The Global Hydro-Intelligence Subseasonal-to-Seasonal (GHI-S2S) Forecast System

Kristi R. Arsenault[1,2], Ryan A. Zamora[1,2], Sarith Mahanama[1,2], Jerry W. Wegiel[1,2], Sujay V. Kumar[2], Eric M. Kemp[2,3], Augusto Getirana[1,2], Yeosang Yoon[1,2], Abheera Hazra[2,4], Kimberly Slinski[2,4], David M. Mocko[1,2], Jossy Jacob[2,3]

1. *Science Applications International Corporation (SAIC), Reston, VA*
2. *NASA Goddard Space Flight Center, Greenbelt, MD*
3. *Science Systems and Applications, Inc., (SSAI), Lanham, MD*
4. *UMD Earth System Science Interdisciplinary Center (ESSIC), College Park, MD*

December 13, 2022

AGU Fall 2022 Meeting

Subseasonal to Seasonal Climate Prediction (A26F-02)

Chicago, IL

Overview

- The GHI Sub-seasonal to Seasonal (S2S) forecast system
- Using Land Information System Framework (LISF)
- Input datasets and model configurations
- Verification of the system
- Extreme event verification examples (e.g., drought events) from around the globe
- Summary

GHI Subsystems

The GHI Subsystems cover four different timescales of monitoring and prediction:

Near real-time (NRT; t_{-12}hours to t_0)

Medium-range (t_0 to t_{16} days)

Subseasonal-to-seasonal (S2S; t_0 to t_9 months)

Inter-annual (t_0 to t_{100} years)

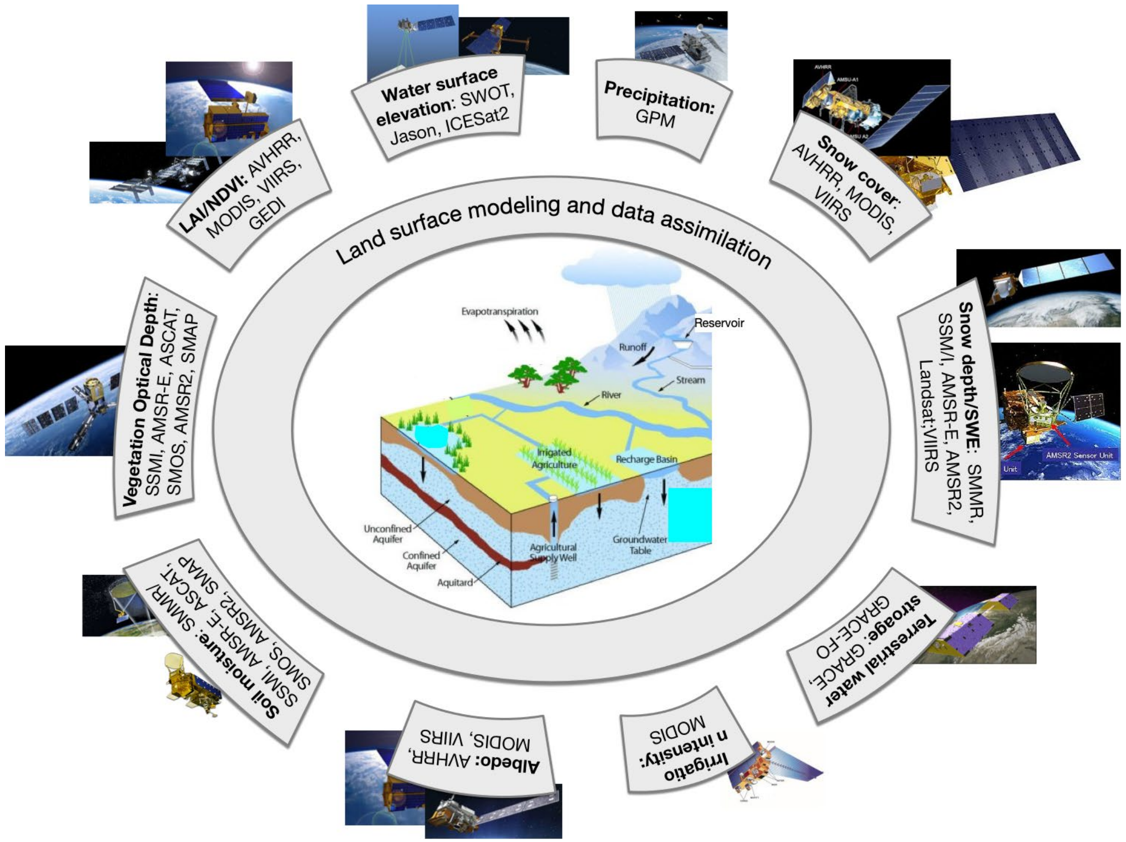
Global Hydro-Intelligence (GHI) S2S-Global system

