Further development of the super-parameterization concept

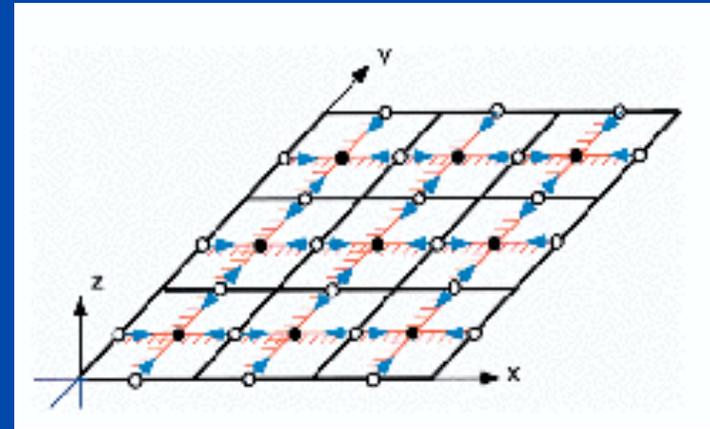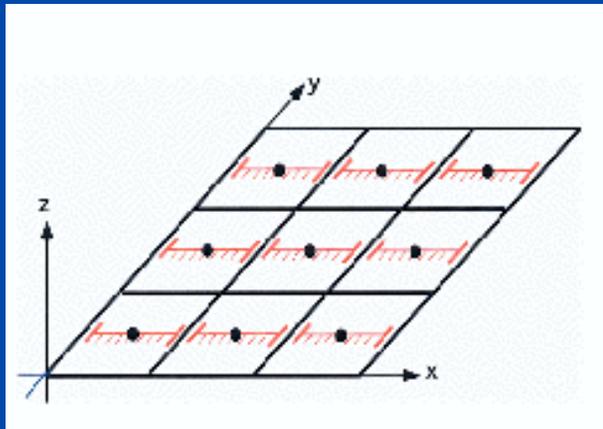**Wojciech Grabowski**

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Plan:

- Clarification of results shown in Jung and Arakawa (MWR 2005; JA05)

- New approach: super-parameterization with large-scale gradients included into the 2D small-scale model
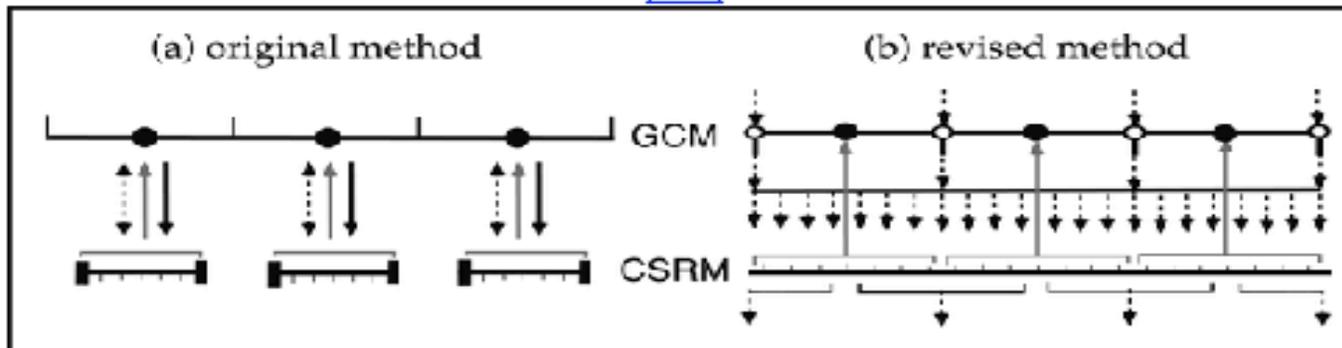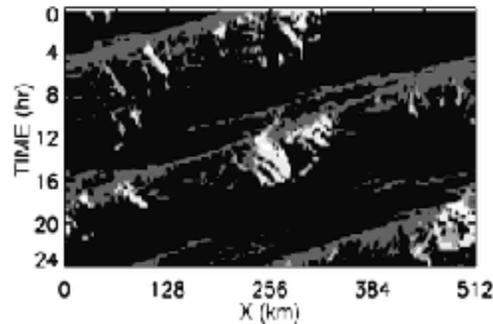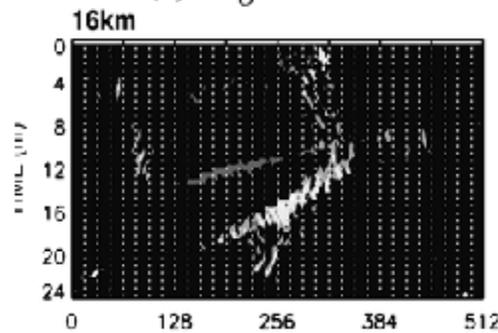
Randall et al. BAMS 2003

FIG. 1. Schematic illustrations of the coupling methods between GCM and CSRM in the MMF. See text for further explanation.

JA05

Cloud Top Temperature

(a) Control (CTL-A)

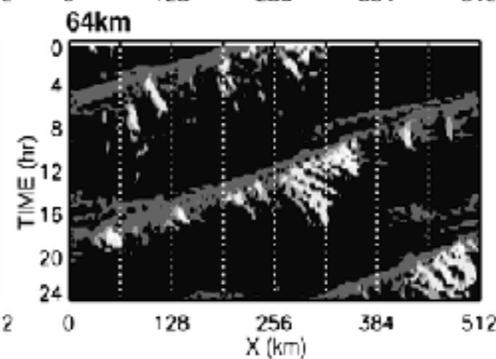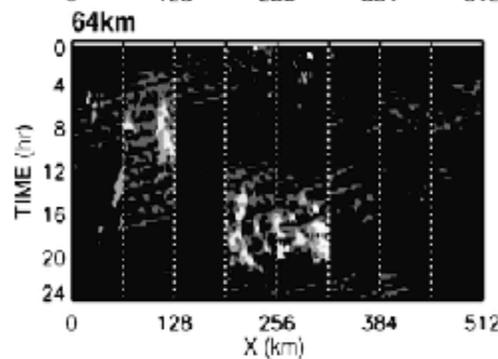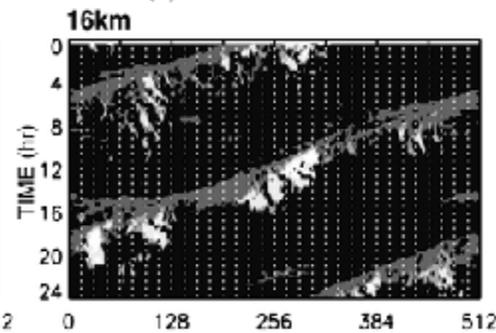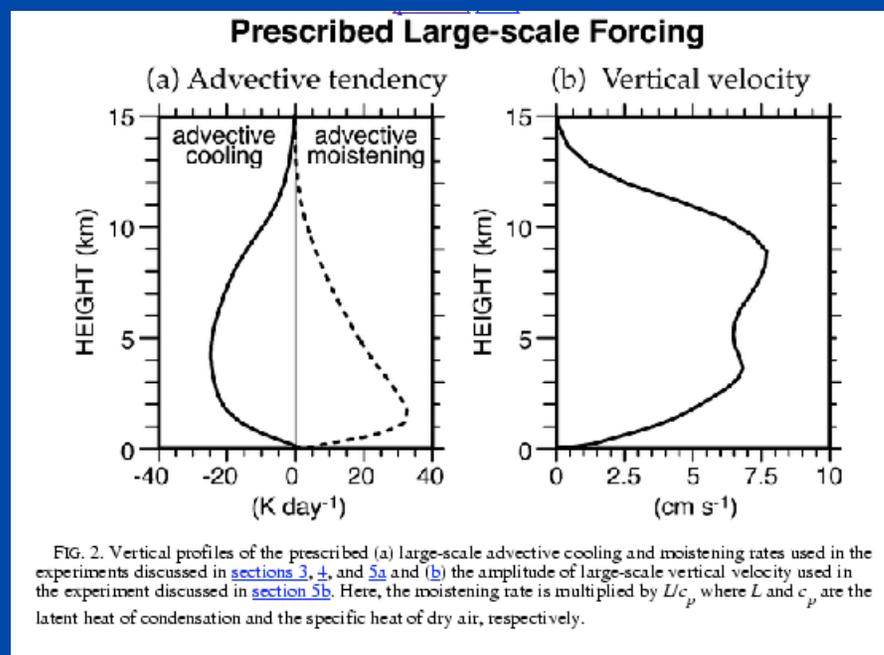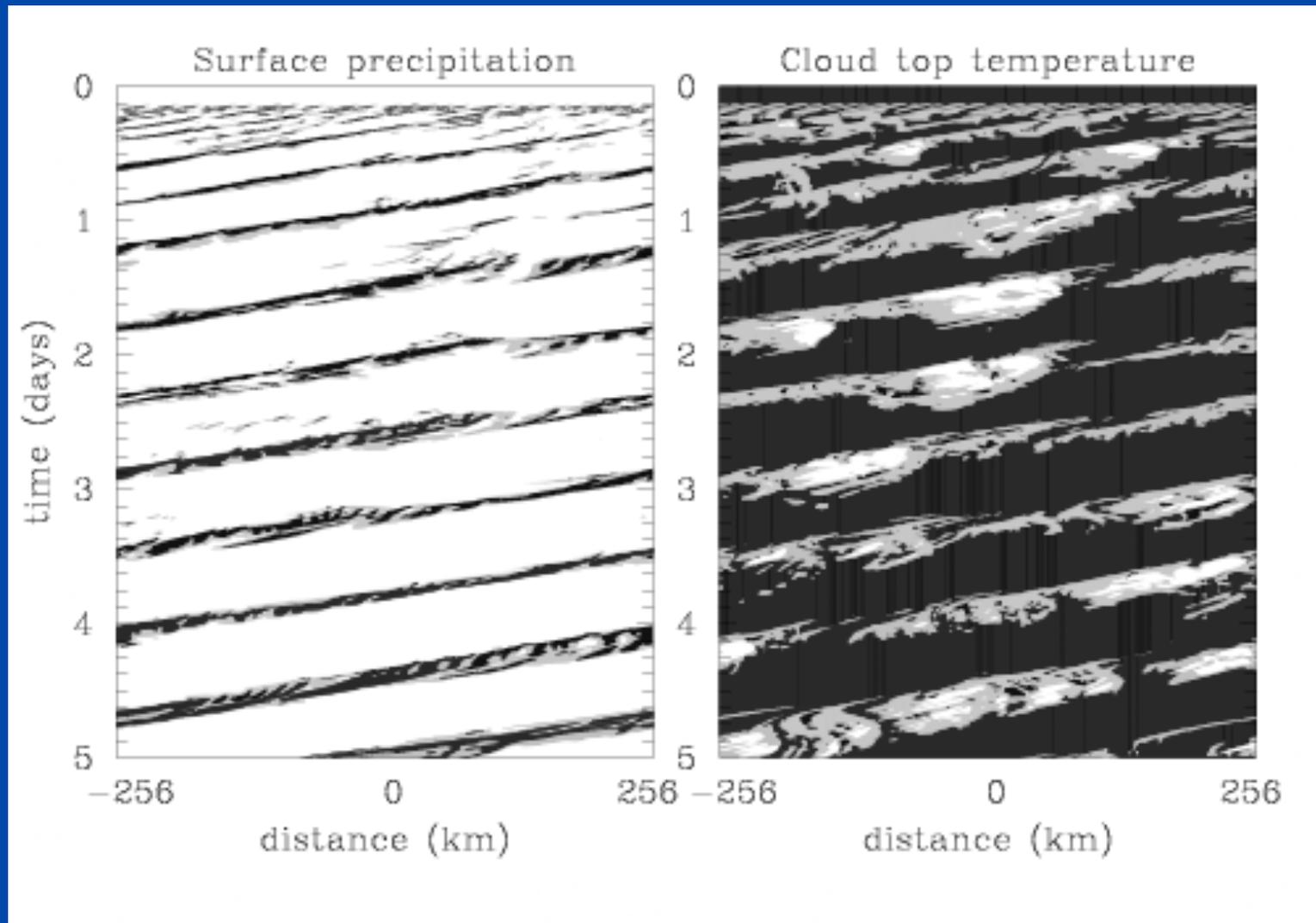(b) Original method

