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SENSITIVITY OF ATMOSPHERIC PARAMETRIC FORMULATIONS TO REGIONAL MESH REFINEMENT IN GLOBAL CLIMATE MODELS, 9/15/2011 -- 9/14/2015

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Summary:

Prof. Mapes and Ph.D. student I-Kuan Hu worked with Community Atmosphere Model developers, seeking to reduce solution artifacts at the seams of variable-resolution grids by introducing appropriate gridlength-dependence to subgrid schemes. We find that such artifacts are relatively subtle for affordable configurations (an 0.5° monsoon in a 2° global background simulation), compared to pervasive biases that remain as challenges in all grid configurations. Convective organization is considered as a possible process-level source of tropical biases.

Reminder of initial project motivations:

Since the real atmosphere has no "grid", the *total solution* of an accurate atmosphere model should have no dependence on grid resolution DX. To achieve this goal, the DX dependences of large-scale fluid dynamics solvers and column process parameterizations need to be balanced. Since dynamics solvers have few arbitrary parameters, the job falls to column process schemes -- motivating the development of "scale-aware" (i.e., appropriately DX-dependent) formulations. Deep convection schemes are thought to be especially important and challenging in this regard.

Nested or stretched grid simulations should serve to spotlight our challenge, since inappropriate DX dependences map into *spatial* patterns of solution error: "seams" along the fine-mesh boundaries or grid stretching zones.

Miami personnel and research activities:

The Miami branch of this project involved co-PI Mapes and his graduate student, Mr. I-Kuan Hu. At Miami, a 3-year grant with tuition is matched for an additional 2 years by the School and University, giving Ph.D. students 5 years of financial support for their work. For this reason, Mr. Hu's research efforts on the project remain ongoing from a scientific perspective, and publications from the project are not yet completed (Hu 2016).

In addition to his classroom studies, Mr. Hu trained in the use of the CAM/CESM model, and obtained a student allotment of computer time on Yellowstone for computations. Collaborators in Michigan helped him use the variable-resolution CAM-SE atmosphere (ready; but in fact still limited, computationally expensive and complicated). Collaboration also opened up the future-oriented convection scheme called UNICON (also ready; but with complications). He also tried the experimental Mapes-Neale (2011) two-plume + prognostic organization scheme for experiments. Several combinations of schemes+grids proved to be not possible technically yet, or were not affordable computationally. Still, a telling set of comparisons is possible (figures below).

The Asian monsoon was targeted for study, since the Mapes group also has other members working on that phenomenon. Mr. Hu's stretched grid is shown in Fig. 1.

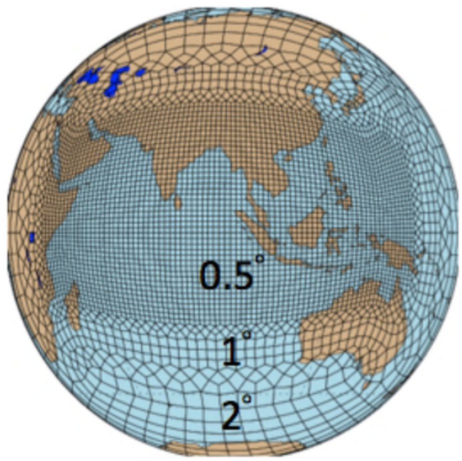

Fig. 1: Variable-resolution (VR) grid for CAM-SE monsoon simulations on the project.

Resolution dependence findings:

Figure 2 shows that monsoon rainfall and other tropical biases are large in all versions, and not very sensitive to the factor of 4 mesh change across the VR grid.