- Building off the S2S efforts of the NASA Hydrological Forecasting and Analysis System (NHyFAS; *Arsenault et al., 2020; Shukla et al., 2020; Hazra et al., 2022*), the new globally based GHI S2S system is geared towards supporting different U.S. government enterprises and their seasonal hydrological prediction needs.

- The GHI-S2S system also incorporates partners' inputs, such as from the U.S. Air Force, to help supply downstream users with a range of drought and flood potential metrics, including meteorological and agricultural drought prediction indicators, occurring across the globe.

Land Information System Framework (LISF)

- GHI-S2S uses ***LISF*** (*Kumar et al., 2006; Peters-Lidard et al., 2007*) as the primary software for:
  - generating the forecast and hindcast ("reforecast") runs,
  - driving the land and hydrological models,
  - the data assimilation (DA) subsystem for the initial hydrological conditions,
  - preprocessor for all the parameter, DA and forecast initial condition files.
- LISF provides most end-to-end capabilities for running our forecasts for operational uses.



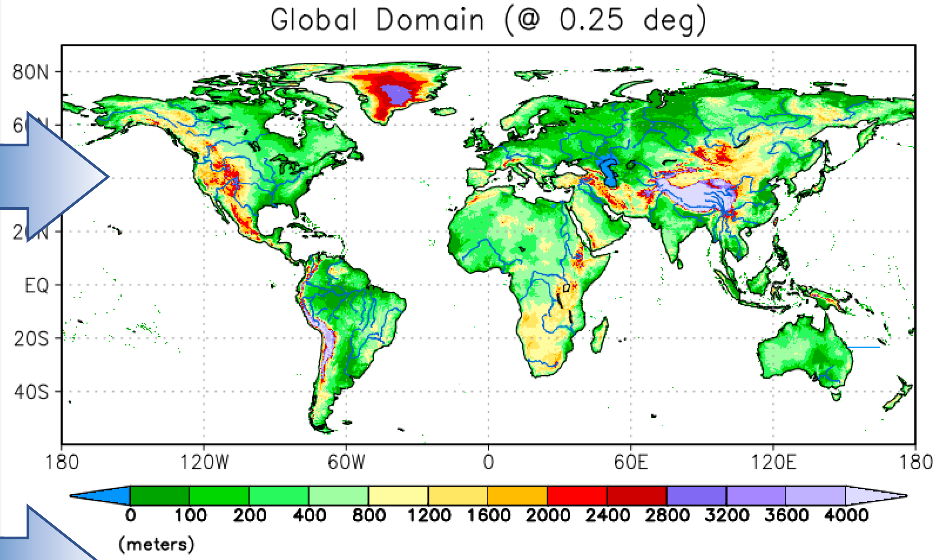
GHI-S2S system components

LDT:
Model parameters;
Initial conditions for DA and Forecasts

Meteorological Forecast Data:
NMME-precipitation
CFSv2 (non-precip.)

Data Assimilation Options:
SMAP and ASCAT soil moisture DA; Satellite-based snow estimates

NOAH-MP v.4.0.1



Land model(s)

LIS-Hydro models
(HyMAP, RAPID**)**

Available Output:
e.g., soil moisture (SM), ET, SWE, TWS, and streamflow

Scripts to produce drought and flood analysis:
Anomalies (e.g., SM, streamflow), forecast skill and tercile maps

LISF Input Datasets

- **<u>Forecast datasets</u>**:

1) Climate Forecast System, version 2 (**CFSv2**; *Saha et al., 2014*):

- 6-hourly files are used to generate the forcing ensemble members for the non-precipitation-based fields (e.g., T_{air}, Q_{air}, wind fields, downward radiation):
- The "time-series" based reforecast ("HPS" and "FL") and operational forecast files are used to take advantage of the 9-lead month forecasts.