(c) Revised method

FIG. 6. Hovmöller diagrams (x–t) of cloud-top temperature obtained from (a) Control (CTL-A) and the IMF experiments using the (b) original and (c) revised methods with (upper) 16- and (lower) 64-km horizontal grid sizes of the LSDM. The vertical dashed lines in (b) and (c) indicate the LSDM grids.
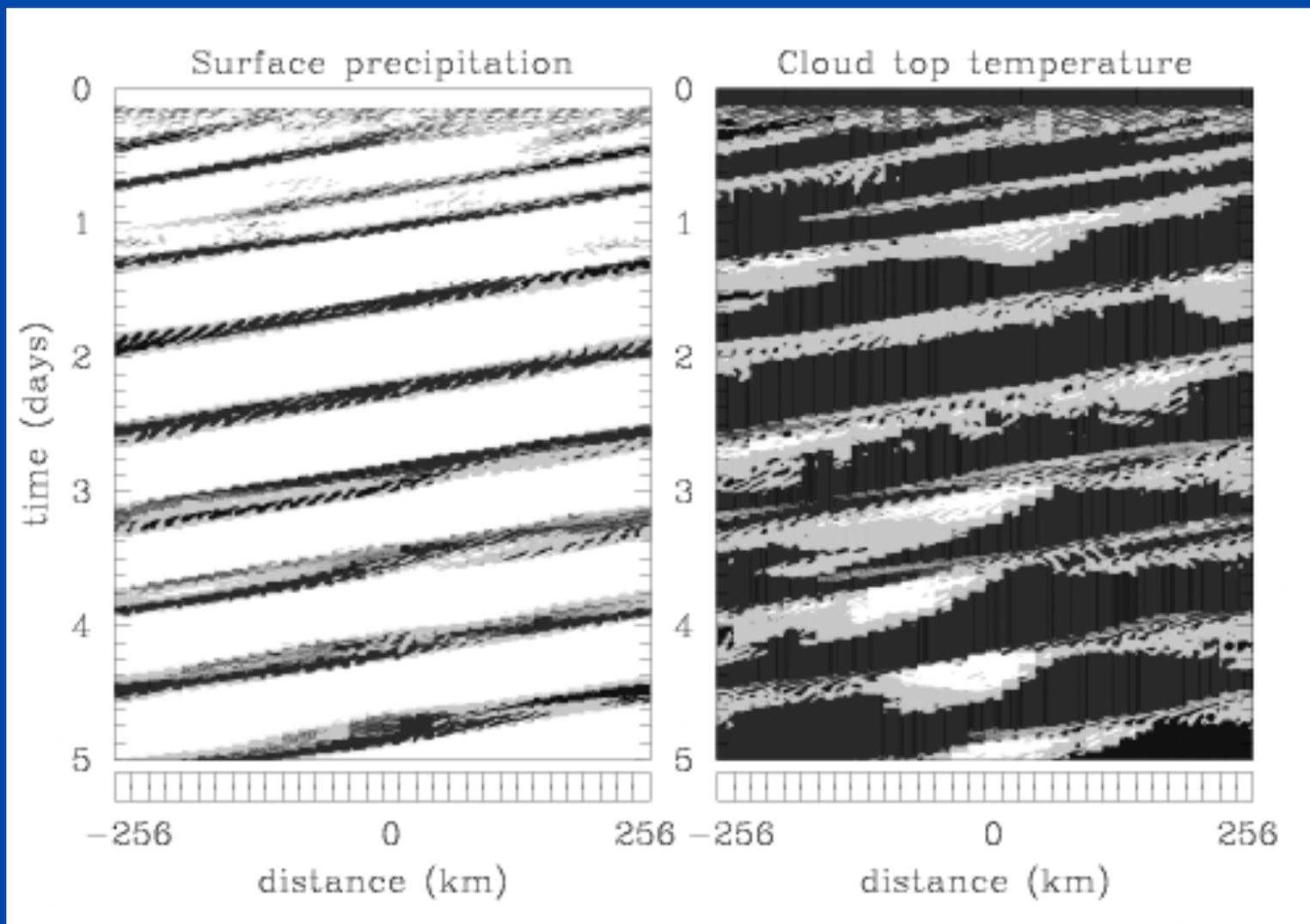
JA05

- Model setup: not exactly as results shown in JA05:
  --- constant SST
  --- no interactive radiation

