Optimizing Cumulus Parameterizations
Ensemble to Improve Precipitation Prediction

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RCM Resolves Orographic Effects Better Than GCM
CMM5 Daily Precipitation

Cascade Range daily-mean precipitation variation during 1983 JFMA

Cascade Range daily-mean precipitation variation during 1983 MJJA

Cascade Range daily-mean precipitation variation during 1983 SOND
Cumulus Schemes Are Not Universal

- While numerous cumulus parameterizations exist, none performs equally well under all conditions (Wang and Seaman 1997; Giorgi and Shields 1999).

- Given incomplete understanding of convective processes, different parameterizations were designed with different conceptual underpinnings and tunable parameters, both of which are not universal but quite uncertain (Arakawa 2004).

- Their predictive skills are thus highly selective of weather or climate regimes (Liang et al. 2004a, b; Mapes et al. 2004).
Figure 1. Spatial distributions of summer (June-August) rainfall diurnal cycles observed by (a) the rain gauge measurement (GAU) and (b) multi-sensor analysis (MUL), and simulated by the CMM5 using (c) Kain-Fritsch (MKF) and (d) Grell (MGR) cumulus schemes. Colors represent the normalized amplitude (i.e., in units of daily mean) while unit vectors denote the local solar time (LST) of the peak (phase clock).
The diagrams depict the normalized rainfall patterns across different regions:

- **Central Rockies**, **Central High Plains**, **Central Plains**, **North American Monsoon**, **Low Level Jet**, and **Southeast**

Each diagram shows the variation of normalized rainfall with Local Solar Time (LST) over a 24-hour period. The graphs display multiple line types, each representing different rainfall models or observations. The y-axis represents the normalized rainfall, while the x-axis represents LST in hours.

- **Central Rockies** shows a peak around LST 09:00 and a second peak around LST 18:00.
- **Central High Plains** has a single peak around LST 12:00.
- **Central Plains** features a broad peak around LST 18:00.
- **North American Monsoon** exhibits a sharp peak around LST 15:00.
- **Low Level Jet** displays variability with multiple peaks, including a notable one around LST 18:00.
- **Southeast** has a distinct peak around LST 21:00.

The line styles vary among different models:
- **OBS/Dal** (black)
- **OBS/MUL** (blue)
- **CMM5/GR** (red, dotted)
- **CMM5/KF** (green, dotted)

These models help in understanding the rainfall patterns and their variations over time.
Much More Than That...
Optimized Physics-Ensemble Prediction

KF Climate Mean (mm/day)

GR

OBS

ECb

EOP
Optimal Weight Distribution Exhibits Large-Scale Features
Ensemble Cumulus Parameterization

- The ECP (Grell and Dvénéyi 2002) couples a single generalized cloud model with multiple closures, similar to applying an ensemble of cumulus schemes at every time and grid, and then feeding back the average of all solutions to the predictive system.

- Since all closures include unknown parameters that are not measurable and must be specified from empirical or statistical assumptions, the degree to which they represent reality can differ substantially. As such, the current use of equal-weighting may under-represent the closures that depict the principal forcing mechanisms while incorrectly including those that are not active.

- The ECP has the potential to achieve significant skill improvement by incorporating varying weights on individual and selective closures that are physically functioning. Our primary goal is to determine optimal closure weights that change with regime, location, and time to best predict precipitation.
Precipitation of 1993 July observed and simulated by CWRF for five major categories of the ECP closures, whose equal-weight average is fed back to the model. The remaining 4/5 result of each category do not interact with the model. The Krishnamurti et al. (1983) closure captures the major Midwest flood but produces excessive rainfall in Canada, northeast U.S. and North American monsoon region. The Arakawa-Schubert (1974) closure essentially fails both flood and monsoon rainfall along with much lighter precipitation everywhere. The closures of Grell (1993), Brown (1979) and Frank-Cohen (1987) closely resemble each other, all generating precipitation systematically much less than Krishnamurti et al.’s closure. Similar underestimation occurs in the Kain-Fritsch (1993) closure except for the northwest U.S. states and their Canada borders. Substantial differences are also identified over oceans. Given the identical weight on all closures, the ensemble mean precipitation that actually impacts the CWRF is unrealistic, much more like the component using the Grell closure.
Conclusions

- The regional model downscaling can significantly reduce biases of the driving global models. The skill enhancement, however, is sensitive to cumulus parameterizations.

- Various cumulus parameterization closures work better under different climate conditions. The optimal weight estimated for the CMM5 Grell and Kain-Fritsch cumulus schemes reveals stable large-scale features, indicating that the two schemes have distinct regional preferences for precipitation predictive skill. Their weighted ensemble mean is better than the individuals.

- The optimal weights may be defined via dependence on distinct regional circulation characteristics (or climate regimes). They can be estimated inversely from minimizing the simulated and observed precipitation differences and further determined though a dynamic parameterization (for interactive prediction) based on resolvable model physical quantities.