Z-grid unified model update and an issue

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Update

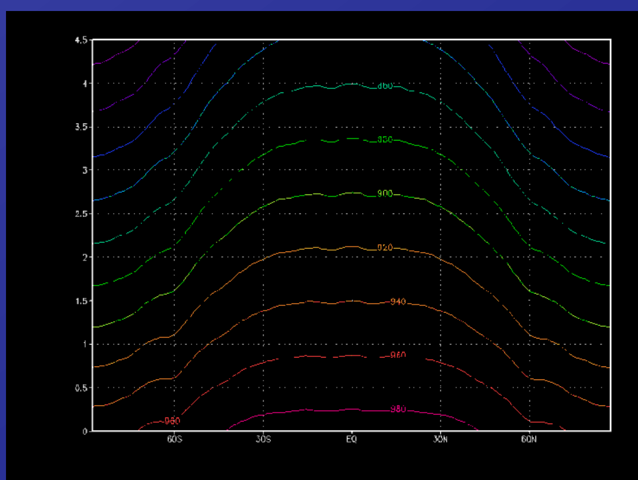
- **April 2009**
  - Z-grid anelastic global model
    - Based on Z-grid hydrostatic model of Ross
- **July 2009**
  - Unified model
    - Cold bubble test in a limited domain (Cartesian)
    - Z-grid unified global model: Jablonowski's test (It was just a lucky.)
- **January 2010**
  - Tentative solution to a problem
    - Model was unstable in a case including larger divergence.
  - Implementing SAM's physics
    - (finished) Surface fluxes
    - (finished) Cloud microphysics
    - (not yet) Turbulence
    - (not yet) Radiation
  - Test simulations with "clouds"

Surface fluxes + -2 K forcing

- SAM's surface flux parameterization
- -2 K forcing for the prognostic equation of potential temperature

Model blows up…

p



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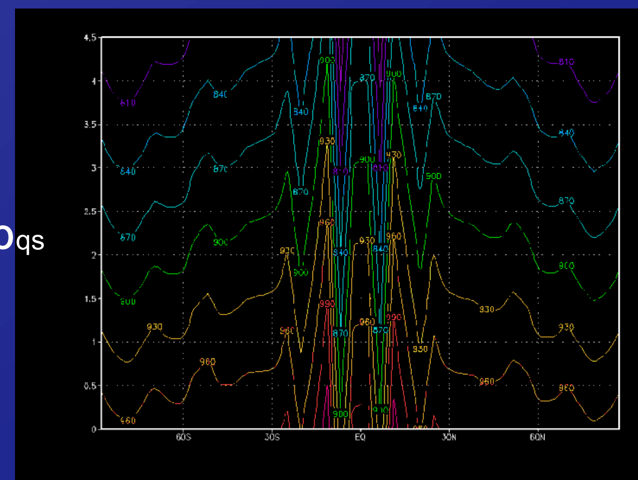
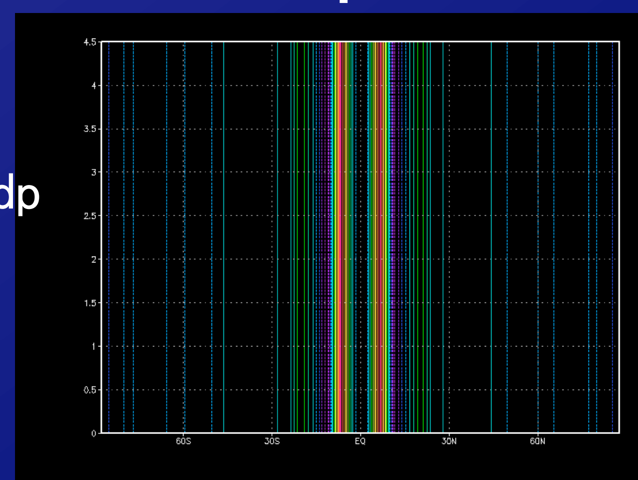
p_{qs}



