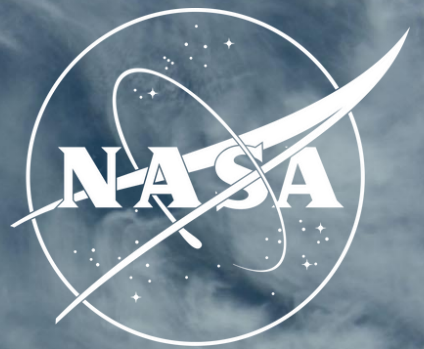


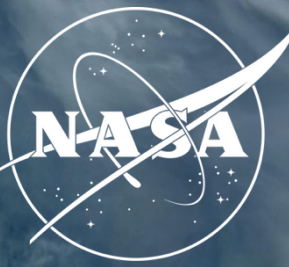


Global Hydro-Intelligence (GHI): Initializing and Predicting Global S2S Hydrometeorological Extremes

Dr. Kristi R. Arsenault, & NASA GHI Team
NASA/GSFC, SAIC
5-Sept-2024



Land characterization mission at USAF / 557 WW

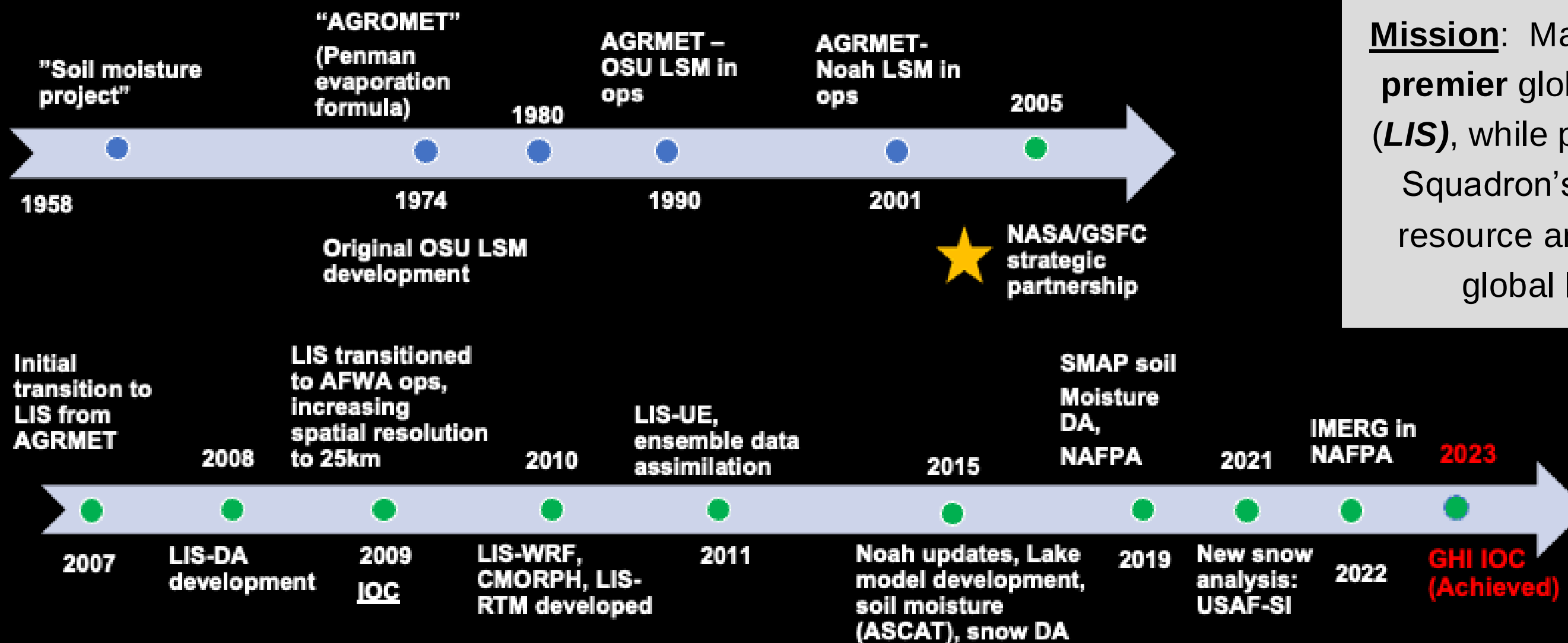


- 557th Weather Wing (557 WW) provides routine geospatial intelligence information to war-fighters, planners, and decision makers for the U.S. military and government, globally. Additional customers include a number of Federal agencies and academic institutions.
- 557 WW and its predecessors (e.g., AFWA) have been home to the DoD's only operational regional and global land data analysis systems (GLDAS) since January 1958.

Land characterization mission at USAF / 557 WW



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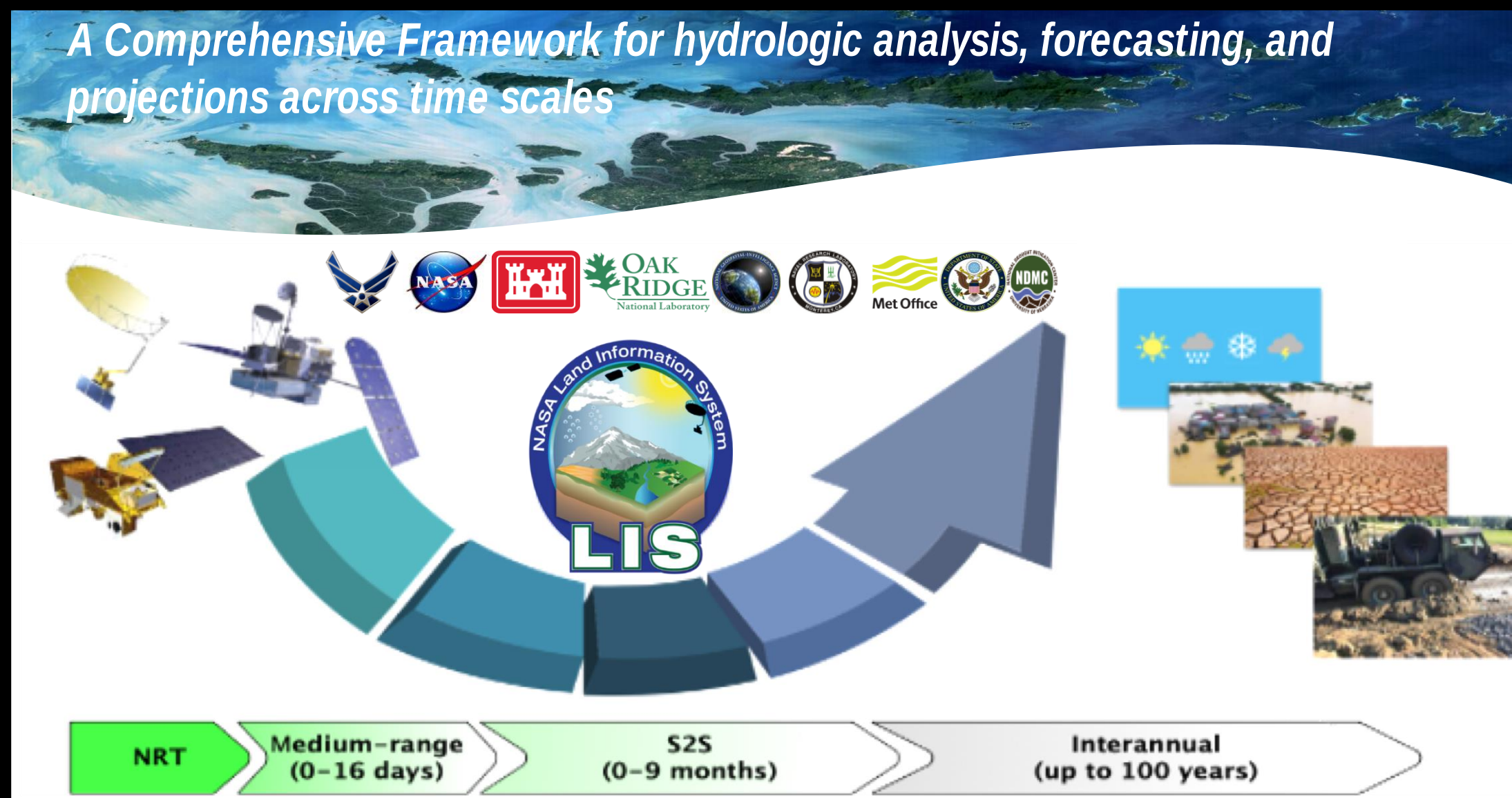


Mission: Maintain and enhance USAF's premier global land information system (**LIS**), while preserving the 16th Weather Squadron's preeminence as a global resource and center of excellence for global land state information.

