Better Advance Warnings of Drought

A New NASA Hydrological Forecast System

Adapted from “The NASA Hydrological Forecast System for Food and Water Security Applications,” by Kristi R. Arsenault (NASA Goddard Space Flight Center), Shraddhanand Shukla, Abheera Hazra, Augusto Getirana, Amy McNally, Sujay V. Kumar, Randal D. Koster, Christa D. Peters-Lidard, Benjamin F. Zaitchik, Hamada Badr, Hahn Chul Jung, Bala Narapusetty, Mahdi Navari, Shugong Wang, David M. Mocko, Chris Funk, Laura Harrison, Gregory J. Husak, Alkhalil Adoum, Gideon Galu, Tamuka Magadzire, Jeanne Roningen, Michael Shaw, John Eylander, Karim Bergaoui, Rachael A. McDonnell, and James P. Verdin. Published online in *BAMS*, July 2020. For the full, citable article, see [DOI:10.1175/BAMS-D-18-0264.1](https://doi.org/10.1175/BAMS-D-18-0264.1).

Many regions in Africa and the Middle East are vulnerable to water and food insecurity—a motivation for the U.S. Agency for International Development’s Famine Early Warning Systems Network (FEWS NET) and other drought warning efforts. These warnings guide life-saving assistance to millions of people each year.

Since 2015, scientists at several U.S. universities and governmental agencies, along with others internationally, have partnered with FEWS NET to develop the NASA hydrological forecast and analysis system (NH_yFAS). This new, multi-land surface model (LSM) ensemble approach to seasonal forecasting is set up specifically for continental Africa and the Middle East and yields more skillful soil moisture, streamflow, and drought detection than a single-model approach. NH_yFAS seasonal-scale hydrologic forecasts extend the lead time of drought warnings beyond what routine hydrologic monitoring can provide. NH_yFAS supports climate seasonal forecast datasets and also subseasonal forecasts.

FEWS NET regional scientists have been using the seasonal hydrological forecasts since August 2018. In turn the regional scientists provide feedback that can help improve NH_yFAS. The partnership with FEWS NET helps operationalize monitoring schemes for food, water, and energy security. The system also benefits from strong collaboration with end users in Africa and the Middle East, who help with the formulation and communication of early warning indicators to water and food security communities. Meanwhile, NH_yFAS enhances FEWS NET’s early warning capabilities by enabling regional experts to visualize the potential hydrologic impacts of forecasted precipitation.

The hydrological forecast system

NHyFAS derives its skill from two sources: (i) accurate initial conditions, as produced by an offline land modeling system applying and/or assimilating satellite data, and (ii) meteorological forcing data during the forecast period from a state-of-the-art ocean–land–atmosphere forecast system.

NHyFAS forecasts build on the main FEWS NET hydrologic monitoring system, the FEWS NET Land Data Assimilation System (FLDAS). FLDAS combines precipitation observations with atmospheric reanalysis to drive advanced LSMs for both long-term and near-real-time monitoring of hydrological conditions.

In one of its key advances, NHyFAS improves the initial hydrologic conditions by assimilating several different soil moisture datasets, including Soil Moisture Active Passive (SMAP) satellite estimates down to 5-cm depth at least once every 3 days. NHyFAS can also assimilate terrestrial water storage anomaly estimates from NASA's Gravity Recovery and Climate Experiment (GRACE; decommissioned in late 2017) and GRACE follow-on (GRACE-FO) satellite missions. These estimates can

help flood prediction and improve drought forecasts.

Due to a paucity of in situ data in Africa and the Middle East, NHyFAS relies on FEWS NET experts to help verify local conditions. Additionally, NHyFAS is driven with a combined satellite and station dataset for estimating precipitation over these regions, known as the Climate Hazards center InfraRed Precipitation with Station data (CHIRPS).

FLDAS used two LSMs to derive 30+ years of historic records and near-real-time hydrological and drought-related products. NHyFAS expands this with two additional LSMs with representative groundwater schemes. The LSMs help generate historic simulations that span almost 40 years.

State-of-the-art, ensemble-based seasonal forecasts provide near-real-time applications with meteorological forcing, translated into hydrologic forecasts by the NASA Land Information System (LIS) software. LIS is the overarching, customizable land modeling software framework used in NHyFAS. It includes many LSMs, thus allowing NHyFAS's multimodel ensemble and multiple data assimilation strategies.

The main NHyFAS flowchart of system components and data inputs. Yellow-highlighted boxes indicate the inputs to the various parts of the system, and the purple-highlighted boxes represent the different system components and outputs derived. * ▼

Skill assessment

We ran the land models for different Africa focus regions (e.g., southern Africa) and the entire continent at a $0.25^\circ \times 0.25^\circ$ spatial resolution and 15-minute model time step from 1981 to close to the present. NASA's wide array of satellite-based products were used to help evaluate the model forecasts in areas with limited surface observations.

Moisture under the land surface tends to persist more than near-surface soil moisture and thus reflects the slow-moving nature of agricultural drought. To see how well the models recreate the overall spatiotemporal variability of past droughts, we determined the areas in southern Africa for which the simulated terrestrial water storage (for November–March, 1982/83–2015/16) exceeded different drought severity thresholds. Several droughts, including 1982–83, 1994–95, 2004–05, and 2015–16, stand out clearly in the simulation results. The 1991–92 and 1994–95 droughts suggest severe low groundwater storage and soil moisture, with almost 60%–80% of Zambia, Malawi, Mozambique, and Zimbabwe under the most extreme category of drought.