+

dp



Cause

$$\frac{\partial(\pi_{qs})_{sf\,c}}{\partial t} = \frac{1}{(p_{qs}/\pi_{qs})_{sf\,c} - (p_{qs}/\pi_{qs})_{top}} \left[\left(\frac{p_{qs}}{\pi_{qs}} \right)_{top} \int_{z_{sf\,c}}^{z_{top}} \frac{g}{c_p \theta^2} \frac{\partial \theta}{\partial t} dz - \kappa g \int_{z_{sf\,c}}^{z_{top}} \underline{\nabla_h \bullet (\rho_{qs} \mathbf{v}_h)^n} dz \right] \quad (2.16)$$

$$(\pi_{qs})_{sf\,c}, \theta \rightarrow \pi_{qs} \rightarrow p_{qs} \rightarrow \rho_{qs}$$

Forward scheme is used to get quasi-static density of n+1.

$$\frac{\rho_{qs}^{n+1} - \rho_{qs}^{n}}{\Delta t} = \underline{-\nabla_h \bullet (\rho_{qs} \mathbf{v}_h)}^{n+1} - \frac{\partial}{\partial z} (\rho_{qs} w)^{n+1} \quad (4.5)$$

Backward scheme is assumed to get a Poisson equation.

Assume del(theta)/del(t) = 0.

- If horizontal momentum is convergent for a vertical column at time “n”, vertically integrated horizontal momentum at time “n+1” must be convergent to satisfy (4.5).

$$\int_{z_{sf\,c}}^{z_{top}} \nabla_h \bullet (\rho_{qs} \mathbf{v}_h)^n dz > 0 \rightarrow \int_{z_{sf\,c}}^{z_{top}} \nabla_h \bullet (\rho_{qs} \mathbf{v}_h)^{n+1} dz > 0$$

- Then, convergent momentum at “n+1” is used to get mass at “n+2”. That means vertically integrated momentum at “n+2” is also convergent.
    - p_{qs} tries to make divergence, but dp does not allow that.
- There is a positive feedback in the vertically integrated horizontal momentum.

Solution

$$\frac{\partial(\pi_{qs})_{sf\,c}}{\partial t} = \frac{1}{(p_{qs}/\pi_{qs})_{sf\,c} - (p_{qs}/\pi_{qs})_{top}}\left[\left(\frac{p_{qs}}{\pi_{qs}}\right)_{top}\int_{z_{sf\,c}}^{z_{top}} \frac{g}{c_p\theta^2}\frac{\partial\theta}{\partial t}dz - \kappa g\int_{z_{sf\,c}}^{z_{top}} \underline{\nabla_h \bullet (\rho_{qs}\mathbf{v}_h)^{n+1}}\, dz\right] \qquad (2.16)$$

Backward scheme for (2.16)?

$$\frac{(\rho_{qs}\mathbf{v}_h)^{n+1} - (\rho_{qs}\mathbf{v}_h)^{n}}{\Delta t} = -c_p\rho_{qs}\theta\left(\nabla_h\pi_{qs}^n + \underline{\nabla_h\delta\pi^n}\right) + \mathbf{A}_{\mathbf{v}_h}^n$$

dp is diagnosed by a Poisson equation assuming (4.5).

$$\frac{\rho_{qs}^{n+1} - \rho_{qs}^{n}}{\Delta t} = -\nabla_h \bullet (\rho_{qs}\mathbf{v}_h)^{n+1} - \frac{\partial}{\partial z}(\rho_{qs}w)^{n+1} \qquad (4.5)$$

r_{qs}(n+1) is computed through (2.16).

We need to make implicit equations to avoid the positive feedback of divergence/convergence.

I tried. But, I have not succeeded yet.

I could not clear the complexity coming from $p_{qs} = p_{00}\pi^{1/\kappa}$.

Temporary solution

Is it possible to estimate dp or to avoid the use of dp?

