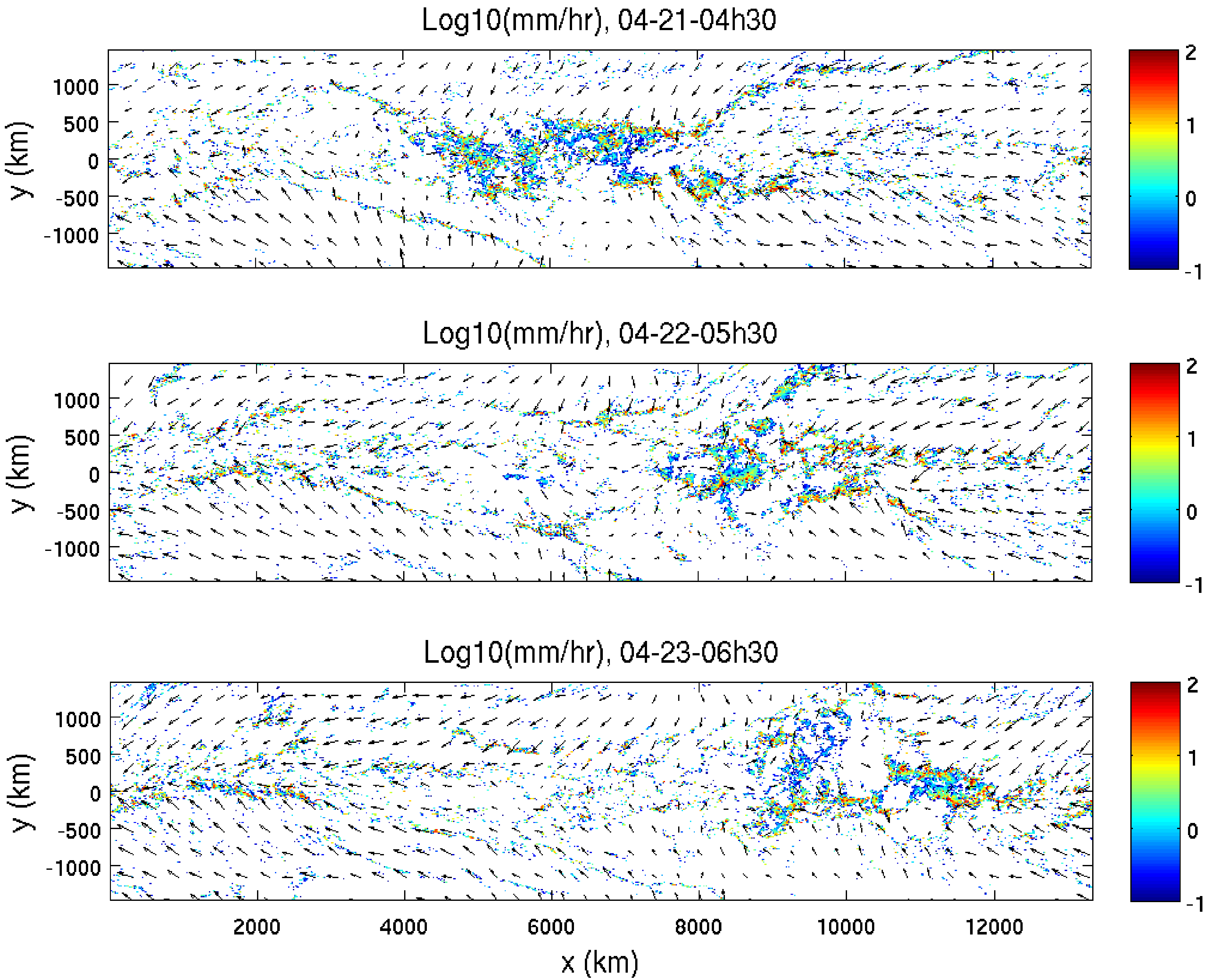


46.35 km, Tiedtke CP

15.45 km, Tiedtke CP

5.15 km, no CP
2592 x 576 grid points

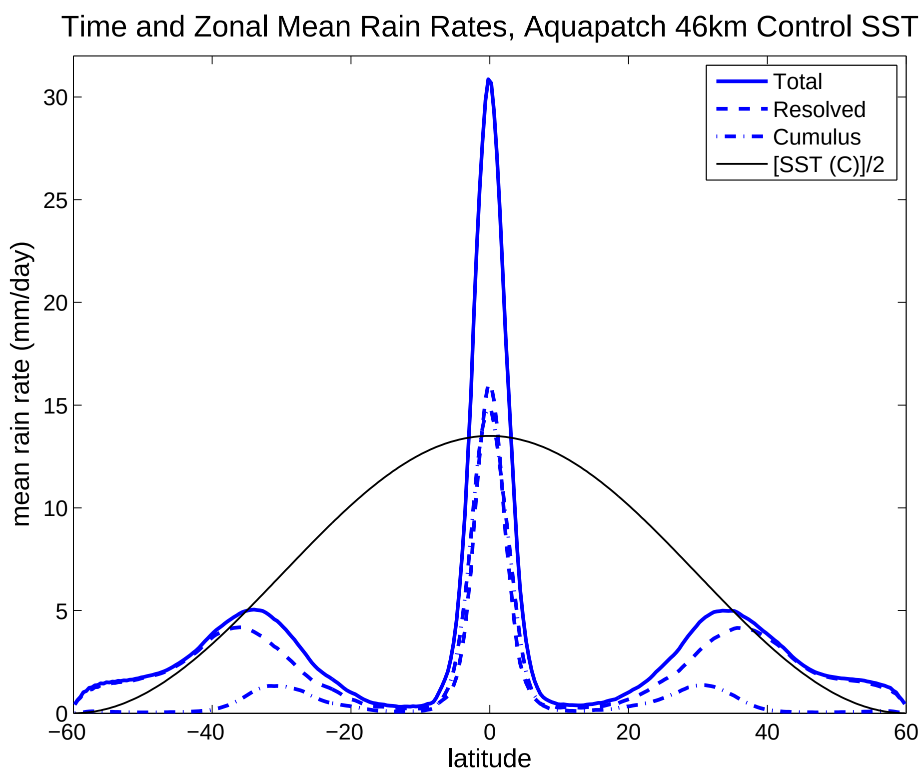
~ 1 hour to run 1 day with 1024 processors (tolerable!)

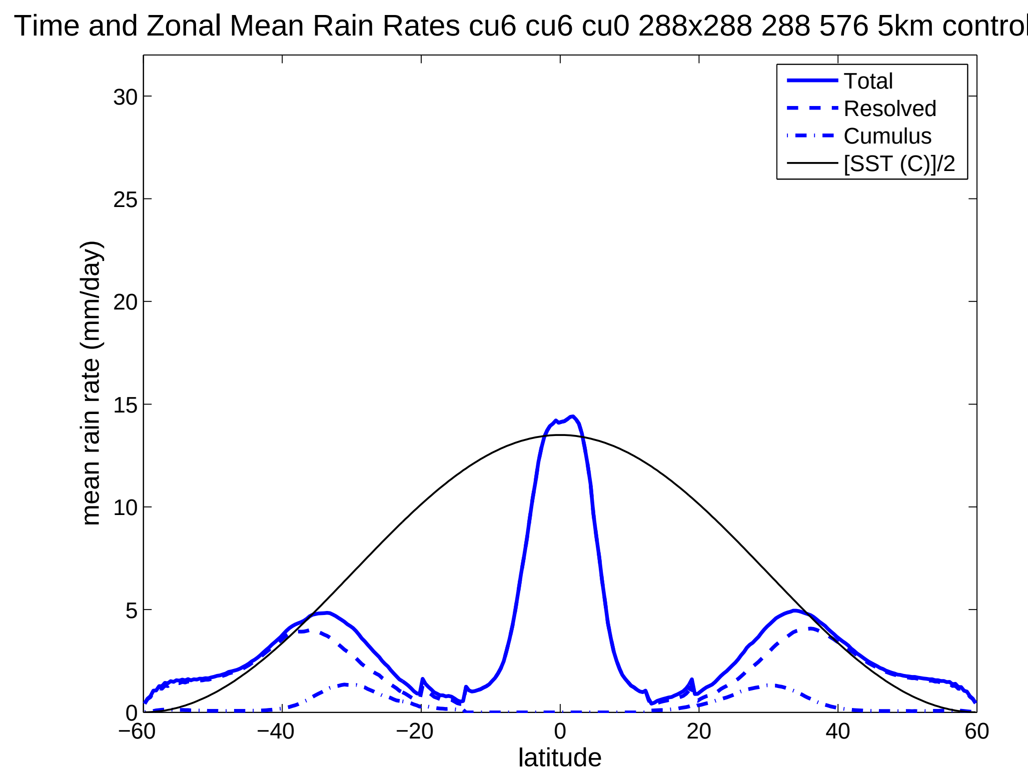


Log10(mm/hr), 04-21-04h30
Log10(mm/hr), 04-22-05h30
Log10(mm/hr), 04-23-06h30
y (km)
1000
500
0
-500
-1000
2
1
0
-1
2000
4000
6000
8000
10000
12000
x (km)

III. Tropical Precipitation: Cumulus Parameterization vs. Explicit Convection

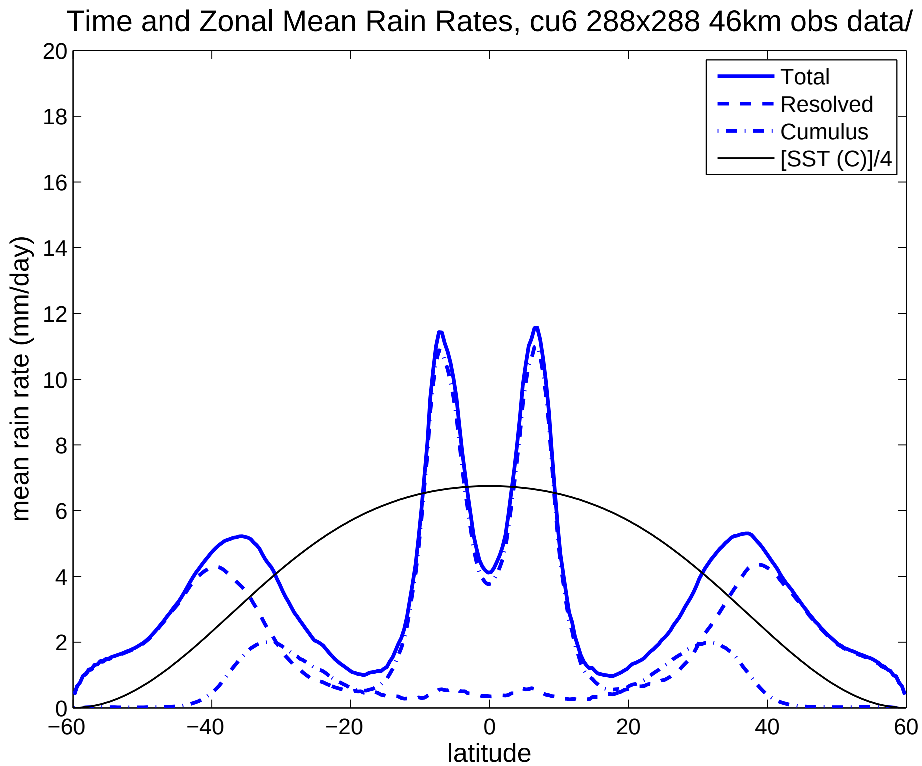
"Control" SST Profile

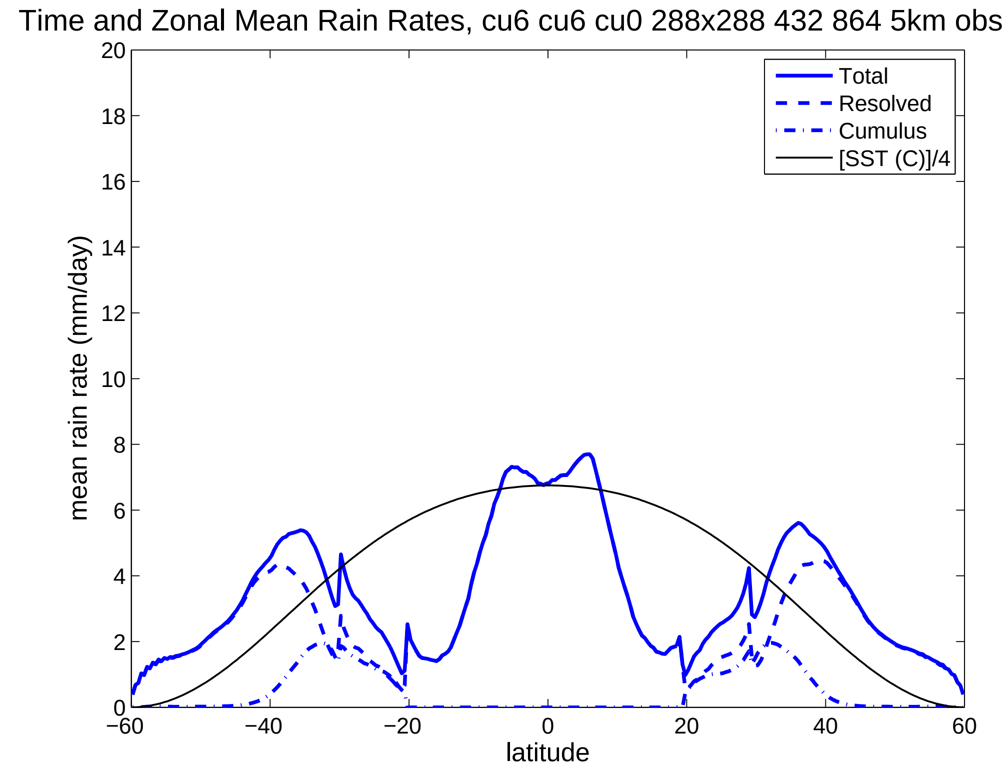




- Both are single-ITCZ, but for explicit convection:
  - * Rainfall is less peaked at the equator
  - * Rainfall spreads more broadly away from equator