Prescribed Large-scale Forcing

(a) Advective tendency

(b) Vertical velocity

advective cooling   advective moistening

FIG. 2. Vertical profiles of the prescribed (a) large-scale advective cooling and moistening rates used in the experiments discussed in sections 3, 4, and 5a and (b) the amplitude of large-scale vertical velocity used in the experiment discussed in section 5b. Here, the moistening rate is multiplied by L/c_p where L and c_p are the latent heat of condensation and the specific heat of dry air, respectively.
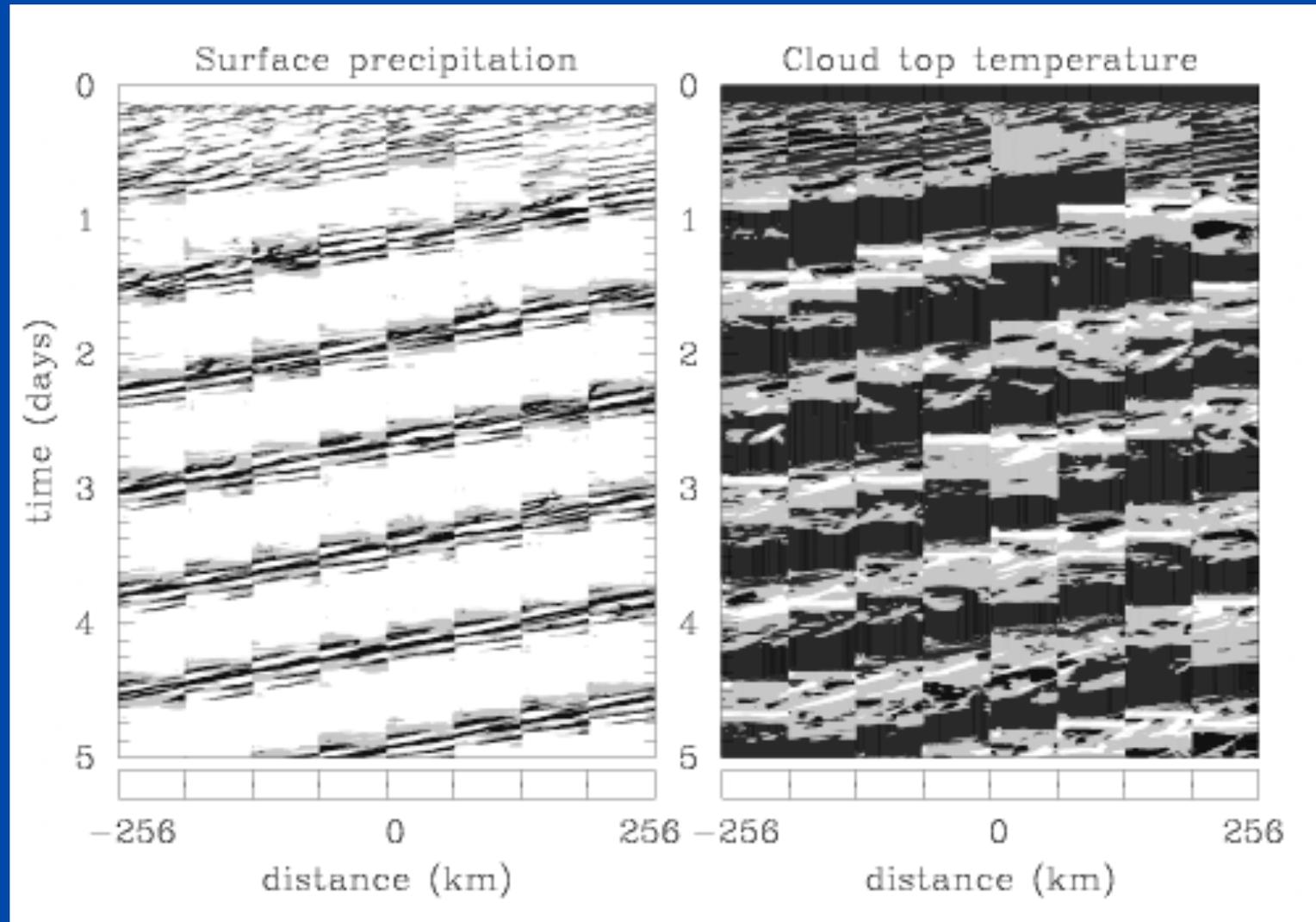
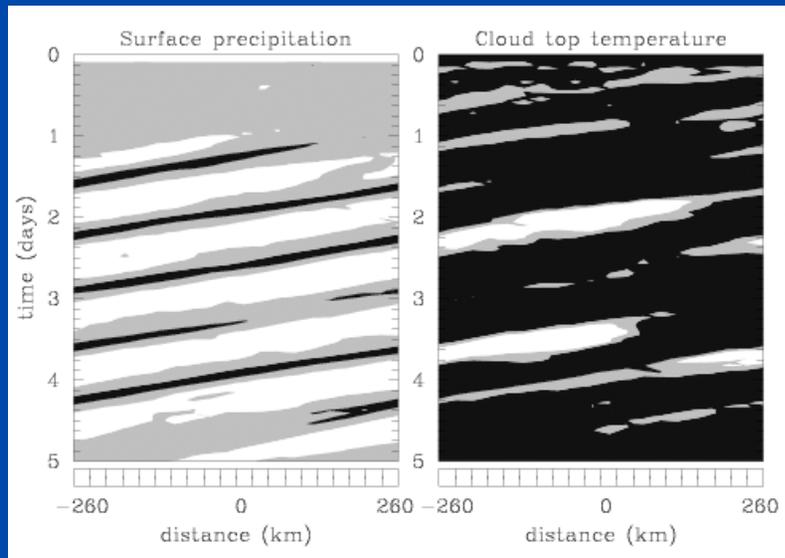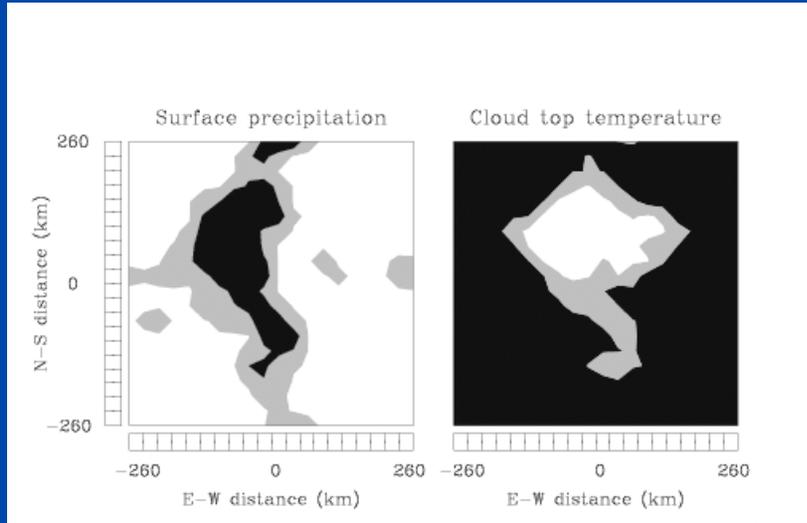JA05

Cloud-resolving simulation (benchmark): Δx=2km

SP simulation: 32 columns with 16-km periodic small-scale models

SP simulation: 8 columns with 64-km periodic small-scale models

3D…

Conclusions:

The original super-parameterization (SP) approach (Grabowski and Smolarkiewicz 1999; Grabowski 2001) seems to perform better than suggested by Jung and Arakawa (2005; JA05). The key is in the coupling between convective dynamics (resolved in 2D by the SP model) and mesoscale dynamics (resolved by the mesoscale model) which, for unclear reason, was not captured in JA05.
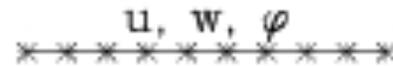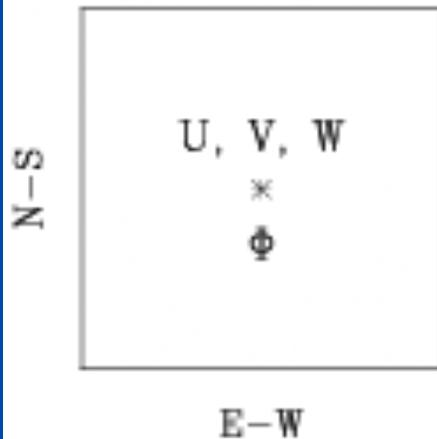
The results suggest that the original approach might be a valuable approach for limited-area models with horizontal grid spacing in the range of 20 to 50 km (e.g., regional climate models).

New Super-Parameterization (NSP):

Super-parameterization domains cannot be periodic for full fields (this implies <w>=0), but can be periodic for small-scale perturbations…

$$\psi = \overline{\psi} + \psi', \qquad \mathbf{u} = \overline{\mathbf{u}} + \mathbf{u}'$$

$\overline{\psi}, \ \overline{\mathbf{u}}$ - large-scale variables

$\psi', \ \mathbf{u}'$ - small-scale variables

Generic form of model equations:

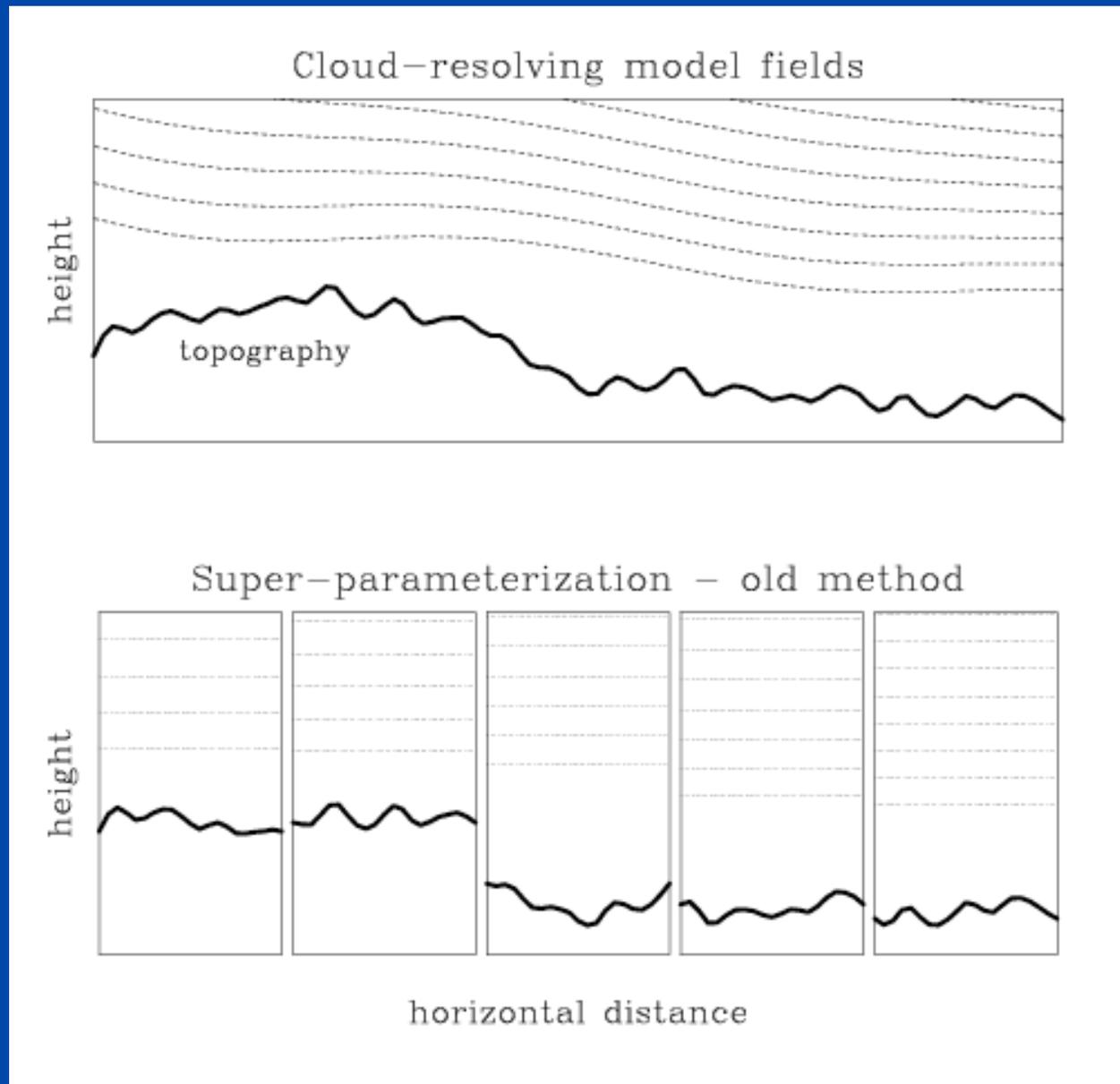$$\frac{\partial \psi}{\partial t} + \nabla(\rho \mathbf{u} \psi) = S_\psi$$

Large-scale equations:

$$\frac{\partial \overline{\psi}}{\partial t} + \nabla_L(\rho \overline{\mathbf{u}} \overline{\psi}) = S_{\overline{\psi}}$$

Small-scale equations:

$$\frac{\partial \psi'}{\partial t} + \nabla_S(\rho \mathbf{u}' \psi') = -\nabla_S(\rho \overline{\mathbf{u}} \psi') - \nabla_S(\rho \mathbf{u}' \overline{\psi}) + S_{\psi'}$$

The original CRCP (or SP) proposal cannot include large-scale gradients (of SST, topography, land-surface processes, etc.)

