Climate Hazards Center

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

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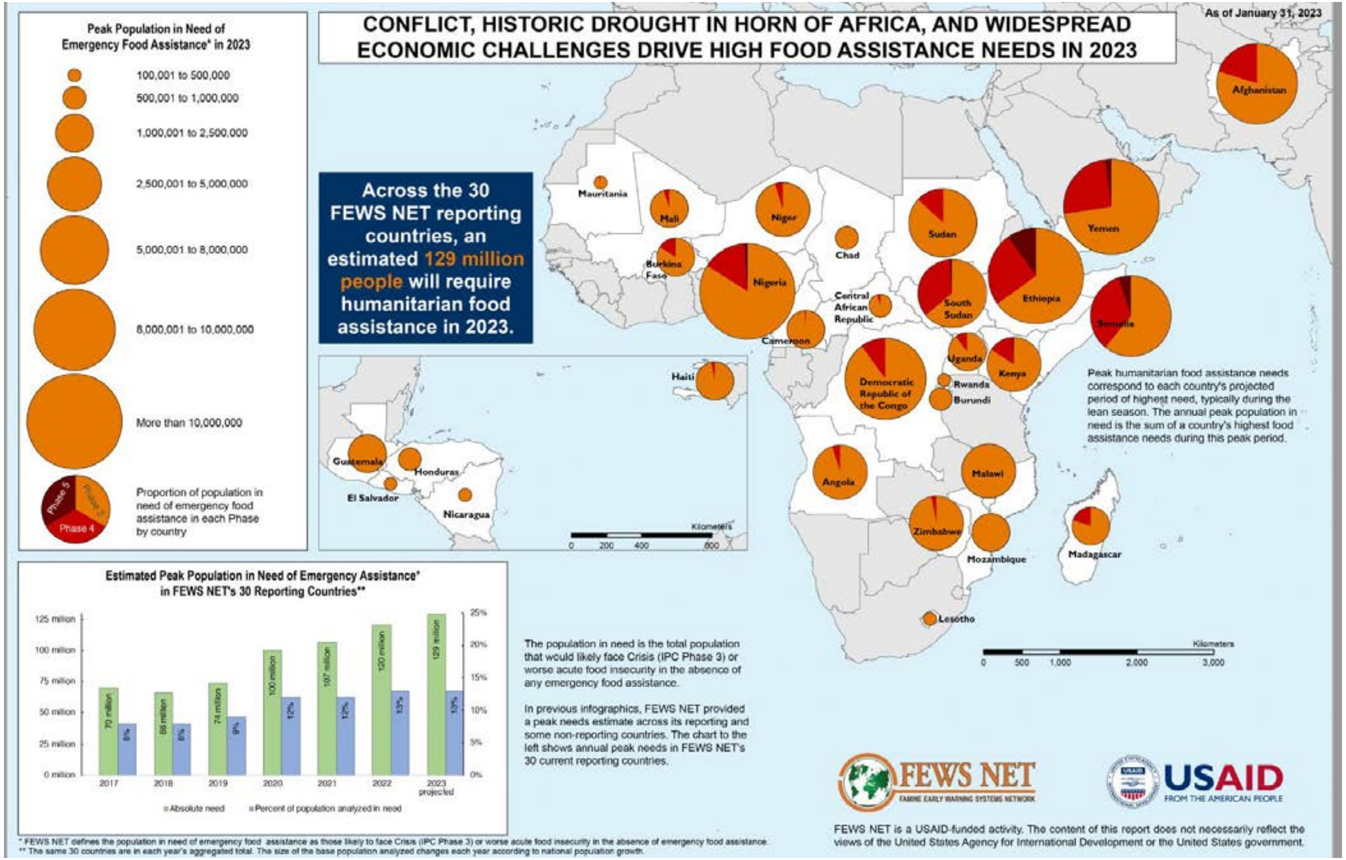
USAID FROM THE AMERICAN PEOPLE · FEWS NET FAMINE EARLY WARNING SYSTEMS NETWORK · NASA · SERVIR · Crop Monitor a geoglam initiative · USGS science for a changing world

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

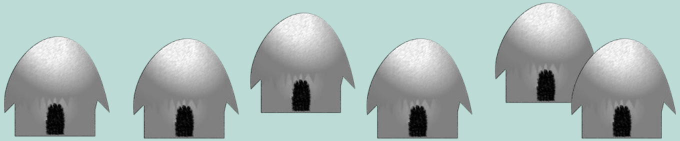
Hazards: Drought | Floods | Cyclones | Earthquakes | Disease | Conflict | Policy

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

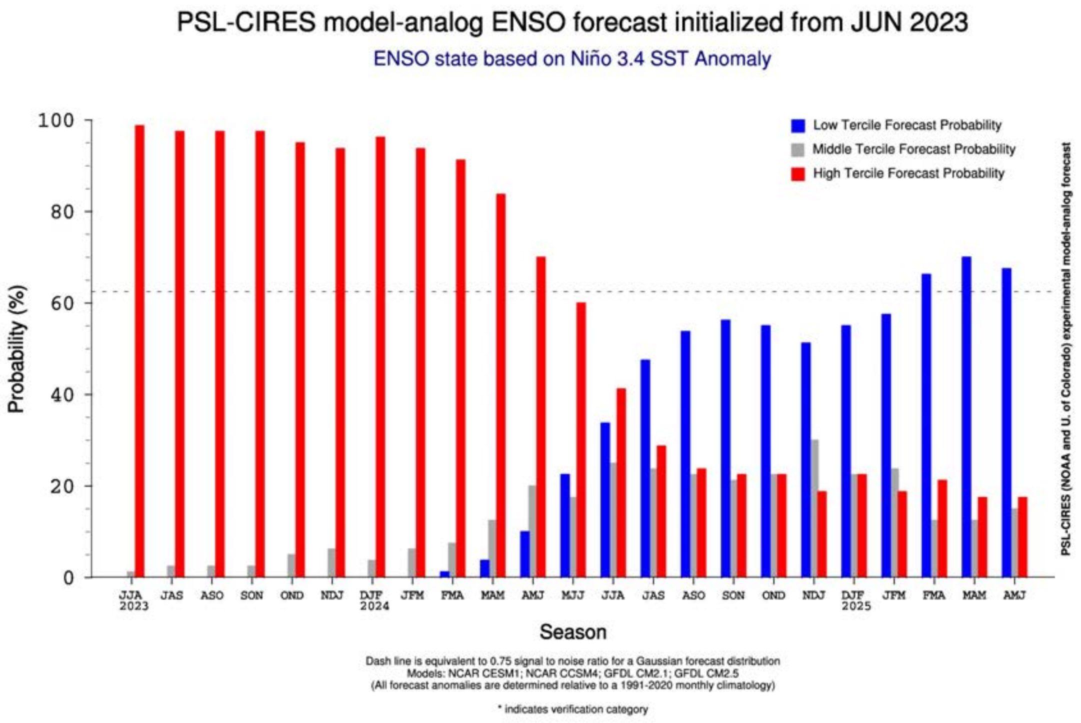
Forecasts	Lead time	Funded by	Region	Operational timeline
Extended outlooks	Up to 24 months	FEWS NET	Global	Operationally available by Dec 2023
Machine Learning (ML) based crop yield forecasting	Up to 6 months	USGS	Sub Saharan Africa	Partially operational for selected FEWS NET countries, fully operational by Dec 2023.
NASA Hydrology Forecast and Analysis System (NHyFAS)	Up to 5 months	Initially by NASA, Currently by FEWS NET	Sub Saharan Africa + Middle East	Currently operational and used by FEWS NET
Water point level forecasting	2 weeks to 6 months	NASA Water Resources	Sahel region	Fully operational by 2025