“Observed” SST Profile





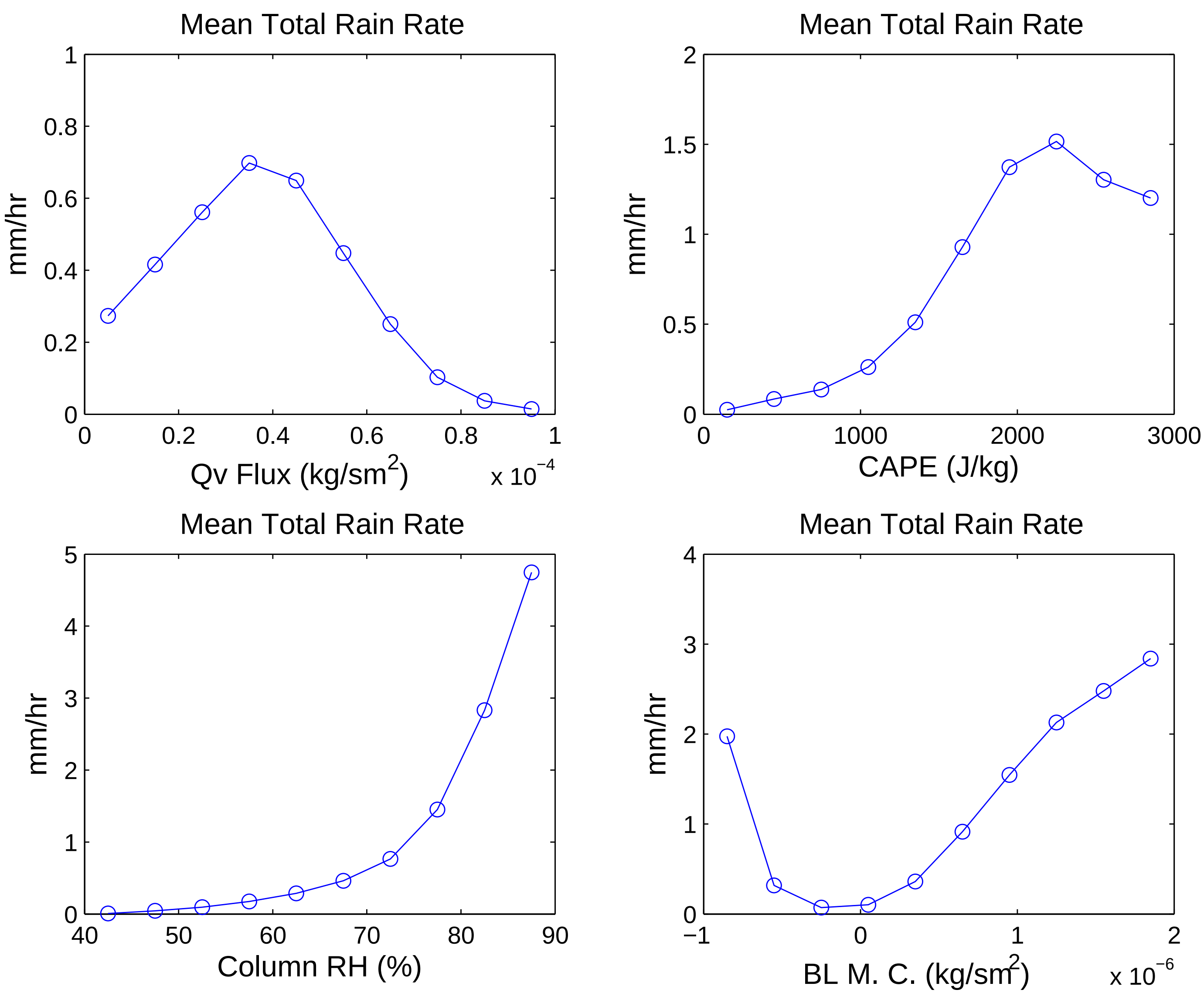
- Tiedtke CP produces a very pronounced double ITCZ.

- Explicit convection has a marginal double ITCZ.

  But again - rainfall is more widely distributed.

Understanding the Precipitation Distributions

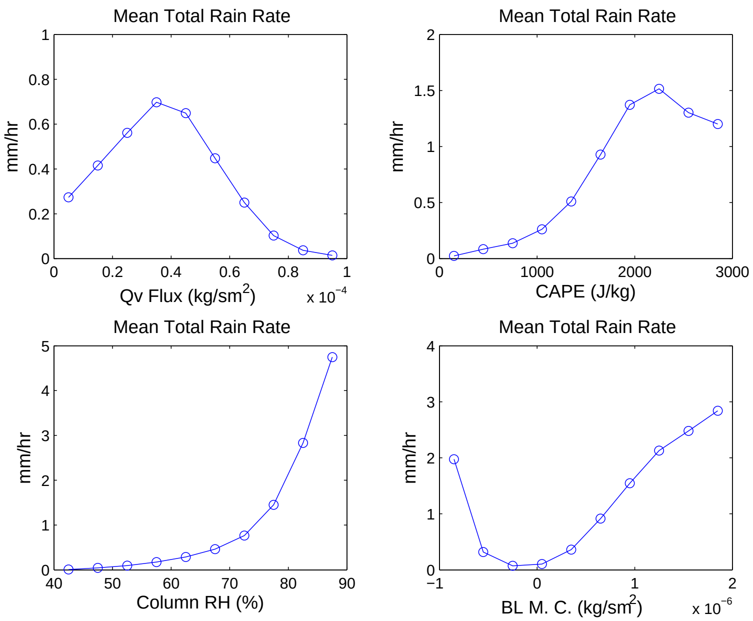
46km, Tiedtke CP



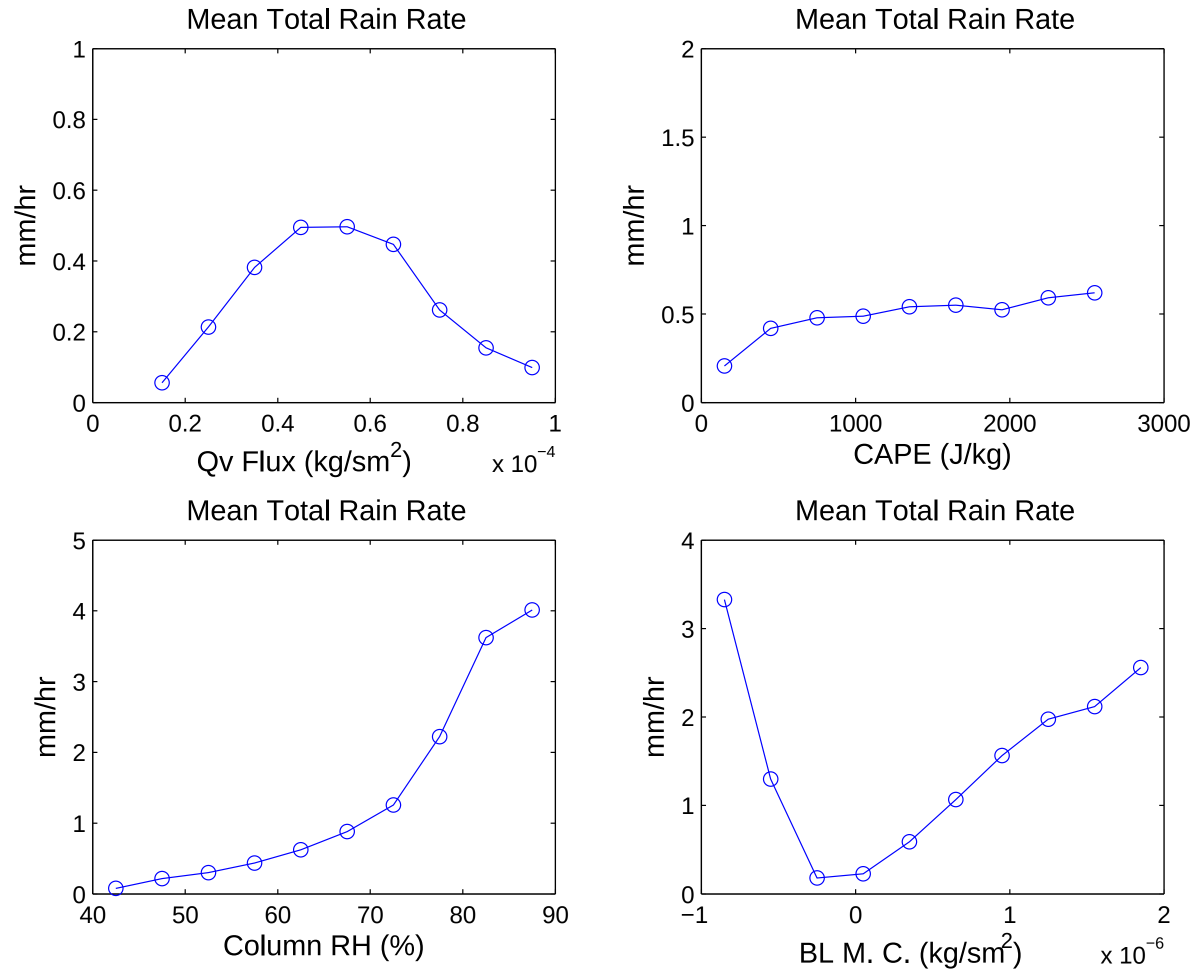
Analyses limited to ITCZ and fringes

Understanding the Precipitation Distributions

46 km, Tiedtke CP



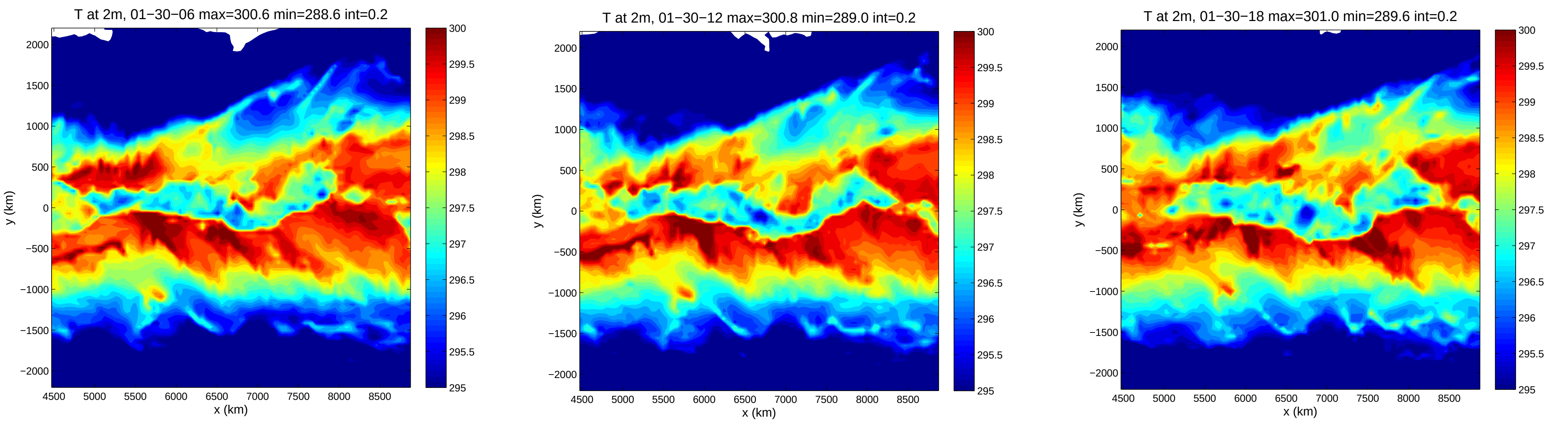
Nested 5 km



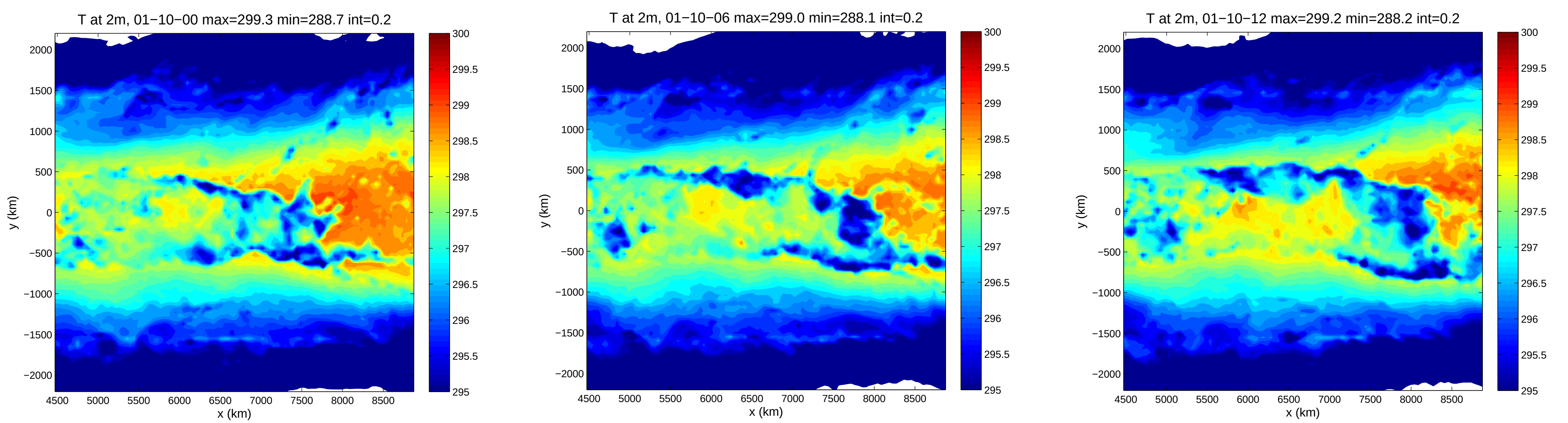
- Compared to CP, 5 km explicit precipitation:
  - * Is *less* focused on high CAPE.
  - * Is *more* active in dry regions.