Cloud−resolving model fields

topography

Super−parameterization − old method

horizontal distance

SP system with cloud-scale models that include large-scale gradients and nonzero mean vertical velocity within cloud-scale models

Cloud−resolving model fields

topography

Super−parameterization − new method

horizontal distance
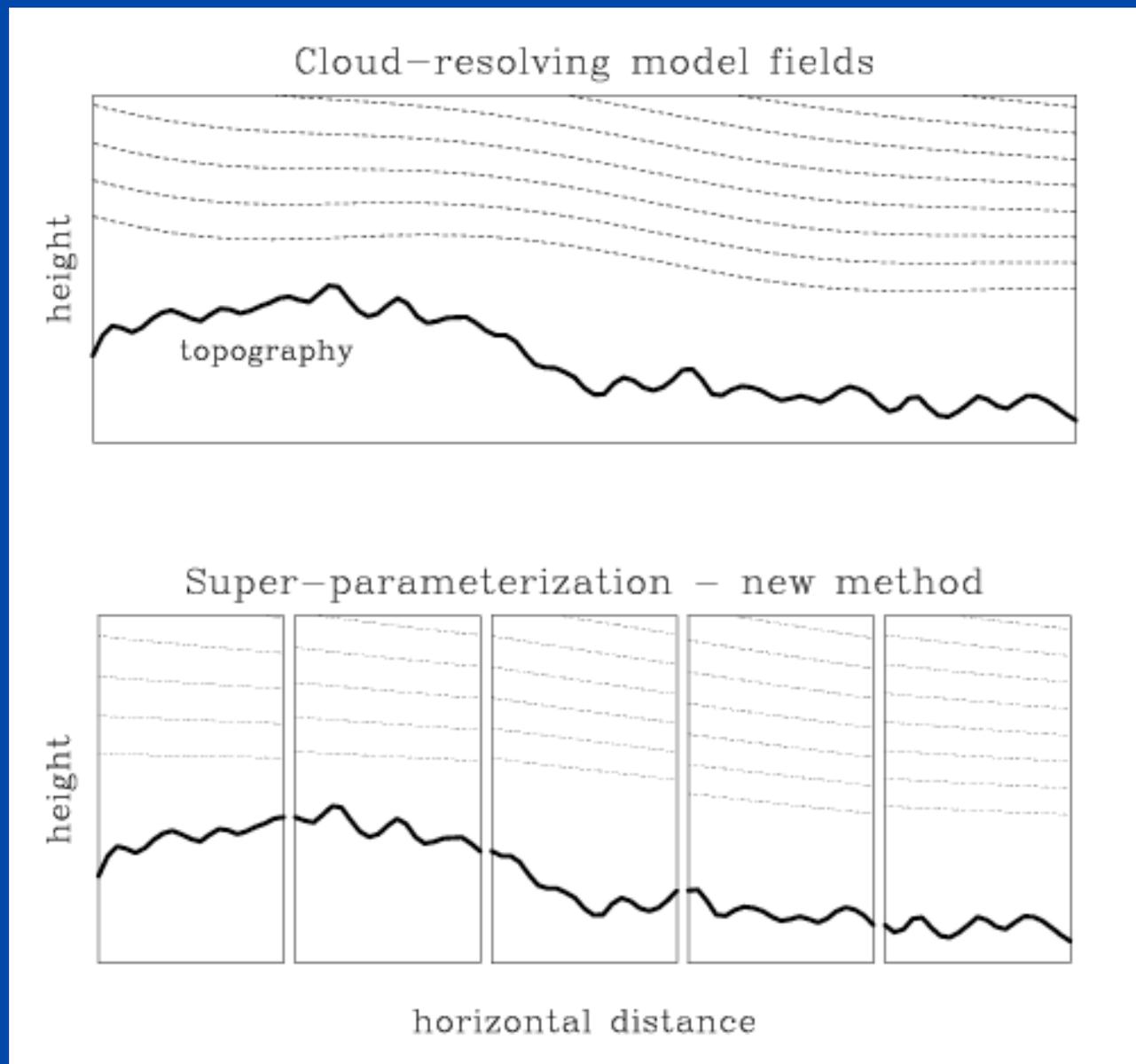
"Cloud-resolving modeling of tropical circulations driven by large-scale SST gradients"; Grabowski et al. (JAS 2000)
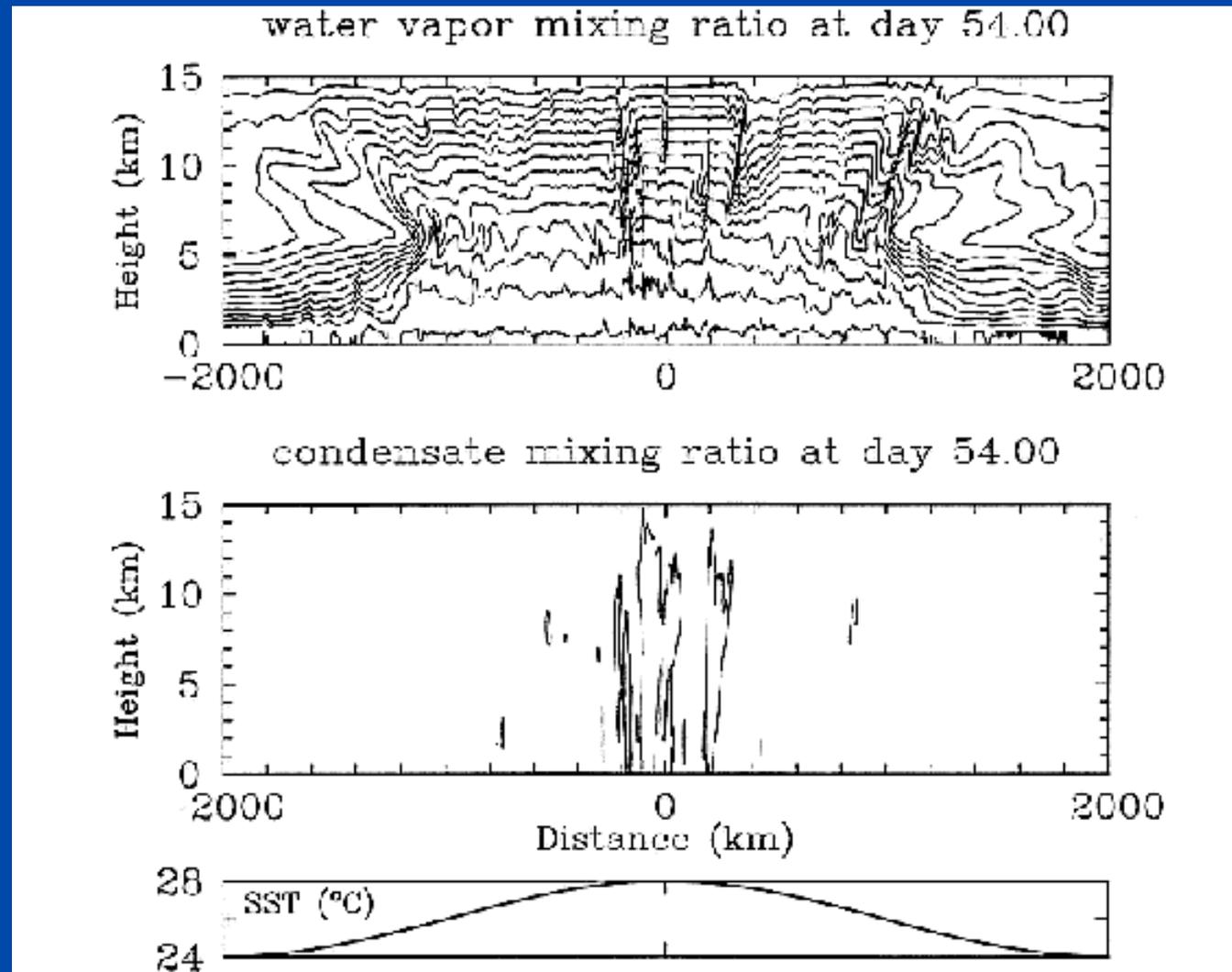

Fig. 12. Snapshots of the water vapor mixing ratio and the total condensate at day 54.00 for the Walker-like circulation simulation. Water vapor mixing ratio is plotted using a decimal-logarithmic scale with three contours per decade. Only one contour ($0.1 \, g \, kg^{-1}$) is shown for the condensate field. The bottom panel shows the prescribed SST spatial distribution.