Selected seasonal to multiyear scale forecasting products supporting FEWS NET

Multi-season ahead forecast of global crop yield outlook

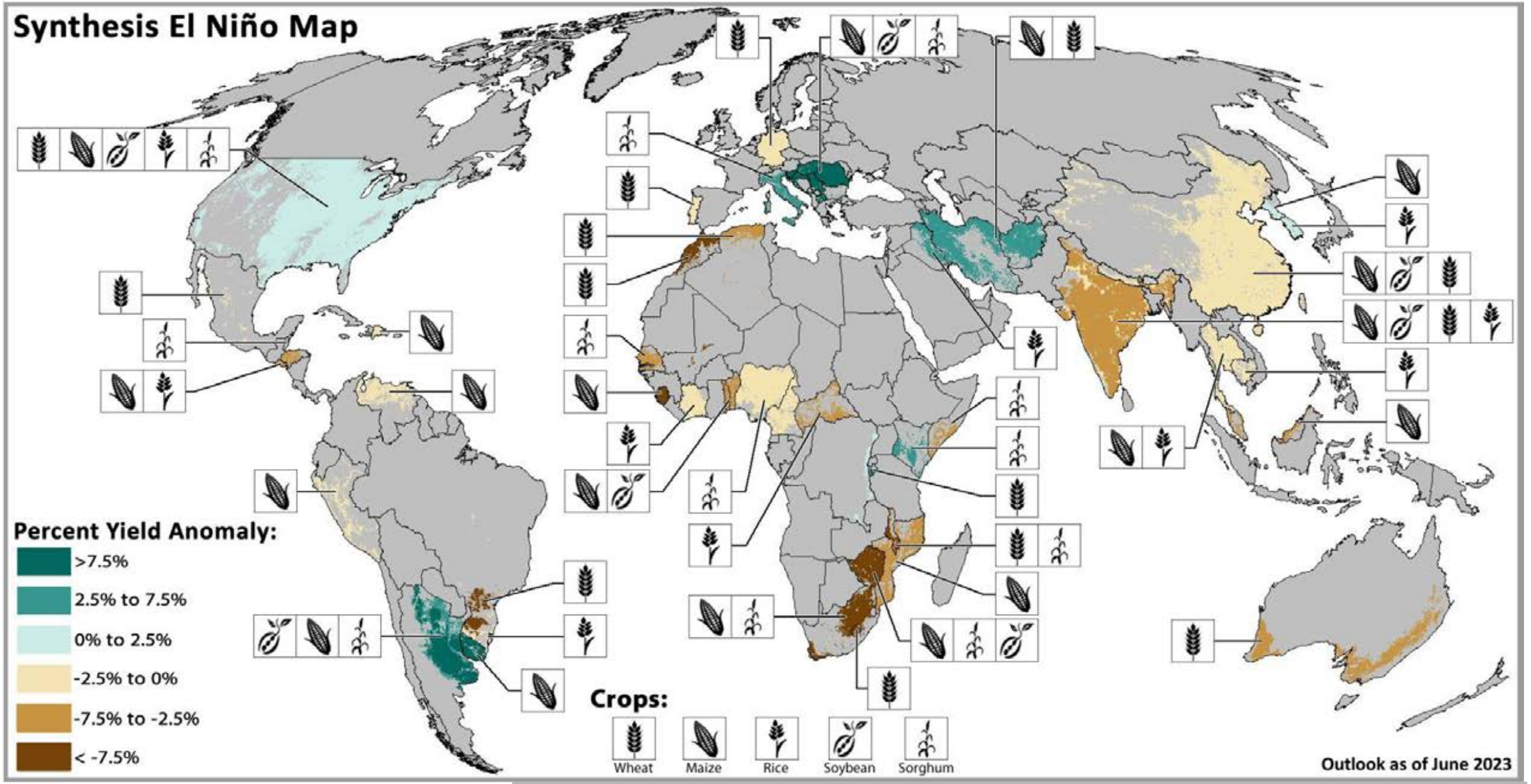
- Recent research showing skill in multi-year-ahead forecasts of large-scale climate modes (e.g., ENSO).

- 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/

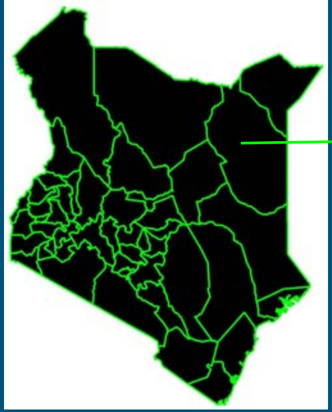
El Niño composites based national scale crop yield anomaly



Source: Weston Anderson (NASA/UMD), Brian Barker (UMD)

In-season Machine Learning (ML) based sub-national scale crop yield forecasts

Subnational-scale



Pre-season | Vegetative growth period (VP) | Reproductive development period (RP)

Dekadal (10 days)	D18	D17	D16	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	Harvest

Lead-time

4 standard EO data set:
- Precipitation – CHIRPS (UCSB)
- Reference ETo – NOAA-PSL
- NDVI – eMODIS (USGS/EROS)
- Temperature – NOAA-PSL

→

33 non-standard EO features:
- Number of dry days
- Growing degree days
- …
- Number of days precipitation above 95 percentile

Lee et al., 2022, Global Food Security

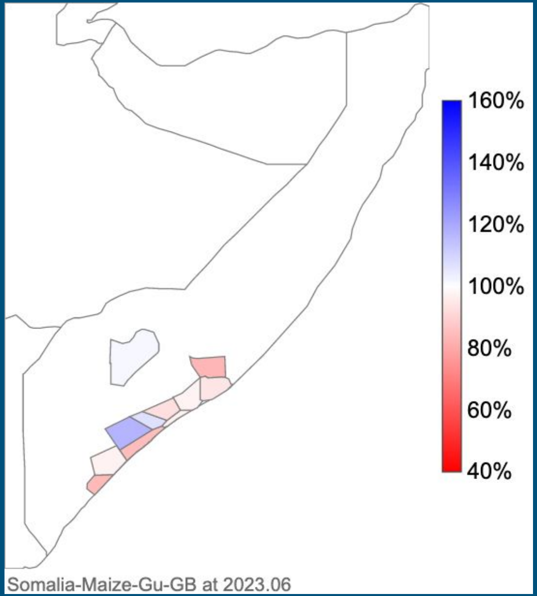
Source: Donghoon Lee CHC

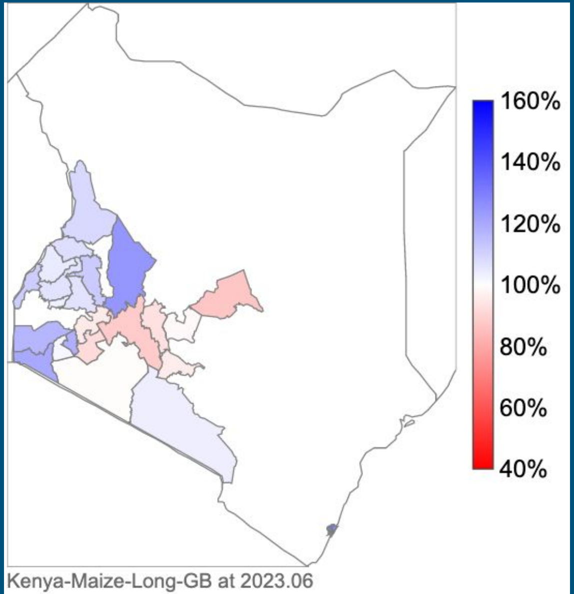
Recent sub-national scale crop yield forecasts

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.

