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

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Overview

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

GHI Subsystems

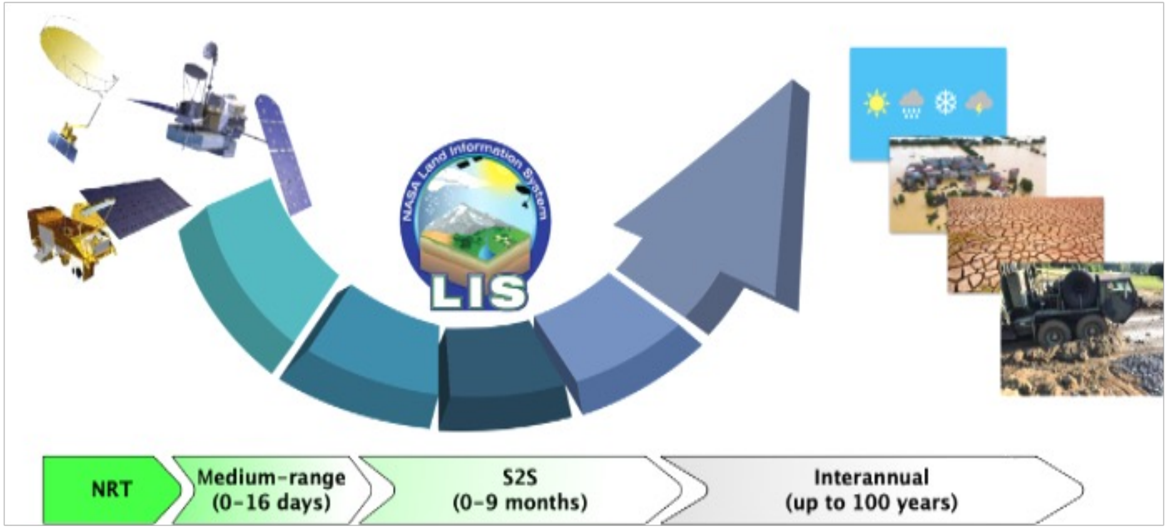
The GHI Subsystems cover four different timescales of monitoring and prediction:

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)



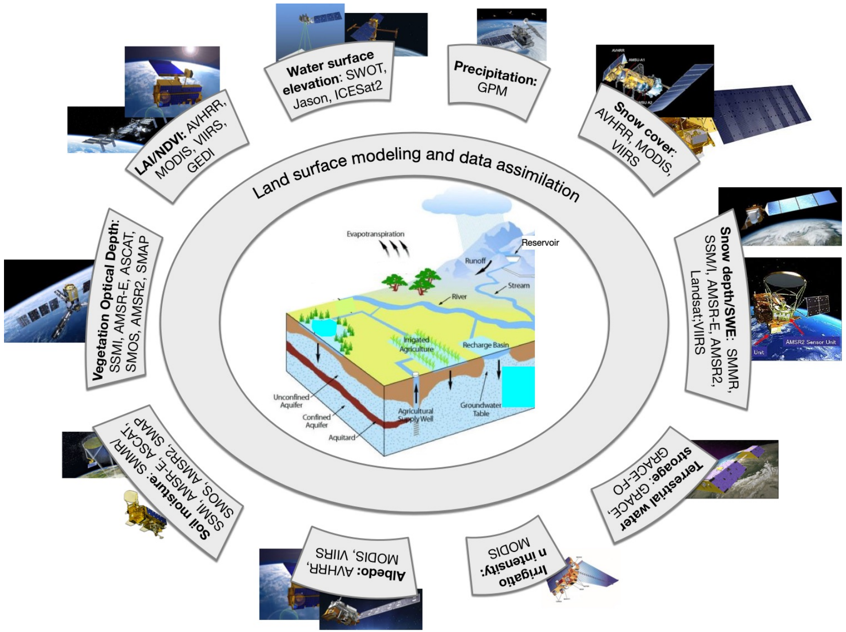
Global Hydro-Intelligence (GHI) S2S-Global Subsystem

- 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., 2023*), this 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.