Surface
precipitation rate in
a simulation with
prescribed radiative
cooling (1.5 K/day
across troposphere)

PR   PRECIPITATION   .2 and 5 mm/hr
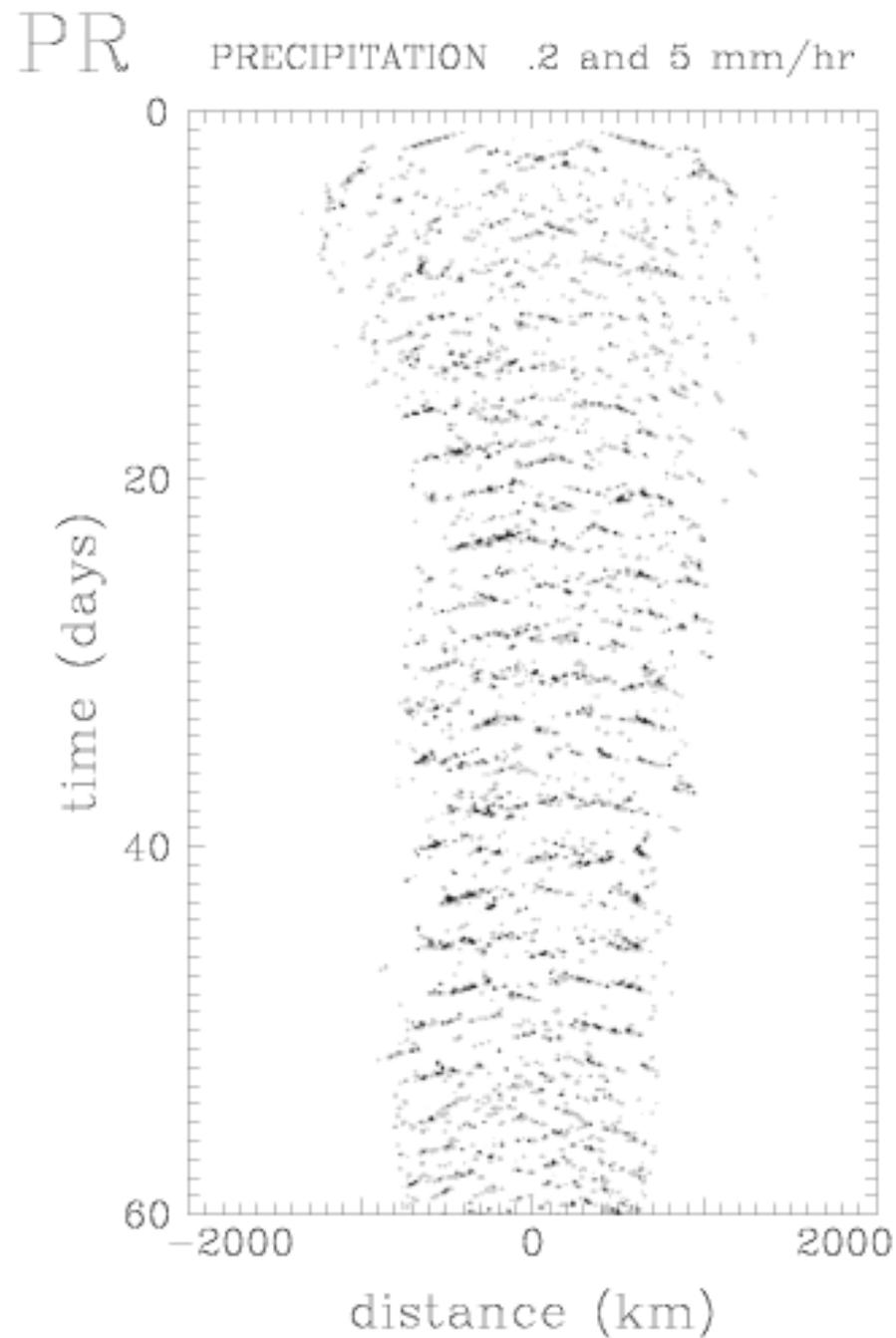
Quasi-two-day oscillations result from the interaction between convection and propagating gravity waves; period comes from gravity wave speed and horizontal extent of the computational domain.
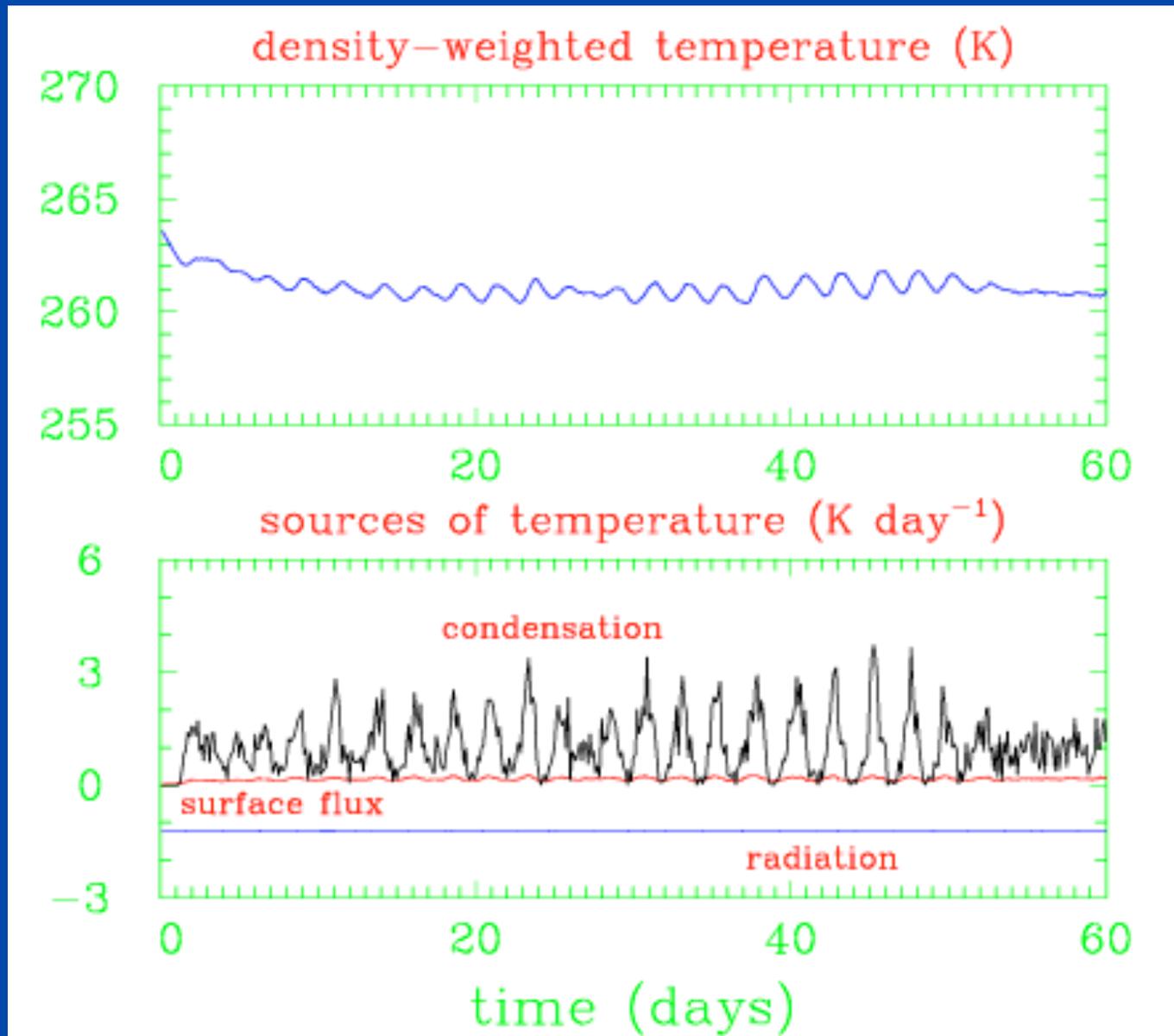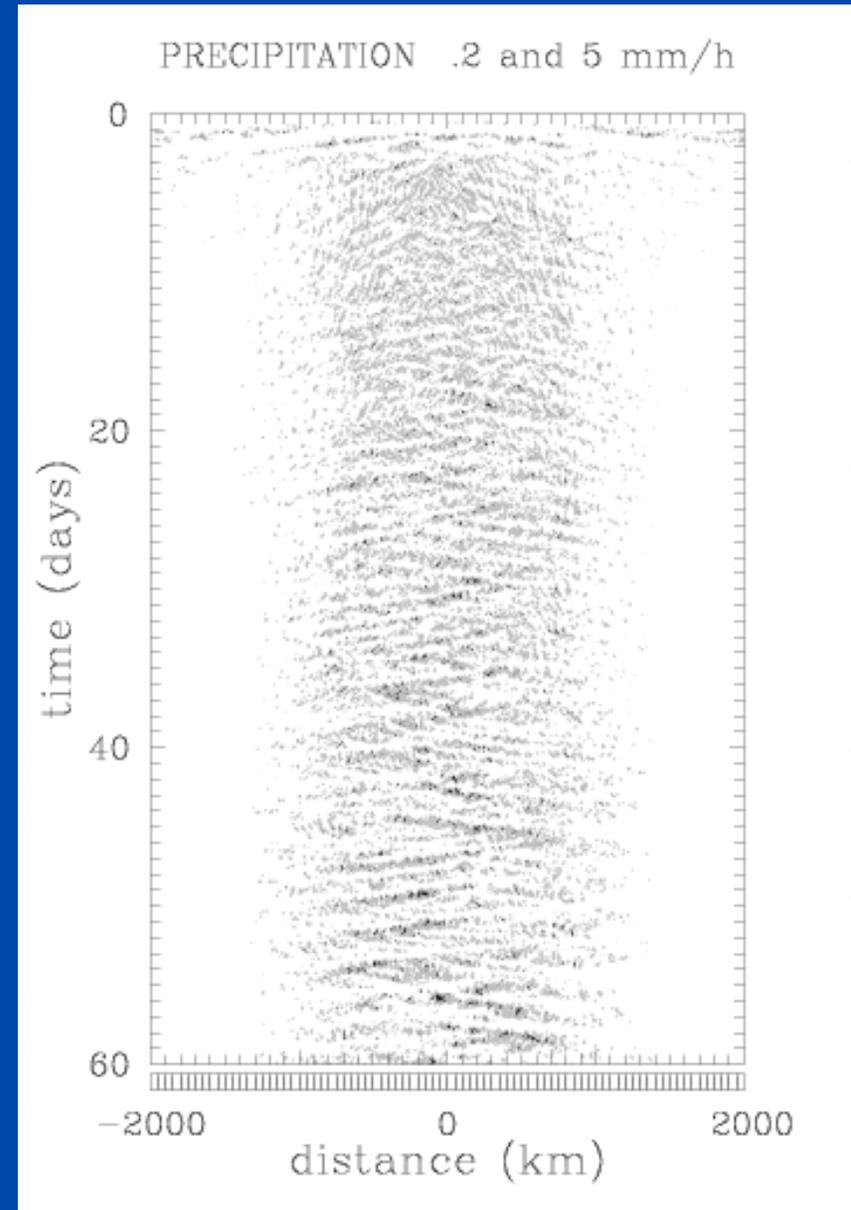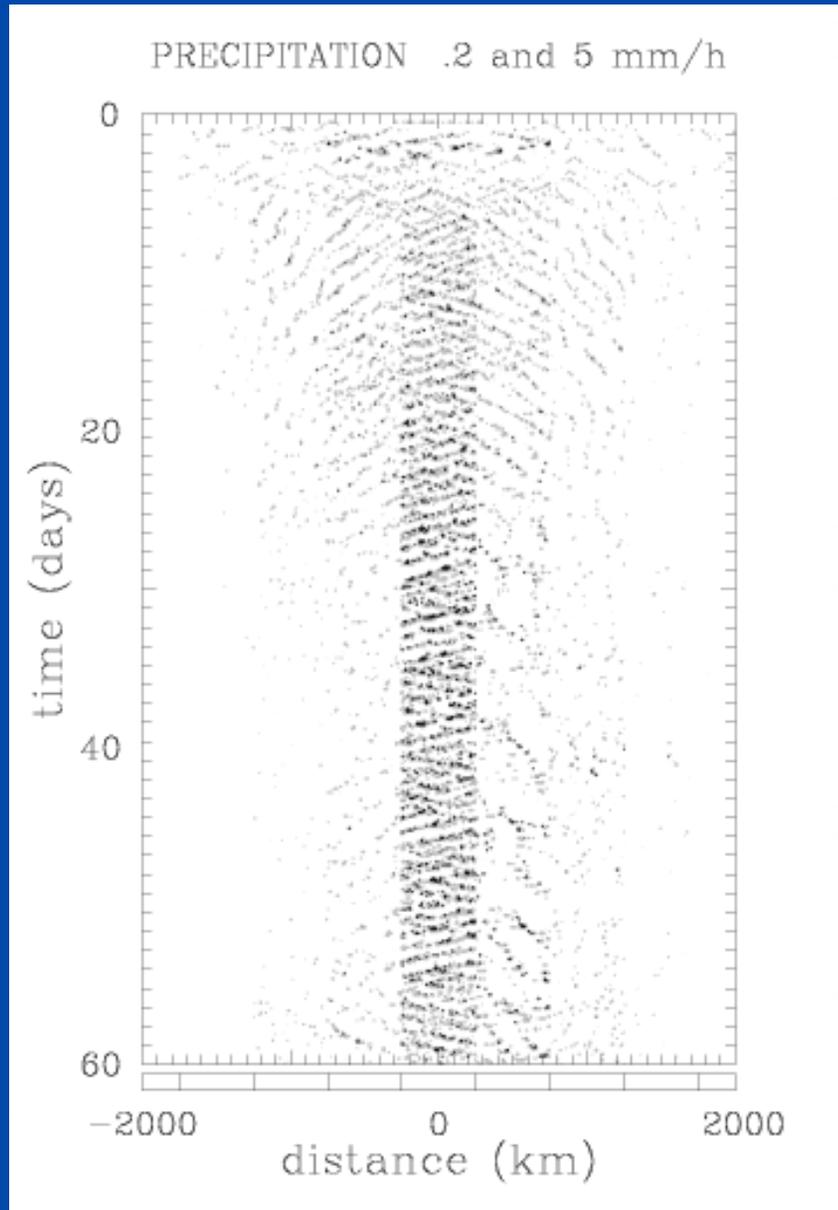
# The same problem with the original super-parameterization…