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





Source: Donghoon Lee, UCSB

Seasonal scale hydrologic forecasts

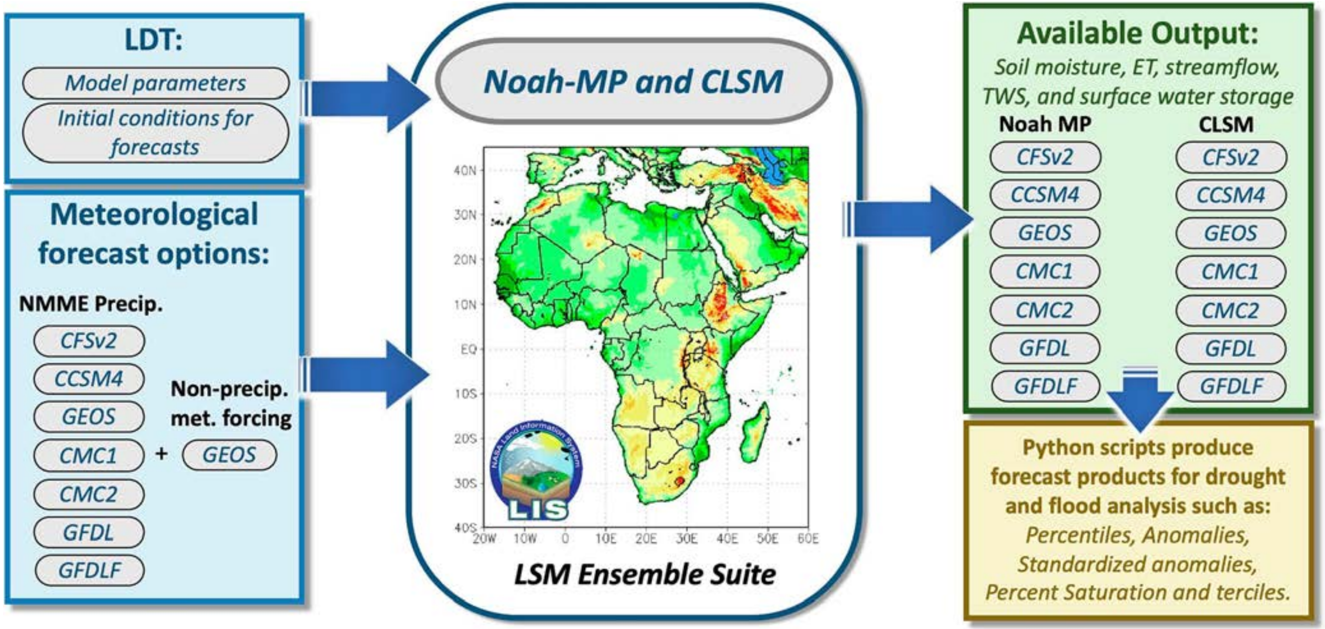
- Seasonal scale hydrologic forecasting system operational since late 2018.
- Based on NMME climate forecasts and LIS hydrologic models.

BAMS Article

The NASA Hydrological Forecast System for Food and Water Security Applications

Kristi R. Arsenault, 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

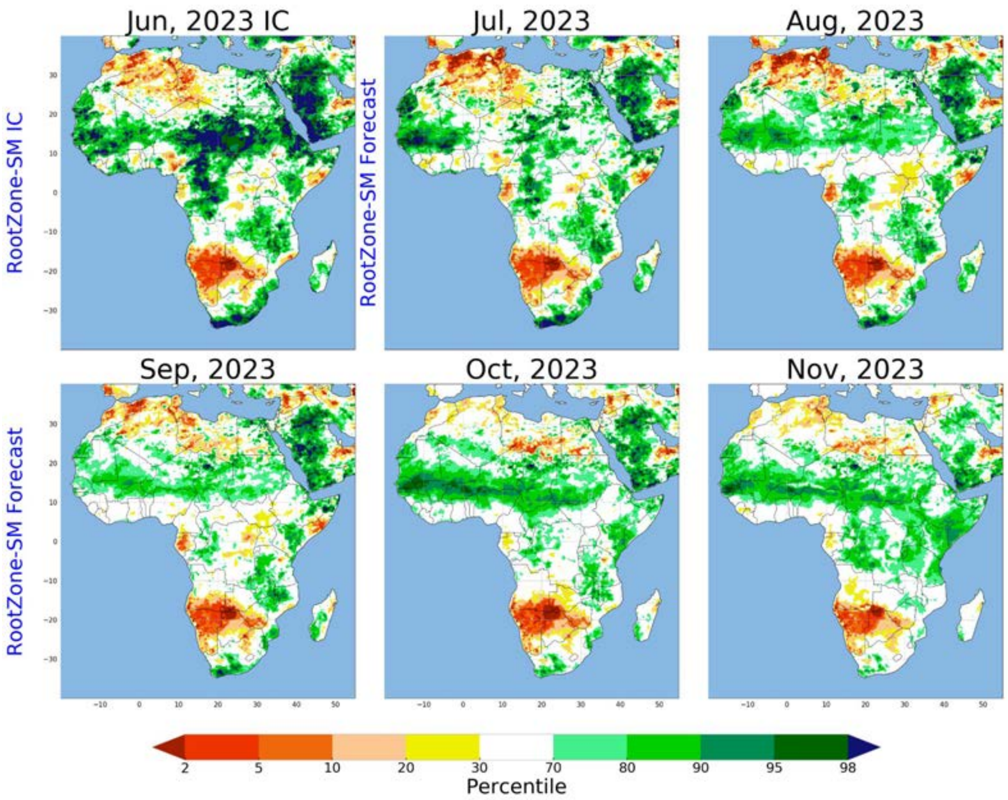
NMME forecasts

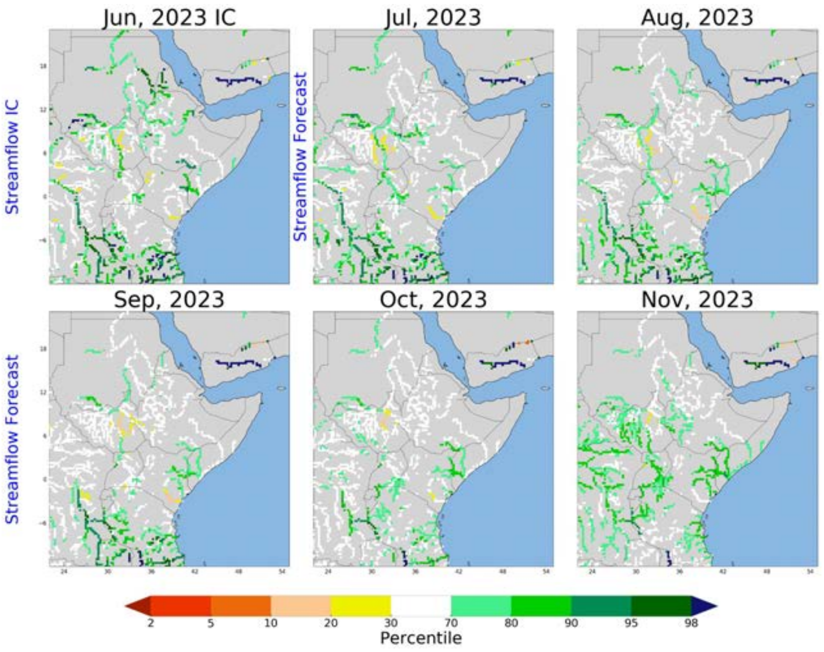


Source: Hazra et al., 2023

FLDAS-Forecasts: https://ldas.gsfc.nasa.gov/fldas/models/forecast

Seasonal scale hydrologic forecasts (updated monthly)