The GHI Subsystems: Spanning different timescales

A comprehensive framework for hydrological information across four sub-systems, each combining multiple models of physical processes and remote sensing data with visualization and decision support across a spectrum of time scales and missions:

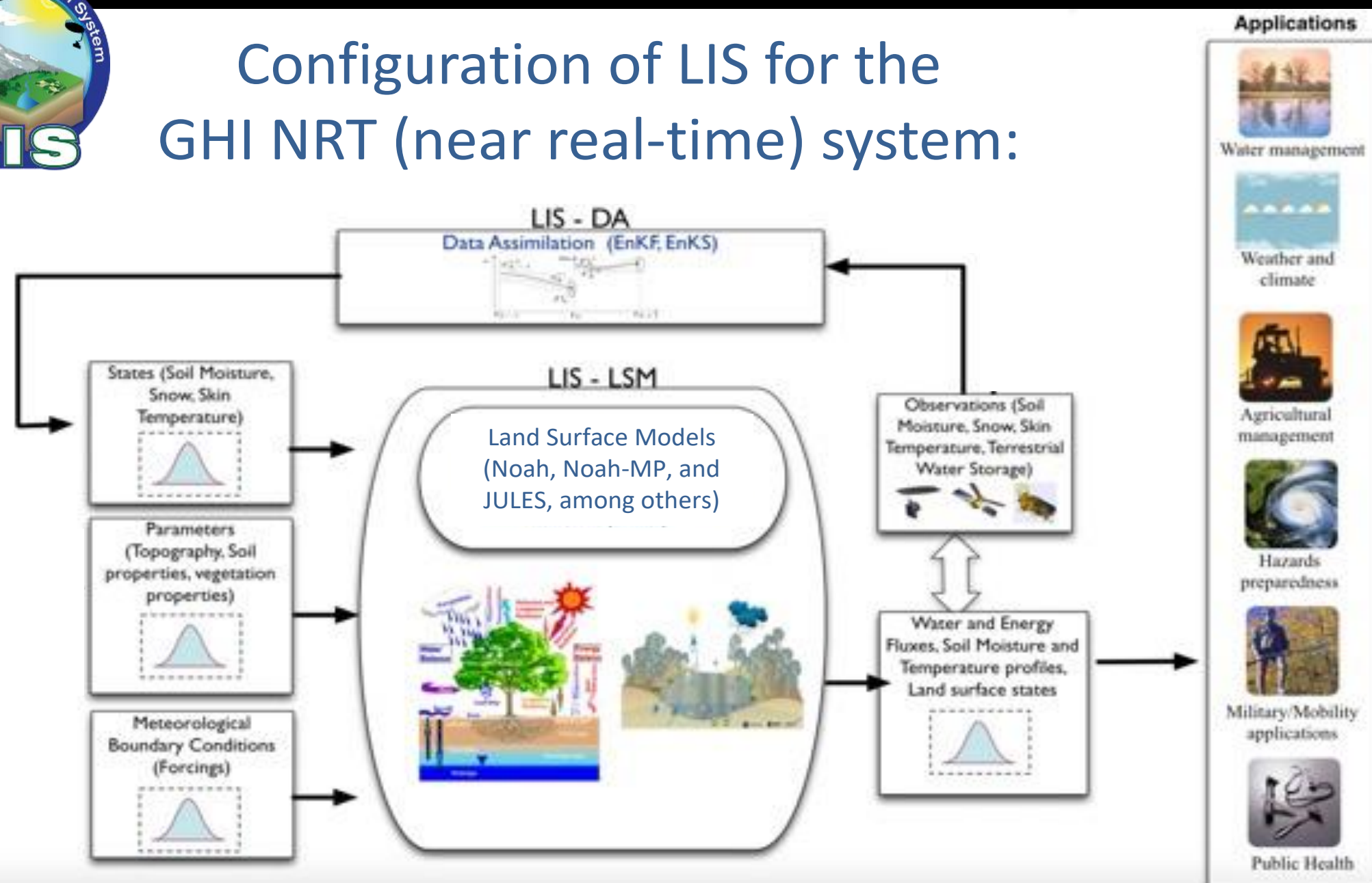
- Near real-time (NRT; t_{-12} hours to t_0)
- Medium-range (MR; t_0 to t_{10} days)
- Subseasonal-to-seasonal (S2S; t_0 to t_9 months)
- Inter-annual / Climate projections (t_0 to t_{100} years)



NASA's **Land Information System** is a high-performance software framework and modeling system with physical land-surface models (LSMs), hydrology models, and data assimilation of remotely-sensed land observations, *including soil moisture, snow, vegetation and groundwater.*



Configuration of LIS for the GHI NRT (near real-time) system:



- A cutting-edge system that simulates land and hydrology processes, integrating various models, and remote sensing data through advanced data assimilation.
- Advanced, global terrestrial hydrology modeling system, offering exceptional capabilities for incorporating remote sensing data.

Ref: Kumar, S.V., C.D. Peters-Lidard, Y. Tian, P.R. Houser, J. Geiger, S. Olden, L. Lighty, J.L. Eastman, B. Doty, P. Dirmeyer, J. Adams, K. Mitchell, E.F. Wood, and J. Sheffield, 2006: Land Information System - An interoperable framework for high resolution land surface modeling. *Environ. Modeling & Software*, 21, 1402-1415, doi:10.1016/j.envsoft.2005.07.004

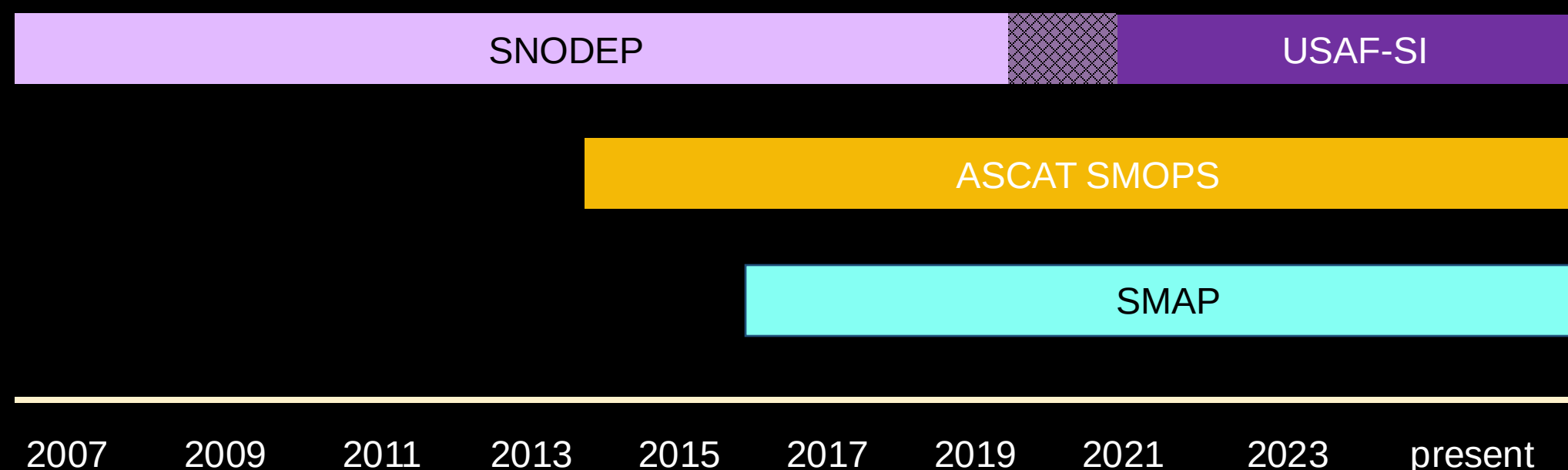
- The surface meteorological forcing is a combination of the NASA – Air Force Precipitation Analysis (**NAFPA**) precipitation, meteorology from NWP and surface observations, and cloud information (e.g., previous World-Wide Merged Cloud Analysis).
- **NAFPA** (Kemp et al., 2022*) uses a Bratseth analysis to combine precipitation from NWP as background with gauge reports and satellite estimates to produce a high-quality real-time analysis.
- The NRT, MR and S2S subsystems use the above inputs for driving the land surface and hydrology models. The S2S subsystem has its forcing extended further back to 1991, using MERRA2 plus CHIRPS precipitation (which are bias-corrected to the USAF+NAFPA dataset).