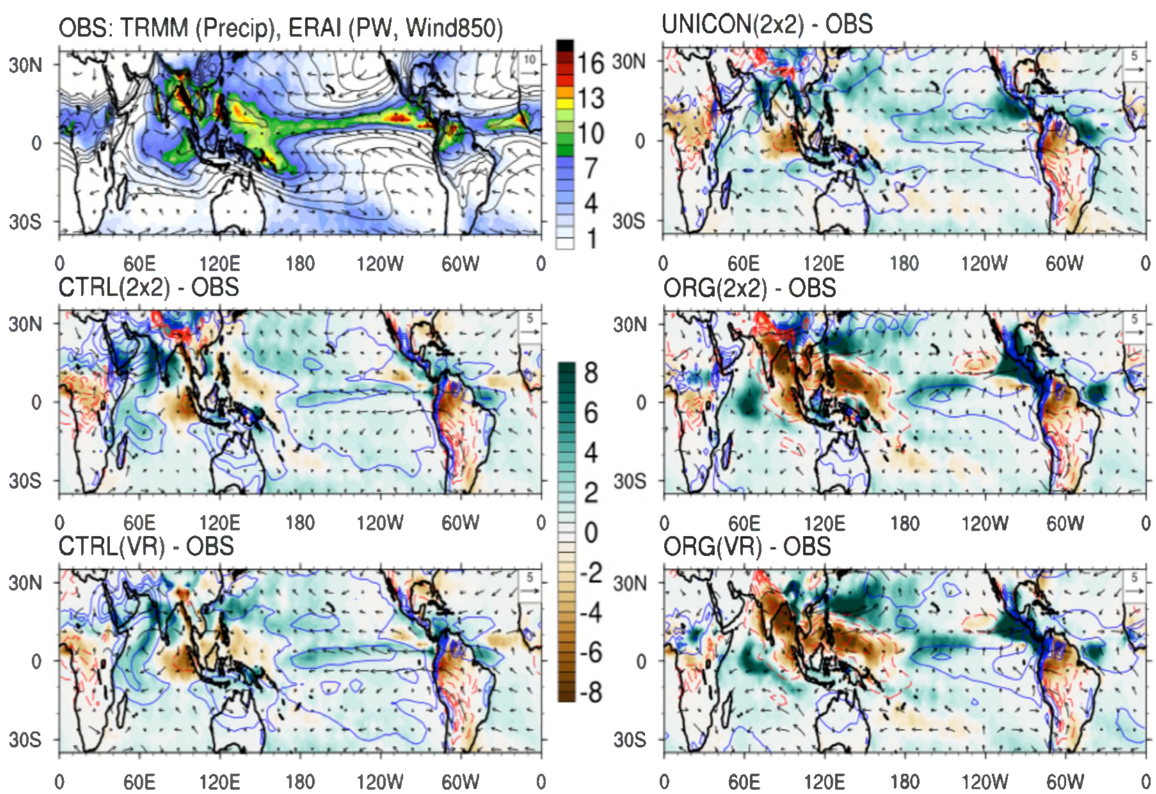

Fig. 2: JJA observations and CAM biases, for various convection schemes and for 2x2 uniform grids vs. the variable resolution (VR) grid of Fig. 1. Here CTRL = CAM5 from CSM v1.2.2, while other convection schemes tried include UNICON (Park 2014) and ORG (Mapes and Neale 2011) schemes.

Belts of rainfall anomaly or other evidence of solution "seams" along the grid stretching areas are not very evident. The need for "scale aware" aspects of convection parameterization may not become strongly evident until resolutions enter the "gray zone," or perhaps the frontier of nonhydrostatic dynamics, on ¼ degree or finer meshes. However, extensive exploration of such fine resolutions is beyond our computing capabilities on our University computer, or student-sized allocations on Yellowstone. For such work (as a part of Mr. Hu's Ph.D.), we will thus take a more secondary role, diagnosing runs performed by collaborators at NCAR who have greater throughput capabilities.

Further experiments with parameterized convective organization:

Is convective organization (as implemented in Mapes and Neale 2011) a useful tool for interpreting spatial patterns of model behavior? While it is clear from Fig. 2 that the two-plume ORG scheme of Mapes and Neale 2011 has a larger bias error than standard CESM schemes which have undergone climate tuning (CTRL and UNICON), an experiment with its Ω (organization) field is revealing of mechanisms, so it is reported here and will be part of Mr. Hu's dissertation work and publications.

The Ω (organization) field is used to partition mass flux between a less-entraining plume and a more-entraining plume in the convection scheme. Entrainment is a process that disfavors deep convection relative to shallow convection, as the entrained air is subsaturated and reduces the buoyancy of plume updrafts. Large values of Ω therefore favor deeper convection.

Artificially suppressing Ω in a region of unwanted excessive precipitation bias (blue box in Fig. 3) reduces precipitation in the box, consistent with the logic above. Instead, the precipitation occurs downstream. This result can be understood at a process level in the lower panels of Fig. 3. Joint histograms of 6-hourly precipitable water (PW) and precipitation rate P are contoured for three tropical regions, while the conditional mean of P at each PW (the "pickup" of precipitation discussed in the works of co-PI Neelin and others) is shown in the heavy black line.

Blue contours at lower right show that, in the blue box in the western Indian Ocean (WIO) where Ω is suppressed, P is suppressed at common values of PW (40-50mm). This finding is consistent with Ω=0 suppressing the low-entrainment-rate plume in that region. The lower-left panel of Fig. 3 indicates that in the control run, Ω is acting to facilitate too much rain in dry regions, via an overactive local positive feedback (P→Ω→P→Ω...). While it is sometimes observed in nature that organized storms can exist in environments too dry to host their development, and capturing this mechanism was an explicit goal of introducing Ω in Mapes and Neale (2011), it appears excessive in these runs. Further work could calibrate the effect better.