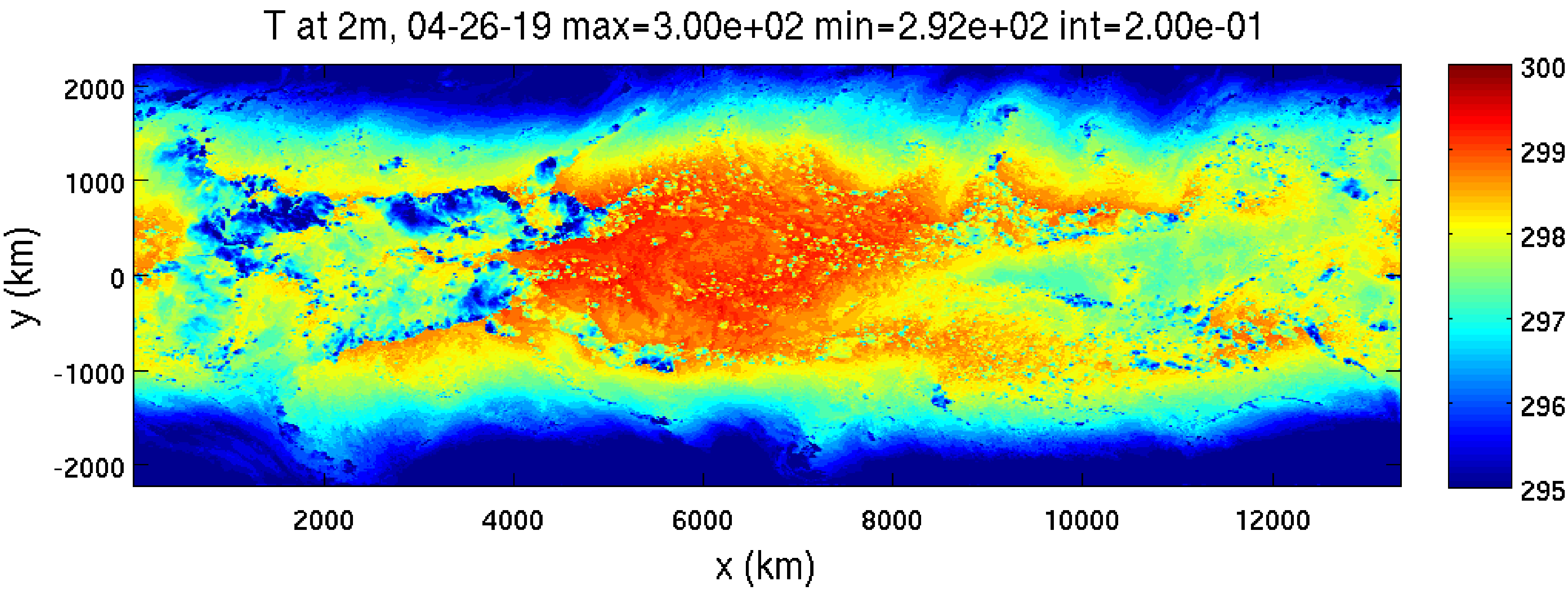
- The reason appears to be due to the production of *stronger cold pools* and *propagating squall lines*.

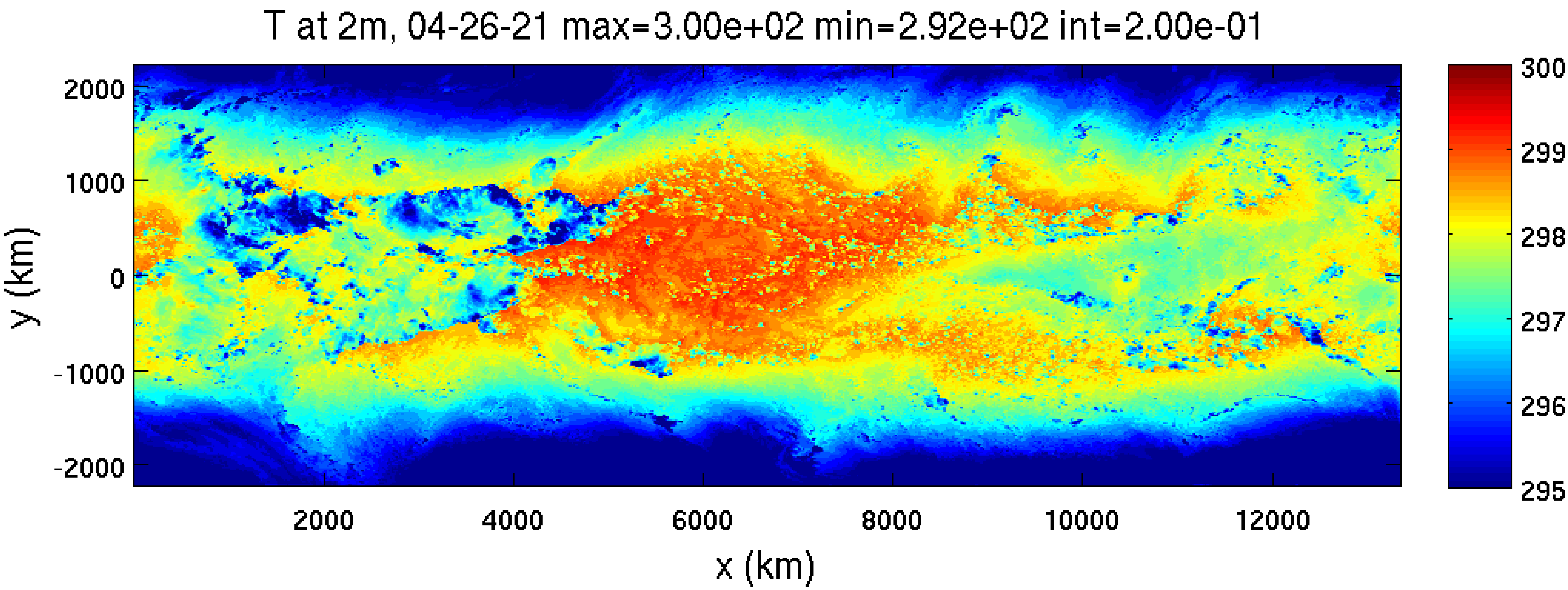
T at 2m, 46 km Tiedtke CP



T at 2m, 5 km nested, on 46 km grid




T at 2m, 04-26-19 max=3.00e+02 min=2.92e+02 int=2.00e-01
y (km)
2000
1000
0
-1000
-2000
2000
4000
6000
8000
10000
12000
x (km)
300
299
298
297
296
295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y (km)
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-1000
-2000
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x (km)
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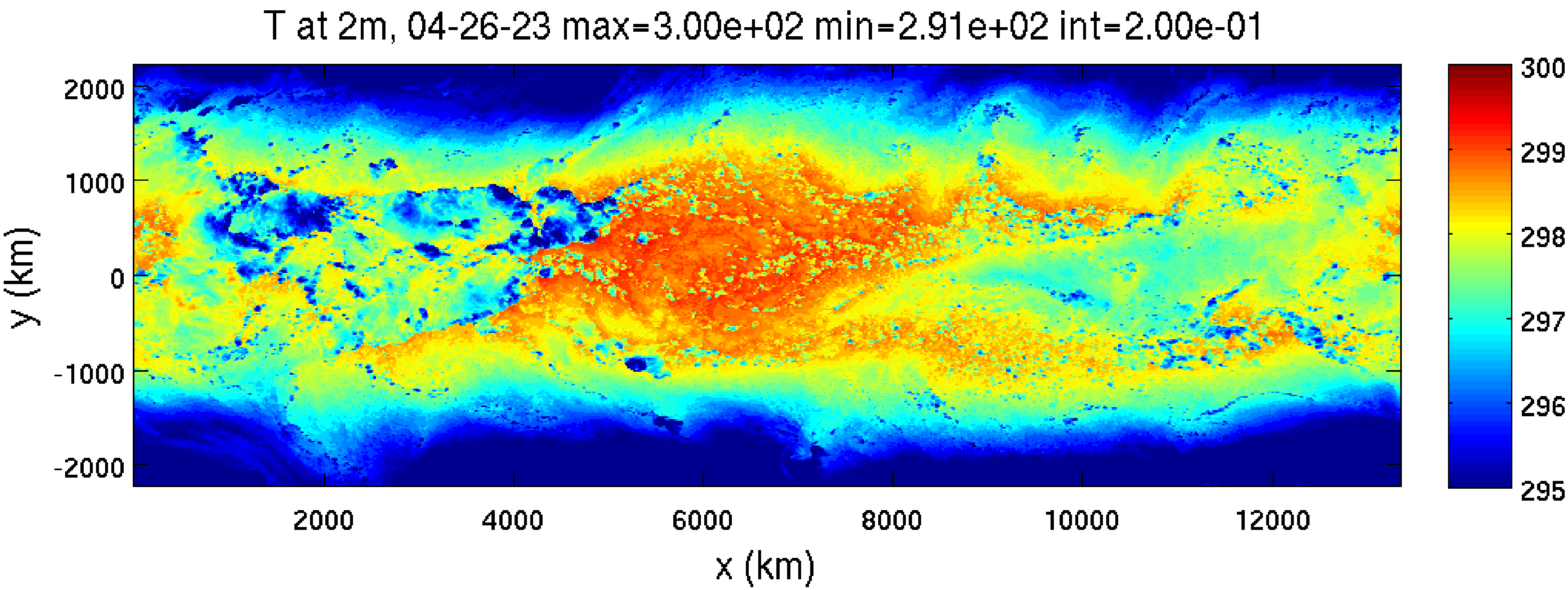