1. Updating momentum without dp.
2. Estimating dp through iteration (Runge-Kutta).
3. Using dp of the previous time step.
4. Combination of 1, 2 and 3.
5. Prognosing vertical mean part of dp.
6. Horizontally explicit and vertically implicit computation of momentum equations.
7. Damping the Lamb wave part in 4.

$$\frac{\partial(\pi_{qs})_{sfc}}{\partial t} = \frac{1}{(p_{qs}/\pi_{qs})_{sfc} - (p_{qs}/\pi_{qs})_{top}} \left[\left(\frac{p_{qs}}{\pi_{qs}}\right)_{top} \int_{z_{sfc}}^{z_{top}} \frac{g}{c_p \theta^2} \frac{\partial \theta}{\partial t} dz - \kappa g \int_{z_{sfc}}^{z_{top}} \nabla_h \bullet (\rho_{qs} \mathbf{v}_h) dz \right] \quad (2.16)$$

⇓

$$\frac{\partial(\pi_{qs})_{sfc}}{\partial t} = 0$$

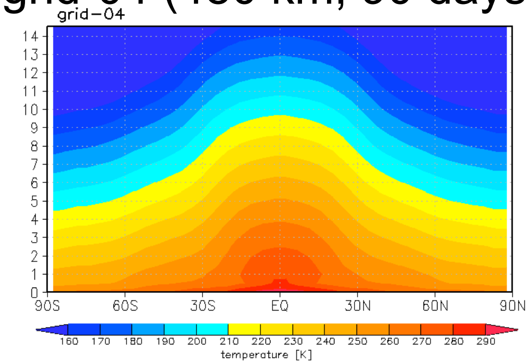
Experimental setup

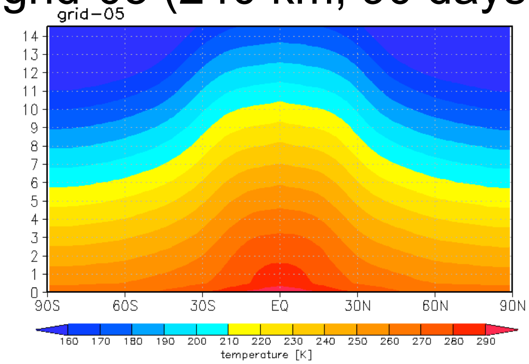
- Z-grid unified dynamical core
  - Fiexed $(p_{qs})_{sfc}$, 2nd-order Runge-Kutta
- SAM's physics
  - w/ surface fluxes, cloud microphysics
  - w/o turbulence, radiation, ice sedimentation
- Horizontal grids and time integrations
  - grid-04 (dx~480 km): 120 days (dt=360 s)
  - grid-05 (dx~240 km): 120 days (dt=150 s)
  - grid-06 (dx~120 km): 59 days (dt=60 s)
  - grid-09 (dx~ 15 km): 5 days (dt=10 s, 24 hr by 2560 PEs)
- Vertical grid
  - dz=500 m, 30 levels (0-15000 m), No sponge layer
- Aquaplanet
  - Control SST (http://www.atmos.ucla.edu/~brianpm/cfmip2_aqua.html)
  - No initial wind
  - temperature lapse rate of -6 K/km (RH=80%)
  - -2 K/day forcing

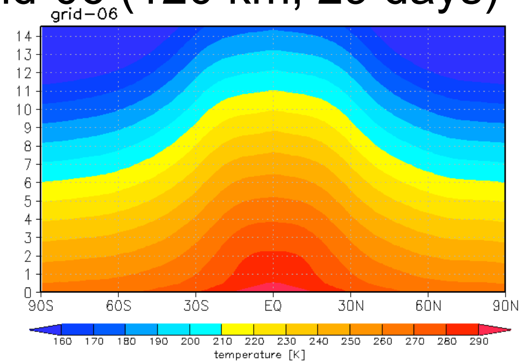
Zonal mean

Temperature

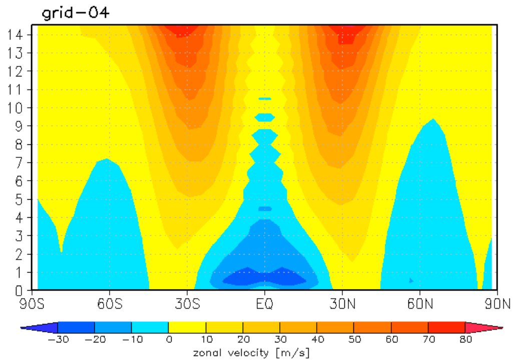
grid-04 (480 km, 90 days) grid-05 (240 km, 90 days) grid-06 (120 km, 29 days)