Cloud-resolving model fields

Super-parameterization – SP2001, SP2004
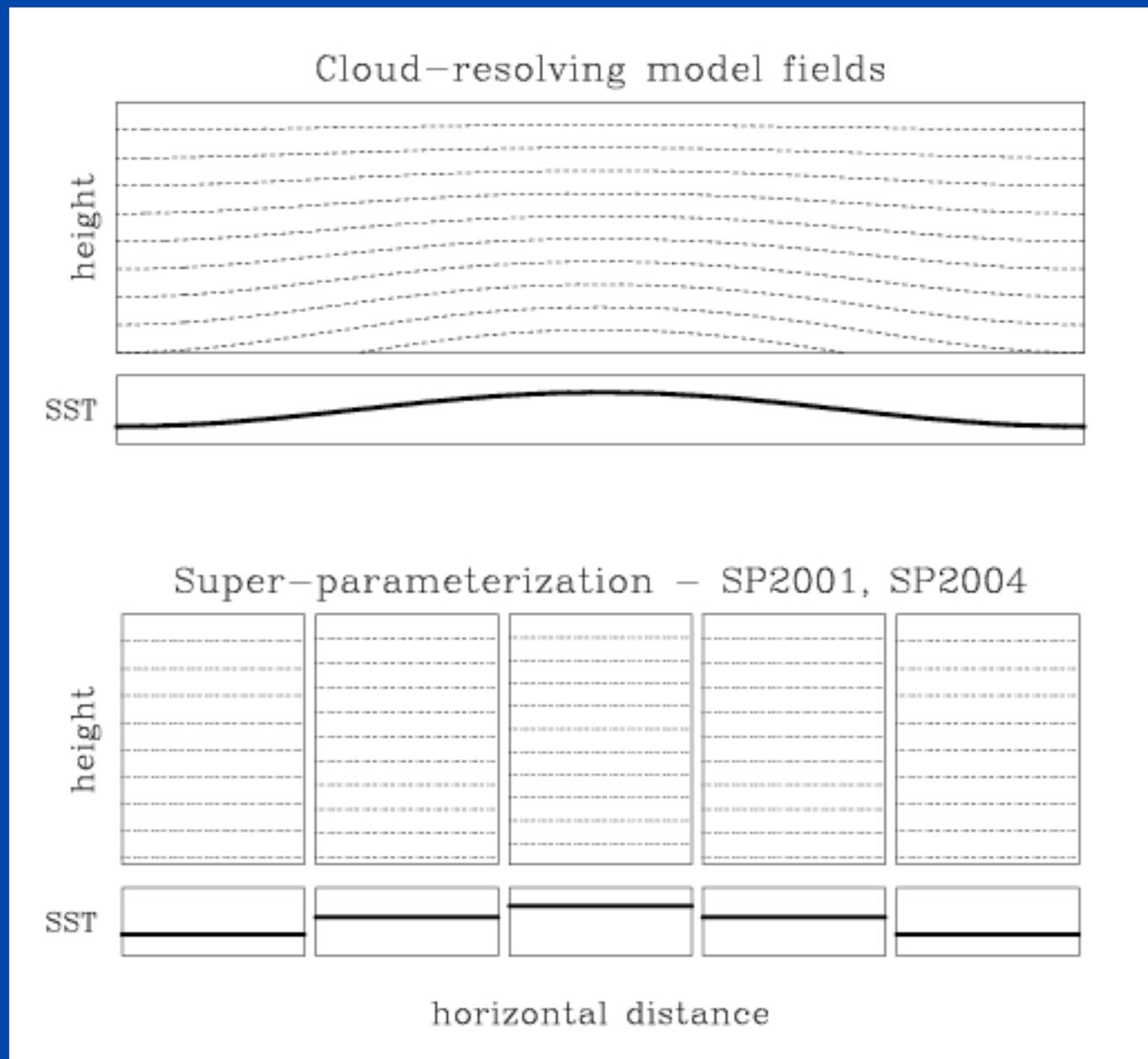
ORIGINAL SP (SP2004)
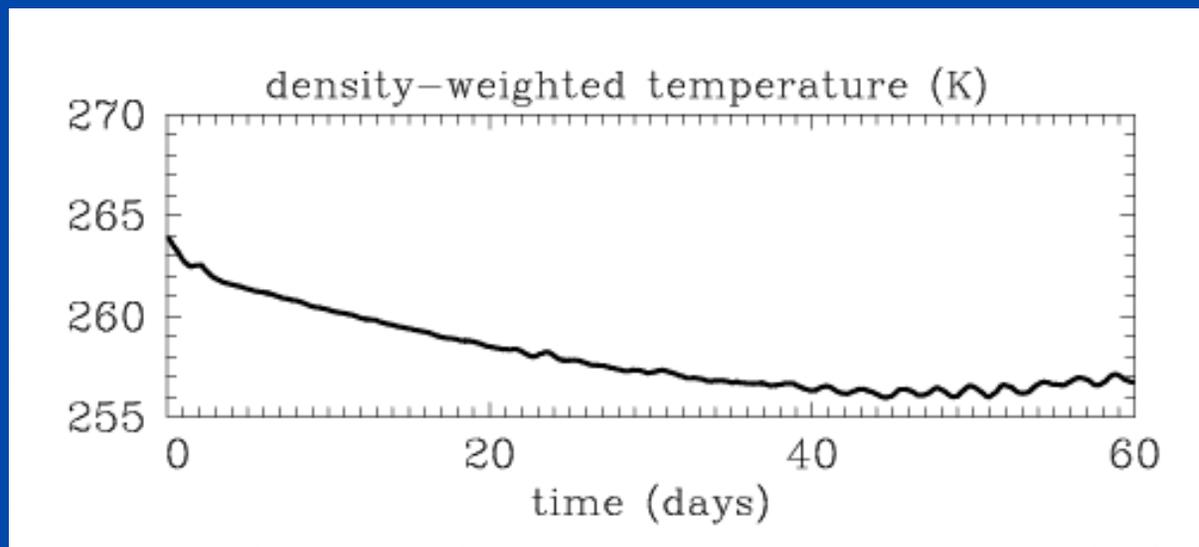
8 large-scale model columns, each 500-km horizontal extent