* **Ref:** **Kemp, E**, J.W. Wegiel, S.V. Kumar, J. V. Geiger, D.M. Mocko, J. Jacob, C.D. Peters-Lidard, 2022: A NASA-Air Force Precipitation Analysis for Near-Real-Time Operations, *Journal of Hydrometeorology*, 23(6), 965-989, doi:10.1175/JHM-D-21-0228.1

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- NRT: t_{-12} hours to t_0 = ~10 km model resolution, 3-hourly output, NAFPA precipitation
- MR: t_0 to t_{10} days = ~10 km model resolution, 3-hourly output, MOGREPS-G or GALWEM MR ensembles
- S2S: t_0 to t_9 months = 25 km model resolution, daily output, NMME (precip) + CFSv2 (non-precip) S2S

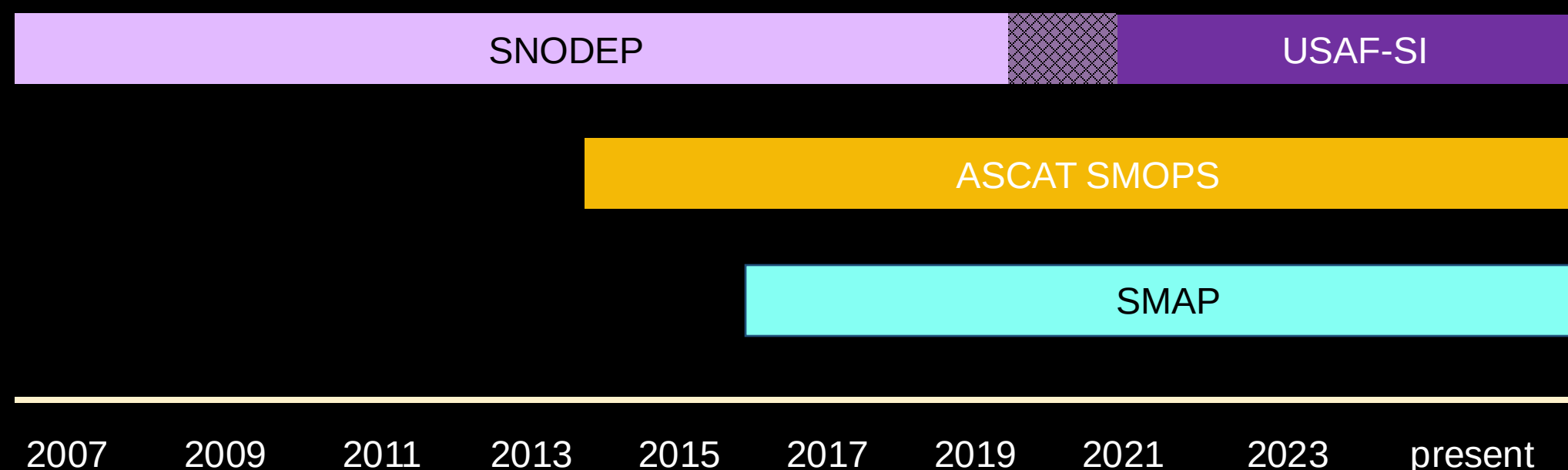
***Ref:** Kemp, E, J.W. Wegiel, S.V. Kumar, J. V. Geiger, D.M. Mocko, J. Jacob, C.D. Peters-Lidard, 2022: A NASA-Air Force Precipitation Analysis for Near-Real-Time Operations, *Journal of Hydrometeorology*, 23(6), 965-989, doi:10.1175/JHM-D-21-0228.1

- Snow products from **USAF-SI** (USAF Snow and Ice Analysis; Yoon et al., 2022*) and from **SNODEP** (USAF's Snow Depth Analysis Model) are assimilated.
- Soil moisture (SM) products from NOAA's **SMOPS – ASCAT** and from NASA **SMAP** are assimilated using CDF matching, with the observations scaled into the LSM's climatology.



* **Yoon, Y., E.M. Kemp, S.V. Kumar, J.W. Wegiel, C.M. Vuyovich, C.D. Peters-Lidard, 2022: Development of a global operational snow analysis: The US Air Force Snow and Ice Analysis, Remote Sens. Environ., 278, 113080, doi:10.1016/j.rse.2022.113080**

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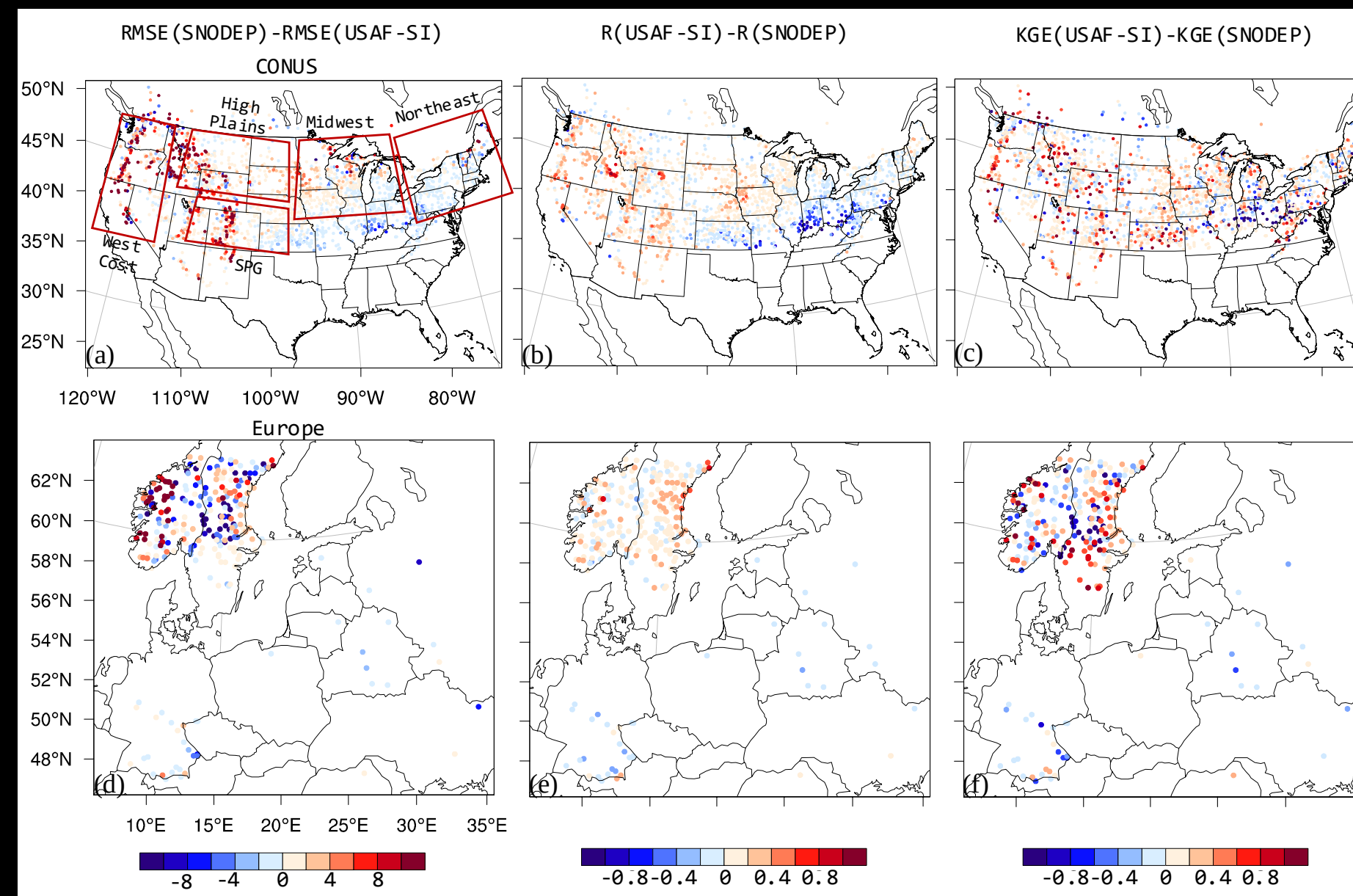


- NRT: Multivariate DA with SNODEP / USAF-SI snow depth, SMOPS – ASCAT and SMAP SM
- MR: Uses the NRT DA run for MR initial conditions
- S2S: Runs a separate NRT DA run with only SMAP DA (at this time)

