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Interactive comment on **"Toward unification of the multiscale modeling of the atmosphere"** *by* **A. Arakawa et al.**

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This paper (referred to as AJW herein) discusses two possible routes to a unified multiscale atmospheric model. The first route is based on a convection parameterization strategy. The authors propose and test an approach to relax one of the key assumptions in traditional convection parameterization schemes, namely the small cloud fraction assumption. The second route is based on the superparameterization approach (SP; often referred to as the multiscale modeling framework, or MMF) and its subsequent extension to what the authors call the quasi-3D MMF. The quasi-3D MMF aims at removing significant limitations of the original SP approach proposed by Grabowski and Smolarkiewicz (1999). The manuscript is based on the Vilhelm Bjerknes Medal Lecture presented by the first author at the 2010 EGU General Assembly in Vienna.

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Overall, I think the paper can be published as is. I have a couple minor comments that I present at the end of this note, and two more general remarks concerning the main themes of the manuscript. I do not think my comments need to be addressed in the revised final paper, but I hope they may stimulate the authors and their collaborators in their future research.

The first comment concerns the behavior of a traditional convection scheme as the host model gridlength is reduced. In the case of a decreasing gridlenth, the small cloud fraction assumption is no longer valid, and additional considerations are needed to ensure that the representation of convective transport is accurate. This is a relatively obvious point and the methodology to deal with the complication of a finite cloud fraction sigma presented in AJW is novel and sound. However, it is clear from the Figure 5 in AJW that there is another important effect when the model gridsize approaches the cloud scale (or more generally, when sigma $\sim$ 1). When sigma $\sim$ 1, one no longer can assume that the compensating unsaturated subsidence in response to convective ascent occurs within the sigma $\sim$ 1 (cloudy) gridbox. In other words, the subsidence has to occur outside the cloudy gridbox when sigma $\sim$ 1, and the fraction of compensating subsidence that has to occur outside has to increase with the increase of sigma. This is an important effect and its impact on the convection parameterization problem is unclear.

From the point of view of the fluid flow resolved by the model configuration illustrated in Fig.5b (i.e., with grid columns with sigma $\sim$ 1, the circulation does not conserve mass. This is because the convective ascent in the cloudy column is parameterized, whereas the flow between columns next to the cloudy one is resolved. This problem can only be fixed if the parameterized convective flux in the cloudy column is included in the resolved model continuity equation. In fact this should be quite obvious: the mass-flux convective scheme is about vertical transfer of mass, but this transfer is never included in the host model equations (because when sigma « 1 the compensating subsidence stays mostly within the column).

This idea is not new. It was used in a relatively simple model developed by David Raymond over a quarter century ago (Raymond 1983, 1984). The key point is that the continuity equation for the resolved flow includes a term with the divergence of the convective mass flux (cf. Eq. 10 in Raymond∼1983). More recently, it was rediscovered in the NWP context (where the concerns discussed in AJW are particularly relevant) by Kuell et al. (2007). Incorporation of this idea into a numerical model may appear straightforward, but one needs to keep in mind that the continuity equation is used when converting advective form of scalar conservation equations into the conservative flux form typically used in numerical models. This implies that one needs to include appropriate modifications to the resolved flux-form advection of model scalars. I feel that developments along these lines, in addition to the scalar vertical flux problem discussed in AJW, are important for the improvements of models with traditional convective parameterizations.

My second point concerns the ongoing development of the quasi-3D MMF. When compared to the original SP proposal (i.e., embedding 2D cloud-resolving model, CRM, in each column of a large-scale model), the quasi-3D MMF is supposed to eliminate (or at least to limit) the two key limitations of the SP approach. The first one has to do with the limited 2D dynamics of the SP model. The second one concerns the periodicity of the embedded SP models which precludes a continuous propagation of small-scale features (e.g., convective clouds) from one large-scale column into another (Jung and Arakawa 2005). Although the latter might be considered a significant limitation, the outer model dynamics may allow propagation of convection-induced perturbations from one outer-model column to another (e.g., Grabowski 2006, Pritchard et al. 2010). The quasi-3D MMF also brings significant complications when practical implementation on massively parallel computers is concerned. In essence, parallelization of the quasi-3D MMF is similar to the parallelization of any 3D model (e.g., through the domain decomposition). In contrast, the traditional SP model is "embarrassingly parallel": the simplest strategy is to distribute all CRMs among all processors and, if possible, let each processor run a single CRM. Such an approach is efficient because CRMs and the large-scale model only exchange profiles (see Grabowski 2004) and the computational cost of the large-scale model is only a small fraction of the entire model cost (e.g., a fraction of 1%, Khairoutdinov and Randall 2001).

