Seasonal to Multiyear Water Cycle Forecasting to Support Food Insecurity Early Warning: Needs and Opportunities

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Global food insecurity outlook

- ~130 million people in need of emergency food assistance.
- Unprecedented increase in food insecurity.
- Primary contributors to food insecurity: Conflicts, drought, economic challenges.

Source: FEWS NET https://fews.net/
Scenario development for early warning

Hazards:
- Drought
- Floods
- Cyclones
- Earthquakes
- Disease
- Conflict
- Policy

Hazard monitoring tools/info:
- Science Team Tools
- Livestock herd model
- Government ministries
- Market and price monitoring systems
- UN information systems
- Conflict analysis
- Research institutions

Intermediate shocks:
- Production shocks
- Price shocks
- Market access shocks
- Safety net program shocks

Proximate cause:
- Livelihood zone problem specifications

Household food security outcomes:
Source: FEWS NET

Slide credit: Lark Walters (EWT, FEWS NET)
Existing seasonal scale to multiyear forecasts
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<td>Machine Learning (ML) based crop yield forecasting</td>
<td>Up to 6 months</td>
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Selected seasonal to multiyear scale forecasting products supporting FEWS NET
Multi-season ahead forecast of global crop yield outlook

- Recent research showing skill in multi-year-ahead forecasts of large-scale climate modes (e.g., ENSO).
- We utilize the long-lead ENSO forecasts from NOAA PSL to provide long-lead crop yield outlook.

Source: NOAA PSL https://psl.noaa.gov/forecasts/seasonal/
El Niño composites based national scale crop yield anomaly

Source: Weston Anderson (NASA/UMD), Brian Barker (UMD)
In-season Machine Learning (ML) based sub-national scale crop yield forecasts

Lee et al., 2022, Global Food Security

Source: Donghoon Lee CHC
Recent sub-national scale crop yield forecasts

Forecast for Somalia and Kenya Maize crop yield relative to 10-year (2009-2018) mean observed yield for selected high yield admin-2 units

**Somalia:** Below average (<90%) to average maize crop yield expected in the high yield admin-2 units.

**Kenya:** Above average (>110%) to average crop yield is expected in high yield admin-2 units with some exceptions in Central and Eastern Kenya.

Source: Donghoon Lee, UCSB
Seasonal scale hydrologic forecasting system operational since late 2018.

Based on NMME climate forecasts and LIS hydrologic models.

**Source:** Hazra et al., 2023

**FLDAS-Forecasts:** https://ldas.gsfc.nasa.gov/fldas/models/forecast
Seasonal scale hydrologic forecasts (updated monthly)

FLDAS Forecasts: https://ldas.gsfc.nasa.gov/fldas/models/forecast
Monitoring and forecasts by Multi-Agency Science Team

FEWS NET/CHC Regional Scientists

(1) FEWS NET scenario development

(2) GEOGLAM Crop Monitor Reports
Needs and limitations
Lack of long-lead hydrologic forecast skill

Top row: Correlation of “open-loop” soil moisture (driven with obs. atmospheric forcings) with SMAP
Bottom row: Correlation of soil moisture forecasts (driven with climate forecasts) with SMAP

Source: Hazara et al., 2023
Lack of long-lead SWE forecasts

- Countries like Afghanistan that are amongst the most food insecure countries rely heavily on snowmelt runoff to support irrigated agriculture.

- At present, Afghanistan is facing unprecedented level of food insecurity partly due to the three consecutive droughts.

- Long-lead SWE forecasts would certainly be a valuable tool for supporting early warning.
Lack of long-lead rainy season onset forecasts

- In the regions with highest food insecurity risks (e.g. Eastern Africa), even a 1 dekad delay makes the drought a most-likely outcome.

- Long-lead prediction of rainy season onset can be beneficial in those regions.

Source: Shukla et al., 2021 (PlosOne)
Opportunities
**ENSO based hydrologic predictability**

- ENSO is shown to influence hydrologic conditions in several parts of the globe.

- Multiyear ahead ENSO prediction is now possible.