* Yoon, Y., E.M. Kemp, S.V. Kumar, J.W. Wegiel, C.M. Vuyovich, C.D. Peters-Lidard, 2022: Development of a global operational snow analysis: The US Air Force Snow and Ice Analysis, Remote Sens. Environ., 278, 113080, doi:10.1016/j.rse.2022.113080

The global, operational US Air Force Snow and Ice Analysis (USAF-SI)

- The NRT global snow analysis (10-km resolution, 6-hourly), USAF-SI, was developed to overcome the limitations of the SNODEP dataset
- USAF-SI provides more accurate and spatially distributed information for **global snow conditions**.
- On the right, validation examples of USAF-SI vs. SNODEP with station observations:
 - USAF-SI demonstrates **improved performance over SNODEP**
 - USAF-SI exhibits **higher accuracy** comparison to other high-latency snow analyses
- Upcoming AI/ML-based snow analysis
 - Applies sophisticated algorithms
 - Improves the monitoring, prediction, and understanding of snow and ice conditions
 - Will Integrate diverse datasets (e.g., satellite imagery, ground-based observations, and models)



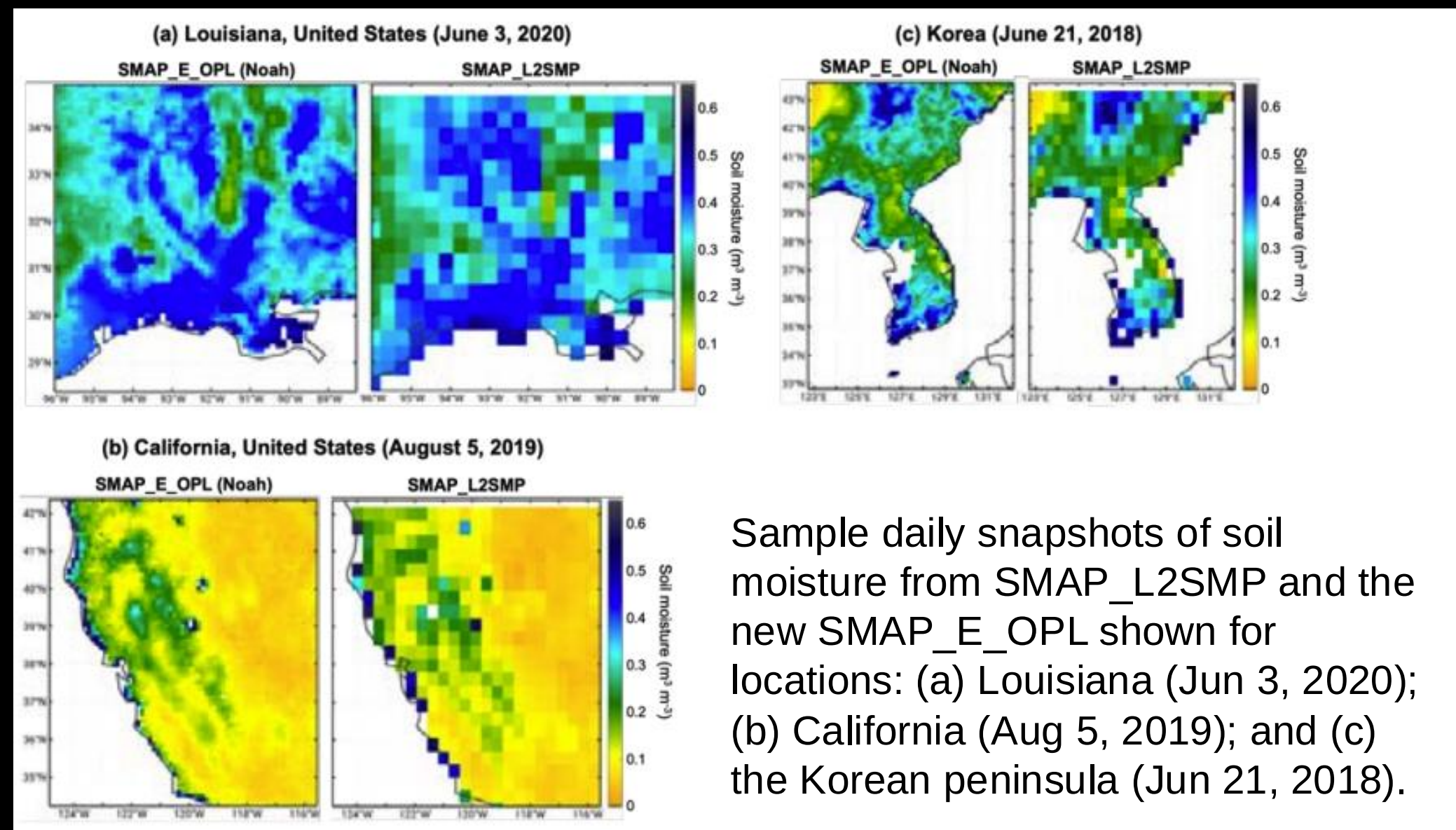
Comparison of the skill of USAF-SI relative to SNODEP

Enhanced Operational SMAP products at 9 km with Lower Latencies

NASA/JPL's SMAP_L2SMP has a latency of 2-3 hours at 36 km resolution. The 9 km product has a delay up to 16-24 hours, which can be later than desired for NRT operations.

NASA/GSFC is developing a 9-km *enhanced operational version* of the SMAP product ("SMAP_E_OPL") with a much lower latency.

The figure (*on the right*) showcases how SMAP_E_OPL offers an increased level of spatial detail of soil moisture. Further, it becomes evident that the wet and dry patterns of soil moisture are much more pronounced in the SMAP_E_OPL product, as opposed to the 36-km SMAP_L2SMP.



Sample daily snapshots of soil moisture from SMAP_L2SMP and the new SMAP_E_OPL shown for locations: (a) Louisiana (Jun 3, 2020); (b) California (Aug 5, 2019); and (c) the Korean peninsula (Jun 21, 2018).

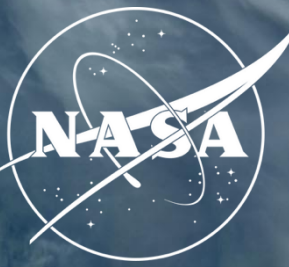
References:

Ahmad, J., B.A. Forman, A. Getirana, S.V. Kumar, 2024, Influence of SMAP soil moisture retrieval assimilation on runoff estimation across South Asia, *J. Hydrology*, [doi:10.1016/j.hydro.2024.131550](https://doi.org/10.1016/j.hydro.2024.131550).

Kwon, Y., S.V. Kumar, M. Navari, D. Mocko, E. Kemp, J. Wegiel, J. Geiger, R. Bindlish, 2022: Irrigation characterization improved by the direct use of SMAP soil moisture anomalies within a data assimilation system, *Environ. Res. Lett.*, [doi:10.1088/1748-9326/ac7f49](https://doi.org/10.1088/1748-9326/ac7f49)

Verification Examples of GHI Subsystems

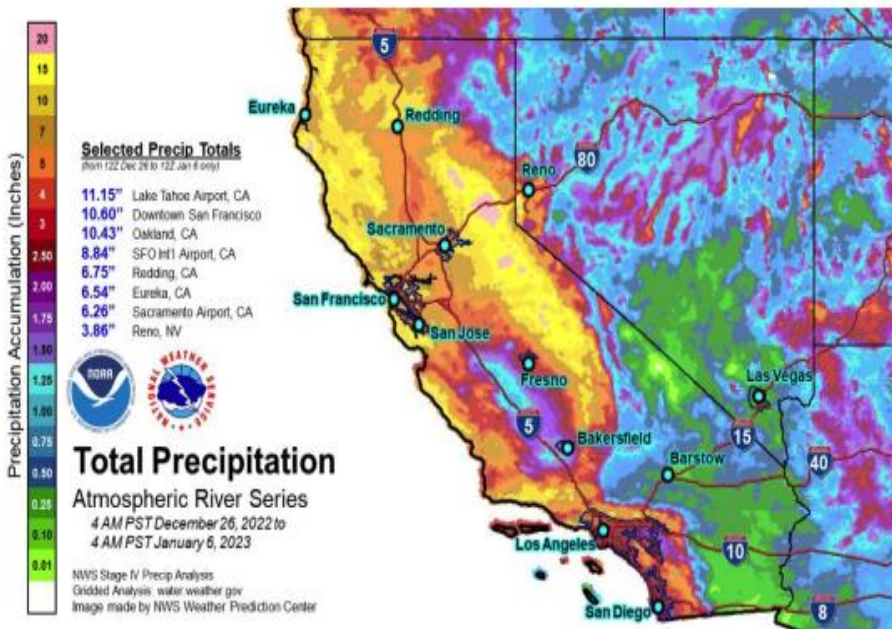
GHI Medium-Range (MR) Extreme Event Verification