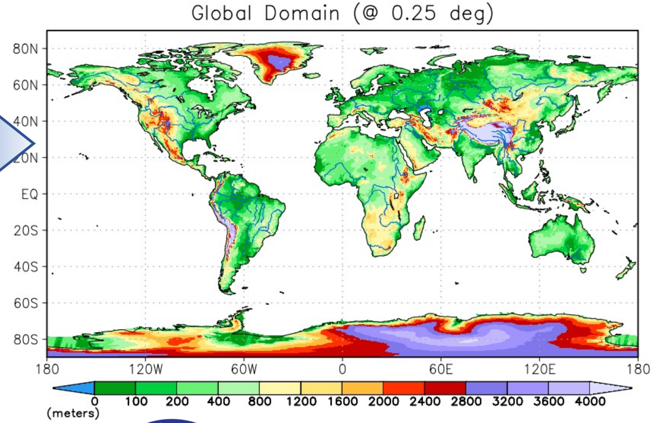
GHI-S2S system components (*with LISF*)

LDT:
Model parameters;
Initial conditions for DA and Forecasts

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

Data Assimilation Options:
SMAP NRT L2 soil moisture data

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}, winds, 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 (our setup has 61 in total)

Models	Centers	Hindcast Members	Forecast Members
CFSv2	NOAA/NCEP	12	12
GEOSv2	NASA/GSFC	4	4
CanCM4i	Env & Climate Change Canada (ECCC)	10	10
GEM-NEMO, v5	ECCC	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>:

- 30 years of forcing (1991-2020) blended with:
  - ***1991-2012***: NASA's **MERRA2** forcing (*Gelaro et al., 2017*) and **CHIRPS**, version 2 (*Funk et al., 2015*), precipitation data, which are bias-corrected to the LIS7.4 557 WW analysis dataset that includes the *NASA-USAF Precipitation Analysis (NAFPA) precipitation dataset* (*Kemp et al., 2022*).
  - ***From 1-Oct-2012 to near present time:*** Models are driven with the **USAF + NAFPA forcing data**.
  - This merged dataset is then used to bias-correct and spatially downscale (*BCSD*) the CFSv2 and NMME hindcast datasets (from 1991-2020) 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 from (a) GDAS, (b) IMERG-Late, (c) MERRA-2, (d) ERA-5, and (e) IMERG-Final.

