National Water Model for Drought Monitoring: A Preliminary Evaluation

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ABSTRACT

As one key innovation in the NOAA hydrological modelling, National Water Model (NWM) was recently upgraded to v2.0 in June 2019. The NWM could provide not only the streamflow prediction for hydrological guidance, but also the real-time high-resolution land state analysis and assimilation. Based on the NWM v2.0 retrospective analysis from 1993 to 2018, we evaluated NWM soil moisture (SM) and evapotranspiration (ET) for the drought monitor application. The Soil Moisture Percentile (SMP) from NWM is compared with the official US drought monitor (USDM) map in major drought events. The drought categories Dx based on NWM, is quantitatively compared with similar drought monitor from the North American Land Data Assimilation System Phase 2 (NLDAS2) ensemble. A long time-series soil moisture monitor from Climate Prediction Center (CPC) leaky bucket model is also compared against NWM, to distinguish the importance of the long temporal record versus high spatial resolution for drought monitor. The Evaporative Stress Index (ESI) based on ET estimation from NWM is also assessed for the rapid drought development, i.e. flash drought, to evaluate evapotranspiration for the drought development. The preliminary results indicated the NWM could well capture the major droughts during 2000 to 2018 and 2019 Southeast flash drought, showing great potential in the future application for drought monitor.

1. Background

Drought is a natural disaster with high hazardous impacts on the society. However, due to the nonlinear nature of climate system, in particular the water cycle associated over the land surface, accurate monitoring and forecast drought remains a challenging scientific problem. Drought not only impacts food/agriculture, but also impacts on livestock, energy production, wildlife, public health, and may even enhance or cause wildfires, among other disasters.

The National Water Model (NWM) is a recent implementation of hydrologic modelling framework that simulates observed and forecast streamflow over the entire continental United States (CONUS). The NWM is based on the WRF-hydro model that simulates the water cycle with mathematical representations of complex physical processes, such as snowmelt and infiltration and movement of water through the soil layers that varies significantly with changing elevations, soils, vegetation types and a host of other variables. The NWM simulates and forecasts streamflow and other hydrologic quantities over the CONUS at 1-km to 250-m spatial resolutions with lead times ranging from hours to weeks. Land-surface processes are modeled using the Noah-Multiparameterization (NOAH-MP) land surface scheme (Niu et al. 2011) as deployed in the Weather Research and Forecasting-Hydrological (WRF-Hydro) modeling framework. The NOAH-MP code was optimized to perform partitioning of latent and sensible heat fluxes from the total radiation budget and provide lower boundary conditions for the Weather Research and Forecasting (WRF) mesoscale meteorological model.

The advantages of NWM over the existing drought-monitoring tools include: higher spatial resolution, decreased latency, and a single integrated model providing all inputs in a physically consistent framework for the CONUS at river-basin resolution. Improvements in the physical representation of the NWM will increase its accuracy. In particular, the near real-time Analysis and Assimilation (A&A) cycle could provide soil moisture state real-time, greatly reduce the lagging of 4-5 days in the NLDAS2 analysis. In the CPC, we recently evaluated the NWM as the monitoring tools for the drought information service.
2. Data

2.1 Rasterized USDM data

Led by the National Drought Migration Center (NDMC), the USDM (http://droughtmonitor.unl.edu and drought.gov) is the nation’s drought monitoring information product of current drought conditions. Established in 1999, the weekly USDM map uses a ranking/percentile system to facilitate the integration of numerous drought analyses and indices and classify the drought into one abnormally dry category (labeled D0) and four drought categories (D1, moderate drought; D2, severe drought; D3, extreme drought; and D4, exceptional drought) that reflect dry conditions below the 30th, 20th, 10th, 5th, and 2nd percentiles, respectively.

A rotating lead author, from the four primary workgroups (the NDMC at the University of Nebraska–Lincoln, the U.S. Department of Agriculture (USDA), the NCEP CPC, and the National Centers for Environmental Information (NCEI)), uses his/her best judgment to reconcile differences from a broad range of input sources to construct a draft USDM map. The draft map is reviewed by over 350 local- to national-level drought coordinators, agency leads, and experts. After their feedback, the lead author incorporates the field feedback to target a “convergence of evidence” consensus indicating a single drought severity category. The resulting final USDM map depicts this category, either for only one (specially noted) type of impact or for all facets of drought combined (i.e., meteorological, hydrological, and agricultural are widely accepted drought aspects). The original USDM outputs are in the ArcGIS shape files. We rasterize all the ArcGIS shape file to the regular lat-lon grid at 1/8 degree resolution.