Atmospheric River events captured by MR subsystem

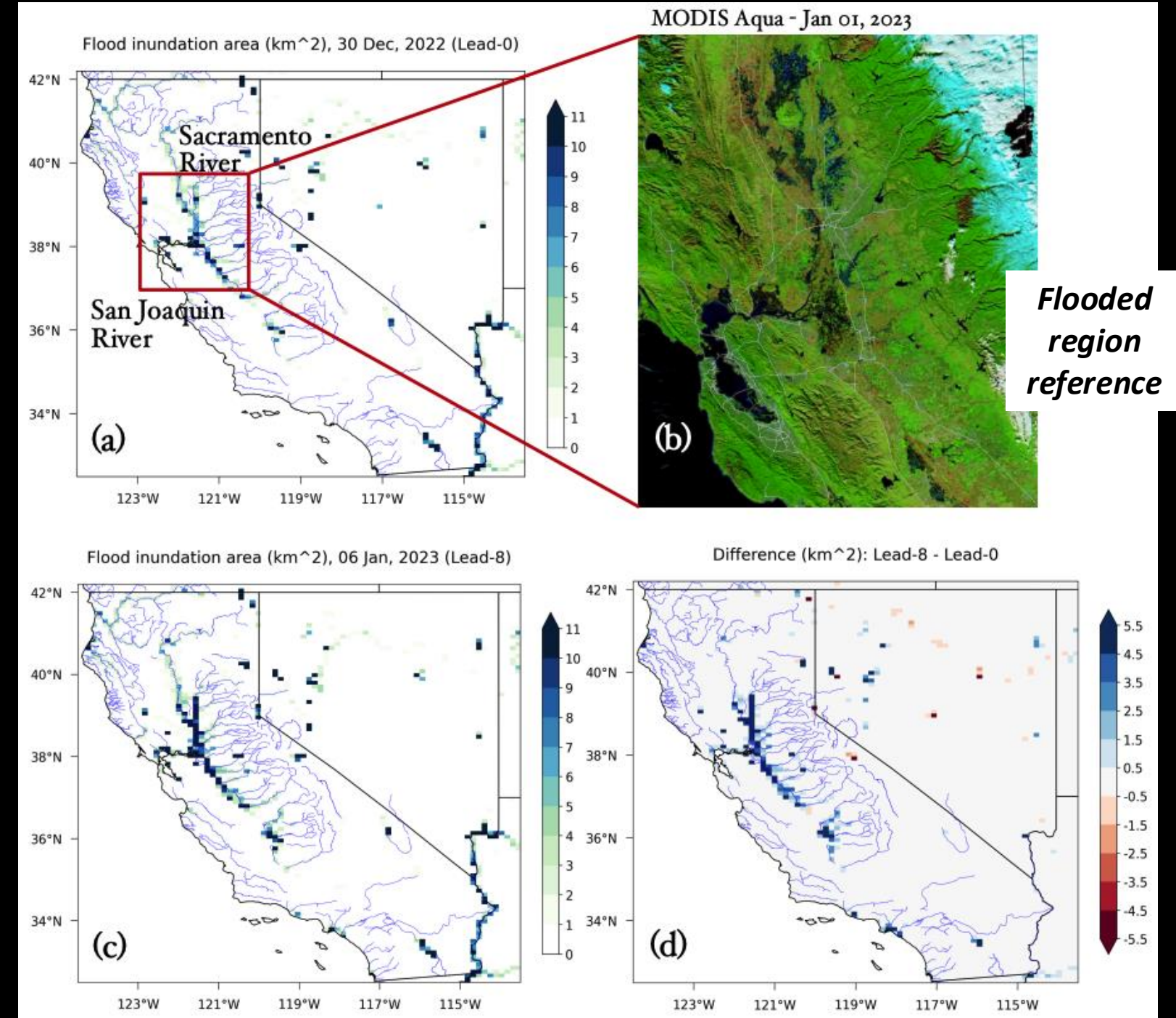
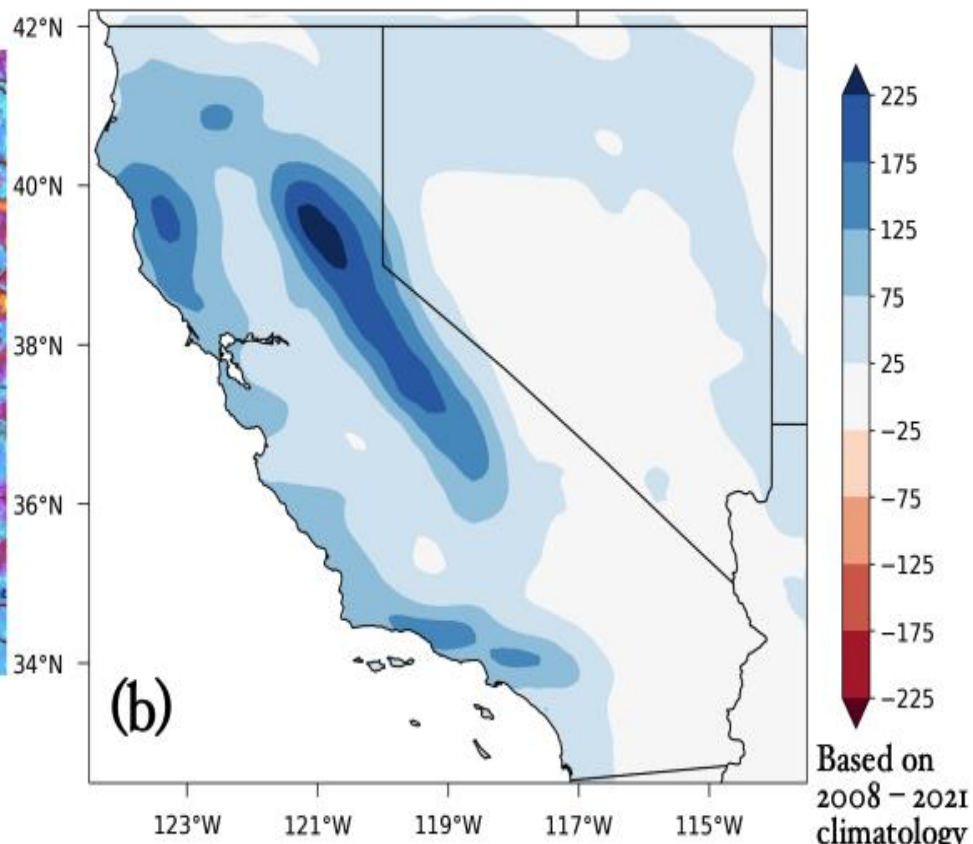
- Late Dec-2022 to early Jan-2023, California experienced a series of several atmospheric rivers that dumped more than 15-20 inches in several parts of the state (see *below figure*).
- GHI-MR captured similar regional high precipitation anomalies during that time.

NOAA WPC Total Precip. Accumulation



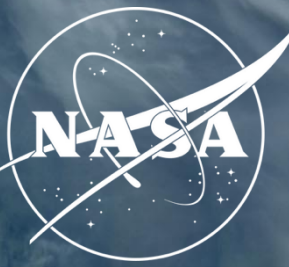
(a) 27 Dec, 2022 to 6 Jan, 2023

GHI-MR Precip Anomaly Forecast 30 Dec, 2022 to 06 Jan, 2023



(a) Initial inundated conditions (30-Dec-2022); (b) Aqua/MODIS (Jan-1); (c) 8-day lead flood inundation forecast (6-Jan-2023); (d) Difference in lead day 8 minus 0 for flooded area (Jan 6 – Dec 30).