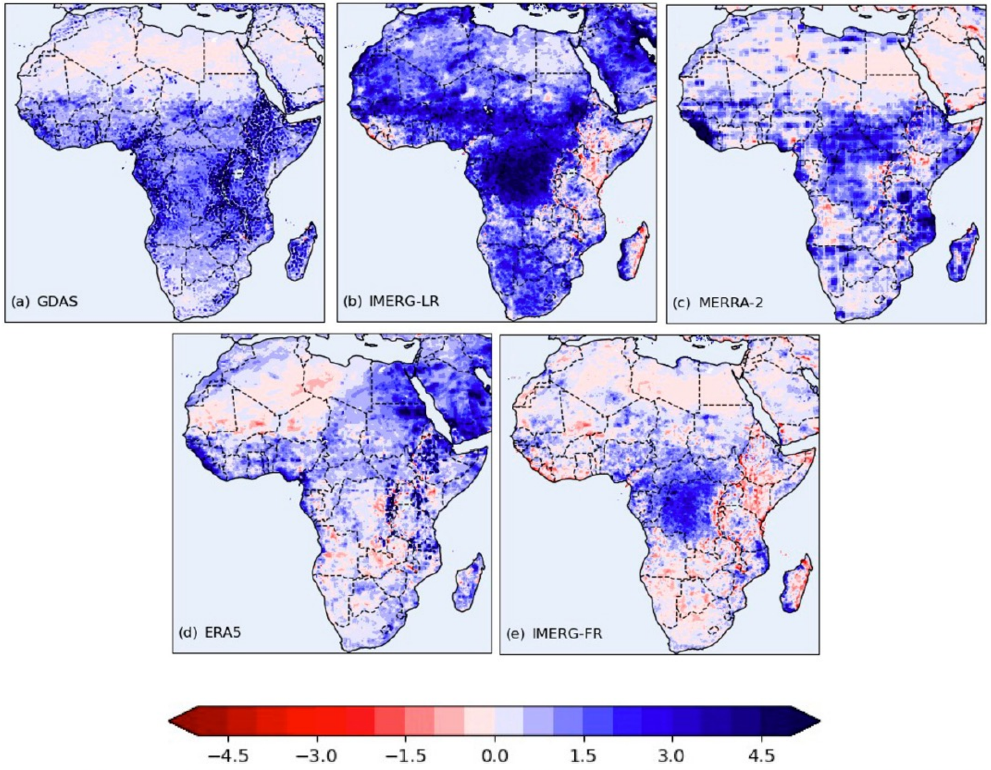


FIG. 11. Differences in 24-h RMSE (kg m^{-2}) in Africa domain, with RMSE from NAFPA subtracted from other products. RMSE scores calculated for 2012–19, using CHIRPSv2-Final as reference. Positive (negative) values indicate superior (inferior) NAFPA accuracy. Results for (a) GDAS, (b) IMERG-LR, (c) MERRA-2,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

Source:

Kemp et al., 2022: J. Hydromet. doi:10.1175/JHM-D-21-0228.1

LISF land and hydrological model setup

- **<u>Land surface model (LSM)</u>**: Noah-Multiparameterization (Noah-MP), version 4.0.1 (NoahMP401, *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) **Current -** Soil moisture satellite-based observations:

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

2) **Future –** Other soil moisture and snow and ice-based observations:

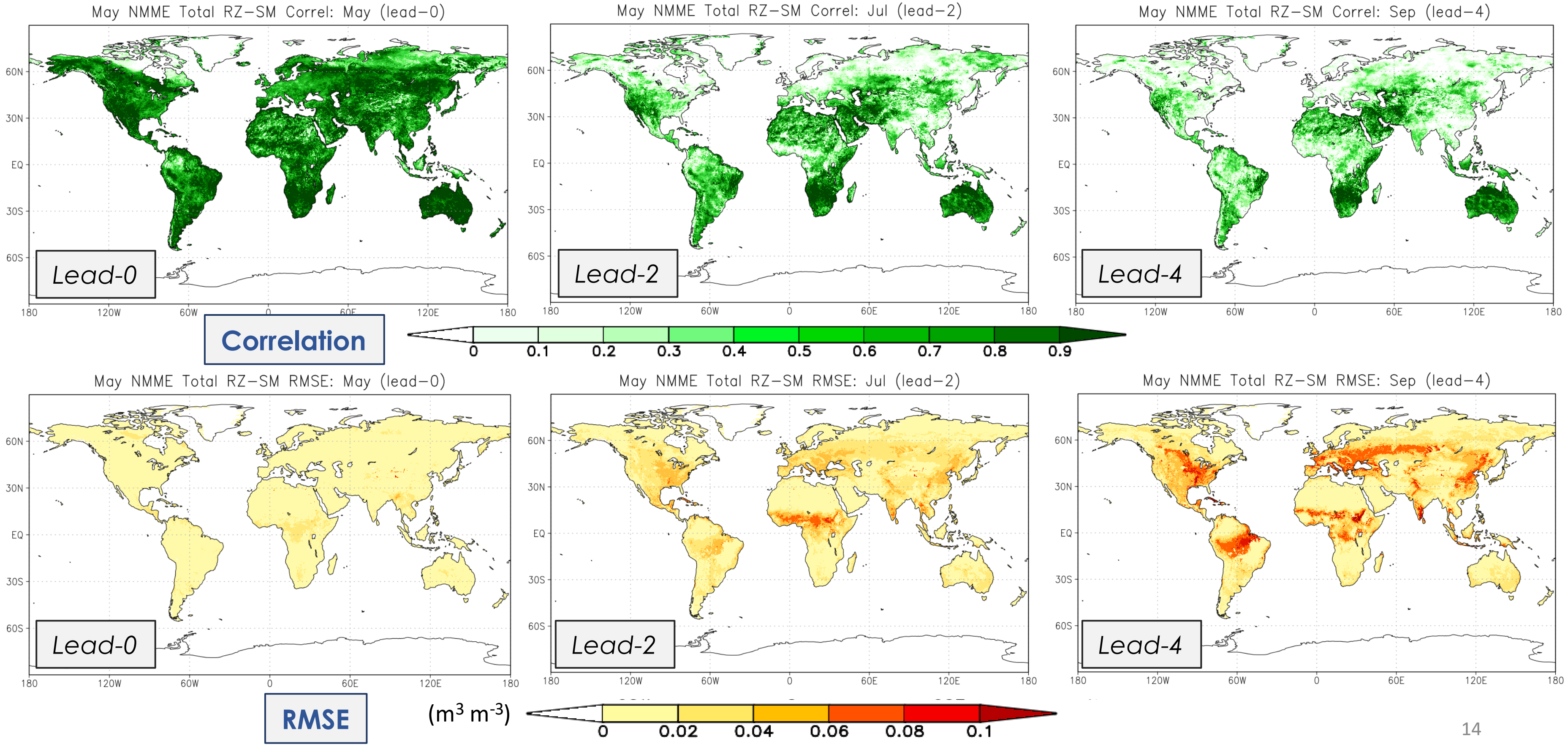
-- The U.S. Air Force Snow and Ice (USAF-SI; Yoon et al., 2022) NRT global product and provides a 6-hourly analysis of snow and ice at 10-km resolution, which is generated from satellite-based and in-situ snow depths and fractional information. USAF-SI is available from Sep. 2018 to near present time.