2) **The North American Multi-Model Ensemble (NMME;** *Kirtman et al., 2014*):

- 6 different climate models from different centers across North America:
  - CFSv2, GEOSv2, GFDL, GEM-NEMO, CCSMv4, CanCM4
- 9-lead months of multi-member precipitation forecasts from each model.

NMME Model Members for the Hindcasts and Forecasts adapted for the Global S2S Subsystem

GHI S2S-Global -- NMME model members

Models	Centers	Hindcast Members	Forecast Members
CFSv2	NOAA/NCEP	12	12
GEOSv2	NASA/GSFC	4	4
CanCM4i	Environment Canada	10	10
GEM-NEMO, v5	Environment Canada	10	10
CCSM4	NCAR	10	10
GFDL-SPEAR	NOAA/GFDL	15	15

Note: Forecast ensemble members will have the same number as the hindcast ensemble sizes to help improve run-time efficiency and ensuring equal number of members for climatology and anomaly file generation.

LISF Input Datasets

- **<u>Retrospective forcing datasets</u>**:
- 31 years of forcing (1991-2021) blended with:
    - NASA's MERRA2 forcing (*Gelaro et al., 2017*) and CHIRPS, version 2, precipitation data (1991-2012), which is bias-corrected to the LIS7.4 557WW analysis dataset that includes the NASA-USAF Precipitation Analysis (NAFPA) precipitation dataset (*Kemp et al., 2022*), from 2013-2021.
    - Then from 1-Oct-2012 to near present time, models are driven with the USAF + NAFPA forcing data.
    - Used to bias-correct and spatially downscale (*BCSD*) the CFSv2 and NMME hindcast datasets (from 1991-2021) and then ongoing forecast runs (2022 and onward), based on *Wood et al., 2002; Arsenault et al., 2020.*

NAFPA Precipitation Validation

- Skill of NAFPA (reduction in RMSE) versus other products for 24-hr precipitation (mm) over Africa, for 2012-2019, using CHIRPSv2 precipitation as the benchmark.
- Blue (red) indicates positive (negative) skill.
- Differences in 24-hr RMSE from NAFPA include precipitation products are from (a) GDAS, (b) IMERG-Late, (c) MERRA-2, (d) ERA-5, and (e) IMERG-Final.