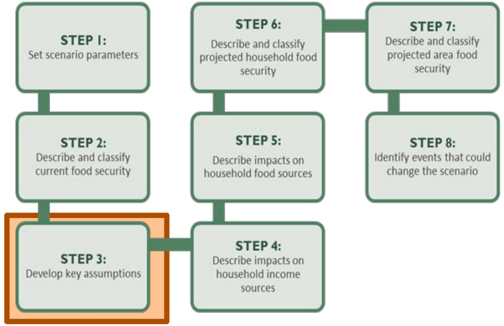
FLDAS Forecasts: https://ldas.gsfc.nasa.gov/fldas/models/forecast

Drought prediction to food insecurity outlooks

FEWS NET/CHC Regional Scientists

Monitoring and forecasts by Multi-Agency Science Team

(1) FEWS NET scenario development



CILSS

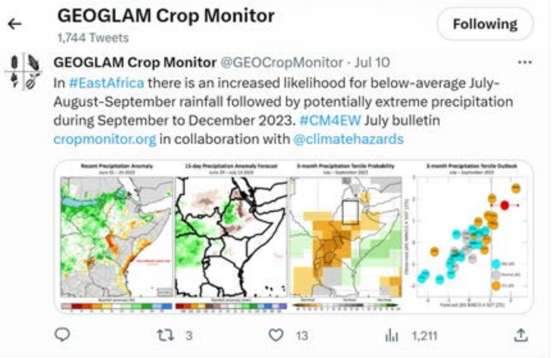
AGRHYMET

IGAD

ICPAC

SOUTHERN AFRICAN DEVELOPMENT COMMUNITY

CLIMATE SERVICES CENTRE

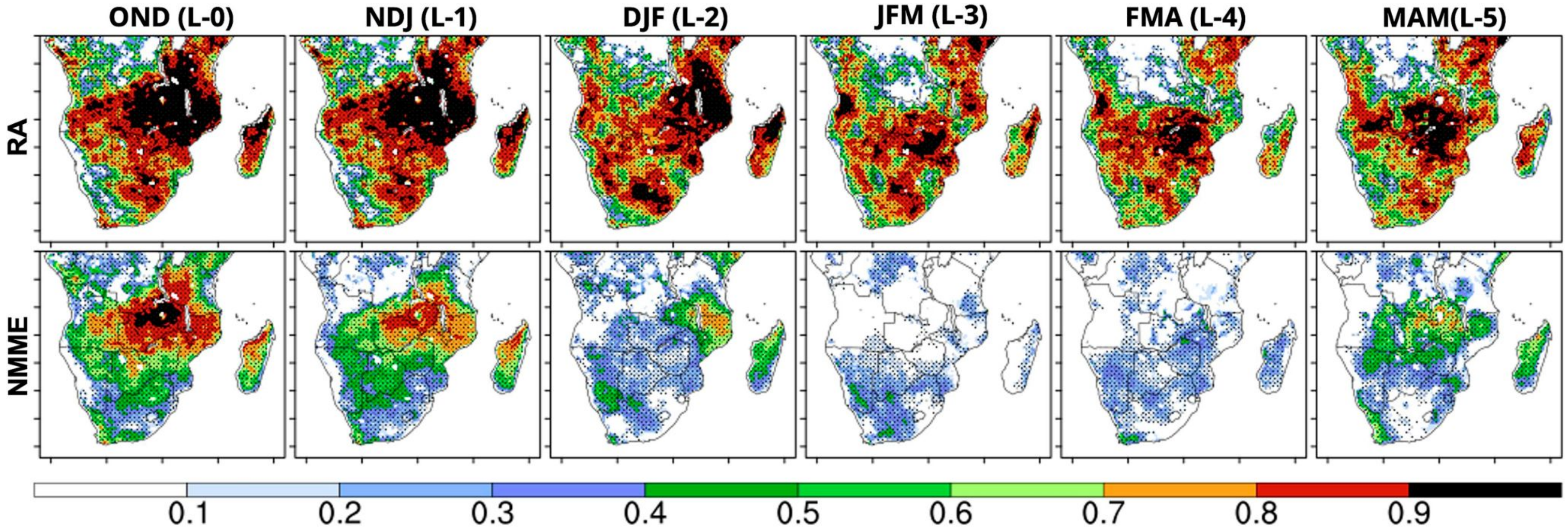


(2) GEOGLAM Crop Monitor Reports

Needs and limitations

Lack of long-lead hydrologic forecast skill

Source: Hazara et al., 2023



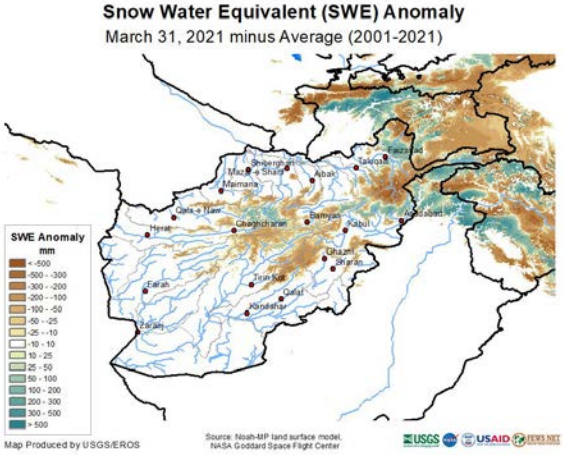
<u>Top row:</u> Correlation of “open-loop” soil moisture (driven with obs. atmospheric forcings) with SMAP
<u>Bottom row:</u> Correlation of soil moisture forecasts (driven with climate forecasts) with SMAP

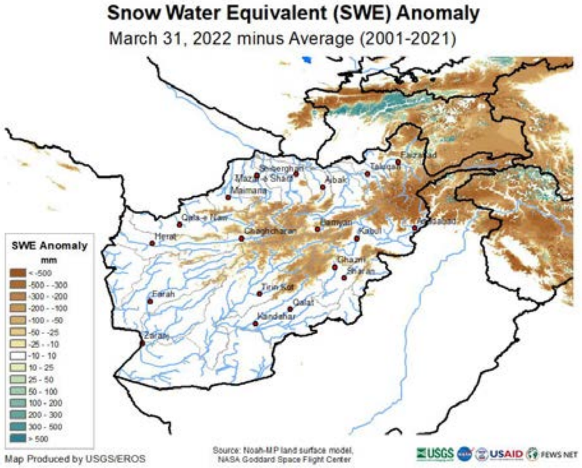
Lack of long-lead SWE forecasts

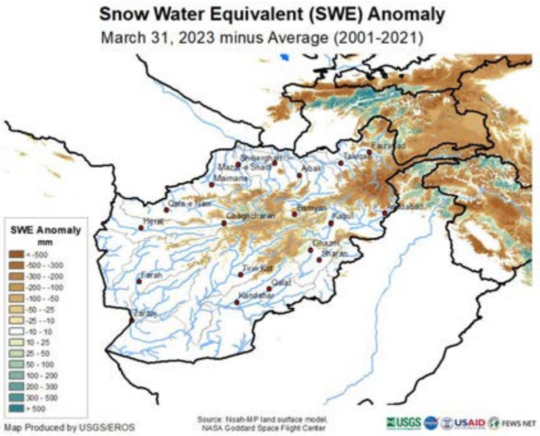
- Countries like Afghanistan that are amongst the most food insecure countries rely heavily on snowmelt runoff to supported irrigated agriculture.