GHI S2S Soil Moisture Hindcast Skill

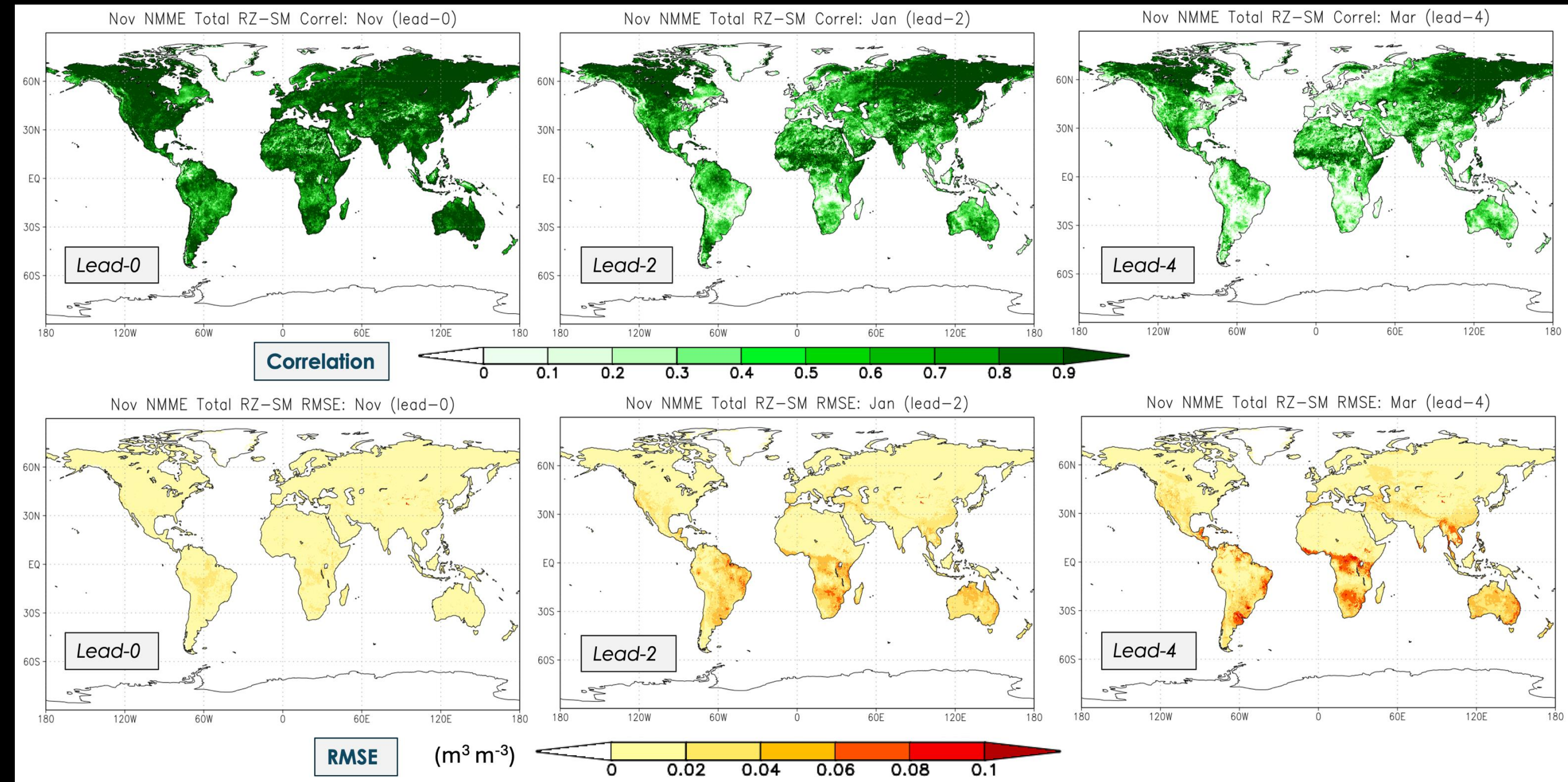


Root-zone Soil Moisture (RZ-SM) Skill for November Hindcasts

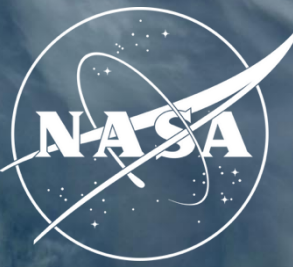
Correlation (top) and RMSE (bottom) of November-based RZ-SM hindcasts.

- Model: Noah-MP-4.0.1
- Used retrospective NoahMP401 OL+ SMAP DA analysis, as the reference.
- Validation performed for 1991-2020.

High correlations and low RMSE values noted in the first lead month, with much skill shown throughout much of the northern hemisphere going out several lead months.

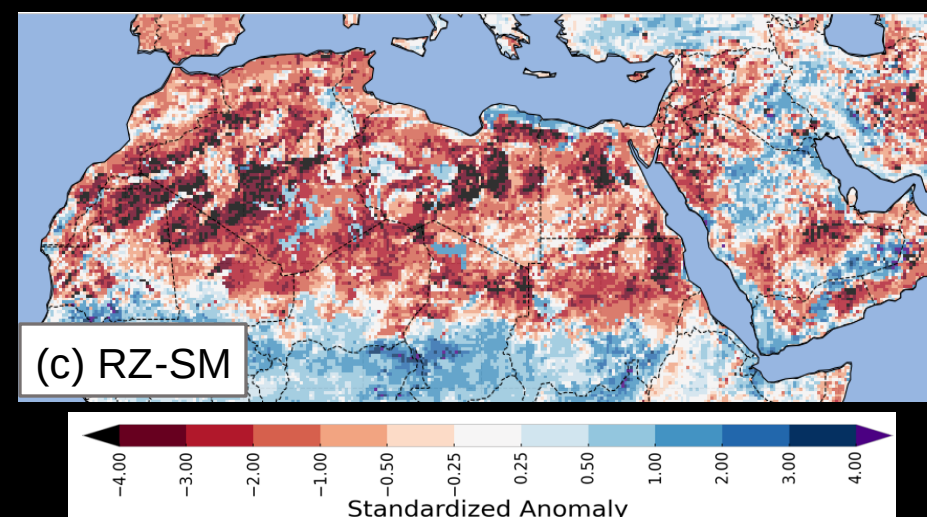
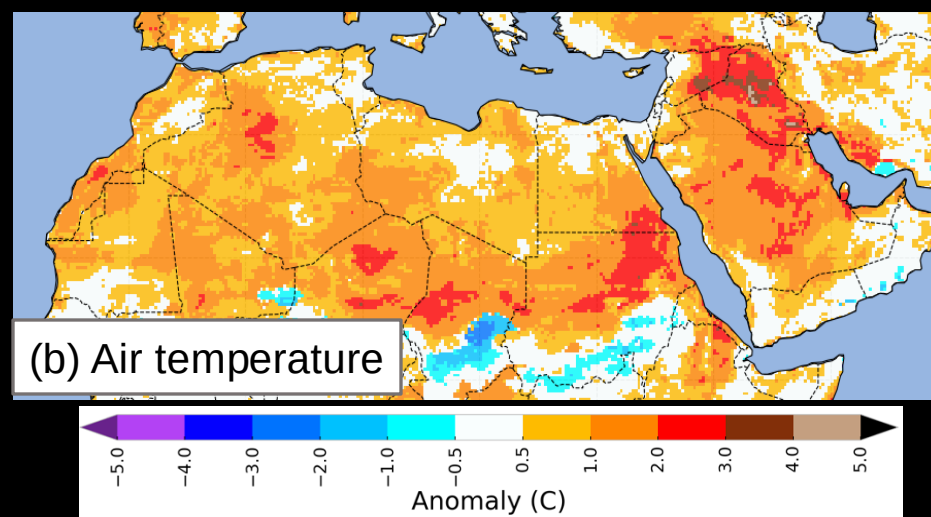
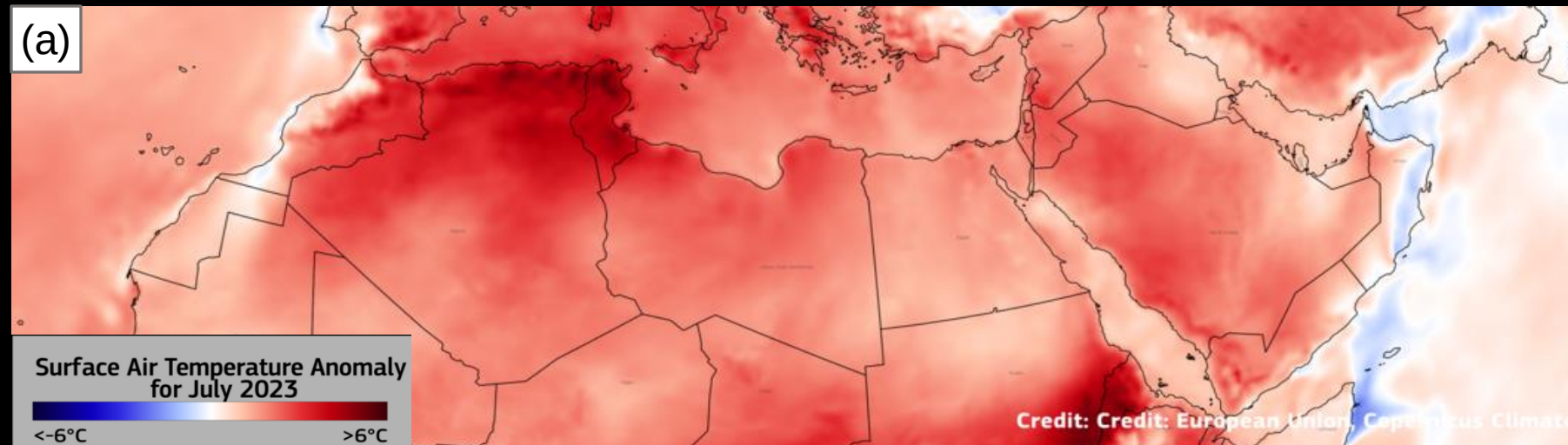