T at 2m, 04-26-23 max=3.00e+02 min=2.91e+02 int=2.00e-01
2000
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y (km)
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x (km)
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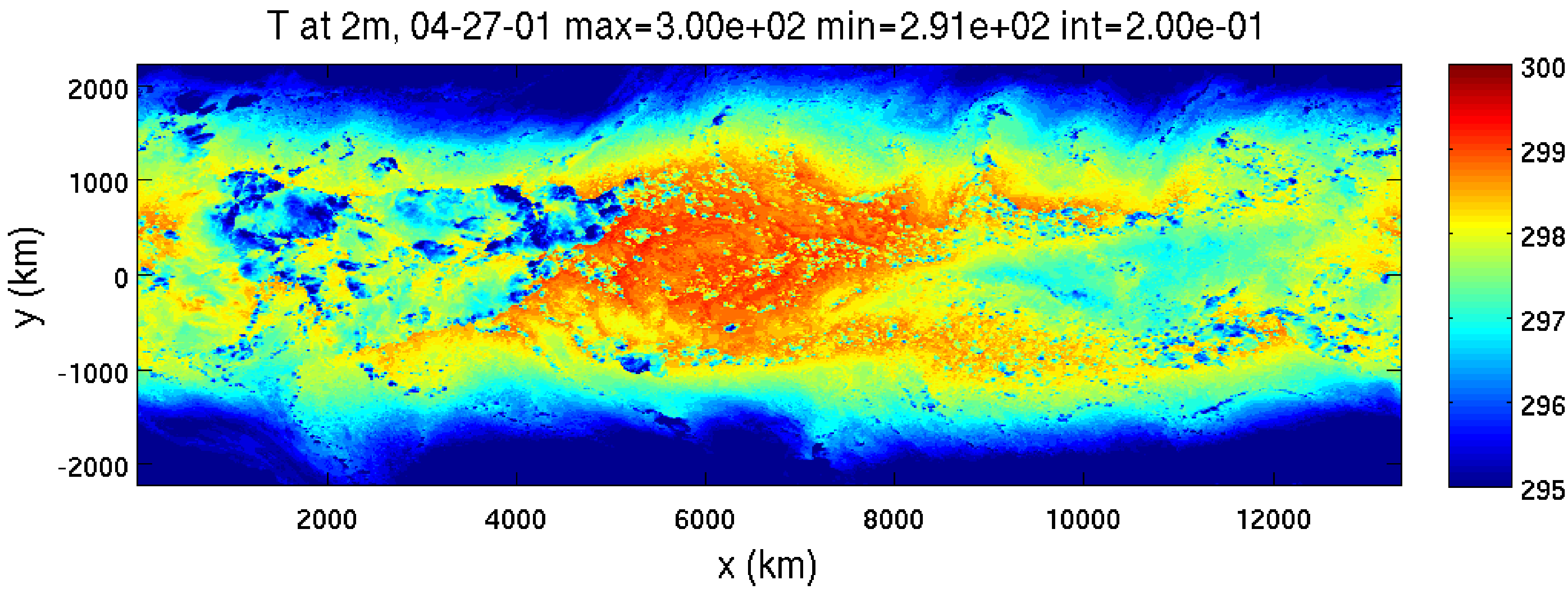
T at 2m, 04-27-01 max=3.00e+02 min=2.91e+02 int=2.00e-01
y (km)
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1000
0
-1000
-2000
x (km)
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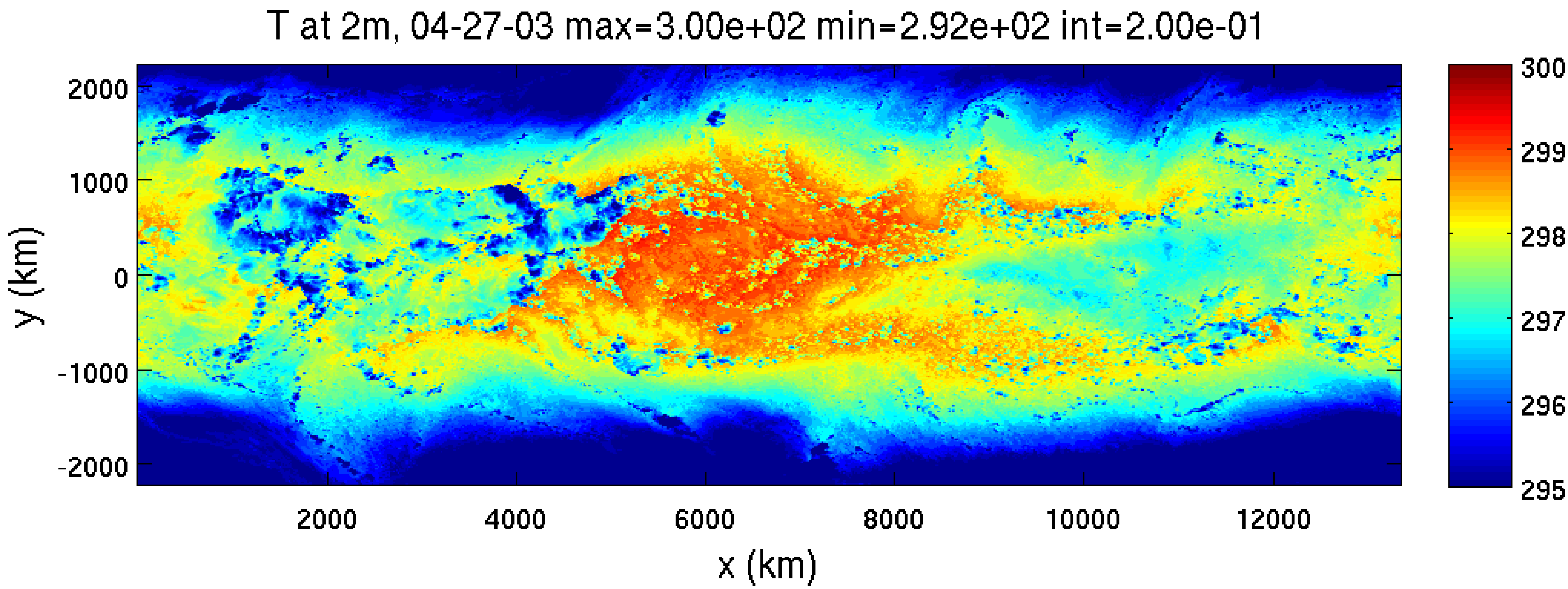
T at 2m, 04-27-03 max=3.00e+02 min=2.92e+02 int=2.00e-01
y (km)
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1000
0
-1000
-2000
x (km)
2000
4000
6000
8000
10000
12000
300
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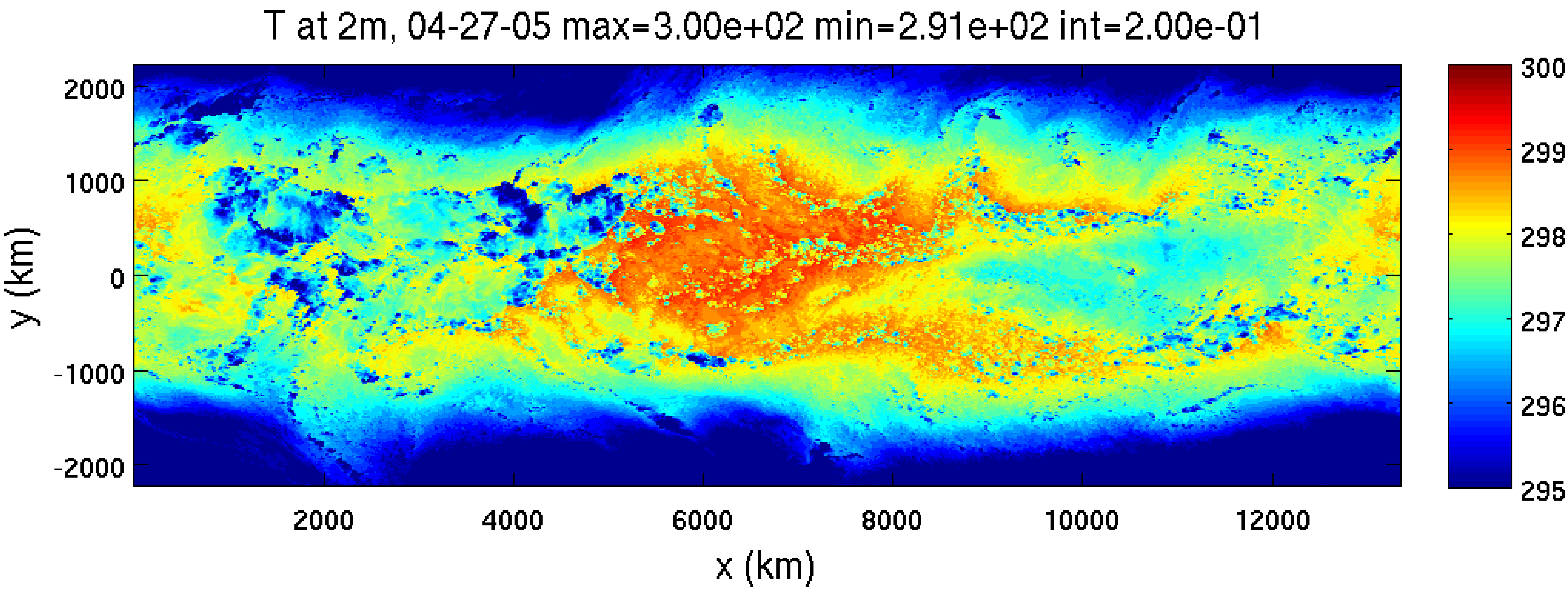
296
295



T at 2m, 04-27-05 max=3.00e+02 min=2.91e+02 int=2.00e-01
y (km)
2000
1000
0
-1000
-2000
x (km)
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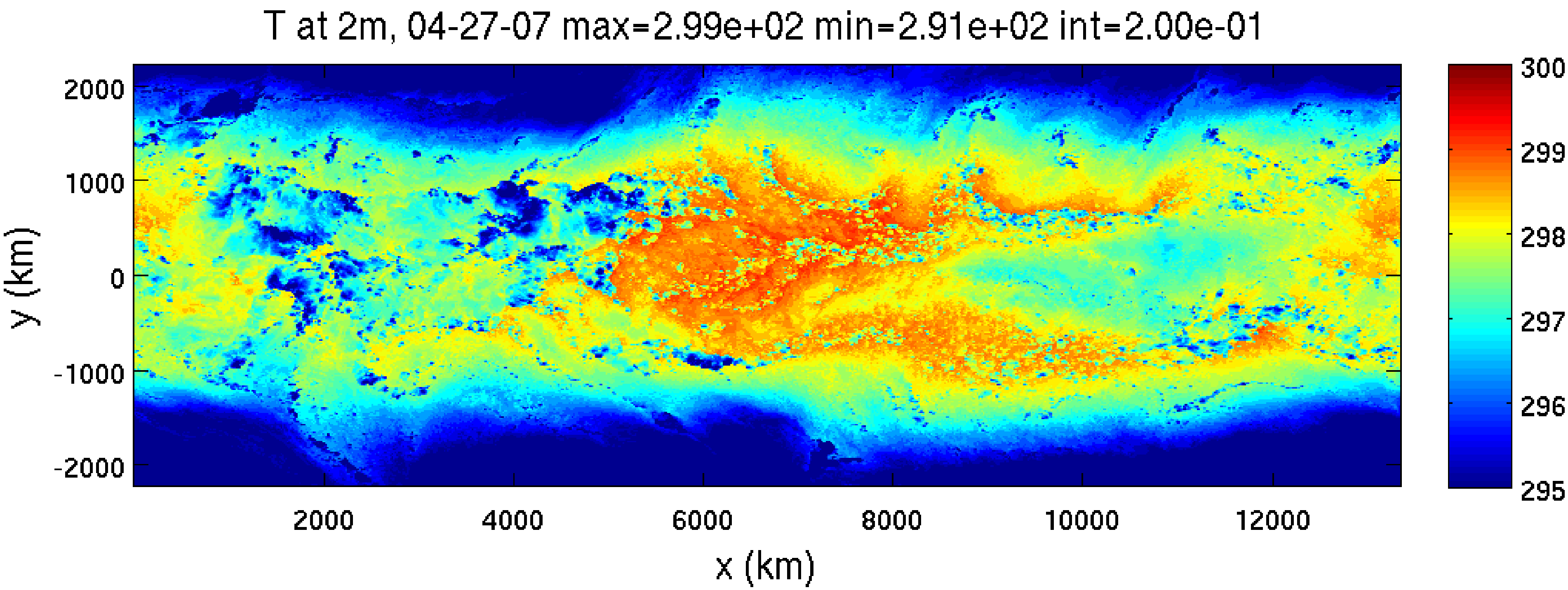