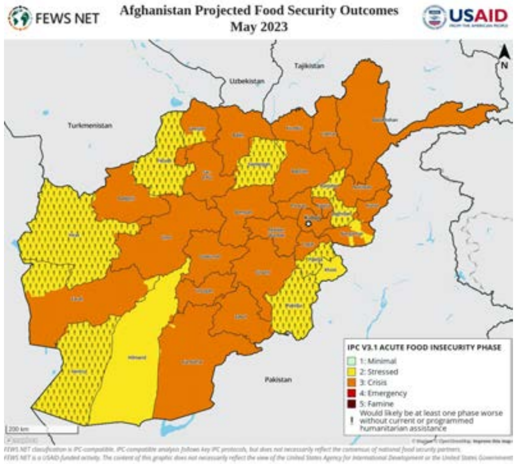
- At present, Afghanistan is facing unprecedented level of food insecurity partly due to the three consecutive droughts.

- Long-lead SWE forecasts would certainly be a valuable tool for supporting early warning.









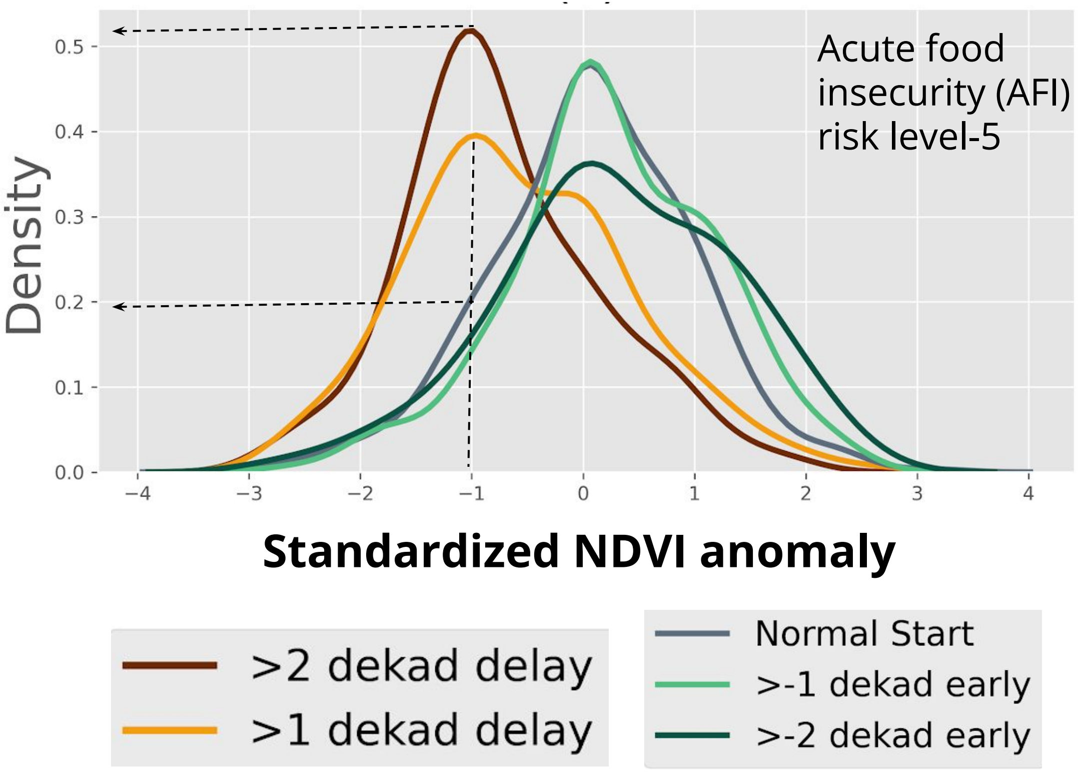
Lack of long-lead rainy season onset forecasts

- 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)

Probability distribution of end of season NDVI anomaly based on the timing of rainy season onset

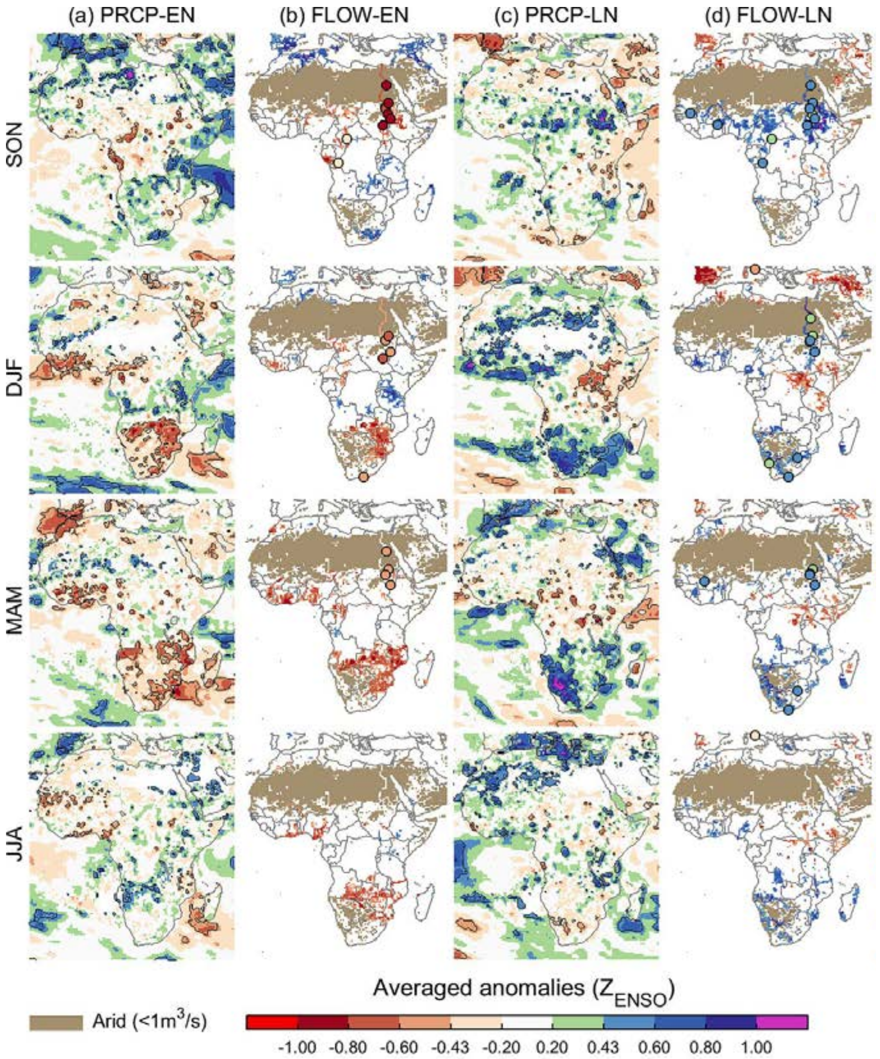


Opportunities

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).