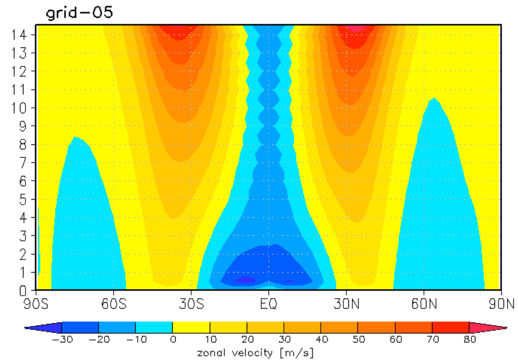


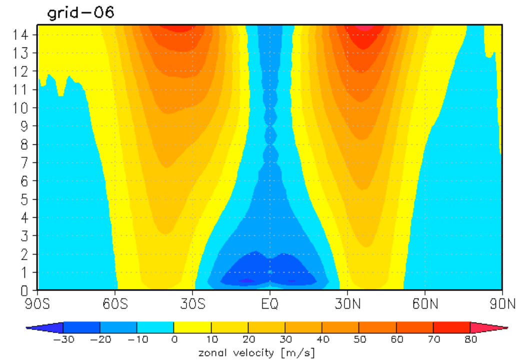




zonal velocity

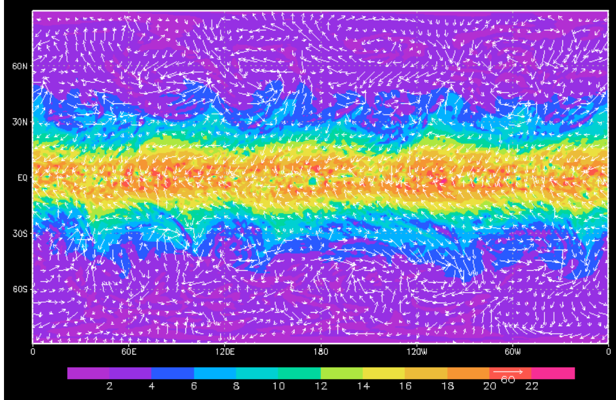




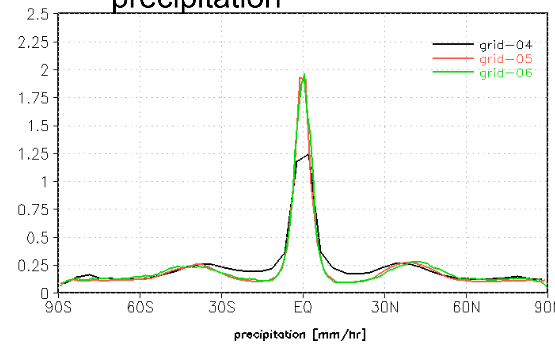


Moisture

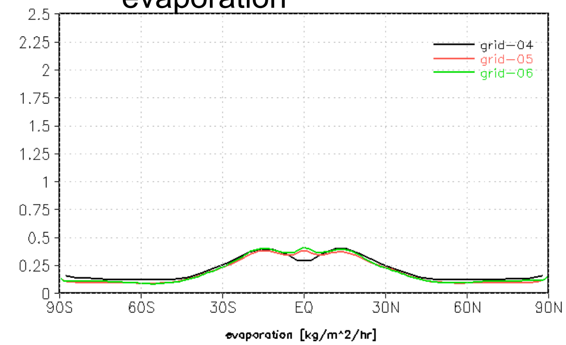
qv [g/kg] & u;v, grid-06, day-59