The results also help to identify some sources of uncertainty in the initial conditions and meteorological forcing. For example, the meteorological forecasts provide true skill at monthly to seasonal leads, sometimes with larger impacts later in the forecasts—that is, at a lead of 3–5 months. The skill and performance of the NHyFAS forecasts is higher in the first lead month (November) and again in lead months 3 and 4 (February and March), which may reflect an ability to capture influential teleconnections from El Niño–Southern Oscillation (ENSO), like in the southern Africa case.

NHyFAS forecasts also have evident potential to provide flood risk early warning, though the skill tends to dissipate sharply after the first month, highlighting the need of at least monthly updates. The system could have forecasted, with at least one-month warning, the higher-than-normal soil moisture and runoff for the extreme rainy period with several deadly and damaging floods throughout East Africa in spring of 2018.

Finally, data assimilation in NHyFAS can improve forecasts. GRACE TWS assimilation improves overall groundwater storage and drought metrics, especially in areas with high interannual precipitation variability.

Operational support of FEWS NET

FEWS NET's monthly food security outlook process brings together African, Central American, and U.S. scientists who routinely monitor large-scale climate conditions and forecasts as well as on-the-ground conditions. Through collaborative, monthly forecast review meetings, food security analysts develop scenarios of crop production and food insecurity for current and upcoming seasons.

NHyFAS has been set up to help support this monthly process. We have routinely delivered hydrological forecasts that show agricultural drought and extreme moisture states ahead of the monthly forecast review meetings. Since it merges precipitation monitoring and hydrological forecasts, NHyFAS is uniquely suited for midseason outlooks.

Summary and future directions

As the need for improved monitoring and prediction of water and food insecurity risks grows, the demands for more enhanced data networks and modeling systems also grow. Future plans for NHyFAS include the use of meteorological forecasts from additional seasonal forecasting systems. The current suite of LSMs can be expanded to take further advantage of the benefits of multimodel analyses. Also, NHyFAS can include more routine assimilation of the different satellite-based products, like SMAP and the latest GRACE follow-on products. Currently, NHyFAS makes precipitation and soil moisture–based forecast products routinely available; it has plans, however, to also provide additional products, such as streamflow, terrestrial water storage, evapotranspiration, and other useful diagnostics such as water stress indices. NHyFAS will continue to provide support for USAID's FEWS NET as well as for other early warning systems. ••

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“Seasonal precipitation forecasts from GEOS-5 are input to NASA’s LIS to produce soil moisture forecasts. Continuing wet conditions forecast for September 2018 suggested an elevated flood risk in Sudan.”

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* (a) Example of routine NASA seasonal hydrologic forecast root-zone soil moisture percentile product, with (top left) July initial conditions and two combined LSMs (the Noah-MP and the NASA CLSM) using GEOS-V2 seasonal forecasts (20 members in total, 10 for each model) for the August 2018 forecast. (b) Real example case where FEWS NET regional scientists utilized the September forecast month to confirm other precipitation-based forecast and preexisting wet soil conditions, contributing to an elevated flood risk in Sudan.

BAMS: What would you like readers to learn from this article?

Kristi R. Arsenault (NASA Goddard Space Flight Center): *A new multimodel hydrological forecast system, using NASA-based models, satellites, and forecast inputs, has been designed and set up to run routinely, serving food and water security efforts in Africa and the Middle East.*

BAMS: What is the principal application of the forecast system?

KRA: *Seasonal hydrological forecasts can serve as a tool and guide in early warning of potential droughts and floods, especially in areas that can be most vulnerable to major climate extremes, like in Africa.*

BAMS: How did you become interested in the topic of this article?

KRA: *I began supporting FEWS NET-related efforts almost 10 years ago, working with other NASA and FEWS NET scientists in helping to develop the FEWS NET Land Data Assimilation System (FLDAS), funded originally by NASA. FLDAS is used operationally as a key monitoring system that produces global estimates of agricultural and hydrological drought and also wet extreme conditions. This effort led to a subsequent NASA-funded project focused on seasonal drought forecasts, known as Forecasting for Africa and the Middle East (FAME), which I was asked to help lead. My interest in this area definitely grew while I was helping with FLDAS, and I really wanted to help expand these efforts to include the new prediction components.*

BAMS: What surprised you the most about the work discussed in this article?

KRA: *The skill in the seasonal forecasts, especially for precipitation, was quite adequate for looking at both water deficit (drought) and flood potential. In terms of seasonal forecasts of precipitation, this meteorological input field typically is the hardest to forecast long term with much skill and accuracy, but we found overall the forecasts captured major categorical events, at least a couple of months in advance.*

BAMS: What was the biggest challenge?

KRA: *One of the greater challenges that we faced involved the operational effort itself. On occasion, systems may go down, errors may creep into the observations being assimilated, and changes in the dynamical models used as the input to the system require rerunning all the hindcasts to keep up in near real-time to support our end-users.*

BAMS: What's next?

KRA: *Currently, NHyFAS is being used routinely to support FEWS NET seasonal hydrological forecasts and has been expanded to include more seasonal precipitation forecast members from the North American Multi-Model Ensemble (NMME) suite of models. This effort is being supported further by USAID, and the follow-on work has led to enhanced forecast skill and expanded capabilities for FEWS NET regional scientists and food security analysts in helping to make food and water security-related decisions.*