Averaged anomalies of seasonal precipitation (a and c) and seasonal streamflow (b and d) in Africa, in El Niño (EN) and La Niña (LN) phases



Source: Lee et al., 2018 (ERL)

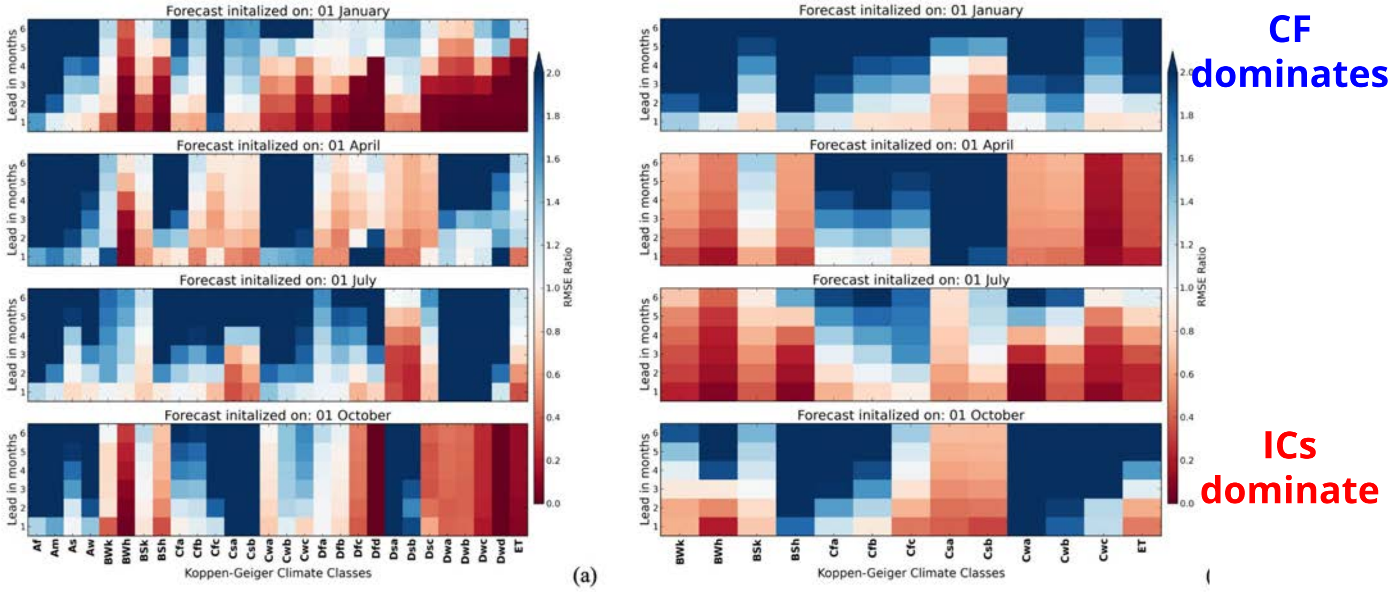
Sources of seasonal scale hydrologic predictability

- 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)

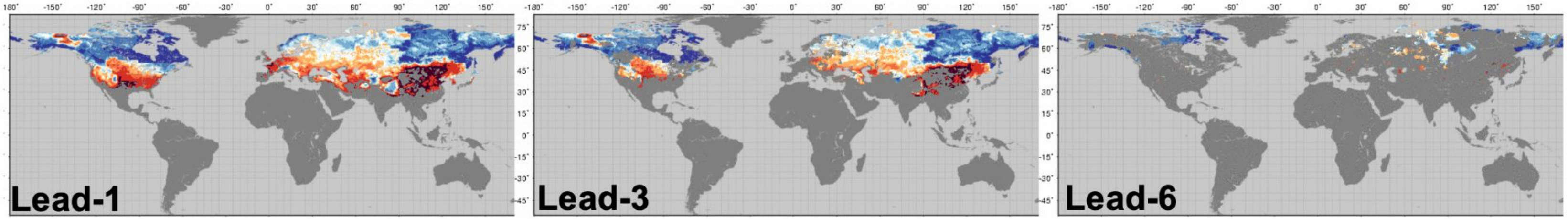


Median of RMSE ratio for cumulative runoff forecasts, over the grid cells in different Koppen-Geiger climate classes in (a) Northern Hemisphere and Tropics and (b) Southern Hemisphere – excluding equatorial climate regions that are included in (a).

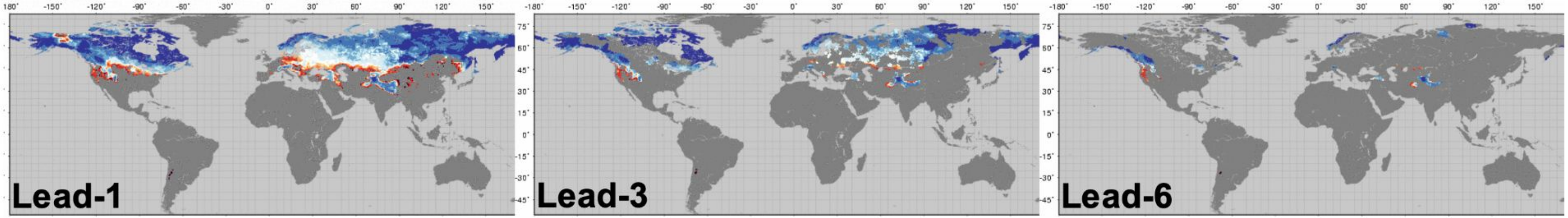
Main climates	Precipitation	Temperature
A: Equatorial	W: Desert	h: Hot arid
B: Arid	S: Steppe	k: Cold arid
C: Warm temperature	f: Fully humid	a: Hot summer
D: Snow	s: Summer dry	b: Warm summer
E: Polar	w: Winter dry	c: Cool summer
	m: Monsoonal	d: Extremely continental

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.