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

Verification examples of the system and extreme events

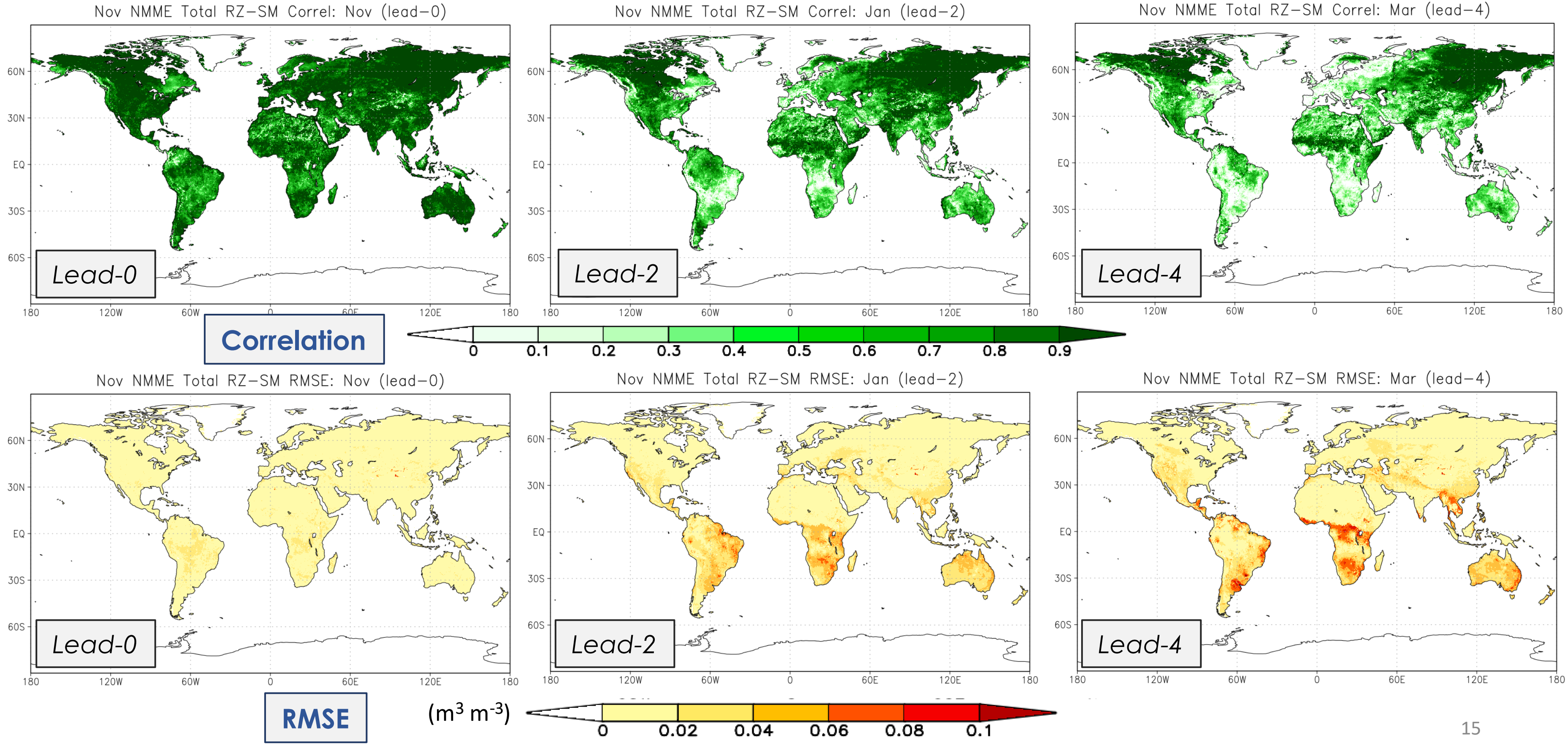
Root-Zone Soil Moisture (RZ-SM) Skill for <u>May</u> Hindcasts

