Title: A Design of Experiments approach to evaluating Parameterization Schemes for Numerical Weather Prediction.

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Numerical Weather Prediction (NWP) is the science of forecasting weather conditions at some time in the future based on present and past observations using complex mathematical/physical model(s) and advanced computational techniques. These predictions can range from hours to months and in some cases years into the future. Spatially, these codes can simulate conditions from small regional microclimates to global climates. Of particular interest to the U.S. Army are codes that can make short term predictions that are valid for a few hours over a roughly brigade sized area of responsibility (AOR).

While both long- and short-term forecasts are of interest to a brigade commander for planning purposes, it is at the meso- and microscales where forecasts can enhance situational awareness for the echelons below brigade. Mesoscale models resolve meteorological features such as thunderstorms or a microbursts that typically are on the order of few than 10 km in extent. Microscale models resolve features are often less than a kilometer in extent such as turbulent flows in an urban canyon. Temporally, these meso- and microscale models fill a gap between coarse synoptic forecasts of large scale features such as weather fronts that update typically every six-to-twelve hours. For U.S. Army purposes, the term “Nowcast” refers to forecasts of mesoscale conditions up to six hours into the future which can be updated as frequently as every 30-60 minutes.

Nowcast models are typically high-resolution applications of research and operational mesoscale NWP models such as the Advanced Research Weather Research and Forecast [1] model (WRF-ARW) with extensions that might include finer terrain resolutions and more detailed representations of the underlying atmospheric physics. Functionally, these models take as initial conditions both very coarse-grained synoptic forecasts and observational data from various meteorological data sources to produce their higher resolution Nowcasts.

The foundation of NWP models is the conservation of mass, heat, motion, and water vapor as well as other gaseous and aerosol materials [2, 3] over the region of interest. NWP codes model these properties through a set of coupled partial differential equations with the first-guess initial and time-dependent later boundary tendencies provided by a forecast from a coarse-grained synoptic model. Because these models seek to represent climate physics at a high resolution, the transition from coarse- to fine-grain is handled via a nesting strategy so that boundary conditions enter into the model more smoothly. Typically, this nesting occurs through telescopic “multi” nesting approach tapering from an outer domain on the order of 1500km by 1500 km to an inner domain that may be a 100km by 100km in extent. In this approach, the outer nest moves the lateral boundaries as far away from the desired model center of interest as possible so that tendencies from the external coarse-grain model pass gradually into the model domain. The middle nest (or several) acts as an intermediate resolution nest(s) for ideal downscaling. Finally, the interior domain captures the domain of interest at the highest resolution desired. Such an approach is also called a “limited-area” mesoscale NWP configuration.

While the conservation balance equations govern the transport of mass, energy, etc., throughout the model, other physics (often non-resolved processes such as turbulence whose effects must be estimated) are incorporated via ‘parameterizations’ which capture effects of cloud cover, turbulence, solar radiation, etc. [4]. The collection of these conservation balance equations (partial differential equations which are linearized and solved numerically) along with the various parameterizations constitutes the typical NWP model.

A single parameterization scheme will fall into one of five groups: Microphysics, Cumulus, Radiation, Planetary Boundary Layer, or Surface effects which capture respectively physics such as moisture, clouds, solar radiation, turbulence and land cover. The sub-grid effects are a consequence of the interaction between representative schemes from each group during the simulation execution for the conservation principles to hold. Within each group, there are a number of different approaches to handling that particular effect, each approach suitable for a range of conditions.

If one considers only the surface layer and boundary layer parameterizations, there are 15 combinations of these two physical schemes possible. If one takes all the available combinations of physics options in WRF-ARW, there are over 2 million possible combinations; thus, on a battlefield or in a remote deployment it is not possible to perform forecasts with all these combinations to find the ‘single’ set that best describes the local weather. Furthermore, each scheme or combination of schemes quite often only works best in certain environments. Given that we cannot know in advance where a brigade will be deployed; we seek a combination parameterizations that works ideally well in all situations, but practically well within a defined region.

If we consider our modeling system a “grey box”, we can model the outputs (for example forecast skill) as a statistical function of the initial conditions along with the internal physics that constitutes the “grey box”. Consequently, our task becomes to appropriately sample that function in a manner that minimizes both the computational burden we face and allows us to maximize the amount of information we can extract from our set of model runs. Ideally, one should approach the selection a candidate set of parameterizations via a method that leads to robust performance under a variety of weather conditions for a given domain, and one such approach is through the use of Design of Experiments techniques. Here we intend a design point be a single sample of the “grey box simulation” whose value will be an output figure of merit such as forecast skill. Consequently, the design as a whole can be used to support identification of a suite of parameterization schemes that collectively produce a “skillful” forecast over a variety of conditions.

References

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