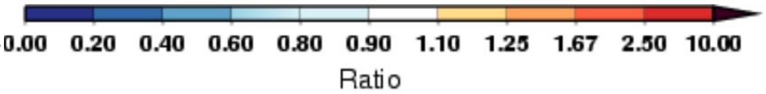


(a) Forecast period: January to June



(b) Forecast period: April to September

Snow dominates



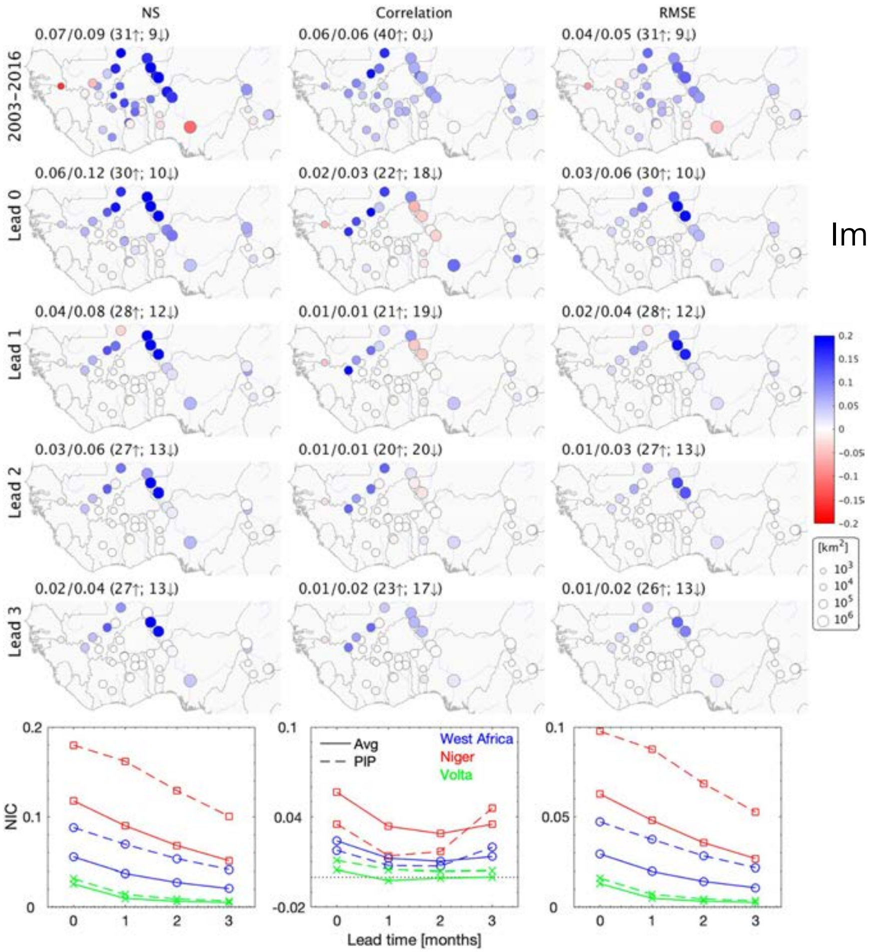
SM dominates

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.



Improvement in skill

Degradation in skill

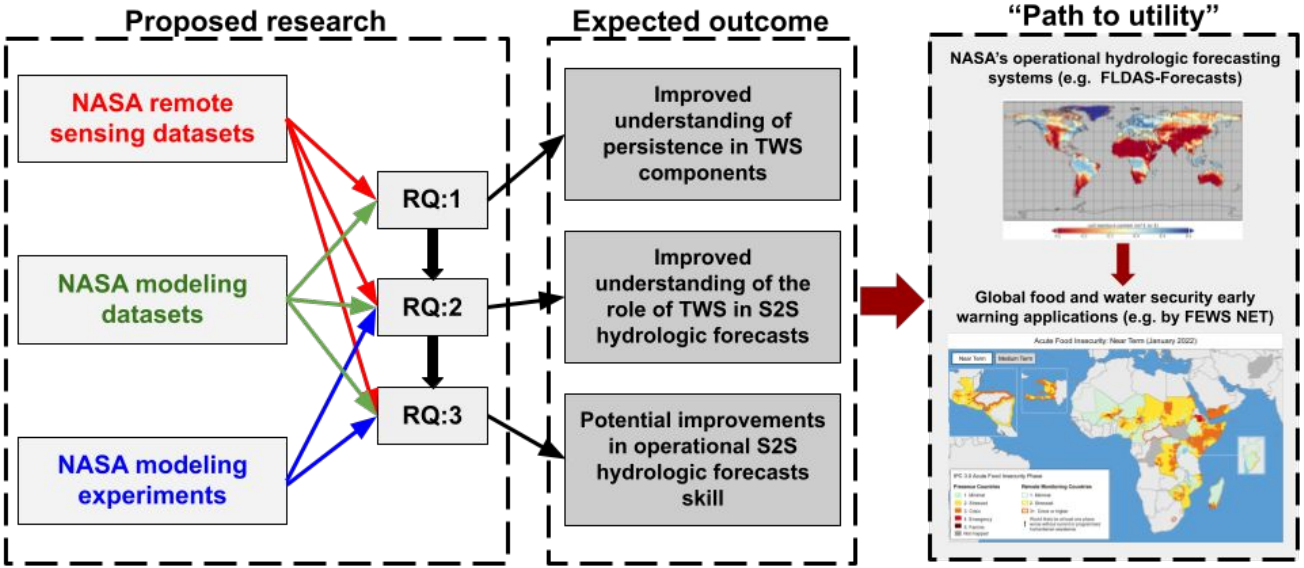
Source: Getirana et al., 2020 (WRR)

(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

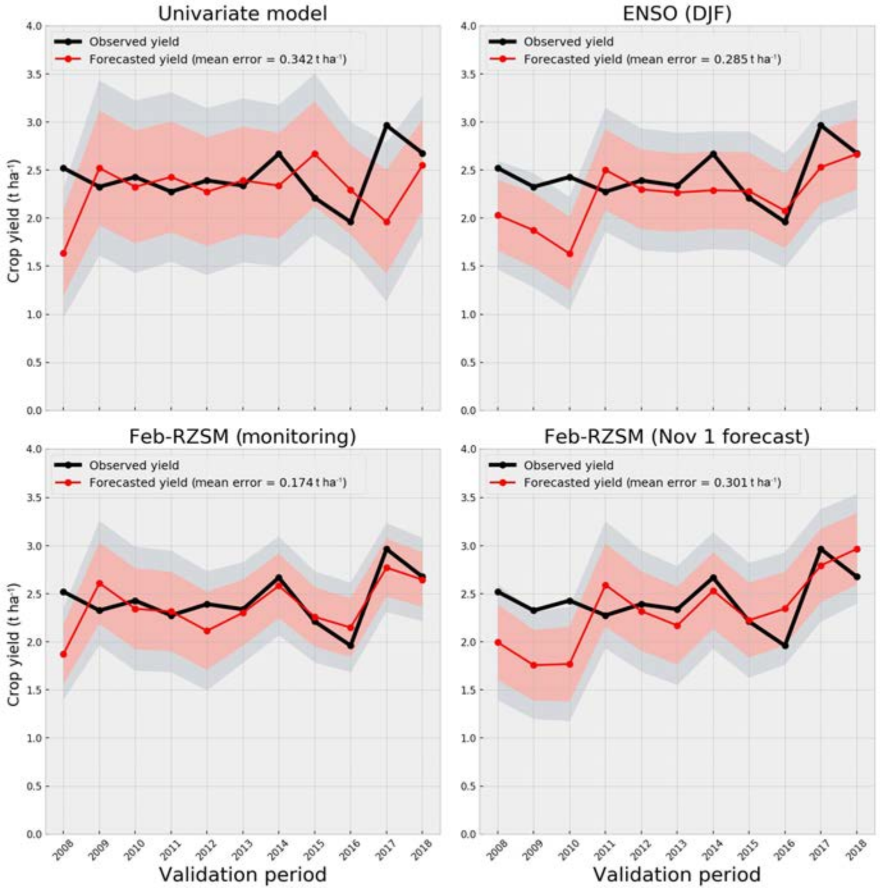


NASA S2S supported project
(Team: UCSB, UMD and NASA)

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.