T at 2m, 04-27-07 max=2.99e+02 min=2.91e+02 int=2.00e-01
y (km)
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1000
0
-1000
-2000
x (km)
2000
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10000
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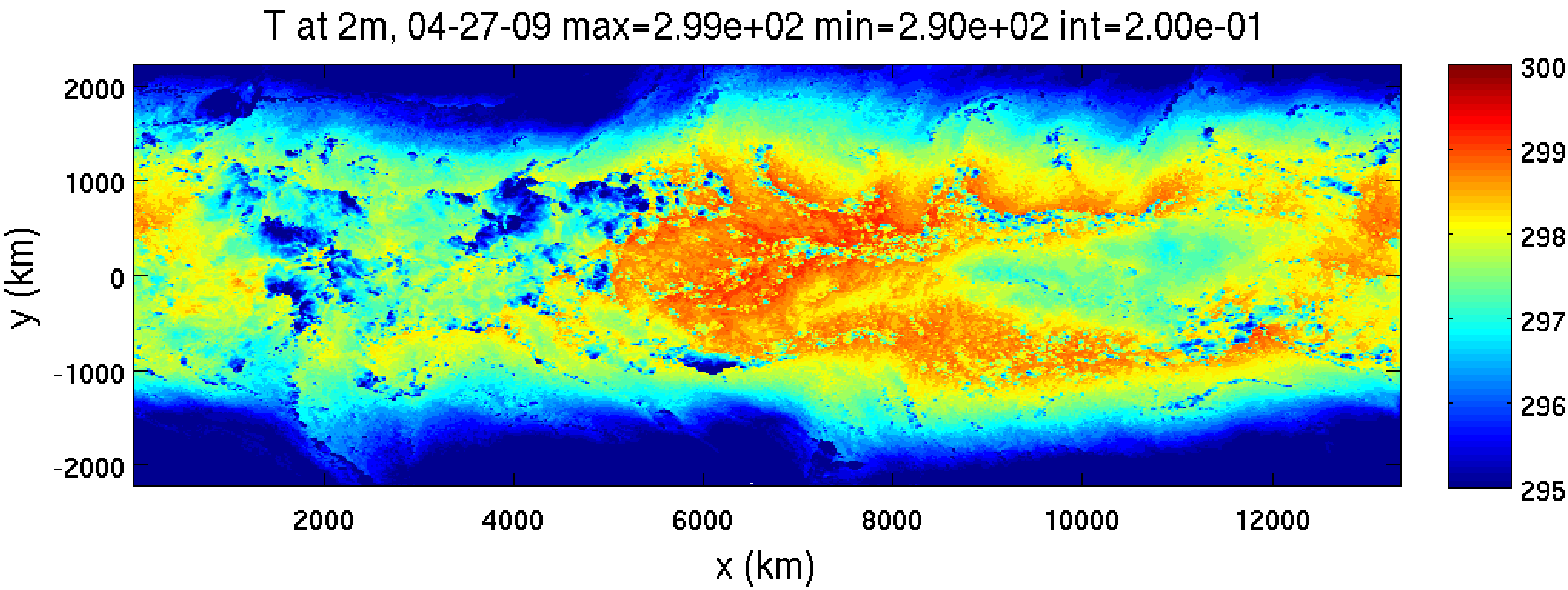
T at 2m, 04-27-09 max=2.99e+02 min=2.90e+02 int=2.00e-01
y (km)
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-2000
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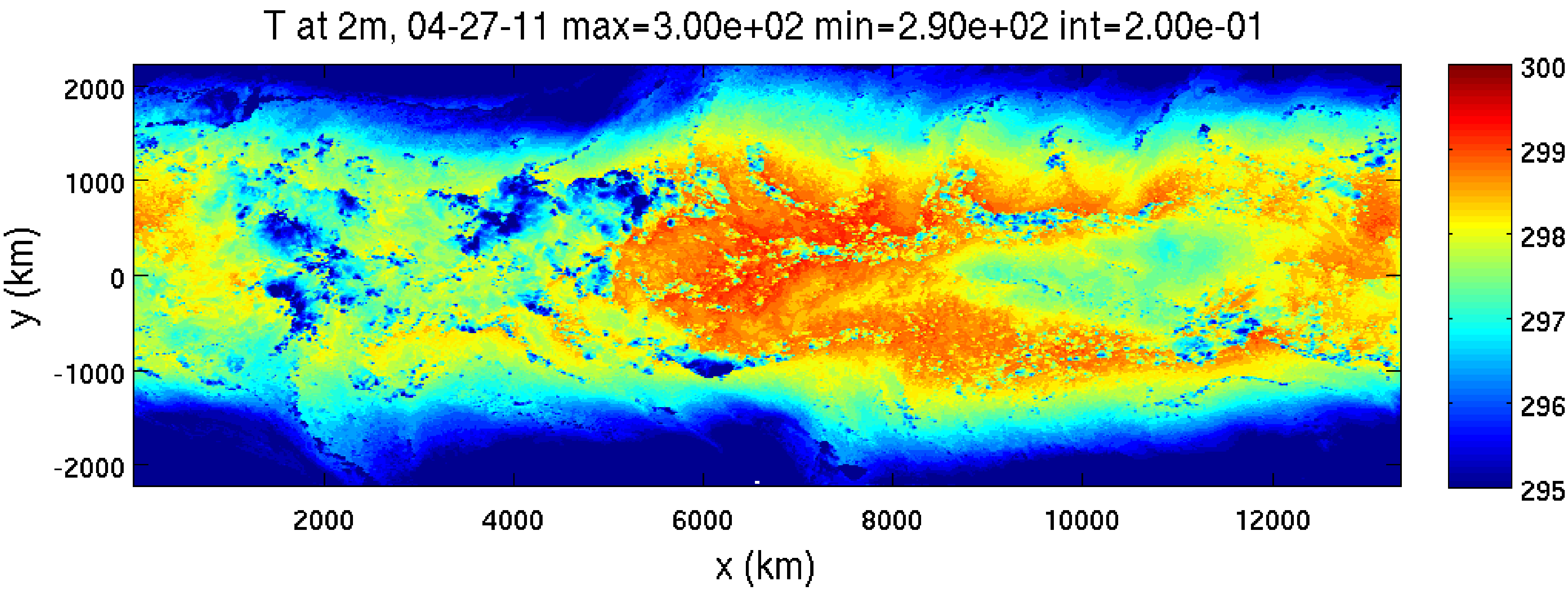
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y (km)
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x (km)
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6000
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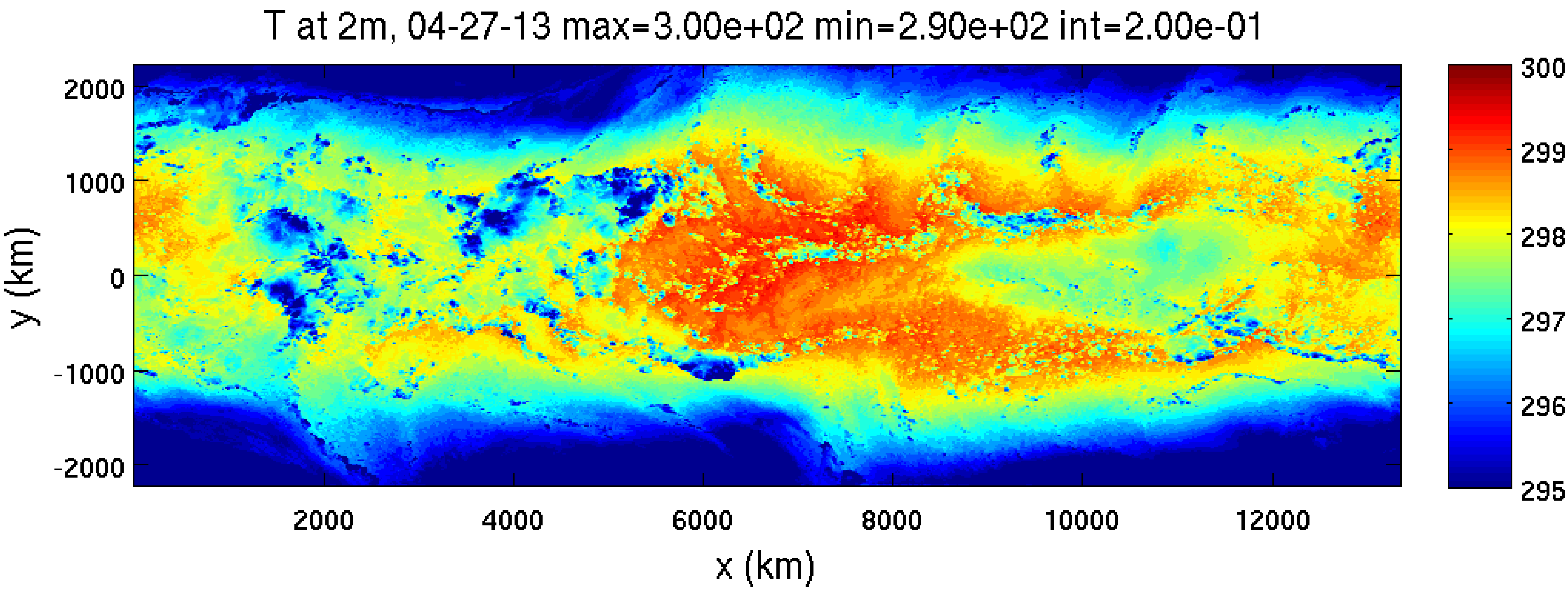
T at 2m, 04-27-13 max=3.00e+02 min=2.90e+02 int=2.00e-01
y (km)
2000
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x (km)
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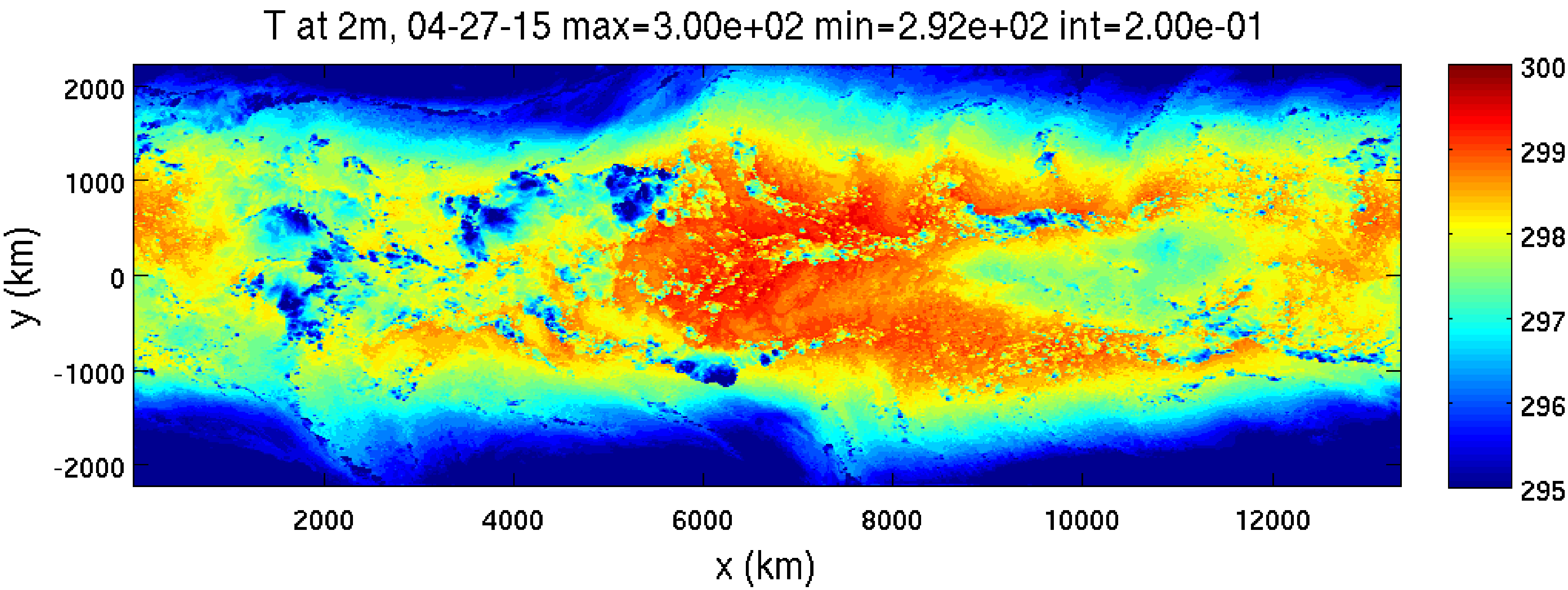
T at 2m, 04-27-15 max=3.00e+02 min=2.92e+02 int=2.00e-01
y (km)
2000
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-1000
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x (km)
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12000
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Result:

ITCZ precipitation is more broadly distributed in 5 km resolution simulations because there are propagating squall lines that can't be represented with CP.

See the paper:

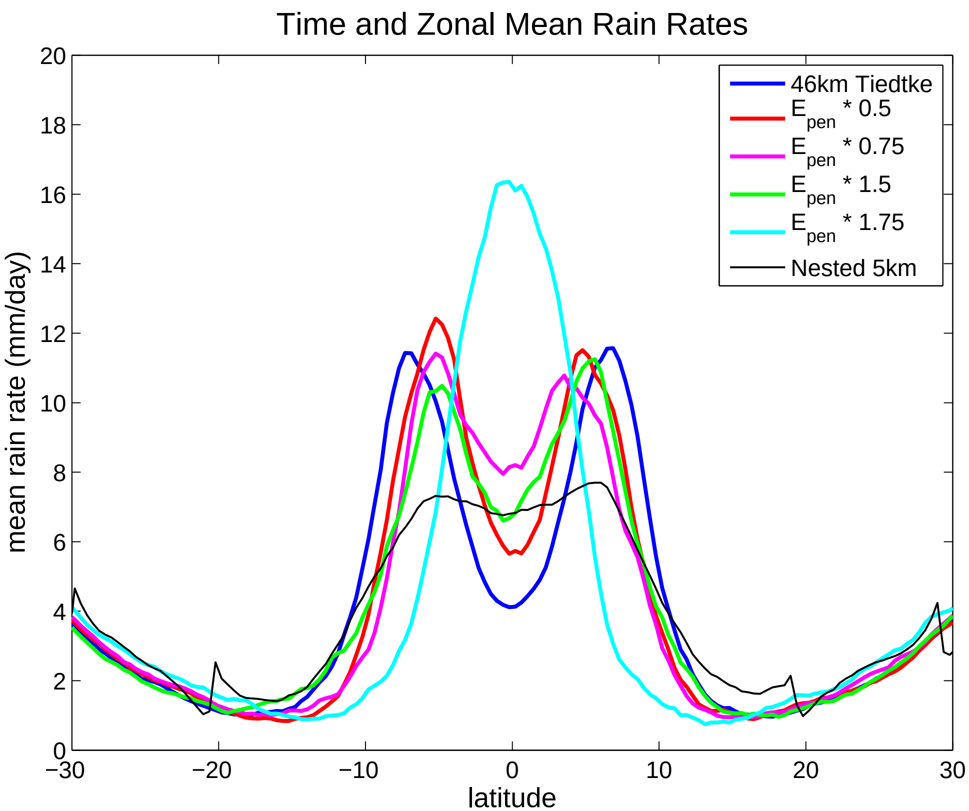
Nolan, D. S., S. N. Tulich, and J. E. Blanco, 2016: ITCZ structure as determined by parameterized versus explicit convection in aquachannel and aquapatch simulations. *J. Adv. Model. Earth Syst.*, **8**, doi: 10.1002/2015MS000560.

Instead...

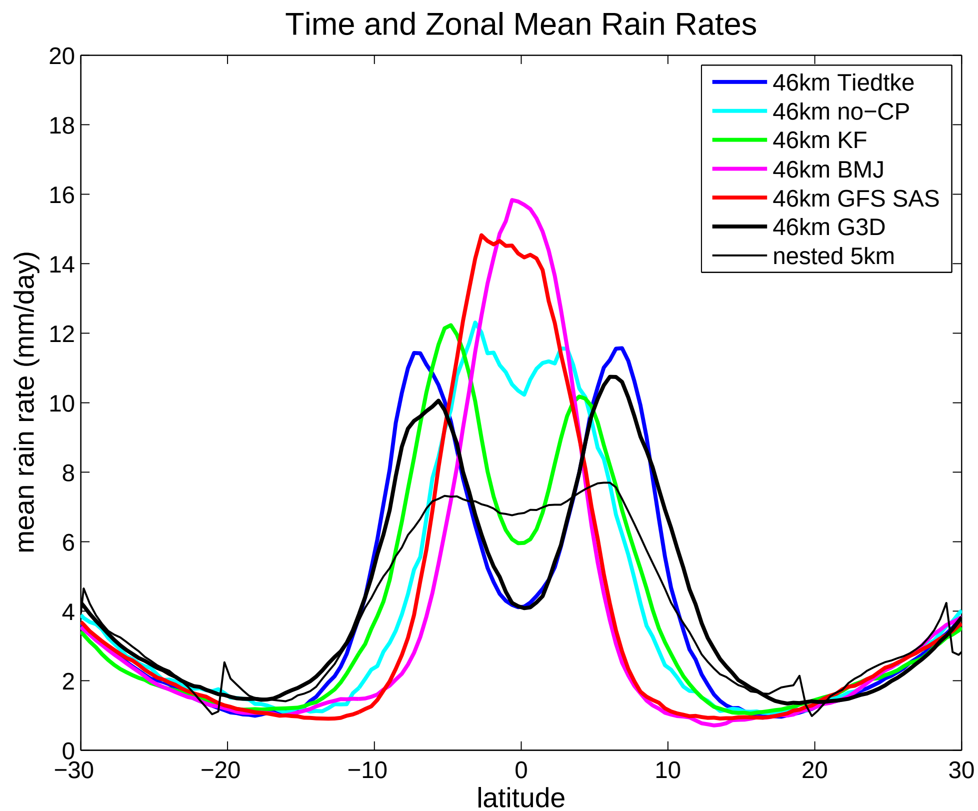
IV. Some Modeling Issues

- Can we make the CP results more like explicit convection by changing:

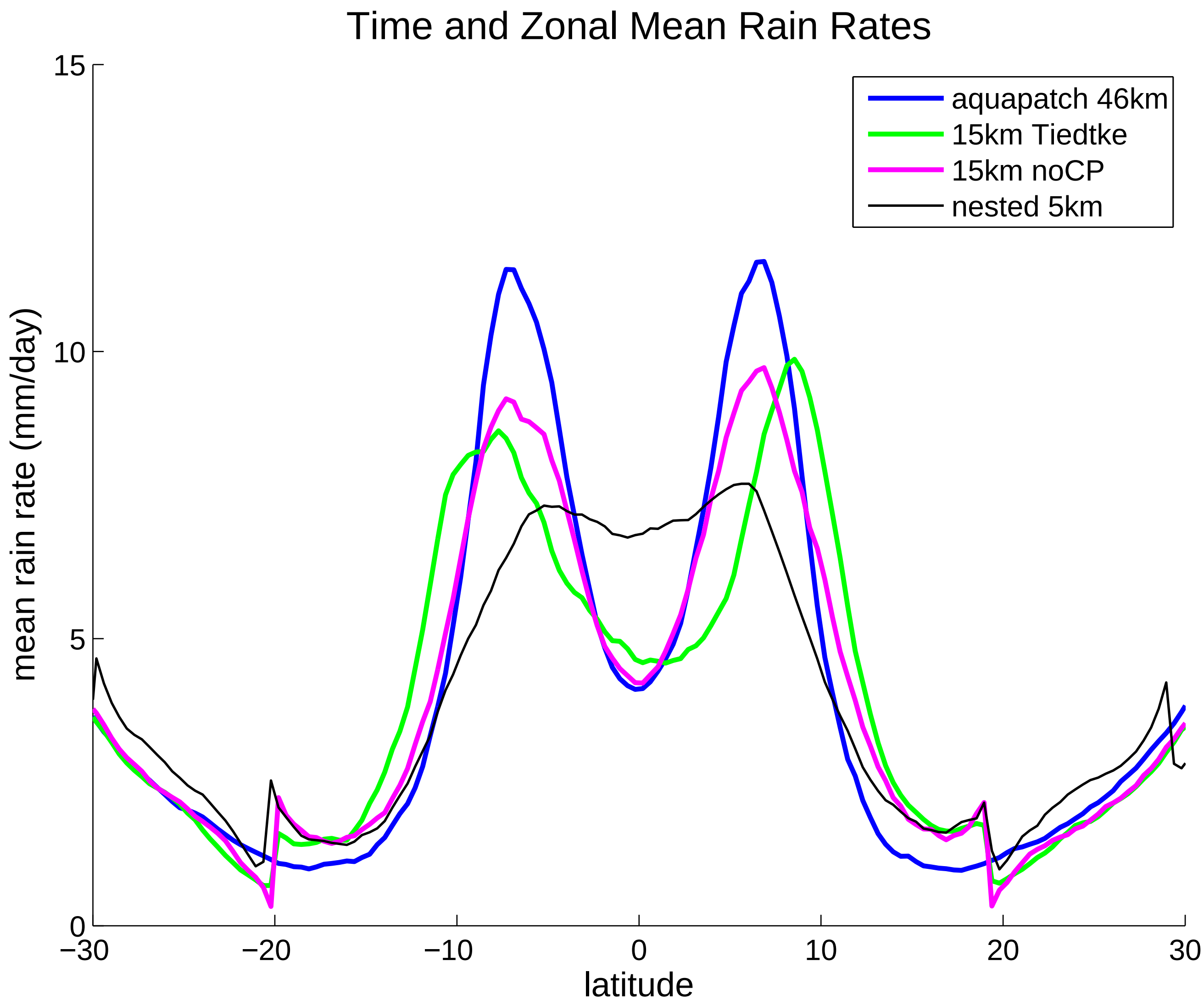
The entrainment parameter?



The parameterization?

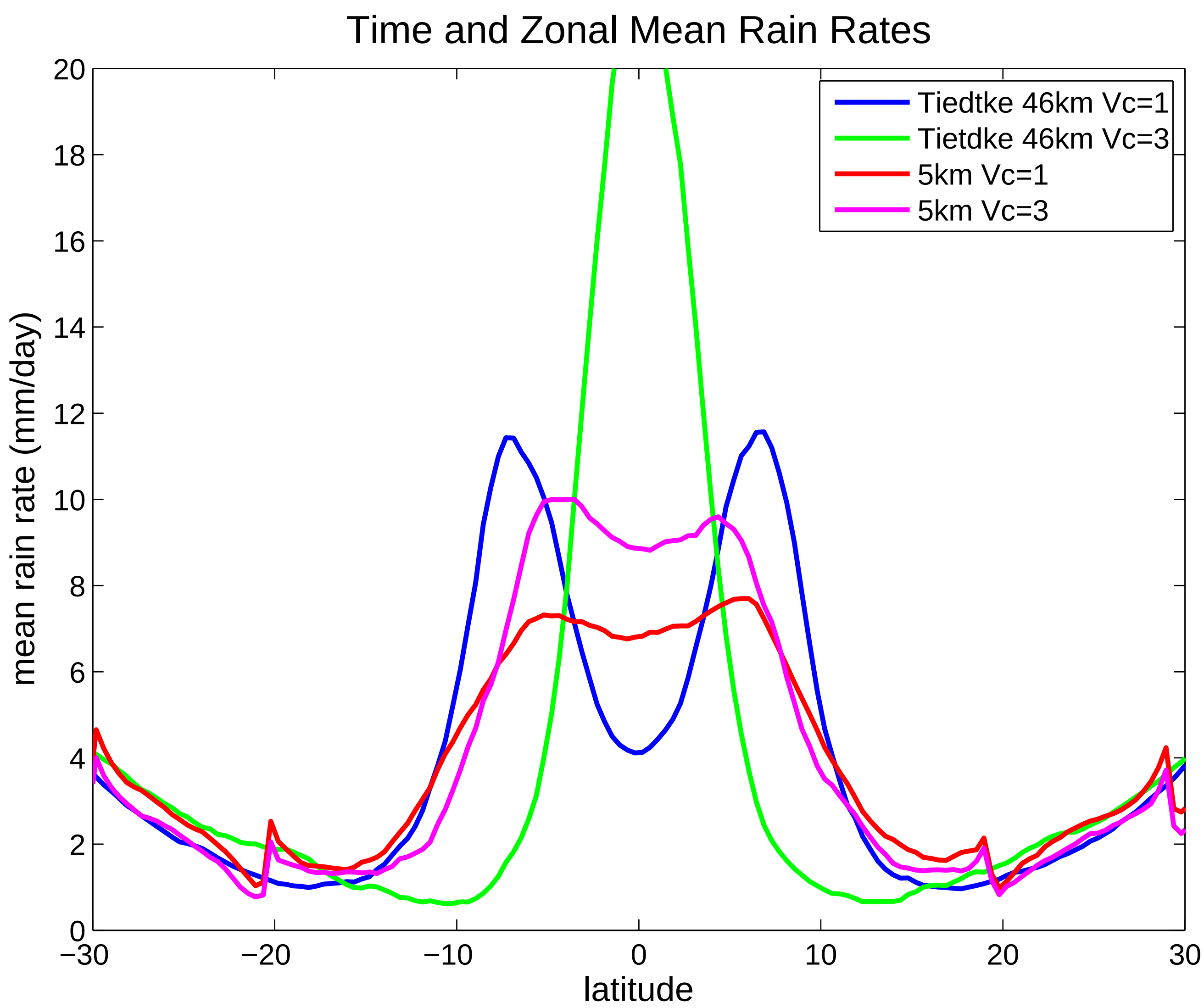


• How much of the difference is due to eliminating CP, how much to resolution?



5 km explicit simulations are *less sensitive to parameterizations!*

Example 1:

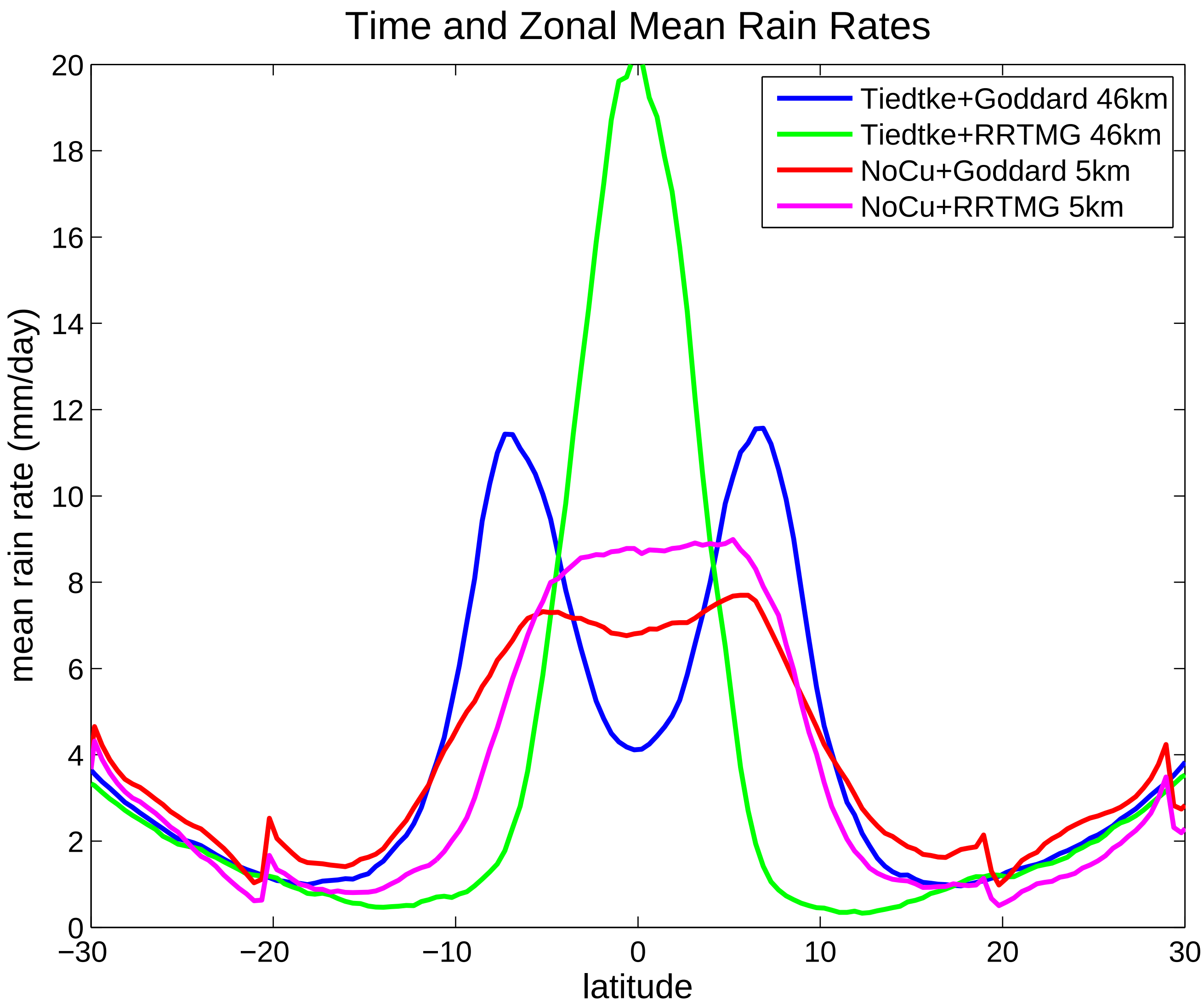


Vc = "convective gustiness"

Added to wind speed in surface flux formula

Largest effect where winds are small

Example 2:



Goddard SW + LW

versus

RRTM-G SW + LW

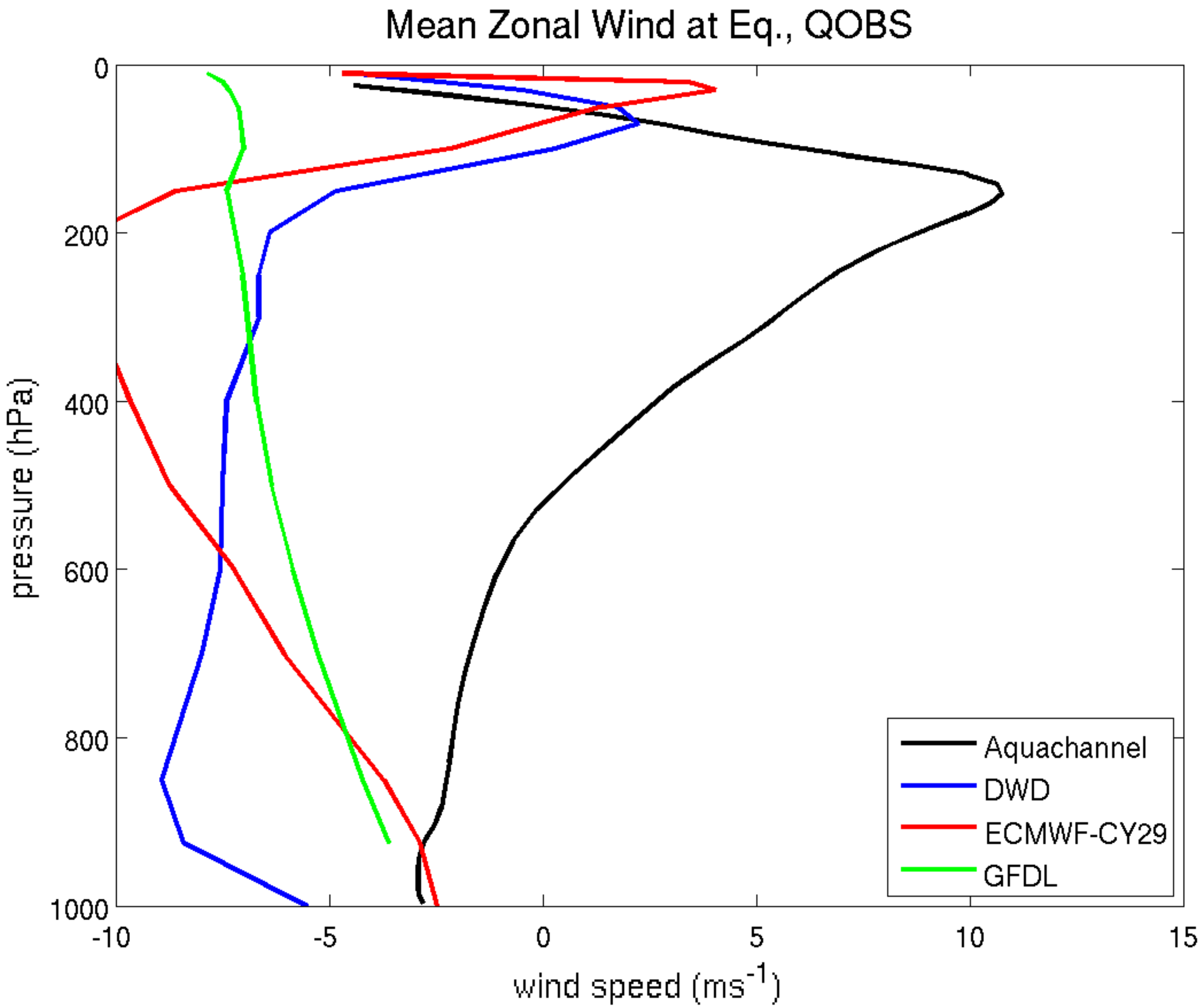
- The nested-channel configuration allows a direct comparison of parameterized and explicit convection in a large tropical band.