GHI S2S Drought and Flood Potential Examples



Drought Forecasts for Northern Africa

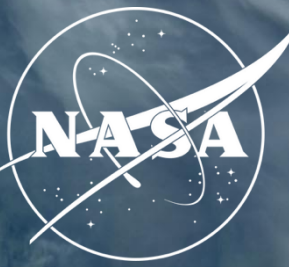
May-2023 forecast, Valid lead (below) = July



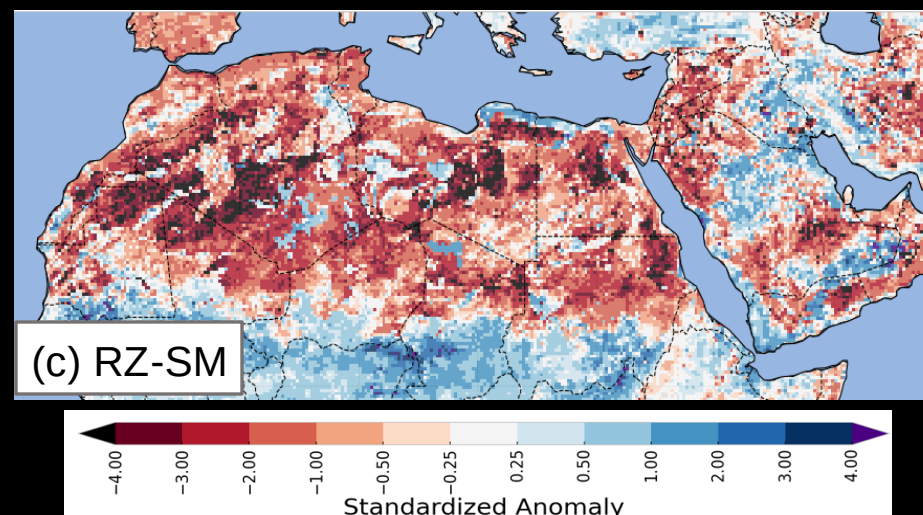
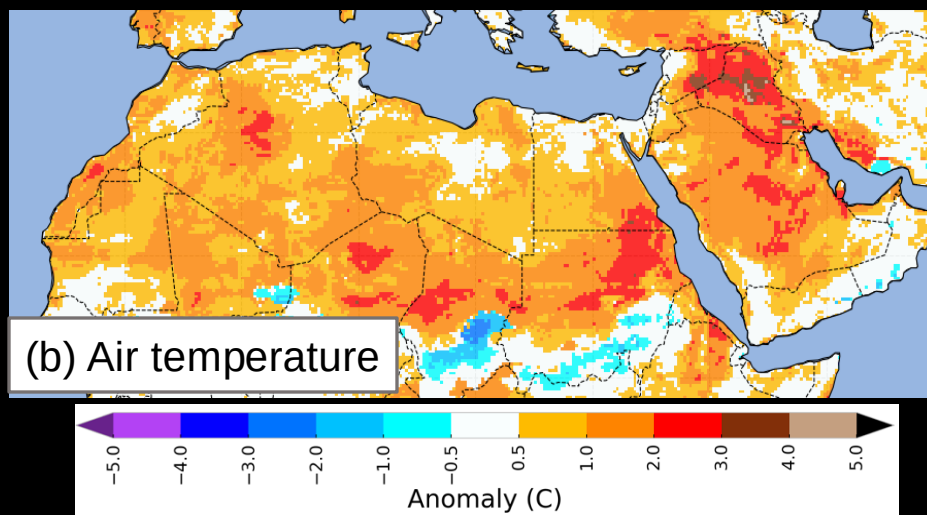
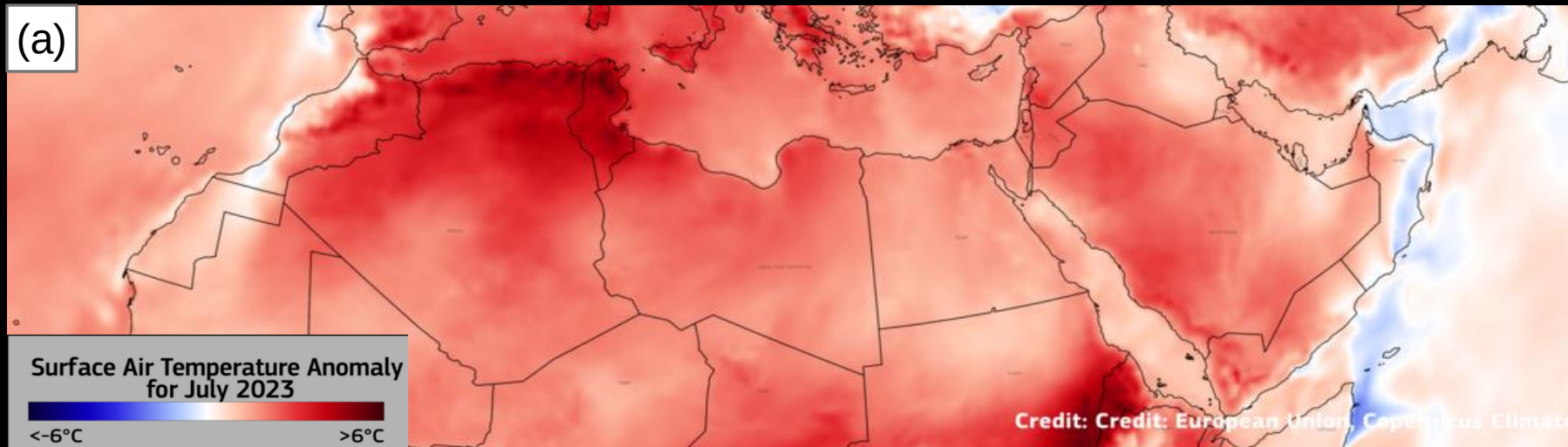
(a) July-2023 surface air temperature anomalies ($^{\circ}\text{C}$), based on Sentinel satellite observations¹. GHI-S2S's forecast of two months *in the future*, for July-2023, of b) CFSv2 air temperature anomalies ($^{\circ}\text{C}$), and c) RZ-SM standardized anomalies.

Anomalies calculated with hindcast years, 1991-2020.