80 large-scale model columns, each 50-km horizontal extent

PRECIPITATION .2 and 5 mm/h
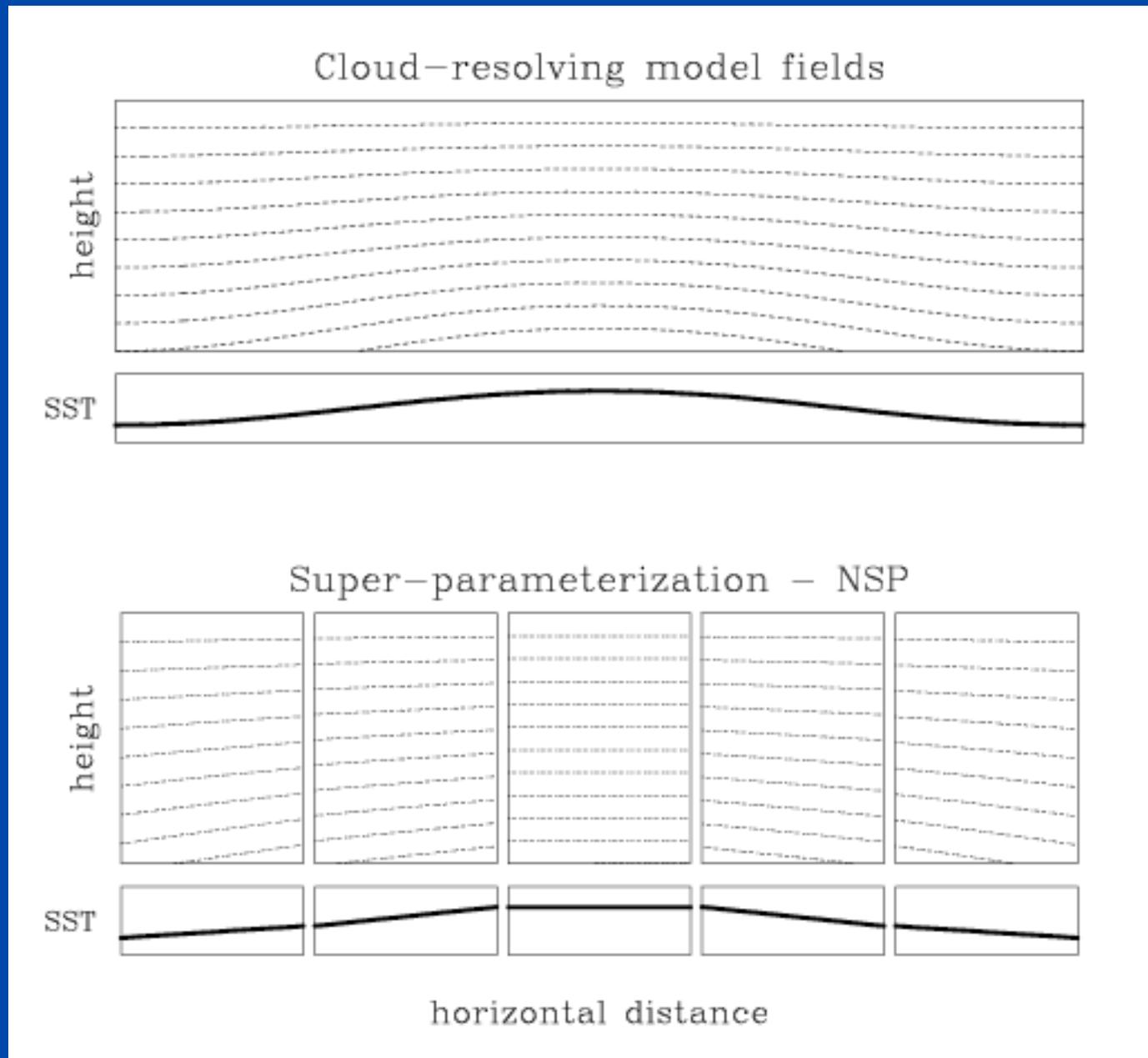

PRECIPITATION .2 and 5 mm/h

8 large-scale model columns, each 500-km horizontal extent
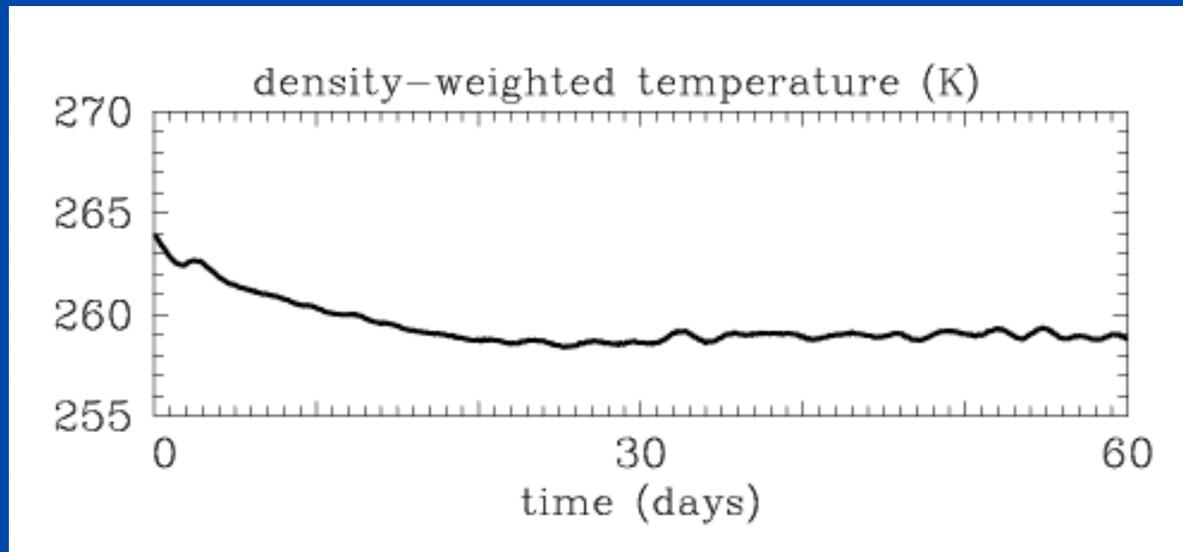
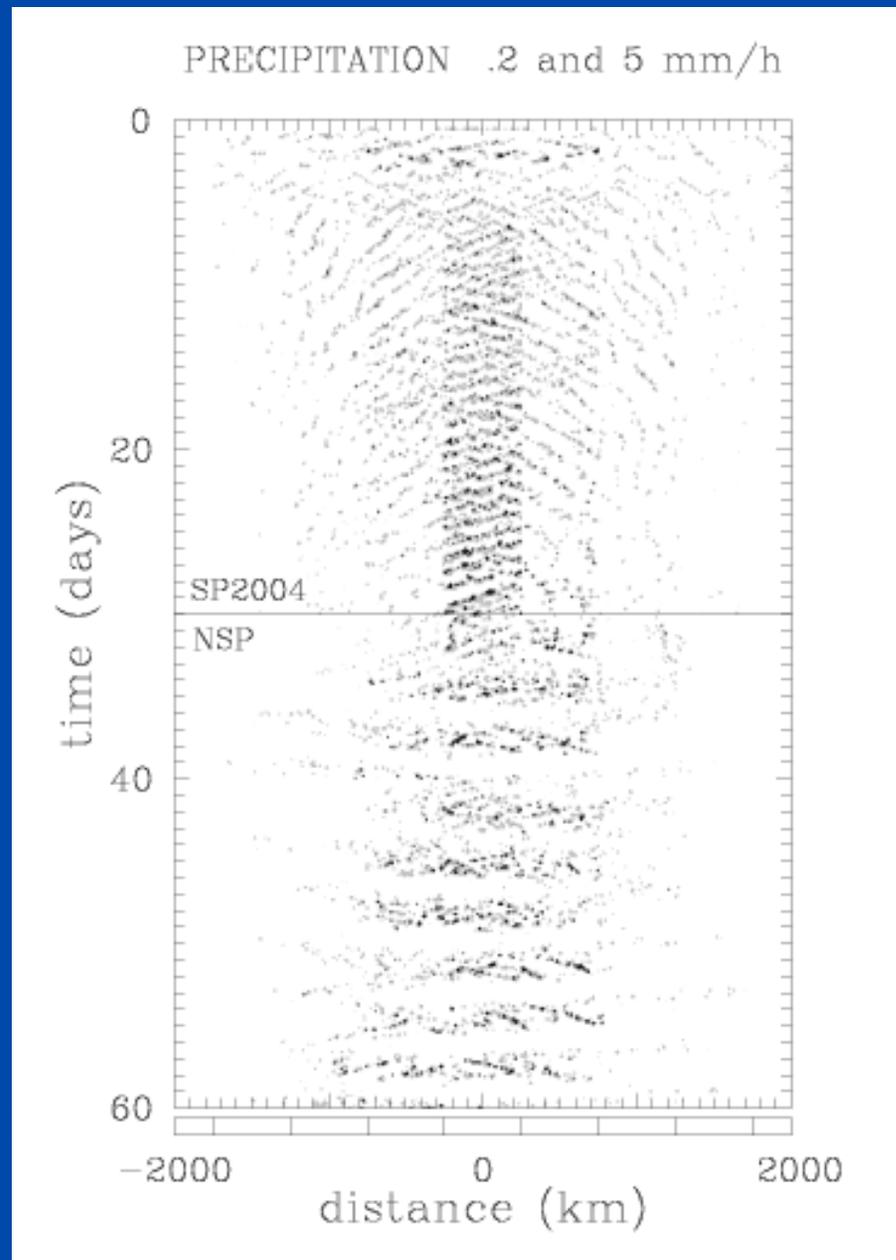80 large-scale model columns, each 50-km horizontal extent