(Period: *1991-2020*; Reference: *Retrospective NoahMP401 run*)



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

(Period: *1991-2020*; Reference: *Retrospective NoahMP401 run*)



Extreme Wet Forecasts for Australia

May-2022 forecast, lead = 2, July

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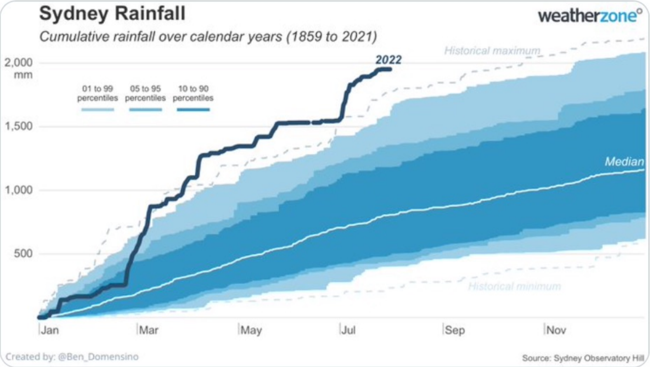
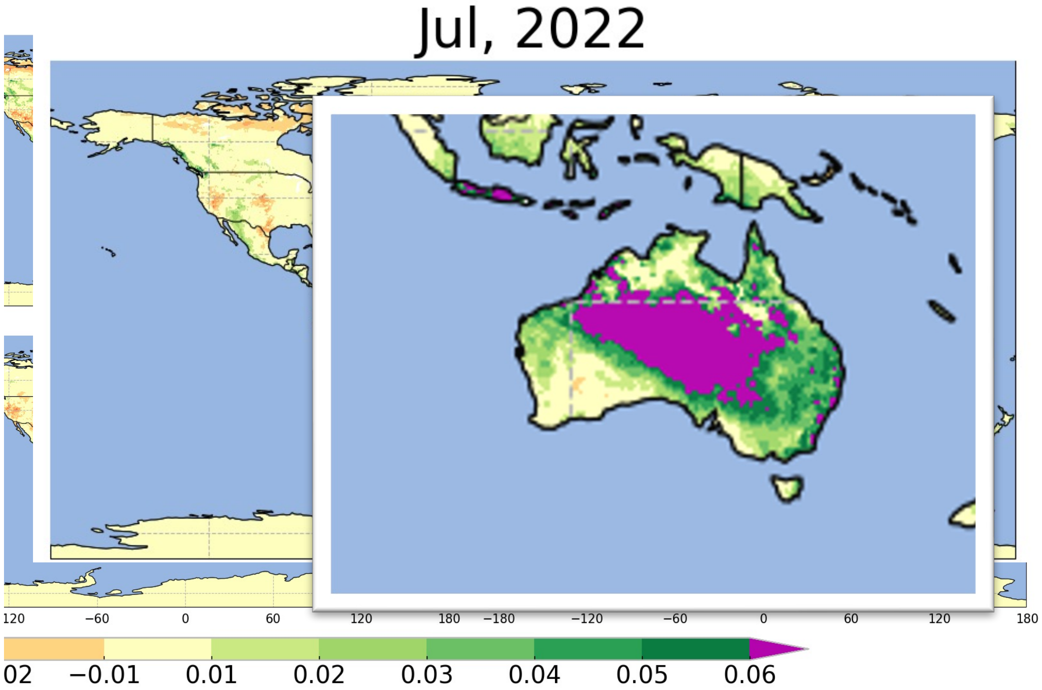
This year has been phenomenal in **#Sydney**. The city has now broken two monthly rainfall records in 2022 (March and July), bringing its cumulative annual total up to 1951.4 mm at the end of July. This is by far Sydney's wettest year-to-date in records dating back to 1859.