GHI S2S Drought and Flood Potential Examples



Drought Forecasts for Northern Africa May-2023 forecast, Valid lead (below) = July

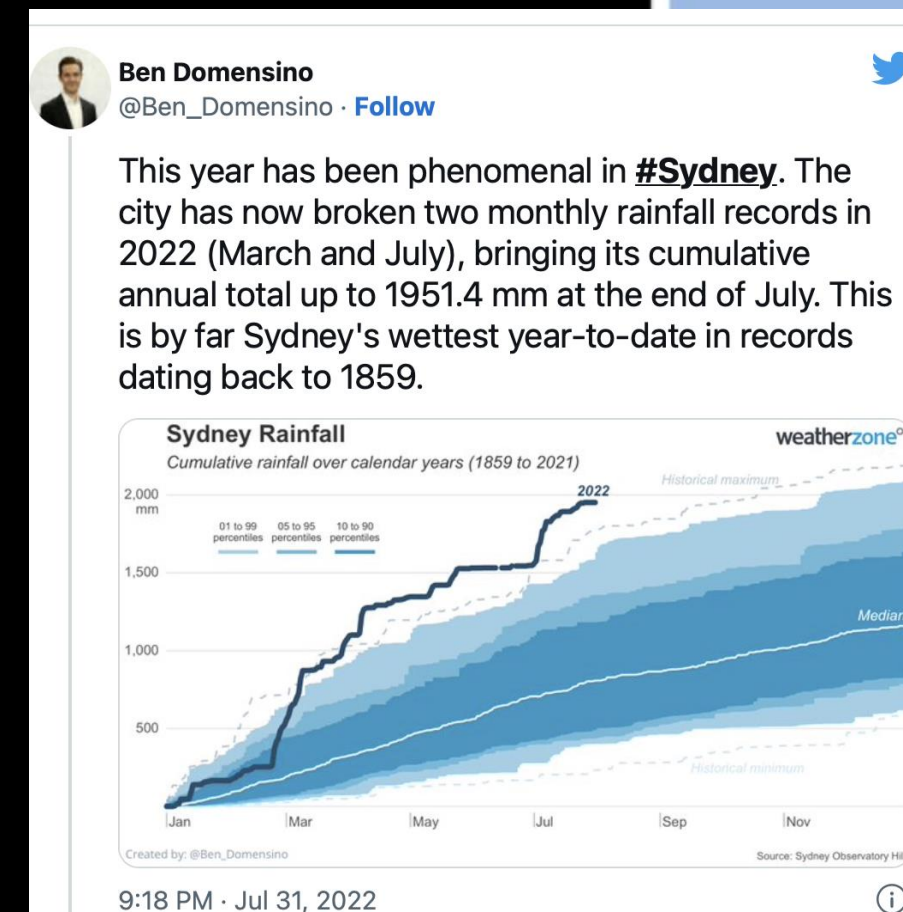
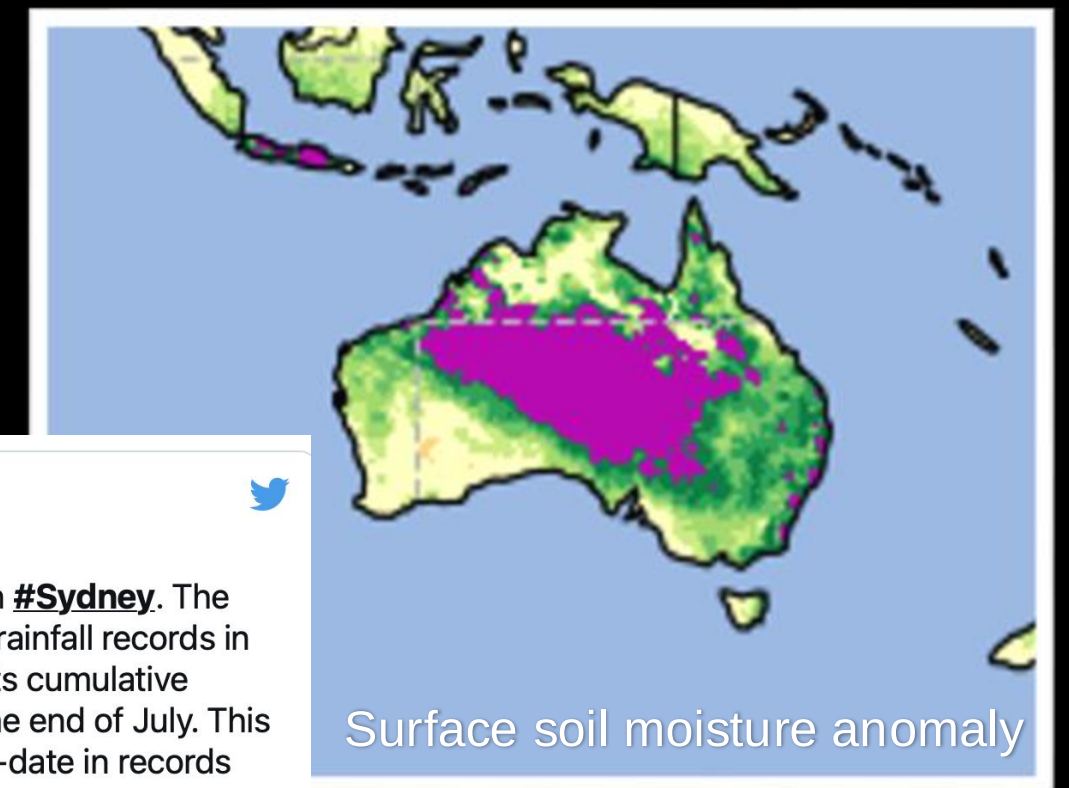


(a) July-2023 surface air temperature anomalies (°C), based on Sentinel satellite observations¹. GHI-S2S's forecast of two months *in the future*, for July-2023, of b) CFSv2 air temperature anomalies (°C), and c) RZ-SM standardized anomalies.

Anomalies calculated with hindcast years, 1991-2020.

Extreme Wetness Forecasts for Australia May-2022 forecast, Valid lead (below) = July

GHI-S2S forecasted the wet extremes that season (March-July, 2022), 2 months in advance.



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

Some major needs identified for S2S hydrometeorological applications:

- Sufficient reforecast or hindcast records (e.g., at least 25 years) and preferably available at $< 1.0 \times 1.0$ deg spatial resolutions.
- More atmospheric forecast fields (e.g., downward solar radiation, u/v wind fields), in addition to air temperature + precipitation, that can be used to drive offline modeling forecast systems and be bias-corrected in a consistent way for all required forcing fields.
- Offering different timescales for the land modeling community, finer than just at monthly, i.e., at daily or sub-daily outputs.
- Routine community announcements when major changes to a forecast system are anticipated or planned -- to give downstream users sufficient time to update and adjust their operational systems that depend on such forecast models as input.

Some challenges identified in producing the hindcast/forecast initial conditions:

- Avoiding or minimizing any “shocks” when going from more model-based open-loop simulations to introducing new satellite data records to improve NRT or forecast initial conditions’ skill.
- Better incorporating of human signals and the impacts on the NRT states and on the forecasts themselves (e.g., via initial conditions or predicted human behaviors, like irrigation practices, groundwater withdrawals).
- Account for non-stationarities in the hindcast period, especially within longer periods of record (e.g., going back to 1990), and any recent climate variations (e.g., significant warming trends within the past few years).

- Main goal in supporting the USAF's global land information system (LIS) – develop comprehensive framework for hydrological information across four sub-systems, combining models of physical processes and remotely sensed data and across a spectrum of time scales and missions.
- The Global Hydro-Intelligence (GHI) mission addresses these needs and timescales, from near-realtime (NRT) to climate forecast projections, out to 100 years in the future.
- GHI employs a suite of land surface and hydrology models, along with multi-variate data assimilation of different satellite-based products of snow and soil moisture, with additional products to be included in the future.
- Validation examples of the GHI NRT, MR and S2S subsystems were presented. Current evaluations and future papers are in preparation.

Thank you!

Kristi R. Arsenault^{1,2}, Ryan Zamora^{1,2}, Sarith Mahanama^{1,2}, Jerry W. Wegiel^{1,2}, Sujay V. Kumar², Eric M. Kemp^{2,3}, Augusto Getirana^{1,2}, Yeosang Yoon^{1,2}, Abheera Hazra^{2,4}, Mahdi Navari^{2,4}, David M. Mocko^{1,2}, Ryan A. Wade^{5,6}

1 - SAIC, 2 - NASA/GSFC, 3 - SSAI, 4 - UMD/ESSIC, 5 - U. Alabama, 6 - NASA/MSFC

- Financial support from the U.S. Air Force Life Cycle Management Center Weather Systems Branch (AFLCMC/HBAW).
- Computing was supported by the resources at the NASA Center for Climate Simulation (NCCS) and DoD High Performance Computing Modernization Program.
- NAFPA (Kemp et al., 2022): <https://doi.org/10.1175/JHM-D-21-0228.1>
- USAF-SI (Yoon et al., 2022): <https://doi.org/10.1016/j.rse.2022.113080>
- LIS website: <https://lis.gsfc.nasa.gov/>
- LIS (Kumar et al., 2006): <https://doi.org/10.1016/j.envsoft.2005.07.004>
- LDT (Arsenault et al., 2018): <https://doi.org/10.5194/gmd-11-3605-2018>
- LVT (Kumar et al., 2012): <https://doi.org/10.5194/gmd-5-869-2012>
- HyMAP (Getirana et al., 2012): <https://doi.org/10.1175/JHM-D-12-021.1>