Question: What is the next direction to take with this method?

* Full-length aquachannel, but with ~5 km grid spacings along the length of the whole equator?
  --> Better for representing convectively coupled waves.
  --> But would prohibit significantly smaller grid spacings.

* Continue with 1/3 or 2/9 aquapatch, but increase resolution further?
  --> Could decrease grid spacing to 3-4 km.
  --> Could eliminate nesting.
  --> Either would be very computationally demanding.

Are aquachannels biased toward super-rotation?



• The aquachannel simulations of Bretherton and Khairoutdinov (2015) did *not* show super-rotation:

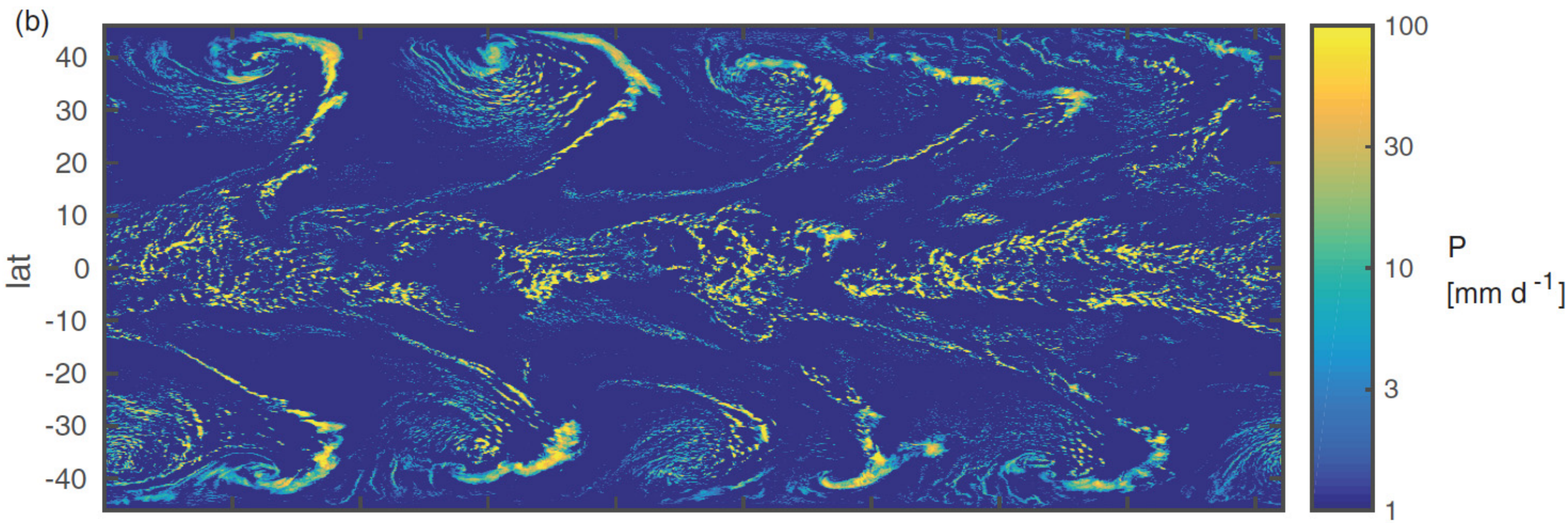
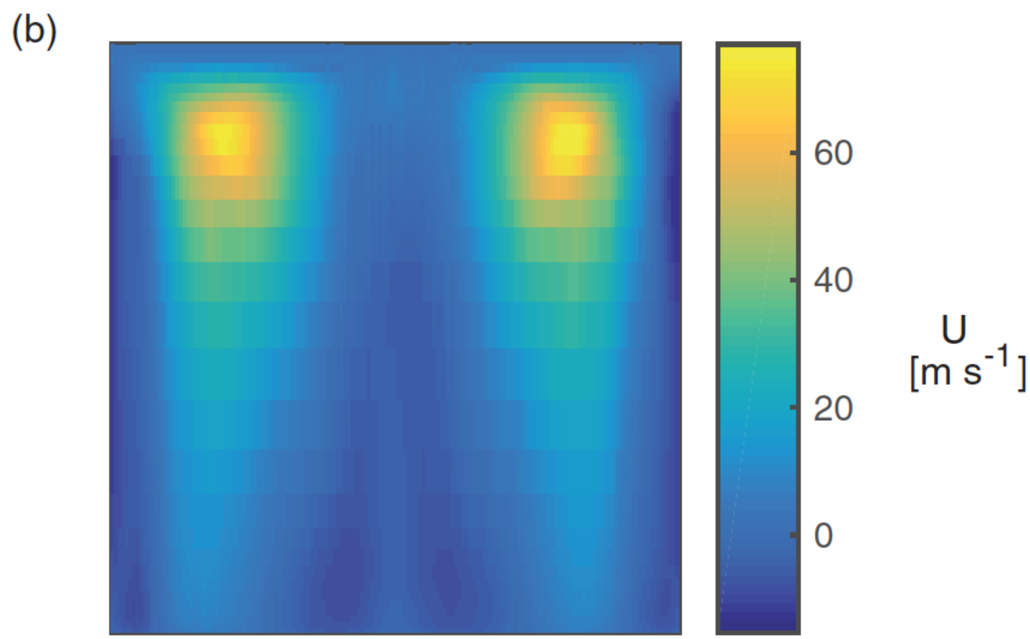
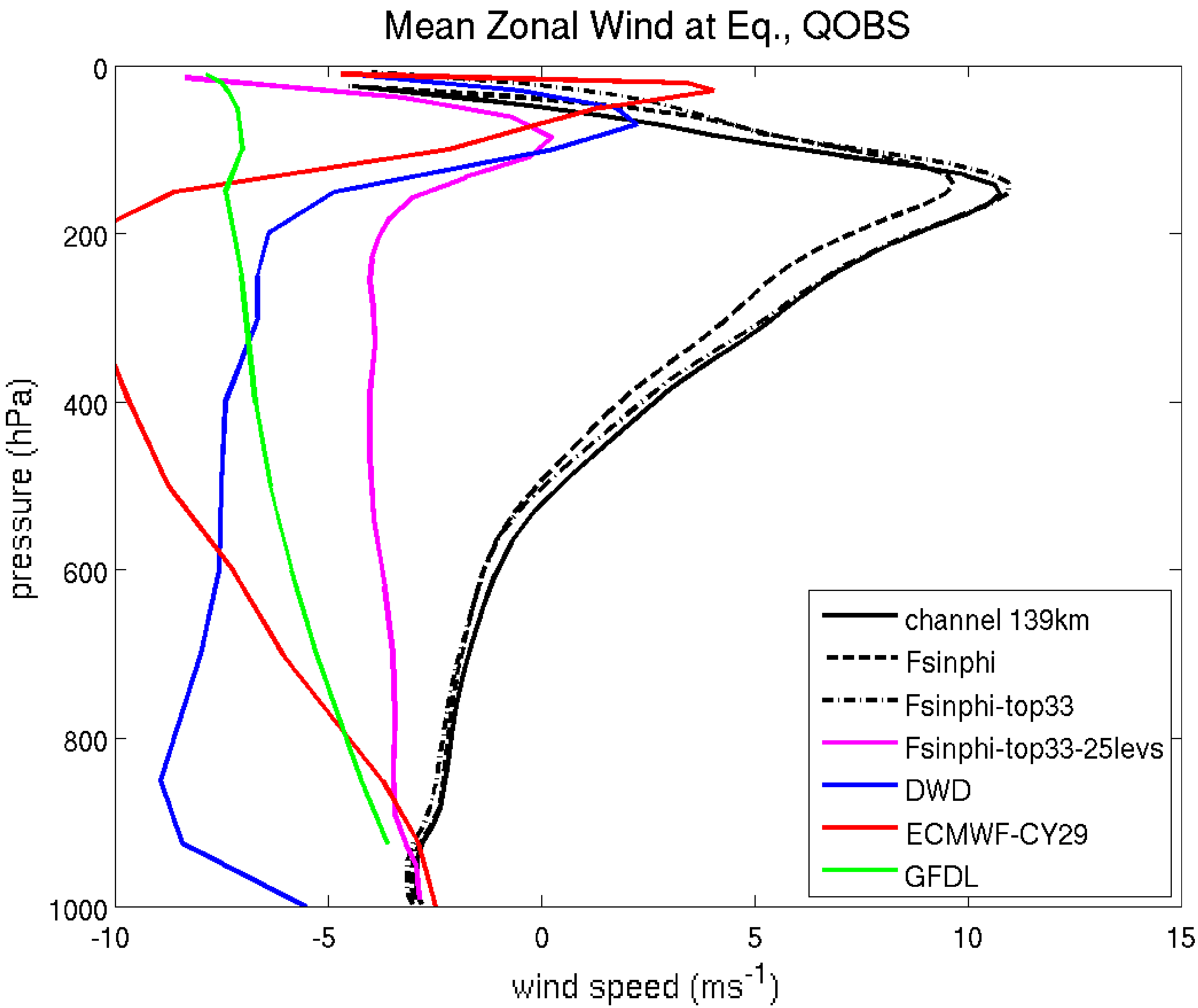
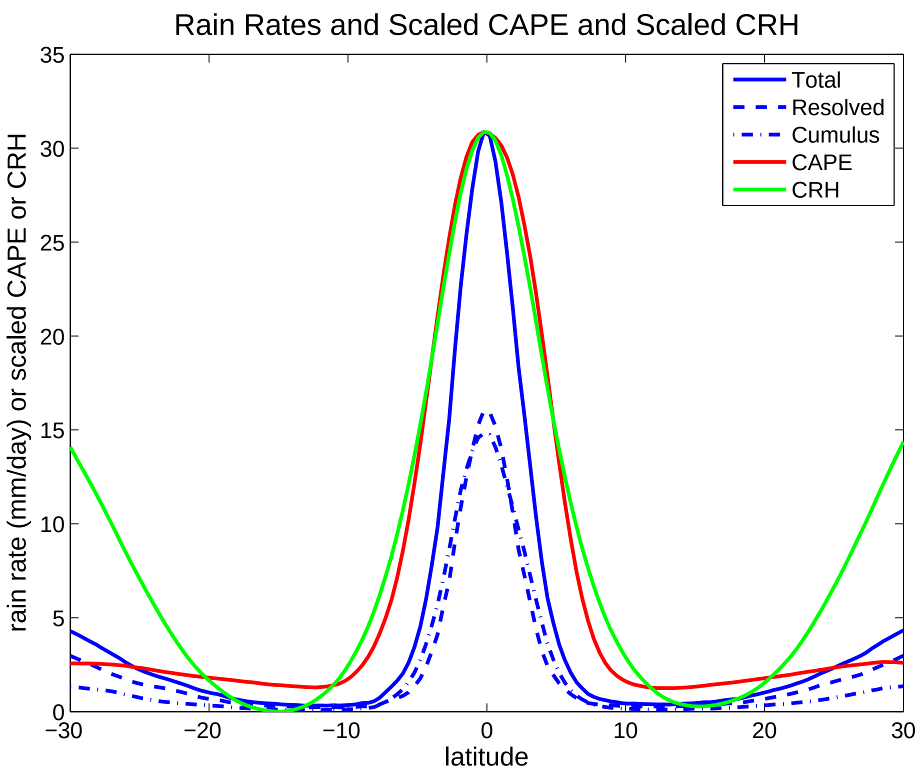


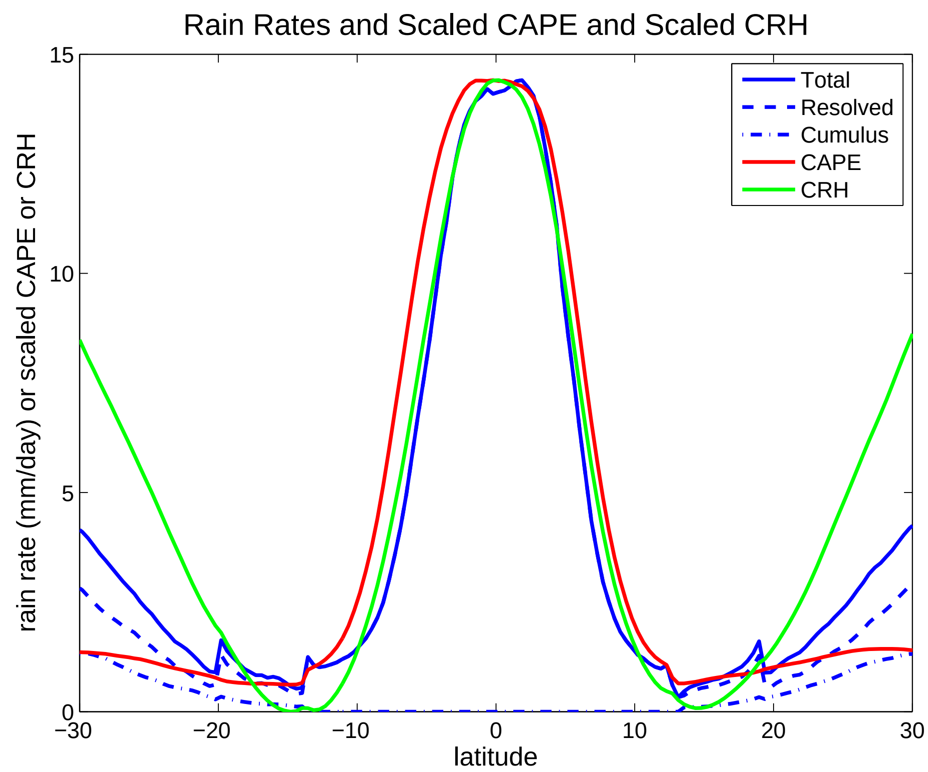
Table 1. CRM Equatorial Channel Configuration