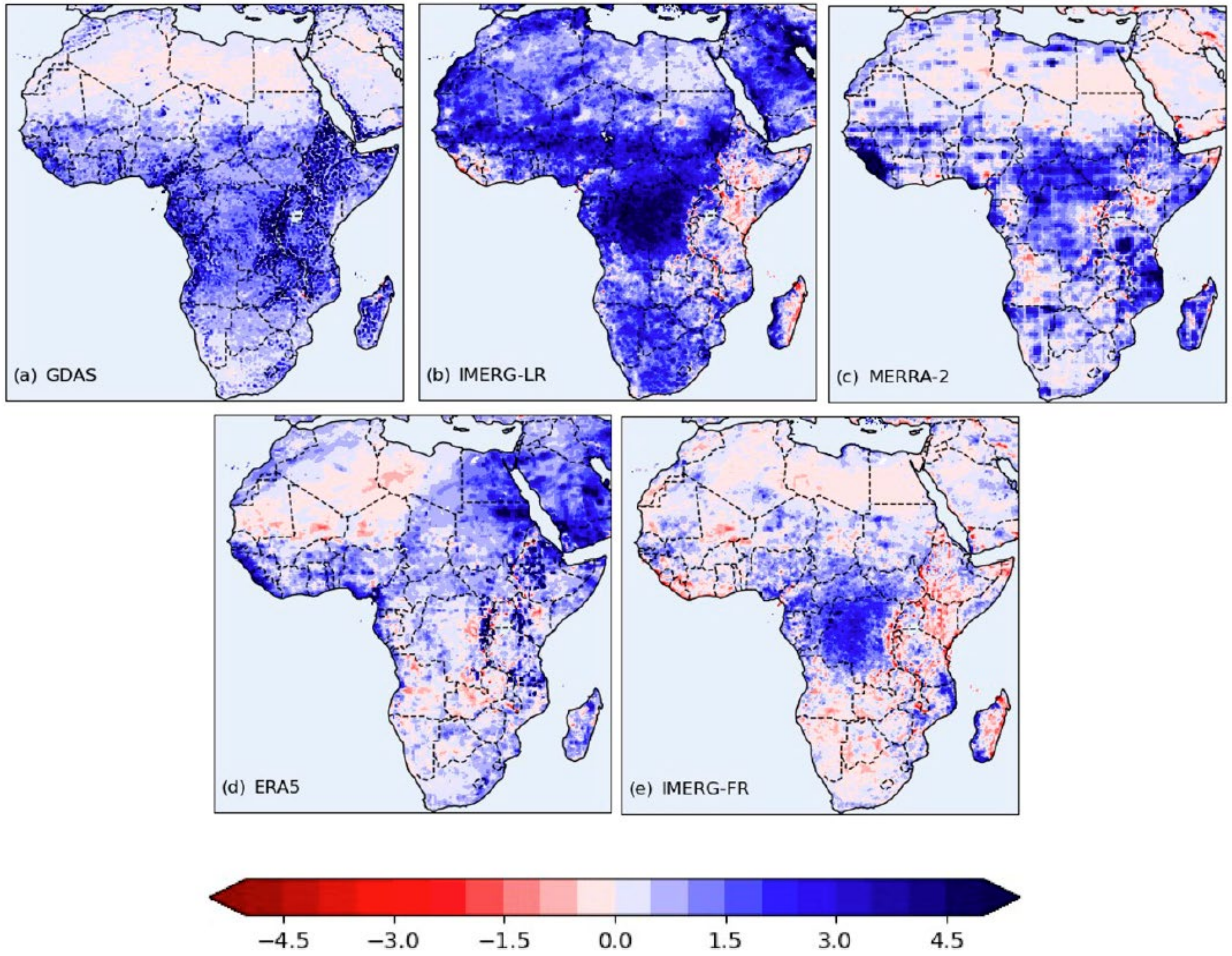


FIG. 11. Differences in 24-h RMSE (kg m^{-2}) in Africa domain, with RMSE from NAFPA subtracted from other products. RMSE scores calculated for 2012–19, using CHIRPSv2-Final as reference. Positive (negative) values indicate superior (inferior) NAFPA accuracy. Results for (a) GDAS, (b) IMERG-LR, (c) MERRA-2, (d) ERA5, and (e) IMERG-FR.

LISF land and hydrological model setup

- **<u>Land surface model (LSM)</u>**: Noah-Multiparameterization (Noah-MP), version 4.0.1 (*Niu et al., 2011; Yang et al., 2011)*
  - Run as a 12-member open-loop (OL) and DA based simulation for hydrological initial conditions (IHCs), globally at 0.25 deg resolution.
  - Running forecasts – each NMME model is run separately, given the different number of members.
- **<u>Hydrological model (LSM runoff routing)</u>**: HyMAP, version 2 (*Getirana et al., 2012*).
  - Runs as a single-member, driven by the ensemble mean of the NoahMP401 total runoff field members, for both the OL/DA runs and hindcast and forecast runs.

DA-based datasets used for Model ICs

Assimilation of satellite and in situ-based datasets into NoahMP-4.0.1:

1) Soil moisture satellite-based observations:

-- EUMETSAT Metop satellite - Advanced Scatterometer (ASCAT), from 2013.

-- NASA Soil Moisture Active Passive (SMAP) satellite (NRT Level 2 and 3 products used at this time), from 04-2015 to near present.