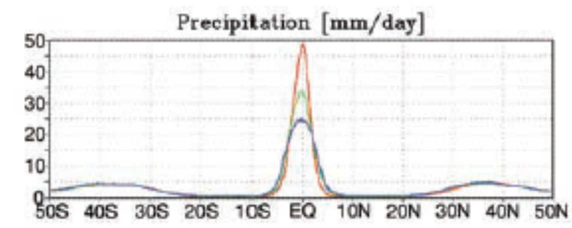


Time- and zonal-mean precipitation



Time- and zonal-mean evaporation

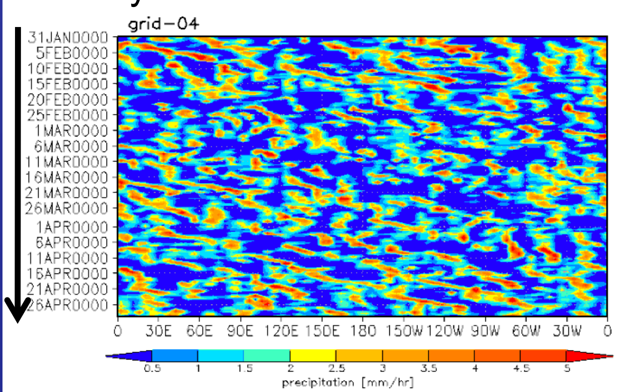




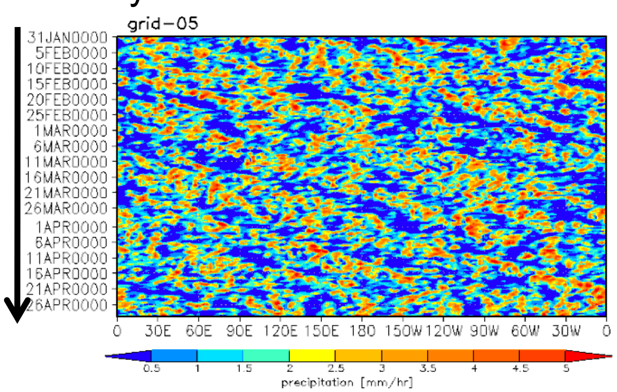
Tomita et al. (2005)

Hovmoller diagnoram (precipitation, 5S-5N mean)

