Comment on “Use of Observing System Simulation Experiments in the United States”

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Observing system simulation experiments (OSSEs) for numerical weather prediction (NWP) use an entirely simulated framework to explore the impact of new observational data on analysis quality and forecast skill. The basis of an OSSE is a nature run (NR), usually a free forecast of a high-resolution NWP model that may be multiple years in length. The NR replaces the real atmosphere (and/or ocean) for the purposes of the OSSE, and as such should be as realistic as possible. Simulated observations are drawn from the NR fields, so the NR should ideally have accurate representations of all those fields that affect real observations, including clouds, moisture, temperatures, winds, and surface characteristics. Additionally, the NR fields are used as the “truth” for verification of the experiment analyses and forecasts. It is best practice for the NR to have higher resolution and more sophisticated physics than the model used for ingesting simulated observations and performing experiments in the OSSE framework. Since the experiments are often performed with operational versions of NWP models, NRs are frequently produced using the highest resolution under development. NRs and other critical issues in OSSE development and application are presented in a white paper on the subject (Errico and Privé 2018) prepared for the World Meteorological Organization.

As operational models and data assimilation systems for NWP are frequently upgraded, there is a need for NRs to undergo similar advancement. The production of a new global NR requires substantial resources for computation and storage. The new NR must also be validated for use in OSSEs, and existing OSSE software must be updated to make best use of the NR. Because of the large investment in resources and effort needed to produce a new NR, large global NRs are often shared between institutions, with new NRs introduced every 5–10 years. Recent examples include the T213 (0.5625°) ECMWF NR (Becker et al. 1996), the T511 (0.351°) NR produced by ECMWF in 2006 (Andersson and Masutani 2010), the C1440 (0.0625°) GEOS-5 NR (G5NR) from GSFC/NASA in 2014 (Gelaro et al. 2015), and the O1280 (0.07°) ECMWF NR in 2018 (Hoffman et al. 2019). These NRs have each been processed by an individual institution and then provided to the community as a set of output files containing state variables at some temporal frequency. These output files are the basis of simulated observations for the OSSEs, and are also used for verification of OSSE analyses and forecasts.

In a recent essay on the use of OSSEs in the United States, Zeng et al. (2020) list as one of their recommendations that “global nature runs based on Earth system models (at 5 km grid spacing, preferably 3 km, and possibly 1 km) should be developed as the basis for a variety of OSSEs for exploring observation impacts over many different regional domains across the globe. This may require access to high-performance computers or partnerships among agencies.” The drive for increased resolution of future global NRs raises issues with the feasibility of microscale simulations and presents challenges that deserve further elaboration, especially as a modified approach will likely be required compared to past community NRs. Here, some of the challenges of producing and working with high-resolution global NR fields are addressed, as well as how this may affect the larger NWP OSSE community in the future.

The simulated observations are generally made by spatiotemporal interpolation of the NR fields, and interpolation between fields that are widely spaced in time may result in unphysical structures for features that are undergoing translation or deformation. If only infrequent temporal output is available, the effective spatial resolution of the NR will be substantially lowered (Privé and Errico 2016). Therefore, as the NR increases in horizontal and vertical resolution, the temporal frequency of output must also increase. For a 5 km horizontal resolution global NR, 10 min output frequency may be desired, with 5 min or shorter frequency for 1–2 km resolution NRs. This results in a very large burden in terms of production, storage, and handling of NR output. Using the NASA G5NR as a guideline, a similar 2-year-long NR with 140 vertical levels, 2 km horizontal resolution, and 5 min output would be approximately 400 PB in total size.

Given that there are millions of observations that need to be simulated each day using the NR fields, the computational cost of working with such a large dataset quickly becomes prohibitive. At high resolutions, simplifications such as treating radiance-observation footprints as single points must be reconsidered. Likewise, atmospheric motion vectors might be simulated with feature-tracking algorithms rather than with statistical methods that are used when the NR does not resolve clouds. If high-resolution NR fields are handled with distributed memory, simulating observations such as radiances, atmospheric motion vectors, and advecting rawinsondes that span a nonlocalized horizontal region will require special handling. Perhaps the greatest computational expense is the input/output (I/O) needed to read the NR files for interpolation. Not only do the NR fields increase rapidly in size as model resolution is increased, the more frequent temporal NR output requires increased calls to I/O when simulating observations.

One possible option for implementing a high-resolution global NR would be the integration of the observation operators for simulating data into the model used to produce the NR. It may be less computationally expensive to repeatedly rerun short segments of the NR than to handle the I/O for static output files. A single full run of the NR would be produced first with limited output. This “quick-look” dataset would be available for validation of the NR and for selection of periods of interest for OSSE experiments. The NR would then be rerun for subsets of the full run using the observation operators to produce the needed simulated observations, and also to produce verification datasets for select variables of interest. One of the major benefits of this method is that temporal interpolation issues would be minimized, as observations would be generated at increments as frequent as the internal model time step. This becomes more important as NRs begin to resolve clouds and other high-resolution, short-time-scale physical processes.

This potential method of “on-the-fly” NRs also has complications. Multiple NR reruns will be required to tune the observation operators, especially to account for likely remaining deficiencies in the NR physics and climatology. The NR will also need to be rerun when simulating new data types. Each institution running global OSSEs would either need to produce their own NR, or infrastructure would need to be developed to allow sharing of a single NR between institutions. Cloud computing might allow the NR to be containerized and shared, but would require significant computational resources and coordination between institutions. A choice would need to be made as to the lifespan of the NR depending on the level of available institutional support. If the NR is intended to be used for several years, the model version used to generate the NR would need to be maintained for community use, similar to reanalysis. However, the NR could also be upgraded more frequently, which would advance the NR ahead of operational NWP models, but comes at a cost of more intensive development efforts both for the production of the NR and for the concurrent integration of observation operators and validation of the OSSE framework.

In addition to the technical and computational aspects of high-resolution global NRs, validation of the NR is also a challenge. As finer-scale processes are resolved by the model, these features should be validated against the real world to determine if they are adequately representative of true dynamical and physical processes. However, available datasets of such high temporal and spatial resolution observations from the real world have limited availability. The effort needed to analyze and validate the NR at these small scales is substantial.

At this point in time, the 2014 G5NR is approaching obsolescence with only 72 vertical levels. The 2018 NR from ECMWF has similar horizontal resolution to the G5NR and higher vertical resolution, but with output at only 3 h intervals, has limited use for 4DVar and 4DEnVar NWP systems. To keep up with improvements to operational NWP systems, planning for the next global community NR should be a coordinated effort. Designing a new global NR framework should include input from stakeholders and developers who are familiar with the technical needs of performing OSSEs to ensure that all community needs are met.

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