2.2 NWM

The standard A&A cycle of NWM produces a real-time hourly analysis of the current streamflow and other land surface states across the CONUS. This analysis and assimilation configuration is internally cycling, with each subsequent standard analysis starting from the previous hour’s run. Meteorological forcing data are drawn from the Multi-Radar/Multi-Sensor (MRMS) Gauge-adjusted and Radar-only observed precipitation products along with the short-range Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) dataset, while stream-gauge observations are assimilated from the U.S. Geological Survey (USGS). The NWM v2.0 retrospective run is available from 1993 to recently, and will be the major dataset for this study.

2.3 NLDAS2 land surface models

The NLDAS2 (Xia et al. 2014) four land surface models (LSMs) output is used as a comparison for NWM soil moisture, since the NLDAS2 is currently considered operationally by USDM authors. The NLDAS2 contains output from four LSMs, i.e., the Noah model, the Variable Infiltration Capacity (VIC) model, the Sacramento (SAC) model, and the NASA Mosaic model. Output from these LSMs is available on a ⅛-degree grid across CONUS from 1979-present, and the same NLDAS2 meteorological fields are used for forcing data as the NWM retrospective simulation.

3. Procedures

3.1 Soil moisture percentile

Soil-moisture percentiles, used in this study, are calculated as follows. An empirical climatological probability density function (PDF) is created for each grid point, total column, and each day of the year using a 29-day centered window to aggregate volumetric soil moisture values. We selected the soil moisture of only 5 days, i.e., two weeks before, one week before, current day, one week later and two weeks later. This PDF is then used to calculate the 2nd, 5th, 10th, 20th, and 30th percentile values as well as the median and interquartile range for each day, grid-point, and level. The full length of record (1993-2018) is used to calculate NWM soil moisture percentile values when not being directly compared with observations.

3.2. Evaluation metric

The contingency table metric is used to compare the fraction of correctly simulated events to the number of observed events. It includes: the probability of detection (POD), the false alarm rate (FAR), the critical success index (CSI) and the bias (BIAS). The CSI is the ratio of correctly simulated events to the total of correct events, missed events, and false alarms. In our evaluation, ‘events’ are days in the NWM retrospective
simulation with soil moisture values below the specific threshold, i.e. 10th percentile, which are then compared with days of soil moisture below this threshold in observations. The CSI ranges between 0 and 100%, with 100% being a perfect simulation. The performance diagram is based on the contingency table to summarize all above information into one diagram (Roebber 2009).

4. Results

Figure 1 shows the performance diagram of SMP evaluated against the USDM. The left panel shows the original SMP <30% evaluated against the USDM D0 drought events over the CONUS. The scatter dots represent every week from 2000 to 2018. The right panel shows the improved SMP monitor by merging with long-term drought events.

Fig. 1 The performance diagram for the NWM model SMP against the USDM drought categories. The left panel shows the original SMP <30% evaluated against the USDM D0 drought events over the CONUS. The scatter dots represent every week from 2000 to 2018. The right panel shows the improved SMP monitor by merging with long-term drought events.

Fig. 2 The 2019 Southeast flash drought monitored by the NWM. The top panel is the percentage of area covered by flash drought indicated by the USDM, and the bottom panel is based on the NWM SMP monitor. For comparison and contrast, the bottom panel y-axis is reversed.
drought (the yellow colored dot during 2012 to 2013). However, due to the short retrospective period (only 26 years available), it is not good for monitoring the long-term droughts in the western region. In particular considering the Western region is in the relative dryer decade in the last 20 years. But, by merging with long-term drought information by joint probability methods, the NWM greatly enhanced the ability to detect the drought events indicated by the USDM (right panel at Fig. 1). The Probability of detection has been greatly enhanced and the overall CSI has been improved to around 0.8.

In particular, the NWM demonstrated great ability to capture the flash drought. Figure 2 shows the example of the real-time NWM SMP monitor during 2019 over the Southeast US region. The top panel shows the percentage area covered by D0-D4 drought as indicated by USDM, and the bottom panel shows the same percentage area as calculated by SMP from NWM for the corresponding threshold for D0-D4 drought. For easy comparison and contrast, the bottom panel’s y-axis is reversed. It can be seen from USDM (top panel) that the drought evolved quickly in September to a D3 category; worsening further to D4 in October, and coming to an end in December. Interestingly, the same timely evolution and the demise of the short-lasting flash drought over the region was also caught well by the NWM based SMP (bottom panel).

5. Conclusions

Based on the NWM v2.0 retrospective analysis from 1993 to 2018, we evaluated NWM SM and ET for the drought monitor application. The Soil Moisture Percentile from NWM was compared with the official US drought monitor map in major drought events. The drought categories Dx based on NWM, was quantitatively compared with the rasterized USDM map. The preliminary results indicated the NWM could well capture the major droughts during 2000 to 2018 and 2019 Southeast flash drought, showing great potential in the future application for drought monitoring.

References