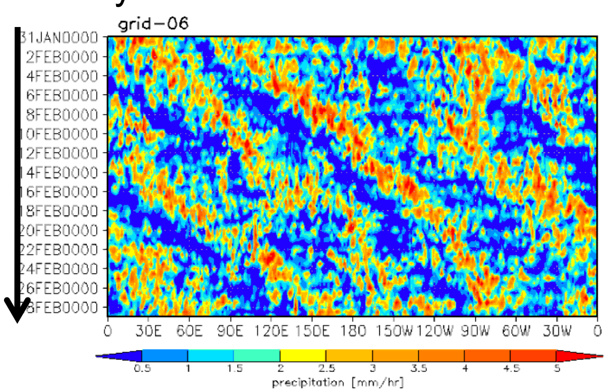
90 days



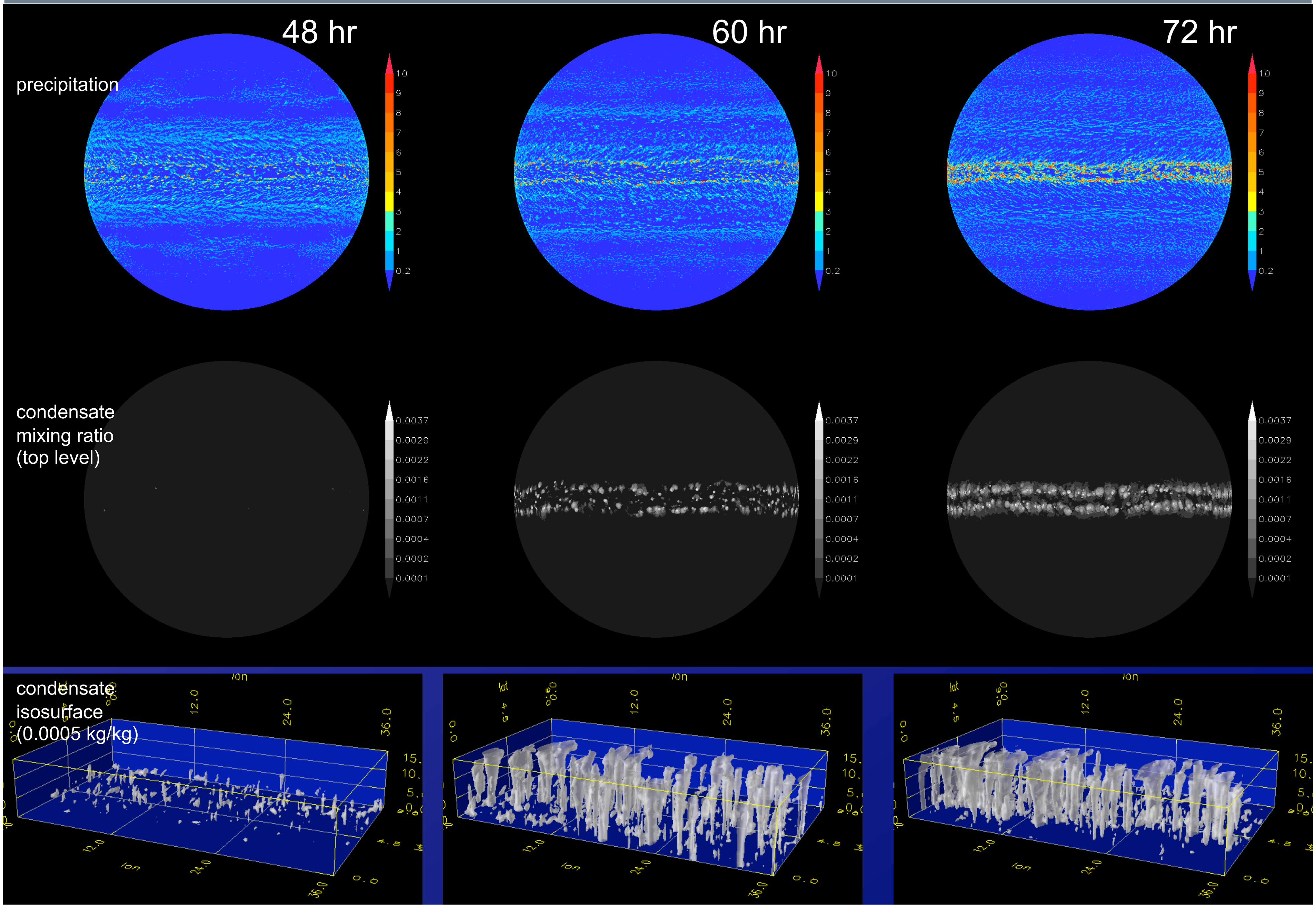
90 days



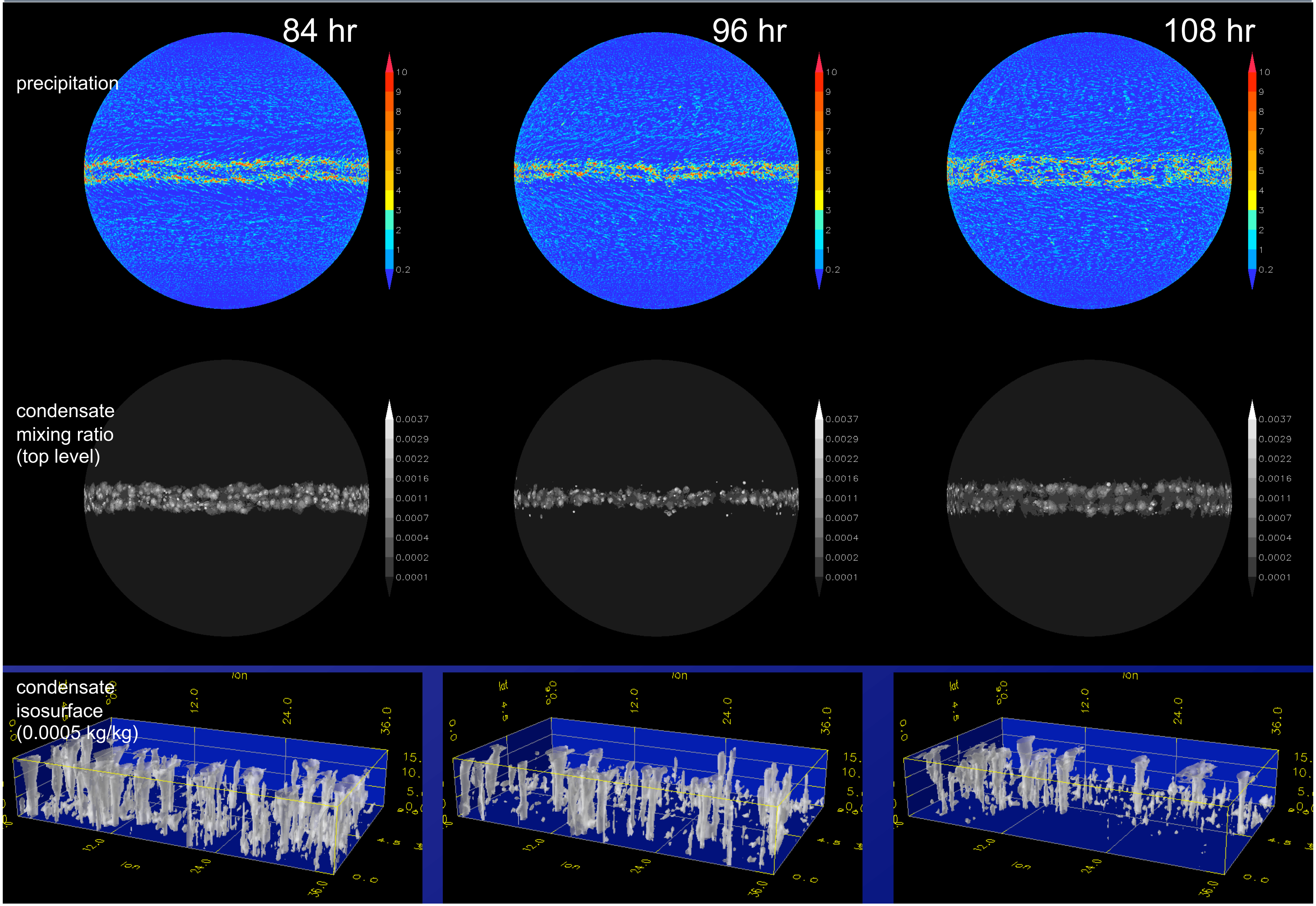
29 days



grid-09 (15 km)


48 hr
60 hr
72 hr
precipitation
10
9
8
7
6
5
4
3
2
1
0.2
condensate
mixing ratio
(top level)
0.0037
0.0029
0.0022
0.0016
0.0011
0.0007
0.0004
0.0002
0.0001
condensate
isosurface
(0.0005 kg/kg)
lon
lat
12.0
24.0
36.0
15.
10.
5.
0.0

grid-09 (15 km)