It follows that further improvements of a traditional SP approach would be desirable, in addition to the development of a quasi-3D MMF. One possibility, related to my point concerning traditional convective parameterizations, is to replace periodic-domain SP models with SP models featuring periodic lateral boundary conditions for small-scale perturbations only. This seemingly minor adjustment of the CRM has important implications. First, it allows to include large-scale gradients (of temperature, moisture, topography, surface characteristics, etc.) into the small-scale model. Such gradients would be inconsistent with the periodicity constraint in the traditional SP approach. Second, periodic lateral boundaries imply that the mean vertical velocity within the SP model has to vanish. It follows that the vertical velocities between CRM and the outer model cannot be coupled. In contrast, vertical velocity within CRM featuring perturbation periodic lateral boundary conditions can be nonzero and can be coupled to the outer model vertical velocity.

To demonstrate that the dynamic coupling between SP and the outer model is important, we performed a series of simulations of a 2D large-scale flow driven by the sea-surface temperature (SST) gradients using model setup as in CRM simulations discussed in Grabowski et al. (2000). The simulations applied the traditional SP approach (already presented in Grabowski 2001) and the new approach with CRMs featuring large-scale gradients of SST and domains periodic for perturbations, not full fields. Figure 1 presents the Hovmoeller (time-space) diagrams of the surface precipitation. The upper row features results from the traditional SP simulations, whereas the lower row shows results with the new SP approach. SP models have 2-km gridlength. The outer model computational domain is 4,000∼km long (with the maximum SST in the center) with SP simulations featuring various SP domain sizes, from 500 km in the left panels (i.e., the outer model has only 8 columns) to 20 km in the right

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panel (200 columns with 20 km gridlength in the outer model). These configurations are show beneath the panels in the bottom row. In addition, a CRM simulation with 2-km gridlength is shown at the bottom for reference. The key point of the figure is that the new approach better represents the results from the fully-resolved CRM simulation. In particular, the propagation of convection from the center of the domain toward the lower-SST edges is better represented in simulations with large SP domains (i.e., left panels). As discussed in Grabowski et al. (2000), the propagation is tied to the presence of large-scale gravity waves that propagate between high- and low-SST regions and affect deep convection. These waves are responsible for mean temperature and moisture oscillations with approximately 2-day period. These oscillations are evident in the CRM simulation and in simulations with the new SP approach, but not in the simulations with traditional SP. Arguably, this is because of the improved coupling between convective dynamics and the large-scale gravity wave dynamics in the simulations featuring the periodic-for-perturbation SP CRM model.

In summary, I believe that further development of models that feature either traditional convective parameterizations (with the convective mass flux tied to the large-scale continuity as in Raymond 1983) or the SP approach (with SP model mean vertical velocity coupled to the outer model vertical velocity) are additional possible developments that ultimately may lead to better cloud-resolving simulations of weather and climate.

Minor points.

1. Sigma is defined on p. 3187 as "the fraction area covered by all convective clouds in the grid cell". I wonder is this is correct. Should sigma be defined as the area covered by convective updrafts? This does not matter when sigma « 1 as convective updraft area is just a fraction (perhaps a small fraction) of the area covered by clouds. But once sigma $\sim$ 1, the distinction may become important.

2. A cloudy point is defined on p. 3188 as the one with the updraft stronger than 0.5 m/s. This does not seem consistent with the way sigma is defined. Should cloudy

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points be defined as those with non-vanishing cloud condensate (i.e., cloud water or cloud ice)? Alternatively—and in the spirit of point 1 above—should sigma be defined based on condensate and vertical velocity, and then the same definition be used in the analysis presented in the paper?

I do not think the above two points make any significant difference for the analysis presented in the first part of the paper, but I think the authors may consider making their definitions consistent.

References.

Grabowski, W. W., 2001: Coupling cloud processes with the large-scale dynamics using the Cloud-Resolving Convection Parameterization (CRCP). J. Atmos. Sci., 58, 978–997.

Grabowski, W. W., 2004: An improved framework for superparameterization. J. Atmos. Sci., 61, 1940–1952.

Grabowski, W. W., 2006: Comments on “Preliminary tests of multiscale modeling with a two-dimensional framework: sensitivity to coupling methods" by Jung and Arakawa. Mon. Wea. Rev., 134, 2021-2026.