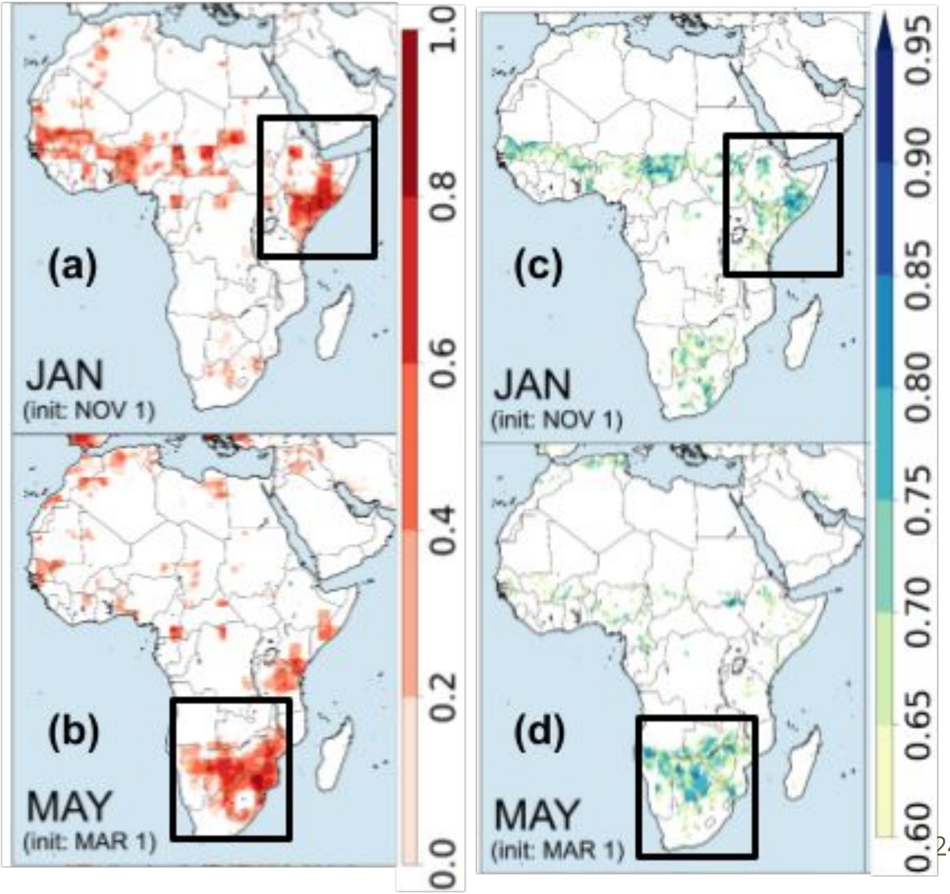


Source: Shukla et al., 2020 (NHESS)

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.

Skill of lead-3 months TWS forecasts initialized on (a) Nov 1, and (b) Mar 1, and TWS based LAI forecasts initialized on (c) Nov 1 and (d) Mar 1.



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

(1) Colleagues at CHC, NASA/UMD, NOAA ESRL, EROS-USGS, UMD and USAID.
(2) Support from USAID FEWSNET, NASA, SERVIR-AST, and USGS.

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Thank you!

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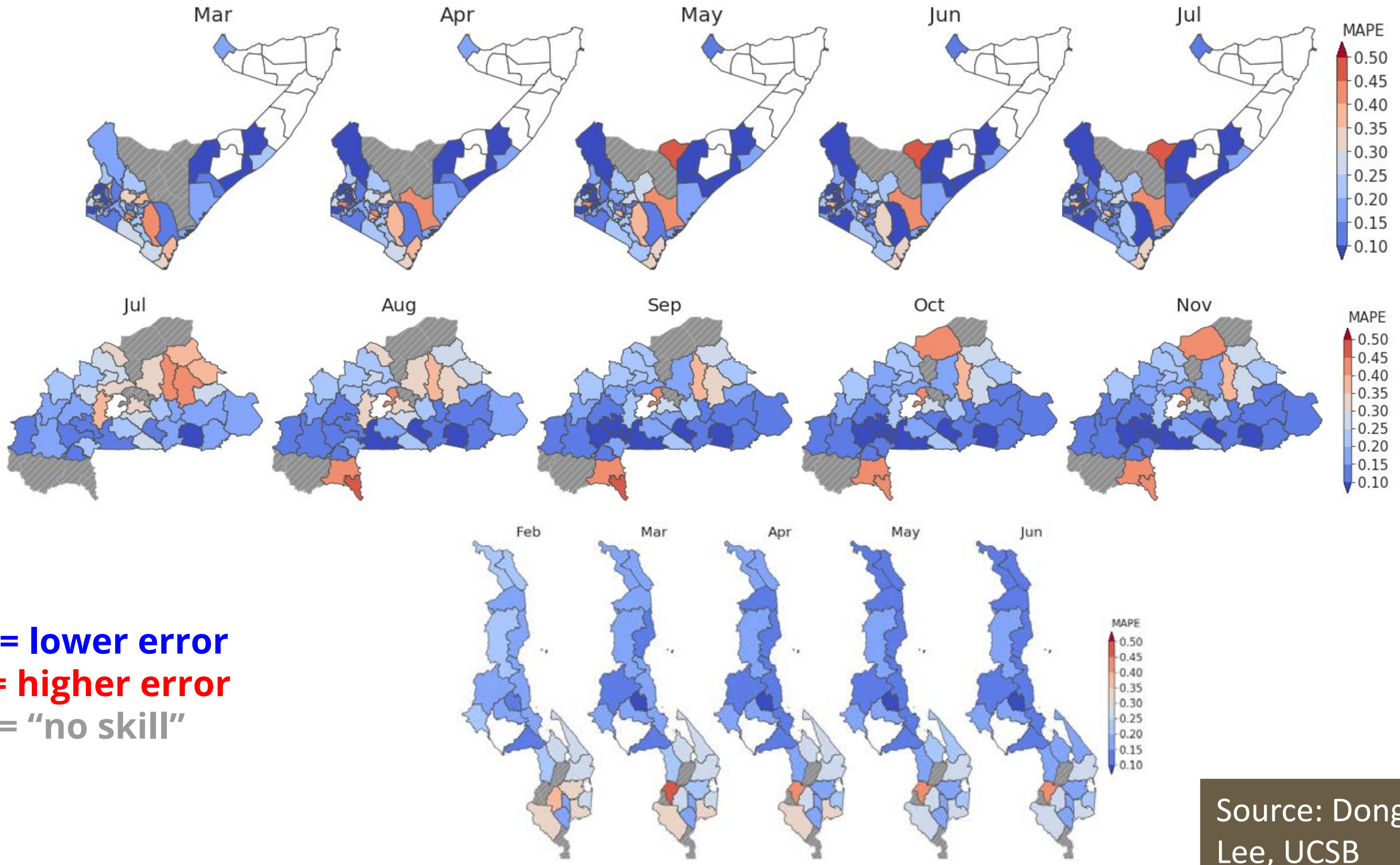
Performance of sub-national scale crop yield prediction



Blue = lower error
Red = higher error
gray = "no skill"

Source: Donghoon Lee, UCSB

Performance of FLDAS-Forecasts

Source: Hazara et al., 2023

- 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.