84 hr
96 hr
108 hr
precipitation
10
9
8
7
6
5
4
3
2
1
0.2
condensate
mixing ratio
(top level)
0.0037
0.0029
0.0022
0.0016
0.0011
0.0007
0.0004
0.0002
0.0001
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(0.0005 kg/kg)
lon
12.0
24.0
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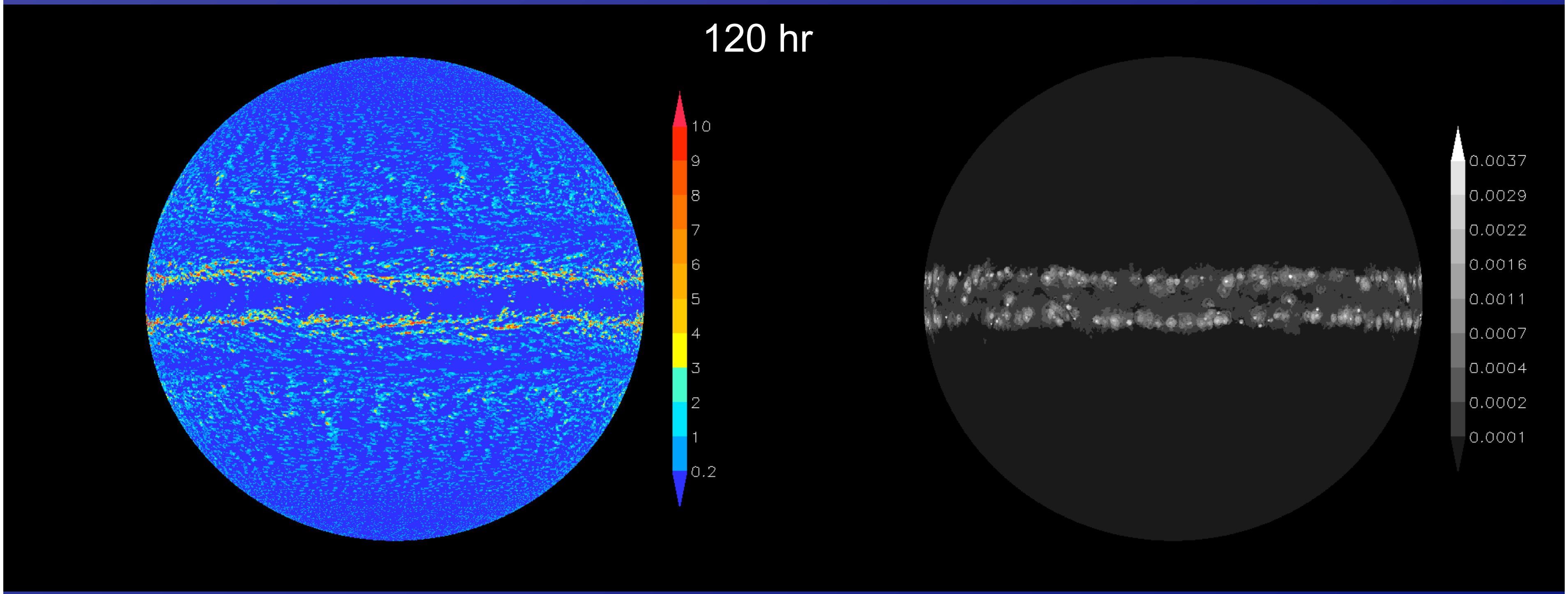
15.
10.
5.
0.0
lat

grid-09 (15 km)


120 hr
10
9
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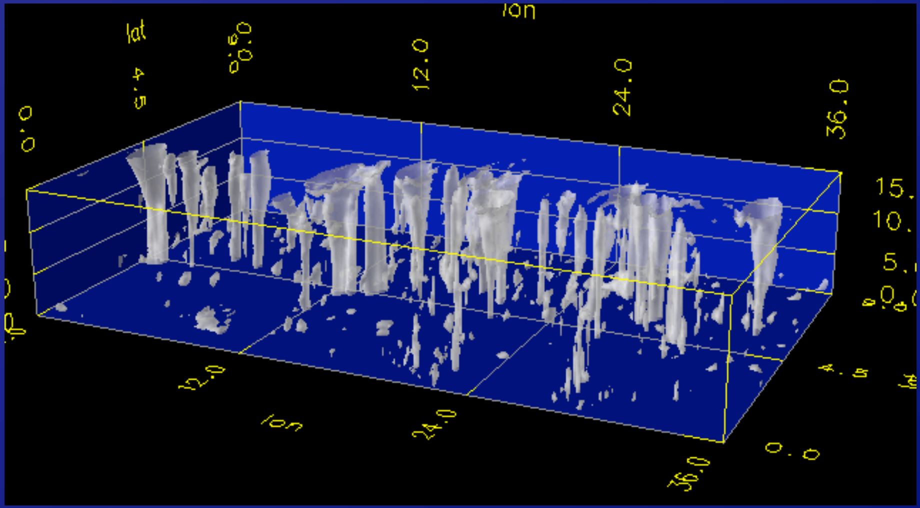
lon
lat
12.0
24.0
36.0
15.
10.
5.

Summary

- **Surface fluxes and a cloud microphysics scheme have been transplanted from SAM.**
  - I would like to thank Marat.
  - I had no time to test turbulence and radiation…
- **Test simulations**
  - Low-resolution simulations appear to reproduce "reasonable" atmosphere.
    - It is of course physically unreasonable to use cloud microphysics scheme.
  - 15-km simulation run for 5 days in its first attempt.
- **There is an issue relating the prediction of the exner function of the surface.**
  - We might need a magic!
  - I need to get a fresh start.