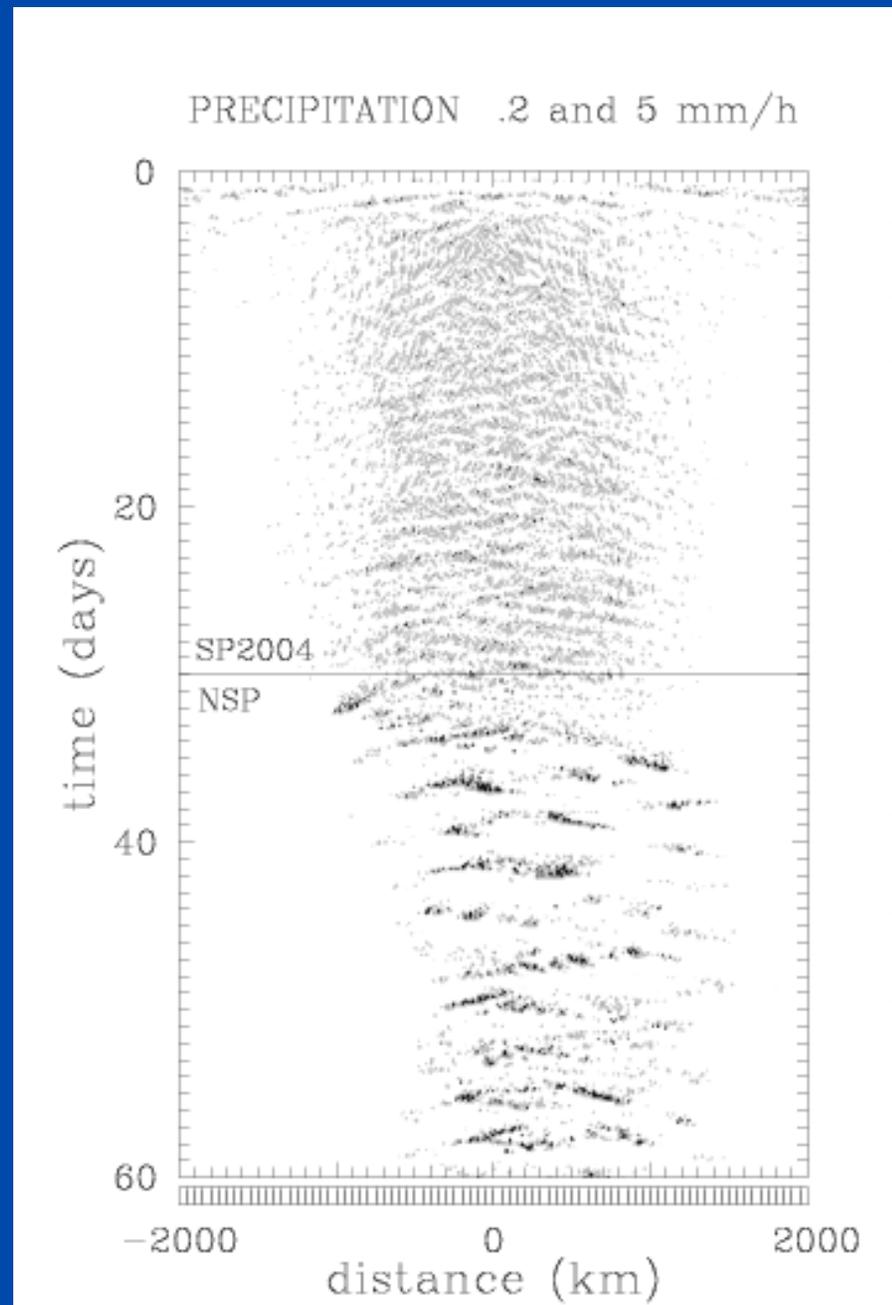# …and with the new super-parameterization approach.

NSP:

8 large-scale model columns, each 500-km horizontal extent; restarted at day 30 from SP2004

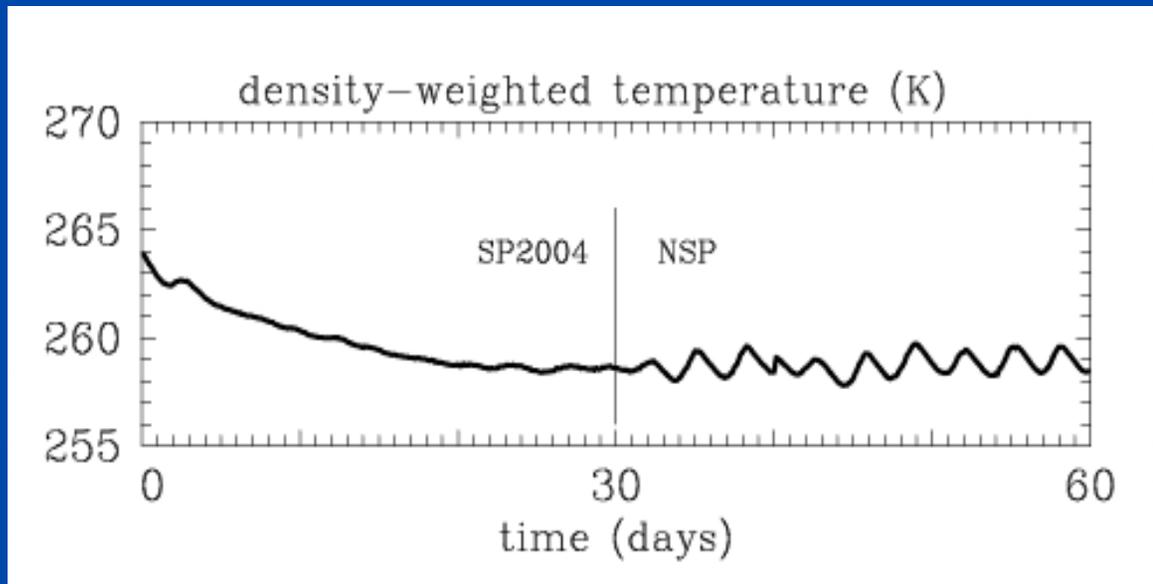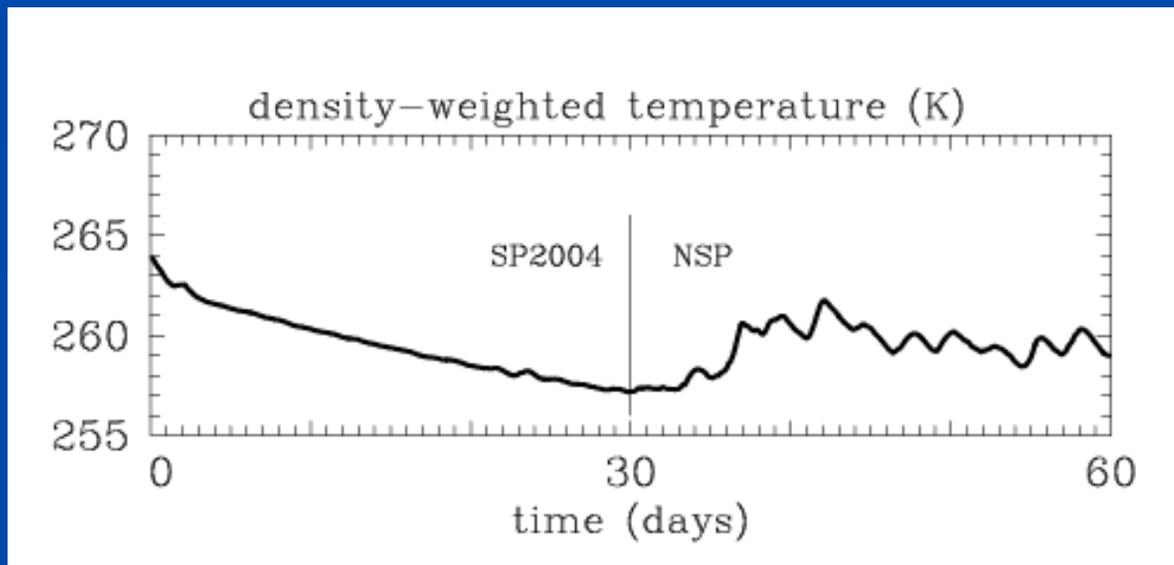PRECIPITATION .2 and 5 mm/h

NSP:

80 large-scale model columns, each 50-km horizontal extent; restarted at day 30 from SP2004

8 large-scale model columns, each 500-km horizontal extent

80 large-scale model columns, each 50-km horizontal extent

Conclusions:

Work is underway to extend the original SP concept. Large-scale gradients of thermodynamic fields are brought into the small-scale model and vertical velocities are coupled between large-scale and cloud-scale models.The new development is particularly relevant to the SP application over land (topography, land-surface processes) and in midlatitudes (baroclinic processes).

The new approach seems promising, but much more testing is needed.