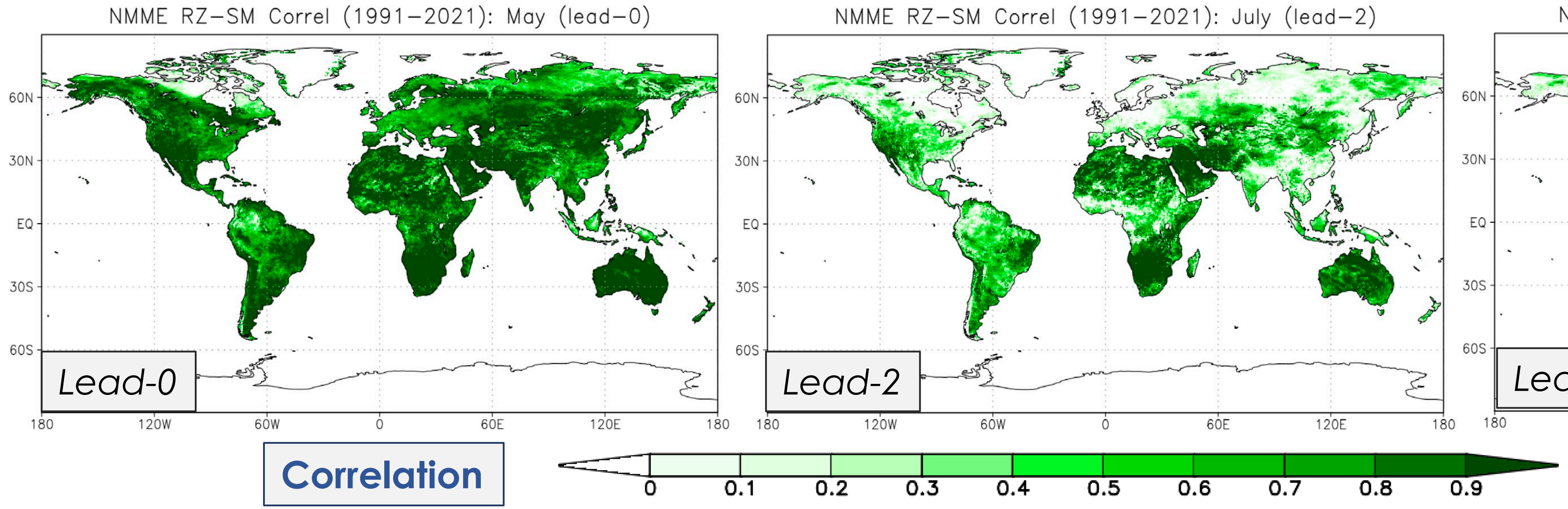
2) Snow and ice-based observations:

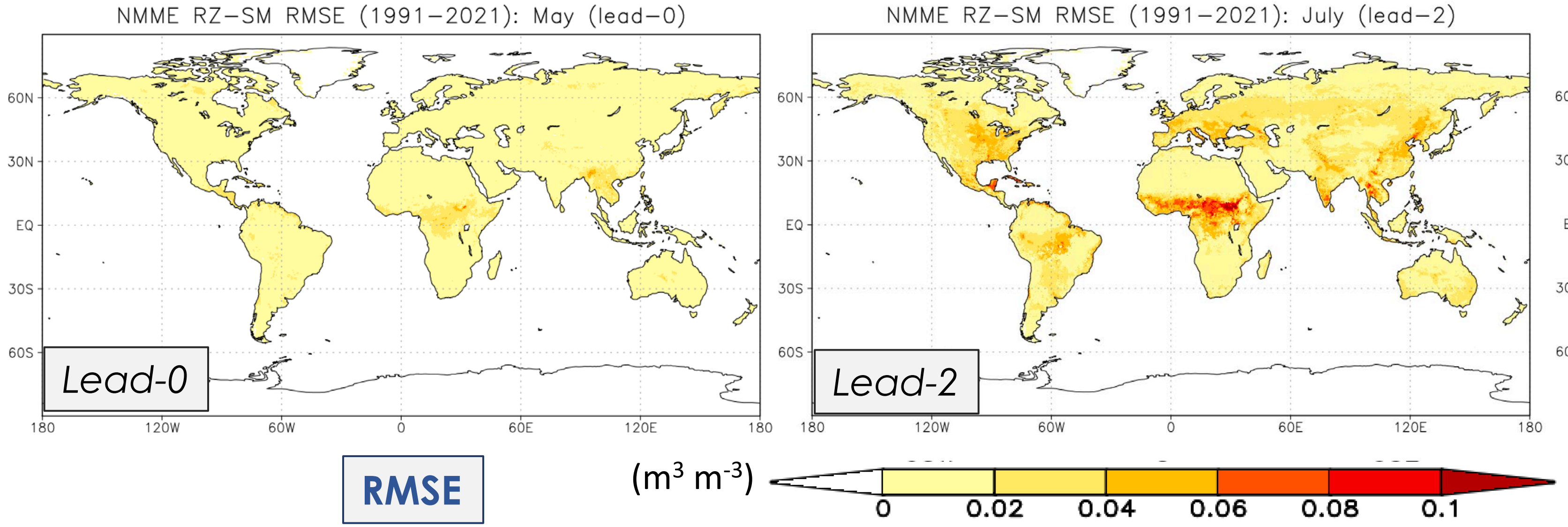
-- The U.S. Air Force Snow and Ice (USAF-SI; Yoon et al., 2022) is a newly developed NRT global product and provides a 6-hourly analysis of snow and ice at 10-km resolution, which is generated from satellite-based and in-situ snow depths and fractional information. USAF-SI is available from Sep. 2018 to near present time.