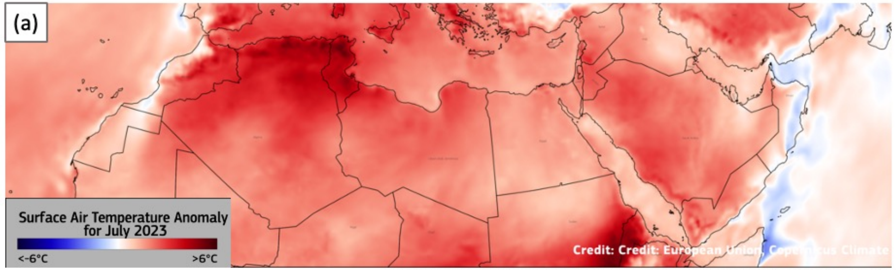
9:18 PM · Jul 31, 2022



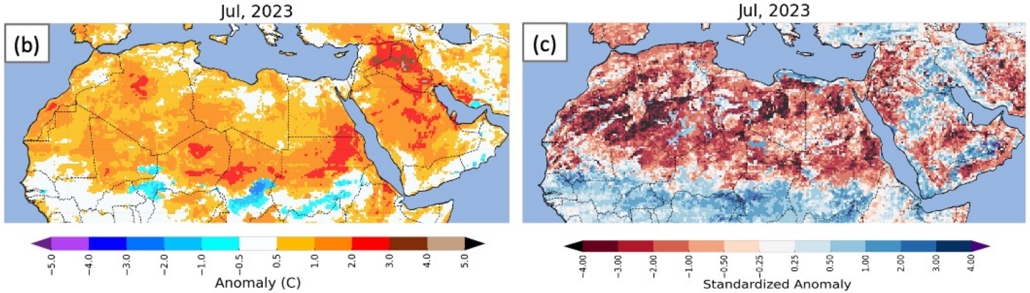
https://www.theguardian.com/australia-news/2022/aug/17/eastern-australia-faces-wet-weather-and-flooding-with-70-chance-of-third-consecutive-la-nina

Drought Forecasts for Northern Africa

May-2023 forecast, lead = 2, July

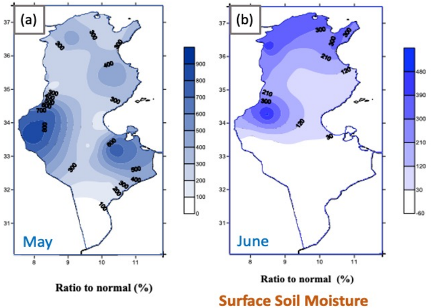


Source: https://en.wikipedia.org/wiki/2023_heat_waves#/media/File:July_2023_was_the_warmest_globally.png