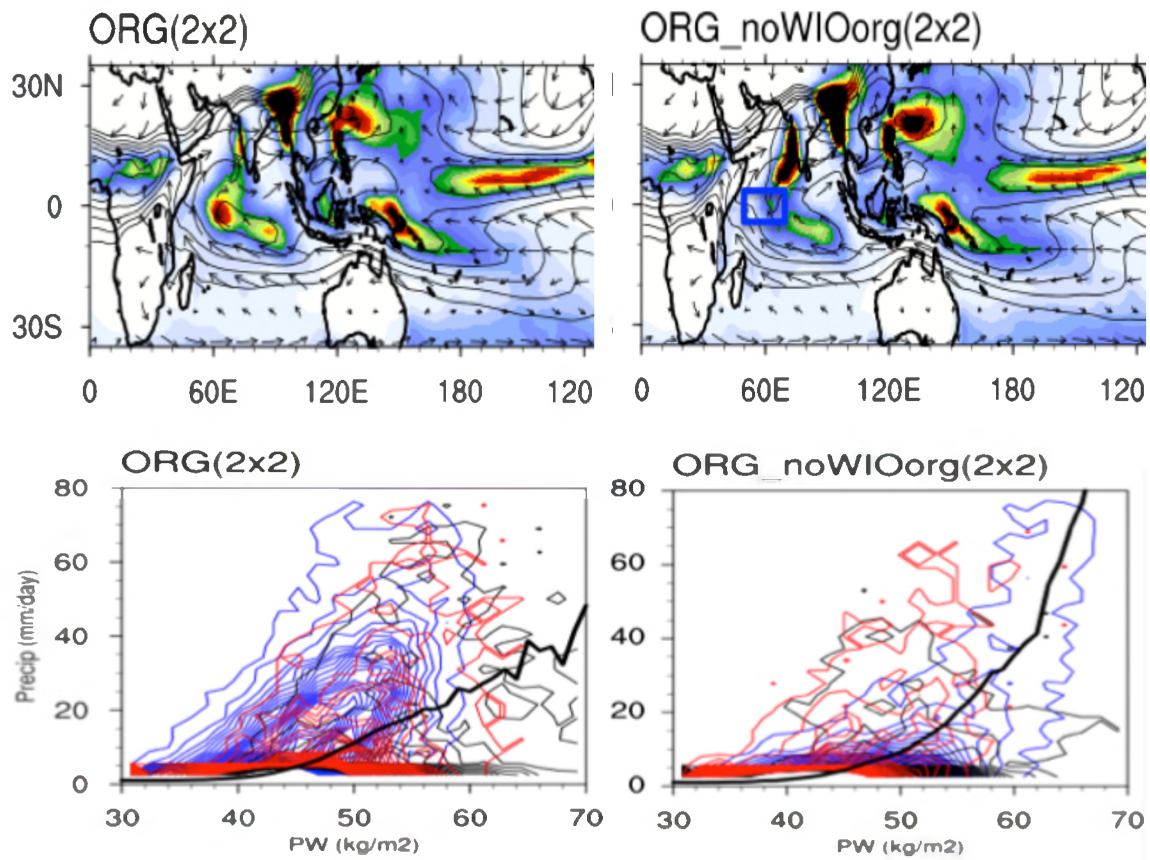

Figure 3: Top row: JJA climatological total precipitation P (colors), PW (contours), and 850 hPa wind. Bottom row: Light contours show joint histograms of 6-hourly PW and P in three Indian Ocean regions, while the heavy curve is the conditional mean P(PW) averaged over a broad region . Blue contours refer to the WIO box indicated at upper right, where organization Ω is artificially suppressed in the experiment ORG_noWIOorg (right column). Without Ω, P is displaced downstream, reducing the excessive rain in the blue box.

Project-facilitated PI efforts beyond experiments above:

Besides the student-centered project works to be published in 2016, the PI has also invested supported time in project-related but broader studies, including an extensive internally reported process evaluating CAM6 convection scheme candidates. Formal publications in preparation will acknowledge the project appropriately.

Hu, I.-K., 2016: *Toward Scale-Aware Unified Convective Parameterization*. PhD. dissertation and related papers in preparation.

Mapes, B.E., and R. B. Neale, 2011: Parameterizing Convective Organization to Escape the Entrainment Dilemma, *J. Adv. Model. Earth Syst.*, 3, M06004, doi:10.1029/2011MS000042. Journal PDF file, link.

Other publications in preparation will also acknowledge this project.