Verification examples of the system and extreme events

Root-Zone Soil Moisture (RZ-SM) Skill for <u>May-1</u> Hindcasts

(Period: *1991-2021*; Reference: *Retrospective run, driven with MERRA2+CHIRPS*)

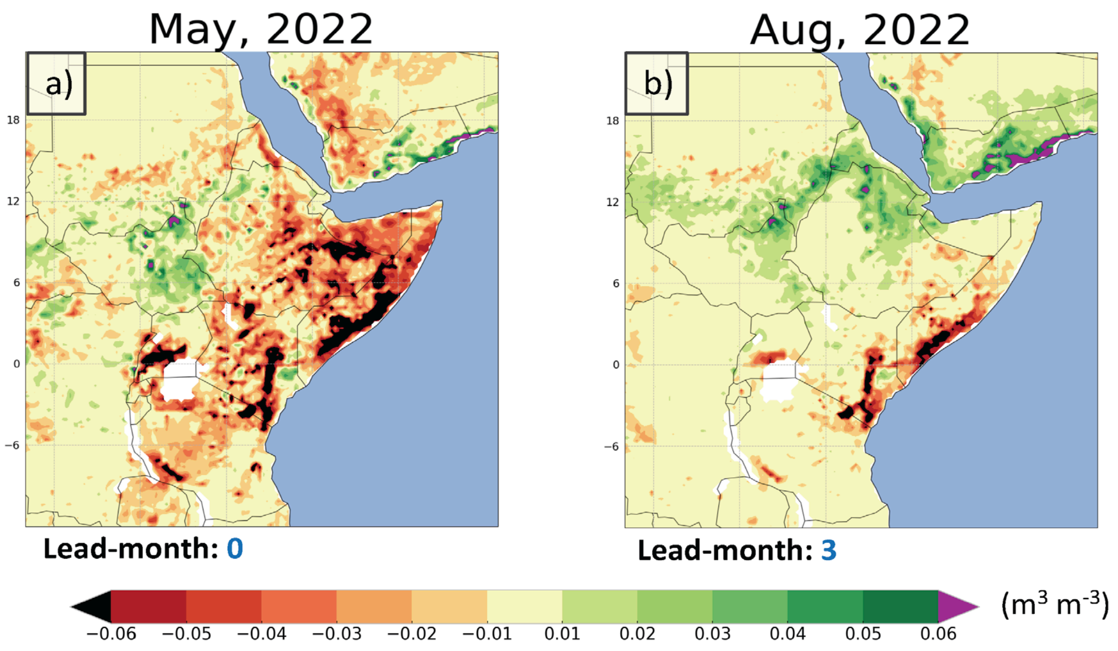




Example of a recent flooding event that occurred in Eastern Africa

The May 2022 GHI-S2S forecast from the captured the persistent drought conditions over East Africa (fig. a). The areas near South Sudan, Sudan border, and northern Ethiopia were forecasted to have wetter conditions (fig. b), consistent with the recent NOAA Climate Prediction Center's (CPC) Africa Hazards Outlook maps (fig. c).

On 28 August, 2022, the UN's ReliefWeb reported that more than 226,200 people were impacted by the <u>*heavy rains and flash floods*</u>, including more than 47,000 homes destroyed or damaged in Sudan. *The GHI-S2S subsystem was able to forecast these wetter conditions almost four months in advance*.