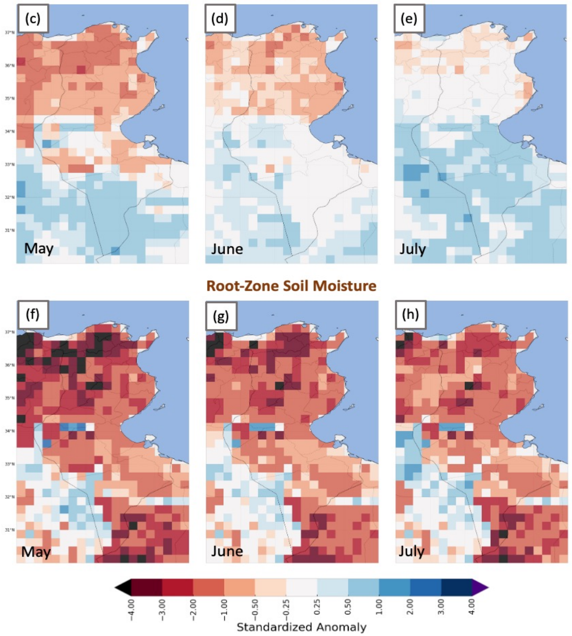


Above: (a) July-2023 surface air temperature anomalies (°C), based on Sentinel satellite observations[1]. GHI-S2S's forecast of July-2023 (lead month=2, initialized from May-1) for b) CFSv2 air temperature anomalies (°C), and c) RZSM standardized anomalies for Northern Africa.

Anomalies calculated with averaged conditions or hindcast normal years, 1991-2020.



Precipitation Observations
(from Tunisia's National Institute of Meteorology)

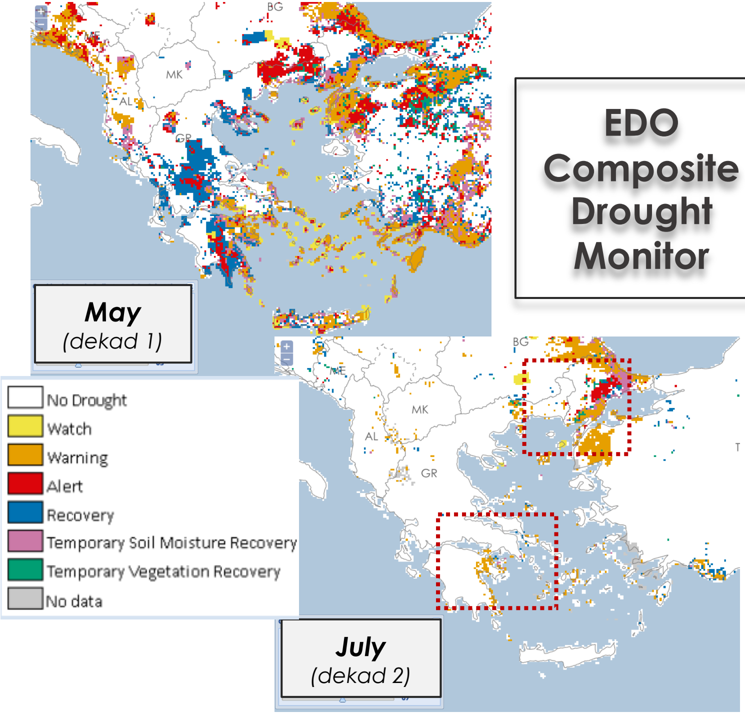


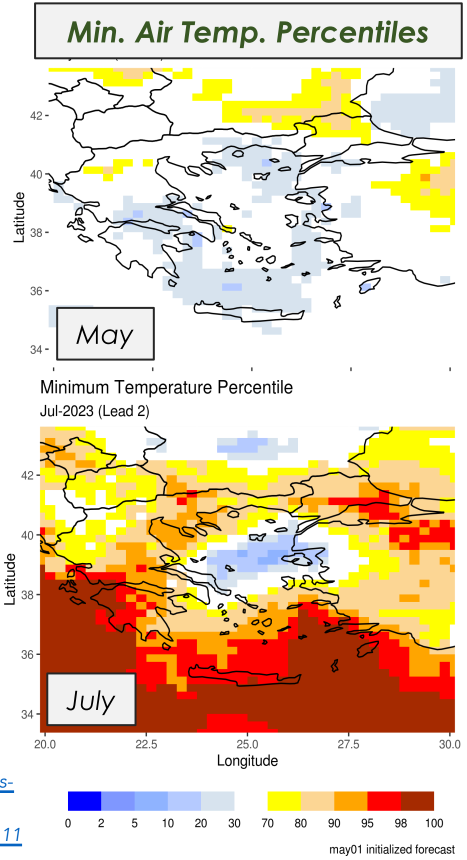
[1] Contains modified Copernicus Sentinel data, 2023, from the C3S Climate Bulletin, 9 Aug, 2023, *https://en.wikipedia.org/wiki/2023_heat_waves#/media/File:July_2023_was_the_earmest_globally.png*