Grabowski, W. W., and P. K. Smolarkiewicz, 1999: CRCP: A Cloud Resolving Convection Parameterization for Modeling the Tropical Convecting Atmosphere. Physica D, 133, 171–178.

Grabowski, W. W., J.–I. Yano, and M. W. Moncrieff, 2000: Cloud–resolving modeling of tropical circulations driven by large–scale SST gradients. J. Atmos. Sci., 57, 2022–2039.

Jung, J.-H., and A. Arakawa, 2005: Preliminary tests of multiscale modeling with a two-dimensional framework: Sensitivity to coupling methods. Mon. Wea. Rev., 133, 649-662.

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Khairoutdinov, M. F., and D. A. Randall, 2001: A cloud resolving model as a cloud parameterization in the NCAR Community Climate System Model: Preliminary results. Geophys. Res. Let., 28, 3617-3620.

Kuell, V., A. Gassmann, and A. Bott, 2007: Towards a new hybrid cumulus parametrization scheme for use in non-hydrostatic weather prediction models. Quart. J. Roy. Met. Soc., 133, 479-490.

Pritchard, M. S., M. W. Moncrieff and R. C. J. Somerville, 2011: Orogenic propagating precipitation systems over the US in a global climate model with embedded explicit convection. J. Atmos. Sci. (in press, early online release http://journals.ametsoc.org/toc/atsc/0/0).

Raymond, D. J., 1983: Wave-cisk in mass flux form. J. Atmos. Sci., 40, 2561-2572.

Raymond, D. J., 1984: A wave-cisk model of squall lines. J. Atmos. Sci.}, 41, 1946-1958.

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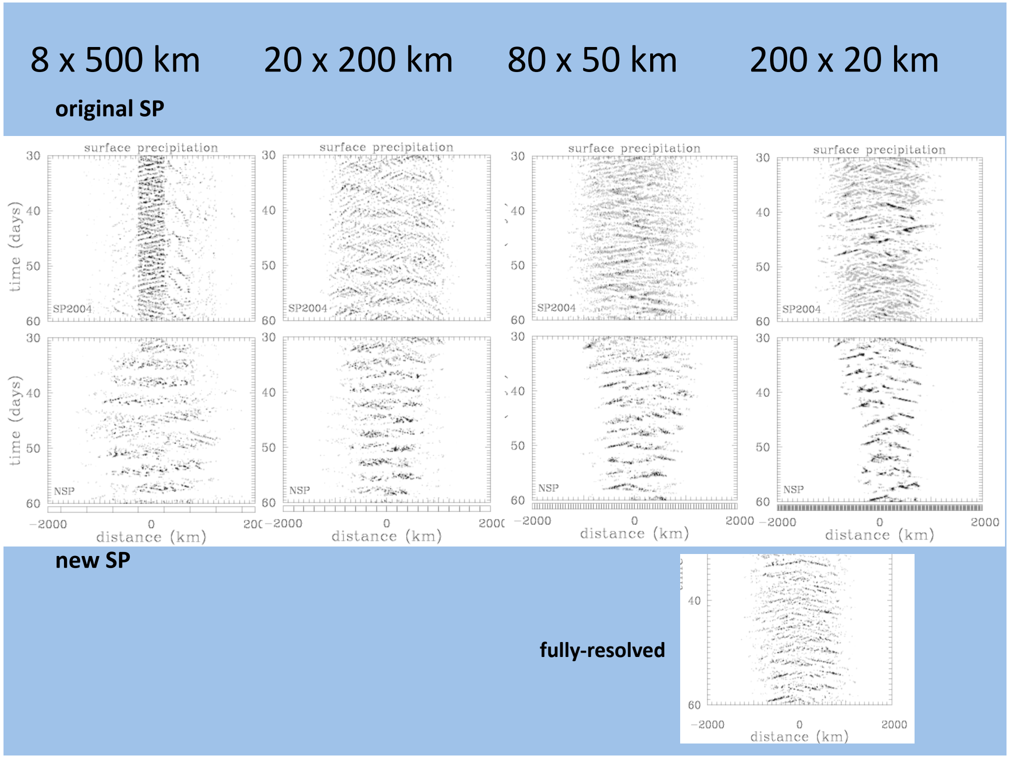

Fig. 1. Results of 2D simulations of deep convection over SST with large-scale gradients. See text for details.

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