CPC Hazards Map: 25-08-2022

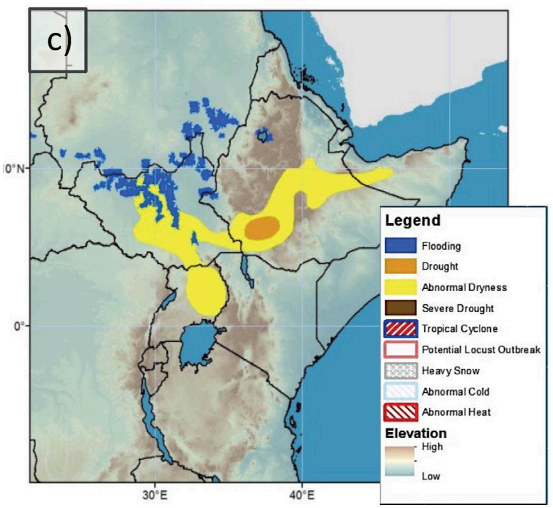
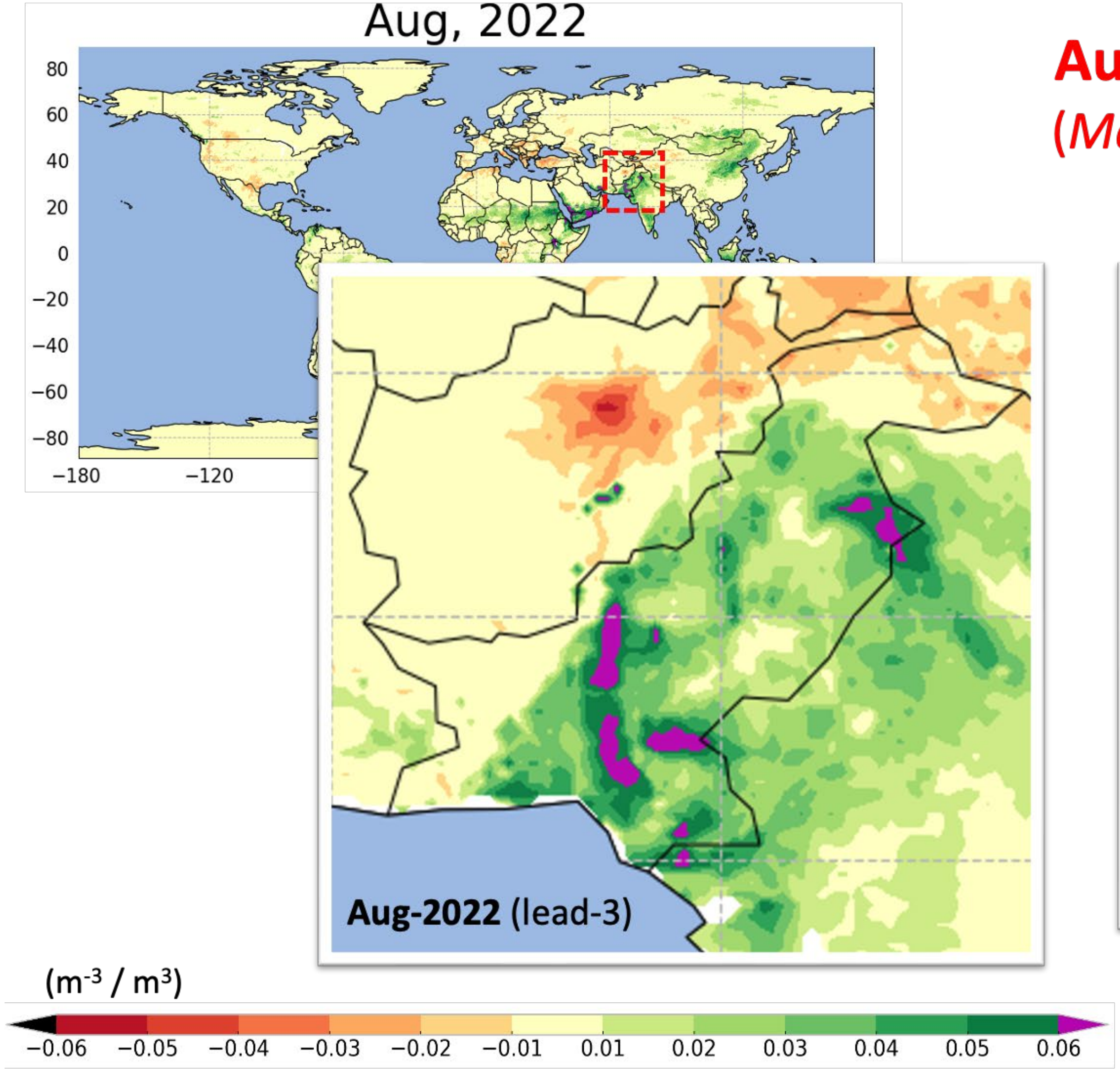