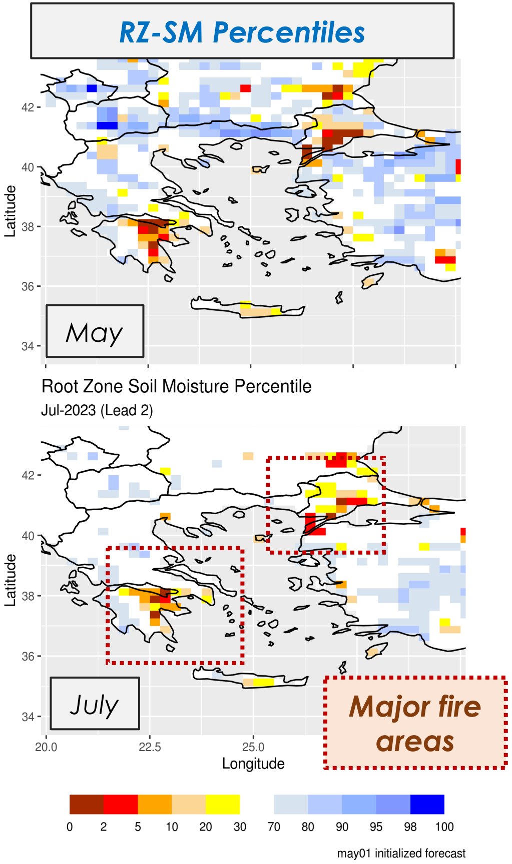
Top Ref.: Tunisia's National Institute of Meteorology's May- and June-2023 reports: *https://www.meteo.tn/en/actualites/climatological-report-month-may-2023-tunisia*

2023 Greek Fires – Forecasted Antecedent Conditions

May-2023 forecast, *leads = 0, 2 (May and June)*



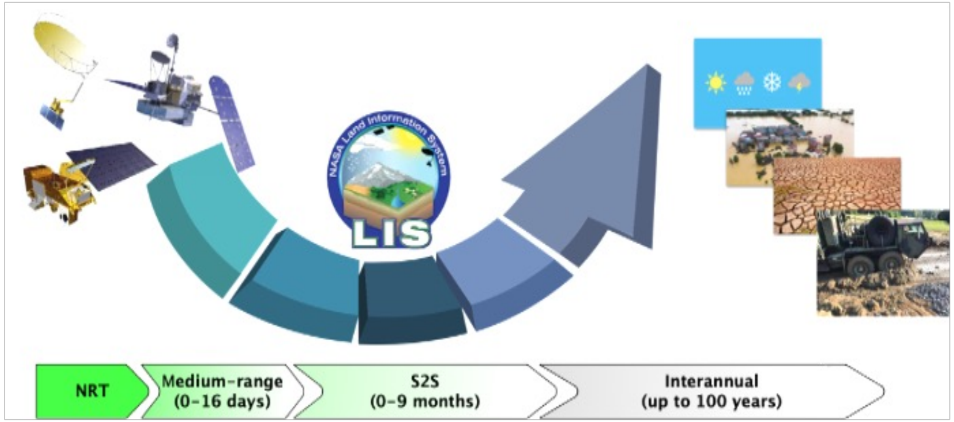




[1] https://earth.org/another-year-for-the-record-books-a-recap-of-the-main-extreme-weather-events-in-summer-2023/

[2] European Drought Observatory Maps: https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1111

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.

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