- Potential exists for ENSO based multiyear streamflow prediction (similar to crop yield outlooks).

Source: Lee et al., 2018 (ERL)
Sources of seasonal scale hydrologic predictability

- The contribution of initial conditions (ICs) is generally highest in Arid and snow dominated regions.
- At higher lead climate forecasts (CF) are the key contributor to the hydrologic forecasts skill.
- The relative contributions of ICs vs CF vary seasonally.

Shukla et al., 2013 (HESS)

Median of RMSE ratio for cumulative runoff forecasts, over the grid cells in different Koppen-Geiger climate classes in (a) Northern Hemisphere and Tropics and (b) Southern Hemisphere – excluding equatorial climate regions that are included in (a).
Potential contribution of Soil moisture (SM) vs snow ICs in seasonal scale hydrologic predictability

Assessment of contribution of SM ICs relative to snow ICs in seasonal hydrologic predictability, at lead-1, -3 and-6 months since the forecast initialization on (a) 1 January, (b) 1 April.

Source: Shukla et al., 2013 (HESS)
Value of data assimilation in improving hydrologic forecasts

- Getirana et al., 2020 (WRR) showed that GRACE DA based improvement in terrestrial water storage (TWS) can lead to improvement in streamflow forecast skill.

- Such experiments need to be conducted at global scale.

Source: Getirana et al., 2020 (WRR)
(1) How does each component of TWS contribute to its persistence in observations as compared to modeled TWS?

(2) How do different components of TWS initial conditions influence S2S hydrologic forecasts of droughts and floods at different lead-times and hydroclimate states?

(3) Can “real-time” S2S hydrologic forecasts skill be improved by TWS data assimilation?

Improving a process-based understanding of how terrestrial water storage can improve S2S hydrologic forecasts skill in data-sparse regions

- **Proposed research**
  - NASA remote sensing datasets
  - NASA modeling datasets
  - NASA modeling experiments

- **Expected outcome**
  - Improved understanding of persistence in TWS components
  - Improved understanding of the role of TWS in S2S hydrologic forecasts
  - Potential improvements in operational S2S hydrologic forecasts skill

NASA S2S supported project  
(Team: UCSB, UMD and NASA)
Potential for application of hydrologic forecasts for anticipating crop production shocks

- Hydrologic forecasts (such as SM forecasts) can be used to anticipate crop production shocks.

- Shukla et al., 2020 shows that SM forecasts generated in early November can provide yield forecasts with the similar skill as in February using DJF ENSO as a predictor.

Source: Shukla et al., 2020 (NHESS)
Potential for application of hydrologic forecasts for anticipating crop production shocks

- Cook et al., 2021, shows promising level of TWS forecasts skill (by FLDAS-Forecasts system) at lead-3 months.
- The study also shows predictability of LAI (indicator of vegetation health) using TWS, at least at 3 months lead-time.
- Hence long-lead TWS forecasts are likely to be helpful for FEWS.

Source: Cook et al., 2021 (JHM)
Summary

(1) Unprecedented level of food insecurity, drought being one of the important contributors.

(2) Seasonal scale forecasting system currently support food insecurity early warning.

(3) At multiyear scale ENSO forecasts are being used to identify sequential and/or synchronous agricultural droughts.

(4) Key limitations include (i) lack of long-lead hydrologic forecasts skill (ii) lack of long-lead SWE forecasts (iii) lack of long-lead rainy season onset forecasts

(5) Opportunities for seasonal to multiyear water cycle prediction include leveraging of (i) long-lead ENSO forecasts (ii) hydrologic initial conditions (e.g. TWS data assimilation) and (iii) hydrologic forecasts for anticipating crop production shocks.
Acknowledgements

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References:

Thank you!

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Performance of sub-national scale crop yield prediction

Blue = lower error
Red = higher error
gray = “no skill”

Source: Donghoon Lee, UCSB
Performance of FLDAS-Forecasts

- Hydrologic forecasts based on NMME climate forecasts improve the skill beyond ESP which is based on climatology.

- Application of multimodel climate forecasts provides improvement relative to a single model.

Source: Hazara et al., 2023