East-west domain extent L_x	20,480 km
North-south domain extent L_y	10,240 km (46°S–46°N)
Horizontal grid spacing $\Delta x = \Delta y$	4 km
Time step Δt	10 s
Vertical grid	32 variably spaced levels up to 32.5 km
Lateral boundary conditions	N and S: wall; E and W: periodic
Top boundary condition	Wall; damping layer above 20 km
Specified (QOBS) SST (°C)	$27(\cos^2(lat/60°)+\cos^4(lat/60°))/2$
Control (CTRL) simulation length	30 days
Humidity perturbation used for QPERT branch	0.1 g kg^{-1} at 700 hPa grid level




Mean Zonal Wind at Eq., QOBS
pressure (hPa)
0
200
400
600
800
1000
-10
-5
0
5
10
15
wind speed (ms^{-1})
channel 139km
Fsinphi
Fsinphi-top33
Fsinphi-top33-25levs
DWD
ECMWF-CY29
GFDL

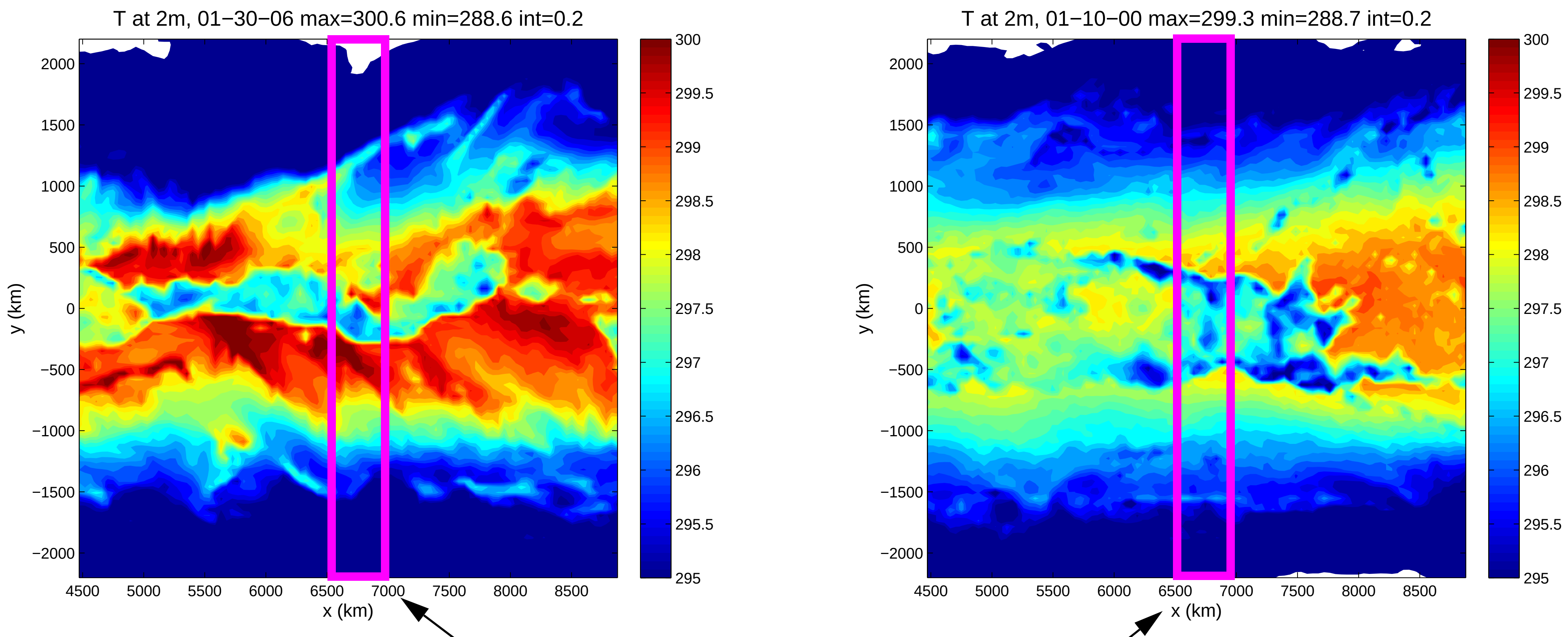




- Parameterized convection focuses convection on highest CAPE and CRH;

  Resolved convection spreads them out, makes them congruent.

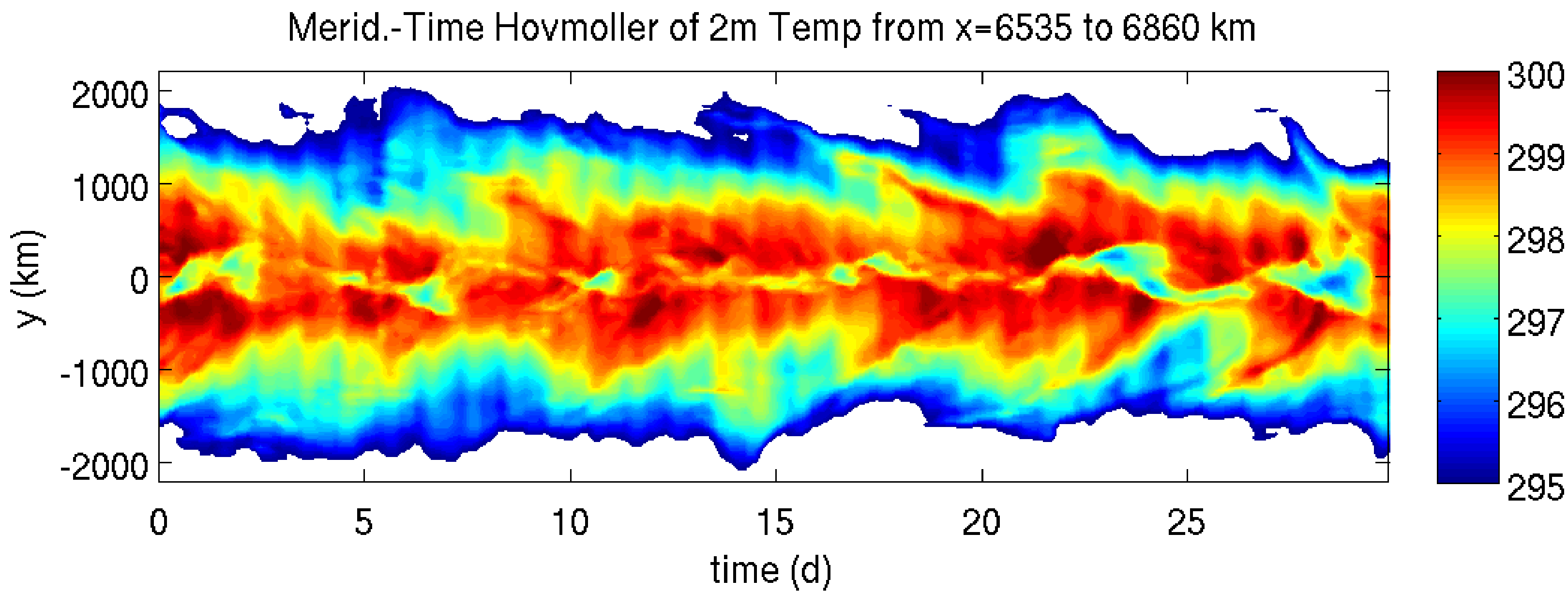
- To show this more objectively - we look at meridional-time (y-t) Hövmoller diagrams for a strip at the center of the domain.



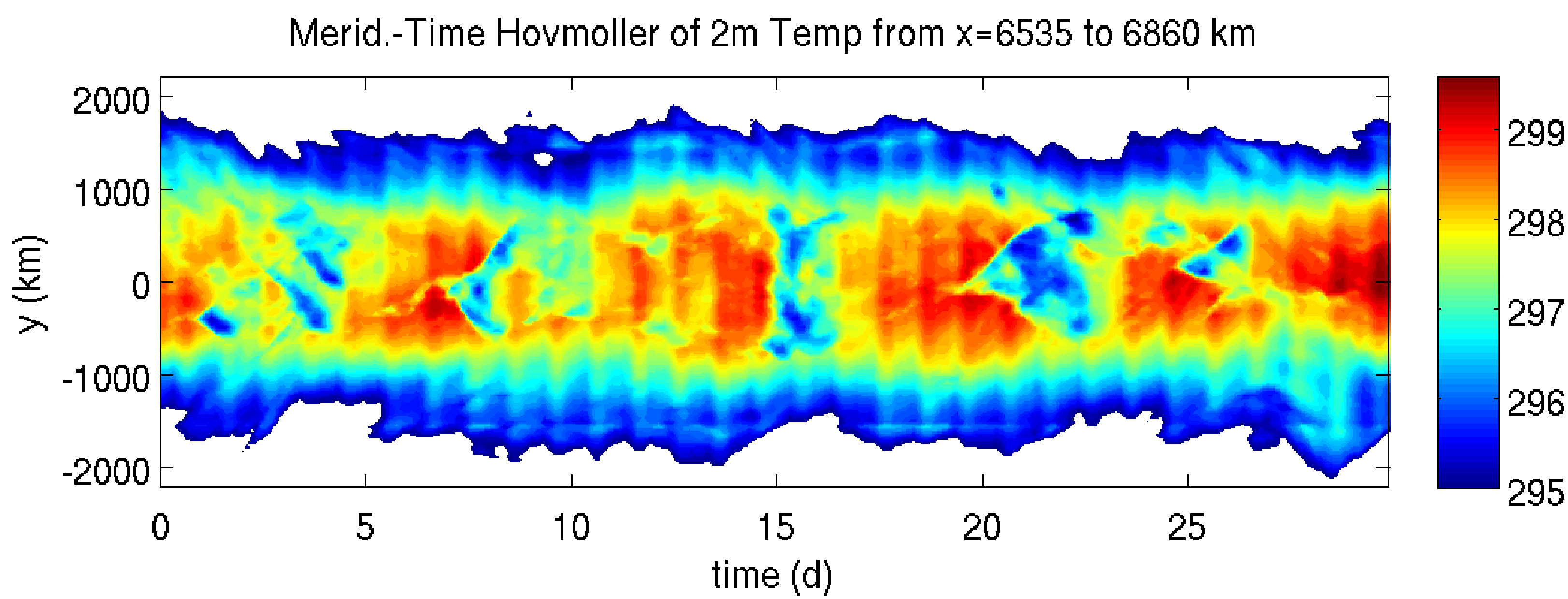
data zonally averaged

- To show this more objectively - we look at meridional-time (y-t) Hovmoller diagrams for a strip at the center of the domain.

CP

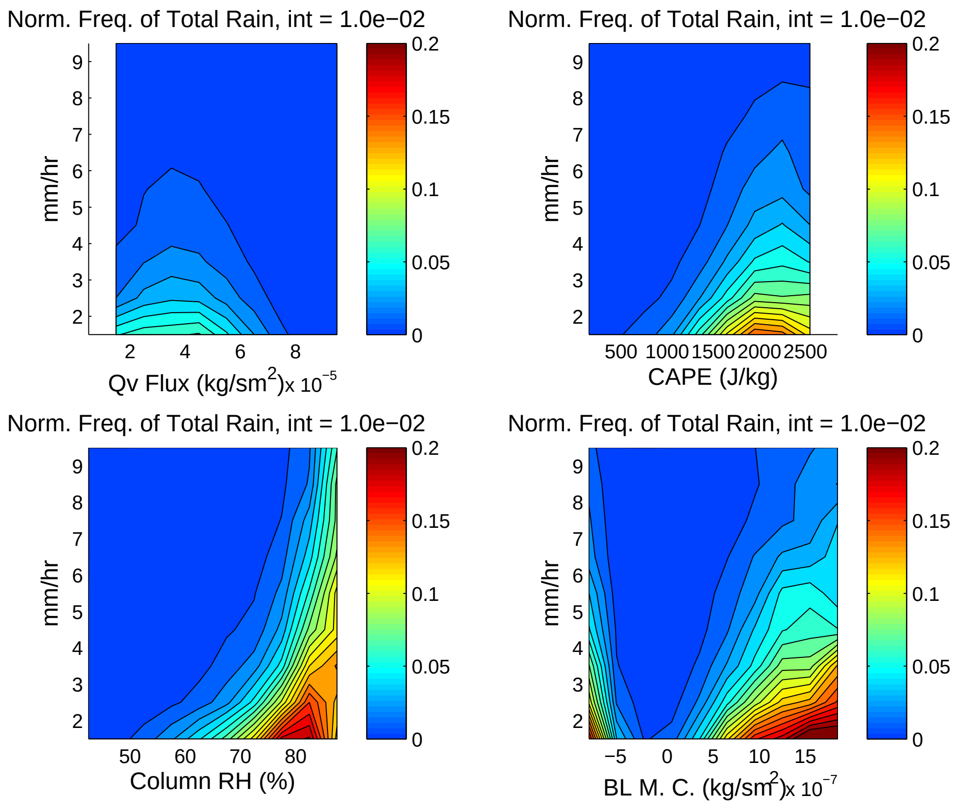


resolved



Normalized Frequency Diagrams of Total Rain Rate as a Function of Environmental Parameters

46 km Tiedtke CP



Nested 5 km