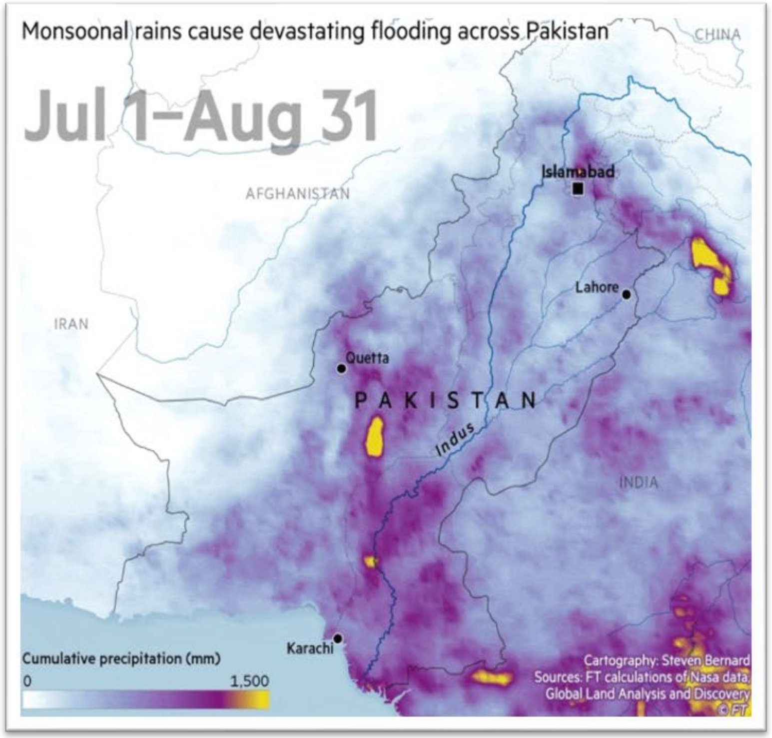
Figure 2: a) Initial May-2022 root zone soil moisture anomaly forecast (lead month 0) and b) its August forecast (lead-month 3) of East Africa. c) NOAA Africa Hazards Outlook map for the region on 25-Aug 2022.

GHI-S2S NoahMP401 Surface Soil Moisture Anomaly



August-2022 forecast

(*May-1 initial conditions*)



Source: https://www.ft.com/content/116f34fc-b44d-487d-822b-d3f1926eaca2

Summary

- The new globally based Global Hydro-Intelligence (GHI) S2S system is geared towards supporting different U.S. government enterprises and their seasonal hydrological prediction needs around the globe.
- The Land Information System Framework (LISF) is used as the main software for setting up and running our global hydrological forecasts.
- Initial results and skill analysis show that extreme events are captured well by the new GHI-S2S system and can provide essential information to stakeholders several lead months in advance.

POC: Dr. Kristi Arsenault (*SAIC, NASA/GSFC*), *kristi.r.arsenault@nasa.gov*

Acknowledgements

- We gratefully acknowledge the financial support for work funded by:
  - U.S. Air Force Life Cycle Management Center (LCMC),
  - NASA Food Security Program,
  - NASA/GSFC Hydrosphere, Biosphere, and Geophysics (HBG) Support Services via contract 80GSFC20C0044,
  - SAMDA NNG17HP01C,
  - UMCP/ESSIC NNX17AE79A,
  - USRA GESTAR NNG11HP16A, and
  - UMBC GESTAR II 80NSSC22M0001.
- Computing was supported by the resources at the NASA Center for Climate Simulation (NCCS) and DoD High Performance Computing Modernization Program.